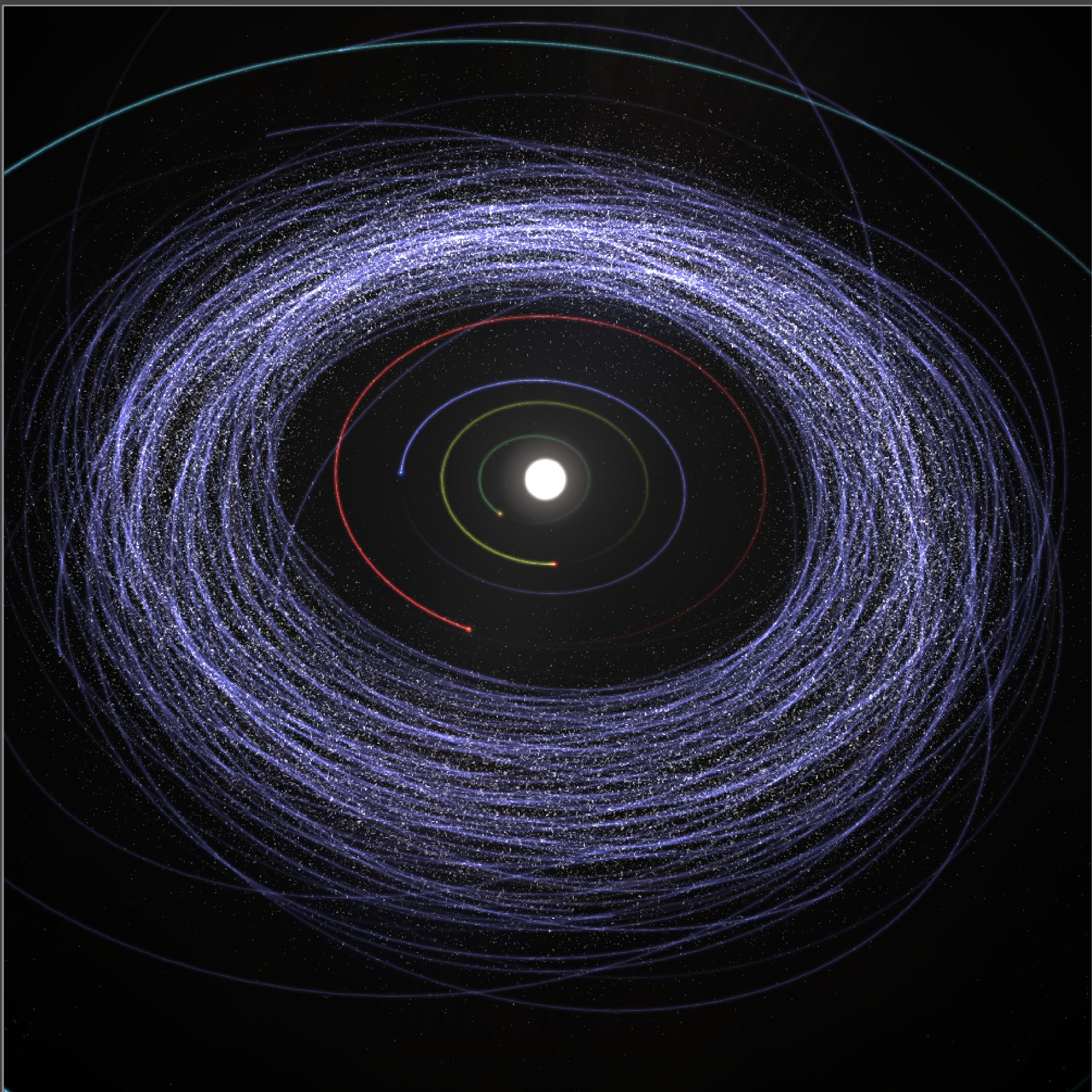
Journal for
Occultation Astronomy

Volume 12 · No.3 2022-03



2022 June 13 - Gaia Data Release 3

Dear reader,

We undertake occultation observations with the goal of improving our knowledge of the occulting object and occasionally learn something new about the occulted target. We also do these occultations because we just enjoy doing them. We especially enjoy the times when we find something unexpected, such as a stellar companion, as described in the discussion on the discovery that the star TYC 2416-00141-1 is double from its occultation by 1994 TY_2 on 2021 October 25.

This issue includes a call for observations of upcoming events to support the *Lucy* Mission, continuing the aid that occultation observers have provided to that mission as our observations are used to refine the orbital knowledge of the mission targets. The Titan occultation described in a separate call will add to our knowledge of Titan's atmosphere, also an aid to the *Dragonfly* mission which will study Titan in the future. A copy of Hans Bode's recording of the 1989 July 3 occultation by Titan showing a good example of a central flash and of the fluctuations from its atmosphere. This will be available for all to review as we prepare to observe the next Titan event.

Those who want to be in the observing campaigns and feel a need for more preparation are encouraged to participate in the training discussions and exercises that are being planned as a part of the IOTA meeting on August 13-14. The training is specific to the 2022 August 16 occultation of TYC 2463-00303-1 by the near-Earth asteroid (3122) Florence, but those not planning to observe that particular occultation are welcome.

If you do attempt one of these occultations, please consider preparing a short note on your experience for inclusion in an upcoming issue of the JOA. I am especially interested in new observers' comments on what value (or lack of it!) the training we offer has provided and will incorporate any notes sent to me in an article on lessons learned from training results.

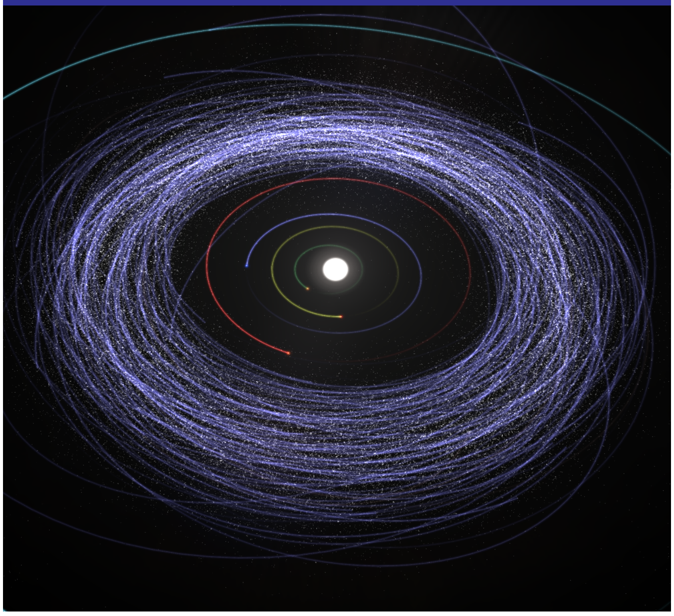
Joan Dunham

IOTA Secretary/Treasurer

JOA Volume 12 · No. 3 · 2022-3 $ 5.00 · $ 6.25 OTHER (ISSN 0737-6766)

In this Issue:

COVER



ESA's astrometric satellite *Gaia* made in 34 months about 23.3 million observations of more than 150,000 minor planets determing thier orbits. About 60,000 spectra of asteroids were measured which contain information about their composition and may reveal their origin. Especially, the astrometric data in Gaia DR3 will improve the accuracy of predictions of stellar occultations by these small bodies in the solar system.

Image made with *Gaia Sky 3.2.0.*, developed by Toni Sagristà, and data from Gaia DR3 (ESA).

Rules for Authors

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

Journal for
Occultation Astronomy

CALL FOR OBSERVATIONS:

Lucy Occultations Campaign

Arnaud Leroy · IOTA ·Uranoscope de l'Ile de France ·
Gretz-Armainvilliers · France · arnaudastro@yahoo.fr

Lucy occultations campaign continues...

You can read about the basics of the goal campaign at JOA 2022-01 [1]; For now, we'll have four upcoming events in Europe. We need to coordinate observations to contribute to *Lucy's* mission targets. *Paris Observatory* and SwRI/NASA will coordinate the observers. *Paris Observatory* could provide some *Timebox* devices and complete video systems to observe.

First event is for the west of Europe, because it's during dawn time. The target is (15094) Polymele on 2022 August 26, observable in the north of Spain and Portugal and in the west of France (Figure 1). The second event is an occultation by (3548) Eurybates on 2022 October 23, the path will cross Europe from the northeast to the southwest (Figure 2). For this event the use of small telescopes is possible because the star is bright (< 9 mag). The third target is (21900) Orus on 2022 December 16. This event will be visible from France to central Europe (Figure 3). And the fourth occultation is by (15094) Poymele again on 2022 December 27 visible from Ireland, southwest UK and France (Figure 4).

Expect path updates predicted by Marc Buie, PI for *Lucy* occultations mission [2], and by the ERC Lucky Star project [3].

You can contact us if you want to contribute:

- Arnaud Leroy, IOTA/Uranoscope de l'Ile de France: arnaudastro@yahoo.fr
- François Colas, Paris Observatory: francois.colas@obspm.fr
- Josselin Desmars, Paris Observatory: josselin.desmars@obspm.fr
- Thierry Midavaine, Club Eclipse/SAF: thierrymidavaine@sfr.fr

[1] Schnabel, C. et al., Collaboration on NASA's Lucy Mission - An Awesome Experience!, Journal for Occultation Astronomy, Vol. 12 No. 1, 3-9, (2022)
[2] Lucy Occultation Events - Predictions by the SwIR, http://lucy.swri.edu/occultations.html
[3] Predictions by the ERC Lucky Star project - https://lesia.obspm.fr/lucky-star/predictions.php

Preliminary path predictions with the use of data from *Gaia* EDR3 and *JPL Horizons*, calculated with *Occult V4.2022.5.12*:

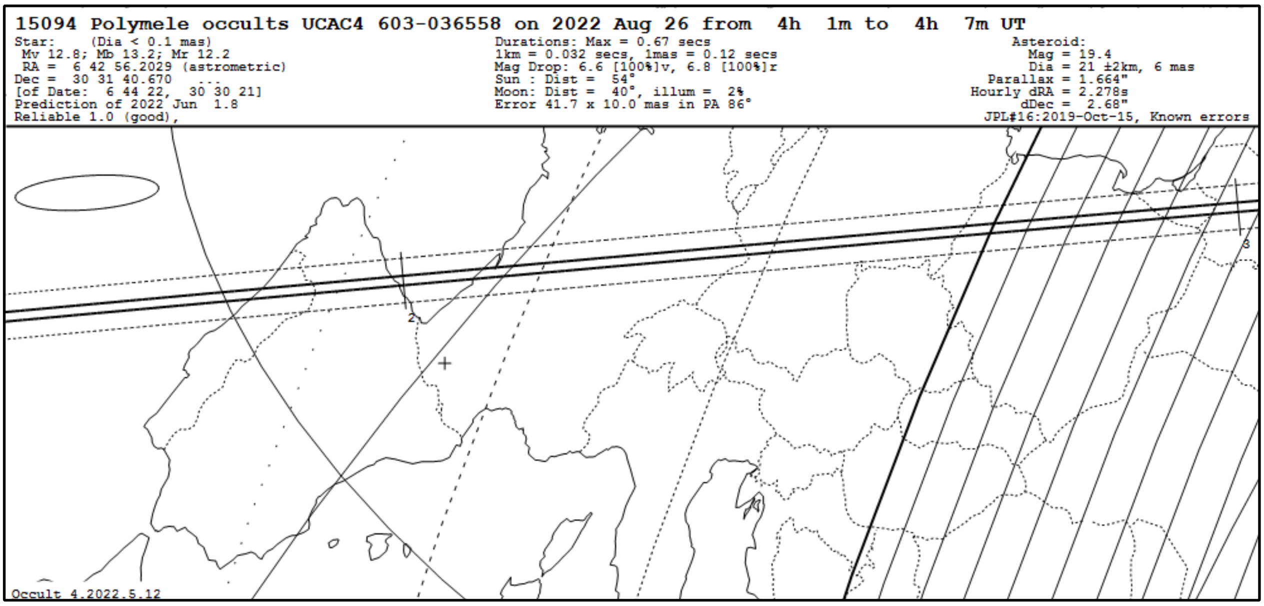
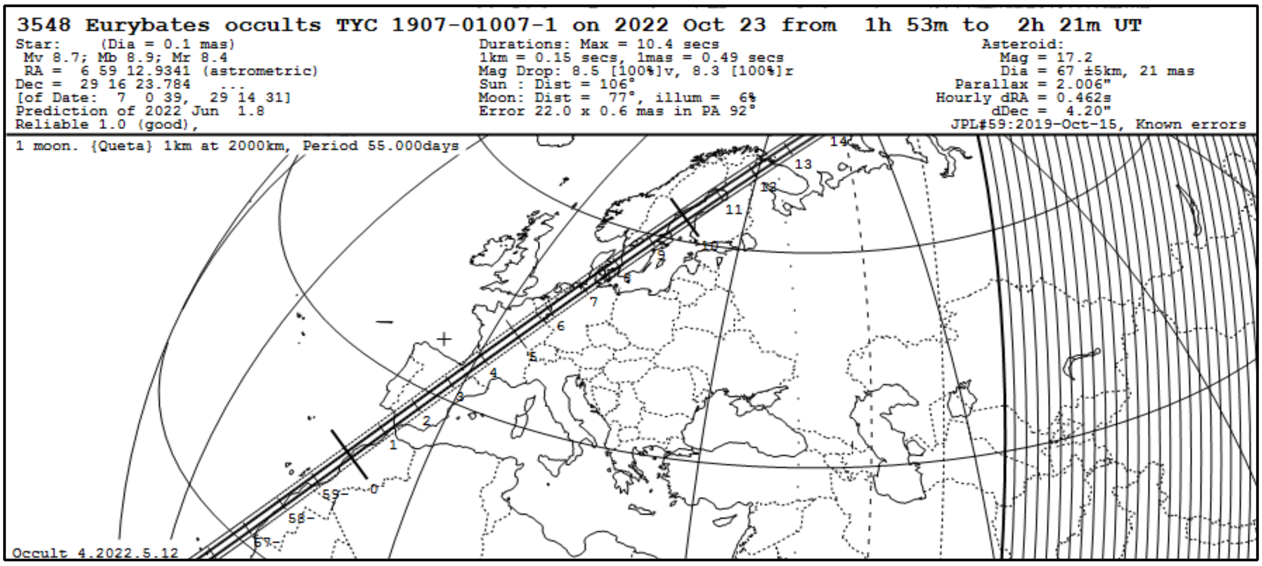
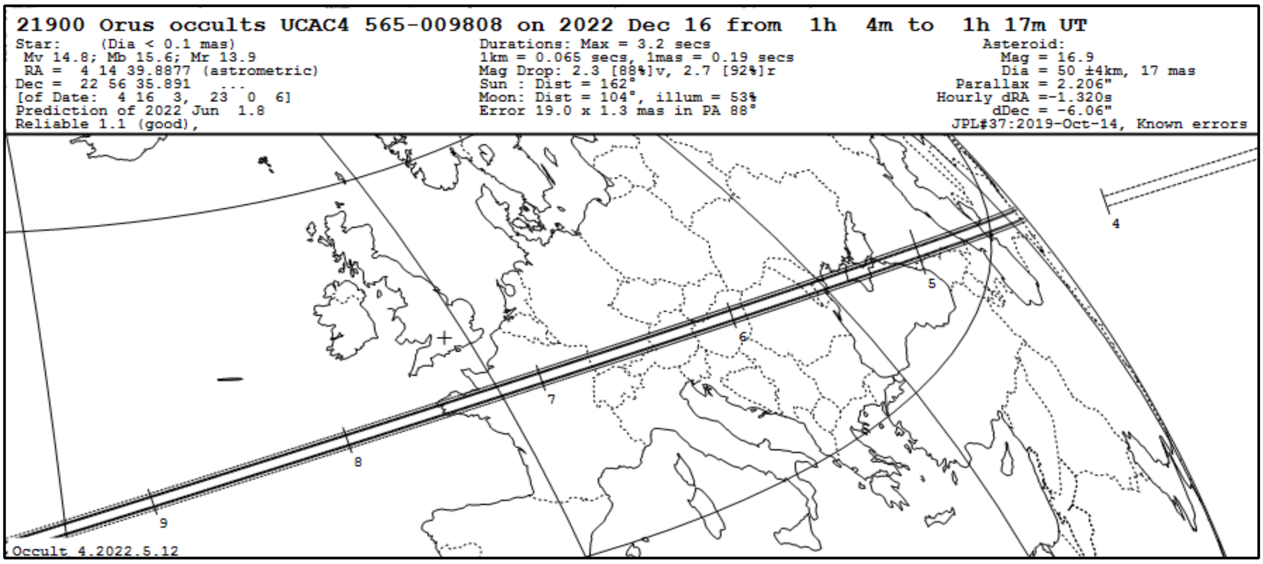
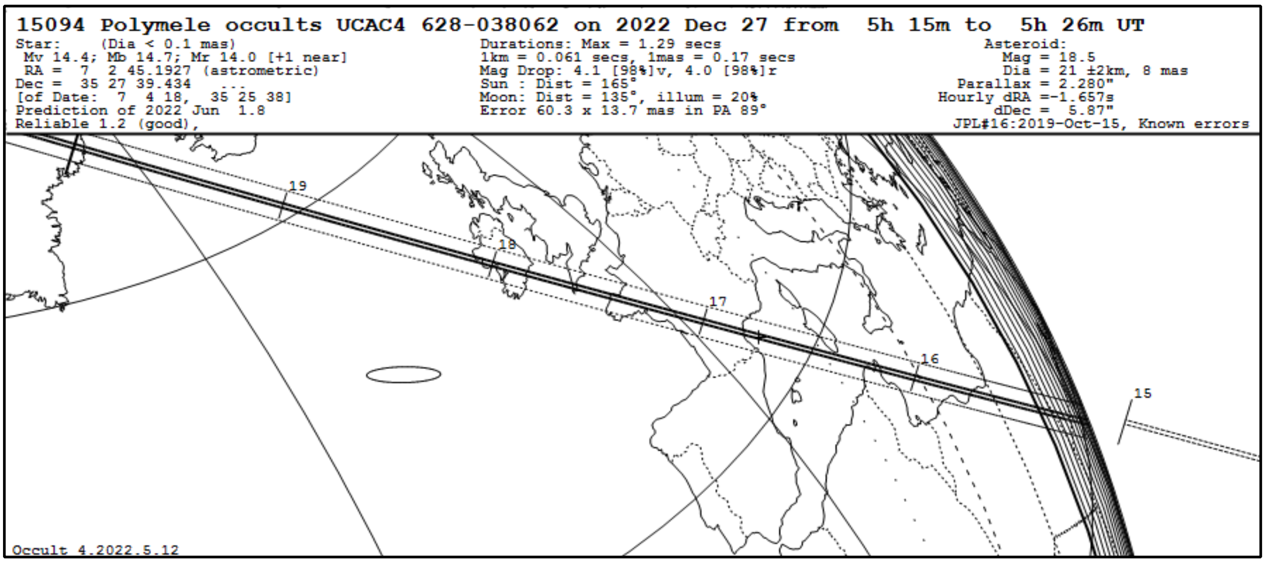


