S E S 2 0 1 9
Fifteenth International Scientific Conference
SPACE, ECOLOGY, SAFETY
6 – 8 November 2019, Sofia, Bulgaria

CURRENT AND FUTURE SPASE MISSIONS WITH LIULIN TYPE INSTRUMENTS

Tsvetan Dachev[1], Jordanka Semkova[1], Borislav Tomov[1], Yury Matviichuk[1], Plamen Dimitrov[1] Nikolay Bankov[1], Rositsa Koleva[1], Krasimir Krastev, M. Jordanova[1], Vyacheslav Shurshakov[2], Victor Benghin[2], O. Ivanova[2], Lev Zelenyi[3], Igor Mitrofanov[3], Alexey Malakhov[3], Maxim Mokrousov[3], Vladislav Tretyakov[3], P. Saganti[4], D. Holland[5], K.-i. Okuyama[6], I. Fajardo[6] A. Zanini[7], S. Vernetto[7], M. Colazo[8], D. Caruso[8], M. Rabolli[8], V. Ciancio[9]

[1]Space Research & Technology Institute, Bulgarian Academy of Science (SRTI-BAS), Sofia, Bulgaria
tdachev@bas.bg, btomov@bas.bg, ymat@bas.bg, pdimitrov1957@abv.bg, ngb43@abv.bg,
jsemkova@stil.bas.bg, rkoleva@stil.bas.bg, werholak@abv.bg, mjordan@bas.bg
[2]State Research Center Institute of Biomedical problems, Russian Academy of Science, Moscow, Russia
shurshakov@inbox.ru, v_benghin@mail.ru, olivette@mail.ru
[3]Space Research Institute, Russian Academy of Science, Moscow, Russia
lzelenyi@iki.rssi.ru, imitrofa@space.ru malakhov@iki.rssi.ru, mokromax@iki.rssi.ru, vladtr@mx.iki.rssi.ru
[4]Radiation Institute for Science and Engineering Prairie View A&M University, TX, USA
pbsaganti@pvamu.edu
[5]Holland-Space LLC, Houston TX, USA
sdholland777@yahoo.com
[6]Kyushu Institute of Technology, Fukuoka, Japan
okuyama@ise.kyutech.ac.jp, q595902f@mail.kyutech.jp
[7]Istituto Nazionale di Fisica Nucleare, Torino, Italy
zanini@to.infn.it, vernetto@to.infn.it
[8]Comisión Nacional de Actividades Espaciales, Buenos Aires, Argentina
colazo@conae.gov.ar, caruso@conae.gov.ar, rabolli@conae.gov.ar
[9]Universitad National de La Plata, La Plata, Argentina
ciancio@netverk.com.ar

Keywords: *Space radiation, Space weather, Dosimetry, Spectrometry*

Abstract: *The paper is divided in 2 parts. The first part describes the current space and ground experiments, which were developed in Space Research and Technology Institute at the Bulgarian Academy of sciences (SRTI-BAS). The second part of the paper describes the following future space experiments: The Liulin-ML particle telescope; The Liulin-AF spectrometers; The Liulin-AR spectrometer; The RD3-B3 spectrometer; The Liulin-L particle telescope and the Liulin-ISS-2 system. Short information for the Liulin Ten-Koh instrument for the new Japanize HTV-X resupply vehicle and Liulin-F2 instrument for the Phobos-Grunt 2 sample return mission are given.*

ТЕКУЩИ И БЪДЕЩИ КОСМИЧЕСКИ ЕКСПЕРИМЕНТИ С ПРИБОРИ ОТ ТИПА ЛЮЛИН

Цветан Дачев[1], Йорданка Семкова[1], Борислав Томов[1], Юрий Матвийчук[1], Пламен Димитров[1], Ст. Малчев[1], Николай Банков[1], Росица Колева[1], Красимир Кръстев[1] М. Йорданова[1], Вячеслав Шуршаков[2], Виктор Беньгин[2], О. Иванова[2], Лев Зелени[3], Игор Митрофанов[3], Алексей Малахов[3], Максим Мокроусов[3], Владислав Третьяков[3], П. Саганти[4], Д. Холанд[5], К.-и. Окуяма[6], И. Фажардо[6], А. Занини[7], С. Вернето[7], М. Колацо[8], Д. Карузо[8] М. Заболи[8], В. Цианцио[9]

Резюме: *Статията е разделена на 2 части. Първата част описва настоящите космически и наземни експерименти, разработени в Института за космически изследвания и технологии към БАН (SRTI-BAS). Втората част на статията описва следните бъдещи космически експерименти: Телескопът за частици Liulin-ML; Спектрометрите Liulin-AF; Спектрометърът Liulin-AR; спектрометърът RD3-B3; Телескопът за частици Liulin-L и системата Liulin-ISS-2. Предоставена е кратка информация за инструмента Liulin Ten-Koh за новият японски спътник HTV-X и инструмента Liulin-F2 за междупланетната станция Phobos-Grunt 2, която ще върне проба от почвата на спътника на Марс – Фобос.*

1. Introduction

Ionizing radiation is recognized to be one of the main health concerns for humans in the space radiation environment.

