Journal for Occultation Astronomy

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Chasing the Shadow of (15094) Polymele for Lucy

Dear reader,

For the first time, observers worldwide have managed to obtain more than 1,000 positive measurements of stellar occultations by asteroids in 2021. Thanks to highly accurate astrometric data from ESA's *Gaia* satellite, predictions of stellar occultations are more accurate than ever before. Whereas 25 years ago the 1-sigma limits of predictions extended over almost an entire hemisphere, today error limits of less than 100 kilometres are the standard. A high accuracy of the profile of the Moon's limb was also achieved through the altitude measurements by *Kaguya* and the *Lunar Reconnaissance Orbiter*. We can use the profile to check the timing accuracy of our equipment and to set up stations for grazing occultations with a high precision for a successful observation.

But we are not just picking up data from space missions. Through our measurements of stellar occultations of asteroids worldwide, we support space missions like *New Horizons*, *Lucy* and *Destiny+*. We help to extend the knowledge of the missions' distant targets before and after the launch of the space probes. One of the latest examples was the collaboration during an occultation by Trojan (15094) Polymele, a target of NASA's *Lucy* mission. It's a win-win situation for both sides.

Let's look forward to more exciting collaborations with space missions in the future.

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COVER

On 2021 October 1st teams from the US and Europe joined in Spain to observe a stellar occultation by Trojan (15094) Polymele, one of the targets of NASA's *Lucy* mission. The cover shows the team T02 on the observing site on track A16, formed by Jack Jewell, Jean-Baptiste Marquette, Juan José Fernández and María Dolores Fernández. The flight path to *Lucy*'s preliminary mission targets is presented in the background.
Cover: O. Klös with a photo by J. Jewell and a graphic by the Southwest Research Institute (SwRI).

Copyright Transfer

Rules for Authors

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

Journal for Occultation Astronomy

Collaboration on NASA's Lucy Mission - An Awesome Experience!

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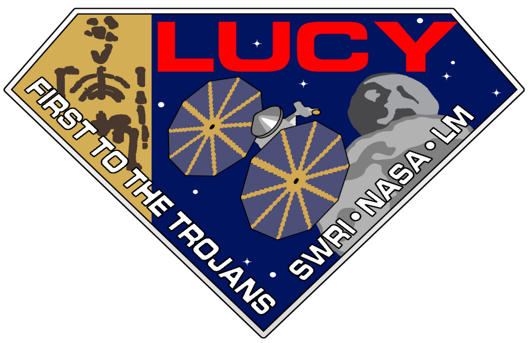
ABSTRACT: On 2021 October 1st the Trojan asteroid (15094) Polymele occulted the star UCAC4 567-010317. The occultation path was precalculated for the Iberian Peninsula. Predictions from the Southwest Research Institute (SwRI) and the Instituto de Astrofisica de Andalucia (IAA) gave different zones for the shadow path. Therefore two expeditions were organised and carried out. The paper shows the organisation, the team training and the experiences of both teams.

Introduction

In the 18th century, Leonhard Euler and Joseph-Louis Lagrange found a restricted solution to the three-body problem of celestial mechanics: There are 5 points at which a celestial body with negligible mass can rest without forces. Today we call these points the Lagrange - or libration points L_1 to L_5. On 1906 February 22, Max Wolf discovered a minor planet near the Lagrange point L_4 on Jupiter's orbit, thus preceding Jupiter by about 60° on its orbit. The planet was named (588) Achilles after a hero of the Trojan War. On 1906 October 17, August Kopff also discovered a minor planet in a Lagrange point of Jupiter's orbit, but following Jupiter. This celestial body is located near the Lagrange point L_5 and was named (617) Patroclus. After further discoveries of celestial bodies in the areas around L_4 and L_5, astronomers decided to name the planets around L_4 after the Greek heroes of the Trojan War, but those in the L_5 position after the defenders of Troy. Thus the "Greeks" and the "Trojans" were originally separate groups. Today, in literature, we often call all these minor planets "Trojans" and also speak of Trojans in other orbits, e.g. in the orbit of Neptune.

The Trojans of Jupiter are considered to be very old celestial bodies that give us information about the formation and history of Jupiter. They are fossils of Jupiter's history. A well-known fossil from the evolutionary history of humankind are the remains of the skeleton "Lucy". That is why the space probe for the exploration of the Trojans was named *Lucy*.



NASA's *Lucy* mission launched from the Cape Canaveral Space Force Station, Florida on 2021 October 16. It will then fly by the Earth twice, in 2022 and 2024, to use Earth's gravitational field to assist it on its journey to the Trojan asteroids [1].

On its way out to the Trojan asteroids, *Lucy* will fly by and observe the Main Belt asteroid (52246) Donaldjohanson on 2025 April 20. Then, *Lucy* will proceed to fly by five of the L_4 Trojans: (3548) Eurybates and its satellite, Queta, on 2027 August 12, (15094) Polymele on 2027 September 15, (11351) Leucus on 2028 April 18, and (21900) Orus on 2028 November 11.

The spacecraft's trajectory will then bring *Lucy* back to the vicinity of the Earth in 2030 for another gravity assist, which will fine-tune its second swing out to the Trojans. In the meantime, the Trojan swarms will have moved in their own orbits around the Sun so that the *Lucy* spacecraft will pass through the L_5 swarm. Arriving on 2033 March 3, *Lucy* will fly by (617) Patroclus and its near-twin binary companion Menoetius. While the closeup observations of this remarkable asteroid pair will complete the primary scientific goals of the mission *Lucy* will remain in a stable orbit which will enable it to visit the Trojan swarms repeatedly for many thousands, and possibly millions, of years.

We know very little about these asteroids, so before the probe reaches them we need to refine their positions, shapes, sizes, etc. in order to direct the probe in the best possible way. To make these studies, one of the most powerful tools we have are occultations. For this reason, Scientists have scheduled several expeditions around the world to observe the occultations produced by these Trojans. The Southwest Research Institute (SwRI) has taken over the calculation of the possible occultations, the expedition planning and the expedition implementation for the mission.

Figure 1.
The mission emblem of the SwRI, NASA, LM mission Lucy.
Credit: SwRI, NASA, Lockheed Martin

Preparing the Observation Campaign

On 2021 October 1, there was an occultation of (15094) Polymele predicted, (the second Trojan to be visited by the *Lucy* Mission) crossing the Iberian Peninsula.

In June 2021, IOTA/ES' President Konrad Guhl contacted Marc Buie (SWRI's top campaign manager) and offered support by members of the association. Marc Buie welcomed this offer and Konrad Guhl immediately forwarded the message to Carles Schnabel. As president of the Astronomical Association of Sabadell and as an active member of the IOTA/ES in Spain, Carles had the opportunity to contact a large community of observers, specialised or not in the observation of occultations. A call was made to observers active in occultations and related fields (mainly astrometry and photometry) and the Spanish Federation of Astronomical Associations (FAAE). Because they were asked to spend four working days on the expedition, many observers said they would not be able to participate. That is why a call was also made to all European observers at ESOP XL held in August 2021 in Białystok (Poland). Some Portuguese and French observers responded. Arnaud Leroy made a remarkable work. He managed to form a group of six people coming from France to Spain. Filipe Dias from Portugal, who teamed up with Juan Carlos Martín and other Palencia amateurs, reinforced one of the tracks proposed by Marc Buie. Also, since Filipe had two QHY cameras, he sent one of these to the teams that worked on the track proposed by José Luis Ortiz. As Filipe noted, that camera travelled even further and went to observe on the other predicted shadow path! So, on this night, his two cameras were farther apart than the diameter of Polymele.

On the Spanish side, 35 observers were recruited, ten of them whom committed to participate in the 4-day campaign focused on Gijón - León (north-western Spain), while the rest remained at their fixed locations or moved only to mobile stations in the night of the event. Some of them went to the observation areas proposed by José Luis Ortiz, of the Instituto de Astrofísica de Andalucía (IAA), as explained further on.

This search for occultations experts and related techniques meant intense coordination work from June to September through e-mail, Slack messaging app, phone calls, and video conferencing. On the other hand, Javier de Cos, from ICTEA (Instituto Universitario de Ciencias y Tecnologías Espaciales de Asturias), co-coordinator of logistics together with Marc Buie, carried out the huge task of recruiting support observers. All this meant a permanent contact between Marc Buie, Javier de Cos and Carles Schnabel.

At the same time, Marc Buie not only was continuously upgrading the path of the prediction and organising American observers; he was also preparing a container full of instruments to be sent to Spain by sea from the United States.

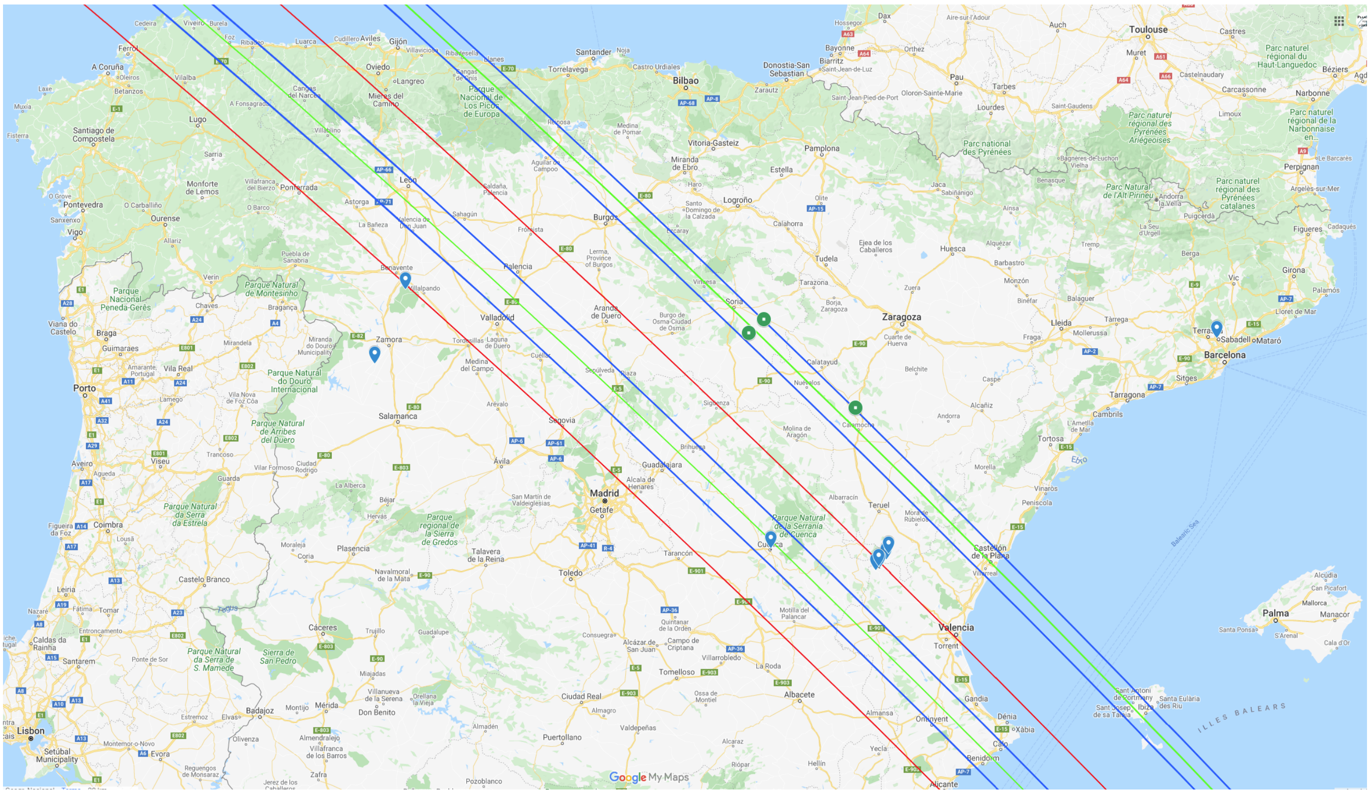


Figure 2. Map of Iberia showing both paths used for spreading out the observing stations. The western one, limited by the 3-sigma limits (red lines) was determined by Marc Buie. The eastern one was calculated by José Luis Ortiz. Green lines: centre of each predicted shadow. Blue lines: limits of each predicted shadow. Blue pins are marking fixed observatories, but most of them were clouded out. The green circles show the positions of the successful stations. (Google Maps)

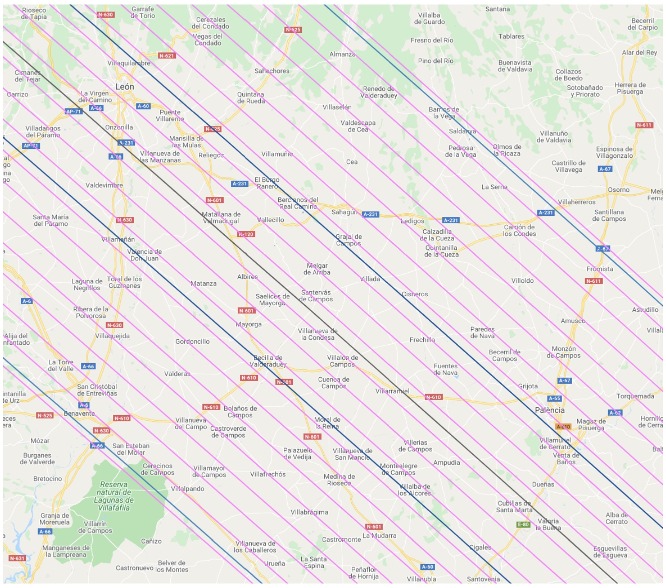


Figure 3. Zoomed detail of Marc Buie's prediction showing the 22 chords evenly distributed between both 3-sigma limits. Separation between chords was 4.7 km and each one was used to establish all the 22 observing stations. (Google Maps)

Because the occulted star UCAC4 567-010317 in the constellation Taurus is of magnitude V 15.56 and the maximum expected duration of the occultation was only 5 seconds, it required wide-aperture telescopes. So SwRI sent 22 16" Sky Watcher telescopes to ICTEA, 25 QHY174M-GPS cameras, and the corresponding laptops and batteries. According to the initial predictions, the shadow's track calculated by Marc Buie passed through Oviedo (Asturias – Northern Spain) and between Burgos and León (Northern Castile – Spain). It was therefore chosen to concentrate all the participants in Gijón (Asturias).

22 teams had to be organised, one for each telescope, made up of by 4 participants: a SwRI collaborator from the USA, an amateur occultation expert who would become the team leader if American people could not come because of COVID, and two amateurs or students from the area. The event was predicted to occur in the early hours of Thursday, Sep 30 through Friday, Oct 1, but Marc Buie set up the campaign to begin on Monday, Sep 27, to use the previous nights to become familiar with the equipment and for training with the instrumentation.

The initial idea was to distribute these 22 teams perpendicular to the trajectory of the shadow between Burgos and León. But as we approached the date, the predictions updates computed by Marc Buie shifted the shadow further west. Instead, the update determined by the aforementioned José Luis Ortiz, a regular contributor to the Lucky Star project, predicted that it would go further east (Figure 2). So, we finally split into two groups: those of us who could be there all the week went to Asturias to be distributed among the 22 observation stations within the 3-sigma limits determined by Marc Buie. Observers not participating in the main campaign were spread over areas covered by both Buie's and Ortiz's predictions.

It is worth mentioning the dilemma that occurred a few days before regarding the predicted track of the occultation. Marc Buie updated his prediction with high-quality astrometric data with the intention to redo the orbit. José Luis Ortiz, on the other hand, applied the method he usually uses for last-minute predictions of transneptunian objects in the Lucky-Star group: corrections to the trajectory based on astrometric measurements obtained a few days earlier. Instead of converging on a similar prediction, the two methods resulted in two tracks separated by 100 km. What would be the correct prediction?

This situation needs to be put into context. Predictions are never 100% accurate, especially for asteroids outside of the main belt. The error must always be taken into account. Let's not forget that the 1-sigma limits indicates only a 68% probability of occurring. In a Gaussian distribution we must consider the 3-sigma limits to arrive at a 99.7% probability to obtain a positive. On the other hand, let us not forget the reason for the great deployment to observe this event. It is a Trojan asteroid, therefore distant and faint, and just the determination of the position was one of its main objectives of the campaign.

Therefore, while the deployment of equipment in the nominal path determined by Marc Buie was continued, it was also very convenient to distribute observers across the path determined by José Luis Ortiz. In this parallel campaign, a total of 27 people were distributed in 13 stations equipped with telescopes ranging from 280 mm to 635 mm aperture. The most used camera model was the QHY174M-GPS, the same for the main campaign.

The Countdown

The adventure began on Monday, September 27: at 4 pm local time we had our first meeting at the Escuela Superior de la Marina Civil in Gijón, where the 22 telescopes from the USA were stored. They told us how everything would work, how to fill the log sheets every day and so on. Each team was responsible for finding the observation site no more than 200 metres apart from the assigned track. Earlier in the morning we found out that the

Figure 4. The equipment packed and ready to be loaded on the truck. (Photo: Antoni Selva)

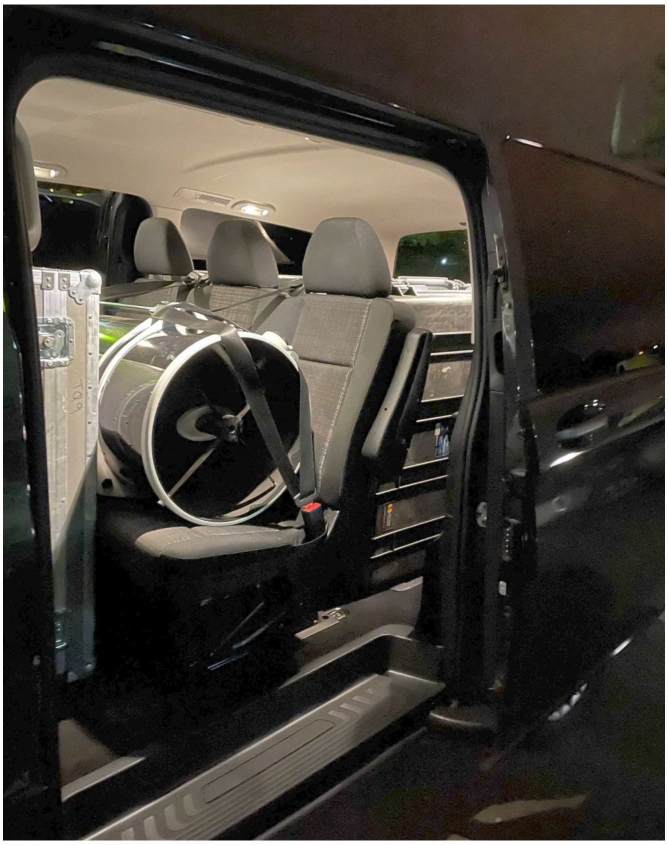


Figure 5. How to carry a large telescope in a not so big car. (Photo: Trina Ruhland)

rented vehicles were not big enough to carry the telescope and all the four members of each team. So, all day long, as the schedule progressed, people were looking for vehicles at all the rental agencies. The organisers finally decided to join the teams in pairs that were on contiguous tracks, so that a large car would carry the two telescopes and one or two small cars would carry the rest of the staff.

From 7 pm to 9 pm we had to pick up our equipment, take it to a university esplanade and assemble it. There would be the press and the public. The sky was overcast, threatening to rain, and we thought they would tell us to do the indoor assembly; but it was not so, they said to go ahead without problem. Each team located the 4 boxes that made up the equipment of the assigned telescope, and proceeded with the first assembly.

Figure 7. The assembly of the instrumentation on the university esplanade attracted the press media. (Photo: Jeff Regester)

The next day, Tuesday 28th in the morning, all the participants (almost 100) travelled to the city of León, 150 km from Gijón to the south, on the other side of the Cantabrian Mountain range, a mountain barrier of 2,000 m in height. The Cantabrian Mountains make a sharp divide between the green Oceanside to the north, and the dry central Iberian plateau called "meseta". The north

Figure 6. Mike Grusin is looking for a site to set up the equipment. (Photo: Carles Schnabel)

Figure 8. Workshop about PyMovie and PyOTE given by John Keller of the University of Colorado. (Photo: Antoni Selva)

facing slopes receive heavy cyclonic rainfall from the Cantabrian Sea, whereas the southern slopes are in rain shadow. León is a city located at the north-western end of the plateau, at an altitude of about 800 metres. On crossing the mountains, the sky changed from overcast to blue.

The operations centre in León was located in the School of Engineering (Industrial, Computer Science and Aerospace) of the University Campus of León. On the same day, many teams took the opportunity to survey the observation points. In the afternoon, in León, all the teams attended a 2nd organising meeting. That night, all 22 teams were assembled on a university esplanade to rehearse the use of the instrument and the location of the star under the real sky.

On Wednesday the 29th in the morning many teams took the opportunity to go and see alternative locations. In the evening, after the 3rd meeting of the organization, the participants had time to have dinner and go to rest for a few hours before leaving for the observation stations to go for a recording rehearsal at exactly the same time in which the occultation should take place 24 hours later. Most teams were able to record the star under a spectacular sky, but some had problems with clouds. This test facilitated the detection of possible problems: difficulties in setting up, the levelling of the mount, problems with the batteries, problems with the humidity, etc.

The morning of Thursday the 30th was dedicated to rest, as we were dragging the sleep of the previous nights, and we had to be well rested for the next night, that of the real event! In the afternoon, a data analysis workshop was held with PyMovie/PyOTE applications working on the data from the previous night (Figure 8). At the next organising meeting we were told that the weather forecast was not very good, but as there were no alternatives, we would keep the locations already chosen.

Reports from the Observation Sites

Luckily, as mentioned above, the cloud front that affected our sites came a little bit later to the location of the teams organised further east by José Luis Ortiz. Indeed, the sky did not cooperate in many of the 22 stations near Leon. At some locations, target star recordings were obtained, but in none of them was the occultation detected.

The three positive observations confirmed so far were obtained in the path updated by José Luis Ortiz in the towns of Almenar de Soria (Soria) and Anento (Zaragoza). The following table contains the basic information about these three stations. These stations used QHY-174M-GPS cameras.

Observers & Assistants	Telescope Aperture Exposure Time	Location
J. L. Ortiz V. Dekert	356 mm 1 s	Almenar de Soria (Soria)
S. Alonso A. R. Reche	635 mm 0.4 s	Almenar de Soria (Soria)
O. Canales D. Zaragoza S. Calavia A. Rivera F. Campos	500 mm 1 s	Anento (Zaragoza)

Table 1. The three observation stations which were able to record positive observations.

