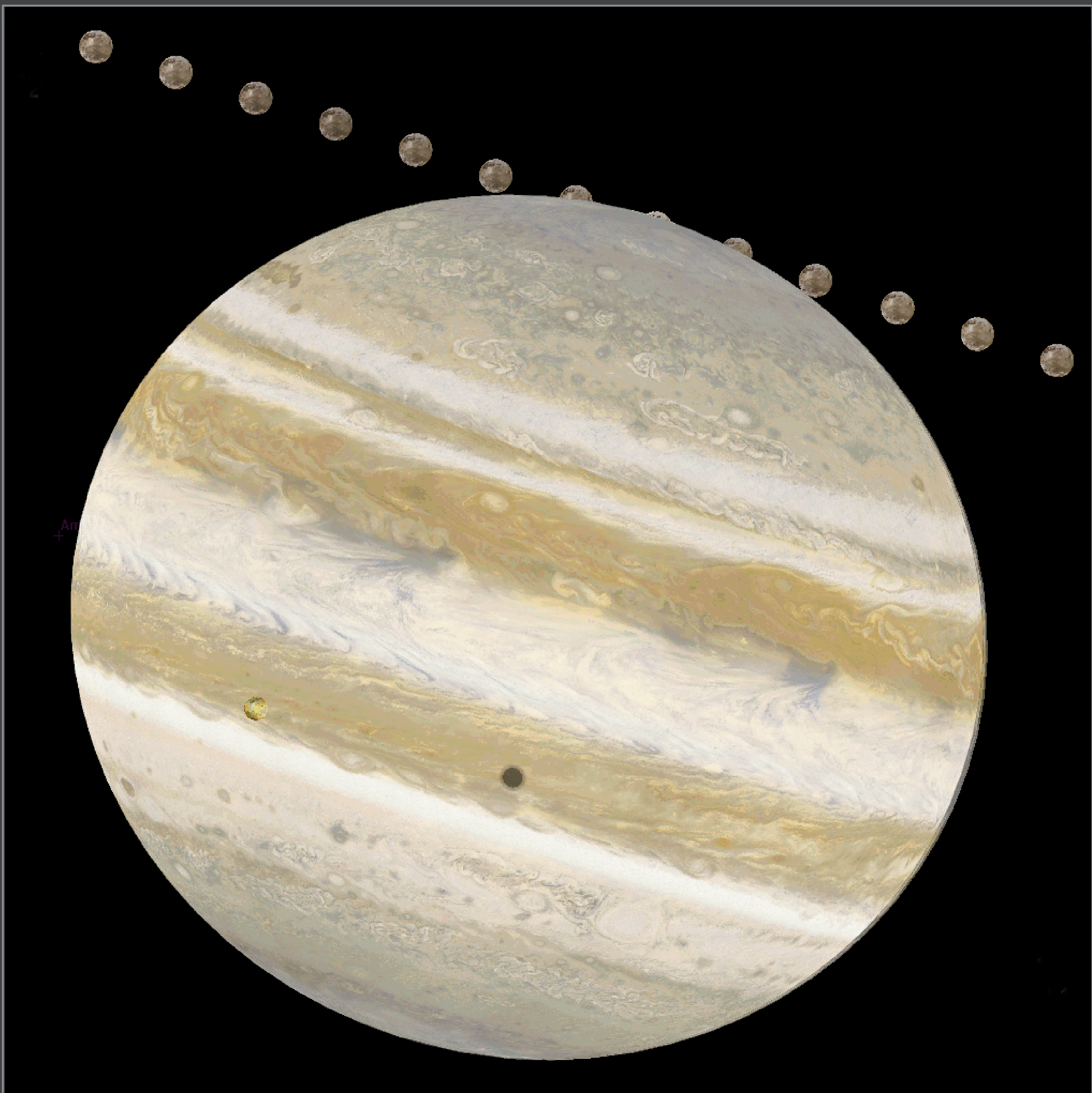
Journal for Occultation Astronomy

INTERNATIONAL OCCULTATION TIMING ASSOCIATION

Volume 13 · No.3

2023-03



Grazing Occultations of Ganymede by Jupiter

Dear reader,

we occultation observers are spread over several continents. Some of us are members of local organisations in your country or region, or work in a group around an observatory. In the age of the World Wide Web, of course, no one is cut off from information, but the form of exchange is inconsistent.

In Europe we have set up a forum for the SODIS data collection programme. It was very busy during the start-up phase of SODIS because of the learning curve. It is quieter now but is a valuable resource of hints and tips. Maybe internet forums are not everyone's cup of tea?

Mailing lists are a nice way to communicate. But when two or three members do their internal communication through the mailing lists, it leads to frustration for the others and they feel left out. Our face-to-face meetings only take place once a year and are too costly for some. The question remains: how can we communicate better?

In this issue of the magazine, we report on a new attempt to improve communication between Europe and the US - the round table. It is an attempt without an agenda to help each other and to exchange and evaluate news. Perhaps not the best solution, but a new way. Let's try it - let's talk!

Take care and clear sky!

Konrad Guhl

President, IOTA/ES

JOA Volume 13 · No. 3 · 2023-3 $ 5.00 · $ 6.25 OTHER (ISSN 0737-6766)

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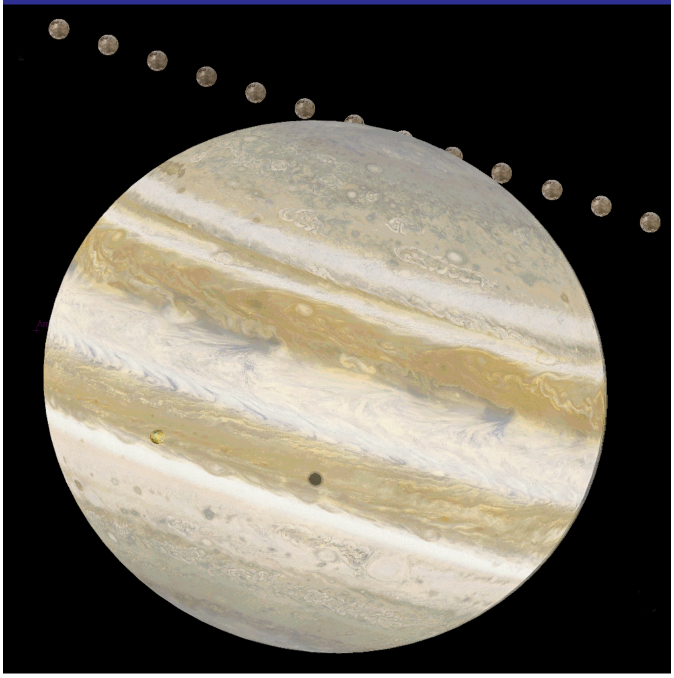
COVER



Rare grazing occultations of Ganymede by Jupiter will happen in September and October 2023. The cover of this issue of *JOA* presents the graze on 2023 October 02. The image sequence from 10:10 - 14:10 UT (right to left) shows the shift in Ganymede's position relative to Jupiter every 20 minutes. Satellite Io and its shadow on the clouds of Jupiter are shown according to their positions at the end of the sequence. View on the sky plane, north is up. Graphic: O. Klös, made with GUIDE 9.1

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 https://www.iota-es.de/how2write_joa.html .

Journal for Occultation Astronomy

CALL FOR OBSERVATIONS:

Grazing Occultations of Ganymede by Jupiter

Andreas Dill · IOTA/ES ·VVS · Kortenberg · Belgium · andreas.dill@vvs.be

ABSTRACT: A series of very rare grazing occultations of the Galilean moon Ganymede by Jupiter occurs in autumn 2023. During seven consecutive superior conjunctions of Ganymede, part of the moon remains visible.

Introduction

Of all the major planets in the solar system, the largest, Jupiter, is remarkably well aligned in its orbit and rotation. Its orbital inclination to the ecliptic is only 1.3°, the second smallest after Uranus. Its axis of rotation is inclined by 3.1° with respect to its orbit; only Mercury's axial inclination is even smaller. Jupiter's four large moons are also quite strictly oriented in their orbits and revolve around the planet almost exactly in its equatorial plane. We observe the greatest inclination of an orbit at the outermost of the Galilean moons, Callisto, with as little as 0.51°.

Escaping Jupiter's Shadow

This situation results in every revolution of each of the four large moons being consistently passing Jupiter's shadow and, for Earth-bound observers, occulted by Jupiter. Let us remember that only shadow events are real eclipses, while occultations are a matter of a favourable position of the outside observer, like us on Earth.

As we all know: The only exception in this perpetual eclipse pattern of Jupiter's Galilean moons is the most distant of them, Callisto, where this is only true within about three years around Jupiter's equinox. If Jupiter is closer to its solstice, the geometric conditions are such that, because of Jupiter's axial tilt and thus the tilt of the system of Galilean moons, Callisto escapes Jupiter's shadow. For us observers from Earth, Callisto is then no longer occulted during superior conjunctions but passes to the north or south of the planet.

Upcoming Grazes by Ganymede

Callisto, the only exception? While preparing the Belgian astronomical almanac "Hemelkalender 2023" [1], we noticed that the third of the Galilean moons, Ganymede, also remains visible to us during seven consecutive superior conjunctions at the northern edge of the planet for a short period in September and October 2023 (Table 1). Even though only part of Ganymede peeks out from behind Jupiter and the moon never remains fully visible, this was still a surprise. We were not aware that such grazing occultations of Ganymede by Jupiter were possible! A small survey of almanac makers all over the world was met with astonishment. We were not the only ones to be surprised that, in addition to Callisto, Ganymede can sometimes remain visible at superior conjunction. Perhaps the reason for this is that it doesn't occur very often. The last time this happened was in 1916 with an even shorter series of only five consecutive superior conjunctions. We do not, however, have to wait that long for the next opportunity, it will happen again in 2030, then at the southern edge of Jupiter.

