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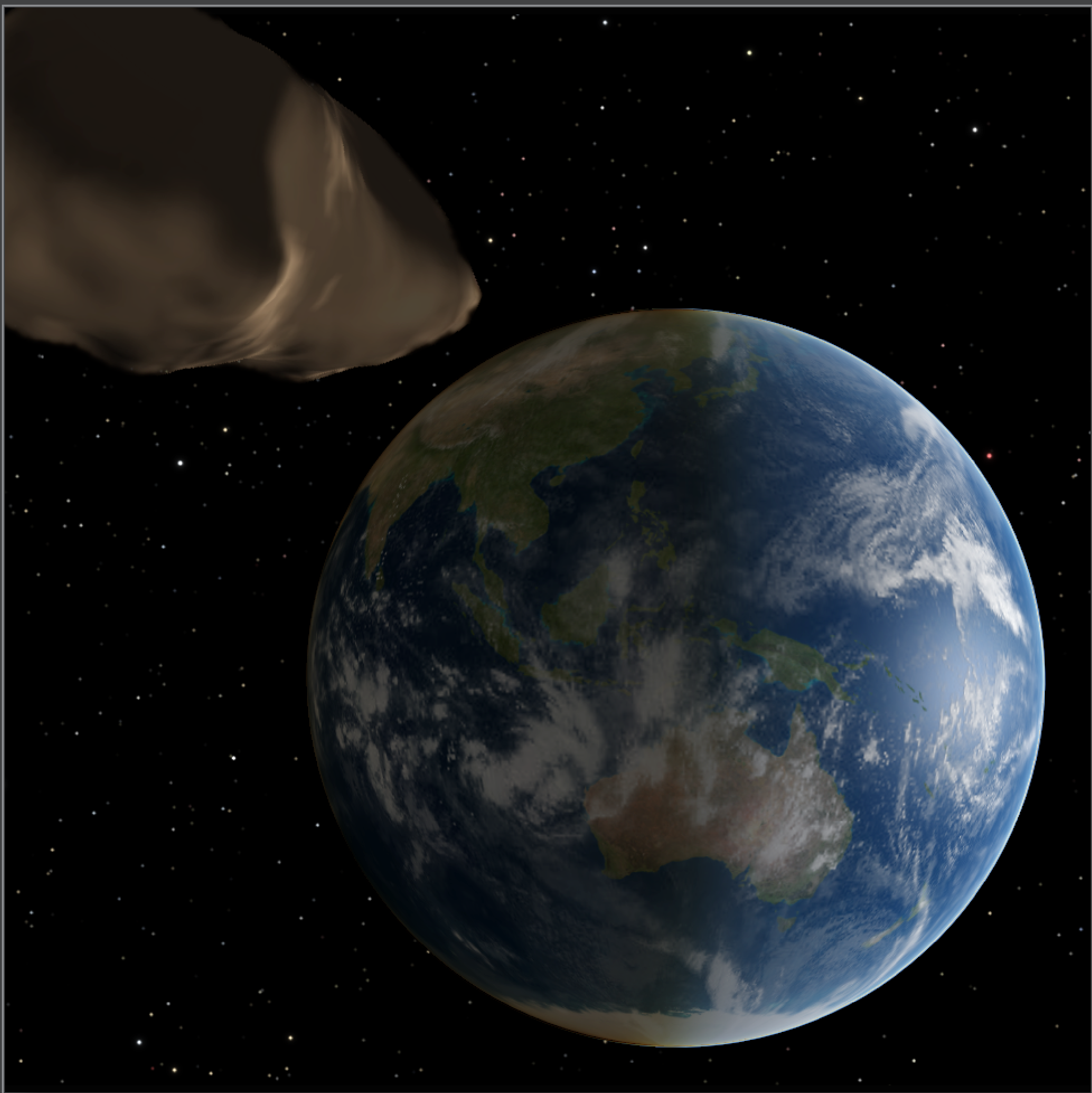

NEAs - An Occultation Observation Challenge

Dear reader,

this issue of the JOA reports on the IOTA meeting in the USA and discusses observations of the, fortunately very small, NEOs. Of course, the Beyond Jupiter series is continued and there is a Call for Observations for upcoming stellar occultations by the Jupiter Trojan (624) Hektor and its satellite Skamandrios.

However, we do not report on an issue that is currently keeping us in Europe very busy: The end of Euraster.net at the end of 2022. With Euraster.net, Eric Frappa operated an excellent portal for the collection of observation data.

Now, IOTA/ES will create a successor solution. At the moment we are still very busy with this, but I would like to thank all those who are involved now and in the future. Even though there are still some problems, it is nice to see how everyone involved is helping to find a solution. Our friends from overseas have also helped energetically from day one in this work. Perhaps this will lead to a globally uniform database and the phrase: "Every problem is an opportunity in disguise" will prove true once again.

Konrad Guhl
President IOTA/ES

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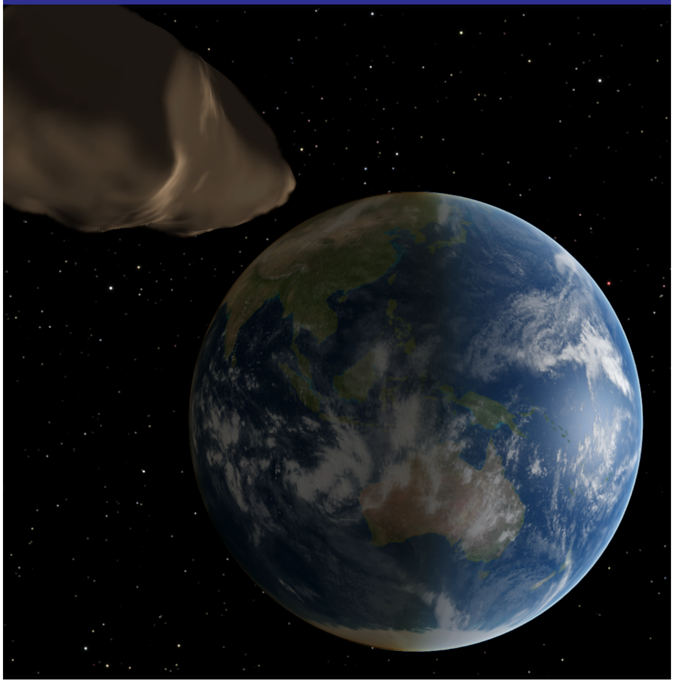
In this Issue:

COVER



The observation of near-Earth asteroids (NEAs) is challenging. The small dimensions of these objects and their fast movements across the sky plane push observers to the limits of their observing capabilities. There are pitfalls in the evaluation process of these occultations as Roger Vernable reports in this issue. Nevertheless, they are an important part of the Pro-Am collaboration today. Artistic impression: O. Klös, with images from *Celestia 1.6.6.2.*

Copyright Transfer

Rules for Authors

In order to optimise the publishing process, certain rules for authors have been set up how to write an article for *JOA*. They can be found in "How to Write an Article for *JOA*" published in this *JOA* issue (2018-3) on page 13. They also can be found on our webpage at http://www.iota-es.de/how2write_joa.html .

Journal for Occultation Astronomy

CALL FOR OBSERVATIONS:

Stellar Occultations by (624) Hektor and Skamandrios, October 2022 - March 2023

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ABSTRACT: Between October 2022 and March 2023, Jupiter's Trojan (624) Hektor and its moon Skamandrios will go through their retrograde phase. Especially, stellar occultations close to the stationary points offer the possibility to obtain high-resolution data on (624) Hektor and to detect the satellite. 19 events with stars brighter than 15th magnitude are observable during this period.

Introduction

Discovered in 1907 by August Kopff at the observatory of Heidelberg, Germany, asteroid (624) Hektor is the largest object among the Trojans in Jupiter's preceding Lagrange point L_4.

Observations of light curves suggest an elongated shape of the asteroid with a dimension of about 225 km [1]. It cannot be ruled out that (624) Hektor may also be a contact binary. In 2006, a satellite was discovered by Franck Marchis et al. [2]. The small object with a diameter of 12 km ± 3 km orbits (624) Hektor with a maximum distance of 623.5 km in 2.9651 days. The orbit of the satellite has a large eccentricity of 0.31 and an inclination of 50.1 ± 1 degrees [3]. On 2017 March 12, the satellite was named after Skamandrios, the son of Hektor and Andromache in the Greek mythology [4]. Several orbit solutions are available from Miriade [5].

Past Observations

As of the end of September 2022 the database in *Occult* shows measurements of six stellar occultations by (624) Hektor [6]. The most successfully observed stellar occultation happened on 2019 August 28. Observers on both sides of the Atlantic recorded six positive and nine negative chords. Another transatlantic observing campaign on 2020 October 28 measured four positive and four negative chords.

Most recently, on 2022 August 30, five stations in Poland, Italy and Algeria successfully observed the stellar occultation of UCAC4 654-034537 (11.3 Vmag) by (624) Hektor (Figure 1). In addition, Oscar Canales in Botorrita, Spain, was able to detect a short occultation of only 0.6 s duration with a SC 200 mm and a QHY174M-GPS recording at 5 fps (Figure 2). This seems to be the first detection of a stellar occultation by the moon Skamandrios. The observation is currently being evaluated by the team of the Lucky Star project [7].

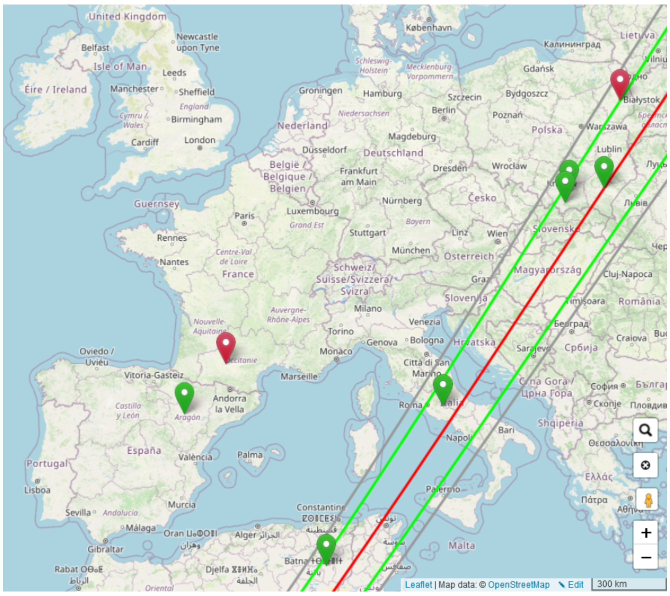


Figure 1. The observing stations of the occultation by (624) Hektor on 2022 Aug 30. Red flags indicate a negative observation, positive ones are in green. The green flag in Spain shows Oscar Canales' observing site of the possible detected occultation by Skamandrios. (Source: Occultation Portal, [8])

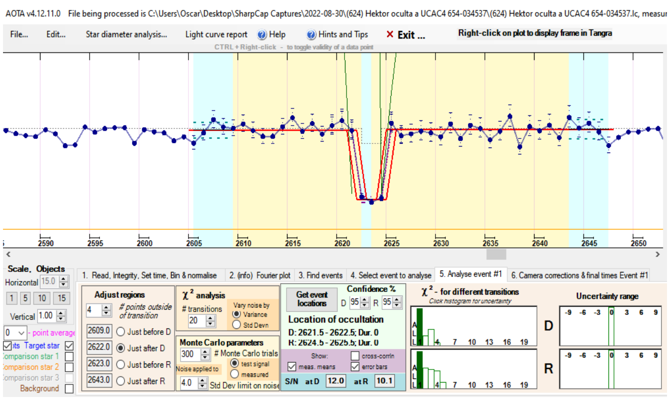


Figure 2. Oscar Canales' lightcurve in AOTA. 3 data points show the occultation by the satellite. (Credit: O. Canales)

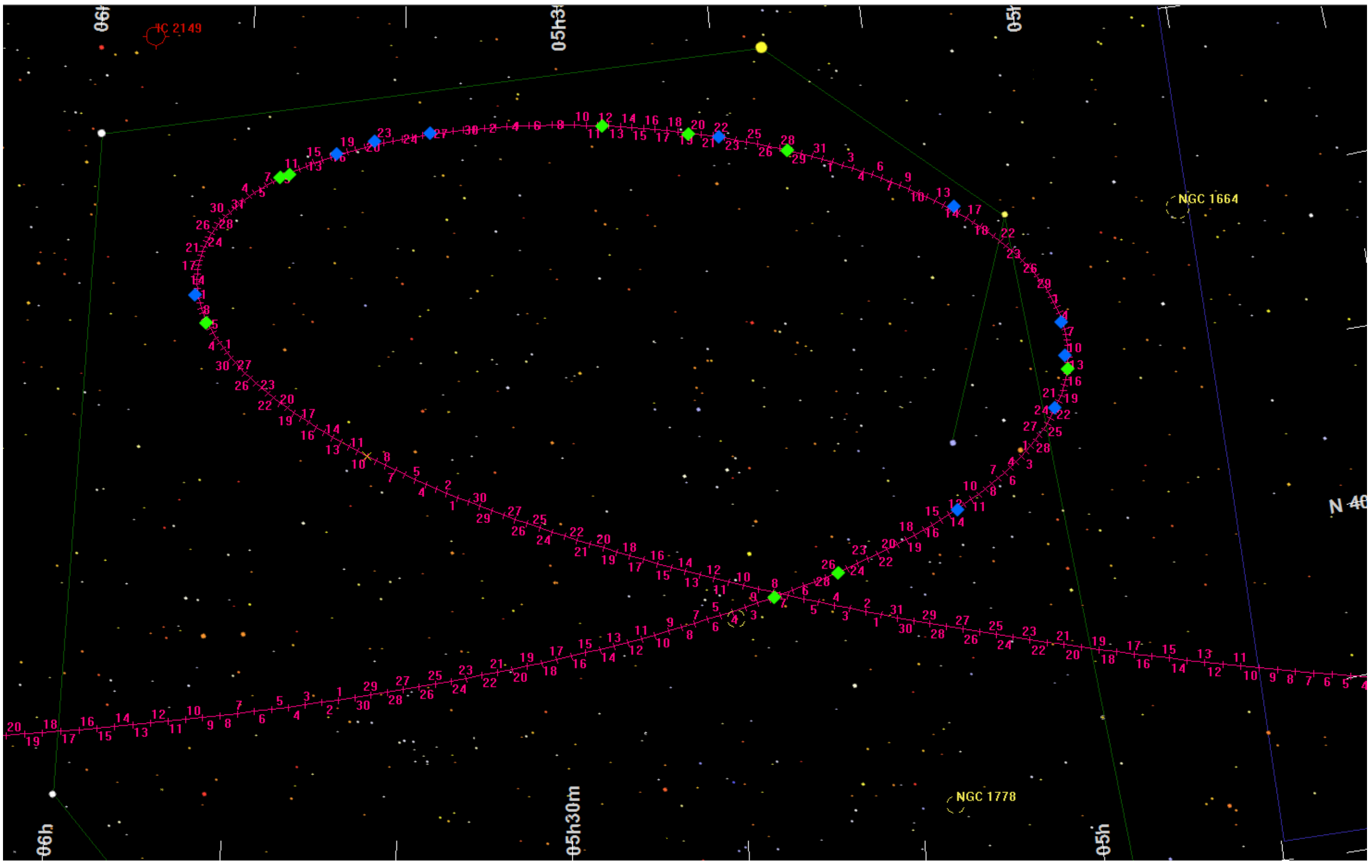


Figure 3. Plot of (624) Hektor's path along the sky plane between July 2022 and May 2023. The diamonds on the path mark the occultations presented in Table 1. Blue diamonds show the fainter occultations (14 - 15 mag). (Plot made with Project Pluto's GUIDE 9.1)

Upcoming Occultations

At the end of 2022 and the beginning of 2023, (624) Hektor is moving through the constellation Auriga with an apparent magnitude of 14 - 15. Its retrograde movement across the sky plane begins in October 2022 and ends it in March 2023.

Since the Jupiter Trojan will occult stars close to its stationary phases and thus moves quite slowly across the sky plane, the duration of an occultation by Skamandrios is relatively long for such a small satellite. Table 1 shows the observable occultations of stars brighter than mag 15 from October 2022 until the end of March 2023.

Date (UT)	Star	Vmag	Max. Duration (s) (624) Hektor	Skamandrios	Observable in
2022 Oct 06, ~05:04	UCAC4 664-041893	13.8	18.9	1.24	Europe, W. Africa
2022 Oct 11, ~01:52	UCAC4 666-042131	14.7	21.2	1.38	Europe, Africa
2022 Nov 08, ~05:23	TYC 2923-00251-1	10.9	16.2	1.07	Europe, N. Canada, Alaska
2022 Nov 10, ~20:27	UCAC4 673-042055	13.9	15.4	1.00	Asia, N. Europe
2022 Nov 16, ~10:17	UCAC4 674-040310	14.6	13.8	0.90	N. Canada, Asia
2022 Nov 21, ~02:42	UCAC4 675-040602	14.3	12.8	0.84	S. America
2022 Nov 26, ~05:52	UCAC4 676-038960	14.4	12.0	0.78	Mexico, Florida, C. America
2022 Dec 11, ~18:49	UCAC4 676-037147	13.9	10.7	0.70	Asia, Europe, N. Africa
2022 Dec 18, ~22:27	UCAC4 676-036283	11.8	10.7	0.73	Asia, E. Canada, E. USA
2022 Dec 22, ~21:27	UCAC4 675-036563	14.3	10.8	0.70	S. Asia, Middle East, Africa
2022 Dec 27, ~21:58	UCAC4 675-035793	13.8	11.0	0.72	Asia, Europe
2023 Jan 14, ~00:51	UCAC4 670-034015	14.4	13.3	0.87	Africa, S. America
2023 Feb 04, ~15:32	UCAC4 664-031199	14.8	19.1	1.25	Asia
2023 Feb 10, ~16:52	UCAC4 662-029770	14.6	-	1.29	E. Europe, E. Africa
2023 Feb 14, ~09:29	UCAC4 661-029848	13.0	19.5	1.28	E. Russia
2023 Feb 21, ~06:36	UCAC4 658-029167	14.1	-	1.15	Florida
2023 Mar 13, ~01:14	UCAC4 653-028642	14.5	-	0.73	Europe
2023 Mar 25, ~23:49	TYC 2900-016541	10.5	8.6	0.57	South America
2023 Mar 31, ~19:53	UCAC4 648-028293	13.9	7.8	0.51	Europe, E. Africa

Table 1. Stellar occultations by (624) Hektor and its satellite Skamandrios between October 2022 and March 2023. For 3 events only an occultation by Skamandrios is observable. Predictions were calculated with data from JPL Horizons and Miriade orbit solution #1 using D. Herald's Occult 4.2022.9.1. on 2022 September 29.

