A NEW SATELLITE OF 4337 ARECIBO DETECTED AND CONFIRMED BY STELLAR OCCULTATION

David Gault
Trans-Tasman Occultation Alliance: (TTOA)
22 Booker Road, Hawkesbury Heights, 2777, Australia
davegault@bigpond.com

Peter Nosworthy
Trans-Tasman Occultation Alliance: (TTOA)

Richard Nolthenius
Cabrillo College, Santa Cruz, CA, USA
International Occultation Timing Association: (IOTA)

Kirk Bender
Cabrillo College, Santa Cruz, CA, USA

Dave Herald
Trans-Tasman Occultation Alliance: (TTOA)

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Two observers in Australia, at two separate sites observed asteroid 4337 Arecibo occult UCAC4 323-126197 and both observers observed a hitherto unknown satellite of the asteroid occult the same star shortly afterwards. Confirmation of the existence of the satellite occurred 20.71 days after the first observation, when two observers in California, at two separate sites observed 4337 Arecibo occult UCAC4 322-116848, and both observers observed the satellite occult the same star shortly afterwards. A third occultation, 20.78 days later, of UCAC4 323-113857 was observed at 3 sites in California however the satellite was not detected. We find the diameter of the main body is 24.4 +/- 0.6 km and the satellite is 13.0 +/- 1.5 km - assuming they are spherical. Their separations at the two occultations were: 2021 May 19.74861: 25.5 ±1.0 mas in PA 105.2° ±1.0°. 2021 June 9.45736: 32.8 ±0.7 mas in PA 94.3° ±2.7°. We find the center of mass of the system is displaced from the main body by about 14% of the distance between the two bodies. However, our observations are insufficient to fix the orbit parameters.

Observations – Australia, 2021 May 19

D. Gault and P. Nosworthy observed 4337 Arecibo occult UCAC4 323-126197 and both observed a hitherto unknown satellite occult the same star shortly after. They observed from their home observatories located in The City of The Blue Mountains, at Hawkesbury Heights and Hazelbrook. The sites are equipped with 28 and 30 cm Schmidt Cassegrain telescopes, Watec 910BD video cameras and IOTA-VTIs that insert an accurate GPS-derived time stamp into the video stream (IOTA, 2017). The occultation occurred at an altitude of 65 degrees.

Observation circumstances and timings are shown in Table 1 and lightcurves of the target and a comparison star are in Figure 1.

For this event the recordings were closely analyzed to determine the limiting magnitude of the recording, noting that during the occultation events the lightcurve dropped to the zero-light level. The occulted star had a Gaia G-band magnitude of 13.59, and stars fainter than 15.0 were visible on the recording. The equivalent magnitude drop of at least 1.4 magnitudes for both events in each recording is much larger than the 0.75 drop that would occur if the star was a double star of equal magnitude – thereby excluding a double star as being an explanation for the event.

Observer	Longitude	Latitude	Altitude	Event	Primary Body		Satellite	
Gault	150 38 27.9	-33 39 51.90	286m	D	17:57:59.61	+/-0.08	17:58:04.73	+/-0.08
				R	17:58:01.89	+/-0.12	17:58:05.41	+/-0.12
Nosworthy	150 27 06.5	-33 42 26.60	648m	D	17:58:01.56	+/-0.16	17:58:06.92	+/-0.08
				R	17:58:03.96	+/-0.16	17:58:07.24	+/-0.08

Table 1: Observation circumstances and disappearance and reappearance times UTC of the 2021 May 19 occultations. The sites were separated by 0.7 km across the occultation path, and 18 km along the occultation path.

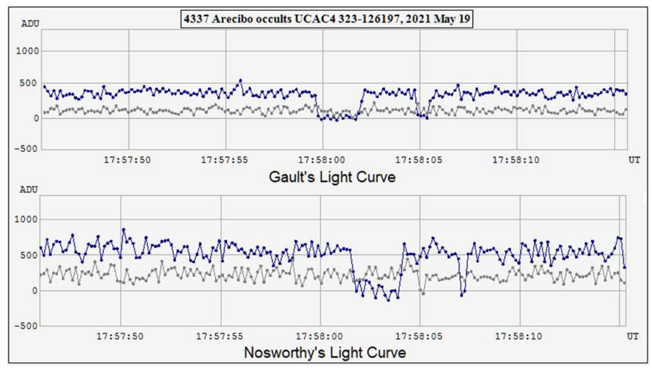

Figure 1: Lightcurves by Gault and Nosworthy of the 2021 May 19 occultations of the target star, by the asteroid main body and satellite. Light values of comparison stars are also shown.

Observations – California, 2021 June 9

R. Nolthenius and K. Bender of Santa Cruz, CA travelled to sites approx. 4 km either side of the predicted occultation path center line, near the towns of San Ardo and Bradley CA. They observed the main body and satellite occult UCAC4 322-116848, noting that during the occultation events the light curve dropped, within error scatter, to zero light. Both observers were equipped with portable 8-inch Schmidt Cassegrain telescopes, Watec 910HX video cameras, and IOTA-VTI video time inserters (IOTA, 2017). The occultation occurred at an altitude of 20 degrees.

