

The "Bastille Day"; GLE 14 July, 2000 as observed by the worldwide neutron monitor network

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Abstract. The preliminary analysis of GLE on 14 July 2000, observed by the worldwide neutron monitor network, was carried out using the asymptotic acceptance cones of different cosmic ray stations. The calculated asymptotic direction maps correspond to a picture where a maximal increase and fast intensity rise were observed by stations looking along the IMF at the sun through their asymptotic cones. The event was superimposed on a disturbed interplanetary background: a strong Forbush decrease was in progress when the GLE began. A complex analysis of many relevant data suppose the particle acceleration up to relativistic energies to be occurred on the early phase of the flare, and the proton enhancement had a relatively soft energy spectrum.

1 Introduction

The flare of X5.7/3B started on 14 July 2000 (one more "Bastille day") at 10:03 UT in the active region NOAA 9077, which crossed a central meridian just in this day. This flare has more rights for this sonorous name than a modest M4.5/1B flare occurred on 14 July 1998 (Aulanier et al., 2000). It was of the N22W07 optical coordinates, but really occupied an extended area along the solar equator, and the associated activity involved the whole central area of the Sun. The X-rays peaked at 10:27 UT and returned to the background only by the end of this day. This flare ranked in X-ray importance below the flare X9.4/2B in November 1997, which also created the GLE, but exceeded it by the total X-ray flux (0.75 against of 0.36 cm⁻²-ster⁻¹). The >10 MeV proton flux reached 24000 pfu. Therefore this flare was the biggest flare in current solar cycle until the April 2001, and the third largest proton event above 10 MeV since 1976. As it is often occurred, the flare X5.7/3B entered into a series of the powerful flares from one active region. Over the period from 9 to 19 July in the group 9077

the fifteen flares were recorded of M1 and higher importance, among of which the significant flares X1 on 11.07 and X1.9/2B on 12.07.

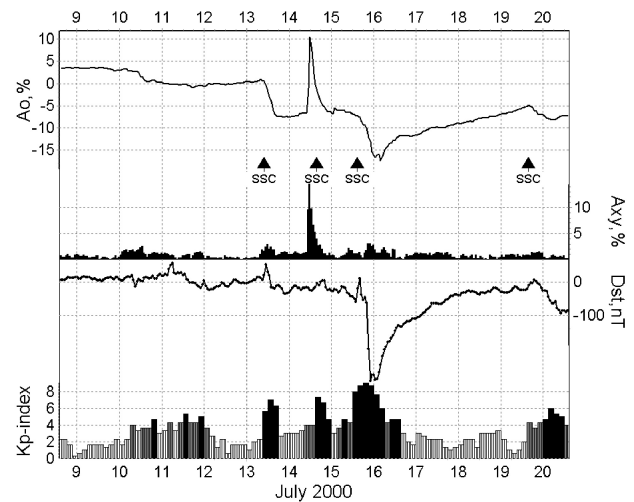


Fig. 1. Variations of cosmic rays together with Kp- and Dst indices of geomagnetic activity during 9 – 20 July 2000. A₀ – density variation of 10 GV cosmic rays (CR), A_{xy} – equatorial component of the CR first harmonic anisotropy. The CR characteristics are inferred by the global survey method for 10GV rigidity except of the GLE period when the effective rigidity was about 1-3 GV.

The coronal mass ejection (CME) associated to this flare, was even more outstanding than the flare itself. During the flare the numerous evidences of the large scale eruption on the Sun were obtained: filament disappearance, powerful type II radio bursts, the noise storm weakening, high post-eruptive arcades, dynamic of the Sun EUV images. It took a little more than 28 hours to get CME related shock the Earth that argues an extremely fast propagation this disturbance between Sun and Earth. By the observations near the Earth (ACE, SOHO) solar wind speed on 15 July exceeded 1000 km/s, and the IMF intensity was about 95 nT. It is not surprising that such a great disturbance (a few

days lasted) created one of the deepest Forbush decrease in 23-rd solar cycle - 10.7 % for 10 GV cosmic rays (Fig. 1). The CR intensity near Earth at the first hours of July 16 is still the lowest in the current cycle. The extreme magnetic storm started at 14:37 UT 15 July, when K_p -index reached of its maximally possible value 9. This is the only case during the last 12 years (since 14 March 1989).

