SPACE MISSIONS WITH LIULIN INSTRUMENTS DURING 2021

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Keywords: *Space radiation, space weather, dosimetry, spectrometry*

Abstract: *The article describes the planned experiments with three new Liulin-type devices, developed in 2021 in Solar-Terrestrial Physics Department of the Institute for Space Research and Technology (SRTI) at BAS. The first experiment was conducted with Liulin-SGO instrument during a successful flight of a zero pressure stratospheric balloon up to 35 km altitude on September 13, 2021. Liulin-SGO instrument is part of a scientific project of the Geophysical Observatory in Sodankilė, Finland. The era of suborbital touristic flights up to 100-110 km above sea level is already opened with the flights of Virgin Galactic (VG) on July 11 and Blue Origin on July 20, 2021. Second device is Liulin-CNR-VG. It was developed under a Cooperation Agreement between SRTI–BAS and the National Research Council of Italy (CNR), the Department of Engineering Information and Communication Technologies and Technologies for Energy and Transport. Liulin-CNR-VG instrument will be used to measure the dose of cosmic radiation during a new VG SpaceShipTwo flight in 2022. The third experiment will be conducted on the Japanese segment of the International Space Station (ISS) for one year starting in March 2021. The instrument Liulin-SET will be used. It was developed under a request from the Space Environment Technologies (SET) Limited Liability Corporation (LLC), CA, USA. The President and Chief Scientist of the LLC is Dr. Kent Tobiska.*

КОСМИЧЕСКИ ЕКСПЕРИМЕНТИ С ПРИБОРИ ОТ ТИПА ЛЮЛИН ПРЕЗ 2021 г.

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

Резюме: *Статията описва планираните експерименти с разработените през 2021 г. три нови прибора от типа „Люлин“ в секция „Слънчево-земна физика“ на Института за космически изследвания и технологии (ИКИТ) към БАН. Първият експеримент е проведен с прибора Liulin-SGO при успешен полет на стратосферен балон до 35 км височина на 12 септември 2021 г. Приборът Liulin-SGO е част от научен проект на Геофизичната обсерватория в гр. Соданкиле, Финландия. Ерата на суборбиталните туристически полети до 100-110 км надморска височина вече е открита с полетите на Virgin Galactic (VG) на 11 юли и на Blue Origin на 20 юли 2021 г. Приборът Liulin-CNR-VG е разработен по договор за сътрудничество между ИКИТ-БАН и Националният съвет за научни изследвания на Италия (CNR), Департамента по инженерство, информационни и комуникационни технологии и технологии за енергетиката и транспорта. Очаква се до края на 2022 г. приборът Liulin-CNR-VG да бъде използван за измерване на дозата космическа радиация при нов полет на VG на височини до 86 км. Третият експеримент ще се проведе с прибора Liulin-SET на японския сегмент на Международната космическа станция (МКС). Експериментът ще продължи една година, започвайки от март 2022 г. Приборът Liulin-SET е разработен в ИКИТ-БАН по поръчка на американската фирма „Технологии за космическото пространство“ (Space Environment Technology, Pacific Palisades, CA, USA), САЩ с президент д-р Кент Тобиска.*

Introduction

Ionizing radiation is recognized to be one of the main health concerns for humans in the space. The dominant radiation component in the space radiation environment are the galactic cosmic rays (GCR). They are not rays at all but charged particles that originate from sources beyond the Solar System [1, 2]. Another component are the solar energetic particles (SEP). The SEP contain mainly protons but also some helium and heavier ions. They may deliver very high doses over short periods, that is why could be associated with lethal equivalent doses in the interplanetary space. 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) consists mostly of electrons. It starts from about 4 Earth radii and extends to about 9–10 Earth radii in the anti-sun direction. The ORB may deliver large additional doses to astronauts during extravehicular activity (EVA) [3].

The 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 these calculations, are far from precise. Therefore experimental measurements are of a great importance for the future planning of manned mission in the interplanetary space and on the surface of Moon and Mars.

Liulin spectrometers developed for space experiments in 2021

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).

