V. SPACE TECHNOLOGY AND ENVIRONMENTAL MONITORING

ACHIEVEMENTS IN SPACE EXPLORATIONS OF SPACE RESEARCH AND TECHNOLOGY INSTITUTE AT THE BULGARIAN ACADEMY OF SCIENCES

Denitsa Borisova, Georgi Jelev, Georgi Sotirov

Abstract: The paper is devoted to the achievements in space explorations of the Space Research and Technology Institute at the Bulgarian Academy of Sciences. There are considered the research activities and shown the projects and perspective directions for work and their applications.

Keywords: space exploration, environmental monitoring, technology transfer

This year marks 60th anniversary of the first manned space flight and 49 years since there were launched in space orbit the first Bulgarian device called P-1 and conducted the first Bulgarian experiments in space.

Bulgaria is, historically, one of the pioneering countries in space activities with the Bulgarian Astronautical Society being founded only two months after the launch of the first artificial satellite in space by USSR. In 1962, during the pioneering years of the space research, International Astronautical Federation (IAF) held its 13th Congress in Varna. The organized participation of Bulgarian scientists in space research started in 1969, when the Bulgarian Academy of Sciences (BAS) established the Research Group on Space Physics with key objectives on conducting fundamental and applied studies in the field of Space Physics, Remote Sensing of the Earth and Planets, and Aerospace Systems and Technologies. Its successor is the current Space Research and Technology Institute at the Bulgarian Academy of Sciences (SRTI-BAS), which is still one of the most active institutes in Space activities in Bulgaria.

Bulgarian scientists have supported scientific programs on the Interkosmos satellites (1, 2, 3, 4, 5,

and 7), by ground-based measurements. In a period 1967-1976 Bulgarian scientists actively participated in the INTERKOSMOS Programme, preparing experiments and designing equipment for Interkosmos satellites IK-8, IK-12, IK-14, IK-19 and the heavy geophysical rockets VERTICAL- 3, 4, 6, 7, and 10.

In accordance with the regulations of the International Astronautical Federation and the United Nations committee on the peaceful uses of outer space this is enough for the declaration of our country as a Space State and Bulgaria became the 18th Space country in the world.

The first Bulgarian device is designed for research in space physics, measuring the temperature and the concentration of cosmic plasma (Pic.1).

Marking this anniversary we cannot not miss the merits of the founders of the Central Laboratory for Space Research academicians Lubomir Krastanov and Kiril Serafimov (Pic.2), the successor of which is the current Space Research and Technology Institute at the BAS. We must also pay tribute to the creators of P-1, Tanya Ivanova, Stephen Chapkanov, Mary Petrunova and Georgi Karamishev, which are shown in Pic.3.

Pic. 1

Pic. 2

Pic. 3

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During all these 49 years regardless of major historical and economic transformations SRTI-BAS manages to be the flagship of the Bulgarian Space Research and protect the highest point of Bulgaria as space-faring nations.

In 1979 Bulgaria became the 6th country in the world with a cosmonaut, when Georgi Ivanov flew on-board the Soyuz 33 spacecraft (Pic.4) and the third, which produces food space after the former USSR and the USA.

Pic. 4

After the first Bulgarian space device there were followed in 1981 by satellites "Bulgaria-1300" (Interkosmos-22, COSPAR ID: 1981-075A) (Pic.5), "Meteor-Nature" (COSPAR ID: 1981-065A) (Pic.6) and more than 100 scientific devices, apparatuses and systems flew in space orbit and were conducted about 500 space experiments.

Pic. 5

Pic. 6

As top of our space research can be noted the flight in 1988 of our second cosmonaut Alexander Alexandrov during which was realized a serious scientific program including the development of 11

scientific equipment and systems and more than 40 experiments conducted on board the "Mir" orbital space station (Pic.7).

