PHOTOMETRIC OBSERVATIONS AND ROTATION PERIODS OF ASTEROIDS 175 ANDROMACHE, 6569 ONDAATJE, AND 2006 NL. ROTATION PERIOD REVISION OF ASTEROID (7335) 1989 JA

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Photometric observations of asteroids 175 Andromache, 6569 Ondaatje, and 2006 NL were conducted in order to determine their synodic rotation period, the absolute brightness with its amplitude and estimate their diameter. For 175 Andromache we found P = 8.324 ± 0.004 h, H = 8.51 ± 0.05 mag, A = 0.40 ± 0.05 mag, D = 105.290 ± 1.170 km (for albedo a = 0.0631) and D = 86.265 ± 1.253 km (for albedo a = 0.094). For 6569 Ondaatje we found P = 5.954 ± 0.002 h, H = 16.44 ± 0.05 mag, A = 0.99 ± 0.05 mag, D = 1.770 ± 0.020 km (for albedo a = 0.15) and D = 1.533 ± 0.021 km (for albedo a = 0.20). For 2006 NL we found P = 6.503 ± 0.003 h, H = 19.65 ± 0.05 mag, A = 1.12 ± 0.05 mag, D = 0.404 ± 0.004 km (for albedo a = 0.15) and D = 0.350 ± 0.005 km (for albedo a = 0.20). We also revised our previously reported synodic rotation period of asteroid (7335) 1989 JA and determined it to be P = 2.588 ± 0.001 h.

We observed asteroids 175 Andromache, 6569 Ondaatje and 2006 NL in order to determine their synodic rotation period, the absolute brightness with its amplitude, and estimate their diameter. Observations took place at four observatories – Simeiz Observatory (MPC code 094) in Crimea, ISON-Kitab Observatory (MPC code 186) in Uzbekistan, Kuban State University Astrophysical Observatory (MPC code C40) in Russia, and ISON-Castelgrande Observatory (MPC code L28) in Italy.

For data processing we used the following software: *Tycho v.9.0.6* (Parrott, 2022) at C40; *APEX v.2021.01.4* (Kouprianov, 2008; Devyatkin et al., 2010) at L28; *Astrometrica v.4.11.1.442* (Raab, 2018) and *FoCAs v.3.66* (Roig et al., 2011) at 094 and 186. All images were calibrated with dark and flat-field frames. Photometry was done in the Gaia G band against reference stars from the Gaia DR3 catalog with near-solar color indices $(G_{BP} - G_{RP})$ = 0.818 ± 10% (Gaia Collaboration, 2022). For the calculation of the absolute brightness, we used a phase slope parameter G = 0.15. For the rotation period search we used a custom-written Python script with the PDM algorithm imported from the *PyAstronomy* package (Czesla et al., 2019); the underlying orbital data was retrieved from the NASA JPL Horizons System (JPL, 2022a) by the imported *Astroquery* package (Ginsburg et al., 2019).

For the conversion from Gaia G to Johnson-Cousins V band we used the transformation:

$$G - V = -0.02704 + 0.01424(G_{BP} - G_{RP}) - 0.2156(G_{BP} - G_{RP})^2 + 0.01426(G_{BP} - G_{RP})^3$$

where: G is Gaia G magnitude, V is Johnson-Cousins V magnitude, and $(G_{BP} - G_{RP})$ is Gaia BP-RP color index (ESA, 2022).

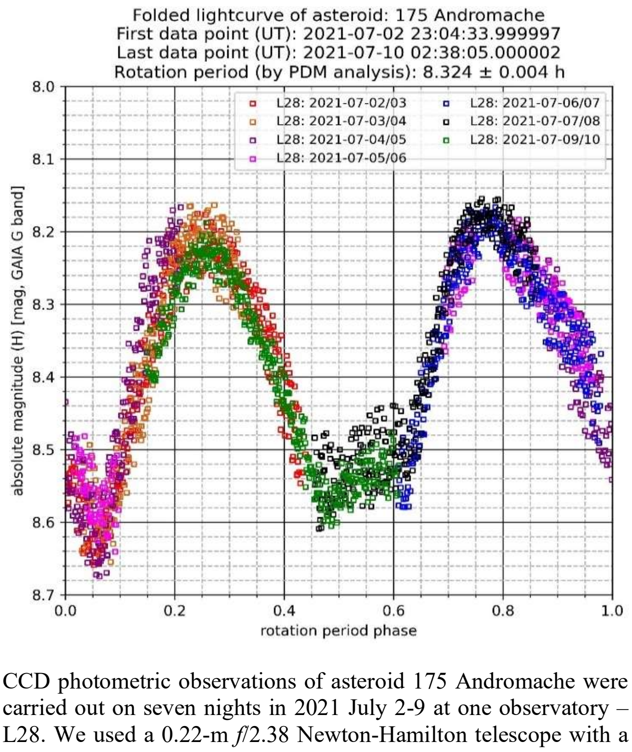
For the estimation of the asteroid diameter, we used the formula:

$$D = 10^{(3.1236- .5\log(\alpha)-0.2H)}$$

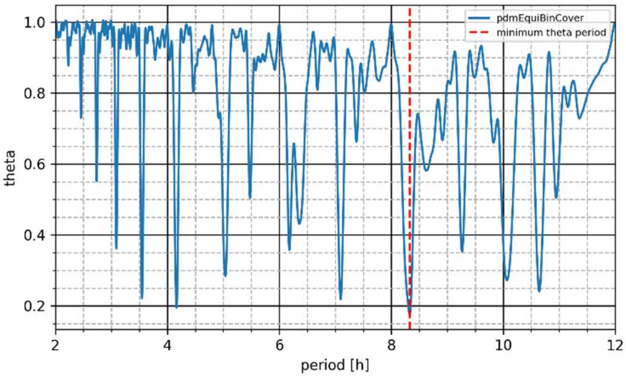
where D is asteroid diameter in km, α is the geometric albedo of the asteroid, and H is the absolute brightness of asteroid in Johnson-Cousins V magnitudes (JPL, 2022b).

Table I shows the observing circumstances and results.

175 Andromache was discovered on 1877 October 1 by J.C. Watson at Ann Arbor (Leuschner, 1936). It is a main-belt asteroid with a semi-major axis of a = 3.18 au, eccentricity e = 0.23, inclination i = 3.22°, and an orbital period of P = 5.68 years; its absolute magnitude has a value of H = 8.63 (MPC, 2022a), other reported values range from H = 8.06 (Warner, 2007) to H = 8.52 (Nugent et al., 2016). In the Asteroid Lightcurve Database (Warner et al., 2009), we found seven reported rotation periods for asteroid 175 Andromache: 7.109 h (Blanco et al., 2000), 7.102 ± 0.001 h (Warner et al., 2009), 8.326 ± 0.001 h (Warner et al., 2009), 8.324 ± 0.004 h (Warner et al., 2009), 8.3296 ± 0.0002 h (Warner et al., 2009), 8.325 ± 0.007 h (Warner et al., 2009), and 8.32801 ± 0.00002 h (Ďurech et al., 2020).



CCD photometric observations of asteroid 175 Andromache were carried out on seven nights in 2021 July 2-9 at one observatory – L28. We used a 0.22-m *f*/2.38 Newton-Hamilton telescope with a FLI PL 16803 CCD camera without filters at 1×1 binning, giving 3.54 arcsec/pix pixel scale, and 30 s exposure times during the nights 2021 July 2-9. In the course of the entire observation campaign, the phase angle of 175 Andromache changed from 21.4° to 20.0°. For the analysis we collected 2105 usable data points.

