

**PARAMETERS OF ROTATION AND SHAPES
OF MAIN-BELT ASTEROIDS FROM
APT OBSERVATORY GROUP:
SECOND QUARTER 2016**

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Using observations made during the second quarter of 2016, the rotation periods and the semi-axis a/b ratio of the projected shape for six main-belt asteroids were determined: 238 Hypatia, 1603 Neva, 1859 Kovalevskaya, 4170 Semmelweis, 3002 Delasalle, and (31013) 1996 DR.

For about the last four decades, photometric analysis of main-belt asteroids has been growing steadily. As of mid-2016, rotation periods for more than five thousand asteroids are reported in the asteroid lightcurve database (LCDB; Warner *et al.*, 2009).

In the LCDB, the quality of almost all lightcurve period solutions is indicated with a quality code (U). The U values range from 0 to 3, with U = 0 indicating that the reported period has been found to be wrong while U = 3 indicates a secure solution without any ambiguities. Some asteroids have no quality code assigned, which means that a valid estimate of the period and amplitude could not be made from the available data.

For this work, I selected asteroids with U = 2 to 3 as well as one other that was not in the LCDB at the time. Even if an asteroid has a U = 3 rating, it can still be useful to observe it. For example, the lightcurve amplitude may be different because it will be observed at a different phase angle or viewing aspect as defined by the phase angle bisector (PAB; see Harris *et al.*, 1984). The changes over several apparitions are important when trying to generate a three-dimensional model of the asteroid.

Observations

All observations were conducted from APT Observatory Group. During the last 10 years, APT has contributed relative astrometry of double stars as well as astrometry and photometry of minor planets. It has published a number of papers in some of Spain's leading scientific journals.

Observatory	Scope (meters)	CCD + Accessories
OIA Obs. Isaac Aznar	0.35 SCT	SBIG STL-1001E + AO
POP Punto Obser. Puçol	0.25 SCT	SBIG ST-9XE + AO

Table I. Equipment used for imaging.

The APT Observatory Group is made up of two observatories. The first is the Isaac Aznar Observatory, located at 1270 meters in Centro Astronómico del Alto Turia, Aras de los Olmos, Valencia, Spain. This observatory is equipped with a 0.35-m telescope, a STL-1001E CCD camera, and adaptive optics (AO) system; the image scale is 1.44 arcsec/pixel. The skies are very dark (22.1 magnitudes/arcsec²) and have very good seeing. The second site is the POP-Punto de Observación de Puçol, Puçol, Spain. This is an urban observatory equipped with a 0.25-m telescope, SBIG ST-9 CCD camera, and AO system.

All images were obtained in 1x1 binning mode and were taken without any photometric filter. Exposures were chosen so that SNR would keep data dispersion to a minimum. Bias frames and twilight sky flat-field were taken to calibrate the images.

Data Reduction

MPO Canopus was used to reduce the images. This program incorporates the Fourier analysis for lightcurves (FALC) algorithm developed by Harris (Harris *et al.*, 1989). A star subtraction technique in *MPO Canopus* (StarBGone) was used when needed to remove the effect of stars located along the asteroid's path. The subtraction is most effective when the SNR of the star is equal to or less than asteroid SNR. (Aznar, 2013).

When analyzing the rotation period for the six asteroids, a period spectrum covering a wide range of potential solutions was used to determine the most likely period. The Fourier analysis used fourth-order or less fits to make sure that the amplitude of the Fourier model lightcurve would not go far beyond the amplitude of the asteroid lightcurve.

Number	Name	Class	p _v	H
238	Hypatia	C	0.428	8.18
1603	Neva	C	0.0594	10.9
1859	Kovalevskaya	C	0.057	10.7
3002	Delasalle	S	0.24	12.6
4170	Semmelweis	S	0.14	11.6
31013	1996 DR	–	0.15*	14.0

Table II. Asteroid classification, albedo, and absolute magnitude. *Assumed. (LCDB, 2016 February).