Pic.7

Pic.8. FREGAT video spectrometric complex

Pic.9. Photo of Phobos – a moon of Mars

Since 1987 SRTI-BAS has started participation in the international program PHOBOS in the designing, constructing and assembling of FREGAT video spectrometric complex (Pic. 8). In 1988 the interplanetary missions Phobos-1 and Phobos-2 have launched. In 1989, photos of Phobos – one of the moons of Mars, were received (Pic. 9).

The Space Research and Technology Institute represents the main actor in Bulgarian Space activities. The field of studies of SRTI-BAS ranges over a variety of fundamental and applied research and technology development activities: investigations in solar-terrestrial physics and high-energy astrophysics; space biotechnologies; instrumentation and technologies for remote sensing, for environment monitoring and security; education programs for PhD students.

Recent years in the field of space research marked change of financing the operation, switch to project financing and strengthening of research and activities and transfer of technology. For the period

2018-2021, SRTI-BAS has developed more than 130 projects, many of them with external non-budgetary funding. The main areas in which the institute works are space physics, remote sensing of the Earth and planets and transfer of space technology. The first major field of projects related to research on space plasma and radiation. Very seriously is Bulgarian participation on board the International Space Station (ISS). Since 2001 Bulgarian devices and modules mounted onboard of the ISS measure the cosmic radiation and potential on the surface of space station (Pic. 10).

In 2010 SRTI-BAS was a major establisher of a non-governmental organization in the Space sector in Bulgaria, the Cluster of Aerospace Technologies, Research and Applications (CASTRA) where business representatives, academic institutions and non-governmental organizations whose intention is to develop aerospace technologies and their applications are members. At the moment SRTI-BAS finished its participation in CASTRA.

In April 2013 successfully was launched in orbit equipment for the "Obstanovka" project including probe "Lengmyur" for the study of plasma around the International Space Station (Pic.11) and apparatus for measuring the electrical potential of

the modules of the station, which indicates that may be raised to 200V. This can cause leakage of equalizing currents bringing the spacecraft to the station and to disrupt normal operation of automatic conjunction with the ISS.

Pic.10

Pic.11

In the Institute research studies related to solar-terrestrial connections and short-term and long-term forecasts of solar impact on people and the climate are performing. A forecast center of solar activity has been created and based on developed models.

The latest information in this field is published daily on the website of SRTI-BAS. Scientists from the Institute are initiators for creation of the largest international initiative in the field of space weather (Pic. 12).

Pic.12

In 2014 Bulgaria became 92nd member state of the Group of Earth Observation (GEO) and the 30th member state of EUMETSAT on 30 April of the same year.

The following year, in 2015, Bulgaria became the 10th country to sign the European Cooperating States (ECS) Agreement with the European Space Agency (ESA) and a year later, in February 2016, the Plan for European Cooperating States (PECS) Charter was signed. In accordance with the PECS Agreement, the Bulgarian Ministry of Economy is coordinating the activities with ESA in order to enable Bulgarian companies to successfully participate in the PECS program. As a result of such Agreement-the expertise and competences in space-related activities of the Bulgarian industry and research institutions are expected to be increased in the programmed period. In according the ESA report about Bulgarian space activities SRTI-BAS is leading participant in PECS calls with 13 projects among in total 36 approved ones.

In the first half of 2018, during the Bulgarian Presidency in the Council of the European Union,

Bulgaria provided a solid platform for a political debate regarding the future long term financial framework and the funds allocated for the space sector and its programs.

In addition, several space-related events were jointly organized with The European Commission and ESA in Sofia (Copernicus Training and Information Session and Space based services for regional strategies in the digital economy: Balkan & Black Sea Perspectives).

Under the PECS program, SRTI-BAS worked in the area of Earth observation, science and human spaceflight and exploration preparation. Their main contributions are related to the dosimetry science payloads for ExoMars Trace Gas Orbiter (TGO) and surface platform, the development of a space greenhouse microgravity simulation environment, technologies for food production and waste disposal for manned space flights life support systems, the basic components for various Earth observation derived prototype services.

