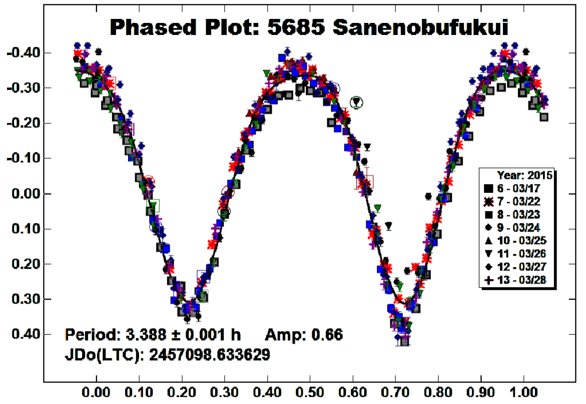
0.09, and a semi-major axis of 2.8 AU (Minor Planet Center, 2015). Additionally, the asteroid has an absolute magnitude of H = 11.6 and currently does not have a measured diameter.

The observations were made at the Etscorn Campus Observatory (ECO, 2015) from 2015 March 17-28. Data were collected using a 0.35-m Schmidt-Cassegrain telescope with an SBIG STL-1001E CCD camera. Image resolution was 1024x1024 with 24-micron pixels, yielding a 22x22 arc minute field-of-view. The telescope was controlled with Software Bisque's *TheSky6* (SB, 2014) and the camera with *CCDsoft* V5 (SB, 2014).

The images were taken with a 5-minute exposure time and were adjusted using a series of darks and flats. The flats were taken using the sky as a background about a half-hour after sunset. These images were then combined into a master flat by using a normalized median tool within *MPO Canopus* version 10.4.1.0 (Warner, 2012). The multiple nights of data were then combined with the FALC algorithm (Harris *et al.*, 1989) within *MPO Canopus* in order to calculate the synodic period.



The resultant lightcurve displays a well-defined, bimodal trend with a period of 3.388 ± 0.001 hours and an amplitude of 0.66 ± 0.07 mag.

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SHAPE MODELS OF ASTEROIDS AS A MISSING INPUT FOR BULK DENSITY DETERMINATIONS

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To determine a meaningful bulk density of an asteroid, both accurate volume and mass estimates are necessary. The volume can be computed by scaling the size of the 3D shape model to fit the disk-resolved images or stellar occultation profiles, which are available in the literature or through collaborations. This work provides a list of asteroids, for which (i) there are already mass estimates with reported uncertainties better than 20% or their mass will be most likely determined in the future from Gaia astrometric observations, and (ii) their 3D shape models are currently unknown. Additional optical lightcurves are necessary to determine the convex shape models of these asteroids. The main aim of this article is to motivate the observers to obtain lightcurves of these asteroids, and thus contribute to their shape model determinations. Moreover, a web page *https://asteroid-obs.oca.eu*, which maintains an up-to-date list of these objects to assure efficiency and to avoid any overlapping efforts, was created.

The motivation for studying density of asteroids is the fact that it belongs to the most important characteristics of asteroids, which is also one of the least constrained. By comparing with densities of meteorites, which can be considered as remnants of collisionally disrupted asteroids that survive entry through the Earth's atmosphere, we can deduce also the nature of asteroid interiors. These physical properties of asteroids reflect the accretional and collisional environment of the early solar system. Moreover, because some asteroids are analogs to the ancient material that formed the terrestrial planets 4.56 Gyr ago, the density and internal structures of minor bodies inform us about the formation conditions and evolution processes of planets and the solar system as a whole.

To determine the bulk density, we need both the mass and the volume of the object. In the following, we briefly describe several methods for asteroid volume estimates, summarize the current knowledge of asteroid densities and masses, and provide a list of asteroids, for which new photometric data need to be obtained in order to derive their shape models.

The most frequent method to determine the size (and volume) of an asteroid is fitting the thermal data observations (typically from IRAS, WISE, and AKARI satellites) by simple thermal models that assume a spherical shape model (e.g., the Near-Earth Asteroid Thermal Model; Harris, 1998). The reported size uncertainties for individual asteroids are usually very small (few percent), however, they are not realistic. Indeed, the uncertainties are dominated by the model systematics – the spherical shape assumption is too crude and also the role of the geometry is neglected (e.g., the spin axis orientation). In the statistical sense, the sizes determined by thermal models are reliable, but could be easily off for individual objects by 10–30%. This implies a volume uncertainty of 30–90%!

