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Solar Particle Event 20 January, 2005 on stratosphere and ground level observations

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Results of balloon measurements carried out at the high latitude point Apatity (N 67.3°, E 33.3°) during the great solar proton event (SPE) on 20 January, 2005, have been considered. Balloon measurements allow accurate determination of a spectrum of solar protons in energy interval from 80-100 up to 350-400 MeV. In the SPE 20 January, 2005, the measured in the stratosphere integral energetic spectra of solar protons had the power-law form with an index ~5. Thus they agreed well with spectra obtained in adjacent energetic intervals: at GOES-11 spacecraft and ones derived from neutron monitor observations in the isotropy phase of GLE. In the earlier anisotropic phase the spectra measured at ground level had exponential dependence on energy. Possible reasons of energetic spectra difference at initial and late phases of SPE are discussed.

1. Introduction

This paper considers the balloon measurements of solar protons during the large SPE 20 January, 2005.
This SPE was characterized by the greatest since 23.02.1956 ground level effect in solar cosmic rays. The parent flare 2B/X7.1 has heliocoordinates N14, W61. The type II radio onset signaling the energetic protons acceleration was reported at 06.44 UT. The flare caused the GLE as detected nearly all neutron monitors over the globe. Balloon measurements allow accurate measurement of spectrum of solar protons in energy interval from 80-100 up to 350-400 MeV [1]. The solar protons spectrum is determined basing on the relation between a detector count rate and air thickness above the balloon as measured during the balloon flight. The cylindrical G-M tube and a vertical telescope of two such tubes with aluminum absorber between them are used as detectors [1]. During the 20 January, 2005, SPE the balloon measurements of solar protons were carried out at launching point in Apatity (joint Lebedev Physical Institute and Polar Geophysical Institute PGI balloon experiment).

2. Observations

The first balloon measurement was done in time interval from 7.20 to 8.00 UT, the mean time 7.40 UT, about 50 min after the first relativistic solar protons were registered at Earth. Since then during the following 25 hours 7 solar proton spectra was measured in consecutive moments of time. These spectra are shown in Fig.1. Indicated moments of time correspond to the middle of a measurement time interval which is on average 30-60 min. All the spectra have the power-law form with an integral power about 5, with a tendency to flattening at energies < 200 MeV. It is notable that spectral form did not change significantly during the whole period of observations, which continued more than a day.

In Fig. 2 the intensity time profiles of integral fluxes of solar protons measured in stratosphere are shown in combination with analogues profiles obtained by the GOES-11 spacecraft in the energy interval from >10 to >100 MeV. The estimated measurement errors of the points in Fig.2 are of order of the size of symbols. It is seen the common character of solar proton intensity behavior with time from >30 to >400 MeV.

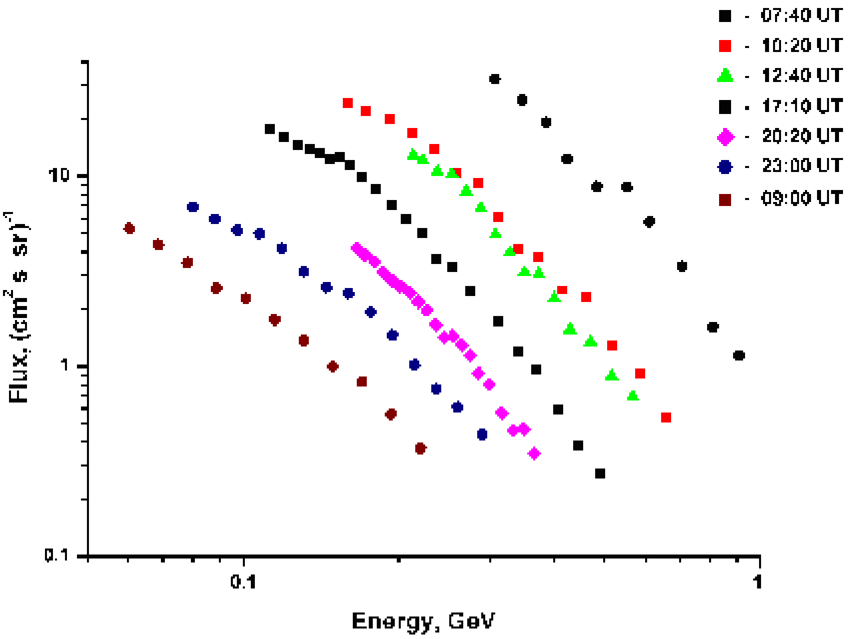

Figure 1. Solar proton integral energy spectra obtained in balloon measurements on 20 and 21 January, 2005.

