EPSC2018

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13 Sep 2018 15:37:19

EPSC Abstracts
Vol. 12, EPSC2018-76-3, 2018
European Planetary Science Congress 2018

The stellar occultation by the Transneptunian Object 2002TC302 on January 28th 2018. Preliminary results.

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Abstract

We will report a multi-chord stellar occultation by the large Transneptunian Object 2002TC302 on 28 January 2018, detected from 12 sites in Europe. This is now the best occultation by a Trans-Neptunian Object ever observed, in terms of the number of chords and the number of near misses. The positive chords of the occultation allowed us to fit an ellipse for the limb of the body at the moment of occultation with kilometric accuracy. Tentative possible three-dimensional shapes are presented from a combination of the occultation results with rotational light curve data obtained from the Sierra Nevada 1.5m telescope and the 1.2m Calar Alto telescope in Spain along several years. Also, an interesting result is the fact that the occultation lightcurve profiles are abrupt from all the observing sites, so we can conclude that there is no global atmosphere around this TNO. It is also worth mentioning that none of the occultation lightcurves show any evidence for brief secondary events that could be linked to a ring.

1. Introduction

At the time of this writing there are 2708 known transneptunian objects (TNOs), Neptune trojans and centaurs [1]. The object provisionally designated as 2002TC302 is an interesting TNO, which is among the group of the ~100 largest TNOs known so far. Its radiometric effective diameter is 584 km according to Herschel measurements [2]. Within our program to obtain physical properties of TNOs we predicted an occultation of the star UCAC4 593-005847 (130957813463146112 in GAIADR1) and arranged observations within a very favorable expected shadow path in Europe. The occulted star was of sufficient brightness (V~15.6 mag) so that even small telescopes of less than 0.4m in diameter could make a good contribution.

2. Observations

Sequences of images were obtained with different telescopes from around 15 minutes prior and 15 minutes after the predicted occultation time. Fortunately, 12 of them recorded the disappearance as well as the reappearance of the star. On the other hand, 4 sites were close to the shadow path, but outside of it and reported close misses. This is major achievement because no stellar occultation by a TNO had ever been observed with so many chords across the main body and with constraining near misses. The telescopes that recorded positive observations were the following ones: the Crni Vrh observatory 0.6m telescope (Slovenia), the Asiago observatory 0.67m telescope, the S. Marcello Pistoiese 0.6m telescope, the Monte Agliale 0.5m telescope, the La Spezia 0.4m telescope, the Varese Schiaparelli Observatory 0.84m telescope, the Val d'Aosta observatory 0.4m telescope, the Tavolaia Observatory 0.4m telescope (in Italy), the Gnosca 0.28m telescope (Switzerland), the Observatoire Cote d'Azur 0.4m telescope, the Biot 0.2m telescope, and the Vinon sur Verdon 0.3m telescope (in France).

3. Main results

From the positive occultation observations, we derived light curves which showed deep drops of different duration around the predicted occultation time. As these curves are abrupt at disappearance and reappearance of the star, 2002TC302 must lack an atmosphere of the type seen in Pluto. On the other hand, we have found no hints for short brightness drops prior or after the main event that could be linked to the presence of a thin ring around this body. From the chords of the occultation we fitted an ellipse, which represents the instantaneous limb of the body at the moment of the occultation. The exact semimajor and semiminor axes of the ellipse and its orientation, together with a precise rotational light curve, allowed us to constrain the full 3D shape of this TNO, which will be presented in the conference. Also, constraints on the density can be obtained under the assumption of hydrostatic equilibrium, and some conclusions can be drawn by comparing with densities of bodies of similar size under similar assumptions.

Acknowledgements

Spanish grant AYA-2014-56637-C2-1-P and the Proyecto de Excelencia de la Junta de Andalucía J.A. 2012-FQM1776 are acknowledged. Part of the research received funding from the European Union's Horizon 2020 Research and Innovation Programme, under grant agreement no. 687378 and from the ERC programme under Grant Agreement no. 669416

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Vol. 12, EPSC2018-526, 2018
European Planetary Science Congress 2018

Jupiter Trojan's shallow subsurface: direct observations by radar on board OKEANOS mission

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Abstract

What are the Jupiter Trojans asteroids? Are they rocky asteroids accreted in the vicinity of Jupiter? Captured Icy bodies? Understanding the genetic of The Jupiter Trojans is the goal of the OKEANOS / JAXA understudy mission. The monostatic radar onboard OKEANOS will be the unique opportunity to directly access the shallow subsurface of the body, imaging its internal structures.

Trojans' Genetic

Dark and red objects (P- & D-types) dominate this small population of objects orbiting the Sun at Jupiter L4 and L5 Lagrange points. They are suspected to have originated further away from the Sun. Particularly, the Nice model predicts that they were born in a Trans-Neptunian planetesimals disk and were implanted in their current orbit during the late-heavy-bombardment (LHB) [1]–[3].

Understanding the genetic of The Jupiter Trojans, their composition and formation region is therefore a high-value science goal to unravel the dynamical history of the Solar System. This is the goal of the OKEANOS (Oversize Kite-craft for Exploration and AstroNautics in the Outer Solar system) mission under study by JAXA to cruise to the outer solar system using a large-area solar power sail, and to rendezvous with and land on a Jupiter Trojan asteroid [4]. This body will be observed by imaging, NIR, X-ray spectroscopy and radar while collected samples will be studied by microscopy and mass spectroscopy.

Planetary radar

In complement to the optical remote sensing, radar sounding of the shallow subsurface would improve our understanding of these unexplored bodies [5], [6]. The sounding of the first tens of meters of the surface would give the structure of the near surface and allows identifying layers, ices lenses covered by a regolith, spatial variability of the constitutive material and possible migration processes of volatile or organic materials. It would support the identification of exogenous materials aggregated in the Lagrange-point gravitational trap in order to understand the relation of Trojans with their environment.

