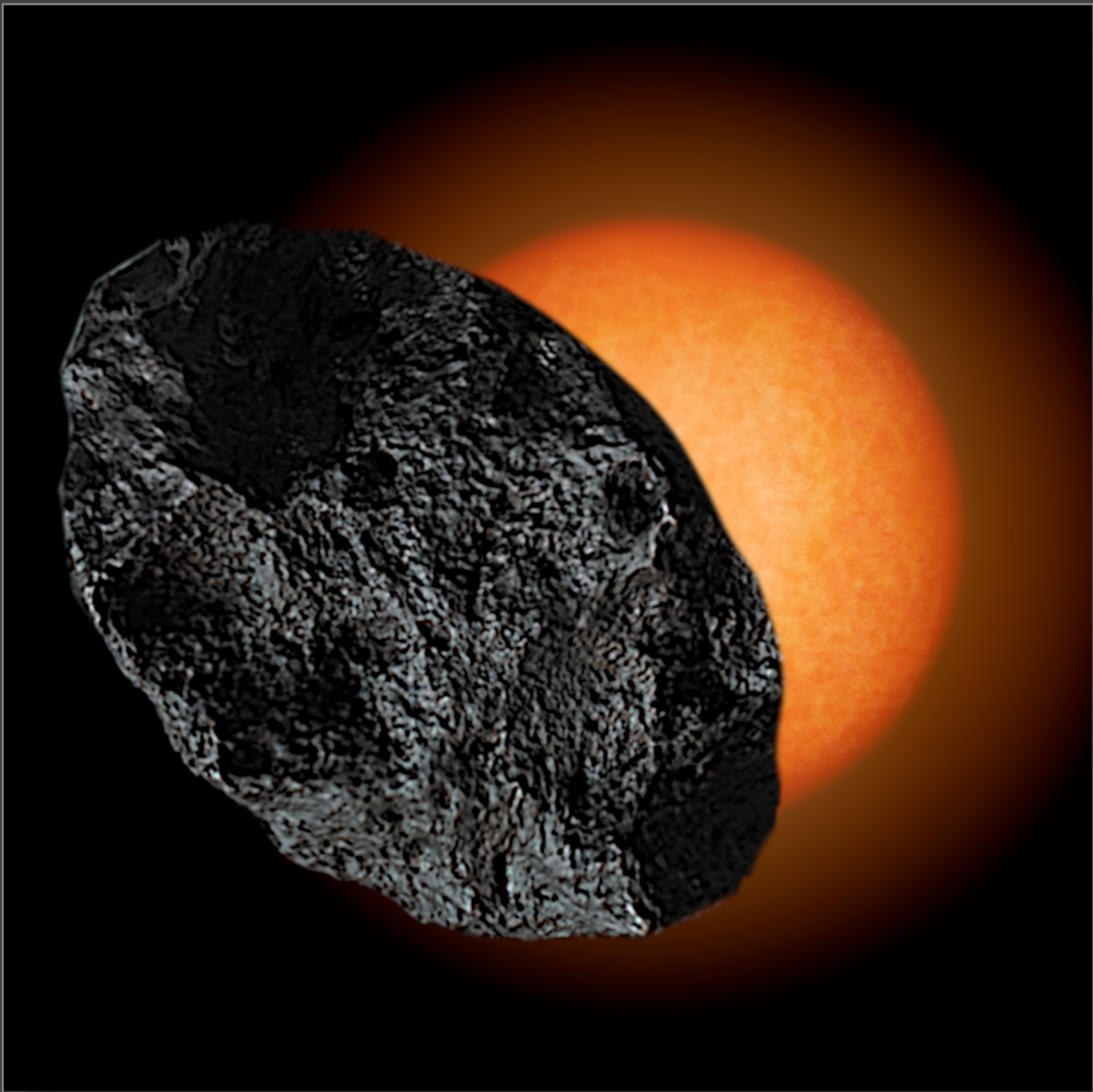
# Journal for Occultation Astronomy

Volume 13 · No. 4 · Rev. 1 2023-04



Occultation of Alpha Orionis by (319) Leona, 2023 December 12

# Dear reader,

Almost all solar eclipse chasers go to the centre line to maximise their enjoyment of nature's wonderful spectacle. However, a small number of dedicated observers locate themselves at the northern or southern limit of totality to record the prolonged displays of Baily's Beads to estimate the Sun's diameter. This edition of JOA contains reports on the solar eclipse of 2023 April 20, where two collaborating teams obtained accurate timings of the Bead phenomena, recorded photometric data on the changing light levels and timed the flash spectrum.

Cooperation and meetings are the lifeblood of our team ethic and this is evident in the recent formation of IOTA/EA catering for occultation observers in East Asia, and the detailed report of IOTA's 41st annual meeting.

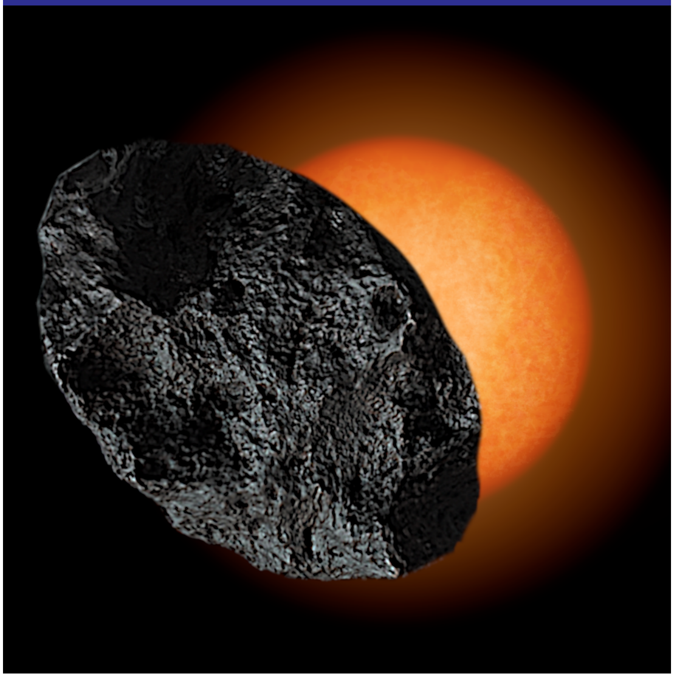
In September, ESOP 42 in Armagh, Northern Ireland was a most enjoyable and productive meeting. The keynote session was on the occultation of Betelgeuse by asteroid (319) Leona on 2023 December 12. The ground track is well defined, but because Betelgeuse and the asteroid subtend similar diameters this 'once in a lifetime' event will most likely be a partial or annular occultation, requiring different techniques to record its high dynamic range. The comprehensive Call For Observations and Practical Advice describe how you can participate in this major pro-am campaign.

Clear skies,

*Alex Pratt*

IOTA/ES

COVER



Artist's impression of the stellar occultation of Betelgeuse by asteroid (319) Leona on 2023 Dec 12. The dimensions of star and asteroid are based on an interpretation of the successful observations of an occultation by (319) Leona on 2023 Sep 13 in the paper by J.-L.Ortiz, et al. The real position angle and the dimensions of the star and the shape profile of the asteroid might be different at the event time on Dec 12. (Graphic: O. Klös)

JOA Volume 13 · No. 4 · Rev. 1 · 2023-4 $ 5.00 · $ 6.25 OTHER (ISSN 0737-6766)

## In this Issue:

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CALL FOR OBSERVATIONS:

# The Occultation of Betelgeuse by (319) Leona on 2023 Dec 12

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**ABSTRACT:** On 2023 Dec 12 the bright naked-eye star Betelgeuse (α Ori) will be occulted by the main-belt asteroid (319) Leona. The occultation path of this transatlantic event starts in eastern China, then crosses Tajikistan, Turkmenistan, Azerbaijan, Armenia, Turkey, Greece, Italy, Spain, Portugal, the southern tip of Florida and finally ends in Mexico. Because the apparent size of the asteroid will likely be smaller than the angular diameter of the star in visible light (~50 mas), this will result in an annular (and/or partial) occultation which is different from the usual (total) asteroidal occultation and will give a big community of pro/am observers a unique opportunity to study this star in detail with small instruments.

## Introduction

Stellar occultations by small Solar System objects like asteroids are usually intended to study the occulting bodies. However, this technique can also be applied to study the occulted body, i.e. the target star. Historically, high cadence observations (photometer, high-speed imaging) of total lunar occultations of stars were performed to study the stars, for example to measure the angular size and/or to resolve close companions. Of course this limits the ensemble of potential targets to stars lying within the apparent path of the Moon in the sky. But stellar occultations by asteroids, in general used to explore the asteroids themselves, have also been successfully applied in the past years to study the target stars [1, and references therein].

*Figure 1. In this view, the usual appearance of Orion (left, in an image taken on 2012 February 22), is compared with an image taken on 2020 February 21 (right), clearly showing the unusual dimming of the red giant star. Both images were taken with identical setups and exposure data: Each is a 30 second exposure taken with a Canon EOS 550D camera at ISO 3200, 17mm f/2.8 lens, Cokin P830 diffuser, tracked with the Vixen Polarie star tracker. Credit: H. Raab and Wikipedia CCBYSA-4.0 : https://commons.wikimedia.org/wiki/File:Betelgeuse.jpg*

In December of this year, we will have the rare opportunity to observe an asteroidal occultation of one of the brightest stars in the northern night sky, the well-known 'shoulder star' of Orion: Betelgeuse (Figure 1).

Betelgeuse (α Orionis, HD 39801, HIP 27989) is a prominent red supergiant star (spectral type M1-M2) located in the constellation Orion. It has roughly 10 times the mass of our Sun and is huge compared to our central star – about 1,400 times larger, so that our Solar System up to the orbit of Jupiter would fit into this supergiant (Figure 2). It is one of the most well-known stars in the (northern) night sky and with V~0.5 mag easily visible to the naked eye. Betelgeuse is nearing the end of its life cycle and will explode in a supernova. This supernova is expected to occur within the next $10^5$ years, but we don't know when exactly. This supergiant star is nearby and large in apparent size, providing an outstanding opportunity for an intensive and spatially-resolved study of its surface, atmosphere and surroundings. However, especially this proximity to us and the brightness makes it for example difficult to precisely determine the apparent diameter and thus the distance to us (see Table 1 and [2]).

Occultation observations will help us to improve these key parameters. Betelgeuse's brightness has been observed and recorded for more than a century, revealing its semi-regular variability, with a primary period of about 400 days and a secondary of about 2,200 days [2, and references therein]. In January and February 2020 the star underwent a historic optical dimming of more than one magnitude (Figures 1, 3), attracting a lot of attention in the scientific community and raising speculations about the fate of this star, including a 'soon to be expected' supernova explosion. The currently accepted explanation for this temporary fading is from disk-resolved VLT images [3], showing that parts of the star were darkened, caused due to a surface mass ejection into space. The material cooled down and formed a dust cloud that partly blocked the light coming from Betelgeuse. In the 1980s Karovska et al. [4] reported the detection of two close optical companions from speckle images taken with the 2.25-m telescope at *Steward Observatory*, located at 0.06" and 0.51" angular distance from α Orionis. However, subsequently these findings were never confirmed.

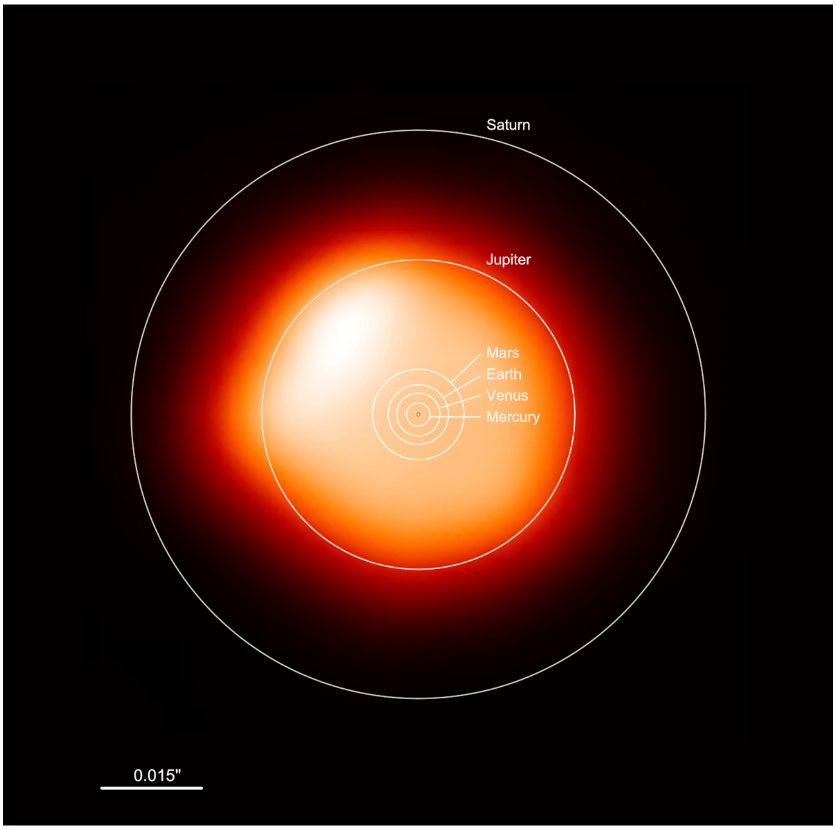


*Figure 2. In the millimetre continuum Betelgeuse is around 1,400 times larger than our Sun. Betelgeuse would engulf all four terrestrial planets - Mercury, Venus, Earth and Mars - and even the gas giant Jupiter; only Saturn would be beyond its surface. Image credit: ALMA / ESO / NAOJ / NRAO / E. O'Gorman / P. Kervella.*

| |
|---|
| V-mag: 0.5 |
| U-B: 2.06 |
| B-V: 1.85 |
| Variability : ~0.3 – 1.2 mag |
| Temperature : 3650 ± 50 K |
| Spectral type : M1-M2 (Ia-Iab) |
| Radial velocity : +21.91 ± 0.51 km/s |
| Angular diameter : 42.05 ± 0.05 mas (2.28–2.31 µm) |
| Angular diam. : 43.15 ± 0.50 mas (1.65 µm, H-band; limb-darkened disk) |
| Angular diameter : 125 ± 5 mas (2500 Å, continuum) |
| Distance : 153 (+22,–17) pc; 168.1 (+27.5,–14.9) pc; 222 (+48–34) pc |
| Radius : 764 (+116,–62) R_Sun; 996 (+215,–153) R_Sun |
| Periodicity (fundamental) : 388 ± 30 days; 385 ± 20 days; 420 days |
| Secondary period : 2050 ± 460 days; 2229.8 ± 6 days |

*Table 1. Fundamental parameters of Betelgeuse*
*References: [2] and Wikipedia [en]*

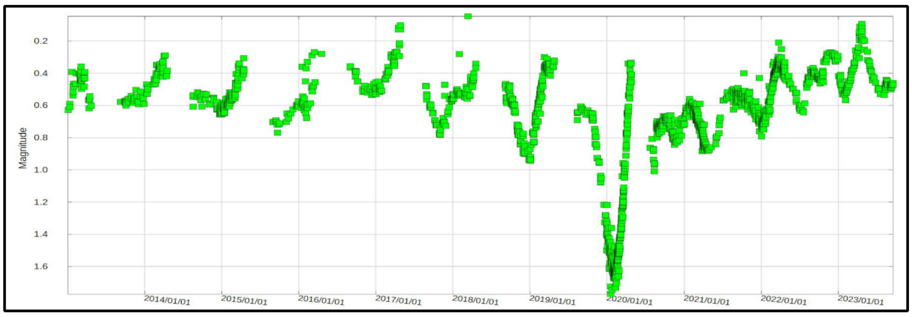


*Figure 3: The visual (V band) lightcurve of Betelgeuse over the past 10 years showing the prominent dimming of about 1 mag during January and February 2020. Plot generated with the AAVSO lightcurve generator.* https://www.aavso.org/LCGv2/

(319) Leona is an outer main-belt asteroid (semi-major axis a = 3.4 au), orbiting around the Sun in about 6.3 yrs. Radiometric diameter estimates (methodically assuming a sphere) reported in the literature are 40 km [5], 66 km [6], and 89 km [7], to mention the lower and higher extremes, and a middle value which also agrees with a count peak in the MP3C database [8].

In 2010 two single-chord occultations were observed from Australia and from Japan, with chord lengths of ~44 km [9] and ~35 km [10]. But these single-chord occultations are not sufficient to constrain the diameter of (319) Leona or even to tell us something about the shape. For that reason and in preparation for the Betelgeuse event, a special campaign to detect multi-chord occultations by (319) Leona was carefully planned. Results from occultations observed on 2023 Sep 13 (Spain and Portugal) with 19 positive detections and Sep 16 (USA) with 3 positive detections indicate that roughly the middle value of about 66 km seems to be a realistic estimate for the mean size of (319) Leona. Thus, it is reasonable to use this value for the occultation predictions.

In the ALCDEF and LCDB light curve databases [11, 12] we find rotation periods of P ~52h (Behrend 2016+2023), P ~14.9h (Alkema 2013) and P1 ~430h / P2 ~1080 h (Pilcher et al. 2017)[1, 2]. The reported light curve amplitudes are in the order of 0.5 - 0.65 mag. Yet no 3D model of (319) Leona exists in the DAMIT database [13]. However, Durech [14] very recently published a preliminary physical model, by combining the published light curve data from Pilcher et al. (2017) with sparse photometric data from ATLAS and Gaia DR3, confirming a tumbling state, but with periods of P1 ~314 h (rotation) and P2 ~1172 h (precession).

[1] The two periods describing a non-principal axis NPA rotation ('tumbler').
[2] References given in ALCDEF & LCDB.

In the following sections, two occultations that have already been observed will be presented and information will be given about further upcoming occultations which may be observed in preparation for the occultation of Betelgeuse.

## The 2023 Sep 13 and 16 Occultations

(319) Leona was predicted to occult a relatively bright G = 11.9 mag star on Sep 13. The event was observable from Algeria, Spain and Portugal (see Figure 2 of [15]), providing an excellent opportunity to improve our knowledge about (319) Leona, especially the (mean) size, projected shape and orbit of the asteroid. An observation campaign was organised in Spain and Portugal, resulting in 19 positive detections at 17 different observing sites [16]. As visible in the profile plot (Figure 4), the projected limb cannot be very well represented by an ellipse – assuming that no chords are displaced due to (yet not identified or resolved) absolute timing errors (note that reported timing uncertainties from the light curve fit are to be considered as relative, not absolute). The asteroid appears somehow irregular, also kind of bi-lobed shape (as seen for contact binaries) seems possible. The projected effective diameter was determined to be 66 km [15]. The success of the event was quickly communicated and because the deviation of the asteroid position from the JPL#69 ephemeris was very small further occultations would likely succeed and encouraged more occultation observations of fainter stars.

On Sep 16 (319) Leona occulted a G = 15 mag star, a much fainter star than that observed on September 13. The occultation was visible from the US [17]. This event was successfully observed

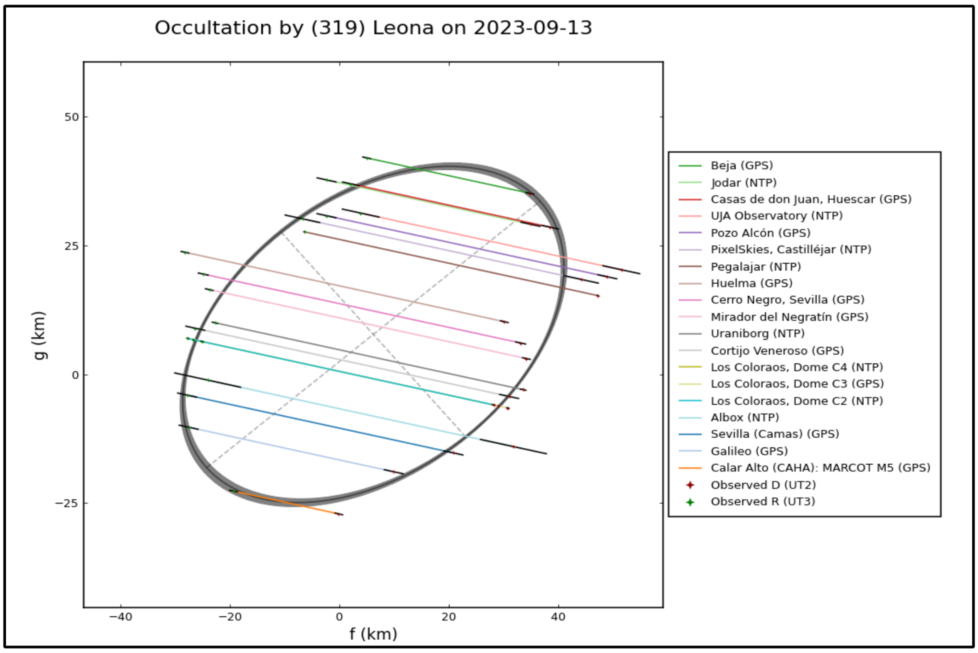


*Figure 4. Ellipse fit to the chords of the Sep 13 occultation observed in Spain and Portugal, projected on the Besselian fundamental plane. The black part and the start and end of the chords are the timings uncertainties derived from the light curve fit. The used time source is given in parentheses after the observing site designation. The projected surface equivalent diameter is 65-66 km.*

by R. Venable from Arizona, deploying three stations, operated alone by himself. The formal ellipse fit to the extremities (chords) yields an ellipse which is smaller than that of Sep 13 with a different orientation (Figure 5), but because we only have three chords, the fit has a much larger uncertainty in these parameters.

These two observed occultations provide us with first important information about (319) Leona: the mean projected size could be constrained by these events (and thus discarding some of the extreme radiometric values) and highly accurate astrometric positions have been derived, to be used to confirm and to improve the JPL orbit, and other independent orbit solutions, like NIMA and CORA. And they provide good constrains for any physical model (derived from lightcurve inversion) of the asteroid.

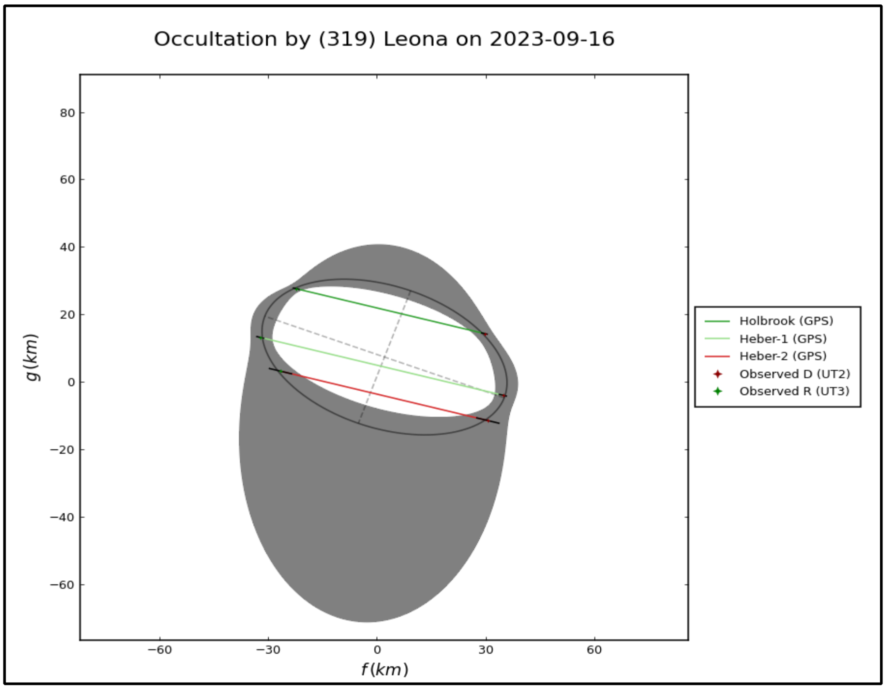


*Figure 5. Ellipse fit to the chords of the Sep 16 occultation observed in the USA (AZ), projected on the Besselian fundamental plane. The black part and the start and end of the chords are the timings uncertainties derived from the light curve fit. The used time source is given in parentheses after the observing site designation. The mean projected size of the ellipse is 55 km. The shaded grey zone is the 3-sigma uncertainty region of the fit. This result (size and orientation of the ellipse) would still be in agreement with the fit in Figure 4 within the parameter uncertainty.*

## Further Occultations Before Dec 12

Further possibilities to observe occultations of stars brighter than G = 15 mag by (319) Leona in advance of the Betelgeuse event will be on Oct 29 from Europe [18], Nov 15 from Mexico and eastern US [19], Nov 19 from Ireland, northern UK, northern Scandinavia [20], and Dec 6 from Morocco, Algeria, Tunisia, Greece, Turkey, Armenia and continued to the Far East [21]. As mentioned in the previous section, getting more multi-chord occultation observations will help to improve and to confirm any of the proposed physical models of Leona.

