NEW RESULTS FOR THE SPACE RADIATION ENVIRONMENT, OBTAINED WITH THE LIULIN TYPE SPECTROMETERS SINCE 2014

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Abstract: *The paper presents some of the new results for the space radiation environment obtained with the following 3 Liulin type spectrometers (LTS) since 2014. The Bulgaria-German R3DR2 spectrometer inside the ESA EXPOSE-R2 platform outside the Russian segment of the International Space station (ISS), The Bulgaria-Russian Liulin-MO spectrometer outside the ESA-ROSCOSMOS ExoMars Trace Gas Orbiter (TGO) and The Bulgarian-USA Liulin-Ten-Koh spectrometer in the Japanize small satellite Ten-Koh.*

НОВИ РЕЗУЛТАТИ ЗА КОСМИЧЕСКАТА РАДИАЦИОННА СРЕДА, ПОЛУЧЕНИ СЪС СПЕКТРОМЕТРИ ОТ ТИПА ЛЮЛИН СЛЕД 2014 г.

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Ключови думи: *Космическа радиация, космическо време, дозиметрия, спектрометрия*

Резюме: *Статията представя някои от новите резултати за космическата радиационна среда, получени със спектрометри тип "Люлин" след 2014 г. Представени са нови резултати от следните 3 експеримента: българо-германският спектрометър R3DR2 извън руския сегмент на Международната космическа станция (МКС), българо-руският спектрометър Люлин-МО извън спътника ExoMars Trace Gas Orbiter (TGO) и българо-американският спектрометър Liulin-Ten-Koh на малкия японски спътник Ten-Koh.*

Introduction

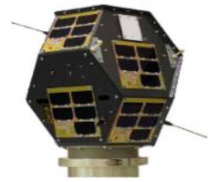
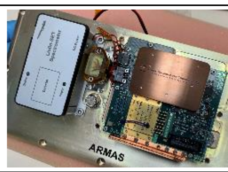
In last 30 years, the Liulin type spectrometers (LTS) are routinely used for the monitoring of the radiation environment at aircraft, balloons and spacecraft. Dachev et al., [1] presented an overview of the LTS, developed and used in space between 1989 and 2014. Table 1 presents the LTS, developed and used in space since 2014 by colleagues from Solar-Terrestrial Department at the Space Research and Technology Institute of Bulgarian Academy of Sciences (SRTI-BAS).

Liulin spectrometers developed for space experiments since 2014

A total of 3 different space instruments were developed, qualified and used in 3 space missions between 2014 and 2022 [2–5]. The paper presents new data from these 3 missions (Table 1, items 1-3).

The forth instrument listed in the table is Liulin-SET [3]. It is part of the ARMAS FM9 module (https://spacewx.com/wp-content/uploads/2021/05/FM9-overview.pdf). It was launched to the ISS on 19 February 2022 and mounted outside the Japanize Experimental Module on March 3, 2022. It will work 12 months against internal memory of the instrument. The data will be extracted and analyzed after returning of the spectrometer to the ground.

Table 1. Liulin type experiments performed during satellite missions since 2014

Item No	Satellite/Station Date begin-Date end Avail. number of meas.	Experiment name PI CoPI Described in Cooperation	Instrument Size [mm]/Mass [kg] Place Shielding [g cm^{-2}] Resolution [sec]/[min]	Instrument Location image	External view of the instrument
1	Outside ISS, Zvezda module 24/10/2014-11/01/2016 3,810,240	ESA, EXPOSE-R2 facility G. Horneck, DLR; D. Häder, UE; T. Dachev, SRTI [2] Bulgaria, Germany	R3DR2 1 DU (76x76x36 mm, 0.19 kg) of the ISS Zvezda module in the EXPOSE-R2 facility >0.6 g cm^{-2}; 10 sec		
2	ExoMars-TGO 22 April 2016 – till now	Liulin-MO I. Mitrofanov, SRI-RAS J. Semkova, SRTI-BAS (Semkova, et al., 2020). Bulgaria, Russia	Liulin-MO 2x2 dosimetric telescopes (172x114x45 mm 0.5 kg) Outside the ExoMars-TGO satellite; >2 g cm^{-2}		
3	Ten-Koh satellite 22/10/2088-29/09/2019 650 spectra	Liulin-Ten-Koh P. Saganti, PVAMU T. Dachev, SRTI. (Dachev et al., 2021) Bulgaria, USA, Japan	Liulin-Ten-Koh 1 DU (110x40x20 mm, 0.098 kg) Inside of the Ten-Koh satellite; >0.6 g cm^{-2}; 30 sec		
4	ISS, Outside Japanize experimental module Installed 03/03/2022	ARMAS Module K. Tobiska, SET, T. Dachev, SRTI. (Dachev, 2021) Bulgaria, USA	Liulin-SET in ARMAS Module, 1 DU (78x60x37 mm, 0.16 kg) >0.6 g cm^{-2}; 10 s		

