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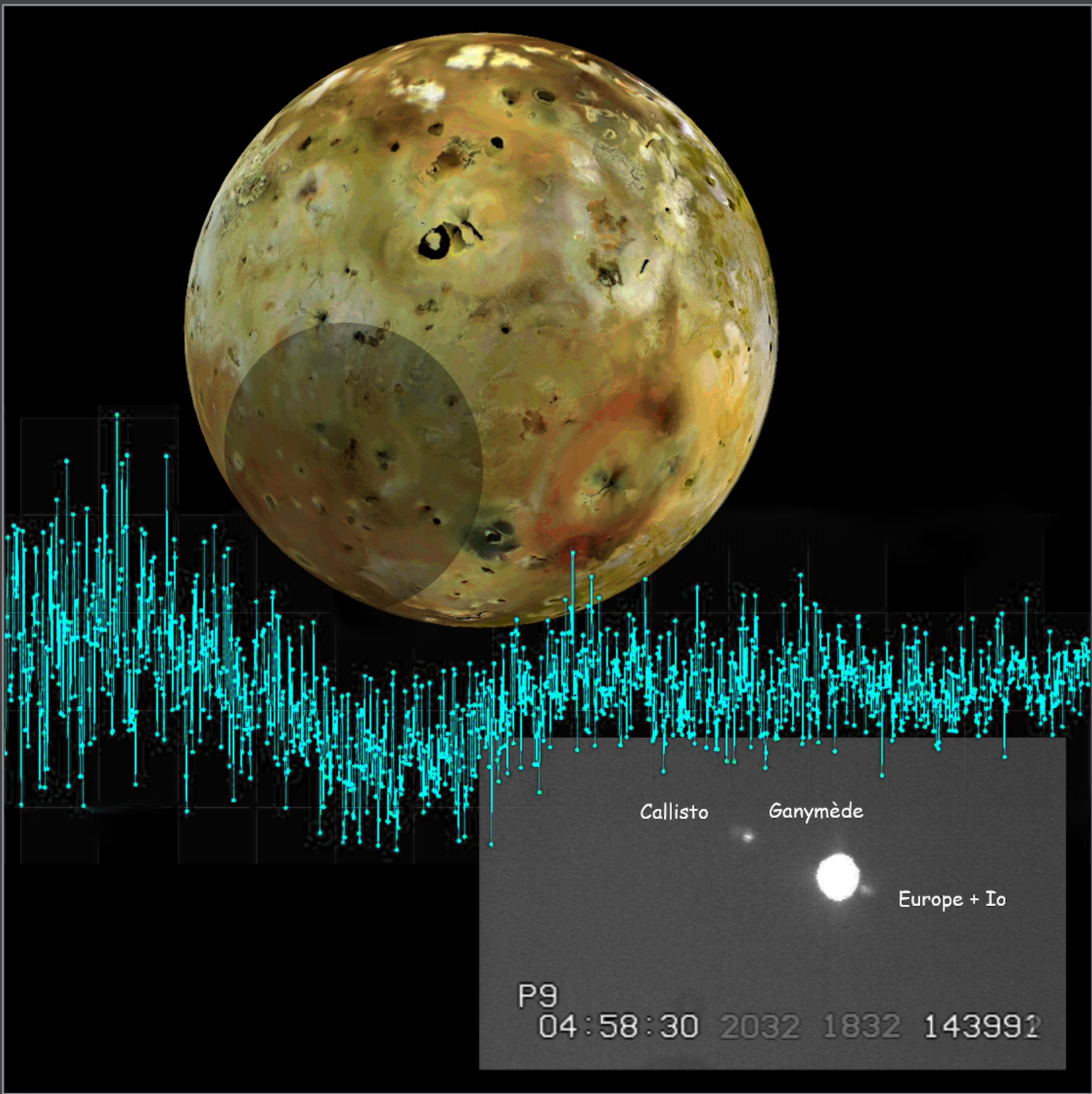


The Observations of Phemu 2021 Have Started

Dear reader,

Do you also have the feeling that the number of observations of stellar occultations by solar system bodies is continuously increasing?

The feeling is correct: In five years (2016 to 2020), the number of observations has risen from 952 observations to 2503 observations. While 302 observers were active worldwide in 2016, there were 853 observers in 2020. These figures only include positive observations. If we read the daily reports in our mailing lists, we have to add many observing hours spent at the instrument and at the computer without positive results. Very few of the observers involved are paid astronomers. For such a basic science as astronomy, a society can only raise a limited amount of money. Great work by many "unpaid" astronomers increases our knowledge about the bodies of the solar system. In astronomy we have known this for many centuries - today there is a term for it: „Citizen Science".

In addition to our daily work, we citizen scientists will be active in the Phemu campaign in the coming months. Our cover picture shows the result of the first observation of the new Phemu season. A report on the opening workshop for our friends in France can also be found in this issue. For the observations, it is above all the "family members" in more southerly latitudes who are called upon. Since 2016, we have been portraying objects of the outer solar system in the series "Beyond Jupiter". For the classification of the objects into different classes and their naming, we have a detailed overview article in this issue.

Clear skies,

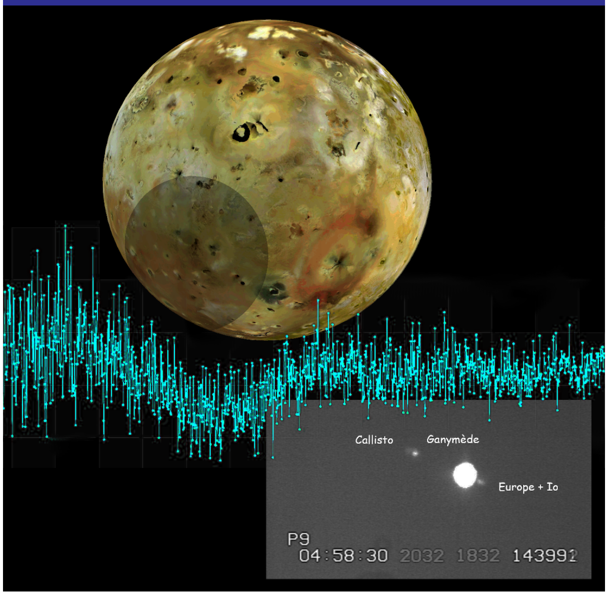
Konrad Guhl

Konrad Guhl
President of IOTA/ES

JOA Volume 11 · No. 2 · 2021-2 (ISSN 0737-6766)

In this Issue:

COVER



With Jupiter at an altitude of only 5° Jean-François Coliac (Observatoire Astronomique du Beausset pour l'Astronomie Collaborative) & Franck Gourdon (Observatoire Astronomique du Gros Cerveau) successfully observed the eclipse of Io by Europa on 2021 Mar 16 through a red filter with a 200mm/f4 Newtonian and a Watec 910HX in windy conditions near Toulon, France. Arnaud Leroy could obtain a lightcurve from the recorded video with *Tangra*. J. Coliac stated: "Astronomy is the school of stronger when together".
Graphic: O. Klös, with images by J.-F. Coliac, F. Gourdon, A. Leroy and Project Pluto's *GUIDE 9.1*

Copyright Transfer

Rules for Authors

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

Journal for Occultation Astronomy

The Irregular Satellites of the Giant Planets

Altair R. Gomes-Júnior · São Paulo State University (UNESP), Grupo de Dinâmica Orbital e Planetologia · Guaratinguetá · Brazil · altair.gomes@unesp.br · altairgomesjr@gmail.com

ABSTRACT: The irregular satellites of the giant planets are a class of objects that were probably captured by their host planets. If they were captured, the mechanism of capture and their origins are not known. There is no known mechanism that is able to permanently capture a satellite in the current solar system. Some authors propose different origins, from the Main-Belt of asteroids to the Trans-Neptunian region. The study of these objects may enlighten how the solar system has evolved to allow the capture of satellites. In this work we use stellar occultations to study their properties and identify possible regions of origin for the satellites.

Introduction

When a planet is born from the proto-planetary nebula, it carries some of the gas and dust from the nebula, which starts to gravitate around the planet. The agglutination of these materials may form what is known by satellites. By the conservation of angular momentum and tidal forces caused by the planet, the orbits of these satellites will very much be prograde (orbits in the same direction of the planet's rotation), almost circular, close and coplanar with the equator of the planet. In most cases, they will evolve into a configuration where their rotations will be tidally locked to their primary, always showing the same face to the planet, for instance, Earth's moon, the Galilean moons, Pluto-Charon, etc. These satellites are classified as "Regular Satellites".

By contrast, the Giant Planets of the solar system, Jupiter, Saturn, Uranus and Neptune, have many more satellites that are very distant, with eccentric, inclined, and, in most cases, retrograde orbits. Because of their orbital characteristics, they were classified as "Irregular Satellites". By 2021 February, 144 irregular satellites are known, 70 Jovian, 58 Saturnian, 9 Uranian and 7 Neptunian ones. Compared to Jupiter and Saturn, the low number of Uranian and Neptunian satellites are probably due to observational bias.

In most cases, these satellites are tiny, with the largest Jovian one, Himalia, being 150 km in diameter. The following are Elara with 80 km, Pasiphae with 60 km, and the remaining with less than 50 km. The majority of them have sizes in the order of 1-3 km. For Saturn, Phoebe is 212 km, Albiorix and Siarnaq with 40 km, and the remaining smaller than 10 km. The largest known irregular satellite is Nereid, Neptune satellite, with 350 km.

In Figure 1, we can see the orbital characteristics of the Jovian satellites. The difference between regular and irregular satellites is apparent. The regular satellites are concentrated within 0.02 Hill radius from Jupiter, while the irregular ones range from 0.1 to 0.6 Hill radius.

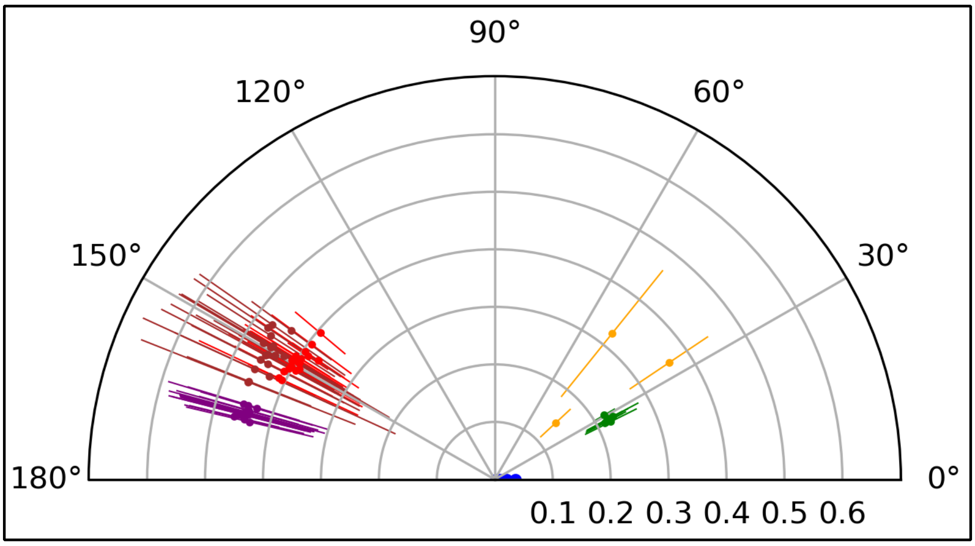


Figure 1. Orbital characteristics of the Jovian satellites from [1]. Each point corresponds to a satellite. The radial axis is the distance in Jupiter's Hill radius. The angle is the inclination relative to Jupiter's equatorial plane, where those with inclination between 90° and 180° have retrograde orbits. The lines show the variation in distance for a satellite along its orbit, i.e. their eccentricities. In blue, we have the regular satellites, in green the Himalia orbital family, in red the Ananke family, in the brown the Pasiphae family, in purple the Carme family, an in orange those that don't belong to any orbital family.

The orbital configurations of irregular satellites are strongly associated with capture rather than in-situ formation. However, there is no known dynamical mechanism capable of capturing a satellite in a stable orbit in the current solar system. If they were captured, it leaves the questions "What mechanisms are responsible for their captures?" and "Where do they come from?" The proposed capture models include Gas Drag [2], where the gas enveloping the young planet would be responsible for dissipating the energy of a passing body. Another model, called Pull-Down Capture [2], states that the increase of a planet's mass due to accretion would increase its Hill radius and trap temporary satellites. Both models demand the capture to be made during the formation of the solar system.

A capture by collision was also proposed by [3] where a collision within the Hill radius of the planet would disrupt one or both bodies. Some of the fragment would not have enough energy to escape the Hill sphere. This model also explains the observed orbital families observed today (Figure 1). Finally, an N-body interaction could also result in the capture of a satellite. For instance, [4] proposed that during the solar system instability, described by the Nice model, the closest approach between the outer planets would be enough to capture a large number of irregular satellites.

[5] showed, through their colours, that the objects of the Himalia family are similar to C-type asteroids. In the same study, Pasiphae was identified as similar to C-type asteroids while the other family members are redder, similar to P- or D-type asteroids. An inverse situation was found for the Ananke family, where Ananke is similar to P- or D-type asteroids while the remaining members are similar to C-type asteroids. Finally, the Carme family was found having colours similar to Centaurs or TNOs.

The Saturnian irregular satellites are, in general, redder in their colours. From these, Phoebe was observed by Cassini spacecraft in a close flyby. The observations showed Phoebe has a density significantly higher than the regular satellites. With a porosity of ~0.15, its uncompressed density would be similar to Pluto or Triton [6]. [7] showed, through spectroscopy, that Phoebe's surface is composed of material of cometary or outer solar system origin.

These conditions further suggest different origins for the irregular satellites. To better understand these satellites, trying to study their origins, captures and evolution, the Rio group has proposed the observations of stellar occultations by such objects. With occultations, we may obtain their sizes and albedos with high accuracy, which will further constrain the orbital families. For instance, Sinope is sometimes classified as a member of the Ananke or the Pasiphae family. However, [8] classify Sinope as the main body of its own family.

Astrometric Observations and Predictions

The Rio Group has observed irregular satellites since 1992. In [9], I have published the astrometric positions of these observations together with observations from the *Observatoire de Haute-Provence* and the *European Southern Observatory*. In total, 6500 positions were obtained. These observations increased by more than 50% the number of observations used in the previously known JPL Jovian ephemeris JUP300 [10]. For Nereid, the total number of observations doubled.

In [11], we generated our ephemeris for the Jovian irregular satellites, optimised to predict stellar occultations for the next few years. We used only the observations published in [9] and integrated them up to 2020. We did not need to use all observations because we only needed a short-term ephemeris, and we had observations covering many orbital periods of the satellites. For the satellite Phoebe, we updated the ephemeris [12] including our observations.

In the same work, we predicted stellar occultations from 2015 up to 2020. We identified an important increase in the number of events for the Saturnian satellites in 2018 (~230 for stars with V<16.5) and the Jovian satellites in 2019 - 2020 (~350 for stars with V<16.5 by satellite). This increase was caused by the passage of the planets in front of the apparent Galactic Plane. For the Uranian satellites, Caliban and Sycorax, and Neptunian satellite, Nereid, no relevant occultation was found in the period. Currently, Uranus and Neptune are crossing a low-density region in the sky.

Stellar Occultations by Phoebe

Although a large number of predictions, the small sizes of the satellites and the ephemeris error, some times larger than the satellites' sizes, made observations challenging. The first observed stellar occultation by an irregular satellite happened on 2017 July 06, in Japan, by Phoebe, observed by M. Owada and K. Hosoi. It was a two-chord event. Occultations by Phoebe were the most likely to be observed due to its more precise ephemeris.

In the year that Phoebe crossed the Galactic Plane, 2018, we observed four single-chord occultations, being one observed in Chile (June 19) and three observed in Australia (June 26, July 3 and August 13). The last occultation by Phoebe was observed in Argentina on 2019 June 7 also a single-chord event.

Because Phoebe already had a 3D shape model obtained from Cassini observations [13], our goal was to compare the chords with the model and infer the satellite's orientation. Using the orientation parameters from [14], we notice that the nominal orientation could not match the 2017 chords suggesting an error in Phoebe's nominal orientation.

Since the pole coordinates were better determined, the orientation's error probably came from the rotational parameters. This

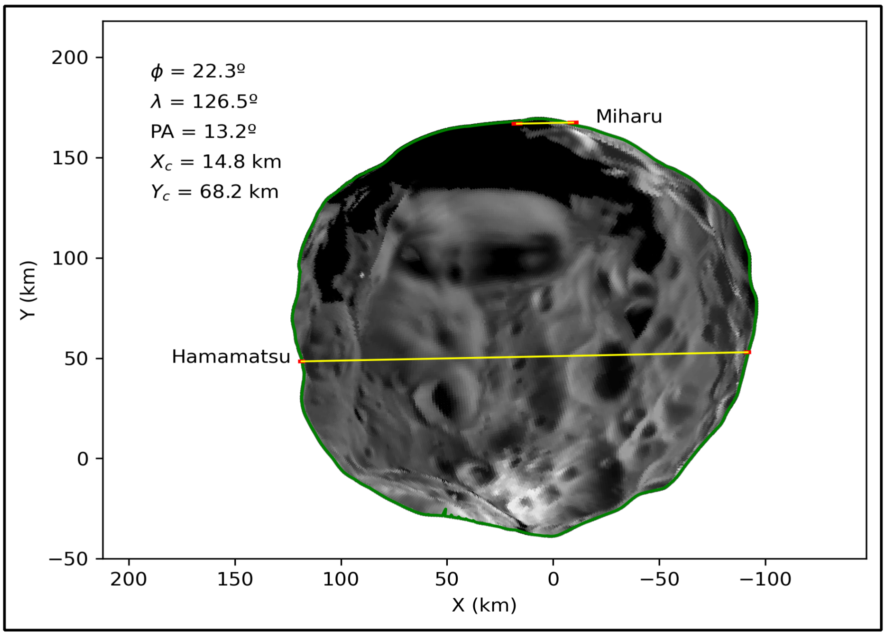


Figure 2. Fit of the 2017 July 06 occultation chords to the 3D shape model of Phoebe, image from [16].

is expected since the error in the rotational period determined by [15] propagated to the occultation epoch generated an uncertainty in the longitude of about 300 degrees.

We then rotated the 3D shape model and compared it to the chords using a chi-square analysis. The best fit happened with sub-observer longitude 126 degrees, compared to the nominal 330 degrees. Figure 2 shows the best fit of the chords to the shape model of Phoebe.

Given the expected 300 degrees uncertainty, this means a difference of +156 or -204 degrees in revolution. Using *Cassini* observations and Phoebe's orientation at the epoch, we manage to identify two possible rotational periods that matched both observations.

Both solutions were propagated to the single-chord events. Comparing these chords with the expected new orientations showed that one of them, which we have called W1, was not probable. For 2018 June 19, the SOAR chord is larger than the shape model, given the chord's direction, in an interval of longitudes close to the nominal W1 longitude, within 1-sigma. The centre of figure for the 2018 June 26, event was also inconsistent with the other events observed in an interval of one month using W1. Because of this, our preferred solution was a rotational period of 9.27365 ± 0.00002 h. The full description of this work can be found in [16].

New occultations may confirm these results, mainly if multiple chords are obtained. However, few good events are expected for the coming years. The ones for 2021 will cross low-populated areas.

Occultations by Jovian satellites Himalia and Lysithea

The propitious epoch for the occultations by Jovian satellites was 2019 - 2020, but already in 2018 we observed two by Himalia. The first one on May 12 in the USA with two positive chords. A quick reduction of this event provided an ephemeris offset for the May 20 event in Europe with a brighter star (G = 10.4). Finally, in 2020, three occultations were observed: two single-chord (July 25 in Australia and August 27 in Brazil) and one double chord, but with one effective chord, in the USA on August 19.

The 2018 May 20, event, only eight days later than the first occultation by Himalia, provided 22 observations, six positives in Poland and Ukraine. Interestingly, the length of the six chords was very similar, ranging between 138 and 149 km. Furthermore, the positive chords were located within an interval of 60 km compared to a body that was supposed to be 150 km in diameter.

A preliminary ellipse fit of these chords would give a very elongated shape of 200 x 150 km. This is not possible due to nearby negative chords and the observations by *Cassini* that showed Himalia to be about 150 x 120 km. Because of the object's size, we suspect some of the chords could be detecting topographical features, such as craters.

Using the rotational period of Himalia determined by [17] and rotational light curves we observed some days after the May 20 occultation, we noticed that both events should present a similar phase to Earth, with a difference of about 10 degrees. Combining the chords of both occultations, we manage to obtain an ellipse with an equatorial radius of 85 km, considering some chords detected a crater (Figure 3).

To improve the fitting, we have observed the rotational light curves of the satellite to obtain a 3D shape that could be matched to the occultation chords. This is an ongoing project and further observations are needed.

A fortuitous observation was the stellar occultation by Lysithea. Lysithea is the fifth largest irregular satellite of Jupiter, with a diameter of about 42 km. The uncertainty in its ephemeris was also larger than Elara's and Pasiphae's, for instance. Lysithea belongs to Himalia's orbital family, and both have similar colours.