## The 2023 Dec 12 Occultation

Betelgeuse will be occulted by (319) Leona on the night of December 11/12 (Figure 6a-c and [22, 23]). The shadow crosses the Earth from east to west with a velocity of 10.7 km/s. No Moon will interfere with the event which will last about 6 s on the central line. However, this value belongs to a theoretical total (on-off) occultation and a mean diameter of about 66 km. As we will have a partial/annular occultation the whole event will cover more time and can last up to about 11 - 12 s at maximum (for visible light wavelengths). The occultation path of this transatlantic event starts in eastern China, then crosses Tajikistan, Turkmenistan, Azerbaijan, Armenia, Turkey, Greece, Italy, Spain, Portugal, the southern tip of Florida (US) and finally ends in Mexico.

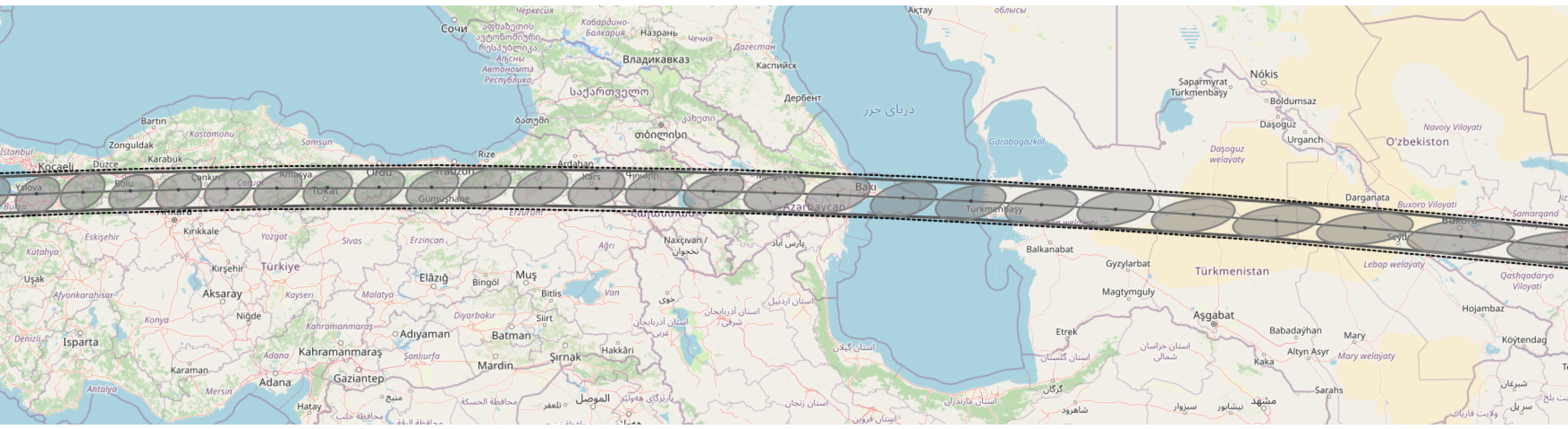

*Figure 6a.*

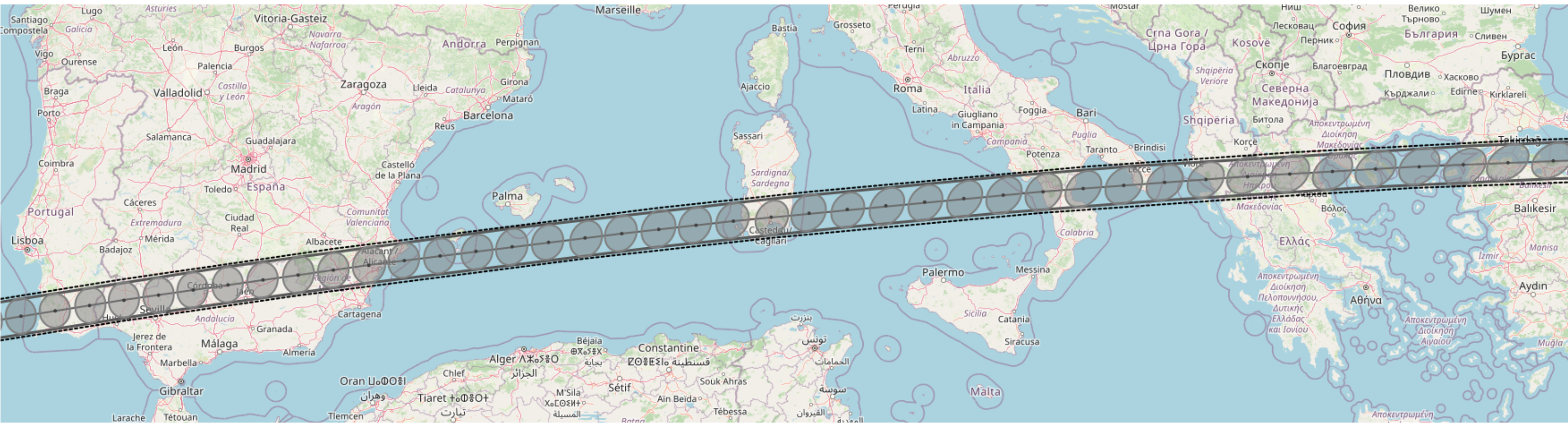


Figure 6b.


Figure 6c. Predicted central (total) occultation shadow path of (319) Leona on 2023 Dec 12. Not shown is the region of partial occultation which extends perpendicular to the path. JPL#69 ephemeris was used for (319) Leona. The position of Betelgeuse was computed by using the epoch 2017.0 position from the USNO-UBAD catalogue [24] and the proper motions were taken from [25]. An interactive online map is provided at [22]. Map created using the OpenStreetMap data service.

Some selected mid-occultation times are: Turkey (Ankara) ~01:11.3 UT, Greece (Ioannina) ~01:12.5 UT, Italy ~01:13 UT, Spain (Jaen) ~01:15.5 and Florida~ 01:24.9 UT. The exact times for a specific observing site can best be taken from interactive maps [22, 23] by clicking on the location of interest. We recommend also to consult dedicated websites and social networks (see web resources at the end of this article) which will provide specific material and maps, especially also for local regions and campaigns. As for the occultation date the geocentric distance of (319) Leona is 1.8008 au, the projected angular scale at this distance is 1.31 km/mas. A mean diameter of 66 km corresponds to 49.6 mas, a projected ellipse of (79.6 x 54.8) km to (60.8 x 41.8) mas. A lot of measurements of the angular size of Betelgeuse can be found in the literature [26], obtained in different wavelengths. The first one goes back more than 100 years (by Michelson at Mt. Wilson, USA). It has to be noted that several aspects influence the measurements (e.g. the wavelength and the limb darkening) and that the diameter is not constant over time. For visible light it seems reasonable to assume a current value of about 45-55 mas. Figure 7 shows a Dec 12 prediction for the projected profile by Durech [14]. From that figure we derive a visually-fitted ellipse of about 74 x 57 km at rotation angle φ ~ 25° with respect to the cross track direction, which by chance is not that far away from the situation we have had at the Sep 13 occultation. In Figure 8 we show simulated occultation light curves for these values.

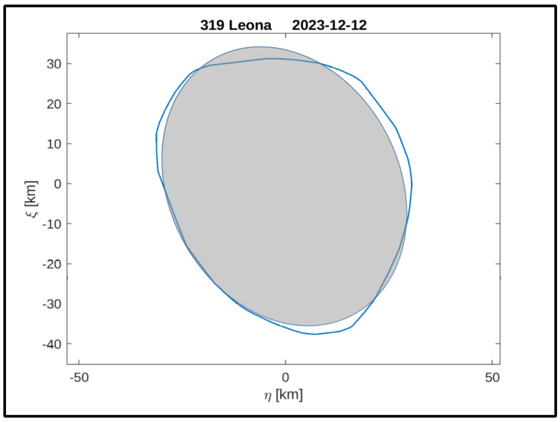


*Figure 7. Predicted profile and orientation (blue line) of (319) Leona for the Dec 12 Betelgeuse occultation (Durech [14]) on the sky plane. The grey shaded ellipse is visually fitted to that profile.The size of that ellipse is 74 x 57 km (projected surface equivalent diameter ~65 km), with rotation angle φ ~ 25°.*

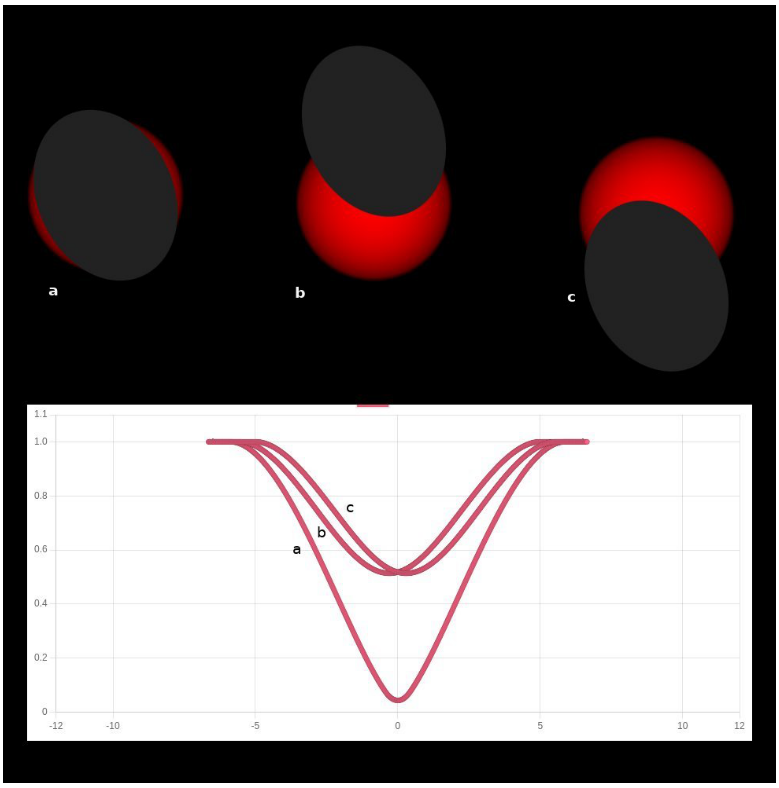


*Figure 8. Simulated display (on the sky plane) and light curves of the Betelgeuse occultation using an ellipse for (319) Leona with values given in Figure 7 and a diameter of 50 mas for Betelgeuse. Three different situations are shown: (a) observer on the central line, (b) 30 km south of observer (a), and (c) 30 km north of observer (a). In each case the asteroid is moving horizontally from left to right. In the upper panel the view at mid-occultation (for that site) is shown. The plot with the corresponding light curves in the lower panel shows the normalized intensity vs time t-t0 in seconds, where t0 is the mid-occultation time for the observer on the central line (case a), thus cases b and c are shifted.*
*Graphic and light curves created with https://starblink.org/occult_simulator_en*

The main aim is to measure the photosphere with high spatial resolution by (visible light) photometry of the ingress and egress. Imaging should be taken therefore at high cadence (20-100 fps or even more) using filters, preferably R, V, and B (but also other bands and even narrow-band filters like Hα can provide interesting and valuable results). As usual with occultation observations, accurate timekeeping is important. If you are doing occultation observations on a regular basis you will have a suitable timekeeping solution. But as for this event also very small and unconventional setups including DSLR cameras and telephoto lenses are possible, you might consider to use smartphone apps like *Occult Flash Tag* [27] for *Android*, or *AstroFlashTimer* [28] for *iOS*. These apps flash the smartphone camera LED triggered by the (GPS or NTP synchronised) smartphone time and thus can be used to set accurate optical time markers on the recording. If you have just one camera but want to record simultaneously in several colours, you can use an objective prism or a grating (e.g. the Star Analyser SA-100 and SA-200) to get low-resolution spectra. An alternative possibility is to modify a (3x) multi-image filter prism trick lens with colour filter inlays in order to get three different-colour images of the star at the same time [29]. Due to the high dynamic range of the event (measuring the gradual occultation light curve of a bright star), detectors with high dynamic range and resolution (bit depth) should be preferred.

Also, consider the drift scan technique (DRS) [30], which is especially suitable for this event because of the brightness of the star. It does not require sidereal tracking, so a camera on a tripod is sufficient. It also simplifies somehow the demands on timekeeping, as only one single image needs to be timed. The program *Scanalyzer* can be used to reduce such a some-tenseconds-exposure drift-scan image.

Finally, another observing aim would be to do high-resolution spectroscopy. Though there are also amateurs and pro-am groups working in this domain, we do not go into details here and refer to web resources and special information (also given at the end of the article) covering that topic.

## Conclusion

The occultation of the supergiant star Betelgeuse will be an extremely rare and amazing event, happening over a densely populated region. It will give the opportunity not only to eyewitness a spectacular astronomical phenomenon, but also to contribute to sophisticated scientific observations and projects with rather simple means. We can also expect that this event gives an excellent opportunity for citizen science projects and pro-am collaborations and thus to enhance the visibility of public observatories and astronomical associations. We recommend potential observers to frequently consult the web resources given at the end of this article, social media and/or to contact the authors about dedicated projects and campaigns in different regions. Regional IOTA coordinators can also be contacted to get involved in specific campaigns.

## References


[1] https://iota-es.de/esop39/lections/richichi-esop39.pdf

[2] Dupree, A. K. et al., 2022. The Great Dimming of Betelgeuse: A Surface Mass Ejection and Its Consequences. The Astrophysical Journal, vol. 936, 18, doi: 10.3847/1538-4357/ac7853.

[3] https://www.eso.org/public/news/eso2109/

[4] Karovska, M., Nisenson, P., and Noyes, R., 1986. On the alpha Orionis triple system. ApJ, vol. 308, 260, doi: 10.1086/164497.

[5] Masiero, J. R., et al., 2014. MAIN-BELT ASTEROIDS WITH WISE/NEOWISE: NEAR-INFRARED ALBEDOS. ApJ, vol. 791, no. 2, 121, doi: 10.1088/0004-637X/791/2/121 .

[6] Usui, F., et al., 2011. Asteroid Catalog Using AKARI: AKARI/IRC Mid-Infrared Asteroid Survey. Publications of the Astronomical Society of Japan, vol. 63, no. 5, 1117–1138, doi: 10.1093/pasj/63.5.1117.
[7] Nugent, C. R., et al., 2016. NEOWISE REACTIVATION MISSION YEAR TWO: ASTEROID DIAMETERS AND ALBEDOS. The Astronomical Journal, vol. 152, no. 3, 63, doi: 10.3847/0004-6256/152/3/63.
[8] https://mp3c.oca.eu/bodies/Leona/ (queried on 2023-09-30)
[9] https://astro.kretlow.de/cora/events/occult/2010-10-22/UCAC4%20480-003465/(319)%20Leona/
[10] https://astro.kretlow.de/cora/events/occult/2010-10-27/Tycho2%200045-01477-1/(319)%20Leona/
[11] https://alcdef.org/ (queried on 2023-09-30)
[12] https://minplanobs.org/mpinfo/php/lcdb.php (queried on 2023-09-30)
[13] https://astro.troja.mff.cuni.cz/projects/damit/ (queried on 2023-09-30)
[14] https://sirrah.troja.mff.cuni.cz/~durech/Leona/ (queried on 2023-10-10)
[15] Ortiz, J. L., et al., The stellar occultation by (319) Leona on 13 September 2023 in preparation for the occultation of Betelgeuse. arXiv, 21-Sep-2023, doi: 10.48550/arXiv.2309.12272.
[16] https://astro.kretlow.de/cora/events/cora/2023-09-13/GDR3%203347400001862704896/(319)%20Leona/
[17] https://astro.kretlow.de/cora/occultations/53a66098-eafc-4c28-b31e-27fb3988a904/
[18] https://astro.kretlow.de/cora/occultations/5dfd8280-0694-4bc3-a0e0-a582dcb91956/
[19] https://astro.kretlow.de/cora/occultations/5ef04740-02a3-430a-958e-a74d923e4e60/
[20] https://astro.kretlow.de/cora/occultations/8707774a-f497-4de8-a38d-c6b885e6f027/
[21] https://astro.kretlow.de/cora/occultations/8ae06798-0072-438ea21c-ede92198fd59/
[22] https://astro.kretlow.de/cora/occultations/aa3579fb-2fa7-4a89-8452-bfc8a87e0704/
[23] https://lesia.obspm.fr/lucky-star/occ.php?p=124370
[24] Munn, J. A., et al., 2022. Accurate Ground-based Astrometry of Naked-eye Stars: The United States Naval Observatory Bright-star Astrometric Database. AJ, vol. 163, no. 3, 131, doi: 10.3847/1538-3881/ac41d2.
[25] Harper, G. M., et al., 2017. An Updated 2017 Astrometric Solution for Betelgeuse. AJ, vol. 154, no. 1, 11, doi: 10.3847/1538-3881/aa6ff9.
[26] https://en.wikipedia.org/wiki/Betelgeuse#Table_of_angular_diameter_estimates
[27] Couto, E., Occult Flash Tag https://apkpure.com/es/occult-flashtag/br.eti.erickcouto.occultflashtag/versions
[28] Grismore, J., AstroFlashTimer, https://sites.google.com/site/astroflashtimer/home
[29] https://astrode.de/esop23c.htm
[30] Broughton, J., Drift-Scan Timing of Asteroid Occultations, https://www.asteroidoccultation.com/observations/DriftScan/Index.htm

## Web Resources

Below are some websites that are general or specifically dedicated to the occultation of Betelgeuse and are therefore recommended to visit. Of course, this list does not claim to be complete. The website language is stated in square brackets [ ].

**Spanish Discord Occultation Channel, Ocultaas [es, en]:**
https://discord.com/channels1124386872693620766/1125268152595521647
Discord account required.
**French pro-am collaboration, Gemini [fr, en]:**
https://proam-gemini.fr/photometrie-et-spectroscopie-de-betelgeuseα-ori-lors-de-son-occultation-par-319-leona-du-12-12-2023/
**Spanish Citizen Science Project [es]:** https://starblink.org/
The website has a nice online simulator:
https://starblink.org/occult_simulator_en
**Webpage by IOTA/ ES [en]:** https://iota-es.de/betelgeuse2023.html
**German Astronomical Association, VdS [de]:** https://sternfreunde.de/2023/07/20/einmal-im-leben-beteigeuze-wird-bedeckt/
**Webpages by B. Gährken [en]:** https://astrode.de/esop23a.htm
**Italian Astronomical Association, AstroCampania ETS [it, en]:**
https://www.astrocampania.it/2023/04/06/betelgeuseoccultazione-2023/
**Predictions by the Lucky Star project (J. Desmars) [en]:**
This link points to the Betelgeuse event:
https://lesia.obspm.fr/lucky-star/occ.php?p=124370
For more occultation predictions by Leona use lesia.obspm.fr/lucky-star/predictions.php and either select "MBA" in the type select box or enter "Leona" into the object search field.
**Predictions by the CORA project (M. Kretlow) [en]:**
This link points to the Betelgeuse event: https://astro.kretlow.de/cora/occultations/aa3579fb-2fa7-4a89-8452-bfc8a87e0704/
For more occultation predictions by Leona use astro.kretlow.de/cora/occultations/ and specify "Leona" in the object field and select the Occ. DB "special".
**The OWC project (H. Pavlov) provides occultation predictions made with Occult by different computers [en]:**
https://cloud.occultwatcher.net/

**The following links were updated on 2023 Oct 31:**
**ESOP42 presentation by M. Montargès [en]:**
https://s3.eu-west-1.wasabisys.com/armagh.space/site/wp-content/uploads/2023/02/19132152/mmontarges_betelgeuse_leona.pdf
**ESOP42 presentation by A. Noschese [en]:**
https://s3.eu-west-1.wasabisys.com/armagh.space/site/wp-content/uploads/2023/02/19132158/Astrocampania_ESOP42_talk_v2_CostaNoschese.pdf
**ESOP42 presentation by W. Beisker [en]:**
https://s3.eu-west-1.wasabisys.com/armagh.space/site/wp-content/uploads/2023/02/19132154/beisker_analyser_1.pdf

# Practical Advice for the Occultation of Betelgeuse by (319) Leona

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**ABSTRACT:** On the night of December 11-12 this year, the minor planet (319) Leona will occult Alpha Orionis (Betelgeuse) for a maximum of 12 seconds. As a very gradual fall and rise of the light level is expected, special techniques will need to be applied on this occasion. But, as always, accuracy in timing and position of the observer are crucial. In this article we try to provide some tips in order to get the most out of this unique phenomenon.

## Introduction

As Mike Kretlow explains in another article on pages 3 - 9 in this same issue, this event will have some unusual features. We will be exposed to a continuous variation in light level in an interval of only a few seconds. Also, it seems that the shape of the light curve will look different depending on the wavelength.

In this occultation, as in any other, it is important to obtain a good signal-to-noise ratio so that there is no doubt as to whether the star is occulted or not, and a good temporal resolution in order to be able to evaluate the occultation time with sufficient precision to coordinate all the recordings altogether. It is essential that both the timebase and the geographical location of the observer be highly accurate.

## What Equipment Can Or Should Be Used?

If using a telescope with a small field of view, it is advisable to use a tracking mount. You can't waste time recentring for a phenomenon that only lasts a few seconds. However, given the brightness of Betelgeuse, a short focal length photographic lens will also be useful. In this way, we will be able to include stars with similar brightness to that of Betelgeuse in the same field. With short focal lengths tracking will not be necessary.

## Imaging

Regarding the camera for recording the occultation, there are several options:

On the one hand, you can have an analogue video camera, such as the Watec 910 HX-RC [1] used for recording stellar occultations by asteroids, whose analogue signal is going through a time inserter controlled by GPS, such as, for example, the IOTA-VTI [2], which allows time to be stamped with a precision of thousandths of a second in each frame. This analogue signal is injected into an analogue-digital converter that allows the signal to be read with the computer to be recorded in AVI format, for example. An advantage of this type of camera is the recording of 25 images per second (PAL version) or, if analysed properly, even 50 images per second. The resulting exposure time is 40 milliseconds per frame, or 20 if what we analyse are the fields. Each frame has two fields.

This is the system used for many years by many occultation observers, but a problem that appears in this method is that the digitization is carried out with only 8 bits (256 grey levels) and the noise is relatively high. In a normal occultation the star disappears completely for a more or less long period of time, but in this case the fall will be gradual. Would the occultation be recorded? Surely yes, but perhaps not all the science can be obtained from the observation with the previous instrumental configuration.

Other equipment available today would use a digital camera equipped with a GPS module to obtain a reliable time. An example is the QHY174M-GPS [3], which gives the time of each image obtained with the appropriate precision. At best this camera records in 12-bit mode, 4096 levels of grey, scaled to 16-bit output, but that could already be enough in this case. As for noise, according to specifications, it ranges from 1.6 to 5.3 e-, depending on the gain used. In addition, it allows you to obtain continuous images with a significant cadence. The DVTI+CAM [4] is another similar camera with GPS time insertion.

Other CMOS or CCD cameras can also be used, with 12 or better, 16 bits, although fast cadences must be achieved, from 10 to 40 images per second, and short exposure times, on the order of a few milliseconds, without dead times between them.