Figure 1.


3548 Eurybates occults TYC 1907-01007-1 on 2022 Oct 23 from 1h 53m to 2h 21m UT
Star: (Dia = 0.1 mas)
Mv 8.7; Mb 8.9; Mr 8.4
RA = 6 59 12.9341 (astrometric)
Dec = 29 16 23.784 ...
[of Date: 7 0 39, 29 14 31]
Prediction of 2022 Jun 1.8
Reliable 1.0 (good),
Durations: Max = 10.4 secs
1km = 0.15 secs, 1mas = 0.49 secs
Mag Drop: 8.5 [100%]v, 8.3 [100%]r
Sun : Dist = 106°
Moon: Dist = 77°, illum = 6%
Error 22.0 x 0.6 mas in PA 92°
Asteroid:
Mag = 17.2
Dia = 67 ±5km, 21 mas
Parallax = 2.006"
Hourly dRA = 0.462s
dDec = 4.20"
JPL#59:2019-Oct-15, Known errors
1 moon. {Queta} 1km at 2000km, Period 55.000days
Occult 4.2022.5.12


21900 Orus occults UCAC4 565-009808 on 2022 Dec 16 from 1h 4m to 1h 17m UT
Star: (Dia < 0.1 mas)
Mv 14.8; Mb 15.6; Mr 13.9
RA = 4 14 39.8877 (astrometric)
Dec = 22 56 35.891 ...
[of Date: 4 16 3, 23 0 6]
Prediction of 2022 Jun 1.8
Reliable 1.1 (good),
Durations: Max = 3.2 secs
1km = 0.065 secs, 1mas = 0.19 secs
Mag Drop: 2.3 [88%]v, 2.7 [92%]r
Sun : Dist = 162°
Moon: Dist = 104°, illum = 53%
Error 19.0 x 1.3 mas in PA 88°
Asteroid:
Mag = 16.9
Dia = 50 ±4km, 17 mas
Parallax = 2.206"
Hourly dRA =-1.320s
dDec = -6.06"
JPL#37:2019-Oct-14, Known errors
Occult 4.2022.5.12


15094 Polymele occults UCAC4 628-038062 on 2022 Dec 27 from 5h 15m to 5h 26m UT
Star: (Dia < 0.1 mas)
Mv 14.4; Mb 14.7; Mr 14.0 [+1 near]
RA = 7 2 45.1927 (astrometric)
Dec = 35 27 39.434 ...
[of Date: 7 4 18, 35 25 38]
Prediction of 2022 Jun 1.8
Reliable 1.2 (good),
Durations: Max = 1.29 secs
1km = 0.061 secs, 1mas = 0.17 secs
Mag Drop: 4.1 [98%]v, 4.0 [98%]r
Sun : Dist = 165°
Moon: Dist = 135°, illum = 20%
Error 60.3 x 13.7 mas in PA 89°
Asteroid:
Mag = 18.5
Dia = 21 ±2km, 8 mas
Parallax = 2.280"
Hourly dRA =-1.657s
dDec = 5.87"
JPL#16:2019-Oct-15, Known errors
Occult 4.2022.5.12

Figures 2-4.

Journal for Occultation Astronomy

CALL FOR OBSERVATIONS:

Occultation by Saturn's Moon Titan, 2022 July 9

Oliver Klös · IOTA/ES · Eppstein-Bremthal · Germany · pr@iota-es.de

On 2022 July 9 a stellar occultation of HIP 107569, SAO 164648 (8.7 mag, spectral type F0V) in the constellation Capricornus by Saturn's largest moon will be observable from large parts of the US, including Hawaii, whole Central America and the northwestern part of South America (Figure 1). The centre line is predicted to cross the Bahamas, Cuba, Belize, Guatemala and southernmost Mexico (Figure 2). The combined magnitude of star and moon of 7.9 mag will drop to 8.5 mag, the apparent magnitude of Titan at the time of occultation. The angular separation between Titan and Saturn is 3 arcmin, so no glare from the planet should disturb the observation (Figure 3). Disappearance and reappearance of the star could be gradual due to Titan's atmosphere. Titan will occult the star with a maximum duration of 326.6 s on the centre line. A central flash could be observed on the centre line as well. Watch out for a peak in the light flux close to mid-time of the occultation. IOTA has a special webapge for such events with D and R times for different locations and a Google map file of the centre line. Watch out for updates of the special webpage for the event [1]. Saturn's satellite Titan is the target for the upcoming NASA mission *Dragonfly*. Launch is scheduled for 2027, arrival at Titan in 2034 [2].

This will be the last opportunity to observe a stellar occultation by Titan for a long time. The next observable occultation will happen on 2048 August 16 when the path will cross Antarctica [3].

Don't miss this rare opportunity!

[1] Dunham, D., Occultation of SAO 164648 by Titan on 2022 July 9, https://occultations.org/publications/rasc/2022/20220709Titan.htm

[2] https://www.nasa.gov/dragonfly

[3] Herald, D. et al., Titan Occultation of 28 Sgr in 1989, Journal for Occultation Astronomy, Vol. 8 No. 2, 6-11, (2018)

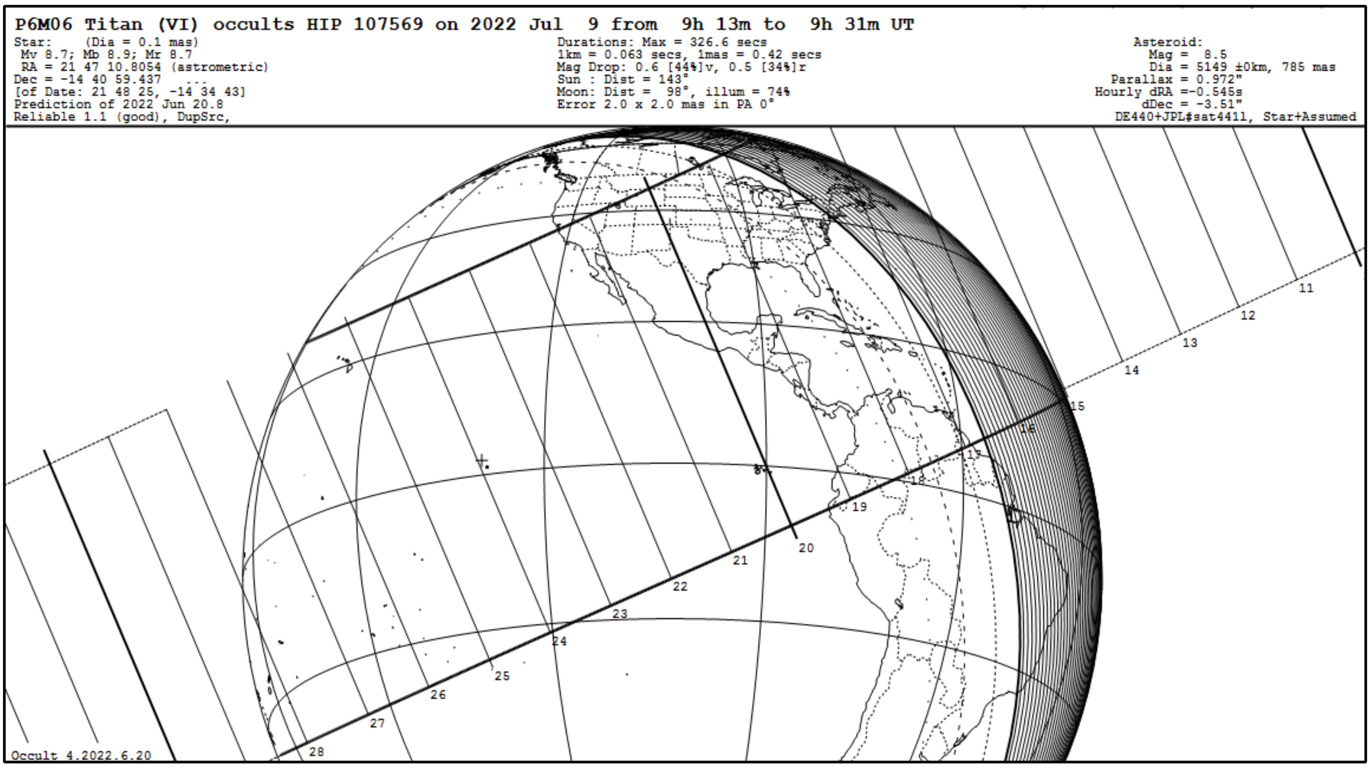


Figure 1. Path prediction for the stellar occultation by Titan on 2022 July 9. Prediction made with Occult V4.2022.6.20 on 2022 June 20.

