Observations of Near-Earth Asteroids at Abastumani Astrophysical Observatory

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Abstract

Over the past five years physical properties of near-Earth asteroids are investigated in the Kharadze Abastumani Astrophysical Observatory. The work was launched in the collaboration with Kharkiv Institute of Astronomy within the Memorandum on scientific cooperation between Ilia State University (Georgia) and V. N. Karazin Kharkiv National University (Ukraine) in 2011. In the framework of this study the regular observations of several dozen asteroids per year are carried out to determine the rotation periods, size and shape parameters of these celestial bodies. A broad international cooperation is involved in order to improve the efficiency of the study. Abastumani is included in the observatory network called the *Gaia*-FUN-SSO, which was created for the ground support of the ESA's *Gaia* space mission.

Key words: Asteroid, photometry, CCD observations, albedo

1. Introduction

Presently mankind has realized and assessed the probability and the scale of the effects of a possible fall of large asteroidal or cometary bodies to the Earth. Recognition of the impact hazard is based on the facts of numerous falls of celestial bodies to the Earth, the Moon and other bodies of the Solar system, which happened in the past and continues to occur today. In the frame of Spaceguard efforts numerous survey projects regularly scan the sky, discovering dozens of near-Earth asteroids (NEAs) each month. Hundreds of professional and amateur observatories around the world are following up newly discovered NEAs getting both astrometric and photometric data for these bodies.

Our work is devoted to the study of physical properties of NEAs through regular photometric observations, which allow us to determine the rotational parameters, size and shape of these bodies, the optical properties of their surfaces etc. NEAs are small bodies from a few meters to several kilometers in diameter. The main objects of observations are NEAs closely approaching the Earth.

First of all, the program of observations includes the newly discovered NEAs which are bright enough to be reachable for high-precision photometric observations.
Study of asteroids began in Kharadze Abastumani Astrophysical Observatory within the Memorandum on scientific cooperation between Ilia State University (ISU, Georgia) and V. N. Karazin Kharkiv National University (KhNU, Ukraine). The investigation is carried out in the collaboration with a number of observatories in the world. The Abastumani Observatory is involved in observations of asteroids in the frame of the International network ISON (International Scientific Optical Network). Abastumani is also a part of cooperation within the *Gaia*-FUN-SSO (the *Gaia* Follow-Up Network for Solar System Objects), created to support the observations of the Solar system bodies by the European space mission *Gaia* (Krugly et al. 2011, 2015)

2. Program of Study the Physical Characteristics of NEAs

Among many causes of the emergency facing humanity in recent years, much attention is paid to the problems of a possible collision of asteroids and comets with the Earth (e.g., Shustov et al. 2013). Even a small body with the diameter of 100-200 meters can cause a catastrophic destruction in an area of thousands of square kilometers. There are a few hundred thousand of such natural bodies in the space surrounding the Earth's orbit (Morbidelli et al. 2002). To date (October 2015) a little more than 12 thousand NEAs have been discovered (MPC 2015). Also, cosmic body drop to the Earth may be associated with the presence of a large number of space debris in the Earth orbit, which was formed as a result of space exploration (Molotov et al. 2013).
The median lifetime of NEAs in their orbits is about 10 Myr (Gladman et al. 2000; Morbidelli et al. 2002). Eventually these bodies collide with large planets or burn down in the Sun or go away to the distant region of the Solar system. The main source of replenishment of the NEAs is the main-belt of asteroids, in which there are millions of asteroidal bodies, being the remnants of the formation of the large planets at the early stage of formation of the Solar system more than 4.5 billion years ago. Currently orbits of 674 thousand asteroids are known, of which over 420,000 objects were numbered (MPC 2015).
Potentially hazardous asteroids (PHAs) among NEAs are defined based on 2 parameters: being larger than 100-150 m in size ($H < 22.0$), and approaching the Earth at distances closer than 0.05 AU (less than 10 Earth-Moon distances). 1546 PHAs were known at the beginning of October 2015. The most hazardous objects are the large bodies with diameters more than 1 km. There are about 1000 ± 100 such bodies from expert's estimates (NEO-Report 2003). Currently 870 objects with diameters greater than 1 km are known (MPC 2015).
The average time of a possible NEA fall on the Earth depends on the size of the body. Small bodies of a few meters in size fall to the Earth more often than larger ones. A body more than 1 km in size falls very rarely, aproximately once in the tens and hundreds of million years. A typical form of the dependence of expected impact time interval is shown in Fig. 1 (Chapman 2004).