The lightcurve of an asteroid can provide information about its shape, especially when the asteroid is near opposition. If the lightcurve is double-peaked (bimodal) and has an amplitude of at least 0.2-0.3 mag, then the asteroid very likely is an elongated body. It is very important to select an appropriate harmonic order to avoid finding the wrong result as the analysis tries to follow the noise in the data.

Assume that the lightcurve has a large enough amplitude. Also assume that the asteroid is approximately a triaxial body where $a > b > c$ and that the asteroid is spinning about the c axis (Harris and Lupishko, 1989). If these assumptions are true, then it is possible to determine a *minimum* a/b axis ratio. The first step is to calibrate the lightcurve amplitude $A(\alpha)$ to its amplitude at zero phase angle $A(0)$ using the formula from Zappala *et al.* (1990):

$$A(0) = A(\alpha) / (1 + m \cdot \alpha) \quad (1)$$

where α is the phase angle and m is the slope that correlates the amplitude to the phase angle.

After finding the amplitude at zero phase angle, it was possible to find the *minimum* a/b ratio for each of the six asteroids using the formula from Zappala *et al.* (1990):

$$\Delta m = 2.5 \log(a/b), \text{ or} \quad (2a)$$

$$a/b = 10^{(\Delta m/2.5)} \quad (2b)$$

where Δm is the peak-to-peak lightcurve amplitude.

These formulae assume that the view of the asteroid is exactly equatorial. If the asteroid's spin axis is tilted towards the Earth,

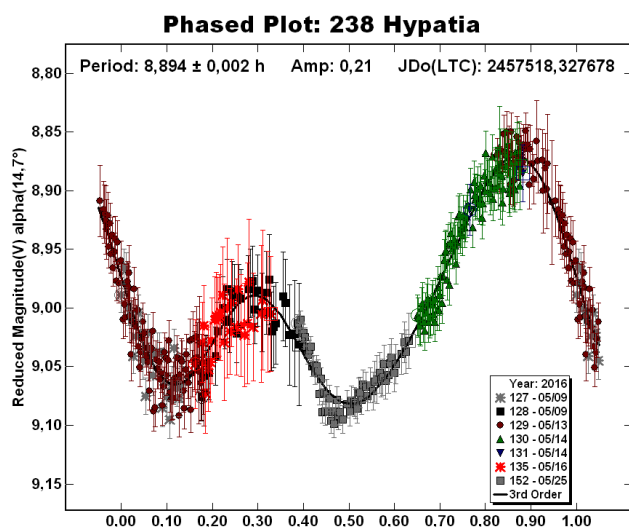
then the a/b ratio is a *minimum* since, when one of the asteroid's poles is pointed exactly towards Earth, the amplitude of the lightcurve is considerably less, sometimes approaching 0.0 mag. See Binzel and Sauter (1992) for the complete formula.

Num	Name	Size	Period (h)	a/b
238	Hypatia	148.48	8.894 ± 0.002	1.172
1603	Neva	36.03	6.430 ± 0.015	1.252
1859	Kovalevskaya	34.40	11.114 ± 0.010	1.272
3002	Delasalle	7.47	6.537 ± 0.010	1.310
4170	Semmelweis	17.0	5.31 ± 0.01	1.563
31013	1996 DR	5.44*	10.52 ± 0.092	1.167

Table III. Physical properties of six asteroids. *Assuming H from Solar System Dynamics (JPL, 2016) and $G = 0.15$ (LCDB).

