THE MINOR PLANET BULLETIN

BULLETIN OF THE MINOR PLANETS SECTION OF THE ASSOCIATION OF LUNAR AND PLANETARY OBSERVERS

VOLUME 51, NUMBER 2, A.D. 2024 APRIL-JUNE 89.

SATELLITE OF 5457 QUEEN'S DISCOVERY AND CONFIRMATION BY TWO STELLAR OCCULTATIONS

Christian Weber
International Occultation Timing Association/European Section (IOTA/ES)
IOTA/ES e.V., Am Brombeerhag 13, D-30459 Hannover, Germany
camera@iota-es.de

Jan Mánek
Czech Astronomical Society (CAS), IOTA/ES
Ondrejov, Czech Republic

Serge Dramonis
Athens, Greece

Stefan Meister
IOTA/ES
Eglisau, Switzerland

Andreas Schweizer
IOTA/ES
Wettswil am Albis, Switzerland

Daniel Antuszewicz
Legionowo, Poland

Jiří Kubánek
IOTA/ES
Strašice, Czech Republic

Michal Rottenborn
Observatory Rokycany and Pilsen
Pilsen, Czech Republic

(Received: 2023 November 19)

We report the discovery and confirmation of a previously unknown satellite of the main-belt asteroid 5457 Queen's (1980 TW5) via GPS-time-stamped video recordings of two stellar occultations. The first occultation on 2023 September 4.93059 resulted in three positive chords from the Czech Republic and Switzerland for the main body, allowing an elliptical fit of 24.6 ± 0.9 km × 16.2 ± 0.7 km, and in a 2.0 ± 0.2 km chord of the presumed satellite. 15.07 days later, on September 20.00597, the satellite was confirmed by an observer in Greece, who determined a chord of 17.5 ± 0.5 km for the main body and a chord of 2.8 ± 0.5 km for the satellite. Using both satellite chords as diameters of spherical bodies, we derived the following satellite distances from the main body: 2023 September 4.93059: separation 11.4 ± 0.7 mas, p.a. 52.2 ± 3.0°; 2023 September 20.00597: separation 20.4 ± 0.5 mas, p.a. 248.8 ± 3.0°. Further observations are required to derive the orbital parameters. We indicate upcoming occultation events until October 2024.

Observations - Occultation event 2023 September 4

The observations of the two occultation events took place within the framework of the International Occultation Timing Association/European Section (IOTA/ES, 2023) and the results were recorded with its SODIS portal (SODIS, 2023). The details of the first occultation event are given in Figure 1, see also OW Cloud (OWC, 2023), *https://cloud.occultwatcher.net/event/976-5457-7484-648603-U000768*.

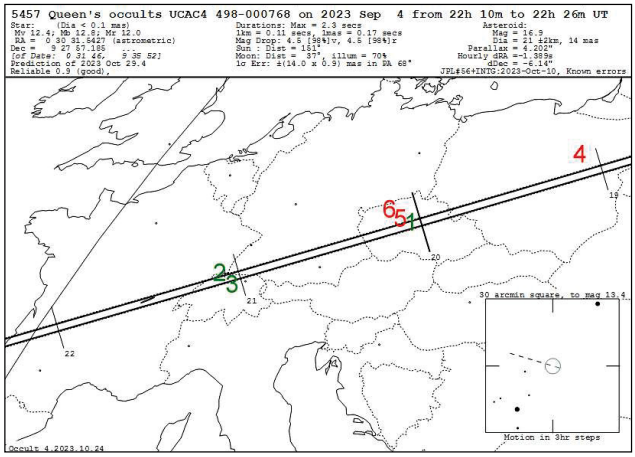

Figure 1: Occultation map (Herald, 2023) of the September 4 event, 1 - 3: stations with a positive result, among them station 1 with a double drop, 4 - 6: stations with negative results. The numbers indicate the locations of the stations only approximately, the exact geographical positions are given in Table III.

