The origins of the telescope

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The origins of the telescope

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Emblematic representation of an early Dutch telescope, taken from:
Johan de Brune, *Emblemata of zinne-werck* (Amsterdam/Middelburg 1624).

Contents

Introduction

In November 1614 the Harderwijk-born Dutchman Ernst Brinck (1582-1649), former secretary of the Dutch consul in Constantinopel, visited Florence. As an educated person (Brinck spoke no less than ten languages) he collected the autographs of renowned scholars in his *Album Amicorum*. During his visit, Brinck introduced himself to the famous Italian scholar Galileo Galilei. In the years following the invention of the telescope, Galileo's reputation had soared as a consequence of his observations with the newly invented instrument. Things went as Brinck desired. He received Galileo's autographic inscription, together with a sketch of one Galileo's telescopic discoveries: Jupiter's four moons.[1] Galileo's depiction of Jupiter's moons, presented in a way resembling the Copernican representation of the solar system (ill. 1), nicely illustrates the rapid development of astronomy since the advent of the telescope, first demonstrated at the end of September during a peace conference in The Hague. In the intervening six years, the instrument not only had amazed people all over Europe by its capacity to enlarge distant objects, but the device also had quickly revealed unanticipated celestial phenomena. The heavens contained far more stars than expected, and a range of spectacular discoveries had been made: lunar mountains, moons orbiting Jupiter, the phases of Venus, spots on the Sun, to name but the most famous. These phenomena not only had been observed, but in the hands of Galileo, they had led to interpretations with far-reaching cosmological implications.[2]

Almost immediately after its invention, the telescope evolved from a mere optical toy into a 'scientific instrument,' an instrument of a new type which at the time was called 'philosophical': the manipulation of such instruments allowed scholars to attain natural philosophical truth. In this way, the telescope

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[1] *Album Amicorum* of Ernst Brinck (c. 1582-1649), Koninklijke Bibliotheek, The Hague. Sign. 135 K 4, fol. 63r. The transcription of Galilei's entry in Brick's Album Amicorum states: *'An: 1614. D. 19 Novembris | Ut Nobili, ac generoso studio | D: Ernesti Brinckii rem grata | facerem Galileus Galileis Flo- | rentius manu propria scripti | Florentie.* Cf. Thomassen, *Alba Amicorum* (1990), 71-72.

[2] Van Helden, 'The telescope in the seventeenth century' (1974), 57.

An: 1614 D. 19. Novembris
Vt nobili, ac generoso studio
D: Ernesti Brinckij rem gratā
facerem Galileus Galileus Flo=
rentinus manu propria scripsi
Florentię.

Ill. 1. Galileo's inscription in Ernst Brinck's 'Album Amicorum' (1614)
[Koninklijke Bibliotheek, The Hague]

paved the way for other scientific instruments which also emerged in the course of the seventeenth century, such as the air pump, the barometer, and the microscope. The emergence of the telescope was an important episode in the history of science and technology not only because it marks the invention of a new device, or because it changed man's image of the universe, but also because it helped change the ways in which natural philosophy was practiced and what counted as 'science.' It is for this reason that we considered it appropriate to organize a conference at the Roosevelt Academy in Middelburg on 25 September 2008, exactly 400 years after the spectacle-maker Hans Lipperhey of this same city received a letter of recommendation to the national government in The Hague to demonstrate some 'sights of glasses' with which 'one can see all things very far as if they were close by.'[3] The conference was organized in cooperation with the Huygens Institute of the Royal Netherlands Academy of Arts and Sciences in The Hague and Ghent University in Belgium. It was supported by the Province of Zeeland and the city of Middelburg.

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[3] See the illustration of the minute of Lipperhey's letter of recommendation of 25 September 1608 in: Zuidervaart, ill. 1, elsewhere in this volume.

The search for the inventor of the telescope has a long tradition which began almost immediately after the invention of the instrument. In *Telescopium*, the earliest book on the telescope, published in 1618, but composed in 1612, Girolamo Sirtori already doubts whether Lipperhey, the first demonstrator of the instrument, was also the inventor of the device:

> In the year 1609 [*sic*] there appeared a genius or some other man, as yet unknown, of the race of Hollanders, who, in Middelburg in Zeeland, visited Johannes Lippersein, a man distinguished from others by his remarkable appearance, and a spectacle maker. There was no other [spectacle-maker] in that city, and he ordered many lenses to be made, concave as well as convex. On the agreed day he returned, eager for the finished work, and as soon as he had them before him, raising two of them up, namely a concave and a convex one, he put the one and the other before his eye and slowly moved them to and fro, either to test the gathering point or the workmanship, and after that he left, having paid the maker. The artisan, by no means devoid of ingenuity, and curious about the novelty began to do the same and to imitate the customer, and quickly his wit suggested that these lenses should be joined together in a tube. And as soon as he had completed one, he rushed to the court of Prince Maurits and showed him the invention.[4]

Since then, the search for the inventor of the telescope has continued unabated. One of the most famous and early examples of the genre is Pierre Borel's *De Vero Telescopii Inventore* (1656), or 'the true inventor of the telescope.' In the first paper of this book Huib Zuidervaart shows how the idea that there must have been one true inventor, who at a well-defined moment in time was responsible for *the* invention of *the* telescope has guided, or better misguided, historical investigations until three decades ago.

Times began to change when in 1974 Albert Van Helden published a paper on 'The Telescope in the Seventeenth Century' in *Isis*. Van Helden's starting point was the book *De uitvinding der verrekijkers*, written in 1906 by the Dutch scholar Cornelis de Waard, who, on the basis of new archival sources maintained that the telescope was invented around 1590, in Italy, from where it moved (in an unknown way) to the Netherlands, probably as nothing more than an optical toy. According to De Waard, the device had remained almost unknown until its usefulness became common knowledge, because of Lipperhey's 1608 patent application and the relating demonstration at Count Maurits' court in The Hague. De Waard's analysis however was far from

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[4] Sirtori, *Telescopium* (1618), as translated by Van Helden, 'The Invention' (1977), 50.

unproblematic. In 1975 Van Helden summarized the remaining problems in his paper 'The Historical Problem of the Invention of the Telescope.' Although the archival and printed evidence relating to the invention of the telescope was fairly extensive, it remained inadequate in several crucial areas. Moreover, Van Helden wrote that 'it varies from the unimpeachable to the patently false. The problem has something for the positivist as well as for the weaver of plausible theories.'[5] He concluded – against De Waard – that the available evidence 'does not necessarily commit us to believing that the telescope was invented in Italy around 1590.'[6] But we do not know who invented the telescope, and when, because, 'the instrument was there before the world knew it.'[7]

In 1977 Van Helden repeated De Waard's efforts by collecting all the then known sources about early telescopic devices, and he published a translation of these documents, for the first time into English. *The Invention of the Telescope* also contained Van Helden's own account of the happenings of 1608. He concluded that the Lipperhey letter of 25 September 1608 indeed was the earliest traceable 'undeniable mention of a telescope,' but his analysis also demonstrated the extreme complexity of the process that had led to the invention of the instrument. Van Helden concluded that 'to award the honor of the invention to Lipperhey solely on that basis is an exercise in historical positivism.'[8] Many others had paved the path, or had developed the instrument further, and by doing so these artisans and scholars eventually had made an optical toy into a useful instrument for obtaining new knowledge. With Van Helden's intervention the question shifted from 'who was the first and true inventor of the telescope' to how the instrument was developed. The reconstruction of the long and complex process of the invention of the telescope, and the identification of the multiple technical, mathematical, and social origins of the telescope is also the aim of this book.

The editors of this volume felt that such a collection was much needed, because of the shifts in the historiography of science and technology in the past decades since Van Helden's seminal *The Invention of the Telescope*, and because of new findings and revisionist accounts on the history of the telescope, especially in the past two decades (after a long silence following the publication of *The Invention of the Telescope*). Most authors responsible for the new perspectives brought to the invention of the telescope have contributed to this

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[5] Van Helden, 'The Historical Problem of the Invention of the Telescope' (1975), 251.

[6] *Ibidem*, 259.

[7] *Ibidem*, 255.

[8] Van Helden, 'The Invention' (1977), 25.

volume on *The Origins of the Telescope*, often with papers which summarize the gist of their arguments. New perspectives have primarily been offered by the study of the material culture of science – in this case, the eyeglasses and the telescope lenses, to which the late Vincent Ilardi drew attention in *Renaissance Vision from Spectacles to Telescopes*.[9] The catalogue of the oldest telescopes (that is, of the first half of the seventeenth century) – many of which were previously unknown – which Marvin Bolt and Michael Korey offer in this volume is therefore a most valuable contribution that makes possible the study of material objects which has produced new insights on lens-making techniques, which are documented in this volume.

While historians' attention to the material culture of science has blurred the boundaries between the history of science and the history of technology and between curatorial issues in museums and historical questions typically raised in university departments, other new perspectives have blurred the boundaries between context and cognition. In the past three decades since Van Helden's *The Invention of the Telescope*, historians of science have emphasized the locality of practices of science and technology. Klaas van Berkel depicts the city of Middelburg as a centre of learning, culture and business, attracting skilled artisans such as glass-makers and painters from the Southern Netherlands, who made the city a less unlikely place for the invention of the telescope. The other locality that mattered to the early history of the telescope in the Netherlands was the court of the Stadtholder Count Maurits of Nassau. Rienk Vermij shows how Maurits' court, 'that was not really his court,' and his patronage shaped the early reception of the instrument. Such contextualizations bring us closer to answering why the Netherlands was such an important place to the invention of the telescope.

Moreover, in reaction to historians' emphasis on the radical locality of science and technology, more recent historiography has stressed the circulation of knowledge.[10] The early history of telescope is perfectly suited to illustrate the force of this concept. Already in 1977 Van Helden noted that the telescope was never invented – in the sense that it was not invented in a single place by one single inventor. This book brings out that the telescope was the result of

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[9] Ilardi, 'Eyeglasses and concave lenses in fifteenth-century Florence and Milan' (1976); idem, *Renaissance Vision from Spectacles to Telescopes* (Philadelphia, 2007); Willach, 'The Development of Lens Grinding and Polishing Techniques' (2001); idem, 'Der lange Weg zur Erfindung des Fernrohres' (2007), translated into English as Willach (2008).

[10] For the notion of 'circulation of knowledge,' see Secord, 'Knowledge in Transit' (2004); Raj, *Relocating Modern Science* (2007); Schaffer *et al.*, *The Brokered World* (2009); Dupré &Lüthy, *Silent Messengers* (forthcoming).

the piece-meal connection of distributed and different bodies of material and textual, practical and theoretical, mathematical and cultural bodies of knowledge, packaged and re-packaged when the instrument moved from one place to another. It is for this reason that the title of this book is not 'the invention of the telescope,' but 'the origins – plural – of the telescope.' Moreover, in this process of circulation not only the instrument that came to be known as 'the telescope' was invented; as Mario Biagioli points out in his contribution to this volume, Galileo also invented new meanings of 'invention' and 'telescope' in the process. Thus, the question of priority – who is the true inventor – is not only the less interesting question; it is also the wrong question – because in the sense underlying this question, the telescope itself fails to be invented. It is worth pointing this out again and again, since the celebrations of the past years also elicited the all too familiar stories mixing priority claims with national pride – of which the claim for the Spanish invention of the telescope made most waves in the media.[11] However, the work of the sixteenth-century Juan Roget is important, not so much because we would be allowed to attribute the invention of the telescope to him, but because – as Tom Settle has recently argued – Roget's work tells us more about the circulation of the know-how of lens-making from which the telescope originated.[12]

So, which narrative on the origins of the telescope does emerge three decades after Van Helden's *The Invention of the Telescope*? Several chapters in this book tell us much more on (in Van Helden's terms of 1977) 'the prehistory of the telescope.' Rolf Willach's contributions to this volume and elsewhere have established the degree of progress of the craft of spectacle-making from the invention of eyeglasses in the thirteenth century. By means of modern optical measurements on a variety of fifteenth- and sixteenth-century spectacle-lenses, Willach has demonstrated that only in the early decades of the sixteenth century – but not before – the craft of lens-grinding had evolved enough to produce recognizable telescopic images. While Willach claims that the 'secret' was in stopping down the objective lens to a small aperture, optical knowledge steered sixteenth-century mathematicians in exactly the opposite direction. The contributions of Sven Dupré and Eileen Reeves show that the theoretical

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[11] Pelling, 'Who Invented the Telescope?' (2008). Pelling's paper was based on two Spanish articles, published earlier by De Guilleuma, 'Juan Roget' (1958) and idem, 'Juan Roget, Optico Espanol Inventor del Telescopio' (1960) See also Pelling's 2009-web-blog on the topic, in which he has put some question marks unto the archival accuracy of De Guilleuma, on www.ciphermysteries.com/2009/06/21/the-juan-roget-telescope-inventor-theory-revisited (consulted on 3 January 2010).

[12] Settle, 'The invention of the telescope. The studies of dr. Josep M. Simon de Guilleuma' (2009).

Perspectivist tradition connected with the speculative magical and mathematical literature of the sixteenth century made contempories believe that the production of large diameter mirrors was the way to the telescope.[13] In Italy, Ettore Ausonio, Giambaptista della Porta, Giovanni Antonio Magini, Paolo Sarpi, and Galilei Galileo, had investigated the properties of concave mirrors in an effort to produce a powerful telescopic device.[14] What is known today, but was not understood in the sixteenth and early seventeenth century, is that optical mirrors require a far more precise shape in order to produce recognizable images than lenses. But as Eileen Reeves shows in her contribution to this volume, the idea of the telescopic mirror had a long literary after-life.

The telescopic mirror also was the subject of sustained optical speculation in Elizabethan England. In the early 1990s Colin Ronan launched the idea of the 'Elizabethan Telescope' produced by Thomas Digges and William Bourne, an apprentice of Leonard Digges, in the late sixteenth century. However, Ronan's 'reconstruction' of the alleged instruments was 'quite removed from the reality of the 16th century,' according to Gerard L'Estrange Turner, who concluded that in Elizabethan England, 'there was neither the conceptual framework nor the technical capacity to make such an instrument.'[15] In his contribution to this volume, Dupré reconstructs Bourne's conceptual framework. In contrast to Turner, he argues that Bourne's design – and his desire for large diameter optics in particular – was based on his understanding of the optical knowledge of his time. Such a design, indeed, failed on the technical capacities of the Elizabethans (or any other spectacle-maker anywhere else at the time). While Bourne had a wrong idea of how a lens or a mirror magnified, A. Mark Smith shows that Johannes Kepler, and not the 11th-century Arab mathematician Alhacen, should be considered the father of modern lens-theory. Crucial elements of Kepler's analysis were missing in Alhacen. Understanding the optics of lenses and magnification was thus less self-evident than we might have thought; neither was the appropriation of eyeglasses in the context of medicine self-evident. Katrien Vanagt argues that eyeglasses were not the only therapeutical option and that physicians struggled with understanding their optical workings. Together, these contributions show that nothing in medicine and

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[13] Dupré, 'Mathematical Instruments and the Theory of the Concave Spherical Mirror:' (2000); idem, Ausonio's Mirrors and Galileo's Lenses' (2005); Dupré, 'The Making of Practical Optics' (2009); Reeves, *Galileo's Glassworks: The Telescope and the Mirror* (2008).

[14] Van Helden, 'Invention of the telescope (until 1630)' (1997); idem, 'Introduction to the second printing' (2008); idem, 'Who invented the telescope?' (2009).

[15] Ronan, 'The Origins of the Reflecting Telescope' (1991); idem, 'There was an Elizabethan Telescope' (1993); Turner, 'There was no Elizabethan Telescope' (1993), 5.

optics prepared a blue-print of the instrument later called ‘the telescope.’

When Galileo first encountered the instrument, ‘the telescope’ was still in the making. In his contribution to this volume Mario Biagioli shows that contrary to his own later words Galileo probably saw a copy of a real instrument in the hands of his friend Paolo Sarpi before he presented his own instrument to the Doge of Venice. Albert Van Helden discusses how Galileo turned this device useful for military purposes into an instrument for astronomical observing. However, astronomy was not the only field in which the telescope caused changes in the hands of its first users. First, the telescope had an enormous impact on the craft of lens-making because of the quality demands which telescope lenses imposed, which were much higher than for eyeglasses. Fokko Jan Dijksterhuis taps the notebooks of Isaac Beeckman to show how Descartes’ friend struggled with new and not-so-new lens-making techniques. Giuseppe Molesini studies surviving telescope lenses to reconstruct the lens-making techniques of Torricelli and other 17th-century Italian telescope makers. Second, in the field of optics, Antoni Malet’s contribution to this volume discusses the legacy of the first theory of the telescope by Kepler. Contrary to received opinion, he argues, Kepler was a determining factor who shaped optical theory until the 1660s, when a new concept of optical imagery emerged. Third, the telescope was important to navigation. Henk Zoomers shows in this volume how through the channels of the Dutch East India Company the telescope travelled as far as Southeast Asia. Finally, Albert Clement, the representative of the 2008-conference’s host (the Middelburg Roosevelt Academy), highlights how the telescope was even influential in music. In all those disciplines, enterprises and fields of endeavour the telescope acquired new functions and meanings, and in this process of circulation and appropriation, the contributions to this book bring out, ‘the telescope’ as a cultural artefact was continually made and re-made.

The 'true inventor' of the telescope. A survey of 400 years of debate

Huib J. Zuidervaart

> There is no nation which has not claimed for itself the remarkable invention of the telescope: indeed, the French, Spanish, English, Italians, and Hollanders have all maintained that they did this.
>
> Pierre Borel, *De vero telescopii inventore* (1656)

I. INTRODUCTION

Cultural Nationalism and Historical Constructs

Who invented the telescope? From the very moment the telescope emerged as a useful tool for extending man's vision, this seemingly simple question led to a bewildering array of answers. The epigram above, written in the mid-seventeenth century, clearly illustrates this point. Indeed, over the years the 'invention' of the telescope has been attributed to at least a dozen 'inventors,' from various countries[1]. And the priority question has remained problematic for four centuries. Even in September 2008, the month in which the 400th anniversary of the 'invention' was celebrated in The Netherlands, a new claim was put forward, when the popular monthly *History Today* published a rather speculative article, in which the author, Nick Pelling, suggested that the honour of the invention should *nòt* go to the Netherlands, but rather to Catalonia on the Iberian Peninsula.[2] Pelling's claim was picked up by the Manchester

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[1] Over the years the following candidates have been proposed as the 'inventor of the telescope': (1) from the Netherlands: Hans Lipperhey, Jacob Adriaensz Metius, Zacharias Jansen and Cornelis Drebbel, to which in this paper – just for the sake of argument – I will add the name 'Lowys Lowyssen, geseyt Henricxen brilmakers'; (2) from Italy: Girolamo Fracastoro, Raffael Gualterotti, Giovanni Baptista Della Porta and Galileo Galilei; from (3) England: Roger Bacon, Leonard Digges and William Bourne (4) from Germany Jacobus Velser and Simon Marius; (5) from Spain: Juan Roget, and (6) from the Arabian world: Abul Hasan, also known as Abu Ali al-Hasan ibn al-Haitham. Cf. Van Helden, 'The Historical Problem of the Invention of the Telescope' (1975) and idem, *The Invention of the Telescope* (1977).

[2] Pelling, 'Who Invented the Telescope?' (2008). Pelling's paper was based on two Spanish articles, published earlier by De Guilleuma, 'Juan Roget' (1958) and idem, 'Juan Roget, Optico Espanol Inventor del Telescopio' (1960). See also: Settle, 'The invention of the telescope. The studies of dr. Josep M. Simon de Guilleuma' (2009).

Guardian and *El Mundo* of Madrid, was broadcast on British television, and was disseminated on a number of websites in various languages, including Spanish and Catalan.[3] The prominence and rapid dissemination and favourable reception through modern media of Pelling's rehash of a claim first published by Sirtori in 1618, shows that, to this day, national and regional pride have been important factors in the various answers to the simple question 'who invented this instrument'? As I will show in this paper 'cultural nationalism,' has indeed played a crucial role in the debate about the invention of the telescope in the past 400 years, together with another well-known phenomenon in historical writing, the so-called 'historical construct.'[4]

The first historical construct concerns the 'invention' itself, because what happened in 1608 was in fact not an invention at all, but merely a recognition of the great potential of a device, which must have been around for some decades, as a kind of toy or as a device whose purpose was to correct or improve vision. Indications of the awareness of the magnifying power of a combination of two lenses, long before the year 1608, are indeed abundant in the contemporary literature. For instance, in 1538 the Italian scholar Girolamo Fracastoro (*c.* 1478-1553) wrote: 'If someone looks through two eye-glasses, of which one is placed above the other, he shall see everything larger and more closely.'[5] Or to quote Albert Van Helden in 1977: 'The telescope was not invented *ex nihilo*.'[6] After seeing or hearing of Lipperhey's telescope, many scholars had a kind of *déjà vu*-feeling. Girolamo Sirtori, who in 1612, only four years after the emergence of the instrument, composed his well-known *Telescopium*, captured this feeling in the following phrase:

> It appeared that this conception was in the minds of many men, so that once they heard about it, any ingenious person began trying to make one, without [the help of] a model.[7]

Then, why did we bother to celebrate in 2008 the 400-year anniversary of the telescope? The answer to this question was already stated in 1645 by

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[3] For instance: 'New focus shows Spaniard, not Dutchman, invented telescope,' *The Guardian* (Monday 15 September 2008).

[4] See about the phrase 'cultural nationalism': Bank, *Roemrijk vaderland* (1990); Van Berkel, 'Natuurwetenschap en cultureel nationalisme in negentiende-eeuws Nederland' (1991).

[5] Fracastoro, *Homocentrica* (1538), 18^v, cited from the English translation by Van Helden, *Invention* (1977), 28.

[6] Van Helden, *Invention* (1977), 24.

[7] Sirtori, *Telescopium*, cited from the English translation by Van Helden, *Invention* (1977), 50. Although the book was published in 1618, the text was written in 1612. Cf. De Waard, *Uitvinding* (1906), 192.

Antonius Maria Schyrlaeus de Rheita, who commented on the events of 1608 that in that year 'a joke was put into a serious thing.'[8] Indeed 400 years ago, in September 1608, the telescope was recognized as a useful device. As Rolf Willach has argued recently, and will outline again in this volume, most likely this breakthrough became possible after a small but crucial adaptation of the instrument, the addition of a diaphragm.[9]

Thus in September 2008 we commemorated, *not* the invention of the telescope, but rather the birth of this device as a functional scientific instrument: the first of its kind in Modern History! For from September 1608 onwards the general recognition of the existence and potential of the telescope and the rapid dissemination and circulation of this knowledge throughout Europe can be followed rather precisely, starting at the instrument's demonstration in The Hague and culminating *inter alia* in Galileo Galilei's spectacular astronomical discoveries with his 'Belga Perspicillum'[10] or 'Dutch telescope' in the years 1609 and 1610. For modern history of science this well documented circulation of newly emerged knowledge is far more important, than any priority dispute.

II. THE DUTCH STORY

September 1608 – Middelburg and The Hague

What happened in The Hague at the end of September 1608? The history of the dissemination of the telescope starts in Middelburg, with a letter of recommendation, dated 25 September 1608, in which the authorities of the Dutch Province of Zeeland wrote as follows to the States General, then the sovereign body of the young 'Republic of the Seven United Dutch Provinces' in The Hague:

> The bearer of this letter declares to have [found] a certain art with which one can see all things very far away as if they were nearby, by means of sights of glasses, which he pretends to be a new invention.[11] (See ill. 1)

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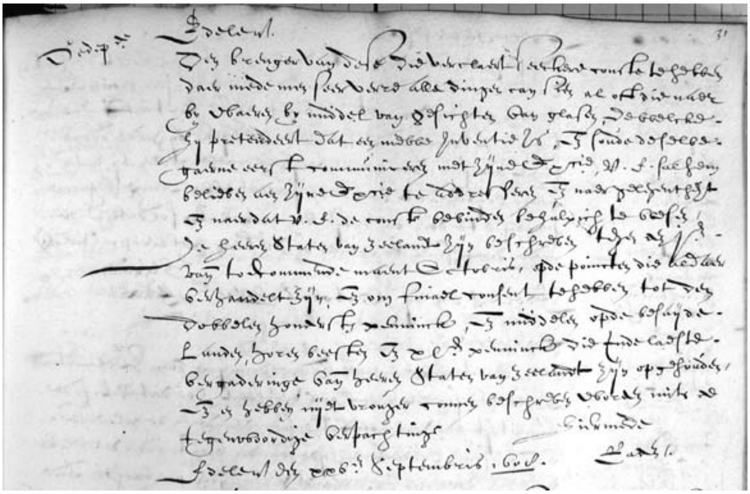
[8] Schyrlaeus de Rheita, *Oculus Enoch et Eliae* (1645), I, 337-338; cited from the English translation by Van Helden, *Invention* (1977), 54.

[9] Willach, 'Der lange Weg' (2007); idem, *The Long Route* (2008).

[10] Van Helden, *Invention* (1977), 45.

[11] 'Die verclaert seekere conste te hebben daer mede men seer verre alle dingen can sien al oft die naer bij waeren bij middel van gesichten van glasen, dewelke hij pretendeert een niewe inventie is.' Van Helden, *Invention* (1977), 35-36.



Ill. 1. Letter of recommendation for Hans Lipperhey, written by the 'Gecommiteerde Raden' of the province of Zeeland, dated 25 September 1608. [Zeeuws Archief, Middelburg].

The archives of the States General in The Hague reveal that 'the bearer of this letter' was in fact the Middelburg spectacle maker Hans Lipperhey, born in Wesel ca. 1570, married in Middelburg, the capital of Zeeland, in 1594 and, a citizen ('poorter') of that city since 1602.[12] It was Lipperhey's intention to present his 'art' to the authorities of the young Dutch Republic in The Hague, and request a patent for this device.

At that very moment The Hague was a city crowded with diplomats from all over Europe. In February 1608 a peace conference had started in The Hague between the Dutch authorities and representatives of the former sovereign of the Netherlands, the King of Spain. In 1609 these negotiations would lead to a long cease-fire, a period which would become known in Dutch history as the 'Twelve-Year Truce.' The main negotiator for the Spanish sovereign was Ambrogio de Spinola, (later Marquis of Los Balbases), commander-in-chief of the Spanish army in the Low Countries. As the Spanish-Dutch negotiations were coming to an end, he was preparing to depart from The Hague on 30 September in order to report to his direct superior, Archduke Albertus of Austria in Brussels, viceroy of the part of the old Burgundian territory still ruled by Spain.

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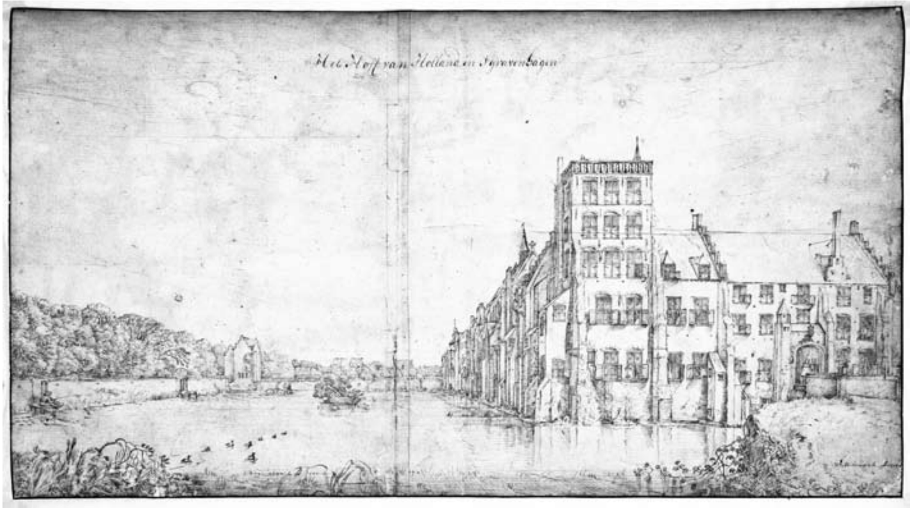
[12] De Waard, *Uitvinding* (1906), 109-110.



Ill. 2. The Maurits Tower in The Hague. Drawing in charcoal by Willem Pietersz. Buytewech (*c.* 1585-1627) [Municipal Archives, The Hague].

But shortly before Spinola's departure, his Dutch host and counterpart as commander-in-chief of the Dutch army, Count Maurits of Nassau, (Prince of Orange after 1618), Stadtholder of the rebelling Dutch Republic, invited him to witness a curious demonstration of a device brought to The Hague by 'a humble and God-fearing man' from Middelburg. The demonstration, which was attended by a few other officials, including Maurits' half-brother and successor Frederik Hendrik, took place on the nearby 'Maurits tower' (ill. 2), built a few years before in a corner of the 'Stadhouderlijk Kwartier,' the governmental palace. Today it is the seat of the both houses of parliament of the Netherlands (still called the 'States General'); in 1608 it contained not only the princely headquarters, but was also the site of the peace conference. A contemporary newsletter presents us with the following account of this event:

> A few days before the departure of Spinola from The Hague a spectacle-maker from Middelburg, a humble and God-fearing man, presented to His Excellency [Count Maurits], certain glasses by means of which one can detect and see distinctly things three or four miles removed from us as if we were seeing them from a hundred paces. From the Tower in The Hague, one clearly sees, with the said glasses the Clock of

> Delft[13] and the windows of the Church of Leiden[14], despite the fact that these cities are distant from The Hague one-and-a-half, and three-and-a-half hours by road, respectively.
>
> When the States-[General] heard about these glasses, they asked His Excellency [Count Maurits] to see them, and he did sent them these, saying that with these glasses they would see the tricks of the enemy. Spinola too saw them with great astonishment and said to Prince [Frederick] Hendrik: *From now on I can no longer be safe, for you will see me from afar*. To which the prince replied: *We shall forbid our men to shoot at you*.
>
> The master [spectacle-] maker of the said glasses was given three hundred guilders, and was promised more for making others, with the command not to teach the said art to anyone. This he promised willingly, not wishing that the enemies would be able to avail themselves of them against us. [15]

The last passage of the pamphlet probably is the most interesting, because this very first account of the telescope already revealed the full potential of the instrument:

> The said glasses are very useful in sieges and similar occasions, for from a mile or more away one can detect all things as distinctly as if they were very close to us. And even the stars which ordinarily are invisible to our sight and our eyes, because of their smallness and the weakness of our sight, can be seen by means of this instrument.[16]

The archives of the States General confirm that Lipperhey received 300 guilders for his device. And although on 2 October, he had asked a thousand guilders for each telescope he made, on 5 October, after an examination of the instrument by a few deputies of the States General the day before, he settled for a much lower price. That day Lipperhey received a down payment of 300 guilders, with the promise to receive another 600 guilders when he delivered three more of these instruments. The conditions stipulated that he would not make such a device for other parties and he was requested to improve the

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[13] In fact there were (and still are) two church towers with large clock dials in Delft: one at the 'Oude Kerk' (Old Church), finished in 1240, and the other at the 'Nieuwe Kerk' ('New Church), finished in 1496. Both churches are located in the centre of the city, at a distance of some 10 kilometres in a straight line from the Maurits Tower in The Hague.

[14] In fact there were (and still are) two churches with large windows in Leiden: one at the 'Hooglandse Kerk' and the other at the 'St Pieters Kerk.' Both Gothic churches are located in the centre of the city, at a distance of *c.* 23 km in a straight line from the Maurits Tower in The Hague.

[15] This pamphlet was first published by Drake, *The Unsung Journalist* (1976) and recently by Zoomers & Zuidervaart, *Embassies* (2008).

[16] *Ibidem*.

instrument by making it suitable for two eyes, and using rock crystal or glass of the very best quality for his lenses.[17] Lipperhey delivered the first binocular instrument in mid-December 1608, and the other two in February 1609. All three instruments were considered to be working satisfactorily by the deputies of the States General who had tested the instruments.[18] The amount of 900 guilders Lipperhey received for his three instruments was large enough for him to buy his neighbour's house in Middelburg, which he appropriately named 'The Three Telescopes' (the 'Dry Vare Gesichten').[19]

The refusal of Lipperhey's patent application

However, Lipperhey did not obtain the desired patent in December 1608. The reason why is quite clear. Within a fortnight of his first demonstration, two other persons had stepped forward claiming that they, too, knew 'the art of seeing faraway things and places as if nearby.' The first one was an unnamed 'young man' of Middelburg, who had shown the Zeeland officials a similar instrument (ill. 3)[20], and the other was Jacob Adriaensz [Metius] of Alkmaar, the son of one of the most prominent engineers of the Dutch Republic. Although the first person was never heard of again, and the latter acknowledged that his instrument was made of very bad material ('seer slechte stoffe') and did not perform as well as the one 'recently shown by the spectacle maker from Middelburg,' it seemed clear that 'the art' could not remain secret for long, 'especially after the shape of the tube has been seen.'[21]

And indeed this fear soon became true. Already in December 1608, Pierre Jeannin, the French ambassador in The Hague, had found a French speaking

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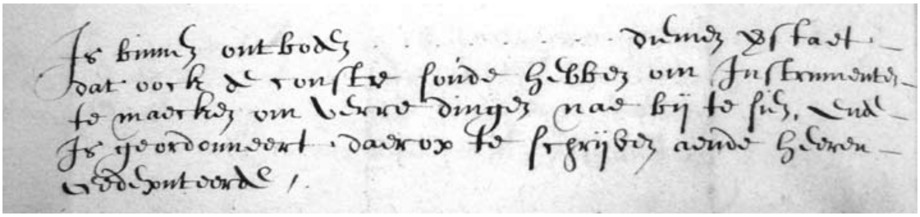
[17] Van Helden, *Invention* (1977), 36.

[18] Van Helden, *Invention* (1977), 42. Lipperhey's instrument was examined by the following deputies of the States General: (1) Johan van Dorth (1574-1624) from Zutphen, deputy of the province of Gelderland, (2) Jacob Simonsz. Magnus (1563-1625), from Middelburg, deputy of the province of Zeeland, (3) Gerard van Renesse van der Aa (d. 1610), from Utrecht, deputy of the province of Utrecht, (4) Tinco (van) Oenema (d. 1631) from Oudeschoot, deputy of the province of Friesland, and (5) Jacob Andriesz. Boelens (1554-1621), from Amsterdam, deputy of the province of Holland.

[19] For references, see also Zuidervaart, 'Uit Vaderlandsliefde' (2007).

[20] 'Is binnen ontboden... die men verstaet dat oock de conste soude hebben om instrumenten te maecken om verre dingen nae bij te sien, ende is geordonneerd daerop te schrijven aende heeren gedeputeerden.' ('Is invited inside ... [*the clerck has not filled in the name*] of whom it is said that he also has the art of making an instrument to see far away objects nearby'). Minutes of the Committee of Councillors of Zeeland, 14 October, 1608. Middelburg, Archive Staten van Zeeland, no. 480, fol. Lxxviiy. See: Van Helden, *Invention* (1977), 38.

[21] Van Helden, *Invention* (1977), 39. See also Vermij, in this volume.



Is binnen ontboden . . . . [illegible] verclaert
dat oock de conste soude hebben om Instrumenten
te maecken om verre dingen naer bij te sien, ende
is geordonneert daerop te schrijven aende heeren
gedeputeerde /.

Ill. 3. Note made in the meeting of the board of the province of Zeeland, on 14 October 1608, stating that an unnamed person [*the clerck has not filled in his name*] also claimed to have 'the art of making an instrument to see far away objects near by'. [Zeeuws Archief, Middelburg].

engineer coming from Count Maurits' army, who was able to reproduce Lipperhey's instrument. For, as Jeannin stated in his letter to the French king: 'there is no great difficulty in imitating that first invention.'[22]

The rapid dissemination of the instrument

Following the September presentation in The Hague, the news about the telescope spread over Europe like wildfire. The newsletter cited above was composed in October 1608 (probably in The Hague) and had arrived in Paris by mid-November, where it was read by the chronicler Pierre de l'Estoile, who sent it to a publisher to be printed. The Paris-issue was reprinted in Lyon in the same month, and that very month a copy had even reached Paolo Sarpi, Galileo's close friend, in Venice.[23]

Within half a year of the demonstration of the telescope in The Hague, copies of the actual instrument were in the hands of several European rulers and magistrates. Probably in February 1609 at least two telescopes were sent from The Hague to the French court,[24] and the same (or the next) month at least two instruments were assembled in Brussels. These clones of the original instrument had been made at the request of the Marquis de Spinola, who immediately after his return in Brussels had reported about the telescope to his superior, Archduke Albertus of Austria, the consort of the Infanta Isabella, daughter of the late Spanish king Philip II. It was probably one of these telescopes, having tubes made by the silversmith Robert Staes, which is depicted

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[22] Van Helden, *Invention* (1977), 43: 'aussi n'y a-il pas grande difficulté imiter cette premiere invention.'

[23] Cf. Pantin, 'La lunette astronomique' (1995), 162; Sluiter, 'The Telescope before Galileo' (1997).

[24] The French ambassador in The Hague, Pierre Jeannin, suggested in his letters that two of the Lipperhey telescopes ordered by the States General were actually meant as a gift for the French king. Cf. Van Helden, *Invention* (1977), 43.

Ill. 4. Archduke Albertus of Austria, governor of the Southern Netherlands, observing a bird with a telescope. Detail of a painting by Jan Brueghel the Elder, c. 1608-1611, representing the archduke in front of his castle Mariemont in Hanaut (Belgium). [Virginia Museum of Fine Arts, Richmond, USA. The Adolph D. and Wilkins C. Williams Fund. Photo Katherine Wetzel].

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on a painting by Jan Brueghel the Elder, dated 1611, representing the archduke in front of his castle Mariemont, near Brussels (ill. 4).[25]

In March 1609, the papal nuncius in Brussels, Guido Bentivoglio attended a heron hunt organised for the archduke just outside the gates of that city, in which one of these Brussels-made telescopes was tested. It amazed him how 'miraculously' the instrument performed, revealing details of a tower more than ten miles away. Bentivoglio immediately ordered another copy to be made, not for himself but for Pope Paul V, which instrument arrived in Rome probably at the end of April 1609.[26] That very month similar telescopes were

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[25] Hensen, 'De verrekijkers van Prins Maurits en van Aartshertog Albertus' (1923). In May 1609 a sum of money was paid to the silversmith Robert Staes in Brussels for making two 'tuyaux artificiels pour veoir de loing.' Cf. Houzeau, 'Le telescope à Bruxelles' (1885); De Waard, *Uitvinding*, 230. The Brueghel-painting was signalled by Inge Keil in her *Augustanus Opticus* (2000) 268. See about the painting, representing a view on the Mariemont Castle, now in the Virginia Museum of Fine Arts, USA, Inv. No. 53.10: Ertz & Nitze-Ertz (eds.), *Brueghel* (1997), 252-253.

[26] The instrument was sent to Cardinal Scipione Borghese, papal secretary and nephew of Pope Paul V. In August 1609 Borghese received from Galileo Galilei a telescope 'similar to the one he had received from Flanders.' Cf. Sluiter, 'The Telescope before Galileo' (1997) and Galilei, *Opere*, 10 (1900), letter 234: Lorenzo Pignoria [from Padua] to Paolo Gualdo [in Rome], 31 August 1609.

on sale in Paris, probably copied after examples brought from Holland, early in 1609, by an engineer from Sedan.[27] Another telescope was presented in May 1609 in Milan, also brought there by a Frenchman (*Gallus*), who claimed to be an associate of the inventor from Holland.[28] This person was possibly the same as the 'foreigner' who at the end of July 1609 demonstrated a telescope in Padua, where Galileo lived.[29] A month later a spyglass had reached Naples.[30] Finally, in the summer of 1609, Simon Marius in southern Germany received a pair of telescopic glasses from the Netherlands, remarking that such glasses 'were becoming quite common' over there.[31] In the fall he even received a set of better glasses 'extremely well polished, one convex and one concave,' which were sent to him from Venice by a certain 'Iohanne Baptista Lenccio,' a person 'thoroughly acquainted with the instrument,' who had returned from the Netherlands to Venice 'after the peace was made,' which means after April 1609, when an agreement had been signed in Antwerp.[32]

Thus, within a year of the demonstration in The Hague, the telescope was disseminated all over Europe, with the result that various European scholars had already used or at least examined the instrument.[33] Before the end of 1609, telescopes were in the hands of Thomas Harriot in London[34], Galileo Galilei in Padua, Giovanbaptista della Porta in Naples, Simon Marius in Gunzenhausen (Bavaria)[35] and Rudolph Snellius in Leiden (Holland)[36], to be followed the next year by Johannes Kepler in Prague*),* Christoph Scheiner in Ingolstadt (Bavaria), Nicolas Claude Fabri de Peiresc in Aix-en-Provence, Willebrord Snellius[37] and Johann Fabricius[38], both in Leiden, and Sir William Lower in Carmarthenshire (Wales).[39]

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[27] Van Helden, *Invention* (1977), 43. Borel (1655) presents a certain Crepius from Sedan as one of the claimants for the invention.

[28] Van Helden, *Invention* (1977), 50, quoting Sirtori (1618).

[29] Cf. Galilei, *Opere*, 10 (1900), 226: Lorenzo Pignoria [from Padua] to Paolo Gualdo [in Rome], 1 August 1609. Cf. Biagioli, *Galileo's Instruments of Credit* (2006), 121. See also Biagioli's paper in this volume.

[30] Galilei, *Opere*, 10 (1900), 252: Giambaptista della Porta to Federico Cesi.

[31] Simon Marius, *Mundus Jovialis* (Nurnberg 1614) 6verso. Cf. A.O. Prickard, 'The 'Mundus Jovialis' of Simon Marius,' *The Observatory* 39 (1916) 371.

[32] *Ibidem*. Prickard in his translation erroneously wrote the name as 'John Baptist Leuccius.'

[33] See for most examples: Sluiter, 'The Telescope before Galileo' (1997).

[34] Chapman, 'The Astronomical Work of Thomas Harriot' (1995) 101.

[35] Cf. ref. 29.

[36] De Waard, *Journal tenu par Isaac Beeckman. Tome 1: 1604-1619*, 11 note.

[37] Cf. Vollgraff, 'Brieven' (1914); De Wreede, *Willebrord Snellius* (2007) 68-69. Concerning a telescope Snellius had ordered for his relative Amelis van Rosendael (1557-1620), or Aemilius Rosendalius in Latin. See also Zuidervaart, *Telescopes from Leiden Observatory* (2007), introduction.

[38] Keil, *Augustanus Opticus* (2000) 33; Wattenberg, *Fabricius* (1964), 21-24.

[39] Chapman, 'The Astronomical Work of Thomas Harriot' (1995) 102.

II. THE PRIORITY QUESTION

Lipperhey, Metius or an unknown a genius

With the rapid dissemination of the telescope the priority question about the inventor soon arose. As early as 1612, Girolamo Sirtori remarked:

> Dutchmen, Frenchmen, Italians from everywhere rushed forward driven by the desire for gain, and there was no one who would not claim himself the inventor.[40]

Sirtori himself downplayed the achievement of the invention by presenting the story of 'Johannes Lippersein' [Lipperhey], who would have grasped the idea from 'a genius or some other man, as yet unknown, of the race of Hollanders,' who had visited this Middelburg spectacle maker. This visitor supposedly ordered 'many lenses to be made, concave as well as convex.' When he returned, the man selected and aligned two lenses, 'a concave and a convex one,' and in this way inadvertently revealed the secret of the telescope. Lipperhey 'by no means devoid of ingenuity, and curious about the novelty' would have imitated the visitor, and after having joined both lenses in a tube, rushed to The Hague, to the court of Count Maurits, to show him the invention.[41]

So, a few years after the demonstration in The Hague doubts were already being raised about the identity and location of the 'inventor.' In Tuscany Raffael Gualterotti asserted to have invented the telescope a decade earlier, and others in Italy were eager to claim the invention for their own region. As far as Gualterotti was concerned, the glory of the Florentines could not be praised enough.[42] However, most people were convinced of the Dutch origin of the telescope. One of those was George Fugger in Venice, a member of the famous banking family who worked as an ambassador for the Holy Roman Empire. On 16 April 1610 he wrote to his correspondent Johannes Kepler in Prague, commenting on Galilei's eye catching demonstrations in Italy:

> The man [Galilei] [...] intends to be considered the inventor of that ingenious spyglass, despite the fact that some Dutchman, on a trip here through France, brought it here first. It was shown to me and others, and after Galilei saw it, he made others in imitation of it and, what is easy perhaps, made some improvements to what was already invented.[43]

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[40] Van Helden, *Invention* (1977), 50.

[41] *Ibidem*. See the citation in the introduction, elsewhere in this volume.

[42] Van Helden, *Invention* (1977), 46.

[43] Sluiter, 'The Telescope before Galileo' (1997) 211, citing Kepler, *Gesammelte Werke* (1937) xvi, 302. See about the question about Galilei's attributed claim: Rosen, 'Did Galilei Claim he Invented the Telescope?' (1954).

But although Galilei was certainly eager to be seen as an ingenious inventor, in this case Fugger was too hard on him. As a matter of fact, in his *Sidereus Nuncius*, published in March 1610, Galilei admitted that the telescope had originated in the Netherlands.[44] From his correspondence we also know that Galilei was aware of the fact that the first demonstration had been at the court of Count Maurits.[45] However, in all these reports the name of the demonstrator – Lipperhey – was never mentioned. And, as time went by, Lipperhey was forgotten.

1614-1637: The canonisation of Jacob Adriaensz Metius as the inventor

In the Netherlands this development was stimulated by the printed works of Adriaen Adriaensz Metius, professor of mathematics at the University of Franeker, the second institution of higher learning in the Netherlands. Adriaen was the learned brother of the Alkmaar 'inventor' Jacob Adriaensz Metius, and in all his astronomical works, starting with the 1614 edition of his *Institutiones astronomicae et geographicae*, he claimed that around 1608 his brother Jacob had invented the 'far sights' ('verre ghesichten'), with which one could observe several planets unknown to the ancient astronomers, among which were also some 'planets' moving around Jupiter. And although Adriaen Metius claimed that his brother Jacob had kept his telescopes secret, other sources suggest that at least some of Jacob's telescopes were disseminated among relatives and close friends. It is known for certain that at least in 1613 Adriaen himself used a telescope for astronomical observations. That year he showed the instrument to his Groningen colleague and friend Nicolaas Mulerius, who used another one for the observation of sunspots. A few years later Mulerius used such a 'newly invented spectacle' for the investigation of the great comet of 1618.[46] Another 'mathematical glass' was used by Pierius Winsemius, a close friend of the Metius family, this time for the observation of ships some 30 miles away.[47] And probably in 1614 even Nicolas-Claude Fabri de Peiresc, in Aix-en-Provence, possessed one of the first telescopes made by Jacob Adriaensz Metius, 'the true first inventor' of the 'new Galilean telescopes,' bestowed on

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[44] Van Helden, *Invention* (1977), 45.

[45] Galilei, *Opere*, 10 (1900), letter 231: Galileo [from Venice] to Benedetto Landucci [in Florence], 29 August 1609.

[46] Waterbolk, 'Van scherp zien en blind zijn' (1995) Cf. Mulerius, *Hemelsche trompet* (1618): 'Want wyluyden connen se anders qualic sien, dan met behulp van de nieu gevonden bril.' ('Because we could only see them properly with our newly invented spectacles').

[47] Winsemius, *Chroniqve* (1622).

him by the same Winsemius, together with Jacobs portrait (since lost).[48] Thus already around 1625, several Dutch officials believed that Jacob Adriaensz Metius was the inventor of the telescope, including the Dutch lawyer Hugo de Groot (Grotius) and the poet-diplomat Constantijn Huygens.[49]

So when, in 1634, professor Adriaen Metius died, no one in the Netherlands protested when Jacob Adriaensz was praised in Adriaen's funeral eulogy at the University of Franeker as the sole inventor of this famous '*tubulus ille opticus*.'[50] For the rest of Europe, Metius' fame as *the* inventor of the telescope was established in 1637 by René Descartes in *La Dioptrique,* an appendix to his famous *Discours de la Methode*, in which Descartes gave the following account of Metius' invention, a story he had probably heard from Adriaen Metius himself, when, in 1629 as a student at Franeker University, he had attended Metius' lectures on optics:

> It was about thirty years ago that a man named Jacob Metius, of the city of Alkmaar in Holland, a man who had never studied, although he had a father and a brother who made a profession of mathematics, but who took particular pleasure in making burning mirrors and glasses, even making them out of ice in the winter, as experience has shown they can be made, having on that occasion several glasses of different shapes, decided through luck to look through two of them, of which one was a little narrower in the middle than at the edges, and the other, on the contrary, much thinner at the edges than in the middle. And he put them so fortunately in two ends of a tube, that the first of the telescopes, of which we are speaking, was put together. And it is entirely based on this model that all the others which have been seen since have been made without anyone yet, as far as I know, having sufficiently determined the shapes that those glasses ought to have.[51]

1655-1656: Inventors reshuffled in Borel's 'De Vero Telescopii Inventore'

In the Netherlands Metius fame as *the* inventor of the telescope remained virtually unchallenged until 1655. That year Sir Willem Boreel gave his judgment.

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[48] Galilei, *Opere*, 16 (1906), letter 2858: Niccolò Fabri Di Peiresc to Galileo Galilei, 24 January 1634 and Gassendi, *The Mirrour of True Nobility & Gentility* (1657/2007). See also: Peiresc to Dupuy, 8 November 1626, in: De Larroque, *Lettres de Peiresc*, 1 (1888) 79-80, in which 'Jaques Methius' [= Jacob Metius] is called 'Le vray inventeur primitif' of the 'nouvelles lunettes de Galilee.'

[49] Hugo de Groot to his brother Willem de Groot, 10 June 1622, cited by Tierie, *Cornelis Drebbel* (1932) 19, 97; Worp, *Briefwisseling Constantijn Huygens* (1911-1917), letter no. 1270 (29 October 1635).

[50] Waterbolk (1995) 198, citing from: Winsemius, *Oratio fvnebris* (1634).

[51] Descartes, *La Dioptrique* (1637), translated from the Dutch edition by J.H. Glazemaker of 1659.

He was a Middelburg-born diplomat, knighted in 1618 by the English king. At the time, Boreel was ambassador of the Dutch Republic at the French court. In France Boreel had been acquainted with Pierre Borel, a court physician with a keen interest in optics.[52] Because in his influential *Oculus Enoch et Eliae* of 1645 Schyrl de Rheita had paraphrased the story published by Sirtori in 1618, the name of 'Ioannes Lippensum of Zeeland' had reappeared on the scene. In discussions about the invention of the telescope with Borel and others, Boreel had been annoyed about the fact that it seemed that 'everyone seeks to claim the honour of that invention for himself.'[53] For instance 'Galilei, Welser, and Metius of Alkmaar had assumed that honour, or it has been ascribed to them, especially to the last.'[54] But according to Boreel, in his youth, he personally had known the 'man who is said to have been the first inventor of the said telescopes.'[55] As Boreel was 'always eager to contribute anything that can add to the honour and renown of my fatherland,' he persuaded Borel to compose a documented account about this 'true inventor of the telescope.'[56] To assist Borel in this noble enterprise, Boreel addressed the Middelburg magistrates with an official request. According to Boreel, the honour of the invention belonged to Middelburg, and he desired to establish this fact once and for all by means of a properly documented investigation. In his request Boreel presented the following description of the person, he remembered to be the inventor of the telescope:

> This man lived in Middelburg in the Capoen Street, on the left side coming from the Green Market, in about the middle of the block, in the little houses against the New Church. He was a man of small means, had a modest shop, and many children, whom I still saw afterwards when I came back to Middelburg when I was older.[57]

A request from such an esteemed person had to be taken very seriously, so the Middelburg magistrates appointed Jacob Blondel, one of their senior members, as official investigator to search for witnesses who could testify about what had happened half a century earlier. Blondel's task did not appear to be very difficult, for Boreel's description of the inventor and his modest

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[52] Cf. Chabbert, 'Pierre Borel' (1968).

[53] Van Helden, *Invention* (1977), 55.

[54] *Ibidem.*

[55] *Ibidem.*

[56] Borel, *De vero telescopii inventore* (1656). See also Nellissen, 'De echte uitvinder van de telescoop' (2007).

[57] Van Helden, *Invention* (1977), 55.

shop, fitted exactly with that of the late Hans Lipperhey and the location of his former spectacle workshop in the Middelburg 'Capoenstraat.' Lipperhey had indeed been a modest man, and had had at least seven children.[58] So Blondel rather quickly succeeded in finding three witnesses, a former son-in-law and two former neighbours, all of whom confirmed that Hans Lipperhey (or Laprey[59]) had indeed constructed 'verresiende brillen oft verrekijckers' in his shop at the Capoen Street, having a sign representing some telescopes. So everything seemed to confirm Boreel's initial memory.

However, at the end of January 1655, just before the investigation ended, two new witnesses suddenly stepped forward, presenting a completely different account of what had happened some fifty years before. The main witness was Johannes Sachariassen,[60] a skilled lens grinder living in Middelburg, who

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[58] The exact location of the houses of Lipperhey and Jansen was found by C.J. Serlé in 1816. He also found that only four of Lipperhey's children (Susanna, Claes, Hans junior and Abraham) were still alive at the time of his death. See about the eldest daughter also: Zeeuws Archief, Middelburg, Rechterlijk Archief Zeeuwse Eilanden, no. 115a, folio 69^{verso}. (Deed of the Middelburg Orphans Chamber, concerning Susanna Lipperhey, dated 4 January 1636).

[59] Over the years the family name 'Lipperhey' appears to have changed into 'Laprij' or 'Lapree.' In the early eighteenth century several members of this family were living in Vlissingen (Flushing).

[60] Johannes Sachariassen (1611- before 1659) was the son of Zacharias Jansen and Catharina de Haene. Already at the age of 19, in April 1630, he is mentioned as a 'brilmaker.' At that time he bought some 'Neurenburgeryen,' most probably referring to toys. In 1632 he married with Sara du Pril (overl. 1659) from Veere, widow of Marten Goverts. At this occasion his aunt Sara Boussé [= Bouché] testified that both his parents were dead. In 1634 Beeckman received from Sachariassen some lessons in the grinding of lenses, in his Middelburg glass grinding workshop. This shop was probably in the 'Sint Janstraat,' where his widow in 1659 died. Cf. De Waard, *Uitvinding* (1906), 153 and 333; De Waard, *Journal Beeckman*, 4 (1953), passim. Zeeuws Archief, Middelburg, Archief Rekenkamer van Zeeland D (list receivers of the 'collaterale successie'), 8 March 1659.

claimed that his father, the late Zacharias Jansen,[61] was the true inventor. His aunt Sara Goedaerts,[62] Zacharias' only sister, supported his claim. According to Sachariassen's account his father had invented the telescope, not in 1608, but already in the year 1590.[63] Of these first telescopes, having a length of about 16 inches, one had been presented to Count Maurits and another one to Archduke Albertus. In the year 1618 he and his father had invented the longer telescopes, which were used for observing the stars and the moon at night. Shortly thereafter, in 1620, (Adriaen) Metius and Cornelis Drebbel[64] had come to their shop to buy such a telescope, which both of them had later tried to copy. According to Sachariassen, it was very regrettable that 'Reynier

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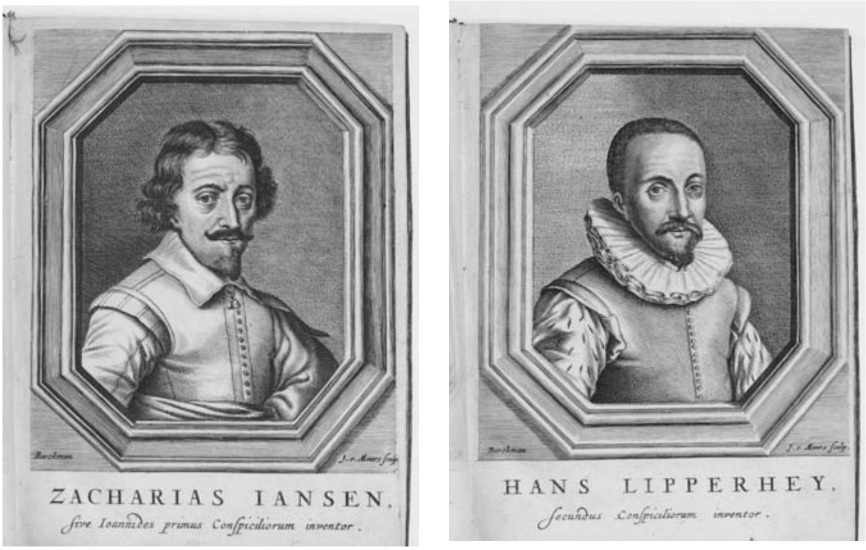
[61] Zacharias (or Sacharias) Jansen (or Janssen) [various spellings were used at the time] was born in 1585 in The Hague. His parents were Hans Martens and Maeyken Meertens, both probably coming from Antwerp. In 1610 he married in Middelburg with Catharina (or Catelijntjen) de Haene from this same city. In 1611 their only son Johannes Sachariassen was born. In 1616 Zacharias was mentioned for the first time as a 'brilmaker.' He had probably inherited the tools of the late Lowys Lowyssen, 'geseyt Henricxen brilmakers,' for in 1615 he was appointed guardian of the two children of this spectacle maker. In 1618 the couple Jansen-De Haene moved to nearby Arnemuiden, after Zacharias has been exposed as a counterfeiter. In 1619, in Arnemuiden, he was again accused for the same offence, together with the local 'schout' (the head of the justice department). After being on the run for a while, Zacharias Jansen returned to Middelburg in 1621, where he bought a house. In 1626 he was engaged in legal proceedings, being accused of not paying his mortgage. In 1624 his wife died, after which he remarried in August 1625 with Anna Couget from Antwerp, the widow of Willem Jansen (perhaps a relative). With her, Zacharias 'den brillenmaker' moved to Amsterdam, where in November 1626 he rented part of the 'Huis onder 't Zeil' at the Dam Square. But in May 1628 he was declared bankrupt. Jansen must have died before 1632, for in that year his sister testified that he was dead. Cf. De Waard, *Uitvinding* (1906); Breen, 'Topographische geschiedenis' (1909), 183, 188 and Wijnman, 'Sacharias Jansen te Amsterdam' (1933) and idem, 'Nogmaals Sacharias Jansen' (1934).

[62] Sara Goedaert (born Sara Jansz), was the only sister of Zacharias Jansen. With her brother she is mentioned in 1622 as the owner of the small house, built against the wall of the 'Nieuwe Kerk' at the 'Groenmarkt' in Middelburg. Her late husband, Jacob Goedaert, 'of Embden' had worked at the Mint, which was located in a neighbouring abbey. In August 1625 Sara Goedaert was a witness at the second marriage of her brother Zacharias Jansen and Anna Couget of Antwerp. In October of the same year she herself remarried with Abraham Bouché, also from Antwerp. In July 1632 she was mentioned again as a widow, after when she returned to bear the former name of her first husband, Jacob Goedaert. Cf. De Waard, *Uitvinding* (1906), 322; 327; 328; 330-331.

[63] Van Helden, *Invention* (1977), 55.

[64] Cornelis Drebbel (Alkmaar, 1572-1633) was a natural philosopher and technician, who invented several devices, including a proto-type submarine. Drebbel is often viewed as the inventor of the compound microscope (*c.* 1620), which according to others had been developed from the telescope by Galilei in the 1610s. Cf. Van Helden, 'The Birth of the Modern Scientific Instrument' (1983) 71. See also: Turner, 'Animadversions' (1985).



Ill. 5. Jansen and Lipperhey, as depicted in Borel's *De Vero Telescopii Inventore* (1656).

Ducartes,' Cornelis Drebbel and the former medal maker Johannes Looff[65] were not alive anymore, for they would surely have confirmed his testimony.[66]

In March 1655, these testimonies were sent to ambassador Willem Boreel in Paris. What then happened next is remarkable. In July 1655, in a letter to Borel, Boreel rephrased his earlier statement about the invention of the telescope. He now followed the testimony of Sachariassen almost to the letter, and added some other particulars. Briefly, Boreel's statement was as follows: in 1591 (the year he was born), near his birthplace in Middelburg, a spectacle maker lived in a house built against the New Church. His name was Hans and he had a wife called Maria. They had three children: two daughters and a son. As a child, Boreel had often played with this boy, called Zacharias. In those days he also frequented their workshop. At one of those occasions he had heard that Hans and Zacharias had first invented the microscope, and after that, the telescope. This lucky event had to be dated around 1610. In 1619, when Boreel visited London, he had seen a microscope at Cornelis Drebbel's house, which according to his memory was made by the two Jansens. As far as

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[65] Johannes Looff (d. 1651) was a silversmith, working in Middelburg at least from 1629. In 1634 he became the official die cutter of the Middelburg Mint, which was located near Jansen's house. Cf. De Man, 'Johannes Looff' (1925) 8-9.

[66] Van Helden, *Invention* (1977), 55.

Lipperhey was concerned, Boreel now rather closely followed Sirtori's earlier account about the unknown visitor, who by a twist of fate had called upon Lipperhey, although he actually been looking for the Jansens. Lipperhey, being a keen spectacle maker, had listened closely to the visitor, and after his departure he had reconstructed the device, solely by the sharpness of his mind. So, according to Boreel, although Jansen had been the first, surely Lipperhey deserved to be called the second inventor.

Pierre Borel, now being presented with two Middelburg candidates for the invention, did not hesitate in drawing his own conclusions. Boreel's high social status did not allow for any objections to be made, so in his book *De Vero Telescopii Inventore*, published in The Hague in 1656, Borel presented the hitherto unknown Zacharias Jansen as the first inventor and Hans Lipperhey as the second (ill. 5).[67] Thus Jansen's claim for the invention remained the favoured one for many decades to come.[68]

1816-1824: Preparations for a memorial for Jansen[69]

A century and a half after the publication, Borel's account generated a lot of activity and excitement in Zeeland. This episode started on 4 January 1816 when Johannes de Kanter Phillippuszoon, the secretary of the *Zeeuwsch Genootschap der Wetenschappen* (the Zeeland Scientific Society) in Middelburg, gave a lecture on the invention of the telescope. His narrative closely followed Borel's account of what had happened, and in his conclusion De Kanter pleaded for the erection of a monument for Zacharias Jansen, to commemorate the wonderful accomplishments of this 'native son of Zeeland.'[70] De Kanter's plea was in harmony with the spirit of the time and fell on fertile soil. In 1816 the 'Kingdom

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[67] In his *De Vero Telescopii Inventore*, Borel honoured both 'inventors' with a portrait engraving. Both portraits were made by the painter Hendrick Berckman[s] (1629-1679), living in Middelburg since 1654. They were engraved by Jacob van Meurs, an engraver (and later publisher) active in Leiden and Amsterdam from 1651 until 1680. Whether these portraits were made after older originals, we probably will never know.

[68] See however the Frisian writer Wiaerda, *Naauwkeurige verhandelinge van de eerste uytvindingen en uytvinders* (1733), who favours Metius, in spite of reading Borel's *De Vero Telescopii Inventore* (1656).

[69] This section is a shortened English adaptation of my paper: 'Uit vaderlandsliefde' (2007). It is based on documents which have survived the Second World War. See: Zeeuwse Bibliotheek, manuscripts of the *Zeeuwsch Genootschap der Wetenschappen*, nos. 211, 249, 257, 1110, 2862, 2863, 3675, 3676, 3688, 3953 en 3977. Courtesy Mrs. Katie Heyning, Middelburg, who brought these documents to my attention.

[70] This was not true. Ironically in 1906 it was found that Jansen actually was born in The Hague (Holland). Cf. De Waard, *Uitvinding* (1906), 323.

Ill. 6. Concept for a memorial for Jansen (1816). [Zelandia Illustrata, Zeeuws Archief, Middelburg].

of the Netherlands' had just been newly formed, and after the Napoleontic era, during which the country had been annexed by France, national heroes were badly needed as icons, to help in the creation of a national feeling (a so-called 'Vaderlandsch Gevoel') for the new centralized state. This cultural nationalism used real and alleged heroes to establish the desired national identity.[71]

Nicolaas Cornelis Lambrechtsen van Ritthem, the president of the *Zeeuwsch Genootschap*, immediately lent his support to this idea for a memorial for this famous Zeelander, who with the invention of the telescope and the microscope had changed the world. However, Lambrechtsen, a gentleman-historian, not only arranged for a design for this memorial (ill. 6), but he also formed a committee with the task of searching the archives, in order to build a stronger case. In June 1816 he approached several persons with the request to check the old records in their possession for any particulars concerning Jansen and the invention of both the microscope and the telescope. Among them were Cornelis Johannes Serlé, director of the Middelburg mortgage registry office; Meinard van Visvliet, secretary of the city council of Middelburg, Paulus Benoit, sexton of the Middelburg churches; Cornelis de Fouw, archivist in The Hague; and finally the (unnamed) librarian of Leiden University.

The harvest of these archival investigations was full of surprises. The most unexpected was that almost nothing could be found on Jansen, whereas all

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[71] Cf. Van Sas, 'Vaderlandsliefde, nationalisme en Vaderlands Gevoel in Nederland' (1989); Bank, *Roemrijk Vaderland*. See also: Van Berkel, 'Natuurwetenschap en cultureel nationalisme' (1991).

Ill. 7. The 'Nieuwe Kerk' in Middelburg. In 1608 the spectacle maker Hans Lipperhey lived in the house depicted at the far right on this engraving. Around the corner – built against the left side wall of the church, near the 'Mint Gate' – the house can be seen which at that time was occupied by the young Zacharias Jansen. Engraving by Th. Koning from *Zeelands Chronyk Almanach*(1779). [Zelandia Illustrata, Zeeuws Archief, Middelburg].

sorts of new details had emerged concerning Hans Lipperhey. Also, only the 1608-patent applications by Lipperhey and Metius were found, a very inconvenient result for the Zeelanders, as everyone knew that Lipperhey was born in Wesel, at that time considered to be a German city. The facts about Metius of Alkmaar were equally displeasing because Middelburg, the capital of the province of Zeeland, could not be the location of a statue erected for 'foreigners,' born in Wesel or Alkmaar.

Even worse were the findings of Serlé. He discovered that Zacharias Jansen was born in 1585, a fact which made it virtually impossible that Jansen could have made a major invention at the age of five! Besides, whereas Lipperhey was mentioned as a spectacle maker in various documents beginning in 1602, Jansen was mentioned only in 1615 as the guardian of the two children of the Middelburg spectacle maker 'Lowys Lowyssen, geseyt Henricxen brilmakers.' The only comforting discovery was the fact that Jansen and Lipperhey had been close neighbours (ill. 7).

In August 1818 Lambrechtsen presented his conclusions to the *Zeeuwsch Genootschap*. The most painful result was the fact that no document could be found in which Jansen, or his father, was mentioned as a spectacle maker. These disappointing archival results had kept Lambrechtsen busy for a quite some time, but in the end he had concluded that ambassador Willem Boreel's authority had to be regarded as decisive. His high aristocratic background was a guarantee for his trustworthiness.[72] So Boreel's judgment that Jansen was the first inventor had to be accepted, in spite of Jansen's securely documented birth date, 1585. Jansen had probably found the two-lens-arrangement, when as a youngster he played in his father's workshop. First he must have invented the microscope – as De Kanter had assured Lambrechtsen – and after that the telescopic arrangement had followed easily. Moreover, Lambrechtsen reasoned, this hypothesis was in harmony with the tradition mentioned by several popular authors, that the invention had been done by children, during their play with some convex and concave spectacle glasses.[73]

Regarding the question as to when prince Maurits had learned about these inventions, Lambrechtsen guessed that these instruments had been presented to him in May 1605, when the prince had visited Middelburg. The telescope's strategic importance must have been the reason why the instrument had been kept a secret. Nevertheless, at some moment, Lipperhey must have heard about Jansen's invention, which stimulated him to produce his own version. It must have been this instrument that in 1608 had been presented in The Hague. It was clear, Lambrechtsen continued, that the invention had been a lucky coincidence. It was amazing that it was achieved by two simple spectacle makers, without any theoretical physical or mathematical knowledge. Nevertheless, such an important invention should be commemorated, and therefore the board of the *Zeeuwsch Genootschap* should now decide which steps were to be taken to honour the remarkable Zacharias Jansen.

However, after the disappointing archival search, the plans for the erection of a memorial for Jansen were tabled. In 1819 De Kanter tried again to revive the initiative by writing a memoir, in which he summarized the known

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[72] On the importance of social status on the reliability of witnesses, see for instance: Shapin, *A Social History of Truth* (1994).

[73] See for instance: 'Bericht van een Engelschen Schryver rakende verscheide nuttige Uitvindingen in de Neederlanden,' in: *Hollandsche Historische Courant*, no. 97 (14 August 1749). Cf. *Time's Telescope* (1818), 169-170: 'The discovery is traced to an incident of the simplest kind. The children of a Dutch spectacle maker, being at play with some spectacle glasses, made use of two of them together, the one convex and the other concave, and looking at the weathercock of a church, observed that it appeared much nearer and larger than usual.'

facts and combined them with what he had learned on the development of the telescope in general. But his efforts were in vain and after Lambrechtsen's death in 1823, De Kanter could do little more than publish his own account in favour of Jansen, without giving credit to Serlé and others for their thorough researches in the archives of Middelburg.[74]

1822-1831: Van Swinden's researches, published by Moll

Without knowing about the investigation by the *Zeeuwsch Genootschap*, the Amsterdam professor Jan Hendrik van Swinden, at that time probably the most renowned Dutch physicist, had at the same time also embarked on a study of the telescope's invention. In 1822 and 1823, in a series of lectures for the Amsterdam intellectual society 'Felix Meritis,' Van Swinden presented the results of his own research. It was the 'swan song of a great scholar,' as his pupil, the Utrecht professor of physics Gerrit Moll, would later write, because Van Swinden passed away before he had time to write up his lecture notes and publish them.[75] Moll completed Van Swinden's mission, which was aimed at enhancing the honour and glory of the Dutch nation. Van Swinden's account was published in 1831 by Moll, in a Dutch and also in a – somewhat shortened – English version.[76]

Van Swinden reached a diametrically opposite conclusion to the one formulated only shortly before by Lambrechtsen and De Kanter. Van Swinden, too, had found the 1608-patent applications of Lipperhey and Metius, and after a very thorough investigation of all sorts of seventeenth-century books and documents, he – and his interpreter Moll – had come to the conclusion that Lipperhey had been the first inventor, followed shortly afterwards by Jacob Adriaensz Metius. Only these two men deserved to be honoured for this invention. So, since then in most English publications, Lipperhey, and not his near neighbour Jansen, was put forward as the telescope's first inventor.[77]

One of the most curious things concerning the Van Swinden-Moll investigation is the fact that they appeared to be completely unaware of the extensive researches that had been conducted only shortly before in the Zeeland archives. It is evident that the rather large harvest of archival information that

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[74] De Kanter, 'Over de uitvinding der verrekijkers' (1824).

[75] Moll [& Van Swinden], 'Geschiedkundig onderzoek' (1831): offprint, page 2.

[76] Moll, 'On the first Invention of Telescopes' (1831).

[77] Moll [& Van Swinden], 'Geschiedkundig onderzoek' (1831), offprint, page 69-71. In both the Dutch and the English version, Moll used the wrong spelling 'Lippershey' – with a 's' – thus introducing the erroneous form under which his name has been spelled in English literature.

had been dug up in the Middelburg archives had been deliberately concealed from the two researchers. As Moll reported the following:

> Mr Van Swinden has called for in investigation into the city archive of Middelburg, in order to verify whether there could be found anything more about Lipper(s)hey or Jansen. However, although a very diligent search was made for such documents, nothing was found. Also the original testimonies [from 1655], given by Boreel to Borel, were not preserved among the papers of the city. [...] Also the houses, where Lipperhey and Jansen used to live, have since been taken down, [and an open space now occupies the place where the telescope was invented].[78]

But Van Swinden had been wrongly informed. The original testimonies of 1655 had probably been discovered in the city archives of Middelburg as a direct result of Van Swinden's request. It was most likely De Kanter himself, who at that time was writing his own nationalistic history of the Province of Zeeland, who withheld these documents. De Kanter published them in 1835, in an explicitly pro-Jansen pamphlet, not long after the publication of the Van Swinden-Moll pro-Lipperhey version of the events. De Kanter even reproduced a facsimile of Sachariassen's testimony, in which he declared that his father, Zacharias Jansen, had invented the telescope in 1590.[79] Remarkably, De Kanter did not make any reference to Moll's publication in the official proceedings of the Royal Institute (Koninklijk Instituut), a periodical De Kanter surely was familiar with.[80]

Van Swinden had also been wrongly informed about the demolition of the houses of both 'inventors.' In the 1830s all houses concerned were still extant: the one once occupied by Jansen, and the two other houses which once had belonged to Lipperhey. The exact locations of these houses had been established in 1816 by Serlé. It was only during the refurbishment of the *Nieuwe Kerk* (The New Church) in 1848-1851, that two of these houses, built against the wall of the church, were taken down. One of them, called *De Amandel Bale*, the house which Lipperhey occupied at the time of his 1608-patent-application, was painted in watercolour in 1848, only shortly before it was demolished (ill. 8-A). After the mid-1850s only the neighbouring house,

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[78] Moll [& Van Swinden], 'Geschiedkundig onderzoek' (1831): offprint, 70. In the citation the addition between brackets comes from the English version.

[79] De Kanter & Ab Utrecht Dresselhuis, *Oorspronkelijke stukken* (1835). In 1854, De Kanters son-in-law and co-author Johannes Ab Utrecht Dresselhuis (1789-1861) later summarized De Kanters pro-Jansen arguments in the periodical *De Navorscher* 4 (1854), 90-92.

[80] Conversely, Moll did not mention De Kanter's 1824-publication, as Elsevier observed in *De Navorscher* 4 (1854) 92.

which Lipperhey had bought in January 1609 with the money he had received for his three telescopes, remained. In about 1835, at De Kanter's request, the old name *De Drie Vare Gesichten* was painted again on its façade. This house was eventually destroyed in May 1940, during the German bombardment of Middelburg (ill. 8-B & 8-C).

1841: The discovery of an alleged Jansen telescope

In 1841, shortly after his inauguration, the Dutch King William II was scheduled to visit Middelburg. In preparation for this event, the antiquarian Pieter Johannes Rethaan Macaré, organized the first exhibition ever to honour the glorious past of Zeeland. On that occasion, out of the blue, a certain Zacharias Snijder stepped forward, claiming that he possessed the oldest examples of a telescope made by Zacharias Jansen as a family heirloom. These objects – four iron tubes with lenses – were put on display and shown to the king, who praised them as the 'first examples of an invention so priceless for the sciences.' From that time onwards these tubes 'which according to tradition were made by Jansen in 1590' were shown on several other occasions, thus establishing a verisimilitude of its own. With the result that in 1850, when Rethaan Macaré's son was an alderman in the Middelburg government, following the demolishment of the old houses at the 'Nieuwe Kerk,' a memorial stone was placed on the spot where Jansen's house had once stood. The text on this 'very humble monument' reads as follows: *'Against this wall stood the house of ZACHARIAS JANSE, Inventor of the telescopes, in the year MDXC'* (ill. 9).[81]

This simple token of honour was not enough in the eyes of the Utrecht professor Pieter Harting, at that time the leading authority on optics in the Netherlands. In 1858, in a widely-read popular journal, he pleaded vigorously for the erection of a large monument in Gothic style for the two Middelburg inventors, thus uniting the conclusions of Moll and De Kanter.[82] And although Harting's appeal went unheeded, he remained very interested in the invention. A few years earlier, in 1853, in an assembly of the Royal Netherlands Academy of Arts and Sciences, Harting had defended Jansen's case as the inventor of the microscope, rebutting an Italian paper by the Abt Redi, in which Cornelis Drebbel of Alkmaar was put forward as the inventor.[83] And so, when in 1866,

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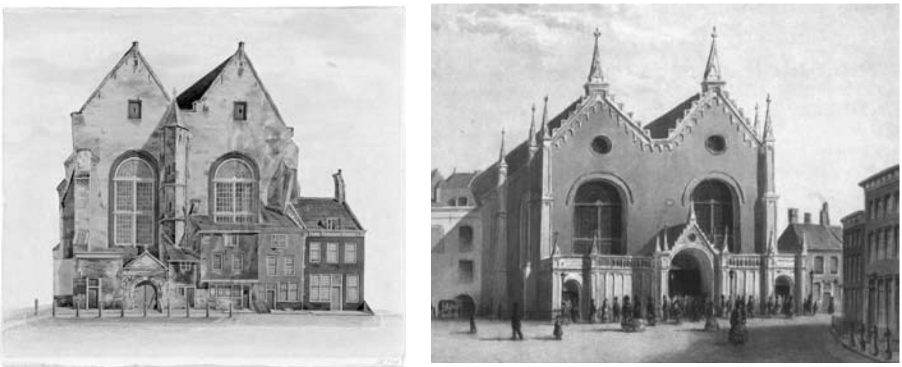
[81] Cf. *Kroniek van het Historisch Genootschap te Utrecht*, 2e serie, 7 (1851), 194-198; *De Navorscher* 1 (Bijblad 1853) 12, 450.

[82] Harting, 'De twee gewigtigste Nederlandsche uitvindingen' (1859).

[83] Harting and Matthes, 'Verslag over den vermoedelijken uitvinder van het microskoop' (1853). Harting was in fact the author of this article, see page 118.



Ill. 8. Façade of the *Nieuwe Kerk* at the Kapoenstraat in Middelburg. *Upper left*: Situation in 1848, the year in which these houses were demolished. The house at the right, was called *De Amandel Bale*. It was here that in September 1608 Hans Lipperhey made his first telescope. In the next year he bought the neighbouring house (not drawn) which he called the *De Drie Vare Gesichten*, after the three telescopes he made for the States General. *Right*: Situation in 1851, representing the refurbished Neo-Gothic façade of the church. The house *De Drie Vare Gesichten* is depicted at the far right. *Bottom*: The ruins of *De Drie Vare Gesichten*, after the bombardment of Middelburg in May 1940. The façade of the church had been re-reconstructed earlier in the 20th century. [Zelandia Illustrata, Zeeuws Archief, Middelburg].

the *Zeeuwsch Genootschap* obtained the 'Jansen-tubes' as a legacy of the late Zacharias Snijder, Harting was the obvious man to investigate them.

Harting's findings on the four tubes were that they were made in the same workshop, at a time when the art of making optical instruments had still been very crude. They certainly had to be dated around the turn of the sixteenth and seventeenth century. As Harting did not know any other opticians working in that period, these tubes were probably made by father and son Jansen. And as the shortest tube functioned as a crude microscope, with only a small magnification, this most likely had to be the oldest extant Jansen-microscope (ill. 10-A

Ill. 9. Memorial stone for the alleged invention of the telescope by Zacharias Janse(n), placed in 1851 in the wall of the 'Nieuwe Kerk' in Middelburg, the church against which Jansen's house once stood. [Photo: Peter Louwman]

and ill. 10-B).[84] As a result, in 1869, in the printed catalogue of the collections of the *Zeeuwsch Genootschap*, the Snijder-tubes were presented as almost certainly made by Zacharias Jansen.[85] And as Harting had 'identified' the smallest tube as a microscope, this tube was sent to the 1876-Exhibition of Scientific instruments in South Kensington, to be placed in the gallery of 'Historical Treasures' (ill. 11).[86] Subsequently, copies of this alleged 'Jansen-microscope' were ordered by a number of museums all over the world (ill. 12).[87] No wonder that in 1890-1891 this 'item of evidence' of Jansen's invention became the centre piece of an exhibition held in Antwerp, commemorating the presumed 300-year anniversary of the invention of the microscope by 'Hans et Zacharias Janssen de Middelbourg, inventeurs du microscope composé.'[88] And even today, in 2009, images of this tube can be found on the internet claiming it to be the oldest extant microscope, of which 'most scholars agree that the invention […] can be credited to Zacharias Janssen in the late sixteenth century.'[89]

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[84] Harting, 'Oude optische werktuigen' (1867).

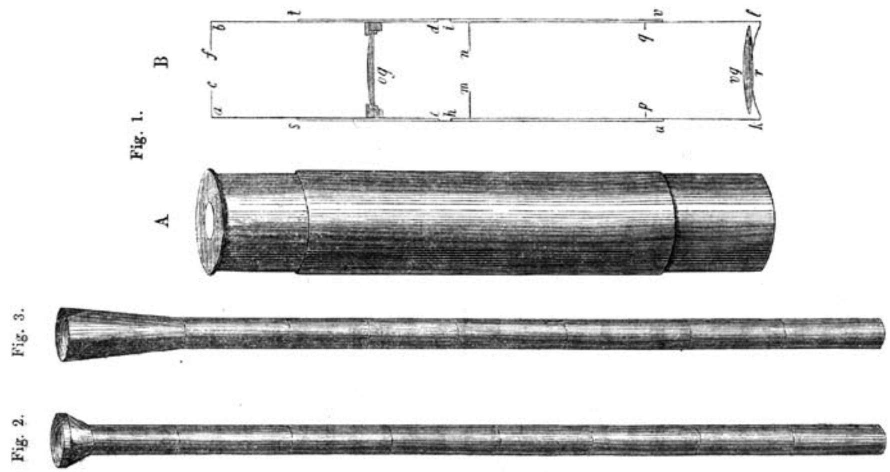
[85] Nagtglas, *Catalogus van Oud- en Zeldzaamheden* (1869), no. 46.

[86] De Clercq, 'The Special Loan Collection' (2002) 11-19; Part 4: Photographs and copies, in: *ibidem*, no. 76 (March 2003) 10-15.

[87] De Clercq, 'The Special Loan Collection' (2002), 13-15. See in more detail about the tubes: Harting, 'Oude optische werktuigen' (1867) and Zuidervaart, 'Uit Vaderlandsliefde' (2007).

[88] On this commemoration, organised by Henri van Heurck, see Becker, 'Eene Neder-landsche uitvinding waardig herdacht' (1892); *Rapport du jury de l'exposition de microscopie générale & retrospective* (1891); Miquel, *Exposition générale et rétrospective de microscopie de la ville d'Anvers* (1892).

[89] Cf. http://micro.magnet.fsu.edu/primer/museum/janssen.html (consulted on January 2009).



Ill. 10. Zacharias Snijder's tubes, alleged to be from the Jansen workshop. The short tube was [wrongly] 'identified' in 1867 by Harting as a 'microscope'. The two long tubes were destroyed in 1940. Steel engravings taken from Harting (1859).

1885: Johannes Sachariassen exposed as a fraud

In the 1880s Jansen's fame as an inventor (of at least the microscope) was, therefore, again firmly established. Yet, the Zeeland historian Frederik Nagtglas wondered why. In 1887, in his biographical work *Levensberichten van Zeeuwen* he wrote:

> In fact, without any special reason the [Jansen]-tradition gradually increased in strength, and was confirmed especially when [...] in the side wall of the New Church a Belgian bluestone was placed, in order to indicate the place where once stood the house of Jansen, a man who was probably held in low esteem. [90]

Nagtglas, who had found in the Middelburg archives the earliest known entry of Lipperhey as a spectacle maker (in 1602), pleaded for a more well-balanced approach. As secretary of the 'Commission for the tracing and conservation of notable antiquities of Zeeland' he proposed the installation of a second freestone plaque, this time in the wall of the remaining house once occupied by Lipperhey. And indeed in 1875 this was done.[91]

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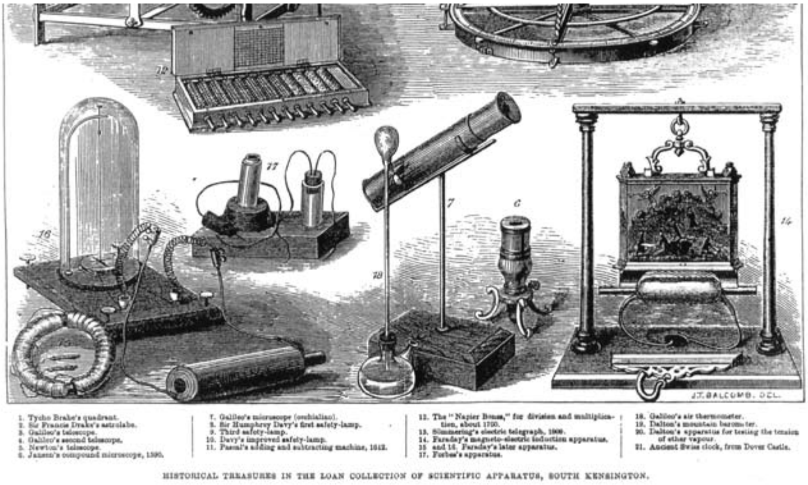
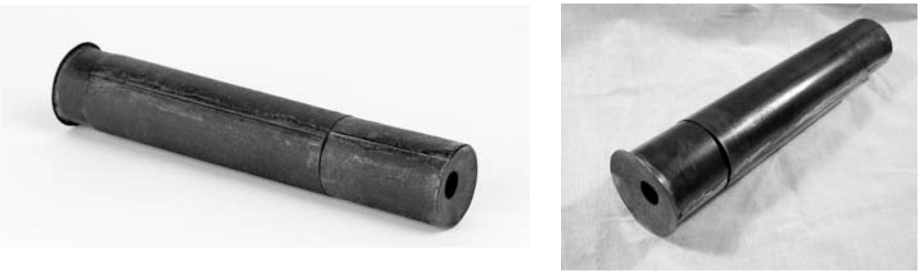
[90] Nagtglas, *Levensberichten*, 1 (1888), 475.

[91] Zuidervaart, 'Uit Vaderlandsliefde' (2007), 32.



Ill. 11. The Jansen 'microscope' (or Snijder's short tube), as exhibited in 1876 at the South Kensington Exposition. From: De Clercq (2003).



Ill. 12. *Left*: The Jansen 'microscope' (or Snijder's short tube), in its present state of preservation (Collection Koninklijk Zeeuwsch Genootschap der Wetenschappen, Zeeuws Museum, Middelburg). *Right*: Copy made in the 1890s by John Mayall. (National Museum of Health and Medicine, Washington, D.C., USA). Other copies are in the British Museum, London and the Deutsches Museum, Munich.

But the most profound contribution to Lipperhey's rehabilitation was made in 1885 by the antiquarian Johannes Godefridus Frederiks. In the Middelburg archives he had found the birth registration of Johannes Sachariassen, Jansen's son, whose testimony in 1655 had established his father's fame as an optical inventor. Now it became evident that Sachariassen had lied about his own age. As he was born in 1611, rather than in 1602 as he had claimed, Sachariassen could therefore not have made any contribution to the claimed invention of the long tubes in 1618. This falsification made his whole testimony extremely dubious and Frederiks was merciless in his final judgement about Jansen, whose fame he labelled as a 'scientific swindle':

> Zacharias Jansse, the new celebrity in the history of civilisation, is – except in the testimony of his own son, and in the protection of his ostensible playmate [Boreel] – an unknown bigwig. It's just that he is mentioned in the book of Borellus, which is written in the [Latin] language of the learned, and thus was spread everywhere. That is why his name was adopted by later writers, and protected by those who should have known better.[92]

According to Frederiks one of the worst things was that the ugly 'Escausian Stone, which was so hurriedly attached to the church wall, was seen as a testimony in its own right of this reprehensible kind of historical belief.' But luckily the inscription was of a 'praiseworthy shortness.'[93]

1906: Cornelis de Waard and his monumental study 'De Uitvinding der verrekijkers'

In spite of Frederiks' severe criticism, an opinion which had been strongly supported in a Dutch national newspaper by the Groningen teacher of astronomy Willem Gleuns[94], the Jansen-priority was still vigorously defended, first in 1890 in a small pamphlet by Herman Japikse, physicist and director of a Middelburg secondary school[95], and almost two decades later, with much more vigour and arguments by the mathematician and historian Cornelis de Waard (1879-1963), in his very well documented study *De uitvinding der verrekijkers.*[96]

In this study De Waard left no stone unturned. Not only had he read all the relevant contemporary literature on the subject, but, being the son of an archivist, he was also a very skilled archival researcher and had searched vigilantly in all the Zeeland archives. De Waard combined a series of findings:

(1) First, De Waard had found in the registers of the daily administration of the States of Zeeland a note stating that 'a young man' (of whom the name was left blank) 'also says he knows the art of making instruments for seeing far.' Thus there was indeed irrefutable contemporary evidence that another person had lived in Middelburg in 1608 with the knowledge how to construct a (crude) telescope. De Waard was convinced that this person had been Zacharias Jansen.

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[92] Frederiks, 'Johan Lipperhey van Wesel' (1885).

[93] *Ibidem.*

[94] W. Gleuns, *Algemeen Handelsblad* (25 December 1889). Critical newspaper article, commenting on the Antwerp exhibition commemorating the 300-year anniversary of the invention of the microscope.

[95] Japikse, *Het aandeel van Zacharias Janse* (1890).

[96] De Waard, *Uitvinding* (1906).

(2) Further, in the judicial archives, De Waard found several hitherto unknown documents relating to Jansen. And although almost all the documents revealed particulars only about Jansen as a counterfeiter, a pedlar or a drunk, De Waard concluded that Jansen must have been very dexterous with his hands, a quality very necessary for an optician.

(3) Then, in Simon Marius' *Mundus Jovialis*, published in Nuremberg in 1614, De Waard found a passage mentioning a telescope with a broken objective, that had been offered for sale by an unnamed Dutchman at the Frankfurt book fair in September 1608. According to De Waard, Jansen, a known pedlar, was a good candidate for this unnamed Dutchman, who apparently had been in the possession of a telescope, a month before Lipperhey's presentation in The Hague.

(4) But De Waard's most crucial discovery was an entry in a notebook of an early seventeenth-century natural philosopher, Isaac Beeckman, a native of Middelburg, who earned his living as rector of the Latin School of Dordrecht. Like many of his contemporaries in the 1630s, Beeckman had become very interested in optics, and his desire to obtain a good quality telescope had brought him *inter alia* to Middelburg to learn the art of glass grinding from Johannes Sachariassen, the son of Zacharias Jansen. In his notebook Beeckman kept a detailed record of all kind of particularities, and De Waard found an entry, dated 1634, in which the following statement was recorded:

> 'Johannes Sacharias says that his father made the first telescope in this country in the year 1604, after an example of an Italian, on which was written: ano 1[5]90.'[97]

Taken together, these 'facts' convinced De Waard not only of Jansen's genuine existence as a historical figure, but also made him very eager to support Borel's claim, which made Jansen the first Dutch telescope maker. And so, De Waard concluded, it must have been Jansen, who in 1604 made the first Dutch telescope, probably after an earlier model, made by one of the many Italians, which at the time were working in the Netherlands. This could have been one of the employees of the glassworks of Govaert van der Haghe, who in 1581 had founded in Middelburg the only glass factory in the Northern Netherlands where glass was made according to the high quality Venetian recipes. But what about Lipperhey? For De Waard, too, he remained the second inventor, and even the first constructor of a binocular telescope.

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[97] De Waard, *Uitvinding* (1906), 154-155 (with a facsimile); Cf. Van Helden, *Invention* (1977), 53.

Although De Waard had made exhaustive researches, in later years Dutch archives continued to reveal more particulars about Zacharias Jansen. In 1909, and also in 1933-1934, the Amsterdam historians Johannes Breen and Hendrik Fredrik Wijnman brought to light that Zacharias Jansen had moved to Amsterdam in November 1626, working there for some time as a spectacle maker. However, in that profession Jansen had not been successful, because he was declared bankrupt in May 1628.[98]

The Jansen-Lipperhey debate: the present state of affairs

So where do we stand in 2009, after 400 years of debate? It is obvious that De Waard, with his monumental investigation of the relevant sources, has contributed enormously to our knowledge about Jansen and Lipperhey, especially as he has printed most of his archival findings *in extenso*. Very luckily indeed, for the majority of these sources were destroyed in the Second World War. Of these documents, the most relevant one's were translated into English by Albert Van Helden in his own thoroughly documented study *The Invention of the Telescope*. In this monograph, published in 1977 (and reprinted in 2008), Van Helden concluded that the question 'who invented the telescope' actually boils down to the question: 'who first realized that such a device could be used for another purpose and set about adapting and improving it in order to obtain the greatest magnification possible?' That question, Van Helden remarked, could not be answered on the basis of the available evidence. He concluded:

> 'When all is said and done, we are still left with the fact that the earliest undeniable mention of a telescope is to be found in the letter of 25 September 1608, which Lipperhey carried to The Hague and that Lipperhey was the first to request a patent on the telescope. But to award the honour of the invention to Lipperhey solely on that basis is an exercise in historical positivism.'[99]

A fresh look at the events of 1608 was presented in 2007 by Rolf Willach, a Swiss optical engineer. He presented a elegant answer to the remaining and

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[98] Breen, 'Topographische geschiedenis' (1909) 183 & 188; Wijnman, 'Sacharias Jansen te Amsterdam' (1933) and idem, 'Nogmaals Sacharias Jansen' (1934). In the latter paper Wijnman distinguished two persons with the name Sacharias Jansen, both living in Amsterdam in the same period: the spectacle maker from Middelburg and a brass founder from Schobel. The latter is erroneously identified as the spectacle maker by Van Kerkwijk, 'Neurenberger rekenpenning in 1628 te Amsterdam door Zacharias Jansz vervaardigd' (1926).

