ABRUPT VARIATIONS OF THE RADIATION FIELD AROUND MARS, MEASURED BY THE LIULIN-MO INSTRUMENT

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Keywords: *Solar proton events (SPE), Numerical Simulation, Detector response*

Abstract: *This work investigates the most significant variations in cosmic ray fluxes measured by the Liulin-MO instrument. The observed variations are linked to period of enhanced solar activity, particularly to solar proton events. Using numerical simulations, a qualitative analysis of the composition of the detected solar proton events has been carried out, providing insight into their characteristics.*

РЕЗКИ ИЗМЕНЕНИЯ НА РАДИАЦИОННОТО ПОЛЕ ОКОЛО МАРС, ИЗМЕРЕНИ ОТ ПРИБОРА LIULIN-MO

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Ключови думи: *Слънчево протонни събития (СПС), Числено моделиране, Отклик на детектора*

Резюме: *Тази работа изследва най-значимите вариации в потока на космическите лъчи, измерен с инструмента Liulin-MO. Наблюдаваните вариации са свързани с период на повишена слънчева активност, по-специално със слънчеви протонни събития. Чрез числени симулации е извършен качествен анализ на състава на регистрираните слънчеви протонни събития, което предоставя по-добро разбиране за техните характеристики.*

Introduction

The radiation field in interplanetary space and in orbit around Mars is primarily formed by solar cosmic rays (SCRs) and galactic cosmic rays (GCRs). SCRs are sporadic and impulsive events resulting from solar flares and/or coronal mass ejections (CMEs) [Reames, 2013; Velinov et al., 2013]. SCRs occur much more frequently during the rising phase of the solar cycle.

ExoMars is a joint astrobiology program of the European Space Agency (ESA) and Roscosmos for the exploration of Mars. ExoMars-2016, part of the ExoMars program, consists of the Trace Gas Orbiter and a landing module known as Schiaparelli. The primary objectives of this mission are to search for evidence of methane and other traces of atmospheric gases that could be signatures of active biological or geological processes, as well as to test key technologies in preparation for ESA's future missions to Mars. The Trace Gas Orbiter and Schiaparelli were launched together on March 14, 2016, aboard a Proton rocket and traveled to Mars in a combined configuration. One of the scientific instruments aboard the Trace Gas Orbiter is FREND (Fine Resolution Epithermal Neutron Detector) – a neutron detector designed to confirm the presence of hydrogen. Liulin-MO, a cosmic radiation dosimeter, is a separate module of FREND.

Figure 1 presents the measurement data obtained by Liulin-MO for the entire period of its operation. The measured cosmic-ray flux is shown as a function of time and detector energy channel, each channel representing the deposited energy of individual particles. One channel corresponds to an energy of 70 keV. In the figure, the solar proton events from October 2021, February 2022, and May 2024, which are the subject of our study, are clearly visible.

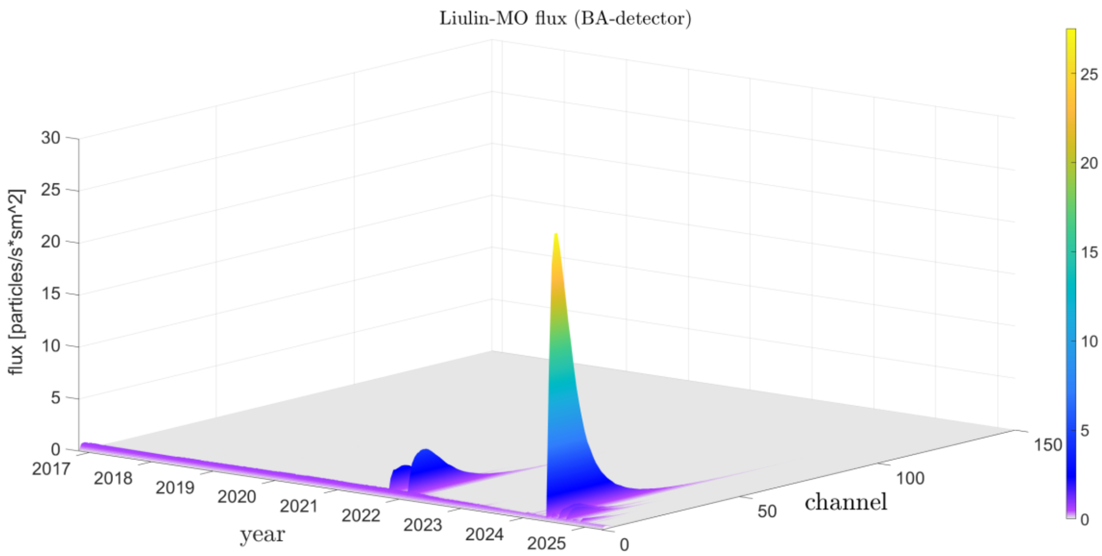

Fig. 1. The measurement data from the Liulin-MO instrument for the entire period of its operation (BA-single detector)

