A History of Star Catalogues

Abstract

Throughout the history of astronomy there have been a large number of catalogues of stars. The different catalogues reflect different interests in the sky throughout history, as well as changes in technology.

A star catalogue is a major undertaking, and likely needs strong justification as well as the latest instrumentation. In this paper I will describe a representative sample of star catalogues through history and try to explain the reasons for conducting them and the technology used. Along the way I explain some relevent terms in italicized sections.

While the story of any one catalogue can be the subject of a whole book (and several are) it is interesting to survey the history and note the trends in star catalogues.

Contents

1. Origin of Star Names

Some common star names come from the ancient Greeks. They named stars according to their place in the constellations, such as "Arcturus", meaning "the bear watcher" because it is near Ursa Major, the Great Bear. (RMSC 2002)

Some stars have names of Arabic origin, though it isn't clear that they were ever formally catalogued. A lot of the Arabic star names are translations of Greek names and refer to Greek constellations.

2. Hipparchus

Hipparchus of Nicaea probably compiled the first star catalogue at Rhodes in 127 B.C. Actually, whether it was really compiled into catalogue form is unclear. No written copy of the catalogue exists today. In whatever form, it may have contained 1025 to 1080 stars. The coordinate system Hipparchus used isn't known. It was undertaken upon the appearance of a new star, or nova. The instrument that Hipparchus used is called by Ptolemy a dioptra.

"Hipparchus was the first who realized the necessity of a second motion of the celestial sphere." (Grasshof 1990) This motion is called precession. Hipparchus believed precession to be 1° per century. He discovered precession through the determination of the equinoxes. The equinox is defined by the moment when the sun's path on the zodiac intersects the celestial equator. (Grasshof 1990) The equinox slowly changes its position among the stars.

• Precession

An important reference point for any star catalog is its epoch. The Earth's polar axis moves in a *circle in a motion called precession. So the north pole doesn't always point at a particular star but gradually traces out a circle over a period of 25800 years. The radius of the circle is 23.5 degrees, really a rather large number. The precession of the poles is about 50.27 arc seconds per year or 1.4 degrees per century. So when a star's position is given, the time of observation must also be given. A star catalog may take years or decades to compile, and it is useful to mathematically back out the precession and make all the measurements appear to be made at the same time. The data processing to do this is called reduction, and the year that the catalog is accurate for is called its Epoch. The Epoch chosen for a star catalog is arbitrary though current practice is to put them on fifty year intervals. Precession was first described in the second century BC by Hipparchus. (Illingworth 1979)*

3. Almagest

Claudius Ptolemy's Almagest, in its seventh and eighth books, contains a catalog of stars. The Almagest star catalog was published in Alexandria around 150 AD. Copernicus included the Almagest star catalog in De Revolutionibus. The catalog contains 1028 stars. Each star entry contains a description of its position within its constellation, its ecliptic longitude and latitude and its magnitude on a scale of 1 (brightest) to 6 (dimmest visible stars). The precision of the catalog is 10' to 15' of arc.

There is some controversy surrounding this catalog, which Ptolemy says he personally observed with a spherical astrolabe in 137 AD. The stars most likely were those observed by Hipparchus between 160 BC and 130 BC. Ptolemy recalculated the positions of these stars. Ptolemy states that the catalog should be dated to 138 AD. Ptolemy precessed Hipparchus' positions forward, but used the wrong value for precession, 1°/century instead of the more accurate value of

1.4°/century. Tycho Brahe was among the first to suspect that the catalogue was “not the product of Ptolemy’s own accomplishments as observer, as the text would have us believe, but had been obtained through a simple conversion of measurements” made by Hipparchus. (Grasshof 1990)

As I mentioned, this important catalog was quoted by Copernicus and also used by Tycho Brahe and Johannes Kepler. Even in the 18th century Edmund Halley used the catalogue and discovered the proper motion of stars. It was not superseded for hundreds of years. It was the first catalog accurate enough to be of modern usage. (Vila-Echagüe 2000)

The Almagest star catalog covers the sky from the north pole to -52° declination. Stars in the catalog were arranged by constellation. In the Almagest, Ptolemy states that the fixed stars always maintain the same position relative to each other. This was an idea that would remain in place for centuries. The Almagest star catalogue lists the ecliptic coordinates of the stars. Due to precession, the ecliptic moves around the pole, so equatorial coordinates get out of date while ecliptic coordinates remain constant.

The Almagest made its way to the Arabian peninsula in the middle ages and influenced the Arabic astronomers. By measuring a few reference stars, the Arabic astronomers adjusted the longitudes of the Almagest stars to their own epoch. The Almagest became known in Europe through the Latin translation of Gerard of Cremona in 1175.

4. Ulugh Beg

Ulugh Beg or Beigh was born in 1393 in Soltaniyeh, Timurid, Persia. He was the grandson of the conquerer Tamerlane or Timur. He was a mathematician and astronomer, and a promoter of the arts. (Washington 2003) He built an observatory at Samarkand, over 50 meters in diameter and 35 meters high. Beg appointed Ali-Kudsi, as director of the observatory. It contained a huge quadrant, a marble sextant, triquetram, and an armillary sphere. He produced several extraordinary scientific works including a Catalogue of the stars, the Zij-i Sultani. The catalogue contains the positions of 992 stars and was published in 1437. (MacTutor, 21 May 2003) Observations for the catalogue were probably made from 1420 to 1437.

For the catalog, Beg re-observed Ptolemy's stars, finding errors in Ptolemy's computations that had stood for some 1300 years. His was the first catalogue since Ptolemy's made from original observations. (Knobel 1917) According to Knobel, the catalogue contains 1018 stars, though 27 of those were not observed, but instead reduced from Ptolemy's catalogue, and one was not found. Knobel states that only about 700 of the stars in Beg's catalog had both longitude and latitude determined by original observations. Beg used a precession value of 1° every seventy solar years in his reductions from Ptolemy.

The original text was most likely written in Persian, though it is hard to tell. Several codices exist written in Arabic but they are incomplete. (Knobel 1917).

Shortly after his father Shahrukh's death, and a short reign of two years , Beigh was overthrown and executed in 1449 by his own son. (Washington 2003)

His star catalog was published in Europe in about 1665.

In his introduction to the catalogue, Beg acknowledges Ptolemy's catalog in the Almagest, noting that 1022 stars had been observed "before the time of Ptolemy" Abd Al Rahman Sufi wrote a treatise on the stars, reducing them to his epoch. Beg found this more modern work to be out of date, and that is what prompted him to make the observations required to create his new catalogue. He says the 27 stars from the Almagest that he did not observe were too far south to be visible from Samarkand. During Beg's time, it was believed that aside from precession, the stars kept the same relative places in the sky.

5. Brahe and Kepler

Tycho Brahe was a Danish nobleman. He was born in 1546 and early on became interested in astronomy.

A new star (supernova) appeared in 1572 and inspired Tycho to write his first book, De Nova Stella, on his observations and theories. The observation of the supernova and the desire to accurately determine its position led to the demand for better equipment and observations than had ever been made before. He built the most precise equipment for measuring the positions of celestial objects before the invention of the telescope.

Tycho designed and used four types of armillary spheres. The first was oriented on the ecliptic and read right ascension and declination directly. This orientation sagged, though, and subsequent instruments were mounted equatorially. His "Great Equatorial Armillary Instrument, Comprising One and a Half Circles" measured 2.6 meters in diameter. Tycho also invented a new transversal method of engraving his circles. Furthermore, he developed sights designed to eliminate parallax errors. The result of all this work was greater precision than had been achieved before.

