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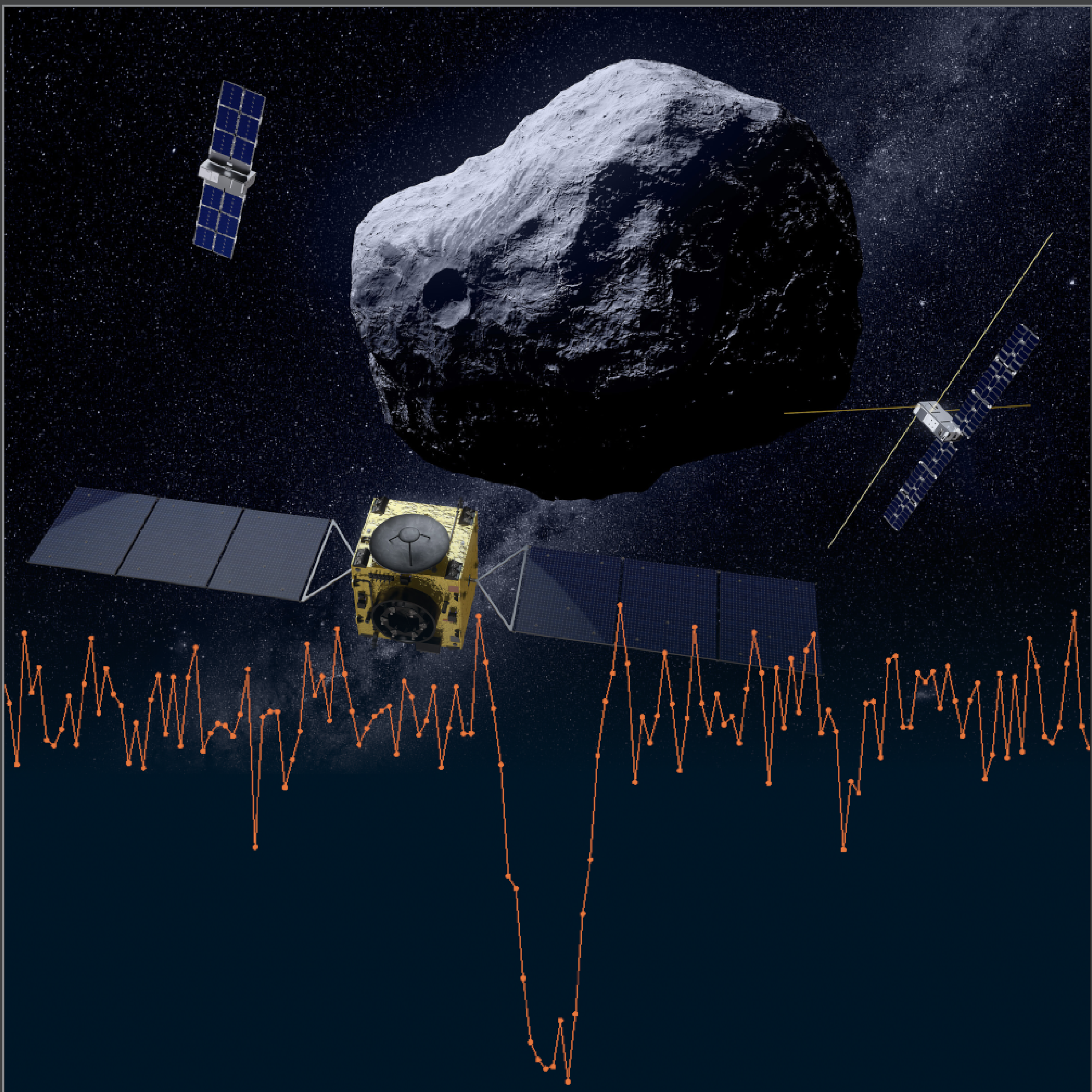

Supporting the Hera Mission with Occultation Observations

Dear reader,

In this first JOA of 2025, the 42nd IOTA meeting report illustrates the breadth and quality of the occultation work undertaken by our community, observing the smallest and largest minor planets from NEOs to TNOs, using the latest hardware and software.

In 'The Hunt for Didymos', experienced observer John Broughton describes the extent of commitment and planning involved in his impressive solo expedition into the Australian outback to set up multiple stations to obtain chords across this binary asteroid.

Damya Souami makes a 'Call for Observations' of the trans-Neptunian object?/Centaur? (468861) 2013 LU_{28} continuing our pro-am collaborations by our networks of observers.

At ESOP in Stuttgart, Eberhard Riedel explained the value of observations of lunar occultations, and here he presents the new features of his GRAZPREP software and accompanying worldwide plots of grazing occultations by stars and planets in 2025.

We owe so much to the high-quality *Gaia* space observatory and the Data Releases from the Data Consortium (through to 2030). Sadly, *Gaia* will cease operations in early 2025, but amateurs are asked to contribute photometry of the craft before it is decommissioned into its retirement orbit. To paraphrase the CAPCOM as *Apollo 13* jettisoned the lunar module 'lifeboat' – "*Farewell, Gaia – and we thank you!*".

Alex Pratt
IOTA/ES

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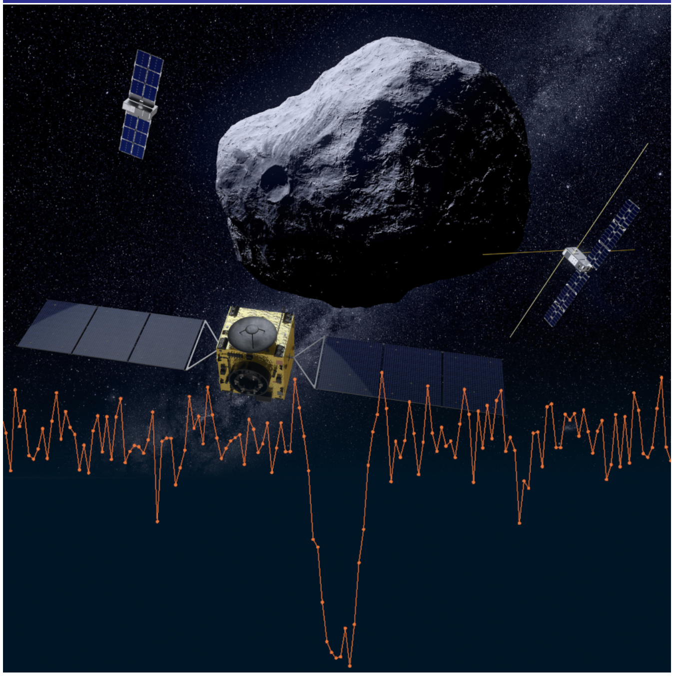
In this Issue:

COVER



The cover shows an artist's impression of *Hera* and its two CubeSats approaching asteroid (65803) Didymos. The lightcurve of an occultation by Didymos on 2024 August 13 was recorded by J. Broughton in Australia. He reports about his extraordinary observation in this issue of JOA on pages 7-15.
(Credits: graphic: ESA/Science Office, lightcurve: J. Broughton, image editing: O. Klös)

Rules for Authors

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

Journal for Occultation Astronomy

CALL FOR OBSERVATIONS:

Trans-Neptunian Object? / Centaur? – Occultations by (468861)2013 LU_{28} in 2025

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ABSTRACT: (468861) 2013 LU_{28} is a fascinating and intriguing object from the dynamical standpoint, with a semi-major axis of ~183.4 AU, an inclination with respect to the ecliptic of ~125.3°, and an eccentricity of ~0.954. There is not much that we know about this object, thus any occultation opportunity must be seized to constrain its size, shape, and improve the orbital solution before we move to other types of observations such as spectroscopy with large telescopes, possibly thermal observations, etc. This paper gives three predictions of upcoming occultations in 2025.

Introduction

The powerful method of stellar occultations is a technique uniquely approaching the performances of planetary space missions. For remote objects such as 2013 LU_{28} stellar occultations are by far the best method we have to determine its size and shape at km-level accuracy, and provide high accuracy astrometry to help better constrain the orbital solution.

We present here a list of the best opportunities to observe occultations by this dynamically fascinating TNO/Centaur, which is sometimes classified as a Damocloid. (468861) 2013 LU_{28} was discovered on 2013 June 8 with the Mount Lemmon Survey at the *Mount Lemmon Observatory* in Arizona. It was at its perihelion on 2024 June 20 at ~8.7 AU. We have been chasing occultation opportunities by (468861) 2013 LU_{28} for about four years, and the year 2025 is an opportunity for good, slow, and accessible events.

This paper is meant to alert the community about the best upcoming opportunities for the year 2025. The attached maps use the Lucky Star NIMAv10 [1]. Based on the given absolute magnitudes from the literature [2], we assume in our prediction a diameter in the range of 100 - 150 km.

In December 2024, there were a few occultation opportunities that are summarised in Table 1 [3,4].

(Editor JOA: No observations were reported of the Dec 17 occultation, the event on Dec 29 took place after the editorial deadline.)

Predictions for the 2025 events will be updated closer to the events' dates with new astrometry as well as data from successful occultations. We will be sending out reminders to the mailing lists and updates closer to each event.

Very High Priority Events

The Best Event:
A trans-Atlantic one, on 2025 Jan 30, at~01:52 UT

This is the very best event we have identified for 2025. We invite everyone in the geographic region covering the 3σ uncertainty region to attempt the event on this night. Past experiences involving trans-Atlantic events have resulted in tremendous success, and we invite observers on both sides of the pond to join the adventure. The star is relatively bright, 12.0 in G mag., and the maximum expected duration is about 2.8 s. Therefore, we expect that achieving an SNR of at least 7 can be achieved by most observers. Figures 1 and 2 show the geographic regions from which the event is observable. The blue lines show the predicted shadow path, and the red dashed lines delimit the 1σ uncertainty area. The same colour code is used throughout this paper for all maps. Table 2 contains a summary of the circumstances of the event, more information can be found on the Lucky Star event page [5].

Event Date and Time (UT)	Stellar G Magnitude	Geographic Region	Max. Expected Duration (s)
2024 Dec 17 21:57	15.7	Europe	2.8
2024 Dec 29 11:17	13.7	Mexico, Southern USA	2.7

Table 1. A selection of two events that were attempted in Dec 2024 and from which we could expect orbital updates for the following 2025 events. The table gives the date, UT time of the event, the maximum expected duration, the Gaia G-magnitude, the geographic region from where the events were observable, as well as the maximum expected durations.

The Star (from Gaia DR3)	**Interactive Sky Chart**
Gaia ID	940752284849363072
G, BP, and RP mag.	12.0, 12.4, 11.5
RUWE / Duplicity	1.03 / False
Star Position (ICRF)	06 57 35.6965 +36 31 56.132

The Event	
Epoch	2025-01-30 ~01:52 UT
Max. Duration	2.8 s
Max. mag. Drop	6.0

Table 2. Circumstances associated with the occultation on Figure 1.

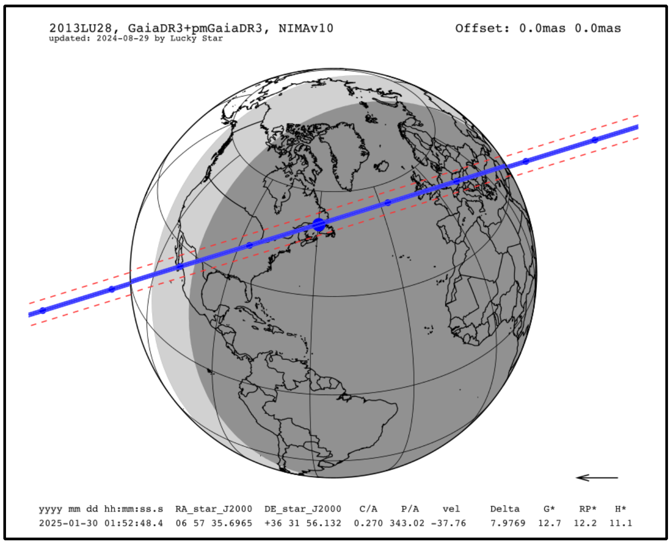

Figure 1. Lucky Star prediction of the 2025 Jan 30 event. Updated on 2024 Aug 29.

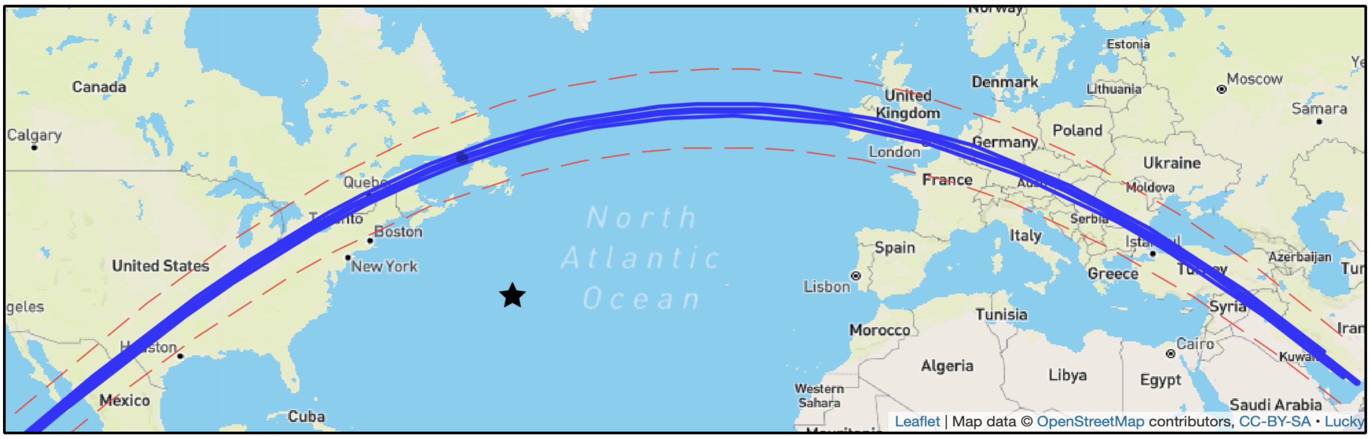

Figure 2. Zoom onto the projected path from Figure 1, showing the areas of interest on both sides of the Atlantic for the 2025 Jan 30 event.

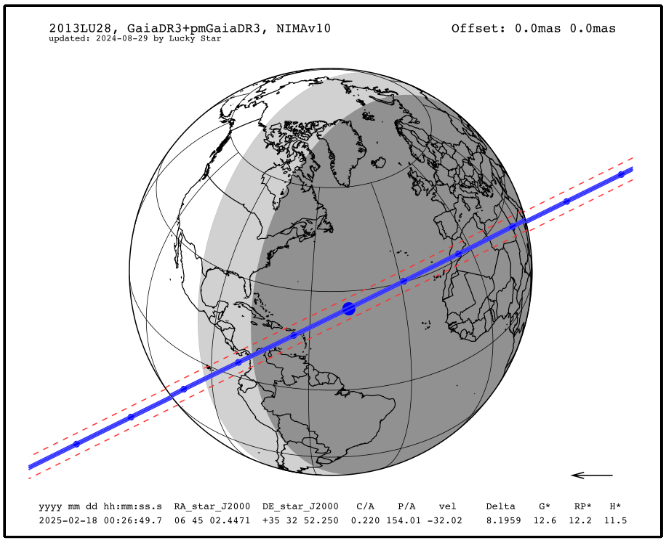

Figure 3. Lucky Star prediction of the 2025 Feb 18 event. Updated on 2024 Aug 29.

The Second Best Event, on 2025 Feb 18, ~ 00:26 UT

We expect a huge improvement in the prediction for the event after that of Jan 30th. We therefore invite you to check the Lucky Star website a few days before the event. Moreover, updates will be sent to the Planoccult mailing list.

While there are very few experienced and equipped observers in these regions, the star is relatively bright, 12.1 mag., and the event is relatively slow with a maximum expected duration of 3.3 s.

The associated preliminary maps are shown in Figures 3 and 4, and Table 3 summarises the most relevant parameters for the event. More detailed information can be found on the Lucky Star event page [6].

The Star (from Gaia DR3)	Interactive Sky Chart
Gaia ID	938998529442368256
G, BP, and RP mag.	12.1, 12.4, 11.7
RUWE / Duplicity	0.85 / False
Star Position (ICRF)	06 45 02.4471 +35 32 52.250

The Event	
Epoch	2025-02-18 ~00:26 UT
Max. Duration	3.3 s
Max. mag. Drop	6.0

Table 3. Circumstances associated with the occultation on Figure 3.

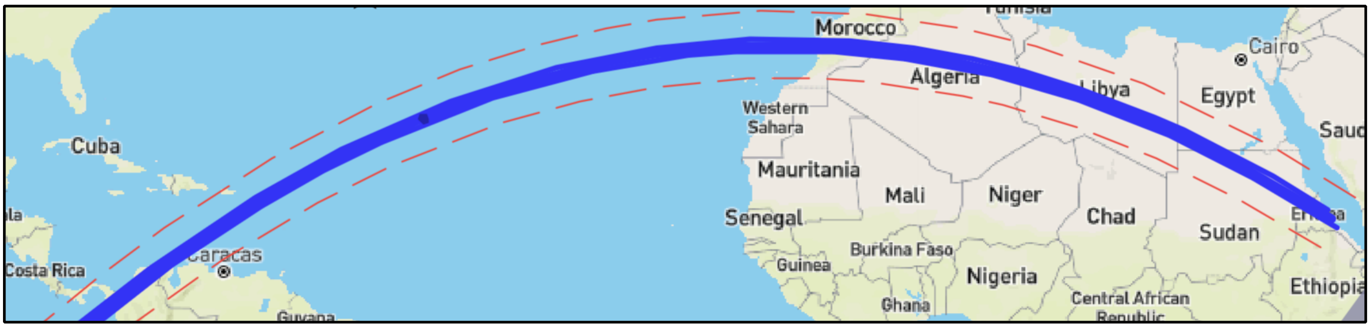

Figure 4. Zoom onto the projected path from Figure 3, showing the areas of interest on both sides of the Atlantic for the 2025 Feb 18 event.

The Third Best Event, on 2025 Mar 18, ~ 05:02 UT

The window of good events for the year 2025 will be closing with this occultation. While we are expecting an updated orbital solution for (468861) 2013 LU_{28} by March and therefore a refined prediction for the shadow path, the maps on Figures 5 are meant to alert observers about this interesting opportunity.

The current prediction (using *NIMAv10* version) crosses the United States from the North-eastern states to California. Moreover the shadow as predicted crosses southern Ontario.

Out of the three events mentioned in this paper, this is the event involving the faintest star (14.0 in G magnitude) and the longest expected duration (~5.0 s). While this event might seem challenging at first glance because of the faintness of the star, it can be compensated by using 12"+ telescopes to achieve good enough SNR (~7). Another advantage is that there are many experienced and well-equipped observers in the region (one could expect some detections with SNR>10).

The associated preliminary maps are shown in Figures 5 and 6, and Table 4 summarises the most relevant parameters for the event. More detailed information can be found on the Lucky Star event page [7].

Finally, in the case where the predicted path does not shift too much, there should be some large (metre-class) telescopes along or in the vicinity of the 1σ region.

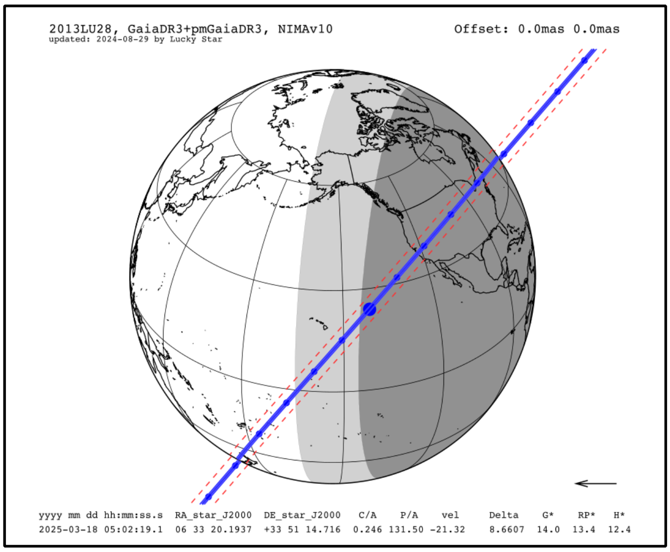

Figure 5. Lucky Star prediction of the 2025 Mar 18 event. Updated on 2024 Aug 29.

The Star (from Gaia DR3)	Interactive Sky Chart
Gaia ID	941378907694491776
G, BP, and RP mag.	14.0, 14.4, 13.4
RUWE / Duplicity	1.04 / False
Star Position (ICRF)	06 33 20.1937 +33 51 14.716

The Event	
Epoch	2025-03-18 ~05:02 UT
Max. Duration	5.0 s
Max. mag. Drop	4.4

Table 4. Circumstances associated with the occultation on Figure 5.

Figure 6. Zoom onto the projected path from Figure 5, showing the areas of interest on both for the 2025 Mar 18 event.

Concluding Remarks

Very little is known about (468861) 2023 LU_{28}. The one certainty we have, at the moment, is its fascinating dynamical behaviour, as it is on a retrograde, highly eccentric orbit. This paper presents the three best occultation events for the year 2025 (Jan 30, Feb 18, and Mar 18). This TNO/Centaur (?) was at perihelion in June 2024, it is now receding from us. While (468861) 2023 LU_{28} was observable from the northern hemisphere over the last few years, it is now moving fast towards the southern celestial hemisphere.

Updates will be made regularly to the prediction as we gather new astrometric data, and as we gather data from occultations. Please, monitor closely the Lucky Star website [8] and Lucky Star's feed on *Occult Watcher Cloud* for updates [9].

For these three events, we request that you record for a total of 20 minutes centred around the event mid-time predicted near your location.

Finally, in order to rapidly and efficiently update the predictions, and in order to keep track of everyone's participation for future scientific papers, we request that you submit, as early as possible, your original recordings (*.avi*, *.fits*, *.ser*, *etc.*), your reports, and any preliminary analysis you might have to our occultation portal [10]. To upload your data (original video or fits recordings) and reports, you should login to the occultation portal. If you do not have a login, you should create an account. Once logged in, find the event on the calendar, then click on it and follow the instructions.

Thank you in advance for your collaboration and your tremendous efforts!

Clear night skies to all!

Acknowledgements

This campaign is carried out under the "Lucky Star" umbrella, an EU-funded research activity that agglomerates the efforts of the Paris, Granada, and Rio teams. See Lucky Star web page for details [11].

References

[1] Lucky Star NIMAv10, https://lesia.obspm.fr/lucky-star/obj.php?p=1183
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[6] Occultation by 2013 LU28 (2025-02-18), ERC Lucky Star project, updated 2024-08-29 https://lesia.obspm.fr/lucky-star/occ.php?p=142910
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[9] Occultations predicted by the ERC Lucky Star project on OW Cloud, https://cloud.occultwatcher.net/events/tagged/LuckyStar
[10] Occultation Portal, https://occultation.trgozlemevleri.gov.tr
[11] Homepage of the ERC Lucky Star project, https://lesia.obspm.fr/lucky-star/

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The Hunt for Didymos

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ABSTRACT: Monitoring the effects of the 2022 DART mission impact on the heliocentric orbit of the Didymos binary asteroid system is highly dependent on mobile occultation observations. After an unfavourable 16-month period for recording these fleeting events, three occultations observed in 2024 were key to tracking down its location at the sub-kilometre level, providing the astrometry scientists needed to measure the post-collision Δv experienced by the system. Here I describe the equipment, time-saving strategies and results of a six-station deployment made in remote outback Queensland on 2024 August 13 and list prospective events.

The DART Mission

This well-conceived NASA mission with the cool acronym standing for 'Double Asteroid Redirection Test', was humanity's first attempt to trial one particular method for diverting near-Earth objects that happen to be on a collision course with Earth. The target was Dimorphos [1], a 170 metre wide rubble-pile moonlet of (65803) Didymos [2] that is not a threat to Earth in the foreseeable future. *DART* [3,4,5] intentionally slammed head on into Dimorphos on 2022 September 26 in order to reduce that body's orbital period around Didymos. It hit within a stone's throw of its aim point, 11 million kilometres from Earth. The impact produced an ejecta plume stretching 30,000 km long that contributed to a recoil in Dimorphos' momentum several times greater than that imparted by *DART*'s kinetic energy alone. As determined soon after from ground-based radar ranging and photometric observations of mutual transits and eclipses, there was a nearly 5% reduction in the orbital period of Dimorphos, moving it an accumulated distance of 200 km in the time since the impact. Another consequence of the impact was a change to its shape [6]. In addition, the change in orbital period means the rotation periods are no longer synchronised, leading to ongoing shape-changing tidal effects that could be affecting Didymos as well, if that is not a completely solid body.

Of importance to planetary defence, as well as navigating a follow-up mission, is how precisely did the collision affect the system's heliocentric orbit. That is proving to be a harder nut to crack.

The Importance of Occultation Observations

With Didymos being out of radar range most of the time, stellar occultations are the primary means available to detect minuscule changes in the orbit over a 4.25-year interval until the European Space Agency's *Hera* spacecraft [7,8] arrives there on 2026 December 28. That wouldn't be feasible without the extreme accuracy of the Gaia star catalogue [9] used nowadays for predictions. The object's small size (<1 km) and rapid apparent motion during the majority of its orbit means Didymos is an elusive and challenging target for mobile observation with small telescopes. The one saving grace however is its relatively small 3.4-degree orbital inclination limiting its apparent motion in ecliptic latitude. At two-year intervals when Didymos is near Earth and opposition, there are occasions when its relative velocity can drop to a few kilometres per second. Given the limitations associated with brief occultations observed on location, they become potentially observable when their durations exceed 100 ms and the star is brighter than V magnitude 13. Didymos is in the southern sky during these periods with Australasia being the most favourable region that is home to active occultation observers, albeit most being confined to coastal areas. Unlike Trojan asteroids to be visited by NASA's *Lucy* mission [10], no agency funding has been made available for Didymos expeditions in the region to provide equipment or encourage the long-distance travel necessary to reach the path of most occultation events. However, I became involved because of the folding alt-alt telescopes I developed over the past decade especially for unattended observation of asteroid occultations, enabling multiple deployments to be made at remote locations. The 25 cm reflectors are compact enough in their folded state that several can sit in a vehicle's passenger seat footwell. They were used to obtain 17 positive chords and five misses for one of *Lucy*'s mission targets; the Trojan binary asteroid pair (617) Patroclus and Menoetius [11], largely during a Marc Buie-led expedition to the Northern Territory in July 2022, and a self-funded one to northwestern Queensland in September 2023. The findings are yet to be published.