The temporal profiles of the three events are shown in Figure 2, illustrating the variations in the measured cosmic-ray flux over time. The three events exhibit distinct profiles, as shown in the figure. For example, the third event exhibits a decrease before the flux rises, a feature not present in the other two events.

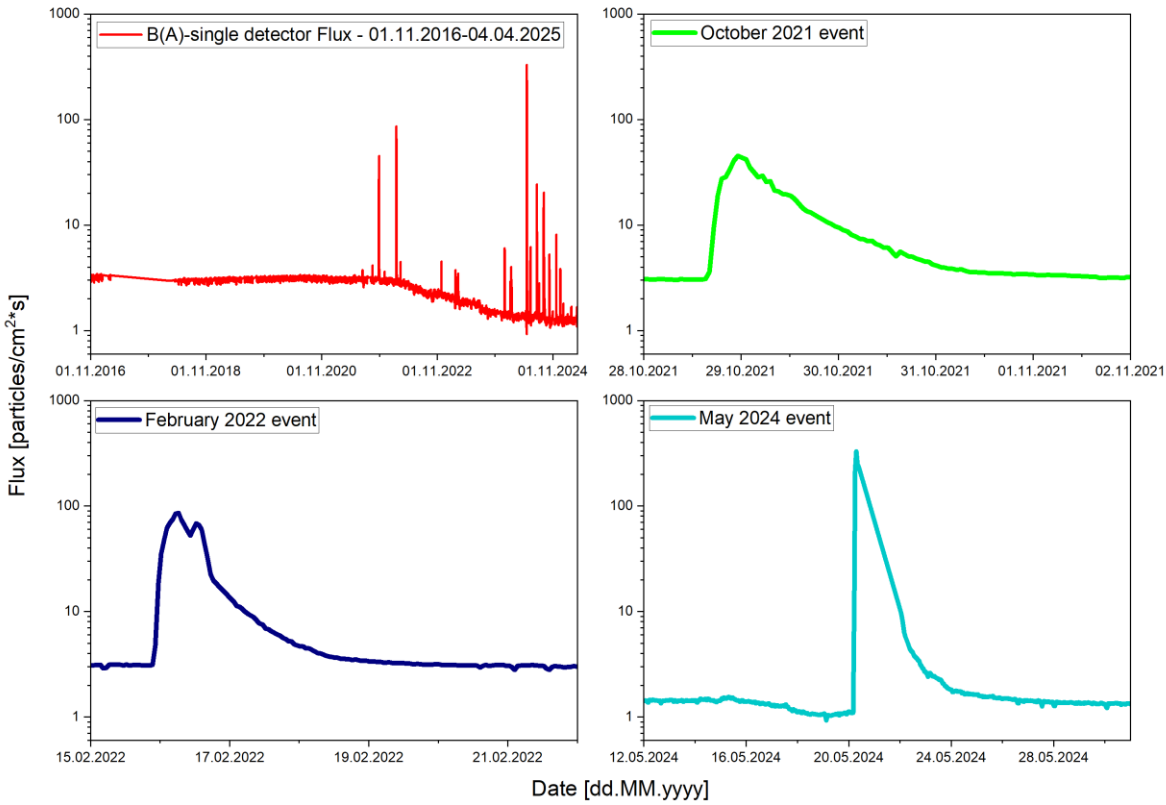

Fig. 2. Time dependence of the measured cosmic-ray flux

Methods

The methodology of the computer simulations follows that described in [Krastev et al., 2023a]. Figure 3 shows the geometric model of the Liulin-MO detector system, which is used in the simulations. This work presents simulations of the operation of the single BA detector, whose operating logic is presented in [Semkova et al, 2018].

