A LIGHTCURVE ANALYSIS FOR NINE MAIN-BELT AND ONE MARS-CROSSING ASTEROIDS

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Synodic rotation periods and amplitudes are reported for: 153 Hilda, 975 Perseverantia, 1203 Nanna, 1366 Piccolo, 1397 Umtata, 1763 Williams, 2168 Swope, 3768 Monroe, 6164 Gerhardmuller, 6601 Schmeer, 7000 Curie

The periods and amplitudes of asteroid lightcurves presented in this paper are the product of collaborative work by the GORA (Grupo de Observadores de Rotaciones de Asteroides) group. In all the studies, we have applied relative photometry assigning V magnitudes to the calibration stars.

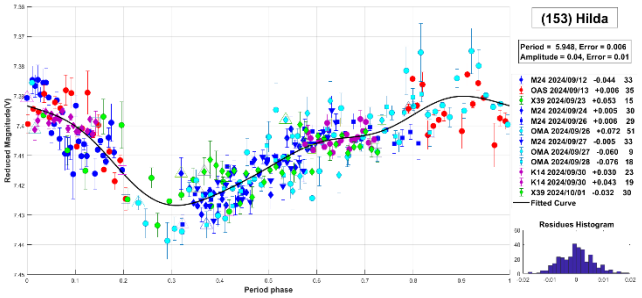
The image acquisition was performed without filters and with exposure times of a few minutes. All images used were corrected using dark frames and, in some cases, bias and flat-field corrections were also used. Photometry measurements were performed using *FotoDif* software and for the analysis, we employed *Periodos* software (Mazzone, 2012).

Below, we present the results for each asteroid studied. The lightcurve figures contain the following information: the estimated period and period error and the estimated amplitude and amplitude error. In the reference boxes, the columns represent, respectively, the marker, observatory MPC code, or - failing that - the GORA internal code, session date, session offset, and several data points.

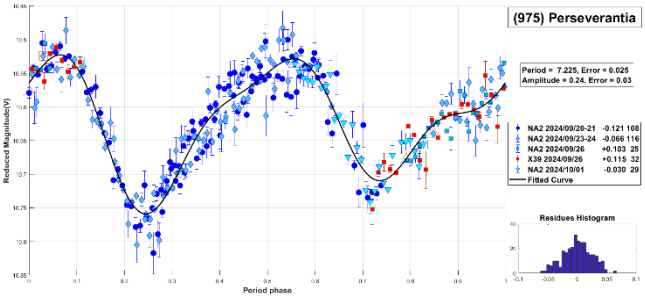
Targets were selected based on the following criteria: 1) those asteroids with magnitudes accessible to the equipment of all participants, 2) those with favorable observation conditions from Argentina or Spain or Italy, i.e. with negative or positive declinations δ, respectively, and 3) objects with few periods reported in the literature and/or with Lightcurve Database (LCDB) (Warner et al., 2009) quality codes (U) of less than 3.

In this work, we present measurements of periods corresponding to asteroids previously analyzed by our team. These lightcurves display improved results and are part of a new long-term project that we are initiating.

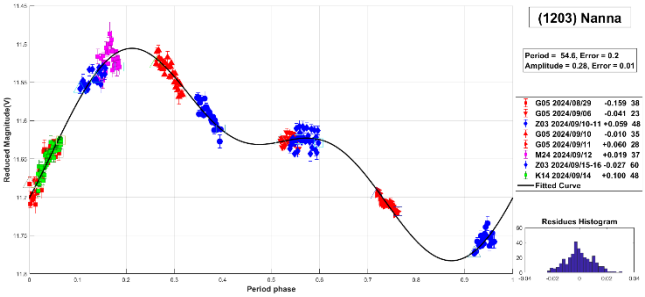
153 Hilda. Hilda is an outer main-belt asteroid, discovered in 1875 by J. Palisa. Classified as a P-type asteroid according to the Tholen taxonomy, it is the parent body of the Hilda family (Nesvorny et al., 2015). The diameter, derived from IRAS observations, is 170.63 km. Shevchenko et al. (2009) measured a rotation period of 5.9587 ± 0.0005 h. Our measurement of the period, P = 5.948 ± 0.006 h, with Δm = 0.04 ± 0.01 mag, agrees well with the value reported by the previous authors.



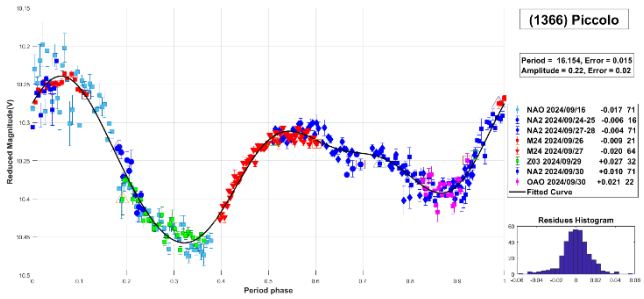
975 Perseverantia. This main-belt asteroid was discovered in 1922 by J. Palisa. Classified as an S-type asteroid according to the Tholen taxonomy, it is a member of the Koronis family (Nesvorny et al., 2015). The diameter is 22.169 km. The reported rotation period for this asteroid is 7.267 h (Behrend, 2003web). Our measurement of the period, P = 7.225 ± 0.025 h, with Δm = 0.24 ± 0.03 mag, agrees well with the value reported by the previous author.



