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CCD PHOTOMETRY OF MINOR PLANETS AT THE BELGRADE ASTRONOMICAL OBSERVATORY 2006-2008

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Abstract. In this paper a summary of activities and results in the field of CCD minor planet photometry performed with 40.6 cm f/10 Schmidt-Cassegrain telescope in the period July 2006 – May 2008 at the Belgrade Astronomical Observatory is presented. Lightcurves were constructed and some basic parameters (rotational periods and lightcurve amplitudes) were obtained for 10 minor planets (9 main-belt asteroids and 1 NEO) using a differential photometry with five comparison stars.

In order to examine possibilities for performing CCD photometric observations of asteroids and obtaining their lightcurves from our Observatory (located practically in the urban area of the city of Belgrade) some preliminary test observations (of some close binary stars) were started with a new equipment purchased and installed in 2004 – Meade 16" LX200GPS f/10 Schmidt-Cassegrain telescope and Apogee AP47-p camera with high quantum efficiency (near 90% in wide spectral range) back-illuminated detector. The detector has dimensions of 1056x1024, 13μm square pixels. The image scale of such telescope and camera combination is about 0.66 arcseconds per pixel. The equipment initially was used exclusively for astrometric observations of solar system minor bodies. By the way, Belgrade Observatory has long tradition in astrometry of asteroids and comets which has been carried out for decades with two small astrographs using classical photographic methods. After short period of tests that gave positive results, the regular photometric observations of selected asteroids were started in second half of July 2006. It was the ***very first*** case of observing asteroids from our Observatory in order to determine some of their proper physical characteristics. The only exception which was not observed from Belgrade Observatory is asteroid (1293) Sonja. It was observed in August 2006 by V. Benishek at Bulgarian National Observatory Rozhen together with Bonka Bilkina from Institute of Astronomy in Sofia, Bulgaria.

As a main source for selecting observing targets was the list of priorities from *Collaborative Asteroid Lightcurve Link* (CALL) web site (Warner and Harris, 2006 ab; 2007 ab; 2008), except in the case of (1095) Tulipa which was the first

observed asteroid and it was selected as a suitable target to check signal-to-noise ratio using a fainter object in the conditions of high light pollution. Practically all observed targets are main-belt asteroids, except one near-earth asteroid 2006 VV2.

The preliminary processing and full calibration of particular images (applying of bias, dark and flat-field frames), as like as necessary rotations (due to lack of field derotator at our Alt-Az mount) were performed in MaxIm DL 3 from Diffraction Limited. The same software was used to control the telescope, CCD camera and Optec TCF-S temperature compensated focuser. Differential photometry with five comparison stars and determination of lightcurve and its parameters (rotation period and amplitude) were done in MPO Canopus software by BDW Publishing that uses Fourier analysis algorithm developed by Alan W. Harris (Harris et al., 1989). Amplitude for each lightcurve has been estimated as a difference between the greatest minimum and maximum by so-called "spreadsheet" method described by Brian D. Warner in his book *A Practical Guide to Lightcurve Photometry and Analysis* (Warner, 2006).

All observations were unfiltered, except in the case of (1293) Sonja.

Obtained results are described below. The enclosed lightcurve plots for all observed asteroids represent function of the brightess change (shown in magnitudes) with the rotational phase. All results were previously submitted to the CALL website and published on the author's web-site:
http://beoastrophot.freehostia.com. The results of observations of first seven asteroids were published in the Minor Planet Bulletin (Benishek and Protitch-Benishek, 2008).

