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Search of Large Super-Fast Rotator between NEAs

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Abstract. Asteroids of size larger than 0.15 km generally do not have periods smaller than 2.2 hours, a limit known as cohesionless spin-barrier. This barrier can be explained by the rubble-pile structure in which the asteroids are made up of collisional breakup fragments bound together by mutual gravitational force. The exceptions to this rule, called Large Super-Fast Rotators (LSFRs), are very few as 2001 OE84 and 2005 UW163. Preliminary results of some NEAs (Near Earth Asteroids) photometric observations are presented, we report the value of new rotation periods for these elusive asteroids.

Key words. Minor planets, near Earth asteroids, rotation periods.

1. Introduction

Asteroids were subject to strong collisional interactions. Pravec et al. (2002a), in their classical analysis on rotation periods, show that objects of size larger than 0.15 km generally do not have periods smaller than 2.2 hours (cohesionless spin-barrier). This spin barrier can be explained by the rubble-pile structure in which the asteroids are made up of collisional breakup fragments bound together by mutual gravitational force (Figure 1).

Rotation with periods exceeding this critical value will cause asteroid breakup and the formation of a binary system (Pravec & Harris 2007), (Jacobson et al. 2014). However, there are exceptions to this rule, as the NEA 2001 OE84 (Pravec et al. 2002b) and the MBA 2005 UW163 (Chang et al. 2014), both with diameters of about 0.6 km and rotation periods of 0.486 and 1.290 hours, respectively. The presence of these objects, called Large Super-Fast Rotators (LSFRs), have been theorized by Holsapple (2007) and others as an effect of size-dependent material strength: for small bodies ($D < 10$ km), also with rubble-pile structure, the presence of even a very small amount of strength allows much more rapid spins than the simple cohesionless spin-barrier value. Therefore, to verify the predictions, it is interesting to measure the rotation periods of asteroids in the range 0.15 km $< D <$ 10 km, looking for spin-barrier value violations.

Here we present the first results obtained with NEAs differential photometry from the Astronomical Observatory of the Aosta Valley (Italy), in the period October-December 2014 in search of new large SFR candidates. NEAs are on average small bodies, and it is not difficult to find them in the range of sizes of LSFRs. These observations form the thesis of one of us (SM) but are not representative of the entire survey which is still in progress. The full and final results will be published in a more complete paper.

2. Choice of the targets and observations

The choice of the observed asteroids took place by considering the NEAs near the flyby with the Earth and with an apparent magnitude within the range of the equipment used (approximately less or equal to magnitude +17), using the tools of the Minor Planet Center website[1]. Asteroids with a proper motion not too high (less or equal to 10 arcsec/minute) were chosen to facilitate the subsequent processing of the lightcurves. For each individual asteroid the photometric observations consisted in a continuous shooting of images for a certain number of hours (with the target to at least 20° of elevation above the horizon to avoid seeing effects), for the days necessary to determine the rotation period. Usually the *C* (clear) filter has been used but, in the case of asteroids sufficiently slow and bright, a photometry with standard filters *B*, *V* and *R* has been made for the determination of the color indices in such a way to have an indication of the taxonomic type and albedo. These data are very useful to have a good estimate of the effective diameter of the asteroids. The list of our targets is shown in Table 1.

Among the observed NEAs, the Amor 2014 VQ is the most interesting because with a rotation period of only few minutes and an absolute magnitude around +20 is a potential LSFR. After the discovery of this short period on November 20, 2014, a collaboration started with P. Pravec and colleagues of the Ondrejov Observatory that made further photometric observations on this target that led to the determination of the color index $(V-R)$ in the Johnson-Cousins photometric system, a better measure of the rotation period and an estimate of albedo and size. For these observations the 1.54-m Danish telescope at La Silla (Chile) was used.

[1] `http://www.minorplanetcenter.net/`

3. Instruments and reduction procedures

In OAVdA the images were captured by means of a modified Ritchey-Chrétien 0.81-m f/7.9 telescope using an FLI 1001E CCD with an array of 1024 × 1024 pixels. The field-of-view of this camera was 13.1 × 13.1 arcmin while the plate scale was 1.54 arcsec per pixel in 2×2 binning mode. All images were calibrated by applying their master dark and flat frames. Lightcurve data analysis was done using the software MPO Canopus[2], version 10.4.7.6, which employs differential aperture photometry and the Fourier period analysis algorithm developed by Harris et al. (1989). Known rotation periods at the time of the observations were all drawn from the asteroids lightcurve database (LCDB), September 07, 2014 update (Warner et al. 2009).

