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RESEARCH ARTICLE

Analytical Studies for Photometric and positional observations of space debris

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Abstract

Results of optical observations of debris in the geostationary orbits (GEO) are presented. Observations were made on the two-meter telescope Zeiss-2000. The results of optical and photometric observations of small objects in GEO in 2013 were analyzed. Determination of space debris orbital parameters, area-to-mass ratios were performed using numerical-analytical theory of artificial near-Earth objects.

Introduction

The present stage of space exploration is characterized by an unworkable situation : the more spacecraft runs in Space, the less useful it becomes for the future use. The near-earth space blockage debris is approaching a critical level. [1]

More than fifty years ago, on June 29, 1961, there was the first explosion in space. The U.S. carrier rocket orbited Ablestar, one of the first navigation satellites -Transit 4A and two small satellites to an altitude of 800 - 1000 km. The mission was successful. But after 77 minutes, the rocket fuel tank exploded . A cloud of debris was observed at an altitude of up to 2,000 km . 300 large fragments were recorded and 176 still remain in orbit. [2]

During the same half-century space activities has become an integral part of the global economy, social development and security systems research. There is a global commercial industry with annual revenues of approximately $ 300 billion and millions of users of space services registered in 110 countries . The ISS project involves 16 countries with a budget of over $ 100 billion and in 2010 more than 60 countries had their own satellites..

Besides, in the same half-century a powerful unmanaged group of man-made space debris appeared. This group represents a danger for environmental safety and for the nature of near space as for the functioning of scientific, civilian and military spacecraft . Random collisions of fragments of space debris with current military spacecraft at any state could provoke a military conflict and this is a serious military and political consequence of debris in space.

Regulatory and legal documents on space debris

Pollution issues of near-earth space raised at the international level already in the 60s but it received the official status of the problem of space debris on December 10, 1993 after a report " The impact of space activities on the environment" issued by the UN Secretary General. The report noted that the problem of space debris is not only problems of individual states - participants in space activities , but also an international and global problem.

The main international legal document, "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies “, was issued in 1967. This treaty was the first to preserve the principles of international space law, including the principle of environmental protection, obliging the States to avoid corruption of the cosmos. [3]

In 1993, to make a formal international body, the only task of which was a comprehensive study of the problem of debris in near-earth space and development of measures to cancel out this process, the International Coordinating Committee on the issue of man-made space debris - Inter-Agency Space Debris Coordination Committee (IADC) was created. The organizers of the Committee were 4 space agencies - NASA, RSA , ESA and the Japanese NASDA. Now it includes the space agencies of 12 countries. Since 2001, this Committee has been an authoritative advisory organization of the UN Committee on the Peaceful Uses of Outer Space (UN COPUOS) on all technical aspects of space debris . The Committee regularly submits to the UN technical reports on the current state and debris of the near-earth space and proposals to reduce its rates. On the basis of these reports, the UN publishes its recommendations on the use of near-earth space. Before scientists and managers work involved in space activities, delivered a few basic tasks, the main of which are:

1. Detection of space debris. Study of its origin, physical and chemical composition , the parameters of its motion , the extent of the hazards to spacecraft and fall to the surface of the Earth;
2 . Development of methods and hardware systems for the purification of near-earth space from dangerous debris.

Currently, these issues are regularly discussed at both levels, the national level and the level of the UN. The most important areas of study of these problems are:

• identification and analysis of the risks to operational spacecraft, including manned ones, arising from the debris objects ;
• analysis of the status and control of the use of the geostationary orbit which is a limited natural resource, access to which is extremely important for communication, television, meteorological observations ;
• long-term analysis of the population dynamics of debris , including small-size fraction;
• analysis of space activities in terms of increasing the practical use of small spacecraft technologies and hidden operations in the near-earth space ;
• analysis of the implications of faint microsatellite systems.

These areas are the basis for the development of regulatory - legal documents.

At the 44th session of the Scientific and Technical Subcommittee of the UN Committee on the Peaceful Uses of Outer Space in 2007 it was recommended to approve a draft document " Guidelines on space debris ." This document was then adopted by the 62nd session of the UN General Assembly.

This document defines the following principles and regulations:

• limitation of the space debris during normal operations conducted in space;
• minimizing the potential for break- ups during operational phases (informed choice of safety components of spacecraft design , installation meteor protection units high pressure to prevent their natural breakdown and destruction;
• reducing the probability of accidental collision in orbit (to provide guaranteed withdrawal of space objects from possible collisions due to perform the necessary maneuvers) ;
• elimination of the calculated destruction ;
• minimizing the possibility of damage caused by energy reserve for post-mission ;
• limitation of the duration of the presence of spacecraft and orbital launch vehicle in the area of a low Earth orbit after the end of their mission (the disposal of spacecraft from orbit followed by braking and combustion in the atmosphere);
• limitation of the long-term presence of spacecraft and orbital launch vehicle in geostationary orbit after completion of their program of work (pulling to the burial area) .