What favourable conditions must come together to make grazing occultations of Ganymede by Jupiter possible for observers from Earth? The main condition is surely that Jupiter is in the vicinity of a solstice (Figure 1). This is when one of the poles tilts the most towards the Sun and thus the interior of the solar system, and when the north-south elongation of the orbits of the Galilean moons spread out the widest. The next summer

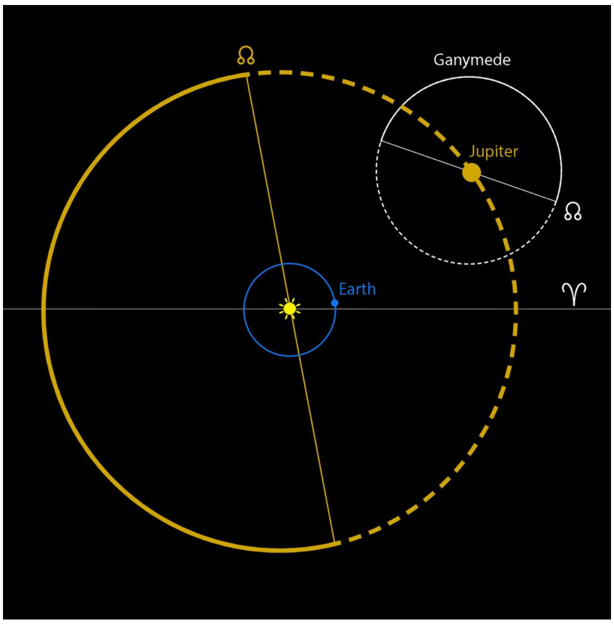


Figure 1. Orbits of Jupiter and Ganymede (schematic, not to scale), with the positions of Jupiter and Earth at the beginning of October 2023. The positions of the ascending nodes of the orbits are shown. Dashed are the orbital parts below and solid above the orbital plane. In this situation, Ganymede is additionally elevated in the outer part of the orbit, which contributes to its visibility during the superior conjunction.

solstice on Jupiter is imminent, taking place on 2024 January 20. But already on 2023 October 15, the Earth reaches its greatest northern declination of 3.9° as seen from Jupiter, not coincidentally amidst the time of this series of grazing occultations of Ganymede by Jupiter. It is also favourable that, almost simultaneously, Jupiter reaches its maximum southern ecliptic latitude of –1.42° during this orbit cycle on 2023 October 22.

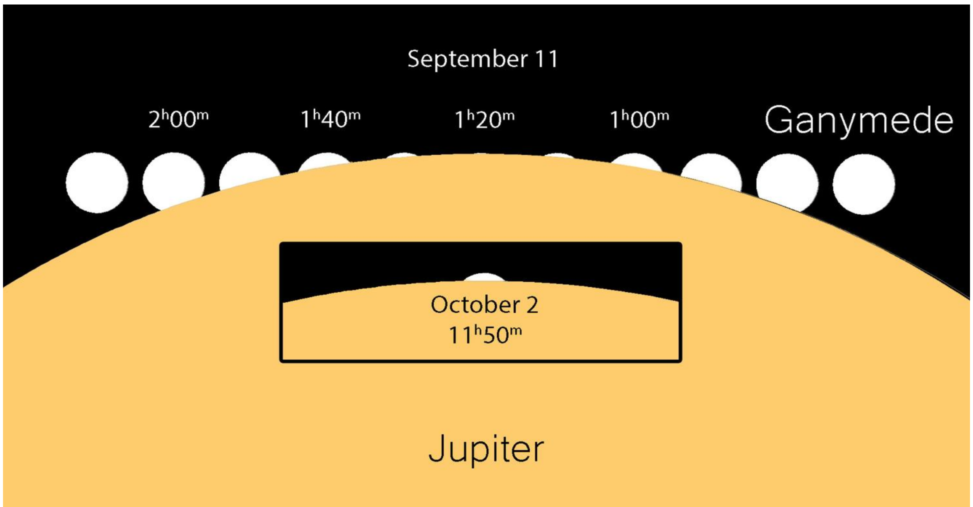


Figure 2. The first grazing occultation of Ganymede by Jupiter on September 11. The image inset shows the October 2 occultation, where the largest piece of Ganymede remains visible within this occultation series.

Last but not least, the orbital parameters of Ganymede contribute favourably: Jupiter reaches its maximum southern ecliptic latitude at 42° heliocentric longitude, while the ascending node of Ganymede's orbit is at 339.8°. This means another additional uplift of the moon in its orbit near the superior conjunction, which, though small, is probably the deciding factor (Figure 1).

A reasonable question is: Are the eclipses of Ganymede in Jupiter's shadow also partial during this time? The answer is "no". It is revealing in this context that, seen from the Sun, no partial occultations of this moon happen either. We learn that this rare series of partial occultations of Ganymede by Jupiter is only for us, due to our particular observing position in the solar system in this period, as described above.

Observing the Events

These grazing occultations will be difficult to observe. Ganymede has an apparent diameter of only 1.6" during this time. It remains to be seen whether any meaningful use can be made of these phenomena. Perhaps some use can be made of the fact that Jupiter's atmosphere near the poles is transilluminated by bright reflected sunlight for quite a while. Using a methane band filter is highly recommended, to improve the contrast between Jupiter and Ganymede, or even to make a successful observation possible at all. To further improve the observations, a camera with good sensitivity in the near-infrared range will be helpful.

References

[1] Dill, A., Steyaert, C., Hemelkalender 2023, Vereniging voor Sterrenkunde, https://www.vvs.be/over-vvs/hemelkalender

[2] IMCCE – MULTISAT - Ephemerides of planets and natural satellites. http://nsdb.imcce.fr/multisat/nssephme.htm

[3] JPL Horizons System, https://ssd.jpl.nasa.gov/horizons/

2023	Smallest distance Ganymede-Jupiter (UT)	Magnitude	Night sky visibility
Sep 11	01^h20^m	0.95	Europe, Africa, W. Asia, E. Canada, E. South America
Sep 18	04^h55^m	0.89	W. Europe, W. Africa, North and South America
Sep 25	08^h24^m	0.86	North and South America
Oct 2	11^h50^m	0.83	E. Asia, E. Australia, N. America except E. part
Oct 9	15^h12^m	0.84	Asia, Australia
Oct 16	18^h31^m	0.87	Asia, Australia, Europe, Africa except W.
Oct 23	21^h48^m	0.92	Asia except far E., Europe, Africa

Table 1. List of superior conjunctions where Ganymede remains partially visible. The magnitude is the maximum occulted part of the diameter of Ganymede, in units of its diameter.
Derived from IMCCE [2] and JPL Horizons [3] data.

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Camera Sensitivity Comparison - DVTI+CAM 174, DVTI+CAM 430, WAT-902H2 Ultimate

Andreas Schweizer · SOTAS · IOTA/ES · Wettswil · Switzerland · aschweiz@mac.com
Stefan Meister · SOTAS · IOTA/ES · Eglisau · Switzerland · meister@dolphins.ch

ABSTRACT: For a long time, CCD cameras were used for the observation of stellar occultations. A common setup was and still is an analogue camera with external video time inserter (VTI box) and frame grabber. In recent years, observers started switching to cameras with CMOS sensors. In this article, we compare the sensitivity of the recent third-generation Sony Pregius CMOS sensors to the first-generation and to a Sony ICX429ALL CCD sensor in an analogue camera.

Introduction

Since the great progress in the development of CMOS image sensors in recent years, several companies have abandoned the production of CCD sensors. Sony was the first company to fully switch to CMOS in 2017, followed in 2020 by On Semiconductor, which had taken over the Kodak and Truesense Imaging sensors (KAF, KAI, KAE) a few years before. Only a few suppliers are still manufacturing CCD sensors today, for example Teledyne e2v based in the United Kingdom and Hamamatsu in Japan. The lack of affordable CCD sensors has triggered a switch to cameras with CMOS sensors in the occultation community.

A CMOS camera usually transmits the image data digitally via a USB connection. It's no longer easily possible to insert the time signal into the data stream between the camera and the computer, as was done with the VTI box for analogue cameras. In addition, all such solutions would suffer from non-deterministic delay of the data packets in the USB driver software. In order to achieve a high repeatable accuracy of the image time stamp, it should be inserted into the data stream directly in the camera. Only a few cameras support this functionality at this time.

A widely-used camera with time insertion is the QHY174M-GPS from the Chinese manufacturer QHYCCD [1]. Other cameras with digital time insertion which have recently become available are the DVTI+CAM 174 and DVTI+CAM 430 [2] developed by members of the Swiss SOTAS community [3]. The QHY174M-GPS and DVTI+CAM 174 cameras both use the IMX174 image sensor from Sony's first-generation Pregius (global shutter sensors) introduced in 2013 [4]. The DVTI+CAM 430 camera uses the newer IMX430 sensor from the third Pregius generation [5].

This article documents the results obtained by the DVTI+CAM development team when comparing the sensitivity of the CMOS cameras DVTI+CAM 174 and 430 and the CCD camera Watec WAT-902H2 Ultimate. In particular, the goal was to gain insight into how the DVTI+CAM 430 camera with a third-generation Sony Pregius CMOS image sensor compares to the camera with a first-generation sensor and to a classic Watec CCD camera in our possession.

It is important to note that the WAT-902H2 Ultimate used in this test is not the most sensitive camera from Watec used for occultation work. IOTA/ES member Christian Weber has compared the more sensitive Watec WAT-910HX-RC camera with a QHY174M-GPS camera and a prototype of the DVTI+CAM 174 and presented his results at ESOP 39. The result regarding sensitivity was that the stellar limiting magnitude for the QHY174M-GPS and DVTI+CAM 174 cameras is about the same and between 0.5 and 1 mag worse than the Watec camera, depending on the configuration. His presentation is available as a PDF document on the web [6].

Method and Material

Three camera models have been tested, including a Watec WAT-902H2 Ultimate with a Sony EXview HAD ICX429ALL interline CCD sensor, a DVTI+CAM 174 with a first-generation Sony Pregius IMX174LLJ-C global shutter CMOS sensor, and a DVTI+CAM 430 with a third-generation Sony Pregius IMX430LLJ-C global shutter CMOS sensor. All three cameras have no active cooling, which is generally not an issue as the dark shot noise is rarely the dominant noise source at sub-second exposure times most often used for occultation work.

The DVTI+CAM 174 and 430 look nearly identical from the outside, with the only difference being the image sensor, which is slightly larger on the DVTI+CAM 174. The camera body is an 8 cm long cylinder made of anodised aluminium with an outer diameter of 2 inches, through which the heat is dissipated to the surroundings. It can be inserted directly into 2-inch focusers and contains 2-inch and M42 inner threads for filters and 1.25-inch adapters (Figure 1).

Figure 1. DVTI+CAM front view (left), with the CMOS image sensor as well as 2-inch and M42 inner threads. The rear view (right) shows the antenna connector which supports active and passive antennas for GPS, Galileo, Glonass and Baidou. The camera gets power and provides data via the USB-C connector at a maximum of 5 Gb/s.