New results from LTS instruments since 2014

Instrumentation

In the mentioned above instruments (including the first detector of the Liulin-MO dosimetric telescope [4]) the doses (deposited energies) are determined by the Hamamatsu S2744-08 silicon PIN photodiodes (Si PIN photodiode S2744-08 | Hamamatsu Photonics). The pulse amplitudes from the ionized particles, gamma quanta and neutrons first pass the charge-sensitive preamplifier, than a 12-bit fast analogue-to-digital (A/D) converter digitizes them. The pulse amplitudes are proportional by a factor of 240 mV/MeV to the deposited energy according to the AMPTEK A225F preamplifier specifications (A225 Specs for pdf (fastcomtec.com). The deposited energy in the detector and respectively the dose are transformed into digital signals and sorted into 256 channels by a multichannel analyser. For every exposure interval of 10 sec, a single 256 channels energy deposition spectrum is collected.

A system international (SI) determination of the dose is used to calculate the absorbed dose in the silicon detector. The dose in SI is the energy in Joules deposited in one kilogram of a matter. The dose *D* (Gy) in the silicon detector is calculated from the spectrum as:

(1) $$D = K * \sum_1^{256}(Ei * Ai)/MD$$

MD is the mass of the detector (in kg), *Ei* is the energy loss (in J) in the channel *i*, *Ai* is the number of events in it, and *K* is a coefficient. The details of the dose calculation procedures were published by Dachev et al., in [1, 2] and by Semkova et al. [4].

The calibration procedures of the three instruments are analogical to those described in [1-3]. The response curve of these instrument is expected to be similar to that published by [6], because all Liulin dosimeter - spectrometers are manufactured using the same electronic parts and schematic.

The data selection procedures [1, 2], recognize in the near Earth space the following four primary radiation sources: 1) The globally distributed primary Galactic Cosmic Rays (GCR) particles and their secondary products; 2) The Inner radiation belt (IRB) protons in the region of the SAA; 3) The relativistic electrons and/or bremsstrahlung in the high latitudes of the station orbits, where the horns of the outer radiation belt (ORB) are situated; 4) The solar energetic particles (SEP) were recognized in the R3DR2 instrument ISS data [7].

Analysis of the variations of the radiation absorbed doses from different radiation sources on the ISS in the period October 2014 - January 2016

The first row of Table 1 present the most informative experiment, performed with LTS on the ISS. The dosimeters-spectrometers of R3D/E/R/R2 type monitor the radiation situation at the International Space Station (ISS) on the European Space Agency (ESA) platforms Expose-E/R1/R2. They were developed in cooperation between the Bulgarian and German teams in 2001–2009 [2].

The simplest method for the source separation in the R3DR2 data is described in [1, 2]. It is based on the Heffner formulae [8] and shows that the data can be simply split in two parts by the value of the dose to flux (D/F) ratio or by the specific dose (SD). When the SD is 1.12 nGy cm2 particle−1, the expected predominant types of radiation are IRB or SEP protons. The GCR source, which has contributions in both ranges, will be divided between the two ranges.

The R3DR2 data were sorted into four separate categories by presumed source: (1) globally distributed galactic cosmic ray (GCR) particles and their secondary products; (2) protons in the South Atlantic Anomaly region of the inner radiation belt (IRB); (3) relativistic electrons and/or bremsstrahlung in the high latitudes of the ISS orbit where the outer radiation belt (ORB) is situated; (4) solar energetic protons (SEP) in the high latitudes of the ISS orbit. Together with the real SEP particles, a low flux of most probably secondary protons were observed in the data.

