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Mutual Events of the Galilean Satellites of Jupiter • Campaign 2021

Dear reader,

in this issue of *JOA* our authors present an important observational project (PHEMU) and review GRAZE-observations that have occupied us for decades on the occasion of a successful expedition. We look back on our recent ESOP and with the early observations with the telescope we have again a look into the history of our branch of astronomy. In the series "Beyond Jupiter", which has been running since spring 2016, this issue also presents another interesting celestial body. So, everything is as usual? Unfortunately, no, because the COVID-19 restrictions also influence our work: We are restricted in expeditions, cannot realize some meetings and had to organize and conduct our ESOP as an internet conference. The new communication steps required for this were complex and we would like to thank everyone who helped. Especially we would like to thank the donators who supported our ESOP:
(In alphabetical order) K.-L. Bath, Philip Denyer, Filipe Dias, Andreas Dill, Patrick Ditz, Esdert Edens, Leonard Entwisle, Timothy Haymes, Adrian Jones, Simon Kidd, Mike Kretlow, Michael O' Connell, Georg Piehler, Roman Prague, Alex Pratt, Robert Purvinskis, Thomas Rolfes, Joan Rovira Picanol, Antoni Selva Diaz, Bruno Sicardy, Peter C. Slansky and Serge Vasseur.

Have fun with reading the JOA, enjoy the occultation astronomy and stay healthy.

Konrad Guhl

Konrad Guhl
President of IOTA/ES

COVER

The cover presents the table of mutual events of the Galilean satellites of Jupiter for a geocentric position calculated by IMCCE for the upcoming observation campaign of 2021. On 2021 March 9 Europa will occult Callisto. Jupiter's satellite Io is located at a distance of only 2.9 arcsec from Callisto at the mid-time of the occultation at 03:33:16 UT. North is up and east to the left in the graphic on the cover.
Graphic: O. Klös, made with data from IMCCE and Project Pluto's GUIDE 9.1

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In this Issue:

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Journal for
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The Campaign of Observation of the Mutual Occultations and Eclipses of the Galilean Satellites of Jupiter in 2021

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ABSTRACT: The goal of this paper is to emphasize the next campaign of observations of the mutual events of the Galilean satellites of Jupiter in 2021. These phenomena occurring during the equinox on the giant planet are worthwhile observing. Past experience has shown the interest of such observations due to their relevant contribution to improve the dynamical models of natural planetary satellites. Such observations have been made for decades through a network of amateur astronomers and provided particularly accurate data, better than all the other ground-based observations. Using the best ephemerides of the Galilean satellites, we calculate the next phenomena to occur in order to prepare the future observational campaign. We provide in this paper the tools to get the dates of the next phenomena and their observational conditions. We explain also how these photometric observations should be made in order to allow a reduction providing highly accurate data.

Introduction

The observation of occultations in the Solar system brought valuable information for the knowledge of moving objects, small bodies as well as large planets, allowing to analyze atmospheres, to measure sizes and to detect double or triple objects. A special mention should be made of the natural planetary satellites, especially the Galilean satellites of Jupiter. These objects present occultations and eclipses by the large planet Jupiter almost every day because of their fast motions. They were extensively observed for modelling their motion around the planet but these observations were abandoned due to their poor astrometric accuracy, replaced by ground-based classical astrometry and later by space probes observations. However, a new type of observation was introduced during the 1970s taking the opportunity of mutual occultations and eclipses between the satellites themselves. These events are rare but their observation provides very accurate data allowing the detecting and quantifying of suspected tidal effects in their motions, signatures of their internal structure and temperature. Fortunately, these observations are easy to perform and international campaigns gathering mainly amateur astronomers have been made with success in the past. The next campaign will occur in 2021 and should bring valuable new data providing that observations be made carefully.

What Are Mutual Occultations and Eclipses?

As seen in Figure 1, the eclipses by Jupiter are not the only phenomena occurring in the Jovian system: the satellites may eclipse and occult themselves since they lie approximately in the same plane which is the jovian equatorial plane. Then, when the Sun (and the Earth which is close to the Sun as seen from Jupiter) crosses the common orbital plane of the satellites, mutual eclipses and occultations occur. It is the time of the equinox on Jupiter i.e. every 6 years (half of the revolution of the planet around the Sun).

Similar events occur for the main satellites of Saturn every 15 years [1] and for the main satellites of Uranus every 42 years [2] but they are rarer and more difficult to observe due to the fainter magnitudes of the satellites and to the apparent closeness to the planet. These observations are then a complement of high accuracy to the direct ground-based astrometric measurements and to data from space probes available only for short intervals of time. It is easy to understand that these events occur at any time and that the observations are possible only from selected geographic areas. More, the observers cannot wait for favourable weather, so that an organized network of observers is necessary.

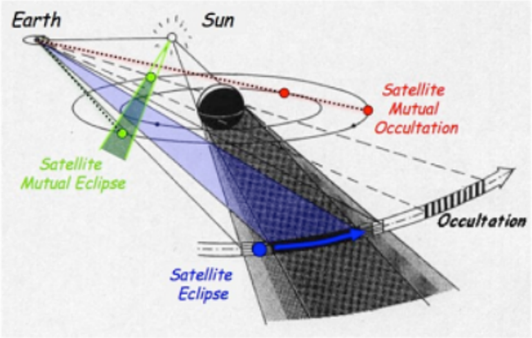

Figure 1. The principle of the phenomena of the Galilean satellites of Jupiter.

Mutual Events: The History

Galileo observed the first eclipse by Jupiter in 1612 but it was only in 1693 that Arnoldt observed an occultation of Europa by Ganymede. Such observations occurred only by chance when observing the satellites but the calculated predictions were not possible at that time. The calculations were diffcult because of the sensitivity of these events to the accuracy of the position of the satellites which would be better than 100 km in latitude (errors in longitude may only change the timing of the event). Such accuracy needs the use of a complete dynamical model for the calculations. At the beginning of the XXth century, the Sampson theory was sufficient for such predictions but the algorithm needed too many calculations by hand. From the 1970's, computers were used for astronomical calculations and precise predictions of mutual events were first published [3,4]. At that time, observations provided relative positions and diameters of the satellites which are now well known thanks to space probes. Since the Galilean satellites are bright, the recording of the events was easy: it needed a fast photometric receptor associated to a telescope the aperture of which being not too small but the increased sensitivity of the receivers allowed using smaller telescopes. An occultation or an eclipse was only a few minutes long and even including calibrations, it will not take the whole night. Since being made by photometrists, the observations were of good quality, well calibrated. The only problem was to be sure of the time scale: each event must be observed in the Universal Time scale in order to be linked to the other events and to the theoretical model.

The first observers were professional astronomers using 50 cm telescopes or larger. They used photoelectric photometers. Some amateurs tried to make visual observations using the methods developed for variable star observations.

Occurrences	Size of telescopes		Photometry	
	amateurs < 60cm	professionals ≥ 60cm	1D	2D
Jupiter				
1973	4	20	24	0
1979	3	7	10	0
1985	12	12	21	3
1991	37	19	39	17
1997	35	10	15	30
2003	34	15	8	41
2009	52	10	0	62
2015	79	16	0	95
Saturn				
1980	0	6	6	0
1995	5	11	8	8
2009	11	8	0	19
Uranus				
2007	4	11	0	15

Table 1. Evolution of the size of the telescopes and of the receptors: the number of telescopes used for the observations may be larger than the number of observing sites.

Table 1 provides the evolution of the telescopes and receptors used for the observation of the mutual events. At the beginning, large telescopes managed by professional astronomers equipped with single channel photoelectric photometers were the more numerous systems of observations. From 1985, 2D receptors such as CCD cameras appeared and were used allowing easily recording a reference object at the same time as the occulted or eclipsed satellites: observations were possible even in difficult conditions such as twilight or fog. The problem was to record images with a high frequency (more than one image per second) that was difficult at the beginning of the use of the CCD's. The progress of that type of 2D receptors led to the disappearance of the 1D photometers for the 2009 occurrence. Correlatively, the number of amateurs' observations grew rapidly due to increases in the sensitivity of the receptors allowing using small telescopes. Specific training of the observers was made in order to learn the basis of photometry and also to understand the need of the use of an accurate time scale linked to UTC.

The Network of Observers

Mutual events of the natural planetary satellites occur only during a limited period of time (around 6 months) and at any time so that the observers must have Jupiter observable at the time of the event. Observing sites should be chosen at all longitudes (for Jupiter observability) and have to be multiple to compensate for bad meteorological conditions. The planet Jupiter may have a positive or a negative declination leading to better conditions in the northern or southern hemisphere. Note that meteorological conditions are more important than the elevation of Jupiter above the horizon. For some occurrences with a positive declination of Jupiter, the best observations were made in the southern hemisphere due to clouds in the North.

Most of the observers of mutual events of the natural planetary satellites are also observers of the asteroidal occultations or photometry. Figure 2 shows the observing sites of the 2015 campaign.

Figure 2. The network of observers in 2015.

Years	1973	1979	1985	1991	1997	2003	2009	2015
Number of sites of observations	27	11	28	56	42	42	74	75
Declination of Jupiter in deg. at equinox	-19	+18	-19	+19	-17	+19	-13	+16
Distance from equinox to opposition in days	112	162	57	108	3	52	53	2
Number of observations made	94	22	166	374	292	377	457	609
Number of observed phenomena	65	8	64	111	148	116	172	236

Table 2. Mutual phenomena of the Galilean satellites: dates, occurrences, number of observing sites and number of observations.

The Results of Forty Years of Campaigns

The First Results

The first use of the observations of mutual events has two purposes: the determination of relative positions between two satellites and the measure of the radii of the satellites (at that time, the space probes had not yet provided these data). These quantities were correlated but numerous observations permitted to decorrelate them. The relative astrometric positions were of high interest: they were much more accurate than the old observations of the eclipses of the satellites by Jupiter or photographic plates and led to improved dynamical models and ephemerides. Table 2 provides the list of all the observations made during the campaigns made since 1973. Note that the observational conditions are different from one occurrence to another, especially the separation between the Jovian equinox (maximum of events) and the opposition of Jupiter (maximum of possible observations). Around the conjunction Sun-Jupiter, no observation is possible.

Exploring the Satellite Spectrum

It appeared that the observations of the mutual events were photometric measurements and may be made in different wavelengths. Most of the photometers were able to record the light flux emitted by the satellites in U, B, V, R standards. The reflectivity of the surface of the satellites had to be taken into account, especially the phase effect making the visible disk of the satellites not uniform. The arrival of the first images from the space probe Voyager have shown that the satellite Io was covered in volcanoes or hot spots. Using this characteristic of the satellite, observations were made in the wavelength where the hot spots were supposed to emit. The observation of the occultation of Io by Europa allowed one to determine the flux and the position of the hot spot at the surface of the satellite [5], (Figure 3).

Nowadays, the hot spots may be observed through specific 2D infra-red receptors. At the present time, taking into account the wavelength used, the analysis of the light curves allows one to determine highly accurate relative positions of the satellites used for the fit of the new theoretical dynamical models.

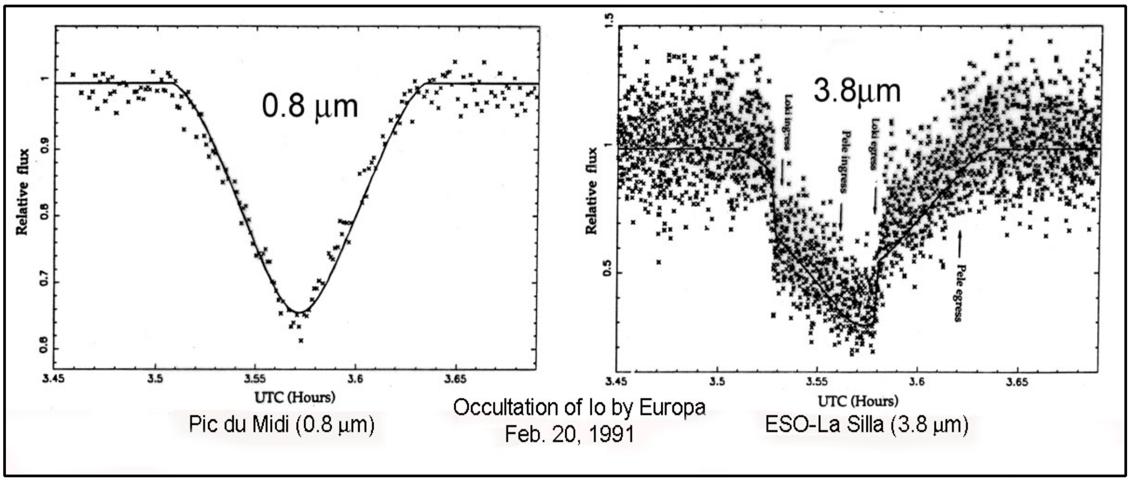

Figure 3. Occultation of Io by Europa: the occultations of the hot spots are visible on the light curve at right.

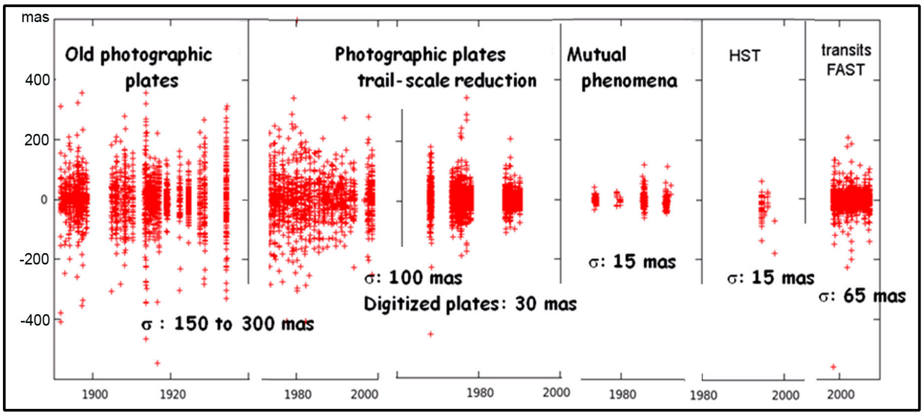

Figure 4. Compared accuracy of all Galilean satellites observations.

Figure 4 shows the quality of mutual event observations compared to the other types of data. After 40 years of observations of mutual events and one century of photographic observations, small effects in the orbital motion of the satellites such as tidal effects and constraints on the internal structure of the satellites may be detected [6].

The Observing Process and the Reduction of the Data

We will describe now the different steps of an observation: the observation itself, the extracting of the signal, the making of the light curve, the reduction of the light curve.

