Photometrical database of GSS and methods of identification satellites on their photometrical characteristics

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ABSTRACT

The review shows the main ideas, methods of identification GSS with using multicolor photometric information. Listed photometric, optical geometric and dynamic characteristics used for identification. It is shown that the effectiveness of the researchers depends largely on the availability of a photometric Database. The Database should include a set of parameters, which are determined or calculated from photometric observations and unambiguously describe the individual characteristics of the observed object, or groups of objects of one functional class. Some examples are shown. A photometric Database is of commercial interest to interested organizations, since information on the status and behavior of a particular satellite can be presented to interested customers.

Key words: GSS, geostationary satellite, non-resolved signature, photometrical features, identification methods, Database.

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INTRODUCTION

In one article, not really describe in detail the methods of identification of the satellites, the role of the photometric database (DB). More details are described in the articles for which there is a reference.
Estimate the behavior of the space object (SO) in orbit, for the identification of an unknown satellite, to study Earth's atmosphere parameters the definition of the optical and physical characteristics of the GSS and other tasks even more often involved non-coordinate information; photometric, polarization, spectral. The role of such information may be the key in such cases.

- Geostationary orbit (GSO) has a high density of "population". Often, in a single orbital slot, there is a compact group of GSS performing one task. Satellite cluster have close to zero inclination to the equator and eccentricity. At present GSO maneuvering vehicles, fragments space debris.
- When the active state of the satellite is changed into passive, when the object is fragmented.
- To determine the **signs** of emergency operation of the satellite.
- On highly elliptical orbits, a difficult situation. Ballistic information on them is not enough. These orbits weakly controlled optical and radar ground facilities [1].
- The planes of the orbits of GSS, due to gravitational factors and light pressure execute oscillations relative to the equatorial plane with a period of 54 years, amplitude of about 15^0. To 2017 y. the old, passive GSS will go in the plane of the celestial equator. To distinguish the elements of the orbits of the new from the old GSS launched in 60-70 years will be difficult.

PHISICAL CHARACTERISTICS OF SURFACE SATELLITE

From official sources do not always know the physical characteristics of platforms, payloads, or they do not correspond to reality. But many characteristics of GSS can be defined from photometric observations. Magnitude m_λ satellite in the observed spectral range *(B,V,R,I)* mainly depends on three parameters: visible area reflecting the surface of the GSS - *S*, the reflective characteristics of the surface - γ_λ, and phase angle - ψ.

$$m_\lambda = F\{\psi, S\,\gamma_\lambda\}$$

From observations we can determine m_λ and calculate the phase angle ψ. Calculation of the spectral reflectance of γ_λ and the visible area *S* is probabilistic in nature and depends on many factors.
The dependence of the reflected light SO on the optical characteristics SO has the form:

$$m_\lambda = m_\lambda^\Theta - 2{,}5\,\lg\left[\frac{S\gamma_\lambda F(\psi)}{d^2}\right] \quad (1)$$

Where m_λ^Θ – is the magnitude of the Sun in a certain spectral range λ; γ_λ – is the spectral reflection coefficient; $F(\psi)$ – is the phase function; d – is the topocentric distance to the SO; $S\gamma_\lambda$ – is the effective reflecting area *(ERA)*. All value in the Eqs.1, except *ERA*, can be reliably measured or calculated from observations. $S\gamma_\lambda$ is a probabilistic variable. Incorrect determination of this value leads to errors in calculation of other physical characteristics GSS.

At the beginning of the 21st century, the main satellite systems remained the same as in 1980s. There is not much variety in satellite shapes; the design of their structures is changing quite slowly. The evolution is driven mainly in direction of improvement of characteristics.

Many researchers indicate the each class GSS can be constructive and dynamic features which appear on the shape of the light curve and have a characteristic appearance [2, 3, 4, 5, 6]. For example, the glare from the scanning mirrors, the period of rotation around the axis, the type of stabilization, platform type, size and power of solar panels, etc. These particularly on the light curves can appear regularly, or at a certain position "Sun-Satellite-Observer". These peculiar properties help to classify unknown satellite on the light curve.