Fig. 1 presents the daily averaged dose rate data for the four separate sources from 24 October 2014 to 16 January 2016. There are five panels in the figure. From top to bottom the different panels presents the variations of the following parameters [9]:

- Fig. 1a, the upper part of the panel presents the Dst index variations against the right hand vertical axes. The Dst index were obtained online from the World Data Center for Geomagnetism, Kyoto, Japan (http://wdc.kugi.kyoto-u.ac.jp/index.Html). Three magnetic storms with Dst index less than minus 100 nT are found in the graphic. The time of the main phases of the storms are extended with red dashed lines over the other 4 panels. This gives the opportunity to correlate the main phase storm time with the variations of the studied parameters;

- Fig. 1a: the lover part presents the R3DR2 daily averaged GCR dose rate against the left hand vertical axes. The major finding is that the R3DR2 daily averaged GCR dose rate did have an ascending linear trend because the measurements were performed in the declining phase of the 24th solar cycle. The effect of solar modulation [10] (Potgieter, 2013) assumes a rising trends in the R3DR2 GCR dose rate measurements (please see the magenta line in the Fig. 1a panels). The daily average dose rate data trend has a minimum value of 71 μGy d^{-1} at the beginning of the measurements in October of 2014 and a maximum of 72 μGy d^{-1} at the end of observations in January of 2016.

The averaged R3DR2 GCR daily dose rate also exhibited short-term variations, which generally correlate with the Dst index and reflect the periods with Forbush decreases [11], connected with the magnetic storm and substorm periods in the GCR data. Most remarkable are the decreases that coincide with the two largest in the data magnetic storms on 16 of March and 22 of June 2015.

Fig. 1b presents the ORB radiation source variations from 24 of October 2014 till January 11, 2016. Two periods are clearly seen in the data. In the relatively “quiet” period between 24 October 2014 and the middle of March 2015, the ORB daily dose rate was relatively small and varied during the interval by 2-200 μGy h^{-1}. During the second period, between the middle of March 2015 and the end of the observations, strong variations in the ORB daily dose rate were observed. The largest maxima (up to 3000 μGy h^{-1}) in the ORB source anti-correlate well with the largest negative Dst index in the upper panel of Fig. 1a (red line).