So, the particle acceleration at the Sun up to relativistic energies occurred near the maximum of one of the most powerful flare at the moment of extraordinary CME initiation. The flare was preceded by a disturbed period: strong magnetic storm and big Forbush-effect started well before this day. By the flare onset 14 July solar wind near Earth became to relatively quiet condition, the IMF was of the low intensity, but very variable by direction. The GLE started under $\hat{E}_p=4$, but in some hours one more shock arrived, and geomagnetic activity rose again up to a severe storm ($\hat{E}_p=7$). These conditions make the GLE analysis to be rather complicated.

2 Data and Method

Short time interval data (1-and 5-minute) from different neutron monitors (27 stations), and hourly data as well have been used in analysis of the flare 14 July and the events resulted. A lot of relevant data, such as the solar wind, interplanetary magnetic field (IMF), hard X-ray and gamma-ray data, radio emission, optical, and geomagnetic activity data from the Earth and spacecraft detectors has been also involved.. Asymptotic directions of the incident solar cosmic rays were calculated on the base of Tsyganenko 89 model for the moment of peak GLE.

3 Results and Discussion

In Fig.2 the profiles of the CR ground level enhancement

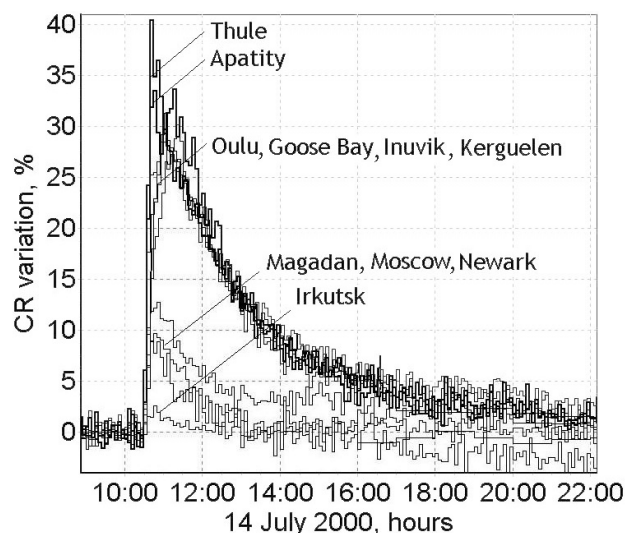


Fig. 2. Time profiles of the CR recorded at different neutron monitors during the GLE 14 July 2000.

are plotted as they observed at the stations of different rigidity. The greatest rigidity among of presented station has

Irkutsk station ($R_c=3.66$ GV), but small effect was recorded at high mountain Alma-Ata station ($R_c=6.7$ GV). In this case thus we can say about acceleration up to 6.7 GeV at least. Data from many stations at once indicate that first particles came to the Earth at 10:30-10:31 UT, and we can not exclude that small amount came even earlier. Charged particle of several GeV energy needs no less than 11m to come in from the Sun. The analysis of the previous proton events at Earth (Vashenyuk, 2000) shows that GLE onset is always delayed relatively to type II radio emission by no less than 14 min. The maximal enhancement at the neutron monitors was reached quickly, and time profile was simple enough and not extended. This indicate the most amount of arrived at Earth hard particles to be accelerated before maximum of the soft X-ray emission (10:24 UT) measured by GOES, or nearly this time.