Betelgeuse is a bright star and its images in your recording must not be over-exposed. Take care to avoid image saturation before, during and after the occultation. A camera with a high dynamic range (12-bit or more) is preferred. Some cameras running at very high frame rates might reduce their quality setting from 12-bit to 10-bit.

Test your equipment before the event!

## Timing

The most important problem with cameras of this type is that their recording is not referencing an exact and precise time base, since the computer clock has fluctuations that can spoil the observation. A solution to this problem is to continuously and systematically update the computer's clock with GPS systems or use an NTP (Network Time Protocol) server. The recommended application that can do this for computers with *Microsoft Windows 10* operating systems and higher can be found at Meinberg [5, 6].

If you do not have access to GPS systems or NTP timing you can use smartphone apps to flash at synchronised time intervals. (See this issue, page 8).

## Filters & Spectroscopy

At this point we have to define what filters to use. The simplest case would be to apply standard photometric filters, B and/or V from Johnson, Cousins R, or the Sloan b, g, r filters [7]. Narrow band filters can also be used in H-alpha, or in the titanium oxide line to see how these lines vary during occultation. Once the observation is finished, calibration images must be obtained, that is, bias, dark and flat shots.

A separate point would be to perform spectroscopy with high temporal and, if possible, also spectral resolution. More and more people in the amateur world have spectrographs and could try to make this type of observation. But what we have said before is required, short exposures and very precise time base.

A very interesting proposal about fast spectroscopy was suggested by Wolfgang Beisker during the last ESOP 42 held in Armagh [8]. It consists of a slitless spectrograph equipped with a low-resolution blazed grating with 100 grooves per mm. In this case the wavelengths to be used can be selected after the observation. The resolution of such a setup can be improved by putting a prism before the passage of the starlight through the diffraction grating.

## Analysis

Regarding photometric analysis, there are different free programs that can be used. Among those specialised in occultations we have two: *Tangra*, by Hristo Pavlov [9] or *PyMovie* and *PyOTE* by Bob Anderson [10]. Obviously, when used for the first time they are not easy, but, with a little practice, they are very useful for this type of observation. A program that could also be used is Julio Castellano's, *Fotodif* [11], well-known in the Spanish speaking world.

There are certainly other free or commercial programs that can be used, but here we have pointed out the most common ones in this field.

## Collaboration Is Needed

The heterogeneity in the different recording methods can create problems when calibrating the registration times with each other. In normal occultations contacts are easily recognised as they are abrupt photometric changes. With Betelgeuse the light variations will be gradual, whether we do white light photometry or through different filters. Changes in the spectra will also be gradual. Another problem is the field of view. If it is of the usual amplitude, we will not have stars for comparison. For these and other reasons, it will be highly advisable to combine different types of recordings at the same observation station: photometry with and without filters, with wide and narrow fields of view, but above all well-synchronised in time, can be an indispensable support for teams that are performing spectrometry in the same place, but do not have precise timing control.

So, the advice is to be attentive to the different teams that are going to join forces to observe. The different regional teams along the path of the occultation are using the Planoccult mailing list [12] to announce the different coordination initiatives and online meetings. Please also announce the expected location of your station in *Occult Watcher* [13]. If you are interested in observing this event, please join us!

## References

[1] http://www.watec-shop.com/en/products/monochrome-cameras/wat-910hx-rc-remote-9.html

[2] https://occultations.org/observing/recommended-equipment/iotavti/

[3] https://www.qhyccd.com/qhy174gps-imx174-scientific-cooled-camera/

[4] https://dvticam.com/home

[5] https://www.meinbergglobal.com/

[6] Pavlov, H., Gault, D., Using the Windows Clock with Network Time Protocol (NTP) for Occultation Timing, Journal for Occultation Astronomy, 2020-02, p. 10-19

[7] https://www.baader-planetarium.com/en/filters/photometric-filters.html

[8] Beisker, W. , Fast Spectroscopy with a Slitless Spectrograph – Using a Blazed Grating with Low Resolution (link updated on 2023 Oct 31) https://s3.eu-west-1.wasabisys.com/armagh.space/site/wp-content/uploads/2023/02/19132154/beisker_analyser_1.pdf

[9] Pavlov, H., Tangra, http://www.hristopavlov.net/Tangra3/

[10] Anderson, B., PyMovie https://occultations.org/observing/software/pymovie/

[11] Castellano, J., Fotodif, http://www.astrosurf.com/orodeno/fotodif/

[12] Planoccult mailing list https://lists.vvs.be/postorius/lists/planoccult.ls.vvs.be/

[13] Pavlov, H., Occult Watcher, https://www.occultwatcher.net/

# Baily's Beads Observation during the Hybrid Solar Eclipse 2023 April 20

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**ABSTRACT:** The timing of Baily’s Beads, observed during a solar eclipse is one of the most accurate ground-based methods for estimating the solar radius. In 2023, IOTA/ES organised an expedition to the northern edge of the total part of the hybrid solar eclipse (TSE) on April 20, where bead observation was possible. The timing was measured by photometry in FITS files. The correction to the solar radius of $\Delta R_s$ = 0.38″ was derived from this observation.

## Introduction

Measuring the angular solar diameter and calculating the real diameter, considering the Earth-Sun distance, has been a fundamental challenge for astronomers for more than two thousand years. After micrometer, heliometer or transit measurements, astronomers found one of the best ground-based methods for finding the solar diameter: The observation of disappearance and reappearance of the remaining sunlight in valleys on the lunar limb during total or annular solar eclipses. As Francis Baily (1774-1844) was one of the first who described tiny points of light on the lunar edge during a total eclipse, the technique was named Baily’s Beads observation. Such observations have been a focus of IOTA and IOTA/ES activities for many years. The aim was a measurement of the solar diameter and detection of possible variations. In 2023, IOTA/ES organised an expedition to the northern edge of the hybrid solar eclipse (TSE) on April 20, where bead observation was possible. Additionally, the observation should be synchronised with an observation of the flash spectrum.

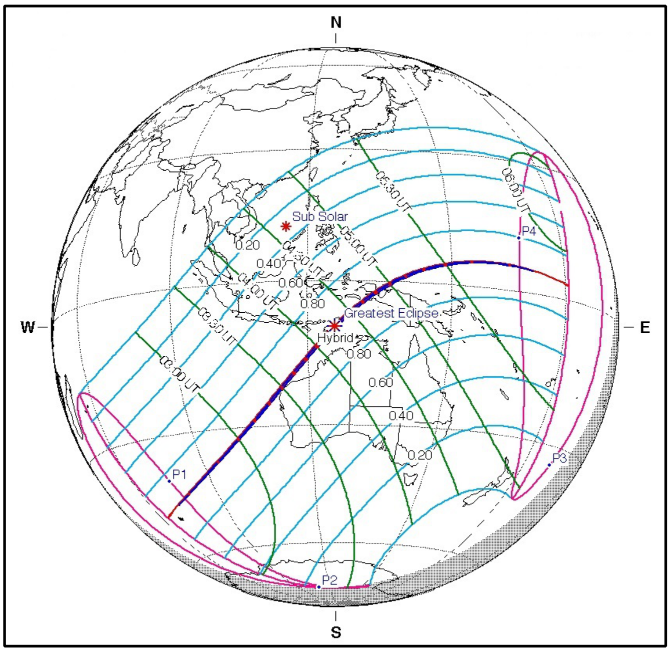


*Figure 1. Area of visibility for the eclipse [2].*

## Eclipse Parameters and Observation Site

The TSE 20042023 started and ended as an annular eclipse. After some seconds as an annular eclipse, the Moon's diameter was big enough to switch to a total solar eclipse. The total zone ran to the Pacific Ocean. The zone of totality “scratched” Australia and touched land in the areas East-Timor, some Indonesian islands and New Guinea. The maximal duration of totality was 1 min 16 s. in the Timor-sea. The area in Australia was the Cape Range National Park (Figure 1).

In collaboration and prior consultation with the group for observation of the flash spectrum [1] an observing site in the Cape Range National Park was selected (Figure 2). It was the plan to make observations of the flash spectrum and beads from the same place. The flash spectrum team selected a site at 113° 56′ 15″ E, -22° 00′ 22″ S. To guarantee the planned synchronisation, the author decided to join them at this site too, realising that it was clear inside the zone of totality.


*Figure 2. Eclipse zone in Cape Range National Park [3].*

## Northern Station 2023AUN1 (Elke & Konrad Guhl)

The northern station was located in the Cape Range National Park. The observation location (Latitude 22° 00′ 22.4″ S; Longitude 113° 56′ 15.3″ E; h=3 m (WGS84)) was within the totality zone and the predicted length of totality was 31.5 s [3], (Figure 3).

*Figure 3. The author at the set-up station with 100/1000 Maksutov on a travel mount and a camera QHY174M-GPS. In his hand the control-box for the fine adjustment of the drive of the mount, on the monitor the Sun as a crescent. (Photo: Elke Guhl)*

Like former TSE and ASE observations, the optical equipment used follows the IOTA/ES recommendation. It is based on a 100/1000 mm Maksutov optic, a 535 nm filter and the IOTA/ES solar filter. After reduction TSE020720219 [4] the type of camera used was changed: A 12-bit digital camera QHY174MGPS was used to record a series of images in FITS format. The time protocol is done by timestamps in the FITS file by GPS synchronisation.

Following the station code created in [5], the station is called 2023AUN1.

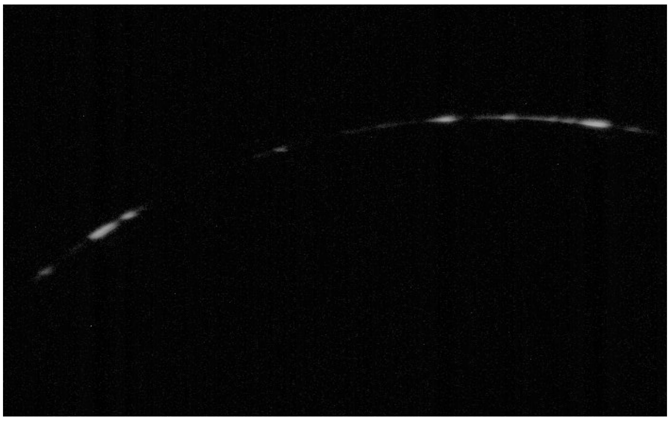

*Figure 4. FITS image of Baily's Beads visible on the lunar limb at 03h 30m 07.18s UTC.*

## Reduction Method and Results

All observations were simulated with the software tool "Baily Bead Analysis" of the software *Occult* [6]. The version V 4.2023.9.26 includes the LOLA data for the lunar limb profile.

Figure 5 shows the simulation for the axis angle 278° till 296° with a radius correction of 0.38″ and image scale 4.0. The time for this simulation is 03h 30m 08.2s UTC.

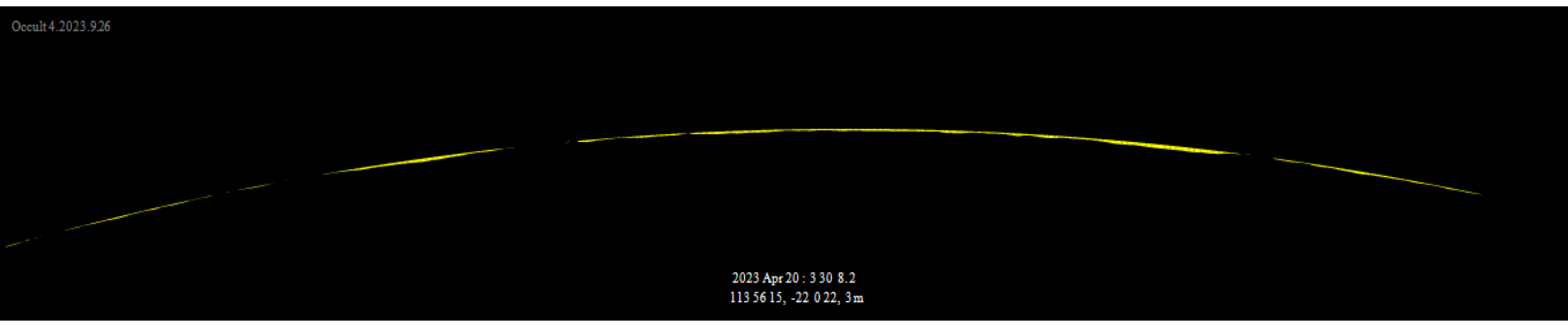


*Figure 5. Simulation in Occult.*

Figure 6 is a detail of the observation. The FITS was taken at 03h 30m 08.18s UTC and shows the region of the Sun at the axis angle like in the simulation in Figure 3. The course of the lunar rim, its interruptions and associated beads match well.

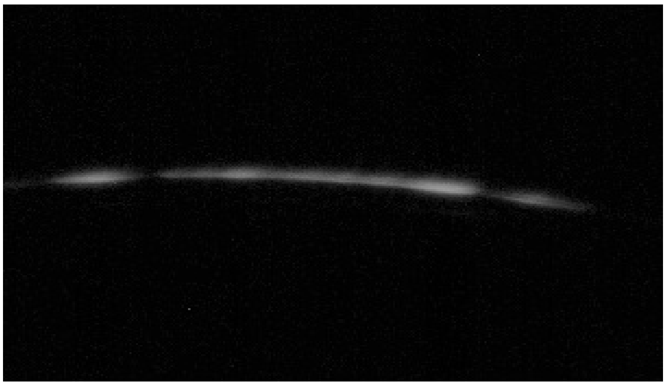

*Figure 6. Detail of FITS image.*

The FITS files have been analysed by using the software *Fitswork* [7]. The photometry in this software is done in a 15px x 15px window. This window would be placed in the position of the beads and the average value (reported as "DC") is used.

For the disappearance, a light curve was created from the disappearing bead using photometry on the FITS images until the disappearance. An example is shown in Figure 7. The signal (DC) of the New Moon in this example is 33 for the 15px x 15px measuring window. When the light curve reaches the brightness value of the New Moon, the bead has disappeared. For the reappearance, the X,Y coordinates of the appeared bead were first determined. Then the brightness of this position was measured on the previously recorded FITS. The first image with a measurable signal at the position determines the time of reappearance.

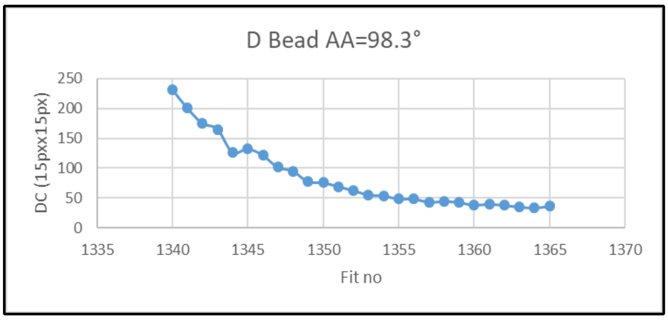


*Figure 7. Light curve disappearing bead at AA=98.3*

The simulation in *Occult* shows the distance of the lunar limb (based on LOLA data) and the calculated solar radius in arcseconds. The offset from the standard solar radius is given as output data. Only those beads easily identified optically were included in the table of results (Table 1). After clear identification of disappearing/reappearing beads, the axis angle of each is given by the eclipse simulation software in *Occult*.

The limb darkening function (LDF) was analysed in single FITS files. The visual solar limb is defined as the inflection point in the LDF. The limb darkening effect is clear to see in the brightness profile to guarantee that no overexposure/saturation influences the measurement (Figure 8).

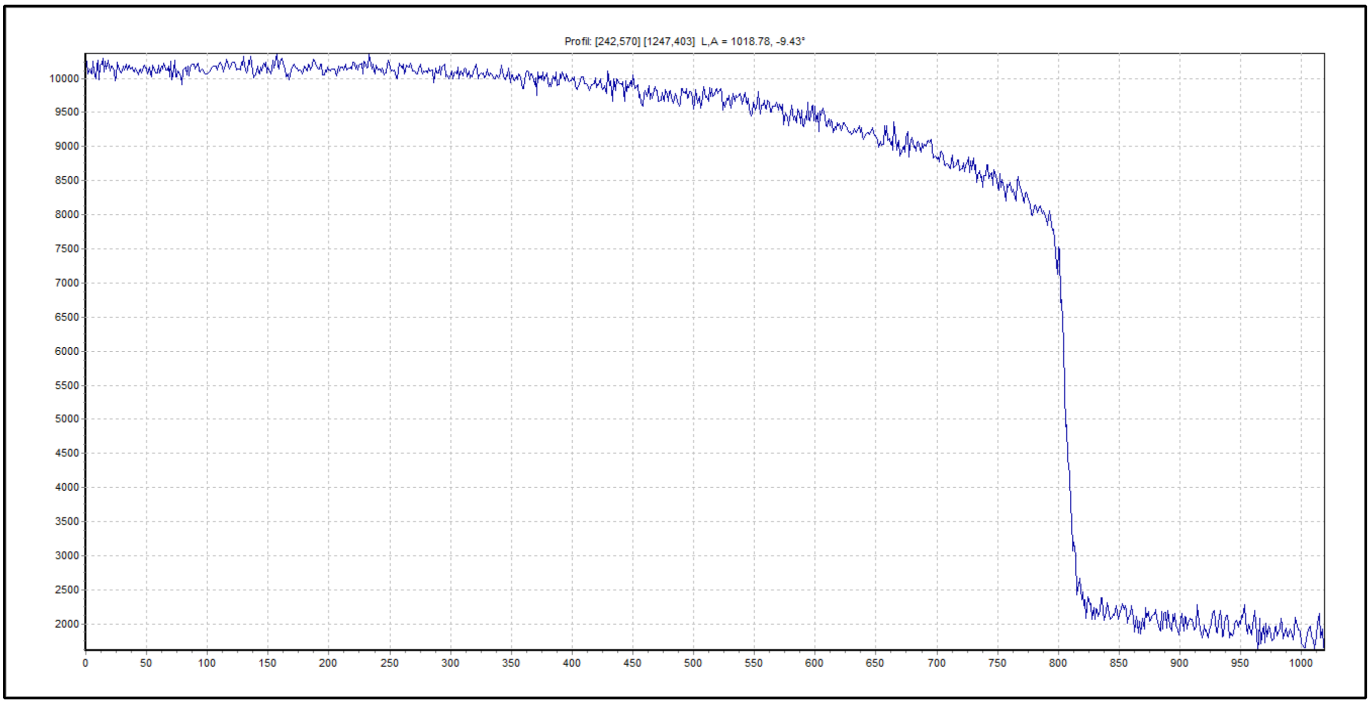


*Figure 8. Brightness profile along the solar radius, station 2023AUN1.*

All data points, following the method described above, are presented in table 1 Following the data table format of [5]:

| **2023AUN1** | | | |
|---|---|---|---|
| Time UTC | Axis Angle | Type | Variation Solar Radius Δ rs |
| 03:28:52.7 | 99.3° | D | 0.55″ |
| 03:28:52.9 | 98.3° | D | 0.60″ |
| 03:29:00.4 | 90.3° | D | 0.32″ |
| 03:29:00.9 | 89.0° | D | 0.25″ |
| 03:29:18.6 | 67.2° | D | 0.37″ |
| 03:29:23.3 | 55.1° | D | 0.48″ |
| 03:29:25.9 | 50.8° | D | 0.39″ |
| 03:29:27.4 | 48.3° | D | 0.34″ |
| 03:29:28.1 | 47.3° | D | 0.61″ |
| 08:29:29.2 | 41.3° | D | 0.33″ |
| 03:29:58.0 | 324.8° | R | 0.34″ |
| 03:29:59.1 | 330.8° | R | 0.31″ |
| 03:30:01.2 | 322.3° | R | 0.33″ |
| 03:30:05.1 | 295.1° | R | 0.35″ |
| 03:30:05.1 | 282.5° | R | 0.30″ |
| 03:30:05.7 | 308.8° | R | 0.24″ |

*Table 1.*
*Data-points, D=Disappearance; R=Reappearance*

The registered third contact was the reappearance of bead AA=324.8° at 03h 29m 58.0s UTC.

## Conclusion

The value adopted by the IAU General Assemblies in Beijing (2012) and Honolulu (2015) for the Astronomical Unit is 1 AU = 149, 597870700 m exactly and for the solar radius $R_\odot$ = 6.957 * $10^8$ m. Calculated in arcseconds, the radius is now fixed to 959.22″.

In [8], the average of the measured solar radius by eclipse observation in 2010, 2012, 2013, and 2015 is given as 959.99 +/-0.06″.

- The solar radius used in [6] is 959.63″.
- In [9] the observed Δ $r_s$ is -0.04″ for September 2016.
- In [10] the observed Δ $r_s$ is +0.03″ for August 2017.
- In [4] the observed Δ $r_s$ is -0.08″ for July 2019.

The average value for Δ $r_s$ station 2023AUN1 is 0.38″ in 535nm wavelength. The reduction is done with [6], so the corrected solar radius is

959.63″ + 0.38″ = 960.01″ +/- 0.12

## Acknowledgements

The author thanks M. Xavier Jubier for the fruitful e-mail discussion in the planning phase of all expeditions from the author and the helpful web page. Further thanks are hereby extended to Luca Quaglia for on-site organisation and collegial discussions, and to John Irwin for supportive calculations.

## References

[1] Quaglia, L. et.al., Estimating the Eclipse Solar Radius from Flash Spectrum Videos, JOA 2022-2
[2] Espenak, F., NASA, https://eclipse.gsfc.nasa.gov/eclipse.html
[3] Jubier; X., Travel and eclipse site, http://xjubier.free.fr/
[4] Guhl, K., Baily's Beads Observation During the Total Solar Eclipse 2019 July 02, JOA 2020-02
[5] Sigismondi, C. et. al., Baily's Beads Atlas in 2005 - 2008 Eclipses, Solar Physics, Volume 258, Issue 2, pp 191-202.
[6] Herald, D., WinOccult V 4.5.3.0. software tool
[7] Dierks, J., Fitswork software tool https://www.fitswork.de/software/
[8] Rozelot, J. P. et.al., A brief history of the solar diameter measurements - a critical quality assessment of the existing data, Proc. International conference on "Variability of the Sun and sun-like stars: from astroseismology to space weather", Baku, Azerbaijan, 6 - 8 July 2015, https://www.researchgate.net/publication/307984954
[9] Guhl, K., Tegtmeier, A., Baily's Beads observation during the annular solar eclipse 2016 Sept. 1, JOA 2016-04
[10] Guhl, K., A. Tegtmeier, A., Baily's Beads observation during the Total Solar Eclipse 2017 August 21, JOA 2018-03

# ATSE2023: Using Photodiode Loggers to Estimate the Eclipse Solar Radius

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**ABSTRACT:** During the 2023 April 20th annular-total solar eclipse (ATSE2023), we estimated the eclipse solar radius to be $S_\odot \approx 960.25''$ by analysing ambient light curves collected with photodiode loggers and to be $959.90'' < S_\odot < 960.02''$ from visual observation of the eclipse flash spectrum. We discuss the apparent discrepancy between these two results and suggest possible causes which highlight the limitations of using ambient light curves to estimate the eclipse solar radius.

## Introduction

We collected ambient light curves during ATSE2023 with the goal of estimating the value of the eclipse solar radius $S_\odot$ (at 1 au). To that aim we built photodiode loggers by following the methodology developed by Philippe Lamy and collaborators [1]. Data analysis was conducted via synthetic light curves generated by integrating the Limb Darkening Function (LDF) over the exposed area of photosphere based on robust eclipse computations. We also manually collected contact times by visually observing the disappearance and reappearance of the photospheric continuum in the eclipse flash spectrum.

## Observation Site

This eclipse was visible on land from only a few places: Exmouth Peninsula and a few nearby islands in Australia; some remote reefs in the Timor Sea; the easternmost part of Timor Leste; a couple of small islands in the Moluccas in Indonesia; and part of central West Papua and nearby islands, also in Indonesia. Based on long-term meteorological statistics, Exmouth Peninsula offered the best prospects for clear skies. To increase the sensitivity of the measurements we looked for a site very near the edge of the eclipse path. As Figure 1 shows, for a site very close to the limit (within 1 km or so) the duration of totality becomes very sensitive to the value of the eclipse solar radius.