Figure 9. The team formed by Sergio Alonso and Antonio Román Reche at the path predicted by José Luis Ortiz. This was one of the three stations obtaining a positive record using a 25″ telescope. (Photo: Sergio Alonso & Antonio Román Reche)

Two observers from Germany (Bernd Gährken & Konrad Guhl) had decided to join the team of observers from the Instituto de Astrofísica de Andalucía (IAA).The IAA group chose a holiday home in Almenar de Soria in the zone predicted by José Luis Ortiz as their headquarters. Konrad Guhl departed by car near Berlin on the morning of September 28 with the IOTA/ES' expedition telescope *M2* on board. In the afternoon of September 29, Bernd Gährken joined them via Toulouse airport, and after a stop-over in the Pyrenees, the two observers arrived at Team Ortiz's quarters on September 30. Bernd Gährken and Mike Kretlow from the IAA were equipped with a 14″ telescope from the pool of mobile equipment and formed a team. As reported, the weather situation for the positions of team Buie had deteriorated. Both teams were in close communication and so team Ortiz decided to position three stations further south in the forecast zone of team Buie. Bernd Gährken and Mike Kretlow with the 14″ telescope, Konrad Guhl with the 20″ telescope *M2* and Miguel Pugnaire and Miguel Gil with a 12″ Skywatcher Dobsonian were chosen. The stations now to be occupied were near the town of Sigüenza. As described, the calculation by José Luis Ortiz proved to be correct and the observers sent out were unsuccessful, but they perfectly performed the instructed observing tasks. The positive observations cited were made near the predicted zone. A supplementary report on the journey can be found on the website of Bernd Gährken [2].

Conclusion

After a couple of hours of rest, exhausted, but satisfied by the experience and the good atmosphere, on Friday the 1st we returned to Gijón, to tidy up and pack all the material. At 2 pm a truck came with the container to load all the boxes. This container

Figure 10. Javier de Cos and Marc Buie (behind) loading the truck. (Photo: Ryder Strauss)

Figure 11. Part of the IAA group at another station where the event was registered as positive. José Luis Ortiz is the first to kneel on the right. (Photo: José Luis Ortiz)

is the one that returned to the US by sea. Many of us who came from far away started our journey back to our places of origin. But the entire American team, along with local helpers, held a data party on all the recorded images collected the night before.

This event has had enormous consequences for the Spanish occultations group. Until now, our group had grown slowly around the Agrupació Astronòmica de Sabadell, and also ASTER - Agrupació Astronòmica de Barcelona. In order to coordinate the *Lucy* campaign, we opened an account in the Slack app. Between June and September we went from being a dozen active members to about 35, spread throughout the Spanish region. In addition, links have been established with Portuguese and French observers.

Acknowledgements

Finally, we would like to thank all the observers and attendees who took part in this campaign, and especially Marc Buie, José Luis Ortiz and Javier de Cos for their great coordination efforts.

References

[1] SwRI's homepage for the Lucy mission http://lucy.swri.edu/
[2] Gährken, B. Personal report
https://astrode.de/reisen/reisen21/palermo21i.htm

Figure 12. Group photo in front of the School of Engineering, León. (Photo: Rose Smith)

Grazing Occultations of Stars and Planets by the Moon in 2022

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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 except for some lunar eclipse events where it is 10.0. An additional world map and table with all the grazing occultations by planets in 2022 conclude these predictions.

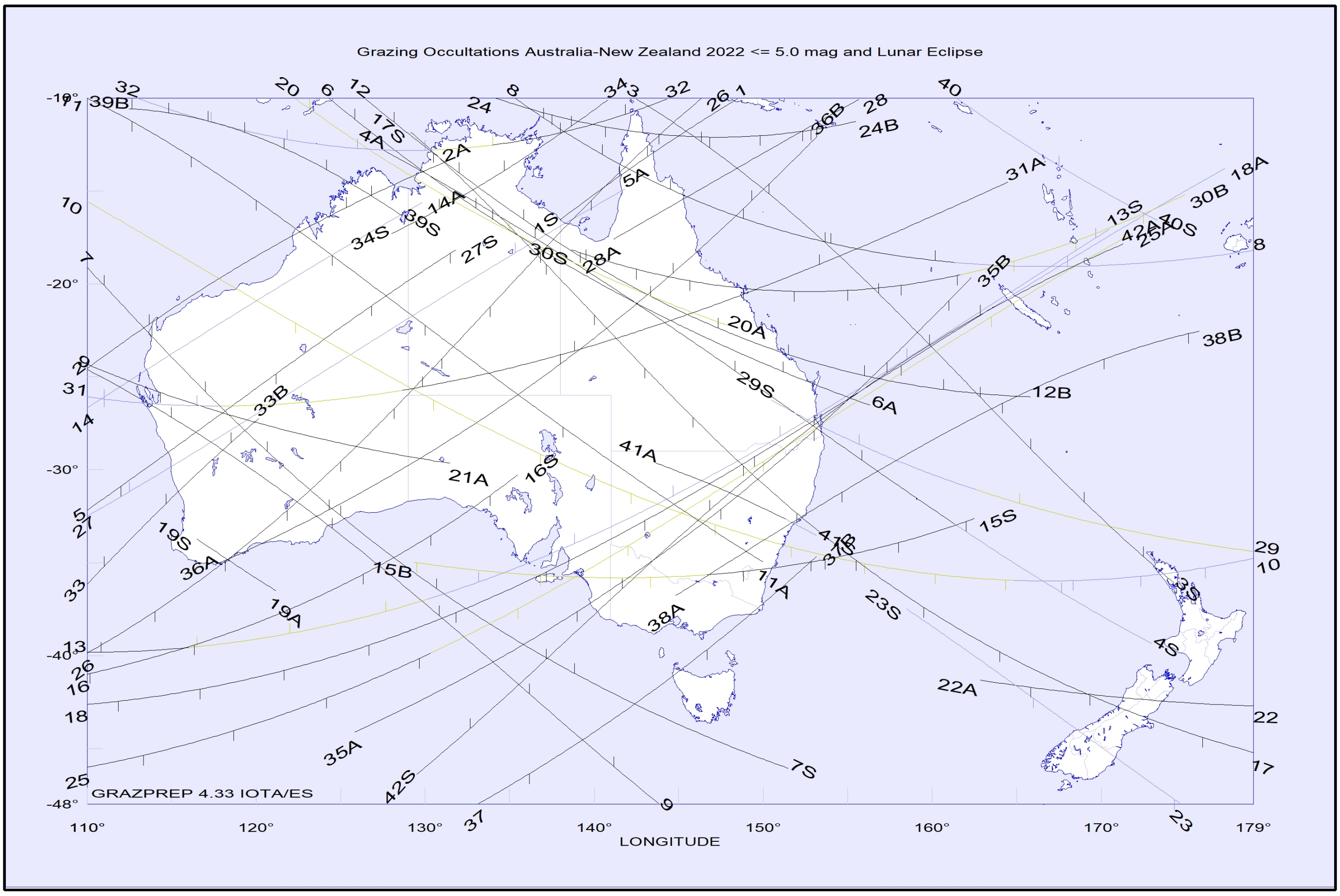
Introduction

Nighttime events along the dark lunar limb are shown with a black line, whereas those events at night at the sunlit lunar limb are given in yellow. All daytime events appear in light blue. Events of stars or planets of 1.5 mag or brighter are highlighted with a bold line.

Tick marks appear along the limit lines every full 10 minutes of time. The northern limb grazes show tick marks pointing downwards, whereas on the southern limb grazes they point upwards.

All tables and pictures 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 under way by graphically showing the expected apparent stellar path through the lunar limb terrain. The fainter stars are calculated with their highly precise positions from the Gaia-DR2-catalogue.

Notice the legend on page 23 to read the tables and maps.

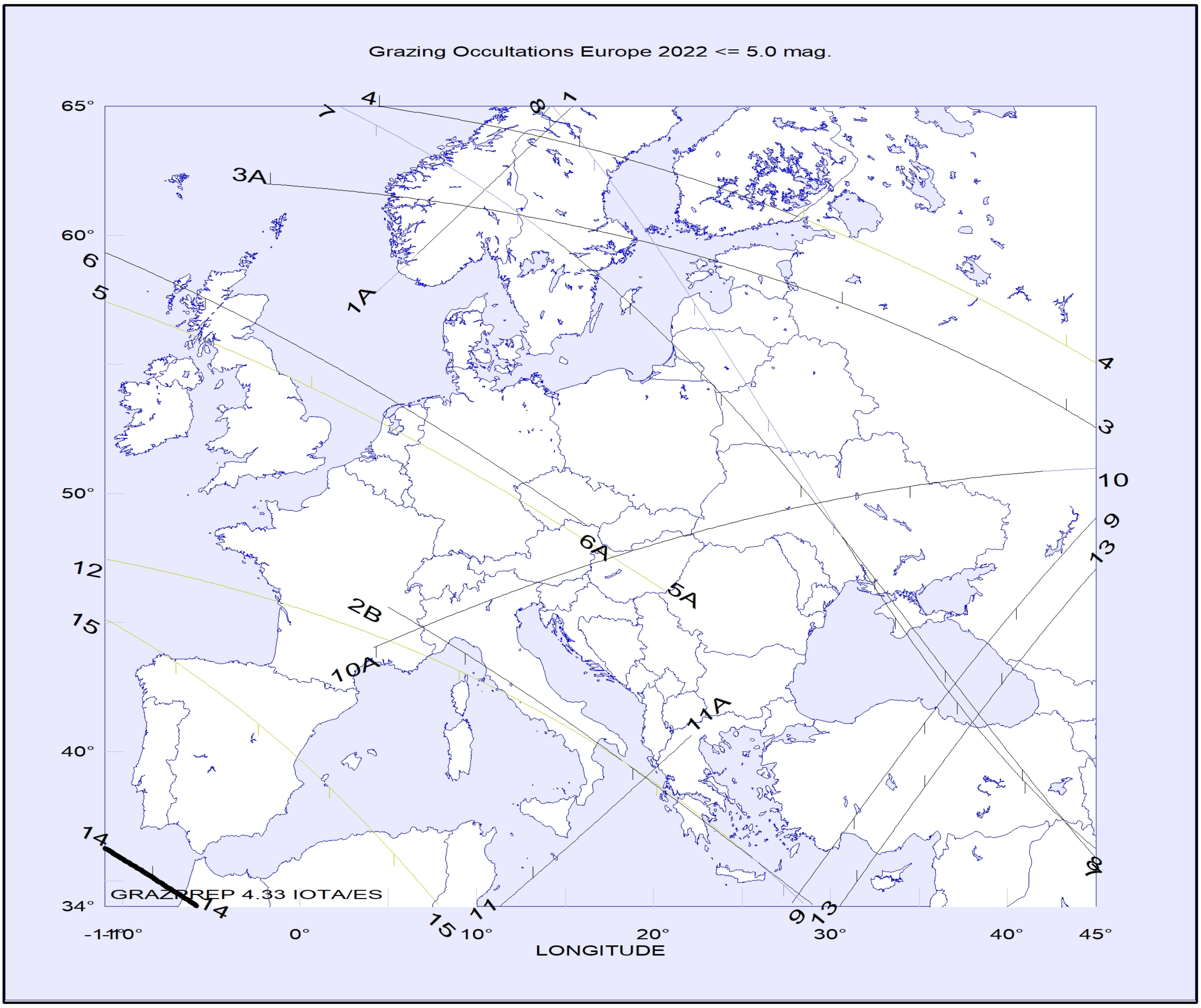


2022	Grazing Occultations Australia-New Zealand 2022									GRAZPREP 4.33, IOTA/ES	
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	Jan 05	ZC 3164	164520 U	4.5	10+	S	9 25.0	138 -17	epsilon Capricorni	5.0	6.3
2	Jan 05	ZC 3175	164593	4.7	11+	S	11 45.2	110 -25	kappa Capricorni		
3	Jan 24	ZC 1941	139390	4.7	60 -	S	16 2.2	142 -10	74 Virginis NSV 06297		
4	Jan 28	ZC 2500	185320 J	3.3	16 -	S	18 7.1	127 -13	theta Ophiuchi	3.6	5.6
5	Jan 30	ZC 2750	187448 Y	2.0	5 -	S	6 46.6	110 -33	Nunki sigma Sagittarii	2.9	2.9
6	Feb 16	ZC 1484	98955 C	3.5	100 -	S	18 47.4	124 -10	eta Leonis NSV 04738	4.1	4.6
7	Feb 18	ZC 1702	119035	4.0	95 -	S	18 6.4	110 -19	nu Virginis		
8	Mar 21	ZC 2118	158840 V	2.8	85 -	S	18 25.4	135 -10	Zuben Elgenubi alpha 2 Librae	3.4	3.8
9	Mar 22	ZC 2241	159442 V	4.8	78 -	S	14 27.0	110 -25	kappa Librae NSV 07200	5.8	5.8
10	Mar 25	ZC 2750	187448 Y	2.0	43 -	N	17 41.7	110 -16	Nunki sigma Sagittarii	2.9	2.9
11	Apr 09	ZC 1149	79533 w	4.1	53+	N	11 42.6	110 -10	upsilon Geminorum NSV 03652		
12	Apr 19	ZC 2359	184382 D	5.0	89 -	S	15 55.9	126 -10	rho Ophiuchi		
13	Apr 21	ZC 2721	187239 X	3.2	68 -	S	21 18.6	110 -40	phi Sagittarii	4.1	4.1
14	Apr 22	ZC 2750	187448 Y	2.0	66 -	N	2 29.1	110 -27	Nunki sigma Sagittarii	2.9	2.9
15	Apr 24	ZC 3175	164593	4.7	35 -	N	18 40.7	129 -35	kappa Capricorni		
16	May 23	ZC 3425	146620 K	4.4	37 -	N	20 50.5	110 -41	psi 2 Aquarii	5.4	5.4
17	Jun 10	ZC 1941	139390	4.7	78+	N	9 6.7	129 -12	74 Virginis NSV 06297		
18	Jun 15	ZC 2750	187448 Y	2.0	97 -	N	18 16.6	110 -43	Nunki sigma Sagittarii	2.9	2.9
19	Jun 30	ZC 1149	79533 w	4.1	2+	N	9 11.7	116 -34	upsilon Geminorum NSV 03652		
20	Jul 03	ZC 1484	98955 C	3.5	17+	S	10 39.0	122 -10	eta Leonis NSV 04738	4.1	4.6
21	Jul 05	ZC 1702	119035	4.0	35+	N	13 25.6	110 -24	nu Virginis		
22	Jul 17	ZC 3419	146598 A	4.2	81 -	N	10 29.5	162 -41	psi 1 Aquarii	4.5	8.5
23	Aug 08	ZC 2500	185320 J	3.3	79+	N	3 43.8	158 -37	theta Ophiuchi	3.6	5.6
24	Aug 09	ZC 2721	187239 X	3.2	90+	N	10 50.8	134 -10	phi Sagittarii	4.1	4.1
25	Aug 09	ZC 2750	187448 Y	2.0	92+	N	15 24.0	110 -46	Nunki sigma Sagittarii	2.9	2.9
26	Aug 14	ZC 3526	147008 A	4.9	90 -	N	17 31.9	110 -40	27 Piscium	5.1	10.4
27	Aug 21	ZC 890	77675 V	4.6	25 -	N	20 58.6	110 -32	136 Tauri NSV 02696	4.8	6.3
28	Aug 23	ZC 1149	79533 w	4.1	11 -	N	18 55.3	141 -18	upsilon Geminorum NSV 03652		
29	Aug 30	ZC 1821	138917 O	2.8	9+	S	6 32.4	150 -26	Porrima gamma Virginis	3.5	3.5
30	Sep 05	ZC 2650	186612	4.7	69+	N	8 38.9	138 -18			
31	Sep 30	ZC 2290	184014 L	2.3	23+	S	9 48.2	110 -26	Dschubba delta Scorpii	3.0	5.0
32	Oct 03	ZC 2784	187683 V	3.3	55+	S	8 30.9	113 -10	tau Sagittarii	4.2	4.2
33	Oct 07	ZC 3419	146598 A	4.2	94+	S	17 17.4	110 -36	psi 1 Aquarii	4.5	8.5
34	Oct 31	ZC 2910	188722 K	4.7	41+	S	9 32.9	128 -17	Terebellum omega Sagittarii	5.6	5.6

(Continued on next page)

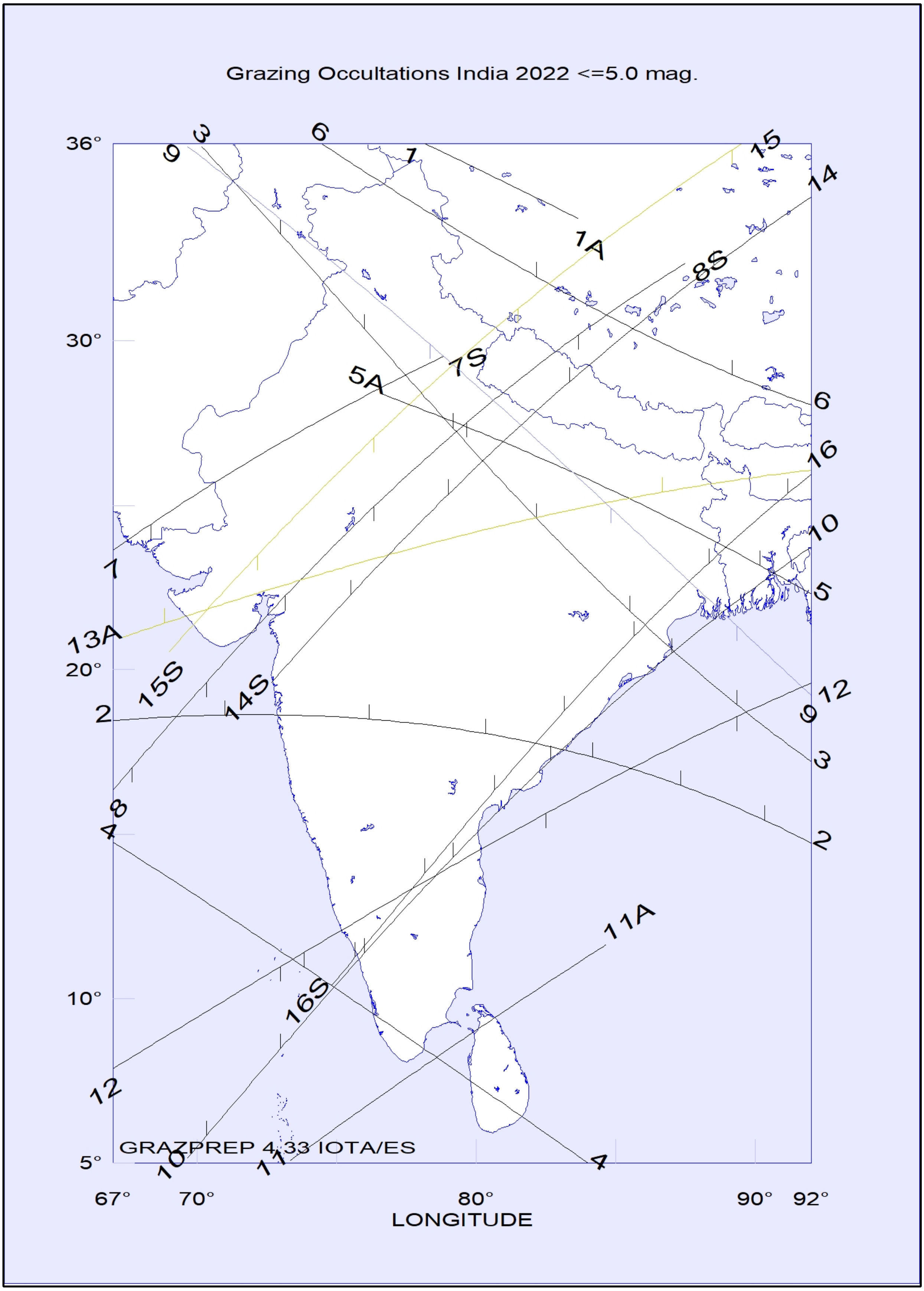
Australia & New Zealand

2022	Grazing Occultations Australia-New Zealand 2022										GRAZPREP 4.33, IOTA/ES
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
35	**Nov 08**	ZC 429	93178	7.0	100 E	N	11 12.6	126 -44	44 Arietis		
36	**Nov 08**	X 3898	93197 M	8.8	100 E	S	11 28.4	118 -35		8.9	11.1
37	**Nov 08**	X 3865	93184	8.8	100 E	N	11 38.3	133 -48			
38	**Nov 13**	ZC 1122	79374 K	3.8	77 -	N	14 5.9	144 -37	iota Geminorum	4.7	4.7
39	**Nov 13**	ZC 1149	79533 w	4.1	74 -	S	19 40.0	112 -11	upsilon Geminorum NSV 03652		
40	**Nov 16**	ZC 1484	98955 C	3.5	46 -	S	23 14.1	161 -10	eta Leonis NSV 04738	4.1	4.6
41	**Nov 22**	ZC 2118	158840 V	2.8	2 -	S	18 42.6	143 -30	Zuben Elgenubi alpha 2 Librae	3.4	3.8
42	**Nov 29**	ZC 3175	164593	4.7	38+	S	10 53.1	129 -46	kappa Capricorni alpha 2 Librae		