The effectiveness of the researchers depends largely on the presence of a photometric DB at the observation point. The DB must include a set of parameters, which are determined or calculated on the basis of photometric observations, and uniquely describe the individual characteristics of the observed object: Physical parameter satellites can be conditionally possible to divide into three groups:

Photometric characteristics. 1) The effective reflecting area (ERA) - ($S_{\gamma\lambda}$). 2) The spectral reflectance index - *(γ_λ)*. 3) The phase coefficient - β *($\Delta m/deg$)*. 4) colour-indices - *CI, (B-V, V-R)*. 5) The magnitude - *m* reduced to a standard distance and phase angle (usually to $\psi = 0^0$ or $\psi = 25^0$).

Opto-geometric characteristics. 1) The GSS linear dimensions. 2) The prevailing shape of an object. 3) Size and power of solar panels and payload.

Dynamic characteristics. The period of rotation about the centre of mass or one of the axes. Instantaneous orientation in space, which defined by the normal to the GSS reflective surface that produces flashes. *X, Y,* Z - the vector components.

Photometric and opto-geometric characteristics can be determined from Eqs. 1. To calculate the ERA used analytically known phase function diffusion of a flat plate, or sphere, reflecting on the Lambert law. Our expertise [7] showed that ERA functions diffuse scattering plate and diffuse sphere on a height of 36 000 km is practically the same. Satellite orientations in space are determined by the method proposed by V. Epishev [8]. To determine the period of rotation has programs that use the Fourier transform, method Deeming, method Lafleur-Kinman.

EXISTING PHOTOMETRIC DATE BASE OF GSS

A database creating is a time problem and using a **single methodology** for determining the physical characteristics of SO. A DB should contain of a set of parameters, which are determined or calculated based on ground-based observations, and unambiguously describe its individual characteristics. They include the effective reflection area, the phase coefficients, CI, satellites periods of rotation around the center of mass, the precession of the axis of rotation, the shape of the light curve at the boundaries of the earth's shadow, etc. The following major photometric DB on GSS is known from publications.

1. DB Astrophysical Institute V. Fesenkova (A. Didenko - Almaty, Kazakhstan). It contains orbital information of more than 850 active and passive GSS no fainter than 15^m. These objects are located in the zone of visibility of optical point of the republic of Kazakhstan. For 210 objects has photometric information [9, 10, 11].
2. The Russian DB "Kosmoten" observation point. He has a few thousand light curves of many satellites classes **[12].**
3. Conducted photometric, spectral, polarization observations of different classes of satellites based on the AF USA - AMOS.
4. Beginning in 2004, compiled a DB of the Astronomical Observatory of I. Mechnikov Odessa National University (Ukraine). It contains about 1 000 light curves in the B, V, R filters more than 140 GSS of different classes. These active, passive satellites, large space debris to $14^m.5$ [13].

Odessa DB compiled by a) the name of the GSS, and b) the calendar principle. DB contains a text file data source, the light curves of the initial data. Each GSS have a description of the conditions of observation, azimuth, elevation, start and end of the observation, the scanning frequency, time of accumulation single of measurement, satellite periods of rotation, satellite sub-point, etc.

