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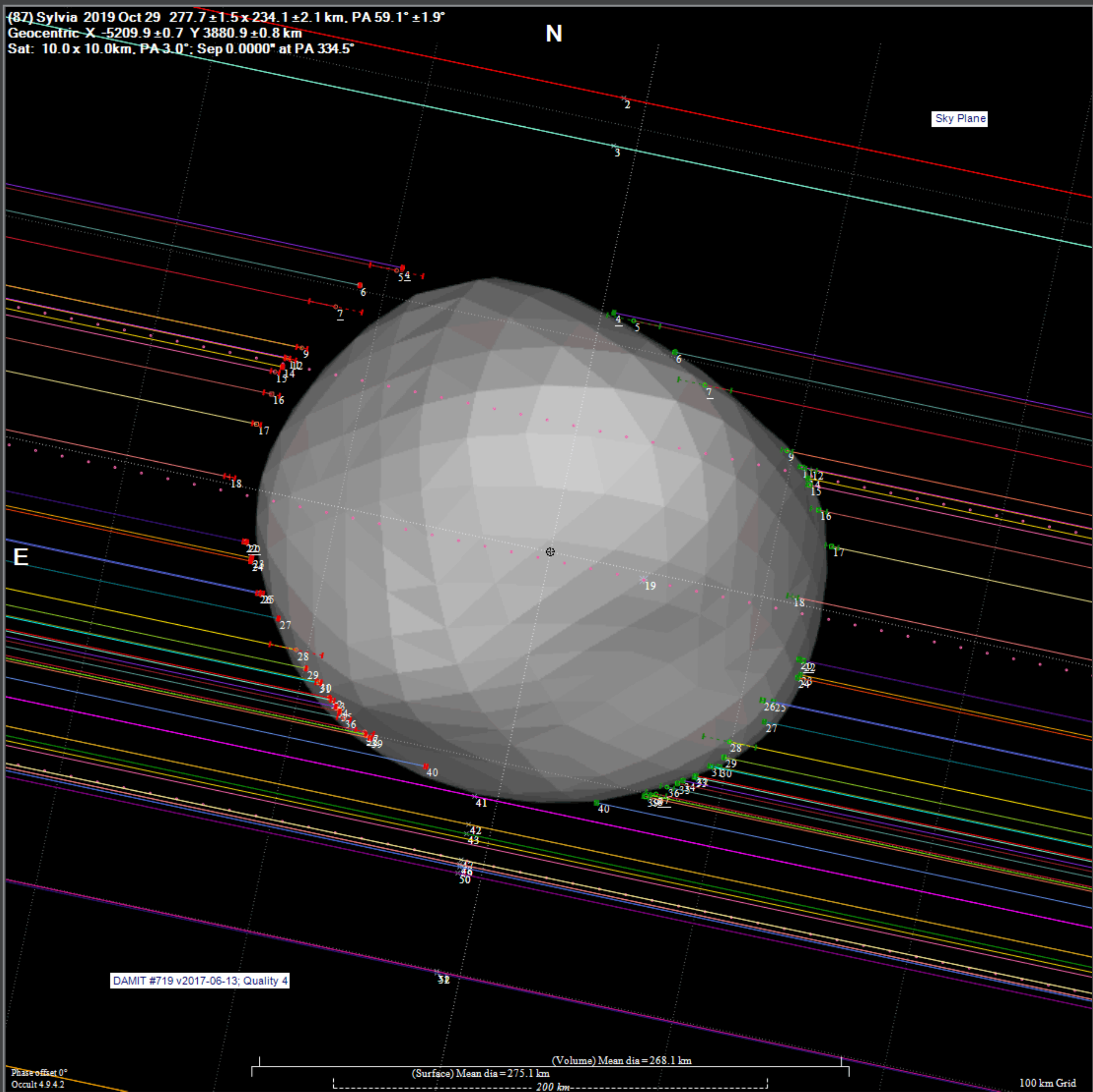

The Occultations by (87) Sylvia & its Moons

Dear reader,

As time goes by: With this issue the *Journal for Occultation Astronomy* has started its 10th year of appearance. But not just this anniversary, also the increasing number of contributions of observers throughout the world prove it's grown in popularity. Thanks to all the authors and especially to those who put it all together for us.
The benefits of the Gaia stellar positions seem to boost the enthusiasm of more and more observers with often thrilling results. One autumn highlight was the extremely well recorded occultation by (87) Sylvia with its 2 moons. The report of Nikolai Wünsche, who luckily recorded a double event that night, proves the functioning of international campaigns within our community at its best.
But still: Successful observations are mainly not a matter of luck but a matter of skill and experience. Lunar occultations therefore should always be a part of occultation work keeping up the routine. Bright star grazing lunar occultations in 2020 are therefore included in this issue as well as discussions about timing techniques.
Hal Povenmire, who passed away on Dec. 6, was a true heavyweight occultation observer who hardly missed any event he could reach. All who knew him remember him as a fine and generous person who contributed so much to occultation astronomy.
Rest in peace, Hal.

Eberhard Riedel

Eberhard Riedel
IOTA/ES

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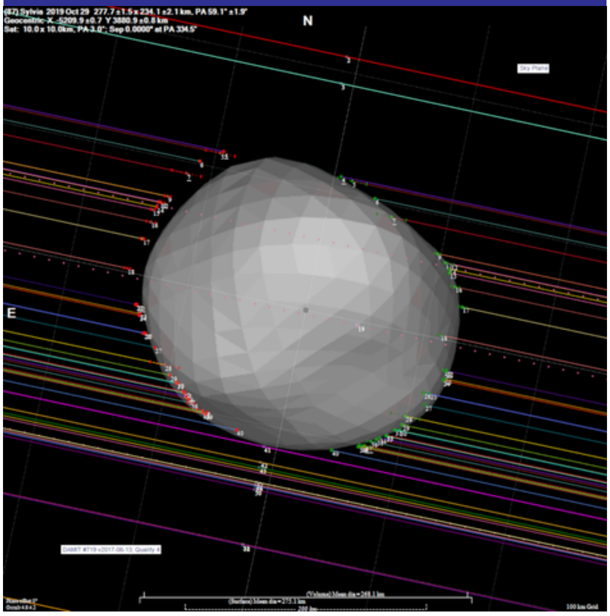
In this Issue:

COVER



50 chords were recorded of the occultation by (87) Sylvia and its moons Romulus & Remus on 2019 Oct 29 across Europe. Besides the successful detections of the shadows of both satellites, 32 positive chords provide the best shadow profile of (87) Sylvia up to now. Eric Frappa, euraster.net, evaluated the measurements and compare the shadow profile with a DAMIT-profile on this issue's cover.

Image credit: E. Frappa, euraster.net
DAMIT - Database of Asteroid Models from Inversion Techniques

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Journal for Occultation Astronomy

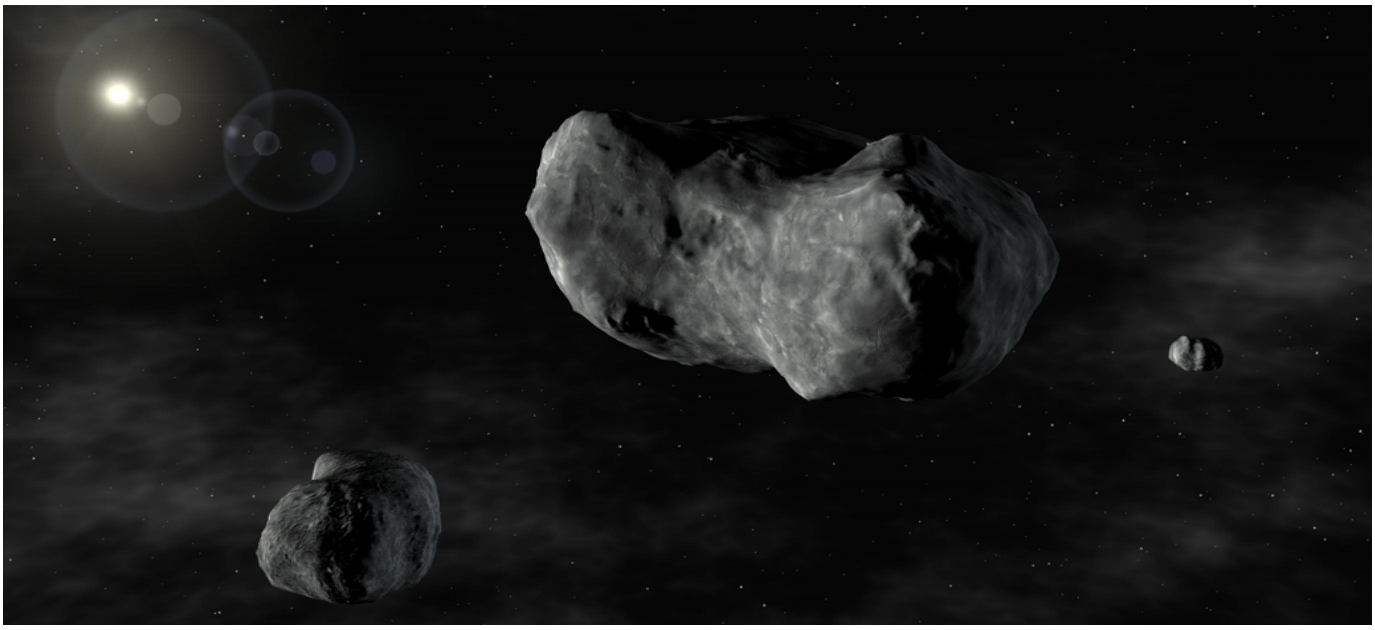

Figure 1. Artist's impression of the triple system (87) Sylvia. Image credit: ESO

A Triple Success - The Occultations by (87) Sylvia and its Moons on 2019 October 29

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ABSTRACT: On 2019 October 29 the triple system (87) Sylvia occulted a 10.1 mag star, observable from across Europe. This paper summarizes a very successful observation campaign, which resulted in the observation of many chords for the primary body (87) Sylvia and double chord observations for both moons Romulus and Remus.

A Triple System

The minor planet (87) Sylvia was discovered in 1866. It belongs to the main belt of the minor planets and moves at an average distance of 3.48 AU from the Sun. With an average diameter of 253 km, (87) Sylvia is the eighth-largest main belt asteroid.

In 2001 a moon of the minor planet was discovered with the Keck telescope. The moon, which was first designated S/2001 (87) 1, has a diameter of 10.8 km and orbits (87) Sylvia at a distance of 1,354 km in 3.65 days. Through further observations with the Very Large Telescope (VLT) in 2004, another companion was found. It was given the provisional designation S/2004 (87) 1. It orbits Sylvia within the orbit of the outer moon and is 10.6 km wide. It moves at a distance of 702 km in 33 hours around the asteroid.

Both objects have almost circular and equatorial orbits around the asteroid (eccentricities below 0.01 and inclinations less than 2°).

Since the minor planet was named after *Rhea Silvia*, the mother of *Romulus* and *Remus* in Roman mythology, the moons were named after these children in 2005 by the International Astronomical Union (IAU).

(87) Sylvia is the first asteroid detected to have two moons, but it remained not the only one. After the discovery of both moons, there were a number of observations of Sylvia and her "children" by the most powerful telescopes on Earth with adaptive optics. A team, led by Franck Marchis, senior research scientist at the Carl Sagan Center of the SETI Institute, has continued to observe this triple asteroid system [1].

Past Occultations

From the 1980s to 2008, several stellar occultations by (87) Sylvia were observed.

After the successful observation by three observers in the USA on 2012 December 22, it was possible to use the Interactive Service for Asteroid Models (ISAM) to generate an initial modelling of the minor planet. The first major campaign for a stellar occultation by (87) Sylvia took place on 2013 January 6. Numerous observers with small telescopes were able to cover the occultation of an 11mag star by the triple system (87) Sylvia in southern France, Italy and Greece.

It is noticeable that there were many “negative” observations at that time. Probably this was due to a less accurate prediction of the occultation path than today.
On 2013 January 6, 15 observers observed a stellar occultation by Sylvia. The occultation by the moon Romulus was registered by four observers. No occultation by the moon Remus was recorded. After this successful campaign, the 3D-model of the minor planet was considerably refined.
Again, on January 6, but in 2014 there was another occultation by (87) Sylvia which was observed by only two observers. On February 11 of the same year, five observers in Japan succeeded in observing an occultation by Sylvia.

The Occultation of 2019 Oct 29

For 2019 October 29, a 10.1 mag star was predicted to be occulted by (87) Sylvia and its moons. As the path crossed Europe and the astronomical conditions such as altitude above the horizon and darkness at the time of event were very favourable, the *Laboratoire d’études spatiales et d’instrumentation en astrophysique* (LESIA), *ERC Lucky Star Project* and the *IOTA/ES* decided to publicise a big campaign.
In addition to the usual publication in *OccultWatcher*, numerous observers were addressed in various ways, who don’t frequently observe occultations [2].

A Great Success!

On the evening of October 29th, another lucky circumstance was added: The weather played along for many places in Europe! However, bad weather prevented observations from southern Germany, Austria and Switzerland and in some regions of France. Shortly after the predicted time of the event there was first positive feedback in Occult Watcher. The mailing list “Planoccult” soon announced the news. Many observers were able to record the occultation by (87) Sylvia.
Two observers were lucky and were able to detect Romulus shortly before Sylvia’s occultation (Figure 3). The shadow path of Remus was predicted right on the southern path limit of Sylvia. Two observers had the luck of the brave and could measure Remus

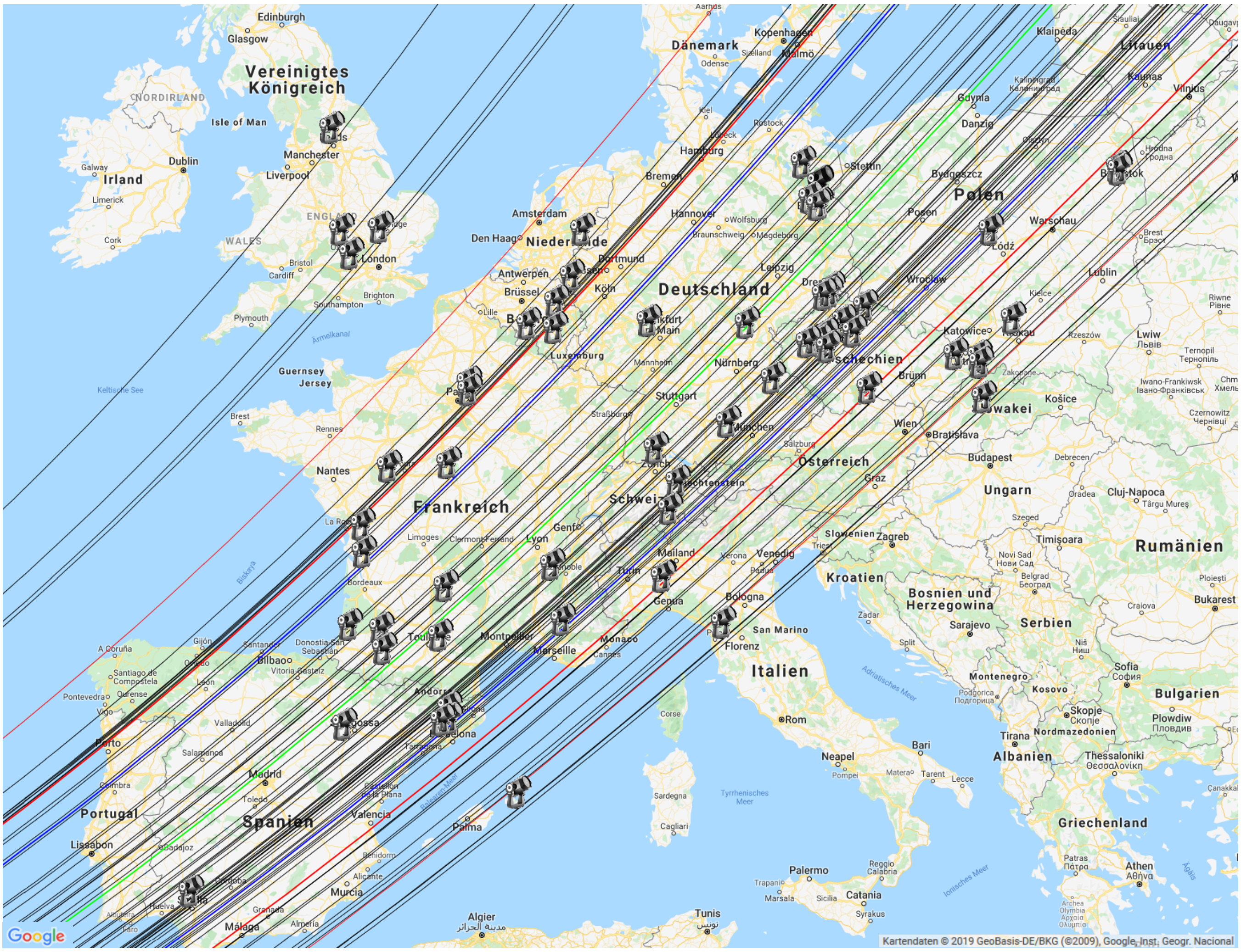

Figure 2. Observers at 64 stations had registered in OccultWatcher for the Sylvia event on 2019 Oct 29.
Map data: © 2019 GeoBasis-DE/BKG, 2019 Google, (©2009), Google)

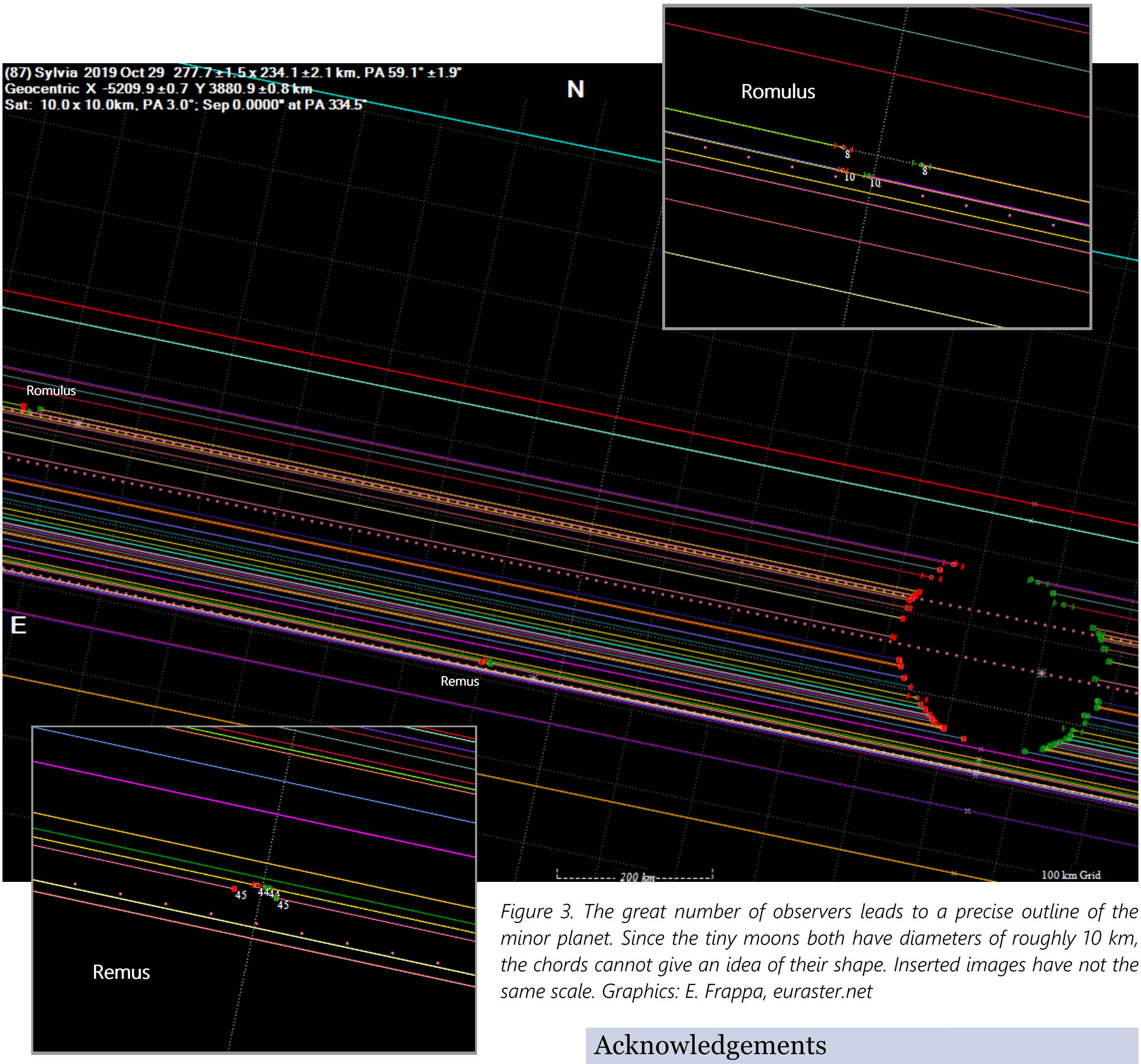

Figure 3. The great number of observers leads to a precise outline of the minor planet. Since the tiny moons both have diameters of roughly 10 km, the chords cannot give an idea of their shape. Inserted images have not the same scale. Graphics: E. Frappa, euraster.net

occulting a star for the first time. However, they recorded negative chords for Sylvia.