Obviously, more complex shape models (instead of spheres and ellipsoids) have to be used for more accurate size and volume determinations. Currently, the leading method is the convex inversion (Kaasalainen and Torppa, 2001; Kaasalainen et al., 2001), which makes use of only disk-integrated photometry and provides a convex shape model with the sidereal rotational period and the pole orientation. A more advanced KOALA method of Carry et al. (2012), which is build on the lightcurve inversion basis, allows a non-convex shape model determination. This method uses among the disk-integrated photometry also stellar occultation measurements and/or disk-resolved images (2D contours) obtained by the 8-10m class telescopes equipped with adaptive optics systems. Moreover, recent inversion method of Viikinkoski et al. (2015) called ADAM can handle, among the already mentioned types of data, also disk-resolved thermal data, interferometry and radar observations.

The disk-integrated photometric data itself are not sufficient to constrain the dimensions of these asteroids. However, there are three methods commonly used to determine the size of the shape model: (i) scaling the asteroid shape projections by disk-resolved images obtained by adaptive optics systems; (ii) scaling the asteroid shape projections to fit the stellar occultation measurements; and (ii) fitting the thermal measurements by the thermophysical model. The shape model can be either an input (typically computed by the convex inversion) or derived simultaneously with the size (KOALA, ADAM).

The method for comparing the AO contours with the asteroid's projections was developed and already used for size determinations of ~40 asteroids in Hanus et al. (2013). Conceptually similar method can be applied when constraining the asteroid sizes with stellar occultation measurements (see Durech et al. 2011). These two methods as well as the KOALA and ADAM methods will be used to scale the sizes of studied asteroids.

With available thermal data (WISE, IRAS, AKARI), it is possible to constrain sizes of asteroids by the means of thermophysical modeling (see, e.g., Delbo 2004; Delbo et al. 2007). By this method, which uses the convex shape model as a fixed input, surface properties such as albedo, surface roughness or thermal inertia can be determined.

The currently available mass and volume estimates allowed the determination of densities with accuracy formally better than 20% for less than hundred asteroids (Carry, 2012). A significant number of the density estimates with uncertainties better than 20% reported in Carry (2012) are determined from sizes based on spherical shape models (i.e., determined by thermal models), and thus the uncertainties are most likely strongly underestimated. This means that our knowledge of accurate densities (<20%) is probably limited too only a few dozens of asteroids, which sizes/volume were determined by more sophisticated techniques.

Recent mass determinations were reported from the astrometric observations, namely based on the planetary ephemeris or orbit deflection methods, and promise a significant improvement of the poor knowledge of the mass. Goffin (2014) published more than one hundred mass estimates with a typical uncertainty of 5–20% (planetary ephemeris). The astrometric observations of the Gaia satellite should also provide masses, namely for ~150 asteroids (for ~50 with an accuracy better than 10%, Mouret et al., 2007, 2008) by the orbit deflection method. The advantage of Gaia masses is in the uniqueness of the mission, which should result in a comprehensive sample with well-described biases (e.g., the current mass estimates are strongly biased towards the inner main belt).

The main limiting factor for meaningful bulk density determinations is the lack of shape models for many asteroids with accurate mass estimates. These shape models can be derived only with the help of additional optical data, because the currently available photometry is not sufficient. Our Table 1 lists observational opportunities until the end of year 2016 for all asteroids with accurate mass estimates we compiled from above mentioned studies, and for which shape models have not yet been determined. Any observational support would be greatly appreciated. This work follows the legacy and even uses the optical data obtained within the framework of a principally similar project "Photometric geodesy of main-belt asteroids" from late 80's (see, e.g., Weidenschilling et al., 1987).

An up-to-date status of this project dedicated to shape model determination of asteroids with accurate mass estimates is maintained on a web page *https://asteroid-obs.oca.eu*. The list of asteroids, for which new photometric data are still needed as well as additional information and tools useful for observers willing to support our project will be provided and regularly updated. The general policy is to include observers as co-authors of publications, where the shape model is presented for the first time. We do not require an embargo on the data, thus the observers can publish their observations independently at any time.

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Table 1. Observational opportunities until the end of year 2016 for all asteroids with accurate mass estimates (compiled from the literature), and for which shape models have not yet been determined. The date when the asteroid is in the opposition, the predicted V magnitude (MPC), the declination, the rotation period in hours and the quality code U (Warner et al. 2009) are shown.