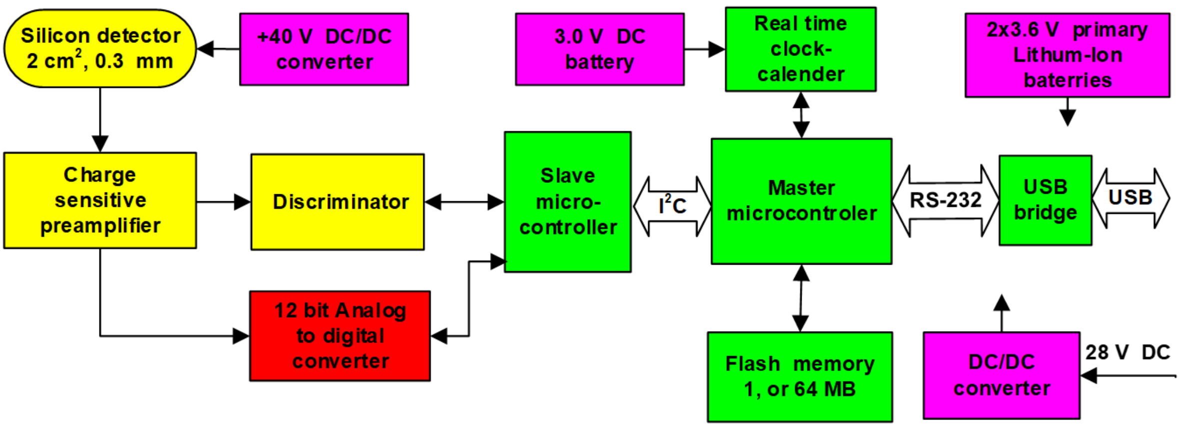

Fig. 1. Unified block-diagram of the three Liulin spectrometers

The unified block diagram of the three Liulins is shown in Fig. 1. The Liulin-SGO spectrometer use 2 D-size Lithium-Ion 3.6 V primary batteries, while the Liulin-CNR-VG instrument use 2 AAA-size rechargeable batteries. Liulin-SET is charged only by external 28 V DC source. DC/DC converters inside the devices produce additional 5, 12 and 40 V voltages. Liulin-SGO and Liulin-CNR-VG contain 1 MB flash memory, while Liulin-SET 64 MB flash memory, which is sufficient for the storage of 390 days non-stop compressed spectra with 10-sec exposition time. Each instrument contains a real time clock-calendar but only in Liulin-SET it is additionally charged by 3 V battery.

Each spectrometer-dosimeter contains one silicon-PIN diode Hamamatsu S2744-08 (2 cm^2 area and 0.3 mm thickness), one ultra-low noise charge-sensitive preamplifier AMPTEK A225F, 2 microcontrollers and 1, 32 or 64 MB flash memory.

After passing a charge-sensitive preamplifier, the signal is digitized by a 12 bit fast analog to digital (A/D) converter. The doses (deposited energies) are determined by a pulse height analysis technique and then passed to a discriminator. According to AMPTEK A225 specifications, the pulse amplitudes A[V] are proportional by a factor of 240 mV/MeV to the energy loss in the detector and respectively to the dose. The amplitude of each signal from the income particles and quanta are transformed into digital signals, which are sorted into 256 channels by a multichannel analyzer. For every exposure interval, a single 256 channels energy deposition spectrum is collected. The energy channel number 256 accumulates all pulses with amplitudes exceeding the maximal level of the spectrometer of 20.83 MeV.

The calibration procedures of the three instruments are analogical to those described in [4, 5 and 7]. The response curve of these instrument is expected to be similar to that published by [8-9], because all Liulin dosimeter - spectrometers are manufactured using the same electronic parts and schematic.

Liulin-SGO instrument for a stratospheric balloon up to 35 km altitude

The Liulin-SGO instrument was part of zero pressure balloon experiment, which was launched on 12th of September 2021 up to 35 km altitude from Kiruna, Finland.

Liulin type spectrometers (LTS) had already participated successfully in a number of balloon missions. The first balloon data were received by the Mobile Dosimetry Unit (MDU)-2, part of Lilun-4C [10] system during a balloon flight launched the 14 June 2000 from the Gap-Tallard aerodrome, France (44.51°N, 6.01°E, Rc=5.18 GV) It was a technological flight of CNES balloon program.