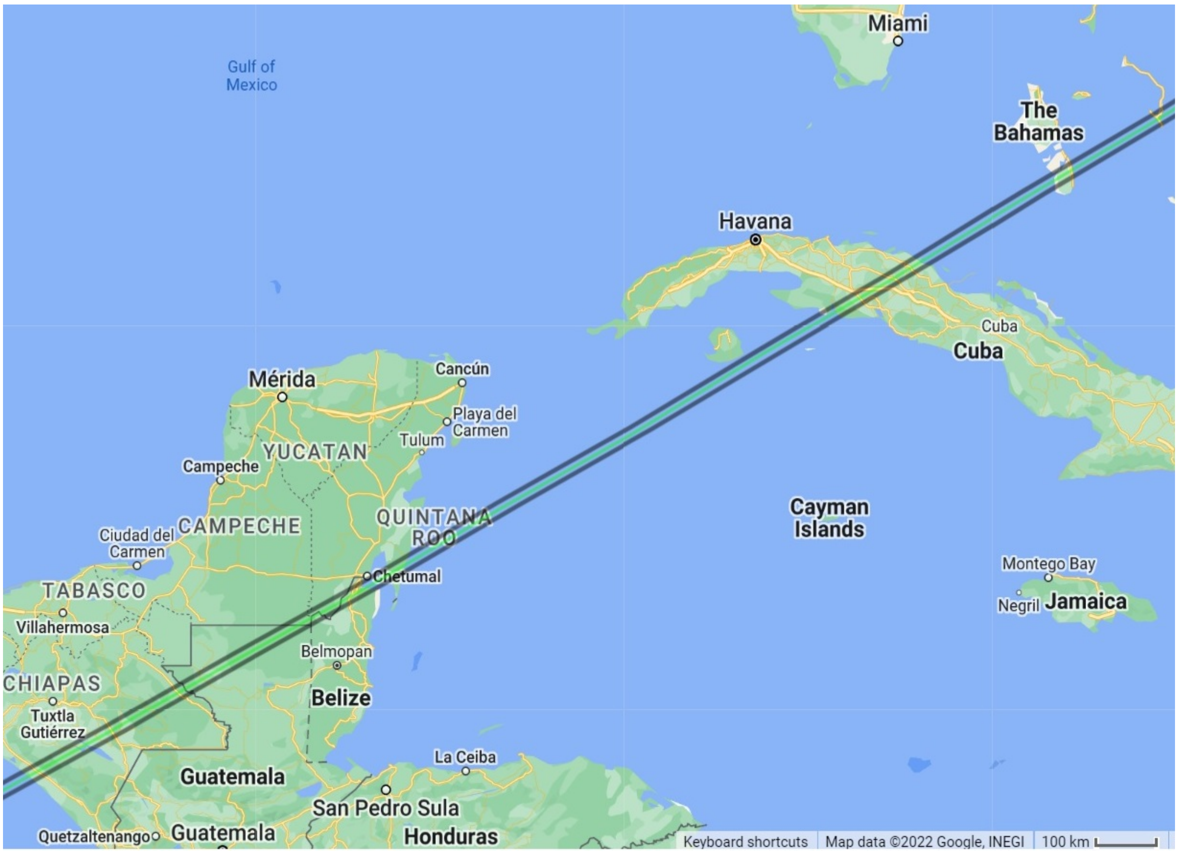


Figure 2. Predicted centre line (green) of the stellar occultation by Titan on 2022 July 9. The dark lines mark the 1-sigma error of the centre line. Observers close to the centre line should be prepared to record a central flash. Screenshot: David W. Dunham (Map data ©2022 Google , INEGI)

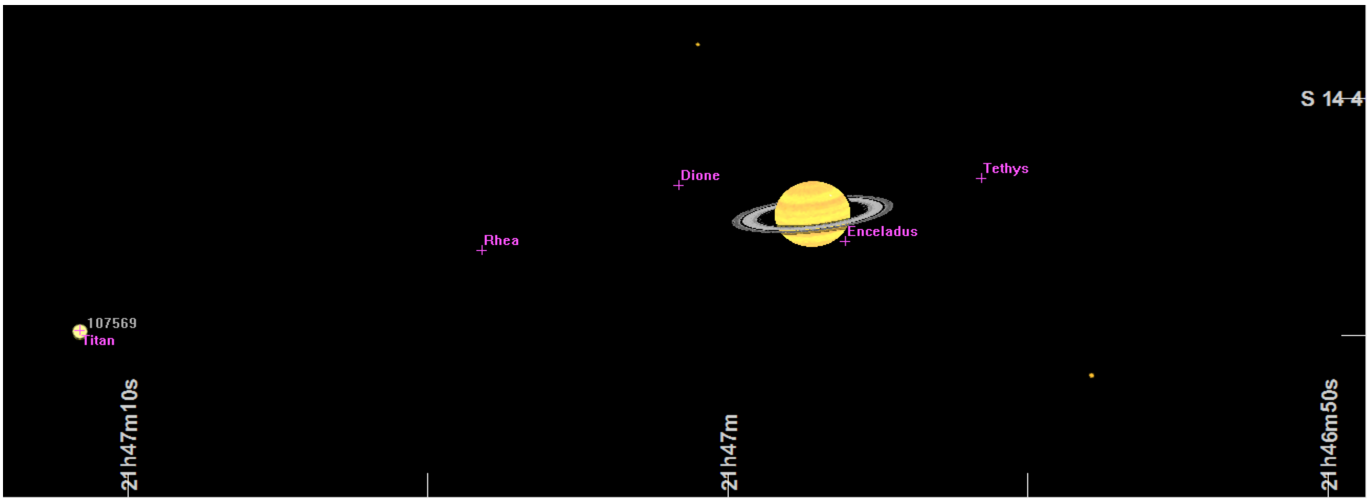


Figure 3. View of the system of Saturn at 09:20:00 UT on 2022 July 9 from a geocentric position. Titan (left) has an angular separation of 3 arcmin to the planet. (Screenshot of Project Pluto's GUIDE 9.1)

Double Star Discovery during an Occultation of a Star by Asteroid (48590) 1994 TY_2

Sven Andersson · IOTA/ES · Berlin · Germany · sandersson@astw.de

ABSTRACT: The observation of an occultation of a star by the minor planet (48590) 1994 TY_2 yielded more than one result. On the one hand it was a positive occultation, on the other hand it could be proved that the occulted star TYC 2416-00141-1 is a previously unknown double star.

Prediction

The occultation was predicted for 2021 October 25, 23:05 UTC, with a maximum occultation duration of 1.4 s and a drop in brightness of $7^m.3$ [1],[2] (Figure 1). The occultation path ran exactly over the *Müggelheim Observatory* (Figure 2) and the star TYC 2416-00141-1 is relatively bright with Mv $9^m.6$. Thus, it was easy to observe the occultation. Only the weather situation was not optimal, so that no other stations could observe.

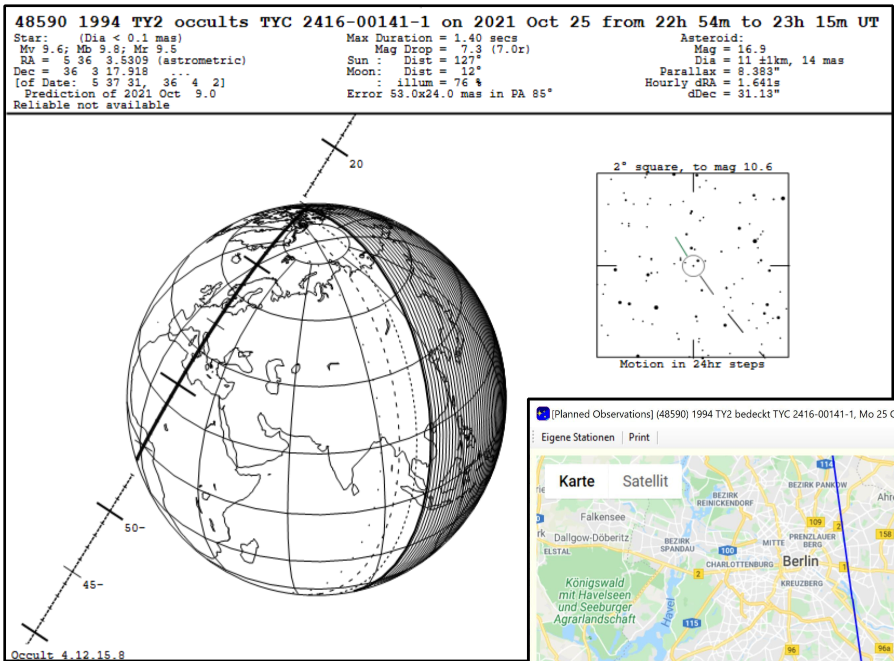


Figure 1. Path prediction of the occultation calculated on 2021 October 9 with Occult V4.12.15.8 .

Observing Technique

For the observation of asteroidal occultations, a C14 EdgeHD (355 mm aperture, 3920 mm focal length) with focal reducer (0.7x) is used at the *Müggelheim Observatory*. The telescope's focal length is thus 2744 mm. Until 2019, a Mintron video camera with video time inserter was used.

Since 2020, a QHY174M-GPS camera is mounted on the telescope (Figure 3). The field of view is 9.2' x 6.1'. *SharpCap 4* (64 bit) [3] is used as the acquisition software. The observatory computer works with an AMD FX-8800P processor (4 cores) and has a working memory of 16 GB. *Windows 10* (64 bit) is used as the operating system. Due to the selected exposure time of 20 ms, a good temporal resolution could be achieved. The evaluation was carried out with the programs *PyMovie* [4] and *PyOTE* [5]. The observation result was sent to the Planoccult mailing list and subsequently published on Euraster [6].

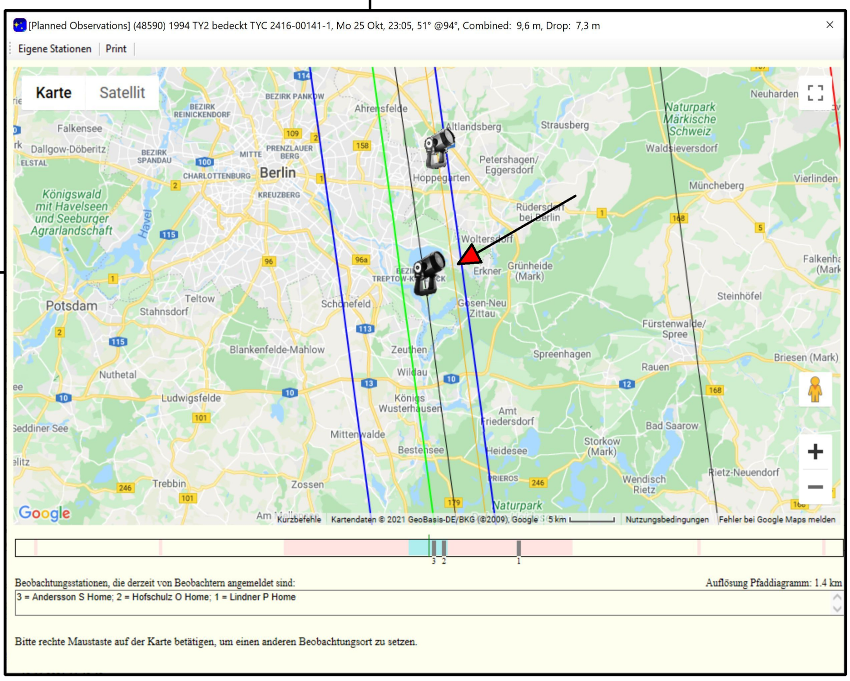


Figure 2. Path over Berlin and the surrounding area in Occult Watcher. Red arrow marks the observatory. (Map data: @ 2021 GeoBasis-DE/BKG (@ 2009),Google)

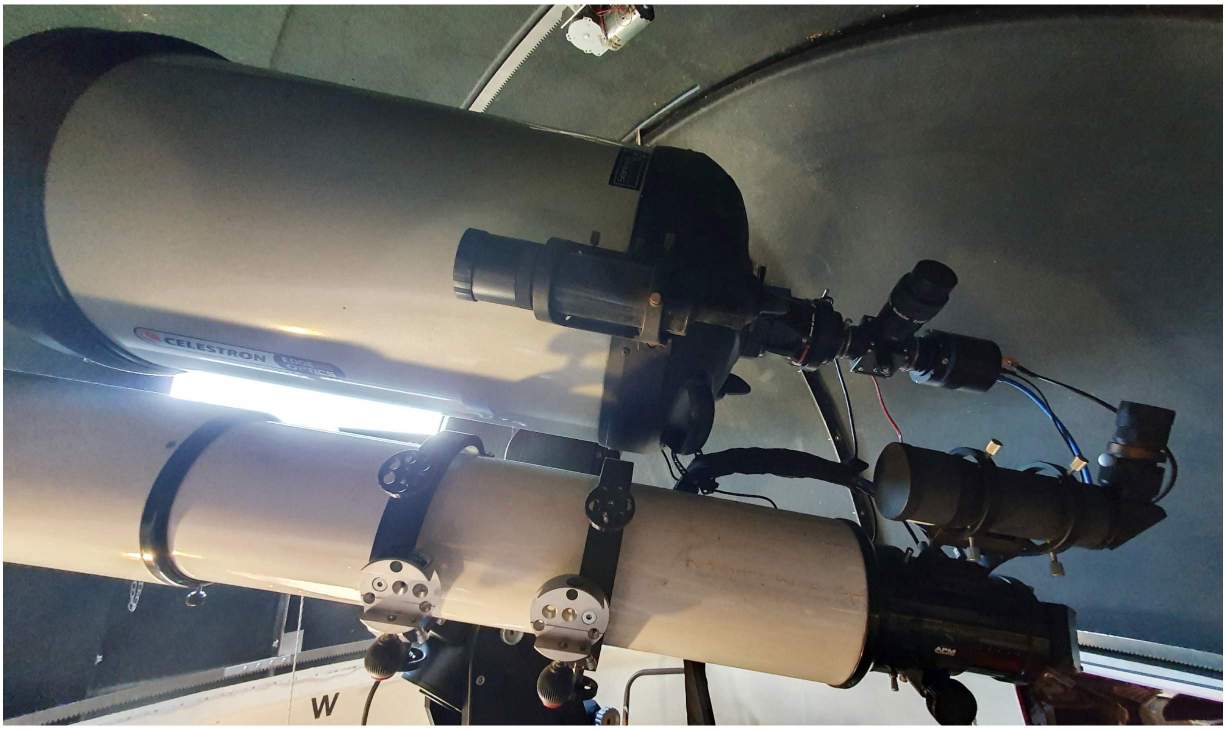


Figure 3. C14 EdgeHD with QHY174M-GPS

Results

The occultation was observed with positive results, with a measured occultation duration of 0.64 s. The occultation time was measured in the same way. According to the ephemeris [7], [8], the sky motion of the asteroid was 0.01"/s, resulting in a diameter of about 5 km. This diameter refers only to the chord through the asteroid measured during this observation and does not indicate the true diameter. The diameter published so far is at least 3 km [6] (11 km is given in the occultation prediction).

The *Occult* database [9] indicates that this occultation is the first positive observation of a stellar occultation by (48590) 1994 TY_2. When evaluating the light curve with *PyOTE* [5], brightness steps (Figure 4, 5) were obtained of the disappearance and reappearance. As a conclusion, the star TYC 2416-00141-1 is a double star. The magnitudes of the stellar components are 10^m and 11^m, respectively, and the separation distance is about 1.4 mas. The magnitudes can be calculated from the measured flux. The separation distance of the components is calculated from the temporal differences in the disappearance and reappearance times and the velocity of the minor planet in the sky.