Exmouth is a small, remote, township in Western Australia with less than 3000 inhabitants and with a delightful Outback feel to it. The eclipse hype made finding reasonably priced accommodation an exceptionally difficult task. We teamed up with Konrad Guhl (IOTA/ES President) and wife Elke to find camping facilities even though such things were extremely scarce. Out of sheer luck we managed to secure a spot on the Mesa campground in the stunning Cape Range National Park. The campsite was rather basic, with no water or electricity, but besides being in a truly idyllic location, it was absolutely the best we could have hoped for as it sat less than a couple of hundred metres from the northern limit of the eclipse. We could not have asked for anything better. Figure 2 shows the location of the Mesa campground and the three sites where photodiode loggers were deployed. Also shown are the theoretical northern path limit lines accurately computed for various values of the eclipse solar radius. The WGS84 coordinates of the three sites were:

| | λ | φ | h |
|---|---|---|---|
| Site 1 | 113° 56′ 14.7″ E | 22° 00′ 22.5″ S | -1 m |
| Site 2 | 113° 56′ 09.9″ E | 22° 00′ 44.6″ S | -8 m |
| Site 3 | 113° 55′ 31.8″ E | 22° 01′ 43.1″ S | -9 m |

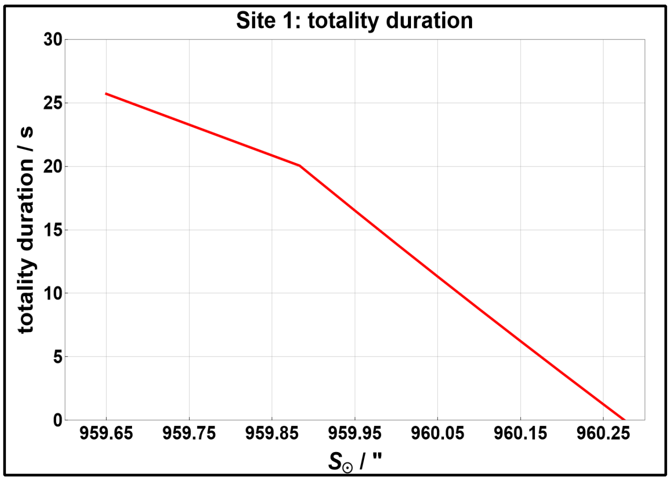


*Figure 1. Duration of totality as a function of the eclipse solar radius $S_\odot$ for a site very close to the umbral shadow path's northern limit for ATSE2023. The bend in the plot is due to a change in the position of the lunar limb valley producing third contact.*

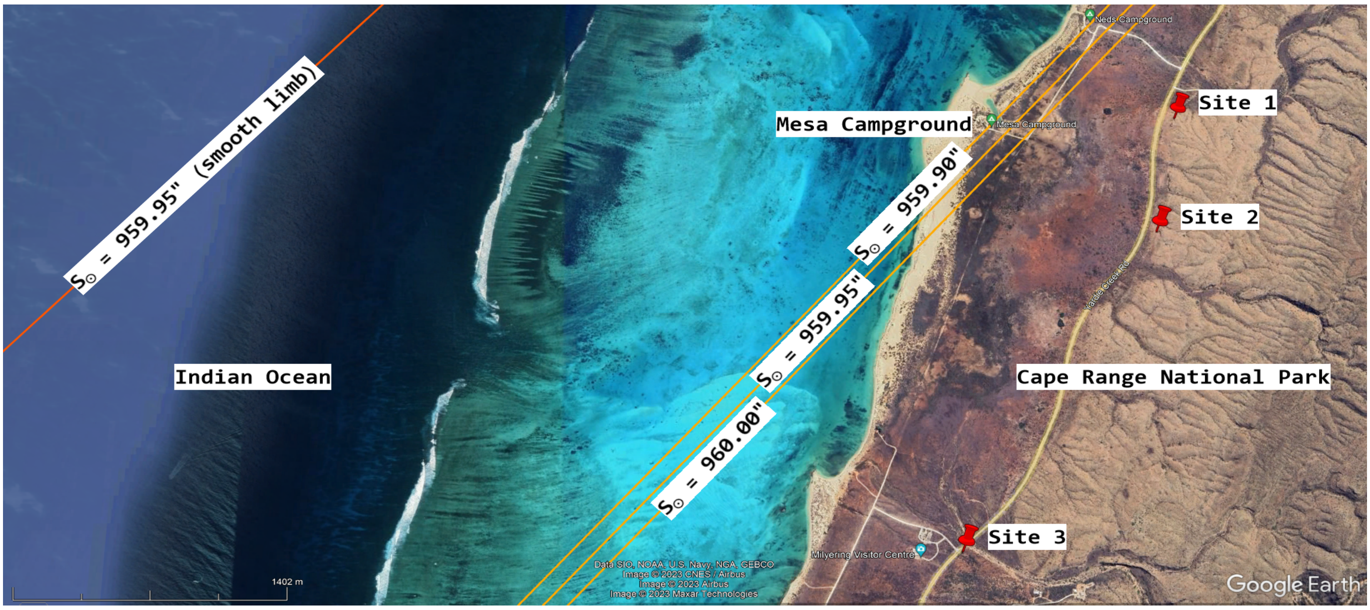


*Figure 2. Locations of the three photodiode loggers (Site 1, Site 2, Site 3) and the Mesa campground. Also highlighted are the predicted northern path limits for a range of configurations. In orange, out at sea, the northern limit computed for a smooth (mean) lunar profile and for an eclipse solar radius of 959.95″. In yellow, near the Mesa campground, the northern limit computed accounting for the lunar limb profile and eclipse solar radii 959.90″, 959.95″, and 960.00″, representative of recent measurements [1, 2]. (Map: Google Earth, data: SIO, NOAA, U.S. Navy, NGA, GEBCO, Images: 2023 CNES, Airbus, Maxar Technologies)*

## Limb Dynamics

After securing the camping spot we performed computations to assess the relative dynamics of the solar and lunar limbs for observation sites near the Mesa campground. Figure 3 shows the expected movement of the limbs as seen from Site 1 for an eclipse solar radius of 959.95″ [2]. At the time of second contact ($C_2$) we should see a string of small Baily's beads vanish relatively quickly over the space of less than 5-10 s. The situation at the time of third contact ($C_3$) is far more interesting. We should see two very faint Baily's beads appear close to each other and remain isolated for almost 15 s, after which a string of Baily's beads would appear. These quite asymmetric dynamics had profound consequences for the shape of the ambient light curve, thus we expected the light curve to descend steeply before $C_2$ but to rise far more gently after $C_3$.

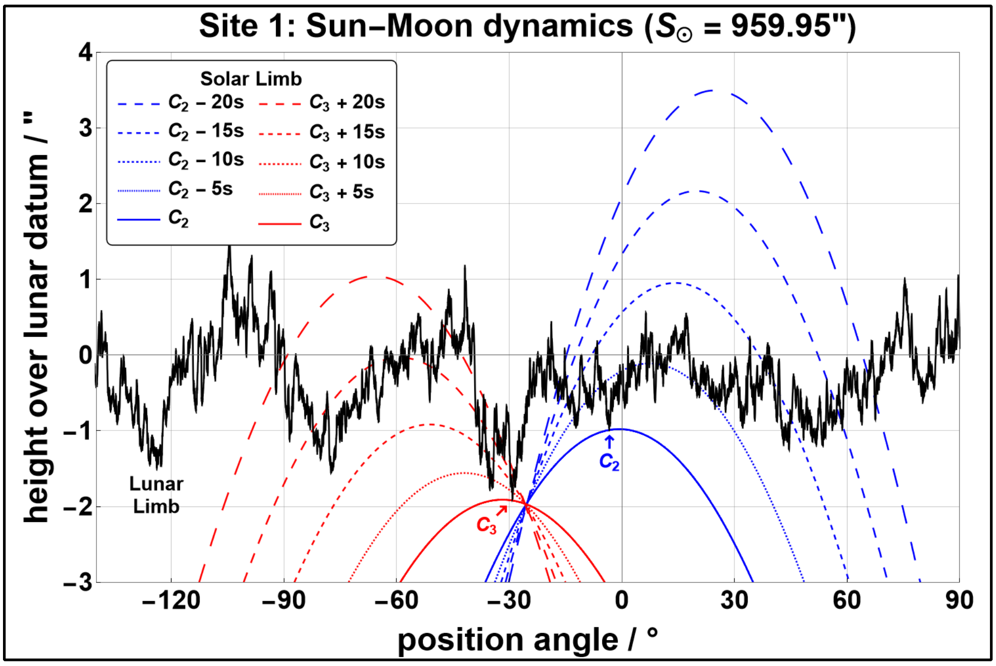


*Figure 3. Dynamics around the times of second and third contact ($C_2$ and $C_3$) of the solar limb with respect to the lunar limb for Site 1 and for an assumed eclipse solar radius of 959.95″. Also indicated are the lunar valleys where second and third contact occur.*

## Method #1: Visual Observations and UTC Event Timer

The eclipse was observed by eye through diffraction grating glasses (Rainbow Symphony Diffraction Grating Glasses 1000 lines/mm) to have a simultaneous view of the white light image of the eclipse and its evolving flash spectrum. This view of the flash spectrum was very sharp. To collect contact times manually we built a device able to record the UTC time when a button is pressed. We observed the disappearance/reappearance of the photospheric continuum in the flash spectrum to determine approximate contact times.

## Method #2: Photodiode Loggers

The photodiode loggers were designed and built to provide similar capabilities and functionalities as the loggers described in [1]. Each logger needs to run autonomously and be able to repeatedly and continuously:

1. Acquire a light intensity measurement.
2. Accurately time-stamp the measurement with UTC.
3. Store the measurement for later retrieval.

We based the design of the loggers around the Arduino UNO Rev3 board. The board is very practical as it provides, in an already assembled package, a microcontroller (ATmega328P) and a series of digital and analogue I/O's. Code is written in a dialect of the C programming language, and it is embedded in the microcontroller's flash memory.

The photodiode sensor used in the loggers is the Hamamatsu S16838-01MS Si photodiode. It has a spectral sensitivity from 320 nm to 730 nm, a peak sensitivity at 560 nm, and a low dark current. We chose this photodiode for its good spectral response in the visible range. As solar radius measurements need to be conducted at a specific wavelength, light is filtered before reaching the photodiode surface by using a Player One 1.25″ Photosphere narrowband filter centred at 540 nm and with 10 nm bandwidth. The filter also functions to eliminate as much as possible the light coming from the main emission lines of the chromosphere. These are due to hydrogen (656.3 nm, 486.1 nm, 434.0 nm, 410.1 nm), helium (587.5 nm, 537.0 nm), magnesium (518.4 nm, 517.3 nm, 516.7 nm), and sodium (589.6 nm, 589.0 nm). The very lowest layers of the chromosphere (sometimes called the mesosphere or fluctosphere) very near the photosphere also emit a forest of faint lines that resembles a pseudo-continuum, some of which will make it through the filter. Albeit faint, light is also emitted from the solar corona noticeably at 530.3 nm due to highly ionised iron (Fe XIV).

Accurate time-stamping is based on the 1PPS signal and on the NMEA sentences generated by a GPS module. The 1PPS signal is a train of 100 ms square waves, the leading edges of which are synchronised to better than 100 ns to the start of every UTC second. The NMEA sentence allows labelling of the time. The time-stamping also relies on the microcontroller's internal oscillator being disciplined, in code, by the 1PPS signal. The overall time accuracy of the system is around 1 ms, which is sufficient for the needs of data acquisition as light intensities around the time of totality change substantially only over time frames longer than 1 ms.

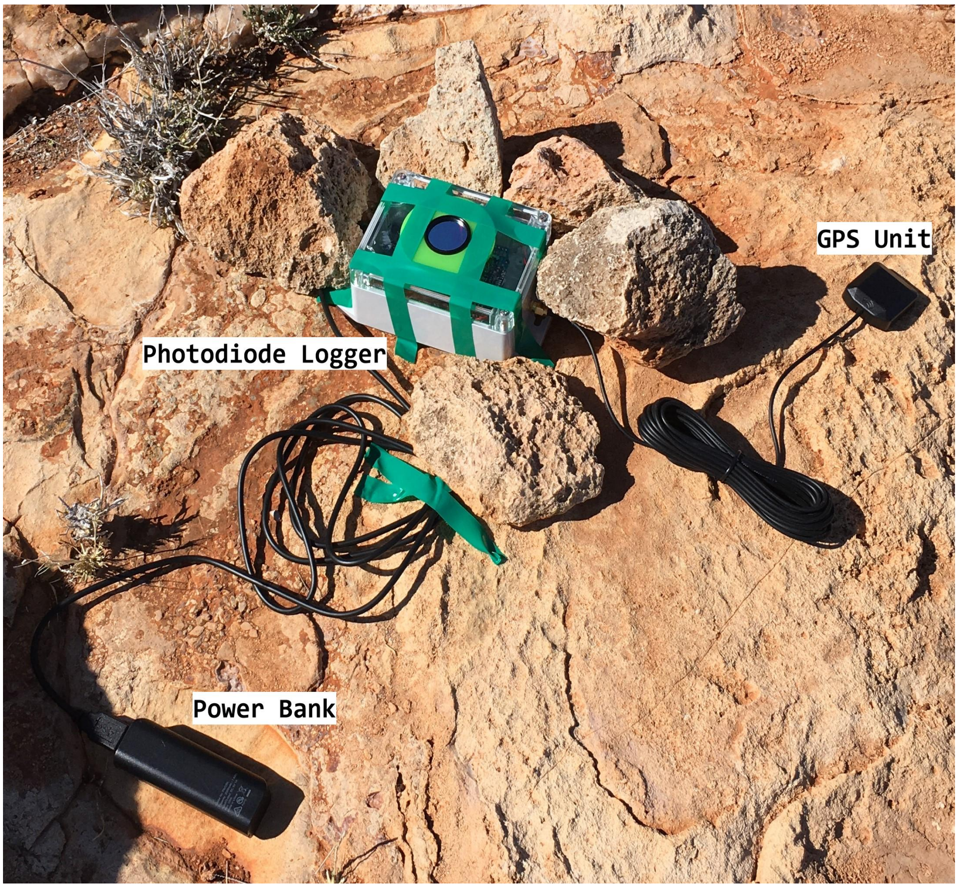


*Figure 4. Photodiode logger deployed at Site 2. The logger was laid horizontally and kept secured by stones piled up around it as it was quite windy at the start of the eclipse partial phase.*

Data were saved onto a fast SD card. We used the Adafruit Ultimate GPS Logger Shield to provide the microcontroller's access to a GPS module and an SD card module. The shield also comes with a small development area that was used to lodge a level shifter to boost the 1PPS signal for better detection and an analogue-to-digital converter (ADC) to measure the photodiode signal. The ADC we used was a DFRobot Fermion MCP3424 18-Bit ADC-4 Channel with Programmable Gain Amplifier. Light intensities vary by over 4 orders of magnitude during a total solar eclipse - about 2 orders of magnitude from the onset of the eclipse to just a couple of minutes before second contact, then another 2 orders of magnitude in the last couple of minutes before totality. Thus, the ADC needs to provide sufficient resolution at the lowest light levels as they are the ones in which we are most interested. There are faster ADCs available, with higher resolution, but the DFRobot was easy to source and already assembled. Retrospectively, a more performant ADC would have been beneficial.

## Synthetic Light Curve Computations

Synthetic light curves were computed by integrating the Limb Darkening Function (LDF) over the exposed area of photosphere. These synthetic light curves were then fitted over the measured light curves to infer an estimate of the eclipse solar radius. Underlying most of this procedure is a detailed eclipse computational model. The model relies on the latest ephemerides and accounts in a very precise way for all the complexity of the lunar topography and the orientation of the celestial and terrestrial reference systems via robust algorithms and procedures. Details of the model can be found in [2].

The LDF is the one described in [3], where φ is the angular distance from the Sun's centre, λ is the wavelength (in µm) and $\Sigma_\odot$ is the topocentric solar semidiameter (directly related to the eclipse solar radius $S_\odot$):

$$LDF(\phi,\lambda) = \left[1 - \left(\frac{\sin\phi}{\sin\Sigma_\odot}\right)^2\right]^{\frac{1}{2}\alpha(\lambda)}$$

$$\alpha(\lambda) = -0.023 + \frac{0.292}{\lambda}$$

The integration of the LDF over the area of exposed photosphere was performed numerically. We used two independent techniques to ensure the results were correct. The LDF is normalised to 1 at the Sun's centre so a suitable linear transformation is required to match the scales of the synthetic and observed light curves.

It is important to stress that we are estimating the eclipse solar radius $S_\odot$ (via $\Sigma_\odot$ ) as it appears in this formulation of the LDF and we have no pretensions of measuring a physical parameter of the Sun, such as the radius defined by some optical properties (e.g., an inflection point in the photosphere). We believe, nevertheless, that $S_\odot$ is useful as an appropriate parameter to be used in eclipse computations to reproduce the visual experience of the eclipse.

## Visual Aspect of the Eclipse

The appearance of the totally eclipsed Sun in the sky was very striking and unlike anything we had ever observed before. When the last Baily's beads vanished and totality started (confirmed by extinction of the photospheric continuum in the flash spectrum that we were observing in parallel through diffraction grating spectacles), the outer corona did not become visible, but the whole lunar limb was surrounded by a thin ring of very intense light. The eclipse looked more like an incredibly thin annular eclipse than a total eclipse. This view of the eclipse was very surprising and unexpected. Anecdotally, some people who sat on the sand dunes just west of the Mesa campground and some rangers who observed from Vlamingh Lighthouse (both locations marginally outside totality) also described this bright ring all around the Moon as their main experience of the eclipse.

A thought we had on the day of the eclipse was that the appearance of the totally eclipsed Sun reminded us of the description that astronomer Clavius gave of an annular-total eclipse he observed in Rome in 1567 [4]. Modern calculations placed Clavius somewhere in one of the transition regions of the eclipse, very close to the region of pure totality, and he described the "beaded" eclipse at its maximum as: "a certain narrow circle was left on the Sun, surrounding the whole of the Moon on all sides". Despite the eclipse in Exmouth being of higher magnitude than the one observed by Clavius, the absence of outer corona and the presence of a bright rim of light all around the lunar limb suggests we both had a similar view of the eclipse.

We hypothesise that the rim of light was due to the lowermost layers of the inner corona which must have remained uncovered on all sides of the lunar limb due to the near-unit magnitude of the eclipse. The light could not have been of photospheric origin as it was continually visible throughout totality when there was no trace of photospheric continuum in the flash spectrum. During higher magnitude eclipses, as it is often the case, only a small section of these layers can be seen at any one time during totality. We also hypothesise that the brightness of the sky must have remained unusually elevated, possibly because of the pristine sky conditions as well as the narrowness of the umbral shadow path which would have allowed a lot of diffuse light to flood the totality zone, especially near its edges. That could explain why the outer corona did not become visible.

## Results

Results of two kinds were collected: (1) manual timings of second and third contact at Site 1 based on observing the flash spectrum visually, and (2) ambient light curves at Site 1, Site 2, and Site 3 collected by the photodiode loggers.

Note: In the listing of experimental results below, times will be expressed in seconds relative to the reference time $T_0$ = 03:29:40.0 UTC.

## Result #1: Manual Contact Timings

The eclipse was observed at Site 1 through diffraction grating spectacles. We concentrated on observing the disappearance and reappearance of the photospheric continuum in the flash spectrum as these two events heralded the start and the end of totality, synonymous with photospheric extinction. The observed times of second and third contact that we obtained are:

$$C_2 = T_0 - 1.6 \text{ s}, C_3 = T_0 + 16.5 \text{ s}$$

Figure 5 shows the dependency of the contact times at Site 1 on the eclipse solar radius. For example, for $S_\odot$ = 959.95″, second contact ($C_2$) occurs at $T_0$ - 2.1 s and third contact ($C_3$) at $T_0$ + 14.4 s. The plot also shows the observed contact times. From the observed timings we can infer the value of the eclipse solar radius:

$$C_2 \rightarrow S_\odot = 960.02'', C_3 \rightarrow S_\odot = 959.90''$$

The observed contact times are very likely affected by reaction time, and the disappearance and reappearance of the photospheric continuum was rapid, but not instantaneous. The real contact times might have occurred slightly earlier than measured, thus the estimated eclipse solar radius is probably slightly lower than that implied by the observed $C_2$ and slightly higher than that implied by the observed $C_3$. Therefore, we can say that the observation supports the following estimate of the eclipse solar radius:

$$959.90'' < S_\odot < 960.02''$$

This eclipse solar radius estimate is compatible with the one we obtained by analysing a flash spectrum video [2] of the 2017 total solar eclipse.

## Result #2: Ambient Light Curves

The three loggers were deployed at the start of the eclipse partial phase (before totality) and collected towards the end of the eclipse partial phase (after totality) between which they recorded the level of ambient light. The loggers were placed horizontally on the ground and left unattended. Figure 6 shows the signal recorded by the data logger at Site 1. The photodiode signal dropped by more than 4 orders of magnitude with respect to its level outside the eclipse. The curve also includes the effect of the Sun's increasing altitude during the observation period, but the effect of the eclipse is clearly seen.

The sky conditions were exceptionally favourable. At dawn some thin scattered clouds were visible towards the south affecting

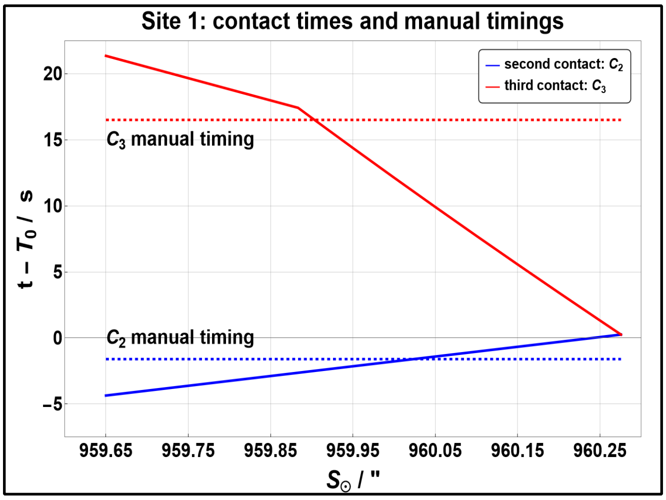


*Figure 5. Predicted contact times $C_2$ and $C_3$ for Site 1 as a function of the eclipse solar radius $S_\odot$. For $S_\odot$ = 960.28″, second and third contacts occur simultaneously, totality lasts 0 s, and the northern limit line passes through Site 1. Also indicated with dashed lines are the manual contact time measurements which loosely support 959.90″ < $S_\odot$ < 960.02″.*

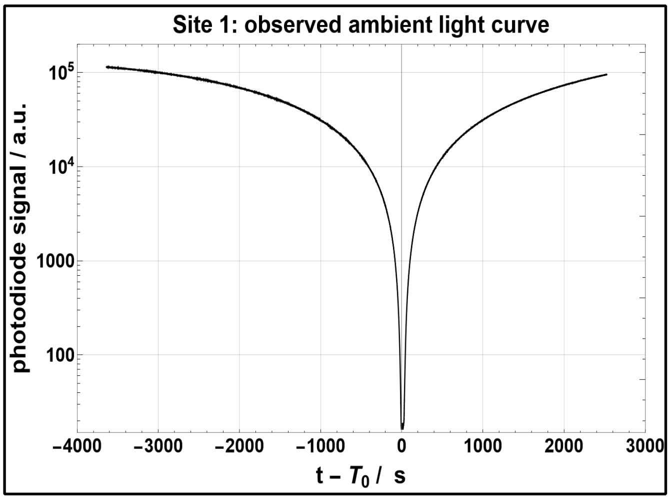


*Figure 6. The ambient light curve recorded by the photodiode logger located at Site 1. Note the greater than 4 orders of magnitude drop of the signal and the absence of any random dips in the signal, a testament to the pristine sky conditions present throughout the eclipse.*

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about one third of the sky, but they quickly dissipated and by the time the eclipse started, just after 10 am local time, the sky was deep blue from horizon to horizon and so remained throughout the duration of the eclipse. The recorded light curves are therefore very clean and do not show any random dips due to passing clouds.