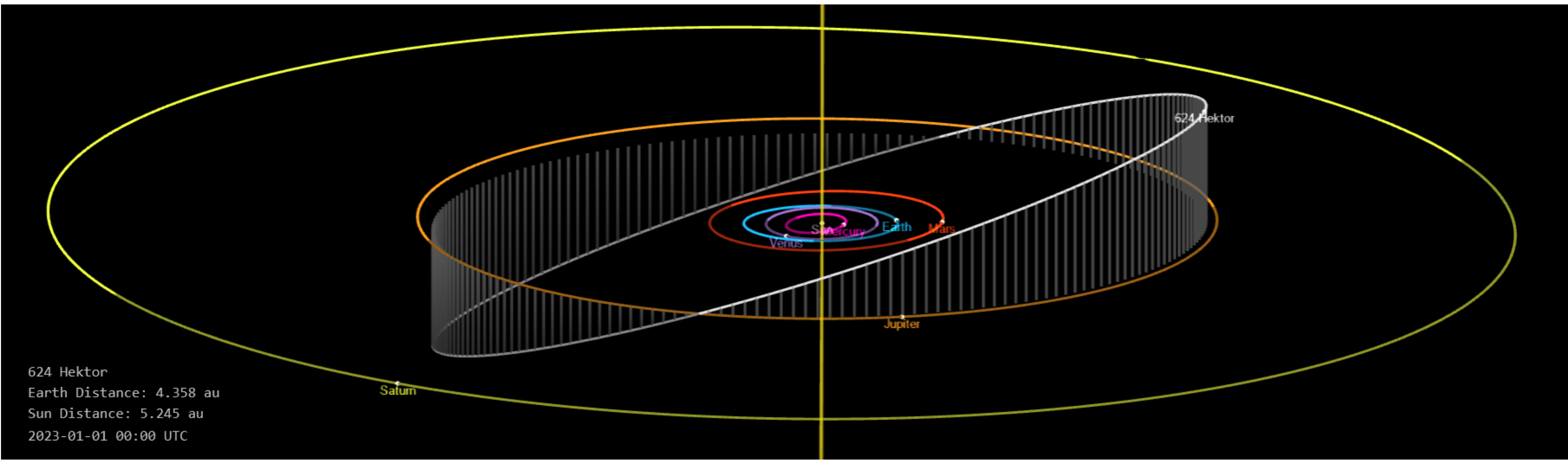
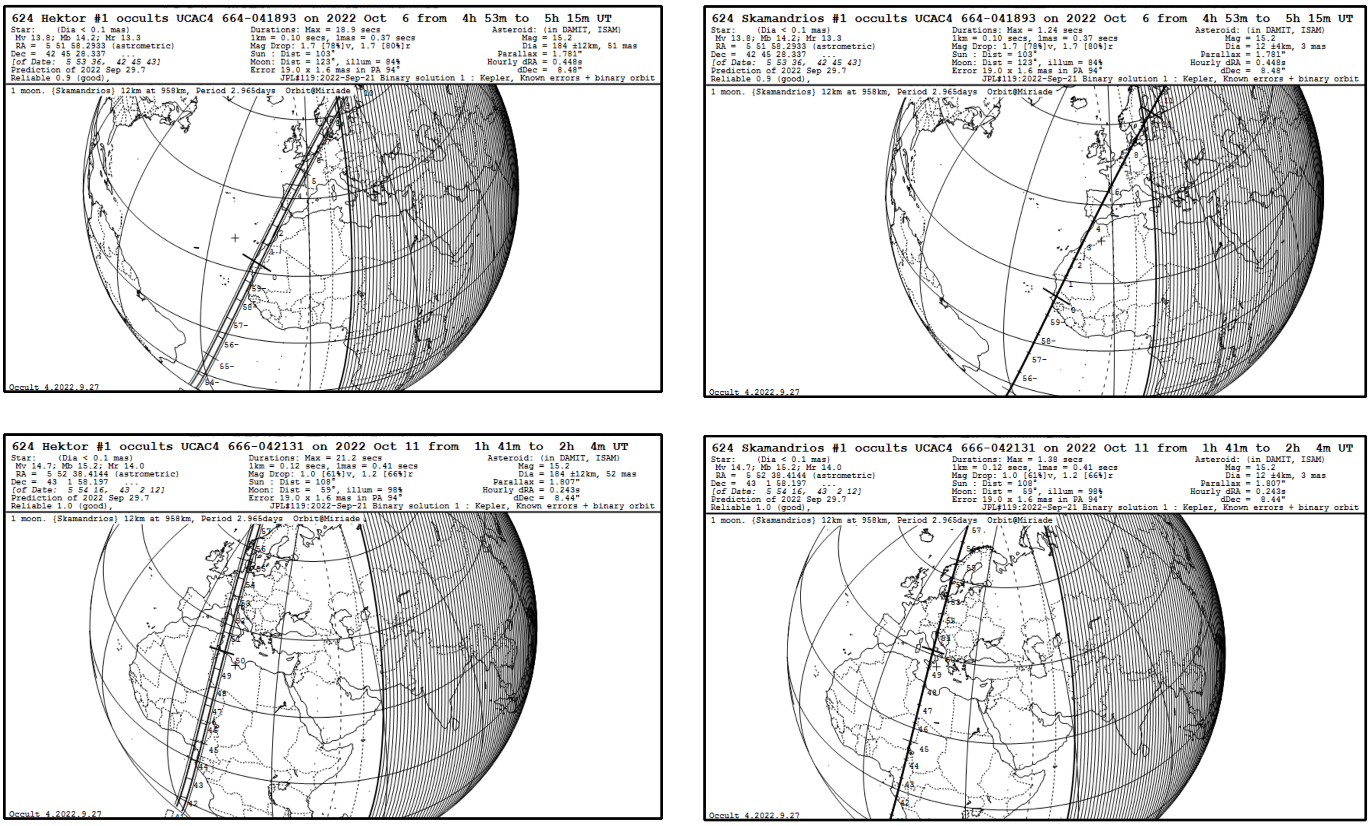


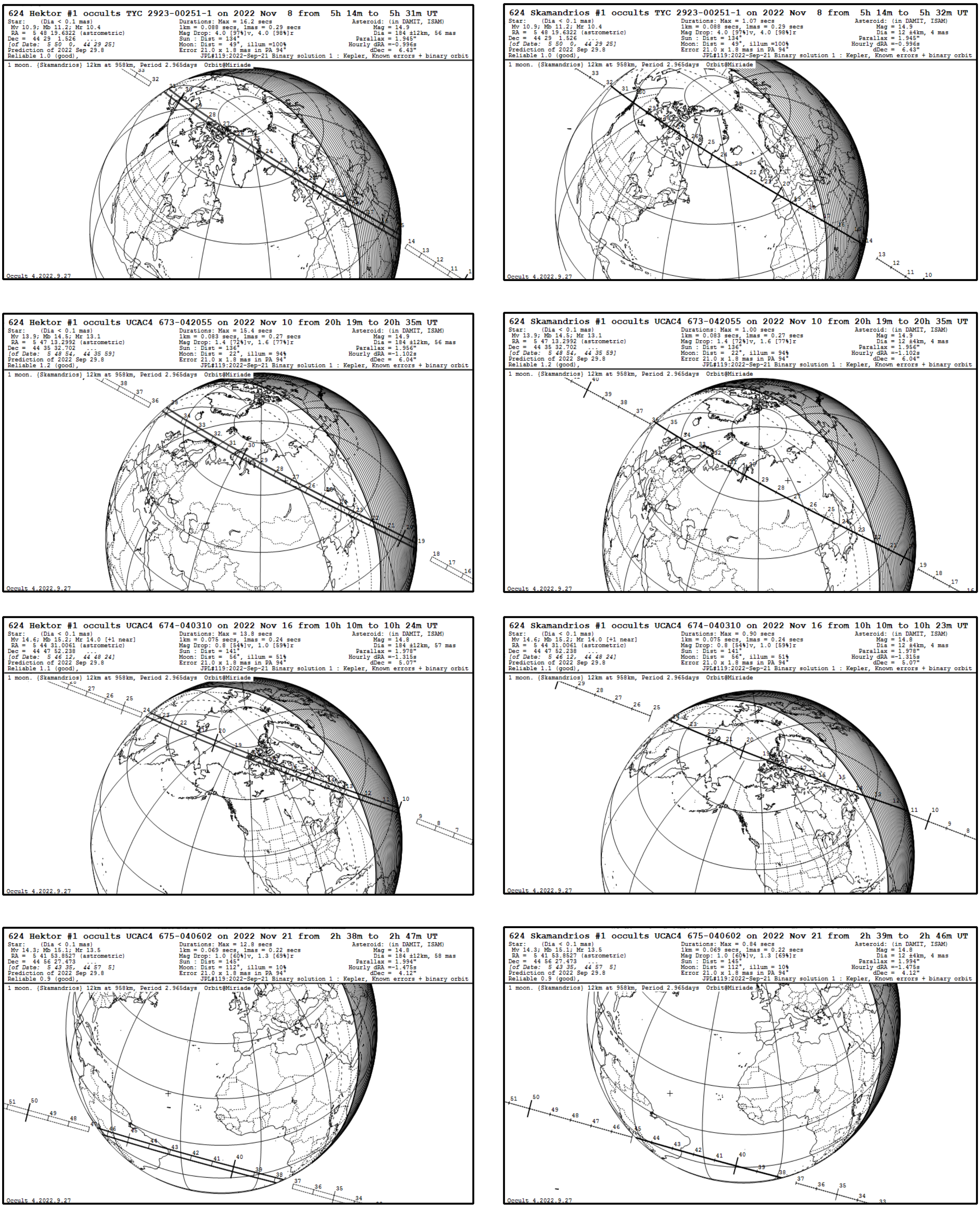
Figure 4. The orbit of (624) Hektor. The plot presents the position on 2023 Jan 1, 00:00 UT. (Source: NASA JPL Small-Body Database Lookup, https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=624%20Hektor)

At the time of publication of this issue of the *Journal for Occultation Astronomy*, Oscar Canales' observation was still being evaluated. Miriade's orbit solution #1 was used for the predictions calculated for this call for observations. This is recommended because this solution is fitted to the complete set of data [9].

Updates to the orbit solutions are highly possible. Potential observers should therefore check the latest data from Miriade via *Occult* before an occultation and the predictions on *Occult Watcher Cloud* [10] and the Lucky Star project webpage [11].



Figures 5 - 8. Path maps of occultations by (624) Hektor and Skamandrios from 2022 Oct 6 and 11 based on data from Miriade and JPL Horizons available on 2022 Sep 29. Plotted with Occult 4.2022.9.27.



Figures 9 - 16. Path maps of occultations by (624) Hektor and Skamandrios from 2022 Nov 8 to 21 based on data from Miriade and JPL Horizons available on 2022 Sep 29. Plotted with Occult 4.2022.9.27.

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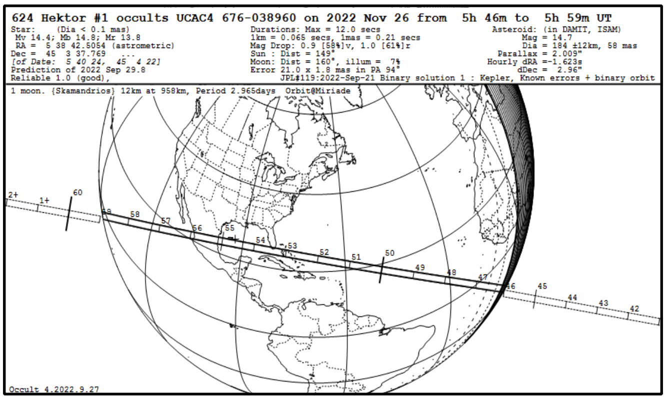
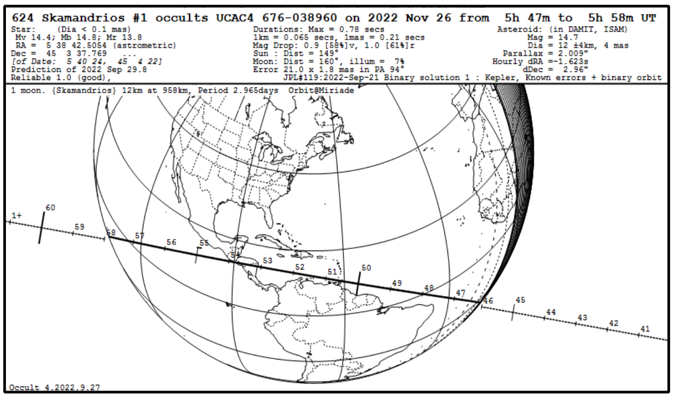
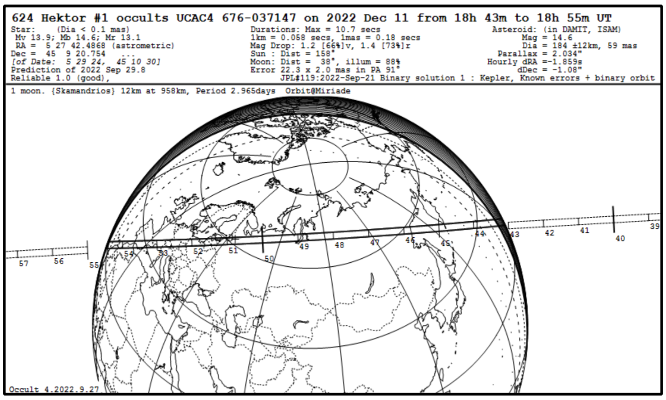
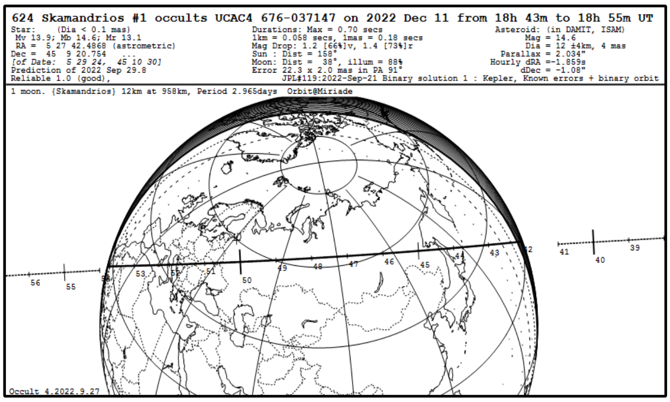
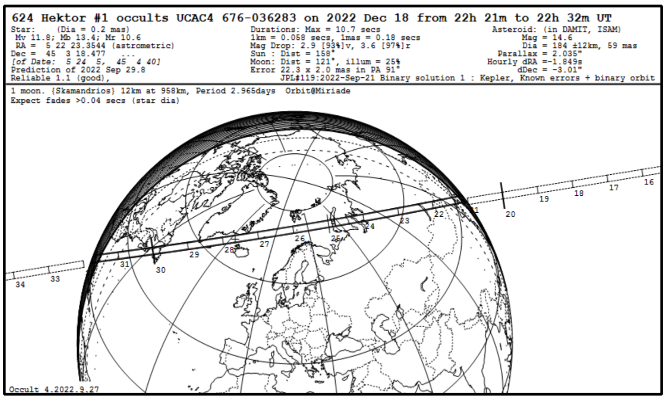
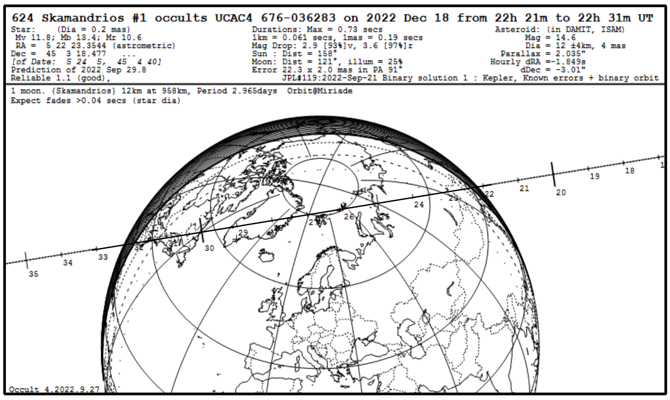


