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Tasks and problems of near-Earth astronomy

L.V. Rykhlova*, P.A. Levkina

Institute of Astronomy, Russian Academy of Sciences, Moscow, Russia

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The study of the state of near-Earth space, which is a very broad field of astronomical science, is of great importance for astronomy, space exploration, ecology and the safety of life on Earth. Research into the population of near-Earth space as natural (meteors, meteoroids, space dust) as well as artificial objects (space debris) involves leading scientific institutions of the developed countries all over the world. International conferences and seminars on the topic are held regularly. The number of space debris objects continues to increase, the number of annual launches is increasing, collisions of objects in densely populated orbits with subsequent destruction are recorded, consequences of spacecraft explosions for various reasons are cataloged. To prevent destruction, to protect space activities, to find ways to clean up near-Earth space, to predict in advance the possible Earth approach by the asteroid, to take effective measures – this is an incomplete list of tasks facing scientists of future generations.

Keywords: near-Earth astronomy, space debris, optical observations

1 Introduction

In 1956, the Soviet government issued a resolution ordering the USSR Academy of Sciences to create a network of observational stations and organize the training of observers to track and monitor the then unknown space objects. The USSR Academy of Sciences entrusted the creation of the network to Academician M.V. Keldysh, and the direct responsibility was assigned to the Astronomical Council of the USSR Academy of Sciences in the person of Professor A.G. Masevich.

To accomplish this task, it was decided to use the astronomical instruments in possession of the system of the USSR Academy of Sciences as well as of higher education institutions. However, the telescopes available in large observatories proved to be unsuitable for tracking low-orbit space objects due to the high angular velocities of the latter. So, by order of the Astronomical Council of the USSR Academy of Sciences, small astronomical "satellite" wide-angle AT-1 tubes with entrance pupil diameter of 50 mm, six-fold magnification and a field of view of 11 degrees were created (see Fig. 1). In August 1957, it was ordered to report the readiness of the network for

*Email: rykhlova@inasan.ru

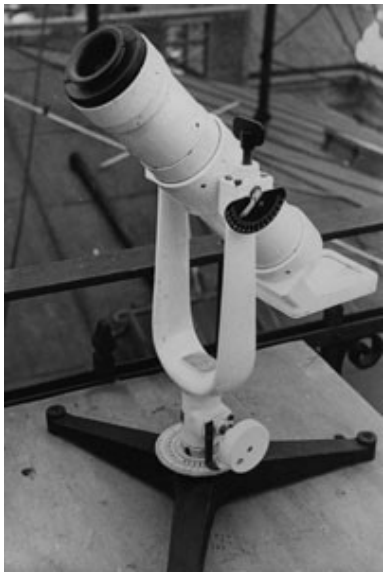


Figure 1 The astronomical tube AT-1.

the spacecraft flight control. By October 1, 1957, 66 stations on the territory of the USSR were ready to fulfill the task. Moreover, several dozen stations were located outside the USSR.

Although the observers had but a vague idea of the orbit of the launched "object", these simple optical observations enabled us to begin thereafter the development of methods for detection, monitoring and recognition of artificial Earth satellites. Figure 2 shows observers from Uzhgorod. In the center – the station director M.V. Bratijchuk.

In the years that followed, new satellites were launched, old ones ceased to give signals, and interest in them was lost, and over time, the orbital motion of previously launched spacecrafts became unknown. In addition, the upper stages of launch vehicles, the orbits of which were of no interest, accumulated in near-Earth space.

In 1961, the first explosion of the US Ablestar-series satellite carrier rocket stage took place, and in 1964, the first targeted explosion (controlled from the Earth) of the Soviet "Kosmos-50" satellite occurred. That was the beginning of the accumulation of useless objects in near-Earth orbits.

In the early 1960s, first, 45 Institutes of the Ministry of Defence, then the Space Monitoring Center and Space Surveillance System (SSS) were created for measurement data processing, orbit determination and tracking of large space objects. The SSS began cataloging space objects (SO), at first, using only optical observations made by universities and observatories. The work of this network was administered by the Astronomical Council (Astrosovet) of the Soviet Academy of Sciences (at present the Institute of Astronomy of RAS). For a sufficiently long time (before the introduction of specialized tools, for example, the optoelectronic complex "OKNO"), the ground-based network of academic and university observatories was the only source of measurement-data on space objects at different heights.