We focussed our analysis on the section of the light curve encompassing totality, as shown in Figure 7. We note that the Sun's altitude hardly changed over the 1-minute interval considered for this analysis. The light level during totality almost reached the lowermost signal the logger could record. We can observe some effects due to the discretisation introduced by the ADC, where just before and just after totality the photodiode signal was changing by increments smaller than the logger could record.

Based on the methodology described in [1] the observed data were fitted with synthetic light curves generated for various eclipse solar radii, which involved finding the best linear transformation matching the synthetic curve to the observed one. Figure 7 shows the result of this procedure for the data collected at Site 1.

To determine which of the synthetic light curves best reproduce the observed data we looked at the least-square error of each of the fitting procedures, as shown in Figure 8. We built an interpolating parabola through the least-square errors and determined which value of the eclipse solar radius corresponded to its minimum. To determine the error bars on the result we followed the empirical criterion described in [1] by looking for the values where the parabola reaches 10% more than its minimum value. The results provide the following estimation of the eclipse solar radius based on the data from the three photodiode loggers:

| | |
|---|---|
| Site 1 | S = 960.25″ ± 0.04″ |
| Site 2 | S = 960.23″ ± 0.04″ |
| Site 3 | S = 960.25″ ± 0.05″ |

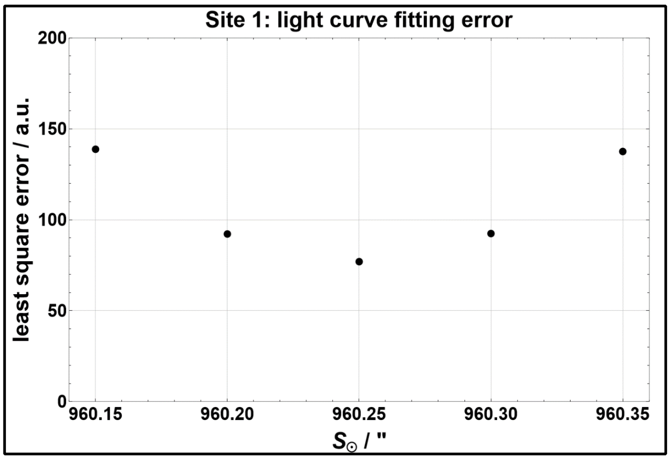


*Figure 8: Least-square error of fitting the ambient light curve collected by the photodiode logger at Site 1 with synthetic light curves computed for various values of the eclipse solar radius $S_\odot$. The best fit is obtained for $S_\odot \approx 960.25''$.*

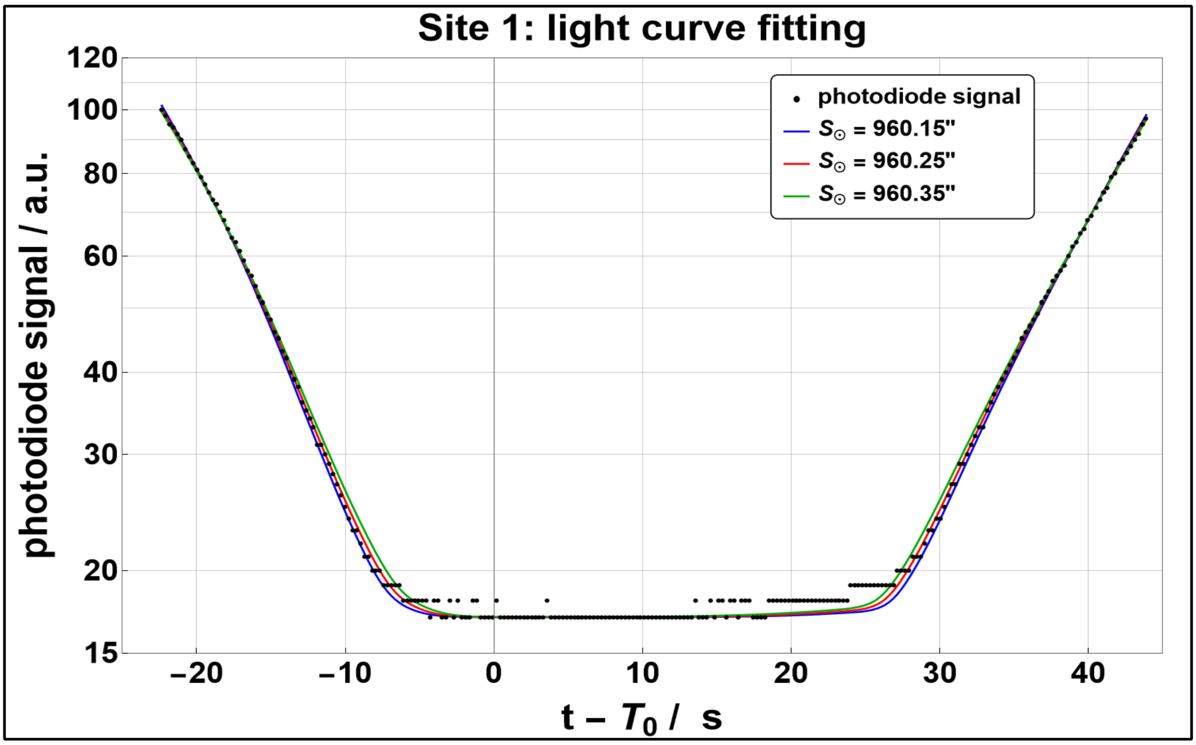


*Figure 7: Observed ambient light curve at Site 1 around the time of totality and three synthetic light curves for various eclipse solar radii fitted to the photodiode signal.*

## Discussion

Lamy and collaborators applied their methodology during various eclipses and measured values of the solar radius $S_\odot$ in the range 959.90″ to 960.10″ [1]. Our team measured an eclipse solar radius of 959.95″ during TSE2017 by analysing a video of the flash spectrum [2].

Our manual contact timings provide an estimate of the eclipse solar radius in the range 959.90″ - 960.02″, in line with previous measurements. The ambient light measurements indicate a far higher estimate of about 960.25″ which, we must admit, leaves us quite puzzled as it would imply that the photospheric extinction should have lasted less than 2 s at Site 1. This is at odds with the visual observation of the eclipse where we experienced a longer period when Baily's beads were absent.

Although the photodiode loggers returned very consistent results across the three sites, we pondered about possible hardware issues. The photodiode sensor is of good quality, and it was still working within its operational range during totality. As already mentioned, the ADC did not have sufficient resolution to capture all details of the signal at the lowermost light levels for a few seconds before second contact ($C_2$) and for a dozen seconds or so after third contact ($C_3$). Referring to Figure 3, we can observe that, due to the geometry of the eclipse, the exposed area of photosphere remained very small for almost 15 s after third contact ($C_3$). Therefore, we expected the ambient light curve to increase very gently, as we observed. A higher resolution ADC would have possibly allowed capturing the light curve with more detail.

One of the advantages of the methodology described by Lamy et al. (and an advantage of the technique described in [2], too) is that the whole of the light curve is fitted and there is no reliance on single-point measurements. To test the effect of the discretisation artefacts near totality, we repeated the fitting procedure on only experimental data points greater than 20 in Figure 7. The estimated eclipse solar radii hardly changed and remained in the range 960.20″ - 960.25″.

The photodiode loggers collected the entirety of ambient light - direct and diffuse. The analysis by synthetic light curves implicitly assumes that the only source of light is the photosphere. The only adjustment is in the synthetic light curves being shifted up to account for the level of diffuse light during totality. If direct and diffuse light have the same temporal behaviour, we should be able to conflate them together. But, if for some reason, the amount of diffuse light changes in a more complex way, the analysis would have become far more difficult, and we have not attempted to go down that route. That might lead to an overestimation of the eclipse solar radius.

The unusually high estimate of the solar radius made us question the assumption that the photosphere (directly, or indirectly as diffuse light) is the only source of light. A filter was placed in front of the photodiode, and it is likely that almost all chromospheric emissions were blocked. But there was that bright ring of light around the rim of the Moon which was likely due to inner coronal light. The coronal light has a bright emission around 530 nm, which lies at the edge of the filter bandwidth. Hence, some of this light might have made it through the filter and been captured by the loggers. Usually, we think about the inner corona as far less intense than the photosphere but the intensity of the Baily's beads that appeared after $C_3$ was rivalled, for 10-15 s, by the brightness of the ring of light. This extra component might have the effect of making the estimated eclipse solar radius slightly larger than it should be because the synthetic curves are unable to account for the temporal dynamics of the light coming from this intense rim of light (its contribution is likely not constant due to the movement of the Moon).

Finally, we would like to highlight the fact that the eclipse computations reproduce the timing of the observations remarkably well. The UTC timing of the observed light curves is accurately matched by the timing of the synthetic light curves. If the eclipse computations did not accurately account for all the complexity of the lunar limb profile, of the movement of the centres of the Sun and Moon, of the reference systems, etc, we'd likely see timing mismatches, especially for locations so close to the umbral shadow's path edge.

## Conclusions

We estimated the eclipse solar radius $S_\odot$ to be in the range 959.90″-960.02″ from manual contact timings obtained by observing the eclipse flash spectrum and to be about 960.25″ by analysing ambient light curves collected with photodiode loggers. The photodiode loggers were very easy to use but their analysis raised several questions. We are aiming to use these loggers again during TSE2024 to assess if the apparent peculiarities of ATSE2023 might have affected the recorded data. However, our main effort will be to collect a time-stamped video of the eclipse flash spectrum as we believe it to be a superior way of estimating the eclipse solar radius.

## References


[1] Lamy, P., Prado, J.-Y., Floyd, O., Rocher, P., Faury, G., Koutchmy, S., A Novel Technique for Measuring the Solar Radius from Eclipse Light Curves – Results for 2010, 2012, 2013, and 2015, Solar Physics, vol 290, pp 2617–2648 (2015)

[2] Quaglia, L., Irwin, J., Emmanouilidis, K., Pessi, A., Estimation of the Eclipse Solar Radius by Flash Spectrum Video Analysis, The Astrophysical Journal Supplement Series, vol 256, no 2 (2021)

[3] Hestroffer, D., Magnan, C., Wavelength dependency of the Solar limb darkening, Astronomy and Astrophysics, vol 333, pp 338-342 (1998)

[4] Stephenson, F.R., Jones, J.E., Morrison, L.V., The solar eclipse observed by Clavius in A.D. 1567, Astronomy and Astrophysics, vol 322, pp 347-351 (1997)

# 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 2023 October 11, the *Minor Planet Center* listed 1545 Centaurs and 3113 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:**

### (58534) Logos and Zoe

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

**ABSTRACT:** Since 2016, the JOA regularly publishes portraits of objects beyond Jupiter's orbit.

This short communication on the trans-Neptunian binary system known as Logos and Zoe tells the story of its discovery, the meaning behind its name and the nature of its orbit. The sizes and physical properties are derived from data published up to 2020.

| 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 |
| 5335 | Damocles | Oliver Klös | JOA 2 2023 |
| 8405 | Asbolus | Oliver Klös | JOA 3 2016 |
| 10370 | Hylonome | Konrad Guhl | JOA 3 2021 |
| 10199 | Chariklo | Mike Kretlow | JOA 1 2017 |
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| 208996 | 2003 $AZ_{84}$ | Sven Andersson | JOA 3 2022 |
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| 486958 | Arrokoth | Julia Perła | JOA 3 2023 |
| - | 2004 $XR_{190}$ | Carles Schnabel | JOA 1 2022 |

## The Discovery

The object was discovered on 1997 February 4 at Mauna Kea by Chadwick A. (Chad) Trujillo, Jun Chen, David C. Jewitt, and Jane Luu. The discovery was made with the 2.2m University of Hawaii reflector (Figure 1). The object was given the preliminary designation, 1997 $CQ_{29}$. Permanent number (58534) was assigned on 2003 June 14.

## The Name

The object was named on 2006 June 13 for the mythological gnostic deity [1].

Before the naming, in 2001, Noll et al. discovered an object near Logos with the WFPC2 camera on the *Hubble Space Telescope* [2], (Figure 2). It received the provisional designation S/2001 (58534) 1 as a satellite of Logos. Later, this object was found to have similar dimensions to Logos and was given the name, Zoe. This trans-Neptunian object is also now referred to as the binary system, (58534) Logos-Zoe.

The term logos (λόγος) in the ancient Greek language denotes (written) speech in the sense of its material basis of letters, words, syntagmas and texts. Logos, however, also denotes the mental faculty and what it produces, furthermore a more general principle of a world reason or an overall sense of reality.

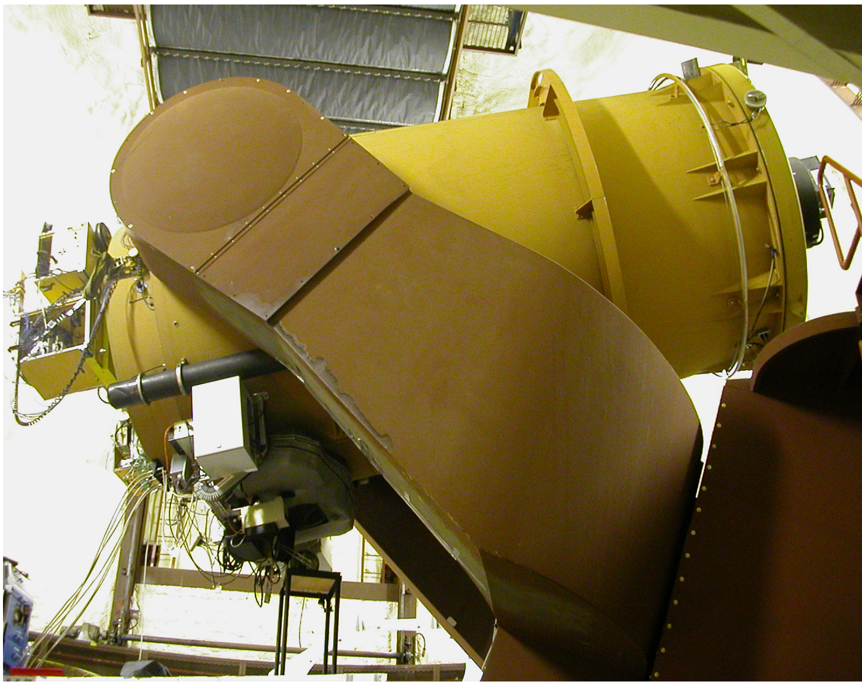


*Figure 1. The University of Hawaii 2.2-metre telescope is located near the summit of Mauna Kea, on the Island of Hawaii. The 2.2-metre telescope was the first large telescope constructed on Mauna Kea. It went into operation in 1970, and its early successes showed the excellent image quality and observing conditions at the top of Mauna Kea.*
*(Source: https://about.ifa.hawaii.edu/facility/maunakea-telescopes/#uh88)*

The words in the Bible: "...In the beginning was the Word. The Word was with God, indeed the Word was God..." are also translated from the term logos. The name Zoe is derived from the ancient Greek vocabulary ζωή zōē "life".

In the Gnostic-Christian teaching of Valentinus (ca. 100 AD -160 AD), Logos and Zoe (Word and Life) are two of the eight eons in the creation of the world.

Like Yin and Yang, Logos and Zoe stand for polar opposites and yet related dual forces or principles that do not fight but complement each other. An ideal designation for a binary planet with almost equally-sized components.

## The Orbit

The orbit is moderately eccentric (0.120) and inclined to the ecliptic by 2.90°. With a semi-major axis of 45.0 au, the distance from the Sun is between 39.6 au and 50.4 au (Ref. JPL 16, dated 2021-Apr-13). The complete orbit is outside that of Neptune. The orbital period is approximately 301.5 years. There is no orbital resonance with the outer planets. So, the object belongs to the cold classical Kuiper Belt group also known as Cubewanos moving on almost circular orbits, unperturbed by Neptune.

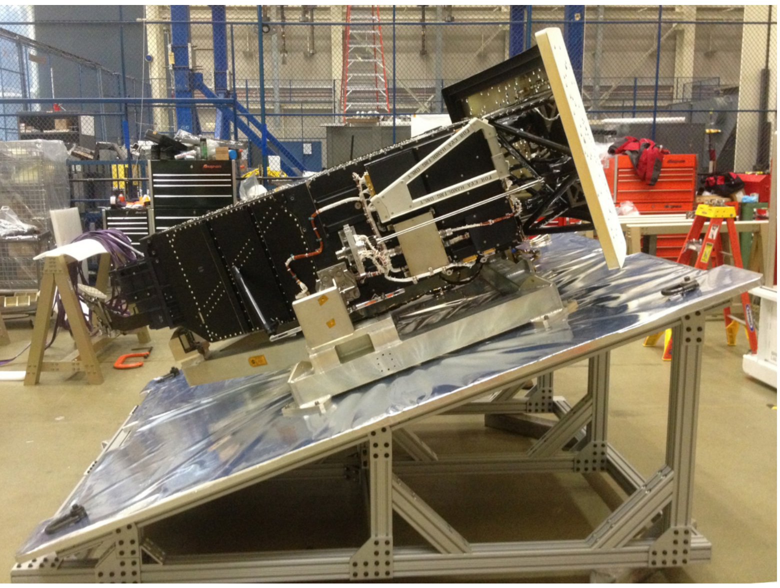


*Figure 2. WFPC2 wide field camera for the Hubble Space Telescope in laboratory.*
*(Source: https://airandspace.si.edu/collection-media/NASM-A20140124000cp01)*

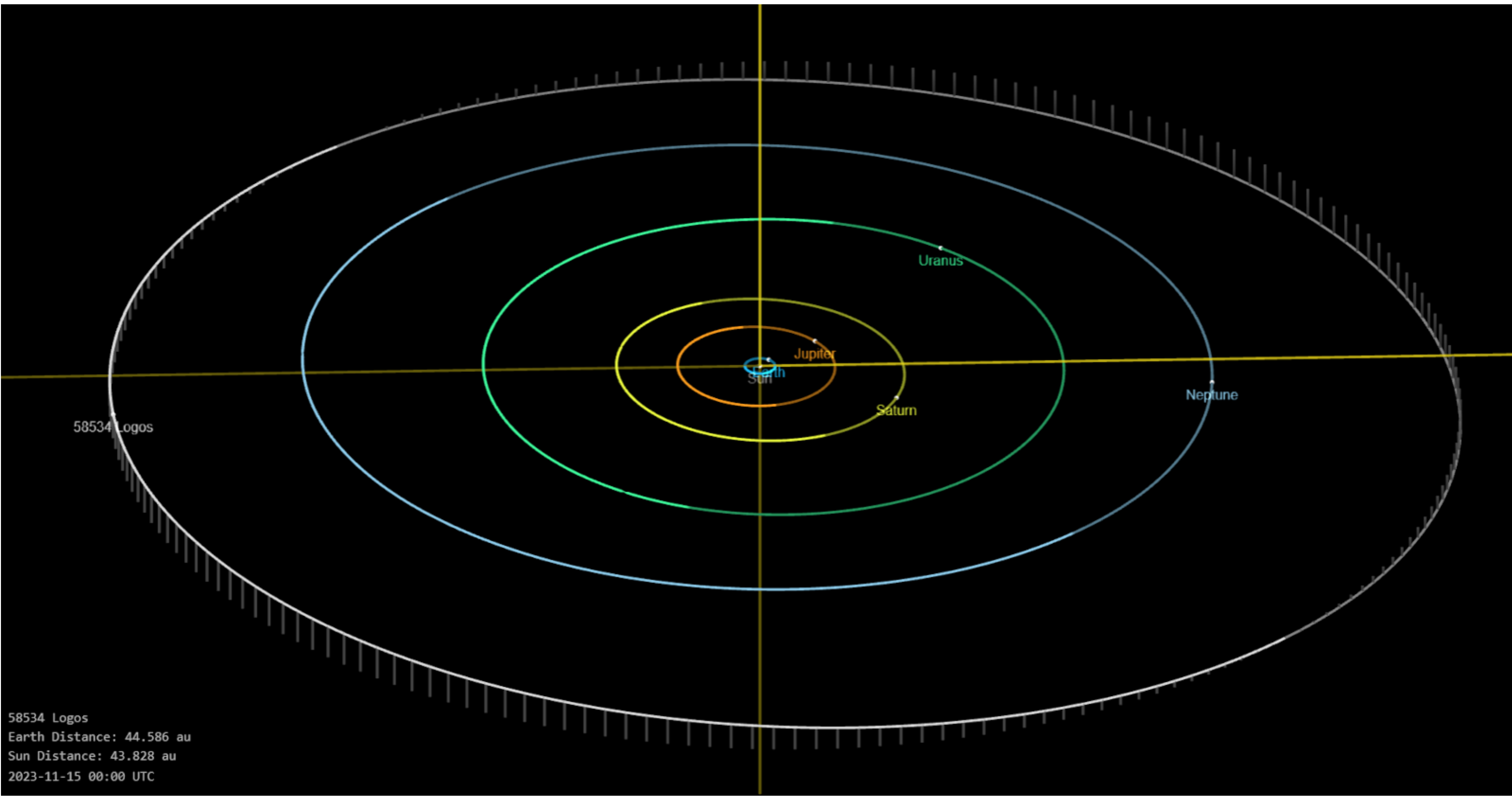



*Figure 3. Orbit diagram and position of (58534) Logos and Zoe on 2023 November 15.*
*(Source: NASA/JPL Small-body database lookup, https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=58534)*

## Physical Characteristics

The images of the two bodies were separated using the *Hubble Space Telescope* and their orbits were determined astrometrically. The two components of 1997 $CQ_{29}$ were separated by 0.20 ± 0.03" in 2001 November [2] and by 0.33 ± 0.01" in 2002 June/July [3,4]. It has also been possible to separate the components from ground-based observations with the *Keck-Telescope* [5].

From astrometric data, the orbit of (58534) Logos-Zoe could be calculated. Figure 4 shows the sky projection of both components [6].

The semi-major axis of the double minor planet was found to be: 8217 ± 42 km, and the orbital period, $P_s$ to be 309.87 ± 0.22 d.

With this being a binary system, it is possible to calculate the mass of each component. By adopting a typical albedo of 0.20, the diameter can then be calculated from the derived mass and absolute magnitude.

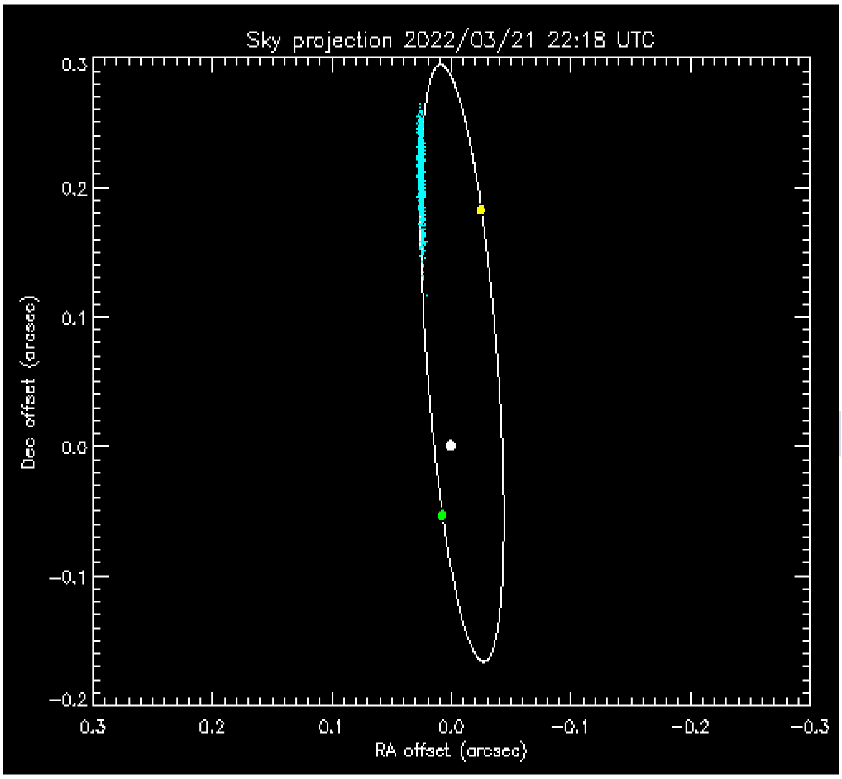



*Figure 4. Orbit of Logos-Zoe in the sky plane [4].*

For Logos, a diameter of 82 ± 18 km has been reported, and for Zoe the diameter is a little smaller at 67 km [7].