In the case of *B*, *V* and *R* photometry, used for the brighter asteroids only ($m_V \leq +14.5$ mag), the procedure applied in OAVdA for obtaining the asteroid's color index is the following. First, we select three images in *B*, *V* and *R* taken in the shortest time interval. We used for comparison six field stars, manually selected, with $SNR \geq 110$ in *B* and with a range of instrumental magnitude to contain the target. Instrumental magnitudes of the comparison stars were linearly calibrated with the magnitudes in the USNO CCD Astrograph Catalog 4 (UCAC4). The images on which we measure the instrumental magnitude of the target were chosen so that they fall on sufficiently flat areas of the phased lightcurve, to avoid sudden changes of magnitude due to the asteroid rotation. Finally, the color indices obtained from the three different set of *B*, *V*, and *R* images (for a total of 9 images) are averaged to obtain the mean value and the standard deviation.

[2] Warner, B. D. (2009). MPO Software, MPO Canopus. Bdw Publishing, `http://minorplanetobserver.com/`

Table 1. The observed asteroids, with rotation periods, lightcurve amplitude, measured absolute magnitude and the number of observed nights. The objects are sorted in order of increasing period.

Asteroid	Period (h)	A (mag)	H_V (mag)	Nights
2014 VQ	0.116032 ± 0.000001	0.75	20.23 ± 0.20	4
1998 SS49	5.999 ± 0.006	0.13	—	4
1998 WQ5	6.03 ± 0.02	0.07	—	2
2004 JN13	6.334 ± 0.001	0.21	15.20 ± 0.4	3
(4401) Aditi	6.675 ± 0.002	0.23	—	4

The 5-band photometry of the UCAC4 catalog came from the AAVSO Photometric All-Sky Survey (APASS): Johnson B and V, plus Sloan g', r' and i'. The APASS catalogue is valid from about 10th magnitude to about 17th magnitude. From magnitude between +9 to +15 the mean error is about 0.03 mag [3] against Landolt's standard reference stars (Landolt 1992). At Ondřejov the determination of the asteroid's color indices was done using the photometric standard stars chosen from Landolt.

The knowledge of the color indices $B - V$ and $V - R$ provides information on the taxonomic type, on the mean values of the geometric albedo p_V and of the constant G of the photometric system HG (Bowell et al. 1989). Therefore, by the same photometric procedure used for the color indices, we can obtain the mean apparent magnitude in V band at a certain date and phase angle ($\overline{m}_V(\alpha)$), from which we can get the reduced magnitude ($\overline{m}_{V_{red}}(\alpha)$) and the absolute magnitude H_V assuming the G value. With these data, the effective diameter D_e of the asteroid is given by (Harris & Harris 1997):

$$D_e = \frac{1329}{\sqrt{p_V}} 10^{-0.2H_V} \tag{1}$$

This procedure, where applicable, allows to have a good estimate of the real size of an asteroid without the need for prolonged observations to obtain the complete phase - magnitude curve.

[3] http://www.aavso.org/aavso-photometric-all-sky-survey-data-release-1

4. The first results

In this section we present the results for the NEAs of Table 1, for clarity we dedicate a subsection to each asteroid. The flyby dates with Earth came from the JPL Small-Body Database[4].

4.1. 2014 VQ

This asteroid is an Amor object. A total of 325 images with C filter were taken over 5.5 hours on a single night on 2014 November 20 (flyby date: 2014-11-13). According to the observations made by P. Pravec and colleagues, the period is refined to 0.116032 ± 0.000001 hours compared to the initial period found in OAVdA (Figure 2). The color index is $(V-R) = 0.483 \pm 0.01$ mag, which is typical for S-type asteroids. Assuming $G = 0.24 \pm 0.11$, typical value for S-type asteroids, the mean absolute magnitude is $H_V = 20.23 \pm 0.20$ mag. If we assume the geometric albedo $p_V = 0.20 \pm 0.05$, which is a 1-sigma range for S-type asteroids (Pravec et al. 2012), we get the diameter $D = 0.267 \pm 0.043$ km. So, if it is an S-type, then it is indeed above the boundary size of about 0.15 km for super-fast rotators.