Observing the Event

The observations of the mutual events are easy: the objects are bright, and a very small telescope (down to 6 cm-aperture!) is sufficient to record the mutual phenomena. However, the stability of the instrument and the guiding are fundamental to record reliable data. A CCD camera, a web-cam or even a camcorder placed in the focus of the instrument are suitable to record the field containing the Galilean satellites: caution, the gain of the camera should not be automatic but fixed during the observation the duration of which being neither too short, nor too long (between a few minutes and one hour).

The field of the Galilean satellites is about 20 arcmin and may not be all recorded. We have to choose a part of the field including the occulted or eclipsed satellite together with another satellite which will be the reference. Be careful to correctly identify the field. If four satellites are present in the field, record the right ones!

A specific attention must be made for the timing of each recorded image. The time must be referred to UTC within 0.1 second of time. The computer's internal clock is not sufficiently accurate: GPS time is accurate enough but needs a special receiver. Note that the time stamping of the observation is essential: if the timing is not reliable, the observation will be rejected. If your clock is not sufficiently well synchronized with UTC, note the difference to UTC at the beginning of the observation and also at the end. Thus, the inaccuracy of the timestamp for each image is the source of the systematic error of the observation result. This will allow one to connect all the observations made. Contrary to asteroidal occultations for which the common time scale connects all the observations of the same occultation, in the case of the Galilean satellites we must connect all the observations made during the whole campaign and also with the former campaigns of observations.

Extracting the Signal and Building the Light Curve

The next step is to obtain the value of light flux from the satellites. This is the so-called photometric processing. This technique consists of summing the illuminated pixels of a satellite, and subtracting the contribution from the sky background. Many different methods and software are used for this. The choice of tool is a subject for special consideration. The use of a 2D CCD or CMOS target all to record simultaneously the occulted or eclipsed satellite together with one or two other satellites which will be used as references. Since we need only relative photometry, the observation of this reference object allows one to eliminate the effect of atmospheric extinction, light clouds or twilight appearing during an event as shown in Figure 5 (above right, the occultation and left the reference satellite at the same time. The calibration of the target should be made with care and the final light curve will appear as shown in Figure 5 (bottom).

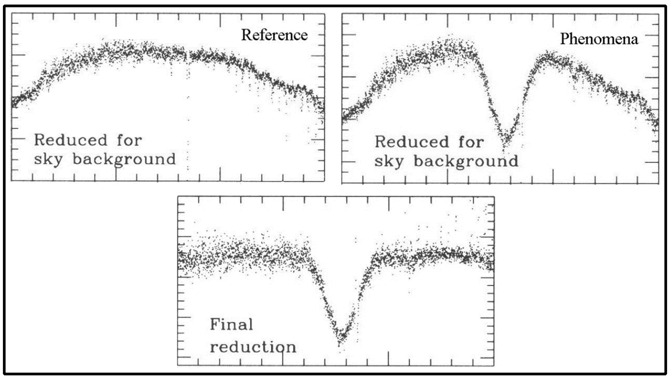

Figure 5. After eliminating the sky background, the signal may be polluted by light clouds. They are eliminated thanks to a constant reference object recorded during the event.

Attention, the measured light flux from each reference satellite must be also recorded and presented separately in a specific file. In the case of a mutual eclipse, it is important to indicate from which source the light flux was measured. It can only be a flux from an eclipsed satellite alone if the eclipsing satellite is far enough apart in the field of view. In other cases this may be the total flux from both satellites: eclipsing and eclipsed. Do not forget to indicate this fact in the data that you will send.

Reducing the Light Curve

The present section focuses on the photometric model of mutual occultations and eclipses of the Galilean satellites and mostly on sources of systematic errors all along the observing and reducing process which will degrade the final astrometric results.

Systematic errors may be introduced in the photometric processing if specific corrections are not made. Let's explain it in more detail here.

Let S be a normalized flux so $S = 1$ when the satellites are outside the occultation. During the event one satellite is occulted or eclipsed so we have $S < 1$. We suppose an equation

$$E = K \cdot S\,,$$

where K is some constant coeffcient and $E = K$ is the flux outside the event. This is the perfect and desired case. In fact, the dependence will be such

$$E = K \cdot S + P\,,$$

where P is some unknown parameter supposed to be constant during the event.

The sources of this parasitic flux can be different. An explainable case may be if we have light from the background of the sky or light scattered in the structure of the telescope assembly. In that case it will be $P > 0$. However, it often happens that $P < 0$.

The reason for this situation can only be the error of the method of photometric processing. After having taken some method to use the observer cannot influence this process.

Cases when $P < 0$ can be detected and seen from observations. To understand the problem let us look at a simplified model of the mutual occultation of two satellites. In this model we suggest homogeneous satellite disks. Let the occulting satellite be "number 1" and the occulted one be "number 2" as well.

Let us denote p_1 , p_2 - disk integrated albedos of the first and second satellites correspondingly. Further notation are r_1, r_2 - apparent radii of the disks. Then the flux from occulting satellite is equal to $Rp_1r_1^2$ and the flux from occulted satellite is equal to $Rp_2r_2^2k_2(d)$, where R is some coefficient, $k_2(d)$ is a share of uncovered portion of the disk of occulted satellite, d being the apparent distance between the centres of the disks on the sky. Normalized flux S can be expressed

$$S(d) = \frac{p_1r_1^2 + p_2r_2^2k_2(d)}{p_1r_1^2 + p_2r_2^2} = \frac{1 + \frac{p_2r_2^2k_2(d)}{p_1r_1^2}}{1 + \frac{p_2r_2^2}{p_1r_1^2}}\,.$$

In the no event case $k_2 = 1$. If a full occultation occurs k_2 is equal to zero and in the case of annular occultation $k_2 = (r_{22} - r_{12})/r_{22}$.

Figure 7 demonstrates the case of full occultation. For the time period (t_1,t_2) we have $k_2 = 0$ and

$$S = \frac{1}{1 + \frac{p_2r_2^2}{p_1r_1^2}}\,,$$

that is, the flux does not depend on the mutual distance of the satellites d.

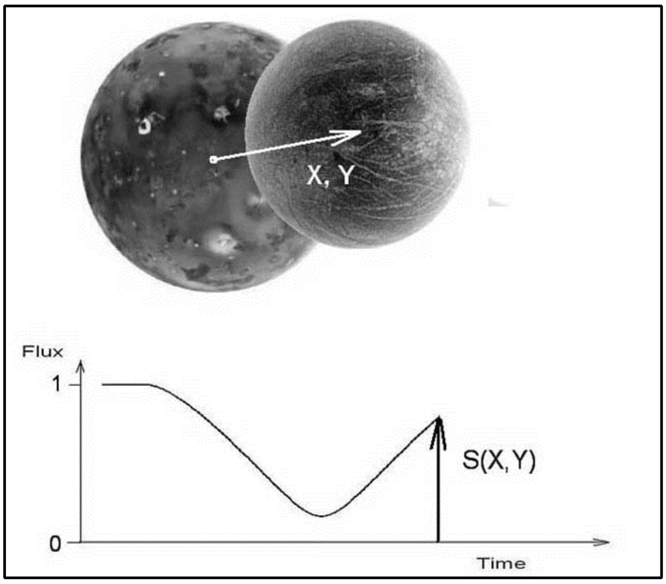

Figure 6. The building of the function S(X,Y), X, Y being the relative astrometric positions of the two satellites during an occultation.

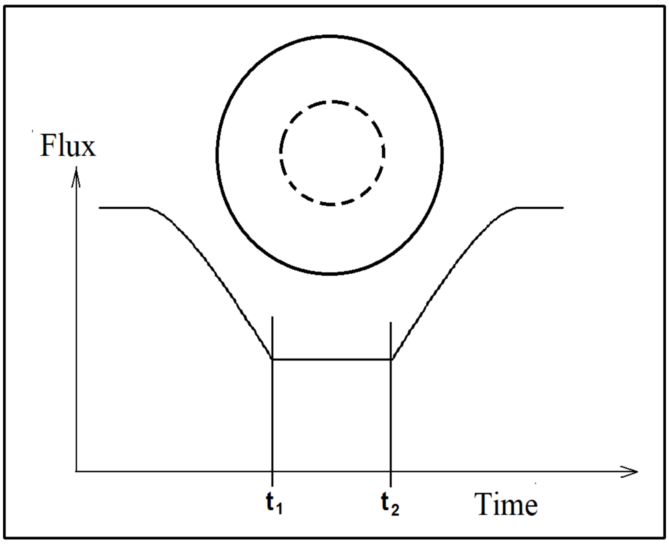

Figure 7. Full occultation of one satellite by another over a period of time (t_1, t_2) and the corresponding section on the curve of the total normalized flux from a pair of satellites.

The problem arises because in many cases the observed value of the flux during full occultation is not equal to the calculated value, i.e.

$$E_{\text{observed}} \neq K \frac{1}{1+\frac{p_2 r_2^2}{p_1 r_1^2}} \ ,$$

where K is equal to the flux beyond the phenomenon. Figures 8, 9, and 10 show examples of such situations. Here we present the values of E_{observed}/K obtained from the measured values of the flux (points) and model changes of S.
These figures demonstrate that the additional flux is present in the measured values during full occultation, and this flux is negative.

There are two ways to correct the model. The first way is to set

$$E_{\text{observed}} = K \frac{1}{1+\frac{p_2 r_2^2}{p_1 r_1^2}} + P \, ,$$

where P is the spurious light flux from an unrecorded background. The second way is to set

$$E_{\text{observed}} = K \frac{1}{1+m\frac{p_2 r_2^2}{p_1 r_1^2}} \ ,$$

where m is some additional factor that appears due to the fact that we inaccurately know the ratio of the satellites' albedos, and corrects this inaccuracy. There is a dilemma which method we should choose among two methods.
The fact that in most such cases the spurious flux in the observations is negative, suggests its real presence, rather than the influence of inaccurate knowledge of satellite albedo.
When processing partial mutual occultations of satellites, we do not suspect the presence of a spurious background in the measurements and do not know about the inaccuracy of the accepted values of the satellites' albedos. Therefore, we have to add the false correction Δ to the mutual apparent distance between the satellites to match the model with the observations, which leads to systematic errors in astrometric results. This fact is illustrated by the following relation:

$$E_{\text{observed}} = K \frac{1+\frac{p_2 r_2^2 k_2(d+\Delta)}{p_1 r_1^2}}{1+\frac{p_2 r_2^2}{p_1 r_1^2}} \ .$$

Here, in our consideration, for a better understanding of the situation, we simplied the photometric model of the phenomenon. However, the problem is also reproduced in our processing of observations using the perfect model described in [7, 8]. The same problem arises when processing observations of mutual eclipses of satellites.

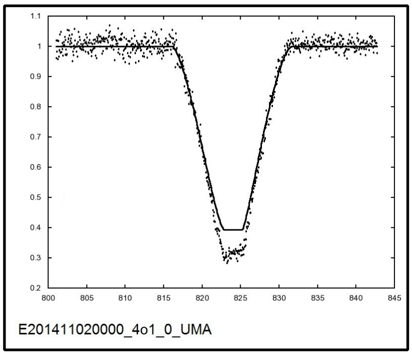

Figure 8. Example of the light curve for the measured normalized flux from the satellite Io during its full occultation by another satellite and the corresponding model curve after refining the model parameters. The observation performed on 2014 November 2. On the horizontal axis, we showed the time in minutes.

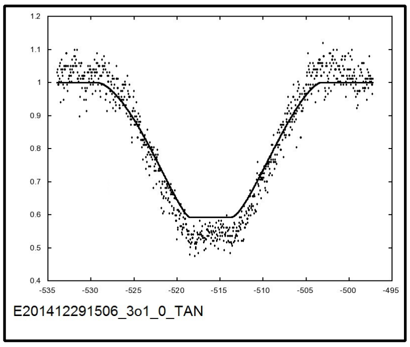

Figure 9. Example of the light curve for the measured normalized flux from the satellite Io during its full occultation by another satellite and the corresponding model curve after refining the model parameters. The observation performed on 2014 December 28. On the horizontal axis, we showed the time in minutes counted from 2014 December 29. A negative background level in the measured flux is clearly visible here.

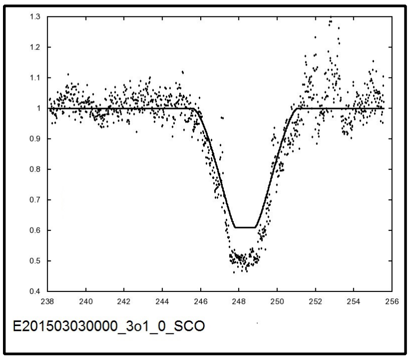

Figure 10. Example of the light curve for the measured normalized flux from the satellite Io during its full occultation by another satellite and the corresponding model curve after refining the model parameters. The observation performed on 2015 March 3. On the horizontal axis, we showed the time in minutes counted from 2015 March 3. A negative background level in the measured flux is clearly visible here.

The Origin of the Errors

We are forced to look for the sources of the above errors. Spurious light can get on the photodetector from a spurious sky background. It can be light scattered through a telescope and camera. A spurious background can be created by the photodetector itself. The calculation of the light flux from satellites from their images on CCD frames is performed by one of the special methods of photometric processing. The error of this method can give some level of background. Only this source can produce a negative background level. Therefore, such a source is the most likely cause of the situation. It is in the method of photometric processing that we should look for the source of spurious background. References to descriptions of existing photometric image processing methods would take up too much space in the present paper. We restrict ourselves to listing the names of the methods that appear in the explanations that accompany the data received in IMCCE: *Source Extractor*, *DAOPHOT* (IDL), *Audela*, *Tangra*, and *LiMovie*. Different observatories use their own special methods. Obviously, a revision of the methods used is necessary to determine the sources of systematic errors.

As we can see from the above simplied consideration of the photometric model, the normalized light flux from satellites depends on the ratio of the surface-integral albedos. This dependence remains in more accurate photometric models. In our processing of observations of the Galilean satellites of Jupiter [9, 1], we average the apparent photometric properties of the satellite, but take into account variations in the integral albedo, depending on the rotation angle of the satellite. More simply, the light flux from a satellite depends on how sideways it faces us. We use data on variations in the integral albedo from publications [10, 11, 12]. These data are not accurate enough. They can be a source of error in the photometric model of mutual occultations and eclipses of the Galilean satellites of Jupiter. The need for intensive photometric observations of the Galilean satellites of Jupiter for different values of the angles of rotation of the satellites from 0 to 360 degrees in different spectral bands is obvious. A special processing of such observations will give refined dependencies of the light flux on the angle of rotation of the satellite.