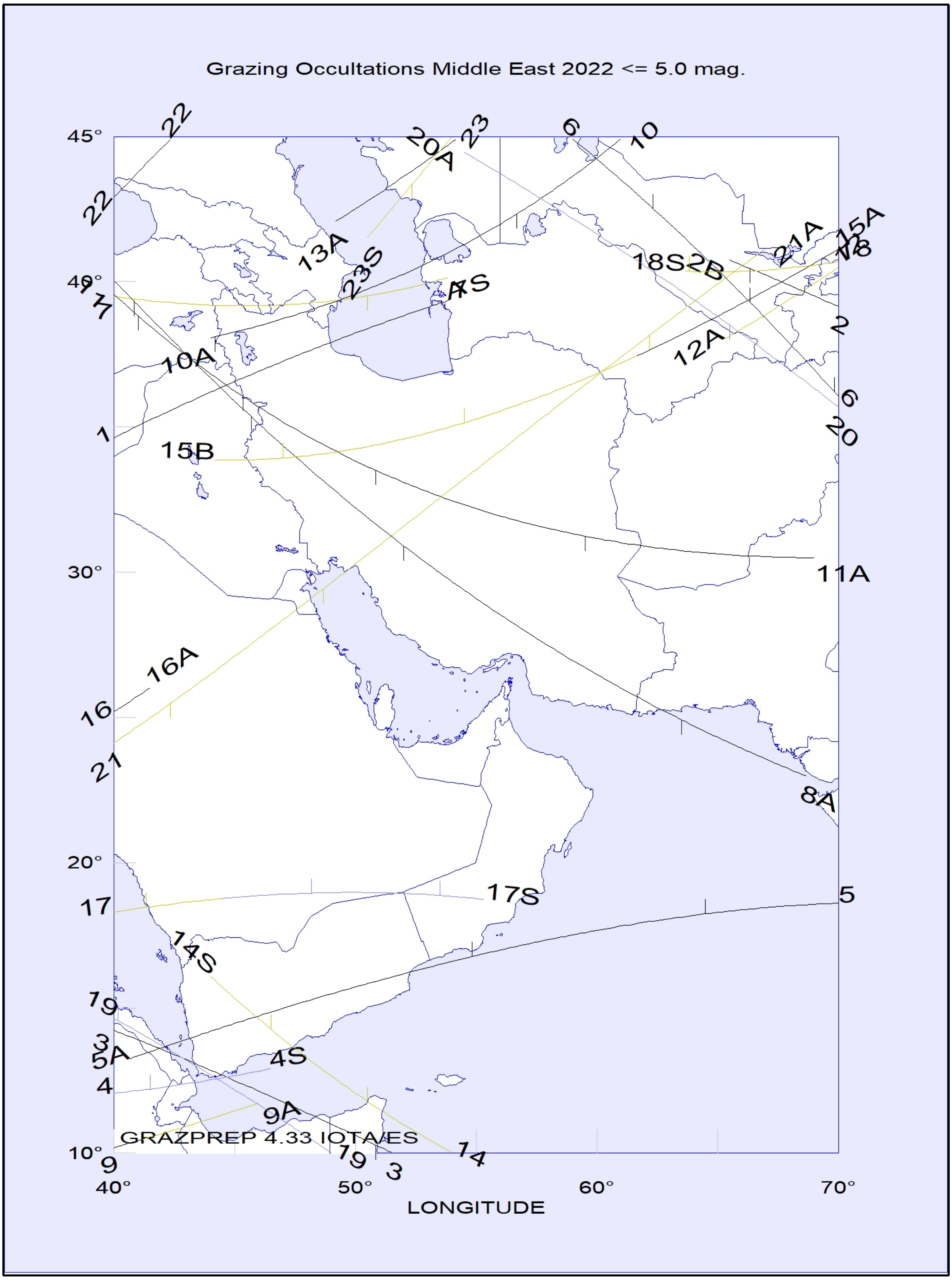


2022 Grazing Occultations Europe 2022 <= 5.0 mag. GRAZPREP 4.33, IOTA/ES

No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	**Jan 17**	ZC 1170	79653 A	3.6	100+	S	15 4.4	4 58	kappa Geminorum	3.7	8.2
2	**Feb 12**	ZC 900	77775	4.8	79+	N	0 14.8	5 46	139 Tauri		
3	**Feb 19**	ZC 1821	138917 O	2.8	88 -	S	21 20.3	-2 62	Porrima gamma Virginis	3.5	3.5
4	**Mar 09**	ZC 709	76721 L	4.3	44+	S	20 30.3	4 65	tau Tauri	4.9	6.4
5	**Apr 05**	ZC 656	76601 V	4.2	19+	S	21 11.7	-11 57	kappa Tauri NSV 01593	5.2	5.2
6	**Apr 05**	ZC 660	76608 V	4.3	19+	N	21 46.9	-11 59	upsilon Tauri	4.6	6.5
7	**May 09**	ZC 1484	98955 C	3.5	58+	N	18 58.0	2 65	eta Leonis NSV 04738	4.1	4.6
8	**Jul 06**	ZC 1821	138917 O	2.8	46+	N	17 17.0	14 65	Porrima gamma Virginis	3.5	3.5
9	**Aug 13**	ZC 3428	146635 A	5.0	95 -	N	23 10.6	28 34	psi 3 Aquarii NSV 14491	5.2	11.2
10	**Sep 23**	ZC 1484	98955 C	3.5	7 -	N	2 50.9	4 44	eta Leonis NSV 04738	4.1	4.6
11	**Oct 29**	ZC 2617	186328 K	4.5	22+	S	17 48.6	11 34		5.1	5.9
12	**Nov 20**	ZC 1821	138917 O	2.8	16 -	N	4 42.1	-11 47	Porrima gamma Virginis	3.5	3.5
13	**Nov 30**	ZC 3349	165321W	4.0	51+	S	15 47.3	30 34	tau Aquarii NSV 14329		
14	**Dec 08**			-1.9	100+	S	5 47.9	-11 36	Mars		
15	**Dec 14**	ZC 1484	98955 C	3.5	71 -	N	4 32.5	-11 45	eta Leonis NSV 04738	4.1	4.6


Grazing Occultations India 2022 <=5.0 mag.
36°
30°
20°
10°
5°
67°
70°
80°
90°
92°
LONGITUDE
GRAZPREP 4.33 IOTA/ES
1A
5A
7S
8S
11A
13A
14S
15S
16S

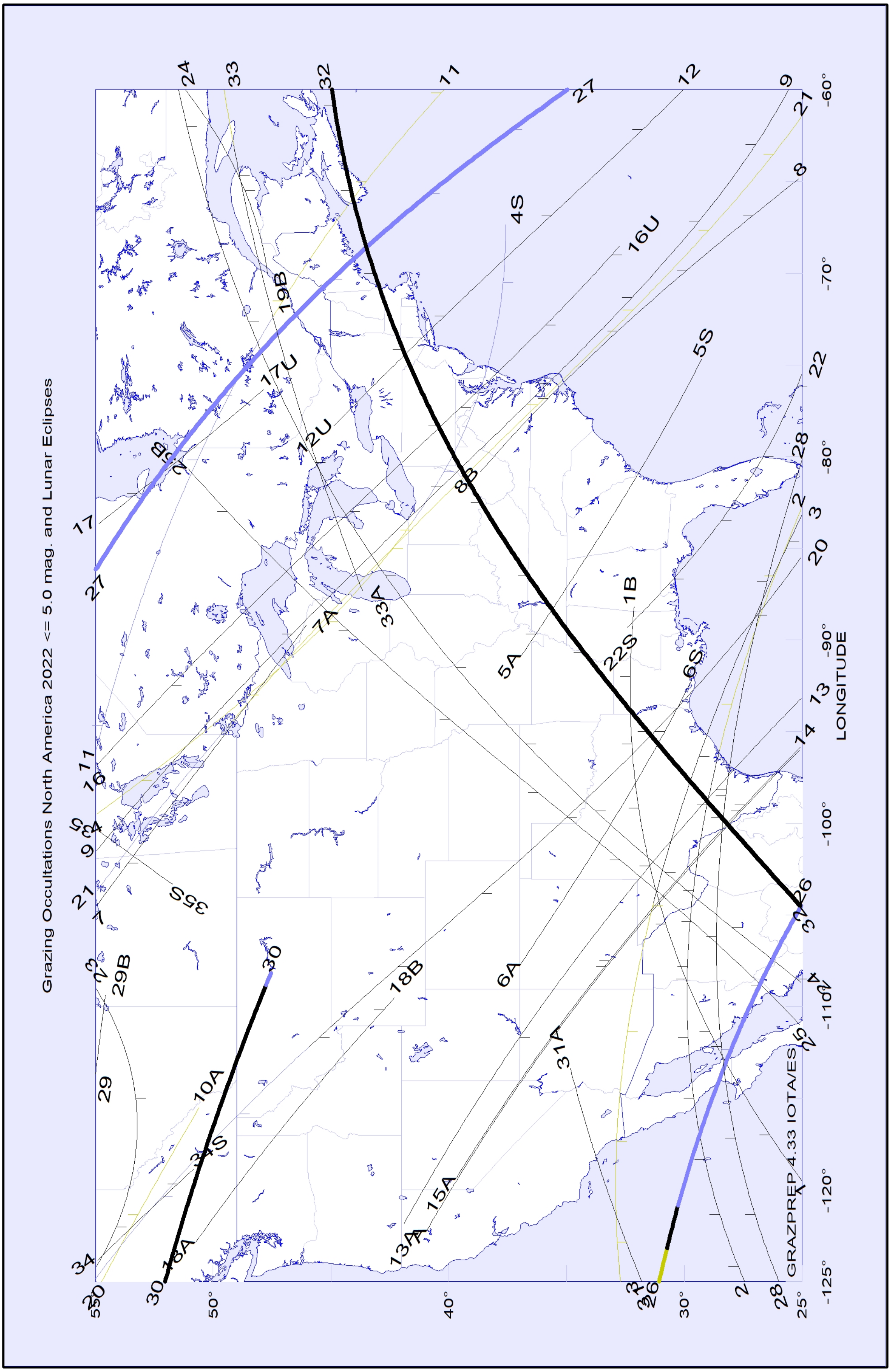
2022			Grazing Occultations India 2022							GRAZPREP 4.33, IOTA/ES		
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG	LAT	STAR NAME	MAG1	MAG2
1	**Jan 13**	ZC 656	76601 V	4.2	85+	N	22 5.0	78	36	kappa Tauri NSV 01593	5.2	5.2
2	**Feb 16**	ZC 1484	98955 C	3.5	100 -	S	15 53.6	67	18	eta Leonis NSV 04738	4.1	4.6
3	**Feb 19**	ZC 1821	138917 O	2.8	88 -	S	22 31.4	70	36	Porrima gamma Virginis	3.5	3.5
4	**Feb 25**	ZC 2650	186612	4.7	27 -	S	22 17.7	67	15			
5	**Mar 21**	ZC 2118	158840 V	2.8	85 -	S	16 34.6	76	28	Zuben Elgenubi alpha 2 Librae	3.4	3.8
6	**Mar 25**	ZC 2784	187683 V	3.3	41 -	S	22 52.6	74	36	tau Sagittarii	4.2	4.2
7	**Aug 14**	ZC 3425	146620 K	4.4	95 -	N	0 8.5	67	24	psi 2 Aquarii	5.4	5.4
8	**Aug 16**	ZC 257	110110	4.3	71 -	N	22 37.6	67	16	Torcularis Septentrionalis omicron Piscium		
9	**Sep 30**	ZC 2290	184014 L	2.3	23+	N	7 42.1	69	36	Dschubba delta Scorpii	3.0	5.0
10	**Oct 07**	ZC 3428	146635 A	5.0	95+	S	17 57.9	69	5	psi 3 Aquarii NSV 14491	5.2	11.2
11	**Oct 30**	ZC 2784	187683 V	3.3	32+	S	16 14.3	73	5	tau Sagittarii	4.2	4.2
12	**Nov 13**	ZC 1149	79533 w	4.1	74 -	N	18 16.2	67	8	upsilon Geminorum NSV 03652		
13	**Nov 16**	ZC 1484	98955 C	3.5	46 -	S	19 39.7	67	21	eta Leonis NSV 04738	4.1	4.6
14	**Dec 28**	ZC 3428	146635 A	5.0	34+	S	12 41.6	72	20	psi 3 Aquarii NSV 14491	5.2	11.2
15	**Dec 28**	ZC 3425	146620 K	4.4	34+	N	12 51.4	69	21	psi 2 Aquarii	5.4	5.4
16	**Dec 31**	ZC 257	110110	4.3	66+	S	12 47.4	74	10	Torcularis Septentrionalis omicron Piscium		



Grazing Occultations Middle East 2022 <= 5.0 mag.
45°
40°
30°
20°
10°
40°
50°
60°
70°
LONGITUDE
GRAZPREP 4.33 IOTA/ES
11A
8A
5
17S
12A
15B
10A
16A
13A
23S
18S
21A
15A
14S
4S
9A

2022			Grazing Occultations Middle East 2022							GRAZPREP 4.33, IOTA/ES	
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	**Jan 06**	ZC 3349	165321W	4.0	20+	S	17 3.5	40 35	tau Aquarii NSV 14329		
2	**Jan 13**	ZC 656	76601 V	4.2	85+	N	21 59.6	65 41	kappa Tauri NSV 01593	5.2	5.2
3	**Jan 13**	ZC 660	76608 V	4.3	86+	N	22 42.3	40 14	upsilon Tauri	4.6	6.5
4	**Jan 26**	ZC 2118	158840 V	2.8	42 -	S	7 58.8	40 12	Zuben Elgenubi alpha 2 Librae	3.4	3.8
5	**Feb 16**	ZC 1484	98955 C	3.5	100 -	S	15 33.8	40 13	eta Leonis NSV 04738	4.1	4.6
6	**Feb 19**	ZC 1821	138917 O	2.8	88 -	S	22 3.0	59 45	Porrima gamma Virginis	3.5	3.5
7	**Apr 26**	ZC 3349	165321W	4.0	22 -	N	1 19.5	40 39	tau Aquarii NSV 14329		
8	**May 09**	ZC 1484	98955 C	3.5	58+	N	20 8.3	40 40	eta Leonis NSV 04738	4.1	4.6
9	**Jun 12**	ZC 2118	158840 V	2.8	91+	N	0 2.7	40 10	Zuben Elgenubi alpha 2 Librae	3.4	3.8
10	**Jun 22**	ZC 219	109926 w	4.8	31 -	N	22 30.4	44 38	mu Piscium		
11	**Jul 06**	ZC 1821	138917 O	2.8	46+	N	18 17.9	40 40	Porrima gamma Virginis	3.5	3.5
12	**Jul 23**	ZC 656	76601 V	4.2	19 -	S	21 1.3	65 38	kappa Tauri NSV 01593	5.2	5.2
13	**Jul 23**	ZC 660	76608 V	4.3	19 -	N	21 54.7	49 42	upsilon Tauri	4.6	6.5
14	**Aug 03**	ZC 1891	139189 T	4.4	31+	S	15 33.0	44 16	Apami-Atsa theta Virginis	4.5	6.8
15	**Sep 03**	ZC 2371	184429	4.8	50+	S	16 35.3	44 34	22 Scorpii NSV 20658		
16	**Sep 06**	ZC 2910	188722 K	4.7	83+	S	22 52.6	40 25	Terebellum omega Sagittarii	5.6	5.6
17	**Sep 23**	ZC 1484	98955 C	3.5	7 -	S	2 48.5	40 18	eta Leonis NSV 04738	4.1	4.6
18	**Sep 29**	ZC 2172	159090 Z	4.5	15+	S	13 30.3	63 40	iota Librae NSV 06981	5.0	6.2
19	**Sep 30**	ZC 2290	184014 L	2.3	23+	S	7 30.1	40 15	Dschubba delta Scorpii	3.0	5.0
20	**Sep 30**	ZC 2290	184014 L	2.3	23+	N	7 38.2	54 44	Dschubba delta Scorpii	3.0	5.0
21	**Oct 30**	ZC 2784	187683 V	3.3	32+	N	15 35.5	40 24	tau Sagittarii	4.2	4.2
22	**Nov 30**	ZC 3349	165321W	4.0	51+	S	16 10.7	40 43	tau Aquarii NSV 14329		
23	**Dec 31**	ZC 257	110110	4.3	66+	N	13 14.7	50 42	Torcularis Septentrionalis omicron Piscium		

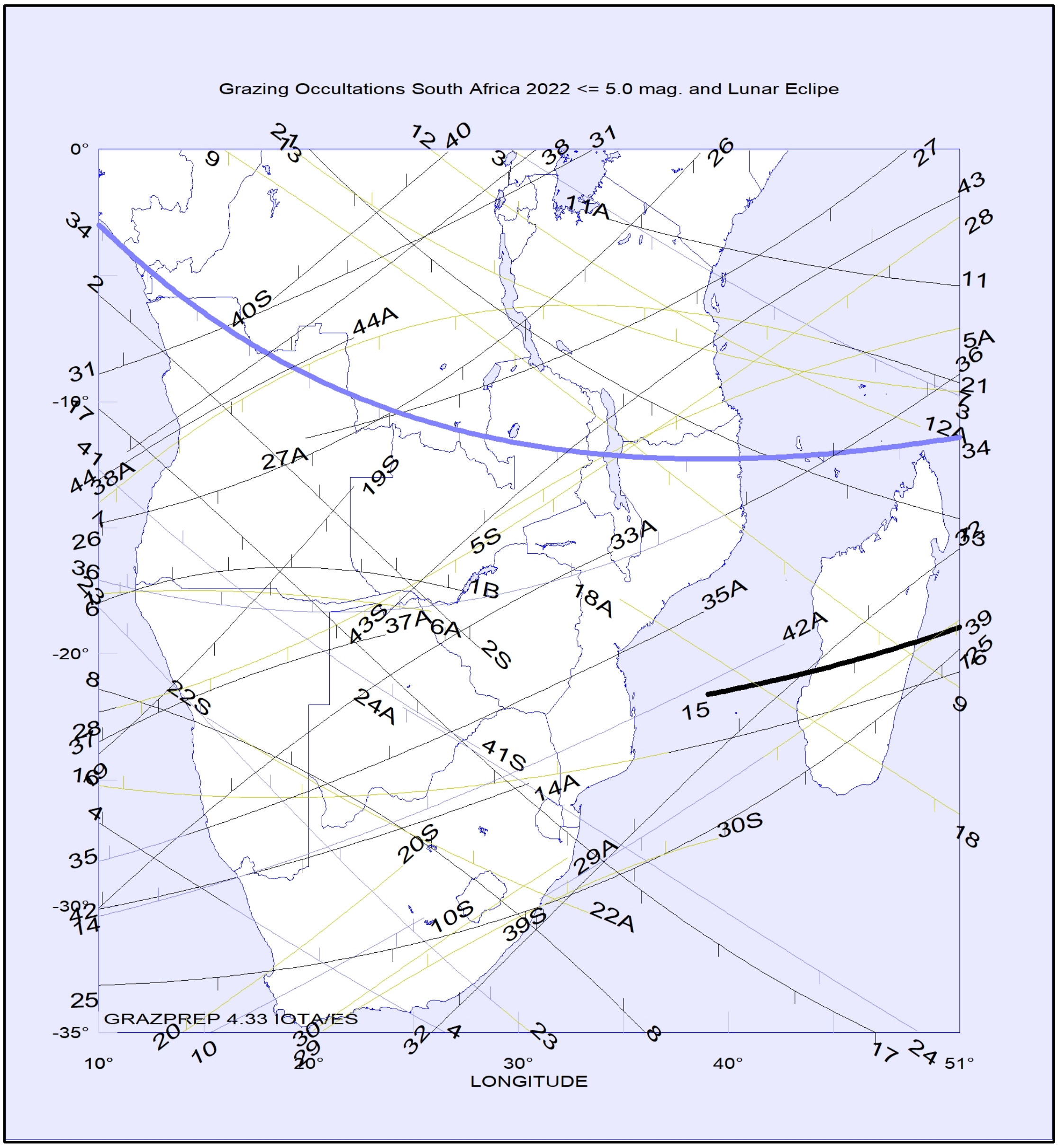
Middle East



Grazing Occultations North America 2022 <= 5.0 mag. and Lunar Eclipses
LONGITUDE
GRAZPREP 4.33 IOTA/ES
-60°
-70°
-80°
-90°
-100°
-110°
-120°
-125°
55°
50°
40°
30°
25°

2022			Grazing Occultations North America 2022								GRAZPREP 4.33, IOTA/ES	
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG	LAT	STAR NAME	MAG1	MAG2
1	Jan 14	ZC 709	76721 L	4.3	87+	S	3 51.8	-119	25	tau Tauri	4.9	6.4
2	Feb 10	ZC 656	76601 V	4.2	64+	S	3 47.4	-125	27	kappa Tauri NSV 01593	5.2	5.2
3	Feb 10	ZC 660	76608 V	4.3	65+	N	5 5.8	-125	33	upsilon Tauri	4.6	6.5
4	Feb 22	ZC 2118	158840 V	2.8	67 -	N	11 47.0	-99	55	Zuben Elgenubi alpha 2 Librae	3.4	3.8
5	Feb 27	ZC 2910	188722 K	4.7	14 -	S	11 19.8	-90	37	Terebellum omega Sagittarii	5.6	5.6
6	Feb 27	ZC 2914	188778 V	4.8	14 -	S	12 31.0	-107	37	Terebellum 60 Sagittarii	5.8	5.8
7	Mar 11	ZC 900	77775	4.8	58+	N	8 8.5	-104	55	139 Tauri		
8	Mar 19	ZC 1821	138917 O	2.8	99 -	S	5 10.8	-80	39	Porrima gamma Virginis	3.5	3.5
9	Apr 19	ZC 2290	184014 L	2.3	92 -	S	6 13.2	-101	55	Dschubba delta Scorpii	3.0	5.0
10	May 03	ZC 656	76601 V	4.2	5+	S	4 58.8	-125	55	kappa Tauri NSV 01593	5.2	5.2
11	May 12	ZC 1821	138917 O	2.8	87+	S	23 49.4	-96	55	Porrima gamma Virginis	3.5	3.5
12	May 16	X 21339	183509	8.8	100 E	S	3 22.2	-78	45			
13	May 16	ZC 2217	159330	5.5	100 E	N	3 48.0	-122	42			
14	May 16	ZC 2214	159317 Y	6.3	100 E	S	3 52.4	-122	41		7.0	7.0
15	May 16	X 21385	159316 B	8.9	100 E	S	3 52.9	-119	40		9.5	9.5
16	May 16	X 21405	159328	9.3	100 E	N	4 27.7	-96	55			
17	May 16	X 21392	183545	8.8	100 E	S	4 58.1	-83	55			
18	May 16	X 21432	183571	8.7	100 E	S	5 2.0	-122	51			
19	May 20	ZC 2914	188778 V	4.8	77 -	N	7 41.7	-70	48	Terebellum 60 Sagittarii	5.8	5.8
20	Jun 06	ZC 1484	98955 C	3.5	35+	N	2 41.3	-124	55	eta Leonis NSV 04738	4.1	4.6
21	Jun 13	ZC 2290	184014 L	2.3	97+	S	2 18.1	-103	55	Dschubba delta Scorpii	3.0	5.0
22	Aug 05	ZC 2053	158489 U	4.5	45+	N	0 51.6	-89	32	lambda Virginis NSV 06621	4.9	6.3
23	Sep 06	ZC 2784	187683 V	3.3	76+	N	3 7.5	-124	55	tau Sagittarii	4.2	4.2
24	Sep 13	ZC 257	110110	4.3	90 -	N	7 50.1	-108	25	Torcularis Septentrionalis omicron Piscium		
25	Oct 07	ZC 3349	165321W	4.0	90+	S	3 33.8	-111	25	tau Aquarii NSV 14329		
26	Oct 24			-1.1	1 -	S	14 12.3	-125	31	Mercury		
27	Oct 24			-1.1	1 -	N	14 41.3	-86	55	Mercury		
28	Nov 08	X 3757	93125	9.2	100 E	S	9 50.6	-125	26			
29	Nov 08	X 3800	93148	8.1	100 E	N	11 51.9	-113	55	NSV 15597		
30	Nov 08			5.6	100 E	S	14 11.5	-125	52	Uranus		
31	Dec 01	ZC 3428	146635 A	5.0	57+	S	7 22.6	-125	32	psi 3 Aquarii NSV 14491	5.2	11.2
32	Dec 08			-1.9	100+	S	2 51.5	-104	25	Mars		
33	Dec 14	ZC 1484	98955 C	3.5	71 -	N	3 34.5	-87	44	eta Leonis NSV 04738	4.1	4.6
34	Dec 20	ZC 2172	159090 Z	4.5	11 -	S	15 56.2	-124	55	iota Librae NSV 06981	5.0	6.2
35	Dec 27	ZC 3349	165321W	4.0	27+	S	22 43.9	-103	52	tau Aquarii NSV 14329		