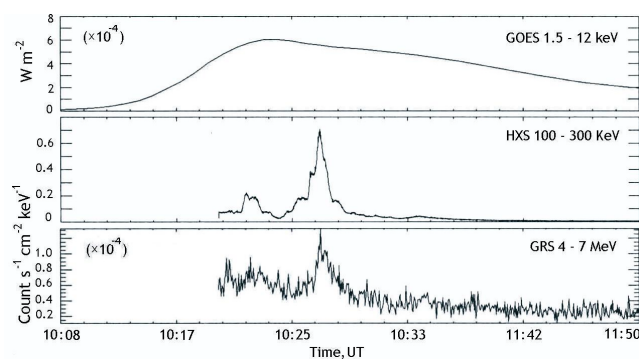


Fig. 3. Time history of the 2000 July 14 flare observed by GOES and the Yohkoh (HXS- and GRS-detectors) (adapted from Share et al., 2001).

This time profile for soft X-rays is displayed in Fig. 3, where the profiles hard X-rays and gamma-ray within 4-7 MeV observed by Yohkoh are also presented. Gamma-ray burst was observed from the beginning of Yohkoh measuring (10:20). The hard X-rays and gamma-rays peaked at 3 m later than soft X-rays, at ~ 10:27 UT, and lasted until 10:40 UT.

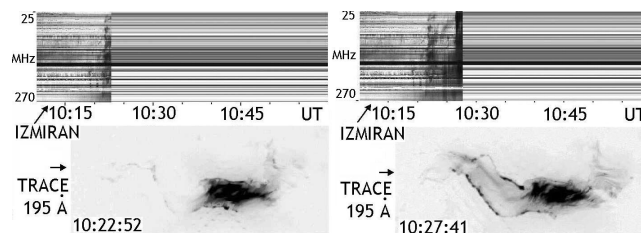


Fig. 4. The compressed inverted IZMIRAN dynamic radio spectra (upper panel) and inverted TRACE images at 195 Å (low panel) illustrate development of the EUV post-eruption arcade with the well-organized loop, two ribbon and spine structure from 10:22:53 to gamma-ray peak at 10:27:41. (from Chertok et al., 2001)

At the same time radio bursts started, although the main of them, of low frequency, evolved later. The first type II radio burst was recorded at 10:19 UT. (Chertok, et al., 2001). The hard X-rays and gamma-ray observations are in

a good agreement with the assumption that most amount of particles was accelerated in the period from 10:19 to 10:29 UT.

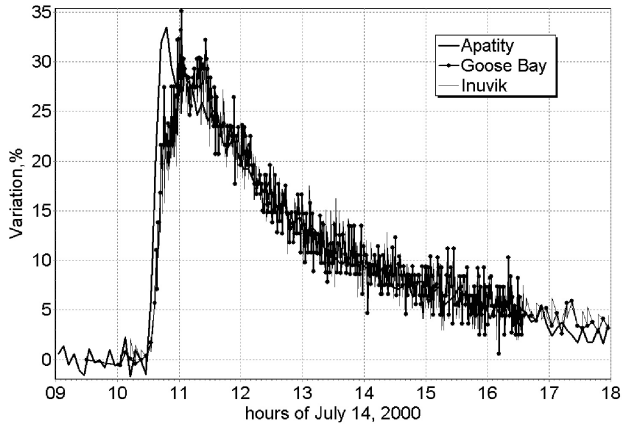


Fig. 5. The GLE profiles on the high latitudinal stations relatively to the base hour (9:00-10:00 14.07)

The flare location (nearby the central meridian) was not the best for the particle direct incoming, and the main amount of the relativistic protons reached Earth after some diffusion. Fig. 5 demonstrates longitudinal anisotropy, and we see that European station Apatity was more comfortable located compared to Canadian stations only during the first 20-30 min of GLE observation. North-south asymmetry (Fig. 6) was about 100% in the beginning, when the enhancement at the north exceeded those at the south, but then reduced very quickly.