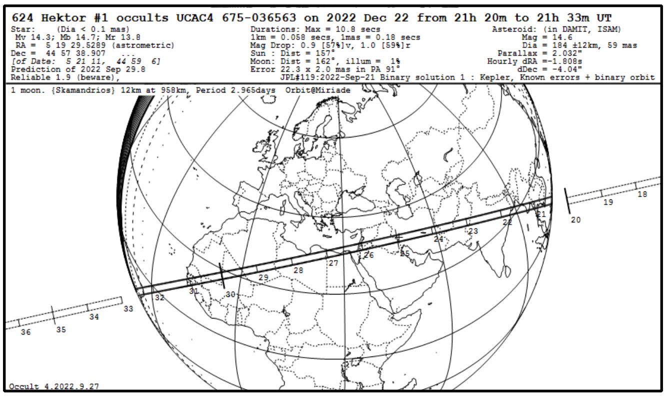


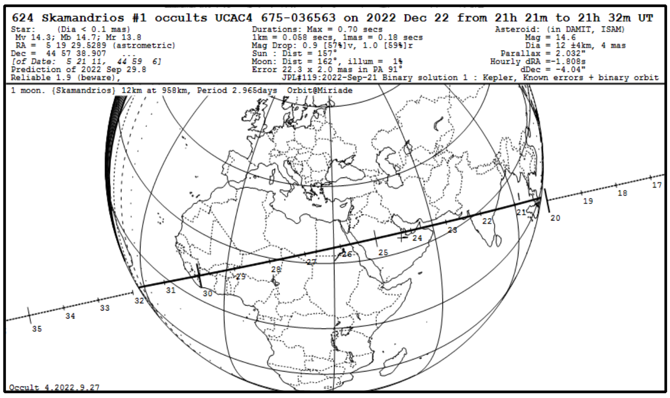




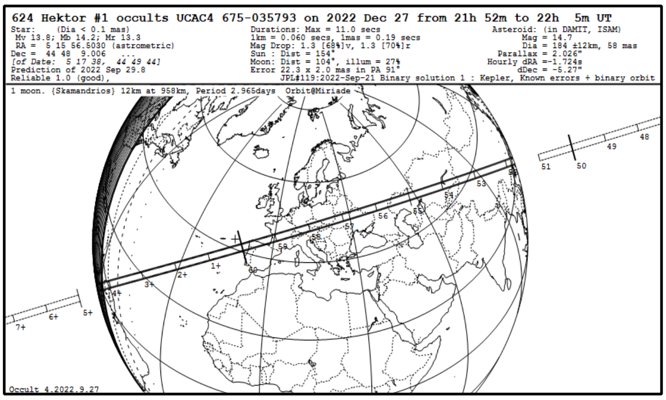


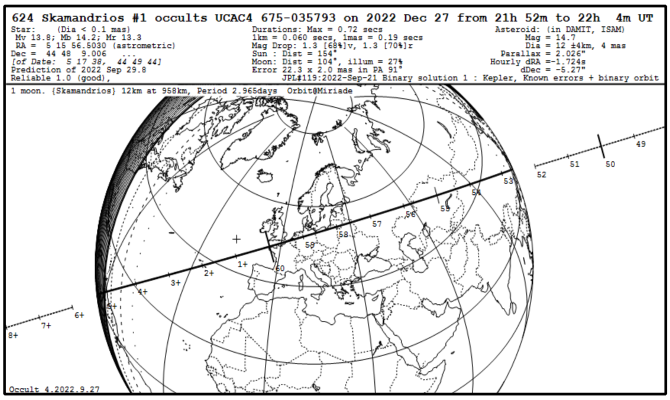


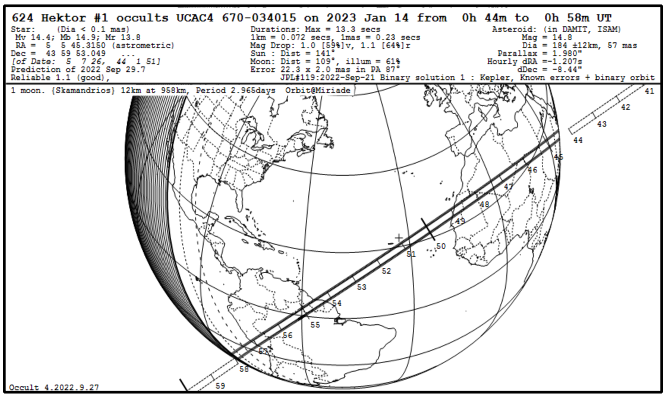


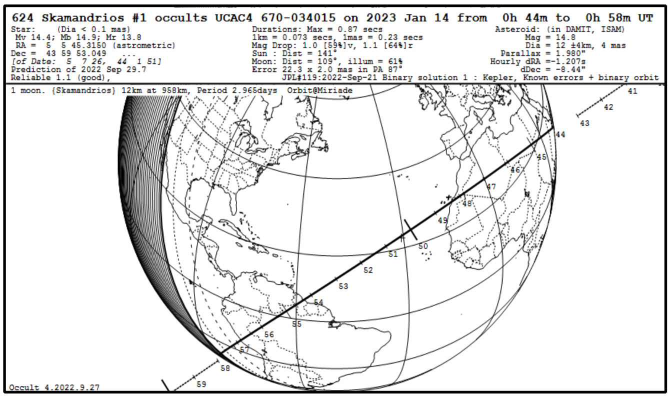


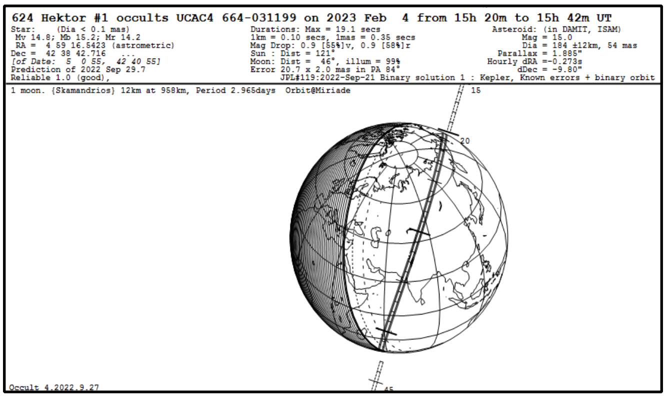
Figures 17 - 24. Path maps of occultations by (624) Hektor and Skamandrios from 2022 Nov 26 to Dec 22 based on data from Miriade and JPL Horizons available on 2022 Sep 29. Plotted with Occult 4.2022.9.27.

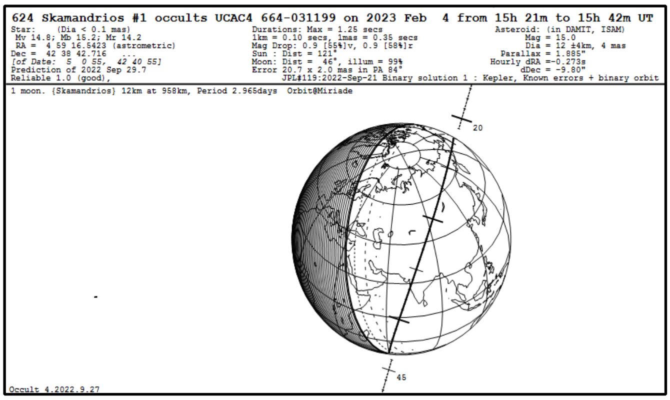




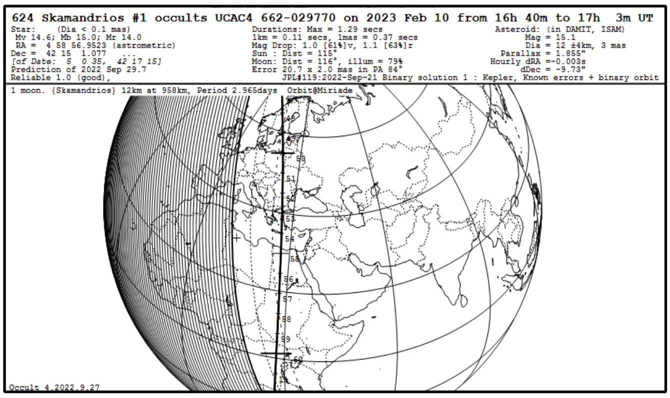




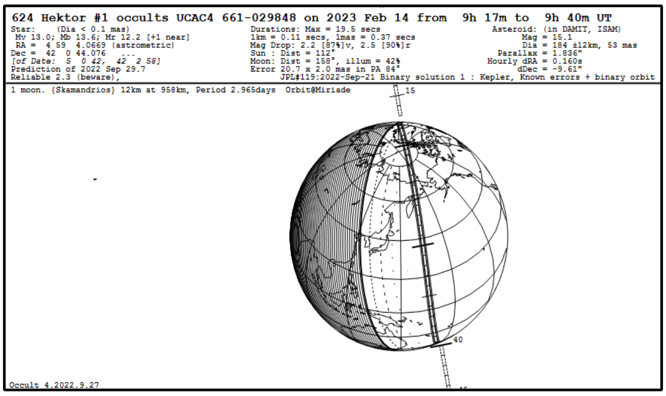


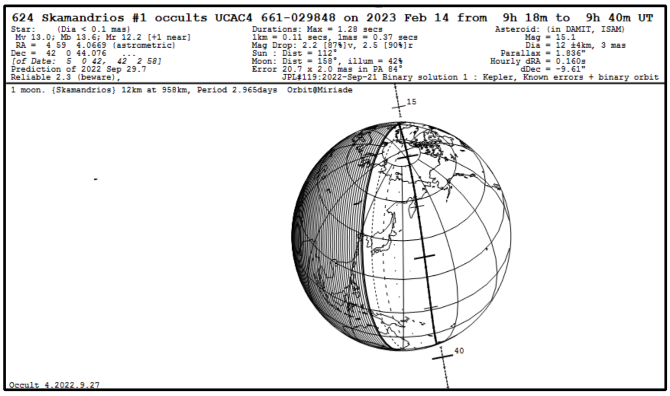


Occultation by (624) Hektor not observable.

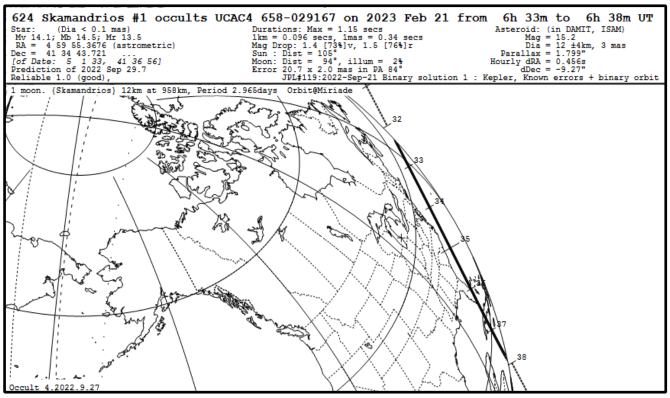


Figures 25 - 31. Path maps of occultations by (624) Hektor and Skamandrios from 2022 Dec 27 to 2023 Feb 10 based on data from Miriade and JPL Horizons available on 2022 Sep 29. Plotted with Occult 4.2022.9.27.

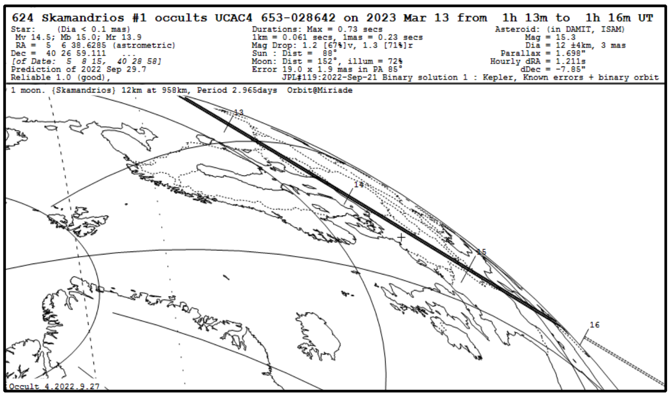


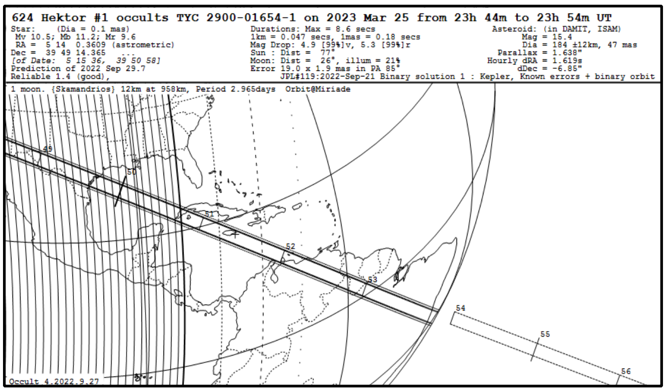


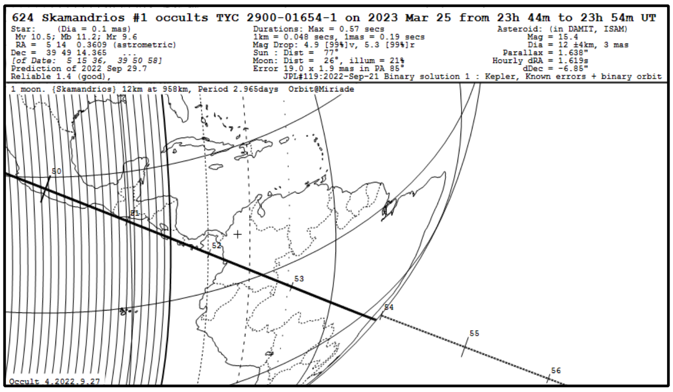
Occultation by (624) Hektor not observable.



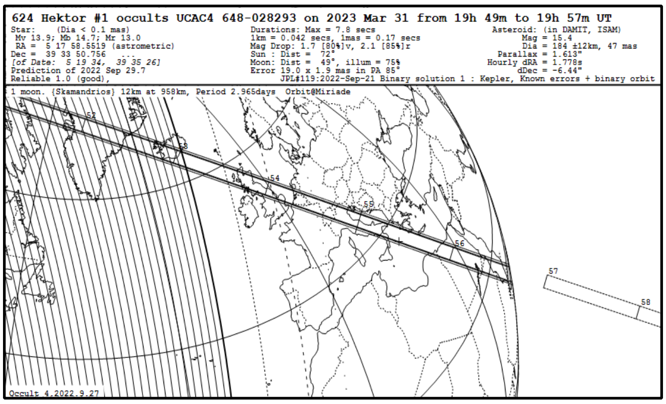
Occultation by (624) Hektor not observable.

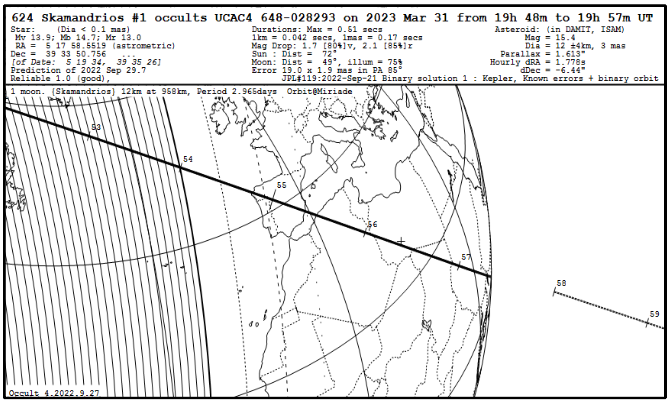






Figures 32 - 37. Path maps of occultations by (624) Hektor and Skamandrios from 2023 Feb 14 to Mar 25 based on data from Miriade and JPL Horizons available on 2022 Sep 29. Plotted with Occult 4.2022.9.27.





Figures 38, 39. Path maps of occultations by (624) Hektor and Skamandrios on 2023 Mar 31 based on data from Miriade and JPL Horizons available on 2022 Sep 29. Plotted with Occult 4.2022.9.27.

Conclusion

There are some good opportunities to determine the profile of (624) Hektor in the upcoming months. Observing a stellar occultation by the moon Skamandrios will be a challenge, but the observation on 2022 Aug 30 by Oscar Canales showed that this is possible. Occultations near stationary points on the asteroid's path across the sky plane facilitate observations and yield high-resolution data.

Don't forget to check any available prediction updates.

Acknowledgements

This research has made use of IMCCE's Miriade VO tool, Dave Herald’s software *Occult*, and JPL Horizons. Special thanks to Oscar Canales, Dave Herald and Frédéric Vachier.

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Thoughts on the Observation of Occultations by Near-Earth Asteroids

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ABSTRACT: Predictions of occultations by near-Earth asteroids (NEAs) have been improved by a step-wise approach in which radar observations are followed by a major campaign of occultation observers, after which some confirmatory observations are made. These occultation observations are difficult due to the narrowness of the paths, the brevity of the events, and the peculiar appearances of the expected light curves. Scintillation noise and instrument noise limit an observer's ability to successfully document these events even when other problems are solved. It is expected that cameras of the near future will have lower noise and will assist in this effort.

Introduction

Few occultations by near-Earth asteroids (NEAs) have been observed, mainly because of poor prediction accuracy. The lack of accuracy has involved star positions and asteroid orbit models. The much improved accuracy in star positions provided by the *Gaia* astrometry satellite has done much to lessen the problem with star positions. However, the small sizes of most NEAs require highly precise orbital models, without which the narrow shadow paths will simply miss the observer. Occultations by NEAs are quite challenging to observe.

Radar observations of 6 km diameter (3200) Phaethon were made in 2007 and in 2017, resulting in a highly precise orbital model [1]. Incorporating *Gaia*'s star position accuracy, a prediction was made that (3200) Phaethon would occult a star on 2019 July 29 visible from the southwestern USA. The campaign to observe this occultation involved 35 observers who set up more than 60 telescopes, of which 52 obtained data and six recorded an occultation. This major effort provided a precise astrometric point that allowed a further refinement of the orbit, which in turn has led to positive observations of about six more (3200) Phaethon events since then. These events are reviewed by Dunham [2].