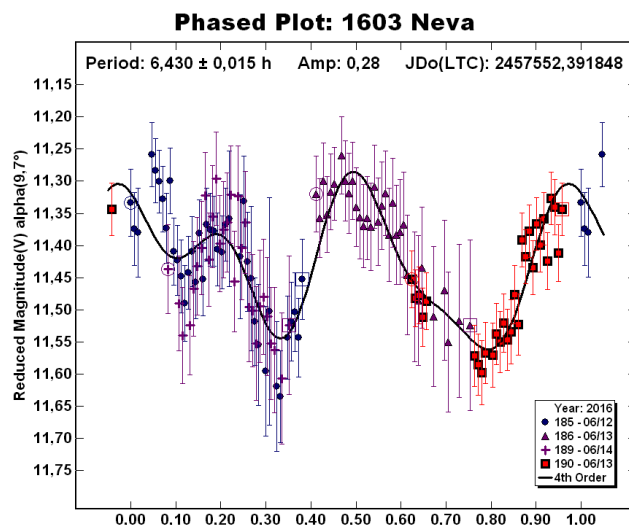
238 Hypatia. This is a 146 km (Mainzer *et al.*, 2011) outer main-belt asteroid was discovered in 1884 by Viktor Knorre in Berlin. Bus and Binzel (2002a; 200b) classified Hypatia as type C. The absolute magnitude is $H = 8.18$ (MPC, 2016). Mainzer *et al.* (2011) found an albedo of $p_V = 0.044$. The LCDB rates the period $U = 3$. Even though the period is well known, it is still useful to get new data in order to evaluate changes in the lightcurve shape and amplitude with different phase angle bisector values (Harris *et al.*, 1984).

The rotation period for Hypatia has been reported by several observers, *e.g.*, Behrend (2011), who reported a period of 8.8749 h and maximum amplitude of 0.12 mag when the phase angle bisector (PAB) values were $L_{PAB} = 181^\circ$ and $B_{PAB} = -0.2^\circ$ while the phase was about 4° . In 2016, a similar synodic rotation period of 8.894 ± 0.002 h was found along with an amplitude of 0.21 mag. The PAB values were $L_{PAB} = 185^\circ$, $B_{PAB} = +2^\circ$ and the phase angle was about 15° . Since the PAB values were similar, the difference in amplitude was probably due almost entirely to the difference in phase angles. Using Eq. 2b, the asteroid's shape projected onto the sky had an a/b ratio of 1.213;



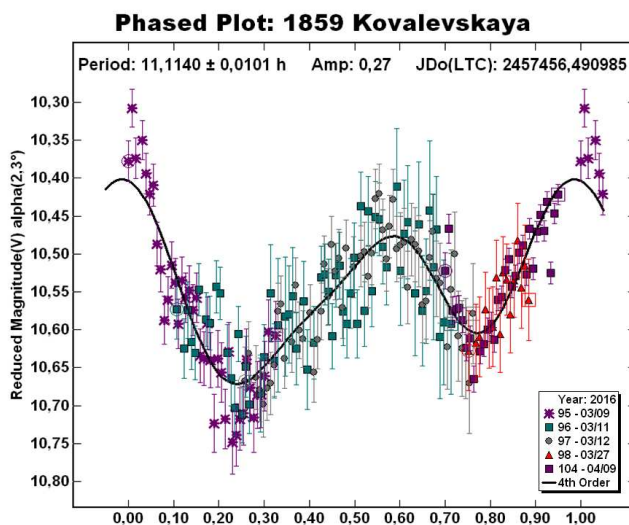
1603 Neva. Discovered in 1926 by Grigori Neúimin, the orbit of this is located at the outer region of the main-belt. This is a C-type asteroid (Bus and Binzel, 2002a; 2002b). Mainzer *et al.* (2011) give a diameter of 36 km based $H = 10.9$ and $p_V = 0.0423$. The only reported rotation period is from Behrend (2004), who found $P = 6.4249$ h and amplitude of 0.22 mag ($U = 2$; LCDB).

Analysis of the data from 2016 found a period of 6.430 ± 0.015 h with an unusual lightcurve shape that has three maximums and three minimums. The maximum lightcurve amplitude is 0.28 magnitudes. The projected shape has $a/b = 1.294$.



1859 Kovalevskaya. This is a C-type asteroid located in the outer main-belt that was discovered in 1974 by Russian astronomer Lyudmila Zhuravleva. The class is assumed based on the albedo $p_V = 0.0427$ found by Mainzer *et al.* (2011) using $H = 10.6$. They gave an estimated size of 46.02 km.

Waszczak *et al.* (2015) found $P = 11.1084$ h and $A = 0.13$ mag using data obtained in 2013. The data from the 2016 campaign show a bimodal lightcurve (two minimums and two maximums) with a period of 11.1140 ± 0.0101 h and amplitude of 0.27 mag. The calculated a/b ratio is 1.282.

