Journal for Occultation Astronomy

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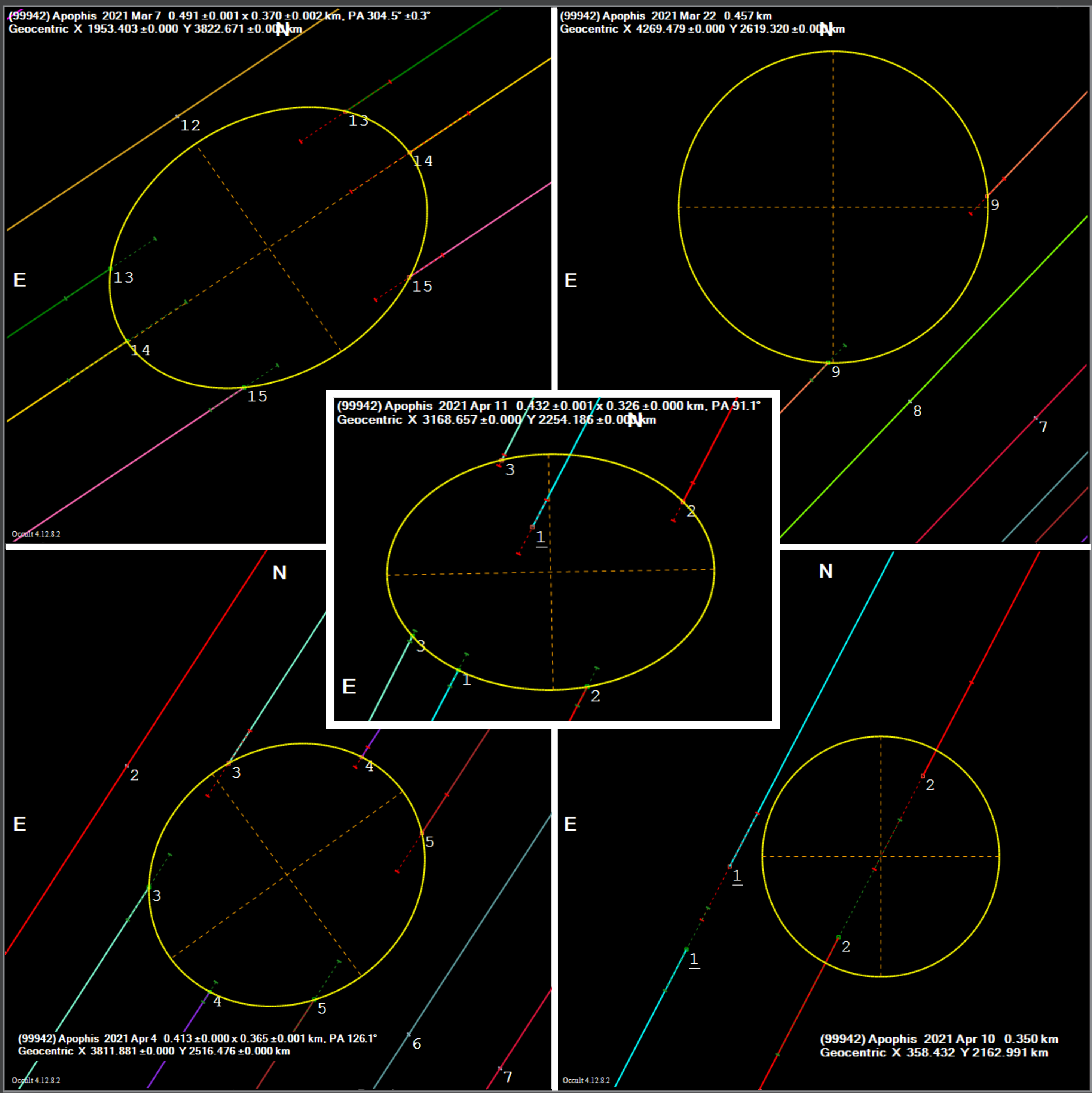

Chasing the Shadow of (99942) Apophis

Dear reader,

Occultation astronomy has advanced in the past 20 years to a powerful technique, to investigate our solar system with an unprecedented angular resolution. The finding of rings around Chariklo and Haumea are only two examples. In the future, objects like the Trojans of Jupiter and Neptune will be under investigation by occultation work. These Trojans give clues about the early development of our solar system and therefore are high priority targets. But due to their faintness it is very difficult to predict occultations. The Neptune Trojans are especially of great interest; they probably outnumber the main belt asteroids.
The potential of the occultation technique for an outer main belt asteroid has recently been shown in the case of (4337) Arecibo. A satellite has been found by two Australian IOTA members and later confirmed by two others in the USA. The finding of binaries is so important, because it allows us to determine the mass of a system. In combination with the shape, it lets us determine the density, a very important planetological parameter.
In IOTA/ES we started to support an observing campaign led by the Astronomical Observatory Institute of Poznan, Poland (Anna Marciniak) for small bodies of the main belt with slow rotations and small amplitudes in their lightcurves. An *Occult Watcher* feed "Slowrotators" has been initiated recently.

Wolfgang Beisker

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IOTA/ES, Research & Development

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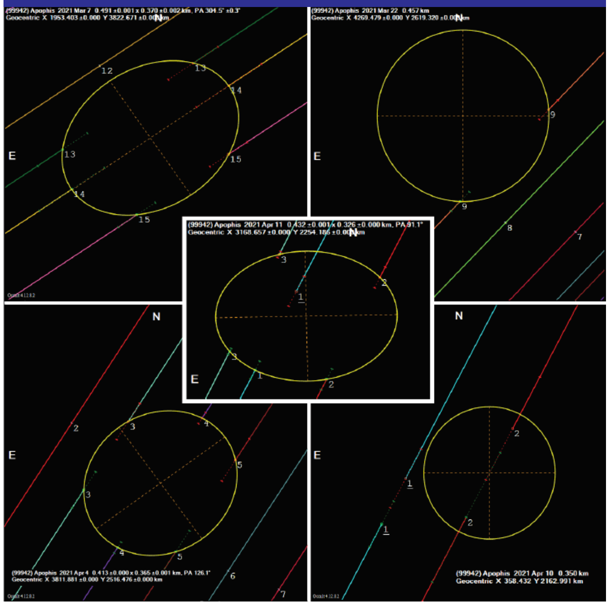
In this Issue:

COVER



High precision astrometry from ESA's Gaia and JPL Horizons database makes successful observations of sub-kilometre objects in the solar system possible. In March and April 2021, observers from the USA and Japan managed to record several positive chords during five stellar occultations by the NEA (99942) Apophis. The tiny asteroid of the Aten group measures less than 0.5 km in diameter.
Graphic: O. Klös, with plots of shadow profiles from the database of *Occult* by D. Herald.

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

Comet 29P/Schwassmann-Wachmann 1: The Appulse of 2020 December 8 and Future Prospects for Stellar Occultations, 2021–2029

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ABSTRACT: The stellar occultation method is a particularly powerful tool for probing the nature of distant solar system objects. Here we report a single observation of a close appulse of comet 29P/Schwassmann-Wachmann 1 to a 14 mag star that showed no significant deviation in the recorded light curve on a 2.25 s time resolution (corresponding to 27 km in projected distance of 29P/SW1). From that we conclude that no significant debris (with sufficient optical depth) existed within 500–1000 km of its nucleus for this specific observation. A new orbit solution has been derived from high-precision astrometry from images taken over a 12-yrs interval using 2.0 m aperture telescopes in Hawaii and Australia (currently 587 positions with a mean residual of ~0.10″). This orbit (together with that using the JPL Horizons ephemeris) has been used to predict two sets of stellar occultations involving 29P/SW1 through to end-2029. Of the 20 most favourable events, 7 take place within the space of 40 days, and four of these shadow paths cross North America. This unprecedented finding warrants a coordinated observing campaign during the crucial period, from 2022 December 19 to 2023 January 28.

Introduction

When 29P/Schwassmann-Wachmann 1 was discovered in 1927 it was classified as a comet because of the activity observed. But 29P/Schwassmann-Wachmann 1 is not an ordinary comet, not only because of its size of about 60 km [1]. Orbital calculations indicate that it almost certainly originated as a trans-Neptunian Object (TNO) and that only very recently, i.e. within the last ~10^5– 10^6 years, has been gravitationally perturbed such that it has vacated its orbit beyond Neptune, moving into a transition state region (which population is called Centaurs), and has become temporarily locked at its present location: a near-circular orbit between Jupiter and Saturn. This region of the solar system has recently been called the Jupiter-family Comet (JFC) 'Gateway' with more than 70 % of JFCs spending some time locked in this region (median time spent = 1700 yrs) [2]. Though 29P should be considered as an active Centaur, we will use the (still) very common term comet hereafter for 29P/SW1.

The comet is of course well known for its frequent outbursts and was only discovered in 1927 thanks to it undergoing a particularly strong outburst reaching 12th magnitude on that occasion. Since that time about 250 strong outbursts have been detected. What causes these outbursts is largely a mystery given that most comets are in highly elliptical orbits and they only show weak outbursts within the short time interval in which they are near perihelion when the intensity of the insolation is near the maximum. We know that the nucleus of 29P/SW1 is very large measuring about 60 km across and that its outbursts are connected with the release of large amounts of cometary dust and also carbon monoxide gas, of which it is likely to have a plentiful supply. A further property of the nucleus is that it almost certainly exhibits an extremely slow rotation rate in that a synodic period of 57.7 days was evident from the periodicity of its outbursts during 2010–2014 [3].

An added impetus for using new ground-based observing methodology to study 29P and raise awareness has been the absence of any plans by NASA or ESA to send a space mission to investigate this interesting object. Two mission concepts had been proposed to NASA in 2019 for Discovery-class missions: one named *Chimera* that would have gone into orbit around the 29P/SW1 (à la *Rosetta*), and another termed *Centaurus* that involved fly-bys of several Centaur objects beyond Jupiter. Neither of these proposals progressed to the next stage.

Astrometric Observations

29P/SW1 appears to be a relatively under-observed target as far as occultation studies go. One reason may be that although it is a Centaur, its precise orbit may be less accurate owing to its frequent outbursts making it difficult to always measure the location of the nucleus when immersed in a bright and often offset outburst coma, the photocentre of which is shifted away from the position of the underlying solid body. In an earlier paper we highlighted this potential problem and pointed out the need to avoid making astrometric measurements in the days following strong outbursts [4]. Indeed, a bright outburst usually attracts more amateurs to observe 29P with small telescopes and report astrometry as a result – this may additionally bias the derived orbit depending on how outlying data are rejected. Although many amateurs use a standard 10″x10″ measurement aperture, which equates with 5″–6″ radius used by some other observers, many others utilise non-standard sized measuring apertures, which may introduce additional bias when the coma is asymmetric in shape.

For this reason, an independent analysis of new astrometric data has been undertaken for the present work based on images taken with 2.0 m f/10 Ritchey-Chrétien telescopes; namely the *Faulkes Telescope North* (MPC code: F65, altitude: 3055 m) on Haleakala, Hawaii, and the *Faulkes Telescope South* (MPC code: E10, altitude: 1116 m) at *Siding Spring Observatory*, Australia. All astrometry of the 2.0 m images were carried out using a single astrometric star catalogue, namely Gaia Data Release 2 (DR2), the aim being to reduce bias and scatter due to different star catalogues and to maximise astrometric accuracy.

In all, 587 astrometric observations were utilised spanning 12 years from 2009 February 17 to 2021 February 11. More than 1000 images (field of view: 5′ x 10′ square; pixel size: 0.27″ to 0.30″) were available for measurement but only a subset was used, being selected on the basis of no significant visible coma present and good seeing / telescope tracking evident. Astrometry was performed using Herbert Raab's *Astrometrica* software (Version 442) and Gaia DR2 stars in the magnitude range 14.5 < G < 17.5, a quadratic plate solution and an 8-pixel radius measuring aperture. Astrometric residuals of the individual reference stars were typically 0.03″-0.05″.

Orbit Computations

More than 36000 astrometric observations are filed at the Minor Planet Center (MPC), provided over more than 100 years by many observatories using different instruments, techniques, star catalogues etc., thus this inhomogeneous set of observations is subject to many individual random and systematic errors and biases. While this issue applies also to any (long-term) asteroidal observation, in case of 29P/SW1, measurements during activity outbreaks or on images with visible coma introduce additional uncertainties which are hard to model in the orbit computation.

We used different (sub-)sets of these MPC observations, combined with our observations mentioned above, to derive different orbit solutions. The orbit solution RMMK for 29P/SW1 based on all (and only) of the 2.0 m positions is summarised in Figure 1. Overall, the positional uncertainties of individual measurements have a mean residual of less than 0.10″. By comparison, the JPL K192/41 orbit solution utilised a total of 33664 observations made over 24 years yielded a mean residual of 0.69″, but the derived orbit is liable to some more unknown (or unmodelled) errors in the observations as discussed earlier.