Until this event, no stellar occultation chords were known for the asteroid 5457 Queen's (Herald, 2023). Moreover, in the common databases (LCDB, 2023; Johnston, 2023) there are no indications of a possible binary nature of 5457 Queen's. Table I lists data of the asteroid, those of the occulted star are shown in Table II.

Class	Main-belt asteroid
Diameter	21 ± 2 km / 14 mas
Visual magnitude	16.9
Rotation period	4.326 h
Geometric albedo	0.048
Moons / Rings	0 / 0

Table I: Asteroid data for the occultation on 2023 September 4 (Herald, 2023; JPL, 2023).

Identifier	UCAC4 498-000768
Gaia DR3 source ID	2750746718513211520
Estimated diameter (Herald, 2023)	0.02 mas
GCRS position at 2023.6772 (Herald, 2023)	RA 0 30 31.54276 Dec + 9 27 57.18572
GDR3 BPmag	12.76
GDR3 Gmag	12.45
GDR3 RPmag	11.95
GDR3 dup flag	0
GDR3 RUWE	0.85
WDS entry	0
Subject of previous stellar or lunar occultations (Herald, 2023)	0

Table II: Data of the occulted star for the occultation on 2023 September 4.

The occultation was recorded by 6 observers getting 3 positive and 3 negative results. One of the positive recordings (station 1, J. Mánek) shows clearly two consecutive drops reaching the same depth, and indicating a possible satellite (Figure 2). The other two positive detections by the stations 2 and 3 (Figures 3 and 4) gave well positioned chords to derive an elliptical fit of the main body (Figure 9).

Table III summarizes the station details and the occultation results using PyMovie aperture photometry and PyOTE to extract the times (PyMovie/PyOTE, 2023).

Sta-tion	Observer, Lon./Lat./Height [m]	Telescope, Camera	Time	Exp. [s]	Disapp. (UT), first/sec. drop	Reapp. (UT), first/sec. drop	Occ. dur. [s]
1	J. Mánek, CZ, +14 46 47.7/+49 54 36.2/524	0.35-m Newt., DVTI+CAM 430*	GPS	0.100	22:20:00.3436 ± 0.0118 / 22:20:02.8780 ± 0.0156	22:20:02.0092 ± 0.0118 / 22:20:03.0780 ± 0.0156	1.666 / 0.200
2	S. Meister, CH, +8 31 26.4/+47 34 9.2/393	0.20-m Newt., DVTI+CAM 430*	GPS	0.065	22:20:54.737 ± 0.025	22:20:57.141 ± 0.025	2.404
3	A. Schweizer, CH, +8 34 14.3/+47 31 10.4/550	0.50-m Newt., DVTI+CAM 430*	GPS	0.020	22:20:55.268 ± 0.008	22:20:56.177 ± 0.008	0.909
4	D. Antuszewicz, PL, +20 54 9.0/+52 22 57.3/81	0.20-m Newt., ZWO ASI120MM	NTP	0.220	Non detection	Non detection	-
5	J. Kubánek, CZ, +13 44 56.3/+49 44 35.7/538	0.30-m Newt., QHY174GPS	GPS	0.040	Non detection	Non detection	-
6	M. Rottenborn, CZ, +13 44 56.3/+49 44 35.7/538	0.25-m Newt., QHY174GPS	GPS	0.025	Non detection	Non detection	-

Table III: 2023 September 4 observing stations details and derived occultation times. *(DVTI, 2023).

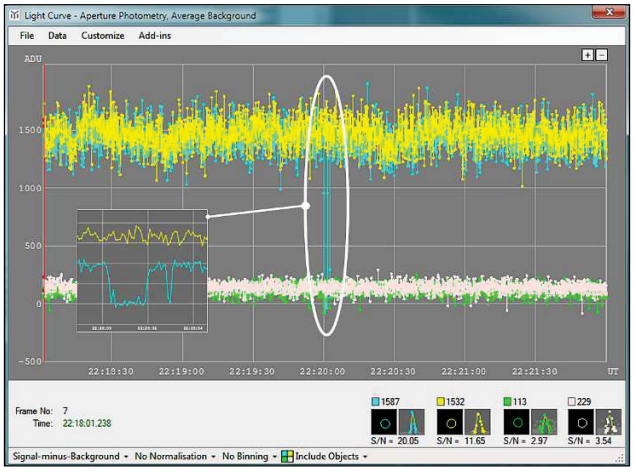

Figure 2: Station 1 Tangra lightcurves (Tangra, 2023), exposure time 100 ms, target star cyan, comparison stars yellow, green and pink.