How to Reduce the Errors?

After all these arguments, the question remains what observers can do to eliminate the systematic errors considered, if possible. There are two ways to act. First, it is necessary to revise the method used for photometric image processing. Second, one should try to measure the fluxes separately from each observed satellite in time periods near the observed mutual phenomenon. This will make some estimates of the disc-integrated albedo of satellites.

In addition to systematic errors, random photometric errors are also present in the observation results. This is the so-called noise in the measurement results. The analysis published in the paper [13] shows that the influence of random photometric errors on astrometric results is significantly less than the contribution of systematic errors. Observers should not be afraid of noise in observations.

In the case of a mutual eclipse do not forget to indicate from which source the light flux was measured. Note also that the time stamping of the observation is essential.

Making Astrometric Data

From the final light curve, we have to extract the astrometric information, i.e. the relative position of the satellites involved in the phenomenon. For that purpose, we will use our model of the photometric flux at any time as a function of the relative position of the satellites (cf. Figure 6) and also as a function of parameters such as the reflectivity of the surfaces, the phase angle. Each photometric point of the light curve allows one to write a conditional equation including all parameters. The solution of the system will provide the X, Y relative positions of the satellites together with the photometric parameters that we choose to keep as unknowns in the equations.

The 2021 Campaign of Observations

The occurrence of the mutual events corresponds to the decrease of the jovicentric declination of the Earth (for occultations) and the Sun (for eclipses). Since the Earth and the Sun are very close in the Jovian sky, occultations and eclipses occur during the same period of time around the equinox on Jupiter (the Sun being in the Jovian equatorial plane). Figure 11 shows the values of the Jovicentric declinations of the Earth and the Sun in 2021. It appears that these declinations become zero in March and April 2021. Note that the conjunction of Jupiter and the Sun occurs in February making impossible any observations at that time. Fortunately, near the opposition (in August), the Jovicentric declinations are about 0.6 degrees making possible the occultations and the eclipses. We must note that the declination of Jupiter is negative making the observations more favourable in the Southern hemisphere, and the number of observable events will be smaller for northern observers. Observations will start in March 2021 and will end in September. 242 phenomena will occur but only 192 will be easily observable.

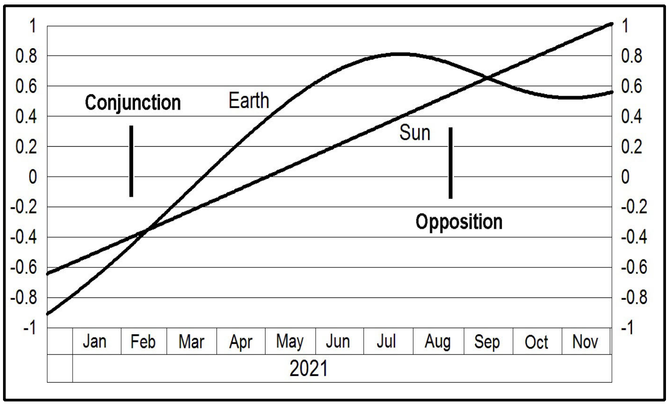

Figure 11. The Jovicentric declination of the Earth and the Sun in 2021 referred to the date of the conjunction and the opposition Jupiter-Sun.

Figure 12 provides the number of events observable per week. Note that a few eclipses of Amalthea and Thebe by a Galilean have been observed in the past [14] (mostly in infra-red wavelengths) and will occur in 2021. Figure 13 provides the number of these eclipses occurring each week.

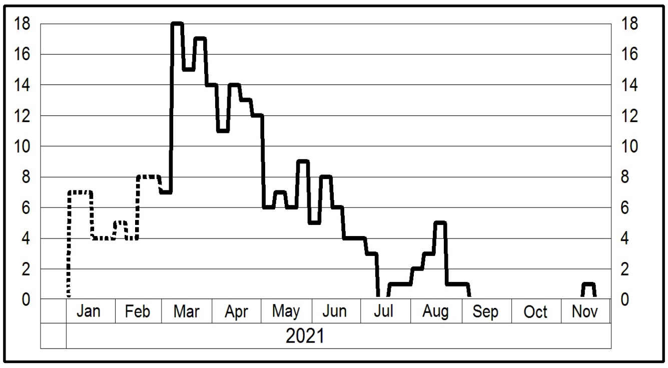

Figure 12. Number per week of the mutual occultations and eclipses in 2021. Dashed line corresponds to events not observable due to the proximity of the Sun.

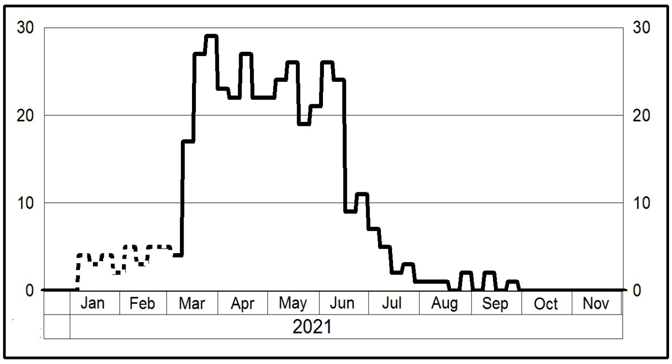

Figure 13. Number per week of eclipses of Amalthea or Thebe by a Galilean in 2021. Dashed line corresponds to events not observable due to the proximity of the Sun.

All the events and their characteristics are provided on our web site as follows.
In order to prepare the observations of the events observable from your own site of observation, please be connected to our web site at:

http://nsdb.imcce.fr/multisat/nssephme.htm

After observing, the observers may send their observations through the web site:

http://www.sai.msu.ru/neb/nss/phemuobsai.htm

You may send e-mails for more information to arlot@imcce.fr and emelia@sai.msu.ru

Conclusion

The mutual occultations and eclipses of the Galilean satellites of Jupiter will occur during the year 2021 and we encourage the observers to join the observational campaign which will take place during this year. All observations made taking into account our specifications will be of great interest for the study of the Galilean satellites: dynamical model, constraints on the internal structure will be improved thanks to the accumulation of accurate observations during decades. These observations will also help in the preparation of the future space missions *JUICE/CLIPPER/IVO*. The help of amateur astronomers have been essential for our past campaigns and will bevaluable for the next occurrence.

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Journal for
Occultation Astronomy

Grazing Lunar Occultations – Still between Science and Beauty?

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ABSTRACT: Observations of total and grazing lunar occultations became less popular following precisely available lunar topography data through the Kaguya- and LRO-missions and incredibly increased stellar position accuracy through the Gaia-mission. The amateur astronomer's contribution in this field is no longer needed. But these occultation phenomena still have their natural beauty so quite a few amateurs still take sometimes tremendous efforts to record these events. As a new focus of this work different ways of exploring stellar systems and atmospheres at the lunar limb come into view. Lunar occultations, beyond being much fun to observe, remain an important educational entrance to astronomy.

The observation of lunar and especially of grazing occultations of stars as one of IOTA's fields of research has experienced a major setback during the last some 10 years. It seems that only few enthusiasts still are willing to take a tremendous effort to observe, time, and report these events. Since the existence of highly precise lunar topographical data and dramatically improved stellar positions by Gaia, no surprises are expected from lunar occultations anymore. Asteroidal and TNO-occultations, standing at the edge of making even grazing occultations of these small bodies observable, appear more challenging to many, promising to contribute more to science than measuring the well-known lunar limb over and over again.

But in spite of that lunar occultation observations did not cease and even show increasing signs of revitalization in some regions. Quite a few observers use their modern camera techniques to record total lunar occultations by the tens as a "by-catch". Also local campaigns are started to coordinate joint occultation observations of grazes over country boundaries. One just recently successfully observed graze was that of 4.7 mag. γ Cancri (Asellus Borealis) on the morning of September 14 by the just 14% sunlit waning Moon in Germany and Poland. Wojtec Burzynski and Macier Borkowski were able to do timings in northeastern Poland right at sunrise. In their video the star is visible right off centre and about half way up from the bottom [1].

Konrad Guhl, Germany, was lucky to record another impressive video further westward close to Leipzig, Germany with less sky brightness yet [2]. Bernd Gährken, Germany, stood even farther west and reported, also having Venus standing close to the Moon, to have witnessed the probably most beautiful graze so far (and he has seen a lot!).

So, needless to say: grazing occultations always had and still have their thrill and beauty. What keeps many observers busy watching is the pure fun they have from it. For them that is reason enough to travel quite some distances to intercept the projected lunar terrain. But what about the scientific value of lunar occultations? The times we were able to complete the Cassini regions of the Moon missing in the Watt's data through timing of grazes are long over. The Kaguya- and the later LRO-mission came up with a complete and dense topographic model of the Moon. The published lunar height values of the LRO laser altimeter have a resolution up to 60 metres on the Moon with an elevation value claimed to be precise to 5 metres.

Neither by the resolution of earthbound recordings, nor for geometric reasons the topography of the Moon can be improved by timing lunar occultations. With an average orbital motion of the Moon of roughly 1 km per second we have an angular velocity of about 0.55″ per second. It would need a frame rate of shorter than 60 milliseconds to reach a horizontal resolution better than the published grid density. While this does appear possible even with video resolution it only works on steep lunar slopes. The softer the lunar surface, the faster the frame rate has to be to reliably also measure these details. 5-metre details would need a frame rate of 5 milliseconds which, also for reasons of sensitivity, are hardly achievable with most of the currently available cameras.

One might respond though it could be possible to improve the lowest and the highest parts of the lunar features as these are not so much time dependent and can be reconstructed geometrically. Here is one of the reasons that cause grief to people (like the author) trying to predict contacts of a star in a flat lunar terrain that merely "scratches" the star for a while. Since surface features much smaller than 5 metres can block the star completely the number of contacts can be none or very high and thus is not really predictable. Figures 1 and 2 illustrate the problem for an upcoming graze of 69 Aquarii on Nov. 22 this year in Europe.

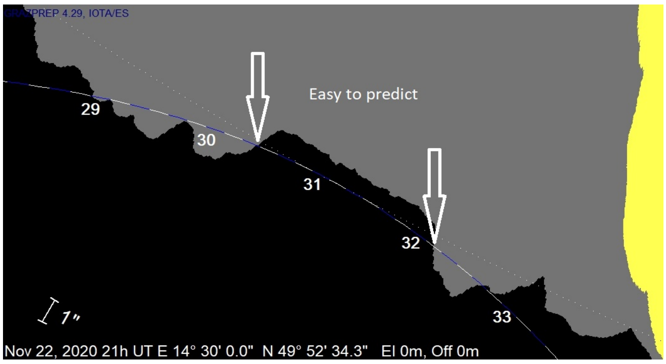

Figure 1. Graze situation in a steep lunar landscape with good prediction chances of contact numbers and times.

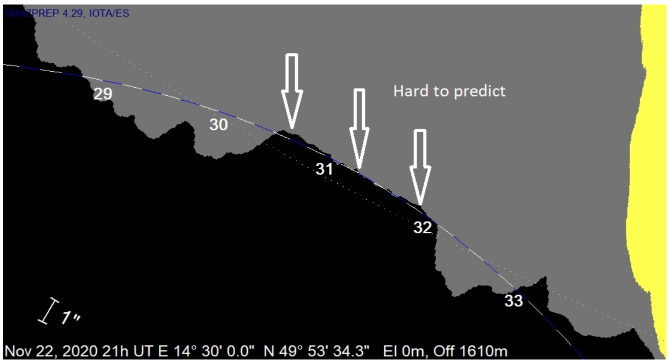

Figure 2. Graze situation in a flat lunar landscape with poor prediction chances of contact numbers and times.

But is that enough reason to emphasize grazing occultation observation? With such timings we do increase the knowledge of the present shadow of the Moon cast onto earth. Unfortunately that measurement only counts for the specific angles of libration of the Moon at that very instant thus only serve as a basis for prediction for the very same libration situation. This might be of value for future Baily's Beads observations which at least limits the libration in latitude to values around zero. The former Watts data were nothing else than libration dependent profile (not surface) data and our earlier observations improved that profile values but not the lunar topography itself.

The reason is a geometric problem: the profile we "see" is always just the sum of lunar features along the line of sight (to the star). What appears to stand at the outer limb of the Moon forming "our" lunar horizon can be caused by features being many kilometres in front or in back of that horizon (Figure 3). Since the lunar terrain can reach up to 6 km above the mean lunar radius within the complete limb area as visible from Earth the surface in a strip up to some +/- 145 km on the Moon away from our visible horizon can contribute to the shape of the profile. Thus it is not possible to determine the precise selenographic longitude and latitude of any part of the measured projected profile.

A campaign started recently to observe the graze of the 7.5 mag SAO 79663 on May 26 resulted in 7 observing stations in the Netherlands and Germany over a range of 6 degrees in longitude. Most observers recorded with video means, but not all of those with 1 PPS inserted timing methods. 3 observations were visible with stopwatch. The Axis Angle was rather stable over the complete longitude range.

The reduction was accomplished by IOTA's collector of grazing occultation timings and the "final authority" in charge of the reduction of the observations, Mitsuru Soma, Tokyo, Japan. His plot (Figure 4) shows a very good match of the observed contacts compared to the LRO data. Soma uses a LOLA data set having a grid density of 237 metres on the Moon. Even the visual timings are remarkably precise as can also be seen in the enlarged insets.

This result is a proof of the skill of the participating observers and may encourage them. But is it more than that? All of the recent reductions actually prove the precision of the lunar laser ranging without any existing necessity for such a proof. Is that the end of science through grazing occultation observations?

I prefer to answer this with a "No". As we remember lunar occultation work changed the justification for its usefulness several times in the past, focusing back and forth on the improvement of stellar positions and the lunar limb, whatever was better known at each time. Now with the lunar laser ranging and with stellar positions from Gaia research on both fields has come to a preliminary end and, sad enough, the observational effort of so many enthusiasts among us could not even contribute to that and will not be able to contribute in the future.

