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Polarimetric survey of main-belt asteroids

V. The unusual polarimetric behavior of V-type asteroids⋆

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ABSTRACT

Aims. We present the results of a polarimetric survey of main-belt asteroids at Complejo Astronómico El Leoncito (CASLEO), San Juan, Argentina. The aims of this survey are to increase the database of asteroid polarimetry, to estimate diversity in polarimetric properties of asteroids that belong to different taxonomic classes, and to search for objects that exhibit anomalous polarimetric properties.

Methods. The data were obtained using the CASPROF and CASPOL polarimeters at the 2.15 m telescope. The CASPROF polarimeter is a two-hole aperture polarimeter with rapid modulation and CASPOL is a polarimeter based on a CCD detector, which allows us to observe fainter objects with better signal-to-noise ratio.

Results. The survey began in 1995 and data on a large sample of asteroids were obtained until 2012. A second period began in 2013 using a polarimeter with a more sensitive detector in order to study small asteroids, families, and special taxonomic groups. We obtained 55 polarimetric measurements for 28 V-type main belt asteroids, all of them polarimetrically observed for the first time. The data obtained in this survey let us find polarimetric parameters for (1459) Magnya and for a group of 11 small V-type objects with similar polarimetric behavior. These polarization curves are unusual since they show a shallow minimum and a small inversion angle in comparison with (4) Vesta, although they have a steeper slope at α_0. This polarimetric behavior could be explained by differences in the regoliths of these asteroids. The observations of (2579) Spartacus, and perhaps also (3944) Halliday, indicate a inversion angle larger than 24–25°.

Key words. minor planets, asteroids: general – techniques: polarimetric

1. Introduction

Polarimetry is an observational technique used to obtain information about the surface of atmosphereless objects. When unpolarized sunlight is scattered by the rough surface of a minor body it becomes partially polarized. The polarized light is usually found to be linear with its azimuth either normal or parallel to the scattering plane, which in the solar system is the plane containing the object, the Sun, and the Earth at the epoch of observation. In the case of asteroids, the degree of linear polarization depends on the illumination conditions and is modulated by surface properties such as composition, albedo, texture, rugosity, and porosity.

The variation of the degree of linear polarization as a function of the phase angle α, which is the angle between the directions to the Sun and to the observer as seen from the object, produces a polarization curve that is described by some parameters whose measured values are found to be diagnostic of the properties of the surface. For phase angles $\lesssim 20°$ the polarimetric curve turns out to be negative, reaching its minimum, $P_{\min}$, at phase angle $\alpha_{\min} \approx 8$–$10°$. Beyond the inversion angle, $\alpha_0 \approx 19$–$20°$, the polarization becomes positive and increases for larger phase angles with a slope h.

This general behavior characterizes all asteroids observed so far with some minor differences depending on the optical properties of the surface (e.g., Dollfus et al. 1989; Muinonen et al. 2002a; Kaasalainen et al. 2003). For example, $P_{\min}$ and h appear to be related to the geometric albedo of the surface by empirical laws (see Zellner & Gradie 1976; Zellner 1979), producing characteristic polarization curves for different taxonomic types: the asteroids with low albedo surfaces have deeper $P_{\min}$ and steeper h than those with high albedo surfaces.

Thus, it is expected that a group of objects with homogeneous surface mineralogy have similar polarimetric properties. This was confirmed by observing asteroids of the same taxonomic type (Gil-Hutton 2007; Gil-Hutton et al. 2007; Gil-Hutton & Cañada-Assandri 2011, 2012; Cañada-Assandri et al. 2012), but there are a few exceptions: the F-type asteroids with small inversion angles (Belskaya et al. 2005), the Barbarian group with strong negative polarization for $\alpha > 20°$ (Cellino et al. 2006; Gil-Hutton et al. 2008), and the albedo differences between asteroids in the X-type taxonomic class (Cañada-Assandri et al. 2012).

