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ИЗУЧЕНИЕ ОБЪЕКТОВ ОКОЛОЗЕМНОГО ПРОСТРАНСТВА И МАЛЫХ ТЕЛ СОЛНЕЧНОЙ СИСТЕМЫ

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НАО

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6. Discussion

This simulation taking into account 364 perturbers and some 6062 target asteroids gives very encouraging results since about 65 masses could be estimated with a precision better than 10%. Keeping in mind that Gaia will actually observe about 350,000 asteroids, so that the number of close approaches is significantly increased, one can expect more mass determinations at that precision level. It is now planned to include these 350,000 asteroids in the simulations as well as more perturbers.

Besides, we noticed that an important number of close approaches (360 with a deflection angle greater than 50 mas), which was found to be not observed by Gaia, either before or after the close approach time. So, a great part of information from the encounter between the perturber and target asteroids is lost. A study of what could bring ground-based observations before and after the space mission seems to be essential for the encounters of which the moment of the minimal distance between the perturber and the target is located at the edge of the Gaia time span observation.

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ABOUT RESEARCH COLLABORATION PROJECT BETWEEN NATIONAL OBSERVATORY OF TURKEY, KAZAN STATE UNIVERSITY AND NIKOLAEV ASTRONOMICAL OBSERVATORY

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Results of long-term collaboration between Nikolaev Astronomical Observatory (Ukraine), TUBITAK National Observatory (Turkey), and Kazan State University (Russia) are given on some research problems which can be solved with positional astronomy, such as determination of link angles between astrometric catalogues, based on radio and optical observations of extragalactic radio sources, and improvement of orbital elements of asteroids, and determination of dynamical parameters. In addition, preliminary estimations are given for photometric observations at the RTT150 telescope of TUBITAK National Observatory.

1. Link between optical and radio reference frames

At first it started as the International Joint Project JP (1996—2006) in the framework of collaborated observatories from China, Russia, Turkey and Ukraine on refinement of the link between optical and radio reference frames. It finished with good results [3].

The final co-operative program list contained about 300 ERS in the selected fields of celestial sphere in declination zone from –40° to +80° and magnitude range from 12th to 21st mag. Some characteristics of the CCD telescopes of collaborated observatories which took part in the Joint Project are shown in Table 1.

Positions of 300 ERS optical counterparts were obtained by CCD direct imaging with reference stars of 14—20 magnitudes mainly at the RTT150 and 1.0m Yunnan telescopes. There were made more than 3500 CCD frames during 2000–2003. Each ERS field was observed 6—7 times on the average.

Standard errors of the ERS positions are σ_α = 38 mas, σ_δ = 37 mas in right ascension and declination, respectively. There was found no dependence of the differences "optical minus radio position" ($\Delta\alpha_{O-R} \times \cos\delta = \alpha_O - \alpha_R$ and $\Delta\delta_{O-R} = \delta_O - \delta_R$ in the sense (UCAC2-ICRF) on right ascension or declination of the source.

The obtained values of the differences were used for calculation of rotation angles between optical and radio systems of coordinates (Table. 2).

Final results:

– accuracy of the obtained values is 5÷6 mas (JP1);

– increasing number of optical positions and accuracy of published positions allow improving the accuracy of determination of the link parameters to 3÷4 mas (JP2).

The error of the solution is dominated by the accuracy of the reference optical catalogue.

Table l. Collaborated CCD telescopes

Telescope	RTT150 (Antalya, TUG,Turkey; KSU,RF)		1.0m Yunnan telescope (ShAO,China)	MCT, (NAO, Ukraine)
φ	+36°		+31°	+47°
Type	Reflector		Reflector	Refractor
D(mm)	1500	1500	1000	160
F(mm)	11700	11700	13250	2044
CCD:	ST-8	Andor DW436	TI	ISD017A
Size, pix	1530×1020	2048×2048	1024×1024	1040×1160
Pixels, μm	9×9	13.5×13.5	24×24	16×16
″/pix	0.″16	0.″24	0.″37	1.″6
FOV	4.1′×2.7′	8.2′×8.2′	6.4′×6.4′	28′×31′
Mode	Stare	Stare	Stare	Stare
		Drift scan		Drift scan
Magnitude	$17^m \div 21^m$	$17^m \div 23^m$	$14^m \div 19^m$	$12^m \div 14^m$
Period of observations	2000—2002	2003	2000—2003	2000—2003

