

ZONE CATALOG AND PRINCIPLES OF GEOSTATIONARY SATELLITES' (GSS) IDENTIFICATION

Didenko A.V., Demchenko B.I., Nifontov S.G., Usoltseva L.A.

V.G. Fesenkov Astrophysical Institute of National Academy of Sciences of Kazakhstan Republic

Resume The brief review of methodics and apparatus which were used for the artificial satellites' observations is conducted. The problem of identification of geostationary satellites (GSS) and the principles of its solutions are examined. The conception of unknown GSS' identification based on the use of coordinate and photometric information and available database is offered.

THE OBSERVATION OF GSS IN KAZAKHSTAN

The ground-based observations, analysis of the received information, and cataloguing of functioning and passive artificial satellites are paramount scientific themes of the Astrophysical Institute from the very beginning of a space age. In 1967 the Astrophysical Institute was included in a Soviet optical tracking stations' network. From that time the 70-cm reflector AZT-8 supplied by an electronic-optical television system (EOTS) and suitable software was used for observations of space objects. In 1987 on the basis of the store of knowledge and the computer SM-1420, there was created and inserted the Astronomical Automatized TV-system (AATS-2), [Demchenko *et al.*, 1990]. The error of determination of satellites' equatorial coordinates was 1".5 - 2".0, operativeness of one position's definition (mean of three) - from 3 up to 15 sec., the satellites' limiting magnitude which may be register by computer - 15.5^m. The methods of positional observations (see Demchenko *et al.*, 1990; Demchenko *et al.*, 1996; Didenko *et al.*, 2000) are not changed much lately, because the receiving equipment remained the same. Last years there was conducted the replacement of computer, software and some auxiliary instrumentation. The essential changes happen in the system's software which is modernized in accord of solved problems.

From 1998 the regular GSS' team observations are carried out by two ground stations: V.G. Fesenkov Astrophysical Institute of National Academy of Sciences, Almaty, $\lambda=77^{\circ}\text{E}$ and Priozersk, $\lambda=73^{\circ}\text{E}$, Closed Joint-stock Company "Institute of Radioelectronics". The important advantages of Priozersk's observational station are: a good astroclimate, many clear nights (up to 280 a year), capability to track not only the geostationary but also the low-orbital objects and to register the coordinate and photometric information simultaneously. The quantum-optical system (QOS) of Priozersk's observational station set on the 50-cm AZT-28 telescope with the coupled telescopic systems. The plant's field-of-view is 9'x12' only and so it does not allow one to make a search of GSS in controlled zone.

While AATS-2 with the 32'x 32' telescope's field-of-view allows to do the views of the inspected geostationary zone. Therefore the regular interchange of necessary information during the joint program's fulfillment is realized. So the information about new objects detected during the AATS-2' reviews in Almaty is operatively transmitted for their tracking with QOS also as the orbital parameters are ephemeris data for those satellites which orbits require confirmation. Thus the observational stations supplement each other on their functionality. The unification of results of observations allows to expand the available database and to realise the monthly maintenance of the existing catalogue. Every station receives the orbital elements for 80-100 GSS during the session of observations.

As a result of team investigations, the second issue of the Zone Catalogue was carried out in 2000 [Didenko *et al.*, 2000]. It includes a list of orbital parameters for 435 active and passive geostationary objects placed in subsatellites points longitudes 10° - 135°E and its international numbers. Some photometric characteristics for 40 selected objects are given also.

Now the regular GSS observations are carried out for maintenance and addition of the existing database. On 1 September 2003 Zone Catalogue tracking by two Kazakhstan ground based

stations include coordinate information about 573 active and passive GSS in longitudes 10°-140°E and photometric information about 130 objects, most of them were observed for 5 - 10 years. The database contains the results of coordinate and photometric BVR observations and some photometric characteristics of all basic types of geostationary satellites. Procedure of identification includes a joint analysis of coordinate and photometric information and the combinations of expert estimations, methods of the incorrect problems' solution and methods of the images' recognition theory. There is also the electronic version of the Catalogue, which shows the operating situation and some necessary information about concrete object in an inspected geostationary zone on any required date at the screen monitor.