With 32 chords for Sylvia (status: 2019 Dec 14) this was an extraordinarily good result (see cover of this issue). The profile of the minor planet can be determined very exactly. There are narrow gaps between the chords at the northern edge only[3].

The Sylvia event can count as one of the most successful campaigns ever for a stellar occultation by a minor planet. Only very few campaigns in Europe have delivered even more chords at an event [4].

The further detailed evaluation of the observations will be done by *LESIA / ERS Lucky Star* in Paris. Surely it will take a while until final publication.

Acknowledgements

Thanks to all the observers who tried - whether they succeeded or not. (Also a 'negative' observation is important.)

Thanks to Eric Frappa, euraster.net, for his evaluation and the creation of the graphics using the *Occult* software by Dave Herald.

References

[1] Keck Observatory News, 2013 Oct 7

[2] Klös, O., Observers Wanted! - Experiences from Publicising the (87) Sylvia Occultation, Journal for Occultation Astronomy, No. 2020-01, Vol. 10 No. 1, p. 32-34, 2019

[3] Frappa, E., Results of occultation by (87) Sylvia, 2019 Oct 29 http://euraster.net/results/2019/index.html#1029-87

[4] Frappa, E., Index of best events and measurements, euraster.net http://euraster.net/results/index_red.html

How I Observed 'Sylvia'

or:

The Less Prepared You Are for an Observation, the Better Are the Odds for Success!

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ABSTRACT: The stellar occultation by minor planet (87) Sylvia and its moons was one of the top occultation events in 2019. The author, who is a passionate meteor observer, got alerted via a mailing list less than 24 hours before the event. Having the experience of just one previous event and without any serious preparation he tried to observe the occultation anyway. Many things could have gone wrong, as described in the report, but against all odds the event was observed successfully in the end. This leads to the (not quite serious) conclusion, that your chances of success are better, the less prepared you are for your observation.

It's Tuesday morning and I'm on vacation in my home state of Brandenburg. I read an e-mail by Konrad (Guhl) on the Astro-Berlin mailing list: *„Don't forget the stellar occultation by minor planet Sylvia tonight. If there are still any questions, don't hesitate to ask"*.

I browse the internet and find it to be **the** occultation event of the year, since (87) Sylvia is not just an ordinary minor planet, but one that has two moons (Remus and Romulus) which may occult the star as well. The star TYC 1932-00469-1 is of 10th magnitude and the dip will be about three mags, which should be manageable with the right equipment. The weather forecast for the night is fine, I have observed only one stellar occultation by a minor planet in my astronomy life so far (back in 2003 by "Bertholda" – with success!) and I am on vacation – so why not? That sounds like an interesting observation and according to my previous experience you have the best chances, anyway, if you are poorly prepared or totally unprepared for such an undertaking.

Unfortunately, I have no astronomy equipment with me on my vacation. So I ask back on the mailing list, if someone has a telescope for me and If I can join some observer group. However, my mail is not delivered since Yahoo groups has stopped service on that very day. Nonetheless, Konrad und Niko (Wünsche) contact me in the afternoon by mail. Both plan to observe at their respective private observatories and have no spare equipment, but I could give it a try at my old astronomical home, the Archenhold Observatory of Berlin. Hmm, in theory I still have a key card, but I haven't used it for 25 years, so I'm skeptical ...

In the evening, Konrad is giving me a call. Yes, my keycard should still be active, but I also need a key for the garden gate. A key? I don't have a key! Or do I? In fact, there has been a key for decades in my pencil case back from high-school times which I cannot link any more. Is that the one? Well, it's worth a try, and if my memory is right, the fence to the observatory is not very tall, anyway. Konrad also tells me, that there are some cameras in the locker of the meeting room: a Watec video camera (which I know as a meteor observer, but I don't have a video recording device at hand) and two USB cameras. I could use the *FireCapture* software for recording. I never used any of these cameras nor the software before, but after all I'm heading primarily for a visual observation. The cameras are only an optional add-on. As I still have some time, I download the software to my notebook and have a look at it. The user interface has a vast number of options, but fortunately the software has a kind of demo mode. So I get at least a rough orientation. Finally, I download the predictions of the event (time of occultation in Berlin at 00:39:20 CET) and the finder charts and get in the car.

My navigation system forecasts a travel time of 1.5 hours, but at this time of day there is only little traffic in Berlin, so I reach Treptow in slightly more than one hour. As in the past, I park my car in front of the observatory (which is probably forbidden nowadays) and give it a stab. Indeed, the key fits into the lock, so I walk to the primary building and insert my keycard into the reader: peeppeeppeep – red light. Damn! The card is not working any more or it has been disabled. I give it a second and third try: peeeeep – green light. Ah, it is still working! Inside the same procedure at the key locker. It opens after the third try and I can take the keys for the largest available telescope of the observatory, a 50 cm Cassegrain, and for the meeting room with the cameras (Figure 1). Wow, the first hurdle is successfully overcome!

I walk to the telescope building and unlock the meeting room. Fine, it's nice and warm and even has a coffee maker (even though I don't drink coffee). I enter the dome and fortunately recognise almost everything. I open the slit of the dome and look for the master switch. Damn! There is now some fancy control box, where it used to be 25 years ago. I search for it but don't find it. A quick call and Konrad tells me it is now located in the hallway, and also where I can switch on the telescope guiding. Both switches activated – voilà: The dome is operating and so is the guiding. So I remove all covers from the instrument and search for Gemini.

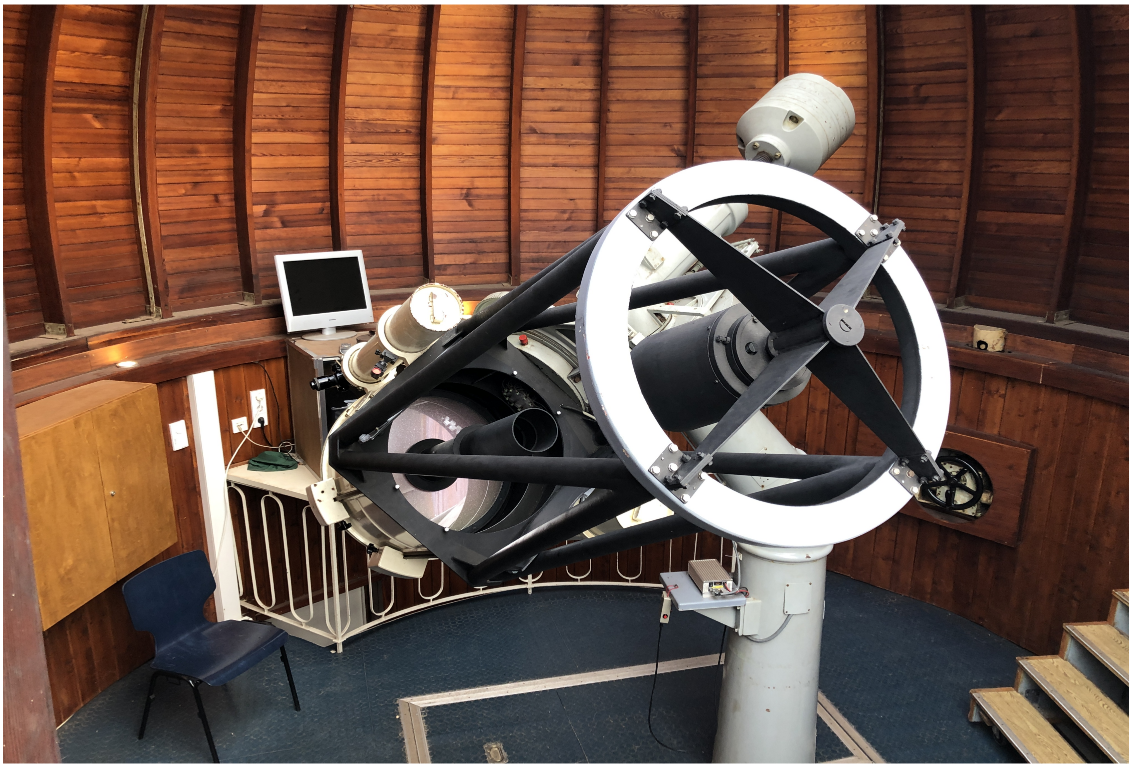

Figure 1. The 500/7500 mm Cassegrain telescope of the Archenhold Observatory in Berlin-Treptow, Germany. (Image: K. Guhl)

Hmm, the constellation is quite close to the trees on the northeastern horizon – the limiting magnitude of misty Berlin skies down there is four mags at best. There are still six magnitudes missing to the star – if that can be achieved by a 50 cm mirror? I point the telescope at Pollux and see … nothing. Damn, I forgot to remove one of the caps. Thereafter it is twinkling at me in the primary tube. And how it is twinkling! I try to focus the star, but with this seeing it remains as big as a planetary disk! Who cares, after all I'm not going for a high-resolution planetary image, but for a stellar occultation.

Now that the telescope is working, I go one floor down to the meeting room. It's 11 pm, hence I still have sufficient time for camera experiments. I open the locker, find the camera box, open it – perfect, everything's together. I attach the camera to my laptop and start the software – nothing. Hmm, probably there is some driver missing. I switch my mobile phone to a hotspot, search for the driver on the internet, download and install it. The camera runs and I have an image. Now I just have to marry the camera with the telescope. In the cabinet I find the necessary adapter. I walk up to the telescope, remove the eyepiece, attach the camera and start the software, I see … nothing. Strange! Pollux should be bright enough in a 50 cm telescope to be found easily. I turn the focus from one end to the other – still nothing. I check once more visually, if the star is really exactly at the centre of the field of view, and attach the camera again – suddenly a faint light is swinging though the field of view. I try to focus it and realize that I still need another spacer ring. After that is attached, I get Pollux in focus – if you can call that a focus at all. The field of view is only a few arc seconds in size and the star is a huge, flickering spot. Anyway, it is working in principle and I still have about half an hour left until the occultation.

Now we come to the trickiest part of all: Star hopping to the target star! I open the star map at my (much too bright) notebook display and try to orient myself in the finderscope: If that is Pollux, then the star next to it should be phi Geminorum. Or the other star? By the way, what is the orientation of the field of view? I try for some time and then I give up. I will never succeed! And with these misty skies it is nearly hopeless, anyway. But I give it one last try: At some time in the past 25 years, the telescope got a stepper motor control with digital display, which seems to have a simple handling. So I quickly search for the coordinates of Pollux and the target star on the internet, calculate the difference in right ascension (0h 36') and declination (2° 4') in Excel and start to drive to the target position with the manual control box. It is twenty minutes past midnight. If the control box is working properly or if the coordinate difference is displayed correctly – I have no idea. I'm using this equipment for the first time! At least the telescope is moving veeery slooowly in the right direction.

It is ten minutes before the start of the occultation and the target position is reached. At least in theory. In the finderscope I see nothing and in the primary telescope I see two faint stars. I decide on one of them and steer it into the centre of the field of view. Now a quick change from the eyepiece to the camera again … nothing. Damn, it seems the star is too faint in the end. No wonder, given these bright Berlin skies!

Five minutes are left. So I switch once more to the eyepiece, point the star exactly at the centre of field of view again, switch back to the camera and – voilà: a blurred spot swings along the lower border. I drive it into the centre with the manual control, focus it once more as good as possible, and have another look at the watch: 00:37!

Ok, I have another quick look at the software settings. I increase the integration time to 0.2s so that the star becomes more prominent. 00:38! It's more than high time to start the recording. It's just about a minute until the predicted occultation time!

I decide not to use the 15 cm steering telescope for visual observation, because the star is barely visible there. In addition, I fear to shake the telescope and lose the star. I better don't move and watch the live image of the camera on my notebook. The chance of looking at the right star is ... small. Really small. But, anyhow, I do have a star and even if it is the wrong one, it was still absolutely amazing that I got that far at all, and I had a lot of fun with that.

I start the voice recorder on my mobile phone in case I see something visually. The computer clock jumps to 00:39 and I start to count the seconds loudly: 1 .. 2 .. 3   15 .. 16. Ok, it would have been too nice, I think. 18 .. 19 .. gone. It is gone. The star has disappeared! I don't believe in my eyes and continue to count: 37 .. 38 .. 39 .. 40 – there it is again. That's impossible. I really caught the right star and I have just recorded against all the odds the stellar occultation by Sylvia!

It takes me a few minutes to realize how fortunate I was. I leave the camera running for another five minutes because I don't know at what time the moons would occult the star, if by any chance I would even be at the right position. The star remains visible. Ok, in the end I will only know when I have analyzed the video, since there were also a few seconds where I did not glare at the monitor.

I close the slit of the dome, cover the mirrors, put the camera into the locker and walk back to the main building. This time the card reader lets me enter already at the second try, and I can lock back the keys. My car is waiting for me without a traffic ticket and I'm driving home. On my way I call Konrad and tell him about my adventure. Unfortunately, he has not been as successful – he had to move his scope to a different spot. Everything was well prepared: camera, time sync, telescope – in the end he was just missing some minutes to point the telescope at the right star. But when we thought about it we quickly agreed, why his observation had to fail contrary to mine: It was simply much too well prepared. And my success rate in observing stellar occultations by minor planets remains even after the second try at 100%.

Postscript: On the next day, Niko regrets that I did not start the recording two minutes earlier, because then I might have even recorded the occultation by the moon Romulus, which was visible at his site and another location in Berlin. The analysis of my video reveals later, that I had started the video indeed just five seconds before the potential occultation. The star was clearly visible at the time in question, hence the moon did not occult the star. It also reveals, that the camera had several half-minute dropouts (Figure 2). The second one just two seconds after Sylvia had uncovered the star. So everything that was potentially to be observed at Archenhold Observatory in Treptow is indeed in the box, namely on my hard disk!

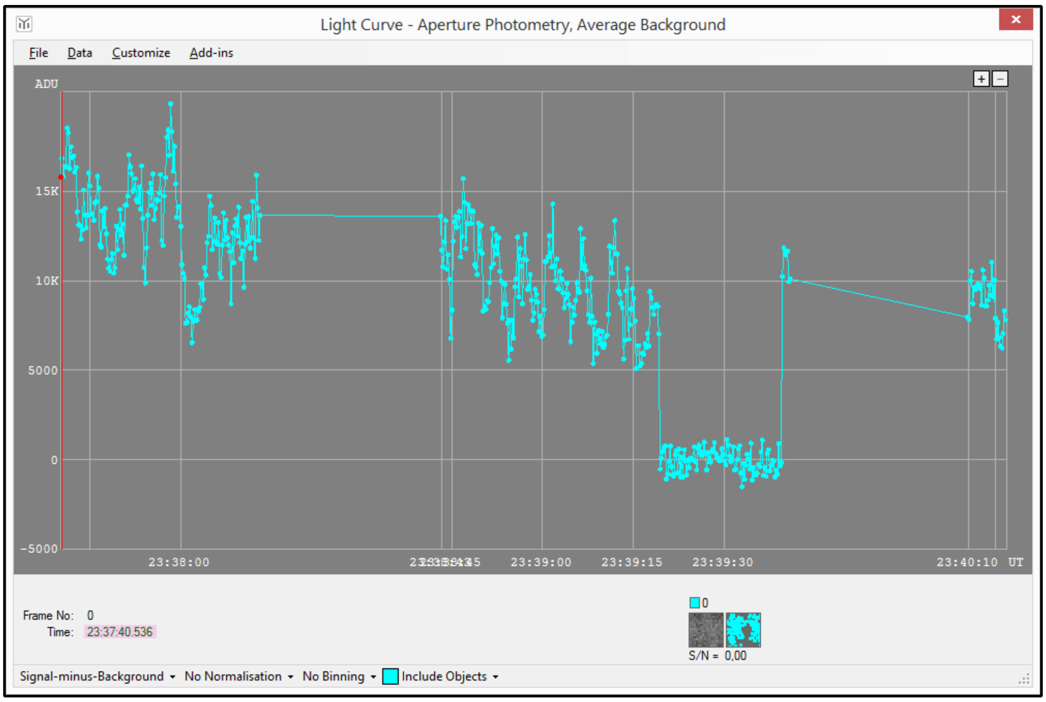

Figure 2.
Lightcurve of the recording of the occultation by (87) Sylvia by Sirko Molau. Notice the dropouts before and just after the occultation.

Journal for Occultation Astronomy

All-Of-System Time Testing Using Lunar Occultations

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ABSTRACT: Getting the time right is imperative when observing occultation events. Correct time *IS* the observation. When using analogue video, it is easy to insert time onto each and every video field, using a Video Time Inserter like KIWI-OSD or IOTA-VTI. However analogue video is a dying medium and new digital video has many varied formats and is becoming popular. Also, methods to Flash Tag video, using various devices (some based on smart-phone technology) are becoming popular.
Other persons might test devices or software in a laboratory environment, but how can you, the observer, the person responsible for the reported event times ensure that your times are correct and are as accurate as you say they are? How can you ensure your event times are right?
We set out an approach to validate your All-Of-System time accuracy, by observing Lunar Occultations.

Introduction

For an occultation event, the single most-important item is reporting the correct event times. Failure to have correct times will lead to your observation being inconsistent with the observations of other observers, and potentially disregarded in the analysis to determine the size and shape of the asteroid. Even if you are the only observer to record an occultation, the highly precise astrometric position that gets reported to the Minor Planet Center as a result of the observation will be 'wrong', and have the potential to degrade the accuracy of occultation predictions in the future. But while it is critical for all observers to be reporting 'correct' times, how does an observer know if their times are 'correct'? Indeed, how does an observer build confidence in the fact they are applying all required corrections to derive the 'correct time'?

