DOI: 10.31401/WS.2023.proc.19

Numerical Simulation of the LIULIN-MO Device

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Abstract.
In this paper, we present the numerical simulation results of the Liulin-MO instrument on board the Trace Gas Orbiter (TGO) of the ExoMars-2016 mission to Mars [Semkova et al., 2018], focusing on the two solar proton events (SPE) of October 2021 and February 2022 [Semkova et al., 2023]. With the help of the simulation it is shown what is the energy of the protons of these events.

Introduction

One of the main problems in the registration and identification of ionizing radiation in space is the influence of the design of the instrument.

The spectrum of galactic cosmic rays is wide in both composition (from protons to the heaviest nuclei) and energies (from a few keV to $10^{21} eV$). The interaction of a specific component of the GCR spectrum, with the construction of the instrument and the detector system, is determined by the type and energy of the corresponding component of the spectrum. The secondary particles generated by this interaction in turn interact with the construction of the instrument and the detector system, thus the received signal from the detector system does not unambiguously determine the characteristics of the primary particle. The specifics of the main task consist in creating a model that reproduces as accurately as possible the environment and operation of the Liulin - MO instrument in interplanetary space.

The volume and complexity of the task require, as the only option, the use of numerical models for the transport of the radiation through the matter. There are many software packages for modeling the interaction of charged particles with matter. Some of them are designed for specific tasks and radiations. Geant4 is one of the most powerful packages, which includes a large set of possibilities and gives great freedom in the modeling of various tasks [Agostinelli et al., 2003]. It was developed by the Geant4 Collaboration (CERN and other institutes) in the object-oriented language C++. The application area of Geant4 includes particle physics and nuclear reaction research, medicine, particle accelerators and space exploration.

When studying the two solar proton events that happened on 28-31 October 2021 and 15-19 February 2022, the task is greatly facilitated because the type of particles (protons) is known. Why we consider the events to be primarily formed by protons is explained below.

Figure 1 shows all available data obtained from the Liulin-MO instrument from 2016 till now. The two SPE events subjects of our task are clearly visible. Figure 1 shows the dependence of the count rate on the energy channel of deposited energy. The two events differ in size but have approximately the same shape, which suggests that in both cases we have the same type of particles with the same energies.

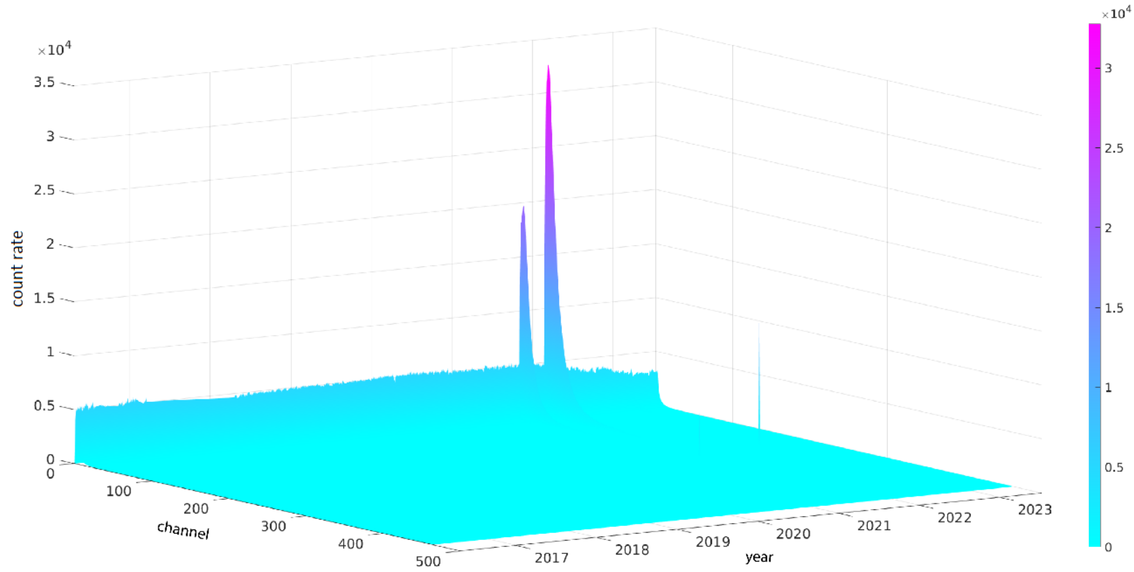

Figure 1: Dependence of count rate on date and channel for the single detector AB – Liulin-MO instrument.