THE PROBLEMS OF GSS' IDENTIFICATION AND PRINCIPLES OF ITS SOLUTION

It is known that the objects' identification is the main problem for creation of any catalogue of artificial satellites. The situation is complicated for geostationary orbits with its high density of population, because of the existence of draughting vehicles. So the specialists try to solve the problem of identification by their own ways dependent on observational material presence. For example, *Hernandez and Jehn, 2000; Sochilina et al., 1994; Sochilina et al., 1996* used the coordinate information. Other authors [*Bagrov and Smirnov, 1986; Vygon et al., 1998; Kljuev et al., 2001*] involve noncoordinate information for this purpose. Our long-term experience shows that the presence of photometric information allows one to determine the type of observed GSS reliably and the joint analysis of the coordinate and photometric information permits to identify the object with sufficient degree of truth. The special complex of programs allows realizing, with a high level of reliability:

- a determination of object's orientation and its dynamic parameters (period of the rotation around its center of weight, the direction of spin axis);
- an estimation of its stabilization's type;
- a calculation of physical GSS' parameters and of its separate elements (an effective reflecting area, relative coefficient of the reflection and character of those factors changes, which depend on duration of the object's stay on an orbit);
- a modelling of equivalent geometrical image;
- an identification of the GSS' type and their international number.

The results of activity of all these programs may have an independent interest, but we use all information for the identification of object. Conditionally one can divide the procedure of identification of unknown GSS at some stages. At these stages the sequential analysis of the coordinate and photometric information and using of auxiliary methods (expert estimations, methods of the solution of incorrect problems, methods of the theory of a recognition of images) are carry out.

1. Analysis of coordinate information

At this stage the approximate date of GSS' launch is estimated. We use the orbital parameters of observed objects, our database and information [*Jonathan Mc Dowel*] are from some other sources for it. One can select all GSS which orbital parameters are unsafe, obsolete or unknown from that source. The international number and date of launch of the objects are known, but the parameters of orbits are unknown. And on the contrary we know the orbital parameters for objects which are necessary to identify, but their dates of launch are unknown.

There is the evolutionary diagram $i - \Omega$ which based on our long-term observations in the Figure. The diagram represents the dependence of an angle of inclination of orbital plane to the plane of equator from a longitude of an ascending node. We know the position of an unknown object on the diagram. One can also select a number of satellites with known international numbers (i.e. with known date of launch) from our data base. Those satellites must have similar parameters and lie on the same branch of the evolutionary diagram. So we may estimate the approximate dates of launch and international numbers of unknown objects. It is necessary to attract the photometrical

information for more reliable identification. It allows to determine the prominent feature of the given objects, its type and number of other items.

