Pulkovo program for research of the near-Earth space objects

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The ecology of neighboring space research certainly includes monitoring of at least two classes of objects: the geostationary objects (GEOs – satellites and space debris) and the near-Earth objects (NEOs – asteroids and comets). Within the framework of the support of radiolocation observations in Russia and Ukraine (Molotov et al, 2002) the study of these objects at Pulkovo Observatory took a new impulse during the last year. The work is executed by two teams dealing with GEO and NEO studies. The scientific activity includes experimental observations of objects with two Pulkovo telescopes, their ephemeris support, and, as well as processing, the research of some questions connected to the real nature of objects and the methodology of their observations. Of course, the observational facilities currently used are very modest, but with their help some positive results were received. The Cassegrain ZA-320 telescope (D=32cm, F=320cm, ST-6 CCD camera) provides a field of view of $9' \times 7'$ and a limiting magnitude of about $18^m.5$. The AKD telescope is still less, but with the ST-8 CCD camera it provides a larger field of view, namely $45' \times 67'$.

GEO activity

The optical observations of geostationary satellites (GS) were recommenced due to periodic sessions of their radiolocation at Evpatoria, in order to make more precise the GS ephemerides (Devyatkin et al, 2002a; Katkova, Guseva, 2002). For getting a good signal-to-noise ratio, the observations were made with the clock drive stopped. The ideal picture should include the tracks produced by the diurnal motion of stars and the point of the GEO image. The coordinates of the point and the centers of the reference stars tracks are to be measured. But really the GEOs also have some drift, sometimes complicated by a variable brightness of the object. So, there are many sources of systematic errors that are to be investigated. The observations of more than one hundred objects were made. The sensitivity of the telescopes proved to be quite good, but the mean accuracy of the observations was still insufficient (up to a few arcseconds). Nevertheless many of these objects have been successfully observed later in radio location.

There is also some experience of test observations at the KOSMOTEN station, and some attempts of cooperation with other stations. The construction of the Pulkovo one-meter telescope in the near future could give progress to this work.

Another part of our program is a search for lost GS. The unknown object 239 of the Zonal Catalog of Geostationary Satellites (A.V.Didenko et al, 2000) serves as an illustration of the identification method. Table 1 contains the orbital plane data for a few satellites, referred to the equator and Laplace planes.

Table 1. Orbital elements from various sources and observations

NN	Name	T (MJD)	i_e	Ω	i_L	Ω_L
72010A	OPS 1570 (DSP F3)	44074.12	5.46	57.3	6.34	133.6
72010B	Transtage	44076.35	5.51	56.5	6.21	132.5
73040A	OPS 6157 (DSP F4)	44083.60	4.80	66.7	7.00	140.9
73040B	Transtage	44093.60	4.79	66.8	7.09	141.5
75055A	OPS 4966 (CANYON 6)	44074.12	5.46	57.3	6.34	133.6
81025A	OPS 7350 (DSP F9)	45615.74	0.51	62.0	7.11	176.2

81025C	Transtage	45605.32	0.15	65.7	7.10	178.9

For identifying this object there are two candidates: 72010A & 73040A. We have only one set of old data for each of these satellites and their Transtage missiles. Usually the differences in orbital data for a satellite and its missile are small, and orbital evolutions are similar. Fig. 1 shows the evolution of the inclination and node for these objects.