The Appulse of 2020 December 8

In the evening of 2020 December 8, the 60 km nucleus of comet 29P/SW1, along with its inner coma, was predicted to occult a 14 mag star in the constellation Aries as seen from Russia, Finland, Sweden, Norway, UK and Ireland. The star was favourably placed (airmass = 1.23) in the moonless sky as seen from the UK. The path predicted by the latest JPL ephemeris crossed Scotland about 23:24 UT as shown in Figure 2.

```
==========================================================================================

Epoch  20210101.0 TT  =  JDT 2459215.5      Ref. = RMMK [210523]         RMS = 0.06"

   T 20190319.93151   +/-    0.0002723      Next = 20340116.20026
   q    5.767982731   +/-  0.000000056
   a    6.035795528   +/-  0.000000073
   n    0.066466421   +/-  0.000000001
   e    0.044370754   +/-  0.000000008          P    (2000)     Q
Peri    48.66743570   +/-    0.0000198     +0.99243842  -0.02467405
Node   312.37360596   +/-    0.0000038     -0.03813428  +0.86912922
Incl     9.36685152   +/-    0.0000006     +0.11666941  +0.49396922
   P       14.82866   +/-    0.0000003

==========================================================================================

MPC      TIME SPAN        OBS TOTAL   RA(w>0)      DE(w>0)    RMS(RA)  RMS(DE)  Used Catalogs
------------------------------------------------------------------------------------------
E10  20110603-20201217   266 =  45%  266 = 100%   266 = 100%   0.080   0.095    Gaia-DR2
F65  20090217-20210211   321 =  55%  321 = 100%   321 = 100%   0.059   0.063    Gaia-DR2
==========================================================================================
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Figure 1. Orbit solution RMMK (R. Miles & M. Kretlow) based on 587 high-precision measurements 2009-2021 of 29P/SW1.

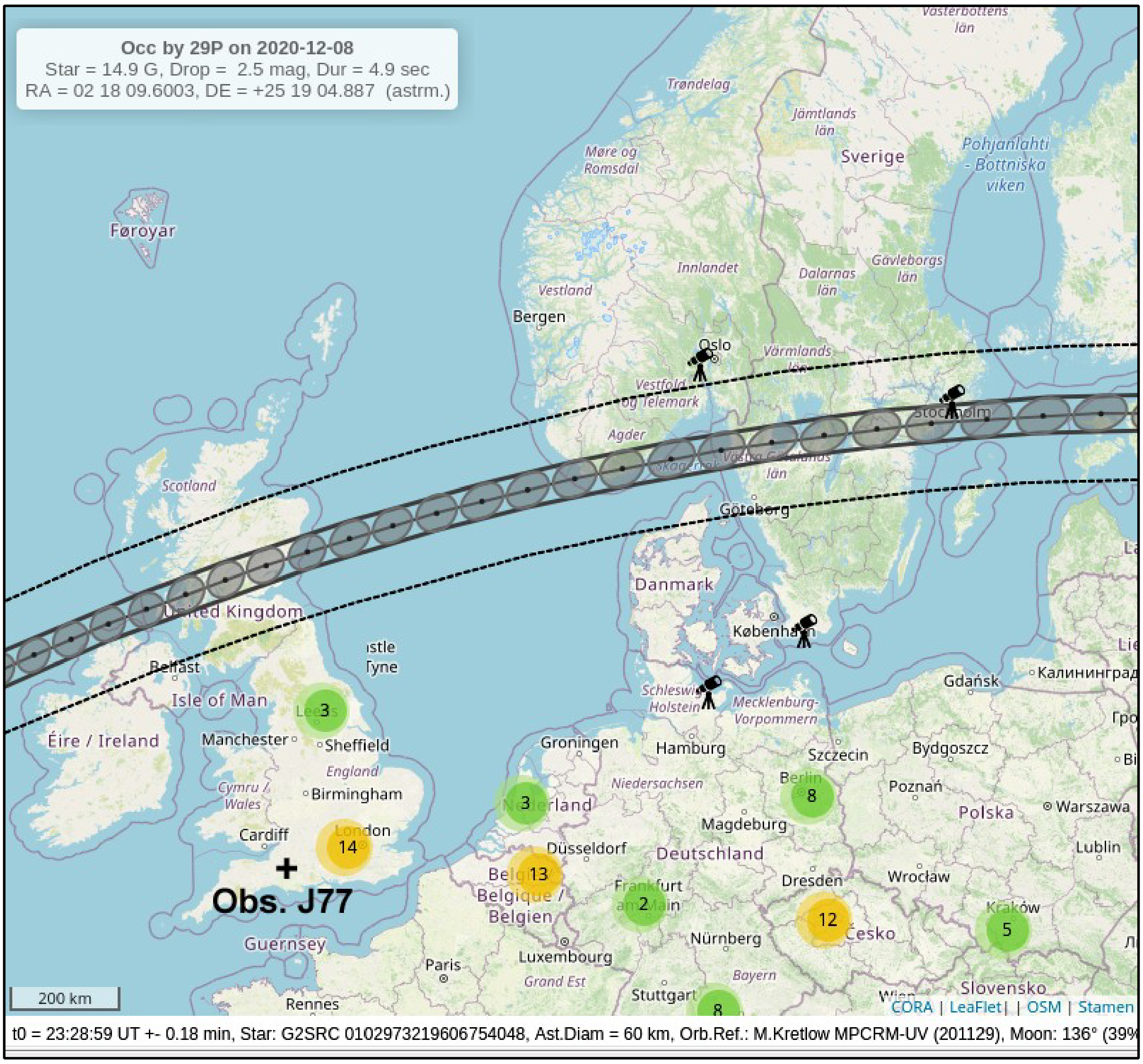

Figure 2. Prediction of an occultation by 29P/SW1 on 2020 December 8, showing position of Golden Hill Observatory, Dorset, UK (J77). The orbit solution MPCRM-UV shown here was very similar to JPL's K192/41 solution.

The occultation path predicted by our orbit solution MPCRM-UV[1], which combined astrometry from the MPC (only those observations which were reduced with either the Gaia DR1 or DR2 catalogue) with our observations made at the 2.0 m telescope (E10, F65) was very similar to the nominal JPL Horizons based ground track (see also Figure 3), and crossed Scotland about 23:24 UT as shown in Figure 2.

The position of the magnitude R = 14.7 star involved is R.A. 02h 18m 09.6s, Dec. +25° 19′ 05″ (ICRS, at the epoch of occultation). The expected maximum duration of the occultation by the nucleus was 5.0 s, but secondary events involving a partial dimming of the star might also have been seen if a debris disk or shell exists embedded within the inner coma. The most likely times for secondary events were within 60 seconds either side of closest approach. Similarly, observations from locations up to 1000 km or so from the nominal shadow track may have detected partial dimming of the star caused by a debris disk.

Most of northern Europe was clouded out for this rare event but observations were possible from Dorset, UK by RM using a 0.35 m aperture telescope, thanks to the sky becoming perfectly clear just minutes before the observing window was due to open. A time-series of CCD images was taken +/- 4 minutes centred on the predicted time of the occultation.

RM's location (J77) was nominally 370 km from the centre of the JPL ephemeris track, but the orbit solution RMMK (based solely on the new high-precision 2.0 m astrometry) indicated a shift some 470 km further northwards which means that the shadow probably missed J77 by about 800 km.

[1] This orbit solution includes all those MPC observations which were reduced using the Gaia DR1 or DR2 catalogue (flags U,V in the 80-column records).

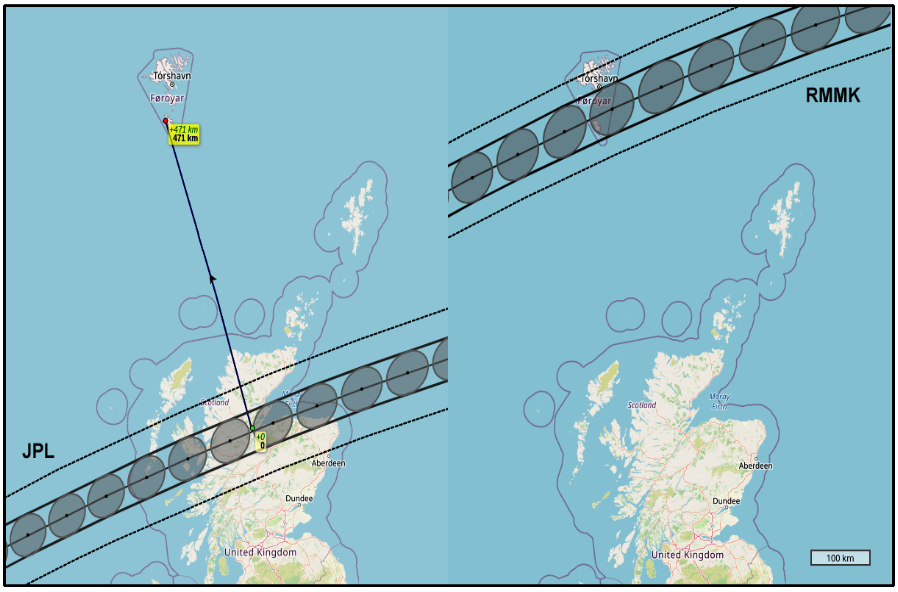

Figure 3. Comparision of occultation paths predicted from the JPL Horizon ephemeris (left) and from our orbit solution RMMK (right) for the 2020 December 8 occultation.

The lightcurve shown in Figure 4 shows no significant deviation of > 15% on a 2.25 s time resolution (= 27 km on the sky plane at projected distance of the comet) that would be indicative of obscuring matter along the line of sight of the star. N.B. If a total occultation of the star had occurred, the measured magnitude would have dropped to about R = 16.4 mag (a drop of 2.0 mag) for 1 or 2 consecutive data points. Alternatively, the stellar disk may have been significant in size compared to the apparent size of the nucleus, in which case only a partial occultation might have occurred.

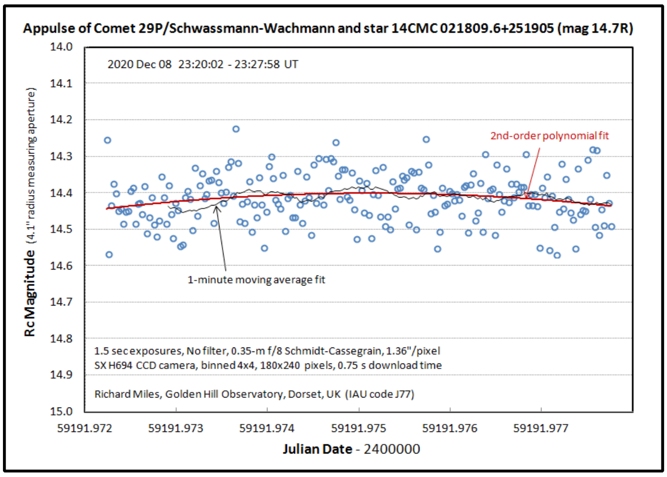

Figure 4. Photometric lightcurve showing the absence of any significant fade due to an occultation of the nucleus or debris disk.

A one-minute moving average shows no evidence for coma extinction greater than 1.5 % in the region down to about 800 km from the nucleus. The photometry uses weighted-mean zero points based on 4 comparison stars as per the following image (Figure 5).

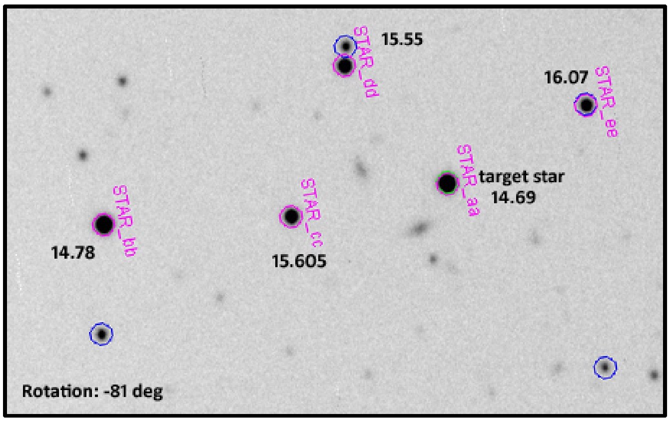

Figure 5. Stack of 213 x 1.5-s duration cropped images (field of view: 3.5′ x 5.6′)

These frame zero points are shown plotted in Figure 6 confirming the clarity of the atmosphere for the duration of the monitoring period.

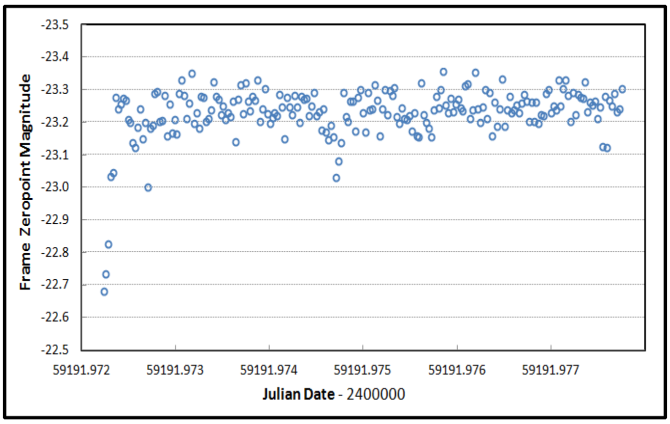

Figure 6. Variation in sky transparency during the occultation monitoring period.

Stellar Occultations during 2021 -2029

Given the rarity of stellar occultations by comets and the need to better understand 29P/SW1, we have utilised the latest ephemeris from JPL alongside that based on our high-precision astrometry from the last 12 years of data to make predictions of future occultation events visible from Earth using Gaia EDR3 star catalogue data. A total of 118 predictions were found meeting the selected criteria and of these 62 were predicted by both ephemerides and most of the remainder were found using a more relaxed set of criteria with the RMMK orbit.

Out of these 87 events, the most favourable 20 were chosen on the basis of: their location across populated areas of the Earth, brightness of the occulted star and their observability. The favourable events are listed in Table 1.

Date + Time	Cent.Occ	MAG(29P)	UCAC4	h	m	s	°	'	"	RMAG	DMAG	MAXDUR	ELS	ELM	SLT	Comments
03/08/2021	02:58:53	17.4	602-013770	4	36	38.05	+30	15	48.2	13.80	3.6	2.2	59	9	27	Greece (pre-dawn)
01/09/2021	11:20:31	17.3	606-015388	4	51	47.19	+31	10	5.8	13.98	3.3	3.9	84	19	30	mid-U.S.*
21/12/2021	06:14:54	16.7	608-013835	4	26	35.71	+31	24	1.4	13.67	3.1	3.6	158	42	96	N. Canada, Spain/Canaries (v.low)?
19/12/2022	**11:49:45**	**16.7**	**598-035716**	**6**	**43**	**51.06**	**+29**	**28**	**12.1**	**12.94**	**3.8**	**3.4**	**166**	**115**	**20**	**West/South U.S., Japan, China**
27/12/2022	**12:25:37**	**16.7**	**598-034929**	**6**	**39**	**30.87**	**+29**	**28**	**29.5**	**13.78**	**3.0**	**3.3**	**173**	**126**	**23**	**U.S./ South-west Canada**
30/12/2022	**02:35:03**	**16.7**	**598-034668**	**6**	**38**	**5.43**	**+29**	**28**	**12.3**	**12.68**	**4.0**	**3.3**	**174**	**90**	**51**	**Colombia / Bolivia / Peru, W. Africa**
02/01/2023	**21:05:42**	**16.7**	**598-034275**	**6**	**36**	**1.11**	**+29**	**27**	**21.6**	**14.81**	**2.1**	**3.3**	**172**	**41**	**85**	**Canaries, S. Meditterranean, S. Europe, Turkey, China**
09/01/2023	**10:58:48**	**16.7**	**598-033556**	**6**	**32**	**27.81**	**+29**	**24**	**50.5**	**14.52**	**2.3**	**3.4**	**167**	**39**	**95**	**West/South U.S., Japan, China**
18/01/2023	**23:38:25**	**16.8**	**597-031355**	**6**	**27**	**37.92**	**+29**	**18**	**50.8**	**14.48**	**2.4**	**3.7**	**157**	**162**	**12**	**Canaries, N. Africa, Spain, S.Europe**
28/01/2023	**05:09:31**	**16.9**	**596-032045**	**6**	**23**	**33.52**	**+29**	**10**	**36.9**	**13.88**	**3.1**	**4.3**	**147**	**62**	**46**	**Canada, Spain, Canaries**
01/04/2023	22:13:36	17.4	589-029894	6	22	13.44	+27	45	11.4	16.00	1.7	3.9	83	49	83	Iceland, Ireland, UK, W. Europe (faint star)*
05/02/2025	23:09:26	16.9	497-054347	9	58	49.66	+9	23	41.9	13.18	3.7	3.3	169	93	57	UK, Europe, Turkey, Iran, N. India
04/03/2025	11:37:32	16.9	501-053188	9	46	52.71	+10	8	38.4	13.82	3.2	3.5	161	100	26	Australia, New Zealand
02/04/2026	07:40:31	17.0	440-052782	11	7	7.85	−2	0	26.7	14.83	2.3	3.8	155	27	100	Central America, Colombia, Peru (low)
24/02/2027	19:22:33	17.1	372-063292	12	53	37.22	−15	44	31.8	11.97	5.2	5.4	137	9	82	S. Australia (pre-dawn, double: companion mag 14.8)
12/04/2027	01:41:20	16.9	378-065034	12	35	20.60	−14	33	48.2	14.40	2.6	3.3	167	107	29	Chile, Argentina, Uruguay, S. Brazil
10/04/2029	17:12:37	17.1	293-093092	16	15	42.32	−31	30	0.4	13.93	3.2	6.9	133	99	9	New Zealand
27/04/2029	23:16:06	16.9	293-091665	16	9	58.97	−31	32	22.9	14.01	3.0	4.3	150	35	100	South-east Europe, Middle East (low)
30/05/2029	22:35:47	16.8	296-087459	15	54	1.75	−30	55	15.9	9.81	7.0	3.4	168	50	87	Brazil, v. bright star (low)
18/08/2029	10:26:00	17.4	308-083823	15	40	59.20	−28	25	40.6	14.40	3.0	5.4	94	19	68	New Zealand*

MAG(29P) : Magnitude of Comet 29P calculated as 9.2+5*LOG(r*delta)+0.035*PhA [i.e. when quiescent, measured using 3 arcsec radius aperture]
RMAG : Rc magnitude of occulted star (579-642 nm passband)
DMAG : Estimated drop in brightness [magnitude, measured using 3 arcsec radius aperture]
MAXDUR : Estimated central line occultation duration [s]
ELS : Elongation to the Sun [deg]
ELM : Elongation to the Moon [deg]
SLT : Moon sunlit in percent [%]
* predicted from RMMK orbit

Table 1. Most favourable occultations of 29P/SW1 during 2021 to 2029.

The magnitude of the comet assumes a 3″ radius measuring aperture and the comet to be essentially close to quiescent – N.B. there always remains a faint coma around the nucleus amounting to 1–2 times the amount of light reflected by the nucleus alone. Although the EDR3 positions of the stars were utilised for the predictions, the UCAC-4 star catalogue identifications have been used along with the corresponding photometry. The nucleus is assumed to measure 60 km across. However, a recent publication indicates this may be a slight underestimate and that a value of 64 km would be more accurate [5]. In this way it is hoped that the predicted maximum drop in brightness will be close to the actual value.

Call for Observation

One very remarkable finding is that of the 20 most favourable events during the nine-year time interval of 2021–2029, seven events all occur within the space of 40 days during 2022 December to 2023 January. These particular events are highlighted in red in Table 1 and the occultation paths predicted using both the JPL K192/41 ephemeris and the RMMK astrometry are shown in the accompanying Figure 7. In the event, the actual shadow of the comet nucleus will most probably lie midway between these two tracks but shifted more towards the RMMK prediction.

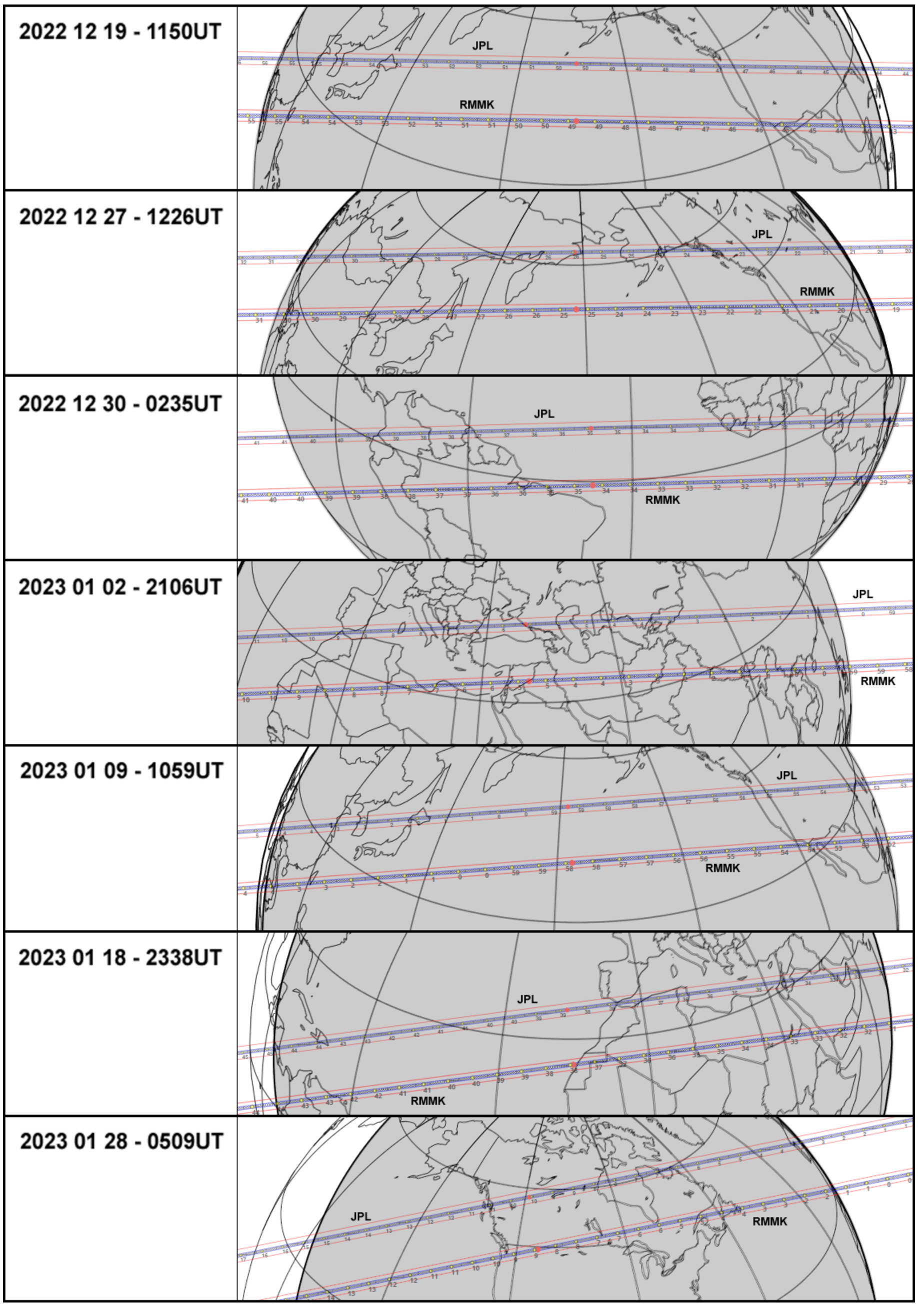

Figure 7. Predicted shadow tracks during 2022 December to 2023 January.

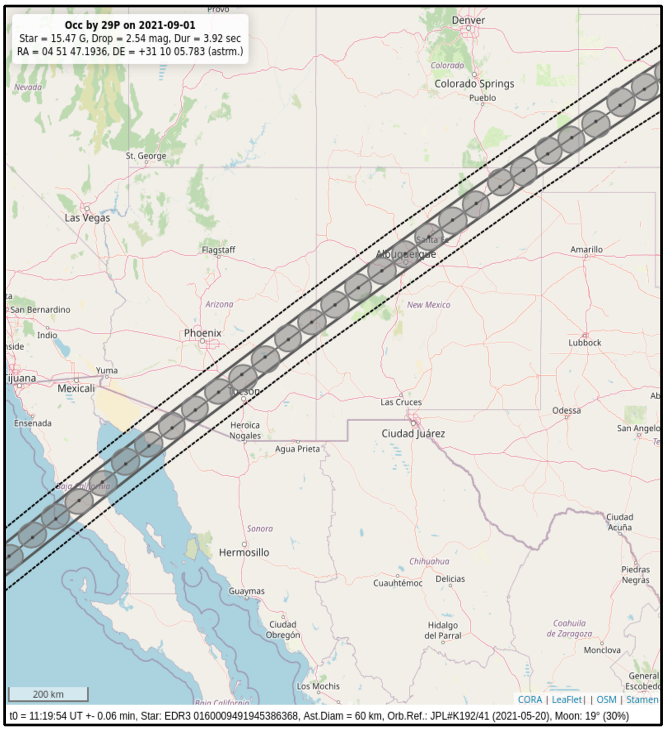

Figure 8a. Occultation of a G = 15.5 mag star by 29P/SW1, based on JPL's K192/41 orbit solution.

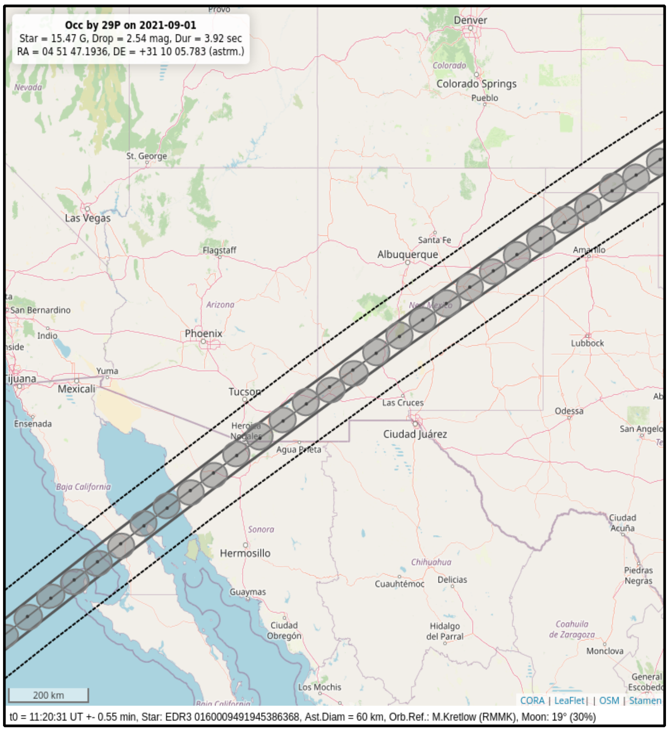

Figure 8b. Occultation of a G = 15.5 mag star by 29P/SW1, based on our orbit solution RMMK.

Strikingly, of the seven shadow tracks, four pass across some part of North America where there exist many professional and amateur observatories. Clearly, given this fortuitous and totally unprecedented coincidence, this will be a great opportunity for the astronomical community to undertake a coordinated observing campaign to intensively probe 29P/SW1 using the occultation method during this short observing window. We hope to work with a group of U.S.-based astronomers to make this a reality!

In addition, there are three opportunities during the remainder of 2021 to achieve the first successful observation of a positive occultation by the comet's solid body: this would then enable the position of future shadow tracks to be refined. The first possibility would be on 2021 September 1 (Figures 8a, 8b), crossing the mid-US, though only the western part will have a dark-enough sky. If this is not possible during 2021, then the first of the series of seven events that takes place on 2022 December 19 crossing the south-west U.S. should provide that opportunity, such that the location of the shadow track for the remaining six events is then accurately known.

One final point concerning this intensive series of occultations within the space of 40 days is that, provided two or more occultation chords are achieved at each predicted event, it should be possible not only to obtain a measure of the silhouette of the solid body (and possible ring(s) or satellite(s)) but also to derive a three-dimensional model of the solid body given that the comet is an extremely slow rotator. Over the interval of 40 days, it is likely that the nucleus rotates on its axis by only ~250° so each event will represent a separate projection of the solid body so that it may be possible to independently confirm the ultra-slow character of its rotation rate. Combined also with data from positive chords from other events over the coming years, an accurate direct measurement of its rotation period and spin-axis orientation should be forthcoming. Let's hope so!