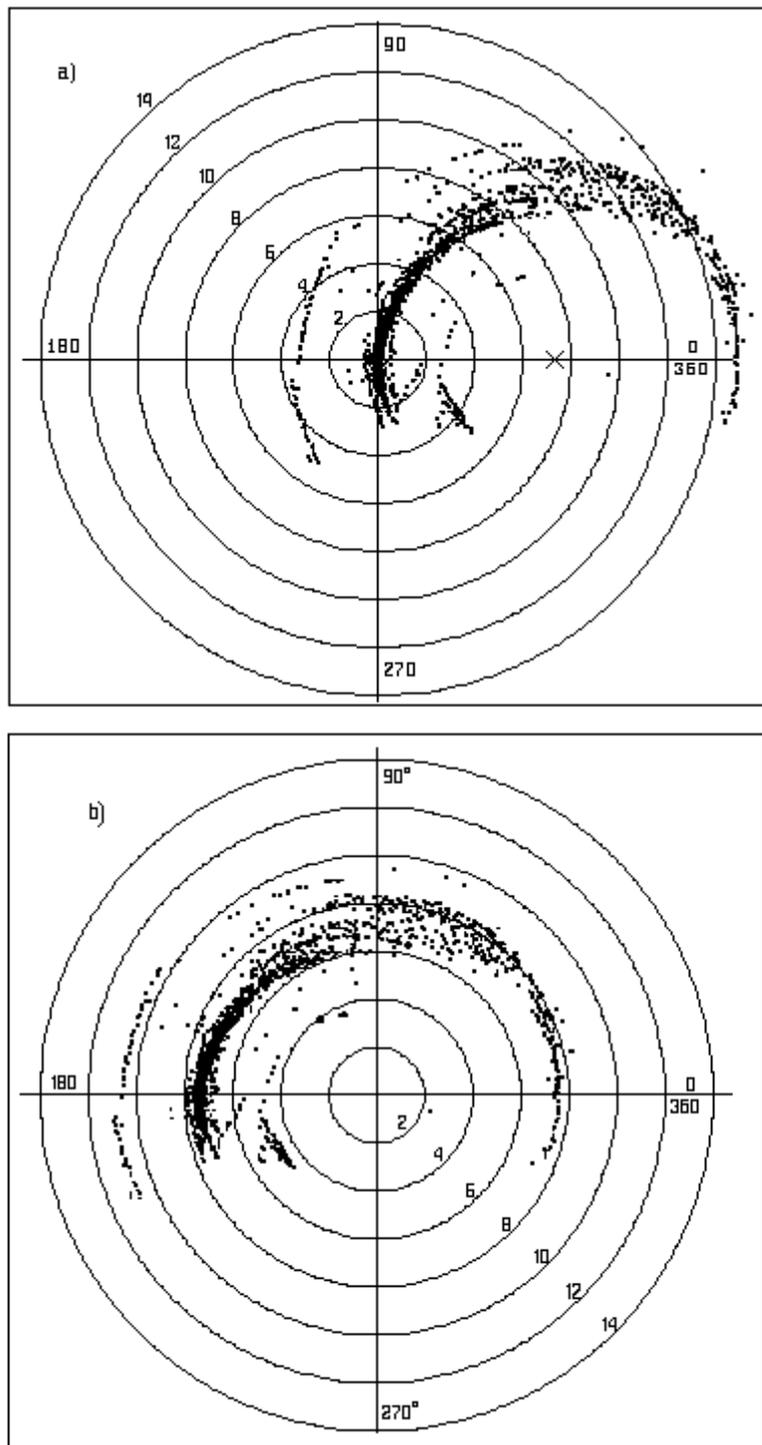


Figure. Evolution diagram "inclination - node":

- a) - relative to equatorial plane, (x on the horizontal axis means the Laplace' plane position)
- b) - relative to Laplace plane.

Inclination of orbital plane to the plane of equator put into the radius, node - into the polar angle. GSS' orbital life increase clock-wise. One can trace the main branch and its fine structure as some additional branches.

2. Analysis of photometric information

Let us dwell on the main theses which are the basis for photometric observations' analysis. The value of a luminous flux reflected from the satellite surface in appropriate range of wave lengths may be represented as, [*Sputniki planet, 1980*]:

$$E_{\lambda} = E_{\lambda}^{\ominus} \frac{a_{\lambda} S F_{\lambda}(\varphi)}{d^2} p_{\lambda}^{M(z)},$$

where p_{λ} and $M(z)$ - transparency and air mass of atmosphere; E_{λ}^{\ominus} - object's monochromatic illumination by the Sun; d - topocentric distance to the object; a_{λ} - its geometrical albedo; S - area of a visible part of sunlit object's surface; $F_{\lambda}(\varphi)$ - phase function.

This expression includes all components of object's visible brightness except for Earth's and Moon's illumination. The Earth's illumination is determined by a phase angle of the Earth in relation to the object and its altitude above a ground surface. The Moon's illumination is not very essential, but in a full moon and at a small lunar phase angle (i.e. angle Moon-object-observer) the reflection from shadowed elements of construction having high reflective abilities may essentially change an observable phase curve.

It is obvious, that such parameters as a_{λ} , S и $F_{\lambda}(\varphi)$ depend on the optical characteristics of coating, geometry and spatial orientation of the satellite. The values of these parameters are individual and they can characterize the observable object.

