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BULGARIAN PARTICIPATION IN ESA-ROSCOSMOS EXOMARS MISSIONS. RADIATION CHARACTERISTICS ONBOARD EXOMARS TGO DURING THE CRUISE TO MARS ACCORDING TO LIULIN-MO DATA

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Abstract: *ExoMars is a joint ESA - Rosscosmos programme for investigating Mars (http://exploration.esa.int/mars/46048-programme-overview/). Two missions are foreseen within this programme: one consisting of the Trace Gas Orbiter (TGO), that 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 14 March 2016; and the other, featuring a rover and a surface platform, with a launch date of 2020. SRTI-BAS participates in both missions with experiments for investigation of the space radiation environment, conducted by dosimeters of Liulin type instruments. The experiment Liulin-MO for measuring the radiation environment onboard the ExoMars 2016 TGO is a part of the Russian Fine Resolution Epithermal Neutron Detector (FREND) onboard TGO. The second envisaged experiment is the Liulin-ML experiment for investigation of the radiation environment on Mars surface. The experiment will be conducted with the Liulin-ML dosemeter as a module of the Russian active detector of neutrons and gamma rays (ADRON-EM) on the surface platform of ExoMars 2020 mission. Presented is the Liulin-MO dosimeter, results from measurements of the dosimetric parameters in the interplanetary space during the cruise of TGO to Mars and first results from dosimetric measurements in high elliptic Mars' orbit.*

БЪЛГАРСКО УЧАСТИЕ В МИСИИТЕ ЕКЗОМАРС НА ЕКА И РОСКОСМОС. РАДИАЦИОННИ ХАРАКТЕРИСТИКИ НА БОРДА НА СПЪТНИКА TGO ПО ПЪТЯ МУ ДО МАРС ПО ДАННИ ОТ ДОЗИМЕТЪРА "ЛЮЛИН-МО"

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Ключови думи: *космическа радиационна дозиметрия, ЕкзоМарс, галактични космически лъчи*

Резюме: *ЕкзоМарс е съвместен проект за изследване на Марс на Европейската и Руската космически агенции (http://exploration.esa.int/mars/46048-programme-overview/). ЕкзоМарс включва две* *космически мисии: 1) една, включваща изпращането на орбитален спътник TGO за изследване на малки атмосферни съставки (метан и др.), които могат да имат биологически или геологически произход и на десантен, и демонстрационен модул към Марс, която беше изстреляна на 14.03.2016г; 2) втора, която ще включва спускаема платформа на повърхността на Марс и марсоход, и която е планирана за изстрелване през 2020г. ИКИТ-БАН участвува и в двете мисии с експерименти за изслезване на радиационните условия в космоса, провеждани с дозиметри от серията “Люлин”. Дозиметричният телескоп “Люлин-МО” е един от модулите на руския детектор на неутрони ФРЕНД на борда на спътника TGO. С “Люлин-МО” се провеждат изследвания на радиационните условия на борда на TGO по време на полета му към Марс и в орбита около Марс. Вторият предвиден експеримент е “Люлин-МЛ” за изучаване на радиационните условия на повърхността на Марс. Той ще се провежда с дозиметъра “Люлин-МЛ”, един от модулите на руския детектор на неутрони и гама лъчи АДРОН-ЕМ на спускаемата платформа на повърхността на Марс. Представен е дозиметърът “Люлин-МО”, рзултати от измерванията му на дозиметричните параметри в междупланетното пространство по време на пътуването на TGO към Марс и първи резултати от измерванията във високо елиптична орбита около Марс .*

Introduction

Mars, like each celestial body, is unceasingly bombarded by energetic particles of galactic cosmic rays (GCR) and sporadically - by particles of solar particle events (SPE). These ionising particles modify the escape rates and the chemistry of Mars atmosphere; affect the evolution of the climate. Mars is known to have no strong magnetic field and very thin atmosphere. Particles of GCR penetrate down to the Martian surface, affect the chemistry at ground and can destroy complex organic materials if existing [1] and references therein). Secondary neutrons are produced within an upper most layer about 1 m thick. These neutrons easily leak out to the near-Mars space and contribute into the local radiation environment of Mars. They also bear important information about the abundances and distributions of light elements, especially hydrogen. GCR and SEP events affect the operation of satellites, and the human exploration of the planet.

GCR represent a continuous radiation source and they are the most penetrating among the major types of ionising radiation. The distribution of GCR is believed to be isotropic throughout the interstellar and interplanetary space. The energies of GCR particles can reach 10^{20} eV/nucleon. Most of the deleterious effects with regard to health produced by this radiation are associated with nuclei in the energy range from several hundred MeV/nucleon to a few GeV/nucleon. The flux and spectra of GCR show modulation that anti-correlates with the solar activity. The GCR flux consists [2]) mainly of protons (85%   90%) and helium (about 11%), with about 1% electrons and another 1% heavy ions. The latter are sometimes referred to as “HZE” particles, for high charge (Z) and energy (E). These are defined as the bare nuclei of lithium (Z = 3) and all heavier elements, fully stripped of their electrons. The HZE particles play a particularly important role in the space dosimetry [3]) as they are highly penetrating and affect strongly the biological objects and humans in space [4]).

