JOINT RAS/PIMS/AIUB GEO SURVEY RESULTS

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ABSTRACT

From June, 2004 until March, 2005 a number of Russian and Ukrainian astronomical observatories working within the framework of a program of the RAS on studying of near-Earth space contamination by space debris as well as Zimmerwald observatory of Astronomical Institute of the University of Bern and observatories of the PIMS network working under support of Observatory Sciences Ltd. have conducted continuous coordinated campaign for GEO region observation and processing of obtained results. During the work the tasks of search, detection and subsequent tracking of unknown GEO objects, their orbital parameters determination and orbital evolution estimation taking into account all essential perturbations have been solved.

Long series of observations for more than 80 objects are obtained. For each observed object the construction of orbit with the help of methods based on numerical models of motion is carried out. For objects, on which there is enough number of precise measurements, the area-to-mass estimations are obtained.

Results of orbital determinations for 60 objects are published in the 7th (January 2005) issue of the "Classification of Geosynchronous Objects", annually prepared by European Space Operations Center (ESOC). The joint researches proceed.

1. INTRODUCTION

The problem of learning of the real population of space debris objects in geostationary region (GEO) is extremely important. Geostationary orbit represents on the one hand a unique area of near space from the point of view of the solution of the various tasks (providing of the TV and communication services, the weather monitoring, the data relay etc.), and on the other hand it is a limited natural resource requiring preservation for usage in the future. Until recently researchers of the GEO area contamination by space debris leaned on the regularly updated orbital data produced and distributed

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by the U.S. Space Surveillance Network, and also on the statistical observations obtained within the framework of coordinated observation campaigns under aegis of Interagency Space Debris Coordination Committee (IADC). The statistical observations have shown presence in GEO region of a significant quantity of objects of various brightness (and, accordingly, various size) on which there no public orbital data are available. Besides special observations which have been carried out in Zimmerwald, Tenerife and Nauchny observatories have revealed presence in GEO area of the whole new class of objects having large area-to-mass ratio value. Orbits of such objects experience significant disturbances causing regular redistribution of objects on GEO altitudes that is not taken into account in modern models of objects population distribution in this area.

With the purpose of a fulfillment of the missing data and obtaining a valuable picture of dynamic distribution of objects in GEO area the regular observations of GEO were started in June 2004 aiming to the search, detection and tracking of unknown objects. The observations were conducted jointly by astronomical observatories working within the framework of a program of the Russian Academy of Sciences (RAS) on studying of near-Earth space contamination by space debris: Nauchny (Crimean astrophysical observatory, CrAO), Pulkovo (Central astronomical observatory of the RAS), Mayaki (Odessa astronomical observatory), and observatories of the PIMS network working under support of Observatory Sciences Ltd. Zimmerwald observatory of Astronomical Institute of the University of Bern (AIUB) have joined the observation team in August, 2004. This work was from its beginning aimed at continuous tracking of each earlier discovered unknown object and collection of measurements on such objects over long time frame. Thus the carried out research is an essential addition to regular IADC GEO survey campaigns. Precise orbit determination parameters, orbital evolution study, estimations of the area-to-mass ratio value for the majority of objects is made on the basis of obtained astrometric positions by the RAS Center on collection, processing and analysis of information on space debris operated at the Keldysh Institute of Applied Mathematics (KIAM).

2. STRATEGY OF OBSERVATIONS CARRYING OUT AND PROCESSING OF RESULTS

2.1. Observation planning

For realization of observation program rather bright - 13^m-14^m in integrated light at a phase angle of 50°-90°, unknown objects originally were selected on which short track measurements were obtained in previous IADC GEO survey campaigns. Correlation of a short tracks related to the same object have been made by Observatory Sciences and the AIUB teams for own measurements. High reliability of these correlations (i.e. very small number of measurement outliers) should be noted. All tracks were processed and orbits were constructed with usage of the software developed in KIAM and KIA Systems. Orbits were calculated in two models and produced in two appropriate formats of representation of orbital data: numerical motion model (orbit presented as state vector in coordinate system of standard epoch J2000) and MSGP4 analytical model (orbit presented as mean elements in the TLE format). Obtained orbits were sent to the observatories where the planning of observations of particular objects was conducted.