Sources of Time Error

There are many possible sources of incorrect event times, of which the following are some:

- Lack of, or incorrect corrections for, the delays within a camera between when the camera takes an image and when the image is output from the camera.
- Recording a video onto a PC, with the PC undertaking the task of time-stamping the video in accordance with the PC clock – with issues of the accuracy of the PC clock, delays in extracting the time from the PC clock to be used in applying the time stamp, and image transfer delays in the PC between when the image was actually taken and when it was processed and timestamped within the PC.
- Synchronising the PC using Network Time Protocol (NTP), where:
  - Land-line telephone networks can have variable propagation delays.
  - The time quality depends on the distance to the time server.
- Synchronising the PC using a USB-connected GPS receiver. These do not usually have the 1-pulse-per-second (1PPS) connection vital for accurate GPS time. Note: All GPS receivers output a serial sentence that describes various attributes, including time as part of the sentence. The output of the sentence is not referenced to UTC accurately enough for our purposes. It is only when the serial sentence is combined with a 1PPS signal that the total output of the GPS receiver can be considered to represent UTC.
- Time signals via mobile phones, where;
  - delays associated with the mobile phone network can vary depending on the cells used and the signal strength.
  - GPS receivers in mobile phones don't usually output the 1PPS signal. (See comment above about GPS receiver output.
- Synchronizing a recorder's clock with a reliable time source well before and then after an event – and assuming the drift in the clock is linear over that period.
- Radio time signals (such as WWV). The transmission path usually involves multiple bounces between the Earth's surface and the ionosphere, with delays dependent upon the number of bounces.

A difficulty with all these issues is that any error in the time stamping is not readily apparent. In the absence of means to assess the accuracy, observers can fall into a trap of overconfidence that their times are right. Observers might express their belief as 'it

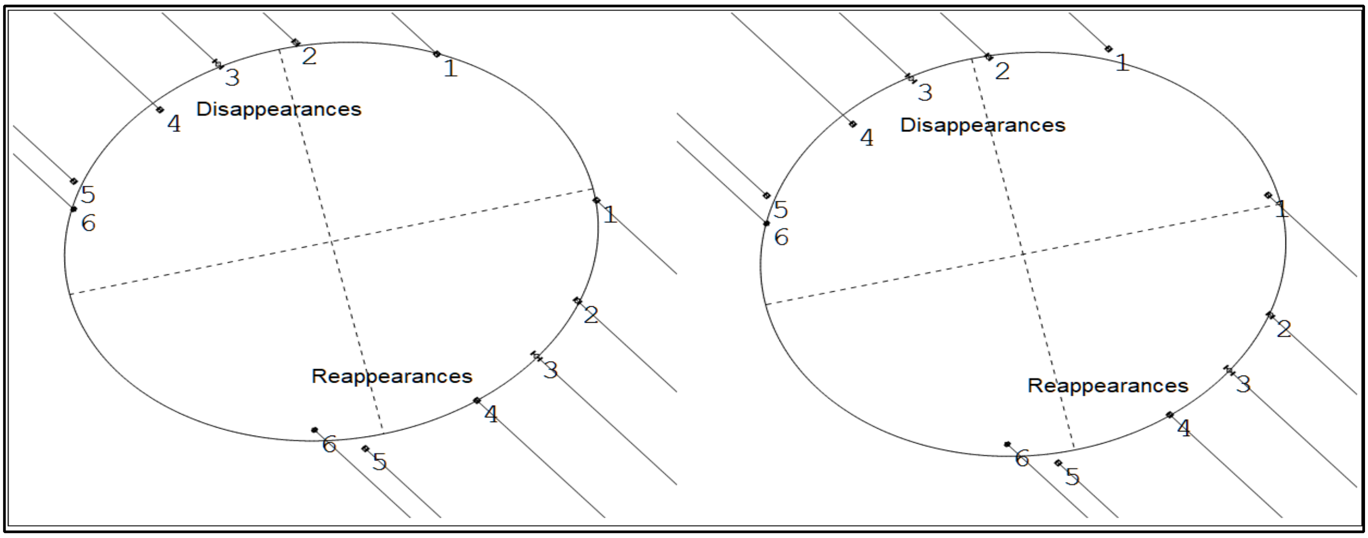


Figure 1. Asteroidal occultation plots of the same event, with one chord offset by -0.1 seconds in the right plot.

must be correct' because they are using such and such software or device. But is that confidence well justified?
Unfortunately, the simple answer is – very often, No.

What Is the Effect of Bad Timings on Asteroidal Occultations?

A possible time-base error can easily be seen in a typical asteroidal occultation plot. See Figure 1.

Examination of the left plot is as follows;

- Chords 1, 2, and 3 fit the ellipse well.
- Chord 4's disappearance appears to be a bit late, but the reappearance fits the ellipse well. The disappearance may well be due to irregularities in the asteroid profile.
- Chord 5's disappearance might appear to be early, and the reappearance might appear to be late, but both are symmetrical to the fitted ellipse.
- Chord 6's disappearance fits the ellipse well, but the reappearance seems a little early, but may well be due to surface irregularities in the asteroid profile.

Examination of the right plot is as follows;

- Chord 1 has been deliberately time-shifted by -0.1 seconds to illustrate why the need for precise time. Note the symmetry – both events appear to be early when compared to the fitted ellipse. This is typical of an error in the time-base.

Of course we'll never truly know which events are early or late or attributable to asteroid irregularities. The goal after all is not to artificially fit event timings to ellipses or even 3D models. The goal is simply to make the best observation timings possible, and to be confident that they are as accurate as stated.
The observer should test their observing system regularly, including their knowledge of corrections that need to be applied. The best way to do that is to observe lunar occultations – regularly.

Why Observe Lunar Occultations?

Up to 10 or 15 years ago, lunar occultations were used as a basis for measuring the irregular rotation of the Earth, and improving our knowledge of the motion of the Moon. There were also issues with our knowledge of the lunar profile including during the Cold War, an attempt to link geographic datum for military applications [1]. For ordinary occultations, lack of precision in the profile resulted in Observed-Computed (O-C) residuals which were typically many tenths of an arc-second.

For the polar regions, grazing occultations were used in an attempt to improve our knowledge of the limb regions.

In recent times there have been important improvements in a number of areas. Specifically:

- The lunar ephemeris has been steadily refined to an accuracy of metres or less, on the basis of lunar laser ranging.
- The lunar surface elevation has been mapped at the 1-metre level by satellite – firstly by Kaguya – SELENE [2]; subsequently by LOLA [3] (Lunar Orbiter Laser Altimeter) on board the Lunar Reconnaissance Orbiter. This has allowed us to accurately compute the height of the lunar limb at any location.
- Star positions are now being taken from Gaia DR2 [4] wherever possible; positions for bright stars that are not in Gaia are taken from the Hipparcos2 [5] catalogue. The number of occulted stars whose positions are not from Gaia DR2 or Hipparcos2 is fewer than about 1%.
- In the *Occult* [6] reduction process, star positions are now being corrected for stellar parallax, and gravitational deflection by the Sun. This has become relevant and necessary because of the preceding three improvements.
- The reduction process also includes Earth Orientation Parameters. These parameters make adjustments for the movement of the location on the Earth of its axis of rotation.

These improvements mean that the occultation of a star at the lunar limb can be predicted and analysed with certainty. In particular:

- The once referred to Marginal Zone of the Moon is no longer marginal.
- Occult predicts lunar occultations with a precision of a few tenths of a second (with the limitation on precision being associated with using only a semi-precise limb correction).
- Most importantly, Occult can analyse the residual of a lunar occultation to single digit milli-arc- seconds (mas) precision.

If an observer observes a statistically significant number of lunar occultations (at least 10), preferably both disappearance (evening) events and reappearance (morning) events of stars at the unlit limb, then Occult will produce a Residual Summary Report that will give you assurance that your All-Of-System times can be relied on, or not.

Method

Firstly, we need a set of lunar occultation observations made using the subject observing system.

- ◦ If an analogue integrating video camera is used, it should be set to non-integrating mode.
- ◦ If a digital camera (of any type) is used, it should be set to an image cadence of 25 frames per second or faster.

The observation times are entered into an Occult - Observation Report. A tutorial [7] has been created to aid this process.

The Occultation residuals report that Occult will produce lists the O-C values for each event. The O-C value is given in two formats:

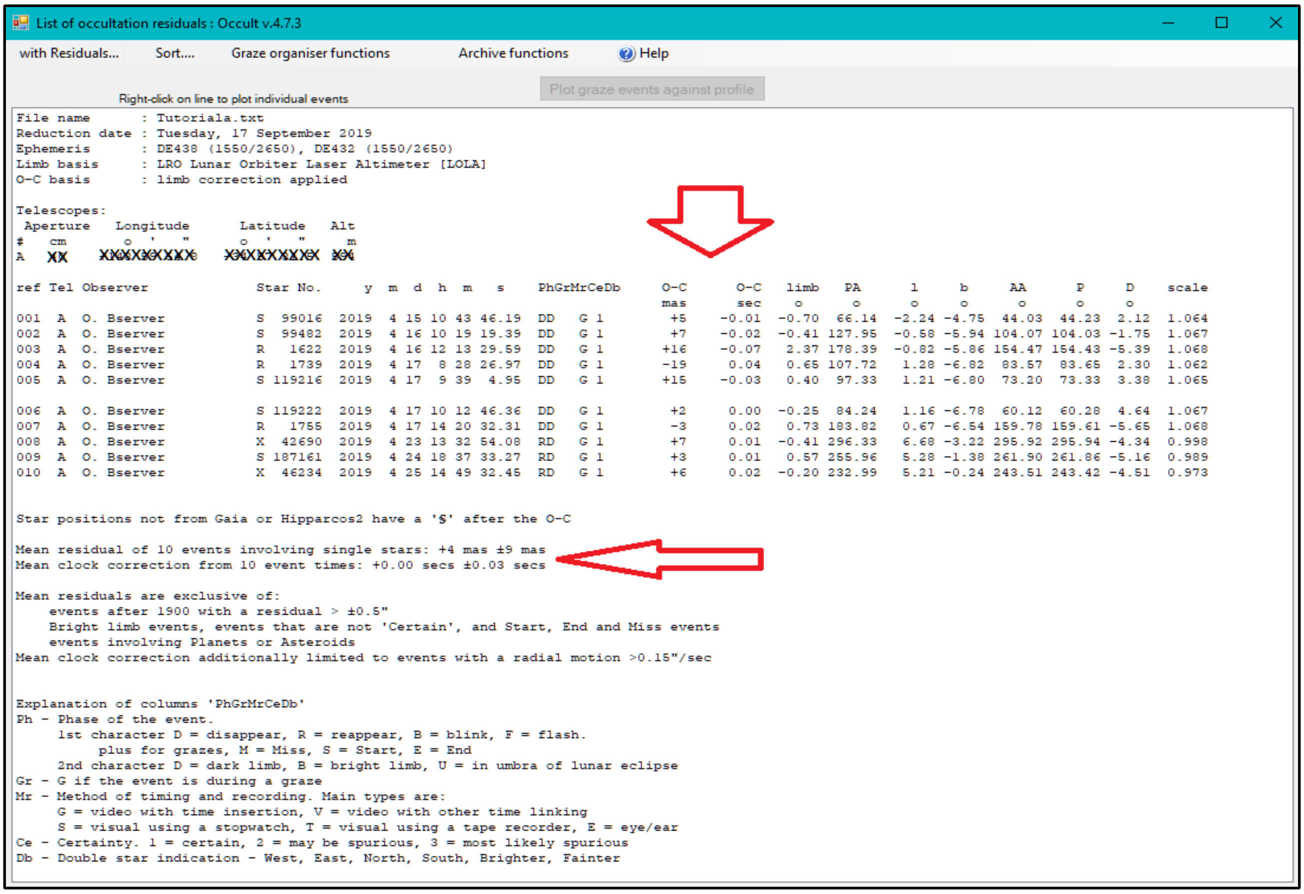
- The computed height of the star above or below the limb at the observed time, reported in angle mas; positive value is above the limb, negative value below the limb.
- The equivalent 'time error' in your reported time, reported in seconds. If this value is negative, your reported time is too early; if it is a positive value, your reported time is too late. The sign of this 'time error' is opposite to that of the computed height error for disappearances, and the same for reappearances (Figure 2).

Some care must be taken with the time error value. It is derived by dividing the computed height residual in mas, by the radial rate of motion of the lunar limb, given as RV (arc-sec/second) in Occult predictions. For near-graze events this has the effect of turning a small height residual into a large time error – and this can be misleading.

The report form provides a statistical analysis of the residuals. To ensure the statistics are reliable, events involving the following, are excluded:

- Double stars.
- Events with an O-C value greater than 0.5" – on the basis that this is may be an indication of a problem with the star position.

Figure 2. The Occult – list of occultation residuals form



```
List of occultation residuals : Occult v.4.7.3
with Residuals...   Sort....   Graze organiser functions   Archive functions   Help
Right-click on line to plot individual events        Plot graze events against profile

File name      : Tutoriala.txt
Reduction date : Tuesday, 17 September 2019
Ephemeris      : DE438 (1550/2650), DE432 (1550/2650)
Limb basis     : LRO Lunar Orbiter Laser Altimeter [LOLA]
O-C basis      : limb correction applied

Telescopes:
 Aperture   Longitude      Latitude    Alt
#   cm        o  '  "       o  '  "      m
A   XX     XXXXXXXXXX     XXXXXXXXXX   XXX

ref Tel Observer          Star No.     y  m  d  h  m     s   PhGrMrCeDb    O-C     O-C  limb     PA      l     b     AA      P     D  scale
                                                                           mas     sec     o      o      o     o      o      o     o
001  A  O. Bserver        S  99016  2019  4 15 10 43 46.19   DD   G 1       +5   -0.01 -0.70  66.14  -2.24 -4.75  44.03  44.23  2.12  1.064
002  A  O. Bserver        S  99482  2019  4 16 10 19 19.39   DD   G 1       +7   -0.02 -0.41 127.95  -0.58 -5.94 104.07 104.03 -1.75  1.067
003  A  O. Bserver        R   1622  2019  4 16 12 13 29.59   DD   G 1      +16   -0.07  2.37 178.39  -0.82 -5.86 154.47 154.43 -5.39  1.068
004  A  O. Bserver        R   1739  2019  4 17  8 28 26.97   DD   G 1      -19    0.04  0.65 107.72   1.28 -6.82  83.57  83.65  2.30  1.062
005  A  O. Bserver        S 119216  2019  4 17  9 39  4.95   DD   G 1      +15   -0.03  0.40  97.33   1.21 -6.80  73.20  73.33  3.38  1.065

006  A  O. Bserver        S 119222  2019  4 17 10 12 46.36   DD   G 1       +2    0.00 -0.25  84.24   1.16 -6.78  60.12  60.28  4.64  1.067
007  A  O. Bserver        R   1755  2019  4 17 14 20 32.31   DD   G 1       -3    0.02  0.73 183.82   0.67 -6.54 159.78 159.61 -5.65  1.068
008  A  O. Bserver        X  42690  2019  4 23 13 32 54.08   RD   G 1       +7    0.01 -0.41 296.33   6.68 -3.22 295.92 295.94 -4.34  0.998
009  A  O. Bserver        S 187161  2019  4 24 18 37 33.27   RD   G 1       +3    0.01  0.57 255.96   5.28 -1.38 261.90 261.86 -5.16  0.989
010  A  O. Bserver        X  46234  2019  4 25 14 49 32.45   RD   G 1       +6    0.02 -0.20 232.99   5.21 -0.24 243.51 243.42 -4.51  0.973


Star positions not from Gaia or Hipparcos2 have a '$' after the O-C

Mean residual of 10 events involving single stars: +4 mas ±9 mas
Mean clock correction from 10 event times: +0.00 secs ±0.03 secs

Mean residuals are exclusive of:
    events after 1900 with a residual > ±0.5"
    Bright limb events, events that are not 'Certain', and Start, End and Miss events
    events involving Planets or Asteroids
Mean clock correction additionally limited to events with a radial motion >0.15"/sec


Explanation of columns 'PhGrMrCeDb'
Ph - Phase of the event.
     1st character D = disappear, R = reappear, B = blink, F = flash.
          plus for grazes, M = Miss, S = Start, E = End
     2nd character D = dark limb, B = bright limb, U = in umbra of lunar eclipse
Gr - G if the event is during a graze
Mr - Method of timing and recording. Main types are:
     G = video with time insertion, V = video with other time linking
     S = visual using a stopwatch, T = visual using a tape recorder, E = eye/ear
Ce - Certainty. 1 = certain, 2 = may be spurious, 3 = most likely spurious
Db - Double star indication - West, East, North, South, Brighter, Fainter
```

- Events where the 'certainty' field in the report of the observationis not specified as being certain; we only want to rely on events that were definitely observed.
- Events where the star position did not come from either Gaia DR2 or Hipparcos2.
- Bright limb events – as there are inherent difficulties in observing bright limb events.
- Events involving planets or asteroids – to avoid the complications associated with the disks of these objects.

Additionally, for the time-error value, events are only considered if the radial rate (RV) of motion of the star is greater than 0.15"/sec. Note that for the great majority of lunar occultations the radial rate of motion will typically be around 0.4"/sec.

The statistical analysis of the observations is provided at the bottom of the report.

Discussion

A first point to note is a limitation in the residuals. The LRO dataset is immense. To render it suitable for dissemination for Occult users, the height values were 'binned'. The bins each extended 0.01 deg in angle around the limb of the Moon, and 0.02 deg in angle towards/away from the Earth – equivalent to an area of 300 x 600 metres. The limb height (in metres) for that binned region was then taken to be the mean of all heights mapped to that bin. At the distance of the Moon, 1 mas equates to approximately 2 metres. Consequently, variations of just a few metres in surface elevation across that 300 x 600 metre binned region could result in 'errors' in the computed limb correction of the order of several (or even many) mas.

The statistical values are usually given as a mean plus an uncertainty. However if there are less than 3 events meeting the above criteria, the uncertainty is not given – and the results are insufficient to draw any conclusions.

The line giving the mean residual and uncertainty will give you a good idea of your general accuracy. For an instrumental observer (e.g. using GPS+1PPS Time-Inserted NTSC or PAL video) you should expect a mean residual of smaller than about 10 mas, and an uncertainty of less than about 30 mas. However these residuals do not give you a good idea of timing accuracy.

The line giving the 'Mean clock correction' provides the information about time accuracy. It provides a mean value and an uncertainty value. Typically, the mean value for an instrumental observer should be less than 0.02secs, and the uncertainty less than 0.04 secs.

The issues to be dealt with here are:

1.

Is the time uncertainty significantly larger than 0.04 secs? If so, there are two possible explanations:

- You don't have enough observations to get a reliable measurement. Solution – make some more observations!
- Your source of time is irregular. That is, your source of time has a variable offset to 'true' UTC. Solution – you need to find a different source of time.

2.

Is the Mean clock correction outside of the uncertainty range (or, indeed, close to the limits of the uncertainty range)? This indicates a constant time offset in your reported times. This could be caused by many factors such as, but not limited to:

- Incorrect correction for camera delays.
- Ignorance of timing issues in a PC when the PC is used to time-stamp a video.
  - If using NTP then you need to ensure the recording PC has the best possible connection with the LAN router, and the NTP Server is as geographically close to your observing site as possible.
  - If using a USB-connected GPS receiver (without the 1PPS signal) you need to use software that assesses USB bus latency.
- If using a 'Flash-Tag' device to provide a time reference, together with frame counting to deduce event times - your recording system may be periodically removing frames or adding duplicate frames. You need to check the consistency of the number of frames between the Flash-Tags, and if there is *any* variability, you need to take action to eliminate that variability.