Post-Impact Observations

Before anyone had succeeded in observing a Didymos occultation, my first attempt involved a star of magnitude 11.4 and a maximum duration of 0.14 s on 2022 September 22, a few days prior to *DART* hitting its target. Unsurprisingly, given the orbital uncertainty at the time, none of my six stations deployed along a 4.3 km stretch of highway in western Queensland produced positive results. However, improved path predictions after impact enabled IOTA's Roger Venable and others to make the breakthrough observations on 2022 October 15 [12], leading to the orbit being refined and the acquisition of more observations until that observational window closed in early 2023. No reliable detections came to light over the following 16 months for scientists to test their models about how the orbit was affected by the impact and whether it was evolving.

2024 Opposition Recovery

The next observational window opened on 2024 May 5, with a mag. 12.5 occultation lasting up to 0.19 s passing through Melbourne, Australia. Several people were involved but only US astronomer Mike Skrutskie (coincidentally in Melbourne on other business at the time) managed to record the star from two locations using 12" SCTs on loan from a local university. He set them up in an inner-city park just one kilometre from accommodation he'd booked before he even knew about the event. A short drop in light appeared in one lightcurve and the other revealed a miss. There was concern at JPL about the reliability of that detection, given its larger than expected difference from prediction, so the JPL#209 orbit being used at the time was not updated.

Two 11th magnitude occultations lasting 0.10 s occurred on 2024 July 12. Roger Venable observing from Georgia, USA, recorded a miss from the centre and a few hours later I recorded a miss near Gladstone, Australia, 200 m south of centre. Clearly, there was a problem with current predictions. Subsequently, JPL scientists integrated the May 5 astrometry into their orbit solution, taking account of the Yarkovsky effect [13] and a theoretical variable called Beta for modelling the effect of ejecta that had escaped the system. The result was a path shift to the south of at least 500 m that placed both July 12 miss chords outside the northern limit.

The Main Event

By far the most favourable Didymos occultation occurring between the *DART* and *Hera* mission arrivals, was due on the evening of 2024 August 13 in my home state of Queensland. It not only had a long duration but was relatively bright at visual magnitude 9.9 [14]. The path crossed Queensland's east coast heading toward inaccessible desert regions of central Australia.

Our original plan was for myself from the Gold Coast and TTOA [15] chairman Steve Kerr of Rockhampton to drive to the coastal region of Gladstone, as it was the least travel distance for both of us. That plan went out the window several days in advance on the certainty that a major weather system heading our way would deliver unseasonably heavy and widespread rain at the worst possible time. There was a chance, however, that western Queensland might be far enough away to remain dry, so I searched major roads in the region that had *StreetView* coverage and found an ideal location an hour northwest of Quilpie, about 14 hours drive from home.

Figure 1 is a diagram for the time of the occultation by Jet Propulsion Laboratory scientist Steve Chesley showing Didymos as a blue ellipse. The black ellipse represents Dimorphos' nominal orbit around Didymos and its estimated position along that orbit is shown in red. The scatter of blue ellipses at left represents where Didymos had shifted to relative to the then current Horizons Didymos #209 orbit solution after the May 5 result had been taken into account.

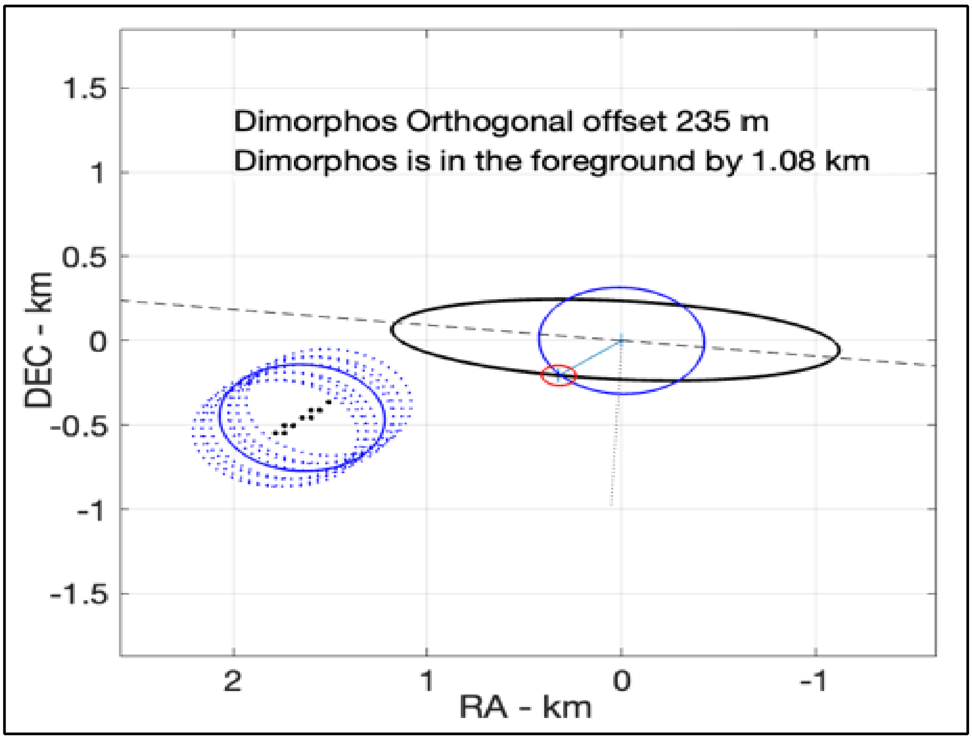

Figure 1. Plot of the Didymos system on the sky plane for 2024 August 13.5. Credit: Steve Chesley, JPL.

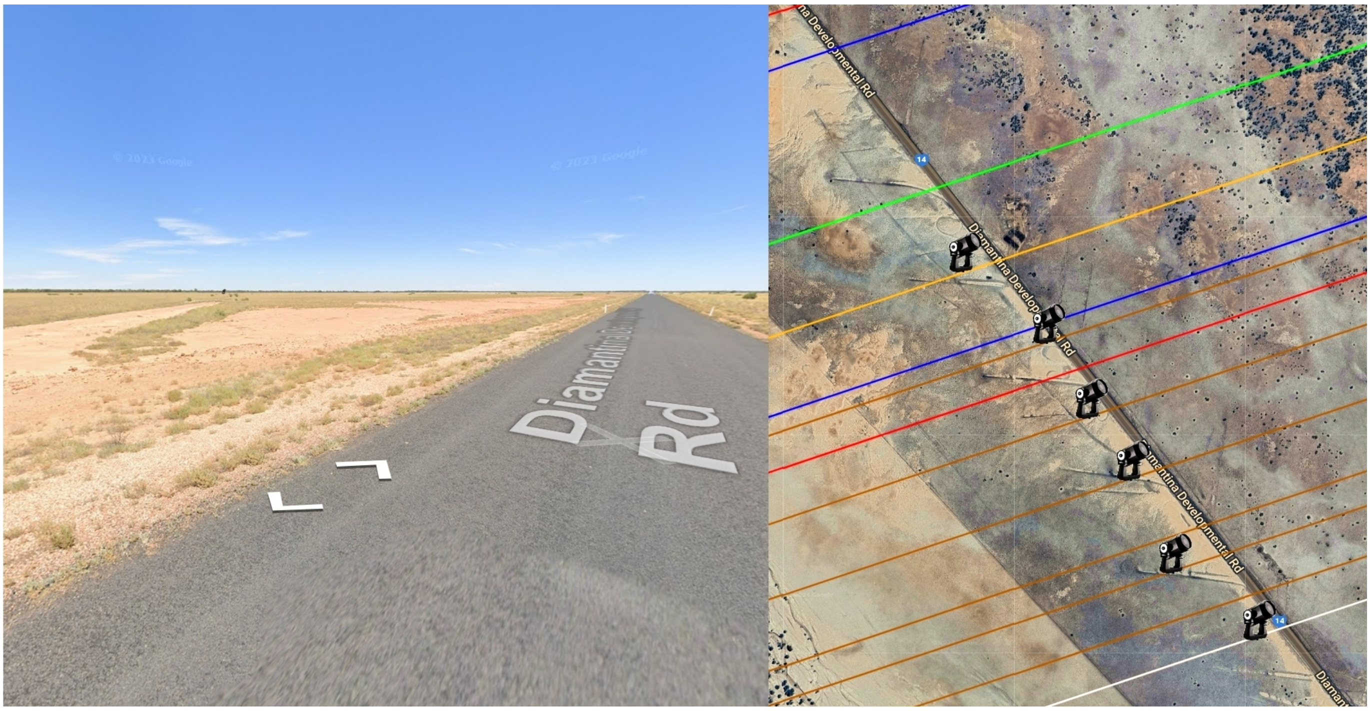

Figure 2. August 13 observing sites. The central line for Horizons' Didymos orbit #209 is in green.
Credit: Google Earth and Occult Watcher.

I planned my stations to well and truly cover this southerly shift. Six sites were selected based on their proximity to isolated bushes within 100m of the road and aligned roughly with guide posts conveniently spaced 200m apart along the roadside (Figure 2).

The trip beginning late afternoon on August 11 was split into two seven-hour legs with an overnight stop at a rest area west of Roma. With telescopes filling the front passenger seat and camp gear on the roof, there was room in the back of my Ford Everest for a mattress, car fridge and solar-charged auxiliary battery. There's enough space to sleep there after moving other gear into the driver's seat. The second leg was completed mid-afternoon on August 12 when I arrived at a large and deserted campsite 16 kilometres short of the shadow path under a mostly cloudy sky. I offloaded a camp chair and table, ate a tin of chunky soup and assembled three short-focus refractors on their mounts ready for deployment. It was prior to sunset and 29 hours before the occultation that I first arrived at the observing sites, by which time the cloud had dissipated. The long drive to get to a spot that only a mobile occultation observer would dream about had been well worthwhile.

Time-Saving Measures

Time is of the essence when you have no more than three and a half hours of dark time and many deployments to make. Anything that might cause delays should be avoided at all costs when the outcome is of some importance to the primary objective of two spaceflight missions. Here are a number of measures I implemented:

- **Recorder Settings**
  Settings for time stamps and scheduled recording times of five mini DVRs were done before I even left home. They took into account known individual time stamp drift rates so that their recordings would start on time.

- **Location**
  Apart from isolated farm homesteads many kilometres apart and far from the road, the region was otherwise uninhabited, fencing was hundreds of metres from the road and there was minimal vegetation. In being the floor of an ancient inland sea, its surface was flat and easy to drive on as long as there was no rain to turn it into a quagmire. The selected location enabled off-road driving directly from station to station and parking close to each telescope. That not only expedited the deployments but eliminated potential delays in dealing with other drivers stopping to investigate whether my vehicle had broken down or had been abandoned. In being out of plain sight, observing by stealth is also a security measure with so much unattended equipment lying around and valuable science at stake.

- **Navigation**
  Satellite navigation along roads in the dark is simple but that's not so when driving off road. To avoid the possibility of becoming disoriented on what is virtually a featureless plain, I had prepared trailer reflectors attached to stakes that I positioned next to every telescope. Before departing each station, the stakes were rotated so that the reflectors faced the direction of the returning vehicle. Also in sight are the reflectors on roadside guide posts and my own tyre tracks to follow.

- **Previous Night Pointing**
  A briefcase seen in Figure 3 is used at every station. It contains a Watec 910HX camera for the telescopic field and an old Watec 120N in combination with a 50 mm camera lens to serve as a video finder. The signal from either camera passes through a video switch into an IOTA-VTI and out through another video switch into either an 8″ monitor or a mini-DVR. The DVR could either be recording the occultation with direct time insertion or having its own timestamp calibrated before and after the occultation. Three of the six telescopes are short-focus refractors on low-profile alt-alt mounts. The mounts were originally developed in 2015 for David Dunham and myself when he and Joan Dunham were on an extended holiday driving around Australia and observing some important occultations along the way. Unlike an alt-az mount, its axes as projected on the sky are always far from the pointing direction and no part of the sky is inaccessible as long as the base has been aligned approximately in the azimuth of the target to begin with. A knob at the back rotates a threaded rod in the base to move the bottom of both side struts forward or backward for slow-motion control in altitude.
  Optionally for this occultation, each mount was configured without its legs to sit on a 9 kg, 30 cm square paving stone to serve as a solid immovable base when set a little into the ground. As shown in Figure 4, pointing is aided by star charts displayed in *ScanTracker* [16] (a *Windows* app I first developed in 2004 for drift scans), after which the moving parts and focuser are tightened in place and the telescope returned to the car for safe keeping, leaving the heavy paver in situ. Time is saved by placing the telescope back on the paver before dark on the day of the event, retaining the pointing integrity and focus it had the night before. The three refractors were located outside the updated path as a contingency measure.

- **Daytime Deployments**
  On the day of the event, all equipment including cameras and recorders were to be put in place around the time of sunset. An android compass app and a digital clinometer device helped point the reflector telescopes in approximately the right direction.

Figure 3. 80 mm refractor mounted on a paver at Station-6 ready for previous-night pointing.

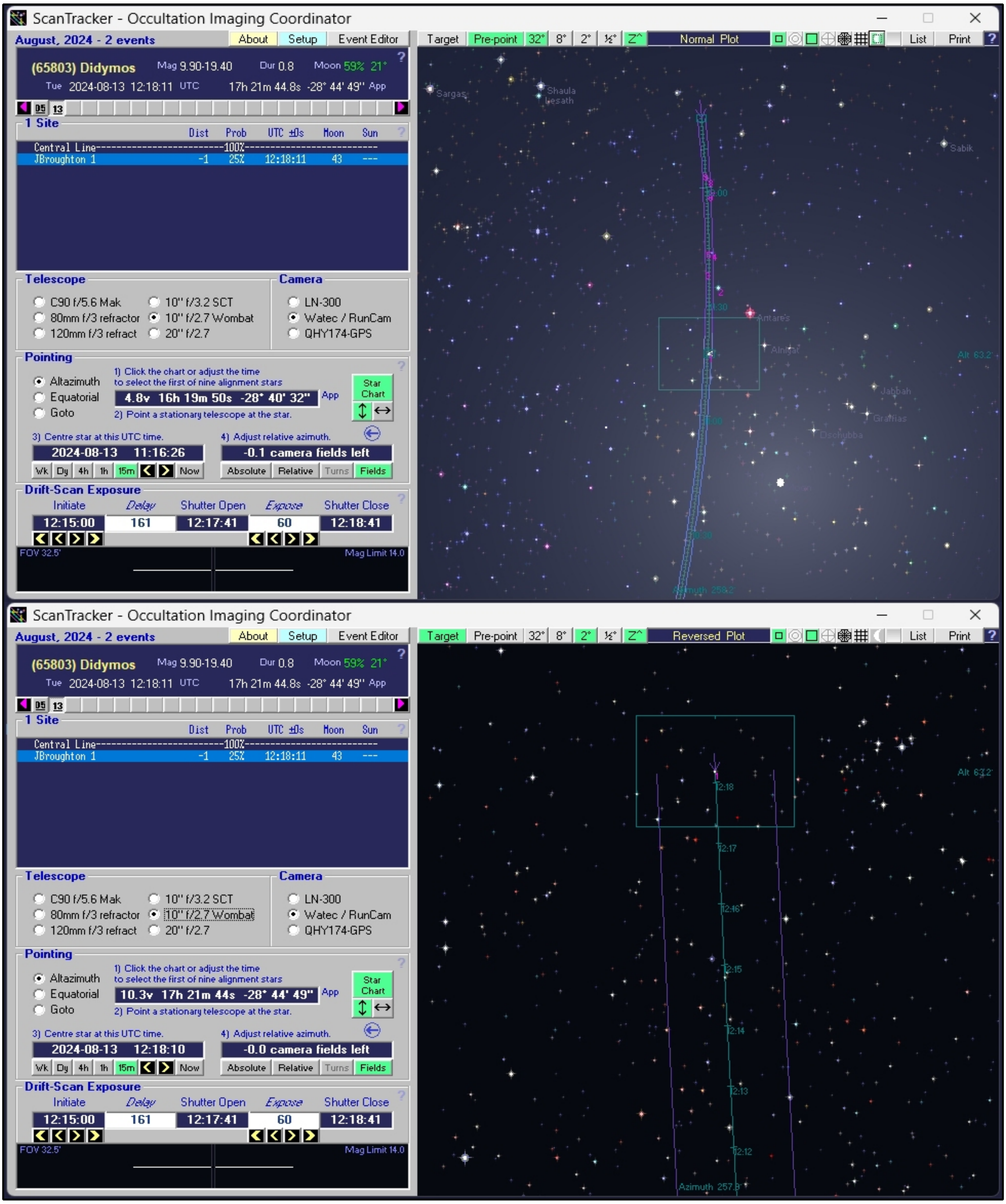

Figure 4. ScanTracker's wide and narrow field charts. The latter is mirror-reversed to match the Wombat-250 view at prime focus.

Figure 5. Wombat-250 alt-alt telescope at Station-5 next to a staked reflector for navigation. The inset shows how compact it is in its folded state. Visible at upper right are my own tyre tracks from the previous night's activities, stretching out into the distance.

The Day of the Occultation

August 13 at the campsite was largely a day of rest. Of great concern was the overcast conditions I had all day, but there was some chance of success if the current weather pattern reflected that of the previous day with diurnal cloud clearing after dark. The main task was to assemble and collimate three Wombat-250 (25 cm) reflectors (Figure 5). They have a single extendable strut supporting a helical focuser at the prime focus, providing a low profile for negligible wind resistance and minimal visibility from the road. The mounts are a 2018 derivative of those I designed for the refractors three years earlier, with the additional function of folding up to become a compact box with dimensions of 36 × 28 × 13cm, equivalent to half a cubic foot in volume. The struts, legs and collapsible shroud supports fit in a separate elongated bag. Incidentally, wombats are tubby short-legged burrowing marsupials, mostly active during the night. Once bedding had been removed from the car, there was enough room in the back for all six fully-assembled telescopes and ancillary equipment. By late afternoon I noticed a hint of blue on the far northeastern horizon slowly heading my way. Whether it would reach me in time was the big question.

I arrived back at the observing site to deploy all the equipment before sunset and waited impatiently for the cloud to begin clearing. Finally, when the Moon came out with just two and a half hours remaining, all of the time-saving measures I'd undertaken started paying off. The first priority was to pre-point three Wombat 250 telescopes located inside the shadow path. During this period, the Moon passed within five degrees of the pointing direction and only a few bright stars were visible on the washed-out video finder screen, one of which was centred in the telescopic field. With reference to *ScanTracker*'s two-degree magnitude 12 charts displayed on a small laptop, I star-hopped my way over a long distance to get to a recognisable star pattern on the pre-point line and removed the video finder from the telescope for use at the next station. A short time-calibration video was recorded on a mini DVR before detaching it from the briefcase electronics. It was then connected to a RunCam that was exchanged for the Watec camera at prime focus. Its recording schedule was verified and the screen blanked to reduce power consumption and visibility in the dark. I then returned the briefcase and computer to the vehicle and was off to the next station.

After finishing setting up the larger telescopes, it was time to turn on the refractor cameras and recorders and verify the pointing and focus done the night before. Subsequently, there was enough time remaining to revisit all stations briefly to verify their DVRs were still receiving video signals. All five DVRs operated autonomously while I at Station-2 manually started a 1-minute sequence of FITS imaging with the QHY camera. No occultation was evident there. During the next hour, all of the equipment was recovered and a second lot of time calibration videos recorded at four stations, so UTC during the occultation could be derived later. The drive back to camp was a slow nerve-wracking one avoiding hitting any one of a multitude of errant kangaroos I passed along the way. I then offloaded the equipment and with great anticipation replayed the recordings.

Results

Distinct occultations were recorded at three stations centred within a 0.09-second interval. As reported by Bob Anderson, their morphology matches that of a single star subject to classic Fresnel diffraction. Station-5 coincides with a line through both components but only one occultation is evident in the lightcurve, indicating that Dimorphos was probably transiting Didymos at the time. Steve Kerr's efforts in the Gladstone region to deploy a telescope each side of my Station-5 line were thwarted by torrential rain.

Station	Distance	Telescope	Camera	Cadence	Recorder	GPS Timing	Outcome
1	-230 m	8 cm refractor	Watec 910HX	80 ms	Mini DVR	Time-inserted IOTA-VTI	Negative
2	-450 m	12 cm refractor	QHY174-GPS	67 ms	Computer	A camera function	Negative
3	-680 m	25 cm reflector	RunCam Astro	40 ms	Mini DVR	Calibrated DVR timestamp	0.54 s
4	-880 m	25 cm reflector	RunCam Astro	40 ms	Mini DVR	Calibrated DVR timestamp	0.56 s
5	-1120 m	25 cm reflector	RunCam Astro	40 ms	Mini DVR	Calibrated DVR timestamp	0.40 s
6	-1340 m	8 cm refractor	Watec 910HX	80 ms	Mini DVR	Calibrated DVR timestamp	Lost signal

Table 1. Station information - all three reflector telescopes delivered positive results... Woohoo!

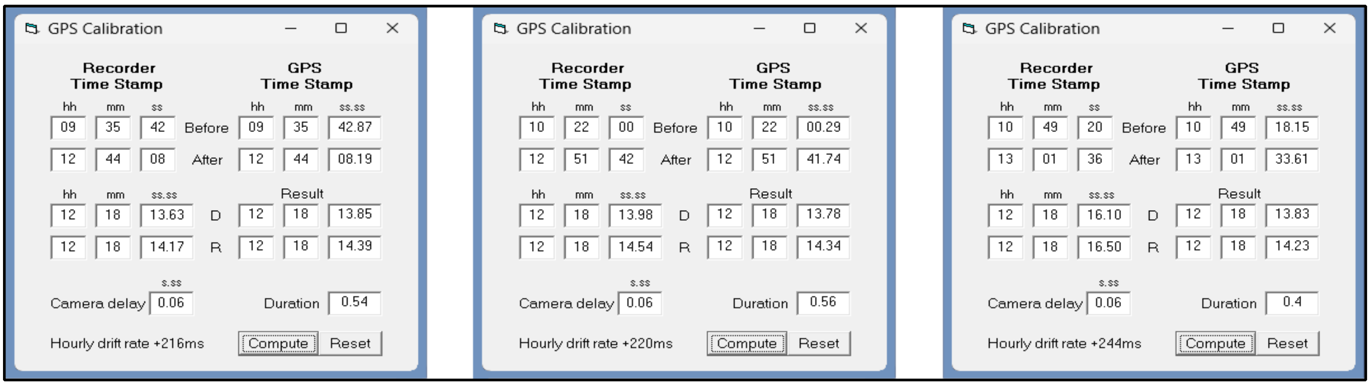

Figure 6. Recovering UTC times for the positive chords from timestamp calibration videos recorded before and after the occultation [16].

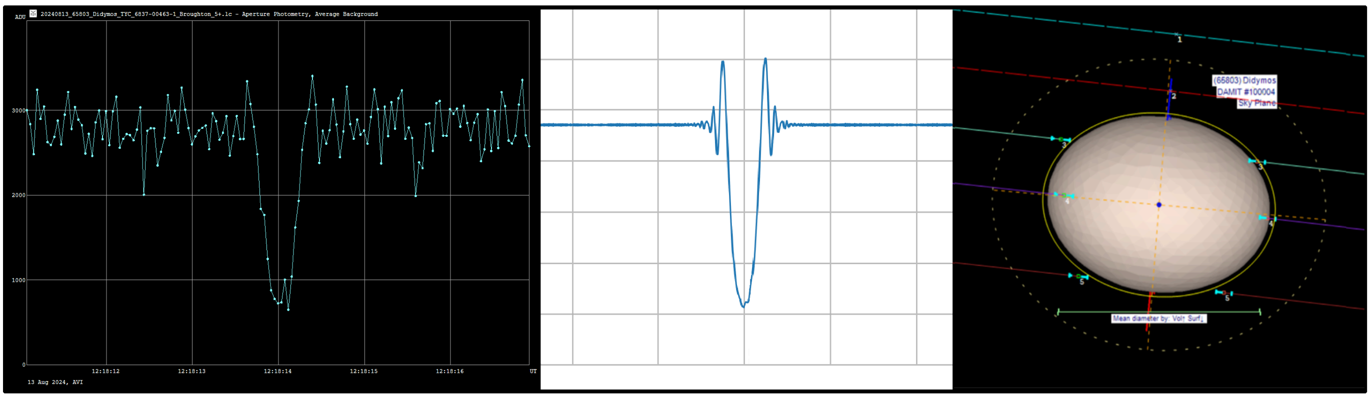

Figure 7. A Tangra lightcurve from Station-5, a PyOTE diffraction curve for comparison and an Occult plot of the chords [17,18,19]

Summary of the 2024 Results

Luckily, a third occultation for 2024 was observed in New Mexico on the evening of September 21 [12]. IOTA President Steve Preston and astronomer Mike Skrutskie each recorded a short disappearance while Kai Getrost and Norman Carlson observed misses. As usual, an astrometric position calculated by Dave Herald was sent to Steve Chesley at the Jet Propulsion Laboratory. In generating an orbital solution including all of the occultation astrometry, a discrepancy of more than a second emerged amongst those from 2024. Alarmingly, the outlier appeared to be that of August 13, leading to dismay on both sides of the Pacific. My investigations soon ruled out any site coordinate or time calibration errors. The only potential source of error remaining was the video time inserter. It was speculated that a one-second error could have occurred before the GPS almanac had been updated and could easily be corrected with a time shift. However, that shouldn't happen to an IOTA-VTI v3 configured during manufacture with the current almanac on board. No such error showed up in comparisons with a Kiwi time inserter where both timestamps appear on video at the same time, demonstrating that the device displays correct time as soon as the timestamp and hourglass appears. That eliminates every possible error mode except for an unlikely and unprecedented malfunction of the device occurring multiple times on one evening only.

