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# Energetic solar particle dynamics during 28 October, 2003 GLE

E.V.Vashenyuk[a], Yu.V. Balabin[a], B.B. Gvozdevsky[a], L.I. Miroshnichenko[b], K.L. Klein[c], G. Trottet[c], and P. Lantos[c]
*(a) Polar GeophysicalInstitute, Apatity, Murmansk region 184 209, Russia*
*(b) IZMIRAN, Troitsk, Moscow region, 142 190, Russia*
*(c) Observatoire de Paris, LESIA, CNRS-UMR 8609, 92195 Meudon, France*
Presenter: E.V.Vashenyuk (vashenyuk@pgi.kolasc.net.ru), rus-vashenyuk-E-abs3-sh15-poster

A ground level solar particle event on October 28, 2003 related with a not well-connected flare 4B/X17.2, S16, E08 possessed of a number of unusual features in the distribution of increase effect over the globe.. From the neutron monitor data by the modeling technique parameters of relativistic solar protons (RSP) were obtained and their dynamics studied in course of GLE. Among RSP two populations clearly could differ: prompt and delayed ones. The prompt solar protons caused an impulselike increase at a few neutron monitor stations looking perpendicular to the mean IMF direction. The delayed solar protons had slow intensity rise and arrived at Earth from the antisunward direction (looking along IMF). It is argued that high-energy solar protons came to Earth along the looplike IMF field line connecting the Earth with the eastern flare on the Sun. Such IMF structure seems to be formed by a CME of preceding flare 3B/X 1.2 on October 26.

## 1. Introduction

The particle event of 28 October 2003 was related to a solar flare 4B/X17.2 that occurred in the active region NOAA 10486 slightly east of the central meridian (S16, E08) nominally not well-connected with Earth. In this paper we study the features of energetic solar protons and electrons generation and propagation to Earth on data of ground based neutron monitors and metric-to-kilometric radio emission from electrons accelerated near the main radioonset observed in a wide wavelength interval. The energetic spectra, and also directional characteristics of relativistic solar protons derived from the data of neutron monitors can reveal possible sources of the accelerated particles on the Sun. The SPE 28.102003 occurred on a disturbed interplanetary background caused by interplanetary CME (ICME), (SSC was registered at 01.31 UT) from a solar flare 26.10. and a corotating high-speed solar wind stream from a coronal hole commenced to Earth about 7 UT, a few hours before the GLE onset. This paper outlines some aspects of the author's analysis of the event [1].

## 2. Neutron monitors observations and modeling results

With the modeling of the NM responses to an anisotropic solar proton flux and comparing those with observations the parameters of primary solar protons can be derived by a least square technique [2-4]. So the parameters of modified power rigidity spectrum with variable slope $J_{\|}(R) = J_0 R^{-\gamma^*}$, $\gamma^* = \gamma + \Delta\gamma\cdot(R\text{-}1)$ where $\gamma$ is a power-law spectral exponent at $R$ = 1 GV, $\Delta\gamma$ is a rate of $\gamma$ increase per 1 GV. The other parameters are: coordinates $\Phi$ and $\Lambda$, defining anisotropy axis direction in the GSE system; and a parameter C, characterizing the pitch-angle distribution in form of a Gaussian: $F(\theta(R)) \sim exp(-\theta^2/C)$. So, 6 parameters are to be determined: $J_0$, $\gamma$, $\Delta\gamma$, $C$, $\Lambda$, $\Phi$ [3,4]. For the very complicated event of 28.10.2003 we had to use a model with two completely independent particle fluxes, accordingly, the number of parameters in this model grows up to 12. In Table1 the parameters of these two fluxes are presented for 6 moments of time. So the dynamics of RSP in course of the GLE can be traced. Figure.1 shows increase profiles at the NM stations Norilsk, Cape Schmidt, Apatity and Barentsburg (Spitsbergen). Numbered arrows are the specified instants

1-7 of model calculations (Table 1). The character feature here is the impulselike increase at Norilsk station (prompt component of RSP) contrasted with a gradual increase at Mc Murdo (delayed RSP component). It is notable that McMurdo station registered the maximum increase, accepted radiation from antisunward direction. And Apatity and Barentsburg stations were turned by their asymptotic cones nearly to the Parker spiral showed very little increase [1]. Dynamical changes of the pitch angle distribution (PAD) of the prompt component (PC) of RSP (initial pulse of intensity) are demonstrated in Figure.1 b (instants 1-3). The peculiarity here is that the maximum intensity of PC was due to the particle flux from a direction nearly perpendicular to the mean IMF and to the symmetry axis of RSP. Also, Figure.1c shows the PAD evolution during the main intensity increase dominated by the delayed component (instants 5-7). In this time all particles arrived approximately along the IMF, but from the antisunward direction. Near the peak of the main increase (instant 7) the PAD becomes broader and additional flux appeared from the Parker spiral direction.