A taxonomic class that could be interesting to study by means of polarimetry is the V-type class. A large fraction of these objects are members of the Vesta family which is located in the inner asteroid belt and was formed from a

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collisional event that excavated a large crater on (4) Vesta (Asphaug 1997). Vesta shows a crust composed of basaltic material (McCord et al. 1970), which is also observed in many Vesta family members (Xu et al. 1995; Lazzaro et al. 2004). Nowadays, several V-type asteroids are known to reside in the inner asteroid belt but outside the Vesta family (Burbine et al. 2001; Florczak et al. 2002; Alvarez-Candal et al. 2006), and a few objects were also found in the outer asteroid belt (Lazzaro et al. 2000; Roig & Gil-Hutton 2006; Duffard & Roig 2009). The V-type objects in the outer asteroid belt are difficult to explain since they are too far from the Vesta family to be considered fragments from the Vesta's crust; this gives support to the possible existence of another differentiated parent body which was fragmented and dispersed in such a way that today it is not possible to identify the resulting family (Michtchenko et al. 2002).

The first V-type identified in the outer asteroid belt during a spectroscopic survey of small solar system objects was the asteroid (1459) Magnya (Lazzaro et al. 2000). Using radiometric methods the geometric albedo of Magnya was reported by several authors, but it value varies from 0.22 ± 0.05 using IRAS data (Tedesco et al. 2002) to 0.37 ± 0.06 obtained with thermal radiometry (Delbo et al. 2006). In the case of Vesta, the geometric albedo varies from 0.29−0.33 using *Dawn* data (Cellino et al. 2016) to 0.37 ± 0.02 using IRAS data (Tedesco et al. 2002). On the other hand, Hardersen et al. (2004) studied the mineralogy of Magnya and found that its spectrum matches a basaltic composition, but it also shows discordant pyroxene chemistries in comparison with Vesta, suggesting that it could have originated from a different parent body. Since polarimetry provides useful information about the physical properties of the asteroid surface, it could be important to obtain polarimetric measurements for these objects to test the differences between Vesta and other V-types.

Since 1995 we have developed a campaign of polarimetric observations at Complejo Astronómico El Leoncito (CASLEO), Argentina, with the main objective of increasing the available polarimetric database of main-belt asteroids. At the same time, we have also developed several observing programs focused on more specific objectives, including an extensive polarimetric survey of taxonomic classes and asteroid groups which began in 2003. The first epoch of this survey ended in 2012 and a second epoch started in 2013 using new and more sensitive equipment. In this paper we present the polarimetric results for V-type asteroids observed during both epochs of the CASLEO survey. In Sect. 2 the observations are described, in Sect. 3 we present the results, and in Sect. 4 we discuss them. Finally, in Sect. 5 the conclusions are presented.

2. Observations

Our observations were carried out during different observing runs between May 2004 and November 2015 at the 2.15 m telescope of CASLEO, using either the CASPROF or CASPOL polarimeters. CASPOL is a polarization unit inserted in front of a CCD camera that allows high precision imaging polarimetry. It was built following the design of Magalhães et al. (1996), and uses an achromatic halfwave retarder and a Savart plate as analyzer. The reduction and analysis of the images is done using IRAF tasks and scrips, and the polarimetric parameters and errors are obtained from a least-squares solution to the measurements made at different halfwave plate positions. A full description of CASPROF polarimeter is given in Gil-Hutton et al. (2008). All the polarimetric measurements made before the last semester of 2013 were taken using the CASPROF polarimeter and those taken after that date were obtained using the new CASPOL unit. All the polarimetric measurements were made using a *V*-band filter.

From the analysis of several standard stars, we found the instrumental polarization to be fairly constant and stable, always below 0.06% for both instruments. Whenever possible, we observed the targets during runs some weeks apart to obtain measurements during the same apparition at different phase angles. Observing nights were generally assigned around the new Moon to minimize the contamination of sky polarization by moonlight. Each night, we observed at least two zero-polarization standard stars and one high-polarization star to determine instrumental polarization. The standard star data were obtained from Turnshek et al. (1990), Gil-Hutton & Benavidez (2003), and Fossati et al. (2007).

We observed the targets consecutively several times each night with individual exposure times long enough to reach final flux signal-to-noise ratios (S/N) ≥30. Since all the objects observed are very faint ($V_{\rm mag} > 16{-}17$) several measurements of each object were co-added to improve the S/N, and the measurement errors were evaluated assuming a Poisson distribution. After correcting for instrumental polarization, we obtained the Stokes parameters for each filter with reduction programs specifically designed for each instrument, with some modifications to optimize the reduction to the specific needs of asteroid polarimetry. This includes computations of the position angle of the scattering plane and of the polarization parameter $P_r = (I_\perp - I_\parallel)/(I_\perp + I_\parallel)$, where $I_\perp$ and $I_\parallel$ are the intensities of the scattered light polarized along the planes perpendicular and parallel to the scattering plane, respectively. As a test of the data reduction process, a histogram of the ratio between the U component of linear polarization and its error was made, and the distribution is to be centered at zero; all points differ from this value by less than 3−4σ, which supports the reliability of the polarimetric measurements.