Observations of the same objects were conducted simultaneously by several observatories for increase of an overall performance of the work. It has allowed to reduce time of observation of separate object within one night by one observatory down to 15-20 minutes. Besides that the necessity of obtaining measurements over as long an orbital arc of argument of latitude as possible was taken into account at observation planning. The necessity of fulfillment of this requirement is considered further. Observations were conducted each night with acceptable weather conditions irrespective of a phase of the Moon.

Gradually quantity of objects included in the schedule of observations was increased. During realization of researches, new objects were detected which also were included in the schedule of observations. Not all objects were observed with identical intensity owing to various reasons.

Actually the idea of quick "pick-up" of newly detected object on the next night was realized in the given work, so observed objects were not lost and were multiply observed at subsequent transits in the zone of visibility of participating facilities. To the beginning of April, 2005 quantity of observed objects has reached almost 100.

2.2. Measurements processing

At processing of measurements, two tasks simultaneously were decided:

- improvement of orbital elements with simultaneous refinement of additional parameter – solar radiation pressure coefficient, and estimation of accuracy of obtained orbits
- estimation of a degree of mutual misalignment of measurements of various stations, estimation of the RMS of measurement residuals

Astrometric positions of observed objects are obtained in view of necessary reductions and are reduced to equator and equinox of J2000. The accuracy of binding of astrometric positions to the UTC time scale is better than 0.01 sec.

The refinement of orbit was conducted with usage of numerical motion model which is taking into account the following essential perturbations:

- Earth gravity field (EGM-96 model truncated down to 16x16)
- the Moon gravity (DE-403)
- the Sun gravity (DE-403)
- direct solar radiation pressure in view of the Earth shadow passages

The calculation of derivatives in the model of orbit determination implements on analytical relations, the integration of equations of motion implements a modified Runge-Kutta method of the 8-th order (Stepaniants et al., 2000).

On rather short intervals of orbit refinement at initial accumulation of measurements (about 3-4 weeks) the solar radiation pressure coefficient was assumed constant equal to some default value. On longer intervals and at enough of measurements distributed in a broad band of arguments of latitude, the solar radiation pressure coefficient was entered as seventh estimated parameter. In this case, distribution of measurements in as broad a band of arguments of latitude as possible appears important. It is necessary since on the one hand actual distribution of measurements influences accuracy of determination of the shape of orbit (eccentricity) and position of orbit in a plane (argument of a perigee). On the other hand, the influence of solar radiation pressure first of all expresses in periodic change of an eccentricity. Thus for simultaneous refinement of orbit parameters and solar radiation pressure coefficient there is a reallocation of two kinds of errors of orbit determination:

- errors stipulated by incompleteness of coverage by measurements of object's positions within one orbit
- errors due to the weak conditionality of a system of normal equations at refinement of a solar radiation pressure coefficient if its value is small (i.e. influence of the direct solar radiation pressure on evolution of object’s orbit is also minor).

To reduce errors in determination of the orbit shape and to increase reliability of determination of value of a solar radiation pressure coefficient the collection of measurements over as broad a band of arguments of a latitude as possible is required.

It should be noted that by results of processing of the obtained measurements the rather bright objects were detected having solar radiation pressure coefficient value several times more than an average one for objects with similar brightness. For such objects the influence of solar radiation pressure on orbit evolution becomes noticeable on an interval of refinement equal only to several days in case of presence of sufficient sampling of measurements from different observation facilities.