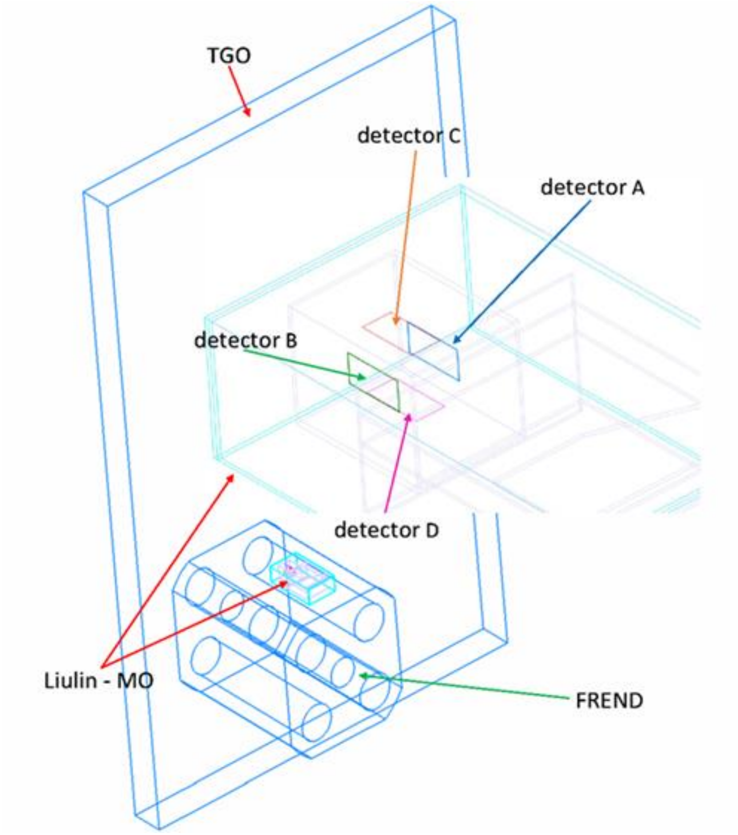

Fig. 3. Liulin-MO instrument detector system model

A series of simulations was performed to determine the response of the single BA detector to various types of particles with different energies. For the simulation, protons with energies ranging from 100 to 500 MeV and alpha particles with energies between 1 and 5 GeV were generated. For each proton energy, 9 billion particles were generated, while for each alpha-particle energy the corresponding number was 1 billion. The source of the generated particles is a sphere with a radius of 150 cm, with the center of the sphere coinciding with the center of the Liulin-MO detector system. The sphere also includes the entire TGO structure.

The response of the detector system can be described by the geometric factor. The definition of the geometric factor is given by [Zhao et al., 2013]:

(1) $$G = \frac{C}{J}$$

where C is the count rate of the detector [s^{-1}]. J is the differential flux of GCRs $[s^{-1}cm^{-2}sr^{-1}]$. For the simulated geometric factor, we have [Zhao et al., 2013]:

(2) $$G = \frac{n_0}{J},$$

Here, n_0 is the number of hits in the detector obtained from the simulation, and J is the simulated differential flux. For a cosine distribution and a spherical source, the number of generated particles N is given by:

$$N = \iint J ds d\Omega = \pi \int J ds = 4\pi^2 R^2 J, \quad (3)$$

where the integration is performed over the entire surface of the source and the solid angle. Here, R is the radius of the sphere. By expressing J from equation (3) and substituting it into equation (2), we obtain:

$$G = \frac{4\pi^2 R^2 n_0}{N} \quad (4)$$

Results

Figures 4 and 5 show the response of the single BA detector, obtained from simulation, to protons and alpha particles, respectively, at different energies.