[99] Van Helden, *Invention* (1977), 25.

intriguing question: 'If the knowledge of the magnification potential of two combined spectacle glasses was already available many decades before 1608, why was the telescope not invented earlier?'

In his paper Willach argued that the rather poor quality of the lenses available in the sixteenth and early seventeenth century could make possible a telescopic image of reasonable usefulness, if a small but crucial modification was made to the instrument; that is a small opening in a cardboard disc mounted in front of the convex objective lens. This so called 'diaphragm' blocks the light passing through the outer part of the imperfect objective lens, as this part would otherwise blur and degrade the telescopic image.[100] Thus, the invention of the telescope has now been reduced to the invention of the diaphragm, which brings Willach to his conclusion:

> There is no doubt that Lipperhey was the first who had this knowledge. He could repeat the construction of the telescope as often as needed, including binoculars, the most difficult construction. His idea was as simple as ingenious, but this simplicity should not diminish its merits. We can see how his success was based on numerous small steps made over many centuries. He just happened to be the last link in a long chain.[101]

In addition to Willach's conclusion, which is based on numerous measurements of surviving spectacle lenses, it is interesting to note that at least one archival source indicates that in 1609 the notion of the diaphragm indeed was known in Holland. In 1642, Théodore Deschamps, a physician from Bergerac, remembered that in 1609, during his stay at Leiden University, he had not only witnessed a demonstration of a telescope by the mathematics professor Rudolph Snellius, but had also met a Delft spectacle maker, who in his telescopes had covered up 'the parts of the convex glass on which the rays coming from the object intersect each other too soon.'[102] However, just as interesting is the remark made by Beeckman that in 1618, when he was shown a telescope

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[100] Willach, 'Der lange Weg (2007). Idem, *The Long Route* (2008).

[101] Willach, *The Long Route* (2008), 99.

[102] Théodore Deschamps to Marin Mersenne, 5 May 1642: 'Or j'estoy à Leyden en l'an 1609, où Rodolphus Snellius, professeur en mathematiques, qui nous lisoit l'*Optique* de Ramus, à la sortie de sa leçon, me monstra les lunettes communes qui n'avoyent qu'un tuyeau' [...] '[Je] recogneus que ce lunetier de Delft n'avoit fait autre chose que mettre les verres en deüe distance, et couvrir les parties du verre convexe sur lesquelles les rayons venants de l'object s'entrecouppent trop près les uns les autres.' Cf. De Waard, *Journal* 1 (1939), 12, 209; idem, *Correspondance Mersenne* 11 (1970), 140-141.

in the French city of Caen, he remembered a Middelburg spectacle maker who constructed telescopes *without* a diaphragm.[103] So probably the last word on this subject has not yet been written.

IV. EPILOGUE

High social status and its importance for the credibility of a testimony

This survey of 400 years of the – mostly Dutch – debate about the invention of the telescope reveals that historiography is indeed a dynamic process, in which the motives of actors fluctuate according to their own background, coloured by national interests, and in which witnesses and their testimonies are valued according to the standards of time and place.

Thus in the early nineteenth-century Van Swinden and Moll came to an interpretation of the facts different from Lambrechtsen and De Kanter's. While the former undertook a critical evaluation of all contemporary documents, leading to one of the earliest attempts in Dutch history to write an archive-based 'history of science,' the latter were clearly obsessed by the wish to highlight the importance of the local history and culture of Zeeland.

The question 'whom to believe in respect to the invention of the telescope,' appears to be one of the leading themes in this historiography. In many ways it resembles the history of the first observations made with this very instrument. When Galileo discovered the moons of Jupiter with his telescope in the winter of 1610, almost nobody believed him at first. Little wonder, for no one had telescopes good enough to show them– And even when observers had access to Galileo's own telescope very few could see Jupiter's satellites because the instrument was so difficult to use and its field of view was so small. (about 15 arc-minutes). Later, in Tuscany, he was more fortunate. Guided by Galilei, Grand Duke Cosimo de Medici was able to observe these heavenly bodies. This grand-ducal testimony was crucial for Galilei to achieve the credibility he needed for his discoveries to be accepted as real and trustworthy.[104]

Similar examples can be given at various occasions through the seventeenth century. Even in natural philosophy the high social status of a witness provided the credibility, which an instrumental observation or experiment could not

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[103] Entry by Beeckman in his notebook on 13 August 1618, commenting on Sirtori's *Telescopium*. In May 1628, also in his notebook, Beeckman discusses the function of the diaphragm in a telescope. Cf. De Waard, *Journal Beeckman*, 1 (1939), 208-209 & 3 (1945), 46.

[104] Van Helden, 'Telescopes and Authority from Galileo to Cassini' (1994), 11.

achieve in itself. This testimonial way of establishing 'facts' could generate authority in its own right, which only few people would dare to question.[105]

With respect to the priority question about the invention of the telescope, this same mechanism has put its stamp on history. The high social rank of Willem Boreel, a nobleman, knighted in 1619 by the English king, was crucial in the acceptance of his verdict, first in the seventeenth century by Borel, and later, in the nineteenth century, by scholars such as De Kanter, Harting, Japikse and others.[106] Even the highly critical scholar Moll accepted Boreel's statement relating to Jansen as the inventor of the microscope. Without Boreel's second testimony, published in Borel's *De Vero Telescopii Inventore,* probably nobody would have paid any attention to Zacharias Jansen. Perhaps his name would have popped up in 1906, when Beeckman's little remark was found by De Waard. But given the fact that Jansen was not mentioned in the archives as a spectacle maker before 1616, Beeckman's small note would never have received such weight. So, in the end, Boreel's high social status remains the most crucial element in the credibility of Johannes Sachariassen's testimony. This feeling was put nicely into words by Harting in 1853:

> 'When one realizes that WILLEM BOREEL, one of our most honourable statesmen in the early seventeenth century, to whom, during this important period of our [Dutch] history, was entrusted the position of ambassador, first to England and later to France, then surely one must acknowledge that the testimony of such a man deserves a very high degree of credibility.'[107]

Curiously, in his turn, Harting's own credibility as a university professor appeared to be crucial for the acceptance of the undocumented Snijder-tube as Jansen's 'first microscope.' Although in 1866, the secretary of the *Zeeuwsch Genootschap* had expressed some doubts about the authenticity of Snijder's legacy, this hesitation had vanished completely after Harting's investigation. Harting's reasoning concerning Snijder's tubes had been extremely speculative, but his authority as a specialist in optical instruments removed all reticence, with the result that the smallest tube was seen by many as *the* original microscope, the oldest product of Jansen's workshop.

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[105] Cf. Dear, "Totius in Verba" (1985) and Shapin, *A Social History of Truth* (1994).

[106] Cf. Gerrits, *Grote Nederlanders* (1948), 45.

[107] Cf. Harting and Matthes, 'Verslag over den vermoedelijken uitvinder van het microskoop' (1853), 70.

Jansen Exit

Today we must conclude, on the basis of all the evidence gathered in the past four centuries, that the story of Zacharias Jansen as the inventor of the telescope appears to be a mere historical fabrication, made up by his only son at a time when 'fame and possibly gain was to be derived from it,' as Van Helden has put it.[108] In the nineteenth century, Johannes Sachariassen was exposed as a fraudulent witness, lying not only about his age, but about almost every other item in his testimony.[109] His remark, recorded in 1634 by Beeckman, that his father had made a telescope in 1604, should have had no more impact than any other remark by a boaster, singing the praise of his own family. And while Boreel's first testimony about Lipperhey is confirmed by the archival sources, his later testimony in which Zacharias Jansen was launched as the inventor, also contradicts some of the available evidence, with the result that Jansen is also discredited as the inventor of the compound microscope.[110] What is more, historical research has shown that the compound microscope only emerged on the scene in about 1620, and therefore Boreel's testimony, too, can be completely disregarded.[111] Still even in the 21st century advocates can be found, who are willing to stand up for Jansen's priority as the inventor

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[108] Van Helden, 'The Historical Problem' (1975), 256.

[109] To summarize the contradictions in Sachariassen's statement of 1655: (1) 'In 1590 my father invented the telescope' [*Zacharias Jansen was born in 1585, so he would have been five years old at the time of the invention*]; (2) At that time examples were given to Count Maurits and Archduke Albertus. [*No archival record whatsoever; it is only recorded that Jansen was active as a spectacle maker since 1616*]; (3) In 1618 my father and I invented the 'long tubes (the astronomical telescope) [*design was published by Kepler in 1611*]; (4) In 1620 Metius and Drebbel bought one of our instruments in order to copy these. [*Metius used a telescope at least from 1613 onwards; Drebbel already wrote on the telescope in 1609*]; (5) 'I am 52 years old [*Actually Sachariassen was 43 in 1655. He probably lied about his own age, in order to validate his own claim for a share in the invention of astronomical telescope*].

[110] Boreel's first testimonial gives an accurate description of Lipperhey and the location of his workshop. To summarize the contradictions in Boreel's second testimonial of 1655: (1) 'Near the house where I was born, … a certain spectacle-maker lived in the year 1591 by the name of Hans' [*Hans Martens died in 1592, when Boreel was only one year old. He could not have remembered him. In no document is Hans mentioned as a spectacle maker*]; (2) 'Hans had a wife Maria and two daughters' [*The wife was called Maeyken and there was only one daughter*]; (3) 'I knew Zacharias intimately, because … we played together from an early age' [*Boreel was born in 1591 and Zacharias in 1585: the difference in years, as well as the extreme difference in social status makes this clam highly unlikely*]; (4) 'Hans, or Johannes, with his son Sacharias, as I have often heard, first invented the microscope' [*This instrument emerged only in about 1620; Boreel's statement that in 1619, in England, he saw a 'microscope of that Sacharias' at Drebbel's house, is probably confused with the instrument Drebbel personally had made*]; (5) 'Lipperhey copied the instrument, after an unknown visitor ordered glasses from Jansen' [*This account follows closely the story published by Sirtori in 1618, which Boreel had read*].

[111] Turner, 'Animadversions' (1985).

of the telescope, and who even wonder why 'the Lipperhey myth' has so 'stubbornly' survived.[112]

But who then was the mysterious 'young man,' who on 14 October 1608 showed a second crude telescope to the Middelburg magistrates? Could it be any one else than Jansen? In my view, there is indeed a better candidate. When we look closely at the evidence presented by De Waard in 1906, it becomes clear that Jansen was (albeit scarcely) mentioned as a spectacle maker only beginning in 1616. It is therefore tempting to assume that Jansen took up this profession just because he had inherited the tools of the late spectacle maker 'Lowys Lowyssen, geseyt Henricxen brilmakers,' whose children had come under Jansen's guardianship in the previous year. As in these same years Jansen was mainly working as a counterfeiter, producing large series of fake Spanish coins, his optical workshop in fact could have functioned as a cover for these highly illegal activities.

Thus, if Jansen did not work as a spectacle maker *before* 1616, which other Middelburg spectacle maker did? Of course, the spectacle maker 'Lowys Lowyssen, geseyt Henricxen brilmakers.' He is evidently a better candidate for this unknown 'young man,' than the wrongly praised Jansen, whose only proven achievement is the production of counterfeit coins.

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[112] Barlow Pepin, *The Emergence of the Telescope* (2004). See also De Rijk, 'Een standbeeld voor Zacharias Janssen' (1975); idem, 'Wie heeft de telescoop uitgevonden?' (1985) and idem, 'Op zoek naar de uitvinder van de Hollandse kijker' (2008).

The city of Middelburg, cradle of the telescope

Klaas van Berkel

Introduction

The telescope was invented in the city of Middelburg, capital of the Dutch province of Zeeland.[1] It is here that the lens grinder and spectacle maker Hans Lipperhey constructed his telescopes and it is from here that in September 1608 the same Lipperhey travelled to The Hague, the seat of the States General of the Dutch Republic, to apply for a patent for this instrument 'for seeing far.' For those who are slightly familiar with the city as it is today, Middelburg may seem to be an unlikely place of origin of an instrument that played such an important and in some respects even decisive part in the development of modern science. Middelburg nowadays appears above all quiet and friendly. Travellers coming from a bustling industrial and commercial city like Rotterdam, more than an hour away by car or by train, get the impression of entering a world almost forgotten. The old abbey buildings with their cloister and the slender steeple of the abbey church, the former city hall in late Gothic style and the weather-beaten warehouses along the quiet quays give the city the appearance of a provincial backwater.

We should be careful however and not project back unto the early seventeenth century a picture that even today may not be true after all. Around 1600, the young Dutch Republic was in technological and economic terms quickly becoming the most advanced nation in Europe and Middelburg occupied a central position in its commercial network. Furthermore, the city was the site of some interesting developments in the arts and the sciences. Culture,

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[1] I am aware that it is misleading to talk about 'the' invention of the telescope as if it were a one time event with a single inventor. Instead, it was a piecemeal development of which the telescope was only the end product. See Van Helden, *The Invention of the Telescope* (1977); Willach, *The Long Route to the Invention of the Telescope* (2008). For convenience sake, however, I will continue to refer to 'the invention of the telescope' and I think this is also justified because recent research, particularly by Willach, has suggested that application of the diaphragm, probably by Lipperhey, was the real breakthrough that turned an inconspicuous optical gadget into a powerful military and soon also into a path-breaking scientific instrument.

as we know, follows commerce, in Zeeland as much as in other places. Finally, Middelburg and the province of Zeeland were part of a country still at war with the Spanish king, their former sovereign. The military front was never far away. Thus Middelburg was almost the opposite of a sleepy and quiet provincial town in the periphery of the Dutch Republic. Consequently, there is every reason to take a closer look at the history of the city of Middelburg around 1600 in order to better understand the context in which the invention of the telescope took place.

Booming Middelburg

Middelburg is located on the island of Walcheren, one of the major islands in the estuary of rivers like the Scheldt and the Rhine, situated between Holland in the north and Flanders in the south. The city had no direct access to the sea, unlike neighbouring cities like Vlissingen and Veere, but it was connected to open water by the river Arne which flowed into the sea at the small town of Arnemuiden. Only in 1532 a more direct connection with open water was established by digging a new canal (ill. 1). Notwithstanding this disadvantage, Middelburg had become the capital city of the island, outdoing its rivals and acquiring the leading position in the province as a whole. In the fifteenth century, the city flourished economically, partly because of its location between northern and southern Europe and partly because of the vicinity of a major trading centre like Antwerp. However, contrary to what is sometimes assumed, Middelburg was not simply an advance port of Antwerp. It is true that some of the ships with cargo destined for Antwerp did unload at Middelburg and had their goods transported to Antwerp in smaller vessels. Yet 50 % of the international trade of Middelburg consisted of the trade in French wine, mainly imported from Rouen, the capital of Normandy. In 1523 the Middelburg merchants had been awarded an imperial monopoly for the trade in French wine in the Habsburg Netherlands and this, together with the trade in raw salt from the French west coast, remained one of the mainstays of the Middelburg economy well into the seventeenth century.[2]

In the early years of the Dutch Revolt, Middelburg suffered greatly. In the spring of 1572, Vlissingen and Veere took the side of the insurgents led by William of Orange, whereas Middelburg, seat of the royal administration

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[2] For a recent re-evaluation of the economic history of Middelburg, see: Enthoven, *Zeeland en de opkomst van de Republiek* (1996). The history by Unger, *De geschiedenis van Middelburg in omtrek* (1954) is out-dated, but a more up to date general history of the city is not yet available.

Ill. 1. View of the city of Middelburg, from the south, with the new canal of 1532 on the right. From: Van der Venne, *Zeeusche Nagtegael* (1623).

and defended by a strong garrison, remained loyal to the Spanish king. The city therefore had to endure a siege by the forces of the rebels which lasted for almost two years. After a Spanish fleet destined to relieve Middelburg was defeated in January 1574, both the Spanish commander and the city government decided that further resistance was useless. The city was treated respectfully – no plundering took place – but it had to pay the substantial fine of 100.000 guilders. Furthermore trade had been interrupted for several years, during which merchants had found other places to go to, and many of the privileges Middelburg once had were abolished. Middelburg lost part of its jurisdiction over the surrounding countryside to the competing towns of Veere and Vlissingen and the proud city had to acquiesce in the fact that Arnemuiden, formerly not much more than an out port of Middelburg, acquired city rights of its own. From then on even Arnemuiden was beyond its control.[3]

Undeterred by these setbacks, the city of Middelburg immediately tried to regain at least some of its former prosperity and political prominence and in this effort the city succeeded remarkably well. In 1576 the city was again recognized as the capital city of the province, which ensured that many corporations and legislative bodies would again reside in the city. Also the trade in French wine revived, Spanish and Venetian merchants who had left the city during the siege returned, and in 1582 the English Merchant Adventurers Company, who had a monopoly in the trade of English woollen cloth, moved their staple to Middelburg. In the late 1590s, Middelburg also became one of the first cities in the Netherlands to fit out a fleet to the East Indies. On the successful return

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[3] The political history of Middelburg is closely connected to the political history of the province of Zeeland. Helpful is Kluiver, *De Souvereine en independente staat van Zeeland* (1998).

of this fleet in 1600, merchants in Middelburg chartered their own East India Company which later on (in 1602) became the Chamber of Zeeland of the new and powerful United East India Company.

The expansion of the trade network of the Dutch Republic clearly stimulated technological innovation. The concentration of trade led to the accumulation of capital, the easy availability of raw materials, a generous supply of energy sources and the speedy gathering of useful information. Cities like Middelburg became attractive to skilled immigrants, who introduced new trades and crafts that were not hindered by existing guild regulations but could profit from an already existing system of patent law. Thus in the field of technology the Dutch Republic in the decades around 1600 emerged as the most advanced country in Europe and it is generally believed that without this prominent position in technology the economic primacy of the Dutch Republic in the seventeenth century would have been much less impressive than it actually was.[4]

An early instance of technological innovation in the Dutch Republic and a clear indication of the advanced state of Middelburg's economic life in the last decades of the sixteenth century was the arrival of the glass manufacturer Govaert van der Haghe, who in January 1581 moved from his native Antwerp to Middelburg and set up a glass factory in his new place of residence.[5] Originally, Venice had been the main centre of quality glass production in Europe and the Venetian government had issued draconic measures to ensure that the secrets of its glass industry were not disseminated all over Europe. Nevertheless, Italian glass workers moved to other places and between 1550 and 1615 the Venetian way of producing crystal glass was introduced in north-western Europe. Before the 1580s, Antwerp was the only city in the Netherlands where glass was produced 'à la facon de Venise.' In 1561 Jacomo Pasquetti, an Italian from Brescia, had been granted a monopoly by the Antwerp city magistrates for the manufacture and trade in this kind of high quality and therefore expensive glass. In 1581 the Middelburg magistrates invited Van der Haghe to come to their city and to produce 'in the Antwerp manner' in Middelburg and so the Antwerp

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[4] Davids, 'Shifts of technological leadership in early modern Europe' (1995), 338-366; Davids, *The Rise and Decline of Dutch Technological Leadership* (2008); Israel, *Dutch primacy in world trade* (1989).

[5] For information concerning glass production see: Hudig, *Das Glas* (1923); Klein, 'Nederlandse glasmakerijen in de zeventiende en achttiende eeuw'; Charleston & Angus-Butteerworth, 'Glass' (1957); Henkes & Zijlstra-Zweens, 'Met wit email versierde beker- en kelkglazen uit ca. 1600 (1992); Henkes, 'The influence of Antwerp on the development of glass production in the 16th and 17th centuries in the Northern Netherlands.' (I thank Daniëlle Caluwé for providing me with the last two references).

monopoly was effectively broken, much to the displeasure of the Italian glass workers in Antwerp. Van der Haghe treated generously by the Middelburg magistrate. He was exempted from taxation and watch-duty, guild restrictions did not apply and on top of that Van der Haghe received an annual subsidy of 100 guilders. Finally he was given a piece of land near one of the gates of Middelburg to build his glass house. Since glass workers used several ovens for melting glass, the fire risk was substantial and glass factories were located at the outskirts of the city (see ill. 2). Apparently the business was successful, since in 1586 Van der Haghe became a man of substance and a well-respected burgher of the city of Middelburg.

In 1591 the States of Zeeland granted Van der Haghe a new and even more profitable patent. Again he was exempted from taxes, got an annual subsidy of 200 guilders (half of which was paid by the city of Middelburg) and an interest-free loan of 800 guilders. The import of crystal glass from Antwerp had been forbidden, but Van der Haghe was allowed to import the necessary firewood (six ships each year) from the southern Netherlands without paying import duties. This monopoly for producing and selling crystal glass in Zeeland was renewed in 1598 and 1605, which was a clear indication that his factory was considered to be important for the economy of the city.[6] Glass produced in Middelburg found its way all over Holland and Zeeland, and was even exported to England. Apart from some glass blowers from Antwerp and Venice Van der Haghe employed dozens of people from Middelburg itself. A report drawn up in 1606 shows that as a rule some sixty women and children were working at the factory (ill. 3). By that time the factory had passed into the hands of a new owner. Van der Haghe had died in 1605 and his factory was sold to Antonio Miotto, a member of a glass blowing family stemming from Venice. Miotto had bought the factory from the heirs of Van der Haghe with borrowed money, but his business was so profitable that he could pay off his debts in just four years. In all probability, the glass which Lipperhey used for his spectacles and his telescopes was manufactured by the Miotto firm. Still, at that time the Middelburg factory had lost its monopoly for glass production in the northern Netherlands. In 1597 a glass factory was set up in Amsterdam by an Italian named Antonio Obizzo (Obisy), who had learned the craft at the factory of Ambrosio Mongardo in Antwerp.[7] Obizzo went bankrupt within a

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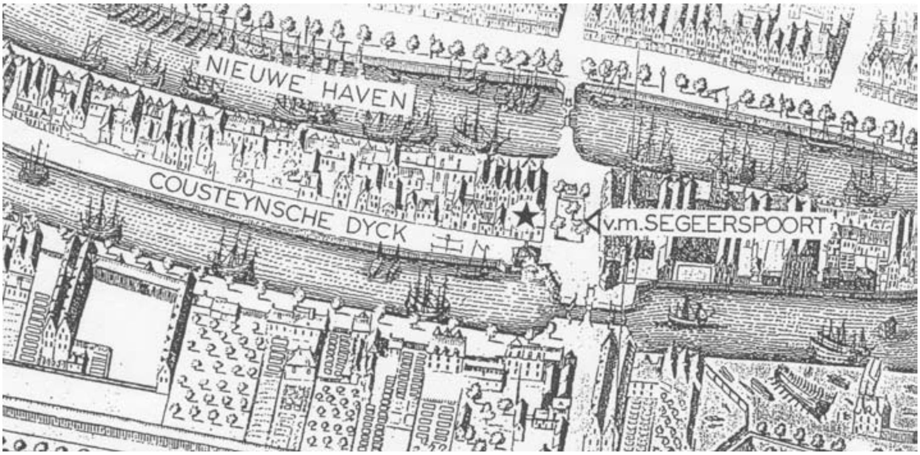
[6] The relevant documents from the Middelburg archives (destroyed during World War II), were published by De Waard, *De uitvinding der verrekijkers* (1906), 307-319.

[7] Van Dillen, *Bronnen tot de geschiedenis van het bedrijfsleven en het gildewezen van Amsterdam,* 1 (1929), 548-549.



Ill. 2. Location of the glass factory of Govaert van der Haghe, near the Segeerspoort (with a star). Detail of the map of the city of Middelburg by Cornelis Goliath (1657) – see ill. 3.

few years, but his business was continued by Jan Janz. Carel, to whom the city council of Amsterdam in 1601 leased out a large piece of land at the southern side of the city. Financially Carel was backed up by a company of Amsterdam merchants who also tried to lure some of Miotto's men to Amsterdam (the Middelburg magistrate protested repeatedly against this kind of piracy, but apparently without success).[8] A third factory was established in Rotterdam in 1614. However, losing the monopoly does not seem to have harmed Miotto at all. In 1618 he had some very elegant houses build in Middelburg and his factory was doing so well that in 1621 a merchant from London even tried to lure him to the English capital, unsuccessfully for that matter. In that very same year he supplied six very elegant and expensive communion beakers for the Old Church in Middelburg (all of them now lost). Middelburg around 1600 was the leading city in the Dutch Republic for the production of high quality glass and since the manufacture of a telescope requires the availability of lenses of such quality it is quite natural for the telescope to have been invented in Middelburg.

Glass production was drawn to Middelburg already in 1581, but after the fall of Antwerp in 1585 many more merchants and industrialists moved their business to Middelburg. Antwerp had been one of the strongholds of Calvinism in the southern provinces, but when the Spanish general Alessandro

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[8] *Ibidem*, 592-596. Previously, Amsterdam merchants had invested their money in the glass factory of Van der Haghe in Middelburg! Cf. Klein, 'Nederlandse glasmakerijen' (1982), 37.

Ill. 3. Workers at a glass house. Painting by Jacob van Loo, around 1658. (Statens Museum of Art, Copenhagen).

Farnese, Duke of Parma, captured the city in 1585, he ordered all Protestants either to leave the city (which they could do while taking along all their possessions) or to convert back to Catholicism. Many decided to do the former and so in the second half of 1585 a large stream of people left the city on the Scheldt to start a new life elsewhere – or perhaps just to sit out the storm at some sheltered place not too far away from Antwerp. Middelburg, with its longstanding ties to Antwerp, offered a convenient place to stay and so of all the Dutch cities Middelburg profited the most from the exodus of poor and rich people from Antwerp. In 1585, Middelburg even sent a small fleet to the old metropolis on the Scheldt in order to pick up those who wished to leave. Between 1580 and 1595, Middelburg registered about 2,500 new burghers, compared to only 1,600 in Amsterdam and about 1,000 in Leiden. Not all of these new full citizens of Middelburg came from the southern provinces. Hans Lipperhey, for example, originated from the German city of Wesel, not far from the Dutch border. Still, a large majority of the immigrants was born in the south and came to Middelburg either directly or through some intermediary station like London or Emden. No fewer than 75 % of the new citizens of Middelburg came from the southern provinces. As a result of this influx of immigrants, the population of Middelburg, estimated at some 6,000 in 1570, grew to perhaps 18,000 in 1600.[9] To accommodate all these new people – together with their businesses – the city had to be enlarged twice and in a period of twenty years, the area within the walls almost tripled. The first phase of expansion, which stretched from the late 1570s to 1591, mostly concerned the construction of a new harbour to the east of the city. One of the new embankments was the Rouen Quay (Rouaanse Kaai), where the ships with French wine arrived. The second phase, which lasted from 1594 to 1598, consisted of building a new ring around the rest of the city (see ill. 4). Everywhere new houses were built, new docks were constructed, and new defensive works were raised. Middelburg around 1600 was indeed booming.

The new prosperity was as remarkable as it was unstable. It depended on the state of war between the young Republic and the Spanish king; otherwise not that many merchants and manufacturers would have chosen to leave their homes in the south and set up their business in Middelburg. In this way, the city directly profited from Antwerp's decline during the war, as it had profited from Antwerp's prosperity before the war. Yet, Middelburg's economy could also suffer from the vicissitudes of the war. In 1595 the Spanish king, Philip II, closed the Spanish and Portuguese harbours for Dutch ships and this directly affected commerce in Middelburg too. For a while, no ships were sent to the Iberian Peninsula. Three years later, the new Spanish king, Philips III, declared a complete embargo on all traffic from the southern Netherlands to the rebellious north. After the fall of Antwerp, the rebels in Zeeland had shut off the Scheldt, thereby cutting off Antwerp from overseas traffic. Ships that were allowed to pass were heavily taxed, as were ships coming from Antwerp with goods destined for the northern provinces. Philips III's predecessor, Philip II, had refused to take any measures against southern merchants who traded with the rebels in the north, since he feared that the struggling economy in the south would not survive being cut off from the north completely. Philip III on the other hand reasoned that the rebels in the north had more to lose than the merchants in the south because the finances of the Dutch Republic heavily depended on taxes on incoming goods (the so-called license fees). Cutting off trade with the rebels would undermine their financial strength and therefore immediately weaken their military power. And to a large measure he was right.

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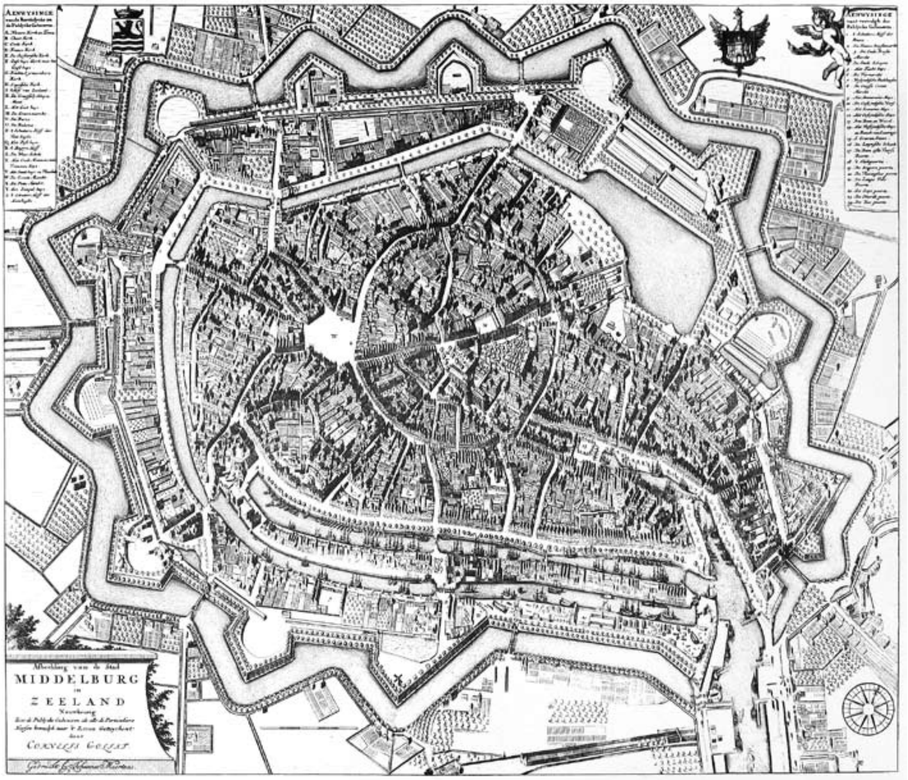
[9] Traditionally higher figures are given, mostly some 30,000 for the beginning of the seventeenth century. The more reasonable number of 18,000 is provided by Priester, *Geschiedenis van de Zeeuwse landbouw circa 1600-1910* (1998), 52-58, 481. The population of Antwerp dropped to some 45,000 after Parma had taken the city in 1585, but in the course of the seventeenth century it grew quite considerably again. Antwerp thus always remained much larger than Middelburg.



Ill. 4. Map of the city of Middelburg by Cornelis Goliath (1657; with additions made in 1688).

When he declared the embargo in 1598, the license fees in Zeeland dropped almost to zero, thereby causing serious problems for the Zeeland administration. Yet it proved very hard to enforce the embargo completely and so after a couple of years the income from license fees was back at its 'normal' figure.

Still, more trouble was on its way. After the fall of Antwerp in 1585, the rebellious provinces went through a severe crisis. Foreign aid against the advancing Spanish forces was hard to find and internally political leadership was a bone of contention. After the murder of William the Silent in 1584 it took some years before it became clear that his son Maurits, in collaboration with the pensionary Johan van Oldenbarnevelt, would lead the country in the fight against the Spanish. In this they succeeded remarkably well. By 1600 almost all of the territories to the north of the great rivers had been cleared from Spanish forces; after ten years of hard fighting the so-called 'fence' of the Republic was closed. Holland was safe behind the rivers and a string of fortresses defending the neighbouring provinces. Thanks to this military success and the energetic policy pursued by Oldenbarnevelt, the international position of the Dutch Republic also improved considerably. The States General concluded an alliance with France and England in 1596, by which the Republic was recognized on the same footing as these two great powers. Finally, in 1609, that is a year after Lipperhey had travelled to The Hague to demonstrate his newly invented telescope, a truce was concluded between the Dutch Republic and the Spanish authorities in the south. Although it was 'just' a truce – peace was still a bridge too far – most people realized that the Spanish king had in fact recognized that he could no longer re-conquer the northern provinces, while the Dutch had implicitly given up the ambition to 'liberate' the southern provinces from Spanish rule.

For Middelburg, this new situation had unexpected and unpleasant consequences. Many of the southerners who had established themselves in Middelburg had done so simply for the time being; they had hoped that one day they could return to their home towns and they therefore had preferred to stay in the vicinity of the southern markets. But now that the separation between the north and the south seemed to become definitive, there was no longer reason to stay in Middelburg. Instead, they might just as well move on to Amsterdam or Leiden, in the heartland of the new country.[10] With a little hindsight we can say that the conclusion of the truce in 1609 was a watershed in the history of Zeeland. Whereas Middelburg was located near the centre of the economic system in the sixteenth century, now the city found itself pushed to the periphery (see ill. 5). Because of its location the city had temporarily profited from the decline of Antwerp, but now that the situation seemed to stabilize, it became clear that after all this was really a disadvantage for Zeeland. Quite a number of merchants in the early decades of the seventeenth century therefore decided to leave Middelburg and to continue their business in Amsterdam, Leiden or Rotterdam. Around 1600 Middelburg had only trailed Amsterdam as far as economic activity was concerned, but by 1620 it had lost this position to Rotterdam. It certainly is true that for a long time Middelburg remained an important city, politically as well as economically, but decline had set in already during the first quarter of the seventeenth century – and it would not stop until the nineteenth century. The Golden Age in Zeeland had come early – and it faded away early too.

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[10] On the relative importance of the influx from the south for the Dutch and more specifically Amsterdam economy, see Gelderblom, *Zuid-Nederlandse kooplieden en de opkomst van de Amsterdamse stapelmarkt* (2000).

Ill. 5. Dutch recovery of territory in the Netherlands (1590-1604). In less then twenty years Prince Maurits managed to clear all of the northern Netherlands from Spanish forces, but Middelburg was now situated at the periphery of the new state. Map reprinted from: Israel, *The Dutch Republic* (1995).

For Lipperhey and his fellow townsmen, however, this was still hidden in the future. For them, Middelburg was a busy and lively city with ample opportunities for local people and newcomers alike.

Scholarship and science

Middelburg had never been a centre of learning before the Revolt of the Netherlands, but within a year after the retreat of the Spanish troops in early 1574, plans were developed to establish a university in the capital of the province of Zeeland. In January 1575, William of Orange, wrote a letter to the States of Holland and Zeeland (the two provinces of which he was still formally stadtholder, representing the sovereign, the king of Spain) urging them to found a university for the liberated provinces. In this way, he answered to an appeal of the Reformed Church in Zeeland to create a university to which the Church could send two students in theology each year. According to the stadtholder, only two cities could be considered for housing this university, to wit Leiden (in Holland) and Middelburg (in Zeeland). We do not know how serious he was in mentioning Middelburg (since he was stadtholder in both provinces he simply had to mention at least one city in each of these provinces), but the mere fact that he did mention Middelburg means that the city was considered to be an appropriate place for an institution for higher education. Some fifteen years later, the States of Zeeland again developed plans, not for a university this time, but for an academic extension of the existing Latin school. Students from the province of Zeeland could start their education close to home (which was much cheaper than at the far away university of Leiden) before switching to a real university in order to get their degrees. In 1591 the city magistrates of Middelburg effectively created a college for the students and in 1592 appointed two lecturers, one in philosophy (the Scotsman and teacher at the Latin school John Murdison) and one for history (the principal of the Latin school, Jacobus Gruterus). Both students and interested merchants followed their lectures, which were given in the so-called New Church, a part of the former abbey in the centre of the city. A few years later even a third lecturer was appointed, the preacher Johannes Isenbach or Hitzenbach, who lectured on theology. We know of at least one printed disputation from 1594, a *Summa physicae thesibus comprehensa*, defended under the supervision of Murdison by the Flemish student Jacobus van der Veste (Vervestius).[11]

In 1598 Murdison left Middelburg to become professor of philosophy at Leiden and the States of Zeeland decided to put their money in scholarships for students from Zeeland at Leiden, but Murdison's colleagues continued their public lectures. When Gruterus died in 1607, the preacher Antonius Walaeus took over his lessons. Around 1610 the developing dispute at Leiden between the orthodox Calvinists led by Franciscus Gomarus and the more moderate followers of Jacobus Arminius caused some concern in the strictly orthodox province of Zeeland and led to new initiatives in higher education in Zeeland. In 1611 a so-called Illustrious school was established in Middelburg, where several professors would provide basic academic education without having the right to confer degrees on their students. Three professors were appointed: one

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[11] Zuidervaart, 'Zeeuws preacademisch erfgoed. Een filosofische disputatie uit Middelburg uit de late zestiende eeuw' (2009).

for Greek and Hebrew (Walaeus), one for theology (Gomarus, who had left Leiden because the atmosphere there was too lenient towards the Arminians in his opinion) and one for philosophy (Franciscus Meyvaert). The appointment of Gomarus indicates that the Middelburg magistrates did indeed hope to provide their youth with an alternative for the more liberal, Arminian university at Leiden. The initiative was however relatively short lived. Gomarus left Middelburg in 1615 to become professor at the Huguenot Academy at Saumur in France and a few years later Meyvaert accepted the position of principal of the Latin school at Middelburg (in 1620 he would move on to the university of Groningen to become professor of philosophy). In fact, by 1620, that is two years after the defeat of the Arminians in Holland, the Illustrious school had ceased to exist.[12]

Gomarus, Meyvaert, and many of the preachers active in Middelburg around the turn of the century were immigrants from the south. Social, religious and intellectual life in Middelburg had for this reason acquired an unmistakable southern flavour, much more so than before the Revolt. Also in the field of the sciences the number of people originating from the southern provinces is remarkable.[13] Middelburg was not only an attractive refuge for Flemish merchants and craftsmen, but also for engineers, math teachers and all kinds of mathematical practitioners. One of them was Simon Stevin, a native of Bruges in Flanders who became the best-known mathematician in the Dutch Republic around 1600, and who wrote books on such diverse subjects as bookkeeping, astronomy, the art of fortification and the science of mechanics. There is evidence that some time after 1577 Stevin set course for Middelburg before settling in Leiden and later on in The Hague. We have an eighteenth-century document from Bruges that states that Stevin, who is denoted as a schoolmaster and a mathematician, had left his home town and went to Middelburg 'because he could not get freedom of taxes on beer.'[14] However, if indeed he went to Middelburg, he certainly did not stay long, since he is registered as an inhabitant of Leiden in 1581. In the same year he published his first book, *Nieuwe Inventie van Rekeninghe van Compagnie* (*New Invention of Calculation of Companies*) in Delft (with a dedication to the magistrates of Amsterdam). In 1582, however, his second book, *Tafelen van Interest*

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[12] Frijhoff, 'Zeelands universiteit: hoe vaak het mislukte en waarom' (1986).

[13] For a survey of the contribution of Zeeland to the history of the early modern sciences: Meertens, *Letterkundig leven in Zeeland in de zestiende en de eerste helft der zeventiende eeuw* (1943), 435-441.

[14] As quoted in: Dijksterhuis, *Simon Stevin* (1943), 7note. Dijksterhuis was not able to confirm this story and research is nowadays practically impossible since most of the Middelburg archives were lost during the Second World War.

(*Tables of Interest*), was published in Antwerp. Stevin evidently had not turned his back on the southern provinces. And why would he? Antwerp at that moment still formed part of the rebellious provinces.

Whereas Stevin, if indeed he opted for Middelburg first, soon moved on to more northern quarters, another well-known mathematician from the south did not travel further than Zeeland and ended up in Middelburg. Philip Lansbergen, who originated from Ghent in Flanders and was trained as a reformed preacher, fled from Antwerp after is was taken by Parma and settled as a reformed minister in the city of Goes on the island of Zuid-Beveland, not very far from Middelburg (see ill. 6).[15] After a clash with the city magistrates in 1613 he settled for good in Middelburg. There he specialized in the writing of astronomical books and in the early decades of the seventeenth century he became one of the very first in the Dutch Republic to openly defend the Copernican system. He did so in his *Progymnasmatum astronomiae restitutae liber I* in 1619 and repeated his theses in 1629 in Dutch in his *Bedenckinghen op den daghelijckschen ende jaerlijckschen loop vanden aerdt-cloot* (*Considerations on the daily and annual course of the earth*), soon to be translated into Latin. But even before Lansbergen had settled in Middelburg, he had developed close ties with fellow immigrants in that city. An early work on trigonometry, his *Triangulorum geometriae libri quattuor*, was published in Leiden in 1591, but it was dedicated to the city magistrates of Middelburg. In his dedication Lansbergen even stated that he had written the book on the island of Walcheren ('in vestra hac insula').[16]

In Middelburg, Philip Lansbergen was probably instrumental in rousing the scientific interest of Isaac Beeckman, one of the earliest proponents, if not the earliest, of a strictly mechanical philosophy of nature. Beeckman was born in 1588 in Middelburg, but his father Abraham Beeckman was a native from the city of Turnhout in Brabant, which he had left in 1567, apparently for religious reasons. He went to London, but in 1585 he moved on to Middelburg, where he settled as a candle maker, also installing water systems for breweries.[17] For one reason or another, Lansbergen and Abraham Beeckman, knew each other very well, for already in the 1590s they corresponded about theological issues and it is more than likely that Lansbergen also visited Middelburg

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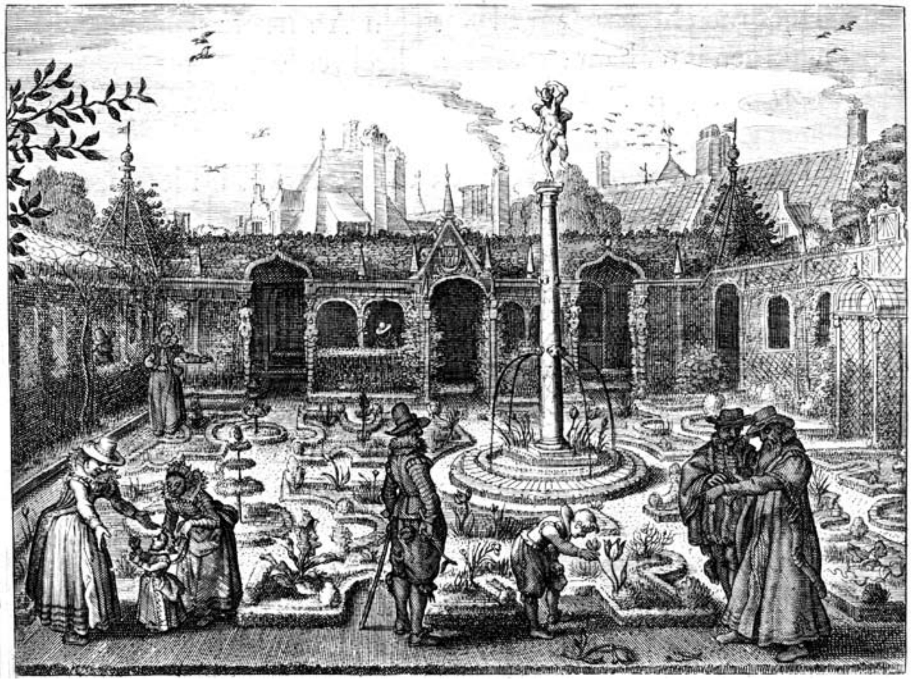
[15] On Lansbergen, see Vermij, *The Calvinist Copernicans* (2002), 73-99.

[16] In the second edition of 1631 Lansbergen assured the city magistrates that he had first conceived of the book in Middelburg, that afterwards was written in Goes ('primum in urbe vestri concepi, post Goesae scripsi'). Vermij. *The Calvinist Copernicans*, 75note.

[17] On Beeckman, see Van Berkel, *Mechanical Philosophy in the Making. Isaac Beeckman (1588-1637)* (in press).

Ill. 6. Philip Lansbergen demonstrating his quadrant, in front of the city of Middelburg. From Ph. Lansbergen, *Verclaringhe vande platte sphære van Ptolemæus anders astrolabivm genaemt* (1628).

regularly – if only to buy the excellent candles that Beeckman Sr., was producing. Scientific topics were discussed too and one can imagine that Lansbergen early on noticed the peculiar interest of his fellow immigrant's oldest son in mechanical and physical matters. From Isaac Beeckman's scientific notebooks, the *Journal*, we can infer that around 1615 Lansbergen stimulated him in studying medicine, helping him out with the books in his, that is Lansbergen's library, and suggesting him that he get a medical degree at the French university of Caen in Normandy. To be sure, Beeckman was in no way a scholar who was detached from everyday life; on the contrary, his *Journal* abounds with examples of his involvement in technological ventures both in his home town Middelburg and in the other cities where he was active for a number of years, cities like Rotterdam and Dordrecht. However, whether Lansbergen and Isaac Beeckman knew about Lipperhey's telescope in 1608 or 1609 remains unclear. In those years, Beeckman was away most of the time; he studied theology and mathematics at Leiden University from 1607 to 1610. It was actually at Leiden



Ill. 7. The garden 'De Lauwerenhof', behind the printers shop of Jan Pietersz van de Venne in Middelburg. From: Van der Venne, *Zeeusche Nagtegael* (1623).

that Beeckman first saw a telescope, since his mathematical teacher Rudolph Snellius used to demonstrate the new instrument to the students who took his course on optics, Beeckman being among them. Lansbergen on the other hand was still living at Goes when Lipperhey went to The Hague. When around 1620 he suggested that Beeckman build his own telescope, he referred, as would be natural at that time, to Galileo's invention, not to Lipperhey's. Much later Beeckman took lessons in lens grinding with Johannes Sachariassen, the son of Sacharias Jansen, who for a long time was regarded as the real inventor of the telescope. During one of their grinding sessions Sachariassen told Beeckman that his father had been the first who invented the telescope, and Beeckman did not contradict this statement – something he would certainly have done had he known about Lipperhey.[18]

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[18] De Waard, *Journal Beeckman*, 3 (1945), 376.

Natural history

Interest in scientific matters in Middelburg was not restricted to the mathematical sciences. Towards the end of the sixteenth century, quite a number of well-to-do inhabitants of Middelburg developed a keen interest in natural history, particularly in exotic plants and beautiful flowers. The town, recently expanded, contained several pleasure gardens within its walls, where lovers of natural history cultivated plants and herbs (see ill. 7). The pensionary and poet Jacob Cats in 1613 described a garden belonging to his Middelburg neighbour Pieter Courten, who was married to a lady called Hortensia del Prado (formerly married to the merchant Jean Fourmenois). In this garden, behind their house in the Lange Noordstraat, which is in the centre of the city, Hortensia could indulge herself in gardening:

There she has many fruits from all foreign lands,
A multitude of plants from divers distant strands,
And nameless flowers, and un-pressed wine
There runs a playful brook with a hundred fountains
There multiply the generous fish, the deer bring forth their young.[19]

Some lovers of plants were more than just avid collectors of rare specimens of flowers and had their contacts in the world of botanical science. In the 1590s there flourished in Middelburg a small but active circle of plant collectors who corresponded with the great botanist Carolus Clusius, who in 1593 came to Leiden to become supervisor of the botanical garden of the university.[20] Members of this circle were the city doctor Tobias Roels, the apothecary Willem Jaspers Parduyn and the clergyman Johannes de Jonge. All of them had gardens where they grew rare plants. Parduyn even had more than one garden. He had one directly behind his apothecary on the Market (a house called 'The Gilded Mortar'), and he had another probably outside the city walls.

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[19] Meertens, *Letterkundig leven*, 251; Bol, *The Bosschaert dynasty* (1960), 16. It is of course impossible to establish who constructed the many fountains in the pleasure gardens of the Middelburg elite, but it is tempting to think that the well-known inventor Cornelis Drebbel was one of them. Although he lived in the city of Alkmaar, in the province of Holland, he is reported as having constructed a fountain outside the North-gate in Middelburg in 1601. Cf. G. Tierie, *Cornelis Drebbel (1572-1633)* (Amsterdam, 1932), 4 (I thank Huib Zuidervaart for bringing this to my attention). Abraham Beeckman of course is another candidate. From Isaac Beeckman's *Journal* it is clear that his father and Drebbel knew each other personally. Did they meet or perhaps even cooperate during Drebbel's visit to Middelburg in 1601?

[20] Eldering, 'Middelburgs biologisch onderzoek in de 17^{e} eeuw' (1986).

The members of the Roels circle exchanged subtropical fruits and wine with Clusius, in exchange for bulbs and seeds of rare plants.[21] For instance, in 1596 Parduyn sent the Leiden botanist Mediterranean products like oranges, wines, marmalade, candied peel, pomegranates, and lemons. In return Clusius sent him tulips, anemones, peonies and other precious flowers.[22] Parduyn however had other ways to lay hands on exotic objects. His brother Simon Parduyn, a one-time burgomaster of Vlissingen and now an auditor at the Exchequer in Middelburg, was a business associate of Balthasar de Moucheron, a Flemish-born merchant who fitted out ships to the East Indies, and through De Moucheron, Simon and Willem Parduyn could easily get what they wanted. Besides, as an apothecary, Willem Parduyn will probably have provided the captains on outgoing ships with medicines and other pharmaceutical requisites, and in this way too he could make contact with the crews of the ships in the harbour of Middelburg. In November 1596 Parduyn wrote to Clusius that he had gone to a newly arrived ship from the island of St Thomé, 'to ask for something rare.'[23] (This time he had no luck, since the ship had only brought with it a group of black slaves – men, women and children, whom the captain had hoped to sell in Lisbon, unsuccessfully, however, because this harbour had just been closed for Dutch ships). Parduyn did not only collect plants and seeds however; other sorts of natural objects were also much in demand. Indeed, Parduyn was known for his cabinet of curiosities in which people could admire alligators, coral, precious stones and horns.[24] Here Roels and De Jonge discussed new specimens with Parduyn and here they jointly read and studied Clusius's books. When the members of this community of plant lovers had provided Clusius with something new, the Leiden botanist always returned their favours with something he had acquired from other sources. He also mentioned and thanked them in his *Rariorum plantarum historia* (1601). Exchange of commodities went hand in hand with exchange of knowledge.[25]

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[21] Hunger, 'Acht brieven van Middelburgers aan Carolus Clusius' (1925). Parduyn and De Jonge wrote their letters in Dutch, as did Jehan Somer and Jacques Noirot, two other members of the Middelburg community of plant lovers, while Roels corresponded in Latin. On Clusius, see: Hunger, *Charles de l'Ecluse* (1927-1942) and Egmond *et al.*, *Carolus Clusius* (2007).

[22] Hunger, 'Acht brieven' (1925), 114.

[23] *Ibidem*, 123: 'Om te vraegen near wat vrempts.'

[24] Willem Parduyn (1550-1602) was born in the city of Veere. See: *Nieuw Nederlandsch Biografisch Woordenboek (NNBW)*, III, col. 958.

[25] The Middelburg plant collectors also served as an intermediary for Clusius and his Spanish correspondents. On the close connection between science and commerce, see: Cook, *Matters of Exchange* (2007).

Despite their common interests, relations do not always seem to have been cordial among the lovers of natural history in Middelburg. Competition for Clusius's favours was sometimes disrupting friendly cooperation. Especially Roels, who was related to some of the most powerful men in Middelburg and for that reason may have felt superior to the other plant lovers, seems to have behaved rather selfish.[26] In 1596 De Jonge complains about Roels in one of his letters to Clusius:

> Two years ago I intended sending Your Honour two Lilies of Constantinopel which then blossomed in my garden, but D. Roelsius requested me to allow him to do this, promising to share with me whatever you should send him, and to this I agreed. Although Your Honour has rewarded him [with plants, seeds and bulbs], as I see, he acts unfaithfully and dishonestly, for he keeps everything for himself.[27]

Some years later the famous botanist Matthias de l'Obel (Lobelius) expressed himself in even stronger terms. Lobelius (1538-1616) was a native of the Flemish city of Lille, had been physician to William of Orange and in 1584 had become city physician of Middelburg. He thus was a direct colleague of Roels. In 1596 he had left Middelburg and went to England to become the personal physician of king James I, but every now and then he returned to the Netherlands, also to Middelburg. In 1603, shortly after the death of Roels, he commented on what he seen in Middelburg in a letter to Clusius: 'I find everything so changed and the city [Middelburg] fallen so low and depopulated, the practise of medicine so corrupted by the errand boys of Roels and his partners, that nothing can be done without protection.'[28] He also found that the pseudo-chemists and the 'kaco-chemists' were held in higher esteem than the really competent physicians.

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[26] Roels's father, who had come to Middelburg from Antwerp already in 1568 to become pensionary to the bishop of Middelburg, stayed in Middelburg after the city was seized by the rebels in 1574 and became pensionary to the States of Zeeland. His son Willem Roels was pensionary of the city of Middelburg from 1578 to his death in 1595 and married the sister-in-law of the second pensionary of the city of Middelburg, Johan van der Warke. Tobias Roels, the son of Willem, also married someone from the Van der Warcke clan. He studied medicine at Leiden and graduated as a medical doctor at some foreign university. On returning to Middelburg, he became one of its city doctors. Though he was just the (grand-)son of an immigrant, he always moved in the highest circles in Middelburg. See: *NNBW*, III, col. 1083; Meertens, *Letterkundig leven* (1943), 161, 471.

[27] As quoted in: Bol, *The Bosschaert dynasty* (1960), 17.

[28] As quoted in Eldering, 'Middelburgs biologisch onderzoek' (1986), 89. The fact that the young city doctor Charles Pelletier, who in 1610 published the first flora of Walcheren, the *Plantarum tum patriarum, tum exoticarum, in Walachria, Zeelandiae insula, nascentium synonyma* (Middelburg, 1610), does not seem to have had contact with the Roels circle may also have to do with the strained relations within the circle of Middelburg amateur botanists.

Painters as observers of nature

Collecting flowers easily led to painting flowers. Around 1600, the flower piece emerged as a new genre in painting in several places almost at the same time. Painters like Jan Brueghel the Elder at Antwerp, Roelant Savery at Prague and Utrecht, and Jacques de Gheyn II at Amsterdam have all been credited with being the first to paint botanical flower pieces. Tradition has it that flower pieces evolved from studies of individual flowers ordered by collectors of plants and exotic flowers. There is a story about Jan Brueghel that explains the origin of the flower piece in this way: a lady who was infatuated with tulips but was not able to buy one for herself is supposed to have asked Brueghel to paint one for her. It was also quite common that connoisseurs of precious bulbs ordered a local painter to draw a picture or paint a 'portrait' of their plants; in this way they could forever preserve the fleeting beauty of the flower. Or they could in this way present their fellow botanists with a picture of their treasures. In 1596 for instance the Middelburg clergyman De Jonge, whom we mentioned before, sent such a colour reproduction by an unnamed painter to Clusius ('a counterfeit of a certain sort of Tulipan'). A year later, on May 8, 1597, another collector from Middelburg, the traveller Jehan or Jan Somer, did likewise: 'I send Your Honour,' so he wrote to Clusius, 'the counterfeit of the yellow fritillary that has thus blossomed in my garden this year.'[29]

The yellow broad-leaved fritillary (*Fritillaria latifolia*) was a favourite of the Middelburg painter Ambrosius Bosschaert (1573-1621).[30] In his flower pieces this flower turns up again and again and it is therefore quite likely that the painter who was engaged by De Jonge and Somer was indeed Bosschaert.[31] Like so many artisans in Middelburg, Bosschaert was of Flemish descent. He was born in 1573 in Antwerp, but in 1587 moved, with his father, to Middelburg, 'for the sake of religion' as the sources tell us. Both father and son were painters and quickly rose to prominence in their new place of residence. It was often said that southern immigrants were much more assertive, that they were conspicuous for their noisier manners, that they always seemed to

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[29] Bol, *The Bosschaert dynasty* (1960), 18: Hunger, 'Acht brieven' (1925), 111, 127. For a refreshing analysis of the growing interest in tulips, which in the end led to the so-called tulip craze (which also affected Middelburg): Goldgar, *Tulipmania* (2007). Somer had travelled extensively in the Eastern Mediterranean and had published a widely read travel report: *Beschrijvinge van een Zee ende Landt Reyse naer de Levante* (2nd ed. Amsterdam, 1649). See: Goldgar, *Tulipmania*, 20-23.

[30] This paragraph is mainly based on: Bol, *The Bosschaert dynasty* (1960). See also: Brenninckmeijer-De Rooy, *Bouquets from the Golden Age* (1992); Bakker *et al.* (ed.), *Masters of Middelburg* (1984).

[31] This was already suggested by Hunger, 'Acht brieven' (1925), 112 note.

fill the whole stage and that they therefore quickly managed to occupy seats on boards and committees. Whether or not this is true, in 1593 Bosschaert is already mentioned as *beleeder* (member of the Board) in the guild books of St Luke (the guild of the painters). From 1597 to 1613 he was also at least six times dean of the guild, and in 1611, four years before he moved to Bergen-op-Zoom in Brabant, he bought an expensive house near St Peter's Church. Perhaps he rose to a prominent position so quickly because was not just a skilful flower painter, but also a well-respected art dealer (in 1612 for instance he sold a expensive painting representing a battle between the Dutch navy and the Spanish galleys of admiral Ambrogio de Spinola to the States of Zeeland). During some years he seems to have been more occupied with buying and selling art than with creating art.

Bosschaert started his career as a painter of individual 'portraits' of exotic plants, probably in commission of wealthy plant growers, people like Tobias Roels or Willem Parduyn. Later he moved on to painting mixed flower pieces and fruit pieces. The first flower piece is dated 1605. It is a rather primitively decorated Wan-Li vase on a gilt foot, decorated with open pomegranates and filled with tulips, roses, fritillaries and lilies (ill. 8). One of his best-known paintings, dated 1607, portrays several flowers standing in a carafe or rummer ('roemer') of which the cylindrical part is ornamented with thorn prunts, i.e. large applied glass drops broadly melted and drawn out to a point (ill. 9). (Perhaps this vase was produced by the glass factory of Govaert Van der Haghe – who knows?) We see a bouquet with a striped tulip as top flower and also containing further tulips, fritillaries, anemones, a paper white narcissus, columbines, lilies and roses. Many other paintings like these were to follow and Bosschaert is usually seen as the founder of a whole dynasty of flower painters in the seventeenth century, including his younger brother-in-law Balthasar van der Ast and his own sons Ambrosius Jr., Johannes, and Abraham. Another artist who was no doubt influenced by Bosschaert was the Middelburg flower painter Christoffel van den Berghe.

The realism in the paintings by Bosschaert and the younger members of his family is striking, but it is easy to understand that these flower pieces in no way represent an actual bouquet of flowers. All flower pieces contain flowers from different seasons.[32] A tulip blossoms in April and the beginning of May, but a columbine does so in June. Furthermore, the relative sizes of the flowers are not always in proportion, while sometimes the vase is too small and its neck too narrow for all the flowers in the bouquet. We should not see a bouquet

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[32] Bakker *et al.* (ed.), *Masters of Middelburg* (1984), 32.

Ill. 8. Flowers in a Wan-Li vase. Painting by Ambrosius Bosschaert the Elder, 1605. Private collection. Reproduced from: Bakker, *Masters of Middelburg* (1984).

as a lifelike depiction of an actual bouquet, but more as a collection of rare flowers and other natural objects (shells and animals mostly). A flower piece brings together rare objects and sets them in a relationship in the same way as the objects in a cabinet of curiosities would have been.[33] It is interesting to see the same flowers appear in different flower pieces of Bosschaert and his pupils. Because of its exceptional appearance, its rareness, or its fine colours and markings one tulip was Balthasar van der Ast's absolute favourite, a flower identified as the late tulip *Zomerschoon* (*Summer beauty*).[34] First he portrayed it (in which year is unknown, probably in the early 1620s) as a single flower, like a precious gem, in an expensive glass carafe with gilt metal mount and base

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[33] Goldgar, *Tulipmania* (2007), 96.

[34] Bol, *The Bosschaert dynasty* (1960), 72.

Ill. 9. Flowers in a glass beaker. Painting by Ambrosius Bosschaert the Elder, 1610. Stichting Piet en Nellie de Boer, Amsterdam. Reproduced from: Bakker, *Masters of Middelburg* (1984).

(ill. 10). Afterwards, he repeated it at least nine times, sometimes in a bouquet, sometimes in a flower basket and sometimes in a fruit dish on a table. In most cases, the flowers in a flower pieces are not drawn from life, but copied from preliminary studies of individual flowers, either in water colour or in oil paint (drawings are also possible). Most of these preliminary studies painters like Van der Ast and Bosschaert will have made themselves – a collection of such pictures and drawings was an indispensable stockpile for any artist – but it is also possible that they imported engravings or even paintings from elsewhere and copied them – in part at least – for their own paintings. Bosschaert at least was not only a painter, but also an art dealer. Notwithstanding the war, he traded with art dealers and painters in his native Antwerp. In 1607 or some time before Bosschaert imported copper plates for his paintings from the metropolis further upstream and in 1612 he sent species of letter wood from the

Ill. 10. A tulip in a glass vase. Painting by Balthasar van der Ast, undated. Private collection. Reproduced from: Bakker, *Masters of Middelburg* (1984).

East Indies (wood with a grain showing capricious figures suggestive of written characters) to Antwerp. In return, paintings by Jan Brueghel may have travelled to Middelburg, which would explain why some elements in Bosschaert's paintings are strikingly similar to Brueghel's pictures.[35] Borrowing details from the work of other artist was quite common in the seventeenth century and in no way detracts from the originality or the quality of the artist's work, as long as these details were absorbed and integrated into his own way of handling the material. And after all, most preliminary studies will have been Bosschaert's own work.

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[35] *Ibidem*, 24.

These preliminary studies point to the fact that Bosschaert not only was a skilful painter and successful art dealer, but also an accurate observer of nature. This is even more strongly suggested by another element in Bosschaert's paintings, the appearance of many insects and other little animals.[36] There is not a painting that does not included a butterfly, a fly or a snail; also caterpillars, beetles and shells are quite common. The 1607 painting mentioned above (with the rummer with the thorn prunts) shows a dragonfly, a painted lady, a bee, and a snail on the flowers and a fly and a marbled shell to the right of the glass. Balthasar van der Ast added some other animals to his repertoire, like grasshoppers, toads and even a mouse (in addition to many shells). Why these painters filled in their pictures with the little creatures is not something that should bother us too much. Insects were considered to be the most inferior elements in living nature and for that very reason the beauty and the delicate structure of these little creatures rendered homage, as some have argued, to God's creative power (ill. 11).[37] It is also possible that these insects have no symbolic value at all and that painters like Bosschaert and Van der Ast simply added them to give their flower pieces a more lifelike character. A fly that is tripping over the leaves of a plant and is so to say 'caught in action' strengthens the reality effect that is considered to be the hallmark of seventeenth century Dutch painting.[38] And finally these painters may have valued the insects just for the possibilities they offered to show their craftsmanship: the representation

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[36] In the literature on Bosschaert and his dynasty, each and every detail of his paintings is carefully analysed. Even the number of dew drops, the holes in the leaves and the place of the signature are scrutinized. Yet the insects and the other little animals hardly get any attention; only the shells have caught the eye of art historians.

[37] Jorink, *Het Boeck der Natuere* (2006), 198-202. Although the theme of the book of nature is prominent in literary texts in the early seventeenth century (Eric Jorink mentions for instance the poetry of the pensionary of Zeeland, Jacob Cats), I doubt whether this was Bosschaert's and Van der Ast's main motive for adding insects to their paintings. Bakker *et al.* (eds.), *Masters of Middelburg* (1984), 37-38, stresses the (Christian) symbolism of the individual flowers, but this tendency to see hidden meanings in seventeenth century Dutch painting is on its decline nowadays.

[38] Westerman, *A Worldly Art: the Dutch Republic* (1996). The Dutch painter-writer Karel van Mander in his *Schilderboek* (1604) says in so many words that painters added little animals in order to strengthen the reality effect of their paintings. He refers to the flower pots and flower glasses of the painter Lodewyck Jansz. van den Bosch and tells us that he 'devoted much time, patience, and accuracy to [his flowers] so that everything appeared natural, also because he painted dewdrops on the flowers and herbs, as well as a few little creatures, for example butterflies, flies, and suchlike ....' As quoted in: Bol, *The Bosschaert dynasty* (1960), 18. No paintings of Van de Bosch are extant today, but Van Mander explicitly mentions that a few fruit pieces and flower pots were to be found at the home of the Middelburg art-lover Melchior Wijntgis, Master of the Mint. Bosschaert and Wijntgis knew each other very well and were even friends. In 1609 the painter was witness at the baptism of one of the children of the art-loving magistrate.

Niet iſſer oyt van God ſoo cleyn en ſlecht geſchapen,
Of 'twijſt ſijn Schepper aan ;
Men kan uyt alle dingh ghelijck met handen rapen,
Dat God dat heeft ghedaan : (den
Siet maar een plantjen aan , een ſtruyckjen kleyn van waar-
Het toont dat God daar is,
Want 'tWeſen dat het heeft, koomt niet eerſt uyt der aarden,
Maar van Gods macht ghewis;
Het Leven dat het heeft, kan niemand haar oock geven
Dan God die boven leeft :

Ill. 11. The existence of God proven from plants and herbs. From: Van der Venne, *Zeeusche Nagtegael* (1623).

of even a simple fly required a combination of acute observation and skilful handling of the paintbrush. Yet whatever the motive that inspired Bosschaert and Van der Ast to add small animals to their portraits of flowers and fruits, one thing is certain: to be able to accurately depict these insects they had to devote considerable time to the careful observation of these animals.

This brings us back to where we began: optics. It is hard to imagine a painter like Bosschaert studying a fly or a caterpillar without the help of a magnifying glass. In the sixteenth and seventeenth century such an instrument was not uncommon in the textile industry. Particularly cloth merchants needed a magnifying glass so that they could count the number of threads in their merchandise, thereby establishing the quality of these goods.[39] In the sixteenth

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[39] One of these cloth merchants was Antoni van Leeuwenhoek, the famous microscopist. In the 1650s, he owned a shop for draper's goods in the city of Delft and it is believed that the handling of a 'thread counter' ('dradenteller' in Dutch) had in some way prepared him for his microscopical research. Cf. Schierbeek, *Van Leeuwenhoek,* 1 (1950), 17.

century, owners of cabinets of curiosities had other uses for an instrument like the magnifying glass. And following on the footsteps of these lovers of natural history, a painter of fruit dishes and flower pieces like Abraham Bosschaert must also have added the magnifying glass to his tools. And when he wanted to get one or two of these hand-held magnifying glasses, where did he go to? Perhaps he went to the shop of best lens grinder in town, Hans Lipperhey, nowadays also known as the inventor of the telescope.

The telescope at the court of the stadtholder Maurits

Rienk Vermij[1]

The invention of the telescope, like any other invention, was a prolonged and intricate process, taking many steps and involving many persons. Whereas the older historiography was mainly concerned with establishing who was the 'true' inventor of the telescope, recent research has tried rather to chart the entire process. In this paper, I want to highlight the role patronage played in the introduction of the telescope. It is by now well recognised that patronage networks largely determined the cultural dynamics of the time, and Hans Lipperhey, too, had to rely on patronage mechanisms when, in 1608, he drew attention to his newly built telescope and tried to get some rewards for it. It is in this context that his application for a patent should be assessed.

The dynamics of patronage in the Dutch Republic were different from those in a monarchy. In the case of Lipperhey and the telescope, the patron in question, count Maurits of Nassau, stadtholder of Holland, was no prince, his court was not really his court, and his possibilities for patronage were therefore limited. Until recently, his role as a patron of the arts, or his place in cultural life generally, was deemed insignificant. However, an exhibition at the Rijksmuseum in Amsterdam in 2001 showed that Maurits' court, although certainly atypical compared to other courts in Europe, was of more weight than hitherto assumed. Maurits was certainly in a position to promote things he liked or deemed important, as the telescope appears to have been.

Maurits' role in the introduction of the telescope has not been analysed so far. The catalogue accompanying the exhibition only briefly mentioned the instrument. It may be argued, however, that he was one of the key figures in the introduction of the telescope. His role in this respect also sheds new light on the dynamics of patronage in the Low Countries.[2]

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[1] I owe gratitude to Dr. Huib Zuidervaart and to Dr. Dirk van Miert for commenting upon an earlier version of this article, and to Dr. Kerry Magruder for correcting the English.

[2] The catalogue: Zandvliet *et al.*, *Maurits* (2000); see page 281 for the telescope.

The political structure of the Dutch Republic

The court of the stadtholder was not an ordinary court, and in order to assess the role of Maurits of Nassau, we should give some account of his position as stadtholder and of the state he served. By 1608, the Dutch Republic consisted of seven or eight provinces, each of which considered itself a sovereign republic. The power of sovereignty resided in the provincial 'States,' the assembly of representatives of the main cities and noblemen of the province, which was basically a medieval body. As the provincial States were not in permanent session, routine administration was delegated to a standing committee, the college of 'gecommitteerde raden' or delegated States. They also had the task of convening the States. The 'Gecommitteerde raden' of Zeeland consisted of seven persons, one delegate from each member of the States, that is, six cities and the first nobleman.[3]

Although the provinces were nominally sovereign, they had many common interests. Matters which concerned all provinces, such as foreign relations, military budgets were decided in an assembly of delegates of all seven provincial States, the States General. The States General, strictly speaking, had no sovereign powers. They were merely a body of delegates who in all important matters had to return to their respective provinces for instructions on how to vote. In practice, it developed into a central organ of the Republic.

The stadtholder was a somewhat strange element in the body politic. Originally, the Habsburg monarchs ruled their widely dispersed territories by appointing in each land a high-ranking nobleman as viceroy, governor, lieutenant, or stadtholder, as representative of their princely power. This governor was assisted and kept in check by a council of lawyers. During the Dutch revolt, these councils, being royalist, lost all political influence. The stadtholder of Holland, William the Silent, on the other hand, had placed himself at the head of the revolt. The function of stadtholder thereupon emerged as an important office in the new state, even if there was no longer a prince to represent. The States General officially deposed their prince in 1581. Originally, they did so with the intention of appointing a new one. But as time passed and candidates fell off, those provinces surviving the revolt in the end found they were better off without a head of state. The stadtholderate was a provincial office and in principle, every province could have its own stadtholder. That made up a possible total of eight. However, after 1589, there were never more than two at the same time.

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[3] For an excellent overview of the history of the Dutch Republic, see Israel, *Dutch Republic* (1995). The authoritative overview of its political institutions is Fruin, *Geschiedenis der staatsinstellingen* (1980).

Formally, the stadtholder was just a high-ranking official, paid by the States. In practice, he was much more. The stadtholder preserved certain royal prerogatives, notably the power to renew town magistrates. His principal source of power and prestige, however, was his commandership of the army, a highly influential post in a country continuously at war. Besides, it allowed him to appoint many officers. All this did not turn him into a monarch, however. Real power lay in the hand of the States, for they disposed of the country's money. The States decided about the budgets, they supervised the collection of taxes, and they made all the payments. The stadtholder had no part in that.

Maurits of Nassau

Born in 1567, Maurits of Nassau was the second son of William the Silent, the leader of the Dutch Revolt. After the assassination of his father in 1584, he became stadtholder of the provinces Holland and Zeeland. In 1590-1591, he also acquired the stadtholderates of Utrecht, Overijssel, and Gelderland. He was to become stadtholder of Groningen and Drenthe as well, but that happened years after 1608. Maurits gained wide recognition for his army leadership. In a series of brilliantly waged campaigns, he captured practically all the Spanish strongholds in the northern Netherlands, thereby securing the independence of the seven provinces. Because of this, he acquired European renown. At the imperial diet at Regensburg in 1597, the Elector of Cologne proposed appointing him as imperial commander in chief against the Turks: no other army general in Europe enjoyed comparable prestige.[4]

His successes in war were largely the result of the army reforms which were carried out under his command. These enhanced discipline and organization, but also introduced a more scientific way of conducting operations. In his reforms, Maurits closely cooperated with his cousin Willem Lodewijk of Nassau, the stadtholder of Friesland (another of the seven provinces). It seems to have been Willem Lodewijk who propagated a more scientific way of warfare in the first place, based on the study of ancient authors. Maurits was less well versed in history, but he certainly had a deep interest in the engineering side. His sieges owed their success a great deal to an intelligent use of engineering. He knew all his engineers, and even all work-masters, by name. Upon his initiative, an engineering school was founded in Leiden. Dutch engineers became

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[4] For a recent biography see Van Deursen, *Maurits van Nassau* (2000). On the Elector's initiative, *ibidem*, 160.

Ill. 1 Count Maurits of Nassau (1567–1625). In 1618 he inherited the title 'Prince of Orange' from his late half brother Philippe-Guillaume (Philips Willem). Engraving by Crispijn Queborn (1639).

leading engineers in Europe and many of them found employment abroad.[5]

Maurits kept himself to his army command and left governing the country to the States, in particular to the powerful pensionary of the States of Holland, Johan van Oldenbarnevelt. He had no princely aspirations, but because of his descent – he was the son of the prince of Orange and a princess of Saxony –, he certainly was the highest-ranking person in the Dutch Republic. Foreigners, to whom his position was not quite clear, often addressed him as a kind of prince. He remained well aware of his rank and the importance of the house of Nassau and kept a princely household. All in all, his court comprised some two hundred persons – noblemen, councillors, guardsmen, servants, a Reformed minister, and others. His attire and his living quarters were richly decorated, as becomes a person of his stature. Outwardly, Maurits' court looked impressive.[6]

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[5] Van Nimwegen, '*Deser landen crijchsvolck*' (2006), 83-102, 116-127. Westra, *Nederlandse ingenieurs* (1992), 74-81.

[6] For a description of Maurits' court, see Zandvliet, 'Het hof' (2000).

However, it was hardly his own court. For one thing, there was the question of money. For the first twenty years of his stadtholderate, Maurits was constantly short of money (after that time, his financial position became gradually more secure). His family had lost most of its possessions during the early years of the revolt, so for his income, Maurits was dependent on his salary as stadtholder and army commander, and on other special remunerations the States might allow him. The splendour in which he lived had been granted to him by the States and was in part not even his property. Many of his courtiers (noblemen, guards, his physician, his minister) were directly paid by the States. His residences in various cities were owned and furnished by the States or the municipalities. Whether Maurits himself had any say in the way they were furnished is doubtful. The amount of money spent on them or the character of the decorations reflected the importance the States attached to their stadtholder, not Maurits' own preferences. In like manner, the many portraits of Maurits that circulated and were presented to foreign dignitaries reflected the States' policy, not any courtly ambitions of Maurits himself.[7]

Maurits was thus hardly in the position to act as a real patron of the arts. Moreover, his own interests were mainly with the army and not with the niceties of courtly culture. He preferred the more rustic sides of noble living. He liked hunting and he kept exotic animals. His favourite pastime was horse-breeding. Indeed, he liked horses ('your dearest courtiers,' as his secretary, the poet Constantijn Huygens called them) more than paintings. The sole painting which was certainly commissioned by him, actually portrays a horse. Only in those arts which were closely related to the military, he took on an active role as a patron. He promoted armoury, attracting armourers of international standing to The Hague. A modern art historian called this 'maybe Maurits' most important contribution to the development of the arts in his time.' [8]

However, Maurits was not an illiterate soldier. In his youth, he had studied at the academies of Heidelberg (briefly) and Leiden, where the famous scholar Justus Lipsius was among his teachers, and where he had been trained not just in horse-riding and fencing, but also in Latin, French, law, history, draughtmanship, and mathematics. His army reforms were carried out in agreement with the scholarly ideals of his time, with constant reference to the works of ancient authors. Some artists, notably Jacob de Gheyn (the Younger), appear

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[7] Zandvliet, 'Het hof' (2000); Kloek, 'Maurits en de beeldende kunst' (2000).

[8] Van Deursen, *Maurits* (2000), 220-221. On the horse's painting: Kloek, 'Maurits en de beeldende kunst' (2000), 144; Zandvliet, *Maurits* (2000), 234-235. On Maurits and armoury: Kloek, 'Maurits en de beeldende kunst' (2000), 140.

to have had a special relationship with the stadtholder. Even if De Gheyn was no real court artist, he often appears to have been in Maurits' vicinity and did some work for his court (among others, he painted the horse of archduke Albrecht of Austria, which in 1600 had been captured by the Dutch at the battle of Nieuwpoort). The fact that Maurits was able to devolve most of the costs of his court upon others, does not mean that he had no say in it at all. The States clearly had the final word, but it is hard to believe that the stadtholder would not have been able to promote activities or artists which he really took to heart.[9]

Maurits and mathematics

The one part of higher culture Maurits was really fond of was mathematics. The pictorial arts, it has been remarked, had his attention especially when they bordered on mathematics.[10] Maurits was interested in mathematics from an early age. He had had the good luck of finding an excellent mathematics teacher in Simon Stevin, one of the leading mathematicians of his day. Maurits probably met Stevin at the university of Leiden during his studies there in 1582-1584. Stevin, several years older than Maurits, had come from the southern Netherlands to make a career in Holland and had also matriculated at Leiden. Stevin became Maurits' personal mathematics teacher – 'my mathematician,' as Maurits called him. Originally, Stevin seems to have been part of Maurits' personal household, but in 1593, Maurits persuaded the States to give Stevin a paid position as quartermaster in the States' army. This did not end the personal bond, however. A list of 1604 mentions him as part of Maurits' household with an allowance of 600 guilders yearly.[11]

Some of Stevin's many works were written at the request of Maurits. The clearest evidence of their close cooperation is offered by the 'Mathematical memoirs,' published by Stevin in 1605-1608. These memoirs contained the mathematics lessons originally given by Stevin to the stadtholder. It appears,

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[9] On Maurits' education: Groenveld, 'Man met de loden schoenen' (2000), 17-18. On De Gheyn and Maurits' court: Kloek, 'Maurits en de beeldende kunst' (2000), 144-145; Zandvliet, *Maurits* (2000), 125, 314-316.

[10] Kloek, 'Maurits en de beeldende kunst' (2000), 140.

[11] The main biography of Stevin is still Dijksterhuis, *Simon Stevin* (1943). For an abbreviated English version: Dijksterhuis, *Simon Stevin* (1970). In several respects, the biography is dated. For a collection of recent studies on Stevin, see Elkhadem & Bracke *Simon Stevin* (2004). On Stevin's relation to Maurits, see *ibidem*, 23-24; Zandvliet, *Maurits* (2000), 276-277; Kubbinga, 'Stevin en Maurits' (1994).

Maurits had been an eager student who often elaborated upon the matter proposed, and Stevin inserted his contributions respectfully into the text. From Stevin's writings, it is therefore possible to get some idea of the kind of mathematics Maurits was interested in. It is not surprising that much is of a purely practical nature: fortification, engineering, and other military affairs figure prominently, as well as book-keeping and the bridling of horses.[12]

However, Maurits' mathematical interests were not limited to practical applications only. Theoretical issues too had his attention. The 'Mathematical memoirs' contain a large section on the principles of astronomy, and here too we find Maurits' comments. Maurits' interest in astronomy appears also in another instance. When in 1597 Maurits learned of the troubles which the famous astronomer Tycho Brahe was having in Denmark, he immediately offered him an asylum in the Dutch Republic. He added that he had to arrange this with the States, who after all had to pay for Tycho's position, but he was confident that this would not present a problem. Tycho declined the offer and instead went to the imperial court of Rudolf II at Prague.[13]

Mathematicians were well aware of Maurits' interests and actively sought his protection. In 1596, Ludolf van Ceulen dedicated his work on the circle to Maurits. The young Willebrord Snellius, who strove to succeed his father as professor of mathematics at Leiden university, translated Simon Stevin's 'Mathematical memoirs' into Latin and published this translation, in the same years as the originals, with a dedication to the stadtholder, which must have pleased both Stevin and Maurits. In 1607, Snellius dedicated still another book to Maurits, the reconstruction of an ancient geometrical text by Apollonius. This was not engineering, but rather pure scholarship (another book of reconstructions of Apollonius was dedicated to Stevin). In later works, Snellius would integrate practical work (surveying, navigation) and philological scholarship, in the same way that Maurits' army reforms were based both on practical insights and field trials, as well as study of classical authors.[14]

Maurits was also interested in gadgets of a technical nature. The best known example of this is the sailing chariot which Stevin built for Maurits, and which the latter used to regale high-ranking guests on trips along the seashore. We know about this chariot mainly from a contemporary engraving by Jacob de

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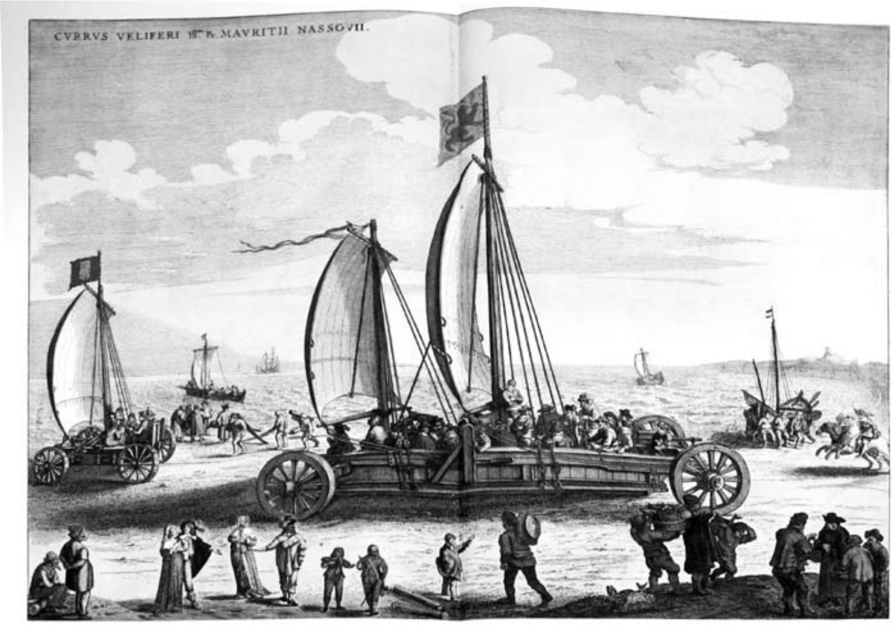
[12] Van den Heuvel, 'Wisconstighe ghedachtenissen' (2000), passim.

[13] On Maurits and astronomy, cf. Vermij, *Calvinist Copernicans* (2002), 63. For the invitation to Tycho, see the letter by Frans Gansneb Tengnagel to Tycho Brahe, 6 July 1598, in *Tychonis Brahe Opera Omnia* (reprint 1972), 82. Cf. also 95, 98.

[14] De Wreede, *Willebrord Snellius* (2007), 52-53, 61-63. See also Vermij, *Calvinist Copernicans* (2002), 22-23.



Ill. 2 Sailing chariot (‘Zeilwagen’), designed by Simon Stevin for Count Maurits of Nassau. Engraving Joan Blaeu, *Toonneel der Steden van de Vereenighde Nederlanden* (1643).

Gheyn, with Latin verses by Hugo Grotius. De Gheyn was paid for his engraving by the States General. There is no indication that Maurits had suggested the production, although this seems probable.[15]

Maurits’ fondness of engineers and inventions must have been widely known. When, by September 1608, a spectacle-maker in Middelburg showed the local regents an instrument with which one could see far-off things as if they were nearby, the stadtholder must have been the obvious person to refer the matter to. On 25 September 1608, the ‘gecommitteerde raden’ of Zeeland sent the man to The Hague with a letter to Zeeland’s representatives there, in which they were asked to gain Lipperhey an interview with the stadtholder. One might ask why exactly the ‘gecommitteerde raden’ wrote this letter, and not the burgomasters of Middelburg, who might be deemed the more obvious body to act in the interest of one of their citizens. Probably, it was because the ‘gecommitteerde raden’ stood in regular exchange with the deputies at The Hague anyway.

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[15] Zandvliet, *Maurits* (2000), 274-275. Kloek, ‘Maurits en de beeldende kunst’ (2000), 144.

Lipperhey at The Hague

The Hague at the time was the scene of negotiations on a possible truce between the United Provinces and the King of Spain (which would indeed be concluded the following year). Not all parties in the Netherlands felt that such a truce was a good idea and the negotiations caused a lot of tension and distrust among the Netherlanders themselves. Maurits was deeply suspicious of the intentions of the people promoting the truce, foremost among whom was the grand pensionary of Holland, Johan van Oldenbarnevelt. The relations between the two men became quite chilly and the stadtholder became, quite uncharacteristically, deeply immersed in politics. People felt that the very existence of the state was at stake, so one would expect that they had other things on their minds than optical instruments. Eventually, the presence of so many high-ranking diplomats would help gain the instrument renown, but initially, it must have seemed that Lipperhey arrived at a rather unlucky moment.

There is no record of what exactly happened when Lipperhey arrived at The Hague, but apparently, even though deeply involved in grave matters of state, Maurits did not miss the opportunity to have the new instrument demonstrated to him and then kept it in his possession. According to a contemporary pamphlet, Maurits showed the instrument to the marquis of Spinola, the commander of the King of Spain's army in the southern Netherlands, who happened to be in The Hague for the negotiations.[16] Spinola left The Hague on 30 September, so the demonstration must have taken place before that date. Lipperhey must, therefore, indeed have gained access to the stadtholder and offered him his telescope within a few days. The official documents corroborate this. When on 4 October the States General decided that they wanted to see and test the instrument, they stipulated that this examination would take place 'on the tower of the quarters of His Excellency' [= Maurits]. Evidently, they would not have bothered the stadtholder, had not his quarters been the place where the instrument was kept.[17]

Having accepted the gift, Maurits of course had also accepted the obligation to give the inventor something in return which showed his satisfaction. As stated before, the stadtholder had only a very limited budget and was accustomed to devolve any extraordinary expenses for his court upon the States. Feeling that a handsome reward for Lipperhey would be in place, he referred him to the States General, no doubt promising him his support. So it is that we find Lipperhey, a week after the letter by the 'gecommitteerde raden' of

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[16] Zoomers & Zuidervaart, *Embassies of the King of Siam* (2008).

[17] Van Helden, *Invention* (1977), 41, 36. The departure of Spinola is mentioned in the resolutions of the States of Holland (H.J. Zuidervaart, personal communication).

Zeeland, presenting a request to the States General, asking for either a patent on his invention or a fitting remuneration. This request is not an ordinary application for a patent by a tradesman. It was clearly a move to offer a legal framework for a payment or a privilege to be offered to Lipperhey. Actually, it was not unheard of in early modern Europe that patents were given as marks of distinction or of the prince's good favour, rather than for purely commercial reasons.[18]

Interestingly, in the first resolution upon Lipperhey's request, the States General already suggested how the instrument might be improved. This is very unusual in a patent application. The States normally decided upon a request for a patent without bothering about the technical details. They did not require any model or prototype. The inventor had to give some kind of a description, but this served the purpose that later, in case of need, he would be able to prove that the patent had been infringed upon. In some cases indeed, a commission of technical experts was asked to investigate the alleged invention. That would be the case where the invention was of possible use to the state, above all with methods for finding longitude at sea, for the solution of which problem a substantial reward had been promised by the States. But in other cases, applicants did not even have to prove that their invention worked.[19]

The telescope clearly was never officially shown in the States' assembly. The resolutions of 2 October state that the States had found that Lipperhey indeed had made such an invention as he claimed, but this probably just means that Maurits had told them so. Only two days later, on 4 October, the delegates at the States General decided that they wanted to see the instrument and that each province should delegate a person to investigate the instrument, to verify whether it really was worth that much money. Apparently, this was an examination by the delegates themselves, not by a panel of experts, as would be the case with an invention to find longitude. As the demonstration would take place on the tower at the Buitenhof which contained Maurits' work- and living-quarters, the resolution presupposes an invitation by the stadtholder. Maurits' ties with the States were close at this time. Because of the peace negotiations, the stadtholder felt he could no longer ignore politics. In 1608, he took part in the deliberations of the States General 'nearly permanently.'[20]

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[18] On the various ways patents could be used, see Biagioli, 'From Print to Patents' (2006).

[19] On patents in the Dutch Republic: Doorman, *Octrooien* (1940).

[20] Resolution of 2 October 1608 as quoted in Van Helden, *Invention* (1977), 36: 'gelijck d'Heeren Staten gebleken is'; Van Helden's own translation ('as had been shown to the... States') seems not wholly accurate. See also Resolution of 4 October 1608. On Maurits' presence in the States see Rijperman, *Resolutiën* (1970), 323, footnote 6.

Still, the decisions made by the States General do presuppose some knowledge of the instrument. Immediately, on 2 October, it was decided to ask Lipperhey whether he would be able to construct it in such a way, that one would be able to look through it with two eyes instead of one (this is normally interpreted as meaning a binocular telescope). On 4 October, the States also demanded that 'christal de roche' (literally rock crystal, but more likely some high quality glass) was to be used for the lenses. These suggestions, made at a moment when the delegates had not even seen the instrument, will hardly have been the result of an open discussion during the meeting. The improvements must have been suggested by Maurits, who in this way commissioned a telescope according to his own wishes and specifications, to be paid for by the States General.[21]

The suggestion of using 'christal de roche' instead of glass is especially interesting, as it must have been made by someone who knew more or less the construction of the instrument and had found that the quality of the glass was vital to the working. Some persons must have investigated the instrument beforehand, discussed it, and formed some idea upon it. I think it is fair to assume that such discussions were waged in the circles around Maurits, where people would have easy access to the telescope. This would first of all include his relatives, among whom his half-brother Frederik Hendrik and his cousin Willem Lodewijk would stand out (it is tempting to think that the three telescopes which were finally commissioned were destined for Maurits and these two men). As would be expected with courtly instruments, Maurits also showed it to distinguished visitors. As stated before, he demonstrated it to the marquis of Spinola.[22]

Whether these men were in a position not just to try and admire the instrument, but also to study it and suggest improvements, might be questioned. Maurits probably admitted, or called in, other people as well, who might be deemed more expert in such matters. A probable candidate would be Jacques Wijts, a army captain with scholarly inclinations who belonged to Maurits' inner circle. Moreover, it is hard to imagine that Maurits, as a mathematician, would not show the gadget to some of his engineers. Simon Stevin at the time was living at The Hague. There is no evidence that he ever saw or handled the telescope, but it seems plausible that Maurits would have consulted him. It is therefore not impossible that the suggestions for improvements stemmed partly from Stevin. Other possible consultants would include the engineer Samuel Cloot, curator of Maurits' collection of maps, mathematical instruments and military models, and the artist Jacob de Gheyn.[23]

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[21] Resolutions of 2 and 4 October 1608, quoted in Van Helden, *Invention*, 36; Rijperman, *Resolutiën* (1970), 623-624, offers just a summary.

[22] On Spinola: Van Helden, *Invention* (1977), 41-42.

[23] On Wijts: Zandvliet, *Maurits* (2000), 239-240, 246-248. On Cloot: *Ibidem*, 78.

Jacob Metius at The Hague

When the second claimant, Jacob Metius, turned up, things went very much the same way. The sources on Metius are few and of dubious quality, and his contribution to the development of the telescope is therefore difficult to assess. That he knew about the basic construction need not amaze us. As is clear from other contributions to this volume, many mathematicians were familiar with the fact that two lenses could have a magnifying effect. Metius stated that he had made the discovery while working on 'the investigation of some hidden knowledge which may have been attained by certain ancients,' actually having another invention under hand. This suggests that he was a kind of alchemist or inventor in the style of his fellow-townsman Cornelis Drebbel. His claim that he had been working for two years trying to perfect his telescope probably should be taken with a grain of salt. But when he heard that someone else had got a large remuneration for it, he came into action.[24]

In the request Metius submitted to the States, he claimed that with his instrument one could see a distant object as clearly as with the instrument presented by Lipperhey, 'according to the judgment of his Excellency [Prince Maurits] himself and of others who tested the respective instruments against each other.' So, Metius had gone to Maurits with his instrument before turning to the States, and probably had turned to the States upon the recommendation of Maurits. It does not appear that Metius showed the instrument to the States, or that the States expected him to do so. It was taken for granted that the States would decide on the basis of the judgment of the stadtholder. It also appears that indeed Maurits still had the first instrument by Lipperhey at his disposal. [25]

Van Helden has suggested that Metius, being the son of a leading regent of Alkmaar, might have heard about Lipperhey's invention via the regular messages from the deputies at The Hague. Alkmaar had session in the States of Holland, so its regents co-decided in matters of state and had to be kept abreast of all developments. However, it seems unlikely that such a message would have contained more than the notion that Lipperhey had been rewarded for offering an instrument to look into the distance. If Metius came into action, it was because he felt that the invention was rightfully his, and this would imply that he had specific information about the construction of the instrument. The obvious source for this would be the engineers around Maurits. Jacob Metius'

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[24] Van Helden, *Invention* (1977), 39-40.