This leaves us with a dilemma in having strong evidence both for and against the occurrence of a timing error on August 13. At the time of writing the issue hasn't been resolved to anyone's satisfaction, nonetheless, the reliability of these and the other observations could be tested with another occultation during the current opposition (Table 2). Irrespective of this problem, Steve Chesley acknowledged that the 2024 occultation results were key to constraining the Δv experienced by the Didymos system in its orbit around the Sun.

Future Occultation Prospects

As listed in Table 2, events remaining before the next solar conjunction are very short in duration (<0.05s) but possibly bright enough to be within reach of QHY174-GPS cameras operating at high sub-frame rates. Anyone who succeeds will be pushing the boundaries of what's possible with Earth-based occultation science. Beyond that, the 2026 opposition might not be as productive as the previous two. Table 3 shows only a few challenging events for the major occultation observing regions in the US, Europe and Australasia and none in Japan, so improving the orbit solution over the next two years won't come easily.

Current Dates	V Mag.	Dur (s)	Regions	Adverse Circumstances
2024-12-31.9	11.2	0.04	Spain	Short duration
2025-01-04.8	8.1	0.04	Norway, Sweden	Short duration, winter weather
2025-01-12.9	10.7	0.04	UK	Short duration
2025-01-26.0	10.6	0.03	Portugal, Spain	Short duration, RUWE 2.2
2025-03-11.5	10.2	0.04	Japan	Short duration
2025-03-24.1	9.6	0.03	Peru	Short duration
2025-04-15.4	8.7	0.03	Japan	Short duration, RUWE 2.2

Table 2. Bright events remaining before the next solar conjunction. RUWE is a measure of a star's positional consistency. The star is usually single for values up to 1.0. When it's over 1.4, the chance of it being single and the path prediction being reliable is lower.

2026 Dates	V Mag.	Dur (s)	Regions	Adverse Circumstances
2026-03-18.2	11.1	0.07	South America	
2026-04-16.0	13.6	0.36	Egypt, Europe	Low altitude in Europe
2026-04-30.6	13.8	0.27	New Zealand, Tasmania	58 degrees from a Full Moon
2026-05-01.7	13.8	0.24	Australia	44 degrees from a Full Moon
2026-05-02.1	13.3	0.27	Brazil	39 degrees from a Full Moon
2026-05-04.1	12	0.19	North Africa	16 degrees from a Full Moon

Table 3. Events occurring during the 2026 opposition.

2026 Dates	V Mag.	Dur (s)	Regions	Adverse Circumstances
2026-05-05.6	13.8	0.17	Australia	6 degrees from a Full Moon
2026-05-06.3	12.7	0.17	Mexico, South Florida	13 degrees from a gibbous Moon
2026-05-10.3	13.9	0.13	South America	
2026-05-17.2	11.5	0.11	South America	
2026-05-26.1	11.9	0.08	South America	
2026-06-11.2	11.4	0.22	South America	Small magnitude drop of 0.26
2026-06-14.4	11.3	0.07	Australia, New Zealand	
2026-06-16.9	10.9	0.07	Spain, North Africa	
2026-06-26.4	10	0.09	Western US	Low altitude, 13 degrees from a gibbous Moon
2026-07-09.3	12.2	0.13	New Zealand	
2026-07-18.7	8.5	0.26	East Africa, India, Sri Lanka, Southeast Asia	Monsoon season
2026-08-07.7	12.8	0.21	South Africa	
2026-10-17.1	9.4	0.03	South America	Short duration
2026-10-21.5	8.2	0.03	East Asia	Short duration
2026-11-04.8	11.3	0.03	North Africa	Short duration
2026-11-07.8	11.5	0.03	Africa	Short duration
2026-11-13.6	10.7	0.03	India	Short duration, low altitude
2026-12-26.7	8.5	0.02	Egypt	Short duration

Table 3 continued. Events occuring during the 2026 opposition.

Acknowledgements

Steve Chesley gave permission to use his diagram and went to great lengths working on variations of the orbit solution.

Dave Herald and Dave Gault played major roles in validating my procedures and results.

Bob Anderson established that the lightcurve shape is fully consistent with Fresnel diffraction.

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New Features of the GRAZPREP-Software

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ABSTRACT: The GRAZPREP-software was designed to allow a complete overview on total and grazing occultations of stars and the major planets by the Moon both for worldwide events and precise circumstances at any random location. The individual prediction of total lunar occultations and a planetarium function to visualise the specific details at the lunar surface of any event were added to the software. The author hopes that this tool helps to increase activities of more observers to time and report lunar occultations.

The Software

More than 20 years ago *GRAZPREP* was originally designed as a tool to easily access the grazing occultation prediction data supplied each year to interested observers worldwide by IOTA/ ES. The software assists in finding and listing individually favourable occultation events and in figuring out the best observing site in advance by graphically showing the expected apparent stellar path through the lunar limb terrain. Through the use of the high-resolution lunar topographic data supplied by NASA's Lunar Orbiter Laser Altimeter (LOLA) on board of the *Lunar Reconnaissance Orbiter* (LRO), recalculated to allow *GRAZPREP* a quick display of the profile in all position angles and any libration combination, the approximate number and times of dis- and reappearances can be predicted for any earthbound site coordinates and elevation.

The main idea of the program is to easily visualise the complete list of all grazing occultation events in an area plus the complete line data for any selected event and (simultaneously on the same screen) both the geographic circumstances on Earth and the enlarged topographic situation at the lunar limb including a fairly realistic display of the sunlit lunar portion as well as the approximate sky brightness due to the Sun's altitude. Thus, a judgement about the entire graze circumstances is easily possible at a few glances and a selection of the best events quick and easy (Figure 1).

In addition, a planetarium function that was optimized for the interest of lunar occultation observers can be used to visualise all stellar and planetary occultation events at the lunar limb as well as stellar occultations of the 8 major planets. There are several ways the planetarium function is connected to the calculated predictions. One of them is by clicking on one of the contact times given in the box named "Times of contact". The planetarium opens at the selected place and time at a very high magnification centering the star very close at the lunar limb. An animation tool (Figure 2) allows to simulate the lunar motion in intervals of 1 or 0.1 seconds to see the star dis- and reappear at the limb. The first step of 0.1 seconds should prove that the calculated contact time matches the graphic display.

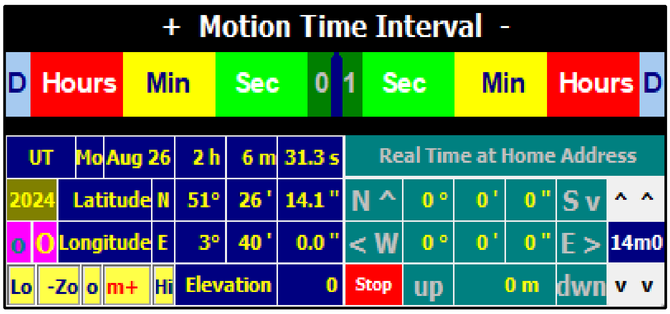

Figure 2. Animation control panel for changes in time, latitude, longitude, elevation, zoom factor and magnitude limit of shown stars.

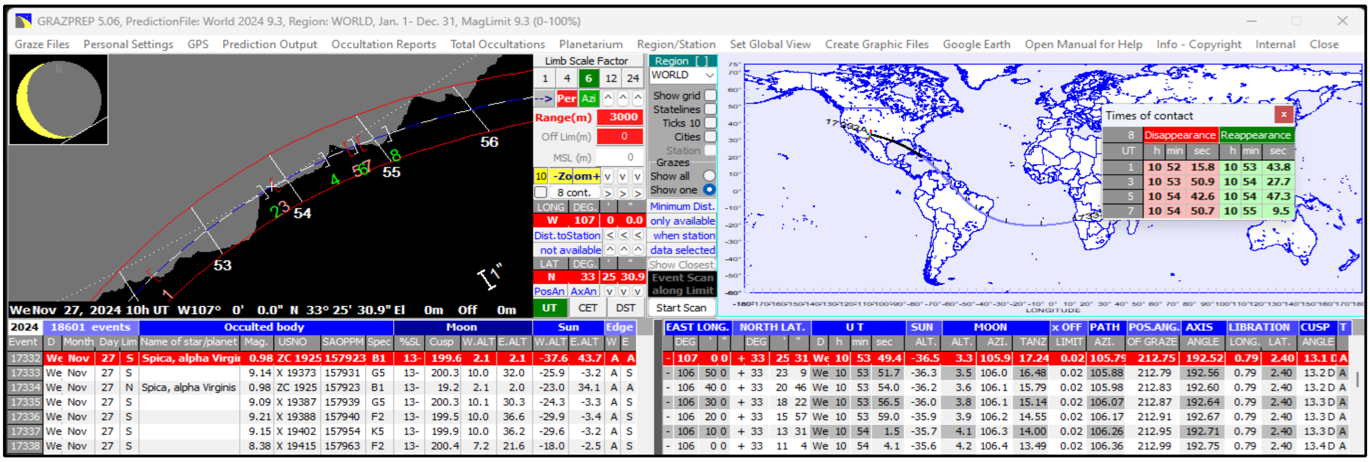

Figure 1. Upper left: lunar limb situation with blue/white apparent stellar path; Upper right: geographic situation with contact times; Lower left: list of all events in prediction file; Lower right: limit line data of selected event

Plotting the "true" lunar limb into the sky in order to match the calculated times of dis- and reappearance precise to 0.1 seconds turned out to be anything but a trivial task in order to target such a precision in time. Different spherical formulae lead to errors of the position angle of up to 0.03° which would result in an accordingly shifted profile and thus in a time difference of around 1 second.

The knowledge of the plotted shape of the "true" lunar surface grazing a star as animated in the planetarium shows the difficulty to calculate highly precise contact times of grazing occultations. Very often there are apparently flat parts of the lunar landscape closely passing along the star for many seconds. Then even a tiny difference in terrain height on the Moon as well as a few metres difference in the location of the observer decide about an occultation or none. Thus the precision of the calculated contact times, despite of the LOLA-measurements, at times lacks due to the yet imperfectly known lunar surface.

The planetarium function is also valuable to prepare for and evaluate occultations of double stars. That way the lunar slopes and peaks can be graphically studied to anticipate the correct sequence of contacts. The planetarium can also be opened directly showing any current sky situation at the home address or at any randomly selected time and place in a time range between 2010 and 2030. Extended ephemerides will be included in the near future.

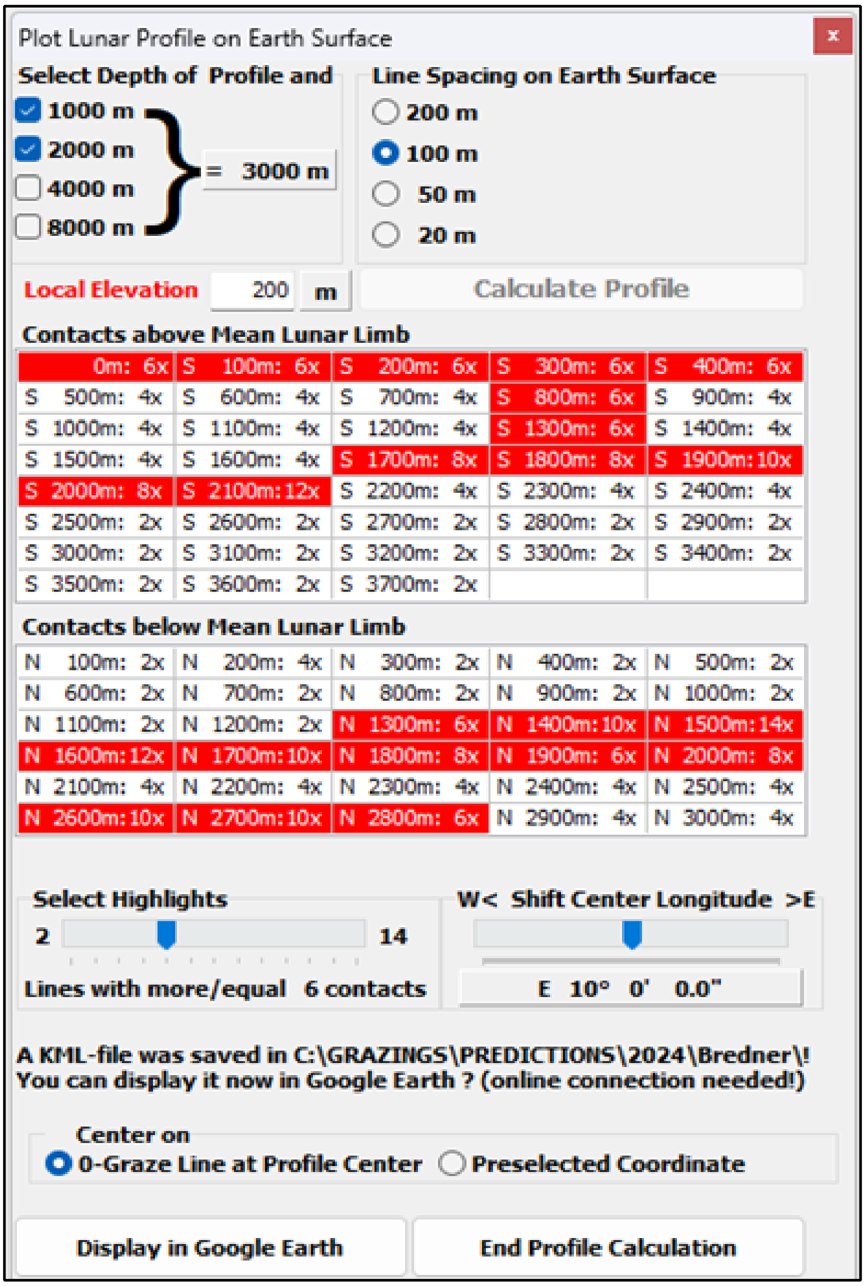

Figure 3.

Using *Google Earth* the optimum site location can be found as *GRAZPREP* plots the outline of the lunar profile on the Earth's surface in the area of the selected observing longitude at the mean local elevation. After a preselection of a probable longitude to observe a grazing occultation the lunar profile as it projects on the Earth's surface in that region can be calculated. After setting the desired depth of the profile (below the mean lunar limb), the desired line spacing (resolution) of the projected profile and the mean elevation of the selected region (Figure 3) first all contacts above the mean lunar limb, if there are any, and then the contacts down to the selected lunar depth are calculated. A right mouse click on each grid entry shows the location, times and axis angles of the calculated contacts. The left trackbar selects the number of lines to be displayed in *Google Earth*: all calculated lines or just those with a desired maximum number of contact events.

The right trackbar allows to move the projected profile for +/-5 minutes of arc in longitude along the graze path.

The plot shows the true heights of the lunar limb as they project on the Earth's surface at a mean elevation of the selected area (Figure 4). The predicted number of contacts at each offset line is given at the edges. When zooming in the terrain underneath the lines becomes visible making a selection of the best observing station easy and any more calculation obsolete.

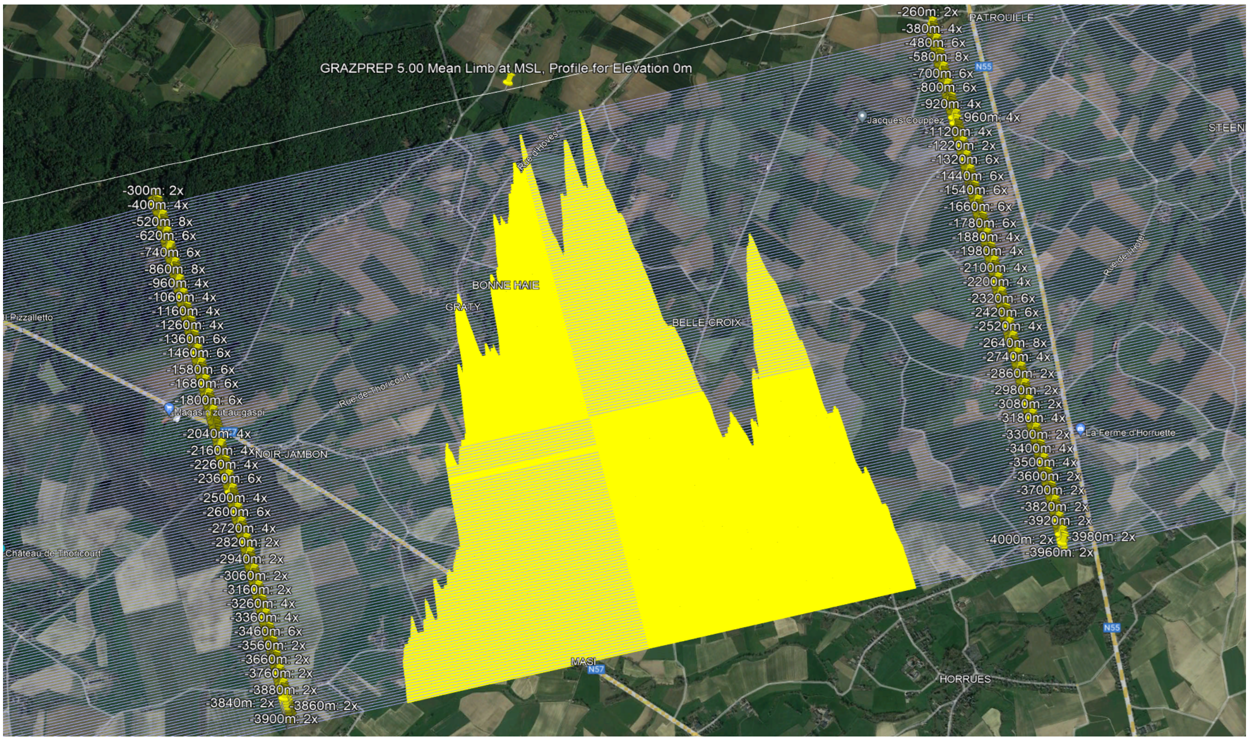

Figure 4.

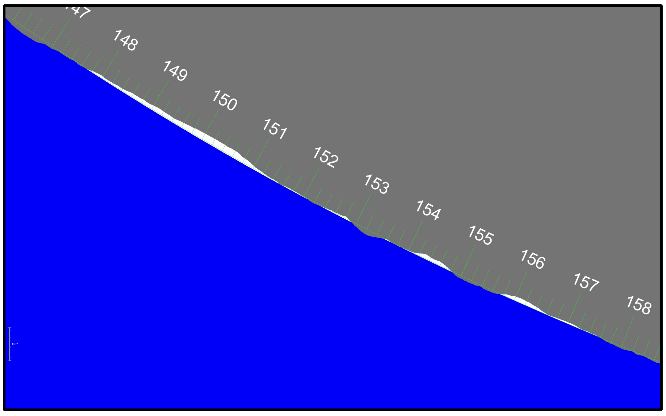

Figure 5.

Making use of the lunar limb data and the planetarium function it is also possible to graphically show Baily's beads events during solar eclipses (Figure 5).

Besides predictions of grazing occultation events *GRAZPREP* now also allows a quick calculation of total lunar occultations by the Moon for any night and place. Whereas the grazing occultation prediction data needs to be downloaded on a yearly basis via IOTA/ES [1] the calculation of total lunar occultations and the planetarium do not need any external data.

When planning an observation of a grazing occultation it is worthwhile to also time total occultations. In that case when *GRAZPREP* is run for total occultations the times of the graze contacts will also be given in the list (Figure 6). The background colour of each row indicates the approximate sky brightness.

Total Lunar Occultations at N 48° 30' 44.1", E 10° 30' 0.0", 0m, from Nov. 21, 2024, 22:42 CET to Nov. 22, 2024, 07:02 CET (Nov. 21, 2024, 21:42 UT to Nov. 22, 2024, 06:02 UT)

Select Starting Date of Night: Do Nov. 21, 2024 | Tonight | CET | Adjust Location | Select Limitig Stellar Magnitude 9.0 + - | Done

Star	Star Name	Mag.	DC	Day (CET)	h	m	sec.	Phenomenom	Limb	Position Angle	Phase	Azimut	Alt. Moon	Alt. Sun
XZ 14269		8.90		Nov. 21, 2024	22	49	14.3	Disappearance	sunlit	94.028°	61%-	68.7°	6.2°	-57.9°
XZ 14269		8.90		Nov. 21, 2024	23	46	39.9	Reappearance	dark	297.522°	61%-	78.7°	14.9°	-61.4°
XZ 14484		8.79		Nov. 22, 2024	4	15	5.4	Disappearance	sunlit	81.790°	59%-	140.9°	54.1°	-32.9°
XZ 14484		8.79		Nov. 22, 2024	5	19	15.6	Reappearance	dark	337.648°	58%-	166.9°	58.6°	-22.3°
XZ 14523		8.52		Nov. 22, 2024	6	42	38.7	Disapp. Graze	dark	211.068°	58%-	203.8°	57.0°	-8.9°
XZ 14523		8.52		Nov. 22, 2024	6	42	52.9	Reapp. Graze	dark	211.411°	58%-	203.9°	57.0°	-8.9°
XZ 14523		8.52		Nov. 22, 2024	6	42	53.2	Disapp. Graze	dark	211.418°	58%-	203.9°	57.0°	-8.9°
XZ 14523		8.52		Nov. 22, 2024	6	45	19.3	Reapp. Graze	dark	214.954°	58%-	204.9°	56.8°	-8.5°
R 1421		7.95		Nov. 22, 2024	6	49	46.0	Disappearance	sunlit	105.714°	58%-	206.7°	56.5°	-7.8°

Figure 6.

Again, when double clicking on any row the planetarium opens to show the situation of the star at the lunar limb.

Several more features are supplied by the software. Since a scientific use of timings of contacts between the lunar limb and the star can only result by reporting the observations *GRAZPREP* also offers an easy handling of the IOTA's standard report form. After filling in the necessary data a textfile in the correct format is produced which can be mailed and evaluated by the coordinators in charge. For worldwide grazing occultations this is Mitsuru Soma, Tokio, Japan, at mitsuru.soma@gmail.com. For total occultations in Europe it is Dietmar Büttner, Chemnitz, Germany, dietmar.buettner@t-online.de. After creating the report file above *GRAZPREP* allows a preliminary graphic evaluation of the timed contacts.

The software also calculates crossing grazing occultation events, defined as two grazes at the same location within a time span of 6 hours, and assists in finding the optimum observing site for both events.

Another feature helps in case a quick change to an alternative observing site due to cloudiness or other insufficient circumstances becomes necessary. For that a PC must be taken along with a USB-GPS-dongle connected. *GRAZPREP* then constantly reads the GPS position which takes control over the calculation of the Moon's position to show the accordingly changing stellar path and possible number of contacts on the run.

Important Hint for the Installation

GRAZPREP is a fully native *Windows*-software independent of the .NET-framework, but not available under *Linux*.

Quite often users have problems to get the software running after installation. The mistake is always the chosen directory which must NOT be the *Windows* program directory as prompted during the installation process. A separate directory has to be created first like C:\GRAZPREP and then chosen for the installation. The requested password is IOTA/ES.

The software can be downloaded along with a matching grazing occultation data file for the individual region [1]. The manual should be read to generate full use of the software.

It is recommended to check the *GRAZPREP*-site every once in a while for a newer version. Before installing it the former version should be uninstalled by simply clicking the UNINSTALL.EXE-file that is in the software's directory. All prediction data and the personal data will stay unaffected by that.

The author is grateful for any correction hint or advice for additional features. Note that despite of a lot of testing and debugging, the software may fail under certain circumstances. If anyone encounters problems when running the program please report these to the author: e_riedel@msn.com.

Outlook

Future plans include the revision of the stellar data especially concerning updated double star information as available through *Gaia*, the improvement of reductions of observations calculated from the most recent LOLA-data for the true libration and an extension of the ephemeris data for future decades. Even a cellphone version might be possible in the future.

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Grazing Occultations of Stars and Planets by the Moon in 2025

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ABSTRACT: The following maps and tables show this year's grazing occultations of the brightest stars and major planets by the Moon in those regions of the world where most of our observers live. The overall limiting magnitude is 5.0.

Introduction

All regional maps are limited to nighttime events along the dark lunar limb where the limit lines of a grazing occultation are shown in black. Events of stars or planets of mag 1.5 or brighter are highlighted with a bold line. The world map shows all grazes of the major planets without any filters. Here the events that occur at the sunlit lunar limb at night are given in yellow, whereas all daytime events appear in light blue. Tick marks appear along the limit lines every 10 full minutes of time. The northern limb grazes show tick marks pointing downwards, whereas on the southern limb grazes they point upwards.

All tables and figures in this article were created with the author's *GRAZPREP*-software. Further precise information on the local circumstances of all grazing occultations, also depending on the lunar terrain and the observer's elevation, is provided by this software which can be downloaded and installed via www.grazprep.com (password: IOTA/ES) including prediction files that are needed additionally for different regions of the world. *GRAZPREP* assists in finding and listing individually favourable occultation events and in figuring out the best observing site in advance or even underway by graphically showing the expected apparent stellar path through the lunar limb terrain. The fainter stars are calculated with their highly-precise position from the *Gaia*-DR2-catalogue.