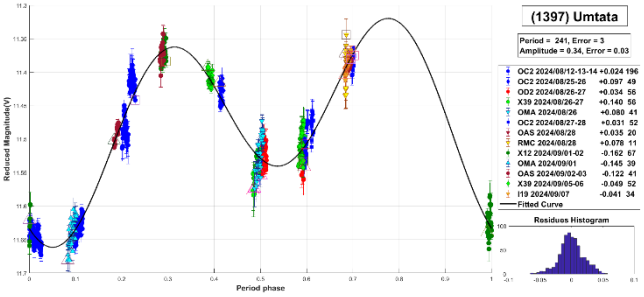
1203 Nanna. This main-belt asteroid was discovered in 1931 by M. Wolf, with a diameter of 35.18 km. The reported rotation period for 1203 Nanna is P = 18.54 ± 0.01 h (Warner, 2011). However, the same author previously measured a longer period: P = 25.80 ± 0.05 h (Warner, 2010). In this work, we propose an even longer period of P = 54.6 ± 0.2 h with Δm = 0.28 ± 0.01 mag.



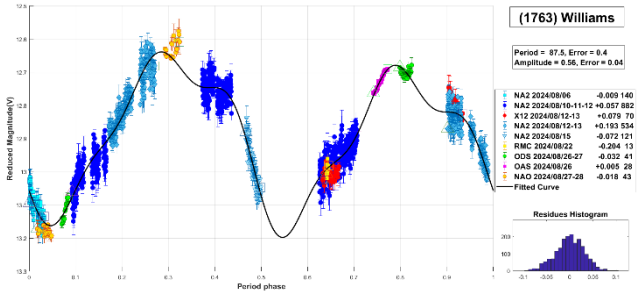
1366 Piccolo. This main-belt asteroid was discovered in 1932 by E. Delporte. It is classified as an X-type asteroid according to the Tholen taxonomy. The diameter is 27.55 km. The reported rotation period for this asteroid is 16.57 h (Binzel, 1987). We measured a period of P = 16.154 ± 0.015 h, with Δm = 0.22 ± 0.02 mag.



1397 Umtata. This main-belt asteroid was discovered in 1936 by C. Jackson, with a diameter of 20.798 km. An intial estimate of rotation period was reported as P = 30 h (Binzel, 1987). In this work, we propose a considerably longer period of P = 241 ± 3 h with Δm = 0.34 ± 0.03 mag.



1763 Williams. Williams is a main-belt asteroid with a diameter of 6.982 km, discovered in 1953 by the Goethe Link Observatory. A previously reported rotation period for this asteroid is P = 88.62 h (Ďurech et al., 2018). Our observations also support the long-period conclusion, yielding a similar value of P = 87.5 ± 0.4 h with Δm = 0.56 ± 0.04 mag.



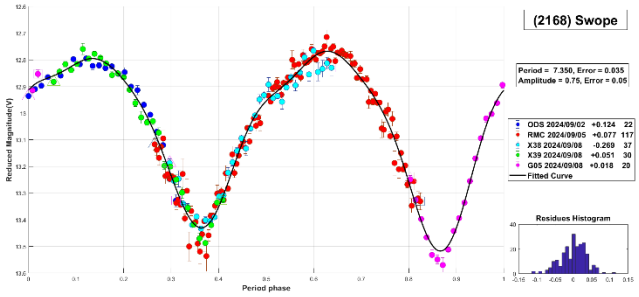
2168 Swope. This main-belt asteroid was discovered in 1955 at the Goethe Link Observatory. It is classified as a V-type asteroid according to the Tholen taxonomy, with a diameter of 8.205 km. Interestingly, we could not find a reported rotation period for this object in the literature. Based on our observations and thorough analysis, we propose a period of P = 7.350 ± 0.035 h and Δm = 0.75 ± 0.05 mag.

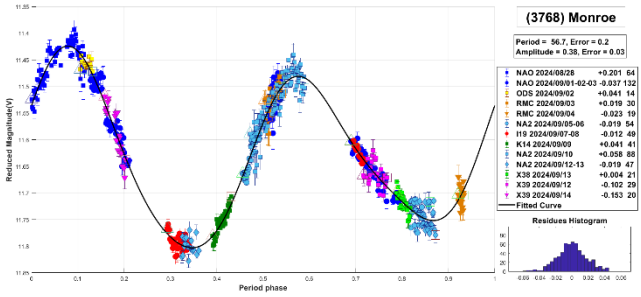
Number	Name	yy/ mm/dd- yy/ mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
153	Hilda	24/09/12-24/10/02	3.8,8.5	340	8	5.948	0.006	0.04	0.01	HIL
975	Perseverantia	24/09/20-24/10/01	3.5,7.7	349	-2	7.225	0.025	0.24	0.03	KOR
1203	Nanna	24/08/29-24/09/16	11.9,04.5	358	6	54.6	0.2	0.28	0.01	MB-O
1366	Piccolo	24/09/16-24/09/30	6.9,01.7	7	-4	16.154	0.015	0.22	0.02	MB-O
1397	Umtata	24/08/12-24/09/08	*3.6,12.4	324	-5	241	3	0.34	0.03	MB-M
1763	Williams	24/08/06-24/08/29	1.0,15.2	315	2	87.5	0.4	0.56	0.04	MB-I
2168	Swope	24/09/02-24/09/08	4.4,02.4	346	4	7.350	0.035	0.75	0.05	MB-I
3768	Monroe	24/08/28-24/09/14	*4.7,04.9	343	-5	56.7	0.2	0.38	0.03	MB-O
6164	Gerhardmuller	24/07/18-24/09/06	*13.7,17.4	316	-5	361	3	0.36	0.04	FLO
6601	Schmeer	24/08/25-24/08/30	9.0,11.9	320	-3	2.667	0.026	0.14	0.04	MB-I
7000	Curie	24/08/27-24/10/04	*16.9,13.5	355	-14	805	20	0.29	0.03	MB-I

Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extremum during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009). MB-I: main-belt inner; MB-M: main-belt middle; MB-O: main-belt outer; FLO: 8 Flora; KOR: 158 Koronis; HIL: 153 Hilda.

Observatory	Telescope	Camera
G05 Obs.Astr.Giordano Bruno	SCT (D=203mm; f=6.3)	CCD Atik 420 m
I19 Obs.Astr.El Gato Gris	SCT (D=355mm; f=10.6)	CCD SBIG STF-8300M
K14 Obs.Astr.de Sencelles	Newtonian (D=250mm; f=4.0)	CCD SBIG ST-7XME
M24 Oss.Astr.La Macchina del Tempo	RCT (D250mm; f=8.0)	CMOS ZWO ASI 1600MM
X12 Obs.Astr.Los Cabezones	Newtonian (D=200mm; f=5.0)	CMOS QHY 174M
X38 Observatorio Pueyrredón	Newtonian (D=300mm; f=4.5)	CCD Apogee U8300
X39 Obs.Astr.Antares	Newtonian (D=250mm; f=4.72)	CCD QHY9 Mono
Z03 Obs.Astr.Río Cofio	SCT (D=254mm; f=6.3)	CCD SBIG ST-8XME
NAO Obs.Astr.Naos	Newtonian (D=250mm; f=4.0)	CMOS QHY 163M
NA2 Obs.Astr.Naos 2	Newtonian (D=200mm; f=5.0)	CMOS ZWO ASI 174
OAO Obs.Astr.Aficionado Omega	Newtonian (D=150mm; f=5.0)	CMOS QHY 174M
OAS Obs.Astr.de Ariel Stechina 1	Newtonian (D=254mm; f=4.7)	CCD SBIG STF-402
OA2 Obs.Astr.de Ariel Stechina 2	Newtonian (D=305mm; f=5.0)	CMOS QHY 174M
ODS Obs.Astr.de Damián Scotta 1	Newtonian (D=300mm; f=4.0)	CMOS QHY 174M
OD2 Obs.Astr.de Damián Scotta 2	Newtonian (D=250mm; f=4.0)	CCD SBIG STF-8300M
OC2 Obs.Astr.de Carlos Ambrosioni	SCT (D=279mm; f=6.7)	CCD SBIG ST8XME
OMA Obs.Astr.Vuelta por el Universo	Newtonian (D=150mm; f=5.0)	CMOS POA Neptune-M
RMC Obs.Astr.de Raúl Melia Carlos Paz	Newtonian (D=254mm; f=4.7)	CMOS QHY 174M

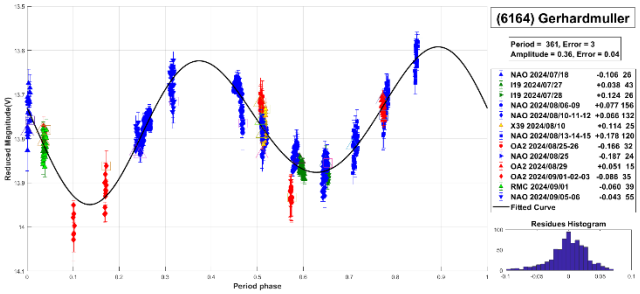
Table II. List of observatories and equipment.



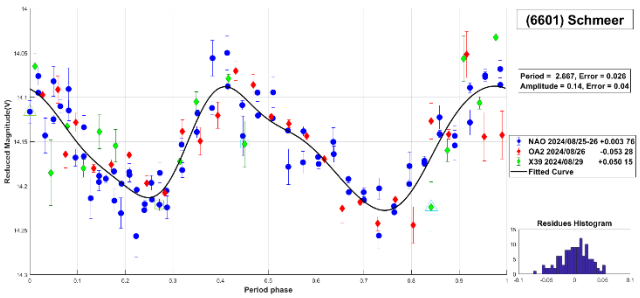


3768 Monroe. This main-belt asteroid was discovered in 1937 by C. Jackson. It is classified as a C-type asteroid according to the Tholen taxonomy, with a diameter of 26.601 km. For this asteroid, we could not find any published rotation periods in the literature. In this work, we propose a period of P = 56.7 ± 0.2 h with Δm = 0.38 ± 0.03 mag.