Methods

The software we use is g4app application [Ivanov, S., 2021] using the Geant4 framework. In order to shorten the machining time we have made a simplified geometry of the Lliulin-MO instrument and TGO. The geometry we use is shown in Figure 2.

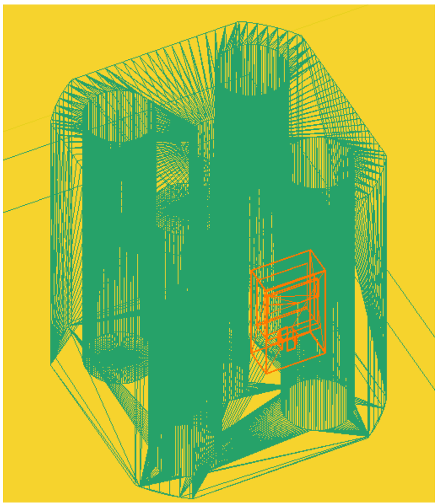

Figure 2: CAD model of the dosimeter Lyulin-MO, FRIEND and TGO. FREND and TGO in green, Liulin construction in orange lines.

The approach used in the modeling of the instrument is presented in [Zhao et al., 2013] and [Pak et al., 2018]. Figure 3 shows the schematic diagram of the simulation. The body of the Liulin-MO instrument is shown in yellow, the detector system is indicated in green. The points of the sphere serve as sources of generated particles, the distribution of generated particles is cosine.

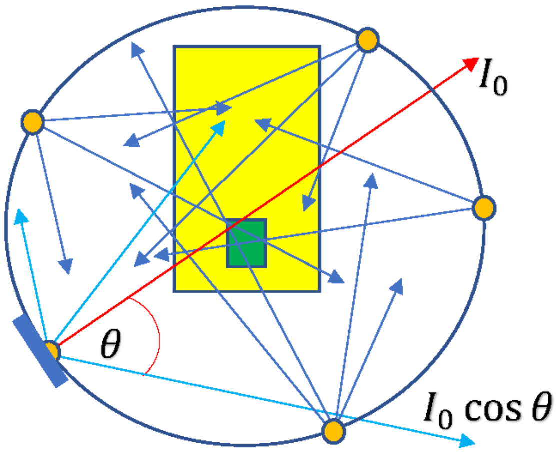

Figure 3: Schematic diagram of the simulation

The assumption we make about the flux of protons is that it is approximately isotropic. This assumption is based on the complex trajectories along which solar protons move in the interplanetary magnetic field. Reaching a distance of 1.5 AU from the sun, the flux can roughly be assumed to be isotropic. 10^8 protons are generated in the program for each of the energies 50, 100, 200, 300, and 400 MeV. In parallel we do a series of simulations for the same energies but the generated protons beam is not isotropic, it falls perpendicular to the surface of the two detectors composing the single detector AB (Figure 4).

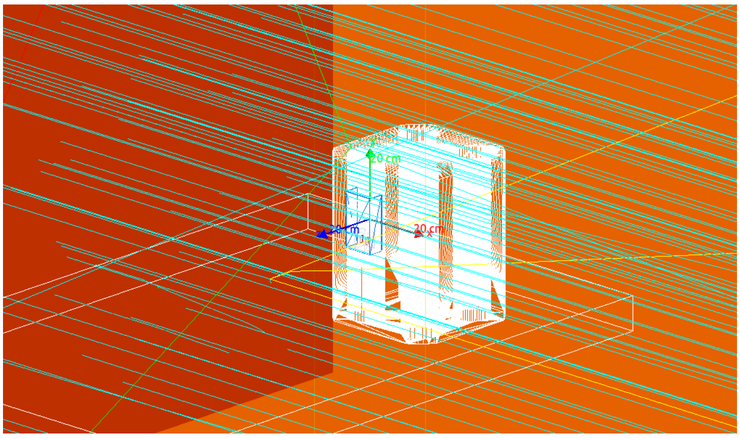

Figure 4: Simulation of a parallel beam of protons, the beam of protons is shown in cyan, in white - FREND+TGO, with blue Liulin-MO.