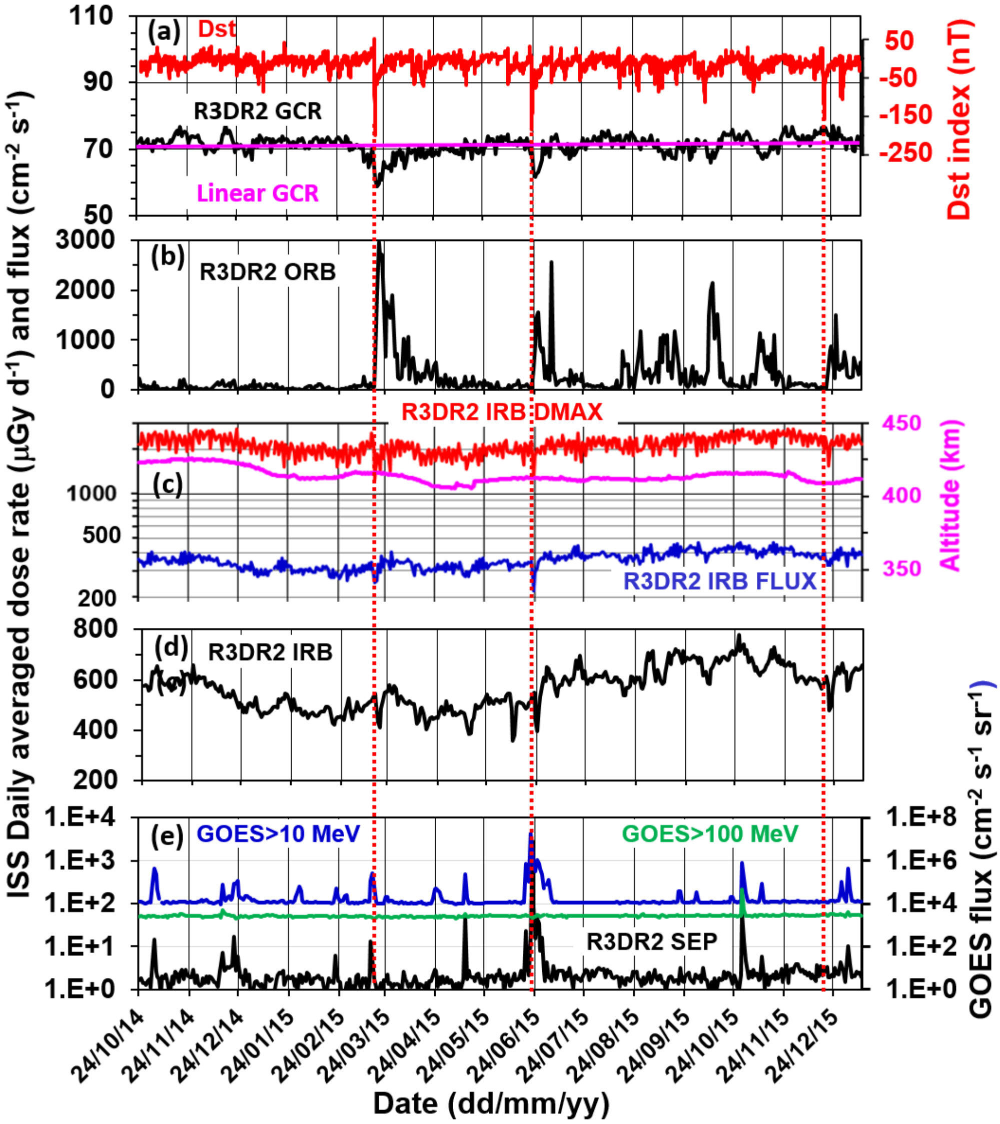


Fig. 1. Results of the separation of the R3DR2 instrument data
for the period 24 October 2014-11 January 2016 in four radiation sources

The R3DR2 ORB daily dose rate averaged over 442 days was calculated to be 278 μGy d^{-1} with a minimal value of 2 μGy d^{-1} and a maximal value of 2,962 μGy d^{-1}. The total accumulated dose for 442 days is 123 mGy.

Fig. 1c and 1d plots the IRB fluxes (in cm^{-2} s^{-1}) (blue), the maximal hourly dose rate (red) and the daily average IRB dose rate values (black), measured by the R3DR2 instrument on the ISS from 24 October 2014 to 11 January 2016. These values are plotted according to the left vertical axes. Along the right axes the average altitude of the station is plotted (magenta line), which was obtained together with the average daily values of the flux and dose rate.

The IRB flux and dose rate were large during the interval October-December of 2014; then, they fell till the end of June 2015 and increased again until the end of the measurements. These long-term variations correlated well with the variations in the average altitude of the station. The altitudinal dependence in the bottom part of the IRB was investigated by the R3DR data [12]. This is a well-known phenomenon, described in details in [13] and will not be discussed here agin.

The R3DR2 IRB daily dose rate averaged over 442 days was calculated to be 567 μGy d^{-1} with a minimal value of 340 μGy d^{-1} and maximal value of 844 μGy d^{-1}. The total accumulated dose for 442 days is 251 mGy.

Fig. 1e presents the averaged SEP daily dose rate variations (black line), measured with R3DR2 on the ISS for the period from 24 October 2014–11 January 2016. These are plotted together with the solar proton fluxes measured in the geosynchronous orbit with the GOES 15 Space Environment Monitor (SEM) instrument (http://goes.gsfc.nasa.gov/text/databook/section05.pdf), with energies more than 10 (blue curve) to 100 MeV (green curve) plotted. We call the low dose rates of a few μGy d^{-1} seen along the bottom of Fig. 1e secondary particle (SP) sources. They are generated by the GCR particles inside the instrument and in the surrounding EXPOSE-R2 material and consists mainly of protons and neutrons.

Eleven maxima are seen in the R3DR2 SEP daily dose rate variations in the bottom of Fig. 1e. All of them coincide well with the >10 MeV GOES SEM maxima. The >100 MeV proton flux channel on GOES had only one well-seen maximum on 29 October 2015, which is also measured with the R3DR2 instrument. The largest maximum, up to almost 3000 μGy d^{-1} on 22 June 2015, was not observed in the GOES >100 MeV channel. It is worth underlining that if a virtual extravehicular activity (EVA) was performed during the period of this SEP maximum, the obtained doses on the skin of the cosmonauts/astronauts could reach 2.84 mGy over six and a half hours. This is equal to the average absorbed dose, obtained inside of the ISS, over 15 days [14, 7].

