

Prediction and Measurement of the Space Radiation Altitudinal Profile during the Flight of the Virgin Galactic SpaceShipTwo

Dachev T.¹, Dimitrov P.¹, Tomov B.¹, Matviichuk Y.¹, Semkova J.¹, Koleva R.¹,

Jordanova M.¹, Bankov N.¹, Mitev M.¹,

Carlucci P.², Cairo F.², Kostadinov I.³, Paciucci L.⁴

¹Space Research and Technology Institute BAS, Sofia, Bulgaria, E-mail: tdachev@bas.bg

²National Research Council of Italy, Institute of Atmospheric Sciences and Climate (CNR-ISAC), Rome, Italy, E-mail: francesco.cairo@artov.isac.cnr.it

³Proambiente CNR Technopole, Bologna Italy, E-mail: i.kostadinov@isac.cnr.it

⁴National Research Council of Italy, Engineering, ICT and Technologies for Energy and Transportation Department (CNR-DIITET), Rome, Italy E-mail: lucia.paciucci@cnr.it

Abstract

The paper presents the design of the Portable Dosimeter-Spectrometer (PDS) Liulin-CNR-VG, which is expected to measure the space radiation altitudinal profile during the flight of the Virgin Galactic SpaceShipTwo in the fall of 2021 (<https://www.space.com/virgin-galactic-announces-unity-23-spaceflight-crew>). The PDS size is 66x56x26 mm and weighs 0.092 kg. The PDS should measure the following parameters: the flux of the charged particles in the range from 0.1 to 20,000 particles per square centimeter in 1 second; the absorbed dose in the range from 0.3 nGy to 1.56 mGy; the dose rate in the range from 0.04 µGy/hour to 0.18 Gy/hour. The altitude profile during the flight of Virgin Galactic SpaceShipTwo up to the 37.2 km altitude is expected to be similar to the profile measured with no shielded Liulin battery operated unit during the June 8, 2005 certification flight of the NASA Deep Space Test Bed balloon flight at Ft. Sumner, New Mexico, USA. During the ascending part of the flight, up to 13.7 km, the dose rate will rise from 0.058-µGy/hour up to 2.4 µGy/hour. The Pfofzer maximum is not expected to be well observed in the ascending part of the SpaceShipTwo flight. Above the maximum, at about 110 km altitude, the dose will fall down to 0.7 µGy/hour. During the re-entry, the SpaceShipTwo will observe the Pfofzer maximum of an expected dose rate of 3.4 µGy/hour. In the glide to land part of the flight, the dose rate will decrease back to 0.058-µGy/hour. The predicted values for the hourly dose rate of 1.83 µSv/hour and accumulated dose of 2.5 µSv reveals that there is no any radiation risk for the crew and astronauts flying at the VG SpaceShipTwo.

Introduction

The era of suborbital touristic flights up to 100-110 km altitude is already open by the missions of Virgin Galactic first crewed spaceflights on 11 July and Blue Origin on July 20 2021. It is rather difficult to say exactly where the atmosphere ends and space starts. A widely accepted definition uses what is called the Karman line (<https://astronomy.com/news/2021/03/the-krmn-line-where-does-space-begin>), which is at 100 km above the sea level as the boundary for space. According to NASA and the U.S. military, space starts at 80 km above the sea level. Richard Branson and his crew in the Virgin Space Ship Unity flew to an altitude of 86 km, whereas Jeff Bezos and other passengers in Blue Origin flew up to 107 km.

Liulin-CNR-VG is part of a Bulgarian - Italian research project "Portable Dosimeter-Spectrometer Liulin-CNR-VG". The project partners are Space Research and Technology Institute of the Bulgarian Academy of Sciences (SRTI-BAS) and the National Research Council of Italy, Department of Engineering, ICT and Technologies for Energy and Transport.

The design of the portable dosimeter-spectrometer Liulin-CNR-VG is not a new one. Since 1989, SRTI-BAS, in international cooperation with scientists from Russia, Germany, Japan, Czech Republic, Italy, Norway, USA and India flew in space with seventeen similar devices [Dachev *et al.*, 2015, 2017, 2020].