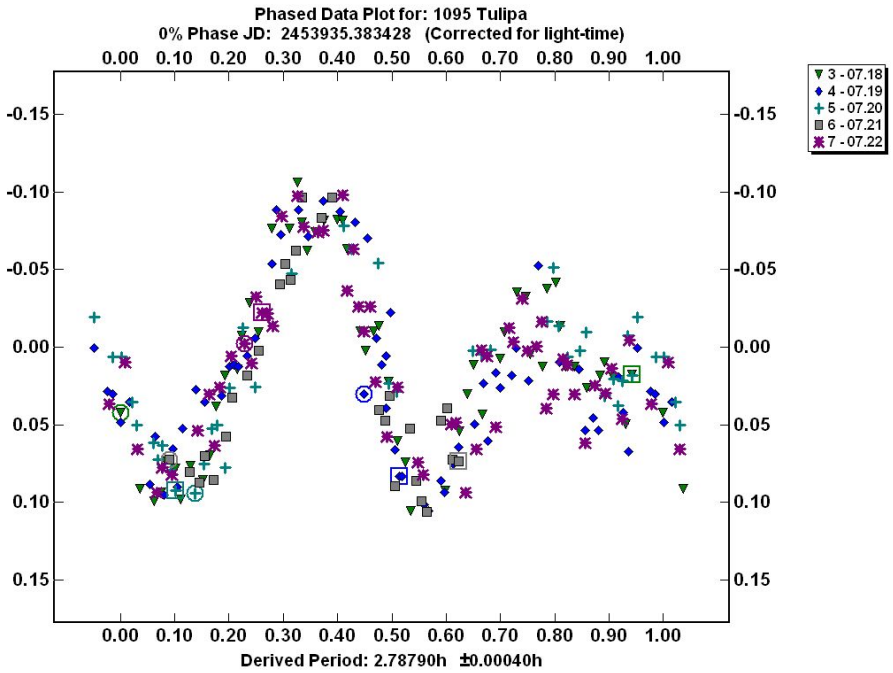

Figure 1: Lightcurve of the minor planet (1095) Tulipa.

(1095) Tulipa This asteroid was observed during 5 nights, 2006 July 18, 19, 20, 21 and 22. Its apparent magnitude was about 14.9. Exposure times were 30.0 seconds and in spite of relatively faint brightness of the object and bad light-polluted sky at our observing site we have reached S/N ratio of about 160-170. Longer exposures were not possible due to field rotation effect. For rotational period (P) and amplitude of the lightcurve (A) we found following values: P = 2.7879 ± 0.0004 h and A = 0.17 ± 0.03 magnitudes.

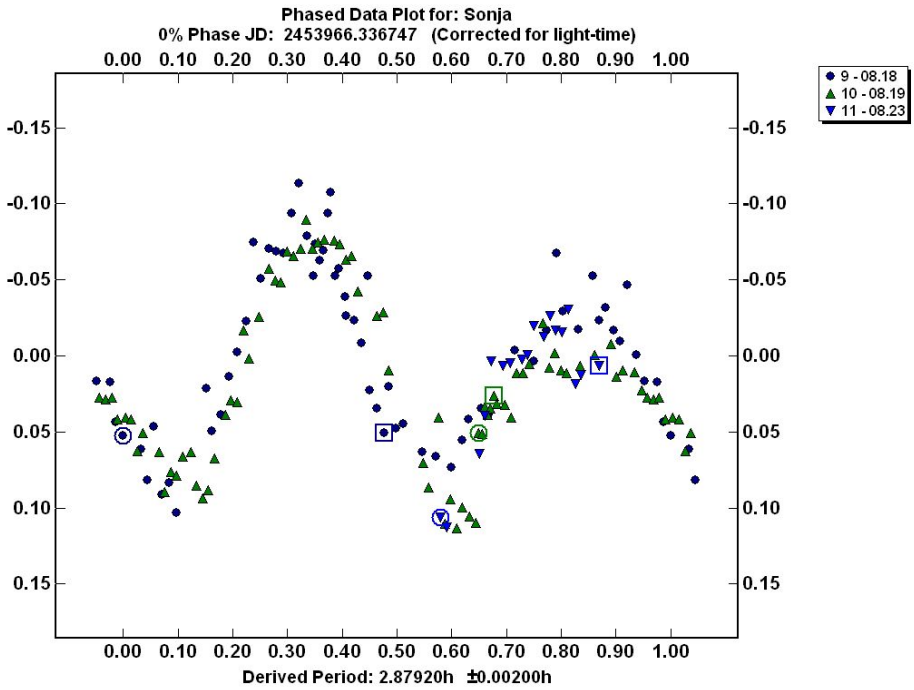

Figure 2: Lightcurve of the minor planet (1293) Sonja.