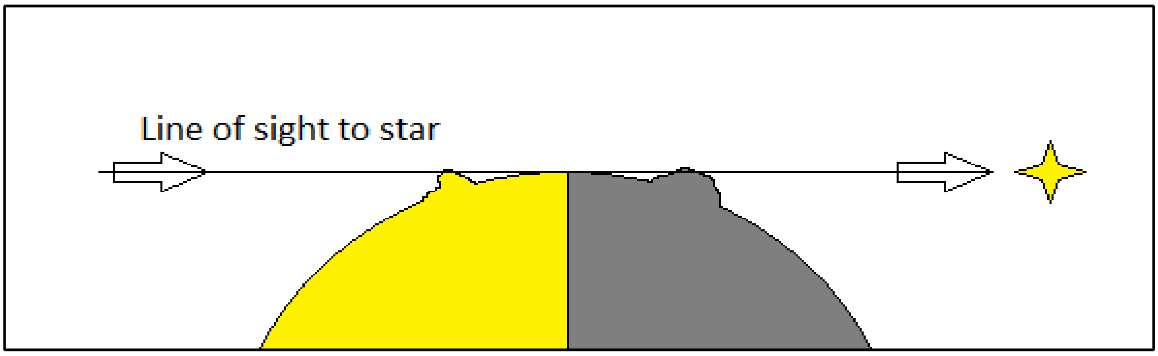

Figure 3. Lunar landscape features also far away from the visible horizon define the lunar profile!

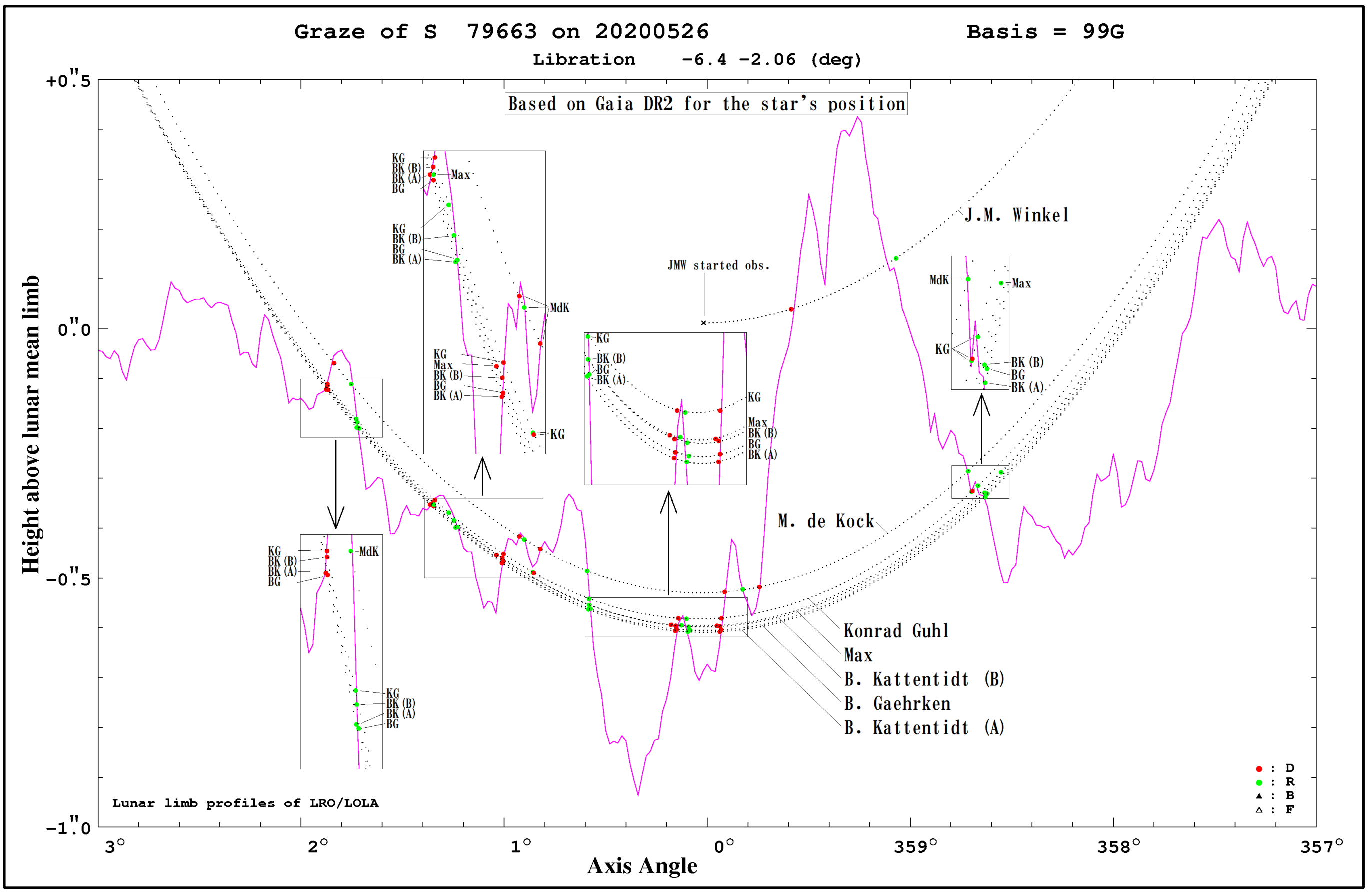

Figure 4. Mitsuru Soma's reduction plot of the joint grazing occultation observation of SAO 79663 on 2020 May 26.

What is necessary instead is a change of the subject to pursue. The lunar limb is a good place to find out more about the occulted stars. The stepwise dis- and reappearances of double- and multiple stellar systems can reveal more about these systems. Especially grazing occultations allow to record several of these events in a single observation making it possible to compare the contacts at different immersion and emersion angles at the well-known lunar surface. A higher time resolution than so far is required though to get useful results.

The determination of stellar diameters is no new subject related to lunar occultations. As Andrea Richichi pointed out at the recent ESOP Zoom meeting it can be possible to distinguish between the chromo- and the photosphere of an occulted star [3]. There are even more sophisticated plans concerning the occultation of stars.
One is pursued by Prof. Peter Slansky, a camera expert teaching at the University of Television and Film in Munich, Germany (he had also been taking part in the last ESOP). He already tried to use the last graze of Aldebaran in the last series of grazes to "take a picture" of that giant with a high speed camera. Naturally such a picture cannot just be "taken" but has to be calculated using filters and dealing with all diffraction fringes and other disturbances. Of course this is again the work of specialists where the amateur astronomer cannot contribute.

But after all: Isn't it the fun and thrill we have from observing these beautiful events that keep us going out for them? Would anyone give up observing solar eclipses just because that doesn't serve science too much anymore? Maybe occultation observers are not much else than fishermen sitting at a lake waiting for their first bite. But as long as they enjoy what they are doing they can and may forget about any possible further use of the data they produce. We still participate in fundamental research, not knowing today what benefit the work may eventually have.

Last but not least: The Moon is the object most beginners start with when their curiosity about astronomy grows. Via occultations the Moon serves as a link to the stars. This is why lunar occultations have an important educational issue for the public which we should not disregard.

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First Telescopic Observations of Eclipses and Occultations

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ABSTRACT: At the beginning of the 17th century, the invention of the telescope created the conditions for more accurate observations of eclipses and occultations. Starting from 1610, astronomers successively collected the results of these observations, which allowed, inter alia, to improve the theory of the motion of the Moon. Some of them are still of scientific importance today.

Introduction

In 1609, a new era in astronomy began - the use of telescopes for observing the sky. Initially, a set of two lenses, allowing for viewing distant objects under magnification, was to be used mainly for the purpose of tracking ships, and perhaps also the movements of troops, which was planned by the accidental discoverer of the device - the spectacle maker Hans Lippershey, and initially also Galileo Galilei himself, who came up with the construction of his own instrument by trial and error in August 1609, after hearing the principles of its construction. The device in question was originally called "spicillum" or "perspicillum" = glasses or spyglass. However, Galileo quickly recognized its importance in astronomy, and from September 1609 he began observing the sky on a more regular basis. The instrument, which soon came to be called the telescopium, reached active astronomers fairly quickly, but its widespread use was still a long way off.

Observations of Lunar Eclipses

The telescope began to be used, among others, for observing lunar eclipses [1, 4, 7]. The first mention of the use of a telescope for this purpose comes from Rome on 1610 July 6. The author of the morning observation was Johann Ruderauf (better known under the pseudonym Johannes Remus Quietanus, 1588-1654), who at that time was studying at the Collegio Romano; he was acquainted with Galileo, from whom he must have obtained a telescope. The observation consisted in determining the moment of the beginning of the partial eclipse. While in the field of optical observations the telescope made significant progress, in the case of determining the moments of phenomena, proven methods were still used like measuring the altitude of objects (of the Moon or selected stars) with a quadrant or determining the sideral time from the passage of brighter stars through the local meridian. The accuracy of these methods was limited and depended on the skills of the observer and the quality of the instruments, as well as on the precise determination of the local meridian; it can be estimated that the moments were determined at that time with an accuracy of about 1 minute. In this case, Quietanus reported that Vega was 49° above the horizon at the start of the partial eclipse, and one minute later the altitude of Capella was 22°. This type of data is valuable to us today, because we can re-calculate the real time using the present software[1] (Table 1).

Date	Place	Observer	C	Timing	UT eq.	Calculated UT		
						Occult	HPET	NASA
1610 Jul 6	Rome	Quietanus	B	Vega h=49° Capella h=22° (a)	2:16 2:17	2:26.5	2:25.9	2:26.7
1610 Dec 30	Ansbach	Marius	E	γ Crv 1° before culmination	4:45	4:42.2	4:40.7	4:41.8
1612 May 14	Copenhagen	Longomontanus	B	Regulus h=35°52′	20:25.5	20:27.4	20:28.1	20:27.8
	Liège	Wendelinus	B	8:37 LST	20:10			
	Rome	Quietanus	B	Vega h=28°12-15′	20:25.0-25.5			
1612 Nov 8	Ingolstadt	Scheiner	E	4:53 LST (b)	15:52	15:51.5	15:49.9	15:50.5
	Nagasaki	Spinola	B	9:30 LST	12:35	12:46.3	12:46.7	12:46.0
	Macao	de Alenis, Uremanni	B E	8:30 LST 11:45 LST	12:42 15:57	12:46.3 15:51.5	12:46.7 15:49.9	12:46.0 15:50.5

(a) One minute later.
(b) At 5h no Earth's shadow was noticeable for sure. The penumbral eclipse was still noticeable for the next 40 minutes.
C– contact: B – beginning, E – end of the partial eclipse.
UT eq. (equvalent) – moment in UT resulted from the original timing (according to Stellarium, Occult and HPET – High Precsion Ephemerid Tool).
LST – local solar time counted from the true solar noon.

Table 1. First telescopic observations of lunar eclipses.

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[1] The calculated data presented in Tables were obtained using the Occult, JPL, HPET (High Precision Ephemeris Tool) and Stellarium software.

The same eclipse was also observed in Forcalquier by Govaert Wendelen (Wendelinus), but he did not provide information on the use of the telescope.

Another lunar eclipse occurred in the same year 1609, namely on December 30, and also in the morning, and was also observed with a telescope. This time the observer of the end of the partial eclipse was Simon Mayr (Marius, 1573-1625), who at that time was probably in Ansbach near Nuremberg and used "a new Galilean instrument" for his observations. To estimate the time he used the star γ Corvi, which passed through the local meridian one minute after the end of the partial eclipse.

The next observed lunar eclipse on 1612 May 14, was seen by more people: Christen Sørensen (Longomontanus) in Copenhagen, Christoph Scheiner in Munich, Wendelen in Liege, and Quietanus in Rome, who reported that he was observing with "an excellent lunette".

But what were the telescopes? The characteristics of Galileo's telescopes give us a view on this matter: the diameter of the convex lens of the objective was 3-4 cm, the focal length - about 1.5 m, and the magnification in the eyepiece which was a concave lens, giving the resulting upright image - 20-30 times [2]. The lenses used had many optical drawbacks, including spherical aberration, which could be partly eliminated by further reducing the inlet diameter of the objective lens using a diaphragm. This, obviously, made the image given by such an instrument, relatively dark.

Nevertheless, observations with the telescope were judged to be more reliable, although there were other problems with this. So, both Wendelinus and Marius found the obvious fact that the lunar limb hidden in the shadow was visible more distinctly when viewed through a telescope than with the naked eye, and hence the assessment of the beginning or end of a partial eclipse is clearly different in both cases. It was probably a finding suggesting the need to standardize the observation technique.

In 1612, two reports were received for the first time from the Far East (at Nagasaki and Macao the eclipse on November 8 was observed by the Jesuits; although they did not explicitly state whether or not they used telescopes, it was very likely).

Observations of Solar Eclipses

The observations of solar eclipses have also been improved by replacing the projection of the solar disc by a camera obscura with the projection onto a screen using a telescope. However, it is not easy to find out who made the first observation using this technique. In any case, the first documented observation seems to be by Longomontanus, who used "spicillo novo" to observe the solar eclipse on 1612 May 30, projecting an image of the Sun onto the screen [5] (Table 2). This instrument was probably one of the first telescopes. At the same time, during the eclipse, he directly observed the Sun through a hole in a paper card.

The eclipse was also observed by: Michael Mästlin in Tübingen, Johann Kepler in Linz, Christoph Scheiner in Munich, Nicolas-Claude Fabri de Peiresc in Aix-en-Provence, Cornelio Ghirardelli in Bologna and Quietanus in Rome [1]. The latter this time reported the lack of a good telescope, but surely some of the above-mentioned observers used a telescope (Scheiner, for example, used the telescope to observe sunspots from 1611). However, the best qualitative observations of eclipses were made by Pierre Gassendi (1592-1655) [1, 3, 4].

Together with his friend Joseph Gaultier (1564-1647) he closely watched through a telescope at Aix the total lunar eclipse on 1620 June 14. Next, he observed at Aix a deep partial solar eclipse on 1621 May 21, with the company of his brother Jean, who controlled the telescope, and Gaultier, who made parallel angular measurements with a quadrant.

The greater phase of this eclipse was recorded, among others, by Johan Philip van Lansberge (Lansbergen) at Middelburg

Date	Place	Observer	C	Timing/ Max. phase	UT eq.	Calculated UT/phase		
						Occult	HPET	NASA
1612 May 30	København	Longomontanus	B	Sun h=51°	9:24	9:23:52	9:23.5	9:23:46
			M	$7\,^2/_3$-8^d=0.64-0.67	-	0.738	0.742	0.739
1614 Oct 3	Linz	Kepler	E	1:47 LST	12:39	12:40:27	12:39.9	12:40:17
	Tübingen	Mästlin	E	Sun h=34° $^2/_3$	12:33	12:35:27	12:35.0	12:35:21
	München	Scheiner	B	23:15 LST	10:18	10:12:40	10:12.1	10:12:35
			E	1:45 LST	12:48	12:38:22	10:37.9	12:38:17
1621 May 21	Aix	Gassendi	B	Sun h=25.5°	6:40	6:41:38	6:41.1	6:41:34
			M	$9^d23'$=0.782	-	0.785	0.786	0.785
			E	Sun h=51°17′	9:06	9:06:29	9:05.8	9:06:24
	Middelburg	Lansbergen	B	19:00 LST	6:41	6:54:13	6:53.7	6:54:07
			M	11.2^d=0.933	-	0.955	0.954	0.954
			E	21:36 LST	9:17	9:19:12	9:18.5	9:19:05
	Dordrecht	Hortensius	M	20:16 LST	7:53	8:04:19	8:03.7	8:04:39
				$10^d07'$=0.882		0.955	0.950	0.951
	Stuttgart	Kepler	M	10^d=0.833*	-	0.858	0.860	0.856

* through the clouds

C- contact: B – beginning, M – greatest phase (maximum), E - end of the partial eclipse.