The first occultation by Lysithea was a single chord observed in New Zealand on 2019 August 28. The chord length was 42.2 ± 3 km, which confirms the diameter of 42.2 km obtained by [18] using thermal modelling from *NEOWISE* observations. The ephemeris offset obtained was 180 km.

A second occultation by Lysithea was observed in the USA on 2020 August 13. It was also a single chord occultation. For this satellite, we only managed to obtain some astrometric positions to improve the ephemeris.

Conclusion

The irregular satellites are an interesting class of objects in the solar system often forgotten. The study of these objects and their evolutionary orbits may reveal characteristics of the formation and evolution of the solar system. Much is yet to be discovered.

The propitious epoch to observe a stellar occultation by these satellites has passed, but we observed some interesting events. The ephemeris has been an issue with predictions. The JPL JUP343 [19], which uses [9] observations, has provided underestimated error bars. For instance, the 2018 May 12 and May 20, Himalia's position was supposed to have an uncertainty of 20 mas by [19], while the observations showed an offset of almost 40 mas.

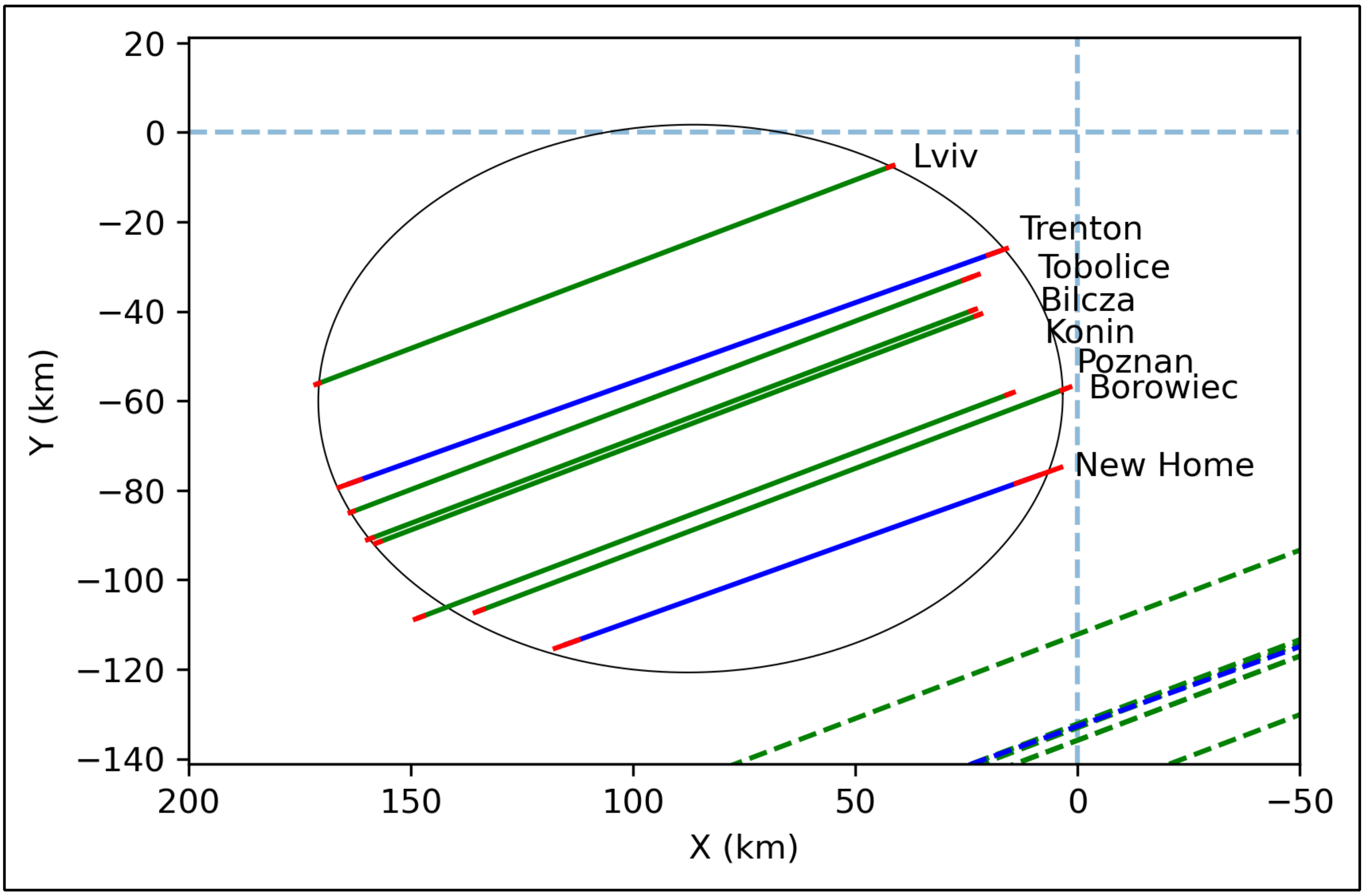


Figure 3. Ellipse fit using the chords of the May 12 (blue) and May 20 (green) occultations. The dashed blue and green lines represent the respective negative chords. The light blue dashed lines show the centre of the predictions. This fit considers a possible crater on the right side of the plot.

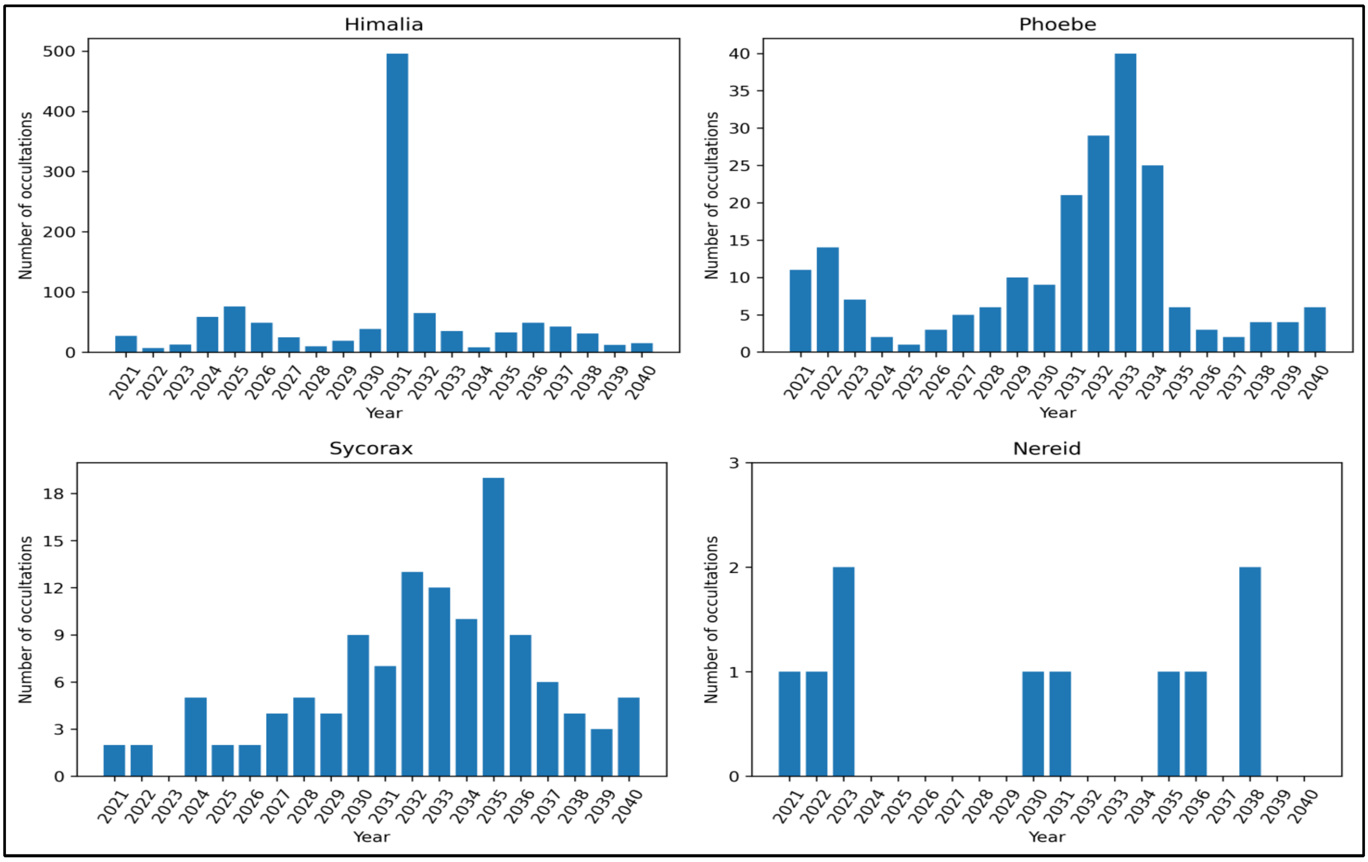


Figure 4. Histograms of predicted stellar occultations between 2021 and 2040 for the main irregular satellites of Jupiter (Himalia), Saturn (Phoebe), Uranus (Sycorax) and Neptune (Nereid).

Some astrometric observations and new orbital models made by the Rio Group have also been made to increase the chances of observing occultations by these objects in other epochs. For statistical purposes, we have predicted stellar occultation up to 2040. We have noticed there will still be many events for Jovian satellites, but not so much for the Saturnian, Uranian and Neptunian ones.

Figure 4 shows histograms of events predicted using Gaia-DR2 stars with G<16.5 for each planet's main satellites. The Jovian satellites will cross the central side of the Galactic Plane again in 2031, increasing the number of events. The Saturnian satellites will cross the far side of the Galactic Plane in 2033, increasing the chances, but not as much as for Jupiter. For Uranus and Neptune, the number will remain very low.

For 2021, one of the most interesting events will be of Caliban, Uranus' satellite, in the USA on September 28. Figure 5 shows the map of this event, which will be the only event with good observation circumstances this year. Other occultations by smaller satellites, like Leda and Ananke (D ~20km), are predicted to cross Europe, but an ephemeris improvement is needed. These predictions are made available on the Rio-satellite feed, with a total of 52 occultations predicted for 12 irregular satellites in the year 2021.

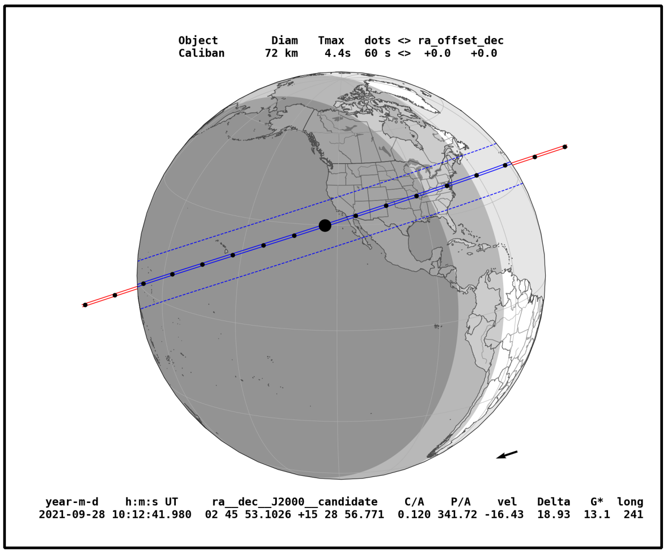


Figure 5. Map of the Caliban occultation predicted to happen on 2021 September 28 in the USA. The dashed lines represent the uncertainty of the ephemeris. We expect to improve the prediction.

Acknowledgements

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Phoebe, 2017 July 06:
M. Owada, K. Hosoi
Phoebe, 2018 June 19:
J. I. B. Camargo, J. Campbell-White, S. Rahvar, C. Snodgrass, E. Jehin, D. I. Machado
Phoebe, 2018 June 26:
T. Barry, A. de Horta, D. Giles, R. Horvat
Phoebe, 2018 July 03:
S. Kerr
Phoebe, August 13, 2018:
W. Hanna, T. Barry, A. de Hora, D. Giles, R. Horvat, D. Maybour
Phoebe, 2019 June 07:
L. A. Mammana, E. F. Lajús, J. I. B. Camargo
Himalia, 2018 May 12:
N. Smith, R. Venable
Himalia, 2018 May 20:
A. Marciniak, B. Marciniak, P. Krzenciessa, R. Hirsch, E. Bredner, M. Zawilski, A. Nowak, O. Kovalyov, A. Pál, G. Dangl, M. Rottenborn, J. Manek, V. Priban, T. Janík, P. Zelený, P. Delincak, K. Guhl, H. Denzau, P. Enskonatus, C. Weber, J. M. Winkel, A. Pratt, D. Ewald, S. I. Böttcher, M. Filipek, H. Bulder
Himalia, 2020 July 25:
D. Hooper
Himalia, 2020 August 19:
R. Bria, K. Green, D. Oesper, G. R. Viscome, B. Dunford
Himalia, 2020 August 27:
C. Jacques, R. Sfair, F. Rommel, T. Moura
Lysithea, 2019 August 28:
P. Graham, B. Loader, M. Unwin
Lysithea, 2020 August 13:G. R. Viscome, D. Oesper, K. Green;

and all those who attempted the occultations without positive results.

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Journal for
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The Solar System Beyond Jupiter

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

ABSTRACT: The outer solar system beyond Jupiter contains a vast population of small bodies. From Centaurs in the region between Jupiter and Neptune, over the trans-Neptunian objects at distances up to hundreds of astronomical units, up to the Oort cloud, at the limit of our Sun's gravitational dominance. This article gives an introductory overview about these objects which are regularly presented here in the 'Beyond Jupiter' series.

Introduction

Classically we divide our solar system into an inner part, in which the rocky planets Mercury, Venus, Earth and Mars orbit the Sun within the asteroid belt, and an outer part, where we find the gas giants Jupiter and Saturn as well as the ice giants Uranus and Neptune. But this outer region of the solar systems also hosts other types of bodies like the Centaurs and the trans-Neptunian Objects (TNOs). Individual objects of this type are regularly presented here in the *Journal for Occultation Astronomy* in the series 'Beyond Jupiter'. In this article I will give a more general view of these bodies of the outer solar system.

In 1930 Clyde Tombaugh discovered the first trans-Neptunian object: Pluto. The existence of a planet ('Planet X') beyond Neptune was postulated since the discovery of Neptune in 1846, because of apparently remaining irregularities in the orbit of Uranus and Neptune. Percival Lowell started a search programme in 1906, but without success until his death in 1916. The programme was continued in 1929. The young amateur astronomer Clyde Tombaugh was hired for this laborious work at Lowell Observatory. On 1930 February 18, after nearly a year of searching, Tombaugh discovered a moving object on photographic plates taken on January 23 and 29. This new distant object was named Pluto and was declared to be the ninth planet of our solar system. However, soon and in the following decades with subsequent refinements of Pluto's mass (only 0.002 Earth masses) it became obvious, that Pluto cannot be Lowell's postulated 'Planet X', causing and explaining the remaining orbit residuals of Uranus and Neptune. The mystery was solved after a refinement of Neptune's mass in 1992 with data derived from the *Voyager 2* flyby.

For decades the main figures in the solar system were the planets, the asteroids in the main belt, and the comets. The latter ones gave rise to formulate theories about the outer solar system. Essentially two classes of comets are distinguished: short-period comets SPCs (with orbiting periods $P < 200$ years) and long-period comets LPCs, with (very) eccentric or even (nearly) parabolic orbits. Short-period comets have usually low-inclination orbits while the orbital inclination of long-period comets is randomly distributed. Furthermore, the mass-loss during one revolution of a short-period comets implies, that they could not have been formed 4.5 billion years before in those regions, where we observe them today, because they would have already lost their volatiles after some 10^5 years (and vanished), if not disrupted or ejected even before. Short-period comets must have formed somewhere else (where they could preserve their primordial state), and by some mechanism they are transferred into their current orbits. Ernst Öpik in 1932 and Jan Oort in 1950 postulated a spherical cloud of primordial icy planetesimals around the Sun, extending about 20,000 to 50,000 au from the Sun. This cloud can serve as a repository for comets and from time to time individual objects are ejected into the inner solar system. While this could explain the observed population and properties of long-period comets, it is harder to explain the existence and characteristics of the short-period comets consistent with this model (how are they captured into their short-period low-inclination orbits?). Between the 1940s and the 1970s, the existence of objects beyond Neptune (or Pluto) was discussed by F. Leonard (1930), K. Edgeworth (1943, 1949), G. Kuiper (1951), A. Cameron (1962), and F. Whipple (1964, 1972). In the 1970s and 1980s these concepts (Oort cloud and the later so-called Kuiper-Belt[1]) and the connection to the short-period comets were further investigated and computer-simulated (e.g. [1], [2], [3]) but they were still theories as long as no observational evidence for the existence of such objects could be found. It took some more years before the first dedicated survey searching for these distant objects was initiated.

In 1992, after some years of search, the second trans-Neptunian object, 1992 QB_1 = (15760) Albion, was discovered by David Jewitt and Jane Luu at Mauna Kea observatory, Hawaii [4]. It was the beginning of the systemically exploration of the Kuiper-Belt, or more generally spoken, of the trans-Neptunian region.

In 2006, the IAU introduced dwarf planets as a new category. Since the 1992 QB_1 discovery in the early 1990s many trans-Neptunian objects were found, including some of similar size and mass as Pluto. At that 2006 IAU assembly, Pluto lost his status as planet

[1] For the sake of consistency with commonly-used abbreviations like KBOs (Kuiper-Belt Objects) I will use the term Kuiper-Belt henceforth, instead of Edgeworth-Kuiper-Belt as sometimes proposed. It should be noted that the importance of the contribution from Edgeworth and Kuiper is probably over-estimated, while that from Leonard and Whipple is under-estimated and under-credited (see http://www.icq.eps.harvard.edu/kb.html).

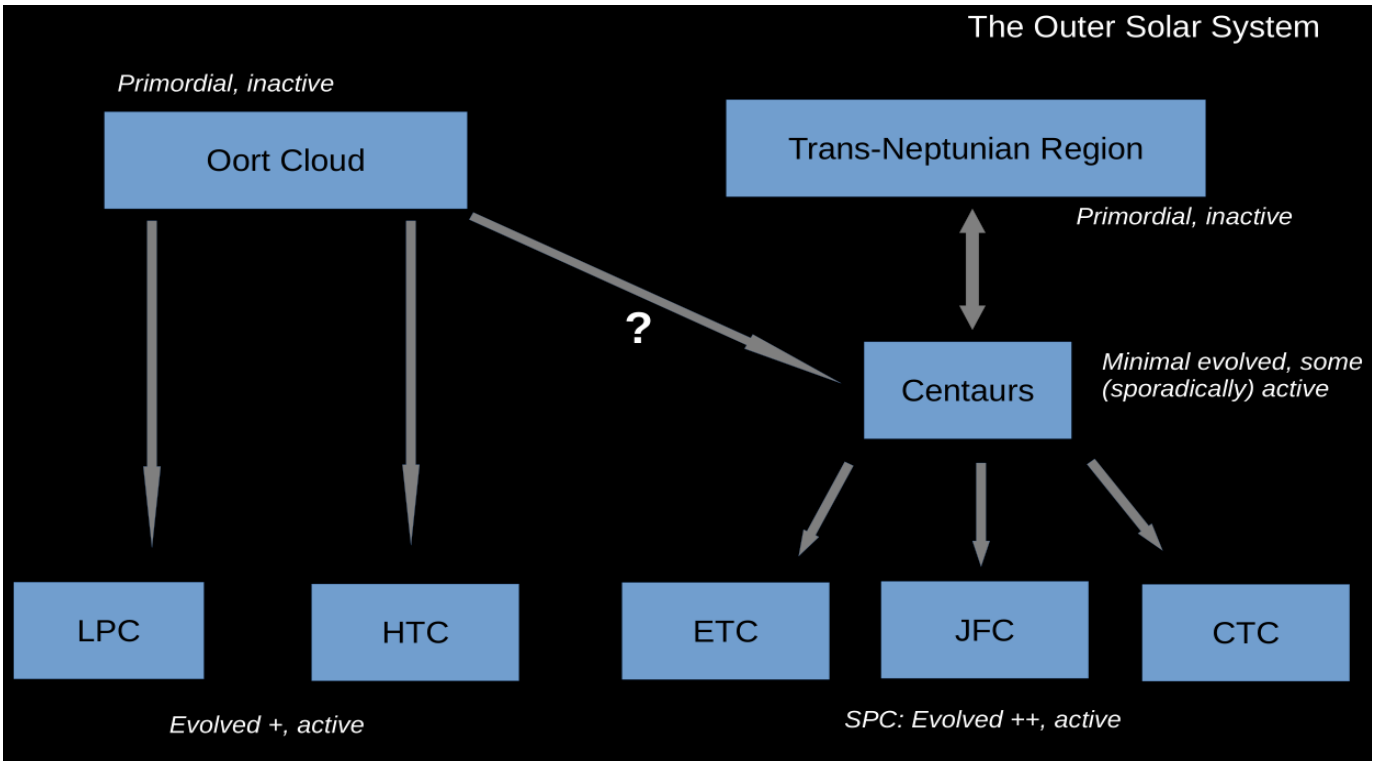

Figure 1. (Dynamical) Classification scheme of objects in our solar system, excluding planets, main belt asteroids, Trojans and natural satellites (like captured irregular satellites). Legend: Long-Period Comets (LPC), Halley-type Comets (HTC), Encke-type Comets (ETC), Jupiter-Family Comets (JFC), Chiron-type Comets (CTC), Short-Period Comets (SPC).

and was categorised as a dwarf planet. Currently, the IAU list five objects in that category: Ceres (in the asteroid main belt) and four TNOs: Pluto, Eris, Makemake and Haumea.