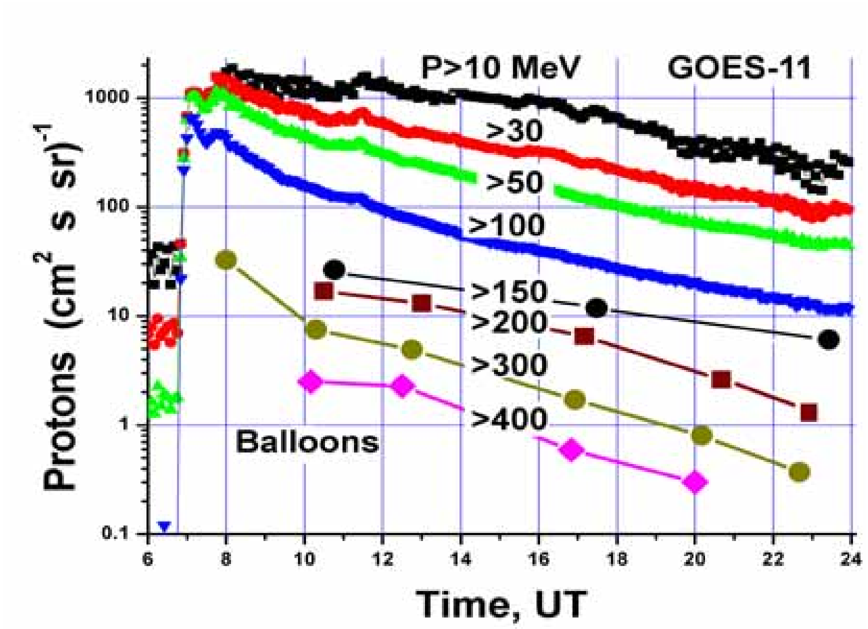

Figure 2. Solar proton integral fluxes from >150 to >400 MeV as measured in the stratosphere and intensity time profiles obtained by the GOES-11 spacecraft at energies from >10 to >100 MeV.

2. Comparison with ground based observations

In Fig.3a the ground level effect of relativistic solar protons (RSP) is shown on the data of the neutron monitor stations McMurdo (Antarctica), Apatity, and EAS array Carpet, Baksan, Northern Caucasus [2]. The vertical arrow indicates the onset time of II type radio emission, shifted back on 8 min. (supposed moment of relativistic particle generation on the Sun [3]).