Pic.13. The Liulin-MO cosmic radiation dosimeter currently measuring the radiation parameters in orbit around Mars on board the Trace Gas Orbiter satellite (the ExoMars joint project of ESA and the Russian Space Agency) [<http://esa-pro.space.bas.bg/node/6>].

Active collaboration with space organizations in Argentina and Japan

The Liulin-AR instruments for the Argentina-Brazilian SABIA-Mar 1 satellite. The SABIA-Mar (Satélite Argentino Brasileño para Información del Mar) is a dual satellite, a joint Argentine- Brazilian

Earth observation mission. Its objective is to study the oceanic biosphere, its changes over time and how it is affected by and reacts to human activity. SABIA-Mar 1 satellite (Pic. 14) is planned to be launched at 702 km sun-synchronous circular orbit in 2023. (<http://www.conae.gov.ar/index.php/espanol/introduccion-sace>).

Pic. 14. The SABIA-Mar 1 satellite

The Liulin-AR (Pic. 15) instrument is developed in SRTI-BAS. It was proposed by Italian and Argentinian scientists. The Liulin-AR is integrated in the scientific payload of the SABIA- Mar 1 satellite (<http://www.conae.gov.ar/index.php/espanol/instrumentos>). It will determine and

quantify the global distribution of the four possible primary sources of space radiation outside the satellite. The Liulin-AR instrument is already built, calibrated and delivered in order to be assembled in the SABIA-Mar 1 satellite.

Pic.15. The Liulin-AR spectrometer

Japan

The Liulin Ten-Koh instrument for the new micro 3U or 6U satellite.

The Liulin Ten-Koh spectrometer on board of the Ten-Koh satellite was very successful. The Ten-Koh satellite, developed in Kyushu Institute of Technology (Japan), was launched on 29 October 2018 at about 623 km altitude and at 98° inclination (Pic.16). Ten-Koh's primary science instrument is the Charged Particle Detector (CPD), developed at the Prairie View A&M University and NASA Johnson's Space Center of Houston, TX, USA. The

Liulin Ten-Koh instrument (see the anodized aluminum box in Pic. 16) was mounted on the top of the CPD and registered three primary radiation sources, i.e. globally distributed primary galactic cosmic radiation (GCR) particles and their secondary products; energetic protons in the South Atlantic Anomaly (SAA) region of the inner radiation belt (IRB); relativistic electrons and/or bremsstrahlung in the high latitudes of the Ten-Koh orbit, where the outer radiation belt (ORB) is situated.

Pic.16. The CPD with mounted on top the Liulin Ten-Koh instrument

After the success of the first Ten-Koh mission, a new satellite mission is discussed with the participation of the Nihon University in Tokyo (Prof. K-I. Okuyama) and Japan Aerospace Exploration Agency (JAXA) in collaboration with SRTI-BAS. The new satellite will be launched in 2023. It will be either 3U or 6U CubeSat. A new, smaller version of Liulin dosimeter-spectrometer is being developed for this satellite.

In recent years, space technologies are playing an increasingly large place in people's lives. Especially there is great application of methods and systems for remote sensing of the Earth from space and active participation in ESA PECS calls.

ESA Project: *Testing Sentinel-2 vegetation indices for the assessment of the state of winter crops in Bulgaria.*

The TS2AgroBG project is motivated by the application potential of remote sensing technology in Bulgarian agriculture sector. While aerial photographs have been used in this sector for a decade for agricultural parcels identification, the full potential of satellite applications for crop growth assessment and crop mapping remains to be explored. The innovative Sentinel-2 mission will expand the possibilities by providing free imagery with high spectral and spatial resolution, suitable for crop state monitoring at field level. The PROBA-V satellite acquires 100 m data at high frequency, allowing crop mapping based on image time series (Pic. 17). In this context, it is appropriate to raise awareness of the capability of these advanced technologies among Bulgarian policy makers as well to agricultural stake-holders. This project could also promote the development of applications and services for this emerging market in Bulgaria.