[25] See the appendix.

father, Adriaen Anthonisz, was not just a local regent, but also the Republic's chief engineer. In 1608, he was in the final days of his career, but still enjoyed an immense reputation. It is most likely that he knew about Lipperhey's invention not just from the official reports to the city government, but directly from his colleagues in the vicinity of the stadtholder who had studied the instrument.[26]

As son of Adriaen Anthonisz, Metius had easy access to the stadtholder and could be sure that his claims would be considered seriously. Maurits apparently referred him also to the States with a recommendation. Whether he really found Metius' instrument as good as Lipperhey's cannot be checked. Metius requested that he be granted a patent so that other persons would not be allowed to copy his invention. This was asking a bit too much. On 17 October 1608 the States replied that 'the petitioner was admonished to investigate further, in order to bring his invention to the greatest perfection.' Only then could they decide upon a patent. Metius more or less had evoked such a response by emphasizing that his instrument was still defective and claiming that he would be able to accomplish much more in the near future. The pill was sweetened by allowing Metius a hundred guilders, no doubt in return for the telescope which he had left in the hands of Maurits. Whether the money accurately represents the value Maurits attached to the instrument, or whether Metius was dealt with somewhat liberally for being the son of an important state-official, is impossible to say.[27]

The telescope and the States of Holland

The Hague was not just the meeting place of the States General. The States of the province of Holland also assembled there, although with intermissions. They therefore were in a good position to follow the discussions in the States General, and probably would feel perfectly entitled to do so, if only because Holland paid more than half of all expenses the States General decided upon. In commissions of the States General, delegates from the province of Holland were generally well represented, especially in affairs which touched on Holland's own interests.[28]

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[26] *Ibidem*, 22. On Metius senior: Westra, *Nederlandse ingenieurs* (1992), 36-44; Wortel, 'Adriaen Anthonisz' (1990).

[27] Van Helden, *Invention* (1977), 40.

[28] For information on the relations between the States of Holland and the States General, I owe gratitude to dr. Ida Nijenhuis (Instituut voor Nederlandse Geschiedenis, The Hague).

In the official resolutions of the States of Holland, the telescope is not mentioned. That it was nevertheless discussed is clear from some notes which the delegates of one of the cities of Holland, Medemblik, made of the meetings. According to these reports, on 4 October a few 'particuliere saecken' (private affairs) were communicated to the States, among these Lipperhey's invention and the resolution of the States General thereupon, to wit, that some were committed to test the instrument and negotiate with the inventor. The States of Holland thereupon appointed not just one person, which they, as a province, were required to, but persons from six different cities. Whether the States felt the affair was really of such importance, or whether they were just curious to see the instrument, is hard to say.[29]

Two weeks later, on 17 October, Jacob Metius' request also was brought to the fore. The same source mentioned that Metius had produced a similar instrument as Lipperhey, had demonstrated it in The Hague, and had also applied for a patent. 'But it has been resolved that, as the negotiations with the other have been initiated first, one cannot grant him [Metius] a patent for now, but that one will make him an allowance of a hundred guilders for his trouble and encourage him to take efforts to improve his instrument so that it will surpass the other, and that one shall have to take that up afterwards.' This tallies neatly with the resolutions of the States General of the same day.[30]

What makes these reports so interesting, is that the information relayed seems to derive from a source close to Maurits, or even from the stadtholder himself. Maurits had been present in the assembly of the States of Holland on 3 October. The 'private affairs' mentioned on 4 October were, apart from the telescope and a point brought up by the delegates of Amsterdam, the affairs of the 'Prince of Portugal' and a report of an engineer on the fortifications in the east of the Republic. These were all topics discussed in the States General but not mentioned in the official resolutions of the States of Holland. Although it is not stated who forwarded the information, the cases appear well in line with Maurits' interests. The said engineer had been sent by his cousin, Ernst Casimir of Nassau. The prince in question is Emanuel of Portugal, a pretender to the Portugese throne, who in 1597 had married Maurits' sister Emilia. The marriage had taken place against Maurits' wishes, but he kept supporting his sister and her husband, financially and otherwise. Only after Maurits' death, in 1626, would Emanuel go over to the Spanish

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[29] Notes of representative of Medemblik, in: Van Helden, *Invention* (1977), 36-37. For the original notes, see the appendix.

[30] *Ibidem*.

side. As for the telescope, as stated above it seems rather unlikely that the States of Holland would appoint delegates to inspect the stadtholder's instrument in his own quarters without the latter's approval.[31]

The meeting of 17 October even took place in Maurits' quarters, as the latter had demanded that the States come over to discuss some political matters with him. These affairs having been finished, two other issues were mentioned: the request by Jacob Metius, and a second invention, an instrument to measure the variation of the compass in order to find longitude (as stated, the States General had offered a reward for the solution of this problem). The inventor is not named, but by other sources can be identified as the Amsterdam mathematician Barent Keteltas. He had asked the States General for a patent on his instrument on 19 August. A decision would not be made before 22 October, but at their meeting with Maurits of 17 October, the States of Holland were already informed of the conclusions of the experts who had examined the invention. It seems that Maurits was closely following the examination of Keteltas' instrument. Apparently, it was not uncommon for him to act as a backstage patron to new inventions.[32]

The Dutch telescope as a courtly instrument

Maurits' position as stadtholder may have been somewhat peculiar, but it left him ample space to act as a patron, and in the case of the telescope he clearly did so. The telescope started its real career at The Hague, not at Middelburg or via any commercial channel. There is indeed a report from 1614 by the German astronomer Simon Marius that a Dutchman ('Belga') had offered a telescope for sale at the Frankfurt book fair of 1608. Even if that be true, this did not really have an effect on the proliferation of the telescopes. The instrument's principles might have been known to earlier mathematicians and some people may have experimented with actual instruments, but only after the telescope was introduced at the court of Maurits, were telescopes produced all over Europe. It was its emergence at the court of the stadtholder, and the personal interest Maurits took in it, which made people all of a sudden realize its potential and its importance. Every prince wanted his own telescope, and craftsmen hastened to supply them.[33]

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[31] On Emanuel of Portugal: Rijperman, *Resolutiën* (1970), 614-615. Van Deursen, *Maurits* (2000), 162, 164, 221-222; Zandvliet, *Maurits* (2000), 173. On the engineer's report: Rijperman, *Resolutiën* (1970), 517.

[32] On Keteltas: Rijperman, *Resolutiën* (1970), 623; Davids, *Zeewezen* (1986), 72. See also the appendix.

[33] For Marius' account, see Van Helden, *Invention* (1977), 47.

Whether courtly connections were the only factor of importance is another matter. Rolf Willach has argued that the quick proliferation from 1608 onward was possible because a simple technical improvement (a diaphragm) had been introduced (elsewhere in the volume). There can be little doubt that Lipperhey's first instrument, in order to impress Maurits, had to be quite good. The reports of the trials made with it confirm this. This does not necessarily mean, however, that later telescopes performed as well. Girolamo Sirtori, who claimed to have seen and handled Lipperhey's very first telescope, noted in 1612 that it was of better quality than all later telescopes he had seen. Willebrord Snellius, who possessed an instrument by 1610, complained that it made things seem larger, but certainly not clearer. People wanted telescopes because they were a courtly fashion, not because of their actual performance, which often was still wanting. Artisans and scholars then started work to perfect the instrument.[34]

However, if Maurits' court promoted the instrument as such, that is not to say that it promoted its scientific use as well. It deserves notice that the Dutch, after having brought the instrument into the world, accomplished little with it, in spite of a flowering culture, an important engineering tradition, and the presence of scholars such as Stevin, father and son Snellius, Lansbergen, and Gorlaeus. Elsewhere, the telescope became instrumental in a series of important astronomical discoveries. The telescope was turned into a scientific instrument in Italy by Galileo, with second parts for Thomas Harriot in England and Simon Marius in Germany. A mathematical explanation was given by Johannes Kepler at Prague. In nearby Eastern Frisia, in 1610 Johann Fabricius used a telescope to discover sunspots. But no Dutch scholar claimed any discovery with the new instrument until others had shown the way.

This is somewhat puzzling. With hindsight, it seems obvious that the telescope offered a rich potential for astronomical discoveries. The 1608 pamphlet already stated that with this instrument one could see 'even the stars which ordinarily are invisible to our sight and our eyes, because of their smallness and the weakness of our sight.' One may well ask whether the fact that nobody in the Netherlands used the instrument for such purposes, had also to do with its introduction as a court instrument. Ever since Biagioli's work on the courtly context of Galileo's work, there is a tendency to see the court, or princely

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[34] Sirtori's account in Van Helden, *Invention* (1977), 48, 50. Snellius to Aemilius Rosendalius, 1610: Utrecht, University Library, Hss VII A 26 ('conspicilia duo... quibus res objectae, multe quidem ampliores sese visui nostro ingerunt; utinam etiam tanto clariores'). Cf. De Wreede, *Willebrord Snellius*, 68-69.

patronage, as one of the main driving forces behind early modern scientific discovery. Without denying the determining influence of patronage for the cultural and intellectual life of the period, it is important clearly to discern what this factor accomplished and what not. Princes promoted certain forms of what we might call science, but certainly not all. Generally speaking, they were interested in activities which enhanced their prestige, which were of direct practical (especially military) use, or which could be seen as part of noble culture. On the other hand, there was little interest in abstract speculations or intricate mathematics.[35]

Maurits' interest in the telescope was well in line with general courtly culture. It was an interesting plaything, a subject for demonstrations and conversations, which gave Maurits credit among his peers. For that, one did not need to be aware of its potential for astronomical discoveries. In line with aristocratic values, its purpose was above all defined in military terms. Of course, this may partly have been to legitimate the spending of considerable sums of state money on it. It would be interesting to know how far the spyglass was really used for military purposes. Sure, there was also a good deal of 'scientific' work on the instrument, as could only be expected at the court of a prince so interested in engineering and mathematics. But these efforts were concerned with ways to improve upon the instrument – turning it into a binocular, or using a different kind of glass. Such improvements did not necessarily make it more apt to offer a new view of the universe. A binocular telescope aims at easy handling and is fit for courtiers rather than investigators.

To ask why something did not happen is probably a wrong question, but it may help us realize that scientific discoveries at the time were not self-evident and required a particular set of conditions, which probably went well beyond the common ideals of the time. Galileo was successful, it can be claimed, not because he was part of a world of courtly patronage, but because, although part of this world, he did not allow himself to be directed by its values. He succeeded in following and imposing his own program, making use, of course, of the social instruments which presented themselves at the time. Maurits, on the other hand, was as interested in mathematics and astronomy as any prince in Europe, but he was a military and a nobleman, not a visionary.

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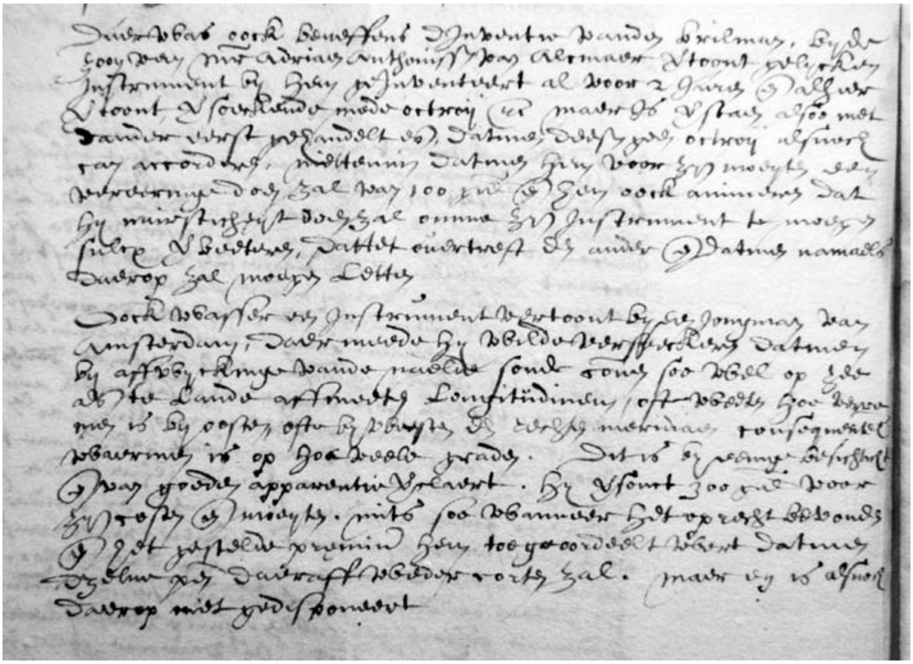
[35] Zoomers & Zuidervaart, *Embassies of the King of Siam*; 49. The observation of hitherto unknown small stars was probably not as revolutionary as it seems. Several sixteenth-century authors attest that the idea of the galaxy as a congeries of many small stars was not uncommon at the time. See *Jaki, The Milky Way* (1972) 84-85. Cf. Bagioli, *Galileo*, *Courtier* (1993).



Ill. 3 Manuscript note, probably by Frans Pietersz, secretary of the city of Medemblik, recording Jacob Metius's presentation of a telescope at Count Maurits' quarters in The Hague on 17 October 1608. (Regional Archive, Hoorn).

APPENDIX

An unpublished record of Jacob Metius' dealings with the States General

As for what happened in the assembly of the States of Holland in 1608, apart from the official resolutions, there is another extant source: an unofficial record written by the delegates of one of the smaller cities of Holland, Medemblik, which had seats in the States. The delegates, burgomaster Jan Cornelisz Schellinger and city secretary Frans Pietersz, apparently kept this record ('Memorien van 't geen ter vergaderinge van de heeren Edelen [en steden] van Holland ende West Frieslandt voorgevallen is in den Hage' = memoirs of what occurred in the assembly of the States of Holland at The Hague) for the information of their city government. The manuscript is preserved in the archives of West-Friesland at Hoorn (oud archief Medemblik, provisional number 7; see ill. 3).

In 1854, the historical journal *De Navorscher* published a passage from this manuscript on the presentation by Lipperhey of his newly invented telescope.[36] This passage was reprinted in the works by De Waard and Van Helden on the invention of the telescope. However, it appears that they simply copied the passage from *De Navorscher* and did not check the original source. In 2008, as part of the activities celebrating the 400th anniversary of the telescope, Huib Zuidervaart, of the Huygens Institute in The Hague, studied the manuscript afresh. This not only gave a better understanding of the exact context of the known passage, but it also resulted in the discovery of another passage on the telescope, this time about the presentation by Jacob Metius. By Zuidervaart's kind permission, the passage, and as much of the context as seemed relevant, is published here for the first time.

Den xvij-en octobris 1608 voor noen waren wij 's morgens by Zijne Excellentie ontboden te comen. [...]

Daer was oock beneffens d'inventie van de brilman, by de zoon van Mr Adriaen Anthonisz van Alcmaer vertoont gelycken instrument by hem geinventeert al voor 2 jaeren ende alhier vertoont, versoeckende meede octroij etc. Maer is verstaen alsoo met dander eerst gehandelt es, dat men deesen geen octroij alsnoch can accorderen, niettemin dat men hem voor zyn moeyten een vereeringe doen zal van 100 gulden ende hem oock animeren dat hy nairsticheyt doen zal, omme zyn instrument te moegen sulcx verbeeteren, dattet overtreft de ander, ende dat men naemaels daerop zal moegen letten.

Oock wasser een instrument vertoont by een jongman van Amsterdam, daer meede hy wilde verseeckeren datmen by affwyckinge vande naelde soude connen soo wel op zee als te lande affmeeten longitudinen, oft weeten hoe verre men is by oosten ofte by westen der rechten meridiaen consequentelijk waermen is op hoe veele graden. Dit is by eenige besichtigt ende van goeden apparentie verclaert. Hy versouct 300 gulden voor zijn costen ende moeyten. Mits soo wanneer het oprecht bevonden ende het gestelde premium hem toegeoordeelt wert datmen dezelve penningen daeraf weder corten zal. Maer en is alsnoch daerop niet gedisponeert.

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[36] *De Navorscher* 4 (1854), 101.

English translation:

October 17, a.m., in the morning we were summoned to present ourselves at His Excellency [Maurits]. [Some matters of state were discussed.]

Besides the invention of the spectacle maker [Lipperhey], a similar instrument was presented, by the son of Mr Adriaen Anthonisz of Alkmaar, already invented by him two years ago and shown here [at The Hague], applying for a patent etc. But it was resolved that, because the negotiations with the other were initiated first, [Metius] cannot be granted a patent for the time being, but that he will be granted an allowance of a hundred guilders for his trouble, and to encourage him to make efforts to improve his instrument, so that it will surpass the other, and that [his application] will be considered afterwards.

Further, a young man from Amsterdam presented an instrument, by means of which he wanted to assure that by the declination of the compass needle one could determine longitude both at sea and on land, or to know how far one is east or west of the correct meridian, and consequently at how many degrees one is. This was inspected by some who found it looks good. He demands 300 guilders for his costs and efforts, with the proviso that when it will be found true and he obtains the reward put on it, the said sum will be subtracted. But on this no decision has been made so far.

The long road to the invention of the telescope

Rolf Willach

Introduction

A brief entry in the minutes of the States General in The Hague, dated 2 October 1608, mentions that a certain Hans Lipperhey, a spectacle maker from Middelburg, had presented a wonderful device with which distant objects could be seen as clearly as if they were nearby. Lipperhey claimed that this device was his own invention, and he requested a 30-year patent on it or a annual stipend for the rest of his life. This is the very first mention (confirmed by numerous historical investigations) of a revolutionary instrument, which can now be regarded as the first serviceable telescope.

The telescope and the microscope (and the devices that evolved from them in the 20th century such as the radio telescope and the electron microscope), operating on similar physical principles, are the instruments which have most advanced our present knowledge about the framework of the universe and the structure of the atom. These facts alone justify the celebration of the 400th anniversary of this epochal event and to reflect on the events which led up to it.

Within a few decades of the telescope's invention, doubts were already raised about its origin and its true inventor; these debates continue to the present day. Another question that has been addressed by historians of science during the past century is why the instrument first turned up in early seventeenth-century Middelburg, and why it was not invented earlier. This problem was already clearly formulated in the 1940s by the Italian optical researcher Vasco Ronchi, who in several publications stated:

> Why, if eyeglasses were known as early as [the] 1280's, did it not occur to anybody before the end of the sixteenth century that two eyeglass lenses might be combined to produce a more powerful optical instrument? Was there some fundamental methodological obstacle that accounts for a three-hundred-year hiatus between the appearance of eyeglasses and the invention of the telescope? [1]

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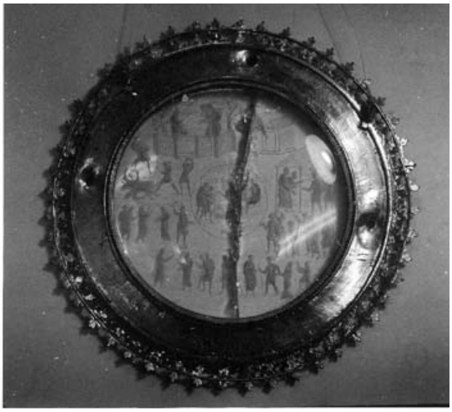
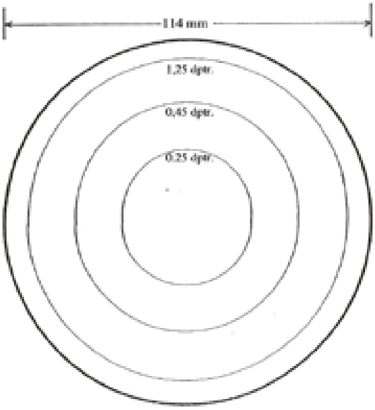
[1] Ronchi, *Optics: the Science of Vision* (1991)





Ill. 1. 'Lothar-crystal'. Metz (France),dated about 855-869. British Museum, Inv. No.1855, 12.1,5.
Ill. 2. Lines of equal refractive power (diopters)

The present author concluded that the only way to solve this riddle was to follow the development of lens-grinding techniques of medieval and early-modern spectacle makers by a comprehensive optical analysis of spectacle lenses dating from the 13th to the early seventeenth century. A summary of the results of this investigation are presented in this paper. [2]

TECHNOLOGY

The technology of grinding crystals in Antiquity and in the High Middle Ages

It has long been recognized that fairly well ground rock crystal lenses date to Antiquity. Examples are the lenses found by Heinrich Schliemann during his excavations of Troy, similar lenses from the Mycenaean culture, now in the Herakleion Museum in Crete, and the Viking lenses found in different treasure-troves on Gotland in the Baltic Sea, now in the Fornsal Museum at Visby.[3] These lenses have one important feature in common: their surfaces are obviously more or less non-spherical. Most likely, they were ground on a

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[2] See also: Ilardi, *Renaissance Vision from Spectacles to Telescopes* (2007) and Willach, *The Long Route to the Invention of the Telescope* (2008).
[3] Ahlström, 'Swedish Vikings and optical lenses' (1950); Schmidt,Wilms & Lingelbach, 'The Visby Lenses' (1999); Lingelbach & Schmidt, 'Aspärische Linsen aus dem 11. Jahrhundert' (2002).

flat rotating grinding-stone. Grinding in a mould would never have resulted in such highly non-spherical surfaces. As an example, I discuss now a rather large rock-crystal lens from the ninth century known as the 'Lothar Crystal' (ill. 1). This crystal, preserved in the British Museum, is biconvex with a diameter of 114 mm. On the rear side (with the smallest curvature), there is an engraving, made with a sharp diamond, depicting the life of Saint Susanna and the inscription states that it was made for the Carolingian king Lothar II (855-869).

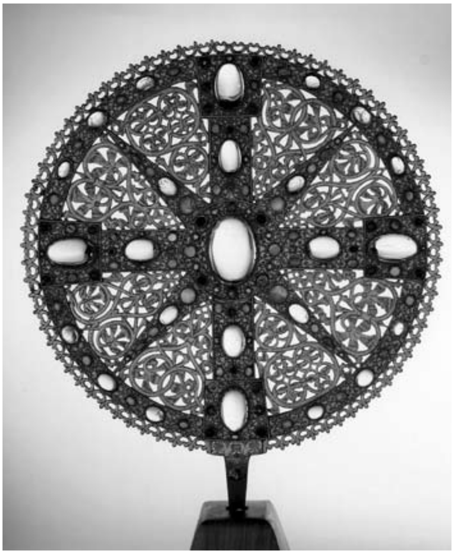
In the diagram (ill. 2) showing the refractive power of this lens as function of distance from the centre, one recognizes – and this is typical for all old lenses – an increase of the refractive power towards the rim of the lens. This indicates that this lens was ground in the antique manner on a flat rotating grinding-stone.

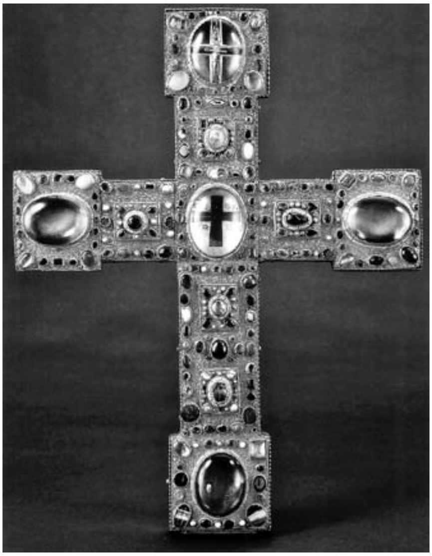
Towards the High Middle Ages the number of surviving crystal-lenses increases slightly. They were made in the workshops of different monasteries for decoration and embellishment of precious liturgical objects of art, especially reliquaries.

An example is the large reading stone *(lapis ad legendum)* at the center of the 41-cm 'disc cross' (*scheibenkreuz*) in the cathedral of Hildesheim (Germany), which dates from about 1140 (ill. 3). Another example is the reading stone in the center of the 48-cm high 'Big Bernward-cross,' made around 1150. Behind the central rock crystal was a wooden splinter from the holy cross (now lost), presented around 1000 by the Holy Roman Emperor Otto III to bishop Bernward of Hildesheim (ill. 4).

Most of these wonderful crafts and techniques for fashioning these objects of art have been lost over the centuries. But in the surviving objects, we can clearly recognize the technique of their manufacture on a rotating flat surface. In most cases the oval-shaped stones were ground to a plano-convex form. If we put such a stone with its flat surface on a manuscript page, we see that the text under it is magnified. This impressive magnification is easy to recognize, so there is no doubt that the optical properties of such stones must also have been known since Antiquity. In the scriptoria of monasteries this property must have been very useful. Older monks who suffered from presbyopia would surely have used them for reading, and such devices became known as 'reading stones.' Their refracting powers are in the range of 20 to 40 diopters.

However, reading stones were not a convenient solution to the problem of aging eyes. They work as magnifying glasses where the text under scrutiny had to be put inside the focal length. Therefore they could not correct the limited range of power of the lens in the human eye, and although the image was magnified, it remained blurred. And, even worse, the stones were totally useless for writing.





Ill. 3. 'Disc-Cross', c. 1140. Treasure Room of the Cathedral of Hildesheim (Germany).
Ill. 4. Big cross of 'Bishop Bernward'. Treasure Room of the Cathedral of Hildesheim. It is the reliquary for a fragment of the holy cross, preserved behind the central stone. The German Emperor Otto III presented it to Bishop Bernward in the year 1150. It is 48 cm high and 37 cm wide.

When we summarize all the difficulties which prevented the invention of spectacles in the 12th century, we therefore find the following:

1. The eye-defects of elderly people were considered to be a medical and not an optical problem.
2. The optical principles of the human eye were completely unknown.
3. The problem of making glass of the required quality was totally unsolved.
4. There was no technology of lens grinding and polishing to obtain the required precision.

The first dioptrical vision aids

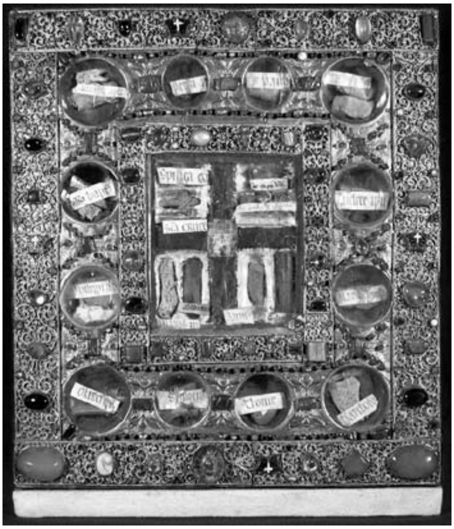
We must realize that making spectacles was not possible until all four of these obstacles had been removed. I therefore have created the following hypothesis:

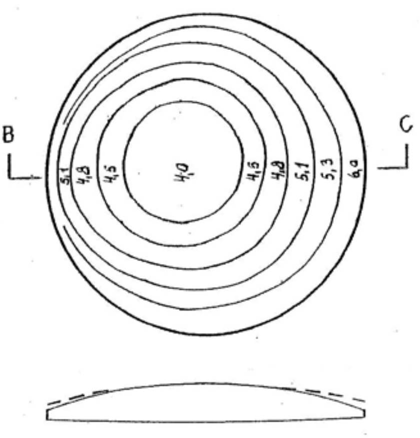
Dioptrical vision aids existed in the monasteries long before the invention of spectacles in the late thirteenth century. Originally they were made in the form of slightly convex rock crystal discs, but for a completely different purpose than for assisting aging eyes. That they eventually served this purpose as well, came about only by sheer chance, probably during the control of the polishing quality of their surfaces by the stone grinding monks.

The question is: can we prove this hypothesis? Towards the end of the eleventh century political events happened which were of highest importance to Western culture. In the year 1095 Pope Urban II called for the First Crusade. As a result the following two hundred years were completely dominated by these expeditions. One of the numerous consequences of the crusades was a flood of relics supposedly from the Holy Land. This huge increase of relics had the consequence that the style of the reliquaries changed dramatically. Before these events, the relics, often consisting of only very small fragments, were put behind the central stone of a cross or in a small receptacle, and were therefore invisible to worshippers. But now, every town and every monastery that could acquire one or more relics, presented them proudly in costly reliquaries. Such a remarkable reliquary can be found today in the treasure room of the Cathedral of Halberstadt (ill. 5).

The plate reliquary of Halberstadt

The relics in this reliquary were acquired by Bishop Bernhard von Krosigk in Constantinople, during the Fourth Crusade. After his return in 1208, he presented them to the cathedral of Halberstadt. The reliquary itself, with thirteen rock crystal discs, was made between 1220 and 1225. Twelve of the windows are round crystal discs, 5 to 6 cm in diameter. Even a cursory examination indicates that several discs have a slightly convex surface. I have measured the surfaces of all these discs with optical measuring equipment (Ill. 6). Many of these discs have an astonishing high rotational symmetry. Nevertheless, nearly all discs show a predictable non-sphericity, namely an increasing curvature towards the rim. Exactly the same non-spherical surfaces which we found in the rock crystals from Antiquity and the High Middle Ages. Therefore it is highly likely that these lens-shaped crystal discs, as well, were made by grinding on a rotating flat surface. The curvatures of their rear surfaces were always very shallow, nearly flat. The regularity in the fairly large central part is astonishing. To achieve this result one surely needed great skill and many years of experience in grinding. To demonstrate the optical properties of these lenses, I made a copy of crystal no. 4, grinding it in the same manner on a flat rotating grindingstone. The surface of this replica has exactly the same non-spherical shape and shows a varying distribution of the refracting power. The fairly large central part has a power of four diopters.





Ill. 5. Plate reliquary. Made between the years 1220-1225. Dimensions 405 mm × 450 mm. Treasure Room of the Cathedral of Halberstadt.
Ill. 6. Lines of equal refractive power in one of the lens-shaped rock crystal windows (No. 4) in the Halberstadt 'Plate-reliquary'. Diameter Cross section BC 64 mm. The numbers indicate the refractive powers in diopters.

When contemporaries perhaps used these crystals for reading purposes, it meant an enormous improvement in reading for presbyopic eyes. Undoubtedly, the skilled and clever monks of that period must have noticed these optical qualities (ill. 7).

Finally, when looking at the result and quality of the grinding and the polishing, they must have become aware of the completely unexpected magnifying effect of such rock crystal discs, which were originally made as protective windows for these reliquaries. All that was now necessary to produce a real reading glass was a wooden frame with a handle to hold the glass in front of the eye. The oldest depiction of such a monocular reading aid is a sandstone sculpture in the Cathedral of Constance, Germany. This so-called 'Holy Grave' in the Mauricius Rotunda dates from 1260, more than twenty years before the recorded appearance of the first spectacles.[4]

With this knowledge the correctness of the hypothesis, mentioned above, is confirmed as far as is historically possible. Thus we have made a substantial step toward the invention of spectacles. Now it must have become clear to

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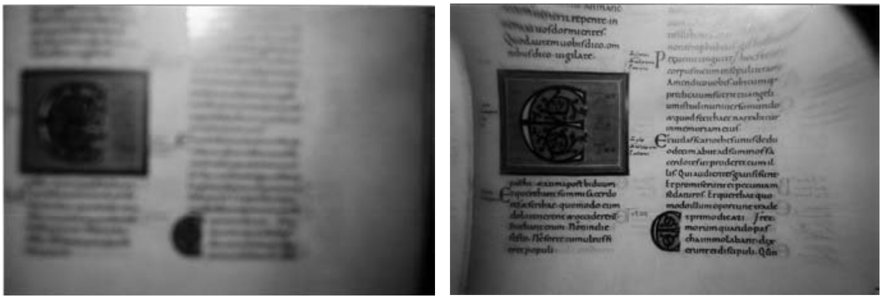
[4] Brommer & Frey, *Das Konstanzer Münster* (2005).



Ill. 7. *Left*: A portion of a medieval text as seen by a presbyopic (unaided) eye of four diopters at a distance of 25 cm., compared (*Right*) with the situation in which the central part of the replica lens is placed in front of this eye. In that arrangement a large part of the script can be read with ease. The non-sphericity of the outer part of the lens surfaces explains the increasingly blurring towards the rim.

the monks that optical means could assist aging eyes much more than could doubtful tinctures or other medical remedies. With this result, the second problem noted earlier – namely the lack in understanding of the human eye – although unsolved, became irrelevant. We are nonetheless still rather far from a solution. Two serious obstacles remained in the process of the invention of spectacles:

1. The problem of the impurities in the fabrication of glass.
2. The grinding technique on a flat surface, which makes it impossible to grind pairs of lenses with equal powers.

Glass techniques in the Middle Ages and the invention of spectacles

Consider in this connection glass-making techniques in the 13th century. Today, as well as then, glass consists of four different components.[5]

1. The main ingredient for glass substance is quartz-sand (SiO_2),
2. A further substance is potash or potassium carbonate (K_2CO_3), which is necessary to reduce the extremely high melting point of 1700 °C of quartz, to temperatures attainable in medieval wood-fired glass furnaces. The higher the amount of potash the lower the melting temperature of the quartz. But if the amount was too high, then after only a few years, the glass began to decompose. In the medieval period this condition was known as 'Glasspest' i.e., 'Glass Plague.'
3. A stabilizer, usually lime ($CaCO_3$), was required.

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[5] Matson, 'The composition and working properties of ancient glasses' (1951).

4. Finally, some additives, usually metal oxides for colouring the glass in this period, were needed.

After the molten glass substance had been heated for many hours, it was still so full of air bubbles that it was completely non-transparent. Therefore the next step was the so-called 'clear-melting.' The furnace was heated by working the bellows day and night until a temperature of some 1200° C was reached. During this process more and more of the bubbles disappeared. But now a new serious inconvenience emerged. In this high heat the fire-clay linings of the furnace wall slowly began to dissolve and ooze as long filaments and striations into the molten glass. Therefore the melt never became entirely clear. There remained a lot of air bubbles and it was full of striations, the remnants of the furnace wall. This glass was completely unsuitable even for simple optical use. This was the state of glass-making technique toward the end of the thirteenth century.

Glassblowing and grinding in Venice in the Thirteenth Century

We will now consider the glass-makers in Venice. In the state archives of Venice in the so-called 'Codex membranaceus,' under the section 'Capitoli delle Arti,' there is a decree of the High Council concerning the crystal-glassworkers.[6] The first part consists of 31 paragraphs and dates from 1284. In the third paragraph we already find something of interest to us. Here we read in the English translation: 'Nobody of the trade is allowed to use ordinary white glass for cristallum.' In many subsequent paragraphs, the use of ordinary white glass for high quality art was also strongly forbidden. Severe penalties were imposed on those who did not comply, and any objects made from this white glass were to be destroyed. It becomes clear that this 'cristallum' was a completely new invention of the Venetian glassmakers, and that it had emerged only a few years earlier. The glass workers who made this new substance were called 'cristalleri.' The codex therefore offers regulations and protocols for this new trade.

In the following years the trade regulations were expanded by further paragraphs. On 2 April 1300 it becomes especially interesting for us. In Paragraph XXXX we read: '…that nobody of the glassmaker's trade should venture to buy or allow others to buy products made of ordinary white glass, imitating cristallum, to make high quality articles, such as knobs or disks for vials for the eyes.' The latter are called *roidi da ogli*.

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[6] Greeff, 'Eine venetianische Brillenmacherordnung' (1922).

There is no doubt that *roidi da ogli* meant spectacle glasses. The invention was still so new that a name for it had not even been invented. In the enactment of 15 July 1301, the expression was even more clear. Now they were called 'vitreos ab oculis ad legendum,' or 'eye-glasses for reading.' Therefore the regulations of the years 1300 and 1301 are the earliest known reports of spectacles. Of course, we should now ask ourselves what clever idea was behind the invention of cristallum?

This invention was a top secret of the Venetian glassmakers, but today it is not difficult to fathom the secret, because there are not many possibilities. And again, there were political events which initiated the invention.

Towards the end of the 13th century, after nearly two hundred years, the crusades ended and friendly trade with the Near East, especially Egypt and Turkey, became possible again. The Venetians, with their large fleet of galleys, were the first to start a lively trade with Egypt. It was probably in the city of Alexandria that they learned of a substance called *natrun*. Natron had been well known for thousands of years to the Egyptians. Near 'Misr al Kahira,' now called Cairo, there is a valley with several dry lagoons with extensive deposits of natron, already highly esteemed by the Romans for glassmaking. Experiments of Venetians glassmakers with this new substance revealed surprising properties.

These were:

1. The substance was so pure that the glass remained uncoloured, except for a very faint yellow tinge.
2. Glass made with natron as a melting point reducer showed many fewer air bubbles and striations after the purifying melt.
3. The glass did not decompose after a few years as a result of humidity.

Today we know that natron is sodium carbonate (actually, a mixture of sodium carbonate and sodium bicarbonate), also called soda. In comparison with ordinary white glass, the cristallum of the Venetians was a great breakthrough. And thus, by about 1280, the Venetians had substantially reduced the problem of impurities in glass.

Rivet spectacles from the monasteries of Wienhausen and Isenhagen

Of our four problems which for centuries had impeded proper spectacle-making, around 1300 three had been solved. Only the last obstacle remained: the completely inadequate grinding-technique on a flat rotating surface. This obstacle was by far the most difficult, but it was solved in only a few decades.

Ill. 8. Two Rivet spectacles. First half of the fourteenth century. Monastery of Wienhausen.

To find the key to this last enigma, we will leave Italy and travel to Northern Germany, in a much later period. In 1953, during the renovation of the nun's choir in the monastery of the small village of Wienhausen, in the dust under the oak floor workers discovered several spectacles among more than a thousand objects from the early fourteenth until the early sixteenth century. The oldest ones were three rivet spectacles, dating from the mid fourteenth century (See ill. 8).[7] It was especially surprising that the glass of all these spectacles was in very fine and transparent condition. Some years later, in the neighbouring monastery of Isenhagen, another half of a pair of rivet spectacles was discovered, again in useable condition.

More glasses of rivet spectacles have been discovered in the recent past in the same region of Germany. In the four edges of the cover of a book-case, dating from 1330 and today preserved in the Museum of Lüneburg, there are four rivet spectacles' lenses, the flat rear sides painted with the symbols of the four evangelists.[8]

Test of the Rivet Spectacles of Wienhausen, Isenhagen and the Gothic Bookcase

Because I had hopes that these oldest existing spectacle glasses contained the secret of their making, I examined each of them very carefully. The surfaces were measured with coordinate measuring equipment and a stereo-microscope, and then optically with a Ronchi-Test. For reasons of space, I can only give a summary of the results. The investigations of the twelve lenses brought me to the following insights:

1. All these lenses are nearly exactly plano-convex. The refractive powers are in the range of 3 to 4 diopters. On all flat surfaces we measured a non-sphericity like that of the rock crystal lenses of Antiquity and the High

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[7] Appuhn, 'Ein denkwürdiger Fund' (1958).

[8] Appuhn, 'Hinterglasmalereien auf den ältesten Brillengläsern' (1963).

Middle Ages, namely with an increase of the curvature, and therefore of the lens power, towards the rim, but with a fairly good rotational symmetry. Therefore these flat lens surfaces, too, had been made, as in Antiquity, by grinding on a flat rotating disc.

2. On all flat surfaces we observed several fine, not fully polished dots, apparently remnants of the grinding process.
3. In contrast, the convex surfaces show no evidence that they resulted from grinding processes. On the contrary, many of these convex surfaces show clearly raised dots, sometimes containing an air bubble or a black intrusion and sometimes longer striations, all of which are easy to feel with the fingertip. Apart from these raised impurities, the surfaces look entirely clear.
4. Without exception, all convex surfaces lack rotational symmetry, resulting in more or less serious astigmatism. Again, this is contrary to the flat surfaces.

From the results of the investigations of these twelve lenses, we finally solved the enigma of their making, and are now able to reconstruct the process. As we saw, by about 1280, monocular vision aids had already been in use in monasteries for more than a century. These had been made of rock crystal in the monasteries' own workshops with the age-old grinding method.. It was tedious work which required great skill and experience, and an acceptable result remained a matter of luck.

Now, it is easy to believe, that the rumours of the invention of the 'cristallum' came to the ears of the monks in their grinding workshops, possibly even in a monastery in Venice itself. One of these monks probably realized that it should be possible to make these vision-aiding discs, not from rock-crystal, but from this new glass, which was as clear as the best rock crystals but much softer. He perhaps brought such a crystal vision aid to a Venetian glassworker and explained his problem. And one of these glass workers must have had the following idea, which, while obvious to a glass blower, was nevertheless ingenious:

> You should not make the vision aid by grinding,' he answered. 'You should rather blow it as a glass ball of cristallum in the required diameter. Then cut this ball into small discs, by an old technique: immediately after blowing the glass ball, a small part of a copper pipe, cooled in a flask of water, with a diameter corresponding to the required diameter of the discs you wish, has to be put on the still-hot glass ball. This sudden cooling results in a circular crack along the rim of the copper pipe.' Then the pipe is cooled quickly again and a second, and a third glass disc are cut with this method, and so on until the whole ball is full of such circular fractures. After careful cooling the glass ball is broken

with a blunt piece of wood into a lot of broken shards, among which will be many meniscus-shaped round discs. These need to be ground and polished to flat planes on the concave surfaces only, and you will have many identical lenses which you can wear in pairs in front of your eyes. [9]

In this way it is easy to understand how lenses, like those of the rivet spectacles in Wienhausen, with flat surfaces (obviously ground on a rotating flat disc) and convex surfaces that show no traces of grinding but contain small raised air bubbles and striations, can only result from this revolutionary glass blowing technique.

In my opinion this appears to be the solution of the old riddle about the making of the first spectacle lenses, and we see that spectacles were not the result of intellectual breakthroughs in the laws of optics. On the contrary, the invention came about through many small steps taken over several centuries for completely different reasons and never for aiding aging eyes. But on one day all the necessary knowledge was available and only a clever mind was needed to combine it and put it together. This ingenious idea to make, by blowing, identical glass lenses that could be worn in pairs in front of both eyes, was the birth of spectacles.

The development of spectacles in the Later Middle Ages and in the Renaissance

We have seen how the technical problems, which were still unsolved in the early twelfth century, had been overcome towards the end of the thirteenth century. All that was now needed was a practical frame for fixing the glasses in a convenient position in front of both eyes. Rivet spectacles were the first solution and it was so successful, that they remained hardly unchanged during the next two hundred years. This is illustrated by a large number of surviving pictures and portraits of persons wearing rivet spectacles. (Cf. ill. 9).

The knowledge of how the earliest spectacle glasses were made, solves the riddle of the observed astigmatism of the convex surfaces. Due to gravity, it is impossible to blow an exactly spherical glass ball, and all lenses made by this technique show some degree of astigmatism. Therefore, such non-spherical lenses were completely unsuitable for use as telescope objectives. The glass-ball-blowing technique, as brilliant as it was for spectacle lenses, was a dead end for the invention of the telescope!

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[9] Strobl, *Glastechnik des Mittelalters* (1990): Aus der Schedula des Theophilus, 57 and 84.

Ill. 9. Rivet spectacles. Detail from the Pentecost panel of the 'Wildunger Altar' (1403) by Konrad von Soest. Stadtkirche Bad Wildungen (Germany)

We should not expect that the Venetians succeeded in protecting their secret for a long time. As we read in a chronicle of 1313 written at Santa Catharina in Pisa, the monk Alessandro Spina was able to make spectacles and taught the art to everyone who was sufficiently skilled to undertake it. Nevertheless, it was not easy to make spectacles, and finding appropriate glass was a particularly great obstacle. Cities such as Florence and Pisa, which at this time also had a flourishing glass trade, did not have access to the Egyptian natron, because the Venetians defended their monopoly in this region. But natron is nothing else than sodium carbonate. It can be produced in exactly the same way as potash is, though not from the ash of burnt trees, but rather from the ash of burnt seaweed.

If dried seaweed is burnt, then after washing the ash and evaporating the solution, we get a white salt, but it is not based on potassium. It is now sodium carbonate because the main salts dissolved in sea water are those of sodium, rather than of potassium. But the available amount of seaweed is much too small for producing glass in high quantities. Therefore the North-Italian cities always used a mix of potash and soda in their glass factories. If the amount of potash is not too high, a usable product will also result. Such glass, however, did not have the same quality as the pure soda glass made in Venice.

An example could be the half rivet spectacles from Isenhagen. It has a fairly distinct green tinge, and it also shows the beginning traces of decomposition. Therefore it contains, besides soda, also a higher amount of potash.

The influence of the invention of printing with movable type

Whether during the fourteenth century spectacles were also made north of the Alps is not known to me. But the invention of printing in the middle of the fifteenth century gave an enormous impetus to the spectacle making trade. The demand for spectacles rapidly increased, and spectacles from Italy became more and more expensive. This led, in the second half of the fifteenth century, to the development of a new spectacle-making trade in Nuremberg.[10] In the minutes of the Nuremberg city council we read that 'anno 1478 Jacob Pfüllmair, Parillenmacher' was given the rights of citizenship upon paying the sum of 14 florins. And in the following years one admission followed the other. By 1500, twelve spectacle makers had received the Nuremberg citizenship.

Towards the end of the century, an appeal was made to the court to grant the spectacle maker's trade the status of a sworn trade. But the court decided against this petition, and ordered that the spectacle trade must remain a banned trade, one that could not be practiced anywhere but Nuremberg. This decision was intended to preserve the secret of the manufacture. But what was the 'secret' of the Nuremberg spectacle makers? Spectacle- making had been well known for more than hundred years because, as we saw, the Venetians could not keep their secret for a long time.

Of course we recognize that the mountings of spectacles clearly changed in the last decades of the fifteenth century. Leather-framed spectacles and those made from rolled copper wire were developed and rivet spectacles disappeared in the first part of the sixteenth century. But the secret which was so jealously guarded in 1498 was not to be found in the new frames, because everybody could see and copy them. It was to be found in a completely new method of making the lenses. For the lenses made by the ball-blowing method, the convex surfaces were part of a blown glass ball, while the flat surfaces were ground on a flat rotating grinding-stone. This grinding technique still remained at the same level as in antiquity.

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[10] Nürnberger 'Parillenmacherordnung,' Bayerisches Staatsarchiv, Nürnberg. Von Pflugk, 'Die Ordnungen der Nürnberger Brillenmacher' (1936); *ZVA. 450 Jahre im Dienste des Sehens* (1985), 15; Müller, 'Das Original der Regensburger Brillenmacherordnung' (1921), 129-130.

A new lens making technique

The Nuremberg spectacle makers solved the problem of astigmatism in exactly the opposite way. They cut round glass discs from plate glass used for windows, which they acquired from Bohemia and Bavaria, the so-called 'Waldglas' or 'forest-glass.' This was green-tinged potash-based glass. For this purpose they hammered from a copper or an iron plate a concave mould in the shape of the convex surfaces of the spectacles. The concave mould was then fixed on a grinding machine, and one of the flat surfaces was ground into a convex shape. In this simple way they avoided the difficulties connected with the glass-ball blowing. At first, the flat side remained unworked. In later years it was also ground flat or convex.

As a result, the lenses of Nuremberg spectacles from the last decades of the fifteenth century with their ground convex surfaces differed markedly from the Italian ones. Due to this revolutionary improvement, ground convex surfaces resulted, when carefully produced, in lenses of much higher optical quality. About this new method of mould and lens making, which had been copied in the first decades of the sixteenth century by the Venetians, we are well informed from an early seventeenth-century source, namely Hieronymus Sirturus's *Telescopium: sive ars perficiendi*[11]14, written in 1612 and published in 1618. There he explained in detail the new technique, but he also complained that the spectacle makers mostly made very poor lenses because they only used the cheapest glass, and did not make the moulds with the necessary care.

In order to obtain detailed information about the development of the lens-grinding technique and the quality of glasses in those days, I examined a total of 57 lenses dating from the early sixteenth to the mid-seventeenth century. For reasons of space I cannot discuss the results for every lens. However, it became clear that we can classify the lens qualities in three different groups. From each of these groups I will discuss a typical example.

Optical test of 57 lenses from the Early Sixteenth to the Mid-Seventeenth Century

In order to find out when lens quality reached the necessary level for use as telescope objective, I used both a Ronchi-test and a telescope test. Therefore I photographed an ophthalmological test-plate at a distance of 6 meters, using a modern lens as eyepiece and the old spectacle glass as the objective. Some results are shown in the next illustrations (Ills. 10-13).

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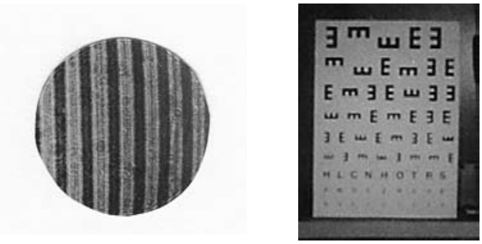
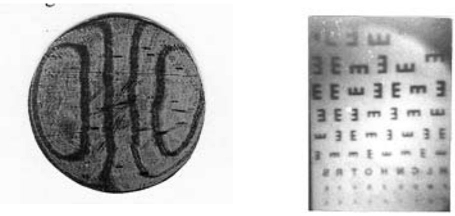
[11] Sirturus *Telescopium* (1618), CAPVT III, 'De hodierna huius artis corruptela.'



Ill. 10. *Left:* Ronchi-image of a modern, perfect lens. In that arrangement all the lines are straight and parallel. *Right:* Ophthalmological test plate as is seen with the naked eye. The last two lines are never decipherable. Therefore a telescopic lens arrangement must make it possible to decipher them in order to be called a 'telescope'.

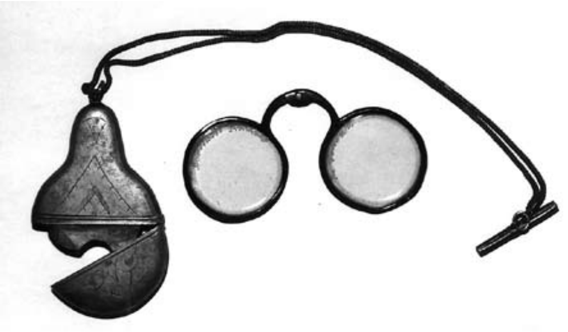


Ill. 11. *Left:* Ronchi-image of the lens of a Wienhousen-spectacle, made before 1530. The lines in the inner part are fairly well parallel. But the outer part is extremely bad due to the increase of the refractive power towards the rim. *Right:* Telescope test with the same lens. The magnification is 3.3 times. The telescope image of the test plate is clearly decipherable, with exception of the last two lines. As the Ronchi-lines are very curved in the outer part of the lens the telescope image is not totally clear. This lens arrangement cannot be called a telescope. But nevertheless it shows the effect of magnification of far objects fairly well. Therefore we will classify this lens as good.

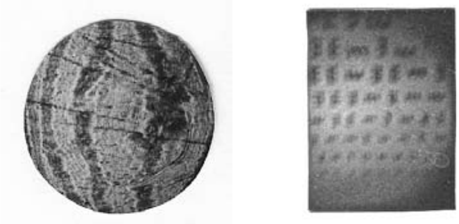
CONCLUSIONS

From the test of these 57 spectacle glasses, dating from the early sixteenth to the mid-seventeenth century, we can draw the following conclusions:

1. Five of these lenses (that is approximately 10%) are comparable to the glass in the leather-framed spectacles of Wienhausen. They are of fairly good quality and with them it is possible to see far-away objects clearly magnified.
2. Four glasses are within the range of the Venetian glass signed 'Picinelli' and are classified as mediocre. In a telescopic arrangement one can recognize far-away objects magnified, but they are very blurred.
3. The remaining 48 glasses are extremely bad. What is of special interest is that several of these glasses possibly date from the early seventeenth century.



Ill. 12. These two spectacle lenses probably date from the middle of the sixteenth century. One of them is signed 'Bernardo Picinelli' and the other has the text 'in Venezia'.



Ill. 13. *Left:* This is the Ronchi-image of the left glass which is signed 'Picinelli'. Although it was made some decades after the Wienhausen spectacles, the lines are very curved even in the central part. *Right:* Therefore the test-image looks fairly blurred and only the largest letters are legible. We classify this lens as mediocre.

Written sources from the Sixteenth Century concerning the combination of two spectacle glasses

These investigations of optical glasses, dating from over more than one hundred years, now clarify four different points:

1. During the sixteenth and the early seventeenth century, the techniques of lens grinding did not undergo any substantial progress. As such, this insight is not new; the data from reliable optical measurements merely confirm what has been well known from written sources for a long time.
2. Sometimes fairly well-made glasses were produced. But this was only by chance; there was no deeper understanding of the grinding process. But even such lenses, when combined with eyepiece lenses, do not give a more detailed image than would the naked eye. Therefore, we can regard such lens arrangements only as 'telescopic systems' or proto-telescopes, but not as real telescopes.
3. Because of the limited number of well-made lenses in this period we only

find a few sources in the sixteenth century mentioning proto-telescopes, such Girolamo Fracastoro in 1535), and in the second half of the century Leonard and Thomas Digges, and (with more detail) William Bourne in 1585.[12] They all mention the fact that an arrangement of two lenses (or a lens and a mirror), one aligned with the other, can magnify far-away objects. Now this becomes understandable, and there is no need to regard them as pure fantasies.

4. However, we are now also able to understand, why in the sixteenth century these different experiments with a magnification effect never resulted in a breakthrough: an instrument that magnifies far-away objects without revealing more details than would the naked eye has no practical use.

The events in Holland in the autumn of 1608 and the breakthrough

Strangely enough, in the first years of the seventeenth century, at the dawn of the invention of the telescope, no technical improvements whatsoever seems to have been made. Neither the written sources nor the optical tests have revealed the faintest hint that towards the beginning of the seventeenth century lenses had reached a level of optical perfection that made it possible to construct optical instruments with more resolving power than the naked eye, that is, instruments which we therefore could call 'telescopes.' So what happened then?

We all know the story of the invention in 1608.[13] First was Hans Lipperhey, whose telescope was tested from the top of a tower in The Hague in the last days of September 1608 and whose device was highly esteemed for its performance. Then, fourteen days later, Jacob Adriaensz Metius and an 'unknown man' presented similar devices, which apparently were inferior in quality. Another story is that of Fuchs von Bimbach who, at the Frankfurt autumn fair of that year, was offered a similar device, albeit one with a cracked object-glass by a 'Belgian,' identified in 1906 by De Waard as possibly the Middelburg pedler Sacharias Jansen.

I will not repeat these accounts here in more detail. But in this story, as known from the old sources, there are puzzles and serious contradictions. This leads to the unsatisfying situation, that during the last 150 years, sometimes Jacob Metius, sometimes Sacharias Jansen, and more lately Hans Lipperhey have been honoured as the inventor of the telescope.[14]

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[12] Van Helden, *The Invention of the Telescope* (1977), 28-35.

[13] *Ibidem*, 36-47; See also Zuidervaart, this volume.

[14] Van Helden, 'The historical problem of the invention of the telescope' (1975).

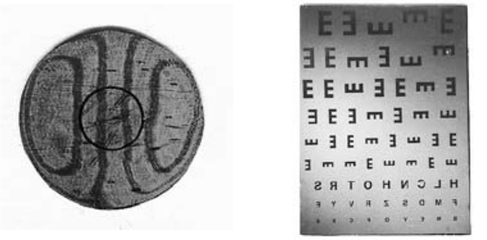
The situation shortly after the invention confronts us with two serious problems:

5. How is it possible that during the last eighty years of the sixteenth century all attempts to improve telescopic systems remained unsuccessful, and then, almost overnight, this mysterious obstacle was surmounted by a common spectacle-maker in Holland?
6. And even more perplexingly, how was it possible that this break-through could have been copied instantly by every spectacle maker in Europe, even when this had been impossible only a few weeks before?

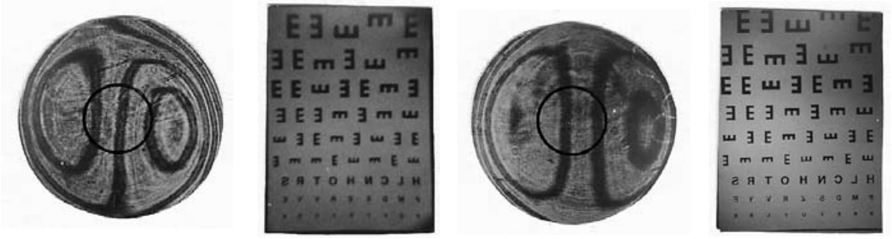
Our investigations have made it clear that it is highly improbable that Lipperhey did have lenses of a better quality than those of Bourne, Digges or even Fracastoro. For if Lipperhey's success had been based on an improved grinding technique, which he had developed years before, then neither of his competitors or any of the other spectacle-makers could have known about it. Therefore Lipperhey would have received his patent, and for many years could have maintained an exclusive right to make telescopes.

However, this historical problem can be solved more easily by making a simple assumption. Lipperhey, who had made a telescopic system (similar to those described in the late sixteenth century) with fairly good spectacle glasses to magnify far-away objects, must have made a modest but crucial change. This modification, however, must have been sufficiently simple that it could be easily discovered – and afterwards copied – by anyone who looked at his device. Nevertheless it must have been so efficient that it transformed the already known ordinary 'telescopic system' into a real telescope; a device which could produce clear and magnified images of distant objects.

To understand how this simple change was made, we must look more closely at the Ronchi-tests of the five best glasses found in our investigations. So, let's examine once again the Ronchi- and telescope-tests of the previously discussed Wienhausen spectacle (ill. 11), made with the earliest of the five best glasses. As the photographs show, the Ronchi-lines in the inner part of the aperture are fairly straight and parallel. But in the outer part, the aberration becomes very large, and this negatively affects the sharpness of the image. The last two lines remain illegible. Now we reduce the aperture with a small circular cardboard diaphragm. In ill. 14 we see the result. The circular diaphragm is indicated by a black ring on the Ronchi-image. For anyone who is not familiar with practical optics, the results are astonishing. The whole text becomes sharp and clear, nearly as good as seen with a modern optical instrument. If we repeat the experiment with two other lenses of the five best ones, we get similar results (ill. 15).



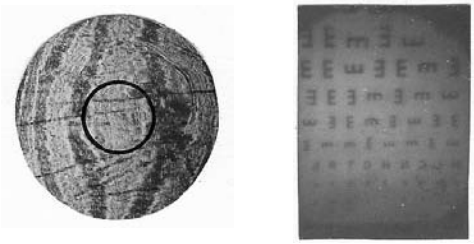
Ill. 14. Test images of the Wienhausen lens (Ill. 12) when covered with a 10-mm diaphragm (here represented by a black ring).



Ill. 15. Telescope test with diaphragm of two others of the five best lenses. Second half sixteenth century. The Ronchi-lines in the outer part are very strongly curved, indicating serious aberration. But the magnification effect can be seen without any problem, even without the use of a diaphragm. And, with a diaphragm, these lenses, too, give a higher resolving power than the naked eye.

When in each of these five best lenses, the diaphragm blocks the aberrations caused by the outer rims of the lenses, the clarity of the telescopic image is improved in such a way, that the instrument clearly shows more details of far-away objects than the naked eye does. Therefore, a suitably constructed diaphragm effectively transforms a simple telescopic device – when made with higher quality lenses – into a real telescope.

However, it is very important to realize that the diaphragm, in the way demonstrated, only works with the best lenses available in the early seventeenth century. Telescopic systems made with mediocre or even bad lenses, when corrected by a diaphragm, do not significantly improve in their performance (See ill. 16). Tests with mediocre quality lenses from the period make it perfectly clear that a practical telescope could be made only by a spectacle-maker who had a varied stock of lenses and many years experience in lens-grinding.



Ill. 16. Test image of a mediocre lense of the late sixteenth or early seventeenth century.

Who is the inventor of the telescope?

All that now remains is to answer the topic of this symposium, namely the question to whom we can give the credit for the invention of the telescope. For an answer we must be aware of the following fact: an inventor of a device must have exact knowledge, not only of its scientific method of working, but of all important principles of its making. Someone who made a working device merely by pure chance, and whose failure to understand why it worked and therefore was not able to repeat it, cannot be declared as its true inventor.

Lipperhey was clearly aware of the problems in making these 'far-seeing' devices. He made at least one single telescope and three binoculars, the latter being far more complicated to construct. There was thus a total of seven telescopes, and all of them met the full satisfaction of the men assigned to test them; otherwise he would not have received monetary compensation. Lipperhey was also the first individual who demonstrated the instrument during an 'official' test and who applied for a patent. For those supporting Metius's or Jansen's claims, the device submitted by the first performed poorly, and the name of the latter is not even mentioned in relation to the telescope in any document before 1655.

Now that we know what did the trick, it is easy to recognize the small diaphragm in all surviving telescopes of the first half of the seventeenth century. After a remarkable improvement in lens polishing, invented by the Capucin monk Schyrl de Rheita in about 1645, and brought to perfection by the Augsburg optician Johannes Wiesel, the aperture of the diaphragm grew considerably. With it the resolving and light-gathering power of a telescope improved enormously. From then on the diaphragm was only necessary to reduce chromatic aberration.

The first person who really made scholarly experiments concerning lens quality and the effect of diaphragm-aperture was Galileo Galilei. And from him we are also informed about how extremely difficult it was to get the required quality of lenses even from skilled spectacle-makers. And the first scholar who succeeded in explaining the marvellous effect of this new instrument was Johannes Kepler. With his *Dioptrice* (1611) he laid the foundations of modern optics which resulted in the unprecedented development of the telescope up to the present time.

The idea of the diaphragm was very simple. Can the simplicity of a modification diminish its merits? Of course, as we saw, Lipperhey's success was based on a lot of small steps made over many centuries, and he was only the last link in this long chain. Today such questions of priority are not of great interest. But the merit that Lipperhey earned by his crucial contribution to the construction of the instrument – a device that has enriched our cultural knowledge over the course of the last four centuries in a way that was completely unforeseeable at that time – cannot be taken away from him by anyone.

Suspicious spectacles. Medical perspectives on eyeglasses, the case of Hieronymus Mercurialis

Katrien Vanagt[1]

Introduction

On the eve of the invention of the telescope, eyeglasses were widespread and commonly used, as a variety of sources testify.[2] Illustration 1 (see page 116) appears to be yet another illustration of a man wearing spectacles. However, there is something odd about it, judging from the surrounding text and context: 'How one can prevent himself from wearing eyeglasses' and 'How one can get rid of the habit of wearing glasses.'[3] The illustration comes from a treatise on eye diseases, *Oftalmodouleia*, written by Georg Bartisch (1535-1606) and first published in 1583, and it is the title page of the chapter on diminishing vision and 'weak' sight. It is clear from the start that Bartisch is more than sceptical about eyeglasses. He uses all his rhetorical skills to convince the reader of the harmfulness of eyeglasses. Surprising as this may be, within the medical profession eyeglasses were not advocated as a correction for diminished sight right away. Was Bartisch representative of the medical sector as a whole? Yes and no. Though most physicians did not go so far as to demonise eyeglasses, it is true that in general they seemed rather reluctant to treat spectacles in their treatises. Some simply ignored them, others warned of their dangers, and yet others mentioned them at some point in their treatises but did not include them in the therapeutic part. If there is one point these treatises had in common, it is

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[1] I would like to thank Fokko Jan Dijksterhuis and Sven Dupré for their helpful comments on earlier versions of this paper.

[2] On the invention and diffusion of eyeglasses, see for instance Rosen, 'Invention' (1956), 13-46 and 183-218; and, more recently, Ilardi, *Renaissance Vision* (2007), 3-152. Ilardi includes numerous contemporary illustrations of men wearing spectacles. In his article 'Eyeglasses and concave lenses,' 341-360, he also provides interesting documentary evidence to prove that concave glasses for myopia were in use at least since the fifteenth century.

[3] Wie man sich vor den Prillen und Augenglesern bewaren und enthalten möge. Item wie man sich von den Prillen und Augenglesern entwehnen und abstechen sölle, Bartisch, *Oftalmodouleia* (1583), fol. 31r.

Das Dritte Teil. 31

In dem Dritten Teil wird angezeiget vnd beſchrieben von abnemen/ blödigkeit/ ſchwacheit/
dunckel vnd trübheit des Geſichtes / Auch wie man ſich vor den Prillen
vnd Augengleſern bewaren vnd enthalten möge / Item wie man ſich von den
Prillen vnd Augengleſern entwehnen vnd abſtehen ſölle.

Ill. 1. Georg Bartisch, *Oftalmodouleia* (Dresden, 1583), fol.31r. (Leiden University Library - sig.1407 B 13).

probably that the link between eyeglasses and therapeutics was problematic.

Why the introduction of eyeglasses in therapeutic counsels was so problematic for physicians can be understood by looking at their ideas about vision and the diseased body. Indeed, besides culturally shaped factors, a great deal of this ambiguity seems due to the difficulty of fitting eyeglasses within the holistic remedies in use, as well as to doubts about how they influenced vision. For speaking about spectacles is not only speaking about vision, but also about *defective* vision. Whereas opticians could speak about how vision occurred in ideal circumstances, physicians had to formulate a theory of vision that was in accordance with their views on the diseased eye.[4] Hieronymus Mercurialis' (1530-1606) exposition of the *modus visionis* and his ideas about eyeglasses is a telling example of this, and it will therefore constitute the core of my paper.

Spectacles will thus be only part of my story. The bigger picture is how physicians thought about vision in general, about the way vision takes place,

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[4] The term opticians refers to those who studied optics.

the so-called *modus visionis*, and how they introduced optical ideas and instruments in their medical discourse. Besides in optical treatises, discussion of the *modus visionis* usually took place in philosophical treatises, often as a commentary to Aristotle's *De anima*. Less known is that in medical books, too, there was in fact a real debate about the *modus visionis*.[5] Early modern physicians are often depicted as mere imitators of Galen, conformist and conservative,[6] but although it is true that medical doctors were never on the central battleground in the history of optics, it is only part of the truth. In my opinion, it does not do justice to contemporary medical thought. A number of physicians were apparently struggling with optical concepts and instruments such as spectacles in an attempt to integrate them succesfully into their medical system.

Evidence of eyeglasses within early modern therapeutic treatises

Searching for eyeglasses in sixteenth-century therapeutic treatises is rather frustrating, because very little evidence can be found in them. Most of the physicians simply ignored eyeglasses when it came to therapy and gave a copious therapeutic advice instead. This was the case with such illustrious physicians as Jean Fernel (1497-1558) and Girolamo Capivaccio (1523-1589).[7] Others did talk about eyeglasses, but with a lot of circumspection. For instance, Johannes Heurnius (1543-1601), a Dutch physician, briefly discusses the question of 'why old people see better with eyeglasses' but immediately adds that 'they are potentially painful for young people.'[8] He does so in the introductory chapter of his book on the diseases of the senses. In the pathological and therapeutic part itself though, he completely ignores them and does not give them a place amongst his other advices.[9] In his *Observationum medicinalium*, Petrus Forestus (1521-1597), another Dutch physician, advises glasses for those who are myopic, but, he does not mention the use of glasses for the opposite defect.[10] In *De morbis oculorum & aurium*, Hieronymus Mercurialis mentions eyeglasses in his chapter on the signs of diminished vision, or defective vision, but, again, does not include them later on when it comes to giving therapeutic advice. Rather than advise

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[5] Arguments and evidence for this statement are developed at length in my forthcoming PhD-thesis *De emancipatie van het oog*.

[6] Lindberg, *Theories of Vision* (1976), 175.

[7] Fernelius,*Universa medicina* (1656), 85-87; Capivaccio, *Opera omnia* (1603), 585.

[8] 'Sed cur Senes specillis melius vident, cum iuvenes illis hebetentur,' Heurnius, *De morbis oculorum* (1608), 7.

[9] *Ibidem*, 27.

[10] Forestus, *Observationum* (1602), 102-110.

them as a vision aid, he thus uses glasses as a diagnostic tool, to distinguish among the different eye-diseases and the different possible causes.

The few occurrences of eyeglasses in medical treatises thus rarely appear as part of the therapeutic advices themselves. From the above-mentioned examples, the only case in which spectacles were mentioned as part of the therapeutic procedure to help people with defective vision was in Forestus' book. That it occurs in a book of case histories and not a traditional textbook is presumably not a coincidence. Mercurialis' book on eye diseases was not a standard textbook either, inasmuch as the work was put together from his lectures on practical medicine at the University of Padua.[11] It would be interesting to see in how far the type of text and context played a part in the way new therapeutic ideas and instruments were introduced, but that goes beyond the scope of this paper.

MEDICAL PERSPECTIVES ON THE MODUS VISIONIS

From modus visionis to disease

Physicians appear to have views on the *modus visionis* different from those of opticians and philosophers. Medical doctors are not so much interested in what happens outside the eye, but in what happens with those images within the eye: where are they received, how are they assimilated, how do they stimulate vision, and not least of all, how can we explain defective vision?[12] This last point might seem somewhat trivial when discussing the 'modus visionis,' but it constitutes, as I will try to show, the biggest problem for doctors in thinking freely about the question: their ideas have to fit within medical theory. When compared to opticians and philosophers, doctors thus have an additional problem: they have to give their thoughts or theories a place within their strictly medical, and thus therapeutic, thinking. In the end, they do not want to know how vision occurs, but rather how defective or diminished vision takes place and can be explained. And the same can be said about eyeglasses: they do not want to know what glasses do with light, but they want to know how they can influence our sight. Mercurialis' exposition of the *modus visionis* is a telling example of this.

Mercurialis was born in Forlí, Italy, in 1530. He studied medicine in Padua and practised for a few years in Rome. This Roman period probably nourished his humanistic interests, thanks to his contacts with famous humanists such as

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[11] On Mercurialis' life and works, and especially his lecture notes, see Cerasoli & Garavini, 'Girolamo Mercuriale's works' (2005), 293-341.

[12] See my forthcoming PhD-thesis *De emancipatie van het oog.*

Justus Lipsius and direct access to classical sources, and these led to the publication of his famous work on gymnastics, *De re gymnastica*, in 1569. In that same year, he was appointed professor of practical medicine at the University of Padua, where he would stay for almost twenty years. In 1587 he took up a teaching position at the University of Bologna, and in 1593 he was invited by Ferdinando dei Medici to teach at the University of Pisa. He died in 1606.

Mercurialis is an interesting figure in many ways. In one way, he is a typical exponent of humanist medicine, and as such he is exemplary of contemporary medical ideas about the eye, the body and vision. In another way, he makes some interesting statements about eyeglasses that, as he himself realizes, 'nobody, as far as I know,' made before.[13] In the first chapter of the book 'On Eye Diseases,' he gives us insight in his ideas about vision and glasses. The chapter is entitled 'On the afflictions of the visual faculty, blindness and diminution of vision caused by obstruction.'[14] It deals with the afflictions that can be attributed to the *virtus visivus* or 'visual power' and that are usually classified under the genre of 'damaged visual activity.'[15] Yet the term is less obvious than it might seem at first glance and raises a serious problem for Mercurialis, for to what extent is seeing an active process, an activity? He is in doubt,

> … since vision is a passion rather than an action; because it is clear that vision happens when the crystalline humour is being affected [...] And because of that explanation one should say that it was the peculiar dogma of the Peripatetics that vision takes place through the reception of species alone, and therefore it is no wonder that the Princeps [Aristotle] said that it was accomplished rather by a passion than by an action.[16]

However, medical doctors had a different opinion and 'they thought that it happened through the reception of species, and the emission of rays. And therefore, since the reception of species is a certain passion, but emission rather an action, it is right to say that they are symptoms of a sort of a damaged action.'[17]

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[13] 'A nemine, quod sciam,' Mercurialis, *Tractatus* (1590), fol. 5r.

[14] 'De visoriae facultatis affectibus, Coecitate, visus diminutione impedimento,' *ibidem*, fol. 1r.

[15] '*Actionis* visoriae loesae,' *ibidem*, fol. 1v. The italics are mine.

[16] 'Cum visio sit potius passio, quam actio; nam clarum est, visionem fieri patiente humore crystallino (...). Pro cuius resolutione dicendum est, fuisse peculiare Peripateticorum dogma, quod visio fiat per solam specierum receptionem, & ideo non est mirum, si Princeps dixerit, magis passione, quam actione perfici,' *ibidem*, fol. 2r.

[17] 'Existimarunt fieri per receptionem specierum, *&* radiorum emissionem; unde cum receptio speciei passio quaedam sit, emissio autem, potius actio, iure dictum est, *esse* haec symptomata in genere actionis loesae,' *ibidem*, fol. 2r, italics are mine.

Mercurialis' statement does not only refer to the age-old debate among philosophers, opticians and physicians about the direction of radiation in vision, i.e. the question whether vision occurs by extramission or intromission, but it also reveals why the extramission theory was so attractive to physicians.[18] Mercurialis's explanation makes me think that medical doctors somehow needed extramission to corroborate their pathology, to keep a direct link with their system of pathology. Because it is exactly this active involvement of the eye that allows doctors to link the symptoms in the eye to afflictions of the body, or in a certain way to reduce the ocular afflictions to afflictions of the body. Thus even if Mercurialis seemed to believe that vision was a passive process of reception, as a physician he is allowed to add a little extramission.

It gives us a very interesting insight in early modern medical thought about vision and the eye. One had to presuppose an active role for the eye to be able to eventually blame a bodily processes. The extramission theory gave an answer that was perhaps not completely convincing – as Mercurialis's initial 'dubium' shows – but it was at least operational, in accordance with the prevailing holistic conception of medicine on which the entire pathological and therapeutic system was built. A system that was so consistent that it was difficult to replace one single piece without causing the entire system to fall. Difficult, but not impossible, and that is exactly what we see in the case of Mercurialis when he tries to fit some new ideas into the existing coherent whole.

From disease to therapy

For Mercurialis, as for most of the Early Modern doctors, the key to good vision lay in the *spiritus visivus* or visual spirits that possessed the visual power and were supposed to carry the forms or species from the world outside into the eye to produce vision. The state of these visual spirits was therefore of capital importance for good vision. And, logically, in case of problems with vision the spirits would be the first ones to be blamed.[19]

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[18] Early Modern physicians are generally believed to be extramissionist, see Lindberg, *Theories of Vision* (1976), 175. My research, however, revealed that the direction of radiation was not taken for granted, and constituted a real point of discussion, see my forthcoming PhD-thesis *De emancipatie van het oog.* I am very grateful to Sven Dupré for showing me that among mathematicians, too, the discussion intromission – extramission was still alive, as he convincingly argues in his forthcoming article 'Optics without hypotheses'.

[19] That visual spirits are responsible for diminished vision is clearly expressed in Capivaccio, *Opera* (1603), 585.

Spirits were supposed to be generated from the blood and the air by a whole series of bodily processes. And because blood in turn was thought to be generated by food, Mercurialis advises his patients to eat meat, especially that of birds, and to avoid wine, because it produces vapours in the brain which upon mixing with spirits make them turbid. And the same goes for the other external factors such as the air, emotions or sleep that might – indirectly by their influence on the bodily processes – influence the state of the spirits.[20] Advice concerning the Way of Life, or 'Regimen' as it was called, touched upon all these external or non-natural factors, and constituted the main therapeutic principle for whatever disease or disorder in the body, be it in the liver or in the eye.[21]

Indeed, in his chapter on diminished vision, Mercurialis states: 'first of all it is necessary to know what kind of life the patients have to lead.'[22] Apart from the kind of food they have to eat, he advises them for instance to keep away from smoky air, to look at green-coloured things but to avoid all that is white. To be happy, to laugh and to read funny stories is also very healthy for the eyes, but not after dinner he warns. Because nothing is more harmful to the eyes, than to read or write after eating. To sleep, to move and to have sex might help one to see well, though he stresses that it should be moderate, because while too much sex is harmful for the eyes, complete abstinence will be harmful too.[23]

Then he goes on to advise exercises (in arms and legs) in order to stimulate the flux of humours, and also to proceed to purging the body. The blood – and thus indirectly the spirits as well – was dependent on the entire complexional state of the patient. This explains why the traditional advices concerning the restoration of the natural balance, the *complexio*, were also applicable in the case of defective vision. We think of one of the many methods of evacuation such as bloodletting or purging, or the application of regulating remedies.

In short, as Mercurialis's example shows, almost all the therapies that were good for the body were thought to be good for the eye as well, because the eye was directly dependent on the body. It ultimately concerned a balance of the entire body, not of the eye alone. And that is why early modern medicine is often called 'holistic': everything is connected and one cannot consider just

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[20] In Galenic medicine they were called the six non-naturals.

[21] For a clear and concise exposition of Early Modern physiological thought, see Siraisi, *Medieval and Early Renaissance Medicine* (1990), 78-114.

[22] 'Primum scire necessarium est, quod vitae genus debeant sequi aegri,' Mercurialis, *Tractatus* (1590), fol. 6r.

[23] For Mercurialis' therapeutic advices in case of diminution of the visual faculty, see *ibidem*, fol. 6r-8r.

one part as an isolated item, not even the eyes. Or as Mercurialis put it: 'the eyes cannot be cured without the head and the head not without curing the whole body.'[24]

The only exception to these holistic therapies was the use of local remedies. But I would like to stress two points. First, that those so-called *localia* or *topicalia* almost always came last in learned treatises, and second that they mainly served as a complement to the foregoing methods. Often they were not supposed to work directly on the disease, but rather to lessen the pain, to keep the eyes humid and so on.

FITTING EYEGLASSES WITHIN THE MEDICAL FRAMEWORK

Eyeglasses and the visual spirits

It is now clear why eyeglasses were not given a place among those therapeutic methods that always focused on the entire body. Indeed, we find no reference to eyeglasses at all when it comes to therapy in Mercurialis' treatise. However, as I stated above, he does mention eyeglasses in another place, in the chapter on the 'signs' of defective vision. Upon introducing them as a diagnostic instrument, Mercurialis mentions explicitly that it was not easy for him to explain the working of eyeglasses, since none of the famous predecessors, nor physicians and philosophers, had written about them. And thus he excuses himself if he is not very accurate in giving the causes of it.[25]

To understand the working of glasses, he tells the reader one has to presuppose that vision takes place by an emission of spirits or rays by which we see. And one should also consider the causes of diminished vision. According to contemporary medical thought, far- sighted people cannot see things that are close to them clearly, because they have fat spirits. Those spirits need distance to become pure. In order to see well therefore, the spirits should be 'thin' (tenues) 'from the beginning of their going out.'[26] And this, says Mercurialis, is exactly what eyeglasses do. How can glasses affect the spirits so directly? This is easily understood, he believes, 'from the nature of the glass itself,' since 'it is full of pores and very small passages.'[27] And thus eyeglasses attenuate the

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[24] 'Quod oculi non possint curari sine capite, neque caput, sine curatione totius corporis,' *ibidem*, fol. 5v.

[25] 'Cum igitur nihil habeatur traditum de perspicillis, ero excusatione dignus, si in reddendis causis non ita satisfaciam,' *ibidem*, fol. 5v.

[26] 'Ut spiritus in principio exitus etiam sint tenues,' *ibidem*, fol. 5v.

[27] Resp. 'ex natura ipsius vitri' and 'scatet poris, & meatibus angustissimis,' *ibidem*, fol. 5v.

spirits because while they penetrate or are forced through those small passages they become less fat.[28]

This is a very interesting statement, because it shows that Mercurialis supposes a direct link between the glasses and the bodily spirits. It allows him to explain the working of glasses without altering his medical view on vision. For it is clear that he is not thinking of visual rays in terms of geometrical entities, but rather of entities produced by the body, and as such subjected to the laws of physiology, even when leaving the body. It is within this medical context that Mercurialis's understanding of eyeglasses should be understood: eyeglasses produce a qualitative change in the state of the spirits in order to make them apt to produce vision.

He also wants to account for the opposite affliction. Let us remember that according to early modern medical thought myopia was caused by spirits so subtle that they were dissipated in the air before reaching remote objects. Thus, in order that the spirits would not get lost, it is necessary that they are brought together, says Mercurialis. And again, in his opinion this is exactly what eyeglasses do: they bring together the spirits and unite them so that they can travel further. How exactly glasses bring the spirits together, he does, unfortunately, not say, but his words seem to refer to perspectivist thought in which glasses are analysed in terms of convergence or divergence of rays.

Petrus Forestus makes a similar statement about the convergence of spirits that is produced by eyeglasses. Yet about the way in which this convergence of spirits is thought to be produced, Forestus is much more explicit. He reminds the reader that these eyeglasses are hollow or concave, thicker or denser at the circumference than in the middle. Thanks to this shape, 'the spirits will be driven together to the centre, just as happens in the pupil of the eye, and go forwards as if bound together.'[29] This seems to me a very curious and original interpretation of how glasses produce a convergence: I believe he considers the very dense circumference as a kind of wall which by its thickness cannot be transgressed. Convergence, then, is not a process that happens while passing through the lens, but something that happens before passing through it, precisely in order to make the passing through possible in the middle where it is thinner. So even if at first sight his ideas seem to refer directly to some optical ideas, he makes his own sense out of them: upon arriving at this thick part of a

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[28] 'Igitur ocularia in illis, qui remota intuentur, id praestant, ut etiam spiritus in principio attenuentur, quia sic per angustissimos meatus penetrantes, extenuantur,' *ibidem*, fol. 5v.

[29] 'Ocularibus ad oculi formam cauis uti, & circumferentia densioribus, quo spiritus in centrum, tamquam pupillam cogantur, & consertim prodeant,' Forestus, *Observationum* (1602), 108.

glass, spirits do not have to move along straight lines as optical laws prescribe, but simply slide towards the middle. Spirits that are bound together in this manner, will be stronger: they literally bundle their forces and will thus be strong enough to carry the visual power all the way to the remote objects. Just as was the case with Mercurialis, Forestus borrows the optical terminology but transposes it into the conceptual framework of medicine. This transposition entails a re-interpretation of the concept.

Forestus also adds another explanation to account for the effect of eyeglasses in case of myopia: 'because the visible species of the letters are made thicker.'[30] Eyeglasses are thought to work in two directions. Not only the outgoing visual spirits benefit when passing through the eyeglasses, but also the incoming species are made bigger thanks to the glasses. The importance of this statement lies in the fact that it shows an attempt to move to a *modus visionis* in which the eye and the eyeglasses are considered in relation to the world outside. This is not to say that Forestus was necessarily thinking in terms of intromission, since the emission theory, too, supposed that the species from the objects came back to the eye, but still it shows a realization that what happens outside the eye should be taken into account when talking about the eye, the defective eye, and the way of seeing.

Eyeglasses and internal light

Back to Mercurialis for his last remark on eyeglasses. He argues that people with myopia sometimes need some extra light in order to see better. How does he relate this argument to the use of eyeglasses? He believes that by making them 'a little more concave and clearer' spectacles can be made especially so that they strengthen ('augent') the light.[31] He does not explain how this is supposed to work, but once again his ideas seem vaguely reminiscent of optical ideas, such as burning mirrors, which were known to strengthen light by a convergence of rays.

Together with the state of the spirits, lack of light was indeed often adduced in medical treatises to explain diminished vision, be it in case of myopia or in the diminishing sight of elder people. Many physicians were thinking of vision in terms of light. In the same way opticians did? No, because whereas opticians referred to external light, physicians mostly referred to internal light. The

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[30] 'Quoniam species visibilies ex literarum singulis elementis crassiores redduntur,' *ibidem*, 109.

[31] 'hac ratione, qui perspicilla faciunt pro istis, id student, ut faciant paulo concaviora, & lucidiora,' Mercurialis, *Tractatus* (1590), fol. 5v.

discussion on the presence of an innate light in the eye was precisely one of the favourite points of discussion in the medical debate on the *modus visionis*. For many physicians believed that the eye itself possessed some kind of light that was necessary for seeing well. This light was ascribed to the presence of the visual spirits, or to the polished surface of the crystalline humour: polished surfaces were believed to be shining, glittering, and thus in a certain sense capable of producing light. This light however was believed to diminish with age, which explains why we sometimes find the term 'obscuring' sight, referring to the diminishing sight in older people.

A clear illustration of this way of thinking can also be found in Heurnius' explanation of why old people see better with eyeglasses than without. He ascribes it to the fact that 'through the shining or *fulgor* of the external crystalline what is lacking in the internal one' is repaired.[32] He compares the crystalline humour, nowadays called the lens, with eyeglasses, and believes that eyeglasses add some light due to their shining nature.[33] However, he immediately adds that young people can be wounded by excessive *fulgor*, because their internal crystalline humour has enough of it.[34] This is important as it shows why from a certain medical point of view the use of eyeglasses was in some cases thought to be harmful.[35]

EYEGLASSES IN OTHER MEDICAL TREATISES

Treatises by oculists

So far I have focused on 'learned' medicine and therapy. Yet there is more to say about eyeglasses and medicine. In the Early Modern period, the medical sector was far from homogeneous. Besides academically trained physicians, there were many other groups who took care of patients and who had something to say about therapy, not only medical professionals, but also laymen and –women. In the case of the eye, there was a special group of so-called 'oculists.' In theory, their task was limited to the very delicate and risky operation of 'couching cataracts. In practice, however, some oculists appeared to be much more ambitious and tried to present themselves as real doctors of the

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[32] 'Nam resarcitur externi crystalli fulgore quod interno deest,' Heurnius, *De morbis oculorum* (1608), 7.

[33] The comparison between the crystalline humour and eyeglasses was typical for anatomical discourse (see below).

[34] 'At immodico splendore iuniores offenduntur, cum internus satis illis sit,' *ibidem*, 7.

[35] As was the case for Georg Bartisch, for instance.

eye, with the proviso that if doctors were giving advice concerning the entire body, oculists were concerned much more with local remedies and therapies. Considering their focus on what was local and their non-academical background, it should not surprise us that in their treatises we find a different approach to eyeglasses. Oculists were ambiguous too, but on different grounds: whereas the conceptual background seemed not such an issue and it was easier to fit spectacles within their topical remedies, they might consider eyeglasses – much more than physicians did – as a threat towards their profession.[36]

Treatises on anatomy

I have focused on therapy because that is the place where eyeglasses seem most relevant – and eventually would become so –, even if, paradoxically, it is precisely the place where the introduction at first appeared most problematic. Yet there was another type of medical discourse about eyeglasses, namely anatomical treatises. Ever since the famous anatomist Andreas Vesalius (1514-1564) had suggested that the crystalline humour was working as a kind of 'specillorum,' eyeglasses would be adduced to explain the working of the crystalline humour.[37]

In anatomical treatises, physicians adopted a different approach to eyeglasses. They were considered not so much in relation to the diseased body with its spirits and its internal light, but directly to the image. In doing so, they were much closer to opticians. With the rise of functional anatomy at the end of the sixteenth century, then, that interest in the function of the crystalline humour, led to an active interest in the working of eyeglasses, which were considered to be like an external crystalline humour.[38] In order to know more about its working, they looked at what opticians, who had a longer tradition of studying the properties of glasses and lenses, had said. I therefore believe that anatomists formed an essential chain in the circulation of knowledge between opticians and physicians. This is not to say that the integration of optical concepts in anatomical tracts went very smoothly. Anatomists, too, were struggling with the concepts in order to accommodate them to their medical 'modus visionis,' but at least they did not have to make a direct link with pathology or therapy.[39]

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[36] On oculists and eyeglasses, see Vanagt, 'Brillen' (2006), 30-32 and idem, 'Early Modern Medical Thinking on the Vision and the Camera Obscura (forthcoming).

[37] Vesalius, *Fabrica* (1543), 646.

[38] On the importance of *functions* and the development towards a more philosophical approach in post-Vesalian anatomy, see French, *Dissection* (1999); Cunningham, *The Anatomical Renaissance* (1997); Cunningham, 'Fabricius' (1985), 195-206.

[39] On the importance of anatomy for the integration of eyeglasses within medical discourse, see Vanagt, 'Brillen' (2006), 34-39.

Conclusion

The example of Mercurialis and others shows that the introduction of eyeglasses within the medical, therapeutic discourse was less evident than we might have thought. Early Modern physicians were struggling to find a way of explaining spectacles in accordance with current medical ideas on disease and vision; a world that was dominated by spirits, visual power and internal light. In order to do so, they vaguely relied on optical concepts. But, when these concepts made their entrance into the medical world, where optical laws appeared to be far less constraining, they easily developed a life of their own. A study of why and how physicians sought to refine the traditional picture, and attributed alternative interpretations to new ideas and instruments, is essential for a proper understanding of the mechanisms of change within medicine and natural philosophy.

William Bourne's invention. Projecting a telescope and optical speculation in Elizabethan England

Sven Dupré

Introduction

In 1608 Dutch spectacle-makers invented a telescope by combining a convex and a concave spectacle-lens. Albert Van Helden's classic *The Invention of the Telescope* has considered the patent application of a spectacle-maker of Middelburg, Hans Lipperhey, to the States General in The Hague in September 1608 as the beginning of the history of the telescope.[1] There had however been numerous reports of alleged telescopic practice for several centuries. Eileen Reeves has recently shown that in many of these stories the projected instrument is a sort of telescopic mirror, and thus of an optical design significantly different from the Dutch telescope (and for that matter, other early seventeenth-century telescopes) which was made of lenses only.[2] The Pharos, the lighthouse in ancient Alexandria, on top of which an enormous mirror was positioned, enabling one to see the enemy's ships from far away (and to set them on fire), is perhaps the most familiar incarnation of legendary telescopic catoptrics. Although available in Latin only since 1575, Reeves has shown that it was preceded by various medieval versions of the same device. Moreover, projected telescopic catoptrics had a continued existence in the later sixteenth and early seventeenth centuries, even after the Dutch telescope had already appeared on the scene. Among these circulating stories of legendary telescopic catoptrics the claims made by the sixteenth-century English mathematicians Thomas Digges and William Bourne stand out, foremost because they (and especially Bourne, as we will soon learn) were incomparably more precise about the optical design of their telescope. The instrument is first mentioned

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[1] Van Helden, *Invention* (1977), 20-25. On the inventor of the Dutch telescope, see also Zuidervaart, this volume, and idem, "Uit Vaderlandsliefde" (2008), 5-58.

[2] Reeves, *Galileo's Glassworks* (2008), 15-46.

in 1571 when Thomas Digges attributed the invention of a telescope to his father Leonard Digges in his edition of his father's *Pantometria*.

> My father by his continual painfull practises, assisted with demonstrations Mathematicall, was able, and sundrie times hath by proportionall Glasses duely situate in convenient angles, not onely discovered things farre off, read letters, numbred peeces of money with the very coyne and superscription thereof, cast by some of his freends of purpose uppon Downes in open fieldes, but also seven myles of declared wat hath beene doon at that instante in private places.[3]

Digges' claim was followed by Bourne's description of a telescopic device in his *Inventions or Devices* (1578). It is unclear whether Digges and Bourne discussed the same design (most likely *not*, as we will see below), but we can be certain that Bourne's discussion of the design was more precise than Digges': Bourne mentioned the necessity to combine 'two glasses.'

> For to see any smal thing a great distance of from you, it requireth the ayde of two glasses, and one glasse must be made of purpose, and it may be made in such sort, that you may see a small thing a great distance of, as this, to reade a letter that is set open neare a quarter of a myle from you, and also to see a man foure or five miles from you, or to view a Towne or Castell, or to see any window or such like thing sixe or seaven myles from you. And to declare what manner of glasses that these must be ...[4]

This announcement was followed by a letter of Bourne to Sir William Cecil, Lord Burghley (*c.* 1580) which was even more elaborate in its discussion of the optical properties of lenses and mirrors. This letter merits close study, and it is therefore the main subject of this essay.

In the early 1990s several authors undertook a material 'reconstruction' of the telescopic projects of Digges and Bourne on the basis of the textual passages, like the ones cited above, that have come to us. This material reconstruction served to support a priority claim. They revived the claim that the 'Elizabethan telescope' was invented in England prior to the emergence of the multiple Dutch claimants to the telescope's invention in 1608. In section 1 of my essay I will discuss the properties of this material reconstruction in detail. However, I will also show why this reconstruction is not satisfying, at least not in as far as it wishes to support an English priority claim. I will focus in particular on

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[3] Digges, *Pantometria* (1571), Aiii^{v}.

[4] Bourne, *Inventions or Devices* (1578), 96.

two points on which the reconstruction significantly belies the historical texts, to the extent that it is probably better to think of the late twentieth-century material 'Elizabethan telescope' as a *construction* instead of a reconstruction. In section 2, this point will receive support from the discussion of the context in which Bourne wrote on the telescope. This context clearly reveals the nature of Bourne's discussion of the telescope as that of a projector in search of Burghley's patronage. Bourne's telescopic design was a scheme that he had not tested and which was most likely never tested until twentieth-century historians invented the Elizabethan telescope.

