SURVEY OF GEOSTATIONARY OBJECTS WITH PHOTOGRAPHIC OBSERVATIONS PERFORMED AT TWO STATIONS - ORBITS EVOLUTION AND PROBABILITIES OF COLLISIONS -

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ABSTRACT

The possibilities of survey photographic observations of geosynchronous satellites from two stations and their identification are given. A distribution of a semi-major axis changes of the geosynchronous satellites in time of their launch are represented.The ways of calculation of probability of satellites collisions with other objects on geostationaries orbits especially in "collocate" zones are outlined.

OBSERVATIONS AND ASTRONOMICAL TREATMENT

Geostationary space objects observations at Space Research Laboratory of Uzhgorod State University (SRL UNU) have been performed from 1977 using the SBG camera (D=0.43 m, F=0.76 m, production Carl Zeiss, Jena) mounted by collaborators of Carl Zeiss corporation Diter Neubert and Hans Ufert. The camera mounting is four-axis. The photoplates of size 9x12 cm correspond to the field of 6° x 8° . The method of geostationary satellites observations [1] at SBG camera provides for satellite positions with an accuracy σ =0.64 ″, the time moments registration are carried out with an accuracy of 0.01 sec.

Three satellites images within two minutes of time interval and four images of stars at the astronegatives are obtained. It facilitates the further objects identification. The survey carried out during the night covers the time angles from 10^0 E to 65^0 W from Greenvich every 5^0 for declination of -7^0. These observations are continued about two hours. It is possible to repeat observations of these regions in half an hour or hour during one night and to receive by such method about hundred satellites till six images for each satellites within the time interval 1^h or 1.5^h at a good transparency.

The regular space objects observations at the Main Astronomical Observatory of the National Academy of Sciences of Ukraine (MAO NASU) in Kyiv have been performed beginning from 1983 [2]. Photographic observations of geostationary region at MAO NASU are carried out using the double wide-angle Carl Zeiss astrograph (D=0.4 m, F=2 m). The telescope has been supplied by the special camera for satellites observations.The photoplate of 24x24 cm corresponds to a field of 6.5^0x6.5^0. The accuracy of the obtained satellites positions is 0.26″÷0.50″. The time moments are defined with an accuracy of $3\text{-}5{\cdot}10^{-3}$ sec. At present the base of data consists of more than 4000 astronegatives with space objects.

The measuring of the satellites and stars images on astronegatives at SRL is carried out at the Askorekord (Carl Zeiss) using an automatic input of measured coordinates to computer. A calculation of the satellite coordinates is adjusted by Terner method in the system of PPM catalogue [3]. There is a computer version of this catalogue.

The identification of star images with catalogue is fulfilled by automatically using a geometric centre position on the astronegative and catalogue number one of arbitrary selected reference star. The reference stars are selected for concrete geostationary object situated on all astronegative field. For control in every such group, exept satellite coordinates, the coordinates of one reference star are calculated. Then the star coordinates are compared with catalogue coordinates.

The star images identification at MAO is fulfilled using two bright stars placed on the line which approximately passed through the astronegative centre on verios sides of it. Since the algorithm of star identification is based on comparison of measurement and ideal star coordinates, then the orientation of the measured coordinates system must be near the orientation of ideal coordinates system.This process is carried out by special above-mentioned camera, fixed on the plate the points

on the stars tracks. This points are used to orient the astronegative during measurement. The object positions (right ascention and declination) reduced to reference frame using the PPM catalogue in J2000.