A typical GSS has a magnitude 11^m - 15^m, the brightest $7^m.5$ - 10^m. The transition to the standard photometric Johnson system took into account the extinction determined by Bouguer's equation. Practice shows that biggest error in the calculation of GSS features can make the right choice of calibration stars. The light satellite calibrated star of spectral type G2-G8 catalog WBVR of Sternberg Astronomical Institute, Moscow State University. It is convenient, because more evenly covers the equatorial area [14]. WBVR catalog contains 13 586 stars from 2^m - 11^m. It has homogeneous, systematically, and contains a large amount of stars with declinations to -14^0. Depending on the spectral class of stars mean square error the catalog is within $0^m.006$-$0^m.02$. Multicolor B, V, R photometric observations were carried on 50 cm, 70 cm and 1 m telescopes with high-speed photometer based on a photomultiplier**.**

KNOWN METODS OF IDENTIFICATION

Let's give a brief overview of the most common methods of identification of SO using photometric data used by CIS countries experts. In the CIS countries, methods of determining the dominant form satellites, the identification of the photometric features began to develop at the end of the 70's of the 20th century and have achieved significant results. Methods of identification of the GSS used by Western experts in the press are not given. Probably, they are in a development stage.

1. The method for identification of low and high-orbit satellites developed in Uzhgorod (Ukraine) by V.P. Epishev I.I. Motrunich, Y.M. Motrunich, I.F. Naybauer et al. - is based on the on the complex approach to problem solving. The photometric data must be used together with positional observation data and colorimetric and polarimetric measurements applied when possible. That allows of determining orientation of a satellite and individual fragments of its surface not only in space, but also relative to an observer and the GSS orbital plane. The authors developed nine criteria which enable to achieve 80% probability of unknown satellite identification even when there is no a priori information on the SO **[15].**

2. The colour-index *(CI)* of an unknown satellite's the key characteristic of the idea developed by A. Murtazov, N. Nosova, V. Kupriyanov (Ryazan, Russia), V. Prokof'eva (Crimean Astrophysical Observatory) et al. This *CI* is compared with *CI* of known types of SO. The phase coefficient β should be applied when there is no similarity between *CI*. Further, the comparison with mathematical simulation results for different geometric shapes is drawn and the scattered-field simulation is used [16, 17].

3. The methods by A. Didenko, B. Demchenko, L. Usoltseva (Astrophysical Institute. V. Fesenkova, Almaty, Kazakhstan). For each type of GSS, a reference photometric phase portrait database is created. The phase portrait of an unknown GSS is compared with the DB by certain criteria. When it is impossible to identify an object, a phase portrait of new GSS type is created for this object [12]. The identification procedure includes the following parameters: phase factor – β, geometric albedo, ERA, spectral reflectance – γ_λ, period of light variation. Apply methods of the theory of pattern recognition [18].

4. The method by M. Smirnov, A. Bagrov, V. Vygon et al. (Moscow) on based on the study of the scattered-field formed by individual elements of the satellite structure. Implementation of this method requires conducting GSS observations over a long period at different phase angles. The mathematical simulation is also applied. A. Bagrov also proposed carrying GSS spectral observations to estimate the chemical composition of the GSS coating surface [19, 20]. However, it is a sophisticated task to obtain a high-resolution spectrum of a faint GSS; maybe that is why the idea has not obtained a wide circulation.

5. A. Dobrovolsky, A. Korobko et al. (Odessa, Ukraine) have been exploring only preliminary stage of identification by light curves at which they are divided into two groups: non-periodic and periodic light curves. All the light curves are divided into two groups: non-periodic and periodic. Each group is divided into several subgroups. However, the accordance between the light curve groups and satellite types has not developed [21].

Which of the following methods is preferable? This depends on the availability of a priori information about the SO. It is understood that the solution of the Ill-posed problems of identification unknown GSS involving photometric data is a long complicated process. It requires additional information about the satellite. Such additional information can be the following: the satellite image, its dimensions, the launch site and date, orbit inclination to the equator, solar array power, nose-cone fairing dimensions, etc.