The variations of the object's brightness may be caused by three main reasons:

- proper satellite's rotation around the centre of weight and precession of spin axis;
- object's rotation around the Earth, which causes the change of the phase angle;
- temporary changes of the satellite's coating characteristics (aging of coatings).

It is simple to determine the orientation of object if there are specular bursts in its curve of brightness, [*Epishev, 1983*]. In order to reveal the latent periodicity caused by rotation of the satellite, it's necessary to calculate a power spectrum of observing temporal row at first stage.

To allocate the regions caused by the different elements of GSS' construction on the curve of brightness, it is necessary to use the information associated with their colour characteristics and changes of these characteristics [*Sputniki planet, 1980*]. It is possible to define a momentary direction of the normal to the reflecting surface of the satellite by the specular reflection, see [*Epishev, 1983*]. To determine it by diffuse reflection, it is necessary to know the dependence of the reflected flux value from the angle of fall. This dependence must be determined in laboratory conditions for known materials of satellite's coatings [*Kuryshv and Murtazov, 1986*] or for an object with the simple known form.

After determination of rotation's period and orientation, it is possible to calculate the value of geometrical albedo [*Moroz, 1967*] assuming that the reflection of the solar light occurs under the Lambert's law.

The majority of observable GSS belongs to non-self lighting objects in visual and near infrared area of spectrum. Therefore, the value of light flux reflected from the satellite depends on the characteristics of its coating. Those characteristics change during time under the influence of space conditions. The value of reflection's coefficients for exploitable materials of the coatings varies from 0.1 up to 1.0 in visual and near infrared area of spectrum. Therefore, the value of a_{λ} at the same law of reflection can vary from 0^m.1 up to 1^m.50 at the same law of reflection (*Moroz, 1967*).

In the process of calculation of albedo for known GSS it is necessary to know the geometrical dimensions of the object. It's necessary to interpolate an observable brightness to the zero phases also. Calculation of the GSS' brightness in the zero phases must be made using the diffusive component of the reflected light flux only.

The analytical expressions of phase functions for the majority of the simple stereometric forms are known [McCue, Williams, 1984], but their practical use is complicated by two basic reasons:

- in order to calculate the phase functions for the objects of the various forms (except spheres) it is necessary to know the satellite's orientation;
- the majority of satellites' bodies are the aggregate of several simple stereo-metric forms.

3. About use of auxiliary methods and some examples of identifications of "unknown" GSS

If there are no a priori assumptions the strict solution of the problem of identification is ambiguous or uncertain in a usual case. For example the initial ambiguity of the definition of the GSS' form by a curve of brightness is associated with the following principal statement: the input information is the function dependent on one argument (brightness from phase or brightness from time). And in the output we must receive a function of the form dependent on two arguments. So we are forced to use some auxiliary methods such as expert estimations, methods of the incorrect problems' solution, methods of the images' recognition theory or their combinations. The in-depth substantiation and description of these methods is conducted in our article [Didenko, Usoltseva, 2001]. And here we shall limit ourself to list those items of information, which can be useful for usage of auxiliary methods.

It is necessary to emphasize, that the number of types of the man-made objects is limited, and every concrete type has an individual set of the characteristics. It allows one to allocate the objects of the common type (i.e. type of the common functional purposes) among a variety of accompanied objects. It also allows to separate new objects and GSS moved from one to another stable point.

The procedure of identification includes the determination of a set of attributes which describe every given type of satellite with a certain probability. Such parameters are: the phase gradients, the geometrical albedo, effective reflection square, the relative coefficients of reflection and the periods of brightness' change.

The phase curve was approximated previously by the system of orthogonal functions consisting of the phase functions by the simple geometrical forms [McCue, Williams, 1984]. It allows one to accept the decision about the dominant form of the object.