UT Date	Star	Star Vis. Mag.	Star Diam* (mas)	Apophis Dist. (AU)	Apophis Sky Motion (mas/sec)	F.L.** (m)	ρ˟	Max. Duration## (sec)	Altitude (degr)	1-sigma Cross-path Uncertainty‡ (pathwidths)	Orbit Calcu-lation	Observers Positive (Parentheses indicate # of observing sites if >1)
2021 March 7	HIP 45887	8.58	0.176	0.11273	56	71	2.4	0.075	48	1.91	JPL#204	D. & J. Dunham (2), R. Nugent
2021 March 22	TYC 0218-00224-1	10.1	0.0709	0.12386	38	75	2.3	0.10	38	0.31	JPL#207	R. Venable (1)
2021 April 4	TYC 0789-01041-1	11.4	0.0671	0.14089	23	80	2.1	0.14	44	0.76	JPL#211	N. Carlson, K. Getrost, R. Venable (1)
2021 April 10	UCAC4 528-046251	12.6	0.0167	0.14889	19	82	2.1	0.17	69	0.76	JPL#211	? H. Yamamura
2021 April 11	TYC 1376-00848-1	10.1	0.0557	0.14983	19	82	2.1	0.16	~ 52	0.75	JPL#211	N. Carlson, K. Getrost, V. Sempronio
2021 May 6	TYC 1929-01244-1	11.6	0.0231	0.16851	15	87	2.0	0.18	~ 55	1.27	JPL#216	S. Aguirre, T. Blank (1), N. Carlson, A. George
2021 Sept 27	TYC 1392-01042-1	8.7	0.0225	0.87972	35	199	0.85	0.015	8	1.27	JPL#216	---
2022 April 9	TYC 5782-01139-1	8.5	0.379	0.53721	58	155	1.1	0.015	8.3	1.27	JPL#216	---

* Star's subtended sky diameter estimated from Gaia DR2 parallax, colour, and g magnitude.
** Fresnel length = sqrt(lambda*distance/2), all in metres. Computed with lambda of 600 nm as this is near the peak sensitivity of most video cameras.
˟ ρ (Greek letter rho) is the asteroid's radius in metres divided by the Fresnel length in metres.
Maximum duration assumes a diameter of 340 metres, which is the mean diameter now used by the Horizons ephemeris system. Some predictions of these events have used a larger diameter, such as 500 metres, to compute duration.
‡ Uncertainty as assessed at event time, based on a diameter of 340 metres. This differs from uncertainties expressed at different times or using different diameters.

The observers who recorded negative observations on March 7 are C. Bicknell, N. Carlson, P. & D. Ceravolo, P. Cervantes, D. & J. Dunham (3), K. Getrost, B. Gowe, J. Horst, R. MacArthur, F. Marchis, R. McClure, J. Moore (2), S. Sivley, M. Skrutskie, R. & S. Tirashi, R. Venable (4), and M. Ziegler.
The two observers of the 2021 Sept 27 event actually had "no observation" results rather than misses.

Table 1. Previous observations of occultations and appulses by (99942) Apophis

The pattern of progressive refinement of the orbital model, beginning with radar observation, followed by a major occultation campaign, followed by further confirming observations was repeated with 340 metres diameter NEA (99942) Apophis in 2021. Table 1 gives details of most of the occultations and appulses by (99942) Apophis that have been observed. We can expect a continuation of this pattern of serial observations yielding progressive improvement in orbital models. For example, NEA (65803) Didymos has already been the subject of radar astrometry, and we are hoping to observe some occultations by it in a campaign in late 2022, perhaps even catching its known moon Dimorphos in the process [3].

Although it may appear that occultation observers are now beginning a golden age of observation of NEAs, in fact any such a golden age may be brief. The star positions will gradually degrade, beginning in just a few years, as their proper motions have been less precisely ascertained than their mean positions [4]. We encourage every occultation observer to seize the present opportunity to capture the uniquely precise astrometric data on NEAs that occultations now provide.

The focus of this paper is to highlight the difficulties and unusual characteristics of some of these events, using a recent (99942) Apophis appulse as an example. It is hoped that these details will foster interest and wisdom about performing and interpreting such observations.

Pitfall #1: The Paths Are Narrow

Small asteroids produce narrow occultation paths. It is unlikely that the small shadow of a NEA will pass over an observer's home observatory, so an observer should be prepared to travel to the shadow path. Observers who often utilize remote stations have made a variety of adaptations to their equipment to make it transportable, such as with collapsible "suitcase" telescopes. Having said that, it is our impression that most mobile observers simply lug their home observatory equipment into the field. The camera and recording computer will require batteries, but miniature computers and monitors can allow the use of relatively small batteries. Skill in prepointing can eliminate the need for a clock drive for the telescope mounting, so the mounting can be simple.

Elevation corrections to the shadow path and to the locations of each observing chord can be very important when the path is very narrow. Initial path predictions are generally made for observers at sea level. In the first successful (3200) Phaethon event, elevation corrections were not made, with the result that two of the six successful chords coincided with one another, effectively yielding five chords across the asteroid rather than six. These two mobile observers were at different elevations at widely separated points along the shadow path. With some of the (99942) Apophis events, the elevations of the observing sites in the western USA would have caused observers to miss the event completely, were the elevation corrections not applied. For several of the (99942) Apophis events in Table 1, elevation corrections were kindly incorporated into the prediction by John Irwin, upon specific request.

If the event is the subject of a campaign, the chords of observers will be close together. The observer will do well to let the campaign organiser assign him or her a chord, so as to avoid the chords of other observers.

Pitfall #2: Event Duration

The maximum durations of the (99942) Apophis events in Table 1 range from 0.18 seconds down to 0.015 seconds. Since the frame duration of a video camera is either 0.033 or 0.040 seconds, the shortest of these events will cause the light drop of the occultation to be blurred with the full light of the star in a single video frame. Keep in mind that this applies not only to the briefest diametric events, but also to events with longer diametric durations when the observer is near the edge of the asteroid's shadow. A higher frame rate will be advantageous in identifying an occultation in these events. Digital cameras can provide higher frame rates than analogue video cameras, with comparable quantum efficiency. Kai Getrost used a frame rate of 100 frames per second for the 2021 April 11 (99942) Apophis event [5], and Venable used 380 frames per second for the events of 2021 September 27 and 2022 April 9. Higher frame rates result in dimmer images, so larger telescope apertures are appropriate.

Pitfall #3: Non-Zero Occultation Bottom

With the briefest occultations, the light is unlikely to drop to zero at the event bottom. This effect is multifactorial, related to diffraction, the frame rate, and the stellar diameter.

The computation of diffraction effects involves double integrals in the complex plane, Lommel functions, and Bessel functions [6, 7], and thus is beyond the capability of most amateur astronomers. In this article, Venable uses Fresnel length and rho values in expressing diffraction ideas because they are simple to calculate and they are helpful in elucidating the expected diffraction pattern. The Fresnel lengths and rho values of the (99942) Apophis events are given in Table 1 and defined in the footnotes of that table.

Fresnel length or Fresnel scale has been defined several ways in the astronomical literature, but for the purpose of this article it is:

$$\text{Fresnel length} = \sqrt{\frac{(\lambda * \text{distance})}{2}}$$

where λ is the wavelength of the incident light, and distance is the distance to the occulting object such as an asteroid. In making this calculation of Fresnel length, if one converts λ and distance to metres, the Fresnel length will also be in metres. Note that the duration of an occultation and the velocity of the asteroid's shadow do not enter into this calculation. Thus, Fresnel length expresses some of the characteristics of diffraction effects in terms of distances alone. Diffraction effects are prominent when an asteroid's radius is approximately equal to the Fresnel length. Accordingly, a simple way to express the importance of diffraction is to divide the asteroid's radius by the Fresnel length, resulting in a value that is often designated by the Greek letter rho: ρ.

When ρ is much greater than 1, diffraction effects are slight, although a Poisson's spot may be detected from the exact centre of the shadow if the object is round. (This central Poisson's spot is not to be confused with the central flash observed from the centreline of an occultation by an object with an atmosphere, such as Pluto or Triton.) When ρ is near 1, diffraction effects are prominent. When it is much less than 1, there will be much light diffracted into the shadow, possibly so much that the shadow cannot be detected and the event will be "diffracted out", to borrow an expression from Marshall Eubanks. An event with ρ = 1 cannot have a brightness of zero at its nadir.

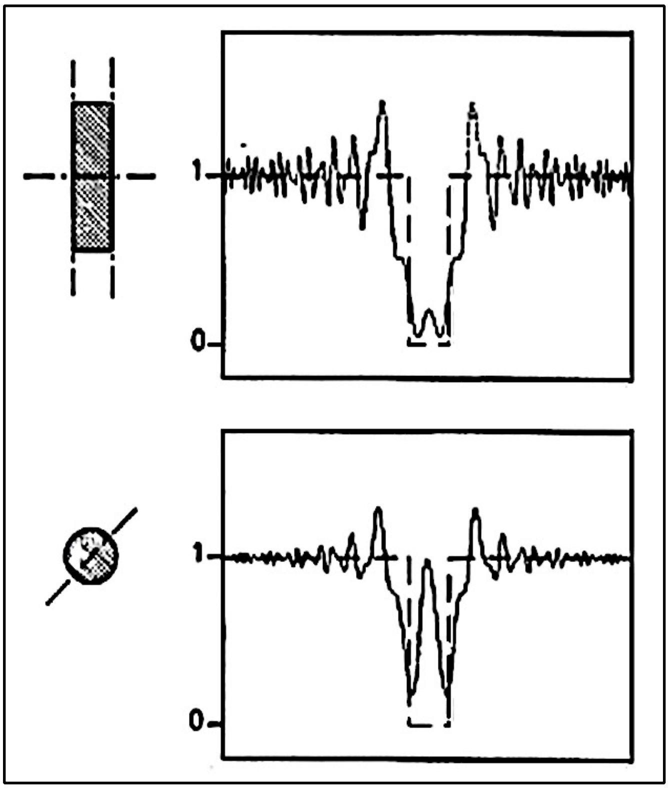

*Figure 1. Simulated diffraction patterns as expected from selected occultation circumstances. The two patterns are with ρ of 0.88. [Rho is the Fresnel length divided by half the length of the chord across the occulting body. Fresnel length = sqrt(wavelength*distance/2).] With a midline event, the pattern on the top can occur when the long axis of the asteroid is in the sky plane, while the pattern on the bottom occurs when the long axis is perpendicular to the sky plane. For further explanation, see the text. Adapted from Roques, Moncuquet, and Sicardy [6].*

Although in this article we refer to occultations by NEAs as being "brief", an understanding the significance of Fresnel length conveys the fact that it is not actually the duration of the event that renders diffraction events to be prominent, but the distances -- the length of the light wave and the distance to the asteroid.

The orientation of a nonspherical body such as (99942) Apophis will have significant effects on the diffraction pattern. Roques, Moncuquet, and Sicardy worked out diffraction computations for various occultation presentations [6]. Figure 1 is adapted from their article. It diagrams two presentations of a hypothetical occulting body detected at a single wavelength when the star is a point source and the ρ value is 0.88. As indicated in Table 1, these values of ρ are similar to those of the (99942) Apophis events of 2021 September 27 and 2022 April 9, and thus suggest the appearance of some of the diffraction effects that might have been expected in those occultations if they had been successfully observed.

The diffraction patterns in Figure 1 can be thought of as due to occultations along an axis perpendicular to the long axis of an elongated body such as (99942) Apophis. The top pattern applies to some cases in which the long axis is in the sky plane, while the bottom pattern applies to cases in which the long axis is perpendicular to the sky plane. The dashed lines are the geometrical edge of the shadow. Notice that the series of diffraction peaks and valleys before and after the occultation are much more prominent than those seen in most asteroidal occultations. These peaks and valleys will be blurred when an occultation is recorded by a camera with a broad spectral sensitivity, though the peaks nearest the occultation will be no less prominent. In Figure 1, the central brightening, which is essentially a Poisson's spot, will be present regardless of wavelength when the occultation is diametric across a circular object (lower panel), but it is markedly suppressed, even with a midline chord, when the occultation crosses the waist of an elongated body (upper panel). Generally speaking, it will not be seen when the occultation is off the asteroid's centre. It is also important to notice in Figure 1 that, due to diffraction, the brightness does not drop to zero during the occultation.

Interestingly, there was a prominent central brightening at the bottom of Miyoshi Ida's light curve in the 2021 October 15 occultation by (3200) Phaethon [2], which is of uncertain nature but may be a Poisson's spot widened by the broad spectral response of the camera. There were prominent diffraction spikes immediately before and after Getrost's recording of the 2021 April 11 occultation by (99942) Apophis, and that recording showed a non-zero bottom [5].

Siraj and Loeb computed diffraction effects that would be seen when interstellar objects occult stars [7]. With regard to diffraction, such light curves could appear similar to occultations by NEAs, because the ρ values can be similar. One of their simulated light curves with ρ of 0.66 is presented here as Figure 2, adapted from their article. The numbers on the abscissa are camera frames, not time *per se*, but serve here to reveal the manner in which the Poisson's spot is obscured by the camera's frame rate when the occultation is very brief. Notice that the camera's response does not record zero brightness during such an event, and with ρ = 0.66 and a video frame duration of 1/2 of the geometrical event duration, its lowest measurement is at 60% of the unocculted brightness.

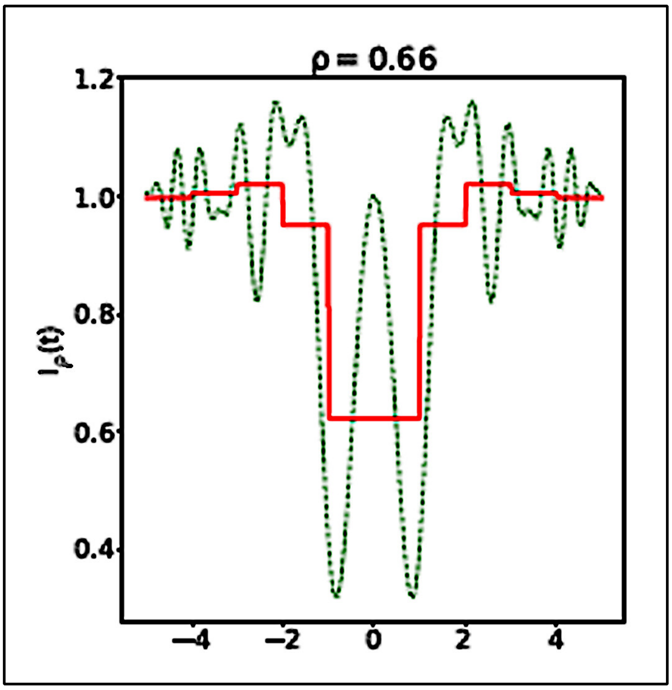

Figure 2. Simulated diffraction pattern and consequential camera response at a frame rate of half the geometrical occultation duration, with ρ = 0.66. The calculation assumed that the star was a point source and that the observation was made through a filter passing a single wavelength. Adapted from Siraj and Loeb [7].

In most occultations by asteroids, the star's apparent subtended diameter does not play a significant role because it is very small compared to that of the asteroid. In contrast, at the 2022 April 9 appulse (99942) Apophis's 340 metres diameter subtended 0.873 milliarcseconds (mas), while the star's diameter subtended about 0.379 mas (see Table 1). The accurate computation of the effect of the star's subtended diameter on the light curve would require knowledge of the limb darkening function of the star, the shape and orientation of the asteroid, and the exact offset of the occultation chord from the asteroid's midline. Although precise calculations cannot be made, Figure 3 presents some geometric scenarios that suggest that the large stellar diameter may affect the light curve by introducing frames of intermediate brightness at the start and end of the event.

Notice in Figure 3 that the large stellar diameter may cause the periphery of the star to be near the middle of the event at the same time that the opposite periphery of the star is near the beginning or the end of the event. In comparison with Figure 1, which shows the diffraction effects from a point source, the large stellar diameter will blur the diffraction effect, as light from part of the star diffracts to the central bright spot at the same time that light from another part of the star diffracts to the adjacent dark part of the diffraction pattern. In short, the occultation will lack a Poisson's spot, and the large stellar diameter will level out the occultation bottom, at a brightness that is near the mean of all the brightness measures that will be obtained within the geometric shadow.

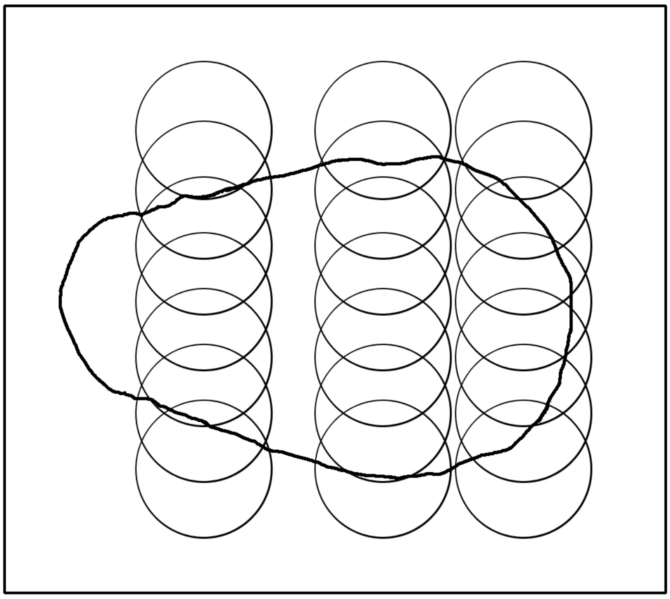

Figure 3. Star diameters superimposed on (99942) Apophis's approximate size for the purpose of illustration, with three vertical paths of occultation across the asteroid. The actual configuration of the asteroid is not well known and its presentation aspect in the 2022 April 9 occultation is not known. The proportions in the diagram are such that the top to bottom distance across the asteroid is 0.873 milliarc seconds, and each of the representations of the star is of 0.379 milliarc seconds diameter, as in the occultation of 2022 April 9. The spacing of the star figures in each of the 3 vertical rows is the distance of a single camera frame, at the frame rate that Venable used in that observation. The central row shows a scenario in which there would be 4 frames in which the star is completely occulted, with at least one additional frame of intermediate brightness at the beginning and end of the occultation. The left row shows a scenario of 3 frames of complete occultation, also with at least one frame of intermediate brightness at the beginning and end. Note that this left scenario increases the duration of intermediate brightness only slightly as compared to the central scenario. The right row shows an incomplete occultation that has at least three frames of intermediate brightness both before and after the central event.