North America

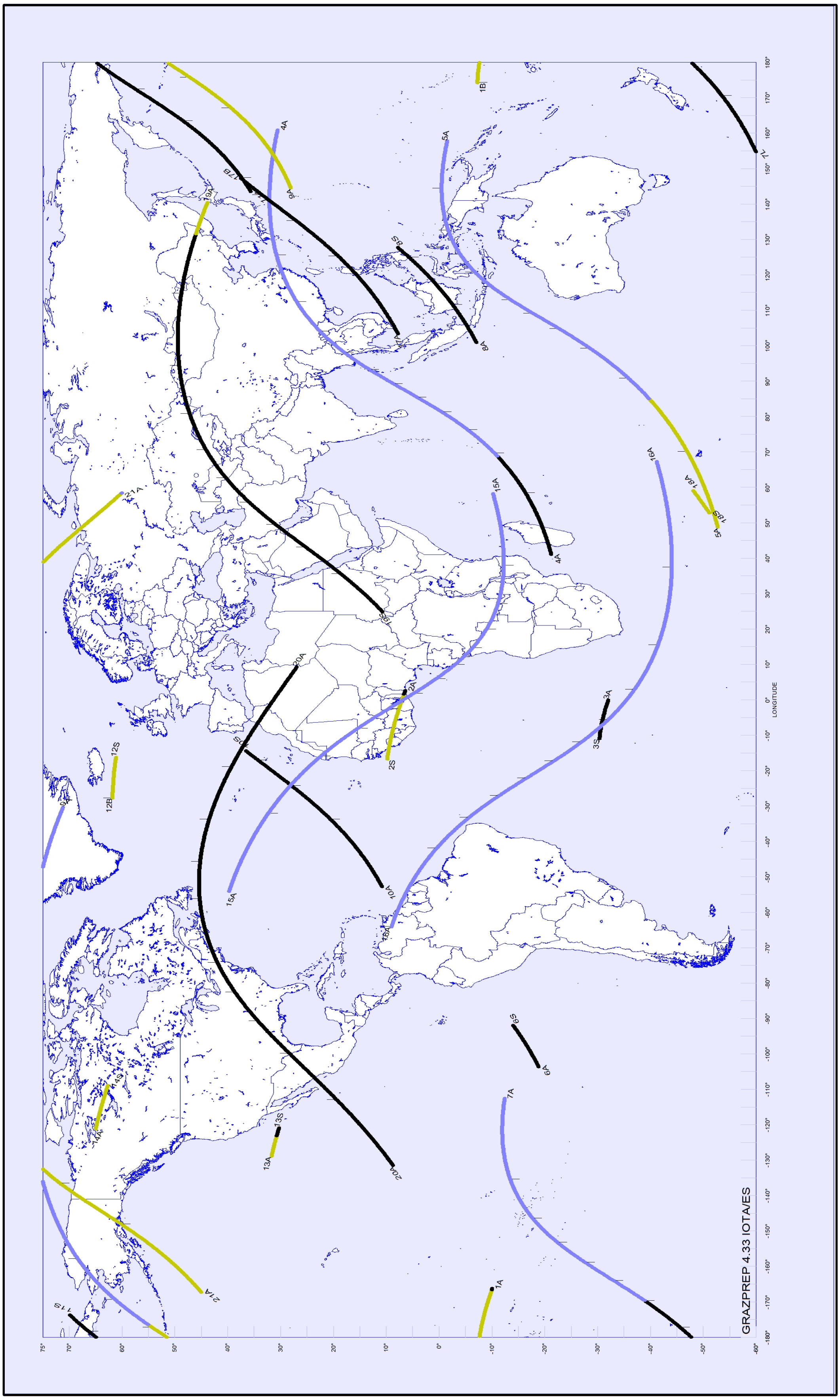


2022	Grazing Occultations Southern Africa 2022 <= 5.0 mag. and Lunar Eclipse								GRAZPREP 4.33, IOTA/ES		
No.	**M D**	**USNO**	**SAOPPM D**	**MAG**	**%SNL**	**L.**	**W.UT**	**LONG LAT**	**STAR NAME**	**MAG1**	**MAG2**
1	**Jan 13**	ZC 660	76608 V	4.3	86+	S	21 16.5	10 -18	upsilon Tauri	4.6	6.5
2	**Jan 27**	ZC 2241	159442 V	4.8	32 -	S	3 7.3	10 -6	kappa Librae NSV 07200	5.8	5.8
3	**Jan 30**	ZC 2750	187448 Y	2.0	5 -	N	4 11.8	29 0	Nunki sigma Sagittarii	2.9	2.9
4	**Jan 30**	ZC 2750	187448 Y	2.0	5 -	S	4 20.4	10 -27	Nunki sigma Sagittarii	2.9	2.9
5	**Feb 03**	ZC 3419	146598 A	4.2	8+	N	16 37.4	28 -15	psi 1 Aquarii	4.5	8.5
6	**Feb 06**	ZC 257	110110	4.3	33+	N	20 22.8	10 -18	Torcularis Septentrionalis omicron Piscium		
7	**Feb 09**	ZC 599	76430 S	4.4	61+	N	17 57.6	10 -14	37 Tauri A Tauri		
8	**Feb 20**	ZC 1941	139390	4.7	81 -	S	21 22.0	10 -21	74 Virginis NSV 06297		
9	**Feb 25**	ZC 2500	185320 J	3.3	36 -	N	0 40.9	16 0	theta Ophiuchi	3.6	5.6

(Continued on next page)

2022	Grazing Occultations Southern Africa 2022 <= 5.0 mag. and Lunar Eclipse									GRAZPREP 4.33, IOTA/ES	
No.	**M D**	**USNO**	**SAOPPM D**	**MAG**	**%SNL**	**L.**	**W.UT**	**LONG LAT**	**STAR NAME**	**MAG1**	**MAG2**
10	**Mar 24**	ZC 2500	185320 J	3.3	61 -	N	9 13.3	15 -35	theta Ophiuchi	3.6	5.6
11	**Apr 26**	ZC 3349	165321W	4.0	22 -	S	0 26.5	34 -3	tau Aquarii NSV 14329		
12	**May 09**	ZC 1484	98955 C	3.5	58+	S	21 5.4	26 0	eta Leonis NSV 04738	4.1	4.6
13	**May 11**	ZC 1702	119035	4.0	77+	N	21 23.9	20 0	nu Virginis		
14	**May 16**	ZC 2205	159253	7.7	100 E	N	3 42.4	10 -30			
15	**May 27**			-3.5	10 -	N	1 8.0	39 -22	Venus		
16	**Jun 11**	ZC 2118	158840 V	2.8	91+	S	23 48.4	10 -25	Zuben Elgenubi alpha 2 Librae	3.4	3.8
17	**Jun 12**	ZC 2241	159442 V	4.8	96+	N	17 57.9	10 -10	kappa Librae NSV 07200	5.8	5.8
18	**Jun 15**	ZC 2750	187448 Y	2.0	97 -	N	16 34.7	34 -18	Nunki sigma Sagittarii	2.9	2.9
19	**Jun 20**	ZC 3425	146620 K	4.4	60 -	N	4 10.6	10 -24	psi 2 Aquarii	5.4	5.4
20	**Jun 26**	ZC 599	76430 S	4.4	7 -	S	5 10.8	14 -35	37 Tauri A Tauri		
21	**Jul 06**	ZC 1821	138917 O	2.8	46+	S	19 2.4	19 0	Porrima gamma Virginis	3.5	3.5
22	**Jul 30**	ZC 1484	98955 C	3.5	3+	S	16 25.0	15 -23	eta Leonis NSV 04738	4.1	4.6
23	**Aug 05**	ZC 2118	158840 V	2.8	53+	S	14 26.6	10 -18	Zuben Elgenubi alpha 2 Librae	3.4	3.8
24	**Aug 09**	ZC 2750	187448 Y	2.0	92+	N	13 30.8	24 -22	Nunki sigma Sagittarii	2.9	2.9
25	**Aug 13**	ZC 3419	146598 A	4.2	95 -	N	20 34.9	10 -33	psi 1 Aquarii	4.5	8.5
26	**Aug 13**	ZC 3425	146620 K	4.4	95 -	N	21 30.0	10 -15	psi 2 Aquarii	5.4	5.4
27	**Aug 16**	ZC 257	110110	4.3	71 -	N	21 7.2	20 -11	Torcularis Septentrionalis omicron Piscium		
28	**Sep 05**	ZC 2721	187239 X	3.2	73+	N	19 54.4	10 -22	phi Sagittarii	4.1	4.1
29	**Sep 06**	ZC 2750	187448 Y	2.0	74+	N	0 32.9	20 -35	Nunki sigma Sagittarii	2.9	2.9
30	**Sep 20**	ZC 1149	79533 w	4.1	29 -	S	2 45.4	20 -35	upsilon Geminorum NSV 03652		
31	**Sep 30**	ZC 2347	184329	4.5	25+	S	18 48.7	10 -9	19 Scorpii NSV 07632		
32	**Oct 05**	ZC 3164	164520 U	4.5	81+	S	21 17.1	26 -35	epsilon Capricorni	5.0	6.3
33	**Oct 06**	ZC 3175	164593	4.7	81+	S	0 10.1	10 -30	kappa Capricorni		
34	**Oct 25**			-3.5	0+	N	12 20.0	10 -3	Venus		
35	**Oct 27**	ZC 2290	184014 L	2.3	6+	S	17 9.6	10 -28	Dschubba delta Scorpii	3.0	5.0
36	**Oct 30**	ZC 2784	187683 V	3.3	32+	S	14 7.2	10 -17	tau Sagittarii	4.2	4.2
37	**Nov 04**	ZC 3419	146598 A	4.2	78+	S	0 40.1	10 -23	psi 1 Aquarii	4.5	8.5
38	**Nov 11**	ZC 890	77675 V	4.6	88 -	N	20 26.9	11 -12	136 Tauri NSV 02696	4.8	6.3
39	**Nov 26**	ZC 2721	187239 X	3.2	10+	N	15 21.2	31 -30	phi Sagittarii	4.1	4.1
40	**Nov 27**	ZC 2910	188722 K	4.7	19+	S	16 47.7	18 -6	Terebellum omega Sagittarii	5.6	5.6
41	**Dec 14**	ZC 1484	98955 C	3.5	71 -	S	6 43.6	10 -13	eta Leonis NSV 04738	4.1	4.6
42	**Dec 21**	ZC 2290	184014 L	2.3	6 -	S	13 17.2	10 -30	Dschubba delta Scorpii	3.0	5.0
43	**Dec 26**	ZC 3164	164520 U	4.5	15+	S	17 1.4	24 -18	epsilon Capricorni	5.0	6.3
44	**Dec 26**	ZC 3175	164593	4.7	16+	S	19 42.6	10 -13	kappa Capricorni		

Southern Africa


GRAZPREP 4.33 IOTA/ES
LONGITUDE

2022	Grazing Occultations Planets 2022							GRAZPREP 4.33, IOTA/ES
No.	M D	MAG	%SNL	L.	W.UT	LONG	LAT	NAME
1	Mar 07	5.8	22+	N	8 0.1	174	-7	Uranus
2	Apr 03	5.8	6+	N	19 21.7	-16	10	Uranus
3	Apr 03	5.8	6+	S	18 42.7	-11	-30	Uranus
4	May 27	-3.5	10 -	N	1 8.4	41	-21	Venus
5	May 27	-3.5	10 -	S	1 16.5	48	-53	Venus
6	May 28	5.9	4 -	N	12 9.5	-103	-19	Uranus
7	Jun 22	0.5	33 -	N	17 47.7	154	-60	Mars
8	Jun 24	5.8	15 -	N	20 33.7	100	-7	Uranus
9	Jul 21	0.3	40 -	S	14 42.2	144	28	Mars
10	Jul 22	5.8	34 -	N	4 42.3	-52	11	Uranus
11	Aug 18	5.7	57 -	N	13 18.2	143	36	Uranus
12	Oct 12	5.7	94 -	S	7 20.3	-28	62	Uranus
13	Oct 24	-1.1	1 -	S	14 11.3	-129	32	Mercury
14	Oct 24	-1.1	1 -	N	14 33.3	-121	65	Mercury
15	Oct 25	-3.5	0+	N	10 14.4	-54	40	Venus
16	Oct 25	-3.5	0+	S	10 20.6	-64	9	Venus
17	Nov 08	5.6	100 E	S	11 4.4	103	8	Uranus
18	Nov 24	-0.7	1+	N	16 7.1	52	-51	Mercury
19	Dec 05	5.7	95+	S	16 1.3	24	11	Uranus
20	Dec 08	-1.9	100+	S	2 30.8	-131	9	Mars
21	Dec 08	-1.9	100+	N	3 24.3	-167	45	Mars

Planets Worldwide

Legend of Tables and Maps

Tables:
No. - Number of the line on the map
M D - Month and day of the event
USNO - Identifier in the XZ or ZC catalogues
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
L. - Limb of the Graze, N - northern limb, S - southern limb
W.UT - UT at westernmost begin of graze limit line
LONG LAT - Position of westernmost begin of graze limit line
STAR NAME - Name(s) of star or planet
MAG1 MAG2 - Vmag of double star components

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

Maps:
Number refers to the line 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

Mutual Planetary Occultations - Have They Ever Been Observed?

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ABSTRACT: Mutual occultations of planets are extremely rare phenomena. In the past, only a few of them were definitely observed and the only certain observations were made in 1737, when the use of telescopes became possible.
The article discusses the results of these observations and reconstructs their circumstances thanks to modern computational methods.

Introduction

Occultations of the stars by the Moon, planets and asteroids have been and continue to be observed. Also, the planets are in close conjunction from time to time. But has it ever been observed when one planet occults another one?

In the past, and especially in pre-telescopic times, such phenomena have been recorded, however, they have usually been noted as very close conjunctions, when the two planets appeared to be in contact with each other. Observations made with the naked eye, even by persons with very good eyesight, could not, of course, be conclusive. Conjunctions, tighter than a few arc minutes, could already appear to be mutual occultations. The invention of the telescope changed the situation radically.

Historical Observations

By analysing historical observations using today's computational tools, we can point to a few phenomena that were just such. The passage of Mars in front of Jupiter, recorded on 1170 September 12/13, is a relatively well-known phenomenon [1]. The original record of this observation can be found in the chronicle by monk Gervase of Canterbury, who likely was the eyewitness of the rare phenomenon:

"On the Ides of September at midnight, two planets were seen in conjunction to such a degree that it appeared as though they had been one and the same star; but immediately they were separated from each other."

In fact, both bodies could be seen as a single object soon after their rising at Canterbury around 21^h UT and for a few more hours before they finally split up.

The same event has been recorded by Chinese astronomers and classified as an "occultation".

A similar phenomenon was recorded on 1590 October 13 at Tübingen by Michael Mästlin, who noticed that in the morning Mars and Venus looked like one object. The same author and independently Johannes Kepler reported that they saw the occultation of Jupiter by Mars on 1591 January 9. According to Kepler "the fiery red colour of Mars showed that Mars was inferior [i.e. nearer the Earth]". However, as we know today, that day there was only a very close conjunction of the two planets which could not be seen separately without the use of a telescope.

By lucky coincidence, however, the only really observed mutual planetary occultation occurred on the evening of 1737 May 28.

Venus occulted Mercury on 1737 May 28

In the 18th century, improved telescopes were used as well as improved algorithms for calculating the positions of the planets existed. Thus, such a close conjunction of planets was previously noticed in an ephemeris, and its observation could serve to improve the theory of planetary motion.

I.a. Jacques Cassini (1677-1756) at the *Paris Observatory* noticed the prediction of this event given by the Bologna astronomer Eustachio Manfredi in his "Ephemerides" [2] and analysed the circumstances of the possible observation [3]. Manfredi gave the general information of a close (*arcte* in Latin) conjunction only (Figure 1), therefore Cassini used Manfredi's tables of the motion of Mercury and Venus.

Figure 1. A fragment of "Ephemerides..." by E. Manfredi for May 1737 with the announcement of the close conjunction of Mercury and Venus on the 28^{th} day.

According to his calculations the conjunction should take place on May 28 at 7^h30^m p.m. at Bologna, so at 6^h54^m p.m. at Paris and Mercury should pass Venus for 1'48" at the south side (this result excluded the mutual occultation since the apparent radius of Venus' disk must be around 30" close to its inferior conjunction with the Sun, which should happen in June 1737). On the other hand, when calculating according to another ephemeris prepared by Philippe Desplaces [4] he obtained the time of the conjunction as 5^h09^m p.m. (assuming all the times corresponded to the local solar time). Cassini added that other astronomical tables gave even greater differences of time.

Therefore, he decided to test the prediction by his own observation which he arranged together with Nicolas-Louis de Lacaille.

According to modern calculations, Venus was at the decreasing elongation of 22° east of the Sun, aiming for the inferior conjunction that occurred on June 13. Mercury, in turn, moved away from the Sun after its superior conjunction on May 5 and reached its greatest eastern elongation on June 6. The apparent diameters of both planets were equal to 51.6" and 6.9", respectively. Venus was illuminated by 8% and Mercury by 55% [5].

Unfortunately, the day 28 of May was cloudy at Paris and observers did not see both planets until after sunset; they continued to come closer to each other. Using an 8-foot telescope, at $8^h29^m30^s$ p.m. the time difference of passage of both planets through the meridional thread of the micrometer was measured as equal to 28^s what was equivalent to 7' in right ascension, and at the same time Mercury was 35" south of the edge of Venus' disc. At 9^h30^m p.m. the lower edges of the two discs were already aligned with each other, and at 9^h44^m p.m. Mercury was only 45" away from the west limb of Venus [3]. According to observers, there were only a few minutes left to the occultation, but further observation was no longer possible as both planets hid in a layer of haze above the horizon. Based on today's calculations, it can be concluded that 9:44 p.m. of the Paris solar time corresponded to $21^h31.5^m$ UT, and then both planets were only 1° above the horizon. They set at 21^h40^m UT [5].

Cassini next used his observation to analyse the accuracy of the available planetary tables, especially with regard to the upcoming two transits of Venus in front of the Sun in 1761 and 1769.

On the other side of the English Channel, another observer was also closely following the same phenomenon: John Bevis (1693-1771) used a 24-foot telescope of the *Royal Greenwich Observatory* (his date of 17 May represents the old style of the calendar – the Julian one) [6]. However, he too could see both planets low above the horizon. At $9^h05^m05^s$ p.m. of the solar time he measured the time difference in right ascension between Mercury and the limb of Venus as 12^s.

At 9^h28^m he made a sketch of both planets (Figure 2). Horizontal line represents the direction of celestial parallel related to one thread of his micrometer.

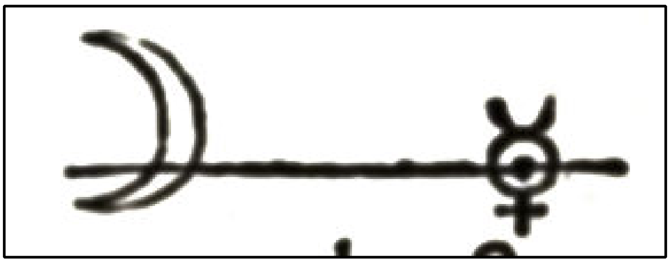

Figure 2. A sketch by J. Bevis a sketch showing the relative positions of the planets at 9^h28^m p.m.

Next, at 9^h44^m p.m. Mercury was distant from the Venus' limb no more than one tenth of its diameter (i.e. about 5")(Figure 3). This moment was equivalent to $21^h40.8^m$ UT when both objects were at an altitude of 2.4° [5].

Figure 3. A sketch by J. Bevis showing the relative positions of the planets at 9^h44^m p.m.

Immediately after that, the planets hid in a cloud. But for the last time they emerged at $9^h52^m06^s$, and then Bevis stated that Mercury was already completely hidden behind Venus. The altitude was only 1.5°. At 22^h05^m UT both planets set at Greenwich.

Using the JPL portal, the author calculated the apparent horizontal positions of Venus and Mercury for Paris and Greenwich in 1 minute steps. According to calculations, at Greenwich the disappearance of the centre of Mercury by Venus was around 21^h44^m UT and the reappearance at 21^h52^m UT (Figure 4). At 21:48 UT Mercury was closest to the centre of Venus – at 20.3" south of it, hidden behind its disc.

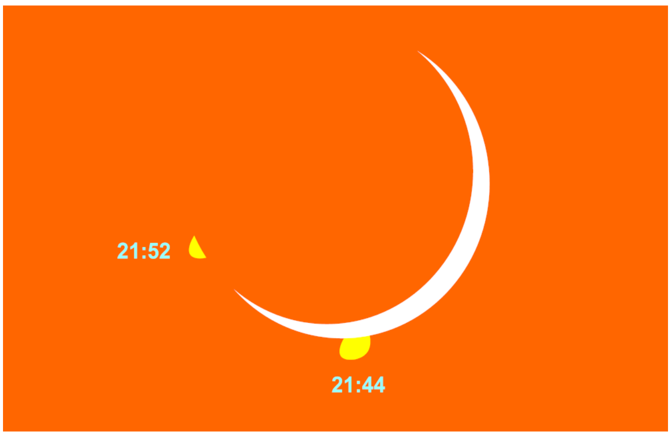

Figure 4. Calculated disappearance and reappearance of Mercury by Venus at Greenwich. Horizontal orientation.

Timespan from the 1st till 4th contact was a little longer and amounted about 10 minutes. The last visibility of both planets in the Bevis' eyepiece can be reconstructed, too (Figure 5).

Figure 5. Last visibility of Mercury and Venus before their mutual occultation according to the report by J. Bevis.

As it turns out, the observation of the described phenomenon was undertaken at one more place - at Berlin [7]. The observer was probably Christfried Kirch. He had the worst conditions of the three cases - both planets were setting at Berlin before the occultation - at 21^{h}19^m UT. Kirch five times measured the angular distance between the centres of the two planets - for the last time at 10^{h}02^m p.m. of the local time, in a haze close to the horizon, getting 3'34 ".

