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Solar Proton Events Recorded by the Lyulin Instrument - Composition Analysis Using Numerical Modeling

Krastev K.

Space Research and Technology Institute, Bulgarian Academy of Sciences

Abstract

In recent years, the Liulin instrument has recorded numerous solar proton events associated with increased solar activity. This paper focuses on several of the most significant of these events. A qualitative assessment of the energy composition and types of solar particle fluxes was carried out based on numerical modeling. The simulations were performed using a numerical model implemented in GEANT4, which reproduces the operation of the Liulin device for detecting ionizing radiation.

1. Introduction

The Liulin-MO instrument, part of the ExoMars TGO mission, has collected an extensive database of radiation field measurements over more than nine years of operation, both in interplanetary space and in orbit around Mars. Figure 1 presents the measurement data obtained by Liulin-MO for the entire period of its operation.

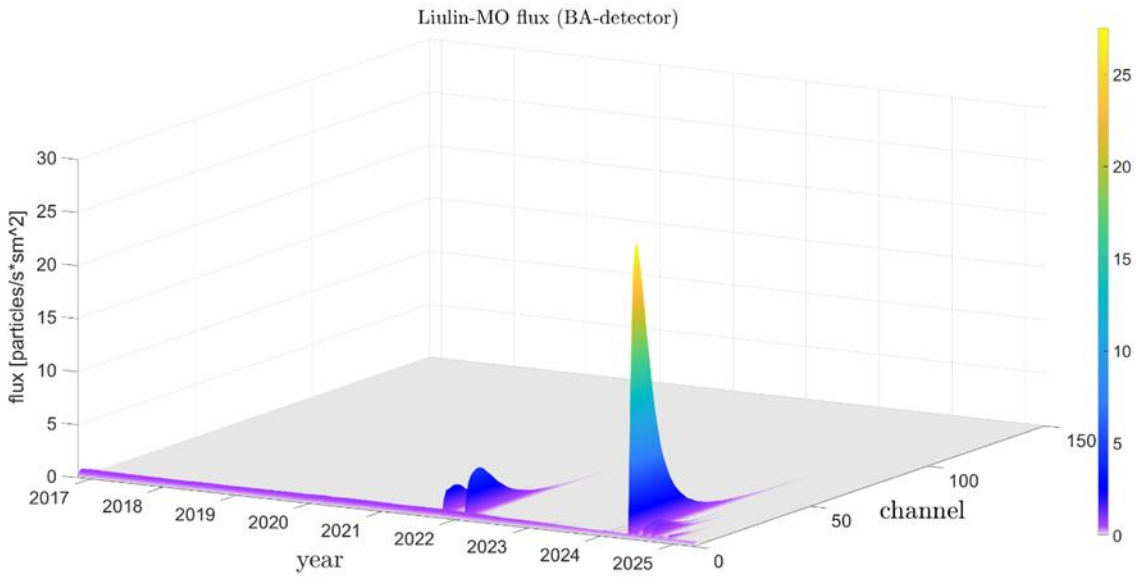

Figure 1. *The measurement data from the Liulin-MO instrument for the entire period of its operation (BA-single detector).*

In the figure, the solar proton events from 2021, 2022, and 2024, which are the subject of our study, are clearly visible.

2. Methods

The methodology of the computer simulations follows that described in [Krastev et al., 2023a]. Figure 2 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].

