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Two-component features of the two largest GLEs: February 23, 1956 and January 20, 2005

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Abstract: Comparative analysis of the characteristics of relativistic solar cosmic rays (SCR) in the two largest GLEs of February, 23 1956 and January 20, 2005 has been performed. Using a modeling technique, the parameters of relativistic solar protons (RSP) were obtained from ground-based observations by neutron monitors (NM) and muon detectors. The two particle populations (components), prompt (PC) with high anisotropy and exponential energy spectrum and delayed one (DC) with moderate anisotropy and power-law spectrum, were shown to exist in both cases. The prompt component was a cause of a giant pulse-like increase at a limited number of NM stations, and the DC caused a gradual increase with moderate amplitude at the most NM stations over the globe. It is argued that only exponential energy spectrum (but not power-law one), in combination with energy dependence of the NM specific yield functions, could cause such great increase effect (~5000%) in both cases.

Introduction

In the study of GLE events the authors obtained convincing evidences of existence of two specific populations (component) of relativistic solar protons (RSP), named as prompt and delayed ones. The prompt component (PC) is formed by the early impulse-like intensity increase with a hard energy spectrum. The delayed component (DC) is responsible for late gradual increases with a soft energy spectrum. It is shown that the PC energy spectrum has exponential form that may be an evidence of the acceleration by electric fields arising in the reconnecting current sheets in the corona [1,2]. The DC energy spectrum may be fitted by a power-law function that can be created in the process of stochastic acceleration [3,1,4].
The specified regularities were confirmed on the basis of the analysis of 11 [5], and 14 [6] large GLE events. On a general background of "ordinary" GLE giant superevents such as January 20, 2006 and February 23, 1956 sometimes, occur. The amplitude of increase on neutron monitors in these events reached ~5000 %. Naturally there arises a question on the physical causes of these huge GLEs. In the present work we shall make a comparative analysis of two giant GLEs: 23.02.1956 and 20.01.2006 and try to find out what is the principal difference between a giant and "ordinary" GLE.

Characteristics of the GLE 05 and GLE 69

The GLE 05 (23.02.1956)

The largest in history GLE 05 of February 23, 1956 has been extensively studied for a period as long as half a century ([6,7,8] and reference therein). The GLE was caused by a large solar flare with importance of 3+ (or 3B) that occurred at 03:31 UT in the active region with heliographic coordinates 25°N, 85°W. Recently interest to GLE 05 has increased because of recent GLE of 20.01.2005, comparable on power with GLE 05. By the data of 14 neutron monitors and 14 muon detectors we studied parameters of the relativistic solar protons (RSP) and their dynamics during the GLE 05. Our new analysis of the GLE 05 has been carried out by the modern modeling technique [2].

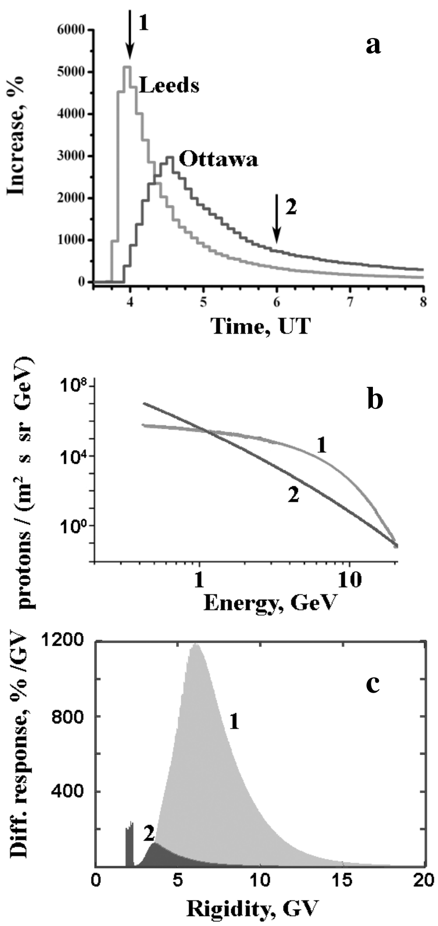

Figure 1: Intensity-time profiles at the Leeds and Ottawa neutron monitors (**a**), energy spectra derived at the moments 04:00 (1) and 06:00 (2) UT (**b**), and differential responses (**c**) of the Leeds neutron monitor to the exponential spectrum at the moment 1 (gray shading) and at the moment 2 to the power-law spectrum (black shading). ,One can see comparable responses of both neutron monitors to the power-law spectrum.

In Figure 1a the increase profiles at the two NM stations Leeds and Ottawa are shown demonstrating behavior of the prompt (Leeds) and delayed (Ottawa) fractions (components) of relativistic solar protons (RSP) [5]. By numbered arrows the moments of time indicated when the prompt (1) and delayed (2) components of RSP dominated. Fig.1b shows energy spectra of RSP derived with modeling technique [2] at the moments 04:00 UT (1) and 06:00 UT (2). As shown in [5,2] the spectrum 1 belong to the prompt component (PC) of RSP and has the character for the PC exponential form. The spectrum 2 belongs to the delayed component (DC) and has the character power-law form.