Why then should we be interested in Bourne's letter if it fails to support a priority claim? Bourne's letter to Burghley reveals the optical knowledge on which his telescope design proposal was based. In section 3, I will discuss the content of this optical knowledge, and I will argue that it was shared knowledge, not unique to Bourne, not material yet practical, as opposed to theoretical knowledge and innovative with respect to the optical tradition prior to the mid-sixteenth century. Most importantly in the context of this paper, I will show that it was precisely the fact that Bourne's telescope design was based on practical optical knowledge that resulted in its failure. As we will see, this optical knowledge put demands on Bourne's design that were difficult, nay impossible, to meet by contemporary optical craft. In contrast to the Dutch telescope which emerged from the world of craft in a local spectacle-maker's shop in Middelburg, the origin of Bourne's invention in optical knowledge impeded its circulation.

1. The reconstruction of the 'Elizabethan telescope'

In the early 1990s Colin Ronan, immediately followed by Joachim Rienitz and Ewan Whitaker, revived the claim that the telescope was invented in Elizabethan England.[5] However, since no specimen of such an 'Elizabethan telescope' – as Ronan baptized the alleged sixteenth-century English telescope – has surfaced to date, the evidence for their claim rests on a material reconstruction of the telescope based on their reading and interpretation of the writings of Thomas Digges and William Bourne. (see illustrations 1 and 2) The reconstructions of the 'Elizabethan telescope' consist of a convex lens and a concave mirror,

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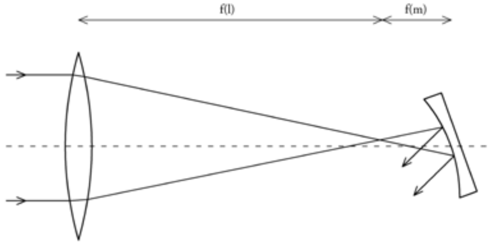
[5] Ronan, 'Origins' (1991); Ronan, 'Elizabethan Telescope' (1993); Rienitz, "Make Glasses to See the Moon Large" (1993); Rienitz, *Historisch-Physikalische Entwicklungslinien* (1999), 66-132; Whitaker, 'Digges-Bourne telescope' (1993). See also Ronan's appearance in Patrick Moore's *The Sky at Night* program on BBC-1, 2 April 1992.



Ill. 1. Dr. Allan Mill's reconstruction of the 'Elizabethan telescope'. The diameter of the convex lens is 95 mm; the focal length 480 mm. The focal length of the concave mirror is 42 mm; the diameter 50 mm. (Louwman Collection of Historic Telescopes).
Ill. 2. William Bourne's telescope design proposal in his letter to Lord Burghley. With f(l) = focal length of the convex lens; f(m) = focal length of the concave mirror.

mentioned by Bourne respectively as the 'perspective glass' and the 'looking glass.'[6] This optical combination gives a wide field of view and an image that is upside down and laterally (left-right) inverted. The light rays go first through the lens and are then reflected by the mirror.[7] In other words, the concave mirror is the ocular and the convex lens is the objective. The observer is supposed to look in the mirror with his back towards the lens and the object. The mirror must be slightly tilted with respect to the lens to avoid the observer's head blocking the light that travels from the lens to the mirror. Ronan maintained that the reconstruction with the mirror tilted with respect to the lens offered an explanation for Digges' reference to the telescope as 'glasses duely situate in convenient angles' in the *Pantometria* passage quoted above.[8]

In the reconstructions the distance between the convex lens and the concave mirror is such that the focal points of the mirror and the lens coincide. In order for the combination to produce magnification, the focal length of the lens needs to be larger than the focal length of the mirror. When allowing shorter focal lengths of the lens, and correspondingly shorter focal lengths of the mirror, the observer's eye needs to be positioned much closer to the mirror and the blocking of the incoming light by the observer's head then becomes a

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[6] Bourne to Burghley [MS Lansdowne 121]; citations taken from the edition in Van Helden, *Invention* (1977), 30-34.

[7] In other words, the reconstructed 'Elizabethan telescope' is not a reflecting telescope. For the history of the reflecting telescope, see Ariotti, 'Cavalieri' (1975); Turner, 'Prehistory' (1984).

[8] Digges, *Pantometria* (1571), Aiii^{v}.

serious problem. The angle between the two optical axes must be kept small in order to avoid image distortion to astigmatism. This means that the focal length of the mirror cannot be so short that the observer's head blocks the incoming light, and therefore the focal length of the objective lens must be accordingly long.

The material reconstructions of Ronan, Rienitz and Whitaker have offered explanations for some references in the documentary sources which would otherwise be difficult to explain. However, the material reconstructions deviate from the textual sources on two points, and also leave many questions unanswered. Let me start with the unanswered questions: how did they arrive at this peculiar design? And why was the design short-lived? In contrast to the Dutch telescope, which spread over Europe (and beyond) in just a few months, the 'Elizabethan telescope' apparently did not travel outside a small circle of English mathematicians.[9] Those questions find an answer in the fact that Bourne's telescope design was based on practical optical knowledge different from the craft knowledge at the root of the Dutch telescope. I say *Bourne*'s telescope, because in contrast to the claims by the proponents of the 'Elizabethan telescope,' who puzzled together passages from the works of several English mathematicians to make a grand priority claim for England, Digges' words in *Pantometria* that 'for multiplication of beames sometime the ayde of glasses transparent, which by fraction should unite or dissipate the images presented by the reflection of other' suggest that the image reflected from the concave mirror was subsequently enlarged by the lens.[10] That is different from Bourne's design suggestions.

Two characteristics of the material reconstructions, in particular, do not find a support in the text. First, the material reconstructions make use of lenses which have smaller diameters than Bourne would have wanted. Bourne insisted that the lens 'must bee made very large, of a foote, or 14. to 16. inches broade,' thus of 30 to 40 centimeters.[11] Bourne did not explicitly specify the focal lengths of the lens, but he advised to make the central thickness of the lens not exceed 'a quarter of an ynche' to allow clear sight given the contem-

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[9] On the dispersal of the Dutch telescope, see Van Helden, *Invention* (1977), 25-26; Sluiter, 'The Telescope before Galileo' (1997). See also Sluiter, 'The First Known Telescopes' (1997).

[10] Digges, *Pantometria* (1571), Gi^v-Gii^r. For this interpretation, see Reeves, *Galileo's Glassworks* (2008), 62.

[11] Bourne, *Inventions or Devices* (1578), 96.

poraneous glass quality.[12] In combination with the given dimensions for the diameter of the lens, this corresponds with a lens of a focal length of 5.5 meters.[13] As far as the mirror was concerned, Bourne did not give any precise dimensions for it. He did mention however that the mirror's diameter needed to be 'very fayre large.'[14] Why did Bourne insist on such large diameters for his lenses and mirrors (especially, since smaller diameters would have been equally effective)?

Second, in the material reconstructions the lens and the mirror are often enclosed in a tube. Sometimes a focusing device is even added to the design. There is little to support this enhancement in any of the writings of Bourne or Digges. In fact, there is no mention of a tube. Bourne mentioned that the convex lens was mounted in a frame and 'set fast.'[15] The concave mirror, on the other hand, did not have such a support. It is likely that the observer held the mirror in his hand. Thus, each observer would have had to position the mirror (at the correct distance from the lens), and tilt and focus it to find the telescopic image. In this connection, it is remarkable that sixteenth-century developments of the camera obscura in Italy led to the same design as that of Bourne's telescope. In the second edition of his *Magia naturalis* of 1589 Giovanni Battista Della Porta proposed to combine a convex lens *and* a concave mirror inside a camera obscura. The design of Della Porta's camera obscura (which he did not recognize as a telescope) was thus identical to that of Bourne's telescope.[16]

> But if you wish for the images to appear upright, this will be a great feat, attempted by many but not discovered by anyone until now. Some place flat mirrors at an oblique angle near the hole, which reflect an image onto the screen opposite that is more or less upright but dark and confused. We, by placing the white screen at an oblique angle to the hole, and looking towards the part facing the hole, saw the images almost erect but the pyramid cut obliquely showed the men without any proportion and confusedly. But in the following way you will have what you desire. Place an eyeglass made from a convex lens in front of the hole. From here the image falls on the concave mirror. Place the concave mirror far from the centre so that the images which it

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[12] 'And for that yf the glasse bee very thicke, then yt will hynder the sighte. Therefore yt must bee not above a quarter of an ynche in thickness: and the sydes or edges very thynne, and so polysshed or cleared.' Bourne to Burghley [MS Lansdowne 121], in Van Helden, *Invention* (1977), 33.

[13] Von Rohr, 'Geschichte der Brille' (1937), 41.

[14] Bourne, *Inventions or Devices* (1578), 96.

[15] *Ibidem*, 96.

[16] Gorman, 'Art, Optics and History' (2003).

> receives inverted it will show upright, because of the distance from the centre. In this way, above the hole on the white paper you will see the images of the things, which are outside so clearly and openly that you will never cease to be delighted and amazed. But here I should warn you, so that you don't waste your efforts, that it is necessary for the lens to be proportioned to the concave mirror, but, as you will see, here we will speak of this many times.[17]

Della Porta did not specify the proportion of the focal lengths of the mirror and the lens, but when the focal length of the lens would have been longer than the focal length of the mirror, and the focal point of the mirror placed a short distance outside the focal point of the lens, the projected image is magnified, upright and not left-right reversed. The image obtained in this type of camera obscura was then perfectly suitable for those interested in visual representation.

That the interest in optics arose in a context of visual representation is also suggested in the case of Digges (but one should add, absent in Bourne's multiple references to a telescope). The complete title of one of Digges' works in which he referred to the telescope was *A Geometrical Practise, named Pantometria divided into three Bookes, Longimetra, Planimetra and Stereometria, containing Rules manifolde for mensuration all lines, Superficies and Solides: with sundry straunge conclusions both by instrument and without, and also by Perspective glasses, to set forth the true description or exact plat of an whole Region*. Digges' edition of his father's work was thus a book on surveying. As to the 'perspective glasses,' Digges explicitly claimed them be useful for the representation of cities, but also for the representation of any details thereof, such as individual buildings.

> Marveylouse are the conclusions that may be perfourmed by glasses concave and convex of circulare and parabolicall fourmes, using for multiplication of beames sometime the ayde of glasses transparent, which by fraction should unite or dissipate the images or figures presented by the reflection of other. By these kinde of glasses or rather frames of them, placed in due angles, ye may not only set out the proportion of an whole region, yea represent before your eye the lively image of every towne, village, &c. and that in as little or great space or place as ye will prescribe, but also augment

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[17] Della Porta, *Magia naturalis* (1589), 589, in the translation of Gorman, 'Art, Optics, and History' (2003), 297-298. For the use of a plane mirror inside a camera obscura, to which Della Porta referred, see Benedetti, *Diversarum speculationum* (1585), 270-271; Danti, *La prospettiva* (1573), 81-84.

> and dilate any parcell thereof, so that whereas at the first apparance an whole towne shall present it selfe so small and compacte together that ye shall not discerne any difference of streates, ye may by application of glasses in due proportion cause any peculiare house, or roume thereof dilate and shew it selfe in as ample fourme as the whole town firste appeared.[18]

I do not wish to claim that this context of topographical representation determined a particular design choice for the telescope – in fact, not at all, since Digges' design was possibly different from Bourne's. But the closeness of Bourne's design to contemporary types of camera obscura and the context of topography in which Digges' 'perspective glasses' arose should be a caveat not to import with hindsight too many characteristics of later telescopes in to Bourne's words – something to which the inventors of the 'Elizabethan telescope' fell victim.

My argument that Bourne designed a telescope on the basis of practical optical knowledge allows me to engage with Gerard Turner's objections against Ronan's argument for an 'Elizabethan telescope' on the basis of a material reconstruction. Turner's objections were twofold: he claimed that 'there was neither the conceptual framework nor the technical capacity to make such an instrument during this period.'[19] I will turn the first of these objections on its head: Bourne's design was based on concepts available in a shared, mid- to late sixteenth-century body of practical optical knowledge. As for Turner's second objection – that it failed on the technical capacity of Elizabethan England – I will argue that this is essentially correct, but that we need to be more precise here. There is no reason to assume that there was a difference in the level of optical craft between Middelburg and England. I will show that it was precisely the practical knowledge at the basis of Bourne's design that would have made the design difficult to make for craftsmen, both in England and Middelburg.

2. The context of William Bourne's letter to Lord Burghley

William Bourne was a jurat, or town councilman, in Gravesend on the lower Thames.[20] In 1571/2 he served as the town's port-reeve, the equivalent of

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[18] Digges, *Pantometria* (1571), Gi^v-Gii^r.

[19] Turner, 'There Was No Elizabethan Telescope' (1993), 5.

[20] On William Bourne, see Turner, 'Bourne' (2004). See also the introduction in Taylor, *Regiment of the Sea* (1963), xiii-xxxv; Taylor, *Mathematical Practitioners* (1954), 33-39; Taylor, *Tudor Geography* (1930), 155-156; Taylor, *The Haven-Finding Art* (1956), 192-214; Bawlf, *The Secret Voyage* (2003), 68-73, 309-311.

mayor. In Gravesend Bourne had everyday contact with sailors, and he also practised gunnery as a citizen volunteer at the defensive bulwark of Gravesend. Thus, although he was not university-educated, unlike some other mathematical practitioners in England in this period, the Gravesend context presumably started him on a career of writing on almanac-making, surveying, navigation and gunnery. How did Bourne come to write to Sir William Cecil (1520/1-1598), Principal Secretary and later Lord Treasurer to Elizabeth I, with a proposal for a telescope design?

The occasion for the letter was (Bourne wrote in his dedication) 'that of late youre honour hathe had some conference and speache with mee, as concerning the effects and qualityes of glasses, I have thought yt my duty to furnish your desyer, according unto suche simple skill, as God hathe given me, in these causes.'[21] This conversation was not the first contact between Bourne and Burghley. In his letter Bourne reminded his potential patron:

> And allso aboute seaven yeares passed, uppon occasyon of a certayne written Booke of myne, which I delivered your honour, Wherin was set downe the nature and qualitye of water: As tuchinge ye sinckinge or swymminge of thinges. In sort youre Honoure had some speeche with mee, as touching measuring the moulde of a shipp. Whiche gave mee occasyon, to wryte a little Boke of Statick. Whiche Booke since that tyme, hath beene profitable, and helpped the capacityes, both of some sea men, and allso ship carpenters. Therfore, I have now written this simple, and breefe note of the effects, and qualityes of glasses, according unto the several formes, facyons, and makings of them …[22]

This 'certayne written Booke of myne, which I delivered your honour' was a manuscript, dedicated to Lord Burghley, that contained two works *Art of Shooting in Great Ordinance* and *Treasure for Travellers* – both of which were published in 1578 – before an editorial decision was made to split them up.[23] As on the one hand Burghley was addressed as 'Lorde Highe Treasurer of Engelande,' a title he was awarded in the summer of 1572, and on the other, Bourne had announced these two works as ready for publication in his *Regiment for the Sea* (1574), the manuscript must have been written in

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[21] Bourne to Burghley [MS Lansdowne 121], in Van Helden, *Invention* (1977), 31.

[22] *Ibidem.*

[23] British Library (London), MS Sloane 3651. My appreciation of the dating of William Bourne's manuscripts is fully based on Stephen Johnston's unpublished and revised (with respect to Taylor's) bibliography of William Bourne. See http://www.mhs.ox.ac.uk/staff/saj/bourne [accessed 12 Sep 2005]. Compare the bibliography of Bourne in Taylor, *Regiment* (1963), 439-459.

1572/3.[24] As 'aboute seaven yeares passed,' it follows that Bourne's letter on the 'effects and qualityes of glasses' should be dated to 1579/80.[25] Between 1572/3 and 1579/80 Bourne had also written 'a little Boke of Statick,' a short hydrostatical text, for Burghley.[26] Moreover, the *Inventions or Devices* – in which Bourne first mentioned a telescopic device – was published in 1578, but a version already existed in 1576 in a manuscript dedicated to Burghley.[27] Thus, Bourne's letter on the optical properties of mirrors and lenses and a suggestion for a telescopic instrument came at the end of a decade in which Bourne had repeatedly sought Lord Burghley's patronage. Bourne's letter of 1579/80 on telescopic optics was thus only the last attempt in a long series.

But what did Bourne's letter look like from Burghley's side? Burghley's patronage of natural knowledge needs to be seen in light of his economic patronage.[28] A distinctive pattern of patronage of natural knowledge accompanied Burghley's economic policy with its focus on the patent of monopoly: Burghley had a firmly utilitarian attitude to natural knowledge.[29] Burghley's economic policy was marked by the development of the patent of monopoly as a means of advancing the commonweal. This technique was also meant to encourage self-sufficiency by bringing (and copying) foreign skill to England's economy. A nice example is the English glass industry. During the same period that Bourne attempted to attract Burghley's patronage with a telescope design, the English glass industry experienced a revival foremost due to the initiative of the formerly Antwerp-based glassmaker Jean Carré.[30] Carré settled in England in 1567 and brought with him glassmakers from Flanders, Normandy, Lorraine and Venice, who provided a strong injection of glassmaking skill in England. Carré tried to procure patents of monopoly for the making of window glass and Venetian crystal.

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[24] *Ibidem*, 278.

[25] Johnston, *Revised Bibliography* (ref. 23). This dating differs significantly from Van Helden's (*c.* 1585) and Turner's (*c.* 1572). Compare Van Helden, *Invention* (1977), 30; Turner, 'Bourne' (2004).

[26] Bodleian Library (Oxford), MS Ashmole 1148, 79-102.

[27] Lawrence J. Schoenberg Collection (private collection, University of Pennsylvania), ljs345.

[28] A recent biography of Burghley is Alford, *Burghley*, which is excellent, but unfortunately, does not cover Burghley's role in the Privy Council and his patronage of natural knowledge projects. For Burghley's economic patronage, see Heal and Holmes, 'Economic Patronage' (2002). See also Graves, *William Cecil* (1998), 149-168.

[29] Pumfrey and Dawbarn, 'Science and Patronage' (2004), 157-160.

[30] Godfrey, *English Glassmaking* (1975), 16-37. See also Charleston, *English Glass* (1984), 42-108; Thorpe, *English Glass* (1949), 86-113.

Applications for such patents of monopoly were addressed to Lord Burghley, a member of Queen Elizabeth's Privy Council, and Elizabeth's most important patronage broker. Burghley actively looked for expertise beneficial to England's economy, and his patronage was continually solicited by projectors who proposed all sorts of inventions. Between 1560 and 1580 Burghley was responsible for the evaluation of Elizabethan 'Big Science' projects (in the recent words of Deborah Harkness).[31] To that end Burghley also developed a network of informants and consultants. Among his clients he counted Digges who in those years acted as Burghley's general consultant on engineering projects. From the point of view of Burghley, then, Bourne's letter appeared as one among many of more or less realistic projects which competed for his attention and patronage. As far as we can tell, Bourne's application for Burghley's patronage went unanswered, and it is likely that Bourne's telescopic project never went beyond the paper stage in which it was at the time of writing his letter (like so many other proposals of other Elizabethan projectors of the period). That this was the status of the project is evident from Bourne's conclusion of his letter to Burghley:

> For that there ys dyvers in this Lande, that can say and dothe knowe much more, in these causes, then I: and especially Mr. Dee, and allso Mr. Thomas Digges, for that by theyre Learninge, they have reade and seene moo [*sic*] auctors in those causes: And allso, theyre ability ys suche, that they may the better mayntayne the charges: And also they have more leysure and better tyme to practyze those matters.[32]

Bourne's concluding words also tell us that he aspired to an intellectual status similar to that of the mathematicians John Dee and Thomas Digges, who had authored books in which they made reference to a telescopic design.[33] The kind of expertise and the type of mathematical knowledge which Dee and Digges possessed were more bookish than his own. Nevertheless, the optical knowledge which Bourne discussed in his letter was a step towards the knowledge and status of Digges and Dee to which Bourne aspired. As we will see, Bourne's optical knowledge was different from the material knowledge of craftsmen such as lens-makers.

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[31] Harkness, *The Jewel House* (2007), 142-180.

[32] Bourne to Burghley [MS Lansdowne 121], in Van Helden, *Invention* (1977), 34.

[33] In his *Mathematicall Praeface* (1570) John Dee included 'perspective' among the mathematical arts. Dee also announced a promise of a telescope not yet fully fulfilled when he wrote that the military man 'may wonderfully helpe him selfe, by perspective Glasses. In which, (I trust) our posterity will prove more skillfull and expert, and to greater purposes, then in these days, can (almost) be credited to be possible.' See Dee, *Elements*, b.j.r.

3. Shared optical knowledge and idiosyncratic beams

Let us now turn to the optical knowledge in Bourne's letter to Lord Burghley. Bourne shared this knowledge with Italian mathematicians, such as Ettore Ausonio and Della Porta, although he had no notion of their work.[34] Their conceptual framework in which to understand the properties of mirrors – and in the case of Bourne and Della Porta, of lenses – was innovative with respect to the Perspectivist tradition of optics in that it combined the imaging and burning properties of lenses and mirrors. Since Bourne (in contrast to his Italian contemporaries) was unfamiliar with the optical tradition, he employed an idiosyncratic terminology of 'burning beams' and 'perspective beams.'[35] Bourne's knowledge was, then, clearly different from the theoretical knowledge embodied in the Perspectivist tradition of optics, because it was based on familiarity with the behaviour of *real* objects, as for example, the perception of images in concave mirrors and convex lenses. However, it was also knowledge on paper. Notwithstanding the misleading nineteenth century title attributed to Bourne's letter – which speaks of 'glasses for optical purposes, according to the making, polishing, and grinding of them' – the optical knowledge in Bourne's letter was not material knowledge, that is information about how to make a mirror (e.g. information about the kind of glass to be used and how to shape it).

In his description of concave mirrors, Bourne noted that the image fills the whole surface of the concave mirror when the eye is placed at a certain distance from the mirror.

> And then this glasse, the property of yt ys, to make all thinges which are seen in yt to seem muche bigger then yt ys to the syghte of the Eye, and at some appoynted distance, from the glasse, accordinge to the forme of the hollowness, the thinge will seem at the biggest, and so yow standinge nearer the thinge will seeme less, unto the sighte of the eye: so that, accordinge unto the forme of the concavity or hollowness, and at some appointed distance from hym that looketh into the glasse, And yf that the glasse were a yearde broade, the beame that shoulde come unto his eye, shall showe his face as broade, as the whole Glasse.[36]

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[34] Dupré, 'Ausonio's Mirrors and Galileo's Lenses' (2005), 160-170.

[35] On the differences between Ausonio and Bourne, see Dupré, 'The Making of Practical Optics' (2009).

[36] Bourne to Burghley [MS Lansdowne 121], in Van Helden, *Invention* (1977), 32.

While the position of this point, where the image fills the whole surface of the mirror, seems not well defined in Bourne's description of the concave mirror, as he implicitly stated that this point is close to the point of inversion of the mirror, his location of this point is much more precise in the case of convex lenses. The location of the point of combustion is determined by the 'burninge beame,' and Bourne identified the locus of the point of combustion with the locus of the point of inversion in a description of the optical properties of the 'glass.'

> And yf that yow doo beholde any thinge thorowe this Glasse, and sette the glasse furder from yowe then the burning beame, and so extendinge after that what distance that yow list, all suche thinges, that yow doo see or beholde, thoroughe the glasse, the toppes ys turned downwardes.[37]

Bourne differentiated this 'burninge beame' from the 'perspective beam,' and specified the location of this 'perspective beame' *vis-à-vis* the point of combustion.

> The quality of this Glass, ys, if that the sunne beames do pearce through yt, at a certayne quantity of distance, and that yt will burne any thinge, that ys apte for to take fyer: And this burnynge beame, ys somewhat furder from the glasse, then the perspective beame.[38]

The 'perspective beame' locates the point where the eye is to be placed in order to perceive the largest possible image, one that fills the entire diameter of the lens before the image collapses when the eye is then placed at the point of combustion of the convex lens.

> The quality of the Glasse, (that ys made as before ys rehearsed) ys, that in the beholding any thinge thorowe the glasse, yow standinge neare unto the Glasse, yt will seeme thorow the glasse to bee but little bigger, then the proportions ys of yt: But as yow do stande further, and further from yt, so shall the perspective beame, that commeth through ye glasse, make the thinge to seeme bigger and bigger, untill such tyme, that the thinge shall seeme of a marvellous bignes: Whereby that these sortes of glasses shall much proffet them, that desyer to beholde those things that ys of great distance from them. … And allso standing further from the glasse yow shall discerne nothing

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[37] *Ibidem*, 33.

[38] *Ibidem*, 33.

> thorowe the glasse: But like a myst, or water: And at that distance ys the burninge beame, when that yow do holde yt so that the sunne beames doth pearce thorowe yt. And allso yf that yow do stande further from the glasse, and beholde any thinge thorowe the glasse, Then you shall see yt reversed and turned the contrary way, as before ys declared.[39]

The knowledge of these optical components did not give Bourne a blueprint for a telescope, but given the magnifying properties of concave mirrors and convex lenses, he was convinced that the effect would be additive if a concave mirror and a convex lens were combined.

> And so reseaved from one glasse into another, beeyinge so placed at such a distance, that every glasse dothe make his largest beame. And so yt ys possible that yt may bee helpped and furdered the one glass with the other, as the concave lookinge glasse with the other grounde and polysshed glasse. That yt ys likely yt ys true to see a small thinge, of very greate distance.[40]

Bourne's knowledge of the imaging properties of concave mirrors and convex lenses informed his telescope design. He was first of all explicit about the distance between the convex lens and the concave mirror, arguing that they should be placed so 'that every glasse doth make his largest beame.' Since the image of a single optical component (a concave mirror or a convex lens) was largest at the location of the 'perspective beame,' and since this point was near the point of combustion, the distance between the convex lens and the concave mirror was determined by the focal planes of the mirror and the lens. Secondly, Bourne's optical knowledge about the locus of a maximally magnified image was the basis of his selection of a large diameter lens. As we have seen, Bourne knew that the magnified image fills the complete surface of the lens when the eye is placed at the point of combustion or point of inversion. It is then reasonable to consider magnification dependent upon the diameter of the lens, instead of upon its focal length, and to search out the largest possible diameter. 'The broader the better' was indeed Bourne's advice for the diameter of the lens.[41]

Not only were the demands posed on the quality of a mirror for a telescope much higher than that of a lens, Bourne's concept of magnification posed a

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[39] *Ibidem*, 33.

[40] *Ibidem*, 34.

[41] Bourne, *Inventions or Devices* (1578), 96.

Ill. 3. Objective lens and aperture stop of Galileo's telescope II. The uneven boundary of the lens is clearly visible. (Museum of the History of Science, Florence).

peculiar problem for craftsmen. This concept made a lens of a large diameter an essential characteristic of his telescope design, and contemporary lens-makers experienced problems with making lenses of such large diameters. When Bourne wrote his letter to Burghley, England still depended upon import from the Continent for its supply of mirrors and lenses.[42] During the reign of Elizabeth I, Venetian *cristallo* mirrors were imported in increasing numbers from Venice, Antwerp and Rouen.[43] Around 1570 imported flat mirrors came in standard sizes, the largest not exceeding 20-25 centimeters. Likewise, spectacle-lenses (of a typical diameter of *c.* 3 centimeters) were imported in large numbers from spectacle-making centres in Germany, Normandy, and Flanders.[44] Thus, the size for the lens mentioned by Bourne – 30 to 40 centimeters – did not fall within the standard range. Moreover, this problem was not peculiar to Elizabethan England. If Bourne had suggested this design in Middelburg, we can be certain that he would have encountered the same problems. To obtain the optical quality desirable for telescope lenses pieces of mirror glass were used in the early seventeenth century.[45] But even more importantly,

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[42] A network of people and goods of cristallo glass, linking Italy (Venice), Antwerp, Middelburg and London, was created during the second half of the sixteenth century. For a recent overview of this network, see Veeckman *et al.*, *Majolica and Glass* (2002).

[43] Godfrey, *English Glassmakin*g (1975), 235-241. On how these changes in mirror-making practices influenced English literature, see Kalas, 'The Technology of Reflection' (2002).

[44] Godfrey, *English Glassmaking* (1975), 241-243. On the import of spectacles and spectacle-makers from Flanders, see Rhodes, 'A Pair' (1982); Dreyfus, 'The Invention of Spectacles' (1988), 101; Stevenson, 'A New Type' (1995).

[45] Willach, 'Lens Grinding and Polishing Techniques' (2001), 14.

lenses were cut to a small diameter, still visible in the uneven border of early seventeenth-century telescope lenses, and then even further stopped down (see Figure 3).[46] Smaller diameters for the lenses were thus the way to go; Bourne's concept of magnification made him chose the opposite direction. The difficulty of translating practical knowledge into recipes, which could be satisfied by technology, was the reason why Bourne's invention did not circulate. That the Dutch telescope was made of two spectacle-lenses, which could be found in any spectacle-maker's shop was important to its success and its rapid dispersal over Europe.

Conclusion

It should be obvious from my argument that we should not attribute the invention of an 'Elizabethan telescope' to Bourne. The material constructions of Ronan and others in the 1990s belie the historical texts on which those reconstructions were based. But then, how does Bourne's 'invention' help us re-write the history of the invention of the telescope and of the events leading up to Middelburg in 1608? If it was not an 'Elizabethan telescope,' then what was it that Bourne invented? Was it a telescope? If circulation is important to invention, then Bourne failed to invent a telescope. His telescope design did not circulate beyond that one letter in which he requested Burghley's patronage for it – one among the many letters from projectors Burghley received. The material 'reconstructions' of the 1990s are also misleading in the sense that they wrongly suggest that Bourne's project moved beyond the stage of paper. If Bourne can be said to have invented something, this invention was a telescope design on paper on which he speculated that it would work.

However, Bourne's speculations were based on sound knowledge. I have shown that Bourne's telescope design was based on shared optical knowledge, however, expressed in Bourne's letter in idiosyncratic terminology because Bourne was not familiar with the optical tradition. Therefore, it is most likely that he himself did not realize that his optical knowledge was innovative with respect to the optical tradition. More importantly in this context, I have stressed that Bourne's knowledge was practical, but not material. Bourne's knowledge was different from craft knowledge on how to make lenses, mirrors or telescopes. Although the body of shared optical knowledge on which Bourne based his telescopic speculations was sound, it also contained one mistake that was crucial for Bourne's concept of magnification. As we have

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[46] *Ibidem*, 14-15. For the importance of the diaphragm, see Dupré, 'Galileo's Telescope' (2003).

seen, because of this, practical optical knowledge put Bourne on a track going exactly opposite to the one that he should have taken to succeed. Beyond the vagaries of patronage, that his telescope design was based on a wrong concept of magnification was a source of Bourne's failure. Bourne's invention also confirms, therefore, how essential the world of the craft of lens-making was to the events in Middelburg in 1608. Bourne's optical knowledge led to failure because it imposed demands impossible to meet by craftsmen, whereas the Dutch telescope emerged from spectacle-maker's shops in which craftsmen could chose among available lenses to invent the Dutch telescope.

Alhacen and Kepler and the origins of modern lens-theory

A. Mark Smith

Introduction

It is pretty much axiomatic by now that, in his compendious, seven-part *Kitab al-Manazir*, or 'Book of Optics,' Ibn al-Haytham revolutionized the science of optics and, in the process, laid the foundations for modern theory. Just how iconic Ibn al-Haytham has become in the historiography of optics is evident from this brief excerpt cobbled together from the current biographical sketch in Wikipedia:

> Ibn al-Haytham is regarded as the 'father of modern optics' for his influential *Book of Optics*, which *correctly* explained and *proved* [my emphasis] the modern intromission theory of vision, and for his experiments on... lenses, mirrors, refraction, reflection, and the dispersion of light into its constituent colours... Considered the... originator of experimental science and experimental physics... Ibn al-Haytham... argued that rays of light are streams of corpuscular energy particles travelling in straight lines. [He] discovered [Pierre de] Fermat's principle of least time... and [he]... discovered a result similar to [Willibrord] Snell's law of sines... [he also] laid the foundations for the later development of telescopic astronomy, as well as for the microscope and the use of optical aids in Renaissance art.[1]

Granted, Wikipedia is not a definitive scholarly source, but this particular biographical sketch is telling in at least three ways. First it is based, however loosely, on the work of respected scholars such as A.I. Sabra, David Lindberg, and Roshdi Rashed. Second, it makes Ibn al-Haytham more than a mere transitional figure in the evolution of modern optics by stressing his anticipation of discoveries or ideas generally attributed to later Western figures, such as Johannes Kepler, Willibrord Snell, Galileo Galilei, Pierre de Fermat, Isaac Newton, and even Albert Einstein. And third, most of these claims to Ibn al-Haytham's modernity reflect various interpretations in reputable sources.

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[1] http://en.wikipedia.org/wiki/Ibn_al-Haytham.

Putting aside such specific, and controversial claims, the core assertion that Ibn al-Haytham fathered modern optics stands pretty much uncontested today. After all, in its medieval Latin form – as Alhacen's *De aspectibus* – the *Kitab al-Manazir* and its Perspectivist offshoots predominated in the scholastic analysis of light and sight from the late thirteenth to the early seventeenth century. As such, it was the authoritative source for optics during that period.[2]

Particularly important in the dissemination of this source was Witelo, whose analysis in the *Perspectiva* followed Alhacen's so closely that the *Perspectiva* amounts to little more than a redaction of the *De aspectibus*. So closely are the two tied, in fact, that Friedrich Risner saw fit to publish both in his *Opticae Thesaurus* of 1572.[3] Thus twinned in this edition, the two works were open to a far wider audience than had been reached by manuscript, an audience that included Johannes Kepler and others responsible for the transition from medieval to modern optics.

Moreover, in terms of theoretical structure, as well as empirical and mathematical rigor, Ibn al-Haytham's analysis of light and sight looks strikingly modern.[4] Granted, Ibn al-Haytham – or Alhacen, as I will henceforth refer to him in his Latin incarnation – made errors, but they were easily correctible using the conceptual and analytic tools already provided by him. In other words, the basic elements of modern optics were readily available in the *De aspectibus*; all Kepler and his immediate successors needed to do was to winkle them out, refine them when necessary, and combine them properly.[5]

I think it is safe to say that a proper understanding of refraction was central to the development of modern optics, and central to that understanding was a proper theory of lenses, the search for which became all the more urgent with

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[2] The core of the Perspectivist tradition consists of Roger Bacon's *De multiplicatione specierum* (*c.* 1262) and *Perspectiva* (*c.* 1267), Witelo's *Perspectiva* (*c.* 1275), and John Pecham's *Perspectiva communis* (*c.* 1280). For the standard account of the development of the Perspectivist tradition from the late thirteenth to the sixteenth century, see Lindberg, *Theories of Vision from Al-Kindi to Kepler* (1976).

[3] Risner, *Opticae Thesaurus* (1572). Friedrich Risner was responsible for popularizing the Latin form 'Alhazen' of Ibn al-Haytham's given name (al-Hasan), but that form occurs in none of the extant medieval manuscripts, the overwhelming majority of which give the rendering 'Alhacen'.

[4] A good example of the apparent modernity (and sophistication) of Alhacen's optical analysis can be found in his solution of 'Alhazen's Problem' in book 5 of the *De aspectibus*. For a recent account of that solution see Smith, 'Alhacen's Approach to 'Alhazen's Problem' (2008).

[5] See esp. Lindberg, *Theories of Vision*, 208, where he describes Kepler's theory of retinal imaging as follows: 'Kepler presented a new solution (but not a new kind of solution) to a medieval problem, defined some six hundred years earlier by Alhazen. By taking the medieval tradition seriously, by accepting its most basic assumptions but insisting upon more rigor and consistency than the medieval perspectivists themselves had been able to achieve, he was able to perfect it'.

the appearance and public dissemination of refracting telescopes in the early seventeenth century. I think it is also safe to say that Johannes Kepler took the first definitive Western step toward modern optics with his analysis of spherical lenses and their focal property in the fifth chapter of his *Ad Vitellionem Paralipomena*, or 'Emendations to Witelo,' of 1604.[6] As the title indicates, Kepler's primary source was Witelo's *Perspectiva*, which, as just pointed out, was a channel for Alhacen's optical analysis. According to the standard narrative, then, Kepler's account of spherical lenses and their focal property must have been heavily dependent upon Alhacen, presumably through his analysis of refraction in the seventh book of the *De aspectibus*. But how much did Kepler actually owe to Alhacen for his account of spherical lenses? Let us take a look, starting with a brief examination of Kepler's account.

Kepler on refraction through spherical lenses

The principles underlying Kepler's account are fairly few and relatively simple. First is that, when light passes at a slant from one transparent medium to another of different 'density,' from air to water, for instance, it inclines toward the normal dropped through the point of refraction when it enters the denser medium and away from the normal when it enters the rarer one. When it strikes the refractive interface along the normal itself, on the other hand, light passes straight through without refraction. Second is that the greater the density-differential between the two media, the more severely the ray of light will be refracted. Third, refraction is reciprocal, so that when a ray of light passes from air to water and back into air, the initial angle of incidence will be equal to the final angle of refraction. The fourth principle is that, as the angle of incidence approaches 0° the resulting angle of refraction approaches equality with it. Fifth and finally, refraction occurs in a single plane perpendicular to the refractive interface.

With these principles in mind, Kepler opens his analysis by demonstrating that light passing through a water-filled sphere undergoes spherical aberration. The gist of the demonstration, without the details of proof, is as follows.[7] Let the circle centred on Z in illustration 1 represent the water-filled sphere, and let axis LAZG be perpendicular to the sphere's surface at A and G. Let arcs AB,

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[6] Kepler, *Ad Vitellionem* (1604). All citations to this work will be from the recent English translation by Donahue, *Johannes Kepler*, *Optics* (2000).

[7] The analysis that follows is based primarily upon propositions 8-14 of chapter 5 of the *Paralipomena* in Donahue, *Kepler, Optics*, 196-205.

BC, and CD be equal at 30° each, and let LA, MB, NC, and OD be parallel rays forming angles of incidence of 0°, 30°, 60°, and 90°, respectively.

Angle ODX_2 of 90° is the outer limit of incidence, which means that, in order for the light actually to be refracted into the sphere rather than graze it along tangent OD, it must strike its surface at an angle less than ODX_2 by some infinitesimally small amount. This angle is so close to ODX_2 that for all practical purposes the two can be treated as equal. The inner limit of incidence will be at point A, where the light striking along normal LA passes straight through the sphere.

Now according to Witelo's tabulations for refraction from air to water, which are taken directly from book 5 of Ptolemy's *Optics*, light striking the sphere at an angle of 30° yields an angle of refraction of 22.5°, so angle ZBB' is 22.5°. On the basis of the same tabulations, angle of refraction ZCC' is 40.5°, and if we extrapolate from those same tabulations for angle of incidence ODX_2 = 90°, angle of refraction ZDD' is 54°.[8]

If we fill the space beyond the sphere with water so that the refracted rays pass straight through edge D'G of the sphere, the innermost ray refracted at B will strike the axis at E, the middle ray refracted at C will strike the axis above E at P, which in turn lies below Q, where the outermost ray refracted at D intersects the axis. If we then evacuate the space beyond the sphere and suspend it in air, then by the principle of reciprocity, ray BB' will refract away from the normal at angle E'B'X' equal to the original angle of incidence MBX (i.e. 30°), and it will intersect the axis at E'. Likewise, ray CC' will refract away from the normal at angle X_1'C'P' = angle X_1CN to reach the axis at P' above E', and by the same token ray OD will refract symmetrically at D and D' to reach Q' above P'. From this we can conclude that, the farther from point A the ray strikes the sphere's surface, the closer to point G on the back edge of the sphere it will strike the axis after the two refractions. We can also conclude that no ray will refract to any point between Q' and G, so Q' represents what Kepler calls the 'nearer boundary' (*terminus citerior*) of intersection.[9]

The 'farther boundary' (*finis ultimus*), on the other hand, will be, in Kepler's own words, 'not greatly distant from the cutting of the radiation that maintains

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[8] For Ptolemy's tabulations for refraction from air to water, see Smith, *Ptolemy's Theory of Visual Perception* (1996), 233. For Witelo's equivalent tabulations, see *Perspectiva*, 10, prop. 8, in Risner, *Opticae Thesaurus*, 412. The raw numbers given in the analysis, which come directly from Witelo, are actually adjusted slightly by Kepler according to his rule of refraction in chapter 4; see Donahue, *Kepler, Optics*, 110-129. The adjustments, however, are so slight that I have chosen to use Witelo's raw values for the sake of clarity and convenience.

[9] Donahue, *Kepler, Optics*, 207.

an obliquity of 10°.’[10] In other words, if ray KH in illustration 2 strikes the sphere at an angle of 10° and eventually refracts at H' to F' on the axis, then the closest possible ray to LA will refract to some point F beyond F'' on the axis. F is thus the outermost point at which the incoming light can reach the axis after refraction through the sphere. This point, Kepler reasons, lies only slightly beyond F' and, again in his own words, ‘is distant by little more than the radius of the sphere, no farther.’[11] So F is the focal point of the sphere, and, although Kepler has failed to pinpoint it exactly, he has come extraordinarily close.[12] According to this model, then, the light effectively focused by the sphere is limited to the narrow shaft defined by the rays from K and K' striking an arc of 20° on the sphere’s surface, and all the light entering the sphere will be refracted to line-segment Q'F. Kepler has a great deal more to say about this model and its implications, particularly with regard to retinal focusing, but time does not permit us to delve any deeper into his discussion at this point.

Alhacen’s refraction-analysis in the ‘de aspectibus’

let us now turn to Alhacen’s analysis of refraction, which unfolds over the seven chapters comprising the seventh and final book of the *De aspectibus*. Anyone expecting to find in that analysis a clear harbinger of the account of spherical lenses offered by Kepler in the *Ad Vitellionem Paralipomena* is bound to be disappointed. What he will find, instead, is a systematic effort on Alhacen’s part to establish the fundamental principles of refraction experimentally and, on that basis, to explain how atmospheric refraction affects our observation of

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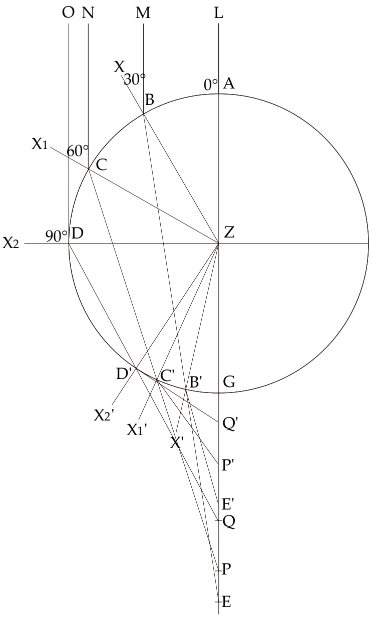
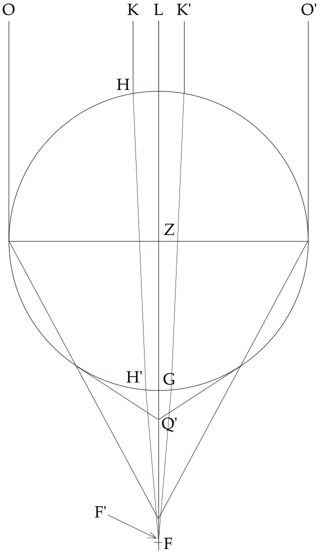
[10] *Ibidem*, 205.

[11] *Ibidem*, 207. Kepler’s conclusion here is based on the assumption that, when light-ray KH in figure 2 is incident at an angle of 10°, the resulting angle of refraction will be 7° 45’ (according to Witelo, who unaccountably changes it from the 8° given by Ptolemy), which will leave GF’ slightly longer than radius ZG of the sphere. Accordingly, since all the neighboring rays between KH and the axis will intersect the axis at points very near F', distance FG between the edge of the sphere and the very last possible intersection F cannot be much more than the radius of the sphere; see esp. Donahue, *Kepler, Optics*, 204-206.

[12] According to the modern thick lens formula, the focal length f of a water-filled sphere of radius r is contingent on the index of refraction n and is found according to the equation $1/f = (n - 1)[2/r - 2r(n - 1)/nr^2]$. If we assume an index of refraction for water of $n = 1.33$ and insert that value in the equation, we end up with $1/f = 1/2r$, so $f = 2r$, which is the distance of the focal point from the centre of curvature. Hence the distance of the focal point from the back edge of the sphere is precisely one radius. In fact, since part of the refraction measured by Kepler is through the glass wall of the flask containing the water, f will be slightly less than one radius, the amount of divergence dependent on the thickness of the glass wall.



Ill. 1



Ill. 2

the apparent position and size of celestial bodies.[13] For that reason he does deal with refraction through convex spherical interfaces because the boundary between the heavens and the denser atmosphere below takes that form. He also deals generally, and qualitatively, with the apparent magnification or diminution of objects seen through convex spherical interfaces. Nowhere, however, does he attempt to quantify the resulting magnification or diminution, and nowhere do focal points enter his analysis, either explicitly or implicitly. In short, nothing in his refraction-analysis in book 7 of the *De aspectibus* has an evident bearing on lenses and their workings. I say 'evident bearing' because,

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[13] The topical organization of book 7 is as follows: chapter one gives a brief outline of the agenda for the book; chapter two describes how to confirm the basic rules of refraction experimentally on the basis of refraction from air to water, air to glass, glass to air, and glass to water; chapter three gives a method for determining the angles of refraction experimentally on the basis of the three media given in chapter two; chapters four and five deal with image-location in refraction when an object lies in a denser or a rarer medium than the centre of sight; chapter six explains how objects are seen through refractive interfaces and ends by showing that all vision occurs by means of refraction through the transparent tunics of the eye; and chapter seven starts with a general analysis of image-distortion in refraction, the primary ones being image-dislocation and apparent magnification or diminution, and then culminates with an analysis of how these distortions can be caused by atmospheric refraction and how they affect celestial observation. Accordingly, almost all of book 7 constitutes a stage-setting for the second and final portion of chapter seven.

as Roshdi Rashed has shown, there are two propositions in book 7 that at least have *implications* for lens theory.[14] According to the numeration in my critical Latin edition of book 7, these are proposition 9 of chapter 5 and proposition 17 of chapter 7, which appear more or less verbatim in book 10, propositions 29 and 43 of Witelo's *Perspectiva*, Kepler's primary source.[15]

Before examining these propositions, though, I must add one more principle crucial to Alhacen's overall analysis of refraction: the so-called cathetus-rule of image-location. According to this rule, which is represented in illustration 3, the image of object-point B viewed by centre of sight A at a slant through a refractive interface is seen along extension RA' of refracted ray RA and is located at point I, where RA' intersects the cathetus of incidence BX dropped orthogonally from object-point B to the refractive interface. That said, let us turn to proposition 9 of chapter 5.[16]

According to the construction for this proposition, the circle centred on Z in illustration 4a represents a sphere filled with glass, which also occupies the space behind the sphere. Centre of sight A on axis AGZD lies in air. Point E on the convex arc facing A is the limiting point of refraction for a ray of light from point B, so angle BEZ is the largest angle of incidence at which B's light can pass through the refractive interface to reach A. It therefore follows that angle HEA of refraction must be infinitesimally smaller than 90°.

Now choose some point of refraction E' on arc EG. There will be some point B' on the axis such that the light from it striking E' will refract to A. This is tantamount to saying – which Alhacen in fact does not – that, given refracted ray E'A, there will be an appropriate incident ray that will trace back from E' to some point B' on the axis. There are innumerable such points of refraction on arc GE, so there are innumerable corresponding points on the axis whose light will refract from those points to A. Consequently, for every

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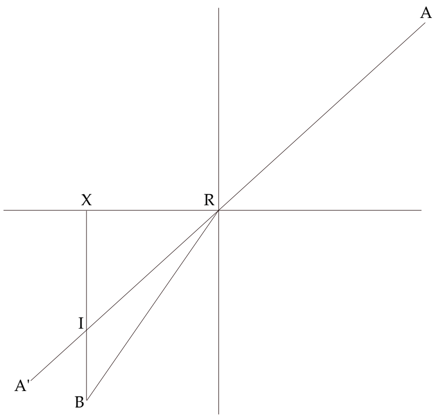
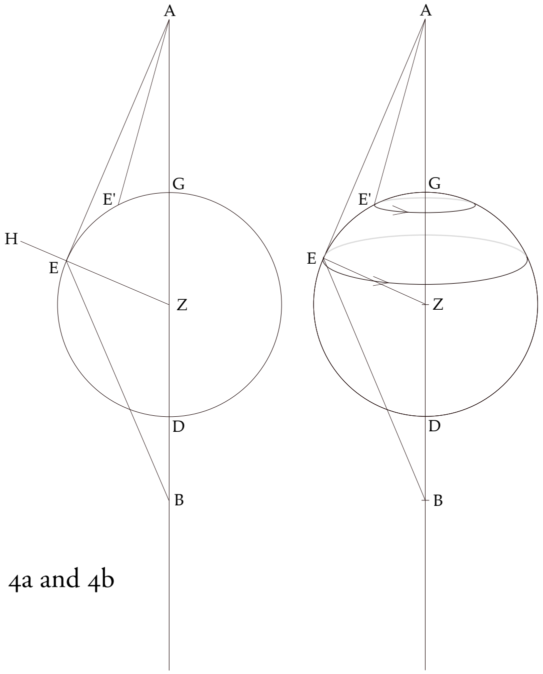
[14] Rashed, *Géométrie et dioptrique au Xe siecle* (1993); see pp. xlii-lx for Rashed's analysis of Alhacen and 84-132 for the original Arabic texts (with French translations) upon which that analysis is based.

[15] Since my critical edition of book 7 will not be published before mid-2010 at the earliest, I will rely on Risner's edition of the *De aspectibus* in the *Opticae Thesaurus* of 1572. This actually makes sense because Risner's edition was the source for Kepler's reading of both Alhacen and Witelo. The relevant propositions in that edition are 29 and 49 on pp. 262-263 and 277, respectively. Propositions 29 and 43 of Witelo's *Perspectiva* are to be found on pp. 430 and 440-441, respectively. The original text of book 7, in both Arabic and Latin, is segmented into chapters only, so Risner's imposition of propositional breaks is arbitrary, as is mine. Witelo, on the other hand, actually did segment his text into the propositional elements that Risner provides in his edition of the *Perspectiva*.

[16] That is, propositions 29 in Risner's edition of both book 7 of Alhacen's *De aspectibus* and book 10 of Witelo's *Perspectiva*.



Ill. 3



Ill. 4a and 4b

point between B and B' on the axis there will be a corresponding point on arc EE' at which the light from that point between B and B' will be refracted to A. If, therefore, BB' is taken as an object-line on the axis, the light from all the points on it will be refracted to centre of sight A from arc EE', and the image of each such point will lie where the cathetus of incidence, which is axis BGA, intersects the refracted ray. Since A lies on that axis, and since every refracted ray converges on A, centre of sight A will be the image-location for all those points, and in that case, Alhacen claims, they will all be seen by A on the refractive interface itself.[17] The image of object-line BB' will therefore be arc EE', and if we rotate the entire illustration about axis AZB, as in illustration 4b, the resulting image will form a ring defined by E and E' according to a full rotation.

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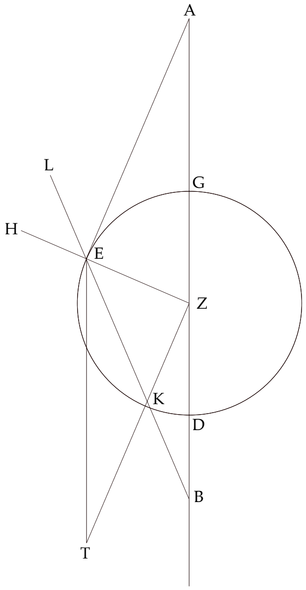
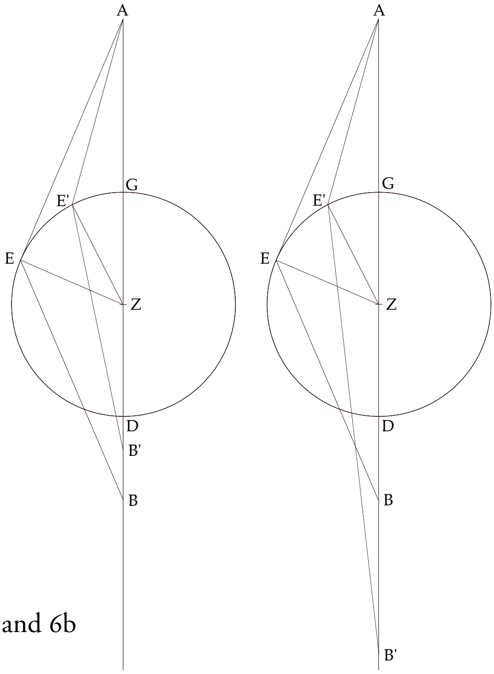
[17] In his analysis of reflection in book 5 of the *De aspectibus*, Alhacen claims that, when the image-location is indefinite—i.e., when it lies neither behind the mirror nor between the mirror and the centre of sight—it will appear as if it lay on the reflecting surface itself; see Smith, *Alhacen on the Principles of Reflection* (2006), 428. By analogy, then, since the image-location in this case is at the centre of sight, the image will appear to lie on the refracting surface.



Ill. 5



Ill. 6a and 6b

Before turning to the next theorem, I want to make one last point. Shown in illustration 5 is the actual diagram accompanying both the Arabic and Latin versions of proposition 9, and you will note that it gives only the limiting refraction-point E and point B of radiation. It does not show E' or B', so there is no indication of whether B' falls between B and G, as in illustration 6a, or whether it falls beyond B, as in illustration 6b. The import of this point will become clear in fairly short order.

Now to proposition 17 of chapter 7.[18] The stated purpose of this proposition is to show that, if centre of sight A in illustration 7a faces a sphere of glass suspended in air, and if axis ABZD is extended indefinitely through and beyond the sphere, there is a line-segment on the axis beyond D whose image will appear as a ring on the sphere's surface. Assume first that the space beyond the sphere is filled with glass. Let a ray of light from some point H on the axis reach point G at angle of incidence HGZ and be refracted to A at angle AGX. Then let a ray of light from some point L on the axis reach point T at angle of incidence LTZ and be refracted to A at angle ATY. That both these refractions

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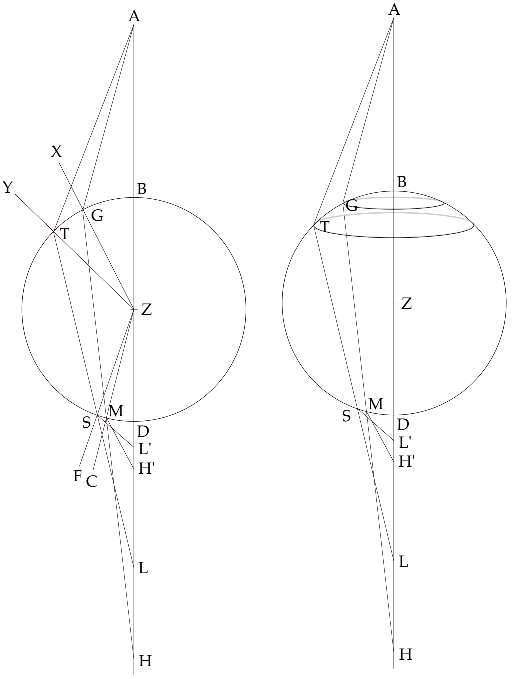
[18] That is, proposition 49 of Risner's 1572-edition of book 7 of Alhacen's *De aspectibus* and proposition 43 of his edition of book 10 of Witelo's *Perspectiva*.

are possible has been demonstrated in proposition 9 of chapter 5.

Now if we take A as a point of radiation instead of as a centre of sight, its light will follow paths AGH and ATL to points H and L, respectively. With A still taken as a point of radiation, let us evacuate the space beyond the sphere so as to suspend it in air. By the principle of reciprocity, ray TS will refract to L' on the axis at angle FSL' equal to the original angle of incidence ATY, and by the same token ray GM will refract to H' on the axis at angle CMH' equal to the original angle of incidence AGX. If we reverse the direction of radiation yet again, the light from H' will follow path H'MGA, and the light from L' will follow path L'STA. In addition, a ray of light from every other point on H'L' will be refracted at some point on arc SM and refracted again at some point on arc TG to reach A. Consequently, the light from the entire line-segment H'L' will be refracted to A from arc TG, and, from the perspective of A as a centre of sight, the image of H'L' will lie on arc TG itself. When we rotate the entire illustration about axis AZH, as in illustration 7b, points T and G will sweep out circles on the sphere's surface, T defining the outer perimeter and G the inner perimeter of a ring surrounding point B. Since arc TG is larger than object-line H'L' (insofar as its chord is larger), the image will appear magnified, and it will be distorted in shape according to the curvature of the surface on which it appears to lie. It will also be inverted because of the crossing of rays. Oddly enough, Alhacen never mentions this fact.

Comparison of Alhacen's and Kepler's analyses

That there are similarities between Alhacen's analysis of light-radiation through a glass sphere in proposition 17 of chapter 7 and Kepler's analysis of light-radiation through a water-filled sphere in chapter 5 of the *Paralipomena* is obvious, especially when point A in illustration 7a is taken as a point of radiation rather than as a centre of sight. These similarities become even more obvious if we add the limiting-point E of refraction from chapter 5, proposition 9, and trace the refraction of outermost ray AE in illustration 8 through the sphere to its intersection with the axis at Q'. Q' is thus the nearer boundary for refraction from A, and it lies higher than L', where the middle ray intersects the axis. L' in turn lies higher than H', where the innermost ray intersects the axis. Implicit in this analysis, therefore, is Kepler's conclusion – which is admittedly based on parallel radiation through a water-filled sphere rather than oblique radiation through a glass sphere – that the farther from axis AB the ray emanating from point A strikes the sphere's surface, the closer to point D on the back edge of the sphere it will strike the axis after refraction through the sphere. From this, it seems eminently reasonable to conclude that Alhacen's



Ill.7a and 7b

analysis in proposition 17 played an instrumental role in the development of modern lens-theory by pointing Kepler in the right direction. This conclusion is bolstered by the fact that, in the course of his analysis of lenticular focusing, Kepler actually cites proposition 17, as mediated by Witelo, and he does so with a proper understanding of its implications.[19]

There are, however, two significant factors that militate against this conclusion. For a start, proposition 17 is not really about radiation from point A through a sphere. Granted, Alhacen uses such radiation as an analytic device, but the explicit purpose of the proposition is to explain how and why line H'L' in illustration 7b forms an annular image on the sphere's surface. Alhacen in fact emphasizes this topical focus by suggesting an empirical verification of the geometrical analysis in the proposition. Posing one eye in front of a moderately large sphere of clear glass or crystal, the reader is to take a ball of black wax the size of a chick pea, stick it firmly on the point of a long needle, and then position it directly behind the sphere in line with the axis passing from the eye through the sphere's centre. If he places the ball of wax properly on the axial line, Alhacen concludes, he will see its image as a black ring on the

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[19] Donahue, *Kepler, Optics*, 202.

sphere's surface.[20] Given the ostensible point of proposition 17, therefore, the implications for lens-theory are fairly deeply buried within it.

A second, and far more significant factor, is the way the proposition is presented diagrammatically in the Latin text. So far our discussion of proposition 17 has been based on the illustration from the Arabic text, which is given in illustration 9 in slightly modified form.[21] Note that rays TSL and GMH refracted through a continuous glass medium cross, as they should, and so do rays SL' and MH' refracted out of the glass sphere into air. This illustration, in short, takes into account the spherical aberration of rays AG and AT after they pass into and through the sphere.

Now let us look at the illustration as it appears in the Latin version of the proposition. Illustration 10, with modern lettering adapted to the previous illustration, is traced directly from a manuscript of the *De aspectibus* held at Corpus Christi College, Oxford.[22] Unlike its Arabic counterpart, this version of the illustration has neither TSL and GMH, nor SL' and MH' crossing, so the radiative model implicit in the illustration is as follows according to illustration 11. First, let us add the case of E, the limiting point of refraction, and assume that the space behind the sphere is filled with glass. Let the light from A refract at E and pass straight through X to Q. Then let it refract at T to pass through S to L and refract at G to pass through M to H. When the sphere is suspended in air, the outermost ray EX will refract symmetrically to Q' on the axis, the middle ray TS to L' just above Q', and the innermost ray GM to H' above L'. According to this model, therefore, point Q', where the outermost ray meets the axis after refraction, represents the *farther* rather than the nearer boundary of intersection.

Clearly, this analysis and the illustration in the Latin version that results from it are erroneous, and I strongly suspect that the error stems from the Latin translator's having assumed incorrectly that point B' in proposition 9 of chapter 5 lies between B and D, as in illustration 6a, rather than beyond B, as appropriately represented in illustration 6b. I also suspect that the error might have been avoided had Alhacen mentioned the inversion of the image of H'L' in proposition 17. But he did not, and as a consequence, whatever implications the proposition may have with regard to spherical aberration are thoroughly masked by the misrepresented illustration.

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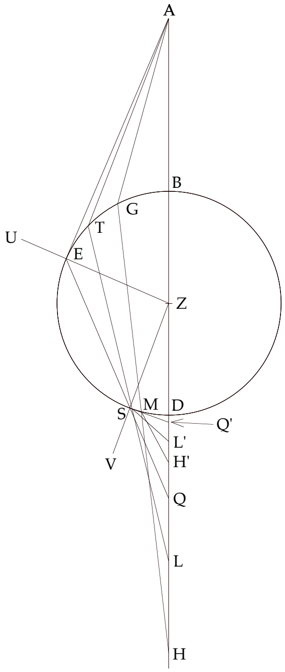
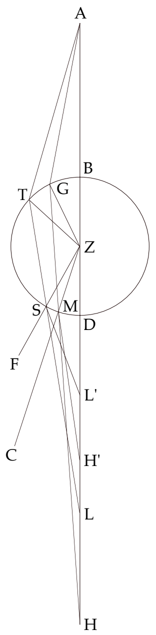
[20] See the end of proposition 43 in Risner, *Opticae Thesaurus* (1572), 277. Witelo describes the same empirical confirmation at the end of proposition 43 in *Ibidem*, 441.

[21] For the original from which illustration 9 was drawn, see Rashed, *Géométrie* (1993), 106.

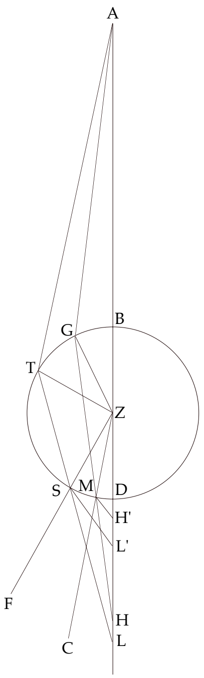
[22] Ms CCC 150, folio 109r.



Ill. 8



Ill. 9



Ill.10

Nor is this an isolated case; every manuscript of the *De aspectibus* that has this illustration –and not all of them do – has it in the form represented in illustration 10. Furthermore, and more to the point, Witelo recapitulated the illustration in that form to illustrate his version of proposition 17 in book 10, proposition 43 of the *Perspectiva*, and Friedrich Risner used the same faulty diagram for the two propositions in his 1572 tandem edition of Alhacen's *De aspectibus* and Witelo's *Perspectiva*. Small wonder, then, that in failing to grasp the underlying implications of the proposition, Alhacen's immediate Perspectivist disciples all mistakenly supposed that light radiating from a single point through a sphere will converge at a single point on the other side. Illustration 12, for instance, shows how John Pecham represents the situation in part 3, proposition 16, of his *Perspectiva communis*, X representing the point-source of radiation and H the convergence of the rays on the other side.[23] This supposition remained commonplace throughout the Middle Ages and Renaissance.

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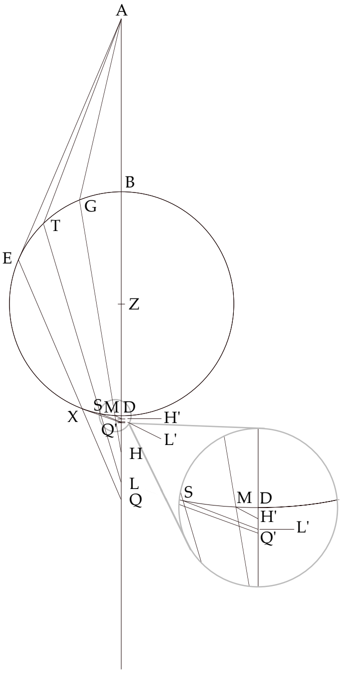
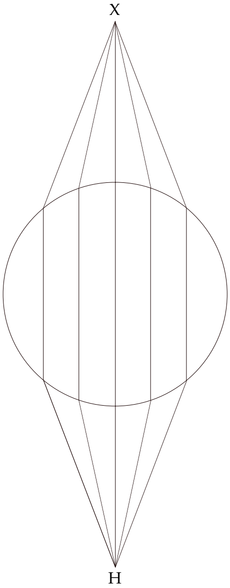
[23] Lindberg, *John Pecham and the Science of Optics* (1970), 231.



Ill. 11



Ill. 12

Kepler's analysis in proper context

So how was it that, unlike all the Perspectivists before him, Kepler managed to grasp the true implications of the proposition despite its being so badly misrepresented in the accompanying diagram? Was it simply because he was more intelligent and insightful? Perhaps so, but I think a likelier explanation can be found in his methodology of theoretical and empirical ray-tracing. We have already seen an example of what I call theoretical ray-tracing in Kepler's use of Ptolemy's values of refraction from air to water – as mediated by Witelo – to demonstrate spherical aberration mathematically.[24] For empirical ray-tracing Kepler used a water-filled flask with a spherical base, through which he allowed sunlight to

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[24] That is, in the earlier analysis based on illustrations 1 and 2. Interestingly enough, the procedure Kepler follows in that analysis is almost identical to the procedure that Giambattista della Porta follows in book 2 of his *De refractione* (1593), yet Kepler claims that, despite his best efforts to obtain a copy of this work, he was unable to do so (see Donahue, *Kepler Optics* (2000), 216). On the other hand, Kepler makes copious references to book 17 of Porta's *Magia naturalis* (1589), where Porta discusses the refraction of light through glass lenses.

pass. Holding a piece of paper perpendicular to the axis on the opposite side of the flask and moving it to and fro, he saw that, when he held it against the flask, a circle of light rimmed by a bright ring was projected on the paper. Removing the paper to a distance of around one-tenth the radius, he noticed that the circle diminished considerably in size and that a small dot of light slightly brighter than the light surrounding it appeared at its centre.[25] Continually removing the paper farther from the flask, he noticed that the circle of light diminished in size ever more slowly while the central dot of light became ever brighter until, finally, all the light was consolidated on the central dot.[26] From these observations Kepler concluded that the bright ring surrounding the circle of light was produced at or near the intersection of neighbouring rays, beginning with the outermost rays and continuing on to the point at which those same rays intersect the axis to produce the central dot of light.

This is illustrated in illustration 13, where XMX' represents the back edge of the sphere. When the paper is drawn from position 1 to position 4, it passes successively through intersection-points a, b, and c, before reaching the intersection of outermost rays XY and X'Y'. The outer circle of light is thus created by the outer intersection points and the central dot by the internal intersection of rays XY and X'Y'. As the paper is withdrawn ever farther from the sphere through positions 5 and 6, the outer circle at intersection-points d and e diminishes in size while the central dot gets brighter, until at last the paper reaches point f at position 7, where the innermost radiation meets the axis. At this point, of course, the outer circle and the central dot coalesce, and if the light congregating at that spot comes from the sun, Kepler observes, it will generate enough heat to ignite gunpower floating in cold water.[27]

As a complement to Kepler's theoretical ray-tracing, such empirical ray-tracing would have served to verify the fact of spherical aberration while, at the same time, offering a way of physically measuring the distance from the edge of the sphere to the point at which the light is fully concentrated. It also offers a way of confirming that the light congregating at or near the focal point is limited to the narrow shaft striking the sphere within an arc of around 20°

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[25] Note Kepler's specification of the actual distance at which the central dot of light first appears: one-tenth the radius ('the twentieth part of the diameter'); see Donahue, *Kepler, Optics*, 210. This of course indicates that Kepler was not only observing the phenomenon but also measuring it.

[26] This test with the water-filled flask is described in chapter 5, proposition 19, in Donahue, *Kepler, Optics*, 210-211.

[27] Illustration 13, illustrating the test with the water-filled flask, is based on the illustration given by Kepler to accompany proposition 19, and Kepler's claim that the congregated light generates enough heat to ignite gunpowder occurs at the end of that proposition; see Donahue, *Kepler Optics* (2000), 211.

centred on the axis. This can be done by blocking the incoming light with a board and boring apertures of various diameters in it until the optimal size has been reached. All of this suggests that, forearmed with a thorough understanding of spherical aberration, Kepler saw through the faulty diagram to the true implications of proposition 17 because he already knew what to expect. And even if that proposition *did* point Kepler in the right direction, it is a pretty vague signpost. It certainly did not point to the precise analytic path Kepler eventually followed.

This point becomes clear when we compare Kepler's analysis of parallel radiation through a glass sphere in chapter 5 of the *Paralipomena* to Alhacen's analysis of such radiation through a glass sphere in his *Treatise on the Burning Sphere*, which was unavailable in the Latin West and has only recently been edited in Arabic and translated into French by Roshdi Rashed.[28]

The gist of Alhacen's analysis is as follows. Let ALC in illustration 14 be a section of a glass sphere with D its centre of curvature and ADC an axis. Let EB be a ray of light parallel to axis ADC, and let it strike the sphere at angle of incidence EBH = 50°. Likewise, let E_1B_1 be a parallel ray of light striking the sphere at angle of incidence $E_1B_1H_1$ = 40°. Drawing upon Ptolemy's tabulations of refraction for air to glass, Alhacen concludes that angle DBK of refraction = 30° and that angle DB_1K of refraction = 20°, so rays BK and B_1K will intersect at K, leaving arc CK = 10°.

According to the principle of reciprocity, ray BK will be refracted out of the sphere at angle of refraction XKN = 50° = original angle of incidence EBH, and ray B_1K will be refracted at angle of refracted XKN_1 = 40° = original angle of incidence $E_1B_1H_1$. Therefore, ray BK incident to the sphere at a greater angle will be refracted out of the sphere to a point N on the axis closer to the sphere's edge than point N_1, where ray B_1K incident to the sphere at a smaller angle is ultimately refracted to the axis. By the same token, a parallel ray incident at any point O between B and L on the sphere will be refracted to some point on the axis nearer the sphere's back edge than N.

Now it can be demonstrated that, if a parallel ray strikes the sphere at a point as close as we please to point A, the ray along which it will be refracted out of the sphere to the axis will be shorter than the radius of the sphere by some amount, however small. Let V be the limiting point of intersection for a ray that strikes the sphere as close to A as possible, and let VC = radius CD on the assumption that the minimally refracted ray will be at least infinitesimally shorter than VC. Let VC be bisected at S so that SC = one half radius CD. It

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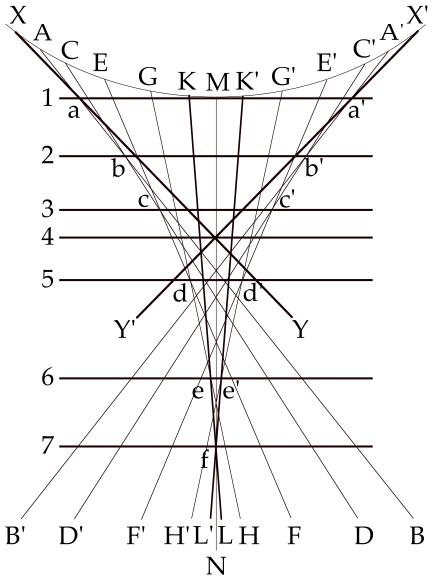
[28] See Rashed, *Géométrie* (1993), 111-132.

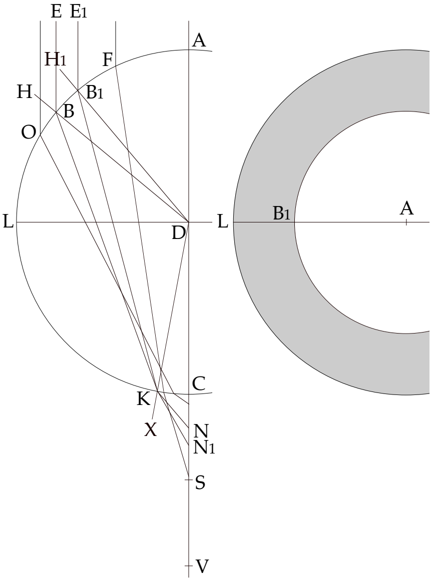


Ill. 13

therefore follows that all parallel radiation through the sphere will refract out of the sphere to points between V and C.

It can then be demonstrated that CN is less than one-fifth radius CD and, moreover, that CN_1 is considerably less than one-half radius CD, so both are less than CS. There are also parallel rays striking the sphere at points, such as F, between B_1 and A that will be refracted to points between N and S. But even if we consider only the parallel rays striking the sphere between B_1 and L, it follows that those rays outnumber the ones striking between B_1 and A. This is clear from the diagram on page 164, which represents a birds-eye view of the sphere from the perspective of point A. The grey ring is the cross-section of the area on the sphere struck by all the parallel rays between B_1 and L, and it is considerably larger in area than the cross-section between B_1 and A. Consequently, the radiation striking the sphere on its outer edge, which is the lion's share of the entire radiation striking the sphere's surface, will be refracted to points between S and C, so the focal area of the sphere will lie between S and C, i.e., within half a radius of the sphere, because that is where most of the radiation congregates.

At first glance, the similarities between this analysis and Kepler's analysis of parallel radiation through a water-filled sphere are striking. Both are based in one way or another upon theoretical ray-tracing, which in turn is based on Ptolemy's tabulations. Both invoke the same refraction-principles, particularly the principle of reciprocity. And both depend on spherical aberration. But



Ill. 14

the differences are equally, if not more, striking. For one thing, Kepler defines the focal area specifically according to the outer limit of intersection, whereas Alhacen defines it generally according to half the distance between that limit and the edge of the sphere. For another thing, Kepler has the outer limit of intersection pretty close to where it actually belongs, whereas Alhacen has it twice too far from its proper location.[29] For yet another thing, Kepler actually homes in on the focal area, isolating it to a small region near the outer limit of intersection, whereas Alhacen defines it vaguely, locating it somewhere within half the radius of the sphere. And perhaps most telling, Kepler concludes that the effectively focused radiation comes from a narrow shaft of incident rays surrounding the sphere's axis, whereas Alhacen has it coming from the outer edge of the sphere. Thus, although both Alhacen and Kepler shared precisely the same analytic principles and followed much the same line of reasoning, they reached radically different, in some ways diametrically opposed, conclusions about the focal property of their respective transparent spheres. Ironically enough, moreover, there is no indication whatever that Alhacen attempted to test his conclusions empirically; his approach, unlike Kepler's, therefore seems

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[29] If we take the index of refraction n for glass to be 1.5, then according to the thick lens formula given in note 12 above, $1/f = 2/3r$, so $f = 3/2r = 1.5r$, which means that the focal point lies precisely half a radius from the back edge of the sphere.

to have been entirely theoretical. The irony, of course, lies in Alhacen's being acknowledged by most current scholars as a consummate experimentalist.

Conclusion

Let me bring things to a close by raising the question I posed toward the beginning of this paper: How much did Kepler actually owe to Alhacen for his account of spherical lenses? The answer is 'not much.' True, Kepler may have learned the basic rules of refraction from Alhacen, but they had already been well established by Ptolemy, from whom Alhacen in fact got them. Likewise, the ray-analytic approach to optics Kepler may have learned from Alhacen originated not with Alhacen but with his Greek forebears, Ptolemy in particular. If, moreover, we descend to particulars, we find absolutely nothing in Alhacen's refraction-analysis in the *De aspectibus* to foreshadow Kepler's rigorous and sophisticated treatment of parallel rays of light refracted through a transparent sphere. At only one point in the entire *De aspectibus* – book 7, chapter 7, proposition 17 – does Alhacen actually deal with radiation through a transparent sphere, and in that case the implications for lens-theory are fairly deeply buried, even in the Arabic version with the correct accompanying illustration. In the Latin version, upon which Kepler and his scholastic predecessors depended, the illustration is so grossly misleading that those implications are buried almost beyond recovery.

In short, Kepler's analysis of spherical lenses and their focal property seems to have been more or less autonomous. This is not to say that Kepler owed nothing to Alhacen. For instance, Kepler may well have borrowed from Alhacen the technique of imagining the space behind the sphere filled with the same medium, following the light-rays through it to the axis, then imagining the sphere suspended in air, and following the same rays after refraction through the sphere. But the truly creative (one might say modern) elements of Kepler's analysis – the theoretical and empirical ray-tracing, the isolation of the narrow beam of incoming rays brought to effective focus, the virtual pinpointing of the focus itself – certainly did not come from Alhacen's refraction-analysis in the *De aspectibus*. If, therefore, Kepler's account of spherical lenses and their focal property marks the birth of modern lens-theory and, by extension, of modern optics, then surely Kepler, not Alhacen, has the legitimate claim to paternity.

Complete inventions: The mirror and the telescope

Eileen Reeves

Introduction

In November 1608, the Venetian friar and inveterate newsmonger Paolo Sarpi received two reports of splendid new optical devices. One account, the sober story of a discovery made by Hans Lipperhey, a god-fearing lens-maker resident in Middelburg, appeared as a stop-press item in a newsletter otherwise concerned with an ambassadorial visit to the United Provinces from Siam, and it is justifiably famous among historians of science today.[1] The second tale concerned a *speculum constellatum* or 'starry mirror' deployed in Paris by Father Pierre Coton (ill. 1), the influential confessor of Henri IV, to spy on rulers throughout Europe, and it was surely the least volatile allegation in a pamphlet devoted, in the main, to the feasting, dancing, drinking, carousing, cross-dressing, and weapon-hoarding members of two Jesuit houses in Austria. Eager to read all manner of news, and yet sceptical of most, Sarpi repeatedly expressed doubts about both reports of telescopic activities, replying to a number of correspondents that he himself had attempted something of the sort decades earlier, that he would have to see it to believe it, and that rumour tended to magnify things en route.

More crucially, from my viewpoint, Sarpi seems privately to have assumed that the two stories referred to the same object, and that the telescopic effect was due to some combination of a lens and a mirror. As I have argued elsewhere, he passed on such impressions to Galileo Galilei in the fall of 1608, and because Galileo, too, was familiar with lens-mirror combinations, they both attempted to obtain more information about the 'starry mirror' from Jacques Badovere, a former student then resident in Paris.[2] Pertinent details, or perhaps the Dutch instrument itself, arrived in the Veneto only in late spring of 1609 via a courier, and Galileo was able to present an improved version of

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[1] *Ambassades du Roy de Siam* (1608); Zoomers & Zuidervaart, *Embassies of the King of Siam* (2008).

[2] Reeves, *Galileo's Glassworks* (2008), 81-166.

the device to the Venetian Senate in August of that year. His grateful acknowledgement of Badovere's aid in March 1610 in the opening pages of the *Starry Messenger* was almost certainly designed to offset a pamphlet published two months earlier, where vicious Latin verses portrayed the Frenchman as the syphilitic confederate, spy, and creature of Father Pierre Coton.[3]

Legendary forerunners

The story of the recent invention from The Hague had a certain currency, for the news and various versions of the instrument itself were disseminated throughout the Netherlands, France, England, Spain, Germany, and Italy within months of the discovery. But the tale of the starry mirror hardly vanished, even or rather especially when no such device circulated along with it. The business about the mirrors was kept alive because of the cultural expectations it met, and those expectations are what I would like to address in this essay.

The shelf-life of the mirror as a progenitor of the telescope was a fairly short one: within several decades those doubtful about the novelty of the Dutch instrument usually referred to alleged precedents distinguished by their tubular shape. In 1627, for instance, the Flemish scholar Libert Froidmont described a corroded artefact of cylindrical contours that would seem to predate the instrument from The Hague: 'Lately in Hainault it is said that they found, among the old furnishings of a certain castle, a dioptrical tube, very rusty and of great age.'[4] Drawing on an ambiguous term for the telescope, *dioptricus tubus,* which meant perhaps nothing more than a cylinder through which one looked, Froidmont made no mention of the lenses, and his silence is typical. In 1632 in his *Dialogue concerning the Two Chief World Systems* Galileo mocked a certain man who had concluded, on the basis of Aristotle's suggestion that individuals peering through tubes or observing from the bottom of a cistern could see stars even by day, that the Dutch device derived from the ancient philosopher, and that vaporous air in the well served as the source for the 'invention of glass lenses.'[5] Two influential Jesuit scholars, writing in 1619 and 1640, alluded to an image in an illuminated manuscript in a Benedictine monastery in Bavaria showing an ancient astronomer pointing a cylinder of some sort at the heavens.[6] The device in question was a sighting tube, and as in the instances of the Flemish artefact and the Aristotelian cistern, the apparent

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[3] De l'Estoile, *Mémoires-Journaux*, 10 (1888), 120, 125-126.

[4] Froidmont, *Meteorologicorum* (1626), 112.

[5] Galilei, *Dialogo,* in: Galilei, *Opere*, 7 (1897), 135.

[6] Cysatus, *Mathemata* (1619), 76 and Borri, *Collecta* (1631), 135.

Ill. 1 Pierre Coton SJ (1564-1626). From: Alfred Hamy, *Galerie illustrée de la Compagnie de Jésus* (Paris 1893).

absence of the lenses could not be explained away to sceptical readers.[7]

Matters were otherwise for the telescopic mirror, which enjoyed less physical resemblance to the telescope, but a much more robust cultural pedigree. Tales of large concave mirrors, mounted in high seaside towers, available only to a political elite, and the guarantor of the bygone glory of the Roman Empire, emerged throughout Europe in numerous thirteenth- and fourteenth-century romances. The Roman motif itself seems to have been a response to an extremely popular late-twelfth century concoction, circulating in Latin and every European vernacular, in which Prester John, a mythical Christian ruler in the Far East in search of Western allies, claimed that he surveyed his fabulously wealthy empire with a polished mirror likewise placed in a high tower and guarded by political insiders. A third and roughly contemporaneous version of this story, involving the Pharos of Alexandria, alleged that a concave mirror once mounted above that lighthouse had been used to survey, and occasionally to set fire to, ships hours or even days from the Egyptian port. The

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[7] Eisler, 'The Polar Sighting Tube' (1949); Michel, 'Les tubes optiques' (1954) and Lewis, *Surveying Instruments* (2001), 36-108.

fact that this last legend, thoroughly familiar to readers of Arabic and Hebrew travel literature, made its way only very slowly into Latin and European vernacular accounts, gave it an unwarranted air of novelty and legitimacy when it emerged in the late sixteenth century, and those who promoted the combination of a lens and a mirror for telescopic vision often alluded to the Pharos of Alexandria, at times suggesting it had functioned as a *camera obscura*.[8]

Though the mirrors associated with Rome, with the undiscovered Eastern kingdom of Prester John, and with Alexandria predominated, writers occasionally referred to analogous surveying arrangements in other port cities such as La Coruña on the northwest coast of Spain, Ragusa or modern-day Dubrovnik, Goletta on the Gulf of Tunis, and of course the capital of the Byzantine Empire, Constantinople or modern-day Istanbul. Crucially, these sites were distant for most European readers, and the fabulous mirrors invariably busted or rusted ages earlier. Descriptions of telescopic devices had also made their way into philosophical, narrative, and dramatic works concerned with the Franciscan Roger Bacon, who had asserted that Julius Caesar had used some sort of glass lens to view Great Britain from Gaul, but who was eventually said to have possessed a mirror himself to see what others were doing anywhere in the world.

The impression that a mirror was involved in telescopic vision increased as glass lenses, and their limitations, became more familiar. Thus, for instance, in a letter of late 1606, an English correspondent of Giovanni Antonio Magini expressed interest in the large concave mirrors the latter was making, and then added 'our own Roger Bacon in his work on perspective reminds us that Julius Caesar placed a certain mirror on the shores of Gaul so that he might make out the endeavours and equipment of the English army.'[9] The same story turned up in 1611 in the *Mercure françois* as the coda to the tale of the telescope, under the rubric of rediscovered inventions of the past, even though the Dutch device was explicitly described there as composed of a tube and two glass lenses.[10]

Each whisper from Prester John

The two other legendary tales coloured contemporaneous accounts of the new invention. Whether or not we accept as genuine the letter purportedly written by Galileo concerning his presentation of the Dutch telescope to the Venetian

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[8] Reeves, *Galileo's Glassworks* (2008), 15-46.

[9] Favaro, *Carteggio Inedito* (1886), 320.

[10] Van Helden, *Invention of the Telescope* (1977), 46-47.

Ill. 2 Telescope, probably used by Archduke Albertus of Austria, governor of the Southern Netherlands, to observe a bird near his castle 'Mariemont' in Hanaut. Detail of a painting by Jan Brueghel the Elder, c. 1608-1611 [See page 17 for a full picture of the painting].

doge and to the most elderly members of the Senate from the highest towers of the city in August 1609 to observe ships at two hours' distance from the port, it seems safe to say that the familiar story of the Roman mirror – the icon of imperial ambitions, maritime power, and the prerogatives of an oligarchy – served as a template for this account.[11] Similarly, some readers of the newsletter that first mentioned the Dutch telescope, the *Ambassades du Roy de Siam*, must have wondered if the story from The Hague were a garbled version of the still current tale of the exotic Oriental potentate Prester John, as if Hans Lipperhey, more crafty than craftsman, had simply appropriated one of the gifts just then arriving from the Far East.

Consider in this connection Thomas Tomkis' *Albumazar,* a play of 1614, generally agreed to be a record of the first appearance of the Dutch telescope on the English stage. This is not to suggest that Tomkis himself, who had mentioned the perspective glass in a play of 1607, and who was in Paris in 1609 when the new invention became commercially available, actually believed either in an Eastern origin for the Dutch telescope, or in its incorporation of a

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[11] Galilei, *Opere*, 10 (1900), 253-254 and Favaro, 'Galileo Galilei e la presentazione' (1891).

mirror.[12] He referred several times in *Albumazar* to the refraction of the device, and to its deployment of a spectacle lens for a thirty-year-old viewer in combination with a 'refractive glass' lying nearby, presumably a concave and a convex glass lens.[13] His comic comparison of the instrument that brought the heavens nearer with the mace, a leaden club terminating in a star-like shape, further suggests that he recognized that these lenses would be housed within a cylinder of sorts. It is likely, in fact, that he was alluding to the leaden tube mentioned by Galileo in the *Starry Messenger,* as well as to the very cursory references to the 'science of refraction' and to a pair of plano-concave and plano-convex glass lenses, and to the depiction of Jupiter's satellites as asterisks in that text.[14] But when a charlatan in the employ of the fraudulent astrologer Albumazar, only very loosely based on the ninth-century personage Abu Maʿshar, describes a tube-like listening device closely modelled on Galileo's 'perspicill' or telescope, the air of novelty dissipates.[15] The telescope itself is compared to a tree trunk, as the sighting tube had been; more significantly, the hint of its Oriental provenance reemerges.[16]

The great *Albumazar* by wondrous Art,
In imitation of this Perspicill,
Hath fram'd an Instrument that multiplies
Objects of hearing, as this [spyglass] doth of seeing,
[So] that you may know each whisper from *Prester John*
Against the winde, as fresh as 'twere delivered
Through a trunke….[17]

In this reading, the new listening instrument, and perhaps the newish telescope from which it derives, is merely an amplification of an utterance originating long before with Prester John.

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[12] Tomkis, *Lingua* (1607), fol. B4; Trevor-Roper, *Europe's Physician* (2006), 145-146 and Casaubon, *Epistolae*, 339.
[13] Ilardi, *Renaissance Vision* (2007), 78-79, 91-92, 95, 100-102, 160, 224-229, 232.
[14] Tomkis, *Albumazar* (1615; ed. 1944), 80-81, 141-142, and Galilei, *Sidereus Nuncius*, 37.
[15] On the historical personage, see: David Pingree, 'Abu Maʿshar', in: *Dictionary of Scientific Biography*, 1 (2008), 32-39.
[16] Michel, 'Les tubes optiques' (1954), 178 and illustration 3.
[17] Tomkis, *Albumazar* (1615; ed. 1944), 82.

Linguistic inertia

The retrograde and somewhat misleading terminology associated with the telescopic mirror clearly offered a ready-made background for the Dutch device. A moment's reflection will suggest that such inaccurate nomenclature is current today: we refer to web pages, to scrolling down, to signing in, to logging out, and to blogging, despite the fact that none of these actions involves paper or pens, much less antique items like scrolls or logbooks. Our allusions to dial tones on digital phones, to carbon copies of electronic mail, to an engine's horsepower, to plasters rather than to bandages, or to torches rather than flashlights are similarly imprecise. Individual languages, of course, have varying tolerance for the neologisms that emergent technologies seemingly require, and regionalisms such as 'icebox' for 'refrigerator' account for some fraction of these retrograde terms. In general, however, we must assume that the invisibility or irrelevance of this linguistic inertia was characteristic of at least some of the early associations of the Dutch telescope with the mirror.

Consider a few such examples: the term *voires perspectifs* or 'perspective glasses' turns up in a Flemish inventory of 1599, and alludes to some sort of optical device which the Count Charles of Arembourg had bought for Archduke Albert and Isabelle, rulers of the Spanish Netherlands.[18] We would suppose, given the date, that this device differed in important ways from the Dutch telescope, and the same archive mentions payment to the silversmith Robert Staës for an *instrument artificiel pour voir loin,* in 1609, and subsequently for *deux buses servans pour voir loing* or 'two organ pipes for seeing far,' in 1610.[19] (Cf. ill. 2). This latter term is reminiscent of Galileo's own effort, in late 1609, to procure in Venice a *canna d'organo di stagno* or 'tin organ pipe' in order to make a new telescope, along with lenses of 'polished German glass.'[20] By 1614, when referring to a lens maker who had been at work for four years on telescopic instruments, the Flemish inventory referred to *canons à veoir loing,* roughly, 'cannon-shaped things for seeing far.'[21] This term was of some currency in correspondence of the period, though the fact that both organ pipes and cannons were slightly flared may have contributed to discrepant

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[18] Desplanque [*et al*], *Inventaire sommair*e, 5 (1885), 371.

[19] Desplanque [*et al*], *Inventaire sommaire*, 8 (1885), 379, and 6 (1885), 50. See about the Staës telescope also Zuidervaart, elsewhere in this volume, note 25.

[20] Galilei, *Opere*, 10 (1900), 270; on the date of the shopping list, see: Strano, 'La Lista della spesa di Galileo' (2009); on the German lens-making and mirror-making industry, see: Ilardi, *Renaissance Vision* (2005), 143-146, 184; on innovations among lens-makers in Nuremberg, see: Willach, *The Long Route* (2008), 70-84.

[21] Desplanque [*et al*], *Inventaire sommaire*, 6 (1885), 70.

impressions of the shape of the telescope.[22]

In this same decade and the next, the instrument of such great concern to us remained poorly differentiated from the 'prospective glass,' for that vague term was routinely adopted to designate the Dutch telescope. In one of the most interesting such instances, in the fall of 1613 English merchants gave, among a host of magnificent gifts, a 'prospective glass cast in silver gilt' made no later than 1611 to a Japanese ruler, the former shogun Ieyasu Tokugawa. When a lesser official from Nagasaki asked for 'a prospective glass' shortly afterwards, the English captain John Saris had to hunt around his fleet for an acceptable substitute, and gave the man 'an old one,' which the disappointed recipient soon returned 'with thankes, not desiring at all to haue it.'[23] The allusions to the age of the second glass, and to its evident inferiority, both suggest that the first gift was a Dutch telescope, and the second one, perhaps, an inadequate precursor of different design. Though more 'prospective glasses' sent from England arrived in Hirado via Bantam in September 1615, optical items such as mirrors and spectacles were singled out by William Eaton, owner of the rejected instrument, as either too fragile for such travel, or unappealing to potential consumers in Japan.[24] But as dissimilar as the two sorts of 'prospective glasses' were, they seemed not to have been distinguished by name.

THREE POST-TELESCOPIC TEXTS

Lost Bargains at the Frankfurt Fair

I'd like to turn to three early modern texts concerning the telescope in order to examine the information they offer, whether accurate or misleading, about the new invention. Consider, first, that offered in 1625 by the Protestant jurist Jakob Bornitz in a treatise on the different forms of trade and industry practiced in European states. This rather sober work entails little in the way of biographical detail, but one does learn that Bornitz visited glassworks in Murano

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[22] On these terms see: Rosen, *The Naming* (1947), 72-73; Vatican Library, Fondo Urb. Lat. 1077, *Avvisi Manoscritti,* fol. 437r; Grillo, *Delle lettere*, 2 (1616), 305; Duplessis-Mornay, *Mémoires*, 11 (1824/5), 375, 431.