The dominant radiation component in the space radiation environment are the galactic cosmic rays (GCR), which are not rays at all but charged particles that originate from sources beyond the Solar System. They are thought be accelerated at highly energetic sources like neutron stars and supernovae within our Galaxy. GCR are the most penetrating among the major types of ionizing radiation [1]. The energies of GCR particles range from several tens up to 10^{12} MeV/nucleon [2].

Another component are the solar energetic particles (SEP). The SEP are mainly produced by solar flares, sudden sporadic eruptions of the chromosphere of the Sun. They T may deliver very high doses over short periods, that is why could be associated with lethal equivalent doses in the interplanetary space. SEP are high fluxes of charged particles (mostly protons, some helium and heavier ions) with energies up to several GeV.

In addition, there are two distinct belts of toroidal shape surrounding the Earth, where high energy charged particles are trapped in the geomagnetic field. The inner radiation belt (IRB), located between about 1.1 and 2 Earth radii, consists of electrons with energies up to 10 MeV and protons with energies up to ~700 MeV. The outer radiation belt (ORB) starts from about 4 Earth radii and extends to about 9–10 Earth radii in the anti-sun direction. The outer belt consists mostly of electrons, whose energy is below 10 MeV. They do not have enough energy to penetrate a heavily shielded spacecraft, such as the Inter-national Space Station (ISS) wall, but may deliver large additional doses to astronauts during extravehicular activity (EVA) [3].

Present calculations show that radiation doses expected on manned space missions can easily exceed the suggested allowed doses, but we must keep in mind that these estimations bear a lot of uncertainties. Present models of all three stages, involved in calculations, are far from precise. Therefore experimental measurements on unmanned missions are of a great importance for the future planning of manned mission in the interplanetary space and on the surface of Moon and Mars.

2. Current space experiments

A total of 10 different space instruments were developed, qualified and used in 16 space missions between 1988 and 2019 [4–6] by the scientists from the Solar-Terrestrial Physics Section, Space Research and Technology Institute, Bulgarian Academy of Sciences (SRTI-BAS).

Currently SRTI-BAS participate in the operation and analysis of data from 2 instruments on 2 satellites. The first, Liulin-MO instrument at the ExoMars Trace Gas Orbiter (TGO) satellite is at about 400 km circular orbit around Mars. The second, Liulin Ten-Koh instrument is at the Japanese Ten-Koh satellite at about 600 km circular orbit around the Earth. Moreover, the Liulin-6MB internet instrument is fully operational measuring since September 2006 the flux and dose rate at the Basic Environmental Observatory (BEO) of the Institute for Nuclear Research and Nuclear Energy (INRNE-BAS) at Musala peak (2925 m A.S.L.) in Rila mountain. Also, the Liulin-ISS system is still in the Russian segment of ISS in potential operation conditions.

2.1 ExoMars missions

The first participation of SRTI-BAS scientists in an interplanetary mission was in the Mars-96/98 missions in 1996. Next is the Fobos-Grunt sample return mission in 2011. For both missions SRTI-BAS developed and qualified for space Bulgarian build instruments. Because of problems with the rocket burns, intended to set the crafts on a course for Mars, both missions failed. The first fully successful is the ExoMars mission.

ExoMars is a joint ESA-Roscosmos program for investigating Mars [7]. Two missions are foreseen within this program. The first: consists of the TGO, which carries scientific instruments for the detection of trace gases in the Martian atmosphere and for the location of their source regions, plus an Entry, Descent and landing demonstrator Module (EDM), launched on March 14, 2016. The second, featuring a rover and a surface platform, with a launch date of 2020. On October 19, 2016 TGO was captured in high elliptic Mars' orbit with an apocenter about 101,000 km and an epicenter about 250 km. Since 1 May 2018 TGO is in a circular ~400 km orbit around Mars.

The Fine Resolution Neutron Detector (FREND) instrument [8] measure thermal, epithermal and high energy neutrons with energies ranging up to 10 MeV, whose variations are an excellent signature of H bearing elements presence in the regolith at up to 1 meter depth.