A radar sounder onboard a Jupiter Trojan mission will strongly benefit to the lander or sample-return part of the mission. A Radar will be the only instrument that can probe the target asteroid down to a significant depth; this will support sampling and landing site selection by providing geological context, and making sure that the site selected is well representative of the asteroid as a whole.

This goals which are crucial to understand the Trojan's origin can be achieved by a radar with a frequency bandwidth ranging from 300 MHz to 800 MHz as the High Frequency Radar (HFR) developed in the frame of the mission study AIDA/AIM [7]. An additional channel at lower frequency (60MHz) could allow a larger penetration depth [8]. This instrument might be used as an altimeter supporting a controlled descent to the Trojan asteroid surface.

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Vol. 12, EPSC2018-598, 2018
European Planetary Science Congress 2018

The Trojan Color Conundrum

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Abstract

The Trojan asteroids of Jupiter and Neptune are widely thought to have been captured from original heliocentric orbits in the dynamically excited ("hot") population of the Kuiper belt. However, it has long been known that the optical color distributions of the Jovian Trojans and the hot population are not alike. This difference has been reconciled with the capture hypothesis by assuming that the Trojans were resurfaced (for example, by sublimation of near-surface volatiles) upon inward migration from the Kuiper belt (where blackbody temperatures are $\sim$40 K) to Jupiter's orbit ($\sim$125 K). Here, we examine the optical color distribution of the *Neptunian* Trojans using a combination of new optical photometry and published data. We find a color distribution that is statistically indistinguishable from that of the Jovian Trojans but unlike any sub-population in the Kuiper belt. This result is puzzling, because the Neptunian Trojans are very cold (blackbody temperature $\sim$50 K) and a thermal process acting to modify the surface colors at Neptune's distance would also affect the Kuiper belt objects beyond, where the temperatures are nearly identical. The distinctive color distributions of the Jovian and Neptunian Trojans thus present us with a conundrum: they are very similar to each other, suggesting either capture from a common source or surface modification by a common process. However, the color distributions differ from any plausible common source population, and there is no known modifying process that could operate equally at both Jupiter and Neptune. The conundrum is described in [1].

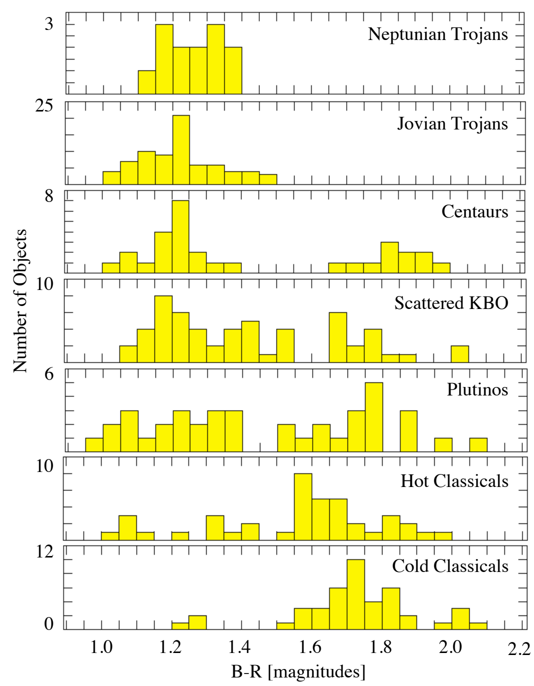

Figure 1: Histograms of the B-R color index for solar system small-body populations, as labelled. For reference, the color of the Sun is B-R = 1.0 while ultrared matter has B-R $\geq$ 1.6. The Trojans of Jupiter and Neptune lack ultrared matter, unlike the outer solar system populations, both dynamically hot and cold, from which they might have been captured.

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Vol. 12, EPSC2018-692, 2018
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An extensive photometric study of the dwarf planet Makemake

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Abstract

We will present a photometric study of the dwarf planet Makemake based on new observational data obtained between 2006 and 2017 using 0.7 to 3.6-m telescopes around the world. Based on this extensive dataset we derive a high precision rotational period estimate. The resulting lightcurve has a small peak-to-peak amplitude variability, that implies an almost spherical shape or an elongated object in a pole-on orientation. Multi-colour observations allowed us to measure surface colours of Makemake. The magnitude phase dependence slope is quite low and is similar to other bodies with methane ice-rich surfaces. Combining our and literature data we tested Makemake for the existence of long-term brightness variations, and searched for the signs of a satellite.

1. Introduction

Dwarf planet (136472) Makemake is one of the largest and brightest known Transneptunian objects (TNOs) [4], [6]. The existence of strong methane absorption bands in Makemake's spectrum suggests that its surface is dominated by methane ice and its irradiation products (e.g. [1], [8]).
Previous photometric investigations proposed a few possible rotational periods: 11.24 h or its double value 22.48 h was suggested in [5], 7.77 h value was proposed by [2] and later preferred by the authors of [10], although other possible period aliases were also detected.
Further photometric observations are needed not only for precise measuring of rotational period, but also, if possible, for the photometric detection of the newly discovered Makemakean satellite [7].

2. Observations and data reduction

The observations were carried out during 53 nights between 2006 and 2017. We used ten middle-sized telescopes at different observational sites, namely, the 3.6-m Telescopio Nazionale Galileo (Spain), the 2.6-m Shain Telescope at Crimean Astrophysical Observatory (Ukraine), the 2.5-m Isaac Newton Telescope at Roque de los Muchachos Observatory (Spain), the 2.0-m telescope at Terskol Observatory (Russia), the 1.5-m telescope at Sierra Nevada Observatory (Spain), the 1.2-m telescope at Calar Alto Observatory (Spain), the 1.0-m Zeisse 1000 telescope at Simeiz Observatory (Ukraine), the 1.0-m East and West telescopes at Tien Shan Astronomical Observatory (Kazakhstan), the 0.7-m telescope at Abastumani Astrophysical observatory (Georgia), and the 0.7-m telescope at Chuguev Observatory of V. N. Karazin Kharkiv National University (Ukraine). All the measurements were made using standard Johnson-Cousins photometric system in BVRI broad-band filters or using no filter at all. Most part of the observational data was obtained in R filter. Image reduction procedure was performed in a standard way which includes dark and/or bias subtraction and flat-field correction. For majority of data only differential photometry was performed, but during some nights the absolute calibration was also made.