In this project, data from these two satellites will be used to generate agriculture-relevant products, including: raster layers with crop bio-physical variables, crop state assessment maps, crop masks and national crop map. Because this is a pilot study, the project will focus on the most important winter crop in Bulgaria – wheat. In addition to the common bio-physical variables like Leaf Area Index (LAI), fraction of Absorbed Photosynthetically Active Radiation (fAPAR) and Canopy Chlorophyll Content (CCC), the project will investigate the possibility to retrieve total nitrogen content, fresh and dry biomass (AGBf and AGBd), and fraction vegetation cover (fCover) from Sentinel-2 Level 1C data. Vegetation indices calculated from Sentinel-2 data will be used to develop empirical regression models for computation of bio-physical variables. Dedicated field campaigns will be conducted to obtain consistent ground truth dataset for the regression models' calibration and validation. The data collected will include the following bio-physical variables: total nitrogen content, total (a+b) chlorophyll content, LAI, fAPAR, AGBf, AGBd, and fCover. To facilitate the generation of crop masks in operational context an extension of the software SPIRITS is proposed to handle and process Sentinel-2 Level 1C data together with the Belgian partner. In addition, sub-pixel crop map at national level will be produced through classification of PROBA-V 100 m time series data. Classifications of Sentinel-2 imagery over two training/test areas will be used to calibrate the national level PROBA-V classification. Finally, the possibility for assimilating the Sentinel-2 derived bio-physical variables into a crop growth model in order to improve winter wheat yield prediction will be examined.

Pic. 17

The ESA-funded project BG2-05 "Satellite Information Downscaled to Urban Air Quality in Bulgaria" (SIDUAQ) started on 15th June 2018. The overall objective of this project is to use the opportunities given by satellite observations for improvement of air quality management at national

and local level in Bulgaria (for the city of Plovdiv). The goal will be achieved by synergetic use of data from ESA satellites (METOP (Pic.18), Sentinel 5P, etc.), in situ air quality monitoring and air pollution dispersion modeling systems. The project results will support local authorities in air quality management,

so to meet the air quality standards on a medium and long term sustainable basis.

The National Institute of Meteorology and

Hydrology, as coordinator, and the Space Research and Technology Institute, as sub-contractor, cooperate to achieve the ambitious tasks planned in the project.

Pic. 18. Orbit track over Europe for MetOp A and B satellites, respectively

Successful is the work of the Institute in the Framework Programs of the European Commission related to the problem-oriented processing and creation of a database for the study of the ionosphere (POPDAT); prepare for a flight demonstration on a planet with atmosphere ("AEROcapture for Future spAce transPorTation", AEROFAST) and projects

"COSMOS" since 2007 (FP7, Horizon 2020).

After winning a competition of Operating Programme "Competitiveness", at the Institute a Technology Transfer Office was created as continuation of PHARE Project BG 2005/353 017.10.06/ESC/G/TTO. It is part of the network of such offices in Europe (Pic. 19).

Pic. 19

The scientific field "Space Medicine and Biology" is developing successfully at SRTI-BAS. Ongoing research is being conducted related to the improvement

of the space greenhouse, which is the Bulgarian know-how and has been in exploitation more than 10 years on the "Mir" orbital space station.

Pic. 20. The Bulgarian SVET Space Greenhouse (SG) mounted in the Crystal module was the only automatic plant growth facility flown onboard the “Mir” orbital space station in the period 1990-2001

16 June – 8 August 1990: In the Svet SG the first long-term experiment with Chinese cabbages and radishes was carried out. For the first time radishes were grown from seeds.

10 August – 9 November 1995: In the Svet SG first wheat experiment was conducted. Plants remain viable but did not complete full life cycle of development.

5 August – 6 December 1996: In the Svet-2 SG super dwarf wheat was grown and 252 spikes were received but with no grains in them. The culprit for this was the gas ethylene presented in the “Mir” orbital space station atmosphere.