Fig. 1. Liulin-MO particle telescope

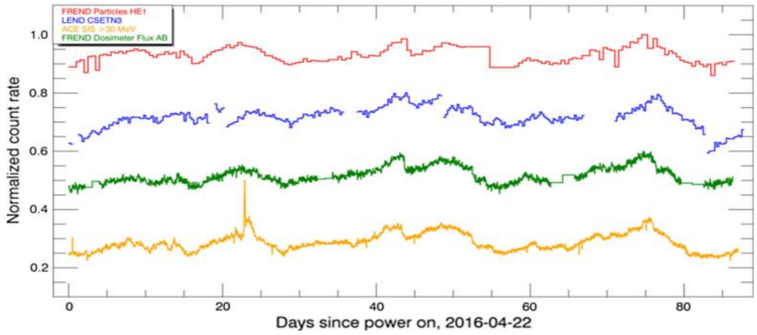

Fig. 2. FREND data compared to LEND onboard LRO, Liulin-MO dosimeter module and ACE neutron telescope

The FREND's dosimeter module (specified as Liulin-MO particle telescope) [5] is another important part of the system, providing measurements of the dose and the flux of charged particles every minute and measurements of the energy deposited and the linear energy transfer spectra every hour.

The Liulin-MO particle telescope (Fig. 1) contains two dosimetric telescopes arranged at two perpendicular directions. Every pair of telescopes consists of two 300 µm thick, 20x10 mm area Si PIN photodiodes (Hamamatsu S2744-08 type), operating in a coincidence mode to obtain linear energy transfer (LET). The detectors, the charge-sensitive preamplifiers - shaping amplifiers, and the voltage bias circuits are mounted in a separate volume inside the box of the Liulin-MO instrument and are connected to printed circuit boards that contain threshold discriminators, pulse height analysis circuits, coincidence circuits, and other circuitry, mounted in another separate volume. The last volume also contains a CPU board, including microprocessor, flash memory for data storage, timer, DC-DC converters, and an interface to the board telemetry/command system. The entire package has a mass of 0.5 kg and consumes less than 3 W.

Fig. 2 [8] shows a set of results compared to other space data for the normalized count rate. In deep space, FREND is sensitive to charged particles that are registered in its lower channels. Thus, it can be explained that the data from FREND's HE1 detector agree quite well with the other particle detectors. The FREND data are compared to Liulin-MO, but also to the data from the LEND in Lunar orbit [9] and ACE [10] spacecraft in orbit close to the L1 Lagrangian point.

Table 1 presents a comparison of the GCR parameters, measured by Liulin-MO instrument onboard of ExoMars TGO during the TGO circular orbit between 1 May 2018 and 15 October 2019 and Oulu Neutron monitor count rates (data (http://cosmicrays.oulu.fi/), averaged in 90 days intervals around the mentioned in column 1 dates. Well seen increase with time of all data in the table is revealed. It is caused by the solar activity decrease, when GCR increase interacts with the decreasing solar wind and its embedded turbulent magnetic field, undergoes convection, diffusion, adiabatic energy losses, and particle drifts because of the global curvature and gradients of the heliospheric magnetic field [11].

2.2 Liulin instrument on the Ten-Koh satellite

Table 1.Comparison of Liullin-MO data obtained during the TGO circular orbit between 1 May 2018 and 15 October 2019 wit Oulu Neutron monitor data.
(The flux was calculated as the number of particles passing through the detector divided by the area of the detector and the measurement time.)

Time frame	F (AB)/ F (DC) $cm^{-1}s^{-1}$	D(Si) (AB)/ D(Si) (DC) µGy h^{-1}	D(water) (AB)/ D(water) (DC) µGy h^{-1}	Q(AB)/ Q(DC)/	H (AB)/ H (DC) µSv h^{-1}	Oulu NM count rate counts min^{-1}
01.05. 2018-31.07.2018	3/3.1	14.26/14.97	18,54/19,46	3.47/ 3.45	64.33/ 67.14	6672-6704
01.08. 2018-31.10.2018	3.02/3.12	14.35/14.98	18,65/19,47	3.48/ 3.48	64.92/ 67.77	6704-6747
01.11.2018-31.01.2019	3.06/3.16	14.47/14.98	18,81/19,47	3.47/ 3.46	65.27/ 67.38	6717-6694
01.02.2019-30.04.2019	3.11/3.2	14.78/15.32	19.21/19.92	3.49/3.48	67.06/69.31	6694-6702
01.05.2019-31.07.2019	3.15/3.24	14.91/15.46	19.38/20.1	3.5/3.47	67.83/69.75	6702-6715
01.08.2019-15.10.2019	3.15/3.24	15.07/15.63	19.59/20.32	3.5/3.47	68.46/70.51	6715-6745