Unfortunately, we cannot rule out that it is a V-type. The color index is consistent with the V class as well. Repeating the same analysis assuming it is a V-type, we have the following

[4] http://ssd.jpl.nasa.gov/

results. The mean absolute magnitude is $H = 20.52 \pm 0.11$ assuming $G = 0.43 \pm 0.08$, typical for V type asteroids. If we assume the geometric albedo $p_V = 0.40$, which is the mean albedo for V-type asteroids, we get $D = 0.165 \pm 0.027$ km.

4.2. (85713) 1998 SS49

This asteroid is an Apollo-PHA object ($H = 15.7$, diameter 2-3 km). A total of 731 images were collected using C filter in 13.5 hours on four nights between the 26th October and 19th November 2014 (flyby date: 2014-11-18). Only two of the four nights (with four sessions), are used for the phased lightcurve. The long session of approximately 6.5 hours in the night between October 30-31 was fundamental to determine the rotation period (Figure 3). November sessions are much shorter than October's ones and do not add anything more. It is important to note how the rotation period is almost an exact sub-multiple of Earth rotation period, so a long session from a fixed longitude was necessary to solve the problem.

4.3. (85804) 1998 WQ5

This asteroid is an Amor ($H = 15.3$, diameter 3-5 km). It was already studied by Oey (2006), that found a rotation period of 3.0089 ± 0.0001 hours with an amplitude of 0.35 mag, but the lightcurve was noisy. A total of 317 images were taken over 11 hours distributed over two nights on 18th and 19th December 2014 using C filter (flyby date: 2015-01-25). The rotation period was difficult to determine, despite a SNR around 100, because of the low amplitude (only 0.07 mag) and because the two long sessions do not overlap perfectly (Figure 4). A period of about 6 hours seems more reasonable than the half value. But it is an uncertain result, more observations are needed.

4.4. (214088) 2004 JN13

This asteroid is an Apollo object, a total of 887 images were taken over 17 hours distributed in three nights on 2014 December 16, 19 and

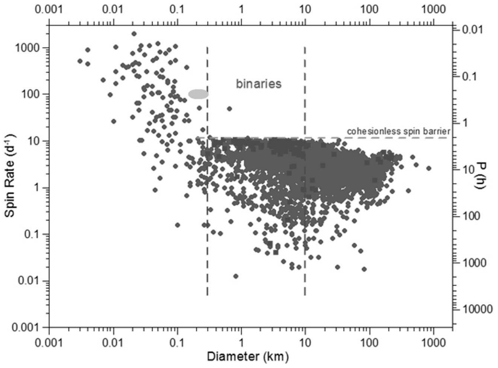

Fig. 1. The diagram spin-rate vs diameter that shows the presence of the cohesionless spin-barrier (from Pravec 2013). The grey ellipse marks the position of the NEA 2014 VQ discussed in the paper.

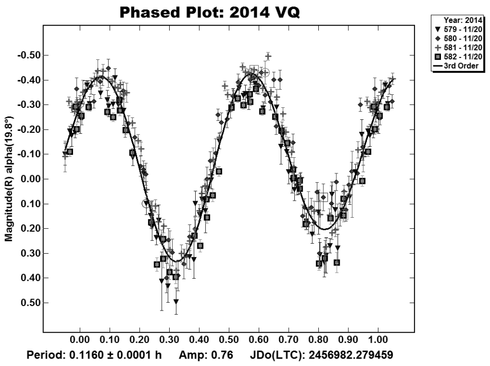

Fig. 2. The phased lightcurve of the Amor 2014 VQ from OAVdA.

