ON THE CONNECTION OF OBSERVING PROGRAMS FOR ARTIFICIAL AND NATURAL NEAR-EARTH OBJECTS.

A.G.Sokolsky, A.S.Sochilina,

Institute of Theoretical Astronomy, Russian Academy of Sciences,
Naberezhnaya Kutuzova 10, 191187 St.Petersburg, Russia

N.S.Chernykh

Crimean Astrophysical Observatory, 334413 Nauchnyj, Ukraine

ABSTRACT

During the last decade the astronomical observatories are intensively supplied with the modern facilities, CCD-cameras and computer techniques. The high technical level permits to automatize not only the process of observations of artificial and natural objects but also to organize the operative identification of objects, the determination of their orbits and the ephemeride service. Such organization allows to raise the efficiency of using the optical means and to participate in some observational programs. There are two rather similar programs: the observations of artificial high orbital objects carrying out with in the frame of program "Space Debris" and the observations of natural Near-Earth Objects (NEO) carrying out by the program "Asteroid Hazard". Both these programs conduct in the regime of operative search of objects, which can damage the functional geostationary satellites or can collide with the Earth and lead to disastrous consequences.

1. INTRODUCTION

The main speciality of the Institute of Theoretical Astronomy is a creation of the national astronomical almanac and the investigations of the motion of artificial and natural bodies. According to the solution of the International Astronomical Union (IAU), starting since 1947 the Institute began to issue the annual volume "The ephemerides of minor planets". These unique volumes are distributed among all the observatories of the World.

The minor planets or asteroids move between the orbits of Earth and Jupiter (Figure 1). The ephemerides of asteroids are calculated on the base of the numerical integration of motion equations with perturbations from all the major planets. The initial data are determined with the use of astrometrical observations obtained during some tens of years. It should be noted that a number of known minor planets continuously increasis and the last ephemeris volume contains the data for about 7000 objects.

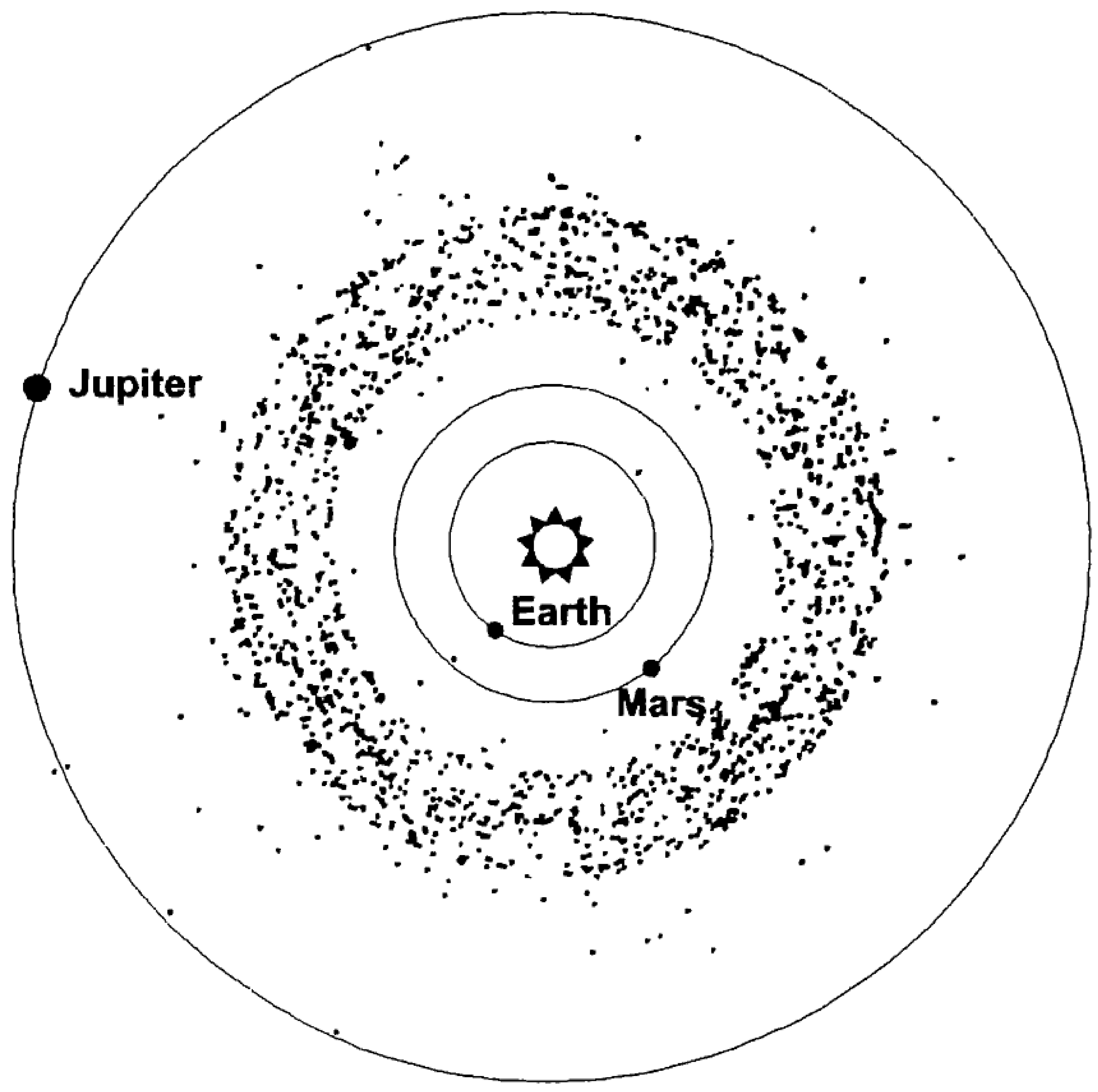

Figure 1. Asteroid belt.

The accuracy of the calculated ephemerides depends on the accuracy of observations and their distribution along an orbit. Therefore the creation of a bank of observational data is one of the most important problems. The Institute supports the contacts with nearly a hundred observatories. But in spite of that since 1964 the Institute created its own group of observers (supervisor N.S.Chernych) in the Crimean Astrophysical Observatory and acquired two instruments: 64 cm wide-field telescope with Richter-Slefogtt camera and Zeiss double-astrograph with D = 40 cm. Due to the efforts of this group about 60 000 observations were obtained and 900 new minor planets

Proceedings of the Second European Conference on Space Debris, ESOC, Darmstadt, Germany, 17-19 March 1997, (ESA SP-393, May 1997)

discovered. At present the Institute undertakes activity in equipping these telescopes by CCD cameras.