An SMA connector for an active or passive GPS antenna and a USB-C connector for power and data are on the back of the camera, along with two LEDs, one to indicate the camera status and a second one to show the 1PPS signal. The satellite receiver module in the camera is a u-blox MAX M8C module with support for parallel reception of GPS, Galileo, Glonass and Baidou constellations.

The Watec WAT-902H2 Ultimate hardware switches were set to AGC high, gamma off, shutter 8, BLC 123 all off (bottom position) during the test.

Table 1 lists the main technical features of the three tested cameras:

One aspect that leads to good sensitivity of a camera is the quantum efficiency (QE) of the image sensors. With a higher QE, more of the incident light can be converted into charge at a given wavelength. Figure 2 shows the QE graphs of the image sensors used in the tested cameras, as specified in the technical data sheets of the sensors. The data sheets are not publicly available.

A second important prerequisite for detecting faint stars is low readout noise. The readout noise of the third-generation Pregius sensors has been halved from 5 e- to 2.5 e- compared to the first-generation [7].

Optimal settings were used for all cameras, as if an observation of stellar occultations were imminent. Both DVTI+CAM cameras

Camera	**WAT-902H2 Ultimate (CCIR version)**	**DVTI+CAM 174**	**DVTI+CAM 430**
Sensor	Sony ICX429ALL	Sony IMX174LLJ-C	Sony IMX430LLJ-C
Shutter	Interline	Global	Global
Integration	Fixed (40ms)	20 ms to 5 s unbinned* 13 ms to 5 s binned*	23 ms to 5 s*
Cooling	Passive	Passive	Passive
Pixels	752 x 582	1920 x 1200	1624 x 1240
Pixel size	8.6 µm x 8.3 µm	5.86 µm x 5.86 µm	4.5 µm x 4.5 µm
Resolution	8-bit	12-bit	12-bit

Table 1. Technical characteristics of the tested cameras. The Interline CCD technology works very similar to the global electronic shutters in a CMOS sensor, providing snapshots at a specific point in time. Integration time range of the DVTI+CAM models is limited by the firmware version at the time of this test; technical lower limits at full resolution are 11 ms (4 ms binned) for the IMX430 and 6 ms for the IMX174 (*).

Since the Watec camera's frame rate is fixed at 25 fps, the frame rate of the two DVTI+CAM models was adapted accordingly. For the Watec camera, the Terratec G1 frame grabber was used. Both DVTI+CAM cameras were set to 2 x 2 binning which has proven useful with the 50 cm telescope, as the light of the stars is typically spread across a large number of pixels. Binning results in a significantly reduced amount of data. It happens on the digital side, so the readout noise of the binned pixels is summed up. Note that technically, the IMX430 sensor supports vertical binning before pixel readout [5] which would reduce the noise, but this feature wasn't available in the camera firmware at the time of this test.

Both CMOS sensors support up to 24 dB of analog gain (before analogue-to-digital conversion), plus an additional 24 dB of digital gain (after analogue-to-digital conversion), in steps of 0.1 db.

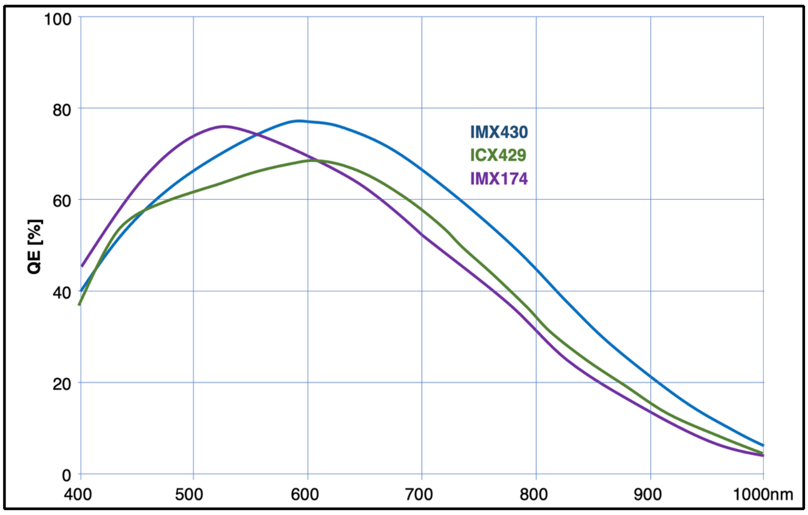

Figure 2. This plot shows the QE graphs (Quantum Efficiency as a function of wavelength) for the 3 image sensors in the tested cameras.

The analogue gain helps to reduce the impact of readout noise on the signal and thus improves the SNR. The digital gain, as it's applied only after readout of the analogue signal, brings no such advantage but simply upscales the pixel values in the digital domain, effectively reducing the dynamic range of the sensor.

The image sensors of the third Sony Pregius generation, to which the IMX430 belongs, contain an additional switch between low and high conversion gain (LCG, HCG) not available in the first generation. According to the technical sensor data sheet (not publicly available), the HCG mode increases the sensitivity of the sensor by a factor of 2.25 at the expense of dynamic range. It works on the analogue side, thus improving the SNR. The HCG mode was supported in the camera firmware at the time of the test and was active for all measurements with the DVTI+CAM 430.

All tests were performed on the night of 2023 January 15 at the *Bülach Observatory* with the 50 cm Newtonian/Cassegrain telescope in Newtonian configuration (Figure 3), [8]. With a focal length of 2.5 m, the focal ratio of the instrument is f/5.

The telescope was pointed at a region in the constellation Perseus, at an altitude of about 70 degrees. Four stars between 11th and 14th magnitude (target 0 to target 3) were selected for the measurement (Figure 4). The sky was clear with stable conditions and a little bit of wind. To compensate for seeing-related differences, short recordings were made and the cameras were changed several times during the test. In retrospect, this turned out to be unnecessary, since the analyses of the different recordings were consistent with each other for all cameras. Therefore, only the evaluations of selected recordings are presented, as shown in Table 2.

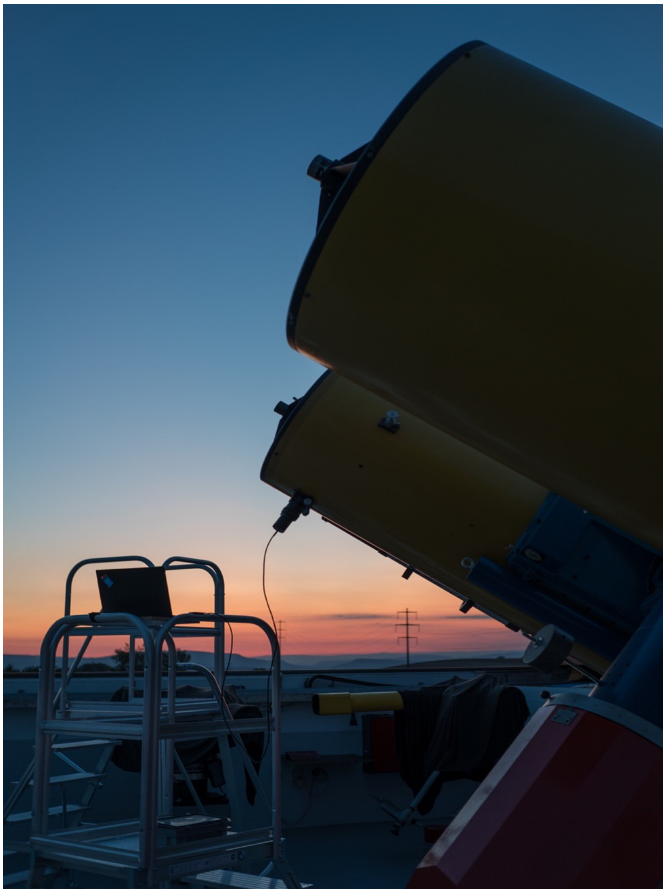

Figure 3. The telescope in the upper right corner of the image is Bülach Observatory's main instrument, an 85 cm Cassegrain reflector. For observing stellar occultations, the slightly smaller 50 cm Newtonian/Cassegrain telescope on the same mount is usually used. In the photo a DVTI+CAM is mounted at the Newtonian focus.

#	UTC	Camera	Format	Bits	Binning	Exp. Time	Gain
1	21:08:16	WAT-902H2 Ultimate	AVI	8	–	40 ms / 25 fps	–
2	20:44:45	DVTI+CAM 174	FITS	12	2 x 2	40 ms / 25 fps	24 dB
3	21:15:19	DVTI+CAM 430	FITS	12	2 x 2	40 ms / 25 fps	24 dB HCG

Table 2. The list shows the parameters of recordings 1 to 3 presented in this article.

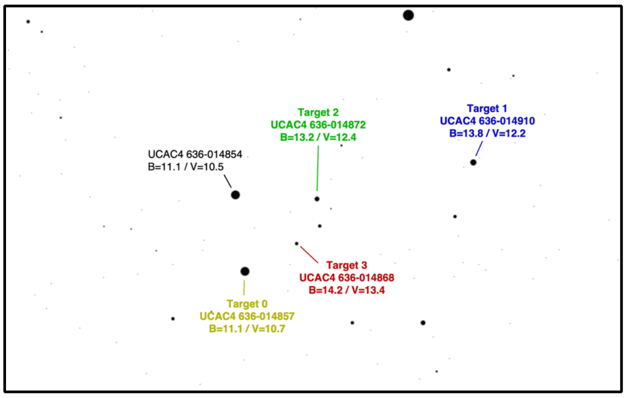

Figure 4. Star field for the sensitivity measurements, with the four selected target stars 0 to 3. Image centre at RA 3h 49m 52s, DEC +37° 02' 28", orientation N down, W left, field of view 15' in x-axis. The star field was about 70 degrees above horizon at the time of the recordings. The colour of the star labels correspond to the colour of the light curves in the PyMovie light curve images below. Source: C2A.

Recordings with the Watec camera were done with *VirtualDub*, version 1.10.4 [9], and the file format was 8-bit AVI. For the DVTI+CAM cameras, the dedicated camera control software *DVTI Cam Control* [10], version 5.5.2, was used to record 16-bit FITS series. Figure 5 shows a screenshot of the tool. The DVTI+CAM cameras work with standard software such as *SharpCap* [11], but some features such as the high conversion gain mode for the IMX430 sensor can only be enabled in *DVTI Cam Control*. In addition, *DVTI Cam Control* provides support for the occultation process such as integration with *OccultWatcher* for automated recording of events, plate solving, telescope control, automated SODIS report generation, on-the-fly dark, flat and noise processing and more.