Solar energetic particles (SEP) are randomly distributed events, but they may deliver very high doses over short periods and that is why they could be associated with the lethal equivalent doses. It is now widely agreed that SEPs come from two different sources with different acceleration mechanisms working: the flares themselves release impulsive events while the coronal mass ejection (CME) shocks produce gradual events [5]). High fluxes of charged particles (mostly protons, some helium and heavier ions) with energies up to several GeV and intensity up to 10^4 cm^{-2} s^{-1} sr^{-1} are emitted. The time profile of a typical SEP event starts with a rapid increase in flux, reaching a peak in minutes to hours. Although SEPs are more likely to occur around solar maximum, such events are at present unpredictable with regard to their times of occurrence and it cannot be assumed that SEPs will not occur under solar minimum. The most intense solar proton fluencies observed were those on August 1972 and October 1989. The flare containing the largest peak flux of highly penetrating particles was in February 1956. On this basis the so-called worst-case flare is composed, that is thought to occur once a century, but statistics are extremely poor.

The deep space manned missions are already a near future of the astronautics. Radiation risk on such a long-duration journey, a great part of which will take place in the interplanetary space, appears to be one of the basic factors in planning and designing the mission.

The estimation of the radiation effects for a long-duration manned space mission requires three distinct procedures: i) Knowledge and modeling of the particle radiation environment; ii) Calculation of primary and secondary particle transport through shielding materials; and iii) Assessment of the biological effect of the dose

i) ***Direct measurements*** of the radiation environment in the interplanetary space and at celestial bodies other than Earth are quite sparse. The first evaluation of the radiation field at Mars orbit was performed by the experiments on board of Mars Odyssey orbiter [6]) using data of three different instruments: MARIE, a dedicated energetic charged particle spectrometer; the Gamma Ray Spectrometer GRS and the scintillator component of the High Energy Neutron Detector HEND. The time period analysed data cover the time span from early 2002 through the end of May 2007, encompassing the maximum, the declining of Solar cycle 23 and most of the extraordinarily deep solar minimum. During a quiet period in 2002 the GCR flux was evaluated to be 0.135 cm^{-2} sr^{-1} s^{-1}. Weakening of the interplanetary magnetic field over this period of time led to an observed doubling of the galactic cosmic ray flux. 23 SEP events (with 25 peaks) were recorded during the period, the large majority of events were quite weak. Peak SEP fluxes between 50 and 100 cm^{-2} sr^{-1} s^{-1} were seen only twice (July 2002 and October 2002), and only in the large event of October 2003 was a flux above 1000 cm^{-2} sr^{-1} s^{-1} recorded. According to HEND data [7] the flux of the secondary (epithermal) neutrons from the Mars surface, produced by GCR only, has increased during this time period in about 1.5 times from 0.73 up to 1.1 cm^{-2} s^{-1}.

During the deep solar minimum at the end of 2008 - first half of 2009 - the RADOM dosimeter-spectrometer on the Chandrayaan-1 satellite [8] registered during lunar transfer trajectory (4th to 6th November 2008) an average GCR flux of ~ 3.14 cm^{-2} s^{-1}, producing an average dose rate of ~13 μGy h^{-1} in the silicon detector of the instrument. In a 100 km circular orbit around the Moon the GCR dose rates fall down because of the Moon shielding to about 9.46 μGy h^{-1} and stayed stable around this value. The average flux was 2.45 cm^{-2} s^{-1}.

The CRaTER experiment on board the Lunar Reconnaissance Orbiter spacecraft provided another evaluation of GCR doses in Moon orbit during an adjacent period of the same deep and prolonged minimum between the 23rd and the 24th solar cycles [9]. Using a validated radiation transport models of the instrument for the period from 16 September 2009 through 6 March 2010 they estimated a direct GCR dose in silicon of ~ 320 μGy d^{-1}. The Moon albedo particles complemented the dose rate to 372 μGy d^{-1}. Thanks to the sophisticated instrument model they succeeded to estimate the contribution of the different GCR components: ~43% of the total dose is delivered by protons, 18.5% by alpha particle and ~30% by all other heavier ions. The albedo particles contribute another 8.5% to the total dose rate.

The most recent measurements of the interplanetary radiation environment were performed aboard of NASA Mars Science Laboratory (MSL, Curiosity) during its cruise to Mars by the RAD instrument [10]. For the period from 6 December 2011 to 14 July 2012 – conditions of increasing solar activity - for solar quiet times (without SEPs) they report an average daily dose rate in silicon is 332 ± 23 μGy/day. The fluence rate of GCR was 3.87 ± 0.34 cm^{-2} s^{-1} [11]. The 4 SEP events during this period produced ~ 25 mGy, from 1.2 to 19.5 mGy/event. The integral particle fluxes for penetrating ion species (protons and other) with $Z = 1$, estimated from RAD during the transit of MSL to Mars from June 11 to July 14, 2012 is 0.225 ± 0.018 cm^{-2} s^{-1} sr^{-1} [12].