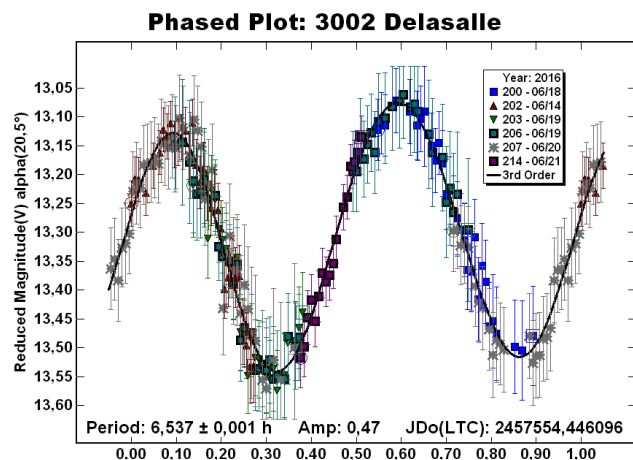


3002 Delasalle. This is a Flora group member that is assumed to be of type S based on it being a part of that group. The asteroid was discovered in 1982 by Henry Debenogne. Waszczak *et al.* (2015) found $H_R = 12.35$. If a V-R color index is not available, the LCDB assumes V-R = 0.45. This gives $H = 12.80$. Masiero *et al.* (2012) used $H = 12.5$ to find $p_V = 0.452$ and $D = 6.3$ km.

A rotation period of about 6.53 hours was reported by Waszczak *et al.* (2015, $A = 0.39$ mag), Pravec *et al.* (2016w, $A = 0.34$ mag), and

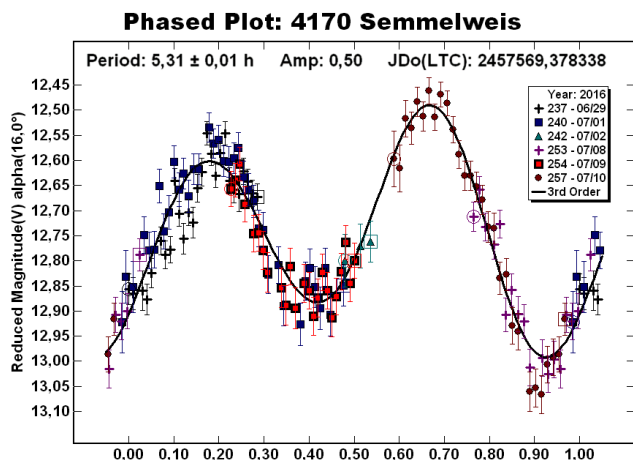
Behrend (2016, $A = 0.35$ mag). The Pravec *et al.* and Behrend results are rated $U = 3$ in the LCDB.

This asteroid was observed by APT during the 2016 opposition. We found a rotation period of $P = 6.537 \pm 0.001$ h, which is consistent with the previous results. The amplitude was 0.47 mag, or a little larger than previous results. The 2016 data were obtained when the phase angle was about 20 degrees, about the same as Waszczak *et al.* but much larger than with the other two results at phase angles < 10 degrees. This clearly shows the amplitude-phase relationship. The projected shape has $a/b = 1.542$.



4170 *Semmelweis* is a member of the Eos group and was discovered in 1980 by Vavrova at Klet. The assumed taxonomic class is S based on the group membership. Mainzer *et al.* (2011) found $D = 17.0$ km and $p_V = 0.1683$ using $H = 11.4$. Waszczak *et al.* (2015) found a period of 5.3051 h.