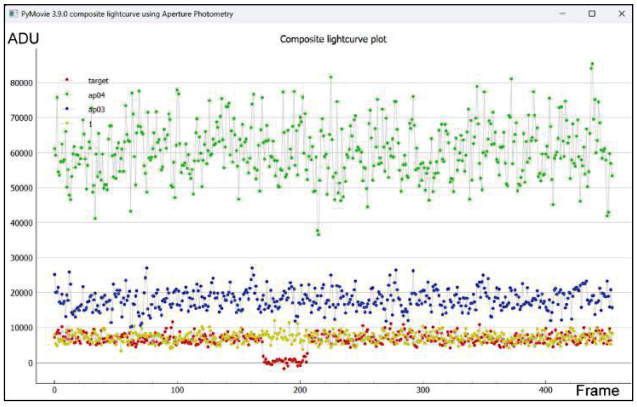

Figure 3: PyOTE lightcurves of the recording of station 2; target lightcurve in red, exposure time 65 ms.

To exclude a possible double star explanation, we determined the limiting magnitude of the recording of station 1. The faintest photometrically analyzable stars are of Gmag 13.84 (GDR3 ID 2750793997513186944) and Gmag 14.92 (GDR3 ID 2750747130830053504).

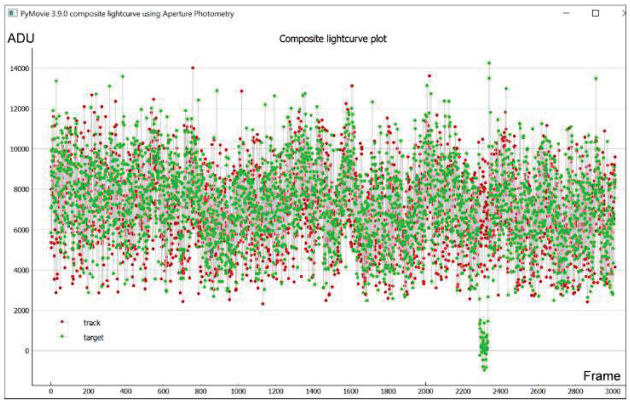

Figure 4: PyOTE lightcurves of the recording of station 3; target star lightcurve in green, exposure time 20 ms.

Figure 5 shows the lightcurves of these stars compared to both occultation drops. For the target star having a Gmag of 12.45, the measured decrease in brightness is more than 2.5 mag, relative to the magnitude of Gmag 14.92 of the faintest comparison star (c4 in Figure 5).

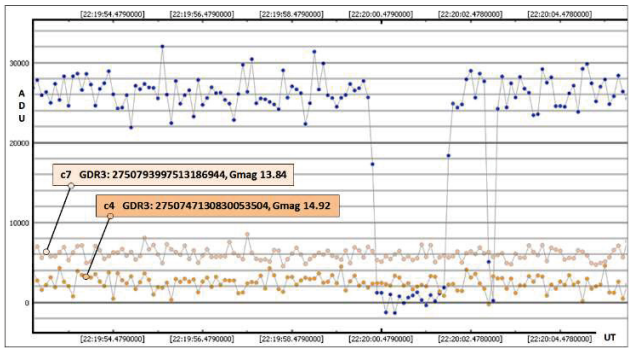

Figure 5: The lightcurves of the faintest comparison stars (c4, c7) and the occultation drops (blue) of the September 4 event.