Table 2. Optical-radio rotational parameters

Source	ω_x (mas)	ω_y (mas)	ω_z (mas)	σ_1(mas)
Joint Project1, 142 ERS	-4.1±6.1	1.9±5.8	12.4±4.9	46
Joint Project2, 234 ERS, with Assafin M. et al.[4]	-1.7±4.4	5.2±3.8	9.1±3.3	39
N. Zacharias et al., 318 ERS [13]	-0.2±3.9	-5.4±3.9	-2.5±3.9	58

where $\omega_{x,y,z}$ are rotation angles with their standard errors; σ_1 is error of unit weight.

2. CCD observations of Solar system small bodies with RTT150

Positional and photometric observations were outlined for small Solar system bodies in the next stage of the international collaboration between three astronomical institutions.

Observations of selected asteroids in the range from 11 to 18 magnitudes for mass determination by dynamical method began at the RTT150 in May 2004 [2]. Particular emphasis was later given to positional observations of the near-Earth asteroids up to 21.5 magnitudes for improvement of their orbits.

So far, we have obtained about 3.5 thousand positions of 53 selected asteroids and 187 positions of 11 NEOs. Almost all the internal observational errors for the selected asteroids up to 17 magnitude are within 0″.1, with a mean value less than 0″.05 in both coordinates. As one can see from Fig.1 and Fig.2, the internal errors do not depend on the magnitudes of the detected objects. The mean values of the external uncertainties of observations are somewhat greater than the internal errors in right ascension and reach 0″.1 (Fig. 1). The internal and external uncertainties in declination are about 0″.05 (Fig. 2). A comparison of the observational results obtained at the RTT150 in 2004—2005 with the observations of these objects at other observatories allows us to conclude that observations at the RTT150 are of high accuracy.

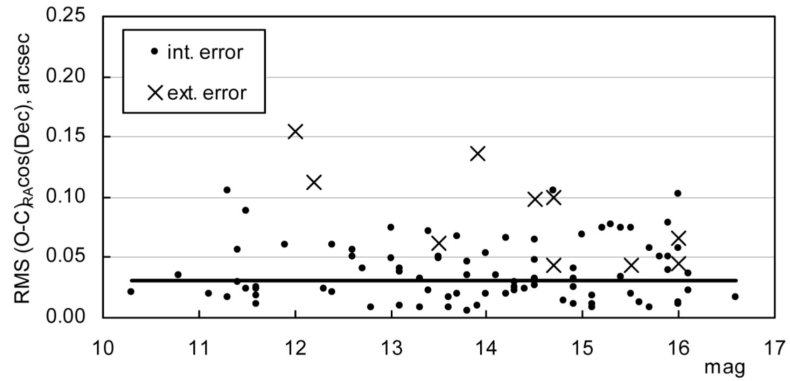

Fig. 1. Dependence of standard error of a single (O-C) in right ascension on magnitude. Dots are internal errors of observations for selected asteroids, crosses are external errors.

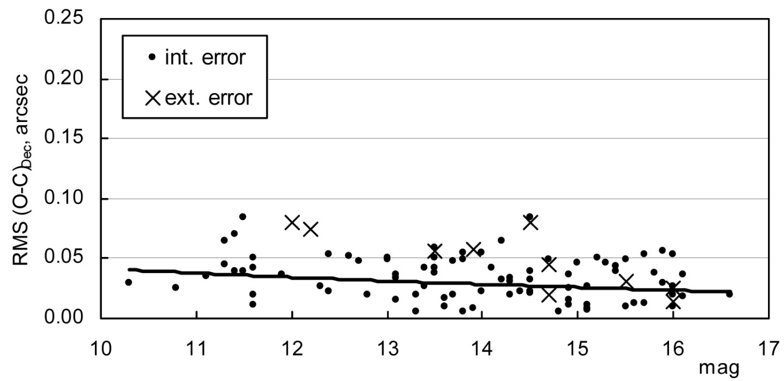

Fig. 2. Standard errors in declination, as in Fig. 1.

In general, the expected positional accuracy of observations with the RTT150 of the Solar system small bodies up to 20 magnitudes, including asteroids in the near-Earth space, could be about 0″.03÷0″.1, if one uses optical reference catalogue of high accuracy and density like the UCAC2.