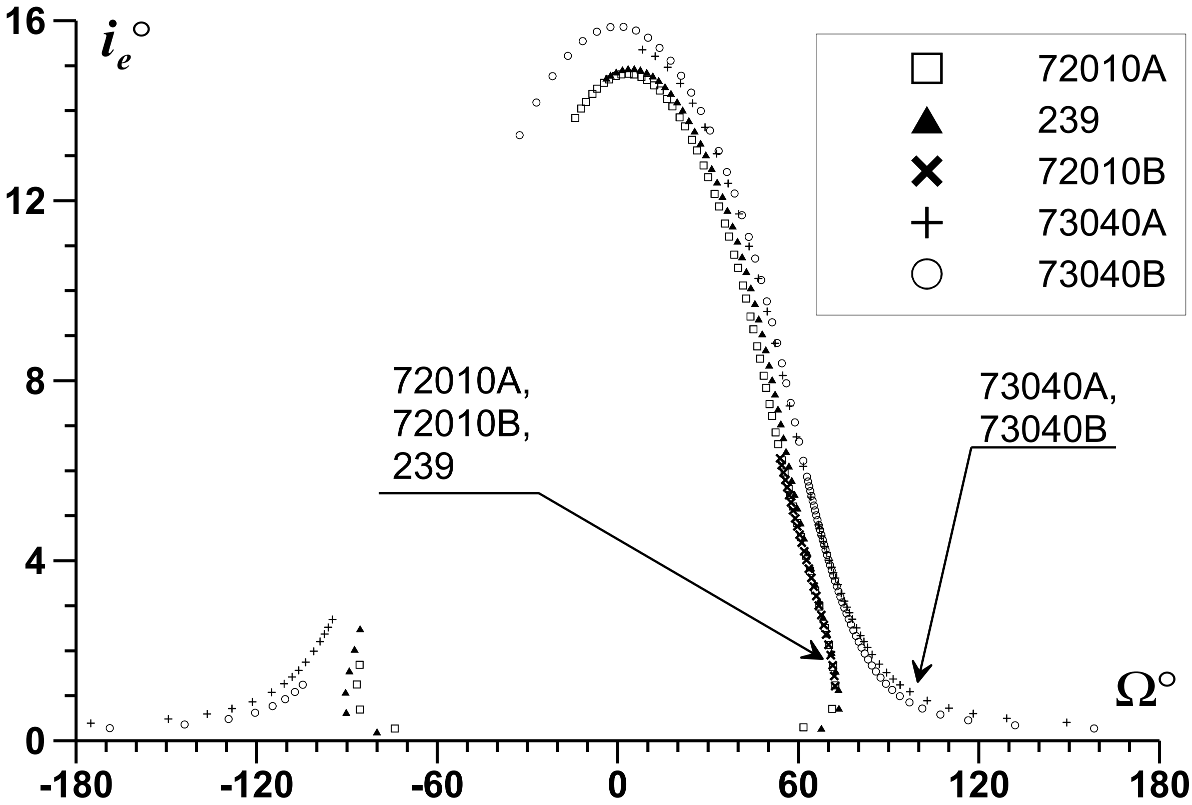

Fig. 1. The evolution of inclinations and nodes referred to the equator

It is clear from Fig. 1 that the object 239 is identified with GS 72010A. The object 75055A was identified by the initial values of inclination and eccentricity for the moment June 18, 1975 (MJD42581), based on the improved orbit of the object 201 of the Zonal Catalog.

Table 2. Osculating orbits of geostationary objects: 72010A, 75055A, 81025A and 82019B, calculated based on the Pulkovo observations in March – April, 2003.

NN	T (MJD)	n	i_e	i_L	Ω	$Ω_L$	e	$M+\omega$	λ
72010A	52700.758943	1.00118	14.°106	7.°115	348.°677	337.°275	.0	158.°583	73.°917
72010A	52703.737594	1.00076	14.094	7.106	348.643	337.191	.0	153.894	73.943
72010A	52697.742664	1.00156	14.067	7.070	348.821	337.491	.0	149.614	73.925
75055A	52718.752560	0.82064	9.208	2.994	16.106	58.205	.0	130.236	57.560
75055A	52719.758429	0.80797	9.086	2.935	16.379	60.434	.0	132.397	56.891
81025A	52700.951933	1.00790	12.981	6.446	17.825	37.772	.0	165.664	40.479
81025A	52702.809850	1.00805	13.028	6.475	17.625	37.251	.0	116.945	40.879
81025A	52702.826604	1.00804	13.030	6.481	17.692	37.372	.0	122.121	40.074
81025A	52704.815429	1.00892	13.042	6.486	17.602	37.165	.0	119.977	39.901
81025A	52704.975061	1.00440	12.859	6.321	17.689	37.895	.0	177.828	40.216

The object 81025A, similar to the object 81025C having some old data, was identified using the evolution of the improved orbit of object 218 of the Zonal Catalog. With the help of calculated ephemeredes, the geostationary objects 72010A, 75055A and 81025A were rediscovered and observed at Pulkovo in March - April, 2003. Table 2 gives their osculating orbits.

It should be noted that the main part of the identification is the long-term evolution of the orbital elements. The longitude control is not always possible, due to some possible transfers of objects to the highest or lowest orbits after the end of their active period.