For this article, the raw data of selected recordings have been analysed in *PyMovie* version 3.7.3 [12] as if the individual stars, target 0 to target 3, had been occulted.

Results and Discussion

On the single images of the Watec camera, significant noise is visible by eye (Figure 6a). The faint star target 3 isn't visible. To position the apertures in *PyMovie*, a finder image with 16 averaged frames was generated (Figure 6b). On the finder image, all target stars are clearly visible and the apertures can be placed.

The individual frames in recording 2 (DVTI+CAM 174) are less noisy than the images of the Watec camera, but the two fainter target stars are not recognizable (Figure 7a). In the finder image averaged over the first 16 individual frames of the DVTI+CAM 174 (Figure 7b), the two fainter stars start to appear. The faintest star 3 is still barely visible however.

On the individual frames of the DVTI+CAM 430 (Figure 8a), all target stars are visible without any problems. The image noise is lower than on the images of the DVTI+CAM 174 and the Watec. Placing the apertures succeeds without a finder image. For comparison purposes, Figure 8b includes a finder image from the first 16 frames of this recording.

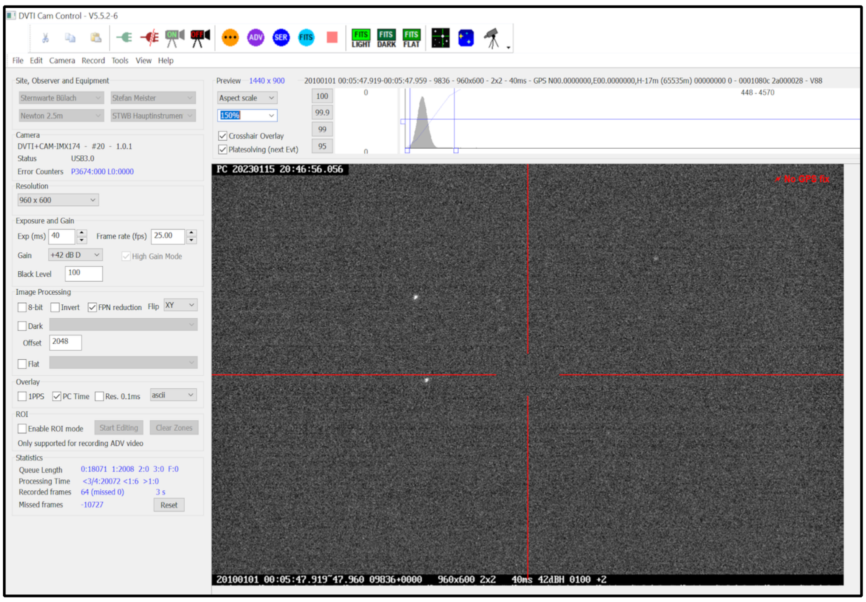

Figure 5. The main window of the DVTI Cam Control software used to create all DVTI+CAM recordings in this test.
The window is split into 3 areas. On the left side are the controls for the camera. A preview of the camera image appears in the preview zone at the bottom right of the window. Controls affecting the preview are above the preview zone.

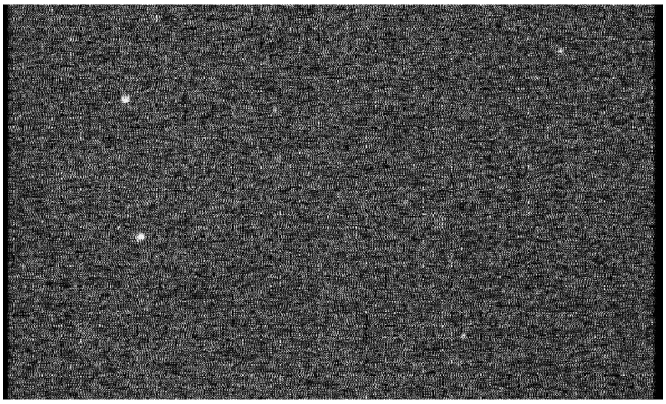

Figure 6a. Single frame from the Watec camera, recording 1.

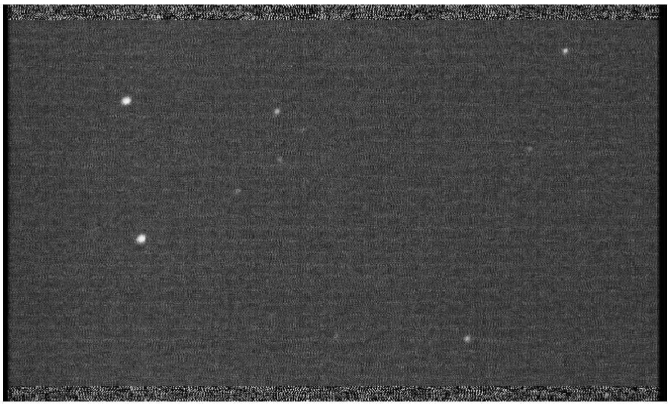

Figure 6b. Finder image, averaged from 16 individual frames recorded by the Watec camera in recording 1.

Figure 7a. Single frame from the DVTI+CAM 174, recording 2. The timestamp that appears at the bottom of the image is invalid because no GPS antenna was connected for the test.

Figure 7b. Finder image, averaged from 16 individual frames recorded by the DVTI+CAM 174 in recording 2. The red arrow points to the faint star target 3 which is barely visible even in this finder image.

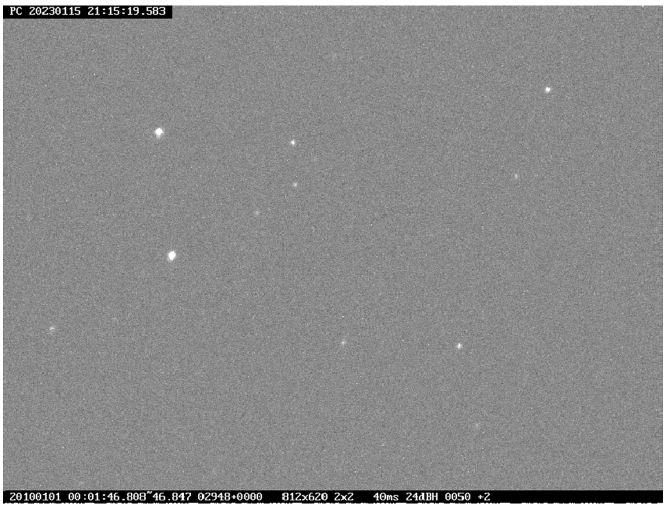

Figure 8a. Single frame from the DVTI+CAM 430, recording 3. All target stars are clearly visible.

Figure 8b. Finder image, averaged from 16 individual frames recorded by the DVTI+CAM 430 in recording 3.

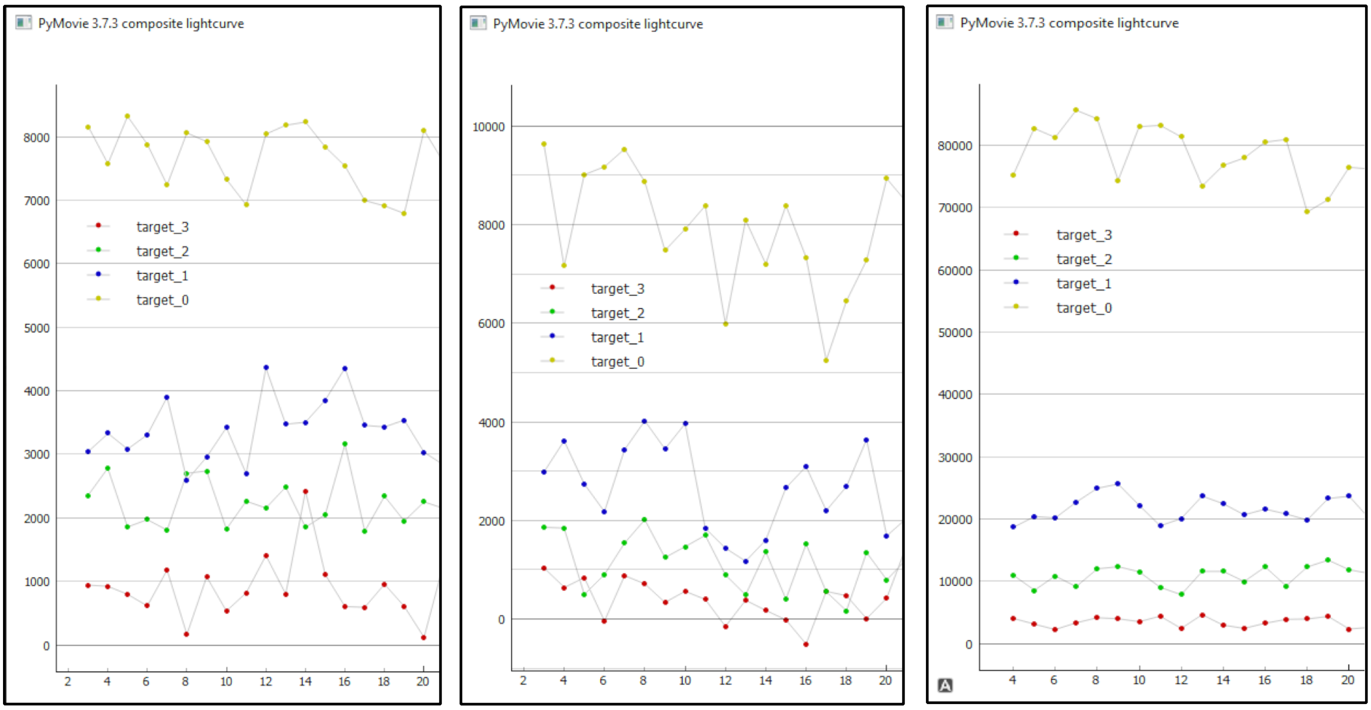

Figure 9a - 9c. Extract from the PyMovie light curves of the three evaluated recordings. The recordings are, from left to right, #1 (Watec), #2 (DVTI+CAM 174), #3 (DVTI+CAM 430).

Figures 9a to 9c show for each camera the light curves of the four target stars, as calculated in *PyMovie*. The aperture was reduced to 31 pixels for all stars and recordings. Mask thresholds proposed by *PyMovie* (2σ above background) and mask radius 3.2 have been used. Target star 1 was selected as the guiding star for all recordings. To make the light curves easy to compare to each other, only 50 frames at the beginning of each recording are included in the *PyMovie* analysis.

