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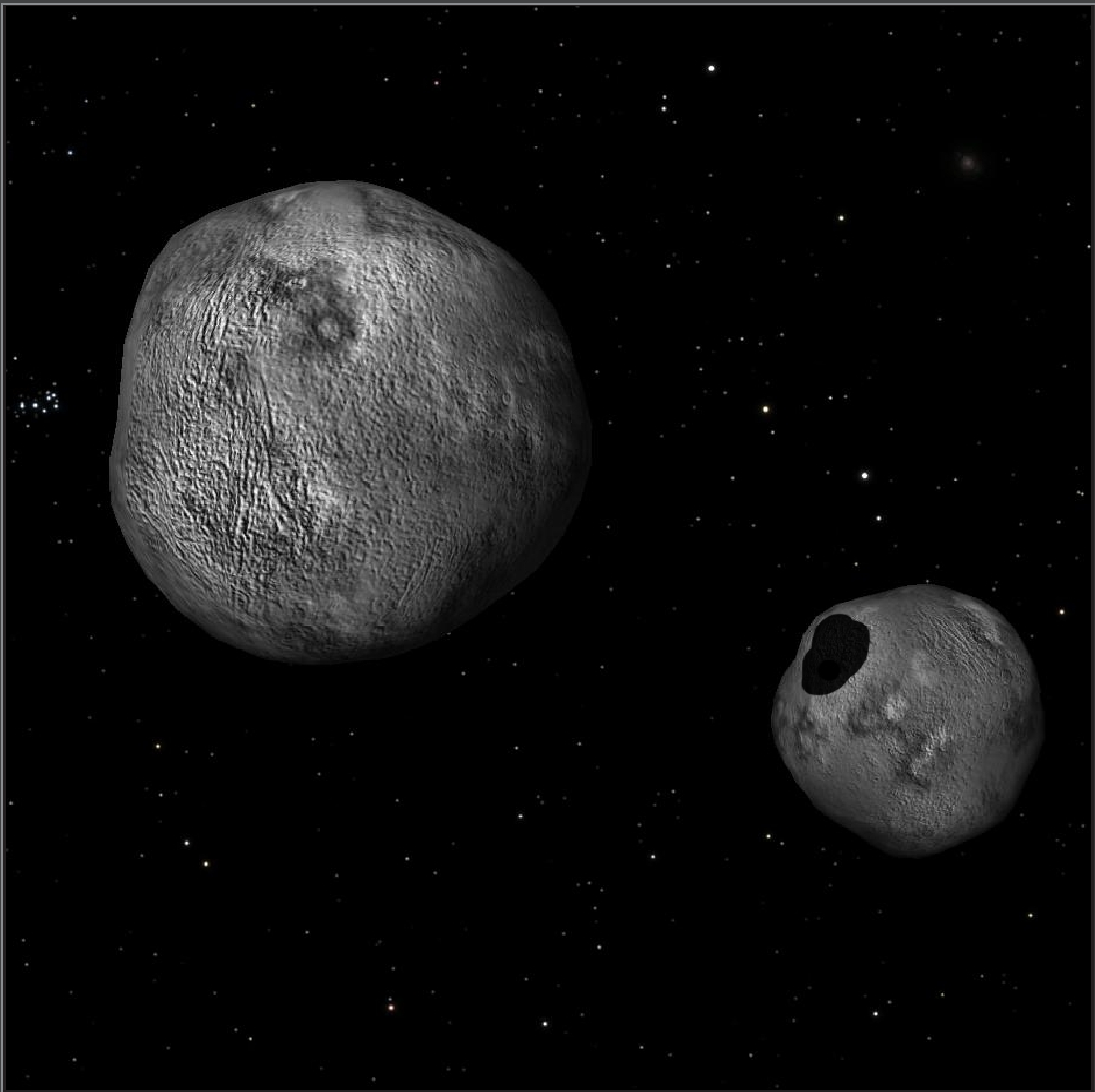

Mutual Events in Asteroid Systems

Dear reader,

With this issue the *Journal for Occultation Astronomy* has reached an important milestone. The online PDF issues of the *JOA* are now freely available to everyone. Over recent decades the internet has replaced printing as the primary mode of publishing for most scientific endeavours. Many of the leading publications in the field of astronomy already offer free online access to most, if not all, of their articles. With this change to the *JOA* access, we have joined the ranks of the major astronomy publications and greatly improved our ability to promote occultation science to astronomers and the general public worldwide.
Given this milestone, it is a good time to recognize the many contributions of our members who provide both money and time to support our shared mission of promoting the science of occultations. At this point in time, the *Journal for Occultation Astronomy* is perhaps the largest single expense in our budgets. Because we believe the *JOA* should be done in a professional manner, we hire a professional editor to create the layout for each issue. Your contributions as members of our various occultation organizations provide valuable funding for ensuring the success of the *JOA*. In addition, many people volunteer time to provide articles for the *JOA* and organize the content and publishing cycle of each issue.
It is hard to overstate the value of these volunteers who contribute their time. None of our organizations employ staff. Everything is accomplished by the time commitment of volunteers. Our various organizations collaborate to provide a wealth of resources for occultations science: educational materials via our websites, mailing lists, and the *JOA*; occultations predictions via *Occult* and *OccultWatcher*; and a database of worldwide occultation observations. These resources are freely available to everyone through the contributions of our volunteers.
Volunteers are the foundation of this work and deserve our thanks for everything they do to support our mission in occultation science. And they need our help. In the last two years, the number of observed asteroidal occultations events has doubled. I believe we will continue to see an increase in the number of people contributing observations. So, I encourage everyone to try to find time to support this work by volunteering in whatever capacity is possible for you.

Steve Preston

Steve Preston
President – IOTA

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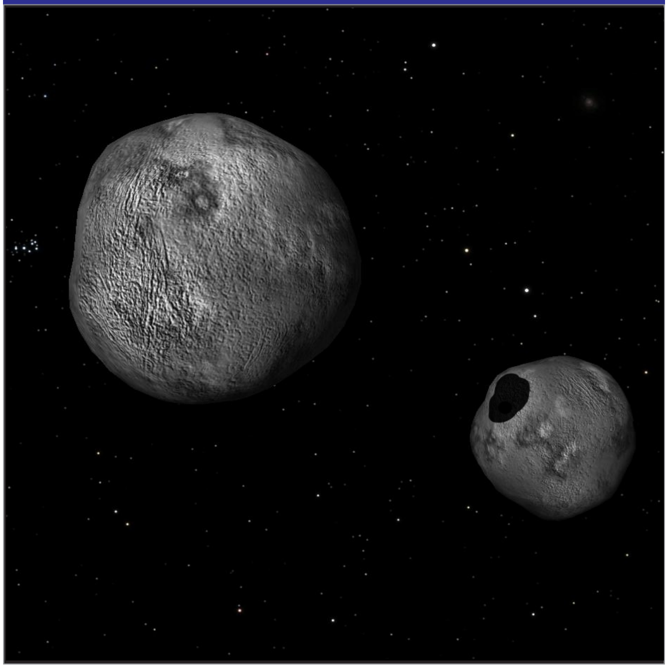
In this Issue:

COVER



Artist's impression of an eclipse in an asteroid system. The satellite casts its shadow on the main body. Therefore a faint drop of the combined magnitude of the system could be detected.
Mutual events by components of asteroidal systems such as eclipses and occultations were observed by amateur astronomers already. Henk de Groot from the Netherlands reports in this issue of *JOA* about his ambitious attempts to measure these hard to observe events.
Cover image: O. Klös, created with Celestia 1.6.1.

Rules for Authors

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

Journal for
Occultation Astronomy

Occultations and Eclipses in Asteroid Systems

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This is a translation by the author of a previous published article in OCCULTUS 131 & 132 published by the Dutch Occultation Association (DOA)

ABSTRACT: Observing occultations is something that especially amateur astronomers have been working on for many decades. In the past most observations were of occultations of stars by the Moon. But not so long ago the emphasis has changed to observing occultations by asteroids. Occultations by TNOs and Centaurs have very recently attracted increasing attention.
A special type of occultation is the mutual phenomena in asteroid systems, where the components of asteroid systems occult or eclipse each other. These can be binary or triple systems, where the components have more or less the same size, or asteroids with moons, where the components differ greatly in size.
The realisation that many more asteroids are multiple or have moons than we ever previously thought also contributes to the increasing interest in observing these phenomena.
This article describes how the author gets involved in observing these phenomena, and how this has progressed.
In addition, observations of Kalliope and Linus, Doppler and Zichichi are discussed.

Multiple Asteroid Systems

Multiple asteroids can arise from mutual collisions of asteroids. The chance of this is very small, and if the collision is very weak, the loose matter will largely fall back onto the parent body. And in the event of a heavy collision, most of the lumps fly off into space. This way of making multiple asteroids systems is not very efficient at this time.
There are strong indications that many asteroids do not consist of one piece, but of a large collection of loose stones and grit, which is held together by the very weak gravity. The density is low, between 1 and 2.5 g/cm^3.
This means that when an asteroid starts rotating too fast, the outer parts can fly off, because the centrifugal force exceeds the weak gravity.
Evidence for this is that we do not find asteroids that spin faster than once every 2.4 hours. If the rotating velocity of an asteroid goes faster, it will fly apart. We also find more and more binary and triple systems. Meanwhile, some 310 binary systems and 13 triple systems have now been discovered (February 2018).

YORP Effect

An important mechanism for the creation of binary asteroids is the Yorp effect, named after a number of astronomers with difficult names who have discovered this (Yarkovsky-O'Keefe-Radzievskii-Paddack). That effect speeds up the rotation of the asteroid body slowly but surely. It arises because the solar radiation hits the asteroid, and this radiation is largely transmitted asymmetrically by the asteroid as thermal radiation. Especially the smaller asteroids are the most affected in relative terms.When a part of the original asteroid is separated, anything can happen. The smaller of the two components can increase its own rotational speed at the expense of the rotational speed of the primary body and at the same time sometimes change the orbital path, and thereby subsequently break in half again, creating a chaotic three-body system. Any escape into space of one of the two smallest parts or the recombining together of two components can again provide a stable binary system.

Synchronous and Asynchronous Systems

A binary system in which the duration of a full orbit of the secondary component is equal to the rotation time of the primary component is called a synchronous binary system.
The orbit of the secondary can also be very eccentric, and in that case it is asynchronous with the rotational speed of the primary.
Finally, a binary system can also coagulate into one asteroid; then a contact binary system arises, more like the idea of a failed potato. With computer simulations, that has already been redrawn. By regularly measuring the orbits of the mutual asteroids in a multiple system, astronomers can learn more about their evolution. The mass of a system can also be determined from the orbital data, and if we can also find out precisely the size of the bodies with, for example, stellar occultations, we can calculate the specific mass or density of the bodies.

How I Started with Occultations and Eclipses in Asteroid Systems

It all started at the ESOP in Guildford in 2016. Oliver Klös then gave a presentation on the subject of "Mutual Events of Binary Asteroids".He was in contact with Frédéric Vachier from the IMCCE from Paris. Oliver gave a short presentation, mainly concerning Kalliope and its moon Linus.

First something about Kalliope: It was discovered in 1852 by J.R. Hind from London, and later designated asteroid number 22. It is a main belt asteroid, which has an orbit around the Sun between 4.96 and 7.50 AU, between the planets Mars and Jupiter. The diameter of Kalliope is pretty well known, and is now estimated at 166 km. It turns on its axis in 4.1483 hours.

The moon of Kalliope, called Linus, was discovered on August 29, 2001 with the Keck telescope, and coincidentally 4 days later also by another team with the Canada-France-Hawaii Telescope. The name comes from Linus, in mythology a son of the muse Calliope. The name is also a tribute to Linus Torvalds, the inventor of the Linux operating system.

Linus is rather large for an average moon of an asteroid. You can also consider the system as a binary asteroid. Actually, Linus is too big for a moon and too small for a binary asteroid.

Observers Wanted

From Oliver Klös' presentation it was clear that the IMCCE was looking for observers to measure Linus's eclipses on Kalliope. This was not entirely new. In 2006 two eclipses were also observed by astronomers.