RAD on MSL is the only experiment measuring the complex radiation environment on Mars' surface. From 7 August 2012 to 1 June 2013 (solar maximum) the average dose rate (in water) from GCR was 210 μGy/day, the only SEP event delivered a dose of 25 μGy [11].

ii) ***Biological effect of the dose***. Energy deposition by charged particles is dominantly due to ionization energy loss, dE/dx. A commonly used term in radiobiology is Linear Energy Transfer (LET) in water. In practice to account for the varying biological effects of different types of radiation is used the quantity dose equivalent H given in units of Seiverts (Sv). It is estimated by means of the quality factor Q, a strictly function of LET. Both CRaTER and RAD experiments provide the possibility to calculate LET and estimate the dose equivalent. They give well comparable values of H though measured under different conditions.

During the period near the last solar minimum, when GCR intensities were greatest, the dose equivalent rate measured by CRaTER in Moon orbit at the altitudes of the Lunar Reconnaissance Orbiter (~50 km) is estimated to be ~ 2.88 mSv d^{-1} or an annual dose equivalent of ~ 1.05 Sv [9].

The dose equivalent rate measured by MSL/RAD near the maximum of the present solar cycle was estimated to 0.64 ± 0.12 mSv d^{-1} on Mars surface and 1.84 ± 0.30 mSv d^{-1} during cruise [10, 11]. This gives a total mission dose equivalent of ~ 1.01 Sv for a round trip Mars surface mission with 180 days (each way) cruise, and 500 days on the Martian surface for the 2012–2013 weak solar maximum. The larger part of that dose (662 ± 108 mSv), which approaches two-thirds of the career exposure limit recognized at NASA to carry a 3% increased risk of fatal cancer at the upper 95% confidence level would be accumulated during the cruise phase. That dose is also two-thirds of the career exposure limit recognized by the Russian Space Agency, European Space Agency, and Canadian Space Agency. It was noted that only about 5.4% of the contribution to the estimated total dose equivalent from both GCR and SEP events of 466 ± 84 mSv during the 253 days MSL's cruise to Mars was due to SEPs and it was surmised (given the relatively low activity profile of solar cycle 24) that the SEP contribution could have been many times larger had it been measured in a different time frame.

Since 1989 the Liulin type dosemeters-spectrometers have been conducting measurements of the radiation environment characteristics onboard a number of manned and unmanned spacecrafts in low Earth orbits or in the interplanetary space [13]. The total number of the built instruments and conducted experiments is 28. Liulin type instruments have been used onboard Mir Space Station, in many experiments on ISS, Foton M2/M3/M4, Chandrayaan-1, Phobos-Grunt, and BION satellites.

New Liulin type instrumentation is used for radiation investigations during the ExoMars TGO mission. The dosimetry experiment Liulin-MO is a part of the Russian Fine Resolution Epithermal Neutron Detector (FREND) onboard the TGO. Main goal of FREND is to map neutron fluxes coming from Mars, which are good indicator of hydrogen abundance in the shallow layer (up to 1 m deep) in the regolith (https://np.cosmos.ru/en-us/instruments/frend). FREND contains four ^{3}He counters for neutrons with energies from 0.4 keV to 500 keV, one stilbene-based scintilator for high energy neutrons (up to 10 MeV) and the dosimetry module Liulin-MO. Liulin-MO has been developed in SRTI-Bulgaria with participation of IMBP-RAS and IKI-RAS.

Liulin-MO scientific objectives

The main goal of the Liulin-MO dosemetric experiments is investigation of the radiation conditions in the heliosphere at distances from 1 to 1.5 AU from the Sun.

The primary science objectives of the Liulin-MO investigation are:

- To measure dose and determine dose equivalent rates for human explorers during the interplanetary cruise and in Mars orbit.
- Measurement of the fluxes of GCRs, SEPs, secondary charged particles and gamma rays during the cruise and in Mars orbit.
- Together with other detectors of FREND instrument to provide data for verification and benchmarking of the radiation environment models and assessment of the radiation risk to the crewmembers of future exploratory flights. ExoMars TGO mission represents the unique opportunity to conduct measurements of the radiation characteristics during the declining phase of the 24th Solar Cycle.More detailed science objectives are to provide during the cruise and on Mars orbit:
- Continuous measurements of the energy deposition spectra, dose rate and particle flux. Investigation of their changes over time (e.g., over the course of the solar activity cycle). Estimation of the absorbed dose D.Measurements of dE/dx (energy loss per path length) spectra in silicon that can be related to the Linear Energy Transfer (LET) spectra in water and then calculation of the radiation quality factor Q according to the $Q(LET)$ relationship given in ICRP – 60 [14]. Estimation of the dose equivalent H as $H = D•Q$.
- Measurements of GCR flux and dose rate in dependence on the heliocentric distance.
- Investigation of the dependence of the GCR radiation parameters in Mars orbit on the distance to Mars.
- Simultaneous registration of SEP events together with other space instruments providing radiation data, including HEND instrument on Mars Odyssey and DAN on Curiosity.
- Assessment of both the charged particle and the neutron fluxes and dose rates during periods of quiet Sun and during SEP events combining data from the dosimeter and the neutron detectors of FREND. Liulin-MO has no capabilities to measure the contributions to dose and dose equivalent from neutral particles, but the neutron detectors of FREND may provide these data [15].
- An additional goal of the Liulin-MO experiment is to increase the accuracy of the neutron measurements by providing information about radiation fluctuations from charged particles that can have an impact on the signals from the neutron detectors of the FREND instrument.
- Comparison of orbital and ground data as measured by the FREND’s dosimeter on TGO and the dosimeter Liulin-ML of ADRON instrument on the ExoMars 2020 Surface Platform.