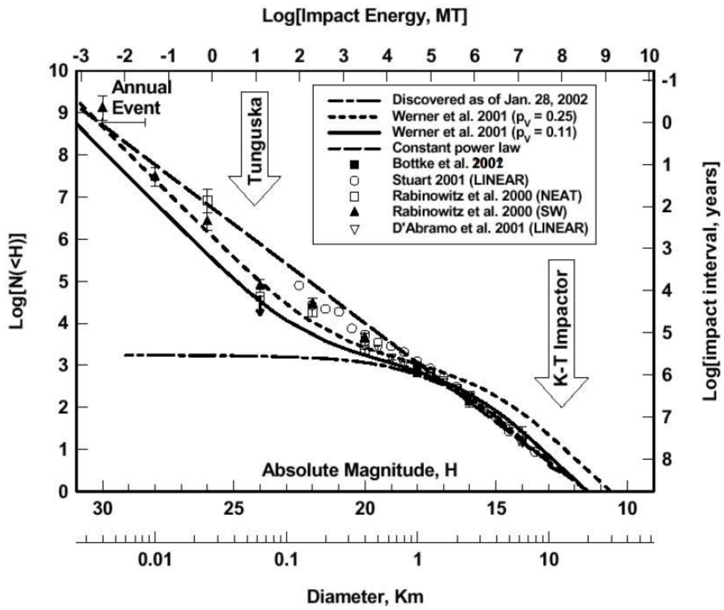

Fig. 1. Cumulative distribution of near-Earth asteroids vs their absolute magnitudes, and a scale for the diameters. Also impact energy and expected impact time interval are shown (Chapman 2004).

CCD observations of near-Earth asteroids at Abastumani Observatory were started in 2010. First of all a group of researchers was created. They have prepared the 70 cm and 1.25 m telescopes for the photometric observations. The test observations of several asteroids were carried out. Since 2011 the regular work on study of asteroids started in Abastumani within the Memorandum on scientific cooperation between ISU (Georgia) and KhNU (Ukraine). In the frame of this Memorandum, the Abastumani Observatory of ISU and the Institute of Astronomy of KhNU perform joint studies of potentially hazardous NEAs. The collaboration involves organizing cooperative observation projects, developing instrumental base, and training highly qualified specialists. The joint program of the asteroid study includes the next directions:

- Monitoring of potentially hazardous and newly discovered NEAs;
- Identification and study of binary NEAs by photometric method;
- Support for radar observations of NEAs by optical observations;
- Study of the YORP-effect (Yarkovsky-O'Keeffe-Radzievskii-Paddack), in particular detection variations of the rotation period of NEA under the influence of thermal photons re-emitted from its surface heated by the sun;
- Astrometry and photometry of asteroids, which will be observed and newly discovered during the *Gaia* mission (ongoing project of European Space Agency) in the frame of the International network *Gaia*-FUN-SSO.

3. Instruments and Technique of Photometric Observations

Recently the optical observations of celestial bodies are carried out using CCD cameras which are highly sensitive panoramic photodetectors of light. At the Abastumani Observatory observations of asteroids are performed with two telescopes: the 1.25 m telescope AZT-11 and the 70 cm Maksutov meniscus telescope AC-32. The telescopes were eqiupped with modern CCD camera manufactured by FLI firm (Finger Likes Instrumentation, USA) in 2010.

The CCD camera PL4301E and a filter-wheel with Bessell's *UBVRI* filters were installed in the Cassegrain focus of AZT-11 (f/12.8). The CCD has dimensions 2084 by 2084 pixels with 24 by 24 μm per pixel that gives a field of view 10.5' by 10.5' in 16 m focus. The limiting magnitude of this instument is 20.5 mag with *R*-band 3-minite exposure.

The AC-32 telescope was modernized in such a way that a flat diagonal secondary mirror was installed in front of the primary mirror to realize a Newtonian focus. The CCD camera IMG-6303E is fixed on a focusing mechanism which has been made and mounted on the telescope tube near the focal plane of the Newtonian focus (the effective focus is equal to 2141 mm). The CCD covers a field of view 44.4' by 29.6' with 3072 by 2048 pixels, with each pixel 9 by 9 μm subtending 0.87". The observations were mostly done in an unfiltered mode in white light. The R filter was used to implement the R-band close to the Johnson-Cousins photometric system. The limiting magnitude in white light was reached 20 mag using this set-up.