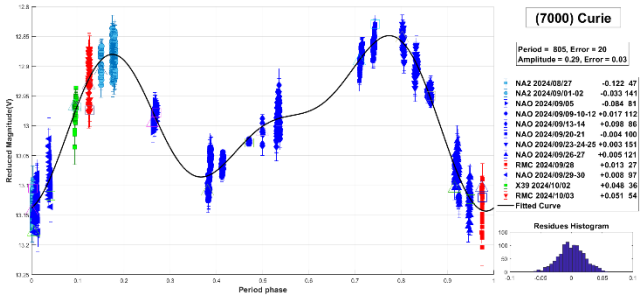
6164 Gerhardmuller. This main-belt asteroid was discovered in 1977 by N.S. Chernykh. It is a member of the Flora family (Nesvorny et al., 2015), with a diameter of 4.912 km. A review of the literature revealed no published rotation periods for this asteroid. In this work, we propose a long period of P = 361 ± 3 h with Δm = 0.36 ± 0.04 mag.



6601 Schmeer. Schmeer is a main-belt asteroid with a diameter of 6.946 km, discovered in 1988 by S. Ueda and H. Kaneda. No published rotation periods for this asteroid were found in the literature. In this work, we propose a short period of P = 2.667 ± 0.026 h with Δm = 0.14 ± 0.04 mag.



7000 Curie. Curie is a main-belt asteroid with a diameter of 6.497 km, discovered in 1939 by F. Rigaux. For this asteroid, we couldn't find published periods in the literature either. In this work, we propose a long period of P = 805 ± 20 h with Δm = 0.29 ± 0.03 mag.



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PHOTOMETRIC ANALYSIS OF PATROCLUS-MENOETIUS MUTUAL EVENTS AND 15 OTHER ASTEROIDS

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Synodic rotation periods and amplitudes are reported for: 617 Patroclus, 903 Nealley, 1205 Ebella, 1962 Dunant, 2032 Ethel, 2046 Leningrad, 2443 Tomeileen, 2801 Huygens, 2821 Slavka, 3583 Burdett, 4225 Hobart, 4916 Brumberg, 5565 Ukyounodaibu, 11441 Anadiego, 13441 Janmerlin, and (47834) 2000 EN114.

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The image acquisition was performed without filters and with exposure times of a few minutes. All images used were corrected using dark frames and, in some cases, bias and flat-field corrections were also used. Photometry measurements were performed using *FotoDif* software and for the analysis, we employed *Periodos* software (Mazzone, 2012).

Below, we present the results for each asteroid studied. The lightcurve figures contain the following information: the estimated period and period error and the estimated amplitude and amplitude error. In the reference boxes, the columns represent, respectively, the marker, observatory MPC code, or - failing that - the GORA internal code, session date, session offset, and several data points.

Targets were selected based on the following criteria: 1) those asteroids with magnitudes accessible to the equipment of all participants, 2) those with favorable observation conditions from Argentina or Spain or Italy, i.e. with negative or positive declinations δ, respectively, and 3) objects with few periods reported in the literature and/or with Lightcurve Database (LCDB) (Warner et al., 2009) quality codes (U) of less than 3.

In this work, we present measurements of periods corresponding to asteroids previously analyzed by our team. These lightcurves display improved results and are part of a new long-term project that we are initiating.

617 Patroclus. In response to the paper "Call for Observations of the Patroclus and Menoetius Mutual Events: Support for the NASA Lucy Mission to the Trojan Asteroids" (Binzel, 2024), we conducted observations of the Patroclus-Menoetius binary system from 2024/08/10 to 2024/10/28. The Patroclus-Menoetius binary is a flyby target for NASA's Lucy mission, scheduled to be reached in March 2033. The binary nature of this system was discovered in 2001 (Merline et al., 2001). We determined an orbital period for its two components of P = 102.9 ± 0.2 h (see Figure 1a). Additionally, we estimated that the two components orbit around their center of mass in 4.28 days (102.786 h; see Figure 1b). These results are in agreement with previous measurements by Marchis et al. (2006) and Mueller et al. (2010).

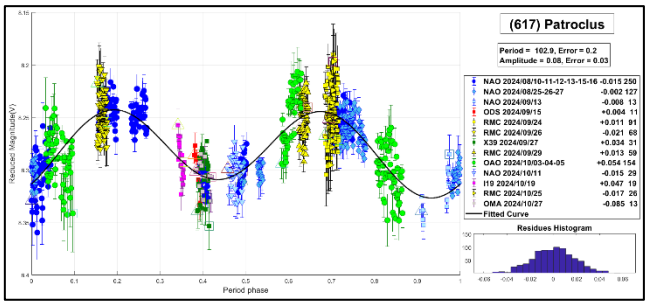


Figure 1a.