The ionizing radiation data obtained by the Liulin type instruments 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>. The instrument data are stored along with the orbital parameters of the satellites. The User Manual of the database is available online at <http://esa-pro.space.bas.bg/manual>. In the future, all parameters obtained with the Liulin-CNR-VG instrument will be added to the database.

Payload Technical Description

The external view of the portable dosimeter-spectrometer (PDS) is presented on Fig. 1. It is situated in an Extruded Aluminum Enclosure with a size 66x56x26 mm. The weight of the PDS is 0.092 kg.

The Portable dosimeter-spectrometer Liulin-CNR-VG measures the following parameters: the flux of the charged particles with an ionizing capacity above 1 MeV/mm in silicon, with a sensitive area of 2 cm², an energy resolution of 100 keV in the range from 0.1 to 20000 particles or quanta per square cm per sec.; absorbed dose in the range from 0.3 nGy to 1.56 mGy; dose rate in the range from 0.04 μ Gy/hour to 0.18 Gy/hour; energy deposited in the detector from 0.08 to 20.3 MeV. The measurement error is no more than $\pm 20\%$.



Fig. 1.

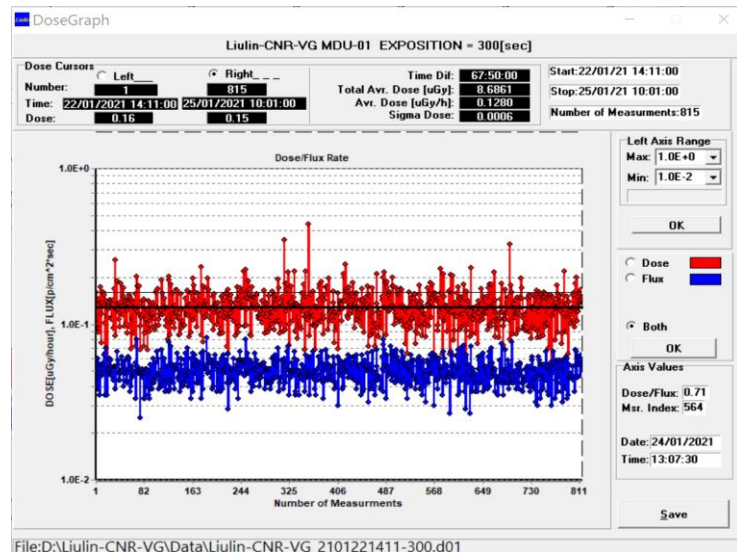


Fig. 2.

Fig. 1. External view of the portable dosimeter-spectrometer; Fig. 2. Example of the long-term measurements of the natural background radiation with Liulin-CNR-VG PDS.

Below the upper panel of the PDS are mounted the ON/OFF switch, the red status LED and the USB mini female connector. Below the panel are situated the two rechargeable cylindrical AAA size Lithium Ion cells 10440 of Portable Power Corp.

Under the 0.5 mm thick bottom panel of the PDS is situated the 2 cm² 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 Liulin-CNR-VG PDS is a Liulin type deposited energy spectrometer (DES) [Dachev *et al.*, 2015]. It uses one silicon detector to measure the deposited energy and the number of particles or quanta that allows calculating the dose rate and the flux.

The spectrometer-dosimeter contains one silicon-PIN diode of Hamamatsu S2744-08 (2 square cm area and 0.3 mm thickness), 1 ultra-low noise charge-sensitive preamplifier of AMPTEK A225F, 2 microcontrollers and 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 A225F 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 that 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.

Liulin-CNR-VG PDS is already constructed and manufactured. It is ready for the flight of the Virgin Galactic SpaceShipTwo. Fig. 2 presents example of the long-term measurements of the natural background radiation with Liulin-CNR-VG PDS. The start of the measurements was on January 22, 2021 at 14:11:00 hour. The end was on January 25, 2021 at 10:01:00. Eight hundred and fifteen measurements of the dose rate (red lines) and flux (blue lines) are presented. The exposition is 300 seconds. It is seen that the total dose for all measurements (67 hours and 50 minutes) is 8.6861 μGy . The average dose rate is 0.1280 $\mu\text{Gy}/\text{hour}$. This value is normal for the SRT-BAS laboratory. Similar values were observed in the last 20 years. The sigma of the dose is 0.0006. A high-energy deposition in the 256th channel is registered. It is depicted close to the center of Fig. 2.