The 23.5-kilograms mass satellite Ten-Koh, developed in Kyushu Institute of Technology by Prof. K. Okuyama and his team [12, 13] was successfully launched on 29 October 2018, at about 623 km altitude and at 98° inclination. 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) is mounted on the top of the CPD. The following three primary radiation sources were expected and recognized in the data obtained with the Liulin

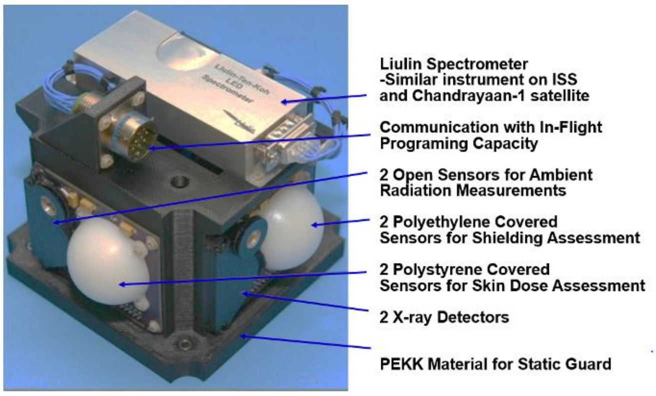

Fig. 3. CPD with mounted at the top Liulin Ten-Koh instrument

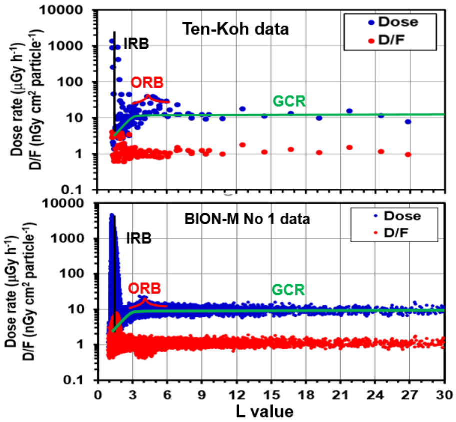

Fig. 4. Comparison of the L value profiles at Ten-Koh and BION-M No 1 satellites

Ten-Koh instrument: (i) globally distributed primary GCR particles and their secondary products, (ii) energetic protons in the South Atlantic Anomaly (SAA) region of the inner radiation belt (IRB); (iii) relativistic electrons and/or bremsstrahlung in the high latitudes of the Ten-Koh orbit, where the outer radiation belt (ORB) is situated [14].

Fig. 4 shows a comparison of the L-value profiles obtained at Ten-Koh and BION-M No 1 [15] satellites. In both parts of the figure are presented the measured dose rates (blue points) and the calculated D/F ratio, which according to the Haffner formulas [16] specifies the type of the radiation.

Fig. 4 reveals that: 1) the shape of the different radiation sources is very similar. The D/F values in both cases are around 1 nGy cm^2 particle^{-1} for GCR source below 1 nGy cm^2 particle^{-1} and above 1 nGy cm^2 particle^{-1} for the IRB source; 2) the GCR dose rates, measured at Ten-Koh satellite are higher than these on BION-M No 1, because the solar activity at the end of 2018 and the beginning of 2019 is smaller than in April-May 2013.

Despite of the fact that the first amount of data from Liulin Ten-Koh spectrometer are relatively limited in number the comparison with the larger amount of BION-M No 1 data shows that they have the expected dose to flux values and shapes of the deposited energy and maybe used for a further more comprehensive analysis of the LEO environment.

2.3 Liulin-6MB internet instrument

The Liulin-6MB internet instrument is fully operational, measuring since September 2006, the flux and dose rate at Musala peak (2925 m A.S.L.) in Rila mountain. It is the last operational internet

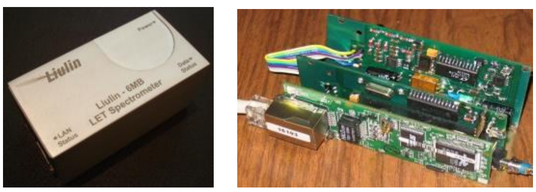

Fig. 5. External and internal view of Liulin-6MB

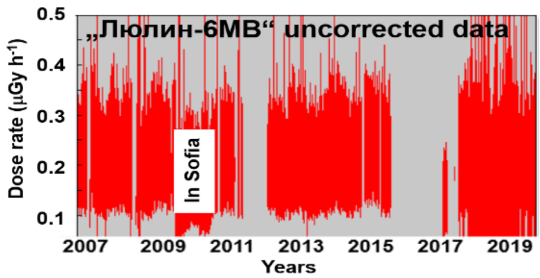

Fig. 6. Long-term dose rate variations

instrument from a series of four. The other 3 were as follows: Liulin-6R operated by Andoya rocket Range, Andoya, Norway from 10/2005 to 07/2010; Liulin-6SI operated by Physikalisches Institut, University of Bern, 10/2007–12/2016 at Jungfrau peak (4158 m) in Switzerland; and Liulin-6K1, operated by Ústav experimentálnej fyziky SAV, Oddelenie kozmickej fyziky, Košice, Slovak republic at Lomnický štít peak (2 634 m), 2009–2015.