Conclusions

Observations of a close appulse of comet 29P/Schwassmann-Wachmann 1 to a 14 mag star in 2020 probed the region about 500-1000 km from the nucleus, wherein no significant dimming of starlight was detected in that single observation.

This work has revealed an unprecedented opportunity, specifically during late 2022 and early 2023, for investigating 29P/SW1 using stellar occultations to characterise the nature of the solid body and its surrounding environment. Though it is presently located 6 au from the Sun, it almost certainly existed for billions of years (until very recently on astronomical time-scales) as a Kuiper-belt object or scattered-disk object far from the Sun.

By 2023 we may know much more about this important and mysterious object, probably an intermediate between a Centaur and a Jupiter-family comet. Possibly enough to warrant a space mission to visit it, preferably one akin to that of the *Rosetta* mission and comet 67P/Churyumov-Gerasimenko but involving several small landers to maximise scientific return.

Acknowledgements

The authors would like to thank Paul Roche and other staff including Alison Tripp of the Faulkes Telescope Project for enabling the use of the 2.0 m robotic telescopes, part of the Las Cumbres Observatory global network. Some of the very latest images taken with the *Faulkes Telescope North* were made with the MuSCAT3 instrument, developed by the Astrobiology Center, Tokyo.

The 0.35 m images of the appulse were analysed photometrically using *AStPhot32* software written by Stefano Mottola for which we are sincerely grateful.

This work has made use of data from the European Space Agency (ESA) mission *Gaia* (https://www.cosmos.esa.int/gaia), processed by the Gaia Data Processing and Analysis Consortium (DPAC). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement.

Data and services provided by the Jet Propulsion Laboratory (JPL) and the Minor Planet Center (MPC) are also acknowledged.

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Phemu 2021: Catching an Eclipse of Io by Europa Near the Horizon in Very Bright Twilight

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ABSTRACT: You should never forget that when you try to observe something, you are not sure to succeed, but if you do not try, you are sure not to succeed! This is the story of the observation of a mutual phenomenon of Jupiter's satellites, an eclipse of Io by Europa on March 16th at 4h58 UT. Nothing very original, except that this Phemu observed from the south of France took place at twilight with a very bright sky and at 4° above the horizon. Of course, we will discuss the technical aspects of this observation, such as the choice of the telescope and observation site, data reduction and analysis of timings, but not only. Indeed, we will see that the observation of this Phemu is also and above all a human story. The story of a cooperation between all the authors of this article to succeed in producing scientifically usable and useful data from this observation, showing us that it is possible to collaborate in amateur science astronomy, whatever distance is between us. So let's not forget either that if alone we go faster, together we go further!

Introduction

Year 2021 is the year of mutual events of Jupiter's moons. Mutual events occur every six years when the Earth and the Sun are crossing the common plane in which the satellites orbit, allowing the moons to eclipse and occult themselves.

And now, let's take a look at how our first attempt at this 2021 campaign went:

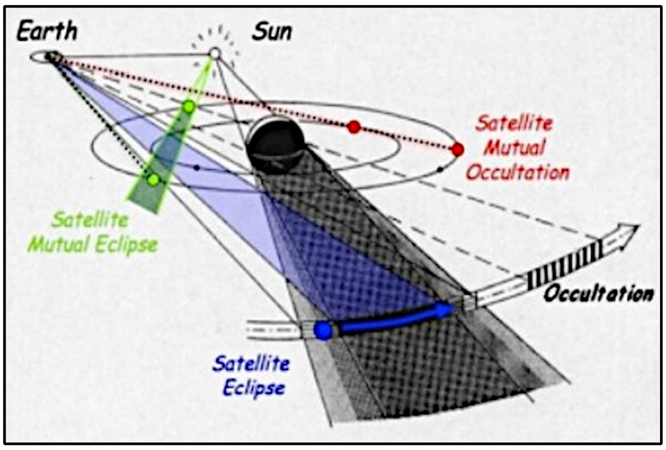


Figure 1. The principle of the phenomena of the Galilean satellites of Jupiter.

The Observation

A Lively Report by Jean-François Coliac & Franck Gourdon

Sunday March 14th - With the great software *Occult 4*, we chose the Phemu on Tuesday March 16th: delta mag 0.7 with a separation to Jupiter's limb of 70 arcsec, altitude of Jupiter 4° above the horizon, the sun at -10°. Europa is eclipsing Io with a duration of around 15 minutes. It is a beautiful Phemu with a large separation from Jupiter and large magnitude difference. This event should give us a chance of success.

Monday, March 15th - Big stress, we are waiting for the travel approval paper from *Paris Observatory* by Jean-Eudes Arlot because of Covid virus. If we do not have this paper, we are not allowed to drive by night.

20h UT: Approval received, yes! Thanks to IMCCE (Institut de mécanique céleste et de calcul des éphémérides)!
All is setup in the car: HEQ5 PRO mount (with polar finder), 200 mm f/4 Newtonian telescope, field corrector, filter wheel, Watec 910HX, video time inserter (VTI), one battery for the mount. Franck asks: "O.k. for the batteries?", "Yes, it is ok!" 2 batteries for computer and camera and a table.

We are doing a Zoom session to discuss about three possible locations:

- One at 787 metres altitude
- One at 226 metres altitude, at the observatory
- One just near the sea at 186 metres altitude

We looked at the weather website to see where there would be no clouds on early Tuesday. We decided on the road near the sea at around 186 m elevation.

21h UT: Did we forget anything? Eyepiece for pointing, finder, batteries, 220/12 V converter, cables, computer. The batteries are charging - very important! We go to bed. It is difficult to sleep.

Tuesday, March 16th

2h UT: Getting up and have a hot coffee. There is a strong wind outside. Doesn't matter, science is waiting for us!

3h 15 UT: Together we drive to the location near the sea. No cars in the streets, because of Covid, it was as if we were in the desert of Atacama...

4h 15 UT: The mount is on the ground, there are clouds in the sky. We do a quick polar alignment with the polar finder! It is very important to have a good polar alignment because the field of the Watec 910HX is very small with 900 mm focal length and shifts of the field of view with the handpad to recentre can be very bad for Tangra to keep track of the star movement. The atmosphere will surely be very turbulent, so we do not want to add another problem. Good... observing is possible. Clouds are in the sky everywhere but not on the eastern horizon!

4h 30 UT: All is setup, mount, camera, VTI. We point the finder and focus on a bright star through the clouds. The VTI is beeping: 8 satellites received on the screen, everything works well, almanac is updated.

4h 40 UT: Jupiter is there, near the horizon, we are "Go" now. Wouah - huge turbulence! Franck comments that Io and Europa are not separated. They should be, it's an eclipse. The turbulence is so high that Europa and Io are merged! We hope we could process the eclipse as an occultation. We try the V-filter, then the R-filter. Yes, it is better with R. We have more flux and less turbulence.

4h 45 UT: Jupiter is centred; we adjust the exposure. Many clouds around in the sky, Polaris is covered but the horizon shows a clear sky! We check for exposure: x2 is too bright, Jupiter is overexposed and the satellites Io/Europa at 70'' near the halo of overexposed Jupiter. We set at 1/50 sec. Io and Europa seem measurable, the satellites are not touched by the Jupiter halo. But Io and Europa are merging, the seeing is near 20'' - distance between the satellites!

Tracking is good, no shift of polar alignment. However, the wind is there.

4h 50 UT: 5 minutes before the predicted start... 3... 2... 1...zero. Ouf - there were no problems until now, hope it will continue! The image of Io/Europa is blurring. Ahh... it is awful! How are we going to get a lightcurve from this?

4h 55 UT: The eclipse of Io by Europa starts... Our breathing is stopping... we hope we will track without problems.

4h 58 UT: Minimum. We are frightened...! A small cloud near Jupiter! Ouff... fortunately it stays below the planet... yes!

5h 01 UT: Eclipse ends!

5h 07 UT: Recording stopped. All worked well.

5h 10 UT: We make a copy of the avi file.

6h 00 UT: All is stored in the car, have to go to work now... The dawn is here, the light of the Sun is arriving, and Jupiter disappears in the daylight. We could not do better than this.

16h 00 UT: Back home from work. Jean uses *Tangra* to try to do a lightcurve. Arghh... he does not succeed, the image of Io/Europa is jumping in the circle. He tries many options with *Tangra* - no success. He sends a message to get some help on Planoccult mailing list and Arnaud Leroy is answering rapidly. "Thanks for your offer to help to reduce the data, Arnaud!" He uploads the big avi file to a server at grosfichiers.com - thanks, that there is an internet!

Figure 2. Site B at 5:07 UT: the observation is over! Jupiter is visible at now 5° above the horizon in a very bright sky, but fortunately with particularly good transparency. (F. Gourdon)

Wednesday, March 17th

We are now to work on this image which shows huge turbulence:

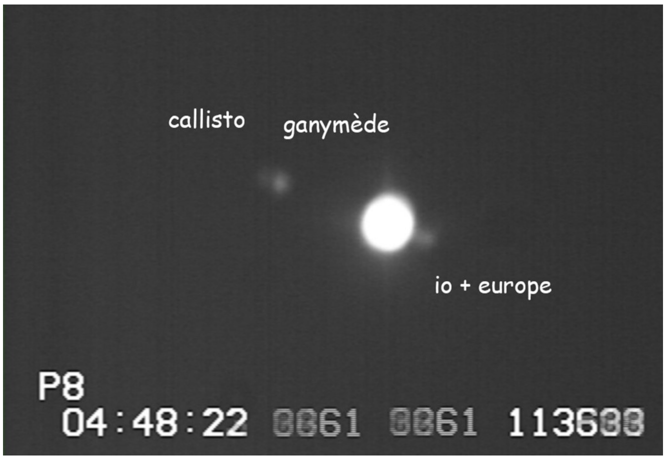


Figure 3.

Arnaud writes: "Hi Jean, I got a lightcurve!" Jean opens the file... what a beautiful lightcurve! Great Job, Arnaud! Tony George answered too, he downloads the avi file and calculates the timing of minimum with *ROTE*: 4h58m30s UT, offset O-C (observed – calculated): +9 s. The time of minimum is delayed by 9 seconds from the ephemeris. Great job, Tony, thanks!

This is how we lived this first Phemu campaign of 2021!

Behind the Scenes

But now we invite you behind the scenes to see in more detail how, all together, we united our efforts to prepare and realise this observation.

Is an Observation Possible?

IMCCE created a web page to give all predictions to catch the Phemus [1]. Moreover, the website Gemini helped to link pro-am projects [2]. But this year, there is a big problem to get lightcurves of mutual phenomena for observers in the northern hemisphere. The first Phemu begins with Jupiter very low near the horizon, around four degrees, and moreover very early in the morning. So the question is «is it possible to catch a lightcurve?» A lightcurve which can give astronomers scientifically usable data.

A Little of Photometry

Is it possible to see a signal embedded in the noise generated by the huge turbulence of the atmosphere?

At an elevation of only a few degrees, the large airmass reduces brightness a huge amount, creates strong turbulence and refracts the light of stars depending on their colour, blue being more absorbed than red. Because of this, any book of photometry tells to do photometry with a minimum elevation of around 30°. Below 30°, the data could be not usable.

Here, the first goal is to measure a «time of minimum», not really the magnitude of the satellites. It is the same kind of goal as for eclipsing binaries, for which we aim to measure the «time of minimum» and compare it with ephemerides so that we can get an offset. The measured offset will tell the astronomers that something is not known, maybe tidal effects, maybe another cause.

So, the scientific goal is possible (as we are not to measure a magnitude) if we can succeed to see the fall of magnitude on the lightcurve. This is the challenge. See a fall of magnitude, see a signal bigger than the noise.

So, let's go and prepare for it.

The first problematic parameter will be the choice of location depending on the weather.

The Preparation of the Observation

Documented by **Jean-François Coliac & Franck Gourdon**

We had decided to try a difficult challenge: get a lightcurve of a Phemu low on the horizon and very near dawn. By chance, we live near the sea in the south of France where the horizon can be very low.

The Choice of the Date of the Phemu with *Occult 4*

The two important parameters were:

- The delta magnitude of the fall in magnitude
- The angular distance of Io from the limb of Jupiter

If the delta magnitude is too low, we could see more noise than signal. If the angular distance is too small, the brightness of Jupiter could overexpose Io and Europa.

We use *Occult* 4 [3] to choose a good Phemu. It is important to notice that the separation displayed in *Occult 4* is the angular distance from the eclipsed satellite to the centre of the planet. So, we have to retrieve the radius to calculate the distance of the target to the limb and check the value with IMCCE ephemeris (73,9'').

We choose the Phemu on Tuesday March 16th.

- Large delta magnitude: 0.8
- Large separation from the limb of Jupiter: 70''
- Jupiter's elevation: 4°
- Sun below horizon at -10°

The other Phemu at 6h UT is too late, because the Sun is too high in the sky (Figure 4). But we see that *Occult 4* does not display the height of Jupiter and should use the IMCCE ephemeris to get the value (Figure 5).

- Time of beginning: 4h55 UT
- Time of ending: 5h01 UT

We want to start the recording five minutes earlier and end five minutes later according to the ephemeris as it gives accurate timings. Our goal was to measure a small offset between ephemeris and observation, in seconds.

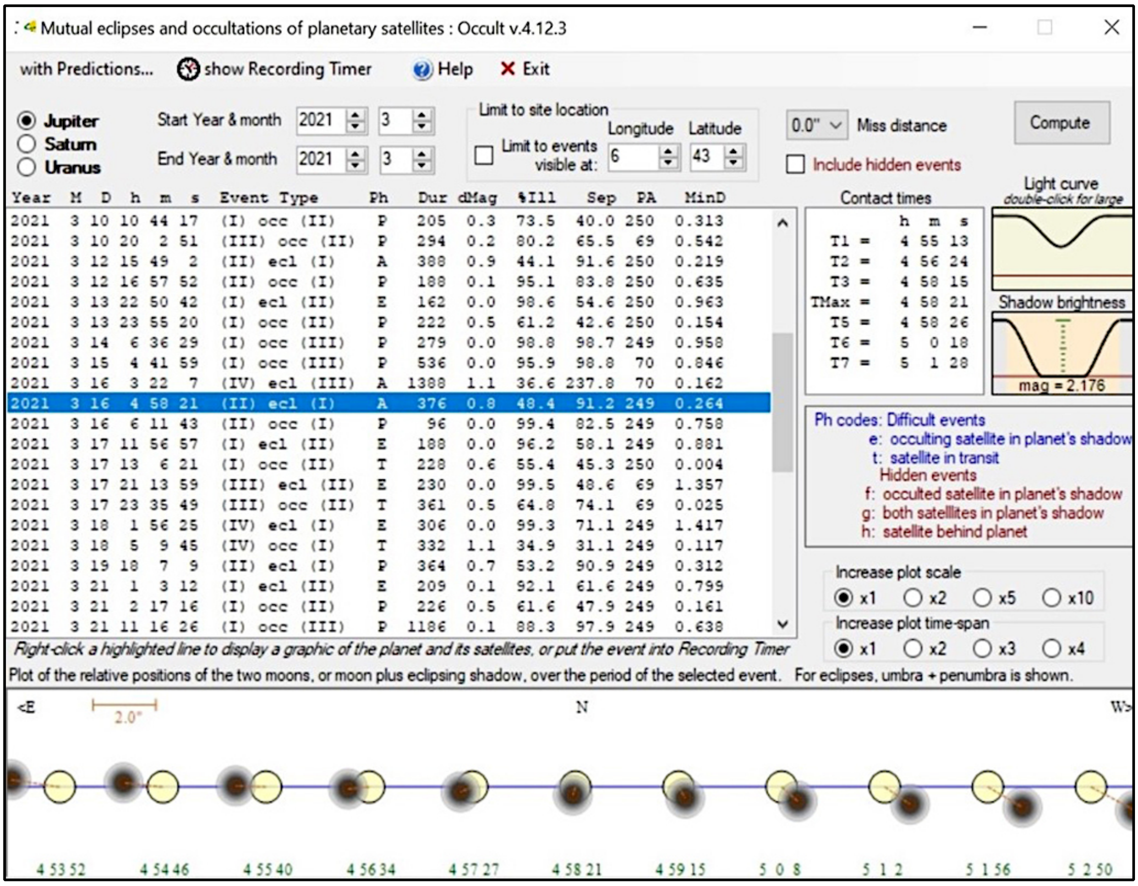


Figure 4. Screen capture of prediction for mutual events of Jupiter's satellites in March 2021. The chosen event is highlighted.