The experience of contacts with observatories shows that new facilities and personal computers may raise the efficiency of their labour. For this aim the Institute prepares a software for observatories such as "STAMP" - an electronic version of the ephemeris volume and "CERES" - software package (Ref. 1), which may calculate the ephemerides of all the natural bodies of the Solar System.

Since 1957 the investigations of the Earth artificial satellite dynamics were included in scientific themes of the Institute. The Institute took part in many international observational programs, providing the soviet observatories with ephemerides of artificial satellites. The difficulties with identification of uncontrolled geostationary satellites (GS) make undertake an attempt to create a catalog of GS initial orbits.

In 1994 the first catalog of the improved orbits of uncontrolled objects (Ref. 2) was published due to Professor W.Flury, who organized the periodic publication of GS orbital data in the European Space Operation Centre, and Dr. G.Janin who prepared these issues (Ref. 3). The catalog helped to identify 12 000 observations, to form series of observations for some GS (Ref. 4) and to begin observations of selected GS at some observatories.

The first catalog contains data for 498 GS. But in reality a number of objects including small fragments, which are invisible for modern facilities, is very significant. All these objects move in a rather compact region, which looks as a ring, inclined to the equator plane. In Figure 2 the distribution of objects in the Geostationary Ring is represented in the spherical coordinate system by K.V.Grigoriev on the base of the evolution of known orbits.

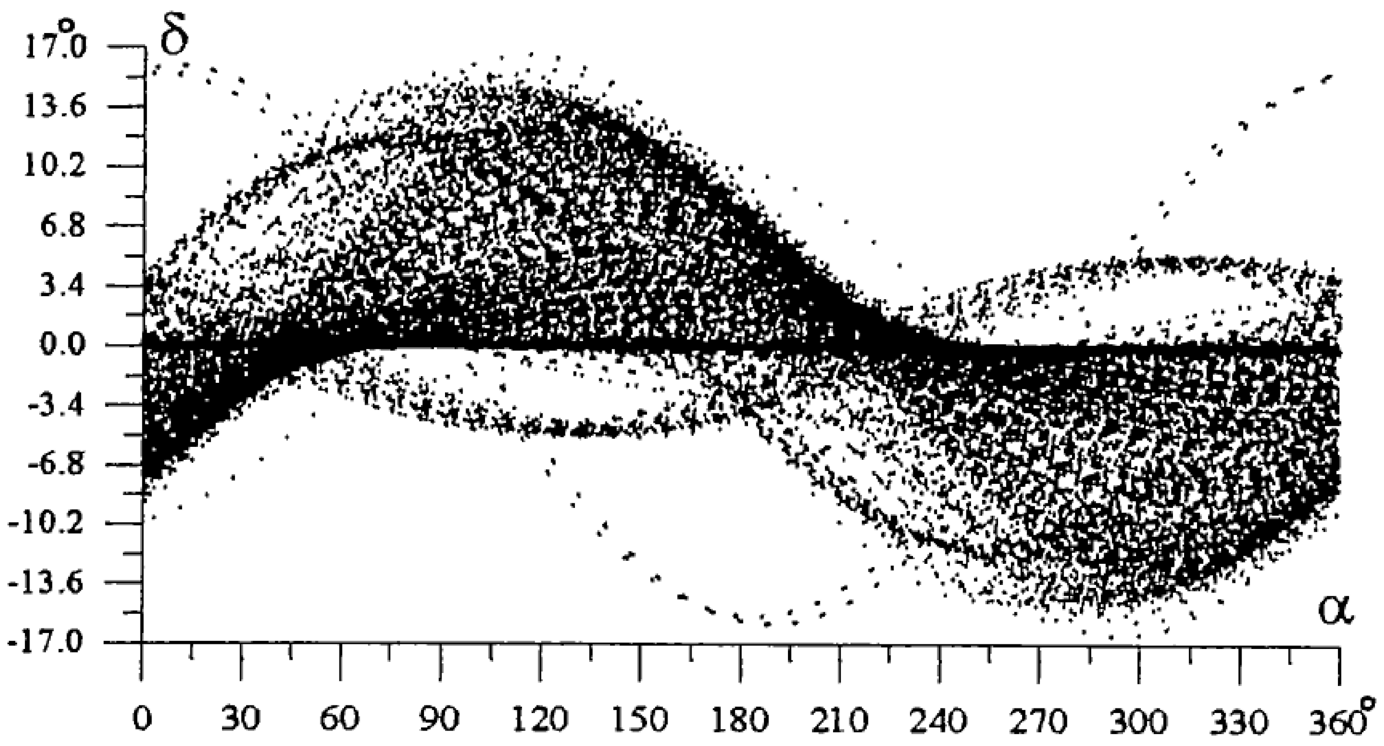

Figure 2. The distribution of objects in the Geostationary Ring and in its vicinity (the spherical coordinate system).

2. ASTEROID - HAZARD PROBLEM

Over the past five-ten years the research of Earth-approaching bodies began to develop. In 1991 IAU formed a Working Group on Near-Earth Objects (NEO). In 1992 for determining priorities in the solution of different sub-problems of "Asteroid Hazard" and coordination of the investigations on the basis of the Institute - the International Institute of Problems of Asteroid Hazard (IIPAH) under the leadership of Professor A.G.Sokolsky was created.

The specialists of more than 30 scientific institutions and observatories take part in the search of NEO and realization of the programs of IIPAH. Among NEO there are both the known asteroids with high elliptic orbits as Apollo, Eros, Icarus, which cross Earth's orbit and the new objects, moving close to Earth's orbit. At present 450 NEO are known. On the base of these data the electronic catalog of these objects is created. The catalog contains information about all the approaches during 1996 - 2010 with distances less then 50 million km.

In Figure 3, prepared by V.L'vov with the use of the software package "CERES", the orbits of 50 NEO are shown only. It is obvious that now and in future the observations of NEO and the determination of their orbits becomes to be a very urgent problem. In detail this problem was discussed in the new book "Asteroid-Comet Hazard" (Ref. 5).