**Table 1**. Energy spectra, pitch-angle distributions and apparent viewing directions of two RSP sources

| № | Time UT | Flux1 | | | | | | Flux 2 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $\gamma1$ | $\Delta\gamma1$ | C1 | $\theta1$ | $\Phi$ 1 | $J1_0$ | $\gamma2$ | $\Delta\gamma2$ | C2 | $\theta2$ | $\Phi2$ | $J2_0$ |
| 1 | 11:25 | 0.63 | -0.16 | 0.40 | -57 | -100 | 80 | 2.2 | -0.31 | 0.17 | 1 | 135 | 7900 |
| 2 | 11:30 | 1.15 | -0.24 | 0.42 | -61 | -107 | 920 | 1.2 | -0.6 | 0.17 | -2 | 144 | 4400 |
| 3 | 11:35 | 2.0 | -0.16 | 0.40 | -60 | -105 | 2200 | 1.2 | -0.7 | 0.15 | -5 | 144 | 3000 |
| 4 | 11:40 | 0.84 | -0.91 | 0.28 | -60 | -104 | 2970 | 0.8 | -0.2 | 10.27 | 60 | 76 | 247 |
| 5 | 11:50 | 4.39 | 0.0 | 0.24 | -59 | -107 | 33100 | 1.5 | -0.42 | 7.41 | 59 | 73 | 3600 |
| 6 | 11:55 | 3.93 | 0.0 | 0.23 | -63 | -100 | 22200 | 0.72 | -0.38 | 11.82 | 63 | 80 | 1450 |
| 7 | 12:10 | 4.38 | 0.0 | 0.44 | -62 | -125 | 33300 | 5.60 | -0.01 | 5.36 | 62 | 55 | 56400 |

The dynamics of derived spectra are shown in double logarithmic (d) and semi logarithmic (e) scales. Spectra derived for instants 1-4 obviously correspond to the prompt component (PC) and are approximated by a dashed curve in Figure. 1 d,e. Spectra derived for instants 5-7 correspond to the delayed component (DC) of RSP. We note that within the estimated error limits the spectrum of PC can be approximated by an exponential in energy: $J = 1.5\cdot10^5\exp(-E/0.4)$ $m^{-2}s^{-1}st^{-1}MeV^{-1}$. During the maximum of the main increase (instants 5-7) the spectrum becomes a power law in energy: $J = 3.5\cdot10^3E^{-3.5}$ $m^{-2}s^{-1}st^{-1}MeV^{-1}$. The direct solar proton fluxes obtained by GOES-11 spacecraft and balloons launched in Apatity (Joint Lebedev Physical Institute and Polar Geophysical Institute balloon experiment [5]) are in good agreement with derived spectra.

## 3. Discussion and conclusions

On the ground of neutron monitor modeling results carried out above and author's analysis with using a great complex of data including solar radioemission, spacecraft particle and radiowave data [1] the energetic particle dynamics can be described in a scheme shown in Figure.2. Early 28 October 2003 the ICME related to the solar flare on 26 October reach the Earth. Soon after that a high-speed solar wind stream has commenced. So at the GLE onset the Earth was at a boundary area between a CME ejecta and the corotating stream (CS).. By means of looped IMF structure inside ejecta the Earth was connected to a flare site in the eastern part of solar disc. And high energy solar protons (HEP) could come to the Earth along the loopelike