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Awareness of these matters can help the observer have a realistic expectation of what an occultation light curve will look like in these very brief events. These light curves will often appear considerably different from most of the light curves that we produce from observations of occultations by main-belt asteroids.

Accordingly, Venable was looking for the following features in the 2022 April 9 light curve:

- Occurrence within the prediction uncertainty range, as the orbit was well known.
- The frame rate of 380 frames per second would be sufficiently fast to allow the identification of the specific features in the light curve that would suggest the occurrence of an occultation.
- A duration consistent with (99942) Apophis's oblong shape and the maximal predicted duration of 0.015 seconds for its volume averaged sphere.
- Readily evident diffraction spikes immediately before and after the event.
- A flat event bottom due to the averaging effect of the star's size, possibly with a contribution from the frame duration.
- A non-zero brightness at the event bottom, due to the diffraction effect, with a possible contribution from stellar size. Upon review of published simulations of light curves at various values of ρ, he judged that the event bottom should have about 40% of the unocculted brightness.
- Possible frames of intermediate brightness between the event bottom and the diffraction spikes, due to the star size.

Although Venable considers all these criteria to have been met by a candidate event involving a 4-frame low point at the centre of Figure 4, there is a problem with this interpretation. Rather than concentrating on the central low point, we shall concentrate on the problem of scintillation.

Pitfall #4: Scintillation

The problem of scintillation is well illustrated by the light curve in Figure 4, which shows the severe scintillation in the light curve of the 2022 April 9 event. The observation was made from a site near sea level with the event occurring at an angular elevation of 8.3 degrees, which yielded a light path equivalent to 6.9 zenithal atmospheres. Scintillation effects are worsened by a low angular elevation in the sky, and by local thermal instabilities in the atmosphere. Scintillation is partially alleviated by high elevation above sea level and by larger telescope apertures, but perhaps surprisingly, it is nearly independent of wavelength [8]. Most observers have limited ability to adjust the variables that affect scintillation when making occultation observations, but we encourage the use of the largest aperture available when making an observation in which scintillation may be a factor.

Our judgement of the likelihood that a drop in brightness is due to an occultation is based on the statistical probability that a brightness excursion of the same depth and duration could be caused by chance due to the random variations in the light curve that we call noise. If the false event probability is measurably greater than zero, then it may be useful to have some confirmation such as a second chord, or some peculiar circumstance of the observation that can serve as confirmation.

When making this analysis, we generally include the full expanse of the noise rather than filtering out a small area of the light curve that has a lesser amount of noise. There is no currently accepted, scientifically justified method of selecting a brief area of a light curve for analysis by virtue of a local area of lower noise. In Venable's April 9th observation, he was able to find his suspected event at the predicted time because there was a moment of less noise at that time. This may have been a real occultation, but in view of the overall noise of the light curve, the feature may have been caused by scintillation. There is no known way to prove either hypothesis. The point here is that a very brief event with a non-zero brightness nadir, such as can be expected in some

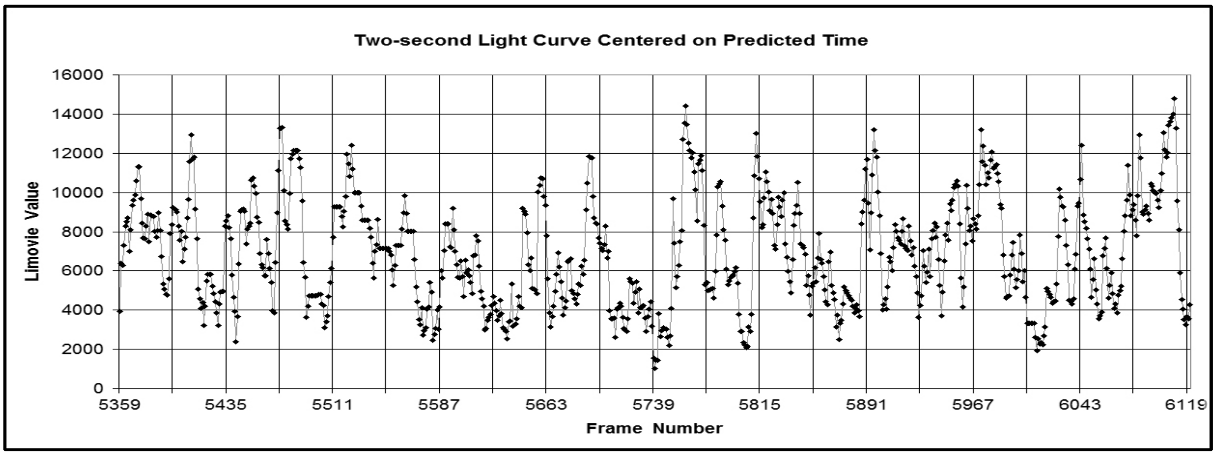

Figure 4. Part of Venable's light curve at 380 frames per second, centred on the predicted event time of the 2022 April 9 occultation by (99942) Apophis. This shows approximately 2 seconds of data. For further explanation, see text.

occultations by NEAs, may not meet the requirement of statistical probability that demonstrates that the event is real, even when light curve features such as diffraction effects are suspected in the light curve.

It could be argued that the presence of each of the features that Venable hoped to find, listed above, is so unusual that an occultation is confirmed. In response, David Herald points out two ideas. First, if it is an occultation, adding the astrometric point to the database will not improve the orbit model, since the orbit and the purported event correspond so well. Second, if it is not an occultation, then adding the astrometric point to the database will degrade the orbit with a new, bad astrometric point. Thus, no astrometric point should be derived from the observation (David Herald, personal communication). This wisdom illustrates pitfall #5: Though these events can be exciting and challenging, it can all be for naught.

Future Work

Since most digital cameras do not place a GPS time stamp on each frame, some other accurate means of assessing the time is needed. Aart Olsen has developed a GPS flasher device using an Arduino together with an attached GPS "shield" that receives GPS signals [9]. With this device, the timing of an event can be measured by interpolating the frame times between the known times of the flashes. A potential problem with such a device is that it does not indicate the possible presence of dropped frames. Therefore, each camera model must be tested by some other standard to ascertain whether it will drop frames at the frame rate that is desired. Further, it should be tested to discover what settings, if any, will cause it to drop frames. The stability of the exposure duration should also be tested.

Scintillation noise does not appear random when evaluated on a sufficiently short time interval to manifest its autocorrelation. Instead of the random-appearing up and downs that we see with low frame rates, a high frame rate can reveal relatively smooth curves of ups and downs, with each such curve defined by many points (see Figure 5). The higher the frame rate, the greater the autocorrelation of the scintillation noise. (Of course, this autocorrelation will be more evident when the scintillation is less severe than that shown in Figure 4.) In the context of smoothly varying brightness values, the pattern of a very brief occultation may be identifiable by virtue of its interruption of the autocorrelation, or by a spike in a graph of autoregression with differencing. Variations in autocorrelation, like the variations in brightness by which we currently judge the occurrences of occultations, are subject to statistical analysis. It remains to be seen whether such analysis can identify brief events that would be hidden amid the scintillation noise if analysed solely by the methods that are currently in use.

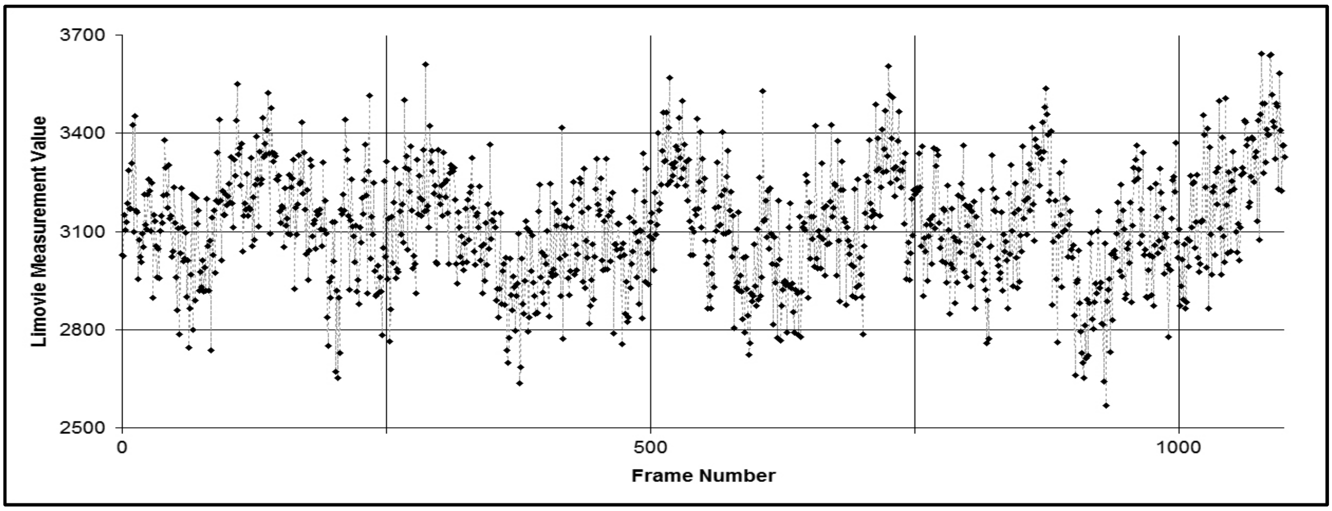

Figure 5. A 1.1-second duration part of a light curve made by recording 7.7 magnitude HIP 96083 on 2022 June 14 at 07:42 UT when the star was at an altitude of 86 degrees. The recording was made at 996 frames per second using a ZWO ASI290MM camera, 2x2 pixel binning, and a region of interest of only 80x60 (equivalent to 160x120 pixels unbinned). A runs test on the entire 29,989 frames (about 30 seconds) reveals the longest run above median to be 75, with many runs longer than 21, while a single longest run of 21 would be significant at the $p < 0.01$ level. This means that the brightness values are not normally distributed. In general, the autocorrelation of brightness values increases with faster frame rates, and such autocorrelation can cause a non-Gaussian distribution. One can plainly see that there are two different types of noise in the light curve: a frame to frame instrumental noise, and a slower, rolling scintillation noise. The presence of two types of noise may be another contributor to the non-normality of the distribution. (The sky background was not black, and the normalized cross-correlation of aperture and background values is 0.010, indicating that the variations in brightness values are not due to variations in exposure duration.) The frame rate is fast enough to reveal the details of the scintillation effects, so that, for very brief occultation events, the instrumental noise of this camera may be more important than the scintillation noise. The camera is not cooled, and a cooled version of the camera would presumably show less instrumental noise. We expect continuing reductions in instrumental noise as camera technology develops, so our ability to detect brief events amid the scintillation will be improved.

Digital cameras are capable of higher frame rates than video cameras, and therefore will be able to record briefer events than video can. Since brief events are likely to show the features of diffraction and stellar size, higher frame rates can help to identify an occultation by revealing those features. Thus, higher frame rates may be able to mitigate the problem of scintillation noise by enabling the identification of an event by pattern recognition. Pattern recognition is what we do now to identify occultations by main-belt asteroids: We look for a pattern of sudden disappearance, a flat bottom, and a sudden reappearance. As discussed here, the pattern may be different for very brief events, and high frame rates are the way to show such patterns.

Future digital cameras will have higher quantum efficiency, less electronic noise, and faster maximum useful frame rates. Already, some cameras enable the observer to distinguish between scintillation noise and instrumental noise in some recordings (see Figure 5). With cooling, the camera used for Figure 5's light curve would presumably have reduced instrumental noise. One of us (Venable) is experimenting with frame rates up to 4,000 frames per second using only a small region of interest in the CMOS chip, and Jonathan Bradshaw has made lunar occultation observations with a frame rate of 1,000 frames per second [10]. Though currently available cameras appear excellent, users should keep in mind that a halving of even a small amount of instrumental noise will result in a doubling of the signal-to-noise ratio. (Signal-to-noise ratio is equivalent to sensitivity.) With cameras of the future that have less instrumental noise, brief occultations with smaller drops in brightness will be detectable. We shall be looking for opportunities to stretch our capabilities in the detection of occultations by NEAs.

Summary

Since the first detection of occultations by (3200) Phaethon in 2019, interest in occultations by NEAs has increased, and campaigns to observe them have been under way, with some success. These efforts have started for each object with a campaign involving a larger than usual number of observers, by which a successful observation has been used to significantly improve the asteroid's orbital model, enabling more modest efforts for confirmatory observations. Due to the very narrow shadow paths made by these small asteroids, observers must travel to the paths, which requires the observer's plans and equipment to be prepared for mobile observing. Occultations by NEAs are very brief, so that some such observations will require high camera frame rates, which in turn may require relatively large apertures in order to obtain adequate video signal. The light curves of such events may be peculiar in several ways. Diffraction effects may be prominent, including momentary brightness increases immediately before the disappearance and after the reappearance, and brightening in the middle of the event consistent with a Poisson's spot, and a non-zero event bottom even when the asteroid is very faint. Large subtended diameters of occulted stars will affect the light curve by creating frames of intermediate brightness that may appear to shorten an already brief event, and may cause a non-zero event bottom. Large stellar diameters can appear to affect the light curves of such brief events much more than they appear to affect light curves of longer duration events. Rapid atmospheric scintillation can mimic an occultation event, and to some extent the use of a high frame rate can mitigate the scintillation effect. With improved camera technology, it is likely that more difficult occultations by NEAs will be within range of amateur observers. The use of new mathematical methods to detect such events should be investigated. We are currently at a historically special time at which NEAs can be studied by occultation means

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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 summarised 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 2022 September 30, the *Minor Planet Center* listed 1451 Centaurs and 2934 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)

In this Issue:

(341520) Mors-Somnus

Konrad Guhl · IOTA/ES · Berlin · Germany · kguhl@astw.de

ABSTRACT: The minor planet (341520) Mors-Somnus was discovered in 2007 and with an orbital period of 248 years, is in resonance with Neptune and so belongs to the Plutino class of trans-Neptunian objects. The elliptical orbit has its perihelion just inside the perihelion distance of Neptune. It was found to be a double asteroid, with each body having approximately the same size, roughly 120 km across.

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
10370	Hylonome	Konrad Guhl	JOA 3 2021
10199	Chariklo	Mike Kretlow	JOA 1 2017
15760	Albion	Nikolai Wünsche	JOA 4 2019
15810	Awran	Konrad Guhl	JOA 4 2021
20000	Varuna	Andre Knöfel	JOA 2 2017
28728	Ixion	Nikolai Wünsche	JOA 2 2018
38628	Huya	Christian Weber	JOA 2-2021
47171	Lempo	Oliver Klös	JOA 4 2020
50000	Quaoar	Mike Kretlow	JOA 1 2020

No.	Name	Author	Link to Issue
54598	Bienor	Konrad Guhl	JOA 3 2018
55576	Amycus	Konrad Guhl	JOA 1 2021
60558	Echeclus	Oliver Klös	JOA 4 2017
90377	Sedna	Mike Kretlow	JOA 3 2020
90482	Orcus	Konrad Guhl	JOA 3 2017
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
174567	Varda	Christian Weber	JOA 2 2022
208996	2003 AZ$_{84}$	Sven Andersson	JOA 3 2022
-	2004 XR$_{190}$	Carles Schnabel	JOA 1 2022

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The Discovery

The object was discovered on 2007 October 14 by Scott S. Sheppard and Chadwick A. Trujillo at the *Mauna-Kea Observatory* on Hawaii. It received the provisional designation, 2007 TY_{430} [1]. That of the second body, or satellite, is S/2007 (341520) 1 [2].

At the time of its discovery it was identified as a binary asteroid. The separation of the two components was approximately 0.6" (13,000 km) at this time.

For the initial discovery and verification three different telescopes were used: the 8.3 m *Subaru Telescope* and the 8.2 m *Gemini-North* both on Mauna Kea, and the 6.5 m *Magellan Telescope* at Las Campanas, Chile (Figures 1-3).

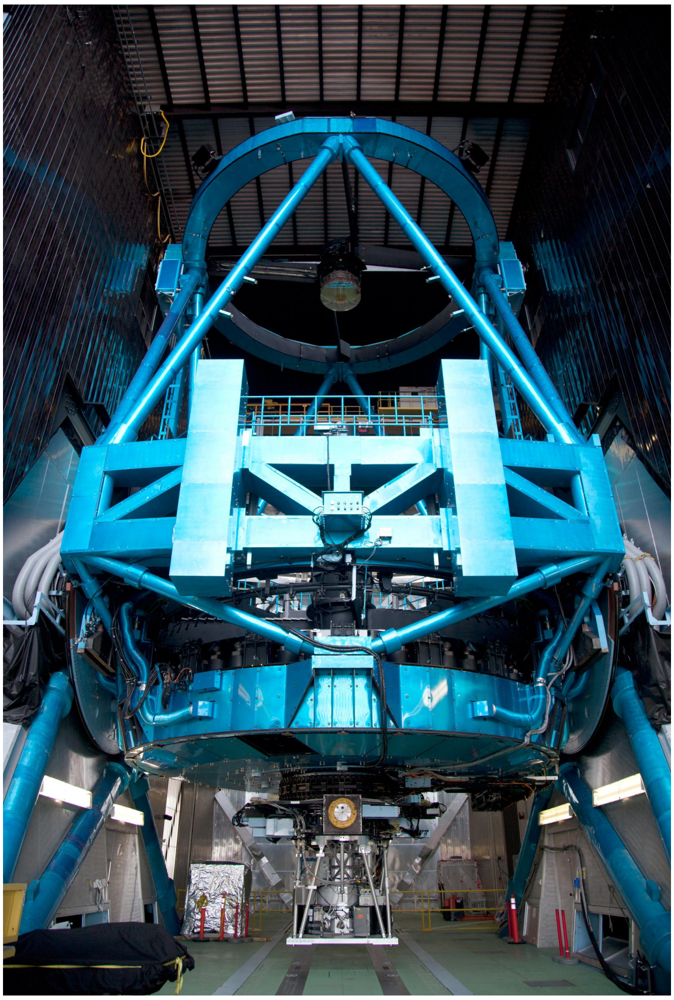

Figure 1. The 8.3-m Subaru Telescope.
Credit: National Astronomical Observatory of Japan

Figure 2. The 6.5 m Magellan Telescope.
Credit: Carnegie Science

Figure 3. The dome of the Gemini North Telescope. Credit: NOIRLab

The Name

Given the duplicity of the system, it was decided to name it after two godheads. The object was officially named on 2015 June 2 after the twin Roman gods of the underworld: Mors (Greek equivalent, Thanatos), the God of Death; and Somnus (Greek equivalent, Hypnos), the God of Sleep (Figure 4), [3].