To the same effect, proposals were made for creation under the support of the UN, international platform data about objects in outer space.

Characteristics of the elements of space debris:

From the very beginning of the space age, space faring nations were carried out over 5000 runs, resulting in about 30,000 of large space objects (larger than 10 cm) in the near earth space. Over the entire period of space exploration about 34,000 objects has been registered. More than two thirds of these are still in the orbit and controlled by means of ground and space observations .

At present, the Earth orbits (regular) conventional monitoring tools are controlled by about 20000 of space objects, 17500 of which were cataloged (catalog of USA). These space objects are larger than 10 cm and out of them about 4500 objects are larger than 1 m (model MASTER- 2001, ESA). Furthermore, in the U.S. there is a directory containing a 100 000 space objects which comprises smaller objects.

Now a little more than 800 spacecraft operate, which is less than 5 % of the total number of the cataloged space objects. The remaining 95 % - is a major space debris with a mass of 300 grams to 20 tons. The total mass of the space debris of this class exceeds 10 000 tones. [4]

Also space objects cataloged and regularly observed in the near earth space are huge number of small, but not less dangerous and usually not visible to radar and optical means, particles. According to the MASTER- 2001 model, the ESA, there are about 600 000 debris of 1 - 10 cm and tens of millions of particles of 0.1 - 1 cm and the number of smaller particles in the near earth space is calculated in billions and trillions .

The results of research professionals in Russia, USA , France, Germany, Japan contained in reports of IADC, indicate the progressive nature of the process of space debris . Analysis of the distribution density of objects in near earth space shows that the most problematic areas are orbits that are most heavily used to organize functional spacecraft at orbit altitude of 800 km, 1000 km, 1400 - 1500 km, the geostationary orbit (GEO). Highlight the area of manned space-orbit with a height of 350-400 km..

Space debris are all non-functioning satellites, rocket stages and their wreckage, rubbish bins and construction details (bird containers with garbage from manned spacecraft ceased in 1995, but a few hundred of these containers are still in space), fragments of explosions (there were about 200) and destruction. The largest contribution to the creation of groups of debris was made by the USSR - Russia, the U.S. and China while France, ESA, Japan and India added another 1-3 %.

Fig. (1) shows the change in the state of technogenic pollution of near earth space since the beginning of the space age to the present time (in large part, cataloged space objects) . Chart based on the data directory of catalog of USA. January 2014 The sharp jump in the number of detected and cataloged space objects attributable to 2007 , part of the ASAT test of China. Curve 1 (top) shows the total amount of space objects in the catalog, curve 2 - the number of fragments produced by the explosions and other damage, curve 3 - the number of spacecraft (both existing and faulty), curve 4 – space debris related to launching and operating satellites and spacecrafts , curve 5 - number of rockets .

Reducing the amount of debris on the orbits is possible by natural descent from orbit of space objects by braking in the upper atmosphere or by the disposal by special maneuvers or air braked.

Annual growth in debris of near earth space is 600 - 700 new objects larger than 20 centimeters.