Summary

- Undertake a series of lunar occultation observations with your usual equipment. The more stars you observe, the better. Aim for a minimum of at least 10 stars, but 20 would be better.
- Create a Lunar Occultations Observation report.
  - Tutorial - How to prepare and reduce lunar occultation observations. [7]
- Analyse the Occultation Residual Report. You can either;
  - Send the report to your Regional Collector for reduction. Your Regional Collector's e-mail address is already in the report form's pull-down menu. You should receive the reduction report returned in a short period of time.
  - Do your own reduction using Occult, AND send your report to your Regional Collector. You need to ensure *Occult* is up to date, with all the latest downloads listed in the *Updating Occult* section of the tutorial.
- If your results are Good, you may be assured that your event times are as accurate as you think they are. This assurance may be applied to asteroid occultation observations, provided;
  - Appropriate Instrument Delay is applied, due to frame integration.
  - All components in the imaging system remain consistent. This includes updates of digital imaging software.
- If your results are not as good as you hoped, you need to take action to improve your results by changing your equipment and methods.
- Observe more lunar occultation events. You never know – you might discover a hitherto unknown double star while testing.

Acknowledgements

The authors wish to acknowledge the Gaia, Hipparcos, Kagaya-SELENE, Lunar Reconnaissance Orbiter projects, as well as NASA and JPL ephemeris services.

References

[1] Wilds, Richard P. - The Mysterious History of Mapping Lunar Incognita.
[2] Kaguya (SELENE) - http://www.kaguya.jaxa.jp/index_e.htm
[3] - https://lola.gsfc.nasa.gov
[4] Gaia DR2 - https:// www.cosmos.esa.int/web/gaia/dr2
[5] Hipparcos 2 - https://www.cosmos.esa.int/web/hipparcos/hipparcos-2
[6] Herald, D. *Occult* – http://www.lunar-occultations.com/iota/occult4.htm
[7] Tutorial - http://www.kuriwaobservatory.com/pdf_files/LunarOccultationReportTutorial.pdf

ESOP XXXIX

39th European Symposium on Occultation Projects (ESOP)

in Freiburg im Breisgau, Germany, August 28 to September 1, 2020

View of the historical city
Credit: FWTM GmbH & Co. KG

We are pleased to invite all interested parties to the 39th European Symposium on Occultation Projects in Freiburg, Germany. As always, the annual science conference of IOTA/ES will include lectures and presentations, as well as interesting post-conference excursions.

Host town this time is Freiburg im Breisgau. The charming city of Freiburg in southwestern Germany is surrounded by the mountains of the Black Forest to the east and opens to the Rhine valley to the west. Freiburg with its cathedral, its "Bächle" and many other sights is always worth a visit.

Freiburg can be reached by car (motorway A5, B31), ICE/TGV trains and by plane via the EuroAirport Basel-Mulhouse-Freiburg. The major international airports of Frankfurt and Zurich are two hours away by train. The conference centre "Waldhof", where ESOP XXXIV will be held, is located in the east of Freiburg and can be easily reached by public transport from Freiburg main station.

The "Waldhof" is framed by old tall trees and in this long-established and stylish mansion we find the best facilities for our conference: a large lecture hall, accommodation and good food.

http://esop39.iota-es.de

Grazing Occultations of Stars by the Moon in 2020

Eberhard Riedel · IOTA/ES · München · Germany · e_riedel@msn.com

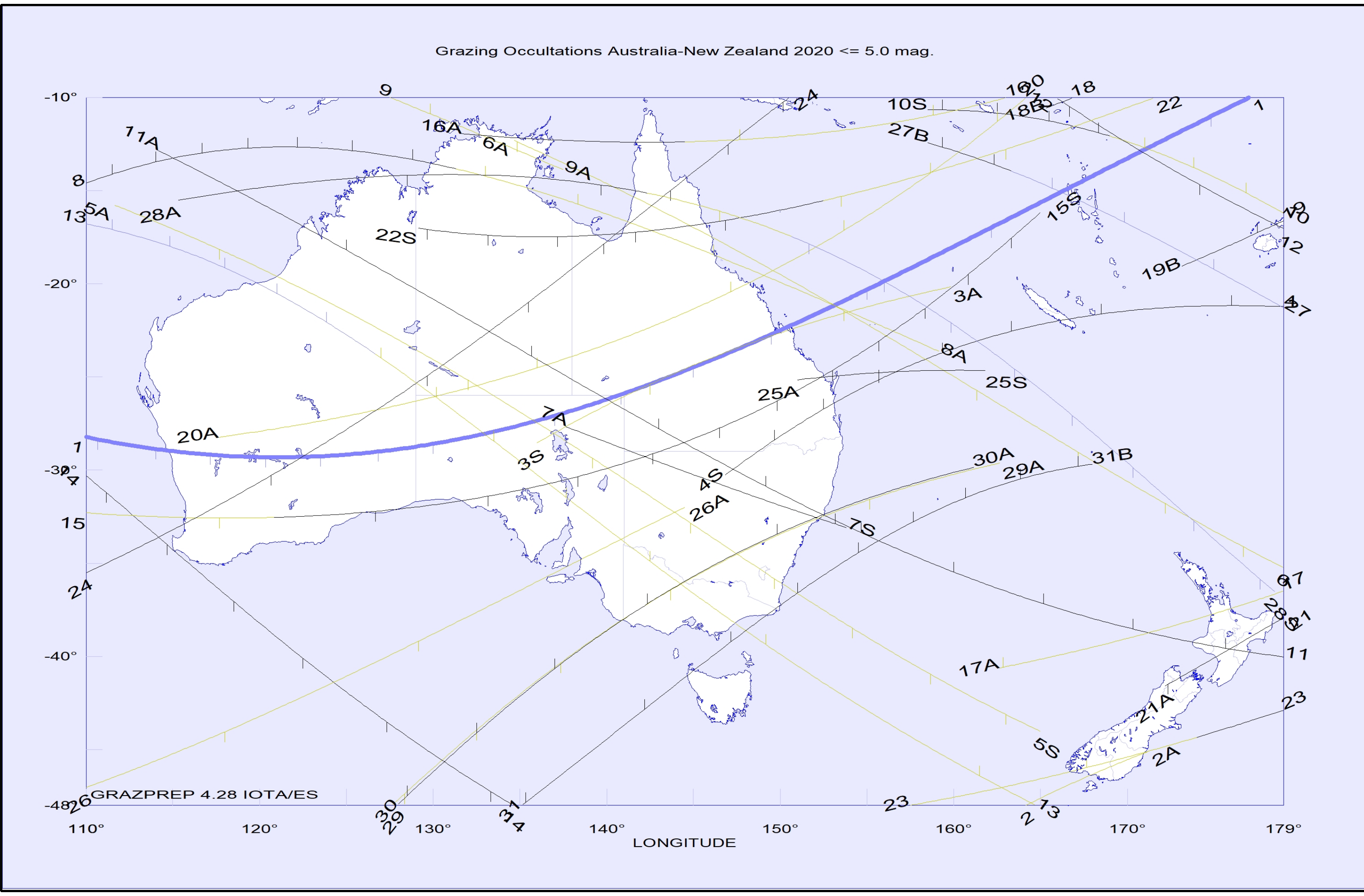
ABSTRACT: Grazing lunar occultations of bright stars and major planets down to magnitude 5.0 for the year 2020 are presented for those regions of the world, where most of our observers live.

Introduction

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

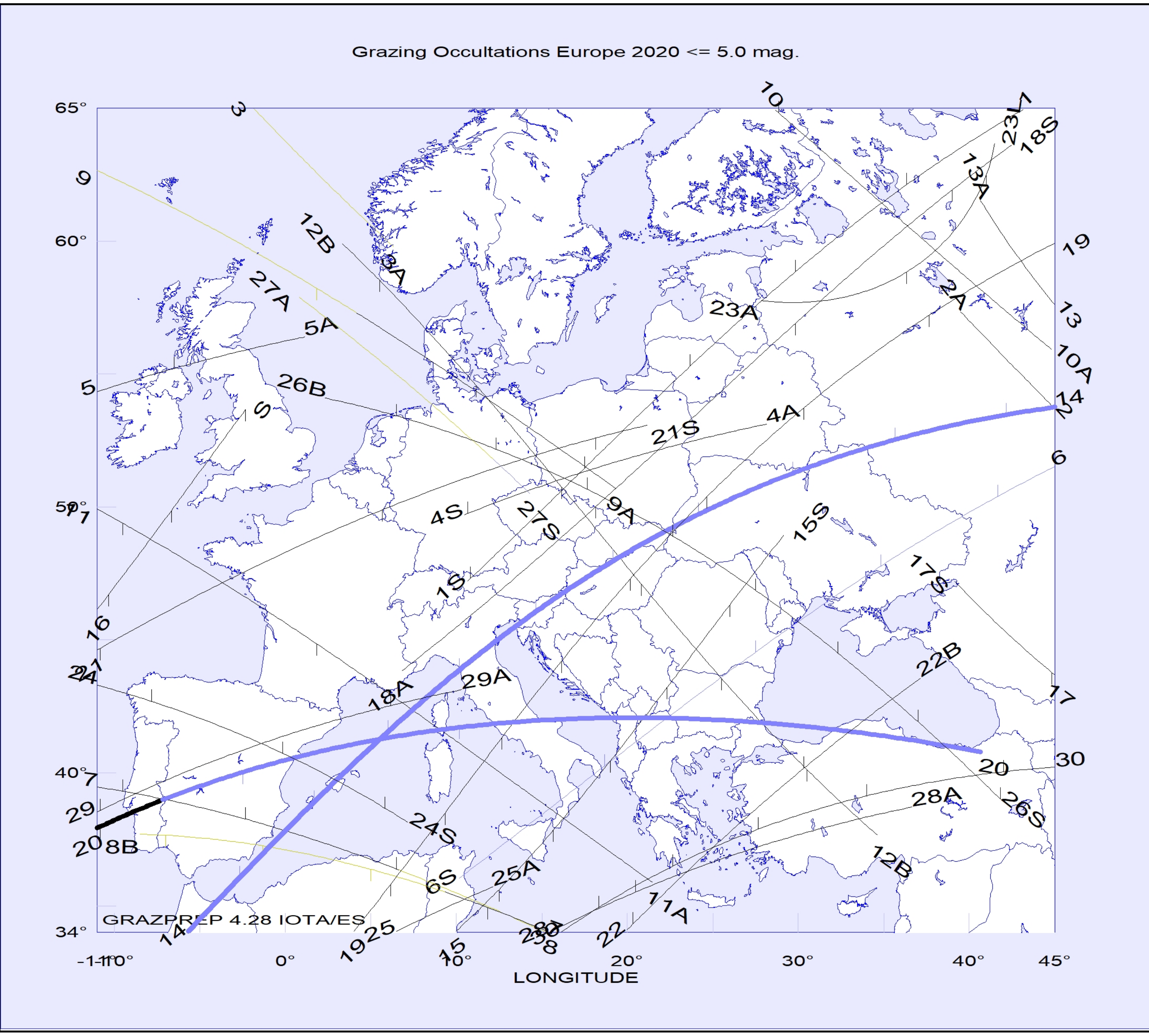
Tick marks appear along the limit lines every full 10 minutes of time. The northern limb grazes show tick marks pointing downwards, whereas on the southern limb grazes they point upwards.

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



2020	Grazing Occultations Australia-New Zealand 2020 <= 5.0 mag.									GRAZPREP 4.28, IOTA/ES	
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG LAT	STAR NAME	MAG1	MAG2
1	Jan 23			-1.9	3 -	N	2 8.2	110 -28	Jupiter		
2	Jan 26	ZC 3171	164560 V	3.7	2+	N	8 47.6	164 -48	Nashira gamma Capricorni	4.6	4.6
3	Jan 28	ZC 3419	146598 A	4.2	12+	N	9 51.7	136 -29	psi 1 Aquarii	4.5	8.5
4	Feb 01	ZC 327	110408 K	4.4	44+	S	9 10.7	146 -30	xi 1 Ceti NSV 00749	5.3	5.3
5	Feb 16	ZC 2361	159918	4.2	41 -	N	17 8.9	111 -16	chi Ophiuchi	4.2	5.0
6	Feb 17	ZC 2498	185296 d	4.4	31 -	N	16 30.0	134 -12	xi Ophiuchi NSV 21541		
7	Feb 21	ZC 3078	189986 M	4.9	3 -	S	19 24.6	137 -28	Chow eta Capricorni	5.0	7.4
8	Mar 03	ZC 792	77097	5.0	58+	S	11 14.8	110 -15	109 Tauri		
9	Mar 30	ZC 752	76920 K	4.6	31+	S	12 38.6	127 -10	iota Tauri	5.4	5.4
10	Apr 03	ZC 1308	80378 V	4.7	70+	S	7 28.0	158 -11	Asellus Borealis gamma Cancri	5.5	5.5
11	May 10	ZC 2630	186437 A	5.0	87 -	S	13 15.5	114 -13	1 Sagittarii	5.1	10.8
12	May 29	ZC 1484	98955 C	3.5	42+	N	9 49.1	166 -10	eta Leonis NSV 04738	4.1	4.6
13	May 29	ZC 1484	98955 C	3.5	42+	S	7 56.0	110 -17	eta Leonis NSV 04738	4.1	4.6
14	May 31	ZC 1734	119164 V	4.7	66+	N	10 56.9	110 -30	pi Virginis	5.0	7.0
15	Jun 12	ZC 3428	146635 A	5.0	54 -	N	17 24.2	110 -32	psi 3 Aquarii NSV 14491	5.2	11.2
16	Jun 13	ZC 3536	147042	4.4	46 -	S	15 55.3	131 -12	30 Piscium YY Piscium	4.4	4.4
17	Jun 16	ZC 327	110408 K	4.4	20 -	S	16 30.5	162 -41	xi 1 Ceti NSV 00749	5.3	5.3
18	Jul 02	ZC 2353	159892	4.5	92+	S	16 17.8	165 -11	psi Ophiuchi		
19	Jul 31	ZC 2589	186061	4.7	90+	S	13 44.9	173 -19	4 Sagittarii		
20	Aug 09	ZC 249	110065	4.5	69 -	S	15 4.9	117 -28	nu Piscium		
21	Aug 15	ZC 1030	78682W	3.1	14 -	N	17 30.4	172 -42	Mebsuta epsilon Geminorum		
22	Sep 22	ZC 2353	159892	4.5	32+	N	9 18.9	129 -17	psi Ophiuchi		
23	Sep 22	ZC 2353	159892	4.5	32+	S	9 52.5	157 -48	psi Ophiuchi		
24	Oct 06	ZC 628	76532 K	4.9	80 -	N	15 24.5	110 -36	omega 2 Tauri NSV 15938	5.0	7.0
25	Oct 14	ZC 1701	119029	4.8	6 -	N	18 39.2	151 -25	xi Virginis		
26	Oct 21	ZC 2630	186437 A	5.0	29+	N	12 50.9	110 -47	1 Sagittarii	5.1	10.8
27	Nov 05	ZC 1030	78682W	3.1	77 -	S	18 17.5	158 -12	Mebsuta epsilon Geminorum		
28	Nov 10	ZC 1651	99587 O	3.9	26 -	N	18 46.0	115 -16	Tsze Tseang iota Leonis	4.0	6.7
29	Nov 23	ZC 3425	146620 K	4.4	64+	N	13 38.5	127 -48	psi 2 Aquarii	5.4	5.4
30	Nov 23	ZC 3428	146635 A	5.0	64+	S	13 39.0	128 -48	psi 3 Aquarii NSV 14491	5.2	11.2
31	Dec 27	ZC 628	76532 K	4.9	94+	S	11 20.1	135 -48	omega 2 Tauri NSV 15938	5.0	7.0

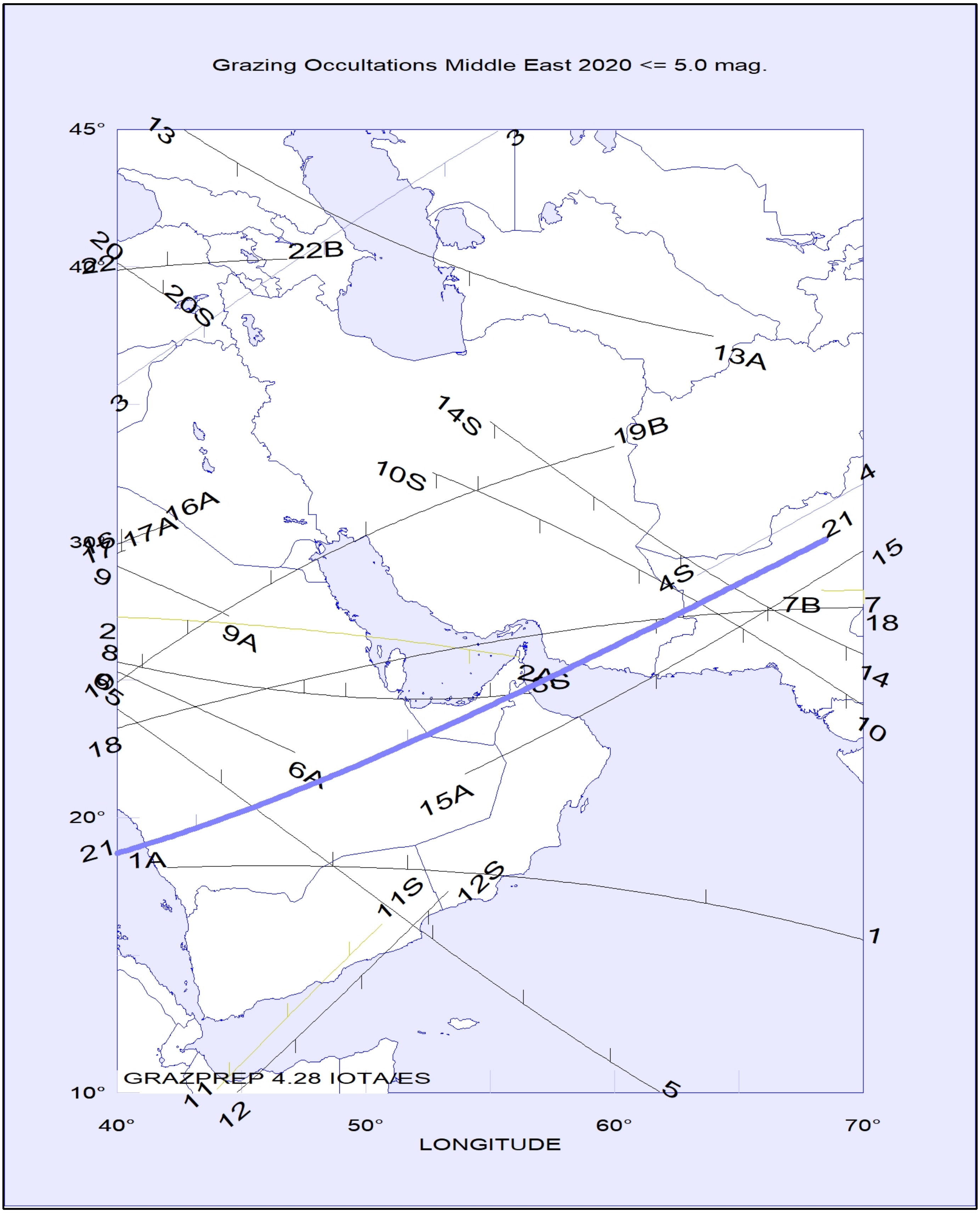
Australia & New Zealand



Grazing Occultations Europe 2020 <= 5.0 mag.
65°
60°
40°
34°
0°
10°
20°
30°
40°
45°
LONGITUDE
GRAZPREP 4.28 IOTA/ES