The accuracy of orbit determination was researched simultaneously with determination of orbit parameters depending on a specific observation facilities providing observations for the same objects, duration of an interval of measurements on one and several night, and also on distribution of measurements within an orbit. By two most important outcomes of these researches were following:

1) with other things being equal, continuous measurements of positions of GEO object on an interval about 2 hours by one facility and simultaneous observations of object by two facilities spaced on a longitude, for example on 30°, on an interval 15-20 minutes give identical result from the point of view of accuracy of orbit determination
2) The errors in determination of orbital period using measurements in one night essentially increase if the observation facility is located in orbital plane of observable object, i.e. near to the equator. For example, at duration of a measurements interval of 1 hour with 1 measured position per minute and accuracy of single measurement of order 1 arcsecond an object with an inclination 0° and subsatellite point longitude 0° the along orbit error of position prediction for 24 hours will be:
    - 3.64° for observation facility located at 0° latitude and 0° longitude
    - 1.14° for observation facility located at 40° latitude and 0° longitude
    - 1.15° for observation facility located at 40° latitude and 30° longitude

These conclusions allow proper corrections of the objects observation schedule from the point of view of optimization of time costs on observations of one object, and optimization of a structure of involved observation facilities from the point of view of accuracy of obtained orbit.

3. RESULTS

To the present time the following results are obtained. It is detected and observed regularly about 100 previously unknown objects, for 60 of which the results of orbit determination are published in (Jehn et al., 2005). For overwhelming majority of the detected objects enough quantity of measurements is obtained. Thanks to this, estimation of value of the solar radiation pressure coefficient (and respectively estimation of the area-to-mass ratio value) is obtained in addition to parameters of orbits. For the subsequent analysis in this paper the 82 most well observed objects were selected.

The processing of measurements using described model has shown that participating observation facilities have ensured high astrometric accuracy of measured positions of objects. Accuracy in this case is understood as residuals RMS value after orbit determination based on whole set of available measurements on long intervals. Residuals RMS value on the average on all objects is from 0.5-1 arcseconds (CrAO and Zimmerwald) to 1.5-2 arcseconds (PIMS and Pulkovo), and completely meets expected values obtained by results of independent calibration of each station.

It is necessary especially to mark that among observed objects there are some for which it is not possible to achieve agreement of measurements with good accuracy in described model of motion. For all such objects the value of solar radiation pressure coefficient exceeds average value calculated for bright (and hence supposedly large) objects from several up to tens times. Moreover essential variability of the value of the solar radiation pressure coefficient is noted at refinement on different time intervals. It can due to some natural reasons (complex attitude motion of object and variability of the cross-section area exposed to the Sun) as well as due to lack of measurements and reallocation of errors of orbit determination discussed above. More deeper understanding of the problem needs additional researches.

Objects having very small value of the area-to-mass ratio value are detected. Such objects can be considered as moving practically only under gravitational forces perturbations and, therefore, are good calibration targets for any optical stations participating and intending participation in observations of GEO objects.

3.1. Inclination distribution

The distribution of an inclination of observed unknown objects as of 01.04.2005 is shown in a Fig. 1. As well as in the earlier presented papers, the main quantity of unknown objects is on orbits with inclinations in range 7°-9° and 12°-14° where a clear excess of uncorrelated detections was observed during IADC GEO survey campaigns (Schildknecht et al., 2003). Besides that, objects with an inclination exceeding 20° - conditional thresholds, traditionally considered as one of limitations of GEO region (including in the DISCOS database in ESOC) - are confidently detected and tracked. Evolution analysis of orbit of these objects on a long time frame shows (as expected) periodic decreasing and increasing of the inclination. For example, inclination of object UI.059 (Jehn et al., 2005) in 1978 reached minimum value 6.4° (Fig. 2), currently it crosses its maximal value and in the future it also will decrease to the value less than 10°, i.e. the object will be considered as being in GEO region in currently adopted treatment. In connection with presence of such objects and their obvious relations with GEO launches it is assumed necessary to expand definition of GEO region on an inclination boundaries up to 25° or even 30°.

