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Initial conditions for radiation analysis: Models of galactic cosmic rays and solar particle events

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Abstract

The space radiation environment of interplanetary missions is determined by fluxes of galactic cosmic rays (GCR) and solar energetic particles (SEP). The particle fluxes of the two high-energy radiation species differ fundamentally in their energy spectra and depend oppositely on solar activity.

One of the key problems of estimating the space radiation environment for missions to the Moon, to asteroids, to Mars, and to other planets is to find the relative balance between galactic and solar cosmic rays, depending on solar activity and on the distance to the Sun for the radiation environment in the open space and inside spacecraft.

This problem can only be solved to within a sufficient accuracy by using the particle flux models (for the above mentioned radiation sources) based on the unified parameters that would describe the current solar activity level. Models of this type, that use the smoothed Wolf numbers as an initial parameter, have been developed at the Skobeltsyn Institute of Nuclear Physics, Moscow State University.

This paper reviews the experimental data on the galactic and solar particle fluxes in interplanetary space at different solar activity levels and analyzes the reliability and consistency of the particle flux data yielded by various computational models.

Keywords: Radiation conditions in space; Galactic cosmic rays; Solar energetic particles; Models of the particle fluxes; Model outputs and experimental data

1. The general problems of the high-energy particle model determination

The necessity of describing the complicated-nature phenomena makes scientists construct different quantitative models. These models can be divided into three groups.

The first group includes the theoretical models. As of nowadays, describing the complicated-nature phenomena by theoretical model is fruitless and far from reality in most cases.

Instead of the models, therefore, the empirical models are often developed and used. In this case, as a rule, only the final effect of the phenomena is generalized by selecting either mathematical or graphical form of the model output without any detailed physical analysis. Most properties of the phenomena are often disregarded in modeling. The models of this type are quite rough or even erroneous sometimes.

The third group includes semi-empirical models that are of intermediate type. They are based on the mathematical formalisms that summarize the regularities of the physical processes or situations in separate stages of the overall formation of the phenomena, leading to the general regularities in the final effect, which is just the description of the variety of the charged particle dynamics patterns. As a rule, the physics of the processes leading to the formalized regularities in the modeling of the given type is not analyzed in detail. The general aim in this case is to tune the model outputs to the peculiarities the total experimental dataset.

Another problem of the high-energy flux modeling consists in reliability of different experimental data. To increase the statistical support accuracy of the models, the authors of

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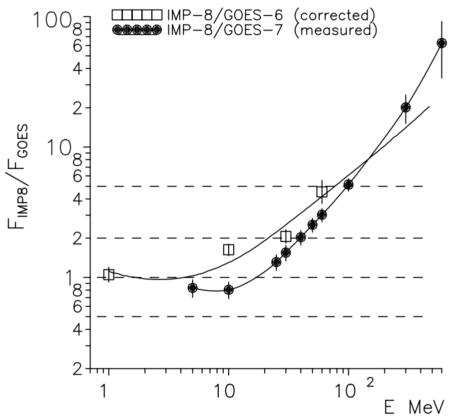

Fig. 1. Energy dependence of the ratio of SEP peak fluxes measured on IMP-8 and GOES. The squares are the ratios of the integral peak fluxes on IMP-8 and GOES-6 (corrected) taken from the respective websites. The solid curve is the ratio of the logarithmic mean SEP particle peak flux energy spectra (see Subsection 4.5) of all events of cycle 22. The curve with black circles is the ratio of the 13 GLE logarithmic mean peak flux energy spectra calculated from the IMP-8 and GOES-7 (uncorrected) differential measurement channels.