Figure 2 Observers from Uzhgorod. In the center – the station director M.V. Bratijchuk.

In 1971, on Zvenigorod base of the Astrosovet, the VAU camera (Maksutov satellite astronomical camera) for observations of space objects in high-elliptical and geostationary orbits was launched. In 2009, after the modernization of the observation equipment, the 50-cm telescope Santel-500 was installed on the VAU tracking mount. The measurements obtained with the Santel-500 are currently used to update the catalog of SO and are valuable in themselves, especially in the case of observations of high-orbit objects.

There is close cooperation between RAS and the 45 Institute in a number of new areas (space threats, space debris). To date, 95% of the SSS catalog objects are space debris objects.

2 The space debris problem

The term "space debris" (SD) is applied to satellites that have exhausted their energy resources, the upper stages of launch vehicles, various details accompanying the launch, debris of satellites which were destroyed for various reasons (including explosions, both accidental and deliberate). The term "space debris" was first introduced in the late 1980s by Walter Flury: "space debris – all the man-made bodies and their fragments in space, which are already faulty, not functioning and never will be able to serve any useful purpose" (Flury and McKnight, 1992).

At the beginning of the space age, no one thought about the possibility of industrial (technogenic) pollution of near-Earth space. Nevertheless, it has become a significant

negative factor in outer space exploration. There is a large uncontrollable group of man-made space debris that represents a danger to the environmental safety to near-Earth space, the functioning of scientific, civil and military spacecraft (SC). But, on the other hand, over the same years, space activities have become an integral part of the world economy, social development, security systems and scientific research.

Since 1957, all space powers have jointly carried out about 6000 launches and about 30000 large (more than 10 cm) artificial objects have been taken into near-Earth space (NES). Of these, more than 20000 are still in orbit.

Space control systems (at present there are only two of them – in Russia and in the US, the European SSS is in the process of creation) maintain dynamic catalogs of large space objects. Of these, less than 5% are active spacecraft, and 95% are space debris with a mass ranging from 300 g to 20 tons. The total man-made mass in earth orbits is about 10000 tons. Currently, about 21000 SO (larger than 10 cm) are tracked. According to estimates, the number of particles of 1–10 cm size is about 100000–500000, the number of smaller particles (0.1–1 cm) is estimated as tens and hundreds of millions.

With the development of the space age, in near-Earth space a new reality was formed – a population of artificial objects, which, on the one hand, opened up opportunities for scientific research of the Earth and space, and on the other hand, placed near-Earth space itself under threat. There is a danger now of stopping space activities completely.

Collisions and explosions of artificial devices in space lead to the formation of a great number of fragments and expansion of the region of space that they occupy. In 1978, D. Kessler published the hypothesis of "cascade effect" – in the case of debris achieving a critical density in some orbital region the process of formation of secondary fragments may begin. This effect is now known as Kessler syndrome (Kessler and Cour-Palais, 1978; Kessler, 1991).

3 Tasks and problems of near-Earth astronomy

The appearance of a new type of celestial objects of artificial origin led to the emergence of a separate branch of astronomical science – near-Earth astronomy. It can be considered as an intermediate between meteor astronomy which is the study of matter of the Solar System near and inside the Earth's atmosphere, and planetary astronomy, which is the study of matter of the Solar System outside the gravitation sphere of the Earth influence.

In the second half of the 20th century, the Russian academic medium has developed several scientific schools engaged in research of the laws of motion of objects in near-Earth space. The traditional approach to space debris research is based on the determination of the orbits of specific space objects and their prognosis. The orbital parameters of large bodies (more than 15–20 cm) are regularly checked by space monitoring systems or on the base of the orbital elements of selected objects obtained by individual observers. The number of smaller objects is estimated either by special space debris models or statistical estimates (Nazarenko, 2013).