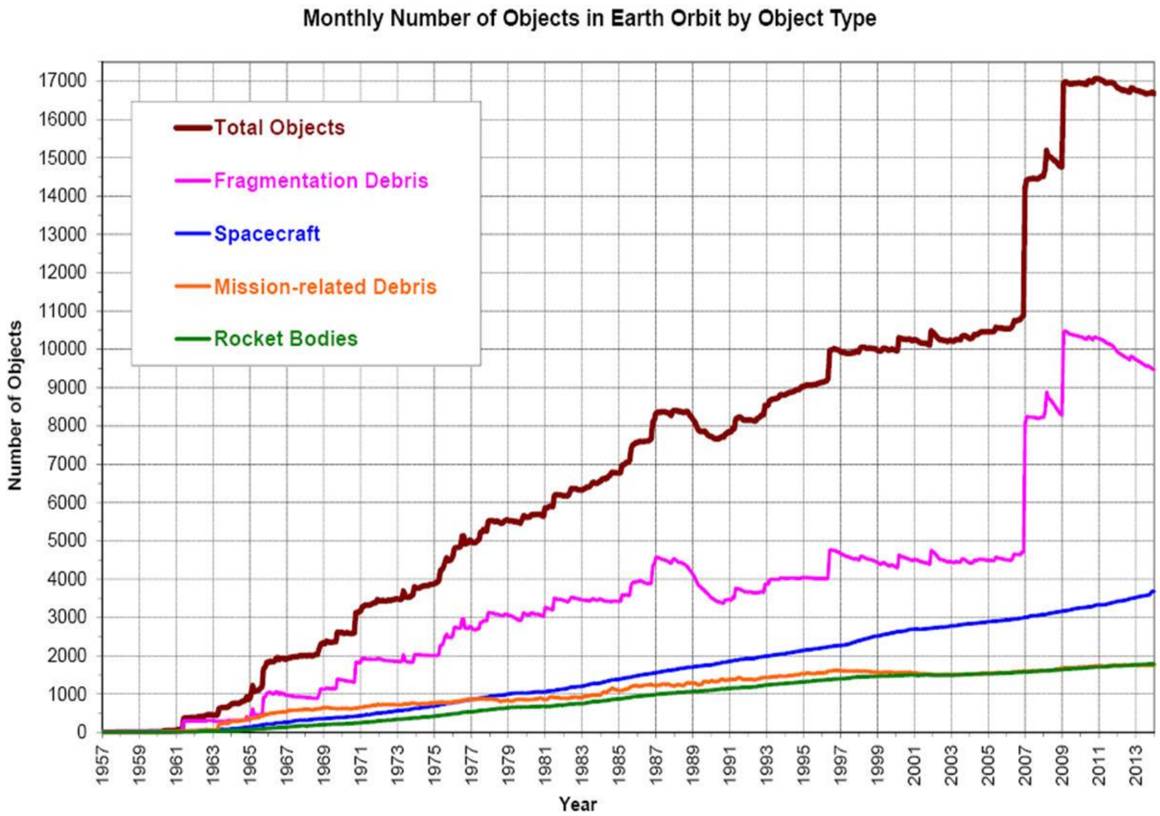

Fig . 1. Changing the status of number of objects of earth orbits from the beginning of the space age to the present time

Hazard analysis of generated debris in space and on Earth:

It is difficult to overestimate the dangers posed by the presence of debris in orbit . The following dangerous situations in the near earth space are related to debris :

• collision with existing space debris or space craft and finding them ;
• danger to the crew of the manned spacecraft collision with space debris;
• damage to the world with uncontrolled fall of bulky debris .

The main threat from the space debris perspective is the cascade effect (Kessler syndrome) is a rapidly growing chain of secondary debris objects in space as a result of the increasing number of collisions of space objects and the excessive density of space debris in outer space [5]. In this tragic phase of clogging up space debris acquires the aggressive nature. The cascade effect will lead to the practical impossibility of use of outer space, scientific, research, industrial, commercial, military, and other purposes. According to some authoritative experts in the field, the cascade effect has begun in part of the fines space debris.

A characteristic feature of space debris-a steady increase in the probability of collisions of space objects and the disastrous thing about a collision even with small MILES because of the gigantic relative velocity of spacecraft during a collision.

High probability of collision of functioning spacecraft with elements of space debris is forcing designers to resort to costly protection-shell. The space is much more mass than is necessary to accomplish the basic tasks of spacecraft, with the additional mass is itself eventually becomes contribution space debris.

The probability of collision with small space debris (<1 mm) now is almost equal to 1. This assessment is confirmed by the analysis of retrieved membranes aposteriornym Zemlûkosmičeskih crafts (Palapa, LDEF, Eureca , Solarwind and many others). After several years of being in space, , they contained flecked plurality of cavities and scratches left by tiny particles. Space platform LDEF stayed in Earth orbit more than 5 years, exploring the consequences of collisions fines space debris with structural materials. [6]

American shuttles have been hit. In the first 33 flights they permanently showed the damage of roofing tiles ablative coating. Eight times shuttles had to maneuver to avoid contact with the space debris. On average, after every two flights windows had to be replaced (there are 18 pcs.) due to serious damage to the small space debris. In General, small space debris significantly reduces the lifetime of the spacecraft. To parry this threat have increased structural panels to prevent penetration and destruction of spacecraft equipment. Risk of fines space debris is not so much in the mass of particles (which is due to insignificant small size), but in a the huge quantity, wide spread throughout the near-Earth space and high relative velocity at the moment of impact. In low orbits it can reach up to 14 km/sec or more.

As for large space debris , there is virtually no way to protect , except for protective maneuver to avoid a collision. There are some known evasive maneuvers. For example, in 2009 only spacecraft controlled by NASA had to make 8 maneuvers :

• January 27 "TDRS- 3" evaded "Proton " ;
• ISS 22marta dodged debris RN "CZ- 4";
• April 23 "CLOUDSAT" dodged the debris of " Kosmos -2251 " ;
• May 1 "EO- 1" dodged debris "Zenit " ;
• July 17 MCS - evasion of debris "Proton " ;
• September 10 Space Shuttle evaded KM to the ISS ;
• On September 29 "Parasol" (France) evaded the wreckage of " Fengyun " ;
• November 25 "Aqua" - avoiding the debris of " Fengyun - 1C" ;
• December 11 "Landsat- 7" evaded " Formsat -3D ."