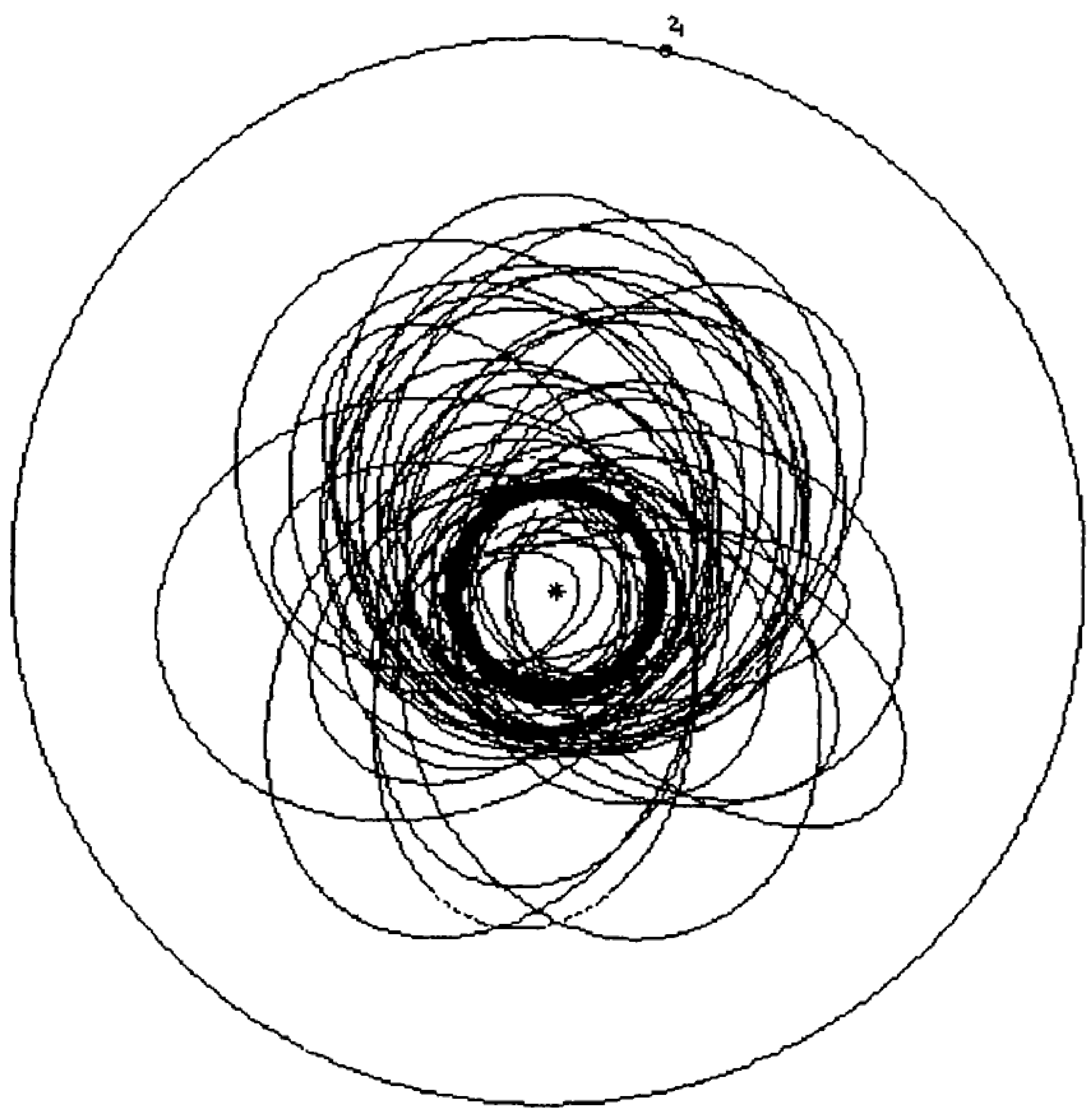

Figure 3. The orbits of 50 NEO on epoch JD 2448800.5 (Earth's orbit is depicted by bold circle).

3. INVESTIGATIONS OF GEOSTATIONARY RING

In 1996 due to receiving of the NASA Two-Line-Elements (TLE) through INTERNET more careful investigations of GS motion began. These data were also used for the improvement of orbits in the new Catalog 96 (Ref. 6). Simultaneously together with the Catalog 96 its electronic version was prepared, which contains the software for the calculation of GS evolution (Ref. 7). In Figure 4 a page of this catalog is demonstrated. Now this version is improving. According to recommendation of observers the interpolation for a given moment of time and the calculation of spherical coordinates are added. The new version will be completed in May-June 97.