3. Main results

A thorough analysis of the large amount of photometric data allowed us to find the rotational period of Makemake with a very good precision. The calculated peak-to-peak lightcurve amplitude is very small (A = 0.037 mag) and can be associated with almost spherical shape or almost polar aspect of Makemake during the observations.

The knowledge of sidereal rotational period allowed us to recalculate the values of absolute magnitude and geometric albedo of Makemake.

From the multi-colour observations we measured surface colours, that appeared to be in agreement with previously reported values as well as with spectral results [3], [9]. The magnitude phase function was measured in the phase angle range of 0.5-1.1º and is similar to other methane ice-rich bodies such as Pluto and Eris.

By using our and literature data we also tested Makemake for the changes in brightness lightcurve amplitude and absolute magnitude with time. Finally, we analyzed the expected influence of the discovered satellite and discuss the possible existence of another satellite(s).

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Vol. 12, EPSC2018-766, 2018
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1I/2017 U1 (`Oumuamua), a Portrait

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Abstract

We present here the analysis of the data we obtained on 1I/2017 U1 (`Oumuamua), combined with data from other teams. We summarize our derived physical characteristics in terms of surface and bulk properties[1], rotational state[2] and orbit[3].

1. Discovery

The Pan-STARRS1 survey detected the object on 2017 Oct. 19; by Oct. 22, additional observations from the Canada-France-Hawaii Telescope (CFHT) and pre-discovery images from Oct. 18 indicated that the object was on a hyperbolic orbit, originating from outside our Solar System[1]. We immediately started a campaign to characterize this unique object during its short period of observability using the CFHT, the ESO VLT, Gemini, Keck, UKIRT and HST.

2. Rotational State

The object presented extremely wide brightness variations, with a range of 2.5 mag. Combining our data with additional photometry published by other authors[4,5,6,7,8,9] (summarized in Fig. 1), we performed a detailed analysis of the rotational state of the object[2], indicating an excited spin state with two fundamental periods at 8.67±0.34 h and 3.74±0.11 h. The object could be spinning in the Short Axis Mode (where the short principal axis of the object circulates around the total angular momentum vector, TAMV), or in the Long Axis Mode (where the long axis circulates around the TAMV). Interestingly, 1I could be either an elongated cigar-shaped object, in which case it would be in a state close to its lowest rotational energy, or an extremely oblate spheroid, pancake-shaped, close to its highest energy for its angular momentum.

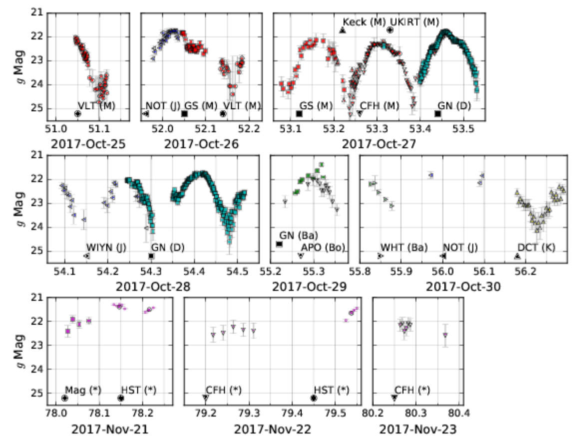

Figure 1. The photometric data used for this study, converted to g band and corrected for geometry and light-travel time to 2017 Oct. 25. Figure from [2].

3. Surface properties

The colours of 1I's surface were measured[1] (g-r = 0.84 ± 0.05, g-i = 1.15 ± 0.10, g-z = 1.25 ± 0.10, g-Y = 1.60 ± 0.20); they correspond to a spectral slope $S_v = 23 \pm 3\%/100$ nm, which is similar to D-type asteroids and comets from our Solar System (see Fig. 2). While our measurements are consistent with a uniform colour over the whole object, Fraser et al. [7] report that one side of the object could be redder.

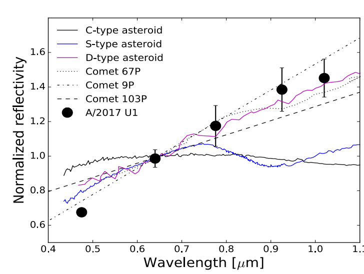

Figure 2. Reflectivity of the surface of 1I/2017 U1 (`Oumuamua) matching that of D-type asteroids and comets (from [1]).

4. Size, shape and density

For a standard cometary albedo of 0.04 and a 0.04 mag/deg solar phase function, the median *g*-band magnitude converts into an effective radius of 102±4 m[1]. Assuming that the light curve is dominated by the shape of the object, its 2.5 mag range corresponds to an elongation of the order of 10:1 (with the solar phase effect tending to decrease this value, and the uncertainty on the geometric aspect increasing it). The third dimension of the object will not be directly constrained by the photometry until the complex light curve is totally solved[2], but the rotation analysis indicates that a cigar-shape object (~10:1:1 axes ratio) is plausible, as is a pancake-shaped object (10:10:1). Scanning over a range of densities and size of the object in the 3rd dimension, we found out that 1I must have some very modest but non-zero internal strength (at least 3 Pa) if its density is comet-like. A long-axis rotator could be held together by gravity only for densities > 1500 kg/m^3 [1].