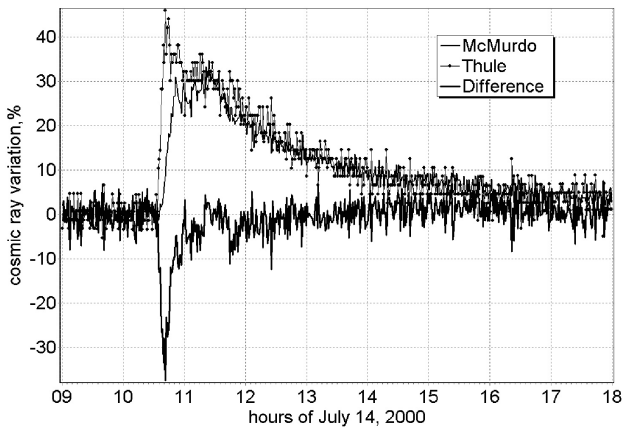


Fig.6. North-south anisotropy of the solar cosmic rays on the main phase of the GLE profile. CR variations observed at two subpolar stations Thule (north) and McMurdo (south) and their difference

As a whole, the enhancement distribution by the stations within the anisotropic phase conforms with the prompt particle arriving along the IMF force line. Fig. 7 shows the asymptotic cones in GSE coordinates for a number of neutron monitor stations in the peak time of GLE, calculated with the use of Tsyganenko model (Tsyganenko, 1989). The equal pitch angle grid has the steps of 10° and plotted from 0° (direct flux) to 180° (sunward reverse flux).

Thule station in this picture has the most suitable position to register a direct prompt flux, since its asymptotic cone was located inside of the small pitch angles ($<40^\circ$). The asymptotic cones of many other high latitudinal stations was turned to IMF by their high rigidity ends and was in a region of big pitch angles for low energy particles. These stations thus didn't register the anisotropy but rather soft diffusive part of the solar protons and showed very similar profiles of CR intensity. Apatity cone was close to Oulu, Goose Bay and other ones, and this NM should have been to show the same behavior of CR. But we see that Apatity and Thule registered the similar anisotropy peak in the first minutes after the onset, whereas Oulu station, similarly to all others, showed the gradual increasing (Fig. 1, 5, 6).

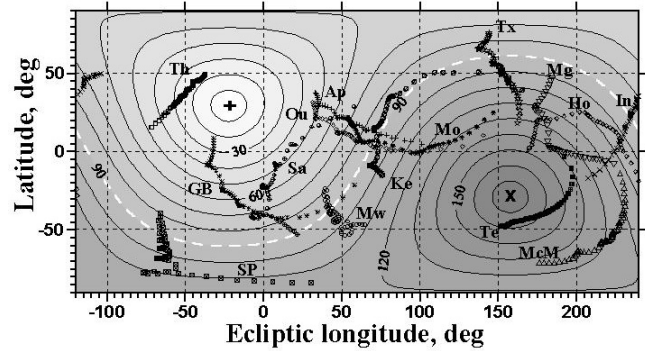


Fig. 7. Asymptotic directions of vertical incident CR at different stations at the time of peak GLE (at 11:00UT) on 14 July 2000 in the ecliptic coordinate system. “+” means sunward, and “x” – outward the Sun the IMF direction as it was observed on the ACE spacecraft around this time. Two first letters from the station name were used for its marking.

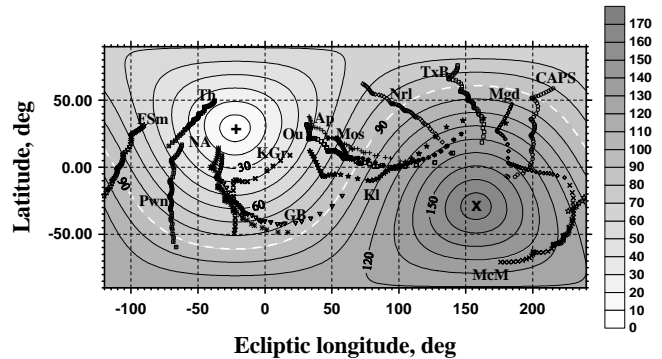


Fig. 8. The same as in Fig. 7, but including the stations from SSE project, which did not operate in those period: NA-Nain, FSm-Fort Smith, Pwn- Pewanuik, Nrl- Norilsk, CAPS- Cape Shmidt