3. Results

During this survey we obtained 55 observations of 28 main-belt V-type asteroids, all of them observed polarimetrically for the first time. Each asteroid's name, date, total integration time in seconds ($T_{\rm int}$), phase angle (α), position angle of the scattering plane ($\theta_\odot$), degree of linear polarization (P) and its error (σ_P), position angle in the equatorial reference frame (θ) and its error (σ_θ), P_r, and Bus taxonomic classification (Bus 1999) are shown in Table A.1.

(1459) Magnya was the first V-type discovered in the outer asteroid belt (Lazzaro et al. 2000) and nine observations of this object were obtained (Fig. 1). A comparison with the polarization curve of (4) Vesta shows that these objects do not have the same polarimetric properties because they do not follow the same polarization curve, indicating that their surface properties could be different or the mineralogy might not be the same, in agreement with Hardersen et al. (2004). Since these objects have the same taxonomic type, and the slope at α_0 for Magnya is steeper than that for Vesta, is is expected that the $P_{\rm min}$ of Magnya must be deeper than that of Vesta, but this is not observed and could indicate that this object has unusual polarimetric properties.

The polarimetric parameters for Magnya can be obtained by fitting the observations to a polarization curve using a function

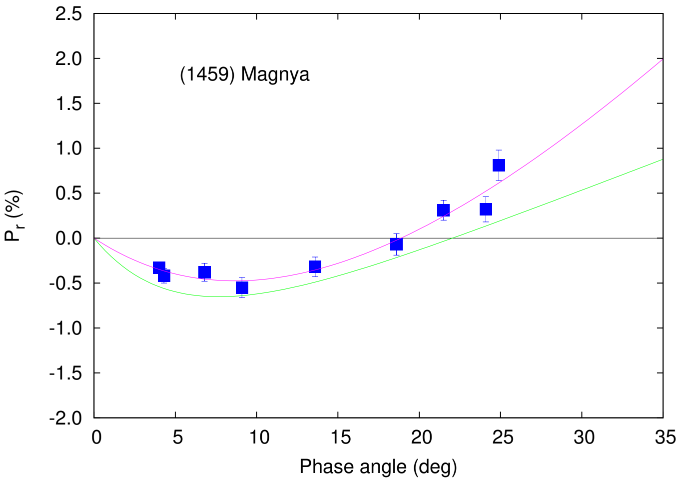

Fig. 1. Polarimetric observations of (1459) Magnya. The best fit found for the polarization curve is shown as a cyan line. For comparison, the polarization curve for (4) Vesta is indicated by a green line.

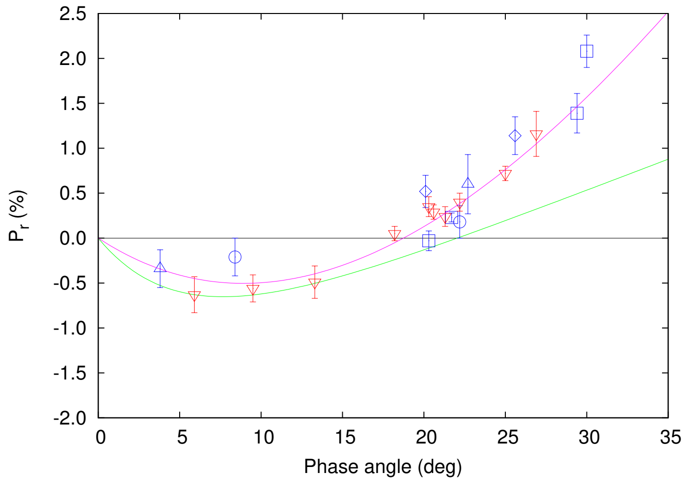

Fig. 2. Polarimetric observations of V-type asteroids with polarimetric properties similar to (1459) Magnya. The observations of (809) Lundia are indicated with squares; (2468) Repin with circles; (2795) Lepage with triangles; (4005) Dyagilev with diamonds; and those of (956) Elisa, (1946) Walraven, (2432) Soomana, (2590) Mourao, (3657) Ermolova, (6976) Kanatsu, and (7302) 1993 CQ are indicated with inverted red triangles since we have only one or two measurements for each object. The best fit found for the polarization curve is shown as a cyan line. For comparison, the polarization curve for (4) Vesta is indicated by a green line.