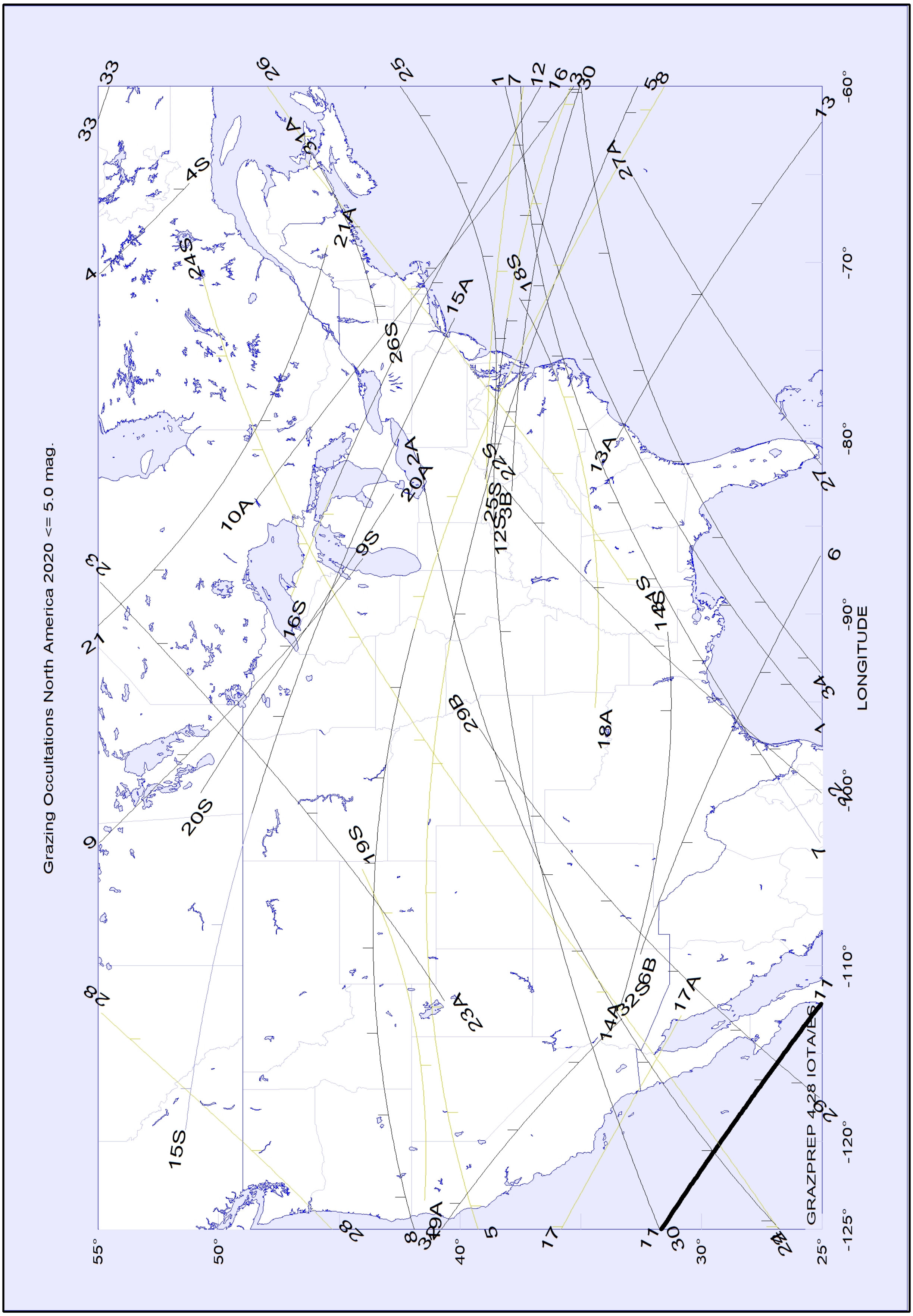
2020			Grazing Occultations Europe 2020 <= 5.0 mag.							GRAZPREP 4.28, IOTA/ES	
No.	**M D**	**USNO**	**SAOPPM D**	**MAG**	**%SNL**	**L.**	**W.UT**	**LONG LAT**	**STAR NAME**	**MAG1**	**MAG2**
1	**Jan 07**	ZC 658	93923 T	4.3	89+	S	15 40.6	10 47	68 Tauri V776 Tauri	4.3	8.4
2	**Jan 22**	ZC 2589	186061	4.7	7 -	S	4 57.2	39 57	4 Sagittarii		
3	**Feb 06**	ZC 976	78297 A	2.9	87+	N	5 31.1	-2 65	Tejat Posterior mu Geminorum	3.2	9.8
4	**Feb 25**	ZC 3536	147042	4.4	4+	S	16 50.4	10 50	30 Piscium YY Piscium	4.4	4.4
5	**Feb 25**	ZC 5	128572 L	4.6	4+	S	18 38.5	-11 54	33 Piscium BC Piscium	5.0	7.5
6	**Mar 04**	ZC 976	78297 A	2.9	69+	S	13 3.5	10 36	Tejat Posterior mu Geminorum	3.2	9.8
7	**Mar 29**	ZC 668	93954 w	3.5	24+	S	19 57.8	-11 39	Ain epsilon Tauri		
8	**Mar 30**	ZC 792	77097	5.0	33+	N	18 57.5	-8 38	109 Tauri		
9	**Mar 30**	ZC 817	77184 T	4.9	34+	N	22 52.4	-11 63	omicron Tauri	5.6	5.6
10	**Mar 31**	ZC 976	78297 A	2.9	44+	S	22 50.2	28 65	Tejat Posterior mu Geminorum	3.2	9.8
11	**Apr 27**	ZC 916	77915 Q	4.3	20+	N	20 48.6	-11 50	Propus 1 Geminorum	4.9	6.9
12	**May 03**	ZC 1702	119035	4.0	82+	N	21 46.9	3 60	nu Virginis		
13	**May 09**	ZC 2523	185470	4.8	91 -	S	22 41.0	40 62	51 Ophiuchi NSV 09037		
14	**Jun 19**			-3.8	4 -	S	7 33.7	-5 34	Venus		
15	**Jul 11**	ZC 3536	147042	4.4	67 -	N	1 23.1	10 34	30 Piscium YY Piscium	4.4	4.4
16	**Jul 11**	ZC 5	128572 L	4.6	67 -	N	3 38.4	-11 46	33 Piscium BC Piscium	5.0	7.5
17	**Jul 24**	ZC 1702	119035	4.0	19+	N	17 1.1	39 47	nu Virginis		
18	**Aug 15**	ZC 916	77915 Q	4.3	18 -	N	0 45.5	6 44	Propus 1 Geminorum	4.9	6.9
19	**Sep 05**	ZC 249	110065	4.5	87 -	N	23 43.8	4 34	nu Piscium		
20	**Sep 06**			-1.9	86 -	N	6 0.1	-11 38	Mars		
21	**Sep 14**	ZC 1308	80378 V	4.7	14 -	N	3 50.5	-11 45	Asellus Borealis gamma Cancri	5.5	5.5
22	**Sep 27**	ZC 3164	164520 U	4.5	85+	S	22 19.7	20 34	epsilon Capricorni	5.0	6.3
23	**Oct 26**	ZC 3349	165321W	4.0	79+	N	14 31.6	28 58	tau Aquarii NSV 14329		
24	**Nov 11**	ZC 1702	119035	4.0	21 -	S	5 46.5	-11 43	nu Virginis		
25	**Nov 22**	ZC 3349	165321W	4.0	56+	S	22 56.1	6 34	tau Aquarii NSV 14329		
26	**Dec 05**	ZC 1308	80378 V	4.7	79 -	S	3 3.2	2 54	Asellus Borealis gamma Cancri	5.5	5.5
27	**Dec 13**	ZC 2302	159682 H	2.6	2 -	N	7 15.0	0 58	Graffias beta 1 Scorpii	3.2	4.2
28	**Dec 21**	ZC 3536	147042	4.4	48+	S	20 45.7	15 34	30 Piscium YY Piscium	4.4	4.4
29	**Dec 21**	ZC 5	128572 L	4.6	48+	S	22 30.2	-11 39	33 Piscium BC Piscium	5.0	7.5
30	**Dec 24**	ZC 327	110408 K	4.4	76+	S	20 24.7	16 34	xi 1 Ceti NSV 00749	5.3	5.3

Europe


Grazing Occultations Middle East 2020 <= 5.0 mag.
45°
40°
20°
10°
40°
50°
60°
70°
LONGITUDE
GRAZPREP 4.28 IOTA/ES
13
3
22B
20S
13A
14S
19B
10S
16A
17A
4
21
15
4S
7B
7
18
9A
2A
14
10
6A
15A
1A
11S
12S
1
5
11
12

2020			Grazing Occultations Middle East 2020 <= 5.0 mag.							GRAZPREP 4.28, IOTA/ES		
No.	M D	USNO	SAOPPM D	MAG	%SNL	L.	W.UT	LONG	LAT	STAR NAME	MAG1	MAG2
1	Jan 15	ZC 1773	119341 V	5.0	68 -	S	20 6.5	42	18	16 Virginis	5.8	5.8
2	Feb 28	ZC 327	110408 K	4.4	21+	N	17 56.0	40	27	xi 1 Ceti NSV 00749	5.3	5.3
3	Mar 02	ZC 668	93954 w	3.5	48+	N	11 23.3	40	36	Ain epsilon Tauri		
4	Mar 04	ZC 946	78135 Q	3.5	67+	S	9 33.7	63	29	Propus eta Geminorum	3.4	5.4
5	Mar 14	ZC 2353	159892	4.5	64 -	S	23 42.8	40	24	psi Ophiuchi		
6	Mar 30	ZC 792	77097	5.0	33+	N	19 55.4	40	25	109 Tauri		
7	Apr 13	ZC 2589	186061	4.7	69 -	N	0 45.3	68	28	4 Sagittarii		
8	Apr 17	ZC 3175	164593	4.7	29 -	S	1 29.2	40	26	kappa Capricorni		
9	Apr 26	ZC 752	76920 K	4.6	12+	N	18 14.9	40	29	iota Tauri	5.4	5.4
10	Apr 30	ZC 1308	80378 V	4.7	48+	N	15 10.1	52	33	Asellus Borealis gamma Cancri	5.5	5.5
11	Jul 11	ZC 3536	147042	4.4	67 -	S	1 48.5	44	10	30 Piscium YY Piscium	4.4	4.4
12	Jul 14	ZC 327	110408 K	4.4	39 -	N	1 31.9	44	10	xi 1 Ceti NSV 00749	5.3	5.3
13	Jul 24	ZC 1702	119035	4.0	19+	N	17 6.9	42	45	nu Virginis		
14	Jul 29	ZC 2322	159764 Y	4.1	74+	N	15 20.2	55	34	Jabbah nu Scorpii	4.9	6.9
15	Aug 13	ZC 752	76920 K	4.6	28 -	N	21 37.1	54	22	iota Tauri	5.4	5.4
16	Aug 25	ZC 2302	159682 H	2.6	50+	S	20 0.2	40	30	Graffias beta 1 Scorpii	3.2	4.2
17	Aug 25	ZC 2303	159683 B	4.8	50+	S	20 0.7	40	30		5.2	7.6
18	Oct 13	ZC 1484	98955 C	3.5	19 -	N	0 17.2	40	23	eta Leonis NSV 04738	4.1	4.6
19	Nov 26	ZC 249	110065	4.5	89+	S	19 41.0	40	25	nu Piscium		
20	Dec 05	ZC 1308	80378 V	4.7	79 -	S	4 16.4	40	40	Asellus Borealis gamma Cancri	5.5	5.5
21	Dec 14			-1.1	0 -	S	11 45.2	40	19	Mercury		
22	Dec 24	ZC 327	110408 K	4.4	76+	S	21 7.9	40	40	xi 1 Ceti NSV 00749	5.3	5.3

Middle East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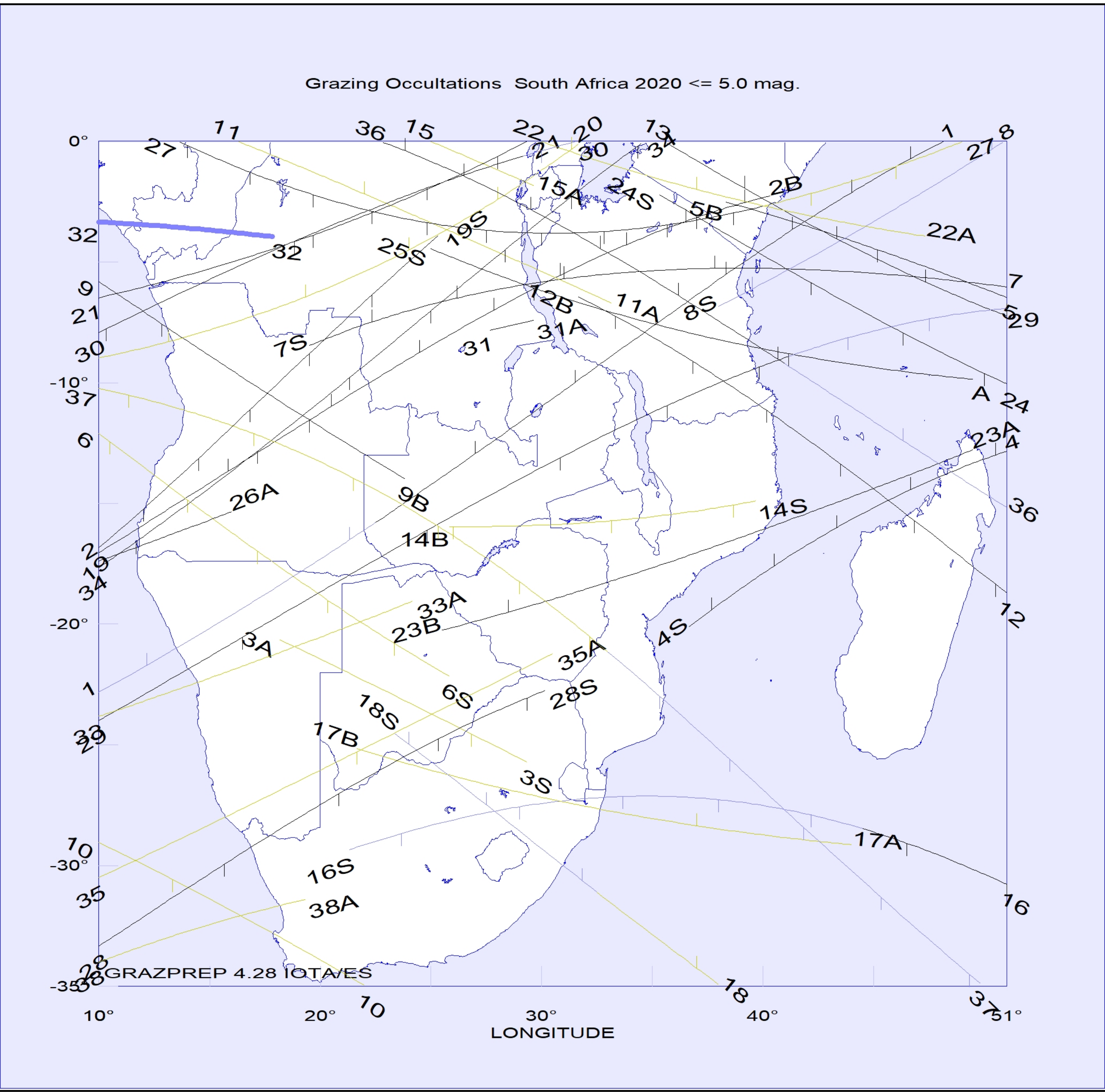
2	**Jan 02**	ZC 5	128572 L	4.6	39+	S	3 18.9	-125	27	33 Piscium BC Piscium	5.0	7.5
3	**Jan 15**	ZC 1702	119035	4.0	75 -	S	4 57.0	-83	38	nu Virginis		
4	**Jan 20**	ZC 2353	159892	4.5	20 -	S	12 14.1	-70	55	psi Ophiuchi		
5	**Feb 04**	ZC 668	93954 w	3.5	70+	N	4 27.6	-125	39	Ain epsilon Tauri		
6	**Feb 05**	ZC 817	77184 T	4.9	80+	N	7 11.9	-109	33	omicron Tauri	5.6	5.6
7	**Feb 06**	ZC 946	78135 Q	3.5	86+	S	0 11.9	-103	25	Propus eta Geminorum	3.4	5.4
8	**Feb 06**	ZC 976	78297 A	2.9	87+	S	4 26.1	-125	42	Tejat Posterior mu Geminorum	3.2	9.8
9	**Feb 16**	ZC 2322	159764 Y	4.1	44 -	S	12 23.8	-103	55	Jabbah nu Scorpii	4.9	6.9
10	**Feb 18**	ZC 2589	186061	4.7	25 -	S	10 12.7	-83	49	4 Sagittarii		
11	**Feb 18**			1.2	24 -	S	11 56.4	-125	32	Mars		
12	**Mar 26**	ZC 327	110408 K	4.4	6+	N	23 53.8	-84	39	xi 1 Ceti NSV 00749	5.3	5.3
13	**Apr 11**	ZC 2322	159764 Y	4.1	87 -	S	3 24.3	-80	33	Jabbah nu Scorpii	4.9	6.9
14	**Apr 18**	ZC 3349	165321W	4.0	19 -	S	11 21.8	-112	33	tau Aquarii NSV 14329		
15	**Apr 26**	ZC 668	93954 w	3.5	8+	S	1 27.3	-119	51	Ain epsilon Tauri		
16	**Apr 27**	ZC 792	77097	5.0	13+	N	1 5.7	-89	47	109 Tauri		
17	**Apr 27**	ZC 817	77184 T	4.9	15+	S	5 10.0	-125	36	omicron Tauri	5.6	5.6
18	**May 17**	ZC 3536	147042	4.4	24 -	N	9 14.6	-95	34	30 Piscium YY Piscium	4.4	4.4
19	**May 17**	ZC 5	128572 L	4.6	24 -	N	11 15.7	-123	41	33 Piscium BC Piscium	5.0	7.5
20	**May 25**	ZC 916	77915 Q	4.3	5+	N	2 32.4	-100	51	Propus 1 Geminorum	4.9	6.9
21	**May 31**	ZC 1702	119035	4.0	62+	N	5 34.8	-90	55	nu Virginis		
22	**Aug 10**	ZC 327	110408 K	4.4	63 -	N	9 51.5	-100	25	xi 1 Ceti NSV 00749	5.3	5.3
23	**Sep 10**	ZC 752	76920 K	4.6	51 -	N	6 14.9	-112	41	iota Tauri	5.4	5.4
24	**Sep 11**	ZC 916	77915 Q	4.3	40 -	S	9 0.4	-125	27	Propus 1 Geminorum	4.9	6.9
25	**Sep 27**	ZC 3175	164593	4.7	86+	N	23 17.6	-82	39	kappa Capricorni		
26	**Oct 22**	ZC 2864	188337 A	4.6	43+	N	21 58.0	-73	43	52 Sagittarii	4.7	9.2
27	**Oct 25**	ZC 3164	164520 U	4.5	65+	S	4 22.8	-81	25	epsilon Capricorni	5.0	6.3
28	**Oct 25**	ZC 3164	164520 U	4.5	65+	N	3 20.8	-125	45	epsilon Capricorni	5.0	6.3
29	**Oct 28**	ZC 3536	147042	4.4	89+	S	5 47.3	-117	25	30 Piscium YY Piscium	4.4	4.4
30	**Nov 09**	ZC 1484	98955 C	3.5	41 -	N	8 44.0	-125	32	eta Leonis NSV 04738	4.1	4.6
31	**Nov 18**	ZC 2809	187882 Q	4.9	18+	N	22 49.9	-88	33	psi Sagittarii	6.2	6.2
32	**Dec 08**	ZC 1702	119035	4.0	44 -	S	13 56.9	-125	41	nu Virginis		
33	**Dec 11**	ZC 2033	158427	4.2	15 -	S	8 34.0	-62	55	kappa Virginis NSV 20060		
34	**Dec 24**	ZC 249	110065	4.5	69+	S	2 57.7	-93	25	nu Piscium		