Greatest phase in digits (1 digit=1/12 of the apparent solar diameter; total eclipse means 12^d).

Table 2. First telescopic observations of solar eclipses.

(11.2 digits = 0.93), and especially by Vincent Wing in Luffenham, who, being close to the limit of the narrow path of the annular eclipse, noticed significant darkness and stars clearly visible in the sky [10]; however, it seems that this observation was still made with the naked eye. The greatest phase of the eclipse calculated today was at this place equal to 0.99.

Observations of Lunar Occultations

For many centuries, observations of lunar occultations have been made by the naked eye and rather by accident. Observations of the occultations thus made by Kepler and several other astronomers date back to the beginning of the 17th century. After the invention of the telescope, the occultation observations could have developed, but the optical limitations mentioned above meant that they could practically only apply to bright stars. An additional difficulty was the lack of an ephemeris: calendars from that era only gave the phases of the Moon and sometimes its approximate conjunctions with planets. Thus, the observer himself had to closely monitor the sky and decide whether there would be any occultation on a given day. The task for the observers at that time was to actually precisely record the conjunctions of the Moon with stars and planets (which made it possible to correct the theory of the Moon's motion), and if an occasional occultation occurred, it was treated as a more precisely measured conjunction [1, 4].

The first documented observation of an occultation of a star by the Moon comes from Ismaël Boulliau (Bulialdus). He reported that at Paris on 1623 July 5, he saw Spica disappear behind the Moon [1, 6]. Unfortunately, although this observation is contained in several modern sources (including the Royal Greenwich Observatory Bulletin of 1981 and the VizieR database [8, 9]), it is false and possibly based on a misunderstanding. That evening, Spica was not covered by the Moon, and in Europe only a close conjunction of both bodies could be observed[2]. At the moment Boulliau reported (9:30 pm local solar time), Spica was still quite far from the edge of the Moon, so even if the phenomenon would be interpreted as the moment of the disappearance of the star in clouds, the report is surprising. Gassendi at the same time observed at Aix and correctly stated in his report only that the Moon passed close to Spica, but no occultation took place (Table 3).

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[2] Occult gives a short grazing occultation on the horizon off the coast of northern Norway during the polar day.

Date	Star/ planet	Place	Observer	Ph.	Timing	Conj	UT eq.	Calculated	
								UT Occult	Conj. HPET
1623 Jul 5	Spica	Paris	Bullialdus	DD?	Moon h=17°20′	-	21:24	22:06	4′ S
		Digne	Gassendi	M	Spica h=10°46′	(a)	22:07	22:06	6′ S
1624 Sep 4	Aldebaran	Bruxelles	Langrenus	RD	Sideral time 351°10′		00:13	00:11.1	
1625 Feb 9	Venus	Paris	Gassendi	M	5^h40^m LST	(b)	17:46	17:24.0	4′ S
		Leiden	Hortensius	M	7^h LST	1′	19	17:31.7	2′ S
1627 Feb 22	Regulus	Bruxelles	Langrenus	RB	10^m20^s after culmin. of Sirius		19:52	19:42.9	
1627 Jun 17	Regulus	Digne	Gassendi	DD			22:05		
		Loudun	Bullialdus	DD	Moon h=16°28′		21:26	22:00.3	
1630 Jun 19	Saturn	Hven	Hevelius		-		-	21:47.8	
		Bruxelles	Langrenus	DD	Sideral time 241°06′		21:55	21:51.1	
				RB	Sideral time 253°42′		22:45	22:43.0	
		Paris	Gassendi	DD	10^h10^m LST		22:01	21:53.6	
				RB	11^h03 or 04^m LST		22:54	22:42.6	
1632 Feb 6	Mars	Paris	Gassendi	DB	Arcturus h=56°10′		03:07		
				RB	Vega h=31°54′		03:40	03:36.9	
		Leiden	Hortensius	M	Moon h=38°51′	1^d (c)	03:30	03:18.5	21″ N
		Madrid	Langrenus	DB	Sideral time 178°38′		03:06	03:02.9	
				RB	Sideral time 193°35′		04:06	04:01.9	
		Charlton Is.	James	DB	Regulus h=21°45′		01:15	01:16.6	

(a) Spica very close to the southern cusp of the Moon.
(b) Venus distant by several arc min from the southern cusp of the Moon.
(c) Mars at a distance of 1 lunar digit (=1/12 of the lunar diameter) north of the lunar limb.

Table 3. First telescopic observations of lunar occultations.

So, we must look for other phenomena.

On the night of 1624 September 3/4, Michael Florent van Langren (Langrenus, 1600-1675) observed in Brussels the reappearance of Aldebaran from behind the dark limb of the Moon [1,4]. According to his report, at that time the sidereal time in the local meridian was 351°10′[3], which is adequate to a moment 2 minutes later than today's data according to Occult. It can therefore be concluded that the observation of the young astronomer was correct. It is therefore the first ever documented stellar occultation by the Moon observed with a telescope.

Gassendi hoped to see Venus covered by the Moon on 1625 February 9. However, at Paris, where he was at that time, he recorded only a close conjunction at about 5:40 pm - the planet, he estimated, appeared to be touching the southern corner of the Moon. The conjunction was also observed in Leiden by Maarten van den Hove (Hortensius, 1605-1639), who at around 19 hours estimated the distance of Venus from the Moon's limb as only 1′.

Another observation of the occultation comes again from Langrenus, who reported that on February 22, 1627, he observed the reappearance of Aldebaran at the bright limb of the Moon (strange that for some reason he did not record the disappearance at the dark limb). After a further 10^m20^s (as measured by a pendulum), Sirius crossed the meridian. This time of the reappearance is 9 minutes late, which can be explained by the fact that the reported result refers to the moment when Aldebaran was first noticed after its reappearance, and not to the sudden phenomenon itself.

Finally, on 1627 June 17, at Digne, Gassendi saw his first occultation – of Regulus at the dark limb of the Moon, and judged this observation very certain. It is known that the telescope donated by Galileo was used for that observation. At the moment of disappearance, the altitude of Denebola (β Leonis) was 25°13′[4]. Compared to the Occult result, however, the moment was delayed by more than half a minute, which could have been due to either the low position of both bodies above the horizon (5°) or the inaccurate measurement of the altitude with the quadrant.

At Loudun, Boulliau simultaneously observed the occultation and gave the Moon's zenith distance as 73°32′ at the moment of the disappearance of Regulus. Unfortunately, such a value gives the moment of observation more than half an hour earlier than the actual one, resulting from Occult data, so an error in the measurement or a mistake in the recording of the zenith distance can be assumed (it should be about 79°).

Young Johann Hevelius noticed his first occultation - of Saturn by the Moon (only the disappearance) while travelling aboard a ship near the Danish island of Hven[5] on 1630 June 19. He allegedly used a telescope borrowed from the ship's captain. The reappearance of the planet was not visible because of the clouds. The same phenomenon was also observed by Langrenus at Brussels and Gassendi at Paris[6].

Gassendi, on the other hand, managed to observe the occultation of Mars by the full Moon on 1632 February 6, (the occultation was close to being a grazing one at the northern limb of the Moon, and lasted only about half an hour). He noticed that a similar phenomenon was recorded in antiquity by Aristotle[7]. The same phenomenon, lasting almost one hour, was observed at Madrid by Langrenus. Hortensius at Leiden saw a very close conjunction of both bodies (at a minimum distance of 1 lunar digit from the north; in fact, it was an even closer distance).

Moreover, on the island of Charlton in James Bay in Canada, this occultation was also seen by Thomas James (where it was the evening of February 5). This is probably the first documented report of an occultation from the American continent.

He also observed one lunar eclipse in 1631, thus trying to determine the geographical longitude of the observation site.

The First Observed Transit of Mercury

The year 1631 brought another crucial observation: on November 7, four astronomers recorded for the first time in history the transit of Mercury in front of the Sun's disc. Johann Kepler predicted this phenomenon in 1629 using the Rudolphine Tables, but he was not able to provide the exact moments of the contacts (he was not even sure about the day of the phenomenon, suggesting careful observations of the Sun from 6 to 8 November).

At Ingolstadt the phenomenon was successfully watched by the Jesuits, at Rouffach in Alsace – by Quietanus, at Innsbruck – by Johann Baptist Cysat and at Paris by Gassendi [1, 11].

Gassendi saw Mercury using a telescopic projection of the Sun's image onto a screen (but he did not record the contacts with the solar limb at the egress; the ingress was below the horizon) [3, 12]. While trying to observe this phenomenon at Aix, Gaultier saw nothing on the face of the Sun, however he probably used a camera obscura. The same negative result was obtained when using the camera obscura at the Court of the Landgrave of Hesse. Hortensius, on the other hand, was unable to observe anything due to the cloudy sky.

Gassendi was surprised by such a small apparent diameter of Mercury, which he estimated as equal to 20″. Quietanus' and Cysat's estimates were 18″ and 25″, respectively. Previously, it was estimated that the apparent size of the planet's disc during the lower conjunction was several times larger. It should be mentioned that the actual apparent diameter of Mercury on that day was only 10.0″, and a similar value to the real one was obtained from observation only in 1661 by Hevelius. The results from 1631 were therefore twice as high, which can be explained by the low quality of the telescopes used and the blurred image of the small planet's disc.

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[3] There is a typographical error in the Pingré's publication, as this value is completely wrongly given as 31°10′.

[4] Another error by Pingré - 15°13′.

[5] Today: Ven, Sweden; the former Tycho Brahe's observatory Uraniborg was located on this island.

[6] The observers did not give details on the disappearance of the planet's disc and its rings. It can be assumed that the disappearance concerned the visibility of the last fragments of the planet at the lunar limb, and the reappearance - a more noticeable presence of Saturn. The same applies to the occultation of Mars, described below.

[7] This occultation, presumably, took place on -356 May 4.

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CALL FOR OBSERVATION:

Trans-Atlantic Occultation by Centaur (54598) Bienor on 2020 Dec 29

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ABSTRACT: On 2020 December 29 the Centaur (54598) Bienor will occult UCAC 672-028789 (13.3 V-mag) for a maximum duration of 9.3 seconds across Europe and North America. Only two single positive chords occultation observations of this Centaur were recorded before. The upcoming event is a great opportunity to measure the shape and the size of Bienor.

The Centaur

(54598) Bienor has a diameter of 187.5 km [1] and an apparent magnitude of 19.1 at the time of occultation. A paper about the physical properties of (54598) Bienor is provided by Fernández-Valenzuela et al. [2] and a portrait of the Centaur was published by Guhl in [3].

The Occultation

The star UCAC4 672-028789 (Gaia 252858679067772032), 13.3 V-mag, in the constellation of Perseus will be occulted from ~01:57 UT until ~02:07 UT. The expected maximum duration is 9.3 seconds with a drop of the combined magnitude of star and asteroid of about 5.8 mag. The predicted path has an 1-sigma uncertainty in time of 13.3 s and 127.3 km across track [4].

The target star is located high above the horizon at the time of occultation with a mean elevation of 44° for Europe and 64° for the USA. The bright Moon at a distance of 24° to the target area may distract the observation.

The Predicted Shadow Path

Because (54598) Bienor is on its apparent retrograde motion the shadow will cross the Earth from East to West.

The shadow will reach the surface of the Earth on the Arabian Pensinsula around 01:57 UT and will pass over Turkey, the Balkan states, Austria ,Germany, Belgium, the Netherlands, England and Ireland before it will cross the Atlantic in less than 3 minutes. Bienor's shadow will pass over Eastern Canada and will enter the USA near Detroit. In Texas the shadow will cross Dallas and will move on to Northern Mexico before it will leave the surface of the Earth at the Pacific Ocean (Figures 1-3).

Occultation Observations

The first observation of a stellar occultation by Bienor was observed on 2017 Dec 29 in Japan, exactly 3 years before the upcoming event. Another observation was accomplished on 2018 Apr 2 in Hungary [5]. Both observations were single positive chords measurements.

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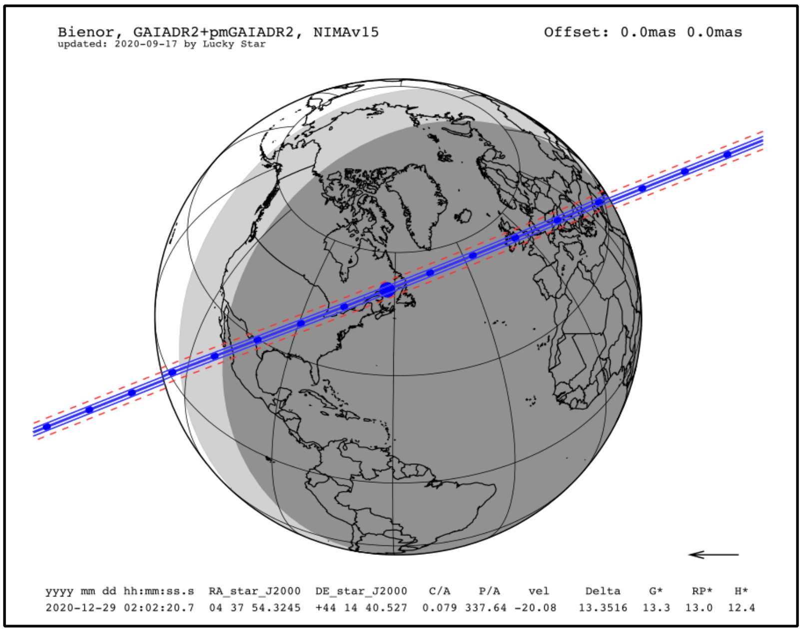
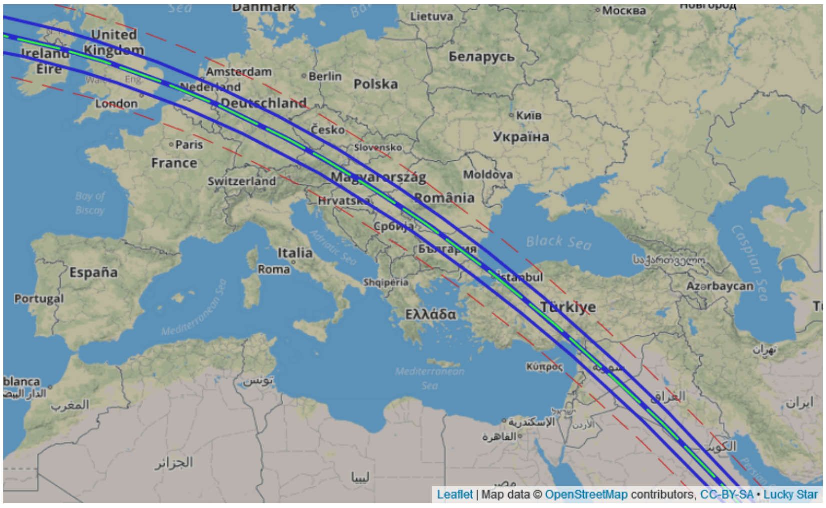


Figure 1.
The predicted path of stellar occultation by Bienor by the Lucky Star project. The prediction was updated on 2020 Sep 17. The blue dots are one minute marks. The big blue dot corresponds to the nominal occultation time 02:02:20.7 UT (the moment of geocentric closest approach). The red dashed line shows the 1-sigma cross-track uncertainty (127.3 km).