2.1. Preliminary results of photometric observations

Photometric reduction of asteroids 2000PN9, 673Edda, 846Lipperta, 2005TF49 observed on 29.03.2006 was made in KSU with software MaxIm.

Conditions of observation:

2000PN9: binning 1×1, exposure time is 60 sec, filter V (16.6), number of frames is 60;

2005TF49: binning 1×1, exposure time is 60 sec, filter V (17.1), number of frames is 44.

The accuracy of a single photometric determination for asteroid magnitude is about 0.01 at 17 magnitude and about 0.05 at 20 magnitude in the Cousins Rc-band.

Results of the reduction are shown in Fig. 3 and 4. There was no change in the brightness of 2005TF49 in comparison with the neighboring star in 2 hours of observations (see Fig. 4). Asteroid 2000PN9 showed brightness variations with amplitude $0^m.11$ (16.36–16.45) with a period of 1.77 hours. These results are similar to the earlier ones by P. Pravec, who obtained a period of 2.5325 hours and amplitude 0.15 magnitude in 2003.

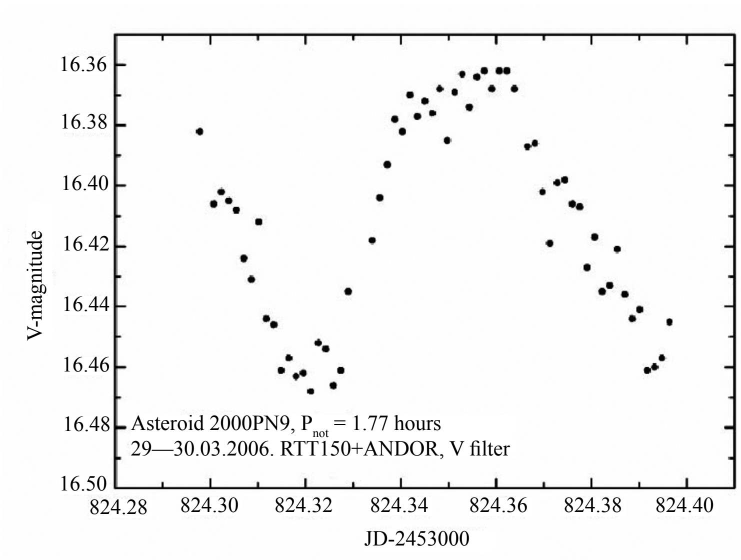

Fig. 3. The observed variability of magnitude is present for 2000PN9. Amplitude is 0.11 (16.36-16.45) and period is about 2 hours (1.77h).

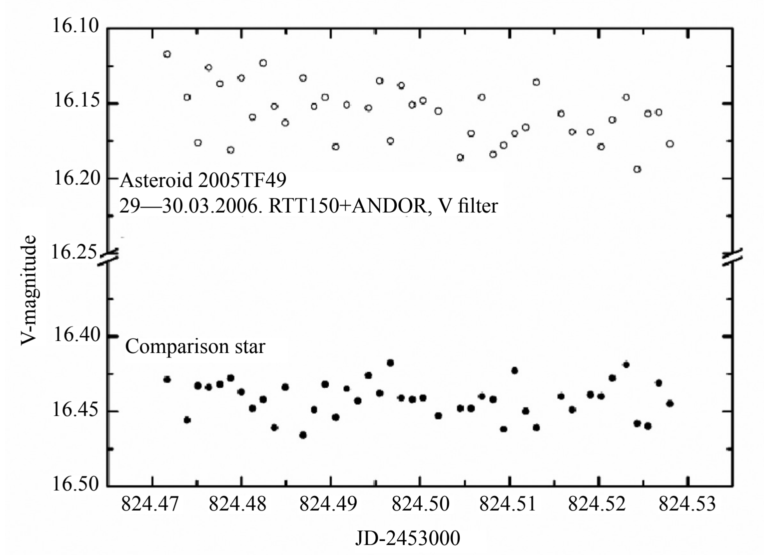

Fig. 4. Lightcurve is given for 2005TF49 in the V-band in relation to the nearest star. Exposure is 60 seconds. The number of frames is 44.