All observations of asteroids were carried out in order to obtain lightcurves. The observations were held as a continuous series for several hours. In most cases, observations of each asteroid included several nights of observations. Especially a lot of lightcurves are necessary for binary asteroids (Scheirich et al. 2015; Pravec et al. 2016). Exposure time was chosen in the range from 20 s to 5 min, depending on the brightness of the asteroid and the angular speed of its sky motion (Krugly 2004). During observations only R.A. tracking at the sidereal rate was used at both telescopes, therefore the limited exposure time is used for fast moving asteroids to obtain their images as a trace with a length of 2-3 seeing diameters of a fixed star (Krugly 2004).

Initial reduction of CCD images includes subtracting the average dark image and the average flat-field (commonly they referred to as the master dark and the master flat). The dark images are averaged using more than 10 ones, usually a few dozen. Images in the opposite to the sun side of the sky obtained during evening and morning twilight in clear conditions are used to calculate the master flat. Magnitudes of an asteroid and comparison stars are measured on calibrated images by a technique of aperture photometry using the AstPhot software (Mottola et al. 1995). More details on the reduction are described in Krugly et al. (2002, 2007).

Attention was paid to obtain high-precision photometric measurements, for which observations are made with an optimal exposure and often without a filter. Average precision of brightness measurements of an asteroid is 0.01-0.02 mag and usually no worse than 0.04 mag.

To show accuracy of asteroid photometry made at Abastumani, we present observations of NEA (3554) Amun obtained at several observatories during its appearance in 2011. The asteroid was observed with 70 cm telescopes at the Abastumani Observatory, at the Chuguev Observatory (Ukraine), and at the Lisnyky Observatory (Ukraine) in February-March 2011. The parameters of setups used at Lisnyky and Chuguev observatories are given in Krugly et al. (2015). Figure 2 shows the obtained lightcurves. On February 14, the asteroid had brightness of 15.8 mag and was observed with an accuracy of 0.03 mag at Chuguev near the bright moon (Fig. 2A). At Lisnyky the lightcurve obtained in the next night on Feb. 15 in clear conditions had better accuracy of 0.02 mag (Fig. 2A). On Feb. 27 the asteroid was as bright as 15.0 mag, and the observations at Chuguev showed the precise data with RMS of 0.01 mag (Fig. 2C). On March 14 Amun's brightness was close to maximum in the 2011 opposition of 13.9 mag, and the observations at Abasumani were carried out with a high accuracy of about 0.007 mag (Fig. 2D).