The second balloon flight, with 3 battery operated Liulins (MDUs), was performed during the certification flight of the NASA Deep Space Test Bed (DSTB) balloon on June 8, 2005. The balloon was launched from Ft. Sumner (34.47°N, 104.24°W, Rc=4.08 GV), New Mexico, USA [11]. Another stratospheric balloon flight with LTS was performed in September 2016 from Fort Sumner, New Mexico. This was the NASA mission RaD-X [12].

Wissmann, [13] described the results of the periodic measurements of the radiation up to 30 km altitude at high altitude balloon flights, using Liulin dosimeters similar to the Liulin-SGO.

LTS were also used as environmental radiation monitoring devices at mountain peaks [14-15] and in high latitude observatories [16].

Fig. 2. Liulin-SGO spectrometer

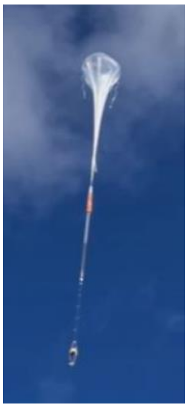

Fig. 3. The balloon

Fig. 4 Retrieval of Liulin-SGO

Fig. 2 presents the external view of Liulin-SGO. Its dimensions are 110x100x45 mm. The total mass (including batteries) is 0.57 kg. The spectrometer works by 2 internal 3.6. V Li-Ion batteries or from aircraft/balloon voltage of 15-36 V DC.

Liulin-SGO has 4 control devices on the front panel and one on the upper side panel: 1) Green Light Emitting Diode (LED) with label next to it “DC Power”. This LED shines always when the MDU is connected to an external 20-35 V DC power supply and is not affected by the “OFF-ON” switch; 2) The OFF-ON switch is used to start/stop the measurement sessions of the instrument irrespective of the power supply. It does not switch OFF-ON the internal clock-calendar of the instrument if there are batteries in it. The setting of the internal clock-calendar is performed automatically during the initialization. 3) The red “Status” LED indicates the operation status of the instrument. It shines for about 0.5 sec at the beginning of each measurement cycle; 4) The micro USB connector is used for connection with PC; 5) The male DB9M type connector is used for connection of the external 20-35 V DC power supply or for the 24 V DC output of the 100-240 V AC 24 V DC converter.

Fig. 3 shows the zero pressure stratospheric balloon. On Fig. 4 two researchers from the Geophysical Observatory in Sodankilė, Finland are working on the Liulin-SGO retrieval from the thermal insulated box after the flight. Liulin-SGO spectrometer is in their hands. (http://cosmicrays.oulu.fi/rg/index.php/2021/09/13/hemera-balloon/) They obtained the data from the flash memory of the Liulin-SGO and expected to finish the analysis till end of the year.

Liulin-CNR-VG instrument for VG flight at altitudes up to 86 km

The Liulin-CNR-VG device was developed under a cooperation agreement between SRTI-BAS and 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 2021 Liulin-CNR-VG will be used to measure the dose of cosmic radiation during a new VG flight at altitudes up to 86 km. Virgin Galactic announces crew for next launch to suborbital space | Space

The external view of the portable dosimeter-spectrometer Liulin-CNR-VG (PDS) is presented on Fig. 5. It is situated in an Extruded Aluminum Enclosure with a size 66x56x26 mm. The weight of the PDS, including the batteries, is 0.098 kg. The control devices on upper panel of the PDS are the same as on Liulin-SET. The ON/OFF switch, the red status LED and the mini female connector USB are mounted on the upper panel of the PDS.