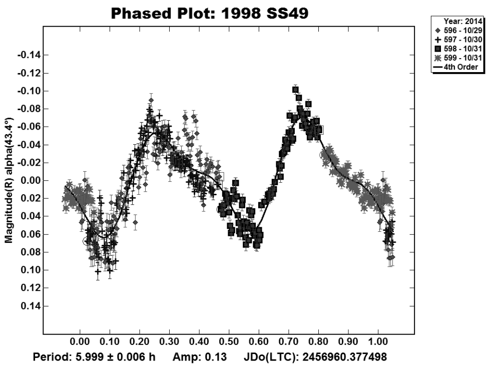

Fig. 3. The phased lightcurve of the Apollo-PHA (85713) 1998 SS49 from OAVdA

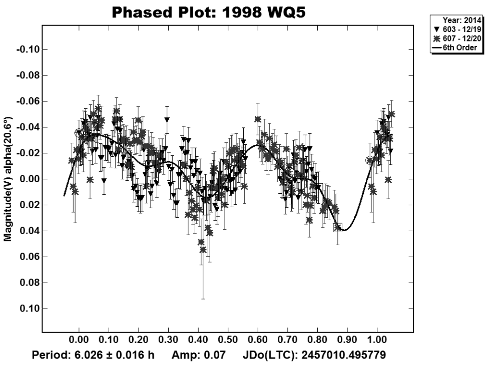

Fig. 4. The phased, low amplitude, lightcurve of the Amor (85804) 1998 WQ5 from OAVdA.

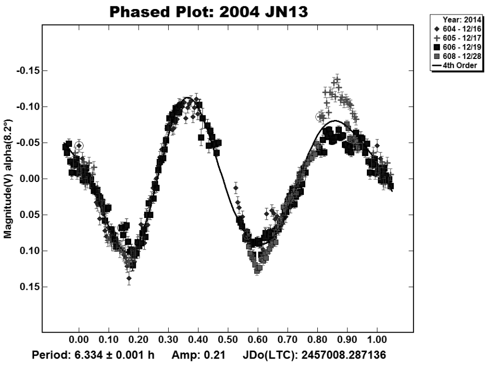

Fig. 5. The phased lightcurve of the Apollo (214088) 2004 JN13 from OAVdA.

28 (flyby date: 2014-11-18). In the first session this object was observed with B, V and R standard filters which has made possible the measure of the color indices with the technique we have described above. The results are the following: $(B-V) = 0.94 \pm 0.01$ mag and $(V-R) = 0.45 \pm 0.01$ mag (mean values of three separate color index measures), so probably is a S-type asteroid (Shevchenko & Lupishko 1998). The corresponding visual absolute magnitude is $H_V = 15.20 \pm 0.4$ mag (in good agreement with the JPL Small-Body Database value) and the diameter, using $p_V = 0.2 \pm 0.05$, is 2.7 ± 0.6 km. In the other two sessions this asteroid was observed only with the V filter. The lightcurve is almost complete and shows a period of little more than six hours (Figure 5).

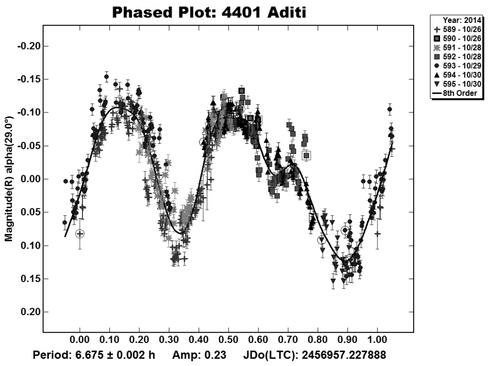

Fig. 6. The phased lightcurve of the Amor (4401) Aditi from OAVdA.

4.5. (4401) Aditi

This is an Amor object ($H = 15.9$, diameter 1.2-3.7 km). A total of 823 images were taken over 14.5 hours distributed in four nights on 2014 October 26, 28, 29 and 30 with C filter (flyby date: 2014-11-06). The lightcurve analysis shows a rotation period of almost seven hours with a discrete amplitude (Figure 6).

5. Conclusions

We have obtained the rotation period for a sample of NEAs and we have determined color indices and effective size for some of it. An object in particular, the Amor 2014 VQ, is a good candidate to be a LSFR. However, the results presented in this brief paper are only partial because the survey is still in progress. Later, it will be published a paper with the final results and a greater number of NEAs lightcurves.

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