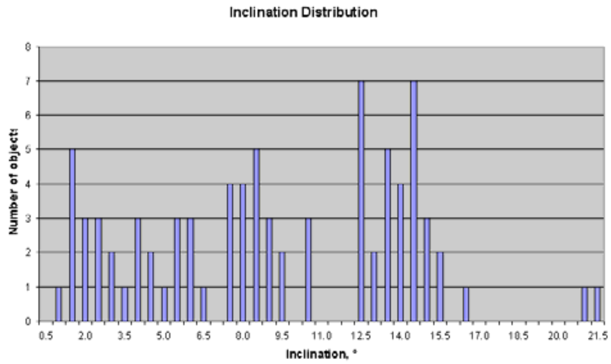

Figure 1. Distribution of inclination value for observed unknown objects as of April 01, 2005.

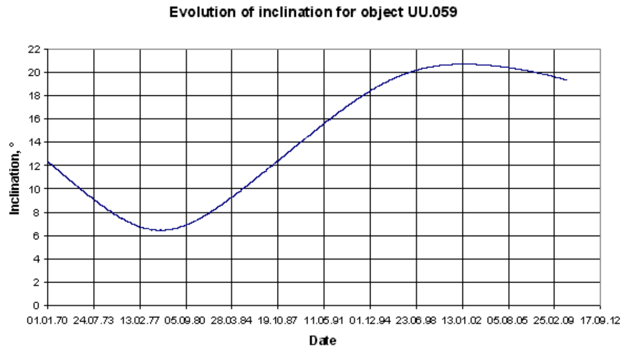

Figure 2. Inclination evolution for object UI.059

3.2. Semimajor axis distribution

The distribution of the semimajor axes of observed unknown objects as of 01.04.2005 is shown in Fig. 3. It is clearly visible that the overwhelming majority of observed unknown objects is concentrated on orbits with value of semimajor axis close to nominal value for controlled, librating and slowly drifting objects in GEO region.

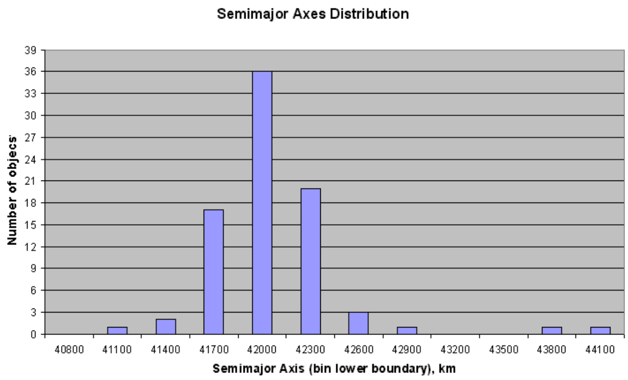

Figure 3. Distribution of semimajor axis value for observed unknown objects as of April 01, 2005.

The given distribution of values of the semimajor axes reflects a real picture of the sizes of orbits of unknown objects in GEO region as compared to distributions of so-called 'inferred' semimajor axes obtained earlier during the IADC GEO survey campaigns where the value of the semimajor axis was determined with assumption of zero eccentricity (Schildknecht et al., 2003).

3.3. Eccentricity distribution

The distribution of eccentricities of orbits of observed unknown objects as of 01.04.2005 is shown in Fig. 4.