Orbit and Classification

The orbit, illustrated in Figure 5, has quite a high eccentricity of 0.27 and is inclined to the Ecliptic by 11°. With a semi-major axis of 39.5 AU, the planet has a distance to the Sun ranging from 28.8 to 50.2 AU according to the Jet Propulsion Laboratory (JPL) Small-Body Database [4]. The current distance from the Sun (as of November 2022) is 29.04 AU having reached perihelion in 2017.

As a TNO, Mors-Somnus is a member of the group known as Plutinos, which are in a 2:3 resonance with Neptune, orbiting the Sun every 248.2 years.

Physical Characteristics

The JPL Database reports an absolute magnitude [H] = 6.83 mag. Photometric observations show a rotation period for Mors of 9.28 h [5]. This means that about 232,285 revolutions around its spin axis ("Mors-day") take place during one revolution around the Sun ("Mors-year").

The double planet has a low albedo (0.057) and appears ultra-red in colour having (g – i) magnitude = 1.49 mag [6]. Mors and Somnus orbit their common barycentre in a slightly elliptical orbit at a distance of 21000 ± 160 km from each other in 961 ± 5 days [7]. This is relatively far apart for a double-asteroid system.

Figure 4. Hypnos or Sleep, (267), British Museum. Dept. of Greek and Roman Antiquities; Walters, Select bronzes, Greek, Roman, and Etruscan, in the departments of antiquities, 1915, Henry Beauchamp (1867-1944), Public domain, copyright expired.

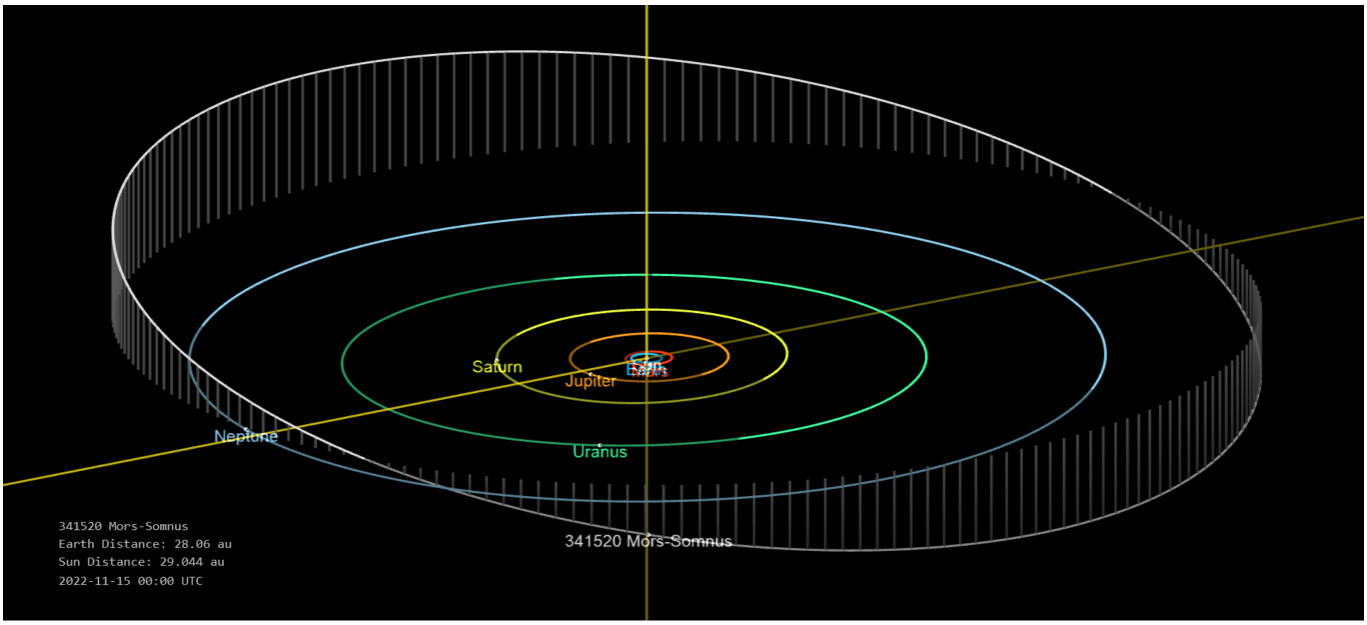

Figure 5. Orbit diagram and position for 2022 November 15.
(Source: https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=341520&view=VOSPD)

The orbital eccentricity is accordingly 0.153 ± 0.003, and the orbital plane of the two components is inclined 15.7 ± 0.2° with respect to the Ecliptic. With knowledge of the orbital parameters, the total mass of the system can be found to be 7.9 ± 0.2 × 10^{17} kg. Calculated from the typical albedo for such ultra-red TNOs, the radius of both bodies is calculated to be about 60 km. Reference [7] comprises a good review article on the properties of this binary system and how it compares with TNOs in general.

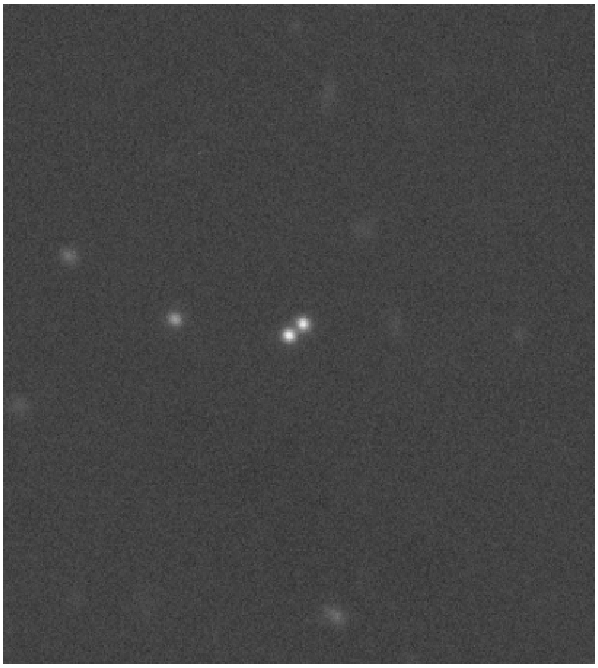

Figure 6. Both components of the binary system separated by 0.7" can be seen in this image taken with the GMOS instrument on the Gemini North telescope in December 2007 at a maximum separation of only 0.7 arcsecond on the sky. Credit: International Gemini Observatory/NOIRLab/NSF/AURA

Future Stellar Occultations

To date, no occultation by this body has been successfully observed. In the *Research and Education Collaborative Occultation Network* (RECON) candidate list, a potential occultation is predicted for 2022 October 14 10:20 UT, which involves the Gaia catalogue star, GA1020:00353908 (G=16.6 mag) [8]. Unfortunately, the majority of the occultation zone will be over water.

Figure 7.
Map for the event on 2022 Oct 14.
The predicted path will cross central America before dawn.
Credit: RECON [8]

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https://www.minorplanetcenter.net/mpec/K08/K08M38.html

[2] IAU Circular 8962, 2008 August 1
http://www.cbat.eps.harvard.edu/iauc/08900/08962.html

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https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=341520&view=OPDA

[5] Thirouin, A., Noll, K.S., Ortiz, J.L., and Morales, N, "Rotational properties of the binary and non-binary populations in the trans-Neptunian belt", Astronomy & Astrophysics, Vol 569, A3 (20pp), 2014 September
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[6] Minor Planet Light Curve Database (LCDB) Query
https://minplanobs.org/mpinfo/php/lcdb.php

[7] Sheppard, Scott S., Ragozzine, Darin and Trujillo, Chadwick: "2007 TY430: A COLD CLASSICAL KUIPER BELT TYPE BINARY IN THE PLUTINO POPULATION", Astronomical Journal, 143(3), 58 (13pp), 2012 March
https://iopscience.iop.org/article/10.1088/0004-6256/143/3/58/pdf

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Further Reading

"The Trans-Neptunian Solar System" edited by D. Prialnik, M.A. Barucci and L.A. Young, Elsevier Science, 478pp., (2019)

The International Occultation Timing Association's 40th Annual Meeting, 2022 August 13-14 via Zoom Online

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ABSTRACT: IOTA's 2022 Annual Meeting was held via Zoom online on 2022 August 13-14. Numerous presentations were made by members of the IOTA community worldwide. More than 70 attendees participated in the meeting.

The 40th annual meeting of the International Occultation Timing Association was held on Saturday and Sunday 2022 August 13-14 via Zoom online. The meeting schedule and agenda are located on the IOTA web site [1].

Video recordings of the session are available on YouTube [2].

Saturday 13th August 2022 - Day 1

IOTA's Vice President **Roger Venable** opened and welcomed everyone to the meeting.

Business Meeting

Treasurer **Joan Dunham** presented IOTA's financials and membership status.

Executive Secretary **Richard Nugent** presented the election results of the IOTA's Officers. All officers were re-elected.

A full report of the business meeting is available [3].

Awards

Richard Nugent then presented IOTA's *Homer F. Daboll*, *David E. Laird* and the *Lifetime Achievement Awards*. The *Homer F. DaBoll Award* is given to recognize significant contributions to the field of occultation science and to the work of IOTA.

This year's recipient is **Fumi Yoshida** from Japan. Fumi Yoshida is the member of *DESTINY+*(**D**emonstration and **E**xperiment of **S**pace **T**echnology for **IN**terplanetary vo**Y**age with Phaethon flyby and dust science) project with plans to observe (3200) Phaethon through spacecraft flyby mission by JAXA and PERC. Phaethon is the special active asteroid also known as the parent body of the Geminid meteor shower. Her team has made and will continue to make preliminary ground-based observations for (3200) Phaethon to ensure the success of the mission. Yoshida is in charge of these ground observations. In cooperation with NASA, SwRI and IOTA, she asked observers around the worldwide to observe occultations by (3200) Phaethon starting from 2018, and organized her own observation team composed of professional researchers and amateur observers. Right after that, the first successful observation was made. The fantastic 2019 July 29 result observed in the western USA was organized because of what her team requested to IOTA in North America. More efforts led by her have resulted in 9 successful occultations worldwide through 2021 of small objects down to 6 km diameter in size. Among them, the occultation on 2021 Oct 3 in Japan was a great success, with 18 sites positive (7 sites misses, the other 11 sites failed) by a 36-site observing party led by her.

Figure 1. Homer F. Daboll Award: Fumi Yoshida

Fumi sent the following message upon her notification of the award:

Thank you very much for the wonderful news. Mr. Hayamizu gave me the details of the award, and I am truly honored to receive this very prestigious award from IOTA. I am also attaching a photo as requested in your previous e-mail. I would like to thank the many amateur astronomers who helped me with the Phaethon occultation observations. There were no professional researchers around me who specialize in occultation observation, so I finally succeeded in the observation while asking for help from amateurs. I am truly grateful for everyone's cooperation. When amateurs and professionals work together, we can indeed accomplish great things. Just like small radio telescopes connected and working as a huge telescope. IAU has recently established a Working Group

(WG) to connect amateurs and professionals [4]. I believe that the cooperation between amateurs and professionals will be further promoted in the future. In Japan, there was a time when amateurs were world-class in asteroid discovery and orbit calculation in around 1970-1980 if my memory is correct. I hope that amateurs from Japan and the rest of the world will play an even more active role in occultation observation in the future. Let's develop new research fields that cannot be done by professionals alone.

Thank you very much.
Fumi Yoshida

The *David E. Laird Award* is given to recognize those who, more than 15 years ago, made significant contributions to occultation science and to the work of the IOTA.

This year's *David E. Laird Award* recipient is **Marek Zawilski** from Poland. Marek Zawilski is retired associate professor in the Faculty of Civil Engineering, Architecture and Environmental Engineering of Lodz University of Technology, Poland. Marek Zawilski is one of the founders of the Occultation Section of the Polish Amateur Astronomers Society, which was established in 1979. He was its Chairman for almost 30 years. Since the late 1960s he made a significant contribution to the field of occultation sciences as the most active promoter of those phenomena in Poland. Marek authored numerous computational programs supporting the observation of occultation events in the 80s and 90s, is an active participant of ESOP conferences since the 80s, and a long-term member of the IOTA/European Section.

The main interests of Marek are historical solar eclipses. Since 1990, he has been creating a monumental solar eclipse canon, which is the catalogue of historical observations of solar eclipses observed from ancient to modern times. To create this work, Marek travelled through various Polish and foreign archives, reads source texts mainly in Russian, German and Latin. Marek presents part of his work on solar eclipses in a movie [5].

Figure 2. David E. Laird Award: Marek Zawislki

Marek sent the following message upon his notification of the award:

Dear Richard,

Wojciech phoned me one hour ago with this news. I am really surprized! I have been active in the field of eclipses and occultations since 1970s, so many years with such phantastic phenomena. I am just very touched that so many people appreciated my work, although I never cared about awards! At the moment it is also a great consolation for me, because I look after my wife who has had extensive cancer. Her cancer therapy is long and requires my help throughout the day and night, so I cannot devote myself to astronomy now as I did even a few months ago. I hope that the therapy will bring a positive effect, but in the near future, for example, I have to give up ESOP in Spain. I will try to be active via e-mail and participate in on-line sessions if necessary. Let me know if you need any information from my side.

Greetings,
Marek Zawilski

The *IOTA Lifetime Achievement Award* is given, as needed, to recognize outstanding contributions to the science of occultations and to the work of the International Occultation and Timing Association over an extended period of the recipient's lifetime. The award is conferred by the IOTA Board as needed.

This year's *Lifetime Achievement Award* 's recipient is **John Broughton** from Queensland, Australia. John has measured dozens of asteroids with over 100 multiple-station deployments starting in 2008, by far the most of anyone outside the USA. He has designed several special compact telescopes optimized for the work, greatly aiding multiple-station deployments, include designs that allow almost routine pre-pointing one or more nights before the event. Earlier, he pioneered the CCD drift-scan technique used by many observers, writing the Scanalyzer software to calculate times from the recorded trails. John developed the suitcase telescopes and has been an active observer for many years. Outside of his occultation work, John is the most prolific amateur discoverer of asteroids in the southern hemisphere, with 1,193 asteroids discovered (including 4 near-Earth objects), 1997 - 2008 at Reedy Creek Observatory in Queensland, AU.

More activities and awards given to John:

- 2002 – Received the Gene Shoemaker NEO grant by the Planetary Society to support his work in near-Earth Asteroids.
- 2003 – Started asteroid occultations using trailed CCD images (CCD drift-scan technique).
- 2005 – Asteroid (24105) Broughton named in his honour.

• 2008 – Awarded the Berenice and Arthur Page Medal by the Astronomical Society of Australia.

• 2010 – started using video cameras for occultations and designed the collapsible telescopes for travelling and multistation deployments.

• 2011 – He formulated a method to derive asteroid dimensions.

Figure 3. IOTA Lifetime Achievement Award: John Broughton

John wrote this after receiving notification of the award:

Hi Richard,

Wow, that's awesome and something I never expected! Thanks to whoever nominated me and all who voted.
I've just returned from a successful expedition to central Australia where I deployed five telescopes for SwRI to record a double occultation by the Patroclus system and will set up a photo with the telescopes once I get organised.

Cheers,
John

For information on IOTA's awards, including previous awardees, see the award webpage [6].

Technical Sessions

Phil Stuart presented the results of the recent occultation by Titan from 2022 July 9. Titan is the only moon in the solar system that has a significant atmosphere being 1.5 bars - about 50 % higher than sea-level pressure on Earth. During the occultation, Titan's atmosphere causes extinction, refraction and photometric effects. Extinction is caused by the atmosphere's haze layer, polar cap, methane clouds and banding.

Phil showed a video of Titan occulting a double star taken with the 200-inch telescope on 2001 Dec 20.