Approximately every 2.5 years mutual phenomena occur in the Kalliope-Linus system for about three months. Sometimes Kalliope is too close to the Sun and there is hardly anything to see. Or it is very low in the summer in the northern hemisphere, which means that the maximum possible observation time is very limited. In the winter in 2017 the conditions were favourable. Kalliope was high in the sky and the nights were long.

Why Observe "Mutual Events"?

In the case of Kalliope and Linus it is possible to observe both at opposition with a large 10 metre telescope and adaptive optics (AO). But Linus is and remains far too small to see it with a telescope other than as a star-like point. The maximum diameter is about 25 milli-arc seconds (mas), while the separation capacity of the Keck with AO does not fall below 55 mas. The estimates of the dimensions of Linus are therefore only based on the amount of light that it reflects.

Kalliope is never larger than a few pixels in the telescope, although the SPHERE instrument has made considerable progress in recent years. The main contributions to the development of a model for Kalliope are the stellar occultations, of which there have been a few since 2006, and photometric observations.

With the help of the "mutual events" it is possible to make the models much more accurate. The orbit of Linus around Kalliope and also how the orbit shifts over the years (precession) depends not only on the mass of both bodies, but also on the shape of Kalliope in particular. The orbit of Linus around Kalliope shows a lot of precession, and that would be because Kalliope is not nicely round in shape, but somewhat elongated.

For example, on the basis of the "mutual events" measurements in 2006 and the stellar occultations observations, the size of Kalliope is better fixed at 166 km, 8% less than the size determined earlier by measurements with the IRAS satellite. The Kalliope-Linus distance is set at almost 1100 km, and the inclination of the orbit of Linus at 99 degrees, with a period of 3.59 days. The diameter of Linus would be 28 km, assuming that Linus is round. A better specific mass of Kalliope can also be determined from the Linus orbit data around Kalliope, and from that more can be said about the origin of the Kalliope-Linus system.

Observing the 2017 "Mutual Events"

The conditions are favourable in early 2017. Kalliope is high in the sky at +35 degrees declination, and is visible for a large part of the night. The details of all "mutual events" can be found on the website of the IMCCE. For January 25th the first eclipse of Linus on Kalliope was announced. The eclipse starts at 10:28 pm, and ends at 1:05 am with a brightness decrease of Kalliope of 0.098 magnitude.

I start with this project, but I don't know exactly what I would get. For observing the eclipse, it is only necessary to continuously record the asteroid with some surrounding stars as reference. It is not necessary to stay next to the telescope all night long. If everything is set, and the recordings are running, you can simply go inside to your warm house. Only when turning the mount when the asteroid goes through the south meridian (a meridian flip), am I needed, and of course I must beware of possible rain showers. I usually go on the couch in the room to get some sleep in between, and then set the alarm clock for every two hours or so to see if everything is going well.

It is clear that you probably should not start with an 8 bit analogue Watec camera. The Watec has only 254 shades of grey, between black and white, and will have a lot of trouble to detect variations smaller than 0.1 – 0.2 magnitudes without problems. For this purpose you need a 16-bit camera, in this case an STBIG ST-8 camera. With 65,534 shades of grey with black and white, it should work better. The light is filtered with a V filter, which is a filter that lets through yellow-green light, and blocks the rest. That does not seem so convenient because you lose about a magnitude, but it is needed to get a good reference of the brightness. You can only measure the relative brightness of the asteroid with regard to other stars, which of course have to remain constant in brightness during the measuring session. The brightness of stars is always available in certain colour bands, such as V (greenish yellow), R (red), or nowadays G (from Gaia).

Further good advice from Oliver's presentation is that the uncertainty in time for the occurrence of the eclipses can be 60 - 90 minutes, and a factor of 2 in brightness.

The first eclipse has been predicted for January 25th. The weather is stable and bright, which is important. In contrast to ordinary

stellar occultations, where a few minutes of cloud clearance in the sky can be a success, you need a good sky for many hours for observing mutual events of asteroids.
That night I start at 8:45 pm with the taking of the images, which is three and a half hours before the start of the predicted eclipse. The recorded images are always illuminated for 2 minutes. The last image is taken at 1:40 am, three quarters of an hour after the predicted end of the eclipse (All times in UT). It is also not possible to continue longer as Kalliope then disappears behind the trees from my observing location.

The First Results

After calibrating and measuring all 316 images, I get a beautiful sinusoidal light curve. Because Kalliope is relatively bright, between magnitude 10.5 and 11.1, the signal-to-noise ratio is excellent. However, I do not see any eclipse.
The recorded light curve is almost 7 hours long, and that is 1.9 times the rotation period of Kalliope. Therefore I copy the first part of the curve and paste it onto the second part. The pieces fit together almost perfectly, so where is the eclipse?
I send the results to Frederick Vachier, and a few days later I get a message back with: "thanks, I will look at it" (Figure 1).

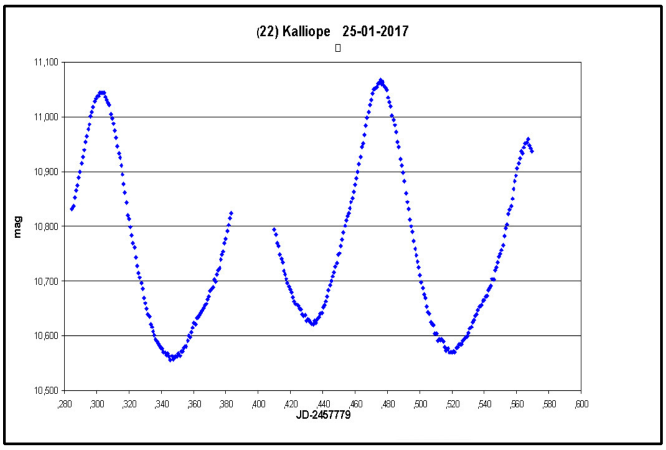


Figure 1. The brightness curve of Kalliope recorded on 25-01-2017. On the horizontal axis the Julian date, minus 245779. On the vertical y-axis the brightness in V magnitudes. Initially I didn't find any eclipse occur in this figure, the curve is flowing smoothly, without dips. But whoever is very smart, could have seen that something could be going on, because the first maximum and minimum are slightly brighter than the second maximum and minimum. The data gap was caused by the meridian flip of the mount and because Kalliope was too close to a nearby star.

Second Chance

On February 12th there is a second chance. An eclipse is predicted with a brightness decrease of 0.05 magnitude. The sky is clear and more than 3 hours before the predicted 2:55 hour eclipse I start again. My last image is 12 minutes after the end of the supposed eclipse.
After calibrating and measuring I get a nice brightness curve, and when I paste the first part of the curve onto the second part, I do indeed see a difference. It seems that the end of the eclipse was recorded, but not the start of the eclipse (Figure 2).

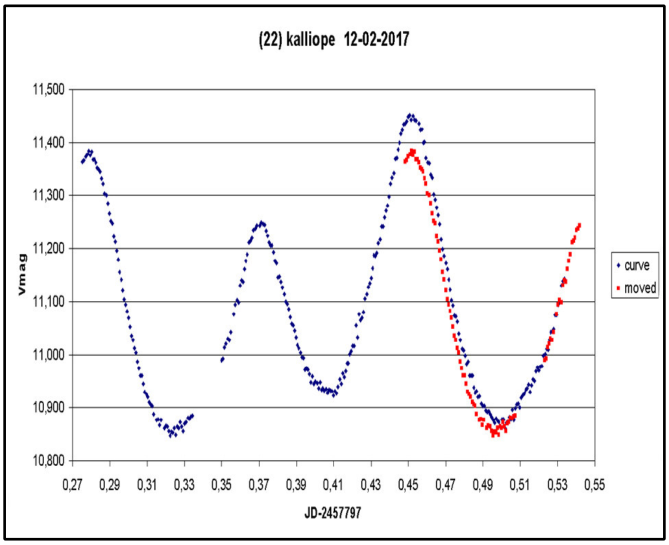


Figure 2. The brightness curve of Kalliope of February 12th 2017. On the x-axis the Julian date minus 2457797 and on the y-axis the V magnitude. The first part of the curve is copied on top of the second part of the curve, in red. The end of the eclipse is now easy to find, at about JD 0.51, but not the start of the eclipse because the first part of the curve cannot serve as a reference.

The end of the eclipse, which I can determine with certainty, was 38 minutes earlier than the prediction. The beginning seems to start only 5 minutes late, if I compare it with the previously found curve of January 25th. The maximum brightness decrease measured by me is 0.08 magnitude, while 0.07 magnitude is predicted here. That is also a nice fit.
However, the shape of the light curve at the eclipse is not what I had in my mind. Stellar occultations show a sudden decrease in brightness. But when the shadow of Linus is in contact with the surface of Kalliope the brightness drops very slowly and follows a particular pattern.

Eclipse Delay?

I send the results back to Frederick, and I quickly receive (on February 24th), the answer that the eclipses occur with a delay of 5.5 hours from the predicted time. That is very different from what I think I have found myself. I do not understand much of it, and a few days later I send an e-mail if it still makes sense to start observing at the times calculated by the IMCCE if the eclipses are still delayed.
On March 8th I receive a message from Pascal Descamps, a colleague of Frederick. He has received a recorded light curve from the Haute Provence observatory a few days before February 12th, and he also thinks the eclipses had shifted in time.

Eclipse Still Reasonably on Time!

On April 7 I receive an email from Pascal with the results. That is a graph with the difference of two curves recorded at Haute Provence without eclipse on February 5th and 6th with my curve of February 12th (Figure 3).

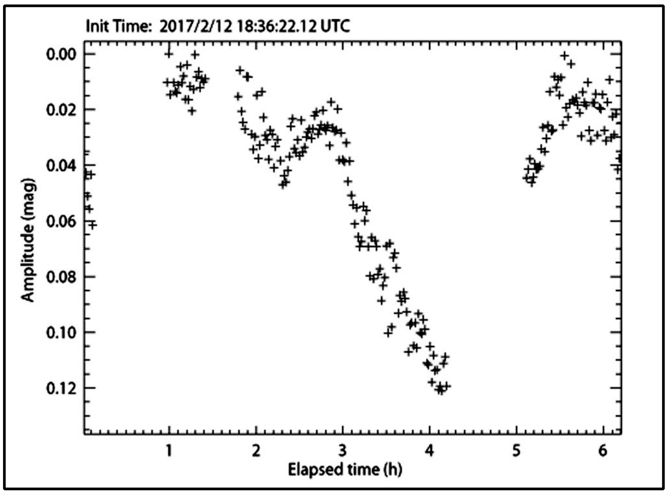
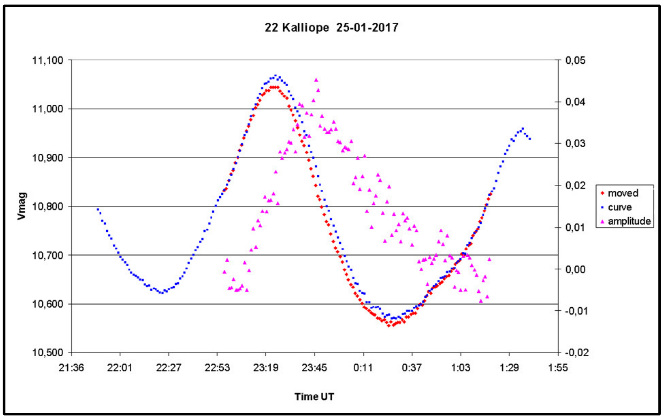


Figure 3. The graph I got from Pascal Descamps from the IMCCE. It is the comparison of two reference curves on February 5 and 6, taken in France with my curve on February 12th. On the x-axis the elapsed time since 18:36:22 UTC, and on the y-axis the difference in brightness between the reference curve and the eclipse curve.

As far as the end of the eclipse is concerned, their conclusion now is that the eclipse has actually ended 38 minutes before the predicted time. Only the beginning has started earlier according to the IMCCE, possibly 2 hours before the predicted start. If true, the duration of the eclipse would also be almost 3.5 hours, which is over half an hour more than predicted. I wonder if that is true, the drop in brightness at the beginning is extremely minimal, only 0.01 magnitude, but we will see.

What Happened on January 25th?