Future Events

Any sky observer would like a similarly spectacular phenomenon to happen in the near future. However, these are extremely rare events. The situation in 1590 and 1591 was an absolute exception, as similar events occur in favourable conditions every few hundred years. In general, the mutual occultations of planets are even more frequent (even several times per century), but they are often practically imperceptible to an observer on Earth due to their small elongation from the Sun. After 1737, a few mutual planetary occultations under better conditions occurred, but were in turn observable in areas where there were no active observers (e.g., 1818 January 3, Venus and Jupiter).

In this century, Venus will pass in front of Jupiter on 2065 November 22, but both planets will be visible in the sky only 8° from the Sun. Then, on 2067 July 15, Mercury will pass in front of Neptune at 18° elongation from the Sun but as seen from near the North Pole. In this situation, the phenomenon will not be observable, either. The next three phenomena at the end of the 21st century will also unluckily occur near the Sun. Only in the evening of 2123 September 14 will it be possible to admire how Venus clearly moves in front of Jupiter (Figure 6). And finally, almost exactly one century later, on 2223 December 2, Mars will be visible in front of Jupiter at the elongation of 89° E (Figure 7), [8]. So, let's wait only some 100 or 200 years!

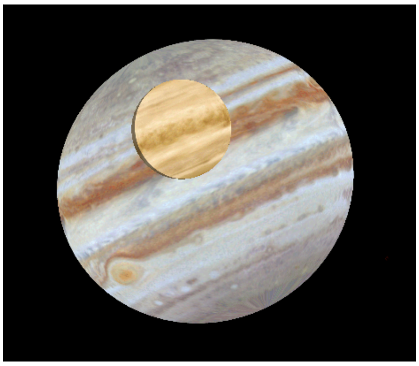

Figure 6, 7. Venus in front of Jupiter on 2123 September 14, 14^{h}25^m UT (top) and Mars in front of Jupiter on 2223 December 2, 12^{h}25^m UT (bottom). The simulations show the view from a geocentric position. (Project Pluto - GUIDE 9.1)

References

[1] Olson, Donald W., Doescher, Russell L., Albers, Steven C.: A Medieval Mutual Planetary Occultation. Sky and Telescope,1992, no.8, p.207.

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Papers about Stellar Occultations Published in 2021

Refined physical parameters for Chariklo's body and rings from stellar occultations observed between 2013 and 2020

B. E. Morgado, B. Sicardy, F. Braga-Ribas, J. Desmars, A. R. Gomes-Júnior, D. Bérard, R. Leiva, J. L. Ortiz, R. Vieira-Martins, G. Benedetti-Rossi, P. Santos-Sanz, J. I. B. Camargo, R. Duffard, F. L. Rommel, M. Assafin, R. C. Boufleur, F. Colas, M. Kretlow, W. Beisker, R. Sfair, C. Snodgrass, N. Morales, E. Fernández-Valenzuela, L. S. Amaral, A. Amarante, R. A. Artola, M. Backes, K-L. Bath, S. Bouley, M. W. Buie, P. Cacella, C. A. Colazo, J. P. Colque, J-L. Dauvergne, M. Dominik, M. Emilio, C. Erickson, R. Evans, J. Fabrega-Polleri, D. Garcia-Lambas, B. L. Giacchini, W. Hanna, D. Herald, G. Hesler, T. C. Hinse, C. Jacques, E. Jehin, U. G. Jørgensen, S. Kerr, V. Kouprianov, S. E. Levine, T. Linder, P. D. Maley, D. I. Machado, L. Maquet, A. Maury, R. Melia, E. Meza, B. Mondon, T. Moura, J. Newman, T. Payet, C. L. Pereira, J. Pollock, R. C. Poltronieri, F. Quispe-Huaynasi, D. Reichart, T. de Santana, E. M. Schneiter, M. V. Sieyra, J. Skottfelt, J. F. Soulier, M. Starck, P. Thierry, P. J. Torres, L. L. Trabuco, E. Unda-Sanzana, T. A. R. Yamashita, O. C. Winter, A. Zapata, C. A. Zuluaga

arXiv:2107.07904 [astro-ph.EP]

(216) Kleopatra, a low density critically rotating M-type asteroid

F. Marchis, L. Jorda, P. Vernazza, M. Brož, J. Hanuš, M. Ferrais, F. Vachier, N. Rambaux, M. Marsset, M. Viikinkoski, E. Jehin, S. Benseguane, E. Podlewska-Gaca, B. Carry, A. Drouard, S. Fauvaud, M. Birlan, J. Berthier, P. Bartczak, C. Dumas, G. Dudzinski, J. Durech, J. Castillo-Rogez, F. Cipriani, F. Colas, R. Fetick, T. Fusco, J. Grice, A. Kryszczynska, P. Lamy, A. Marciniak, T. Michalowski, P. Michel, M. Pajuelo, T. Santana-Ros, P. Tanga, A. Vigan, O. Witasse, B. Yang

arXiv:2108.07207 [astro-ph.EP]

Asteroid 16 Psyche: Shape, Features, and Global Map

Michael K. Shepard, Katherine de Kleer, Saverio Cambioni, Patrick A. Taylor, Anne K. Virkki, Edgard G. Rivera-Valentin, Carolina Rodriguez Sanchez-Vahamonde, Luisa Fernanda Zambrano-Marin, Christopher Magri, David Dunham, John Moore, Maria Camarca

arXiv:2110.03635 [astro-ph.EP]

Neptune's ring arcs from VLT/SPHERE-IRDIS near-infrared observations

D. Souami, S. Renner, B. Sicardy, M. Langlois, B. Carry, P. Delorme, P. Golaszewska

arXiv:2110.12669 [astro-ph.EP]

Volatile transport modeling on Triton with new observational constraints

T. Bertrand, E. Lellouch, B. J. Holler, L. A. Young, B. Schmitt, J. Marques Oliveira, B. Sicardy, F. Forget, W. M. Grundy, F. Merlin, M. Vangvichith, E. Millour, P. Schenk, C. Hansen, O. White, J. Moore, J. Stansberry, A. Oza, D. Dubois, E. Quirico, D. Cruikshank

arXiv:2110.11992 [astro-ph.EP]

Analysis of four-band WISE observations of asteroids

Nathan Myhrvold, Pavlo Pinchuk, Jean-Luc Margot

arXiv:2110.12098 [astro-ph.EP]

Understanding the trans-Neptunian Solar system: Reconciling the results of serendipitous stellar occultations and the inferences from the cratering record

Andrew Shannon, Alain Doressoundiram, Françoise Roques, Bruno Sicardy

arXiv:2111.00391 [astro-ph.EP]

Pluto's atmosphere in plateau phase since 2015 from a stellar occultation at Devasthal

Bruno Sicardy, Nagarhalli M. Ashok, Anandmayee Tej, Ganesh Pawar, Shishir Deshmukh, Ameya Deshpande, Saurabh Sharma, Josselin Desmars, Marcelo Assafin, Jose Luis Ortiz, Gustavo Benedetti-Rossi, Felipe Braga-Ribas, Roberto Vieira-Martins, Pablo Santos-Sanz, Krishan Chand, Bhuwan C. Bhatt

arXiv:2112.07764 [astro-ph.EP]

*This compilation is intended to provide more in-depth information on individual topics.
It neither claims to be complete nor does it represent an evaluation of the scientific work.*

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 2021 December 30, the *Minor Planet Center* listed 1394 Centaurs and 2907 TNOs.

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

No.	Name	Author	Link to Issue
944	Hidalgo	Oliver Klös	JOA 1 2019
2060	Chiron	Mike Kretlow	JOA 2 2020
5145	Pholus	Konrad Guhl	JOA 2 2016
8405	Asbolus	Oliver Klös	JOA 3 2016
10370	Hylonome	Konrad Guhl	JOA 3 2021
10199	Chariklo	Mike Kretlow	JOA 1 2017
15760	Albion	Nikolai Wünsche	JOA 4 2019
15810	Awran	Konrad Guhl	JOA 4 2021
20000	Varuna	Andre Knöfel	JOA 2 2017
28728	Ixion	Nikolai Wünsche	JOA 2 2018
38628	Huya	Christian Weber	JOA 2-2021
47171	Lempo	Oliver Klös	JOA 4 2020

In this Issue:

2004 RX_{190} "Buffy"

Carles Schnabel · IOTA/ES · Agrupació Astronòmica Sabadell · Sabadell · Spain · cschnabel@planetari.cat

ABSTRACT: The TNO 2004 XR_{190} was discovered in 2004, orbiting the Sun every 433 years. It is currently the thirteenth most distant known large body in the Solar System with a well determined orbit. Indeed, the high orbital inclination of 47° makes it very special. At the beginning of 2021, an occultation was observed yielding a good estimation of his dimensions.

No.	Name	Author	Link to Issue
50000	Quaoar	Mike Kretlow	JOA 1 2020
54598	Bienor	Konrad Guhl	JOA 3 2018
55576	Amycus	Konrad Guhl	JOA 1 2021
60558	Echeclus	Oliver Klös	JOA 4 2017
90377	Sedna	Mike Kretlow	JOA 3 2020
90482	Orcus	Konrad Guhl	JOA 3 2017
120347	Salacia	Andrea Guhl	JOA 4 2016
134340	Pluto	Andre Knöfel	JOA 2 2019
136108	Haumea	Mike Kretlow	JOA 3-2019
136199	Eris	Andre Knöfel	JOA 1 2018
136472	Makemake	Christoph Bittner	JOA 4 2018

The Discovery

2004 XR_{190} was discovered on 2004 December 11 by a team of astronomers led by Lynne Allen of the University of British Columbia, Canada, during the Canada–France Ecliptic Plane Survey with the 3.6-m Canada–France–Hawaii Telescope (CFHT) on Mauna Kea, Hawai'i. The members of the team were Brett Gladman, John Kavelaars, Jean-Marc Petit, Joel Parker and Phil Nicholson [1].

Later, in 2015, it was found that it also appeared on three images obtained in 2002 and three others in 2003 all taken in the course of the Sloan Digital Sky Survey from Apache Point, USA.

The Name

No official name has been assigned yet, but the discovery group proposed the provisional name *Buffy*, as well as others related to far-north Inuit mythology. Buffy refers to the fictional vampire slayer, Buffy Summers, who features in a movie and TV series [2].

The Orbit

2004 XR_{190} is truly an amazing object in this regard. It orbits the Sun over a period of 433 years, with a perihelion of 51.1 AU and an aphelion of 63.4 AU (eccentricity 0.11) [3], [4]. It currently lies at a heliocentric distance of 56.9 AU making it the 13th farthest known TNO and will next reach perihelion in 2117. Even more striking is its orbital inclination of 46.7° from the ecliptic. In this sense, it is the largest object in the entire Solar System having an orbit inclined by more than 45° (Figure 1).

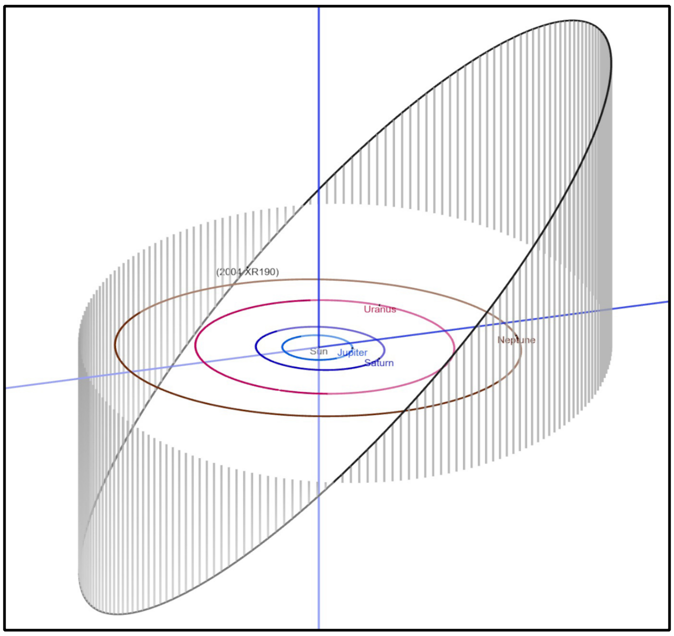

Figure 1. Orbit diagram of 2004 XR_{190}
Credit: JPL Small-Body Database Browser [4].

This unusual object belongs to the same group as 2014 FC_{71}, 2014 FC_{72}, 2015 FJ_{345} and 2015 KQ_{174}, which also have relatively distant perihelia and moderate orbital eccentricities [5], (Figure 2).

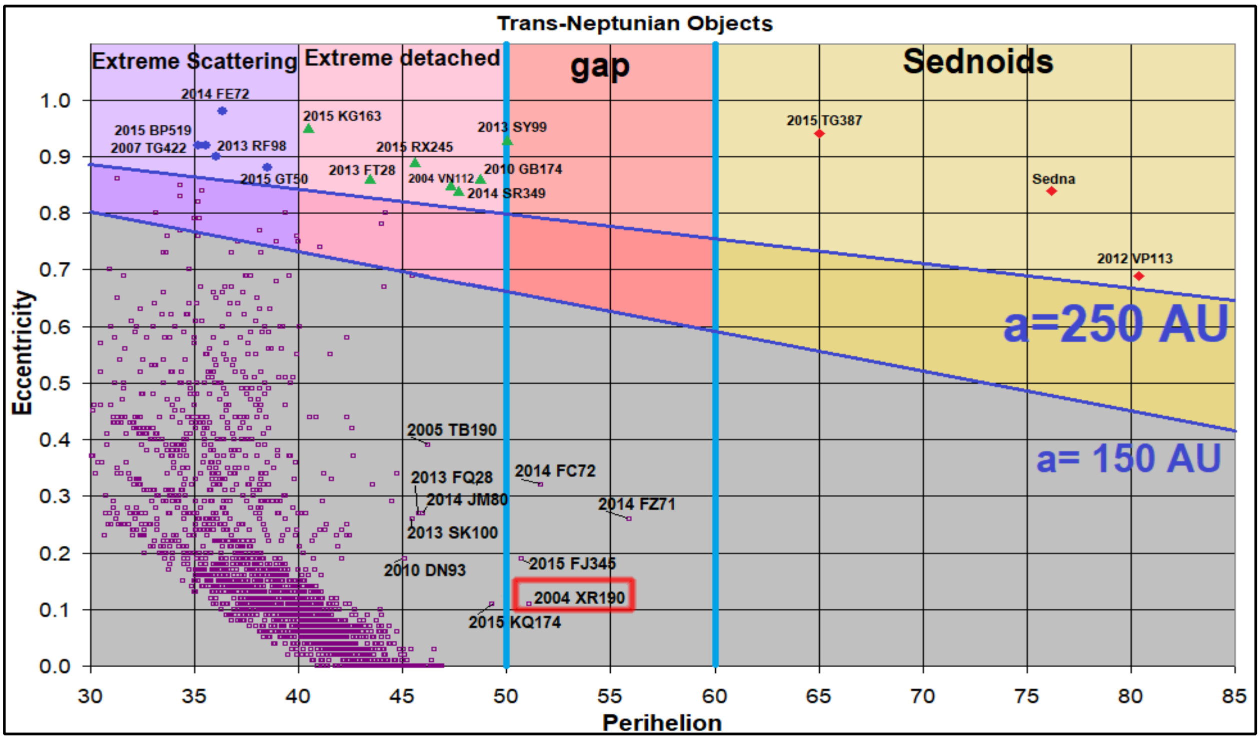

Figure 2. The red box highlights the location of 2004 XR_{190} among other TNOs in a gap between Detached Objects and Sednoids. Graphic: Tom Ruen. Licensed under the Creative Commons Attribution-Share Alike 4.0 International license.

From the characteristics of its orbit, it is considered to be both a Scattered Disk Object (SDO) and a Detached Object: Scattered, because the effect of gravitational scattering caused by the giant planets; and detached because its perihelion is outside the gravitational influence of Neptune. However, its low eccentricity is abnormal for a detached disk object, and it becomes difficult to explain the combination of low eccentricity with high inclination. This is why exotic origins are hypothesised such as being disturbed by the passage of a nearby star, or by the presence of an as yet undiscovered planet, or by the passage of a rogue planet. It could also have been influenced by a planetary embryo from the Solar System itself or by Neptune in the process of migrating to its current orbit [1], [6], [7].

At the moment, it is the only object that has been found with such peculiar orbital features, but this is probably because these objects spend more than 95% of their time at high ecliptic latitudes, while the search for TNOs is mostly done in areas close to the ecliptic. Surely there are many more "Buffys" to discover?

Physical Parameters

Spectrophotometric and photometric observations are compatible with a fairly large range of diameters, from 335 to 850 km, taking into account albedo values between 16% and 4% [1]. Johnston's Archive (https://www.johnstonsarchive.net/) lists the object as taxonomic type "BR" or intermediate Blue-Red, with a (B-R) colour magnitude of +1.24 [5] [8]. Colour indices according to [9] are (G-R) = +0.55 ±0.04 and (R-I) = +0.30 ±0.04 placing this body within the neutral or grey range. The absolute magnitude according to the Minor Planet Center [3] is H_{mag} = 4.5 whereas the value in [4] is given as H_{mag} = 4.3. As for the possible values of the albedo, they fluctuate between 0.04 and 0.25 depending on the sources [1], [5], [10], but most likely it is close to 0.10 [11], especially considering the size deduced from an occultation, as explained below.

Successful Observation on 2021 January 21

On 2021 January 22, the first stellar occultation by 2004 XR_{190} was recorded [12], (Figure 3, 4), (Appendix). In this way, a size limit of approximately 640 x 450 km was derived. The occultation was observed on both sides of the Atlantic Ocean: The team of Kevin Green and C. Gao of the *Westport Astronomical Observatory*, 70 km north of New York, and the author of this article located 25 km north-west of Barcelona recorded two chords of 23.93 and 28.32 seconds in length, respectively. Luckily, the two observations seem to outline the body well enough. This occultation, therefore, gives a fairly reliable limit to the actual size of the object, as well as facilitating a very high-precision position in its trajectory relative to the stellar background.

This means that, as Jean Lecacheux (LESIA, *Paris Observatory*) [13] told the author in a personal communication, this observation is very important in defining similar events in the future. Accurate prediction of forthcoming occultation events will benefit from this positive record (Figure 5).

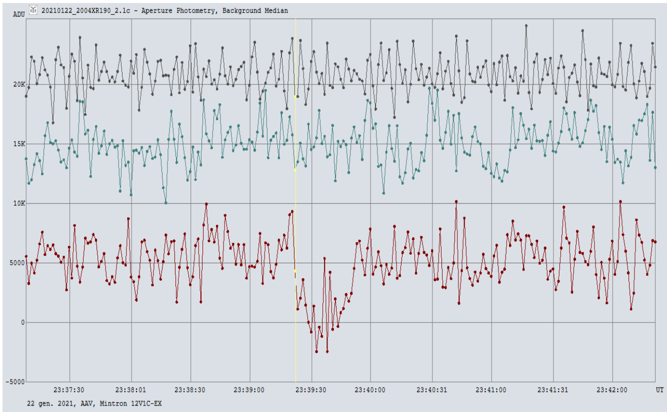

Figure 3. Light curve of the occultation by 2004 XR_{190} on 2021 Jan 22, recorded by the author with a f/4 0.4 m Newtonian, a Mintron 12V6HC-EX camera, which was set to a frame rate of 6.25 fps, and a Kiwi time inserter. The star image stability was reported as bad to fair.

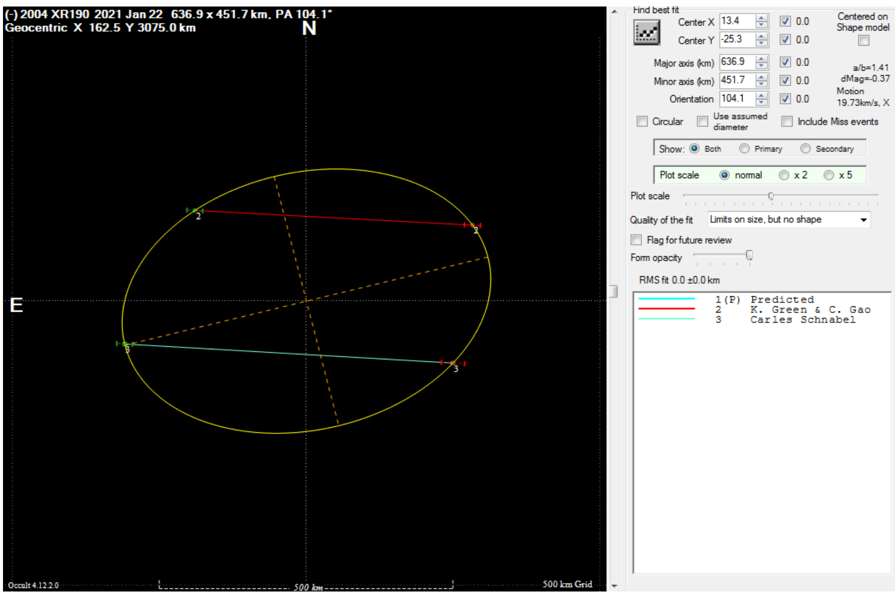

Figure 4. Best fit of the two chords observed by K. Green and C. Gao at Westport Astronomical Observatory (USA) and C. Schnabel at Sant Esteve Sesrovires (Spain).
Credit: E. Frappa, euraster.net
https://www.euraster.net/results/2021/index.html#0122--

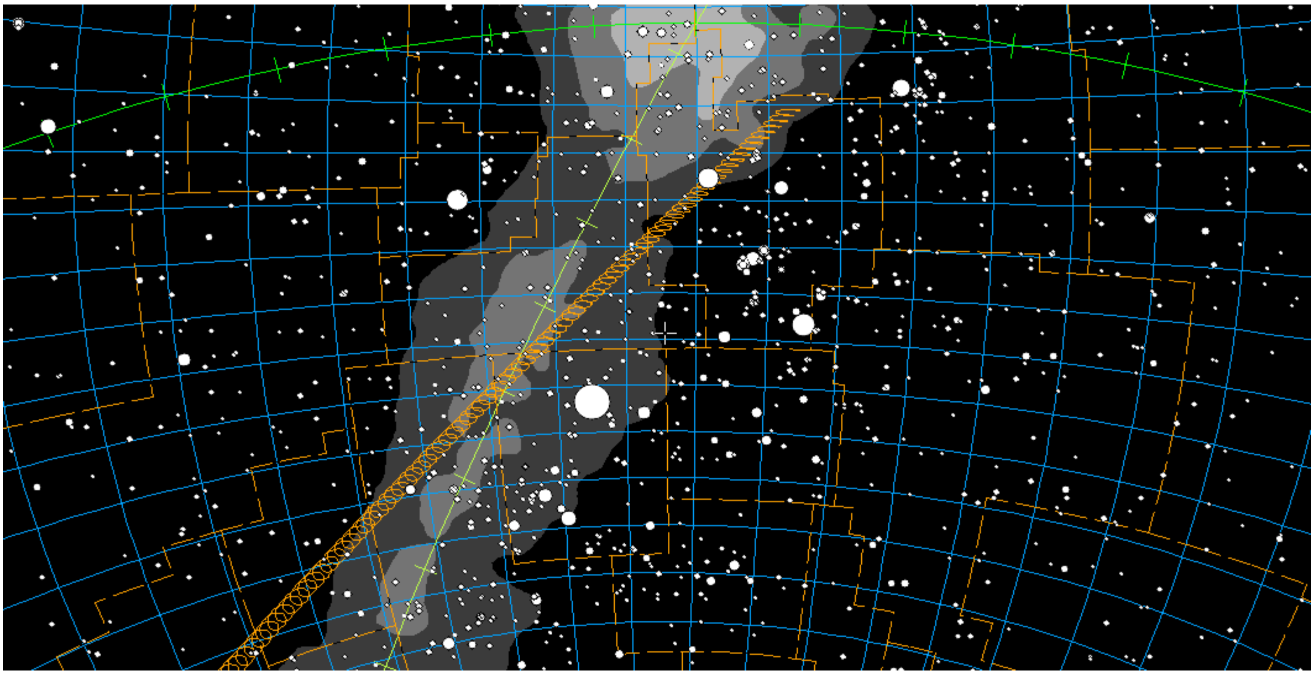

Figure 5. 2021-2106 track of 2004 XR_{190} in front of the Milky Way. A nice string of 85 small parallactic loops, caused by Earth's motion around the Sun. Credit: Jean Lecacheux, made with Project Pluto's GUIDE 9.