Photometric observations in different filters indicate a red spectrum with a V-R colour index of 0.68 ± 0.06 [8]. This suggests these two bodies are primordial objects, the surfaces of which have been largely unaltered by collision.

## Future Occultations

This system would be an excellent target for occultation studies but unfortunately it is currently moving very slowly through a relatively starless region of the sky in the constellation of Virgo. Consequently, no occultations are predicted for the near future.

## References


[1] Minor Planet Circ. 56962
https://minorplanetcenter.net/iau/ECS/MPCArchive/2006/MPC_20060613.pdf

[2] IAUC 7824: 2002 BM_26; 1997 CQ_29; 2002au
http://www.cbat.eps.harvard.edu/iauc/07800/07824.html

[3] IAUC 7959: 2002ep, 2002eq, 2002er, 2002es, 2002et; 1997 CQ_29
http://www.cbat.eps.harvard.edu/iauc/07900/07959.html

[4] Noll, K. S. et al.: "Detection of Two Binary Trans-Neptunian Objects, 1997 CQ29 and 2000 CF105, with the Hubble Space Telescope", The Astronomical Journal, 124:6, 3424-3429 (2002)
https://arxiv.org/abs/astro-ph/0210593

[5] Grundy, W. M. et al.: "Five new and three improved mutual orbits of transneptunian binaries", Icarus, 213:2, 678-692 (2011)
https://arxiv.org/ftp/arxiv/papers/1103/1103.2751.pdf

[6] http://www2.lowell.edu/users/grundy/tnbs/58534_1997_CQ29_Logos.html

[7] http://www.johnstonsarchive.net/astro/astmoons/am-58534.html

[8] Barucci, M. A. et al.: "Compositional Surface Diversity in the Trans-Neptunian Objects", The Astronomical Journal, 120:1, 496-500 (2000)
https://iopscience.iop.org/article/10.1086/301416/pdf


## Useful Links

About objects like TNOs and Centaurs:

NASA/JPL Small-Body Database Lookup
https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/

Spacewatch, Lunar and Planetary Laboratory, University of Arizona
https://spacewatch.lpl.arizona.edu

Minor Planet Center
https://minorplanetcenter.net//

### *30 Years Ago – Last-Minute Updates of Predictions via E-mail*

From *IOTA News* by David W. Dunham, *Occultation Newsletter* Vol. 6, No. 1:

E-mail: The October 9th occultation by 27 Euterpe was quite successfully observed in the southwestern USA, based on a good astrometric update obtained at Lowell Observatory four days before the event. Electronic mail (specifically, Internet) was valuable for distributing updated predictions quickly to dozens of observers. I mailed (regular postal service) the same information to a couple of dozen other ON subscribers in or near the path for whom I did not have E-mail addresses, but I think at best 25% of those may have arrived in time. In the USA and many other countries, Internet is available at most universities, colleges, government agencies, and large businesses. If you don't have access at work, Internet can be reached for reasonable prices via Compuserve, MCIMail, GEnie, and other vendors in the USA and in other countries; a few IOTA members have already purchased access. Local and regional coordinators are encouraged to gain Internet access to facilitate communication about last-minute updates. Those with E-mail also have a duty to try to inform other IOTA members without E-mail in their areas of local time-critical events.

More communications from the past – ***The Occultation Newsletter Heritage Project***
https://www.iota-es.de/on_heritage.html

# Forming a New Occultation Observation Group in East Asia

## Introduction

A new organisation for occultation observation in East Asia : the International Occultation Timing Association - East Asia (IOTA/EA), has just started with its inaugural meeting on 2023 August 27 (UT). It is a joint organisation of professional and amateur astronomers. It consists of eight core members, three regional directors, and ordinary members who are officially registered after the inaugural meeting. The goal of IOTA/EA is to promote occultation observation and to be a partner in planetary exploration and other research.

## Background of the Formation of IOTA/EA

There have been many amateur astronomers in Japan with experience in occultation observation. They have been exchanging information and accumulating know-how on occultation observation through the mailing list called JOIN since 1995, and JOIN members are always making efforts to obtain better observation results and improve data analysis techniques based on the activities of individual observers. These activities are fully appreciated. However, in recent years, in response to the rapidly increasing demand for occultation observations and the increasing scientific research obtained from occultation observations, to respond to these needs, organized occultation observations are necessary. Therefore, we decided to create an organized group for occultation observers. This is the IOTA/EA, which so far consists mainly of Japanese occultation observers and includes observers from neighbouring countries.

There is a particularly deep connection between planetary exploration flyby missions and occultation observations. For example, it was systematic occultation observations that led to the discovery of the snowman-like shape of (486958) Arrokoth, the flyby target of NASA's *New Horizons* mission. The *Lucy* mission, which is the first space mission to flyby a population of small bodies known as Trojans, includes occultation observations as a fundamental part of the mission.

In Japan, prior to the formation of IOTA/EA, the Japanese occultation community was asked by JAXA's *DESTINY+* planetary mission team to determine the size and shape of asteroid (3200) Phaethon (the flyby target of *DESTINY+*) through occultation observations. This is because the *DESTINY+* team needs to know the exact size of (3200) Phaethon and create a 3D shape model of the asteroid for mission planning. In response to this request, a joint team of professional and amateur astronomers was formed and began the occultation observation of (3200) Phaethon. It was in 2019. Since then, the joint team carried out many observations, such as stellar occultation by Triton on 2022 October 6, stellar occultation by (3200) Phaethon on 2022 October 21 (for *DESTINY+*), stellar occultation by (65803) Didymos from October to November 2022 (for *DART*), and stellar occultation by (98943) 2001 CC21 in January-March 2023 (for *Hayabusa 2#*). Through the series of occultation observation experiences, many Japanese occultation observers are now able to observe occultation events under difficult conditions, such as the brightness of the occulted star fainter than 11-12 mag or the duration of dimming as short as 0.1 sec. A series of successful systematic occultation observations and followed by significant contributions for planetary exploration missions and scientific researches encouraged occultation observers.

*Figure 1. IOTA/EA logo selected from among 21 applications from the general public.*

Another reason that occultation observations have become so popular in Japan is the development and popularisation of CMOS cameras and GPS receivers. They are very important tools to improve the efficiency of occultation observations and data analysis to obtain accurate results. In addition, there are external forces (1) *Gaia*'s catalogue has improved the positional accuracy of faint stars that were not previously used to predict occultation observations, (2) the All Sky Survey made the orbital accuracy of asteroids higher. These have led to more accurate occultation predictions. Therefore, there is less chance for observers to be misled. All these circumstances have encouraged the establishment of IOTA/EA.

## IOTA/EA's Projects

IOTA/EA will conduct the following five projects:

- Holding annual meetings
- Providing information, discussion, research, analysis, and data storage on occultation and eclipse phenomena
- Website and mailing list management
- Cooperation and collaboration with related organisations
- Other activities necessary to achieve the purpose

The IOTA/EA provides information on occultation and eclipse phenomena observable from the East Asia region through the website. This website is open to the public:

https://www.perc.it-chiba.ac.jp/iota-ea/wp/

Any member of IOTA/EA can discuss and exchange information through the mailing list :

ml@iota-ea.org

The IOTA/EA will prepare data storage to hold the raw data, analysis result, etc. of each observed event (asteroid occultation and lunar occultation) by the IOTA/EA members, and make a data archive. The IOTA/EA cooperates with other IOTA organisations to improve and disseminate the quality of occultation observations and to derive scientific results. The IOTA/EA conducts outreach and dissemination activities to promote awareness of and support for IOTA/EA activities and holds workshops to promote occultation observing and improve observation/analysis techniques.

The lack of a common language in East Asia makes it difficult to share information. Therefore, we have appointed Regional Directors in the major regions. The role of the Regional Directors is to communicate with the observers in the regions where the Director resides and to provide information from IOTA/EA to the local observers. And the Regional Directors are also responsible for reporting the observation results of the observers in their regions to IOTA/EA. In other words, the Regional Directors act as a liaison between IOTA/EA and the observers in each region. IOTA/EA currently has Regional Directors in Mainland China, Hong Kong and Taiwan, and hopes to expand this observer network further.

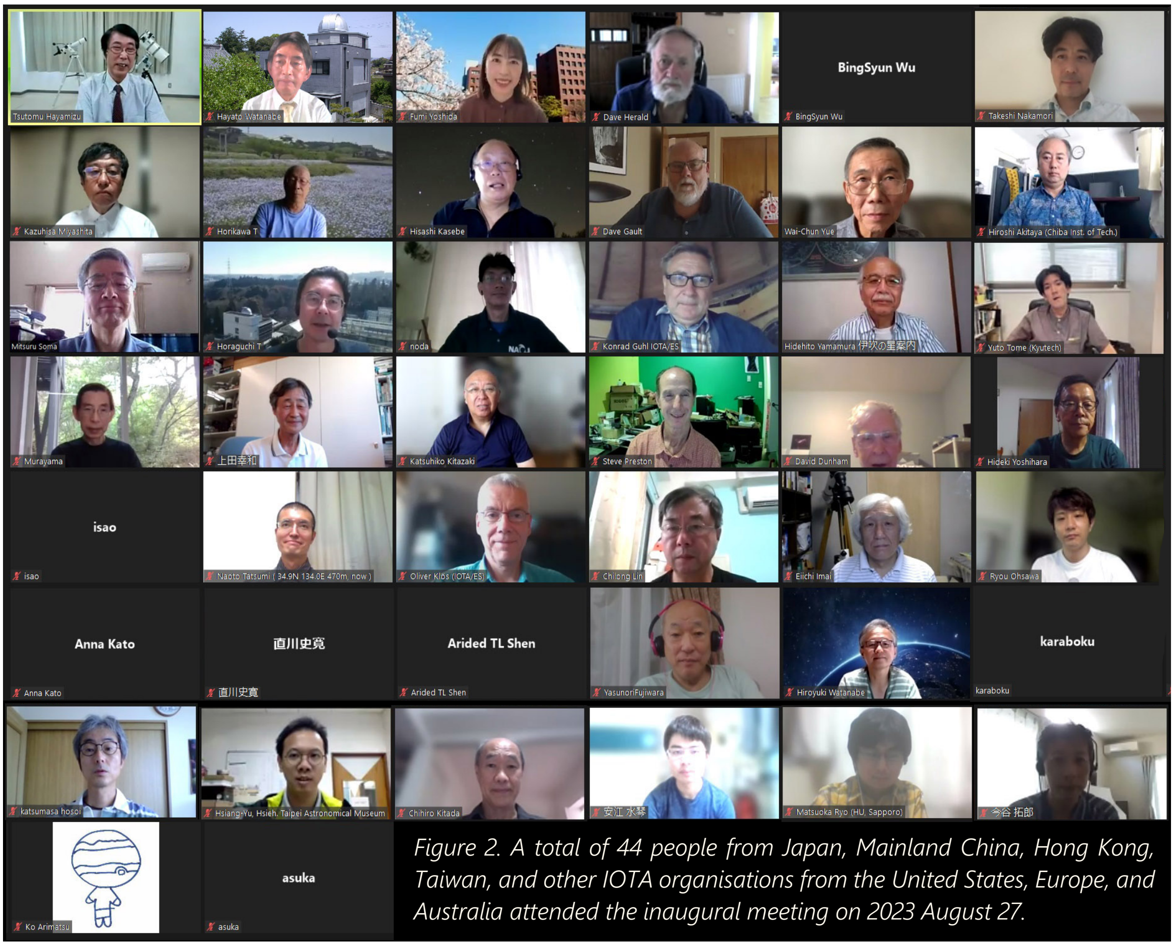



*Figure 2. A total of 44 people from Japan, Mainland China, Hong Kong, Taiwan, and other IOTA organisations from the United States, Europe, and Australia attended the inaugural meeting on 2023 August 27.*

## Everybody Can Join IOTA/EA

Those who wish to become a member of the IOTA/EA can join the group, even if they do not live in the East Asia. Membership registration is available on the IOTA/EA website https://www.perc.it-chiba.ac.jp/iota-ea/wp/about-iota-ea/join-iotaea/.

IOTA/EA has two types of members: regular members and associate members. The membership fee for regular members is 1,500 yen per year, and there is no membership fee for associate members. No membership fee will be charged in Fiscal Year 2023 that is the special founding year of IOTA/EA. All members will be registered as regular members. A request for payment of membership fee will be sent from IOTA/EA before the start of the FY2024. Those who have paid their fee will continue as regular members in FY2024, and those who have not paid will automatically become associate members.

Communication is basically in English. Members who are not fluent in English can use automatic translation functions. IOTA/EA organises workshops to improve the skills of local occultation observers. The purpose of the workshop is to train newcomers to occultation observation in each region, so the workshop is basically conducted in the local language. However, the observation manuals, observing tools, and data analysis software distributed at the workshop will later be made available in English.

IOTA/EA will contribute to the dissemination and technical improvement of occultation observation in the Asian region. We look forward to working with occultation observers around the world. We hope that you will follow the activities of IOTA/EA closely and support us.

*Fumi Yoshida*
*Director, IOTA/EA*
*Public Relations and Training*

## *Organisation of IOTA/EA* (Alphabetical order by last name)

***Chairpersons***
Tsutomu Hayamizu [Saga Hoshizora Astronomy Center, Japan] (早水 勉)
Fumi Yoshida [University of Occupational and Environmental Health, Japan / Chiba Institute of Technology] (吉田 二美)
***Secretary***
Hayato Watanabe [JOIN (Japan Occultation Information Network)] (渡部 勇人)
***Directors***
Hiroshi Akitaya [Chiba Institute of Technology] (秋田谷 洋)
Tsutomu Hayamizu [Saga Hoshizora Astronomy Center, Japan] (早水 勉)
Kazuhisa Miyashita [JOIN (Japan Occultation Information Network)] (宮下 和久)
Hirotomo Noda [National Astronomical Observatory of Japan] (野田 寛大)
Mitsuru Sôma [National Astronomical Observatory of Japan] (相馬 充)
Hayato Watanabe [JOIN (Japan Occultation Information Network)] (渡部 勇人)
Fumi Yoshida [University of Occupational and Environmental Health, Japan / Chiba Institute of Technology] (吉田 二美)
***Regional Directors***
Chilong Lin [National Museum of Natural Science, Taiwan] (林 志隆)
Ye Yuan [Purple Mountain Observatory / Chinese Academy of Sciences] (袁烨)
Wai-Chun Yue [Hong Kong Astronomical Society] (余 惠俊)
***Auditor***
Toshihiro Horaguchi [National Museum of Nature and Science,Tokyo] (洞口俊博)

***Departments***
(1) ***Planetary and Asteroidal Occultations***
Provide predictions of planetary and asteroidal occultations, receive and compile observation reports, and report to IOTA.
(2) ***Lunar Occultations***
Provide predictions of lunar occultations, receive and compile observation reports, and report to IOTA.
(3) ***Website Management***
Maintain and manage the Association's website.
(4) ***Storage of Observation Data***
Store and maintain observation data reported to the Association.
(5) ***Public Relations and Training***
Publicise the Association's activities and conduct training and other activities necessary to achieve the Association's objectives.
(6) ***Local Branches***
Organize and publicise activities in each region.
Each branch appoints one regional director to serve on the Board of Directors.

# The International Occultation Timing Association's 41$^{st}$ Annual Meeting, 2023 July 15-16 via Zoom Online

Richard Nugent · IOTA · Dripping Springs, Texas · USA · RNugent@wt.net

**ABSTRACT:** IOTA's 2023 Annual Meeting was held via Zoom online on 2022 July 15-16. Numerous presentations were made by members of the IOTA community worldwide. More than 60 attendees participated in the meeting.

The 41st annual meeting of the International Occultation Timing Association was held on Saturday and Sunday 2023 July 15-16 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 15th July 2023 - 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.

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

### Awards

**Richard Nugent** then presented IOTA's *Homer F. Daboll Award.* This award is given to recognize significant contributions to the field of occultation science and to the work of IOTA. This year's recipients are **Russ McCormick** and **Tony George.**

**Russ McCormick** is honoured for his development and maintenance of IOTA Video Capture and its companion, IOTA Video Playback. His attention to what observers wanted led to the development of a software package that can be programmed to capture data automatically from remote, unattended, small Windows computers and tablets. This program is a mainstay of many observers' data capture kit, a dependable and easy-to-use facility. Also, it should be noted that he provides a detailed user guide, a great benefit for those first using these programs. Russ sent the following message upon his notification of the award:

*Richard,*

*Thanks for notifying me about the Homer Daboll Award.*
*I am honored and hope to perpetuate IOTA members trust in the IOTA Capture and Playback software as we press on into the future. I still have multiple years of work to do as I begin to support digital cameras along with the current support for analog cameras. I started programming the two applications seven years based on a user error on my part while trying to use the currently available recording software. I had just purchased an analog camera used by IOTA members and found that it did not work on my laptop computer. So ultimately I decided to write a program to see if I could make it work, and that was the start of my two applications.*
*The best part of writing the applications is that it has permitted me to interface with many of the IOTA members, both for beta testing the software and after the official release for reporting issues. The membership has kept me intellectually stimulated, which is important to me because I have long since been retired from programming for a company.*

*Regards,*
*Russ McCormick*

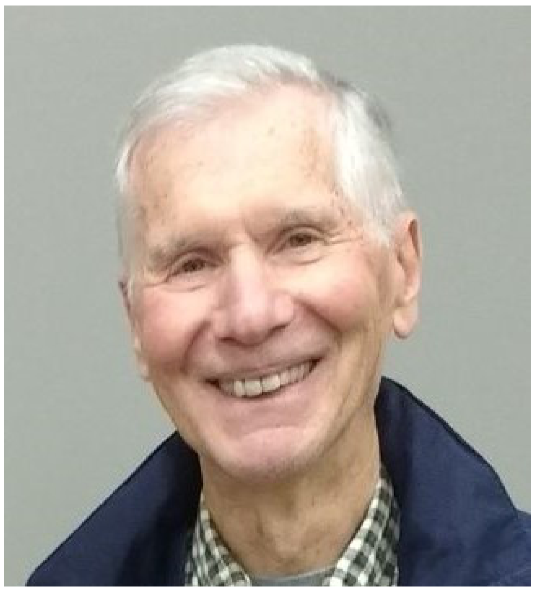


*Figure 1. Homer F. Daboll Award: Russ McCormick*

**Tony George** has not only been an outstanding observer but assisted in the development of *Occular*, the first publishable occultation analysis software. He is a collaborator with Bob Anderson in the design and refinement of *PyOTE* and *PyMovie*. He has reviewed many, many observations made by others regarding the findings and significance of their observations. He has been faithfully available to help anyone who asked for his opinion or advice about an observation. He has for many years been the goto guy for troublesome videos and light curves both from newbies and experienced observers. Both John Moore (and Brad Timerson before that) and Eric Frappa make frequent use of Tony's expertise and willingness to take the time to explain and many cases actually do the data reduction and help them sort questionable observations. There are a number of cases where he was able to find a positive from an apparently hopeless observation. Tony worked with the manufacturer of the RunCam video camera and was responsible for developing the Astro version of the camera. There are a lot of chords that have Tony's initials on them as he has been an active observer for many years. On 2022 March 27, Tony made an observation of a moon of (15094) Polymele confirmed on 2023 February 4 by a campaign in Kansas. The *Lucy* mission is scheduled to arrive at (15094) Polymele in September 2027. Tony's work has been universally appreciated among occultation observers.

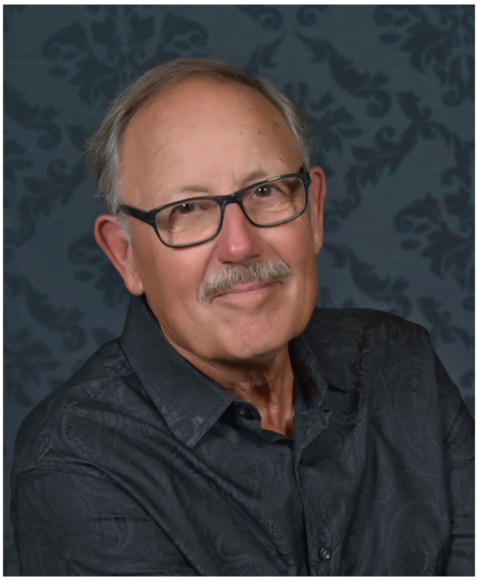


*Figure 2. Homer F. Daboll Award: Tony George*

Tony sent the following message upon notification of the award:

*Richard,*

*Thank you for presenting me with the DaBoll Award for 2023. Occultation astronomy is a field where amateur astronomers can make a significant contribution to science and astronomy. Over the last 30+ years I have enjoyed contributing my own personal occultation observations to IOTA. During that period, I also worked as a volunteer analyst and beta tester for many of the programs we use today. Best of all, I got to work with some amazing people, including the late Brad Timerson, Bob Anderson, Steve Preston, Dave Herald, Dave Gault, Hristo Pavlov, Ted Blank, David and Joan Dunham, Paul Maley, and many many others.*
*I have learned a lot and had a lot of fun along the way.*
*Occultation astronomy has a place for everyone to contribute their skills, energy, and interest. I encourage all IOTA members, new and old, to contribute wherever you can and hope that you have as much fun as I have in the process.*
*Thank you again for awarding me with the DaBoll Award for 2023.*

*Tony George*

For information on IOTA's awards, including previous awardees, see the award webpage [4].

## Technical Sessions

**Norm Carlson** presented a list of the "*Best Observed North American Asteroidal Occultations*". Norm is on IOTA's report team. He showed the sky plane plot of the observed chords for the (90) Antiope binary asteroid event on 2022 August 8. This August 2022 observation's chords were in excellent agreement with the shape models. Another (90) Antiope event occurred on 2022 November 21. Despite some difficulty in interpreting the data from the occultation of two stars, the end result was chords in very good agreement with the shape models.

Norm mentioned other discoveries for 2022/2023:

- (276) Aldeheid, 2022 Aug 31
  Yielded a possible satellite observed by Kevin Green.
- (906) Repsolda, 2023 Jan 25
  Possible satellite discovery by Kirk Bender.
  Dr. Rick Nolthenius also observed this event.
- (175) Andromache, 2022 Dec 21
  Likely double star discovery.
- (2102) Tantalus, 2023 May 7
  A small 1.7 km asteroid which might be a potential NEO.

Several occultations by (65083) Dimorphos and its satellite Didymos were observed in 2022 and early 2023. This was NASA's *DART* (Double Asteroid Redirection Test) mission by slamming a spacecraft into Didymos to see if its orbit could be changed. The successful occultation observations allowed highly accurate asteroid positions providing accurate orbit updates confirming the success of the NASA *DART* mission.