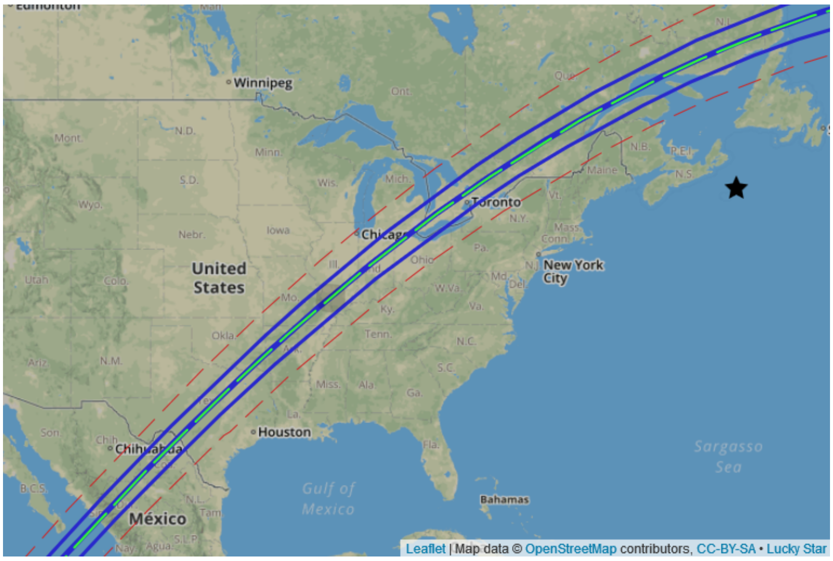


Figure 2 (top) and Figure 3 (left).
The shadow path of the occultation based on the prediction by the Lucky Star project. These maps are available as interactive maps on the webpage of the prediction [4].

Beyond Jupiter

The World of Distant Minor Planets

Since the downgrading of Pluto in 2006 by the IAU, the planet Neptune marks the end of the zone of planets. Beyond Neptune, the world of icy large and small bodies, with and without an atmosphere (called Trans Neptunian Objects or TNOs) starts. This zone between Jupiter and Neptune is also host to mysterious objects, namely the Centaurs and the Neptune Trojans. All of these groups are summarized as "distant minor planets". Occultation observers investigate these members of our solar system, without ever using a spacecraft. The sheer number of these minor planets is huge. As of 2020 Oct 05, the *Minor Planet Center* listed 1164 Centaurs and 2536 TNOs.

In the coming years, JOA wants to portray a member of this world in every issue; needless to say not all of them will get an article here. The table shows you where to find the objects presented in former JOA issues. (KG)

No.	Name	Author	Link to Issue
944	Hidalgo	Oliver Klös	JOA 1 2019
2060	Chiron	Mike Kretlow	JOA 2 2020
5145	Pholus	Konrad Guhl	JOA 2 2016
8405	Asbolus	Oliver Klös	JOA 3 2016
10199	Chariklo	Mike Kretow	JOA 1 2017
15760	Albion	Nikolai Wünsche	JOA 4 2019
20000	Varuna	Andre Knöfel	JOA 2 2017
28728	Ixion	Nikolai Wünsche	JOA 2 2018
50000	Quaoar	Mike Kretlow	JOA 1 2020
54598	Bienor	Konrad Guhl	JOA 3 2018
60558	Echeclus	Oliver Klös	JOA 4 2017
90377	Sedna	Mike Kretlow	JOA 3 2020
90482	Orcus	Konrad Guhl	JOA 3 2017

In this Issue:

(47171) Lempo

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ABSTRACT: The Plutino (47171) Lempo is a highly dynamic triple system in the Kuiper Belt comprising a close pair of two objects of similar size and a third, smaller, circumbinary component. The characteristics of the objects and their orbits are poorly defined making it difficult to identify how the system formed. Although the triple system was selected as one of four possible TNO targets for a space probe flyby, this will not now happen and so occultation studies are particularly valuable. Four forthcoming occultations of stars brighter than 15.2 V-mag during 2021-2030 have been identified using *Occult V.4* software.

No.	Name	Author	Link to Issue
120347	Salacia	Andrea Guhl	JOA 4 2016
134340	Pluto	Andre Knöfel	JOA 2 2019
136108	Haumea	Mike Kretlow	JOA 3-2019
136199	Eris	Andre Knöfel	JOA 1 2018
136472	Makemake	Christoph Bittner	JOA 4 2018

The Discovery of the Triple System

Louis-Gregory Strolger took images at *Kitt Peak National Observatory* (Arizona, USA) in 1999 while his colleague Eric Rubenstein searched these images as part of the Low-Z Supernova Search programme. On 1999 October 1 they discovered an object far out in the Kuiper Belt. The new object received the provisional designation 1999 TC$_{36}$. [1]

On 2001 December 8 and 9, C. A. Trujillo and M. E. Brown recorded images of the distant object with the *Hubble Space Telecope*'s imaging spectrograph (STSI) in a survey for trans-Neptunian binaries and found 1999 TC$_{36}$ as an object of two components (Figure 1). Separations of 0.365" +/-0.001" in a position angle of 2.0 +/- 0.1 deg and 0.367" +/- 0.001" in p.a. 3.7 +/- 0.1 deg were measured on the two dates, respectively [2].

The data obtained was re-analysed by Benecchi et al. and they could identify 1999 TC$_{36}$ as a binary system [3].

Jacobson et al. suspected as early as in 2004 that the binary system could be triple. The primary should resolve as a point source due to the distance to 1999 TC$_{36}$ and the restricted size of the primary from the system mass. However, the point spread function (PSF) fitting revealed that a single point source for the primary did not adequately fit the data. Further analysis showed that, with a 99% confidence, the data require two PSF components in order to properly model the primary [4]. A triple configuration had also been independently hypothesized due to the unexpectedly low density of 1999 TC$_{36}$ [5].

Another analysis of archival images taken with the *Advanced Camera for Surveys* (ACS) of the *Hubble Space Telescope* by Benecchi et al. led to the confirmation of the triple system in 2007 (Figure 2), [6].

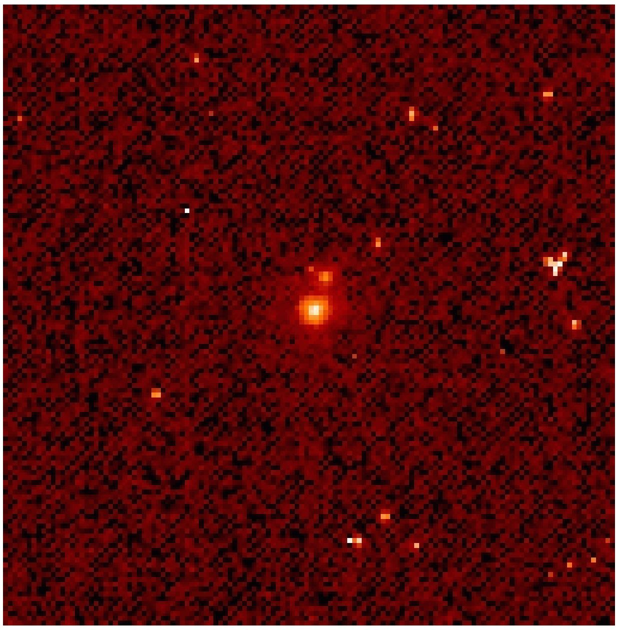

Figure 1. 2001 Hubble Space Telescope image of (47171) 1999 TC36. This image shows 1999 TC36 as a binary object (components A +B). (NASA, STScI)

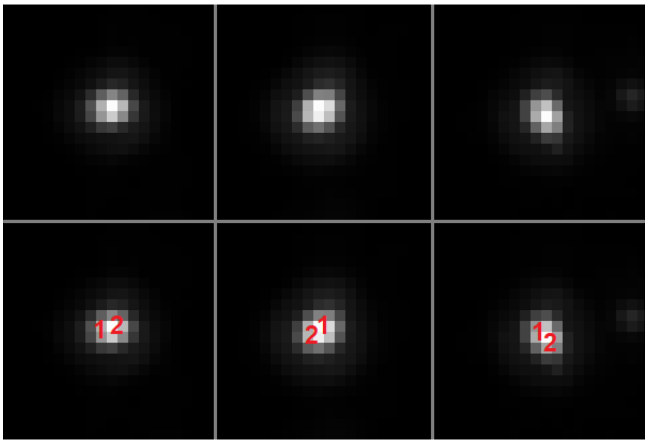

Figure 2. The separation between the two components is only about half the diffraction limit of the Hubble Telescope, making it impossible to fully resolve the system. The system instead appears elongated, revealing its binary nature. In the image, the positions of the components have been marked "1" (Lempo) and "2" (Hisii). Sample images used: J8RL04011, taken 2006-07-06 J8RL08011, taken 2003-08-23 J8RL09011, taken 2004-05-26 Each image is a 2440s exposure of Hubble's ACS instrument, using the F606W filter. The native image resolution is 0.025 arc-seconds per pixel. HST Proposal 9746 by Margot [7], processed by D. Bamberger, based on method described in [6]. (NASA, STScI) https://commons.wikimedia.org/wiki/File:Lempo_Hiisi.png

The Name

Because the main body of the object 1999 TC$_{36}$ was named after Lempo, an ancient Finnish devil, who brought down the hero Väinämöinen, the two smaller objects were named after Lempo's two demon cohorts, called Paha and Hiisi [3].

The Orbit

Pre-discovery images of Lempo were found on DSS-plates of the *Siding Spring Observatory* from June 1974 and May and Sep 1976 [8]. A total of 501 observations over an interval from 1974 June 18.703 to 2020 July 22.613 were obtained (Status: Sep 2020). It takes 247.20 years for Lempo to complete its orbit around the Sun with a semi-major axis of 39.39 AU. The KBO passed perihelion in January 2015 at a distance of 30.54 AU. Perihelion is just outside of the orbit of Neptune and Lempo's minimum distance to Neptune's orbit is as close as 2.16 AU. The orbit follows a 2:3 mean-motion resonance to Neptune and therefore (47171) Lempo belongs to the dynamical group of Plutinos. At aphelion the triple asteroid is 48.23 AU away from our Sun. The orbit has an inclination of 8.42 deg and an eccentricity of 0.22 (Figure 3), [9].

Physical Characteristics

Physical characteristics given below for each component are taken from the Johnston's Archive [10]. Diameters were also obtained by Mommert et al. using observations with the *Photometer Array Camera and Spectrometer* (PACS) onboard the *Herschel Space*

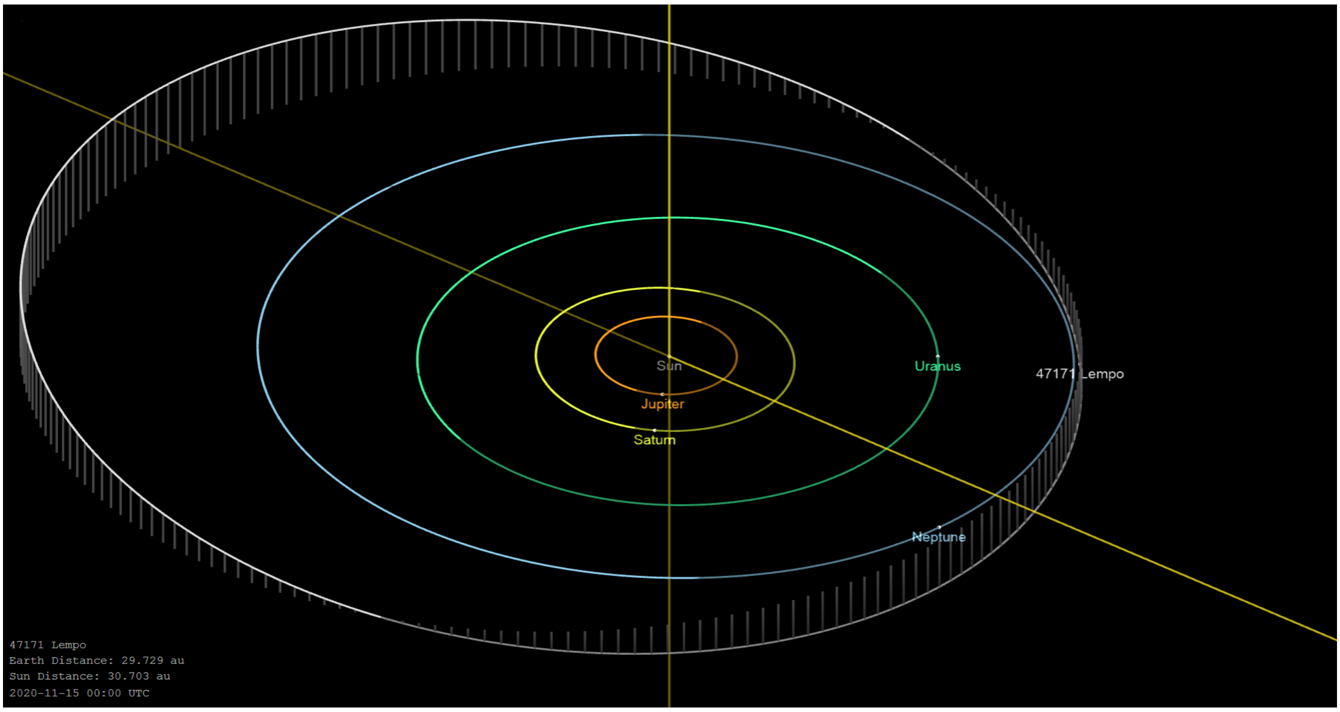

Figure 3. The orbit of (47171) Lempo. JPL Small-Body Database Browser, https://ssd.jpl.nasa.gov/sbdb.cgi?sstr=47171

Observatory and the *Multiband Imaging Photometer for Spitzer* (MIPS) of the *Spitzer Space Telescope* [11]. Rotation periods, orbital periods and semi-major axes were submitted by Benecchi et al. [6]. Diameter ratios are estimated values.