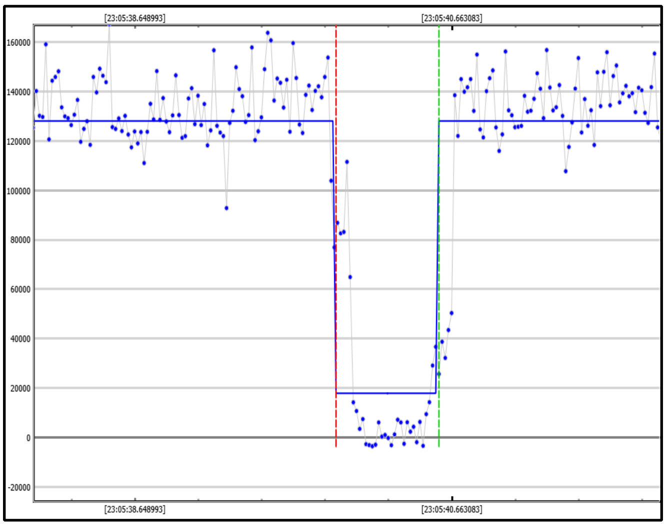


Figure 4. Occultation of TYC 2416-00141-1 (A-Component)

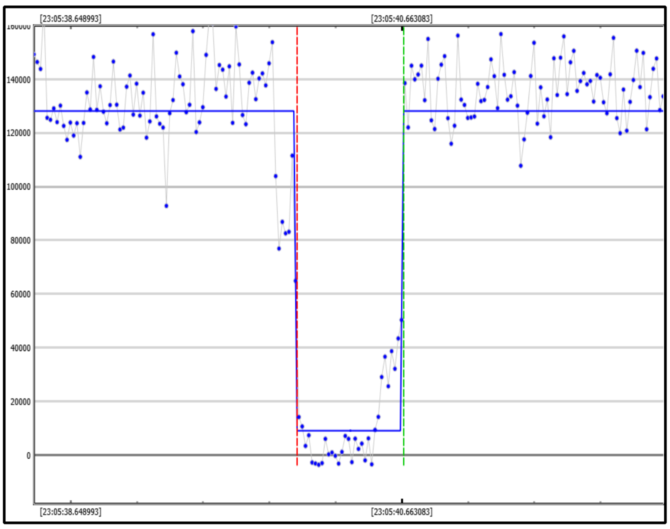


Figure 5. Occultation of TYC 2416-00141-1 (B-Component)

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The program *Occult* [9] provides the following values:

Solution	Sep (mas)	P.A.
# 1	1.4	212.3° ± 0.0° (Figure 6)
# 2	8.4	130.5°
# 3	1.4	209.6° ± 0.3°
# 4	8.4	291.4°

There is no evidence in the known databases that TYC 2416-00141-1 is a double star [10]. According to the *Occult* database [9], the star has never been the target of an occultation by an asteroid. A search in *Occult Watcher Cloud* [1] for occultations of this star in the period until 2022 March 12 yielded no result.

Summary

Stellar occultation observations can not only determine the diameter and shape of the minor planet, but in some cases also reveal new information about the occulted star. Further observations of (48590) 1994 TY_2 are needed to determine its diameter and shape. Likewise, the star TYC 2416-00141-1 should be kept in mind as an occultation candidate. A short paper was submitted to the *Journal of Double Star Observations* [11].

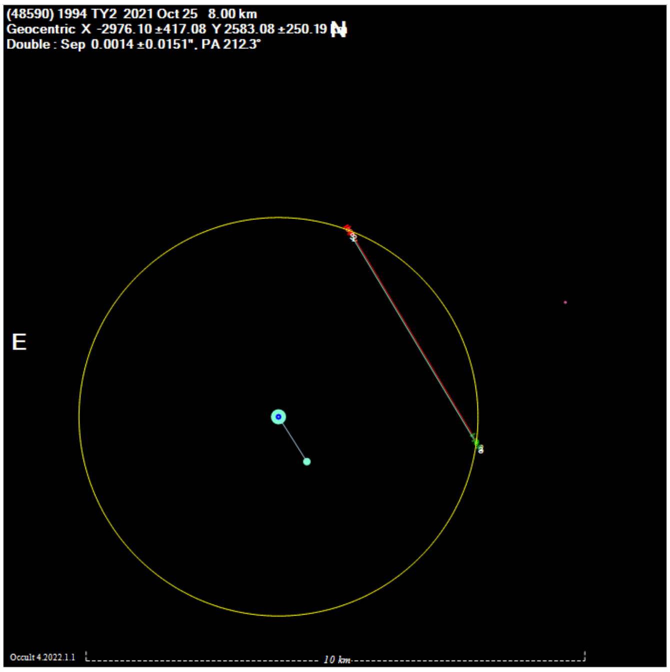

Figure 6. Plot in Occult of the measured chord and the double star solution # 1.

References

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

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

[3] Glover, R., *SharpCap 4* https://www.sharpcap.co.uk

[4] Anderson, B., PyMovie - Stellar Occultation Aperture Photometry Program https://occultations.org/observing/software/pymovie/

[5] Anderson, B., *PyOTE* -Occultation Time Extractor https://occultations.org/observing/software/ote/

[6] Frappa, E., Euraster.net - European Asteroidal Occultation Results 2021 http://www.euraster.net/results/2021/index.html#1025-48590

[7] Orbit Parameters in the JPL/NASA Small-Body database https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html#/?sstr=48590

[8] Minor Planet & Comet Ephemeris Service https://minorplanetcenter.net/iau/MPEph/MPEph.html

[9] Herald, D., *Occult V4* http://www.lunar-occultations.com/iota/occult4.htm

[10] http://cdsportal.u-strasbg.fr/

[11] Andersson, S., Double star discovery during an occultation by the minor planet (48590) 1994TY2, JDSO, Vol. 18, No. 2, (2022) http://www.jdso.org/volume18/number2/Andersson_207_209.pdf

A Stellar Occultation by the Nucleus of Comet 28P/Neujmin 1 – an Observational Account

Stefano Sposetti · IOTA/ES · Gnosca · Switzerland · stefanosposetti@ticino.com

ABSTRACT: An occultation of the nucleus of periodic comet 28P/Neujmin 1 visible from Europe took place on 2022 February 08. Five observing stations monitored the potential occultation, of which three stations recorded a positive event: two in Switzerland and one in Italy. For all three, the occultation appeared to be total with no significant dimming evident either before or after the main event. From the observational data it was possible to determine the approximate size of the nucleus at 18–20 km assuming it is spherical in shape.
This article includes an account from the personal diary of one observer, Stefano Sposetti.

Introduction

Comets are generally thought to be very different from asteroids in that most people consider comets to have a tail, whereas asteroids do not. This has been the traditional view until very recently in that comets contain ice and volatile components as well as rocks, minerals and dust, the latter being the essential components of asteroids. More recently in the scientific literature, the distinction between comets and asteroids appears to have become blurred: there are objects that once were seen as cometary in nature but now no longer show any activity; and other objects that although in the past had never shown this peculiarity, or perhaps their activity had been overlooked, now have become "activated" or "re-activated" acquiring the attribute of a comet. This premise that there is in reality a comet-asteroid continuum, is a useful concept and one that might be further tested via the occultation method: the subject of this article. Comets typically occupy highly elliptical orbits and start to emit dust and gas when they approach the Sun and stop exhibiting a tail or coma when they are far from our star. A few comets have been active objects when discovered but, after a few perihelion passages, have grown inactive, the most notable example being Comet 107P/Wilson-Harrington and now also known by the asteroid name (4015) Wilson-Harrington.

The list of objects that have this "dual nature" is relatively short. One of them is (2060) Chiron, or 95P/Chiron [1]. This body belongs to the group of objects known as Centaurs, namely objects that have an orbit with a perihelion located beyond the orbit of Jupiter (>5.2 au) and a semi-major axis less than that of Neptune (<30.1 au). Lying between the orbits of Jupiter and Neptune, their orbits are not stable having thought to originate from the Edgeworth-Kuiper belt and have been gravitationally perturbed by the outer planets to reach their present centaur-like orbit. Several of the inner Centaurs have been seen to exhibit cometary activity.

On 1993 November 07, 95P/Chiron (~200 km in diameter) was 'measured' for the first time using the occultation method [2]. A second occultation on 1994 March 09 was also successfully observed [3] as was a third event on 2011 November 29 – it was this last event that was observed with the 2.0-m *Faulkes Telescope North* and the 3.0-m NASA IRTF that confirmed the existence of a double ring system close to the main body [4]. Likewise for centaur object 174P/Echeclus (~180 km across), the discourse appears very similar. Initially classified as asteroid (60558) Echeclus, it was later observed exhibiting cometary activity [5]. Today it also carries the designation 174P/Echeclus. It too has been seen to undergo stellar occultations most recently in 2019, 2020 and 2021 [6].

To return to the more usual category of comet, these have fairly small nuclei and so successful observations of a positive event are exceedingly rare. In the literature there have been two such occultation events reported: one involving C/1995 O1 (Hale-Bopp) seen from Arizona in 1996 [7,8], and a second involving Jupiter-family comet 21P/Giacobini-Zinner observed from Ukraine in 2018 [9]. For both, the events appeared to show only a partial attenuation of the star's brightness possibly caused by the passage of the star behind the coma situated very close to the nucleus, and/or a partial eclipse of the stellar disk.

Observational Circumstances

The occultation by comet 28P/Neujmin 1 was predicted to occur on 2022 February 08 01:47:52 UT (midtime of the shadow track across Earth). The comet had reached its perihelion (1.58 au) about 11 months earlier and at the time of the occultation it was 3.33 au from the Sun, i.e. roughly midway between perihelion and aphelion. The apparent motion at the time was 0.24 arcsec/min in the direction, position angle 133°.

• COMETOCC Feed (Carlos Perelló)
• Rank: 25
• Probability: 12.8%
• Combined magnitude: 11.9 mag
• Star magnitude: 11.9 magV, 11.0 magR
• Comet magnitude: 18.3 mag
• Mag drop: 6.4 magV, 6.8 magR
• Max. duration: 3.5 s
• Event date: 2022 Feb 08
• Event time: 01:47:27 UT
• Error in time: 10 s

Table 1. Details of the path prediction in Occult Watcher Cloud.

• Telescope: Celestron 8" f10 Schmidt-Cassegrain, equatorial mount with drive, focal lenght ~500 mm (with double focal reducer)
• Video camera: WAT-910HX-RC, CCIR, 1/2", ICX429ALL sensor
• Camera settings: Shutter x32, Gain 41db, Gamma 1.00 Integration time 0.640 s
• Device of recording: Personal computer, hard disk
• Recording: Logilink USB Grabber VG0001, composite signal, VirtualDub V 1.10.4, Huffyuv codec
• Time insertion device: IOTA-VTI, V. 1.1.42.
• Time keeping: GPS with 1PPS (US Global Sat EM-406A)

Table 2. Observational setup on Sposetti's mobile station.

Personal Diary of the 28P/Neujmin 1 Event

Some days before the predicted event, I made preparations for the observation of the occultation of Comet 28P (Table 1). According to *Occult Watcher* [10], the probability of having a positive event for my location (about 200 km outside the predicted centre line) was around 13% (14.4% at the centre of the track). It was still a relatively high probability for a cometary occultation and well worth attempting, but there was an obstacle. My local horizon at Gnosca, Switzerland was too high in the direction of the comet and so I needed to move elsewhere with my equipment (Table 2) to have any chance of monitoring the star in question. Of course, the expectation of observing yet another negative was very high but I did not spend much time thinking about that - It was clear to me that it was worth a try.

The night beforehand, I loaded the equipment into the car. After finishing some video recordings of the first-quarter Moon that evening, I went to bed at 21:30 local time. The occultation was scheduled for 02:47 CET. The alarm clock woke me at 01:30 and I got up and drove to a place ~20 km from home where there was a low horizon. I parked next to a military building and started to get the equipment out of the car. I set up the mount, the telescope, the video camera and the computer. I had to manually point the scope at *epsilon Persei* (a bright star near to the target) using a *Telrad* finder as I do not have a GoTo-type mount. From there it was a question of gradually 'star hopping' towards the target following the star map displayed on my laptop. This involved pressing buttons on a hand paddle to move the mount down and left until I found the target. By then it was 02:40 CET and luckily there were still a few minutes left so I started the recording.

Every now and then the star seemed to disappear but this behaviour may have been caused by atmospheric turbulence since the target was at an elevation of only 15 degrees. I spoke the remaining time out aloud, as if I wanted to tell some imaginary person standing next to me, and as my trepidation increased. "Three minutes", "two minutes", "one minute"... The image of the target star seemed to disappear. I wondered if that was it, the event, but I immediately doubted this thought as there was still some time left according to the prediction. Then, without warning, perhaps five seconds before the expected instant, the star actually disappeared for sure! It stayed away for maybe what seemed like one second. The drop in light was very evident. I realised that this disappearance was clear proof to me that the occultation had been positive and I also instantly realised that the moment was a very special one.

I then thought of my friend Alberto Ossola and began to hope that he too was at the telescope and trying to monitor this special event. I continued the recording for another four minutes, after which I pressed the ESC key to end monitoring and watched to see that the files were successfully stored. Only then was I able to breathe a sigh of relief and relax a little. I started to put away the equipment and meanwhile to do the analysis using *Tangra* [11]. The resulting raw light curve showed a drop over two integration frames. I was hoping for a better temporal resolution, but those two integrations should be enough to validate the event (Figure 1).

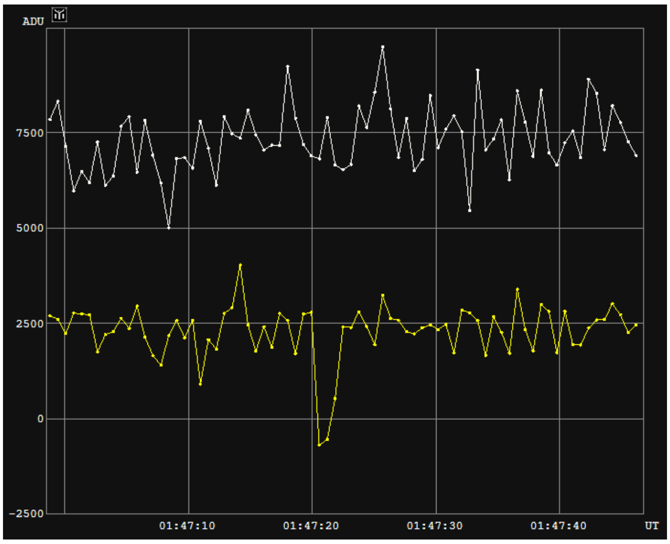

Figure 1. *The lightcurve (yellow) of the event and comparison star (white) obtained by S. Sposetti (0.64 s integration time, 0.20 m aperture telescope). Observed duration of the occultation: 1.76 ± 0.58 s, derived with Tangra.*

I was still hoping that Alberto had observed. Our observing stations were only a few kilometres apart and if it was positive for me it was probably positive for him, too. Eventually I disassembled all the equipment and stored the kit safely in boxes, not thinking too much whilst doing this. Surprisingly, during the entire period spent at the remote observing station I did not meet or see anyone. Feeling very happy, I started the car engine and drove home.

An exchange of e-mails with other observers took place during the following few days. I soon learned that Alberto had also recorded the event having detected an obvious drop in light for the star (Figures 2, 3).

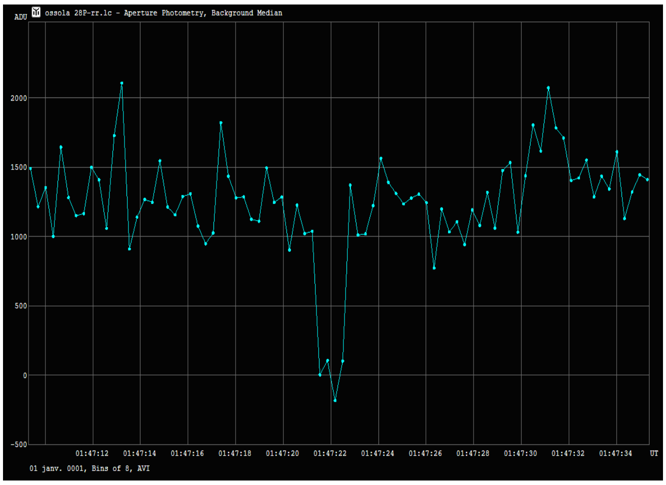

Figure 2. The lightcurve obtained by Alberto Ossola, Muzzano, Switzerland, 0.32 s integration time.
Observed duration: 1.28 ± 0.23 s, derived with Tangra.