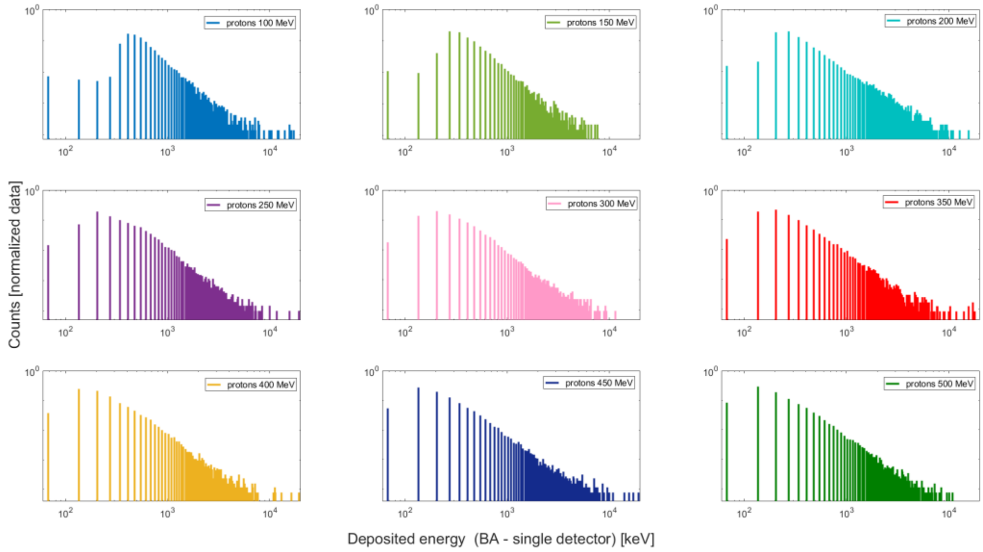

Fig. 4. The response of the single BA detector to protons at different energies

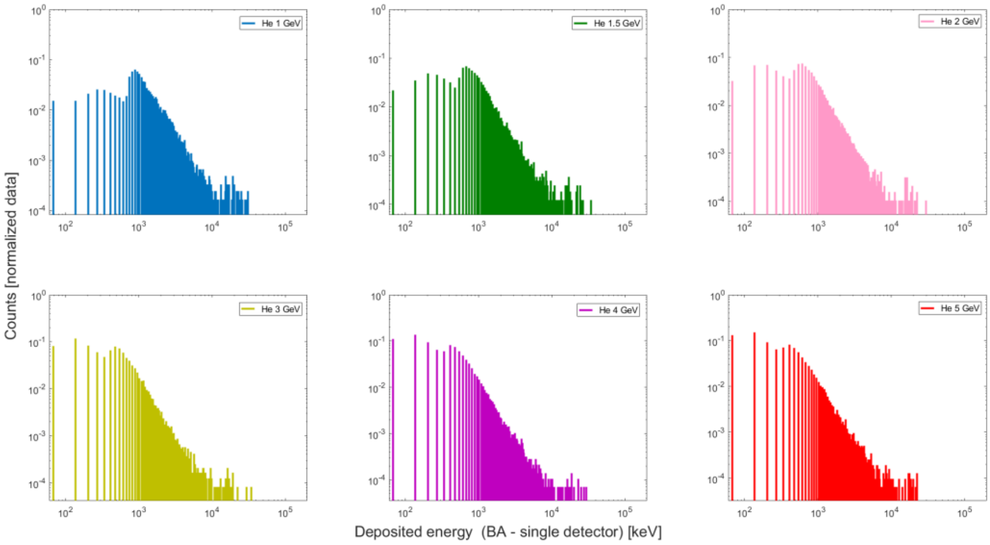

Fig. 5. The response of the single BA detector to alpha particles at different energies

The geometrical factor for alpha particles with different energies, calculated from the numerical simulation, is shown in Figure 6. The analytically calculated geometrical factor for a single detector is 4π $cm^2 sr$. The higher values obtained from the numerical simulation can be explained by secondary electrons, which distort the detector's response.