The exploration and our knowledge of Centaurs and TNOs have advanced a lot in the past years: recent surveys like *CFEPS* (Canada-France Ecliptic Plane Survey), *OSSOS* (Outer Solar System Origin Survey), *DES* (Dark Energy Survey) etc. have significantly increased the number of TNOs with well-established orbits. Physical properties for a number of objects have been derived by dedicated observational studies (e.g. rotational light curves) and not least also because the number of successfully observed occultations has increased significantly due to better predictions (impact of the *Gaia* star catalogue), providing physical properties like size and shape, densities, or even leading to the discoveries of rings around Centaurs and TNOs [5], [6].

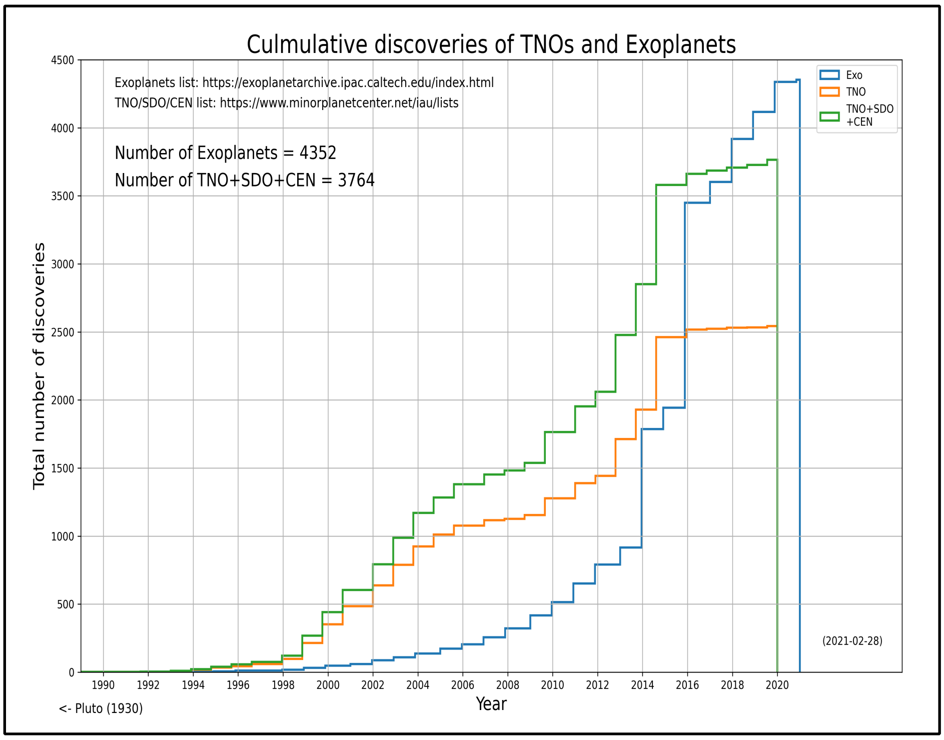

Figure 2. Cumulative number of discovered exoplanets vs Centaurs plus TNOs of our solar system. In 2018 the number of confirmed exoplanets (blue) exceeded the total number of Centaurs (including SDOs) plus TNOs (green) of our solar system.

On the other side, our sample of known Centaurs and TNOs is still relatively small and suffers from observational biases. Thus, our population models are probably not well determined. Meanwhile, we know more exoplanets than distant objects in our own solar system (Figure 2), due to dedicated ground-based projects like *HARPS*, *HATNet* , *MOA*, *OGLE*, *SuperWASP*, *Trappist*, and space-based observatories like *CoRoT*, *Kepler* and *TESS*.

Though our sample of objects is still small and biased, it is nevertheless possible to compare dynamical models with observational data [7] and to put conclusions into a larger context, e.g. as constraints to proposed Neptune migration models.

We are at the beginning of a new epoch of research into distant objects. New generations of telescopes and surveys like the *Rubin Observatory / LSST* (Large Synoptic Survey Telescope), the *James Webb Space Telescope* (JWST) and the *Extremely Large Telescope* (ELT) will answer some of the current questions, but will also raise new questions.

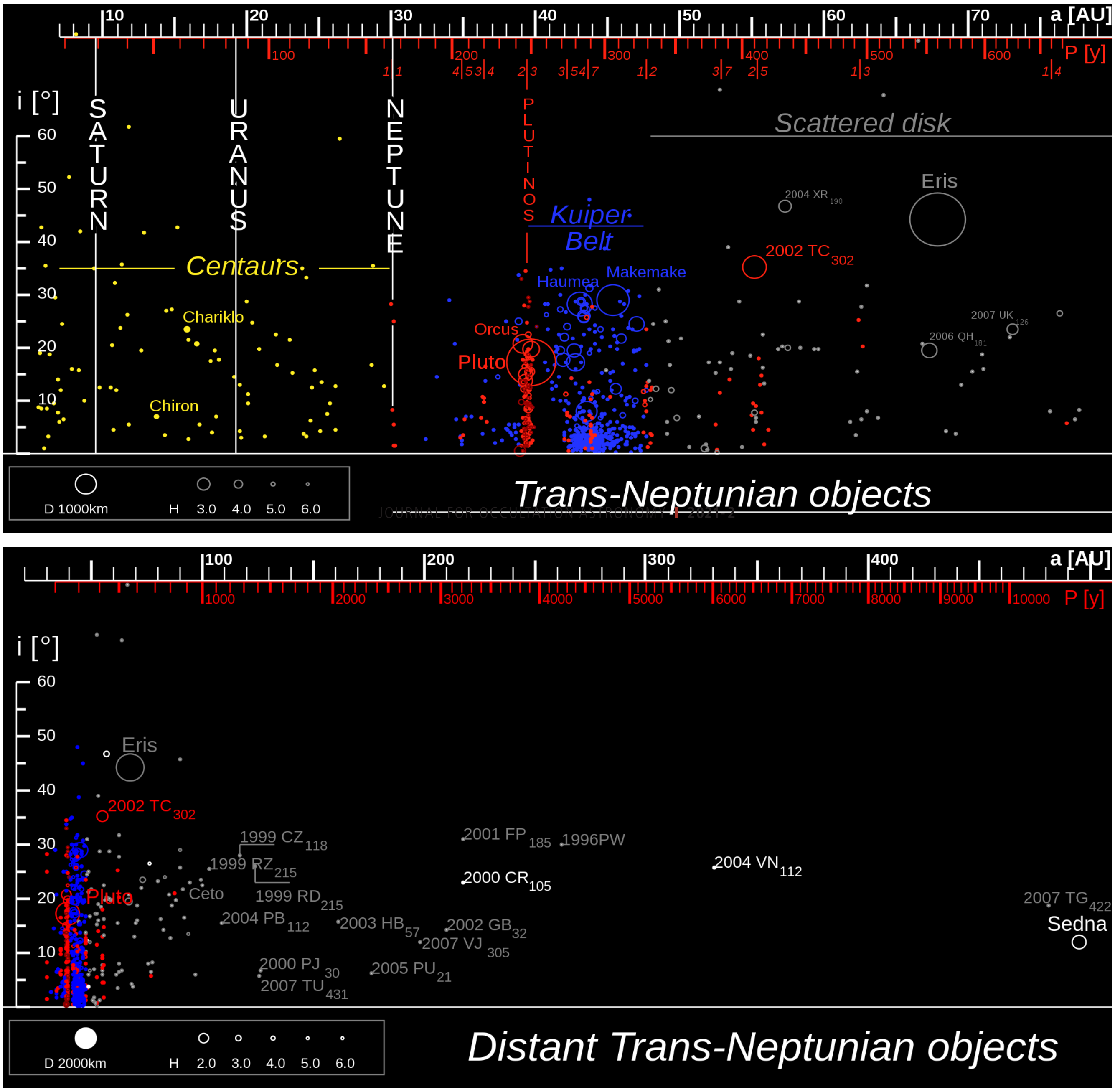

Figure 3. The region beyond Jupiter is populated by Centaurs, Kuiper-Belt Objects (KBOs), Scattered-Disc Objects (SDOs), and finally by the detached objects (bottom). The region beyond Neptune is more generally described as the trans-Neptunian region. From: en.wikipedia.org (authors: anonymous (top) and Eurocommuter (bottom)).

Trojans

Jupiter Trojans are not located beyond Jupiter. Rather, they share its orbit and travel as a cloud around the Lagrange points 60° ahead (L_4) or 60° behind (L_5) the planet around the Sun. Though we know meanwhile of Neptune, Mars and even Earth Trojans, I refer in this article only to Jupiter Trojans. Even if they are not located beyond Jupiter, they are interesting primitive bodies. Most Trojans are D-type, but we find also P-types as well as C-type (which are common in the main belt) among the Trojans [8]. It is not clear whether they formed at or near their present location or whether they have formed in outer regions and then have been captured into their current orbits during the early stages of the solar system's formation or slightly later, during the migration of the giant planets (Nice model [9]). If they are captured from outer regions, they could serve (similar to Centaurs) as easier-to-study proxies for primitive bodies / TNOs (in fact a space mission is soon to be launched to study the Trojans). Despite we yet have no good population distribution model, its is predicted, that the *Rubin Observatory / LSST* will discover almost 300,000 Jovian Trojans. The largest three members are (624) Hektor (diameter ~225 km), (617) Patroclus (diameter ~140 km)[2] and (911) Agamemnon (diameter ~130 km).

[2] One of the targets of the *Lucy* mission.

Centaurs

Centaurs are small bodies of our solar system moving around the Sun between Jupiter and Neptune (Figure 3), gravitationally influenced by the giant planets. There is no 'official' (dynamical) definition; several are in use. The Minor Planet Center (MPC) for example defines Centaurs as objects having perihelia q beyond the orbit of Jupiter and semi-major axes a inside the orbit of Neptune, whereas the *Jet Propulsion Laboratory* (JPL) just restricts the semi-major axis a to be between those of Jupiter and Neptune (5.5 au $\leq a \leq$ 30.1 au). Jewitt [10] defines Centaurs as bodies having orbital perihelia and semi-major axes between the orbits of Jupiter and Neptune and which are not in 1:1 mean-motion resonance with any planet. Because they strongly interact with the giant planets, their dynamical mean lifetime is short (~$10^{5\text{-}7}$ yr) [11], [12].

Centaurs are assumed to be in a transition phase between trans-Neptunian Objects (TNOs) and other populations of the inner solar system, particularly Jupiter-Family Comets (JFCs), though this relationship and the transition process is yet not well studied (Figure 1, 4 and 5). They can also be transported outward or even ejected from the solar system [12]. Currently several hundred Centaurs are known[3]. The whole population of Centaurs more than 1 km in diameter might range from 10^4 up to 10^7 [12], [13].

[3] The MPC lists Centaurs and Scattered-Disk Objects in one table which currently numbers 951 objects as of 25 Feb. 2021.

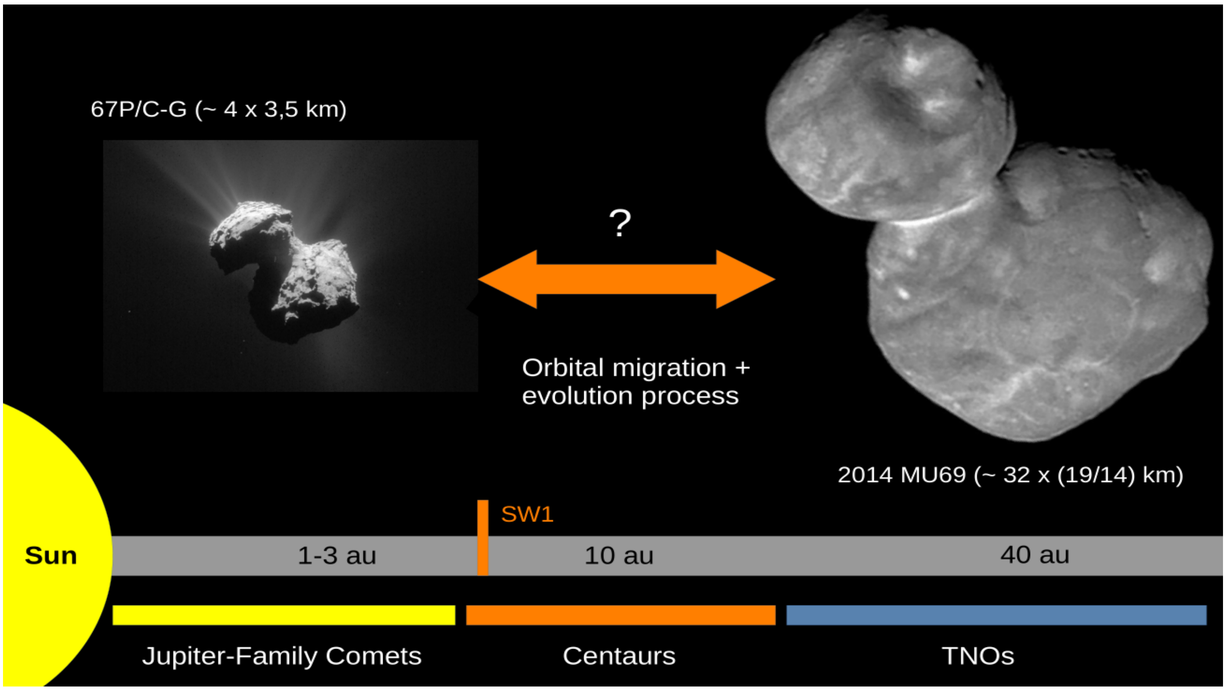

Figure 4. (486958) Arrokoth = 20014 MU_{69} was the second trans-Neptunian object imaged by a spacecraft (in 2016). This contact binary is in a rather primordial (less evolved) state. The Jupiter-Family comet 67P/ Churyumov-Gerasimenko was studied by the Rosetta spacecraft for more than two years (2014-1016). Before entering the Jupiter family, comets spent ~1-10 Myr in the dynamically unstable Centaur region, which is fed from the TNO/SDO reservoir (and perhaps also from the Oort cloud). The transition from TNO over the Centaur stage to JFCs is yet not well understood. Credit: images of 67P/ C-G and 2014 MU_{69}: ESA and NASA, Johns Hopkins University Applied Physics Laboratory, Southwest Research Institute.

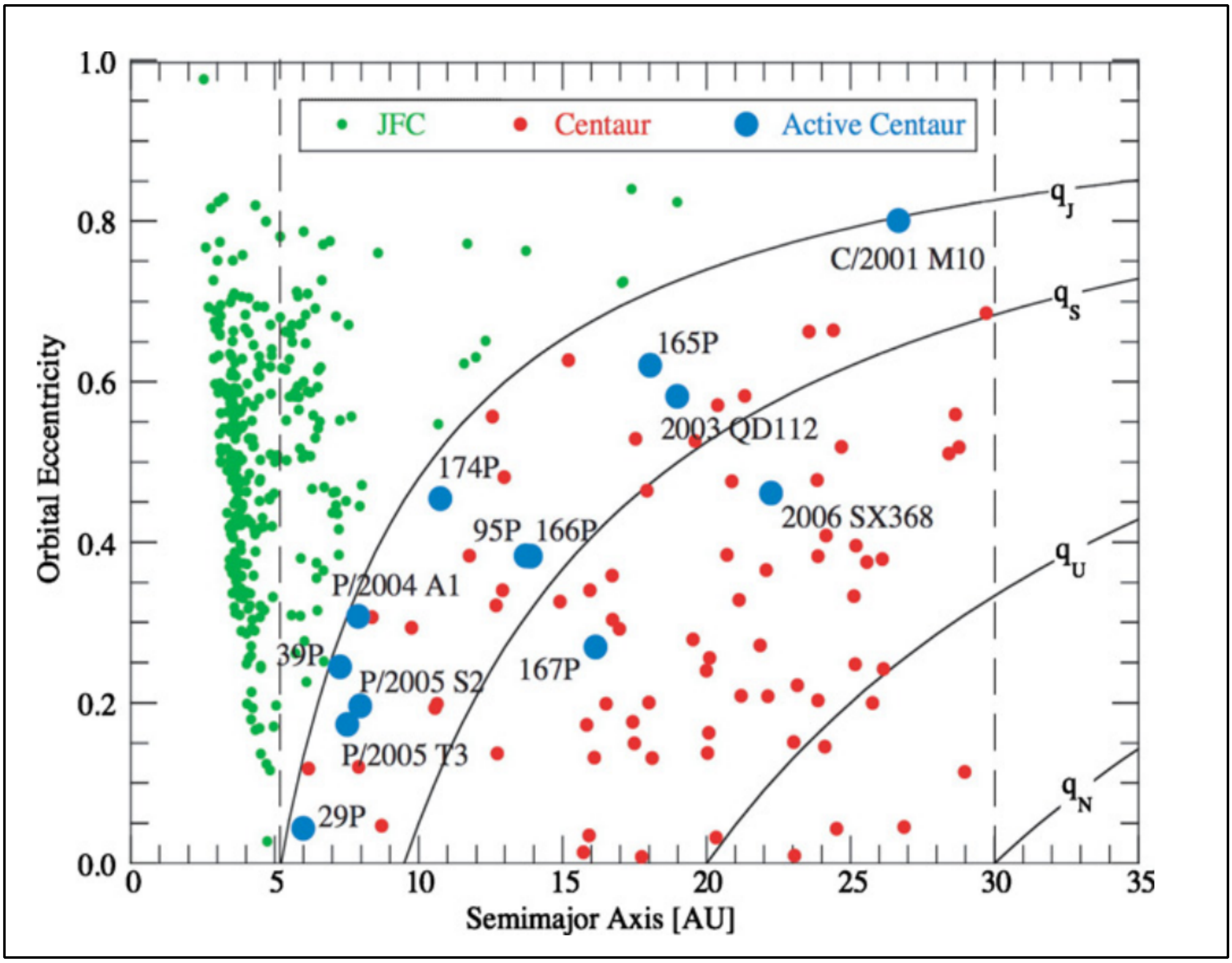

Figure 5. Orbital semi-major axis vs. eccentricity for active (blue) and inactive (red) Centaurs, and for JFCs (green). Vertical dashed lines show the semi-major axes of Jupiter and Neptune, bounding the region of the Centaurs. From Jewitt (2009) [10].

Beside their dynamical life history, Centaurs are remarkable and interesting objects, because they can show cometary-like activity (even beyond the snow-line, probably triggered by the crystallisation of the amorphous water ice), have (sometimes) brightness outbursts, and can have satellites and even rings. The largest currently known Centaur is (10199) Chariklo [14], with a mean diameter of about 250 km (q = 13 au, e = 0.17). It is also remarkable, that Chariklo has a ring system, which was discovered by a stellar occultation [6].

The first Centaur (which was recognised as such) was (2060) Chiron (q = 8.5 au, e = 0.38, diameter ~220 km), discovered in 1977 by Charles Kowal at *Palomar Observatory*. At the time of discovery it was the most distant known minor planet – the first Trans-Neptunian Object (TNO) was discovered 15 years later. Nevertheless, it should be noted that (2060) Chiron is not the first ever discovered Centaur. (920) Hidalgo (q = 1.9 au, a = 5.7 au, e = 0.66), discovered in 1920 by Walter Baade at *Bergedorf Observatory*, belongs to the Centaurs per JPL definition [15]. But at that time, Hidalgo was considered to be a (maybe somehow special) asteroid, because this population of objects was not recognized as a distinct class until the discovery of Chiron.

Centaurs (especially the inactive ones) can also serve as proxies for trans-Neptunian objects, because they are dynamically young and not so much evolved, but they are brighter (because of their smaller distance to Earth) and thus can be better studied with smaller telescopes than it is necessary for distant and weak TNOs. 29P/Schwassmann-Wachmann 1 is another well-known Centaur beside (10199) Chariklo and (2060) Chiron = 95P/Chiron.

Trans-Neptunian Objects (TNOs) / Kuiper-Belt Objects (KBOs)

A trans-Neptunian object orbits the Sun at a greater average distance than Neptune, which has a semi-major axis *a* of 30.1 astronomical units (Figure 3). Trans-Neptunian objects are further classified according to their distance from the Sun and other orbital characteristics.

Classical KBOs (CKBOs), also called Cubewanos (after 1992 QB_1), have orbits with semi-major axes between about 40 to 47 au. Classical KBOs are not moving in a mean motion resonance (MMR) with Neptune. In an MMR, the ratio of the orbital periods of both objects is a ratio of integer numbers (2:3, 3:4, etc.). There are two main groups within the classical KBOs, referred as 'hot' and 'cold' objects. This term is not related to the temperature, but rather to the orbital dynamic, specifically due to the strength of the gravitational influence of Neptune. Cold classical KBOs have low-eccentricity, low-inclination orbits, and are much less dynamically evolved by Neptune as the hot classical KBOs. The hot classical KBOs had more interactions with Neptune, resulting in more eccentric and more tilted orbits. The first example of a classical KBO was 1992 QB_1 = (15760) Albion. Other well-known CKBOs are: Makemake, Quaoar, and Varuna.