EXAMPLE FROM THE DATABASE

From the Odessa DB show the light curves of the GSS "DSP-18" "Fig. 1", and "SBIRS GEO 2" "Fig. 2" with the characteristic constructive and dynamic features peculiar to these classes of space vehicles. On the behavior these two GSS in orbit in more detail in [22]. Tac.- time of accumulation of a single measurement

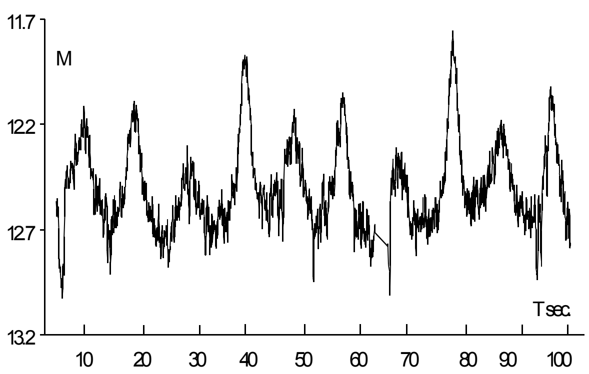

Figure 1. Fragment of the light curve GSS "DSP-18", V-filter, 29 Sep 2014. Tac. = 0.2sec

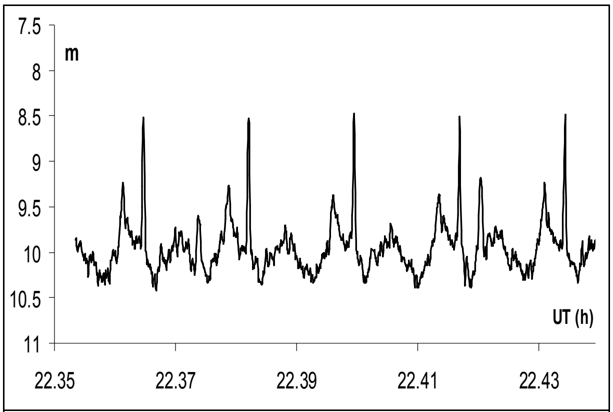

Figure 2. GSS "SBIRS GEO 2". V-filter, 29 Aug 2014. Tac. = 0.2 s.

"Fig. 3" shows a typical light curve for tumbling R/B "Milstar 5R".

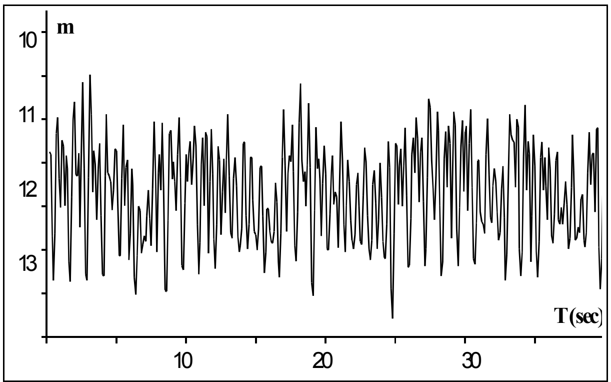

Figure 3. R/B "Milstar 5R". V-filter. 28 Aug 2014. Tac. = 0.1s.

On Fig. 4 shows GSS emergency early warning system "Cosmos 2397" (2003-015A). This satellite was launched into GEO on April 2003.

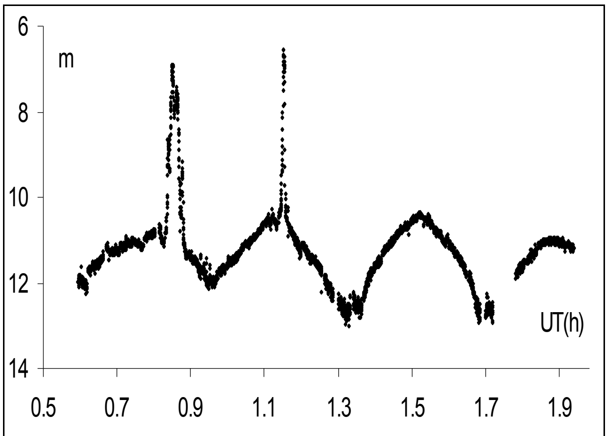

Figure 4. The light curve "Cosmos 2397" after exit from the shadow. 12 Sep 2004. Tac. = 2sec

After the satellite's exit to the GEO, it could not stabilize around one of the axes and began to drift. Calculation of orientation of components vector of a normal X,Y,Z to the flashing surface allowed assuming the following. There is a cone-shaped rotation of the device to solid angle about 5^0 rather components Y with the period about 18 minutes. It causes brightness change by amplitude near $3^m.0$ generally from solar panels [6].