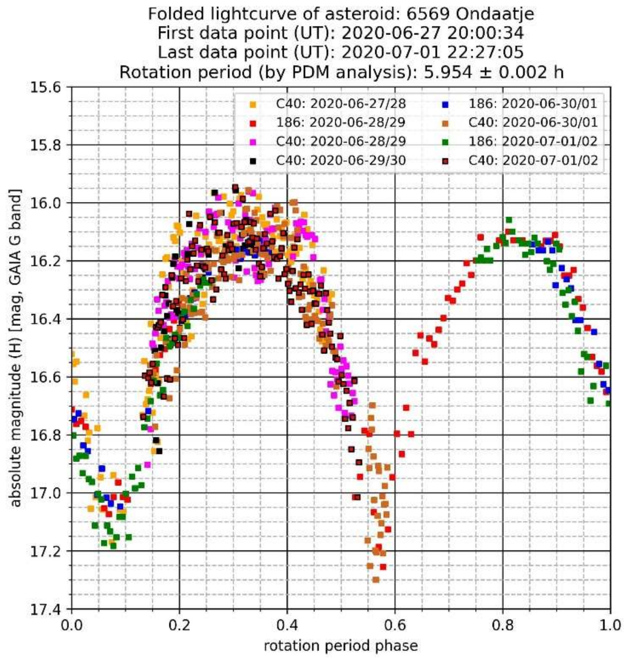


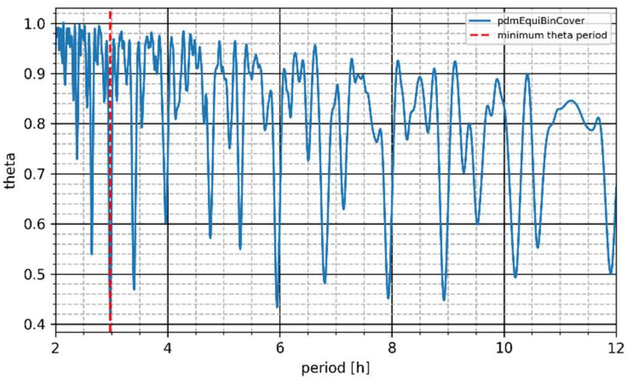
We found a synodic rotation period P = 8.324 ± 0.004 h, median absolute brightness H = 8.51 ± 0.05 mag in Johnson-Cousins V band, and brightness amplitude of the folded lightcurve A = 0.40 ± 0.05 mag. For albedo a = 0.0631 we estimated asteroid diameter D = 105.290 ± 1.170 km; using an albedo α = 0.094, we estimated asteroid diameter D = 86.265 ± 1.253 km. The PDM power spectrum covers a rotation period range between 2 and 12 hours with a red dashed line indicating the best probable rotation period corresponding to the one we found; other potential solutions either produced monomodal folded lightcurves, or didn't produce well-fitted folded lightcurves.

6569 Ondaatje was discovered on 1993 June 22 by J.E. Mueller; it was named in honor of Michael Ondaatje, a Canadian novelist, poet and writer, best known for his novel *The English Patient* (MPC, 2006a). It is a near-Earth asteroid of the Amor family with a semi-major axis of a = 1.63 au, eccentricity e = 0.22, inclination i = 22.64°, and an orbital period of P = 2.07 years; its absolute magnitude is H = 16.68 (MPC, 2022b). Other reported values are: H = 16.2 (Pravec et al., 1996), H = 16.443 ± 0.006 (Waszczak et al., 2015), and H = 16.00 (Carry et al., 2016). In the Asteroid Lightcurve Database (Warner et al., 2009), we found three reported rotation periods for asteroid 6569 Ondaatje: 5.959 h (Pravec et al., 1996), 5.916 ± 0.0052 h (Waszczak et al., 2015), and 5.295 ± 0.001 h (Warner and Stephens, 2020); also, a period of 5.96 ± 0.01 h has been reported by (Warner and Stephens, 2022).

CCD photometric observations of asteroid 6569 Ondaatje were carried out on five nights in 2020 June 27 to July 1 at two observatories, 186 and C40. At 186 we used a 0.36-m *f*/8 Ritchey-Chrétien telescope with a FLI ML 09000 CCD camera without filters at 2×2 binning, giving 1.72 arcsec/pix pixel scale, and 60-s exposure times during the nights 2020 June 28, 30 and July 1; at C40 we used a 0.51-m *f*/7.93 Ritchey-Chrétien telescope with a FLI PL 16803 CCD camera without filters at 3×3 binning, giving 1.37 arcsec/pix pixel scale, and 60-s exposure times during the nights 2020 June 27-30 and July 1. In the course of the entire observation campaign, the phase angle of 6569 Ondaatje changed from 26.6° to 21.4°. For the analysis we collected 722 usable data points.