There are many facts of collisions in space. However, collisions of large objects is fixed up a bit. For the first time, the clash, which led to the destruction of expensive existing spacecraft occurred June 24, 1996 when military signals intelligence SPACECRAFT of France "CERISE" faced with wearing PH Arian and ceased to function..

February 10, 2009 satellites provide global satellite communications facilities United States "Iridium 33" collided with the not functional Russian satellite Cosmos 2251 "with the formation of a large number of wrecks. It was the first time a collision of two satellites in space. The clash occurred on the territory of the Russian Federation (Taimyr peninsula over, above the point n, 72.5 97.4 degrees East longitude), at a height of 789 kilometers. The speed of both were roughly equal at about 7470 MPs. taking into consideration that was almost perpendicular to the trajectory, the relative velocity is about 10500 m/s. SATELLITE Cosmos 2251 "belonging to the space forces of Russia, was launched in 1993, and functioned until 1995. Iridium 33 ", one of 72 satellites satellite telephone operator Iridium, was launched into orbit in 1997 year. As a result of the collision both satellites were destroyed completely. The mass of American satellite Iridium was 600 kg and Russian apparatus "Cosmos-2251-1 ton. As a result of the clash was formed about 600 major wrecks.

Impact of technogenic pollution of circumterrestrial space clearly manifested in the operation of the international space station (ISS). In 2008, there were 246 dangerous approaches to ISS with elements of KM, including 41-in a so-called "red zone" (extremely dangerous). The ISS had to perform maneuvers to avoid clashes with the KM 1, on average once a year. Until now, the ISS has been able to avoid clashes by evasive action. In addition, it is impossible to predict the rapprochement with small, not catalogued space objects, which are also extremely dangerous for the ISS. Fall to the ground of large chunks of space objects after re-entry into occur repeatedly and caused great public interest. It is enough to mention such featured cases are falling on the ground fragments of the Cosmos 954 SATELLITE "with radioactive materials on Board (Canada) in 1978, the u.s. space laboratory Skylab in 1979, HIS" Cosmos 1402 "(with an on-board nuclear reactor) in 1983, the orbital station Salyut 7-Cosmos 1686" in 1991, the transport ship progress m-17 "in 1994, HIS" space "in 1995, 389.China FSW capsules of ran-1-5, the Russian spaceship "Mars-96" in 1996, etc.

International cooperation in space debris

The Russian Federation research related to various aspects of the dangers of space is conducted in many specialized institutes and enterprises. For coordination of research in this area with the Council_RAN on outer space established an expert working group on space threats "under the supervision of the Director of the Astronomical Institute of the RUSSIAN ACADEMY of SCIENCES corresponding member of RUSSIAN ACADEMY of SCIENCES B.m. SHUSTOV. [7]

The term " cosmic threat " refers to the problem of asteroid-comet hazard and debris . The expert group included experts from many academic institutions , universities, industrial enterprises and organizations.

Institute of Astronomy is working on issues related to the study of fragments of debris and its characteristics since the 80s of XX century. Currently, the work is being done in almost all the most important areas designated Committees IADC (see below) , namely, finding new pieces of debris, keeping motion parameters of cataloged fragments to study their origin, physical properties , the degree of hazard to spacecraft , as well as on maintenance of objects once they are enter the atmosphere.

INASAN takes an active part in the work on the International Program "Astronomy in the Elbrus region in 2006-2014 . ". Commissioned in 2004 Zeiss -2000 telescope mounted on Terskol at an altitude 3150 m is used in a wide range of scientific problems by scientists from Ukraine, Russia, Poland, Germany and other countries. Much of the time given to the observations of space debris, as will be discussed below.

In addition, observations on the subject of space debris are being done by INASAN employees at Zvenigorod observatory with a telescope Santel -500 and the telescope Zeiss -1000 Simeiz Observatory in Crimea.

The Space Debris Office coordinates ESA's research activities in all major debris disciplines. These include measurements, modeling, protection, and mitigation. It also coordinates such activities with national research efforts with space agencies in Italy (ASI), the United Kingdom (BNSC), France (CNES) and Germany (DLR). Together with ESA, these national agencies form the European Network of Competences on Space Debris (SD NoC). Agency expertise is mainly concentrated at the European Space Operations Centre (ESA / ESOC), Darmstadt, Germany, and the European Space Research & Technology Centre (ESA / ESTEC), Noordwijk, The Netherlands.

The debris team at ESOC have developed long-standing experience in the areas of:

• Radar and optical measurements and their simulation
• Development of space debris and meteoroid environment and risk assessment models
• Analysis of debris mitigation measures and their effectiveness for long-term environmental stability
• In-orbit collision risk assessments
• Re-entry safety analyses
• Space debris database issues

The debris team at ESTEC have a strong background in:

- In-situ impact sensor technology
- Vulnerability and impact damage analyses
- Hypervelocity accelerator technologies
- Hypervelocity impact shielding and protection

Since the mid-1980s, ESA has been active in all relevant research, technology and operational aspects related to space debris. [8]

The Inter-Agency Space Debris Coordination Committee (IADC) is an international governmental forum for the worldwide coordination of activities related to the issues of man-made and natural debris in space.