Liulin-MO relies on previous and recent flight heritage of Liulin type dosimetric instruments. It is a further development of the Liulin-5 and Liulin-Phobos dosimetric telescopes already flown in space [16, 17].

Description of Liulin-MO

The dosimeter Liulin-MO contains two dosimetric telescopes - A&B, and C&D arranged at two perpendicular directions. Each pair of dosimetric telescopes consists of two 300 µm thick, 20x10 mm area rectangular Si PIN photodiodes. The distance between the parallel Si PIN photodiodes is 20.8 mm. A schematic view of the location of the detectors is presented in Fig. 1, the block diagram of the instrument is shown in Fig 2. The geometry factor of the telescope for isotropic radiation is ~ 1,38 cm^{2}sr. The geometry factor of a single detector is ~ 12,56 cm^2 sr. The external view of FREND with its dosimeter Liulin-MO is shown in Fig. 3.

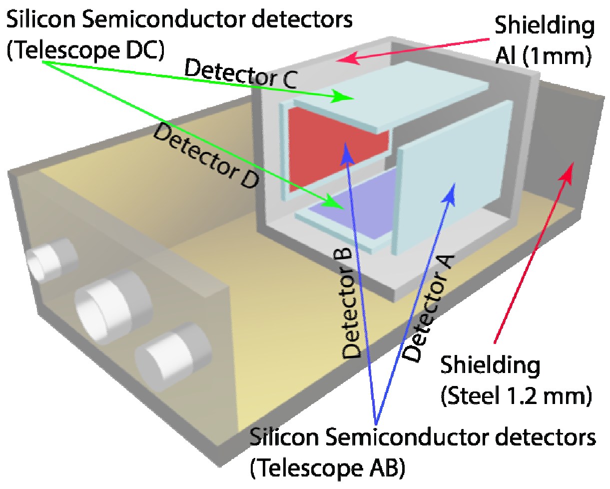

Fig. 1. A schematic view of the location of Liulin-MO detectors

The primary measured parameters are the amplitudes of voltage pulses at the outputs of charge-sensitive preamplifiers - shaping amplifiers CSA1 to CSA4, connected to the detectors. The amplitude of a voltage pulse is proportional to the energy deposited in the corresponding detector by a charged particle or a photon crossing the detector, and to the respective dose. These amplitudes are digitized with an 8-bit ADC and organized in a deposited 256 channel's energy deposition spectrum for each of the detectors. The energy deposition spectrum in a single detector A (or B) is obtained by summing the energy deposition spectrum measured by B - CSA2 in the range ~ 0.08 ÷ 15.9 MeV with the energy deposition spectrum measured by A - CSA1 in the range ~ 16 ÷ 190 MeV. The same procedure is used to obtain the energy deposition spectrum in single detectors C and D. In that way each pair of two parallel detectors and their corresponding CSAs provide data in the energy deposition range ~ 0.08 ÷ 190 MeV. The energy deposition spectra measured in A and B (C and D) detectors in coincidence mode are recorded separately and used to obtain the linear energy transfer (LET) spectrum in the direction of A - B (C - D). The LET is used for calculation of the radiation quality factor Q, according to the Q(LET) relationship given in ICRP – 60. Totally 9 energy deposition spectra in anti-coincidence and coincidence modes are measured and provided in Liulin-MO output data.