I now have more of an idea about what an eclipse might look like, and look again at my January 25th results. I paste the first part of the recorded brightness curve onto the second part again, and also suddenly realise what I initially did not do the right way. When I initially pasted the first part of the brightness curve on top of the second part of the curve I had shifted the curve in both the X and the Y directions. Of course I should only shift the curve in the time line (X direction) not in brightness (Y direction). Now that I am shifting it in only the time direction, I suddenly see the eclipse coming up (Figure 4).



Results from Both Observations

On January 25th, according to my own observation and elaboration, the eclipse appears to have started 37 minutes later, and ended 12 minutes later than according to the prediction. This is not entirely in line with the eclipse of February 12th, which started almost on time, or even 77 minutes earlier according to the IMCCE, based on a very dim brightness drop, and ended 38 minutes earlier (IMCCE 8 minutes earlier).

The measured brightness drop on January 25th is a maximum of 0.045 magnitude, and that is not half of what was predicted, while on February 12th the drop is a little more than predicted. Most important is that the results did not match the predictions completely, so the models can now be refined.

For the Next Time...

If you want to observe an eclipse or occultation in an asteroid system, you also have to get a reference brightness curve shortly beforehand, or if not otherwise, shortly thereafter. That sounds so logical, but I had not thought about it. And of course also observe as long as possible, predictions are sometimes wrong. Unfortunately, I could not see a third eclipse later because of the clouds. The next mutual phenomena of asteroids followed soon: those were the eclipses of the asteroid Doppler, which I observed a few months later.

Doppler

(3905) Doppler is a main belt asteroid, which orbits the Sun in 4 years at a distance of 2.5 AU. Doppler has a diameter of 6.3 km, rather small. The rotation period is about 50 hours.

The second component is estimated to be 4.8 km in size, and orbits the primary, or more accurately, the common centre of gravity, in 2.1 days. The binary component was discovered in 2013 from photometric curves. The density of Doppler is also estimated to be low, about 1.6 g/cm^3, which means that the asteroid consists of a loose collection of stones and grit.

The Discovery of the Second Component

The discovery was made by a group of students from the University of Maryland with L Franco from the Balzaretto Observatory in Rome. For the recording of the photometric curves, a 0.43 m internet controlled telescope was used in Spain and a 20 cm telescope in Rome. The group states that the evidence of the

Figure 4. The brightness curve of January 25th, with the first part of the graph correctly placed over the second part. On the x-axis the time in UT, on the yaxis on the left the V magnitude. On the y-axis on the right the difference in magnitude between the reference (first part curve) and the eclipse curve (second part). Blue (the squares) the second part of the recorded curve. Red, the first part of the curve pasted on the second part, and purple, the triangles, the difference between the two.

The brightness decrease is only 0,045 magnitude, about the half as predicted. The shape of the eclipse of January 25th this equivalent to the eclipse of February 12th.

companion's presence is apparent from the sharp decrease and then the increase in brightness, preceded and followed by a less steep decrease and increase (Figure 5).

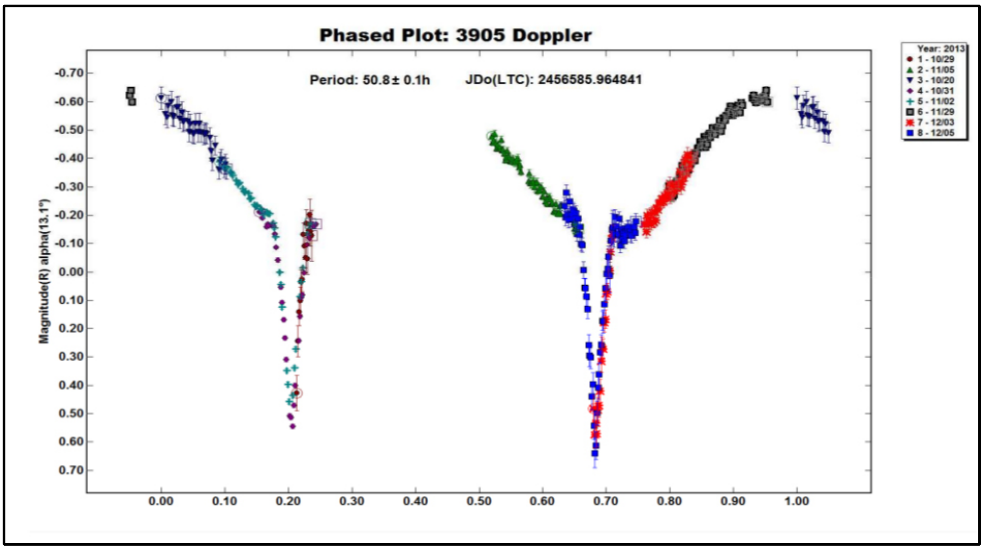


Figure 5. A graph from the publication of the Maryland and Franco group of the discovery of the binary of Doppler. On the x-axis the rotation period of Doppler, from 0 to 1. On the y-axis the brightness in the R-band. The eclipse would occur during the brightness dip with the steeper gradient.

Observing

Doppler comes into view at the end of September 2017. The nights will be significantly longer, so that it is possible to record for a long time. Around mid-October Doppler is at opposition; its declination is + 26 degrees, an ideal position for observers in light polluted areas, with many trees and houses along the horizon. But the asteroid is not really bright; the average V-magnitude is about 15.2. Unfortunately, the weather is bad for weeks. There are only three long clear nights in October; one night I was unable to observe, but the other two, on October 14th and 15th, I tried.
On October 14th I was able to take 96 images for more than 4 hours. The next day, October 15th, even 142 images, with a total observation time of 7 hours.

Analysis

On both nights I see Doppler increase in brightness. Assuming a rotation time of 50 hours would mean that on the second night, I see exactly the other side of Doppler. I do not see any brightness drop, which would point to an eclipse (Figure 6). My results are to be sent to Pascal Descamps of the IMCCE in Paris, and Raoul Behrend of the Geneva Observatory, just like with Kalliope in spring 2017.
For the record, I was not the only observer of Doppler, especially in the South of France there were also some who participated, among others at the Observatoire du Haute Provence. That's a good thing too, because if all the discoveries of space had to be done in the Netherlands, we would be back a century ago.

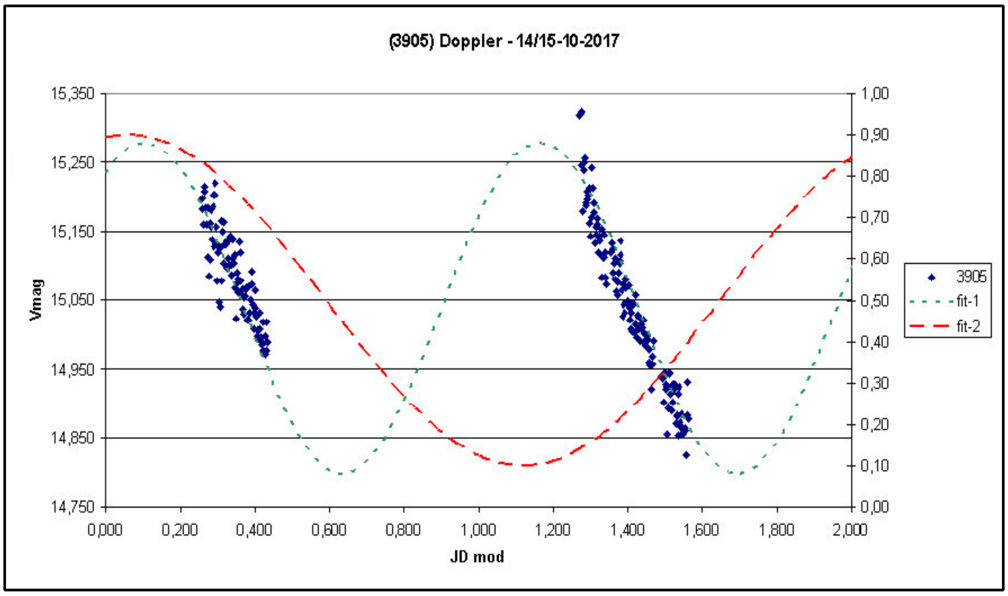


Figure 6. The recorded brightness of Doppler on October 14th and 15th. On the x-axis the time in days. The length is 2 days, just a little less than the rotation period of Doppler, which is 1.05 day. On the left y-axis the brightness in magnitude in the V-band. The red dashed line indicates the rotation of Doppler and the green dot line half the rotation time.

The southern European observers are strongly favoured by the number of nights compared to us in the Netherlands. More than 200 clear nights are just there. Yet it remains anxiously silent on the observation front. Has Doppler lost its companion?

Next Chance

After October 15th it remains cloudy for three weeks. Gradually, the chances of a success fade away, but what can you do about that? Finally, on the 6th of November 2017 there is a clear night. I succeed in observing Doppler for six and a half hours, and am able to take 124 images before Doppler disappeared behind the tree branches near my home.

Doppler has also become somewhat fainter since mid-October; I now measure it at about magnitude 15.6. According to the well-known rotation period of about 50 hours and the position on October 14th and 15th, Doppler should now be at about its minimum brightness of the curve.

Caught!

After working out the images, it strikes me that the minimum does not behave smoothly, but it peaks somewhat. But because I have never been able to record the minimum of Doppler during this opposition, I do not know if the brightness is normal or deviated (Figure 7).

On November 10th I send the results away, and on November 11th I get an answer from Pascal that I probably recorded the first eclipse. Raoul Behrend also comes back later with the same message, and he also publishes a list of predicted future eclipses on the web.

For me, after this one night, it's just over. The following weeks, many rain clouds gather again above the Low Countries and observations are not possible.

Last Observation

Sixteen days later the sky is clear in the Netherlands, and Doppler is at or near its minimum that night. On November 22nd and 23rd I am able to observe the two minima again. The photometric curves obtained are comparable with the previously established curve of November 6th (Figure 8).

However, it is becoming increasingly difficult to capture Doppler. As the opposition date passes further the brightness of Doppler fades, and it disappears too early behind the trees. It is therefore the last time that I managed to capture an eclipse. Only Olivier Labrevoir manages to observe an eclipse in December.

With regard to the brightness curve and the duration of the eclipse compared to that of 2013, it is noticeable that it is less intense and, moreover, somewhat shorter. That will have to do with the orientation of the bodies in the system.

(3951) Zichichi

You cannot always have good luck. An example is the binary asteroid Zichichi. It was discovered in 1986, and is also a main belt asteroid with an estimated diameter of about 6.4 km, also rather small.

The second component was discovered in 2006, also on photometric curves, among others by the group of Raoul Behrend. In 2006 it was not possible to establish a rotation period of the companion of Zichichi. In 2011, people from the Appalachian State University, also with photometric observations, derived an orbital period of 27.6 hours. The rotation time of Zichichi itself is 3.39 hours, so this system, unlike Doppler, is not synchronous but asynchronous. In 2011 it was determined that the brightness variation due to the rotation of Zichichi itself is 0.26 magnitude,

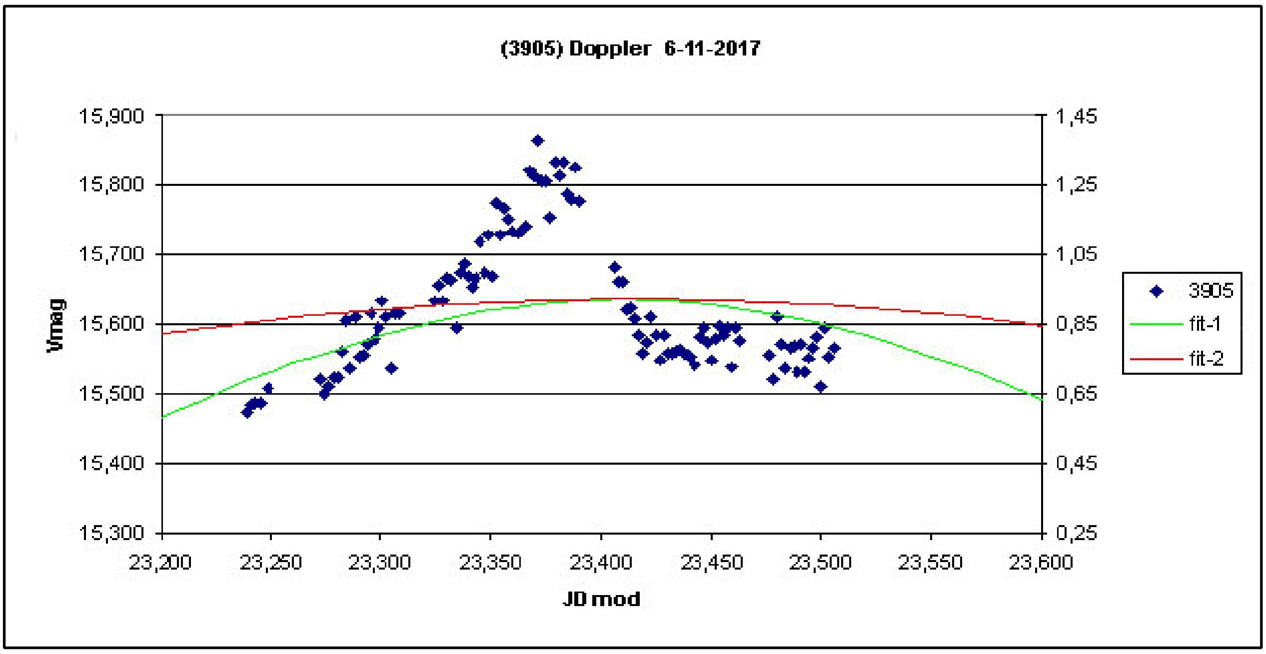


Figure 7. The recorded brightness curve of Doppler on November 6th 2017. On the x-axis the time in days, since the first observation, and on the left (y-axis) the V magnitude. The brightness drop gradient appears to be larger for a certain time, indicating an eclipse. The solid lines indicate the half (green) and full (red) rotation period of Doppler, and it is clear that Doppler is here at its minimum.