Left part of Fig. 5 presents the external view of the Liulin-6MB LET spectrometer. It is an aluminum box with size of 84x40x40 mm and weight of 0.12 kg. In the right part of the figure are seen the 3 internal plates. The back one produces all necessary voltages from external 12 V DC. The middle plate contains the LET spectrometer. The top plate is commercial internet module with its own microprocessor unit and a LAN connector at the left side. The module generates and posts WEB page, open for all interesting users. It also performs, via FTP protocol, the transmission of the stored in the flash memory data toward the users. The instrument is designed for multi-session use. Specially developed software and hardware allow changing Internet settings parameters. Liulin-6MB is integrated in the WEB page of BEO Musala and the described above features was not used.

Fig. 6 shows the long-term dose rate data obtained from http://beo-db.inrne.bas.bg/moussala/index.php on Musala peak (2925 m A.S.L.) between October 2006 and October 2019. The data are not corrected for the atmospheric pressure. That is why these data keep all the time an average value of 0.2–0.3 μGy h^{-1}, as expected. The latter are a bit higher than the data obtained in 2010, when the instrument was moved to work in INRNE-BAS in Sofia at about 600 m.

3. Future space missions with participations of SRTI-BAS instruments

At the end of 2019 there are 8 projects, including participation of Liulin type instruments in future space missions. Some of them as Liulin-ML are at the stage of a ready flight instrument for 2020, while another are at the stage of preliminary discussions. Next part of the paper will overview them.

3.1 Liulin-ML instrument on the ExoMars surface platform

Fig. 7. Schematic presentation of the experiments with the Liulin-MO and Liulin-ML instruments on ExoMars TGO around Mars and in the surface platform at Mars

Fig. 7 illustrates the schematic presentation of the experiments with the Liulin-MO and Liulin-ML instruments on ExoMars TGO satellite around Mars and on the surface platform and rover at Mars. Liulin-ML particle telescope is in the scientific payload of the surface platform and will measure the dose rate and flux on the surface of Mars. All data will be transmitted to the ExoMars TGO and together with Liulin-MO data will be retransmitted to the Earth for analysis. The flight instrument was already delivered to Space Research Institute, Russian Academy of Science (SRI-RAS) for integration in the payload of the platform.

According to the now a days plans of ESA and ROSCOSMOS not later than August 2020 the second part of the ExoMars project will begin with the launch of the interplanetary station. The latter payload includes ESA Mars rover and ROSCOSMOS surface platform. The station will land on Mars surface in March 2021 (https://exploration.esa.int/web/mars/).

3.2 Liulin-AF instruments for the Matroshka-III phantom on the ISS

2 Liulin-AF instruments are part of the Matryoshka-III research project. Participants from Germany, Russia, Japan, Poland, Hungary and Bulgaria will study the dynamics of the cosmic radiation accumulation in a tissue-equivalent phantom in the Russian segment of the ISS.

Fig. 8 presents the main idea of the proposed configuration of two Liulin-AF instruments in the both sides of Matroshka-III phantom. In Fig. 8a demonstrates the calculated SAA 500 MeV proton directional distribution [17]. It is seen that the main amount of protons in the SAA region is coming from a relative small azimuthal angle, i.e. there is large asymmetry. In figures 8b and 8c, a view from above of the phantom is presented. The two Liulin-AF instruments are painted in yellow, while their detectors – in red. Fig. 8b illustrates the best situation, when the two Liulin detectors are exposed perpendicularly to the ion drift velocity. The first detector will be exposed on the direct flux of SAA protons, while the second will measure and analyze the effect of the shielding in the material of the phantom.