The primary purposes of the IADC are to exchange information on space debris research activities between member space agencies, to facilitate opportunities for cooperation in space debris research, to review the progress of ongoing cooperative activities, and to identify debris mitigation options.

The IADC member agencies include the following:

- ASI (Agenzia Spaziale Italiana)
- CNES (Centre National d'Etudes Spatiales)
- CNSA (China National Space Administration)
- CSA (Canadian Space Agency)
- DLR (German Aerospace Center)
- ESA (European Space Agency)
- ISRO (Indian Space Research Organisation)

- JAXA (Japan Aerospace Exploration Agency)
- NASA (National Aeronautics and Space Administration)
- ROSCOSMOS (Russian Federal Space Agency)
- SSAU (State Space Agency of Ukraine)
- UKSpace (UK Space Agency)

A Steering Group and four specified Working Groups covering measurements (WG1), environment and database (WG2), protection (WG3) and mitigation (WG4) make up the IADC.

This site provides information to the public about the IADC, its member agencies, and past and current debris-related activities. Furthermore, it is meant to act as a communication platform for the IADC member agencies. [9]

The NASA Orbital Debris Program Office, located at the Johnson Space Center, is the lead NASA center for orbital debris research. It is recognized worldwide for its initiative in addressing orbital debris issues. The NASA Orbital Debris Program Office has taken the international lead in conducting measurements of the environment and in developing the technical consensus for adopting mitigation measures to protect users of the orbital environment. The work at the Center continues with developing an improved understanding of the orbital debris environment and measures that can be taken to control debris growth. [10]

The Orbital Debris Quarterly News (ODQN) is a quarterly publication of the NASA Orbital Debris Program Office. The ODQN publishes some of the latest events in orbital debris research, offers orbital debris news and statistics, and presents project reviews and meeting reports, as well as upcoming events. Illustrating graphs, charts, photographs, and drawings support the articles and provide a detailed understanding of the topics. Each issue is available as a downloadable PDF file.

INASAN work within space debris in near space:

For over 40 years, Institute of Astronomy has been studying the process of space pollution of man-made debris . In addition, theoretical studies in INASAN are being conducted on intensive observation of space debris on the telescope Zeiss -2000 (Ø = 2 m , F = 16 m) and Terskolskogo branch INASAN telescope Santel -500 (Ø = 0.5 m , F = 1.25 m) Zvenigorod Observatory. Telescope Zeiss -2000 CCD Fli PL 4301 in the Ritchey-Chrétien focus (2084 x 2084 pixels, FOV = 12 x 12 arcmin) is mainly used to determine the physical characteristics of small fragments of debris within the international program "Astronomy in the Elbrus region in 2006-2014 years " [11]. Wide (FOV = 100 x 100 arc min) telescope Santel -500 equipped with a CCD detector FLI PL- 9000 (3056 to 3056 pixels) , was constructed and installed on a three-axis camera mount in Zvenigorod specifically for observation of space debris on high earth orbits and geostationary orbits. Tasks observations are:

1. Maintaining Russian catalog of space objects (debris)
2 . Search and discovery of new space objects
3 . Participation in international programs to support space objects in highly elliptical orbits before burning up in the atmosphere of the Earth.

Consider the advantages and disadvantages of these telescopes .

Telescope Zeiss -2000 has the sharp force to 22^{nd} magnitude in good nights (actually observed objects 21^{st} magnitude - is of size less than 10 cm at a distance of 40,000 km) with a small field of view of 12 x 12 arc min . During the night of observations in the field of view across several faint objects are not cataloged . Unfortunately, most of these objects are further lost because of the small number of large telescopes involved in observing programs of debris, and allocated to the observing time. Many pieces of debris have large brightness variations up to 5 or more magnitudes and a two-meter telescope is essential for the construction of a complete light curve of such objects. Example measured on Zeiss -2000 light curve is given in Fig. (2). This telescope is also important for the study of populations of certain regions of the small-sized space debris fragment .