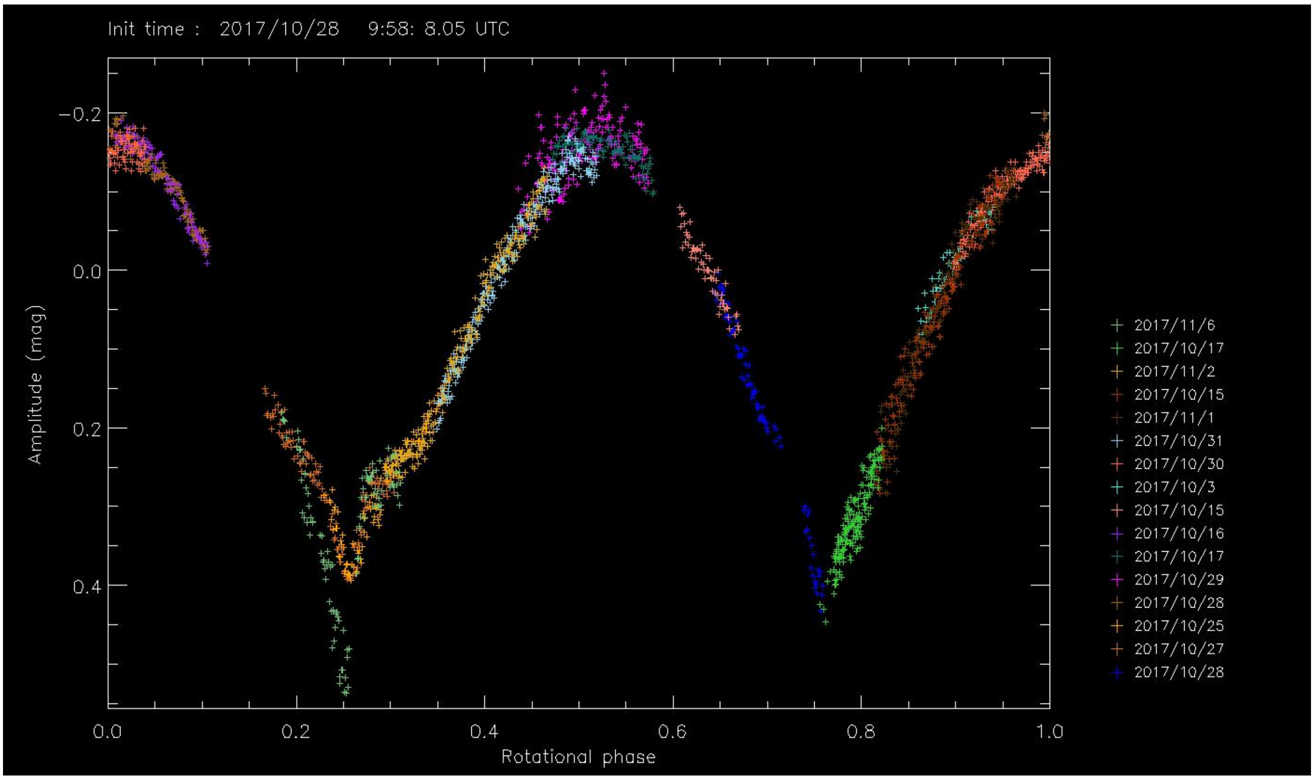


Figure 8. A curve created by Pascal Descamps from IMCCE, with the latest observation of November 6th. In previous observations made by observers in France at the second minimum (right side) is still nothing to see of a possible eclipse.

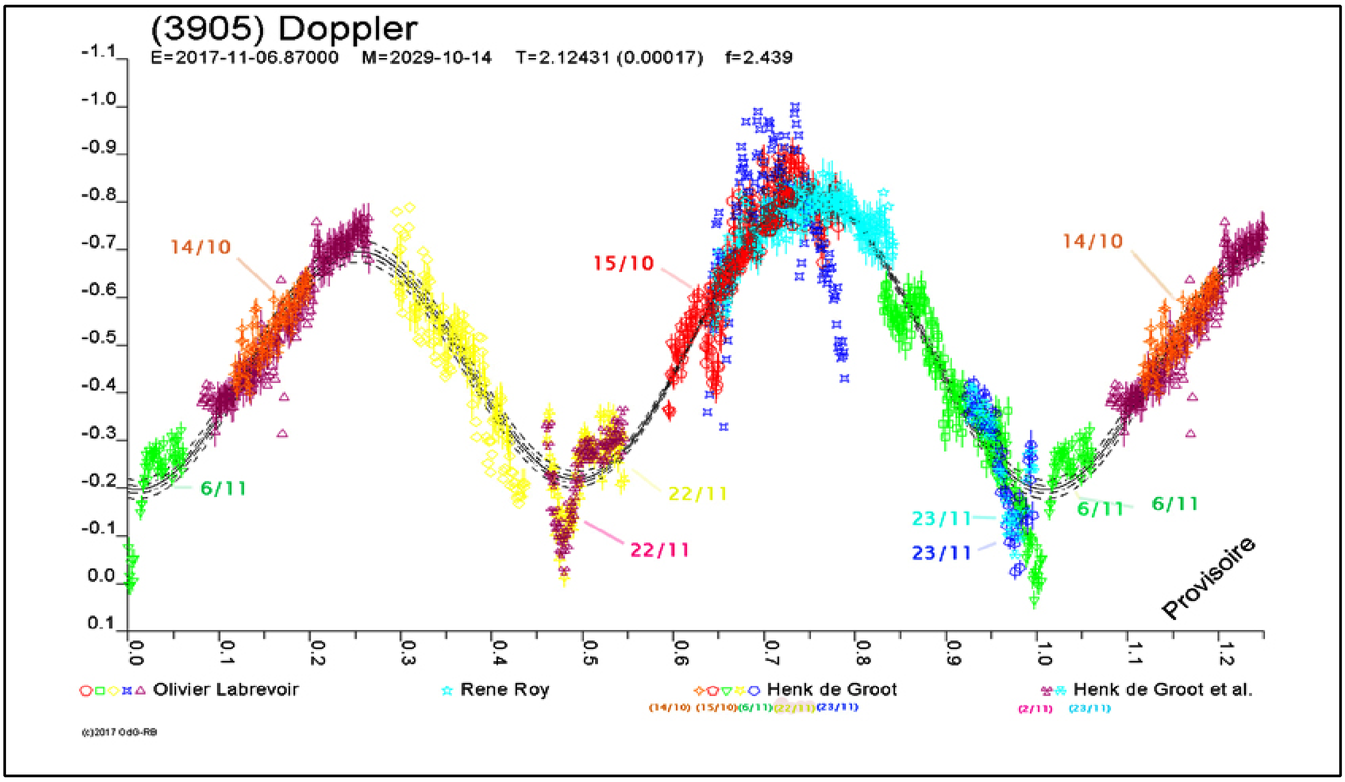


Figure 9. The complete brightness curve of Doppler, drawn up by Raoul Behrend of the Observatoire de Geneve, which contains the measurement data of several observers.

and the eclipse or occultation causes an extra brightness change of 0.12 to 0.23 magnitude.

From these data it can be deduced that the density of the system is only 1.6 g/cm^3, so really a collection of loose rubble.

Observing Zichichi

After again a long period of clouds and rain a high pressure area arrives on February 7th, with a cold dry east wind with lots of clearings. So the telescope is directed at Zichichi. It is relatively faint in brightness, in the beginning magnitude 16, but later slightly fainter. The air is very clear and Zichichi moves very slowly past the stars, initially not even 0.1 arc second / minute. Exposure times of up to 4 minutes are then easily achievable.

Later in February I get more problems with high thin cirrus and the many 'plane condensation trails that spoil the images. The signal-to-noise ratio then deteriorates so much that the measuring accuracy is reduced. Actually, a real observing star amateur would no longer have to think about flying at night!

Together with the emerging Moon, the observation sequence has to be terminated after February 17th. By that time Zichichi has been observed for a total of 23 hours. Two other amateurs also observed Zichichi. Unfortunately, we did not manage to observe an eclipse or occultation. Probably it did not occur, probably because the positioning of the system in relation to the Sun was not suitable for this (Figure 10). There is not enough information on this system yet. Zichichi is now too far away, and hopefully we will be more successful with the next opposition.

Further Reading

Light curves can be found on the website of R. Behrend of the Observatoire de Geneve: https://obswww.unige.ch/~behrend/ page_cou.html and on the website of the Minor Planet Center.

You will find a lot of information about multiple asteroid systems on the website: www.johnstonsarchive.net/astro/asteroidmoons.html