Fig. 5. Liulin-CNR-VG Spectrometer

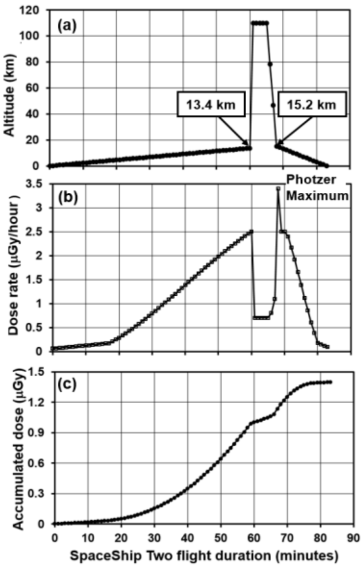

Fig. 6. Predicted (a) altitude (b) dose rate and (c) accumulated dose rate

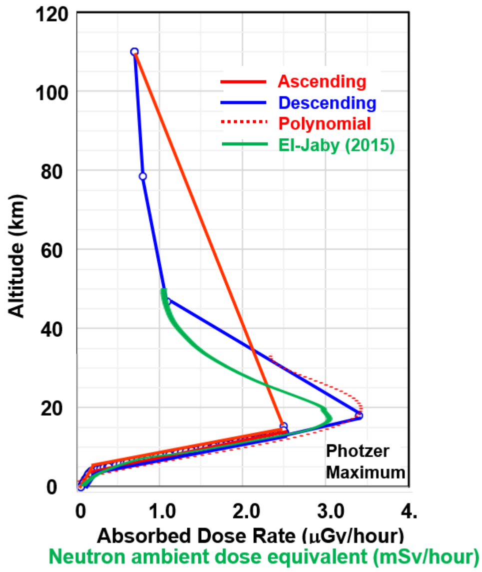

Fig. 7 Predicted altitudinal profile of the absorbed dose rate

The instrument uses two AAA type, 3.6 V, 360 mAh 10440 type rechargeable batteries of Portable Power Corp.

Below the 0.5 mm thick bottom panel is situated the 2 cm^2 Hamamatsu PIN diode detector. In addition, there is a technological shielding of 0.07-mm copper and 0.2-mm plastic material. They all provide a total shielding of 0.25 g cm^{-2}. The calculated required kinetic energies of normally falling particles to the detector are 0.67 and 12.5 MeV for electrons and protons, respectively (https://www.nist.gov/pml/stopping-power-range-tables-electrons-protons-and-helium-ions). This indicates that only protons and electrons with energies higher than the values listed above can cross the PDS shielding materials and reach the surface of the detector.

The following approximate flight times and altitudes are expected during a typical flight of VG SpaceShipTwo: The two mated vehicles climb to an altitude of approximately 45,000 feet (13.7) km for 60 minutes; Boost: ~60 seconds up to 110 km; Coast (microgravity) at 110 km: 3 minutes; Re-entry: ~2-3 minutes back to 15.24 km; Glide to Land: ~15 minutes. Fig. 6a presents the time profile of the altitude of SpaceShipTwo during the flight up to the altitude of 110 km with 1 minute resolution.

The data of the approximate flight times and altitudes are used to predicted the hourly-absorbed dose rates and the accumulated dose rates during the flight (Fig. 6b and 6c).

We also use the available polynomial approximation of the dose rate altitudinal profile (dashed line in Fig. 7) from the second balloon flight, performed during the certification flight of the NASA Deep Space Test Bed (DSTB) on June 8, 2005 (see the previous page), to predict the dose rate profile up to 15.2 km during the expected flight of the VG SpaceShipTwo in the fall of 2021. This is possible to be done because: First, the coordinates of the VG Spaceport America are 106.95W 32.98°N. As SpaceShipTwo will take off and land after almost a vertical flight up to 110 km, the difference in the coordinates between the Spaceport America and Ft. Sumner of 2-3 degrees is neglectable for the space radiation profile. Second, the predicted F10.7 radio flux value in the fall of 2021, when the flight is expected, is between 77 and 89 s.f.u. (https://www.swpc.noaa.gov/products/solar-cycle-progression). These values are close to the F10.7 radio flux value during the balloon flight in June 2005 of 94 s.f.u. The above allows to consider 2005 data relevant to the expected measurements in 2021-2022.

Polynomial data of order of four (red dashed line in Fig. 7) from the second balloon flight in 2005 was used for the altitudes above 3.9 km. Other dose rate profiles were predicted by linear rise equations in Fig. 6 and 7.

