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Creation and development of domestic scientific and educational space infrastructure and its use as a tool for ground-based and space astronomy

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Abstract. An overview of current advances in the use of small spacecraft for astronomical research and space education is provided. Existing projects, their goals, achievements and plans for implementation are reviewed. The current results of the authors in creating a scientific and educational digital platform for research and educational space activities are presented.

Keywords: space vehicles, site testing, instrumentation: miscellaneous

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1 Introduction

Technologies are becoming more and more accessible. Today in Russia there are programs that allow scientific and educational organizations (universities and schools) to launch their own small spacecraft. These satellites, having a small size and standardized shape, make it possible not to spend large amounts of money on a mission, while at the same time they have great potential for conducting serious scientific experiments and research. An example of this is the scientific results obtained from dozens of small satellites launched by organizations in different countries in recent years. In addition, projects are being developed in the ground segment, which, with the right approach and connection with space technologies, can create a unique research and educational infrastructure in the world for the development of methods for various astronomical activities.

2 Small space technologies

The first spacecraft, which were launched in the 60–70s of the last century, weighed more than one ton, and were used for a seemingly simple task: photographing the earth's surface from space.

With the rapid development of microelectronics, it became possible to create lighter satellites, and the number of tasks performed by one device increased. In 1999, a satellite format called CubeSat was invented. Its goal was to reduce the cost and time of satellite development and increase the availability of launches.

One of the important requirements for this format is the monolithic structure of the spacecraft, i.e. a CubeSat cannot contain detachable parts. This condition makes it possible to reduce the formation of space debris in Earth orbits. Another important condition for the CubeSat configuration is that it is prohibited to install explosive devices or tanks with explosive substances, as well as tanks under a pressure of more than 1.2 atmospheres, on board the device. This limits the range of possible equipment (primarily propulsion systems), but it creates the possibility of launching devices from the International Space Station without a threat to the crew. This launch scheme is considered promising in light of the ease of manufacturing devices, the developing technology for creating satellite formations and the regularity of launches of transport spacecraft to the ISS.

Figure 1 made by Erik Kulu (Nanosats[1] database) shows launch statistics by type of organization responsible for the satellite. Significant increase in recent years is present. Despite the fact that the majority are commercial satellite networks, the

[1] https://www.nanosats.eu

number of scientific and educational equipment on nanosatellites does not cease to grow from year to year. This can also be evidenced by the large number of publications on the results of experiments carried out on small satellites in recent years.

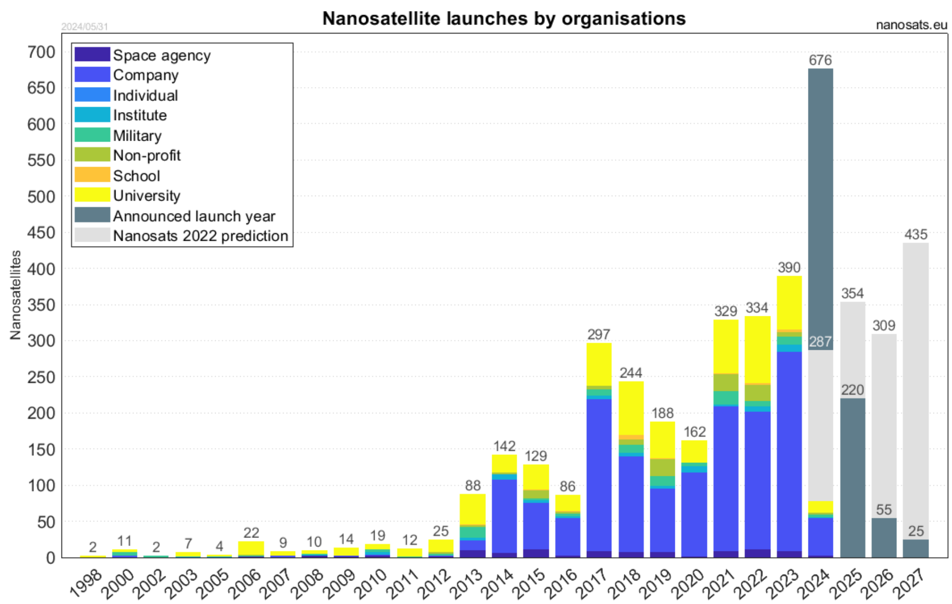

Fig. 1. Number of CubeSat launches by organizations.

For example, in Bogomolov et al. (2022) Moscow State University has shown the development of a project for a multi-satellite constellation designed to monitor cosmic radiation. A number of small satellites of CubeSat format by the institution were launched into selected orbits crossing the wide range of magnetic drift shells. The primary scope for the project is the operational monitoring of near-Earth's radiation environment, i.e. fluxes of electrons and protons of Earth's radiation belts and energetic particles of solar and galactic origin. This multi-satellite constellation made it possible to simultaneously measure particle and quantum fluxes in various regions of near-Earth space using the same type of instruments. A special compact detector of gamma quanta and energetic charged particles (electrons and protons) DeCoR has been developed for these satellites, allowing radiation monitoring using CubeSats.