Observation circumstances and timings are shown in Table 2 and light curves of the target and a comparison star are shown in Figure 2.

Observer	Longitude	Latitude	Altitude	Event	Primary Body		Satellite	
Nolthenius	-120 52 22.8	35 56 13.3	158m	D	10:58:36.86	+/-0.06	10:58:41.46	+/-0.06
				R	10:58:38.90	+/-0.06	10:58:42.47	+/-0.06
Bender	-120 50 16.2	35 52 22.2	159m	D	10:58:36.64	+/-0.06	10:58:41.01	+/-0.06
				R	10:58:38.41	+/-0.06	10:58:42.12	+/-0.06

Table 2: Observation circumstances and disappearance and reappearance times UTC of the 2021 June 9 occultations. The sites were separated by 8.2 km across the occultation path, and 8.0 km along the occultation path.

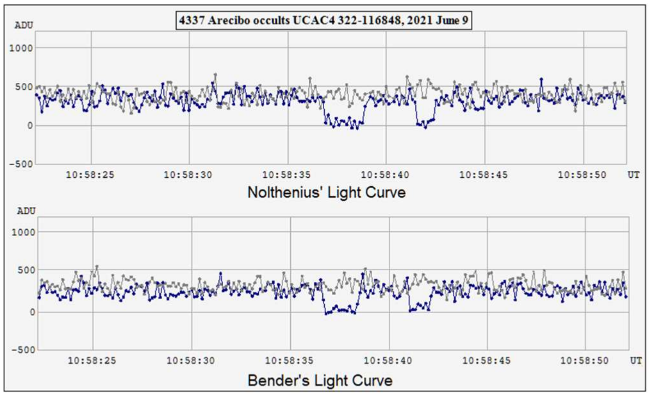

Figure 2: Lightcurves by R. Nolthenius and K. Bender of the 2021 June 9 occultations of the target star, by the asteroid main body and satellite. Light values of comparison stars are also shown.

Observations – California, 2021 June 30

20.78 days later, an attempt was made by observers at 15 sites across the USA to observe an occultation by 4337 Arecibo of UCAC4 323-113857, however due to challenging conditions and weather, only 5 sites made successful observations (Nolthenius, 2021). R. Nolthenius, K. Bender, and C. L. Kitting recorded occultations of the main body and did not detect the satellite, and T. Swift and H. Throop observed misses.

Reduction of the observations

Event times and observation circumstances were entered into Occult (Herald, 2021) and reduced for each observation and the sky-plane plots are shown on Figure 3.

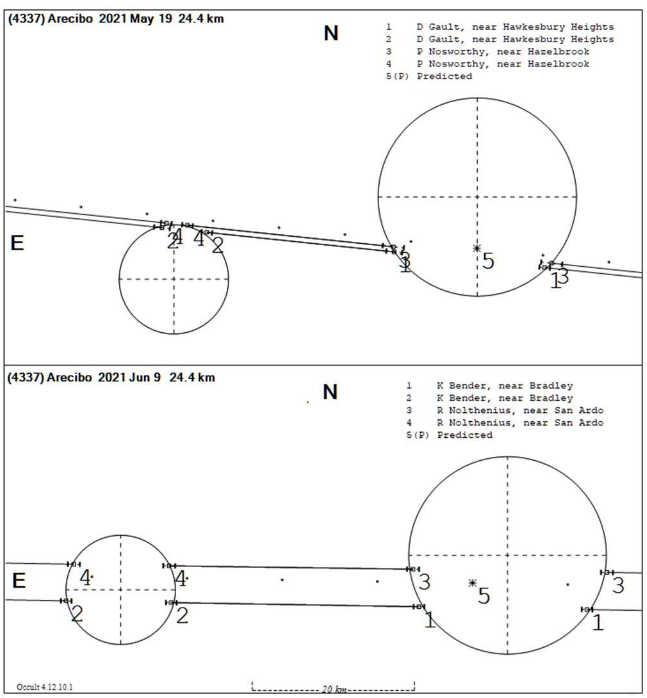

Figure 3: Reduction sky-plane plots of the 2021 May 19 and 2021 June 9 occultations, showing the asteroid and satellite for both occultation events.

The sizes of both the main body and the satellite were poorly determined by the 2021 May 19 occultation, because of the close across-path separation of the observers. Their sizes were better determined from the 2021 June 9 occultation, because the across-path separation was larger, and the chords were favorably positioned against both bodies. Regrettably the number and location of the chords, as well as their associated time uncertainties (indicated by the tick marks on the chords in Fig 3), preclude any reliable fit of an ellipse to the observations. Indeed, either body could have substantial ellipticity yet be consistent with the observed chords. Accordingly, we have determined their diameters on the basis of a fit of a circle to the chords.

The diameters determined from the 2021 June 9 occultation, using a circular fit, are:

Main body 24.4 ± 0.6 km
Satellite 13.0 ± 1.5 km

These diameters were used to then derive the position of the satellite relative to the main body for both occultations. Those positions are:

2021 May 19.74861: 25.5 ±1.0 mas in PA 105.2° ±1.0°
2021 June 9.45736: 32.8 ± 0.7 mas in PA 94.3° ±2.7°

The fit of the three positive chords of the 2021 June 30 occultation is, within errors, consistent with a circle fit of 24 km diameter.