Resonant KBOs are in or near a mean motion resonance with Neptune. Pluto, for example, is in a 2:3 MMR, that means that Pluto completes two orbits around the Sun while Neptune has completed three revolutions at the same time. Many other resonant KBOs are located in this 2:3 MMR and this family is called 'Plutinos'. These resonances stabilise the orbits because they avoid close encounters between both objects, resulting in a strong perturbation of the much smaller KBO. Drastic orbit changes including even an ejection from that region could be the consequence. Pluto, Ixion, Huya and Orcus are some prominent examples of Plutinos.

Scattered KBOs (also known as scattered-disc objects, SDO) cover the region which stretches far beyond Neptune, with perihelia beyond about 30 au. Neptune has scattered them into highly elliptical and highly inclined orbits. As they are not protected against the perturbations from Neptune (e.g. due to a resonance), at least a fraction of them is expected of being lost over time – some of them possibly scattered into the inner solar system ('Centaurs'). Eris is an example for an SDO.

Detached KBOs (also know as detached objects) have perihelia beyond about 40 au. It seems unlikely that they have been significantly perturbed by Neptune (like in the case of SDOs). Presumably other forces are responsible for shaping their orbits, such as perturbations from an undiscovered, distant planet, the gravity of closely passing stars, or gravitational perturbations as the Kuiper Belt was formed in the early age of the solar system (planet migration). Sedna (q ~76 au, Q ~900 au) is an example of a detached KBO.

Farther out we find objects which are called **extreme-TNOs** (ETNOs), with very large semi-major axes (a > 150 au according to [16]) and perihelia well beyond Neptune (q > 40 au). At a solar distance ranging from about 2,000 to 200,000 au we find the inner Oort cloud, a disc-shaped part of the Oort cloud complex.

The chase for 'Planet X' in the late 19th and early 20th century was briefly described in the Introduction, leading to the discovery of Pluto (though more by chance and random coincidence of the predicted position of Planet X). The study of some peculiarities of ETNOs, especially the clustering of the arguments of perihelion of Sedna and other detached objects, has, according to Konstantin Batygin and Michael Brown, only a probability of 0.007% to be due to chance, thus requiring a dynamical origin. They postulate a planet ('Planet Nine') far out (~400-500 au) with ~5-10 Earth masses [17], [18]. In contrast, Kevin Napier et al. found no evidence for an angular clustering by selecting a similar small sample of 14 ETNOs from three different surveys (*DES*, *OSSOS*, and the survey by Sheppard & Trujillo) under consideration of observational biases etc. of each survey [19].

Outlook

The search for TNOs requires deep surveys (i.e. large apertures) and, in order to establish a reasonable orbit, on average around 16 months of observation is needed (in case of *OSSOS* [20]). *TESS* data, being a mission dedicated to exoplanet search and research, have been successfully demonstrated to be used for the search of TNOs down to about V = 21...22 mag [21], [22].

This situation will change drastically with the operation of the *Vera C. Rubin Observatory*, formerly *Large Synoptic Survey Telescope* (LSST), scheduled to enter into full science operation in mid 2022. It is predicted that about 40,000-60,000 TNOs/SDOs/CENs will be discovered during the nominal 10 years operation [23], including precise orbits due to high precision astrometry (σ ~10 mas) over years. This much larger observed population will enable us to proof and refine dynamical models, reveal interactions and will increase the number of objects to be studied individually, also by stellar occultations.

The *James Webb Space Telescope* (JWST), planned to be launched end of this year, will open another window on TNOs, especially for radiometric measurements [24], [25].

Beside ground-based and space-based observatories the third option to explore trans-Neptunian objects are spacecraft encounters and flybys. After the successful flyby of the *New Horizons* mission at dwarf planet Pluto in 2015 and TNO (486958) Arrokoth = 2014 MU_{69} (nickname 'Ultima Thule') in 2019 (distance to Earth = 44.3 au at time of flyby), the next opportunity to study this kind of objects in-situ will be the *Lucy* space probe, a 12 year NASA Discovery Program mission to six Jupiter Trojans. *Lucy* is scheduled to launch in October 2021. After flying by the inner main-belt asteroid (52246) Donaldjohanson in 2025, *Lucy* will arrive in 2027 at the L_4 Trojan cloud.

Another mission, though still a concept, is the *Interstellar Probe*, a multi-generation NASA Heliophysics Division mission proposal to leave the solar system in a 50-years prime mission to study the heliosphere and the interstellar medium (goal is to go beyond ~350 au within these 50 years, depending on the propulsion technology). On its way there are opportunities to explore trans-

Neptunian objects (TNOs) during a flyby. 2002 MS_4, Quaoar, Pluto, Ixion, and Gonggong are reasonable targets for spacecraft outbound trajectories within +/- 20° heliocentric ecliptic latitude [26]. Launch could be in the 2030s, the spacecraft speed depends on the technology, currently the concept states about 7 to 8 au per year.

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Further Reading

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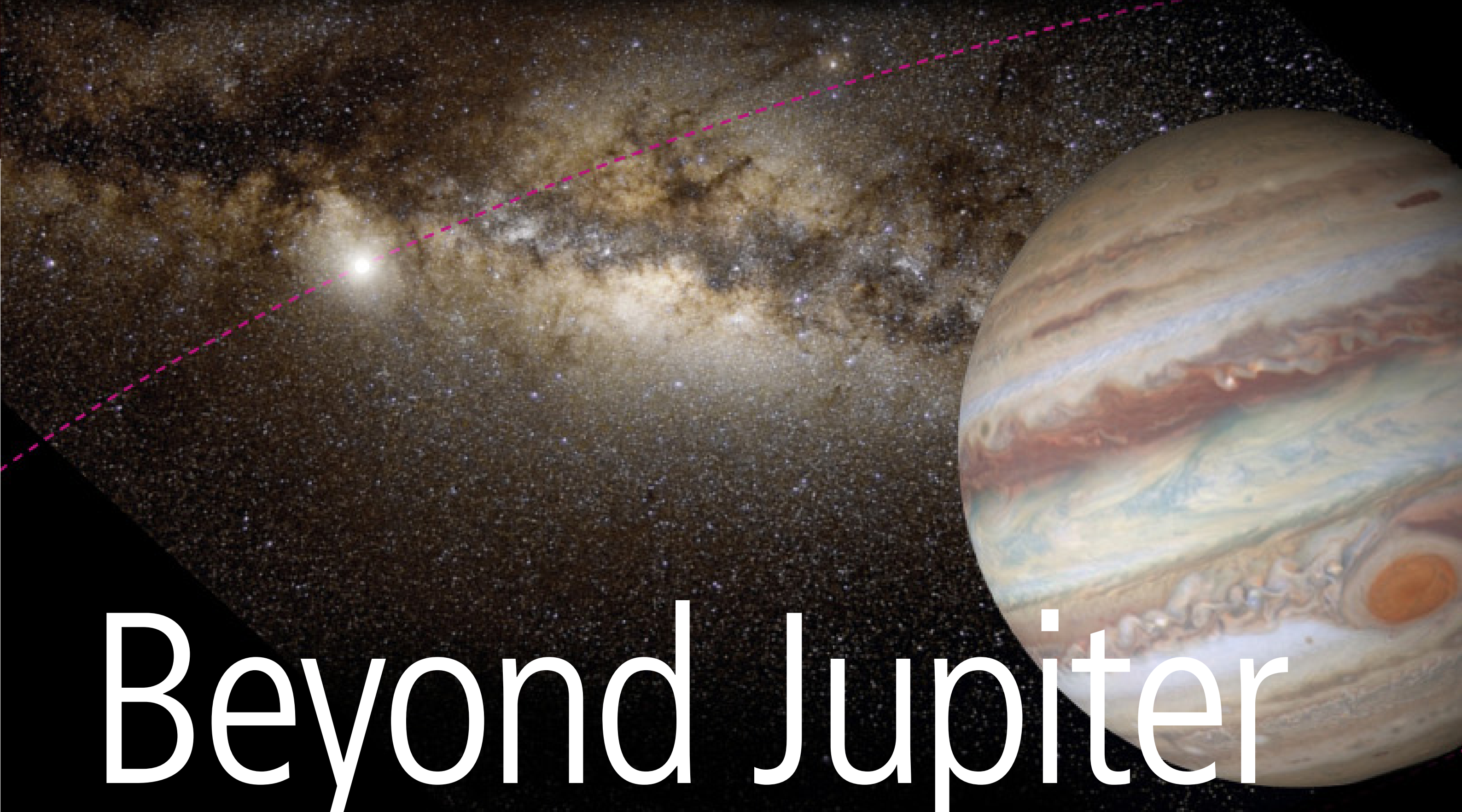

Beyond Jupiter

The World of Distant Minor Planets

Since the downgrading of Pluto in 2006 by the IAU, the planet Neptune marks the end of the zone of planets. Beyond Neptune, the world of icy large and small bodies, with and without an atmosphere (called Trans Neptunian Objects or TNOs) starts. This zone between Jupiter and Neptune is also host to mysterious objects, namely the Centaurs and the Neptune Trojans. All of these groups are summarised as "distant minor planets". Occultation observers investigate these members of our solar system, without ever using a spacecraft. The sheer number of these minor planets is huge. As of 2021 Mar 28, the *Minor Planet Center* listed 1208 Centaurs and 2550 TNOs.

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

No.	Name	Author	Link to Issue
944	Hidalgo	Oliver Klös	JOA 1 2019
2060	Chiron	Mike Kretlow	JOA 2 2020
5145	Pholus	Konrad Guhl	JOA 2 2016
8405	Asbolus	Oliver Klös	JOA 3 2016
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
47171	Lempo	Oliver Klös	JOA 4 2020
50000	Quaoar	Mike Kretlow	JOA 1 2020
54598	Bienor	Konrad Guhl	JOA 3 2018
55576	Amycus	Konrad Guhl	JOA 1 2021
60558	Echeclus	Oliver Klös	JOA 4 2017
90377	Sedna	Mike Kretlow	JOA 3 2020

In this Issue:

(38628) Huya

Christian Weber · IOTA/ES · Berlin · Germany · camera@iota-es.de

ABSTRACT: (38628) Huya is a binary Trans-Neptunian Object (TNO) located in the Kuiper Belt (Kuiper Belt Object, KBO). Huya was discovered in 2000 by I. Ferrin at *OAN Observatory* in Merida, Venezuela. The only known companion S/2012 (38628) 1 was found on *Hubble Space Telescope* images in 2012. Huya is in mean-motion resonance with Neptune. The size of the primary component is 406±16 km and that of the satellite 213±30 km. The stellar occultation method is an excellent tool for exploring the Huya system. So far, only one occultation event has been successful, namely that of 2019 March 18 when 22 positive chords were recorded, mostly from Europe. By 2030, some 23 forthcoming occultation events involving Huya are predicted from *Occult v4* calculations using JPL and Gaia EDR3 reference data.

No.	Name	Author	Link to Issue
90482	Orcus	Konrad Guhl	JOA 3 2017
120347	Salacia	Andrea Guhl	JOA 4 2016
134340	Pluto	Andre Knöfel	JOA 2 2019
136108	Haumea	Mike Kretlow	JOA 3-2019
136199	Eris	Andre Knöfel	JOA 1 2018
136472	Makemake	Christoph Bittner	JOA 4 2018

The Discovery

On 2000 June 3, the MPC's Minor Planet Electronic Circular MPEC 2000-L09 [1] reported 8 observations of an object provisionally designated 2000 EB_{173}, obtained between March 1-15, at the *Llano del Hato National Astronomical Observatory* (IAU code 303) in Merida, Venezuela. The observations were made with the observatory's 1.0-m Schmidt telescope of Askania Werke Berlin, Germany, (Figure 1). The telescope was equipped with a specially developed mosaic array of 16 2k x 2k CCDs (Figure 2) [2].

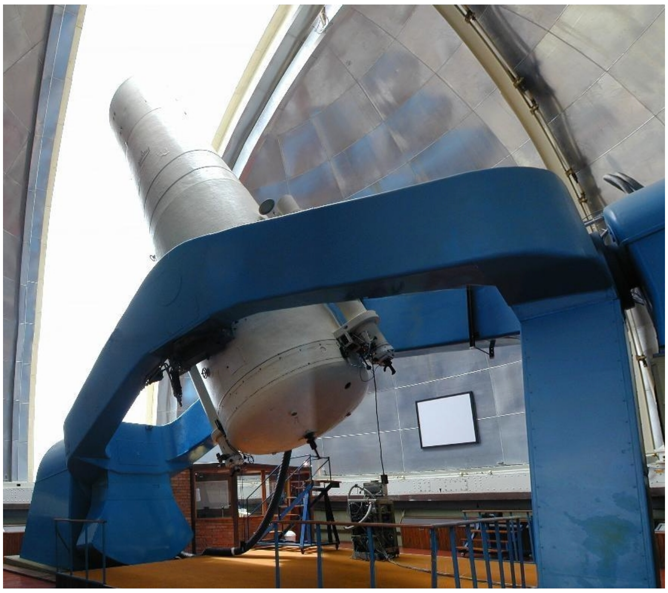

Figure 1. 1.0-m Schmidt telescope at Llano del Hato National Astronomical Observatory, Merida, Venezuela.

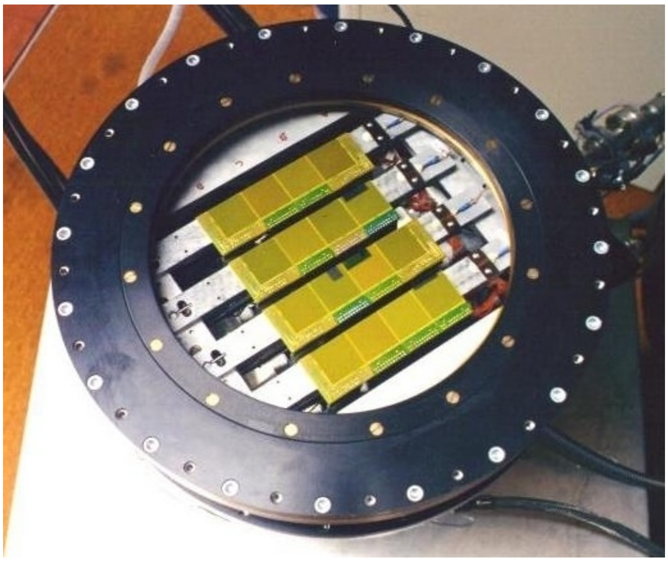

Figure 2. CCD array (16 x 4k = 64 megapixels) of the 1.0-m Schmidt telescope.
Credit Figure 1 & 2: C. Briceno. (CIDA) - YETI Collaboration Meeting. 2010 Nov. 15-17. https://www.astro.uni-jena.de/yeti/workshop/yeti-talks/briceno_oan2010.pdf

The actual discovery was made during the evaluation of the data on 2000 March 10 by Ignacio Ferrin and his team [3]. The discovery team searched also for precovery detections and found the first evidence in images taken with the *Palomar Observatory's Samuel Oschin telescope* on 1996 April 9 [3].
From *Hubble Space Telescope* (HST) observations (Wide Field Camera 3) obtained on 2012 May 6, a team led by Keith Noll identified a companion of Huya (Figure 3) [4].

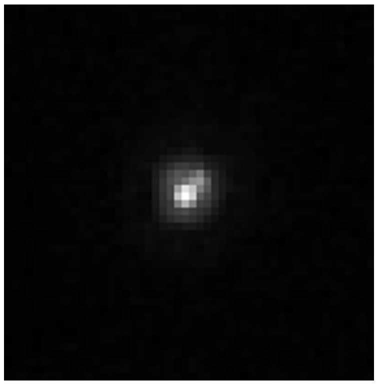

Figure 3. Hubble Space Telescope image of Huya and its moon of 2012 May 6. Credit: Wikipedia Creative-Commons.
https://de.wikipedia.org/wiki/Datei:Huya_Hubble.png

They also confirmed the satellite in earlier HST images made with its Space Telescope Imaging Spectrograph on 2002 June and July. The satellite has the provisional designation S/2012 (38628) 1 and is the only known companion, there being no evidence for any ring present. Figure 4 shows an artist's rendition of the Huya binary system.

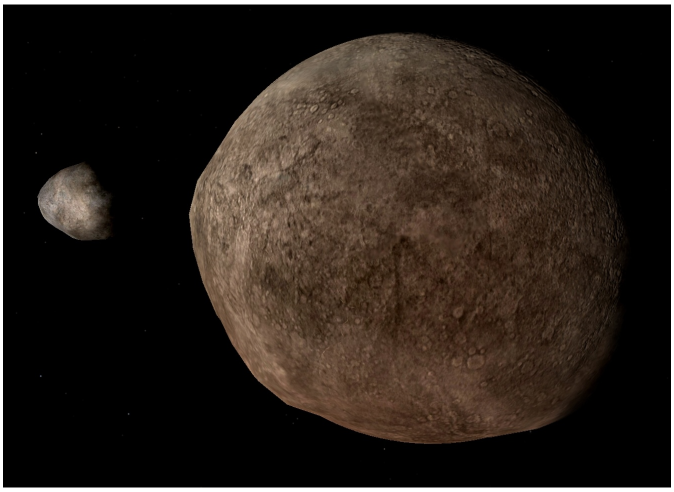

Figure 4. Artist's rendition of the binary TNO (38628) Huya and its satellite S/2012 (38628) 1. (Not to scale).
Credit: Wikimedia Commons.
https://de.wikipedia.org/wiki/Datei:Huya_Hubble.png

The Name

Following the MPC's naming rules [5], the discovery team considered more than 20 potential names [6]. I. Ferrin proposed *Juyá* (English Huya), the name of the rain and winter god of the Wayuu people (Figure 5) of the Guajira Peninsula in northern Venezuela, a region near the observatory. On 2003 May 1, the name Huya was recognised by the MPC [7].

Figure 5. Wayuu women working on mochilas, Wayuu bags. Credit: Miller Sierra - Own work. Public domain.
https://commons.wikimedia.org/w/index.php?curid=5892415

Orbit and Classification

Huya's elliptical orbit around the Sun (Figure 6) has an inclination of about 15.47 deg, a semi-major axis of about 39.76 AU and an eccentricity of 0.282. According to *DES* (Deep Ecliptic Survey) Huya is classified as 3:2E+6:4II [8], meaning that there are two types of mean-motion resonances with Neptune. Hence, Huya is classified as a plutino [3, 9]. There is ambiguity in the literature regarding the demarcation between the classes, so that the MPC currently only classifies Huya as a "distant object" [10]. Huya's Sun distance varies between 28.55 AU (perihelion, occurred 2015) and 50.97 AU (aphelion, 2140). The orbital period of Huya is 250.75 yr. The orbit data refer to JPL, epoch of 2020 May 31 [11]. Over the next few years, Huya moves through the constellation of Ophiuchus. In 2027 December, Huya will move from the constellation of Ophiuchus into Serpens.

The orbit of the Huya satellite is unknown with the exception of the semi-major axis of about 1740 km and the period of 3.2 d [12].