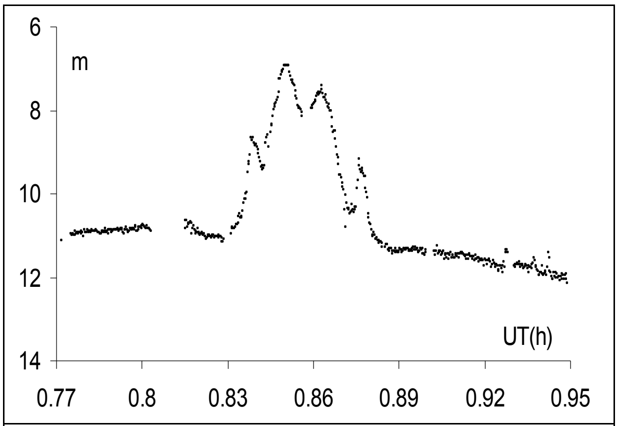

Figure 5. Detailed structure the first flash "Cosmos 2397". 12 Sep 2004. Tac. = 2s.

Mirror flashes of brightness were recorded on September 12, 2004 (Fig. 4) after exit from the shadow of the Earth. They show a fine structure, indicating the reflection of light from 4 solar panels "Fig. 5". But in the manufacturer's brochure this satellite has two solar panels!
In Fig. 6 and Fig. 7 shows the light curves of two military communication GSS "Sicral 2" and "Sicral 1B", perform one function.

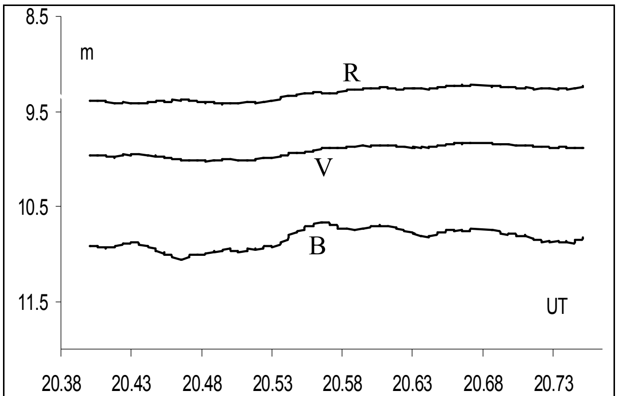

Figure 6. "Sicral 2", R – upper curve, V- mean, B – lower. 22 May 2015, Tac. = 1sec

GSS "Sicral 2" (2015-022B, launch date 26.04.2015, platform "Spacebus-4000B2"). The light curve "Sicral 2" was obtained; 2 months after the release of the sub point 37^0 E.
"Sicral 1B" (2009-020A, April 20, 2009, platform GeoBus "Italsat-3000") is deployed sub point on 12^0 E. This light curve "Sicral 1B" was obtained after 6 years of satellite output. The reflective characteristics of the satellite's surface have changed during this time. Due to the temporary degradation of the reflective characteristics and differences in the platforms of these

2 satellites; the effective reflection area, the phase coefficient, the color indices, and the magnitude are significantly different. This can be seen in the figures. Curves of color-index for 6 years after the launch GSS "Sicral 1B" confirm that the color-index of the satellite significantly changes during the first 3 years.