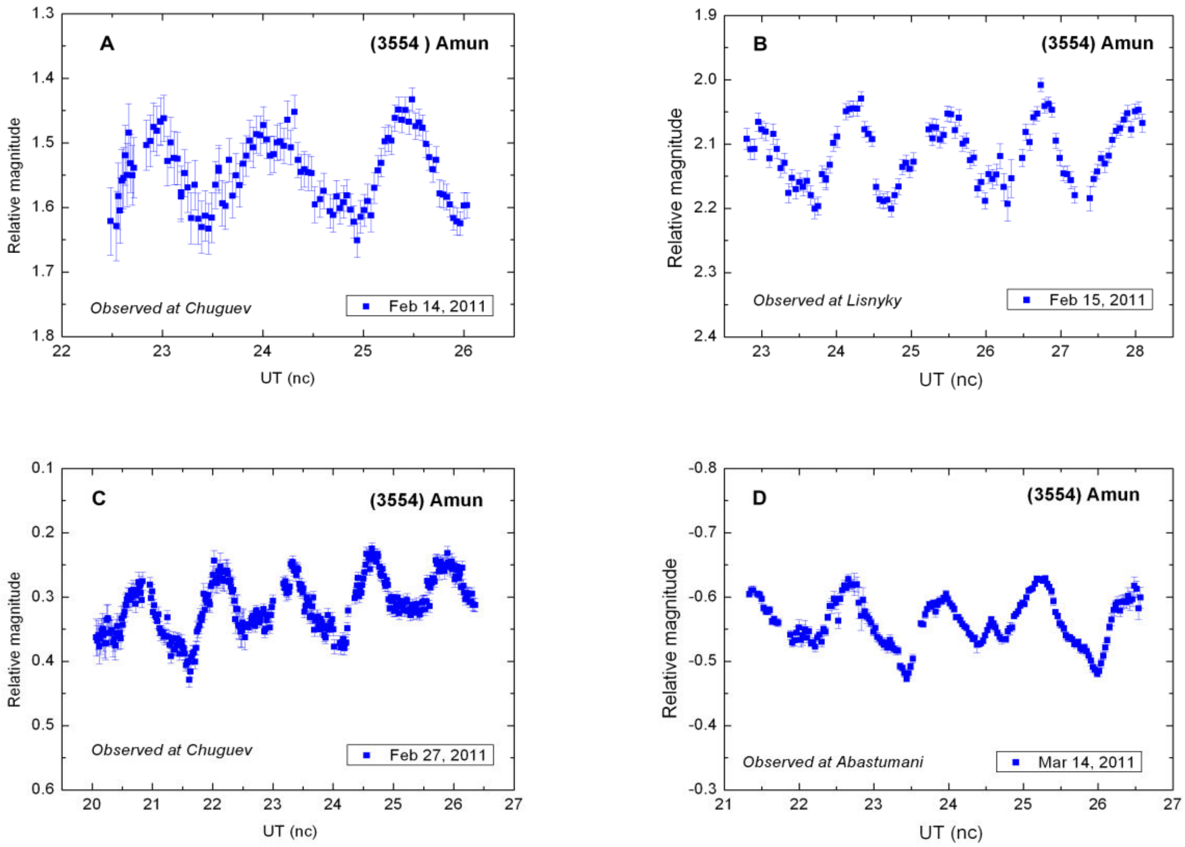

Fig. 2. Lightcurves of the asteroid (3554) Amun obtained in 2011 opposition: A) in Chuguev on February 14; B) in Lisnyky on Feb. 15; C) in Chuguev on Feb. 27; D) in Abastumani on March 14.

4. Results of Photometry

Regular CCD observations of asteroids have been started in Abastumani since the beginning of 2011. Each year about 25-35 NEAs are observed photometrically. More than hundred NEAs have been investigated in 2011-2015. Among the observed NEAs there are potentially hazardous objects, such as the asteroid (99942) Apophis. For more than thirty NEAs the rotation periods have been determined or substantially improved, and sizes and shapes of the observed bodies have been estimated. During the work 14 binary NEAs were observed, and Abastumani participated in the discovery of 6 of them (Krugly et al. 2010; Pilcher et al. 2012; Pravec et al. 2016). More than 15 NEAs have been observed in parallel with the radar observations (among them 3 binary asteroids discovered from the radar observations). Several asteroids were observed to detect the YORP effect including NEAs (1862) Apollo (Kaasalainen et al. 2007), (1620) Geographos (Durech et al. 2008), and (3103) Eger (Durech et al. 2012) for which the effect was discovered. The photometric data were obtained for two well-known binaries (88710) 2001 SL9 and (175706) 1996 FG3 (Scheirich et al.

2015) to verify the existence of the Binary YORP effect (BYORP, see in Cuk & Burns 2005), which supposes orbital variation of a synchronously rotating secondary in a binary system under the YORP influence.

Below, we present observations of four NEAs which demonstrate results obtained on different tasks of our research.

(4055) Magellan discovered by Helin E. F. at Palomar Observatory in 1985 belongs to the Amor asteroids. The orbit of the asteroid lies beyond the Earth orbit with the following parameters: semi-major axis a = 1.8201 AU, eccentricity e = 0.326, inclination i = 23.258 deg, and perihelion q = 1.22 AU. The asteroid is known as the V-type asteroid (a possible source of the basaltic meteorites on the Earth) with albedo p_v = 0.36 and diameter D = 2.46 +0.53/-0.41 km. (Thomas et al. 2011, 2014). Taxonomic type is defined based on observations of the color indices and spectra (Visible + NIR) of the asteroid. The asteroid was firstly classified as the V-type by Cruikshank et al. (1991) due to measurements of color indices U-B = 0.52, and B-V = 0.22. Pravec et al. (2000) obtained lightcurves of the asteroid and determined a rotation period of P = 7.496 hours in 2000, and determined parameters of the phase-relation in the R band to be equal to Hr = 14.45, G = 0.25. In January-February 2014 the asteroid was observed by Warner (2014) which obtained a wrong period of 6.384 h, because of very sparse observations (Warner 2015a). New observations of Warner (2015a) in 2015 give a period of 7.496 hours (the lightcurve amplitude of 0.63 mag at phase angle 39 deg) consistent with the Pravec et al. (2000).