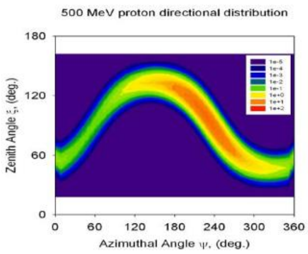

Fig. 8a. Directional distribution of the SAA drift

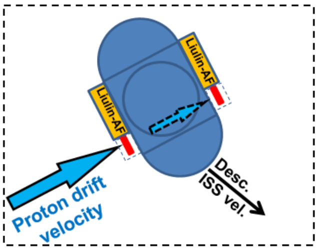

Fig. 8b. Descending configuration

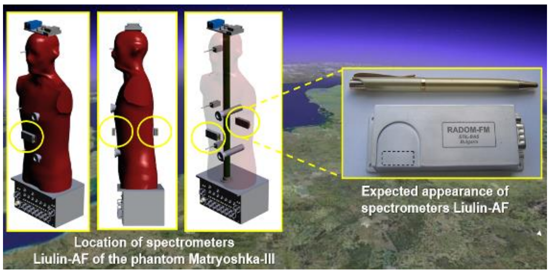

Fig. 8c. Location of the Liulin-AF instruments and their expected appearance

In the left part of Fig. 8c reveals the Matroshka-III phantom surrounded by different instruments. The Liulin-AF instruments are located in the yellow circles. At the right part of the figure the expected appearance of the Liulin-AF instruments is shown. MATROSHKA-III experiment is scheduled for launch to the ISS in 2021 (https://event.dlr.de/en/maks2019/matroshka-iii/).

3.3 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 (Fig. 9) is planned to be launched at 702 km sun-synchronous circular orbit in 2023 (http://www.conae.gov.ar/index.php/espanol/introduccion-sace).

Fig. 9. The SABIA-Mar 1 satellite

Fig. 10. Liulin-AR spectrometer

The Liulin-AR [18] instrument was proposed by Italian and Argentinian scientists and involved in the scientific payload (http://www.conae.gov.ar/index.php/espanol/instrumentos) of the SABIA-Mar 1 satellite for determination and quantification of 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 for use to Dr. A. Zanini.

3.4 РД3-Б3 (RD3-B3) instrument for the BION-M No2 satellite

SRTI-BAS, in collaboration with the University of Erlangen, Germany and State Research Center Institute of Biomedical problems, (IMBP-RAS) Russia, will participate in the experiment of the BION-M No 2 in the 2022 mission at an altitude of 800-1000 km and an inclination of the orbit 62°.

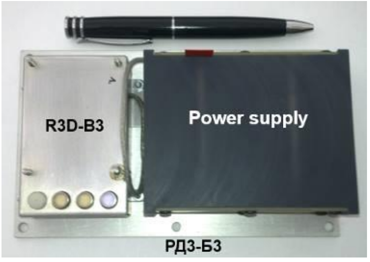

Fig. 11. РД3-Б3 spectrometer

Fig. 12. РД3-Б3 in BION-M No.1 capsule

РД3-Б3 (RD3-B3) instrument (Fig. 11) was created for the flight of the BION-M No 1 satellite [15]. It contains the R3D-B3 instrument, which was developed through collaboration of the Bulgarian and German teams, and flown into the Biopan-6 facilities on Foton-M3 satellite [19]. The second block, seen in Fig. 11, is a power supply unit with 2 D size Li-Ion batteries. This will be the third space flight of the R3D-B3 instrument. The first was on Foton-M3 satellite. The second was on BION-M No 1 satellite (Fig. 12). The aluminum box of RD3-B3 instrument has a size of 53x82x28 mm and 120g weight. The launch of BION-M No 2 satellite is foreseen for 2023 (https://3dnews.ru/980441).

3.5 Liulin-L instrument of the Luna-26 satellite

The Liulin-L instrument is foreseen to be flown at 100–200 circular orbit on the Russian Moon-26 Moon satellite, which will be launched into orbit in 2024.

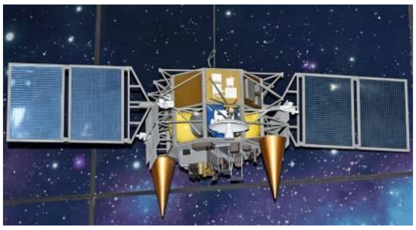

Fig. 13. The Luna-26 satellite

Fig. 14. Expected view of the Liulin-L particle telescope

The following objectives of the experiment with the Liulin-L instrument on Luna-26 were specified:

- Measurements of the space radiation doses and fluxes in the Earth magnetosphere and on the route to Moon. Mapping of the space radiation distribution at 100 km from the Moon surface;
- Measurements of the dose contribution of relativistic electrons, protons, He+ ions and HZE particles in the dose composition;
- Estimation of the radiation doses received by the components of the spacecraft;
- Contributions to the verification of the radiation environment models and assessment of the radiation risk for the crewmembers of the future exploratory missions to the Moon.