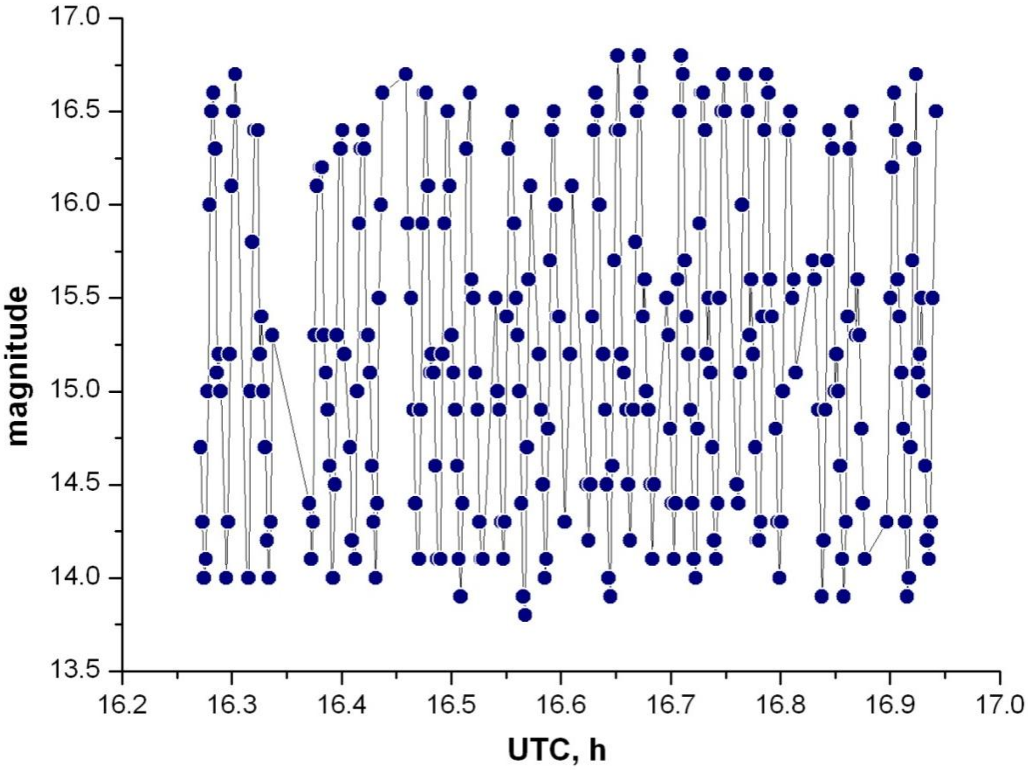

Fig. 2. Changing the brightness of the object 95633 observations at the telescope Zeiss -2000 Terskolskoy Observatory December 12, 2013

Telescope Santel 500 is relatively small but with wide tools. Main observational measurements being given to debris in highly elliptical orbit . Although the real penetrating power of this telescope is only 17 magnitude (in bad weather conditions and moon even less) for Santel -500 most of the cataloged debris objects (faint objects at maximum brightness) is measured. Large field of view offers advantages in search of the lost fragments of debris observations with inaccurately known ephemeris , as well as new not previously observed objects . For example, an unknown object was discovered and observed for a few nights in Zvenigorod

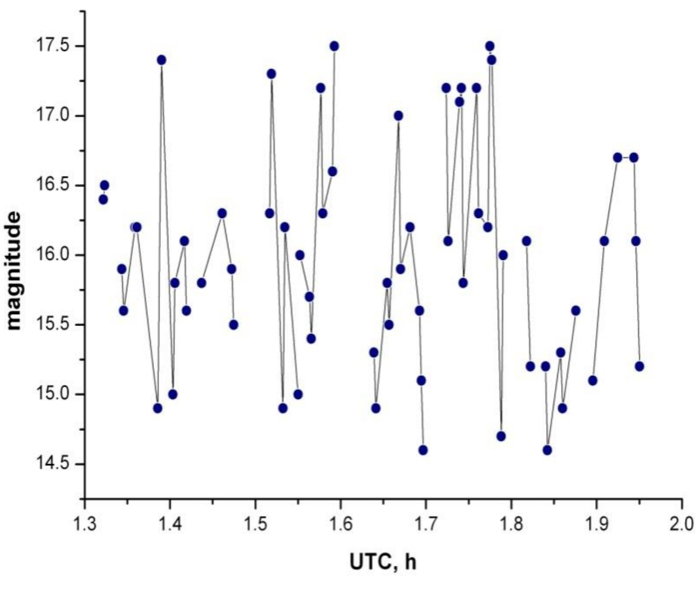

Fig. 3 . Changing of the magnitude of the object 95633 observed with the telescope Zeiss -2000- Terskolskoy Observatory December 16, 2013

Great dignity Santel telescope-500 is the fact that almost all of the telescope time allocated for observational study. In 2013, with the help of this telescope for 88 nights of observations conducted over 45 thousand coordinate definitions and assessments of shine more than 850 low-orbiting space objects.
Value telescope Santel -500 appeared and accompanied by falling objects such as " Molniya " on Earth.