Refer to the article about the *GRAZPREP* software in this volume of JOA, page 16 - 19.

For all abbreviations in the tables and maps refer to the legend below.

Legend of Tables and Maps

Tables:

No. - Number of event corresponding to the number labels on the map
M D - Month and day of the event referred to UT at the westernmost beginning of the graze limit line
USNO - Identifier in the XZ or ZC catalogue
SAOPPM - Identifier in the SAO or PPM catalogues
D - Double star code from the XZ80Q catalogue
MAG - Vmag of the star/double star system
%SNL - Percentage of sunlit lunar disc, +: waxing Moon, -: waning Moon, E: during lunar eclipse
L. - Limb of the Graze, **N** - northern limb, **S** - southern limb
W. UT - UT at the westernmost beginning of graze limit line
LONG LAT - Position of westernmost beginning of graze limit line
STAR NAME - Name(s) of star or planet
MAG1 MAG2 - Vmag of double star components

Labels on Maps:

Number - corresponding to the number of the event in the table
Labels at end of graze limit lines:
A - limit line begins or ends due to altitude of moon/star
B - limit line begins or ends due to brightness of the lunar surface
S - limit line begins or ends due to bright sunlight/sky brightness
U - limit line begins or ends due to edge of umbra

Double Star Codes:

C - double, component in XZ80Q, Separation <1″
c - double, component not in XZ80Q, Separation <1″
D - double, component in XZ80Q, Separation <10″
d - double, component not in XZ80Q, Separation <10″
W - double, component in XZ80Q, Separation >10″
w - double, component not in XZ80Q, Separation >10″
M - multiple system, all components in XZ80Q
S - multiple system, some but not all in XZ80Q

Additional codes were used in the obsolete XZ80N and XZ80P catalogues. Refer to the ReadMe.txt of the XZ80N for details.

Europe

2025 — Grazing Occultations Europe 2025 <= 5.0 mag. dark limb at night GRAZPREP 5.05, IOTA/ES

No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	Jan 04			1.4	25+	S	17 57.8	7 34	Saturn		
2	Jan 10	ZC 537	76131 U	3.7	81+	N	2 6.9	12 42	Electra 17 Tauri	3.9	7.0
3	Jan 24	ZC 2263	183854 V	4.6	27 -	S	6 33.2	-11 42	1 Scorpii	5.6	5.6
4	Feb 09			-0.8	92+	S	18 50.0	-11 57	Mars		
5	Mar 02	ZC 146	109627 K	4.3	9+	S	15 54.0	25 55	epsilon Piscium	5.2	5.2
6	Mar 19	ZC 2263	183854 V	4.6	73 -	S	21 53.1	31 39	1 Scorpii	5.6	5.6
7	Apr 01	ZC 537	76131 U	3.7	16+	N	20 58.5	22 65	Electra 17 Tauri	3.9	7.0
8	Apr 01	ZC 541	76155 V	3.9	16+	N	21 37.4	-11 56	Maia 20 Tauri	4.4	5.4
9	Apr 01	ZC 539	76140 V	4.3	16+	N	21 35.8	-11 46	Taygeta 19 Tauri	4.6	6.1

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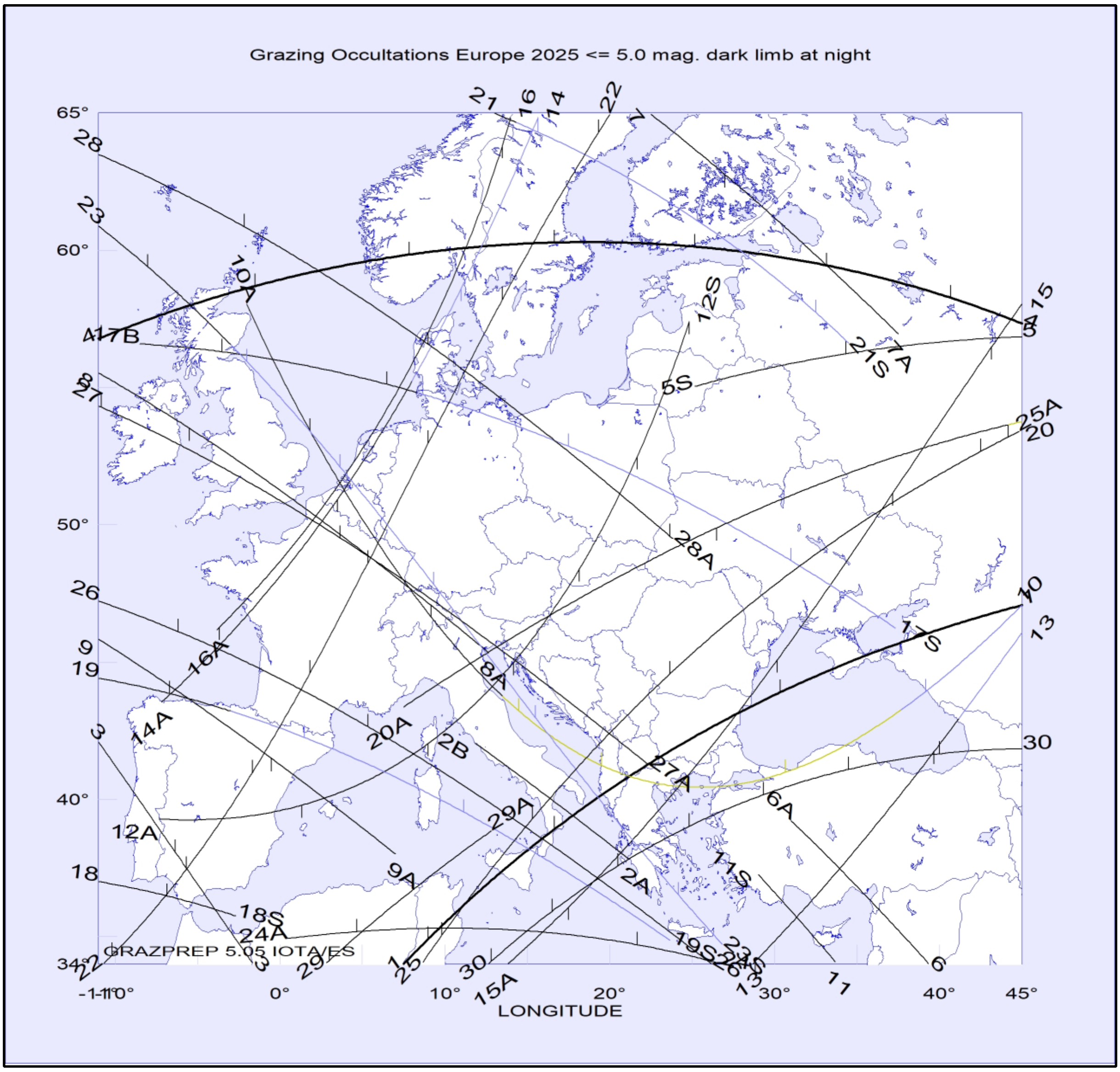

2025 Grazing Occultations Europe 2025 <= 5.0 mag. dark limb at night GRAZPREP 5.05, IOTA/ES

No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
10	Apr 17	ZC 2383	184481	2.8	85 -	S	1 47.3	-2 58	Alniyat tau Scorpii		
11	Jun 09	ZC 2268	183896 H	4.5	98+	N	17 22.0	29 37	2 Scorpii	5.6	5.6
12	Jun 18	ZC 3412	146585	4.2	58 -	N	0 34.9	-7 39	phi Aquarii NSV 26044		
13	Jun 23	ZC 537	76131 U	3.7	7 -	N	1 30.5	28 34	Electra 17 Tauri	3.9	7.0
14	Jun 23	ZC 552	76199 K	2.9	7 -	N	2 44.5	-7 44	Alcyone eta Tauri	3.0	4.6
15	Sep 12	ZC 539	76140 V	4.3	67 -	N	20 28.9	14 34	Taygeta 19 Tauri	4.6	6.1
16	Sep 12	ZC 541	76155 V	3.9	67 -	N	21 0.1	-4 46	Maia 20 Tauri	4.4	5.4
17	Oct 10	ZC 537	76131 U	3.7	87 -	S	5 34.7	-8 57	Electra 17 Tauri	3.9	7.0
18	Oct 10	ZC 539	76140 V	4.3	87 -	S	6 3.4	-11 37	Taygeta 19 Tauri	4.6	6.1
19	Oct 10	ZC 541	76155 V	3.9	87 -	S	6 14.1	-11 44	Maia 20 Tauri	4.4	5.4
20	Oct 14	ZC 1308	80378 V	4.7	36 -	N	23 34.9	7 43	Asellus Borealis Gamma Cancri	5.5	5.5
21	Oct 17	ZC 1547	118355 M	3.8	16 -	S	6 7.9	13 65	rho Leonis	4.6	4.6
22	Nov 01	ZC 3412	146585	4.2	81+	S	17 49.3	-10 34	phi Aquarii NSV 26044		
23	Nov 10	ZC 1170	79653 A	3.6	71 -	S	7 35.6	-11 61	kappa Geminorum	3.7	8.2
24	Nov 14	ZC 1600	118615 w	5.0	30 -	S	1 28.9	0 35	59 Leonis		
25	Nov 27	ZC 3237	164861 V	4.3	44+	S	18 27.6	8 34	iota Aquarii	5.2	5.2
26	Dec 04	ZC 537	76131 U	3.7	98+	S	3 35.2	-11 47	Electra 17 Tauri	3.9	7.0
27	Dec 04	ZC 552	76199 K	2.9	99+	S	4 30.1	-11 54	Alcyone eta Tauri	3.0	4.6
28	Dec 04	ZC 560	76228 U	3.6	99+	S	4 54.7	-11 63	Atlas 27 Tauri	4.1	5.6
29	Dec 23	ZC 3078	189986 M	4.9	12+	S	18 30.7	2 34	Chow eta Capricorni	5.0	7.4
30	Dec 30	ZC 440	75673 M	4.7	82+	S	18 60.0	12 34	epsilon Arietis	5.2	5.6

Southern Africa

2025 Grazing Occultations Southern Africa 2025 <= 5.0 mag. dark limb at night GRAZPREP 5.06, IOTA/ES

No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	Jan 18	ZC 1712	119076 C	3.6	76 -	S	21 37.6	10 -33	Zavijava beta Virginis	3.8	8.8
2	Jan 24	ZC 2237	183686	5.0	29 -	S	0 25.5	11 -19	42 Librae NSV 20363		
3	Jan 24	ZC 2366	184415 O	1.1	21 -	S	22 43.8	43 -22	Antares alpha Scorpii	1.2	5.5
4	Feb 24	ZC 2784	187683 V	3.3	18 -	S	1 35.7	12 -17	tau Sagittarii	4.2	4.2
5	Mar 16	ZC 1925	157923 Z	1.0	94 -	S	18 19.3	21 -14	Spica alpha Virginis	1.3	4.5
6	Mar 17	ZC 2029	158401	4.9	88 -	S	19 12.4	16 -22	ET Virginis	4.9	5.0
7	Mar 19	ZC 2268	183896 H	4.5	73 -	S	22 40.0	12 0	2 Scorpii	5.6	5.6
8	Mar 20	ZC 2287	183987W	2.9	72 -	S	2 57.8	21 0	pi Scorpii	3.4	4.6
9	Apr 13	ZC 1925	157923 Z	1.0	100 -	N	3 41.5	10 -33	Spica alpha Virginis	1.3	4.5
10	May 15	ZC 2617	186328 K	4.5	90 -	N	23 45.1	30 -12		5.1	5.9

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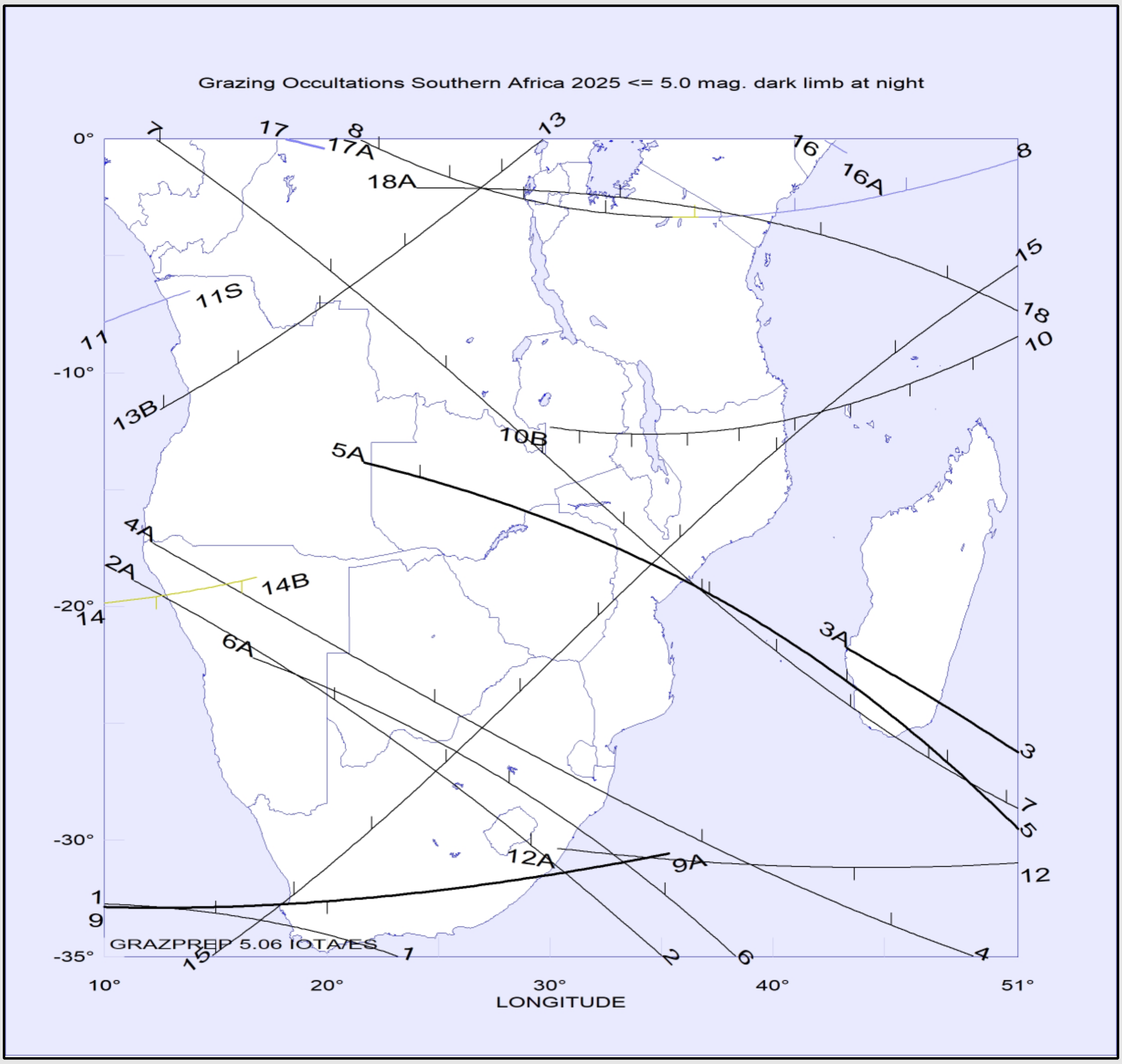
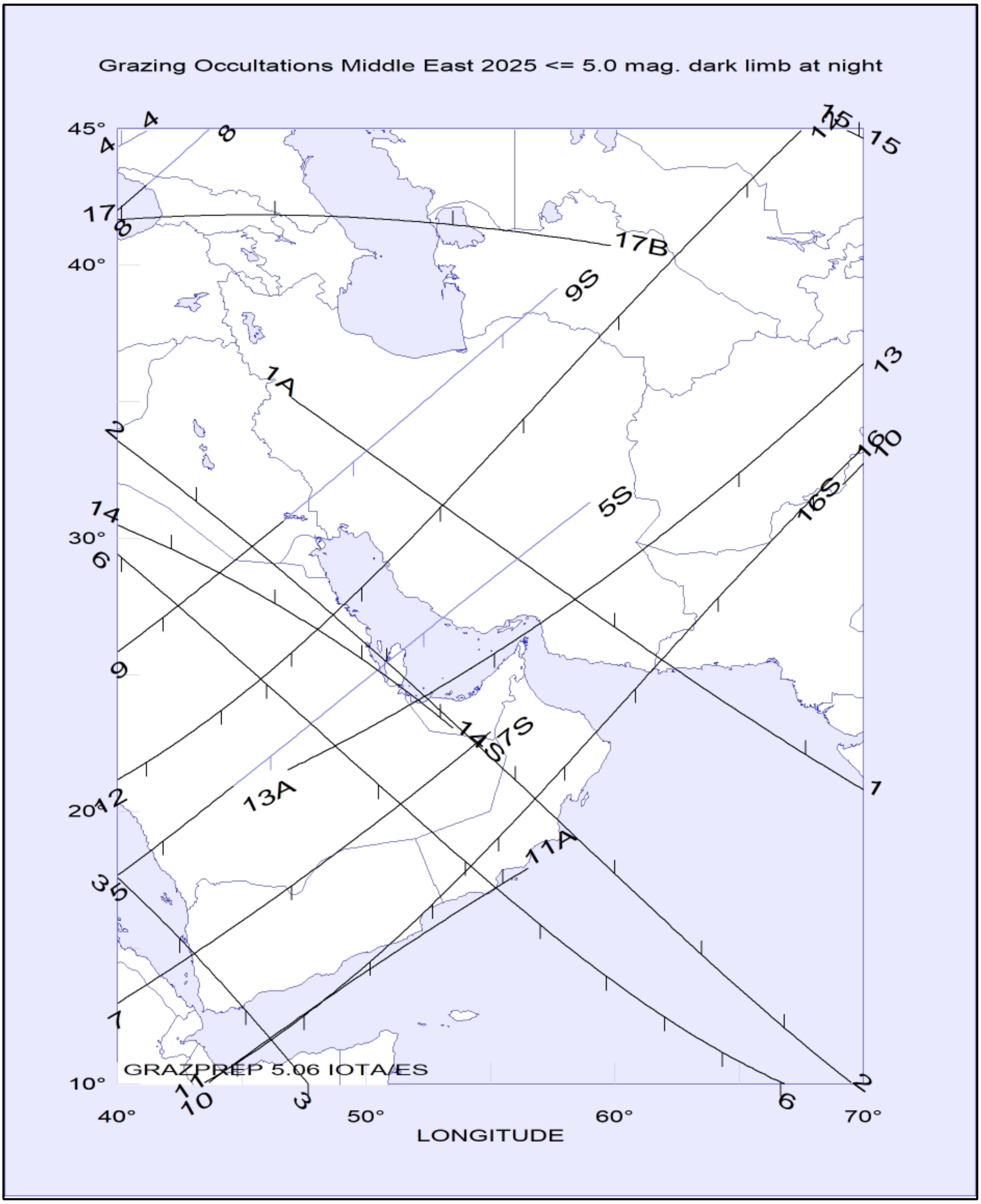


2025	Grazing Occultations Southern Africa 2025 <= 5.0 mag. dark limb at night									GRAZPREP 5.06, IOTA/ES	
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
11	May 21	ZC 3353	146362	3.7	41 -	N	11 1.0	10 -8	lambda Aquarii	3.7	3.8
12	Jul 14	ZC 3353	146362	3.7	82 -	N	19 15.4	30 -30	lambda Aquarii	3.7	3.8
13	Aug 06	ZC 2784	187683 V	3.3	93+	S	22 20.1	12 -12	tau Sagittarii	4.2	4.2
14	Aug 30	ZC 2268	183896 H	4.5	45+	N	19 3.7	10 -20	2 Scorpii	5.6	5.6
15	Oct 02	ZC 3078	189986 M	4.9	77+	S	20 0.6	14 -35	Chow eta Capricorni	5.0	7.4
16	Nov 08	ZC 810	77168 Y	1.6	90 -	N	5 12.7	42 0	El Nath beta Tauri	2.6	2.6
17	Dec 10	ZC 1487	98967 S	1.4	66 -	S	9 24.4	18 0	Regulus alpha Leonis		
18	Dec 11	ZC 1663	118875 M	5.0	48 -	S	22 45.3	24 -2	tau Leonis		

Middle East


Grazing Occultations Middle East 2025 <= 5.0 mag. dark limb at night
45°
40°
30°
20°
10°
40°
50°
60°
70°
LONGITUDE
GRAZPREP 5.06 IOTA/ES
17B
9S
1A
5S
16S
14S
7S
13A
11A

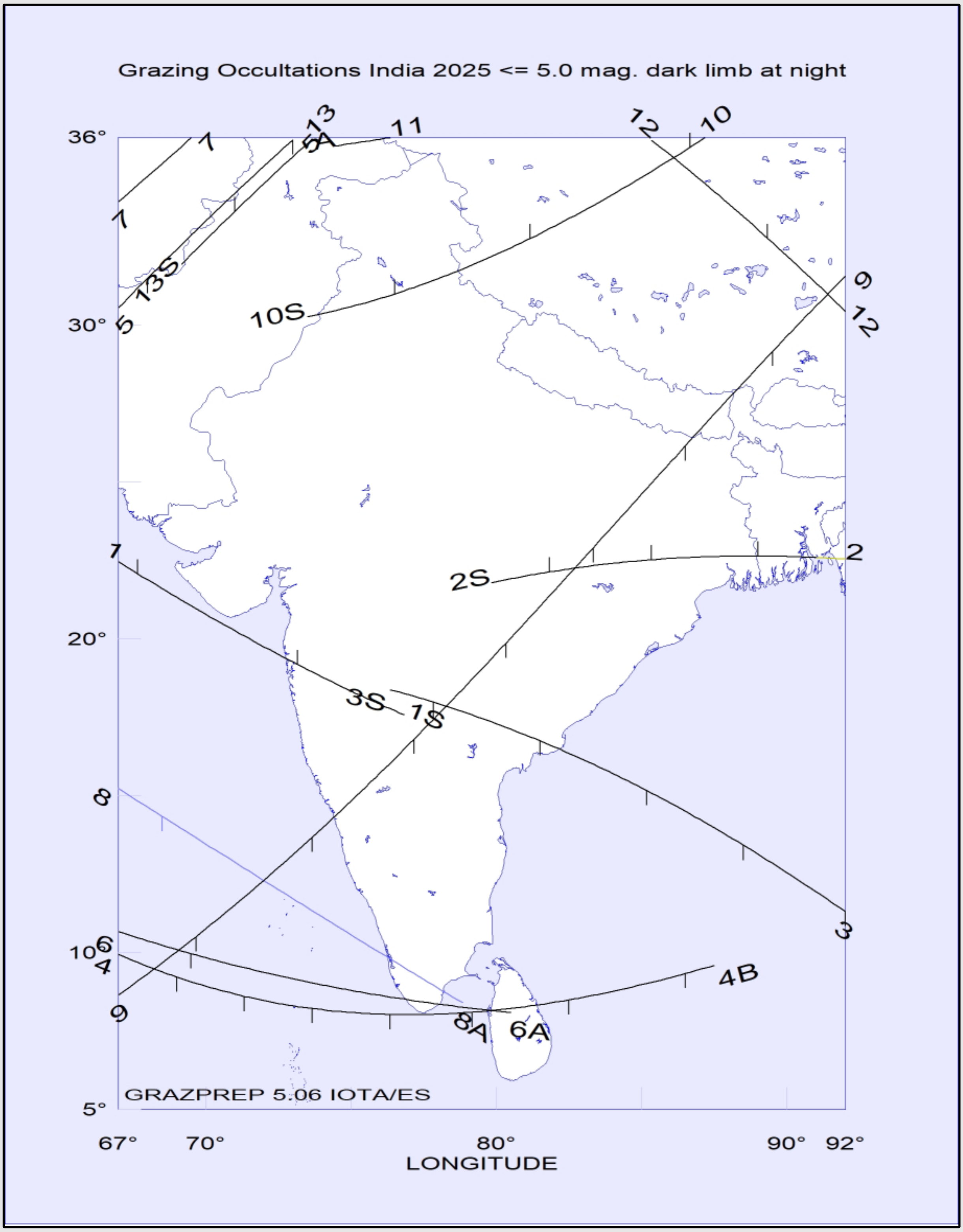
2025 Grazing Occultations Middle East 2025 <= 5.0 mag. dark limb at night GRAZPREP 5.06, IOTA/ES

No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	Feb 23	ZC 2609	186237 V	4.7	27 -	S	0 42.2	47 35	W Sagittarii	5.1	5.1
2	Mar 19	ZC 2263	183854 V	4.6	73 -	S	21 57.4	40 34	1 Scorpii	5.6	5.6
3	Apr 09	ZC 1609	118648 C	4.6	91+	N	18 11.9	40 18	chi Leonis	4.7	11.0
4	Apr 17	ZC 2383	184481	2.8	85 -	S	2 50.8	40 44	Alniyat tau Scorpii		
5	May 17	ZC 2784	187683 V	3.3	83 -	N	2 15.3	40 18	tau Sagittarii	4.2	4.2
6	Jun 09	ZC 2268	183896 H	4.5	98+	N	17 30.6	40 29	2 Scorpii	5.6	5.6
7	Jun 23	ZC 539	76140 V	4.3	7 -	N	1 25.2	40 13	Taygeta 19 Tauri	4.6	6.1
8	Jun 23	ZC 537	76131 U	3.7	7 -	N	1 40.6	40 42	Electra 17 Tauri	3.9	7.0
9	Jun 23	ZC 541	76155 V	3.9	7 -	N	1 48.2	40 26	Maia 20 Tauri	4.4	5.4
10	Jul 13	ZC 3237	164861 V	4.3	89 -	N	21 35.6	43 10	iota Aquarii	5.2	5.2
11	Aug 06	ZC 2784	187683 V	3.3	93+	S	23 23.8	43 10	tau Sagittarii	4.2	4.2
12	Aug 09	ZC 3190	164644 J	2.9	100 -	N	19 46.5	40 21	Deneb Algedi delta Capricorni	3.2	5.2
13	Aug 15	ZC 440	75673 M	4.7	53 -	N	19 56.3	46 22	epsilon Arietis	5.2	5.6
14	Nov 14	ZC 1600	118615 w	5.0	30 -	S	2 5.8	40 30	59 Leonis		
15	Dec 13	ZC 1853	139033 V	4.8	29 -	S	23 29.7	69 45	psi Virginis	5.0	8.3
16	Dec 25	ZC 3307	165134 V	4.8	27+	S	12 25.5	69 32	sigma Aquarii	5.7	5.7
17	Dec 30	ZC 440	75673 M	4.7	82+	S	20 0.0	40 42	epsilon Arietis	5.2	5.6