Physical Characteristics

From thermal emission measurements with *Herschel Space Telescope's* PACS and SPIRE instruments the mean diameter of the Huya binary system is estimated to be 458±9.2 km whereas the size of the primary component is to be 406±16 km and that of the satellite 213±30 km [13]. *ALMA* (Atacama Large Millimeter/Submillimeter Array) observations confirmed the size of the overall

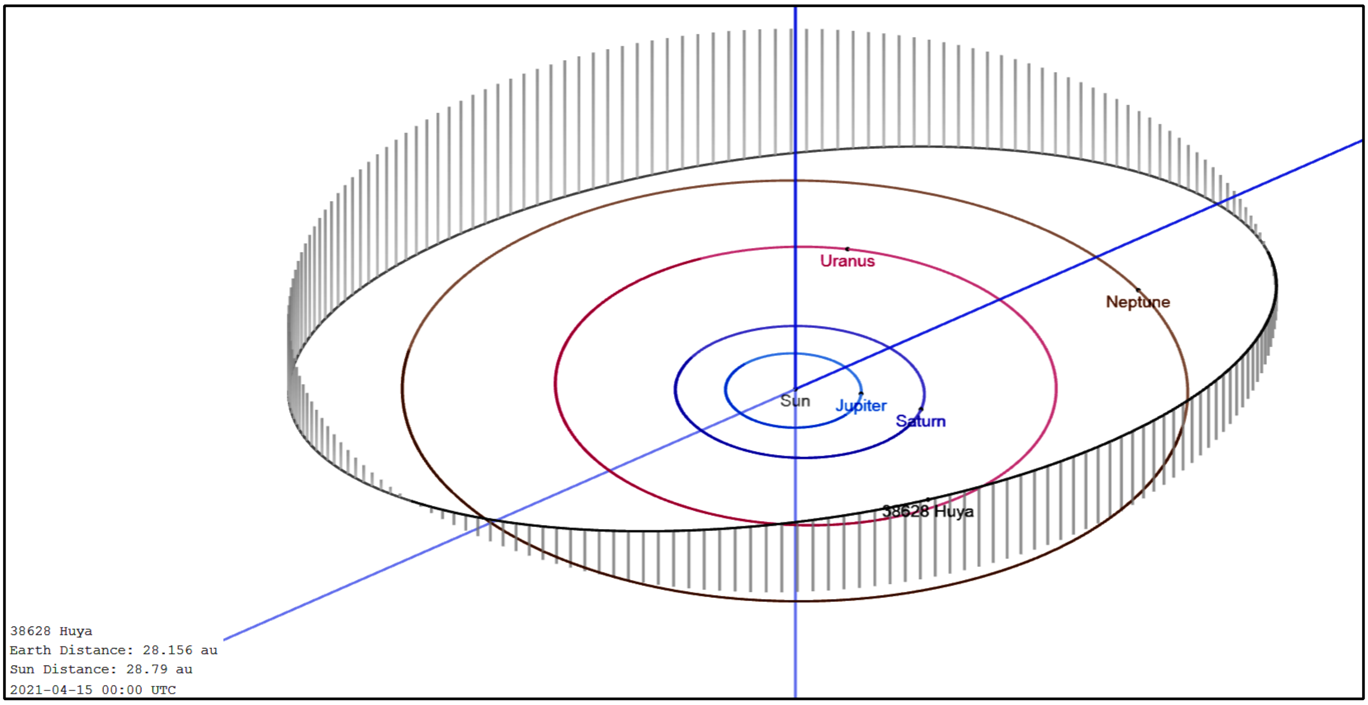

Figure 6. Huya's orbit diagram. Credit: JPL Small-Body Database Browser [11]

system [14]. With a presumed lower limit density of 1.43 g/ cm^3 [15] and assuming a spherical shape Huya's mass would be about 5.0×10^{19} kg. However, this is not confirmed as the actual shape is not yet known. There are reasons to hope that size and shape will be further refined (see section Stellar Occultations).

A possible status as a dwarf planet is also disputed in the literature. Because with its size of only 406 km Huya is on the lower limit to be identified as a dwarf planet. Brown [16] considers Huya a "probable" dwarf planet. According to Grundy et al. that seems rather unlikely, since no hydrostatic equilibrium would be achieved due to the relatively small diameter [17].

Huya lightcurves are very flat with brightness variations only in the range of a few percent. From photometric observations with the 1.5-m *Sierra Nevada Observatory* (OSN) telescope and the 1.23-m *Calar Alto* telescope Thirouin et al. derive lightcurves that give Huya's rotation period of 5.28 h [15] (according to [11] up to 30% erroneous due to only fragmentary photometric data). The rotation period of Huya's satellite is currently unknown but it is likely to be tidally locked to the primary.

Further physical data are (main body, in [brackets] satellite): Geometric albedo 0.081±0.008 [14] [0.083, assumed [13]], Absolute V-band magnitude 5.04±0.03 [13], [6.44 [4]], Apparent magnitude 19.8 to 21.6 depending on the orbital position and the filter used.

According to Fornasier et al. [13], there are several studies of Huya's spectral properties showing partially contradicting results. Early investigations reported two absorption bands in the visible light possibly indicating the presence of aqueously altered silicate minerals. However, these results were never confirmed later. The infrared spectrum is usually described as largely lacking in properties. In contrast, Alvarez-Candal et al [18] derived evidence for water ice due to an absorption feature at 2.0 µm.

In a recent work, Fernández-Valenzuela et al [19] present photometric observations using data from the Infrared Array Camera (IRAC) of NASA's *Spitzer Space Telescope*. The broadband filters applied were centred at 3.6 µm and 4.5 µm. By comparing the measured data with those of a developed synthetical model, the authors derive the surface composition of Huya to consist of 40±20% water, 30±10% silicates and 30±10% organic substances.

Potential Space Missions

NASA's *New Horizons* mission [20] shows the great potential of space projects to also explore objects of the Kuiper Belt, e.g. (486958) Arrokoth, formerly called Ultima Thule/2014 MU_{69}. There are several design studies for spacecraft missions targeting Huya. For energy gain, most of the concepts use Jupiter flybys, some also gravity assists from Saturn and/or Uranus. In 2012, Gleaves et al. [21] identified ideal start dates for Huya orbiter missions in 2027 and 2039. The concept considers flight durations of 20 to 25 years. Depending on the launcher and the flight duration the potential payload masses vary from 44 to 384 kg. Johnson et al. [22] propose a multi-target flyby mission to Huya and (50000) Quaoar, the latter being one of the biggest TNOs and a dwarf planet candidate [23]. None of the projects seem to have reached the implementation phase.

Stellar Occultations

In addition to traditional observation methods, time-resolved recordings of stellar occultations offer the possibility of determining the size and shape of occulting objects. Stellar occultations also allow the investigation of the object's surroundings to identify possible atmospheres, rings and satellites. A remarkable number of TNO results have been derived from stellar occultations. D. Herald's *Occult v4.12.1.0* software [24] reports 41 TNO events (from 22 different objects) with at least one positive observation. The data is also available via NASA's Planetary Data System (PDS) [25]. The Lucky Star project lists on its database (2005 to 2021 January 25) 78 TNO occultations (34 different objects) with at least one positive chord [26]. All *Occult v4.12.1.0* events are also Lucky Star listed. From the Lucky Star archive, the event with the second most chords is the Huya event of 2019 March.

Huya's Stellar Occultation on 2019 March 18

Only one successful observation is known for a Huya stellar occultation. On 2019 March 18 Huya occulted a 10.6 mag star, observable from wide regions of Europe and the Middle East (Figure 7).

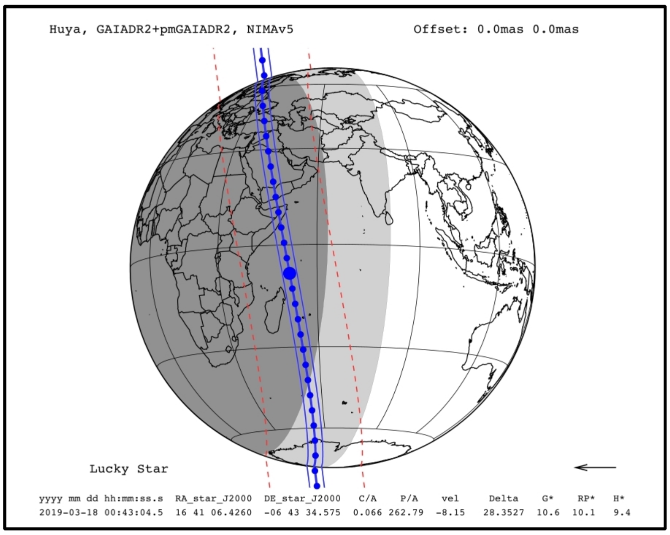

Figure 7. Lucky Star prediction of Huya's occultation of a 11.5 mag star on 2019 March 18.
Credit: ERC Lucky Star project. Occultation by Huya (2019-03-18). https://lesia.obspm.fr/lucky-star/occ.php?p=15369

A campaign organised by the Lucky Star team resulted in at least 22 positive chords and a few near misses (the latter include the author's own observation) [27]. An impressive example of a positive chord shows E. Petrescu's detection from Romania [28].

Preliminary results [27] derive an elliptical fit of the positive chords. Figure 8 shows the preliminary fit of positive chords of Romanian observers [29]. According to [27], no evidence for an atmosphere or a ring was found. Also the satellite was not detected. The campaign's final results are not yet published. But already now it is clear that we have an outstanding example of a successful collaboration between professional and amateur astronomers.

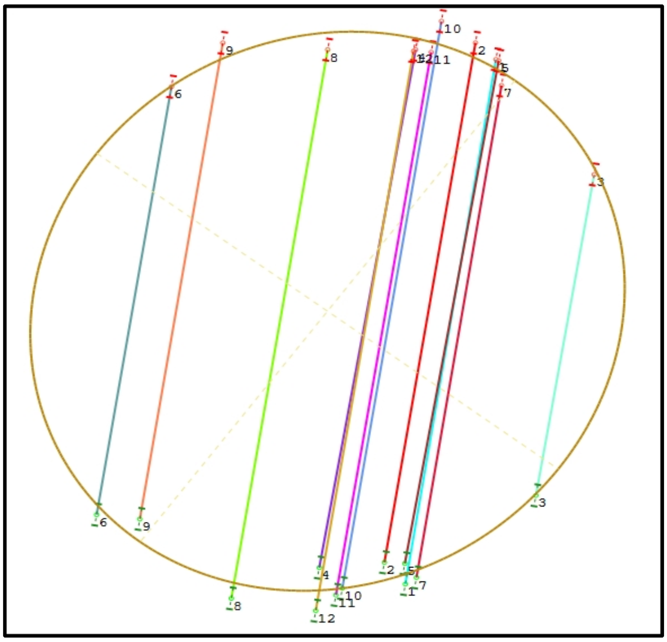

Figure 8. Huya's occultation of a 11.5 mag star on 2019 March 18: Preliminary fit of positive chords from Romania. (Scale and legend were removed by the Lucky Star team because data are still under analysis, final publication pending) [29].
Credit: https://stargazerslounge.com/uploads/monthly_2019_04/PreliminaryEllipticalFit_2.PNG.582a5f901ae4556f010454babc1f1e81.PNG

Upcoming Stellar Occultations by Huya

Regarding the relatively low magnitude of the occulted star the above event was an exception. From today's perspective, almost all the Huya occultations found will occur with stars that are fainter than about Mv 15.

There are several resources available for predicting stellar occultations by TNOs. S. Preston's/IOTA's high probability predictions list no Huya event until December 2021 [30]. The *CORA* project of M. Kretlow currently does not predict a Huya event either [31]. Presently to 2021 May 5, the Lucky Star project offers predictions [32], usually having a high precision (NIMA ephemerides [33]). In the Mv range up to 17 there is only one Huya event [34], see also Table 1. To optimise campaign planning, Lucky Star predictions appear in the "LuckyStar" feed of H. Pavlov's software *Occult Watcher* [35]. Besides there is still M. W. Buie's "Global TNO event candidate list", containing TNO predictions up to eight years and updated if actualised ephemerides become known [36]. There are currently 15 events in Buie's list for Huya through 2028, most of which appear also in Table 1.

Table 1 contains the author's predictions, made with *JPL Horizons* ephemerides of 2021 February 9 and D. Herald's *Occult* software [24]. The current *Occult version v4.12.2.0* provides for the first time predictions basing on Gaia EDR3 [37] for stars up to 16 mag. Based on Gaia EDR3 data from Tap VizieR [38] and Huya's upcoming orbital positions, an additional *Occult* user catalogue for the magnitude range Mv 16 to 17 was created. As can be seen from Table 1, a total of 24 events was found up to and including 2030, ranging from star magnitudes Mv 11.8 up to the faint star limit of Mv 17.0. The maximum occultation durations are in the range 10.8 to 45.9 s and the magnitude drop range is 2.8 to 8.0. The individual drop values and much additional data can be found in the occultation maps provided (Figures 9 - 32).

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This research has made use of the VizieR catalogue access tool, CDS, Strasbourg, France (DOI : 10.26093/cds/vizier). The original description of the VizieR service was published in 2000, A&AS 143, 23.

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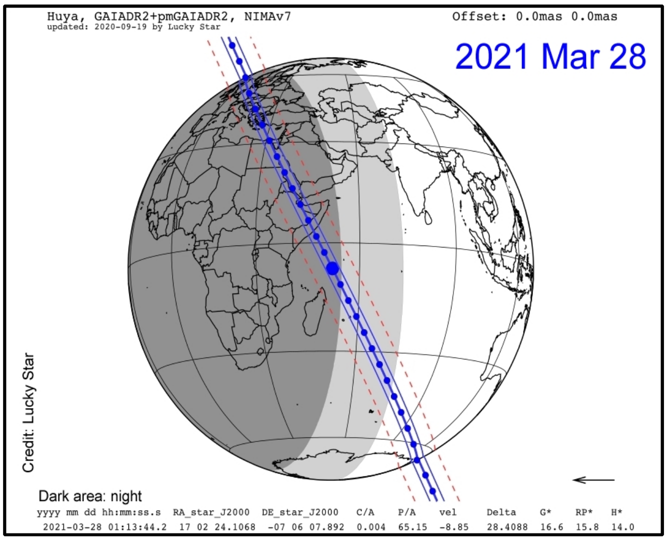
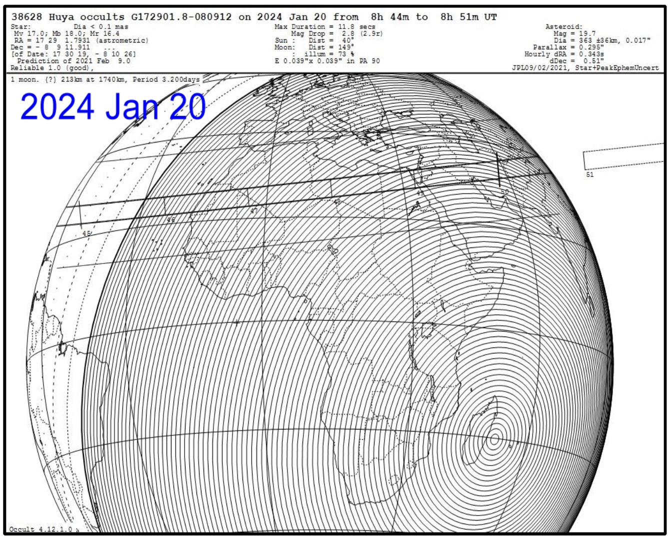
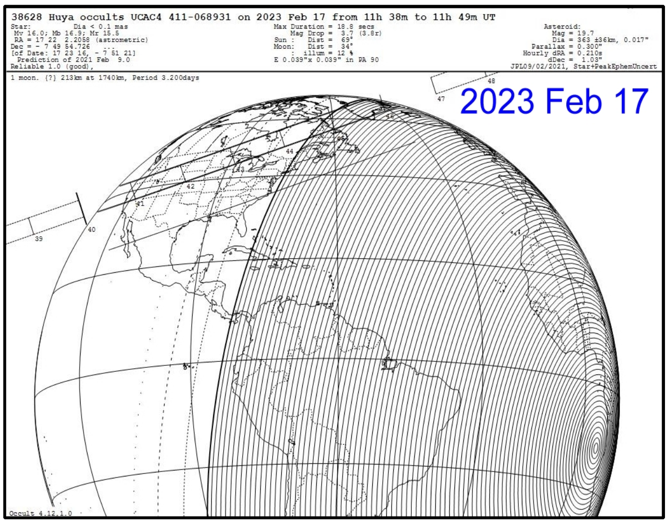
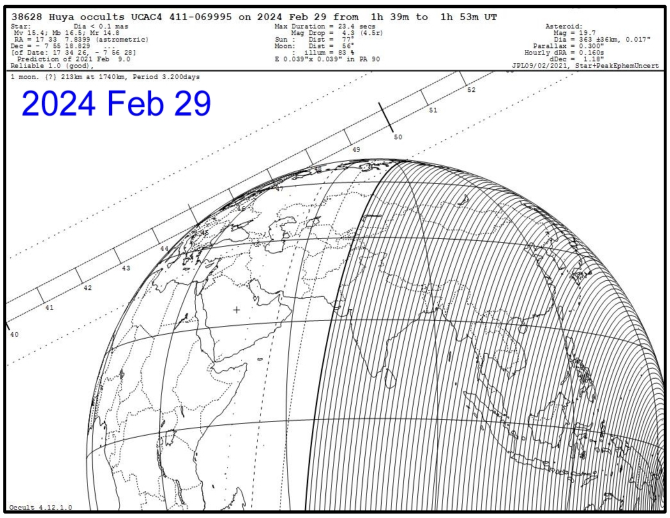
Date	UT	Star Designation	St. Mv	Max. Drn. [s]	Region	Source	B
2021 Mar 28	01:14	4339984398716279808	17.5	45.9	N. Africa, Europe	LckSt/DR2	
2023 Feb 17	11:51	UCAC4 411-068931	16.0	18.8	N. America	Occ/EDR3	x
2023 May 14	04:25	4360282375500788224	16.8	18.0	S. America	Occ/EDR3	x
2024 Jan 20	08:45	4167772664163648256	17.0	11.8	Caribbean	Occ/EDR3	
2024 Feb 29	01:36	UCAC4 411-069995	15.4	23.4	N. Europe	Occ/EDR3	x
2024 Oct 27	23:47	4167955153033403264	16.1	13.1	S. America	Occ/EDR3	
2024 Nov 18	17:01	4167767888161513856	16.9	10.8	Africa	Occ/EDR3	
2025 Oct 07	12:06	4168489064711821568	16.7	19.5	Australia	Occ/EDR3	x
2026 Sep 15	12:42	UCAC4 410-072949	16.7	38.9	Australia, India	Occ/EDR3	x
2027 Jun 01	16:00	UCAC4 412-072761	15.3	16.8	Indonesia	Occ/EDR3	x
2027 Jul 14	05:54	4171601271038855168	16.5	17.1	S. S. America	Occ/EDR3	x
2027 Jul 14	19:20	4171507503316136320	16.7	17.1	S. Africa, Indonesia	Occ/EDR3	
2027 Nov 10	21:42	UCAC4 407-074163	11.8	12.5	S. America	Occ/EDR3	
2028 Feb 13	13:24	UCAC4 408-078705	14.3	14.2	N. America	Occ/EDR3	
2028 Feb 21	21:48	UCAC4 408-078846	15.6	16.0	Taiwan, India	Occ/EDR3	x
2028 Feb 23	08:27	UCAC4 408-078856	15.3	16.6	N. America	Occ/EDR3	x
2028 May 12	13:55	UCAC4 411-075906	14.6	22.0	New Zealand, Australia	Occ/EDR3	
2028 Jul 09	03:30	UCAC4 411-075216	15.8	16.3	Africa, S. America	Occ/EDR3	
2029 Jul 21	09:50	UCAC4 411-076248	15.9	17.3	New Zealand	Occ/EDR3	
2029 Nov 26	17:48	4159357075198276352	15.7	11.3	Africa	Occ/EDR3	
2030 Feb 05	00:13	UCAC4 407-078802	15.7	12.0	India	Occ/EDR3	
2030 Aug 01	17:43	UCAC4 410-078429	15.6	18.9	Australia	Occ/EDR3	
2030 Aug 20	01:31	UCAC4 409-076699	16.0	25.9	S. S. America	Occ/EDR3	
2030 Oct 13	22:00	UCAC4 407-077698	15.1	23.2	Africa, Canada	Occ/EDR3	

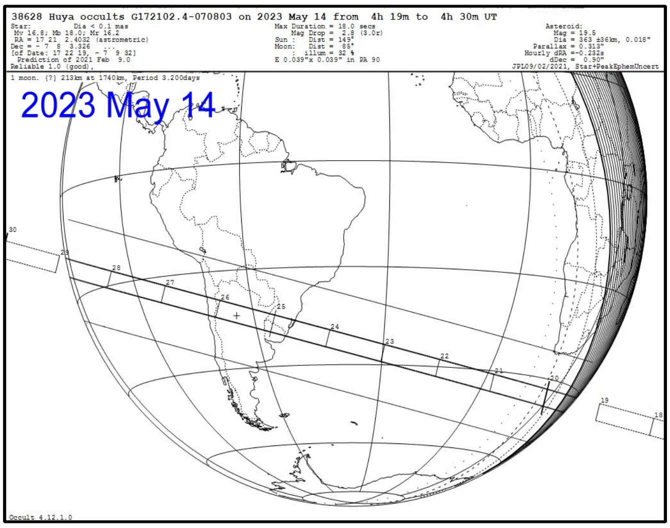
Table 1. Upcoming stellar occultations by (38628) Huya until 2030 for stellar magnitudes up to Mv 17. Star designations according to Gaia EDR3 (GDR2 in case of the first line), UCAC4 star names were used for existing matches with EDR3 stars. "LckSt/DR2" Lucky Star prediction [32], "Occ/EDR3" author's predictions with Occult 4.12.2.0 using JPL Horizons ephemerides of 2021 February 9 and Gaia EDR3 star data, "B" indicates matches with M. W. Buie's predictions [36]. For each event listed there is an occultation map with additional data (Figures 9 - 32).