His book "*Astronomiae instauratae progymnasmata*" (Introduction to the New Astronomy) contains a catalogue of 777 stars. (Watbooks-Brahe 2003) They are measured with far greater accuracy than any previous measurements. The book was printed between 1588 and 1598 by Tycho's private press on the Island of Hven, where his observatory called Uranaborg was located. After Tycho died his associate Johannes Kepler completed the work. The star catalog itself was completed by 1592. Later work increased the size of the catalog to 1000. Kepler's version of Tycho's catalog is called the Rudolphine Tables (for his patron Rudolph II) and was published in 1627 in Ulm. (Dreyer 1917)

Tycho's primary work, and the part Kepler was interested in was planetary positions. Scientists of the time needed accurate planetary positions to verify and extend Copernicus' theory. The star catalogue was a means to this end. Using Tycho's measurements, Kepler was able to formulate his three laws. (Kusukawa 1999)

6. Bayer

In 1603 Johann Bayer compiled a list of stars. Within each constellation he assigned Greek letters to the stars, roughly starting with the brightest. Alpha Orionis is the Bayer designation of Betelgeuse. Betelgeuse is really the second brightest star in Orion, after Rigel, but gets to be the Alpha star because of its more northerly position. After the 24 letters in the Greek alphabet were exhausted, Bayer used lower-case Roman letters then upper case Roman letters. Bayer only catalogued naked-eye stars, and even then not all of those. (UIUC 2000)

7. Hevelius

Johannes Hevelius was born in 1611 in Danzig. His father wanted him to become a businessman and politician, but Johannes' love of mathematics and astronomy won out. His professor Krüger inspired him to follow the path of Tycho Brahe, the great observer. After marrying and spending some time in business, he returned to astronomy at the urging of Krüger. The solar annular eclipse of June 1, 1639 was the turning point.

Galileo's use of the telescope was revolutionizing astronomy, and Hevelius obtained a telescope and made a large and detailed map of the moon. In doing so he ground lenses and built two telescopes of his own. Hevelius did the observing, the drawing, and even the engraving of the plates himself. He printed the lunar maps in 1647. They were the best lunar maps ever made, and remained the best for many years despite the progress made in astronomy. The lunar map book is called the Selenographia, and contains drawings of each phase of the moon. Many of the features Hevelius named on the moon are still in use today.

Scientists of the time were interested in whether the heavens are indeed immutable as previously thought, or whether there were in fact motions among the "fixed" stars. This has great philosophical importance because it was believed that heaven was perfect and changeless. Another important question being discussed was whether the sun or the earth was the center of the universe. An accurate catalog of the positions of the stars, against which the motions of the planets could be calculated, was essential. Remember that Copernicus had only published his Revolutionibus in 1543, and Galileo had been tried for supporting Copernican theory around 1600. Navigators also had use for accurate star charts, as it was a challenge to find one's longitude at sea. For these reasons, Hevelius decided to compile a star catalogue.

Hevelius designed several instruments to use in compiling his star catalogue. He built an observatory in one of his houses in Danzig and put a quadrant and a sextant there. He did not use the astrolabe and armillary sphere previous astronomers used because of their inaccuracy. A sextant, named for a sixth of a circle, is an instrument for measuring the angles between two stars. In a large sextant, one person looks through a fixed sight at a reference star, tracking its motion, while the other person adjusts a movable sight to point at the unknown star. The sextant is engraved with degrees and usually has a vernier scale for determining angles to very high resolutions.

Hevelius was not pleased with his initial results. Luckily the city of Danzig gave him an azimuthal quadrant, two meters in radius, that had belonged to Krüger. He built several more instruments, but was not happy with their accuracy until he designed a nine foot radius sextant. Altogether he had more than a dozen different instruments. He checked the accuracy of his measurements by repeating them on different instruments, and measuring the same quantity in different ways. This re-checking of one's results was advanced science in its day. One check Hevelius made was to measure the distances between stars all the way around the sky.

For this huge instrumentation he needed a larger observatory. He built a platform across the roofs of three of his houses, above the city of Danzig. This observatory was named Stellarburgum and was the finest astronomical observatory of its day.

With his azimuthal quadrant (the one from Krüger, which Hevelius completed) he could measure the altitude (height above the horizon) and the azimuth (compass direction) of a star. With those measurements and an accurate clock, the right ascension and declination could be calculated. By aligning the azimuth to 0 (north and south), the altitude of objects as they crossed the meridian could be accurately measured. In this arrangement it was used like the yet-to-be-invented mural arc. Hevelius counterbalanced his quadrant so it could be moved by hand in fine increments and could read angles to within a few seconds of arc on the scales. Of course one could not see stars to such high resolution without a telescopic sight, which Hevelius shunned. This instrument was used to determine the positions of selected reference stars.

The other major instrument used by Hevelius was a sextant. This was mounted on a ball joint so it could be easily and accurately pointed. This instrument was used to measure the angles between stars. To use it, one observer aligned a reference star in the fixed sight and the other moved the moving sight to line up with the star being measured. Then the angle was read from the scale. By taking the measurements from two reference stars and doing some spherical trigonometry, one could determine the position of a third star.

Again Hevelius shunned the telescopic sights being promoted by Robert Hooke of England. Hooke pointed out that with a telescopic sight, one could see the star in question to much higher precision. Hevelius was basically sighting naked-eye. Hevelius had extraordinarily good eyesight as demonstrated by his lunar maps, and performed several experiments to prove that his technique was better than that achievable with telescopic sights. The problem with telescopic sights of the time was that the repeatability and collimation were not as good as fixed sights.

The controversy between Hevelius and Hooke played out in the Royal Society for some time until the Society sent a third party, the young Edmond Halley to verify the accuracy of Hevelius' method. Halley was very impressed with the repeatability of Hevelius' measurements, and the catalog was allowed to proceed.

This was an expensive project, and was funded by grants from Louis XIV of France. Hevelius wanted to publish his results in a series of books, *Machina Coelistis*, the first of which described his instrumentation and methods. He wanted to hold off the actual star catalogue until the last. In about 1679 he published the second volume, containing his twenty thousand astronomical measurements. Still no actual catalog was published, though in fact it was already finished.

How accurate were Hevelius' measurements? Comparison to modern measurements show that he was within about 27 arc seconds, an amazing feat for naked-eye observations. Later measurements by Flamsteed using telescopic sights were not much better.

Just as Hevelius was preparing to publish his catalog of fixed stars, disaster struck. A fire started in one of his houses on September 26, 1679 and totally destroyed the observatory and his fine instruments. Very few of his books were spared. Luckily his only copy of the manuscript for the star catalog was saved by his daughter Katharina.

He immediately set out to publish the fixed star catalog and rebuild his observatory with the financial support of Louis XIV and the new king of Poland, Jan III Sobieski.

Hevelius died at age 76 in 1687, his catalogue of fixed stars only half printed. His widow Elizabeth completed the job of printing the *Catalogus Stellarum Fixarum* in 1690. In addition to the numerical positions, the catalogue contained beautiful maps of the constellations. Hevelius named several previously unnamed constellations, names which we still use today: Lynx, Sextans, Canes Venatici, Lacerta, Leo Minor, Scutum, and Vulpecula.

The original manuscript of the star catalog survives, and contains valuable information which didn't make it to the printed version. Each star measurement is accompanied by an indication of the instrument used to determine it, sextant or quadrant. The manuscript is now at Brigham Young University.

For each star in the catalogue, the following information is given:

1. Constellation name
2. Tycho's order within the constellation
3. Tycho's magnitude
4. Hevelius' magnitude
5. Hevelius' calculated longitude and latitude in ecliptic coordinates for stars measured with the sextant
6. Hevelius's longitude and latitude in meridianal coordinates for stars measured with the azimuthal quadrant
7. Tycho's values for longitude and latitude, corrected to epoch 1660
8. Position determined by William, landgrave of Hesse
9. Position determined by Jesuit Giovanni Battista Riccioli
10. Position determined by Ulugh Beigh

11 Position determined by Ptolemy in his Almagest

12 Hevelius' calculations in right ascension and Declination, or equatorial coordinates.

(Volkiff 1971)

• *Coordinate Systems*

A very basic coordinate system we can use is altazimuth. In this one, we make measurements of *the altitude of an object above our horizon, then its azimuth or compass direction. This coordinate system can be measured easily and precisely, but has a basic flaw. The sky rapidly moves over us in a different coordinate system called the Equatorial coordinate system due to the Earth's rotation around its pole. If we align our coordinate system to the polar axis of the Earth, and synchronize it to the movement of celestial objects, then we can specify the coordinates of celestial objects by their right ascension and declination. These coordinates remain relatively constant for years, and catalogs can be made that specify the right ascension and declination of astronomical objects. Many telescopes are aligned on this equatorial coordinate system. Precession due to the movement of the pole makes equatorial coordinates eventually get out of date. A more fixed system uses the ecliptic coordinate system, which is independent of precession.*

Another coordinate system is the Galactic coordinate system, where the zero point of galactic longitude is in the direction of the center of the galaxy, and the latitude measures the distance above or below the plane of the galaxy.

8. Flamsteed

In 1712 Reverend John Flamsteed (1646-1719), first Astronomer Royal, published a catalog of 2866 stars observed from London. The faintest stars in the catalog are 8th magnitude. The numbers of the stars were not given by Flamsteed, but by Joseph Jerome de Lalande. The Flamsteed numbers were assigned east to west within a constellation, e.g. 58 Orionis.