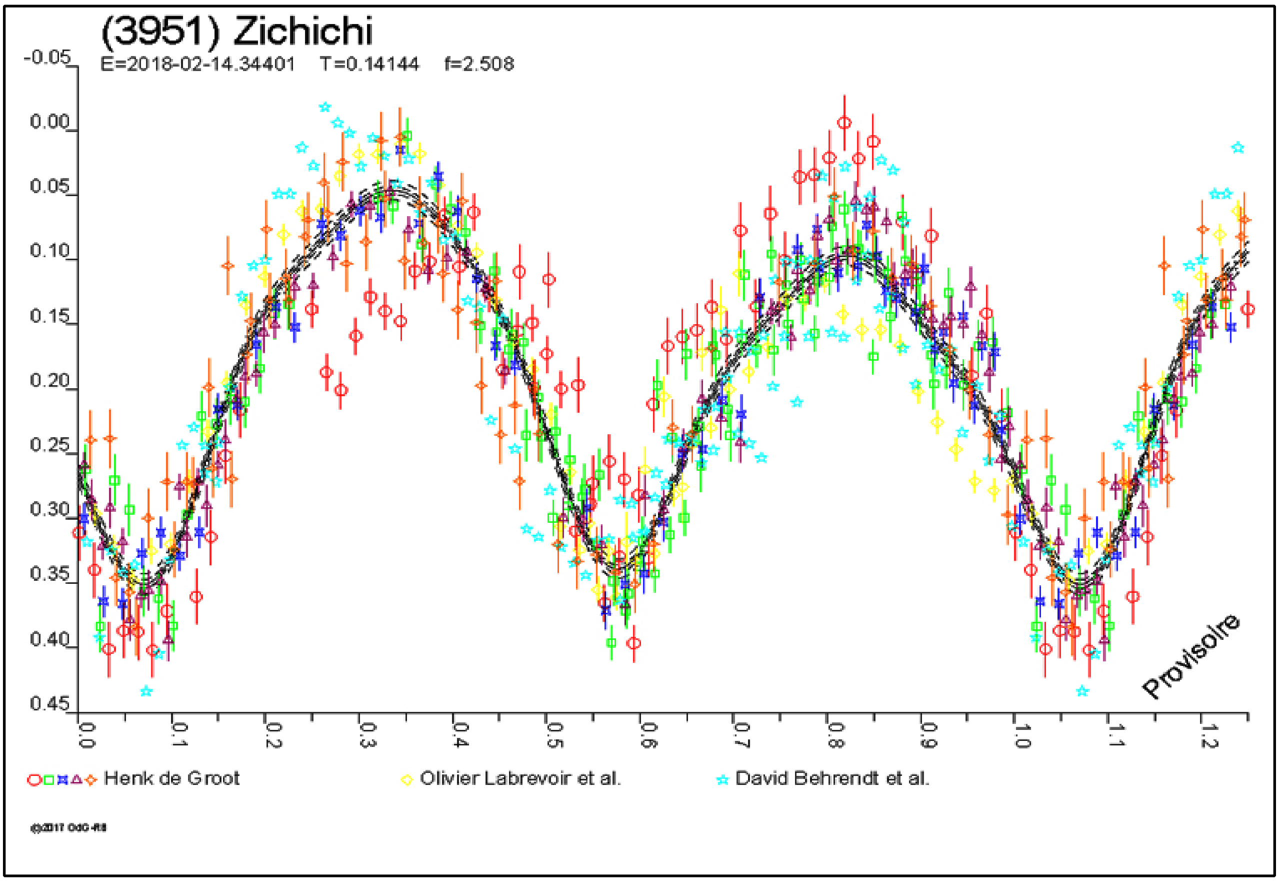


Figure 10. A brightness curve of Zichichi made by R Behrend from the Observatoire du Geneve, with the results of several other observers, Olivier Labrevour and David Behrendt et al.. The amplitude of the brightness is 0.3 magnitude. Unfortunately, no sign of an occultation of eclipse has been found here.

Journal for
Occultation Astronomy

The 2018 September 2 Occultation by (50000) Quaoar, Observed in Southern Africa and an Outlook on Occultations in 2019

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Lucky Star project (P.-I. B. Sicardy, Sorbonne University and Paris Observatory)

ABSTRACT: We report here the observation of a stellar occultation by Kuiper Belt object (50000) Quaoar. We recorded a positive occultation of a 12.7 G-mag star designated as Gaia DR2 source ID 4145444851530756224 on 2018 September 2 at two stations; one fixed station in Namibia (ATOM, H.E.S.S. site), using a 0.75 m telescope and one mobile station placed about 50 km north of Upington (South Africa), using a 0.254 m telescope, which got an almost diametric chord.

Introduction

(50000) Quaoar is a trans-Neptunian object in the Edgeworth-Kuiper Belt (semi-major axis a = 43.6 AU), orbiting the Sun in a non-resonant, almost circular (e = 0.04) and moderately inclined (i = 8°) orbit. Such objects are commonly classified as Classical Kuiper Belt Objects (CKBO or Cubewano). Another prominent Cubewano is (136472) Makemake. The minimum orbit intersection distance (MOID) to Neptune is 12.3 AU, to Pluto the MOID is 2 AU.

Quaoar was discovered by Chadwick Trujillo and Michael Brown in 2002 on images obtained with the 48-inch Samuel Oschin Telescope at Palomar Observatory, though it was already imaged by Charles Kowal in 1982 (but he did not recognise it as a (distant) Solar System object). Further pre-discovery images back to 1954 were found in plate archives.

Quaoar measures approximately 1100 km in diameter (derived from a multi-chord occultation observation on 2011 May 4 [1]) or about half the size of Pluto, and is therefore one of the largest known TNOs (Fig. 1). Quaoar has one known moon (Weywot), measuring about 70 - 80 km in diameter. Michael Brown classifies the object as "nearly certainly" a dwarf-planet [2].

Figure 1. The currently largest known TNOs in our Solar System. Credit: Wikipedia.

On 2016 July 13 and 14 Quaoar was imaged by New Horizons' Long Range Reconnaissance Imager (LORRI), see Fig. 2 and [3], which displays also an animated GIF.

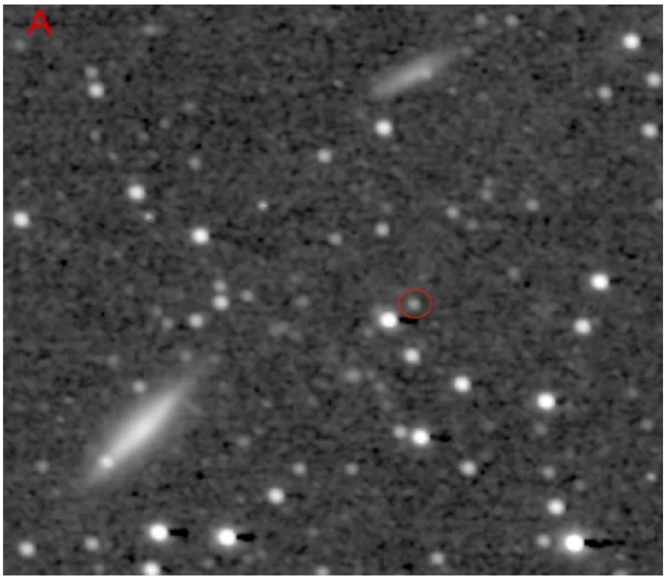

Figure 2. Quaoar was imaged by New Horizons' Long Range Reconnaissance Imager (LORRI) on 2016 July 13 and 14. Credit: NASA/JHUAPL/SwRI.

Previous Occultations

In total seven occultations by Quaoar were successfully observed so far including that one reported in this work. Three of them are single-chord observations, two are double-chord and two occultations were observed by more than two sites (Table 1):

Date UT	Region	No. of Chords
2011 Feb 11	USA	1
2011 May 4	Brazil, Chile	5
2012 Feb 17	France, Switzerland	2
2012 Oct 15	Chile	1
2013 Jul 9	Venezuela	1
2018 Jul 26	Australia	3
2018 Sep 2	Namibia, South Africa	2

Table 1. Summary of successful observed stellar occultations by (50000) Quaoar (as of 2019 January).

The 2018 September 2 Occultation

Quaoar was predicted to occult a Gaia-DR2 star (G-mag 12.7, Gaia RP-mag 11.9, Source ID 4145444851530756224), observable from Southern Africa, on the evening of Sep. 2, 2018. Unfortunately Gaia's DR2 does not contain the proper motion for this star due to an excess of an astrometric fit limit (DR2 fields: astrometric_excess_noise εi = 6.317 mas and astrometric_excess_noise_sig D = 9.10E+03; a value of εi = 0 signifies that the source is astrometrically well-behaved, otherwise it is larger than 0; εi is considered as significant, if D > 2). A possible (and probable) reason for this is a double or multiple nature of the source (star), as Gaia DR1 and DR2 does not handle most of such cases with separations below ~1.5 arcs [4]. Double stars will be added in DR3. As an alternative source for proper motion HSOY and UCAC5 were considered, as these catalogs are based on Gaia DR1, but derived the proper motions (which are completely missing in DR1) by other means, i.e. by using other existing star catalogs with different observing epochs than Gaia. These two catalogs had some intermediate function between the release dates of Gaia DR1 and DR2. Figure 3 shows two predictions by the Lucky Star Team [5], (a) using the Gaia DR2 position plus the proper motion given in HSOY (-6.415 mas/yr and -3.514 mas/yr in RA·cos(DE) and DE) and (b) by applying the proper motion given in UCAC5 (-7.9 mas/yr and -1.1 mas/yr in RA·cos(DE) and DE). It should be noted that neither HSOY nor UCAC5 flags any possible duplicity of the star. The basic occultation data and circumstances are given in Table 2.

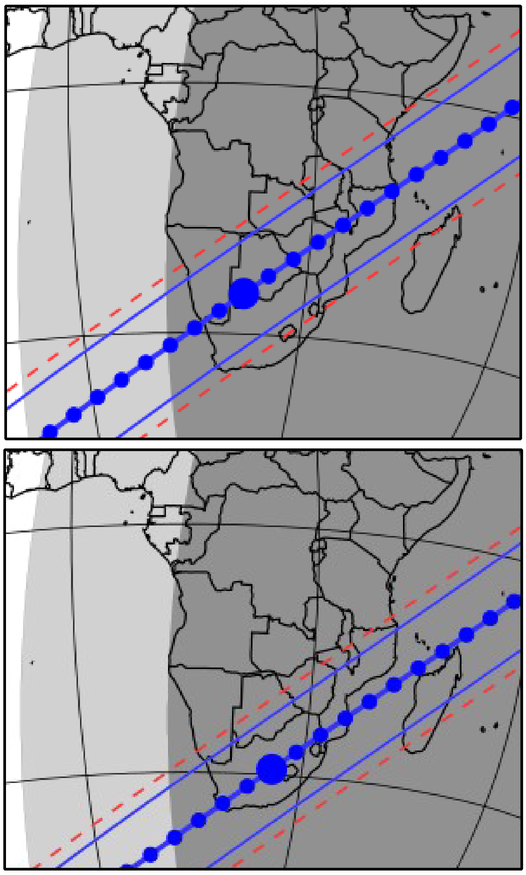

Figure 3. Predictions of the 2018 Sep 2 occultation by the Lucky Star project [5], using the Gaia DR2 position plus applying the proper motion given in the HSOY catalog (top) and the UCAC5 catalog (bottom).

Beside the difference in the proper motion values to be used for the prediction, the situation remained somehow fuzzy, because of the unknown duplicity of the source, with all the consequences for the ground track(s) of the individual components in case of a double (or even multiple) star / source.

Table 2. Summary of occultation data and circumstances

Date @ UT (pmNULL, pmHSOY, pmUCAC5)	2018 Sep 02 @ (18:16:02, 18:17:55, 18:17:51)
Star position (ICRF, catalog epoch)	RA: 17 59 02.0593 DE: -15 27 30.201
Proper motion (HSOY), (UCAC5) in RA·cosDE, DE	(-6.415, -3.514) mas/yr, (-7.9, -1.1) may/yr
G-mag, RP-mag	12.7, 11.9
G-mag, RP-mag normalized to v = 20 km/s	11.5, 10.6
Velocity of body shadow v	6.29 km/s
Magnitude drop	6.2 mag
Maximum duration (for an assumed diam of 1110 km)	176.5 s
Geocentric distance of the object	42.5 AU
Elongation of the Moon to the object	156°
Fraction of illuminated Moon	54%

Observations

Observations were planned to be performed in Namibia and South Africa. Due to the fact that it was not sure whether observing sites like *IAS* (*International Amateur Observatory*, Hakos) , *ATOM* (H.E.S.S. site) or Windhoek (*Cuno Hoffmeister Gedächtnis-Sternwarte*) will be inside the ground track or not, additional mobile stations were considered to fill the region in the southern part of Namibia and / or northern part of South Africa. Unfortunately, due to several reasons, finally only one mobile station could be established (see next paragraph). In South Africa, the *South African Astronomical Observatory* (*SAAO*) and the *Boyden Observatory* planned to observe the occultation, which would have covered the central part or the southern hemisphere of Quaoar, depending on the version of prediction to be considered.

The Mobile Station 'Adventure'

I (M.K) planned to travel to Spingbok at the north-west coast of South Africa, where the use of a Meade 12-inch telescope owned by amateur astronomer Christo de Witt was offered in short-term after getting into touch with him less then ten days before the occultation date. But this option was subject to some uncertainties, as the telescope's electrics were damaged in the past and would be repaired just a couple of days before I would arrive and moreover all this was untested and Christo de Witt himself was not in South Africa at all at that time. He offered to give me access to his house and observatory via his daughter-in-law who is living in the neighbourhood. To have a plan B, I decided to travel first to Hakos in Namibia to pick up a Meade 10-inch LX90 telescope and to take it with me on the trip to Spingbok in order to have a) a spare telescope in case of a nonoperational 12-inch telescope and b) to be mobile in case of any weather issues in that region.