Lempo

The Johnston's Archive lists a rotation period of 45.763 ± 0.002 h and a diameter of 272 ± 17/19 km. On the Light Curve Database (LCDB) a rotation period of 6.21 hours is given. But this value can be erroneous because it is based on fragmentary lightcurve(s) [12]. Mommert measured a bulk density of 0.64 ± 0.15/0.11 g/cm^3 [11].

Paha - The Second Component

The small second component with a diameter of 132 ± 8/9 km and a diameter ratio of 0.486 ± 0.1 has a semi-major axis of 7411 ± 12 km and an orbital period of 50.302 days.

Hiisi - The Third Component

Hiisi's orbit lies inside the orbit of Paha and has a semi-major axis of 867 ± 11 km. The orbital period is about 1.907 days. With a diameter of 251 ± 16/17 km Hiisi is close to twice the size of Paha. Hiisi has a near-spherical shape with a diameter ratio of 0.927 ± 0.19.

Near-infrared photometric and spectroscopic observations of (47171) Lempo by Protopapa et al. in October 2006 with the ESO VLT revealed a mixture of Triton tholin, Titan tholin, serpentine and Triton tholin diluted in water ice. This composition fits best the description of the measured spectra [13].

Models for the Triple System

The origin of the system is still unkown. While the systems of Haumea and Pluto are considered to be formed by collisions, the formation by gravitational capture is more likely for the Lempo system [6].

Orbital solutions were discussed in detail by Alexandre C. M. Correia [14]. The best fitted orbital solution used point-mass non-interacting Keplerian orbits [6] but Correia stated that the observed data requires a more advanced model especially for long timescales when tide effects become efficient. For one model the calculations used spherical models for all three components. But the real shapes and rotation periods are an important factor for long-time calculations. Correia compared the data of radius and density of the Lempo's system with similar data for other objects in the solar system and found relevant models in two of Saturn's irregular formed moons. Hyperion fits this comparison and therefore semi-axes as for Hyperion of 180×133×103 km were assumed for the inner bodies of the triple system, Lempo and Hiisi respectively. The radius and density of Paha can be compared to Epimetheus, which has a mean volumetric diameter of 116 km and a mean density of 0.64 g/cm^3. Therefore Correia assumed in his calculations the same semi-axes as Epimetheus: 65×57×53 km.
Correia concluded that a more precise analysis of this system requires a better knowledge of the present orbits, spin states and shapes of all components of the system.

Exploration

The Lempo system was considered as a possible target for the NASA mission *New Horizons 2*, a clone of the highly successful *New Horizons* probe to Pluto and (486958) Arrokoth. Launch windows in 2008 and 2009 would have made *New Horizons 2* the second spacecraft after *Voyager 2* to make a flyby of Uranus. Three or four KBOs would have been visited by the probe [15]. Unfortunately this mission was not further developed. One of the reasons for refusing the development was the shortage of the isotope Plutonium-238 for the electricity-generating Radioisotope Thermal Generator (RTG) onboard the probe at this time [16].

Stellar Occultations

No stellar occultations by the Lempo system have been observed to date (Sep 2020). Currently (47171) Lempo can be found in the constellation of Aries and will enter Taurus at the end of 2023. From October 2029 until July 2031 the triple system will pass the open cluster of the Hyades.

The author has calculated upcoming occultations of stars brighter than 15.2 mag until 2030 with *Occult V. 4* software and *JPL Horizons* data for the Plutino (Table 1), (Figure 4-7).

Conclusion

The triple system Lempo is one of the most interesting objects known in the Kuiper Belt. The shape, spin-axis and rotation periods of the components are important for the calculations of orbital solutions for this highly dynamic system over an extended time span. Such values are measured with high precision during stellar occultations. Stellar occultations of stars brighter than 15.2 V-mag will not happen before October 2021.

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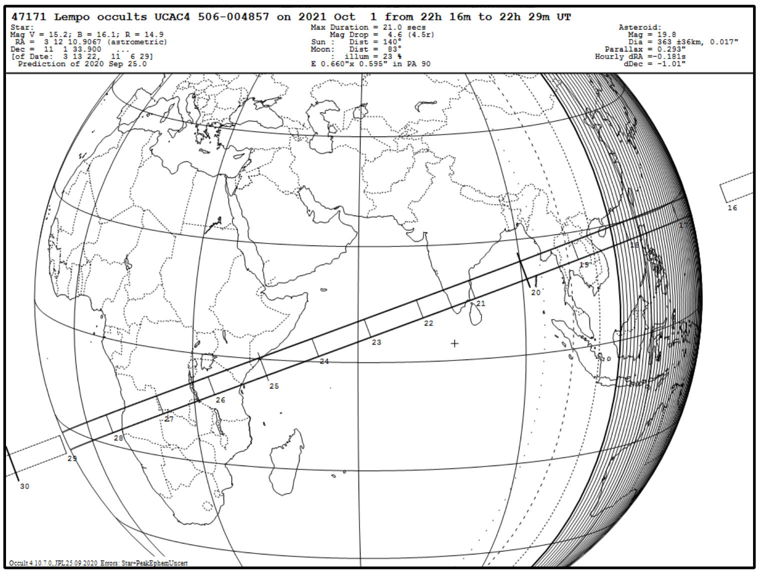
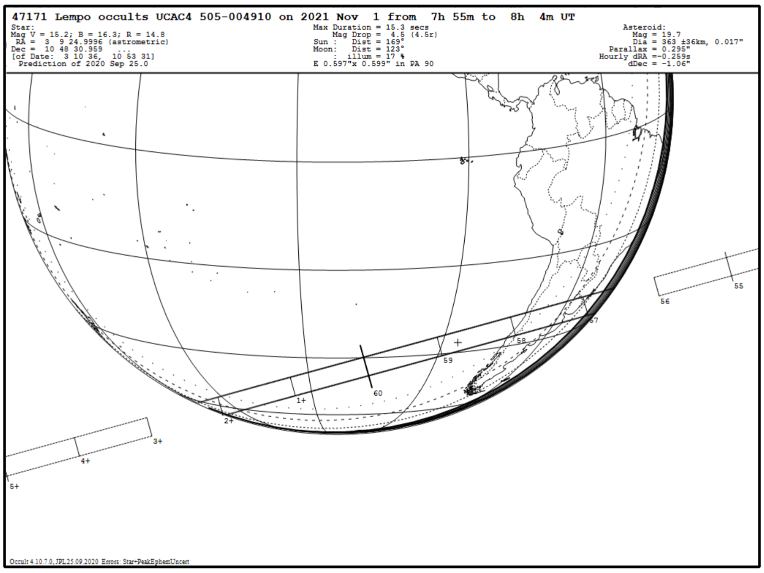
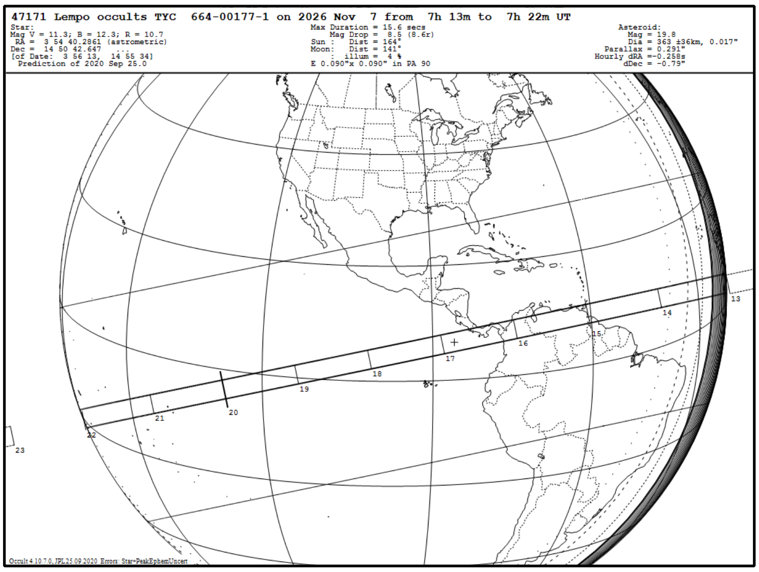
Date	UCAC4	S	Region	V-mag	Duration
2021 Oct 1	506-004857	U	Asia & Southern Africa	15.2	21.0 s
2021 Nov 1	505-004910	G	South America	15.2	15.3 s
2026 Nov 7	525-007093	G	Central & South America	11.3	15.6 s
2029 Jul 11	536-008641	G	Western Europe (at dawn)	14.2	13.3 s

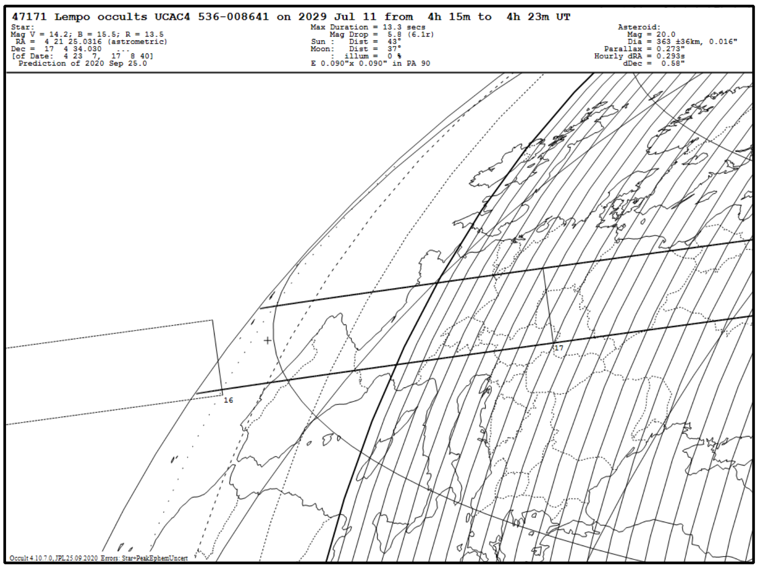
S - Source of star position: U = UCAC4, G = Gaia DR2

Table 1. Upcoming stellar occultations by (47171) Lempo of stars brighter than 15.2 V-mag until year 2030.









Figures 4 - 7.
Path maps of predictions of stellar occultations by (47171) Lempo. Calculated on 2020 Sep 25 with data from JPL Horizons and Dave Herald's software Occult V. 4.

ESOP XXXIX – Report of the 39th European Symposium on Occultation Projects

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ABSTRACT: The 39th ESOP was planned to take place in Freiburg im Breisgau, Germany, but because of travel restrictions due to the COVID-19 pandemic it was decided to hold the Symposium as an online video conference using Zoom software. A total of 114 amateur and professional occultation observers and researchers from the following countries and region registered and attended the 2-day web event: Argentina, Australia, Austria, Belgium, Brazil, Catalonia, Czechia, France, Germany, Greece, Ireland, Italy, Japan, Netherlands, Poland, Slovakia, Spain, Switzerland, Thailand, Turkey, Ukraine, United Kingdom and the USA.

This year's ESOP followed the usual format of themed sessions conducted by a chairperson, with the addition of a chatcom, whose role was to monitor the questions and comments submitted online, and to discuss these at the end of each talk in a 5 minute questions and answers interval.
Full details of the Symposium can be found here:

https://esop39.iota-es.de/

including the set of Abstracts and the Programme with PDFs and recorded live videos of many of the speakers' presentations.

Saturday 29th August 2020 - Day 1

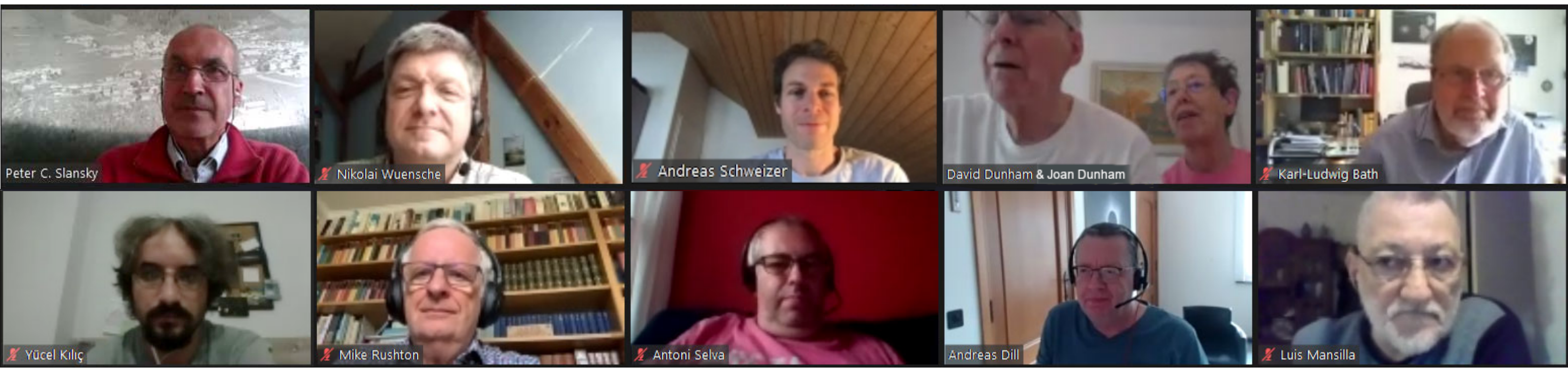
Before the formal opening of the Symposium, Oliver Klös asked everyone to follow the netiquette of using the conference software to ensure the best experience for all delegates.
The President of IOTA/ES, Konrad Guhl welcomed everyone to the 39th ESOP which had to be conducted as a 'virtual' conference due to the exceptional circumstances.

Session - Results and Perspectives
chaired by Wolfgang Beisker - (chatcom Konrad Guhl)

Mike Kretlow (Germany) presented the first talk and he discussed the families of small bodies in the solar system. He explained how occultation observations provide high-quality astrometry, 2D profiles (from accurate chords) and 3D shape models complete with dimensions when combined with light curve inversion techniques, giving estimates of a body's volume and mass. Mike is developing SiMDA, a web-based archive of Size, Mass and Density of Asteroids.