The R3DR2 SEP+SP daily dose rate, averaged over 442 days, was calculated to be 9 μGy d^{-1} with a minimum value of 0.64 μGy d^{-1} and a maximum value of 2,848 μGy d^{-1}. The total accumulated dose for 442 days is 4 mGy.

Table 2 presents a comparison between the daily averaged absorbed doses rates, observed during the EXPOSE-E/R and R2 missions, behind 0.25–0.5 g cm^2 shielding. We consider that the flux and dose rate errors of the R3DR2 measurements on the ISS are within 10% on the base of the calibration results [15, 1].

Table 2. Comparison of the daily averaged absorbed dose rates measured during the EXPOSE-E/R and R2 missions

Daily averaged absorbed dose rate (in Si) (μGy d^{-1}) R3DE/R/**R2**	Minimum	Average	Maximum
GCR	76/79/**68**	91.1/81.4/**71.6**	102/90/**82**
IRB	110/326/**340**	426/506/**567**	685/704/**844**
ORB	0.25/0.64/**1.66**	8.64/89/**278**	212/2348/**2960**
SEP (only in **R3DR2** data)	**0**	**9**	**2846 (on 22/06/2015)**

It is evident that during the EXPOSE-R2 mission the IRB and the ORB doses are higher than those observed during the EXPOSE-E/R missions, while the GCR dose rate is smaller than that measured during the EXPOSE-E/R missions. The reason is the relatively higher solar and geomagnetic activity during the EXPOSE-R2 mission, which diminished the GCR doses but increased the population of the ORB and the dose rate respectively.

The registered with R3DR2 instrument total daily average dose rate during the EXPOSE-R2 mission is 916.6 μGy d^{-1}. It is larger than the obtained dose rate of 368 ± 27 μGy d^{-1} by passive thermoluminescence detectors (TLDs) during the EXPOSE-R mission. The R3DR2 detector was shielded behind 0.25–0.5 g cm^{-2}, while the TLDs was shielded behind a few g cm^{-2} and therefore saw a smaller dose rates.

Table 3. Comparison of the accumulated absorbed dose rates measured with R3DE/R/R2 instruments

Measured accumulated dose (mGy)			
Source	R3DE	R3DR	**R3DR2**
IRB	181.1 for 425 days	144.7 for 263 days	**250.7** for 442 days
ORB	3.2 for 432 days	22.9 for 286 days	**123.1** for 443 days
GCR	39.4 for 394 days	23.3 for 286 days	**31.8** for 444 days
SEP			**4.04** for 444 days
Total (mGy)	223.7	190.9	**409.5**

Table 3 compares the accumulated absorbed doses measured during the EXPOSE-E/R and R2 missions. The EXPOSE-R2 mission accumulated doses are the highest because of the higher altitude of the ISS, which increases the IRB doses and of the higher geomagnetic activity that increase the ORB doses.

Long-term variations of the dose rate and flux measured by Liulin-MO instrument in the circular orbit around Mars

