OBSERVATIONS OF APOPHIS IN NSFCTC (YEVPATORIA) AND RI NAO (MYKOLAIV)

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ABSTRACT. The results of observations of potentially hazardous asteroid Apophis, performed in January-February 2013 are presented. Technical characteristics of equipment and method of observation are described. The results are shown in comparison with the observations of this object by other observatories.

Introduction

History of the discovery and the first observations. The asteroid was discovered at the Kitt Peak Observatory on June 19, 2004 and received preliminary designation 2004 MN4. The analysis of the orbit calculated from the results of the first observations has found out that this object has a relatively high (2.7%) probability of collision with the Earth at close approach in April 2029. This is the highest value for all known asteroids.

New optical observations and radar measurements with the Arecibo radio telescope in 2005 have greatly clarified the parameters of orbit. New orbit has shown significant decrease in the collision probability with the Earth. Precision of the orbit was sufficient to assign this object of numbered value 99942 and own name Apophis.

The problem of "keyhole". Refined estimates of the orbit have shown that the asteroid will pass at a distance of about 37,000 km from the Earth's surface in 2029 (Chodas, 2005). The uncertainties of the orbital parameters allowed us only approximately determine the areas the closest approach of Apophis. The probability of collision with Earth in 2036 may be increase due to gravitational interaction when asteroid will pass through certain points within calculated area of closest approach in April 2029. This problem is called "keyhole" (see, e.g., Chesley et al., 2006). There are many work (Bancelin et al., 2012; Chesley et al., 2006; Farnocchia et al., 2013; Giorgini et al., 2008; Ivashkin et al., 2007; Królikowska et al., 2009; Włodarczyk, 2008; Zabotin et al., 2009) devoted to estimating of the uncertainties of the orbital parameters and modeling possible orbit of Apophis after its close approach.

Due to the nature of the orbital motion, Apophis can be observed from the Earth only in limited periods of time, usually during the close approaches (Chesley et al., 2006). Apophis was available for both optical and radar observations during the close approach in the winter 2012-2013 year. This was of particular importance to improving the accuracy determination of the orbital parameters of the asteroid (Giorgini et al., 2008) and the main reason for carrying out the international campaign of Apophis observations by GAIA-FUN-SSO group.

RI NAO and NSFCTC have made observations of the Apophis as members of the GAIA-FUN-SSO group, as part of the observation campaign announced by coordinators of the network.

Equipment and methods of observations

Telescope Mobitel (RI NAO). The telescope Mobitel (D=0.5 m, F=3.0 m) has begun regular observations of selected asteroids and NEO objects since 2011 (Ivantsov et al., 2012). The CCD camera Alta U9000 (3056x3056 pix, 12x12 mkm2) of Apogee Imaging Systems allows us to get frames with 42.0'x42.0' field of view with 0.83″/pix of scale. The observations were carried out in time delay and integration mode with time of exposure 85 seconds using R filter close to R photometric band of Johnson-Cousins-Bessel system. The astrometric reductions of observations were made using Astrometrica software. Model of linkage of 4th order polynomial between measured and tangential CCD coordinates was chosen. The UCAC4 (Zacharias et al., 2013) catalog was used as reference catalog for processing of all data.

Telescope AZT-8 (NSFCTC). The modified telescope AZT-8 (D=0.7 m, F=2.8 m) have made Apophis observations in NSFCTC (Yevpatoria). The telescope is also equipped with CCD camera FLI PL09000 (3056x3056 pix, 12x12 mkm^2) and filter R (based on the color glass OG-12). The camera was used in binning mode so the actual size of the images was 1528x1528 pix, pixel size – 24x24 mkm^2. Telescope field of view with this camera was 44.0′x44.0′. Time synchronization of camera work was carried out with GPS Trimble Resolution-T.

The observations of Apophis were carried out in the frame mode only when zenith distance according calculated ephemeris was less than 70 degrees for reducing the effect of refraction. Exposure time was chosen depending on the rate of apparent motion for obtaining maximal SNR for point source. The time of exposures ranged from 30 to 90 seconds.

The observations were processed with Astrometrica software. Catalogs UCAC3 (Zacharias et al., 2010) and UCAC4 were used as the reference catalog. The model of cubic polynomial was chosen as the linkage model between measured and tangential CCD-coordinates.