[23] Satow, *The Voyage of Captain John Saris* (1900), 91, 11, 159. On this and other exchanges, see: Screech, 'Pictures' (2005).

[24] See: Screech, 'Pictures' (2005), 68, and Farrington, *The English Factory*, 1 (1991), 534-535, 552; 2 (1991), 1291, 1364, 1370.

in 1600,[25] and more importantly, that he encountered a concave mirror of remarkable capabilities just two years later. Such information entirely overshadows Bornitz's cursory reference to the Dutch telescope and to Galileo, and comes in the course of the author's gesture to contemporaneous discussions of catoptrics.

> Giovanni Antonio Magini published Ettore Ausonio's *Theoretical Discussion of the Concave Mirror,* in which the marvellous effects of reflection appear:
>
> For first of all, with the primary light of the sun the heat of the air is increased so that it burns both black and white objects, bakes bricks, and liquefies lead that has been moulded into plates. It reflects heat so that the difference between summer and winter can be detected, and projects letters on a distant wall so they can be read. Secondly, the secondary light offers various images: right-side up and inverted ones, big ones, small ones, and of these it shows both whole and partial images, the observer's own eye, and the images of one thing in two different places… Thirdly, in the darkness, [this mirror] paints a wall or a paper with a marvellous picture of whatever is outside, provided the sun is shining. And with candles or flares it allows one to see by night what they are doing in the enemy's camp, or to read letters at a distance in a dark place, and so forth. I saw this mirror myself, and the images on it in the darkness when the candle was brought near, at the Frankfurt Fair, in 1602; one could have it for the price of 20 000 thalers. Indeed in truth I can give surety about the mirror; thus far I am withholding information about its moulded shape. Nor will I add anything here about magic mirrors, composed of various metals and made under a particular constellation.[26]

Bornitz's observations about the various properties of the concave mirror are lifted from Magini's edition of Ausonio's treatise, which as Sven Dupré has shown, were also well known in manuscript form to Magini's rivals Galileo and Sarpi, and published for the first time in 1602.[27] A less specialized public would have seen much of the same information, albeit in more confused form, from 1589 in Giambattista della Porta's *Natural Magic,* the seventeenth book of which was devoted to mirrors and lenses. What is interesting to me is the assertion that the mirror showed up at the Frankfurt Fair alongside the theoretical work, and that it functioned both within a *camera obscura,* and as a means of projecting light to remote, but not especially distant places.

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[25] Bornitz, *Tractatus* (1625), 142.

[26] *Ibidem*, 168.

[27] Dupré, 'Mathematical Instruments' (2000) and Dupré, 'Ausonio's Mirrors' (2005), 145-180.

I doubt that such a mirror was actually on sale at the Fair in that year: letters from Adriaan van Roomen, a regular visitor to the Frankfurt Fair, suggest that he encountered the treatise, but not the mirror itself, whose shape he imagined to be parabolic rather than spherical. Magini's reply likewise refers to Van Roomen's acquaintance with the text, rather than with the object, and insists on the mirror's spherical shape. These exchanges, published in Magini's *Tabulae Primi Mobilis* of 1604, might have been known to Bornitz, whose suppression of the adjective 'spherical' in reference to the treatise is curious.[28] It is in any event worth noting that Magini did send at least two large concave mirrors there in 1609, and also sought to sell them in this period to Marie de Médicis, Queen of France, and to Archduke Albert, ruler of the Spanish Netherlands. The latter was approached by the Flemish nobleman Gaston Spinola, who recently was related by marriage to Count Charles of Arembourg. As we have seen, the Archduke had reimbursed Arembourg for 'perspective glasses' in 1599, and would pay the silversmith Robert Staës for a Dutch telescope in the spring of 1609, perhaps the one demonstrated to the papal nuncio Guido Bentivoglio, but he seemed to find the price of the mirrors 'swollen,' and turned down Spinola's offer.[29]

Bornitz's disclosure of the exorbitant cost of this item, coupled with his unwillingness or inability to offer more information about its shape, has a certain logic: the optical requirements for mirrors were much more stringent than for glass lenses; a mirror with a certain flaw distorted much more than a lens with an identical flaw. The perfectly formed mirror remained, in other words, an elusive ideal, out of the price range of even the wealthiest patrons, and never described in any detail.[30]

Moreover, while the mirror Ausonio, Magini, and Bornitz described had a sometime connection, especially in travel literature concerning the Lighthouse of Alexandria, with *specula constellata* or mirrors forged under a particular constellation, the cursory end to this passage strengthens this association, and suggests, somewhat misleadingly, that this particular setup had telescopic properties. Just this sort of conflation is, I would argue, what had driven Sarpi, Galileo, and Magini to imagine to imagine in the fall of 1608 that popular reports about 'certain glasses' in the Netherlands and about a 'starry mirror' in Paris referred to the same object.

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[28] Favaro, *Carteggio inedito* (1886), 248-250, 254-256, 438-440.

[29] Favaro, *Carteggio inedito* (1886), 449-450. On the Archduke's telescope, see: Sluiter, 'The Telescope before Galileo'; on the kinship of Spinola and the Count of Arembourg, see: Purnell, *Report on the Manuscripts of the Marquess of Downshire*, 2 (1937), 95-96.

[30] Watson, *Stargazer* (2004), 110-112.

Such connections were maintained, probably as a way of discrediting Paracelsians and Rosicrucians, in my second example, a squabble between alchemists around 1615. In an attack on Oswald Croll, the German scholar Andreas Libavius gestured toward the excessive claims of various scholars, among which were:

1. Making an instrument that allows a man to walk in the sea and underwater. Some Dutch peasants are said to be versed in this art, such that they light fire and sing beneath the surface…
2. Making a bridge beneath palisades and pilings.
3. Making marvellous mirrors; see Giambattista della Porta's *Catoptrics*.
4. Conjuring up by means of such mirrors a vast army, and reducing men to terror. This would be something to use against the Turks, if they are susceptible to terror…
5. [Making] other mirrors, in which very distant things seem near by. With this technique we can read the smallest letters, and see stars that are otherwise hidden, as through a Dutch telescope, by which means some people think they have seen the satellites of Jupiter, and spots in the sun. They can make other mirrors in which nearby objects seem remote. Julius Caesar was said to have seen events in Britain with enormous mirrors, if one can believe it.
6. [Making] other mirrors in which [an object's] quantity and location are altered.
7. [Making] mirrors to manifest things hidden in crevices or traps, as [Albertus Magnus] says Socrates did with the dragon…[31]

What is striking about this list, of course, is that it conflates a certain amount of medieval lore with very recent developments, and that it insists on the dubiety and on the relatedness of all such claims. It also suggests, with some degree of accuracy, that those who were the alleged inventors or potential consumers of one technological venture might well be connected with another one. Consider in this connection the reference to the 'Dutch peasants' and their alleged underwater activity. The allusion appears to be to Anabaptists, some of whom were associated with Paracelsians and Rosicrucians, but Libavius was thinking especially of the Dutchman Cornelis Drebbel, an Anabaptist magus

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[31] Libavius, *Syntagmatis* (1615), 58. On Libavius' intellectual mission, see: Trevor-Roper, *Europe's Physician* (2006), 85-92, 129-130 and Moran, *Andreas Libavius* (2007); for the quarrel with Croll, see: especially 215-223, 239-242.

then resident at the English court. Drebbel was known in later years for his rustic appearance, his invention of an underwater apparatus, and his interest in both the *camera obscura* and the telescope. It is thus noteworthy that when the Dutch poet Pieter Corneliszoon Hooft was asked, in early 1608, about something that allowed men 'not closed up in any device or ship to move about underwater and stay there a long time,' that his interlocutor was Jacques Badovere, linked just a year later in the popular imagination to the *speculum constellatum* or 'starry mirror' of Pierre Coton, and in the actual transmission of information regarding the Dutch telescope to Galileo.[32]

That Libavius knew of Jupiter's satellites and of the sunspots, but somehow believed that the device that had made them visible actually involved a mirror is not entirely evident to me. It is significant, however, that when next he mocked the *speculum constellatum,* he associated it with Spanish chivalric romances concerning the later adventures of Amadis of Gaul, where the hero scrutinizes the whole world from the so-called 'Tower of the Universe,' and where pairs of enchanted lovers see each other from great distances through the use of mirrors. Libavius contrasted the claims made in these popular works – books so ridiculous that they were the very first to be heaved onto the celebrated bonfire in *Don Quixote* – with items that he found only slightly more plausible.[33] These were legendary armour made two centuries earlier in Nuremberg – incidentally, just at the point, as Rolf Willach has shown, when other artisans in that city began to improve their convex lenses – and a defensive device that sounds something like the telescope.[34]

> In these mirrors of various virtues I would see everything in the cosmos more certainly than if I were in the Tower of the Universe with Amadis of Gaul… And were I to ask about its composition, I would be told that it was made of minerals of all the planets under a certain constellation, and that it can put the enemy to flight far more powerfully than can the armour of the Achillean burgrave [Albert III, Elector of Brandenberg, 1414-1486] and the starry tube [*fistula constellata*].[35]

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[32] On Drebbel's rustic persona, see: Tierie, *Drebbel* (1932), 18, 27, 96 n. 3, n. 4; on his interest in optical devices see: Worp, Huygens, 'Constantijn Huygens. Fragment eener Autobiographie' (1897), 119, and Tierie, *Drebbel* (1932), 50, 52. For his tardy renown as inventor of the telescope, see: Van Helden, *Invention* (1977), 55, 58, 61, 62, 63, 64; for Badovere's letter see: Van Tricht, *Hooft. De briefwisseling*, 1 (1976), 91.

[33] The burning of these books is described in *Don Quixote* I, vi, published in 1605.

[34] Willach, *The Long Route* (2008), 70-84.

[35] Libavius, *Syntagmatis* (1615), 271.

There is a sort of contagion here: whatever Libavius knew about the Dutch telescope – and the reference to the tube and perhaps to another Nuremberg product suggest that he understood its most basic components – it is clear both that he associated it with the starry mirror, and that he saw the discoveries made with it and announced in publications such as the *Starry Messenger* and the *Letters on the Sunspots* as only slightly more believable than the lore surrounding the latter device.

See what you lack

As one might expect, such associations, and the willingness to exploit the comic possibilities they offered, were even stronger in the first months after the invention of the telescope. In this connection I'd like to turn to my final example, *The Entertainment at Britain's Burse,* a court masque by Ben Jonson, which dates to April 1609, but remained undiscovered until 1997, when it turned up in the papers of Sir Edward Conway, who had been the English lieutenant governor of the cautionary town of Den Briel in the Netherlands, and an onlooker of the events in The Hague in the fall of 1608.[36] The *Entertainment* was designed to celebrate the opening of the New Exchange in London, and the overall conceit – the glories of consumerism – was imposed on Jonson by Robert Cecil, 1st Earl of Salisbury. Not coincidentally, Robert was the son of William Cecil, the powerful statesman whom William Bourne had approached, not very successfully, a generation earlier about the combination of a very large convex lens and a sizeable concave mirror, promising that that an observer so equipped would read a letter at a quarter of a mile away, and recognize a particular individual from a mile.[37] Robert Cecil appears to have shared his father's interest in optical devices, and these items are well represented in the *Entertainment at Britain's Burse.* Because Dutch telescopes also became commercially available in another brand-new shopping venue, the Pont Marchand in Paris, in April 1609, one might well expect to encounter them here.[38]

The initial plan of the masque, described in a letter of 10 April 1609, was to move from a comic interlude featuring a mountebank in beard and visor, his assistant, and their trashy wares to a tasteful display of a few valuable goods,

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[36] Knowles, 'Jonson's *Entertainment*' (1999) and Ioppolo, *Dramatists* (2006), 159-169. On Conway's participation at The Hague see: Shaw, *Report on the Manuscripts of Lord de l'Isle and Dudley,* 4 (1942), 71.

[37] Van Helden, *Invention of the Telescope* (1977), 14-17, 29-31 and Dupré, 'Making of Practical Optics' (2009).

[38] Van Helden, *Invention of the Telescope* (1977), 44.

some of which were to be offered as gifts to Cecil himself, to the royal family, and to the court when the production ended and the merchants removed their disguises.[39] Cecil and Prince Henry would have been very suitable recipients of the Dutch telescope, and within the next few years both sought instruments superior to those made by the Dutchman Cornelis Drebbel, then resident at the English court. They were given such devices through the offices of William Trumbull, the English *chargé d'affaires* in Brussels. Trumbull's superior in Brussels, Sir Thomas Edmondes, seems to have taken up observational astronomy in connection with his visits to the Archduke Albert's castle in April 1609, and from 1610 through 1612 Trumbull himself appears to have relied on the Flemish nobleman Gaston Spinola, formerly the middleman in Magini's attempt to sell concave mirrors to the rulers of the Spanish Netherlands, to procure the lenses for Cecil and Prince Henry, and on the Italian-born Francesco Petrosani to grind them.[40] Trumbull was in London in April 1609, and an item in his correspondence suggests that he, like Sir Edward Conway, had access to a schematic overview of the masque, whether or not he actually saw the production.[41]

Here, then, is the shop-boy's opening gambit, meant to embody spectacular vulgarity:

> What do you lack? What is't you buy? Very fine China stuffs, of all kinds and qualities? China chains, China bracelets, China scarves, China fans, China girdles, China knives, China boxes, China cabinets, Caskets, Umbrellas, Sundials, Hourglasses, Looking glasses, Burning glasses, Concave glasses, Triangular glasses, Convex glasses, Crystal globes, Waxen pictures, Ostrich eggs, Birds of Paradise, Muscats, Indian mice, Indian rats, China dogs and China cats? … Beards of all ages, Visors, Spectacles! See what you lack![42]

Though the glassy items appear in the midst of merchandise from the Far East, they are neither explicitly associated with such wares, nor entirely differentiated from them. The emphasis upon objects that alter vision through reflection or refraction, the fact that the spiel ends with the crescendo of

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[39] Knowles, 'Jonson's *Entertainment*' (1999), 115-116.

[40] Purnell, *Report on the Manuscripts of the Marquess of Downshire*, 2 (1937), 88, 90, 97, 104, 106, 186, 228, 229, 239, and 3, 238, 268; for payment to Petrosani's wife or widow, see: Devon, *Issues of the Exchequer* (1836), 167.

[41] Purnell, *Report on the Manuscripts of the Marquess of Downshir*e, 2 (1937), 89.

[42] Knowles, 'Jonson's *Entertainment*' (1999), 134. In this and the following passage I have slightly modernized the spelling, and added punctuation.

'spectacles!' and the producer's reference to the entire masque as a 'spectacle' would have given new meaning to the hackneyed market cry, 'See what you lack!' Consider, then, the mountebank's display of his glassware:

> *[Mountebank]:* Here be Glasses, too, that I almost forgot… First, a triangular which laid thus, shows you all manner of colours by refraction, and instructs you in the true natural cause of your rainbow. A convex that diminishes forms… A concave that augments them… Then here's a spectacle, an excellent pair of multiplying eyes… But here's my jewel, my perspective. I will read you with this glass the distinction of any man's clothes ten, nay, twenty miles off, the colour of his horse, cut or long tail, the form of his beard, the shape of his face.
>
> *[Shop-boy]:* Nay, [only] if it be toward you.
>
> *[Mountebank]:* Your Majesty, if it be but half [i.e., in profile] I care not. Nay, I will tell by the moving of his lips what he speaks and in what language. If the sun shines anything strong, I will stand you in Covent Garden and decipher at Highgate the subtlest character you can make, as easily as here. But I am promised a glass shortly from a great master in the Catoptrics, that I shall stand with on the top of [Saint] Paul's when the new spire is built, and set fire on a ship twenty leagues at sea in what[soever] line I will by parabolical fiction.[43]

This passage, the messiest of the entire manuscript, was written by three different hands, and was subject to costly eleventh-hour revisions the night before the production took place.[44] It is notable for its random assortment of glasses and mirrors – a feature that may explain the mountebank's apparent confusion of convex and concave lenses – and for the comic and yet familiar extravagance of his claims. The prism or 'triangular glass' may well have come from the collection of Sir Walter Cope, who had lent just such an item to Thomas Harriot in this period, and whose *wunderkammer* might have been the source for other objects in the masque; the fact that Cope's prism, for all its novelty, was rather badly polished might justify its inclusion with the optical rubble the mountebank was trying to unload.[45] The 'prospective,' as it is presented here, rests on the usual assertions about deciphering subtle characters, whether alphabetical or moral, from a great distance. Whatever its physical configuration, it also

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[43] Knowles, 'Jonson's *Entertainment*' (1999), 137.

[44] Knowles, 'Jonson's *Entertainment*' (1999), 117-123 and Ioppolo, *Dramatists* (2006), 161-169.

[45] Gage, *Colour and Meaning* (1999), 132 and Knowles, 'Jonson's *Entertainment*' (1999), 116.

seems reminiscent of a *camera obscura,* as the precondition 'if the sun shines anything strong' would suggest. The audience would have certainly understood that most of what was reported about this instrument, like the patter about the burning mirror promised from the 'great master in Catoptrics' was hyperbole, and a 'parabolical' or parable-like fiction.

After this elaborate display of trash, the stage seems set, then, for the presentation of the genuine article, the Dutch telescope, to Prince Henry or to Cecil. It never happens. Either because the new invention, like the long-awaited burning mirror, simply could not be procured in time – a possibility raised by a worried reference to the short supply of the 'diverse toys whereupon conceits are ministered' just ten days before the performance – or because once it was available it seemed an insufficient improvement over the 'prospective,' the Dutch telescope simply does not figure among the three gifts. An automaton superior to the sort allegedly created by Jonson's 'antagonist at Elthan,' Cornelis Drebbel, is substituted instead.[46]

See what you lack, indeed. As frustrating as the absence of the Dutch invention is, it is also illuminating: just when the telescope is about to be differentiated from the exotic *chinoiseries* of Prester John, from the trumped-up sunlit 'perspective,' and from the vast concave mirrors that always elude even royal patrons, such important distinctions collapse. For all the court's interest in the brand new device, its failure to appear would have publicly reinforced, in those initial months, its popular connections with those legendary mirrors and lowly instruments whose logic of resemblance we can now barely discern.

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[46] Knowles, 'Jonson's *Entertainment*' (1999), 116.

Galileo and the telescope

Albert Van Helden

Introduction

If everything leading up to the invention of the telescope might be called its prehistory, its history begins when Hans Lipperhey set out from Middelburg, on 25 September 1608, to go to The Hague with his new spyglass. Between Count Maurits' observation of the church clock in Delft at the end of September of that year and Galileo's observations of the Moon a year later, spyglasses spread rapidly over Europe, and we may assume that a number of owners turned these gadgets to the heavens. Indeed, in the newsletter printed in The Hague in October the author reported that '... even the stars which ordinarily are invisible to our sight and our eyes, because of their smallness and the weakness of our sight, can be seen with this instrument.'[1] There were also attempts to improve the device, of which we have evidence from the papers of Thomas Harriot, who drew a likeness of the 5-day old Moon seen through a six-powered instrument on 2 August 1609, and from the introduction of Simon Marius' *Mundus Iovialis* of 1614.[2] But the first observations that produced publishable results were the Moon drawings made by Galileo late in 1609, and not until the beginning of 1610 did Galileo have instruments good enough to observe the planets. What followed was a period of celestial discovery that culminated in the first telescopic observations of sunspots – by Harriot in December 1610, followed by Johannes Fabricius, Christoph Scheiner, and Galileo in 1611. After the summer of 1611, no new discoveries were made, except for the observation of the Andromeda Galaxy by Simon Marius in 1612.[3] In this paper I want to examine why the Galilean telescope's potential for discovery was exhausted so quickly.

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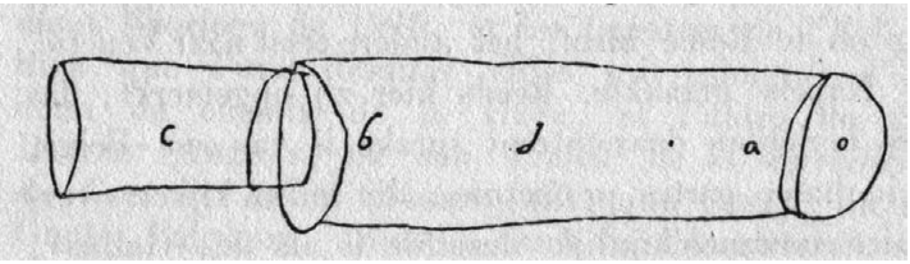
[1] *Ambassades* (1608), 10. See also: Zoomers & Zuidervaart, *Embassies* (2008), 37, 43, and 49.

[2] East Sussex Records Office, Harriot Papers, HMC241/9, p. 2b.; Marius, *Mundus Iovialis* (1614), first two unnumbered pages of the 'Praefatio ad candidem lectorem'. See also: Prickard, 'The "Mundus Jovialis" of Simon Marius' (1916), 370-371; Schlör (ed.), *Simon Marius Mundus Iovialis-Die Welt des Jupiter* (1988), 36-37.

[3] *Mundus Iovialis*, fifth unnumbered page of the 'Praefatio'; Schlör (ed.), *Marius – Die Welt des Jupiter* (1988), 45.

The earliest spyglasses

The first description of a spyglass to emerge during this first year is to be found in a letter from Giambaptista della Porta, the Neapolitan polymath, whose *Magia Naturalis* of 1589, well known all over Europe, contained a tantalizing hint at what might be accomplished by a combination of a convex and concave lens: 'With a concave you shall see small things afar off, very clearly; with a convex, things neerer to be greater, but more obscurely: if you know how to fit them both together, you shall see both things afar off, and things neer hand, both greater and clearly.'[4] In a letter to the founder of the Accademia dei Lincei, Prince Federico Cesi in Rome, dated 29 August 1609, Della Porta made a sketch (ill. 1) of an instrument that had just reached him, and he wrote:



Ill. 1. Sketch of a telescope made by Giambaptista della Port in a letter to Prince Federico Cesi (29 August 1609). Note the letter 'O' at the end, which in fact is very small diaphragm.

> About the secret of the spyglass [*occhiale*], I have seen it and it is a hoax [*coglionaria*], and taken from the ninth book of my *De refractione*.... It is a small tube of soldered silver, one palm in length, *ad*, and three fingerbreadths [*diti*] in diameter, which has a convex glass in the end, *a*. There is another tube of the same [material], 4 fingerbreadths long, which enters into the first one, and in the end *b* it has a concave [glass], which is secured like the first one. If observed with that first tube, faraway things are seen as if they were near, but because the vision does not occur along the perpendicular, they appear obscure and indistinct. When the other concave tube, which produces the opposite effect, is inserted, things will be seen clear and erect. And it goes in and

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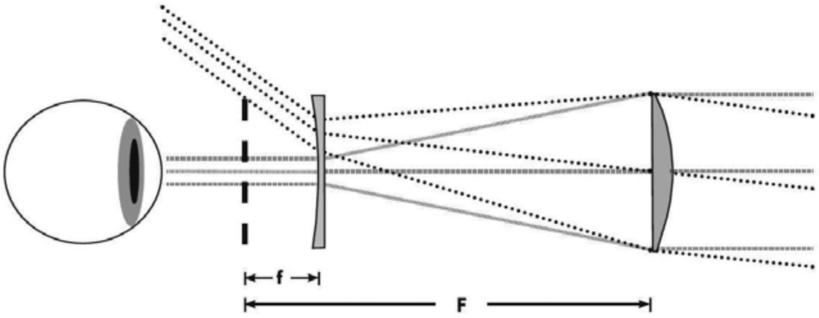
[4] Della Porta, *Magia Naturalis* (1589), book xvii, ch. 10. Cited from the first English edition, *Natural Magick* (1658), 368.



Ill. 2. Schematic diagram of a Dutch or Galilean telescope. F = focal distance of the Objective; f = focal distance of the ocular. Note that the exit pupil of the telescope (indicated by the vertical dotted line) is larger than the entrance pupil of the eye. Courtesy of Pope and Mosher (ref. 24).

out, as in a trombone,[5] so that it adjusts to the eyesight of [particular] observers, which all differ.[6]

With this information, we can reconstruct the optics of this instrument. A seventeenth-century Neapolitan palm is 26.4 cm, and thus the total length of the instrument is about 35.2 cm – for convenience, 36 cm.[7] If we assume a magnification of, say, 4, we know that: $L = F + f$, where L is the length of the spyglass, 36 cm, F is the focal length of the objective, and f is the focal length of the eyepiece, negative in this form of the instrument (ill. 2). Further, the magnification $M = |F/f| = 4$. Solving the equations, we find that $F = 48$ cm and $f = -12$ cm. Likewise, for $M = 3$, $F = 54$ cm and $f = -18$ cm. These illustrations are about what one would expect: focal lengths of 48 and 54 cm are around 2 diopters, which is close to the lowest strength of reading glasses at that time, and thus the weakest convex lens one would ordinarily find in

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[5] Della Porta is referring here to the short straight shank which served to lower the pitch in trumpets and trombones. See: Kurtzman and Koldau, '*Trombe, Trombe d'argento, trombe squarciate, tromboni,* and *pifferi* in Venetian Processions and Ceremonies of the Sixteenth and Seventeenth Century' (2002), sections 28.1-30.5, 41.3-41.4, and 45.1-45.2. On the early history of the slide trombone (*trombe a tiro*), see Grove & Sadie, *The Grove Dictionary of Music*, 19 (1980), 166-168.

[6] Giambaptista della Porta to Federico Cesi, in: Galilei, *Opere*, 10 (1900), 252.

[7] In 1609 Johannes Walchius described a spyglass 'a cubit' long – about 18 inches or 46 cm. in length – and 3 fingerbreadths in diameter (Walchius, *Decas fabularum humani* (1609), 249-250). It seems reasonable to assume that the spyglass described by della Porta is representative in length.

a spectacle-maker's shop.[8] They are also supported by the resulting aperture ratio, of about *f*/ 50, which became standard for 'Galilean' telescopes.[9] The spyglass seen by Della Porta, then, was made with off-the-shelf lenses, and if the invention of the telescope had simply been a matter of inserting a weak convex and strong concave lens in a tube, it would be hard to believe that no one prior to Lipperhey had taken that step. No wonder that Della Porta called the device a *coglionaria*.

Della Porta's sketch is not very accurate, and he clearly means *c*, not *d,* as the place of the eyepiece. We have to be careful, therefore, not to over-interpret it. With that reservation in mind, let us examine the front of the spyglass. From left to right, the letter sequence is *c b d a*, but the next letter, surely, is not an *o*. It is, in fact, the aperture itself of the spyglass, and if the sketch is drawn roughly to scale, its diameter is of the order of 1 cm. Such an aperture agrees well with Rolf Willach's conclusion that in the best convex spectacle lenses only the inner 1 cm of the lens was sufficiently accurately shaped to allow its use in a spyglass. And Willach's conclusion is further supported by depictions of spyglasses in the first half of the seventeenth century, some of which are included in this volume. This, then, gives us a good idea of the optical configuration of the first spyglass Galileo built in the summer of 1609.

Galileo's telescopes

There have been two questions about Galileo's first telescope: if his friend Paolo Sarpi received the The Hague newsletter by November 1608, why did Galileo not make his first spyglass until the middle of the summer of 1609; and how much information did Galileo have about the device before he made his own? The first question has recently been answered by Eileen Reeves, who argues convincingly that it was a combination of circumstances. First, those in Italy trying to make devices for seeing faraway things had put their hopes on a large mirror as the primary receptor. Large mirrors up to perhaps a meter in diameter were being made by Galileo's colleague, Giovanni Antonio Magini at the

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[8] Willach, *The Long Route to the Invention of the Telescope*, 70-84. Note that Thomas Harriot's 6-powered telescope with which he observed the Moon in August 1610 was perhaps a combination of $F = 60$ cm and $f = -10$ cm, lenses that may just have been available in a spectacle-maker's shop. See Harriot MSS, HMC 241/9, fol. 2b. See about Harriot's telescope also: North, 'Thomas Harriot and the first telescopic observations of sunspots' (1974).

[9] The ratio of the focal length to the aperture of the telescopes ascribed to Galileo are 65 and 51, respectively. See Van Helden, *A Catalogue of Early Telescopes* (1999), 30-32. This high ratio was necessary to minimize chromatic aberration. In the astronomical telescope, the convex eyepiece made chromatic aberration even worse, and aperture ratios were in excess of 100.

university of Bologna. Up to that point no one had succeeded in producing such a device. These mirrors were, presumably, hammered and then ground and polished, and their curvature could hardly have been perfectly spherical or parabolic. The problem was compounded by the fact that the curvature of the mirror in a reflecting telescope has to be several times as accurate as the curvature of an objective lens.[10] Second, reports of miraculous and even magical optical devices were so rampant that Sarpi – and presumably Galileo as well, had developed a healthy scepticism about reports such as the one that reached Sarpi from The Hague. Sarpi wanted confirmation and, as his correspondence shows, it took some months for it to arrive.

But by the time his correspondents in Paris had confirmed that spyglasses really existed and that they were, in fact, for sale in Paris,[11] the device itself had reached Italy. As Girolamo Sirtori writes in his *Telescopium: sive ars perficiendi*, in May a Frenchman appeared at the court in Milan and offered a spyglass to the Duke of Fuentes.[12] In his paper in this volume, Biagioli answers the second question. Sarpi had seen such a spyglass by about the middle of July, and there is little doubt that if Galileo did not see it – it all hinges on the questions of when Galileo may have been in Venice during these days – he surely received crucial information from Sarpi, such as the device's length, the curvature of the two lenses, and the size of the aperture.

But as the officials in Zeeland had written to their colleagues in The Hague, nine months earlier, the device could not be kept secret because '… after it is known that the arts exists, attempts will be made to duplicate it, especially after the shape of the tube has been seen, and from it has been surmised to some extent how to go about finding the art with the use of lenses…'.[13] Putting together a spyglass by putting a weak convex and strong concave spectacle lens into a tube and stopping down the aperture was simple enough even if one had only heard a cursory description, and, as Galileo himself tells us, he made a spyglass in a day.[14] The question was, how could he improve the device?

Like others, Galileo initially worked with spectacle lenses. Strong concave lenses were available, and judicious combinations with the weakest spectacle lenses, may just have sufficed to reach a magnification of 8 – say an objective with a focal length of 80 cm and an eyepiece with a focal length of 10 cm – as

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[10] Watson, *Stargazer* (2004), 109-112.

[11] *Le Mercure François, ou la suitte de l'histoire de la paix* (Paris 1611), 338^{v}-339^{v}.

[12] Sirtori, *Telescopium* (1618), 23-24.

[13] Van Helden, *The Invention of the Telescope* (1977), 39

[14] *Il Saggiatore* (1623); Galilei, *Opere*, 6 (1896), 258. See also Drake and O'Malley, *The Controversy of the Comets of 1618* (1960), 211-213.

Galileo did in the instrument he presented to the Venetian Senate a month later, at the end of August. But around this time it must have been obvious there was a limit to such combinations. For one thing, spectacle makers could not make convex lenses with longer focal lengths,[15] and for another, larger objectives were necessary in order to increase the area around the optical axis where the curvature was accurate enough for use in a telescopic combination: Galileo had to learn to make his own lenses.

A shopping list dating from the winter of 1609-1610 gives us some idea of how complicated this task was going to be. Among a list of household supplies he was to buy in Venice, Galileo jotted down a number of items necessary for lens-making. For the lenses, he needed high-quality glass (crystal) blanks, and he listed polished glass, pieces of mirrors, and perhaps pieces of rock crystal; the tools for concave lenses were artillery balls (perhaps 10 cm in diameter), and those for convex lenses were to be bowls made or iron or stone. He also needed Tripoli powder, pitch, and felt for the grinding and polishing processes.[16] The fact that the list contains several directions to particular addresses (for example, 'In the Calle delle Aqque they make cutting tools') could mean that Galileo did not go to Venice himself, but sent his assistant (or technician) Marcantonio Mazzoleni.[17] The fact that Galileo did not yet have the tools of the trade – the artillery balls and the dish-shaped moulds – indicates that the shopping trip must have come during the transition from using existing spectacle lenses to making telescope lenses.

After obtaining materials for grinding and polishing,[18] Galileo could finally begin the laborious process of grinding the flat discs on one side to the desired convex curvatures.[19] It appears that he realized early on that in order to make the accurately figured area near the optical axis larger, one needed to start with

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[15] Marius, *Mundus Iovialis*, second unnumbered page of Praefatio; Prickard, 'The "Mundus Jovialis" of Simon Marius' (1916), 370-371; Schlör (ed.), *Die Welt des Jupiter* (1988), 39; Sirtori, *Telescopium* (1618), 23-30. See also Van Helden, *The Invention of the Telescope* (1977), 47-51.

[16] Galilei, *Opere*, 10 (1900), 270, note 1. See also Strano, 'La Lista della Spesa di Galileo' (2009).

[17] Marcantonio Mazzoleni entered Galileo's household in 1599 where he made the new military compass that Galileo had invented. He remained there until Galileo went to Florence in 1610. Galilei, *Opere*, 19 (1908), 132-147).

[18] Bedini, 'Lens Making for Scientific Instruments in the Seventeenth Century' (1966).

[19] A list of materials needed for lens making, to be purchased in Venice, written on a letter from Ottavio Brenzoni to Alessandro Piersanti of 24 November 1609, includes 2 artillery balls, a tin organ pipe, polished German lenses, polished rock crystal, pieces of mirror, Tripoli powder, various iron and stone forms, Greek pitch, and felt; Galilei, *Opere*, 10 (1900), 270. The list bears close resemblance to items mentioned by Della Porta in his brief description of lens manufacture. See: Della Porta, *Magia naturalis* (1589), book XVII, Ch.21, 278-279. See also Strano, 'La lista della spesa di Galileo' (2009).

larger glass blanks.[20] But even so, the process was tedious, and success was not a matter of course. By his own testimony, Galileo made a large number, 60 or 100 objectives over the course of perhaps eight months, and of these, only a handful were deemed good enough to show the celestial phenomena he had discovered.[21] It is clear, therefore, that this time-consuming and difficult task went on more or less continuously in Galileo's house

These increasingly powerful telescopes now produced were not very easy to use. To the first-time user, the concave eyepiece shows the inside of the telescope tube, with a small, round window, the objective, at the end. Image placement would initially have been something of a hurdle because the observer had to concentrate on that little window and to look through it; only then would an image appear.[22] Once the eye had, so to speak, emerged from this window into the world at large, finding an earthly target or even the Moon would by no means have been easy, and locating a planet or star would have taken considerable practice. A solid mounting was required: 'the instrument must be held firmly and therefore, in order to escape the shaking of the hand that results from the motion of the arteries and even breathing itself, it is good to fix the tube in some stable place.'[23] And at this point a peculiar feature of the Galilean or Dutch form of the telescope made life even more difficult.

The exit pupil of a Galilean telescope – the beam of light refracted by the objective and then by the eyepiece – is usually larger than the pupil of the observer's eye (cf. ill. 2). There is, moreover, no fixed point to position the eye, as there is in the astronomical telescope, and holding the eye a few millimetres behind the eyepiece is difficult and unstable. The field expands and contracts accordingly. Moreover, when the eye moves laterally (keeping the telescope fixed), different parts of the exit pupil are seen, and the field of view tends to wander. The size of this field is determined by the aperture of the objective, the exit pupil, the pupil of the observer's eye, and the distance of the latter from the eyepiece. Since the size of the eye's pupil can vary greatly, the field of view varies accordingly. All other things being equal, the dark-adapted pupil of an

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[20] In September 1610, Christoph Clavius wrote to Galileo that several of his telescopes circulated in Rome, and he asked why the objective lenses were so large, only to be stopped down to a small aperture (Galilei, *Opere*, 10 (1900), 485). Galileo replied that there two reasons: first, to be able to shape the lens more accurately; second, if one wanted to see a larger field of view, one could uncover the objective entirely and use it with a weaker eyepiece and a shorter tube (Galilei, *Opere*, 10, 561). It may be that this was also one of the reasons why Galileo ordered polished German spectacle lenses, which were usually 5 cm or more in diameter.

[21] Galileo to Belisario Vinta, 29 March 1610. Galilei, *Opere*, 10 (1900), 301.

[22] On image placement, see Ronchi, *Optics* (1991), 124-204.

[23] Galileo to an unidentified correspondent, 7 January 1610. Galilei, *Opere*, 10 (1900), 278.

observer looking at stars and planets – say 7 or 8 mm – allows a larger field of view than this same pupil contracted to 2 or 3 mm when observing the Moon. That of Galileo's 20-powered telescope could thus vary from perhaps 10 to 20 arc-minutes.[24]

Galileo's observations

Galileo seems to have been in Florence in October 1609 to show the Moon as it appeared through a telescope with a magnifying power of perhaps 10 to the young Grand Duke, Cosimo II, whom he had tutored in mathematical subjects during previous summers. By this time, Galileo had made telescopes of quality sufficient to show some detail on the Moon; he helped the Grand Duke see these features, and suggested an interpretation. As he wrote several months later, 'That the Moon is a body very similar to the Earth had already been ascertained by me and shown to some extent to our Most Serene Lord, although imperfectly because I did not yet have an instrument of the excellence that I have now.'[25] By November, Galileo managed to make a lens for a twenty-powered instrument. His labours were at this point beginning to produce important results: he could now discern the rough lunar surface even more clearly, and he had entered into the universe of the telescope. He embarked upon an observation project that lasted from the end of November to the middle of December 1609, observing the Moon from the age of three days to a few days beyond the Full Moon, and making a number of drawings.[26] He almost certainly intended to publish these results, for a long unsent letter of 7 January 1610 contains much of what was to appear about the Moon in *Sidereus Nuncius*, two months later.[27]

It has been argued that Galileo was particularly well equipped to see relief on the Moon because of both his training in *disegno* – the art of drawing and

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[24] North, 'Thomas Harriot and the First Telescopic Observations of Sunspots' (1974). See esp. the appendix (158-160): 'On the Early Dutch (so-called 'Galilean') Telescope, and its Field of View.' See also the website CCD *Images from a Galilean Telescope* (2006) by Tom Pope and Jim Mosher, http://www.pacifier.com/~tpope/index.htm (5 September 2010). Johannes Kepler, in his *Narratio de Iovis satellitibus* (1611), related his observations made with a telescope made by Galileo. He noted that its field of view 'barely showed half the Moon's diameter.' See Galilei, *Opere*, 3 (1893), 185.

[25] Galileo to Belisario Vinta, 30 January 1610, *Opere*, 10 (1900), 280; Drake, *Galileo at Work* (1978), 142. I have used a part of Drake's translation.

[26] Whitaker, 'Galileo's Lunar Observations and the Dating of the Composition of *Sidereus Nuncius*' (1978).

[27] Galilei, *Opere*, 10 (1900), 273-278.

arranging – and his association with artists.[28] As his telescopes improved, in the autumn of 1609, he began to distinguish the interplay of light and shadow on the surface of the Moon that depended on the relative positions of the Earth, the Sun, and the Moon: the changing locations and widths of the shadows were the result of unevenness on the lunar surface. During his observations of the waxing Moon he also paid close attention to the so-called 'ashen' or secondary light of the Moon. From painters, especially his friend Lodovico Cardi da Cigoli, he had learned much about indirect light, and it is highly likely that Galileo had long since satisfied himself that the Moon's secondary light was caused by reflection from the Earth.[29] This light was to become an important argument in *Sidereus Nuncius*, further strengthening the argument that the Earth was a planet just as bright as the Moon.[30]

It is interesting to note that Galileo had not shown much interest in the Copernican question before this time. As a professor of mathematics, he had no warrant to speak about cosmology and had duly lectured on traditional technical astronomy, concentrating in his research on questions of motion. In 1597, when he received a copy of Johannes Kepler's *Mysterium Cosmographicum*, he wrote to the author that he, too, was of the Copernican opinion, but that he had not yet dared to go public with this view because, while Copernicus was held as a great man by a few, he was ridiculed by an infinity of uninformed people.[31] The issue quickly disappeared from his (extant) correspondence. But in the fall of 1609, the telescope showed that the Moon's surface, like that of the Earth, was rough, and the secondary light demonstrated that, like heavenly bodies, the Earth was bright. Galileo, as it were, brought the Moon down to Earth, and lifted the Earth into the heavens. Toward the end of December, he began preparing his discoveries for publication.

Galileo inevitably turned his telescope to the planets as well, but such observations were more complicated. Mars and Saturn were then close to conjunction with the Sun and could therefore not be observed at all. Venus was in the morning sky, but the optics of Galileo's best telescope were apparently not

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[28] Edgerton, 'Galileo, Florentine Disegno, and the 'Strange Spottednesse' of the Moon' (1984); idem, *The Heritage of Giotto's Geometry* (1991), 223-253.

[29] Reeves, *Painting the Heavens* (1997), 91-137.

[30] David Wootton points out that Galileo added this material to strengthen his Copernican argument, and that his explanation of earth-shine was specifically meant to undermine Tycho Brahe's world system in which the Earth was still fundamentally different from the heavenly region. See Wootton, 'New Light on the Composition and Publication of *Sidereus Nuncius*' *Galilaeana* 6 (2009) 123-140, at 138.

[31] Galileo to Johannes Kepler, 4 August 1597. Galilei, *Opere*, 10 (1900), 70.

good enough to reveal anything about that bright planet. Even Jupiter, which was at opposition early in December, must have been beyond the requisite optical quality of Galileo's instrument. How else can we explain the fact that in the first half of December, when he was observing the Moon, he saw nothing worth recording about Jupiter, the brightest body in the evening sky after the Moon?

Some time near the beginning of January 1610, Galileo finished a 20-powered telescope that *did* have the quality needed for observing the planets and the fixed stars. In the letter of 7 January, Galileo described the instrument as having a magnification of 20, and gave the following advice: 'It is good that the convex glass, which is the one farther from the eye, should be partly covered and that the opening left should be oval in shape, since in this way objects are see much more distinctly.'[32] The oval aperture probably indicates that even relatively near the optical axis, this objective still exhibited astigmatism. Perhaps the shape was less important than the size: the aperture appropriate for observations of the Moon was too large for observations of the planets and stars. Almost a year later, when telescopes made by Galileo were being sent to various important people, Father Christoph Clavius SJ wrote to Galileo that these instruments had very large objectives, but covered so that there remained only a small opening, and he asked what purpose was of this large size covered in this way.[33] Galileo answered that he did this for two reasons:

> The first is to make it possible to work it more accurately because a large surface is more easily kept in the proper shape than a smaller one. The other reason is that if one wants to see a larger space in one glance, the glass can be uncovered, but it is then necessary to put a less acute glass near the eye and shorten the tube, otherwise the objects will appear very fuzzy.[34]

Presumably, the telescopes available to Clavius and his colleague mathematicians had smaller objectives, probably the normal size for spectacle lenses, about 3 cm, whereas Galileo's objectives were more like the broken lens that still survives, which has a diameter almost twice that size.

Galileo's second reason is interesting as well. These telescopes were dual-purpose instruments. For observing the planets and stars at night (with a dark-adapted pupil of 7 or 8 mm) one used a small aperture, because these bodies

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[32] Galileo to Antonio de Medici, 7 January 1610. *Ibidem*, 273, 278.

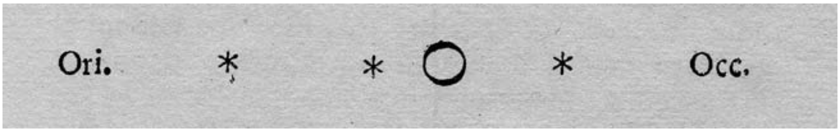
[33] Clavius to Galileo, 15 December 1610. *Ibidem*, 485

[34] Galileo to Clavius, 30 December 1610. *Ibidem*, 502.

are very bright for their size, but for observing earthly things during the day-time (with a pupil constricted to 2 or 3 mm) a larger aperture could be used as long as an eyepiece with a longer focal length was used. The tube had to be shortened accordingly, and the magnification was less. This dual purpose use remained common for the rest of the seventeenth century, even when the concave eyepiece had been replaced by a compound eyepiece consisting entirely of convex lenses that produced an erect image for day-time observation and a single convex ocular for astronomical purposes.

In the letter of 7 January 1610 cited above, Galileo discussed his lunar observations in detail and at the end added a brief statement about the fixed stars and planets:

> And besides the observations of the Moon, I have observed the following in the other stars. First, that many fixed stars are seen with the spyglass that are not discerned without it; and only this evening I have seen Jupiter accompanied by three fixed stars, totally invisible because of their smallness; and the configuration was in this form:[35]



Ill. 3. Galilei's observation of 'three fixed stars' (in fact moons) around Jupiter on 7 January 1610.

This passage is pregnant with the discovery of Jupiter's satellite, but its brevity should also be noted. The instrument that allowed these observations to be made must have been finished very recently, and Galileo had only examined the brightest planet in the heavens, Jupiter. He had nothing, yet, to say about the other planets.

When Galileo returned to this formation the following evening, he found that Jupiter had moved with respect to these 'stars,' and over the next few days he observed that they changed their positions relative to Jupiter and to each other, while at the same time accompanying the planet in its motion with respect to the fixed stars. Solving this problem was by no means easy. The field of view of the telescope was small and on 8 January he missed one of the moons that was at its furthest elongation; the optics were by no means perfect, and when a moon was close to the planet it was lost in the glare; and on 9 January

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[35] *Ibidem*, 277.

the sky was clouded over. It was thus a brief and incomplete sequence of formations made by four bodies when the observer thought there were three. The notes became more elaborate from day to day. On 11 January, after four evenings of observations, he concluded that 'around [*intorno a*] Jupiter there are three errant stars invisible to everyone up till this time.' The mounting still left something to be desired, and on 13 January he noted that he had fixed the telescope more firmly. On that night, too, he noted that there were four of these 'errant stars' rather than three.[36] The very passage that shows the power of the new instrument that allowed Galileo to make this discovery also reveals the problems of this instrument: the imperfect optics that made it difficult to observe the moons when they were close to the planet, and the unseen fourth moon because of the instrument's small field of view.

Others had surely observed that there were many more fixed stars than were visible with the naked eye,[37] and it would have been naïve to suppose that rivals were not studying the Moon while trying to make better telescopes. The four moons of Jupiter were, however, an entirely different matter: they were cosmological dynamite. Galileo had to rush into print. The rest is, as the saying goes, history.

Between the middle of January and the beginning of March, when *Sidereus Nuncius* was about to come off of the press, Galileo made observations of the fixed stars, especially the constellation Orion and the asterism of the Pleiades. From his observation notes, it is clear that he began by trying to map the belt and sword region of Orion. With the naked eye he located the brightest stars on a grid, and then located the telescopic stars in relation to them, measuring their distances from the bright stars in 'minutes' (see ill. 4). In *Sidereus Nuncius* he wrote: '... to the three in Orion's belt and six in his sword that were observed long ago, I have added eighty others seen recently, and I have retained their separations as accurately as possible.' To measure the distances of Jupiter's moons from the planet and each other, the diameter of Jupiter was a convenient unit.[38] But this method could not be used for measuring the distances between fixed stars. The fact that Galileo showed these distances in 'minutes,' as in illustration 4, means that within two weeks of his first observations of Jupiter's satellites he had found a method of measuring small distances within

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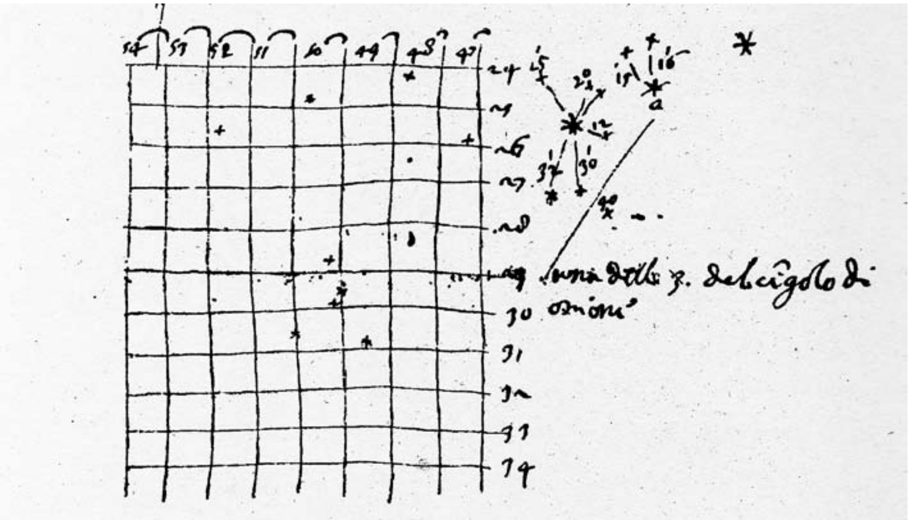
[36] Gingerich and Van Helden, 'From *Occhiale* to Printed Page: The Making of Galileo's *Sidereus Nuncius*' (2003), 252, 264; Galilei, *Opere* 3 (1893), 427.

[37] *Ambassades* (1608), 11.

[38] Although this unit is independent of Jupiter's distance from the Earth, optical inaccuracies and improper focusing of the telescope could introduce errors in this method. See Drake, *Telescopes Tides, and Tactics* (1983), 63-67.



Ill. 4. Grid used by Galilei to chart telescopic stars in relation to the brightest stars seen with the naked eye. January- March 1610.

the field of the telescope – a micrometer of some sort.

Much has been written about the stubborn resistance to Galileo's discoveries. The philosopher Cesare Cremonini, a colleague of Galileo's at the university of Padua, refused to look through a telescope. To him this optical (i.e. mathematical) instrument was irrelevant to any discussion of cosmology.[39] Galileo's friend, the artist Lodovico Cardi da Cigoli, reported from Rome as late as September 1610 that Father Christoph Clavius SJ, the senior mathematician at the Collegio Romano, had said that if the telescope revealed four new 'planets' around Jupiter to Galileo, then Galileo must have put them in the telescope to begin with.[40] Two months later, Clavius had observed Jupiter's moons himself.[41]

But the most telling episode took place around Easter 1610 in Bologna, a month after the appearance of *Sidereus Nuncius*. On his way back from Florence to Padua, Galileo visited his rival and colleague Giovanni Antonio Magini, professor of the mathematical sciences at the university of Bologna. Magini, who was jealous of Galileo's sudden fame, had invited a number of

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[39] Paolo Gualdo to Galileo, 20 July 1611. Galilei, *Opere*, 11 (1901), 211. Cremonini's reaction and his relationship to Galileo are discussed in: Muir, *The Culture Wars of the Late Renaissance* (2007) 1-59.

[40] Lodovico Cigoli to Galileo, 1 October 1610. Galilei, *Opere*, 10 (1900), 442.

[41] Antonio Santini to Galileo, 4 December 1610; Christoph Clavius to Galileo, 17 December 1610. *Ibidem*, 480, 485.

guests to come look through Galileo's telescope. This was enemy territory, and Galileo had little control over the setting in which he showed the guests the satellites of Jupiter. His telescope was not user-friendly, and not all the guests were mechanically inclined. A few minutes at the eyepiece was simply not enough for those not accustomed to this new instrument. It is worth recalling in this connection that in the fall of 1608, the members of the Dutch States General, similarly unused to the device, had found it difficult to scrutinize distant objects with only one eye.[42] Thus while visiting Magini, Galileo himself saw two of Jupiter's satellites on 24 April and all four on the 25th,[43] but others saw or claimed to have seen none at all. Magini argued that the moons of Jupiter were an optical illusion, and his assistant, the Bohemian mathematician Martin Horky, published a tract shortly afterwards in which he heaped scorn on Galileo. With an instrument so difficult to use, controlling the setting in which discoveries were demonstrated was essential, and Galileo did not make the same mistake again.[44]

The rhythm of the heavens

One further aspect needs to be examined: the Galilean telescope, the rhythm of the heavens, and the pace of discovery. Half a century after Galileo's discoveries, Christopher Wren began a little tract, *De corpore Saturni*, a theory to explain the cause of Saturn's various and mysterious appearances, as follows:

> The incomparable Galileo, who was the first to direct a telescope to the sky – although the telescope had then only recently been invented and was not yet in all respects perfected – so overcame yielding nature, that all celestial mysteries were at once disclosed to him.[45]

From Wren's historical perspective (and from ours), this was reasonable enough, but a detailed look at the events of 1609-1612 shows that the disclosure of 'celestial mysteries' took some time, and that, in fact, only a handful were revealed. Galileo's telescope could reach out only so far into space, limiting it to discovery within the solar system. But not all targets were easily accessible

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[42] Van Helden, *Invention* (1977), 36.

[43] Galilei, *Opere*, 3 (1893), 436. See also*: Biagioli, Galileo's Instruments of Credit* (2006), 113-115.

[44] Martin Horky to Johannes Kepler, *Opere* 10 (1900), 342-343. See also: Biagioli, *Galileo's Instruments of Credit* (2006), 113-115.

[45] Van Helden, 'Christopher Wren, *De corpore Saturni*' (1968), 219.

at all times. Some astronomical events are exceedingly rare: transits of Venus can be more than a century apart, and transits of Mercury occur about every decade. Accurate predictions of these events did not become possible until the publication of Kepler's *Rudolphine Tables* in 1627. In 1631 Pierre Gassendi, Christoph Scheiner S.J., and Johannes Remus Quietanus observed a transit of Mercury.[46] In the case of Venus, the heavens were cooperative indeed, producing two transits, in 1631 and 1639, the latter observed by Jeremiah Horrocks and William Crabtree. But luck aside, it was the rhythm of the heavens that did not allow a transit of Venus to be observed until three decades after Galileo first began observing the heavens with his telescopes.[47]

Until January 1610, the optical quality of his telescopes and, as shown above, also his mountings limited Galileo to observations of the Moon. Jupiter had just passed opposition and was the brightest body in the evening sky ($m = -2$). But where were the other planets? Mars was close to the Sun. It was not in opposition – its closest distance to the Earth – until 19 October 1610, so a favourable time for observation was the autumn of 1610. Galileo wrote in December of that year,

> As for Mars, I would not dare to affirm anything as certain, but having observed it for the past four months it appears to me that in these past few days it has grown in size by scarcely a third of what it was this past September; and it is seen somewhat reduced on the eastern part if the expectation (*affetto*) does not deceive me, which I don't believe.[48]

It appears that Galileo was checking whether he could verify the slight phase phenomenon that depended on the angle between Mars and the Sun. He felt satisfied that he had (probably) been able to do so, and pointed out that this effect would be much more pronounced when Mars had reached quadrature. But its disc would then be so small that its precise shape would be difficult to determine.[49]

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[46] Van Helden, 'The Importance of the Transit of Mercury of 1631' (1976).

[47] Indeed as early as December 1611, Christoph Scheiner tried to observe a transit of Venus at superior conjunction: if the Aristotelian/Ptolemaic order of the planets was correct, and Venus and Mercury were always 'below' the Sun, then Venus should be observed transiting the Sun; if Venus's shadow did not appear on the Sun, then the planet was beyond ('above') the Sun, as predicted by the theories of Copernicus and Tycho Brahe. Thomas Harriot's second sunspot observation was made on the same date, 11 December, and it contains astronomical shorthand to indicate that there was a conjunction of Venus and the Sun on this day. Harriot MSS, HMC 241/8, 2.

[48] Galileo to Benedetto Castelli, 30 December 1610. Galilei, *Opere*, 10 (1900), 502-504, at 503.

[49] *Ibidem*.

Saturn, the farthest and dimmest of the planets, was moving toward conjunction with the Sun, and Galileo could not make useful observations of it until after its heliacal rising in the spring of 1610, when, presumably, his telescopes had been improved even further. It was in the summer that he discovered the tricorporeal appearance of that planet. He sent an anagram containing the discovery to his correspondents.[50] It is interesting to note that at a magnitude of slightly over 8, Saturn's largest satellite, now called Titan, must have been within the grasp of Galileo's instrument in the summer of 1610, and we may assume that he looked for moons of Saturn as the planet approached opposition. But Titan's orbit, in the plane of the ring, is inclined at more than 20° to the ecliptic and therefore describes an ellipse around Saturn except when the ring is edge-on. Then it moves back and forth about Saturn in a straight line, as Jupiter's satellites do. This was not the case in 1610, but it was in 1612. In the meantime, however, since the lateral bodies showed absolutely no motion with respect to the central body, Galileo stopped observing the planet for two years. When, in 1612, he happened to look at the planet again, the lateral bodies had disappeared. He gave a remarkably accurate prediction of when and how the lateral bodies would reappear (based on a satellite model),[51] but there is no evidence that he searched for Saturnian satellites at this time. It is, however, precisely when the ring is edge-on that Saturn's satellites move back and forth on a straight line, like those of Jupiter. It is not unreasonable to assume that Galileo might just have discovered Titan in 1612.

In September 1610 Galileo moved to Florence, and in his new house he installed the machinery for lens-making. The quality of his lenses continued to improve, and I think it is safe to say that by the end of that year he had improved the optical quality of his telescopes about as much as was feasible, and now better observations of Venus were possible.[52] When he began examining the planets, early in 1610, Venus was moving toward superior conjunction, which it reached in the middle of May 1610. During this period it shrank in size and moved from gibbous to near-full moon shape. Given the brightness of Venus, it is to be doubted that these changes in shape could be observed at that time. As the planet began to move away superior conjunction, in the summer and fall of 1610, it slowly grew in size while it became gibbous, and on 16 December it reached its greatest elongation from the Sun. At this point

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[50] On Galileo and Saturn, see Van Helden, 'Saturn and his Anses' (1974).

[51] Deiss and Nebel, 'On a Pretended Observation of Saturn by Galileo' (1998).

[52] Only two records of observations of Mercury can be found in Galileo's notes. See: Galilei, *Opere* 3 (1893), 450-452.

its shape was that of a half-moon. Galileo wrote: 'Now it is beginning to become a sickle, and as long as it is in the evening sky it will continue show its horn thinner until it [Venus] vanishes [in the rays of the Sun].'[53] He added that unlike Mars, Venus could be seen as clearly delineated as the Moon itself, and that its diameter was half the Moon's seen with the naked eye. Galileo had determined that Venus's apparent diameter at this point was about one arc-minute. The instrument Galileo used for this observation therefore had a magnification of about 15.[54]

As in the case of Mars, Galileo was checking to see if Venus behaved in a matter predicted by the Copernican theory.[55] To show that Venus – and by implication Mercury – were not always 'below' the Sun, as Aristotle had it, or 'above' the Sun, as Plato had maintained, but sometimes above (beyond) and sometimes below the Sun, one had to show that Venus exhibited the complete range of phases, from nearly full near superior conjunction, to a very thin crescent-shaped near inferior conjunction. By December 1610, Galileo (and the mathematicians at the Collegio Romano) had seen enough: like the Moon, Venus goes through a complete series of phases, or 'The mother of love emulates the figures of Cynthia,' as he phrased it in the anagram he sent around.[56]

Venus made demands on the optical qualities of telescopes, but the Sun posed a different sort of problem. Direct observation was almost impossible. Only under special conditions can this body be observed with the naked eye, as when it is on the horizon or almost completely hidden behind a thin veil of clouds. Direct observation through a telescope, even with the small apertures used in the telescopes of Galileo and others was difficult and painful, and the available filters – pieces of colored glass – were of poor quality and thus gave a poor image. Thomas Harriot observed the Sun just after sunrise and could stand the pain for perhaps ten or fifteen minutes before the Sun had risen high enough to make further observations impossible. Johannes and David Fabricius quickly switched to a camera obscure technique. Christoph Scheiner may have used colored glass, and he certainly used a camera obscura as well.

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[53] Galileo to Benedetto Castelli, 30 December 1610; See also: Galileo to Christoph Clavius, 30 December 1610. Galilei, *Opere*, 10 (1900), 499-503.

[54] Galilei, *Opere*, 5 (1895), 100, 196-197. At about the same time, the mathematicians of the Collegio Romano verified the phases of Venus with a 30-powered instrument. See Christoph Grienberger to Galileo, 22 January 1611. Galilei, *Opere*, 11 (1901), 34.

[55] Note that although Copernicus did not predict the phases of Venus, he did discuss the order of Mercury, Venus, and the Sun, in a manner that could in retrospect be interpreted as such a prediction. See Copernicus, De revolutionibus (1543), Book I, chapter 10; Copernicus, *On the Revolutions* (1978), 18-20.

[56] Galileo to Giuliano de' Medici, 11 December 1610. Galilei, *Opere*, 10 (1900), 483

Galileo demonstrated sunspots by direct observations during his visit to Rome in the spring of 1611. Whereas he had jealously guarded his priority in other celestial discoveries, he seems not to have been particularly eager to pursue sunspots at this time. He was preoccupied with the study of floating bodies in the autumn of 1611, and he was also ill. But one can't help feeling that the difficulty of observing them also had something to do with the lack of notes on this phenomenon in Galileo's notes. His first recorded observation dates from 12 February 1612, within days of receiving a copy of Christoph Scheiner's *Tres epistolae de maculis solaribus*.[57] Only slowly did his drawings begin to show details of individual spots. It is fair to assume that Galileo was slowly developing techniques to make these observations somewhat less painful, and was formulating his theory about their nature in the interplay between hand and eye, as Horst Bredekamp has argued.[58] But, according to Galileo himself, it was his student Benedetto Castelli who came up with the instrumental improvement that made sustained observations at any time of the day possible. The use of a camera obscura for projecting the Sun's image was obvious and had long preceded the telescope. Johannes and David Fabricius as well as Christoph Scheiner availed themselves of this method, in addition to the telescope, to observe sunspots. And five years earlier Kepler had used such a method to observe what he thought was Mercury crossing the face of the Sun but was in fact a sunspot. But the image produced by this method was small, and moving the target back farther in order to make the solar image larger only made it more dilute. It was almost impossible to study the fine details of the sunspots. Projecting the Sun through a telescope produced a large image within a foot or two behind the eyepiece, and on this image, projected onto white paper, one could trace the sunspots. This set-up was sufficiently novel to deserve a new name, *helioscope*, first used by Christoph Scheiner. Needless to say, this instrument was used for all telescopic studies of the Sun, from solar eclipses to transits, for the rest of the seventeenth century and beyond.

Conclusion

From the time Galileo began to make telescopic observations of the heavens, in the autumn of 1609, to the sunspot observations of Thomas Harriot, Galileo, and Christoph Scheiner, in 1611, was about two years. The rough surface of the Moon, the myriad fixed stars, the moons of Jupiter, tricorporeal Saturn,

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[57] Galilei, *Opere*, 5 (1895), 253-254.

[58] Bredekamp, *Galilei der Künstler* (2007), 230-236.

the phases of Venus, and spots on the Sun were the results of telescopic observations made by a handful of men in Europe. But with the limitations of the Galilean telescope with its concave eyepiece – the difficulty of use, the limited field of view and the limit this imposed on magnification – meant that (except for a few minor discoveries such as the Andromeda Nebula by Simon Marius in 1612)[59] there was nothing left to be discovered. Further discoveries required better optics and higher magnifications, and these came in the 1640s with the astronomical telescope. The discovery phase of the first telescopes lasted about two years, after that, the potential of the Galilean telescope as an instrument of discovery was exhausted. What remained were routine observations of the Moon, Sun, and satellites of Jupiter, with the exception of the extraordinary observations of the transits of Mercury in 1631 and Venus in 1639.

With the publication of *Istoria e dimostrazioni intorno alle macchie solari e loro accidenti*, in 1613, Galileo's amazing run of discovery ended. What remained now was to put all his observations together into a convincing text concerning the Copernican world system. This work was finally published in 1632, and because of his condemnation in 1633, Galileo finally returned to his less controversial (but in the long run just as radical) studies on motion, an investigation that had been interrupted by the news about a spectacle maker in The Netherlands.

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[59] Marius, *Mundus Jovialis* (1614). See Schlör, *Simon Marius* (2008)..

Did Galileo copy the telescope? A ‘new’ letter by Paolo Sarpi

Mario Biagioli

An Italian-born Huguenot, Francesco Castrino was one of the several Protestants with whom Fra Paolo Sarpi maintained regular correspondence – the kind of relationship that fueled the Church’s suspicions that the Venetian Republic had chosen a heretic as their chief theologian. They exchanged letters between Venice and Paris from October 1608 to March 1611 until Sarpi was forced to break off the correspondence after realizing that, for some reason, his letters to Castrino tended to land on the desk of the Papal *Nuncius* of that city.[1] The two started to trade news about the telescope in early December 1608, when Sarpi acknowledged receipt of Castrino’s summary of *The Embassy of the King of Siam Sent to His Excellency Maurice of Nassau*, containing, in an appendix, the news about the invention of the telescope by a Dutch spectacle maker.[2] He added, however, that he had already received that same report from others, around the beginning of November.[3] (It was this report that reached Galileo, most likely through Sarpi himself).[4]

A letter from Sarpi to Castrino dated 21 July 1609 presents, however, a more interesting piece of information:

> There is nothing new here in Italy, except that a spyglass has arrived that make faraway things visible. I admire it very much because of the beauty of the invention and the

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[1] On Francesco Castrino and the Papal interception of his correspondence with Sarpi, see Busnelli, ‘Un carteggio inedito’ (1928).

[2] *Ambassades du Roy de Siam* (1608), 9-11.

[3] Sarpi to Castrino, 9 December 1609: ‘Recevei dalla Haga, un mese e,’ il riporto che Vosra Signoria mi manda, sopra l’ambasciata al conte Maurizio del re Indo di Siama, e sopra li nuovi occhiali fabbricati da quell valent’uomo […]’ (‘One month ago, I received from The Hague the report that you sent me about the embassay of the King of Siam to Count Maurice, and about the new glasses made by that craftsman’), in: Sarpi, *Lettere ai Protestanti*, 2 (1931), 15.

[4] ‘[…] News came that a Hollander had presented to Count Maurice a glass by means of which….’ Galilei, *The Assayer* (Rome, 1623), cited in: Van Helden, *Invention* (1977), 52.

skill of the manufacture, but don't value it at all for its military uses, either on land or at sea.[5]

First published in 1833, this letter was surprisingly excluded from Galileo's *Opere* and, perhaps because of that, has remained invisible to the current generation of Galileo scholars.[6] It establishes the arrival of a telescope in Venice about two weeks earlier than commonly reported in the literature – not at the very beginning of August but, as I will show, somewhere between the 8th and the 20th of July.[7] Two or three weeks may not seem like much, but in fact they force us to seriously rethink crucial elements of the chronology and originality of Galileo's development of the telescope, and to reconsider the accuracy of the narratives about these events he offered in the *Sidereus nuncius*, *The Assayer*, and the letter of 29 August 1609 to his brother-in-law, Benedetto Landucci.[8] It also re-opens old debates about Sarpi's role in the development of Galileo's instrument.

In particular, Sarpi's letter to Castrino indicates that, by the time Galileo put his telescope-making efforts in high gear, he may have known a lot more about other people's telescopes than he cared to admit. He always maintained that he had only heard that the telescope existed, but it now seems most likely

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[5] Sarpi to Castrino, 21 July 1609: 'In Italia non abbiamo cosa nuova: solo e' comparso quell'occhiale che fa vedere le cose lontane; il quale io ammiro molto per la bellezza dell'invenzione e per la dignita' dell'arte, ma per uso della Guerra ne' in terra ne' in mare, io non lo stimo niente,' in: Sarpi, *Lettere ai Protestanti*, 2 (1931), 45.

[6] The virtual invisibility of the letter remains a bit of a puzzle, given that it has been published numerous times – in 1833, 1847, 1863, and 1931 (Sarpi, *Scelte lettere inedite* (1833), 72; Sarpi, *Scelte lettere inedite* (1847), 182; Sarpi, Lettere, 1 (1863), 279; Sarpi, *Lettere ai Protestanti*, 2 (1931), 45). In recent times it has been noticed only, to the best of my knowledge, by one Sarpi scholar – Libero Sosio – who, however, did not recognize its relevance to the chronology of the invention of the telescope. (Sosio, 'Fra Paolo Sarpi e la cosmologia' (1996), CLXV). More puzzling is Antonio Favaro's decision not to include it in the *Opere*, despite having known and cited this letter twice early in his career, prior to embarking on the *Opere* project: Favaro, 'Fra Paolo Sarpi fisico e matematico secondo I nuovi studi' (1883), 909; Favaro, 'Il telescopio' (1883, reprinted 1966), 277. In a later article, he even seemed to forget that that letter existed: 'non abbiamo documenti i quali provino che lo strumento abbia fatta la sua comparsa in Padova avanti la fine del Luglio' ('We do not have documents that would prove that the instrument had made its appearance in Padua before the end of July'; see: Favaro, 'La invenzione del telescopio' (1907), reprinted in Favaro, *Galileo Galilei a Padova* (1968), 175).

[7] Lorenzo Pignoria to Paolo Gualdo, 1 August, 1609: 'Uno degli occhiali in canna, di che ella mi scrisse gia`, e` comparso qui in mano d'un Oltramontano' ('One of the glasses in a tube, about which you wrote me has appeared here in the hands of a foreigner'), in: Galilei, *Opere*, 10 (1900), 250.

[8] Favaro, 'Galilei e la presentazione del cannocchiale alla Repubblica Veneta' (1891); Rosen, 'The Authenticity of Galileo's Letter to Landucci' (1951).

Ill. 1. Fra Paoli Sarpi (1552 - 1623). Engraving by George Vertue.

that Galileo had access to a detailed description of the construction and performance of an actual telescope brought to Venice by a northern European artisan or merchant. He might even have inspected the instrument itself.[9] Sarpi's letter to Castrino – together with other evidence about Galileo's movements in that period – places him in Venice on the same days when a foreigner was offering his own telescope to the Venetian Senate and the instrument was being tested and inspected by his close friend Paolo Sarpi. This was, I argue, the instrument Sarpi referred to in his letter of 21 July to Castrino.

Filippo de Vivo has shown that Sarpi timed his letter-writing to the scheduled departures of the couriers rather than to the pace of the news – typically every week or fortnight.[10] Several of his letters to Northern European correspondents bore, in fact, the same dates. On 21 July 1609 he wrote to both Castrino and Christoph von Dohna, and on 7 July (the date of the previous

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[9] This is a hypothesis that, surprisingly enough, has been seriously entertained only in the last few years: Strano, 'Galileo's Telescope' (2009), 19. Favaro, who was initially more open-minded than most, acknowledged the possibility, but brushed it off as irrelevant: 'poco importa il discutere se in Padova od in Venezia, sulla semplice voce, cioe` sine exemplo, oppure dopo aver anche veduto uno di quei volgari tubi, la vista del quale ben poco poteva aggiungere alla sommaria descrizione che ne avesse udita o letta [...]' ('It matters little to discuss whether in Padua or Venice, on the mere rumour, that is, without an example, or after having also seen one of these common tubes that could add little to the summary description which he had heard or read'; Favaro, 'La invenzione del telescopio' (1968), 176).

[10] De Vivo, 'Paolo Sarpi and the Uses of Information in Seventeenth-Century Venice' (2005), 39.

letter to Castrino) he also posted letters to Jerome Groslot de l'Isle and Von Doha. The telescope mentioned in Sarpi's letter, therefore, could have arrived anytime between 7 and 21 July. This is supported by the content and tone of the letter, which gives no indication that Sarpi was rushing to report breaking news about the telescope. With the exception of the few lines quoted above, the letter deals mostly with political matters.

Since hearing about the telescope in late 1608, Sarpi's remarks about the instrument oscillated between cautious and skeptical. They were uniformly vague. To Castrino he wrote that: '[the report about the telescope] has given me much to think about. However, because the philosophers teach us that one should not speculate about the cause prior to seeing its effects with one's eyes, I have resigned myself to waiting for this very noble thing to spread throughout Europe'.[11] He expanded on that in a January 1609 letter to Groslot de l'Isle:

> The reports about the new spyglasses [...] are credible enough to make me look and philosophize no further, having Socrates prohibited to speculate over phenomena that we have not seen ourselves. When I was young, I thought about a similar device, and it occurred to me that a glass made in the shape of a parabula could produce such a [magnifying] effect. I had demonstrative arguments, but because they are abstract [by nature] and do not take into account material constraints, I hesitated. For that reason, I did not pursue that work, which would have been labourious. Consequently, I neither confirmed nor refuted my hypothesis through experience...[12]

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[11] Paolo Sarpi to Giuseppe Castrino, 9 December 1609: '[...] m'ha dato assai da pensare; ma perche' questi filosofi comandano che non si specula la causa prima di vedere con propri sensi l'effetto, mi son rimesso ad aspettare che una cosa cosi` nobile si diffondi per l'Europa,' ('It has given me much to think about, but because these philosophers command not to speculate on the first cause of vision by itself without the effect, I have submitted and wait for such a noble thing to spread through Europe'), in: Sarpi, *Lettere ai Protestanti*, 2 (1931), 15.

[12] Paolo Sarpi to Jerome Groslot de l'Isle, 6 January 1609: 'L'avviso delli nuovi occhiali [...] lo credo per quanto basta a non cercar piu' oltre, per non filosofarci sopra, proibendo Socrate il filosofare sopra esperienza non veduta da se' proprio. Quando io era giovane, pensai ad una tal cosa, e mi passo' per la mente che un occhiale fatto di figura di parabola potesse far tal effetto; aveva ragioni demonstrative, ma perche` queste sono astratte e non mettono in conto la repugnaza della materia, sentiva qualche opposizione. Per questo non [mi] son molto inclinato all'opera, e questa sarebbe stata faticosa: onde ne' confirmai ne' reprobai il pensiero mio con l'esperienza,' ('I believe the news about the new glasses as far as it goes for it suffices not to search further and not to philosophize about it. Socrates prohibits philosophizing about experiences not personally seen. When I was young, I thought about such a thing, and it occurred to me that a glass made in the shape of a parabola could produce such an effect; there were demonstrated reasons. But because these are abstract and do not take into account the stubbornness of the material, some opposition was heard. Because of this, I am not much inclined toward the task – and it would have been tiring; and thus I neither confirmed nor disproved my my idea by experience'), in Sarpi, *Lettere ai Protestanti*, 1 (1931), 59.

Sarpi's position had not changed much by the end of April, when he wrote to Jacques Badovere:

> [...] About the Dutch spectacles, I have given your Lordship my thoughts, but I could be wrong. If you gather more about them, I'd like to hear what is thought there. I have almost stopped to think about physical and mathematical topics. Either because of age or habit, my brain has become a bit thick for those reflections.[13]

The same polite skepticism is found in a letter to Groslot de l'Isle, dated 12 May, thus making Sarpi's statement of 21 July about the 'beauty of the invention' stand out as a distinct shift in his views on the telescope.[14] (It may also indicate his surprise at seeing the instrument's two-lens optical scheme, which Sarpi seemed to have previously imagined to involve a concave mirror).[15] Even his negative evaluation of the telescope's potential as a military instrument marks a shift in Sarpi's views about the instrument. In previous letters he repeatedly abstained from passing judgment on the telescope until he saw one himself, but on 21 July he explicitly commented on its performance. This double shift indicates that Sarpi tested a telescope prior to writing to Castrino. His disparaging remark about the military uselessness of the telescope derive, I believe, from his having noticed the modest enlarging power of the instrument (likely to be in the 4-power range) as well as the narrow field of view typical of all Dutch-type telescopes, which would have made it almost impossible to use on pitching and rolling ships and inconvenient to use on land. (The Dutch authorities' request to Hans Lipperhey – the first to file a patent application on for the telescope on 4 October 1609 – to develop a binocular version of the instrument may have been an attempt to address that same problem).[16]

Sarpi's reference to the instrument's military performance matches the fact that, starting with Lipperhey, early telescopes were consistently presented as tools for military reconnaissance – an application that Galileo was going to stress in great detail in the presentation of his own instrument to the Venetian Senate on 24 August 1609.[17] The foreigner who came through Venice in July 1609 seeking a reward from the Senate in exchange for the 'secret' of his telescope obviously advertized it for that same use. Because we know that the

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[13] Paolo Sarpi to Giacomo Badoer, 30 March 1609, in: Paolo Sarpi, *Opere* (1969) [my translation].

[14] Paolo Sarpi to Jerome Groslot de l'Isle, 6 January 1609, in: Sarpi, *Lettere ai Protestanti*, 1 (1931), 79.

[15] Reeves, *Galileo's Glassworks* (2008), 115-138.

[16] 'Minutes of the States General,' 15 December 1608, printed in: Van Helden, *Invention* (1977), 42.

[17] Van Helden, *Invention* (1977), 36; Galilei, *Opere*, 10 (1900), 250-251.

Venetians commissioned Sarpi with the testing the foreigner's instrument (and that he eventually rejected the foreigner's petition), his saying to Castrino that 'I but don't value it at all for its military uses, either on land or at sea' may reflect the negative assessment of the telescope he was about to deliver to the Senate.[18]

Vague narratives

In *Sidereus Nuncius*, Galileo wrote that:

> About 10 months ago a rumor came to our ears that a spyglass had been made by a certain Dutchman by means of which visible objects, although far removed from the eye of the observer, were distinctly perceived as though nearby. About this truly wonderful effect some accounts were spread abroad, to which some gave credence while others denied them. The rumor was confirmed to me a few days later by a letter from Paris from the noble Frenchman Jacques Badovere. This finally caused me to apply myself totally to investigating the principles and figuring out the means by which I might arrive at the invention of a similar instrument, which I achieved shortly afterwards ['at once' in the ms.] on the basis of the science of refraction.[19]

(Sarpi's name is not mentioned in the *Nuncius*, but Galileo probably heard of both the telescope's invention and of Badovere's letter from his Venetian friend).[20] More than two decades later, responding to Orazio Grassi's challenge to his inventorship of the telescope, Galileo took a few pages of *The Assayer* to flesh out the bare-bone narrative first proposed in the *Nuncius*. He added some chronological specificity to his previous story, while also re-stating a key point, that is, that all the technical information contained in the early reports he heard about the telescope amounted to 'nothing more' than the instrument

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[18] Giovanni Bartoli to Belisario Vinta, 29 August 1609, in: Galilei, *Opere*, 10 (1900), 255.

[19] Galilei, *Sidereus Nuncius or Sidereal Messenger* (English translation, 1989), 36-37.

[20] In the *Nuncius*, Galileo does not say that Badovere's letter was to him (which leaves open the possibility that Galileo read a letter sent to Sarpi). In any case, Sarpi had heard of the telescope in early November 1608, and would have been most likely to share the news with Galileo very soon after receiving it. Eileen Reeves presents a more complicated story, arguing that Badovere sent the same report to both Sarpi and Galileo, through the same courier. She argues there were two letters from Badovere in response to the queries from Venice. The first one, she argues, was disappointingly vague, but the second was more detailed (Reeves, *Galileo's Glassworks* (2008), 133-138). None of these possible letters, however, survive.

made faraway things look nearby.[21] The implication being that he set his mind on developing his instrument without the help of any specific clue about the manufacture of the telescope – apparently, not even that it had two lenses.[22]

Galileo actually went so far as to propose that the 'rumors' he had heard did not help him at all to solve the puzzle of the telescope:

> I say that the aid afforded me by the news awoke in me the will to apply my mind to it; but beyond that I do not believe that such news could facilitate the invention. I say, moreover, that to discover the solution of a known and designated problem is a labor of much greater ingenuity that to solve a problem which has not been thought of and defined, for luck may play a large role in the latter while the former is entirely the work of reasoning.[23]

Unlike the lucky Dutch spectacle-maker who, Galileo argued, stumbled by chance upon an instrument he was not looking for, the rumors of the existence of the telescope had confronted Galileo with a puzzle – a puzzle that could not be solved by chance but only through reasoning or, as he put it in the *Nuncius*, through the 'science of refraction.'[24] And yet the description of how he discovered the 'secreto' of the telescope by 'means of reasoning' was, by Galileo's own admission, surprisingly simple:

> My reasoning was this. The device needs either a single glass or more than one. It cannot consist of one alone, because the shape of that one would have to be a convex (that is, thicker in the middle than at the edges), or concave (that is, thinner in the middle), or contained between parallel surfaces. But the last named does not alter visible objects in any way, either by enlarging or reducing them; the concave diminishes them; and the convex, while it does indeed increase them, shows them very indistinctly and confusedly. Therefore, a single glass is not sufficient to produce the effect. Passing next to two, and knowing as before that a glass with parallel faces alters nothing, I concluded that the effect would still not be achieved by combining such a one with either of the other two. Hence I was restricted to trying to discover what would be done by

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[21] 'Ne' piu' fu aggiunto' ('That was all'), in: Galileo, *Il saggiatore* [The assayer] (1623), cited in: Van Helden, *Invention* (1977), 51.

[22] Even the discussion on the telescope with unnamed friends in Venice, which Galileo first reported in *The Assayer* was not described as providing any additional information (Galileo, *Il saggiatore* [The assayer] (1623), cited in: Van Helden, *Invention* (1977), 51-52).

[23] Galileo, *Il saggiatore* [The assayer] (1623), cited in: Van Helden, *Invention* (1977), 52-53.

[24] '[...] which I achieved shortly afterward on the basis of the science of refraction'; Galileo, *Sidereus Nuncius or Sidereal Messenger* (1989), 37.

a combination of the convex and the concave, and you see how this gave me what I sought. Such were the steps of my discovery, in which I was not at all assisted by the conception that the conclusion was true.[25]

Galileo's claim that knowing of the existence of the telescope made the discovery of its secret a more difficult task than the original invention looks like a bit of a stretch. Also peculiar is the gap between his high-sounding claims about his use of 'reason' and the 'science of refraction' and his description of his actual path to discovery which looks like a series of reasonably simple guesses – guesses that, contrary to Galileo's assumption, could have been within the reach of a 'simple maker of ordinary spectacles.'[26] Taken together, these features of Galileo's narrative suggest an attempt to maximize the distance between his instrument and those developed in Northern Europe: He had learned nothing from them and, in any case, his had been developed following a method that was utterly alien to theirs. Galileo's emphatic amplification of the differences may be a sign that the differences were, in fact, too small for comfort.

His chronologies are not straightforward either. Those in the *Nuncius* and *The Assayer* offer no explicit dates, only time intervals between events. Some of those intervals are identified with specific markers ('the following day…'), but more often with vague expressions ('for over a month…'). Those interested in the actual timeline of Galileo's work are left to reconstruct the chronological structure *within* his narrative (the distance between the various events) and to then find an event that can be attached to a specific date *outside* of the narrative to function as the chronological anchor for the whole story. Galileo's multi-dimensional vagueness about dates, people, and information was, I believe, not accidental but tactical. He did not necessarily report things that had

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[25] Galileo, *Il saggiatore* [The assayer] (1623), cited in: Van Helden, *Invention* (1977), 53.

[26] 'Con tutto il debito rispetto per ogni cosa che risguarda Galileo, ci e` forza riconoscere che quando Galileo affermava speculazioni di prospettiva averlo condotto alla costruzione del cannocchiale, egli non sapeva che cosa dicesse: anzi questa sola affermazione […] basterebbe a sostenere ch'egli non vi adopero` maggior studio di quello che abbia fatto quell primo occhialaio di Middelburgo. […] Galileo non era maggiormente sincero quando affermava che specolazioni istituite sulla rifrazione lo avevano condotto al cannocchiale. Galileo infatti non ebbe mai una chiara idea della rifrazione….' ('With all the respect due all matters that regard Galileo, one must recognize that when Galileo affirmed that speculations about perspective led him to the construction of the telescope, he did not know what he was saying; on the contrary, that single affirmation would be enough to maintain that he did not undertake greater study than the first spectacle maker in Middelburg. Galileo was no more sincere when he affirmed that speculations on refraction had led him to the telescope. In fact, Galileo never had a clear idea of refraction.') Cf. Favaro, 'Il Telescopio' (1883/1966), 274-275.

not happened, but omitted important events and people while also 'loosening up' the chronological relations between the events so as to render his narrative of inventorship more defensible by making it less falsifiable.

Historians have painstakingly tried to piece together the actual chronology of Galileo's development of the telescope. Although they have not openly voiced the possibility that these chronologies may be intrinsically incompatible, their efforts have at least shown that serious discrepancies exist, and that reconciling them requires taking several of Galileo's chronological references somewhat metaphorically.[27] Comparably friendly readings are necessary to resolve discrepancies between manuscript and print versions. For instance, Edward Rosen tells us that replacing 'eight months' with 'ten months' between the manuscript of the *Nuncius* and its printed version should not be read as evidence of Galileo's creative interventions on the timeline but rather as the benign trace of his attempt to recalibrate his narrative to account for the fact that it took two months between the writing of the manuscript and the printing of the book.[28]

But, aside from these specific philological issues, why hasn't Galileo's remarkable chronological vagueness and 'elasticity' been noticed and treated as something to be explained, rather than explained away? Why haven't we asked why Galileo never provided any specific chronological statement about his telescope-making activities (despite the fact he included plenty of other dates in the *Nuncius*)?[29] As it often happens in philological judgments, the meaning of certain elements of the text depends on the assumptions one makes about the author and his/her intentions. In Galileo's case, the tendency has been to assume that his chronologies were fundamentally correct, and that one should

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[27] For instance Rosen does not believe that Galileo heard about the telescope on the day he reported in *The Assayer* (17 July) because that chronology does not match what Galileo says in the *Nuncius*. (Rosen, 'When Did Galileo Make His First Telescope?' (1951), 50). At the same time, Rosen reconstructed the chronology of the *Nuncius* to minimize the discrepancy with *The Assayer*, as when he concludes that Galileo heard of telescope in June 1609 (*ibid.*, 47) when the end of May seems to be a more reliable date. Rosen also remarked on the conspicuous differences between *The Assayer* and *Nuncius* (*ibid.*, 47). In 'Il Telescopio ', Favaro states that '[…] dee riconoscersi che le tre narrazioni non sono interamente conformi; oltrediche' esse contengono assolute inesattezze […]' ('it must be recognized that the three narrations are not entirely consistent; in other words these contain absolute inaccuracies'). Favaro, 'Il Telescopio' (1883/1966), 272.

[28] Rosen, 'When Did Galileo Make His First Telescope?' (1951), 45. Analogously, the change between 'at once' (in the manuscript of the *Nuncius*) to 'shortly afterwards' (in the printed version) should be treated as a mere stylistic change in the pursuit of elegance: 'Such instantaneity [of 'at once'] may have sounded out of step, on second hearing, with the preceding slow notes' (*Ibidem*, 48).

[29] Galileo listed, for instance, the dates of all his observations of the satellites of Jupiter.

adjust the meaning of expressions like 'shortly after', 'a few days later', or 'afterwards', so as to match his timelines with the documentary evidence we have about them. This might be a reasonable course of action if one were dealing with chronologies of no particular significance. In this case, however, Galileo's chronologies were a *means to establish himself as an independent inventor of the telescope*, not mere descriptions of how and when he invented the telescope.[30] In other words, there has been a tendency to assume that Galileo was indeed the author he was representing himself to be, and to then use this assumption as a guiding philological principle to sort through the chronological discrepancies in his narrative. Taking this road, however, has produced literature that confirms the very claim to inventorship that Galileo was trying to establish.[31]

We know that Galileo was not the first inventor of the telescope, and that telescopes were showing up with increasing frequency in both Northern Europe and Italy as he was developing his own. These telescopes were not simply being transported from the Netherlands to other parts of Europe, but were copied and reproduced *in situ* with substantial ease. (The facility with which telescopes could be copied and the quick diffusion of telescope-making skills were among the reasons for the Dutch States General's decision to turn down Hans Lipperhey's patent application).[32] That Galileo managed to have his name closely associated with the invention of the telescope was a truly remarkable achievement. And because the way he presented his telescope-making program in the *Nuncius* and then in *The Assayer* played a crucial role in gaining that recognition, we need to take such narratives as instruments whose function and functioning we need to investigate. (We also need to be careful about the meaning of 'telescope' and 'to invent').

The first thing we need to notice is that the Venetian Senate had already recognized Galileo as the inventor of the telescope several months prior to his publication of the *Nuncius*. He offered the instrument to the Senate on 24

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[30] For a smart discussion of the relationship between the establishment of discoveries, discovery narratives, and authorship, see: Schaffer, 'Scientific Discoveries and the End of Natural Philosophy' (1986).

[31] Rosen concluded his 'When Did Galileo Make His First Telescope?' (1951) by saying that: 'In his three separate accounts [of his invention], *Galileo gives us a period of about two months to be filled with the following intervals*: a few days, at once, six days, more than a months, four days' (page 50). I can hardly imagine a better example of a historian assuming the illustration of the author as the ordering principle of philological work: *Galileo gives us a period and some intervals of his choosing* and it is our job to put together the pieces of the jigsaw puzzle he has designed. But what about considering the possibility that the pieces may not be made to fit the puzzle, or that there may be no coherent puzzle?'

[32] Minutes of the States General, 15 December 1608, cited in: Van Helden, *Invention* (1977), 42.

August 1609 and was rewarded with tenure and a doubling of his salary as professor of mathematics at the University of Padua. Keep in mind that Galileo's self-representation as the inventor of the telescope does not contradict his simultaneous acknowledgment that the 'Hollander' invented it first.[33] In a period in which 'inventor' was construed as the person who put a new technology to work in a certain place (either by developing it *in situ* or bringing it in from elsewhere) and 'invention' was defined by its performance and uses rather than by the idea embodied in it, Galileo was indeed the rightful inventor of the telescope *in Venice*.[34] (This performance-based notion of invention explains why the foreigner who brought a working telescope to Venice before Galileo's was not recognized as the inventor of the telescope: his instrument was not deemed to perform well enough – at least not for the asking price). The focus on performance rather than absolute novelty also explains why the path that Galileo followed to develop his instrument had no bearing on his claim to inventorship. From the Venetian Senate's point of view, Galileo was the inventor of the 8- 9-power device he showed them, no matter whether he discovered it, copied it from some foreign exemplar, or a bit of both. He was not the inventor of *the* telescope, but of *that* telescope.[35] The evidence in Sarpi's letter to Castrino does not, therefore, challenge the legitimacy of Galileo's claim to his inventorship – that is, *Venetian inventorship* – of the telescope. What it does challenge are the claims Galileo put forward in *his printed books* about how little he relied on information about other instruments as he set out to develop his own telescope.

What he wrote in the *Nuncius* and *The Assayer* about the history of his telescope-making program was not aimed at the Venetian Senate but a very different credit regime – one of philosophical authorship rather than technological inventorship. (The letter accompanying his gift of the telescope to the Republic did not, in fact, offer any chronology of its development – only a detailed description of its military uses). His printed narratives, instead, were meant for people who were much less interested in the military use of the telescope than in the *discoveries he had made with it*. Through these printed

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[33] Biagioli, *Instruments of Credit* (2006), 77-134.

[34] Biagioli, 'From Print to Patent' (2006), 147-152. More precisely, Galileo was not the inventor of the family of instruments we now call refracting telescopes (or of the specific Dutch design), but of the specific instrument whose performance was much appreciated by the Venetian senators who tested and rewarded it in August 1609.

[35] I do not think that the definition of 'telescope' had any legal meaning in so far as patents and rewards were concerned. What was being evaluated and possibly rewarded were *things*, not *ideas embodied in things*.

narratives, Galileo was trying to establish his inventorship of the telescope so as to enhance the authorship of his discoveries, but he was also trying to make the connection between authorship of the discoveries and inventorship of the telescope run in the other direction. By establishing that he was the first to discover what he discovered, he was effectively marking his telescope as different from the telescopes of others (implying that the owners of the other telescopes circulating throughout Europe had not been able to make those discoveries). In turn, that helped establish him (in an a posteriori fashion) as the first inventor of a new kind of telescope – the 'discoveries-making' telescope.

The dedication of the *Nuncius* shows that, at the time he was writing the book, the Medici were Galileo's privileged audience – the potential patrons he was trying to connect with. And the workings of the patronage system made it virtually necessary for Galileo to cast his work (both the telescope and his discoveries) as something that he did all by himself, perhaps with some divine inspiration, so that he (and he alone) could offer it to his patron, thus establishing the kind of personal relation typical of high-end patronage. This means that, while the Venetians could not care less about how Galileo got his telescope – what mattered was that it worked and worked well – it would have been difficult for Galileo to appear to publicly court the Medici with a gift he had already given to others (as he had), developed in collaboration with others (which he may have), or through the information provided by others (which he most likely did).[36]

It is therefore not surprising that the *Nuncius* remained silent about Galileo's presentation of the telescope to the Venetian Senate and of the rewards he received for it, despite the fact that such a public recognition could have provided evidence of the reliability and quality of the instrument.[37] Nor did Galileo mention anyone who helped him develop the telescope, leading Libero Sosio to speculate (credibly, I think) that Sarpi name went unmentioned in the

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[36] The Medici, of course, knew perfectly well about the widespread presence of the telescope in Europe and that, therefore, Galileo was part of a process of innovation rather than its originator. Still, the story of Galileo's 'invention' of the telescope had to be told – that is, *publicly* told – in a certain way so as to make it appear that the Medici were rewarding Galileo for his unique originality.