The further representation of GSS brightness by E vector with components B, V, R (where B, V and R - the value of brightness in the appropriate filters) enables one to construct the three-dimensional "phase portrait". (If other parameters are included, the portrait will have more than three dimensions). The value of vector E depends on the reflecting ability of the coating. The form of the generated surface is connected with the constructive features by the changes of the color characteristics. Such a procedure allows to state the assumption about the type and the spatial orientation of GSS. While constructing a phase portrait of an object with the variable brightness, it is necessary to take into account the short-periodical component which is associated with the object's rotation. This component also contains useful information.

Our photometric database contains information practically for all known types (classes) of GSS and allows to create their so-called "phase portraits". The received phase portrait of an unknown object is compared to the characteristics available in database "standard" GSS, whose types are known. If the type of an object was not possible to identify, then the precision photometric observation of this satellite are made during half of a year. After that the "standard" of a new GSS' type is created.

The analysis of satellites' tables of launchings and other information shows that there are not any orbital data for some objects. More often these "unknown" objects are identified with satellites such as IMEWS, BMEWS and with launch vehicles such as Transtage or others. Now there are

about 100 such "unknown" GSS, which can be traced by optical means, 55 of them are involved in our catalogue.

Let's show some results of identification of such GSS. For example we have chosen the libration GSS designated as Unknowns 19,20,21 in our Catalogue. First of them was observed from the beginning of 1994, second - from 1991 and Unknown 21 - only from February 1999. They are quite old GSS and parameters of their orbits (inclination and node) lie on the right edge of the diagram's main branch. There are some known GSS whose evolutionary tracks are partially overlapped with tracks of selected unknown objects. The international numbers of those objects are 75123A, 76092F and 78073A. Comparing the positions of these six objects on the evolutionary diagram we can state that Unknown 20 and Unknown 21 were removed (or launched) into the geostationary orbit at the end of 1970 - beginning of 1971. Six unknown objects with known numbers and dates of launch are in that time's interval from [Jonathan McDowel, 2002]. It may be the following most probable candidates from these: for Unknown 20,21 - 71039A and 71039B (may be contrary), for Unknown 19 - 73040A or 73013A. All the other objects do not approach, because of inclination, guessed drift of a longitude or brightness; the analysis of the photometric information lower.

The photometric information for Unknown 19 and Unknown 20, obtained during last 5 years, has a large volume (more than 200 implementations). It represents the arrays of measurements with the $0^s.5-0^s.01$ step in time which are executed in three filters. The photometric system is close to a Johnson BVR-system. The accuracy of binding the array's origin to universal time is $0^s.01$.

The phase portrait of Unknown 20, with probability 99 % concerns a cluster describing objects such as IMEWS type. So it allows one to identify Unknown 20 as 71039A.

The identification of Unknown 19 was quite difficult and we could not identify it with any known GSS' types of our database for a long time. Character of brightness' change and equivalent area of reflection calculated under the standard factors ($30i^2$) allows to relate it to the Magnum type. We believe 73013A is the more likely version for Unknown 19, but we have not 100% confidence.

The photometric information for Unknown 21 has a smaller volume, but it indicates reliably enough that this object concerns the Transtage type. Comparison with the coordinate information allows to identify it with 71039B.

As another example we shall take objects designated as Unknowns 4,7,9 in our Catalogue. According to their orbital parameters these GSS belong to the left evolutionary branch of our diagram. The observations show that they are corrected, but the correction was carried out in the plane of orbit only, i.e. they have such evolution "inclination - node" as a passive GSS. As appears from the comparing of their evolutionary diagram's tracks, these three objects were put into orbit with an interval of 5-6 years. Unfortunately, we do not have any known objects in a left additional branch of the diagram practically, so there is no capability to execute the "absolute" binding in time. We can also contend that Unknown 4,7,9 were put into geostationary orbit not later than November 1996, February 1991 and April 1991 correspondingly, because we observed them from those moments.