(1293) Sonja Target was selected from CALL list of Potential Observational Targets July-September 2006. One of the criteria for choosing this object was its relatively short rotation period (about 2.87 h) known with insufficient accuracy. It was observed during three nights – 2006 August 18, 19 and 23 (more observing sessions were not possible due to variable weather conditions) at Bulgarian National Observatory using Schmidt telescope with 50 cm Schmidt plate, 70 cm mirror and 172 cm focal length equipped with SBIG ST-8 CCD camera and R-band photometric filter. The apparent magnitude of asteroid was about 13.1. Usual exposure times were 90 seconds. Analyzing our observations we found following values for rotation period and amplitude respectively: 2.8792 ± 0.002 hours and 0.16 ± 0.02 magnitudes.

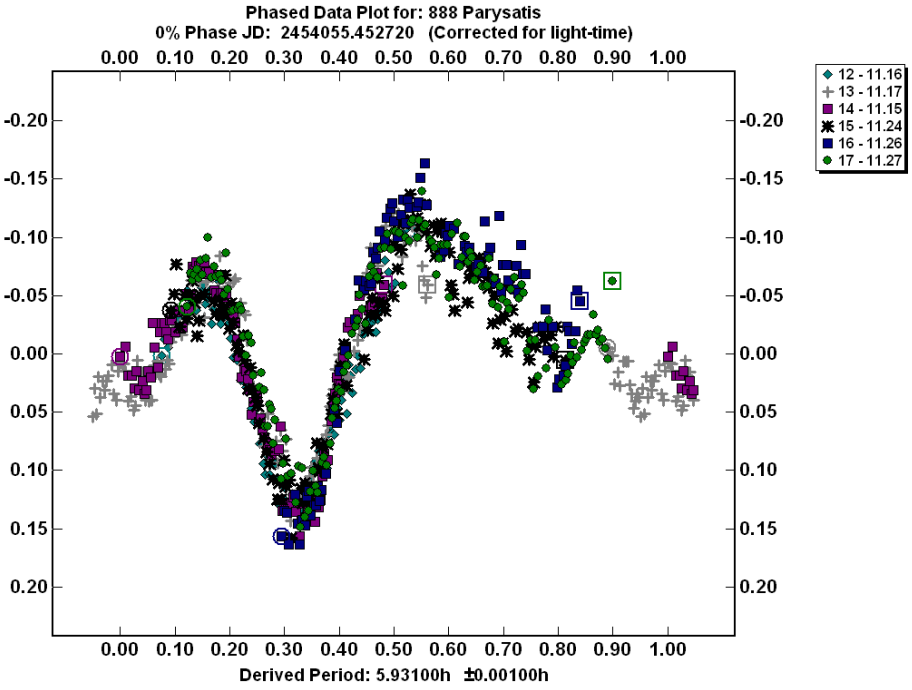

Figure 3: Lightcurve of the minor planet (888) Parysatis.