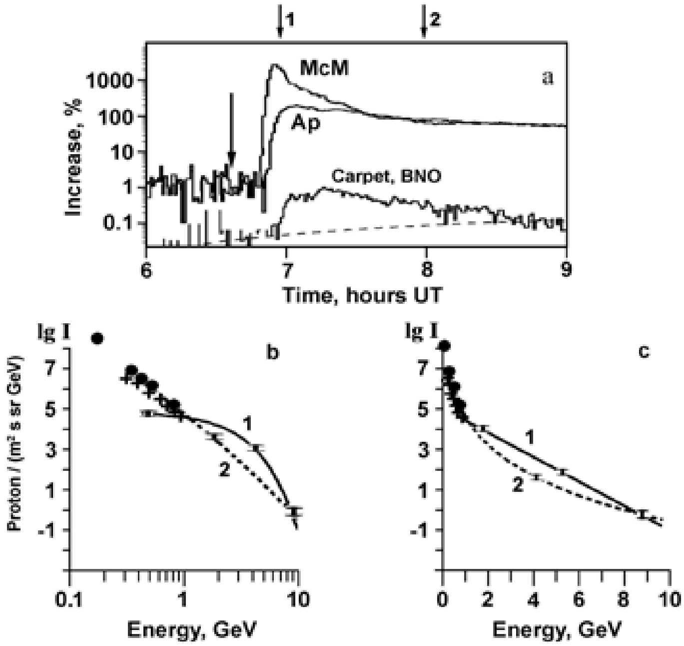

Figure 3. (***a***) Intensity-time profiles at the NM stations McMurdo (McM), Apatity (Ap); and EAS array "Carpet" The vertical arrow indicates the supposed moment of relativistic particle generation on the Sun. (***b, c***) Derived energy spectra at moment 1 (solid line) and 2 (dashed line). Direct solar proton data are crosses (balloons) and blacked dots (GOES-11 spacecraft)

The numbered arrows correspond to the moments of time when in the RSP flux dominated the prompt component (PC), (1) and the delayed component (DC), (2) [4]. Figures 3 b,c show the derived by modeling technique [2, 4] spectra of PC (1) and DC (2) in the double logarithmic and semi-logarithmic scale, respectively. In Fig.3 b,c are also presented the data of direct solar protons measurements by GOES 11 spacecraft (blacked dots) and balloons in Apatity at 07.40 UT (crosses).

3. Discussion and conclusions.

The strong anisotropy existed at the initial stage of the event. So the increase in McMurdo exceeded that in Apatity as many as 30 times [2]. Anisotropy disappeared after about 7.30 UT. As can be seen from Figures 3b,c, the PC spectrum would have an exponential dependence on energy (straight line in semi-logarithmic scale) and within the limits of shown error bars can be described by expression: $J = 1.5\times10^5\exp(-E/0.72)$ [4].

The DC spectrum (2) depends on energy under the power law $J = 7.5\times10^4 E^{-6.2}$, and within the limits of error bars it is a straight line in double logarithmic scale [4]. A good agreement is noticeable between a spectrum of DC obtained from the NM data and intensities of solar protons in adjacent interval of energy directly measured on balloons and GOES-11 spacecraft. Moreover, the spectrum of *in situ* measured solar protons also depends on energy under the power law and appears to be an extension of DC spectrum of relativistic solar protons into the energy range from 700 to 100 MeV. Thus, the mechanism of generation of DC is effective enough in a wide energy range. As suggested in [4] an appropriate mechanism for the DC generation could be, for instance, acceleration by MHD turbulence during explosive energy release in a flare [5, 6]. As to the PC spectrum, it proved to have exponential form in energy, and this may be evidence of acceleration by electric fields arising in the reconnecting coronal sheets (e.g., [7, 8]). At impulsive magnetic reconnection in a current sheet an electric field arises which is directed along a null magnetic field line. The particles of surrounding plasma move along this electric field and gain energy, which is proportional to a path traveled in the electric field. At the same time, the number of particles traveled a given path in reconnecting area falls exponentially with increase of this path because of losses owing to a leaving of particles the acceleration volume due to drifts. So, the spectrum of particles accelerated by an electric field inside a volume, where reconnection proceeds should have exponential dependence on energy. The extrapolated intensity of the prompt component (spectrum 1) at energy 100 MeV, however, is about 3 orders of magnitude lower than that for DC (spectrum 2), so it turned out to be at background level and inaccessible to direct measurements. One should take into account also very short lasting and anisotropic character of PC [2, 4], that may escape of detection by balloon measurements with great gaps between launches. The discussed here features of solar proton spectra obtained in the balloon and ground level observations may be explained in frame of high-energy solar proton generation and release scenario suggested recently in [4]. The prompt component of RSP is produced during initial energy release in a low-coronal magnetic null point. This process is linked with the H-alpha eruption, onset of CME and type II radio emission [9]. The accelerated particles of PC leave the corona along open field lines with diverging geometry that results in high anisotropy due to strong focusing of a particle bunch. The DC particles are trapped originally in magnetic arches in the low corona. As the disturbance grows, DC particles are accelerated by a stochastic mechanism at the MHD turbulence in expanding flare plasma. Accelerated particles can be then carried out to the outer corona by an expanding (lifting) CME. They are released into interplanetary space after the magnetic trap is destroyed giving rise to an extended in time and azimuth particle source.

4. Acknowledgements

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