We found a synodic rotation period P = 5.954 ± 0.002 h, median absolute brightness H = 16.44 ± 0.05 mag in Johnson-Cousins V band, and brightness amplitude of the folded lightcurve A = 0.99 ± 0.05 mag. For albedo a = 0.15, we estimated asteroid diameter D = 1.770 ± 0.020 km; for the albedo a = 0.20. we estimated asteroid diameter D = 1.533 ± 0.021 km. The next figures show the folded lightcurve of asteroid 6569 Ondaatje and the PDM power spectrum in a rotation period range between 2 and 12 hours with a red dashed line indicating the best probable rotation period at 2.977 h, which produced a monomodal folded lightcurve. However, the second-best probable rotation period at 5.954 h is the one that we consider the real rotation period; other potential solutions didn't produce well-fitted folded lightcurves.

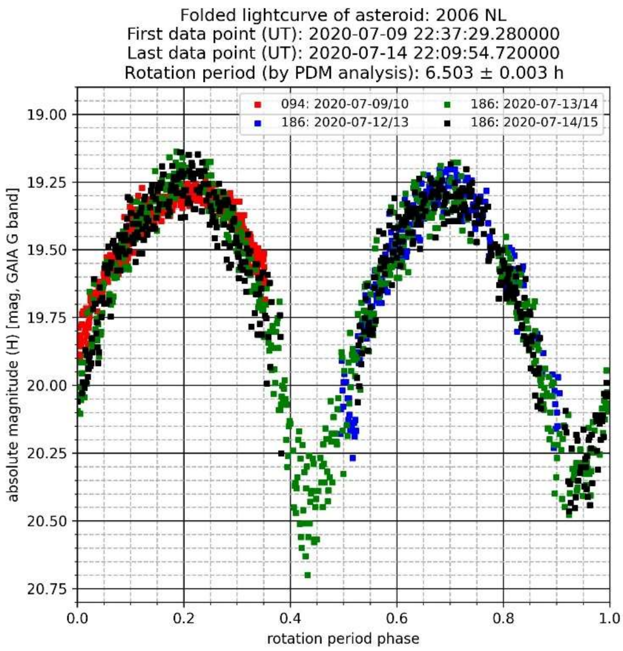


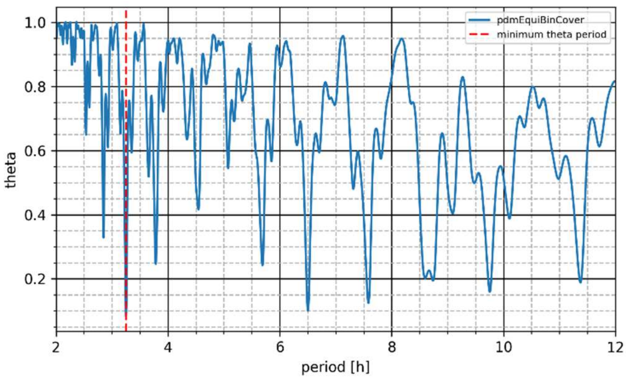


2006 NL was first observed on 2006 July 2 at the Lincoln Laboratory ETS, New Mexico (MPC, 2006b). It is a near-Earth asteroid of the Aten family with a semi-major axis of a = 0.85 au, eccentricity e = 0.58, inclination i = 20.09°, and an orbital period of P = 0.78 years; its absolute magnitude has a value of H = 19.97 (MPC, 2022c). In the Asteroid Lightcurve Database (Warner et al., 2009) we found three reported rotation periods for asteroid 2006 NL: 6.50 ± 0.02 h, 6.44 ± 0.05 h, and 6.503 ± 0.001 h (Warner and Stephens, 2021).