[37] Galileo did eventually invoke the recognition by the Venetian Senate as evidence for his inventorship, but that was in the 1623 *The Assayer* in response to Grassi (Van Helden, *Invention* (1977), 52).

Nuncius because of patronage *realpolitik*.[38] Furthermore, an acknowledgment of Sarpi's role would have opened a window on a whole series of borrowings – not only from him but also from the foreigner's instrument and the other people the foreigner may have borrowed from. Crediting Sarpi could have popped a rather large bubble.[39]

It was in fact important for Galileo to cast his telescope as different as possible from the many others mushrooming throughout Europe. Without that kind of product differentiation, his gift could have appeared quite generic. I cannot assess the role (if any) that the 'science of refraction' may have played in Galileo's development of the telescope, but it is very clear that such a presentation was effective in casting an aura of distinction around himself and his instrument – a distinction he surely needed to play the patronage game. Effectively, Galileo tried to claim that there were two species of telescopes – one discovered by accident by the Dutch spectacle maker and one discovered through reason by Galileo himself. Galileo's emphasis on the modality of his discovery of the telescope's 'secret' seeks to achieve something more than simply conferring on Galileo the aura of the natural philosopher (in contrast to Lipperhey's merely artisanal status). What Galileo was trying to do, I think, was to say that his telescope was different from all others because it was conceived and produced by different means. It was different because it was genea-

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[38] Sosio, 'Fra Paolo Sarpi e la Cosmologia' (1996) clxviii. The erasure of Sarpi from *The Assayer*, however, may not have been the result of the same considerations that excluded him from the *Nuncius*. By 1623, Galileo was in the viewfinder of the Inquisition, and it might have been politically wise for him not to mention the name of a notoriously unorthodox theologian like Sarpi at that point in time.

[39] Also to patronage logic we may trace Galileo's decision to mention in print only the first telescope presented to Count Maurits in the Netherlands, while skipping the dozens that had been sold and shown around Europe by the summer of 1609 – a population that would have impaired Galileo's claim to uniqueness. It also seems that, in an attempt to make the origin of the telescope a bit less humble and a little more Medici-compatible, Galileo referred to the original discoverer as 'a certain Dutchman,' but refrained from saying that he was an ignorant artisan (which he effectively said years later in *The Assayer*: 'The Hollander who was first to invent the telescope was a simple maker of ordinary spectacles [...].' Cf. Van Helden, *Invention* (1977), 53). Disparaging the original maker would have cheapened Galileo's own gift in 1610, but could be brought up two decades later, when his patronage relationship with the Medici was a long established fact. In sum, Galileo had plenty of good patronage reasons for writing a vague narrative about his development of the telescope.

logically different.[40] And Galileo could try to claim the authorship of that specific genealogy (and of the product that resulted from it). While I am skeptical about Galileo's claims of the role of the 'science of refraction', 'perspective', and 'reason' in his achievement, it is easy to see how crucial those claims were to constitute him as an author.

Galileo's chronologies

Having reviewed Galileo's possible reasons for writing vague narratives about his development of the telescope (including vague gestures toward the role of the 'science of refraction' in that process), we need to look at the narratives themselves and see how they are challenged by Sarpi's letter to Castrino, dated 21 July.

The *Nuncius*' story is not only vague, but also very difficult to reconcile with the one in *The Assayer*. Taking mid-March 1610 (the date on which the *Nuncius* came off the press in Venice) as the chronological benchmark for his statement that, 'about 10 months ago a rumor came to our ears that a spyglass had been made by a certain Dutchman…' that would place the rumor around 15 May 1609. (This sounds remarkably late, given that his friend Sarpi received the same rumor in early November 1608 and that the two were in

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[40] If you think this is strange, try Favaro 'La invenzione del telescopio' (1907/1968), 176: 'Quello che a noi parve di poter chiamare il 'periodo eroico' della storia della invenzione del telescopio incomincia il giorno in cui Galileo, poco importa il discutere se in Padova od in Venezia, sulla semplice voce, cioe` *sine exemplo*, oppure dopo aver anche veduto uno di quei volgari tubi, la vista del quale ben poco poteva aggiungere alla sommaria descrizione che ne avesse udita o letta, costrui` da se` lo strumento e lo presento` alla Signoria.' ('That which it seems we can call the 'heroic period' of the history of the invention of the telescope began on the day – it makes little difference whether in Padua or Venice – on the simple rumour, that is without an example, or after having also seen one of these common tubes that could add little to the summary description which he had heard or read, construcded 'all by himself' the instrument and presented it to the Senate'). In this article, Favaro constructs a tripartite genealogy of the telescope: 'Fabled,' 'Embrionic,' and 'Heroic' – the latter phase starting with Galileo. That allows Favaro to admit that several, even many, people invented and re-invented the telescope prior to Galileo, but that Galileo was the first inventor of the last phase – the one that really counts, the period in which 'la conquista puo` dirsi compiuta e prelude a quell seguito di meraviglie con le quali gli astronomi, armati di strumenti e di mezzi […] ci hanno resi oggi familiari' ('the conquest can be said to be completed and a prelude to the suibsequent miracles with which astronomers, armed with instruments and dimezzi have produced the familiar world of today'). In sum, he uses Galileo's astronomical discoveries (retrospectively) to confirm that his telescope was different (because others did not make those discoveries with other telescopes), and that Galileo, being the inventor of the telescope with which he made those discoveries, invented a 'different' telescope of which he was the first inventor. It is Galileo as the author of his discoveries, who constructs Galileo as the inventor of the telescope.

frequent contact).[41] Instead, Galileo's subsequent statement that 'The rumor was confirmed to me a few days later by a letter from Paris from the noble Frenchman Jacques Badovere' matches reasonably well with other things we know, namely that Sarpi had written Badovere on 30 March 1609 asking about the telescope, and that a complete correspondence cycle between Venice and Paris took about two months.[42] This would have placed Badovere's response in Venice toward the end of May – 'a few days' after 15 May.

It is at this point that, as Galileo put it, Badovere's letter 'finally caused me to apply myself totally to investigating the principles and figuring out the means by which I might arrive at the invention of the instrument, which I achieved shortly afterward on the basis of the science of refraction.'[43] If we take 'shortly after' to mean less than a week, then Galileo had figured out how to build the telescope sometime around 5 June. If, instead, we replace 'shortly after' with 'right away' (as it originally was in the manuscript of the *Nuncius*), then we get something like 30 May. It is a real puzzle, then, why Galileo would have kept the telescope to himself from early June until presenting it to the Venetian Senate on the 24th of August. (Even if we add up a couple of weeks in case the post was exceptionally slow between Venice and Paris that summer, there would still be nine weeks between invention and presentation – a small eternity to somebody who, like Galileo, was keenly concerned with priority).

In addition to these questions, we need to consider the substantial incongruities between the chronologies of the *Nuncius* and *The Assayer*. For instance, the statement in the *Nuncius* that hearing of Badovere's response, 'finally caused me to apply myself totally to investigating the principle …' is re-elaborated in *The Assayer* as:

> I wrote [in the *Nuncius*] that in Venice […] news came that a Hollander had presented to Count Maurits [of Nassau] a glass by means of which distant things might be seen

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[41] Favaro: 'E` strano, stranissimo, anzitutto, che la notizia dell'invenzione olandese, pervenuta a Venezia nel novembre 1608, come gia` abbiamo notato, non sia giunta agli orecchi di Galileo che nel giugno dell'anno successivo, e che il Sarpi, che ne era al fatto, non ne abbia tenuto parola all'amico suo o non gliene abbia scritto[…]' ('It is strange, very strange, very strange,above all that the news of the Dutch invention, which had arrived in Venice in November 1608, as we have already noted, did not reach the ears of Galileo until June of the following year, and that Sarpi, who was up on the facts, did not tell his friend or did not write to him.'], Favaro, 'Il Telescopio' (1883/1966), 277. Add Reeves, *Galileo's Glassworks*, 135 on Galileo's possible contact with Badovere much earlier, in late 1608. Also add that Vincenzio Viviani's 'Life of Galileo' places that rumour a little earlier 'around April or May 1609.'

[42] Paolo Sarpi to Giacomo Badoer, 30 March 1609, in Sarpi, *Opere* (1969), 282.

[43] Galileo, *Sidereus Nuncius or Sidereal Messenger* (1989), 37.

> as perfectly as if they were quite close. […] Upon hearing these news, I returned to Padua […] and set myself to thinking about the problem. The first night after my return, I solved it, and the following day I constructed the instrument and sent word of this to the same friends in Venice with whom I had been discussing the subject the previous day.[44]

In the *Nuncius* Galileo clearly separates hearing the news of the Dutch telescope, receiving Badovere's confirmation 'a few days later ', and developing his telescope 'shortly after' seeing Badovere's letter. In *The Assayer*, however, the whole action is packed in one day: Galileo heard of the presentation of the telescope to Count Maurits in The Hague while discussing with friends in Venice about the telescope (which, one has to assume, included the contents of Badovere's letter), returned to Padua immediately and discovered the 'secret' of the telescope that same night. I am not necessarily questioning this dramatically compressed chronology presented in *The Assayer*, but simply want to point out that if one reconstructs the whole chronology laid out in that book (as Edward Rosen, Stillman Drake, and Antonio Favaro have done) then the day of the Galileo's invention of the telescope would have to be placed around 4 August (Drake) or 18 July (Rosen) or 15 July (Favaro) and *not* at the very beginning of June as implied by the *Nuncius*.[45] Perhaps the chronological vagueness of the *Nuncius*' narrative may have been intended to suggest that Galileo had developed his telescope earlier than he actually did, thus casting him as a relative forerunner rather than a follower, but there is really no way to know.

The chronology of the *Nuncius* loses further credibility when we consider a meeting that Galileo had with Piero Duodo regarding the improvement of his contract at the University of Padua toward the end of June.[46] Had Galileo developed the telescope by then (as *any* reading of the *Nuncius* would imply he should have), he would have brought that up with Duodo as leverage. Of course the *Nuncius*' chronology would become much more tenable and closer to that of *The Assayer* if one tweaked the 'about 10 months ago' mentioned in the printed version with something closer to the 'about 8 months ago' found in the manuscript, but that would only show how unreliable the printed version of the chronology really is.

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[44] Galileo, *The Assayer*, in Van Helden, *Invention* (1977), 52.

[45] Rosen, 'When Did Galileo Make His First Telescope?' (1951), 50; Drake, 'Galileo's First Telescopes at Padua and Venice' (1959), 251. The letter to Landucci (29 September 1609) says 'about two months ago.' Galileo *Opere*, vol 10 (1900), p. 253.

[46] Duodo refers to that conversation in a 29 June letter to Galileo from Venice: Galilei, *Opere*, 10 (1900), 247. The letter is discussed in Drake, 'Galileo's First Telescopes at Padua and Venice' (1959), 250.

I agree with Drake that it makes sense to concentrate on the chronology in *The Assayer* because it contains more specific references – ‘the same night ‘, ‘the following day ‘, ‘six days later ‘, etc. Probably Galileo decided to add more details in 1623 because by then the patronage relation with the Medici was already cemented and he no longer needed to stick to his initial minimalist story – not to mention that he needed to invoke some additional evidence to counter what he saw as Grassi’s questioning of his claim to inventorship. He still avoided specific dates but, luckily, he referred to an event whose date we can pinpoint: ‘Finally [...] I presented it to the ruler in a full meeting of the Council. How greatly it was esteemed by him [...] is testified by the ducal letters still in my possession.’ This was Galileo’s presentation of the telescope to the Venetian Senate on 24 August 1609, and the ‘ducal letters’ were written and signed on the 25th of August.[47] Anchoring ourselves on these two safe chronological posts, we can then attach specific days to the events listed in *The Assayer*.

Starting with end of the story (in 24-25 August), and moving backwards while considering the dates on Galileo was reliably in Padua (based on letters he wrote or entries he made in his accounting ledger), Drake has reconstructed the following timeline, which include a few interpretive interpolations involving events he could not safely pin on specific dates:

ca. 19 July	Galileo leaves Padua to visit friends at Venice.
20 July ff.	He hears rumors of the Holland instrument for the first time and listens to discussions pro and con.
ca. 26 July	He visits Sarpi to ask his opinion and is shown corroborating letters, perhaps including one from Badovere.
ca. 1 August	He hears that a foreigner has arrived at Padua with one of the instruments and is exhibiting it here.
2 or 3 August	He returns to Padua, but learns that the stranger has already departed for Venice to sell the ‘secret.’ He attempts to deduce the construction of the instrument, using information from letters and descriptions by those who have seen it.
4 August	He verifies by trial that suitably separated convex and concave lenses will enlarge distant objects. He sends word to Venice (probably to Sarpi) that he has the ‘secret.’
5-20 August	He succeeds in constructing an instrument of about ten diameters magnification, and sets out again for Venice. [This is the period that

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[47] Galilei, *Opere*, 19 (1908), 115-117; ibidem, 10 (1900), 250-251.

	Galileo referred to as 'more than a month ', but that Drake argues that it must have been 'less than two weeks.']⁴⁸
21 August	He exhibits this instrument to officials from the Tower of St Mark.
24-25 August	He exhibits the telescope to the Signoria and the Senate.

Notice the strong match between Drake's placement of Galileo in Venice and hearing rumors about the telescope starting on 20 July, with Sarpi's saying to Castrino on 21 July that: 'it has arrived here, that spyglass' – an event that, as we have seen, could have happened anytime between 8 July and 21 July.[49] This means that what Galileo heard in Venice was not just a 'that a Hollander had presented to Count Maurice [of Nassau] a glass by means of which distant things might be seen as perfectly as if they were quite close. That was all.'[50] What Galileo must have heard during the conversations he mentions was, at a minimum, Sarpi's detailed description of an actual instrument.

Sarpi's letter also allows us to fix a problem in Drake's reconstruction. Not knowing about this letter, Drake hypothesized that Galileo, about a week after arriving in Venice around 20 July, heard that a stranger was displaying a telescope in Padua. Drake hinged this reconstruction on a letter by Lorenzo Pignoria on that subject, dated 1 August.[51] Based on that, Drake assumed that Galileo rushed back from Venice to Padua around 2 or 3 August to catch a glimpse of the telescope. But, according to Drake's hypothetical narrative, Galileo failed to see the telescope because by the time he got to Padua the foreigner had already moved on. Sarpi's letter, however, indicates that Galileo had no need to rush back to Padua to catch a glimpse of the telescope because the telescope was right there in Venice when he got there on 19 or 20 July.

As a result of this imagined detour, Drake effectively gave Galileo a 'late start' on the telescope. He placed Galileo's remark that 'The first night after my return [to Padua], I solved it' at 2 or 3 August, when in fact Sarpi's letter shows that those lines must have referred to events that took place around 21 July. But while Drake attributed an incorrect late start to Galileo, he still had to put that together with the 24 August date on which Galileo presented

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[48] Drake, 'Galileo's First Telescopes at Padua and Venice' (1959), 249.

[49] Sarpi, *Lettere ai Protestanti*, 2 (1931), 45.

[50] Galileo, *The Assayer*, in Van Helden, *Invention* (1977), 52.

[51] Lorenzo Pignoria to Paolo Gualdo, 1 August 1609: '[…] Uno degl'occhiali, di che ella mi scrisse gia`, e` comparso qui in mano d'un Oltramontano' ('One of the glasses about which you write me has already arrived here in the hands of a foreigner'), in: Galilei, *Opere*, 10 (1900), 250.

the telescope to the Senate. As a result, he compressed the time between the development of the telescope and its official presentation, concluding that Galileo's statement that he showed the telescope around Venice for 'more than a month' after building it had to be taken to mean 'less than two weeks.' But if we revise Drake's chronology according to the evidence provided by Sarpi's letter of 21 July, we then see that Galileo claim of having had the telescope for more than a month prior to showing it to the Senate was almost correct. Having developed the telescope earlier, he did show it around for longer prior to the official presentation on 24 August. I propose, therefore, the following revised chronology:

18 July	Galileo in Padua (ledger entry).
ca.19- 20 July	Galileo in Venice. Hears full report from Sarpi or perhaps sees the telescope itself.
ca. 21 July	Galileo back in Padua: 'Upon hearing these news [in Venice], I returned to Padua, where I then resided, and set myself to thinking about the problem.'
ca. 21 July	Galileo uncovers the 'secret' of the telescope: 'The first night after my return [to Padua], I solved it.'
ca. 22 July	Galileo builds prototype: 'the following day I constructed the instrument and sent word of this to the same friends in Venice with whom I had been discussing the subject the previous day.'
ca. 27 July	Galileo takes his 9-power telescope to Venice: 'Immediately afterwards, I applied myself to the construction of another and better one, which I took to Venice six days later.'
24 August	'[The telescope] was seen with great admiration by nearly all the principal gentlemen of the that republic for more than a month on end.'

21 August	Exhibits the telescope to some Venetian gentlemen and senators (as described in Priuli's 'Cronaca').[52]
24 August	'I presented [the telescope] to the ruler in a full meeting of the Council.'
25 August	'[...] ducal letters [...] reappointing and confirming me for life to my professorship at the University of Padua.'

Rosen amended

Like Drake, Edward Rosen has offered a reconstruction of Galileo's chronologies, coming up with a substantially earlier date for Galileo's invention – sometime between 5 July and 19 July. The difference between Rosen and Drake has much to do with their sources. Drake looked at both *The Assayer* and Galileo's correspondence, but also at the dates of Galileo's bookkeeping entries, using them as evidence of his presence in Padua. Rosen did not look at Galileo's ledger, thus allowing for the possibility of Galileo being in Venice and performing the tasks described in *The Assayer* when, in fact, he could not have been there. Rosen also tried (and failed) to reconcile Galileo's various chronologies ending up (after some ad hoc adjustments) with a 5-19 July 'window of invention' – 19 July being the latest possible date allowed by his reconstruction.[53]

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[52] Dalla Cronaca di Antonio Priuli: '21 Agosto. Andai io [Antonio Priuli], Geronimo Priuli Procurator in Campanil di S. Marco con l'Eccellente Gallileo, et [...] l'Eccellente Dottor Cavalli, a vedere le meraviglie et effetti singolari del cannon di detto Gallileo, che era di banda, fodrato al di fuori di rassa gottonada cremesina, di longhezza tre quarte ½ incirca et larghezza di uno scudo, con due veri, uno [...] cavo, l'altro no, per parte; con il quale, posto a un ochio e serando l'altro, ciasched'uno di noi vide distintamente, oltre Liza Fusina e Marghera, anco Chioza, Treviso et sino Conegliano, et il campanile et cubbe con la facciata della chiesa de Santa Giustina de Padoa: si discernavano quelli che entravano et uscivano di chiesa di San Giacomo di Muran; si vedevano le persone a montar e dismontar de gondola at traghetto all a Collona nel principio del Rio de' Verieri, con molti altri particolari nella laguna et nella citta` veramente amirabili. E poi da lui presentato in Collegio li 24 del medesimo, moltiplicando la vista con quello 9 volte piu`' ('August 21. I [Antonio Priuli], Geronimo Priuli, Procurator of the Tower of St Marc, went with the excellent Mr. Galileo, [...] and the excellent Dr. Cavalli to see the marvels and singular effects of the tube of the said Galileo. It was made of tin, decorated on the outside with light red cotton satin, about three quarters and ½ braccia long, the diameter of a scudo, with two glasses, one [...] concave and the other not, on each side. With it, looking with one eye while keeping the other shut, each of us saw distinctly beyond Liza Fusina and Marghera, also Chioggia and Treviso and even Conegliano and the belltower and [...] the façade of the Church of Saint Giustina in Padova. We could see those entering and exiting the Church of Saint Jacob in Murano, and the people who climbed on and off the gondole at the ferry at the column near the beginning of the Rio de' Verieri, and many other truly admirable details in the lagon and the city. [This instrument] was then by him presented to the Senate on the 24th of the same month. It magnifies 9 times.' (Galilei, *Opere*, 19 (1908), 587).

[53] Rosen, 'When Did Galileo Make His First Telescope?' (1951), 50.

According to Drake, 19 July is the earliest date by which Galileo could have arrived in Venice from Padua, thus starting the chain of events ending up with his invention. Rosen assumes instead that by 19 July at the latest Galileo was already back in Padua with his telescope. The scenario that best matches the accounting schedule, *The Assayer*'s chronology, and Sarpi's letter is, I think, the one I have just presented above – an amended version of Drake's chronology. There are, however, two additional scenarios that could technically match Rosen's reconstruction while also taking into account the additional evidence he left unused.

If we assume that the dates on Galileo's accounting ledger match the dates on which he made them, then Galileo was in Padua on 23, 28, 29 June; 6, 11, 18 July; and 3, 10 August.[54] He wrote to Florence from Padua on 3 July, citing an illness.[55] There are, however, two intervals (11-18 July and 6-11 July) in which Galileo could have gone to Venice and quickly returned to Padua after having heard a detailed description of the foreigner's instrument from Sarpi. For the latter window to work, however, the telescope would have had to arrive in Venice right after Sarpi's 7 July letter to Castrino. The second window – 11-18 July – would be more probable in that regard. Both of them, however, would increase the amount of time between Galileo's invention and the presentation to the Senate (a six-week period in which his telescope would have been in Venice without anyone mentioning it).[56]

While technically possible, these earlier windows of invention do not look probable. If Galileo had a telescope as early as 6 July, why did he not rush to present it to the Senate *before* the foreigner had a chance to do so? If he already had an 8- or 9-power telescope by early or mid-July, why would he have risked missing on financial rewards and the recognition of his inventorship? This makes me side with Drake over Rosen. I think Drake got the wrong date but through the right reasoning. He understood that, contrary to Galileo's public narratives, what got his telescope-making program in high gear were not the reports of the invention of the telescope but rather the news of the actual arrival of the instrument in Venice. What I have done here is to show that the

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[54] Galilei, *Opere*, 19 (1908): 23 June (158), 28 June (145, 165), 29 June (174), 6 July (197), 11 July (145), 18 July (145, 166), 3 August (166), 10 August (166). The page numbers in parentheses refer to the bookkeeping entry for the dates that precede them.

[55] Enea Piccolomini to Galileo Galilei: 'La gratissima di V.S. delli 3 di Luglio […]. Mi duole poi in estremo della sua indisposizione […]'('The most welcome letter of Your Lordship of July 3 [...] It pains me very much to hear of your health problems'). Galilei, *Opere*, 10 (1900), 254-255.

[56] The first independent mention of Galileo's telescope is Priuli's 'Cronaca' entry for 21 August 1609, Galilei, *Opere*, 19 (1908), 587.

news arrived earlier than previously assumed, and that Galileo got more than just the news.

Galileo & Sarpi revisited

The long-standing debate over Sarpi's contribution to Galileo's work has been typically framed in terms of philosophical and theoretical influences: suggestions or full-fledged theories that Sarpi may have communicated to Galileo about mechanics, optics, tides, and magnetism. What Sarpi's letter to Castrino brings up, instead, is a less philosophical and more mundane contribution – something like technology transfer.

Until now, there were two main pieces of evidence linking Sarpi to the development of Galileo's telescope – traces that now gain new meaning and robustness in light of Sarpi's letter to Castrino. The first was a letter from Giovanni Bartoli (the secretary of the Medici representative in Venice) who, writing to the Florentine court on 29 August 1609, claimed that:

> It is reported that the foreigner who came here with the secret [of the telescope], having heard from I do not know whom (some say from Brother Paolo, the Servite theologian) that he was not going to get anything by pretending 1,000 zecchini, he departed without making any further effort. And therefore, being Brother Paolo and Galileo friends, and having him given an account of the secret he had seen, people say that Galileo, through his own reasoning and with the help of another similar instrument (but not a very good one) from France, sought the secret and found it..[57]

Bartoli's letter was largely dismissed as motivated by unfriendliness toward Galileo, which Bartoli had indicated elsewhere in his correspondence.[58] Setting aside the issue of bias, Bartoli's remarks have previously seemed irrelevant to the genealogy of Galileo's telescope because by the time he wrote that letter (August 29) Galileo had already presented his telescope to the Venetian Senate on (August 24).[59] Bartoli did mention the foreigner's presence in Venice and his attempt to sell his telescope to the Senate in an earlier August 22 letter to Florence, but we have reliable reports that Galileo was already demonstrating his telescope to Venetian patricians on August 21.[60] It was therefore easy to assume that Galileo

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[57] Giovanni Bartoli to Belisario Vinta, 29 August 1609: Galilei, *Opere*, 10 (1900), 255.

[58] Parenthetically, the last part of the report suggests the presence of two telescopes in Venice – one inspected by Sarpi and a second ('French') instrument allegedly used (owned?) by Galileo.

[59] Galileo Galilei a Giovanni Donato [Doge of Venice], 24 August 1609, Galilei, *Opere*, 10 (1900), 250-251; 'Deliberazione del Senato,' 25 August 1609, Galilei, *Opere*, 19 (1908), 115-116; 'Ducale,' Galilei, *Opere*, 19 (1908), 116-117.

[60] Priuli, 'Cronaca,' in Galilei, *Opere*, 19 (1908), 587-588.

had already built his telescope by the time Bartoli reported an alleged exchange between Sarpi and Galileo. However, this all changes – dramatically so – once we realize that Sarpi's July 21 letter to Castrino indicates that Bartoli may have been lagging behind in his correspondence with Florence. Some of the events he wrote about on August 22 and 29 could have taken place (or were at least set in motion) significantly earlier.

Furthermore, there is a report of what appears to be the same exchange in the 'Life of Fra Paolo Sarpi' written several years later by one of his closest friends and collaborators, Fulgenzio Micanzio – a scholar who had direct access to Sarpi's documents and recollections:

> The manufacture of the spyglass known in Italy as Galileo's (but invented in the Netherlands) was discovered by him when [the instrument] was presented to the Doge with a request of a 1,000-zecchini reward. Brother [Paolo] was put in charge of testing its uses and give a report, but because he was not allowed to open it up and inspect it, he guessed what he could. He then shared this with Mr. Galileo (who thought that Sarpi had got it right), as well as with others.[61]

This passage should be taken seriously. No doubt Micanzio was eager to give Sarpi some posthumous credit for the development of the telescope, but he was by no means an enemy of Galileo's. He supported him during the trial, attempted to publish his *The Two New Sciences* in Venice a few years later and, when that proved unfeasible, he facilitated the transfer of Galileo's manuscript to Amsterdam to have it published by the Elseviers. Furthermore, Micanzio's and Bartoli's reports seem to be independent of each other. As Micanzio would have had no need to rely on Bartoli's information, the remarkable similarity between the two reports indicates that they came from same source, most likely Sarpi himself.[62]

This passage from the 'Life of Fra Paolo' seems to have gone largely unused by Galileo scholars possibly due to the fact that Micanzio failed to attach a

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[61] Fulgenzio Micanzio 'Vita del Padre Paolo': 'L'occhiale, detto in Italia del Galileo, trovato in Olanda, fu da lui [Galileo] penetrato l'artifizio quando, presentandone uno alla serenissima signoria con dimanda di mille zecchini, fu al padre dato carico di far le prove a che potesse servire e dirne il suo giudizio; e perche' non gl'era lecito aprirlo e vedere, imagino` cio` che potesse, e lo conferi' col signor Galileo, che trovo` il padre aver dato nel segno; e tanti altri,' in: Sarpi, Istoria del concilio tridentino, 2 (1974), 1372-1373.

[62] A recent book by Filippo de Vivo mentions a Giovanni Bartoli – a lawyer active in Venice in this exact period – connected to Sarpi's unorthodox religious networks and its nodes, including the 'Golden Ship' (De Vivo, *Information and Communication in Venice* (2008), 125. The Golden Ship was the shop of Bernardo Sechini, where Sarpi, Galileo, Acquapendente, and Asselinau regularly convened. (Favaro, 'Galileo e Venezia,' 2 (1966), 87).

specific date to the events he was describing. It did not help, of course, that Favaro decided not to include this text in the *Opere*. (Incorrectly believing it to be an anonymous text of dubious origin – not a biography written by Micanzio – Favaro took the whole 'Life of Fra Paolo' to be untrustworthy).[63] But if we agree that, given their strong resemblance in content and structure, Micanzio's narrative and Bartoli's letter refer to the same events, and that Sarpi is referring to the foreigner's instrument when he writes on July 21 that the telescope has arrived in Venice, then these three pieces of evidence gel with each other (and with *The Assayer*'s chronology) to provide a substantially new picture of Galileo's development of the telescope.

As relayed by Micanzio, Sarpi did not provide Galileo with a full disclosure of the 'secret' of the telescope, but rather with a close description and some thoughts about how it functioned – guesses Galileo seemed to agree with. Still, by reporting to him the overall dimension of the instrument, the approximate diameter of the lenses, and the fact that the objective lens was convex and the eyepiece concave, Sarpi could have put Galileo very close to the 'secret' of the telescope (if there was any secret left at that point), and helped him to narrow down the range of further experimentation to the focal length of the two lenses or, if we follow Rolf Willach's recent work, the diaphragm applied in front of the objective lens.[64] Sarpi's detailed input may account not only for Galileo's initial development of the telescope, but also for the exceptionally short time – about 24 hours – he claimed it took him to get there.

What Sarpi's technology transfer does not account for, however, is the development of Galileo's subsequent higher-power instruments – 9X, 20X, and finally 30X. Still, as discussed by Albert Van Helden in this volume, those developments were much more material than theoretical – expanding grinding and polishing techniques beyond those of traditional spectacle-makers to handle larger blanks and produce weaker convex lenses, selecting the best kind of glass (flat mirror glass), and produce tens of lenses from which to select only a handful of suitable ones, and so on.[65] The 'secret' of the telescope, therefore, appears to have been closer to a 'guild secret' than to a theoretical understanding of telescope optics.[66]

Finally, if we properly understand Sarpi's role in this process we do not need to speculate – as Drake did – that Sarpi may have blocked the foreigner's

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[63] Favaro, 'Il telescopio' (1883/1966), 268.

[64] Willach, The Long Route (2008), part 5.

[65] Van Helden, 'Galileo and the Telescope,' this volume.

[66] Biagioli, G*alileo's Instruments of Credit* (2006), 116, 120.

application to favor his friend.[67] Sarpi was, no doubt, a friend of Galileo's but he was first and foremost the *Consultore* of the Republic doubling as technical expert on *res telescopica*. Having written Castrino that, '[I] don't value it at all for its military uses, either on land or at sea,' it would seem that Sarpi ended the foreigner's bid not because of his friendship with Galileo, but because of his telescope's poor performance relative to the 1,000 *zecchini* he demanded. Furthermore, being an *ex parte* examiner for the Republic, it would have been expected of Sarpi (and ethical according to the technology transfer customs of the time) to pass on to Galileo (as local talent, not just a personal friend) whatever information could have enabled him to come up with a better instrument that could then be offered to the Senate.[68] Sarpi may have viewed Galileo as a means for achieving the (Venetian) common good.[69]

Galileo and the 'oltramontano'

Sarpi's letter connects Galileo's invention of the telescope to the foreigner's instrument, but it says little about the timeframe of that technology transfer.[70] For instance, did Sarpi view and look through the foreigner's telescope prior to being asked by the Senate to evaluate it? How long did the foreigner stay in Venice? Were Bartoli's reports of the demise of the foreigner's application as out of date as they appear to be, or did they indicate that the evaluation process of the foreigner's telescope did indeed drag into August? (This is not unreasonable, as it would have taken some time for the *Oltramontano* to develop the appropriate connections with the Venetian bureaucracy and Senate to float his proposal).

Sarpi could have already recommended the Senate against the foreigner's offer by the time he wrote to Castrino on 21 July. But it is as likely that he was still in the process of evaluating the instrument, and passing crucial information to Galileo along the way. If that were the case, it could explain the remarkable rush with which Galileo got to work on the telescope, and the urgency

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[67] Drake, 'Galileo's First Telescopes at Padua and Venice' (1959), 250-note 15.

[68] 'Finally, at the suggestion of one of my friendly patrons, I presented it to the ruler in a in a full meeting of the Council.' (Galileo, *The Assayer*, cited in: Van Helden, *Invention* (1977), 52). It is possible that the 'patron' mentioned here was Sarpi.

[69] This fit the logic (and ethics) of early modern patent law, as first promoted and then articulated in Venice.

[70] Based on other letters, we know that Venice was quickly becoming populated with more telescopes in August, suggesting that Galileo may have seen or heard about other telescopes as well, as suggested by Bartoli's report of 22 August.

with which he immediately sent news back to Venice about his invention: 'the following day I constructed the instrument and sent word of this to the same friends in Venice with whom I had been discussing the subject the previous day.'[71] Perhaps he wanted to let Sarpi and other officials know that he was in the running too, and that they should wait before deciding on the foreigner's device?[72]

Given the circumstances, a 'race to the Senate' might have then developed between the foreigner and Galileo. If, for instance, Bartoli's report of 22 August that 'many have seen and tested [the foreigner's telescope] from St Mark's bell-tower' is chronologically accurate, that would make that test virtually contemporaneous with Antonio Priuli's report of having seen 'those marvelous and singular effects of Galileo's tube' together with some Venetian notables on 21 August.[73] Up and down St Mark's tower, the two telescopes may have been publicly tested in the same days.

Conclusion

These last remarks are hypotheses that we may be able to test in the future, if new documents surface. Still, the fact that Sarpi's letter to Castrino has been hiding in plain sight for almost two centuries suggests that we may not have asked all the questions we could have. In particular, we have been too eager to accept Galileo's narratives as descriptions rather than discursive instruments. Sarpi's letter has brought up some of the chronological and empirical problems in these narratives, but one can find other tensions as well. Consider, for instance, Galileo's predicament in the narrative of invention he presented in *The Assayer*.

In it, Galileo is caught between rebuffing Grassi's accusation that the telescope was not his child but only his pupil, while also having to acknowledge that the telescope did have a Dutch father already. This would not have been a problem in the economy of inventions, where there could be as many inventors of the telescope as there were countries. Claiming local (that is, Venetian) inventorship of the telescope would have allowed Galileo to acknowledge extensive borrowings from foreign inventors (as they had no relevance for that definition of inventorship). But Galileo, trying to develop the right profile for

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[71] Galileo, *The Assayer*, cited in: Van Helden, *Invention* (1977), 52.

[72] It would seem, in any case, that those 'same friends in Venice' mentioned by Galileo must have been very few and quite tight-lipped to account for the 'media silence' over Galileo's telescope for the six weeks until the test on 21 August witnessed by Priuli.

[73] Galilei, *Opere*, 10 (1900), 250; *Ibidem*, 19 (1908), 587.

a recipient of princely patronage, decided to cast himself as a 'purer' inventor. What Grassi did was to force Galileo to confront the problems he had created for himself by adopting that figure.

In turn, Galileo tried to evade the paradox of claiming to be the biological father of a child who already had a biological father by positing the existence of two types of telescopes – one accidentally fathered by the Dutch spectacle maker, and a very different one fathered by Galileo through reason. That is, in *The Assayer* he did not argue that he was the inventor of a telescope that was unique by virtue of having better resolution and enlarging power than all previous instruments. (That would have been an engineer's argument, and Galileo, eyeing the court, did not want to cast himself as an engineer, not even a very good one). He claimed, instead, a kind of inventorship defined by a specific process of invention (a reason-based one) rather than by the quality of the product resulting from that process.

The issue here is not whether these two breeds of telescope existed or not, whether one could tell them apart, or whether they were twins or distant cousins. The point is to recognize that Galileo's narrative is not an empirical answer to Grassi's accusation, but rather an attempt to reframe it in terms that would allow Galileo to come up with an answer – not necessarily a good answer, but something that looked like an answer. In other words, that Galileo's telescope was unique by virtue of having been produced not by chance but through 'reason,' 'the science of refraction,' and the 'knowledge of perspective' is a kind of conceptual product differentiation aimed at defining an object that Galileo (and, in his narrative, only Galileo) could then claim inventorship for. In doing so, he was creating an opposition between him and his telescopes and the 'simple spectaclemakers' and theirs. But while there were of course substantial differences between Galileo's instruments and the others, there is no guarantee whatsoever that those differences could be reduced to the kind that Galileo had posited.

The same applies to the 'secret' of the telescope. No doubt, there were all sorts of steps and problems that needed to be sorted out in order to produce the kind of telescope Galileo was able to produce – problems that could easily straddle the line between so-called practical and theoretical knowledges. But there are very good reason to doubt that the concept of 'secret' would be able to adequately describe the nature of these challenges. As a concept, 'secret' seems as overdetermined as Galileo's claims to inventorship based on the 'science of refraction': it is precisely the kind of object Galileo needed to be the inventor of in order to be able to cast himself as the kind of inventor he wanted to be.

As Galileo was ‘inventing’ the object we now call the ‘telescope,’ he was effectively inventing a new notion of invention and a new illustration of the inventor to go with it. That adds to the fun of tracing and retracing these materials, especially if we pay as much attention to his narratives and concepts of invention as we do to the material results of his innovation.

Acknowledgements. Nico Bertoloni Meli, Nick Wilding, Eileen Reeves, Matteo Valleriani, and especially Al van Helden have offered important help and criticism. The present chapter represents a substantial expansion of the 2010 Alan Binder Lecture at the University of California, San Diego. I wish to thank Provost Don Wayne for the kind invitation, and the Binder Endowment for its generosity.

The world's oldest surviving telescopes

Marvin Bolt & Michael Korey

Introduction

The first documented public presentation of the telescope in 1608 by Hans Lipperhey in the Netherlands displayed the instrument's potential both for long-distance surveillance and for seeing stars not visible to the naked eye. As is well known, within the next year, at least six users observed the heavens *before* Galileo Galilei made his significant astronomical discoveries and demonstrated the potential economic benefits for those watching ships arriving in port. Indeed, the device soon spread throughout Europe and into Asia.[1]

Scant evidence survives on the extent of early telescope production, but numerous references to the appearance of this device at book fairs and merchant stalls shortly after Lipperhey's demonstration suggest that many hundreds, if not many thousands, were produced prior to 1650. In his important paper on the development of telescope optics in the early seventeenth century, Rolf Willach provided a census of known surviving telescopes made before 1650 (and largely) with still intact optics.[2] Surprisingly, this well-researched list included only eight examples, summarized below with their current locations, ordered as in Willach's article:

1. Pierre Dujardin, Paris; Willach Collection, Switzerland;
2. unknown maker, Italy; Adler Planetarium, Chicago (M-421);
3. unknown maker; associated with King Gustav Adolf of Sweden; Livrustkammaren, Stockholm;
4. unknown maker; associated with King Gustav Adolf of Sweden; Livrustkammaren, Stockholm;
5. unknown maker; associated with Pierre Gassendi; Hermitage Museum, St Petersburg;

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[1] Details of the new device, its first users, and its quick dissemination appear in Zoomers & Zuidervaart, *Embassies* (2008); Sluiter, 'The Telescope before Galileo' (1997) and Sluiter, 'The First Known Telescopes' (1997).

[2] Willach, 'The Development of Telescope Optics' (2001).

6. unknown maker; possibly associated with Francisco Fontana; Monte Mario Observatory, Rome;
7. unknown maker; part of the *Pommerscher Kunstschrank*; Kunstgewerbemuseum, Berlin;
8. Heinrich Stolle, Prague; British Museum, London.

In addition, Willach listed four objectives dating from *c.* 1645 connected to Evangelista Torricelli, as well as the two telescopes associated with Galileo at the Museum of the History of Science (IMSS, soon to be renamed the Museo Galileo) in Florence. These latter instruments raise many interesting questions of provenance, but their obviously early construction merit their inclusion (as telescopes No. 5 and No. 6) in our expanded listing here. Motivated by Willach's important study, the authors began to conduct a search for additional surviving telescopes made prior to 1650.

The search

Why should we look for additional examples, and where? The current small sample size makes it difficult to assess rhetorical or other claims about the power of the new instrument or to confirm oft-repeated generalizations about its early history and development. Much remains to be learned about the grinding and polishing of lenses, the overall shape and form of the telescope itself, its materials, and its decorative elements. None of these questions have canonical, *a priori* answers. Broader issues loom. Who could get access to such an instrument? How might its possession or craftsmanship demonstrate prestige or status, perhaps associated with patronage or natural philosophy?[3]

The authors have begun a project to advance our ability to understand such issues by locating unknown early telescopes, systematically investigating both these and previously known instruments, and compiling visual and literary images of early telescopes. This artefact-based project has several components: evaluating existing information; conducting a preliminary investigation of items identified; documenting them thoroughly with photographs and precise measurements of key optical and physical characteristics; identifying materials, details, and, as possible, recorded provenance peculiar to each instrument; and making these data available on an important, well-known institutional website.

Our purpose is to provide access to evidence concerning the evolution, distribution and social significance of the telescope. Such data will enable

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[3] Biagioli, *Galileo, Courtier* (1993) provides extensive details of the intricacies of patronage.

classification of unsigned telescopes, detection of historic trends in the manufacture of lenses and supplementation of other forms of evidence on the dissemination of craft knowledge. This work requires amassing data for many telescopes, especially signatures, dates, known provenance information, and key optical measurements. A prerequisite for the accuracy and consistency of this documentation is gaining access to telescopes in diverse museums and private collections.

Accustomed as we are to thinking of telescopes as part of a large, permanently installed astronomical observatory, we might easily overlook the settings in which telescopes typically appeared in their first decades. Our collaboration has begun to tease out some of these 'other' settings for the telescope, thereby showing the telescope's function not only as a powerful tool of science but also as a fashionable device in aristocratic and courtly circles. For example, the 1611 inventory of the *Kunstkammer* of Emperor Rudolf II in Prague reveals that he had more than a dozen telescopes, none of which apparently still exists. Archival records in Dresden indicate that three telescopes entered the *Kunstkammer* of the Saxon Elector in 1613; at least one of these was likely the world's oldest, extant, securely-datable telescope until 1945, when it was destroyed in the bombing of Dresden. Recent research shows that telescopes were made by Jesuit students in Portugal in the 1610s, and were carried to China and Japan in that decade; although none of these devices seems to survive, further investigation is needed.[4]

Then, as now, most telescopes were used for terrestrial rather than for astronomical purposes. But whether used for navigation, surveying, commercial, military or astronomical application, the production of high-quality or highly adorned telescopes carried with it the possibility of patronage and funding. Local conditions influenced the overall appearance of early telescopes: instruments made in Venice, Florence, or Nuremberg, for example, feature different kinds of paper on the draws or differing details on their main tubes. Building especially on the work of Rolf Willach and Rolf Riekher, our inventory of these features will assist in identifying telescopes with no provenance or in linking the production of telescopes with objects made of metal, paper or leather. Telescopes covered in paper and leather were often worked by bookbinders or other artisans, whose techniques and artistic styles have been catalogued

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[4] For an analysis of the Dresden telescopes, see Dupré and Korey, 'Optical Objects' (2009). The role of the Jesuit dissemination of the telescope was discussed by Henrique Leitao in his presentation 'G.P. Lembo's lecture notes on the telescope in Lisbon, 1615-1617' at *The Invention of the Dutch Telescope: Its Origin and Impact on Science, Culture, and Society, 1550-1650* in Middelburg 27 September 2008.

in the context of decorative arts and material culture, but not yet extensively in that of the history of the telescope.[5] For example, our recent match between marbled paper found on the pre-1617 telescope from the *Pommerscher Kunstschrank* (telescope No. 1, below) with the paper lining the compartments of a similar *Kunstschrank* in Dresden (housing telescope No. 9, below) has implications for both objects and for the study of historic telescopes.

These diverse issues underlying the evolution of the art of lens-making and, more broadly, of telescope-making as a whole concern the production and transmission of knowledge in the early modern era, and the relationships between artisans and scholars. A fuller understanding of these important elements should greatly enrich the history of the telescope, extending the work of Willach, Riekher, Henry King and Albert Van Helden on its technical details. It will also augment textual analyses of early telescope treatises and communications, as well as interdisciplinary investigations of cultural history. Our synthesis of traditional historical methods aided by laboratory techniques provides powerful analytical tools to support and guide more richly contextualized studies of the telescope, the broader goal of this project.

Results

As of April 2009, we have located several good candidates to expand Willach's 2001 list, from both public and private collections. The first, and likely most important one, No. 9 below, comes from the Kunstgewerbemuseum (Museum of Decorative Arts) in Dresden. The second, No. 19, is in the Astronomisch-Physikalisches Kabinett in Kassel; additional investigation of its optics and its decorative tooling is still needed in order to confirm the dating, which is based largely on the macroscopic form of its uniform-diameter cylindrical shape. News of an early instrument from Japan comes from Tsuko Nakamura; archival evidence indicates the pre-1650 dating of this intriguing instrument (No. 18). Four examples (No. 8, 11, 12, 13) belong to the Peter Louwman Collection of Historic Telescopes. Two telescopes (No. 3 and 7) come from a Swiss private collection; the first of these is a leather-covered pasteboard telescope, complete with end caps, whereas the second is a cylindrical metal tube. Further investigation of the optics of both is still needed in order to bolster the dating. Finally, in March 2009, we became aware of another candidate in a European private collection.

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[5] A pioneering study in the context of English instruments is Turner, 'Decorative Tooling' (1966).

The list

Our current inventory of the surviving telescopes made prior to 1650 follows. Entries found in the original list of Willach's paper are indicated by an asterisk below. We have personally inspected, at least to a limited extent, the majority of these – No. 1, 2, 3, 4, 7, 8, 9, 10, 11, 13, 14, 15, 17, 19 – although we ourselves have so far been able to conduct a thorough optical analysis of only No. 9 and 10.

Following Willach,[6] our list does *not* include examples of early telescope objectives that survive without their tubes, such as the broken objective of Galileo held in Florence and the four objectives made by Torricelli *c.* 1645, though any further study of early telescopes must, of course, include such lenses. Each entry below provides a photo and details, where available, according to the following scheme:

Approximate date: maker, original location; current collection,
location (accession No.).
Physical information (length, number of draws, materials).
Optical information (number of lenses and types).
Provenance and commentary.

1. *1617 or prior: unknown maker, Augsburg, Germany, part of the* Pommerscher Kunstschrank*; Kunstgewerbemuseum, Berlin, Germany (P 23).*

Consisting of a main tube and five draw tubes made of pasteboard, this beautiful instrument extends to some 927 mm. Each draw is covered in marbled paper, with the main tube and rings at the end of each draw covered in silk velvet and embellished with gold-thread needlework. With the draws collapsed, the rings and main tube form a cylinder – that is, the rings of varying inner diameter have a common outer diameter (48 mm), a distinctive feature of several other telescopes found on this list; cf. 2, 4, 9, 10, 11, 17, 19, 20 and 21.[7]

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[6] Willach, 'The Development of Telescope Optics' (2001).

[7] That this is a common characteristic of early telescopes seems first to have been noted by Inge Keil in *Augustanus* (2000), 276f., and by Rolf Willach in 'The Development of Telescope Optics' (2001). Confirmation comes from inspection of the instruments listed in this paper, as well as from numerous early illustrations of telescopes, as well as paintings.

The objective is plano-convex, the ocular plano-concave; both planar surfaces face outward. The objective of diameter 40 mm is stopped down to just under 17 mm, whereas the ocular is stopped down from 25 mm to 10 mm. The objective focal length is ca. 950 mm, that of the ocular just under 60 mm, yielding a magnification of about 16 times. Typical of Galilean telescopes, it provides a small field of view – only about 4 m at a distance of 1000 m, or under 15 arc minutes, for an eye pupil opening of 6 mm – yet one that gives a surprisingly clear and sharp (upright) image.[8]

Within the group of the earliest surviving telescopes, this one stands out for its exceptionally well-documented provenance. Along with mathematical instruments, tools, games, toiletries and other artefacts, this telescope formed part of the original contents of an elaborately-decorated curiosity cabinet known in German as a *Kunstschrank*. This piece of princely furniture was (with its contents) assembled for Duke Philipp II of Pomerania by the Augsburg diplomat, dealer, and art connoisseur Philipp Hainhofer, who coordinated the activities of two dozen Augsburg-based craftsmen and instrument makers in its manufacture, beginning in 1610. At the start of August 1617, the *Kunstschrank* was sent from Augsburg to the Duke's court in Stettin (now Szczecin, Poland). Correspondence between Hainhofer and German dukes around the procurement of suitable telescopes goes back to 1611, but the instrument discussed here was apparently delivered only in 1617 as part of the accompanying cabinet.[9] The *Kunstschrank* (with its contents) later passed to the Elector of Brandenburg, eventually passing to the Prussian royal *Kunstgewerbemuseum* (Museum of Decorative Arts) in Berlin. During the Second World War, the contents were stored separately from the cabinet; the latter was destroyed, whereas the former, including this telescope, survived largely intact.

The cabinet also contained documentation of the many artisans involved in the assembly of the *Kunstschrank*, in the form of an (imaginary) group portrait showing them arrayed at the presentation of the instrument to the Duke, along with an accompanying list identifying the men portrayed and their respective trades. Lessing and Brüning singled out the Augsburg bookbinder on this list, Gabriel Mehlführer, as the possible maker of the telescope's tubes, the marbled paper covering its draws and the leather covering of its main tube, with the lenses believed to have been acquired by Augsburg merchants in Venice.[10]

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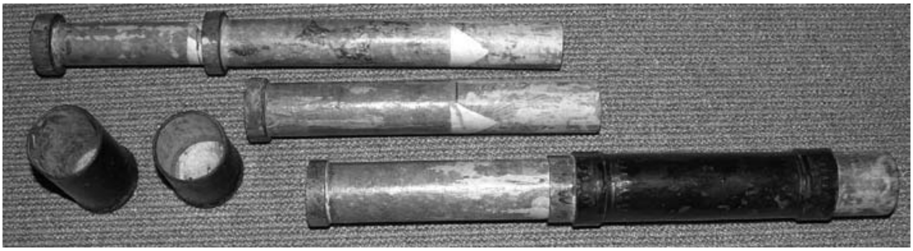
[8] Riekher, *Fernrohre* (1990), 47. We thank Rolf Riekher for sharing with us with his insights and meticulous optical measurements, as well as for many stimulating conversations.

[9] Keil, *Augustanus* (2000).

[10] Lessing and Brüning, Kunstschrank (1905); Mundt, *Kunstschrank* (2009), 177 f.

Hainhofer's inventory of the cabinet, as delivered to the Duke, describes this instrument as follows: 'a tube or helioscope, of [the type of] Galileo Galilei, constructed with markings for near and distant viewing, which can be accommodated to any [user] according to his near- and farsight[edness?] and his age, the lenses of which [he] especially has to keep clean; the farther one will see with it, the more serviceable it is when aimed [at an object] at least three miles distant.' Its documentation makes this instrument the world's oldest surviving, securely-datable telescope.[11]

2. *c.1620: Pierre Dujardin (?), Paris, France; Willach Collection, Switzerland.*[12]



Ascription of the maker comes from the initials 'PD' embedded in a 'fish-skeleton' form tooled with gold leaf on the main tube, which is mostly covered with brown leather. Each of the four cardboard draws is covered in blue and pink marbled paper, largely faded on the halves of the tube that are usually drawn out. When collapsed, the telescope forms a cylinder, enclosed by the surviving end caps.

The telescope has Galilean optics, the bi-convex objective of 23 mm having a free aperture of 19 mm. Typical of early lenses, this objective features numerous bubbles and is not polished around the edges. The eyepiece is plano-concave. The combination yields an upright image magnified 14 times.

More information is needed about Dujardin. Current best indications are that he lived from 1594-1645. Few instruments of his survive, but those (all non-optical) are dated from 1614 to 1645. A diptych dial ascribed to Dujardin at the Adler Planetarium (M-257) is marked '16_7' and dated to 1627, but the

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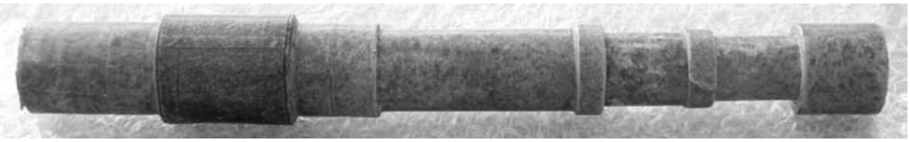
[11] *Ibidem*, 39: 'ain tubus oder helioscopion, von dem Galilaeo Galilaejs, mit seinen Zaichen zu kurtzem und weitem absehen gerichtet welches doch Ihm ieder, nach seinem kurtzen und weiten Gesicht, und nach seim alter auch selbs accomodiren, und sonderlich die gläser ieder zeit sauber halten muß, und ie weiter man darmit sehen will, ihe dienliche es ainem wenigst auf 3. meil wegs gerichtet ist.'

[12] Willach, 'Telescope Optics' (2001), 383-385. We thank Rolf Willach for extensive tutoring using his marvelous collection, and for many of the details on this and other instruments.

fading of the crucial third digit on the instrument leaves wide open its own dating and thus any inference about this early telescope.

3. *c. 1625-1650: unknown maker, Italy; private collection, Switzerland.*



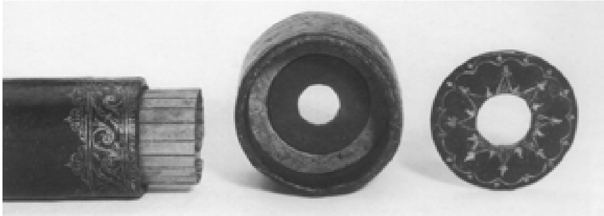
Made of cardboard, with a main tube and three draws; many indicators point to an early date. Galilean optics provide an upright image. The objective is stopped down about 50%, off-centre, to 29 mm. Additional investigation of the optics and instrument is needed to confirm its dating.

4. *Before 1626: Heinrich Stolle, Prague, Czech Republic; British Museum, London, England (1890,0209.2).*

A small Galilean spy-glass, it is protected inside a brass case, itself stored inside a gold-tooled, red-leather etui lined in vellum and paper. Each of the four tubes is made of gilt brass. The three draws have equal-sized rings, extension marks, and collinear notches – the last presumably to help to locate the target object, a task otherwise made difficult by the small field of view. The brass case features a delicate crown (possibly a 19th-century addition) and, on one base, the inscription 'Henr[icus]. Stolle. Vhrm[acher]. Prag fec[it].'

Collapsed, the telescope measures 63 mm; the brass case is of length 83 mm, the etui of length 88 mm. While the extended telescope has an overall length of 150 mm, the plano-convex objective has a focal length of 169 mm, a full diameter of 12.5 mm, and a free aperture of 9 mm. With its original eyepiece, the instrument provides a magnification of about 2 times. It was acquired by the British Museum in 1890 from the collection of Sir Augustus Franks. A clock and instrument maker, Heinrich Stolle lived in Prague prior to his death *c.* 1626. He was well acquainted with astronomer Johannes Kepler and was apprenticed to the important instrument maker Jost Bürgi (1552-1632).[13]

5. *1610-30: Galileo (?), Italy; Museum of the History of Science, Florence, Italy (2428).*



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[13] Willach, 'The Development of Lens Grinding' (2001); Riekher, *Fernrohre* (1990), 46; Ward, *A Catalogue* (1981); a partial listing of other instruments by Stolle is in Zinner, *Astronomische Instrumente* (1956), 545. Fischer, 'Uhrmacher' (1966), 54, indicates that Stolle worked independently from 1616, after his apprenticeship to Bürgi. We thank Liz Gatti and Silke Ackermann of the British Museum for information from the object file on this instrument. The date of Stolle's death (and hence the terminus ante quem for this telescope) is given as c. 1626 in Haupt, *Fürst Karl I*, 1:1 (1983), 67 and 1:2 (1983), 338; Stolle was listed in 1623 as the court clock maker to Karl I of Liechtenstein, and Stolle's widow is known to have received payment for work done by him in 1626 and 1627. We are most grateful to John Leopold for communicating this latter information to us.

The overall length of the telescope is 927 ± 1 mm. The main tube was fashioned using a barrel stave construction, with thin strips of wood running the length of the tube. Originally red (now brown) gold-tooled leather covers it. Similar short tubes fit over the exposed wood strips at each end; one such tube holds the objective, the other the ocular. The plano-convex objective of diameter 37 mm is stopped down to a free aperture of 15 mm. The replacement biconcave ocular, dating from at least the 19th century, provides magnification of *c.* 21 times. An inventory of the Medici Collection from 1704, the first explicit reference to this telescope, describes it as belonging to or made by Galileo.[14] It has recently been suggested that this telescope may have been the instrument promised by Galileo to Cosimo II, the Grand Duke of Tuscany, in March 1610 and presented to him shortly thereafter.[15]

While some uncertainty remains about the exact provenance, the extent to which the objectives of this telescope, its companion (No. 6, below), and the broken objective of Galileo (IMSS 2429) have been optically examined is almost surely without parallel. Indeed, beginning with the fundamental studies of Giorgio Abetti and Vasco Ronchi in the 1920s – pioneering work setting the benchmark for optical analysis of historic lenses – and continuing through to ongoing interferometrical and replicative studies of Giuseppe Molesini *et. al.*, these lenses have justifiably long been at the focus of expert optical attention.[16]

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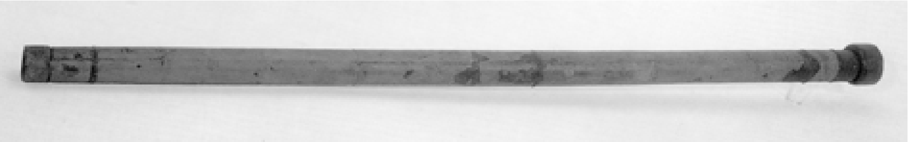
[14] Van Helden, *Catalogue* (1999), 30-31. We thank Giorgio Strano for providing us with the corrected length of this telescope and no. 6, below. As pointed out in Strano, 'Lista' (2009), Willach's optical argument doubting the authenticity of this and the subsequent telescope is logically correct, but based on the false length measurements given in Van Helden, *Catalogue* (1999) and is thus moot.

[15] Strano, *Galileo's Telescope* (2008), 136.

[16] Abetti, 'cannocchiali' (1923); Ronchi, 'cannocchiali' (1923); Greco, Molesini, and Quercioli, 'Optical tests' (1992); Mandò *et al.*, 'Quality' (2008).

6. *1609-40: Galileo (?), Padua (?), Italy; Museum of the History of Science, Florence, Italy (2427).*



The main tube, 1273 ± 1 mm long, consists of two semi-circular wooden half-pipes bound together by copper wire in two places. It tapers from a maximal diameter of 50 mm at the objective end to 40 mm toward the ocular end. At both ends, a wooden tube insert holds a lens and provides modest capacity for adjustment. The 51 mm bi-convex objective stops down to 26 mm; in combination with the 26 mm (diameter) plano-concave ocular, it yields a magnification of about 14 times.

Handwriting consistent with that of Galileo and expressing a length in Paduan units on paper forming part of the upper layer at the end of the main tube was discovered during a recent conservation project. This discovery suggests the tantalizing possibility that the telescope dates from Galileo's time in Padua (1609-1610), though the ascription or connection to Galileo is not secure.[17] Although the provenances of the Galileo telescopes are not secure, that of the broken Galileo objective is quite convincing.

7. *1625-1670 (?): unknown maker; private collection, Switzerland.*

Two brass pieces, soldered together, extend just over 1.000 mm. Each brass component shows its seam along its entire length, and is free of ornamentation. The ivory-mounted objective combines with a compound eyepiece mounted in a cardboard tube that nestles into a brass tube, which adjusts for focusing. Further study of this instrument is needed.

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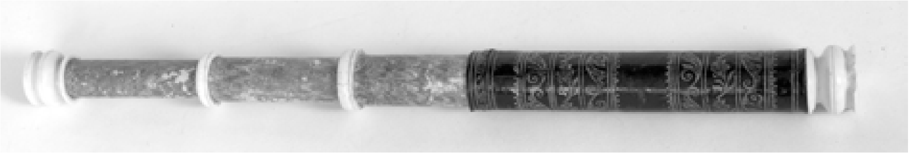
[17] Van Helden, *Catalogue* (1999), 32-33.

8. *1625-1675 (?): unknown maker, Italy (?); Louwman Collection of Historic Telescopes, Wassenaar, The Netherlands.*[18]



Made of cardboard, covered on the two draws with marbled paper and on the main tube with elaborately gold-tooled leather, each tube measures about 200 mm and extends to 480 mm. The ivory rings, and cells for the missing optics, add to the beauty of this small Galilean telescope. The finely preserved tooling and marbling may yield additional information. Zuidervaart notes that the shape of these ivory rings resembles the shapes on the elaborately mounted broken Galileo lens made by Vittorio Crosten in 1677 (now in Florence as IMSS 2429 along with telescopes No. 5 and 6). He has also observed that a similar example is in the collection of the Luxottica Museum in Agordo (Italy).[19]

9. *1628 or prior (?): unknown maker, likely Augsburg, Germany; Kunstgewerbemuseum, Staatliche Kunstsammlungen Dresden, Pillnitz, Germany (part of the* Arbeitstisch *of Electress Magdalena Sibylla, 47714).*

Study of the telescope from the *Pommerscher Kunstschrank* (No. 1, above) led the authors to consider whether another *Kunstschrank* or similarly complex piece of upper-end furniture might have a telescope associated with it.[20] This led to the identification of a collapsible desk-table at the *Kunstgewerbemuseum* (Museum of Decorative Arts) in Pillnitz, near Dresden, which had been as-

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[18] Our thanks go to Peter Louwman for providing us with generous access to his collection, and permission to publish photos of several of his telescopes.

[19] A brief description appears in Cocquyt, 400 Years of Telescopes (2008), No. 3. Further details are derived from Huib Zuidervaart's unpublished catalogue of the Louwman Collection of Historic Telescopes (2008). We gratefully acknowledge his granting us access to this catalogue. See Van Helden, *Catalogue* (1999), 13, 32, 33 and Del Vecchio, In View (1995), 52-53.

[20] Cf. Hauschke, 'Scientific Instruments' (2006), for instruments in this context.

cribed to the circle of Philipp Hainhofer of Augsburg (cf. No. 1). Continued investigation of archival sources and prior inventories of the contents of the desk-table led to an unidentified leather object in storage. Inspection showed that it contained glass lenses and was undoubtedly a telescope; it is presented here for the first time.

This thin telescope has three pasteboard draws and a main tube decorated in gold-tooled leather. The leather is abraded in many places, but certain details of the tooling (a small bird, fleur de lis) are visible upon close examination. It has a plano-convex objective and a plano-concave eyepiece; as in No. 1, both planar surfaces face outward. The objective of diameter 31 mm has been stopped down by a lignum vitae ring to *c.* 18 mm; the eyepiece of diameter 23 mm has a free opening of 12 mm. The lenses could be removed for optical measurement and proved to have focal lengths of *c.* 1010 mm and 78 mm, respectively, yielding a magnification of 13 times.[21] Though the inner diameters decline from 34 mm for the main tube to 27 mm for the innermost draw, the outer diameters appear to be constant (two rings are missing), yielding the familiar cylindrical form when the instrument is drawn in.

The collapsible desk-table (the so-called *Arbeitstisch*) is thought to have belonged to Electress Magdalena Sibylla (1586-1659), second wife of Elector Johann Georg I of Saxony (reigned 1611-1656). Besides the telescope presented here, it contains a virginal and compartments for a wide range of mathematical

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[21] Note that it was not possible to remove the second draw, but extrapolating from the lengths of the main tube and the first and third draws, the total length of this instrument was surely long enough to accommodate the requisite separation of the two lenses, namely 932 mm = 1010 mm – 78 mm.

instruments and writing implements, an apothecary, board games and a folding armchair, all of which can be collapsed to rest on top of, or nestle within, the long, flat rectangular wooden base of the desk. Another piece of complex furniture in the Kunstgewerbemuseum in Pillnitz is often regarded as the pendant to this *Arbeitstisch*: the portable hunting and tool chest (so-called *Jagd- und Werkzeugtisch*, inv.-nr. 47724) belonging to Elector Johann Georg. Interestingly, it is *her* furniture, not his, that contains mathematical instruments, a musical keyboard and the telescope described here. It should also be recalled that the Electress possessed her own *Kunstkammer*, which was visited by Philipp Hainhofer on his second trip to Dresden in 1629.[22]

Many stylistic associations link both these works to the circle of Hainhofer – and to those which have been noted before we now add the observation how the marbled paper used to line several compartments of the *Arbeitstisch* closely resembles that used on the draws of the telescope from the Pommerscher Kunstschrank (No. 1). Moreover, there is also some evidence – in the form of payment receipts – that both pieces may have been acquired from Hainhofer shortly after his 1629 visit.[23] In addition, an inventory of the contents of the desk-table includes a calendar from 1628, which may tentatively be taken as for the dating of the telescope.[24] If the connections to Augsburg can be strengthened, then it is even tempting to speculate that Johann Wiesel might have been the maker of this telescope (cf. No. 20, 21 below).

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[22] That is, if these attributions are correct. A 1636 inventory of the contents of the Jagd- und Werkzeugtisch is preserved in the Armoury (Rüstkammer) in Dresden – see Eichhorn, 'Kunstkammertische.' By contrast, no seventeenth-century inventory of the contents of the Arbeitstisch is currently known; the first such inventory is from 1741, which includes an entry for the telescope, describing it simply as a 'perspectiv' on fol. 132v.

[23] For the contents of the Arbeitstisch see Haase, 'Catalogue entry' (1981); for more on such Hainhofer pieces, see Heikamp, 'Reisemöbel' (1966). For the Electress's own Kunstkammer, her patronage of the arts and her contacts with Hainhofer, see most recently Peschel, 'Kurfürstinnen' (2000). There still remain many open questions regarding these pieces of furniture, their dating, ownership and contents. For example, Heikamp cites correspondence showing Hainhofer's difficulty in finding a buyer for several of his cabinets, which caused him to offer them to a number of prospective buyers. In this light, the Arbeitstisch or at least some of its contents may not originally have been intended for the Saxon Electress; we note, for example, that the perpetual calendar on a rod in the back of the folding chair is Gregorian (with 21 March for the vernal equinox), a fact which – if noticed – might well have been seen as an affront to the then (still adamantly Julian) Saxon court.

[24] The 1741 inventory of the Electoral *Kunstkammer* in Dresden lists a 'printed and illuminated calendar from 1628' on fol. 132v. In describing a calendar contained within the Hainhofer Kunstschrank now in Uppsala, Böttiger drew a parallel to the Dresden Arbeitstisch, mentioning that it also held an almanac by Georg Galgenmeyer for 1628 – see Böttiger, Kunstschrank, 3 (1910), 22 (nr. 15). Alas, no such calendar is preserved in the collections in Dresden and Pillnitz.

The presence of a telescope in such a noble setting underscores how the users of 'scientific instruments' in the early modern period were not just scholars such as astronomers, navigators, and the like, but also wealthy patrons and collectors; indeed, these categories often overlapped. Optical devices in such settings are often specifically described as intended to amuse the eyes.[25] Telescopes and other instruments in a *Kunstkammer* or a *Kunstschrank* functioned in ways beyond the practical and the technical; their decorative elements and location alongside other collectables tell their stories in ways as significant as their optical performances. By locating and examining surviving telescopes in such social settings as the princely court, we may learn a great deal more about the history and functions of scientific instruments and natural philosophy in an earlier era.

10. *c. 1630-1640: unknown maker, Italy; Adler Planetarium, Chicago, USA (M-421).*

All tubes consist of cardboard, with the five draws covered with plain paper, the main tube with red, tanned, gold-tooled leather; decorations include birds, flames, flowers and other designs. (A smaller Galilean style telescope in the Willach Collection has similar, but mirror-imaged tooling.) The aperture disk is also gold tooled. The main tube is distinctly (and linearly) tapered towards eyepiece end. The leather ferrules or rings are built up on successive draws; these rings form a cylindrical shape.

The bi-convex objective glass shows numerous bubbles and striations, and is marked with an 'X' on the ocular side. It has a focal length of 730 mm, and is stopped down from 63 mm to 27 mm. Like other early lenses, it is not polished but broken around the edge. The original ocular is missing, replaced

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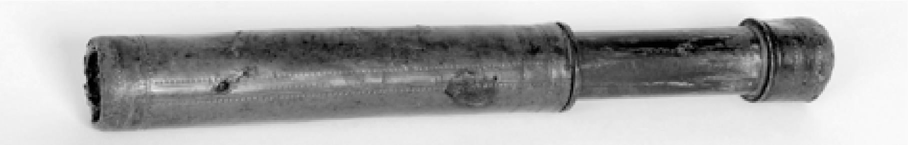
[25] For example, the Hainhofer Kunstschrank in Uppsala contains a flea glass, a pair of faceted ('vexier') eyeglasses, and a paperweight in the form of a prism; an analogous object in the collection of Duchess Sophia Elisabeth of Braunschweig is described in 1636 as 'a 3-sided glass, with which to refresh the eyes, around and about which one can see rainbows, as well as to be used to weigh down letters on a table' – cf. Böttiger, Kunstschrank, 3 (1910),, 21 (nr. 12). See also Dupré & Korey, 'Optical objects' (2009).

by a non-optical piece of glass prior to its arrival at the Adler in 1930. When collapsed, the telescope measures 270 mm; the extension marks on the draws yield a length of 660 mm, indicating a negative or concave lens, hence Galilean optics, and a magnification of around 10 times. The Ronchi test shows that the aperture disk masks off the relatively poorly shaped portion of the objective. Though its use makes little difference for terrestrial objects, its placement over the objective lens makes a significant difference when viewing faint point sources or celestial objects, confirming that the telescope was used for celestial observations, and not just terrestrial ones.

Its unusual trumpet shape makes it one of just a handful of such telescopes, first illustrated in the frontispiece to Galileo's *Istoria e Dimostrazioni intorno alle Macchie Solari* (1613). A telescope very similar to M-421 appears in *Sleeping Endymion*, a painting by Guercino (Giovan Francesco Barbieri, 1591-1666), now in Rome's Galleria Doria Pamphilj. As part of our ongoing investigation into the early iconography of telescopes, we seek to understand the context of telescopes and to locate as many actual early telescopes, illustrations of telescopes or paintings with telescopic imagery as possible.[26]

11. *1625-1650 (?): unknown maker; Louwman Collection of Historic Telescopes, Wassenaar, The Netherlands.*



The main tube and single draw, each made of tin plate, measure about 160 mm and 180 mm, respectively. The main tube and draw ring are of the same diameter and covered in blind-stamped calf leather with simple tooling. The telescope extends from 200 mm to 290 mm. Handwriting on the leather, now nearly invisible to the naked eye, may refer to an earlier owner. Under infrared photography the ink does not appear to contain carbon, so that the signature remains invisible; innovative imaging techniques may provide further information. The old objective lens, a replacement, and plano-concave ocular are both of low quality, yielding a very poor image.[27]

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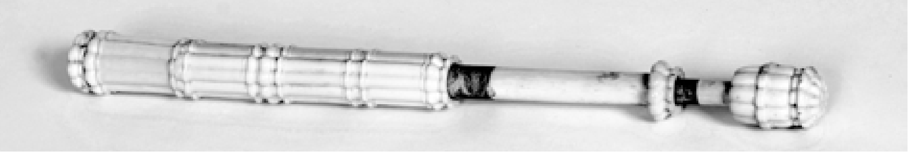
[26] A list of known trumpet-shaped telescopes appears in Bolt & Korey, 'Trumpeting the Tube' (2007). Our thanks go to Edward Hirschland for drawing our attention to the Guercino painting.

[27] Rolf Willach (personal communication) has determined the focal length of the objective to be *c.* 650 mm (and that of the ocular *c.* 50 mm), so that the maximal length of the tubes is far too short for this pair of lenses to have yielded a working Galilean telescope.

12. *1625-1675 (?): unknown maker, The Netherlands (?); Louwman Collection of Historic Telescopes, Wassenaar, The Netherlands.*

Made of fruitwood, this spy-glass measures about 310 mm in length, 40 mm in diameter. It includes one draw; both turned wooden end caps survive. In view of the lathe work, related to that on Dutch furniture of the seventeenth century, this instrument was possibly made in the Netherlands. The original optics were surely Galilean, but the current small objective is likely a replacement, and the ocular is missing. With original leather etui.[28]

13. *1625-1650 (?): unknown maker, France (?); Louwman Collection of Historic Telescopes, Wassenaar, The Netherlands.*



With a total length of 210 mm, this very thin ivory telescope features longitudinal turning/fluting. The main tube, measuring about 130 mm, has four sections, and tapers from 22 mm to 18 mm. The single draw is half-covered with marbled paper towards the objective end. Both ivory end caps survive. Although the original ocular does not survive, the asymmetrically bi-convex objective is likely original. Its yellow-green colour and numerous small bubbles, as well as the Ronchi test performed on it, reveal consistency with period lenses, as do its unpolished edges. The objective's focal length of 274 mm, in

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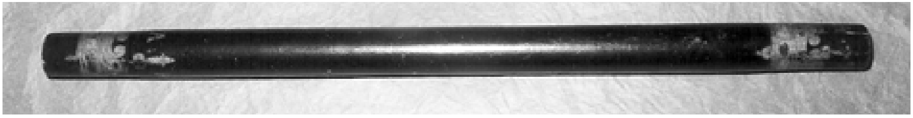
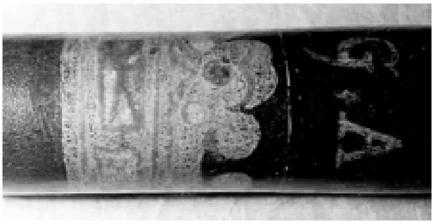
[28] A brief description appears in Cocquyt, *400 Years* (2008), no. 1. The stylistic comparison is due to Zuidervaart (note 19).

conjunction with a reconstruction of the ocular (now replaced by a plano-concave lens of focal length 65 mm), suggests a magnification of 4 times.[29]

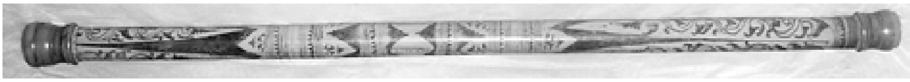
13. *before 1632: unknown maker; Livrustkammaren, Stockholm, Sweden (202).*





This is a Galilean stick telescope, in the form of a commander's or field marshal's staff, of black-stained wood with gold-painted decoration and details and shadowing in brown. Gold initials 'G. A. R. S.' (Gustavus Adolphus Rex Sueciae) and a painted crown wrap around the tube at both ends. It has a total length of 540 mm, a diameter of 29 mm; it is non-adjustable and may have been constructed specifically for the near-sighted king. The focal length of the objective (aperture 13 mm) is *c.* 460 mm, that of the ocular *c.* 70 mm, yielding a magnification of *c.* 6.5 times. The telescope came to the Livrustkammaren (Royal Armoury) in 1956 as a deposition from the State Historical Museum, originating from the old collections of the Collegium of Antiquities. King Gustav II Adolf of Sweden reigned from 1611 until his death in 1632.[30]

14. *Before 1632: unknown maker; Livrustkammaren, Stockholm, Sweden (9956, formerly 06/4145).*



The tube, with a length of 800 mm and a diameter of 30 mm, is of bamboo reed with burnt decoration. The convex objective is held in position by a brass wire ring; its free aperture is stopped down to 17 mm. The ocular is missing. The distance between the objective and ocular is not adjustable. The focal length of the objective is 850 mm. With a separation between the objective

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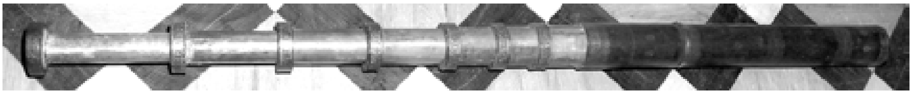
[29] We thank Rolf Willach for his measurements of this instrument in 1999. A brief description appears in Cocquyt, *400 Years, No.* 31, with further information from Huib Zuidervaart. This example is described and illustrated along with other ivory telescopes in Talbot, 'Telescopes: Perspicillum' (2008).

[30] We thank Nils Drejholt for the physical description and provenance information and Rolf Willach for the optical measurements.

and ocular of 770 mm, the telescope would have had a negative ocular of focal length 80 mm. The telescope was thus an instrument of Galilean type with about a 10 times magnification and a very limited field of view. Lindblad suggests that this might be the 'perspectife' known from archival records to have been among the belongings of Gustav II Adolf that were shipped in 1628 from Poland to Sweden, though this is not certain.[31]

15. *1630-1635 (?): unknown maker, France or Italy; State Hermitage Museum, St Petersburg, Russia (TX-891).*



Seven green draws, apparently covered in vellum, with a brown-leather (original?) main tube having decorative gold tooling. The built-up rings seem to provide the distinctive cylindrical shape when the tubes are collapsed. The lenses are missing; the length of the telescope, as indicated by the number of draws, rules out Galilean optics.

A (later) gold-tooled Latin inscription on the main tube suggests that this telescope was left by the French polymath Pierre Gassendi (1592-1655) to his last secretary Antoine de la Poterie: 'Gassendus: vtebatvr. Liqvit: poteriae: svo' ['Gassendi used it. He left it to his de la Poterie']. According to Anthony Turner, Gassendi owned at least eight telescopes: one in red morocco using the lenses that Nicolas-Claude Fabri de Peiresc got from Galileo, which was bequeathed to Henri Louis Habert de Montmor; one of 4.5-foot focal length sent to him by Johannes Hevelius in 1646 with lenses by Hevelius; one by Eustachio Divini given to Gassendi by Kenelm Digby, which was signed and also bequeathed to Montmor, who found it better than the other instrument he already had; and at least five others, all of whom could have been inherited by De la Poterie, to whom Gassendi is reported to have bequeathed all of his instruments at the time of his death in 1655 (though only three – one green, one black, one small – are mentioned in the inventory taken in Paris).[32]

Several suggestions have been offered as to how this instrument reached St Petersburg,g from France. Quite possibly, it was part of the cabinet of Tsar

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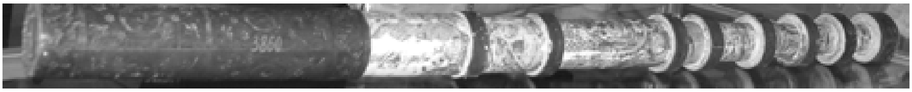
[31] Lindblad, 'äldre fältkikare' (1939), 216ff. Willach provided us with the variant values of 770 mm for the length, 810 mm for the objective focal length and 40 mm for the ocular focal length, leading to a magnification of *c.* 20 times.

[32] A basic entry on this telescope is in Majstrov, *Naučnye* (1968), 67, nr. 3 and Ill. 131. Our main source has been personal communication with Gassendi authority Anthony Turner, whose assistance we gratefully acknowledge.

Peter the Great, but the academician Joseph-Nicolas Delisle has also been suggested as the agent.[33]

16. *c. 1645 (?): unknown maker, Rome, Italy; Museo di Monte Mario, Rome, Italy.*



This stunning, large telescope features a main tube covered in gold-tooled brown leather, and eight draws covered with a map of Rome. The tooling includes many stars and fleurs-de-lis, but most of the gold leaf has come off. Each tube, about 330 mm long, includes extension marks, mostly at about 200 – 230 mm, indicating an extended length of about 1600 mm. The draw ferrules all measure 66 – 69 mm in diameter and around 21 mm in width, with the exception of the last, which measures 38 mm. The objective lens is stopped down from 60 mm to 35 mm by a leather disk and to 30 mm by a paper disk, the missing ocular from 30 mm to 20 mm by a paper aperture stop. The great length of this telescope rules out Galilean optics; its eyepiece tube mostly likely held one lens.

17. *1645-1650 (?): unknown maker, Japan; Tokugawa Art Museum, Nagoya, Japan.*

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[33] We also acknowledge the assistance of Inge Keil in Augsburg, who told us that the late Nina Newskaja had reported a possible link to Joseph-Nicolas Delisle during a visit to the Hermitage in 1993, and to Grigory Yastrebinsky, curator at the Hermitage.

From Professor Tsuko Nakamura, we have learned of an intriguing telescope, perhaps pre-dating 1650. It consists of a main tube, four draws, and an eyepiece unit. Fully extended, it measures 1190 mm, collapsed 410 mm, with a diameter of 50 mm. The tubes consist of paper, painted with lacquer. A tortoise-shell aperture stop cuts the objective's free aperture of about 40 mm down to 24 mm. The ocular is stopped down to 11 mm. The combination provides a magnification of about 4 times. It came as a great surprise to find that the eyepiece unit is a compound one, like the configuration first published by Schyrle de Rheita in 1645. Nakamura discusses some evidence which brings him to the conclusion that this device was once owned by an important Japanese feudal warlord, Tokugawa Yoshinao, who died in 1650. These data raise many interesting questions. A more detailed investigation is clearly needed, including careful comparisons with early telescopes in China and in Japan.[34]

18. *c. 1650(?): unknown maker; Astronomisch-Physikalisches Kabinett, Museumslandschaft Hessen Kassel, Kassel, Germany (F. 265).*

The main tube and the first two of three draws each measure about 150 mm; the final draw runs 170 mm. Extension marks indicate a usable length of 585 mm, consistent with the current original objective. The main tube and draw ferrules are covered with simple gold-tooled brown leather, whereas the draws are covered with plain brown paper.[35] When collapsed, the successively larger ferrules of the smaller draws form the cylindrical shape specific to early telescopes. The main tube has a diameter of 32 mm. The Galilean optics provide a characteristically small field of view. The objective is stopped

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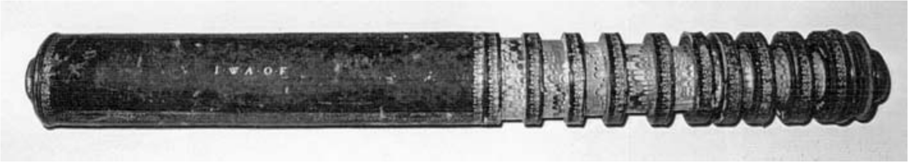
[34] Nakamura, 'The earliest telescope preserved in Japan' (2008).

[35] Konrad Wiedemann of the Manuscript Division of the Murhardsche Bibliothek, Kassel, notes that combination of zigzag lines and lilies within the tooling on the main tube is datable on book bindings beginning in the middle of the seventeenth century – we thank Friedrich Trier of the Museumslandschaft Hessen Kassel for relaying this information, as well as for the estimated magnification of the telescope.

down from 27 mm to 14 mm, the ocular from 27 mm to 12.5 mm. The lenses cannot be removed, but the magnification is estimated to be 5 times.[36]

19. *c. 1650: Johann Wiesel, Augsburg, Germany; Skokloster Slott, Sweden (10643).*



This telescope features an incredible eleven tubes: the main tube is covered with gold-tooled leather and each of the ten inner draws with marbled paper (possibly by Wiesel himself, as Keil suggests). The outer tube bears the tooled signature 'I. W. A. O. F.' in one line (read as 'Ioanne Wiesel *Augustanus* opticus fecit'). The lenses are missing. According to Willach's reconstruction, based on the position markings on each draw tube and contemporary analogies and correspondence, this terrestrial telescope had an objective and a four-lens erecting eyepiece (making unlikely its dating much before 1645, the year of Schyrle de Rheita's publication of the terrestrial telescope and his reference to Wiesel as its competent maker). In this reconstruction, the eyepiece consisted of a field lens of focal length 85 mm, an erecting lens of focal length 170 mm, and two eye lenses of focal lengths 340 mm and 140 mm, respectively. The resulting total focal length of the eyepiece was 69 mm, leading to a magnification of *c.* 28 times. The telescope has the form of a 'reverse taper,' meaning that the objective was mounted in the draw of *smallest* diameter. Adjustment markings on this smallest draw indicate focusing possibilities for four eye strengths. Length 690 mm when contracted, 2650 mm extended. A cap on the outer tube has a concave eye cup with a 9 mm diameter opening.

Since the mid-seventeenth century, this telescope and its companion, No. 21 below, the only two known surviving telescopes by Wiesel, have been at Skokloster Castle near Uppsala, the estate of Field Marshal Carl Gustav Wrangel

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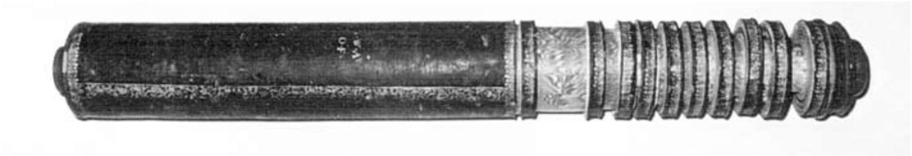
[36] Interestingly, the 1765 inventory entry seems to record the presence of an alternative ocular: 'A tube with two lenses and four [total] draws covered in brown, gilt leather. Additionally a black etui, in which another ocular glass is to be found' ('Ein Tubus mit 2 Gläsern und vier Zügen mit braun verguldetem Leder überzogen. Nebst einem schwartzen Futeral, worinnen noch ein Okular-Glas befindlich ist'). We thank Karsten Gaulke for providing us with this information, as well as the caution (with Friedrich Trier) that the post-Seven Years' War grouping of objects within the 1765 inventory is not always reliable.

(1613-1676), who commanded the Swedish forces in northern Germany toward the end of the Thirty Years' War. Though Wrangel himself never visited Augsburg, Keil has suggested a plausible date for the acquisition: during the post-Peace of Westphalia negotiations (*Friedensexekutionskongress*) between April 1649 and July 1650 in Nuremberg, in which Wrangel took part.[37]

20. *c. 1650: Johann Wiesel, Augsburg, Germany; Skokloster Slott, Sweden (10641; case 10642)*



The physical description and provenance of this terrestrial telescope (now missing its lenses) closely match that of its predecessor, No. 20 above. The individually stamped letters 'I. W. A. [/] O. F' now run over two lines. Here Willach also proposes a four-lens eyepiece, but with two field lenses, an erecting lens, and an eye lens. As the draws between the second and third of these eyepiece lenses are stuck in place, it was not possible for him to measure interlens distances and obtain a complete reconstruction of the optical system.

Other candidates

From our own preliminary and very brief investigation of telescopes surviving in Beijing's Forbidden City, we can identify three categories of instruments there: 1) telescopes made in Europe in a European style; 2) telescopes made in Europe decorated in a putative Chinese style; and 3) telescopes made in China by artisans belonging to the Chinese imperial court. Curatorial investigation of examples of each of these three categories has provided tantalizing suggestions on the transmission of telescope technology and aesthetics not only between the West and China but also between China and Japan, as well as the possibility of early telescopes made in China still surviving there.

In March 2009, we received notice of a private collector in Italy who owns a telescope with provenance going back to at least the 1640s. It was not possible to confirm this report prior to publication, nor to investigate the four Torricelli lenses held in Florence and Naples.

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[37] Keil, *Augustanus* (2000), 114f., 241-243, 295-306, esp. 301f., 436 and figs. 15, 16, 30-35; Willach, 'Telescopic Optics' (2001), 390-395 and Willach, 'Skokloster' (2002).

Finally, there remain other telescopes in private and public collections that are good candidates to add to this list. As mentioned earlier, Willach's collection includes an instrument with tooling similar to that on telescope No. 8; the Louwman collection also contains a few other small Galilean telescopes for potential inclusion in this list, as well as an English telescope with equal-diameter rings similar to one owned by Eugene Rudd.[38] We hope that this list encourages collectors and curators to bring additional early telescopes to light.

Future information-gathering

The telescope became widely known and reached its iconic status despite suffering from two shortcomings: first, the unavailability of high quality optical glass, and, second, the physical deficiencies inherent in spherically curved lenses (the only shape then readily available). As Van Helden has noted, after the initial flurry of discoveries, it wasn't until the invention of the compound eyepiece around 1645 that a new wave of discoveries took place.[39] Perhaps the rarity of earlier surviving telescopes stems partly from their obsolescence once the new and improved telescope became available.

We have identified about two dozen institutions and private collections whose representatives have agreed to provide us with access to their collections for studying telescopes made prior to 1750. We continue to seek additional institutions and collections with candidate instruments. Only by investigating many artefacts now scattered throughout these collections can we sample enough historic artefacts to provide sufficient evidence about their evolution. Whereas photographs of many of these telescopes or images exist, physical examination of artefacts is essential to confirm data accuracy, to provide consistency, and in many cases to investigate optical features.

We have developed a standardized approach for cataloguing, photographing, and conducting optical measurements of each telescope under review. As the telescope is (carefully) disassembled, we identify the materials, coverings, structures, and other physical details peculiar to each instrument, and include this information in our database. Experience indicates that careful investigation even of previously catalogued instruments often reveals additional information.

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[38] Rudd, 'Twin telescopes from the Mid-Seventeenth Century' (2005).

[39] Van Helden, 'The Development of Compound Eyepieces' (1977).

In addition to taking basic physical measurements of diameter, thickness, focal length, and surface curvatures of each objective lens, we strive to make additional tests, measurements and photographs, in order to determine glass quality and optical aberrations. Further details are described at the project website http://historydb.adlerplanetarium.org/dioptrice, where an updated version of the list in this paper will be maintained.

Labour on lenses: Isaac Beeckman's notes on lens making

Fokko Jan Dijksterhuis

> '15th June 1635. I have ground a glass and polished it on my metal form in this way: On one side as I was accustomed to do, but on the other side I constantly put my fingers on the left and the right side; not in the middle, nor above or below. And there where my fingers applied pressure, it [the glass] first began to become clear, while I ground the very thin glass without a cap. But I ground it until it became evenly clear all over, always keeping my fingers on the same places, causing those places to be most abraded and therefore thinner than above and below, where my fingers did not touch'.[1]

Introduction

Clearly, a skilled lens grinder was at work on the 15th of June 1635. His name was Isaac Beeckman (1588-1637) and he was the rector of the Latin school in Dordrecht. He had acquired the art of lens grinding during the previous few years and he had become quite skilled at making lenses. The quote is from the journal he kept over some thirty years. The entry continues in an interesting way.

Then, putting this glass in a hole in the window of my dark office (so that the regions where no pressure had been applied were below and above while the regions where pressure had been applied were on the sides) thus the *erecta* (which are the things that stand upright) outside in the air projected through the glass on the paper, appeared

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[1] De Waard, *Journal tenu par Isaac Beeckman*, 3 (1945), 422: '15^{en} Junij 1635 hebbe ick een glasken geslepen ende gepolyst op myn metalen becken in deser voeghe: Aen d'een syde gelyck ick gewoon was, maer aen d'ander syde stelde ick geduerich myn vynghers op de slyncker ende rechterkant; in de midden noch boven noch onder niet, also dat daer myn vyngers douwden, het eerst begon klaer te worden, dewyle ick sonder dop sleep ende het glasken was seer dunne. Doch ick sleep so langhe totdat het allom even klaer wert, de vyngers altyt op deselfde plaetsen houdende, waerdeur gebeurt is dat die plaetskens meest geschuert syn geweest ende daerom dunder dan onder ende boven, daer de vyngers niet en rochten'.

more clear when one brought the paper a bit nearer to the glass while the *transversa* appeared more clear if one held the paper further away. This differed so much that if one held the paper close [by the glass], one only saw the *erecta*, as if there were no *transversa*; while holding it further away, one only saw the *transversa*. What I saw was an iron [bar] on the front of a house standing across [the street] with two or three small horizontal bars crossing it.[2]

After grinding his lens, Beeckman tested its performance and properties. This is something one rarely finds in seventeenth-century writings on lenses. Even in private notes, considerations of the actual quality of lenses are rare. The particular way in which he assessed this lens is interesting too, using a camera obscura-like setting. The quote shows that Beeckman was an acute observer. There is still more, the journal entry continues:

> From which it transpires that the *concursûs radiorum* comes closer or nearer as more or less pressure is applied to the glass here or there, and that in this way, one can make all the rays gather with the middle [ray] in one point, as if it [the surface of the glass] was a hyperbola...[3]

Beeckman interpreted his observations in dioptrical terms – using the mathematical theory of refraction – and he added a word on a much discussed topic in seventeenth-century lens making: aspherical lenses. In this case, he figured out how a hyperbolic shape might be crafted by carefully

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[2] De Waard, *Journal Beeckman*, 3 (1945), 422: 'Dit glasken dan stellende int gat van den veynster van myn doncker kantoor (also dat de plaetskens, die niet gedouwt en waren, onder ende boven stonden ende de gedouwde ter syden) so schenen de erecta (dat is t'gene dat recht overeynde stondt) buyten in de locht door het glasken opt pampier kommende, klaerder alsmen het pampier wat naerder het glasken brocht ende de transversa schenen klaerder als men het pampier verder af hielt. Hetwelcke soveel scheelde dat men het pampier naby houdende, de erecta alleen sach, alsoffer geen transversa en waren; ende verder afhoudende, sach men de transversa alleen. Hetgene ick sach was een yser op een gevel van een huys recht overeynde staende met 2 of 3 yserkens dweers horisontaliter daerdoor gaende, kruyswys'.