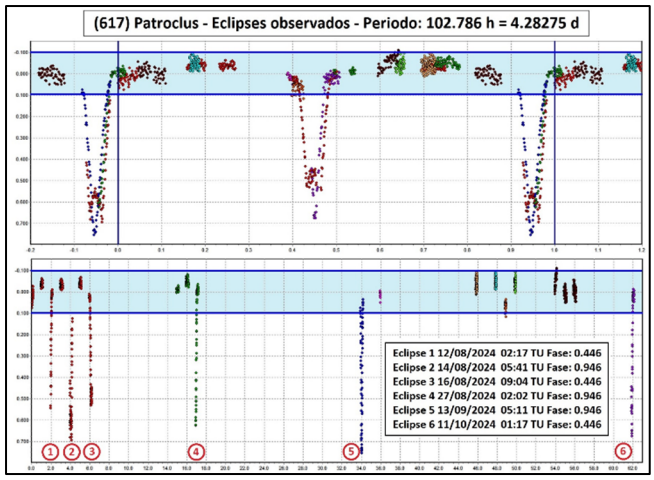
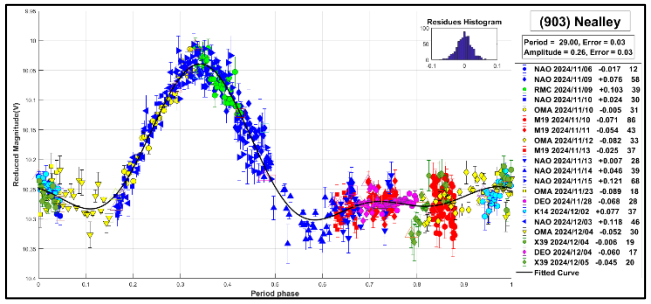
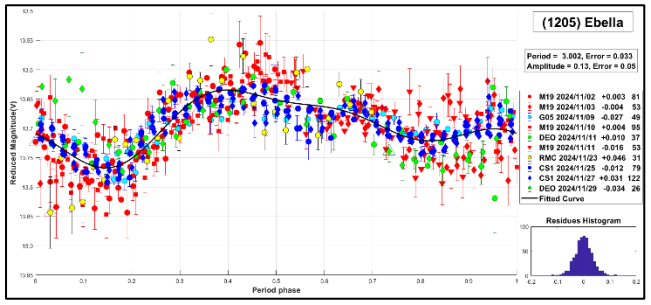


Figure 1b.

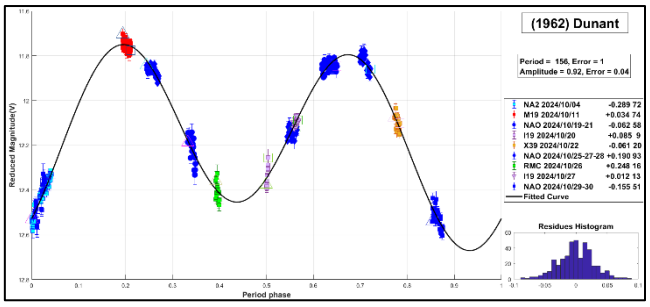
903 Nealley. This outer main-belt asteroid has a diameter of 58.065 km, discovered in 1918 by J. Palisa. The reported rotational period for this asteroid is P = 19.72 h (based on less than full coverage; Warner, 2012). Our observations suggest a longer period, yielding a value of P = 29.00 ± 0.03 h with Δm = 0.26 ± 0.03.



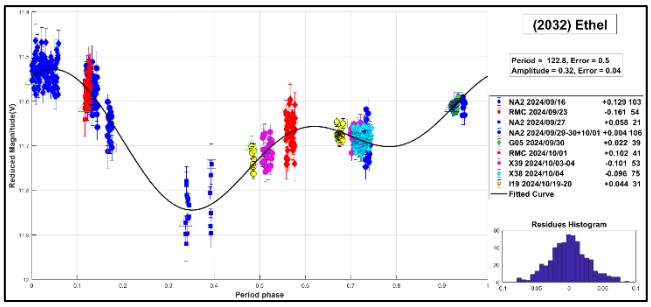
1205 Ebella. This main-belt asteroid has a diameter of 5.747 km, discovered in 1931 by K. Reinmuth. For this asteroid, we couldn't find published periods in the literature. In this work, we propose a short period of P = 3.002 ± 0.033 h with Δm = 0.13 ± 0.05 mag.



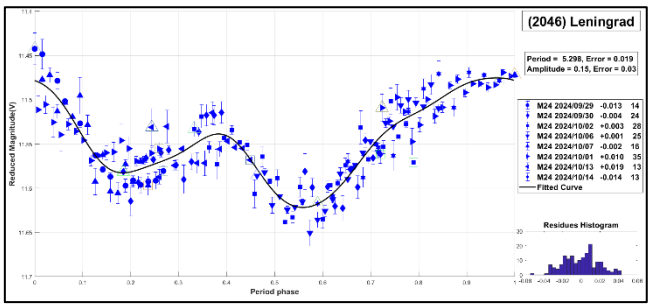
1962 Dunant. This main-belt asteroid was discovered in 1973 by P. Wild. It is classified as a C-type asteroid according to the SDSS-based Asteroid Taxonomy (Carvano et al., 2010), with a diameter of 18.927 km. For this asteroid, we could not find any published rotational periods in the literature. In this work, we propose a long period of P = 156 ± 1 h with Δm = 0.92 ± 0.04 mag.