To be a double star, the occulted star must have components showing a 0.75 mag drop each (components not fainter than 13.20 mag). It can be seen that both drops are of similar depth and fall below the magnitude of the comparison star c4 (Gmag 14.92), excluding a double star hypothesis. By a thorough analysis of all circumstances, we can also rule out the possibility that atmospheric or noise influences are the reason for the secondary drop.

Sta-tion	Observer, Lon./Lat./Height [m]	Telescope, Camera	Time	Exp. [s]	Disapp. (UT), first/sec. drop	Reapp. (UT), first/sec. drop	Occ. dur. [s]
1	S. Dramonis, GR, + 23 33 50.9/+38 37 6.4/342	0.40-m Newt., ZWO ASI183MM	GPS	0.060	00:08:36.0860 ± 0.0376 / 00:08:37.9390 ± 0.0344	00:08:36.3082 ± 0.0376 / 00:08:39.3740 ± 0.0344	0.222 1.435

Table IV: 2023 September 20 observing station details and derived occultation times.

Observations - Occultation event 2023 September 20

Figure 6 shows the shadow path and the parameters of this second occultation event of 5457 Queen's, see also OW Cloud *https://cloud.occultwatcher.net/event/992-5457-5157-648549-U000567*.

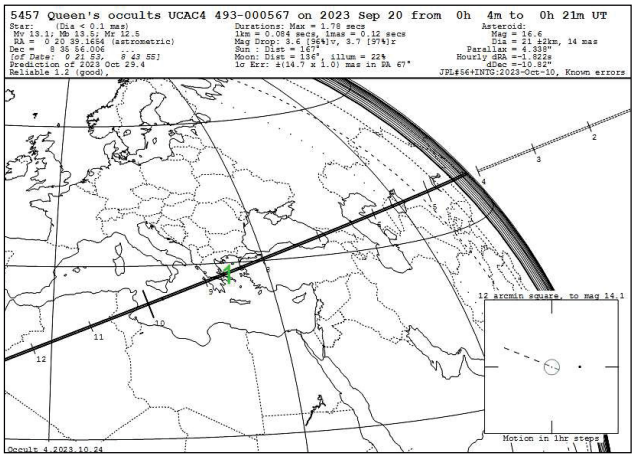

Figure 6: Occult map (Herald, 2023) of the September 20 event, 1 indicates the position of the station that has recorded a double drop.

Except for the slightly changed visual magnitude of the asteroid (16.6), its data for this occultation have not changed compared to those given in Table I for the September 4 occultation. Table V shows the parameters of the target star.

Identifier	UCAC4 493-000567
Gaia DR3 source ID	2749281138232702080
Estimated diameter (Herald, 2023)	0.02 mas
GCRS position at 2023.6772 (Herald, 2023)	RA 0 20 39.16540 Dec + 8 35 56.00643
GDR3 BPmag	13.54
GDR3 Gmag	13.08
GDR3 RPmag	12.46
GDR3 dup flag	0
GDR3 RUWE	1.2
WDS entry	0
Subject of previous stellar or lunar occultations (Herald, 2023)	0

Table V: Occulted star data for the occultation event on 2023 September 20.

As can be seen in Figure 6, only the station of S. Dramonis, Greece, observed this event. Figure 7 presents the lightcurve, showing a short drop (satellite) followed by the main body drop.

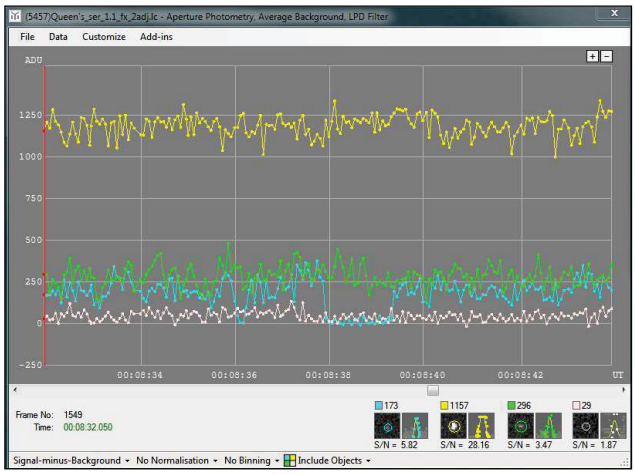

Figure 7: Station 1 Tangra lightcurves, exposure time 60 ms, target star cyan.