The researchers of the motion of space debris rely in their work mainly on the classic works of G.N. Duboshin, who has developed the theory of motion stability and

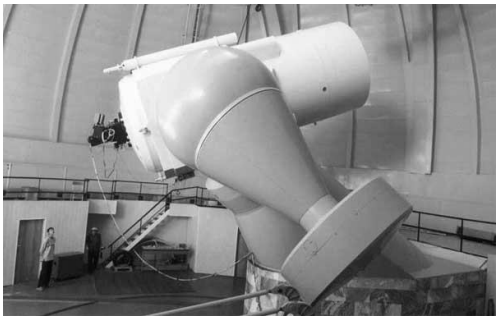


Figure 3 The Zeiss-2000 telescope of the Terskol observatory.

qualitative theory of differential equations of celestial mechanics (Duboshin, 1952; Duboshin, 1964); E.P. Aksenov (SAI MSU), who developed a complete analytical theory of the motion of the satellite, based on non-Keplerian intermediate orbit (Aksenov, 1977); Yu.V. Batrakov (ITA RAS) who has demonstrated the existence of relative equilibrium positions (libration points) for satellites of the ellipsoidal planet (Batrakov, 1957).

The launch of artificial Earth satellites in the geostationary orbit (GEO) was started in the 1960s. At present, geostationary satellites moving in exact commensurability with the rotation of the Earth have found wide application in telecommunications, intercontinental communication and others. The problems of solving the equations of motion of geostationary satellites, and, as a consequence, the possibility of predicting the motion of these satellites, are investigated in the works by A.S. Sochilina (Kiladze and Sochilina, 2008).

The tasks of near-Earth astronomy consist of the observations and cataloguing of fragments of space debris, modeling the situation at different heights of near-Earth space, taking into account the traverse by the Earth of numerous meteor streams, and identification of the most dangerous directions of arrival in near-Earth space of natural space objects (within the asteroid-comet hazard).

One of the most important tasks for the near future should be the control of the functioning of existing devices in space: determination of their shape, orientation and other characteristics in order to recognize their purpose, to develop a mechanism for controlling the peaceful use of outer space.

The practical task of determining the shape and orientation of space objects is being solved on the basis of photometric observations. This is very time-consuming work, requiring several nights of long-term observations during the entire period of the object visibility.

Designs of specialized satellites and special equipment were proposed (Grishin et al.,1997) for the observation of fragments of space debris in geostationary orbit.

Since the early 2000s, near-Earth space comprehensive studies are being carried out at the high-altitude astronomical observatory in the Elbrus region at the peak of Terskol (height 3150 m) with the help of the mirror telescope “Zeiss-2000” produced by the company “Carl Zeiss” (Yena) (see Fig. 3). The telescope is equipped with an automatic control system, standard scientific instruments, modern high-sensitivity radiation receivers and hardware and software for information support of astronomical

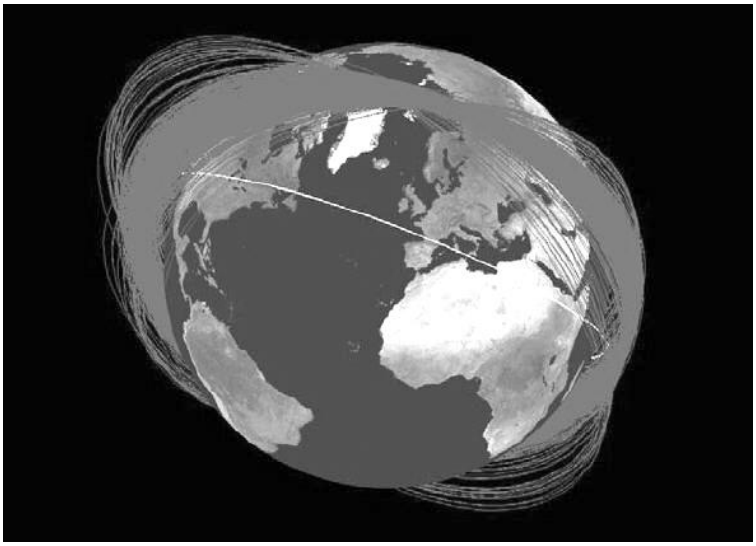


Figure 4 Orbital plains of Fengyun-1C fragments a month after the device breakup.

observations. One of the tasks is to detect and characterize small fragments of space debris that are difficult to reach by telescopes with smaller apertures. Research of space debris objects is one of the lines of the international program "Astronomy in the Elbrus region" (Yatskiv et al., 2016).