5. Cometary activity

We searched deep stacked images of the object for hints of a dust coma surrounding it. The photometric profile of 1I matches that of field stars, and various image enhancement techniques failed to reveal any extended source. The most constraining stack sets a limit of 1 kg of 1 μm-sized dust grains in the direct vicinity of 'Oumuamua (<2.5" or <750 km from the nucleus) on October 25-26, based on the dust limiting magnitude for dust g > 29.8 mag arcsec^{-2}. A much larger dust production could be present, but only if the mass is concentrated in large dust grains.

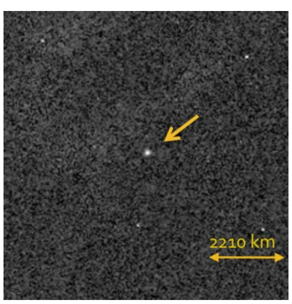

Figure 3. Composite HST image obtained on Nov. 17, 2017 at 1.89 au from the Sun and 1.22 au from Earth. There was no evidence of coma to g > 29.8 mag arcsec^{-2}

6. Orbit

We are measuring the astrometric position of all our ground-based and Hubble data, and we will combine them with published astrometry in order to refine and characterize the orbit of 1I using the longest possible observational arc. The recent publication of the Gaia DR2 catalogue could open possibilities of identifying –or at least constraining– the stellar system where 1I originated.

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EPSC Abstracts
Vol. 12, EPSC2018-793, 2018
European Planetary Science Congress 2018

Search for sub-kilometre sized trans-Neptunian objects using MIOSOTYS observations

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Abstract

We present here our preliminary results of the search for the sub-kilometre sized trans-Neptunian objects (TNOs) using the first 4 years campaign of a dedicated ground-based instrument MIOSOTYS ((Multi-object Instrument for Occultations in the SOlar system and TransitorY Systems). We will report in this conference how many more detections of possible occultation events (POEs) by analyzing these observations with the serendipitous stellar occultation method.

1. Introduction

MIOSOTYS is a fibre-based, high-speed (20Hz) photometer designed mainly for detecting serendipitous occultation events caused by sub-kilometre sized TNOs. MIOSOTYS mainly monitors stars with the angular sizes $\leq 2F_s$ (Fresnel Scale, $F_s = (\lambda D/2)^{\frac{1}{2}}$) because a passing TNO through the line of sight of a small star produces a diffraction-dominated phenomena. MIOSOTYS observes regions around the Opposition where the relative velocity of TNO is higher, the possibility of finding occultations is higher. MIOSOTYS has been mounted as a visitor instrument on the 1.93m telescope at Observatoire de Haute-Provence (OHP) since early 2010, and on the 1.23m telescope at Calar Alto Observatory (CAHA) since late 2012.

2. Observations

Between 2010-2013, MIOSOTYS has successfully carried out 18 observational runs: 14 runs at OHP and 4 runs at CAHA. We obtained more than 6000 image data cubes, and the total exposure time after screening is $\sim 3.0 \times 10^7$ sec, which is about 8426.69 star-hours, from 81 nights.

We used deviation method for the search of possible flux-drop outliers. After removing instrumental ones, we checked the reality of outliers by fitting with

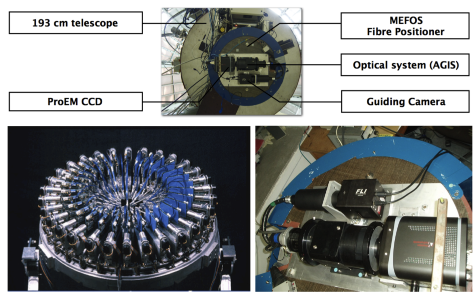

Figure 1: MIOSOTYS consists of three parts: 30 fibre positioning arms (MEFOS) fixed on a platform, an Acquisition and Guiding Image System (AGIS) above the arm platform, and a CCD camera (ProEM CCD).

a database of synthetic patterns. We will compare our preliminary results with other surveys ([1] , [2]).

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EPSC Abstracts
Vol. 12, EPSC2018-821, 2018
European Planetary Science Congress 2018

Chariklo's body and ring system: three multi-chord stellar occultations in 2017

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Abstract

We present the results obtained in 2017 during three multi-chord occultations by the Centaur (10199) Chariklo and its rings. Two of the occultations were predicted using pre-released Gaia's DR2 stellar positions. This allowed predictions at the milli-arcsec (mas) level accuracy, corresponding to about 10 km projected at Chariklo's distance. These multi-chord occultations permit the refinement of shape models for the main body. They confirm the W-shape structure of the main ring C1R, and show virtually opaque and sharp edges for that ring. A simultaneous detection at two different wavelengths (450-650 nm and 700-1000 nm) show no difference in the profiles, suggesting ring particles larger than several μm.

1. Introduction

Two dense and narrow rings around Chariklo (the largest Centaur object known to date with a diameter of ~260 km) were discovered in 2013 using a stellar occultation [1]. From 2013 to 2016, 16 other occultations by Chariklo were observed, refining the physical parameters of Chariklo's system [2, 3, 4]. Here, we focus on three occultations observed in 2017.

Rings subtend about 80 mas projected in the sky and are only resolved by using stellar occultations. Until Sept. 2016, the prediction accuracy (~40 mas), was the main limitation for organizing efficient and successful campaigns. The Gaia DR1 catalogue reduced the uncertainties on star positions to ~10 mas (~100 km at Chariklo), due to the still unknown star proper motions. This is solved in the DR2 catalog, which provides sub-mas accuracies (a few km at Chariklo).

2. DR1 and DR2-based predictions

Gaia DR1 [5] contains the astrometry of one billion stars (with no proper motions). It allowed us to improve the accuracy of our predictions by a factor of about 5. We then used various methods to improve stellar proper motions (UCAC5, TGAS, UCAC4-DR1), while reducing our previous Chariklo occultation and astrometric observations against DR1. This was used to feed NIMA (Numerical Integration of the Motion of an Asteroid, see [6]).