Table 1: Results of observations of the Apophis in RI NAO (according MPC and NeoDys centers)

Date	Number	(O-C)_RA, arcsec	RMS_RA, arcsec	(O-C)_DEC, arcsec	RMS_DEC, arcsec
24/ 01*	26	0.09	0.12	-0.43	0.21
05/ 02	29	0.02	0.11	-0.04	0.15
12/ 02	24	-0.03	0.07	-0.02	0.07
13/ 02	29	-0.04	0.08	-0.02	0.11
26/ 02*	30	0.17	0.10	0.06	0.12

* Results were obtained combined method (Shulga et al., 2007): Shulga O.V.; Sybiryakova Y.; Kozyryev Y.; Kulichenko N.; Vovk V.

Table 2: Results of observations of the Apophis in NSFCTC (according MPC and NeoDys centers)

Date	Number	(O-C)_RA, arcsec	RMS_RA, arcsec	O-C_DEC, arcsec	RMS_DEC, arcsec
22/ 01	21	0.09	0.11	-0.26	0.06
24/ 01	15	0.2	0.17	0.2	0.11
30/ 01	17	0.14	0.18	0.03	0.16
05/ 02	7	0.14	0.14	0.02	0.13
06/ 02	6	0.17	0.13	0.06	0.12
08/ 02	3	0.46	0.23	0.06	0.02
12/ 02	14	0.23	0.20	-0.1	0.20

Table 3: Top 15 observatories on results of Apophis observations (December 2012 – May 2013).

MPC Cod, Observatory	Frame number	Date number	(O-C)_RA, arcsec	RMS_RA, arcsec	(O-C)_DEC, arcsec	RMS_DEC, arcsec	Catalog
D20, Zadko Observatory, Wallingup Plain	391	14	0.05	0.10	-0.03	0.10	PPMXL, UCAC-3
071, NAO Rozhen, Smolyan	379	10	0,04	0,54	-0.03	0.31	USNO-B1.0
C40, AO Kuban State University	253	10	-0.09	0.30	0.07	0.24	UCAC-2
C20, Kislovodsk Mtn. Pulkovo Obs.	244	3	0.02	0.11	0.02	0.13	UCAC-4
A84, NO TUBITAK	241	2	-0.34	0.18	0.07	0.15	UCAC-2
H45, Arkansas Sky Obs.	125	19	0.06	0.23	-0.04	0.20	UCAC-4
B17, AZT-8 Evpatoria	83	7	0.20	0.17	0.00	0.11	UCAC-3, 4
089_1, Nikolaev	82	3	0,00	0,09	-0.03	0.12	UCAC-4
188, Majdanak	58	2	-0.02	0.17	0.05	0.09	-
089_2, Nikolaev	56	2	0.04	0.13	-0.17	0.30	UCAC-3
300, BiseiSpaceguard Center-BATTeRS	53	4	0.15	0.31	-0.15	0.20	USNO-B1.0
H21, AO Westfield	49	5	0.03	0.17	0.01	0.14	UCAC-3
F65, Haleakala-Faulkes Telescope North	48	13	0.00	0.16	0.01	0.11	PPMXL
585, Kiev comet station	33	2	0.00	0.18	0.05	0.16	UCAC-3
I47, Pierre Auger Observatory, Malargüe	32		0.10	0.09	-0.05	0.11	UCAC-3
168, Kourovskaya	30	2	-0,16	0,38	0.16	0.48	UCAC-2

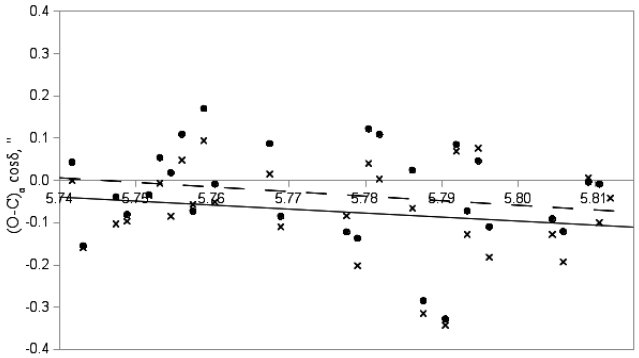

Fig. 1. The distribution of differences (O-C) in right accession at February 5, 2013 (Mobitel, RI NAO). Points (dotted line) correspond to the positions of new ephemerid; crosses (solid line) correspond to the positions of ephemerid without observations were made in February and later.