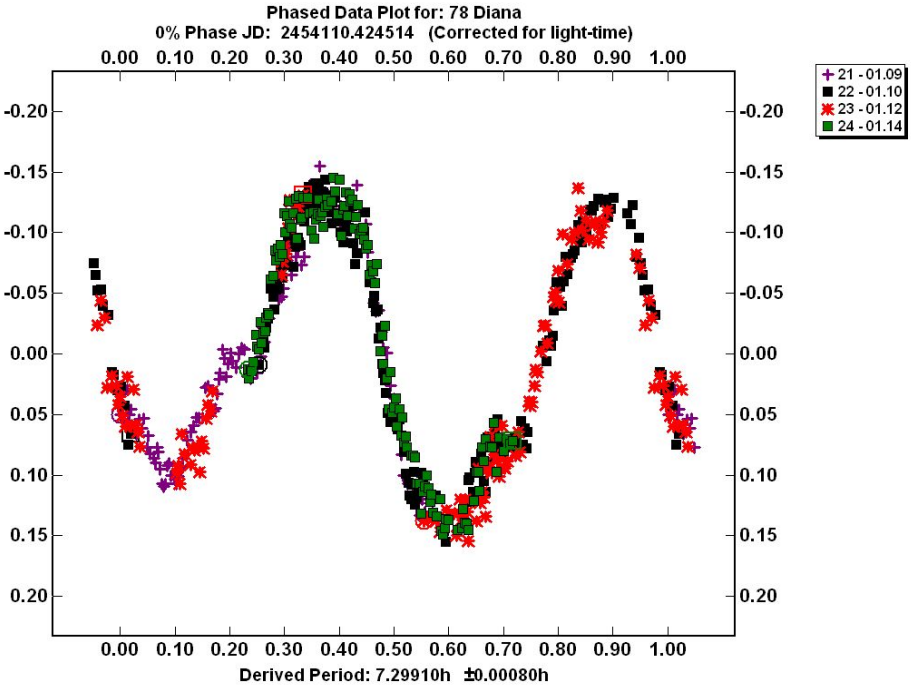

Figure 4: Lightcurve of the minor planet (78) Diana.

(888) Parysatis This MBA target was selected from CALL Potential Observational Targets October-December 2006. An uncertain rotation period was known earlier (5.49 h). The observations started in November 2006 and lasted over 6 nights - 2006 November 15, 16, 17, 24, 26 and 27. Apparent magnitude of the asteroid during that period was about 12.3. Usual exposure times were 10 or 15 seconds depending of the session. Obtained lightcurve shows presence of one very deep minimum without any other characteristic features. Found parameters are: 5.9314 ± 0.0002 h for period and 0.22 ± 0.03 magnitudes for amplitude.

(78) Diana Main-belt asteroid observed in January 2007 over 4 nights (January 9, 10, 12 and 14). It was selected from the Potential Observational Targets list January-March 2007 on the CALL web-site. A value of rotation period was reported earlier (7.225 h) and was qualified as uncertain. From the found bimodal lightcurve we found following values of rotation period (P) and amplitude (A): P = 7.2991 ± 0.0008 h and A = 0.26 ± 0.03 magnitudes.

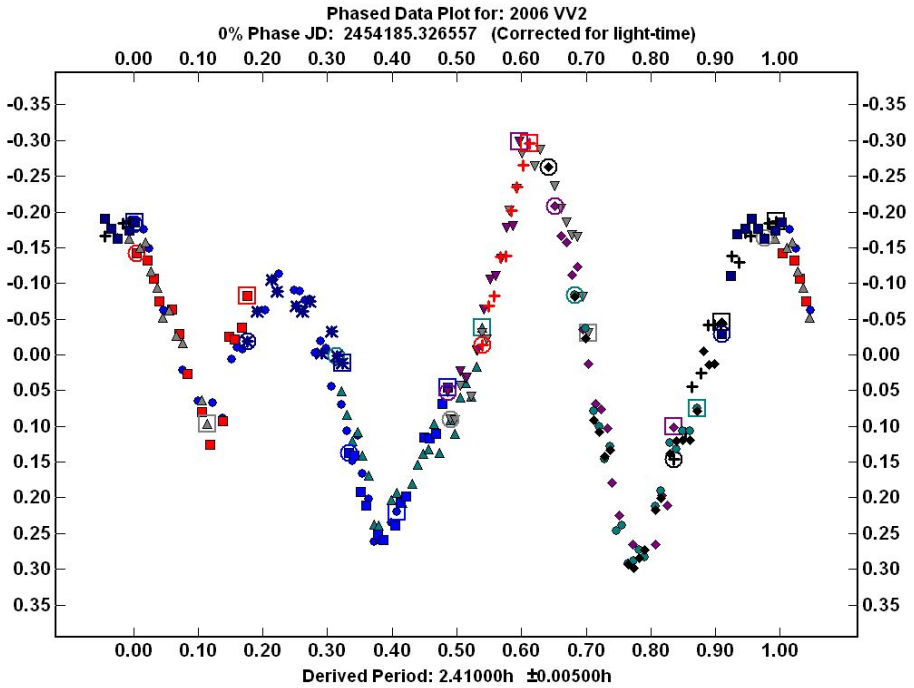

Figure 5: Lightcurve of the minor planet 2006 VV2.