Between 1683 and 1690, John Flamsteed became dissatisfied with the measurements he could take with his sextant and built a mural arc that reached from the north pole all the way down to where the meridian crossed his horizon. With this instrument, which he said was "built too slight, and could not be well fixed" he exceeded the precision of Tycho's measurements. (Baily 1835)

Unfortunately both his benefactors, Sir Jonas Moore and the king of England, died, so he had to take on the cost of building an improved instrument himself.

What was Flamsteed's reason for creating a catalog? Quoting Flamsteed himself, "In the mean time, considering that the distances I had taken, though not so exact as I desired, were much better than Tycho's; and finding the want of a better catalogue of the fixed stars than his, I set myself to calculate a small one [catalog] of those most useful to me, from my own observations made with the sextant, and this slight arc; and perfected it in the spring of the next year, 1687" This small catalog contained about 130 stars reduced to the year 1686.

The British government was interested in better sea navigation, especially the determination of longitude and on Flamsteed's recommendation built the Greenwich Observatory. Flamsteed worked from there but provided his own instruments and skilled assistants. (Moore 1987)

After inheriting some money from his father, Flamsteed and his servant Stafford constructed a stronger mural arc, of the same radius. This was around 1688. Stafford died and was replaced by A. Sharp. Sharp was "not only an excellent geometrician and ready calculator, but (which I no less valued him for, at this time) a most expert and curious mechanic". Flamsteed writes that the arc was attached to a meridian wall and planed by a special method, a process that took some fourteen months.

• *Mural Arc*

A Mural Arc or mural quadrant consists of a graduated arc with a swiveling arm to which is attached a sighting mechanism. The arc is graduated, and is often quite large to give good resolution. The whole thing is attached to a wall aligned with the observer's meridian. The elevation of a star is determined by reading the height of the sighting mechanism at the time the star crosses the meridian. From that its declination can be determined if one knows the latitude of the observatory. The right ascension of the star is determined by noting the exact sidereal time when the star crosses through the eyepiece. Alternatively the sidereal clock can be set by noting when a particular star whose R.A. is known passes through the eyepiece.

Unfortunately, Flamsteed discovered some errors in his measurements, which he later traced to the north end of his meridian wall sinking.

With the improved mural arc, Flamsteed "calculated and formed a catalogue of the fixed stars, containing the places of 3000 of them, with all the requisites relating to them." This was two years after Newton, a frequent correspondent, had published his Principia.

Over the next several years Flamsteed measured the positions of many more stars, though he interspersed a lot of lunar and planetary measurements and had a falling out with Newton, who requested many measurements of the moon's position in order to improve his lunar theory. Flamsteed became worried that Newton was taking advantage of him.

As the number of pages of the catalogue exceeded 1400, the expense of printing it was recommended to Prince George instead of the Royal Society of which Flamsteed was a member and Newton was the president. After a lot of wrangling the first sheet of Flamsteed's catalog, now known as the British Catalogue, was printed in May 16, 1706. The first printing was fraught with errors. Finally a corrected and enlarged catalogue was printed in December of 1712.

The value of Flamsteed's catalog was in determining the "true obliquity of the ecliptic", as well as the "inequality of the earth's motion". (Baily 1835)

9. Lacaille

The French observer Nicolas Louis de Lacaille was born in France in 1713. In 1750, he traveled to the Cape of Good Hope in South Africa. He named many of the southern constellations, using modern names such as Telescopium (the telescope) and Circinus (the compass). He published a catalog of 9766 stars called *Coelum Australe Stelliferum* (Southern Sky Star Catalog) in 1742. He is also known for discovering many southern nebulae and clusters. He died in 1762. (Hawaiian Astronomical Society 2003)

10. Piazzi

In 1792 the Catholic priest Giuseppe Piazzi undertook the precise determinations of the coordinates of the fixed stars. He worked at the project for ten years and published *Praecipuarium Stellarum Inerrantium* in 1803 in Palermo. It was the most precise catalog to date, with each of 6748 stars measured repeatedly. He used equipment built by Ramsden of England and completed in August 1789. The equipment included a five-foot vertical circle for readings in altitude by two microscopes. Palermo was at the time the southernmost observatory in Europe, and had favorable conditions for astronomical observation. Piazzi catalogued nearly 8000 stars. (Watbooks 2003)

11. Baily

Francis Baily's *General Catalogue of 8377 Stars* published by the British Association for the Advancement of Science in 1845. Also known as the B.A.C., the catalogue "hs constituted the first and last attempt of this kind to collate the results of meridian-observations upon the stars in a large and comprehensive way" (Boss 1910). The catalogue was widely used by astronomers for the next fifty years. Smaller catalogs proliferated over that time, but nothing comprehensive.

12. Fundamental Catalogues

In star catalogues, the positions of the vast majority of stars are measured relative to a lesser number of fundamental stars. The absolute positions of the fundamental stars are measured carefully using transit circles at different observatories. Often the stars are measured many times to reduce random errors. The observatories then compare their measurements and seek to eliminate any systematic errors.

Observatories that have specialized in absolute positions include Royal Greenwich Observatory, the US Naval Observatory, the Royal Observatory, Cape of Good Hope, and Pulkova Observatory. (Moore 1987)

The first fundamental catalogue or FundamentalKatalog was prepared by A. Auwers and published in 1879 and 1883. (ibid.) That was the beginning of a series that extends to the current fifth edition, the FK5. The second one, Neuer Fundamentalkatalog was published by Astronomisches Rechen-Institut of Heidelberg in 1907 and covered epochs 1875 and 1900.

12.1. FK3-FK5

The *Dritter Fundamentalkatalog des Berliner Astronomischen Jahrbuchs* or FK3 was published in 1937 and covered epochs 1925 and 1950. (ARI 2001) The author was A. Kopff.

FK4 was published in 1963 by Fricke and Kopff and contains 1535 stars.

FK5 was published in 1988 for epoch J2000 by Fricke et al. It provides improved positions and proper motions for the 1535 stars in FK3 and FK4. Several systematic and individual corrections were made relative to FK4, and the FK5 introduces the IAU(1976) system of astronomical constants. It contains data from some three hundred star catalogs around the world.

13. B.D.

Between 1859 and 1886, Friedrich Wilhelm Argelander and his students in Bonn, Germany, published the huge star catalog known as the Bonner Durchmusterung Des Nördlichen Himmels (Bonn Examination of the Northern Sky) or B.D. It gave the positions and estimated visual magnitudes of 457848 stars, complete to magnitude 9. (Küstner 1903). He was assisted by E. Schönfeld and A. Krüger. The B.D. covered declination zones +89 to -1 degrees. The instrument used was the 78 mm Bonn telescope equipped with a transit line, a wire visible in the eyepiece. Some stars dimmer than magnitude nine were recorded, some fainter than 10. Positions are given to the nearest 0.1 arc second in right ascension and 0.1 arc minute in declination. (Russian Academy 1998). The B.D. was first published by Argelander in 1859-1863, then republished by Küstner in 1903, Becker in 1951, and Schmidt in 1968.

(please bear with me on this, the German is very old and technical and was hard to translate by a native speaker)

"The first band contains the stars 2° through 20° declination for Epoch 1855 under cooperation of E. Schönfeld and A. Krüger from "the Royal Observatory of Bonn observed and calculated by F. Argelander, Director of the Observatory."

The second edition has a better printing than the first, with corrections made "with a quill pen", and larger print. Herr Ristenpart of the Berlin Academy made the numerical corrections. (Küstner, 1903)

The observations were made in an observatory in Bonn paid for by Friedrich William of Prussia. The refracting telescope used for the observations in now in the lobby of that observatory. The B.D. did not contain proper motions, but had more refined magnitude estimates than previous catalogues.

• Meridian Telescopes

A meridian telescope is one confined to move only in one axis from north to south along the meridian. The precise time that a star crosses the crosshair in this telescope is used to determine its position in right ascension. The declination can be determined from the altitude of the instrument at the time of the crossing.

13.1. Sudlich Durchmusterung

Schönfeld, one of Argelander's assistants, surveyed the stars in the southern hemisphere creating the Sudlich Durchmusterung (SD) catalog. Both the BD and SD give positions to 0.1 arc second in R.A and 0.1 arc minute in declination. The SD reaches approximately magnitude 10. He wanted to correct the catalogues made by Lacaille and Lalande. He was looking for parallax, comparing the positions of stars to see which ones were near and which were far.