Dave Herald (Australia) reviewed the best asteroidal occultation results of 2019 and he showed how the Gaia star catalogues have contributed to our growing numbers of positive events. These included the discovery of 8 double stars and he illustrated the quality of asteroid shape models compared with satellite measurements, including those derived of (3200) Phaethon, and (32) Sylvia and its moons.

Not all occultation observations are made by amateur astronomers. Andrea Richichi (INAF - Arcetri, Italy) spoke about the work done by himself and other professionals in this field.



They use large telescopes such as 1.2 m (Trebur, Germany – hosted ESOP in 2003), 1.8 m (Asiago, Italy), 3.6 m (Devasthal, India) and 6 m (Caucasus, Russia) equipped with high-speed photometers to record lunar and asteroidal occultations in spectrally dispersed wavelengths.

Many asteroid shape models are derived from light curve inversion of bodies with short duration periods and large amplitudes. Prof. Anna Marciniak (Poznan Astronomical Observatory Institute, Poland) described her involvement in a worldwide project to monitor main belt asteroids with long periods and small amplitudes.Occultation observations can contribute to this work by constraining the shape profiles.

Prof. Bruno Sicardy (Observatoire de Paris, France) summarised the latest successes of the Lucky Star project (funded by the European Research Council), which uses occultation techniques to study bodies in the outer solar system. This pro-am cooperation obtained a large number of chords across the trans-Neptunian object 2002 MS_4 on 2020 August 8 and Bruno shared some information about Triton's atmosphere, derived from analyses of the major occultation event of 2017 October 5.

In the next talk Altair Gomes-Júnior (Sao Paulo State University, Brazil) explained that the giant planets are accompanied by some irregular satellites moving in highly inclined and eccentric orbits. A programme of occultation observations, is helping to measure and refine the shape profiles of these primordial bodies, such as Himalia (Jupiter VI) and Phoebe (Saturn IX).

Session - Technology

chaired by Alex Pratt - (chatcom Nikolai Wünsche)

The Watec 910 analogue video camera with GPS-VTI has been called our 'gold standard', although the future lies in digital CMOS technology. Christian Weber (Germany) described his evaluation of Prototype V2 of the DVTI camera (Digital Video Time Insertion) a Kickstarter project developed by Andreas Schweizer and Stefan Meister (Switzerland). It uses the same sensor as the QHY174GPS, so is not quite as sensitive as the Watec 910, although it applies accurate timestamps with no calibration required, unlike the QHY174GPS. The Swiss camera is operated via the 'DVTI Cam Control' GUI with FITS, ADV and SER output options. Prototype V3 will be available soon.

Analogue video cameras obtain accurate timings from video time inserters. This is more of a challenge for digital cameras using their computer's clock time; there can be some uncertainties with NTP solutions. Cesar Valencia Gallardo (France) is the designer and developer of TimeBox, a device which accurately synchronises Windows computers with UTC obtained from GPS satellites. He described the accuracy of TimeBox in both computer synchronisation and trigger modes.

Session - Astrometry
chaired by Mike Kretlow - (chatcom Nikolai Wünsche)

João Ferreira (Observatoire de la Côte d'Azur, France) explained the performance of occultation astrometry with Gaia DR2. The archive of observations obtained using old star catalogues were debiased compared to DR2 and by applying subtle corrections and weightings this method can improve the asteroids' orbital elements. The best results are obtained from multi-chord observations. These better orbits, combined with Gaia DR2 star positions, are delivering higher quality predictions.

This theme was continued by David Dunham (USA), who described a method of improving predictions by considering the observed path shift of an asteroid's previous occultations. Applying this technique to predictions of occultations by (3200) Phaethon, the parent of the Geminids meteor shower, secured a valuable series of chords across this 5 km-wide NEO. His presentation included examples of other campaigns and mentioned that many bright stars have large positional uncertainties in Gaia DR2.

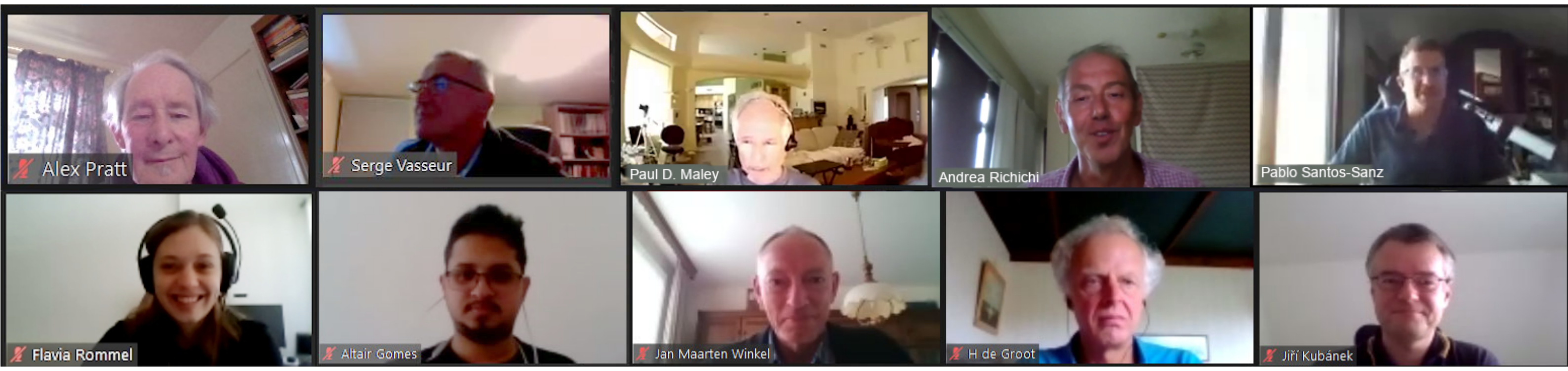
This completed the first day of ESOP XXXIX. We asked everyone to enable their video settings so we could take group photos of our multiple screens. The Zoom meeting remained open for quite some time afterwards for delegates to discuss the day's topics and to chat with their friends.

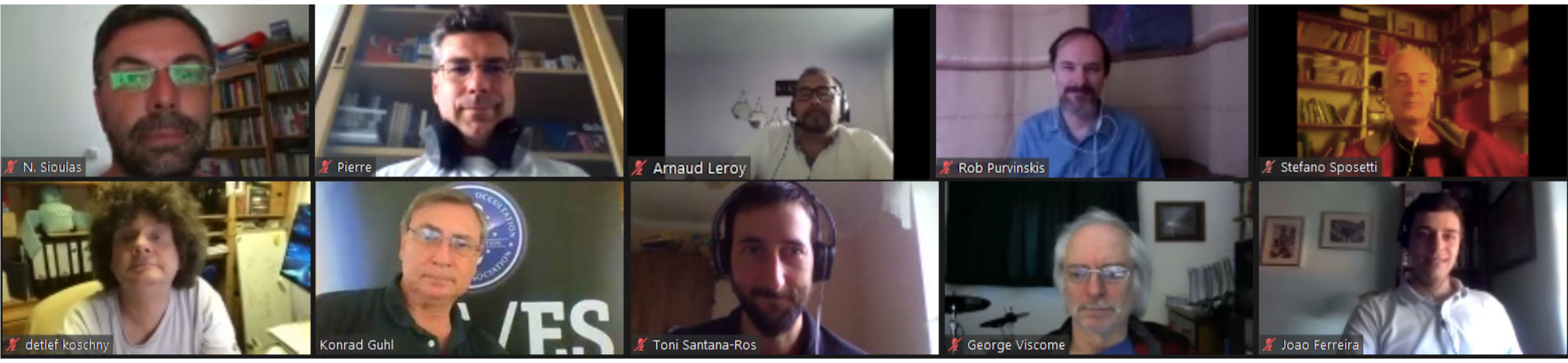
Sunday 30th August 2020 - Day 2

Session - Predictions & Campaigns
chaired by Konrad Guhl - (chatcom Nikolai Wünsche)

Josselin Desmars (IMCCE, Observatoire de Paris, France) was the first speaker on day 2 and he invited observers to take part in the PHEMU 21 campaign (PHÉnomènes MUtuels, mutual phenomena) which takes place next year. Every 6 years Jupiter crosses the plane of the ecliptic and the orbits of the 4 Galilean satellites (plus Amalthea and Thebe) are then edge on to us, so we see them undergo numerous mutual eclipses and occultations. Good quality photometry of PHEMUs is used to derive precise astrometry of the satellites and this is important for planning the JUICE, CLIPPER and IVO missions, and for studies of Jupiter.

Oliver Klös (Germany) has a particular interest in asteroids that are known to have satellite companions and he publicised the major event in October 2019 when European observers timed many chords across (87) Sylvia and its moons Romulus and Remus. He highlighted a series of predictions for 2021 of occultations by asteroids and their moons occurring across Europe, North Africa, North America and Australasia.





Session - Software

chaired by Tim Haymes - (chatcom Nikolai Wünsche)

The planetarium program C2A is an excellent add-in to Occult Watcher, then in 2018 Andreas Eberle (Stuttgart, Germany) released an add-in for Guide 9. Wojciech Burzyński (Poland) now announced a new add-in, written by his colleague Grzegorz Czepiczek, which supports the popular and free software Cartes du Ciel (CdC). Wojciech described how to download and configure the new CdC add-in for occultation observing.

Yücel Kiliç (TÜBİTAK National Observatory, Antalya, Turkey) discussed the problems for researchers when collating all observations of an occultation from disparate sources, such as when analysing major Lucky Star events. He announced a common online platform being developed at TÜBİTAK National Observatory which would become a datacentre for FITS data and other image formats.

Occult Watcher offers a number of prediction feeds. Robert Purvinskis (Germany) discussed his proposal for a new deep feed to magnitude 17 for large aperture telescopes. It will use selected Gaia DR2 star fields along the ecliptic (but avoiding dense Milky Way areas), G magnitudes between 14 and 17, and only main belt asteroids with diameters between 7 km and 50 km.

In his earlier talk at the Symposium, Christian Weber mentioned that the QHY174GPS camera provides limited GPS data output and it requires calibrating to deliver its most accurate timestamps. In this talk he explained how to upgrade the camera's firmware to obtain more GPS status information with stable calibration and no dropped frames. (It is a tricky procedure; it is likely to violate the manufacturer's warranty and it risks damaging the camera). Christian's presentation led to a lively online discussion.

Session - Observations

chaired by Martina Haupt - (chatcom Sven Andersson)

Alex Pratt (UK) described his experience of recording 2 positive asteroidal occultations within 10 minutes and discussed how such opportunities will occur more frequently when the final Gaia Data Releases could deliver several high-quality predictions per night.

Wojciech Burzyński (Poland) reported on observations of the long-awaited grazing occultation of Propus (Gem). The observers knew the star was double and prepared accordingly, but even so its predicted graze track displayed significant movement. He explained the mystery of the true identification of Propus and the uncertainties in its position.

Many observers are deterred from a minor planet occultation with a drop in brightness < 0.1 magnitudes. Paul Maley (USA) rises to such challenges, including encountering wildlife when observing from remote locations, and he described how the 0.06 mag. drop of a mag. 12.8 star was successfully recorded by 2 stations in the USA.

Costantino Sigismondi (ICRA/Sapienza, IIS Caffè, Rome, Italy) has a long-term interest in timing the disappearance and reappearance of Baily's Beads during solar eclipses to estimate the diameter of the Sun. His talk on video recording and analysing the partial and nearly grazing solar eclipse of June 21, 2020 was given as a pre-recorded video then he joined us live to answer questions on his work.

Session - Next ESOPs & Closing

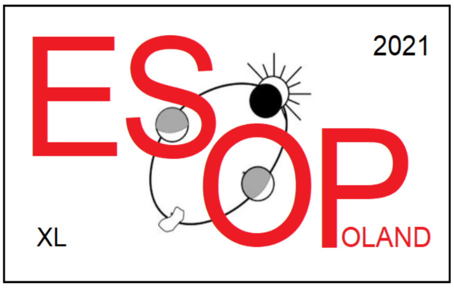
chaired by Konrad Guhl - (chatcom Nikolai Wünsche)

ESOP XL in Bialystok, Poland in 2021.
Wojciech Burzyński, on behalf of the Local Organising Committee and the Occultation Section of the Polish Astronomers Society, invited delegates to attend next year's Symposium to be held from August 27-31 at the Faculty of Physics, University of Bialystok, NE Poland.

ESOP XLI in Granada, Andalucia, Spain in 2022.
Pablo Santos-Sanz (Spain) & Carles Schnabel (Catalonia) also invited everyone to meet in Granada, southern Spain, the home of the Andalusian Institute of Astrophysics, in 2022. They illustrated the alternative venues for hosting ESOP and the cultural and astronomical options for excursions.

Closing remarks
Konrad Guhl (IOTA/ES President), thanked everyone for attending this virtual ESOP and those delegates who had generously donated to support its running costs. It wasn't quite the same as meeting in person but everyone had enjoyed this format and he hoped we could all meet in person at next year's Symposium in Bialystok, Poland. The Zoom meeting remained open for a while as we took more photos of our screen thumbnails, thanked the members of the Local Organising Committee and said our goodbyes.

See you



Journal for Occultation Astronomy

IOTA's Mission

The International Occultation Timing Association, Inc was established to encourage and facilitate the observation of occultations and eclipses It provides predictions for grazing occultations of stars by the Moon and predictions for occultations of stars by asteroids and planets, information on observing equipment and techniques, and reports to the members of observations made.

The Journal for Occultation Astronomy (JOA) is published on behalf of IOTA, IOTA/ES and RASNZ and for the worldwide occultation astronomy community.

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IOTA on the World Wide Web

IOTA maintains the following web sites for your information and rapid notification of events:

www.occultations.org
www.iota-es.de
www.occultations.org.nz

These sites contain information about the organisation known as IOTA and provide information about joining.

The main page of occultations.org provides links to IOTA's major technical sites, as well as to the major IOTA sections, including those in Europe, Middle East, Australia/New Zealand, and South America.

The technical sites hold definitions and information about all issues of occultation methods. It contains also results for all different phenomena. Occultations by the Moon, by planets, asteroids and TNOs are presented. Solar eclipses as a special kind of occultation can be found there as well results of other timely phenomena such as mutual events of satellites and lunar meteor impact flashes.

IOTA and IOTA/ES have an on-line archive of all issues of Occultation Newsletter, IOTA'S predecessor to JOA.

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