The parameters, provided by Liulin-MO simultaneously for two perpendicular directions have the following ranges: absorbed dose rate in the range 10^{-7} Gy h^{-1} ÷ 0.1 Gy h^{-1}; particle flux in the range 0 ÷ 10^{4} cm^{-2} s^{-1}; energy deposition spectrum and coincidence energy deposition spectrum in the range 0.08 ÷ 190 MeV. The large dynamic ranges of the flux and the dose rate measurements allows Liulin-MO to measure the fluxes and dose rates both of the relatively low–intensity GCR and the occasional high–intensity powerful SEP events. The dynamic range of the energy deposition spectrum allows assessment of the contribution to the absorbed dose, LET, and dose equivalent of the gamma rays, electrons, protons and heavy ions of GCR, including the

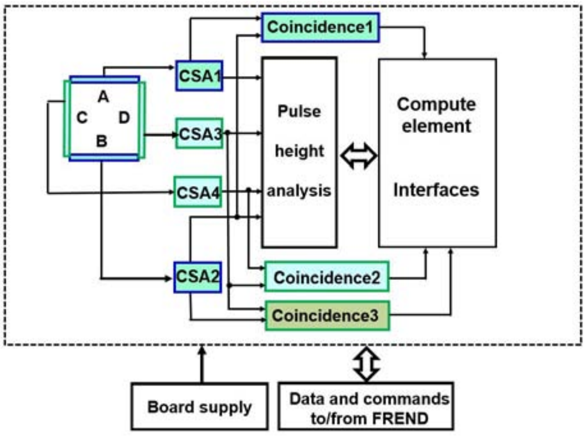

Fig. 2. Block diagram of Liulin-MO dosimetry module

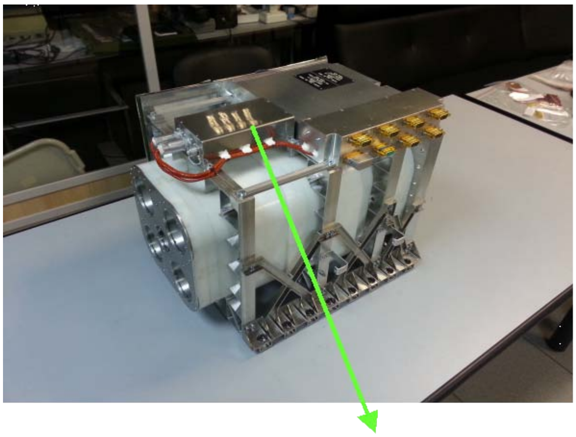

Fig. 3. FREND instrument. The arrow shows Liulin-MO module. *Credit: ESA/Roscosmos/FREND/IKI*.

most dangerous iron ions.The dose rates and the fluxes are resolved every minute, while the energy deposition spectra and the LET spectra are resolved every hour.

The dosimeter receives power directly from TGO, but sends all acquired data to FREND. The data transferred to FREND is 2 Mbits/day. FREND then retransmits it together with its own scientific data.

The entire package Liulin-MO has a mass of 0.7 kg and consumes 2.2 W.

More detailed description of Liulin-MO dosimeter can be found in [18].

Liulin-MO data during the TGO cruise and discussion

FREND and its dosimeter Liulin-MO were turned on for the first time on 06.04.2016 during initial check of the science instruments onboard TGO. All modules of FREND performed nominally.

From 22.04.2016 to 18.07.2016 one of the ^{3}He and the scintillate detectors of FREND, as well as Liulin-MO were turned on almost continuously. From 19.07.2016 to 11.08.2016 during Deep Space Maneuvers of TGO all FREND modules were turned off. From 11.08.2016 to 15.09.2016 Liulin-MO was turned on periodically. During the TGO cruise the dosimeter has measured the dosimetric parameters of GCR. No SPE were registered.

On 15.09.2016 FREND was turned off for the period during the operations for Mars orbit insertion and EDM release. TGO was inserted into Mars orbit on 19.10.2016. FREND, including Liulin-MO, were turned on again on 31.10.2016 already in Mars high elliptic orbit.

In Fig. 4 the fluxes and dose rates recorded in the perpendicular detectors B(A) and D(C) of Liulin-MO from 22.04 to 18.07.2016 during the interplanetary cruise are shown. A good correlation between the flux and dose rate data is observed. The average dose rate in B(A) is 15.45 μGy h^{-1}, in D(C) it is 16.23 μGy h^{-1}. The average flux is 3.12 cm^{-2} s^{-1} in B(A) and 3.29 cm^{-2} s^{-1} in D(C). The linear approximations of the dose rates are also shown. The difference between the corresponding values of the dose rates and fluxes in B(A) and D(C) is due to the different shielding of the detectors in two perpendicular directions.shows the dose rates recorded in detectors B(A) and D(C) from 22.04 to 18.07.2016 and count rates of the Oulu neutron monitor for the same period (https://cosmicrays.oulu.fi/). A good agreement of the variations in Liulin-MO dose rates with the neutron monitor count rate over the time is observed. The increase of the dose rates and particle fluxes with time correlates with the decreasing of the solar activity in the declining phase of the 24-th solar cycle and the increase of GCR fluxes.