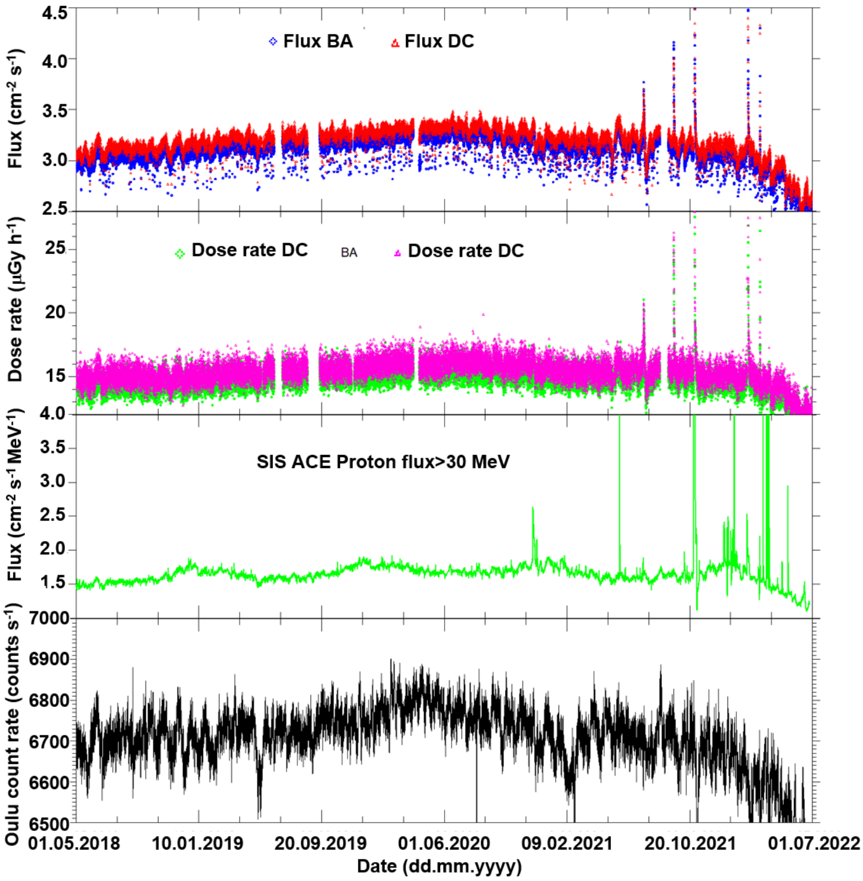


Fig. 2. Variations of the measured with Liulin-MO dosimetric telescope flux and dose rate in circular orbit around Mars between 1 May 2018 and 1 July 2022

ExoMars is a joint ESA - ROSSCOSMOS program for the investigating Mars. The first ExoMars mission, named Trace Gas Orbiter (TGO), was launched on March 14, 2016. In March 2018 TGO was inserted into circular Mars science orbit with a 400 km altitude. The dosimetric telescope Liulin-MO for measuring the radiation environment onboard the ExoMars TGO is a module of the Russian Fine Resolution Epithermal Neutron Detector (FREND). In this section we discuss the measurements in a Mars circular orbit with 400 km altitude obtained in the period from 1 May 2018 to 1 July 2022.

The fluxes and dose rates recorded in the 2 perpendicular detectors BA and DC of Liulin-MO, the proton flux>30 MeV, measured by SIS instrument on ACE satellite (located at L1 point), and the neutron count rate of OULU, Finland neutron monitor on Earth from May 2018 to June 2022, are shown in Fig. 2. Increase of the dose rates and fluxes from May 2018 to February 2020, which corresponds to the increase of the galactic cosmic rays (GCR) intensity during the declining of the 24th solar cycle, is observed. The averaged dose rate for the period is 15 µGy h^{-1}, the averaged particle flux is 3.14 cm^{-2} s^{-1}. In March-August 2020 the radiation values are maximal, corresponding to the minimum of the 24th cycle and of the transition to the 25th cycle. The dose rate is 15.9 µGy h^{-1} and the flux is 3.3 cm^{-2} s^{-1}. Since September 2020, a decrease of the dose rates and fluxes is seen corresponding to the increasing phase of the 25th solar cycle.

Until July 2021 the dosimeter has measured the dosimetric parameters of the GCR. No solar particle events (SPE) were registered. Five SPEs are observed from July 2021 to March 2022. SPEs in October 2021 and February 2022 are observed also on the ACE. During all these SPEs, the Earth and Mars are on the opposite sides from Sun. The October SPE was observed over a wide longitude range from the Earth, STEREO-A, to Mars [16]. During this event the first ground level enhancement of the Solar Cycle 25 was observed [17]. The February 2022 SPE is the most powerful event observed in our data. The SEP dose measured by Liulin-MO during this event is 14.2 mGy - equal to the dose for 38.5 days from GCR in quite conditions. At the peak of the event the dose rate is about 2 orders larger than the dose rate in quite conditions.

Latitudinal distributions of the Liulin Ten-Koh data

The Liulin Ten-Koh spectrometer main purpose is to measure the spectrum (in 256 channels) of the deposited energy from primary and secondary particles in the Ten-Koh satellite radiation environment.

It is designed as spectrometer-dosimeter for a continuous monitoring of the satellite radiation environment, which can consist of GCR particle, Inner radiation belt (IRB) protons, outer radiation belt (ORB) relativistic electrons and energetic protons from solar origin (SEP).

The last sources selection procedure was developed and published recently in [2].