```
v5.20.11i     Planet: Jupiter CALCEPH:  (INPOP17a)
 Planet
    Observatory N: 509 - La Seyne sur Mer
        Timescale: UTC
Mean equator and equinox of J2000.  ICRF.

Mutual events of satellites:
Date  begin: h  m  s end: h  m  s   Type  Dur(m) Impact   m   Δm   limb(") dist(") Planet(º)  Sun(º) Moon phase

2021  1  7  15  9 23    15 43 47   2O1    34.4  0.369   5.1 0.328   70.18         :   20.109    9.542  0.410
2021  1  7  16 42 14    17  6 13   2E1    24.0  0.057   5.1 0.870   77.00    6.12 :    8.370   -4.412  0.406
2021  1  8   8 18 55     8 33 48   2E3    14.9  0.845   4.9 0.044  122.62    9.41 :    1.558    9.594  0.358
2021  2 12   6 18  7     6 26 59   2E1     8.9  0.055   5.1 0.896   77.86    4.54 :    0.342   -4.309  0.044
2021  2 12   6 45 22     6 52 39   2O1     7.3  0.107   5.1 0.566   76.39         :    4.798    0.469  0.045
2021  2 28   7  0  9     7 11 10   4E2    11.0  0.212   5.4 0.947   80.99   40.26 :   15.073    7.440  0.920
2021  3 14   6 34 28     6 39 34   1O3     5.1  0.903   4.7 0.016   81.35         :   18.159    7.320  0.064
2021  3 15   4 37 52     4 47 27   1O3     9.6  0.789   4.7 0.052   82.80         :    0.727  -13.624  0.118
2021  3 16   4 55  7     5  1 37   2E1     6.5  0.256   5.1 0.689   73.90   20.33 :    4.189  -10.170  0.178
2021  3 16   6 11  8     6 12 25   2O1     1.3  0.970   5.1 0.003   65.36         :   15.916    3.736  0.181
```

Figure 5. Screen capture IMCCE ephemerides which shows the altitude of Jupiter above the horizon at the observing site.

The Choice of Equipment

So, now, what kind of telescope should we use? Jean-François will bring the telescope and the Watec 910HX and a VTI. He has three different possible telescopes: Newtonian 200 mm f/4, Refractor 120 mm f/7.5, Cassegrain 200 mm f/12. We discussed about the diameter: the Cassegrain has a high focal ratio and is not suitable with a small sensor camera as the 910HX, the refractor 120 mm f/7.5 has a small diameter. Jean-François did the Phemu 2015 and used the refractor 120 mm f/7.5 but Jupiter was high in the sky. Here, with a large airmass, there is a high probability that we need more flux. So, we decide to bring the Newtonian 200 mm f/4 with field corrector.

The Analysis of the Weather

We decide to do a Zoom session to choose the good location, Monday night. Weather conditions are particularly important for observing a Phemu, but more importantly, the fact that the phenomenon takes place above your local horizon. For this reason, we had to give up the use of our observatory (OAGC), this Phemu at 4° above the horizon not being observable there.

We therefore have chosen two alternative sites with quite different characteristics, but in both cases a totally clear eastern horizon:

Figure 6. Satellite map with sites A and B and the location of the OAGC. The arrows point to the azimuth of Jupiter at the predicted time of event. Map: Google Earth

• Site A: site 8 kilometres inland located on the highest peak in the region at about 787 metres above sea level, with the direction of the Phemu above the land.

• Site B: seaside site at about 186 metres above sea level, on the steep slope of a relief facing east, with the direction of the Phemu above the sea.

For this observation at 4° above the horizon with about 11 airmass, we know that the turbulence would be very strong and hope that the transparency would be very good, and therefore the humidity low.

It's the day before the observation, and it's time for us to study the weather forecast. For this, we use the ECMRWF (European Centre for Medium-Range Weather Forecasts) model which is for our region one of the most accurate and reliable. A quick check shows us that the current forecasts are in line with what we are seeing outside (Figure 7). We can now study the forecasts provided for the Phemu time slot (from 1 hour before to 1 hour after):

• Partial cloud cover at medium altitude above our region, therefore higher than our two sites, but a clear sky to the east, which will make the Phemu visible but may pose a problem for the polar alignment of the mount.

• A strong north-westerly wind, called Mistral, with quite different values for sites A and B. For site A at altitude, we have an average wind of around 31 knots, but gusting to almost 45 knots. At the lower altitude of site B, we have an average wind of around 25 knots with gusts to 35 knots. But this site being located on the leeward side of the relief, we know that we will have a much less strong wind at this location

The good news is on the humidity side as this north-westerly wind is known to dry up the atmosphere. And indeed, the forecasts tell us a very low humidity on the two sites, around 45 %.

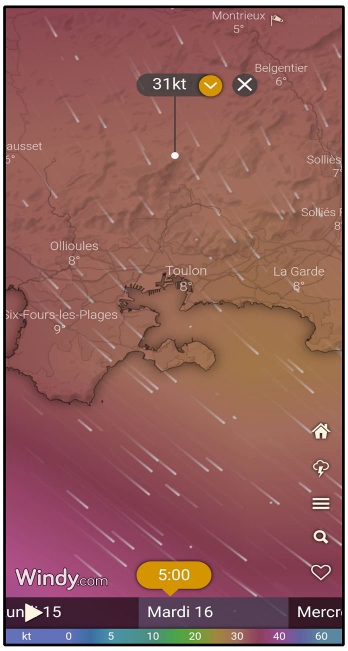


Figure 7. Screenshot of the forecast for the wind at time of event.
Forecast provided by ECMWRF and windy.com

Now all we have to do is summarize these forecasts in the form of a comparative table between the two sites for the important criteria:

		Site A	Site B
Visibility	Polaris	😐	😐
	Phemu	🙂	🙂
Seeing		☹️	☹️
Transparency		🙂	🙂
Instrument vibrations		☹️	😐

Table 1.

Therefore, the die is cast. We will try to observe this Phemu from site B!

Of course, success is not guaranteed. But it is from this location that we will have the best chance to catch this Phemu.

The Analysis of the Lightcurve by Arnaud Leroy

Jean-François tried to process the data with *Tangra* [4] and the eclipsing modelling but without success. So, he sent the message on the Planoccult mailing list, Arnaud decided to help us. Here he describes his process:

"For the analyse, I used Tangra V3. First, I tried to use the dedicated function for mutual events, but without success. The tracking of the two satellites involved in the event being not steady: the two satellites were very near of the limb of Jupiter and Jupiter was only 5° above horizon (bad seeing). For the second run, I used the classical function for asteroid occultation (Figure 8).

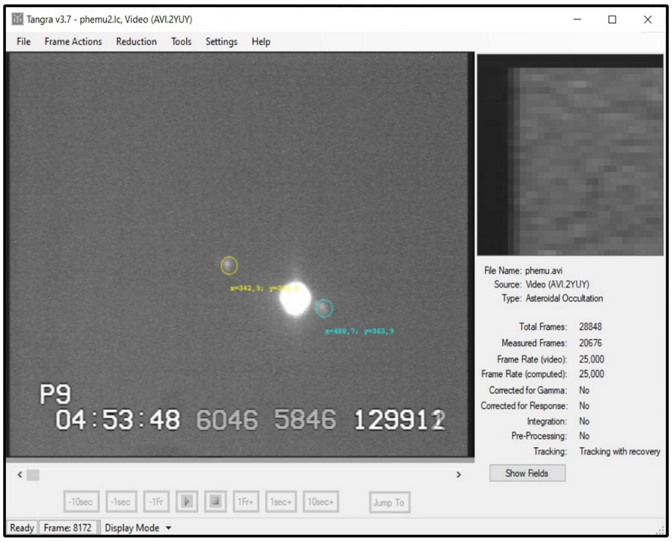


Figure 8.

Then, I adjusted the aperture of photometry measurement manually and used (III) Ganymede and (IV) Callisto (in one circle) for tracking and reference. The aperture radius was 12/35 (background). The background for (I) Io and (II) Europa was contaminated by the limb of Jupiter but I got the result!"

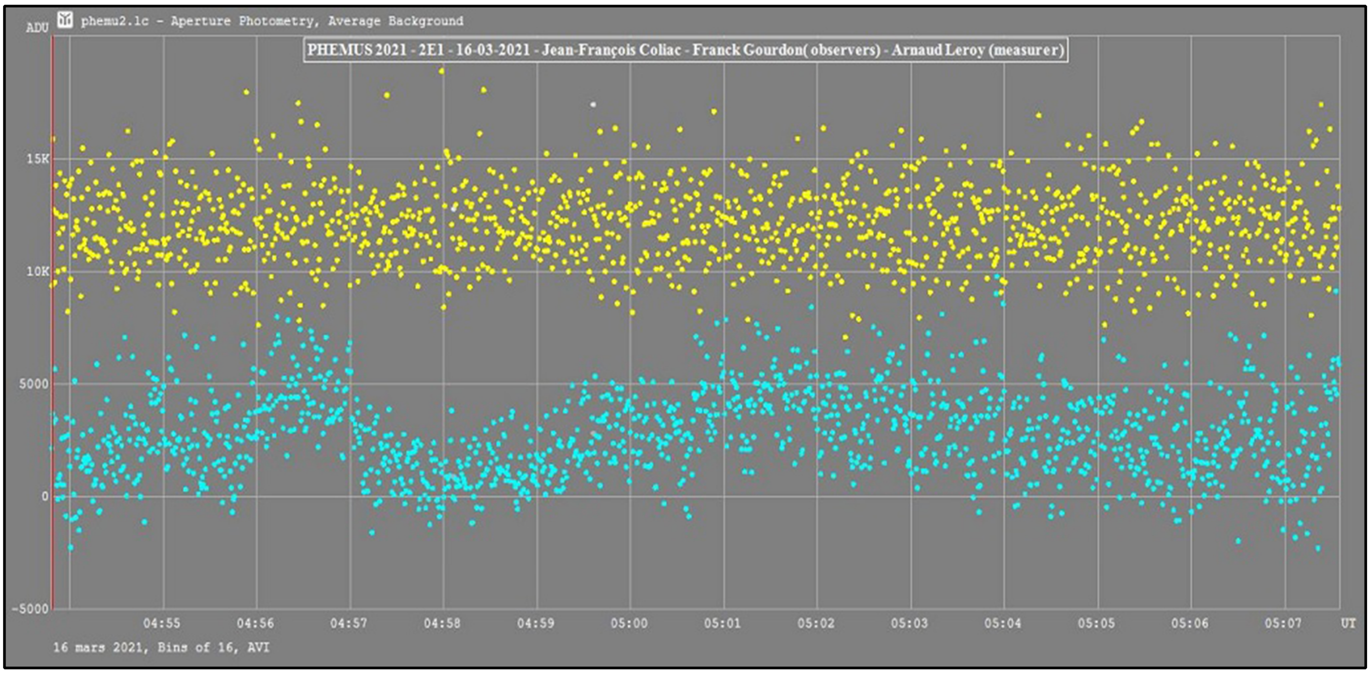


Figure 9. Light curve normalized with the reference (yellow) - binning 16 frames.

The Analysis of the Timings by Tony George

Following the capture of the IIEI Phemu event by Jean-François & Franck, Tony saw a message on Planoccult indicating Jean-François had difficulty in getting a clean light curve using Tangra. Since he had recently completed my own difficult Phemu observation and data analysis using *PyMovie* [5], he sent an offer to Jean-François to analyse his video and send him the results of the analysis. Here is Tony's report:

"On 2021 March 16, I received the video. I used PyMovie to analyse the video. The event was Europa eclipsing Io, however, both moons were so close during the event, they could not be easily separated, so both were included in the same aperture. Also, Jupiter was so close, it too could not be excluded from the measurement aperture. However, with PyMovie we can apply some tricks to the analysis. First, I set Jupiter as a tracking aperture. The aperture was 71-pixels wide, edge-to-edge. Second, I set another 71-pixel aperture over the combination of Europa and Io. Within the second aperture, I set a 15-pixel static aperture to measure the occultation. Then, I set the PyMovie background to 'lunar' so that the bright limb of Jupiter would be excluded from the measurement.

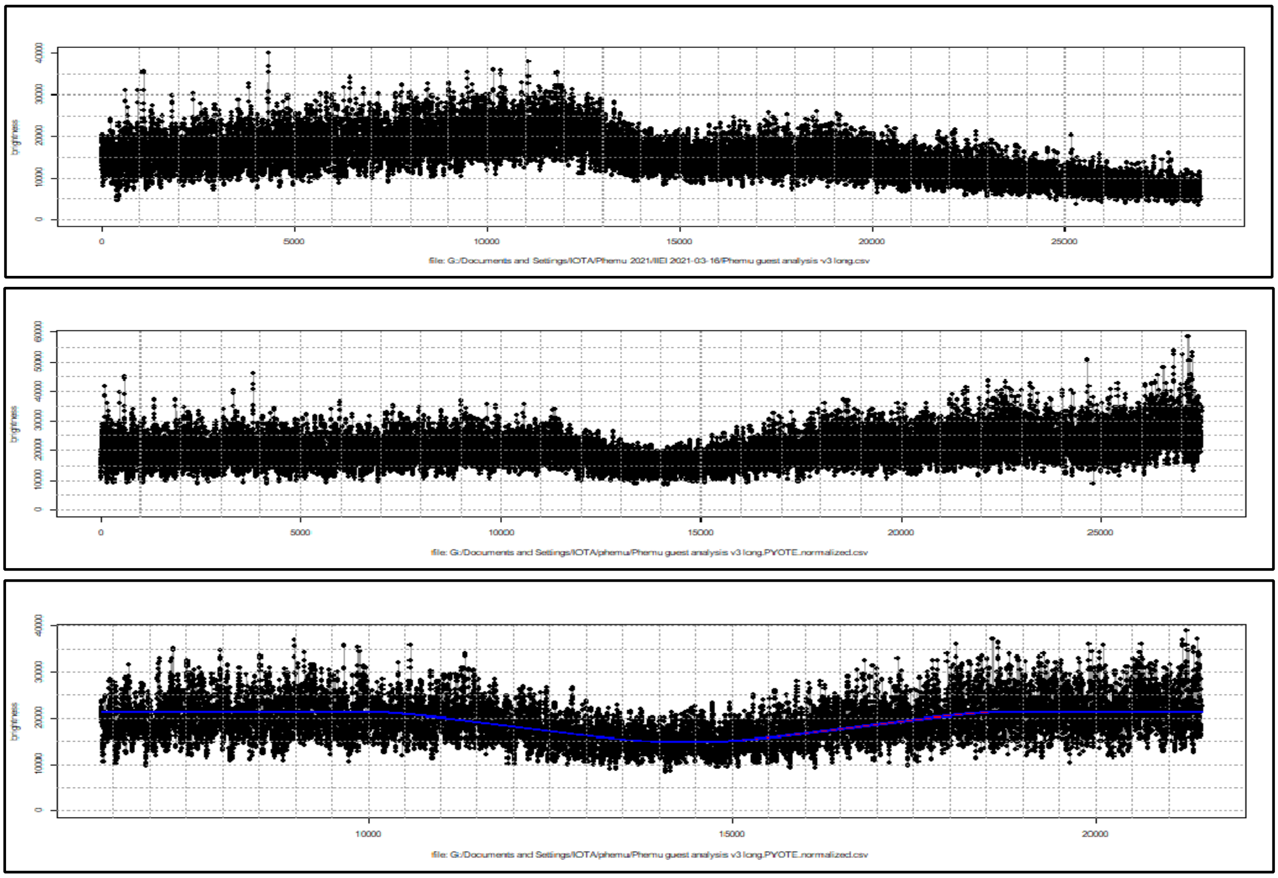
Finally, I set a 71-pixel aperture on Ganymede with a standard 'snap-to-blob' aperture that traced the actual size of the Ganymede image in the aperture. The resulting raw occultation light curve is shown in Figure 10a.

As can be seen, the light curve has a pronounced hump in it. This is due to the moons rising slowly through dense atmosphere near the horizon in the rising part of the hump and then due to increasing twilight in the decreasing part of the hump. The 'notch' in the middle of the hump is the eclipse event.

In order to better see the true shape of the event and to perform a timing analysis on it, the raw light curve was normalised to the Ganymede light curve using the program ROTE [6].

The resulting light curve resulted in a reasonably flat light curve with the event clearly visible (Figure 10b). This light curve was saved as a separate .csv file for further analysis in ROTE.

The new normalized .csv file was analyzed in ROTE using the edge-on-disk (EOD) penumbral light curve analysis methodology. While this was an eclipse and not an occultation, and while both Europa's shadow and Io's disk were both circular, experience has shown that the EOD methodology provides are very good fit to Phemu light curves and that it can provide reasonable approximate start, middle, and end times for the Phemu event to check results against predicted event times. The EOD analysis fit a smooth curve to the normalized light curve resulting in the graphic shown in Figure 10c.



Figures 10a, 10b and 10c.

The EOD analysis resulted in the following event times:

Duration (seconds) = 190.237279 (+/-) 2.493

Without camera delay and VTI offset:

D_{begin} 04:55:35.180400
D_{end} 04:58:15.179760
R_{begin} 04:58:45.411679
R_{end} 05:01:25.423039

MagDrop

Nominal = 0.39
Maximum = 0.39
Minimum = 0.38

Based on the D_{end} and R_{begin} results, the midpoint time of the event is 04:58:30 UT.

Compared with the predicted midpoint of the event, the O-C is 9 seconds. This is a very good result for such a 'tenous' observation (low altitude, onset of dawn twilight, proximity to Jupiter, and merged moons).

I congratulate the observers for getting this data in the face of such difficult conditions!"

Sending Reports and Measurements to IMCCE

The file generated by Arnaud with *Tangra* was modified to three columns: julian date, flux of target, flux of reference satellite. This file is joined to the report, indicating useful information for astronomers: latitude, longitude, altitude, telescope, camera...

As a result, we can see that it is possible to do a collaborative work in amateur science astronomy, whatever distance is between us.

Yes, astronomy is the school of... "stronger when together"...

Acknowledgements

We would like to thank Planoccult mailing list, IOTA and IMCCE for all precious advice they give on their web site and all amateurs that contribute on the web and elsewhere to share their experience and techniques. This paper was made using software *Occult*, *Tangra*, *PyMovie* and *ROTE*.

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"Triple" in February or the Bonus of the Month?

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ABSTRACT: After careful preparation, Czech astronomers Karel Halíř and Jiří Kubánek successfully observed 3 stellar occultations by minor planets in one night. This report describes the logistics, the adventure and the satisfaction of their successful occultation observations of (932) Hooveria, (33074) 1997 WP21 and (6546) Kaye. Karel Halíř's timings of (33074) 1997 WP21 suggest it has a satellite or is a binary asteroid.

Introduction

What is a "double"? At ESOP XXXVII in Rokycany, Czech Republic, in 2018 I was interested in Bernd Gährken's lecture about doubles, triples, Bayern Munich and occultations. Football fans talk about a double or triple when a team wins 2 or 3 important titles in one season.