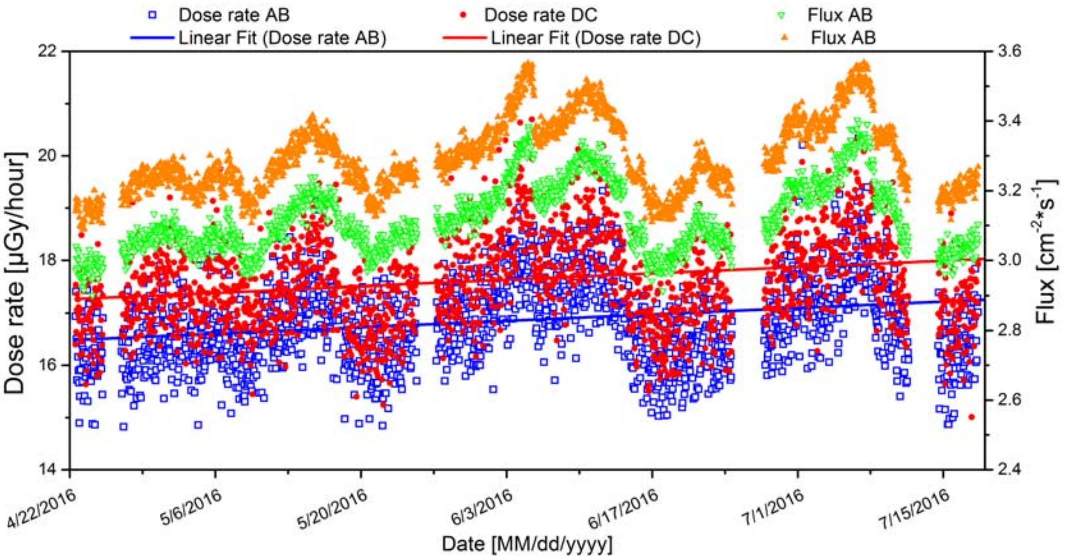

Fig. 4. Particle fluxes and dose rates recorded in the perpendicular detectors B(A) and D(C) of Liulin-MO from 22.04 to 18.07.2016. The straight lines are the linear approximations of the dose rates.

Table 1. Comparison of the dose rates in silicon, measured by RAD and Liulin-MO

RAD (MSL cruise)	**Liulin-MO (TGO cruise)**
GCR dose rate (06.12.2011-14.07.2012)	GCR dose rate (22.04-18.07.2016)
332±23 μGy d^{-1}	372±30 μGy d^{-1} in B(A) 390±31 μGy d^{-1} in D(C)

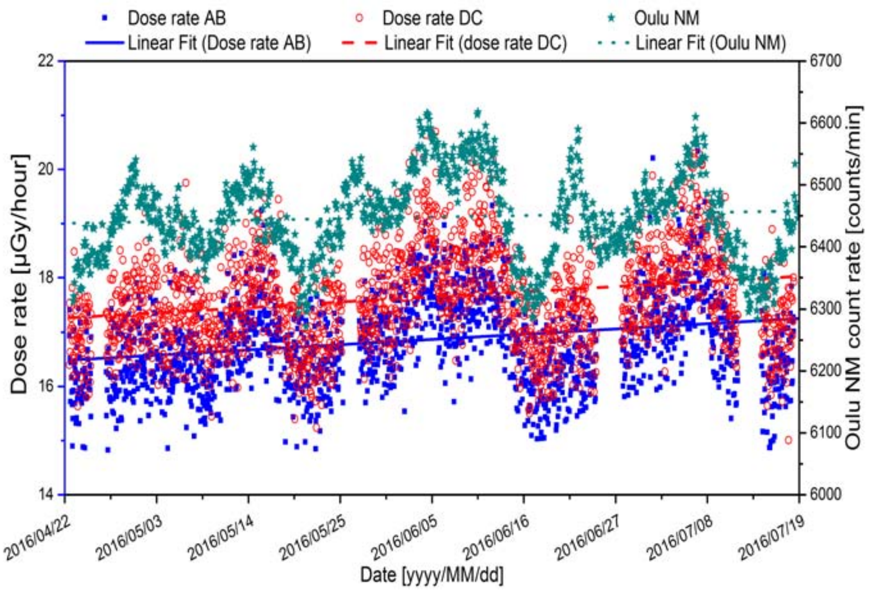

Fig. 5. Dose rates recorded in detectors B(A) and D(C) from 22.04 to 18.07.2016 and count rates of the Oulu neutron monitor for the same period. Shown are also the linear approximations of the measured values.

Table 1 presents a comparison of the dose rates in silicon, measured by RAD instrument onboard Mars Science Laboratory (MSL, Curiosity rover) during the cruise to Mars in 2011-2012 year [10] and by Liulin-MO from 22.04 to 18.07.2016 during the cruise of TGO to Mars. The daily doses measured by the two instruments in the interplanetary space differ by about 10-15%. This is due to the different shielding of the instruments, but also to the increased GCR flux in 2016 compared to the GCR flux in 2012.

The LET spectra and the preliminary results for the radiation quality factors were evaluated, and the dose equivalent rates in the interplanetary space were obtained. Fig. 6. shows the LET spectra in directions B-A and D-C and the comparison with the LET spectra obtained by RAD instrument during In B-A direction Q = 3.97; in D-C direction Q = 4.27 for GCRs, H (BA) = 1.8 ± 0.3 mSv d^{-1}, H (DC) = 2 ±0.3 mSv d^{-1}. RAD estimated H = 1.84 ± 0.30 mSv d^{-1} in the interplanetary space.