Space debris research at the Institute of Astronomy of the Russian Academy of Sciences, carried out using the Zeiss-2000 and Santel-500 telescopes, includes: regular observations of SD objects in high and high-elliptical orbits; the detection, tracking of new fragments and cataloging (in the catalog of the SSS); study of the motion (evolution) of small-sized debris under the influence of various disturbances; solution of applied problems, most of which are out of reach of the standard tools, such as: observation of spacecraft maneuvers, monitoring of launches, observations of gas emissions of active vehicles.

The evolution of the Earth's man-made environment cannot be accurately predicted because of the ever-increasing number of users (including commercial launches), the emergence of new technologies for the launch of small satellites and entire swarms of communication satellites (such as "Iridium"), and finally because of the uncertainty of future explosions and collisions of all these objects in orbits. The number and size of the fragments resulting from the object collisions depend on the mass and speed of colliding objects.

In 2007, after the disintegration of the meteorological satellite Fengyun-1C, the total level of pollution of the NES by known objects rose by 15% from the beginning of the year. The number of fragments > 5 cm in size exceeded 2000, the number of fragments of 1 cm and more was estimated as 35000. Figure 4 shows the planes of known Fengyun-1C debris a month after its disintegration in January 2007 (NASA, 2007).

Figure 5 shows the orbital planes of almost three thousand Fengyun-1C fragments at two years after the explosion (NASA, 2009a).

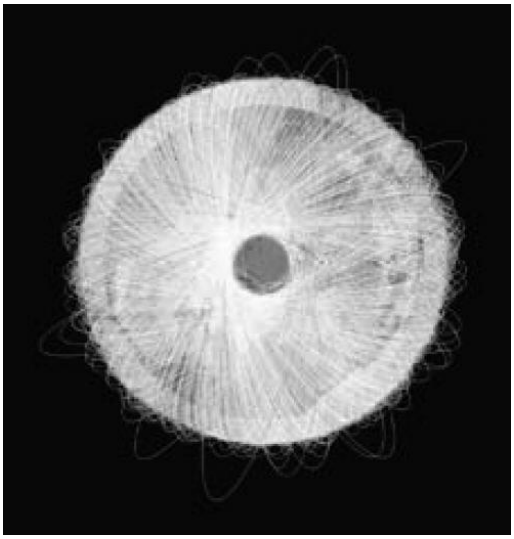


Figure 5 Orbital plains of 2800 Fengyun-1C fragments 2 years after the explosion.

4 The problem of space debris In Russia and on the international level

The questions of near-Earth space pollution have been raised at the international level as early as the 1960s, in particular, at sessions of the UNO General Assembly. The first official report on space debris was issued by NASA in 1981 (AIAA, 1981). In 1988, the report on the SD problem was prepared by the ESA (ESA, 1988). But the space debris problem acquired an official status only in 1993, when the International Coordinating Committee on debris in outer space (IADC) was established. The Committee was created by 4 space agencies: NASA, Roscosmos, ESA and NASDA (Japan). Now the space agencies of 13 countries have joined. Since 2001, the Committee has been an authorized Advisory body of the UNO Committee on the peaceful uses of outer space.

From the very beginning of space exploration in the USSR, satellite observation stations (the most Western of them located in Uzhgorod and Lviv, the most Eastern, in Yuzhno-Sakhalinsk and Yakutsk, the most northern one in Arkhangelsk and the most southern, in Ashgabat and Byurakan) were conducting regular meetings, training observers and exchanging experience. The first conference was held in Moscow in 1993, and at the same time the Institute of Astronomy of the Russian Academy of Sciences released the book "The problem of space pollution (space debris)" (Moscow, Kosmosinform, 1993) dedicated to the pollution of near-Earth space – the first such publication in the Russian scientific literature. The book editor Professor A.G. Masevich and the reviewers – Academician A.A. Boyarchuk and Professor V. Nesterov pointed out that the problems of outer space pollution by objects of artificial origin, the possibilities of modeling the evolution of the distribution of anthropogenic particles and objects, and also the problem of the evolution of high-orbit space objects under the impact of light pressure were being comprehensively addressed for the first time in the Russian scientific literature.

The development of these works, the problem of cataloging all of the observed objects, the identification of Russian and American catalogues of space objects, explosions and observations of small-sized debris in the geostationary orbit, the prospects for the development of optical observations, optical characteristics of fragments of SD modeling based on studies of the dynamics of the radiation force and other problems all became the topics of the next book "Collision in near-Earth space (space debris)", which was published in 1995 under the editorship of Professor A.G. Masevich (Kosmosinform publishing house).