Future Stellar Occultations

The European Research Council (ERC) Lucky Star Project [14] includes five stellar occultations by 2004 XR_{190} for the year 2022.

A calculation using *Occult* software [15] for the following years until 2030 (down to V magnitude 18) yielded some potentially observable occultations (Table 1). However, these predictions should be treated with caution as the ephemeris used may be subject to significant errors.

Event	Date	UT	Star	MV	Max Dur	Region	Source	B
1	2022 Mar 16	13:37	3390170523145706368	16.1	111.9 s	Oceania	LckSt/DR3	X
2	2022 Aug 01	11:39	3389431101576854400	14.0	26 s	N. America	LckSt/DR3	
3	2022 Nov 27	06:11	3389202123984033792	17.4	23.1 s	America	LckSt/DR3	
4	2022 Dec 04	16:55	3389383582058752896	16.8	22.4 s	S. Asia, Oceania	LckSt/DR3	X
5	2022 Dec 16	02:18	3389385433187414144	17.5	22.2 s	Arctic	LckSt/DR3	
6	2023 Jan 01	14:35	UCAC4 517 012161	13.3	17.6 s	Asia, Oceania	Occ	
7	2027 Apr 19	22:56	UCAC4 506 012808	14.1	22.9 s	S. America	Occ	
8	2027 Nov 08	08:40	UCAC4 503 014530	15.6	21 s	America	Occ	
9	2027 Nov 25	06:18	UCAC4 503 014347	17.7	17.7 s	America	Occ	
10	2027 Nov 26	07:30	UCAC4 503 014330	14.6	17.6 s	America	Occ	
11	2028 Oct 25	09:30	UCAC4 501 015031	11.5	28.1 s	America	Occ	

Table 1. Upcoming stellar occultations by 2004 XR_{190} until 2030 for stellar magnitudes up to Mv 18. Star designations according to Gaia EDR3 and UCAC4. "LckSt/DR3" Lucky Star prediction [14], "Occ" author's predictions with Occult 4.12.16.0 [15] using Astorb ephemerides of 2021 October 30 and UCAC4, "B" indicates matches with M. W. Buie's predictions [16].

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Further Reading

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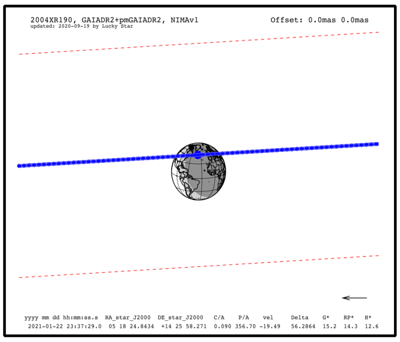
The Trans-Neptunian Solar System
Editors: Prialnik, Dina, Barucci, Antonella & Young, Leslie
Elsevier, 2019, eBook and paperback
https://www.elsevier.com/books/the-trans-neptuniansolarsystem/prialnik/978-0-12-816490-7

Journal for Occultation Astronomy

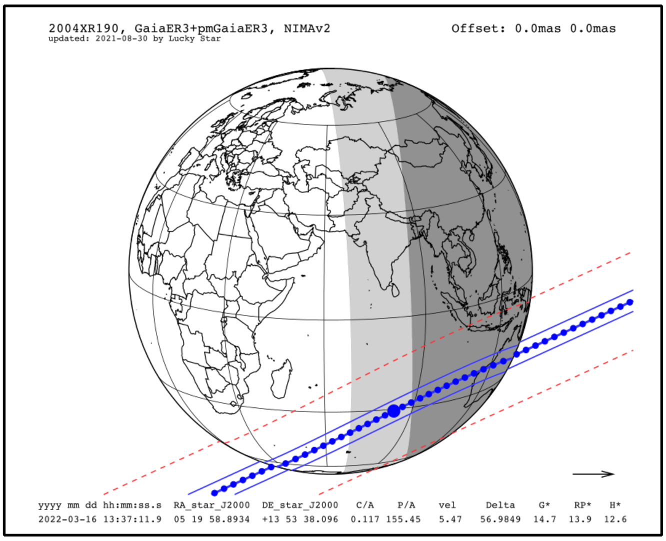
Appendix

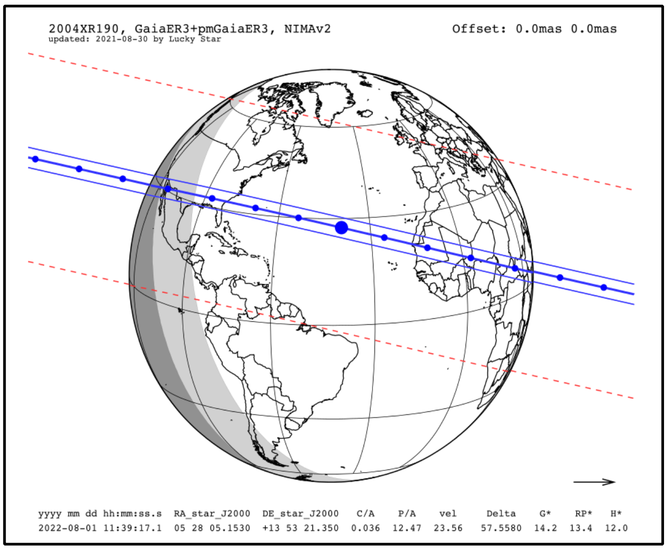


2021

Lucky Star prediction of 2004 XR_{190} occultation of a 15.2 mag star on 2021 Jan 22. To emphasise the huge inaccuracy of the prediction of the successful observation. Credit: ERC Lucky Star project. https://lesia.obspm.fr/lucky-star/ occ.php?p=44326

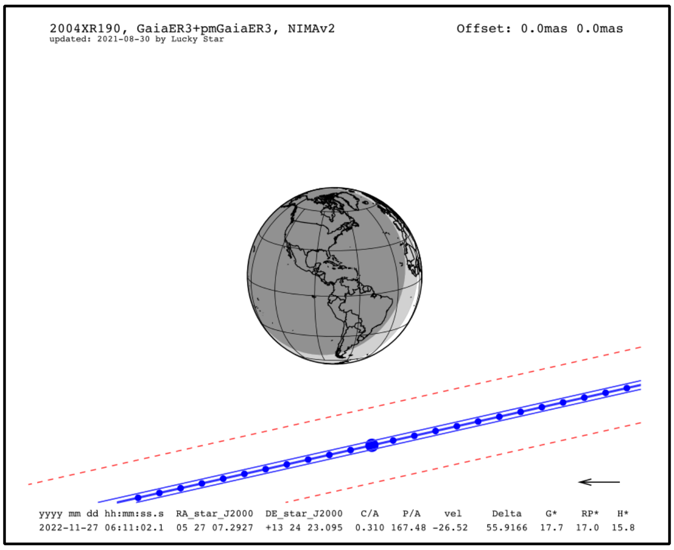
2022

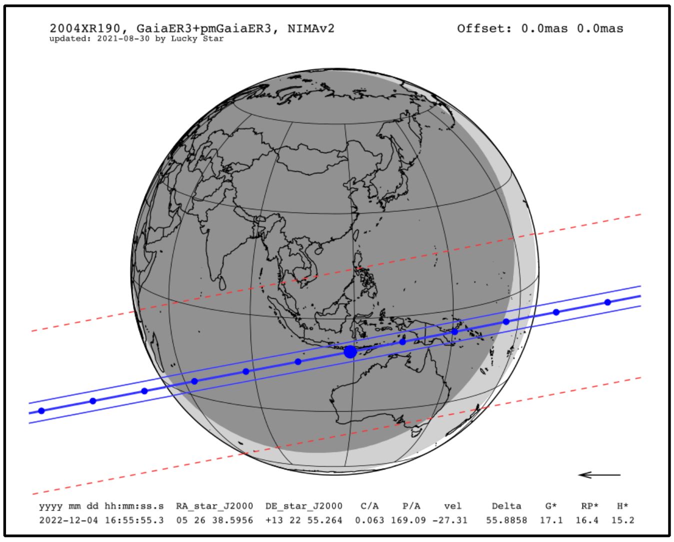


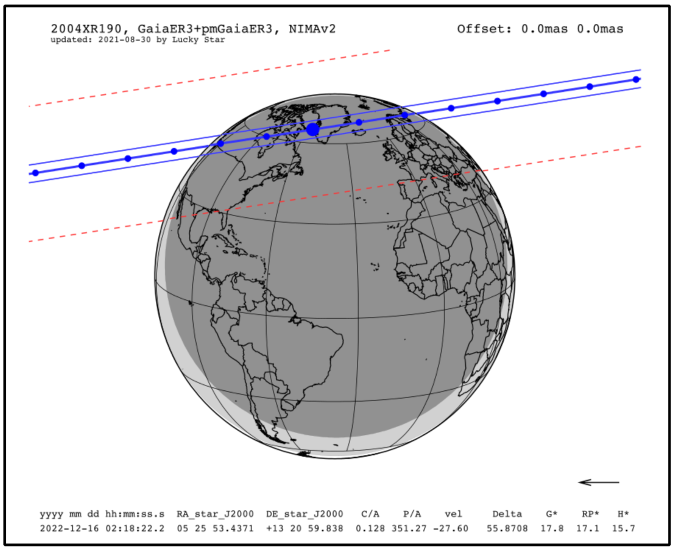


Events 1 - 2

2022

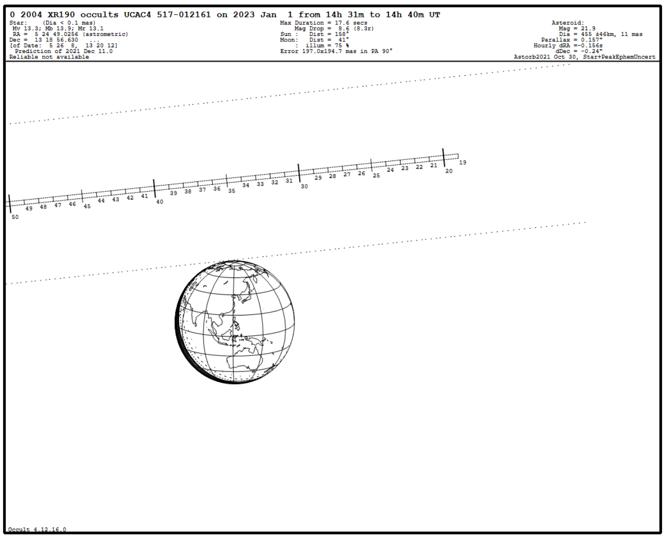


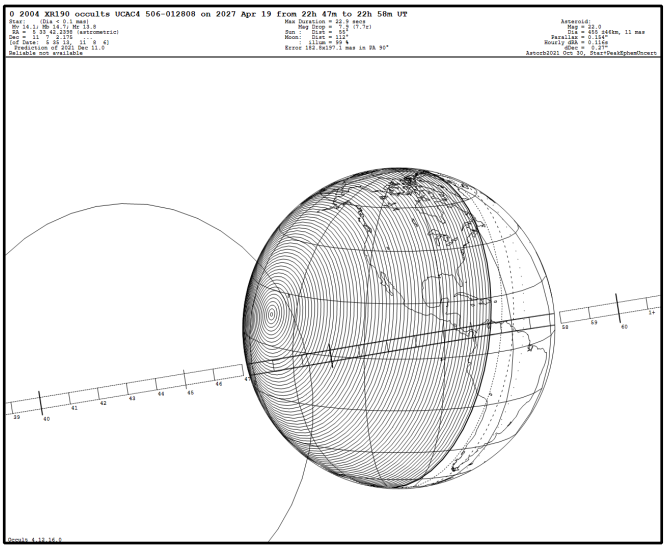


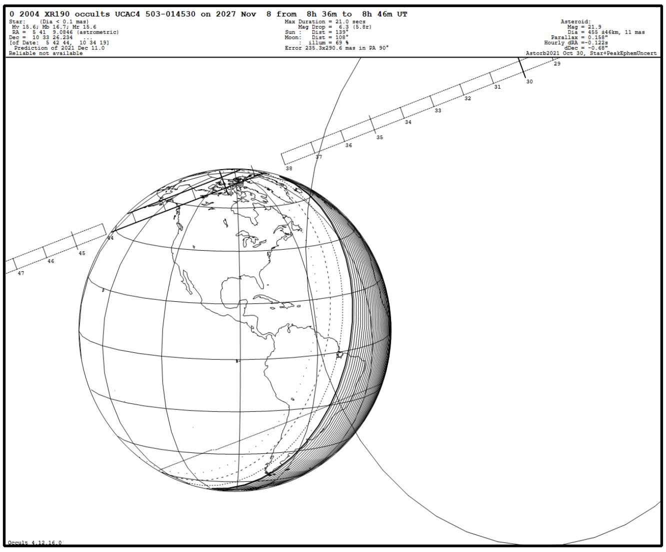


Events 3 - 5

2023 - 2027

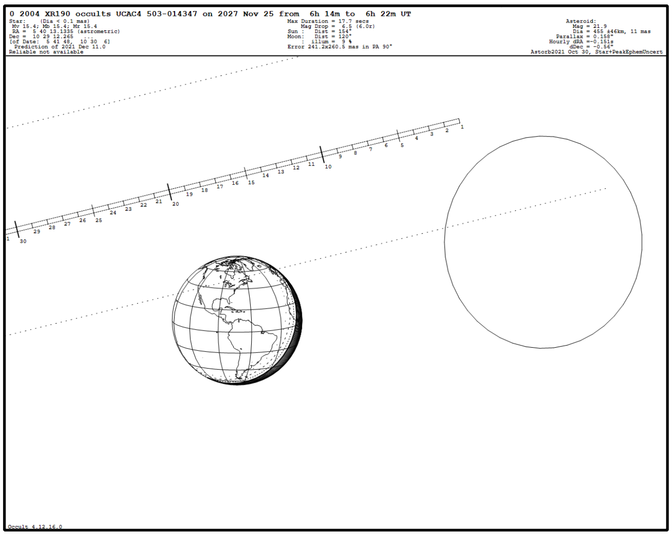


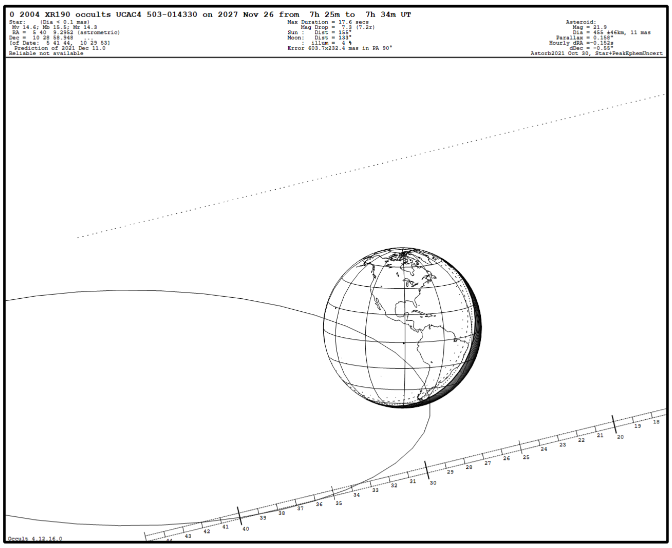


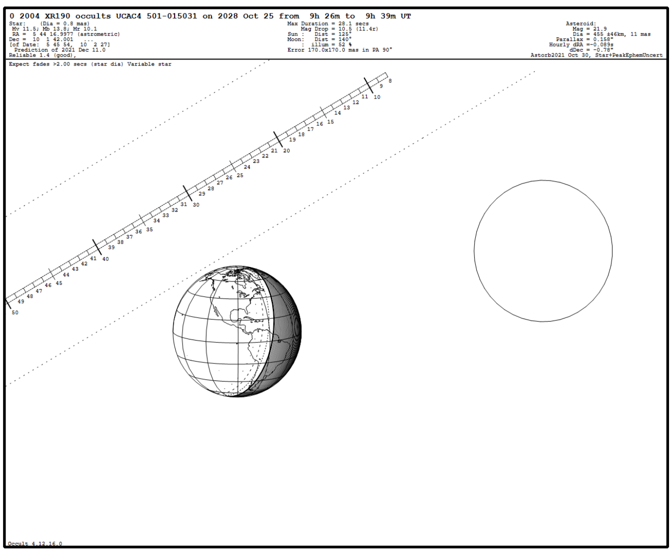


Events 6 - 8

2027 - 2028







Events 9 - 11

Eberhard Bredner awarded the VdS Medal

The *Vereinigung der Sternfreunde e.V.* (VdS) is the largest amateur astronomy community in Germany with more than 4,000 members. During their general assembly on 2021 November 13th, the *VdS Medal*, the German Amateur Astronomy Award, was presented for the 17th time. This year's laureate was the internationally renowned observer of stellar occultations, Eberhard Bredner. As the general assembly was held online, Eberhard Bredner was astonished when co-opted assessor of the board of the VdS, Werner E. Celnik, suddenly appeared at his door and presented him with the award. This is a translation of the laudation given by Werner E. Celnik:

Dr. Eberhard H. R. Bredner from 59229 Ahlen-Dolberg is internationally known as an active, systematic observer of stellar occultations for decades (even today). Because occultation events such as grazing occultations by the Moon or stellar occultations by minor planets can only be observed at specific locations, he often travels 500 to 800 kilometres in one night with his standard astronomical equipment to observe a specific event lasting only a few seconds.

Eberhard Bredner is a graduate physicist and has been retired for many years. He worked professionally as head of the natural sciences department at the adult education centre in Hamm. There he very successfully promoted astronomical education, offered an astronomical lecture programme for the public and led a local astronomical working group for many years.

He has been involved in several astronomical organisations for decades:

In the International Occultation Timing Association - European Section (IOTA/ES e.V.) he filled the office of "Secretary" for many years. In this capacity he was involved in the organisation of international ESOP meetings of IOTA throughout Europe.

Since the early 1980s, Eberhard Bredner has been an active member of the VdS and for many years has been head and editor of the VdS specialist group "Stellar Occultations". He is a regular author in the VdS Journal für Astronomie, where he presents his observational results and at the same time promotes the observation of stellar occultations.

At his home Eberhard Bredner (right) receives the VdS Medal from Werner E. Celnik. Image: Birgit Wickord

For decades, Eberhard Bredner can be found not only at international conferences all over Europe, but also at the VdS conferences, and usually with a lecture: like this year at the VdS conference, where he always also speaks with commitment at the general meeting of our association. But he also regularly lectures at the Würzburg Spring Conference and the Bochum Autumn Conference, as well as at planetariums and public observatories. His inimitable way of lecturing has earned him much admiration and also led to a flying word, quote: "The picture may not be pretty, but it's from me!" One of the professional highlights of his lectures, from my point of view, was an impressive video showing how the star Regulus was partially (!) occulted by the Moon during a grazing occultation.

Eberhard Bredner maintains intensive contacts with stellar occultation observers from all over the world, especially in the Netherlands and France. He organises joint observations of certain events across national borders and coordinates the evaluations. I myself have experienced how observers met at the German-Dutch border and then spread out over the observation line significant for grazing occultations, carried out the observation and at the end concluded the event together in intensive conversation over a joint meal (even at 3 o'clock in the morning!). Contacts that last. With all his astronomical observing zeal, Eberhard Bredner never forgets the VdS, for which he always tries to recruit members.

With his constant and systematic commitment to amateur astronomy, Eberhard Bredner has identified to a high degree with the goals and the statutory mission of the Vereinigung der Sternfreunde and supported them. With the award of the VdS Medal, he rightly deserves the German Amateur Astronomy Award of the Year 2021.

The International Occultation Timing Association's 39th Annual Meeting, 2021 July 17-18 via Zoom Online

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

ABSTRACT: IOTA's 2021 Annual Meeting was held via Zoom online on 2021 July 17-18. Numerous presentations were made by members of the IOTA community worldwide. More than 80 attendees participated in the meeting.

The 39th annual meeting of the International Occultation Timing Association was held Saturday and Sunday 2021 July 17-18 via Zoom online. The meeting schedule and agenda are located on the IOTA web site [1].

Ted Blank was in charge of the technical operation of the Zoom meeting throughout. Video recordings of the session are available on YouTube [2].

Saturday 17th July 2021 - Day 1

IOTA's Vice President **Roger Venable** opened and welcomed everyone to the meeting. Ted Blank gave instructions for using Zoom functions for this year's fully online meeting.

Business Meeting

Treasurer **Joan Dunham** presented IOTA's financials and membership status. A full report is available [3].

Awards

Executive Secretary **Richard Nugent** presented IOTA's *Homer F. Daboll, David E. Laird* and the *Lifetime achievement awards*.

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 is **Bob Anderson** from Oregon. Bob emphasized the statistically rigorous computation of occultation timing parameters. In 2007, at the suggestion of Tony George. Bob developed the program *Occular* to reduce occultation light curves using the method of least squares.