Fig. 7 shows the charged particle counts (in arbitrary units) by 4 different instruments located at different location in the heliosphere, taken from 22.04 to 18.07.2016: 1) the Solar Isotope Spectrometer (SIS) protons with energies ≥ 30 MeV on the Advanced Composition Explorer (ACE satellite) located at L1 libration point at about 1.5 million km from Earth (http://www.srl.caltech.edu/ACE/ASC/level2/lvl2DATA_SIS.html); 2) Liulin-MO FREND dosimeter on

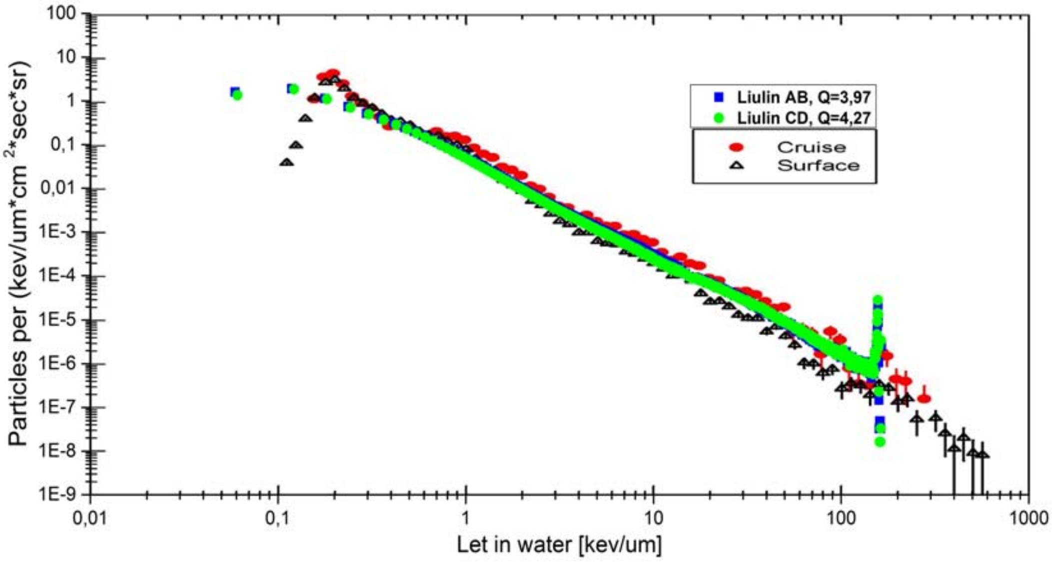

Fig. 6. GCR LET spectrum in the interplanetary space measured from 22.04 to 18.07.2016. Comparison with RAD data for GCR LET spectrum during the transit and on Mars surface.

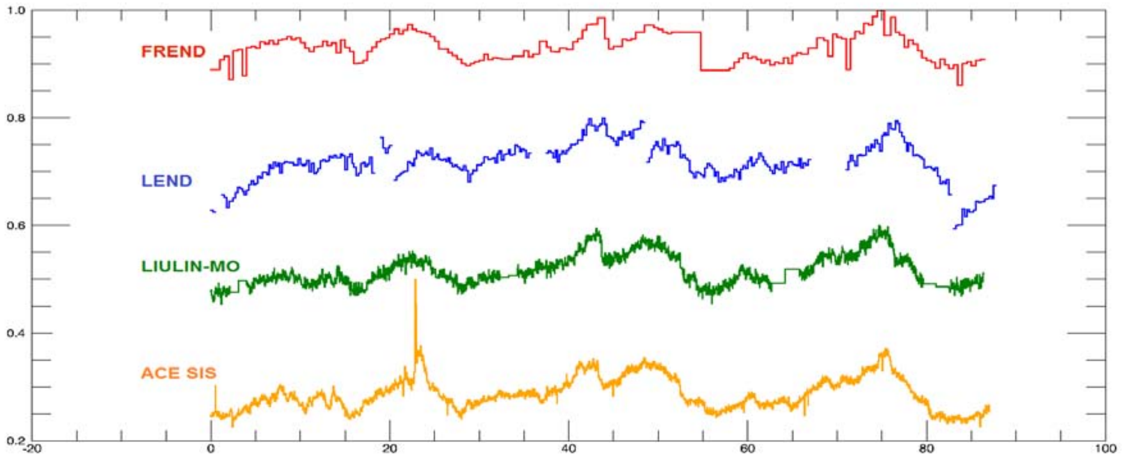

Fig. 7. Charged particle counts (in arbitrary units) by : 1) SIS-ACE protons with energies ≥ 30, 2) Liulin-MO-TGO protons with energies ≥ 30 MeV and other charged particles 3) LEND - LRO GCR on (in blue), 4) FREND -TGO GCR

TGO - electrons with energies ≥ 2.5 MeV, protons with energies ≥ 30 MeV, heavy charged particles; 3) the ^{3}He detector of LEND instrument on Lunar Reconnaissance Orbiter LRO (https://np.cosmos.ru/en-us/instruments/lend) and 4) FREND He1 detector on TGO – particles fitted counts (https://np.cosmos.ru/en-us/instruments/frend). A good agreement of all 4 instruments GCR counts is observed, particularly of SIS and Liulin-MO.