13.2. Cordoba Durchmusterung

A similar effort in the southern hemisphere was undertaken by J. M. Thome but he died in 1908 before it was completed. The Córdoba Durchmusterung (Co. D. or just CD) contains 578802 stars to the tenth magnitude measured at the National Observatory of Argentina. It was compiled between 1892 and 1914 but not published until 1932. (Perrine 1932)

The German Astronomical Society later remeasured the brighter stars of the B.D. with meridian telescopes and created the catalog known as the Astronomische Gesellschaft or A.G. The A.G. was published between 1890 and 1910.

Stars in the BD are divided into declination strips one degree wide then serially numbered from west to east by right ascension. Vega is "BD+38° 3238 or the 3238th star in the strip at 38° north.

The CD stars are similarly numbered, Canopus being CD-52°914. Sometimes the two catalogs are combined and given numbers starting with DM.

13.3. Cape Photographic Durchmusterung (CPD)

David Gill and J. C. Kapteyn produced the Cape Photographic Durchmusterung in 1896 for the equinox 1875. The catalogue was produced in three volumes and reached from -18° to -90°. (Gill & Kapteyn 1896) It contained 454875 stars.

The catalogue has an interesting history. In the course of photographing a comet in 1882, David Gill at the Cape Observatory in South Africa hit on the idea of photographing the sky and thus making a star catalogue. He applied for a grant from the Royal Society and began his work in 1885. J. C. Kapteyn became interested in the project and took on the task of measuring the plates and cataloging the stars. It was recognized that photographic magnitudes would be different from visual magnitudes. The camera used for the work was called a rapid rectilinear Dallmeyer lens, of six inches aperture and 54 inches focal length (f/9). A smaller telescope was used for guiding.

The work was really groundbreaking in that a lot of new methods had to be developed for obtaining good results. Several different emulsions were tried, and on each one a series of exposures were taken to compare to plates taken with previous emulsions. The emulsions were coated on glass plates. Each area was photographed at least twice, so that stars could be differentiated from dust specks on the plates. Star magnitudes were derived from the diameters of the images on the plates. A special apparatus was designed by Kapteyn whereby the readings from the plates were directly in spherical coordinates. Comparisons of selected stars were made with previous meridian telescope measurements to determine the baseline for star positions.

14. Carte du Ciel

A whole-sky photographic atlas was proposed in 1887 in Paris. The project was to involve 18 observatories around the world. Technical and administrative problems interfered and the project got off to a slow start. Meanwhile technical advances occurred that made the original plan obsolete.

The goal was to measure the positions of all stars to the eleventh magnitude with an accuracy of half an arc second. The observatories were all to use the same type of telescope. The plates covered 2 degrees square, with an overlap pattern causing each area to be photographed twice. The sky was divided into zones which were assigned to the participating observatories. Decades passed, with some observatories not completing their assigned zones. (USNO 2003)

The Astrographic Catalogue completed in 1958 lists stars to the 11th magnitude.

15. Greenwich Catalogues

The Royal Observatory at Greenwich published numerous catalogues of stars over the years, made with the transit circle located there. In particular the *Greenwich Second Nine-Year Catalogue of Stars for the Epoch 1900.0* contains observations made with the transit circle from 1897 to 1905. (Christie 1909). That catalogue was divided into two sections, Fundamental and Zodiacal Stars, and Astrographic Reference Stars for the Greenwich Section. The first section contained Greenwich clock stars, some stars of interest to nautical navigation, and some miscellaneous stars. The second section of the catalog includes all stars down to ninth magnitude that had been assigned to the Greenwich observatory as part of the Carte du Ciel.

Stars within 15° of the pole were recorded with a chronograph and transit micrometer. Lower stars were observed “chronographically in the usual way” (ibid.).

In 1924 another catalog was released called First Greenwich Catalogue of Stars for 1925.0, containing 2643 stars observed at Greenwich from 1915 to 1921 under the direction of Sir Frank

Watson Dyson, Astronomer Royal (Dyson 1924). The star positions were reduced to epoch 1925.0 in accordance with a resolution of the International Astronomical Union. In this catalogue, "Before the observations for this catalogue were commenced, an impersonal micrometer moved by hand was substituted for the "tapping" system previously employed". (ibid.). This apparently an effort to remove some systematic error. Prior to this a "Personal Equation" was applied to each observer to take into account that observer's delay between seeing a star cross the wire and his tapping of the chronograph. The moving wire of the micrometer system reduced these personal equations to essentially zero. The value of repeating observations is this sort of incremental improvement in accuracy from one catalogue to the next.

16. AGK

The "Katalog der Astronomischen Gesellschaft" (Catalog of the Astronomical Society) First Section contains stars down to the ninth magnitude from 80° North to 2° south declination. It is valid for epoch 1900. It was observed at the observatory of Berlin. It contains 8468 stars. (de Ball)

The Reason for the catalog

Observatory Dorpat took over an observing program in bands 17, 18, 19, and 20 and observed for many years but never completed them.

The A G attempted to make a catalog in 1875, but didn't complete it. First, not all of the stars were previously measured twice. Second, the machinery didn't work right, and Third, some measurements of the BD were unreliable, and finally, half the reductions of the band 17 and band 19 were unreliable. (ibid.)

The instrument used was a seven inch meridian circle made by Pistor and Martinsschen of the Berlin observatory with a magnification of 230. The telescope was outfitted in 1905 with a manual micrometer by Repsold and a declination micrometer.
The second Katalog der Astronomischen Gesellschaft (AGK2) was recorded on photographic plates in 1928 in Bonn and Bergedorf.

16.1. AGK3

The AGK3 was planned to repeat the 1939 photographic plates from the AGK2 using the same plate centers and the same camera. (Dieckvoss & Heckmann 1975) From 1956 to 1963 or 1964, the nearly two thousand plates of the AGK2 were re-taken with the same plate centers and the same camera.

By repeating the same plates with the same optics it was hoped that extraction of proper motions between the epochs of the AGK2 and AGK3 should be easy. Reference to standard stars measured with meridian circles would give absolute accuracy to the effort. There were indications, however, that the optics of the cameras at Bonn and Bergedorf had changed, so a technical study had to be run.

The photographic plates used in this and other surveys are actually made of glass, with an emulsion coated on them. Long after the rest of the photographic world had switched from glass plates to plastic film, observatories stayed with plates because of their dimensional stability. Locations of stars on these plates are measured to resolutions of about a micron, so the stability of glass plates is essential.

Plates were measured with a microscope attached on a screw-driven axis. In 1958 the operation of determining proper motions was computerized. Prior to that the calculations were done with desk calculators. The advent of computers allowed for considerably greater data processing and led to the decision to compute absolute positions in addition to proper motions, eliminating many of the absolute position errors that were inherent in the AGK2 data.

The catalogue contains positions and proper motions north of 2.5° declination.

17. Yale Bright Star Catalog

The Yale Bright Star Catalog (BSC) contains 9096 stars brighter than magnitude 6.5. It initially contained 9110 objects at its original release in 1908, but some objects have been found to be novae or extragalactic objects. Its latest edition cross references other catalogs and contains equatorial and galactic coordinates, proper motions, UBVRI photoelectric data, Morgan-Keenan (MK) spectral types, and other information such as double star separation and magnitude differences, and variability. The catalog is now in its fifth edition published in 1991 and is available online. (ADC)

The catalog began life in Harvard Annals, Vol. 50, 1908. Hoffleit (1964) attributes the first edition of the catalogue to E.C. Pickering's *Harvard Revised Photometry*, and F. Schlesinger "who increased its scope and value in his first edition of the more comprehensive Bright Star Catalogue." The second edition was published in 1940, and the third edition in 1964. For a while it was called the Harvard Revised (HR) catalog before Yale took it over. Between the second and third editions, spectral classes on the Morgan-Keenan system were added for 40% of the stars.

The General Catalogue of Radial velocities published in 1953 added new information on star motions in a direction perpendicular to proper motion for 6404 of the stars. And in 1953 Louise Jenkins published her General Catalogue of Trigonometric Parallaxes, which gave distance information for 30% of the stars. (Hoffleit 1964)

The data for the third edition were entered onto punched cards and processed with IBM computers. The availability of computer processing allowed for greater statistical analysis of the star populations, compared to previous star surveys. The catalogue was made available in three forms: printed, on computer tape, and on punched cards. Data on each star included its BS number, same as its HR number, Bayer or Flamsteed designation, DM number, HD number, Boss General Catalogue number, other catalog numbers, right ascension and declination for 1900, galactic longitude and latitude, right ascension and declination for 2000, visual magnitude, UVB color, spectral class, annual proper motions, parallax, radial velocity, and double star information. Note that no new observations were taken for a catalog. It was yet another compilation of data from other catalogues.