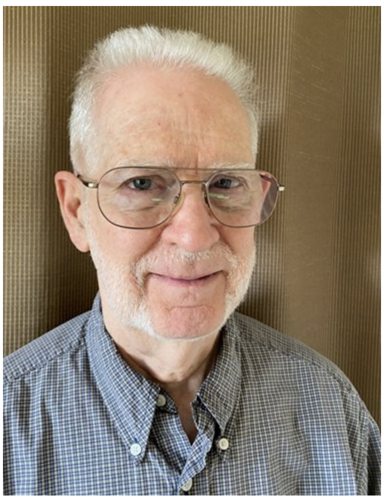


Figure 1. Homer F. Daboll Award: Bob Anderson

Bob then later developed *R-OTE* to replace *Occular*. In 2017 Bob introduced *PyOTE* at the IOTA annual meeting. *PyOTE* [4] is a multi-platform program to replace *Occular* and *R-OTE*. It works with Windows, Mac and Linux. He then introduced *PyMovie* [5]. Bob also developed the program *ArtStar* – to test CCD cameras by introducing an artificial star to simulate occultations [6].

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

Thank you for this award. It is an honor to be included in the group of prior recipients of the IOTA Homer Daboll award.

I can easily trace my involvement with 'things IOTA' to a specific date: on June 7, 2007, I was on a plane headed to Florida to observe a Shuttle launch (STS-117) scheduled for the next day (and it did launch!). I was accompanied on that trip by Tony George. During the flight, he explained the difficulties he was having using Excel to extract D and R times from occultation light curves. It was then that I uttered those fateful words: "Maybe I can use what I know about extracting known-shape signals from noise to help with that". Tony may have responded with: "Great, when can you have it done?"

From that conversation soon flowed Occular, with R-OTE, PyOTE, and PyMovie following at a more sedate pace in the following years. Much of the development of those programs was guided by Tony's suggestions of ways in which the programs could be made easier to apply to the issues faced by occultation observers.

I had thought that, by this time, I would be doing only routine maintenance on PyMovie and PyOTE. But with the work that Dave Herald has done in making the Gaia catalog accessible and Steve Preston's increasingly precise predictions, I realized that it was likely that there would be more occultations in which diffraction would need to be taken into account, so I undertook a project to add diffraction effects to the model light curve used by PyOTE; this is the subject of a talk that I will give tomorrow. As I prepared the diffraction talk for this meeting, I realized that with the Gaia/ prediction advances, a tool that I used in my diffraction studies - calculation of the diffraction pattern of an arbitrary shape object - may be useful in analyzing observations of asteroids with 'companions' (which will have interacting diffraction patterns), so I *am contemplating a future project to make that tool available as a separate program.*

Thank you again for this award.

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

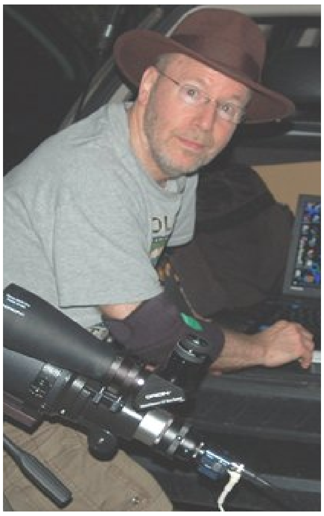


Figure 2. David E. Laird Award: Richard Wilds

This year's David E. Laird award recipient is **Richard Wilds** from New York.

Richard was a major graze observer and organizer and did extensive work with grazes and occultations in the 80's and 90's in the Kansas City area. He and Craig and Terry McManus (former IOTA Secretary-Treasurers) were the first IOTA folks to put together an image intensifier in the 90's to reach fainter asteroid events. Richard has also done numerous TV interviews to introduce upcoming occultation events. In 2008 he published a labeled version of "*The Marginal Zone of the Moon"* from Chester Watt's original charts of the lunar topography. He published an extensive article recently on "*Lunar Grazing Occultations*" in the Encyclopedia of Lunar Science. Richard has published numerous articles in both magazines, astronomy newletters and professional journals. From Sky & Telescope: "*Mapping Asteroid Shapes by Video*", "*Observing a Solar Eclipse from the Edge*", (plus numerous other articles on bright and dark nebulae). An Astronomy magazine article from 2018, Richard described the RunCam camera and how to use it for video: "*IOTA RunCam Night Eagle Astro Edition*". In 2017, Richard received the prestigious *Donald E. Osterbrock Book Prize*, for the Biographical Encyclopedia of Astronomers by the American Astronomical Society, Historical Astronomy Richard also published the book: Bright and Dark Nebulae: A Guide to Understanding the Clouds of the Milky Way", CreateSpace, 2017

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

I want to thank everyone for the honor of being selected for the IOTA David E. Laird Award. In Dr. David Dunham's educational travels through universities such as Yale and Texas, he would spend part of his time in the 1960s at the United States Naval Observatory (USNO), and it was at the USNO that he produced the first effort at a Manual for Grazing Occultations. It is interesting that this first Manual included something similar to the 1960s Mission Impossible quote – "Should you or any member of your team have difficulty with any law enforcement agency, then the USNO and the U.S. Government will disavow any knowledge or association with your efforts." How could any person looking for adventure in science ignore such an offer!

I did not have a Driver's License, so I volunteered to draw the early Lunar Grazing Occultation Profiles to help Graze Leaders and joined Lunar Grazing Occultation Expeditions as an observer. Once I obtained my Driver's License, then I began my Graze Leader efforts of several hundred Lunar Grazing Occultations. I spent a number of years in the 1990s as IOTA's Grazing Occultation Coordinator. There were also Solar Eclipses from the Edge, Asteroid Occultations of Main Belt and Jovian Trojans along with Jupiter and Saturn Mutual Events among their moons. Perhaps one of the more interesting moments came with a phone call from NASA at 1AM one morning demanding assistance with the Lunar Reconnaissance Orbiter mission. They were trying to coordinate ground based images with the LRO imaging from Lunar orbit and needed help in identifying what they were imaging. They had heard that I was a Lunar Limb specialist and asked me to identify the objects in their images. By 1:30AM I had been able to identified multiple craters that had appeared in their view.

The main point of it all is that IOTA has provided me with the framework for service in the pursuit of knowledge in science. We all have an opportunity to accept the mission! Remember, should you or any member of your team…

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

Figure 3. IOTA Lifetime Achievement Award: Roger Venable

This year's *IOTA Lifetime Achievement Award* 's recipient is **Roger Venable** from Georgia. Roger has observed asteroidal occultations for 33 years, including 100's of multi-station deployments. This includes over 770 stations set up (at the time of this writing), many of which were unattended video stations. With 306 occultation events observed, he obtained good data on 572 stations and 199 stations that didn't get good data. Roger authored Chapter 10 of the IOTA manual, "*Unattended Video Stations*", refining the drift thru technique.

Roger has made especially long trips for near-Earth asteroid events during the last two years, helping nail down first the orbit of Phaethon. He did the same for the smaller and more threatening Apophis, verifying its orbit by recording occultations on March 22 and April 4 from multiple stations – adding orbital precision that shows that Apophis will miss the Earth during its several close approaches for at least the next 100 years. He also drove 2,647 miles (4,240 km) for the May 2012 annular eclipse in California (Georgia to California). Roger is also very active in ALPO and is the Mars section coordinator. Roger is a retired physician, having practiced family medicine and emergency medicine for 43 years.

For information on IOTA's awards, including previous awardees, see the award webpage [7].

Technical Sessions

President **Steve Preston** presented a list of the best asteroid occultations of the coming year. He picked events (not necessarily because a bright star was occulted) based on larger asteroid sizes and favourable ground coverage. One of the anticipated events was by (6) Hebe across the USA on 2021 July 26. Paul Maley observed the occultation by (6) Hebe in March 1977 and he reported a short blink from north of the actual path, indicating a possible satellite of Hebe, hence the need for additional occultation observations to possibly see if such a satellite exists. Several events by (6) Hebe will occur in the next few months and observers are encouraged to make the effort to observe them.

Bill Hanna next spoke about a remote permanent observatory. Bill made his first occultation observation some 10 years ago. He lived in Australia for many years (now he lives in Montana) and chose a site in Australia for his remote observatory. The observatory houses 7 telescopes. His equipment consists of a 20-inch Planewave f/6.8 telescope, with Paramount ME II absolute on-axis encoders, QHY174m camera, and Compulab IPC2 i7 computer. All the equipment was cheaper to buy in the US, but with all the hassles of mailing, customs, etc. he decided to buy the equipment in Australia. Most of the equipment is mounted on the telescope. Bill showed several photos of his setup.

Bill runs the whole system off his Asus gaming laptop (because of its computing power) and typically can have the whole system turned on and running for data collection in 15 minutes. The MPA Home Page Bill uses to monitor the operation has an all-sky camera, observatory webcam, weather status and an observatory roll-off open/closed status.

In the past 3 years, Bill has scheduled
1278 occultation events
He sent in 532 reports
410 - misses
122 - positives

Going forward, Bill plans to be doing astrometry of mostly *Lucy* mission targets (with an MPC observatory code Q56) and Jupiter satellite events.

Hristo Pavlov next presented the *Occult Watcher (OW) Cloud* [8]. The basic *Occult Watcher* program notifies observers which events are generally near to them. It also allows you to post your expected path position for an upcoming event so that other observers don't duplicate your position. The need for *OW cloud* comes as the result of the large Gaia catalog, the huge number of events predicted worldwide and the number of parameters associated with each event. One can search by object such as numbered asteroid, comets, interstellar objects, planetary satellites and event date to within the next 2 months. As an example, Hristo chose asteroid (2207) Antenor for 2021 July 30 and the program searched over 20 million stars and within a few seconds, 10 events were output. Certain events may be "tagged" such as the need for observations (such as the recent moon discovered around (4337) Arecibo) or an asteroid with a few or no observations. The program can bring up a Google map of your intended location, a DSS image of the star field and predicted error margin ellipses.

Peter Nosworthy presented the observations leading up to the discovery of a satellite of the asteroid (4337) Arecibo. Dave Gault and Peter Nosworthy reported to CBAT the discovery from the occultation of the star UCAC4 323-126197 on 2021 May 19.74861. The observers were separated by 0.7 km across the occultation path, and 18 km along the path. Both observations were made using GPS time-stamped video. Peter played the four videos from the observers (his video, Dave Gault, Kirk Bender, and Richard Nolthenius) of Arecibo showing the double disappearance of the target star.

Figure 4. Lightcurve recorded by Peter Nosworthy.

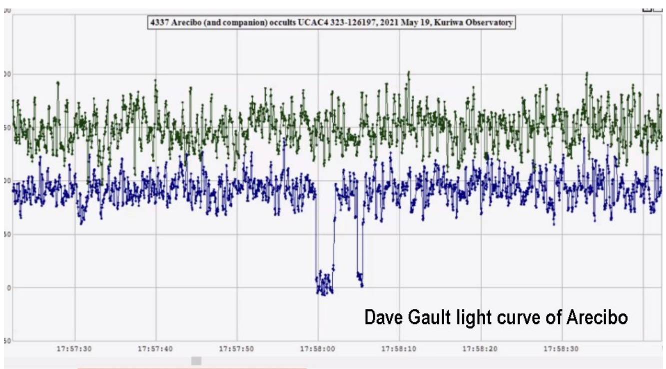


Figure 5. Lightcurve by Dave Gault.

Both observers recorded two occultation events with the following characteristics.

Observer	Location (Australia)	Chord Lengths Main Body	Satellite
D. Gault P. Norsworthy	Hawkwesbury Heights Hazelbrook	18.7 km 19.7 km	5.6 km 2.6 km

Table 1. Chords lengths measured by Gault & Nosworthy.

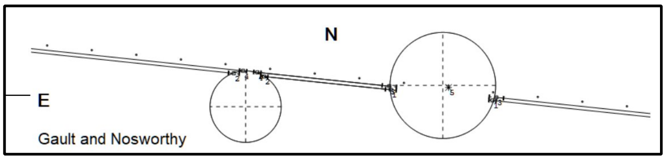


Figure 6. Chords and Profiles by Gault & Nosworthy.

Just 3 weeks later after Nosworthy and Gault's observation, Richard Nolthenius and Kirk Bender reported the confirmation of the satellite (from California) from the occultation of the star UCAC4 322-116848 on 2021 June 9.45736. The observers were separated by 8.2 km across the occultation path, and 8 km along the path. Both observations were made using GPS time-stamped video. Both observers recorded two occultation events with the following characteristics.

Observer	Location (California)	Chord Lengths Main Body	Satellite
R. Nolthenius K. Bender	San Ardo Bradley	23.9 km 20.8 km	11.7 km 13.0 km

Table 2. Chords lengths measured by Nolthenius & Bender.

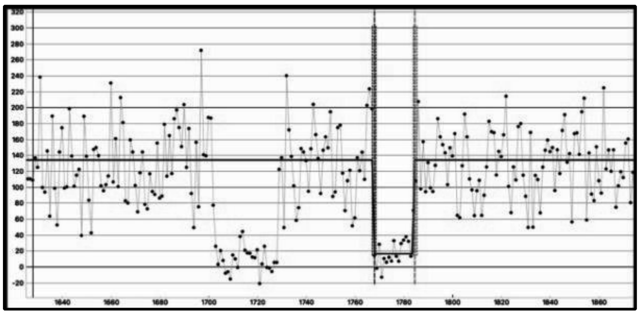


Figure 7. Lightcurve by Richard Nolthenius.

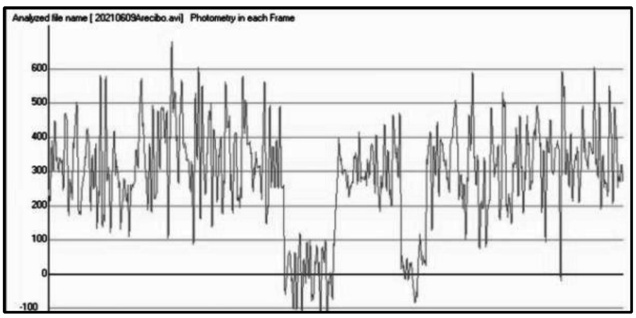


Figure 8. Lightcurve by Kirk Bender.

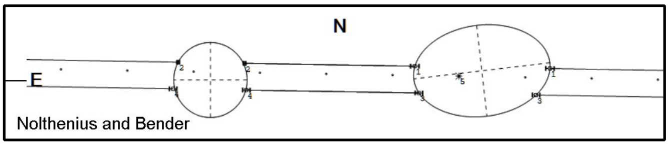


Figure 9. Chords and Profiles by Nolthenius & Bender.

The sizes of both the main body and the satellite were poorly determined by the first occultation, because of the close across-path separation of the observers. The sizes of both bodies were well determined from the second occultation, because the across-path separation was larger, and the chords were favourably positioned against both bodies. On the assumption that the bodies presented a circular profile, the diameters determined from the second occultation are:

Main body: 24.3 ± 0.6 km, Satellite: 13.0 ± 1.5 km

These diameters were used to derive the position of the satellite relative to the main body, for both occultations. Those positions are:

2021 May 19.74861 25.5 ±1.0 mas in PA 105.2° ±1.0°
2021 June 9.45736 32.8 ±0.7 mas in PA 94.3° ±2.7°

Richard Nolthenius presented follow-up observations of the (4337) Arecibo occultation on June 30th across California and the preliminary orbital constraint estimates for the Arecibo satellite. Richard first described how he chose sites for Kirk Bender and himself, with potential wind-shake of video records as primary determiner for Kirk Bender who was without a car to help as a wind shield. He showed successful light curves from his 3 person team, including CSU Professor Chris Kitting. All showed no evidence of the satellite. He showed the sky plane plot of the satellite's changed position between the Gault/Nosworthy May 19 discovery to the Nolthenius/Bender June 9 confirmation 20.7 days later (Figure 10). He showed an estimate of the smallest reasonable semi-major axis *a*, about 100 km (giving a period of ~2.5 days), and also the largest possible of *a*=293 km, set by Jupiter's tidal pull, assuming a representative mean density of 1.9 g/cm^3. He showed a 20 day period most simply suggested by the earlier data, is impossible as it puts the satellite beyond the Jupiter tidal limit. Instead, periods of 10, 5, or 2.5 days are more likely. Even these assume the May 19 and June 9 observations saw the satellite on the same side of the sky plane, which it has a 50% chance of being correct. Finally, he suggested the best way to determine the period and finalize the orbit is to search photometric data from PANSTARRs and/or SuperWASP for a photometric period, as tidal locking is likely to ensure this period is also the satellite orbital period. Then, matching with the two satellite-observed occultation observation dates would fix the orbit and allow accurate placement of future occultation observers.

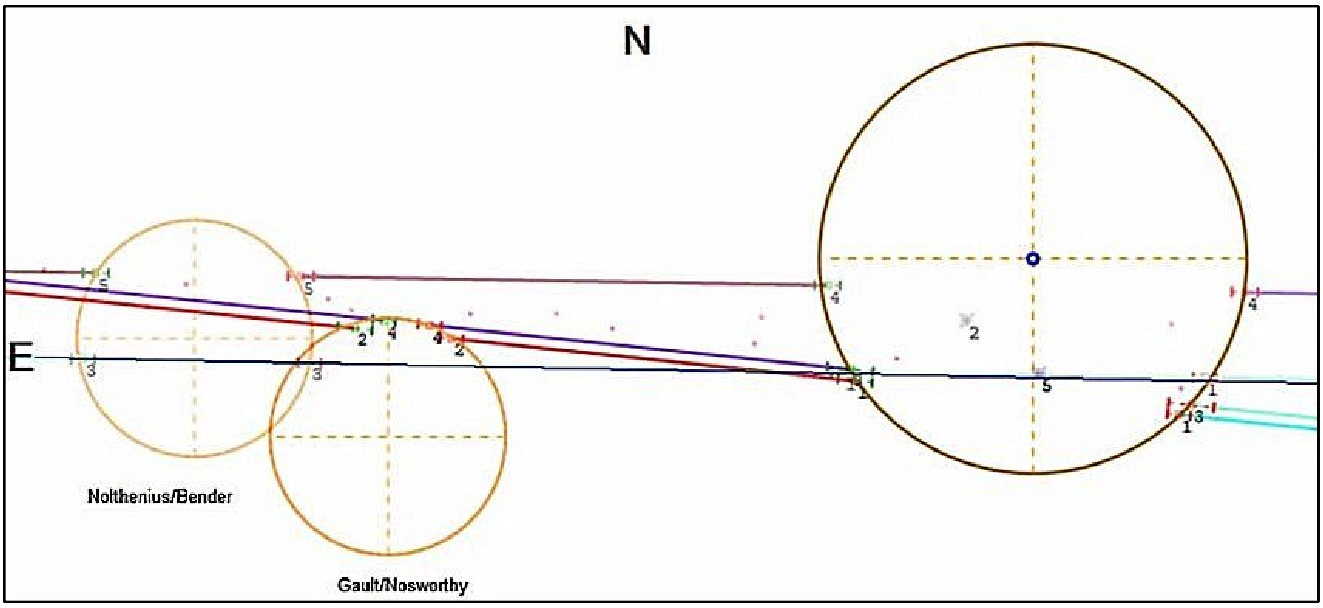


Figure 10. Combined sky plane profiles of both occultations by (4337) Arecibo and its satellite.

David Dunham talked about some unusual asteroid occultations. He first mentioned (234) Barbara observed at IOTA's meeting in 2009 in Florida and that its strange lobed shape warranted further observations. He showed sky plane plots of other asteroids observed with satellites and strange shapes:

- (2258) Viipuri 2013 Aug 3 and 2018 Sep 19 (each of these occultations had a secondary occultation, probably by the same moon of Viipuri)
- (9634) 1997 WP21, 2021 Feb 14. (NEW satellite)
- (479) Caprera, 2020 Mar 28. The prediction wasn't good. He, Joan and Ted Blank set up several stations, Ted got 2 chords.
- (513) Centesima, 2020 Dec 20. Unusual shape, maybe like Barbara
- Ganymede, 2020 Dec 21
- (1224) Fantasia, 2021 Feb 21. Was good practice for (2300) Apophis the following month
- (8) Flora, 2021 Mar 18. Very close double star
- (14758) 6519 P-L, 2021 May 29. Main belt (not Trojan), peanut shaped asteroid with a bulge on the far east side.
- (4337) Arecibo, 2021 June 30. 4 stations, resources spread too thin, and all failed to get data.
- (477) Aguntina, 2021 July 12. A rank 100 event, a large asteroid, no positives and 2 misses made by Steve Messner and Henry Throop.

David next spoke about NEO occultations starting with the (2300) Phaethon event from 2019 July 29. He showed observer stations and the resulting sky plane profile that resulted in 6 positive chords.

The success of this (2300) Phaethon event allowed an update to the orbit to prepare for the 2019 Sep 29 event and future events. On 2020 Oct 5 - Roger Venable made a successful observation of (2300) Phaethon further refining its orbit. David then showed some future (2300) Phaethon events include 2021 September 22 across the eastern USA.

For the (99942) Apophis occultation on 2021 March 7, stations were set up at 107m intervals at a private airport in Louisiana due to its small size. 3 positive events were obtained: Dunhams (2) and R. Nugent (1). The next (99942) Apophis event was 2021 March 22 and Roger Venable set up 5 stations and his most eastern station had the only positive chord.

For the next (99942) Apophis occultation prediction on 2021 April 4, he suggested down-weighting the position of the asteroid/star position from the March 7 event. This was due to the fact that the star occulted on March 7 was an eclipsing binary. This meant that the position of the occulted primary (brighter) star was moving at a non-uniform rate altering its position and motion from the gravitational influence of the second star.

At the (99942) Apophis event on 2021 April 4, 3 positive chords were obtained - 1 each by Roger Venable (he also had 4 negatives, valuable for constraining the path) Kai Getrost and 1 by N. Carlson.

(99942) Apophis, 2021 May 6: 5 successful observations in a north-south path over northwestern Mexico and southwestern USA. One of the successful positive observers was Hermosillo Sonora. These latest observations further refined (99942) Apophis's orbit.

Upcoming events included 2021 September 5 over the Middle East and 2021 September 27 over the Georgia coast with only an 8 deg altitude!

Dave Herald presented the observed events of last year worldwide.

2020 - Nearly 900 events/year observed and growing. In 2019, just under 600 events were observed. The unusable events have been dropping also, with only 3% of 2020 events still under scrutiny

Events by location:
Australasia 157
Europe 316
Japan 66
N. America 316
S. America 21

Most of 2020 (876 observations) were single-chord observations, 2-3 chords=250 events, 4-9 chords=80 events, 10+chords = 10 events. Other statistics Dave showed were the # of observers per event, which has been on the decline in the past 10 years, # of successful events by region and double star discoveries. Double star discoveries have separations in the range of 10-100 milli-arcseconds.