All results have been exported as CSV files in *PyMovie* and summarised by calculating the average and standard deviation for each light curve, in digital units. Table 3 shows the results of these calculations.

Some pixels were saturated for the bright star target 0 in the recording 1 taken with the Watec camera. Consequently, this star appears too dark compared to the next fainter star target 1 in the evaluation of the Watec measurement.

To make it easier to compare the values in Table 3 with each other, the data in the table has been normalised to a value of 5,000 DU for target star 1 and plotted as a bar graph diagram in Figure 10. For each bar, the ±1σ limits of the noise in the corresponding light curve is shown as a light-grey rectangle.

	Star	**Target 0**		**Target 1**		**Target 2**		**Target 3**	
	B	11.1 mag		13.8 mag		13.2 mag		14.2 mag	
	V	10.7 mag		12.2 mag		12.4 mag		13.4 mag	
#	**Camera**	**μ [DU]**	**σ [DU]**	**μ [DU]**	**σ [DU]**	**μ [DU]**	**σ [DU]**	**μ [DU]**	**σ [DU]**
1	WAT-902H2 Ultimate	7,462*	535*	3,290	545	2,139	529	916	534
2	DVTI+CAM 174	8,254	1,046	2,632	788	1,055	537	655	361
3	DVTI+CAM 430	77,068	4,902	21,401	1,889	11,021	1,803	3,133	708

Table 3. For all four target stars 0 to 3, this table shows the apparent magnitudes of the star in the blue (B) and visual (V) bands, together with the aggregate values μ (average intensity) and σ (intensity standard deviation) of the light curves (figures 9a to 9c) in each recording, in digital units (DU). Details about the camera configuration for each recording are provided in table 2. Note that the target star 0 was overexposed in recording 1 (*).

All stars in recording 1 (WAT-902H2 Ultimate) produce a clear signal, although the level varies considerably from image to image. For the faintest star target 3, detection of a brightness drop would be difficult depending on magnitude and duration of the drop.

The *PyMovie* light curves for recording 2 (DVTI+CAM 174) can detect the two faint stars, but clearly identifying a short stellar occultation over a few frames would probably not be possible.

The light curves for recording 3 (DVTI+CAM 430) reflect the good signal and low noise levels of the recording. For the two faint stars target 2 and 3, shorter and fainter occultations could be evaluated than with the other two cameras.

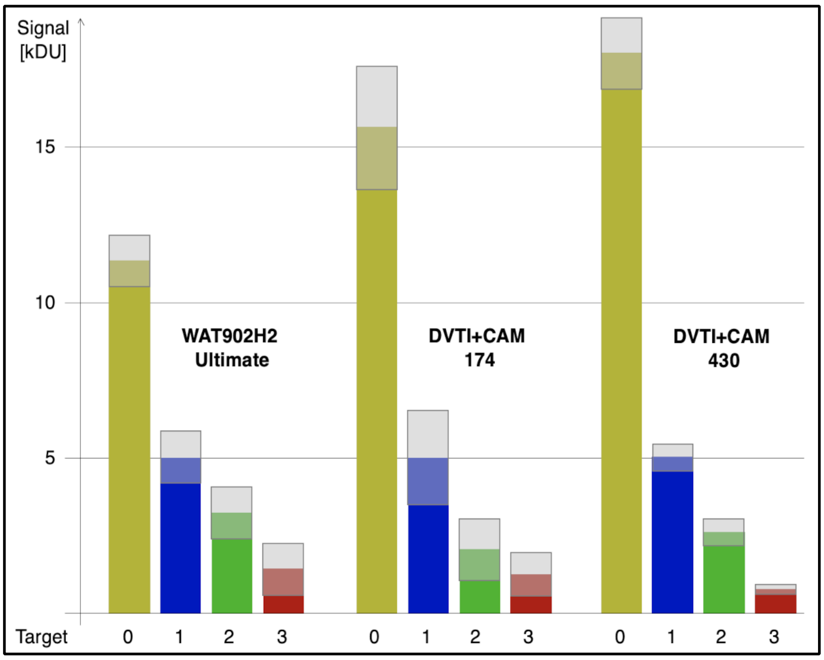

Figure 10. Average and standard deviation of all light curves for each camera. Each recording has been normalized for a value of 5 kDU for target star 1. For each light curve, the ±1σ bounds are shown as a light-grey rectangle. Colours correspond to the light curve colours in Figures 9a to 9c.

Summary

Our measurements show that the sensitivity of first-generation Sony Pregius CMOS image sensors is slightly lower compared with the best CCD sensors used in the past. This disadvantage is often offset by the advantage of easier and more convenient handling of these cameras, as neither a separate frame grabber device nor a VTI box are needed. Depending on the connection technology, the additional external power supply can be omitted and software specifically tailored to the recording of stellar occultations, such as SharpCap or DVTI Cam Control, is available to support the observation process.

Sony's third-generation Pregius sensors offer observers of stellar occultations a significant improvement over the first generation. Thanks to lower image noise, approximately half the readout noise and high quantum efficiency, these sensors catch up with or even overtake the sensitivity of the Watec WAT-902H2 Ultimate camera.

Which camera is superior in a particular case is difficult to predict as it depends not only on the image sensor model but also on various other factors. For example, different frame grabbers used with analogue cameras may introduce different levels of noise, the spectral class of the star might match one camera's QE graph better than that of another camera, the camera electronics adds different amounts of noise to the image e.g., due to the noise of the sensor power supply, and the series dispersion within the individual sensor families might result in more or less sensitive sensors. And very often, of course, seeing is the limiting factor.

And the development continues. In the consumer sector, a newer Pregius generation is already available from Sony, and very sensitive scientific CMOS sensors (sCMOS, scientific CMOS) are becoming more affordable. Observers of stellar occultations will certainly benefit from this technological progress.

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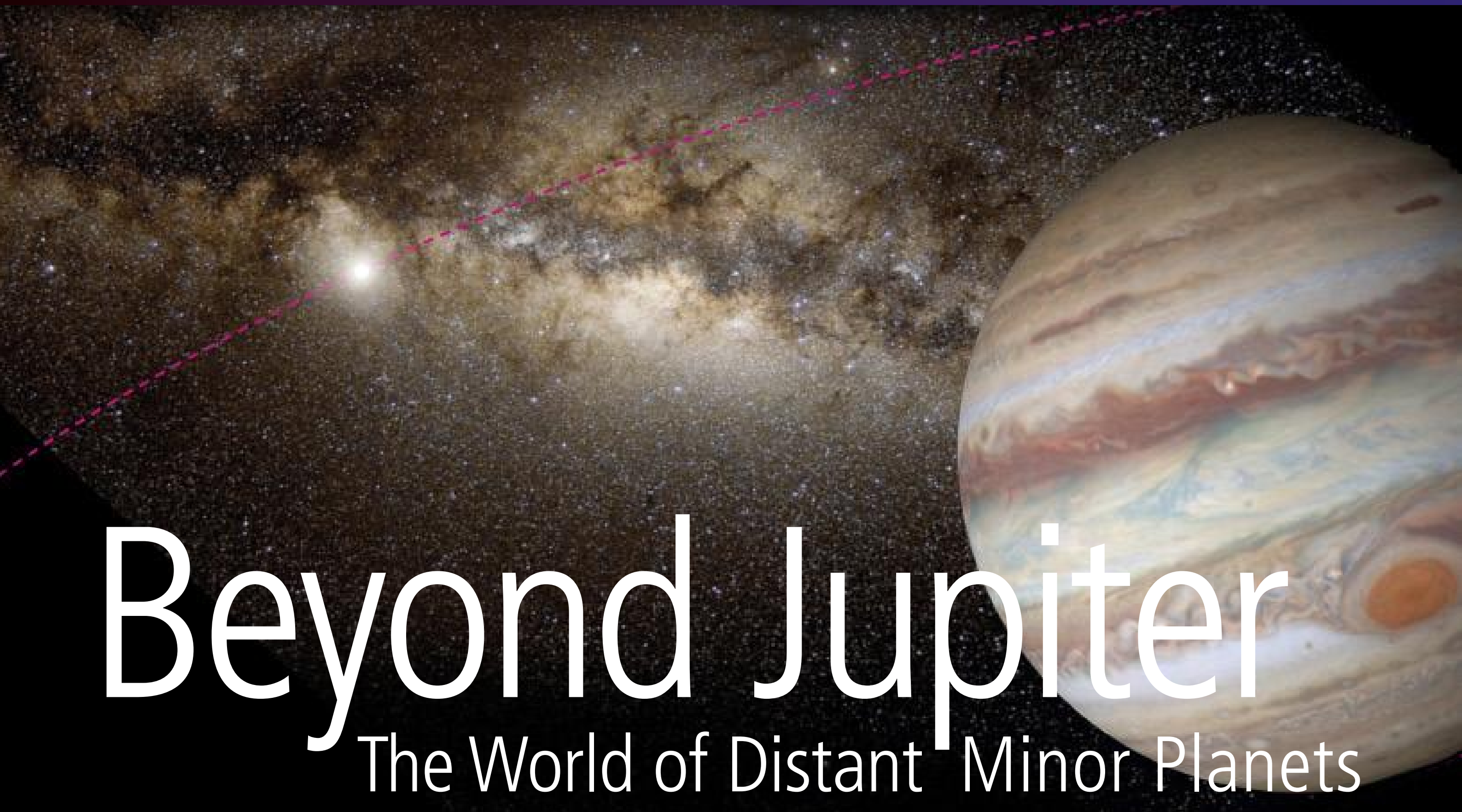

Beyond Jupiter

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 2023 June 26, the *Minor Planet Center* listed 1535 Centaurs and 3109 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
5335	Damocles	Oliver Klös	JOA 2 2023
8405	Asbolus	Oliver Klös	JOA 3 2016
10370	Hylonome	Konrad Guhl	JOA 3 2021
10199	Chariklo	Mike Kretlow	JOA 1 2017
15760	Albion	Nikolai Wünsche	JOA 4 2019
15810	Awran	Konrad Guhl	JOA 4 2021
20000	Varuna	Andre Knöfel	JOA 2 2017
28728	Ixion	Nikolai Wünsche	JOA 2 2018
32532	Thereus	Konrad Guhl	JOA 1 2023
38628	Huya	Christian Weber	JOA 2-2021
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

In this Issue:

(486958) Arrokoth

Julia Perła · Adam Mickiewicz University · Poznań · Poland · julia.perla@outlook.com

ABSTRACT: (486958) Arrokoth is a Cold Classical Kuiper Belt Object discovered in 2014. The object was visited by the *New Horizons* space probe on 2019 January 01. The close flyby near (486958) Arrokoth allowed the determination of composition, density, dimensions (including diameters of lobes and the whole body), surface colour, albedo, geological topography, and many other physical properties. It is the furthest object ever studied in situ by a space probe. Several major stellar occultation campaigns were conducted in 2017 and 2018. Stellar occultation data proved to be extremely significant in planning missions to (486958) Arrokoth.