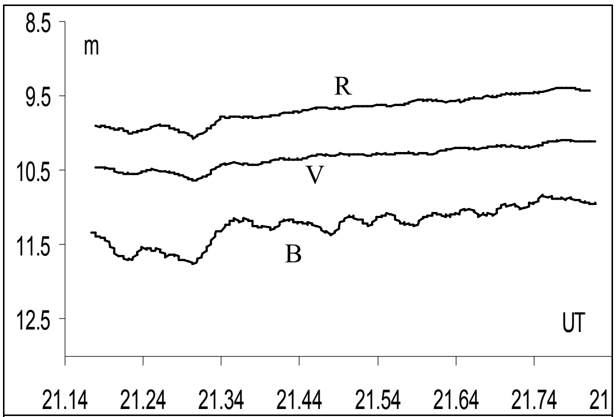

Figure 7. "Sicral 1B", R - upper curve, V-mean, B -lower. 22 May 2015. Tac.= 1sec

In Figure 8 the phases light curve of the satellite "Thuraya 2" when entering the shadow. Periodic low-amplitude changes in the brightness are visible. They increase in amplitude from $0^m.5$ ($\psi = 10^0.75$) to $1^m.0$ ($\psi = 10^0$). Such periodic low-amplitude changes in brightness are characteristic for tiny cell structure of a "fishing net" of the type. Such a structure has a 12.25 meter satellite radio antenna [25].

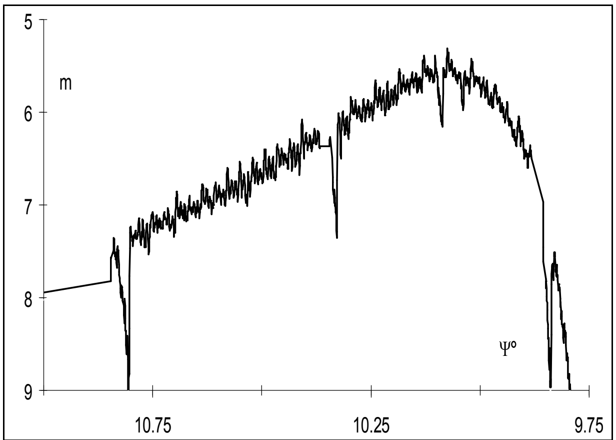

Figure 8. Phase light curve entry to the shadow "Thuraya 2", V-filter, 17 Sep 2014. Tac. =0.1sec

For different classes of GSS having the same type of platform, mean ERA - $S\gamma_\lambda$ and spectral coefficients - γ_λ are calculated. In Table 1, these characteristics are shown for only three types of platforms.

Table 1. $S\gamma_\lambda$ and γ_λ for 3 types of platforms.

Type platform	SP	γ_λ	$S\gamma_\lambda$, m^2 $\psi = 0°$
Eurostar 3000	B	0.18 ±0.02	17.58 ± 1.00
	V	0.34 ±0.02	32.44 ± 1.00
	R	0.22 ±0.02	20.26 ± 1.00
Eurostar 3000S "Skynet 5B, 5A"	B	0.14 ± 0.02	11.86 ± 0.50
	V	0.11 ± 0.02	9.74 ± 0.50
	R	0.12 ± 0.02	10.80 ± 0.50
GeoBus (Italsat-3000) «Sicral 1, 1B»	B	0.12 ± 0.05	5.41 ± 1.60
	V	0.12 ± 0.05	5.17 ± 1.60
	R	0.14 ± 0.05	6.22 ± 1.60

CONCLUSIONS

- Photometric DB, additional information, simplification of input data in solving the inverse problem, combined with orbital information allow modern methods, with a probability of up to 80%, to classify unknown SO [15, 23, 24].
- The own DB of the observation point helps to monitor the dynamic, physical characteristics of any SO, their temporal evolution in the GSO control zone.
- Analysis of the temporal evolution of the satellite's light curves, from the moment output into orbit makes it possible to draw important conclusions about the behavior of a SO in orbit, the transition to passive state, the process of defragmentation.
- It is possible to determine not only the periodicity of its motion around the center of mass, but also to reveal the features of the design and form of the SO.
- Using information from the DB on many GSS classes, it is possible to determine (find) a set of characteristics that can characterize a specific class of satellites.
- A photometric DB is of commercial interest to interested organizations, since information on the status and behavior of a particular satellite can be presented to interested customers.