proposed by Piironen et al. (2000), Kaasalainen et al. (2001a,b), and Muinonen et al. (2002b)

$$P_r(\alpha) = A_0\left[\exp\left(-\frac{\alpha}{A_1}\right) - 1\right] + A_2\alpha, \qquad (1)$$

where A_0, A_1, and A_2 are constant coefficients. In the case of Magnya we found a minimum of the polarization curve of $|P_{\rm min}| = 0.48 \pm 0.22\%$ at $\alpha_{\rm min} = 8.7 \pm 1.8°$, a slope of the polarization curve at α_0 of $h = 0.085 \pm 0.014\%/°$, and an inversion angle of $\alpha_0 = 18.9 \pm 0.5°$. For comparison, the polarization curve for Vesta is also shown in Fig. 1 with polarimetric parameters $|P_{\rm min}| = 0.65 \pm 0.03\%$, $\alpha_{\rm min} = 7.7 \pm 0.1°$, $h = 0.065 \pm 0.001\%/°$, and $\alpha_0 = 22.1 \pm 0.6°$.

It is usual to find the mean polarimetric albedo p by applying empirical relations linking it with $P_{\rm min}$ or h, but in this case the value of $P_{\rm min}$ is lower than normally expected, so we apply only the relation linking it with h, which is expressed by means of a very simple mathematical form,

$$\log p(h) = C_1 \log h + C_2, \qquad (2)$$

where C_1 and C_2 are constants. In this paper we use the set of constants proposed by Cellino et al. (2015) for asteroids with $p > 0.08$, namely $C_1 = -0.780 \pm 0.037$ and $C_2 = -1.469 \pm 0.036$. Using this empirical relation with the polarimetric slope found previously, we obtain $p(h) = 0.23 \pm 0.02$ for (1459) Magnya, but this result must be taken with caution since the polarization curve for this asteroid seems to be unusual.

This polarimetric behavior is also observed in other V-type asteroids. Figure 2 shows the polarimetric observations of 11 objects that seem to follow a polarization curve similar to that of (1459) Magnya. Ten of these asteroids are objects of the inner asteroid belt and only (7302) 1993 CQ is in the intermediate asteroid belt. Among the ten inner belt objects, (2468) Repin, (2590) Mourao, (3657) Ermolova, and (4005) Dyagilev are Vesta family members. Considering all these asteroids as a group, we found a best fit polarization curve with $|P_{\rm min}| = 0.50 \pm 0.22\%$ at $\alpha_{\rm min} = 8.9 \pm 1.9°$, $h = 0.097 \pm 0.017\%/°$, and $\alpha_0 = 18.7 \pm 0.4°$, which agrees very well with the polarimetric parameters found for Magnya.

The polarimetric observations of the remaining 16 V-types studied in this survey are shown in Fig. 3. These are asteroids