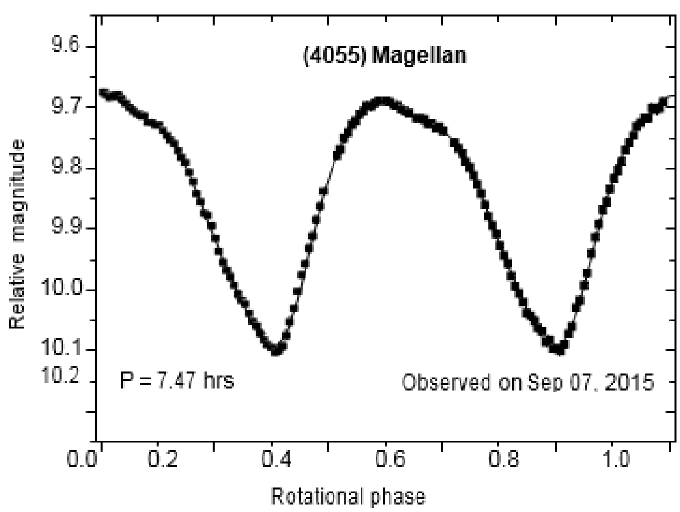

Fig. 3 Composite lightcurve of asteroid (4055) Magellan following observations on September 7, 2015. A solid line is an approximation with Fourier series of the asteroid's brightness variations with time using a period 7.47 hours.

We observed Magellan at Abastumani on September 7, 2015. The observations allow us to estimate the value of the period P = 7.47 ± 0.2 hours in a good agreement with the value previously defined by Pravec et al. (2000). The composite lightcurve showed in Fig. 3 covers a whole rotation period of Magellan. The maximum amplitude of the lightcurve is 0.41 mag at phase angle 3 deg, that close to the value 0.46 mag obtained by Pravec et al. (2000) in 2000.

We expect to estimate an infuence of the YORP effect on Magellan's rotation period in the future after carrying out observations in its next appearances in 2017, 2019, and 2020. During the former opposition the asteroid will be near its perihelion with a high brightness V = 15.8 mag. A good estimate of the YORP will be obained if a model of the asteroid's shape will be constrained as a result of radar observations carried out in that time.

(137925) 2000 BJ19 is Apollo asteroid with diameter 2-4 km which was discovered within the

Catalina survey in January 2000 (MPC). The asteroid has highly elongated orbit (a = 1.292, e = 0.764, i = 31.1 deg) with an orbital period 1.47 years and crosses Mercury's orbit near the perihelion q = 0.305 AU. In 2015 opposition the asteroid was well visible on the Northern sky throughout a whole night in February-March. In this time the brightness of asteroid has reached maximal magnitude 16.7 mag that provides a good opportunity for photometry.

The CCD observations of 2000 BJ19 were carried out at Abastumani for four nights in the interval from 23 February up to 13 March 2015. The obtained data have allowed us to determine definitely the rotation period of 5.516 ± 0.003 hrs. The lightcurves of the asteroid composed of this period are shown in Fig. 4. The ordinates represent the relative magnitudes of the asteroid. There are two composite lightcurves for different dates of observations: from February 23 to March 3, and for the night on March 13. Shapes of the lightcurves differ significantly. February's lightcurve has smaller amplitude of 0.15 mag and asymmetrical minima with unusual shape. As opposed to February, the lightcurve on March 13 has a symmetrical shape with the maximum amplitude of 0.24 mag. The difference between amplitudes and shapes of the lightcurves may be related with an increase in phase angle from late February to mid-March from 26 to 43 deg, respectively. Also, the changing shape of the lightcurve may be connected with variation of aspect of the observations on more than 30 deg. We can say that the shape of the asteroid is irregular and markedly different from the equilibrium shape. An estimate of elongation of the body's shape can be made taking into account the correction of the amplitude of asteroid's variation to zero phase angle. If we assume that the growth of the amplitude with phase angle as m = 0.023 mag/deg (Zapalla et al. 1990), then the ratio of the largest semiaxes of the approximating ellipsoid is 1:0.9.

Warner (2015) observed this asteroid in mid-February 2015 and estimated the rotation period to be equal 48 or 24 hrs. This rough error in determining the period may be due to a poor accuracy of the observations. It could be caused by both the observations in the bad weather conditions (as was noted by the author) and a small aperture of the used telescope.