India

2025 Grazing Occultations India 2025 <= 5.0 mag. dark limb at night GRAZPREP 5.06, IOTA/ES

No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	Feb 23	ZC 2609	186237 V	4.7	27 -	S	0 59.1	67 22	W Sagittarii	5.1	5.1
2	Mar 05	ZC 539	76140 V	4.3	38+	S	12 44.4	80 22	Taygeta 19 Tauri	4.6	6.1
3	Apr 05	ZC 1149	79533 w	4.1	56+	N	13 6.4	76 18	upsilon Geminorum NSV 03652		
4	Jun 09	ZC 2268	183896 H	4.5	98+	N	18 51.7	67 10	2 Scorpii	5.6	5.6
5	Jul 13	ZC 3237	164861 V	4.3	89 -	N	22 57.7	67 31	iota Aquarii	5.2	5.2
6	Jul 28	ZC 1663	118875 M	5.0	16+	N	15 17.4	67 11	tau Leonis		
7	Aug 15	ZC 440	75673 M	4.7	53 -	N	20 13.0	67 34	epsilon Arietis	5.2	5.6
8	Aug 18	ZC 810	77168 Y	1.6	27 -	N	8 29.2	67 15	El Nath beta Tauri	2.6	2.6
9	Sep 09	ZC 105	109474 w	4.4	94 -	N	17 34.4	67 9	delta Piscium		
10	Sep 29	ZC 2609	186237 V	4.7	46+	S	12 53.4	73 30	W Sagittarii	5.1	5.1
11	Dec 10	ZC 1547	118355 M	3.8	60 -	S	18 3.9	74 36	rho Leonis	4.6	4.6
12	Dec 13	ZC 1853	139033 V	4.8	29 -	S	23 51.2	85 36	psi Virginis	5.0	8.3
13	Dec 25	ZC 3307	165134 V	4.8	27+	S	12 25.5	69 32	sigma Aquarii	5.7	5.7

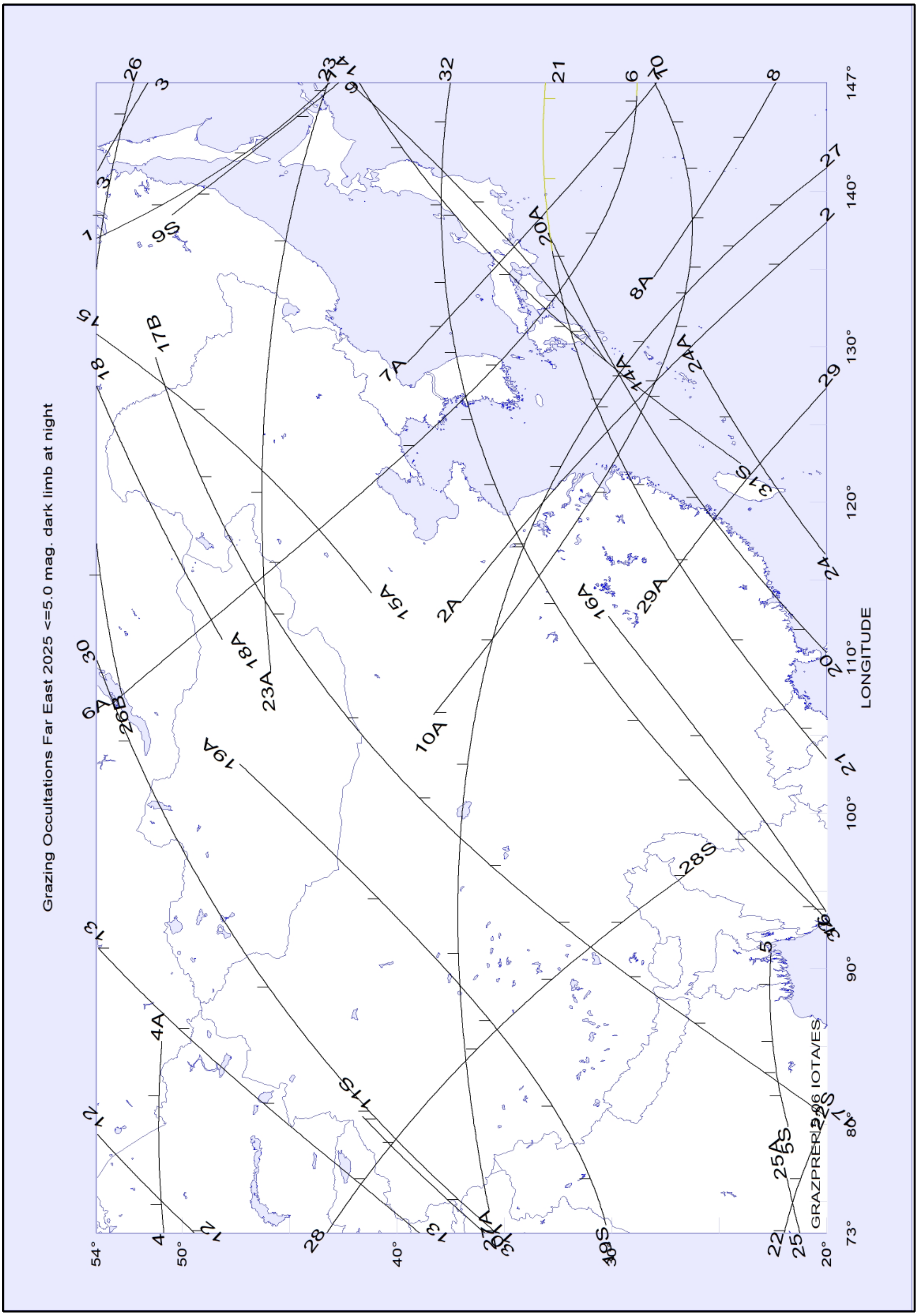


Grazing Occultations India 2025 <= 5.0 mag. dark limb at night
36°
30°
20°
10°
5°
67°
70°
80°
90°
92°
LONGITUDE
GRAZPREP 5.06 IOTA/ES
10S
2S
3S
1S
4B
8A
6A
13S

Far East

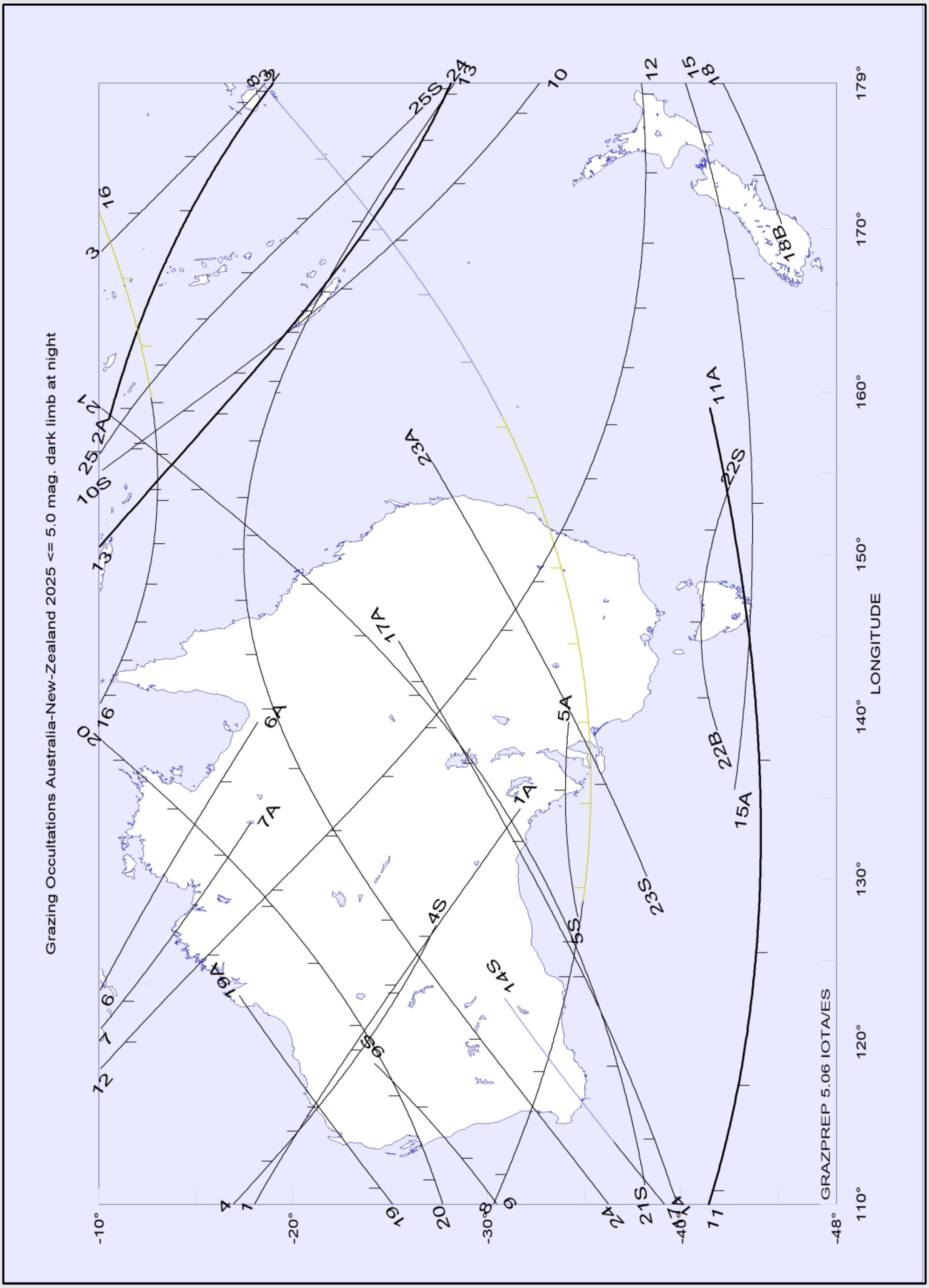
2025 — **Grazing Occultations Far East 2025 <= 5.0 mag. dark limb at night** GRAZPREP 5.06, IOTA/ES

No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG	LAT	STAR NAME	MAG1	MAG2
1	Feb 14	ZC 1663	118875 M	5.0	95 -	S	19 53.1	137	54	tau Leonis		
2	Feb 20	ZC 2287	183987 W	2.9	49 -	S	18 2.0	113	37	pi Scorpii	3.4	4.6
3	Mar 05	ZC 541	76155 V	3.9	38+	N	13 44.9	141	54	Maia 20 Tauri	4.4	5.4
4	Mar 05	ZC 552	76199 K	2.9	38+	S	13 37.3	73	51	Alcyone eta Tauri	3.0	4.6
5	Mar 05	ZC 539	76140 V	4.3	38+	S	12 44.4	80	22	Taygeta 19 Tauri	4.6	6.1
6	Mar 20	ZC 2383	184481	2.8	66 -	S	19 4.5	107	53	Alniyat tau Scorpii		
7	Apr 18	ZC 2609	186237 V	4.7	73 -	S	15 59.3	129	40	W Sagittarii	5.1	5.1
8	Apr 20	ZC 2914	188778 V	4.8	54 -	S	16 26.6	134	28	Terebellum 60 Sagittarii	5.8	5.8
9	May 31	ZC 1308	80378 V	4.7	24+	N	10 47.4	138	50	Asellus Borealis Gamma Cancri	5.5	5.5
10	Jul 10	ZC 2784	187683 V	3.3	100+	N	12 40.4	106	38	tau Sagittarii	4.2	4.2
11	Jul 13	ZC 3237	164861 V	4.3	89 -	N	23 10.1	73	36	iota Aquarii	5.2	5.2
12	Aug 09	ZC 3190	164644 J	2.9	100 -	N	21 10.0	73	49	Deneb Algedi delta Capricorni	3.2	5.2
13	Aug 15	ZC 440	75673 M	4.7	53 -	N	20 23.4	73	39	epsilon Arietis	5.2	5.6
14	Aug 16	ZC 539	76140 V	4.3	46 -	N	14 45.1	129	30	Taygeta 19 Tauri	4.6	6.1
15	Aug 16	ZC 541	76155 V	3.9	45 -	N	15 13.1	114	41	Maia 20 Tauri	4.4	5.4
16	Aug 31	ZC 2383	184481	2.8	54+	S	14 49.8	93	20	Alniyat tau Scorpii		
17	Sep 09	ZC 105	109474 w	4.4	94 -	N	18 10.8	80	20	delta Piscium		
18	Sep 17	ZC 1308	80378 V	4.7	16 -	N	18 13.2	111	48	Asellus Borealis Gamma Cancri	5.5	5.5
19	Sep 29	ZC 2609	186237 V	4.7	46+	S	12 53.4	73	30	W Sagittarii	5.1	5.1
20	Oct 03	ZC 3190	164644 J	2.9	85+	S	16 37.9	110	20	Deneb Algedi delta Capricorni	3.2	5.2
21	Oct 11	ZC 810	77168 Y	1.6	71 -	N	17 36.8	103	20	El Nath beta Tauri	2.6	2.6
22	Oct 15	ZC 1308	80378 V	4.7	36 -	S	0 19.8	73	22	Asellus Borealis Gamma Cancri	5.5	5.5
23	Oct 17	ZC 1600	118615 w	5.0	12 -	S	19 56.7	109	46	59 Leonis		
24	Nov 26	ZC 3078	189986 M	4.9	33+	S	13 4.8	116	20	Chow eta Capricorni	5.0	7.4
25	Nov 28	ZC 3353	146362	3.7	55+	S	18 52.1	73	21	lambda Aquarii	3.7	3.8
26	Dec 07	ZC 1170	79653 A	3.6	89 -	S	15 51.6	107	53	kappa Geminorum	3.7	8.2
27	Dec 10	ZC 1547	118355 M	3.8	60 -	S	18 3.9	74	36	rho Leonis	4.6	4.6
28	Dec 13	ZC 1853	139033 V	4.8	29 -	S	23 33.1	73	43	psi Virginis	5.0	8.3
29	Dec 17	ZC 2287	183987 W	2.9	4 -	S	21 43.0	115	27	pi Scorpii	3.4	4.6
30	Dec 25	ZC 3307	165134 V	4.8	27+	S	12 35.2	73	35	sigma Aquarii	5.7	5.7
31	Dec 28	ZC 105	109474 w	4.4	57+	S	9 10.4	122	24	delta Piscium		
32	Dec 31	ZC 539	76140 V	4.3	89+	S	11 58.7	93	20	Taygeta 19 Tauri	4.6	6.1


Grazing Occultations Far East 2025 <=5.0 mag. dark limb at night
LONGITUDE
73°
80°
90°
100°
110°
120°
130°
140°
147°
20°
30°
40°
50°
54°
GRAZPREP 2.06 IOTA/ES

Australia & New Zealand

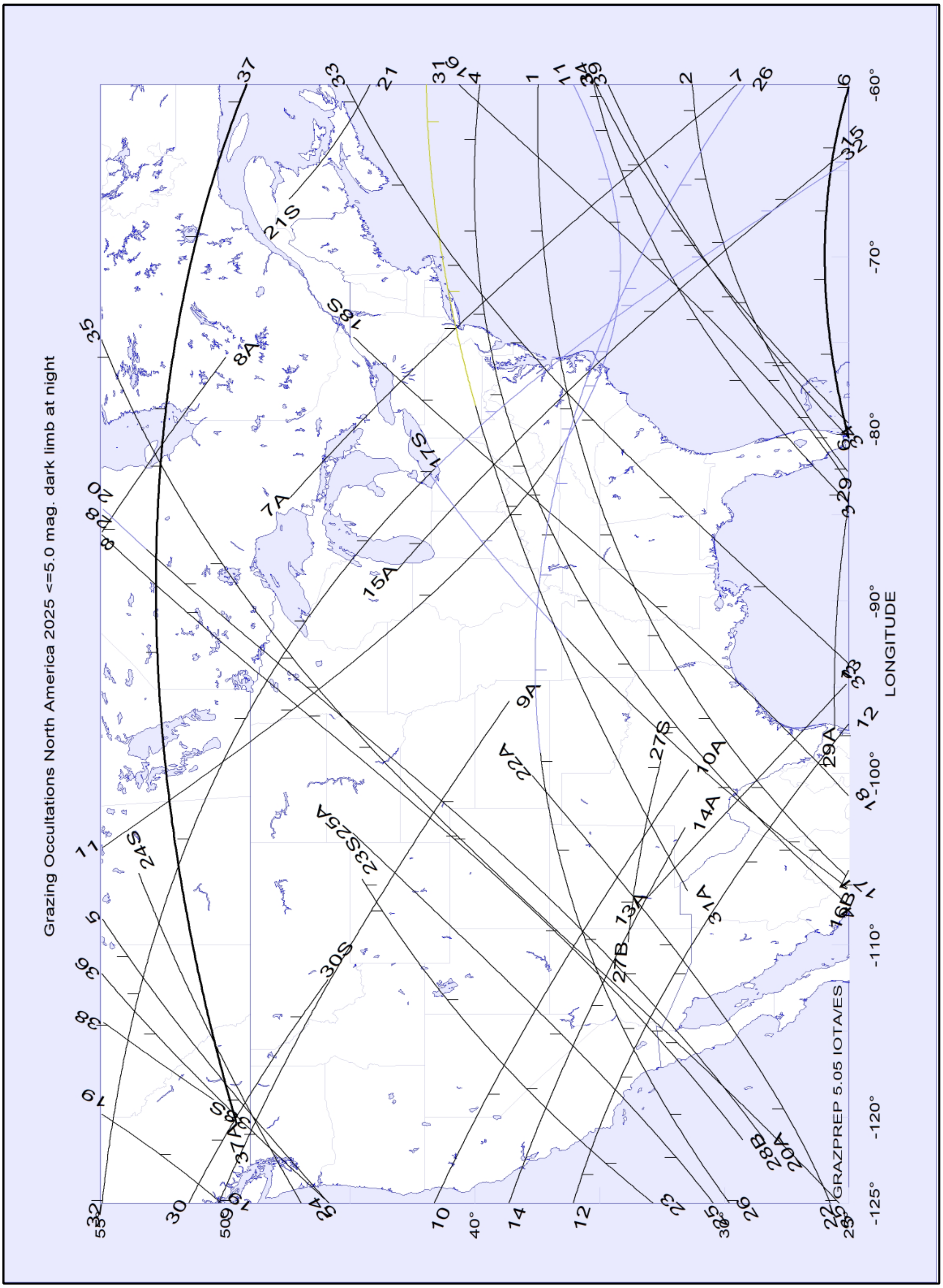
2025 Grazing Occultations Australia-New-Zealand 2025 <= 5.0 mag. dark limb at night											GRAZPREP 5.06 IOTA/ES	
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG	LAT	STAR NAME	MAG1	MAG2
1	**Jan 11**	ZC 810	77168 Y	1.6	94+	S	17 12.4	110	-18	El Nath beta Tauri	2.6	2.6
2	**Feb 17**	ZC 1925	157923 Z	1.0	79 -	S	11 2.5	158	-11	Spica alpha Virginis	1.3	4.5
3	**Feb 20**	ZC 2268	183896 H	4.5	51 -	S	15 44.2	168	-10	2 Scorpii	5.6	5.6
4	**Feb 20**	ZC 2298	184068	5.0	48 -	S	20 32.4	110	-17			
5	**Mar 02**	ZC 105	109474 w	4.4	8+	S	10 3.7	127	-35	delta Piscium		
6	**Apr 02**	ZC 638	76558 A	5.0	22+	N	11 11.8	123	-10	phi Tauri	5.1	8.5
7	**Apr 05**	ZC 1149	79533 w	4.1	56+	N	14 48.6	120	-10	upsilon Geminorum NSV 03652		
8	**Apr 19**	ZC 2784	187683 V	3.3	62 -	S	18 17.5	110	-30	tau Sagittarii	4.2	4.2
9	**May 20**	ZC 3307	165134 V	4.8	45 -	N	22 11.9	110	-30	sigma Aquarii	5.7	5.7
10	**Jun 03**	ZC 1609	118648 C	4.6	52+	N	7 24.7	155	-10	chi Leonis	4.7	11.0
11	**Jun 06**	ZC 1925	157923 Z	1.0	81+	N	15 38.7	110	-41	Spica alpha Virginis	1.3	4.5
12	**Jun 09**	ZC 2237	183686	5.0	97+	N	10 37.4	118	-10	42 Librae NSV 20363		
13	**Jun 10**	ZC 2366	184415 O	1.1	99+	N	9 23.8	150	-10	Antares alpha Scorpii	1.2	5.5
14	**Jun 12**	ZC 2721	187239 X	3.2	97 -	N	23 34.7	110	-39	phi Sagittarii	4.1	4.1
15	**Jun 17**	ZC 3353	146362	3.7	63 -	N	13 54.3	135	-43	lambda Aquarii	3.7	3.8
16	**Aug 03**	ZC 2268	183896 H	4.5	68+	N	9 48.4	140	-10	2 Scorpii	5.6	5.6
17	**Aug 03**	ZC 2298	184068	5.0	70+	S	15 45.4	110	-40			
18	**Sep 05**	ZC 3078	189986 M	4.9	93+	S	9 35.3	170	-45	Chow eta Capricorni	5.0	7.4
19	**Sep 29**	ZC 2617	186328 K	4.5	47+	S	15 39.3	110	-25		5.1	5.9
20	**Oct 03**	ZC 3171	164560 V	3.7	84+	S	11 17.4	110	-28	Nashira gamma Capricorni	4.6	4.6
21	**Oct 04**	ZC 3307	165134 V	4.8	91+	S	10 42.7	111	-38	sigma Aquarii	5.7	5.7
22	**Oct 10**	ZC 638	76558 A	5.0	81 -	S	18 36.0	139	-42	phi Tauri	5.1	8.5
23	**Oct 24**	ZC 2268	183896 H	4.5	8+	S	9 45.2	130	-38	2 Scorpii	5.6	5.6
24	**Dec 05**	ZC 810	77168 Y	1.6	99 -	S	13 33.5	110	-36	El Nath beta Tauri	2.6	2.6
25	**Dec 08**	ZC 1308	80378 V	4.7	81 -	S	16 9.6	156	-10	Asellus Borealis Gamma Cancri	5.5	5.5


Grazing Occultations Australia-New-Zealand 2025 <= 5.0 mag. dark limb at night
LONGITUDE
GRAZPREP 5.06 IOTA/ES

North America

2025	Grazing Occultations North America 2025 <=5.0 mag. dark limb at night									GRAZPREP 5.05, IOTA/ES		
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG	LAT	STAR NAME	MAG1	MAG2
1	Jan 07	ZC 146	109627 K	4.3	50+	S	1 55.5	-106	25	epsilon Piscium	5.2	5.2
2	Jan 10	ZC 552	76199 K	2.9	82+	S	1 20.4	-82	25	Alcyone eta Tauri	3.0	4.6
3	Jan 10	ZC 545	76172	4.1	81+	S	0 28.9	-84	25	Merope 23 Tauri		
4	Jan 10	ZC 560	76228 U	3.6	82+	S	1 21.8	-107	25	Atlas 27 Tauri	4.1	5.6
5	Jan 12	ZC 890	77675 V	4.6	95+	S	1 13.6	-125	46	136 Tauri NSV 02696	4.8	6.3
6	Jan 14			-1.4	100 -	S	2 40.4	-80	25	Mars		
7	Jan 24	ZC 2287	183987W	2.9	27 -	S	9 45.8	-84	47	pi Scorpii	3.4	4.6
8	Feb 06	ZC 537	76131 U	3.7	60+	N	7 30.2	-86	55	Electra 17 Tauri	3.9	7.0
9	Feb 06	ZC 541	76155 V	3.9	61+	N	8 0.7	-125	50	Maia 20 Tauri	4.4	5.4
10	Feb 06	ZC 539	76140 V	4.3	60+	N	7 55.8	-125	42	Taygeta 19 Tauri	4.6	6.1
11	Feb 21	ZC 2383	184481	2.8	43 -	S	11 33.8	-104	55	Alniyat tau Scorpii		
12	Mar 07	ZC 810	77168 Y	1.6	55+	N	4 37.0	-125	36	El Nath beta Tauri	2.6	2.6
13	Mar 22	ZC 2609	186237 V	4.7	51 -	S	9 2.3	-107	33	W Sagittarii	5.1	5.1
14	Apr 01	ZC 440	75673M	4.7	10+	N	3 44.8	-125	39	epsilon Arietis	5.2	5.6
15	Apr 16	ZC 2263	183854 V	4.6	91 -	S	4 19.6	-88	43	1 Scorpii	5.6	5.6
16	Jun 13	ZC 2784	187683 V	3.3	96 -	N	6 9.8	-106	25	tau Sagittarii	4.2	4.2
17	Jul 13	ZC 3171	164560 V	3.7	93 -	N	10 44.4	-106	25	Nashira gamma Capricorni	4.6	4.6
18	Jul 20	ZC 539	76140 V	4.3	24 -	N	8 58.7	-101	25	Taygeta 19 Tauri	4.6	6.1
19	Jul 20	ZC 537	76131 U	3.7	24 -	N	9 17.4	-125	50	Electra 17 Tauri	3.9	7.0
20	Jul 20	ZC 541	76155 V	3.9	24 -	N	9 16.0	-121	28	Maia 20 Tauri	4.4	5.4
21	Jul 28	ZC 1600	118615 w	5.0	11+	N	0 11.8	-66	47	59 Leonis		
22	Aug 04	ZC 2383	184481	2.8	74+	S	6 11.2	-125	26	Alniyat tau Scorpii		
23	Aug 13	ZC 105	109474 w	4.4	80 -	N	11 34.4	-125	33	delta Piscium		
24	Aug 21	ZC 1308	80378 V	4.7	4 -	N	11 54.1	-125	47	Asellus Borealis Gamma Cancri	5.5	5.5
25	Sep 02	ZC 2609	186237 V	4.7	68+	S	5 5.2	-125	30	W Sagittarii	5.1	5.1
26	Sep 14	ZC 810	77168 Y	1.6	50 -	N	11 30.3	-125	30	El Nath beta Tauri	2.6	2.6
27	Oct 09	ZC 440	75673M	4.7	92 -	S	12 26.6	-110	34	epsilon Arietis	5.2	5.6
28	Oct 10	ZC 539	76140 V	4.3	87 -	N	3 57.5	-121	29	Taygeta 19 Tauri	4.6	6.1
29	Oct 18	ZC 1663	118875M	5.0	9 -	S	10 22.0	-97	26	tau Leonis		