After arriving in Namibia and the same day at Hakos guest farm I tested the 10-inch Meade telescope in the night together with our Merlin Raptor EM247 CCD camera on the target field. Some technical issues had to be solved and after two days I hit the road towards South Africa. Having had good weather during the past few days the sky became now cloudy as soon as I arrived at the border with South Africa. Obviously a bad weather front came in from the ocean side (see Figure 4).

In the late afternoon I arrived in Springbok and after making myself familiar with the house, the observatory and the telescope the sky was meanwhile completely clouded, preventing any test that night. The next morning the weather was still bad, the forecast was even worse for the evening of the occultation, expecting heavy rain. So I decided not to stay in Springbok but rather to try to escape the bad weather by driving to the East towards Upington and to look in that region for a suitable location (lodge, guest house) for the observation.

As I was driving towards and around Upington until sunset in order to observe the weather and to find a place with less light pollution, finally I had to drive into the town to look for a hotel, because it was already night and the weather was bad. So I stayed over night in Upington. The next morning we had rain and strong

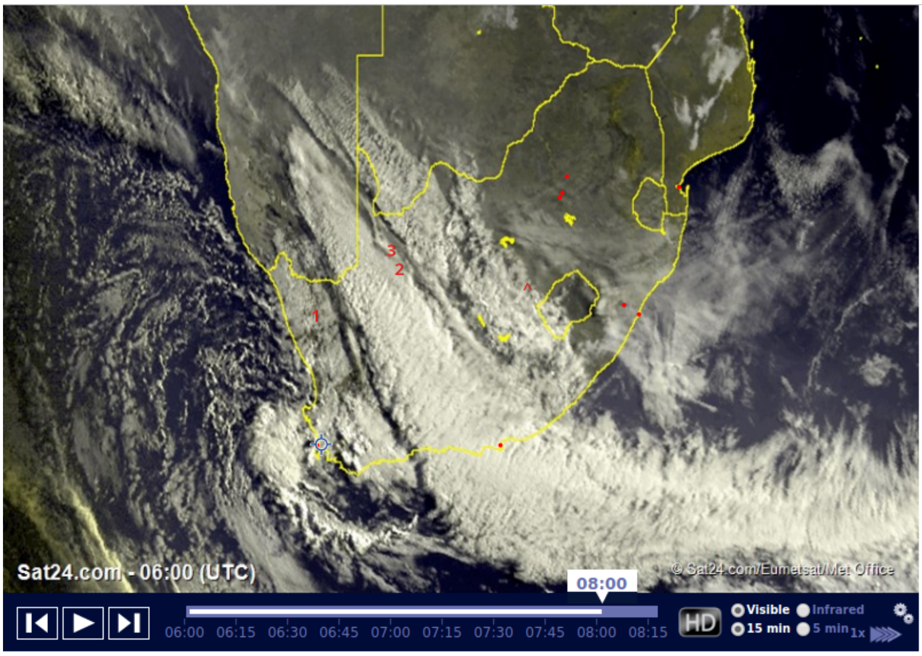

Figure 4. Weather situation on the morning of 2018 Sep 2. At the time this screen shot was taken, M.K. was at site 2 (Upington) in a hotel, facing rain and strong winds. He left site 1 (Springbok, overcast) the day before driving towards the East, because for Springbok the weather forecast was very bad for the coming days. The final destination for the observation was site 3, about 50 km north of Upington, where the sky cleared up just a couple of hours before the occultation. Credit: Sat24.com/Eumetsat/Met Office

wind. It was occultation day. It seemed hopeless to find better weather and a good place to observe within a couple of hours. After checking and considering all options (weather forecast, roads, range in the next couple of hours, potential observing sites, accommodation, etc.) while having breakfast I decided to drive about 200 km to the north to Askham (Kgalagadi Transfrontier Park, border to Botswana), which I expected to be still inside the ground track, though possibly near the northern limit (depending on the version of prediction).

On the way to Askham and just a couple of hours before the event the sky started to clear and by chance in this sparsely populated area I found a farm right next to the road.

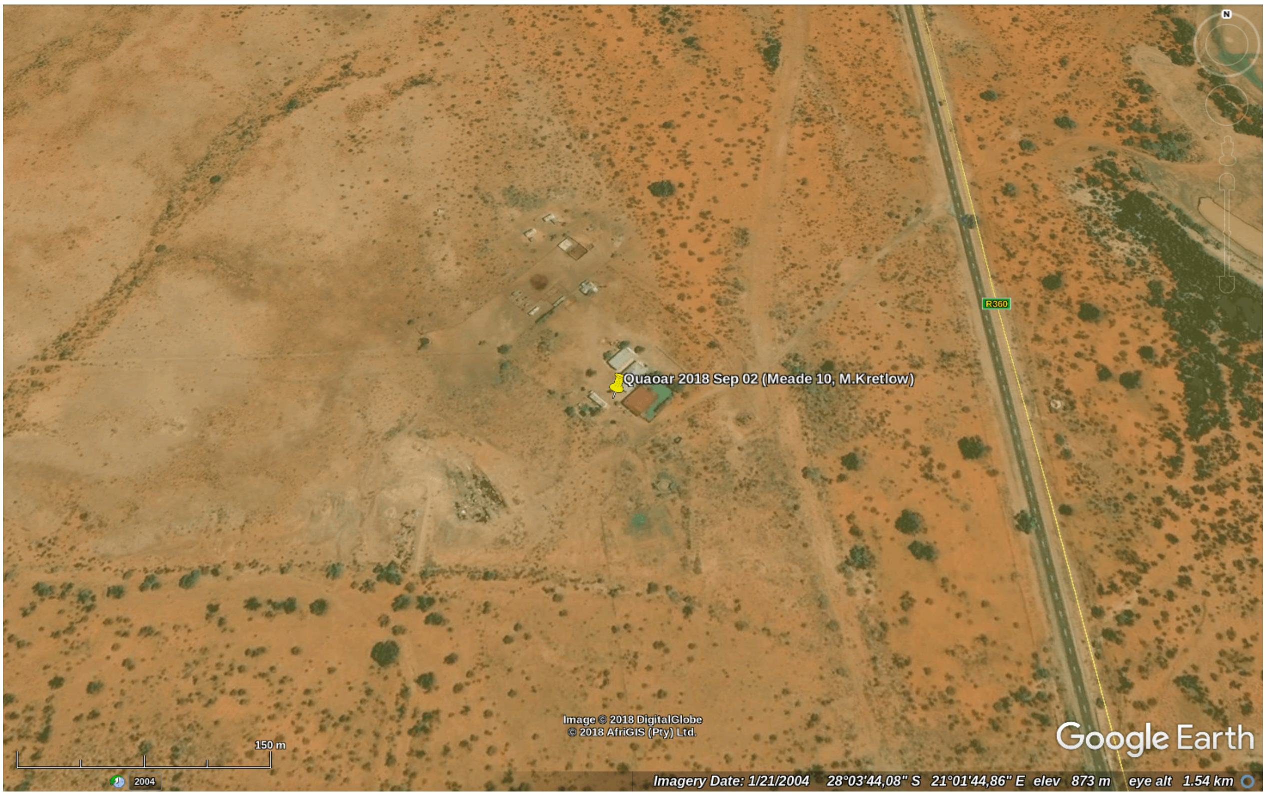

Figure 5. Google Earth view of the farm near Upington, where M.K. finally arrived after driving ~1500 km, starting in Namibia. Credit: Google Earth, DigitalGlobe, AfriCIS (Pty) Ltd., 2018

Figure 6. Set up of the instruments (Meade 10-inch LX90 + Raptor Photonics Merlin EM247 EMCCD camera), immediately after arriving at this site, where the sky started to clear up.

Though in a hurry I decided to stop there, to check out the location and to ask the farm owners if they would allow me to stay there overnight nearby their house in order to make my observation and to be on a safe ground, even if they have no accommodation for me and I would have to sleep in the car. I was really very lucky, as they could not only offer me a perfect observing place including power, but also a guest room and even a great late lunch (I only had cookies with me).

So, a rather hopeless situation in the morning had transformed into the complete opposite, as the sky was clearing up completely and the transparency was great after this lot of rain. As it turned out in the night the faintest star limit was also remarkably good as this was a lonely farm and the owners even switched all lights off for me. Despite some problems with the telescope synchronizing and the finder scope I managed to find the target field and to start recording just a couple of minutes before the occultation. It was a great moment to see the star magnitude dropping (the star did not disappear totally) and while counting the seconds on my watch I soon realized at the end of the occultation, that I must have hit the central region of the shadow. A scary moment came up in the second half of the occultation when the tracking stopped working properly and I had to manually keep the target and comparison star inside the small field of view by using the hand control (worst case would have been to have the reappearance of the star outside the cropped camera field). This happened probably due to observing almost in the zenith with that alt-az mounted scope.

After a thrilling and challenging couple of days on the way from Hakos over Springbok and Upington to this farm near the border to the Kalahari in Botswana, it was very satisfying to finally have recorded this occultation.

Observational Results

Figure 7 shows the occultation light curve derived from the mobile station operated by M.K.. Shortly after the occultation it was obvious, that an occultation duration of about 168 s means, that this station got an almost diametric chord. This result will also favour the prediction based on the proper motion from HSOY, but this conclusion has to be considered with care, because of the yet unknown duplicity of the star and the question, which 'object' (resolved or unresolved component etc.) the proper motion in HSOY and UCAC5 actually represents. Apart from this issue, the prediction made by the Lucky Star project was pretty good; especially the observation of the 2018 July 26 occultation, with 3 chords detected by D. Herald, T. Barry and D. Gault, was important to improve Quaoar's ephemeris for the 2019 September 2 event. A second chord was recorded by the 0.75 m ATOM telescope at the H.E.S.S. site in Namibia, with higher time resolution (exposure time 0.095 s) and a better signal-to-noise ratio, compared to the mobile station measurement. Unfortunately the two stations south of the central line (SAAO and Boyden) were clouded out. No secondary events were found in the light curves so far. Table 3 summarizes the campaign.

Site / Location / Telescope	Observer(s)	Result
C-H-G-S, Windhoek, Namibia, 0.356 m	M. Backes	No result (not on target)
ATOM / H.E.S.S, Namibia, 0.75 m	F. Jankowski	Positive: 2.34 s
Mobile station near Upington, 0.254 m	M. Kretlow	Positive: 167.44 s
Boyden Observatory, South Africa, 1.5 m	H. van Heerden, B. van Soelen	Clouded out
SAAO, South Africa, 1 m	NN	Clouded out

Table 3: Summary of observing sites (ordered from North to South) and observation reports. Light curves and occultation timings based on analysis in this work and by [6].

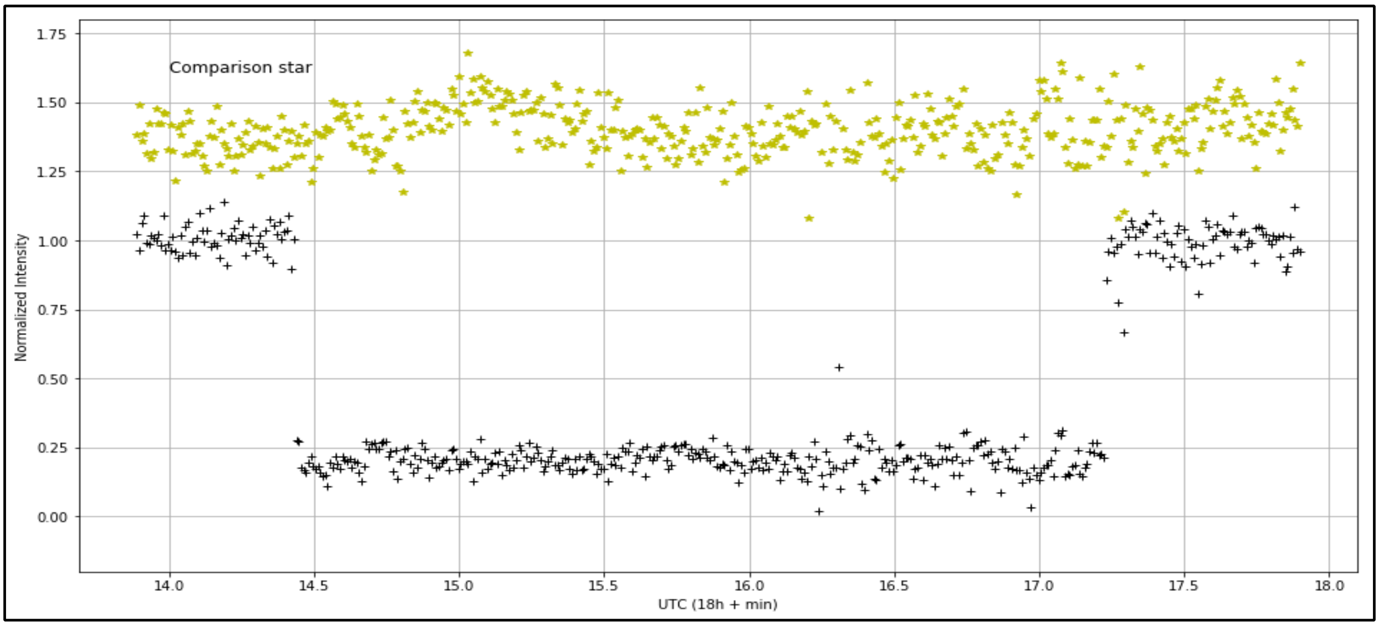

Figure 7. Occultation light curve acquired by the mobile station using a 0.254 m SCT + Raptor Photonics Merlin EM247 EMCCD camera. Exposure time was 0.5 s. Site location : lat 28 03 35.150 , lon 21 01 31.631 , alt 873 m. Observer: M. Kretlow. Due to wind and tracking problems the quality of the photometry decreases partly after about mid-occultation.