Ast	Date	V	Dec	Period	U
117 Lomia	2015 07 04	12.4	-43.3	9.127	3
308 Polyxo	2015 07 04	11.6	-16.0	12.029	3-
31 Euphrosyne	2015 07 08	12.6	-56.1	5.530	3
488 Kreusa	2015 07 22	12.9	-29.4	32.666	2+
60 Echo	2015 07 22	11.9	-15.2	25.208	3
772 Tanete	2015 08 03	13.2	-53.4	17.258	3
442 Eichsfeldia	2015 08 09	12.6	-16.2	11.871	3
65 Cybele	2015 08 13	11.0	-13.4	6.0814	3
200 Dynamene	2015 08 25	11.5	-9.8	37.394	3
790 Pretoria	2015 08 29	12.6	18.9	10.37	3
334 Chicago	2015 09 13	13.0	-7.7	7.361	3
328 Gudrun	2015 09 15	13.0	-3.2	10.992	3
259 Aletheia	2015 09 18	12.4	-16.0	8.143	3
206 Hersilia	2015 09 26	12.2	-2.3	11.128	3
356 Liguria	2015 10 13	10.8	13.6	31.82	3-
96 Aegle	2015 10 18	12.7	28.8	13.82	3
212 Medea	2015 10 20	12.1	15.9	10.283	3
705 Erminia	2015 10 22	12.6	28.4	53.96	2
203 Pompeja	2015 10 23	12.0	14.6	24.052	3
106 Dione	2015 10 31	10.8	11.1	16.26	3
375 Ursula	2015 11 01	11.9	33.9	16.83	2
49 Pales	2015 11 26	10.7	24.3	10.42	3
762 Pulcova	2015 12 05	12.6	37.8	5.839	3
268 Adorea	2015 12 08	12.7	20.1	7.80	3
379 Huenna	2016 01 03	13.3	20.7	14.141	3
202 Chryseis	2016 01 07	11.2	15.5	23.670	3
150 Nuwa	2016 01 12	12.5	18.6	8.1347	3
12 Victoria	2016 01 13	11.2	10.8	8.6599	3
654 Zelinda	2016 01 28	10.1	-4.3	31.735	3
702 Alauda	2016 01 28	11.9	9.2	8.3531	2+
144 Vibilia	2016 02 04	11.9	22.3	13.819	3
419 Aurelia	2016 02 16	12.3	7.1	16.784	3
46 Hestia	2016 02 23	12.2	8.8	21.040	3
173 Ino	2016 03 14	12.3	10.6	6.163	3
455 Bruchsalia	2016 03 15	13.9	17.4	11.838	2+
566 Stereoskopia	2016 03 19	13.3	6.3	12.103	3
238 Hypatia	2016 03 25	12.3	-1.6	8.8749	3
81 Terpsichore	2016 03 29	12.8	-4.8	10.943	3
324 Bamberga	2016 04 12	12.0	-20.5	29.43	3
128 Nemesis	2016 04 21	11.8	-5.7	39.	3
78 Diana	2016 04 21	11.3	-23.6	7.2991	3
139 Juewa	2016 05 04	11.0	-28.1	20.991	3
381 Myrrha	2016 05 25	12.5	-4.5	6.572	3
241 Germania	2016 05 26	11.8	-24.6	15.51	3
50 Virginia	2016 06 10	12.9	-18.6	14.315	3
554 Peraga	2016 06 10	12.5	-25.8	13.7128	3
120 Lachesis	2016 06 18	12.0	-33.5	46.551	3
704 Interamnia	2016 06 18	10.4	-29.5	8.727	3
758 Mancunia	2016 07 28	12.7	-21.5	12.7253	3
59 Elpis	2016 07 30	11.4	-9.1	13.69	3
159 Aemilia	2016 08 09	12.7	-16.2	24.476	3
48 Doris	2016 08 14	11.4	-8.3	11.89	3
211 Isolda	2016 08 15	12.3	-9.4	18.365	3
56 Melete	2016 08 15	10.3	-2.2	18.147	3
24 Themis	2016 08 16	11.9	-14.7	8.374	3
751 Faina	2016 08 17	11.8	-36.0	23.678	3
154 Bertha	2016 08 27	12.7	-34.3	25.224	3
451 Patientia	2016 09 05	11.1	-26.5	9.727	3
388 Charybdis	2016 09 11	12.2	-5.2	9.516	3
31 Euphrosyne	2016 09 12	11.6	-28.2	5.530	3
488 Kreusa	2016 09 17	13.1	-16.4	32.666	2+
405 Thia	2016 09 22	13.0	15.0	10.08	3
92 Undina	2016 09 22	10.7	-13.6	15.941	3
117 Lomia	2016 10 01	12.0	10.3	9.127	3
51 Nemausa	2016 10 13	10.6	1.7	7.783	3
65 Cybele	2016 10 20	11.7	6.8	6.0814	3
18 Melpomene	2016 10 23	8.0	-6.3	11.570	3
308 Polyxo	2016 10 24	11.8	8.5	12.029	3-
772 Tanete	2016 10 27	13.2	-8.1	17.258	3
334 Chicago	2016 11 05	13.1	10.0	7.361	3
790 Pretoria	2016 11 14	13.2	28.0	10.37	3
194 Prokne	2016 11 19	11.4	-8.7	15.679	3
259 Aletheia	2016 11 24	12.7	14.3	8.143	3
60 Echo	2016 11 27	10.1	15.6	25.208	3
442 Eichsfeldia	2016 12 09	13.2	14.3	11.871	3
328 Gudrun	2016 12 16	13.0	47.8	10.992	3