Table IV summarizes the station details and the occultation times, derived with PyMovie/PyOTE.

We also examined the limiting magnitude for this recording (Figure 8). Assuming the target star with a magnitude of Gmag 13.08 was a double star with the same magnitudes of both components, they would each require a magnitude of 13.83 mag. As can be seen from Figure 8, the magnitude of both drops of similar depths is at minimum light lower than that of the comparison star c5 (GDR3 source ID 2749274712961627520, Gmag 14.21). So, a double star can be ruled out. We also rule out that atmospheric effects or noise can be the cause of the secondary drop. The satellite's light fall-off comprises three images of nearly equal depth, which is not consistent with a noise event.

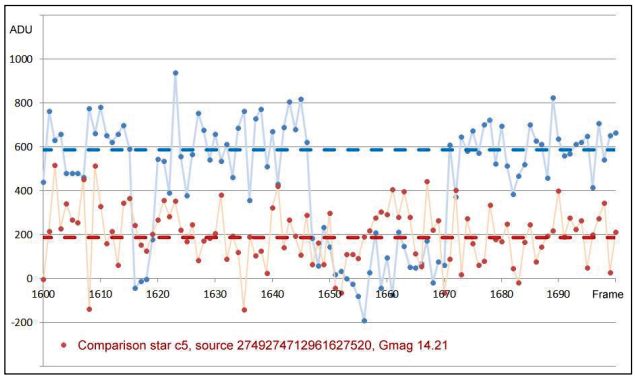

Figure 8: Part of the station 1 recording showing the target star (blue) and the faintest comparison star c5 (red brown). The dotted lines indicate the average light levels.

Reduction of the observations

We reduced both observations with the *Asteroid Observations Editor*, being part of Occult (Herald, 2023).

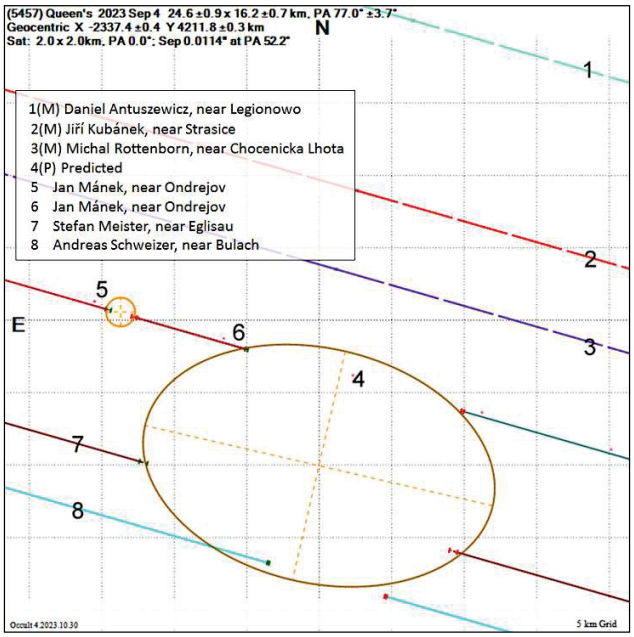

Figure 9: Occultation sky-plane plot of the September 4 event. The chord numbers do not correspond to the station numbers. In the positive chords 5 - 8, the red markings mean D (disappearance), the green ones R (reappearance). The error bars are mostly too small to be seen on the picture.