The April 9, 2017 occultation was predicted using the NIMAv11 ephemeris and DR1 + UCAC5 stellar proper motion. The 1σ accuracy of the event was about 20 mas in right ascension (ra) and declination (dec), mostly dominated by the ephemeris and stellar proper motion uncertainties.

In May 2017, the Gaia project released two preliminary DR2 stellar positions for the June 22 and July 23[1]. This included the proper motion and yielded accuracy to 0.2 mas in ra and dec, while NIMAv11 ephemeris provided typical accuracies of 10 mas in ra and dec.

Finally, the positive detection of the June 22 event provided the NIMAv13 ephemeris, that has a accuracy of 2 mas both in ra and dec (Fig.1). This is much smaller than the ring angular span (80 mas) and Chariklo diameter (25 mas). This clearly illustrates the quantum leap brought by Gaia concerning stellar occultation predictions, as it permits an efficient and optimized coverage of the occultations.

[1] https://www.cosmos.esa.int/web/gaia/news_20170523

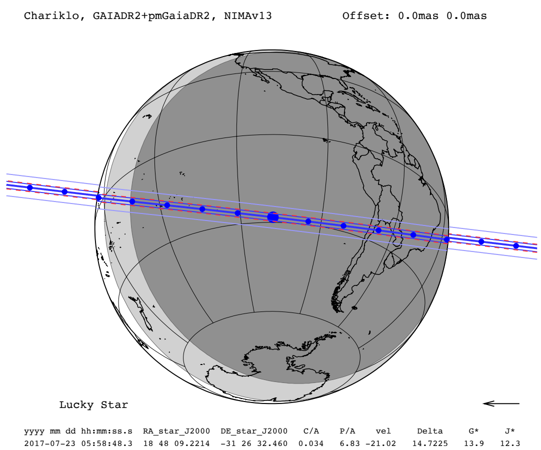

Figure 1: Prediction map of the July 23, 2017 event using the NIMAv13 ephemeris and the pre-released Gaia DR2 star position + proper motion. Blue dots are spaced by 1 min (the larger dot corresponding to closest geocentric approach), the arrow (bottom right) indicating the direction of the shadow motion. Dark blue lines represent main body shadow limits, whereas light blue lines represent rings shadow boundaries. Red dotted lines represents the 1σ uncertainty on prediction.

3. Results

The refinement of the Chariklo's orbit and the Gaia DR2 positions have allowed multichord observations for the three events. The April 9 event was observed at 3 different stations, the June 22 event, from 6 stations and the July 23 from 14 stations. The July 23 post-occultation residual shows a difference of 10 km (about 1 mas) compared to our prediction.

We will present updated results on refined shape models for Chariklo, the orbital elements of the ring system, and the width variation of the main ring C1R. Finally, the dual Lucky Imager of the Danish telescope provides simultaneous profiles of Chariklo's main ring C1R, see Fig. 2 for details.

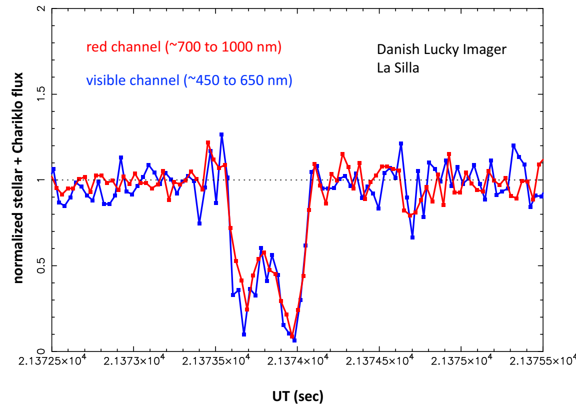

Figure 2: The simultaneous profiles of Chariklo's main ring C1R obtained during the July 23, 2017 stellar occultation in two channels (as indicated in the figure). Note (1) the conspicuous W-shape of the ring optical depth profile, (2) its almost opaque edges and (3) the similarity of the profiles in the two channels, indicating that the optical depth is dominated by particles larger than several μm.

Acknowledgements

Part of the research leading to these results has received funding from the European Research Council under the European Community's H2020 (2014-2020/ ERC Grant Agreement n 669416 "LUCKY STAR"). This work 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.

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EPSC Abstracts
Vol. 12, EPSC2018-1103, 2018
European Planetary Science Congress 2018

1I/‘Oumuamua - probably too small to ever be an active comet

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Abstract

The nature of the first interstellar object observed in the Solar System, 1I/‘Oumuamua, was speculated about since its discovery. Though no cometary activity was observed, it was suggested that 1I/‘Oumuamua might be in fact a dormant comet with a thin, devolatilized surface layer. We evaluated this scenario with a simple model of rotational acceleration and stability of cometary nuclei. It turns out that under reasonable physical assumptions cometary origin of 1I/‘Oumuamua can be ruled out.

1. Introduction

On 19 October 2017 the first interstellar object, 1I/‘Oumuamua, was discovered. Immediately after the discovery the object was extensively observed, however, it was discovered already after the closest approach to the Earth and Sun and thus faded quickly. At first, ‘Oumuamua was though to be a comet based on general expectations concerning interstellar bodies, but deep images soon revealed that it did not show any cometary activity [1, 2]. Consequently, it was reclassified as an asteroid. According to models, many more comets than asteroids were ejected from the Solar System shortly after its formation, thus the lack of activity of ‘Oumuamua was surprising. Despite having obviously no cometary activity, reddish color of its surface led to suggestions that ‘Oumuamua might be a dormant comet [3, 4].