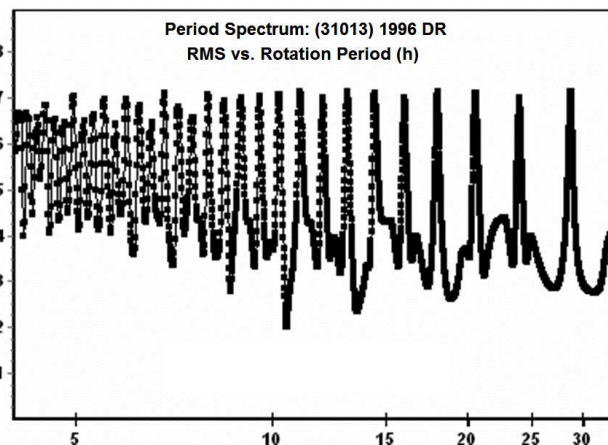
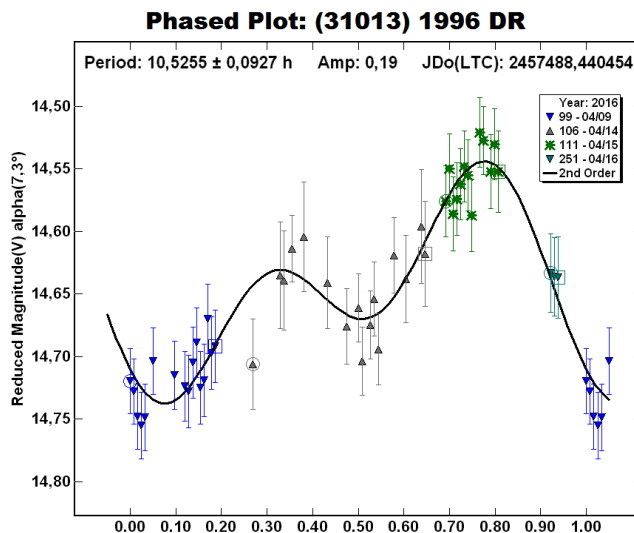
Our analysis of the data from 2016 found a rotation period of 5.31 ± 0.01 h. The lightcurve shows a bimodal shape with an amplitude of 0.50 mag. This amplitude is higher than the two amplitudes reported by Waszczak *et al.* (0.36 and 0.48 mag) using data from 2012 August and September, respectively. The PAB values for our observations were about $L_{PAB} = 237^\circ$ and $B_{PAB} = 12^\circ$. It appears that the main reason for the changes in amplitude from 2012 to 2016 was due to differences in L_{PAB} . The calculation a/b ratio is 1.585.



(31013) 1996 DR. This asteroid was discovered in 1996 by Takao Kobayashi at Oizumi (Japan). The MPC (2016) gives $H = 14.1$. The LCDB gives an assumed taxonomic type of S and $p_V = 0.20$

based on the inner main-belt location. The estimated diameter in the LCDB is 4.5 km.

Pravec *et al.* (2016w) reported a period of about 280 h with an amplitude of 0.5 mag. The analysis made in this campaign reveals a bimodal lightcurve with an amplitude of 0.20 mag with a period of 10.52 ± 0.092 h but the period spectrum shows that there are other solutions possible. Since there are such different results, observations in the future should be made. The estimated a/b ratio is 1.191.



Acknowledgments

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References

- Aznar, A. (2013). "Lightcurve of 3422 Reid using star subtraction techniques." *Minor Planet Bull.* **40**, 214-215.
- Behrend, R. (2004, 2011, 2016). Observatoire de Geneve web site. http://obswww.unige.ch/~behrend/page_cou.html
- Binzel, R.P., Sauter, L.M. (1992). "Trojan, Hilda, and Cybele Asteroids: New Lightcurve Observations and Analysis." *Icarus* **95**, 222-238.

Bus, S.J., Binzel, R.P. (2002a). "Phase II of the Small Main-Belt Asteroid Spectroscopic Survey. The Observations." *Icarus* **158**, 106-145.

Bus, S.J., Binzel, R.P. (2002b). "Phase II of the Small Main-Belt Asteroid Spectroscopic Survey. A Feature-Based Taxonomy." *Icarus* **158**, 146-177.

Harris, A.W., Young, J.W., Scaltriti, F., Zappala, V. (1984). "Lightcurves and phase relations of the asteroids 82 Alkmene and 444 Gyptis." *Icarus* **57**, 251-258.

Harris, A.W., Lupishko, D.F. (1989). "Photometric lightcurve observations and reduction techniques". *Asteroids II*; Proceedings of the Conference, Tucson, AZ, Mar. 8-11, 1988 (A90-27001 10-91). Tucson, AZ, University of Arizona Press, 1989, p. 39-53.