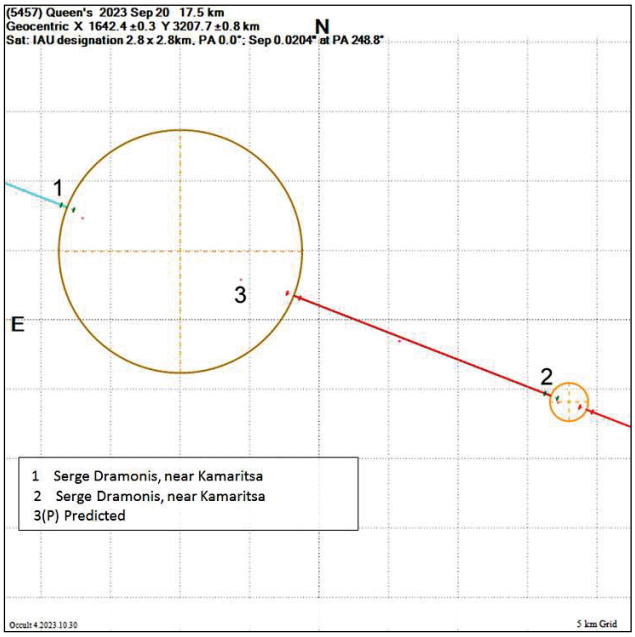

Figure 10: Occultation sky-plane plot of the September 20 event. The red marks stand for D, the green for R. The marks also show the uncertainties.

Figure 9 presents the plot of the September 4 occultation. We were able to fit the main body through an ellipse, giving the first fair shape of the asteroid (24.6 ± 0.9 km × 16.2 ± 0.7 km; p.a. 77.0 ± 3.7°). This is in rough agreement with the NEOWISE thermal diameter of 20.6 ± 2.2 km (Herald, 2023); the AKARI Acura data fit slightly better at 22.3 ± 3.4 km (Herald, 2023). Having only one chord for the satellite, we assumed a spherical shape, resulting in a diameter of 2.0 ± 0.2 km.

Figure 10 shows the reduction of the September 20 event. In this historically only second successfully observed stellar occultation by 5457 Queen's, one chord was achieved due to a single observation station. As a result, we fit the primary and secondary bodies into circles, whereby the chord of the main body with a length of 17.5 ± 0.5 km does not contradict the elliptical fit from the September 4 event. However, as there is only one chord, it is not possible to use the elliptical fit from 4 September here. The resulting diameter of the satellite is 2.8 ± 0.5 km.

Using the Asteroid Observations Editor and the diameters of the satellites derived from both occultation events, we calculate the following satellite positions relative to the main body:

2023 Sep 04.93059: separation 11.4 ± 0.7 mas, p.a. 52.2 ± 3.0°
2023 Sep 20.00597: separation 20.4 ± 0.5 mas, p.a. 248.8 ± 3.0°.

5457 Queen's system
Center of mass, orbit and upcoming occultation events

Based on the data obtained from the two occultations, the center of mass of the system will not differ significantly from the center of mass of the main body. It is therefore unlikely that wobbling effects of the photo center can be detected from current data (Gaia).

During the occultation on 20 September, 15.07 d after the first occultation, the satellite was on the opposite side of the main body. One could therefore speculate about a possible orbital period of the satellite of around 30 days. However, the period could also be a fraction of 30 days.

Our results from two occultation events do not allow to derive the orbital parameters, further observations are required.

To indicate upcoming occultation events of 5457 Queen's, Occult was used for a global search until 2024 October 31 (search parameters: JPL orbit solution #56, JPL ephemerides, Gaia EDR3 down to 16 mag). We found 116 potential occultation events. The preferred ones (most of them in America in August and September 2024) are listed in Table VI.

The observations of 2023 September 4 and September 20 are subject of CBET 5318 (CBET, 2023).