2006 VV2 A great opportunity to make photometry of this Near-Earth object discovered by LINEAR telescope in November 2006 was during few days at the end of March 2007 when it had the closest approach to the Earth – within 0.023 AU or 8.8 lunar distances on 2007 March 31. The authors had possibility to observe it over two nights on March 25 and March 27 when its apparent magnitudes were

about 13.9 and 12.8 respectively. Since the motion of the object was extremely fast and actual CCD field of view is quite small that causes frequent changes of field comparison stars, it was neccessary to divide single night session into the several portions – 14 sub sessions. Such procedure was successful for March 25 observations, but linking of the data was very hard to achieve and at least impossible for the second night, unfortunately. March 25 observations cover two full rotations of the asteroid. In spite of all difficulties the lightcurve from single night observations was constructed and rotational period of 2006 VV2 found with limited accuracy. Due to reasonable reasons of complicated observational conditions it slightly differs from values found by other authors, i.e. Gianluca Masi (Masi, 2007) from Bellatrix Observatory found value 2.4302 h. Our value is 2.410 ± 0.005 hours. Value for amplitude is: 0.57 ± 0.02 magnitudes. Our results are cited on the web-site *Asteroids with Satellites* by Wm. Robert Johnston (Johnston, 2007) at following Internet address:
http://www.johnstonsarchive.net/astro/asteroidmoons.html

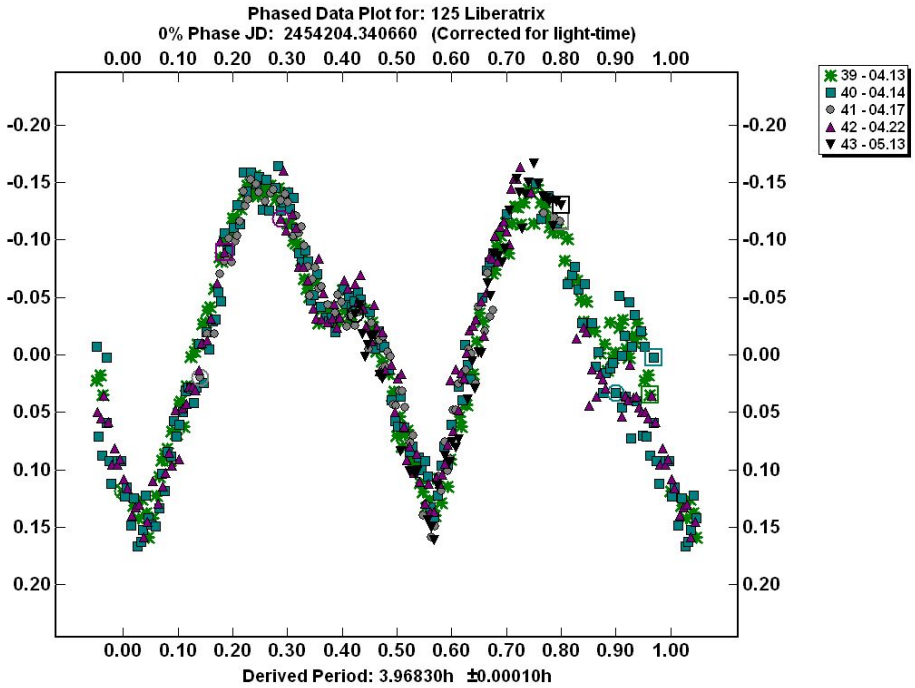

Figure 6: Lightcurve of the minor planet (125) Liberatrix.