Figure 1c shows the differential response of the NM at Leeds to the exponential spectrum (1) at 04:00 UT (grey shading) and to the power-law spectrum (2) at 06:00 UT (black shading). The differential response was obtained as a product of a specific yield function by a differential spectrum of solar protons with taking in account the allowed and forbidden rigidities of a given NM station. The integral response of the Leeds NM to the exponential spectrum (1) is about 5170% and to the power-law spectrum (2) - of 354%. The spike in the profile 2 (Fig. 1c) is a contribution of a penumbra into the NM Leeds response to the power-law spectrum, due to excess of low rigidity particles. As it may be seen from Figure 1b, at low energies (rigidities) the power-law spectrum exceeds the exponential one.

Although the spectra (1) and (2) on absolute values at low and high energies are comparable, the effect of exponential spectrum is quite distinguishable. It can be explained by the energy (rigidity) dependence of the specific yield functions for a neutron monitor [7,9].

Thus, the giant increase at the European neutron monitors during the GLE05 was caused, most likely, by a short-lived proton flux of the prompt component (PC). The prompt component had a short duration, strong anisotropy and hard exponential energy spectrum. At the same time, on the majority of neutron monitors and muon telescopes, which were exposed with a power-law spectrum of the delayed component (DC), the increase was not such large. The DC was less anisotropic and had the softer power law spectrum.

The GLE 69 (20.01.2005)

The super GLE 69 January 20, 2005 was the greatest event since February 23, 1956. The parent solar flare 2B/X7.1 has heliocoordinates N14 W61. The type II radio onset was reported at 06.44 UT. The GLE was extremely anisotropic as observed by the ground based cosmic ray detectors. As observational data and modeling study show [10, 11] the GLE 20 January, 2003 was formed by two fluxes of relativistic solar protons (RSP) with different characteristics. The short-lived and extremely anisotropic Flux 1 with exponential energetic spectrum (prompt component) has caused the giant impulselike increase at two southern polar stations South Pole and Mc Murdo.

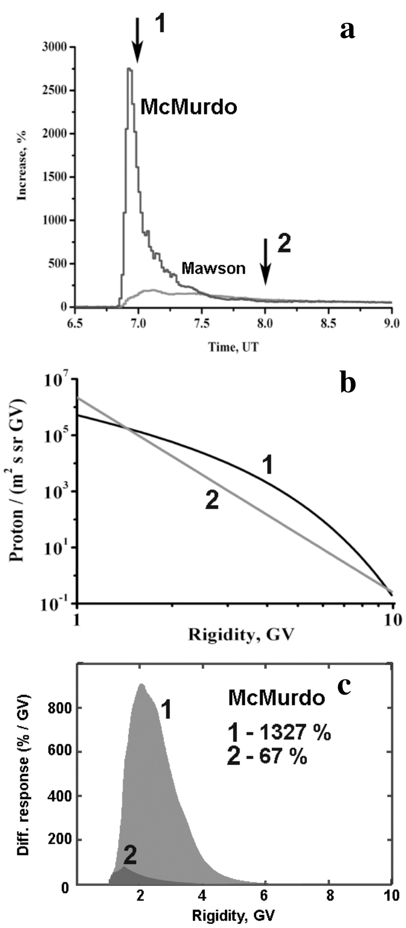

Figure 2: Intensity-time profiles at the McMurdo and Mawson neutron monitors (**a**), energy spectra derived at the moments 07:00 (1) and 08:00 (2) UT (**b**), and differential responses (**c**) of the McMurdo neutron monitor to the exponential spectrum at the moment 1 (gray shading) and to the power-law spectrum at the moment 2 (dark shading). One can see comparable responses of both neutron monitors to the power-law spectrum.

Fig.2 shows increase profiles at the McMurdo and Mawson neutron monitors (**a**), energy spectra derived at the moments 07:00 (1) and 08:00 UT (2) (**b**), and differential responses (**c**) of the McMurdo neutron monitor to the exponential spectrum at the moment 1 (gray shading) and at the moment 2 to the power-law spectrum (dark shading). By numbers the moments are marked, when the prompt component (1) or delayed one (2) were dominating. One can see comparable responses of both neutron monitors to the power-law spectrum (at moment 2).

Discussion

The above consideration clearly shows the presence of the prompt and delayed components of RSP in superevents 23.02.1956 and 20.01.2005. Moreover, as was shown above the huge increases in both events on a limited number NM stations were caused by the prompt component having an exponential energetic spectrum. The power law spectrum of the delayed component caused increases of moderate amplitude on the majority other stations of a worldwide network. It is necessary to note, that in moderate energies (tens to hundreds MeV) the event 20.01. 2005, and also 23.02.1956 looked as rather ordinary ones. The prompt component was observed almost in all events with relativistic solar protons [2, 12]. By distinction of superevents 23.02.1956 and 20.01.2005 was that, the relative intensity of PC in relation to DC was much greater, than for the majority of "ordinary" events.

The probable mechanism of generation of prompt component is the acceleration by an electric field arising at magnetic reconnection in coronal current sheets [1,5]. It is necessary to keep in mind that the super GLEs 05 and 20.01.2005 have taken place in the period close to the minimum of a solar cycle: The 23.02.1956 GLE: at early rise phase of the 19th cycle and 20.01.2005: at late decline phase of the 23rd cycle. Then it is possible to assume, that the structure of magnetic fields in the solar corona and interplanetary space could enable generation on the Sun and propagation to the Earth of PC particles of unusually large intensity. Such conditions should be realized rather seldom, as for the period of a half of century only 2 events of scale of GLE 05 and 69 occurred.

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