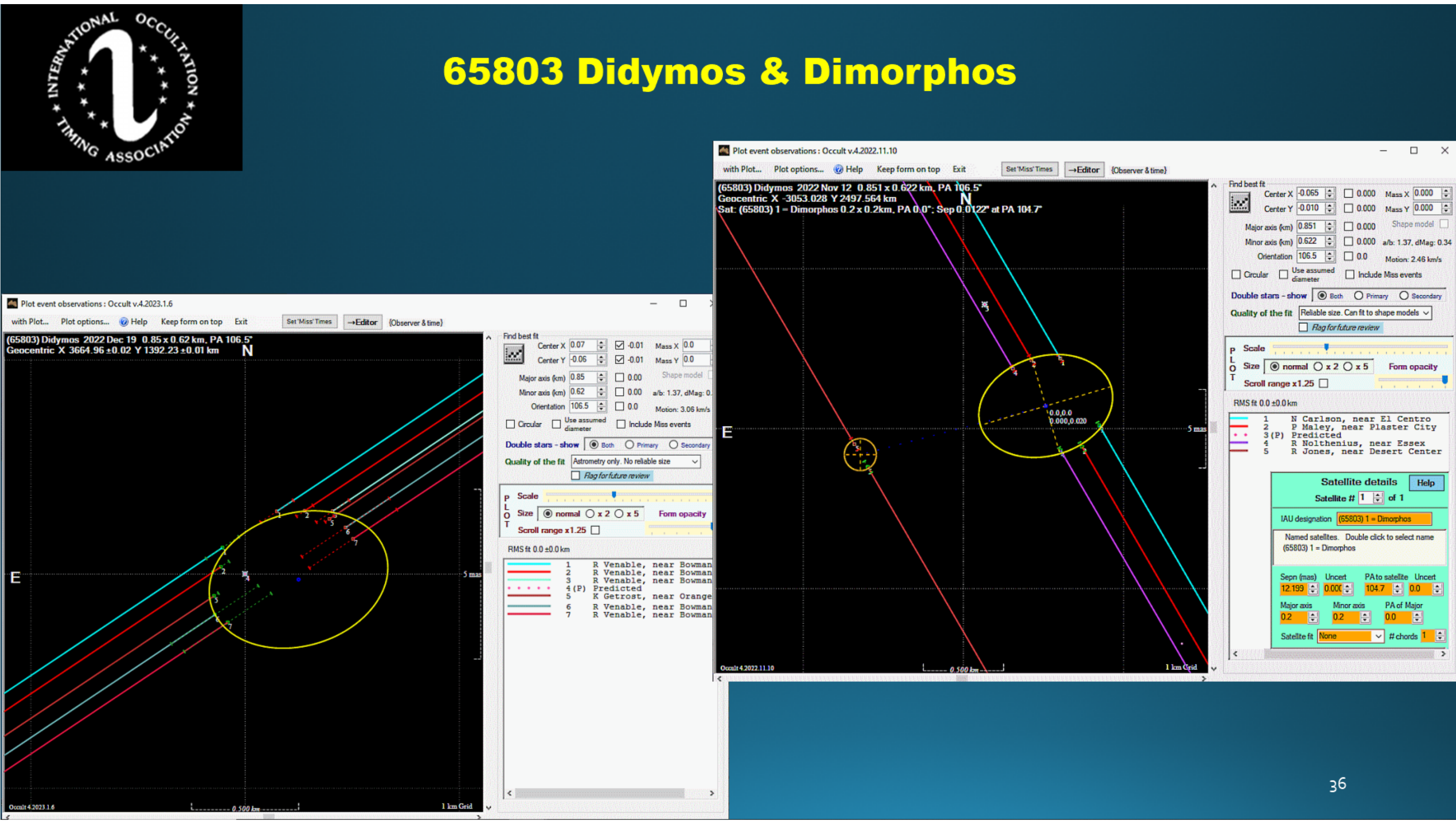



*Figure 3. Profiles recorded during occultations by (65803) Didymos and its satellite. (Source: Occult V4, screenshot of N. Carlson's presentation)*

Norm acknowledged the North American Report Team: Jerry Bardecker, Bob Dunford, Ernie Iverson, Steve Messner, John Moore - Coordinator Emeritus, Tony George - Difficult Observations Analyst (aka "The Shadow Whisperer"), Johnny Barton & Dave Eisfeldt- Tangra Support, Dave Gault and Dave Herald.

discovering double stars. With several stations observing these occultations, the uncertainty in separation can approach <0.001". In 2022, 15 double stars were discovered by IOTA observers (Figure 4). Discoveries are usually published in the Journal of Double Star Observations [5] and will be added to the Washington Double Star Catalog (WDS) [6] maintained at the USNO.

**Dave Herald** presented "*Best Observed non-North American Asteroidal Occultations from 2022*." A record 1,488 events were observed worldwide in 2022. While the number of observed events have been growing, the number of unusable events has been dropping rapidly. Dave showed statistical results of observations of 2020 compared to 2022 based on region and asteroid diameter. More statistical results were shown covering years 2000 to 2022 of the number of observers per event and number of individual observers. Occultations also are

**15 double stars discovered in 2022**

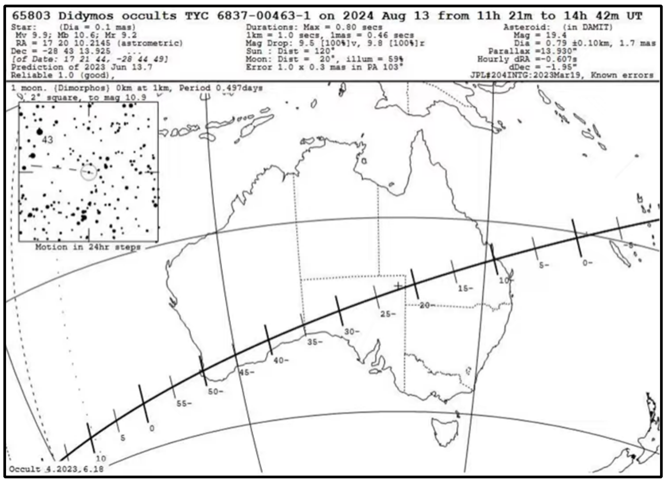
| Cnt | Star number | Soln | Sep (masec) | P.A. | Date | Asteroid |
|---|---|---|---|---|---|---|
| 108 | HIP 66653 | #1 | 1.0 ± 0.0 | 147.5 ± 0.2 | 2022 Jan 15 | 278480 2007 UU |
| 109 | UCAC4 480-002385 | #1 | 22.5 ± 1.0 | 300.6 ± 1.6 | 2022 Jan 25 | 877 Walkure |
| 110 | Tycho2 1363-00863-1 | #1 | 16.5 ± 1.4 | 49.3 ± 6.1 | 2022 Feb 21 | 371 Bohemia |
| 111 | UCAC4 553-019591 | #1 | 15.8 ± 0.2 | 260.7 ± 0.2 | 2022 Feb 23 | 4213 Njord |
| 112 | UCAC4 546-030935 | #1 | 13.4 ± 0.4 | 192.3 ± 0.8 | 2022 Feb 28 | 5687 Yamamotoshinobu |
| 113 | UCAC4 341-179199 | #1 | 1.6 ± 1.4 | 53.5 ±33.7 | 2022 Mar 3 | 2313 Aruna |
| 114 | UCAC4 561-133587 | #1 | 9.0 | 308.0 ± 0.2 | 2022 Jul 2 | 2363 Cebriones |
| 115 | UCAC4 240-111559 | #1 | 21.0 ± 5.3 | 250.2 | 2022 Jul 7 | 32772 1986 JL |
| 116 | UCAC4 479-129046 | #1 | 5.3 ± 0.6 | 239.2 ± 1.1 | 2022 Sep 11 | 59592 1999 JW58 |
| 117 | Tycho2 5768-01712-1 | #1 | 6.2 | 98.1 ± 0.1 | 2022 Nov 6 | 667 Denise |
| 118 | UCAC4 357-192034 | #1 | 4.3 ± 2.2 | 286.0 | 2022 Nov 8 | 3923 Radzievskij |
| 119 | UCAC4 544-010397 | #1 | 7.1 ± 0.1 | 255.8 | 2022 Nov 20 | 1549 Mikko |
| 120 | UCAC4 359-201760 | #1 | 53.5 | 312.5 ± 0.3 | 2022 Nov 21 | 90 Antiope |
| 121 | UCAC4 513-019292 | #1 | 5.9 ± 2.0 | 22.1 ±18.1 | 2022 Dec 2 | 1347 Patria |
| 122 | UCAC4 481-006032 | #1 | 5.9 ± 2.6 | 245.9 ±35.8 | 2022 Dec 14 | 53436 1999 VB154 |
| 123 | UCAC4 589-022925 | #1 | 16.0 ± 2.4 | 54.1 ± 8.7 | 2022 Dec 21 | 175 Andromache |

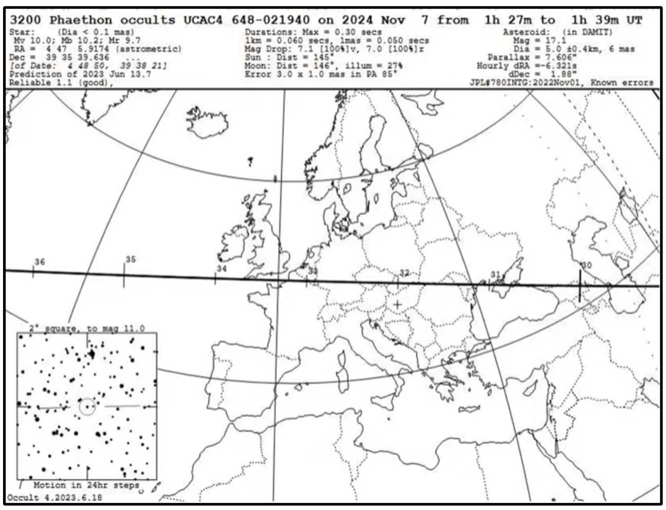
*Figure 4. Table of the 15 double star discoveries made with asteroidal occultation observations in 2022. (Screenshot of D. Herald's presentation)*

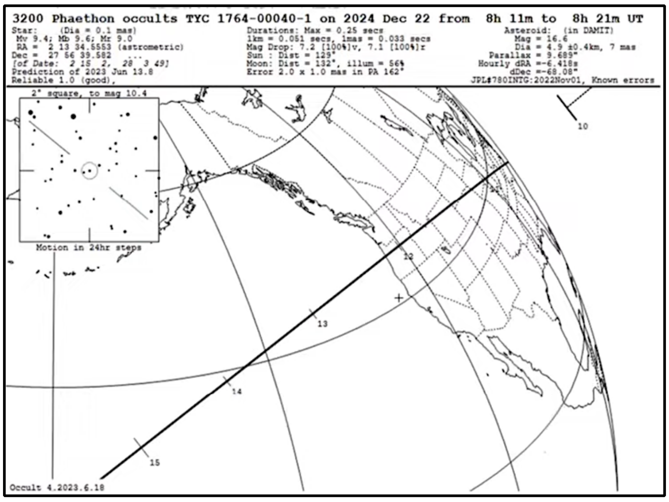
Dave showed several individual asteroid profiles from well observed events. Occultation-derived sizes were compared to those estimated by the satellites: *NeoWise*, *AcuA* and *IRAS*. Occultation-derived sizes matched very well with the satellite data within the uncertainties. He showed a few asteroid events in which a single chord was obviously off compared to those made by other observers. Dave postulated the source of these mismatched chords was due to timing errors.

**Steve Preston** presented *"Best/Brightest Asteroidal Events of the Coming Year 2024"*. In earlier years before Gaia, there weren't that many bright star occultation events whose path could be predicted accurately. Now with much improved predictions, there are so many bright star easy to observe events. Thus it's been difficult to choose the "best" events. Steve will have a webpage of these events posted soon. Some important NEA events for 2024 (Figures 5a-c):

- Aug 13: (65083) Didymos - a crucial event to refine its orbit.
- Nov 7: (3200) Phaethon, Europe
- Dec 22: (3200) Phaethon, USA



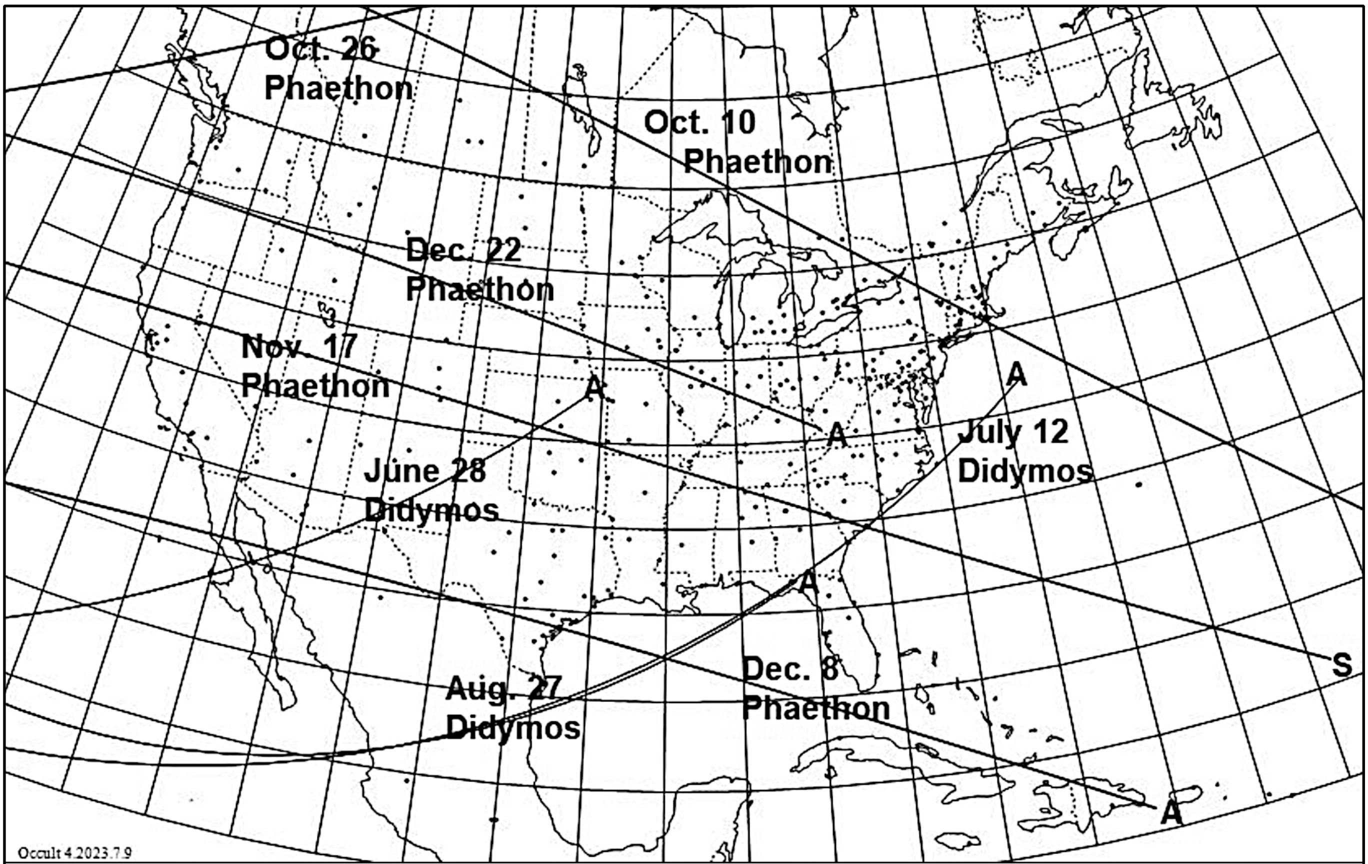




*Figures 5a-c. Important NEA events for 2024.*
*(Screenshot of S. Preston's presentation, Occult V4.2023.6.18)*

Steve then did a quick run through of the best worldwide events over Europe, Australia, and Japan. Then he showed maps of the best 2024 events over North America.

**David Dunham** presented "*NEA Observations: Recent and Upcoming*". The motivation for studying NEA's is for planetary defence. Unlike the dinosaurs who had no way of knowing their species would end from the Chicxulub event some 65 million years ago, humans now rule and can predict when an NEA is approaching the Earth. The first observed NEO occultation was 1975 January 24 of kappa Gem by the asteroid (433) Eros. (3200) Phaethon was the first asteroid discovered by the *IRAS* spacecraft. The first occultation observationof the 6 km size (3200) Phaethon was made 2019 July 29 over central California. The chord profile of this 2019 event can be found one-half way down the page at [7].

In 2021, occultation (plus radar) observations helped end the risk of the asteroid (99942) Apophis striking the Earth in 2029. Other NEO occultations mentioned were of (65083) Didymos/Dimorphos in 2022/2023, and (98943) 2001 CC21, an NEA flyby target of *Hayabusa2*. David then showed 2 maps of NEA events in North America during 2023 to mag 12.0 and mag 13.0 for (3200) Phaethon. He showed a list of 20 km sized objects that could be hazardous events during the next 1,000 years. David then showed a map of the 2024 (65083) Didymos and (3200) Phaethon events over North America (Figure 6). For more information see the presentation [8].




| Date | U.T. | Diameter | | Durn | Star | Mag-Drop | | Elon | % | Star | d | Rely | Planet | | Min | | Moon | | § ● | R.A. (J2000) | Dec. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| m d | h m | km | " | sec/m | mag | V | R * | o | Ill | No. | | <1.4 | No | Name | D | Error | Dist | ill | ☾ | h m s | o ' " |
| Jun 28 | 9 35.3 | 0.78 | 0.002 | 0.10s | 11.9 | 6.7 | 7.3 | 176 | | UCAC4 317-188802 | s | 0.70 | 65803 | Didymos | 0.65 | ±0.00 | 84 | 56 | §☾ | 18 27 38.574 | -26 44 55.46 |
| Jul 12 | 6 17.1 | 0.81 | 0.002 | 0.10s | 11.2 | 7.7 | 7.4† | 160 | | TYC 6850-02664-1 | | 0.55 | 65803 | Didymos | 0.72 | ±0.00 | 88 | 34 | §☾ | 18 0 23.331 | -27 49 44.70 |
| Aug 27 | 3 49.5 | 0.81 | 0.002 | 0.29s | 12.6 | 7.0 | 7.2 | 108 | | UCAC4 306-128451 | | 0.85 | 65803 | Didymos | 0.76 | ±0.00 | 172 | 42 | §☾ | 17 22 59.921 | -28 55 5.98 |
| Oct 10 | 8 32.3 | 5.0 | 0.004 | 0.90s | 13.5 | 4.8 | 4.7 | 113 | | UCAC4 640-025673 | | 0.95 | 3200 | Phaethon | 0.01 | ±0.00 | 159 | 45 | § | 5 25 11.454 | 37 51 1.87 |
| Oct 26 | 6 19.9 | 5.0 | 0.005 | 0.42s | 12.6 | 5.1 | 5.0 | 131 | | UCAC4 646-025365 | | 0.95 | 3200 | Phaethon | 0.33 | ±0.00 | 65 | 31 | § | 5 10 38.671 | 39 4 40.52 |
| Nov 17 | 9 14.9 | 5.0 | 0.007 | 0.24s | 13.4 | 3.3 | 3.6 | 158 | | UCAC4 647-018191 | | 1.70 | 3200 | Phaethon | 0.02 | ±0.00 | 14 | 97 | § | 4 16 21.394 | 39 13 9.36 |
| Dec 8 | 8 16.7 | 5.0 | 0.008 | 0.22s | 12.6 | 3.7 | 3.8 | 151 | | TYC 2334-00386-1 | | 1.10 | 3200 | Phaethon | 0.22 | ±0.00 | 70 | 47 | § | 2 57 36.488 | 34 3 38.05 |
| Dec 22 | 8 12.9 | 4.9 | 0.007 | 0.25s | 9.4 | 7.2 | 7.1 | 129 | | TYC 1764-00040-1 | s | 0.95 | 3200 | Phaethon | 0.03 | ±0.00 | 132 | 56 | § | 2 13 34.555 | 27 56 39.58 |

*Figure 6. Best 2024 NEA occultations across North America. (D. Dunham, Occult V4.2023.7.9)*

**David Dunham** then presented a talk about "*Trojans, Centaurs, KBO's and Main Belt Asteroids with Moons*." He showed maps of occultations of distant objects for the rest of 2023 in N. America: Titania, (19521) Chaos, (468861) 2013 LU28, (50000) Quaoar and Weywot, (54598) Bienor and Titan. Then he showed events of Trojan asteroids (at Jupiter's $L_4$ & $L_5$ Lagrangian points) for the rest of 2023 in N. America. SwRI has a page [9] showing *Lucy* mission targets and their paths over N. America for 2023. David showed more predictions by special main-belt asteroids for 2024 that will appear in the 2024 RASC Handbook. After showing several more important occultation events, he closed with a map of the best Lunar Grazing events for 2023 over N. America.

**David Dunham** next presented a talk about the upcoming "*319 Leona Asteroid Occultation of Betelgeuse on December 12, 2023*." Betelgeuse is the brightest star to date with the most likelihood of having its occultation visible. The path of this event is visible from South Florida across the Atlantic Ocean through southern Europe. Asteroid (319) Leona and Betelgeuse are nearly the same size so the star will fade and have a possible 50%-80% drop in brightness. This can be an unprecedented opportunity to have an "annular type" eclipse of Betelgeuse. (319) Leona's long rotation period of 430 ± 2 hours complicates determining its size and shape.

David showed detailed maps of the path over South Florida and Europe. On 2023 August 27, there is an occultation of (319) Leona over N. America. Observers are encouraged to try this one to help pin down (319) Leona's size. This Betelgeuse event might be recorded by DSLRs using a smart phone timing app. David encouraged this event to be observed by astronomy clubs, college and advanced high school students near the path to introduce them to occultation observations and their scientific value.

**Mike Skrutskie** presented his talk on "*Automated Observations from a Fixed Site Using SharpCap Sequencing*." *SharpCap* [10] is a "free" *Windows* application that can be adapted with integrating cameras. Mike mentioned that one must pay a $15 fee to unlock the Pro features to be used. The basic recipe for starting to record an event is to:

1) Turn on the telescope
2) Slew to the target
3) Use *SharpCap* to platesolve and sync
4) Slew to target and platesolve again to get pointing to approx. 1 arcminute precision
5) Wait until event time
6) Set integration time
7) Capture required no. of frames

With this method, Mike can do multiple events in a single night from a single location. Mike listed the required hardware/software components to make the system work which includes a go-to mount, *ASCOM* focuser, platesolving software (plus their databases) and a *SharpCap* compatible camera and a data acquisition computer with remote desktop software. Mike then showed a sample script and described how the sequence works step by step.

Mike does searches using *Occult V4* [11] typically 3 days in advance for events he'll try. For a typical night he might have a list of 30 events to choose from. So how does the system fare? From his patio, Mike has been averaging 1 positive occultation event/week or about 50/year, this with an 8" telescope. He recently acquired a 16" telescope and may be able to double these numbers. Not too shabby!

Vice President **Roger Venable** presented the upcoming "*704 Interamnia Campaign on September 13, 2023.*" The purpose of this campaign is *not* just to obtain shape and size data about (704) Interamnia. Roger showed a map of the path of the 340 km sized (704) Interamnia. The path goes from southern California, central Arizona all the way to the northeast USA. The conditions are favourable for this event: The target star is bright at mag 9.0, pathwidth 340 km ± 37 km, magnitude drop = 2.7, maximum duration of 17.3 seconds, high altitude of the target star and the Moon just 3% illuminated. The rationale for the campaign is that such an easy bright star event will enable observers to concentrate on the mobile aspects of observing rather than on the difficulties of the event. It is hoped that observers who have never made a mobile observation will see this as an opportunity to try their first mobile observation. He encouraged observers to save the date. The path is wide enough so chord duplication is not a problem, nevertheless contact Roger is you plan to observe so he can assign you one or more chords.

**Dave Herald** showed how using *Google Earth* in conjunction with *Occult V4* can create fence lines at any separation one chooses. This can greatly simplify the spacing and assignment of observers both at fixed and mobile sites.

The Meeting formerly ended at 2:05 UT, July 16th.