(125) Liberatrix This main-belt asteroid has well-determined lightcurve and rotation properties. The main reason for choosing it to observe is that it is listed on Mikko Kaasalainen's Alert List (Kaasalainen and Warner, 2007) as a potential shape modeling target. Intention is to collect original observational material for shape modeling and to make contribution of our Observatory in that field of solar system investigations in the future. The observations were made during four nights

in April and one night in May 2007 – 2007 April 13, 14, 17 and 22 and May 13. Found rotational period (3.9683 ± 0.0001 h) is well-agreed with previously found value 3.968 ± 0.001 h (Bucheim, 2006). Value found for amplitude is: 0.28 ± 0.01 magnitudes.

(702) Alauda This asteroid was selected from Potential Observational Targets July-September 2007 list at the CALL web-site. Previously known uncertain rotation period was 8.36 h. Observing of this target was a real challenge because of small values of its amplitude range (0.07-0.1) as it was stated at the CALL web-site. Systematical and insistent observations of the target during eight nights over approximately one month (2007 July 19, 20, 22, 23, 27, 28 and August 15 and 16) allowed us to get a little bit noisy, but quite good lightcurve to determine rotation period with satisfying accuracy. Every particular session is thickly covered with numerous observations (about 100-150 per session) and the sessions cover full rotation without even a small gap. Found values for period and amplitude respectively are: 8.3539 ±0.0007 hours and 0.09 ± 0.02 magnitudes.

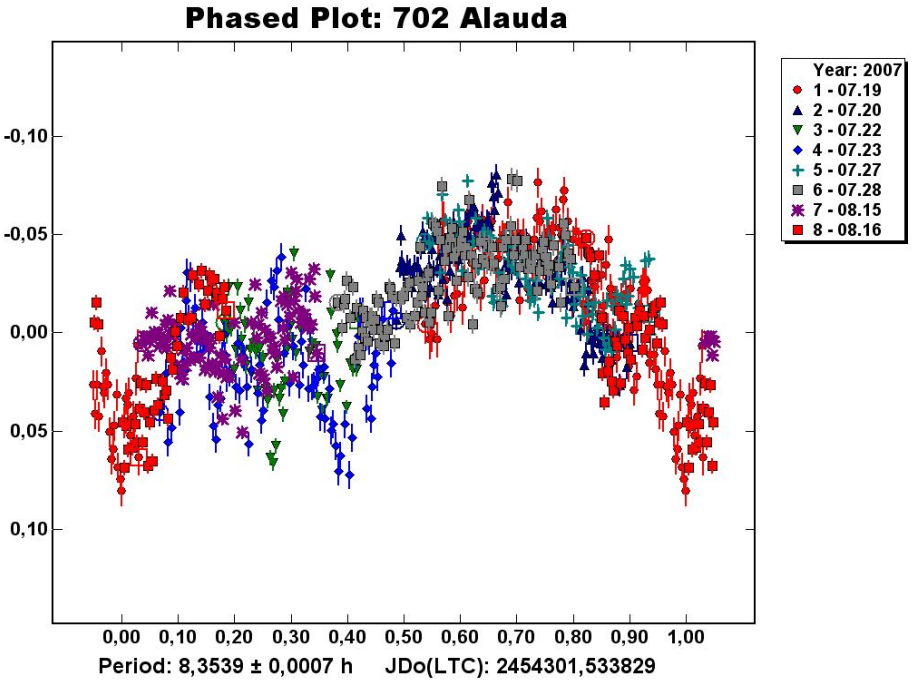

Figure 7: Lightcurve of the minor planet (702) Alauda.

(1071) Brita The asteroid was selected from CALL list of potential targets for observing in the period January – March 2008 as a bright one and with previously determined very preliminary value of rotational period and high amplitude of 0.38 magnitudes. Observations started on 2008 January 28 when apparent magnitude of the object was 13.6. Eight observing sessions were performed until the full period

of rotation was thickly covered with many data points. Some of observations were carried out in quite unfavorable sky conditions – during intensive moonlight and through tiny cirrus clouds, which made final lightcurve noisier than it was expected. Last of total 8 sessions was performed on 2008 March 9. From the obtained lightcurve following values for period (P) and amplitude (A), respectively, were found: P = 5.8169 ± 0.0003 hours and A = 0.20 ± 0.04 magnitudes.