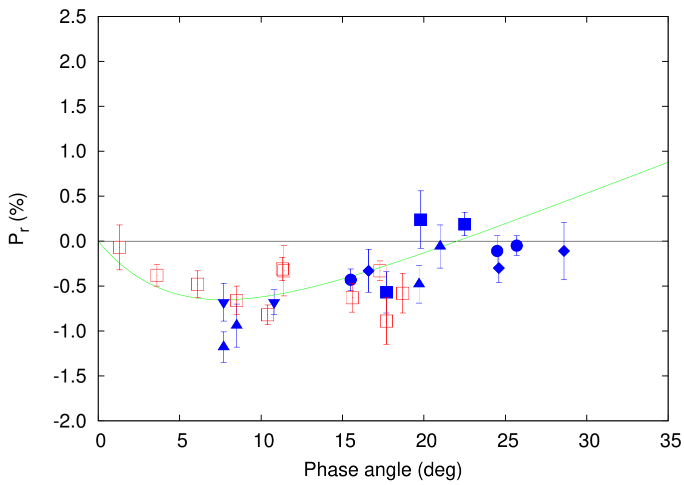

Fig. 3. Polarimetric observations of V-type asteroids not included in Figs. 1 or 2. The observations of (2045) Peking are indicated with filled squares; (2579) Spartacus with filled circles; (2763) Jeans with filled triangles; (2851) Harbin with filled inverted triangles; (3944) Halliday with filled diamonds; and those of (1273) Helma, (1929) Kollaa, (1933) Tinchen, (2011) Veteraniya, (2442) Corbett, (2640) Hallstrom, (2653) Principia, (3153) Lincoln, (4215) Kamo, (4546) Franck, and (6406) 1992 MJ are indicated with red squares since we have only one measurement for each object. For comparison, the polarization curve for (4) Vesta is indicated by a green line.

with few observations, but in several cases it is possible to obtain some results. The observations of (2045) Peking indicate that this object has a slope at α_0 larger than that of Vesta indicating a lower albedo. (2763) Jeans has a minimum of the polarimetric curve that is deeper than Vesta's and an inversion angle $\alpha_0 \simeq 22{-}23°$. This object must have a slope of the polarimetric curve that is steeper than that found for Vesta, but we do not have measurements at phase angles larger than 22.5° to confirm that. The polarimetric observations of (2579) Spartacus suggests that the inversion angle must be larger than ≃24−25°, but it seems that its polarization curve does not show strong negative polarization for $\alpha > 20°$ as in the case of the Barbarians (Cellino et al. 2006; Gil-Hutton et al. 2008). The observations of asteroid (3944) Halliday show the same behavior as (2579) Spartacus suggesting that it also has a large inversion angle, but in this case the accuracy of the measurements is not very good and may lead to erroneous conclusions about the shape of its polarization curve. The other objects show different behaviors, including objects with observations that follow the polarimetric curve of Vesta very well indicating similar polarimetric properties.

4. Discussion

The polarization curves of (1459) Magnya and the group formed by 11 small V-type asteroids exhibit remarkable differences from that of (4) Vesta. It was hoped that the $P_{\rm min}$ of these polarization curves should be deeper at their minimum than Vesta's, but this was not observed; instead, they show a shallow negative branch of the polarization curve which is not easy to explain. These objects have minor differences in their spectra, but they all were classified taxonomically as V-type (e.g., Binzel & Xu 1993; Florczak et al. 2002; Duffard & Roig 2009), so it is expected that the differences observed between them are not due to strong differences in the mineralogy, but we must also take into account that for these small and faint asteroids misclassification is not fully excluded. Nevertheless, four of these asteroids are members of the Vesta family giving some support to the assumption of a similar mineralogy for all these objects.

One possible explanation for the polarimetric behavior came from the analysis of the asteroid sizes. Eighteen of the 28 V-type objects observed in this survey have WISE diameters, and all of them are small objects with sizes <11 km (Masiero et al. 2010), while (1459) Magnya was observed by thermal radiometry and its albedo and diameter indicate that it is also a small asteroid (Delbo et al. 2006). This could make a great difference when we try to compare the polarization curves of small objects with a large asteroid whose diameter is 530 km because it is expected that the physical properties of the regolith are completely different in one case and in the other. For Vesta a mature regolith of fine particles is expected, but in the case of the small asteroids it is highly probable that the regolith is formed mainly by dust-free bare rocks since in a small object the escape velocity is very low and it would be difficult for it to retain the small particles.

Although the polarization curves of particulate surfaces do not always change significantly its shape in function of the particle sizes, it is known that in the case of a basalt surface the behavior is similar to what we observe for these objects: the polarization curve of an intact basalt sample has a shallow minimum, smaller inversion angle, and almost the same slope at α_0 as a pulverized sample of fine particles (Shkuratov et al. 1994). The same result is obtained for olivine if the samples are of particulate surfaces with very different particle sizes (Shkuratov et al. 2006) where the surface with larger particles shows a polarimetric behavior similar to that observed for an intact surface. On the other hand, this scenario and the polarimetric parameters obtained also agree very well with the traditional α_0 vs. $|P_{\rm min}|$ plots of Geake & Dollfus (1989).

5. Conclusions

Using the CASPROF and CASPOL polarimeters at Complejo Astronómico El Leoncito we obtained 55 polarimetric measurements for 28 V-type main belt asteroids, all of them polarimetrically observed for the first time. The data obtained in this survey provide polarimetric parameters for (1459) Magnya and for a group of 11 small V-type objects with similar polarimetric behavior.