Why only bright stars? These stars hold the most interest, being visible, and they have the best data. No single research purpose was driving this catalogue as drove Boss' or Draper's, but such a catalogue is generally useful for a wide variety of research purposes. For example, by sorting techniques, one could find a range of radial velocities from the BSC, then go to the source catalogs for more information on just those stars.

18. Preliminary General Catalogue

Lewis Boss at the Dudley Observatory in Albany New York produced the *Preliminary General*

Catalogue of 6188 Stars in 1910 (Boss 1910). This catalog appears to be a compilation from previous catalog with no new observations made. "The General Catalogue of 6188 stars herein contained is the result of an attempt to deduce for those stars the most accurate positions and motions that are readily attainable from the means at command. Computation of the motions has been the primary aim of this work."

The work was financially supported by the Carnegie Institution. Even without the obvious expense of obtaining new observations, compiling a catalog of this type is a major undertaking. The computational work in recognizing and removing systematic errors from previous catalogs is tremendous. Boss felt that there did not exist at the time a comprehensive reliable catalog since the publication of the *General Catalogue of 8377 Stars by Francis Baily* in 1845. And that catalogue did not provide reliable measurements of proper motion.

Boss argued that the proliferation of meridian observations in the late 1800's precluded the construction of a new comprehensive catalog of star positions. Any such catalog would be quickly out of date. But the same proliferation of observations made the time ripe for a catalog primarily devoted to star motions.

Boss concentrated his catalogue on the visible stars on the belief that these stars are of the greatest general interest and in general are closer and exhibit the greatest proper motions. He also included 2158 stars fainter than sixth magnitude for which accurate measurements were obtained before 1850. These stars were capable of providing very accurate proper motions.

Many years prior to this work, a general plan was formed at Dudley Observatory "for a critical discussion of the motions of all stars to which have been attributed, with reasonable probability, motions as great as 10” per century.” (Boss 1910). It was important that the work be comprehensive, not fragmentary. At this time in history, our place in the galaxy was not yet well known, and it was not known that other galaxies existed besides our own.

The comprehensive catalogue was compiled by consulting some eighty previous catalogues dating back to Piazzi’s of 1800. For each of these the systematic errors had to be removed.

18.1. Albany Zone Catalogues for the Epoch 1900

A later effort of Lewis Boss was the Albany Zone Catalogues. Boss measured 8276 stars between 20° and 41° south declination and his collegue Arthur Joy measured 2800 stars between 2° south and 1° north. The observations were completed by 1906. (Boss 1918)

“The trend of the investigations accomplished by Professor Lewis Boss previous to undertaking this catalogue led him to believe that the time had finally arrived when it would be possible to determine stellar proper-motions with a sufficient degree of refinement to shed some light on the problems of the structure of the sidereal system and the determination of the motion of the sun in space”. (Boss 1918)

Boss’ ambitious plan was to combine observations taken by others with his own observations to determine these motions. He decided to break the large project into separate pieces and publish his results whenever they were of scientific value. “Because of the magnitude of the undertaking, in the formulation of plans he was governed by two rules: first, that the program of work should be organized into distinct, successive steps, in such a manner that each should contribute to the problem sufficient in value to warrant the undertaking of it in and for itself; second, that he

should not in advance promise to accomplish more than one of these steps." (Boss 1918)
Boss began observing stars in the zone from 20° to 41° south declination, for the most part reaching to the eighth magnitude. He finished observing around 1906 but was not able to publish his results due to lack of funding until 1918 when Carnegie Institution picked up the cost. Arthur Roy observed stars in the zone -2° to +1°. All the observations were made with the Olcott Meridian Circle. This instrument has eleven threads, five on each side of a central one at distances up to twenty arc seconds. The distances from each side thread to the central thread were carefully determined to a precision of 0.1 arc second. Then stars were watched as they crossed the threads: "Transits, except of close circumpolar stars, were usually taken with the aid of the chronograph over the 11 threads and the mean of the 11 threads was used as the zero of reference." (ibid.). Comparing the positions of the stars in these measurements with positions from previous catalogs, the proper motions were determined. For each star in the catalog, the following were recorded: name, magnitude, right ascension (1900), precession and variation, declination, precession in declination and variation, epoch, and the number of observations taken of that star.

18.2. San Luis Catalogue

This catalog comprises 15333 stars for the Epoch 1910 observed from San Luis, Argentina. It was created through the joint efforts of the Carnegie Institution of Washington and the Dudley Observatory at Albany, New York. (Boss 1928)

The originator of the program was professor Lewis Boss, who wanted to produce a catalog of positions and proper motions for all stars brighter than magnitude 7.0. At this time astronomers were trying to determine our place in the galaxy, and there was a great need for large samples of proper motions. Lewis Boss planned a program to observe from both northern and southern observatories nearly simultaneously in an effort to reconcile the discrepancies found in previous catalogs. What was needed was a system of reference stars reaching from pole to pole. Boss' plan was to use the same instrumentation and the same observers to further eliminate variables. The observing sites chosen were San Luis, Argentina, and Albany, New York.

The San Luis site was chosen as a result of the adverse report given by professor W. J. Hussey who was looking for a site in Australia. The meteorological office of Argentina recommended San Luis for its lack of clouds. An observatory was built starting September 1908 and was ready to use in April 1909. The instrumentation previously used in Albany was moved there and set up. 87000 observations were taken in less than 22 months.

The instruments included the Olcott Meridian Circle. This telescope was built in 1856 by Pistor and Martins and has and aperture of 20.3 cm and a focal length of 3 meters. The objective was refigured by Alvan Clark and Sons. This type of telescope is mounted so it can only look along the meridian. The eyepiece has several vertical wires for determining when a star crosses the meridian, and a horizontal wire for determining its elevation.

The other essential instruments were a pair of clocks for keeping track of sidereal time. The moment a star crosses the meridian is noted and that is its right ascension.

For measuring magnitudes, a telescope was used that included an artificial star whose brightness could be controlled with a rheostat. During an evening's observations, the system was calibrated using Harvard comparison stars. The observer would adjust the rheostat until the artificial star and the unknown star had same magnitude, then the voltage of the rheostat was read. Each star was thus measured twice, with a precision of ± 0.08 magnitude.

18.3. Albany Catalog

The Albany Catalog of 20811 stars for Epoch 1910 was the "second step in the general program which when completed, will furnish positions and motions of some 30000 stars distributed over the sky from pole to pole." (Boss 1931). It is a continuation of the work started with the San Luis catalog. Again with the help of the Carnegie Institution, which by now had formed the Department of Meridian Astrometry, the Dudley Observatory completed the work.

After the observations had been made for the San Luis catalog, the instruments were moved back to Albany, New York. "The program of observation adopted at Albany was essentially that followed at San Luis" (Boss 1931).

All the stars brighter than magnitude 7 not observed from San Luis were observed from Albany, as well as selected stars dimmer than magnitude 7 that were in the General Catalogue. Fundamental stars, those to which the other stars are compared, were measured in common with the measurements taken at San Luis for intercomparison.

Note that this catalog was completed by a Benjamin Boss. His relation to Lewis Boss is unclear, but he took over as director of the Department of Meridian Astrometry in 1912.

19. Henry Draper Catalog

"In the development of any department of Astronomy, the first step is the accumulate the facts on which its progress will depend." (Cannon & Pickering 1918). That is how Edward C. Pickering, director of the Observatory of Harvard College begins the Henry Draper Catalog.

By the late 1800's it was recognized that stars had different spectra. "A few years ago, astronomers learned that many properties of the stars depend on the class of their spectra" (ibid.). Photographing stars through a prism spreads their light according to wavelength, and the resulting spectra contain absorption lines. "It was shown in May, 1885, that by placing a prism in front of the objective of a photographic telescope, excellent spectra could be obtained of all the stars of sufficient brightness in the field of the instrument" (ibid.). This is called an objective prism. The telescope is driven at a rate slightly different from sidereal in the axis perpendicular to the prism's spreading in order to broaden the line spectra into bands. The absorption lines tell physicists what atoms and molecules are present in the star's atmosphere. The spectra also tell physicists about the temperature of the star. The first stellar spectrum photograph was taken by Henry Draper in 1872.