2. Model

The loss of mass in a process of sublimation exerts torques on cometary nuclei. The torques changes the rotation rate of cometary nuclei, finally leading to rotational disruption. To test the hypothesis of cometary origin of ‘Oumuamua we employed a model of rotational acceleration and stability of a prolate spheroid as a function of the thickness of the speculated volatile surface lost by sublimation. The model consists of two components. First, for the assumed shape of cometary nuclei, the maximum allowable rotation rate to remain intact is given by:

$$\omega_{\mathrm{c}} = \sqrt{\frac{4}{3}\pi G\rho S + \frac{4T}{\rho R^2}\left(1-\phi^2\right)^{\frac{2}{3}}}, \tag{1}$$

where $G = 6.67384 \times 10^{-11}$ m^3 kg^{-1} s^{-2} is the gravitational constant, T is tensile strength and $\phi = \sqrt{1-1/f^2}$ is a function of the long-to-short axis ratio f and S is a shape factor given by:

$$S = \frac{3}{2}\frac{(1-\phi^2)[\ln\left(\frac{1+\phi}{1-\phi}\right) - 2\phi]}{\phi^3} \tag{2}$$

For a spherical body, S approaches unity. Moreover, for a given gas sublimation velocity v and effective moment arm [5] κ measuring acceleration efficiency, a change of rotation rate depends solely on initial and final volume-equivalent radius of nucleus R_1 and R_2 respectively:

$$\omega_2 - \omega_1 = \frac{15}{2}v\kappa\left(\frac{1}{R_2} - \frac{1}{R_1}\right) \tag{3}$$

Thus, the ultimate fate of such a body depends on its shape, density, tensile strength and the effective thickness of the sublimated layer.

3. Results

We assume that maximum allowable rotation rate change is the sum of a rotation rate of ‘Oumuamua $\omega_2 = 2.31 \times 10^{-4}$ s^{-1} corresponding to its measured rotational period of 7.56 hr [2] and maximum allowable rotation rate calculated with equation 1. That represents the most optimistic scenario at which the sublimating body rotated with maximum allowable rotation rate at the beginning of its active phase, decelerated its rotation and started to rotate the opposite direction before the activity deceased. We consider typical asteroid density in the range of 1 - 3 g cm^{-3}, gas expansion velocity $v \sim 250$ m s^{-1} [6] and tensile strength ranging from 0 to 50 Pa, consistent with observations of

Solar System comets [7]. We also assume the final volume-equivalent radius of ‘Oumuamua $R_2 = 75$ m as estimated in [2] and axis ratio between 5 - the smallest value possible for ‘Oumuamua [2] and 10 for less optimistic case. We note that for typical $\kappa \sim 0.04$, derived for comet 9P/Tempel [8] and consistent with model [5], sublimation of layer < 1 meter thick is enough to break the comet nucleus apart even if it has non-negligible tensile strength. Some comets exhibits atypically low acceleration efficiency, e.g. for 103P/Hartley the measurements show $\kappa \sim 0.0004$ [9]. Such an object would sublimate ~ 10 meters before breaking apart. The results are presented in Figure 1.

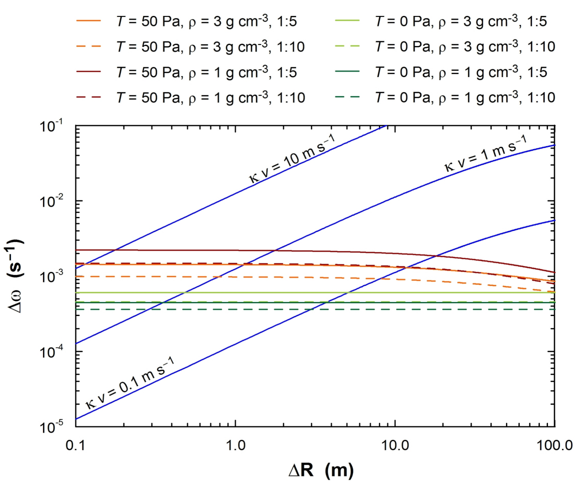

Figure 1: Rotational stability of sublimating minor body under different assumptions on tensile strength, density, axis ratio and acceleration efficiency. Blue solid lines represent change in angular rotation frequency, while orange, brown and green lines represent the critical frequency change for various scenarios.

As previous investigations showed, a typical periodic comet may loose ~ 1 meter [10] of its equivalent surface layer during one perihelion passage, yet we observe periodic comets for dozens of passages (e.g. 1P/Halley or 2P/Encke) and there is no single example of an active comet known to have devolatilized and become dormant. This indicates that in order to build an insulating mantle on cometary nucleus, sublimating surface layer of thickness of a few dozens of meters is not enough. On the other hand, such a loss of matter is much more than needed to rotationally disrupt the object of size and shape of ‘Oumuamua, thus we conclude that 1I/‘Oumuamua has most probably never been an active comet.

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Acknowledgements

Authors are grateful for support from the National Science Centre of Poland through SONATA BIS grant number 2016/22/E/ST9/00109 to M.D.

EPSC Abstracts
Vol. 12, EPSC2018-1118, 2018
European Planetary Science Congress 2018

Detailed photometric characterization of ‘Oumuamua with Gemini North

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Abstract

‘Oumuamua is the first astronomical object known to science to have entered the Solar System from the interstellar space, having been ejected from its original planetary system. Using the Gemini North telescope in Hawaii, our team obtained the most detailed photometric characterization of this unique body. A combined ultra-deep image shows no signs of cometary activity, implying that the body is physically an asteroid, and an accurate light curve reveals an enormous range of brightness variation, suggesting a highly elongated shape. We also discovered that ‘Oumuamua is a non-principal-axis (or tumbling) rotation state, which is consistent with an ancient collision that occurred in the body’s home planetary system.

1. Introduction

‘Oumuamua is the long-awaited first bridge between extrasolar planetary systems and our own Solar System. The body was discovered with the Pan-STARRS telescope on 19 October 2017 UT and became intensively observed nearly immediately after. The visit of ‘Oumuamua was hardly a surprise, though. That is because almost all the original small Solar System bodies have been lost to the interstellar space as a result of dynamical perturbations, and thus free-floating minor objects ejected from other planetary systems should also be abundant.