North America



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Journal for Occultation Astronomy

2020	Grazing Occultations South Africa 2020 <= 5.0 mag.										GRAZPREP 4.28, IOTA/ES
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1	Jan 07	ZC 668	93954 w	3.5	90+	S	16 48.5	10 -23	Ain epsilon Tauri		
2	Jan 08	ZC 817	77184 T	4.9	95+	S	18 30.9	10 -17	omicron Tauri	5.6	5.6
3	Jan 23	ZC 2749	187445 V	5.0	3 -	N	3 17.4	18 -21	Ain Al Rami nu 2 Sagittarii	5.8	5.8
4	Jan 31	ZC 249	110065	4.5	37+	S	16 16.2	36 -20	nu Piscium		
5	Feb 04	ZC 752	76920 K	4.6	76+	N	20 51.2	38 -3	iota Tauri	5.4	5.4
6	Feb 16	ZC 2271	159563 X	4.1	47 -	N	3 18.9	10 -12	theta Librae	5.1	5.1
7	Feb 28	ZC 327	110408 K	4.4	21+	S	17 1.9	19 -8	xi 1 Ceti NSV 00749	5.3	5.3
8	Mar 02	ZC 668	93954 w	3.5	48+	S	10 29.3	38 -7	Ain epsilon Tauri		
9	Mar 06	ZC 1308	80378 V	4.7	89+	N	23 45.0	10 -6	Asellus Borealis gamma Cancri	5.5	5.5
10	Mar 15	ZC 2498	185296 d	4.4	53 -	N	22 49.0	10 -29	xi Ophiuchi NSV 21541		
11	Mar 30	ZC 792	77097	5.0	33+	S	19 54.8	16 0	109 Tauri		
12	Apr 04	ZC 1484	98955 C	3.5	84+	N	18 5.6	31 -6	eta Leonis NSV 04738	4.1	4.6
13	Apr 12	ZC 2589	186061	4.7	69 -	S	23 32.6	35 0	4 Sagittarii		
14	Apr 19	ZC 3428	146635 A	5.0	13 -	N	3 10.5	26 -16	psi 3 Aquarii NSV 14491	5.2	11.2
15	Apr 26	ZC 752	76920 K	4.6	12+	S	18 25.9	25 0	iota Tauri	5.4	5.4
16	Apr 29	ZC 1170	79653 A	3.6	37+	N	13 36.4	21 -29	kappa Geminorum	3.7	8.2
17	May 31	ZC 1773	119341 V	5.0	69+	S	22 13.3	21 -25	16 Virginis	5.8	5.8
18	Jun 25	ZC 1484	98955 C	3.5	21+	S	14 28.3	23 -25	eta Leonis NSV 04738	4.1	4.6
19	Jul 10	ZC 3428	146635 A	5.0	76 -	N	3 32.2	10 -17	psi 3 Aquarii NSV 14491	5.2	11.2
20	Jul 11	ZC 3536	147042	4.4	67 -	S	0 15.9	10 -9	30 Piscium YY Piscium	4.4	4.4
21	Jul 14	ZC 327	110408 K	4.4	39 -	N	0 34.1	10 -6	xi 1 Ceti NSV 00749	5.3	5.3
22	Jul 24	ZC 1702	119035	4.0	19+	S	18 6.1	30 0	nu Virginis		
23	Jul 29	ZC 2353	159892	4.5	75+	S	22 27.3	25 -20	psi Ophiuchi		
24	Jul 31	ZC 2630	186437 A	5.0	91+	N	15 47.2	35 -2	1 Sagittarii	5.1	10.8
25	Aug 21	ZC 1773	119341 V	5.0	9+	N	16 23.8	25 -4	16 Virginis	5.8	5.8
26	Aug 25	ZC 2322	159764 Y	4.1	51+	S	22 58.3	10 -17	Jabbah nu Scorpii	4.9	6.9
27	Aug 27	ZC 2589	186061	4.7	72+	N	17 19.4	13 0	4 Sagittarii		
28	Sep 11	ZC 882	77592 V	5.0	42 -	N	3 21.5	10 -33	132 Tauri	5.7	5.7
29	Sep 12	ZC 1030	78682W	3.1	32 -	N	2 25.4	10 -24	Mebsuta epsilon Geminorum		
30	Sep 13	ZC 1170	79653 A	3.6	22 -	N	3 29.7	10 -8	kappa Geminorum	3.7	8.2
31	Sep 30	ZC 3425	146620 K	4.4	97+	N	2 34.4	27 -8	psi 2 Aquarii	5.4	5.4
32	Oct 03			-2.5	99 -	N	5 32.5	10 -3	Mars		
33	Oct 19	ZC 2353	159892	4.5	12+	N	19 1.6	10 -24	psi Ophiuchi		
34	Nov 02	ZC 628	76532 K	4.9	95 -	N	21 27.5	10 -18	omega 2 Tauri NSV 15938	5.0	7.0
35	Nov 17	ZC 2589	186061	4.7	8+	N	18 21.7	10 -30	4 Sagittarii		
36	Dec 04	ZC 1170	79653 A	3.6	87 -	S	1 56.2	22 0	kappa Geminorum	3.7	8.2
37	Dec 08	ZC 1651	99587 O	3.9	48 -	N	2 8.0	10 -10	Tsze Tseang iota Leonis	4.0	6.7
38	Dec 20	ZC 3425	146620 K	4.4	39+	N	22 5.5	10 -34	psi 2 Aquarii	5.4	5.4

Southern Africa

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 summarized 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 2019 December 18th, the *Minor Planet Center* listed 1096 Centaurs and 2413 TNOs.
In the coming years, JOA wants to portray a member of this world in every issue; needless to say not all of them will get an article here. The table shows you where to find the objects presented in former JOA issues. (KG)

No.	Name	Author	Link to Issue
944	Hidalgo	Oliver Klös	JOA 1 2019
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
54598	Bienor	Konrad Guhl	JOA 3 2018
60558	Echeclus	Oliver Klös	JOA 4 2017
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

In this Issue:

(50000) Quaoar

Mike Kretlow · IOTA/ES · Lauenbrück · Germany · mike@kretlow.de

ABSTRACT: Quaoar is one of the largest trans-Neptunian objects (TNO) we know so far and could be classified as a dwarf planet in the future. Spectroscopic studies reveal that Quaoar is a very intriguing object which might have retained a tenuous atmosphere. Quaoar is also discussed as a possible target for proposed space missions intending to explore the heliosphere.
This paper summarizes some current knowledge about Quaoar and its moon Weywot. Predictions of stellar occultations for the time span 2020-2022 are presented as well.

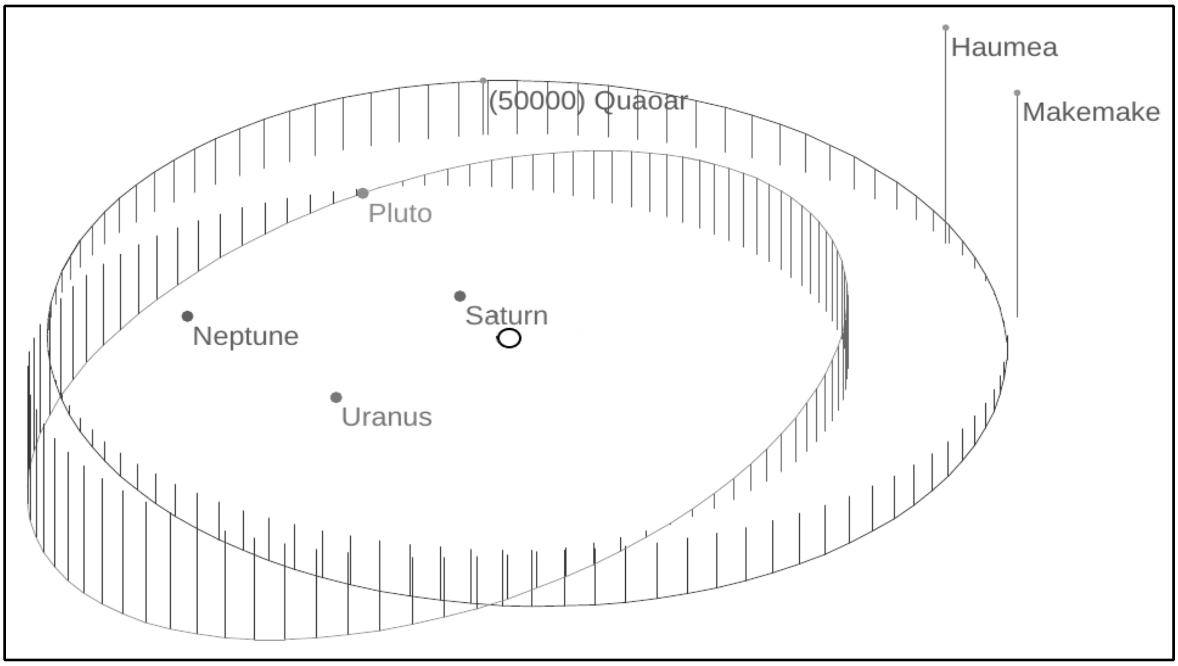


Figure 1. Orbit and position of Quaoar and the dwarf planets Pluto (orbit also shown), Haumea and Makemake for the date 2020 June 1 from a view above the ecliptic. Vernal equinox is to the left. Figure made with EasySky [4].

Introduction

Quaoar is one of the largest trans-Neptunian objects we know so far. When Quaoar was discovered in 2002 it was the largest object found in our Solar System since the discovery of Pluto in 1930 and raised a discussion whether Quaoar should be considered as planet ("Planet X") or whether Pluto and similar objects need to be re-classified. Soon after Quaoar's discovery even bigger TNOs were found in the outer Solar System (Eris and Haumea in 2003, Makemake in 2005). At the IAU 2006 General Assembly the definition of what is a planet was revised and the class of dwarf planets was introduced (resolution B5), taking Pluto as prototype into this new object class (resolution B6) [1]. Up to date Quaoar has still the status of a TNO, though the co-discoverer Mike Brown classifies Quaoar as a "nearly certain" dwarf planet [2].

Discovery and Name

Quaoar was discovered by Chad Trujillo and Mike Brown in June 2002 on images acquired with the 1.2-m Samuel Oschin Schmidt telescope at Palomar observatory and got the provisional designation 2002 LM_{60}. Prediscovery images were found on Palomar Observatory DSS plates (POSS-I) imaged on 25 May 1954, on one 1982 Siding Spring plate, on 1983 Palomar DSS plates (POSS-II) and further sky survey images in the 1990s (NEAT). In total 19 prediscovery positions are filed at the Minor Planet Center [3].

2002 LM_{60} was numbered (and named Quaoar) in November 2002. It was given the "round" number 50000 to emphasize the significance of the discovery. Quaoar is the great force of creation in the diverse myths of the Tongva, the indigenous people of the Los Angeles basin (MPC 47170, 2002 Nov. 20).

Orbit

Quaoar orbits the Sun in a non-resonant, almost circular (e=0.04) and moderately inclined (i=8°) orbit (Figure 1). The semi-major axis is 43.6 AU, thus the orbital period is about 289 years. Objects in such orbits constitute the group of Classical Kuiper Belt Objects (CKBO) or "Cubewanos", in the case of relatively unperturbed orbits (as for Quaoar) this population of CKBO is called "cold" classical KBOs. The first discovered KBO, (15760 Albion) = 1992 QB_1 gave rise to the term "Cubewano" [5]. Quaoar's minimum orbit intersection distance (MOID) to Neptune is 12.3 AU, and respectively 2 AU to Pluto. The last closest approach between Quaoar and Pluto occurred on 2003 March 24 with a distance of 13.6 AU between them, see Figure 2.

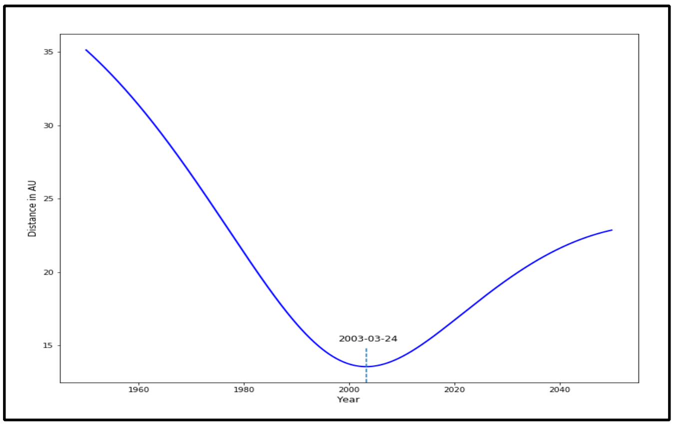


Figure 2. Geometric distance between Quaoar and Pluto over the time span 1950-2050. On 2003 March 24 a local minimum of d = 13.6 AU was reached. Data from JPL Horizons.

Moon

Quaoar has one known moon, Weywot, which was discovered in February 2006 on Hubble Space Telescope images by Brown and Suer [6].

Physical Characteristics

The first published size estimate of 1260 ± 190 km was based on images taken with the Hubble Space Telescope (HST) [7]; also a (relatively high) albedo of around 10 % was estimated in that work. Quaoar's size was subsequently revised by different works using various methods. The first successful multi-chord observation of a stellar occultation in 2011 (Table 1) allowed the derivation of a direct profile measurement, which yielded an estimate of an equivalent diameter of D(equiv) = 1100 ±5 km and a geometric visual albedo of p = 0.109 ± 0.007 by Braga-Ribas et al. [8]. By combining Herschel Space Observatory observations with (revised) Spitzer data and a NEATM thermal model, Fornasier et al. [9] derived a diameter of 1074 ± 38 km for the Quaoar/Weywot system, from which a diameter of 1070 ± 38 km for Quaoar itself and a diameter of 81 ± 11 km for the moon Weywot was estimated, if the same albedo for both bodies is assumed. On 2019 August 4 a secondary event was observed during a stellar occultation by Quaoar [10], which was probably caused by the moon Weywot. If so, then the derived size estimate for Weywot (occultation chord length was about 170 km) is in disagreement with the thermal derived size mentioned above, which could only explained by a much lower albedo for Weywot. Quaoar's absolute magnitude is H = 2.82 ± 0.06 according to [11].

From the orbit of Weywot a mass for Quaoar was estimated as M = (1.40 ± 0.21) x 10^{21} kg [12]. Depending on which diameter we use this yields to a mean bulk density of about 2 ± 0.4 g / cm^3.

Two rotational periods are found in the literature, 17.68 h from a double-peaked light curve [13,14] and 8.84 h from a single peak solution [15], which is considered by some authors to be more reliable.

Quaoar is very red and spectroscopic observations show water ice in the amorphous and crystalline phase, CH_4 in N_2, NH_4OH, Titan+Triton tholine, and other ices [16]. The spectrum of Quaoar showing these volatile ices, together with the size (mass) of Quaoar allows the assumption, that Quaoar is a cold object losing its volatiles by escape to a tenuous atmosphere which might retain around Quaoar. However, such an atmosphere was yet not detected by stellar occultations and Arimatsu et al. derived from their observation of a stellar occultation an upper limit of 6 nbar (1-σ level) surface pressure for a pure methane atmosphere [17].

Exploration

Quaoar is a potential flyby target for both US (Interstellar Probe, IsP, [18]) and Chinese (Interstellar Express, [19]) spacecraft mission concepts to explore the outer heliosphere. Nominal concept launch of the Interstellar Probe IsP would be in the 2030's, targeting a solar distance of 1000-2000 AU within fifty years. The Chinese mission may even contain two spacecraft travelling in opposite directions (nose and tail regions of the heliosphere). Quaoar is a reasonable and logical target for such missions because of its physical characteristics and its proximity to the nose region of the heliosphere. It would be possible to reach Quaoar after only eight years of flight time, if the probe will be launched on 2028 December 31. After a Jupiter gravity assist on 2030 August 1 the spacecraft would arrive at Quaoar on 2036 December 30 [20].

Occultations

Up to date fifteen occultations have been recorded since 2011, six of them with three or more chords (see Table 1, References [8,21-23]).

Date	Country Code	# Chords	Main Result / Note
2019-10-16	CL	3	
2019-09-26	NA, ZA	4	
2019-08-04	NA	1	Secondary event (probably by Weywot)
2019-06-28	JP	1	
2019-06-05	SP, MA	3	CH4 atmospheric constraint of 6 nbar (1-σ level), Chord length = 1121 +- 1.2 km
2019-05-28	EUROPE	7	
2019-04-28	CL	2	
2019-03-27	BR	1	
2018-09-02	NA, ZA	2	Double star detection
2018-07-26	AU	4	
2013-07-09	VZ	1	
2012-10-15	CH	1	
2012-02-17	FR, CH	2	
2011-05-04	CL, UY, BR	5	D(equiv) = 1110 +- 5 km, D(equa) = 1138 (+48/-34) km
2011-02-11	US	1	

Table 1: Summary of observed stellar occultations by Quaoar. D(equiv) is the equivalent diameter, D(equa) is the equatorial diameter of a MacLaurin spheroid, estimated from the occultation. Not all of these events are finally processed and / or results are still not published.

A search for occultations by Gaia DR2 stars down to G-mag 17 was performed for the time span 2020-2022. For the computation the NIMA [24] ephemeris (v14) of Quaoar was used, which is available from the Lucky Star project website as binary SPICE kernel file [25]. A subset of these occultation events (focused on America, Australia/Tasmania/New Zealand, Europe, Japan and southern Africa as regions of interest) is presented in the Appendix.

References

[1] "IAU 2006 General Assembly: Result of the IAU Resolution votes | Press Releases | IAU." [Online]. Available: https://www.iau.org/news/pressreleases/detail/iau0603/. [Accessed: 16-Nov-2019].

[2] "Astronomer Mike Brown." [Online]. Available: http://web.gps.caltech.edu/~mbrown/dps.html. [Accessed: 16-Nov-2019].

[3] "IAU Minor Planet Center." [Online]. Available: https://minorplanetcenter.net/db_search/show_object?utf8=%E2%9C%93&object_id=50000. [Accessed: 16-Nov-2019].

[4] "EasySky." [Online]. Available: http://www.easysky.de/index.htm. [Accessed: 16-Nov-2019].

[5] N. Wünsche, "Beyond Jupiter - (15760) Albion," *Journal for Occultation Astronomy*, vol. 9 no. 4, p. 14, Oct. 2019.

[6] "IAUC 8812: Sats OF 2003 AZ_84, (50000), (55637),, (90482); V1281 Sco; V1280 Sco." [Online]. Available: http://www.cbat.eps.harvard.edu/iauc/08800/08812.html. [Accessed: 17-Nov-2019].

[7] M. E. Brown and C. A. Trujillo, "Direct Measurement of the Size of the Large Kuiper Belt Object (50000) Quaoar," *AJ*, vol. 127, no. 4, pp. 2413–2417, Apr. 2004.