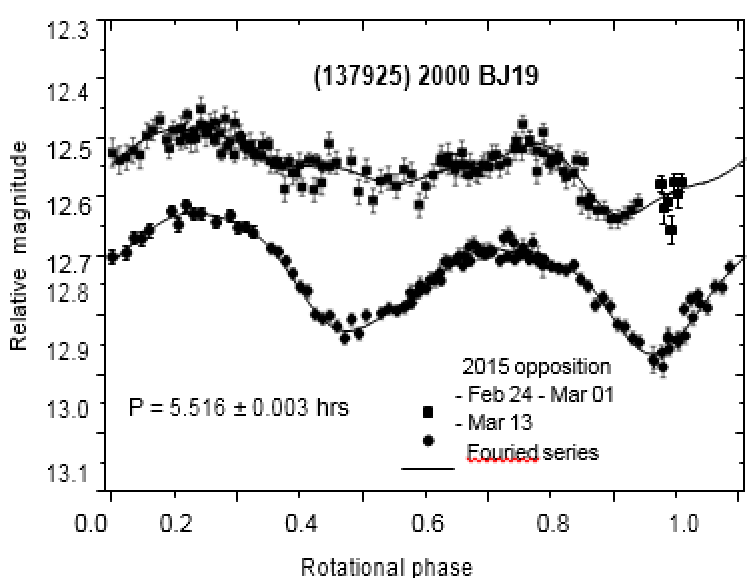

Fig. 4. The composite lightcurves of asteroid (137925) 2000 BJ19 following observations in February-March 2015. A solid line is an approximation with Fourier series of the asteroid's brightness variations with time using a period 5.516 hours.

(326290) Akhenaten is Aten asteroid with a small diameter about 100 m which was discovered in the private observatory Goodricke-Pigott in Tucson (USA) by R. A. Tucker in April 1998 (previously named 1998 HE3). The asteroid is listed at the MPC as Potentially Hazardous Asteroid due to the absolute magnitude H = 21.8 and Earth MOID = 0.0034 AU (EMOID is the minimum distance between the Earth and the minor planet). The asteroid orbit is highly eccentric (a = 0.879 AU, e = 0.440, i = 3.378) with aphelion Q =1.266 and perihelion q = 0.492. The asteroid positions were measured during 6 oppositions and now Akhenaten belongs to asteroids for which evidences of the Yarkovsky effect have been found (Farnocchia et al. 2013). Moderate albedo of the asteroid (SQ type) and its diameter of 0.1 km were assumed in Binzel et al. (2002).

In April-May 2012 the asteroid approached to the Earth. A close pass to the Earth at 12.4 lunar distances (0.032 AU) was on May 10, 2012. First photometric observations of the asteroid were made in April with the 2.6 m telescope of Crimean Astrophysical Observatory. They showed that the asteroid rotated very fast with a period of several minutes (Fig. 5A). Observations at Abastumani on May 9 confirmed very fast rotation of the asteroid with the period 3.921 min. There are some other published data on the value of the rotation period. The composite lightcurve constructed using the determined period is shown in Fig. 5B. The maximal amplitude of the brightness variations is as small as 0.06 mag. A small amplitude suggests either a nearly spheroidal shape of the asteroid or observations close to a polar aspect. Radar observations at Arecibo Observatory with 305 m radar in early May 2012 have confirmed a fast rotation of the asteroid (Nolan & Taylor 2012).

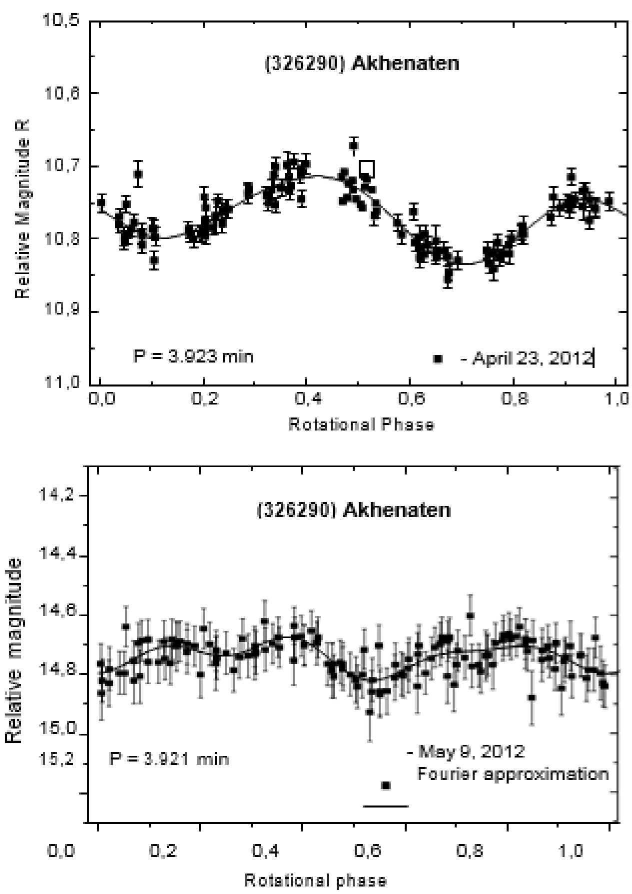

Fig. 5. The composite lightcurve of asteroid (326290) Akhenaten following observations at CrAO (A) on April 23, and at AbAO (B) on May 9 in 2012. A solid line is an approximation with Fourier series of the asteroid's brightness variations with time using periods (A) 3.923 and (B) 3.921 minutes.