2.2 Program of observations for asteroid mass determination

We defined basic criteria for the selection of perturbed asteroids, based on perturbations, instrumental possibilities and conditions of good astrometry as the follows:

– perturbation value not less than 50 mas in any coordinate;
– interval of brightness from 13 to 19 magnitudes;
– maximum zenith distance of the observed object less than 60°;
– elongation of the object from the Sun greater than 90°.

Finally 30 asteroids were selected which made up the RTT150 observation program in 2005—2007 (Table 3).

So, the accuracy of asteroid positions from the observations at the RTT150 is good enough for use in mass determinations by the dynamical method, based on the analysis of the perturbations of small asteroids by big ones. Preliminary calculations were made for mass determinations for few asteroids by the adjustment of dynamical model parameters (both initial conditions and perturbing masses for asteroids).

2.3. Mass values of some asteroids

Masses of 21 asteroids were obtained through the dynamical method using ground-based optical observations, mainly from the RTT150 and Minor Planet Centre (MPC). The determinations are distinct as they are based on a larger number of observations with the set requirement of mass positiveness. The last condition makes the fitted dynamical model physically meaningful in any case.

Table 3. List of asteroid pairs for the observation programme at the RTT150 in 2005—2007

Perturbing asteroid	Diameters of the largest asteroids in km	Numbers of the perturbed asteroids from the lists of		
		Fienga [5]	Galad [6, 7]	Thuillot [11]
1 Ceres	940		5303	119
4 Vesta	538		17	535
10 Hygia	407	75, 410, 209, 983	3946, 6006, 11215, 24433	
13 Eregia	208		14689	
16 Psyche	253	60,316, 468, 1054, 1082		331
29 Amphitrite	212		987	
31 Euphrosyne	256	965		
45 Eugenia	215		673	834
52 Europa	302		124	110
87 Sylvia	261	846		
511 Davida	326		11985	1295
704 Interamnia	317	253, 977		

Some comments to the Table 4 are in order. Nine masses have relative errors less than 30% and 16 masses have relative errors less than 50% from the general list of 21 asteroids. There are no systematic differences between our determinations and those made by Kochetova and Michalak [8, 9]. It can be interpreted as a good sign that the order of estimates is correct. The differences with the earlier determinations by Vasiliev are evident [1]. Mass of the asteroid 1686 was determined for the first time (it is not present among 300 asteroids used for the DE ephemerides calculations). The present calculation is unweighted and was made after rejecting the apparent outliers.

3. Collaboration development in project of GAIA

The large RTT150 Data Base (RDB) of high accuracy observations of selected asteroids was obtained from the collaboration between TUG, KSU and NAO. Enlarging of the data base is possible with continuation of CCD observations at the RTT150 and NAO telescopes.

Additionally, a new possibility appeared to use the NAO Fast Robotic Telescope FRT (D=300mm, F=1520mm) for observations of objects up to 16 magnitude with the CCD camera (ISD017A, 1040×1160, 16×16mkm, 2.″17/pix, FOV 38′×42′). The FRT is especially useful for observations of the asteroids with big apparent velocities. Observation of geostationary satellites showed satisfactory results with standard errors of position in right ascension and declination of about 150 mas. Also, Nikolaev Axial meridian circle (D=190mm, F=2480mm) with CCD camera (ISD017P, 1040×1160, 16×16mkm, 1.33″/pix, FOV 23′×26′) provided observations up to 16 magnitudes with the accuracy less than ±100 mas. Astrograph AZT8 (D=700mm, F=2650mm), located in the vicinity of Evpatoria, will take part in this program with the CCD camera (ISD-017A, 1040×1160, 16×16mkm, 1.″24/pix, FOV 22′×24′). The results obtained are promising: the standard errors of positions in right ascension and declination are no more than 100 mas.