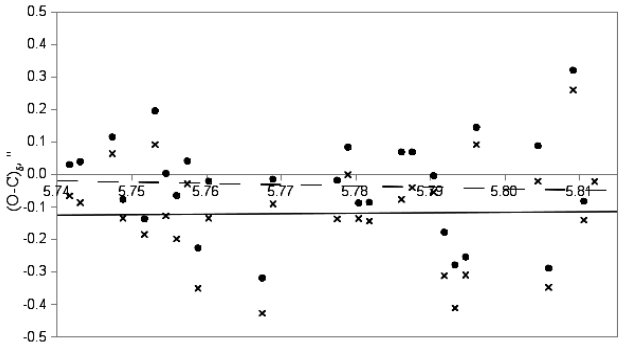

Fig. 2. The distribution of differences (O-C) in declination at February 5, 2013 (Mobitel, RI NAO). Points (dotted line) correspond to the positions of new ephemerid; crosses (solid line) correspond to the positions of ephemerid without observations were made in February and later.

Results of observations

138 astrometric positions of Apophis were obtained by two groups of observers from RI NAO for 5 nights in January-February 2013 in total. For the same period 83 positions was obtained for 7 nights in NSFCTC. Detailed results of observations according of the NeoDys data are presented in Table 1 (RI NAO) and 2 (NSFCTC). Unfortunately, the bad weather conditions are typical for this season and that is not allowed to get more observations.

The observations of Apophis were performed by 66 observatories during this period, but the 15 most productive observatories got around 80% of all positions. The Table 3 are shown the place RI NAO and NSFCTC among other observatories where observations of Apophis were performed. Underlined lines are names of observatories-members of GAIA-FUN-SSO, bold – results obtained by NSFCTC and RI NAO. Database of MPC contains 4,131 optical positions of asteroid Apophis received from 128 observatories for observations between March 15, 2004 and May 27, 2013. The 2,607 (63.1%) positions of the total number were received during last close approach with Earth (end 2012 – beginning 2013). The 63.6% (1,657) observations of the total were obtained by observatories which are member of GAIA-FUN SSO (MPC codes: 071, 089, 188, 300, 585, A84, B04, B17, C01, C20, D20).

Statistics for the 15 most productive observatories is presented in table 3. It should be noted that most productive observatories for observation of Apophis are members of the GAIA-FUN SSO. The Table 3 is given the values of (O-C) differences, where O means observed position, C – ephemeris position. It should be noted, that C values were calculated taking into account these observations. The Table 3 also contains root mean square (RMS) errors of (O-C) values as a measure of the accuracy of positions. The RMS value includes not only the measurement accuracy but the accuracy of the reference catalog because data for different dates were averaged. Data of the table shows that NSFCTC and RI NAO are quite well in comparison with other observatories. For the telescope AZT-8 RMS errors are less than 0.17" in right ascension and 0.11" in declination, for the telescope Mobitel – nearly 0.11" in both coordinates.

An analysis of the values (O-C) revealed a gradual decrease of these differences with respect to the HORIZONS ephemeris of JPL. The Fig. 1 and Fig. 2 show distribution of (O-C) differences for observations in RI NAO at February 5, 2013. Points and dotted line (trend) corresponds to (O-C) were calculated with new ephemerid which are included all observed positions during close approach in 2012-2013. Crosses and solid line (trend) corresponds to (O-C) were calculated with old ephemerid. As can be see, the values of the (O-C) differences for new ephemerid are closer to zero. This indicates that the using of the new high-precision positions allows us to refine the calculated ephemeris. According to NASA calculations, the new orbit of Apophis, calculated with using the results of observational campaign 2012–2013 yr., practically excludes the possibility of the asteroid collision with Earth in 2036.

Conclusions

The organization of special campaign of ground observations provides a sufficient number of observations for qualitative refinement of the orbits in a relatively short period of time.

It is shown, that even small telescopes with a diameter of less than 1m equipped with modern CCD cameras, can be used for observations of such NEO objects with using of high-precision catalogs for astrometric reductions.

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