First Liulun-MO data in high elliptic Mars' orbit

On 19.10.2016 TGO was captured in high elliptic Mars' orbit with apocenter about 101 000 km and pericenter about 250 km.

In Fig.8 the particle flux measured by Liulin-MO on 01.11.2016 immediately after switching on of all FREND detectors in high elliptic Mars orbit is plotted. The observed decrease of the GCR particle flux is due to the shadowing of Liulin-MO field of view by the planet when TGO is close to or in pericenter. Simultaneously in the same figure the part of the TGO solid angle not shadowed by Mars is plotted. A good correlation between the trend of the measured particle flux and the part of the TGO solid angle not shadowed by Mars is observed.

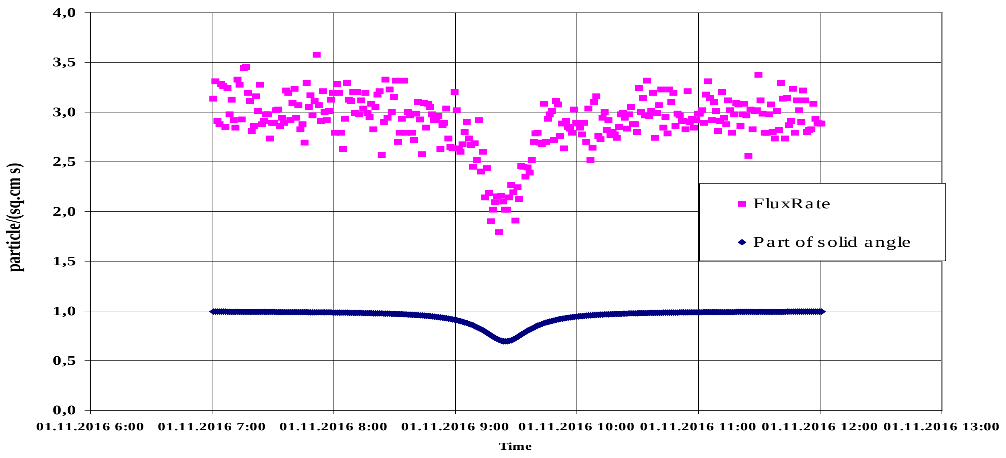

Fig. 8. Top- data for the particle flux rate near the pericenter. Bottom-part of the TGO solid angle not shadowed by Mars.

In Fig. 9. the scheme for calculation of the TGO shadowing by Mars is presented, where Rm is the Mars radii, D is the distance of TGO to Mars, Θ is half of the TGO solid

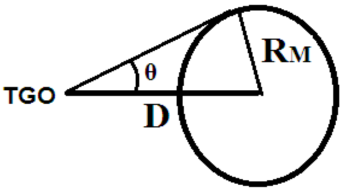

Fig. 9. Scheme for calculation of the TGO shadow by Mars

angle shadowed by Mars. The part η of the angle not shadowed by Mars is calculated as: $\eta = [1 - \cos(\Theta)]/2$ (1).

The effect of the shadowing of the particle flux by Mars is observed from the pericenter to TGO altitudes of 1500-3000 km from the planet.

Conclusion

New dosimetric telescope Liulin-MO for measuring the radiation environment as a module of FREND neutron instrument has been launched onboard the ExoMars 2016 Trace Gas Orbiter satellite.The average measured dose rate in Si from GCR during the transit to Mars for the period 22.04-18.07.2016 is 372 ± 30 mGy d^{-1} and 390 ± 31 mGy d^{-1} in two perpendicular directions. The average flux in the interplanetary space is 3.12 cm^{-2} s^{-1} and 3.29 cm^{-2} s^{-1} in two perpendicular directions.

This is in good agreement with previous radiation dose measurements in the interplanetary space and with current solar activity.

The preliminary data shows dose equivalent rates for the same period 1.8 ± 0.3 mSv d^{-1} and 2 ± 0.3 mSv d^{-1} in two perpendicular directions.

A good agreement between the measurements of GCR count rates taken during the TGO transit by all FREND detectors and measurements taken by other instruments in different locations in the heliosphere is observed.

The first dosimetric measurements in high elliptic Mars' orbit demonstrate strong dependence of the GCR fluxes near the TGO pericenter on the part of the TGO solid angle not shadowed by Mars.

A similar to Liulin-MO module, called Liulin-ML for investigation of the radiation environment on Mars' surface as a part of the active detector of neutrons and gamma rays (ADRON-EM) on the Surface Platform is under preparation for ExoMars 2020 mission.

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