Fig. 7 presents the same data with 1-minute time resolution as in Fig. 6b but in dependence of the altitude. The doses during the ascending part of the orbit are presented with red points and lines, while the descending part with blue lines. The polynomial presentation of the Liulin data in 2005 is shown with red dashed line.

As illustrated in Fig. 6 and 7, during the ascending part of the flight, the dose rate will rise from 0.058-μGy/hour up to 2.5 μGy/hour at 13.4 km altitude. The Pfotzer maximum [17] with a dose rate of 3.5 μGy/hour is not expected to be seen in the ascending part of the flight because of the very fast crossing through it. Above the maximum, the dose will slowly decrease up to 110 km altitude where it will fall down to 0.7 μGy h^{-1} and in a similarity of the El-Jaby, and Richardson, 2015 profile (green line) [18]. The dose rate will not change during the 4 minutes of microgravity. It will start to increase during the re-entry, going through the Pfotzer maximum. In the “glide to land” part of the flight, the dose rate will decrease back to 0.058-mGy h^{-1}.

The increase of the accumulated dose rate alters in μGy from zero to 1.4 μGy in Fig. 6c. The equivalent dose during the flight is calculated to be about 2.5 μSv for 1.5 hours because the mean quality factor is about 1.8 for a subsonic flight (1.4x1.8=2.5 μSv). Having in mind that, a passenger, flying from London to New York at a height of 11 km, will receive for about 7 hours a dose of 32 μSv (4.6 μSv/hour), the equivalent of a panoramic dental X-ray scan https://www.radioactivity.eu.com/site/pages/Radioactivity_in_Flight.htm, the calculated dose of 2.5 μSv is about 10 times less and fully acceptable. The obtained above values revels that there is no any radiation risk for the crew and astronauts flying at the VG SpaceShipTwo.

Liulin-SET instrument for the Japanese Experimental Module at the International Space Station

Liulin-SET instrument was developed under a request from Space Environment Technologies (SET) Limited Liability Corporation (LLC) with a Chief Scientist Dr. Tobiska. Liulin-SET is part of the flight module number 9 (ARMAS FM9 https://spacewx.com/wp-content/uploads/2021/05/FM9-overview.pdf), which is scheduled to operate outside of the Japanese Experimental Module (JEM) of the International Space Station for 1 year with expected start in March 2022.

Fig. 8. Liulin-SET spectrometer

Fig. 8. ARMAS FM9 module

The Liulin-SET spectrometer external view is shown in Fig. 8. Its real dimensions are 78x60x37 mm. The total mass is 0.16 kg. The black plastic bezel is made by polycarbonate (http://www.hammondmfg.com/pdf/1455C1201.pdf), which is widely used in space applications. The front panel is lightweight from the backside down to 0.7 mm aluminum. This allowed registration of relativistic electrons from the outer radiation belt (ORB) [3]. The Liulin-SET spectrometer is situated inside of the ARMAS FM9 module (Fig. 9), which is developed by the Space Environment Technologies LLC). The FM9 module provides to Liulin-SET 28 V, 10 mA voltage from the JEM.

The spectrum, together with information for the real time, is saved in the flash memory of the instrument. The capacity of the memory is 64 MB, enough for the storage of 390 days non-stop compressed spectra with a 10 sec exposition time.

Conclusions

The data received from the new missions with Liulin spectrometers in 2021-2022 will contribute to the detailed evaluation and understanding of the radiation environment in space and in the Earths’ orbit. This is especially important, as the era of the space tourism has already been opened.

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 [19]. 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.

Acknowledgements

The authors are thankful to the following colleagues, who are ready to use Liulins in their projects: Prof. Ilya Usoskin, head of Oulu Cosmic Ray Station (https://www.oulu.fi/university/researcher/ilya-usoskin), Dr. Lucia Paciucci, National Research Council of Italy, Engineering, ICT and Technologies for Energy and Transportation Department (CNR-DIITET), Rome, Italy (https://www.cnr.it/peoplepublic/peoplepublic/index/scheda/u/lucia.paciucci) and President and Chief Scientist Dr. Kent Tobiska, Space Environment Technologies, Pacific Palisades, California, USA (https://spacewx.com/).

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