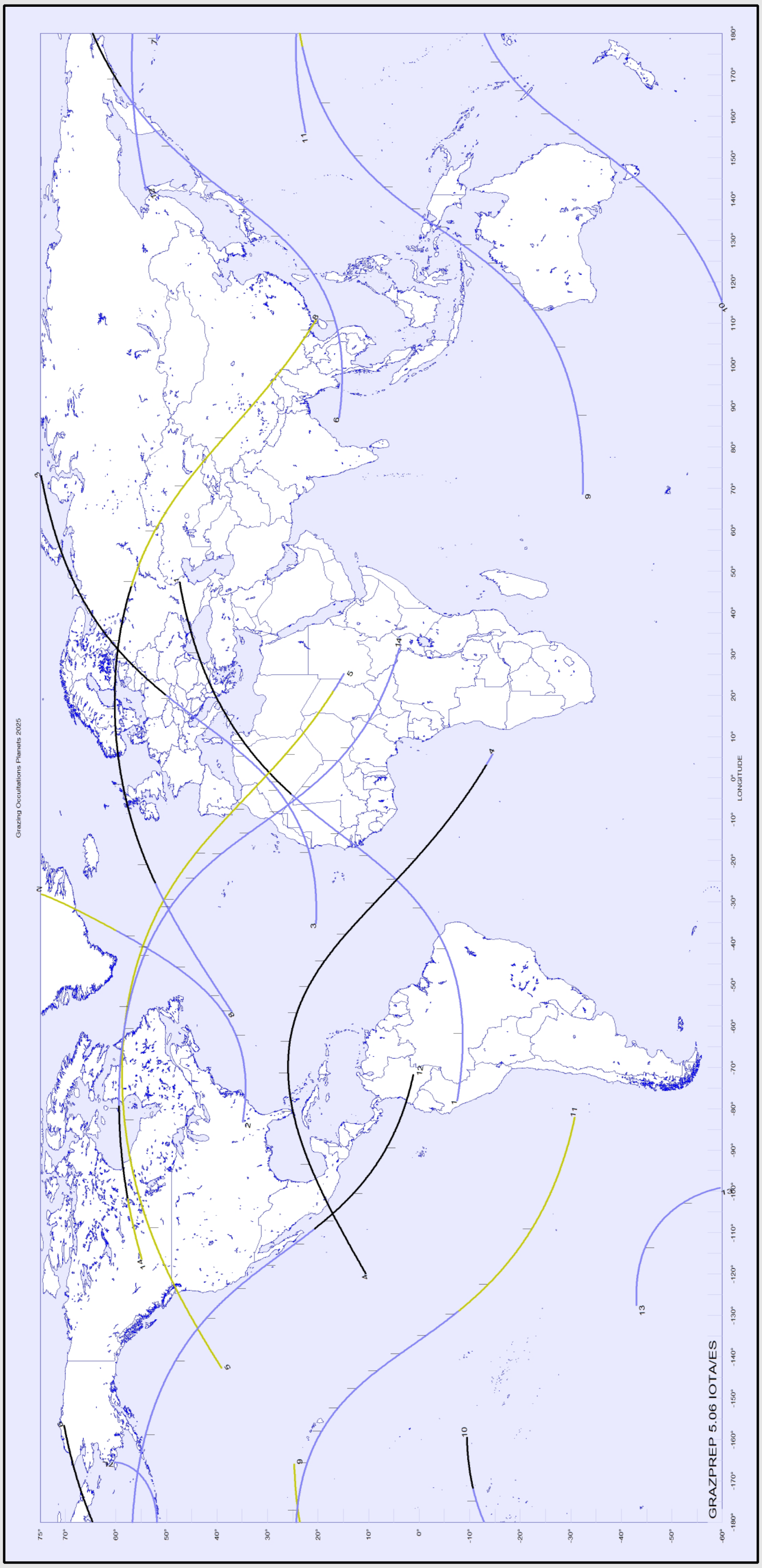
(Continued on page xx)


Grazing Occultations North America 2025 <=5.0 mag. dark limb at night
LONGITUDE
GRAZPREP 5.05 IOTA/ES

2025	Grazing Occultations North America 2025 <=5.0 mag. dark limb at night									GRAZPREP 5.05, IOTA/ES	
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
30	Nov 08	ZC 890	77675 V	4.6	87 -	S	14 4.9	-125 51	136 Tauri NSV 02696	4.8	6.3
31	Nov 11	ZC 1308	80378 V	4.7	60 -	N	5 52.2	-106 31	Asellus Borealis Gamma Cancri	5.5	5.5
32	Nov 13	ZC 1547	118355 M	3.8	38 -	S	11 20.3	-125 55	rho Leonis	4.6	4.6
33	Dec 04	ZC 537	76131 U	3.7	98+	S	1 12.4	-93 25	Electra 17 Tauri	3.9	7.0
34	Dec 04	ZC 541	76155 V	3.9	99+	S	2 1.3	-79 25	Maia 20 Tauri	4.4	5.4
35	Dec 04	ZC 552	76199 K	2.9	99+	S	2 0.1	-125 25	Alcyone eta Tauri	3.0	4.6
36	Dec 04	ZC 560	76228 U	3.6	99+	S	3 3.6	-125 46	Atlas 27 Tauri	4.1	5.6
37	Dec 10	ZC 1487	98967 S	1.4	66 -	S	6 10.8	-120 50	Regulus alpha Leonis		
38	Dec 24	ZC 3237	164861 V	4.3	21+	S	23 52.5	-119 50	iota Aquarii	5.2	5.2
39	Dec 26	ZC 3353	146362	3.7	30+	S	0 22.1	-80 25	lambda Aquarii	3.7	3.8

Planets Worldwide

2025	Grazing Occultations Planets 2025					GRAZPREP 5.06, IOTA/ES	
No.	M D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME
1	Jan 04	1.4	25+	S	15 17.2	-78 -8	Saturn
2	Jan 04	1.4	25+	N	16 3.8	-83 35	Saturn
3	Jan 05	8.0	35+	S	13 14.9	-35 20	Neptune
4	Jan 14	-1.4	100 -	S	2 4.4	-120 11	Mars
5	Jan 14	-1.4	100 -	N	2 26.8	-142 39	Mars
6	Feb 01	1.4	9+	S	2 49.8	87 16	Saturn
7	Feb 01	8.0	14+	S	21 20.7	178 52	Neptune
8	Feb 09	-0.8	92+	S	18 20.1	-56 37	Mars
9	Mar 01	-1.0	2+	N	2 32.4	68 -32	Mercury
10	Mar 01	-1.0	2+	S	2 56.0	61 -66	Mercury
11	Jun 29	1.5	24+	S	23 23.0	156 22	Mars
12	Jun 29	1.5	24+	N	23 40.5	142 54	Mars
13	Jul 28	1.6	16+	N	17 54.6	-127 -43	Mars
14	Sep 19	-3.4	6 -	S	10 48.0	-116 55	Venus


Grazing Occultations Planets 2025
GRAZPREP 5.06 IOTA/ES
LONGITUDE

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 2024 December 22, the *Minor Planet Center* listed 1819 Centaurs and 3548 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:

(65489) Ceto and Phorcys

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

ABSTRACT: Since 2016, JOA regularly publishes portraits of objects beyond Jupiter's orbit. This short communication on the trans-Neptunian binary system known as (65489) Ceto and Phorcys 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
7066	Nessus	Konrad Guhl	JOA 1 2024
8405	Asbolus	Oliver Klös	JOA 3 2016
10370	Hylonome	Konrad Guhl	JOA 3 2021
10199	Chariklo	Mike Kretlow	JOA 1 2017
15760	Albion	Nikolai Wünsche	JOA 4 2019
15810	Awran	Konrad Guhl	JOA 4 2021
20000	Varuna	Andre Knöfel	JOA 2 2017
28728	Ixion	Nikolai Wünsche	JOA 2 2018
32532	Thereus	Konrad Guhl	JOA 1 2023
38628	Huya	Christian Weber	JOA 2 2021
47171	Lempo	Oliver Klös	JOA 4 2020
50000	Quaoar	Mike Kretlow	JOA 1 2020
53311	Deucalion	Konrad Guhl	JOA 2 2024

No.	Name	Author	Link to Issue
54598	Bienor	Konrad Guhl	JOA 3 2018
55576	Amycus	Konrad Guhl	JOA 1 2021
58534	Logos & Zoe	Konrad Guhl	JOA 4 2023
60558	Echeclus	Oliver Klös	JOA 4 2017
90377	Sedna	Mike Kretlow	JOA 3 2020
90482	Orcus	Konrad Guhl	JOA 3 2017
120347	Salacia	Andrea Guhl	JOA 4 2016
134340	Pluto	Andre Knöfel	JOA 2 2019
136108	Haumea	Mike Kretlow	JOA 3 2019
136199	Eris	Andre Knöfel	JOA 1 2018
136472	Makemake	Christoph Bittner	JOA 4 2018
174567	Varda	Christian Weber	JOA 2 2022
208996	2003 AZ_{84}	Sven Andersson	JOA 3 2022
341520	Mors-Somnus	Konrad Guhl	JOA 4 2022
471143	Dziewanna	Wojciech Burzyński	JOA 3 2024
486958	Arrokoth	Julia Perła	JOA 3 2023
-	2004 XR_{190}	Carles Schnabel	JOA 1 2022
541132	Leleākūhonua	Konrad Guhl	JOA 4 2024

The Discovery

The object was discovered on 2003 March 22 at *Palomar Observatory* by Mike Brown and Chadwick A. (Chad) Trujillo. The discovery was made during the Near-Earth Asteroid Tracking program (NEAT) at *Palomar Observatory*. The program ran from December 1995 until April 2007 at Hawaii (Haleakala-NEAT; observatory code 566), as well as at *Palomar Observatory* in California (Palomar-NEAT, observatory code 644). A picture of the telescope used for NEAT is given in [1]. The object was given the preliminary designation 2003 FX_{128}. The permanent number (65489) was assigned on 2003 June 14 [2].

Figure 1. Ceto (right) and Phorcys (centre) on a Roman mosaic.
Credit: Dennis G. Jarvis - Flickr: Tunisia-4751 - Phorkys, CC BY-SA 2.0, https://commons.wikimedia.org/w/index.php?curid=22469688

The Name

(65489) was named on 2006 November 9 for a Greek goddess [3], (Figure 1). Before the naming, in 2006 April 11, Noll et al. discovered an object near (65489) Ceto with the WFPC2 camera on the *Hubble Space Telescope* [4]. It received the provisional designation S/2006 (65489) 1 as a satellite. The object was found to have similar dimensions to (65489) and both objects were given the name Ceto and Phorcys (also Phorkys) in [3].

The goddess Keto (Κητώ) in Ancient Greek, is the daughter of Pontus and Gaia. She gave birth to the Gorgons and Graias as well as Echidna and Ladon, whereby her brother, the ancient sea god Phorcys (Φόρκυς), a man's head with crab's claws and a fish's tail, was the father. According to the Greek poet Euphorion, Keto also had children with Typhon.

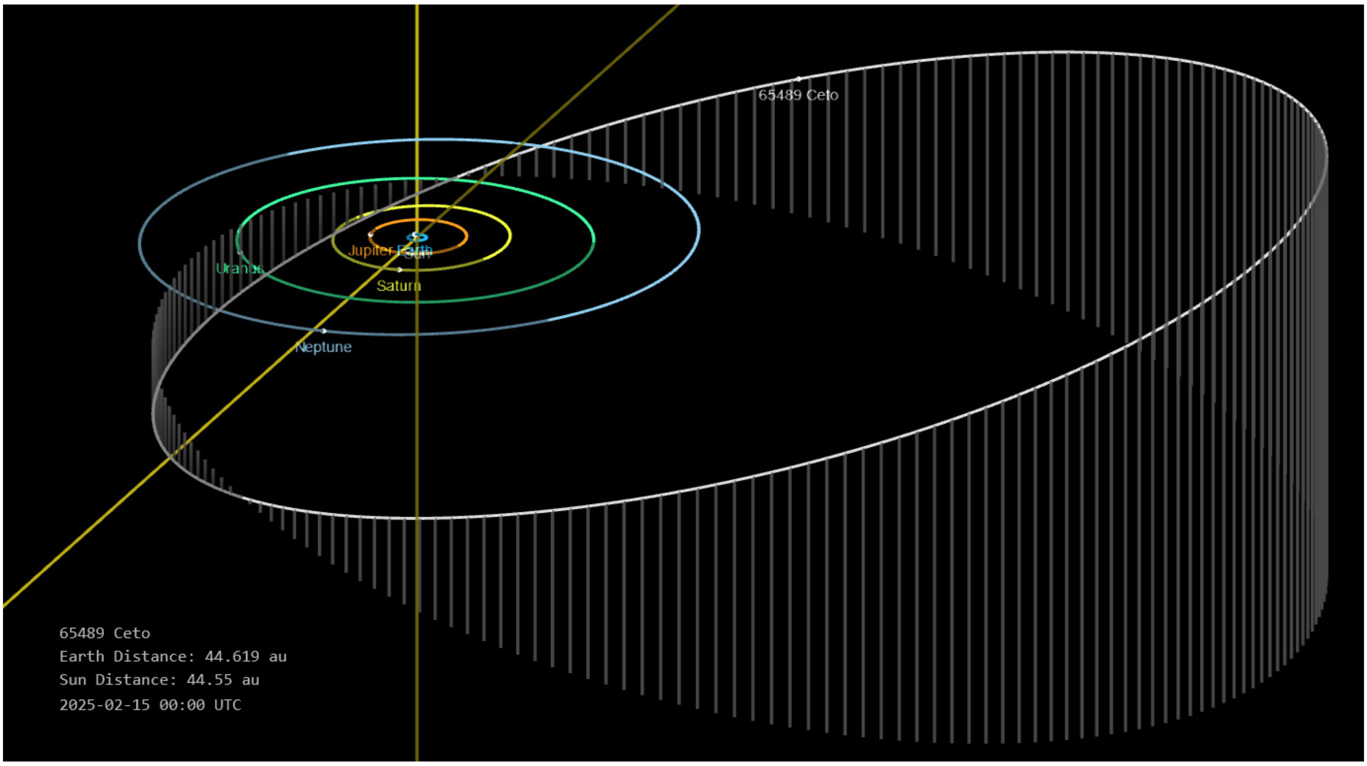


Figure 2. Orbit diagram and position of (65489) Ceto and Phorkys on 2025 February 15.
(Source: NASA/JPL Small-body database lookup, https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=65489)

The Orbit

After discovery, the object was identified in pre-discovery observations back to January 1987 at *Siding Spring Observatory* [5]. The orbit is highly eccentric (e 0.8225) and inclined 22.31° to the Ecliptic (Figure 2). With a semi-major axis of 99.677 au, the distance from the Sun is between 17.70 au and 181.66 au. With this orbit, Ceto is both an SDO and a Centaur making it one of the very few Centaurs known to be binary. The orbital period is approximately 995 years.

Physical Characteristics

The images of the two bodies (Figure 3) were separated using the Hubble Space Telescope and their orbits were determined astrometrically. The two components of the system were separated by 0.085 ± 0.002" on 2006 April 11.9 [4].

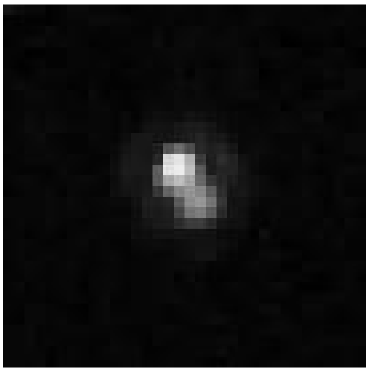


Figure 3. Hubble Space Telescope image of the trans-Neptunian object (65489) Ceto and its companion Phorcys, taken on 2006 May 6. Credit: HST

Phorcys at that time was about 0.6 mag fainter than Ceto and it was located in the direction, p.a. 11.8 ± 0.2 degrees from Ceto.

Both bodies orbit a common centre of gravity separated by a distance of between 1813 km and 1868 km from the common centre. This is 16.5 Ceto-radii or 21.5 Phorcys-radii. The orbital eccentricity of Phorcys is at most 0.015, the orbit is inclined 68.8° to the equatorial plane of Ceto. The orbits of the two bodies around each other is remarkable: the orbit of Ceto around Phorcys differs significantly from the orbit of Phorcys around Ceto due to an inclination of 116.6°, the orbits are thus inclined to each other by 47.8°. In addition, according to the different angles, the two bodies orbit around the barycentre in different directions of rotation: Phorcys prograde and Ceto retrograde. The rotation period is 9d 13h 18m. The system was observed by the *Spitzer Space Telescope* in July 2006 and the *Herschel Space Observatory* in August 2010. In [5] the group published diameters for both bodies: with an equivalent diameter D = 281 km as one object it gives D_{Ceto} = 223 ± 10 km, and $D_{Phorcys}$ = 171 ± 10 km. The calculation was based on the same albedo for the two components and Δm = 0.58 ± 0.03 mag. The absolute magnitude of the system is HV = 6.614 ± 0.021 with an albedo of 0.084 +0.021/-0.014 [6].

The group led by Will Grundy [6] also published interesting information regarding the colour: Ceto seems a little bit redder than Phorcys. The average V–I colour for the system is reported as 1.07 ± 0.04, the B–V is 0.86 ± 0.03 and the V–R 0.56 ± 0.03 [6].

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 constellations of Serpens and Ophiuchus. Consequently, no occultations are predicted for the near future. Its most recent astrometry was obtained on 2020 May 12 and so the calculation of possible occultations in 2029 (Australia) and 2030 (Europe and North America) is still too imprecise. Hopefully, new astrometry will be undertaken when the innovative 8.4-m aperture wide-field *Simonyi Survey Telescope* housed in the *Vera C. Rubin Observatory* on Cerro Pachón, Chile, comes into operation in 2025.

References

[1] Andersson, S., Beyond Jupiter - (208996) 2003 AZ_{84}, Journal for Occultation Astronomy, Vol. 12 No. 3, p. 23
https://www.iota-es.de/JOA/joa2022_3.pdf
[2] Minor Planet Circ. 48995
https://minorplanetcenter.net/iau/ECS/MPCArchive/2003/MPC_20030614.pdf
[3] Minor Planet Circ. 57952
https://minorplanetcenter.net/iau/ECS/MPCArchive/2006/MPC_20061109.pdf
[4] Noll (2006), IAUC 8778
http://www.cbat.eps.harvard.edu/iauc/08700/08778.html
[5] Santos-Sanz; P. et.al, "TNOs are Cool": A Survey of the Transneptunian Region. IV.
http://arxiv.org/pdf/1202.1481
[6] Grundy,W. M. et. al., The orbit, mass, size, albedo, and density of (65489) Ceto/Phorcys: A tidally-evolved binary Centaur, Icarus 2007
https://arxiv.org/pdf/0704.1523

Useful Links

About objects like TNOs and Centaurs:

NASA/JPL Small-Body Database Lookup
http://ssd.jpl.nasa.gov/sbdb.cgi
Spacewatch, Lunar and Planetary Laboratory, University of Arizona
http://spacewatch.lpl.arizona.edu
Minor Planet Center
http://www.minorplanetcenter.org

News

End of ESA's Gaia Mission – A New Task for Observers

The European Space Agency (ESA) has announced on its website that the *Gaia* mission will end on 2025 January 15. After this date, the satellite will no longer be used to collect scientific data. The cool gas propellant, which is essential for the satellite's rotation, has almost been used up. The collected data will continue to be processed and published in Data Release 4, which is planned for 2026. The final Data Release 5 is expected at the end of the decade.

Technological experiments will be carried out after January 15. The remaining cool gas propellant is expected to last for 15 days and will used for several tests (Figure 1). These tests should provide information on the behaviour of individual instruments and components of the satellite. The data will be used to calibrate the data obtained by *Gaia* and will be incorporated into future mission planning.

Details of the upcoming tests can be found here:

https://www.cosmos.esa.int/web/gaia/technology-tests

After these tests, Gaia will leave its stationary point at Lagrange Point L_2 and move into a heliocentric orbit, to avoid any harm or interference with other spacecraft.

Gaia may then be switched off in March/April 2025.

GBOT – Gaia Ground Based Optical Tracking

Most of the time *Gaia* was observable at a brightness of 21 mag in the red bandpass (Figure 2). The upcoming technological experiments will change *Gaia*'s orientation relative to the Sun and this may increase its brightness up to 14 mag in the red bandpass. The *Gaia* team is calling on the community of observers to carry out photometric observations. A website with the probe's ephemeris for cities with more than 100,000 inhabitants (Figure 3) will be available:

https://gaiainthesky.obspm.fr/index_gaia.php?page=FOV&sous_menu=public

Details will follow in the coming weeks on this website:

https://www.cosmos.esa.int/web/gaia/observe-gaia

(O.Klös)

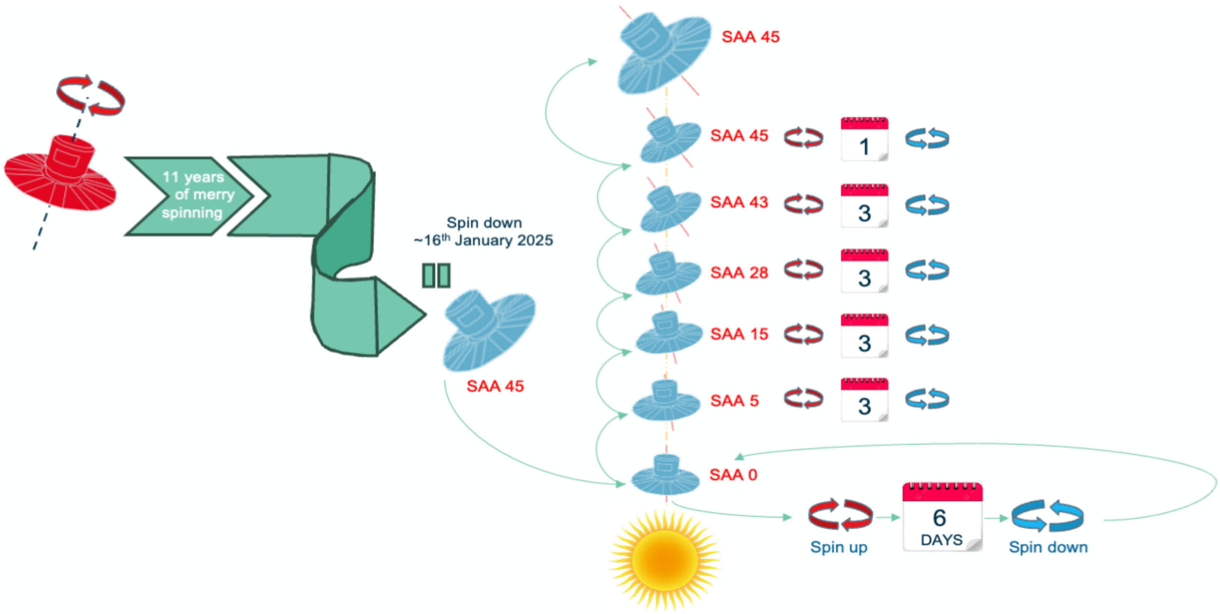


Figure 1. Gaia's expected attitude profile following the end of Gaia science observations on 2025 January 15. The planned timing may still change. Credits: ESA/Gaia/DPAC - CC BY-SA 3.0 IGO. Acknowledgements: Gaia Flight Operations Team.