Mainzer, A., Grav, T., Bauer, J., Masiero, J., McMillan, R.S., Cutri, R.M., Walker, R., Wright, E., Eisenhardt, P., Tholen, D.J., Spahr, T., Jedicke, R., Denneau, L., DeBaun, E., Elsbury, D., Gautier, T., Gomillion, S., Hand, E., Mo, W., Watikins, J., Wilkins, A., Bryngelson, G.L., Del Pino Molia, A., Desai, S., Gomez Camus, M., Hidalgo, S.L., Konstantopoulos, I., Larsen, J.A., Maleszewski, C., Malkan, M.A., Mauduit, J.-C., Mullan, B.L., Olszewski, E.W., Pforr, J., Saro, A., Scotti, J.V., Wasserman, L.H. (2011). "NEOWISE observations of near-Earth objects: Preliminary results." *Ap. J.* **743**, A156.

Masiero, J.R., Mainzer, A.K., Grav, T., Bauer, J.M., Cutri, R.M., Nugent, C., Cabrera (2012). "Preliminary Analysis of WISE/NEOWISE 3-Band Cryogenic and Post-Cryogenic Observations of Main Belt Asteroids." *Ap. J. Letters* **759**, L8.

MPC (2016). Minor Planet Center. MPCORB data file.
<http://www.minorplanetcenter.net/iau/MPCORB.html>

Pravec, P., Wolf, M., Sarounova, L. (2016).
<http://www.asu.cas.cz/~ppravec/neo.htm>

Warner, B.D., Harris, A.W., Pravec, P. (2009). "The asteroid lightcurve database" *Icarus* **202**, 134-146. Updated 2016 Feb 20.
<http://www.MinorPlanet.info/lightcurvedatabase.html>

Waszczak, A., Chang, C.-K., Ofek, E.O., Laher, R., Masci, F., Levitan, D., Surace, J., Cheng, Y.-C., Ip, W.-H., Kinoshita, D., Helou, G., Prince, T.A., Kulkarni, S. (2015). "Asteroid Light Curves from the Palomar Transient Factory Survey: Rotation Periods and Phase Functions from Sparse Photometry." *Astron. J.* **150**, A75.

Zappala, V., Cellini, A., Barucci, A.M., Fulchignoni, M., Lupishko, D.E. (1990). "An analysis of the amplitude-phase relationship among asteroids." *Astron. Astrophys.* **231**, 548-560.

LIGHTCURVE AND ROTATION PERIOD OF MAIN-BELT ASTEROID 10259 OSIPORVYURIJ

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CCD photometric observations of main-belt asteroid 10259 Osiporvyurij were made over four nights in 2016 June and July. Fourier analysis rendered a synodic rotation period of 6.370 ± 0.004 h.

The purpose of this research was to find the synodic rotation period of main-belt asteroid 10259 Osiporvyurij. The Asteroid Lightcurve Database (LCDB; Warner *et al.*, 2009) did not show any previously reported results for this object. This asteroid was chosen for its magnitude and opposition near the time of the observation.

Images were taken throughout four consecutive nights from 2016 June 28 to July 1. The first set of observations was carried out using a 0.3-m *f*/8 Maksutov-Cassegrain robotic telescope and (FLI) PL-16803 CCD camera located at Las Campanas Remote Observatory (Chile; Hoot 2015, 2016; Long *et al.*, 2016). A luminance filter was used for the 360-s exposures. The other three observations were performed with a 0.4-m *f*/8 Meade robotic telescope and ATIK-383L CCD camera located at the Center for Solar System Studies in Landers, CA (USA; Hoot 2016; Stephens, 2016). A clear filter was used for the exposures of 240 s.

The images were acquired with *Maxim DL v5.24*. All image processing and photometry, as well as Fourier analysis of the data, was done with *MPO Canopus*. The lightcurve shows a synodic rotation period of $P = 6.370 \pm 0.004$ h and an amplitude of $A = 0.32$ mag.