Henry Draper was a doctor and amateur scientist in America. He had interest and experience in scientific photography, and spent a year abroad where he visited Lord Rosse's observatory, home to the world's largest telescope, the Leviathan. He returned and promoted and furthered astronomical photography. He died young and his wife established the Henry Draper Memorial to support photographic research in astronomy. The Memorial funded the Henry Draper Catalog at Harvard College.

The Henry Draper Catalog contains spectral classifications for 225300 stars. Annie Jump Cannon, Curator of Astronomical Photographs and Edward C. Pickering, Director of the

Observatory are its authors. It is Volumes 91 through 99 of the Annals of the Astronomical Observatory of Harvard College. It was published between 1918 and 1924.

Cannon invented the classification of spectra used in the catalog, also known as the Harvard classification based on some previous but more complicated systems. This is the now-familiar sequence in decreasing temperature O, B, A, F, G, K, M. Each letter was subdivided into ten numerical classes. For example, A5 is halfway between A0 and F0. Cannon herself classified the spectra of the great majority of the stars. She started in October 1911 and finished September 30, 1915. Her rate of classification was phenomenal, reaching three per minute.

The northern hemisphere plates were taken with the eight inch Draper telescope at Cambridge. A similar telescope, the Bache, mounted at Arequipa, Peru, took the southern plates. (ibid.). Each telescope used an 8-inch Voightländer Portrait lens, corrected by Alvan Clark and Sons. The telescopes were fitted with prisms having angles of 13° and 5°. Different prism combinations were used (with correspondingly different dispersions) depending on the density and brightness of the stars being classified. For some of the plates, different telescopes were used.

While most stars fit into one of the aforementioned classes, there were exceptions. Some stars were so far from fitting in any class they were marked Pec for peculiar. In other stars, the normally sharp lines were diffuse. This was proven to be a peculiarity of the stars themselves and not the instrument when a plate was taken that included alpha Cygni, which is sharp, and alpha Aquilae, in which they are diffuse.   We now know that movement or magnetic fields can broaden absorption lines. Some stars even exhibited bright emission lines.

Each star in the Henry Draper catalog was listed with its DM, CD, or CPD number if it was in those catalogs. Stars in the HD catalogue are numbered sequentially by right ascension. Groups of stars with the same right ascension are ordered by declination, starting with the north. Vega is HD 172167. Also listed are photometric and photographic magnitudes.

19.1. Henry Draper Extension

Volume 100 of the Annals is known as the Henry Draper Extension, written by Cannon. It was released in 1925. The extension contains four thousand spectra from a plate taken with the 10-inch Metcalf telescope at Arequipa, Peru on September 7, 1923. These stars reach to almost magnitude 12. (Cannon, 1925) The HD contains only 514 stars in the same area.

19.2. Michigan Catalogue

In 1975 the University of Michigan Catalogue of 2-Dimensional spectra reclassified all the HD stars on the Morgan & Keenan (MK) system. This system is two-dimensional in that it divides stars both into luminosity classes and spectral type. (Houk 1975). "The stars were classified visually on objective-prism plates taken with the Michigan Curtis Schmidt telescope at Cerro Tololo Inter-American observatory." (ibid.). Houk herself did all of the spectral classifications, totaling 40235 independent spectra.

20. Cape Photographic Catalogue for 1950.0

By the middle of the twentieth century it was realized that the positions of the stars of the Astronomische Gesellschaft had gotten out of date and proper motions were not accurate enough to update them. "Schlesinger (of Allegheny Observatory) showed how the amount of labour required could be greatly reduced by the use of photography." (Jackson & Stoy 1954) The basic idea was to accurately measure a restricted number of standard stars from each photographic plate with a meridian circle, then measure the rest of the stars on the plate relative to those. With this technique as the plan, a new, photographic version of the AGK was planned. The outbreak of World War II delayed the work of the German and Russian observatories that were to observe the northern hemisphere. Yale University covered the zones from +30 to -30, and the Cape took the part from -30° to the south pole. This became known as the Cape Photographic Catalogue for 1950.

21. Apparent Places of Fundamental Stars

An ongoing effort started in 1941 is the annual publication of the *Apparent Places of Fundamental Stars* subtitled *Containing the 1535 stars in the Third Fundamental Catalogue (FK3).* This effort was started under the auspices of the International Astronomical Union. The first nineteen volumes were published by H.M. Nautical Almanac Office of the Royal Greenwich Observatory. From the twentieth volume onwards the task was taken over by the Astronomisches Rechen-Institut, Heidelberg. (IAU 1960). The positions of stars in these catalogs are computed, not measured.

22. Smithsonian Astronomical Observatory

In 1959 the Smithsonian Astronomical Observatory (SAO) started an effort to compile a computer-accessible star catalog for tracking artificial Earth satellites. The catalog was to include position and proper motions and cover the entire sky. Rather than re-observing the sky, the data were to be taken from previous catalogs and computer processed to Epoch 1950. For stars in catalogs without proper motions, comparisons would be made to previous catalogs to determine proper motion.

Proper motion of a star is really something that has been searched for for hundreds of years. After removing apparent motion of stars due to precession, over long periods of time stars are seen to move relative to the background stars as a result of their actual motion through the galaxy. Motion in the direction of our line of sight can't be seen in this way (red shift or blue shift reveals that) but the motion perpendicular to line of sight can be seen by comparing the positions of the star taken several years apart.

The catalog was made available to the general public, both in computer tape form, and in printed form. The printed form is in four parts while the tape form is available in eleven-word binary format and several other formats.

Fred L. Whipple was the director of the Smithsonian Astrophysical Observatory during the production of the catalog, which was released in 1965. Dr. George Veis acted as general supervisor. The catalog was partly funded by a grant from NASA. The catalog contains positions and proper motions for 258997 stars.

As previously mentioned, the SAO catalog is really a compilation of previous catalogs: FK4, FK3, GC, AKG2, AKG1, Greenwich AC, Yale, Cape, Cape Zone, ME 3, and ME 4. These catalogs were combined in a computer and duplicates were removed. The catalog gives positions and proper motions for nearly 259000 stars, with a standard deviation of 0.2 arc seconds.

Information for each star includes:

Assigned Number

Right Ascension and Declination for epoch 1950.0

standard deviation at epoch 1950.0,

right ascension and declination at the mean epoch of original observations

standard deviations of the above

mean epochs of the original observations

annual proper motions in right ascension and declination

standard deviations of the above

visual magnitudes

photographic magnitude

spectral type

Durchmusterung number

source catalog

star number from source catalog

explanatory notes.

With data coming from so many sources, systematic corrections had to be applied. For example, data from the Greenwich AC required a correction in right ascension dependent upon magnitude. Stars from catalogs with epochs other than 1950.0 were precessed to 1950. Proper motions were computed for the AGK 2 stars by comparing to the original AGK or Greenwich AC. Duplicates were carefully screened out by comparing positions and magnitudes. Stars were categorized by separating them into bands by declination then sorting by right ascension within the band. They are assigned six digit numbers.

Of the 258997 stars in the SAO catalog, 8712 are double and 499 are variable

23. Perth 70

This catalogue contains positions 24978 primary southern stars obtained by means of meridian observations by the Hamburg Observatory expedition to Perth, Australia from 1967 to 1972. (Torino 2003). Epoch is 1970. These measurements are accurate to 0.17 arc second, achieved by a novel photoelectric multislit micrometer.

24. Hubble Guide Star Catalog

This catalog was created to support the Hubble Space Telescope. (TDC) All telescopes, even the Hubble Space Telescope need guide stars to lock onto while photographing the sky. The HST uses pairs of guide stars in its off-axis guiders to maintain accurate alignment on its object of interest. The GSC was based on the Epoch 1982 Palomar Quick-V for objects north of +6° and the UK SERC J survey (Epoch 1975) in the southern hemisphere. The instruments used were the UK Schmidt Telescope at Siding Spring in Australia and the 1.2 m Oschin Schmidt Telescope at the Palomar observatory in California. A Schmidt telescope is a design that has an especially wide corrected field and a fast focal ratio. Schmidts are especially good for star surveys compared to narrow-field long focal length instruments designed for looking at single objects.