3.6 Liulin-ISS-2 system for the Russian segment of the ISS

The engineering version of Lyulin-ISS-2 system was developed between 2014 and 2019 [20]. The aim was to create a service dosimetric system for monitoring of the personal dose of crew members in the Russian segment and outside the ISS. The priority is measuring the dynamics of the

Fig. 15. Liulin-ISS-2 system

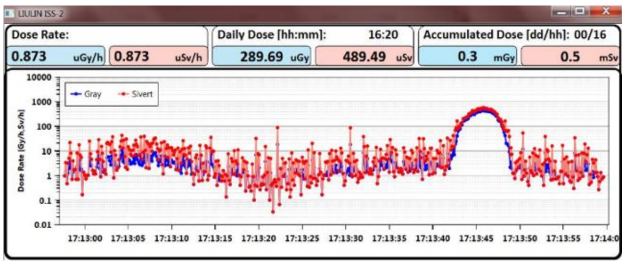

Fig. 16. Expected view on the screen of the IB when ISS crosses first the ORB and next the IRB

dose accumulation, while the crew member moves out of the station in the outer space. The instrument "Lyulin-MKS-2" consists of five blocks: 4 personal dosimeters and one interface block (IB) with a stationary dosimeter. The IB is based on a fully rugged tablet Getac T800.

3.7 Liulin Ten-Koh instrument for the new Japanese HTV-X resupply vehicle

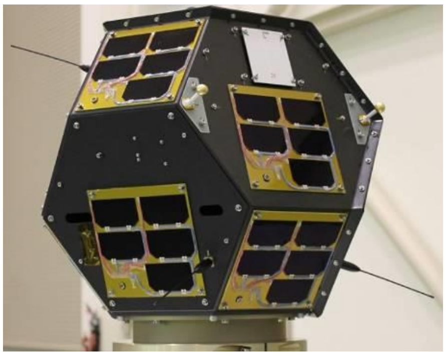

Fig. 17. Ten-Koh satellite

New mission with similar to Ten-Koh satellite (Fig. 17) was discussed between Prof. K-i. Okuyama and Japan Aerospace Exploration Agency (JAXA) in the end of November 2019. The new Ten-Koh satellite will be launched in the exposed area of the new HTV-X ISS resupply satellite.

3.8 Liulin-F2 instrument for the Phobos-Grunt 2 sample return mission

IMBP-RAS has sent a formal proposal for the inclusion of a Liulin-F2 instrument in the scientific composition of the Phobos-Grunt 2 instrumentation, which will return to the Earth from Phobos after 2024 (http://www.russianspaceweb.com/phobos_grunt2.html) Liulin-F2 instrument will be similar to Liulin-AR.

Conclusions

The Bulgarian instruments in future space missions will contribute to the evaluation of the radiation environment in Earth orbit, in transit to Moon and Mars, in Moon and Mars orbits and on the surface of Mars. Data obtained will be used for the validation of models for dose and flux assessment, estimation of the radiation doses received by the components of a spacecraft, assessment of the radiation risk to crewmembers of future exploratory flights and evaluation of the shielding requirements on future manned Earth, Moon and Mars spacecraft.

Acknowledgements

This work is partially supported by the Bulgarian Academy of Sciences, Agreement between BAS and RAS on fundamental space research, contract 4000117692/16/NL/NDe funded by the Government of Bulgaria through an ESA contract under the Plan for European Cooperating States (PECS) and contract on the project input N 129, funded by National Science Fund-Bulgaria under the competition for financial support for bilateral projects Bulgaria – Russia 2018–2019.

Notes

Dose rate, flux and depositing energy spectra from 10 space experiments performed between 1991 and 2019 are part of the “Unified web-based database with Liulin-type instruments”, which are available online, free of charge at the following URL: http://esa-pro.space.bas.bg/database.

The database of long-term dose monitoring of aircraft flights (3285 flights, 16925 hours) by the Czech airline CSA is available online: http://hroch.ujf.cas.cz/~aircraft. The database was created by scientists from Nuclear physics institute at the Czech Academy of Sciences [21].

References:

1. Mewaldt R. A.,Cosmic Rays, available online at http://www.srl.caltech.edu/personnel/dick/cos_encyc.html, 1996.
2. Simpson, J. A., in: Shapiro M.M. (Ed.) Composition and origin of cosmic rays, NATO ASI Series C: Mathematical and Physical Sciences. Vol. 107, Reidel, Dordrecht, 1983.