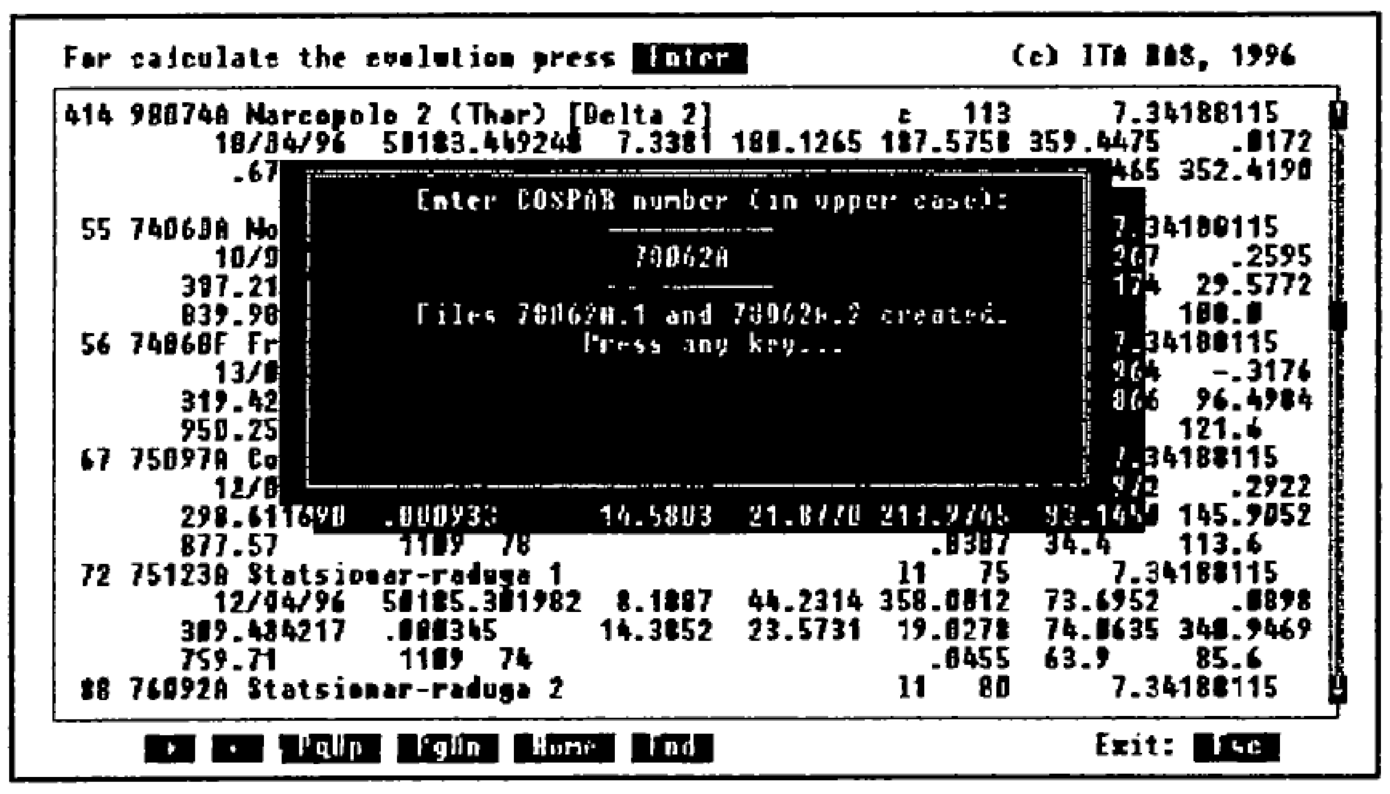

Figure 4. Electronic catalog (view of screen).

The motion of GS is very various. In Figure 5 all the types of motion in the phase plane (stroboscopic longitude λ - rate of longitude drift dλ/dt) are represented. In this Figure all the controlled GS are distributed along the λ - axis (dλ/dt = 0). At the distance of geostationary orbit (GEO) the variation of dλ/dt, equal to 1°/day, corresponds to the change of the distance about 80 km. From Figure 5 it can be noted that the librating satellites cross the GEO twice per a period of libration. The librating and drifting GS cross GEO every day if the following relation between dλ/dt, eccentricity e and argument perigee ω is fulfilled:

$$e \cos \omega = - 2/3 \, d\lambda / dt / n$$

where n is mean motion GS, which can be adopted for 361°/day.

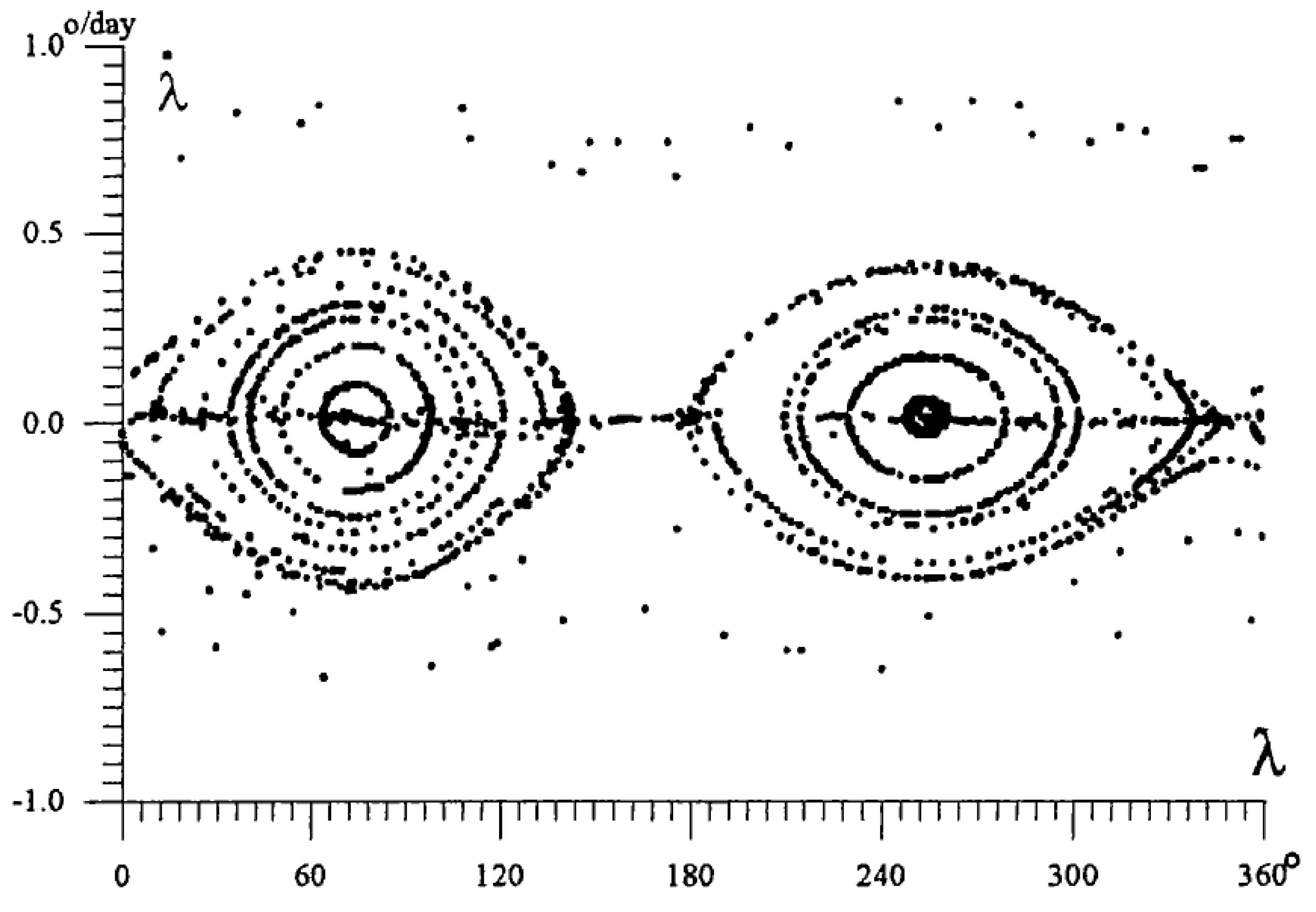

Figure 5. The distribution of Geostationary satellites in the phase plane.