NEO activity

This work includes the following items: NEO database maintenance, ephemeris support for observations including the radiolocation sessions, NEO optical observations before, during and after approaches, orbit improvement, and a refinement of physical characteristics of the objects (L'vov et al, 2002).

The first two tasks are solved with the help of the EPOS software package (L'vov, Smekhacheva, Tsekmejster, 2001). EPOS includes the database with more than 200 thousand asteroids and about 400 comets. There are more than 2.5 thousand near-Earth asteroids (NEAs) in the database. The data are permanently renewed using several well-known sources including the catalogs of B.Marsden and E.Bowell. It is possible to distribute the objects of various classes into different catalogs, to work with user's elements for real and model objects, and to get a selection in accordance with various conditions. EPOS provides an effective ephemeris support for observers. For example, it is possible to get a list of objects visible within a specified sky area at a predefined moment, or a list of observable objects for a specified place and night. For any object, or for a number of objects, one can calculate the ephemerides of various types and accuracies with many useful parameters. The program also helps to compare the observed objects' positions and velocities with the calculated ones, to appreciate the mean accuracy of observations, to reject large errors, and to make an identification of the objects. Finally, EPOS can generate impressive pictures of perturbed orbital motions of several objects in space and their apparent motion on the sky against a star background. Besides the incorporated data, EPOS can use various modern numerical ephemerides and star catalogs distributed on compact disks.

Realistic technology is proposed and used in support of the current catalog work for Pulkovo NEO observations. It combines the Internet possibilities and the EPOS application features. Now the ephemeris support covers all NEOs accessible for observations at Pulkovo, including the latest discovered objects. Some observers at the other stations have also taken our ephemeris support.

Now the ZA-320 telescope, oriented mainly to the NEO observations, is fully automated (Kanaev et al, 2002), and can be controlled by computer. New software tools provide a link to various time sources, a support of the work with several frame formats, journal maintenance, frame browse in blink-comparator mode, and many other useful functions. The program regulates the drives of the quick and fine telescope motions, collar clamp devices, filter change, setting the dome, etc. The turn control system consists of a digitized limb and mini CCD camera. By the special micro objective the image with the strokes and digits is projected to a CCD camera, then a digitized image is analysed by the original Pulkovo computer programs in order to recognize a picture and put out the limb reading. The accuracy of setting the telescope is about 10 arcseconds.

CCD frames are processed by the APEX software package (Devyatkin et al, 2000) that can get the coordinates and magnitudes of the objects. APEX can use various modern star catalogs (HIPPARCOS, TYCHO-2, USNO A2.0, USNO SA2.0) with a choice of objects' approximation model and a method of reduction.

The optical observations during a long arc are necessary for the orbit improvement. But observations at Pulkovo are not always possible, due to the weather conditions and rapidly varying brightness of NEOs. Nevertheless the ZA-320 telescope has a great level of readiness and productivity. More than 1000 observations of about 150 asteroids and comets aremade, processed, and sent to the to the Minor Planet Center (Devyatkin et al, 2002b). The accuracy of one observation varies from 0.2″ to 0.6″ and depends mainly on the brightness and apparent angular velocity of an object.

Much attention is paid to the investigation and improvement of the ZA-320 telescope automatic control system and the methods of observations for obtaining high quality astrometric and photometric results. The geocentric coordinates of the ZA-320 telescope are revised based on GPS measurements.

Besides classic follow-up activity, the program of experimental observations of three other types is in progress now. The first type is an astrometric monitoring of close apparent approaches of asteroids to the stars or to each other. It is the high accuracy astrometry with only one reference star (Kiselev, 1989, Kiseleva et al, 2002), or without any star at all (L'vov, 2000). The apparent angular distance between two or more objects in the frame is measured here, this value being a function of orbital elements. The second type represents CCD photometry of variable thickness tracks of the fast moving NEAs with short period of rotation. The third type is the fast photometry of possible occultations of stars by asteroids (Devyatkin et al, 2001). This can give the accuracy comparable to that of radio frequency observations. But the crucial item here is the last minute astrometry (a refinement of an ephemeris just before a phenomenon). For bright objects this work can be done with the help of our small telescopes. As for faint objects it would be very desirable to get support (even episodic) of large instruments.

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