the latter use the maximum accessible measurement data and neglect any noticeable systematic errors in the outputs of different instruments. As a result, the outputs of the models based on copious unreliable measurement data prove to be indefinite and even erroneous sometimes. Note that two main monitoring experimental datasets from IMP-8 and GOES are quite different and, when applied to particle modeling, lead to quite different model outputs. The situation with the above mentioned experimental data is exemplified in Fig. 1 that shows the averaged ratio of the solar energetic particle (SEP) peak fluxes for 13 Ground Level Enhancement (GLE) events (25 July 1989, 16 August 1989, 29 September 1989, 19, 22, and 24 October 1989, 15 November 1989, 21, 24, 26, and 28 May 1990, 11 and 15 June 1991) measured on the above two spacecraft. Note that the large events are presented and there is no problem with the galactic background in all of the IMP-8 (CPME instrument) and GOES-7 (TELESCOPE and DOME instruments) measurement channels. Fig. 1 presents two datasets. The first has been calculated by the integral fluxes presented by the authors of the experiments in Internet (the IMP-8 data from http://hurlbut.jhuapl.edu/IMP/ and the GOES data from http://www.sec.noaa.gov). The second dataset has been calculated by us using the data of the IMP-8 and GOES-7 (uncorrected) differential channels. From Fig. 1 it follows that the SEP event proton peak flux sizes depend strongly on proton energy, so that the >100 MeV proton peak flux ratios differ by a factor of above 10. This is a very great difference, and the problem is which of the data are more reliable (if they are used in the SEP peak flux or fluence models).

2. The galactic cosmic ray and SEP fluxes in interplanetary space

Increasing solar activity is well known to be accompanied by a decreasing galactic background and by an increasing SEP event occurrence frequency. The question thus arises if we can neglect the SEP fluxes (fluences) during low solar activity. The most convincing answer can well be found in the latest reliable experimental data. We analyze the galactic particle and SEP fluences for two periods. The first is the high solar activity period (September 1999–July 2002), when the mean monthly sunspot number $W > 100$ ($\langle W \rangle = 122$). The second period (December 1993–December 1997) is sometimes called the quiet Sun period, when $W < 40$ ($\langle W \rangle = 20$). The results of such analysis are displayed in Figs. 2, 3 as model-calculated total galactic proton differential energy spectra and as cumulative SEP event proton fluences measured by the GOES-7 and 8 differential measurement channels during the respective periods. The high-activity period does not need any comment, compared with the low-activity period. During the latter, the <100 MeV SEP event protons fluence exceeds the background galactic particle fluence, the difference reaching factor 10,000 at $10 \div 20$ MeV.

This conclusion is very important when choosing an optimal period for long-term interplanetary missions and in developing the SEP peak flux and fluence models. Most

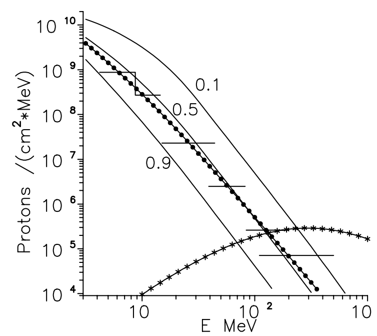

Fig. 2. The differential proton fluence spectra for SEP events (the line with circles) and galactic cosmic rays (the line with the stars) during the last solar minimum covering the 4-year period from December 1993 to November 1997. The curves 0.9, 0.5, and 0.1 are the MSU model outputs for the respective probabilities (to exceed the displayed curves).The horizontal lines are the GOES-measured cumulative fluences.

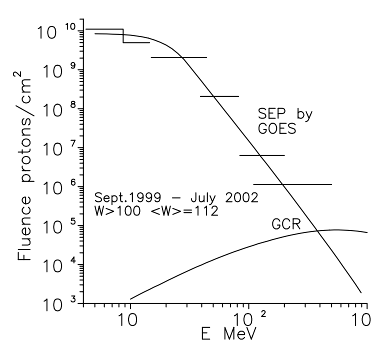

Fig. 3. The differential proton fluence spectra for SEP events (the line with circles) and galactic cosmic rays (the line with the stars) during the last period of high solar activity (the active Sun period from September 1999 to July 2002), when the mean-monthly sunspot number was $W > 100$ ($\langle W \rangle = 122$). The horizontal lines are the GOES-measured cumulative fluences.