Here's a screen shot from that video:

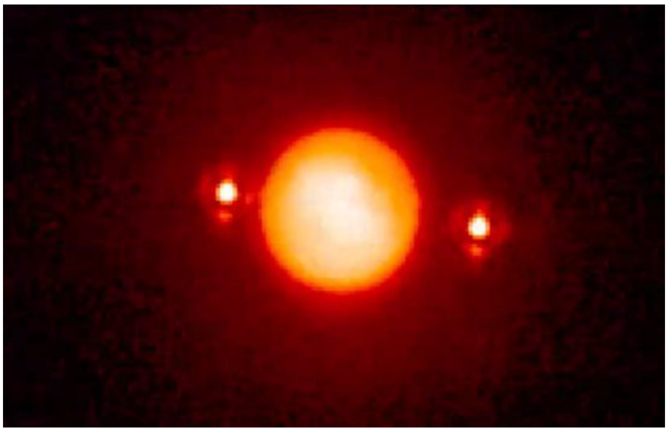
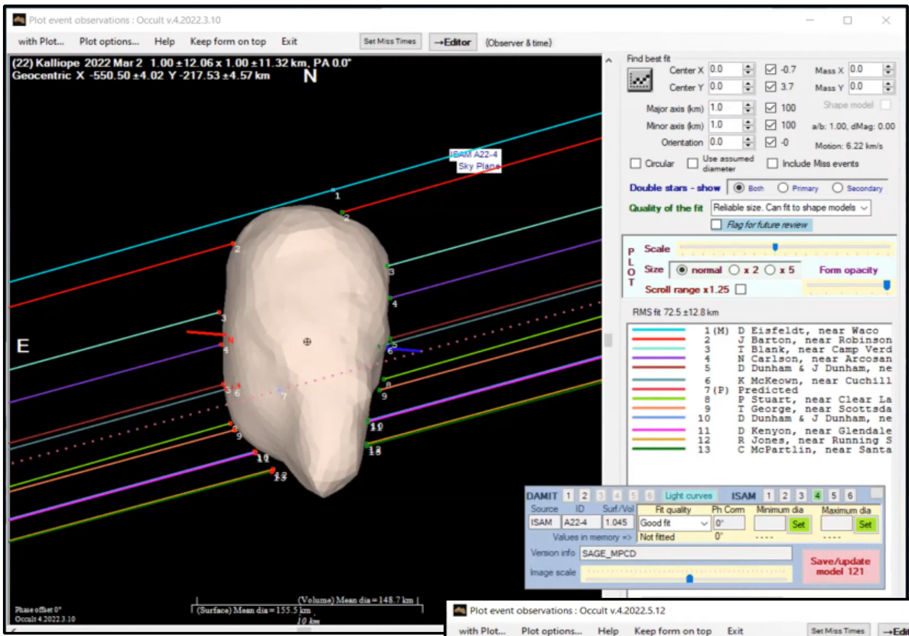


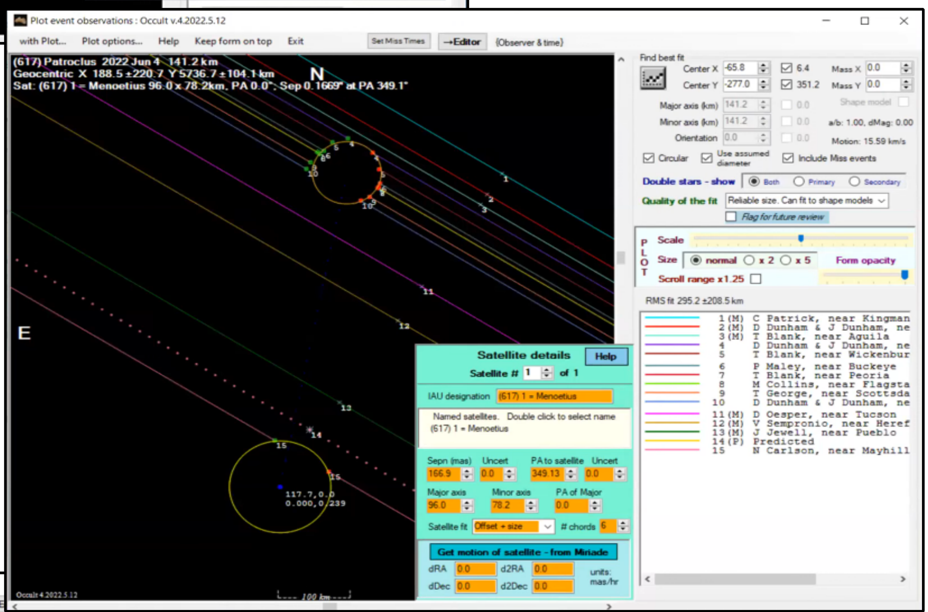
Figure 4. Titan occults a double star on 2001 Dec 20. Screenshot of a video recorded with the 200" telescope at Palomar.

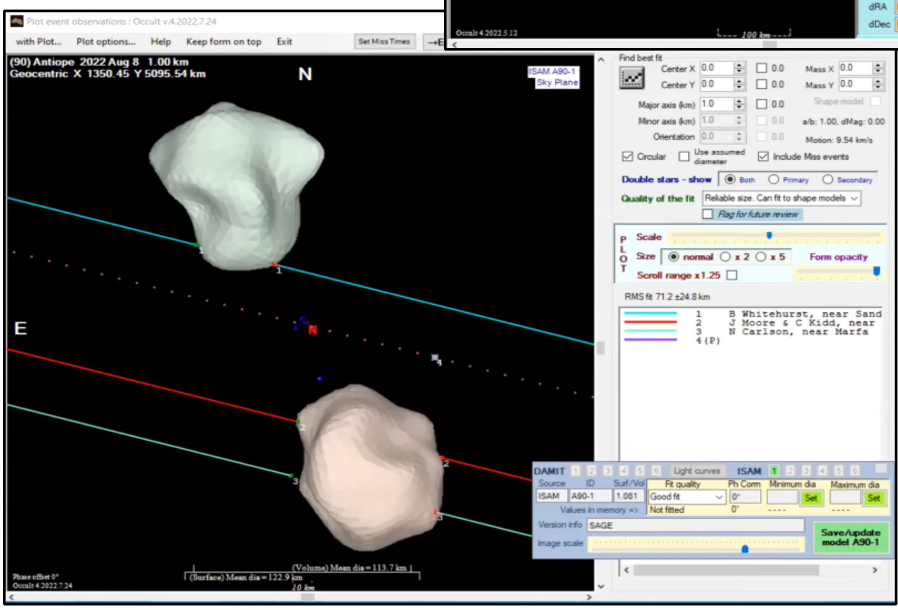
The 2022 July 9 event had a low 0.66 SNR ratio, due to the small magnitude diffrerence between the target star and Titan. Thirty-six observers participated in the event in the USA and Canada including Filipp Romanov from Russia who used a remote telescope in New Mexico using *itelescope.net*. D and R times were poorly defined due to the gradual decline of brightness of the target star due to Titan's atmosphere. Following an analysis of the light curves, Phil deduced an approximate height of the atmosphere from Peter Ceravolo's chord. Peter's chord grazed the upper levels of the atmosphere implying its effect extends to approximately 500 km.

Vice President of Planetary Occultation Services **John Moore** presented recent well observed North American asteroid occultations during the past 12 months. John showed sky plane profiles and in some cases 3D-profiles of events from the DAMIT shape models. Most occultation chords and the DAMIT shape models had excellent agreement. Events shown:

• (957) Camelia: 2021-09-15
• (780) Armenia: 2021-11-09
• (535) Montague: 2021-11-10
• (84522) 2002 TC_{302}: 2021-11-11
• (308) Polyxo: 2021-12-05
• (877) Walkure: 2022-02-15
• (22) Kalliope: 2022-03-02
• (17) Thetis: 2022-05-04
• (617) Patroclus/Menoetius a two-body binary asteroid: 2022-06-04
• (90) Antiope another 2-body system: 2022-08-08.







Figures 5a-c.
Sky plane profiles measured during the occultations by (22) Kalliope on 2022 Mar 3, (617) Patroclus/Menoetius on 2022 Jun 4 and (90) Antiope on 2022 Aug 8 (from top).

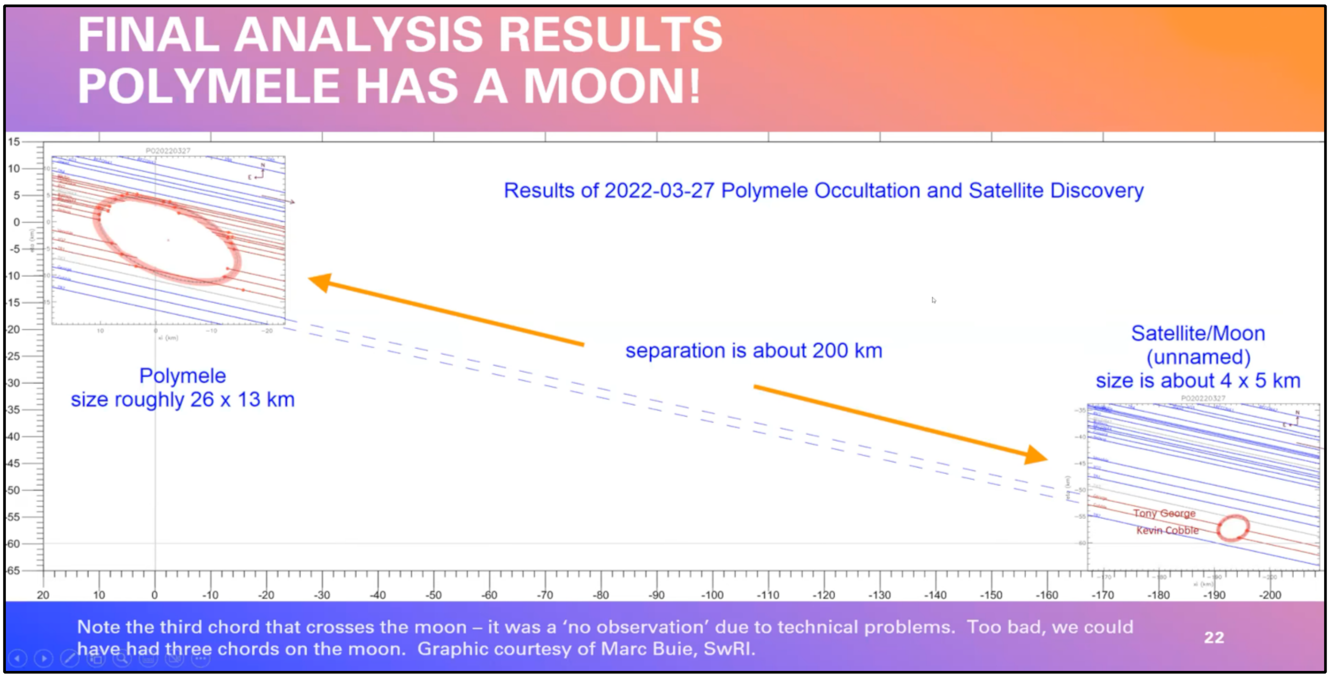


Figure 6. Profiles for (15094) Polymele and its satellite at the sky plane. Graphic courtesy of M. Buie, SwRI.

Tony George presented the discovery of a satellite of the Trojan asteroid (15094) Polymele. The occultation occured on 2022 March 27. 26 observers participated on this expedition arranged by the SwRI. Polymele is one of seven asteroids scheduled to be observed by the *LUCY* mission - six Trojans and one main-belt object. *LUCY* was launched in October 2021 and is expected to reach Polymele on 2027 September 15. Tony's site was near Salina, Kansas - a 7-hour drive from his house. The predicted time of the event at his site was predicted to +/-0.1 s accuracy, but his event was 6 seconds late. The occultation results showed a normal size for the asteroid and then Tony's event occured 6 seconds later which turns out to be the discovery of a small moon of Polymele (Figure 6).

The unofficial name of the moon chosen by Tony is "Shaun". Hopefully the *LUCY* spacecraft will confirm this exciting discovery when it reaches Polymele in September 2027. Congratulations Tony !!

John Moore talked about the rapid growth in the number of asteroid observations and review of the teamwork associated with the reductions. Worldwide events for sky plane profiles of North American observers with 20 or more observations in 2021: Bill Hanna, Paul Maley and Roger Venable led the list. Several reasons for the large increasing number of observations are due to the *Gaia* data plus Dave Herald's and Hristo Pavlov's enhancements to *Occult [7]* and *Occult Watcher [8]* (Table 1).

And let's not forget the reduction programs *PyOTE [9]*, *PyMovie [10]*, *Tangra [11]* and *AOTA [7]*. John gave special thanks to his team of persons that help reduce the observations: Jerry Bardecker, Norm Carlson, Bob Dunford, Ernie Iverson, Steve Messner, Tony George (IOTA's difficult event genius) plus Johnny Barton and Dave Eisfeldt - for *Tangra* support. Many comments from the meeting attendees praised John for the outstanding work he and the group has done.

Number of asteroidal occultations by region
Period 2021 to 2021

Region	Total	By diameter range (km)					by magnitude drop				Number of chords			
		<10km	10-20km	20-50km	50-100km	>100km	<0.2	0.2-0.5	0.5-1.0	>1.0	1	2-3	4-9	10+
Australasia :	296	23	71	86	52	64	6	25	44	221	226	68	2	0
Europe :	437	46	71	106	101	113	5	45	52	335	306	91	35	5
Japan :	116	4	7	35	36	34	3	16	24	73	60	26	27	2
Nth America :	469	27	41	155	141	105	7	38	76	348	326	112	27	3
Sth America :	55	5	10	7	17	16	1	6	14	34	41	14	0	0
Other :	0													
World :	1373	105	200	389	347	332	22	130	210	1011	959	311	91	10

Double stars : 12

Binary asteroids : 5

Total individual observations : 3214

Table 1. Number of asteroidal occultations by region for 2021.

Ted Blank presented a talk about controlling the heat buildup and associated thermal noise in the RunCam Night Eagle astro cameras. A 2-inch PVC part can be used to provide insulation and insert the camera into a 2-inch eyepiece holder to achieve the needed focus. Nowadays a 3D printer can make the same adapter. Ted showed a video clip of the noise buildup after 30 minutes of operation. The increased background noise makes extracting the occultation events more difficult. He suggested using just 5V to run the camera versus the usual 12V power. Also one can use a passive heat sink to reduce the heat and noise buildup (Figure 8). Another idea Ted uses is a small fan to cool the camera. Ted then showed a comparison video of the heat buildup on the bare camera versus adding the heat sink, fan and using just 5V to operate the camera.

Figure 7. 3D-printed carrier for the Run Cam Eagle (left).

Figure 8. Heat sink mounted on the camera.

Richard Nolthenius presented ideas to help identify and time the occultations of faint stars in bright backgrounds using *PyMovie* and *PyOTE*. The core idea is to make use of *PyMovie*'s ability to create "finders". The original intent of finders was to better position the apertures before analysis. However, finders have an advantage versus simply increasing the integration setting. If the sky is bright (twilight, nearby bright moon, light pollution), it may be impossible to increase the integration setting without saturating the pixels. In this case, what is needed is not to sum the brightness, but instead average it over a longer time interval. For longer events, this could still capture the actuality of an occultation but which might fail the usual tests with the standard *PyMovie*/*PyOTE* procedures. By averaging frames, the random bright sky pixels include the darkness which is not the case with the star's pixels.

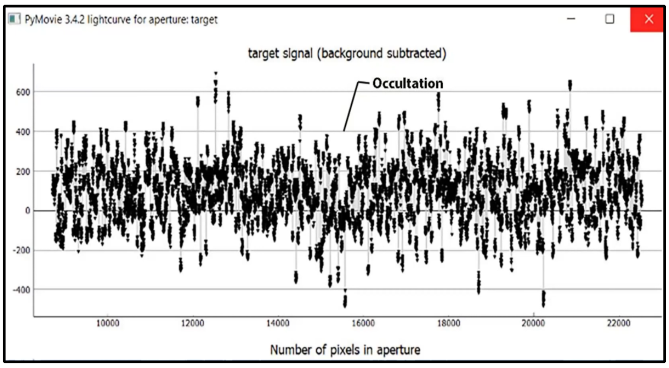


Figure 9. Example of an occultation at the edge of detection shown during the lecture.

Further, *PyMovie* already has coding to construct finders and then adjust the brightness/contrast to better show the star against the sky. If *PyMovie* can be induced to create a new video from an automated assembly of "finders", or even perhaps "finders" which overlap in time, this would be useful. If the finder is optimally significantly longer than the integration exposure setting, then the time resolution can be improved closer to the original setting versus the longer "finder" setting. *PyOTE* and *PyMovie* would require new coding to accommodate this.

He illustrated this technique with a 1 minute series of "finders" for the 2022 Aug 8 occultation by (50000) Quaoar, a high rank event with high probability the occultation seen is real. This is a 15.3 magnitude target only 12 degrees from a 90% Moon, seen in an 8" telescope at 16x Watec integration. He also showed the *PyOTE* reductions by standard means, for both Kirk Bender and his data. Rick's *PowerPoint* talk is available [12].

Tony George presented two new functions of *PyOTE*: 1) Evaluation of detectability and 2) Analysis of a single point event. The Single-point Event Tool can analyze a single-point event to determine if it is statistically distinct from baseline noise in the light curve. A Monte Carlo simulation of correlated noise equivalent to the light curve noise added to a straight line 50,000 times is used to determine if any noise spikes are representative of the single-point event. If the single point passes the test, it is statistically significant at the equivalent 4-sigma level and can be further investigated as a potential event. If it does not pass the test, the event should be considered to be due to noise, except if there are corroborating chords nearby to evaluate the validity of the single-point event.

Next was the Event Detectability tool. This tool can be used to determine if an event was detectable, in the event an observer believes there was a miss. If the test indicates that an event of a certain mag drop and duration was detectable, and no such event was observed, then the observer can reliably claim there was a qualified miss for any event longer than the detectability limit. Also, it was demonstrated how the tool could be used to process any light curve, with or without an embedded event, to use for future planning of observation sessions. Users were encouraged to record a variety of light curves for different cameras and integration settings, as well as at different altitudes and observing seasons to use for planning for future events. Then when a future event presents itself, the recorded light curve that would approximate the equivalent camera/settings/altitude/seasonal noise could be used to see if the upcoming event would be detectable given the upcoming mag drop and duration. Roger Venable suggested that open galactic clusters could be used to record a variety of star magnitudes at the same time.