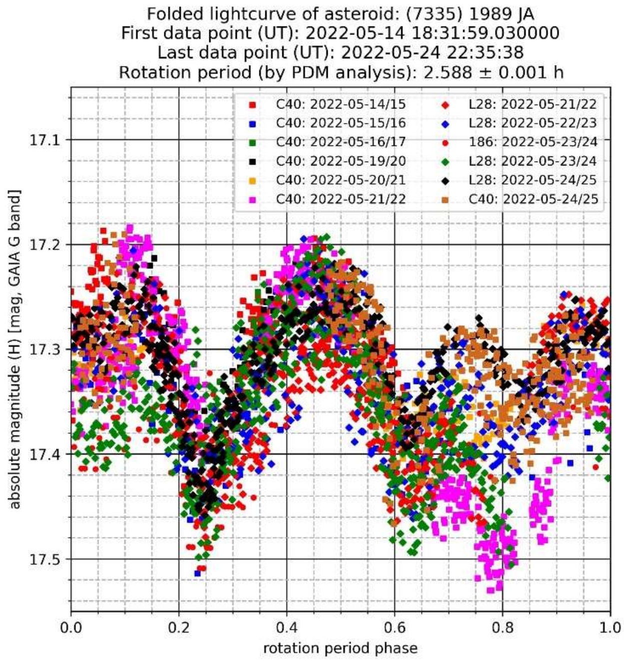
CCD photometric observations of asteroid 2006 NL were carried out on four nights in 2020 July 9-14 at two observatories, 094 and 186. At 094 we used a 1-m *f*/12.7 Cassegrain telescope with a FLI ML 09000 CCD camera without filters at 3×3 binning, giving 0.58 arcsec/pix pixel scale, and 15-s exposure times during the night 2020 July 9; at 186 we used a 0.36-m *f*/8 Ritchey-Chrétien telescope with a FLI PL 09000 CCD camera without filters at 2×2 binning, giving 1.72 arcsec/pix pixel scale, and 30-s exposure times during the nights 2020 July 12-14. In the course of the entire observation campaign, the phase angle of 2006 NL changed from 56.8° to 30.8°. For the analysis we collected 1791 usable data points.

We found a synodic rotation period $P = 6.503 \pm 0.003$ h, median absolute brightness $H = 19.65 \pm 0.05$ mag in Johnson-Cousins V band, and brightness amplitude of the folded lightcurve $A = 1.12 \pm 0.05$ mag. For albedo $a = 0.15$ we estimated asteroid diameter $D = 0.404 \pm 0.004$ km; for the albedo $a = 0.20$, we estimated asteroid diameter $D = 0.350 \pm 0.005$ km. The next figures show the folded lightcurve of asteroid 2006 NL and the PDM power spectrum in a rotation period range between 2 and 12 hours, with a red dashed line indicating the best probable rotation period at 3.251 h, which produced a monomodal folded light curve. However; the second-best probable rotation period at 6.503 h is the one that we consider the real rotation period; other potential solutions didn't produce a well-fitted folded lightcurve.





(7335) 1989 JA. In (Schmalz et al., 2022), we reported a synodic rotation period of $P = 5.177 \pm 0.005$ h, indicating also a second-best probable solution with a rotation period of 2.589 h; This didn't produce a well-fitted folded lightcurve and, thus, was excluded as a possible solution. In our analysis we forgot the fact that (7335) 1989 JA was found to be a binary asteroid (Benner, 2022); hence we were getting a slightly changing brightness amplitude, which caused the misfit in the folded lightcurve. After considering the binary nature of asteroid with a 10-day long observational campaign and revising its analysis, we determine a synodic rotation period of $P = 2.588 \pm 0.001$ h as the correct solution. Similar solutions have been reported: $P = 2.590 \pm 0.002$ h (Loera-González et al., 2022) and $P = 2.588 \pm 0.001$ h (Franco et al., 2022). The next figure shows the folded lightcurve of asteroid (7335) 1989 JA.



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Number	Name	20yy/mm/dd	Phase	L_{PAB}	B_{PAB}	Period(h)	P.E.	Amp	A.E.	D	Grp
175	Andromache	21/07/02-21/07/09	21.4,20.0	333	-3	8.324	0.004	0.40	0.05	105.290 86.265	MBA
6569	Ondaatje	20/06/27-20/07/01	26.6,21.4	294	9	5.954	0.002	0.99	0.05	1.770 1.533	NEA
7335	1989 JA	22/05/14-22/05/24	26.9,35.1	227	11	2.588	0.001	0.27	0.05	0.849 0.748	NEA
	2006 NL	20/07/09-20/07/14	56.8,30.8	283	22	6.503	0.003	1.12	0.05	0.404 0.350	NEA

Table I. Observing circumstances and results. The phase angle is given for the first and last exposure time. 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).

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