Expected Dose Rates during the Flight of Virgin Galactic SpaceShipTwo

Goals of the study

The following objectives of the study are foreseen: Assessment of the human exposure to radiation into the cabin of SpaceShipTwo; Data collection for space weather modelling; Scientific publications; Optimization and proposal for new on-board equipment, useful for human exposure monitoring and standardization of the procedures to guarantee high safety levels. Project partners consider using Liulin-CNR-VG PDS in other experiments.

Expected flight times and altitudes

The following approximate flight times and altitudes can be expected during a typical flight of 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.

Altitude profile of the galactic cosmic radiation

Dachev in 2013 studied experimentally the altitude profile of the galactic cosmic radiation, which is the main, always-existing component of the radiation environment between the ground and the Moon orbit. Fig. 3 visualizes this profile. The altitude profile during the flight of SpaceShipTwo is expected to be similar in the range from ground up to 110 km altitude.

Overview of the radiation profiles data, obtained during three balloon flights

There are three experiments on balloons with participation of battery operated Liulin type instruments:

The first balloon flight, with one Liulin battery operated mobile dosimetry unit (MDU) [Spurny *et al.*, 2000], was launched from Gap-Tallard aerodrome, France (44.46°N, 6.03°E)

during a technological flight of CNES balloon program at 07:58 UTC on 14 June 2000. The effective cutoff rigidity at the coordinates of the Gap-Tallard aerodrome at 29 km altitude was calculated by SPENVIS, Magnetocosmics model (<http://www.spennis.oma.be/>) and was found to be equal to 5.18 GV. The measured maximal dose rate was $2.74\text{-}\mu\text{Gy/hour}$. The conditions are solar activity maximum. The Pfofzer maximum [Regener, E. & G. Pfofzer, 1935] was found at about 18.5 km altitude.

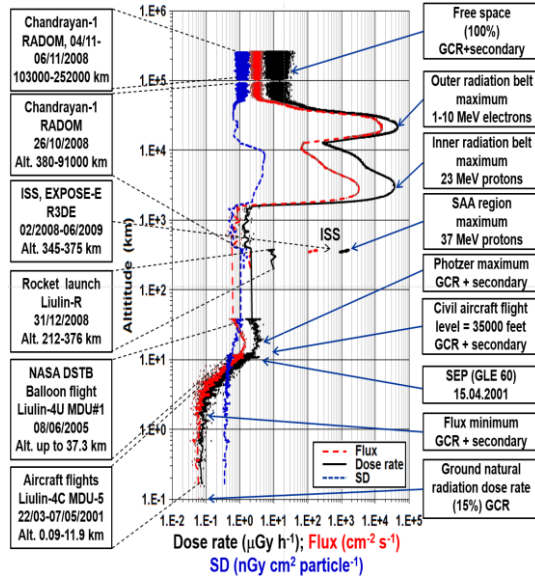


Fig. 3.

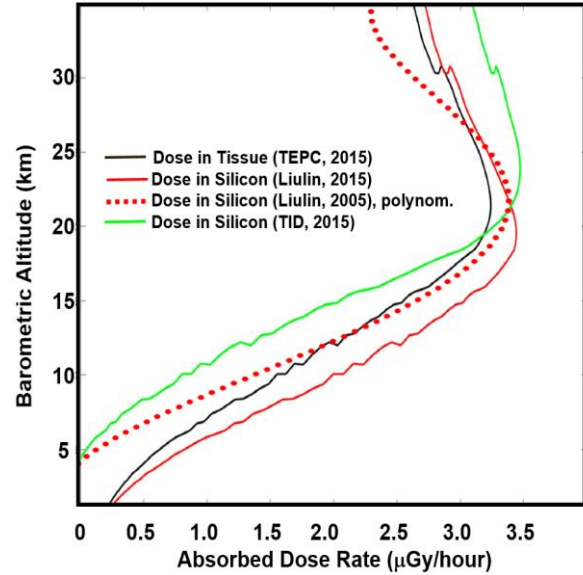


Fig. 4.