Analysis of the available photometric information shows, that Unknowns 4,7,9 have a three-axis stabilization and reflection's areas: 85, 65, 75 i^2 (under the standard factors) correspondingly. Then the value of coefficients of reflection $\gamma_{(B-V)}$ и $\gamma_{(V-R)}$ show that April - July 1995 may be the approximate date of launch of Unknown 4. We can receive indirect confirmation of these dates, if we assume the next. The initial values of inclination and node of GSS put into orbit with parameters appropriated to left branch of the diagram, do not exceed $5^{\circ}.3$ and 240° as a rule. According to the first list (selected from [Jonathan McDowel, 2002]) among the objects launched in that interval of time only USA 110 (95022A) may have such optical characteristics.

Let us suppose that the identification of Unknown 4 is correct. Then it is possible to realize the binding of a scale of the diagram's left branch in time. In turn it enables to establish the approximate dates of Unknown's 7 and 9 launch. Character of brightness' behaviour and calculating

optical characteristics allows one to identify those objects as Magnum I (85010B) and Magnum II (89090B).

Of course all those conclusions, as well as any expert estimations, are not free from a considerable share of uncertainty and subjectivity. In spite of correct usage of observation information, the process of identification depends on the experience and intuition of the expert, in many respects, it is arduous and it yields to formalizing quite difficultly. Computer programs offer some variants of decision during the process of analyzing of information, but the deciding vote is an expert, and overall decision depends on his competence and experience. Nevertheless our practice shows that one can identify a majority of controlled GSS. The existing set of programs is under review in order to reduce the operator's interference in the identification process.

Acknowledgments

Authors thank their colleagues from Artificial Satellites Monitoring Laboratory and Closed Joint-stock Company "Institute of Radioelectronics" for the given opportunity to use the materials of joint observations.

Reference

- Agapov, V. (2001) *Novosti kosmonavtiki*, № 11, (in Russian)
- Bagrov, A.V., Smirnov, M.A. (1986) *Nauchnye Informatzii Astrosoveta*, 58, (in Russian)
- Demchenko, B.I., Didenko, A.V. et al. (1981) *Trudy AFI AN Kaz SSR*, 37, p.115, (in Russian)
- Demchenko, B.I., Didenko, A.V. et al. (1990) *Avtomatizatsija nabljudeniji podvizhnykh kosmicheskikh ob'ektov*, Alma-Ata, Nauka, p.160, (in Russian)
- Demchenko, B.I., Didenko, A.V. et al. (1996) *Zone catalogue of Geostationary satellites*, Almaty, Gylym, p.92, (in Russian)
- Didenko, A.V., Demchenko, B.I. et al. (2000) *Zone catalogue of Geostationary satellites Issue 2*, Almaty, Gylym, p.106, (in Russian)
- Didenko, A.V., Usoltzeva, L.A. (2001), *KAU Transactions №2*, Almaty, p.p. 83-91
- Epishev, V.P. (1983) *Astrometrija i Astrophizika*, 89, v.50, Kiev, (in Russian)
- Hernandez, C., Jehn, R. (2000) *Classification of geostationary objects*. Issue 2, ESOC, Darmstadt, Germany, p.89
- Jonathan McDowel (2002) *Geostationary Orbit Catalog* <http://hea.www.harvard.edu/~jcm/ space/ logs/geo/log>
- Kljuev, N.F., Kochelaev, Ju.S, Terekhov, V.K. (2001) *Algoritmy raspoznanija kosmicheskikh ob'ektov po rezultatam izmerenija ikh bleska* M., Geos, (in Russian)
- Kuryshv, V.I., Murtazov, A.K. (1986) *Preprint 6851-B86*. M., (in Russian)
- McCue, G., Williams, J.G. (1984) *Space Sci.*, 851, No.19
- Moroz, V.I. (1967) *Phizika planet*. M., Nauka, (in Russian)
- Powe, J. (1985) *Spaceflats*, 27, number 3
- Sochilina, A.S., Vershkov, A.N. et al. (1994) *Katalog uluchshennykh orbit neupravlyaemykh geostatsionarnykh ob'ektov*, 1,2, ITA RAN, St.-Petersburg, (in Russian)
- Sochilina, A.S., Kiladze, R.I. et al. (1996) *Catalogue of geostationary satellites* St.-Petersburg (in Russian)
- Sputniki planet*, (1980) M., p.207, (in Russian)