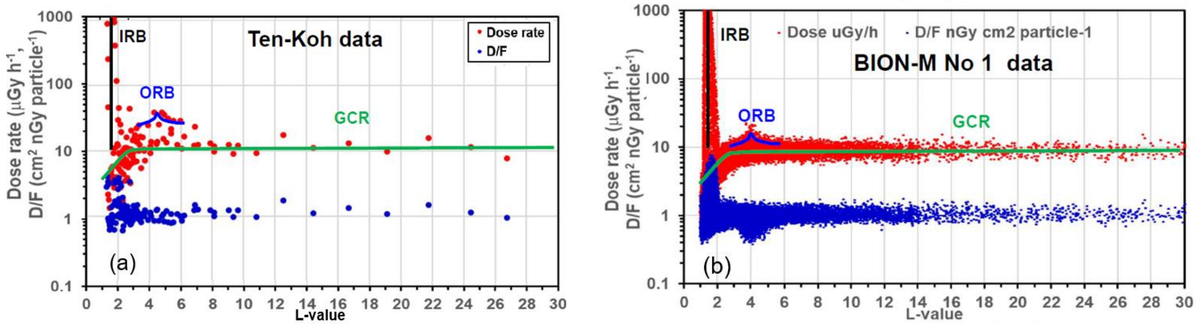


Fig. 3a. Variations of the measured with Liulin-Ten-Koh instrument dose rate in dependence from the L-value in comparison with the analogical data from BION-M No 1 satellite in Fig 3b

Fig. 3a presents the distribution of the obtained dose data and the calculated specific dose (SD) values in nGy cm^2 part^{-1} against the L value up to 30 [18].

The dose rate and flux data in Figure 3 have two obvious maxima – one at L values of about 1.25 and another at about 4. The lower L value maximum corresponds to the inner (proton) radiation belt, which is populated mainly by protons with energies from a few tens to a few hundred MeV. The higher L value maximum corresponds with the outer (electron) radiation belt, which is populated mainly by electrons with energies from hundreds of keV to a few MeV.

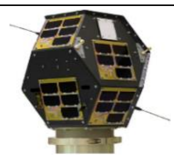
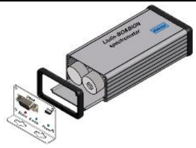
The SD value is provisionally divided into two parts – below and above 1 nGy cm^2 part^{-1}. This value divides the range of the SD delivered by relativistic electrons and/or bremsstrahlung below about 0.7 nGy cm^2 part^{-1} and by protons above 1.12 nGy cm^2 part^{-1}.

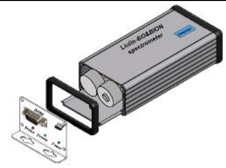
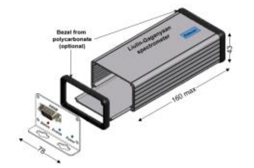
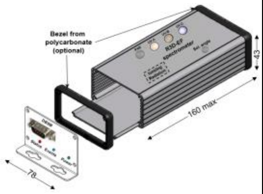
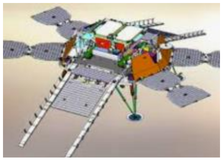
The comparison (Fig. 3b) with analogical data from BION-M No 1 satellite [19] shows a good coincidence of the main features in both figures.

Planned LTS instruments

Table 4 presents information about the planed space missions with the LTS. It is structured in the same way as Table 1.

Table 4. Planned Liulin type experiments on satellite missions

Item No	Satellite/Station Date begin-Date end Avail. number of meas.	Experiment name PI CoPI References	Instrument Size [mm]/Mass [kg] Place Shielding [g cm^{-2}] Resolution [sec]/[min]	Instrument Location image	External view of the instrument
1	Inside Virgin Galactic SpaceShip II. Launch late 2022.	Liulin-CNR-VG Lucia Paciucci, (CNR-DIITET; Ts. Dachev, SRTI (Dachev et al., 2021) Bulgaria, Italia	Liulin-CNR-VG (66x56x26 mm, 0.098 kg.) 1 battery operated DU >2 [g cm^{-2}]; 60 s		
2	Inside the Japanize Ten-Koh-2 satellite Launch in 2023.	Liulin-Ten-Koh-2 T. Dachev, SRTI (Dachev et al., 2021) Bulgaria, USA, Japan	Liulin-Ten-Koh-2 1 DU (110x40x20 mm, 0.098 kg) Inside of the Ten-Koh satellite; >0.6 g cm^{-2}; 30 sec		
3	Blue Origin New Shepard rocket. Launch 2023.	Liulin-BO	Liulin-BO (120x78x43 mm, 0.25 kg) 1 battery operated DU >2 [g cm^{-2}]; 60 s		