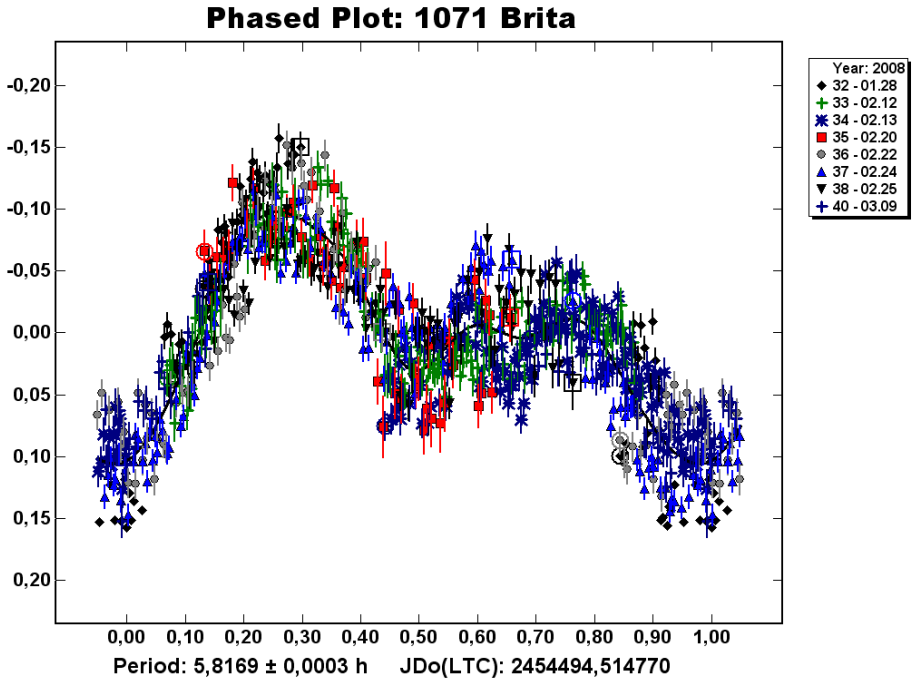

Figure 8: Lightcurve of the minor planet (1071) Brita.

(1022) Olympiada This asteroid was observed previously by Brian D. Warner in 1999, when its period was initially found (4.589 h). Originally published value was revised by the same author due to better symmetry of the curve with the shorter period (3.83 ± 0.01 mag.). Observing this asteroid again in two nights in March 2008 from Belgrade Observatory intention was to try to check and refine value found by B. D. Warner previously. The asteroid was also listed as an observing target at the CALL web-site for period January-March 2008 with remark that error of the period could be up to 30% or period is an ambiguous solution. Two observing sessions were realized on 2008 March 26 and 28. Newly-found values of the rotation period and amplitude are: 3.8331 ± 0.0006 hours and 0.35 ± 0.02 magnitudes respectively.

(1724) Vladimir This asteroid was discovered by E. Delporte in 1932 and rediscovered by M. B. Protitch at the Belgrade Observatory in 1952. No parameters have been published for this asteroid previously. As a relatively faint target of