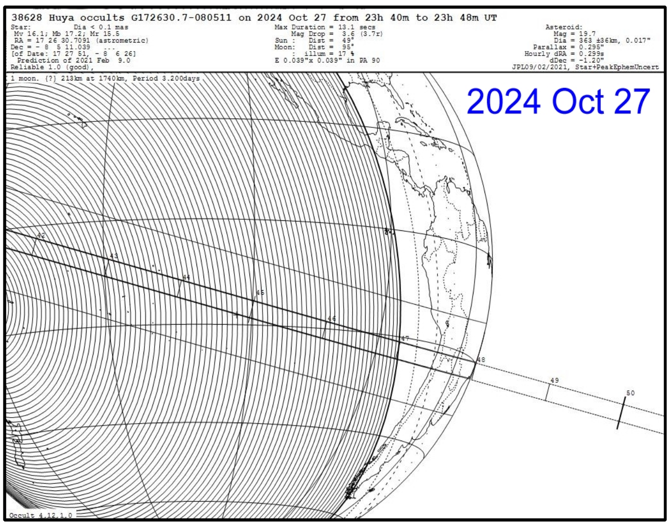






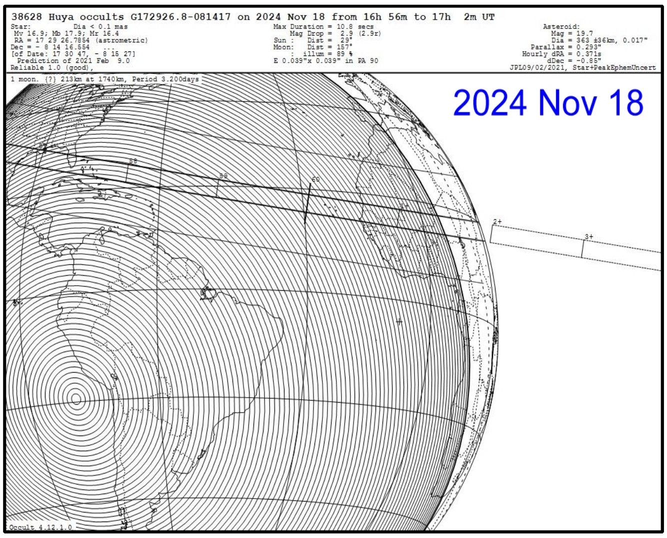


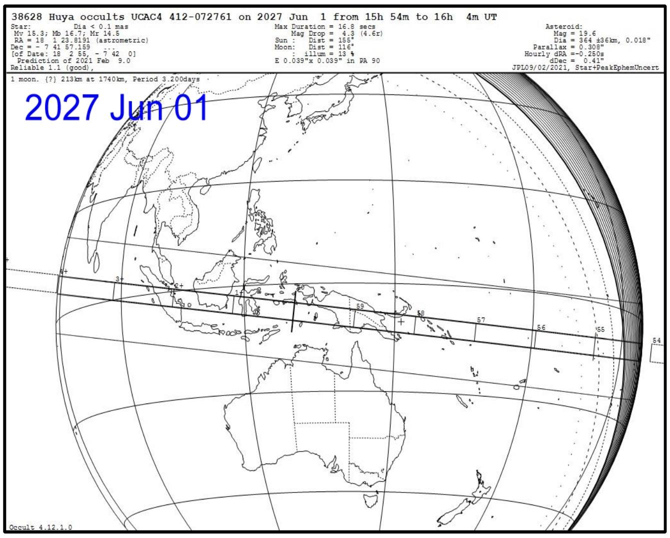


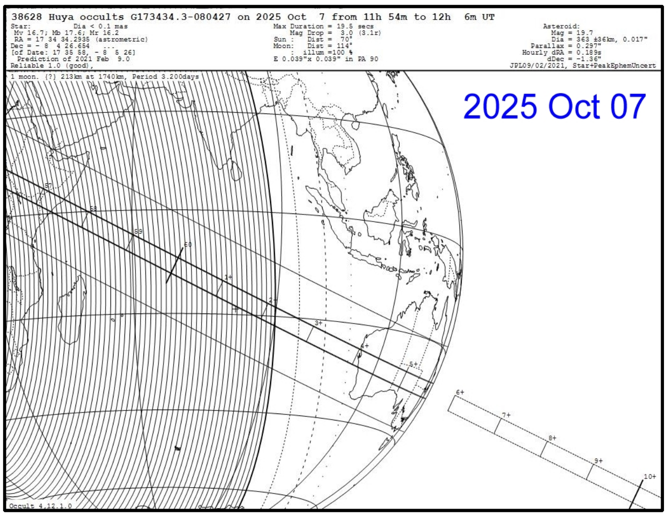


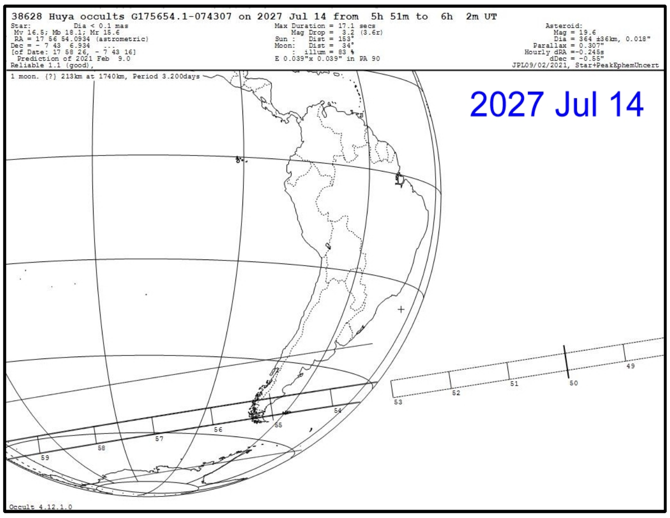
Figures 9 - 11.

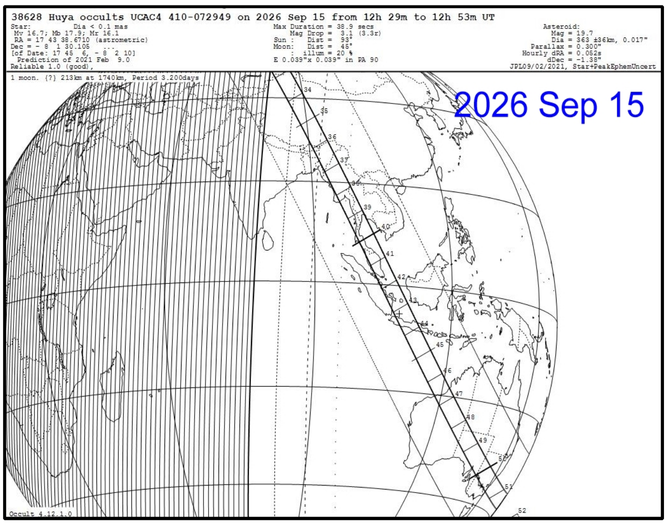
Figures 12 - 14.

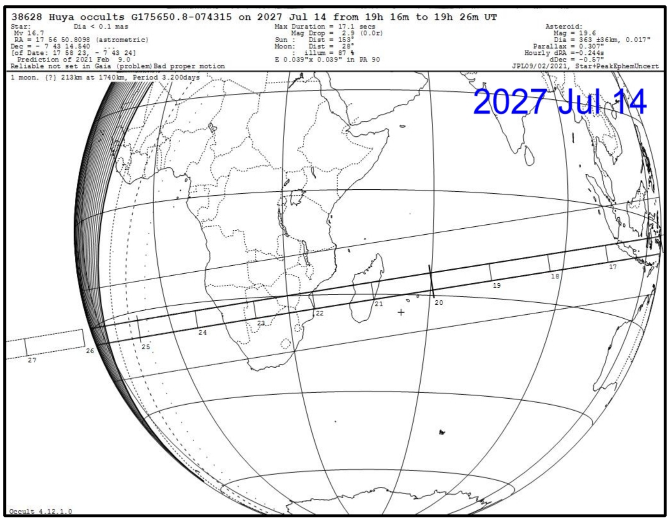












Figures 15 - 17.

Figures 18 - 20.

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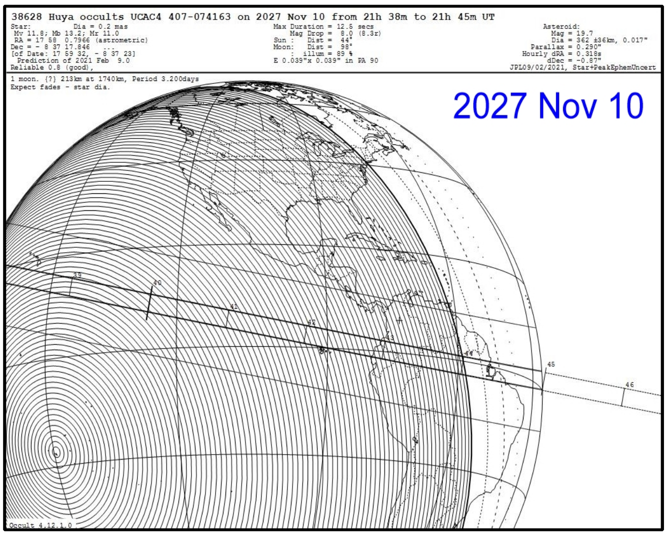
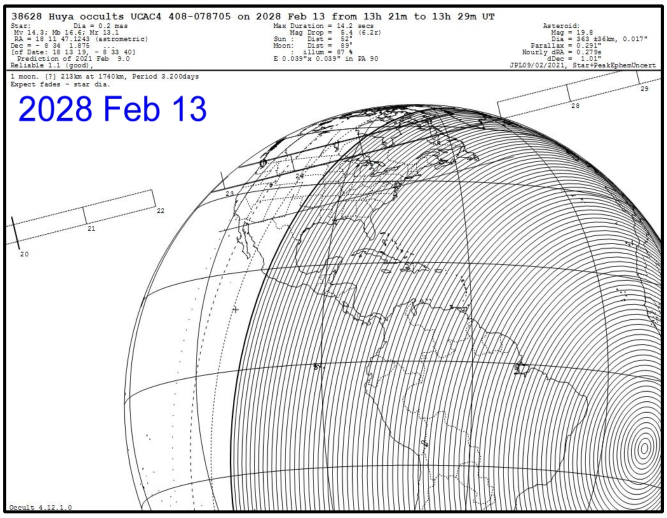
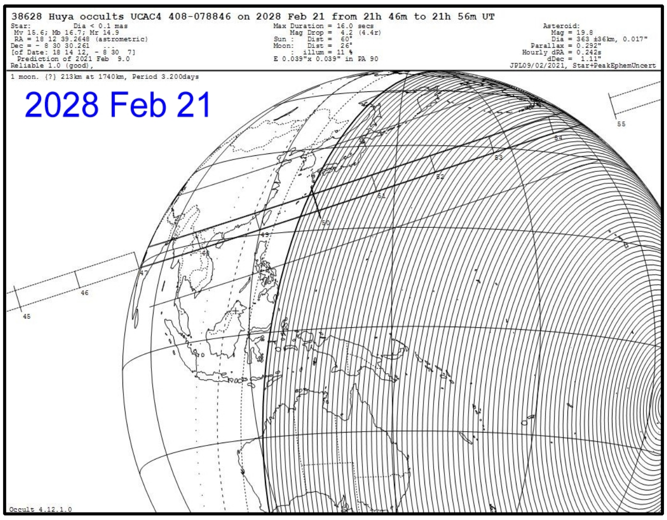
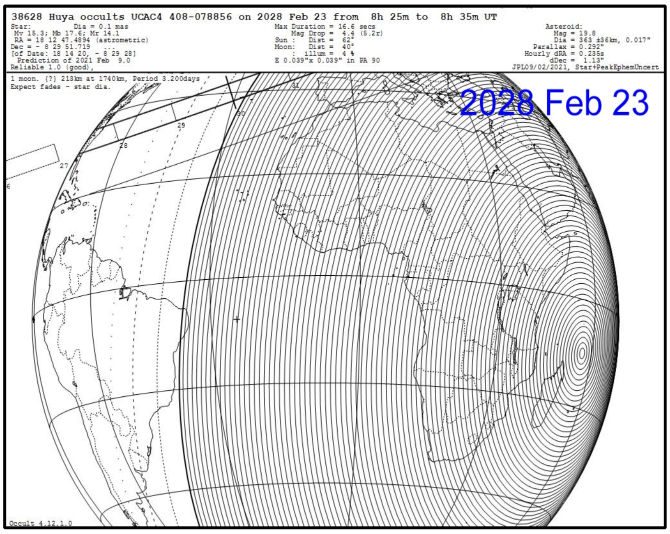
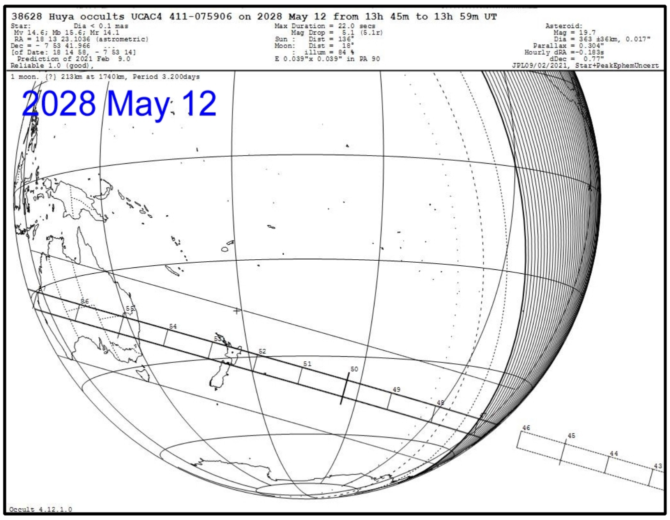


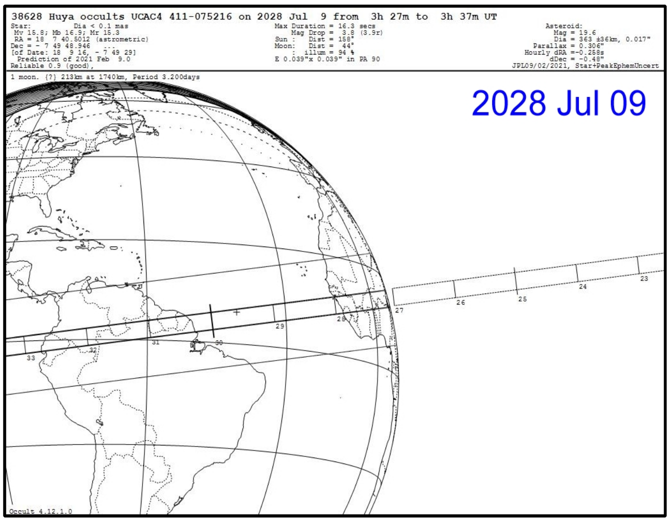




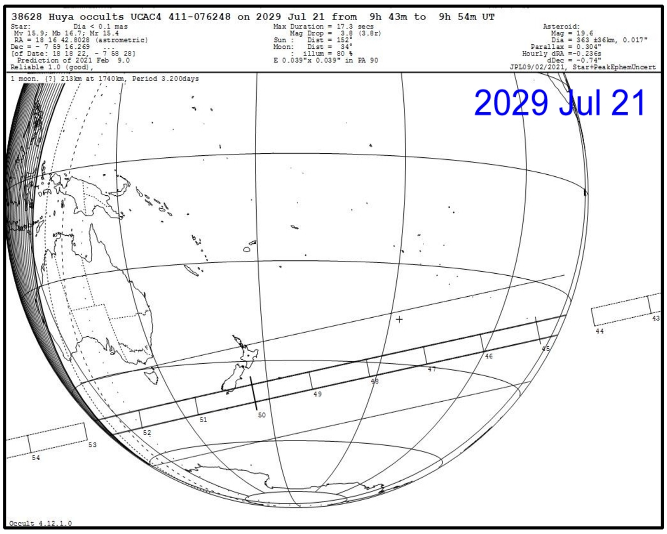
Figures 21 - 23.

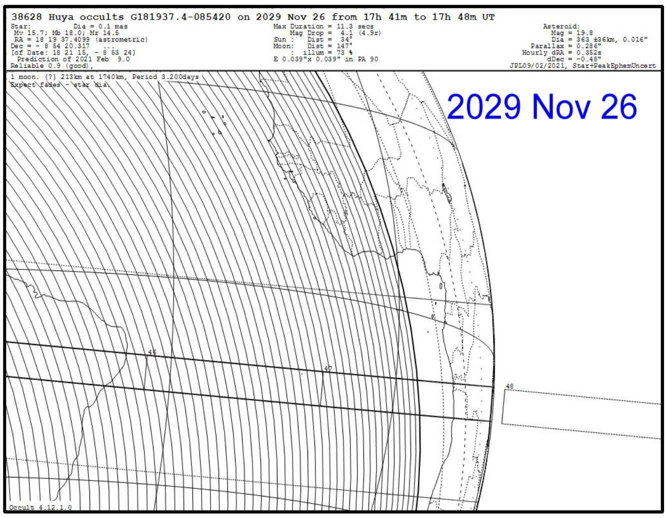


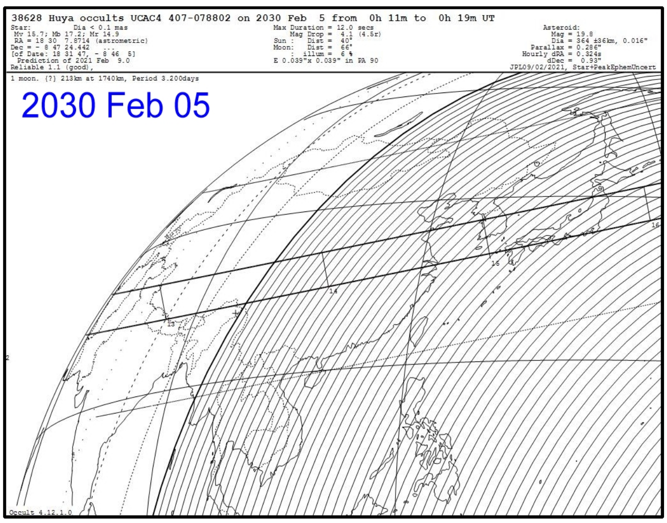




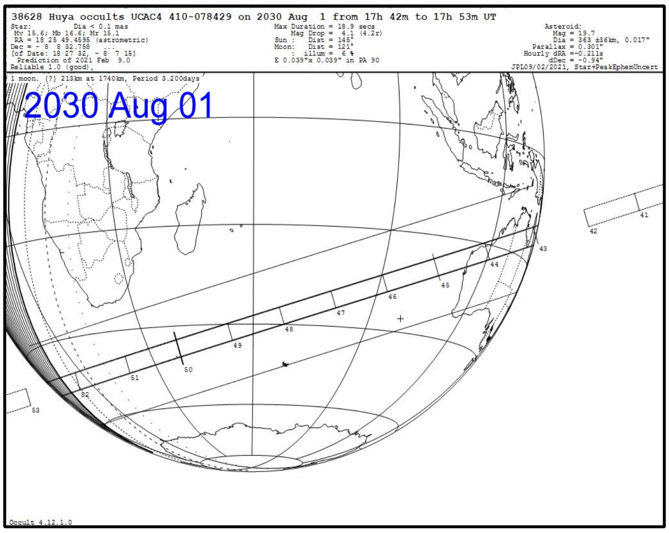
Figures 24 - 26.

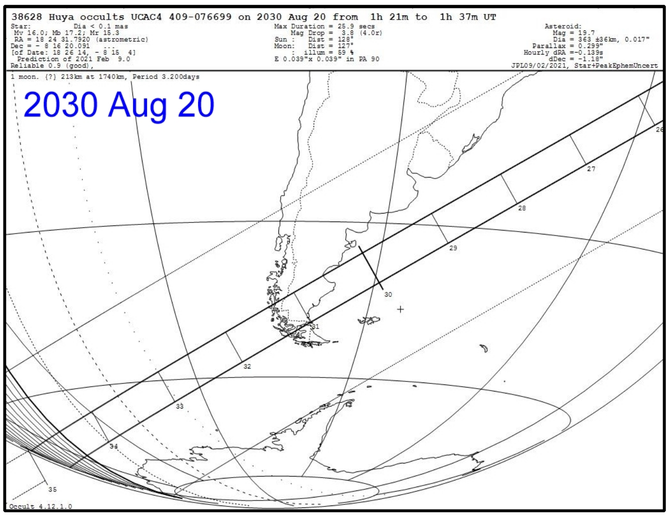


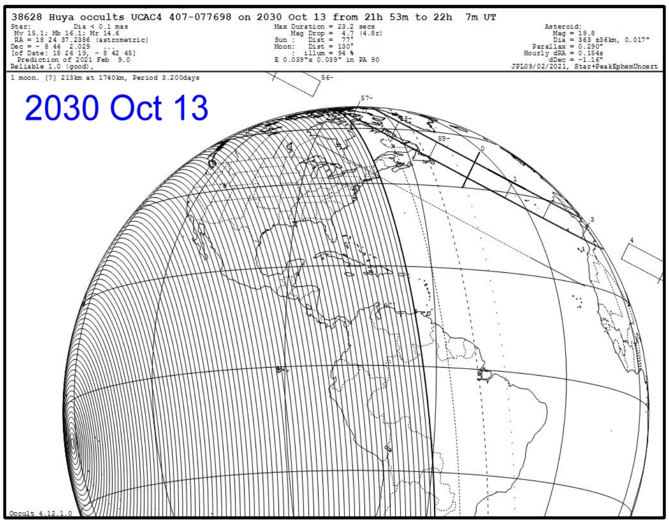




Figures 27 - 29.







Figures 30 - 32.

The forty-year jubilee ESOP conference will be held in Białystok, Poland, on 2021 August 27 - 31.