REFERENCES

1. Molotov, I.; Konovalenko, A.; Agapov, V.; Sochilina, A.; Lipatov, B.; Gorshenkov, Yu.; Molotov, E.; Tuccari, G.; Buttaccio, S.; Liu, X.; Zhang, J.; Hong, X.; Huang, X.; Kus, A.; Borkowski, K.;Sika, Z.; Abrosimov, V.; Tsyukh, A.; Samodurov, V.; Falkovich, I.; Litvinenko, L.; Stepaniants, V.; Dementiev, A.; Antipenko, A.; Snegirev, S.; Nechaeva, M.; Volvach, A.; Saurin, V.; Pushkarev, A.; Deviatkin, A.; Guseva, I.; Sukhov, P. (2004). Radar interferometer measurements of space debris using the Evpatoria RT-70 transmitter. *Advances in Space Research*, Volume 34, Issue 5, pp 884–891.
2. Bagrov, A.V. (2007). Okolozemnaya astronomiya: issledovaniye iskustvennykh i yestestvennykh nebesnet tel v okolozemnom kosmicheskom prostranstve. *Disser.*

na Soiskaniye uchenoy stepeni doktora fiz.-mat. nauk. Moskva, 2002, p 98-106.

3. Tamara E. Payne; Stephen A. Gregory; Jill Tombasco; Kim Luu; Laura Durr. (2007). Satellite Monitoring, Change Detection, and Characterization Using Non-Resolved Electro-Optical Data From a Small Aperture Telescope. *AMOS Technology Conference,* p 28.
4. Payne, T.E., Gregory, S.A., Tombasco, J., Luu, K., Durr, L. (2007). Satellite Monitoring, Change Detection, and Characterization Using Non-Resolved Electro-Optical Data from a Small Aperture Telescope, *Proc. AMOS Technical Conference*, pp 441-454.
5. Frederick J. Vrba; Michael E. DiVittorio; Robert B. Hindsley; Henrique R. Schmitt; J. Thomas Armstrong; Paul D. Shankland, Donald J. Hutter; James A. Benson. (2009). A survey of geosynchronous satellite glints. Naval ObservatoryFlagstaff AZ, *Proc. AMOS TechnicalPapers*.
6. Sukhov, P. P. (2013). Particularity photometrical elected GSS on the small phase angles. *Dissertation of candidate degree on Physics and Mathematics sciences*. Odessa I. Mechnikov National University. Odessa, 104 p.
7. Epishev, V.P., Karpenko, G.F., Sukhov, P.P., Klabukova, A.V., Volkov, S.K. (2009). Opredeleniye effektivnoy ploshchadi otrazheniy i razmerov nekotorykh geostatsionarnykh sputnikov po krivoy bleska. *Okolozemnaya astronomiya-2009.* Sbornik trudov konferentsii, Kazan', 22-26 Avg. 2009, M. GEOS, p 87-92.
8. Epishev, V.P. (1983). Opredeleniye oriyentatsii INT v prostranstve po ikh zerkal'nomu otrazheniy. *Astrometriya i astrofizika* AN USSR, p 89-93.
9. A.V. Didenko; L.A. Usoltzeva. (2001). Methods of geostationary satellites' identification by the photometric information. *Transaction of the Kazakh - American University*, № 2, pp 83-91.
10. Demchenko, B.I.; Didenko, A.V.; Usol'tseva, L.A.; Bocharov, I.Y.; Afonin, A.N. (1996*). Zonal'nyy katalog geostatsionarnykh sputnikov*. Vyp. Almaty, Gylym, 92 p.
11. Didenko, A.V.; Demchenko, B.I.; Usoltseva, L.A. (2003). Zone Catalogue and Principles of Identification of Geostationary Satellites. *Fifth US /Russian Space Survaillance Workshop*. Sep 24-27, pp 316-324.