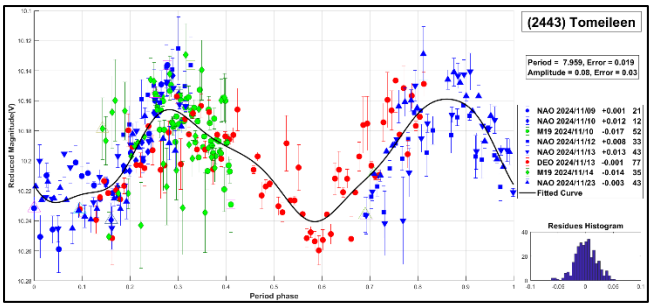
2032 Ethel. This main-belt asteroid has a diameter of 36.007 km, discovered in 1970 by T. Smirnova. For this asteroid, we could not find any published periods in the literature either. In this work, we propose a long period of P = 122.8 ± 0.5 h with Δm = 0.32 ± 0.04 mag.



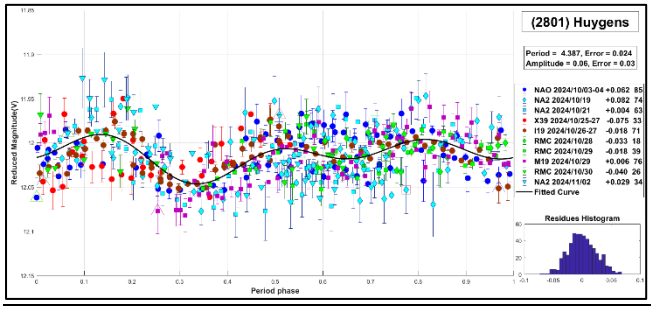
2046 Leningrad. This main-belt asteroid was discovered in 1968 by T. Smirnova. It is a member of the Themis family (Nesvorny et al., 2015), with a diameter of 23.968 km. The reported rotational period for this asteroid is P = 5.296 h (based on less than full coverage; Simpson et al., 2013). Our observations also support the short-period hypothesis, yielding a value of P = 5.298 ± 0.019 h with Δm = 0.15 ± 0.03.



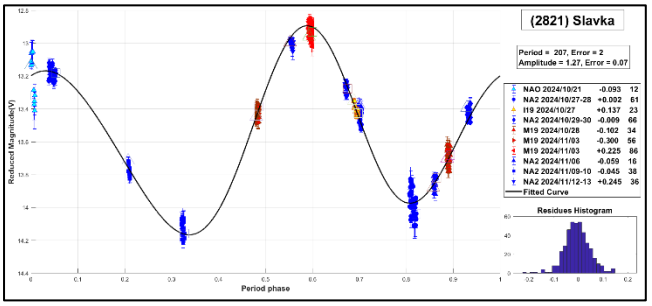
2443 Tomeileen. This main-belt asteroid was discovered in 1906 by M. Wolf. It is a member of the Eos family (Nesvorny et al., 2015), with a diameter of 31.878 km. The reported rotational period for this asteroid is P = 7.954 h (based on less than full coverage; Bonamico, 2020). Our measurement of the period, P = 7.959 ± 0.019 h, with Δm = 0.08 ± 0.03, agrees well with the value reported by the author.



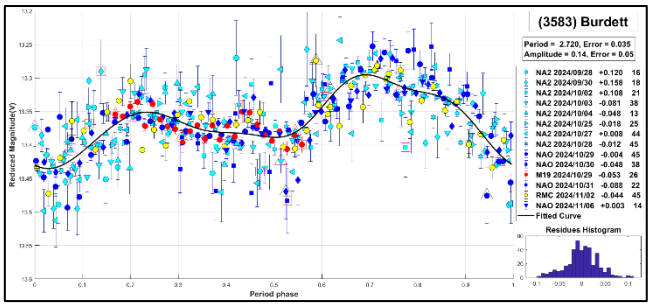
2801 Huygens. This main-belt asteroid was discovered in 1935 by H. Van Gent. It is a member of the Gefion family (Nesvorny et al., 2015), with a diameter of 11.525 km. It is an S-type asteroid in the SMASSII spectral type scheme (Xu et al., 1995; Bus and Binzel, 2002). Interestingly, we could not find a reported rotational period for this object in the literature. Based on our observations and thorough analysis, we propose a period of P = 4.387 ± 0.024 h and Δm = 0.06 ± 0.03 mag.



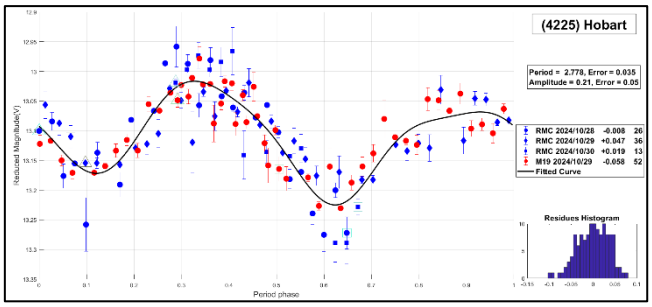
2821 Slavka. This main-belt asteroid has a diameter of 3.935 km, discovered in 1978 by Z. Vavrova. For this asteroid, we could not find published periods in the literature either. In this work, we propose a long period of P = 207 ± 2 h with Δm = 1.27 ± 0.07 mag.