Observation of satellites such as " Molniya " before they hit the dense layers of the atmosphere
In 2013, Zvenigorod Observatory - INASAN had useful observations of satellite "Molniya 1-92 " for 9 nights in March and April, received 740 object positions . Fig. 4 shows the residuals coordinates measured after improvement of motion parameters. Such observations are relevant for determining the time and place of the satellite falling to Earth. [12] Prior to that, there were successful observations of satellite "Molniya 3-39 " [13]

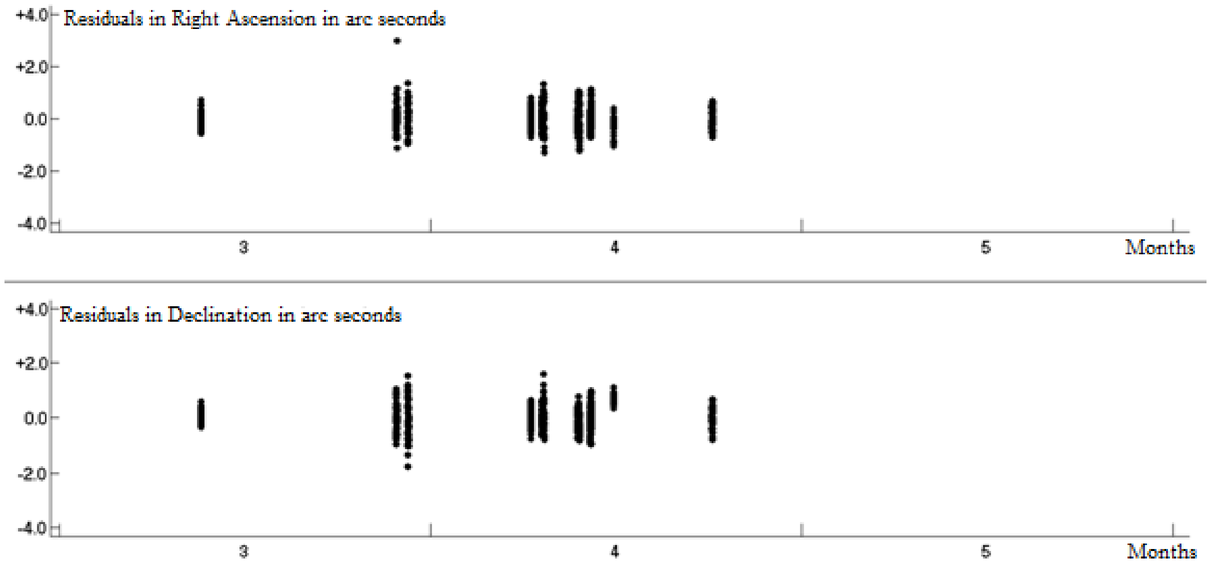

Fig. 4. Residuals coordinates measured of satellite "Molniya 1-92" in arc seconds from the observations in Zvenigorod - February-April 2013.

Satellite "Molniya 3-53" was observed during 13 nights in March, April and May 2013, received 496 positions.
Fig. 5 shows the residual deviation of the measured coordinates after improvement of motion parameters

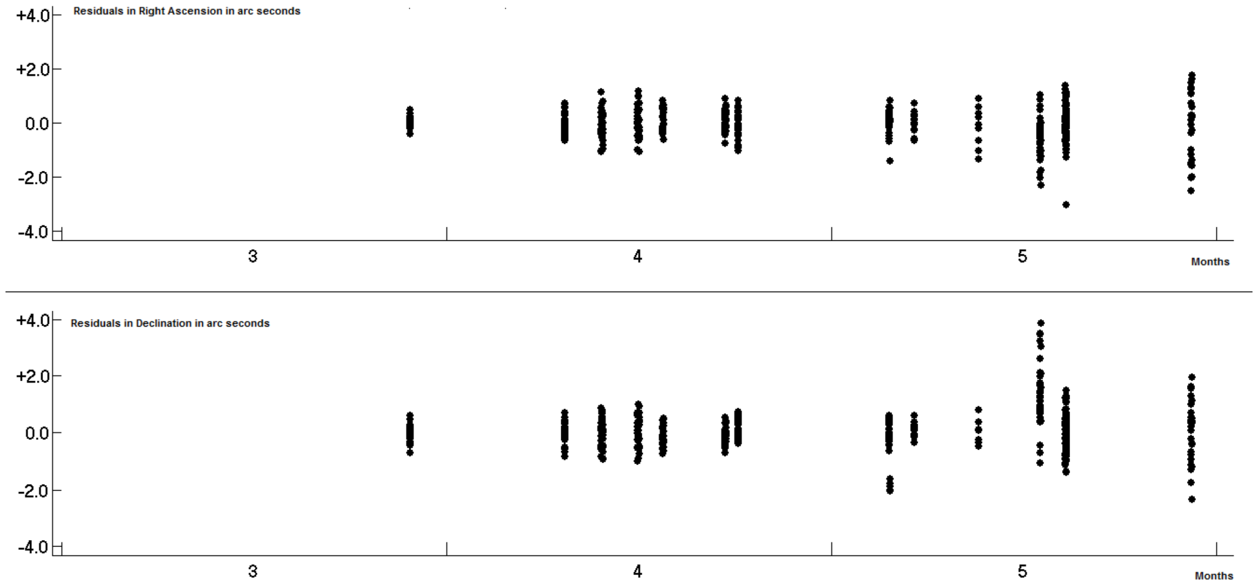

Fig . 5 . Residuals coordinates measured of satellite "Molniya 3-53 " in arc seconds from the observations in Zvenigorod March-May 2013.