No.	Name	Author	Link to Issue
60558	Echeclus	Oliver Klös	JOA 4 2017
90377	Sedna	Mike Kretlow	JOA 3 2020
90482	Orcus	Konrad Guhl	JOA 3 2017
120347	Salacia	Andrea Guhl	JOA 4 2016
134340	Pluto	Andre Knöfel	JOA 2 2019
136108	Haumea	Mike Kretlow	JOA 3-2019
136199	Eris	Andre Knöfel	JOA 1 2018
136472	Makemake	Christoph Bittner	JOA 4 2018
174567	Varda	Christian Weber	JOA 2 2022
208996	2003 AZ_{84}	Sven Andersson	JOA 3 2022
341520	Mors-Somnus	Konrad Guhl	JOA 4 2022
-	2004 XR_{190}	Carles Schnabel	JOA 1 2022

The Discovery

(486958) Arrokoth was discovered by Marc Buie on 2014 June 26, as a result of searching for an extra, post-Pluto target to be visited by the *New Horizons* spacecraft. The detection of this Kuiper Belt Object was made with the *Hubble Space Telescope* (HST). Having a mean R magnitude of 27, it is worth adding that (486958) Arrokoth was at the limit of capability of HST and there was no chance to detect this object from ground-based telescopes [1, 2, 3, 4].

The Name

Initially, the transneptunian object was given a provisional designation 2014 MU_{69}. Based on a plebiscite conducted by NASA and the SETI Institute in 2018, the object was named Ultima Thule, which means "beyond Thule – beyond the borders of the known world" [5]. However, the new name of this object aroused strong controversy. Newsweek published an article criticizing the name "Ultima Thule", due to the association of the word "Thule" with the Nazis [6]. Due to this situation, the International Astronomical Union decided to change the name of the object to (486958) Arrokoth. The new name was proposed by the *New Horizons* team. Arrokoth is a Powhatan word of the indigenous American Algonquian people, meaning the sky [7].

Orbit and Classification

(486958) Arrokoth is a Cold Classical Kuiper Belt Object (CCKBO) [8]. Its orbit (Figure 1) is almost circular, with a semi-major axis of 44.520 au. Arrokoth's distance from the Sun changes between 42.572 au and 46.469 au. The inclination to the ecliptic is low and amounts to 2.446 degrees [1]. (486958) Arrokoth orbits the Sun in 296.069 years [9].

Since (486958) Arrokoth was the target of the *New Horizons* mission, its orbit had to be determined with the best precision possible. By analysing HST Wide Field Camera 3 (WFC3) images using the appropriate pipeline and pre-release versions of the ESA Gaia Data Release 2 (DR2) catalogue, it was possible to determine the orbit so accurately that in July 2017 a stellar occultation was correctly predicted [10]. Subsequent observations of four stellar occultations helped significantly improve the object's orbit [2].

Physical Characteristics

(486958) Arrokoth is an icy contact binary with a maximum dimension of 36 km. It consists of two lobes named Wenu (22 km at the longest axis) and Weeyo (14 km at the longest axis) [8]. Wenu's shape is more lenticular than Weeyo's, which is more equidimensional [8]. (486958) Arrokoth's period of rotation was calculated to be 15.9380 hours, based on analysis of *New Horizons* approach images and stellar occultation data [2].

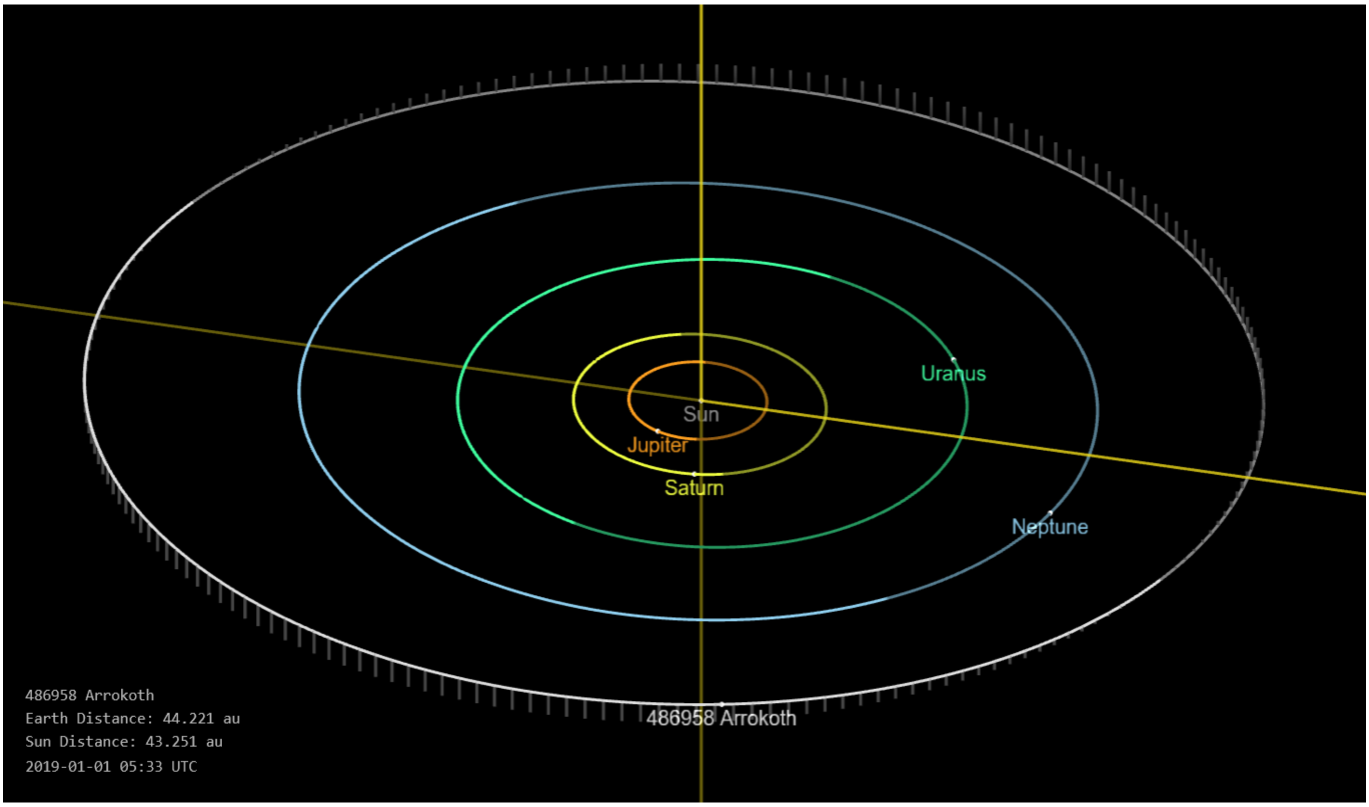

Figure 1. Orbit of (486958) Arrokoth at the time of New Horizons flyby on 2019 January 01 [9].

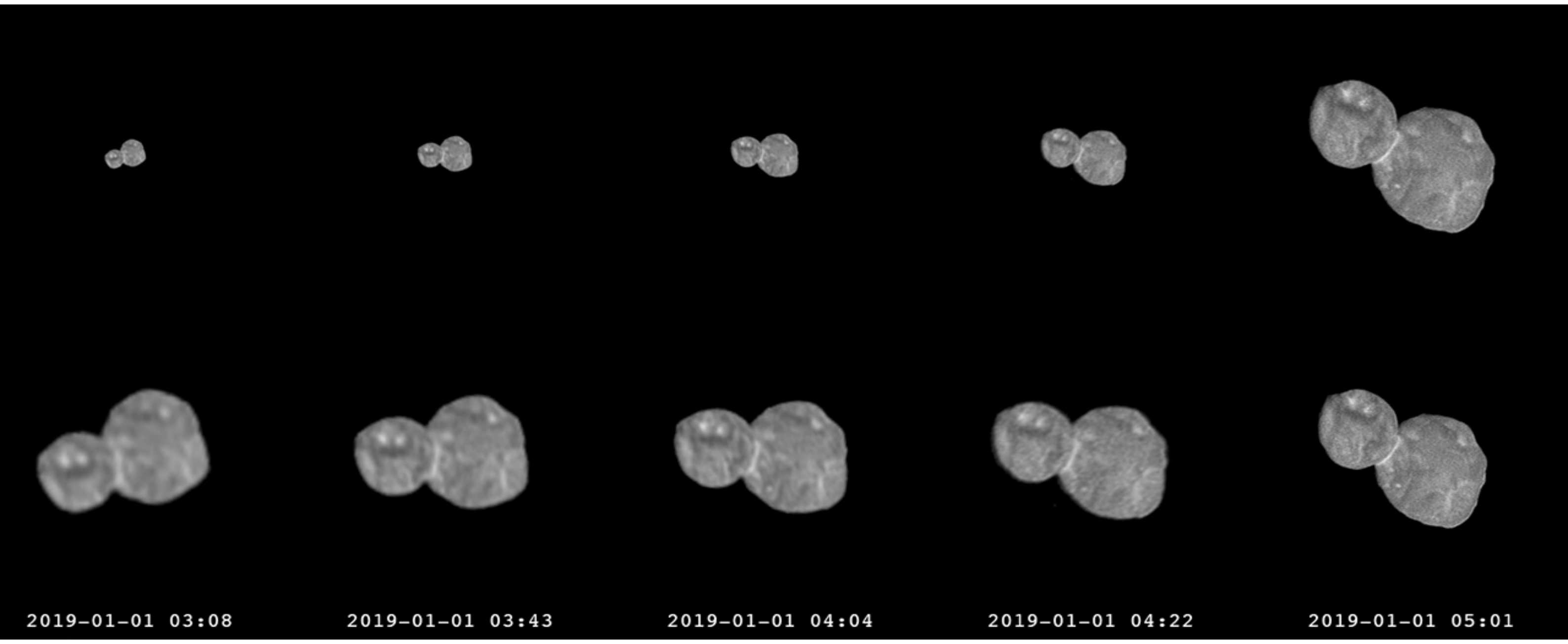

Figure 2. Images of (486958) Arrokoth made with the Long Range Reconnaissance Imager (LORRI) onboard New Horizons. Source: NASA/Johns Hopkins University Applied Physics Laboratory/Southwest Research Institute https://solarsystem.nasa.gov/resources/2245/new-horizons-arrokoth-2014-mu69-approach/

Determining mass and density for (486958) Arrokoth is problematic. The *New Horizons* flyby was too distant and had too much speed to determine the object's mass by measuring the spacecraft trajectory perturbations [11]. Moreover, no natural satellite was found in (486958) Arrokoth's Hill sphere. That would be the second option to calculate the mass and consequently the density of the object [8]. Due to the lack of satellite and gravity data from the flyby, scientists were forced to determine the density of the object based on geophysical inferences [11]. The density of (486958) Arrokoth is around 500 kg/m^3 and is similar to cometary material. Its internal structure is most likely porous [8].