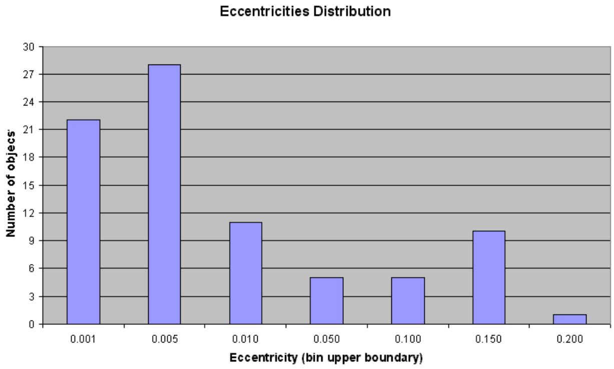

Figure 4. Distribution of values of an eccentricity of orbit of observed unknown objects as of April 1, 2005

The figure for the first time demonstrates real distribution of eccentricities of orbits of unknown observable objects in GEO region confirmed by observations from a broad cooperation of scientists. The presence in GEO region of rather large objects with an eccentricity in range 0.05-0.16 (Agapov et al., 2003) is confirmed. As with inclination, the obtained results raise the question about a need to extend the definition of GEO region and to include the eccentricity of orbits. At present different researchers approach this problem differently. In particular, in the ESOC DISCOS database a high bound for an eccentricity of objects referred to GEO region is the value 0.1. The Russian researchers assume as a high bound of an eccentricity value 0.2 (Agapov et al., 2003).

3.4. Inclination and Right Ascension of Ascending Node

The distribution of orbit inclination of observable unknown objects with right ascension of ascending node as of 01.04.2005 is shown in a Fig. 5. It is clearly visible that among the detected objects there are groups (with an inclination close to 2-4°, 6° and 8°) whose orbital plane parameters are not stacked in well known distribution "inclination – right ascension of ascending node" of objects in GEO region formed due to the explained 52-year period of precession of the orbital planes.

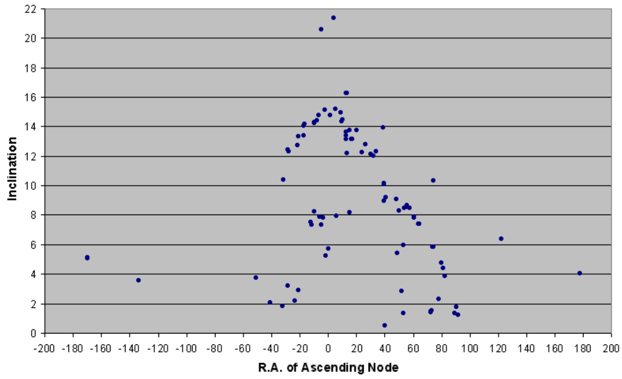

Figure 5. Inclination versus right ascension of ascending node of observed unknown objects as of April 1, 2005

At the same time results obtained in our research are well correlating with the previously published data (Schildknecht et al., 2001, Agapov et al., 2003)

3.5. Area-to-mass ratio value distribution

In Fig. 6 the distribution of value of the area-to-mass (AMR) ratios for observed unknown objects is shown. This value is obtained from an estimation of a direct solar radiation pressure coefficient used as seventh estimated parameter in orbit parameters determination.

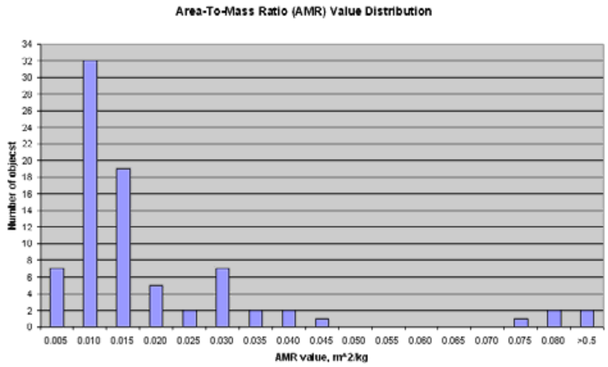

Figure 6. Distribution of the area-to-mass ratio values for observed unknown objects