What does he mean when an observer of asteroidal occultations says he has seen a double? It is the observation of two positive events in one night. (To be clear, I don't mean positives of the same asteroid from multiple stations by one observer). I have found that some observers have occasionally succeeded in doing this. I managed a double for the first time on the night of 2019 November 9-10 with asteroids (1048) Feodosia and (1017) Jacqueline.

Last year, for example, Alex Pratt talked very nicely at ESOP XXXIX about doubles, when he "caught" such a double within 10 minutes in May 2020. A few weeks later Simon Kidd observed a double within an even shorter time interval (less than 4 minutes).

I tried something similar on the evening of 2020 September 24th (the asteroid (488) Kreusa was a positive event and less than 4 minutes after that (111) Ate was possibly positive – but my observation was affected by clouds). I'll just ask the question: how do we measure a double? Is it the time between the end of the first event and the start of the second? Or is it the interval between the midpoints of the two events? It also depends on the durations of the individual occultations.

Let's go to the title of the article. I don't know who managed a triple (in football I'm sure many clubs did)? Anyway, I already know of two observers who were this successful on the night of Feburary 14-15 this year (besides the author, it was also Karel Halíř).

So, let's describe one by one, how it went from my point of view. For the sake of clarity, I will reveal in advance which asteroids they were and I will also state the times of the phenomena:

18:05 UT - (932) Hooveria
19:16 UT - (33074) 1997 WP21
01:10 UT - (6546) Kaye

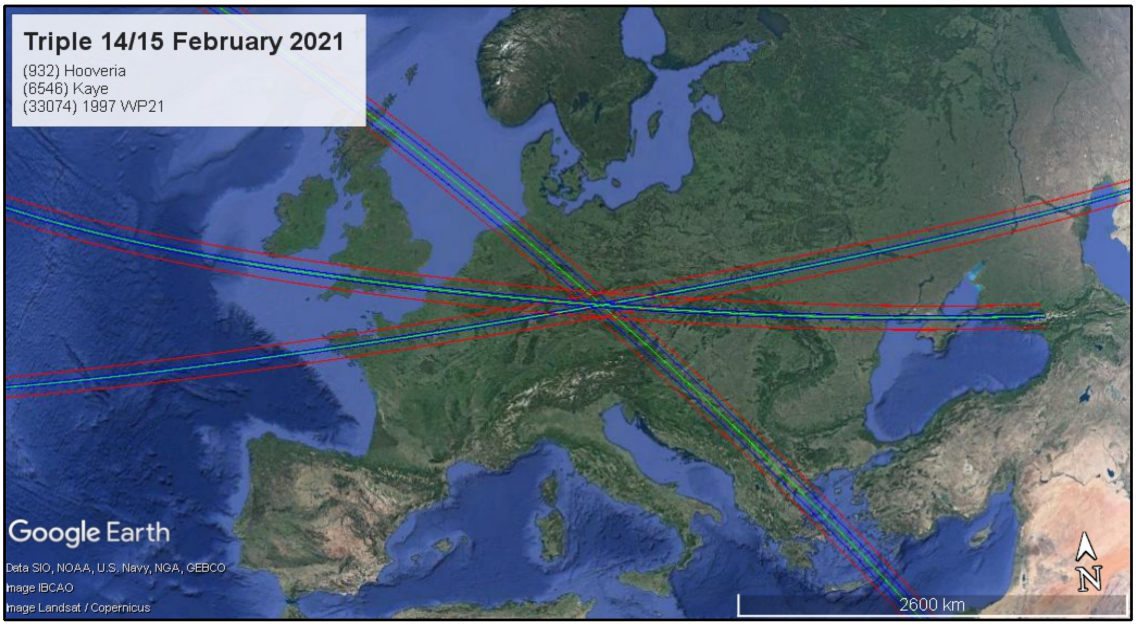

Figure 1. Map of central Europe showing the predicted tracks of asteroid occultations for the night of 2021 February 14/15. The shadows of asteroids (932) Hooveria, (6546) Kaye, and (33074) 1997 WP21 are successively in the left part of the map, from north to south. Generated by Occult (by Dave Herald). © Google Earth.

(932) Hooveria

At 16:31 UT in the evening I prepare to set up the camera on my outdoor telescope. There is a mount and a 20 cm Newtonian on a fixed stand in the garden. I'm going to attach the Watec 120N+ analogue camera and the GPS time inserter to it. It is still light, the Sun has only just set at 16:22 UT and civil twilight lasts until 16:56 UT. Capella can be seen in the sky, high above my head.

The first event, of the asteroid (932) Hooveria, occurs in the constellation Auriga. My daughter Lucie helps me set up the field orientation in the camera. I don't have a GoTo telescope, so I have to search and manually locate the field using the finderscope. I get the star theta Aurigae (2.6 mag) in the finder, the occulted star is nearby. Just move about 2 degrees south in declination. Shortly after 6 o'clock (local time) I have the field set in the telescope. I have to adjust the gain, it's still light. I set gamma OFF, turn the gain towards maximum (after all, the occultation will take place in less than an hour, at the end of astronomical twilight). I hesitate on the integration setting – whether to choose 0.64 s or risk 0.32 s. In the end I select the shorter exposure time.

The maximum duration of the occultation is predicted to be 13.6 seconds. According to my own prediction using *Occult* the probability from my home station Strašice is 50.0% (and even 66% according to the *Occult Watcher* feed ITALOccult). Not far away (560 metres) from me my colleague Miroslav Poláček is preparing his telescope.

Since this is a more promising event, I have a second station registered for (932) Hooveria, namely in the village of Tlustice and I have my 15 cm Schmidt-Cassegrain telescope with a QHY174MGPS camera loaded in my car. By the way, it's freezing outside. Automatic recording is already set up at my home station using IOTA Video Capture.

Figure 2. Photo of the 203/810 mm Newtonian telescope observing a positive occultation of the asteroid (893) Leopoldina on 2020 July 1 over the Danube Valley in Lower Austria.

It's about 17:20 UT; we have to leave.

We arrive in Tlustice at 17:40 UT and we know it's going to be a rush. Behind the gate in the backyard we are surprised by a snowdrift about 30 centimetres deep. I back off and luckily we get through. We quickly take out the mount (I usually like to be on site at least 40 minutes, preferably 60 minutes, in advance). Now we have only about 20 minutes before we start recording. Thanks to the excellent help of Lucie and her grandmother, everything goes quickly. The mount is set up, immediately oriented to Polaris, the telescope deployed, the camera attached and all the cables connected. Although using the 150/1500 mm telescope it is harder to find the target star than with the brighter Newtonian, I am already looking for the same field for the second time that evening. Everything is going well.

At 18:02 UT I have the field. I still have to set the correct exposure (I select 400 ms) and at 18:03:39 UT I start recording. That is about 1.5 minutes before the actual occultation. As I find out later in the log file, a few seconds before the recording starts I get a 3 seconds jump (caused by it updating its GPS satellite almanac and leap seconds data), so everything came out beautifully. The disappearance occurs at 18:05:11.31 UT. The star has practically vanished. It didn't reappear until 18:05:21.34 UT. The occultation lasted 10.03 seconds in Tlustice. Well done!!

Lucie and her grandmother are already inside in the warmth of the house. It's -8 degrees Celsius outside. I'm going to look for the field in Lynx, that's where the next occultation will take place. It is the asteroid (33074) 1997 WP21. This event has a probability of 10.5% for Tlustice (IBEROC prediction), it is after all a smaller asteroid than (932) Hooveria.

(33074) 1997 WP21

I was considering from which location I would observe this phenomenon. Whether to return home immediately after (932) Hooveria or wait an hour in Tlustice and observe the smaller asteroid here. Since we were closer to the predicted track here and Mirek Poláček told me that he would also try to observe it from Strašice, so we stayed. And we did the right thing.

The field in Lynx was harder to find, fortunately after half an hour I had everything set up and I could also go into the house to get warm. I tried to connect to my home station via the internet, it wasn't easy to see, but I had recorded that occultation as well. I also spoke on the phone with colleagues Mirek Poláček and Michal Rottenborn, both of whom had positive results at their stations. Since the camera had been disconnected, about a quarter of an hour before the event it was high time to go out again with the computer and reconnect the GPS camera so that the almanac and the leap seconds would be downloaded. I connected the camera at 19:00 UT and the almanac was loaded at 19:06 UT.

I started recording at 19:14:14 UT and to my delight at 19:16:10.51 UT the star disappeared! Double!!! The second positive occultation in the same evening. It reappeared at 19:16:12.22 UT, so the occultation lasted 1.71 seconds (the maximum duration was predicted to be 1.6 seconds). Amazing!

I phoned other observers to see what they had seen, but I knew of no other positives for this event. So, we quickly packed up, loaded the car and drove home. Along the way I talked to Karel Halíř, who told me that both occultations were positive (the second one for only a few tenths of a second). Great, we both congratulated each other on the double. During the night I planned to try three more phenomena with probabilities from 7.2% to 14.5% at Strašice.

(6546) Kaye

After arriving home I went to check and get the first results from my automated observation of (932) Hooveria. As I already knew from Mirek, the (932) Hooveria occultation at Strašice was longer than at Tlustice. In my case it was 13.12 seconds from home. I was waiting for a replacement camera for the main 20 cm telescope so I connected the QHY to the Newtonian. The air temperature was already dropping below -10 degrees Celsius (Arctic air was invading central Europe from the north).

At 22:21 UT I recorded a negative observation of asteroid (7536) Fahrenheit. At 23:25 UT I also tried the asteroid (821) Fanny, but the star was too faint due to its elevation of only 14 degrees above the horizon. There was only one chance left that I would catch another positive occultation that same night, namely asteroid (6546) Kaye (I had a 14.5% probability from the UKOCL prediction). It was already -12 degrees Celsius outside, so I set the field onto the (6546) Kaye asteroid and, thanks to a script written by my colleague Jiří Polák I set up an automatic recording using SharpCap.

At 00:40 UT I went to bed; the occultation was to occur at 01:10 UT. But since I didn't fall asleep right away after such a successful evening, I connected to the computer in the garden using the computer and Wi-Fi. I watched the (6546) Kaye event live and despite the remote connection the disappearance of the star was evident. On our bulletin board that my colleagues and I share, I wrote, "I would say triple".

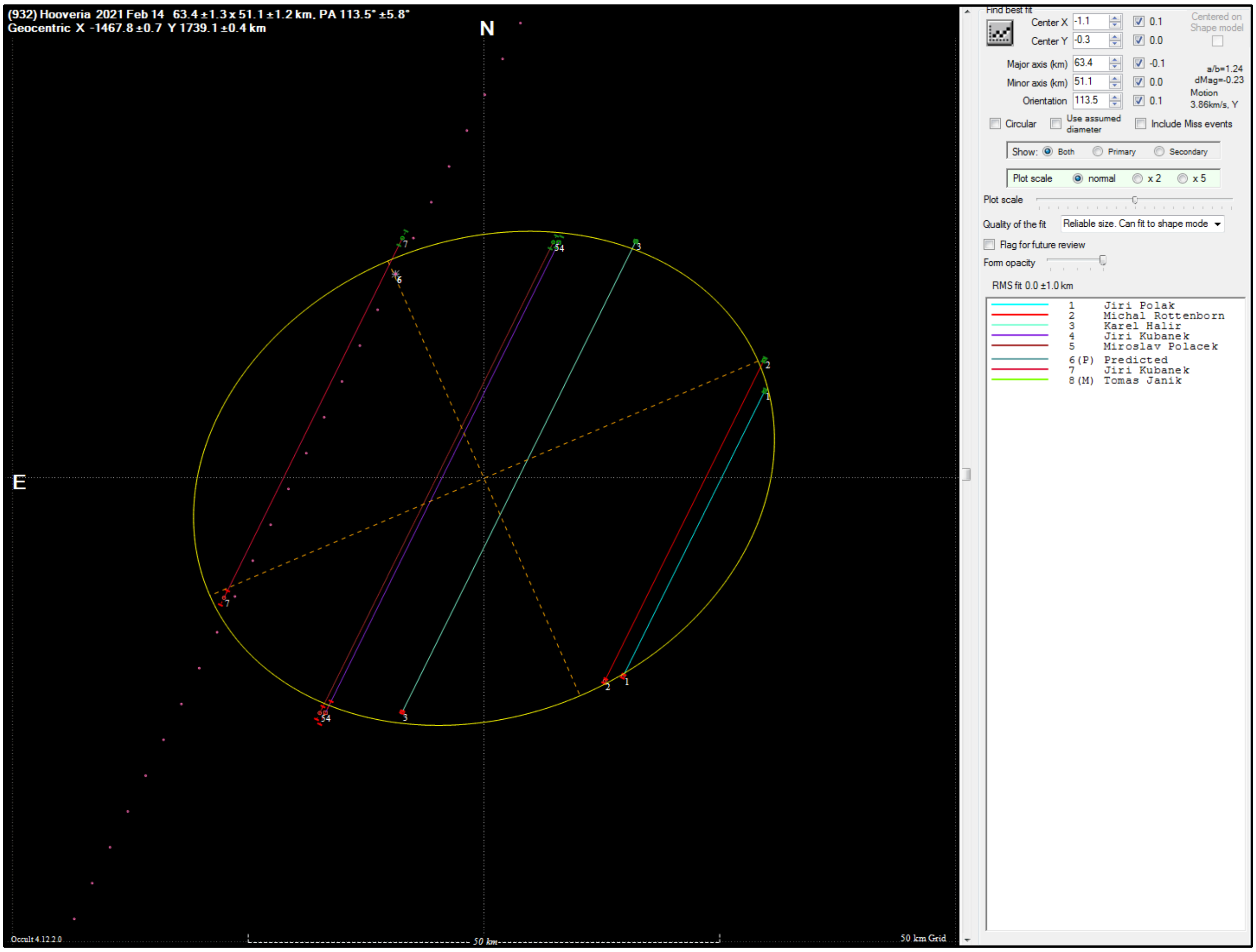

Figure 3. The dimensions of asteroid (932) Hooveria from observations of the occultation on 2021 February 14, generated by Occult (www.euraster.net, Eric Frappa). The asteroid projection shown is 63.4 x 51.1 km. Positive observations by Karel Halíř, Jiří Kubánek (2 stations), Miroslav Poláček, Jiří Polák, Michal Rottenborn and negative observations by Tomáš Janík and Jan Mánek (all CZ).

A Triple and a Surprise

In the following days Jiří Polák processed all the recordings for me, for which I thank him very much, because in February I was very busy in my profession as a financial advisor. As I found out, Karel Halíř also obtained positives for all the same phenomena, namely from the Observatory in Rokycany using a 50 cm telescope with a Watec 910HX camera. So, Karel Halíř had a triple with 3 positive observations and I also had a triple with even 4 positive observations (since I had two stations that successfully recorded (932) Hooveria).

For the record, the occultation by (6546) Kaye was predicted to have a maximum duration of 4.7 seconds (I measured the event as 5.2 s and Karel as 5.26 s). The complete results from all observers can be found on Eric Frappa's website (www.euraster.net), whom I thank for checking, correcting, and communicating about these occultations.

Lest we think that sending the report files was the end of the story, there was a surprise waiting for us a week later. For the asteroid (33074) 1997 WP21, my timings and Karel's were about 6 seconds apart after rechecking the locations. So, a big and thorough check was started, especially of our recordings, but also of the other observers' data. First of all, Mirek Poláček was on the closest chord to Karel – clearly a negative observation with 180 ms integration.

Karel's duration of the occultation was 0.56 s with input and output errors of only 0.02 s; in my case the duration was 1.71 s +/- 0.1 s. Karel's time inserter was on all night without interruption for all three positive events (and for (932) Hooveria and (6546) Kaye his observations matched mine and other observers' respectively). The log files were checked by me. In addition, I also check the time with another source (opening the Emerald Time app on my phone) when I make an observation, and the time in Tlustice exactly matched the whole seconds.