[8] F. Braga-Ribas et al., "The Size, Shape, Albedo, Density, and Atmospheric Limit of Transneptunian Object (50000) Quaoar from Multi-chord Stellar Occultations," The Astrophysical Journal, vol. 773, p. 26, Aug. 2013.

[9] S. Fornasier et al., "TNOs are Cool: A survey of the trans-Neptunian region. VIII. Combined Herschel PACS and SPIRE observations of nine bright targets at 70-500 µm," Astronomy and Astrophysics, vol. 555, p. A15, Jul. 2013.

[10] K. Poschinger, "Private communication," 19-Aug-2009.

[11] F. E. DeMeo et al., "Visible and near-infrared colors of Transneptunian objects and Centaurs from the second ESO large program," A&A, vol. 493, no. 1, pp. 283–290, Jan. 2009.

[12] W. C. Fraser, K. Batygin, M. E. Brown, and A. Bouchez, "The mass, orbit, and tidal evolution of the Quaoar-Weywot system," Icarus, vol. 222, p. 357, Jan. 2013.

[13] J. L. Ortiz, P. J. Gutiérrez, A. Sota, V. Casanova, and V. R. Teixeira, "Rotational brightness variations in Trans-Neptunian Object 50000 Quaoar," Astronomy and Astrophysics, vol. 409, p. L13, Oct. 2003.

[14] A. Thirouin, J. L. Ortiz, R. Duffard, P. Santos-Sanz, F. J. Aceituno, and N. Morales, "Short-term variability of a sample of 29 trans-Neptunian objects and Centaurs," Astronomy and Astrophysics, vol. 522, p. A93, Nov. 2010.

[15] D. L. Rabinowitz, B. E. Schaefer, and S. W. Tourtellotte, "The Diverse Solar Phase Curves of Distant Icy Bodies. I. Photometric Observations of 18 Trans-Neptunian Objects, 7 Centaurs, and Nereid," *The Astronomical Journal*, vol. 133, p. 26, Jan. 2007.

[16] M. A. Barucci *et al.*, "The young surface of (50000) Quaoar," *European Planetary Science Congress*, p. EPSC2015, Oct. 2015.

[17] K. Arimatsu *et al.*, "New constraint on the atmosphere of (50000) Quaoar from a stellar occultation," *arXiv e-prints*, p. arXiv:1910.09988, Oct. 2019.

[18] K. D. Runyon, K. Mandt, S. A. Stern, P. C. Brandt, and R. L. McNutt, "Kuiper Belt Planet Geoscience from Interstellar Probe," presented at the AGU Fall Meeting 2018, 2018.

[19] C. Wang and H. Li, "Interstellar Express: A New Chinese Space Mission to Explore the Outer Heliosphere," *AGU Fall Meeting Abstracts*, vol. 2018, p. SH32C, Dec. 2018.

[20] D. M. Sanchez, A. A. Sukhanov, and A. F. B. A. Prado, "Optimal Trajectories to Kuiper Belt Objects," *Revista Mexicana de Astronomia y Astrofisica*, vol. 55, p. 39, Apr. 2019.

[21] F. Braga-Ribas *et al.*, "Database on detected stellar occultations by small outer Solar System objects," *J. Phys.: Conf. Ser.*, vol. 1365, p. 012024, Oct. 2019.

[22] "Results • Lucky Star." [Online]. Available: http://lesia.obspm.fr/lucky-star/results.php . [Accessed: 16-Nov-2019].

[23] M. Kretlow, "The 2018 September 2 Occultation by (50000) Quaoar, Observed in Southern Africa and an Outlook on Occultations in 2019," *Journal for Occultation Astronomy*, vol. 9, no. 2, p. 11, Mar. 2019.

[24] J. Desmars et al., "Orbit determination of trans-Neptunian objects and Centaurs for the prediction of stellar occultations," Astronomy and Astrophysics, vol. 584, p. A96, Dec. 2015.

[25] "Ephemerides • Lucky Star." [Online]. Available: http://lesia.obspm.fr/lucky-star/nima.php. [Accessed: 16-Nov-2019].

Appendix

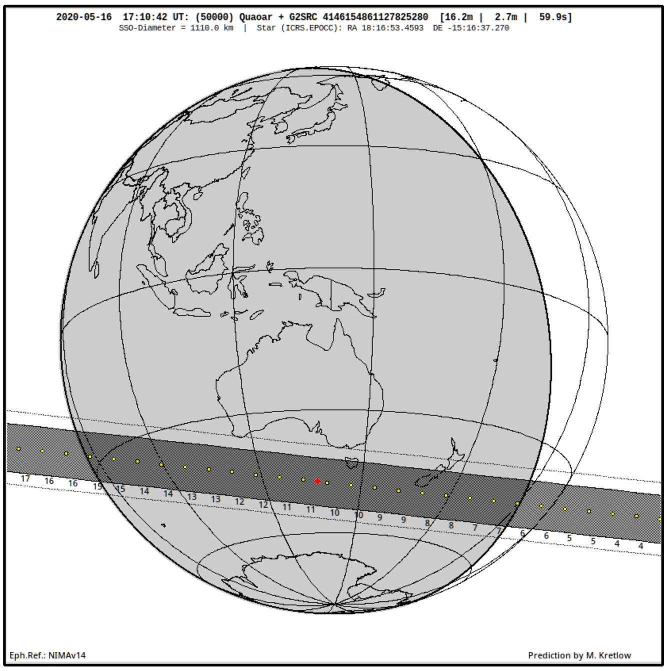
Compilation of Stellar Occultations by (50000) Quaoar for the Years 2020-2022 [Prediction by M.Kretlow (IOTA/ES)]

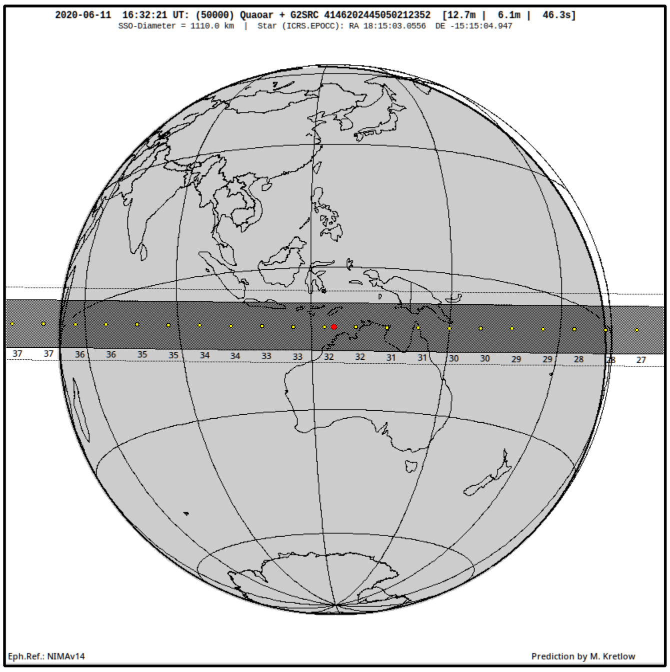
Date + Time Cent. Occ t0	StarCat + Designation	RA (ICRS.EPOCC) DE	M(S)	DMAG	MXDUR	ELS	ELM	SLT
2020-05-16 17:10:42 UT	G2SRC 4146154861127825280	18 16 53.4593 -15 16 37.270	16.2	2.7	59.9	141	077	030
2020-06-11 16:32:21 UT	G2SRC 4146202445050212352	18 15 03.0556 -15 15 04.947	12.7	6.1	46.3	165	061	065
2020-06-16 08:38:23 UT	G2SRC 4145839022104776192	18 14 40.8010 -15 15 02.310	16.1	2.7	45.5	169	116	022
2020-09-01 15:52:11 UT	G2SRC 4146056072564017792	18 09 52.3618 -15 23 12.734	15.3	3.6	146.9	112	062	100
2021-06-18 21:47:58 UT	G2SRC 4098130456654338944	18 19 59.8523 -15 11 42.022	15.1	3.7	45.4	169	087	058
2021-07-15 20:03:40 UT	G2SRC 4146167917830081280	18 17 51.1625 -15 13 11.897	16.1	2.7	48.0	159	091	033
2021-08-27 11:00:55 UT	G2SRC 4146198047004695040	18 15 26.7167 -15 19 21.084	14.3	4.6	107.8	119	120	076
2021-10-18 13:06:50 UT	G2SRC 4146145412200224896	18 15 56.8580 -15 28 39.329	14.8	4.1	68.1	069	088	096
2022-04-16 00:02:12 UT	G2SRC 4103946362090219264	18 29 00.4436 -15 13 17.369	16.4	2.5	186.7	109	081	099
2022-06-11 09:13:57 UT	G2SRC 4103995015544995456	18 26 06.6715 -15 07 47.494	14.5	4.3	47.2	162	059	087
2022-07-05 14:49:47 UT	G2SRC 4098183581115513984	18 24 10.1649 -15 08 36.313	16.1	2.7	45.4	169	099	035
2022-08-09 06:34:14 UT	G2SRC 4098214367441486592	18 21 42.8695 -15 12 45.965	15.3	3.5	63.2	138	012	089

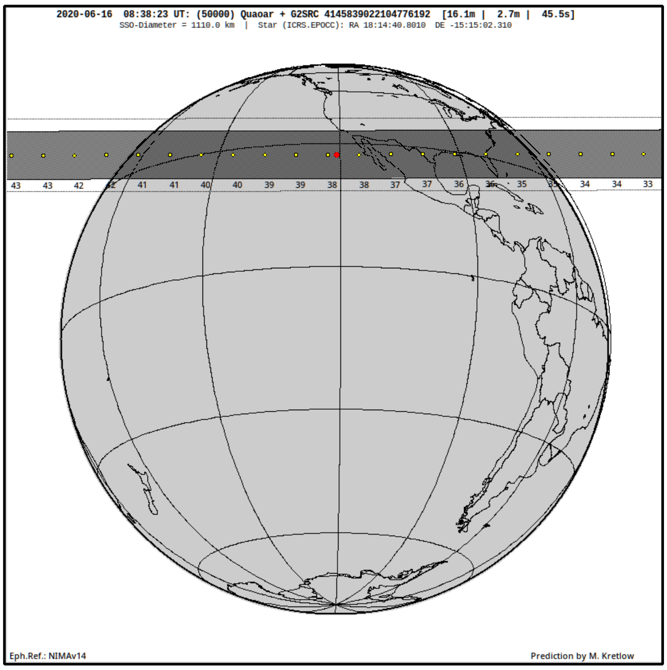
Notes:
RA/DE: Astrometric position of the star for the epoch of occultation (ICRS)
M(S) : Gaia magnitude of the target star [G-mag]
DMAG : Estimated visual light drop [mag]
MXDUR: Estimated central line occultation duration [s]
ELS : Elongation to the Sun [deg]
ELM : Elongation to the Moon [deg]
SLT : Moon sunlit in percent [%]

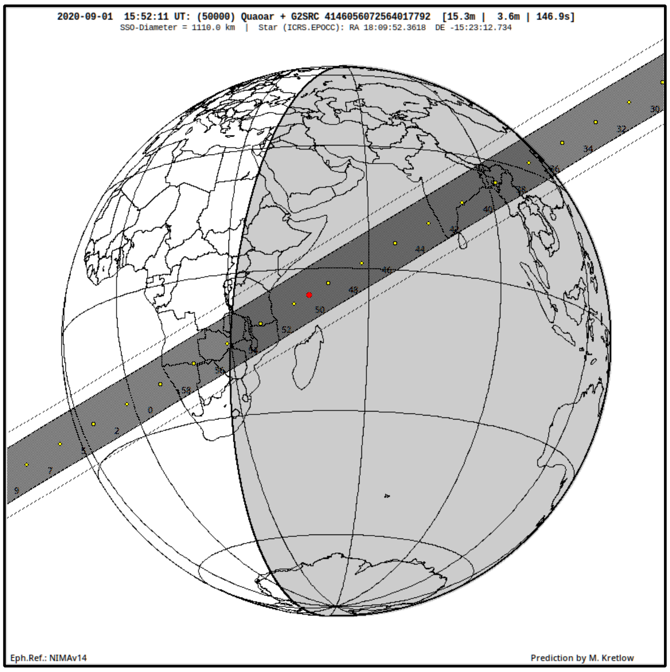
Mag. of Quaoar is always between V18.7-18.9

2020

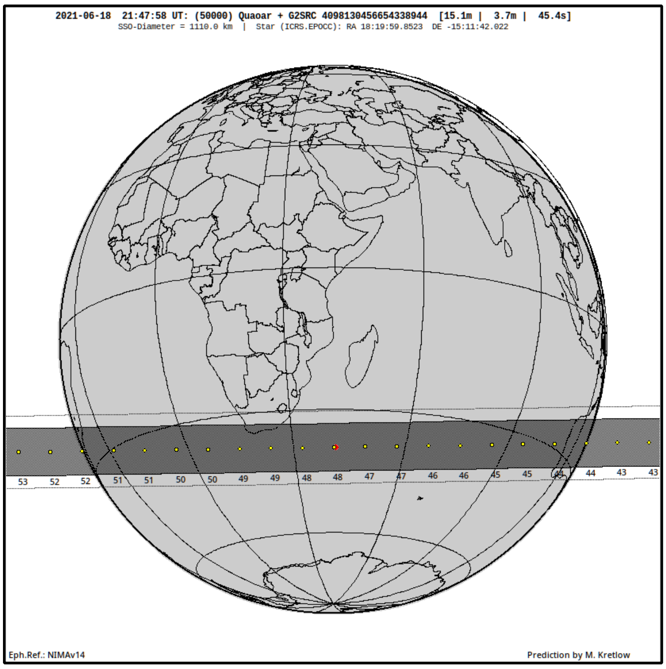

2020-05-16 17:10:42 UT: (50000) Quaoar + G2SRC 4146154861127825280 [16.2m | 2.7m | 59.9s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:16:53.4593 DE -15:16:37.270
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

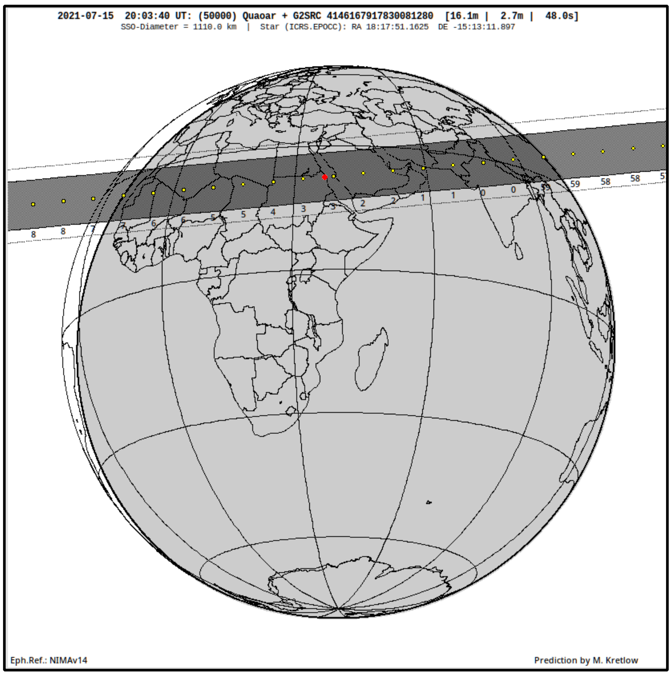

2020-06-11 16:32:21 UT: (50000) Quaoar + G2SRC 4146202445050212352 [12.7m | 6.1m | 46.3s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:15:03.0556 DE -15:15:04.947
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

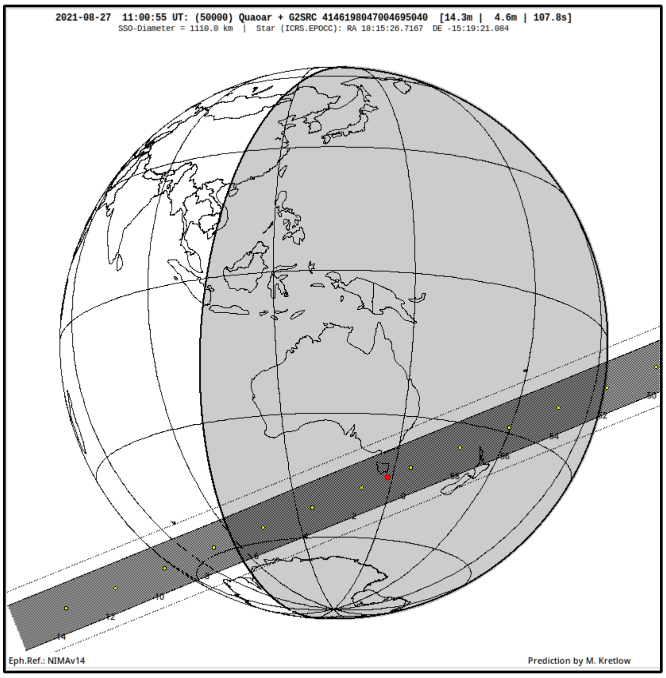

2020-06-16 08:38:23 UT: (50000) Quaoar + G2SRC 4145839022104776192 [16.1m | 2.7m | 45.5s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:14:40.8010 DE -15:15:02.310
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

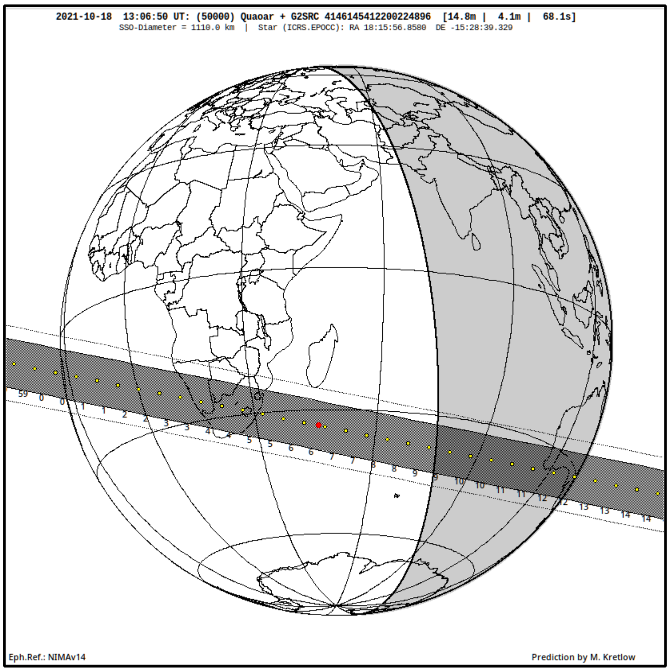

2020-09-01 15:52:11 UT: (50000) Quaoar + G2SRC 4146056072564017792 [15.3m | 3.6m | 146.9s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:09:52.3618 DE -15:23:12.734
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

2021

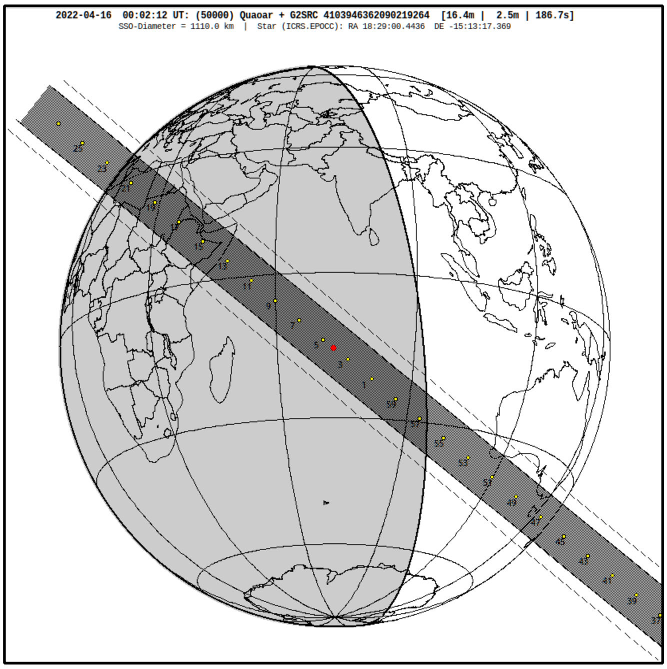

2021-06-18 21:47:58 UT: (50000) Quaoar + G2SRC 4098130456654338944 [15.1m | 3.7m | 45.4s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:19:59.8523 DE -15:11:42.022
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