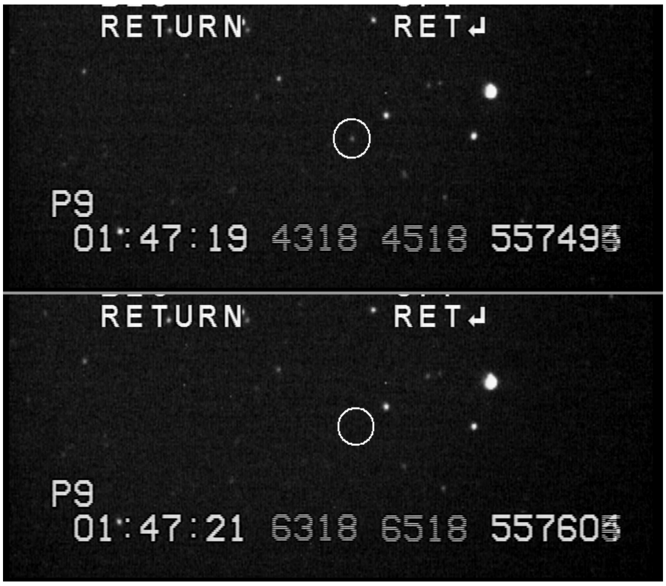

Figure 3. The 11.9 magV target star before and during the occultation as seen on two frames extracted from the video file of Alberto Ossola, Muzzano, Switzerland (0.23 m aperture telescope).

I then also learned that working at the *Schiaparelli Astronomical Observatory* of Monte Campo dei Fiori in Varese (Italy), Luca Buzzi and Andrea Aletti had also photographed a beautiful star track and gap showing the occultation using the CCD drift-scan method (*Figure 4*).

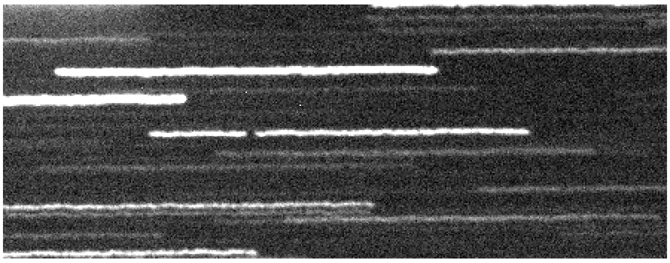

Figure 4. 40 s duration CCD drift-scan exposure shows a 1.1 s gap arising from the occultation recorded by Luca Buzzi and Andrea Aletti from Varese, Italy (0.84 m aperture telescope). Observed duration: 1.08 ± 0.24 s. Data: euraster.net, [12]

Alberto has more than sixty asteroid occultations to his credit. Luca and Andrea have now recorded their third positive event. Two other observers, Pietro Baruffetti and Gianni Casalnuovo at two other locations witnessed no occultation. Having sent Eric Frappa my preliminary report and a copy of the video file for validation, the results soon appeared on the *euraster.net* website a few days later [12]. Assuming the nucleus is spherical in cross-section, it was modelled to measure between 18–20 km in diameter (Figure 5).

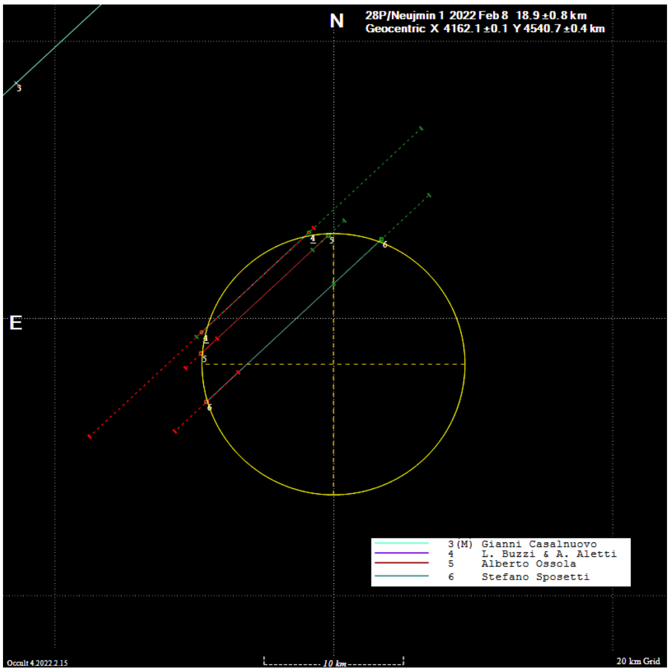

Figure 5.The best fit showing the three chords. The circle shown is the fit to the observational data of the two video records. The drift-scan record was subject to a large absolute timing uncertainty and so the positive chord has been shifted in time to coincide with the best-fit circle. Source: euraster.net, [12], image edited by O. Klös.

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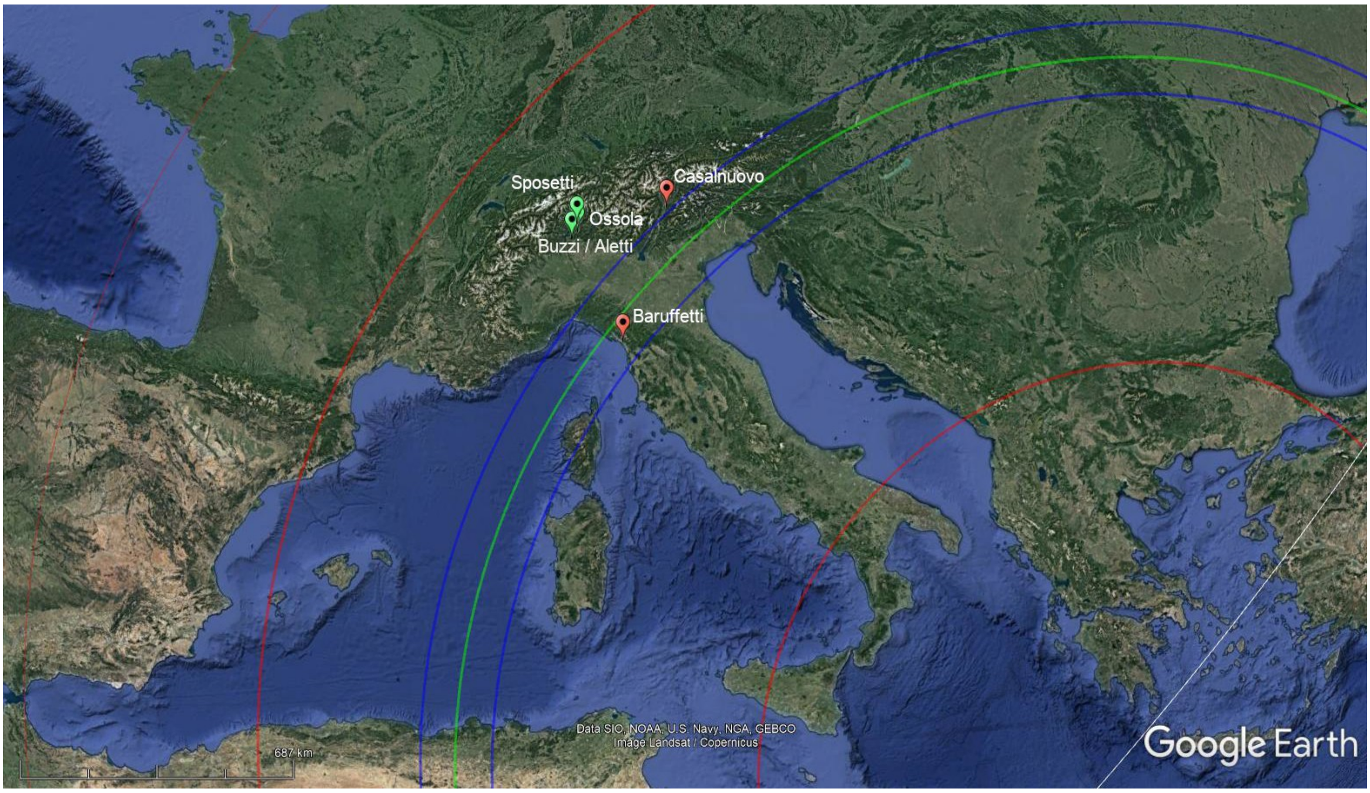

Figure 6. Map of the path prediction from the COMETOCC Feed. The green markers show the positions of sites with a positive observation, the red ones recorded negative. The green line indicates the centre line of the prediction. The region between the two blue lines mark the shadow path and the region between the two red lines the wide 1-sigma uncertainty path. (Map: Google Earth)

Conclusion

Stellar occultations by comet nuclei are extremely rare. We have been very fortunate to witness as many as three positive chords in the case of Comet 28P/Neujmin 1 on 2022 February 08 as seen from southern Europe. These results appear to be the first detection of a solid-body occultation by a Jupiter-family comet. Thanks to the fact that the observing sites were concentrated in a restricted geographical area (Figure 6), three out of five stations recorded positive events and using these data it was possible to determine the approximate size of the nucleus assuming it is spherical in shape, approx. 18–20 km diameter.

Acknowledgements

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Differential Measurements of ΔUT1 at the Meridian Line of Santa Maria degli Angeli in Rome and the Rediscovery of the Boscovichian Sinus

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ABSTRACT: The meridian line of *Santa Maria degli Angeli* (1702) has been inspected with modern observing methods. The IGEA (Informatized Geometrical Ephemerides for Astrometry) observational campaign 2018-2021 has been completed by ZIA (Zenithal Image Analysis) measurements in 2022 to allow us to determine exactly the local deviation from the North direction on many positions on the line, with respect to the pinhole, a source of the sunlight for the measurement of the solar position, over the 45 m-long meridian line built in *Santa Maria degli Angeli* basilica (Rome) in 1701-1702.

A partial historical documentation on the so-called Boscovichian sinus (claimed but not localized on the line) has been supported with precise measurements of that deviation in the equinoctial sector of the meridian line during the ZIA 2022 campaign, and we rediscovered the exact locations of such deviation with the submillimetre accuracy limited by the atmospheric turbulence. It is as large as 4.7 mm and 2.3 s of extra delay in the meridian passage just near the equinoxes.

The comparison between 10 and 13 observations made on the same dates separated by 3 years 2019-2022 (from April 25th to June 2nd) yields results of ΔUT1=UT1-UTC in good agreement with the IERS service of Paris for the same dates.

Introduction

UT1 is the astronomical time, the mean solar time at the zero (Greenwich) meridian, corrected from UT0 for polar motion. The ephemerides work with UTC and uniform Earth's rotation hypothesis, until a new leap second is introduced to account for the Earth rotation's slowing down. Between January 2017 and May 2022, no leap seconds were issued by IERS, and ΔUT1=+0.1 s on 2019 May 2, remained constant until 2021 July 17 when ΔUT1=-0.1 s up to the present date (2022 June 5), as we could verify in our observations, here described.

Both ΔUT1 and Boscovichian sinus are obtained by using positional astrometry procedures on timings of solar meridian transits video-recorded on the Clementine meridian line of 1702.

The meridian line of the Basilica of *Santa Maria degli Angeli* in Rome (Figure 1), built in 1701-1702 by Francesco Bianchini, upon the will of Pope Clement XI, is famous worldwide [1] and has been the subject of accurate checks of its north-south orientation: 1732 Celsius, 1750 Boscovich, 2006 Sigismondi, and 2018-2022 Sigismondi and Pietroni. During the last series of measurements we discovered the sinus mentioned by Boscovich just before the days of the spring equinox, while we were checking ΔUT1 by comparison between the measurements taken on the same dates in 2019 and 2022.

ΔUT1, Sidereal Day and Solar Meridian Transits

By definition, ΔUT1=UT1-UTC, where UTC includes the atomic reference time (since 1962) and UT1 is the astronomical Universal Time. Being something we use daily, automatically, through the radio synchronisation or via NTP protocol over high-speed broadband, it may be interesting to explore the astronomical origin of such reference by observing solar meridian transit timings in relationship with the ephemerides of the Sun.

In the hypothesis of a constant Earth's rotation rate, the ephemeris of the Sun provides for a given place the accurate prediction timing for the meridian transit, when the Sun's azimuth is exactly 180° 00′ 00″ (due south).

The theory of apparent solar motion, which includes all Earth's orbital parameters, is nowadays very accurate, so that the ephemerides of NASA (JPL Horizons), IMCCE and even *Stellarium 0.20* [2] and newer versions, are accurate enough to the nearest 0.01 s. These ephemerides, as well as the *Occult* [3] package, can be corrected for an external input about the ΔUT1, provided by the IERS (International Earth Rotation and Reference

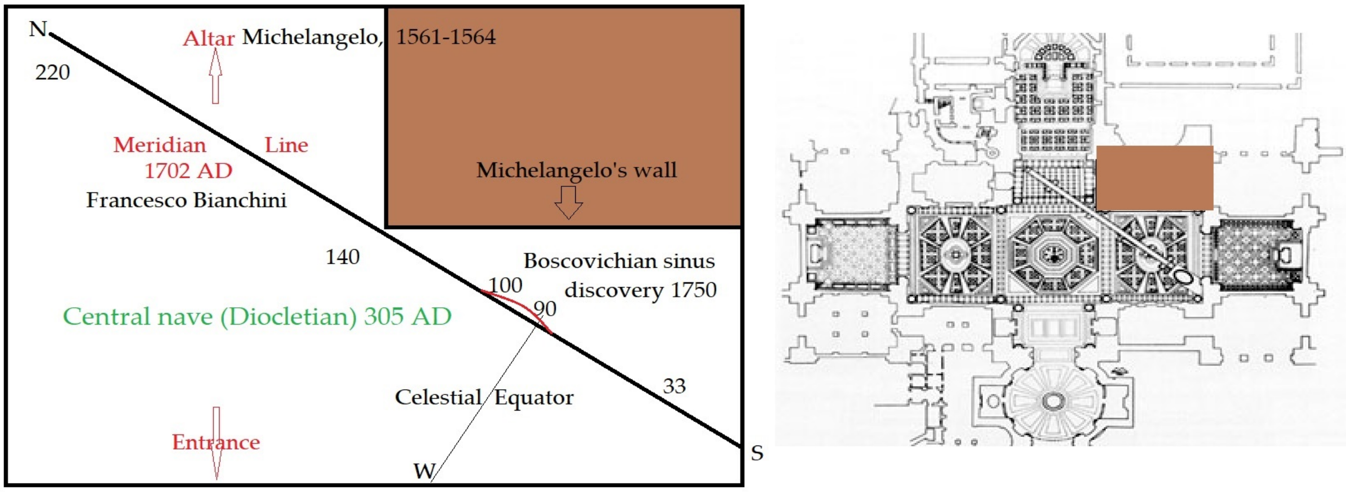

Figure 1. Schematic of the meridian line with the Boscovichian sinus (between the 100 and 80 centesimal parts) compared with the planimetry of the Basilica from the archives of the photo gallery of the website. http://www.santamariadegliangeliroma.it/ (G. M. Blanda, 2012)

Systems Service) by bulletins with 0.1s accuracy, which may affect the timing of an eclipse by some tenths of a second. (Thanks also to the accurate lunar limb and altitude data from the *Kaguya* and *LRO-LOLA* spacecraft). This happens because the sidereal day, an average of 23 h 56 m 04.09 s, is not really constant over the years, at the level of 0.1 ms and less. Typically, Earth's rotation accumulates +1 s over 3 years, which equates to +1 ms/day on average.