2. Observations

Our the team was awarded 12 hr of observation time on the Gemini North telescope in Hawaii — the longest run ever allocated to observations of ‘Oumuamua on a telescope of this class. On 27 and 28 October 2017 UT, we obtained over 400 images suitable for accurate time-resolved photometry, having an effective integration time of 3.58 hr and spanning a total of 8.06 hr [1].

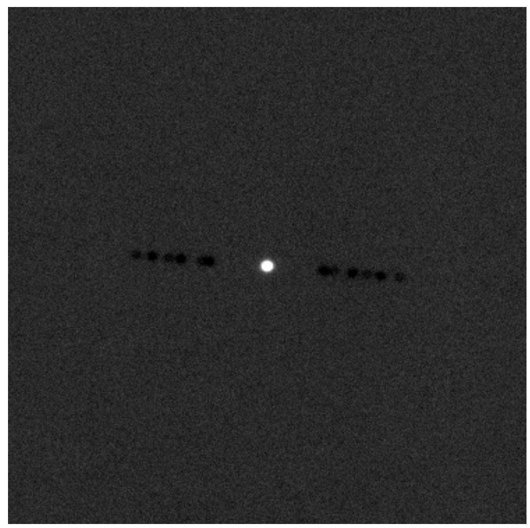

Figure 1: Deep stack of the r′-band imaging time series of ‘Oumuamua. The negative images of the target to the left and right of the positive image are artifacts produced by our background subtraction algorithm and do not affect the photometry. The presented region is 1.0×1.0 arcmin. North is to the top and east is to the left. Despite having a very high surface brightness sensitivity of 28.2 mag arcsec^{-2} measured in a 1 arcsec^2 region, the image does not show any signs of cometary activity.

3. Results

A combined ultra-deep image of ‘Oumuamua (Fig. 1) shows no signs of cometary activity, providing the most stringent limit to ice sublimation and the most compelling evidence that the object is physically an asteroid. This means that — contrary to general expectations — interstellar minor bodies might predominantly be comets. An accurate light curve reveals an enormous range of brightness variation with a full range reaching 2.6 ± 0.2 mag, suggesting a highly

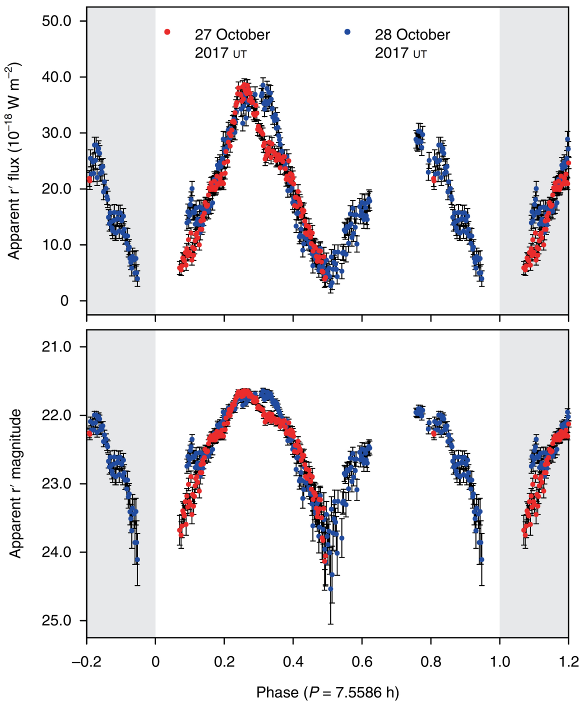

Figure 2: Changes in 'Oumuamua's brightness over two subsequent nights. The top panel shows the brightness in the linear flux scale and the bottom panel shows the brightness in the logarithmic magnitude scale. The grey areas indicate replicated data. It is evident that the light curve does not repeat exactly from one night (27 October 2017 UT) to another (28 October 2017 UT), consistent with a non-principal-axis rotation state, or tumbling.

elongated shape of the body with the long-to-short axis ratio of > 4.9. We also determined the effective rotation period to be 7.56 ± 0.1 hr, the equivalent size to be ~ 150 m, and we found that the density —- contrary to previous reports by other teams —- may not be different from the typical density of Solar System's asteroids. The light curve also revealed an imperfect repeatability of the changes in brightness between the subsequent rotation cycles, implying that 'Oumuamua is a non-principal-axis rotation state. 'Oumuamua's tumbling is consistent with an ancient collision that occurred in the body's home planetary system, suggesting that collisional processing of small body populations in other planetary systems might be common.

Acknowledgements

The findings of this paper are based on observations obtained at the Gemini Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the NSF on behalf of the Gemini partnership: the National Science Foundation (United States), the National Research Council (Canada), CONICYT (Chile), Ministerio de Ciencia, Tecnología e Innovación Productiva (Argentina), and Ministério da Ciência, Tecnologia e Inovação (Brazil). We are indebted to the director of the Gemini Observatory, L. Ferrarese, for rapid evaluation and approval of our director's discretionary time request. We also thank our telescope operator, A. Smith, for excellent work including real-time brightness monitoring of the target, and other Gemini Observatory staff members for vital contributions to making the GMOS-N observations possible. Special thanks to the 'Alopeke instrument team for flexibility and cooperation during the observations, which disrupted their commissioning work. M.D., P.G. and B.H. are grateful for support from the National Science Centre of Poland through SONATA BIS grant number 2016/22/E/ST9/00109 to M.D.

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EPSC Abstracts
Vol. 12, EPSC2018-1263, 2018
European Planetary Science Congress 2018

2013 UL10: the first very red active Centaur

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Abstract

We present observations of 2013 UL10, a Centaur orbiting between Jupiter and Uranus and dynamically similar to the few tens of active Centaurs so far known. We analyzed BVR images of the Centaur obtained at the TNG (La Palma, Canary Islands, Spain). We observed that Centaur 2013 UL10 is the unique Centaur so far known that has both very "red" surface colors and revealed an episode of comet-like activity. Its nucleus has a color index [B-R] = 1.88 ± 0.11, and we derived an upper limit for its size of $D \leq$ 10 km. We estimated a rather low dust production rate of Q_d ~ 10 kg/s at 6.2 au, just after its perihelion passage.