It is obvious, that for predicting of collisions the initial orbits and calculation of their evolution have to be very precise. The comparison TLE (O) with elements of orbits, obtained from the evolution of improved orbits (C), shows that mean errors of (O-C) in the longitudes are usually equal to 0°.02-0°.04 during 1000 and more days. But there are some cases, when these mean errors exceed 0°.1. In Figure 6 (O-C) of the longitude, obtained from improvment on the interval of 2670 days for the ordinary GS 84016a Raduga 14 are depicted. In Figure 7 the same date for GS 79087C Ekran 4 (launcher) on interval of 1150 days are shown. The careful analysis of all such cases shows, that these residuals are due to the collisions with space debris. The paper about the foundation of this conclusion has been prepared by Professor R.Kiladze (Ref. 8)

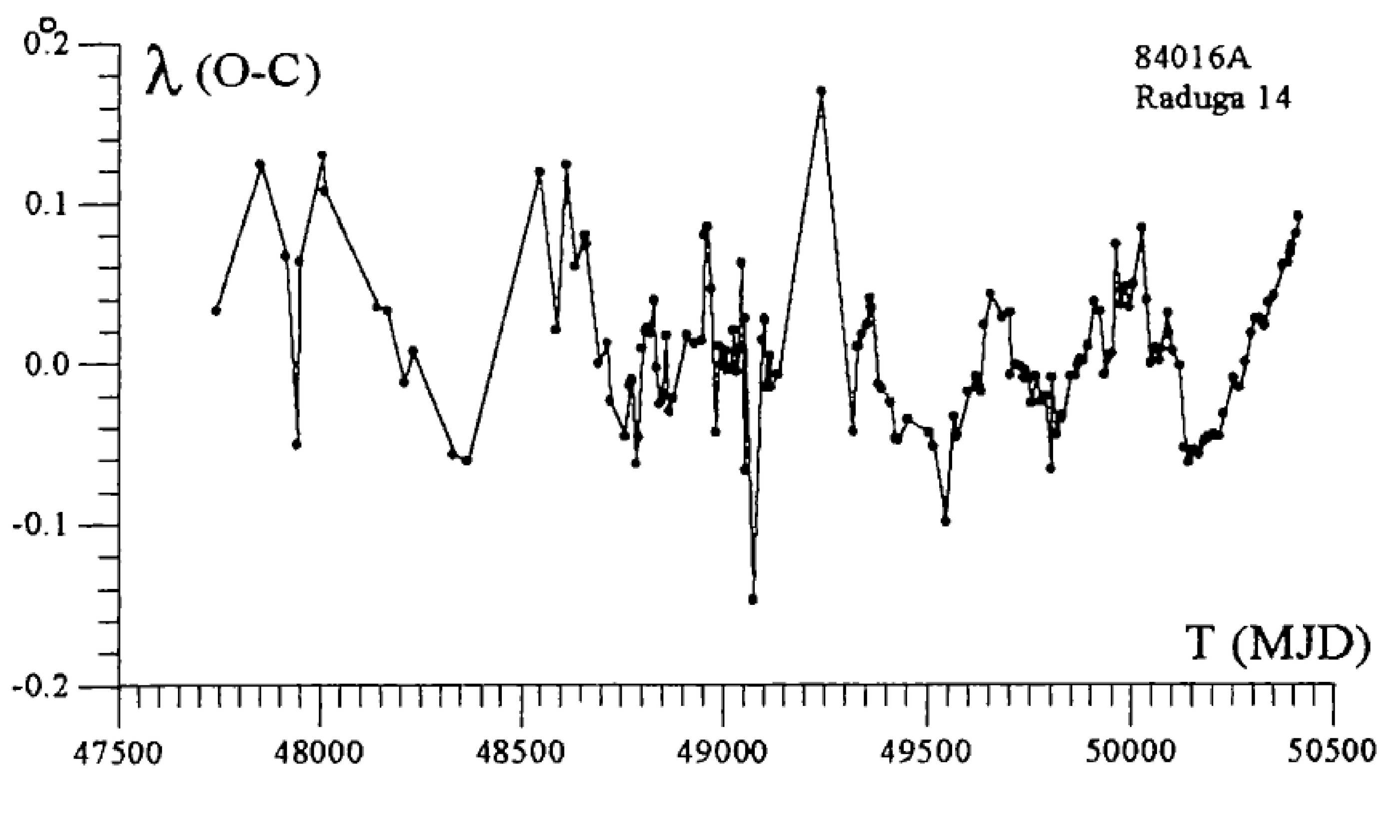

Figure 6. The comparison of the calculated longitudes of GS 84016A with the longitudes defined from TLE on the time interval 2670 days.