Occultations in 2019

For the current year three occultations were identified suitable for observation campaigns. The first one on July 6 crossing South America and the last two events (August 4 and September 26) crossing Southern Africa, see Figure 8. The August 4 event will happen before astronomical darkness for sites in Namibia and the west coast of South Africa. The occultation on September 26 is favourable because the star is about 1 mag brighter compared to the other two occultations, and the shadow velocity is quite slow (v = 7.3 km/s vs. 24.1 km/s and 17.8 km/s).

Acknowledgements

I (M.K.) would like to thank the Kalahari guest house (South Africa) for their hospitality and great help by fulfilling all my needs which were necessary for a successful observation. I would also like to express my appreciation to Hakos guest farm (Namibia) for the great support of our projects, as always in the past years. My sincere thanks to Christo de Witt and his daughter-in-law Jackie (Springbok, South Africa) for their kind hospitality, support and welcome.
This work has received funding from the European Research Council under the European Community’s H2020 2014-2020 ERC Grant Agreement n°669416 “Lucky Star”.

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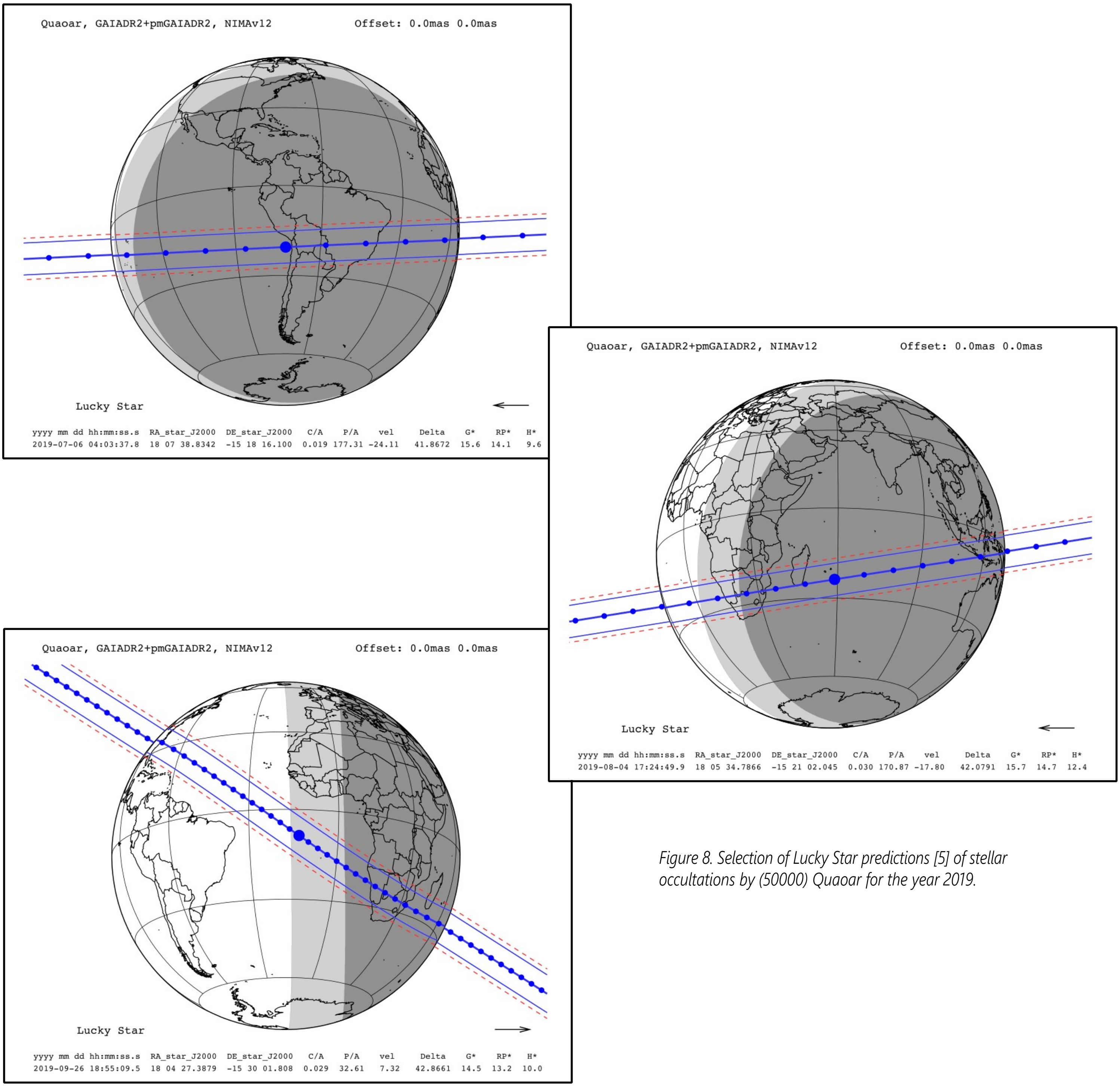
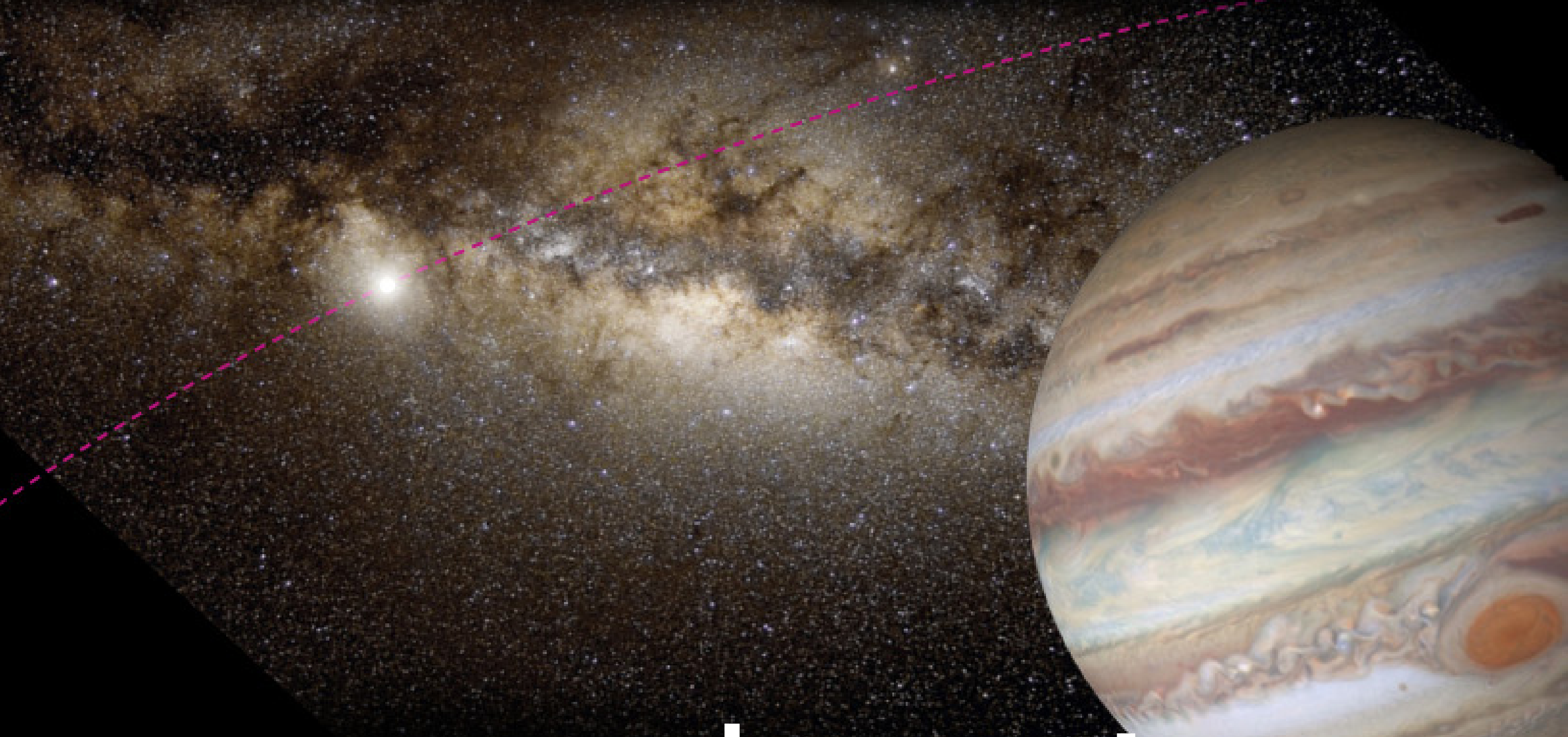


Figure 8. Selection of Lucky Star predictions [5] of stellar occultations by (50000) Quaoar for the year 2019.



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 March 2019, the *Minor Planet Center* listed 866 Centaurs and 2443 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	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 Kretlow	JOA 1 2017
20000	Varuna	André 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
136199	Eris	André Knöfel	JOA 1 2018
136472	Makemake	Christoph Bittner	JOA 4 2018

In this Issue:

(134340) Pluto - The "Downgraded" Planet

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ABSTRACT: Pluto looks back on a changing fate: For 76 years he was considered the ninth planet in the solar system - but in this function he was an exception: very small and on a very inclined orbit that did not fit quite well with the other eight planets. Over time, other Trans-Neptunian objects were discovered, which have similar orbits as Pluto and are referred to as Plutinos.
In 1998, Brian Marsden suggested that Pluto be given a second status: in addition to planetary status, as an asteroid with the particular number 10000. This proposal was rejected.

The Discovery

As early as the discovery of Neptune, orbital disturbances of Uranus pointed to another planet in the solar system, so Adams and Le Verrier respectively calculated its possible position relatively accurately and on September 23, 1846 Galle, with the help of d'Arrest and Encke, actually was discovered at the Berlin Observatory.
Also Neptune orbit discrepancies were observed and another planet was suspected. Here, however, it was rather a coincidence that an object was found in February 1930, after 25 years of searching, by Clyde Tombaugh during the evaluation of photographic plates taken in January and February 1930 in the constellation Gemini (Figure 1).
This object was much too small for the supposed orbital disturbances of Neptune. On old photographic plates, the position of Pluto could be found back to the year 1908. Even Lowell, who financed the search for the 'Planet X', was able to photograph Pluto on plates in March and April 1915, but overlooked it because of its low brightness (Lowell expected a brighter object).