[3] De Waard, *Journal Beeckman*, 3 (1945), 423: 'Waeruyt blyckt dat de concursûs radiorum verder of naderby kommen naerdat het glas hier of daer meer of min gedouwt is, ende dat men so doende, alle de radij met de middelste in één punt kan doen vergaderen, gelyck of t'een hyperbool ware, die hier paste. Ick bevont oock in dese actie, als ick de syde vant glasken, dat so extraordinair geslepen was, na buyten toe stelde, so scheen hetgene ick nu geseydt hebbe, alderbescheelickst. Men moet weten dat hetgene lanck ende smal synde, opt pampier gesien wort, sich aldermeest verliest als het inde smalte sich verspreydt. Daerom het glas so staende dat het aen weersyden dunst was, so quam het vergaerpunt deur die syden verder af, waerdeur de erecta, verspreydt werdende, verdwenen. Aut contra'.

grinding the lens.[4]

Beeckman used his everyday surroundings for his inquiries, his office, the cramp on the house across the street, his window shutters. Thus, a couple of lines further in his journal, he added observations in order to clarify the effects he was seeing. In one of these he relates how he observed *in latrinà meâ* the projection of the lattice in the window. The picture of the horizontal and vertical lines was similar to the effect in his lens. It was typical for Beeckman to notice natural effects during all his activities, including, it appears, while going to the toilet.

Beeckman's journal entry of 15 June 1635 is illustrative of his work on lenses. He combined practical skills, acute observation and penetrating inquiry, using both theoretical and empirical considerations. And he recorded all of this in detail in his diary, which makes it an unmatched source for early seventeenth-century lens making. The notes on lens making are extensive and almost entirely dominate the final part of Beeckman's journal covering the last two recorded years.

This article outlines the contents of Beeckman's notes on lenses. It explores Beeckman's knowledge of lenses and telescopes and how he acquired this. Beeckman's journal offers a unique source for questions like these. There is rather little contemporary documentation on the art of lens making and the assessment of actual products. Surprisingly, this source has hardly been used in earlier studies on this topic. Beeckman's journal has been studied in detail regarding his natural philosophical ideas and his influence on the ideas of René Descartes (1596-1650) but rarely for his skills in craftsmanship. The records of his lens making have only been mentioned in general terms. Except for Cornelis de Waard's description of them in his edition of the journal they have never been subject to systematic study.[5]

Beeckman had always been interested in optical issues, judging from his earliest journal entries dating to around 1610. His first notes consisted of observations of everyday optical phenomena and reflections thereon, which he increasingly enriched with book learning. During the 1620s he became interested in actual lenses and telescopes, acquiring them elsewhere but always

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[4] Hyperbolic and other conical shapes were a promise to perfect lenses that was much sought after in the seventeenth century. Except for some possible incidental successes it did not work in practice. For an informative, though not entirely flawless account see: Burnett, *Hyperbolic Quest* (2005).

[5] On Beeckman's natural philosophy, see Van Berkel, *Beeckman* (1983); Van Berkel, 'Descartes' Debt to Beeckman' (2000) and Schuster, 'Descartes Opticien' (2000), 291-295. De Waard's 'Notes sure le rodage et le polissage des verres' are printed in De Waard, *Journal Beeckman*, 3 (1945), separately numbered between page 369 and 371.

subjecting them to inventive considerations. Finally, in the 1630s he began making his own lenses,learning the art from different experts. He developed a method of his own and recorded his activities in detail. Eventually he became an expert in his own right. Remarkably, the product of his exertions – and the grinding of lenses was tiresome – seems to have been a goal in itself. There is little or no record of applying the lenses to any uses.

Isaac Beeckman was born in 1588 in Middelburg in the Dutch province of Zeeland. He studied theology and mathematics in Leiden (1608-1611) and medicine in Zierikzee and Caen (1612-1616). In 1618 Beeckman started his career as schoolmaster at the Latin School of Utrecht, moving to Rotterdam in 1620 to assist his brother who was rector at the Latin School. In 1627 he became rector of the Latin School in Dordrecht, where he stayed until his death in 1637. In Dordrecht Beeckman participated in the prominent intellectual circles and organized all kinds of experimental and observational projects. In the course of his life, he established contacts with international scholars such as Descartes, Mersenne and Gassendi.[6]

Ready-mades

Beeckman's early notes on optics mainly concerned vision, in which he combined all kinds of observations with dioptrical analyses and ideas on the nature of light. As early as 1617, he discussed the topic of myopia, later correcting Franciscus Aguilonius (1567-1617) on the matter and chastising Francis Bacon (1561-1626) for not understanding it. Later in his life he became myopic himself, as a result, he thought, of his compulsive reading. The issue of judging distance with a single eye occupied him very much. He had come to the conclusion that the image of an object on the retina was characterized by the breadth of a pencil of rays and the number of rays, and that the eye was able to detect these. Typical is the way in which Beeckman unflaggingly used original observations as a starting point for imaginative reflections on their causes. Early 1630 he wrote that he was sitting in church and watching the stained-glass windows. He noticed how the perspective of vertical lines was affected when one glances right under the brim of one's hat. This knowledge of visual perception seeped into his dealings with lenses.[7]

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[6] For the life and work of Beeckman, see Berkel, *Beeckman* (1983).

[7] On myopia, see De Waard, *Journal Beeckman*, 1 (1939), 112; 2 (1941), 377; 3 (1945), 63; 221. On judging distance, see Beeckman, *Journal*, 1 (1939), 315-6; 2 (1941), 213; 231-239. The observation in church is in De Waard, *Journal Beeckman*, 3 (1945), 146.

In 1622 Beeckman was in Middelburg. The astronomer Philippus Lansbergen (1561-1647) advised him to have a telescope made. Knowing where to find the materials and the skills for making a good telescope was the first step to the goal of obtaining a useful telescope. This was a problem for many early telescope makers. For Adriaan Metius (1571-1635) in Franeker, none other than the brother of the Alkmaar claimant for the invention of the telescope, it was not easy to obtain good lenses. Although caution should be taken regarding claims that he went as far as Middelburg to get lenses, it can safely be assumed that one had to know the right people to contact.[8]

Lenses by this time were ground and polished in metal forms by turning a piece of flat glass fixed to a pistil. From the late fifteenth century this method had begun to replace the method of moving a piece of glas over a turning wheel. The metal forms made with hammer forging and verified with a filed template. The use of forms in combination with the new types of Italian glass resulted in lenses with better spherical shape and optical characteristics. These new lenses eventually enabled the construction of magnifying configurations, although optical defects still had to be resolved by stopping the outer edge of the lens. Like all artisanal expertise, techniques of lens making were little documented publicly in the first half of the seventeenth century. The exception is Girolamo Sirtori, who around 1612 recorded methods of lens making for the construction of telescopes in fair detail in *Telescopium*, which was published in 1618. Still, Sirtori's account too is insufficient to understand, let alone learn to master, the actual proces of lens making. In this regard, Beeckman's journal is indeed unique for its time, containing hands-on descriptions and evaluations of materials and methods in meticulous detail.[9]

Middelburg was well equipped for lens making, which saved Beeckman the trouble of travelling around. In 1581, Govaert van der Haghe established the first Dutch glassworks in Middelburg, succeeded in 1605 by Anthonio Miotto from Venice. In 1626 Wilhelmus Wynants from Amsterdam took over the patent of the Middelburg glassworks. Glass industry in the Dutch Republic was stimulated by urban governments in the form of monopolies, tax exemptions, and the like. Middelburg was the only town to have a provincial monopoly on glassmaking, though. Glass industry, for windows, mirrors, lenses, and domestic products in all degrees of artistic sophistication, required high

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[8] On Metius, see Zuidervaart's contribution in this volume.

[9] On the history of lens-making and Lipperhey, see the contributions of Willach and Molesini to this volume. See also Willach, 'Lange Weg' (2007), 103-104; 109-113; Ilardi, *Renaissance Vision* (2005), 224-235; Bedini, 'Lens Making' (1966).

investments. The Middelburg glassworks was financed by Amsterdam merchants, who traded the output. Besides glassmakers of repute, Middelburg had good lens makers, including Hans Lipperhey (-1619), the inventor of the telescope who apparently had set himself to the production of high quality products. By 1622, Lipperhey had passed away and it is unknown to which lensmaker Beeckman went.[10]

Beeckman had a large lens made that he instantly subjected to study. The journal entry is interesting because he discussed the defects of the lens in much detail. He considered spherical aberration, referring to Kepler's *Dioptrice* (1611) and also took into consideration possible faults in the grinding of the lens. Beeckman had pondered over telescopes earlier, in 1618, when he discussed Sirtori's description of a Galilean telescope. Books were an important source of knowledge for Beeckman, but he always read them critically and juxtaposed his readings with his own observations.[11] In 1624 he made some notes on the 1622 lens in which he described its limitations in clear, empirical terms:

> I found that the gathering point was so large, that one could not bring it to perfection, because it was as much larger than the gathering points of other glasses as the glass was larger than the other glasses.[12]

The occasion of his recollection was a visit, on 24 June 1624 to The Hague, where he bought a 'burning glass'. He described an original way of determining the position of its focus by burning a hole in a piece of paper. The focus of the newly procured glass was further from the lens than was the case with small glasses, but it was also much larger. This led him to ask the grinder to make a glass with a long focal distance but a small gathering point, 'hoping by this means to get to my intended telescope'. The grinder, however, answered that this was not possible for anyone in the world.[13]

Artisans were somewhat of an obstacle for Beeckman's inventiveness. Four years later, in 1628, he thought of a way to determine whether an ocular glass

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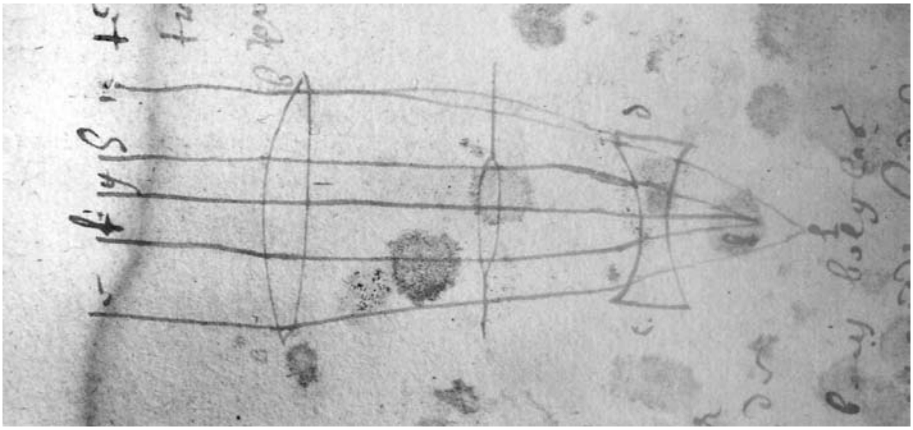
[10] On the Middelburg glassworks see Hudig, *Glas* (1923), 22-28. On the development of the Dutch glass industry, see Davids, 'Beginning Entrepreneurs' (2005), 169.

[11] On Beeckman's lens, see De Waard, *Journal Beeckman*, 2 (1941), 209-211. On Sirtori, see De Waard, *Journal Beeckman*, 1 (1939), 208.

[12] De Waard, *Journal Beeckman*, 2 (1941), 295: 'ick bevondt dat dit vergaerpunt so groot was, dat men t tot gheen perfectie en konde brenghen, want het was wel sooveel grooter als de vergaerpunten van andere glasen, als het glas grooter was dan andere glasen'.

[13] The report of the visit to The Hague is in De Waard, *Journal Beeckman*, 2 (1941), 295-296. The quote is on page 295: 'hopende daerdoor tot mynen voorgenommenen verrekyker te geraken'.



Ill. 1. Sketch of Beeckman on the relationship between the curvature of a concave ocular and a convex objective lens. (Beeckman, *Loci Communes*, Fol. 313r. Zeeuwse Bibliotheek, Middelburg)

was too concave or flat for an objective. He covered the centre with a piece of paper to find out how much the telescope needed to be adjusted. The curvature of the ocular should fit the curvature of the objective to make a good telescope and according to him, the diaphragm used to remedy aberrations hid the actual defects of a telescope (cf. ill. 1). Somewhat later he asked a local spectacle maker to find an objective lens for the ocular he had, but the artisan replied that this would be a hopeless enterprise for he would have to test innumerable glasses.[14]

By this time Beeckman was living in Dordrecht, where he had found a position as rector of the Latin school. Until then, he had not made lenses himself but now he was actively engaged with them, combining book reading and discussions with artisans with observations and considerations of his own.

Homemades

Somewhere in late 1631 or early 1632 Beeckman began grinding his own lenses. In the journal we find a growing attention to lenses, starting with a reading of Scheiner's *Disquisitiones Mathematicae De Controversis et Novitatibus Astronomicis* (1614), ideas to read letters over long distances with two convex

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[14] On assessing the curvature of lenses, see De Waard, *Journal Beeckman*, 3 (1945), 46-47. The lens maker's reaction is in *Ibidem*, 69. On the grinding machines of Huygens, see Dijksterhuis, *Lenses and Waves* (2004), 57-63.

lenses, a combination of a Galilean and a Keplerian telescope (suggesting a compound eyepiece), and ideas on making grinding forms. The first entry on grinding forms is interesting because Beeckman described a construction with a rod to guide the grinding top. This arrangement became known much later, with the work of Huygens and Campani in the 1660s. Beeckman added another remarkable idea: guiding the grinding stone by means of a rope suspended from two points, thus producing an elliptical shape.[15]

What exactly made Beeckman turn to the actual grinding of lenses remains unclear. The move from Middelburg to Dordrecht may have had something to do with it, Beeckman finding the lens makers there less skilful. He nowhere says so, and the move was some four years before the lens work commenced. After his move to Dordrecht, he had a small observatory built at the roof of the Latin school where he made metereological and astronomical observations. This may have induced a need for optical instruments.[16]

Interest in lenses was definitely growing in Holland at that time. Constantijn Huygens (1596-1687), secretary to the Stadtholder and prominent intermediary in the cultural life of the Dutch Republic, was very interested in optics. He had urged Jacobus Golius (1596-1667) to investigate refraction, apparently with some success. He also organized the people and means for Descartes's project of grinding aspherical lenses. Although the project bore no fruit, it is clear that the pursuit of optics was strongly stimulated in Holland in the 1630s. Beeckman was very close to these circles. He was well acquainted with Descartes and by this time they had resumed their contacts. Andreas Colvius (1594-1671), the minister of the Walloon Church and a central figure in Dordrecht's cultural circles, corresponded frequently with Huygens. He was an important intermediary and stimulator of Beeckman, who used his rich library for reading recent books on natural philosophy.[17]

Networks like these provided an additional access to knowledge and expertise on lens making. Through these travelled not only paper descriptions, but also people and artifacts, which probably was the most important way in which knowledge and expertise circulated in the early modern period. For example, in 1627 Beeckman's old friend Justinus van Assche (1596-1650),

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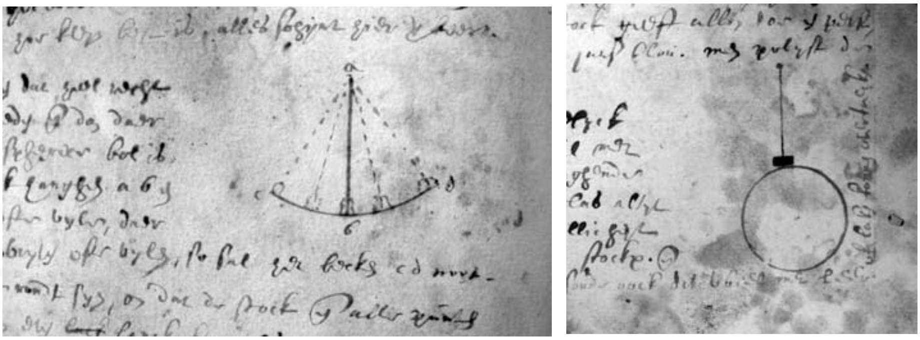
[15] The topics mentioned are in De Waard, *Journal Beeckman*, 3 (1945), 228-233. Beeckman in October 1633 first mentioned Scheiner's *Rosa Ursina* (1630), a main point of reference for seventeenth-century telescopists which contained a Keplerian configuration.

[16] On Beeckman's observatory, see Van Berkel, *Beeckman* (1983), 104-105.

[17] On Golius, see De Waard, 'Manuscript perdu' (1935), 53-54. On Descartes's project, see Dijksterhuis, 'Constructive thinking' (2007), 65-67. On Colvius, see Van Berkel, *Beeckman* (1983), 112-115.



Ill. 2. Sketches of Beeckman relating to the use of a rod for grinding. The one on the right is made with the note on the visit to Willem Jansz Blaeu. (Beeckman, *Loci Communes*, Fol. 291v and 405r. Zeeuwse Bibliotheek, Middelburg).

minister in Cologne, told him of the grinding methods of his colleague Johan Moriaen (c. 1591-1668), who was also trained as lens maker. A couple of years later, Moriaen travelled to the Republic and visited Beeckman. They exchanged tricks of the trade.[18]

After Beeckman had begun grinding his own lenses his journal brims with detailed descriptions and inventive ideas. I will indicate a few of the most prominent themes. In the first place the method of grinding by means of a rod. The journal contains many detailed instructions and over time Beeckman devised all kinds of variants. This all was aimed at acquiring a constant and even pressure during the grinding. Notes on a conversation on globe making with Willem Jansz Blaeu (1571-1638), suggest that the use of the rod was inspired by the methods of mirror makers (ill. 2). A crucial issue was grinding the lenses evenly, particularly preventing the edges from being abraded too quickly. This, as we have already seen, at the same time suggested ways to make aspherical lenses.[19]

There is also much talk about the materials used. A smith tells him which iron is best for making forms. Beeckman explains how to select the best pieces of glass for making a lens. What material to use for grinding and polishing: types of sand, leather and cloth. Typical for Beeckman is that he linked such considerations to his ideas about the mechanical nature of things. In February

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[18] On transfer of technology see Davids, *Rise and Decline* (2008), 204-207; 229-230; 238-243. On Moriaen see De Waard, *Journal Beeckman*, 3 (1945), 300-302; 380-381.

[19] On grinding rods, see passages in De Waard, *Journal Beeckman*, 3 (1945), 242-252; 255-260; 261-264. The conversation with Bleau is in *Ibidem*, 263-264. On aspherical lenses, see: *Ibidem*, 375 and 384.

1634 we find an entry in which he asks whether polishing is a form of grinding or just cleaning the glass. 'Per microscopium' – with a looking glass or perhaps a low-power microscope – he inspected the effect: 'ergo it appears that one scrubs or rubs the roughness off the glass by the polishing, like the cloth is shaved by croppers'.[20]

Methods for evaluating the quality of lenses were a recurring topic. We have already seen the method of burning holes in paper for determining the position and the width of the focus. Beeckman also used mirrors to inspect lenses. The method of projecting images into a darkened room, which he used in my opening quote, was described in the entry of 26 July 1634. This was particularly useful for identifying the astigmatical properties of lenses. Beeckman always tried to find an explanation for the defects he observed. Covering the central part of a lens, he got a double image, which he understood to reveal that the plane face was slanted. Considerations like these were informed by his prior knowledge of dioptrics, and subsequently informed his understanding. He gave the familiar proportion between curvature and focal distance, in order to find out what difference the thickness of the glass made. This was directly linked to grinding practice, expressed in terms of various pieces of glass ground in the same mould or the effect of final polishing.[21]

It seems that Beeckman started out on his own, but after some time his contacts with experts became more frequent. He had no choice, for, as he remarked late 1634: 'In all this writing and polishing on this matter one sees how difficult it is to learn a craft by oneself perfectly'. He had conversations with lens makers and observed how they mastered the art, imitated their methods, worked together with them, and so on. Spectacle makers, we read, frequently brush the outer two or three inches of their form with a feather, to prevent the sand from heaping up. Beeckman's inquisitiveness was boundless. 'I have observed grinding several times and I have ground with masters myself, and asked them what I wanted, and having come home, I always have more to ask'. These kind of apprenticeship visits may have been the best way to exchange

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[20] De Waard, *Journal Beeckman*, 3 (1945), 374: 'ergo schynt dat men de asperitaten vant glas door het polysten afscropt of afvryft, gelyck het laken van drooghscheerders geschoren wort'. On using iron for forms, see *Ibidem*, 233-232. On the selection of glass, see *Ibidem*, 300-301.

[21] Methods for inspecting lenses are discussed in De Waard, *Journal Beeckman*, 3 (1945), 258; 296; 299; 373; 387; 397. On the slanted lens, see *Ibidem*, 260. On the thickness and focal distance of lenses, see *Ibidem*, 258.

expertise in lens grinding.[22] They were quite helpful to Beeckman:

> The servant, who showed me, was always very concerned that I did not roughen the edges enough in the beginning, saying that matters very much. The master,... , often said to me 'You have to push hard already'. He made me sweat. He wanted that I kept my hand on top of the top while grinding, saying 'This works better'.[23]

With two lens makers Beeckman had particularly intensive contacts. In Amsterdam, an Englishman had a shop on the Dam, which Beeckman visited at least three times. He combined these visits with visits to Descartes, who was living nearby at that time. In Middelburg, Johannes Sachariassen (1611-after 1655) made a living of lens making. He was the son of Sacharias Jansen (*c.* 1585-*c.*1632) and was the principal source of the dubious claims that his father had invented the telescope. Often Beeckman juxtaposes the opinions of Sachariassen and the anonymous Englishman in his journal.[24]

Beeckman corresponded with Sachariassen and visited him several times. In September 1634, he writes he had 'once again learned to grind and polish on my iron form with Johannes Sacharias'. He described his methods in much detail. Sachariassen cut a line on the lens for the position in the tube; he spat regularly on the lens, especially in the final stages of polishing; he knew when he was ready: when the colour of the grindings was the same as the glass.[25]

The exchange was not unilateral. On 1 May 1634 Sachariassen had polished – for nine consecutive hours! – a glass that had been ground on Beeckman's form. They spoke a lot about the way to hold that glass while grinding. Customarily a top was used, but it was difficult to move the glass evenly around in the form and prevent some parts from being abraded too much. It was

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[22] The quotes are from De Waard, *Journal Beeckman*, 3 (1945), 403. 'Aen al dit schryven ende wryven an dese sake siet men hoe moyelick het is een ambacht by syn selven perfect te leeren'. and 'Ick hebbe verscheydenmael sien slypen ende selve by de meesters geslepen, ende al gevraecht, dat ick doen wilde, ende thuys gekommen synde, hebbe ick altyt noch meer te vraghen'. On cleaning with a feather, see *Ibidem*, 371.

[23] De Waard, *Journal Beeckman*, 3 (1945), 392. 'De knecht, die my wees, was altyt seer bekommert dat ick de kanten int eerste niet genoech en rocht, seggende dat daer veel aen geleghen was. De meester, als ick de eerste reyse sleep, seyde dickwils teghen my: 'Gy moet al hart douwen'. Hij dede my sweten. Hy wilde hebben dat ick int slypen myn hant boven op den top van den dop hielde, segghende: 'Het gaet so beter".

[24] On the visits to lens makers, see De Waard, *Journal Beeckman*, 3 (1945), 383; 389-391. On Descartes, see *Ibidem*, 349; 4 (1953), 224. On the claims of Sachariassen, see Zuidervaart, 'Vaderlandsliefde' (2007), 10-12 and 21-22, and his contribution to this volume.

[25] De Waard, *Journal Beeckman*, 3 (1945), 249-250 and 395-395. The quote is on 395: 'tot Johannes Sacharias wederom leeren slypen ende polysten op myn yser becken'.

necessary, Beeckman noted, to always apply pressure to the centre of gravity, but the top tends to make the glass wobble. Sachariassen always ground with two hands. Making lenses always was a matter of 'Fingerspitzengefühl'. When Beeckman on one occasion proposed that Sachariassen should finish a glass he had started, the latter replied that he ought to continue himself because 'his movements would not precisely correspond to mine'.[26]

Overdone

Eventually Beeckman became an expert in his own right and began outdoing professional lensgrinders. On 23 September 1633 he visited the Englishman in Amsterdam who ground a lens in a couple of hours. Beeckman was not impressed. 'The glass [lens] was not good, mine are much better'.[27] Sachariassen was impressed by Beeckman's command of the art:

> Seeing that my glass was so good, yes better than his, he said that he was surprised because my glass was so much 'sifted' (he calls it sifting when it is not finely ground enough on the form) and when it is polished directly on the form then it cannot sift, he says.[28]

In 1634 and 1635 Beeckman seems to have been grinding lenses almost daily and he recorded all of it. '11 October 1634. I ground well in this way: The glass was one-and-a-half inch in diameter. Put on the form a large thimble full of wet grinding sand. With this I ground until the glass was dusted all around, yet with a moist sponge I wiped off the form halfway, not wiping the middle, but all around the rim'.[29] And so on.

This entry was made after a disappointing discovery a month earlier: '*Nota*. On 2 September 1634 I suddenly discovered that all my tinkering during the

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[26] De Waard, *Journal Beeckman*, 3 (1945), 376-377 and 399: 'syn handelinghe juyst met de myne niet overeenkommen en soude'.

[27] De Waard, *Journal Beeckman*, 3 (1945), 307-309; quote on 308: 't glas was niet goet; de myne syn veel beter'.

[28] De Waard, *Journal Beeckman*, 3 (1945), 376: 'Hy siende dat myn glas so goet was, ja, beter dan syne, seyde dat hy daerover verwondert was doordien dat myn glas soseer sifte (hy noemt siften alst opt becken niet fyn genoech geslepen is) ende alst opt becken meteenen gepolyst wort, dan en kant niet siften, seght hy'.

[29] De Waard, *Journal Beeckman*, 3 (1945), 398-399: '11^{en} Oct. 1634 sleep ick goet aldus: Tglas was 1½ duym in den diameter. Dede opt becken een groote vyngerhoet vol nat schuersant. Daermede sleep ick totdat het glas alom gerocht was, doch vaeghde ick met een natachtighe sponsy het becken wel half af, de midden niet vagende, maar ronsom den boort'.

summer had been in vain, because I had not paid enough attention to my form: that it was somewhat slanted at the side, that is, it was there a bit flatter than the rest'. The faulty mould was not only the cause of fruitless handiwork, but also made the reflections on his labour useless: 'From all this tinkering during this half year, something useful may still come, although my meditations had no foundation'.[30]

Beeckman decided to dispense with the top for grinding the glass and the results were better.

> 'On 24 May 1635 I ground without a top for the first time and I polished it clearly on my metal form. The glasses were better than ever before, because there was no imperfection in curvature whatsoever, which may happen because of the wobbling of the top'.[31]

He had now truly mastered the art. In October 1635, a 'showdown' with Sachariassen followed:

> I ground against Joh. Sachariassen to decide who was the best, with identical glass forms, but mine was much better, as he said himself after trials in the dark room at Dr. Lansbergen. But he did not know that I had ground it without a top, because I will reveal that to nobody.[32]

It is interesting to see that Beeckman had collected knowledge of lens making from everywhere and from everyone, but that he was not willing to share the secrets he had developed himself.

Conclusion

Despite Beeckman's immense labour on lenses, it is unclear what his eventual goal was. He made astronomical observations and he may have envisioned

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[30] De Waard, *Journal Beeckman*, 3 (1945), 395: '*Nota*. Den 2^{en} September 1634 hebbe ick bescheelick bevonden dat al myn futselen den geheelen somer geleghen is geweest dat ick niet genoech gelet en hebben op myn becken: dat het aen den rant wat afhelde, dat is, wat platter was dan de reste.... Uyt al dese futselinghen deses half jaer mach misschien wat goets kommen als synde meditatien gefondeert op geene gront'.

[31] De Waard, *Journal Beeckman*, 3 (1945), 419: 'Den 24^{en} Mey 1635 heb ick de eerste maal sonder dop geslepen ende klaer gepolyst, ende was op myn metale becken. De glasen waren beter dan oyt te vooren, want hier en is gansch geen causale bollicheyt, die bygevalle kompt door het wagghelen van den dop'.

[32] De Waard, *Journal Beeckman*, 3 (1945), 430: 'Ick sleep teghen Joh. Sacharias om best, van gelyck glas, maert myne was veel beter, so hyselve seyde, beproeft in een doncker kamer tot Dr. Lansbergen. Maer hy en wist niet dat ick sonder dop slype, want dit en openbare ick niemant'.

a microscope to observe the corpuscules that he thought were the building blocks of nature. Still, there are no records in his journal entries that show the application of lenses in instruments.

In the foregoing I have explored Beeckman's efforts in lens making, outlining the kind of knowledge he developed and the way how he acquired it. His journal is a very rich source on early lens making practices that deserves further study. Beeckman's work can then be positioned in the broader context of local knowledge of Dordrecht doctors, artisans, and the like, and to the optical pursuits of the Descartes circle.

Acknowledgements. I would like to thank Klaas van Berkel, Arjen Dijkstra and Tim Nicolaije for their valuable comments and suggestions. This article is part of the NWO-funded research project 'The Uses of Mathematics in the Dutch Republic' (016.074.330).

Testing telescope optics of seventeenth-century Italy

Giuseppe Molesini

Introduction

Looking at the properties of a lens tells us much about its history: the glass it is made of, the fabrication process and its possible use in a working instrument. Lenses preserved in museums and private collections can be regarded as documents that can provide historians of science with information about specific aspects, such as provenance, the grinding and polishing process, the optical performance, and more. With the aim of retrieving this information, as a collaboration led by the Institute and Museum of the History of Science (now Museo Galileo) in Florence, in the early 1990s a testing campaign was started on the seventeenth-century Italian lenses and telescopes in the Museum's collection. In recent years, the research was also extended to lenses at the Museo della Specola in Bologna, and to a lens by Evangelista Torricelli at the Physics Museum of the University of Naples. This research is still in progress, because meanwhile the capabilities of the measuring instruments have been improved, and new inspection techniques have become available.

The measuring techniques used have been carefully selected from among non-invasive ones, in order not to risk damaging the lenses. Geometrical, physical and functional characteristics of the lenses have been measured, and most of the results obtained so far have been reported in the literature.[1] These examinations, together with written accounts of the time, make possible a better reconstruction of the advances in lens-production technology in Italy in the first few decades of seventeenth-century. In this paper, the main results will

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[1] Greco, Molesini & Quercioli, 'Optical Tests of Galileo's Lenses' (1992); Greco, Molesini & Quercioli, 'Telescopes of Galileo' (1993); Baiada, Bònoli & Braccesi, *Catalogo* (1995); Molesini & Greco, 'Galileo Galilei: Research and Development of the Telescope' (1996); Van Helden, *Catalogue of Early Telescopes* (1999); Miniati, Van Helden, Greco & Molesini, 'Seventeenth-Century Telescope Optics of Torricelli, Divini, and Campani' (2002); Bònoli, Miniati, Greco & Molesini, 'Telescope Optics of Montanari, Cellio, Campani and Bruni' (2002); Molesini, 'The Telescopes of Seventeenth-Century Italy' (2003); Molesini, 'Testing the Lenses of Campani' (2004); Molesini, 'The Optical Quality of Seventeenth-Century Lenses' (2007) and Strano, *Galileo's Telescope* (2008).

be reviewed, the technological problems posed by the craft of telescope making will be discussed, and the implements and the working procedures devised by the artisans to surmount these difficulities will be outlined.

Lens production technology

A thorough account of lens making for scientific instruments in seventeenth century has been given by Silvio Bedini.[2] Other interesting information is available in Girolamo Sirtori's *Telescopium* of 1618[3] and Carlo Antonio Manzini's *L'occhiale all'occhio* of 1660.[4] A 1643 letter of Torricelli to Raffaello Magiotti in Rome is particularly detailed and informative on lens making practices, and also contains the description of original findings, revealed for the first time to his correspondent. [5]

The lenses needed in a Galilean telescope are the objective and the eye-lens; the former was almost invariably a plano-convex lens, and the latter plano-concave. While the eye-lens could be made with the processes in use in the craft of spectacle-making, the objective required the development of new implements. In the case of spectacles the portion of the lens that is used when looking at a particular object is quite small, approximately the size of the eye's pupil; the lens quality requirement then only extends over such a area at any one time. The eye-lens in a telescope works in a similar way. In the case of the objective, however, the entire lens is used all the time, no matter what particular object in the field of view the observer examines; the quality requirement then extends over the entire lens diameter. In practice, the convex surface ought to be entirely regular, and exactly spherical. In addition, to obtain a focal length of a metre or more, as in most telescopes of the time, the radius of curvature must be longer than those of contemporary spectacle lenses. New tools had to be made and new production techniques devised. Basically, the glass blank in the form of a plate had to undergo the preliminary step, during which the lens was roughly shaped, the grinding step, where the surfaces were made spherical, and the polishing step, where the surfaces were finely lapped to remove the residual micro-roughness. Each step needed specific tools and techniques, which only in small part could be borrowed from the craft of spectacle makers, and were mostly developed by the artisans on their own. As a final step, the lens was tested for optical performance, and then accepted or discarded.

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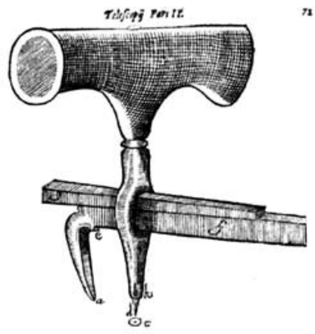
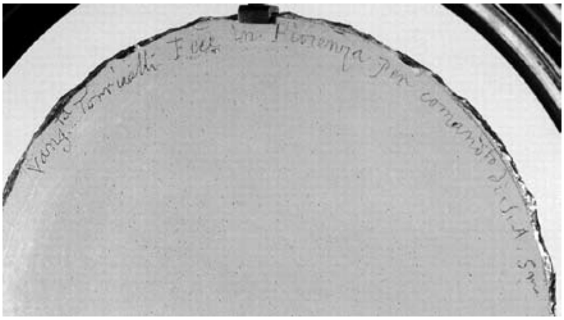
[2] Bedini, 'Lens Making for Scientific Instrumentation in the Seventeenth Century' (1966).

[3] Sirtori, *Telescopium* (1618).

[4] Manzini, *L'occhiale all'occhio* (1660).

[5] Letter of Evangelista Torricelli to Raffaello Magiotti, 4 December 1643, in: *Opere di Torricelli*, 3 (1919), 150-156.





Ill. 1. Iron divider used to mark circumferences. From: Sirtori, *Telescopium* (1618).
Ill. 2. Telescope objective of Torricelli at the Physics Museum of the University of Naples. Traces of the rounding mark about the edge are visible.

Lens generation

Once carefully selected for the absence of visible defects, the glass plate had first to be rounded. To this purpose, a circle was marked with a divider (Ill. 1), probably with a cutting diamond attached to the turning arm. Evidence of such a practice was found for example in the lens of Torricelli in Naples (Ill. 2). This lens dates to the period 1642-1647, when Torricelli was in Florence and worked on lens making. It was recovered, sometime before 1886, by Gilberto Govi[6] and re-examined in detail in recent years.[7] The lens is plano-convex, 11.1 cm in diameter, 6.0 m in focal length. About the edge there is an inscription that says *Vang.ta Torricelli fece in Fiorenza per comand.to di S. A. S.ma* (Evangelista Torricelli made in Florence by order of His Very Serene Highness). Examining the lens' periphery, here and there one notices marked arcs remaining. Besides, the lens is rounded by chipping the outer glass with cutters and pincers.

Next, the lens surfaces had to be given a preliminary shaping. This required on one side the securing of the lens to a holder, and on the other side a tool plate with some curvature (opposite to that to be generated) to abrade against.

As to the holder, Ill. 3 shows the drawing of a handle used by spectacle-lens makers. The glass plate was attached with pitch, bitumen or similar adhesives to the top disc of the handle; the use of plaster is also reported. As to the tool

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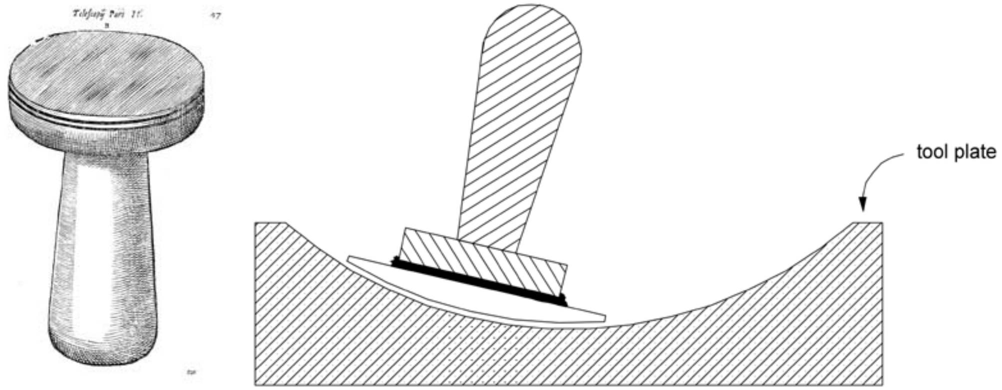
[6] Govi, 'Di una lente per cannocchiale, lavorata da Evangelista Torricelli' (1886).

[7] Greco & Molesini, 'Prove ottiche sulla lente di Torricelli' (1994); Paternoster, Rinzivillo & Schettino, 'Studio di una lente per cannocchiale di grandi dimensioni lavorata da Evangelista Torricelli' (1996).



Ill. 3 & 4: *Left*: Handle serving to attach the lenses in the craft of spectacles making. From: Sirtori, *Telescopium* (1618). *Right*: Generating a convex surface with a handle (cross section).

plate used at this stage, it was generally made of metal (iron, typically, but also copper or other materials); the generation process is schematically indicated in illustration 4.

In the case of telescope lenses, and particularly objectives, the shape of the holder was changed, taking the form of a small grinding stone (illustration 5).[8]

Among the advantages of such new holder is the fact that, being driven with the palm of the hand instead of the fist, less of unbalance was conferred to the lens. In addition, making the holder from lead or another dense material, the artisan had to push less when grinding. The tool plate used at this stage was a rough one; only preliminary shaping with loose abrasive was given, to reduce the time necessary afterwards for precise grinding.

Lens grinding

Grinding is the key operation performed in optical workshops that gives the lens surfaces a spherical shape. The tools are similar to those used for preliminary shaping, although the process is more refined. Metal tool plates might have been used at first. Sirtori reports a technique to generate the mild concavity of the plate by means of a curved file (Ill. 6). However, it was observed that this method was quite crude, each stroke removing the plate material along a line and the end results, in terms of surface regularity, were poor. Also, the use of moulds to examine the actual profile, reported by Sirtori, appears to be

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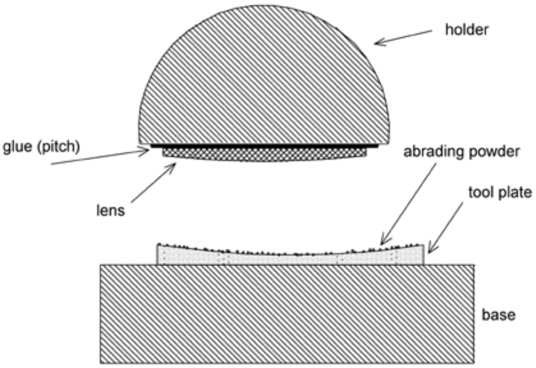
[8] Torricelli to Magiotti (ref. 5).



Ill. 5. Rough shaping of a convex surface of a lens against a tool plate in the new art of telescope making (cross section).

Ill. 6: Curved file to produce a tool plate. From: Sirtori, *Telescopium* (1618)

difficult to put into practice, considering the mould's shallowness in cases of long radii of curvature.

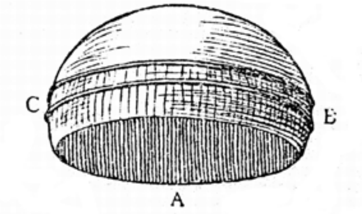
Torricelli is generally given credit for first understanding in scientific terms the wear process that produces spherical surfaces during grinding. Following his prescriptions, the tool plate was a disc of glass, firmly attached to a heavy block of material, so that it remained stable during the work. To abrade the plate, so that it acquired a concave shape roughly matching the convex shape of the surface to be ground, Torricelli used a disc of glass of smaller diameter, and sharp emery powder in between the two. In this manner the material removed by abrading occurred over a *surface* rather than a line, thus averaging out the figure and making it smoother. The end result did not need to be perfect since it was the following operation of lens grinding that adjusted the shape. The principle stated by Torricelli says that abrading two surfaces against each other by means of various and random movements produces a pair of spherical surfaces, one concave and the other convex, or in the limit both plane. For a successful process, however, the surfaces need to be moved over each other with a perpendicular pressure, i.e., with no tilt between them.

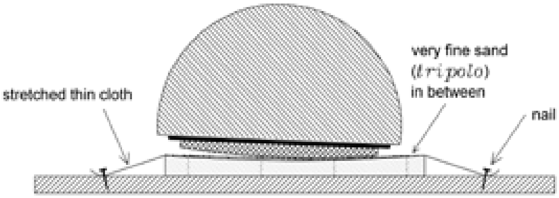
The use of a handle as in illustrations 3 and 4, instead tends to tilt the glass surfaces, causing an uneven wear of the surfaces which get more abraded at the edges than at the centres. The introduction of the new holder, not claimed by Torricelli as his own invention, effectively reduced the errors at the edges. Going further, but confiding it as a secret to his friend Raffaello Magiotti, he realized the importance of the relative size of the tool plate with respect to that of the lens, and understood the effect of the hot glues then used to attach the lens to the holder, recommending instead cold glues. The lens holder drawn by Torricelli is shown in illustration 7. It consisted of a hemisphere of lead, with the base somewhat larger than the lens to be attached. First, a disc of soft cloth was placed over the bottom (A), and then a piece of soft leather was stretched over it, and secured with a piece of string (BC). The leather was soaked with red wax, and thus became sticky. The lens was therefore easily attached and detached at will, without imparting any thermal stress to the glass.

The grinding process was accomplished with the so-called *spoltiglia*. According to Sirtori, this was a fine abrasive produced from emery, dissolved in a bowl of water and allowed to precipitate partly. The liquid was then transferred to a new bowl, water was added again, and the largest particles in the liquid were allowed to deposit on the bottom. The process was repeated three or more times, so that only the smallest emery particles remained. In the process described by Torricelli, the abrasive was added when needed, until the entire surface was uniformly ground. Then, no more abrasive was added, continuing the grinding with the remaining *spoltiglia*, only adding a little drop of water, or just breathing on the surfaces if they were drying up. The operation was only terminated when the powder had become white, very fine and greasy ‘like butter’. Carefully carried out, such a process produced very finely ground surfaces, of excellent spherical shape and already almost capable of forming an image.

Lens polishing

The final polishing required a further tool plate to rub against, and particular skills. The previous tool plate could not be used, since the surface would become shiny first at the edge, and only at a far later stage at the centre; the spherical figure of the surface would then be severely impaired. Torricelli used an almost plane tool plate made of slate, worn just a bit to concavity with some pumice. The tool plate was firmly placed on a wooden table; a piece of thin cloth was then stretched over the plate and fixed to the table with nails





Ill. 7. Implement described by Torricelli to hold lenses in the production process. (Letter of Torricelli to Magiotti, 4 December 1643).
Ill. 8. Polishing a lens surface against a stretched thin cloth with fine abrasive.

all around (Ill. 8). The abrasive then in use was the so-called *tripolo*, a powder made of extremely minute grains of silicon dioxide. The powder was dampened and spread as an ointment on the cloth, with just a few drops of water. The artisan then vigorously rubbed the lens along various directions on the cloth, adding abrasive and water when needed, until the micro-roughness had entirely disappeared from the surface.

The process was certainly lengthy and laborious. However, Torricelli mentioned in a letter that he succeeded producing two good objectives out of six in about eight days of work.[9] In addition to remarking the mastery of the lens fabrication technology achieved by Torricelli, this letter is interesting because it points out the common practice of producing lenses in (small) batches, probably using the same tools; at the end the best performing ones were selected, and the others were discarded. On the other hand, due to the production process described above, Torricelli did not have good control over the radii of curvature of the surfaces he ground, since these depended on the depth of the depression in the tool plate. For this reason, it is interesting to note that the Museo Galileo in Florence houses a Torricelli lens 11.5 cm in diameter and 6.0 m in focal length, with the inscription *Vangelista Torricelli. Fiorenza. 1646. Braccia 10 ¼*, whose characteristics are strikingly similar to those of the Torricelli lens in the Physics Museum of the University of Naples. Such a lens is shown in ill. 9.

Lens testing

Not very much is known about lens testing practices in seventeenth century. Apart from the visual inspection of the lens itself for defects, the most obvious

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[9] Letter from Evangelista Torricelli to Rafael Magiotti, 6 February 1644, in: *Opere di Torricelli* 3 (1919), 165-166.

Ill. 9. Telescope objective of Torricelli in Florence (Museo Galileo, Inv. 2571).

test was a trial of its performance, mounting the lens (the objective) in the telescope and observing a bright star or planet. In fact it is known that in some cases Galileo suggested oval apertures because of defective optics.[10] While this proves the awareness of Galileo that appropriate adjustments could perfect the optical performance of his telescope, it also testifies to his ability to carry out testing procedures: the actual size and shape of the diaphragm should have been a compromise between image quality and brightness, depending on the features of the lens being used.

Although the lenses of the same batch were produced under similar conditions, a sizeable fraction did not pass the final test and had to be discarded. Considering the hard work, the time and the cost of producing lenses, the main reason for discarding one was probably something else than an evident defect of the lens material, such as gas bubbles, seeds, glass turbidity and colour: in that case the glass plate would not have been used for lens making. Hidden defects only showed up after the lens was finished and mounted in a telescope. Typical defects of this kind were inhomogeneity of the refractive index due to the presence of swirls and knots within the glass. These distort the light path through the lens and result in image degradation. It was understood that, in spite of some screening that was performed before the glass plate was used for lens making,[11] slightly defective material could not be detected and discarded in advance.

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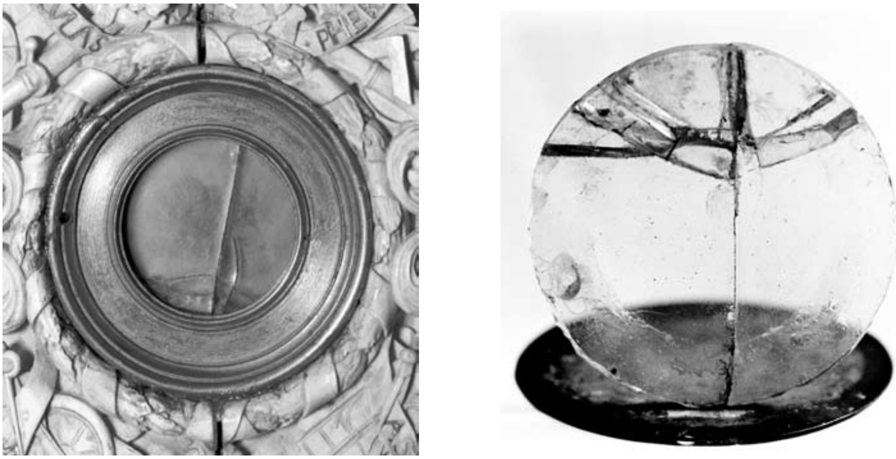
[10] Letter of Galileo to [Antonio de' Medici?], 7 January 1610, in: Galilei, *Opere*, 10 (1900), 273.

[11] Torricelli, 'Condizioni richieste nei vetri', note attached to the letter to Magiotti (ref. 9).



Ill. 10. Galileo's broken objective lens, housed at the Museo Galileo in Florence, inv. 2429. *Left:* the lens in its ivory frame of 1677. *Right:* the lens out of its frame.

Concluding remarks

A number of seventeenth-century Italian telescope lenses have been tested so far, in particular of Galileo, Torricelli, Eustachio Divini and Giuseppe Campani. The most relevant result is that the optical quality of the objectives was surprisingly good. Galileo's broken objective lens, shown in Ill. 10, was almost diffraction limited, i.e., optically perfect for visual use.

Similar levels of quality were almost routinely achieved by Campani. Although Galileo used to purchase a great number of lenses, choosing from them the best ones, already at the time of Torricelli the lens fabrication process had become a well defined technology, in which the single production steps were understood, and brought to perfection.

Investigations are still ongoing. Present research is aimed at determining the composition of the glass the lenses are made of. Techniques being used are spectrophotometric analysis and X-ray fluorescence. The former can point out the presence of a few typical compounds in the glass melt. The latter is a more direct determination of particular atomic elements within the lens material. It is hoped that the information on the chemical composition of the glass can help in locating the lenses themselves, and the telescopes they belong to, more precisely within their historical framework.

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L. Mercatelli, M. Miniati, A. Pecchioli, F. Principe, F. Quercioli, E. Schettino, G. Strano, M. Vannoni and M. Verità. The illustrations used in this paper are the copyrighted property of the Museo Galileo, Florence, and the Physics Museum of the University of Naples: thanks are given for permission to include them in this paper.

Kepler's legacy: telescopes and geometrical optics, 1611-1669

Antoni Malet

Introduction

Johannes Kepler's *Dioptrice* (published in 1611) produced the first theoretical explanation of the Dutch telescope. Notwithstanding the unanimous recognition of the founding role of the *Dioptrice* for modern geometrical optics, questions such as whether it was widely read, how well it was understood, or how influential it actually was remain open. While some scholars from an older generation regarded Kepler's work as *the* major influence behind the improvements in telescope construction, yet others pointed out that the *Dioptrice* seemed forgotten for decades, its seminal ideas developed by no one.[1] Following a hint by Galileo Galilei, some scholars even advanced that the *Dioptrice* was little read and appreciated because of its obscurity – as is well known, Galileo at least once said (in 1614) that the *Dioptrice* was so difficult that not even Kepler understood it.[2] Puzzlingly, therefore, while the *Dioptrice* has been claimed to be a seminal work, it is also claimed that it has hardly had any theoretical or practical influence. As we shall see here the tension between the foundational character of the *Dioptrice* and the doubts about its audience found in the historiography is at least in part a consequence of the nature of Kepler's geometrical optics. On the one hand, Kepler set forth notions, techniques, and explanations that were henceforward to play a crucial role in optics – including ray pencils, pinhole images, the projection of *picturae* by lenses, and the optical properties of the eye. These and other features of Kepler's optics were fully incorporated in most optical treatises from the 1620s on. On the other hand, Kepler's explanation of the working principles of the Dutch telescope does not include geometrical optical images. His account of the telescope is

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[1] For appraisals of Kepler's legacy in optics see G. Simon, *Structures,* 1 (1979), 574-575; Dijksterhuis, *Mechanization* (1964), 390; Hoskin, 'Introduction' (1962), vi; Caspar, *Kepler* (1959), 198-201.

[2] Drake, *Galileo at Work* (1978), 237-238; idem, *Telescopes, Tides and Tactics* (1983), 23; Geymonat, *Galilei* (1957), 45. On the obscurity of Kepler's writings see Hall, *The Revolution in Science* (1983), 133; Caspar, *Kepler* (1959), 201; Ronchi, *Optics* (1991), 47.

therefore different in kind to the explanations found in optical treatises from the eighteenth century on.[3] Geometrical images, and with them new ways of understanding the magnification produced by two or more lenses, were first introduced in works published in the 1660s. Among them Isaac Barrow's *Optical lectures* (1669) stands out for its originality and complexity and for the influence it had. These works obliterated so to speak Kepler's theory of the telescope. They are all silent about the *Dioptrice*, which is perhaps understandable given that they crucially depart from its theory of the telescope. This may help explain that some historiography belittled the *Dioptrice*'s influence in the first two thirds of the seventeenth century. Furthermore, recent scholarship by Albert Van Helden and others that demonstrates the practical or experimental origins of most improvements in seventeenth-century optical instruments also reinforces the suggestion that Kepler's theory of the telescope was largely irrelevant.[4] However, before explanations of optical instruments grounded on the notion of geometrical optical image came to substitute for Kepler's, the *Dioptrice* found a wide audience. It was several times reprinted up until 1683, a French paraphrase of it was twice published, and Kepler was widely recognised as an authority as well by authors writing on telescope observations as by those writing on telescope making. Clear evidence of the influence Kepler's theory had up to the 1670s is the place it occupies in both Carlo Manzini's *Occhiale all'occhio* (1660) and Cherubin d'Orleans *Dioptrique oculaire* (1671) – perhaps the most comprehensive and best known seventeenth-century treatises on the practice of telescope making. These treatises enlarge the purview of Kepler's *Dioptrice* by adding new results on the astronomical or Keplerian telescope and by setting forth new combinations of lenses. As we shall see below, the new results are grounded on Kepler's notions and principles and some new designs are inspired by Kepler's results and arguments. In this sense Kepler provided a general theoretical framework for optical instruments in the first two thirds of the seventeenth century. To conclude the article we will analyse the continuities between Kepler's *Dioptrice* and the classical geometrical optics based on the notion of geometrical image that started in earnest in the last third of the century.

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[3] Ronchi, *Optics* (1991), 47-49; idem, 'L'ottica del Keplero e quella di Newton' (1956); King, *The History of the Telescope* (1979), 44; Park, *The Fire within the Eye* (1997), 166-168; Dijksterhuis, *Lenses and Waves* (2004), 24-50.

[4] Van Helden, 'The Telescope in the Seventeenth Century' (1974); idem, 'The Development of Compound Eye Pieces, 1640-1670' (1977); idem, *The Invention of the Telescope* (1977); idem, 'The Astronomical Telescope' (1976).

Kepler's explanation of the Dutch telescope

We shall first provide an abstract of Kepler's main results concerning the Dutch telescope as published in *Dioptrice*.[5] It works with the notions and techniques Kepler introduced in his *Ad Vitellionem paralipomena* (1604). To simplify the law of refraction he used there, Kepler takes as an axiom that for small angles of incidence, the angles of incidence and refraction are proportional in such a way that, for rays falling from air on glass with incidences smaller than 30°, refracted rays make an angle with the perpendicular to the interface fairly equal to two thirds of the angle of incidence ($r = 2i/3$).[6] Kepler did not use the word 'focus', but he had recognised in the *Ad Vitellionem paralipomena* that after refraction in a convex lens most rays parallel to the axis converge around a point whose distance to the lens depends only on its convexity.[7] In the *Dioptrice*, the axiom just mentioned allowed Kepler to prove that rays parallel to the axis of a bi-convex lens have their focus at a distance equal to the radius of convexity of the lens (radius of its spherical surfaces).[8] Moreover he knew that rays coming from a point on the axis distant to the lens by twice the radius of convexity are refracted so that they gather into a point on the axis symmetrically located with respect to the lens. This was all the theoretical knowledge Kepler had about the refraction of light rays in lenses. With it he set out to understand how lenses do combine with the eye to modify vision.

Magnification Kepler explained by the modification of the visual angles. In Illustration 1, the lens AB refracts the rays so that those that come from the end points D and E of an object DE reach the eye by the lines DAC and EBC. The eye C perceives DE enlarged because it appears to the eye C under the larger angle ACB, instead of DCE under which the object appears to the eye in unaided vision.[9]

The inversion of things seen through a lens, Kepler explained by the relative positions of the ray pencils falling on the eye. In Illustration 2, the eye IG, located between the lens AB and the focus of the pencils coming from object CE, sees CE upright because the pencil from the left falls on the eye from the left and the pencil from the right arrives from the right. In illustration 3, the eye OP, located beyond the focus DF of the pencils of rays coming from the object CE, sees CE inverted. The eye sees the pencil originating in E as

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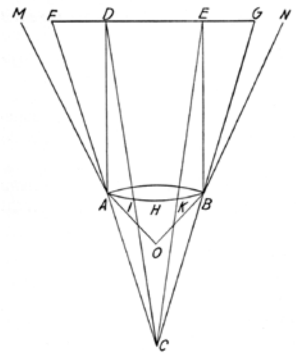
[5] In this article all references to the *Dioptrice* are to Kepler, *Gesammelte Werke*, 4 (1941), 329-414.

[6] Kepler, *Dioptrice* (ref. 5), 357. For a full discussion of the geometrical optical content, see Malet, 'Kepler and the Telescope' (2003).

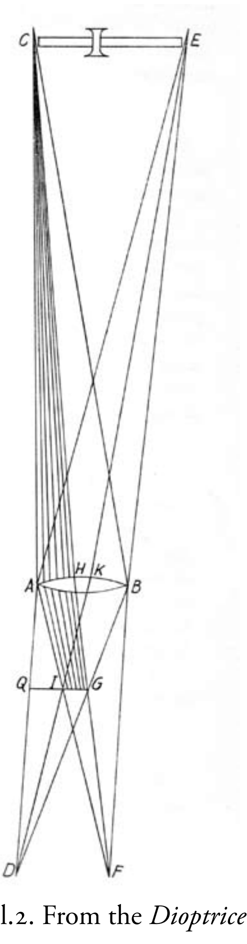
[7] Kepler, *Ad Vitellionem* (1968), 191; see Malet, 'Keplerian Illusions' (1990) 15-17.

[8] Kepler, *Dioptrice* (ref. 5), 361.

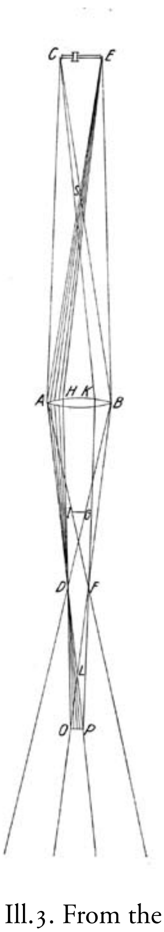
[9] *Ibidem*, proposition 80, 381-382.



Ill.1. From the *Dioptrice*, page 382



Ill.2. From the *Dioptrice*, p. 377



Ill.3. From the *Dioptrice*, p. 379

coming from the left, while it sees the pencil from C as coming from the right, therefore CE 'is represented inverted to the eye'.[10] Notice that there is nothing drawn between the focal points DF, nor does Kepler make any reference to an image of CE being projected there. In other words, Kepler's argument does NOT include that the eye sees CE inverted because the lens produces an inverted image of CE. In Kepler's *Dioptrice* there is no location for the images and therefore the eye OP is assumed to see nothing in the focal points DF. I shall come back to this important point.

Kepler's theory of the telescope is introduced by a formal but merely descriptive definition of telescope or 'tube': 'By 'tube' we understand a hollow opaque cylinder whose two openings are closed by transparent glasses; i.e. that optical instrument by which we perceive far away things as almost near at hand'.[11] Then follow propositions 107 through 115, the theoretical climax of the treatise with the main results of Kepler's theory of the Dutch telescope. Notice that assuming all of his tubes to be of the Dutch kind, Kepler does not even suggest that other kinds of telescopes are possible. What Kepler proves about the Dutch telescope is the following. First, *some* combinations of a convex objective lens and a concave ocular lens allow the distinct vision of upright, enlarged objects (propositions 107, 108).[12] Not *all* the combinations of convex and concave lenses work because the radius of convexity of the objective lens must be greater than the radius of concavity of the ocular lens. Second, in such combinations, the concave ocular lies between the objective lens and its focus, but is never 'very far' (sic) from the focus of the convex objective (proposition 109; no quantification of the place of the ocular lens is given). Third, the greater the concavity of the ocular lens, the nearer to the focus of the objective lens it must lie (proposition 110). Fourth, for a given ocular, the smaller the convexity (i.e., the greater the radius of convexity) of the objective lens the greater the distance between the lenses must be (proposition 112). Fifth, for a given objective lens, the greater the concavity of the ocular lens the greater the magnification (proposition 113). And sixth, for a given ocular lens, the smaller the convexity of the objective lens the greater the magnification (proposition 115).

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[10] *Ibidem*, propositions 70 and 75, 377-378 & 379-380.

[11] *Ibidem*, 395. Definition 101 reads: 'Tubus usurpatur pro opaco cavo cylindro, cujus bina ostia clauduntur vitris perspicuis; scilicet pro oculari illo instrumento, quo res longinquas quasi cominus aspicimus'.

[12] *Ibidem*, 395-402, propositions 107 to 115.

To get a sense of Kepler's arguments let us sketch his demonstration of proposition 107, where he proves that any convex lens set a certain distance of a concave lens magnifies vision and makes it distinct – provided the objective lens comes from a sphere the radius of which is greater than the radius of concavity of the concave ocular. Kepler argues that the concave lens when applied close to the eye produces blurred vision because it makes the rays diverge too much for the eye. When the eye is placed between the convex lens and its focus, he adds, vision is also blurred because of the convergence of the rays sent by the objective. Therefore, both effects may cancel each other when the lenses are set up at the appropriate distance. That distance depends on the relative degrees of convexity and concavity, but he has no rule to determine it. The magnifying power of such combination of lenses is a consequence of the eye's location between the convex lens and its focus, since Kepler has geometrically proved in a previous proposition (no. 80) that in such a position the visual angle is necessarily increased. Kepler points out that the enlargement produced by the convex objective is diminished by the action of the concave ocular. However, he has proved in a previous proposition that the enlargement produced by convex lenses as well as the diminution produce by concave ones increase with the distance to the eye (propositions 82 and 98). Since the concave ocular is close to the eye but the convex objective is much further away, the magnification will predominate.[13]

Before we conclude with Kepler's *Dioptrice* we must mention its last propositions. They are devoted to instruments that Kepler called in Greek 'krypsis' (κρυψισ), translated here by 'cryptical', whose external appearance belies their optical properties. In these little known propositions Kepler proves, first, that the focal distance of two equally convex lenses applied contiguously is half as long as the focal distance of either of them, although they together magnify less than one lens by itself does. He also finds the focal distance of some special meniscus-shape lenses. Then he solves problems such as how to make a telescope whose objective lens is of small convexity (and the telescope should therefore be very long) and yet the instrument is shorter than it should be. The solution of course comes from a compound objective made of two convex lenses set contiguously. Kepler solves other similarly puzzling or 'cryptical' instruments.[14] By using objective or ocular pieces which contain two convex (or concave, respectively) lenses, and also by using meniscus, Kepler suggests for instance a telescope whose objective and ocular lenses both are (or seem to

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[13] *Ibidem*, 397-398; see also Malet, 'Kepler and the Telescope' (2003), 121-122.

[14] Kepler, *Dioptrice* (ref. 5), 405-414.

be) concave and yet still produces the magnifying effect (problem 139). In the next problem (problem 140) he shows how to make another 'cryptical' instrument in which both the ocular and the objective lenses are both convex. His solution is to use an eye-piece consisting of one meniscus that shows its convex side to the eye.[15]

Let me add a note on the 'Keplerian' or astronomical telescope, i.e. on Kepler's would-be proposal of a 'telescope' fitted with a convex ocular. In contrast with what he does for the Dutch or Galilean telescope, Kepler does not include his study of vision through two convex lenses among the propositions he devotes to 'tubes' or telescopes. Actually, he devotes just one single proposition to explain that two convex lenses may be set in such a way that things are seen distinct, inverted, and enlarged (proposition 86). The demonstration is in the same style as the one I have just sketched above for proposition 107. Nothing else is said about the combination of two convex lenses and the distances that must separate them.[16] Secondly, remember that among the 'cryptical' instruments just referred to Kepler mentions one in which both the ocular and the objective lenses appear to be convex lenses. Kepler does not bring here a comparative discussion between the different optical properties of the 'Keplerian' or astronomical design and the 'cryptical' design. In fact, the convex ocular of the 'cryptical' telescope would not be surprising per se once the astronomical telescopes were known. The only puzzling effect would the inversion of the image, but Kepler ignores the matter completely. I think this suggests that the idea of turning his theoretical combination of two convex lenses into a working telescope may have never crossed Kepler's mind.

How well-known was Kepler's Dioptrice?

There is wide and strong evidence that the *Dioptrice* was widely read, understood, and appreciated through the mid seventeenth century and beyond – pace Galileo. It enjoyed not less than five new printings as a companion to Pierre Gassendi's *Institutio astronomica*, the first one in 1653, the last one in 1683. Gassendi's popular *Institutio* introduced the cosmological systems of Claudius Ptolemy, Tycho Brahe and Nicolaus Copernicus. It was printed in

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[15] *Ibidem*, 414.

[16] *Ibidem*, 387; Kepler devotes another problem (proposition 89) to solve the problem of 'showing things distinctly, enlarged, and upright' by the combination of three convex lenses (389). An additional proposition analyses the combination of two convex lenses that diminishes instead of enlarging visible things (proposition 87, 387-388). See Malet, 'Kepler and the Telescope' (2003), 119-120 & 134-136.

a single volume accompanied by Galileo's *Sidereus Nuncius*, which supported Copernicus' system, and by Kepler's *Dioptrice*, which supported Galileo's observations. As Gassendi tells his readers, the presence of the *Dioptrice* in such a collection was meant to give mathematical authority to the new instrument by demonstrating 'the method to build [it]'.[17] Besides providing evidence of the *Dioptrice*'s authoritative status, Gassendi's popular volume alone ensured that Kepler's little treatise was widely known. There is yet more evidence of the popularity and influence of *Dioptrice*. Pierre Herigone's popular five-volume mathematical encyclopaedia, *Cursus mathematicus* (published in Paris in 1634-37 and again in 1644) includes a treatise on dioptrics that closely paraphrases Kepler's *Dioptrice*. In the second edition Herigone acknowledged his debt to Kepler.[18]

If we turn to practicing astronomers, Johannes Hevelius' *Selenographia*, the major work he published in 1647, opens with two chapters devoted to lenses and telescopes. While Hevelius does not enter into details, he highlights Kepler and Christopher Scheiner as the main authorities on the mathematical optics involved in telescopes.[19] Schyrleus de Rheita, whose main contribution to telescope design was the compound eyepiece and who popularized the use of the convex ocular in astronomical telescopes, acknowledged his debt to Kepler's *Dioptrice* in his *Oculus Enoch et Eliae* of 1645. Kepler is mentioned first along with René Descartes and Galileo (*sic*) as the authorities on the 'theoretical parts of dioptrics and their demonstrations'. Elsewhere Kepler is credited as having mentioned in the *Dioptrice* that a tube might be fixed with two convex lenses.[20] Starting from here, Rheita investigated (apparently by trial and error) what was the best convexity of the ocular lens for an objective lens of a given convexity.[21] Finally, let us turn to analyse the role Kepler's theory of the telescope plays in treatises dealing with the design and construction of telescopes. I will focus on the treatises by Cherubin d'Orleans and Manzini, which are among the most comprehensive and influential of the seventeenth century.

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[17] Gassendi, *Institutio astronomica* (1653), 'Nota ad lectorem', [A2] *verso*. Gassendi's *Institutio* was first published in 1647 and last printed in 1702. Other editions were dated 1653, 1656, 1675, 1680, and 1682-83. I have not been able to see the editions of 1647 and 1702 but apparently they do no contain Kepler's *Dioptrice*.

[18] The second edition contained a sixth supplementary volume, in which we find Herigone's acknowledgement of his debt to Kepler's *Dioptrice* (p. 242). In both editions Herigone's 'La Dioptrique' - 'Dioptrica' occupied 127-189 of the fifth volume.

[19] Hevelius, *Selenographia* (1647), 14 & 19.

[20] Schyrleus de Rheita, *Oculus Enoch et Eliae* (1645), 340 & 351.

[21] On Rheita, see Willach, 'The Development of Telescopic Optics' (2001).

Kepler in Cherubin d'Orleans' La dioptrique oculaire

Cherubin d'Orleans' *La dioptrique oculaire*, published in French in 1671, has been called 'the most exhaustive treatise on lens making in the seventeenth century'. It is a six-hundred folio page long, comprehensive, cogently-argued treatise on telescope making. It contains an impressive amount of theoretical and practical, first-hand information on all of its facets – from explanations of the telescope's working principles, to descriptions of lens grinding and polishing, to rules for the right distances between lenses, to methods to find the right apertures, to descriptions of the shapes and articulations of the wooden parts and bolts and screws needed to properly point a telescope to the skies, to the construction of tubes, and so on and so forth. On the strength of his optical contributions, Cherubin d'Orleans (1613-1697), a Capuchin friar, was one of the selected company of scholars, mathematicians and natural philosophers who tutored the *Dauphin*, the crown-heir of Louis XIV.[22]

The full title of d'Orleans' treatise, *La dioptrique oculaire, ou la theorique, la positive et la mechanique de l'oculaire dioptrique en toutes ses especes*, indicates its parts and contents. The first, shorter part of the book is devoted to the theory of vision, including the optical properties of the main parts of the eye. It follows Kepler's account but complements it with views taken from the Jesuit Christopher Scheiner's *Oculus* (1619) and *Rosa ursina* (1630).[23] The second part, which dedicates more than one hundred pages to the theory of the telescope, pervasively shows the deep influence of Kepler's *Dioptrice*. The basic notions and axioms come from Kepler, including the approximate refraction law for angles of incidence no greater than 30° mentioned above (pp. 8 & 25).[24] To Kepler's results about the focus of convex lenses and meniscus, d'Orleans adds a few new results, but not a full treatment of the problem. He takes into consideration only the focus of radiation parallel to the axis of the lens. For it he finds the focal distance for a plano-convex lens, a biconvex symmetrical lens, a

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[22] Orleans, *La dioptrique oculaire* (1671). Cherubin d'Orleans' books for the use of the Dauphin, now kept in the Bibliothèque Nationale in Paris, have their covers richly gilded with dolphins all around. For its many pages – almost half of the book – devoted to lens grinding and polishing, see Burnett, *Descartes and the Hyperbolic Quest* (2005), 107-121 [quotation on 107].

[23] Scheiner, *Oculus, hoc est fundamentum opticum* (1619). In demonstrating the formation of the Keplerian 'picture' on the retina, Scheiner modifies the geometry of Kepler's pencils of rays and inconsistently reintroduces perspectivist pyramids; see 155-158 (quoting from the 1652 London edition). He elaborates his melange of Keplerian pencils and perspectivist pyramids in his *Rosa ursina sive sol* (1630). D'Orleans' words in *La dioptrique oculaire* (1671), 8-11 are reminiscent of Scheiner's in *Rosa ursina* (1630), 117-118.

[24] Pagination refers to D'Orleans, *Dioptrique oculaire* (1671).

biconvex meniscus with two general radii of convexity, and a concavo-convex meniscus whose surfaces have two general radii. He also improves Kepler's results about the focus of two contiguous equal convex lenses.[25] D'Orleans also takes up in full Kepler's understanding of magnification, his procedure to measure it, and his explanations for the inversion of the image (pp. 11-13 & 158). More importantly, d'Orleans closely follows Kepler's analysis of the ways in which a convex or a concave lens combine with the eye separately (pp. 67-71 & 73-78). Next, he presents the theory of the Dutch telescope as it appears in the *Dioptrice* (pp. 80-89).

The full treatment of astronomical or Keplerian telescopes is one important addition to Kepler's *Dioptrice* we find in d'Orleans' treatise (pp. 91-108). Astronomical telescopes are called telescopes 'of the second kind (*oculaire dioptrique de deuxième espèce*)', while the Dutch or Galilean telescopes belong to the 'first kind' (*première espèce*). D'Orleans' analysis of the combination of two convex lenses closely follows Kepler's. Recognising these telescopes to be the most important ones for the purposes of astronomical observation, d'Orleans carefully explains many practical problems posed by their actual construction. In particular he insists in the one physical feature that outwardly distinguishes them from Dutch telescopes, i.e. that objective lenses in Keplerian telescopes had smaller diameters than ocular lenses, which made Keplerian telescopes to be thicker at the end to which the eye was applied and thinner at the end pointed to the sky (pp. 178 & 190). The astronomical telescope occupies pride of place in the carefully designed frontispiece of d'Orleans' treatise (see Illustration 4). Other second-kind telescopes may include three, four or even five convex lenses (pp. 109-118). Their properties are explained with the same techniques Kepler (and d'Orleans) used to explain the combination of two convex lenses (exemplified above by the demonstration of *Dioptrice*'s proposition 107).

The second important theoretical addition to Kepler's *Dioptrice* we find in d'Orleans' treatise concerns the theory of microscopes with one, two and three convex lenses (pp. 125-140), a topic Kepler ignored. The last and longer division of d'Orleans' *Dioptrique oculaire* (almost 300 pages) concerns the 'positive and mechanical' parts of telescope making, i.e. the actual construction of tubes and its parts, and techniques for lens grinding and polishing. In the opening pages of his treatise d'Orleans claims himself to be Kepler's 'follower', and calls Kepler the main author of the 'modern theory' (*doctrine moderne*) of dioptrics.[26]

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[25] *Ibidem*, 61-65.

[26] *Ibidem*, 'Au lecteur', eii verso; similar reference on 6.

Ill. 4. Cherubin d'Orleans's *La Dioptrique Oculaire* (1671), frontispiece. The engraving may be read as an ancients versus moderns scene, with the moderns, left, lead by Louis XIV himself. He is wearing an imperial Roman attire (as he used to in contemporary courtly parades) and carrying a telescope (with engraved fleur-de-lis) as if it were a wand or sceptre. Angels are holding a microscope (right), a Dutch telescope, and (in central position) an astronomical or Keplerian telescope.

In fact Kepler is (sometimes with an explicit reference, sometimes without) the main authority for d'Orleans general principles and notions, including the law of refraction (p. 25) and the axioms linking visual angle and size magnification (pp. 11 & 81). D'Orleans also takes up Kepler's understanding of the interaction between eyes and lenses (pp. 67-86), as well as Kepler's method for analysing combinations of lenses (pp. 86-105). Not surprisingly, d'Orleans produces a paraphrase of almost all the particular results in the *Dioptrice* that concern lenses and the Dutch telescope. D'Orleans enlarged Kepler's theory of the telescope by adding new results concerning the astronomical telescope and the microscope. However, d'Orleans did not change Kepler's theoretical framework, since his new results were based on Kepler's notions, principles, and arguments. In this sense one may say that Kepler's *Dioptrice* dictated the conceptual structure of the theoretical parts of d'Orleans' treatise.

Kepler in Manzini's L'occhiale all'occhio

The second book that shows the impact of Kepler's theory of the telescope on contemporary optics is Carlo Antonio Manzini's *L'occhiale all'occhio*, published in 1660. Manzini's treatise, similar in its wide scope to d'Orleans's, deals with refractions, the human eye and vision, and the making of lenses, telescopes and microscopes.'[27] The late Vincent Ilardi called Manzini's book 'the most comprehensive book on the subject' of spectacle and telescope making.[28] Count Manzini from Bologna, who had set up his own observatory and was highly skilled in the art of lens grinding and telescope making, highlighted hands-on practical knowledge as the crucial element to become skilled in the art, or a 'perfect master'. As Ilardi justly emphasized, Manzini recommended reliance on experience and ingenuity rather than on books. He opens the many pages he devoted to telescopes by saying that 'experience by itself may be enough for this … undertaking', i.e., for the practical assemblage of a convex objective and a concave ocular to get a working magnifying telescope.[29] However, Manzini's emphasis on practical knowledge, which is overwhelming in the pages that deal with the grinding and polishing of lenses, is complemented by theoretical references in the pages he devoted to telescope making. The preface mentions a long list of authorities – Alhacen, Witelo, Roger Bacon, Jean Baptiste du Hamel, Franciscus Maurolico, Giambattista della Porta, Kepler, Scheiner, Hevelius, Herigone, Marin Mersenne, Rheita, Emanuel Maignan, Descartes, Francesco Bonaventura Cavalieri and Niccolò Zucchi – although few of them play any role in Manzini's directions for telescope-making. Among the few that do, Kepler is by far the one most frequently cited. As we shall see, Manzini uses Kepler's theory in many ways and discovers in the *Dioptrice* results that seem to suggest to him new telescope designs.

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[27] Manzini, *L'occhiale all'occhio* (1660).

[28] Ilardi, *Renaissance vision from spectacles to telescopes* (2007), 229-234 [quotation on 229]. On Manzini, see also Bedini, 'An Early Optical Lens-Grinding Lathe' (1967).

[29] Manzini, *L'occhiale all'occhio* (1660), 128-129.

For one thing, Manzini appeals to Kepler's authority to back well-known basic results of telescope making, as if they gained a new status by Kepler's demonstrations in the *Dioptrice*. This is the case for the claim that in Dutch telescopes lenses must stand as fart apart as the focal distance of the convex objective lens or nearly; that the aperture must change according to the brightness of the observed object; or that objective lenses of great convexity require eye-pieces of great concavity.[30] Contrariwise to what d'Orleans does, Manzini never follows or repeats Kepler's geometrical arguments closely. However, he brings Kepler in when he wants to explain some relevant optical effect. For instance, he provides a qualitative, very general explanation of vision through telescopes with two or more convex lenses grounded on proposition 80 of the *Dioptrice* (the upright image of a visible thing seen through a convex lens is enlarged necessarily); Manzini uses it to explain why the combinations he sets forth will produce magnified vision.[31] In another instance, he explains why astronomical telescopes have a wider field of view than Dutch telescopes do with references to *Dioptrice*'s propositions 81 (in which Kepler links the distance of the eye to the focus of a convex lens to the field of view), 86 (which contains Kepler's account of the combination of two convex lenses) and 109 (where it is proved that in Dutch telescopes the concave ocular is always located very near the focus of the objective).[32] In other instances, Manzini uses results from the *Dioptrice* to ground new rules of his invention. For instance, Manzini produces a table for Dutch telescopes that gives the recommended aperture size in relation to focal length. This is complemented by a new table that determines the best concavity of the ocular in relation to apertures. Manzini's calculations of concavities for ocular lenses involve a geometrical argument grounded on Kepler's theoretical understanding of the role of ocular lenses and on his law of refraction.[33] In other instances, Manzini uses results from the *Dioptrice* to analyse instruments that Kepler never mentions. This is the case for the microscope (with one or more lenses), whose workings Manzini grounds on Kepler's proposition 37 in the *Dioptrice*.[34]

As mentioned above, Kepler's interest in 'cryptical' instruments lead him to explore the optical effects of new combinations of lenses. Manzini does

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[30] Manzini, *L'occhiale all'occhio* (1660) includes references to Kepler in 128, 129, 131, 138, 142, 144, 145, 149, 150, 154, 163, 174, 187, 195, 197, etc. Manzini's references to the results mentioned above are found on 128-129, 138, 131 & 153-154.

[31] *Ibidem,* 194-196; reference to *Dioptrice*'s proposition 80 on 196.

[32] *Ibidem,* 197-198.

[33] *Ibidem,* 142-145.

[34] *Ibidem,* 174.

not talk of 'cryptical' instruments, but suggests a vast array of new telescope designs in which three, four and even five lenses are combined, and whose optical properties Manzini knows in a qualitative general way thanks to Kepler's results about 'cryptical' instruments. He analyses first in some detail a variation upon the basic design of the Dutch telescope in which the tube is fitted with an additional convex lens whose convexity is about ¾ that of the main objective lens and which is located about half the length of the tube. Rules for fixing the ocular are to be obtained by trial and error. This design, says Manzini, comes from experience. Manzini reveals, however, that he knows in advance its main properties because they are foretold by two propositions Kepler devoted to 'cryptical' instruments. The instrument will be shorter, as demonstrated in the *Dioptrice*, proposition 135 (it shows how to make a working Dutch telescope whose objective is of small convexity but shorter than the focal distance of the objective lens), and it will magnify less, by proposition 125 (which proves that the contiguous application of two equally convex lenses halves their focal distance).[35] On the other hand, experience shows that images are clearer and more distinct and the field of vision is wider. Manzini fills ten pages of his book (from page 177 to 186) with recipes, such as the ones shown in Illustration 5, which seem to originate in a combination of practical knowledge and general theoretical rules provided by Kepler's *Dioptrice*.[36]

For instance, Manzini's telescope on top of Illustration 5, features as main objective one convex lens (of 4-foot focal length), plus a convex lens (9-inch focal length), plus a concave lens (4-inch focal length), plus a convex lens (2 and ¾ -inch focal length). They are separated by 3 feet 4 inches, 3 inches, and 6½ inches, respectively. As Manzini points out, this yields an inverted but very distinct image and good magnification. Manzini suggests that most of his designs must have been meant for terrestrial or maritime uses, since most of them have as major virtue an enlarged field of vision.[37] They do not seem to be appropriate for astronomical observation, since additional lenses came at the heavy price of loss of illumination. Manzini concluded his ten-page presentation of many varieties of telescopes by suggesting the reader to try his own designs guided by the designs and general rules he is setting forth: 'chiasceduno da se, con l'essempio di queste, se ne potrà componerse cento, e mille altre'. He advises the reader to use his designs as a sort of blueprints, and then improve them by trial and error.[38]

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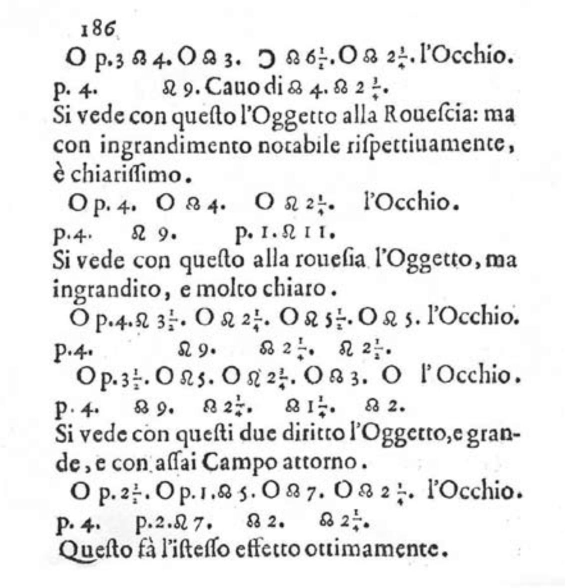
[35] Kepler, *Dioptrice* (ref. 5), 405 & 412.

[36] Manzini, *Occhiale all'occhio* (1660), 148-151 [references to Kepler on 149-150].

[37] *Ibidem,* 186-188 [for Manzini's reference to his telescopes as being particularly useful in 'mare e campagna', see 188].

[38] *Ibidem,* 189-190 [quotation on 189].



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O p.3 ℥ 4. O ℥ 3. Ↄ ℥ 6½. O ℥ 2¼. l'Occhio.
p. 4. ℥ 9. Cauo di ℥ 4. ℥ 2¾.
Si vede con queſto l'Oggetto alla Roueſcia: ma con ingrandimento notabile riſpettiuamente, è chiariſſimo.

O p. 4. O ℥ 4. O ℥ 2¼. l'Occhio.
p.4. ℥ 9. p. 1. ℥ 11.
Si vede con queſto alla roueſia l'Oggetto, ma ingrandito, e molto chiaro.

O p.4. ℥ 3½. O ℥ 2¼. O ℥ 5½. O ℥ 5. l'Occhio.
p.4. ℥ 9. ℥ 2¼. ℥ 2½.

O p.3½. O ℥ 5. O ℥ 2¾. O ℥ 3. O l'Occhio.
p. 4. ℥ 9. ℥ 2¼. ℥ 1¼. ℥ 2.
Si vede con queſti due diritto l'Oggetto, e grande, e con aſſai Campo attorno.

O p. 2½. O p. 1. ℥ 5. O ℥ 7. O ℥ 2¼. l'Occhio.
p. 4. p.2. ℥ 7. ℥ 2. ℥ 2¼.
Queſto fà l'iſteſſo effetto ottimamente.

Ill.5. Manzini's representation of telescopes, from his *Occhiale all'occhio*, page 186. Here **O** means a convex lens; **)**, an inverted C, means a concave lens; **p** means *pied*, foot; the remaining symbol means *once* or *onze*, inch, of which there are twelve in one foot. This is the Bolognese foot, equal to five quarters of the ancient Roman foot. Numbers between lenses indicate the distance which separate them. Numbers below a lens indicate the diameter of convexity or concavity.

Notice that Kepler's results provide the conceptual structure that enables both d'Orleans and Manzini to articulate their new results and new designs. In making public their practical innovations, both authors cannot avoid bringing in Kepler's conceptualization of the telescope. Kepler's terminology and understanding of the different parts of the telescope are the tools they use to explain how the new designs work. Moreover, in Manzini we find hints that some of his new combinations of lenses were inspired by results he found in Kepler (such as propositions 125 and 135 from the *Dioptrice*; see above).

The Dioptrice *versus classical geometrical optics*

Now to the last question. What role does Kepler play in the development of seventeenth-century geometrical optics? What is the relationship between

Kepler's *Dioptrice* and classical geometrical optics as it was developed from the 1660s on? The answer is complex. While Kepler's founding role for the contributions of James Gregory, Isaac Barrow, Isaac Newton, Christiaan Huygens, and others is recognized, yet it is somehow questioned by historical evidence – or rather by the lack of it. Their works appear more than 50 years after Kepler's, and they do not recognize themselves as followers of Kepler but as innovators rather. Actually, there are some disparaging remarks about Kepler's *Dioptrice* in the correspondence between Huygens and Burchard de Volder (or Fullenius) in 1683.[39]

The grounding role of the *Ad Vitellionem paralipomena* and the *Dioptrice* for classical geometrical optics is justified by the many conceptual and methodological innovations found there. They include, not to mention visual theory, the notion of pencils of rays, the notion of 'picture' or projected image, the solution to the problem of pinhole images, and partial but substantial results on the focal properties of lenses. It is a substantial contribution. In a general sense, therefore Kepler did start geometrical optics as it was understood in the seventeenth and eighteenth centuries. However, as we shall see now, a crucial notion in the classical theory of lenses and optical instruments is missing in Kepler, which helps explaining why the *Dioptrice* was superseded in the 1660s by the works of Barrow and others.

Telescopes were used both for projecting images on screens and for increasing the power of sight by putting the eye to it. In Kepler's time, one important difference between the telescope *qua* projective device and the telescope *qua* peep-through device had to do with the mathematical theories involved in each case. It is of course consequential for my purposes that this difference does no longer exist today. From the eighteenth century on telescopes were always understood to work by producing geometrical optical images, real or virtual, regardless of whether or not someone is peering through them. From our present-day understanding of telescopes, it does not matter whether an eye, an screen, or just empty space gets the light rays coming out of the ocular lens – in *all* these cases the telescope equally produces one geometrical image whose location and mathematical or physical properties just depend of the shapes and location of the lenses and the visible object. However, in Kepler's time and up to the last third of the seventeenth century, when somebody looked through a telescope, the telescope was not assumed to work by producing images similar to the 'pictures' projected upon screens. This may sound confusing, but we will try to clarify the matter with this example.

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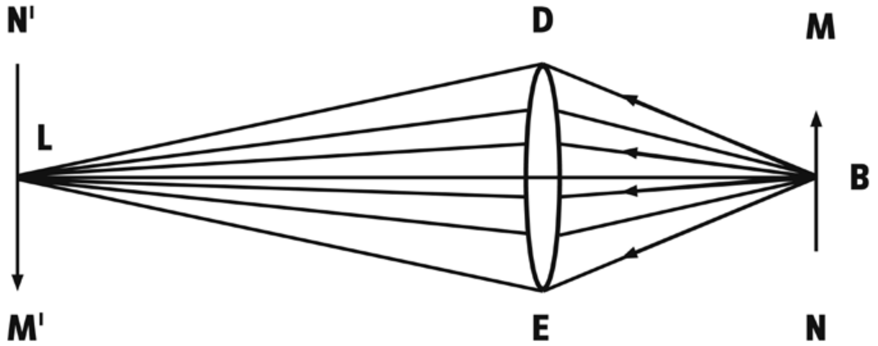
[39] Huygens, *Oeuvres complètes*, 8 (1899), 443-451, 474-478 & 533-536.



Ill.6. Kepler's 'picture': Kepler used the infinitely many pencils of rays coming from the points in MN to explain how the lens DE produced an inverted 'picture' of MN upon a screen (doted lines M'N').

Kepler explains the formation of 'pictures' through the notion of pencil of rays (Ill. 6). This, one of his conceptual innovations, he used crucially in his theory of vision in his *Ad Vitellionem paralipomena*. However, the notion plays a minor role in the *Dioptrice*. In particular, it is never used when he needs to explain the combined effect of two or more lenses. Kepler never introduces or makes use of it to explain how lenses modify sight, and a fortiori, never uses 'pictures' to explain how the telescope works. In other words, it is never the case that Kepler assumes the eye A (see Illustration 7) to see the image of MN as M'N', located between itself and the lens. When this kind of assumption was made (that is, when the focal points are assumed to affect the eye in such a way that it sees the object in the position occupied by the focal points), then it was argued that A sees MN inverted and enlarged because its image M'N' is inverted and enlarged.[40]

The transformation of focal points into images appears here and there in France and England, but does not take flight until the 1660s. In the 1630s Walter Warner wrote a few propositions about the geometrical determination of the image in spherical mirrors (the unpublished manuscript is still extant in the British Library). His solutions are only of particular cases, but a new principle of image location seems to be there.[41] John Flamsteed credited William Gascoigne for considering telescopes 'in a different manner from that which

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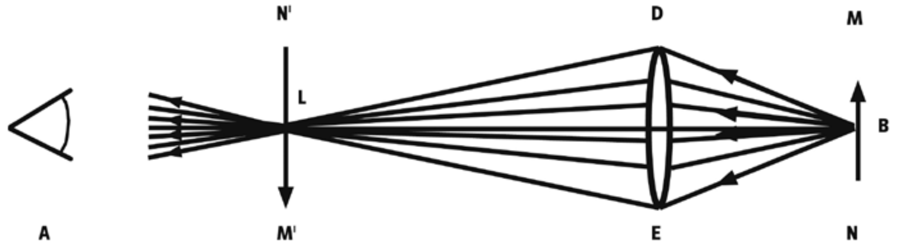
[40] See Gregory, *Optica promota* (1663), propositions 31, 46, 47; Molyneux, *Dioptrica nova* (1692), 122 & 160-161.

[41] W. Warner, 'De loco imaginis', British Library, Ms Harley 6756, fol. 5-26.



Ill.7. Geometrical optical image: Regardless of whether or not a screen receives the 'picture' of MN, the 'picture' (M'N') is assumed to exist in its proper position, hanging in the air so to speak. The eye A perceives MN closer and enlarged because it perceives M'N' instead of MN.

they had been hitherto treated'. For in his investigations, he found straight away that... 'the rays... delineate an image of the object at the base [here "base" probably refers to the focus] of the telescope'. That was about 1640. Gascoigne's papers are no longer extant but what Flamsteed attributes to him sounds very similar to the modern principle of image location.[42] Its first printed formulation is found in Mersenne's *L'optique et la catoptrique* (1651), but it is Gilles Personne de Roberval's contribution. Roberval fully characterized the new notion of optical image, but did not develop a theory of optical instruments based on it.[43] The first theory of this kind is found in James Gregory's *Optica promota*, published in 1663. Gregory argued (see Illustration 8) that when the eye A receives rays originating in B but actually coming to the eye *as if* they originated in L, then the eye 'applies itself' to process the rays, and therefore the eye makes the mind 'see' B in L.[44] There is therefore a strong assumption to be made to believe that the focal points M'N' (going back to Illustration 7) may be perceived as a representation of the object MN—the assumption that the mere divergence of the rays coming from visible things enables the mind (by means of the accommodation of ocular humours) to determine their location. For some reason by the late seventeenth century this assumption was easily made, and not only by opticians. Robert Boyle, for instance, agreed with it. He mentions the eye's ability to tell distances (i.e., the distance separating a visible point to the eye) and therefore to identify the location of visible things, as an example of the (necessarily limited) abilities of reason.[45] Edmé

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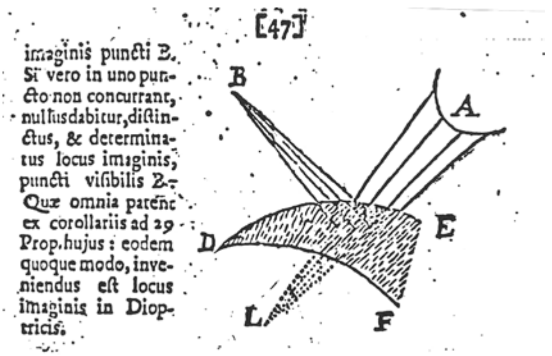
[42] Chapman, *Preface to Flamsteed* (1982); quotation on 104.

[43] Mersenne, *L'optique et la catoptrique* (1651), 112-114.

[44] Gregory, *Optica promota* (1663), 1 [for the geometrical definition of image], 41 & 46-47.