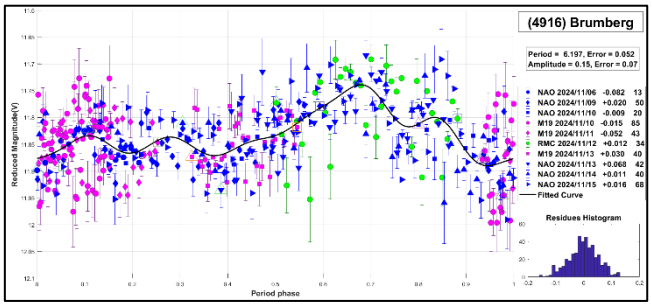
3583 Burdett. This main-belt asteroid was discovered in 1929 by C.W. Tombaugh. It is a member of the Nysa-Polana family (Nesvorny et al., 2015), with a diameter of 6.598 km. It is classified as an LS-type asteroid according to the SDSS-based Asteroid Taxonomy (Carvano et al., 2010). For this asteroid, we could not find any published rotational periods in the literature. In this work, we propose a period of P = 2.720 ± 0.035 h with Δm = 0.14 ± 0.05 mag.



4225 Hobart. This main-belt asteroid has a diameter of 6.397 km, discovered in 1989 by T. Hioki and N. Kawasato. For this asteroid, we couldn't find published periods in the literature either. In this work, we propose a short period of P = 2.778 ± 0.035 h with Δm = 0.21 ± 0.05 mag.



4916 Brumberg. This main-belt asteroid was discovered in 1970 by Crim. Astroph. Obs. The diameter is 16.507 km. The reported rotational period for this asteroid is 6.683 h (based on less than full coverage; Behrend, 2010web). Our measurement of the period, P = 6.197 ± 0.052 h, with Δm = 0.15 ± 0.07, agrees well with the value reported by the author.



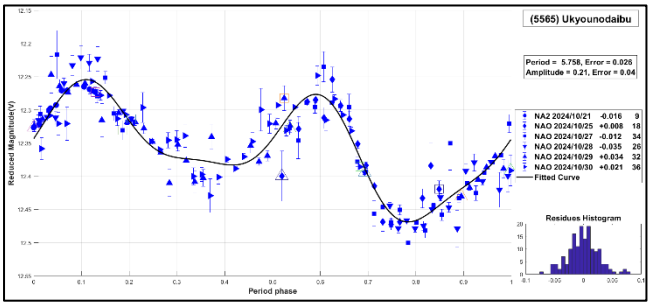
5565 Ukyounodaibu. This main-belt asteroid has a diameter of 12.286 km, discovered in 1970 by Natori and Urata. It is classified as an LS-type asteroid according to the SDSS-based Asteroid Taxonomy (Carvano et al., 2010) and as an S-type in the SMASSII spectral type scheme (Xu et al., 1995; Bus and Binzel, 2002). For this asteroid, we couldn't find published periods in the literature either. Based on our observations and thorough analysis, we propose a period of P = 5.758 ± 0.026 h and Δm = 0.21 ± 0.04 mag.

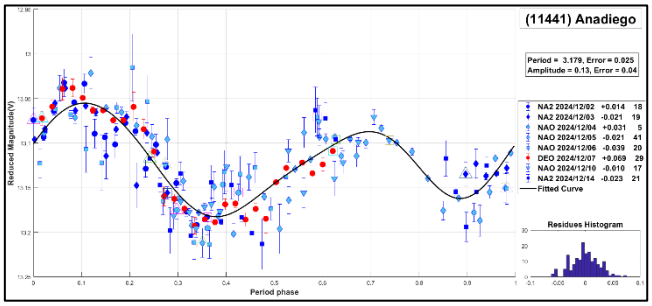
Number	Name	yy/ mm/dd- yy/ mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	Grp
617	Patroclus	24/08/10-24/10/28	*10.7,07.6	5	-17	102.9	0.2	0.08	0.03	HUN
903	Nealley	24/11/06-24/12/05	*07.8,07.1	60	-14	29.00	0.03	0.26	0.03	MB-O
1205	Ebella	24/11/02-24/11/29	*11.6,07.8	57	7	3.002	0.033	0.13	0.05	MB-I
1962	Dunant	24/10/04-24/10/30	01.2,12.8	9	0	156	1	0.92	0.04	MB-O
2032	Ethel	24/09/16-24/10/20	00.9,13.7	352	-1	122.8	0.5	0.32	0.04	MB-O
2046	Leningrad	24/09/29-24/10/14	13.4,07.7	37	-2	5.298	0.019	0.15	0.03	THM
2443	Tomeileen	24/11/06-24/11/15	07.9,05.6	62	-12	7.959	0.019	0.08	0.03	EOS
2801	Huygens	24/10/03-24/11/02	*02.9,13.6	11	-4	4.387	0.024	0.06	0.03	MB-O
2821	Slavka	24/10/21-24/11/13	19.6,07.7	61	-1	207	2	1.27	0.07	MB-I
3583	Burdett	24/09/28-24/11/06	*17.4,03.7	37	0	2.720	0.035	0.14	0.05	HER
4225	Hobart	24/10/28-24/10/30	13.3,14.2	13	-3	2.778	0.035	0.21	0.05	MB-I
4916	Brumberg	24/11/06-24/11/15	08.9,06.6	60	-14	6.197	0.052	0.15	0.07	EOS
5565	Ukyounodaibu	24/10/21-24/10/30	19.7,16.7	64	-13	5.758	0.026	0.21	0.04	MB-O
11441	Anadiego	24/12/02-24/12/14	12.4,09.3	84	-13	3.179	0.025	0.13	0.04	MB-I
13441	Janmerlin	24/09/29-24/11/16	*09.2,17.4	22	-3	23.082	0.049	0.58	0.07	MB-M
47834	2000 EN114	24/11/02-24/12/15	*17.8,28.2	53	25	29.087	0.046	0.40	0.07	PHO