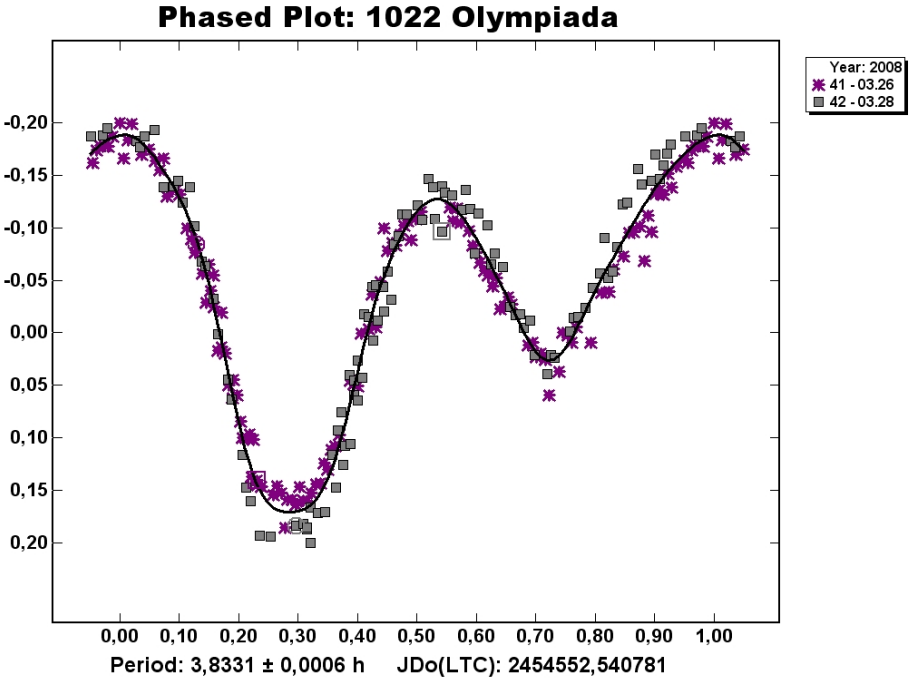

Figure 9: Lightcurve of the minor planet (1022) Olympiada.

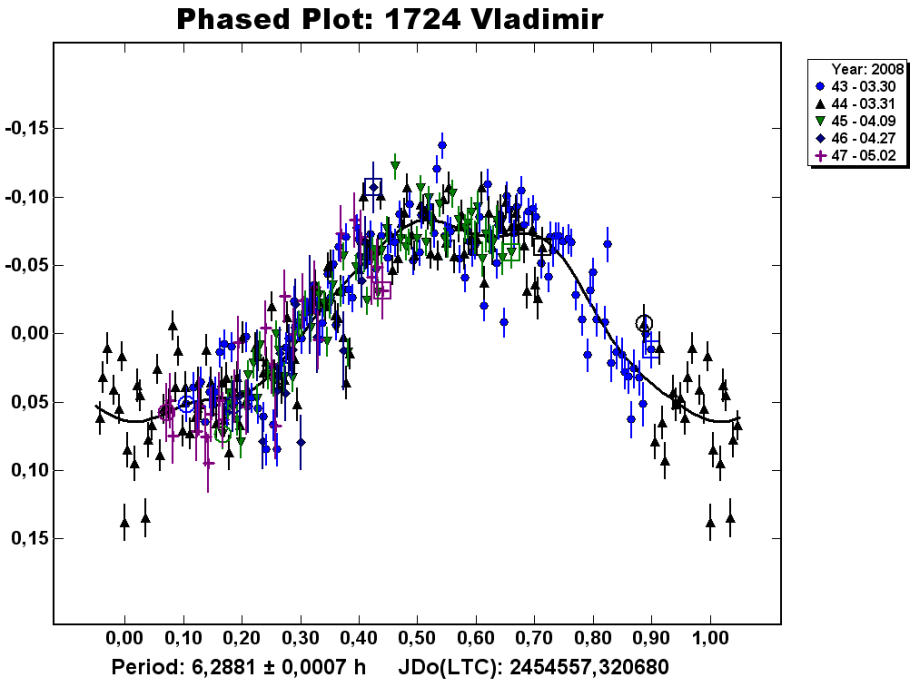

Figure 10: Lightcurve of the minor planet (1724) Vladimir.

about 15th magnitude it was a real challenge for observing. The observations started on 2008 March 30 and lasted in five sessions till May 02. With the individ ual exposures of about 60 seconds for every frame it was possible to achieve reasonably good signal-to-noise ratio, which provides satisfying photometric accuracy. Unfortunately, it was impossible to observe the asteroid longer than approximately 5 hours during the single night due to local observing circumstances. Nevertheless, the lightcurve was constructed successfully from several sessions and its basic parameters were found although the part of the curve was covered with observations just during single session. The period value is: 6.2881 ± 0.0007 hours. The value estimated for amplitude is: 0.14 ± 0.03 magnitudes.

Acknowledgements

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