Fig. 3. Variations of the absorbed dose rate, flux and specific dose for the altitudinal range from 0.1 to 250,000 km.

Fig. 4. Altitude profiles of the absorbed dose rates measured in tissue (TEPC) and in silicon (Liulin and TID) during the ascent phase of the RaD-X balloon flight using the Fourier transform filtering: TEPC (black line), Liulin (red line), and TID (green line). The dashed red line presents the profile, obtained with the non-shielded Liulin MDU during the second balloon flight in June 2005.

The second balloon flight, with three MDUs, was performed during the June 8, 2005 certification flight of the NASA Deep Space Test Bed (DSTB) balloon at Ft. Sumner 104.24°W, 34.47°N, New Mexico, USA with an effective cutoff rigidity $R_c=4.08$ GV [Benton, 2005]; [Adams et al., 2007]. Data in Fig. 4 present the altitude profile between 12.5 and 37 km altitude obtained from the no shielded MDU. One of the other three MDUs was below 5 g/cm² shielding. The last one was below a carousel with a variable shielding. The measured maximal dose rate in the Pfofzer maximum, with the no shielded Liulin, was $3.5\text{-}\mu\text{Gy h}^{-1}$. The other 2 devices showed a bit higher dose rates and accumulated doses because of the higher amount of secondary particles generated in the shielding.

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. That is why we may consider that the data obtained during this balloon flight are relevant to be extrapolated to the expected radiation profile up to ~37.2 km (122,000 feet) altitude.

The predicted F10.7 radio flux value in the fall of 2021 and the first half of 2022, when the flight is expected, is between 77 and 89 s.f.u. These values are close to the F10.7 radio flux value during the balloon flight in June 2005 of 94 s.f.u. This is another reason to consider 2005 data relevant to the expected measurements in 2021-2022.

The third balloon flight was the NASA high-altitude RaD-X mission [Mertens et al, 2016]. It was performed again from Ft. Sumner on 25 of September 2015. Four radiation dosimeters

were on the board of RaD-X: a Far West HAWK tissue equivalent proportional counter (TEPC version 3) (<https://www.fwt.com/detector/fw-ad1ds.htm>), a Teledyne dosimeter (UDOS001), a Liulin dosimeter (MDU 6SA1) and a RaySure dosimeter (version 3b).

Fig. 4 in this paper represents Fig. 10 of [Mertens *et al.* 2016]. Three altitude profiles from the flight in 2015 are depicted. The Liulin-6SA1 profile is with a red line. It is seen that the Liulin-6SA1 profile is very similar to TEPC and TID profiles, which confirms the Liulin instruments quality of measurements. The three profiles from TEPC, TID and Liulin-6SA1 seen in Fig. 4 do have almost linear rise in the range from ground up to 15-16 km altitude.

The polynomial presentation (4th order) (Fig. 4 red dashed line) is used to illustrate Liulin doses obtained during the flight in 2005. As expected, the Liulin profiles in 2005 and 2015 are very similar. The latter again backs up the decision Liulin 2005 data to be used in the predicted dose rate profile during the flight of Virgin Galactic SpaceShipTwo.

Predicted dose rates during the flight of Virgin Galactic SpaceShipTwo in the fall of 2021

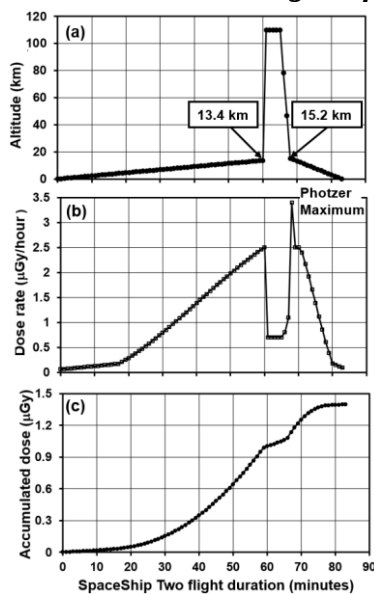


Fig. 5.