1. Introduction

Centaurs form a dynamical class of small bodies in the Solar System (SS) moving on highly chaotic and unstable orbits in the region between Jupiter's and Neptune's orbits. They are considered "transition objects" from the inactive Kuiper Belt Objects to the active Jupiter Family Comets, therefore the study of their physical properties is a main topic to assess the relationship and establish reliable patterns between the object classes, and to constrain the evolution of small bodies in the SS. Around 10% of the whole sample of Centaurs have been observed with a comet-like coma in optical images: the activity among Centaurs is part of a wider debate on the activity of small bodies at great distances from the Sun, outside the so-called "water zone", where it cannot be explained with classical water ice sublimation, and other mechanisms (i.e., release of trapped gas upon ice crystallization) should be invoked to explain the phenomenon.

It is still unclear which is the real fraction of active Centaurs, why more than half of the Centaurs that could potentially be "comets" are inactive instead, which is the real fraction of sustained activity cases with respect to episodic ones, if there is any intrinsic difference among active Centaurs, and, most of all, how and to which extent the physical studies of Centaurs are stymied by a possible underestimated coma contribution.

2. Results and discussion

During our observations in December 2015, Centaur 2013 UL10 showed clear hints of comet-like activity (Figure 1), previously unreported. Assuming that its nucleus is a point-like source embedded in a surrounding coma, we sample the nucleus contribution (plus an unknown, but presumably small, contribution from the near-nucleus coma) using all the flux inside the photometric aperture corresponding to the stellar PSF. We derived the following preliminary nucleus colors: [B-V] = 1.13 ± 0.10, [V-R] = 0.75 ± 0.12, [B-R] = 1.88 ± 0.11.

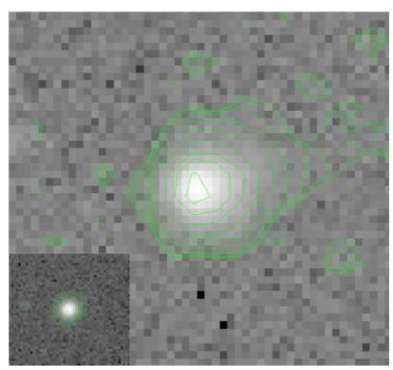

Figure 1: R image of Centaur 2013 UL10, taken at TNG on 11 December 2015 (linear scale 5.3 × 10^4km). The inset in the low-left corner is the image of the inactive Centaur 2008 FC76, obtained in the same observing night (reported for comparison)

These colors would pose 2013 UL10 among the traditional "red group" of Centaurs, significantly distant from the active Centaurs hitherto known (Figure 2).

We estimated a preliminary upper limit for the nucleus of 2013 UL10, adopting a value for the albedo $A = 0.12$, following the recent studies on the dependence of albedo on objects' color (1,2): we obtained $D \leq 10$ km, quite a small size when compared to average size of inactive Centaurs, more than one order of magnitude larger (3,4). This is consistent with the fact that, in general, active Centaurs are found to be smaller than inactive ones (5).

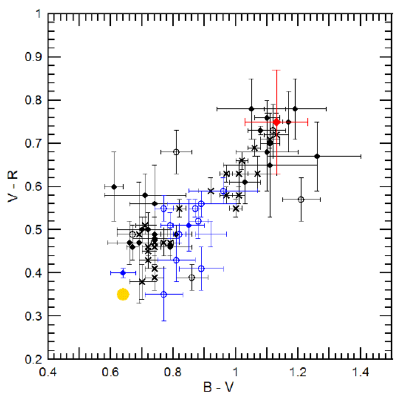

Figure 2: Color-color diagram comparing the inactive Centaurs (black symbols) with the active one (blue symbols): black and blue diamonds (6); black asterisks (7); blue open circles (3); black and blue open diamonds (8); blue cross (9). The yellow dot is the Sun. The red diamond is 2013 UL10 (this work).

In order to obtain a first-order estimate of the dust production rate, we applied the "photometric method" (3). Results should be regarded as a crude order of magnitude, since they are strongly model-dependent: making the assumption of average grain size $a \sim 30$ µm and velocity $v = 20$ m/s, we obtained an estimate of $Q_d \sim 10$ kg/s at 6.2 au (just after the perihelion passage).

The color diversity among Centaurs is a still unexplained feature of the class: they could reflect their different formation location (a primordial, temperature-induced, composition gradients), or could be due to the combined effect of quite recent evolutionary processes. An effect of the "fall back blanketing" (8) could be the "destruction" of the red matter eventually present on the surface by fallback debris composed by "fresh", un-irradiated material expelled during comet-like activity. Timescales for the blanketing process are very uncertain, but are estimated to be quite short (≤ 100 years) with respect the average lifetime of Centaurs on their unstable orbits (10^7 years): therefore, the probability to observe outgassing activity on red surface among the Centaurs, as we actually observed for 2013 UL10, is very low.

This fact, combined with the observation that 2013 UL10 showed significant difference in the colors of nucleus and surrounding dust, with the latter being more neutral than the underlying nucleus, points to the conclusion that: 1) either the blanketing physics should be further constrained, as its timescale can be rather larger than expected (as it is strictly dependent on the dynamical and physical properties of the Centaur and on the level of persistency of its comet-like activity); 2) or we have been extremely lucky to actually observe in December 2015 the comet-like activity of 2013 UL10 just after its onset; 3) or in the specific case of 2013 UL10 the comet-like activity observed in December 2015 has been only episodic and is due to an isolated event (e.g., collisional), and should not be considered the starting point of a sustained comet-like activity able to (rapidly) bluish the Centaur.

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