The Oschin plates were taken in the V (visual) passband, chosen for being similar to the passband of the HST's fine guidance sensor. The plates were taken between 1982 and 1984 by Charles T. Kowal. Due to the quickness with which the survey was taken, the plates are not of uniform quality.

The plates taken in the southern hemisphere came from the 1.2m Schmidt (similar to the Oschin) at Siding Spring. These plates were taken between 1975 and 1980 on hypersensitized Kodak IIIa-J emulsion and are deeper than the northern plates.

Some supplemental plates were taken with other instruments for the areas not covered by these two surveys.

The guide stars are in the magnitude range 6-15, and non-stellar objects are eliminated to prevent trying to guide on a fuzzy source. The catalog itself contains nearly 19 million objects, of which some 15 million are stars.

The sources of the catalog are photographic plates from Schmidt telescopes. It is an "all-sky, single epoch collection of Schmidt plates." (AJ 1990). The plates were digitized using microdensitometers to a resolution of 25 μm which works out to 1.7 arc seconds, and the features recognized by computer software. Guide stars are chosen by software called the Guide Star Selection System (GSSS). Interestingly, about 20% of the guide stars chosen turn out to be close binaries, something that can't be determined from the GSC, and is only recognized when the HST tries to lock onto them. These potential guide stars must be rejected.

A corrected version of the catalog, called GSC 1.1 was created using Hipparcos (see below) and Tycho data. Tools exist for finding data about each star. Corrections are needed because the original catalog goes out of date due to proper motions of the stars, many of which are not accurately known.

Entries in the GSC take the form GSC rrrrr nnnnn where rrrrr specifies the region and nnnnn specifies the ordinal number of the object within the region. There are 9537 regions. Each object in the catalog is classified as stellar or nonstellar. Its position in J2000 coordinates, its magnitude, and its error estimates are recorded and the photometric passband of the plate from which the entry came.

24.1 GSC-ACT Star Catalog

The GSC-ACT (Astrographic Catalog/Tycho) is an effort to recalibrate the GSC 1.1 using data from the US Naval Observatory.

The ACT catalog contains 988758 stars covering the entire sky and contains accurate proper motions for the majority of the stars in the Tycho catalogue (the satellite, not Brahe).

25. PPM Star Catalog

The Positions and Proper Motions (PPM) catalog covers 181731 stars north of 2.5 degrees southern declination for equinox and epoch J2000.0 (Röser 1991). "Its main purpose is to provide a convenient, dense, and accurate net of astrometric reference stars on the northern celestial hemisphere". (ibid.) It is a "representation of the FK5 system at higher star densities and fainter magnitudes". (ibid.) Previous AGK3 and SAO catalogs had gotten out of date, being based on the earlier FK4 system. Also, those catalogs did not have the ultimate accuracy promised by the PPM. Furthermore, those catalogs derived proper motions from only two sources. The PPM apparently uses a greater number of sources, and the redundancy increases the reliability of the measurements.

At the time of initial publication, the PPM did not cover the southern hemisphere, but that was added in 1992.

The PPM was a compilation effort. No new measurements were taken. The starting point was a magnetic tape version of the AGK3. To that were added the FK5 stars, to give the final list of 181731 stars. Several other catalogs were added in, with corrections of systemic and gross errors. A least-squares method was employed. The catalog was an effort of the Astronomisches Rechen-Institut of Heidelberg.

26. Hipparcos and Tycho

This satellite, whose name reminds us of Hipparchus, the first cataloguer of stars, was launched in 1989. The name is an acronym for *Hi*gh *P*recision *Par*allax *Co*llecting *S*atellite. The satellite measured parallaxes and brightness of more than a million stars. Parallax is the most direct method for measuring the distance to stars, and is the basis for all other astronomical distance measurements. The parallax of a star is a movement against the background stars seen as the observer moves from one side of our orbit around the sun to the other side. In the simplest case, the baseline of a triangle is a distance of 2 Astronomical Units (one AU is 93 million miles). The change in position of most stars is in the range of milliarcseconds, so special instruments and techniques are used.

Hipparcos was funded by the European Space Agency. It measured accurate distances to 118000 principal stars, down to magnitude 12.5 to a resolution of 1 milliarcsecond. After that it measured one million stars down to magnitude 11.5 with a resolution of 25 milliarcseconds. The two catalogues are called the Hipparcos Catalogue and the Tycho Catalogue. The two catalogues were released in June 1997. The mission of the Hipparcos satellite has since ended and in fact nearly ended before it began when one of the boosters of the launch vehicle failed, leaving the satellite in a highly elliptical orbit. Ground controllers worked around the orbit problems and made the mission a success.

The significant contribution of this satellite was a many fold increase in the number of stars whose position is known to an accuracy of one percent. Before Hipparcos only a few dozen stars were measured to such precision, but the satellite provided such measurements for more than 400 stars. This leads to refinements in the cosmic distance scale, and a vast improvement in the Hertzsprung-Russell diagram. (Turon 1998)

Another important measurement made by Hipparcos is photometric or magnitude measurement. Above the atmosphere and with special instrumentation, Hipparcos measured the magnitudes of 118000 stars to a resolution of 0.002 magnitude.

The satellite also measured positions of multiple star systems and magnitude curves of variable stars.

The Tycho catalog contains 1058332 stars, each measured 130 times during the mission to an accuracy of 25 milliarcseconds. (TDC)

27. 2MASS Point Source Catalog

2MASS stands for Two Micron All Sky Survey. This catalog was produced by the University of Massachusetts and the Infrared Processing and Analysis Center and funded by NASA and the National Science Foundation. It contains 470992970 objects and covers the entire sky. It was conducted using two 1.3m telescopes, one at Mt Hopkins, AZ and one at Cerro Tololo, Chile. The telescopes are highly automated and scanned the sky in three infrared bands. The catalog was released May 2, 2003. (TDC)

28. Representation of Stars in Various Star Catalogs

The star catalogs accumulate over time. The software program I use (Voyager III by Carina Software) lists the following names for Betelgeuse: Alpha Ori (Bayer), 58 Ori (Flamsteed), HR 2061 (Harvard Revised), SAO 113271 (Smithsonian) HD 39801 (Henry Draper), FK5 224 (FK), BDM +7 1055 (Durchmusterung), Hipp 27989 (Hipparcos).

29. Other Astronomical Catalogues

There have been literally hundreds of other star catalogs over the centuries, specializing in double stars, variable stars, ultraviolet stars, infrared sources, radial motions, and a host of other topics. Many of these specialty catalogues are subsumed into the major catalogues. See http://archive.eso.org/starcat/astrocat/astrocat_screen_list.html for an impressive list.

Throughout history, other types of catalogues have taken shape listing non-stellar objects such as Messier's Catalog and the NGC. Abell listed galaxy clusters, and Caldwell lists a lot of deep space objects. The largest non-stellar catalog is the ongoing Sloan Digital Sky Survey, which is concentrating on measuring position and redshifts of galaxies and quasars.

30. Summary

We've seen a sampling of star catalogues through history. As they have occurred, obviously the technology for measuring star positions has evolved greater precision. The general trend is for larger and larger catalogues. Here is a summary of catalogues:

Catalog	Observer	# Stars	Published
Rhodes	Hipparchus	1025	-127
Almagest Star Catalog	Ptolemy	1028	150
Zij-i Sultani	Ulugh Beg	992	1437
Astronomiae instauratae...	Tycho Brahe	777	1592
	Bayer		1603
Rudolphine Tables	Kepler	1000	1627
Catalogus Stellarum Fixarum	Hevelius	1564	1690
British Catalogue	Flamsteed	2866	1712
Coelum Australe Stelliferum	Lacaille	9766	1742
Praecipuarium Stellarum Inerrantium	Piazzi	6748	1803
FK		1535	1879
Bonner Durchmusterung	Argelander	457848	1886
Cordoba Durchmusterung	Thome	578802	1932
Carte du Ciel		1958	1887
Cape Photo Durchmusterung	Gill & Kapteyn	454875	1896
Greenwich			1900
AGK		8468	1900
BSC-HR		9096	1908
PGC	Boss	6188	1910
Henry Draper	Pickering, Cannon	225300	1918
SAO	Smithsonian	258997	1966
Perth 70		24978	1970
Hubble GSC		15000000	1990

PPM	181731	1991
Hipparcos	118000	1997
2Mass Point Source	470992970	2003

Table 1. Summary of Star Catalogues

But the more interesting story is how scientific thinking has evolved. Man's view of the universe changes with time and the questions he asks change. The reason behind most of the star catalogs was to verify or disprove the contemporary world view. Early astronomers from Hipparchus to Ptolemy and Beg wanted to know whether the positions of the stars changed, and found that to a first approximation they didn't, except for precession. Astronomers then became interested in the motions of planets and needed much greater precision in the measurement of the fixed stars against which the positions of the planets could be measured. These measurements led to the adoption of the Copernican system.