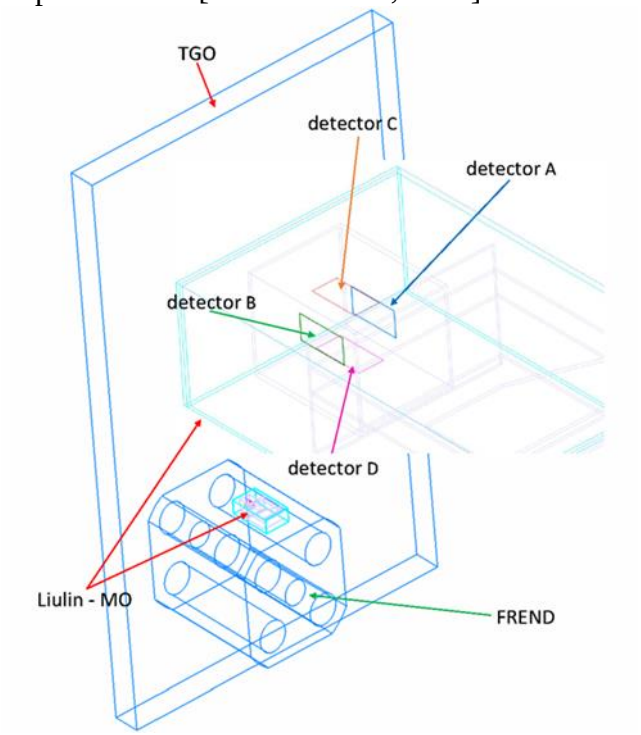

Figure 2. *Liulin-MO instrument detector system model.*

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.

3. Results

Figures 3 and 4 show the reaction of one BA detector obtained from simulation to protons and alpha particles, respectively, at different energies.

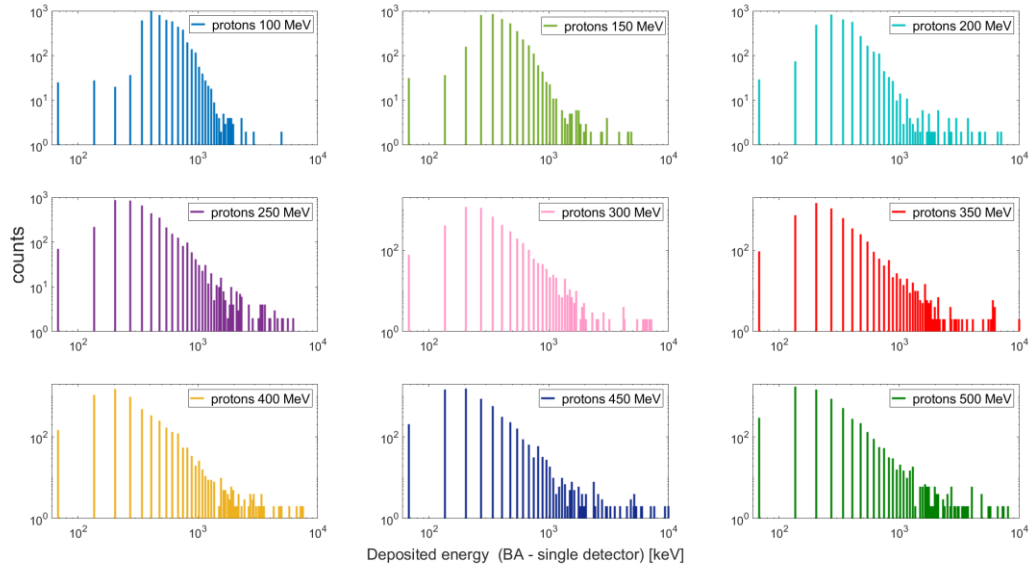

Figure 3. *The response of the single BA detector to protons at different energies.*