Results

Figure 5 shows the simulation results for isotropic proton flux. For each of the channels it is shown what percentage of the entire count rate is registered in it. It can be seen that we have the best match between the measured events and a simulated flux of protons with energies between 200 and 300 MeV. Of course, the real spectrum is a sum of protons with different energies, but from the obtained results we can claim that the main flux is protons with energies between 200 and 300 MeV. One might wonder why we only consider protons in modulation. The answer is that the minimum energy that can deposit helium or heavy nuclei in silicon detectors is about 450 keV. The maximum of both events is about 200 keV deposited energy.

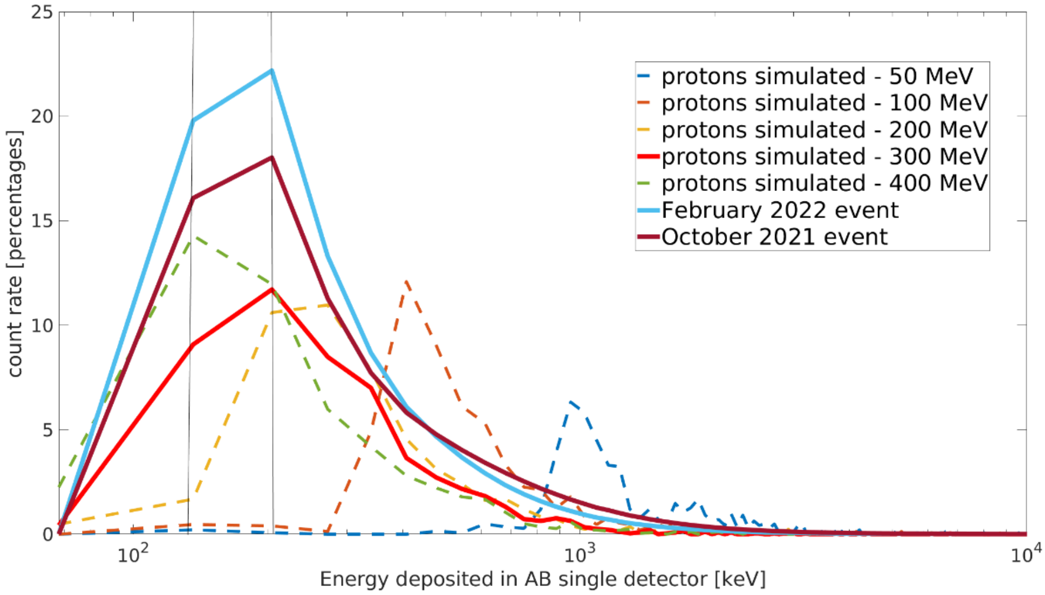

Figure 5: Simulation for isotropic radiation, proton count rate for different energies and both events (February and October). With solid lines are shown the February event in blue, the October event in wine and the 300 Mev protons simulation in red.

Figure 6 shows the simulation for a parallel beam of protons. It is again seen that the flux is composed of protons with energies between 200 and 300 MeV. Naturally, the accuracy of the obtained results is mainly formed by the assumptions stated above (about the isotropicity of the flux and the geometry of the task, which we have simplified). Comparing Figure 5 and Figure 6 we can conclude that the assumption of isotropic flux is very rough. If we abandon the isotropicity of the flux of solar proton events, then the task is reduced to finding the orientation of the instrument with respect to the direction of the flux. The task thus set becomes too complex and can be considered in the future.

For a flat detector the geometric factor is given by $2\pi S$ [Thomas & Willis., 1972], where S is the area of the detector. For the single Lulin-MO detector this formula gives a geometric factor $4\pi = 12{,}56\ cm^2 sr$. The resulting formula is true for isotropic radiation. Figure 7 shows the calculated geometry factors from the simulation for protons with the energies considered. The figure shows that for energies from 200 to 300 MeV, the geometric factors calculated from the simulation are 1.1 smaller than the analytically calculated geometric factor i.e. to get the actual flux of solar proton events we need to multiply Liulin-MO's data by coefficient 1.1.