Another reason to compile star catalogs in ancient times was the search for parallax. Astronomers were looking for small movements among the stars that would tell how far away they were. Such movement is small, though, with a maximum of 0.75 arc second, and would have to wait hundreds of years to be seen.

Along the way, it was discovered that stars move relative to each other, that they exhibit proper motion. The change from an Earth-centric point of view with changeless heavens to a view of the Earth being a small part of a changing universe was complete.

Practical questions relating to navigation also pushed astronomers to greater levels of precision both in measuring position and in measuring time. The huge catalogs of the 1800's started. Also catalogs began to cover both the northern and southern hemisphere as Australia, Africa, and South America were settled by Europeans.

The rise of astrophysics led to questions about the composition of stars. Spectroscopy took a major step forward in the Henry Draper Catalogue.

A new tool entered the arsenal. With the introduction of astrophotography, huge and very deep catalogues could be constructed with much less effort than manual measurement. Carte du Ciel, however, was a case in point of how too much ambition can lead to failure.

Several catalogues incorporated proper motion, driven by the desire to know how the stars around us moved, possibly leading to discovering the place of our sun in the galaxy. Proper motion measurements also provided a way to increase the longevity of catalogs. By knowing the direction and speed of each star, its position could be calculated well into the future.

The rise of computers in the middle of the twentieth century revolutionized star catalogues. Calculations could be applied to hundreds of thousands of stars, an impossible feat in the days of manual calculation. Huge compilation catalogues arose, and automated searches could be implemented.

The space age is driving the current generation of star catalogs, both the technology push created by the demands of the Hubble Space Telescope and the need for other navigational catalogues; and the technology pull of the Hipparcos satellite which provided a quantum leap in the precision of star measurements.

So star catalogues are in a push-pull relationship to science and technology, and will probably remain so for the forseeable future.

References

ADC (Astronomical Data Center), no date given, *Astronomical Catalouges*, http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/5/5050/

ARI (Astronomisches Rechen-Institut Heidelberg) 2001, *Database of publications of the institute*, http://www.ari.uni-heidelberg.de/publikationen/vbe/vbe054/vbe054.htm

Baily, F., 1835, *An Account of RevD John Flamsteed, the first Astronomer-Royal* (London, Lords Commisioners of the Admiralty, reprinted 1966, London, Dawsons of Pall Mall)

Boss, B. 1931 *Albany Catalogue of 20811 Stars for the Epoch 1910* (Washington, D.C., Carnegie Institution of Washington)

Boss, L., 1910, *Preliminary General Catalogue of 6188 Stars for the Epoch 1900* (Washington, D.C., Carnegie Institution of Washington)

Boss, L., 1918, *Albany Zone Catalogues for the Epoch 1900* (Washington, D.C., Carnegie Institution of Washington)

Boss, L. & Boss, B, 1928, *San Luis Catalogue of 15333 Stars for the Epoch 1910* (Washington, D.C., Carnegie Institution of Washington)

Cannon, A., 1925, *The Henry Draper Catalog Extension*, Annals of Harvard College Observatory, Vol 100 No. 1. (Massachussetts, Harvard College)

Cannon, A., and Pickering, E., 1918, *Henry Draper Catalog*, Annals of Harvard College Observatory, Vol 91-99 (Cambridge, Massachussetts, Harvard College)

Christie, W. H. M, 1909, *Second Nine Year Catalogue of Stars for the Epoch 1900.0* (Edinburgh, His Majesty's Stationery Office)

Dieckvoss, W and Heckmann, O., 1975, *AGK3* (Hamburg-Bergedorf, Hamburger Sternwarte)

Dreyer, J., 1917 *On Tycho Brahe's Catalogue of Stars*, *The Observatory* 40 (1917), pp. 229-233

Dyson, F.W.D, 1924, *First Greenwich Catalogue of Stars for 1925.0* (London, His Majesty's Stationery Office)

Engelmann, W, 1910, *Katalog der Astronomischen Gesellschaft* (Leipzig)

Flammarion, C., 1964, *The Flammarion Book of Astronomy*, (Simon and Schuster)

Gill, D. and Kapteyn, J. C., 1896, *The Cape Photographic Durchmusterung for the Eqinox 1875* (London, Her Majesty's Stationery Office)

Grasshof, Gerd, 1990, *The History of Ptolemy's Star Catalogue* (New York, Springer-Verlag)

Hawaiian Astronomical Society 2003, *Deepsky Atlas*, http://www.hawastsoc.org/deepsky/cir/

Hoffleit, D., 1964, *Yale University Observatory Catalogue of Bright Stars* (New Haven, Yale University)

Houk, N and Cowley, A, 1975, *University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars*

Illingworth, V., 1979, The Facts of File Dictionary of Astronomy (New York, Facts on File)
Vila-Echagüe, E, Almagest Star Catalogue for Guide Users
http://www.projectpluto.com/almagest.htm, August 2000

IAU (International Astronomical Union), 1960, Apparent Places of Fundamental Stars 1961, Heidelberg, Astronomisches Rechen-Institut

Jackson, J., and Stoy, R. H., 1954, Cape Photographic Catalogue for 1950.0, Annals of the Cape Observatory Volume XVII (London, Her Majesty's Stationery Office)

Knobel, E.B. 1917, Ulugh Beg's Catalogue of Stars (Washington, Carnegie Institution)

Küstner F., 1903, Second Edition, Bonner Durchmusterung Des Nördlichen Himmels (Bonn, A. Marcus und E. Weber's Verlag)

Kusukawa, S., 1999, Kepler and Astronomical Tables,
http://www.hps.cam.ac.uk/starry/keplertables.html

MacTutor, 2003, Ulugh_Beg, http://turnbull.dcs.st-and.ac.uk/history/Mathematicians/Ulugh_Beg.html

Moore, P., 1987, International Encyclopedia of Astronomy (New York, Orion Books)

Perrine, C. D., 1932, *Resultados del Observatorio Nacional Argentino* Vol 21. (Córdoba, Observatorio Nacional Argentino)

RMSC (Rochester Museum & Science Center) 2002, *Star Names*, http://www.rmsc.org/planetarium/qandi/snames.htm

Röser, S & Bastian, U., 1991, *PPM Star Catalogue*, (Heidelberg, Spektrum Akademischer Verlag)

Russian Academy of Sciences, 1998, *Bonner Durchmusterung*, http://www.asc.rssi.ru/mdb/stars/1/1122.htm

Smithsonian Institution, 1966, *Smithsonian Astrophysical Observatory Star Catalog* (Washington DC, Smithsonian Institution)

TDC (Telescope Data Center) *HST Guide Star Catalog*, http://tdc-www.harvard.edu/software/catalogs/hstgsc.html

TDC (Telescope Data Center) *Hipparcos Tycho Catalog*, http://tdc-www.harvard.edu/software/catalogs/tycho.html

TDC (Telescope Data Center) *2MASS Point Source Catalog*, http://tdc-www.harvard.edu/software/catalogs/tmpsc.html

Torino 2002 *PERTH70*, http://www.to.astro.it/astrometry/Astrometry/DIRA2/DIRA2_doc/PERTH/PERTH70.HTML

Turon, Catherine, 1998, *From Hipparchus to Hipparcos*, http://wwwhip.obspm.fr/hipparcos/SandT/hip-SandT.html

UIUC 2000, *Star Names*, http://www.astro.uiuc.edu/~kaler/sow/starname.html

USNO 2003, *USNO AC 2000 Home Page*, http://ad.usno.navy.mil/ac/ac.html

Univ. Washington, 2003, *Samarkand: Ulugh Beg's Observatory* http://depts.washington.edu/uwch/silkroad/cities/samarkand/obser.html

Volkiff, I., 1971, *Johannes Hevelius and his Catalog of Stars* (Provo, Utah, Brigham Young University Press)

Watbooks (W. P. Watson Antiquarian Books) 2003, *Piazzi, Giuseppe...*, http://www.polybiblio.com/watbooks/2022.html

Watbooks (W. P. Watson Antiquarian Books) 2003, *Brahe, Tycho* http://www.polybiblio.com/watbooks/2129.html