The mean polarimetric parameters obtained for Magnya are $|P_{\rm min}| = 0.48 \pm 0.22\%$ at $\alpha_{\rm min} = 8.7 \pm 1.8°$, $h = 0.085 \pm 0.014\%/°$, and $\alpha_0 = 18.9 \pm 0.5°$, while for the case of the group of small asteroids we obtained $|P_{\rm min}| = 0.50 \pm 0.22\%$ at $\alpha_{\rm min} = 8.9 \pm 1.9°$, $h = 0.097 \pm 0.017\%/°$, and $\alpha_0 = 18.7 \pm 0.4°$ which agree very well with the polarimetric parameters found for Magnya.

These polarization curves seem to be unusual since they show a shallow minimum and a small inversion angle in comparison with (4) Vesta, even though they have a steeper slope at α_0. This unusual polarimetric behavior could be explained by differences in the regoliths of these asteroids.

The observations of the remaining 16 objects observed in this survey do not allow their polarization curves to be determined because the data is scarce, but in several cases we can glimpse some results as the slope at α_0 of (2045) Peking, the $P_{\rm min}$ of (2763) Jeans, and the large inversion angles of (2579) Spartacus and, perhaps, (3944) Halliday. In any case, the V-type population at the main asteroid belt shows a variety of polarimetric behavior that justifies a more complete study of this taxonomic group in the future.

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Appendix A: Additional material

Table A.1. Asteroids observed with the CASPROF and CASPOL polarimeters.