Date	UT	Region	Duration [s]	Star Vmag [mag]	Drop [mag]	UCAC4
2023 Dec 23	14:21	Indonesia	1.36	14.7	3.3	475-000153
2023 Dec 26	15:30	South Asia	1.25	14.9	3.1	476-000207
2024 Jul 24	10:42	South America	0.58	14.4	4.0	571-013135
2024 Aug 02	03:45	Great Britain	0.62	14.6	3.8	573-014688
2024 Aug 08	08:05	South America	0.65	16.0	2.5	573-016037
2024 Aug 14	22:35	Indonesia	0.70	15.7	2.7	574-016038
2024 Aug 17	21:01	USA	0.72	15.3	3.1	574-016357
2024 Aug 19	07:58	South America	0.73	15.8	2.6	574-016525
2024 Aug 23	09:55	Guatemala	0.76	15.2	3.2	574-017177
2024 Aug 31	11:27	USA	0.86	12.1	6.2	574-018794
2024 Sep 05	08:21	USA	0.92	14.8	3.5	574-019912
2024 Sep 10	11:19	USA	1.00	12.7	5.5	574-020981
2024 Sep 11	01:43	France - Latvia	1.02	15.5	2.8	574-021122
2024 Sep 13	12:07	Mexico	1.06	14.7	3.5	574-021713
2024 Sep 14	04:12	Great Britain	1.08	13.2	4.9	574-021839
2024 Sep 14	05:33	Portugal - Spain	1.08	13.7	4.5	574-021847
2024 Sep 15	09:15	Canada	1.11	12.5	5.6	* G060009.5 +244120
2024 Sep 30	07:30	Mexico, USA	1.64	15.7	2.4	573-026064
2024 Oct 04	18:40	Mexico, USA	1.93	15.7	2.4	573-026695
2024 Oct 07	06:05	Guatemala	2.10	15.9	2.2	573-026974
2024 Oct 14	17:48	Japan	3.20	14.3	3.5	573-027632

Table VI: Preferred 5457 Queen's upcoming occultation events from an Occult search until 2024 October 31 (search parameters: JPL orbit solution #56, JPL ephemerides, Gaia EDR3 to 16 mag); * Gaia RA/Dec coordinates.

Acknowledgements

We thank the maintainers of the Occult Watcher Cloud prediction feeds (J. Kubánek, CentralEurope feed; C. Perelló, IBEROC feed) who predicted the occultation events, and the SODIS team for managing the observation reports. We would like to thank D. Herald and D. Gault (both Trans-Tasman Occultation Alliance) for an independent assessment of our data. We acknowledge the developers of the software used in this work, especially D. Herald (Occult), B. Anderson (PyMovie, PyOTE) and H. Pavlov (Tangra). This work has made use of data from the European Space Agency (ESA) mission Gaia (*https://www.cosmos.esa.int/gaia*), processed by the Gaia Data Processing and Analysis Consortium (DPAC, *https://www.cosmos.esa.int/web/gaia/dpac/consortium*). Funding for the DPAC has been provided by national institutions, in particular the institutions participating in the Gaia Multilateral Agreement. This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

References

CBET (2023). Central Bureau for Astronomical Telegrams. CBET 5318 web site. *http://www.cbat.eps.harvard.edu/iau/cbet/005300/CBET005318.txt*

DVTI (2023). DVTI+CAM web site. *https://dvticam.com/home*

Herald (2023). Herald, D. Occult4 web site. *http://www.lunar-occultations.com/iota/occult4.htm*

IOTA/ES (2023). International Occultation Timing Association / European Section web site. *https://iota-es.de/index.html*

Johnston (2023). Asteroids with satellites web site. *https://www.johnstonsarchive.net/astro/asteroidmoons.html*

JPL (2023). Small-Body Database Browser web site. *https://ssd.jpl.nasa.gov/tools/sbdb_lookup.html*

LCDB (2023). Warner, B.D.; Harris, A.W.; Pravec, P. (2009). "The Asteroid Lightcurve Database." *Icarus* **202**, 134-146. Updated 2023 August 8. *https://alcdef.org/index.php*

OWC (2023). Pavlov, H. Occult Watcher Cloud web site. *https://cloud.occultwatcher.net*

PyMovie/PyOTE (2023). Anderson, B. PyMovie/PyOTE web site. *http://occultations.org/observing/software/pymovie/*

SODIS (2023). Stellar Occultation Data Input System web site. *https://sodis.iota-es.de/*

Tangra (2023). Pavlov, H. Tangra web site. *http://www.hristopavlov.net/Tangra3/*