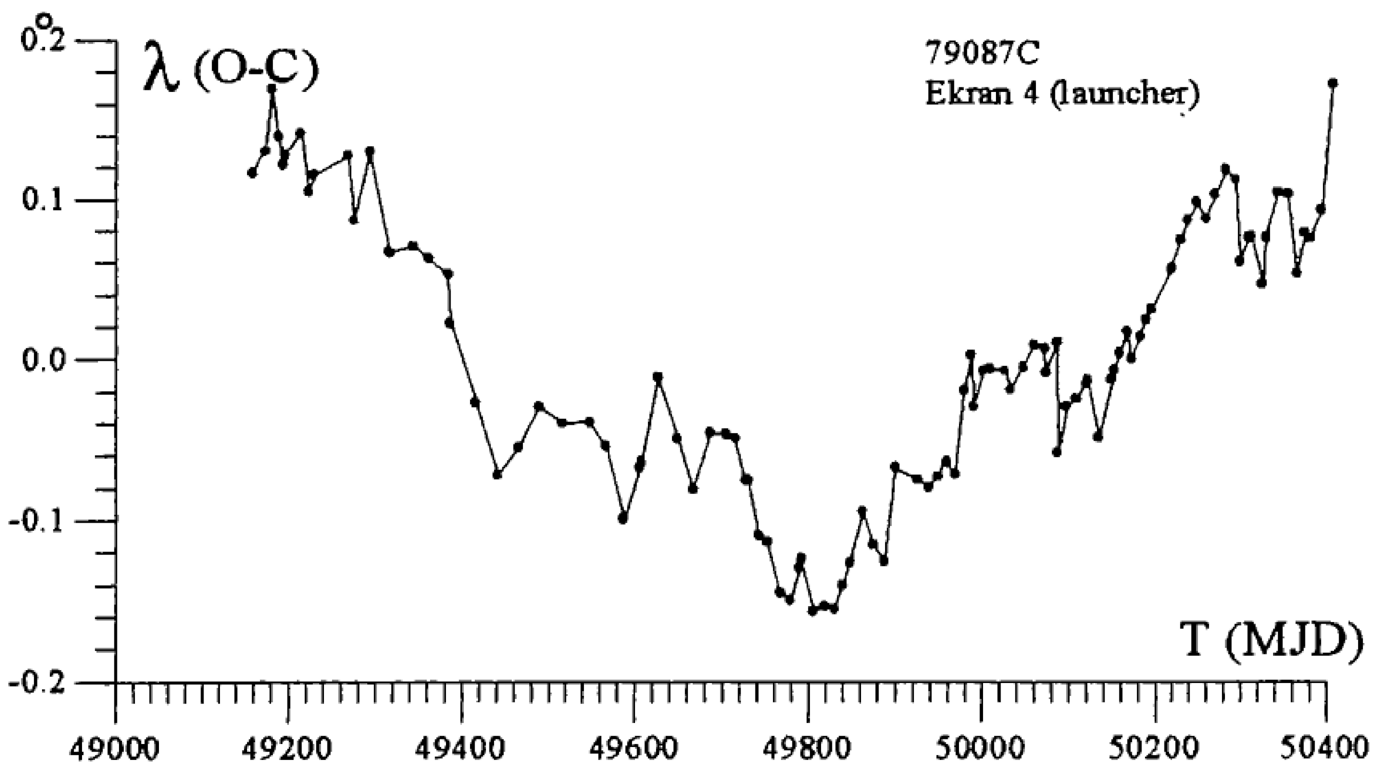

Figure 7. The comparison of the calculated longitudes of GS 79087C with the longitudes defined from TLE on the time interval 1150 days.

Undoubtedly, the accumulated NASA TLE contain a very interesting information as well, which may be obtained from their treatment. The analysis of eccentricity (*e*) and argument of perigee (ω) variations shows, that for the last two years the accuracy of their determination have been increased and in some cases the parameters of the solar radiation may be defined from the variations of *e* and ω.

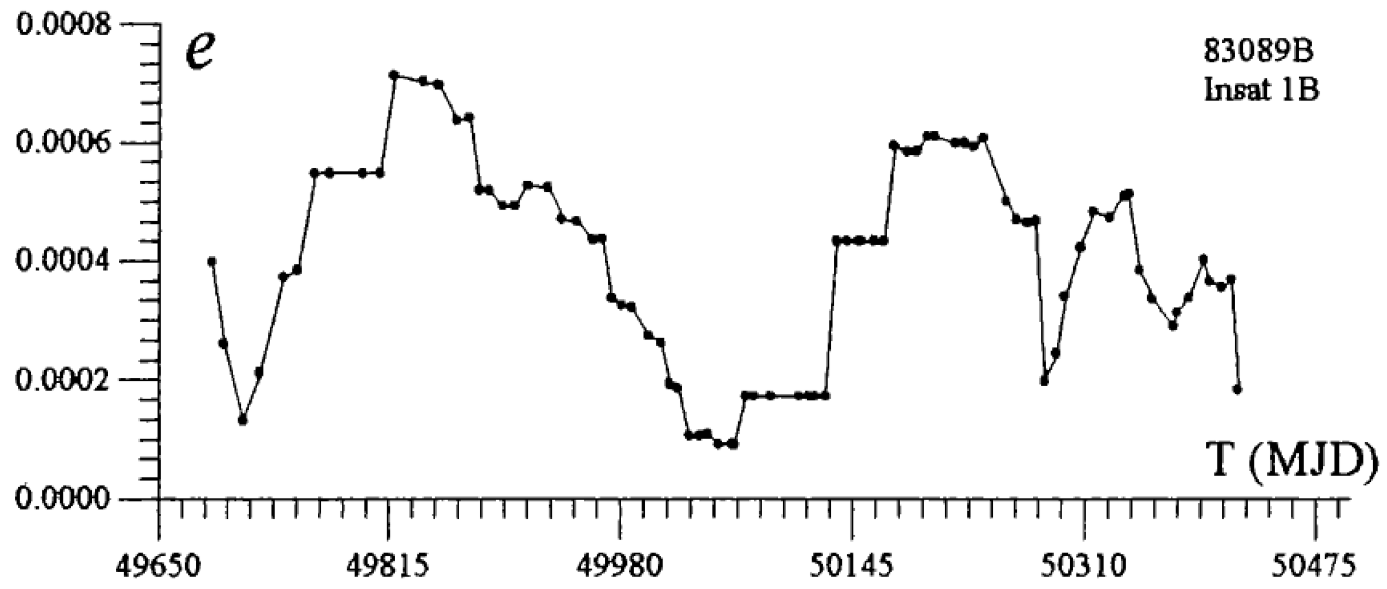

Figure 8a. The evolution of eccentricity.