According to Münz et al. (2024), gamma-ray burst detection was implemented on the GRBAlpha and VZLUSAT-2 CubeSats. These satellites carried a pair of identical detectors. These instruments, which detect gamma rays in the range of $30 - 900$ keV, consist of a 56 cm^2 5 mm thin CsI(Tl) scintillator read-out by a row of multi-pixel photon counters (MPPC or SiPM). The scientific motivation is to detect gamma-ray bursts and other HE transient events and serve as a pathfinder for a larger constellation of nanosatellites that could localize these events via triangulation. In early July 2024, GRBAlpha detected 140 such transients, while VZLUSAT-2 had 83 positive detections confirmed by larger GRB missions. Almost a hundred of them are identified as gamma-ray bursts, including extremely bright GRB 221009A and GRB 230307A, detected by both satellites. Authors were able to characterize the degradation of SiPMs in polar orbit and optimize the duty cycle of the detector system also by using SatNOGS radio network for downlink.

An example of achieving results using astrometry is the Bobcat-1 CubeSat mission. Croissant et al. (2020) shows the mission design with a very detailed description of all the decisions taken during the mission preparation phase. The main objective of the mission was to evaluate the performance of GNSS inter-constellation time offset estimation from Low Earth orbit (LEO). A preliminary data analysis was performed in Croissant et al. (2021).

3 Ground technologies for small space

Recently, open technologies for the ground segment have been actively developing. A striking example, described in Croissant et al. (2022), is SatNOGS — a network of satellite ground stations around the world, optimized for modularity, built from readily available and inexpensive tools and resources. The rate of Low Earth Orbit (LEO) satellite launches increases with the participation of old and new entities. In this growing environment, SatNOGS provides many tools to track, identify, receive telemetry from sateliites, monitor them and assist operators in command/control operations. SatNOGS has built a global community dedicated to its values of free and open source code, developing ground station hardware designs (antennas, rotators, electronics), SDR-based communications software, satellite planning and mission monitoring platforms. Although SatNOGS has created a huge number of useful tools over its history, user experience shows that integrating this type of network into the educational and scientific process remains difficult. To achieve the goals of making this kind of technology more useful for schools and universities, the SONIKS project was created. It is an open source project, as it is based on SatNOGS technologies, but the main goal of the project is to create a new scientific and educational environment for the development of various types of important work related to space.

4 Space-π

Our domestic space infrastructure for educational and scientific purposes is gradually developing. At the moment there are two projects which provide opportunities to launch scientific and educational missions in space: Space-π and Universat (Roscosmos).

Universat is focused only on solving specific applied problems. Space-π is more of a scientific and educational project, in which schoolchildren, students, universities and domestic companies participate. The project allows schoolchildren to learn how small spacecraft are designed, how a payload is created and how a space experiment is implemented with its help. Young people study systems for obtaining space information and the possibilities of controlling a satellite in orbit.

When implementing their ideas, schoolchildren receive professional support from university professors, designers, programmers — all those who create satellite platforms, payloads and ground stations.

The goal of Space-π is to form a network of 100 CubeSats within several years for the mass involvement of school-age youth in space technology. As of July 2024, the Space-π project has launched 45 satellites since its start in 2021. These CubeSats have been used for various types of scientific and applied missions: remote sensing, observations of the Sun and its flares, deep space observation, testing of space components and technologies, the Internet of Things, launching a lilac sprout, etc.

5 SONIKS

In 2023, the domestic open-source educational project SONIKS[2] — Network of complexes of open ground research stations – began operating. Based on SatNOGS technology, its main objectives are scientific research and educational areas. SONIKS is focused on developing new open and easy ways to connect domestic youth — students and young scientists — with space research and modern technologies, providing free access to all data and code base developed.

One of the current achievements is the launch of a satellite radio signal reception network. Thanks to the Geoscan company, which provided 50 ground stations with antennas throughout Russia free of charge, schoolchildren from different regions of the country can now receive signals from many satellites. Currently, the SONIKS network contains information on more than 1800 satellites and 3482 transmitters. At the moment, more than 30 ground stations are connected to the network. Over the 8 months of network operation, more than 5.5 million data packets were received from

[2] https://sonik.space

satellites in space. The platform itself is open to all. Users can work with satellite data for educational or research purposes: space photos, data from satellite payloads (sensors, receivers, engines) and telemetry.

This platform is unique for Russia and opens up a lot of opportunities for the development of domestic scientific and educational infrastructure. The development of an open radio telescope and an open network of optical ground stations is planned for the future.

6 Summary

In conclusion, it should be noted that in Russia today there is a very good pace of development of the scientific and educational space, which, as my work has shown, is capable of solving serious research problems with a thorough approach. To cope with such a pace, we need both government support in the form of developing projects to launch scientific and educational satellites and obtain data from these devices,as well as local work — in universities and scientific organizations — creating scientific laboratories and design bureaus where students, graduate students, and young scientists could work together with professionals on real projects that will be launched into low-Earth orbit, and in the future, with real series of observations obtained using their own equipment. Such activities will certainly have a positive impact on the youth and the scientific environment — making it more accessible, more exciting and more interesting to implement. It can also help increase scientific data for certain experiments and ultimately reduce the cost of expensive scientific equipment that has been launched so far.

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