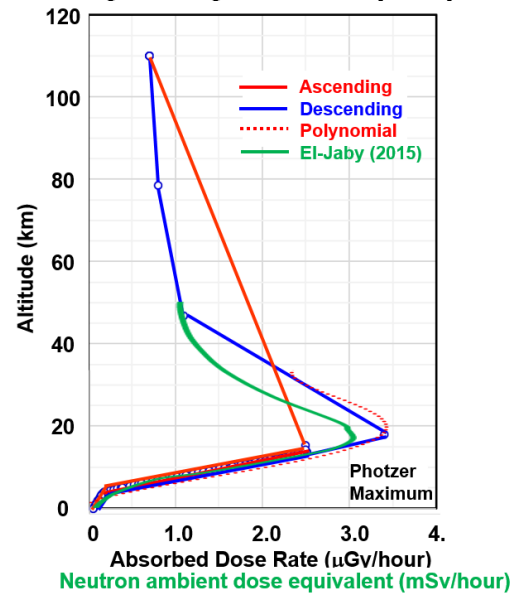


Fig. 6.

Fig. 5. Predictions: Fig. 5a SpaceShipTwo altitude during the flight; Fig. 5b Hourly absorbed dose rates; Fig. 5c Accumulated absorbed dose rate.

Fig. 6. Predicted altitudinal profile of the absorbed dose rate during the flight.

Fig. 5a presents the time profile of the altitude of SpaceShipTwo during the flight with 1-minute resolution up to altitude of 110 km. The data shown in section ***Expected flight times and altitudes*** is used. Fig. 5b shows the predicted hourly-absorbed dose rates during the flight. Polynomial data of order of four from the second balloon flight in 2005 (Fig. 4), was used for the altitudes above 3.9 km. Other dose rate profiles were predicted by linear rise equations. The similarity of the data is explained with similarity of the solar activity in 2005 and 2015. Similar moderate solar activity is expected during the VG flights in 2021-2022 (<https://www.swpc.noaa.gov/products/solar-cycle-progression>).

During the first part of the flight, the dose rate rises from 0.058-μGy/hour up to 2.5 μGy/hour. The Pfozter maximum with a dose rate of 3.4 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 falls down to 0.8 μGy/hour and slowly decreases up to 110 km altitude in a similarity of the [El-Jaby, and Richardson, 2015] profile (green line). The dose rate does not change during the 4 minutes of microgravity. It starts to increase during the re-entry, going through the Pfozter maximum. In the “glide to land” part of the flight, the dose rate decreases back to 0.058-μGy/hour.

Fig. 6 presents the same data with 1-minute time resolution as in Fig. 5b but in dependence of the altitude. The doses during the ascending part of the orbit are presented with red points and line, while the descending part with blue line. The polynomial presentation of the Liulin data in 2005 is shown with red dashed line.

As illustrated in Fig. 5c, the increase of the accumulated dose rate alters in μGy from zero to $1.4 \mu\text{Gy}$. The equivalent dose during the flight is calculated to be about $2.5 \mu\text{Sv}$ for 82 minutes ($1.83 \mu\text{Sv}/\text{hour}$) because the mean quality factor is about 1.8 for a subsonic flight ($1.4 \times 1.8 = 2.5 \mu\text{Sv}$). 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 $32 \mu\text{Sv}$ ($4.6 \mu\text{Sv}/\text{hour}$), the equivalent of a panoramic dental X-ray scan https://www.radioactivity.eu.com/site/pages/Radioactivity_in_Flight.htm. The calculated by us accumulated dose of $2.5 \mu\text{Sv}$ is about 13 times less. The predicted values for the hourly dose rate of $1.83 \mu\text{Sv}/\text{hour}$ and accumulated dose of $2.5 \mu\text{Sv}$ reveals that there is no any radiation risk for the crew and astronauts flying at the VG SpaceShipTwo.

Conclusions

The paper presents the design of the Portable Dosimeter-Spectrometer Liulin-CNR-VG. The latter will measure the space radiation altitudinal profile during the flight of the Virgin Galactic SpaceShipTwo in the fall of 2021.

It is very important and interesting to obtain the dose rates between 37 and 110 km altitude as this region is rather poorly studied.

The data obtained will be beneficial for the space tourism, the newly developing segment of the aviation industry that seeks to give tourists the ability to become astronauts and experience space travel for leisure or business purposes.

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