Asteroid	Date UT	$T_{\rm int}$ s	α °	$\theta_\odot$ °	P %	σ_P %	θ °	σ_θ °	P_r %	Tax
(809) Lundia	2005-09-02	2160	30.0	77.2	2.39	0.18	152.4	2.2	2.08	V
(809) Lundia	2005-09-05	1440	29.4	77.8	1.54	0.22	154.9	4.0	1.39	V
(809) Lundia	2005-10-04	3150	20.3	87.6	0.16	0.11	127.8	17.5	−0.03	V
(809) Lundia	2015-06-24	2880	21.7	65.1	0.25	0.05	142.8	5.7	0.23	V
(956) Elisa	2015-06-24	2880	25.0	63.0	0.73	0.08	148.5	3.3	0.72	V
(1273) Helma	2013-06-08	1920	3.6	46.2	0.38	0.12	46.3	8.7	−0.38	V
(1459) Magnya	2004-07-15	1440	24.9	68.5	1.12	0.17	0.2	4.3	0.81	V
(1459) Magnya	2004-08-25	1440	21.5	77.5	0.32	0.11	164.4	9.2	0.31	V
(1459) Magnya	2004-10-14	1080	4.3	124.6	0.47	0.08	137.9	5.1	−0.42	V
(1459) Magnya	2004-10-15	1080	4.0	130.0	0.37	0.06	117.1	4.9	−0.33	V
(1459) Magnya	2013-05-05	1920	6.8	125.2	0.38	0.10	129.3	7.6	−0.38	V
(1459) Magnya	2013-06-08	1920	13.6	115.0	0.33	0.11	110.6	9.4	−0.32	V
(1459) Magnya	2014-06-29	4800	9.1	72.5	0.62	0.11	86.0	5.1	−0.55	V
(1459) Magnya	2015-06-26	1080	24.1	65.9	0.32	0.14	155.9	11.8	0.32	V
(1459) Magnya	2015-11-14	2880	18.6	58.4	0.07	0.12	59.2	29.0	−0.07	V
(1929) Kollaa	2013-09-05	1440	11.4	49.3	0.69	0.28	18.8	11.1	−0.33	V
(1933) Tinchen	2014-11-29	1920	6.1	152.2	0.46	0.15	168.9	8.8	−0.38	V
(1946) Walraven	2014-06-29	2400	20.3	102.4	0.35	0.11	13.9	8.7	0.35	V
(1946) Walraven	2014-06-30	E440	20.6	102.7	0.31	0.08	3.0	7.3	0.29	V
(2011) Veteraniya	2014-07-26	4800	10.4	83.0	0.83	0.11	77.9	3.7	−0.82	V
(2045) Peking	2004-07-16	1440	17.7	74.7	0.89	0.23	99.9	7.1	−0.57	V
(2045) Peking	2004-10-16	1800	19.8	67.2	0.86	0.32	120.4	10.3	0.24	V
(2045) Peking	2015-06-25	2880	22.5	71.0	0.20	0.13	171.5	16.5	0.19	V
(2432) Soomana	2015-11-17	1680	22.2	67.6	0.80	0.10	127.5	3.7	0.40	V
(2442) Corbett	2013-10-05	1440	8.5	71.2	0.66	0.16	67.7	6.8	−0.66	V
(2468) Repin	2004-07-15	1080	8.4	125.7	0.97	0.21	86.8	6.2	−0.21	V
(2468) Repin	2015-11-14	3360	22.2	68.5	0.37	0.18	127.8	13.0	0.18	V
(2579) Spartacus	2013-06-08	960	25.7	70.8	0.90	0.11	114.3	3.4	−0.05	V
(2579) Spartacus	2013-10-05	1680	24.5	78.6	0.81	0.17	119.7	6.0	−0.11	V
(2579) Spartacus	2013-09-04	3360	15.5	85.6	0.54	0.12	104.1	6.2	−0.43	V
(2590) Mourao	2013-10-06	1680	21.3	78.4	0.25	0.11	176.4	11.2	0.24	V
(2590) Mourao	2013-09-06	1440	9.5	100.4	0.63	0.15	86.5	6.6	−0.56	V
(2640) Hallstrom	2013-10-08	1440	1.3	96.0	0.56	0.25	54.8	11.9	−0.07	V
(2653) Principia	2013-10-08	1680	17.3	74.0	0.46	0.11	96.4	6.6	−0.33	V
(2763) Jeans	2004-05-17	720	8.5	111.1	1.29	0.24	132.8	5.2	−0.94	V
(2763) Jeans	2004-05-19	720	7.7	113.2	1.27	0.17	124.0	3.9	−1.18	V
(2763) Jeans	2004-07-17	1440	21.0	97.7	0.50	0.24	139.1	12.8	−0.06	V
(2763) Jeans	2015-06-25	2100	19.7	105.0	0.48	0.21	108.3	12.0	−0.48	V
(2795) Lepage	2013-09-04	3840	3.8	141.6	0.51	0.21	165.8	11.1	−0.34	V
(2795) Lepage	2014-09-02	2880	22.7	109.7	0.92	0.33	44.1	9.9	0.60	V
(2851) Harbin	2005-09-02	1440	10.8	92.4	0.89	0.14	112.6	4.4	−0.68	V
(2851) Harbin	2005-10-04	2790	7.7	28.5	0.71	0.21	21.1	8.1	−0.68	V
(3153) Lincoln	2014-07-26	2400	15.6	84.0	0.63	0.16	83.1	6.9	−0.63	V
(3657) Ermolova	2013-09-05	1200	5.9	140.7	0.81	0.20	160.1	6.9	−0.63	V
(3657) Ermolova	2013-10-05	1440	18.2	81.0	0.37	0.08	129.7	6.0	0.05	V
(3944) Halliday	2013-09-06	1680	24.6	78.1	0.76	0.16	44.9	6.0	−0.30	V
(3944) Halliday	2013-10-05	1680	28.6	80.0	1.31	0.32	122.5	6.9	−0.11	V
(3944) Halliday	2013-06-08	1920	16.6	86.3	0.37	0.24	99.9	16.4	−0.33	V
(4005) Dyagilev	2013-06-11	2880	20.1	115.0	0.52	0.18	26.4	9.5	0.52	V
(4005) Dyagilev	2014-07-27	2400	25.6	71.8	1.21	0.21	171.3	4.9	1.14	V
(4215) Kamo	2013-10-08	1440	11.3	82.2	0.32	0.13	88.0	11.0	−0.31	V
(4546) Franck	2013-10-08	1920	17.7	74.3	0.99	0.26	86.9	7.4	−0.89	V
(6406) 1992 MJ	2013-10-08	1440	18.7	56.4	0.59	0.22	61.6	10.2	−0.58	V
(6976) Kanatsu	2015-11-17	2100	26.9	60.6	1.31	0.25	136.8	5.3	1.16	V
(7302) 1993 CQ	2015-11-15	3360	13.3	107.8	0.54	0.18	95.3	9.2	−0.49	V