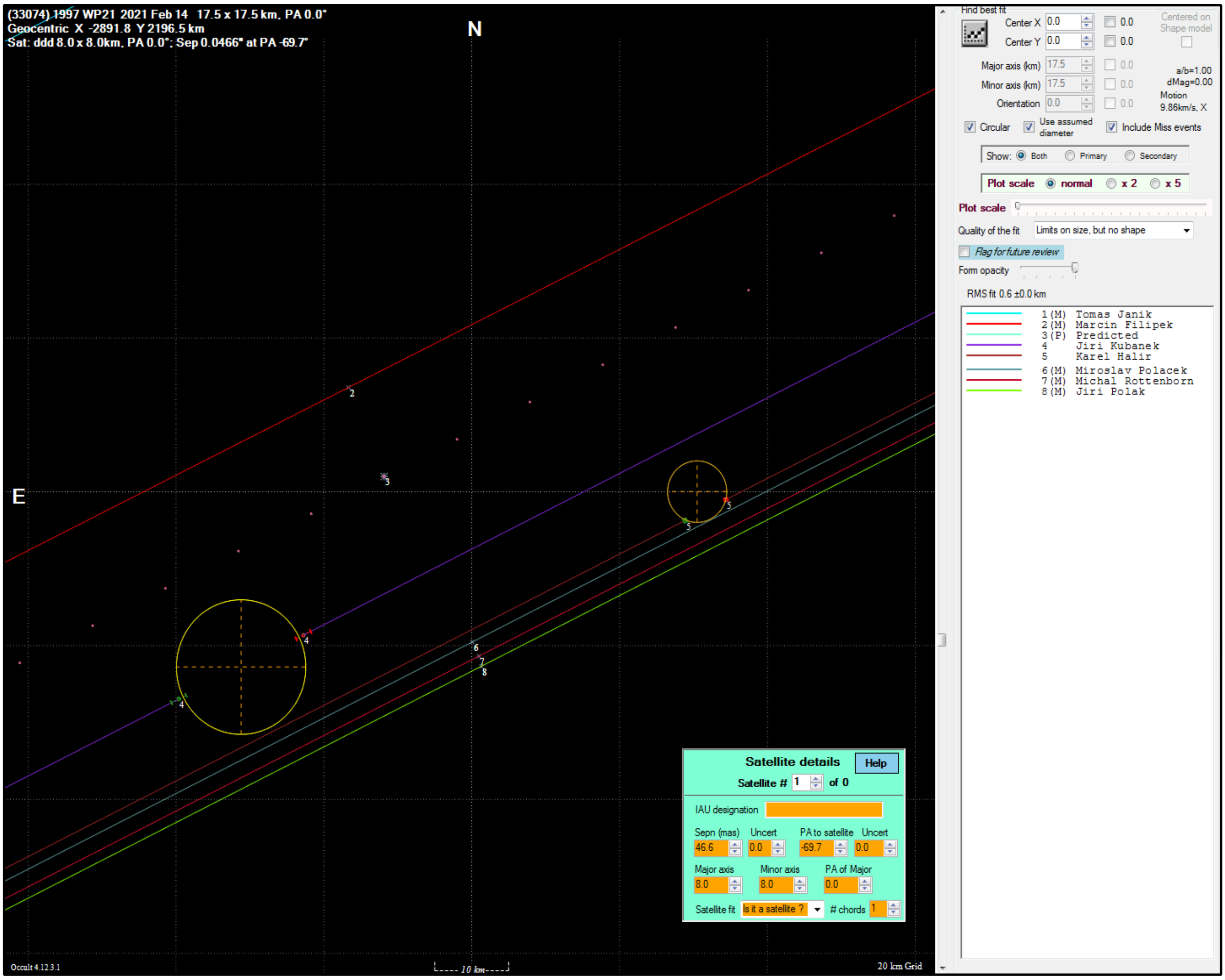

Figure 4. Sky plane projection of asteroid (33074) 1997 WP21 from observations of the occultation on 2021 February 14, generated by Occult (www.euraster.net, Eric Frappa). For the asteroid and satellite hypothesis displayed here, the sizes of the bodies are 17.5 km and 8 km, respectively. Positive observations by Karel Halíř, Jiří Kubánek (both CZ), negative observations by Tomáš Janík, Miroslav Poláček, Jiří Polák, Michal Rottenborn (all CZ) and Marcin Filipek (PL).

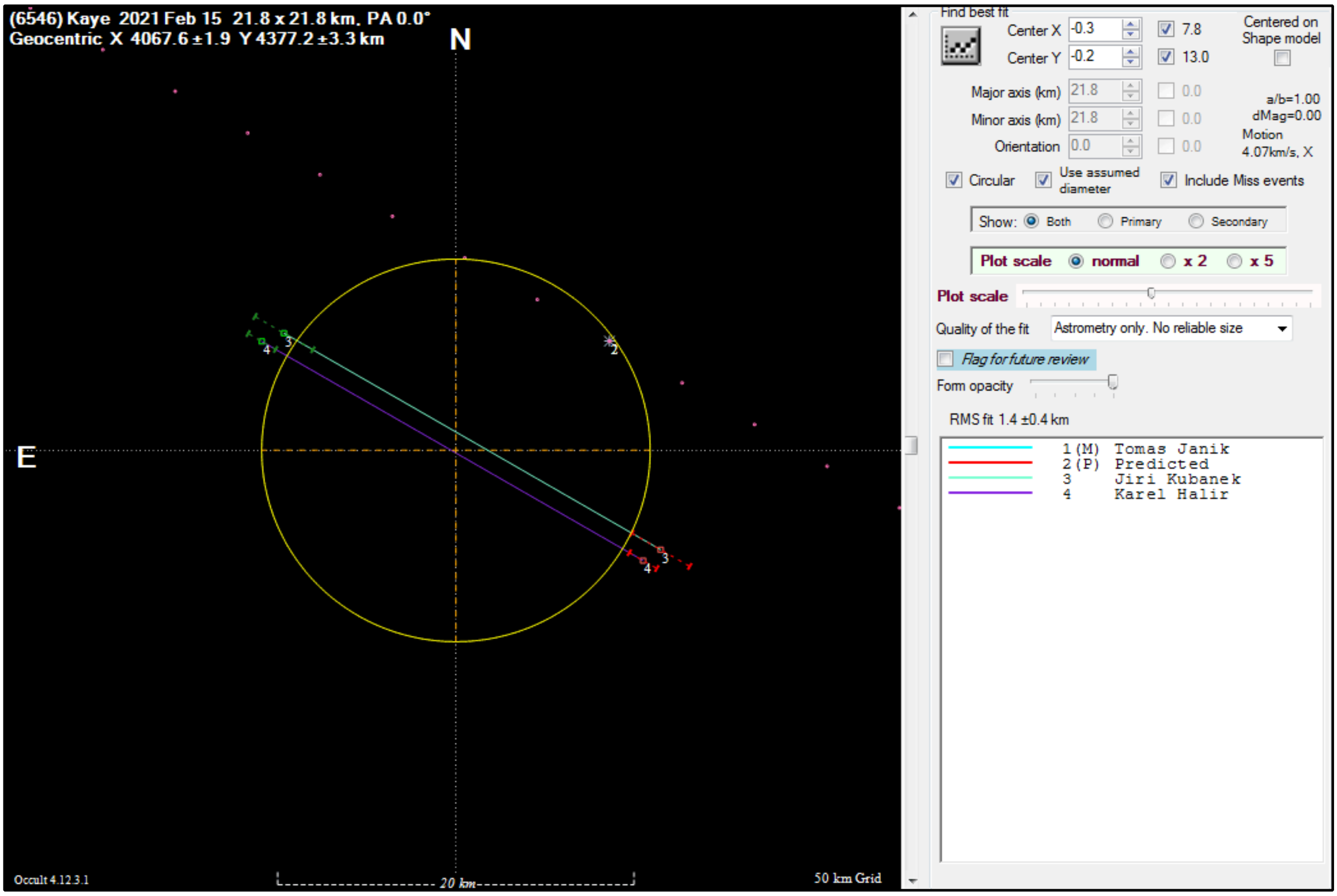

Figure 5. The diameter of asteroid (6546) Kaye from the observations of the occultation on 2021 February 15, generated by Occult (www.euraster.net, Eric Frappa). The size of the asteroid projection shown is 21.8 km. Positive observations by Karel Halíř, Jiří Kubánek, negative observations by Tomáš Janík (all CZ).

So, in my view, the simplest explanation is given by a satellite of asteroid (33074) 1997 WP21, which was captured by Karel in Rokycany and I encountered the main body in Tlustice.

This should come as no surprise because there are now hundreds of asteroids with known satellites, and according to theory, asteroid duplicity is not unusual. However, capturing the satellite of an asteroid during an occultation is really rare.

I believe more observations like this will come. What I like about the (33074) 1997 WP21 asteroid binary hypothesis is the coincidence of the locations of the two positive observations. After all, my wife Milena was born in Rokycany (there is a hospital near the observatory where Karel observed) and grew up in a house in Tlustice from where I observed from its backyard.

Acknowledgements

I would like to thank the *Observatory in Rokycany and Pilsen* and Michal Rottenborn for the loan of observing equipment, without which neither the triple nor the discovery would have been possible, and I wish all observers clear skies and many experiences and successes in observing stellar occultations by asteroids!

Quantifying Gaia Star Problems for Asteroidal Occultation Predictions

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ABSTRACT: The title for this paper might rather be, "Beware of High RUWE and Duplicated Source Flag", since that is the main lesson learned from the occultations that we describe. All three stars have high RUWE (Renormalized Unit Weight Error), a measure of the quality of the astrometric solution for the Gaia positional information of the star. Also, of concern is the "Duplicated Source Flag" that may (but not always) mean that the star's astrometric information might be degraded by unresolved close duplicity of the star. Fortunately, in each of these cases, we were able to deploy enough stations so that at least a few had occultations, showing where the actual occultation path was, and thus, giving a measure of the actual error in the Gaia astrometric information for the star. One of the stars was a close double; the prediction for it turned out to be more accurate than expected. In another case, the asteroid was (99942) Apophis, opening a new age in near-Earth asteroid precision astrometry.

First Occultation - 2020 March 28

TYC 0303-00112-1 by (479) Caprera in Arizona

The star was 10.4 mag, making it the best asteroidal occultation of the month in Arizona. At the time, we only had Gaia DR2 information for the star; the DR2 RUWE [1] for the star was 1.93, well above the recommended value of 1.4 for a good positional determination. We were wary of that, because of an experience with an occultation of a similar-magnitude star that was occulted by (1409) Isko on 2019 December 17. In that case, the orbit wasn't updated with *Gaia* observations of (1409) Isko, and although we had fairly good coverage across the path and the northern 1-σ zone, all stations had no occultation.

A calculation with the current JPL orbit, which now includes the *Gaia* observations of the asteroid, and the Gaia EDR3 position of the star (RUWE is 0.9 for it, indicating no problems), showed that the actual (1409) Isko path was nearly two path-widths south of our coverage. That means the VERITAS array was in the path, but I believe they could not try it because the 69 % sunlit Moon was 32° from the target, too close for their sensitive detectors [2].

Again, on 2020 January 7, an occultation of 11.5 mag UCAC4 440-046486 (= TYC 4866-02026-1) was observed from several stations in the UK and Europe, giving good coverage of the expected path and some of the 1-sigma zone, but everyone had no occultation.

The 1.4 value for dividing "good" (lower values) from "bad" higher values is only a general rule of thumb; actually, the transition is quite fuzzy, with only a gradual increase in the probability for astrometric problems developing as the RUWE value increases in this area.

Figure 1 shows 13 of the stations that were deployed for the occultation, including two positives and 11 negatives. The observations covered Steve Preston's prediction [3] that used Gaia DR2 data for the star, from the 2-σ southern limit almost to the 3-σ northern limit, purposely spread wide to maximize the chances for obtaining any positives.

T. George and S. Insana observed from their homes in the greater Phoenix area. N. Carlson travelled from Tucson into the path. Not shown (because he didn't file an IOTA report) was another negative mobile observation by P. Maley near Preston's predicted (green) central line west of Sun City Festival at latitude 33.6683° N., longitude 112.6480° W., elevation 467 m [4], and Ted Swift, who observed off of the Figure 1 map in northern California, only about 2 km southwest of Sam Insana and P. Facuna's line. Ted Blank, and D. and J. Dunham, set up remote automated attended stations, primarily with 12 cm "maxi" refractors, with Blank covering the extreme southwestern stations around Gila Bend, while the Dunhams covered the northeastern side from sites near AZ Highway 87, but including one (#3) at their home in Fountain Hills.

All stations used black and white video cameras with NTSC format, mostly Runcam Night Eagle Astros, but Watec 910HX cameras were used at some stations. The thin blue lines mark Preston's limits while the red lines are his 1-σ limits.

D. Dunham sought advice on the prediction a few days before the event from D. Herald, who noted that the star was not in the Gaia DR1 TAGS catalogue. He generated 3 predictions: The first based on JPL Horizons for (479) Caprera and Gaia DR2 for the star; the second based on Horizons and UCAC5 [5] for the star; and third, Horizons and UCAC4 [6]. The first was about 35 km (0.4 path-width) north-east of Preston's prediction, while the second was another 35 km northwest of the first. However, the third (UCAC4) prediction, the only one that did not use any Gaia data, was far to the southwest, with only its northern limit shown as a turquoise line in the southwestern corner of Figure 1.

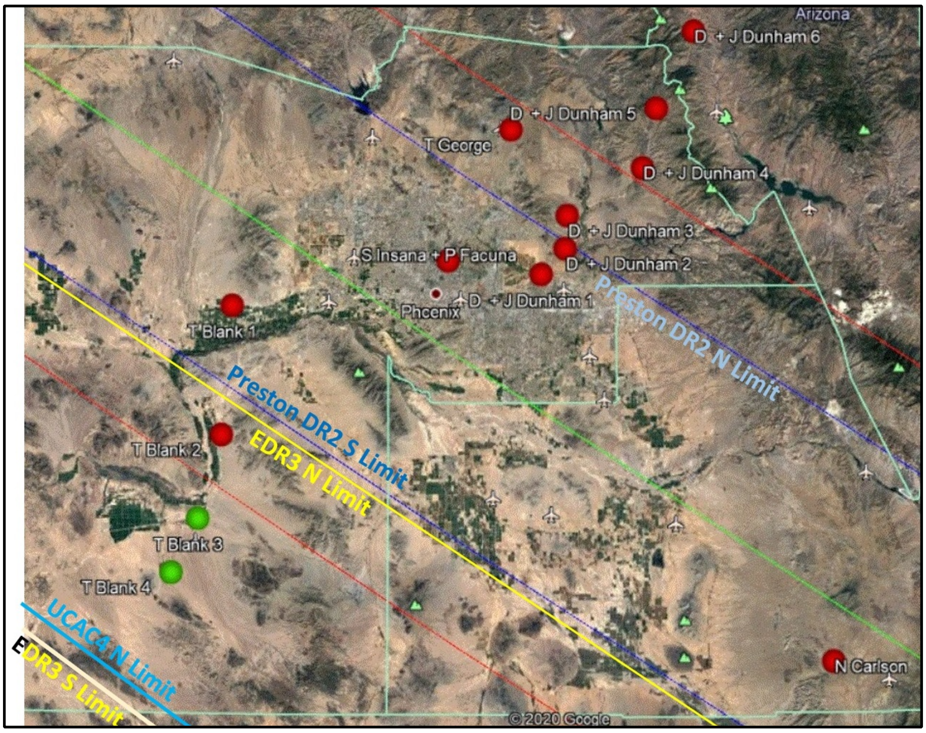

Figure 1. Stations deployed for the (479) Caprera occultation in central Arizona on 2020 March 28, adopted from John Moore's map on the IOTA North American reviewed asteroidal occultation report page [7]. Green dots were positive and red ones were negative. Three predicted paths shown are described in the text.

With these disparate predictions, we were uncertain which might be correct, so we maintained our plan to bracket Preston's prediction as widely as possible. As can be seen, the actual path was almost 1.2 path-widths (almost 4-σ) southwest of what we expected.

Fortunately, the shift was not as large as UCAC4 indicated, so that Ted Blank's two southernmost stations were positive; the result is shown in the sky plane in Figure 2. Also, in Figure 1 we have plotted the limits for a much better current postdiction, only about 0.1 path-width too far northeast, shown in yellow, using JPL Horizons for (479) Caprera and Gaia EDR3 data for the star. The good result with EDR3 is remarkable since the EDR3 RUWE has increased to 6.4; hopefully with DR3, it will be small. The solution in Figure 2 shows that the actual northern limit must have almost reached Blank's negative #2 station. None of the occultation light curves indicated any duplicity of TYC 4866-02026-1, the occulted star.

Second Occultation - 2021 March 7
NY Hydrae by (99942) Apophis in Louisiana

Josselin Desmars, of the Lucky Star Project, found that on March 7th, Apophis would occult 8.4-mag NY Hydrae (HIP 45887) in a path crossing the central USA. Observing an occultation by the small potentially hazardous asteroid, about 340 metres across that was expected to be occulted for only 0.08 second, posed unique challenges that are described well in a paper [8] that we gave recently at the 7th Planetary Defense Conference [9].

This was the brightest and first of five Apophis occultations that have been observed so far; details of these, and predictions for a few future occultations, are given on IOTA's Apophis occultations Web page [10].

The IOTA Excel reports given on that Web page include information about the equipment used at each positive (and a few negative) stations, including about the cameras used and the observational cadence. Like for the other events, Runcam (which records frames with its rolling shutter) and Watec (standard field rate) cameras were used, but for some of the Dunham's stations, old Supercircuits PC164C-EX2 cameras were used since like Watec cameras, they record fields, not just frames. With the short occultations expected, the Dunhams thought the field recordings would be advantageous, but they didn't have those cameras for all of their telescopes.

A few observers used QHY 174M GPS cameras to record at faster than video rates. Kai Getrost, with his 20-in. telescope, succeeded with his QHY camera for the positive occultations on April 4 and 11 (10 ms integrations for that one), but his observations were negative for the two March occultations. Unistellar eVscopes were used with 100 ms integrations, as fast as those scopes can record, at 12 stations organized in Colorado by Franck Marchis, but all of their stations were outside the actual path and were negative.

NY Hydrae was found to be an eclipsing binary by the Hipparcos satellite and project; follow-up ground observations showed the

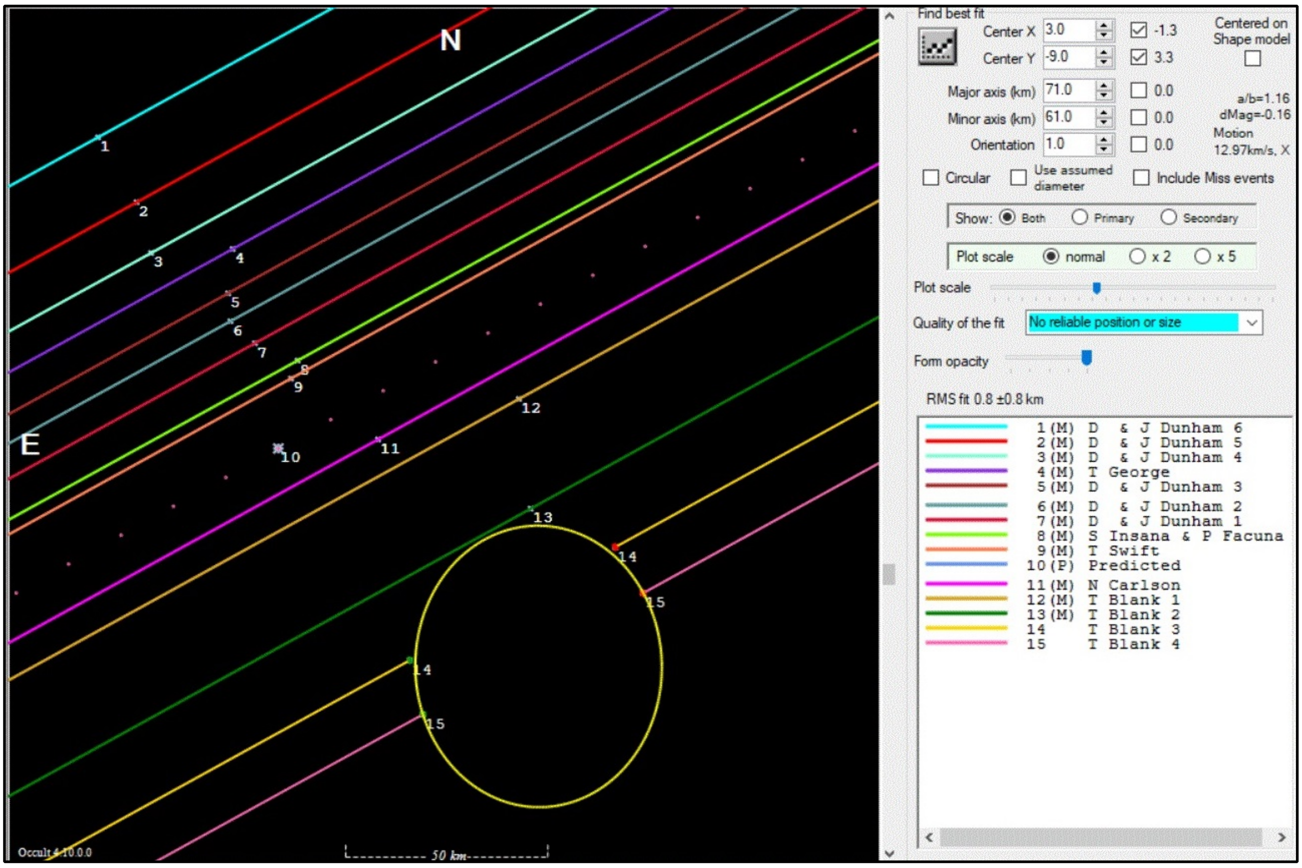

Figure 2. Sky plane plot of the observations for the (479) Caprera occultation of 2020 March 28, adopted from John Moore's chords plot on the IOTA North American reviewed asteroidal occultation report page [7].

components are nearly equal Sun-like stars in a circular orbit with a period of 4.8 days [11]. With this short a period, the separation should be only about 0.8 mas (milli-arc-second) at the star's distance of about 100 parsecs.

Nevertheless, that was enough to "confuse" *Gaia*, causing the EDR3 RUWE to be 1.45, a little above the "good" values that are less than 1.4. Davide Farnocchia, at NASA's Jet Propulsion Laboratory, was able to accurately fit an orbit (JPL 214a) to observations of (99942) Apophis' occultations on March 22, April 4 and April 11, as shown in Table 1, adopted from [8].

As you can see, the residuals are much larger for NY Hydrae (March 7th event) than for the other stars, quantifying the size of the effect of its high RUWE. The relatively large error for this first event threw us off for the next one, which was only saved by Roger Venable running 5 stations on March 22nd, with one far enough east to be positive; otherwise, we might have lost (99942) Apophis' accurate orbit [8].

