Research Article

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20 Years of Near-Earth Astronomy. Research into small bodies of the Solar System and space debris. How did it all begin

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Abstract: In this paper we retrace the course of near-Earth astronomy from its beginnings. We emphasize the problem of space debris, which has arisen somewhat unexpectedly, and only keeps on growing and growing. We also cast a glance over the conferences, held by our Institute biennially

Keywords: near-Earth objects, space debris, satellites, observations

1 How did it all begin

Back in 1956, one year before the launch of the first Earth's artificial satellite, the Soviet Government issued a special decree, commanding the Astronomic Council at the USSR Academy of Sciences (now Institute of Astronomy of the Russian Academy of Sciences) to set up a tracking network and to train the personnel therefor. Implementation of this task was made incumbent upon academician M.V. Keldysh and the Council's chairwoman professor A.G. Masevich. No dedicated satellite tracking facilities had yet existed anywhere, whereas the large astronomical telescopes could not track satellites due to their high angular velocities.

By October 4, 1957, 66 tracking stations, scattered all over the Soviet Union, were ready for the observation of 'something somewhere'. The westernmost were located at Lviv and Uzhgorod (Figure 1), the easternmost – at Yakutsk and Yuzhno-Sakhalinsk; the northernmost and southernmost – at Arkhangelsk (Figure 2) and Ashgabat, respectively. In general, the stations tended to be found on the premises of observatories or universities. During the summer of 1957 training courses were run at Ashgabad for the observers of the forthcoming satellite.

Figure 1. Uzhgorod station in Ukraine. Directress M.V. Bratijchuk surrounded by students.

In order to simulate its optical signature, a staff member, carrying a torch upon a pole, was striding downhill, whilst the trainees below were trying to spot a twinkle on the star background and to establish its location, using the recently procured AT-1 (Astronomical tube) monoculars. These had a 50 mm aperture, 6x magnification and 11° field of vision. 45 years later it will be written: "The AT-

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1 was the first optical instrument, designed especially for the observation of satellites. It can be rightfully considered the progenitor of all the subsequent, including the sophisticated OKNO (Optoelectronic complex for space surveillance).

Figure 2. The northernmost Arkhangelsk station, Russia Array of TZK (Zenithal Tube or Truba Zenitnogo Komandira) binoculars readied for observation.

A beacon, carried by an aircraft, succeeded that simple artifice, providing a far better imitation of swiftly moving across the heaven satellite.

A number of the stations had also been set up abroad, but all the tracking data were processed by the members of the Astronomical Council, using the computer power of the USSR Academy of Sciences.

2 The first scientific findings

The accuracy of the visual observations did not exceed 0.1° in space and 0.1 sec in time. No real science seemed yet possible with such low-resolution data - the sole objective of those initial observations was just to find the faintly gleaming man-made starlet in the celestial vastness, and not to lose it there again. Nevertheless, the first scientific findings came streaming in almost immediately. The satellites' orbital dynamics allowed for the estimation of thermospheric-exospheric density at 200-800 km altitudes and for the study its fluctuations due to the solar flares. The scientists were getting insights into the geomagnetic storms. This soon was followed by the discovery of the Earth's radiation belts.

3 New cameras, new visions, new objectives

In 1959, the Presidium of the USSR Academy of Sciences established in the vicinity of Zvenigorod city near Moscow an experimental station (now called Zvenigorod Observatory, (Figure 3)), which undertook development and testing of the new observational equipment and techniques. In 1961-62 Zvenigorod worked out the well-performing NAFA (Night aerial camera or Nochnoy Aerofotoapparat), and took its first 4000 images. Then, in 1965 appeared the famous AFU-75 (Astronomical Photographic Unit), designed by M.K. Abele at the Riga University. This camera had 736 mm focal length, 210 mm aperture and 10° × 14° field of vision, and easily could register the objects from 3 to 10 stellar magnitudes with 2 arcsec angular and 1 ms temporal resolution. AFU-75 became the prime instrument of satellite photography in the Soviet Union. The one at Zvenigorod has taken over 10000 images of various satellites.

Figure 3. The Zvenigorod Observatory.

In 1964, Zvenigorod began construction of a new pavilion for VAU (Vysokotochnaya Astronomicheskaya Ustanovka) – high-precision astronomic camera for satellite observations, which came online in 1971. This camera surpassed all current competition, including the American Baker-Nunn model, and could already look into the highly-elliptical and geostationary orbits. Then became available the high-sensitivity television equipment and laser range-finders, capable of pinpointing satellites at up to 20000 km altitudes.

Many other observatories in the USSR and Eastern Europe relied upon the German-made SBG (Satelliten Beobachtung Gerat) cameras, which, in addition to satellite tracking, collected large amounts of ephemeris data, and proved of use to geophysics. Over the years the satellite imaging gave way to laser ranging.

The advent of the intercontinental ballistic missile had also given a tremendous impetus to the development of radar satellite tracking – quite accurate, daytime- and weather-independent. Both USSR and USA deployed the vast early-warning radar networks. The current technology can spot 10 cm objects in the geostationary orbit, and offers many opportunities to science.

In the 1960s, the rapid exploration of the near-Earth space entailed the need for its effective monitoring. The upper stages of the launch vehicles, dead satellites and their fragments began endangering the piloted spacecraft. Accordingly, in 1964-66 the Soviet Union set up a reliable Space Monitoring System, which Centre assumed control over the observational assets nation-wide. The Astronomic Council actively cooperated with the Centre from the beginning.