This paper deals with the accurate timing of some solar meridian transits in April-June in the years 2019 and 2022 at the Clementine Gnomon (1702). Every instrumental systematical error remains the same for observations in the same meridian position, so the differences between the measured timing and the ephemerides are direct measures of the ΔUT1 difference during the last three years. They are a tool to verify daily, with the Sun, the IERS service which was originally based on timing transits of "fixed stars'" and now uses global averages from GPS satellites.

"Stellar Occultations" by the Sun on the Meridian Line

During the year the Sun's declination ranges from -23° 26′ to +23° 26′ between the winter and summer solstices. On the meridian line of *Santa Maria degli Angeli* in Rome, called the Clementine Gnomon after Pope Clement XI (1700-1721) who financed it when he was the Cardinal, there are engraved the declinations of the brightest stars within this range, along with their ecliptic longitudes in the year 1701.

The solar image crosses the meridian line "over" such stars, on various occasions, here documented in the Figures 2-8. Only Regulus, alpha Leonis, is really approached by the Sun on August 21-22, because it is very close to the ecliptic; for the other stars the "occultations" occur only for one of their two coordinates. The use of a pinhole allowed us to produce a solar image at whatever focal distance, all year long, while a lens would have produced a focused image only at its own focal length.

The Solar Images on the Gemini-Taurus Section of the Clementine Gnomon (1702)

The following Figures 2-6 show the Sun's projected image next to the meridian line, before the meridian transits, where ΔUT1 has been measured and compared between 2019 and 2022.

Figure 2. The image of the Sun before the meridian transit on 2022 May 4: there is also the position of Regulus, Cor Leonis, near marker 54, which means 54% of the pinhole height or 11 m from the pinhole's vertical projection. The measurements end at 37% of the same height, or 7.5 m.

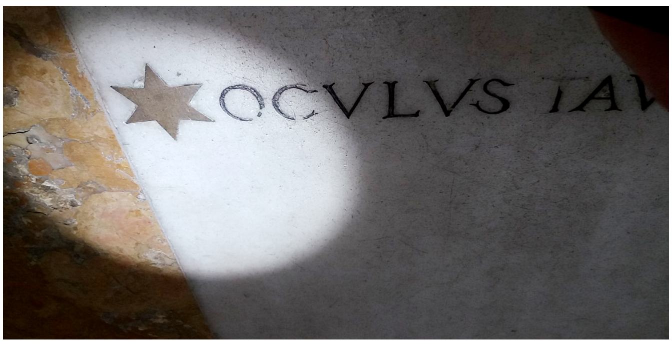

Figure 3. The image of the Sun on Aldebaran, Oculus Tauri (J1701) on 2022 May 4, just before the meridian transit at the meridian line of Santa Maria degli Angeli.

Figure 4. The Sun projected onto Regulus' declination on 2022 April 25.

Geometrical Characteristics of the Meridian Line: Global and Local Deviations from North

The line is globally deviated from the North by 5′ 11″ starting from the summer solstice to the winter one (i.e. from the 33 to 217 centesimal parts). Locally, there are much smaller deviations. The larger deviation is the "Boscovichian sinus" which has been recently (March 2022) re-discovered near the equinoxes (from the 90 to 80 centesimal parts) which contributes 2 seconds of delay with respect to the already globally-deviated meridian line's ephemerides. After that deviation there are much smaller local deviations, due to the junctions between different segments of the brass meridian line.

To avoid such types of systematic errors, we concentrated our measurements on the segment described above, starting from Regulus (Cor Leonis), to Arcturus (alpha Bootis, the Shepherd's star).

The global deviation of the line has been parameterised according to the following equation:

(1) DELAY [s]=(22.4-10.6)·(CENTESIMAL PART-33.3)/(217.5-33.3)+10.6

where 10.6 is the delay (in seconds) of the meridian passage at the summer solstice, with respect to the IMCCE ephemeris, calculated for the pinhole's geographical coordinates, and 22.4 is the delay (in seconds) at the winter solstice. This delay is added to the IMCCE ephemeris for each day, yielding the true passage of the Sun on the ideal line, to predict the real passage's timing.

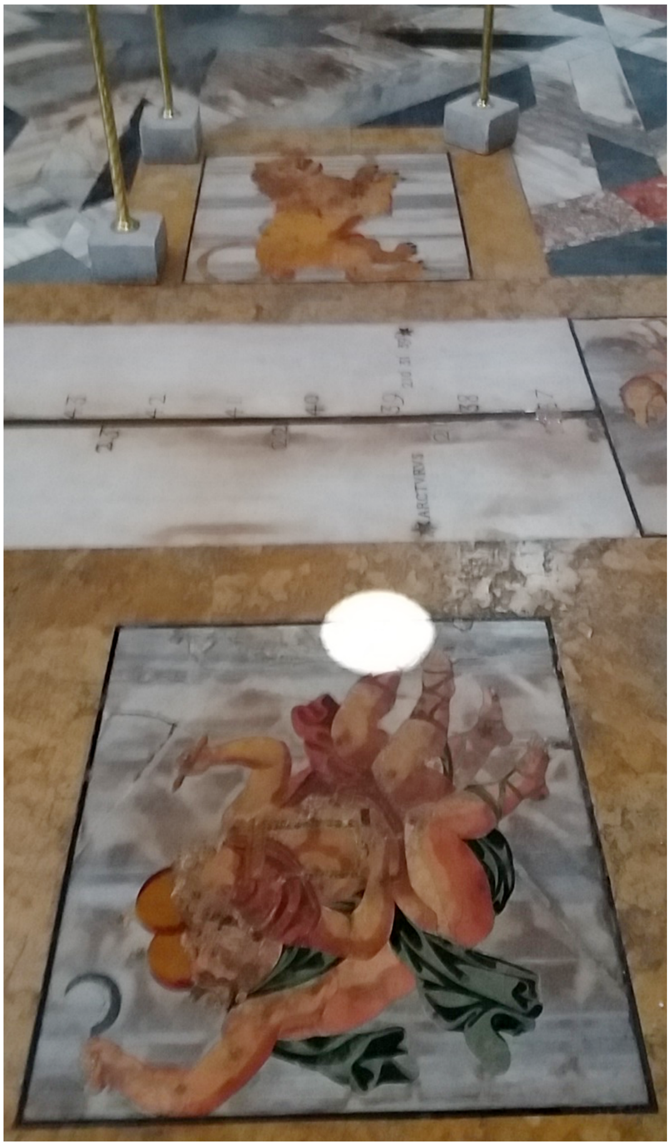

Figure 5. The image of the Sun in the sign of Gemini, a few minutes before the transit on 2022 May 22. The 37 centesimal part is the last one before the sector of Cancer, where the meridian line is no longer visible.

Figure 6. The image of the Sun on Arcturus' declination before the meridian transit on 2022 May 23.

First clear rediscovery of the Boscovichian sinus after 1750

It was detected between the 90 and 80 centesimal parts, just near the Spring equinox of 2022, with an extra delay of 2 s with regard to the one calculated using the above formula. The identification of such a feature was claimed by Roger J. Boscovich (1711-1781) but the presently available historical sources [4] do not say where it is located on the nearly 45 metres of the meridian line.

With a series of measurements made in 2006 with a 45 m wire and a laser pointer, we found the sinus with an error bar of ±1.5 mm. The maximum amplitude appeared near 165, starting from nearly zero at 55 centesimal parts [5].

The research on the Boscovichian sinus was restarted again after the 2018 IGEA campaign, with the new pinhole of 25 mm diameter. The region of 165 ±15 centesimal parts is illuminated by the meridian Sun between January 24 till February 9, and symmetrically from November 1 till November 18.

These dates can easily include cloudy days, and the display occurs in front of the altar, where the holy masses and baptisms are celebrated. That's why the measurements were complicated. During the 2020-2021 season with very limited access due to the pandemic restrictions, a series of measurements was conducted on this section of the meridian line, to make the comparisons between the ephemerides and the real solar meridian transits.

Finally, in March 2022, we found that the sector presenting a clearly sensible deviation, around +2 s, from the ephemerides was located on a segment between the 90-80 centesimal parts, and not the previously indicated one.

A new kind of observation, the ZIA (Zenithal Image Analysis), has been developed from January to April 2022 in order to carefully measure the extension of the image by identifying the solar edges with the location of the inflexion point of the limb darkening function, exactly as it was done in the researches of Dicke in 1967 [6], Hill, Stebbins and Oleson in 1975 [7] and Raponi et al. [8] in 2012, the latter using Baily's beads luminosity evolution.

The measurement of the Boscovichian sinus was always included in the meridian analyses, and it appeared in a region with strong interference from reflected ambient light. The sunlight coming from the big windows was reflected by the painting of St. Jerome's preaching onto the zone of the meridian line, and the normal screening from the west adopted for the ZIA images failed. Once the source of ambient light was found, the images were improved and the systematic difference of up to +2 s became apparent.

Another reason for the difficulty in mechanically identifying the Boscovichian sinus is due to its passage across a protective glass on the meridian line, covering parts 105 to 120.

Figure 7. The image of the Sun near alpha Ceti, on 2022 March 29, with the solar limbs projected onto two white cards during the transit, and recorded with the camera placed parallel to the ground from a fixed distance of 16 cm.

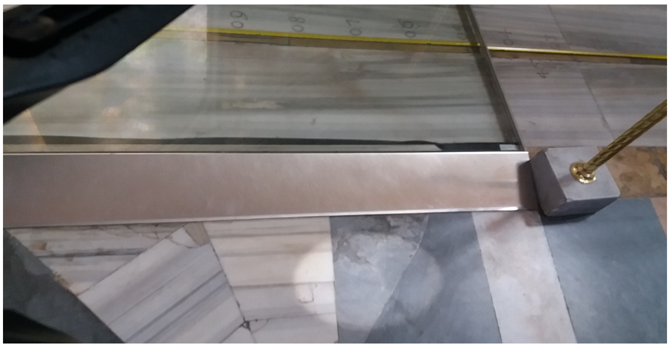

Figure 8. The image of the Sun on 2022 March 7, before the meridian transit at 107.5 centesimal parts. The deviation from the line was evident by comparing to the meter under the glass from the 120 to 80 parts.

Finally, there are local deviations of the meridian line with respect to the junctions between brass segments of the line. These deviations are as small as 1 mm. The motion of the solar image in relation to the meridian line varies from 3.3 mm/s - 1.5 mm/s between the two solstices, then in the locality of the sinus it is about 2 mm/s, with a whole departure from the general line of 4-5 mm due to the Boscovichian sinus.

Differential ΔUT1 Measurements between 2019 and 2022

The difference between the observed solar transits of the meridian line and the ones calculated accurately with the ephemerides (IMCCE and *Stellarium 0.20.2*, which is in agreement with IMCCE to the nearest hundredth of a second), is ΔUT1.

The systematic error in *Santa Maria degli Angeli*, due to the deviation of the line, is computed by formula (1), but to reduce it to minimum influence we can compare the observations on the same location of the line from one year (2019) to the other (2022).

In May 2019 this value was ΔUT1=+0.1 s and in July 2021 it became ΔUT1=-0.1 s. Between these dates, and from 2021 up to now (May 2022) it remained nearly constant according to the IERS Institute in Paris.

Since the ephemerides are computed using, by default, a constant Earth rotation rate, with a sidereal day equal to 23h 56m 04.09 s, the goal for solar transits is to measure them to the highest timing accuracy. This is limited by the atmospheric turbulence, and for the analysed case it is nearly ±0.25 s, as explained below.

A recent measurement of the global turbulence effect between the two meridian limbs gave 10″ of angular standard deviation of the solar diameter for a two seconds' sequence carried out on 2022 March 29, which corresponds to 1.6 mm. On March 29 the solar diameter is nearly 32′, the average annual value.

At the speed of 2 mm/s, this length corresponds to 0.8 s, showing that the time accuracy for a single measurement cannot be better than $\pm 0.8/\sqrt{2}=0.56$ s.

We used parallel lines transits, i.e. a plot of 11 parallel lines each separated by 15 mm to the main meridian line, one of them, the central one is exactly on the meridian line, (e.g. 2019 May 1 video) with the possibility to average on 9 couples of transits, with a final result theoretically equal to 1/3 of the single couple, and we verified that under normal atmospheric conditions (mainly due to the heat next to the pinhole) the accuracy cannot be better than ±0.25 s. The measurements of the meridian transits in 2019 and 2022 from April 25 till June 2 are reported in Table 1 with the date, position on the line, measured ΔUT1, IERS ΔUT1. The evolution of ΔUT1 in the last three years is obtained by comparison. The position in centesimal parts allows us to compute the systematic difference between the 2019 and 2022 position in terms of seconds by using formula (1): it is 64 ms per centesimal part, and it is the same for each position on the meridian line.

The average derivative of the meridian line deviation's delay is given after (1) by the formula

(2) DIFFERENTIAL DELAY: +64 ms/CENTESIMAL PART

Dates 2019	Position on the line	Measured delay [s]	Dates 2022	Position (2022)	Delay 2022 [s]	Differ-ential ΔUT1	2019 IERS ΔUT1 [a]	2022 IERS ΔUT1 [a]
25 April	54.8	63.0 t_2	25 April	54.62	63.08 t_2	-0.092	-0.144	-0.098
27 April	53.3	11.76	27 April	53.19	11.52	0.233	-0.147	-0.098
1 May	50.6	12.12	30 April	51.05	12.4	-0.251	-0.148	-0.098
3, 5 ,6 May	48.2	12.03	4 May	48.48	11.85	0.201	-0.149	-0.098
10 May	45.1	10.96	10 May	45.00	10.8	0.166	-0.150	-0.097
12 May	44.0	11.15	11, 13 May	43.91	11.30	-0.156	-0.153	-0.096
22 May	39.4	63.75 t_1	21, 22, 23 May	39.34	63.67 t_1	0.076	-0.166	-0.098
2 June	35.85	10.45	29, 31 May 2 June	36.31 35.78	10.62 10.73	-0.17 -0.276	-0.168	-0.099

t_1 https://datacenter.iers.org/data/6/bulletina-xxxii-017.txt
t_2 https://datacenter.iers.org/data/6/bulletina-xxxv-020.txt

[a] https://datacenter.iers.org/singlePlot.php?plotname=GPSRAPID_OUT-UT1-UTC&id=11

Table 1. The differential ΔUT1 has been obtained by subtracting the 2019 datum from the 2022 one, including the increment of 64 ms per centesimal part corresponding to the difference of the positions in 2019 and 2022. The positions of 2019 May 3, 5 and 6 have been averaged along with the corresponding delays with respect to the ephemerides, as well as the data of 2022 May 11 and 13, 21 to 23 and 29-31.