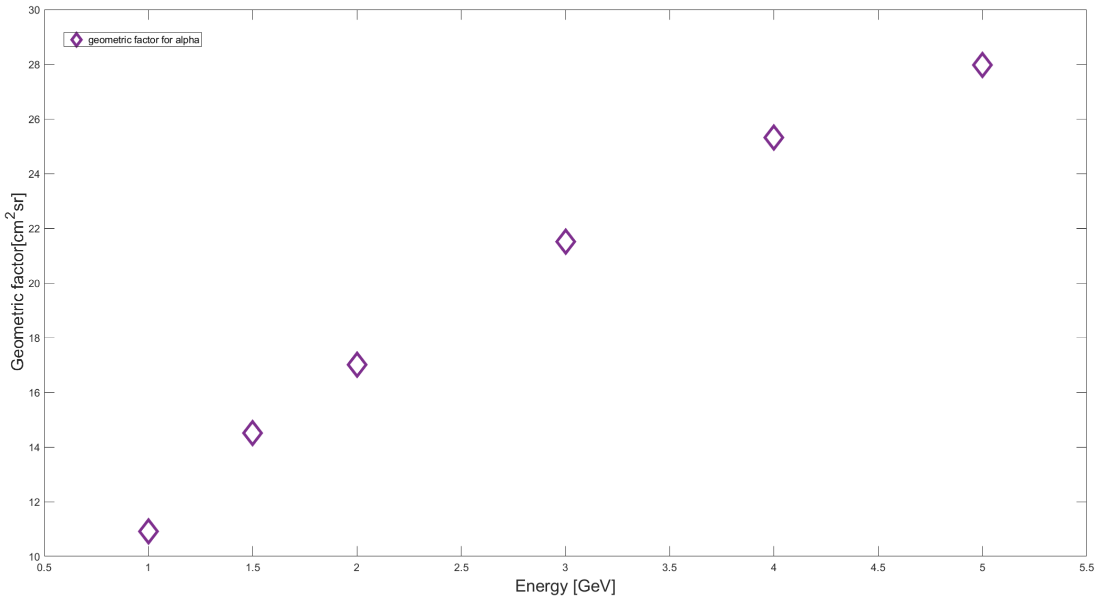

Fig. 6. The geometric factor for alpha particles calculated from numerical modeling

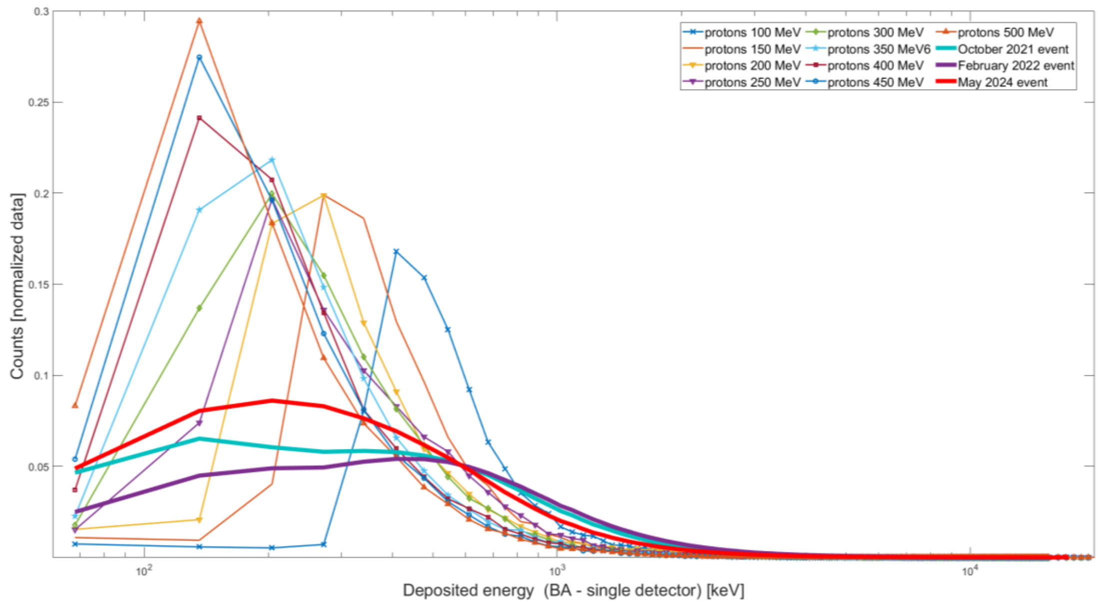

Fig. 7. Comparison between measured and simulated data

Figure 7 shows the measured values of the cosmic ray flux for the three events under consideration, as well as the detector's response to protons with different energies. The normalized values for the corresponding quantities have been used. From the figure, a rough idea of the composition of the individual events can be obtained. For instance, the May 2024 event is primarily produced by protons with energies in the range of 200–450 MeV. The February 2022 event is formed mainly by protons with energies between 50 and 100 MeV (the cutoff energy for the Liulin-MO design is 30 MeV), while the October 2021 event is produced mainly by protons with energies greater than 400 MeV.

Conclusion

The present work aims to demonstrate the capabilities of numerical modeling, without claiming absolute accuracy or completeness. Determining the component composition of solar proton events is not one of the scientific tasks of the Lyulin-MO instrument. The present work aims to reveal the additional functionalities possessed by the instrument.

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