Table I. Observing circumstances and results. The phase angle is given for the first and last date. If preceded by an asterisk, the phase angle reached an extremum during the period. L_{PAB} and B_{PAB} are the approximate phase angle bisector longitude/latitude at mid-date range (see Harris et al., 1984). Grp is the asteroid family/group (Warner et al., 2009). MB-O: main-belt outer; MB-I: main-belt inner; HUN: Hungaria; HER: Hertha; EOS: 221 Eos; THM: Themis; MB-M: main-belt middle; PHO: Phocaea.

Observatory	Telescope	Camera
G05 Obs.Astr.Giordano Bruno	SCT (D=203mm; f=6.3)	CCD Atik 420 m
I19 Obs.Astr.El Gato Gris	SCT (D=355mm; f=10.6)	CCD SBIG STF-8300M
K14 Obs.Astr.de Sencelles	Newtonian (D=250mm; f=4.0)	CCD SBIG ST-7XME
M19 Osservatorio Explorer	Newtonian (D=254mm; f=3.8)	CCD Atik 414EX
M24 Oss.Astr.La Macchina del Tempo	RCT (D250mm; f=8.0)	CMOS ZWO ASI 1600MM
X38 Observatorio Pueyrredón	Newtonian (D=300mm; f=4.5)	CCD Apogee U8300
X39 Obs.Astr.Antares	Newtonian (D=250mm; f=4.72)	CCD QHY9 Mono
CS1 CapoSudObservatory	RCT (D=400mm; f=5.7)	CCD Atik 383L+Mono
DEO Dark Energy Observatory	Refractor (D=115mm; f=7.0)	CMOS QHY 294M pro
NAO Obs.Astr.Naos	Newtonian (D=250mm; f=4.0)	CMOS QHY 163M
NA2 Obs.Astr.Naos 2	Newtonian (D=200mm; f=5.0)	CMOS ZWO ASI 174
OAO Obs.Astr.Aficionado Omega	Newtonian (D=150mm; f=5.0)	CMOS QHY 174M
ODS Obs.Astr.de Damián Scotta 1	Newtonian (D=300mm; f=4.0)	CMOS QHY 174M
OMA Obs.Astr.Vuelta por el Universo	Newtonian (D=150mm; f=5.0)	CMOS POA Neptune-M
RMC Obs.Astr.de Raúl Melia Carlos Paz	Newtonian (D=254mm; f=4.7)	CMOS QHY 174M

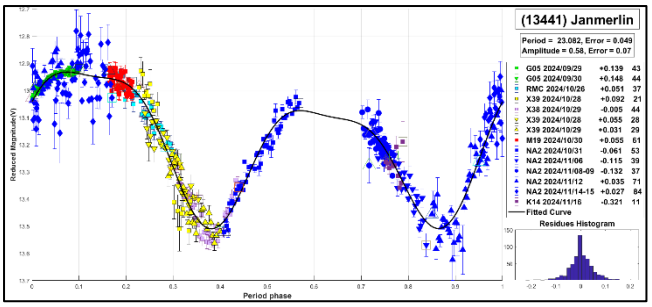
Table II. List of observatories and equipment.



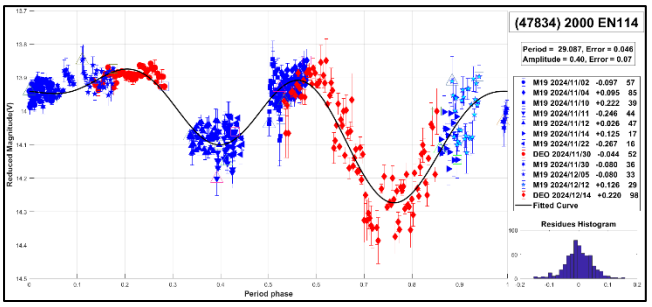


11441 Anadiego. This main-belt asteroid has a diameter of 6.833 km, discovered in 1975 by M.R. Cesco. It is classified as an S-type asteroid according to the SDSS-based Asteroid Taxonomy (Carvano et al., 2010). The reported rotational period for this asteroid is 3.179 h (based on less than full coverage; Hills, 2014). Our measurement of the period, P = 3.179 ± 0.025 h, with Δm = 0.13 ± 0.04, agrees well with the value reported by the author.

13441 Janmerlin. This main-belt asteroid was a diameter of 6.351 km, discovered in 1960 by C.J. Van Houten and I. Van Houten-Groeneveld on Palomar Schmidt plates taken by T. Gehrels. No published rotational periods for this asteroid were found in the literature. In this work, we propose a period of P = 23.082 ± 0.049 h with Δm = 0.58 ± 0.07 mag.



(47834) 2000 EN114. This Mars-crossing asteroid has a diameter of 4.398 km, discovered in 2000 by LINEAR. No published rotational periods for this asteroid were found in the literature. In this work, we propose a period of P = 29.087 ± 0.046 h with Δm = 0.4 ± 0.07 mag.



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