Example of Calculation: 2019 June 2 Compared with 2022 May 31 and 2022 June 2

- Centre's positions:
  35.85 vs 36.31; difference (36.31-35.85)=0.46 centesimal parts
- Difference in timing due to the line's global inclination (formula 2):
  0.46x64 ms=29.44 ms; this means that the 2022 datum at 36.31 centesimal parts is 29.44 ms more in delay with respect to the ephemeris because it is in a position more distant from the pinhole's vertical point.
- Ephemeris for the meridian passage on 2019 June 2:
  13:07:58.3, observed passage 13:08:08.75
- Delay 2 June 2019: 10.45 s
- Ephemeris for the meridian passage on 2022 May 31:
  13:07:42.75, observed passage 13:07:53.4
- Delay 2 June 2019: 10.65 s
- Subtraction of the global deviation of the meridian line for the delay 31 May 2022 with respect to 2019 June 2:
  10.65 s- 0.029 s = 10.62 s
- Observed Differential ΔUT1 (2019-2022)= -0.17 s
- IERS Differential ΔUT1 (2019-2022)= -0.168 s-(-0.099) s=-0.069 s

- Centre's positions:
  35.85 vs 35.78; difference (35.78-35.85)= -0.07 centesimal parts
- Difference in timing due to the line's global inclination (formula 2):
  -0.07x64 ms=-4.48 ms; this means that the 2022 datum at 35.78 centesimal parts is 4.48 ms in advance with respect to the ephemeris because it is in a position closer to the pinhole's vertical point.
- Ephemeris for the meridian passage on 2019 June 2:
  13:07:58.3, observed passage 13:08:08.75
- Delay 2 June 2019: 10.45 s
- Ephemeris for the meridian passage in 2022 June 2:
  13:08:01.92, observed passage 13:08:12.66
- Delay 2019 June 2: 10.74 s
- Subtraction of the global deviation of the meridian line for the delay 2022 June 2 with respect to 2019 June 2:
  10.74 s + 0.045 s = 10.785 s
- Observed Differential ΔUT1 (2019-2022)= -0.276 s
- IERS Differential ΔUT1 (2019-2022)= -0.168 s-(-0.099) s=-0.069 s

In three cases only the first contact t_1 or the second contact t_2 were available, because of a partially cloudy transit. Other contacts were obtained by averaging 3 timings of the solar image on the brass meridian lines' borders and centre. The meridian transit was obtained from 6 averaged timings.

The Differential ΔUT1 averaged over the 8 values obtained in April-May 2019 and 2022 yields (0.016±0.179) s, while the ΔUT1 averaged from IERS service data is (-0.055±0.0087) s.

Comparing the two results 16±180 ms and -55±9 ms, the former, obtained at the Clementine Gnomon of 1702 with video inspection is compatible with the latter obtained by averaging modern observations at IERS in Paris.

The difference between the two results is 71 ms. But the atmospheric turbulence measured at *Santa Maria degli Angeli*'s meridian line affects the time measurements of a single transit as much as ±250 to 300 ms. Therefore, the result obtained with this instrument and this method is very good, and it can confirm the official bulletins on DUT1:

DUT1 = (UT1-UTC) transmitted with time signals
= -0.1 seconds beginning 2019 January 17 at 0000 UTC
= -0.2 seconds beginning 2019 May 2 at 0000 UTC
= -0.1 seconds beginning 2021 July 17 at 0000 UTC
Beginning 2017 January 1: TAI-UTC = 37.000 000 seconds

The comparison (subtraction) of 2019 DUT1 with 2022 ones yields 0.0 s until 2019 May 2 and -0.1 s from 2019 May 3, when compared with the corresponding dates of 2022.

Observations' Database for ΔUT 1-19-22 Special Campaign

Data on YouTube channel (search: aprile 2019, maggio 2019, giugno 2019, 2022 transito meridiano meridian transit):

2019	
April 25	https://youtu.be/dM4noWFktQE
April 27	https://youtu.be/O5R6H0G_1Ls
May 1	https://youtu.be/BimpuZqY0y4
May 3	https://youtu.be/RRPiOCX-xA0
May 5	https://youtu.be/0eb9fo79xG8
May 6	https://youtu.be/Xs48N-_iNZE
May 10	https://youtu.be/FYla20Db7EE
May 12	https://youtu.be/1PV58DdGSF8
May 22	https://youtu.be/ciR7-kM6Wjo
June 2	https://youtu.be/YzbYV5nGj8c
2022	
April 25	https://youtu.be/axWz5zbC94M
April 27	https://youtu.be/k6d-E45_Vx4
April 30	https://youtu.be/OykGir86VuY
May 4	https://youtu.be/evgrHgBppBQ
May 10	https://youtu.be/975paidbYV0
May 11	https://youtu.be/cbX2u_HpfQo
May 13	https://youtu.be/VhZrVMuqBkE
May 21	https://youtu.be/zNvx_2KzZpI
May 22	https://youtu.be/otdrmmAIQ4o
May 23	https://youtu.be/Bt8nxqgOWdc
May 29	https://youtu.be/tPpfhAnfwFI
May 31	https://youtu.be/avlj01xzZok
June 2	https://youtu.be/LJjB-q2vejU

Table 2. Links to separate videos, a playlist is available [9].

Boscovichian Sinus' Observations (2022)

A YouTube playlist [10] presents nine videos of observations of meridian transits with the ZIA Zenithal Image Analysis technique from March 5 to 29 at *Santa Maria degli Angeli*, on the locations of the Boscovichian sinus, the largest deviation from the line Summer-to-Winter solstice.

The sinus came out evident by comparing the timings of the transits with the ephemerides generated for a line's constant deviation of +64 ms/centesimal part (formula 2), with 10.6 s of delay at summer solstices and 22.4 s of delay at winter ones (formula 1).

The observed difference was as large as 2.3 s and 4.7 mm.

Conclusions

The Earth's rotation maintained its constant, average rotation rate.

The differences between the observed solar transits and the ephemerides, when compared between the same dates of 2019 and 2022, remained constant.

The average value of the observed differential ΔUT1 in the last three years, from 2019 April 25 to 2022 June 2, was +25±191 ms. The statistical uncertainty is due, essentially, to the strong atmospheric turbulence experienced immediately from the pinhole during each observation.

The IERS averaged value of ΔUT1 was -53 ± 7 ms.

The Earth's rotation rate did not change in 1096 days by more than (25 ± 190) µs/day according to our observations, in agreement with the IERS datum of (-53 ± 7) µs/day, obtained with modern observatories and GPS satellites' averaged data.

With this meridian line in 2006 we discovered the stellar aberration effect on Polaris, measured but not recognised by Bianchini in 1701 (the effect was discovered by James Bradley in Greenwich in 1727 and published either in the book (1703) [11] and on the boreal meridian line as the measured latitude of the pinhole (41° 54′ 30″ (27″) instead of the real one 41° 54′ 11.2″).

In the year 2021 we verified the stellar aberration of Sirius either in ecliptic latitudes (Bianchini, page 301) and longitudes (what Anni Cardines of 1703 published in the marble inscription in the presbyterium of *Santa Maria degli Angeli*).

The occurrence of no change in the Earth rotation rate during three years is not new in the last decades, but the effect is still not predictable on timescales of longer than a month, nevertheless the periodical influence of the Moon is evident from the daily plots of IERS [12].

The observing campaign presented in this paper, conducted near the limit imposed by the atmospheric turbulence, allowed us to detect within ±0.3 s, or to submillimetre accuracy, being the solar image's motion on the Clementine meridian line reaching nearly 2 mm/s at the equinoxes, the location of the Boscovichian sinus just before the spring equinox (or after the autumn one). The amplitude of that sinus is larger than 4.7 mm or 2.3 seconds of time.

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Further Reading

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Sigismondi, C., Pinhole giant meridian lines: a review on ancient data retrieval and modern observations (IGEA-ZIA campaign), Gerbertus 16, 29 (2022) https://ui.adsabs.harvard.edu/abs/2022Gerb...16...29S/abstract

Upcoming Meetings

The annual meeting of IOTA will be held via Zoom on Saturday August 13 and Sunday August 14, from 4:00 PM EDT to 8:00 PM both days. The meeting will be on-line, with no in-person component. Future announcements on IOTAoccultations@groups.io will provide the links and meeting schedule.

On Tuesday, August 16, the NEA (3122) Florence is predicted to occult 9.9 mag TYC 2463-00303-1 at approximately 8:34 UTC, early morning in the US. The predicted occultation path is in the eastern US and Canada, from Florida to Prince Edward Is. The 2022 IOTA Annual Meeting on the previous weekend, August 13-14, will include training in finding targets and recording occultations, with the Florence occultation, as well as the multiple Didymos and Phaethon occultations to follow, in mind.

We will be trying something new for the occultation training: A coordinated on-line evening practice for the Florence occultation with provision to accommodate those who cannot be online when observing. Evening targets from the occultation pre-point line will be used for this practice since TYC 2463-00303-1 will not be visible until early morning. The evening practice is scheduled for August 14, after the end of the 2022 Annual Meeting with an option to change to the evening of August 13 depending on the weather forecasts.

Joan Dunham, IOTA Secretary/Treasurer

On September 10-11 the 41th European Symposium on Occultation Projects (ESOP) will be held in Granada, Spain. On the afternoon of September 10 the General Assembly of IOTA/ES will take place at the conference site.

Registration for the Symposium is already open. Please note that you have to register if you plan to join the meeting in person or online via Zoom.

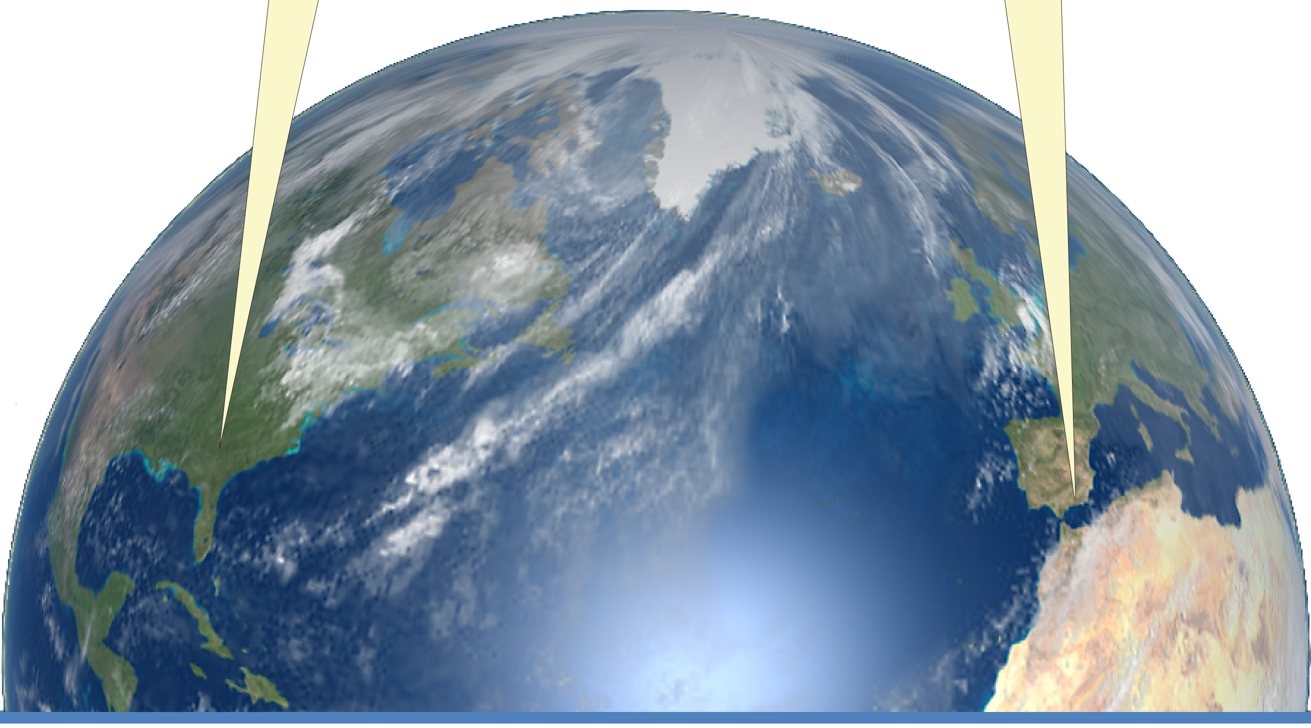
The LOC awaits your contributions!
Please announce your lectures (presented online or in person) and posters. Deadline of this call is on August 1.

The days after the meeting you can join us on excursions. Trips to Calar Alto, a guided tour of the Alhambra and a visit to the science museum P*arque de las Ciencia*s in Granada are planned.

All details can be found on the webapge:
https://www.iota-es.de/esop41/

See you in Granada,

Oliver Klös, IOTA/ES Public Relations



Beyond Jupiter

The World of Distant Minor Planets

Since the downgrading of Pluto in 2006 by the IAU, the planet Neptune marks the end of the zone of planets. Beyond Neptune, the world of icy large and small bodies, with and without an atmosphere (called Trans-Neptunian Objects or TNOs) starts. This zone between Jupiter and Neptune is also host to mysterious objects, namely the Centaurs and the Neptune Trojans. All of these groups are summarised as "distant minor planets". Occultation observers investigate these members of our solar system, without ever using a spacecraft. The sheer number of these minor planets is huge. As of 2022 June 29, the *Minor Planet Center* listed 1440 Centaurs and 2930 TNOs.
In the coming years, JOA wants to portray a member of this world in every issue; needless to say not all of them will get an article here. The table shows you where to find the objects presented in former JOA issues. (KG)

In this Issue:

(208996) 2003 AZ_{84}

Sven Andersson · IOTA/ES · Berlin · Germany · sandersson@astw.de

ABSTRACT: This article in the series "Beyond Jupiter" describes the object (208996) 2003 AZ_{84}. It describes the discovery, the orbit and interesting results of its stellar occultations. An outlook on upcoming stellar occultations is also given.

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

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
174567	Varda	Christian Weber	JOA 2 2022
-	2004 XR_{190}	Carles Schnabel	JOA 1 2022

The Discovery

(208996) 2003 AZ_{84} was discovered at Palomar (IAU code 644) on 2003 January 13 by C. A. Trujillo (observer), M. E. Brown, E. F. Helin, S. Pravdo, K. Lawrence and M. Hicks [1] with the 1.2-m *Oschin Schmidt Telescope* at *Palomar Observatory* [2, 3, 4, 5], (Figure 1). A pre-discovery image taken in 1996 was found, also at *Palomar Observatory*, but with the 18-inch Schmidt telescope. With this single astrometric observation, the observed trajectory arc could be extended and thus the accuracy of the orbit could be improved. 2003 AZ_{84} was repeatedly observed by the *Herschel* and *Spitzer* space telescopes and ground-based telescopes.