GEOSTATIONARY OBJECTS CATALOGIZATION IS ONE OF THE MAIN PROBLEMS OF THE SPACE DEBRIS PROGRAM

The geostationary objects catalogization is necessary, first of all, because of objects orbit evolution : orbital plane precessiones with a period of 52 years and amplitude up to 15^0 [4]. In consequence of this in 2017 many objects will return in the equatorial plane. Fig.1 shows the changes of semi-major axis da of geostationary objecs according to the year of their launches. It is selected 280 objects from catalogue on epoch 09.1999 with da = (a - 42164 km) > 100 km .The dotted line da= - $6.671253x^2$+ 26482.812 x - 26281514.9, is calculated by least squares adjustment, where x is the date (year) of launch.
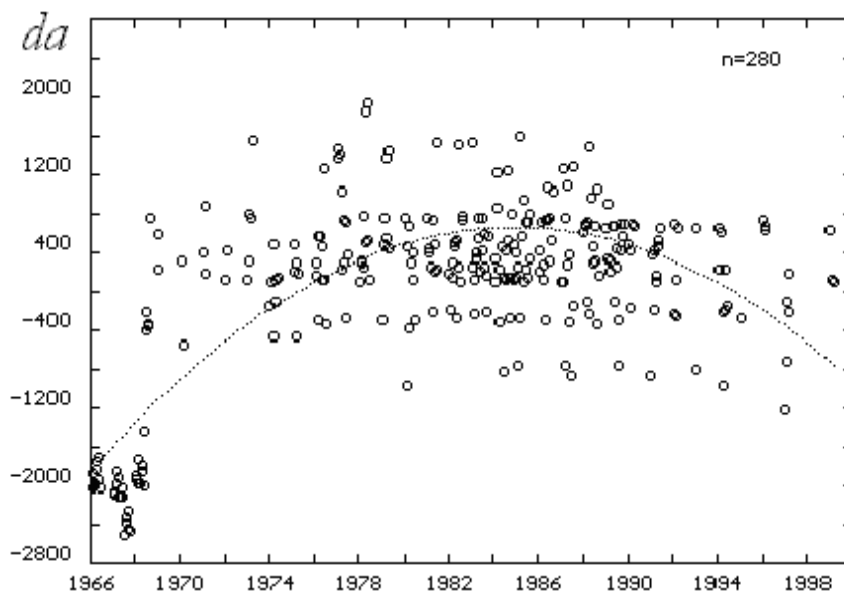

Fig.1. Change of objects semi-major axis according to the year of their launches

A dependence of change of the satellite semi-major axis on longitude drift $\dot{\lambda}$ is straightforward with a high correlation coefficient, p=0.99985.

The survey observations of geostationary objects from two stations allow the observations to be made during one night up to 150 objects. So in 1999 the Uzhgorod station has observed about 100 objects in longitude window from 35^0 E to 40^0W, the Kyiv station - 69 objects from 80^0E to 9^0W. It is obtained more than 2.5 thousand accurate positions with a precise time fixation.

The satellites identification is one of the important problems.We shall consider only identification using the photographic observations though the necessity of photometric observations of close objects is especially evident. By our method [5] the identification is carried out using the calculated osculating orbital elements on short arcs of observations. The basis of method of orbit determination is the calculation of geocentric subsatellite coordinates by using real observations. For the change of orbital elements only the first order is taken into consideration. About 80 per cent of all observed objects are identified according to international catalogues.

At first sight the identification of controlled (active) geostationary objects is not difficult. But there are some problems in their identification :

 1. Not all active objects are available in the catalogues as one can see from our observations [6-9].

 2. The information about orbital manoeuvre of active objects to other longitudes and also transition in uncontrolled (passive) objects is insufficient.

 3. In "collocate" zones the active satellites are difficult to identify especially after correction.

4. The calculation of orbital elements on small arcs for the objects with a large eccentricity leads to errors. It is necessary to take into account coefficient 2esinM for subsatellite longitude λ.

5. The engines start during correction for a time Δt with a force F changes a satellite drift and naturally its equatorial coordinates α,δ.

Solving an inverse problem it is possible to calculate approximately force impulse $Ft = -m\Delta\dot{\lambda}R$ (m -the satellite mass, R- geocentric distance, drawing, by least squares method the change of λ before correction and after correction. Fig.2 shows that as a result of correction $\dot{\lambda}$ changes from value - 0.00010^0/day up to 0.00048^0/day and the impuls, acquired by the satellite is |FT | = 14,2 Hc (the satellite mass is 2900 kg). It is possible to calculate an additional satellite acceleration knowing a force impuls.
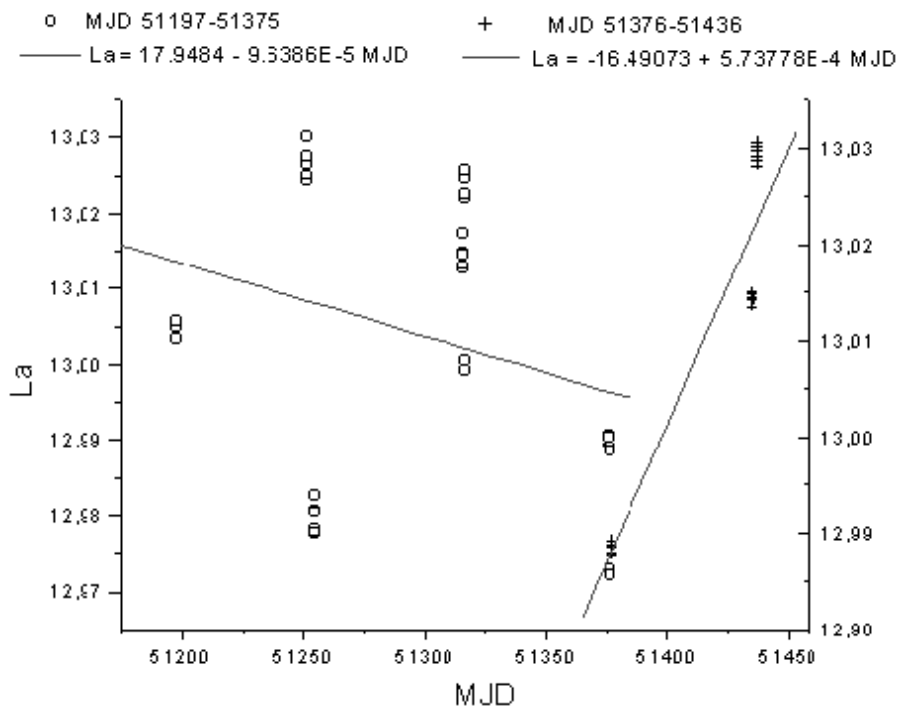