Among NEAs with diameters larger the 200-300 m, almost all bodies rotate slower than about 11 revolutions per day (Pravec & Harris 2006). There is a rotation speed limit for these asteroids called “spin barrier”. It is suggested that these bodies may composed of many individual parts, which held together only by the gravity. Such a composite body may be formed after catastrophic impact between asteroids and called “rubble-pile” asteroid (Richardson et al. 1998). In the same time a large number of NEAs with diameters less than 200 m show a very rapid rotation with periods less than 2.2 hours (Hergenrother & Whiteley 2011; Hetch & Wiegert 2015). A little of “rubble-pile” asteroids can spin faster than 2.2 hours, so it is assumed that the most rapidly rotating asteroids are monolithic bodies. Asteroid (326290) Akhenaten rotates very fast making about 367.25 revolutions per day, and its diameter about 100 m is close to the maximal diameter limit of fast-rotating asteroids. Therefore there are many reasons to assume that Akhenaten is a monolithic body.

2013 TV135 is Apollo asteroid discovered in the Crimean Astrophysical Observatory in October 2013. The asteroid is a small NEA with diameter of 400 m estimated from the absolute magnitude H = 19.5 (MPC) and essuming its albedo 0.18. The asteroid 2013 TV135 is located on an elongated orbit (a = 2.438 AU, e = 0.593, i = 6.75 deg, q = 0.987 AU). During the first weeks after its discovery the asteroid was assumed to be a potentially hazardous object.

Observations were carried out at Abastumani and Chuguev observatories immediately after its discovery in October 2013. The asteroid was observed at Abastumani with the 70-cm meniscus telescope AC-32 on Oct. 21-22 and 24-25, and Dec. 4, and at Chuguev with the 70-cm telescope AZT-8 on Oct. 23. The rotation period of the asteroid equals to 2.351 ± 0.001 hours was firstly found as a result of our observations. The maximum amplitude of the brightness variations of the asteroid is equal to 0.38 mag at phase angle of 55 deg. Lower estimate of the ratio of the largest semi-axes of an ellipsoid approximating the shape of the asteroid is a:b = 1:0.86 using m = 0.023 mag/deg (Zapalla et al. 1990). Figure 6 shows the lightcurve of the asteroid obtained at Abastumani on October 21.

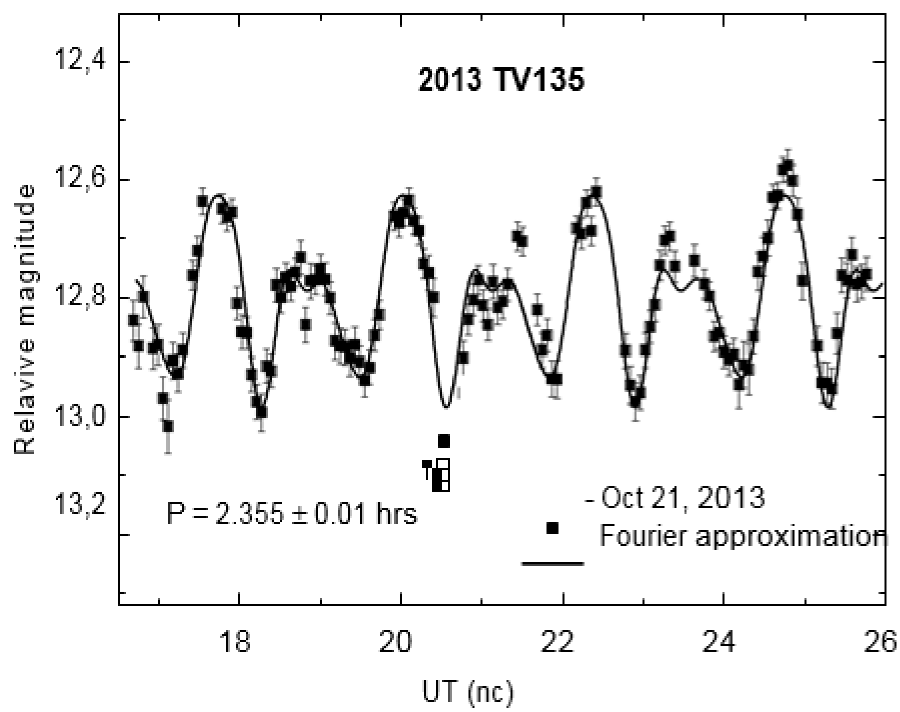

Fig. 6. Lightcurve of asteroid 2013 TV135 following observations on October 21, 2012. A solid line is an approximation with Fourier series of the asteroid’s brightness variations with time using a period 2.355 hrs