3. Dachev, T. P., Relativistic Electron Precipitation Bands in the Outside Radiation Environment of the International Space Station, Journal of Atmospheric and Solar-Terrestrial Physics, 177, 247–256, 2018, https://doi.org/10.1016/j.jastp.2017.11.008
4. Dachev, T. P., et al., Overview of the Liulin type instruments for space radiation measurement and their scientific results, Life Sciences in Space Research, 4, 92–114, 2015. http://dx.doi.org/ 10.1016/j.lssr.2015.01.005.
5. Dachev, T. P., et al., Analysis of the First Space Radiation Data, Obtained by Liulin Ten-Koh Instrument on the Japanize Ten-Koh Satellite, Proceedings of Eleventh Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere", 171–178, Primorsko, Bulgaria, June 3÷7, 2019, ISSN 2367-7570, https://doi.org/10.1016/j.asr.2014.01.004
6. Semkova, J., et al., Charged particles radiation measurements with Liulin-MO dosimeter of FREND instrument aboard ExoMars Trace Gas Orbiter during the transit and in high elliptic Mars orbit. Icarus, Volume 303, 15 March 2018, Pages 53–66, 2018. https://doi.org/10.1016/j.icarus.2017.12.034
7. Vago, J., et al., ESA ExoMars program: the next step in exploring Mars. Solar Syst. Res. **49**(7), 518–528 2015. https://doi.org/10.1134/S0038094615070199
8. Mitrofanov I., G. et al., Fine Resolution Epithermal Neutron Detector (FREND) Onboard the ExoMars Trace Gas Orbiter, Space Sci Rev, 214:86, 2018. https://doi.org/10.1007/s11214-018-0522-5
9. Mitrofanov, I., G. et al., Lunar exploration neutron detector for the NASA Lunar Reconnaissance Orbiter. Space Sci. Rev. 150(1–4), 183–207 (2010a). https://doi.org/10.1007/s11214-009-9608-4
10. Stone, E. C. et al., The Advanced Composition Explorer. Space Sci. Rev. 86(1/4), 1–22, 1998. https://doi.org/ 10.1023/A:1005082526237
11. Strauss, R.D. and Potgieter, M.S., 2014. Where does the heliospheric modulation of galactic cosmic rays start?. Advances in Space Research, 53(7), pp.1015–1023. https://doi.org/10.1016/j.asr.2014.01.004
12. Okuyama, K.-I., et al., Observation of Ionospheric Disturbance Near the End of the 24th Solar Cycle Period and Space Deterioration Situation of Advanced Materials Using the Micro-Sat Ten-Koh, 32nd International Symposium on Space Technology and Science, ISTS Japan, June 2019.
13. Fajardo, I.,et al., Design, Implementation, and Operation of a Small Satellite Mission to Explore the Space Weather Effects in LEO, Aerospace 2019, 6, https://doi.org/10.3390/aerospace6100108
14. Dachev, T. P., et al., Analysis of the First Space Radiation Data, Obtained by Liulin Ten-Koh Instrument on the Japanize Ten-Koh Satellite, Proceedings of Eleventh Workshop "Solar Influences on the Magnetosphere, Ionosphere and Atmosphere", 77-83, Primorsko, Bulgaria, June 3–7, 2019, ISSN 2367-7570, https://doi.org/10.31401/WS.2019.proc
15. Dachev, T. P., et al., "BION-M" №1 spacecraft radiation environment as observed by the RD3-B3 radiometer-dosimeter in April-May 2013, Journal of Atmospheric and Solar-Terrestrial Physics. 123, 82–91, 2015. http://dx.doi.org/10.1016/j.jastp.2014.12.011
16. Haffner, J. W., Yadernoe izluchenie i zashchita v kosmose (Nuclear Radiation and Protection in Space), pp 115, Atomizdat, Moscow, 1971. (book in Russian)
17. Badavi, F., Correlation of ISS Liulin/TEPC Measurements with HZETRN Simulations 41st International Conf. on Environmental Systems 17-21 July 2011, Portland, Oregon, AIAA 2011-5250, pp. 1–27.
18. Zanini, A., et al., Liulin-AR spectrometer for radiation environment observation on SABIA-MAR 1 satellite, 3rd International Conference and Exhibition on Satellite & Space Missions, May 11-13, 2017 Barcelona, Spain, DOI: 10.4172/2168-9792-C1-017
19. Häder, D. P., et al., R3D-B2 - Measurement of ionizing and solar radiation in open space in the BIOPAN 5 facility outside the FOTON M2 satellite, Adv. Space Res. 43, 1200-1211, 2009. doi:10.1016/ j.asr.2009.01.021
20. Dachev, T. P., et al., "LIUILIN-ISS-2" system for cosmonauts' dosimetric control in the ISS radiation environment, Aerospace Research in Bulgaria, 28, 38-58, 2016. http://journal.space.bas.bg/ arhiv/n%2028/Articles/4.pdf
21. Ploc, O., I. et al., Publicly available database of measurements with the silicon spectrometer Liulin on board aircraft, Radiation measurements, 58, 107–112, 2013. http://dx.doi.org/10.1016/j.radmeas.2013.09.002