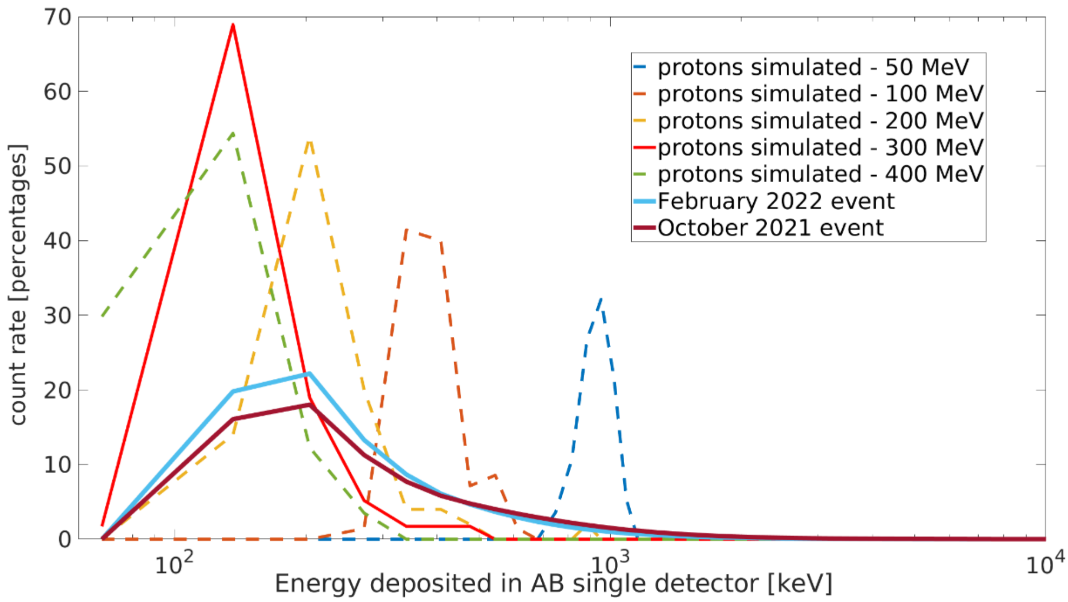

Figure 6: Simulation for a parallel beam of radiation, proton count rate for different energies and for both events (February and October). With solid lines are shown the February event in blue, the October event in wine and the 300 MeV protons simulation in red.

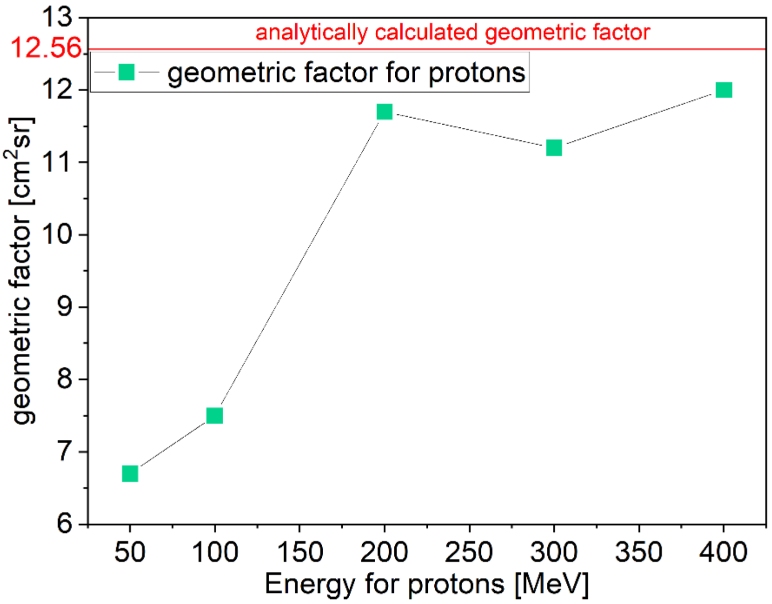

Figure 7: Simulation for isotropic radiation, the calculated geometry factor from the simulation for protons with different energies.

Conclusion

The numerical modeling is a powerful method for solving problems of radiation passage through matter. In many cases, this is the only possible approach for similar tasks. The results obtained in the present work are an initial stage of the development and application of more accurate models. Despite these simplified models, the obtained results show a good agreement with the experimental data. The main results obtained in the present work are:

1. It is shown that the flux of protons of the two solar proton events under consideration is with energies between 200 and 300 MeV.
2. To get the actual flux of solar proton events we need to multiply Liulin-MO's data by coefficient 1.1.

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