2021 Date	mag [a]	Loc. [b]	Number of stations	Number of positive	Δα [c]	Δδ [c]	Δt [c]	RUWE
March 7	8.4	LA, OK, CO, BC	29	3	-11.0	+1.2	+0.17	1.45
March 22	10.0	FL, AL, IL	9	1	+0.4	-0.5	-0.02	1.15
April 4	11.0	NM	8	3	+0.3	-0.1	-0.01	0.90
April 11	10.1	NM	3	3	+0.5	-0.5	-0.03	0.85

[a] This is the Gaia g magnitude of the occulted star.
[b] For location, the 2-letter US State/Canadian Province codes are given.
[c] The O-C residuals are relative to JPL orbit 214a, in mas, but in seconds for Δt.

Table 1. Summary of all observed positive Apophis occultations, using Gaia EDR3 for the stars.

Third Occultation - 2021 March 18
HIP 19975 by (8) Flora in southern USA & northern Mexico

The star, also known as SAO 93840, was 7.2 mag, involving one of the larger asteroids, making it the best asteroidal occultation of 2021 in Arizona. Some of us travelled east to escape clouds from a front approaching from the west, but in the western areas, the clouds were thin enough for some observers to record the occultation, anyway. The problem with this star is that it is a close double, with a 9.07 mag companion about 0.3" to the north.

For our deployment, we sought advice from Dave Herald and Paolo Tanga. Herald wrote: *"Is the Gaia position for the primary star, or for the photo centre? And if this cannot be firmly decided, do you stretch observers across the path, plus across an equivalent distance to the south of the path. Maybe Paolo Tanga can assist".*

And he did, saying: *"In such situations it is very difficult to know exactly the behavior of the astrometric solution provided by Gaia, so special caution should be used to deploy the observers in this case. This said, in general Gaia works on "peaks" of the flux distribution, so it should favor the brightest component. As the RUWE is slightly high (but not terribly) I would say that the astrometry of the bright component is provided, somehow perturbed (how much? Impossible to say). So, yes, the advice to extend deployment beyond the prediction core looks totally appropriate to me".*

With this advice, we decided to try to cover the predicted path, as well as a full path-width farther south. In addition to the duplicity, the RUWE was 1.7, indicating a probable problem with the Gaia astrometric solution. Since the secondary star is north of the primary, the occultation of it would be in a path well south of the path for the primary. So, if *Gaia* effectively detected a blend of the two stars, the path should shift south by an unknown amount. We encouraged observers across the expected path and the possible more southern zone to try the event from home, if they didn't have a mobile capability. Ted Blank and the Dunhams drove to eastern Arizona, to increase the chance for clear skies, since the event occurred at an altitude of 21° in the west, with the clouds approaching from that direction.

Ted Blank set up three stations to the south of the path (he also pre-pointed a telescope at his home in Fountain Hills the night before; that station was successful), while the Dunhams set up in the predicted path, but along a twisty mountain highway (US 191) that did not allow travelling very far in the three hours of usable dark time that we had for prepointing our remote stations before the occultation. All stations used black and white video cameras with NTSC format, mostly Runcam Night Eagle Astros, but Watec 910HX cameras were used at some stations.

The actual coverage that we achieved is shown on the map in Figure 3, where the thin green line is the predicted centre, while the blue lines mark the limits and the red lines are the 1-σ limits, very close to the blue lines since the formal prediction errors were very small. The 11 stations that had an occultation are shown with green dots (the Dunhams had 3 positives and one negative, but two of their stations are covered by the dots of other stations with the small-scale map), while the 10 miss stations are indicated with red dots.

As can be seen, the actual path was close to the predicted one; the *Gaia* observations were clearly of the primary star only, not a blended position. All of the chords projected in the sky plane are shown in Figure 4.

The southern limit was a few km of its expected location, while the northern limit was about 30 km farther north (not well determined due to the poorer coverage on the north side of the path), since the long axis was perpendicular to the motion. Thus, the centre shifted about 15 km north of Steve Preston's prediction that we used. Curiously, the errors for the prediction were anomalously small, only about 3 km 1-σ, which is hard to achieve with Gaia data for an asteroid so large since *Gaia* by its design observes at high phase angles where the object is poorly illuminated. Thus, the centre of mass (or centre of figure) can't be determined well. The real errors, due to this effect, should be about 10% of the object's size, like we had for the 2019 (55) Pandora occultation, so for (8) Flora, that would be about 15 km, comparable to the observed shift.

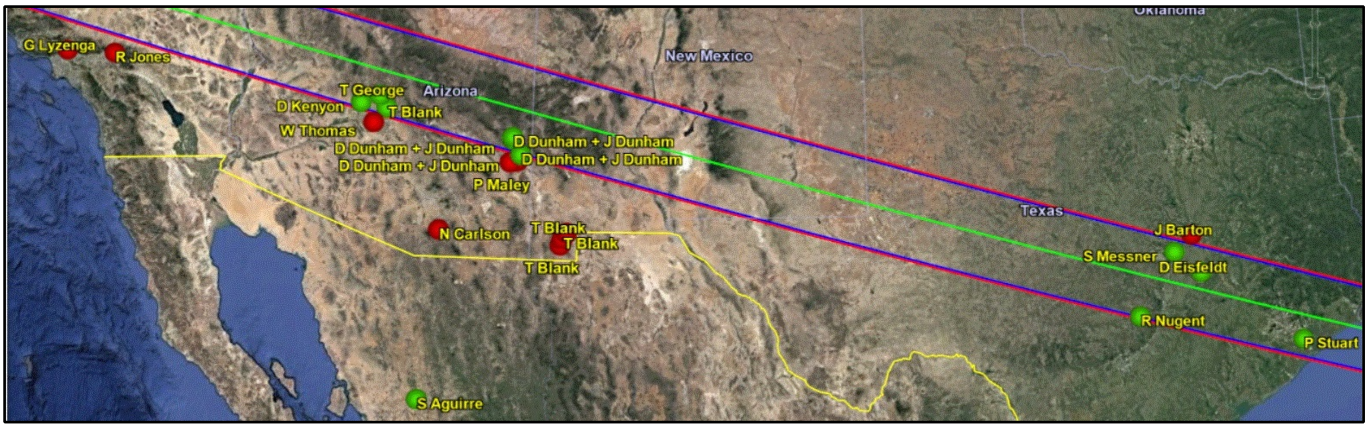

Figure 3. Stations deployed for the (8) Flora occultation in the southwestern USA and Mexico on 2021 March 18, adopted from John Moore's map on the IOTA North American reviewed asteroidal occultation report page [7]. Green dots were positive and red ones were negative.

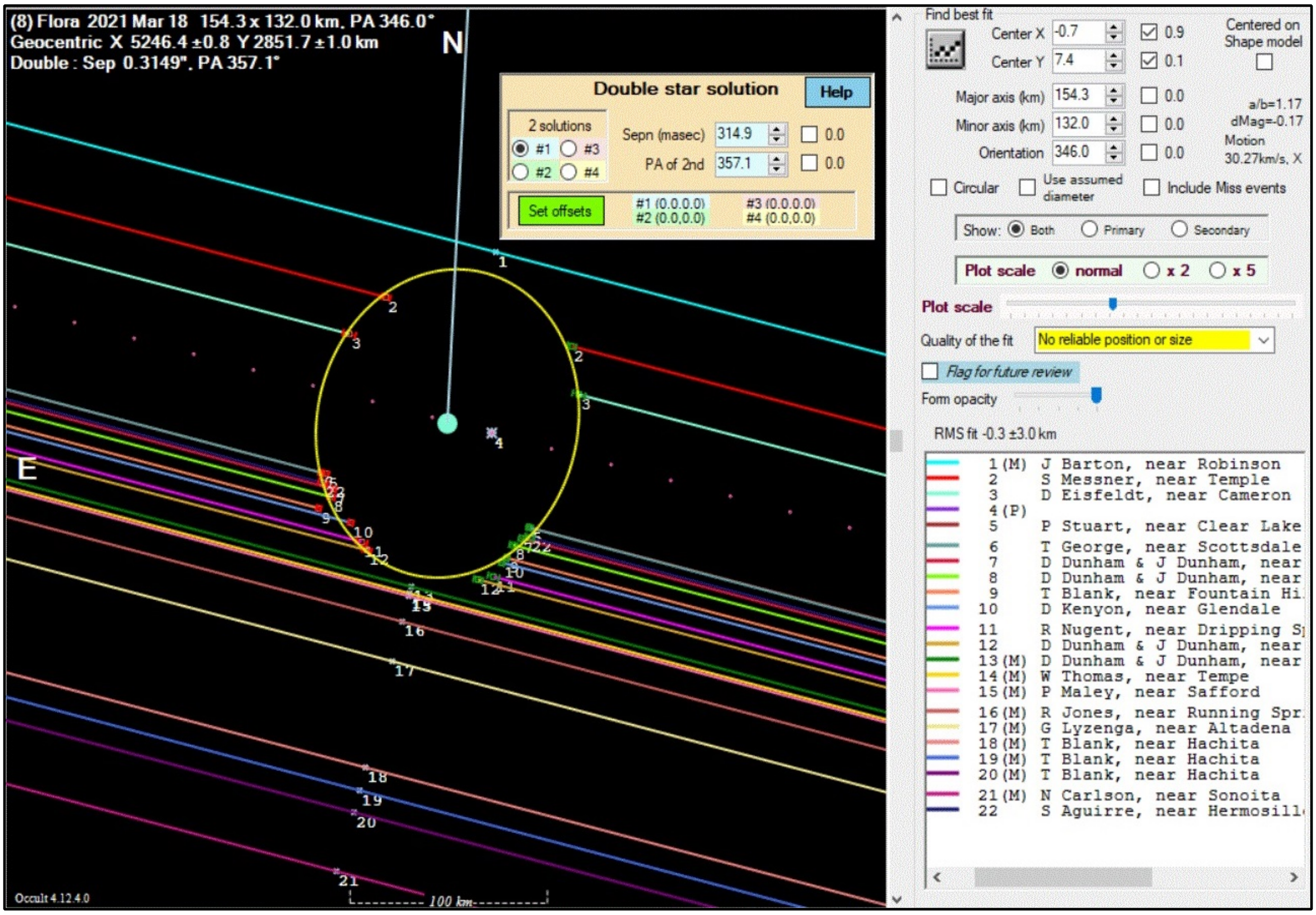

Figure 4. Sky plane plot of the observations for the (8) Flora occultation of 2021 March 18, adopted from John Moore's chords plot on the IOTA North American reviewed asteroidal occultation report page [7].

Not shown in Figure 4 is Salvador Aquirre's negative observation of the occultation of the primary star from Hermosillo, Sonora, Mexico. He was far enough south that he recorded an occultation by the secondary star, as shown in Figure 5, allowing a rather good determination of its separation and PA, as given in Figure 4.

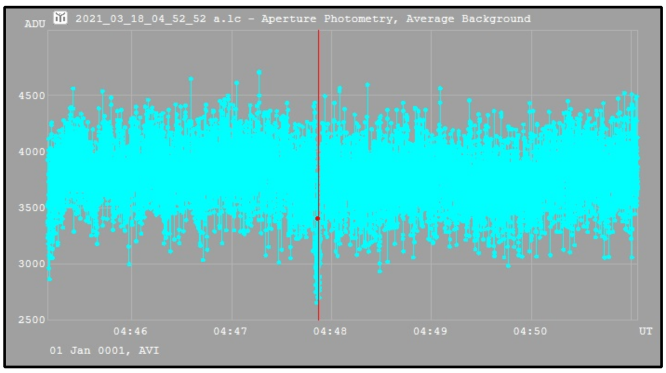

Figure 5. The light curve obtained with Tangra showing the shallow secondary star occultation obtained by Salvador Aguirre from Hermosillo, Mexico.

Figure 4 also shows that (8) Flora's long axis (154 km, while the short axis was 132 km) was perpendicular to the direction of motion, resulting in a path that was a little wider than predicted. There was also a north shift of the path, by about 15 km. The bottom line for this event was that the Gaia data were correct for the primary star, in spite of the rather high RUWE, and not for a blended position of the components. This is similar to the result we obtained for the 2019 December 7th multiple-station deployment for the occultation of 6.5 mag 18 Aurigae (HIP 24832) by (55) Pandora [12]. The star has an 11.9 mag companion 3.9" away; we thought at the time, that that star might affect the prediction for the main event. But that double was clearly resolved by *Gaia*, with separate DR2 data for each component.

Compared to the Pandora situation, on March 18th for (8) Flora, the double separation was ten times less, the component magnitudes differed by two rather than by six, and for (8) Flora, there is no separate EDR3 entry for the secondary star, so before March 18th, it was not certain that the EDR3 data for the star was actually for the primary component only.

Date	Asteroid	Star mag	Shift path widths/σ	Number of stations	Number of positives	EDR3 RUWE
2020 Mar 28	(479) Capera	10.4	1.2s/3.9s	15	2	6.3 [a]
2021 Mar 7	(99942) Apophis	8.4	2.2s/1.2s	29	3	1.45
2021 Mar 18	(8) Flora	7.2	0.1n/4n	21	11	1.7

[a] The Gaia DR2 RUWE available for the event was 1.93.

Table 2. Summary of the three occultations described in this paper.

Conclusions

The astrometric cornucopia from ESA's *Gaia* mission have created a revolution for asteroidal occultations, vastly increasing the number of successful asteroidal occultation observations [13]. But the *Gaia* mission is not complete, and the three occultations described here underscore some pitfalls that remain, and how observers can plan coverage to mitigate these problems to optimize results. As was seen for the first event, there was a great improvement in the prediction from Gaia DR2 to EDR3, so we can expect even better results with the full DR3 and the final *Gaia* data release. An important result is that *Gaia* does very well at homing in on the primary component for close double stars.

Table 2 summarises the results from the three occultations described, although comparison is hampered by the great differences in the path widths. The shifts given are relative to the best prediction available shortly before the event.

We can be more selective for the events we try, including concentrating efforts on objects of special interest, such as small near-Earth asteroids (NEAs) and asteroids that have evidence of satellites. The successful (99942) Apophis occultations usher in a new age of NEA occultation observations that can greatly benefit future planetary defence efforts. We hope that more observers will become interested in occultations in general and take part in this exciting new activity. Since the paths are very narrow, coordinated mobile efforts are needed for them.

Acknowledgements

We thank Marshall Eubanks for alerting the authors, and the IOTA community, to the close duplicity of NY Hydrae for the March 7th Apophis occultation. We thank Davide Farnocchia for maintaining the JPL Horizons Web site [14] and updating the orbital elements there for these, and many other, IOTA occultation campaigns. We thank Marc Buie at the Southwest Research Institute; members of the Paris Observatory Lucky Star Project, and members of ESA's *Gaia* consortium for valuable advice. We are indebted to the many observers who contributed positive as well as negative observations for these occultations.

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Beyond Jupiter

The World of Distant Minor Planets

Since the downgrading of Pluto in 2006 by the IAU, the planet Neptune marks the end of the zone of planets. Beyond Neptune, the world of icy large and small bodies, with and without an atmosphere (called Trans Neptunian Objects or TNOs) starts. This zone between Jupiter and Neptune is also host to mysterious objects, namely the Centaurs and the Neptune Trojans. All of these groups are summarised as "distant minor planets". Occultation observers investigate these members of our solar system, without ever using a spacecraft. The sheer number of these minor planets is huge. As of 2021 June 28, the *Minor Planet Center* listed 1213 Centaurs and 2602 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:

(10370) Hylonome

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

ABSTRACT: The Centaur (10370 Hylonome) was discovered in 1995 and orbits the Sun every 126 years. The orbit is gravitationally controlled by Uranus (near perihelion) and by Neptune (near aphelion). The diameter is approximately 75 km. To date no rotation parameters are known and no moon was detected yet.

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

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

The Discovery

The object was discovered 1995 February 27, by David C. Jewitt and Jane Luu at *Mauna-Kea Observatory* (IAU-Code 568) with a 2.2 m reflector + CCD in the constellation of Virgo. The apparent brightness was 21.2 mag (R-band) and the object received the provisional designation, 1995 DW_2 [1].