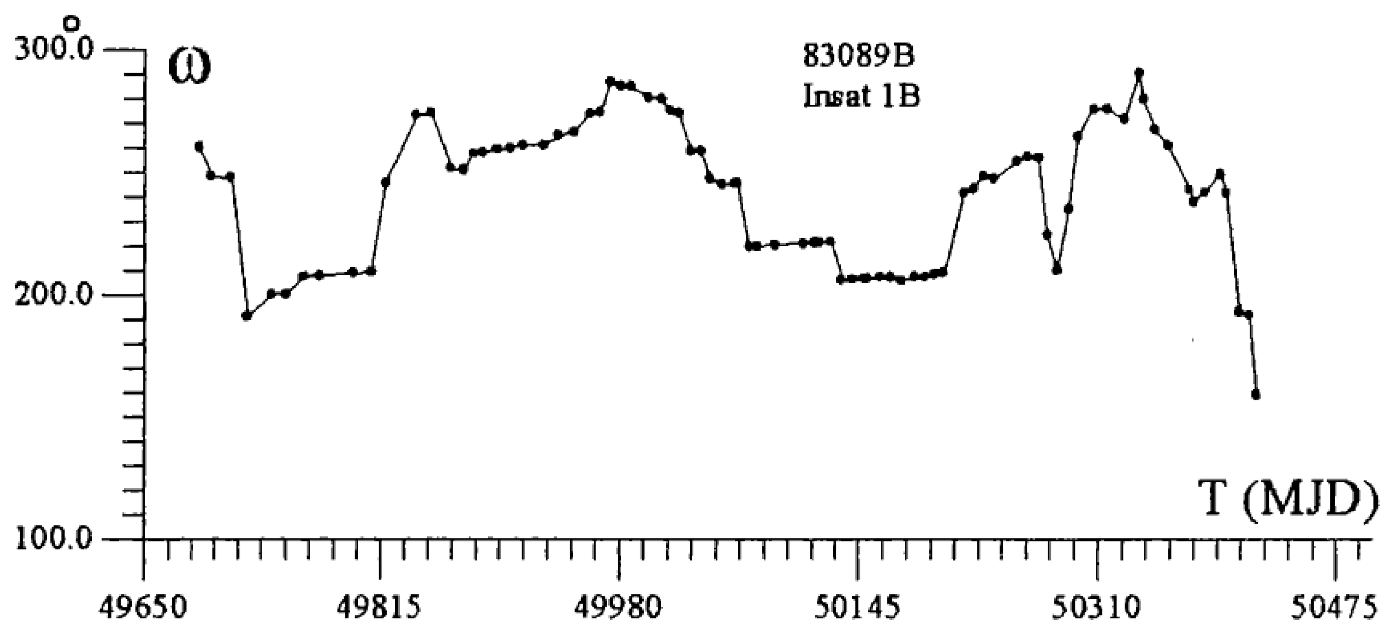

Figure 8b. The evolution of argument of perigee.

In Figure 8 the evolution of *e* and ω for GS 83089B (Insat 1B) is given. It can be seen, that there are some cases of an incorrect orbital improvement, when *e* and ω remain constant during a month or more. Therefore the method of determination of orbital elements should be changed.

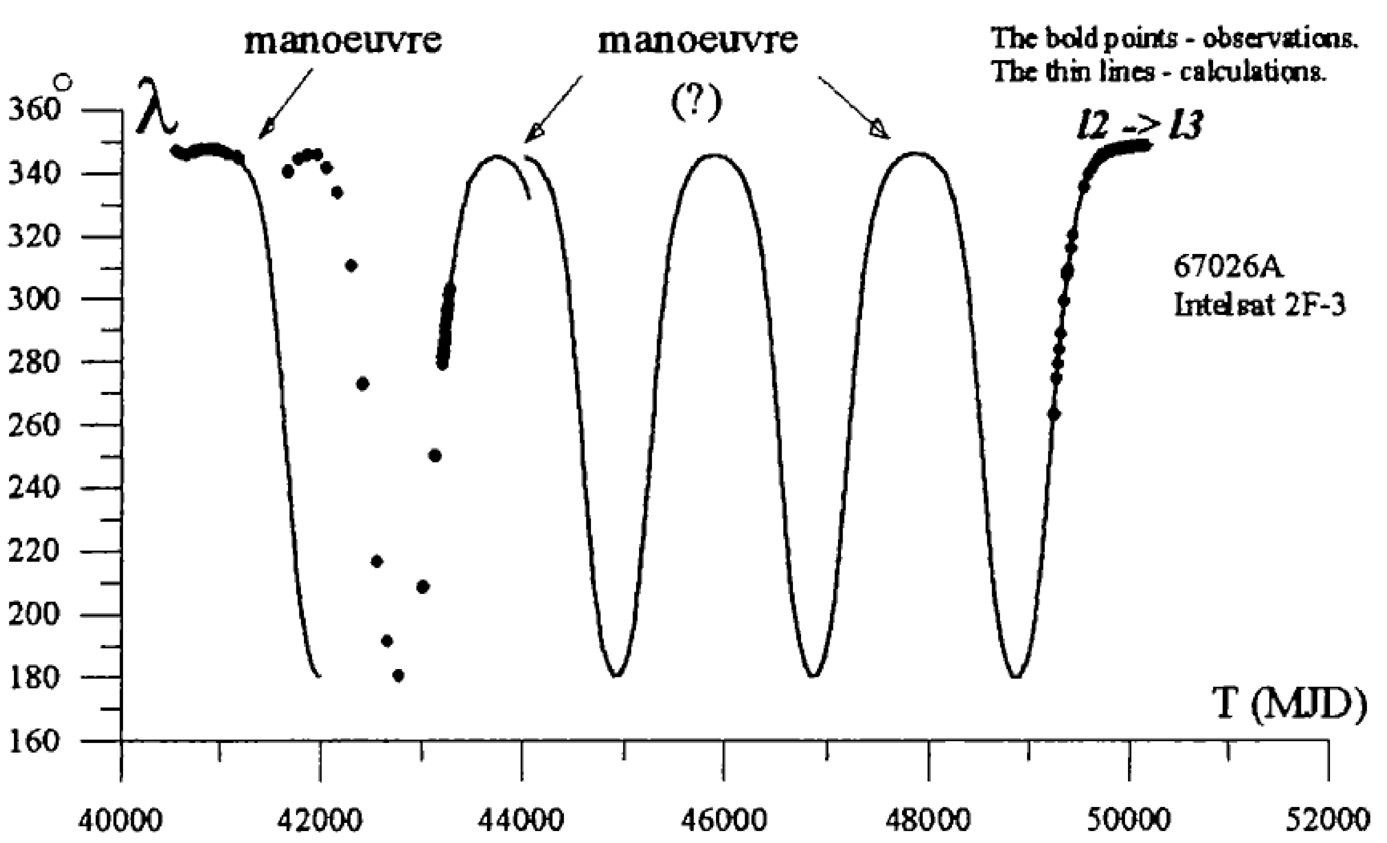

Figure 9. The evolution of longitude.

The analysis of long-term evolution of librating GS is especially interesting for the control of the motion theory and parameters of the geopotential. In Figure 9 the interpretation of orbital data, which the Institute has for GS 67026A, is given; a discrepancies of observed and calculated longitudes as function of time are shown, which can be explained as an extra manoeuvre.

The study of behaviour of the TLE over large time interval shows that the longitudes of GS are determined with the satisfactory precision (0.°01-0°.02) and can be used for control of parameters of the geopotential. These data helped to discover and explain the phenomenon of the change of regime motion for some satellites (Ref. 9, 10). In Figure 10 the evolution of longitude of 86027A Cosmos 1738, which will change its regime of motion under the influence of luni-solar attraction, is given.