## Sunday 16th July 2022 - Day 2

### Technical Sessions

**Mitsuru Soma,** Vice President for Grazing Occultation Services started the meeting with a talk about "*Lunar Grazing Observations.*" M. Soma talked about important results from analyses of observations of lunar grazing occultations from 2021-2023. The ZC 2061 graze on 2022 January 25 was observed by M. Ishida and H. Yamamura in Japan. Their observations clearly showed that the star is double, and the relative positions of the star's components were obtained from their observations (Figure 7). Actually the star's duplicity had already been detected in 2014 by D. Gault and D. Herald in Australia through their lunar occultation observations. It turned out that the newly-obtained results about the relative positions (separation and position angle) are significantly different from those obtained in 2014. The ZC 1049 graze on 2021 September 2 was observed by J. Bourgeois and B. Goffin in Belgium. They found that the star is a new double star. The ZC 709 graze on 2021 September 27 was observed at two stations by B. Gährken in Italy and at one station by M. Turchenko in Russia. B. Gährken also detected the star's companion at his first station. For all of the three events mentioned here it was found that significant corrections to the positions of the stars in *Gaia* DR3 were also required (Figure 8). This demonstrates the importance of observations of lunar grazing occultations not only to find double stars but also to analyse positional errors.

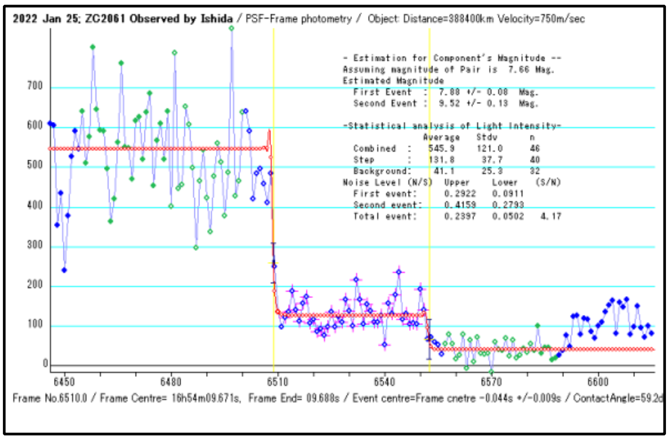



*Figure 7. Light curve from Limovie [12] of the first disappearance of the main and secondary component of ZC 2061, observed by M. Ishida on 2022 January 25.*

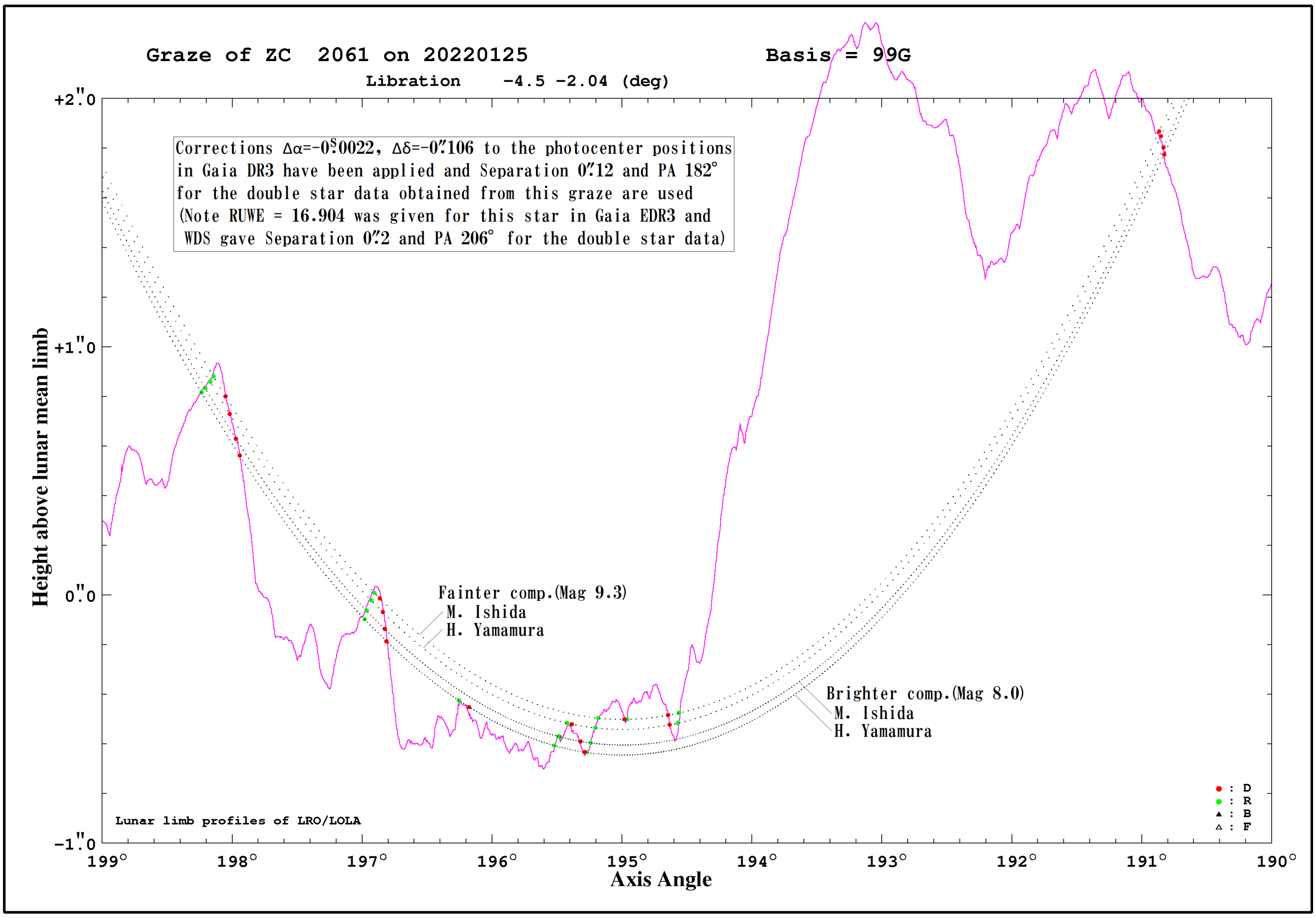



*Figure 8. Observations of the graze of ZC 2061 fitted to the lunar limb profile. The graze was observed by M. Ishida and H. Yamamura on 2022 January 25 in Japan.*

**Fumi Yoshida** discussed the new occultation observing organisation, the International Occultation Timing Association East Asia (IOTA/EA), in East Asia. This organisation will be officially launched with its inaugural meeting on 2023 August 27. IOTA/EA is a joint organisation of professional and amateur astronomers. It consists of core members, regional directors, and a large number of members who are officially registered after the inaugural meeting. The organisation of IOTA/EA was planned mainly by Japanese members. The reason was a request from the *DESTINY+* mission ((3200) Phaethon's flyby mission) for Japanese occultation observers to perform an occultation observation of (3200) Phaethon. The *DESTINY+* mission needed to know the exact size of (3200) Phaethon and create a 3D shape model in order to carry out the mission. A joint professional/amateur team was organized to observe the occultation of (3200) Phaethon. The unity of professionals and amateurs at this time was the motivation for the creation of IOTA/EA.

Some examples of international occultation observations in which Japanese observers have participated can be found in [13, 14].

Joint professional and amateur observing teams have been formed several times and the following observations have been made: stellar occultation of Triton on 2022 October 6, stellar occultation of (3200) Phaethon on 2022 October 21 (for *DESTINY+*), stellar occultation of (65083) Didymos in October - November 2022 (for *DART*) and for the stellar occultation of (98943) 2001 CC21 in January - March (for *Hayabusa2*).

Now Japanese observers can observe occultation events with durations as short as 0.1 seconds, the brightness of the occulted object < 11-12 mag. There are many amateur astronomers in Japan who have made occultation observations. Since 1995, they have been accumulating their expertise in occultation observation by exchanging information through a mailing list called JOIN. In JOIN, occultation observers collect observation results and data analysis experience, and also study to improve observation and analysis techniques.

While JOIN is a group of individual observers, IOTA/EA will disseminate and share the knowledge and experience accumulated by JOIN and expand the number of occultation observers.

IOTA/EA also cooperates with neighbouring countries and aims to become an organisation that can collaborate on planetary exploration missions and scientific observations by researchers. IOTA/EA will do the following: Provide predictions of occultation events observable in East Asia, submit observation reports to the IOTA, then IAU and create data archives (light curves, AVI files, etc.). IOTA/EA will initiate observing campaigns for important objects and conduct workshops to train beginners in observation/analysis methods and tools, distribute observing manuals and publish its activities on the web, so that the activities of IOTA/EA are known to occultation observers around the world.

IOTA/EA will carry out occultation observations associated with planetary exploration missions and scientific observations proposed by researchers. In 2023, IOTA/EA's observing plan includes (155140) 2005 UD, a candidate for the second *DESTINY+* flyby target, and outer objects such as TNO and Trojans, with the aim of discovering rings and satellites. Since there is no common language in East Asia, it is difficult to share information. Therefore, they have appointed Regional Directors in major countries/regions. The role of the Regional Directors is to communicate the information provided by IOTA/EA (written in English) to observers in the countries/regions, in a language that local observers can understand, and to help communicate reports and questions from observers to IOTA/EA. IOTA/EA will help them to communicate their reports and questions to IOTA/EA. In other words, the Regional Directors act as a liaison between IOTA/EA and the observers in each region where the Director resides. IOTA/EA currently has regional directors in mainland China, Hong Kong, and Taiwan, and hoping to extend this observation network to our friends in the Southeast/Central Asia regions in the near future. With the establishment of IOTA/EA, they would like to contribute to occultation observations in the East Asia region in close cooperation with IOTA. The IOTA/EA webpage can be accessed at [15].

**Joan Dunham** presented this year's IOTA outreach at the annual North East Astronomy Forum (NEAF) and other meetings. One problem is how can IOTA find new observers and how effective are our methods? Roxanne Kamin gave the IOTA presentation on chasing tiny shadows. IOTA's NEAF booth received lots of visitors. Joan mentioned for potential new IOTA members that in-person meetings can be expensive, meeting info may not be disseminated and online meetings are time-consuming.

The Asteroid, Comets and Meteors conference was in Arizona 2023 June 18-23. There were multiple presentations including recognizing occultation work by observers. An advantage of an in-person meeting is the face to face interactions with scientists from around the world. This conference does not make the presentations available nor are there conference proceedings published. The *Gaia* team highlighted the (4337) Arecibo satellite discovery by the two occultations in May and June 2021.

At the conference, SwRI gave talks about the *Lucy* mission targets. One target is the asteroid (15094) Polymele in which Tony George's observation in March 2022 and light curve indicated a possible moon. Marc Buie mentioned that he has a Sky and Telescope article for the September 2023 issue on occultations and the *Lucy* mission targets. Joel Castro had a poster presentation on "The Mexican Network for Stellar Occultations: A Professional and Citizen Science Collaboration." And the Minor Planet Center (MPC) announced major upgrades to manage their data volumes. Joan also mentioned they have started a monthly newsletter to communicate with their users as well as the general public.

**Kevin Green** spoke about a "*Possible Adelheid moonlet and Other Upcoming Events*." The (276) Adelheid occultation of 2022 August 31 yielded a possible moon, this observation Kevin made (Figure 9). He showed the orientation of (276) Adelheid at the time of the occultation. He showed an animation using the shape model of (276) Adelheid's 6.4 hour light curve - it was fairly consistent with very little light variation. The estimates of the moon's probability of detection during an occultation was 400 to 1 - so he was quite lucky. With an estimated mass he postulated a 1.8 day orbital period for such a moon around (276) Adelheid. With 15 previous occultations, no light curves showed evidence of a satellite. The shape models matched quite well with the light curves with only minor disagreement.

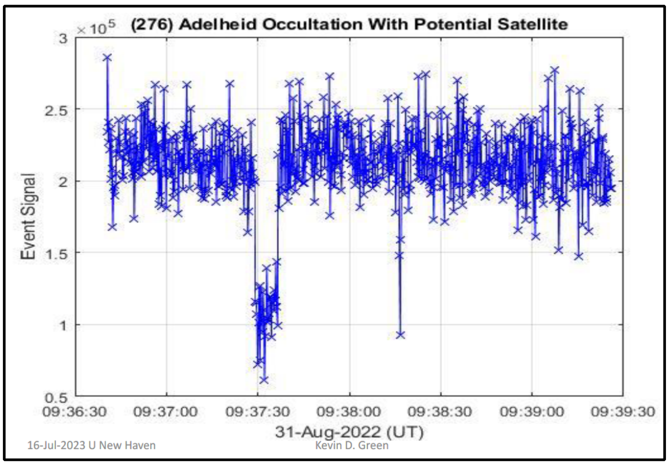



*Figure 9. The light curve from the occultation by asteroid (276) Adelheid shows about 40 s after the reappearance of the star a second event with a duration of 0.75 s. The occultation was recorded by Kevin Green on 2022 August 31.*

Kevin showed upcoming maps of future (276) Adelheid events in USA including 2023 September 23 (near where he lives) along with an estimated orientation of (276) Adelheid's rotational axis. He is currently trying to recruit observers for this September 2023 event.

**Kevin Green**'s next talk was about "*Stellar Multiplicity & Asteroidal Occultations*". The basic question is how many stars are multiple systems? Kevin showed a graph showing it depends on the star size. It is estimated that half of all stars belong to multiple systems. A possible double star occultation will occur 2023 September 13 by the asteroid (256) Walpurga.

**Dave Herald** talked about "*What Happens to an Observation after Submission*". Observations are first sent to the Regional Coordinators (Australasia, Europe, USA, Japan, South America, Unistellar) They consolidate all the observations, identify and try to resolve problems, fit an ellipse to observations and shape models, initiate double star analysis, asteroid satellite analysis and coordinate with other coordinators when the event crosses other regions. Following analysis, the events are sent to the Global coordinator (Dave) in batches of 10 events. Dave then begins a quality assurance process: he closely reviews the analysis of shape model fitting, double star solutions, possible satellite discoveries. If an observation appears to have a hidden problem, further analysis and questions arise. The Unistellar telescopes observers are now entering the field and these folks are now submitting observations. Dave then showed a table from *Occult* showing asteroid diameters with uncertainties from shape model fitting (DAMIT, ISAM).

For determining size and shape of asteroids, we need multiple chords. Currently, most observations are single person/single chord observations. Shape model investigators need occultation chords to improve models. While shape models can give shape, occultation observations give size. More studies are used in combination with mass measurements from orbital perturbations to derive densities of some asteroids.

After submitting observations to the MPC for years, in 2019 - 2023 they were put on hold. A serious review began detailing an error model with assistance from JPL Horizons. MPC has been developing a new reporting system using the standard Astrometry Data Exchange Standard (ADES). A new MPC observatory code has been assigned for occultations - 275. For some special events, there is direct reporting to JPL Horizons with rapid orbit updates as needed especially for predictions for future spacecraft encounters. Dave showed an ADES sample page for submission of data. An example of the high credibility of our observations came with 14 (65083) Didymos occultations through 2023 January 22 as compared to the *DART* OpNavs and radar measurements.

For double star discoveries, they will only be added to the WDS by publication in a recognised journal such as the Journal of Double Star Observations (JDSO). Since the regional coordinators don't have the time to write the papers, Dave suggested a standard *pro-forma* (template) paper which would enable observers to easily prepare a paper for submission to JDSO. Dave next discussed archiving with NASA's PDS system. The current archive has been paused for several years. The next archive is ready to be submitted. There is a tremendous amount data for each event - 260 columns of data, with each observer for each event has 42 columns of data. Currently there is more than 36,000 rows of data and each field needs a description of the data! Dave asked for assistance for the descriptions as this is a huge task!

**Mark Simpson** discussed the Raspberry Pi timing device: ASTRID - NextGen OTE: It represents the development of a standardised digital camera, timing and mount control system based on a Raspberry Pi. The tightly integrated system includes a Mono Global Shutter Camera, highly precise frame timing, timing audit trail, GPS timing board, 12 Volt Power complete with Plate Solving, Goto and Polar Align. ASTRID also doubles up as an astrophotography camera when not being used for occultations. Mark demonstrated an occultation acquisition including plate solving, focusing, and time stamping. He also detailed the design and features of ASTRID.

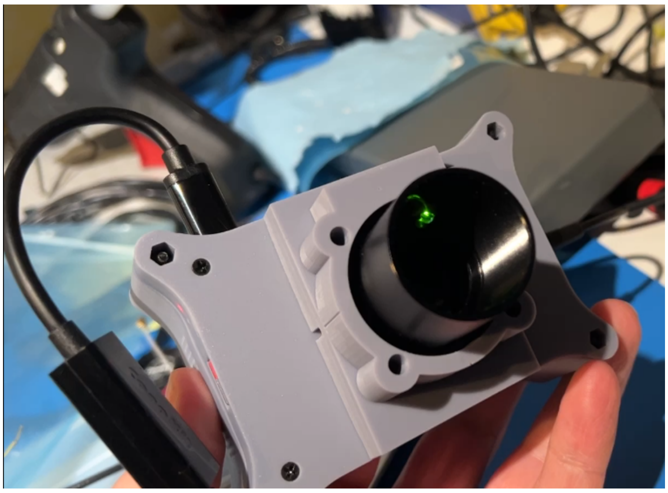


*Figure 10. Prototype of ASTRID. The green LED for verification of the timing is visible in the 1 1/4" nose piece.*

**Bob Anderson** spoke about "*Methods for Improving Light Curve Extractions from Videos*." He elaborated on the tried-and-true technique for extracting improved light curves from occultation videos – "measure many ways; pick the best". Three extraction methods were described and illustrated using real-life case studies. The controversial problem of determining the "best" was discussed at length. During that discussion it was proposed that edge-time uncertainty (time error bar value) should be the primary metric in selecting the light curve for reporting.

**Bob Anderson** continued with his talk about "*A Set of Calibrated Video Files for Evaluating Light Curve Extractions*." In this presentation, Bob announced the public availability of a suite of test videos useful for testing light curve extraction programs. The videos are calibrated in the sense that the underlying light curves are known and so can be compared with the 'answer' produced by programs like *PyMovie*. The videos are synthetic because they are the result of simulations of the major factors present in real-life occultation recordings: shot noise; scintillation noise; high and low altitude turbulences; telescope/ optics; camera characteristics. The talk included a slide for each of the underlying light curves available in the test suite and concluded with a link to the files [16].

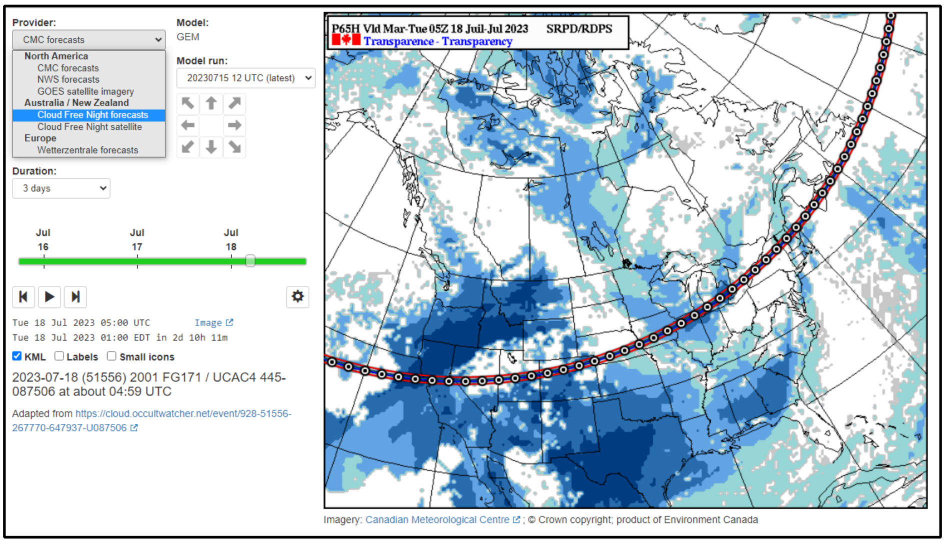



*Figure 11. Screenshot of the OccuWeather tool developed by Kai Getrost. The cloud maps could be chosen from different providers.*

**Kai Getrost** next discussed a Weather Forecaster for Occultations: "*OccuWeather - A Tool to Aid Occultation Weather Planning*." A typical occultation plan includes looking at several online weather cloud forecast maps. The problem is these weather maps don't have the occultation paths - one must mentally recall the occultation path while looking at the cloud forecast map. Kai created a website (currently under construction) for cloud forecasting [17]. Kai integrated the *Google* KML files to overlay the occultation paths on the cloud maps. Both graphical forecasts and satellite imagery are supported. The website currently has several time-lapse cloud cover maps with the occultation paths overlaid on them for North America, Australia/NZ and Europe (Figure 11).

Right now, Kai has to enter each occultation event map manually which only takes a minute.

Kai's future work will include:

- Automatically set the forecast to the predicted event time -The goal here is not having to "do the math" every time one is checking the weather, e.g. not having to select "+72 hours" when checking 3 days before the event, then "+48 hours" when checking 2 days before, etc.
- Clicking on the map to get lat/long at any point
- Mobile/ tablet support
- Possibly integrate with *Occult Watcher Cloud* [18].

The meeting ended at 01:50 UT, July 17th.

## References

[1] Agenda on IOTA Meeting 2023 https://occultations.org/community/meetingsconferences/na/2023-iota/

[2] Playlist of recordings of IOTA Meeting 2023 https://www.youtube.com/playlist?list=PLPYvLiLF-6zsVP4-tFsbsalAQWEaxYW-a

[3] IOTA's Business Meeting 2023 https://www.poyntsource.com/Richard/IOTAMeeting2023.htm

[4] https://www.asteroidoccultations.com/observations/Awards/IOTA Awards.htm

[5] Journal of Double Star Observations, http://www.jdso.org

[6] Washington Double Star Catalog, http://www.astro.gsu.edu/wds/

[7] http://www.poyntsource.com/Richard/IOTAMeeting2019.htm

[8] https://occultations.org/publications/rasc/2023/ACM2023.htm

[9] Lucy mission targets, SwRI, https://lucy.swri.edu/mission/Targets.html

[10] Glover, R., SharpCap, https://www.sharpcap.co.uk/

[11] Herald, D., Occult V4 software, http://lunar-occultations.com/iota/occult4.htm

[12] Miyashita, K., Limovie software, https://astro-limovie.info/limovie/limovie_en.html

[13] https://academic.oup.com/pasj/article/75/1/153/6947807

[14] https://www.esa.int/Enabling_Support/Space_Engineering_Technology/Shadow_hunters_capture_Didymos_asteroid_eclipsing_stars

[15] IOTA/EA web page, https://www.perc.it-chiba.ac.jp/iota-ea/wp/

[16] Anderson, B., PyMovie software, https://occultations.org/observing/software/pymovie/

[17] Getrost, K., Occuweather, https://occuweather.info/

[18] Pavlov, H., Occult Watcher Cloud, https://cloud.occultwatcher.net/

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## 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.

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## Imprint

Publisher: International Occultation Timing Association/European Section e.V.
Am Brombeerhag 13, D-30459 Hannover, Germany
Responsible in Terms of the German Press Law (V.i.S.d.P.): Konrad Guhl
Editorial Board: Wolfgang Beisker, Oliver Klös, Alexander Pratt, Carles Schnabel, Christian Weber
Additional Reviewers: Richard Miles
Contact: joa@iota-es.de
Layout Artist: Oliver Klös
Webmaster: Wolfgang Beisker
JOA Is Funded by Membership Fees (Year): IOTA: US$15.00 IOTA/ES: €20.00 RASNZ: NZ$35.00
Publication Dates: 4 times a year

## Submission Deadline for JOA 2024-1: November 15


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

**www.occultations.org**
**www.iota-es.de**
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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, East Asia, 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.

**Journal for Occultation Astronomy**
(ISSN 0737-6766) is published quarterly in the USA by the International Occultation Timing Association, Inc. (IOTA)
PO Box 20313, Fountain Hills, AZ 85269-0313
IOTA is a tax-exempt organization under sections 501(c)(3) and 509(a)(2) of the Internal Revenue Code USA, and is incorporated in the state of Texas. Copies are distributed electronically.

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