News

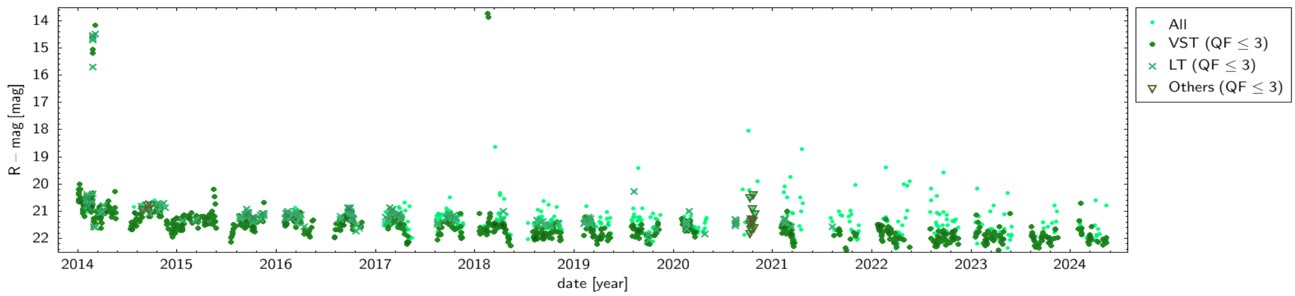


Figure 2. Gaia Ground-Based Optical Tracking measurements showing apparent magnitude of Gaia as a function of time, with a clear peak at the start in 2014 when Gaia was in its commissioning period, and another clear peak around 2018 when Gaia was oriented differently with respect to the Sun with a commanded safe-attitude manoeuvre to avoid the Draconid storm. Credits: ESA/Gaia/DPAC - CC BY-SA 3.0 IGO. Acknowledgements: Gaia GBOT team

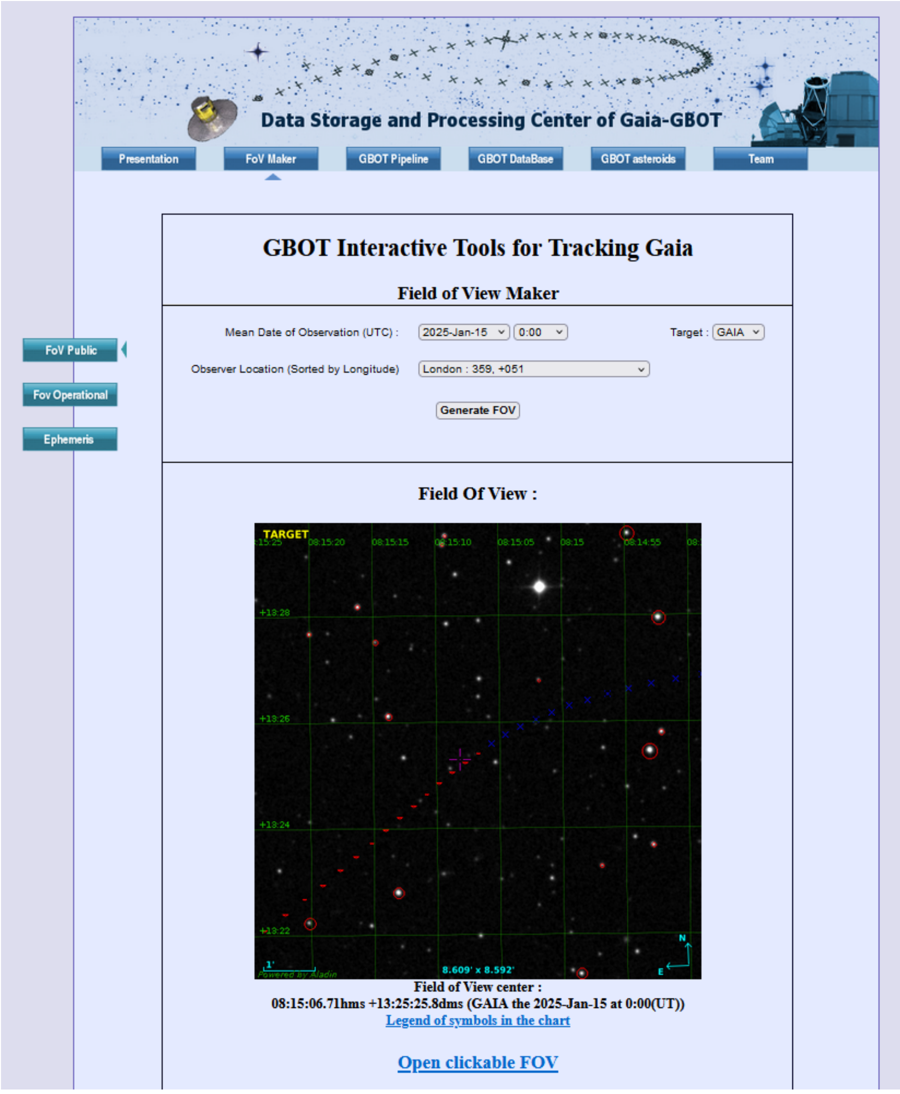


Figure 3. Screenshot of the webpage of GBOT Interactive Tools for Tracking Gaia. The portal provides ephemeris for Gaia and sky maps for worldwide observer locations. (Screenshot: O. Klös)

The International Occultation Timing Association's 42nd Annual Meeting, 2024 September 28-29

Ted Swift · IOTA · Davis, California · USA · tjswift@omsoft.com
Richard Nugent · IOTA · Dripping Springs, Texas · USA · RNugent@wt.net

ABSTRACT: IOTA's 2024 Annual Meeting was held online via Zoom on 2024 September 28-29. Numerous presentations were made by members of the worldwide IOTA community. More than 60 attendees participated in the meeting.

The 42nd annual meeting of the International Occultation Timing Association was held on Saturday and Sunday 2024 September 28-29 online via Zoom.

Video recordings of the sessions are available on YouTube [1].

Saturday 28th September 2024 - Day 1

Vice President Roger Venable was not able to attend and open the meeting: Hurricane Helene had knocked out his power and internet. **Ted Blank** stepped in and welcomed everyone to the meeting.

Business Meeting

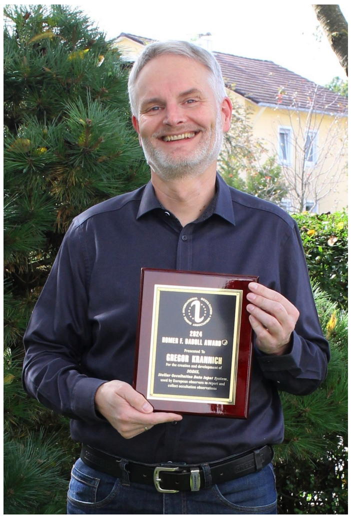
Treasurer **Joan Dunham** presented IOTA's financials and membership status.

A full report of the business meeting is available [2].

Awards

Ted Swift presented IOTA's Homer F. DaBoll, David E. Laird and the Lifetime Achievement awards [3].

The *Homer F. DaBoll Award* is given to recognise significant contributions to the field of occultation science and to the work of IOTA. This year's recipient of the *Homer F. DaBoll Award* went to the **SODIS Team (Stellar Occultation Data Input System) from IOTA/ES: Sven Andersson, Karl-Ludwig Bath, Wolfgang Beisker, Konrad Guhl, Gregor Krannich, Mike Kretlow, Christian Weber, Nikolai Wünsche. Software Engineer: Erik Tunsch**. The Stellar Occultation Data Input System (SODIS) was created to collect occultation observation data in an automated manner [4]. Prior to SODIS, Eric Frappa had collected, reduced and posted occultation observations on the IOTA/ES website from European observers, which was quite a task!



Figures 1 - 4. Some of the recipients of the Homer F. DaBoll Award: Christian Weber, Mike Kretlow, Konrad Guhl and Gregor Krannich (clockwise).

The *David E. Laird Award* is given to recognise those who, more than 15 years ago, made significant contributions to occultation science and to the work of the IOTA. This year's *David E. Laird Award* recipient is **Berton L. Stevens, Jr.** from Las Cruces, New Mexico. Bert helped form IOTA in 1975 and was IOTA's first Secretary and point of contact for three years. He completed *ACLPPP*, the *Automatic Computer Lunar Profile Printing Program* which advanced lunar graze predictions. Bert has discovered 78 asteroids and reported over 30,000 asteroid astrometric positions, including over 17,000 NEOs.

Figure 5. David E. Laird Award: Berton L. Stevens, Jr.

Upon notification of the award, Bert sent the following e-mail:

I am honored to receive this award for my past contributions to IOTA and our work on occultations. The David E. Laird award is a meaningful reminder that our efforts can resonate over time. Thank you for recognizing the value of my work in helping to form IOTA and writing ACLPPP. I hope to start contributing occultation observations in the near future, only they will be of minor planets and not the lunar limb.

Thank you again!
Clear and dark skies!
- Bert

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

This year's Lifetime Achievement Award recipient is **Dave Herald** from Murrumbateman, Australia.

A partial list of Dave's contributions to the occultation community includes:

• Dave is the author of the widely acclaimed program, *Occult* [5], in use since the 1990s which predicts all types of occultation events, eclipses, transits and more.
• Maintains the database of all observed asteroidal occultations, plus lunar limb data from grazes and total occultation observations from all the IOTA Sections worldwide (Dave Gault also plays a key role in this).
• Deals directly with the Minor Planet Center to send updated astrometry from asteroid and other occultation results. High precision astrometry is key for updating asteroid orbits – JPL Horizons relies on MPC to update their database (1.3 million asteroids, 3900 comets, 293 planetary satellites).
• Communicates with VizieR to send asteroid occultation light curves.
• Author/Co-author of over 100 papers in peer-reviewed journals.
• Longtime involvement with the solar radius measurements during solar eclipses.
• Dave is one of the world's most respected occultation astronomers.
• Asteroid (3696) Herald named in his honour.

Figure 6. IOTA Lifetime Achievement Award: Dave Herald.

Upon notification of the award, Dave sent this e-mail.

I am truly honored to receive this award. It has caused me reflect on some of my many notable memories:

-1956 opposition of Mars. As a 5yo, my father showing me Mars through a telescope he made using a blank lens for spectacles and an eyepiece from a very old microscope, which he mounted in a length of downpipe.

-1966 May 7 – my first lunar occultation, which I subsequently 'reduced' using 7-figure log tables. Observed with a 4cm telescope.

-1970/71. My first programing to compute a lunar ephemeris. Back in the days of Hollerith punch cards, and core memory.

-1990. The beginning of Occult – programmed on a Commodore 64 as several modules.

-2003 Meeting Gareth Williams (the then directory of the MPC) in Sydney, which led to the reporting of asteroid astrometry from our occultations

-2005 Following a work meeting at the US Patent Office in Washington, staying a couple of days with David & Joan Dunham – which led to me taking on the collection of asteroidal occultations globally

-Recent times – seeing the results of our observations for some critical objects providing astrometry of greater precision than all the professionals – a testament to the power of what we can achieve. And, at long last, substantiated discoveries of asteroidal satellites.

A satisfying journey of almost 70-years
A journey where the time to pass things on has begun.

Thanks to IOTA and 30 reviewers and exporters, and commenters. Thanks to the observers, without whom this would be nothing.

Technical Sessions

Norm Carlson spoke about "*Recent Well Observed North American Asteroid Occultations*." Norm leads the North American Asteroid Occultation Report Team. There has been a large increase in the number of observations, so there have been plenty to choose from: Big Events (large asteroids), small but important events, asteroids and satellites and double star events.

Recent Large events:

• (704) Interamnia, 306 km dia across USA, including 3 observations by J. Moore. Well covered. (Ted Blank chat: I posted a video of my Interamnia positive on YouTube if you need an example of an occultation [6]).

• (P7M03) Titania, 1577 km dia, across most of USA and S. Canada. Well covered, and had several valuable constraining misses. There was a 200 km south shift, so this will improve future orbits.

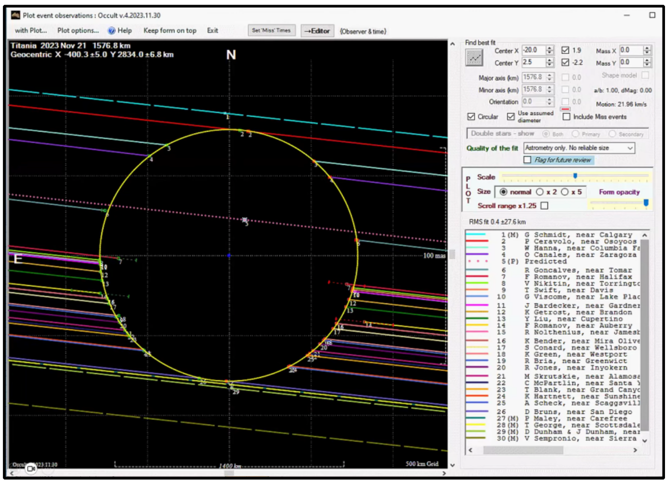


Figure 7. Profile recorded during an occultation by Titania, satellite of planet Uranus on 2023 Nov 21.
(Source: Occult V4, screenshot from N. Carlson's presentation)

Lessons:

• Live life on the edge: Edge chords are more valuable for discerning maximum shape and improving astrometry.

• Elevation corrections were very important for several small high-value events this year. These corrections can be done in OWC. OWC draws a line to the elevation-corrected location. Two (65803) Didymos events (800 m diameter!), two in Sep. The second one on 2024 Sep 22 got 4 tracks. There were 2 positives on the 2024 Sep 19 event. (65803) Didymos was about a half a pathwidth south of the predicted path. Yanzhe Liu got a tentative positive, went through the diffraction patterns. Points: Pay attention to the little white lines for elevation corrected lines in *Occult*.

Asteroids and Satellites: (4337) Arecibo 2021 May 19 Discovery. (276) Adelheid discovery. "Less typical" satellite discovery for (5232) Jordaens: Observers saw either the primary OR the secondary, but not both.

Observation just in for the Arecibo event from Sep 14: Overlapping bodies. Point: Multiple stations on an event often provides more information than single stations on multiple asteroids.

Light curves: Pay more attention to them: Examine them carefully for features that might reveal double stars, etc. Seek out Dave Gault's video about sending your light curves into VizieR. Point: Slow down for the curves: Pay attention to details, add comments, "possible steps, possible peak". Send your light curves into VizieR if not submitted by the regional coordinators.

Appendix: Review of the review process: Number of reports has risen steeply in 2020 through 2024, though there has been an increase each year since 2012. There were 840 North American events as of end of Sep 2024; projecting ~1100 by end of Dec. (Causes would include Gaia data releases and thus vastly improved path uncertainties, beginning with DR 1 in Sep 2016, DR2 in Apr 2018, Early DR3 in Dec 2020, and DR3 in Jun 2022).

Norm Carlson next spoke about *"The Review Process for North American Asteroid Occultations."*

Send the log, report file, CSV file, light curve. Then all files are sent out to a reviewer. First the report form is reviewed: Reviewers have seen errors in just about every report filed. Reviewers process the CSV to compare with the observer's results. They use *AstRepToXML* and *Occult 4* to check and combine observations, generate sky plane plot, site location plot, update web page, The Coordinator sends light curves to VizieR.

The North American Review Team is looking at a more automated system, like SODIS, but for now the review team consists of Jerry Bardecker, Steve Conard, Bob Dunford, Ernie Iverson, Steve Messner, John Moore, and Kevin Green is getting up to speed. Tony George handles difficult cases. Johnny Barton and Dave Eisfeldt provide Tangra report. Dave Gault does final review.

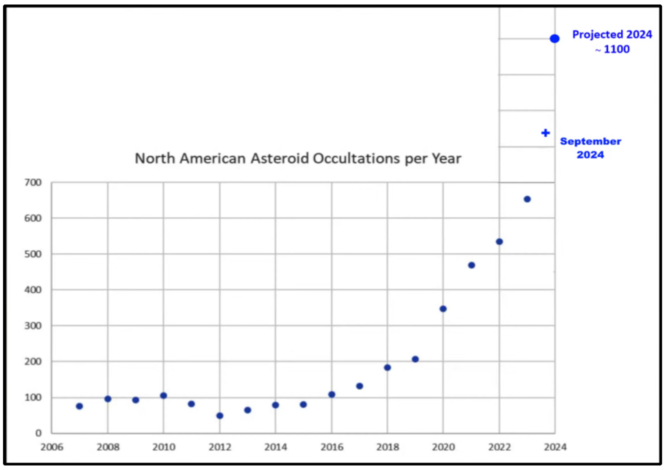


Figure 8. The number of observations still rises in North America. (Screenshot from N. Carlson's presentation)

Ted Blank, as host, thanked Norm and the review team for all their work, and suggested that if anyone wants to join the reviewer team, contact Norm at reports@asteroidoccultation.com.

Jean-François Gout presented the observation of an occultation by (10424) Gaillard, which revealed the binary nature of this main-belt asteroid. Details were shown of how the light curve was analysed to rule out alternative hypotheses (such as a binary star) and how he acquired additional data (light curve) to confirm the binary nature of this asteroid. Asteroids can have moonlets. Equipment used: C11 Edge HD Hyperstar STD, large FOV, ZWO ASI533MM, 1.2 deg FOV. He made a small roll-off shed observatory for his setup.

(10424) Gaillard has an estimated diameter of 6.5 km. Discovered 1999 by OCA-DLR Asteroid Survey. Named for Boris Gaillard by Alain Maury (Note the French theme; though Gout is in Mississippi, USA).

Figure 9. The roll-off observatory with the C11. (Screenshot from J.-F. Gout's presentation)

The event on 2024 Jan 14 was max dur 0.71 s, Probability 76.6%. Jean was very excited when viewing in real time. The two events with a total duration about as long as expected. It was not scintillation, a cloud, bird or an airplane. Was it a binary asteroid or binary star? Looking more closely at the light curve: With a binary asteroid, each component would be expected to block 100% of light from the target star. A binary star would have different depths, except in worst case with both components being the

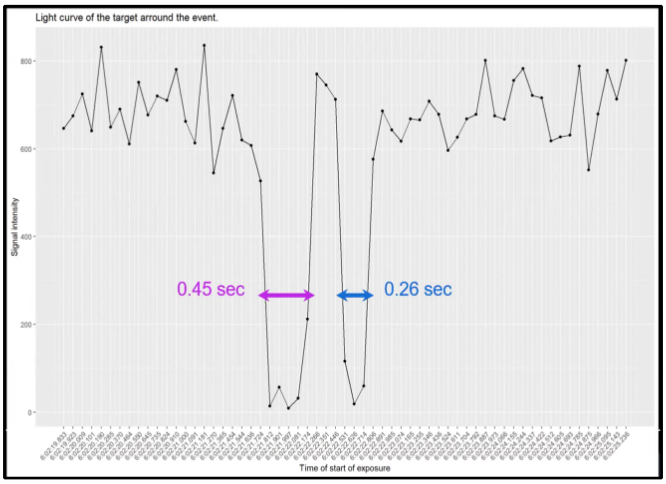


Figure 10. Lightcurve of the (10424) Gaillard occultation. (Screenshot from J.-F. Gout's presentation)

same magnitude. The point is to check the total mag drop and drop to background black. Still to be resolved: Is it a binary asteroid or dog bone shape? Collaboration with Matthieu Conjat and a 40″ telescope, light curve details and confirmation by Tony George and Dave Herald and the event was reported to CBET.

There have been three officially recognised asteroidal satellites in just 18 days!

Conclusion: Keep observing. Small ~10 km asteroids are likely to be binary. Improved SNR is needed to detect difference between noise and a binary.

President Steve Preston gave a talk presenting a few of the better "easy to observe" asteroid events for the rest of the year. The events were mostly in the North American region with a few crossing other regions.

Best 2025 North American asteroidal events were presented with bright stars, path well constrained, etc., < 0.1 diameter uncertainty.

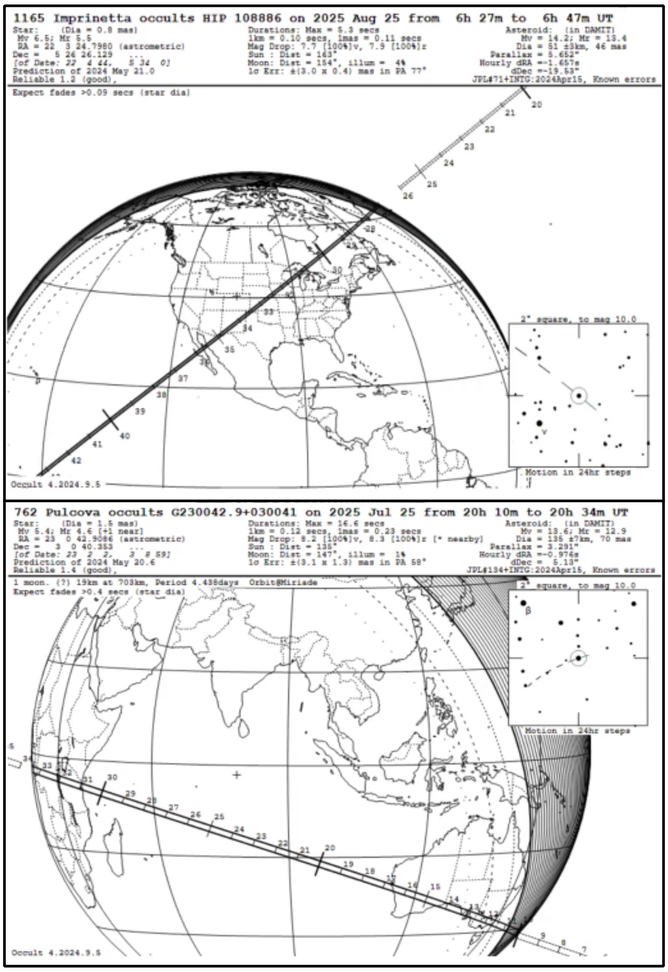


Figure 11. The two events presented by Steve Preston. (Screenshot from presentation, Occult 4.2024.9.5)

Good worldwide events 2025:

- Europe: (88) Thisbe on Jan 9, (200) Dynamene over N. Europe on Aug 15.
- Asia/Africa: (777) Gutenberga on Apr 22, (577) Rhea across Japan on May 25, (163) Erigone across S. Australia on Jul 18, (762) Pulcova across S. Australia and E. Africa on Jul 25.

David Dunham presented a talk about "*Important NEO, Trojan and KBO Events for the Coming Year*. David acknowledged Steve Preston's contributions for 2024 and 2025. The 2025 events will added into the Handbook of the Royal Astronomical Society of Canada (RASC). First, David presented preliminary results of the observation of the occultation by (4337) Arecibo on 2024 Sep 14 with plots by D. Herald (Figures 12, 13).

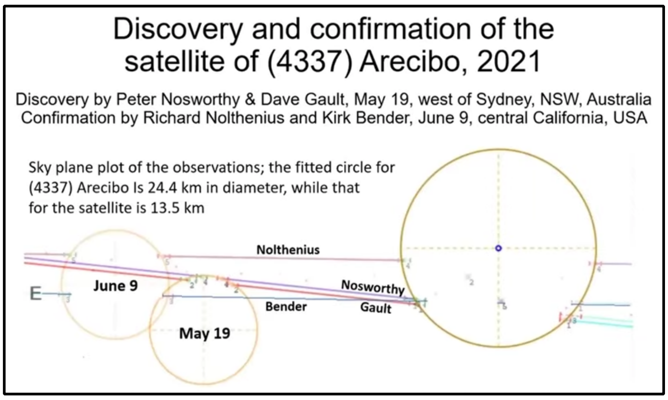


Figure 12. Sky plane plot of the occultations by (4337) Arecibo. (Screenshot from D. Dunham's presentation)

The Occultation of 2024 September 14, Preliminary Results

Line	km	
--	16.4s	Damien Lemay, Rimouski, Quebec – Miss (CCD drift scan obs.)
5.2s	10.5s	UVA1 – Miss (Univ. VA exped. to Mich., planned by Ted Oakey)
4s	8.0s	UVA3 – Clouded out
3s	6s	Dunham3s – 0.74s by main body
2.6s	5.2s	UVA2 – 0.7s by main body
1.3s	2.6s	Bill Yeung – cancelled
-2.4n	-4.8n	Dunham3n – used site Dunham3s instead
-3.5n	-7n	Tharan – didn't get on target in time
-4.5n	-9n	Nolthenius – Miss ("Pillar of Hercules")
-5.6n	-11n	Dunham2 – operator problem with Astrid, no recording
-7n	-14n	Bender – 0.[illegible]s by satellite
-9n	-18n	Nikitin – Miss
-11n	-22n	Dunham1 – Miss

Sky Plane Plot Later, after all reports in. The quick look shows the French prediction was rather good, with the satellite a little farther north than expected. Positives and constraining misses are underlined.

Figure 13. List of chords of the occultation by (4337) Arecibo on 2024 Sep 14. (Screenshot from D. Dunham's presentation)

An astrometric "wobble" was found by *Gaia*. Maps in David's presentation show important upcoming NEO, Trojan and KBO events for the end of 2024 and for 2025 (Figures 14, 15). Interesting events include the occultation by contact binary (234) Barbara on 2025 Jan 1 observable in the SF Bay area to GA. The asteroid (10253) Westerwald will be a target for a space mission by the United Arab Emirates and will occult a 9.4 mag star on 2025 Dec 7. David concluded his talk with the best lunar grazing occultation events for North America.