Fig.2. Change of subsatellite longitude during correction of 96067A Hot Bird 2

The knowledge of ephemerides is needed for passive objects observations with a large drift. They can be calculated by any observational station using the electronic version of catalogue [10] and so the series of observations [7-9]. Using the special programs the harmonics and linear components of evolution of the orbital elements with a purpose of obtaining the ephemeris are adjusted by the least squares method :

$$E = E_0 + \dot{E}_0(t - t_0) + \sum_{i=0}^{N} S_i(t) + C_N(t)$$

where

$$S_i(t) = A_i\cos(2\pi v_i t) + B_i\sin(2\pi v_i t)$$

$S_i(t)$ armonics are found such that the residual term $C_N(t)$ decreased when N increased and the velocity of decreasing is diminished.

"COLLOCATE" ZONES IS A SOURCES OF COLLISIONS RISK

The catalogues analysis [11,12] and observations showed that there are 140 "collocate" zones - longitude windows with a radius of 0.1^0 within the longitude interval of 280^0 long. Each of these longitude windows have from 2 to 8 objects at the given moment. Fig.3 shows the satellites distribution for 2 "collocate" zones in 6 observations series for the Uzhgorod station (MJD 50845.9-51130.9).
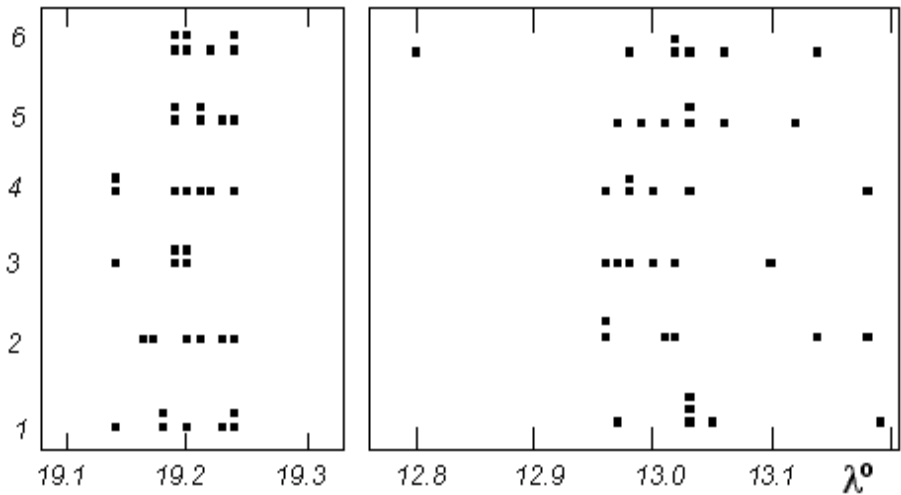

Fig.3. Satellites distribution within two "collocate" zones on longitudes of 12^0 and 19^0 during 6 series of Uzhgorod observations