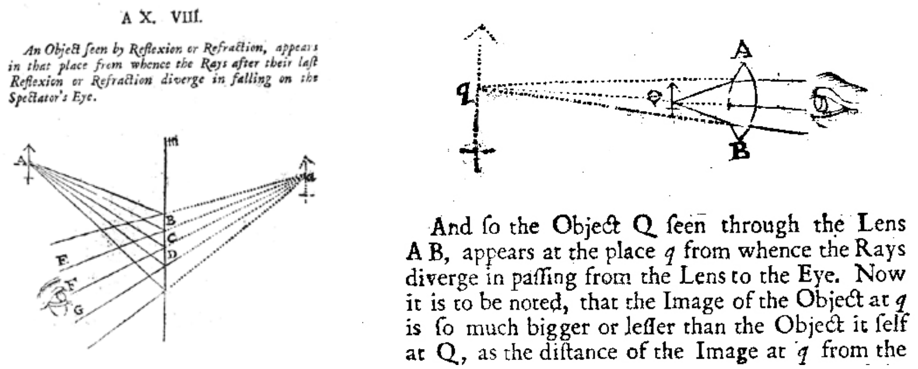
[45] Boyle, *Discourse of Things above Reason*, in: Birch, *Works*, 4 (1772), 414.



[47]

imaginis puncti B. Si vero in uno puncto non concurrant, nullus dabitur, diſtinctus, & determinatus locus imaginis, puncti viſibilis B. Quæ omnia patent ex corollariis ad 29 Prop. hujus: eodem quoque modo, inveniendus eſt locus imaginis in Dioptricis.

Ill.8. Reflected geometrical optical image in James Gregory's *Optica promota* (1663), p. 47.



A X. VIII.

An Object ſeen by Reflexion or Refraction, appears in that place from whence the Rays after their laſt Reflexion or Refraction diverge in falling on the Spectator's Eye.

And ſo the Object Q ſeen through the Lens A B, appears at the place *q* from whence the Rays diverge in paſſing from the Lens to the Eye. Now it is to be noted, that the Image of the Object at *q* is ſo much bigger or leſſer than the Object it ſelf at Q, as the diſtance of the Image at *q* from the

Ill.9. Reflected and refracted geometrical images in Thomas Harris's *Lexicon Technicum* (1708-10).

Mariotte, the natural philosopher in Paris, also accepted this principle of image location and in 1678 explicitly linked it to his faith in the ability of sight to tell distances to the mind.[46] However, there was no consensus on the matter. Other natural philosophers, including Descartes, Huygens and followers of Descartes, expressed misgivings about the eye's ability to tell distances and did not take seriously the new principle of image location.[47] Gregory, who knew his Kepler very well, stressed his definition of optical image was an innovation which took him much time to produce.[48] It was taken up by Barrow in his

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[46] Mariotte, *Essai de logique* (1992), 148-155.

[47] Descartes, *La Dioptrique*, in: *Oeuvres de Descartes*, 6 (1996), 144 ; See also ref. 39.

[48] Gregory, *Optica promota* (1663), preface, A3 *verso*. On Gregory as reader of Kepler's optics, see Malet, 'Gregory, Descartes, Kepler, and the Law of Refraction' (1990).

Optical Lectures of 1669 and by Newton in his 'Lectures' in Cambridge in the early 1670s.[49]

For a few decades around 1700 this notion of optical image is found in most optical books published in England. Illustration 9 shows Thomas Harris' introduction of geometrical optical images in his popular *Lexicon Technicum* (1708-10), where he credits the innovation to Newton (most optical writers however credited it to Barrow).[50] George Berkeley, the philosopher, attacked this notion of image and the underlying assumption about the eye's ability to learn how to evaluate distances in his *Essay towards a New Theory of Vision* (1709) and by 1730 it was already in trouble.[51] By the second half of the eighteenth century it had been mostly abandoned. Yet the geometrical determination of 'geometrical image' formation (even if 'geometrical image' now was no longer taken to be the place were objects are seen, but merely the set of focal points) had become a central part of optics.

We conclude, therefore, with a different set of assumptions concerning telescopic vision than the one we found in Kepler's explanation of the Dutch telescope. To summarize, Kepler's *Dioptrice* proved influential up until the 1660s and in this period some of his followers did manage to enlarge the purview of Kepler's theory of the telescope without essentially modifying its principles. Then, by the 1660s the crucial notion of image formation in optical instruments appeared, and it provided new ways of analysing the properties of optical instruments. The works of Gregory, Barrow, etc. enlarged Kepler's results on the focal properties of lenses. They also took up Kepler's notions of ray pencil and *pictura*, and crucially transformed the latter into a geometrical optical image. With the help of this notion they provided a new (and now classical) explanation of how telescopes work. As it often happens, the new optical works published from the 1660s on obliterated the more primitive theoretical accounts of telescopes directly stemming from Kepler's, thus creating the optical illusion that the influence of Kepler's theory of the telescope was nil or negligible.

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[49] Whewell, *The Mathematical Works of Isaac Barrow* (1860), 36; Shapiro, *The Optical Papers of Isaac Newton*, vol. 1 (1984), 215.

[50] Harris, *Lexicon Technicum* (1710), Lemma 'Optics'. On the reception of the new principle of image location, see Shapiro, 'The *Optical Lectures*' (1990).

[51] Priestley, *The History and Present State of Discoveries* (1772), 638 & 688; Priestley, who did not agree with Berkeley's criticism, pointed to him as the first to seriously rise objections against the new principle of image location A strong and highly articulate criticism of the new principle of image location is found in Smith, *A Compleat System of Optics* (1738), 50-51, where he embraced and developed Berkeley's views. Smith's work concludes with a long series of 'Remarks' independently paginated. He took up the topic again on 35-44.

The Netherlands, Siam and the telescope. The first Asian encounter with a Dutch invention

Henk Zoomers

Introduction

The year 1608 saw two remarkable interacting events in the Dutch United Provinces, which are both mentioned in a French newsletter, published in early October 1608.[1] These coinciding events were the first demonstration of a working telescope and the first embassy to a European country of diplomats from far-away Siam (now Thailand). Both events took place when important diplomatic negotiations were going on in The Hague between Spain, the Dutch Republic and diplomats from France, England and the Palatinate (a Rhineland state in Southern Germany) to negotiate a cease-fire in the ongoing war of independence of the Dutch against the Spanish Crown.

In 1568 the Dutch Low Countries started an insurrection (later known as the Eighty Years War, 1568-1648) against the regime of the powerful Spanish empire under the reign of King Philip II, in which revolt William the Silent, the Prince of Orange, took the lead. Initially it was an uprising against the Catholic faith and the high taxes imposed by the Spanish regime, but gradually it became a war of independence. In 1608 William's son, Count Maurits of Nassau, was the military commander-in-chief of the Republic of the United Dutch Provinces, in the service of the sovereign States General. Initially the Dutch troops had suffered defeats against the Spanish army, but gradually Maurits achieved military parity. As a result of financial problems and war-weariness of both parties, peace negotiations started in 1606, and they eventually led to the Twelve Years Truce (1609-1621). A major demand of the Spanish government was the termination of the Dutch trade with the East

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[1] There were two editions of this newsletter, but only three copies have survived worldwide. See: Zoomers & Zuidervaart, *Embassies* (2008), 9. Also: Pelliot, 'Les Relations du Siam et de Hollande en 1608' (1936) and Drake, *The Unsung Journalist and The Origin of the Telescope* (1976).

Indies, but as this was unacceptable to the Dutch, both parties compromised to keep the status quo in this region.

Until the end of the sixteenth century the lucrative trade in spices had been monopolized by the Portuguese. At the end of the sixteenth century private companies, notably situated in Holland and in Zeeland, sent their ships to the East to take their share of the huge profits gained from this trade, using the knowledge and experience of individual Dutchmen, like Jan Huygen van Linschoten (1562-1611), who had worked in the service of the Portuguese. In March 1602, on the initiative of the States General, the United East India Company ('Verenigde Oost-Indische Compagnie' [VOC]) was established, to prevent the earlier fierce competition between some trading companies chartered in Holland and Zeeland. In the VOC six chambers (Amsterdam, Zeeland [Middelburg], Rotterdam, Delft, Hoorn and Enkhuizen) were united. The 1602 charter of the States General granted the VOC a monopoly on trade, warfare, minting, building fortresses, appointing officials and concluding treaties with local and regional rulers, for the whole region between the Cape of Good Hope and Cape Horn. The damaging of Portuguese and Spanish interests in Southeast Asia, by capturing their fortresses and ships with their rich cargoes, also meant a contribution to the war effort against the Spanish armies on the home front.[2]

Besides the promotion of trade with Asia, and the continuous struggle with Portugal (both on land and the high seas), the development of new navigational techniques to make the voyages to the East safer, was also in the interest of the Board of Directors of the VOC. This body was also called the 'Heeren XVII' ('Gentlemen XVII'). In 1636 one of these VOC-directors, the former Governor-General Laurens Reael (1583-1637), drew the attention of his colleagues to a new invention of 'Galileus Galilei, a great mathematician and astrologus, in the service of the Duke of Tuscany'.[3] With this invention, based on Galilei's new celestial observations, the measurement of longitude, both on land and sea, could be brought to perfection. For VOC shipping to and from Asia this invention could be very useful. The Gentlemen XVII decided that this invention should be investigated by a committee of Dutch scholars, among which the Dutch astronomer and mathematician, Martinus Hortensius (Maarten van den Hove, 1605-1639), the scholar Isaac Beeckman,

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[2] Sluiter, 'The First Known Telescopes carried to America, Asia and the Arctic' (1997), 142-143.

[3] Resolutiën Staten Generaal, 11 november 1636, printed in: De Waard, *Journal tenu par Isaac Beeckman*, 4 (1953), 253.

and the cartographer Willem Janszoon Blaeu (1571-1638).[4] Reael received 1.000 guilders from the VOC to purchase the instruments which were necessary to investigate Galilei's claim. In addition, Hortensius received a sum of 2.000 guilders from the VOC in 1639 to travel to Galilei for instructions on his proposed invention. Unfortunately Hortensius never got further than Leiden, where according to Pieter van Dam (1621-1706), the lawyer of the VOC records, he squandered away his stipend and died shortly afterwards. So in the end the VOC efforts did not lead to success.[5]

In September 1608 a Siamese embassy, the first from this country ever to visit Europe, arrived in The Hague. They were received in an official audience by the Stadtholder, Count Maurits, and presented a letter and presents from the Siamese King Ekathotsarot (who reigned from 1605 until 1610).[6] Around the same time 'a humble spectacle-maker' from Middelburg, Hans Lipperhey, a man of German descent, had made a rudimentary, although working telescope, probably by inventing 'the diaphragm that made the instrument such a success'.[7] During the sojourn of the Siamese embassy Lipperhey demonstrated his recently invented telescope at the so-called Maurits Tower of the princely palace in The Hague (nowadays the Houses of Parliament). Lipperhey showed the new instrument to Count Maurits, his brother Frederik Hendrik and the chief negotiator of the Spanish delegation at the peace negotiations, Marquis Ambrogio de Spinola. With the telescope, the assembly could discern the clock tower of Delft as well as the windows of a church in Leiden at distances of respectively some 10 and 23 kilometres from The Hague.[8] Some modern authors have asserted that the Siamese ambassadors also were present at this demonstration, however there is no evidence to confirm this.[9] As both the visit of the Siamese embassy as well as the demonstration of the telescope are mentioned in the newsletter mentioned above, these authors probably concluded that the Siamese diplomats were also present at the demonstration. However, as the Siamese were the official representatives of the king in Ayutthaya, a ruler

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[4] Cf. Van Berkel, 'Hortensius' (1997), 76.

[5] Van Dam, *Beschryvinghe van de Oostindische Compagnie*, 1:2 (1929), 676. Willem Jansz Blaeu published the book *Institutio astronomica* (1634) in cooperation with Hortensius.

[6] Valentijn, *Oud en Nieuw Oost-Indien*, 3:2 (1726), 72-73; Ruangsilp, *Dutch East India Company Merchants* (2007), 30-32; Duyvendak, 'The First Siamese Embassy to Holland' (1936).

[7] Zoomers & Zuidervaart, *Embassies* (2008), 21; Van Helden, 'Who Invented the Telescope' (2009).

[8] See: Zuidervaart, this volume.

[9] Abrahams, 'The Meaning of the 'Anniversary of the Telescope'' (2009), 3; Brummelhuis, *Merchant, Courtier and Diplomat* (1987), 11; Brozius, *De Koning van Siam*, (1996), 9; Zandvliet, *Maurits Prins van Oranje* (2000), 281; Wap, *Het gezantschap van den Sultan van Achin* (1862), 83.

who could be instrumental to Dutch VOC merchants in their efforts to gain entrance to the promising Chinese market, it is not unlikely that they also saw the telescope, or even had a look through this instrument.

In this article I present a *tour d'horizon* of seventeenth century developments concerning the spread of the telescope in East and Southeast Asia, and in particular in Siam, the present-day Thailand. The details of the return voyage of the Siamese ambassadors to their capital Ayutthaya (about 70 kilometres north of Bangkok) are not known. One would expect that after the arrival in Bantam, in December 1610, of the Dutch fleet, which carried the embassy to Java on its way back to Siam, the ambassadors would leave in the beginning of 1611 for Patani (present-day Southern Thailand) to travel from there on another vessel destined for Ayutthaya. Unfortunately, the VOC records of 1611 are missing, so there is no evidence of their arrival in Ayutthaya. However, my point of interest is not so much the return route of the embassy, but the quality of the presents the embassy received from both Count Maurits and the States General. If the embassy had received a telescope as one of the presents, it would have meant the first introduction of the telescope in Asia. However, I could not trace a telescope belonging to the presents from the Dutch authorities to the king of Siam. According to Engel Sluiter, around March 1609 six parties in Europe possessed a telescope: the Dutch States General, Count Maurits, the French king and his prime minister, the Archduke of Austria and Pope Paul V.[10] I expect that if a telescope had been part of the Dutch presents for the Siamese king, it would have been noted somewhere. So we must conclude that the first official documented presence of the telescope in Asia occurred in Japan.

Japan

Captain John Saris (*c.* 1580-1643), sailing in the service of the English East India Company, left England on 18 April 1611 with three ships: his flagship *Clove*, the *Hector* and the *Thomas*. He first went to Bantam, where he purchased pepper.[11] From Bantam the *Clove* ventured alone to Japan and arrived with a crew of 70 persons on 12 June 1613 in Hirado, a city in the Nagasaki prefecture and a major centre for foreign trade. With the local daimyo he made arrangements to visit the court. After being received by the Emperor on

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[10] Sluiter, 'The telescope before Galileo' (1997), 226. See also Zuidervaart, in this volume.

[11] Note that all dates mentioned by Saris are in the Julian calendar, which differs ten days with the Gregorian calendar.

8 September 1613 at his castle at Surunga, a week later, on 17 September, Saris was given an audience at the castle of Edo (present-day Tokyo) by the powerful retired Japanese Shogun Iyeyasu (reigned 1603-1605) and his son Hidetana, the actual Shogun. During this audience Saris presented the Shogun with a letter from King James I, in which peace and friendship was offered, requesting the establishment of an English trading post. Among the presents were '5 peeces very fine Baftaes' (fine woven cotton fabric), '1 verye faire Burning Glasse' and '1 peece Cambrick, verye fine' (lightweight cotton cloth). The *pièce de résistance* was '1 prospectiue Glasse cast in siluer Gilte'. In addition, all the high dignitaries received some pieces of fine quality fabric.[12]

Saris left Japan on 5 December 1613 with his vessel the *Clove* and returned to Plymouth on 27 September 1614. After his arrival the Company discovered that Captain Saris had brought home 'certain lascivious books and pictures', which were considered a great scandal to the East India Company. Instead of being praised as the first documented western collector of *shunga* prints, Saris' collection of 'wicked spectacles' was burned. Saris never voyaged to the East again.[13]

Some remarks on Saris' visit to Japan have to be made. First of all, Saris left England on 18 April 1611. This meant that his superiors must have already decided several weeks or even months beforehand what kind of presents should be given to the Japanese officials and nobles. So, the gilded telescope must have been available for transport in early 1611. Saris also showed that he was a child of his time. In his journal he reports that during his voyage, on 24 April 1613 at about 07.30 hours, during full moon a large lunar eclipse occurred, such as never seen before.[14] Both Saris and his crew experienced this natural phenomenon as strange and frightening.[15] So in this matter there was not a great difference in perception between an early seventeenth century sea captain and modern-day Southeast Asian superstitions regarding eclipses.

Also, as all the presents for the shogun were mentioned in Saris' journal, together with their purchase prices, it is possible to make a comparison between the articles and their prices, which offers some insight in the actual price of the telescope. For instance, each piece of the fine cotton fabric (baftas) cost five rial, the piece of cambrick 45 rial, the burning glass two rial and the telescope

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[12] Satow, *The Voyage of Captain John Saris to Japan* (1900), 113; Paske-Smith, *Western Barbarians in Japan and Formosa* (1968), 19-20.

[13] Satow, *Voyage* (1900), lxvii.

[14] The text mentions 24 April 1611. However there was no lunar eclipse on 24 April [= 4 May Gregorian] 1611, but there was one on 4 May 1613.

[15] Van der Aa, *Agtste Oost-Indische Reys* (1707), 81; Satow, *Voyage* (1900), 65-66.

six rial. During the reign of Queen Elizabeth (1533-1603) a rial was a gold coin worth fifteen shillings sterling. So the price of the English telescope in early 1611 almost equalled the price of one piece of fine cotton fabric, which sounds far cheaper than the amount Lipperhey received from the Dutch States General in October 1608 for just one telescope (300 guilders, each of which in turn equalled 20 stuivers).[16]

Finally, the 'prospective Glasse' is only mentioned in the list of presents for the Japanese shogun, but is not further referred to in Saris' journal, so there is no record of how it was received at the Japanese court. In addition I have checked the diary of Richard Cocks, who, together with seven other Englishmen, remained in Japan after Saris' departure in December 1613 as the Cape-merchant in the newly established English factory in Hirado. The VOC had established a factory there in 1609 and was allowed by the Japanese to send one or two ships annually from Europe. But Cocks did not mention the telescope, either in his journal, or in his correspondence, both covering the period 1615-1622. This suggests that in those days the instrument was not imported on a regular basis by the English East India Company.[17]

Despite the lack of any entry on telescopes in the diary of the English chief-merchant in Japan, one cannot conclude that the telescope had made little impact on the Japanese authorities. Dutch VOC sources, such as the letters from the Governor-General and Council in Batavia to the Gentlemen XVII in Amsterdam, provide some interesting information, which proves that the Japanese cultural and intellectual elite in the mid-seventeenth century showed a genuine interest in this instrument, going far beyond a simple taste for gadgets as a pastime. For instance, in 1633 the inventory of a cargo vessel destined for Hirado listed, amongst other items, three spectacles for fun, seven real spectacles in old frames and two telescopes, the cost of which for lenses and mounting were 652 taels.[18] In 1640 the Shogun Iyemitsu was delighted with the presents the Dutch had brought for him, such as: two bronze field-guns, some copper candelabras, 500 wax candles and a telescope inlaid with gold. The last item was especially pleasing to the Shogun, who had the gift constantly carried about for him by a retainer, and even took it with him to Nikko (120 kilometres north of Tokyo), where he paid homage to his grandfather Iyeyasu's mausoleum.[19] In 1650 the Japanese Emperor received as annual

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[16] Satow, *Voyage* (1900),113.

[17] Thompson, *Diary of Richard Cocks*, 1 (1883).

[18] Cf. Michel, 'On Japanese Imports of Optical Instruments in the Early Edo-Era' (2004) and Abrahams, 'The History of the Telescope in Japan' (2005).

[19] Boxer, *A True Description* (1971), liii; Mulder, *Hollanders in Hirado* (1980), 68, 199.

presents from the VOC, amongst other things, a large octagonal mirror, a large Persian carpet and a gold-enamelled telescope. The Emperor's son received both a gold-enamelled telescope and a silver one.[20]

A clear indication that the Japanese made a proper use of the telescope can also be found in the 'Generale Missiven' of January 1654, stating that the master of the vessel *Princesse Royale* brought six silver telescope tubes, sent by their owners from Japan to Batavia. They were destined to receive 'fine new glasses' in Holland and to be sent back to Japan again. The report also states that the Japanese owners were not so much interested in the quality of the tubes, but definitely in the quality and clearness of the glasses. So we can conclude that the Japanese owners of these telescopes were very keen to have their telescopes improved.[21]

The development of the telescope and the growing diversity of this instrument are reflected in the demands of the Japanese grandees to the VOC in 1679. Their demand consisted of two lunar telescopes, 50 [ordinary] telescopes, two army telescopes, and 100 fine crystal spectacles, besides 20 sabre blades, twelve large mirrors and four chests with a distillery.[22] Judging from the specificity of these telescopes, this wish list clearly shows that the Japanese knew the diverse opportunities a telescope could provide and that they were quite able to specify the details of their wishes. The general public in Japan probably had access only to domestic copies of the European telescope, but their quality was inconsistent and imported telescopes were therefore preferred. However, the Kobe City Museum in Japan has in its collection a sophisticated, beautifully decorated telescope, made with such skill that it was long thought to have been imported from outside Japan. Such extremely beautiful telescopes drew the attention of westerners too. The Swede Johan Arnold Stutzer, from December 1787 to August 1789 senior surgeon at the Dutch factory of Deshima, purchased six Japanese glass telescopes and later presented them to the Tsarina Catherine the Great of Russia.[23] In 2004, the chief curator of the Cultural Promotion Division, Nagasaki Prefectural Government, confirmed the presence of these Japanese glass telescopes in the *Kunstkamer* of St. Petersburg. Four of them are inscribed 'Japan 1788', and all were made to the standard of Nagasaki glass engraving.[24]

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[20] Coolhaas, *Generale Missiven,* 2 (1964), 421.

[21] *Ibidem*, 423-424.

[22] Coolhaas, *Generale Missiven,* 4 (1971), 367.

[23] Shirahara, *Japan Envisions the West* (2007), 139.

[24] *Ibidem*, 163; Blussé & Remmelink, *The Deshima Diaries* (2004), 561.

On the regional level, astronomical knowledge was also transferred to Japan, mostly from China, based on Chinese works written by Jesuits, who were practically the sole source of Chinese knowledge about Western astronomy.[25] A good example is Yi Yi's *Tienjing Huowen* [Questions and Answers about Astronomy]. The Chinese edition of 1675 of this rare treatise was brought to Japan in the late 1670s. The first Japanese edition appeared in 1730, with a second edition following around 1750. The treatise incorporates knowledge of the constellations of the South Polar region and was the seminal work that provided the Japanese scholars with their first knowledge of these stars. The treatise was to have considerable influence on the development of Japanese astronomy.[26]

From this fragmentary overview it is clear that the telescope was used in Japan in the seventeenth and eighteenth century not only as on ordinary device, but also in a scholarly way, at least amongst intellectual and cultural elites. Also, by the late eighteenth century Japanese craftsmen were able to produce telescopes of high quality.

China

The interest in astronomy and the telescope in Japan is equivalent to the interest in China. The history of science and technology in China is long and rich. The earliest recorded observations of comets, solar eclipses, and supernovae were made in China. The four great inventions of ancient China, the compass, gunpowder, papermaking, and printing, were among the most important early technological advances, and only became known in Europe toward the end of the Middle Ages.[27]

The Jesuit missions to China in the sixteenth and seventeenth centuries with men like Allessandro Valignano (1539-1606), Michele Ruggieri (1543-1607) and Matteo Ricci (1552-1610) introduced western science and astronomy – then undergoing its own revolution back in Europe – to China, and knowledge of Chinese technology was brought back to Europe. The Jesuits in China not only aimed at proselytizing, but they also employed western science (particularly astronomy and cartography) to demonstrate that Christianity was a superior teaching and that those who followed its doctrines could solve

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[25] See also Nakamura, 'The earliest telescope preserved in Japan' (2008), for possible Chinese and Jesuit influences on early Japanese telescope making.

[26] Yi, *Tienjing Huowen* (c. 1750). See Yoshida, '"Dutch Studies' and Natural Sciences' (2000), 91-94.

[27] Temple, *China* (1986), 29-30, 33-34.

practical problems. The first Chinese text on the discoveries of Galileo was published in 1615, in the translation of a treatise by the Portuguese Jesuit Emmanuel Diaz: 'Explicatio sphaerae coelestis'. This early publication is an example of the effectiveness of the Jesuits' communication network. Scientific knowledge gained the Jesuits a hearing both among Chinese scholar-officials and at the imperial court, as in China sciences such as astronomy, geography, and agronomy were connected to a belief system and a state ideology in which nature played a pivotal role.[28]

In this respect, although referring to the Siamese Ayutthayan period (1350-1767), the historian Ian Hodges provides an elaborate underpinning of the importance of astronomy to traditional astrology, which is also appropriate to China. Important rituals had to be performed on precisely calculated auspicious moments. The heart of traditional astrology was a scientifically based system of calculating the positions of sun, moon and planets. In a society that believed that celestial bodies directly influenced human affairs, astrologers possessed expert knowledge of the heavens, based on exact mathematical calculations – the means to 'calculate celestial causes and predict their effects'.[29] In order to assist their predictions, astrologers had kept detailed records of events that were used to predict the future. They were both custodians of the horological system and producers of the annual calendars. The calendar itself was recognized as an instrument of political importance, and calendar reform was often used by new rulers, both to establish their power and to demonstrate the harmony of their rule with the cosmos. These complex astrological and calendrical systems were based on observation of the night sky, the cycles of the sun and the moon, and the movements of the planets.

The Jesuit Johann Adam Schall von Bell (1591-1666), who stayed in Beijing in 1644 during the violent transition from the Ming to the Qing dynasty, had the opportunity to demonstrate publicly, the superiority of western astronomy over what he knew to be the less precise techniques of the Chinese and Muslim astronomers who had previously dominated the Imperial Bureau of Astronomy. His prediction of an eclipse on 1 September 1644 was more accurate than the one calculated by his Chinese contesters. For this success Schall was appointed to the Directorate of Astronomy under the new dynasty.[30] But

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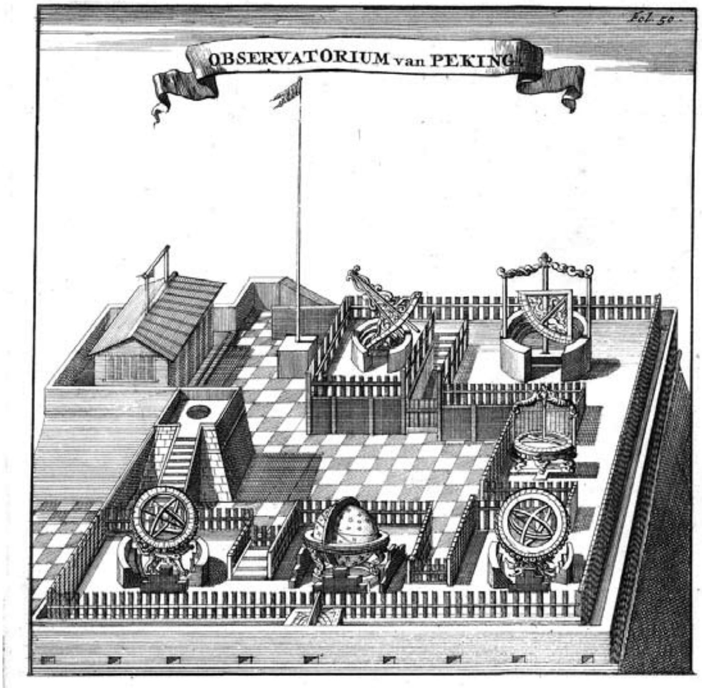
[28] Diaz, *Thien Wên Lüeh* (1615); Parker, *Windows into China* (1978); Gallagher, *China in the Sixteenth Century* (1953); Fairbank [*et al*], *East Asia* (1975), 244-251; Dunne, *Generation of Giants* (1962), 68-69.

[29] Hodges, 'Western Science in Siam' (1998), 85-86.

[30] Merson, *Roads to Xanadu* (1989), 102-103; Dunne, *Generation of Giants* (1962), 199-200, 220-222; Udías, 'Jesuit Astronomers in Beijing' (1994), 467-469.



Ill. 1. The Imperial Observatory in Beijing with several bronze instruments, such as a quadrant, an ecliptic armillary sphere and an altazimuth instrument (1674). Engraving by Caspar Luyken from Le Comte, *Beschryvinghe van het Machtige Keyserryk China* (1698).

competition between Jesuit and Chinese and Muslim astronomers flared up repeatedly.

In 1660 Schall invited his fellow Jesuit Ferdinand Verbiest (1623-1688) to come to Beijing. Verbiest's treatise *Yixiang tu* (1674) presents a visual record of the refurbishing of the Imperial Observatory in Beijing with new bronze instruments such as an astronomical quadrant, an ecliptic armillary sphere and an altazimuth instrument (see Ill. 1). The old observatory in Beijing, situated on a watchtower of the former city wall is now located in the urban Beijing area and the site can still be visited today. After Schall's death in 1666 a collection of his manuscripts was deposited in the Vatican library.[31]

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[31] Reed & Demattè, *China on Paper* (2007), 182-185; Zezong, 'On the Mistakes of Emperor Kangxi's Scientific Policy' (2001), 69-74; Qiao & Shizhu, (eds.), *China's Ancient Large Astronomical Instruments Exhibition* (2001); Temple, *China*, 36-39.

After the fall of the Ming dynasty, in 1644, the Dutch East India Company sent an embassy to China in 1656, led by Pieter de Gooyer and Jakob de Keizer, followed by a second embassy in 1662, in order to obtain permission for free trade in the Chinese empire. As both *Embassies* were not successful, the VOC governor in Batavia decided to send a third embassy in 1666, led by Pieter van Hoorn (1653-1711). He sailed to China with five ships, loaded with merchandise and presents. I have compared the three printed travelogues of these VOC-*Embassies*, published in one volume in 1670 and found one striking difference. No telescope is mentioned as far as the first and second *Embassies* are concerned, but the third embassy carried several telescopes as presents. During the audience, granted by the Emperor, each of the four Chinese Imperial privy counsellors received amongst other items six spectacles and one telescope; the three chairmen of the Imperial office received a telescope and six nose spectacles each, and the Emperor himself received four telescopes. No further details are given in the text. Despite the telescopes and the spectacles the last embassy was only partly successful.[32]

Laos

As the dominant foreign power in the Siamese capital Ayutthaya, the Dutch next attempted to extend their control over other countries in Indochina. They did this by founding trading stations in Cambodia and Vietnam and by trying to establish direct relations with the landlocked kingdom of Vieng Chan (Vientiane), now part of the Lao People's Democratic Republic. In 1641 the under-merchant Gerrit Wuysthoff departed on behalf of the VOC to Vieng Chan. King Suryawongsa (who reigned from 1638 to 1695) viewed the Dutch as suitable trade partners. He had invited a VOC representative, and so Wuysthoff was the first official European visitor of the country. Wuysthoff, his assistants Willem de Gooyer, Huybert van Lochorst and his party travelled from Phom Penh in Cambodia (where the Dutch kept a trading post), up the Mekong river to Vieng Chan. They used several *pirogues* (a large canoe-like proa), facing currents, rapids and underwater rock formations.

When the Dutch arrived in Vieng Chan they were questioned by the king's advisers and the presents for the king were inspected. As many of the presents (parcels of cloth) had been damaged during the long journey, the king's counsellors suggested a larger tribute for the king. The VOC party was told that

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[32] Dapper, *Gedenkwaerdig Bedryf* (1670), 356-358; Vixseboxse, *Hollandsch Gezantschap naar China* (1946).

this would not only be to the king's benefit, but it would also cause him to become favourably disposed towards the VOC and compensate her generously. Wuysthoff therefore improved the tribute by adding an engraved silver telescope and three pieces of yellow and green damask cloth, both made of colours exclusively reserved for the royal court. Wuysthoff calculated the value of the telescope at 58 taëls, only 60% of the original price. On 16 November the Dutch delegation was received in an official audience by the king. The next day the interpreter was summoned to come to the king's uncle, who asked him about the use of the telescope and whether it was not possible to straighten his sabre. He replied that this would probably spoil it. The term 'sabre' probably is the translation of the Dutch word 'houwer', used in the original printed text, a variation of 'houder', meaning 'holder,' that is, the tube of the telescope itself. The king's uncle also told the VOC representatives that the king liked the telescope very much, adding: 'I have just started building a new tower [probably a Buddhist stupa]. It is nearly finished and now you arrive here all of a sudden to present me with such a suitable instrument with which I can see so far, I take this for a good omen'.[33]

The Dutch embassy left Vieng Chan on 24 December 1641. The interesting point of this story is that the telescope which was presented to the Laotian king was not meant to be a present at all. So at least one member of the Dutch embassy must have possessed a richly decorated telescope for private use. In an additional report, two Dutch assistants mentioned that during their stay in the kingdom of Laos, in July 1642, two Portuguese Roman-Catholic priests, Leria and Cebrián, had arrived at the Laotian court. Besides two little white dogs and a rabbit as presents for the king, they also brought a telescope in order to curry favour for their request to be permitted to publicly preach the Christian religion in the kingdom of Laos. However, the Laotians answered that this would never be permitted. De Marini (1663) refers in his report to the presents of the two priests however without mentioning the telescope.[34]

Burma

During a relatively short period, 1634-1680, the VOC also kept a formal relationship with Burma. The VOC sent one ship annually to the capital of Ava,

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[33] [Van Wuysthoff], *Vremde Geschiedenissen* (1669), 24; Casteleyn, *Strange Events* (2003), 31; Lejosne, *Journal de Voyage de G. van Wuysthoff* (1986), 147; Nepote & Levy, 'A propos du 'Journal de voyage au Laos' de G. van Wuysthoff et de ses assistants' (1986); Valentijn, *Oud en Nieuw Oost-Indien*, 50-52; Stuart-Fox, *The Lao Kingdom of Lān Xāng* (1998), 86-95, 148.

[34] Casteleijn, *Strange Events* (2003), 45-46; Lejosne, *Journal Van Wuysthoff* (1986); Marini, *Description of the Lao Kingdom* (1998), xxv-xxvi, xxxix.

situated near the last royal capital, Mandalay, in central Burma. The first impressions the Dutch had of Burma were those of an impoverished country and stagnant trade. They had to learn to cope with the various negative aspects of dealing with Burma, such as relatively high customs duties, royal monopolies, trading on credit and having to relinquish all their ship's weaponry for the duration of their stay in a Burmese port. Against this, there were several decades when the VOC used large ships for its Burma trade and increased its yearly shipments from one to two. In the final decade of Dutch operations in Burma the country's trade deteriorated steadily, at last causing the Dutch to decide to abandon Burma. The factories were closed down in 1680.[35]

I have checked the lists of VOC exports to Burma during the period 1634-1680 to see if telescopes are mentioned. Only the account of the year 1646 mentions the import of two telescopes by the VOC yacht *Grijpskerck*. In view of the small number of the devices, the two telescopes probably were not commodities, but rather formally registered gifts from the VOC for the king or high Burmese dignitaries. Telescopes were not used as merchandise, just as diplomatic tools.

Siam

To complete this overview, I return to Siam. The kingdom of Ayutthaya was established in 1350 by King Ramatibodi and lasted until 1767, when the capital was captured and destroyed by the Burmese. After the destruction of Ayutthaya most of the historical records were destroyed. However four hundred years of Thai history is collected in the preserved 'Royal Chronicles of Ayutthaya'.[36] Of course I have consulted these 'Royal Chronicles' for references to the telescope during the Ayutthayan period. Regrettably the first Siamese embassy to Europe in 1608, which probably had been an eyewitness of the newly invented telescope, is not mentioned at all. On the other hand they do mention another – later – event in which a telescope was involved. This concerned the discovery of a Buddha Footprint by a hunter on a hillside near Saraburi, which matched with the description in the Buddhist Holy Scriptures of this phenomenon.

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[35] Dijk, *Seventeenth-century Burma and the Dutch East India Company* (2006), 203-205.

[36] It took Richard Cushman about twenty years to translate all the known versions of the *Royal Chronicles of Ayutthaya* in a coherent way. The result is an epic of 375.000 words; In later years seven major versions and several smaller fragments were rediscovered and published in the original Thai. See: Cushman, *Royal Chronicles of Ayutthaya* (2000), 210. See also: Pombejra, *Siamese Court Life* (2001), 126; Garnier, *Auytthaya* (2004), 92; Raben & Pombejra, *In the King's Trail* (1997, 34-35, 39.

The discovery happened during the reign of King Songtham (1611-1628), the successor of King Ekathotsarot, who had sent the first embassy to Europe. To pay homage to the Buddha and to perform a good deed, the king ordered the construction of a temple and dormitories for monks in the vicinity of the Footprint, called Phra Phuttabat. As the Royal Chronicles state:

> Two brigades of Farangs (westerners) were ordered to survey and cut a wide passage for a land route all the way straight to the boat landing [at the Pasak river, HZ], to cut down the jungle with knives and to pound the surface level so it was pleasingly smooth to form a finished imperial highway.

In order to make the road as straight as possible a Dutch engineer was sent out with a telescope. The road from the landing stage at Tha Rua runs in one straight line to Phra Phutthabat, located at a distance of some 20 kilometres. This road is still called by local villagers 'thanon farang song klong' (the road of the westerner looking through a telescope) and is partly still in use at Ban Song Sok. In addition I refer to a report, dated 8 February 1623, written by two employees of the English East India Company in Batavia, informing the Directors in London that, among other things, 'a curious perspective glasse faire and good, a faire and neate case of pistols, an English watch' would be most acceptable to the king of Siam.[37]

Dhiravat na Pombejra refers to the depiction of Dutchmen who featured in several mural paintings and other pictorial representations from the late Ayutthayan to the early Bangkok period. In Thai mural art a 'Dutchman' is recognisable by his red hair, European-style dress, and the association with fire arms or telescopes. In this respect the Thai iconography is comparable to the Japanese iconography of Dutchmen: red hear, big nose, with a Gouda clay pipe and a telescope. Dhiravat also describes a lacquered manuscript cabinet of Wat Anongkharam, depicting a Dutchman with a telescope firing a cannon, which he judges to be perhaps the most interesting representation of a Dutchman in Siamese art of the early modern period.[38]

The most important and influential Siamese king during the seventeenth century in regard to the telescope is King Narai (reigned 1656-1688). Even as a *chaofa* (prince of the royal blood), he already showed his interest in scientific and technological advances in Europe. The king's fascination with European

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[37] Farrington & Pombejra, *The English Factory in Siam*, 1 (2007), 311-312.

[38] Pombejra, 'Keynote speech' (2004), 46-47; personal communication. Unfortunately according to recent information from the Fine Arts Department the cabinet has disappeared from the temple

clocks and telescopes, and his overall interest in astronomy, was something which had begun in his youth and which he maintained right up to the end of his life. Considering that King Narai's tastes and interests were well-known to the foreign merchants in Ayutthaya, it was natural for the Dutch to curry favour with the king by presenting him scientific tools such as telescopes.[39]

Before ascending the throne, Prince Narai had regular contacts with the VOC. In early 1656 the VOC factory in Ayutthaya reported that Prince Narai had asked the Company to supply him with coral, amber, luxurious textiles, diamond rings, a telescope and an hourglass. A year later the Dutch factory recommended that the VOC would bring the king satin from Europe and some telescopes. The VOC ship *Betuwe*, arriving from Holland in January 1675, carried the following goods for the king of Siam: 'two enamelled silver telescopes, two *custodien* [probably mountings] to go with them, and twelve hats'.[40] King Narai was also keen to learn about the latest technical innovations in the West, and probably in China and the Islamic world as well. Against this background he ordered telescopes from the Dutch. In the period of intense diplomatic contact with France, his thirst for knowledge was also in evidence. The king was a keen astronomer, and was impressed by the French Jesuits' broad knowledge of mathematics and astronomy.[41]

During the reign of the French King Louis XIV (reigned 1643-1715), various influential courtiers as well as a number of members of the French Academy were all keen to gather more detailed information about various countries lying so far eastwards. On the other hand King Narai was for years very interested in making contact with the king of France, hoping to control the Dutch influence and power in his country. The French answer to the Siamese overtures therefore grew into a regular scientific expedition to the East, whereby it ought to be noted that the chief aim was not Siam, but China. The expedition was equipped by the Royal Academy of Paris with scientific instruments that contained an assortment of the largest telescopes ever to be carried across the oceans; they ranged from twelve to eighty feet in length: 3.6 to 24 metres, some of which were to be left behind in the observatory of Beijing.[42] In addition, the Jesuits carried thermometers, barometers, quadrants, magnets, orreries, mirrors, compasses, magnifying glasses, clocks, globes, maps

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[39] Hodges, 'Time in Transition' (1999) , 33-44; Pombejra, *Siamese Court Life* (2001), 126.

[40] Pombejra, *Siamese Court Life* (2001), 154.

[41] *Ibidem*, 166; Ruangsilp, *Dutch East India Company Merchants* (2007), 145-147.

[42] Tachard, *Voyage de Siam* (1686), 7-11; idem, *A Relation of the Voyage to Siam* (1999), 5; Landry-Deron, 'Les Mathématiciens envoyés en Chine par Louis XIV en 1685' (2001); Hennequin, 'Les premières observations astronomiques occidentales' (2004) 63-102.

Ill. 2. Astronomical observations made in the summer of 1685 by the French Siam expedition, during their sojourn at the Dutch settlement at the Cape of Good Hope. Their 12-foot telescope, made by the Paris instrument maker Le Bas, is clearly visible, as is – in the tower – the Thuret clock. Engraving by Jan Luyken from Tachard, *Reis na Siam* (1687).

and scientific tables.[43] These six Jesuits, also called ‘the mathematicians’, agreed to make astronomical observations in China and during their voyage. The French Royal Academy also provided tables for the satellites of Jupiter, which served for determining the geographical longitudes of places.

The expedition left the French naval port of Brest in March 1685 and arrived at the end of May at the Cape of Good Hope. There the Jesuits made some observations of the Jovian satellites with a 12-foot telescope made by the late Monsieur [Philippe-Claude] le Bas and a pendulum clock beating seconds, made by Monsieur [Isaac] Thuret of Paris (Ill. 2).[44] The French vessels arrived at the end of September before Siam, at the entrance of the Menam Chao Phraya. After the ambassador and his retinue had been received in audience by King Narai in Ayutthaya, the king left with all his wives for Louvo

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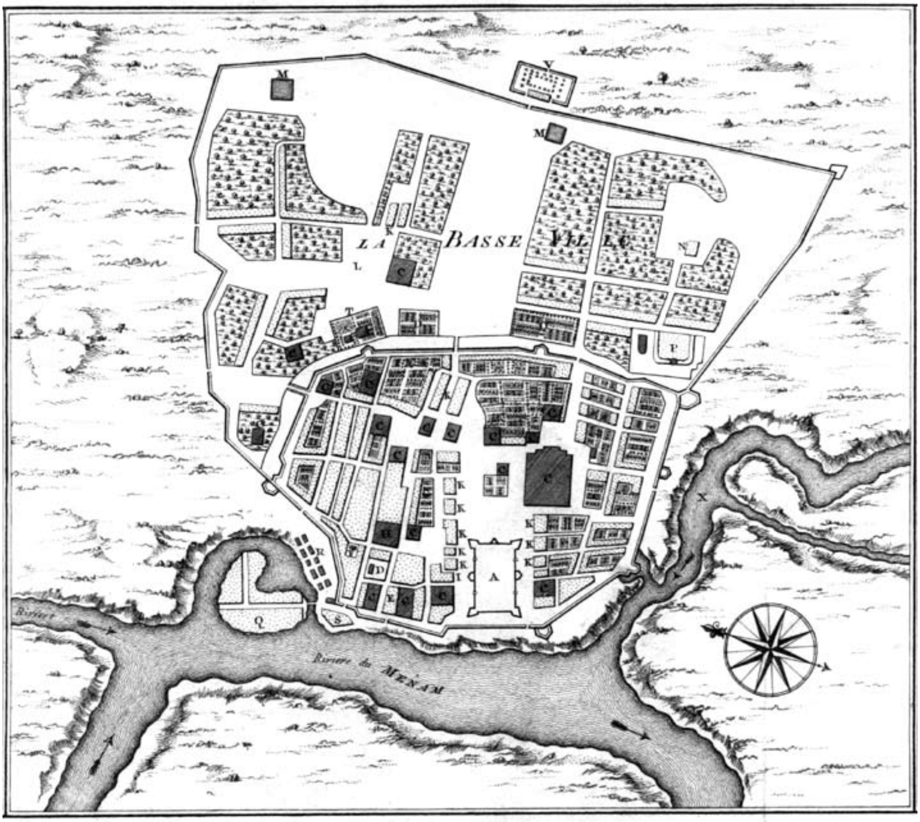
[43] Tachard, *Voyage* (1686); idem, *Voyage* (1999), xix-xx; Frey and Frey, ‘The Search for Souls in China’ (2003), 231-233.

[44] Tachard, *Voyage* (1686), 74-77; idem, *Voyage* (1999), 41; Bouvet, *Voiage de Siam* (1963), 45-48; Goüye, ‘Observations Physiques et mathematiques’ (1729), 611-613.



Ill. 3. Contemporary map of the town of Louvo (Lopburi), the residence of King Narai, showing the location of the octagonal tower (P) in front of the building where the actual astronomical observations took place. Engraving from: Prevost, *Histoire Générale des Voyages,* tome 12 (1755).

(present-day Lopburi, about 150 kilometres north from Bangkok), where he spent nine or ten months of the year. The Jesuits were assigned two ceremonial barges to transport their luggage and another barge, of 24 oars, to transport their persons.[45]

As soon as they had arrived in Louvo the Jesuits started to make observations and prepared themselves for observing an eclipse of the moon, which was to happen on 11 December 1685. As they were lodged in a wooden house, the smallest motion caused the building to shake so much that the pendulums and quadrants were useless. For this reason King Narai invited them to a royal

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[45] Tachard, *Voyage* (1686), 264-266; idem, *Voyage* (1999), 163.

Ill.4. Observation by the Siamese King Narai of the lunar eclipse of 11 December 1685, made together with French Jesuit priests in Louvo. The king is distracted from the observation by the presentation of two crucifixes. Engraving by Jan Luyken from Tachard, *Reis na Siam* (1687).

house called 'Thlee-poussonne', not far from the forest where the king used to hunt elephants. It was a one-storey hall made of bricks and cement, and is presently known as 'Phra Thinang Yen' or 'Thale Chup Son Hall', about four kilometres from the centre of the town.[46] King Narai used this location to observe the lunar eclipse together with the French Jesuit priests. The location of this building, just outside the city walls, can be found on a contemporary map of Louvo, drawn by a French engineer (see Ill. 3). The actual lunar eclipse took place at around three o'clock in the morning. For the king the Jesuits set up a very good telescope, five foot long and placed on a tripod, in the window of a room at Phra Thinang Yen that looked into the gallery from where the mathematicians made their observations (see Ill. 4). At his request King Narai also looked through a telescope twelve feet long and made several inquiries. Father Thomas Goüye (1650-1725) has left us a remarkably detailed

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[46] Tachard, *Voyage* (1686), 318-320, 326-334; idem, *Voyage* (1999), 163, 196.

description of both the observations at Cape of Good Hope and the lunar eclipse in Louvo.[47]

Father Guy Tachard (1651-1712) noted that a Brahmin astrologer, who was at Louvo, had foretold this eclipse almost to a quarter of an hour correctly; but he was mightily mistaken as to the duration of it, saying that the moon would not emerge from the earth's shadow until it was below the horizon (*i.e.* after sunrise). But the Brahmin astrologer stipulated he did not share the belief of the Buddhist monks (like the popular belief in China) that when the moon is eclipsed, it is eaten by a dragon, which could only be chased away by beating drums and making noise.[48]

The French delegation left Ayutthaya on 14 December 1685, and arrived in Brest on 18 June 1686. On the morning of 30 April 1688, King Narai again observed an eclipse at the new observatory, this time a solar eclipse, together with a few Jesuit mathematicians who had remained behind in Siam, with the intent to staff the observatory at Peking at a later date. King Narai died on 10 July 1688. With his death the Prasat Thong dynasty ended. His successor Petracha seized power in a Siamese *coup d état*, which led to the expulsion of all French troops, Jesuits and civilians from Siam. As a consequence the Dutch VOC regained her influence in Ayutthaya.

Exactly 180 years later King Mongkut (Rama IV), who reigned from 1851 to 1868 and who was a keen astronomer, calculated the circumstances for a total eclipse of the sun. He had studied traditional astrology when he was a monk and supplemented this with modern books, telescopes and other equipment ordered from London. Mongkut's own calculations, based on the astronomical tables computed by the Royal Observatory of Greenwich, showed that on 18 August 1868, the path of a total eclipse of the sun would cross the southernmost part of Siam, south of Petchaburi. His calculations proved correct, but during his sojourn at the observation site King Mongkut contracted malaria and died on 1 October 1868. Astrologers had prophesied that the eclipse was an evil omen of disease and death.[49]

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[47] Goüye, *Observations Physiques et Mathématiques* (1692), 61-119; idem, 'Observations Physiques et mathematiques' (1729), 614-635.

[48] Tachard, *Voyage* (1686), 334-335; idem, *Voyage* (1999), 204-205; Loubere, *A New Historical Relation* (1693), 64-65; Hennequin, 'Archives astronomiques de France concernant le royaume de Siam' (2001), 188-195; Smithies, 'Eclipses in Siam' (2003), 189-204.

[49] Chakrabongse, *Lords of Life* (1967), 211-213; Hobden, *The King of Siam's Eclipse* (2006), 24-31; Harding, 'The Eclipse of the Astrologers' (2008), 6-8; Stephan, 'Rapport sur l'Observation de l'Éclipse' (1868).

Final remarks

This overview, notwithstanding its limited range, leads to some interesting conclusions. First of all I refer to the astrology/astronomy paradox. A casual reader about astronomy would expect that astrology is an unscientific mode of predicting future events by just observing or computing the positions of the sun, the moon and the planets. In the seventeenth century both the Chinese emperor as well as the Siamese king based their principal decisions on the advice of the court astrologers to determine the auspicious moments of sowing, harvesting, warfare, coronations, weddings etc. But to be able to present their masters with accurate advice, the astrologers needed data which were collected systematically, as we have seen in the continuous struggle between Jesuit astronomers and regular court based Chinese, Muslim or Brahmin astrologers.

The Dutch East India Company (VOC) was instrumental in the early spread of the telescope in Asia. From mid-seventeenth century telescopes were used frequently on their vessels for navigation and other purposes. Also in the journals and travelogues we find frequent evidence of telescopes used both as presents and deliveries on demand of local rulers. We also have demonstrated that the newly invented telescope did not limit itself to scientific, military or amusement purposes. On several occasions telescopes, especially the well-decorated ones and those made of precious material, were used as diplomatic tools to achieve certain commitments from the foreign ruler.

In particular China and Siam were governed by rulers with a genuine interest in astronomy. As far as Siam is concerned, two kings were predominant, namely King Narai in the seventeenth century and King Mongkut (King Rama IV of the Chakri dynasty) in the nineteenth century. Underlining the western scientific approach of King Mongkut versus traditional belief systems, as a remembrance of his correct eclipse calculation, 18 August is celebrated in Thailand as National Science Day. Adding to the hagiographic historiography of the ruling Chakri dynasty, King Mongkut is also officially designated as Father of Modern Science and Technology.

Music as a liberal art and the invention of the telescope

Albert Clement

Introduction

In this contribution I will focus on the function and meaning of music and its relation with other disciplines.[1] Although we are nowadays inclined to regard music purely as an art form, or as a discipline belonging to the Humanities, this has not always been the case. Studying the history and sources of western music teaches us that the position of music is not a one-dimensional one. In fact, it is easy to point out clear connections with mathematical disciplines, including astronomy. For instance, in Plato's *Politeia* [*The Republic*] Socrates even stated that astronomy and music are like sisters in science, for as the eye is focussed on astronomy, so is the ear receptive to harmony.[2]

In Plato's *Timaeus*, and in Aristotle's *Politics*, these connections are further explained. Musical sounds and rhythms were ordered by the use of numbers, and these numbers were thought to exemplify the general concept of *harmonia*: the unification of parts in an orderly whole. Through this concept, Greek scholars perceived music as a reflection of the order of the universe. Music was, thus, closely connected to astronomy through this notion of harmony. It may therefore not come as a surprise that the leading astronomer of antiquity, Claudius Ptolemy, was an important author on music as well. Mathematical laws and proportions were considered the underpinnings of both musical intervals and the motions of the heavenly bodies. Planets, their distances from each other, and their movements were all believed to correspond to particular musical tones, intervals and/or scales.

Anaximander, a younger associate of the – proverbially first – Greek philosopher Thales, introduced the idea of 'heavenly spheres' wrapped around the central earth-column. Plato came up with an evocative tour of these spheres

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[1] I am indebted to my brother, the philosopher Dr. Hans Clement, for his valuable remarks made on the draft of this contribution, and to Sally Holman for her critical reading of the English text.

[2] Plato, *Politeia*, VII, 530d. Cf. Vetter, *Concentrische cirkels* (2000), 68.

Ill. 1. ‘Schema huius praemissae divisionis sphaerarum’: the celestial orbs as drawn in Peter Apian, *Cosmographia* (Antwerp, 1539).

in his ‘Myth of Er’, the eschatological legend concluding his dialogue known as *The Republic* (see above), in which he described the ‘Spindle of Necessity’. This early form of a spinning wheel was a wooden dowel, tapering at its ends, which was fitted with a whorl, usually made of stone and shaped as a doughnut. The spindle consisted of three main parts: a hook, a shaft, and a whorl. On this whorl of the celestial spindle, eight ‘orbits’ were placed, each creating a perfect circle. The eight circles of the cosmic whorl – from the outermost moving toward the spindle – were: the ring of fixed stars, the moon, the sun, Venus, Mercury, Mars, Jupiter, and Saturn. A siren stood on each ring and as the celestial whorl revolved, they were carried around with the movement, thus uttering the concords of a single musical scale.[3] The orbits can be identified as those of the planets corresponding to the Aristotelian planetary spheres, and shown in Ill. 1.

Already to the Pythagoreans it seemed that the distances between the planets would have the same ratios as the harmonious sounds produced by a plucked string. According to them, the spheres of the solar system produced sounds, just like a projectile when moving through the air. The inner spheres gave lower tones, while those further away moved faster, thus giving higher pitched tones. All combined into a beautiful harmony: the music of the spheres. It is clear that Plato derived his ideas as described in *The Republic* from the Pythagoreans.

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[3] Plato, *Politeia*, X, 616-617.

Also in his *Timaeus*, Plato describes the circles of heaven subdivided according to the musical ratios. This notion of 'harmony of the spheres', referring to the unheard music produced by the revolutions of the planets, was invoked over and over again by later scholars, writers and composers (including William Shakespeare in The Tempest, John Milton in Paradise Lost, Johannes Kepler in his *Harmonices mundi,* and Gustav Holst in *The Planets* – see below).

Both Plato and Aristotle stressed the importance of music in education, because they were of the opinion that music helped in building up a *harmonious* personality and in calming human passions. According to them, the human soul was kept in harmony by numerical relationships. And because music reflected this *orderly* system, music could penetrate the soul and restore its inner harmony. This idea that music could affect one's ethical character, or way of being and behaving, would become highly important for composers and writers on music of the seventeenth century, the century in which the Dutch telescope was invented, and even later. It is striking to notice that the invention of the Dutch telescope on the one hand and completely new perspectives of western music on the other hand both occurred in the first decade of the seventeenth century, with musicians and music theorists in the forefront of the new musical experiments being well aware of the telescope's invention.

From the early Christian church to the turning point

Musicians of the early Christian church drew on the music theory and philosophy of ancient Greece, and during the early Christian era, this legacy was gathered, summarized, modified, and transmitted to the West, most notably by such writers as Martianus Capella (see Ill. 2) and Boethius. In his widely read treatise *De nuptiis Philologiae et Mercurii* [*The Marriage of Mercury and Philology*], an allegory written in the early fifth century, Martianus Capella codified the so-called *Seven Liberal Arts*, basing himself on the types of studies that were pursued in the Classical world. In this allegory, Philology's bridesmaids at the wedding feast were personifications of these liberal arts. The *Seven Liberal Arts* were divided into the *Trivium* ('the three paths', being the verbal arts: grammar, dialectic, and rhetoric) and the *Quadrivium* ('the four paths', being the mathematical disciplines: arithmetic [numbers by themselves], geometry [numbers in space], harmonics (music) [numbers in time], and astronomy [numbers in space and time]).[4]

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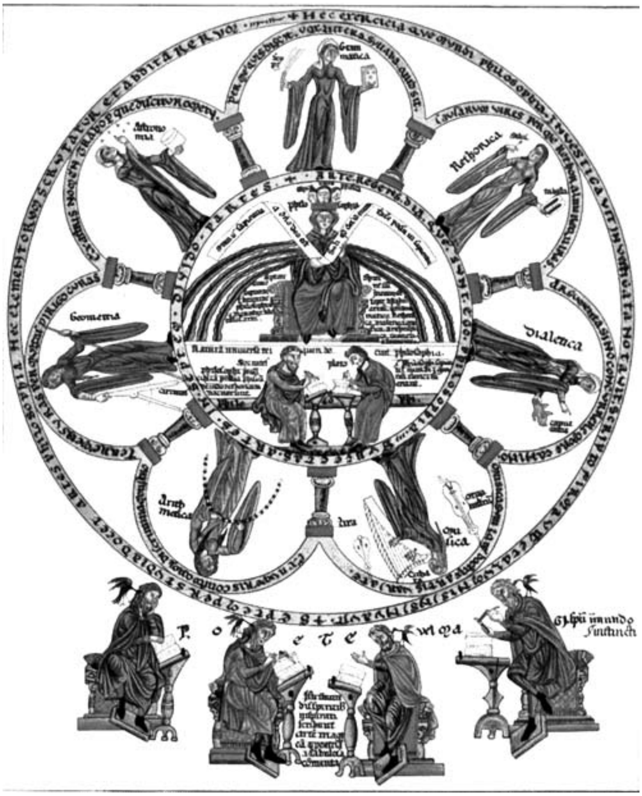
[4] Cf. Stahl, *Martianus Capella* (1977).

Ill. 2. Martianus Capella, teaching. In: Martianus Capella, *Noces de Philologie et de Mercure La Grammaire et son amphithéâtre d'élèves Commentaire partiel de Rémi d'Auxerre Italie,* 10th century. Bibliothèque nationale de France, 'Manuscrits, Latin 7900 A fol. 127v'.

In the Middle Ages, the *Seven Liberal Arts* offered a canonical way of depicting the realms of higher learning. In medieval Europe, music – being one of the liberal arts – belonged to the *Quadrivium* and not to the verbal disciplines. A beautiful, well-known depiction of the seven liberal arts can be found in the so-called *Hortus Deliciarum* [*Garden of Delight*] of Herrad of Hohenberg, or Hohenbourg, abbess of Mont-Sainte-Odile (see Ill. 3). Herrad was named abbess of the women's monastery of St Odile at Hohenberg (or Hohenbourg), near Strasbourg in the mid-1170s. She managed to produce an encyclopaedic compilation of sources concerning the history of human salvation, from the creation to the end of the world. Besides the theological texts, the book also



Ill. 3. Herrad of Hohenberg, *Hortus deliciarum* (*c*1185), f. 32: Queen Philosophia and seven noble ladies representing the Seven Liberal Arts; below four Poets inspired by black birds, a parody of Gregory the Great inspired by the Holy Spirit.

contained poetry and hymns, some accompanied by musical notation.[5]

An ancient concept that regards proportions in the movements of celestial bodies as a form of music was the so-called *musica universalis*, the universal

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[5] Her work consisted of over 300 parchment leaves of folio size. In interpreting the Holy Scriptures, she made use of the work of scholars such as Anselm and Bernard of Clairvaux, but she also took into account the newest insight by contemporaries including Peter Lombard and Peter Comestor, whose works formed part of the core curriculum of the new schools. It seems that she was aiming to bring together the best of the old and new theological writing in a teaching manual of both words and pictures in order to educate her canonesses. In addition to the Latin texts, over 344 illustrations were used, including more than 130 brightly coloured full-page illuminations. The manuscript survived fires and the suppression of monasteries, but was destroyed in the 1870 bombardment of Strasbourg. All that exists now are copies of parts of the manuscript, made between *c.* 1840 and 1870 for the French antiquarian Comte Antoine de Bastard, now preserved in the Bibliothèque Nationale de France. Cf. Green, *Hortus deliciarum* (1979).

Ill. 4. Anicius Manlius Severinus Boethius (480-524), instructing his students. Miniature (initial on folio 4r) from Book I of Boethius' *On the Consolation of Philosophy* (1385), written in prison while awaiting his execution. Glasgow University Library.

music. This is what the Greek philosophers called, as we saw, the music of the spheres. This 'music' was not literally audible, but it was in fact a harmonic concept. Boethius (see Ill. 4), the most important authority on music in the Middle Ages, compiled Greek sources dealing with this concept in his book *De institutione musica* [*The Fundamentals of Music*], written in the early sixth century. For Boethius, music was a science of numbers, with numerical ratios and proportions determining intervals, consonances, scales and tuning. He divided music into three types:

1. *musica mundana* (the music of the universe, or the music of the spheres)
2. *musica humana* (the internal music of the human body and soul)
3. *musica instrumentalis* (audible music, made by singers and musical instrumentalists)

The sun, the moon, and the planets were thought to revolve around the earth, all in their proper spheres. These spheres were thought to be related by the whole-number ratios of pure musical intervals, thus creating musical harmony.

Boethius' book was widely cited for the next thousand(!) years.[6] And then we encounter another writer on music who was strongly influenced by the Greek theorists: Franchinus Gaffurius (1451-1522). Being both a music theorist and a composer, the influence and importance of Gaffurius in the history of western music theory is considerable. The major writings of his years in Milan were *Theorica musicae* (1492), *Practica musicae* (1496), and *De harmonia musicorum instrumentorum opus* (1518). Together they offered a complete course of study in theoretical and practical music. The second of these, the *Practica musicae*, is the most thorough and most valuable treatise. It consists of four books, each of which was originally a separate manuscript written in a different year.

Being aware of the existing writings on systems of scales, music of the spheres, muses etc., it may not come as a surprise that many scholars tried to relate them. The title page of Gaffurius' most important work testifies to this. According to the heading, Apollo – being depicted here as a king, accompanied by three virtues – rules the waves and the muses. The left column shows eight muses instead of nine, in order to correspond with the eight spheres mentioned in the right column:

Urania	Celum stellatum
Polyhymnia	Saturnus (Saturn)
Euterpe	Jupiter
Eratho	Mars
Melpomene	Sol (Sun)
Terpsicore	Venus
Caliope	Mercurius (Mercury)
Clio	Luna (Moon)

The ninth muse, Thalia, appears at the bottom, together with the four elements (*ignis*, *aer*, *aqua*, *terra*). The expressions in the middle columns, relating to Archimedes and the affections of the musical modes, are in line with the columns framing the title page.

In his *Practica musicae*, planets, tones, bodily fluids, muses, and modal characteristics from the theory of affections are all brought together within one

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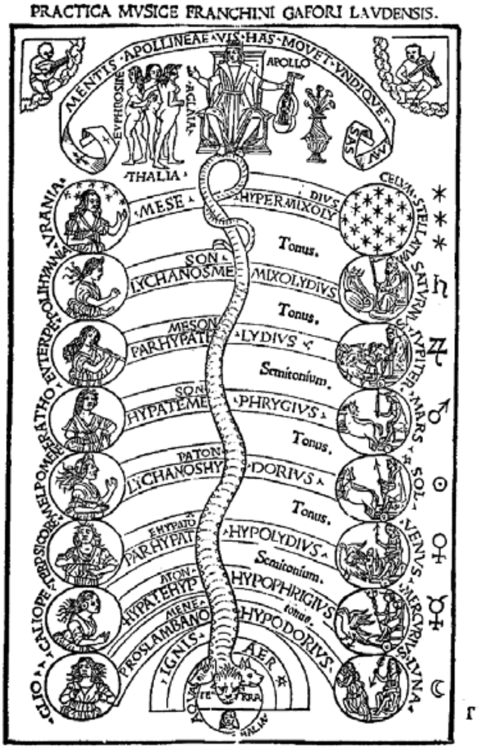
[6] Manuscript copies of *De Institutione* in a great many medieval libraries testify to the work's prestige. Particularly noticeable is the fact that it remained a core text for the teaching of music theory at Oxford until 1856, according to Robert Reilly ('Is Music Sacred?' The Philadelphia Society, National Meeting, Chicago, April 30, 2000).



Ill. 5. Franchinus Gaffurius, *Practica Musicae* (1496).

model.[7] The planet Mars was related to anger, Jupiter to fortune and bringer of happiness, etc. (see Ill. 5). These ideas continued to play a role in music long after the invention of the telescope, e.g. in the work of Gustav Holst.

Great composers of the Renaissance were still clearly connected to the *Quadrivium* in their own times. The greatest composer of the fifteenth century, Johannes [Jean de] Ockeghem (*c.* 1420-1497), who served the kings of France for almost half a century, was celebrated as a singer, composer, and teacher of many composers of the next generation. His *Missa prolationum*, for instance, was a technical tour de force, being notated in two voices but sung in four, using the four prolations of mensural notation. But let us avoid technical details and concentrate on how he was described by a contemporary visitor. In all books on music, Ockeghem is shown as one of nine singers from the French

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[7] Cf. http://www.chmtl.indiana.edu/tml/16th/GAFHAR4_TEXT.html; for a short discussion of the modes and their meaning within this context, cf. Clement, 'Affect en muziek' (2008).

Ill. 6. Johannes Ockeghem and his singers. Miniature Ms Français 1537, f. 58v. Illustration from ‘Chants Royaux sur la Conception Couronnée du Puy de Rouan’, depicting the choir singing the Gloria, conducted by Ockeghem. In its immediate neighbourhood a poem (1523) by Nicolle le Vestu, dedicated to Ockeghem. Bibliothèque Nationale, Paris, France.

royal chapel as depicted in the miniature in Ill. 6. Ockeghem is always said to be the older person wearing glasses, perhaps because modern writers find this a remarkable fact.[8] But to those familiar with the history of all kinds of glasses – including spyglasses – this is not particularly striking. Moreover, the artist responsible for the miniature would have tried to convince his contemporaries of Ockeghem’s outstanding position in his capacity as choirmaster, and in doing so he would have made use of other means, as well as contemporary common knowledge of the then deceased and highly regarded composer. The miniature (31 × 20 cm), in a French manuscript of about 1530, is placed near to a poem by Nicolle le Vestu, which begins with the following lines:

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[8] I do not know of any exceptions in scholarly books. However, my esteemed teacher Willem Elders has shown that this is highly unlikely by pointing out that the man in the scarlet robe must be Ockeghem. See Elders, ‘Fantasierijk’ (1997). I am much indebted to him for drawing my attention to this.

Okhem, très docte en art mathématique,
Aritmétique, aussy geométrie,
Astrologie et mesmement musique…

Ockeghem is referred to as a very learned man in all disciplines of the *Quadrivium*. Indeed, he was highly esteemed by the French kings and he received many royal presents. The accounts of the Royal Court provide some additional information. In 1465, the year in which he was appointed chapel master, 'Maistre Jehan Okeghan' received 'la somme de 77 livres tournois … pour avoir une longue robe déscarlate fourrée de gris, pour estre mieulx en point et plus honnestement en sa compaignie et service'.[9] The scarlet robe served to demonstrate his special position and to honour him within his circle. Francesco Florio, who visited the court of Tours in 1477, testified that it was impossible not to love this man [Ockeghem], standing out by the beauty of his body, his wisdom and habits, and his elegance.[10] Generally, a choirmaster can be recognized by his position (very close to the music stand). Knowing all this, it is clear that Ockeghem can only be the distinguished person with the elegant face, standing near to the music stand and wearing a scarlet robe.

New perspectives

Completely new perspectives were opened in the history of western music by the Florentine *camerata* (camerata meaning 'circle' or 'association'). A Florentine scholar, the historian and humanist Girolamo Mei (1519-1594), who worked in Rome as a cardinal's secretary, embarked on a thorough investigation of Greek music and in 1572 he started to communicate his thoughts to colleagues, notably Giovanni de' Bardi, Count of Vernio (1534-1612), patron of music and art, and Vincenzo Galilei (*c.* 1520-1591), a lutenist, composer, music theorist, singer, and teacher. In the same year Vincenzo Galilei migrated to Florence.

Bardi was the founder of a Florentine academy where a group of scholars and musicians discussed literature, science, and the arts, particularly the music of Greek antiquity, and where musicians performed as well; the whole group was active in promoting monodic music shortly before 1600.[11] The meetings

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[9] *Johannes Ockeghem en zijn tijd* (Dendermonde 1970), 110 (quoted after Elders 'Fantasierijk' (1997), 8).

[10] Elders, 'Fantasierijk' (1997), 10.

[11] The ideas seem to resemble those of the Middelburg *Roosevelt Academy* – the new (2004) international Honors College of Utrecht University, and the only Liberal Arts College in the Netherlands where applied music is also taught.

took place in Bardi's palace. Vincenzo Galilei – indeed, he was the father of Galileo Galilei – and Giulio Caccini (1551-1618), an important composer, were members of Bardi's academy, which became known as the *Camerata.* Galilei strongly suggested a new type of accompanied solo singing, and Caccini wrote numerous songs with *Basso continuo* – which we now call figured bass and probably all know from Johann Sebastian Bach's *Passions*, but which was something completely new then. Caccini published these songs in 1602 under the title *Le nuove musiche* [*The New Music*], and he called those songs with strophic texts 'arias' (Italian for airs) – a term also known to many people in our times from Bach's *Passions*, but already 'invented' in 1602.

Vincenzo Galilei contributed to the discussion of the 'new music' with his *Dialogo della Musica Antica, et della Moderna* (Florence, 1581), a famous treatise, written in the form of a dialogue between Giovanni de' Bardi and Piero Strozzi (also a member of the *Camerata*). Galilei's purpose was to further the cause of monodic music, but he also dealt with tuning, modal theory, counterpoint and music history. The discussion of tuning caused a controversy with his teacher Gioseffo Zarlino (1517-1590). The use of recitative in opera, oratoria and cantata – all being new genres, resulting from the experiments by the *Camerata* and nowadays seen as major genres representing 'baroque' music – is attributed to Galilei because he was one of the inventors of monody.

In addition, Galilei made substantial discoveries in acoustics involving the physics of vibrating strings and columns of air. He was able to demonstrate that while the ratio of an interval was proportional to string lengths (e.g. a perfect fifth has the proportions of 3:2) it varied with the square of the tension applied (and the cube of concave volumes of air). He found the correct ratio by hanging weights from strings. It was an experiment that produced numbers and bore directly on the age-old theoretical discussions. During his final years he drafted a number of essays concerning topics that can be found in his son Galileo's *Dialogo sopra i due massimi sistemi del mondo* [*Dialogue Concerning the Two Chief World Systems*] of 1632 in which he compared the (new) Copernican system with the (traditional) Ptolemaic system. It seems very likely that Vincenzo influenced his son Galileo by directing him towards experimentation.[12]

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[12] Is it not striking that in the Netherlands there was also a father and a son who took an interest in both optical instruments and music? Christiaan Huygens needs no further introduction in this volume, but Constantijn Huygens introduced with his *Pathodia sacra* (a collection of music, printed in France in 1647), the *Basso continuo* in France, which is not known by many people.

The invention of this new style in music is fully comparable to the invention of the telescope in at least one respect: it is not always the originator of an idea, but the first person to show its full potential who gives it a permanent place in human history.[13] It is easier in music than in astronomy to single out just one name: Claudio Monteverdi.

In the first decades of the seventeenth century, a new musical practice – the so-called *seconda pratica* or *stile moderno* – was developed. This is why the first decade of the seventeenth century, the decade we connect with the invention of the Dutch telescope, also represents a turning point in the history of western music: from now on composers had the choice of composing in two styles. The old style was the one used by the generations of the fifteenth and sixteenth centuries; the new style was invented in Italy around 1600 by musicians looking for new ways of making music: the members of the Florentine *Camerata* (see above). Musicians came up with new idioms including 'Basso continuo' and 'monody'. Their interest in innovation paralleled new ideas in science and politics.

When Johannes Kepler (1571-1630) and Galileo Galilei demonstrated new insights in the field of astronomy in 1609 (Kepler: publication of the *Astronomia nova* [*The New Astronomy*], with research on the motion of the planet Mars) and 1610 (Galilei: publication of the *Sidereus Nuncius* [*The Starry Messenger*], with observations of Jupiter's moons), Claudio Monteverdi (1567-1643) had just published his *Fifth Book of Madrigals* (1605). This collection represents, in its turn, a milestone in western music history.

In his preface to the collection, Monteverdi introduced the *Second Practice*, or – as he called it – the *Perfection of Modern Music*. In doing so, he reacted on the attack by Giovanni Maria Artusi, published in 1600, in which Monteverdi was accused of breaking the rules of counterpoint. Indeed, Monteverdi's new practice must have sounded extremely modern to his contemporaries. Monteverdi was of the opinion that composers were free to violate quite a few of the rules of the first practice for the sake of expressing a text.[14]

'Music as the servant of the words': this is how one could summarise this new style. Although this style – with its emphasis on rhetoric, text expression and text depiction – clearly moved towards the Humanities (the medieval

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[13] Unlike my friend Dr. Huib Zuidervaart (see above in this volume), I do not have to come up with a list of candidates: in music there is just one.

[14] Fine and well-known examples of Monteverdi's music, performed in the times of the invention of the telescope and of an equally groundbreaking importance, are his madrigal *Cruda Amarilli*, with its use of unprepared dissonances to express words such as 'cruda' (cruel) and 'ahi' (alas), and 'Vi ricorda o boschi ombrosi' from his opera *L'Orfeo*, which sets an early example of a strophic aria.

Trivium), one should not fail to notice that the concept of music as a science still remained important in the early seventeenth century. In fact, it turns out that writers on music and musicians have always had a keen interest in mathematics and astronomy as related disciplines. Again, it is striking that in the seventeenth century a number of scholars who wrote on astronomy were at the same time dealing with musicological matters. Examples of such scholars are René Descartes (1596-1650) in France, Isaac Beeckman (1588-1637) in the Netherlands and Athanasius Kircher (1602-1680) in Italy.[15] And it was a small world (what is new!): Descartes dedicated his principal contribution to music theory, his *Compendium musicae*, written in 1618, to his friend Beeckman. For Descartes, the impact on a listener's emotions was, it is true, important, but at the same time it was for him an element incapable of being scientifically measured. He described it as a phenomenon belonging to the field of aesthetics and metaphysics (of which he was to develop the principles later in his philosophical writings). Beeckman, born in Middelburg in 1588 and aptly characterised as 'one of the strangest characters of the entire Scientific Revolution',[16] not only wrote on music itself, but also on many related subjects such as the process of hearing (after all he had studied medicine) and tuning the harpsichord. Unfortunately, his writings have received little attention by musicologists so far.

On the other hand, Athanasius Kircher wrote one of the really influential works of music theory: almost every German music theorist until well into the eighteenth century drew upon his *Musurgia universalis* (Rome, 1650). Its popularity was greatly aided by a German translation (of a major part of it) in 1662 by Andreas Hirsch. On p. 268 of this edition, Plato and others are referred, and the harmony of the spheres is mentioned as well. One page later Kircher states that a harmony as claimed by ancient writers cannot exist, because there is no ordering of spheres as described by them. He then refers to Kepler (bottom of the page) and continues: 'die Sonn sei unbeweglich, die Erd aber beweglich' (p. 270). The question relevant within our context is of course: does he also refer to the telescope? The answer is: he does, indirectly. A few lines above the middle of p. 270, he refers to the Capuchin Antonius Maria Schyrleus de Rheita (1597-1660) and his *Oculus Enoch et Eliae* (Antwerp, 1645). This work contains very valuable information on the telescope, and

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[15] One of the many other authors to be mentioned here was of course Johannes Kepler (see above), whose theories also stemmed to an important extend from his theological convictions. In his *Harmonices mundi* he also wrote extensively about the *musica univeralis* or 'music of the spheres'.

[16] Cohen, *Quantifying music* (1984), 116.

Hans Lipperhey is introduced as its inventor, albeit in 1609.[17]

Kircher refers to the new world view, but he does not entirely abandon the Greek idea of music of the spheres. Instead, he offers a theological context and states that the heavenly music belongs to God and 'die Ausserwehlten im Ewigen Leben' (p. 271). So, there is indeed a harmony in heaven according to Kircher. This idea is clearly represented by the frontispiece of his study (see Ill. 7). The engraving shows the angels singing glory to God,[18] like Kircher says on p. 269 at the top (followed by a citation taken from the *Sapienta Salomonis*): 'die Himmel erzehlen die Ehre Gottes'.[19]

While scholars in the seventeenth century took an interest in musicological matters, composers at the same time continued to relate music to science and the liberal arts. The developments in astronomy and music, in which father and son Galilei were involved in the beginning of the century, soon found their way to a young man who would later be held in high esteem, and who is now regarded as the greatest composer of the seventeenth century: Heinrich Schütz (1585-1672).[20] He belonged to the first students of the *Collegium Mauritianum*, a new school of liberal arts founded in 1599 by Moritz der

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[17] Cf. Wilde*, Geschichte der Optik*, 1 (1838), 139, 154f., 170. In doing so, Rheita followed the example of Sirtori, who had introduced the name 'Johannes Lippersein' in 1618 (cf. the above-mentioned contribution of Huib Zuidervaart in this volume). Rheita actually introduced a number of crucial improvements in his work, leading to a real break-through in telescope design. First, Rheita suggested a new and much better method of polishing lenses, leading to a strong reduction of deviations; secondly (and even more importantly), he found that a compound ocular, composed of three or four lenses, resulted in a much better quality than using only a single (compound) ocular.

[18] There is of course much more to it. At the foreground left, there is Pythagoras while the lady holding the cornet on the right side is Music. Both figures have musical instruments at their feet (ancient and modern), while the men inside the opening in the centre represent the *musica instrumentalis*. Above them in the distance of the beach are nine satyrs and eight sea-gods. Slightly off to the right, a shepherd speaks to a cliffside with a quote from Virgil 'Pascite ut ante Boves' ('graze, cattle, as before'), which bounces back as an echo '…oves' – no doubt signifying Kircher's extensive interest in acoustics. Further to the right of that cliff, a long stone staircase leads to a landing on which is perched Pegasus, ready to take flight in service to the muses. The central sphere contains signs of the zodiac and a quote from Job: 'Quis concentum coeli dormire faciet?' ('Who shall still the harmony of the spheres?') Apollo sits on top carrying a kithara in his right hand and panppies in his left (compare this with Ill. 5 above). The 36 parts of the canon by Romano Micheli (with the Latin indicating where the solution to the canon can be found) are broken down into four groups of nine (3 × 3) voices: an hommage to the significance of the three-fold divinity, as well as to the nine muses. More significantly, this canon pays hommage to a famous 'lost' 36-voice canon by Johannes Ockeghem, the master of mensuration. Cf. Lowinsky, 'Ockeghem's Canon' (1969).

[19] The Heavens declare the glory of God, and the firmament sheweth his handiwork: Psalm 19:2.

[20] Already in his own times Schütz was famous, especially after the publication of his *Symphoniae Sacrae* (1629). It has been claimed that a no lesser artist than Rembrandt painted him, but nowadays this portrait is considered as dubious. Yet, there is a musician depicted (he is holding a roll of paper with music notation) who looks like Schütz and matches his age.

Ill. 7. Athanasius Kircher, *Musurgia Universalis* (Rome 1650), Frontispiece.

Gelehrte von Hessen-Kassel (1572-1632). Schütz got an excellent education and received a scholarship in order to study music with Giovanni Gabrieli in Venice (1609-1613). Not only is it certain that he learned the Second Practice in Italy (his first book of madrigals was published in Venice in 1611), but moreover, he may have attended the demonstration of Galilei's telescope in the same place in 1609.[21] At least twice Schütz wrote down a statement reflecting the Copernican view that not the sun, but the earth is the planet that moves: 'Ut Sol inter planetas, ita MUSICA inter Artes liberales in medio radiat'.[22]

Also living in the century of the invention of the telescope was another important musician: the organist of St. Mary's [the 'Marienkirche'] in Lübeck,

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[21] On the website of the Heinrich-Schütz-Haus as well as in texts by other modern writers, Schütz' presumed attendance is presented as a fact. Cf. e.g. http://heinrich-schuetz-haus.de/exponate/exponat_juli_2008.php.

[22] Cf. Fechner, 'Wie die Sonne' (1984).

Dieterich Buxtehude (1637-1707). He was instructed by Schütz's last pupil, the younger Johann Theile (1646-1724), with whom he became close friends.[23] In turn, Buxtehude taught a no lesser genius than Johann Sebastian Bach (1685-1750), and today Buxtehude is regarded as one of the best composers of his time. St. Mary's was the most important church of Lübeck. It was the official place of worship of the city council, and Buxtehude practised a range of musical activities there for a period of about fourty years. He had a documented interest in rendering the cosmos in music. His seven planetary suites for harpsichord (BuxWV 251) testify of this: together they were referred to as *Die Natur oder Eigenschafft der Planeten, in sieben Clavier-Suiten*.[24] Unfortunately, these seven keyboard suites, in which Buxtehude is supposed to have described the qualities of those planets, are lost.[25]

A reminiscence of more recent times

It is remarkable that another 'planetary suite' was composed more than 200 years after Buxtehude's death, thus more than 300 years after the invention of the Dutch telescope. 'Recently the character of each planet suggested lots to me, and I have been studying astrology fairly closely', the British composer Gustav

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[23] The composer can be identified on a painting (1674) by the Dutch painter Johannes Voorhout (1647-1723), now called 'Musizierende Gesellschaft (Musical Party) in Hamburg', with Buxtehude playing the viola da gamba. See e.g. Snyder, *Buxthehude* (2007), 109ff. The painting is now in the Museum für Hamburgische Geschichte.

[24] According to Mattheson, *Capellmeister* (1739), 130.

[25] The planets represented by Buxtehude must have been Saturn, Jupiter, Mars, the Sun, Venus, Mercury, and the Moon. Cf. Spitta, *Bach* I, 259f.: '[...] den sieben Planeten – mehr kannte man damals nicht, und rechnete Sonne und Mond mit hinzu – [wurden] bestimmte Charakter-Eigenschaften beigemessen [...], nach denen die Astrologen ihren Einfluß auf das Leben und die Geschicke der Menschen berechneten. Offenbar hat Buxtehude diese in den Suiten wiederspiegeln und so sieben Charakterstücke schaffen wollen, was nach Matthesons Urtheil ihm durchaus gelungen ist. [...] Daß die musikalische Kunst ein Spiegelbild des harmonisch geordneten Universums sei, und ein geheimnißvoller Zusammenhang bestehe zwischen dem Leben und Weben der reinen Töne und der ewigen Bewegtheit des Weltalls mit all seinen kreisenden Himmelskörpern in den lebendurchgossenen unendlichen Räumen, dieser Gedanke hat von Alters her bis in die neueste Zeit die tiefsinnigsten Geister erfüllt. [...]. Unsere Vermuthung würde sich noch befestigen, wenn jene sieben Suiten auf die sieben verschiedenen Stufen der Tonleiter gegründet wären [...]. Dann möchte eine directe Reminiscenz an das griechische Alterthum vorliegen: die Pythagoreer lehrten, daß die Abstände der sieben Planetenbahnen den Verhältnissen der Töne der siebensaitigen Lyra gleich seien. Leider ist wenig Aussicht vorhanden, daß das interessante Werk noch wieder zum Vorschein kommt.'
It is very likely that Buxtehude was at least to some extent inspired here by the presence of an astronomical clock in St. Mary's, dating back to *c.* 1566 and considered to be a real treasure. It was located behind the high altar in the ambulatory but was destroyed in 1942.

Holst (1874-1934) wrote to a friend in 1913.[26] His studies resulted in an orchestral suite in seven movements, written in the years 1914-1916, the full score of which was completed in 1917.[27] This work is now generally known as *The Planets* (Op. 32), but its original title was *Seven Pieces for Large Orchestra*.[28] Its first performance took place in the autumn of 1918,[29] and today it is one of the most-performed works by a British composer.

Holst was well acquainted with astrology and mythology, as well as with the Greek idea of the 'music of the spheres', and he drew heavily on this knowledge in his composition. His stepmother had introduced him to theosophy (eternal truths were to be found in the texts of ancient cultures and religions) and this gave rise to his interest in astrology – an interest to which he later referred to as 'my weakness'. In 1913 he went on holiday to Majorca with Henry Balfour Gardiner, and the brothers Arnold and Clifford Bax. Clifford spent the holiday discussing astrology, whetting the appetite of Holst. Holst also studied the writings of the astrologer Alan Leo (William Frederick Allan, 1860-1917). Holst returned from holiday with a feeling of being ready for the composition of a new work, and when he heard Albert Schoenberg's *Five Pieces for Orchestra* in 1914 he got the idea of writing an orchestral suite himself: as a work in progress, the composition was originally scored for a piano duet (with the exception of the final movement, which was scored for organ, because Holst found that the sound of the piano was too harsh for such a mysterious and distant planet as Neptune. Holst then scored the suite for a large orchestra, and as such it became enormously popular.[30] His imaginative and colourful use of orchestration shows the influence of Schoenberg and other continental composers, especially of Igor Stravinsky's compositions *The*

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[26] Cf. Holst, *Gustav Holst* (1969), 43.

[27] Painful neuritis in his arm restricted Holst's possibilities and in writing the score he was helped by assistants.

[28] This is the only title in the original full score, now in the Bodleian Library, Oxford; moreover the individual movements only have the description of the planets ('The bringer of war', etc.) instead of any mention of their names.

[29] It was a private performance by the Queen's Hall Orchestra, conducted by Sir Adrian Boult on 29 September 1918, and given to Holst as a present by Henry Balfour Gardiner.

[30] For instance, a famous poem was later set to the 'Jupiter music', and the two have been inseparable ever since. The first verse was played at the Royal Wedding of Charles and Diana, while its second verse was sung at Princess Diana's funeral: 'And there's another Country / I've heard of long ago, / Most Dear to them that Love her, / most Great to them that Know. / We may not count her Armies. / We may not see her King. / Her Fortress is a faithful Heart;/ her Pride is Suffering. / And Soul by Soul and silently, / her shining Bounds increase / and her ways are ways of Gentleness / and all her paths are Peace!' But Holst's work has also used over and over again in modern films and media.

Firebird, *Petrushka*, and *The Rite of Spring*. The seven movements are:

1. The Bringer of War (Mars)
2. The Bringer of Peace (Venus)
3. The Winged Messenger (Mercury)
4. The Bringer of Jollity (Jupiter)
5. The Bringer of Old Age (Saturn)
6. The Magician (Uranus)
7. The Mystic (Neptune)

Compared to Buxtehude's suite, the (presumed) order of the planets was changed; Uranus and Neptune were added while the sun and the moon were left out.

Uranus was the first planet to be discovered by using a telescope. The announcement was made on 13 March 1781 by the British astronomer Sir William Herschel (1738-1822), who had used a 15-centimetre telescope designed and built by himself. Interestingly, Herschel was also a composer. When the Middelburg medical doctor, anatomist and obstetrician Paulus de Wind (1767-1797), who later (1792) became lecturer at the 'Illustre School' in Middelburg, met Herschel during his stay in London (from the second half of 1790 until the month of May the year after), Herschel kindly permitted him to look through his telescopes[31]. De Wind described his visit on 9 April 1791 as follows:

> Having intended a little trip for pleasure in company with Mr. Rowntree and Mr Saunders, and with the cousin of the former, who is a Lawyer in the Temple, we departed, after having taken some cold meat &c before, from London at 2 o'clock (being the Lawyer and I in a Chaise with a horse, and the two others on horseback) and arrived at about 4 o'clock in Kensington, Brentford &c at Crawford Bridge, where Men and Beasts refreshed a little, and then we travelled to Slough, a village situated 2 miles from Windsor, where the famous Dr. Herschel lived, whom we asked to see his instruments, to which he agreed most kindly. His largest telescope is 40 feet long, and 4 feet ten inch in diameter, it is hanging at Pulleys between two bucks, each 50 to 60 feet high, and besides the telescope a little house for the Observatory on an edge of stone, being able to turn around in the way of a mill; the small telescope of about 20 feet long, and the other Apparatus of proportion likewise attracted our attention, but we had no opportunity to look through either of the instruments, however the Doctor let us look through a small Telescope of 14 feet long, which he and his servant rolled forward on wheels, and through which we saw Jupiter by the size of four to five inches

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[31] Cf. Michael Hoskin, 'Herschel, William (1738–1822)', *Oxford DNB* [accessed 1 March 2007].

diameter, as well as three of its satellites. Then we went to our inn to eat, and to bed.[32]

Neptune was the first planet inferred from mathematical predictions rather than by observations through a telescope, although Galileo had already recorded it as a background star during his observations of 1612 and 1613. When Uranus did not travel as astronomers expected, the French mathematician Urbain Joseph Le Verrier (1811-1877) suggested that the presence of another, as yet unknown, massive planet could cause the observed errors in Uranus' orbit. He sent his predictions to Johann Gottfried Galle (1812-1910) at the Berlin Observatory, who found Neptune directly in 1846.

Although the invention of the telescope clearly influenced Holst's choice of planets, it is crystal-clear that the movements were to express the 'character' of each planet as described in ancient history and in astrology. In the opening movement (Mars) we meet battle music (with the god Mars being related to war, and the 'red' planet to anger); the music for Venus is much quieter, based on the work by Alan Leo, who described Venus as creating orderly and harmonic motion; Mercury – the only entirely autograph movement in the full score – seems to flit swift-footed through this piece; the spirit of Jupiter's music seems to be much in keeping with the astrological significance of Jupiter as the planet of benevolence and generosity. The musical representation of Saturn is characteristic for its sad procession and waves of sound receding into the far distance, while the next movement (Uranus) testifies of humour spilling over into flamboyant orchestral excess. The final movement (Neptune) creates a sense of a floating cascade through empty space, through Neptune's watery

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[32] Translation after the transcription in an unpublished small thesis (2007) by *Roosevelt Academy* student Gerda Joosse, supervised by Dr. Tassilo Erhardt, who kindly draw my attention to it): 'Voorgenomen hebbende om in gezelschap met Mr Rowntree en Mr Saunders, en met den eerstens Neev, een Advocaat in de Temple, een klein pleiziertochtje te doen, reeden wy, na vooraf eenig koud vleesch &c, genuttigd te hebben, ten 2 uuren uit London (zynde de Advocaat en ik in een Chaise met een paard, en de twee andere te paard gezeten) en arriveerden om 4 uuren over Kensington, Brentford &c aan Crawford Bridge alwaar Menschen en Beesten zich een weinig verfristen, en waarna wy verder reeden tot Slough, een dorp 2 mylen van Windsor gelegen, en waar de vermaarde Dr Herschel woond, by wien wy belet vroegen om zyne instrumenten te zien, 't geen hy ons zeer vriendelyk accordeerde. Zyn grootste Telescoop is 40 voet lang, en 4 voet tien duym in Diameter, het hangd aan Katrollen tusschen twee bokken, die 50 a 60 voet hoog zyn, en benevens het Telescoop, een huysje voor d'Observatory op een steene rand in de manier van een molen ronddraayen kunnen[d]; den kleinen Telescoop van omtrend 20 voet lang, en d'andere Apparatus na proportie trok insgelyks onze attentie, doch door geen van beide hadden wy occasie te zien, echter liet de Doctor ons zien door een klein Telescoop van 14 voet lang, hetgeen hy en zyn knecht op wielen voortrolden, en waardoor wy Jupiter ter grootte van vier a vyf duim diameter, benevens drie zyner satelliten zagen. Wy gingen vervolgens in ons logement eeten, en na bed'.

depths; its sound is remote and mysterious, with a female choir gradually fading out at the end. As such, the music for Neptune was the first piece of music to have a fade-out ending, and this may in turn be explained more from an astronomical than astrological point of view, with the planet Neptune then being the most distant object known in the solar system.[33]

The invention of the telescope had an influence on a number of disciplines, music included. But even before that invention, astronomy and music were also regarded as sister disciplines. Greek philosophers put forward the idea that planets, twirling and whirling around through space, must have hummed a tone as they went along in their courses: the 'music of the spheres'. They knew of seven planets and western music evolved with seven-tone scales. Throughout all ages, music and astronomy have kept their intriguing relationship, and many scholars have devoted studies to both disciplines. And although we cannot share many ideas of earlier times anymore as a result of the invention of the telescope, planets continue to inspire artists, composers included, again and again, until the present day, just as the planets continue to travel through the solar system.

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[33] Pluto was discovered in 1930, four years before Holst's death. He expressed no interest in writing an additional movement for it, having become disillusioned by the popularity of his suite and believing that it drew attention away from his other works. Many other composers did, and the Holst specialist and composer Colin Matthews wrote an eighth movement for the Suite, entitled 'Pluto, the Renewer', dedicated to Holst's daughter Imogen. It was first performed in Manchester, on 11 May 2000. However, in 2006 Pluto was offically demoted by the International Astronomical Union to the class of dwarf planets.

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