The geometric albedo of (486958) Arrokoth is 0.16 ± 0.01 [8] which is typical for CCKBOs [12]. The albedo is not homogeneous and varies between the object's regions. As a typical CCKBO (486958) Arrokoth is more reddish than a typical KBO according to spectral analysis. Differences in colours on the surface of two lobes and a neck are subtle [8]. The neck is bluer than the lobes and the smaller lobe is redder than the larger one [13]. The colour difference may be due to the different compositions, but this effect may also be caused by differences in particle size, porosity, etc. Based on the spectra from the Linear Etalon Imaging Spectral Array (LEISA), the surface of (486958) Arrokoth was found to contain methanol, hydrogen cyanide, water ice, tholins, and other complex organic compounds [8].

There are seasonal and diurnal temperature changes near the surface of (486958) Arrokoth. The differences in insolation between perihelion and aphelion are minor, due to the low eccentricity of the orbit, and amount to 17%. (486958) Arrokoth experiences polar days and nights as a consequence of the very small inclination of the spin axis. Polar days and nights are extremely long because of the orbital period [8].

(486958) Arrokoth's surface is divided into regions of varying brightness and topography. The surface is full of pits, craters, and mounds. The biggest depression is called Sky (previously Maryland) and is located on the smaller lobe. Its depth is 0.51 km and its diameter is 6.7 km [14]. The Sky feature was most likely caused by a collision with another body [8]. (486958) Arrokoth has only a few small craters on its surface. Based on the data collected by *New Horizons*, including images of (486958) Arrokoth, it was concluded that there are fewer small objects (less than ~1 km in diameter) in the Kuiper Belt than in the asteroid main belt and collisions in the Kuiper Belt were less frequent [15].

Past Stellar Occultations

Observing a stellar occultation by such a tiny and distant body as (486958) Arrokoth was an extreme challenge. However, results from stellar occultation campaigns provided crucial information about the target body of the *New Horizons*, such as improving astrometric data, searching for material around (486958) Arrokoth, and determining the shape of a body. Fortunately, in 2017 and 2018, following an initial attempt, three successful occultation campaigns were carried out [2].

The first attempt to observe an occultation by (486958) Arrokoth took place on 2017 June 03. The predictions of stellar occultations were based on HST and *Gaia* DR2 data. The shadow path was very difficult to predict due to relatively poor orbital data and not entirely known (486958) Arrokoth diameter. In the campaign, observers were located in South America and Africa. Unfortunately, none of the stations detected a decrease in brightness that could have indicated the occultation [2].

The first fully successful campaign was on 2017 July 17. This was achieved thanks to new HST data that refined the orbit of (486958) Arrokoth. The occulted star was the brightest compared to other observations in 2017. Almost all of the stations collected useful data, with the telescopes located in southern Argentina and Chile. There were five positive observations for this event. The results showed that the shape of (486958) Arrokoth is more complicated than a simple ellipsoid and appears more like a contact binary object (Figure 3). A second solution was to assume that the occultation happened during a mutual event between two closely orbiting bodies and just looked like a contact binary due to the projection effect. Moreover, the option of a very irregular shape for (486958) Arrokoth was also considered [2].

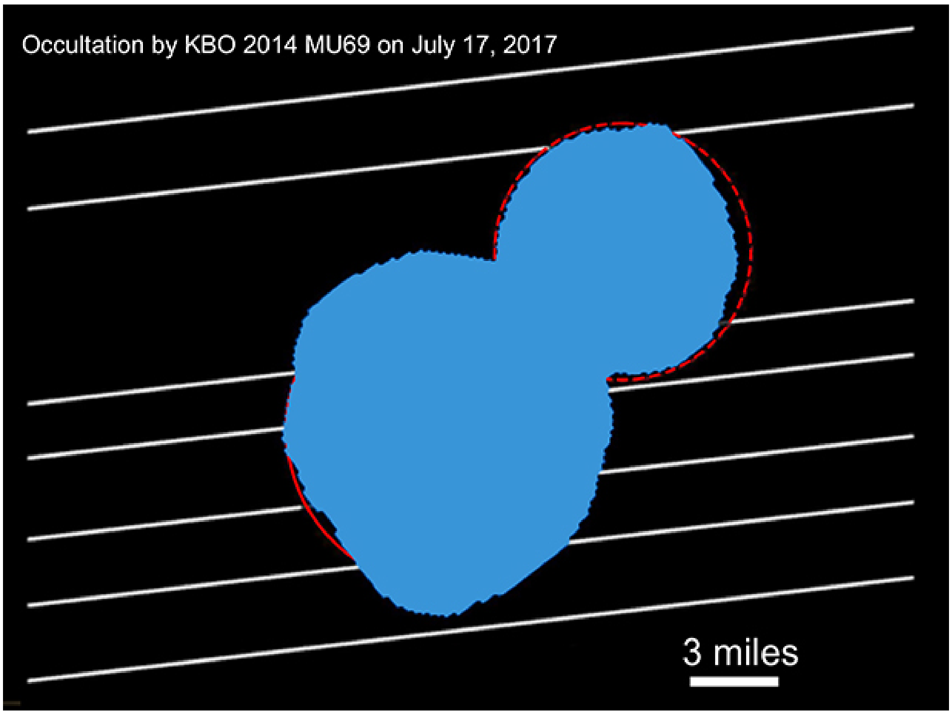

Figure 3. Results from the stellar occultation campaign on 2017 July 17, 1.5 years prior to the New Horizons flyby.
Source: NASA/Johns Hopkins University Applied Physics Laboratory/ Southwest Research Institute,
http://pluto.jhuapl.edu/News-Center/Press-Conferences/index.php? page=2019-01-02

The last occultation event before the *New Horizons* flyby was on 2018 August 04. Stations for this event were located in northern Sénégal and central Columbia. The weather was a challenge for the observers, as the observations were made during the rainy season. The campaign had two positive results and one unambiguous miss. Plotted chords from observations indicated that (486958) Arrokoth is more likely a contact binary. In addition, the results helped significantly in improving astrometry and refining the orbit of (486958) Arrokoth [2]. During this occultation, the object was also observed through the HST, which was much further from the shadow path. HST did not detect any decreases in brightness, so it was clear that there are no hazardous rings or debris up to 1,600 km from (486958) Arrokoth [16].

By combining all the results of the observations, it was possible to determine the approximate size and shape of the TNO and classify it as a contact binary. Conducted campaigns and their results were "a new pathway for understanding the Kuiper Belt" [2]. The combination of data from stellar occultations, HST, and *Gaia* DR2 contributed greatly to the success of the *New Horizons* flyby [2].

Conclusion

(486958) Arrokoth is a 36 km body that shows characteristics typical for CCKBOs. The class of these objects is extremely interesting because it is believed that they are relics of the formation of the Solar System's outer regions. Also noteworthy is the shape of (486958) Arrokoth, which consists of two lobes and a neck. This shape was probably created by the slow-velocity merger of two bodies. The *New Horizons* flyby provided a wealth of information about the structure, composition, and many other physical properties of (486958) Arrokoth. It is worth stressing that the observations of the stellar occultations brought a lot of valuable information, without which the mission could have failed.

Acknowledgement

Many thanks to Anna Marciniak for her help with editing the article.

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Further Reading

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IOTA/ES Presents Citizen Science at 24-Hour-Lecture

Image: Zan Vidmar Zorc

The Students' Union Executive Committee (German: Allgemeiner Studierendenausschuss (AStA)) of the University Greifswald, Germany, organised a 24-hour-lecture at their premises on 2023 June 23/24. From Friday afternoon till Saturday afternoon more than 30 scientists presented in three lecture rooms highlights from their research work in the German language. At times it was possible to choose from three parallel lectures, and even at night there was always something interesting to learn. Additionally, a dinner and breakfast were offered from the AstA.

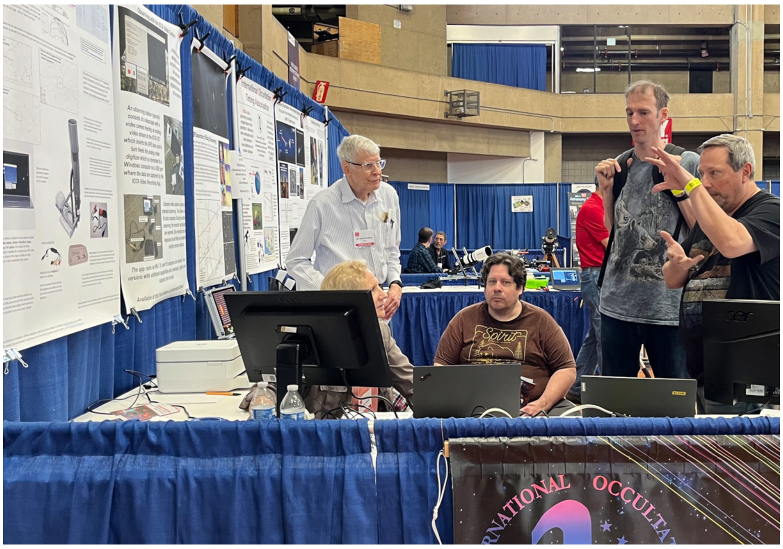
IOTA/ES was present with a lecture „Citizen Science – Exploring the Bodies of the Solar System with Occultation Observations" held by K. Guhl. 20 students followed the lecture and asked interesting questions.