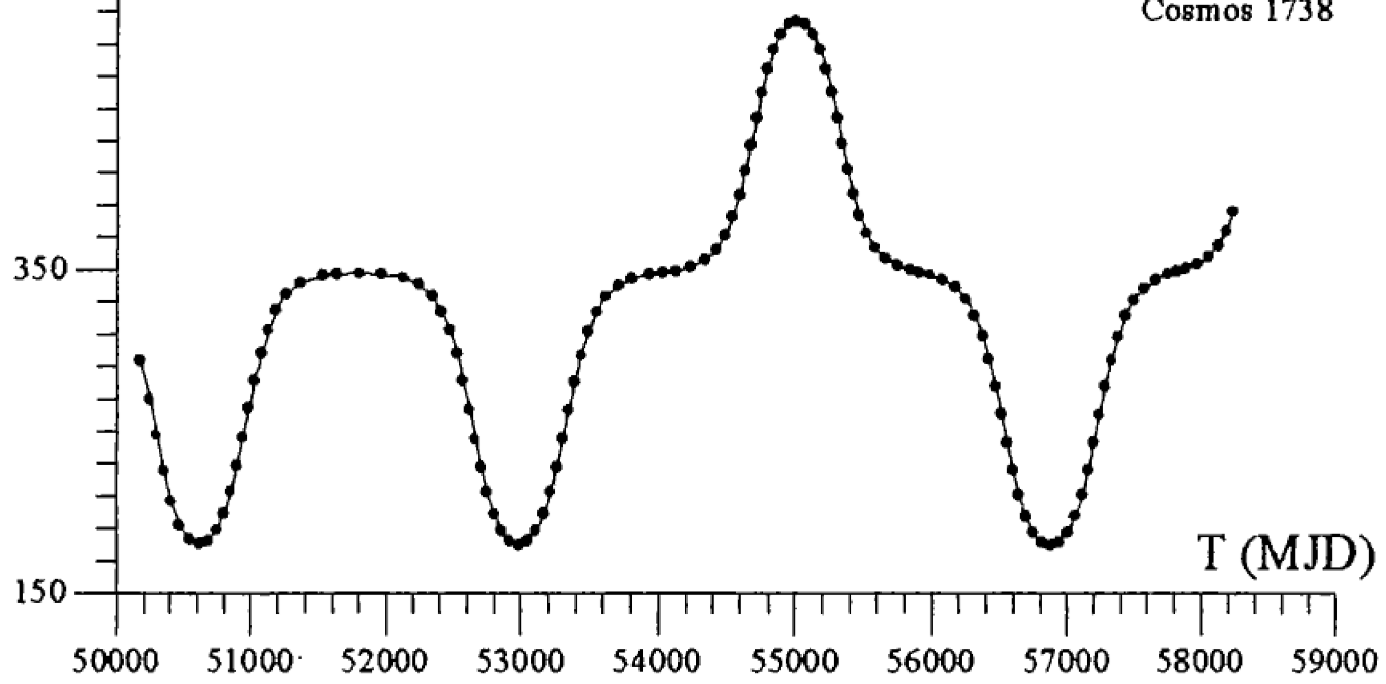

Figure 10. The evolution of longitude.

4. CONCLUSIONS

1. The Institute of Theoretical Astronomy has experience of creation of software packages for the treatment of observations of both artificial and natural objects. These softwares are used at many observatories of the former Soviet Union, which collaborate with the Institute. The most part of tests was conducted at the Crimean station of the Institute.

2. Two programs are proposed to combine: observations of artificial high orbital satellites and observations of natural Near-Earth Objects. Both these programs are conducted in the operative regimes of search and have similar methods of ephemeris providing. The Institute of Theoretical Astronomy is ready to help in organizing observational programs of GS and NEO and will give electronic catalogs to participants of these programs.

3. One of the most important problems is the creation of the bank of data containing the observations of GS, available for investigators, because one country can not obtain the full information about the Geostationary Ring from its own territory. It should be useful for the investigators to have observations of artificial objects, which are accumulated in the Space Operative Centers.

4. The studies of space debris evolution have to be supported by scientific observational programs, such as "Resonance", put forward by the Institute, and others, for instance, an observational program for the investigation of the solar radiation influence.

5. REFERENCES

1. Chernetenko, Yu., et al., Controlling the observational data on minor planets with the "Ceres" software package. *Proc. Dynamics, ephemerides and astrometry of the Solar System.* Editor S.Feras-Mello et al., Paris, France, July 3-8, 1995.

2. Vershkov, A.N., et al., *Catalogue of Improved Orbits of Uncontrolled Geostationary Orbits*, Institute of Theoretical Astronomy, St.Petersburg, Russia, 1994.

3. Janin, G., *Log of Objects Near the Geostationary Ring*, Issues 1-16, ESOC, Darmstadt, Germany, 1996.

4. Grigoriev, K.V., et al., On the Collection of the Photographic Observations of Geostationary Objects, *Space Forum*, Vol.1, Nos. 1-4, 57-62, 1996.

5. Medvedev, Yu.D., et al., *Asteroid-Comet Hazard*, Editor A.G. Sokolsky, Institute of Theoretical Astronomy, St.Petersburg, Russia, 1996.

6. Sochilina, A.S., at al., *Catalog of Orbits of Geostationary Satellites*, Institute of Theoretical Astronomy, St.Petersburg, Russia, 1996.

7. Vershkov, A.N., The Electronic Form of the Catalog of Orbits of Geostationary Satellites 1996, *Abstracts of All-Russian Conference with International Participation, "Observations of Natural and Artificial Bodies of the Solar System"*, St.Petersburg, Nov 26-28, 1966, Editor A.G.Sokolsky, 46, 1996.

8. Kiladze, R.I., et al., On investigation of long-term orbital evolution of geostationary satellites, *12th International Symposium on Spaceflight Dynamics*, Darmstadt, Germany, 2-6 June, 1997 (in press).

9. Kiladze, R. and Sochilina A., On project "Resonance", *Abstracts of the All-Russian Conference with International Participation "Programs of Observations of High Orbital Artificial Satellites and Bodies of the Solar System"*, St.Petersburg, Dec. 13-15, 1994. Editor A.G.Sokolsky, 70-71, 1994.

10. Kiladze, R. and Sochilina A., On the program "RESONANCE", Space Forum, Vol 1, No 1-4, 15-22, 1996.