6 December 1996 – 17 January 1997: In the Svet-2 SG for the first time in vivo and in situ photosynthesis and transpiration – the most important plant physiological parameters – were measured on 42-day old wheat plants.

31 May – 30 September 1997: In the Svet-2 SG

the leafy mustard plant completed full life cycle of development “from-seed-to-seed”. For the first time in microgravity first and second generation seeds were received.

18 November 1998 – 26 February 1999: In the Svet-2 SG for the first time an ethylene resistant variety of wheat produced first generation seeds.

9 March – 17 August 1999: In the Svet-2 SG from the first generation space wheat seeds new plants were grown which completed full life cycle of development and produced second generation seeds in microgravity.

21 May – 15 June 2000: In the Svet-2 SG leafy vegetables – Chinese cabbage, leafy mustard, mizuna (Japan cabbage) and rocket (rucola) were grown and tasted by the Russian cosmonauts Alexander Kalery and Sergei Zalyotin.

The total duration of plant experiments in the Svet SG and the Svet-2 SG was 681 days (Pic.21).

Pic.21

Pic. 22. Next Generation Svet Space Greenhouse Concept

Based on the obtained results and the gained experience from the space plant experiments, a concept for a new generation of the Svet Space Greenhouse – Svet-3 SG has been developed (Pic. 22). The concept provides adaptive control of the environmental parameters in the space greenhouse based on the readings of sensors that monitor the climatic parameters of the environment as well as the readings of systems that measure plant physiological parameters – photosynthesis, transpiration, etc. Plant status has prevailing role in

maintaining the environmental parameters.

The attention in SRTI-BAS is also focused on capacity increasing and training of the scientific staff. Successfully has been complete a project under the Operational Programme "Human Resources" (VG051RO001/07/3.3-02/63/170608 SRF) for training and keeping a team of young scientists in the field of aerospace technology associated with environmental monitoring and prevention of technogenic and natural disasters. (Pic. 23).

Pic. 23

The Institute is the publisher of a scientific journal "Aerospace Research in Bulgaria" ranked in Master Journal List at Web of Science platform. Our top scientists are authors of many publications,

monographs and patents. It has become a good tradition every year the Institute to organize the International Scientific Conference "Space, Ecology, Security". (Pic. 24)

Pic. 24

And the last but not least, SRTI-BAS has activities in PhD student education in 5 accredited doctoral programs: “Astrophysics and Stellar Astronomy”, “Physics of the Ocean, Atmosphere and Space”, “Dynamics, Ballistics and Flight Control of Aircraft”, “Automated Systems of Information Processing and Management (by branches)”, and “Remote Sensing of the Earth and Planets”. The scientific staff of SRTI-BAS has training education in Bachelor’s and Master’s degrees in different Universities in Bulgaria.

Future activities of the Space Research and Technology Institute could be summarized in the following areas:

- Fundamental space research
 - Space Physics;
 - Remote sensing of the Earth and planets;
 - Space biology and medicine;
 - Space materials science;
 - Microgravity space research.
- Applied space research
 - Global Monitoring for Environment and

Security - Copernicus Program;

- Space Information and Navigation Systems - Galileo program;

- Meteorological research and monitoring based on space technology.

- Aerospace technologies and transfer
 - Transfer of medical and psychological methods;
 - On-board measuring and computer systems;
 - Stabilized platforms;
 - UAV and helicopters.
- Education and human resources
 - International workshops, conferences and schools;
 - Centers for education in Doctoral, Master and Bachelor and High school students.

The presented work is based on the Annual Reports of the Space Research and Technology Institute at the Bulgarian Academy of Sciences.

Denitsa Borisova, Georgi Jelev, Georgi Sotirov

Space Research and Technology Institute-BAS
Acad. G. Bonchev Str., Bl.1
Sofia 1113, Bulgaria

e-mails: dborisova@stil.bas.bg
gjelev@space.bas.bg
gsotirov@space.bas.bg