Programme of the 24-hour-lecture:
https://stud.uni-greifswald.de/kultur-und-beratung/veranstaltungen/24-stunden-vorlesung/

Konrad Guhl
President IOTA/ES

IOTA at NEAF

IOTA participated in the 32nd *North East Astronomy Forum and Space Expo* (NEAF 2023, www.neafexpo.com), an annual event hosted by the Rockland Astronomy Club on April 15 & 16 at the SUNY Rockland Community College in Suffern, New York. This restarted the annual inperson meeting series after three years of cancellations or on-line only events due to COVID restrictions.



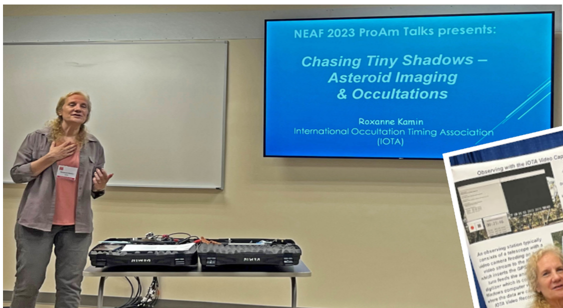
Visitors at the booth of IOTA. David Dunham (left) & Roxanne Kamin (at the computer) answer questions.

In addition to two days of lectures and workshops, NEAF includes a large display of vendors, clubs, schools, government agencies, all astronomy-related or supporting astronomical activities. IOTA was one of those vendors, with a double display booth providing ample space for posters and videos on occultation observing techniques. We had an active SEXTA box (popular with people taking test photos with their smart phone), along with several telescopes and laptops providing a hands-on display of our observing software and how to use it. A standard feature at NEAF is the ProAm lecture series where this year, IOTA member Roxanne Kamin gave a talk on "Chasing Tiny Shadows – Asteroid Imaging & Occultations".

Seven IOTA members were on-hand to support the booth: David and Joan Dunham, Ted and Peggy Blank, Steve and Cindy Conard, and Roxanne Kamin. It was a full and fun weekend offering time to visit with astronomy friends and to check out the latest in amateur astronomy equipment.

Copies of our posters and flyers are available at occultations.org/publications/NEAF_2023

Joan Dunham
IOTA Secretary & Treasurer



Roxanne Kamin presents her ProAm talk.

Peggy Blank (left) at the booth.

Roxanne Kamin, David Dunham, Ted Blank

Cindy & Steve Conard

Joan & David Dunham

IOTA/ES Round Table - A New Step in Communication

Introduction

Local astronomy clubs have a decisive advantage over a worldwide association. The members can meet regularly at an informal meeting in the clubhouse to exchange ideas, prepare joint observations or solve problems. This form of communication is only possible to a very limited extent in our community, as our members are usually widely scattered. But since the digital push during the pandemic, there are new possibilities.

How We Communicate Today and in the Future

In our worldwide community, mailing lists such as PLANOCCULT or IOTAoccultations are the platforms for an exchange across national borders and oceans. But this form of communication is time-consuming and slow. Verbal communication within the community is much more efficient and faster.

When the board of IOTA/ES considered last year which services could be offered to members of IOTA/ES, a regular meeting via the *Zoom* access of IOTA/ES was an option. Thus, the idea was born to move the exchange of ideas on current hot topics from the mailing lists to a *Zoom* meeting. Problems, whether of a technical nature or in setting up software, can thus be solved quickly without having to send e-mails back and forth.

The round table is intended for a spontaneous exchange of ideas. It is therefore not a platform for lectures or tutorials. For example, there are special meetings for evaluators and participants of the SODIS programme.

The round tables will not replace ESOP or other annual meetings in any way. Nor can the round table be a substitute for face-to-face meetings, but it does allow members to get to know each other much better. This is especially important for newcomers to the association.

Who Can Join the Roundtable?

The round table is open to all members of IOTA/ES. There is no obligation to attend, the meeting can be entered and left at any time. It is explicitly desired that participants spontaneously contribute topics. The screen can be shared by all participants e.g., to show occultation videos, maps and light curves. Please, no complete lectures. We have our annual meetings for that.

The new IOTA/ES logo for virtual meetings.

The First IOTA/ES Round Table

The Board of IOTA/ES organised the first round table on 2023 June 4th at 18 UT. In order to arouse interest, a few topics were given in the invitation as a basis for discussion. Among them was the occultation highlight of 2023, the occultation of Betelgeuse by (319) Leona on December 12th across southern Europe. This special topic also attracted members of IOTA on the other side of the Atlantic, so that more than 20 participants were present at this first meeting.

The two hours of this virtual meeting were moderated by Konrad Guhl. IOTA/ES members Claudio Costa and Carles Schnabel presented plans for observation campaigns. The participants discussed to what extent local groups, such as schools and the general public, could be involved in the observation. The large uncertainties in the path position and the unknown decrease in magnitude during the very short occultation play a major role. A rough timetable for preparations was drawn up. Terry Redding (IOTA) showed on a map the possible shadow path over the Florida Keys in the US.

It was somewhat difficult to follow the verbal discussion and the exchange in the chat at the same time. A solution still needs to be found here.

Although the discussion about the (319) Leona occultation took up the entire time of the meeting, there were also spontaneous topics. Jan Maarten Winkel (IOTA/ES) had a problem with his frame grabber after a *Windows* update. Ted Blank (IOTA) from the US was able to help him spontaneously with a replacement device. It was a matter of a few minutes - problem solved without sending e-mails back and forth. The round table was set up precisely for such cases.

At the end of the first round table, the participants agreed that this form of communication should be continued regularly. Konrad Guhl suggested a bi-monthly interval, always on the evening of the first Sunday (European time).

As the exchange of ideas across the Atlantic worked so well at this first meeting, the participants decided that invitations to future round tables should go not only to members of IOTA/ ES but also to IOTA.

Individual guests i.e., non-members, are welcome at the round table and can be invited by a member if they can contribute content to the topics.

An exchange with our partner organisations in Asia and Oceania is desirable, but difficult due to the time shift, as the round table there would take place during the night. However, the Board of IOTA/ES would welcome the establishment of another round table between the US and these territories in the future.

One disadvantage of the round table compared to the mailing list should not be concealed. In mailing lists the exchanged information is stored, here it is only available for the moment. There are no plans to keep minutes of the meetings. However, ideas can arise in the round tables which are then carried forward in the mailing lists.

We Meet Again

The next meeting is scheduled for August 6th at 18 UT. The *Zoom* link will be sent to all members of IOTA and IOTA/ES in time. The *Zoom* link should be kept confidential and not distributed via the mailing lists. The *IOTA/ES Round Table* is a forum for our paying members behind "closed doors", supported by their annual membership fees. Hopefully, this approach will also help to welcome new members to IOTA/ES or IOTA in the future.

Oliver Klös
IOTA/ES Public Relations

Schedule of IOTA Meeting Presentations on 2023 July 15th/16th

2023 IOTA Meeting Presentations -- Preliminary Tentative Schedule

	UT	EDT	Speaker	Topic	Minutes
July 15th					
	20:01	16:01	Joan Dunham	Treasurer's report	14
	20:15	16:15	Steve Preston	Comments on investment fund	5
	20:20	16:20	Richard Nugent	IOTA Awards	15
	20:35	16:35	Norm Carlson	Best-observed North American asteroidal occultations	25
	21:00	17:00	David Herald	Best-observed non-North American events	30
	21:30	17:30	Steve Preston	Best / brightest asteroidal events of the coming year	25
	21:55	17:55	David Dunham	NEA observations: recent, and upcoming	45
	22:40	18:40	David Dunham	Trojans, Centaurs, KBO's, & MB's with moons	20
	23:00	19:00	David Dunham	319 Leona occults Betelgeuse on Dec. 12th	40
	23:40	19:40	Roger Venable	(704) Interamnia IOTA campaign Sept 13, 2023	20
	0:00	20:00	Mike Skrutsky	Automated observations from a fixed site	30
	0:30	20:30	--- adjourn for the day ---		
July 16th					
	20:00	16:00	Mitsuru Soma	Lunar grazing observations	20
	20:20	16:20	Fumi Yoshida	Forming a new East Asian occultation group	15
	20:35	16:35	Joan Dunham	IOTA's outreach at NEAF	15
	20:50	16:50	Kevin Green	Possible Adelheid moonlet & upcoming events	20
	21:10	17:10	Kevin Green	Stellar multipicity & asteroidal occultations	20
	21:30	17:30	David Herald	What happens to an observation after submission. . .	30
	22:00	18:00	Mark Simpson	Raspberry Pi timing device: "Astrid: NextGen OTE"	45
	22:45	18:45	Bob Anderson	Methods for improving light curve extractions from videos	45
	23:30	19:30	Bob Anderson	A set of calibrated video files for evaluating light curve extractions	15
	23:45	19:45	Kai Getrost	Weather forecaster for occultations: "OccuWeather"	15
	0:00	20:00	--- adjourn ---		

Please find the schedule of the upcoming IOTA Zoom conference. I hope that everyone has saved the dates of July 15th and 16th. The emphasis in the talks about upcoming events will be on events visible from North America, but many of the presentations will have universal applicability, of interest to every occultationist in the world.

The link to the online conference will be sent to the IOTA list a day or two before the event(s).

I hope that every one of you can attend.

Roger Venable
IOTA Executive Vice President

https://occultations.org/community/meetingsconferences/na/2023-iota/

Journal for
Occultation Astronomy

IOTA's Mission

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

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

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Imprint

Publisher: International Occultation Timing Association/European Section e.V.
Am Brombeerhag 13, D-30459 Hannover, Germany
Responsible in Terms of the German Press Law (V.i.S.d.P.): Konrad Guhl

JOA Is Funded by Membership Fees (Year): IOTA: US$15.00 IOTA/ES: €20.00 RASNZ: NZ$35.00
Publication Dates: 4 times a year

Submission Deadline for JOA 2023-4: August 15

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

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

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

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

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

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

Journal for Occultation Astronomy

(ISSN 0737-6766) is published quarterly in the USA by the International Occultation Timing Association, Inc. (IOTA)
PO Box 20313, Fountain Hills, AZ 85269-0313

IOTA is a tax-exempt organization under sections 501(c)(3) and 509(a)(2) of the Internal Revenue Code USA, and is incorporated in the state of Texas. Copies are distributed electronically.

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