It has been tested by the accuracy of determining the requirements for synchronous satellite observations with three points. On May 17, 2013 joint observation session of the object " Molniya 3-53 " was carried out with three observation points : Kitab, Nauchnyy, Zvenigorod. The total duration of observation was 2 hours . A total of 302 of the element. Improving the initial motion parameters based on observations showed that the mean square error of a single measurement is 1.5 " . Figure 6 shows the measuring residuals of three points obtained by the developed motion parameters.

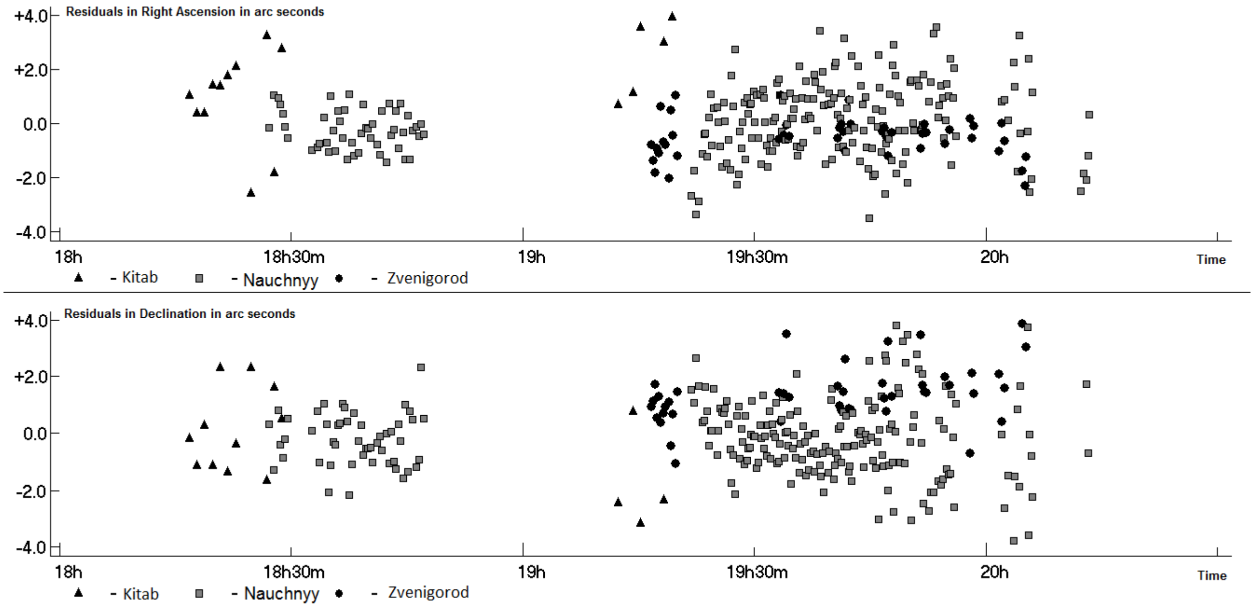

Fig . 6 . Residuals Observations of Molniya 3-53 in May 17, 2013 in arc seconds. Triangles marked observation Kitab , squares - Nauchnyy , circles - Zvenigorod .

Accompanying the launch of the satellite ANIK G1 in Zvenigorod:

In April 2013, Zvenigorod Observatory participated in the launch of the ballistic accompanied the satellite ANIK G1. April 15 at 22 h 36 min. Moscow time from the launch pad complex number 200 Baikonur cosmodrome launchers calculations of rocket - space industry Russia produced launch (ILV) " Proton-M" with the upper stage (RB) "Breeze -M" , dedicated to the orbit telecommunications spacecraft «ANIK G1» (Press Service of the Russian Space Agency) .

Despite the distant location from Baikonur to Zvenigorod, successful observations were conducted at three sites run trajectory. Traffic parameters are defined with the spacecraft propulsion stage and breakaway fuel tank with an accuracy sufficient for their subsequent maintenance on these flights and cataloging as space debris. [14]

Telescope Zeiss -2000 also held regularly accompany GSC launches from Baikonur and detected small-sized fragments (debris).

Conclusion

Experience of INASAN observations showed the applicability of different telescopes for debris research . Despite the participation of different telescopes of various observatories to study debris, observation posts for full studies are not enough. In particular, Egypt is not involved in the field of observations . It would be good to bring existing astronomical telescopes to such research, as well as the open items of observations with small telescopes in different areas of Egypt.

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