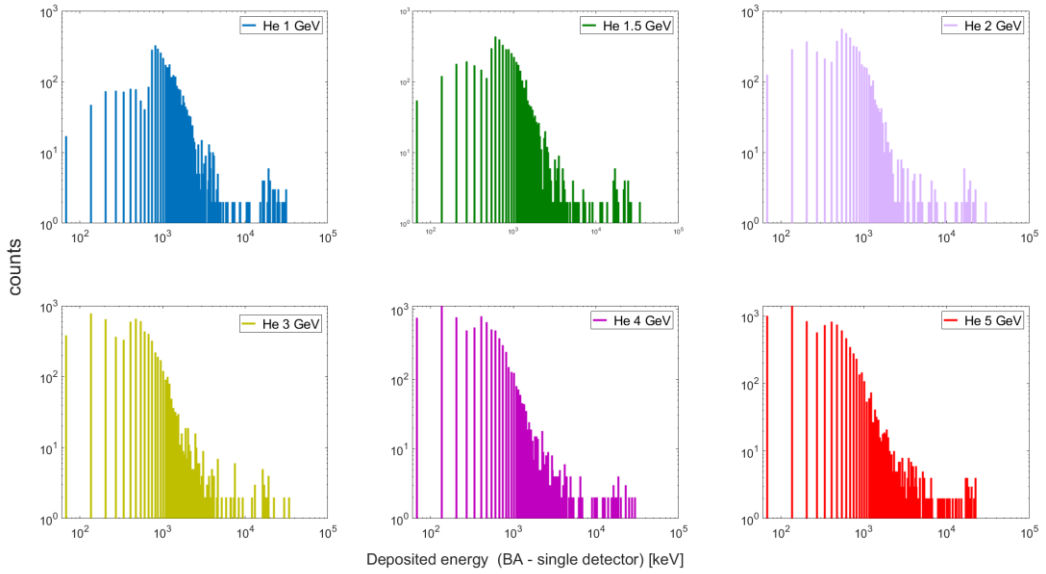

Figure 4. *The response of the single BA detector to alpha particles at different energies.*

Figure 5 allows a preliminary analysis of the contribution of protons with different energies to the formation of the events shown in the graph. For instance, the May 2024 event is primarily produced by protons with energies in the range of 300–450 MeV. The February 2022 event is formed 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 by protons with energies greater than 450 MeV.

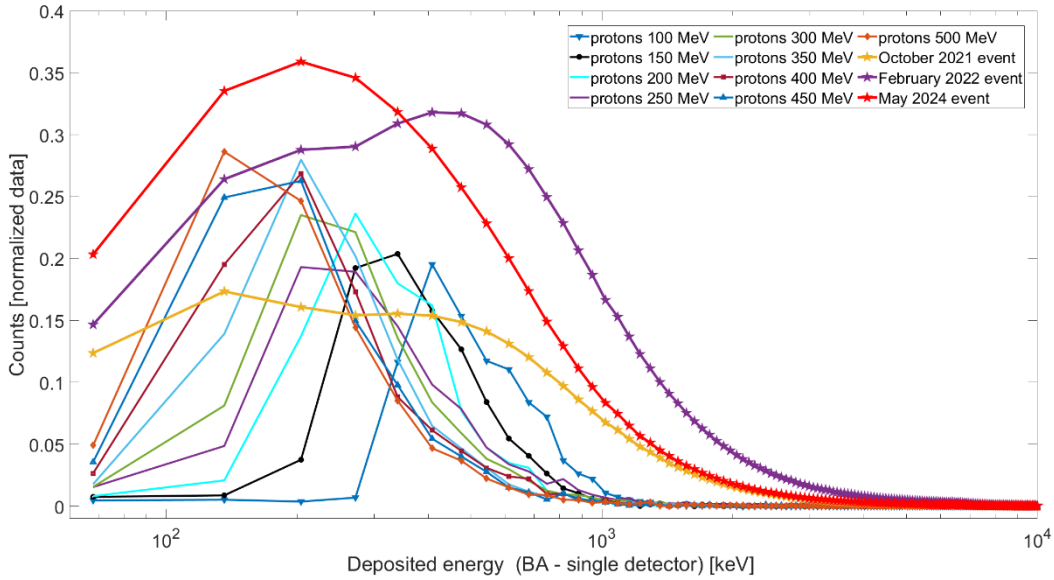

Figure 5. *Comparison between measured and simulated data.*

4. Conclusion

Instruments such as ACE-SIS are specifically designed to study the composition of solar proton events. Nevertheless, the results obtained demonstrate that numerical simulations can offer an initial approximation of the composition of solar proton events detected by instruments of the Liulin-MO type. While this task was not part of the instrument's original scientific mission, this additional functionality is particularly valuable, as Liulin-MO currently remains the only dosimeter operating in orbit around Mars.

References

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