Table 4. Mass values for 21 asteroids, masses in $10^{-11}M_\odot$

Asteroid	Standish [10]	Vasiliev [1]	Michalak [9]	Kochetova [8]	Present calculations
7	0.53	2.0 ± 0.9	no value	1.41 ± 0.14	2.52 ± 0.32
10	3.74	7.8 ± 2.5	5.57 ± 0.70	5.01 ± 0.41	2.16 ± 0.38
15	1.27	1.0 ± 0.4	1.26 ± 0.30	1.06 ± 0.16	0.90 ± 0.35
16	2.42	12.7 ± 1.8	1.49 ± 0.31	1.34 ± 0.22	2.76±1.49
19	3.79	5.3 ± 1.1	no value	no value	0.96 ± 0.50
24	0.37	1.0 ± 0.4	no value	no value	0.29 ± 0.20
28	0.13	no value	no value	no value	0.07 ± 0.02
45	0.46	-1.5 ± 1.8	no value	no value	1.18 ± 0.33
52	1.44	-6.4 ± 1.6	2.61 ± 0.88	1.27 ± 0.25	1.44 ± 1.13
65	0.66	3.9 ± 1.3	no value	0.58 ± 0.15	0.46 ± 0.40
87	0.94	2.7 ± 1.0	no value	no value	3.45 ± 1.15
107	0.63	1.6 ± 2.4	no value	no value	4.75 ± 2.62
111	0.13	no value	no value	no value	3.45 ± 2.04
165	0.19	4.1 ± 3.1	no value	no value	3.50 ± 1.63
216	0.36	14.5 ± 9.0	no value	no value	7.93 ± 1.11
324	0.56	4.9 ± 3.0	no value	2.29 ± 0.38	1.10 ± 0.72
451	0.58	5.4 ± 3.8	no value	1.02 ± 0.34	0.60 ± 0.50
511	1.81	29.4 ± 4.3	3.34 ± 0.28	2.40 ± 0.24	3.23 ± 1.83
704	1.75	6.2 ± 6.6	3.52 ± 0.93	0.81 ± 0.42	5.48 ± 1.71
1669	no value	2.1 ± 1.6	no value	no value	1.38 ± 0.20
1686	no value	no value	no value	no value	0.36 ± 0.17

The enlarging of the RDB should considerably heighten its value for the improvement of asteroid orbits and masses. Moreover, by the time of the space project GAIA (2011-2015), the database will be of great importance within the framework of international observation network "GAIA Follow Up". The wide project of GAIA is interesting to us, as far as the observations of about 100 asteroids with encounters are planned for asteroid mass determinations. A network of automatic telescopes is being organized for observations both with narrow-field and wide-field CCDs. It can be used for coordinated and accurate observations of Solar system bodies before GAIA is launched, or during the mission, in alert mode. We have optimal conditions in this case for organization of fruitful research within the program "GAIA-Follow Up" [12].

4. Conclusions

The principal points of the International Research Collaboration should include:

1) CCD-observations of the near-Earth asteroids up to 20th magnitude, which will have proximities to the Earth less than 0.1 a.u. The observations allow determination and improvement of orbital elements of these asteroids;

2) calculation of selected asteroid positions from CCD-observations for determination and improvement of masses of some big asteroids;

3) possibilities of collaborated telescopes allow one to start investigation of Solar system small bodies (especially mass determination) in the period before GAIA program.

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ASTROMETRY AND PHOTOMETRY OF SMALL BODIES AT THE NATIONAL ASTRONOMICAL OBSERVATORY, ROZHEN, BULGARIA

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We present the results of observations of comets and asteroids, obtained during the last 2 years at the National Astronomical Observatory, Rozhen, Bulgaria. The observations were obtained with a CCD camera ST8E, attached to the Schmidt telescope. The astrometric reduction of the observations is performed using the GSC and the USNO-A V2.0 catalogues. We describe our procedure for automated identification of all catalogue stars in the field of view, and its using for the astrometric and photometric reductions of the images. Astrometric results, obtained by using different methods, are compared. The astrometric parameters of the Schmidt telescope are presented and discussed. We illustrate the results of our research with examples of astrometrically and photometrically reduced observations of comet 9P/Tempel 1 and the Near Earth Object 2004FN18.

1. Introduction

Orbital evolution of small bodies in the Solar system is closely related to their physical properties. The diurnal asymmetry of sublimation from the surface of a cometary nucleus causes nongravitational forces. Marsden [1] was the first who included jet forces into the Newtonian equations to describe the perturbed motion of comets. Later, the deeper understanding of water sublimation at different heliocentric distances [2] improved the models dealing with nongravitational forces [3]. Motion of asteroids is also a subject to dissipative forces. The most interesting now perturbation is caused by the Yarkovski effect,