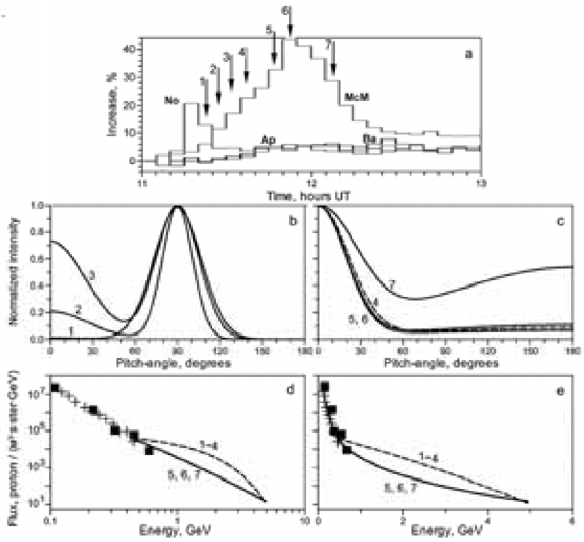


**Figure 1.** Relativistic solar proton dynamics in the GLE 28.10.2003. **(a)** increase profiles at Norilsk (No) and McMurdo (McM), Apatity (Ap) and Barentsburg (Ba) neutron monitor stations. Numbered arrows are the moments of time, when parameters of RSP were derived (Table1); dynamics of derived pitch angle distribution: **(b)** during the initial impulsive increase; **(c)** during the main intensity maximum; dynamics of derived energetic spectra: (**d**) in double logarithmic, **(e)** in semi-logarithmic scale. Direct solar proton data are: crosses (balloons) and blacked squares (GOES-11 spacecraft).

IMF from antisunward direction. The similar idea that in the 28 October, 2003 GLE relativistic solar protons arrived at Earth from antisunward direction propagated along the IMF magnetic loop originated in the eastern AR10486 was also considered in [6]. The subrelativistic electrons, meanwhile, arrive to the Earth from a source in western part of solar disk along a Parker spiral IMF line, connected with a corotating stream [1]. The weak delayed flux of RSP along the Parker spiral direction could be explained by effects of coronal propagation. Figure.2 b shows the spatial structure of IMF near the Earth during the 28 Oct 2003 GLE reconstructed with use of IMF and solar wind data. The dotted lines are the IMF field lines and arrows are average directions of relativistic proton flux registered by neutron monitors in Mc Murdo (McM) and Norilsk (No). By essential detail here is the sharp kink of a magnetic field with the radius of curvature $3\cdot10^6$ km comparable with Larmor radii of relativistic solar protons. We carried out trajectory computations in the magnetic structure shown in Figure. 2 b. The RSP of the prompt component having small pitch-angles, were strongly deviated at the IMF kink. On the contrary, the particles with great pitch angles are scattered a little on the kink and pass through it keeping the direction of movement along the magnetic field. This can explain the observed effect, namely that the strongly anisotropic particle bunch of prompt solar protons that was registered by neutron monitor at Norilsk and other stations with their asymptotic cones oriented nearly perpendicular to the IMF. The delayed component particles, in the majority having large pitch-angles, scattered a little on the kink of the IMF. So the McMurdo station looking nearly along the IMF registered a delayed RSP, coming along the IMF from antisunward direction.

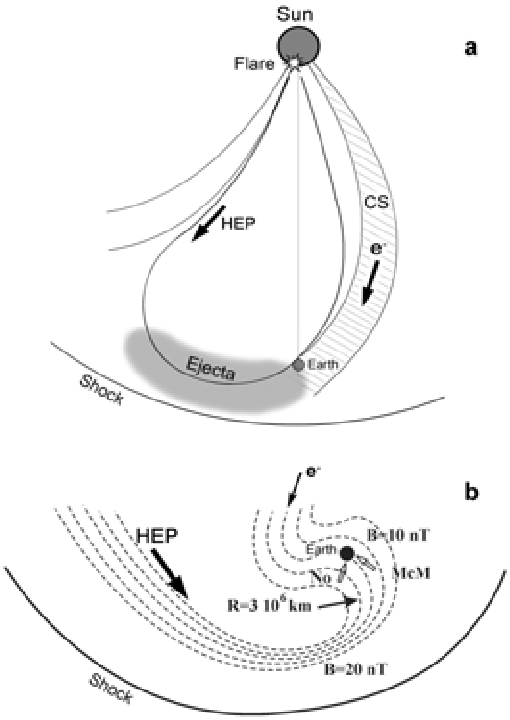


**Figure. 2**. **a.** The proposed model for the IMF structure during the 28 October, 2003 SPE. The earth is at a boundary area between an ejecta from the flare 26 October and the corotating stream (CS) commenced to Earth shortly before the event. By means of looped IMF structure inside ejecta the Earth is connected to a flare site in eastern part of solar disc. High energy solar protons (HEP) come to the Earth from antisunward direction. At the same time, the subrelativistic electrons can arrive to the Earth from a source in western part of solar disk along of a Parker spiral IMF line, connected with a corotating stream.
**b.** The spatial structure of IMF near the Earth during the 28 Oct 2003 GLE, reconstructed with use of IMF and solar wind data. The dotted lines are the IMF field lines and arrows are average directions of relativistic proton flux registered by neutron monitors in Mc Murdo (McM) and Norilsk (No). By essential detail here is the sharp kink of a magnetic field with the radius of curvature $3 \cdot 10^6$ km comparable with Larmor radii of relativistic solar protons

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