Binary satellites - 2 discoveries so far in 2021 - (9634) 1997 WP21 and (4337) Arecibo. With the estimated number of satellites asteroids should have, the first 5000 asteroids have 118 satellites discovered = 2.3%. In 2020 we observed 876 sevents, this should amount to 20 asteroid satellites. But in 2020 we observed just 2 satellites, only 0.2% of all events! Dave questioned whether or not we are interpreting these observations correctly. One theory is that if the recording doesn't include stars more than 1 mag fainter that the target star, you cannot reliably distinguish between a double star and a satellite.

Dave mentioned another issue with some observations - not every chord matches the expected profile. He showed a few asteroid profiles illustating this. He stressed the need for accurate times taking into account camera delays and recording delays from different recorders (DVRs, computers). A time-base shift could also be an issue.

Dave Herald then discussed the evolution of astrometry from asteroid occultations. The first astrometric position reported from an asteroid occultation was in 2008. The Minor Planet Center has assigned for occultation derived positions Observatory Code 244.

The intial problems with determining astrometric positions was the maths used and the exact time of conjunction of the star and asteroid. Another such issue is the gravitational deflection caused by the Sun - it is different for the star and asteroid. Another issue is whether to use Sun-centred or Earth-centred coordinates. He decided the solution was to report the (x,y,z) coordinates of the asteroid's shadow at the location in the centre of the Earth. Dave showed a sample MPC report showing the observers' names, time of central occultation, residual RA and Dec and other parameters. The typical astrometric accuracies from occultations are 1-10 mas which it is 10-100X better than the typical astrometric position obtained using other methods such as ground-based telescopes. As a result, occultation positional accuracies are highly sought by the MPC and JPL Horizons.

Sunday 18th July 2021 - Day 2

Technical Sessions

Aart Olsen started the day with a talk about the GPS + Ardunio LED flasher. This simple device makes precisely-timed flashes that are recorded on an occultation video. Its a useful device since phones, computers, WWV or internet aren't needed, just a GPS signal. Aart showed images of this device and how it is powered. It can use a USB power input or the 12v power that are used for our cameras.

Users will need only minimal assembly of the device -- soldering a few wires. The Arduino Integrated Development Environment (IDE), the program that lets you write the code and program the Arduino, is available [9] and Aart's flasher code can be copied from [10] and pasted into the IDE.

He showed the steps needed to program and load the code into the device. Once the code is loaded, it will remain and not be erased even if the device is turned off, or put away for long periods. Once turned on, the LED flasher will flash at the intervals the user previously specified into a file Input.txt in an SD card.

The precise flashes are seen as spikes in the background of the video which is seen by *PyOTE* and *PyMovie*. Aart showed an example light curve showing the flashes from an occultation John Moore observed in 2020 (Figure 11).

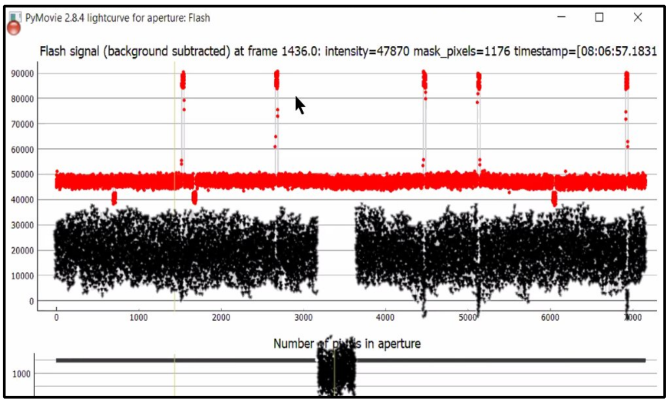


Figure 11. Flashes (red spikes) on occultation recorded by John Moore.

Aart Olsen then spoke on a "Simple Exposure Time Analyzer." Aart showed how to make a device similar in function to the established *EXTA* and *SEXTA* camera analyzers using the same Arduino-GPS timer as the LED flasher, plus some inexpensive LED displays easily found on eBay or Amazon. The MIDWEXTA (Aart says you don't have to call it that if you don't want to), shows UTC, with subseconds displayed as a rapidly moving dot on the 512 LED matrix. The code used to program the Arduino using the

IDE can be copied from here [12].

The device outputs digital UT times, number of GPS satellites. It's coded just like the Arduino flasher. He showed several video frames comparing the IOTA VTI GPS times vs. the time analyzer. The comparison times from both devices were in excellent agreement (Figure 12).

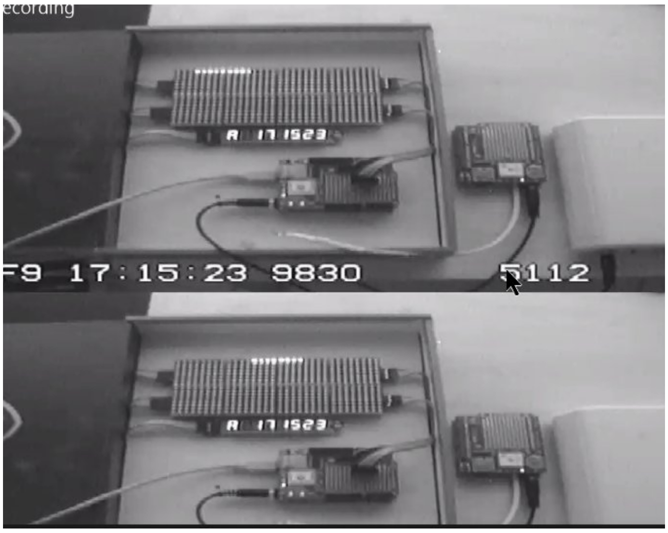


Figure 12. Video frames comparing the IOTA VTI GPS times vs. the time analyser

Richard Nugent presented a program available as a cell phone app to predict Baily's beads during solar eclipses. The program "*Eclipse Calculator 2*" is a free download from the Google Play Store for Android phones. Written by Eduard Massana from the University of Barcelona, the program features predictions and data for solar and lunar eclipses plus planetary transits from the years 1900 - 2100, expandable to years 1550 to 2300. Some of the many features of this program include start and end times for any eclipse for 100's of locations/cities in every country (including user-created locations), altitudes, azimuths, ΔT values (along with estimates for future eclipses), Google-style maps for

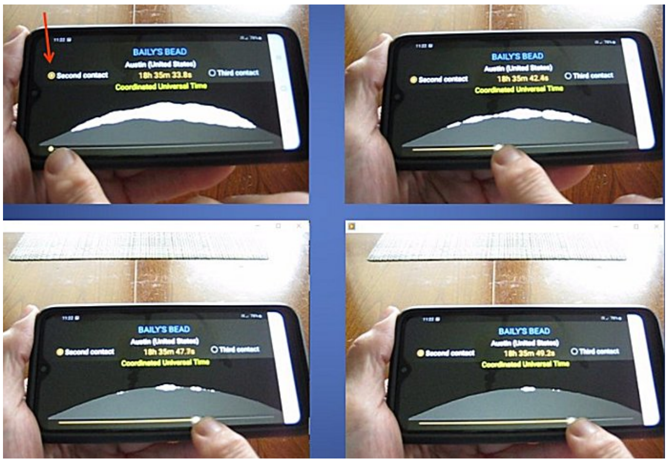


Figure 13. You can run through the animation by wiping with your finger.

each eclipse, path and shadow simulations, plus a lunar limb Baily's beads feature. Richard has been in contact with the author and suggested modifications to the app for IOTA purposes which the author implemented.

For any eclipse, you can tap on the Google-style map and a pop-up window appears displaying eclipse circumstances for that location. The Baily's beads feature allows the user to move their finger on a sliding bar and watch how the beads appear, grow and disappear with Universal Times displayed to the nearest tenth of a second. Nugent showed screen shots of Baily's beads videos he and the Dunhams have obtained compared to the app. The results *Eclipse Calculator 2* displayed were in excellent agreement with the actual videos.

Figure 14 shows *Eclipse Calculator 2* Baily's beads screen shots and comparison to Joan and David Dunham's Baily's beads video frame from the 2019 July 2 eclipse in Argentina.

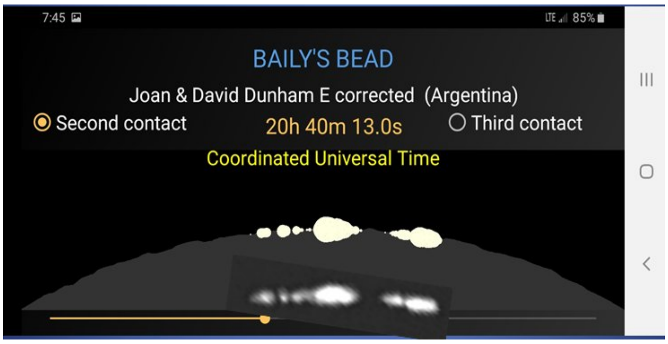


Figure 14. Comparison between animation and real video frame.

Bob Anderson talked about how he has added diffraction modelling in PyOTE. Diffraction fringes between the star and asteroid during an occultation can sometimes cause a false D and R, so hence the need for diffraction model in the light curve reduction program. Bob wrote the modification based on research from Raymond Dusser, Michael Richmond and Seymour Trestor. Bob showed an image of the classical diffraction pattern curve from an occultation. Bob then showed the expected diffraction pattern for an 8 km-sized asteroid, with a distance of 2.57 AU. The Fresnel length came to 0.311 km. He then showed the Fresnel unit diagrams for a 930 km asteroid at the same distance. Bob's tests showed that there's an insignificant difference between a single wavelength diffraction curve vs. one with a passband with multiple wavelengths. With diffraction implemented in PyOTE, one can use this tool to rule out a possible short blink from a satellite compared to a diffraction fringe effect. Dave Herald mentioned that the star diameter if known in advance should be taken into account.

Kevin Green spoke about electronic line noise in our videos. Line noise produces non-uniformity in the background between video frames and between reference stars and the target. Kevin showed how to elminate the line noise and showed a video frame showing the result. When removing the line noise, the signal to noise S/N increases. For high S/N events, line noise is not affected, for low S/N events, it could mean detection vs non-detection of a D or R event.

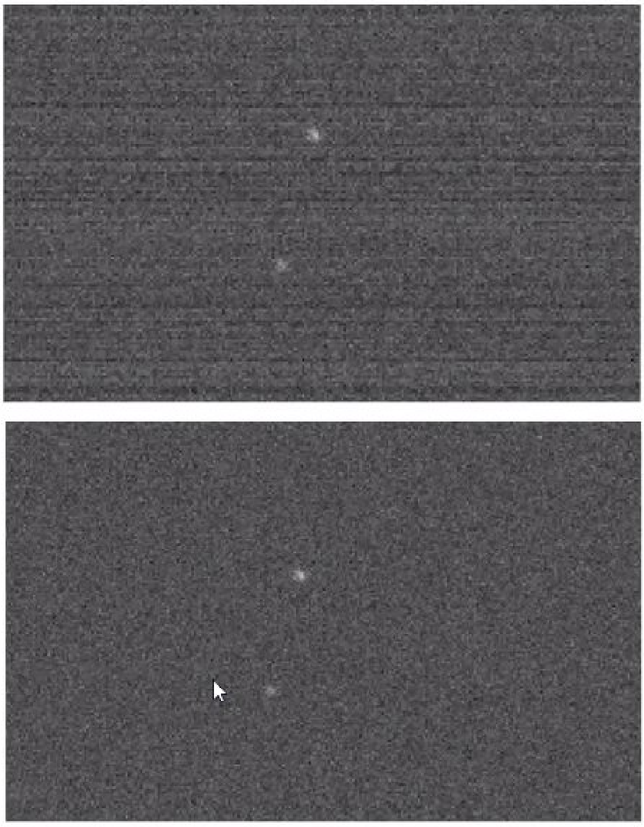


Figure 15. Comparison of the same image without (top) and with a median signal normalisation. Standard deviation reduced by 8.5 %.

Kevin next discussed D & R timing when there are dropped frames. He used the example of the occultation by (940) Kordula from 2020 October 19. The telescope used was a Celestron 14Edge SCT. Although the light curve looked good, zooming in showed some dropped frames unfortunately near the D and R times. Kevin estimated that 8.9% of the frames were dropped in the video. To help solve the problem, Kevin showed an example using a Monte Carlo simulation to show where the D and R times likely should be.

With the (940) Kordula event, the D and R times and error estimates were:

D = 4:42:06.33 +0.33/-0.35
R = 4:42:38:315 +0.14/-0.66

Tangra gave times differing by 0.4 sec which was lower than *PyOTE* for this event. Kevin concluded that dropped frames aren't fatal as they can be quantified.

Atila Poro from IOTA's Middle Eastern Section presented a value of Pluto's atmospheric pressure based upon 2020 stellar occultation light curve results. The Pluto event observed by the IOTA Middle Eastern section was on 2020 June 6. The star magnitude was 12.97. The data was used to obtain the atmospheric pressure of Pluto. The observation was made at a private observatory north of Karaj City, Iran. The main telescope used was a 24" SCT, 2nd scope used a 14" SCT. Two identical SBIG CCD 1100M cameras were used on both telescopes.

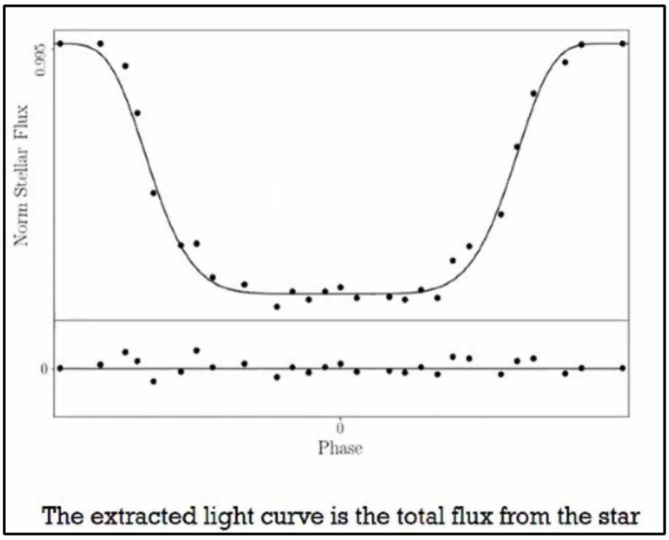


Figure 16. Lightcurve of Pluto occultation on 2020 June 6.

Method of analysis and light curve fitting:
- We fit the occultation light curve through a spherical and transparent atmospheric model of Pluto with a synthetic profile (DO15 model).
- By using our ray-tracing code based on:
- the pressure at the reference radius of R=1215 km
- and the relative Pluto + Charon flux as a reference value

234 images were taken simultaneouly with both cameras with 24 usable images from the occultation. From the light curve he determined the Pluto's atmospheric pressure 6.72 +/- 0.21 µbars in reasonably good agreement with past stellar occultations.

Altila and his colleagues published a paper on their results [12].

Atharva Pathak gave an overview of IOTA-India's activities. This IOTA section was born on 2019 May 3. Members observe lunar and asteroid occultations, variable stars, meteor showers as part of India's oldest amateur astronomy club: Jyotirvidya Parisanstha (JVP).

Their website http://iota-india.in/ includes:

- Observing Basics
  (what is an occultation, and how to observe it)
- Occultation Predictions
- Occultation Observational data
- Educational Materials
- Software
- Recommended equipment
- Reporting Observations

Their website also encourages engaging with the public to recruit new observers. Regarding timing, Atharva mentioned that ordering the IOTA-VTI is expensive for their budget in addition to the mailing costs involved which could run to $60 USA and higher. Atharva introduced a new Android App developed SAT TIMER, which was developed because the *Time Sat* app doesn't work on some android versions.

Their future plans include developing low-cost setups, planning training sessions across the country for reporting lunar and asteroid occultations, engaging in outreach activities for popularising occultations, designing University-level projects for occultation observation and analysis and exploring new apps and web tools. IOTA-India also have a Facebook page [13] and a YouTube channel [14].

David Dunham spoke on rethinking the RASC (Royal Astronomical Society of Canada) handbook's occultation section. He gave some ideas he has for updating the 2022 handbook. The current handbook, has 17 pages for lunar occultations which includes graze maps for North America with tables, 5 pages for asteroid/planetary occultations. David proposed for 2022 lunar occultations - 14 pages, asteroid/planetary - 8 pages.

David showed the history of the handbook's occultation predictions:

- 1988 - ILOC-Japan did the lunar events, planetaries by Bob Millis (Lowell Obs), E. Riedel and David did the graze section
- 1990 - Larry Wasserman took over planetary predictions from Bob Millis
- 1992 - Graze section credited to Dunham
- 1999 - E. Riedel added explicity as main author of grazes
- 2000 - Planetary Occultation section done solely by IOTA
- 2003 - Lunar occultations section solely by IOTA, Dave Herald and David Dunham credited as authors of the total occultation section.

The new layout will keep the introductory pages, ZC star names, double star list and total occultations. Total occultations will have bright stars with the list more compact. There will be only 1 graze map and 1 table for bright stars only. Other lunar graze maps will be on the web. The 3 pages of tables and notes for asteroid events will be replaced with maps of different classes of events: Main-Belt asteroids, Trojans, TNO's and Centaurs with tables and explanations of each.

Filipp Romanov provided information on occultations of stars and planets he has observed from Russia. Filipp is 24 years old, and has limited resources. He has discovered (by self-education) 74 variable stars, 10 planetary nebula candidates, and other objects, he is an author of two scientific papers in astronomy published in journals. He made his first presentation ever to the AAVSO 109th Annual Meeting on 2020 November 13 on one of his eclipsing binary discoveries: Romanov V20. He talked about his observing history of occultations from his first lunar occultation on 2012 March 29/30 and then the Venus occultation in August 2012. For the first time he attempted to observe the (1107) Lictoria asteroid event from Primorsky Krai (from his small homeland, on the Far East of Russia) on 2012 December 27/28 of Theta1 Tauri.

In Moscow, he observed by video the egress of HD 95848 (7.2 mag) occulted by Jupiter on 2016 April 12; the lunar occultation of Neptune in June 2016; a daytime occultation of Aldebaran on 2017 August 16 and he showed the star visible in photos.

On 2016 September 1, in the capital of Russia, he observed the asteroid event of (159) Aemilia occulting TYC 6349-00855-1. He used a Canon EOS 60D camera attached to a telescope. He used a time exposure to catch the event (see the star missing in the time exposure) and obtained a >7.5 sec occultation (only reappearance: disappearance happened during 4-sec interruption between photos).

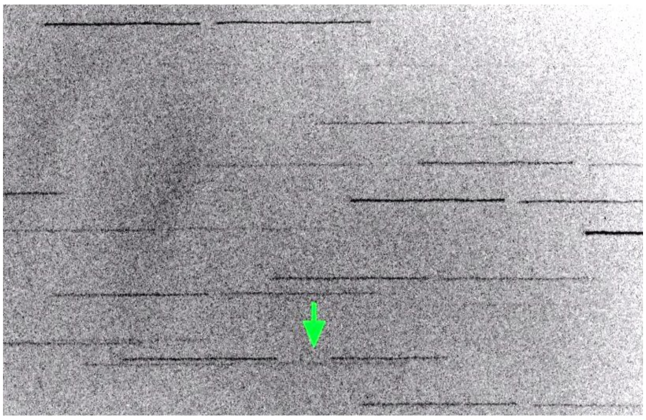


Figure 17. Observation of occultation of TYC 6349-00855-1 by (159) Aemilia on 2016 September 1.

He also observed the occultations of Aldebaran in Moscow Oblast: in April and August 2015 (in science city Korolyov) and in February 2018 (in science city Protvino) - by video with his DSLR camera and 135mm telephoto lens.

Due to housing trouble in a communal apartment in Moscow, from 2017 to the present Filipp has had to travel in wanderings around regions of Russia. His goal is to attend a university and study astronomy. You can contact Filipp by e-mail: filipp.romanov.27.04.1997 at g - mail. Filipp also has pages on Facebook, Twitter, Instagram, Flickr and a YouTube channel, where the descriptions for some videos contain details of his difficult life situation. His webpage (mostly Russian but can be translated) can be found here [15].

Roxanne Kamin spoke on the challenges of introducing new observers to occultations. Some of the best location site candidates for occultations are fixed-site observatories managed by local clubs and universities. Typical challenges include scheduling practice sessions, recruiting volunteers on a weeknight and working with equipment limitations due to budget cuts and COVID restrictions. Other issues include out of pocket start-up costs (e.g. camera, IOTA-VTI, and cables) with an $800-$1500 outlay being the typical cost to get started.

New observers note that not all of the cameras listed are currently available and if all of the software noted on IOTA's website is required. In addition, IOTA's reliance on *Windows*-based software (update sensitive) was also a concern with the use of specialized cameras (e.g. mono video) vs the use of more popular MallinCam and ZWO ASI Air systems was also a deterrent. Our documentation noting the use of visual timing, VCRs and outdated technology can be overwhelming and confusing to apply occultation efforts and camera use.

Roxanne encouraged the use of local observatories to employ public outreach, offer networking within the scientific community, participation in citizen science and the potential for publication (e.g. newsletters, web articles, academic papers). Noting that having one's name published for an occultation observation may assist in providing additional funds for the observatory and encourage recruitment of new long-term observers and future IOTA contributors.

Joan Dunham next talked about citizen science opportunities for IOTA. The idea is to give ideas during presentations and talks to astronomy clubs and enthusiasts. Joan has recently made a citizen science page on the IOTA website [13].

IOTA members provide predictions, coordinate observations, provide software, report and publish observations and teach others techniques, how to observe and how to utilize the software.

Joan suggested encouraging people to observe without requiring IOTA membership, provide examples of recent successes such as (3200) Phaethon and (99942) Apophis (whose possible danger to the Earth was dismissed following radar and occultation observations), make predictions available for bright stars and interesting events local to the area and the websites for occultation information. Any talk should have an equipment demo - people respond better when they see the actual equipment (small telescope, camera, recorder, IOTA VTI) vs. just photos on a PowerPoint. Joan also mentioned it's a good idea after a talk to leave flyers and lists of the next visible occultations event for the area.

Joan then discussed a Boot Camp Proposal for Occultation Observers. A bootcamp can include a daytime session for using software, an evening session on equipment use, and even a session for high-profile events (SwRI, Lucky Star).

Observing sessions can include: observe when the Moon is near dense star fields, IOTA annual meeting events. Software sessions can be done in person, via Zoom, anytime anywhere. Participants should have a telescope, camera, and a way to record the data - visual observations are discouraged. Joan listed items to be covered: sessions before observing, practice session and data reduction sessions. Sessions can also be during a member or public star party.

The IOTA Meeting 2021 adjourned at 00:40 UT, July 19

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

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

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

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

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