Dave Herald talked about the use of the double star function in *Occult*. An important point is to treat the observer's identification of the brighter/fainter star with scepticism if the magnitude differences aren't great. This is a major issue in matching events to components. He described the basic process of fitting the observations using least squares to generate a position angle and separation. Light curves are also encouraged to be submitted to determine the magnitude drop for step events on the D and R sides of the occultation. Smaller step events are sometimes difficult to verify compared to the noise in the data.

Double star events can result in more than one solution for the position angle and separation. With a unique solution - you know where the asteroid is relative to both stars. Double solution - you know where the asteroid is relative to one star, but the fit is ambiguous for the other star. In this case, one observer might record both step events and a second observer might only record one step event. A four solution case - the asteroid location is ambiguous for both stars.

An astrometry issue: occultation discovered double stars are not usually resolved in the *Gaia* data. The issue here is to match the photo-centre of the event to the *Gaia* position. Dave showed how *Occult* does this with the double and 4 solution cases.

Occult has a database of double star discoveries by asteroid occultations - as of today's date there are 199 discoveries. To get a discovery of a new double star into the Washington Double Star Catalog (WDS), the USNO requests that the discovery must be published - they will not accept a direct notification. The *Journal of Double Star Observations* [13] is the preferred journal for announcing the discovery.

The Meeting formerly ended at 0:50 UT August 14th. Discussions continued among the attendees.

Sunday 14th August 2022 - Day 2

Technical Sessions

Vice President **Roger Venable** talked about making unattended remote observations. He showed example locations for good sites using *Google Earth* and how he sets up just off highways. He recommended painting your equipment black so as not to be visible from passing cars. In setting up a pre-point station, he uses a small piece of wood for the tripod legs to rest on so they don't sink into the ground. Dew shields are also advised especially in humid climates. He also leaves a note on the equipment for onlookers requesting that they "DO NOT TOUCH" with an explanation of what the equipment is for. Care must be taken when setting up telecopes so as not to break any laws such as trespassing, going past or opening gates to a fence, setting upon private lands without permission, etc. A group discussion followed with experiences of observers dealing with Police, landowners and identifying equipment parts in the dark such as battery terminals.

Figure 10. Roger Venable at a remote station with a 5" Celestron SC. The laptop for recording is stored in the box.

Roger Venable next talked about the appearance of light curves of near-Earth asteroid events. For faint main-belt objects at occultation time the brightness usually drops to zero (as the asteroid is usually not visible with our equipment) and the D and R are usually instantaneous. He showed a few light curves of near Earth objects and some common features of the light curves. Spikes in the light curves can be caused by Fresnel and diffraction effects and by the star's diameter. Sometimes a central spike appears on a light curve of an asteroid - this is a diffraction effect (wavelength dependent) due to the size of the asteroid and not due to a non-existent atmosphere. Diffraction spikes can occur depending on what part of the asteroid is occulted (centre or edge) from the ground position of the observer. A high recording frame rate can help identify diffraction spikes. Diffraction, frame duration and star diameter can affect the occultation timings of small objects such as Apophis (~500 ft size) compared to larger main-belt objects of 20 km and larger.

President **Steve Preston** next presented the best asteroid occultations opportunities in North America for 2023. The events were of stars down to magnitude m = +10 and he showed the *Occult* path maps for each one. The best one is when (319) Leona occults Betelguese on 2023 December 12 over south Florida, Mexico plus Europe. If visible, this should be a spectacular naked eye event with the maximum duration of up to 11 seconds.

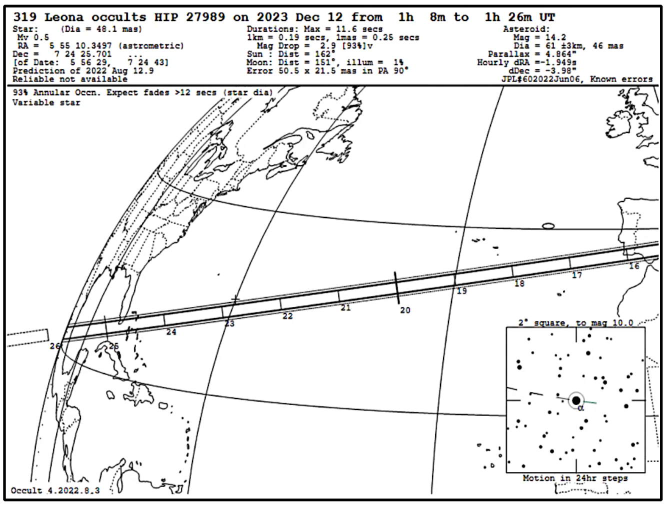


Figure 11. The highlight of 2023. Asteroid (319) Leona occults Betelgeuse on Dec 12. Note: Path may shift based on revised position for Betelgeuse.

David Dunham talked about near-Earth asteroid events in the coming year. These include:

- (433) Eros
- (1620) Geographos
- (1866) Sisyphus
- (2102) Tantalus
- (3122) Florence
- (3200) Phaethon
- (4179) Toutatis
- (29886) Randytung
- (65803) Didymos - has 160m moon 1.2 km away
- (95802) Francismuir
- (99942) Apophis
- (10995) Bennu
- (163693) Atira - has an approx 1 km size moon 6 km away

Trojans occultations for 2023:

- (617) Patroclus - has the moon Menoetius
- (624) Hektor
- (911) Agamemnon
- (1143) Odysseus
- (1173) Anchises
- (2241) Alcathous
- (3548) Eurybates - has a small 1 km moon Queta discovered by HST.
- (11351) Leucus - *LUCY* mission target
- (15094) Polymele - has a 5 km moon 200 km away
- (21900) Orus
- (58931) Palmys

Special main-belt asteroids in 2023 (Figure 12):

- (16) Psyche
- (90) Antiope
- (26) Kleopatra - has 2 small moons
- (234) Barbara - possible contact binary asteroid
- (253) Mathilde
- (319) Leona
- (513) Centesima
- (762) Pulcova- has a 15 km Moon
- (957) Camelia
- (2258) Viipuri - may have a 5 km moon
- (4337)Arecibo - Binary discovered in 2021 confirmed by *Gaia*
- (4552) Nabelek
- (33074) 1997 WP21 - might have a 9 km moon
- (52246) Donaldjohanson - *LUCY*
- (172376) 2002 YE25 - possible binary asteroid

David then showed a list of (50000) Quaoar (size ~ 550 km) and Weywot (moon of Quaoar, size ~ 170km) occultations for the remainder of 2022 and 2023. He then showed a map of occultation stars brighter than m = +9.0 for North America he is working on for the RASC Handbook.

David Dunham next talked about the (65803) Didymos events for the rest of 2022 and 2023. Didymos is the target of the *DART* mission to impact it and test the planetary deflection technique of a non-hazardous asteroid. Following the impact, the orbit will change slightly. Events in 2022 with stars down to m = +12.0 are numerous - major ones are: Aug 17, Aug 23, Aug 24 and Aug 25, Sep 3, Oct 2, Oct 8, Oct 10, Oct 12, Oct 15, Oct 17.

Didymos opportunities for 2023: Jan 1, Jan 3, Jan 5, Jan 5, Jan 6, Jan 9, Jan 10, Jan 12, Jan 16, Jan 18, Jan 21, Jan 23, Jan 28, Mar 2, Mar 20, Apr 9, Apr 25, May 4.

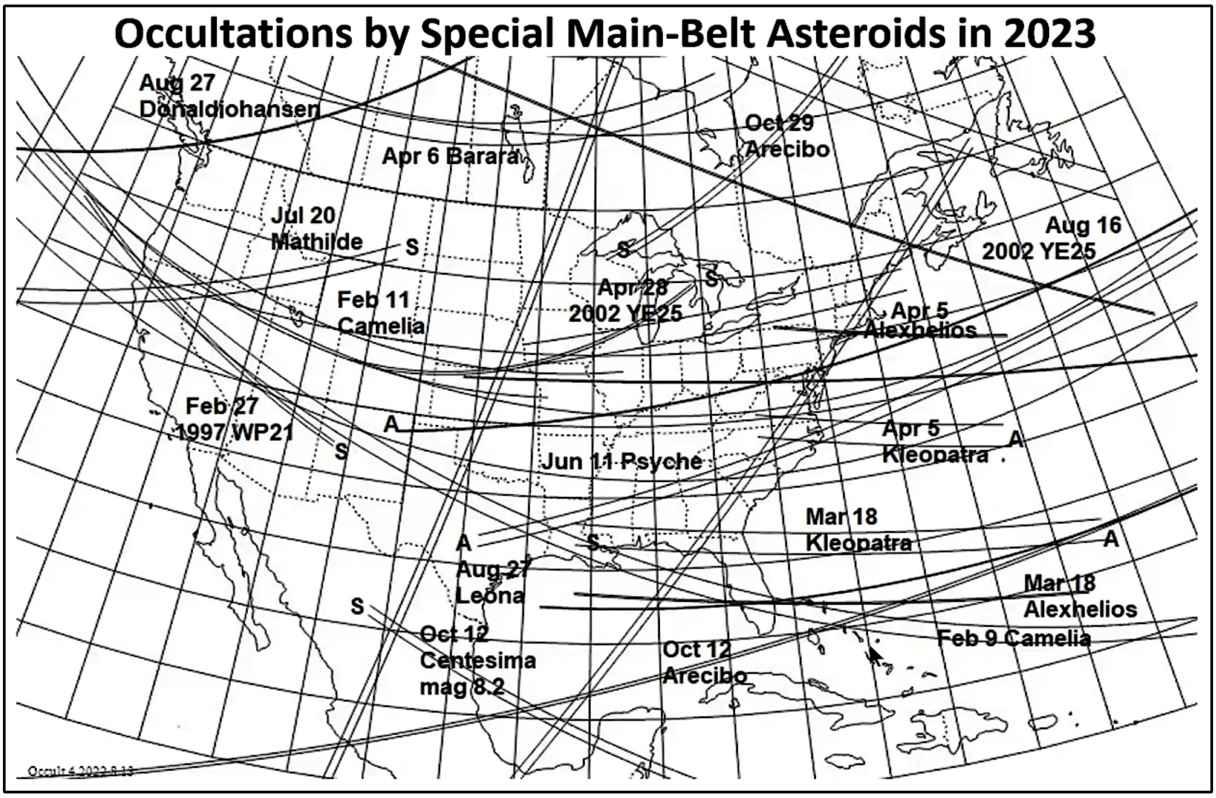


Figure 12. Occultations by special main-belt asteroids across North America in 2023. (source: Occult 4.2022.8.18)

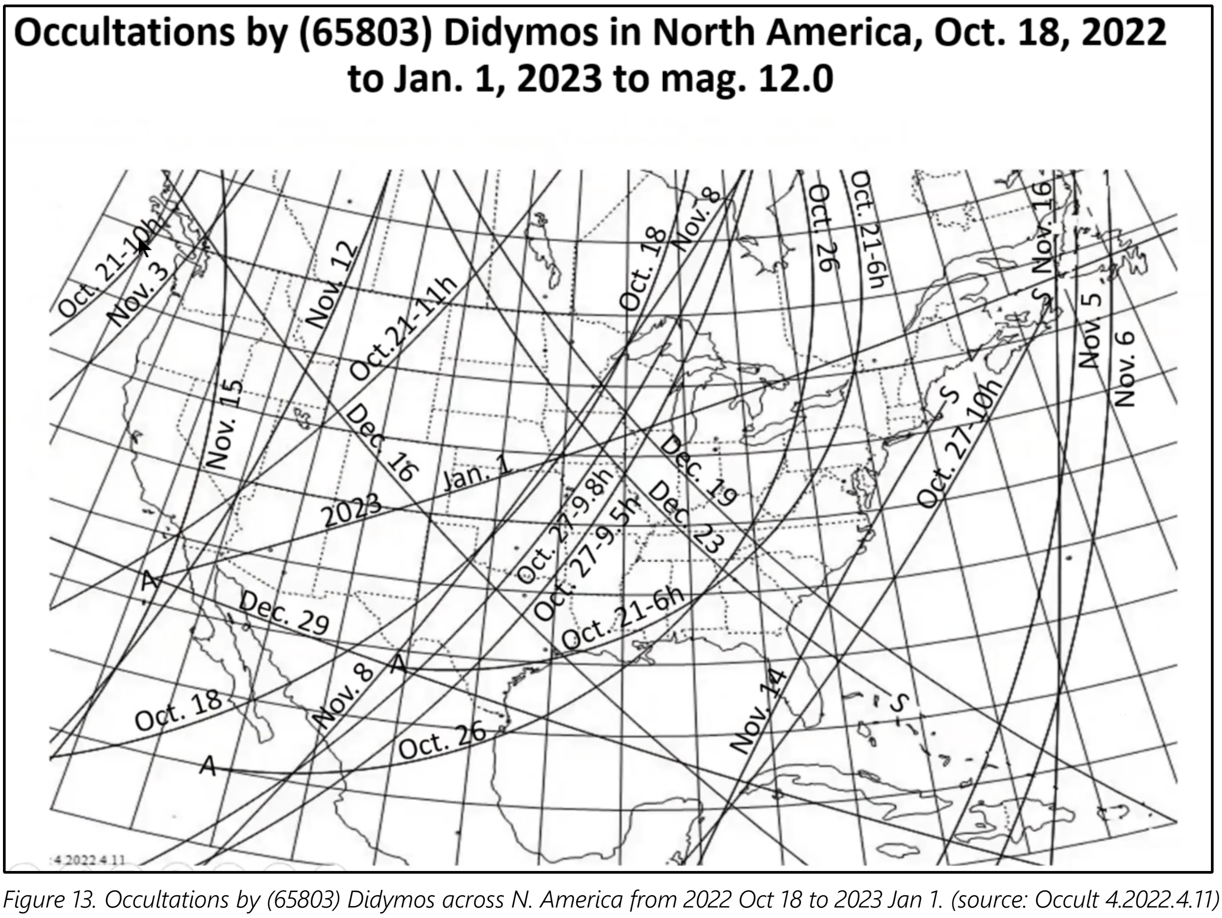


Figure 13. Occultations by (65803) Didymos across N. America from 2022 Oct 18 to 2023 Jan 1. (source: Occult 4.2022.4.11)

Dave Herald talked about issues to think about regarding light curve analysis. Event time accuracy - should we aim for highest time precision? When is sub-frame timing desireable? Fact is 95% of occultation astrometry has an uncertainty of >1.0 mas. Shape resolution depends on the number of chords. Single chord events have no shape info, the more chords (with good spacing) the better in determining the shape. With a better shape the "centre of figure" can be determined resulting in a more accurate astrometric position for orbit updating. Then he discussed dealing with background subtraction. The purpose of background subtraction is to set the zero level of the light curve to zero light. He showed 3 light curves of the (718) Erida event 2022 Jun 24 recorded by Richard Nolthenius. The light curves were made by *PyMovie* and *Tangra* with usual and average background subtraction in *AOTA*. Background subtraction results in a more distinguishable event from the data points compared to not using it.

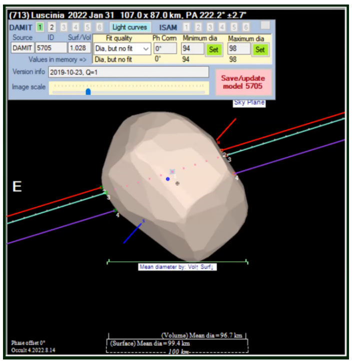
Magnitude drops - realistically with our video equipment mag drops can be measured down to 0.1 mag precision. Noise in the event can influence this. Some observers have reported mag drops to 0.001 mag! This is not credible or sensible - Dave suggested we report mag drops as a percentage of full light.

Gamma function - On our video cameras the gamma function changes the vertical response in a non-linear manner. It should always be set to 1. With instantaneous events the non-linear vertical response has a minimal effect to event time. Gamma set to less than 1 affects magnitude changes. Magnitude changes are generally poorly determined from our 8-bit light curves. However if adjusting Gamma enables one to make an observation, by all means do it.

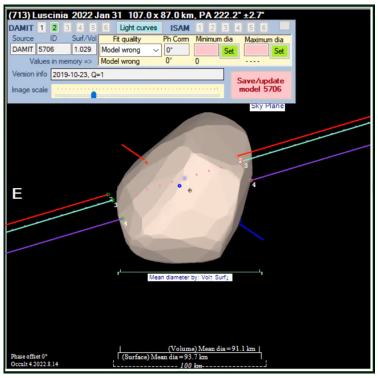
Dave Gault talked about time stamping delays associated with the computer. There are acquisition delays, delays from VTI to camera and internal camera processing delays to the computer. More delays are within the PC's used for timing. Questions are: does anyone test their system for these delays? And correct their times for this delay? Delays can be 53 - 68 ms. Hristo Pavlov and Dave Gault wrote an article on this problem in the *Journal for Occultation Astronomy* (JOA) issue 2020-02 [14].

Dave Herald next talked about shape model analysis with *Occult*. Shape models provide the shape, not size of the asteroid. The shape provides a volume-equivalent diameter to be measured. Well observed events can help locate the centre of mass and not the centre of figure. Dave showed sample *Occult* plots overlaid with DAMIT shape models and location for the centre of figure (Figures 14a, b). The centre of figure point is used to determine the astrometric position for MPC reporting. Multiple occultations by the same asteroid can also be used to get the axis of rotation. With the axis of rotation known, the asteroid can be rotated to show different orientations.

He then showed an *Occult* demo of (433) Eros rotating based on shape and axis models.



Figures 14a,b. While the chords fit the DAMIT model 5705 of asteroid (713) Luscinia (left), there is no match with model 5706 (below). (Source: Occult 4.2022.8.14)



The meeting ended at 00:10 UT August 15th.

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Journal for Occultation Astronomy

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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.

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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.

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