In April 2009, 2003 AZ_{84} was assigned the minor planet number 208996 by the Minor Planet Center.

Orbit and Classification

(208996) 2003 AZ_{84} is a Plutino-type object, outside the orbit of Neptune with a 2:3 resonance (Figure 2). Of all the known trans-Neptunian objects, it ranks as about 20th in terms of its intrinsic brightness (H value) [6]. Because of its size, it could well be considered a dwarf planet, but its mass and density are still unknown.

According to the JPL Horizons Small Body database [7], (208996) 2003 AZ_{84} orbits the sun in 246.5 years, with an inclination of 13.6°. The perihelion distance is 32.2 au, the aphelion distance 46.4 au, the orbital eccentricity 0.181. It passed its aphelion in 1982 and will reach its perihelion in 2107, not crossing Neptune's orbit.

Figure 1. The 1.2-m Oschin Schmidt telescope at Palomar Observatory. (Coutesy of Palomar Observatory/Caltech)

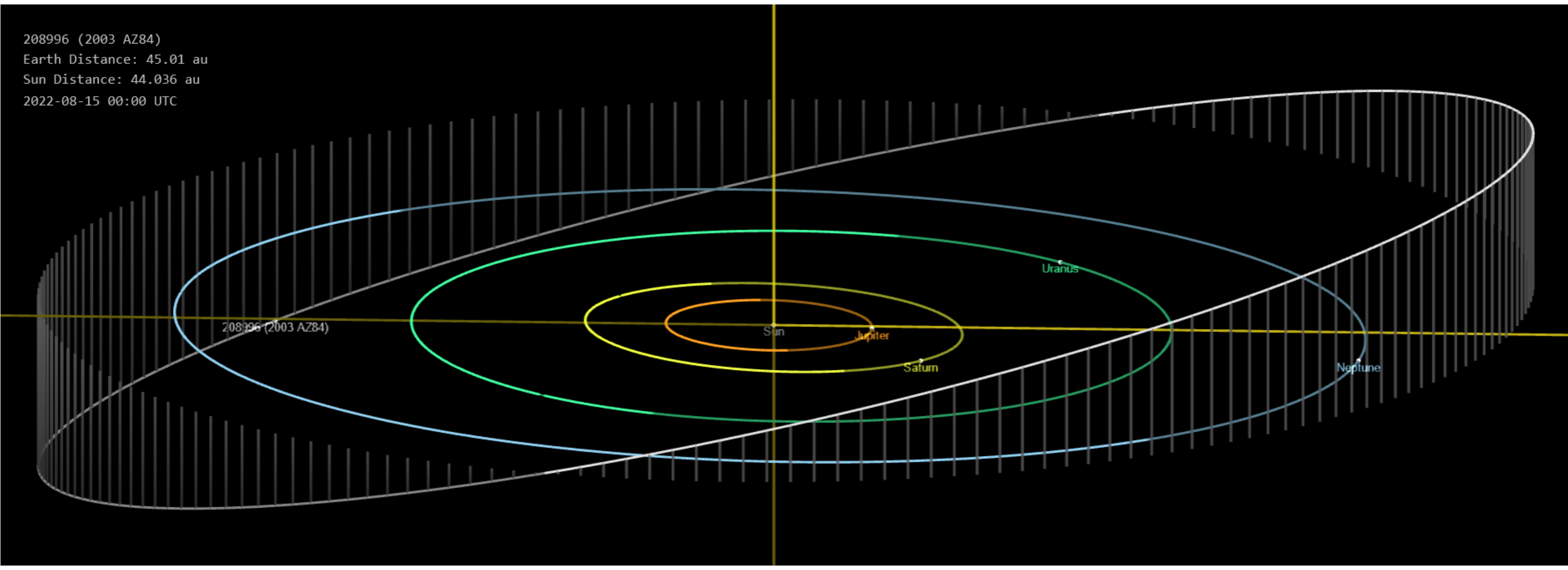


Figure 2. Orbit diagram for (208996) 2003 AZ_{84}. Credit: JPL Small-Body Database

Physical Characteristics

Observations of four stellar occultations in 2011, 2012, 2013 and 2014 show a Jacobi tri-axial ellipsoid with semi-axial ranges of a = 470 ± 20 km, b = 383 ± 10 km and c = 245 ± 8 km [8], which equates to a mean diameter of 772 ± 12 km assuming it is in hydrostatic equilibrium [9]. Thus, this object is rather similar to the dwarf planet Haumea in that the planetoid has a pole-toequator ratio of about 1:2. The apparent V magnitude of 2003 AZ_{84} around opposition is 20.3. The light curve shows small albedo spots. Observations of the rotational lightcurve found a period of 6.71 h (single peak) or more probably 13.42 h assuming a double-peak lightcurve [10]. The observed amplitude, Δm was found to be 0.14 ± 0.03 [10, 11].

Also, an occultation trace from 2014 indicated the existence of a topographic feature! The analysis was consistent with a deep chasm (23 km width, >8 km depth) or a depression with shallow slopes (width of ~80 km, depth ~13 km) [8]. This topographic feature was found thanks to the grazing chord observation. (Figure 3). More observations are needed to verify the exact shape of this body.

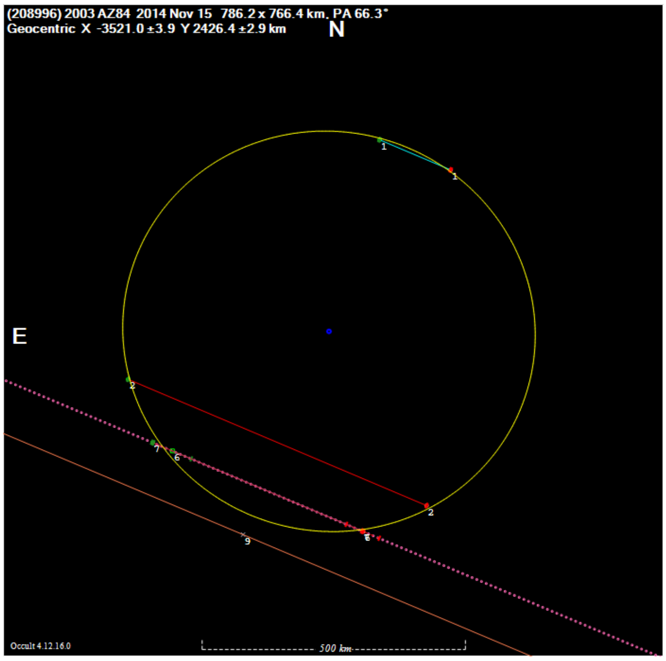


Figure 3. Shadow profile from the occultation on 2014 November 15 showing grazing occultation (chord 1). Source: Occult 4.12.16.0

Plutino (90482) Orcus is comparable in spectrum and colour to (208996) 2003 AZ_{84}. Both bodies have a flat featureless spectrum in visible light and moderately strong water ice absorptions in the near infrared, although 2003 AZ_{84} has a lower geometric albedo (0.10 vs 0.23). Both bodies also have weak absorption near 2.3 µm, which could be from ammonia or methane ice. An observation with the new *James Webb Space Telescope* (JWST) is planned [12]. In this observing proposal, ammonia is to be searched for spectroscopically.

Since it can be assumed that 2003 AZ_{84} is in hydrostatic equilibrium due to its size, despite its shape being non-spherical, according to M. E. Brown, it should fulfil the criteria for classification as a dwarf planet [13] but has yet to be classified as such.

Natural Satellite

Observing with the *Hubble Space Telescope* on 2005 December 02, Michael E. Brown and Terry-Ann Suer discovered a moon [14]. The companion was tentatively named (208996) 2003 AZ_{84} 1. The discovery was announced on 2007 February 22. The distance to (208996) 2003 AZ_{84} was 0.22" (semi-major axis ~7200 km), the brightness was 5.0 mag fainter [14, 15] and it has an orbital period of ~12 d (Figure 4). The diameter is about 72 ± 12 km. The diameter was calculated on the basis of the albedo. The apparent brightness was 25.3 mag. This is the only observation of the moon and so it is hoped that future stellar occultations could confirm its existence.

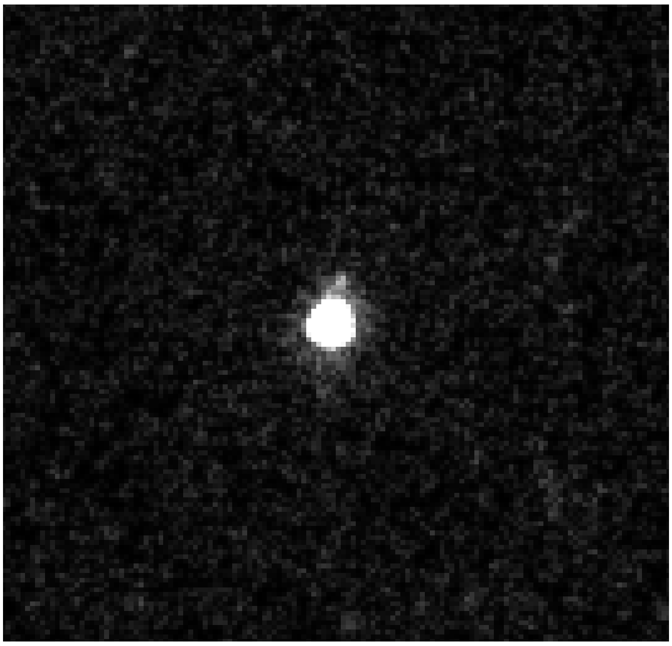


Figure 4. (208996) 2003 AZ_{84} with moon, picture from Hubble Space Telescope (STScI, NASA), Editing from Hubble images j9fs07s4q and j9fs07saq (proposal ID 10545) by Renerpho, CC BY-SA 4.0

Future Stellar Occultations

Using Dave Herald's Occult4 software [16], two future stellar occultations could be found, namely those of 2024 October 6 and 2027 January 15 (Figures 5, 6). The event on 2024 October 6 as seen from Europe takes place around sunrise but observation may be possible low in the sky as seen from Newfoundland. The event on 2027 January 15 should be easily observable as it crosses south-east Asia and northern Australia. Importantly, it should also be observed far from the predicted occultation tracks to check for a possible occultation by the moon of (208996) 2003 AZ_{84}.

Acknowledgement

The author would like to thank Richard Miles for reviewing this article.

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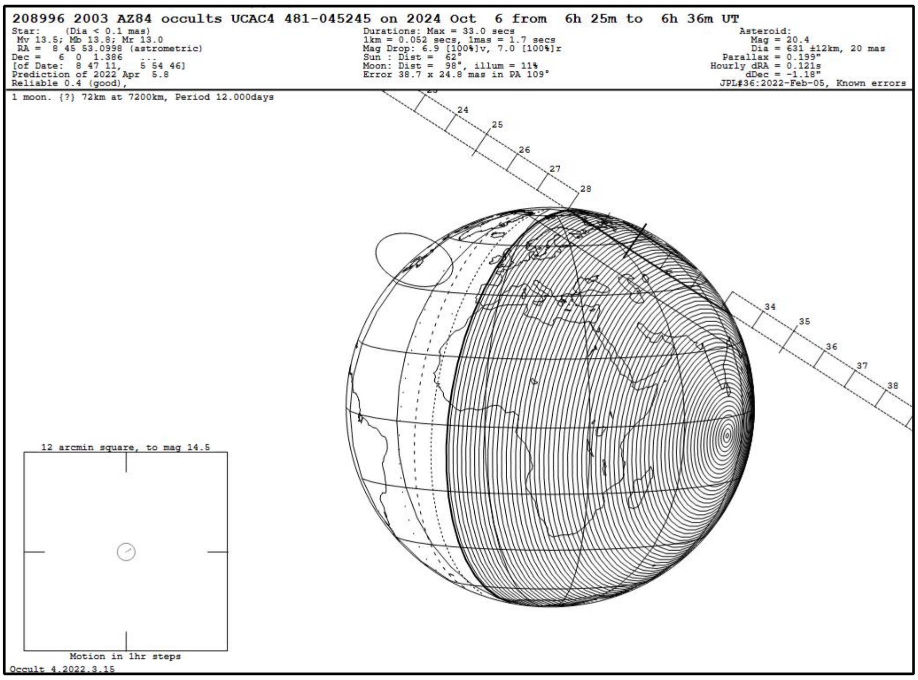

Figure 5. Predicted occultation on 2024 October 6. Credit: Occult V4.2022.3.15

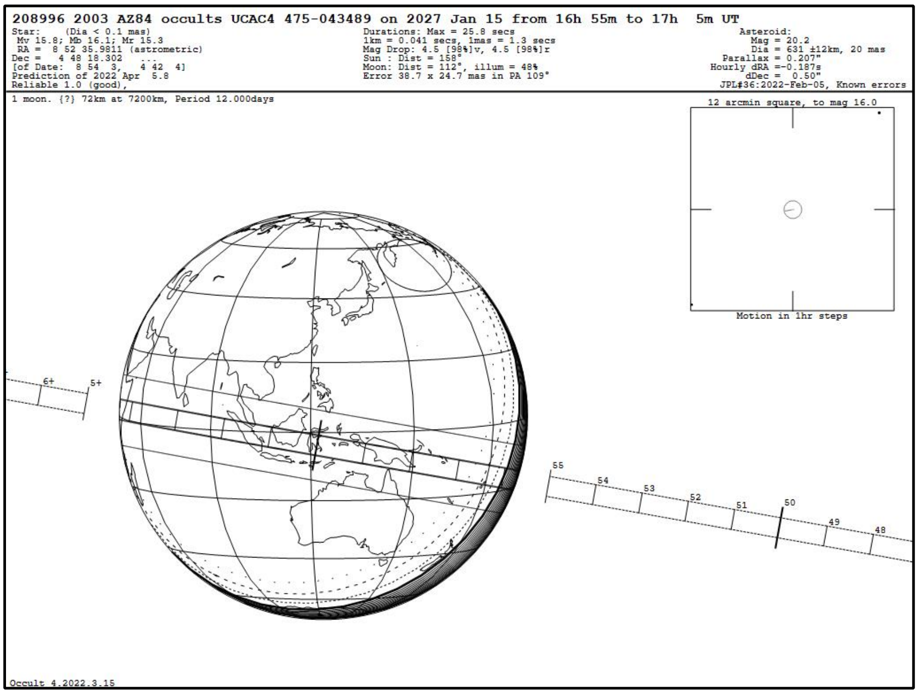

Figure 6. Predicted occultation on 2027 January 15. Credit: Occult V4.2022.3.15

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IOTA's Mission

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

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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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