The current orbit in the JPL Small-Body Database is based on 78 observations spanning the interval 1995 March 9 to 2010 June 14 [2], the discovery astrometry having been excluded owing to residuals in excess of 2″.

The Name

The object was identified as a member of the sky object family called Centaurs. It was named in 2000 as Hylonome (Greek: Ὑλονόμη), a female centaur from Greek mythology who married the handsome centaur, Cyllarus [3]. Together with him she fought at the wedding of the Pirithous and killed herself with the javelin that had tragically killed her husband. Figure 1 shows Hylonome on a Roman mosaic. The mosaic is now on display at the Bardo Museum in Tunis, Tunisia.

The Orbit

The orbit (Figure 2) has an eccentricity of 0.245 and is inclined to the ecliptic by 4.14°. With a semi-major axis of 25.19 AU, the solar distance is between 19.02 AU and 31.4 AU, Hylonome belongs to the Centaur population [4]. At present, Hylonome has approximately the same distance of 24.5 AU from the Sun and the Earth. The orbital period is 126.3 years, it is currently moving out from the Sun and is expected to reach aphelion in 2057.

Currently, the orbit is controlled by the gravities of Uranus (perihelion) and Neptune (aphelion) and it is expected to remain in this configuration for around 7 million years (half-life according to [5]).

Figure 1. Hylonome on a Roman mosaic.
Source: *https://de.wikipedia.org/wiki/Kentaur#/media Datei:Mosaico_con_centauresse.jpg*
Repro: *https://it.wikipedia.org/wiki/Utente:Giorces*

Physical Parameters

Stansberry et al. published in [6] a diameter of < 168 ±48 km calculated from observations by the *Spitzer Space Telescope*, based on the Standard Thermal Model (STM). The observations are made in wavelengths near 24 and 70 µm in 2008. Later, in 2018, R. Duffard et al. observed the object with the *Herschel Space Telescope*. Using these observation and the data from [6] they calculated a diameter of 74 ±16 km [7].

The absolute magnitude according to the Minor Planet Center is H_{mag}= 8.6 whereas the value in [6] is given as H_{mag}= 9.41 mag, and that in [7] is given as H_{mag}= 9.51 ±0.08 mag.

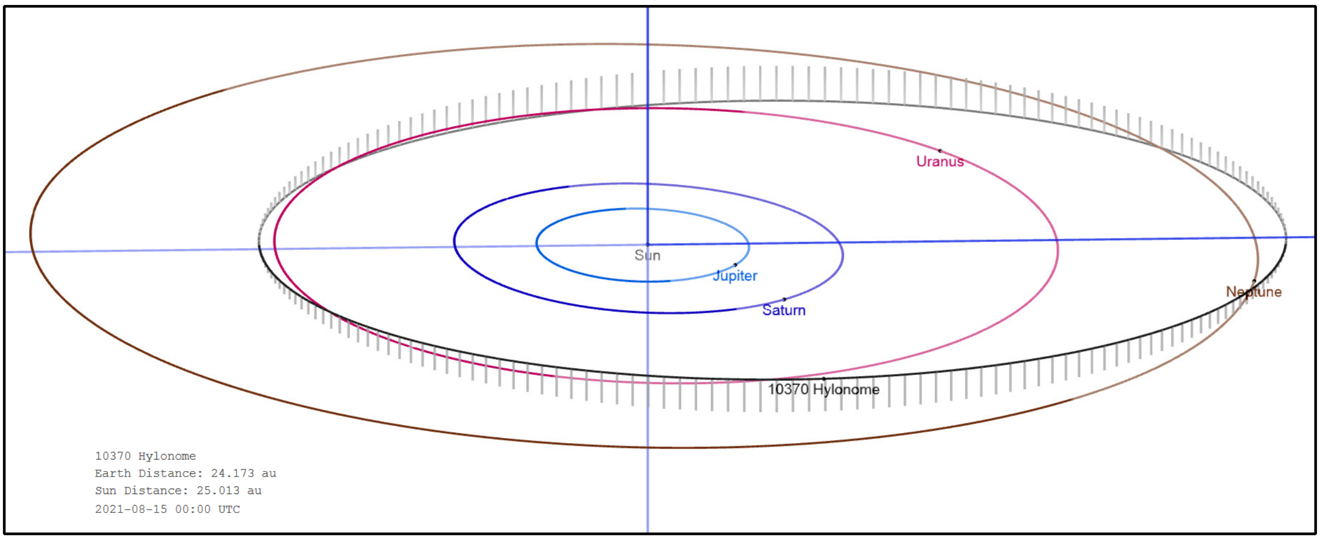

Figure 2. Orbit diagram and position for 2021 August 15. Source: https://ssd.jpl.nasa.gov/sbdb.cgi?sstr=Hylonome

W. Fraser and M. Brown analysed HST observations and found an absolute brightness H_{606}= 10.12 ±0.06 mag [8]. So there appears to be a significant uncertainty in its intrinsic brightness. In the paper by Fraser and Brown, the authors show the existence of two separate classes in the group of Kuiper Belt objects (KBOs), a red class and a blue class. Hylonome is member of the blue class of objects having a B–V magnitude of 0.64 ±0.08 and V–R of 0.46 ±0.06 [5].

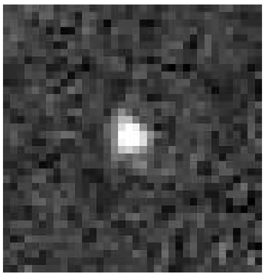

Figure 3. (10370) Hylonome, HST picture, 2009 September 3 (Credit: NASA)

Its rotational period is yet to be determined. In [7] the authors report that its amplitude must be smaller than 0.04 mag.

Stellar Occultations

To date, no occultations by the planet have been observed. A calculation with [9] for the next 4 years (down to star magnitude = 16 mag) yielded some possible observable occultations (Table 1). Of course, the predictions have an error and have to be specified closer in time to the occultations.

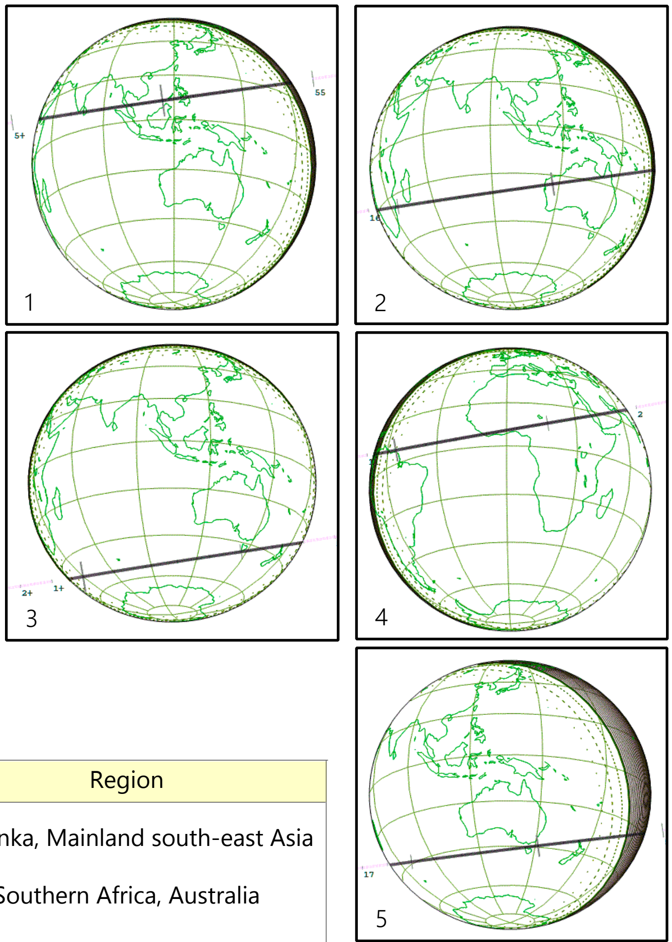

Figure 4. Path maps for the predictions of the events listed in Table 1.

Event	Date, Time (UT)	Star Identifier	mag (V)	Region
1	2022-06-29, 17h00	UCAC4 361-190070	14.3	Sri Lanka, Mainland south-east Asia
2	2022-07-02, 18h10	UCAC4 361-189962	15.2	Southern Africa, Australia
3	2022-07-15, 17h00	UCAC4 361-189409	15.7	Tasmania
4	2022-07-25, 23h00	UCAC4 361-189015	15.8	Africa, Arabian Peninsula
5	2023-06-13, 17h05	UCAC4 364-173358	14.3	Tansmania

Table 1. Possible observable occultations for (10370) Hylonome (2021-2025).

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Further Reading

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

About the Near Earth Asteroid Tracking: https://web.archive.org/web/20040829233039/http://www.lowell.edu:80/Research/DES/index.html

About objects like Centaurs: http://ssd.jpl.nasa.gov/sbdb.cgi http://spacewatch.lpl.arizona.edu http://www.minorplanetcenter.org

IOTA's Annual Meeting Online, 2021 July 17th & 18th

Roger Venable · IOTA · Chester, GA · USA · rjvmd@hughes.net

Invitation

On Saturday and Sunday, July 17 & 18, IOTA will hold its annual meeting online. In contrast to our meetings of previous years, we plan to have presentations from 4:00 PM to 8:00 PM Eastern Daylight Time (that is, starting at 20:00 UT and lasting 4 hours). Note that the daily hours of the conference are different this year. Australian attendees - this is the morning of Sunday the 18th and Monday the 19th.

Please save the dates!

How to Attend Online

The conference will be via Zoom, and the link to the web address will be posted on the IOTAoccultations mailing list [1] and on the webpage [2] a day or two before the conference. Last year we had a max of 87 attendees, and we expect you to be in good company this year also.

Programme

In addition to the Treasurer's report and the IOTA awards presentations, we'll have talks about the discovery of a satellite of asteroid (4337) Arecibo, what we've learned from recent occultations by (3200) Phaethon and (99942) Apophis (see cover of this issue of JOA), best observed recent events and the most promising upcoming events, and some useful software updates. We'll also hear of personal experiences with a prediction application for cell phones, a remote observatory, unusual timers, and getting newbies interested in occultation work. A preliminary agenda is listed in Table 1.

Links

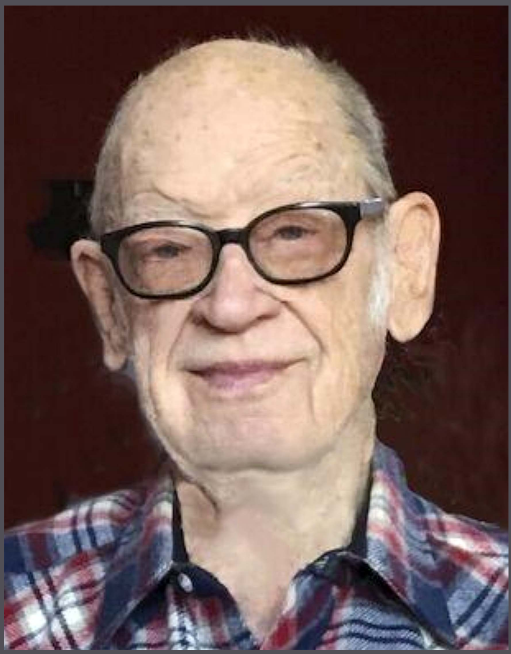
[1] https://groups.io/g/IOTAoccultations
[2] https://occultations.org/community/meetingsconferences/2021-iota-annual-meeting/

Presenter	Topic	EDT	UT
		July 17	
Dunham, Joan	Treasurer's Report	4:00	20:00
Nugent, Richard	IOTA awards presentations	4:20	20:20
Preston, Steve	Best asteroidal occultations of coming year	4:40	20:40
Hanna, Bill	A remote permanent observatory	5:00	21:00
Pavlov, Hristo	Occult Watcher Cloud	5:30	21:30
Nosworthy, Peter	Arecibo satellite discovery	6:00	22:00
Dunham, David	Asteroid satellites & occultations	6:20	22:20
Dunham, David	NEO occultations & planet defence	6:50	22:50
Herald, Dave	Best observed events of last year	7:20	23:20
		July 18	
Olsen, Aart	LED flasher	4:00	20:00
Olsen, Aart	Camera analyzer	4:20	20:20
Nugent, Richard	Bailey's beads cellphone app	4:40	20:40
Anderson, Bob	Diffraction function in PyOTE	5:00	21:00
Green, Kevin	Electronic line noise in our videos	5:30	21:30
Green, Kevin	D & R timing when hay dropped frames	5:50	21:50
Dunham, David	Rethinking the RASC occultation section	6:10	22:10
Kamin, Roxanne	Challenges in intro of new observers	6:25	22:25
Dunham, Joan	Citizen science opps in IOTA	6:40	22:40
Dunham, Joan	Boot camp for occultation observers	7:00	23:00

Table 1. Preliminary agenda of the IOTA annual meeting. The schedule will be updated from time to time, as the meeting approaches.

Derald Nye

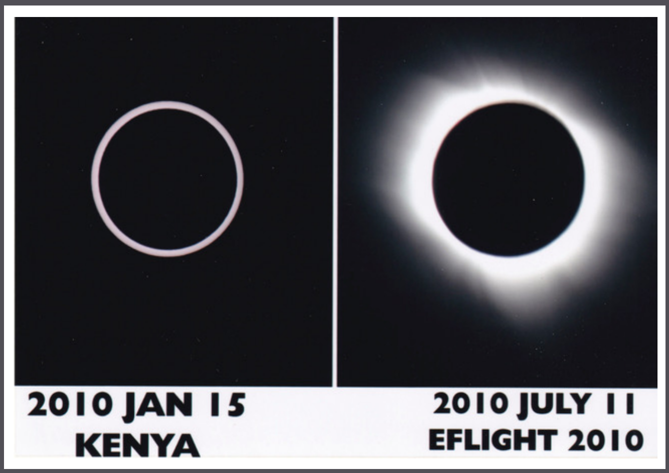
1935 – 2021



Astronomy lost a keen advocate when Derald Nye passed away on 2021 March 26. Until Parkinson's disease limited his travel and observing, he was a regular contributor of occultation and eclipse data to IOTA as well as an advocate for the Association of Lunar and Planetary Observers (ALPO), an active member of the Astronomical League (AL) and the Tucson Amateur Astronomy Association; he organised early efforts to create a national amateur astronomy organisation (a function effectively assumed by the AL), and held the position of Distributor for the ALPO Minor Planet Bulletin for 37 years. He also was active in the North American Sundial Society.

Derald was noted for his observing of eclipses (42 in all), grazing and total lunar occultations, and asteroidal occultations. He observed from most of the countries of the world, multiple islands, from boats, and two eclipses from airplanes. Before her death, Derald and his wife, Denise, travelled widely for observing and for love of travel. Her obituary in the 2006 *Occultation Newsletter Vol. 13 No. 1* gives his list of countries and islands they visited together.

One unusual event Derald and Denise saw was the simultaneous lunar occultations of Jupiter and Venus, observed from Ascension Island on 1998 April 23, a rare occurrence only observable on land from that island and one that will not repeat for 4000 years. Derald played a video of that event for after-dinner entertainment at the 1998 IOTA annual meeting in Brentwood, Tennessee.



Derald's seasonal card for 2010, with an annular and a total eclipse. The total eclipse photo EFlight 2010 was taken from an Airbus A319ER from Tahiti to view the total eclipse at 39,000 ft. The duration of the eclipse was extended to 9 minutes 39 seconds.

Derald recorded multiple events during two grazes of the same bright star, Nunki (ZC 2750), from the same place in 1965. Nunki is only one of two 2nd mag stars that can be occulted by the Moon. The grazes took place on 1965 May 19 and August 9, which he observed from near his home on Merritt Island, Florida. These were the first two of 15 lunar grazing occultations that Derald observed from 1965 to 2000.

He also recorded an asteroidal occultation observed from a boat floating down the Amazon River in 1998 when he observed (15) Eunomia occult SAO 127300, a feat that may never be repeated. In researching his observations it was discovered that a typographical error had been made in the boat location coordinates. That has been corrected so that now Derald's results will provide future observers improved knowledge of (15) Eunomia's orbit and size.

Derald was the recipient of awards from multiple organisations in recognition of his work. These include:

- The Astronomical League's Leslie C. Peltier Award
- ALPO's Walter H. Hass Observer's Award
- A Special Service Citation for his work as the ALPO's Minor Planet Bulletin Distributor
- IOTA's David E. Laird Award

The Nyes were also honoured with an asteroid named for them, (3865) Derdenye.

Joan Dunham
IOTA Secretary & Treasurer

Derald on board Costa Classica off Iwo Jima after a successful total eclipse in July 2009.

Derald with Ann Bullen in Derald's observatory in Tucson, AZ, 2004.

Annular eclipse observing beside the road near Zion Canyon, Utah, in May 2012.

Derald at Mount Kenya Mountain Lodge during a visit for the total eclipse in June 2001.

We are grateful to Derald's friends and family for providing information on his life and these accompanying images.

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

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

The main page of occultations.org provides links to IOTA's major technical sites, as well as to the major IOTA sections, including those in Europe, Middle East, Australia/New Zealand, and South America.

The technical sites hold definitions and information about all issues of occultation methods. It contains also results for all different phenomena. Occultations by the Moon, by planets, asteroids and TNOs are presented. Solar eclipses as a special kind of occultation can be found there as well results of other timely phenomena such as mutual events of satellites and lunar meteor impact flashes.

IOTA and IOTA/ES have an on-line archive of all issues of Occultation Newsletter, IOTA'S predecessor to JOA.

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