Investigating the objects distribution in ″collocate″ zone and so the passive objects, which approach them, we come to conclusion about necessity to investigate the risk of collisions during the dangerous object approaches. Fig.4 shows the objects movements in "collocate" zone using the observations of the Uzhgorod station. Circles is initial satellite positions, squares - final positions, figures - satellites numbers. Fig.5 gives the movements of these objects using the observations at MAO on January 1999. The objects numeration for two stations are the same.
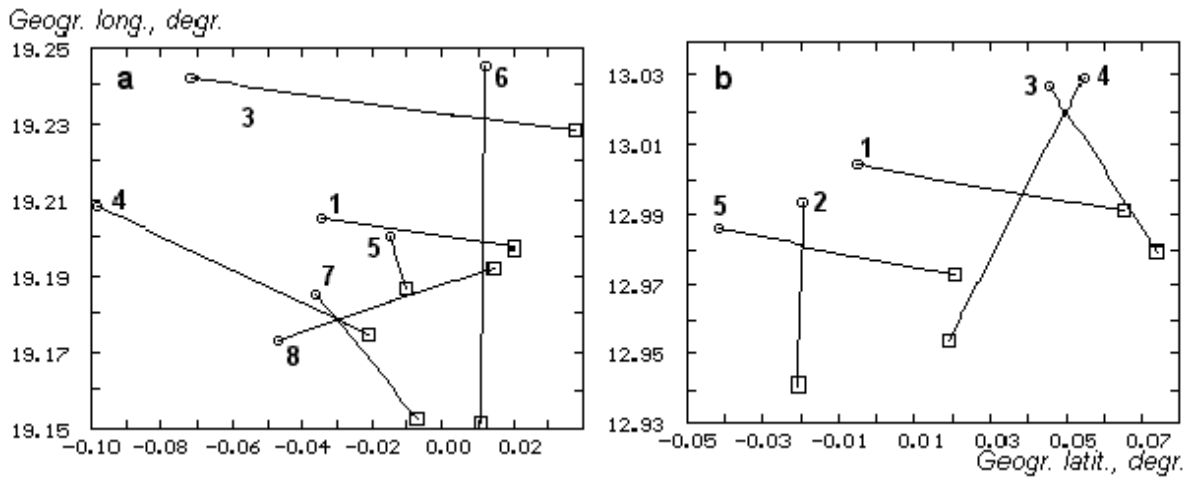
Fig.4. The movement of 8 geosynchronous satellites of Astra type (a) and 5 geosynchronous satellites of Hot Bird type (b) for 4 days on March (Uzhgorod) in 1999
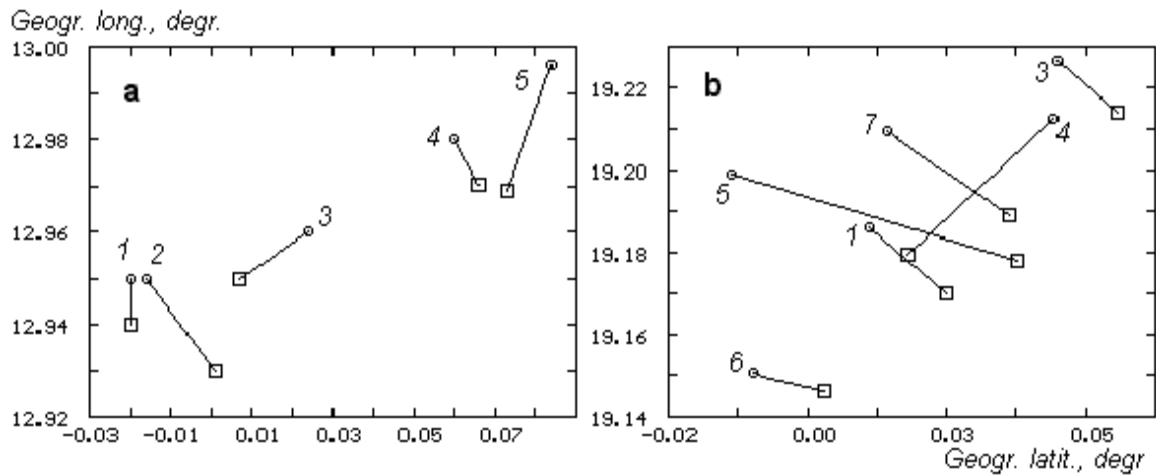

Fig.5. Geosynchronous satellites movements using the results of MAO (Kyiv) observation in 1999 on January in two "collocate" zones : (a) for 1.1 day; (b) for 0.12 day.

A collisions risk for "collocate" zone is large enough. It is possible to define the probability of collisions on geostationaries orbits by the method using for low orbits [13]. The probability P of two geosynchronous objects collision during the dangerous approaches may be approximately presented as :

$$ P = p_{\varphi\lambda} \cdot \int p(h) \left(\int\limits_{h-(R+r)}^{h+(R+r)} p(x)dt \right) dh , $$

where $p_{\varphi\lambda}$ is the probability of collision under condition that the objects have the same height, $p(x)$ is the density of distribution of object distance from ideal geostationary orbit. The observations of the Uzhgorod station for three years were used for determination of this function. The statistic is small because of the small number of satellites observed at this station. The density $p(x)$ may by presented as a normal distribution with a parameter $\sigma = 46.3$ km adjusted by least squares method.

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