5. Observations in the Frame of the Optical Telescopes Network *Gaia*-FUN-SSO in Support of the *Gaia* Mission

The Abastumani Observatory joined the international optical network the *Gaia*-FUN-SSO in 2011 (Krugly et al. 2011, 2015). The network of observatories organized by the IMCCE - Paris Observatory and the Observatory of Nice (France) for astrometric and photometric observations of asteroids, which will be discovered or studied in details (UBVRI-photometry and spectrophotometry) during observations with the *Gaia*, a mission of the European Space Agency. The *Gaia* spacecraft has been placed in a special orbit near the Sun in the Lagrangian point L2 of the Sun-Earth system on December 2013. Throughout 2014, the equipment of the satellite was tested and observations of selected sky fields were made. In the spring of 2015 the mission has elaborated its main program to carry out the survey of the sky in order to obtain high-precision measurements of positions and magnitudes of the stars across the sky up to 20-21 mag. It is expected that the satellite will work at least 5 years. Currently, timely detection of asteroids in a flow of the *Gaia*'s observations is tested to start working on discovery of asteroids.

In 2011-2014 in order to prepare observatories participated in the *Gaia*-FUN-SSO network to follow-up observations of the asteroids, the organizers of the cooperation have been proposed several NEAs for test observations (Thuillot et al. 2015). The participation of the Abastumani Observatory in the test is reproduced in Table 1, which shows the observed asteroids and the dates of their observations. The observations were carried out at the 70 cm meniscus telescope with a CCD camera IMG-6303E. Accuracy of measured positions of asteroids is determined mostly by an accuracy of the used astrometric catalog (USNO-A20, UCAC3, UCAC4). On the average, accuracy is better than 0.5-0.7 arcsec.

In particular, one of the most dangerous (at that time) NEA (99942) Apophis was included in the program of observations. An astrometric observation campaign was launched during the latest period of observability of Apophis in 2012-2013 before its dangerous passing the Earth in 2029. Results of Apophis' observations show that the accuracy of astrometry obtained in Abastumani is high enough to be suitable for analysis of such a task (Thuillot et al. 2015).

Table 1. Asteroid observations, which were carried out at Abastumani in the framework of a test program to support the *Gaia* mission.

Asteroid	Interval of campaign	Dates of observations
(308635) 2005 YU55	Nov-Dec 2011	2011 Nov 17-19; Dec 17
(175706) 1996 FG3	Nov 2011 - Mar 2012	2011 Nov 22,25; Dec 1, 17-18, 30; 2012 Jan 21; Feb 24, 25
(99942) Apophis	Feb 2012	2012 Feb 24 – asteroid was not found
(99942) Apophis	Jan-Apr 2013	2013 Jan 28, 30, Feb 2-3, 11, 13- 14; Apr 1
2012 DA14	Feb 2013	2013 Feb 17
(163249) 2002 GT	Jun 2013	2013 Jun 19-20, 30
2013 TV135	Oct-Dec 2013	2013 Oct 21-22, 24-25; Dec 4
2014 HQ124	Jun 2014	2014 Jun 10

5. Conclusions

The program of investigation of physical properties of NEAs was launched in Kharadze Abastumani Astrophysical Observatory in the cooperation with the Institute of Astronomy of V. N. Karazin Kharkiv National University in 2011. The collaboration includes a participation in organizing observation projects, improving the instrumental base, and training highly qualified specialists. In the frame of this work the CCD photometric observations of NEAs are carried out at Abastumani on a regular base. More than hundred asteroids have been investigated during 2011-2015.
Our plans are aimed at the continuation of the study of asteroids in the following areas: characterization of potentially dangerous and newly discovered NEAs; detection of binary asteroids; study of the YORP effect; support of radar observations of NEAs. We are prepared to begin observations of the asteroids newly discovered by the *Gaia* mission.
We expect on technical improvements of the 70 cm telescope AC-32, which consist in using a more sensitive CCD camera, installing the camera in a primary focus, and modernization of the control system of the telescope. A significant contribution to the work would be made in case of upgrading of the 1.25 m telescope AZT-11. All these will improve the accuracy of photometric measurements and will provide an opportunity to observe more faint celestial objects.

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