12. V. Vygonl V. Shargorodskiy. (2009). Catalog of Brightness Curves for Geo Space Debris. *AMOS. Abstarcts of technical papers*, p 21.
13. Sukhov, P.P.; Sukhov, K.P. (2015). About methods of identifying GSS from photometric characteristics. *Near - Earth Astronomy – 2015.* Proceedings of the International conference. 31 Aug –5 Sep 2015 г. Terskol, pp 286-290.
14. Kornilov, V.G.; Volkov, I.M. (1991). *Katalog WBVR-velichin yarkikh zvezd severnogo neba*. Pod red. Kornilova V.G.. *Trudy GAISH. T. 63*, M.,: Izd-vo Moskovskogo un-ta, 400 p.
15. V.P. Epishevl; I.I. Isaak; I.I. Motrunich; I.F. Naybauer; E.I. Novak; A.A. Tsikavyy. (2004). Identifikatsiya iskusstvennykh kosmicheskikh ob"yektov: puti resheniya. Sbornik trudov. *Okolozemnaya astronomiya-2005*, p267-273.
16. Murtazov, A.K. (2010). *Monitoring zagryazneniya okolozemnogo kosmicheskogo prostranstva opticheskimi sredstvami*. Ryazanskiy gos.univer. Im. S.Esenina. Ryazan' , 248 p.
17. V.I.Kuryshev; A.K. Murtazov. (1985). Fizicheskoye modelirovaniye poley rasseivaniya geostatsionarnykh sputnikov. *Nablyudeniya iskustvennykh nebesnykh tel*. AN USSR, p 28-32.
18. Didenko, A.V.; Usol'tseva, L.A. (2007). Ispol'zovaniye effektivnoy ploshchadi otrazheniya geostatsionarnogo sputnika pri identifikatsii yego tipa. *Izvestiya NAN RK, Seriya fiziko-matematicheskaya*. № 4, p18-24.
19. Smirnov, M.A. (1994). Fotometricheskiye nablyudeniya iskustvennykh nebesnykh tel. *Disser. na Soiskaniye uchenoy stepeni doktora fiz.-mat. nauk.* Moskva, p163.
20. Bagrov, A.V. (2002). Okolozemnaya astronomiya: issledovaniye iskustvennykh i yestestvennykh nebesnet tel v okolozemnom kosmicheskom prostranstve. *Disser. na Soiskaniye uchenoy stepeni doktora fiz.-mat. nauk.* Moskva, p 98-106.
21. A.A. Korobko, A.V. Dobrovolsky, Y.A. Medvedev. (1999). Numerical parameters of KO light curve determing its classification attributes. *Gamov memorial international conference*. Odessa, August 16-22, p122.
22. Sukhov, P.P.; Epishev, V.P.; Karpenko, G.F.; Sukhov, K.P.; Kudak V.I. Photometrical observations. (2015). "Sbirs Geo 2”. *Near - Earth Astronomy – 2015.* Proceedings of the International conference. 31 Aug –5 Sep, Terskol, p 281-285.
23. Douglas, A. Hope. (2014). A new approach to computing information in measurements of non-resolved space objects by the Falcon Telescope Network. Online at (as of 20 March 2017) h*ttp://www.amostech.com/TechnicalPapers/2014/Poster/HOPE.pdf*
24. Phan Dao; Elisabeth Heinrich-Josties and Todd Boroson. Automated Algorithms to Identify Geostationary Satellites and Detect Mistagging using Concurrent Spatio-Temporal and Brightness Information (as of 20 March 2017). *http://www.amostech.com/TechnicalPapers/2016/Poster/Dao.pdf*
25. Thuraya 2. Online at (as of 25 March 2017) *http://space.skyrocket.de/doc_sdat/thuraya-2.htm*