ESOP 2021 XL POLAND

Register here:
https://esop40.iota-es.de

Images: Wojciech Burzynski

It will be the fifth ESOP in Poland, twelve years since the previous one in this country, which was organised by the unforgettable Paweł Maksym in Niepołomice.
Białystok is a beautiful city with a population of 300,000 situated in the north-eastern part of Poland, it is the capital of the Podlasie region. You can get to Białystok within 3 hours from the Warsaw international airport by comfortably fast intercity trains. If you choose a car please use S8 expressway, the 200-kilometre journey between Warsaw and Białystok will take about 2.5 hours.
The city is close to the Belarus and Lithuania borders, which creates an opportunity to start deeper cooperation with astronomy enthusiasts in these countries on the occultation projects.
The main organiser will be the Polish Amateur Astronomers Society, Białystok Branch, and the observers of occultation events associated in the Occultation Section of the PAAS.
Białystok city is a strong academic centre and that is why the municipal university will be a co-organiser of the ESOP. The authorities of the Faculty of Mathematics and the Faculty of Physics of the University of Białystok were convinced to cooperate.

We will have a large lecture hall, which, even despite possible epidemic restrictions, will fit at least 120 participants.
Traditionally, after the lectures on Sunday, it will be possible to stay longer in Poland. Two days of optional excursions are planned, showing the beauty of the Podlasie region, especially the historic towns of Tykocin and Supraśl as well as the Tatar Trail.
On behalf of the organisers, I invite occultation observers not only from Europe but also from the rest of the world to participate in the XL ESOP. Let XL not only mean the 40th edition, but also an extra large symposium ...

Wojciech Burzyński
Chairman of the PAAS Occultation Section

2021 Phemu Campaign Workshop - Report of the 2021 February 6 French Meeting

Thierry Midavaine · Club Eclipse · Société Astronomique de France · Paris · France · thierrymidavaine@sfr.fr

ABSTRACT: IMCCE and Club Eclipse organised a Zoom workshop dedicated to the 2021 Phemu campaign with the support of SAF and SF2A within the framework of the Gemini ProAm partnership. 106 participants attended the three sessions. This report is a summary of the meeting.
First session (professionals): J.-E. Arlot, V. Lainey and J. Desmars, from IMCCE, presented the results of previous campaigns and the motivations for Phemu21. N. Emelianov (Moscow Lomonosov University) described the data processing pipeline.
Second session (amateurs): J.-M. Vugnon, L. Rousselot, P. André, C. Valencia, P. Baroni and T. Midavaine presented feedback from Phemu15 and discussed the new equipment and ideas available to observers.
Third session (inner moons of Jupiter) : B. Christophe discussed Phemus of Jupiter's inner satellites and presented his recording (with O. Dechambre) of Amalthea eclipsed by Europa in 2015. Observers with 60 cm-class telescopes are urged to record eclipses of Amalthea and Thebe.

Introduction

During the IOTA/ES ESOP XXXVIII Symposium held in Paris in 2019 [1], a French session gathered Francophone observers. One of the outcomes was to promote meetings in France to increase the number of amateurs involved in occultations. The Phemu campaign is a nice opportunity for newcomers to start making such recordings. Jupiter is an easy target to find, and the Galilean satellites are in the range of small 60 mm diameter refractors. Unfortunately, Covid restrictions prevented us from organising a physical workshop in the Paris Observatory facilities as we did for the WETO2014 (Week-End Technique Occultations) [2]. Therefore, with Jean-Eudes Arlot at the end of 2020, we decided to organise a virtual workshop via Zoom. We quickly mobilised good friends from IMCCE (Institut de Mécanique Celeste et de Calcul des Ephemerides) and Club Eclipse to prepare the programme, and with the help of the Gemini partnership between SAF (Société Astronomique de France) and SF2A (Société Française d'Astronomie et d'Astrophysique) dedicated to Pro-Am collaborations, we announced the workshop with a call for papers. 106 participants were registered through December 2020 and January 2021. I don't propose to summarise here the three sessions, but to present some interesting highlights for JOA readers well aware of the Phemu campaign thanks to previous papers on the topic published in earlier issues of JOA [3]. The PDFs and Zoom video recordings of the talks in French are available on the Gemini web site [4].

Workshop Programme

Thierry Midavaine
Zoom welcome and Workshop Introduction

Session 1 : Phemu campaign professional motivations
1. Jean-Eudes Arlot
40 years of Phemu campaigns
2. Valery Lainey
Detection of tidal effects from observations
3. Josselin Desmars
Reading the Ephemeris tables, selection of phenomena
4. Nikolai Emelianov
The data reduction pipeline and the problems to be solved

Session 2 : Amateur last campaign feedback and new set up
5. Jean-Marie Vugnon
From preparation to data delivery, experiences from the last Phemu campaign
6. Lionel Rousselot
New digital acquisition setup with time-stamping
7. Pascal André
A video time inserter based on the MiniMOSD module
8. Cesar Valencia
Time-stamping, alternative solutions with the TimeBox
9. Patrick Baroni
Low-cost sensitive cameras and focus on new IDS ones
10. Thierry Midavaine
Preparing the observation report and extracting the data

Journal for
Occultation Astronomy

Session 3 : Phemus of Jupiter's internal satellites and wrap up
11. Bernard Christophe
Europa eclipsing Amalthea – recording with a 60 cm telescope
12. Pierre Barroy, Arnaud Leroy,... round table
Projects with 60 cm telescopes: AT60, TJMS, Astroqueyras,
13. All
Take away, wrap up, action list and conclusions

Useful Web Links

To prepare the workshop we issued useful web links for participants in the weeks before the workshop:

IMCCE web site:
https://www.imcce.fr/recherche/campagnes-observations/phemus/phemu#1
Phemu ephemerids tables visible from your location:
http://nsdb.imcce.fr/multisat/nsszph517he.htm
To submit your raw photometric data:
http://www.sai.msu.ru/neb/nss/phemuobsai.htm
Gemini web site (in French) :
https://proam-gemini.fr/?s=mutuels
Club Eclipse web site from the previous WETO (Week End Technique sur les Occultations) (in French):
http://www.astrosurf.com/club_eclipse/_html/associatif/occultations/weto2014/weto2014actes.html
DIY video time inserter based on a MinimOSD module:
https://www.qfastro.club/lib/exe/fetch.php?media=projets:transformation_minimosd_vtiv6.pdf

Workshop Highlights

Jean-Eudes Arlot started to work on the Phemu events of Galilean satellites in preparing the first campaign in 1973 [5], (Figure 1). This project is now nearly 50 years old! Eight campaigns have been organised since the first one. The last two campaigns included 7 recordings of the small inner satellites Amalthea and Thebe.

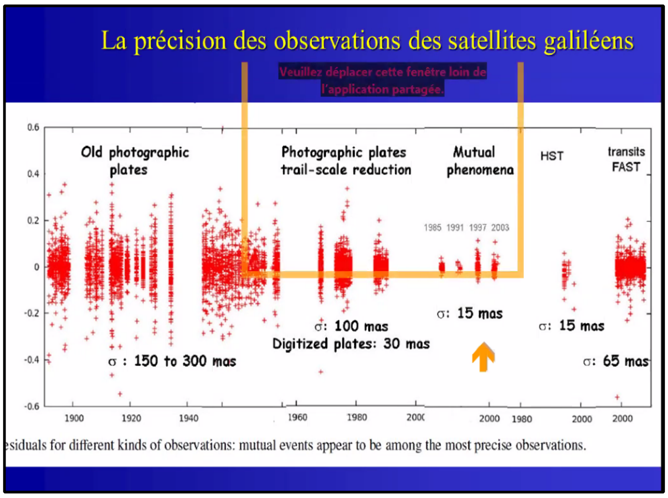


Figure 1. Astrometric accuracy of observations of the Galilean satellites - from Jean-Eudes Arlot's presentation.

Compared to asteroidal occultations of stars where the accurate timing of the disappearance and reappearance of the event is requested with 10 ms or even 1 ms accuracy, here for Phemus the issue is to record a complete time-stamped light curve with an accuracy of 100 ms. This 2021 campaign is difficult for observers in the northern hemisphere due to the low declination of Jupiter.

Then Valery Lainey explained how he got involved in Phemus with his PhD 20 years ago. He developed the new dynamical model of Jupiter's satellites used today to calculate the Galilean ephemerides and Phemu predictions with the V. Lainey 2.0 theory. Understanding the physical constraints on the satellite systems (internal oceans, volcanism on Io...) and smart propellant management of the scheduled space probe missions (*CLIPPER*/ NASA 2029, *JUICE*/ESA 2029, *IVO*/NASA 2033) are the two main motivations to continue Phemu observations (Figure 2). The Laplace resonance between Io 1:1, Europa 2:1 and Ganymede 4:1 brings an increasing eccentricity in Io's orbit due to Europa and the same for Europa's eccentricity due to Ganymede. Valery discovered [6] that the radius of Titan's orbit is increasing 100x larger than forseen in previous models due to a tidal effect in Saturn. An open question is: does a similar tidal effect exist in Jupiter? The answer could be delivered by the measurement of Callisto's orbit radius evolution not involved in the Laplace resonance. In addition, Phemu observations and stellar occultations by Jupiter's satellites could allow the measurement of the shift between the centres of gravity and the centres of volume of the satellites. This data is only known today for the Earth, the Moon and Mars.

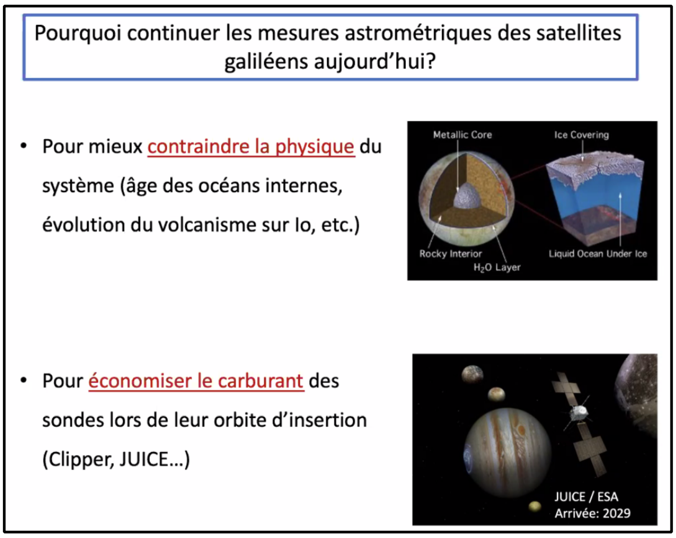


Figure 2. Understanding the internal structure of the satellites and smart management of space probe propellant are the main motivations to follow the Phemu events in the coming years - Valery Lainey.

Josselin Desmars came back on the Phemu ephemerides details (Figure 3) and the selections of the events in order to prepare observations. For any location you may get the calendar of events from the IMCCE web site or from [8]. A smart way is to feed the

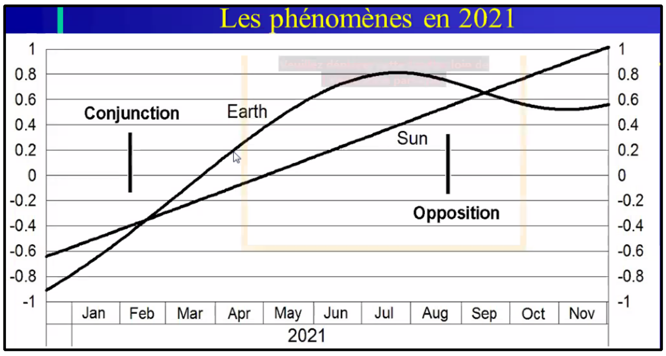


Figure 3. The jovicentric declination of the Earth and the Sun in 2021 referred to the date of conjunction and opposition Jupiter-Sun - Josselin Desmars.

web page with the closest IAU observatory code you may get from Josselin's map [9] in finding the closest MPC IAU referenced observatory location.

Josselin reviewed the events predicted for the location of Paris. Many events are long ones with eclipse or occultation durations more than 10 minutes or even more than 60 minutes. The impact data is quoted from 0 to 1, it is the relative satellite centre minimum shift compared to the radii of the two involved bodies. 0 stands for central eclipse or occultation giving an event with a maximum magnitude contrast, while 1 is a grazing event. M is the combined magnitude of the two satellites and Dm, the maximum magnitude drop of the event. Then, the visibility of the event is quoted with the distance to Jupiter's limb, Jupiter's elevation and the Sun's elevation. Most of the events are difficult, with phenomena during the day, and this allowed Josselin to produce a table of selected easier events visible from France (Figure 4).

Nikolaï Emelianov closed the first session with the explanation of the data processing pipeline, from the observer report submissions to the V. Lainey model update and the final publication (Figure 5). Nikolaï has been involved in the IMCCE collaboration for the last 24 years. Four image processing programs are certified to derive the aperture photometry light curve: *Tangra*, *LiMovie*, *Audela* and *DAOPHOT*. The processing is difficult due to light diffusion coming from Jupiter and the satellites themselves. It brings a discrepancy in zeroing the background in the light curve. Most of the time, systematic errors are well above the stochastic errors. The data reduction is not limited to the start, the maximum phase and the end of the event, the purpose is to deliver a complete light curve of the event. From this light curve the satellite astrometry is extracted.

PHEMU visibles depuis Paris

Les hauteurs du Soleil et de Jupiter sont depuis Paris: très favorable, favorable, faible drop, peu favorable, très difficile

Date			begin: h	m	s	end: h	m	s	Type	Dur(m)	Impact	m	Dm	limb(")	dist(")		Planet(d)	Sun(d)	Moon phase
2021	1	7	15	9	23	15	43	47	2O1	34.4	0.369	5.1	0.328	70.16		:	16.534	7.269	0.410
2021	1	7	16	42	14	17	6	13	2E1	24.0	0.057	5.1	0.870	77.00	6.12	:	6.717	-4.879	0.406
2021	1	18	8	54	39	9	6	42	2O1	12.0	0.431	5.1	0.279	79.10		:	6.302	9.305	0.350
2021	2	28	7	0	9	7	11	10	4E2	11.0	0.212	5.4	0.947	80.99	40.26	:	9.513	3.395	0.920
2021	3	14	6	34	28	6	39	34	1O3	5.1	0.903	4.7	0.016	81.35		:	12.457	3.949	0.064
2021	3	16	6	11	8	6	12	25	2O1	1.3	0.970	5.1	0.003	65.36		:	10.388	0.802	0.181
2021	3	18	5	7	11	5	12	53	4O1	5.7	0.129	5.2	1.113	13.21		:	2.417	-9.051	0.298
2021	3	26	4	50	4	4	57	19	1E4	7.3	0.481	5.2	0.295	34.08	73.37	:	3.977	-9.020	0.810
2021	3	28	4	37	14	4	40	29	1O2	3.2	0.603	5.0	0.169	35.53		:	3.111	-10.366	0.952
2021	4	4	5	26	21	5	31	2	1E2	4.7	0.396	5.0	0.506	57.38	36.29	:	13.304	-0.029	0.510
2021	4	12	4	16	38	4	42	54	1E4	26.3	0.098	5.1	0.483	8.43	63.36	:	7.793	-8.423	0.023
2021	4	17	3	9	17	3	13	26	2E1	4.1	0.692	4.9	0.170	69.39	38.58	:	0.430	-16.338	0.307
2021	4	24	5	24	12	5	27	30	2E1	3.3	0.805	4.9	0.085	68.11	42.55	:	21.354	5.853	0.779
2021	4	27	2	34	7	2	40	46	2E3	6.7	0.696	4.6	0.162	51.73	69.46	:	0.512	-17.447	0.983
2021	5	6	3	26	34	3	32	5	1E2	5.5	0.159	4.8	0.626	86.55	46.06	:	12.887	-8.533	0.342
2021	5	14	3	43	53	3	52	43	3E1	8.8	0.162	4.4	0.567	56.22	67.49	:	18.742	-4.425	0.147
2021	5	21	2	36	9	2	40	23	3E2	4.2	0.905	4.4	0.036	97.09	76.13	:	13.612	-11.408	0.596
2021	5	29	2	27	55	3	17	31	3E1	49.6	0.145	4.3	0.567	36.61	42.13	:	16.448	-11.052	0.790
2021	6	7	1	36	22	1	41	18	1E2	4.9	0.648	4.6	0.205	112.72	45.15	:	14.238	-14.614	0.200
2021	6	14	3	53	58	3	58	33	1E2	4.6	0.736	4.5	0.130	117.69	43.07	:	28.990	0.240	0.237
2021	7	4	0	6	19	0	10	0	3E1	3.7	0.896	4.0	0.040	85.08	64.74	:	16.193	-18.402	0.365
2021	7	7	0	47	13	0	49	3	1E3	1.8	0.970	4.0	0.005	96.70	65.92	:	22.174	-17.763	0.184
2021	7	9	0	5	54	0	7	19	1E2	1.4	0.985	4.4	0.002	130.49	30.49	:	18.543	-18.924	0.064
2021	8	1	22	0	49	0	5	35	3O2	124.8	0.997	4.0	0.000	149.17		:	15.055	-18.744	0.415
2021	8	8	20	13	42	21	18	44	3E2	65.0	0.635	4.0	0.205	84.22	7.68	:	4.181	-8.856	0.034
2021	8	9	3	37	8	4	44	41	3E2	67.5	0.343	4.0	0.465	174.12	6.66	:	17.412	-9.010	0.050
2021	8	19	4	15	7	4	34	14	1E3	19.1	0.709	3.9	0.112	3.19	2.92	:	6.158	-6.013	0.760
2021	8	30	19	2	52	19	15	28	3E2	12.6	0.766	4.0	0.120	205.20	13.26	:	7.250	-5.013	0.470

Figure 4. Selection of Phemu events visible from France - Josselin Desmars.

Nikolaï Emelianov recommends:

- Record the reference satellites flux during all the event.
- Record the well separated satellites flux before and after the event.
- Upload your data on the web interface instead of delivering it by e-mail (see section *Useful Web Links*)
- Low SNR data are welcomed. Noisy photometric data could be processed to extract the light curve.

Then we moved to the amateur session.

Jean-Marie Vugnon reminded us how 6 years ago he recorded events with a Watec analogue camera, video time inserter and frame grabber. Training is a main issue to be ready for the dates of Phemus.

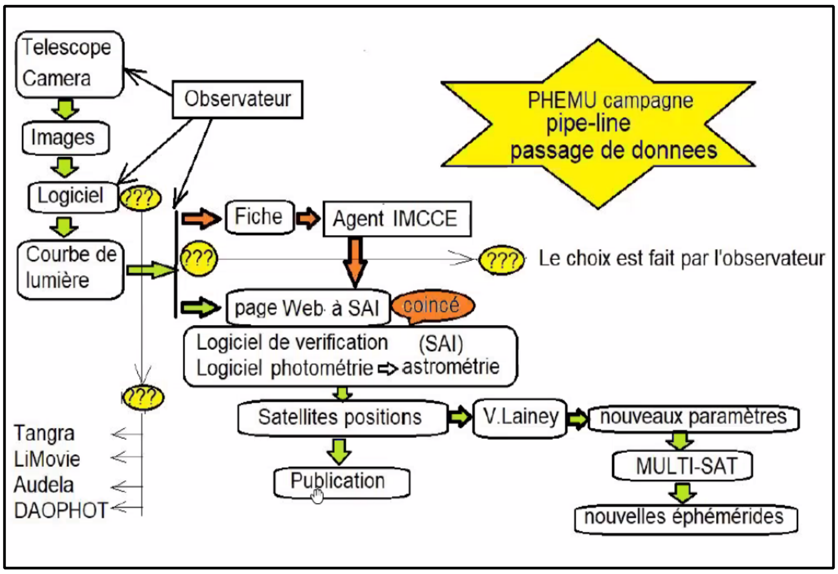


Figure 5. Phemu data processing pipeline - from observers' reports to deriving satellite astrometry, revising the V. Lainey model (satellite orbital elements), and final paper - Nikolaï Emelianov.

Lionel Rousselot shared his expertise of digital CMOS cameras and acquistion software. He showed how *Genika 2.13* and *SharpCap 3.2* allow accurate time-stamping with less than 2 ms noise. On the other hand, *FireCapture 2.6* gives a 40 ms peak to peak noise. In addition, he made experiments with a ZWO 1600, he demonstrated the benefits of accurate time-stamping with 1600x1200 windowing mode without digital binning instead of a 2000x2000 window or 2x2 binning modes. Digital time-stamping was succesfully tested with the TimeBox and with DCDTracker.

Pascal André explained how you may assemble an analogue video time inserter from Piotr Smolarz's project DIYDRONES.COM with a budget of less than 25 € if you are prepared to solder electronic components, wires and connectors.

Cesar Valencia introduced his TimeBox now in mass production and distributed by Sheliak. JOA has just published in the first quarter issue of 2021 a thorough analysis of the TimeBox compared to previous solutions [7].

Patrick Baroni gave a focus on the latest IDS CMOS cameras. BSI (Back Side Illuminated) CMOS arrays with a quantum efficiency up to 90 % and 1e$^-$ noise are available. The UI3240LE quoted at 400 € gives you an enhanced sensitivity in Near IR.