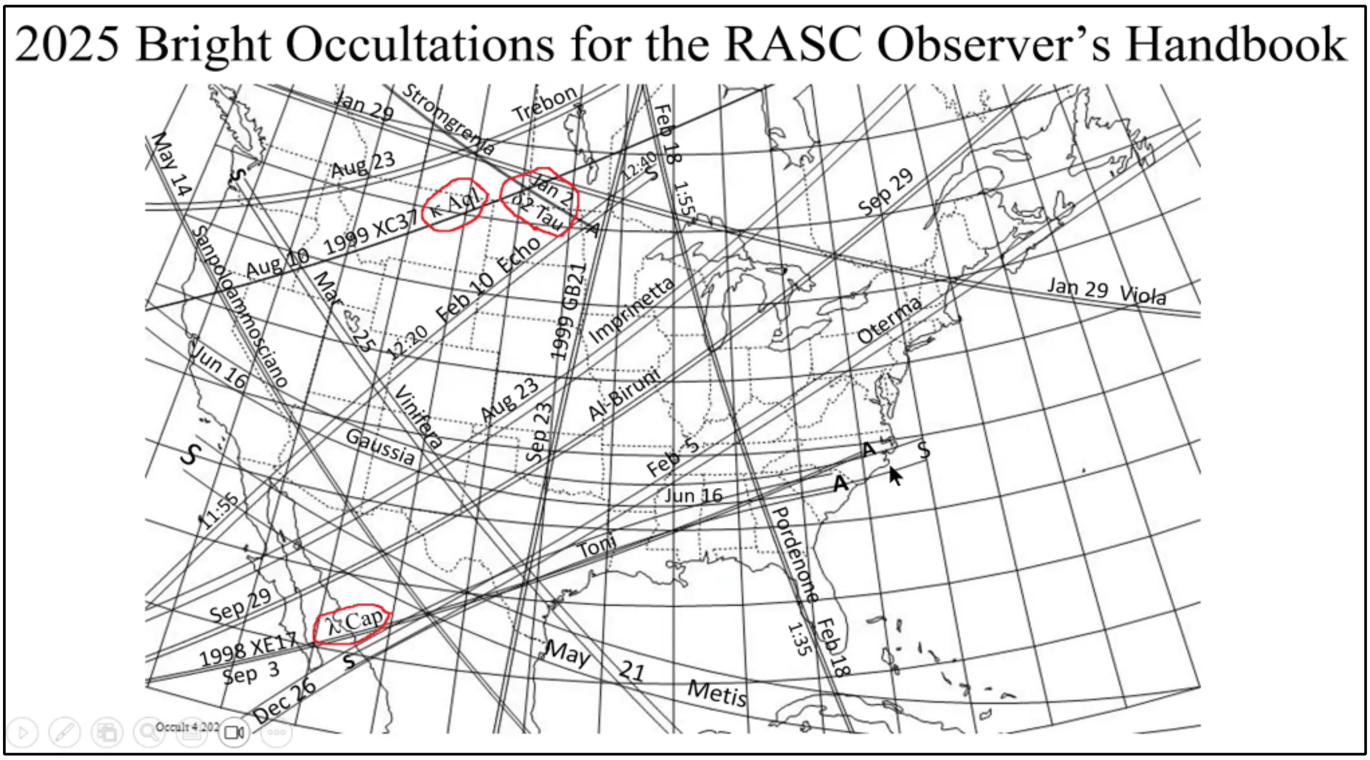


Figure 14. Shadow paths of bright occultations by asteroids across North America in 2025. (Screenshot from D. Dunham's presentation)

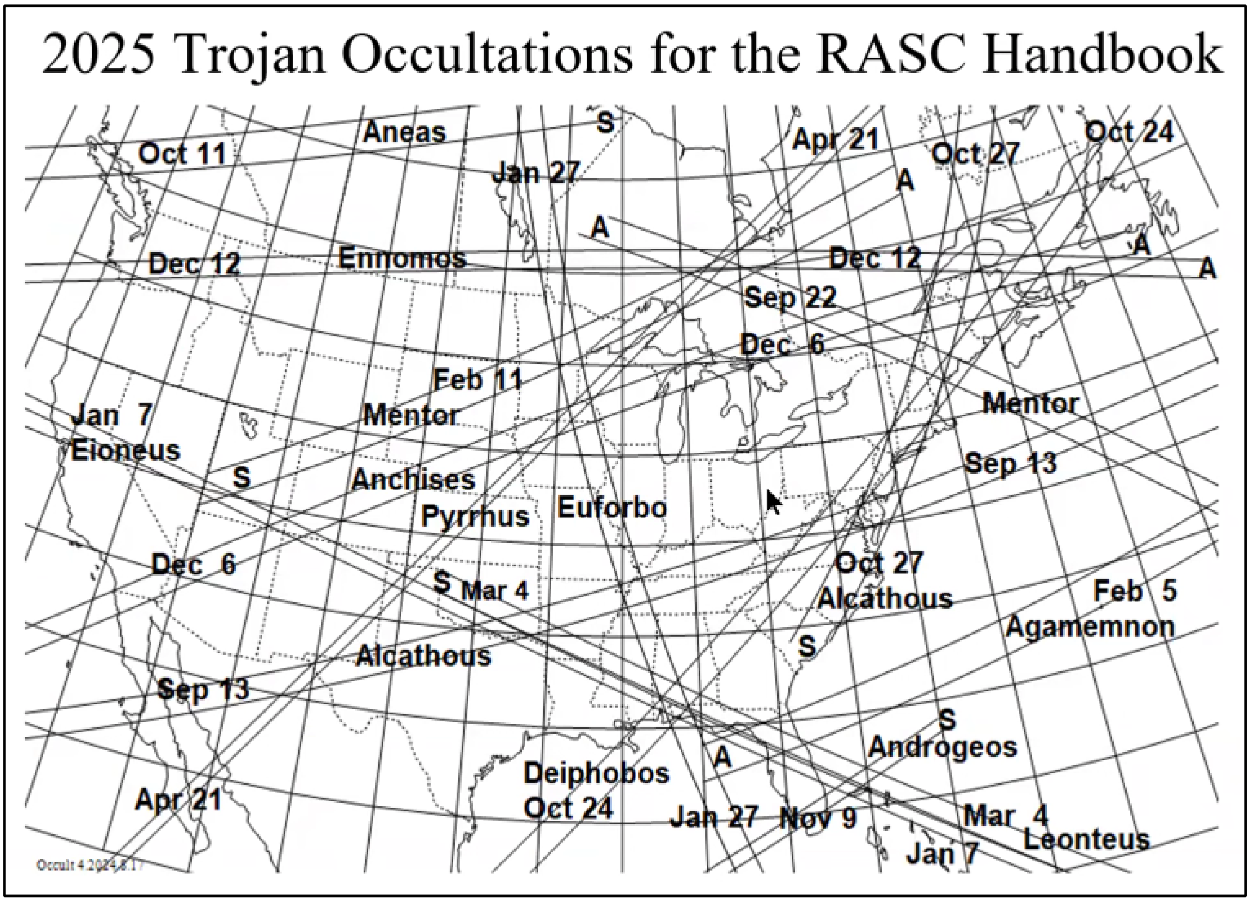
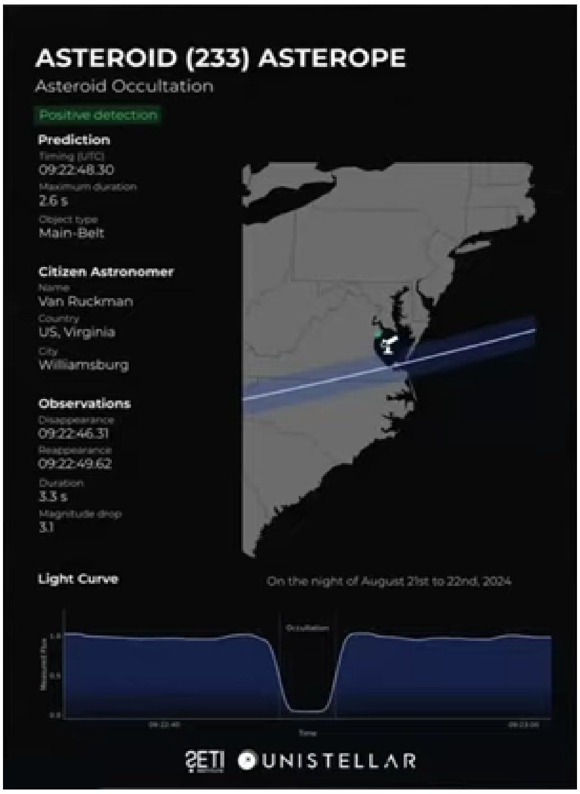


Figure 15. Shadow paths of Jupiter Trojans across North America in 2025. (Screenshot from D. Dunham's presentation)

Frank Marchis, Tom Esposito, Ryan Lambert presented the talk: *"Stellar occultations by the Unistellar Network."* Marchis is with the SETI institute.

Unistellar started as a Kickstarter project, it now consists of four models. These smart telescopes are small, compact, easy to use and have a CMOS sensor. Images/videos are sent directly to cell phones with an approximate ~70 ms delay. Some 17,000 of these telescopes have been sold. The tag line to encourage occultation participation is "Come for the images, Stay for the Science". There are telescope software updates every 3 months or so. The education foundation Unistellar College Astronomy Network (UCAN) is for developing Citizen Science. Dr. Daniel O'Connor Peluso was a Unistellar Education Associate & Exoplanet Assistant Researcher from 2020-2023. He has a paper in regards to this research submitted to the Astronomical Journal (AJ). These telescopes have been donated to Astro Clubs, where one can get in contact. The majority of these telescopes are in US, Europe, Japan; more are coming in Argentina, E. Africa. A Citizen Science program with Charles University in Prague has been established with Dr. Josef Hanuš as the occultation lead.

The science pipeline is housed on *Google Cloud*; and reported on Slack. Unistellar's main website has a live view of uploaded observations, live view for processed data (Figure 16), [7]. This site is not only for Unistellar users! There are Citizen Science programs on several topics: asteroid occultations, planetary defence, exoplanets, comets, cosmic cataclysms and observations of satellites, the most concentration is on occultations.



The telescope/camera field of view (FOV) is about 0.5 deg. The software can generate a light curve automatically. The controlling computer/tablet/phone sends observer reports to the analysts. The program is open to all. For occultations, Unistellar can reach a brightness of ~11.6 mag, durations of >0.5 s, a magnitude drop of >0.9 mag, and an asteroid size of >5 km. Globally over 1,600 asteroid occultations have been observed (positive and negative) [8] with predictions for specific observer positions. Automatic processing is in the works for rapid reporting. A decision was made to prioritise science on space mission targets and NEOs.

On how to observe: From the Unistellar website, join Citizen Science, generate a calendar under "Find your event". The group would like to formalise prediction arrangements between Unistellar and IOTA.

Contacts: fmarchis@seti.org and hanus.hom@gmail.com

A few Q&A's after the presentation:

Q: After an occultation, how long does it take to get to IOTA?
A: One year. Leaders wanted to make sure the pipeline is accurate. Want 95% positive/negative before speeding up transfer to IOTA.

Q: Are there plans for future telescopes with larger apertures?
A: Yes, but challenge is to keep weight managed. The market for small telescopes is higher than for large telescopes.

Roger Venable was scheduled to speak, but he's out of communication from Hurricane Helene. So **Joan Dunham** talked about using a *Windows 11* laptop for occultation recording – "*Ideas on how to prepare Windows 11 laptops for unattended occultation recording*".

Past efforts to make an automatic recorder worked with *Windows 10*. It is more difficult with *Windows 11*: There are different versions of *Windows 11*, so a single instruction set is hard to provide. Thus, Joan presented this for data capture, but NOT unattended operation. She gave several hints on how to handle occultation observations with this operating system and showed preferred settings and issues which should be avoided. In the future there will be a table on IOTA's webpage of options found under settings in *Windows 11*, notes which features may affect an observing session, and suggestions.

The talk was followed by a discussion and an exchange of experiences by several participants about computer issues due to operating systems and hardware configurations.

Figure 16. Example of a Unistellar occultation report. (Screenshot from the presentation)

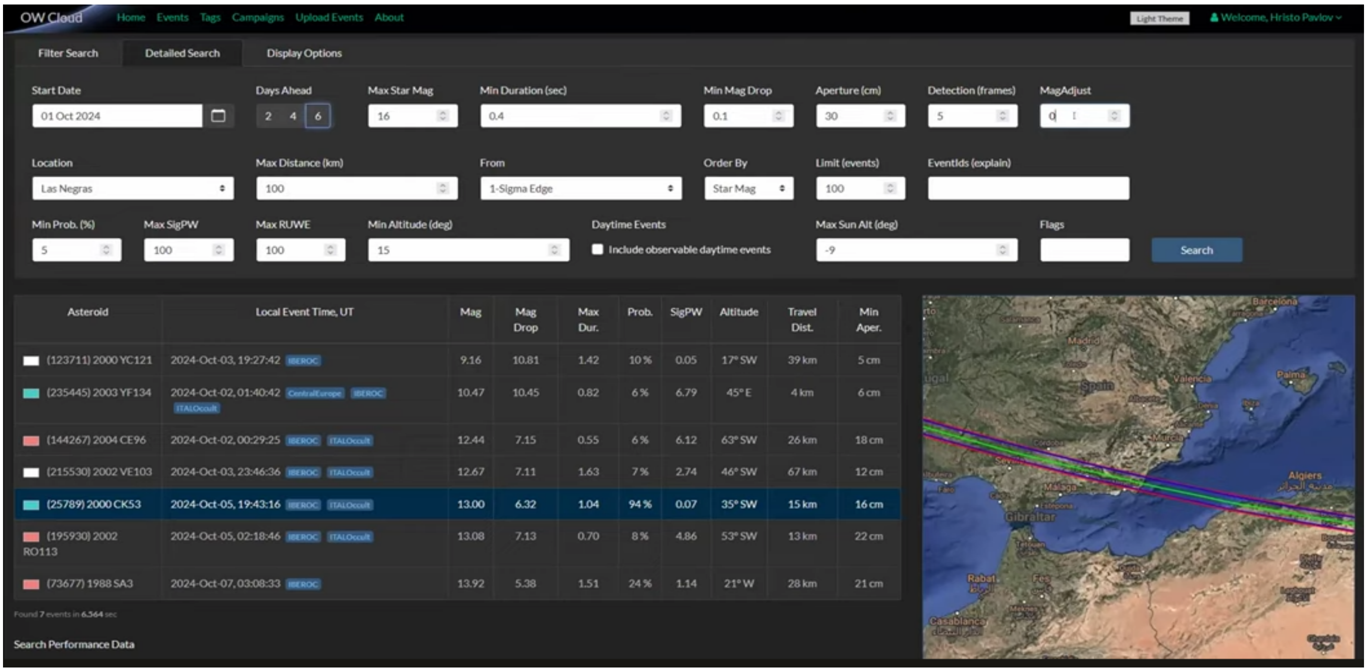


Figure 17. Screenshot of Occult Watcher Cloud's filter options. (Screenshot from H. Pavlov's presentation)

Hristo Pavlov next discussed *Occult Watcher Recent Updates*. A lot of development in the *Occult Watcher Cloud* (OWC) [9] space in the past few months. A group of beta testers have been commenting, almost ready to present. Most observers use *OWdesktop* [10], which has a couple of limits: Limited to feeds, and some people want to do more. *OWC* will precompute a lot of events through the next two months and make them available. One search page is for search by object, where you have a number and date. There is a need for a more advanced search: Filter events based on visibility based on set of parameters (Figure 17). Hristo discussed several parameters and options for doing searches and advanced searches such as your location, distance from the errors in the path, etc. *OWdesktop* event filters are more limited. And *OWC* is working with a much larger pool of potential events.

Sunday 29th September 2024 - Day 2

Technical Sessions

Roger Venable called the meeting to order on time. His power and internet had been restored after Hurricane Helene. 56 attendees joined the meeting.

Mark Simpson began the day's session presenting *"The Astrid Imaging System."* Mark described the ASTRID [11] system. He started doing occultations in March 2023 and wanted to figure out the best method for doing them. Some of the problems regarding recording equipment were that cell phones have variable frame rates, QHY174M-GPS required problematic firmware updates, and the EVScope's raw video couldn't be converted (it required extraction from Cloud; not available) Cell phone timestamps are only accurate to 1 s, and their compressed video is poor. This impacts the quality of the scientific data and has resulted with many questions. Analogue is going away and is difficult to source. Digital is here now. And time-based accuracy is the key.

Wish list: The system needs to be cheap and easy to repair, double duty (astrophotography and occultations), easy to deploy, with a consistent paradigm (ASI Air/Nina, etc.), a global shutter and accurate timing to eliminate debate. And all this in a single unit, connected by wireless. Thus the ASTRO Imaging Device (ASTRID) was born. ASTRID is a self-contained unit (with a Rasp Pi 4 camera, timestamp and software) that plugs into the eyepiece, has a wireless connection (VNC, Remote Desktop) and provides accurate timing. Operates off a 12v DC supply, Mark did not recommend cheap 12v "power banks" as they can't supply advertised current. Exception: Celestron power packs are fine. ASTRID has switchable camera sensors, mono or colour (it's shipped with mono now), has GoTo plate solving, polar alignment, synchs to *OWC*, thus reduces user error, has audit trail, report fitting (for North America form). There's no compression, frame triggered, all this in a 3D-printed case with a small fan on the back.

Figure 18. The control unit of ASTRID. (Screenshot from M. Simpson's presentation)

ASTRID camera is an all-encompassing occultation recording system. ASTRID can be attached to a T-slot telescope mount made by John Broughton [12].

An extensive discussion followed. Watch the recording of the session on YouTube for details [13].

Joan Dunham talked about plate solving with *SharpCap Pro* [14]. She discussed plate solving and illustrated using that technique with *SharpCap Pro*, with particular attention to plate solving for assisting in observing with non-automated telescopes. With plate solving the software compares the field of view of the telescope/video to the stellar database and makes adjustments of the two until the desired FOV is acquired. This is analogous to image registration.

"Plate solving/Plate reductions" is a term that came from matching star catalogue positions to images on glass photographic plates. Astrometry.net provided a rapid method for solving: Indices of quads, data and software are in the public domain. Nova.astrometry.net is freely offered.

SharpCap requires some external programs for *SharpSolve* to work properly. Good plate solving requires about 100 stars. Plate solvers need FOV and focal length; astrometry.net can provide a first guess.

Michael Camilleri spoke about inexpensive GPS timing - "*How to turn any astrophotography setup into an occultation rig for < $20*." Two inexpensive and accurate methods of timing, GPS flash timing and GPS PPS to PC timing are described. These can be used with most PC setups and any type of camera (CMOS, CCD, rolling or global shutter) with remote and/or unattended use possible. At < $US20 for the cheapest method they are ideal for new or casual occultation observers to get started using their existing equipment.

Figure 19. Components of the inexpensive DIY GPS-timing device. (Screenshot from M. Camilleri's presentation)

Steve Preston talked about "*The GPS Flasher Device.*" The GPS flash timer is for cameras that don't have timing built in, e.g. planetary camera. Ways of transitioning to occultation observing are needed and the flash timers offer an approach. Components are the IOTA-GFT device (printed box by John Moore), LED holder on scope, GPS antenna, the recording computer that has an *IOTAGFT* app and FitsReader app (provided by Bob Anderson). The current release supports *SharpCap*. The device can tell *SharpCap* to start recording, then flashes, records event, then flashes, then stop recording. The log file records flash timings, timestamps frames that have timestamps, interpolates automatically, unless it has problems.

Future releases can support *Linux* or *iOS* assuming we can identify recording software on these platforms. Gout said that *FireCapture* [15] works well on *Linux* and *iOS*.

Status: The timer is ready for beta testers, more will be built after the testing. The cost will be about $US150/unit and it's open source if someone wants to make one.

Kevin Green reported a summary of "*College and High School Student Involvement with Occultation Observations in Connecticut (CT)*." At the University of New Haven; he's trying to get students involved in occultations including people from the local astronomy club. The NE USA has a Yahoo group: OccultNEUS [16]; Several IOTA members are in this discussion group: Viscome, Conard, Kamin and others; the goal is to get more scopes on more events to get more chords for asteroid events. The stations are still too far apart to get multiple stations.

Goals: To get multiple scopes on more events which leads to better astrometry, detailed asteroid shapes and possible satellite detections. Automated scopes via *SharpCap* allowing for unattended observation are being considered, details are still being worked out. Some university departments require some research activity and this provides an opportunity to recruit more observers.

Public involvement and local training will create the next generation of scientists, engineers and educators. We see a lot of grey/white hair in this meeting. We're helping the next generation get started.

The *John J. McCarthy Observatory* in western CT has been doing astrometry for years and has a pipeline of students. The main telescopes are a 12" Skywatcher and a 9.25" second scope. There is a course in astronomy with a lab scheduled to be offered in spring, this will require buying more scopes. Cameras have been purchased via a NASA CT Space Grant; not just for academics.

The hook: "Do you want to do science that will get to NASA? Something new that no one has ever done before?"

Dave Herald's original presentation was scheduled to be "*The Best World-Wide Asteroidal Occultations Since Last Year*." This was changed to subjects that are important to consider for our future. Dave has several concerns (though not criticisms) of the occultation process.

One concern that Dave mentioned was time issues which is the most critical component of our observations. Three recent observations were compromised by time issues, two involving Didymos – the asteroid of NASA's *DART* mission. With video, we have documented extensive testing by Gerhard Dangl and others like Bob Anderson. However, we don't have an equivalent analysis for time devices.

Concerns are:

1. Have camera delays been adequately tested for accuracy and reliability?
2. Any variations depending on camera?
3. What assumptions are made? -How do you know what you know?
4. Does IOTA need to have some formal process of certification of a time system reliability, with testing documented?
5. Does camera behaviour change with sub-framing, other delays?

Occultations provide the most precise method for astrometric positions, and timing is the most important underlying measurement. A lack of confidence in timing opens up controversy. Example: Reviewing all observations: Two neighbouring chords with an offset.

On sub-frame timing: Some people desire the greatest time precision/resolution, down to 1/10 of one exposure time. Half an exposure or less may be reasonable. Given the typical noise, that accuracy is unjustified. When pulling together several observations, high precision is probably unjustified. For single chord events, the uncertainty will be a large fraction of the asteroid's size. For multiple chords, shape and consistency are issues. Doubling the exposure can't maintain time accuracy as time resolution is lost.

Astrometry issues and single chord observations: Single chords on small asteroids are highly valuable. A small mag drop event can present a challenge since the interpretation can be questionable. The real challenge is to distinguish between a positive and a negative event. Dave is seriously considering situations for events where a mag drop is <0.4, without a light curve. Thus submission to VizieR may not occur.

Prediction uncertainties: With drastically reduced uncertainties, the focus for a multichord observation should aim at shape size determination, not astrometry. Single chords are very valuable for the astrometry. Greater uncertainty of small asteroids make single chords more valuable.

Light curves: We are now getting light curves (LC) for the great majority of the observations. In *Occult*, they are displayed with the event. Some are extremely clear, with easy processing. Others raise questions. We've found several instances of double stars, and a satellite that were not identified by the observer. The value of having experienced interpreters reviewing light curves increases the credibility. Dave is involved in combining occultation astrometry with Gaia FDR3 asteroid astrometry. There were quite a few events where the reliability of the occultation result had questions. When LCs were available, the focus rapidly switched to the Gaia data issues. People should consider creating LC files for past observations. You might find some interesting new features.

Quick demo of what *Occult* does with LCs. Something came up in discussion group: Events missing in OWC and issues in processing. *Occult* is the source of all processing. *Occult* can display past events searched by observer, etc. To view an event, select Historical Observations. There are many options for plotting, including LCs used for event: If you see the full AND partial drop - is that due to double star, or poor SNR? Thus always try for a better SNR.

Workloads: Huge increase in number of events observed, >50% year over year, no sign of reducing, several automated observers. There are many single chord events involving small asteroids, especially for automated systems. Current reporting systems had evolved when most observations had multiple chords, now this is the exception. This raises the question: For observers who report a large number of events/year (>40) if the asteroid is smaller than a certain size (10 km), should the observers submit a fully completed OBS.xml file ready for inclusion in the main database? Consultation with regional coordinators needed, but it might reduce the workload, though quality control (QC) and quality assurance (QA) is still needed. The real problem is our multiple regions, each has a different way of collecting and analysing events. The reporting system needs to be reviewed.

Succession planning: As one gets older, one must consider the future. Concentration of expertise. There is a high dependency and workload on a small number of people. Hristo, Herald, Gault. There is open source software, but expertise is a concern. (software backups are only part of the solution).

IOTA's knowledge and expertise is too concentrated. At least one person in each region is needed who is fully competent to fully process observations, where they can be added to the main database to Herald's level. This will ensure there are several people who can take over. This is needed by the organisation. Strong quality assurance (QA) is critical. Our results have a high reputation because we have rigorous QA processes (which could be better documented). Significant learning is involved in succession. QA is challenging in amateur groups; people don't like being questioned, people are enthusiastic about their observations and interpretation. Unusual observations need to be backed up by evidence of high quality.

QA can provide challenges, and potentially arguments. Rejecting a review is unacceptable. The other extreme: If an observer is uncertain about their observation they may not challenge the reviewer. The balance is right and proper when we've got the right result !

Workload pressures: We can't afford the luxury of lengthy debates on an individual observation unless it's a significant event (e.g., Didymos). And there is desire to spend time on single frame events.

A discussion followed:

Q: Vince Sempronio: Good stuff. Our data might save the world. As for dealing with backlog, is there a priority system in place? Obviously NEAs have priority. Could other regions take on part of the load? Is that too political? Some regions have large number of events. There is no spare capacity. Europe's SODIS system has 20 people involved; Wolfgang Beisker might comment. Language issues are a challenge but manageable. Dave Herald is concerned about how much time is spent in taking individual observations. Main other challenge is to get astrometry out promptly to update orbits; would like to get to reporting to MPC monthly.

Wolfgang Beisker: One of the issues is emphasis on light curve; you don't necessarily see the length of the light curve; not all the noise reflected; should set guideline of requiring full CSV, make event only 20% of the lightcurve. Dave Herald agrees. He would like to have the whole lightcurve recorded as a matter of course. Steve Preston urged submitting full light curve. Observers should be easily able to upload CSV files to VizieR (maybe through *Occult*). Sending the CSV without tying it to the event would be a problem. *PyOTE* [17] picks up the metadata from the *Excel* spreadsheet.

Dave Herald wants to see more testing of assumptions in practical settings. We can put things on a basis of mathematical principles, but we need to test things related to time that are based on untested assumptions. One possible test: A variety of equipment can be tested at the same place on an event. Roger Venable argues for only changing one variable at a time. We need to scrutinise our "unknown unknowns".

The meeting ended at 2:00 UT, 2024 September 30th.

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Journal for Occultation Astronomy

IOTA's Mission

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

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

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

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

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

The main page of occultations.org provides links to IOTA's major technical sites, as well as to the major IOTA sections, including those in Europe, 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.

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JOA will always try to produce an article as soon as possible based to date & time of other articles it received – but actual announcements have the priority!