A Mission to Pluto and Resolution 5A

Of course, Pluto was always an exotic object, so it's no surprise that NASA wanted to send a research space probe to it. Already in 1992 there were first ideas to pay a visit to Pluto. At the turn of the millennium, plans became more concrete and manifested in the *New Horizons* project. After some delays for mostly technical reasons, the mission started on January 19, 2006 directed at the ninth planet.
Half a year later, the famous resolution 5A was made at the 26th General Assembly of the International Astronomical Union in Prague, which redefined the definition of planets and "downgraded" Pluto from a planet to a dwarf planet. Instead of the number 10000 proposed by Brian Marsden (this number was already taken), Pluto was now among many other asteroids in the normal pipeline of numbering and now bears the less distinctive number 134340. Many collaborators on the New Horizons project, especially their PI Alan Stern, ignored for years the new definition and still spoke of the ninth planet.

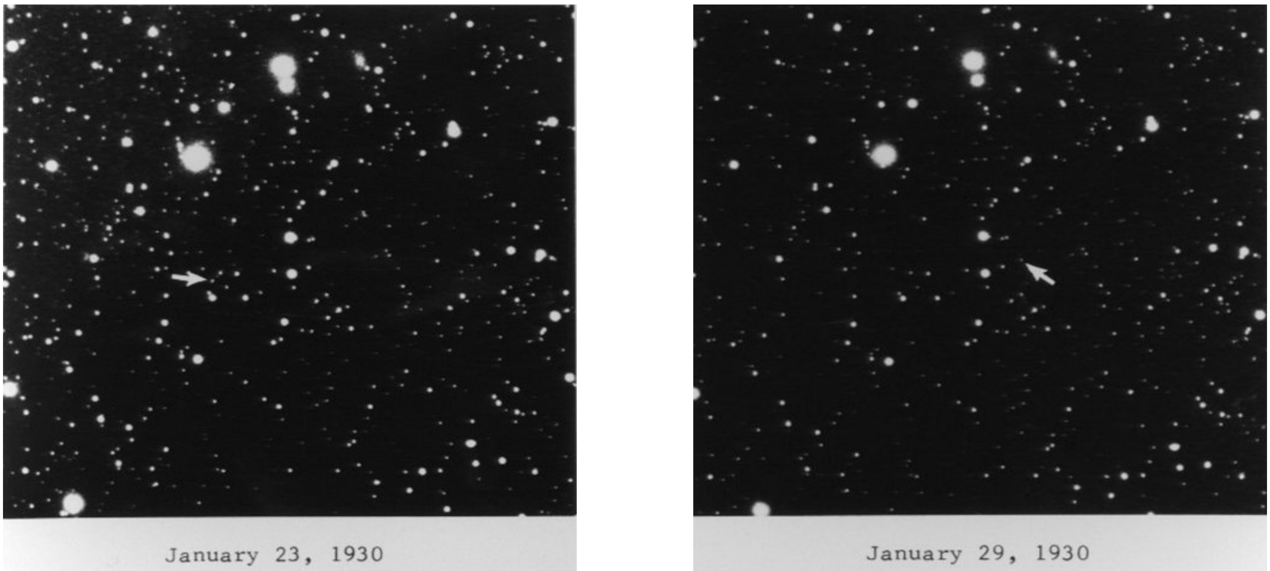

Figure 1. The Pluto Discovery Plates. The photographic plates, taken 6 days apart with the 13 inch telescope, with which Clyde Tombaugh discovered Pluto. The arrows point to the position of Pluto on each of the two days. Lowell Observatory Archives

The Discovery of Pluto's Atmosphere

During a stellar occultation by Pluto on August 19, 1985, an indication of an already suspected atmosphere of Pluto could be found for the first time. With the observations during another occultation of a star by Pluto on June 9, 1988, the first observation results were verified. In the following years, the frequency of stellar occultations by Pluto increased because he moved through the Milky Way near the galactic centre. Thanks to better technology, the observations became more and more accurate and in addition to the measurement of the extent of the atmosphere it was now possible to determine their density, pressure and temperature. Observations over the last 30 years show that the atmosperic pressure has increased by a factor of three since 1988.

New Horizons

Undaunted by the discussions, the *New Horizons* space probe continued its journey, eventually reaching Pluto on July 14, 2015. The probe flew past Pluto at 14.5 km/s at a distance of 12500km and was able to capture high-resolution images at 25m / pixel of the surface of the dwarf planet and its moon Charon. Measurements of Pluto's atmosphere made by the scientific instruments on board of *New Horizons* are in good agreement with almost simultaneous ground-based observations of occultations. These observations were accomplished succsessfully by many amateur observers worldwide [1].

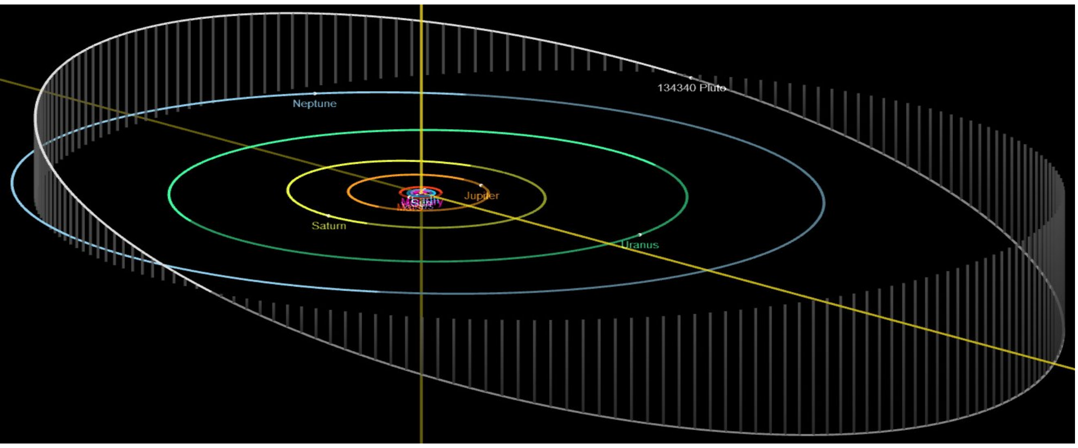

Figure 2. Orbit of Pluto with the position at the discovery date (first plate). JPL Small-Body Database Browser

The Orbit & Physical Characteristics

Pluto needs 251 years for its trajectory around the Sun. Since the discovery about 90 years ago, it has therefore made just about a third of its orbit. Its shortest distance to the Sun is 29.71 AU at perihelion (September 1989) and 49.92 AU at aphelion (February 2114). The orbit of Pluto is in a 2 : 3 resonance with the planet Neptune, similar orbits are e.g. also the TNOs (28897) Ixion, (38628) Huya, and (90482) Orcus and are therefore referred to as Plutinos. At the time of its discovery the size of Pluto was assumed to be the diameter of the Earth but it has been downsized more and more during the years. Now we know, Pluto has a nearly round shape with a diameter of 2374km. Thus, Pluto is only slightly larger than the TNO (136199) Eris. The density of Pluto is 1.860 g / cm^3, indicating a core of rock and a coat of nitrogen ice and water ice. Pluto has a thin nitrogen atmosphere with admixtures of carbon monoxide and methane, and extends to the height of 1600km according to the measurements of the *New Horizons* space probe. Pluto rotates in 6.387 days around its axis inclined by 122.53°. This relatively slow rotation period for this size is caused by the largest of its currently five known moons, Charon. With a diameter of 1208km, Charon is half the size of Pluto. Both bodies also revolve around a circulation time of 6.387 days. The barycentre of both bodies lies far outside of Pluto. Pluto and Charon have a double bonded rotation, that means they always present the same side to the other body. There are therefore considerations to recognize Pluto/Charon as a double (dwarf) planet.

Figure 3. Surface of Pluto. Natural-colour image result from refined calibration of data gathered by New Horizons' colour Multispectral Visible Imaging Camera (MVIC). NASA/Johns Hopkins University Applied Physics Laboratory/ Southwest Research Institute/Alex Parker

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Figure 4. Pluto's moon Charon. Charon in Enhanced Colour NASA's New Horizons captured this high-resolution enhanced colour view of Charon just before closest approach on July 14, 2015. NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute

Journal for Occultation Astronomy

TTSO13

The Thirteenth Trans-Tasman Symposium on Occultations

May 20 and 21, 2019 – Devon Hotel, New Plymouth, New Zealand

Steve Kerr · RASNZ · Rockhampton · Australia · director@occultations.org.nz

TTSO

Occultation observers and interested amateur astronomers are invited to attend *TTSO* – the thirteenth annual meeting coordinated by the *Royal Astronomical Society of New Zealand* (*RASNZ*) *Occultation Section*. As per the established tradition, *TTSO* is being held immediately following the *RASNZ* annual conference and at the same venue – the Devon Hotel, 390 Devon Street, New Plymouth in New Zealand. A programme of talks and presentations is proposed to run over Monday and up to midday Tuesday covering a wide range of topics related to occultations – past observation results, interesting future predictions, new equipment and techniques and demonstrations and hands-on training in software. The programme is not yet fixed and any speakers interested are strongly encouraged to make a contribution and should contact via Director@occultations.org.nz with details.

Registration

Registration for TTSO is done through the same process as for the RASNZ Conference – note that it is not a requirement to attend the conference to attend TTSO. The registration can be done at http://www.rasnz.org.nz/groups-news-events/conf-next .

Webcast

As we have done for recent *TTSO*'s, we are intending to webcast most of the sessions using the MeetCheap platform. This allows remote participants to receive any screen projections and hear audio from the session and ask questions by typing.
Details for accessing MeetCheap will be posted to:
http://www.occultations.org.nz/meetings/TTSO13/TTSO13.htm

Location

New Plymouth is a small industrial city on the west coast of the North Island of New Zealand. It is around five hours drive from either Auckland or Wellington or domestic flights are available from Auckland, Wellington or Christchurch. While the weather in May can be quite wet and cool, the area is blessed with spectacular scenery from the black sand beaches to the towering Taranaki volcano just to the south of the city.

We look forward to seeing you there.

Steve Kerr
RASNZ Occultation Section Director

Michael Busse

1955 – 2019

Michael Busse died on 19.02.2019 at the age of 63 years.

He was one of the fathers of the IOTA/ES' 50-cm-Dobsonian ***M2*** and the graphic designer and layout editor of the *Journal for Occultation Astronomy*.

Our friend Michael Busse died unexpectedly on 19.02.2019 at the age of 63.

After a breakdown he fell into a coma from which he did not wake up any more.

At a young age Michael was a member of the "Astronomische Arbeitskreis Hannover" (AAH), an astronomical workgroup which was led by our late president Hans-Joachim Bode, who passed away in July 2017. Here he also discovered his love for astronomy and occultation phenomena. The AAH was the cradle of IOTA/ES, and it was logical that he becomes a member of this new group; he was even one of the founding members (# 7).

Michael had a very strong interest in astrophotography and technology in general besides occultation astronomy. He designed many different telescopes out of different materials, like aluminum, carbon fibre, etc., always striving to have only the most necessary and to "throw overboard" the unnecessary.

He was also always available for testing new digital cameras for use in astronomy.

In December 2011 IOTA/ES bought a 50-cm-Dobsonian, which he converted into a "light" travel Dobsonian with drive and GoTo equipment. Due to various illnesses, however, the conversion was delayed so much that Michael Dohrmann from Berlin had to complete the conversion. These 2 **M**ichaels were the also the namegivers for our ***M2***.

When the big rebirth of IOTA's own journal "*Occultation Newsletter*" (*ON*) was imminent in 2010, Michael Busse was one of the mainstays for the creation of the "*Journal for Occultation Astronomy*" (*JOA*), also due to his profession as a graphic designer. In the meantime, it has become an internationally recognized journal. Until the end, he was responsible for "typesetting and printing". He also created the blue-coloured version of the original IOTA/ES-logo and designed the IOTA/ES-flyer and -poster.

Michael Busse died much too early, I lost a dear and good friend.

My deepest sympathy goes to his wife Metta and his mother Anna.

Andreas Tegtmeier, IOTA/ES

Less is more - one of Michael's own telescope constructions.

At the inauguration party of the first version of the ***M2*** *at the Archenhold Sternwarte, Berlin, 2016. (from left to right: Sven Andersson, Michael Busse, Wolfgang Rothe, Michael Dohrmann, Hans-Joachim Bode, Konrad Guhl, Martina Haupt and Brigitte Thome-Bode)*

Journal for
Occultation Astronomy

IOTA's Mission

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

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

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

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

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

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