In 1984, the Military-Industrial Commission at the USSR Council of Ministers mandated the establishment of the Ground Optical Observation Network, which integrated the observational capabilities of the astronomical observatories across the Soviet Union still further. The network's tasks included:

- spacecraft detection in the geostationary and highly-elliptical orbits;
- spacecraft tracking in high orbits, spacecraft insertion monitoring, monitoring of the malfunctioning spacecraft;
- data gathering in the defence research.

All problems, encountered by the observers, were being solved at the brainstorming sessions, held regularly on the invitation of one observatory or another.

The swift advances in the satellite technology began entirely new sciences and novel fields within the old. Thus, there emerged the space geodesy, which made possible the measurement of intercontinental distances with very high precision. In addition, the global satellite positioning systems GPS, GLONASS, later Galileo and Compass have brought about an amazing increase in the accuracy of spatio-temporal measurements both on the ground and in the near space.

4 What is "space debris", whence it comes?

Now, we turn our attention to the space debris. The very first artificial satellite, once it had run out of power, became the father of space debris. The year 1961 was marked not only by the first manned spaceflight, but also by the first recorded spacecraft fragmentation: the Ablestar booster, having inserted into a polar orbit Transit 4A – one of the earliest navigation satellites – exploded 77 minutes into the flight in an 800 by 1000 km orbit, scattering a cloud of fragments at up to 2000 km altitudes. A lot of them still swarm out there, but the acknowledgement of their genesis was published only in 2011 – no less than half-a-century after the event.

The term 'space debris' was coined by Walter Flury in the late 1980s (see (Flury 1991)). Space debris, in his words, is the totality of the dysfunctional artificial space objects and their fragments, which have no use and never will.

The first official report on the growing problem of space debris was issued by NASA in 1981 (NASA 1981). ESA (European Space Agency) extensively reviewed it, too, in 1988 (ESA 1988).

In the Russian scientific literature the first space-debris compilation appeared back in 1993 (Space Debris 1993). Its editor – prof. A.G. Masevich, remarked that "it is for the first time that Russian scientists discuss the theoretical and practical aspects of near-earth space pollution with the artificial objects".

The next compilation followed in 1995 (Space Debris 1995) which for the most part, was devoted to orbital collisions and their forecast, and to the influence of solar radiation and its pressure (Yarkovsky effect, Poynting-Robertson effect) upon the small celestial bodies, which, by and large, determines their destiny.

The third compilation (Space Debris 1998) saw light in 1998 which already treated the artificial and natural objects under the separate chapters.

Each compilation drew on the proceedings of a preceding scientific conference. The abstracts from the first were published in the "Orbital Debris Monitor" of April 1992. V.5(2) P3 under the caption: Technogenic Space Debris: Problem and Directions of Research. Moscow conf., whereas the proceedings of the second conference in part appeared in the "Space Forum" almanac. V.1. Overseas Publishers Association. 1996.

In the first half of 1990s, we (Orbital Debris Quarterly News 2011) formed a fruitful partnership with Darren McKnight and Nicolas Johnson, who represented Kaman Aerospace Corporation and, since 1988, published the "Orbital Debris Monitor". Since 1996 "Orbital Debris. Quarterly News" is available online at http://orbitaldebris.jsc.nasa.gov/.

Discussion turned around the National Asteroid Hazard Mitigation Program 2012-2020. Many reports addressed the hazardous Apophis asteroid, making projections of its orbit and estimations of its earth collision probability. Quite naturally, the observational technology again had been on everybody's mind.

"The Near-Earth Astronomy-2013" worked on the base of the Kuban State University in Tuapse, and its proceedings were published in the Ecologic Courier, circulating among the members of the Organization of the Black Sea Economic Cooperation. Chelyabinsk meteor dominated the discussions. New theoretical research into the NEO impact trajectories and resonant returns as well aroused lots of interest. The practical side put forward the Firmament NEO identification and tracking project, the Stereoscopic Orbital Observatory project, and the Coordinated Observation of the Hazardous Celestial Bodies program.

The "Near-Earth Astronomy-2015" conference at Terskol was for the third time organized by the Institute of Astronomy jointly with the International Centre for Astronomical, Medical and Ecological Research. Most of the reports dealt with the comets, asteroids, their observation and theoretical studies. Chelyabinsk meteor again did feature prominently. The participants also discussed the prospects and problems of setting up the Russian segment of the prospective global NEO monitoring system. Two contenders – the Firmament and the Space Barrier – emerged as the most feasible. For the first time the conference had been attended by the representatives of the Russian Ministry for the Emergency Situations, who delivered a report, entitled The Anti-Crisis Management of Ministerial Assets and Capabilities in the Face of Asteroid Hazard.

The "Near-Earth Astronomy-2017" evaluated the results of photometric observations of various spacecraft and debris by the new 1.6 m AZT-33 VM telescope (Astronomical reflector telescope) within the first two years of its existence. This telescope of the Sayan observatory, affiliated to the Irkutsk Institute of Solar and Terrestrial Physics, does also make space debris surveys. Under review then came the latest draft proposals on a spacecraft mission to the selected main-belt asteroids, advancements in asteroid hazard mitigation, and other topics.

5 Conclusions

The scope of near-Earth astronomy today includes all natural and artificial objects in the Earth's vicinity, as well as those traversing it. Some of these NEOs pose a real Earth collision hazard. Their detection at 90% probability requires the constant monitoring of the entire celestial sphere. However, the changing weather and the solar glare disrupt and limit the ground-based monitoring sessions, thus necessitating the use of spacecraft-borne instrumentation in the future. It would also improve space debris tracking.

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