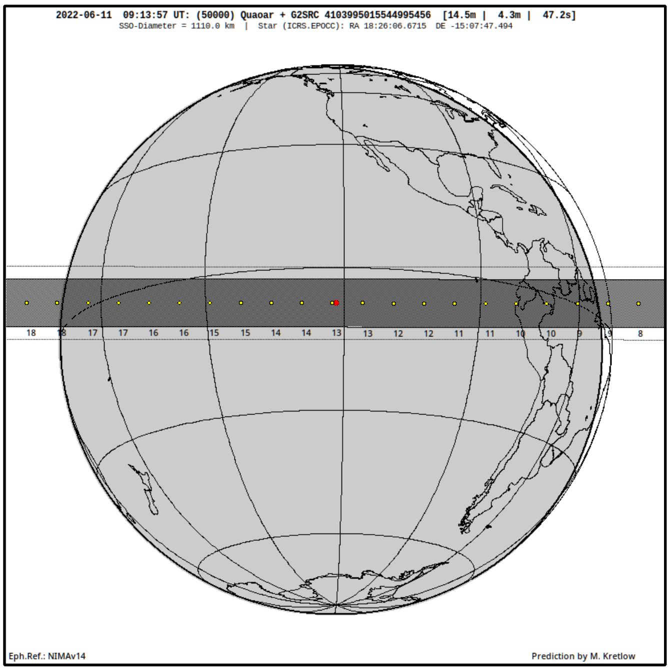

2021-07-15 20:03:40 UT: (50000) Quaoar + G2SRC 4146167917830081280 [16.1m | 2.7m | 48.0s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:17:51.1625 DE -15:13:11.897
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

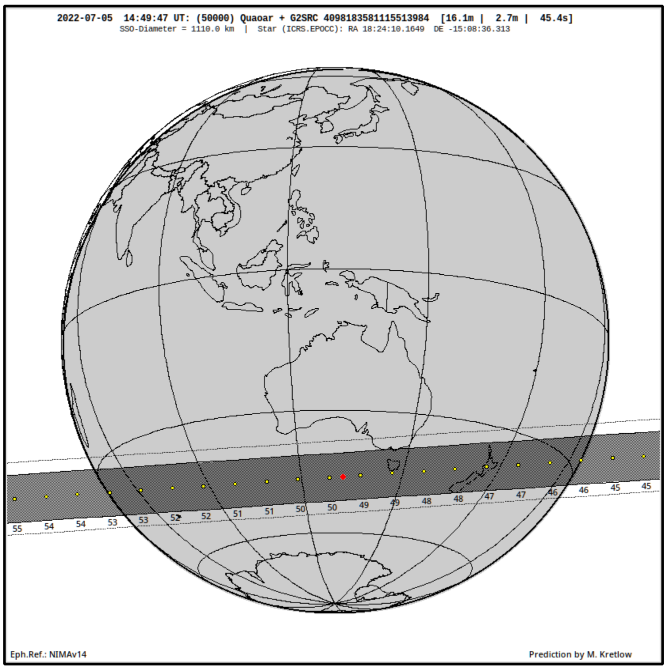

2021-08-27 11:00:55 UT: (50000) Quaoar + G2SRC 4146198047004695040 [14.3m | 4.6m | 107.8s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:15:26.7167 DE -15:19:21.084
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

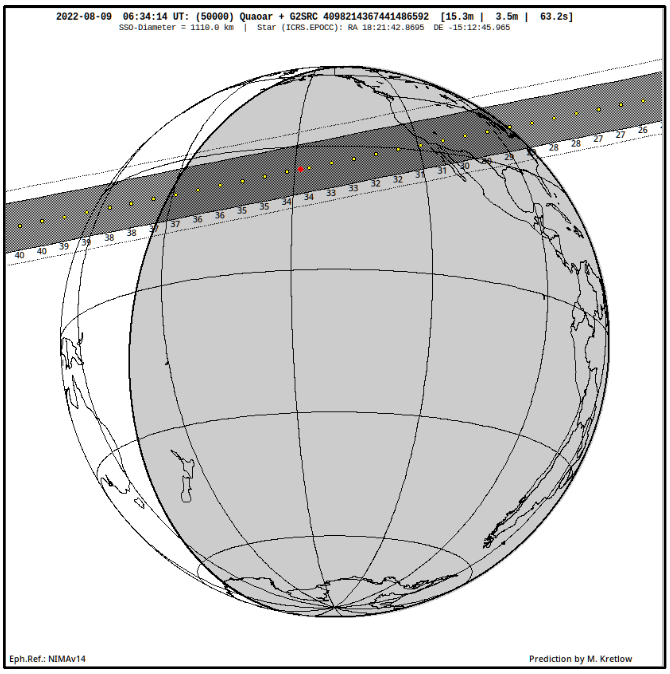

2021-10-18 13:06:50 UT: (50000) Quaoar + G2SRC 4146145412200224896 [14.8m | 4.1m | 68.1s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:15:56.8580 DE -15:28:39.329
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

2022


2022-04-16 00:02:12 UT: (50000) Quaoar + G2SRC 4103946362090219264 [16.4m | 2.5m | 186.7s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:29:00.4436 DE -15:13:17.369


2022-06-11 09:13:57 UT: (50000) Quaoar + G2SRC 4103995015544995456 [14.5m | 4.3m | 47.2s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:26:06.6715 DE -15:07:47.494
Eph.Ref.: NIMAv14
Prediction by M. Kretlow


2022-07-05 14:49:47 UT: (50000) Quaoar + G2SRC 4098183581115513984 [16.1m | 2.7m | 45.4s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:24:10.1649 DE -15:08:36.313
Eph.Ref.: NIMAv14
Prediction by M. Kretlow


2022-08-09 06:34:14 UT: (50000) Quaoar + G2SRC 4098214367441486592 [15.3m | 3.5m | 63.2s]
SSO-Diameter = 1110.0 km | Star (ICRS.EPOCC): RA 18:21:42.8695 DE -15:12:45.965
Eph.Ref.: NIMAv14
Prediction by M. Kretlow

Observers Wanted!

Experiences from Publicising the (87) Sylvia Occultations

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

ABSTRACT: Good coverage of the shadow path is essential for a successful result of an occultation observation. Potential observers have to be found and motivated even if they have never measured an occultation before. A highlight event like the occultation by (87) Sylvia on 2019 Oct 29 is a good opportunity to find new observers and to promote the special field of stellar occultations as well.

Introduction

Measuring stellar occultations is a minor field in astronomy compared to astrophotography, comet hunting and observing planets. At a meeting of astronomy clubs and teachers the author talked to some participants about stellar occultations and got the comment: *"Oh, yes - exoplanets!" - "No, they are transits, these are not stellar occultations, which are measured by our observers wordwide."* How is it possible that transits of exoplanets are widely known compared to stellar occultations? And what can we do to make our work more popular? A highlight of an occultation can help.

Publicising the Occultation by (87) Sylvia

Since the first prediction by Steve Preston (IOTA) it was obvious that an event like this would be a good opportunity to present stellar occultations to a wider community in astronomy. The chase for the satellites of (87) Sylvia would require the efforts of many observers inside and outside the predicted path [1].

A first short call for observation was placed in an annual journal for observing highlights in 2019 [2]. Readers got months before the event first path maps and links to the predictions. With the publishing of the prediction on the front page of Steve Preston's web site a path map for Europe was placed on IOTA/ES' call for observation blog [3]. These maps were updated with every new calculation made by him.

The updates of this blog were announced on the online forum of the VdS (Vereinigung der Sternfreunde e.V.), the largest astronomy community in Germany, Austria and Switzerland with more than 4,000 members [4].

During the "hot phase" of the promotion an article about the occultation appeared on *Spektrum.de*, a popular science web site in Germany [5], an article in *astronomie - DAS MAGAZIN* [6] and a special call for observations was placed on iota-es.de [7] and on the VdS-Forum [8]. The author wrote e-mails to some astronomy clubs inside the path to fill gaps visible on *OccultWatcher*. Finally, potential observers were informed about the latest developments of path coverage via the new Twitter account of IOTA/ES [9], (Figure 1).

Guide for Promoting an Event

"What's buried in the back pages was on the front just yesterday." stated Stan Ridgway in his song "Newspapers" [10]. And he is even more right in the digital age. If you place your messages too early they will fall out of view for potential observers due to other latest news. Therefore a timetable for your messages is important.

1. Start the year before. If predictions are already available try to place these into yearbooks. Path maps are essential for observers. You may use the map provided with the prediction or make your own with *Occult* or other mapping software.

2. Keep in mind astronomy magazines and their editorial deadlines. Write an article about the occultation for the issue which will be published before the date of occultation. Provide links to the predictions, to guidelines for observing and to the report form.

3. "Hot phase" starts about 10 days before the occultation event. Now it's time to feed online media and to contact potential observers via personal contact (e-mail, phone calls). They need time to get prepared and you have to be prepared for questions by some first-time observers. First postings on your social media channels should be placed.

4. The day of occultation. Social media and blogs spread latest news very fast. Any news should be placed here in the latest hours before the occultation.

5. After the occultation. The audience is curious about what had happened. So spread news about incoming reports - positive and negative. Be aware that our closed mailing lists like *IOTAoccultations* or *PLANOCCULT* are for our internal commu nication. There are many more interested people out there.

6. Days after the occultation. First-time observers may need your help with analysis, light curves and reports. First profiles are published and could be shared via social media. Be sure you have got the permission of the calculators to spread the profiles.

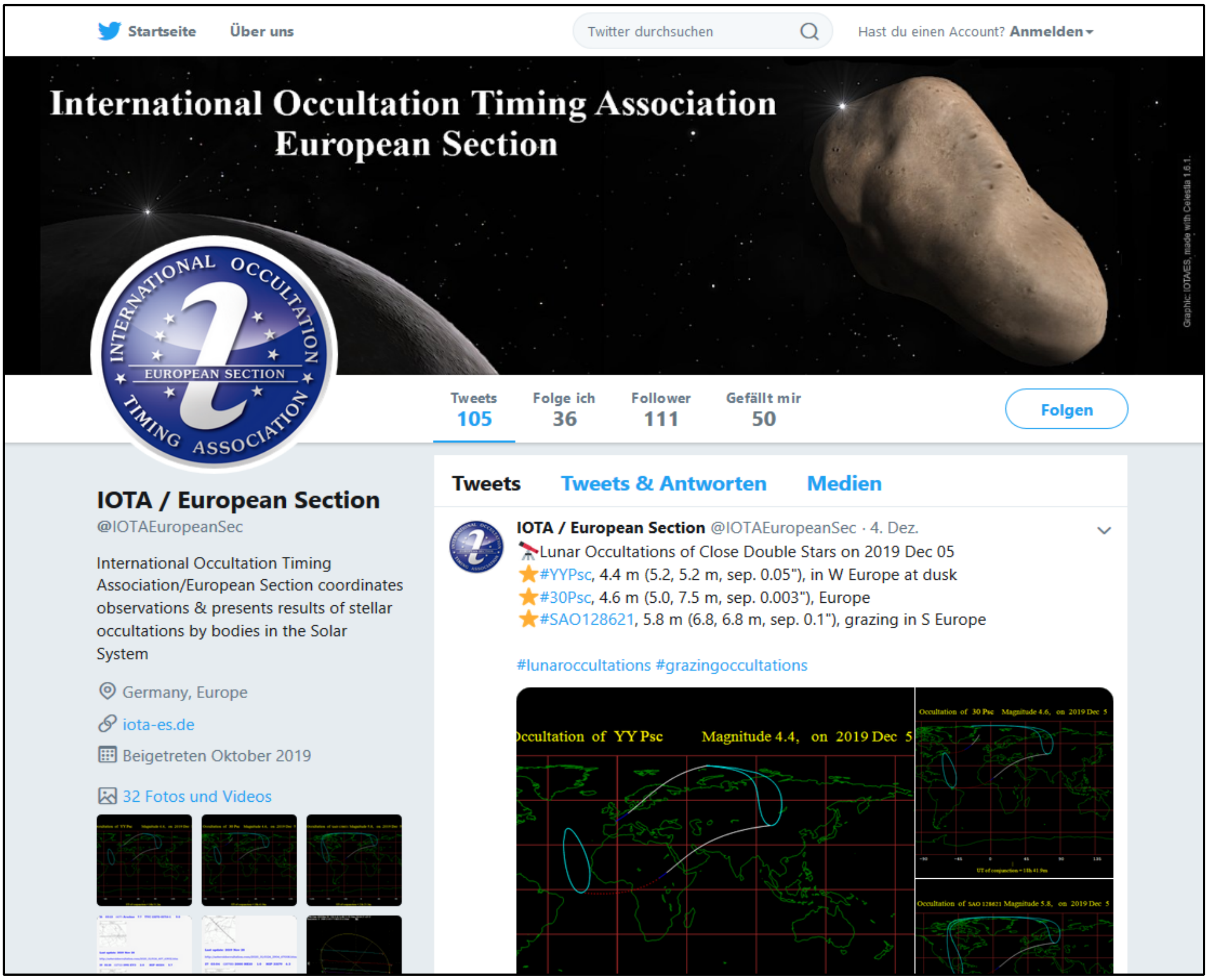


Figure 1. Screenshot of the Twitter start page of IOTA/ES, 2019 Dec 05

Occultations - on Air

A live broadcast of an occultation to a larger audience is possible today. Scotty Degenhardt (IOTA), was an experimenter in this field and made the first live coverage of an occultation expedition with the (488) Kreusa event in Missouri, USA, in June 2009 via *Upstream*. It was difficult to accomplish such a task in those days. However, he gave more live coverage a chance with the occultations by (240) Vanadis in August 2009, (234) Barbara in November 2009 and (90) Antiope in July 2011 [11].
Several social media providers have tools for live coverage today. Before you consider such a coverage you have to practice the process in advance. Use a stationary camera or let another person be the camera operator. Make sure you have your full attention on the recording of the occultation. It would be a pity if something goes wrong with the measurement caused by a distraction by the live broadcast.

Promotion of (87) Sylvia - A Success Story

A useful tool for the author's promotion of the event was a travel guide for astronomical sites in Germany [12]. This guide has a foldout map where all the sites are marked. Comparing this map with the map of chords in *OccultWatcher* gave an overview of which observatories or clubs should be contacted to fill gaps inside the predicted paths. The author contacted 4 sites via e-mail. One site was not ready in time, two did not show a real interest in participating and one was successful and provided the important chord on the most northern edge of (87) Sylvia. Members of IOTA/ES in the area of Berlin motivated some observers as well. The vivid report of one of these observers is published in this issue of JOA [13]. Last but not least, a first-time observer who had read about the occultation on Spektrum.de, was very successful. He provided one of the two chords which captured the shadow of Sylvia's moon Romulus [14].

Conclusion

Publishing our results in scientific papers is very important. But we should not forget the people interested in astronomy in general. Greater promotion campaigns are work-intensive and should be done for occultation highlights only or should be spread across several shoulders. But social media accounts should be fed regularly to keep "stellar occultations" in the mind of the astronomical community. It is possible to attract new observers to our scientific field.

We are very successful with our observations. We should talk more about it!

References

[1] Preston, S., IOTA/IOTA-ES occultation update for (87) Sylvia / TYC 1932-00469-1 event on 2019 Oct 29, 23:43 UT, Visible from Russia, Europe
http://asteroidoccultation.com/2019_10/1029_87_61910.htm

[2] Deiters, S. et al., Abenteuer Astronomie Himmels-Almanach 2019, Oculum Verlag, Erlangen, 2018

[3] IOTA/ES: Call for Observations - Highlights of Asteroid Occultations in Europe http://call4obs.iota-es.de/

[4] Online-Forum of the Vereinigung der Sternfreunde e.V. (VdS) https://forum.vdsastro.de/

[5] Klös, O., Ein Dreifach-Asteroid bedeckt einen Stern, Spektrum.de, 2019
https://www.spektrum.de/news/dreifachasteroidverdeckteinenstern/1681278

[6] Klös, O., (87) Sylvia, Romulus und Remus - dreifache Schattenjagd, astronomie - DAS MAGAZIN, No. 05, p. 47, Astronomie Medien GmbH, Hamburg, 2019

[7] Call for Observation: Occultation by (87) Sylvia and its Satellites Romulus and Remus, 2019 Oct 29, website IOTA/ES, http://www.iota-es.de/sylvia2019x01.html

[8] Klös, O., (87) Sylvia und ihre Monde bedecken 10 mag Stern über D, CH und AUT, 2019 Okt 29./30. , VdS-Forum, 2019
https://forum.vdsastro.de/viewtopic.php?f=63&t=5861

[9] IOTA/ES - Twitter account
https://twitter.com/IOTAEuropeanSec

[10] Mosquitos - second album of Stan Ridgway,1989, Wikipedia, 2019, https://en.wikipedia.org/wiki/Mosquitos_(album)

[11] Degenhardt, S., Videos of occultation broadcasts available at scottyssky on youtube.
https://www.youtube.com/user/scottyssky/videos

[12] Steinicke, W., Binnewies, S., Sparenberg, R., Reiseführer Astronomie Deutschland, Oculum Verlag, Erlangen, 2018

[13] Molau, S., How I observed ´Sylvia´, Journal for Occultation Astronomy, No. 2020-01, Vol. 10 No. 1, p. 6-8

[14] Wünsche, N., A Triple Success - The Occultations by (87) Sylvia and its Moons on 2019 October 29, Journal for Occultation Astronomy, No. 2020-01, Vol. 10 No. 1, p. 3-5

Brian Loader hands over IOTA's Double Star Programme to Martin Unwin

2019 December 09

Brian Loader, RASNZ, New Zealand, coordinated the double star programme for the determination of true separations and PA's from geographically separate lunar occultation observations for many years. His reports were regularly published in the *Journal of Double Star Observations* (JDSO). He was awarded the *Homer F. DaBoll Award* in 2014 "*for Total and Grazing Occultations, The Jovian Satellite Eclipse Program, Lunar Double Star Coordination, Publications, and Nurturing of New Occultation Observers Worldwide.*"

Brian Loader decided to hand on the responsibility to collect the data of the double star observations to Martin Unwin, New Zealand. Dave Herald stated, that the reporting address will be updated to that of Martin in *Occult*.

The editorial team of *JOA* want to thank Brian for his contributions and efforts for the worldwide community of occultation observers for many years. We thank Martin for assuming the task from Brian and we wish him a good start.

Prix Paul Doistau-Émile Blutet Awarded to Bruno Sicardy

Professor Bruno Sicardy received this award from the French Academy of Sciences to acknowledge his scientific achievements in applying occultation techniques to the study of solar system bodies.

The worldwide occultation community also wish to congratulate him for his work in promoting camaraderie amongst professional and amateur astronomers.

Bruno Sicardy (left) receives the prize from Patrick Flandrin, Vice-President of the Académie des Sciences.

Image: Simon Cassanas

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

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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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