Arecibo system: center of mass and orbit

Assuming the density of the two bodies is the same, and that they are both spherical, the center of mass of the system is displaced from the main body by about 14% of the distance between the two bodies. That position is within the main body, and is separated from its center by about 60% of its radius.

The small change in satellite separation and PA between the first two events, 20.78 days apart, is suggestive this might be the approximate orbital period. However, we do not know whether this is coincidence with the orbital period being a fraction of the 20.78 days, or whether the satellite is moving very slowly. We also do not know if the satellite was on the near or far side of the sky plane for either the May 19 or June 9 events. Therefore, our observations do not fix the orbit parameters.

The apparent closeness of the satellite to the main body, and its relatively large size, suggests that mutual eclipses and occultations may presently be occurring.

We are not aware of any lightcurve measurements of this asteroid.

The observations of 2021 May 19 and 2021 June 9 were the subject of CBET 4981.

Acknowledgements

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ROTATION PERIOD DETERMINATION FOR ASTEROID 663 GERLINDE

Rafael G. Farfán
Uraniborg Observatory (Z55)
Écija (Seville, Spain)
uraniborg16@gmail.com

Faustino García (J38)
La Vara, Valdés (Asturias, Spain)

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Photometric observations of the main-belt asteroid 663 Gerlinde were taken from the Uraniborg Observatory, in Écija (Seville, Spain), in order to determine its synodic rotation period. The results are: P = 10.254 ± 0.001 h, A = 0.190 mag.

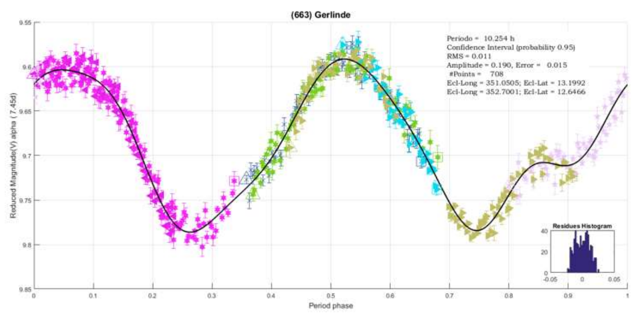
All observations were performed at the Uraniborg Observatory, (MPC-International Astronomical Union code Z55) using a 0.28-m Schmidt-Cassegrain telescope operating at f/6.3. The optical tube is mounted on NEQ6 Pro Skywatcher mount, and equipped with an ATIK 414exm CCD camera. It is a high Quantum Efficiency CCD. No filters used so as to optimize the signal-to-noise. Exposure time for all images was 90 sec. The camera was binned at 1×1. The image scale after 1×1 binning was 0.78 arcsec/pixel and the field of view 18×13 arcmin. In these fields, the asteroid and three comparison stars were measured for differential photometry.

All images were reduced in the standard manner using nightly flatfield files as well as dark-current and bias images. Photometric measurement and lightcurve analysis were performed using *FotoDif* software version 3.138 (Castellano, 2020) and *Períodos*, a script for Matlab software (Observatorio Astronómico Salvador, 2020). Besides, the light time effect was corrected. The *Cartes du Ciel* (2021) was used as the planetarium software with the most recent ephemerides downloaded from the Minor Planet Center, and *MaximDL Pro 6.0* (2021) was used for image capture.

<u>663 Gerlinde</u> (1980 DG; 1948 AB; 1952 WF; 1958 XP) is located in the main asteroid belt, with a semi-major axis of 3.072 AU, eccentricity 0.1455, inclination 17.81°, and an orbital period of 5.39 years. Its spectral type is X and its diameter is 107.8 km. It was discovered on June 24, 1908 by the German astronomer Augustus Kopff at the Heidelberg Observatory and named after the German female's name.

Our goal was to check if the rotation period of 663-Gerlinde has changed in recent years since the latest observations published correspond to the years 2005-2006, (Behrend, 2020) although there is only one more in 2019 according to the consulted bibliography (ALCDEF, 2020). In all these studies, the calculated period was 0.4274 days.

The asteroid phase angle was 7.5° when our observations started and 9.8° when they finished. The period analysis shows a solution for the rotational period of P = 10.254 ± 0.001 hours with an amplitude A = 0.190 ± 0.015 mag, which is very close to the previously aforementioned published results.



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Number	Name	20yy/mm/dd	Phase	L_{PAB}	B_{PAB}	Period (h)	P.E.	Amp	A.E.
663	Gerlinde	21/08/01-21/08/17	7.5,9.8	351.9	12.9	10.254	0.001	0.190	0.015

Table I. Observing circumstances and results. Phase is the solar phase angle given at the start and end of the date range. If preceded by an asterisk, the phase angle reached an extrema during the period. L_{PAB} and B_{PAB} are the average phase angle bisector longitude and latitude.