Since the real reflective characteristics of observed objects are not known, at calculation of value of the area-to-mass ratio from value of solar radiation pressure coefficient it was assumed that the reflection coefficient of a material of a surface of objects is equal to 1.3. It is clearly visible that majority of observed objects represents rather compact bodies with specific weight per unit area of 100-200 kg/m^2. At the same time nearly two dozen objects having specific weight per unit area less than 40 kg/m^2 are discovered. Two observed objects have specific weight per unit area less than 2 kg/m^2. Probably all similar objects represent operational fragments, fragments produced in anomalous events observed in LEO orbits or fragments of explosions. In particular, according to (SMC, 2001) an IR-telescope sunshade cover separating from DSP satellites has diameter of 0.61 m and weight of 0.54 kg that gives specific weight per unit area equal to 1.8 kg/m^2 while exposing maximal area to the Sun direction. There are 20 of such covers in GEO region (Jehn et al., 2005). It is possible that some of them were observed among considered unknown objects.

It should be noted that the tracking of objects with high area-to-mass ratio value represents certain complexity when there are interruptions in observations. It is explained by fact that for such objects the solar radiation pressure renders noticeable influence on eccentricity evolution already on an interval just of several months. As an example eccentricity evolution for object UI.005 is presented in Fig. 7.

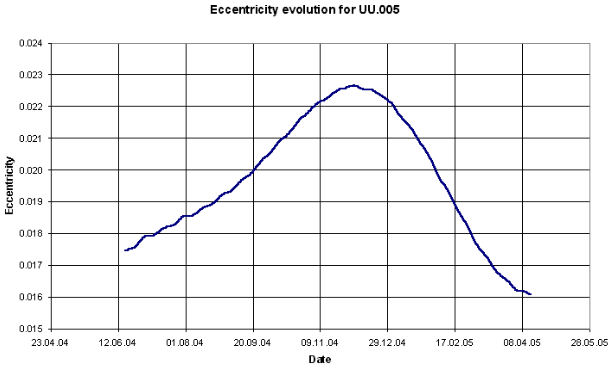

Figure 7. Eccentricity evolution for the UI.005 object

It is clearly visible that during 4 months (from beginning of December, 2004 till beginning of April, 2005) the eccentricity of this relatively bright and supposedly not so small object changes by 1.4 times. Errors in determination of both orbital elements and solar radiation pressure coefficient based on measurements obtained on short intervals (several nights) are presented in this case. The absence of additional observations for a long time results in not only a growing object along track error, which is actually equivalent to time shift or shift in right ascension, but also essential uncertainty of object position in declination due to error in eccentricity. This error increases time required for reacquisition of object by instruments with a small field of view (less than 1 sq. degree).

4. CONCLUSIONS

As the results of the joint research of unknown objects in GEO region almost 100 unknown relatively bright GEO objects have been found and tracked. The presence of objects on orbits with an eccentricity essentially distinct from 0 has been confirmed. In turn, it confirms an earlier stated hypothesis (Schildknecht et al., 2001, 2003) about an incorrectness of the supposition about a zero eccentricity during statistical processing of measurements obtained within the framework of the IADC GEO survey campaigns. Objects with inclination higher than 20 deg are also detected. Probably it makes sense to discuss new definitions of GEO region boundaries. Besides that, the presence of relatively bright and supposedly not small objects with high area-to-mass ratio value is confirmed. Direct solar radiation pressure renders the main influence on orbit evolution of such objects. Taking into account quick evolution of eccentricity and argument of perigee for such objects the statistical samplings of measurements obtained on various nights even with a time span a little bit of months can contain measurements on the same object whose eccentricity has undergone significant change. The results of calculation of summarized quantity of objects in such sampling can appear uncertain if an eccentricity evolution is not be taken into account.

The obtained results can be used for refinement of models of a GEO region population distribution, and also as a starting point for organization of continuous monitoring of GEO region with the purpose of obtaining of the maximum reliable information about a population of objects in it. Moreover measurements obtained during previous IADC GEO survey campaigns can be reprocessed and correlated with orbits of newly found unknown objects.

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