Données sur Jupiter et les satellites galiléens

Soleil	Temperature de corps noir	5800 K	
Terre		1 UA	1.50E+08 km
Jupiter			
Distance de Jupiter au Soleil		5.2 UA	
Distance de Jupiter à la Terre		4.346 UA	le 6 fevrier 2015

Données sur Jupiter et les satellites galiléens	Rayon de l'orbite	Elongation max	Diametre	Diametre Angulaire	Diametre Angulaire	Albedo	Magnitude	B-V	U-V
Unités	km	arcsec	km	arsec	rd		V		
Jupiter			142984	45.3	2.20E-04	0.52	-2.7	0.83	0.48
Io (I)	4.22E+05	1.38E+02	3642	1.16	5.60E-06	0.63	5.02	1.17	1.3
Europe (II)	6.71E+05	2.20E+02	3130	0.99	4.81E-06	0.67	5.29	0.87	0.52
Ganymède (III)	1.07E+06	3.51E+02	5268	1.67	8.10E-06	0.44	4.61	0.83	0.5
Callisto (IV)	1.88E+06	6.18E+02	4806	1.52	7.39E-06	0.2	5.65	0.86	0.55
Amalthea (V)	1.81E+05	59	131			0.07	14.1	1.5	
Thebe (XIV)	2.22E+05	73	55			0.04	15.7	1.3	
Adrastea (XV)	1.29E+05	42	13			0.05	19.1		
Metis (XVI)	1.28E+05	42	20			0.05	17.5		

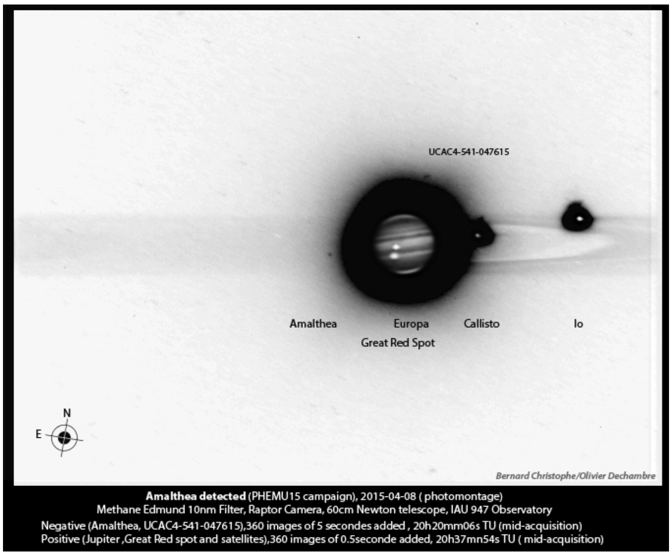
Figure 6. Astrophysical Quantities extract related to the Jupiter system - Thierry Midavaine.

I closed the amateur session in reminding how easy it is to record a Phemu and become a co-author of the scientific paper published by the IMCCE team. The following table gives angular and photometric data of Jupiter's satellites including the small inner satellites (Figure 6). The Callisto Gamymede maximum elongations are 4.7 mrd (~16 arcmin), this means with a 1 m focal length a 4.7 mm wide CMOS array is sufficient to cover the maximum required field of view. An APSC DSLR covers the field of view with a 3 m focal length telescope. You may start recording an event with a very simple setup. We may wonder to make a Phemu with a smartphone mechanically fixed behind the eyepiece of your telescope or in using the video mode of your reflex or hybrid cameras. You will get an RGB recording. The time-stamping could be recorded on the sound track with the camera microphone listening to the PPS beep by calling 3699 Horloge Parlante - the French Speaking Clock.

The colour index of the satellites gives an advantage to work in the red and near IR bands compared to the sky background and the diffusion of the Sun-illuminated disc of Jupiter. A more than 1000 pixel wide array allows one to cover the field of view and is fitting the satellite disk spatial sampling. To train yourself with your setup before a Phemu you could record an eclipse of Io by Jupiter. After Jupiter's opposition you could record Io's disappearance in Jupiter's shadow. It is about a 5 minute long photometric event.

The third session was dedicated to observing the Phemus involving the inner satellites Amalthea, Thebe and even Adrastea and Metis. They are quoted as numbers 5, 6, 7 and 8 on the IMCCE Phemu table of the inner satellites. These events are always an eclipse of one inner satellite by a Galilean satellite. Bernard Christophe shared a presentation of Europa eclipsing Amalthea recorded with Olivier Dechambre in 2015 with a 60 cm telescope (Figure 7). Amalthea is 14.1 V magnitude and Thebe is 15.7 V magnitude in the range of 50 cm class telescopes. Of course, the difficulty comes from the diffusion of light from Jupiter and the possible proximity of Galileans. Clean optics are a first requirement. Then you may adopt three solutions to reduce the glare. Francois Colas put a mask directly onto the CCD chip and recorded Thebe and Amalthea. Bernard Christophe used a methane band filter. In a FWHM 10 nm band within the methane band between 880 nm and 900 nm you get a x10 extinction of Jupiter's disk luminance compared to the luminance of Jupiter's satellite. Of course, you reduce the satellite flux in such a band. The third solution is to adapt an occultation disk in the focal plane of the telescope and to use a combinaition of one lens or two lenses (field lens and reimaging lens) to perform the conjugation of the telecope focal plane with the CMOS or CCD array plan. Olivier Dechambre noticed that a favourable Phemu with Amalthea and Thebe will occur on the night of July 14.

Participants having access to 60 cm class telescopes were enthusiastic to try these challenging Phemus! The IMCCE team is very interested in processing several inner satellite Phemus to undergo accurate analysis of the dynamics of these objects.



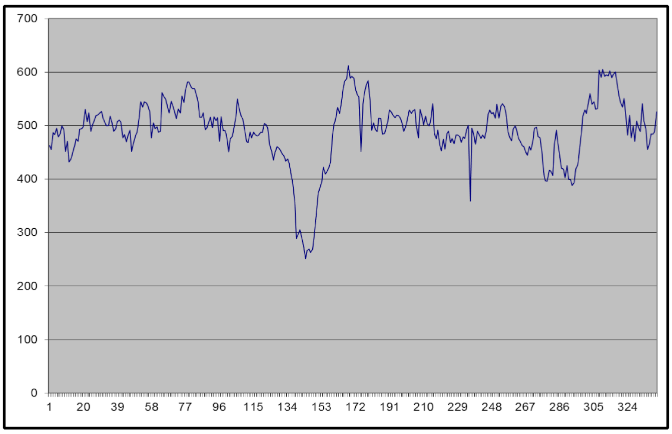


Figure 7. Detection of Amalthea and light curve of the Europa eclipsing Amalthea event of 2015 April 8 - Bernard Christophe Olivier Dechambre.

Conclusion

We concluded the workshop in reviewing the good ideas, actions to keep on track and organisation of our network for this campaign. Here is a summary of the ideas and proposals from the participants:

- About inner satellites Phemus: this is challenging but may be within the range of 300 mm telescopes. New sensitive low noise small pixel CMOS arrays are to be tested. Arnaud Leroy and Pierre Barroy proposed to undertake a common effort with AT60 and TJMS to record several inner satellite Phemus involving Amalthea and Thebe.
- Patrick Baroni proposed to test a Near Infrared sensitive IDS camera.
- Valery Lainey prioritised Events with Callisto (4). On April 12 we have a Callisto eclipse.

- Negative recordings are interesting for grazing events (impact close to 1)
- Edouard Ruelle proposed to investigate a smartphone configuration to record Phemus
- Christian Drillaud proposed to resume previous work made 5 years ago in using a DSLR in video mode
- All participants agreed to share their e-mail address for Phemu networking
- The Gemini web site will host the PDF and Video of the workshop [4].
- Nikolaï Emelianov recommended us to use *Tangra* for the aperture photometric processing in a single combination of *Tangra* options to unify all the data delivery to be uploaded to his web page. Then he suggests to process the recording with a second program to check for discrepancies or benefits. Currently he approves the use of *Tangra*, *Limovie*, *Audela* and *Daophot*. In addition we may test other processing programs: *AstroImageJ*, *Muniwin*, *Siril*, *Pymovie*,...
- The organisation of a tutorial could be prepared.
- Nikolaï will increase the 10,000 lines of data to take into account the long Phemu events

1. Clean your optics to reduce light glare and diffusion
2. Select and define one single configuration to record several events during the campaign
3. The field of view to cover the longest elongation is 4.7 mrd, a larger field of view is not useful
4. A narrower field of view could be sufficient to cover the two satellites involved in the event and a third satellite to get a reference far from Jupiter's disk.
5. Try the smartphone video mode with mechanical mounting behind the eyepiece
6. DSLR video mode delivers an RGB light curve and solves the chromatic atmospheric refraction effects
7. For the spectral band record the event either (from the simplest to the finest):
    a. in full detector band
    b. or in wide spectral band
    c. select R band
    d. or select I band
    e. or methane band 880 nm – 900 nm
    f. Thermal Infrared recordings are valuable if you have access to IR cameras
8. UTC time-stamping accuracy of 0.1 s is required
9. A camera able to record a sound track showed an accurate synchronisation with picture frames and could be used to get the time-stamping by listening to the beep from horloge parlante (3699) or a tone driven by DCF 77.
10. Train yourself and your setup by recording Io being eclipsed by Jupiter (you have several events every month)
11. Prepare for each event by identifying the planet's elevation, the Sun's elevation before, during and after the event
12. The low elevation produces chromatic atmospheric dispersion which could be solved with a filter and the crepuscular sky background effect could be reduced with an R or I filter
13. Prepare for each event by identifying the satellites involved in the event and in identifying the best reference satellite [8]
14. Will the satellites involved in the event be angularly separated?
15. Don't saturate the satellite signal, stay at half the saturation level of the sensor
16. For an occultation keep in mind the maximum flux will be the addition of the two involved satellites just before and after the event. They will not be separated by your setup and by the turbulence effects
17. Defocused recording brings a higher photometric dynamic without the risk of saturation:
18. If it is possible, record the satellites' maximum flux well before the event and after to get the referenced photometric flux of the separated bodies.
19. Start recording 5 minutes before the event, the accuracy of the ephemerides is about 5% the duration of the event
20. After the event, process your recording with one of the following programs: Tangra, Limovie, Audela, DAOPHOT
21. The aperture photometry processing subtracts the background
22. The background is a combination of the sky background, and light diffusion in the optics from Jupiter's disk and the satellites
23. Try to process your data with a second program: Astro Image J, Muniwin, Siril, Pymovie,...
24. Low SNR data is welcome
25. Upload your data on Nikolaï's web page

Table 1. Phemu check list assembled by Thierry Midavaine from questions and ideas during the Phemu meeting.

The 2021 Jupiter Agenda

January 3	Begining of the Phemu events but Jupiter is too close to the Sun
January 29	Jupiter conjunction with the Sun
March	First events in the morning sky
March 24	Earth in Jupiter's equatorial plane (best day for Phemu occultations)
April 2	Jupiter conjunction with 44 Cap (6.0 mag)
April 16	Jupiter conjunction with μ Cap (5.2 mag)
May 2	Jupiter equinox (best day for Phemu eclipses)
May 21	Jupiter western quadrature
June 21	Jupiter stationary
August 20	Jupiter opposition at 4.0132 AU
August 29	Jupiter conjunction with μ Cap
October 18	Jupiter stationary
November 15	Jupiter conjunction with 45 Cap (5.9 mag)
November 15	Jupiter eastern quadrature
November 16	Last Phemu event of the 2021 campaign

We closed the workshop with the aknowledgement of the preparation of all the professional and amateur contributions and in thanking all the participants for their active participations with questions, good ideas and proposals for the coming months.

Post Workshop

After the workshop several actions and initiatives were scheduled:

- March 5: Pascal André - Zoom conference from Club Astro Quint Fonsegrives and Adagio : How to record a Phemu event
- March 6: CT2A commission - Zoom meeting: CCD and CMOS array comparisons
  - May Numéro spécial d'Observations et Travaux dedicated to the Phemu mai 2021 Société Astronomique de France
- Organise a tutorial on *Tangra*
- Jean-Eudes Arlot proposed to sign dispensation forms to permit travel to locations to observe Phemu events during periods of COVID restrictions.
- Valery Lainey announced the quadruple occultations on April 2 by Metis, Io, Amalthea and Thebe of 44 Cap, a 5.8 G mag star. This is an exceptional set of events involving inner satellites, but it occurs in daylight conditions during the Phemu period (Figure 8 - 11).

The PDFs and recorded videos in French of this meeting are available on the following web page :
https://proam-gemini.fr/campagne-dobservations-des-phenomenesmutuels-des-satellites-de-jupiter/

«GEMINI – PHEMU 2021» : https://www.youtube.com/playlist?list=PL78ug7UrzPF2OjzyoqGATfgbxlRIFLRMF

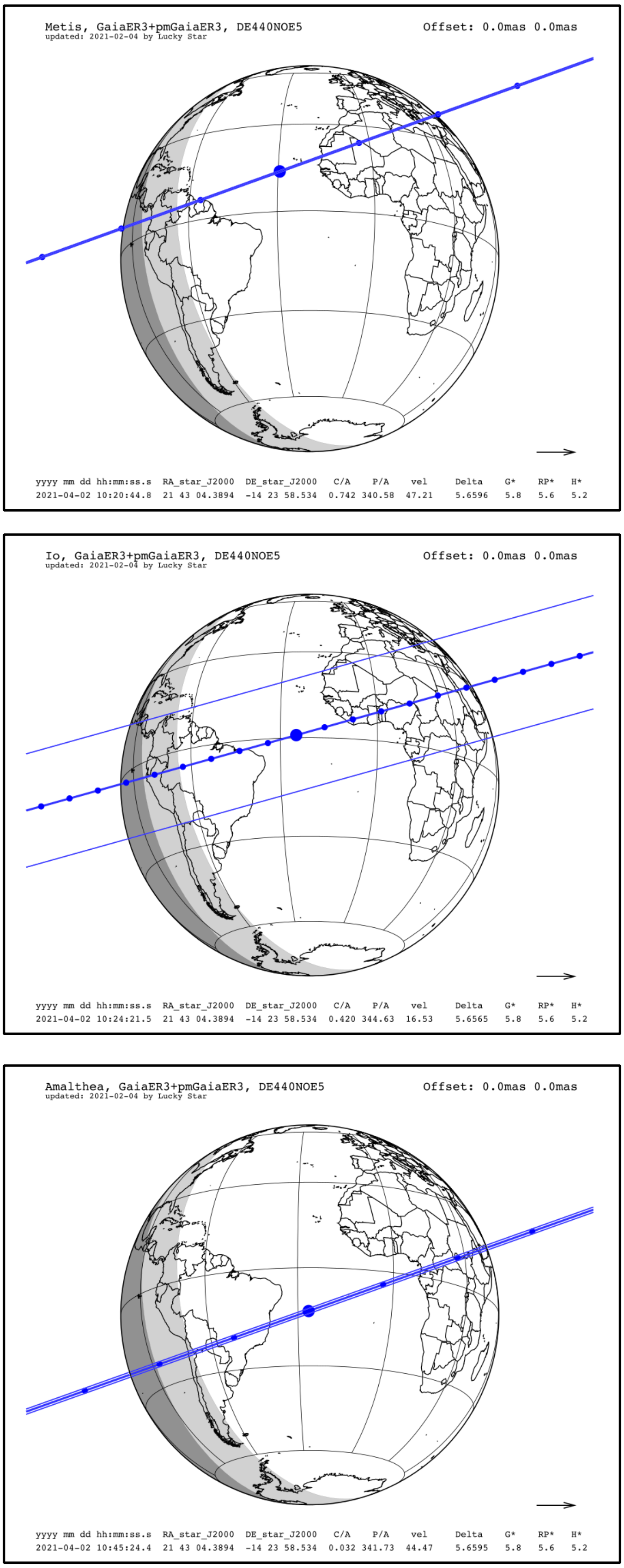


Figure 8 - 10. Occultations of 44 Cap by Metis, Io and Almathea.

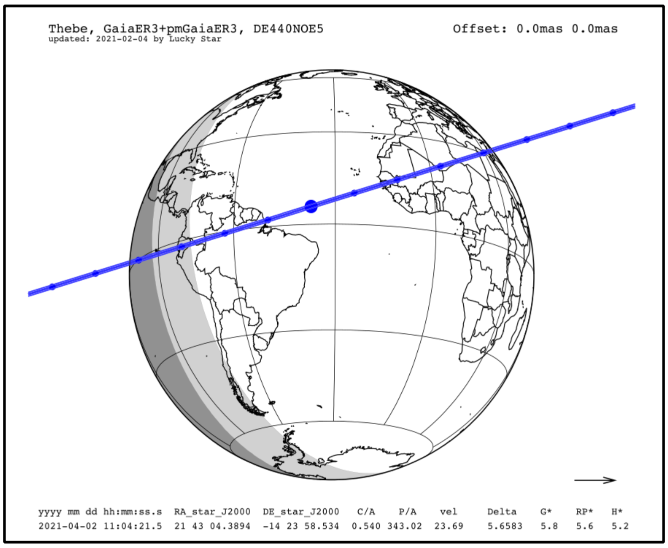


Figure 11. Occultation of 44 Cap by Thebe.

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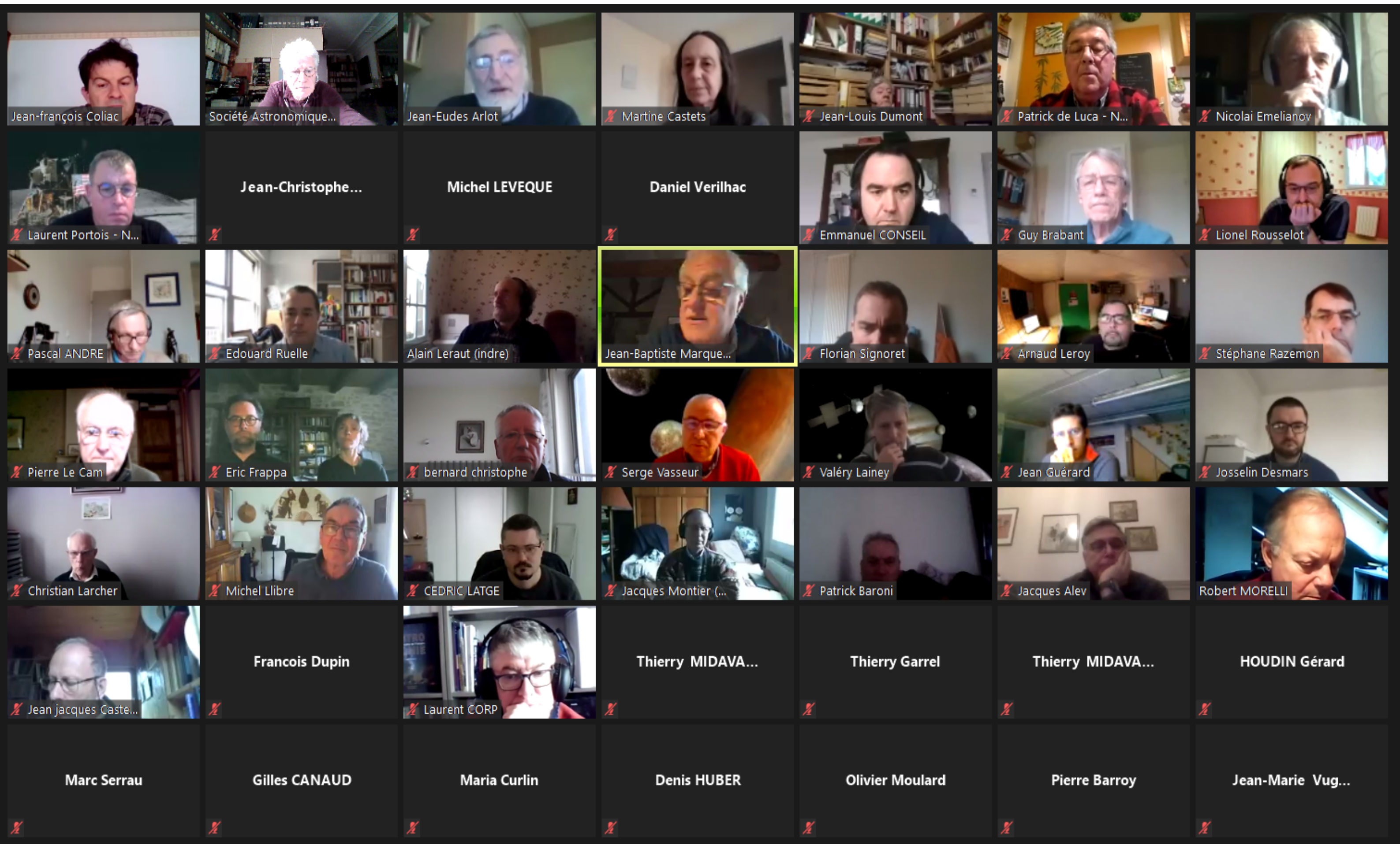

Figure 12. Zoom mosaic of some workshop participants. 82 participants attended simultaneously.

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

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