The study, identification and evolution of artificial Earth satellites and a special set of fragments of space debris, from the very beginning of their appearance, were distinguished as an independent section of astronomical research. But the study of the behavior of small bodies of the Solar System: asteroids, meteoroids, comets – is also associated with their unexpected occurrences in the vicinity of the Earth's orbit and the threat that they pose not only to spacecraft but also to the entire Earth civilization. The methods of observation and research of natural and artificial celestial bodies located near the Earth can be combined into a General section of astronomy – near-Earth astronomy.

"Near-Earth astronomy and the problems of studying small bodies of the Solar System" (Moscow, 2000) – that is the title of the proceedings of the first conference on the subject of research of near-Earth space, which was held at the Obninsk Institute of Nuclear Energy. The conference gathered more than 70 participants and the meetings were held in two thematic sections.

In 2001, at the conference "Near-Earth astronomy of the XXI century" representatives of industrial organizations: TSNIIMASH, 4 TSNII MO, SIC-2, Center for Space Observations of Rosaviakosmos, NIIVT "Space", OKB MEI, KB Salyut, Khrunichev them., S.A. Lavochkin and others, actively participated, in addition to delegates from academic and university observatories and other scientific institutions.

Since 2003 up to now, international conferences under the general title "Near-Earth astronomy" are held every two years, in odd years, and based at different Russian institutions. In 2003–2017, the conferences were held twice at the invitation of Kazan State University (2005 and 2009, when the conference was attended by G.M. Grechko), Siberian State Aerospace University (2011), Kuban State University (in 2013 and in 2017), and three times in the Terskol (North Caucasus) on the base of the Terskol Branch of INASAN (2003, 2007, 2015). In the jubilee year 2007 – the year of the 50th anniversary of the launch of the first satellite and the beginning of the space era, the conference was attended by V.P. Savinykh, who gave an anniversary talk "50 years of space research". The important areas of fundamental and applied research to be carried out in the future were described, and the talk touched upon training and education of future users of space services.

The events of the last decade have slightly shifted the emphasis in the scientific program of the conferences. In 2011, for the first time, the proposed concept of creating a Russian system to countermeasure space threats was discussed, and many reports were devoted to the calculations of possible trajectories of the dangerous asteroid Apophis. And in the same year official information about the explosion of the fuel tank booster Ablestar (USA) in 1961 after the successful launch of the satellite Transit 4A was first published (NASA, 2009b). At that time, the existing orbital population of space debris numbered 54 objects and was replenished with three

hundred fragments of the Ablestar stage. The debris still exists and may be observed at altitudes of up to 2000 km.

The 2013 conference was mainly concerned with the phenomenon of the Chelyabinsk meteorite: the talks of the participants were devoted to theoretical studies of the trajectories of asteroid collisions with the Earth, the possibility of resonant returns. Several projects aimed at detecting and determining the parameters of Earth-hazardous asteroids and comets motion were presented.

In 2015, at the conference in Terskol the prospect of creation of the Russian segment of the detection and monitoring of hazardous celestial bodies was reported. For the first time the conference was attended by representatives of the MOE, who gave the talk "Anti-crisis management of forces and means of EMERCOM of Russia under the conditions of the asteroid-comet hazard".

The 2017 conference was dedicated to the 60th anniversary of the launch of the first Earth Artificial Satellite and the 20th anniversary of the conference "Near-Earth astronomy". The conference attracted 92 participants from 40 organizations from 6 countries.

5 Conclusions

The twentieth century proved to be, in a sense, a turning point in the character of man–nature interaction. The scientific and technological revolution, the surge in science and productive forces on the one hand, and the equally rapid development of the aggressive nature of the consumer society have led to the recognition of a number of problems faced by mankind. In particular, the environmental problem, the problem of natural disasters and technogenic safety, the problem of non-renewable resources, etc., and in addition – the problem of space debris, which reflects the changes that have occurred and continue to occur in near-Earth space. This is not only the continual saturation of the NES with new spacecrafts, but also the ever-growing population of space debris: the products of disintegration, breakup, collisions and other causes of destruction of artificial objects. Space debris has now become an integral part of the near-Earth space environment, and therefore this factor should be taken into account not only in the study of outer space, but also in the planning of any operations in space, including the design of spacecraft.

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