4	Outside of the Argentina-Brazilian SABIA-Mar 1 satellite at circular 700 km orbit. Launch in 2024.	Liulin-AR A. Zanini, INFN, Torino, Italy Ts. Dachev, SRTI Bulgarian, Argentina, Italy	Liulin-AR (110x40x20 mm, 0.1 kg)		
5	Inside BION-M № 2 Satellite. Launch in 2024 for 1 month at 800 km circ. orbit. Incl.=64.9°.	Liulin-BION Bulgaria, Russia,	Liulin-BION (120x78x43 mm, 0.25 kg) 1 battery operated DU. >2 [g cm^{-2}]; 60 s		
6	Inside Indian Gaganiaan space station. Launch in 2024.	Liulin-Gaganiaan Ts. Dachev, SRTI	Liulin-Gaganiaan (80x78x43 mm, 0.25 kg) >2 [g cm^{-2}]; 10 s		
7	Inside ESA Exobiology Facility at ISS Launch in 2025.	R3D-EF Ts. Dachev, SRTI	R3D-EF (80x78x43 mm, 0.25 kg) >2 [g cm^{-2}]; 10 s		
8	Kazachok platform Launch in September 2026? Land on Mars in March 2027?	Liulin-ML I. Mitrofanov, SRI-RAS J. Semkova, SRTI-BAS (Semkova, et al., 2020). Bulgaria, Russia	Liulin-ML 2x2 dosimetric telescopes (172x114x45 mm 0.5 kg) Outside the Kazachok platform; >2 g cm^{-2} Dose and flux 60 s		

The stage of readiness of the instruments in Table 4 is as follows:

- Liulin-CNR-VG instrument is developed, calibrated and delivered to colleagues from the National Research Council of Italy (CNR), the Department of Engineering Information and Communication Technologies and Technologies for Energy and Transport. It is expected that in the fall of 2022 (or in 2023) Liulin-CNR-VG will be used to measure the dose of space radiation during a new Virgin Galactic flight at altitudes up to 86 km;
- Liulin-Ten-Koh-2 instrument was developed in SRTI for Prof. P. Saganti, PVAMU, USA. Later it was delivered to Doctor of Engineering and Professional Engineer in Aerospace, Kei-Ichi Okuyama, Professor in the Department of Aerospace Engineering, College of Science and Technology, Nihon University, Japan for integration within the Ten-Koh-2 satellite;
- Liulin-BO instrument is under development based on a Scientific Cooperation between the Space Research and Technology Institute of the Bulgarian Academy of Sciences and Prof E. Benton from Oklahoma State University (OSU), Radiation Physics Laboratory, Oklahoma, USA. It has to be delivered till the end of 2022. After the flight of Liulin-BO Blue Origin New Shepard rocket it will be returned to SRTI-BAS for use on .
- Liulin-AR instrument was developed for Prof A. Zanini from Istituto Nazionale di Fisica Nucleare Sezione di Torino. It worked between 2017 and 2020 in ground based experiments. Later it was delivered to Dr. Mariano Sanahuja, Unidad de Servicios de Ingeniería Gerencia de Proyectos Satelitales, Comisión Nacional de Actividades Espaciales (National Space Activities Commission), Argentina. Now the instrument is undergoing an integration with the Argentina-Brazilian SABIA-Mar 1 satellite;
- Liulin-BION instrument is in fact the Liulin-BO instrument after its return from OSU;
- Liulin-Gaganiaan instrument is under development and the agreement between SRTI-BAS and Indian Space Research Organization (ISRO) is expected to be officially signed till the end of November 2022;
- R3D-EF instrument will be part of ESA Exobiology Facility (EF) at the Columbus module of the ISS. The negotiations for its development of it with KAYSER ITALIA S.r.l. are in progress;
- Liulin-ML instrument was constructed, calibrated and qualified for space. It was delivered to the colleagues from Space Research Institute, Russia.

Conclusions

The paper presents some of the new results for the space radiation environment, obtained with 3 Liulin type spectrometers since 2014.

The ionizing radiation data obtained by the Liulin type instruments in space are part of the "Unified web-based database with Liulin-type instruments", available online, free of charge at the following URL: http://esa-pro.space.bas.bg/database [20]. The data are stored along with the orbital parameters of the satellites. The User Manual of the database is also available online at: http://esa-pro.space.bas.bg/manual.

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