An explanation of the observed difference between Apatity and Oulu stations is proposed in (Vashenyuk et al., 2001) by means of some magnetospheric effect promoting the direct penetration of high energy solar protons to one of the stations and leaving out the calculated asymptotic cone. Fig. 8 demonstrates the asymptotic cones at the same moment, but including the stations of Space Ship Earth project (Bieber et al., 1995), which were not operated yet in those time. Stations Peawanuck and Fort Smith seems to be able to see the initial prompt increase on the onset phase in

this GLE, since their asymptotic cones are more close to Thule rather than to Goose Bay. These stations can't help with this analysis since they started to operate only at the end of 2000, but they were happened already to record two GLEs in April 2001.

The event 14 July 2000 by the amount of ultra relativistic particles at Earth is in order less than the most abundant event 29.09.1989 in the previous cycle and in two orders ranks below the record enhancement on 23 February 1956. Along with this, it exceeds the absolute majority of other GLEs and may be considered as the great one. A comparison of the discussed GLE with well known event on 15 June 1991 is presented in Fig 9 (GLE 59 and GLE 52). The maximal enhancements by different stations in these two GLEs are well correlated (correlation and regression coefficients are found as 0.97 and 1.32 ± 0.08 , respectively). Accounting a difference in the background intensities on these two events we can conclude that CR of >1 GeV in GLE 59 reached Earth in ~ 1.6 times more amount than those in GLE 52. We used the energy spectra calculations carried out in (Belov et al, 1994) for the solar CR on 15 June to estimate peak differential flux of 3 GeV protons for GLE 59, and obtained it as of $1.4 \cdot 10^{-5}$ ($\text{cm}^2 \cdot \text{s} \cdot \text{sr} \cdot \text{MeV}$).

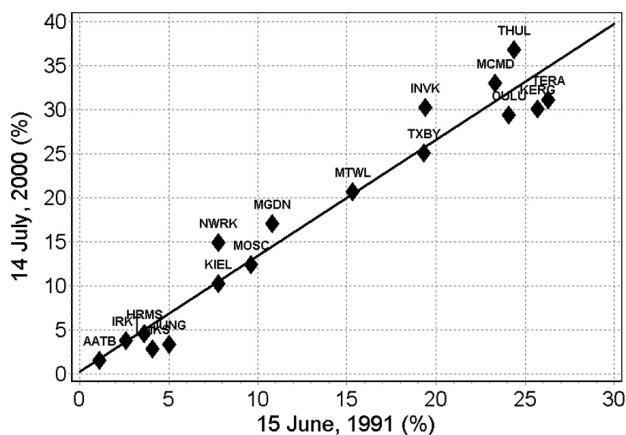


Fig. 9 Correlation between the CR peak enhancements at different stations during GLE52 and GLE59.

Judging from the Fig.9, the spectra tilts in the high energy range in these two events were similar. However, it is disrupted for the low energies. Indeed, in the peak of proton enhancement on July 14 the flux of >10 MeV protons was ~ 24000 pfu against of ~ 1200 on 15 June 1991. Thus, if a ratio of the hard particle fluxes was ~ 1.6 , then, for >10 MeV protons it was about 20. It indicates that the solar proton spectra was relatively soft in the Bastille Day event near Earth. In this event the slope of energy spectrum appeared to be less depended on energy rose than in the majority of great GLEs in 22-nd solar cycle (Belov et al., 1996).

4 Conclusion

The energy spectrum of the solar CR arrived to the Earth at 14 July 2000 was relatively soft. However, it contained high energy particles up to 6-7 GeV at least. Timing of GLE and other characteristics of this event lead to conclusion that relativistic particles (all, or the majority) suppose to be accelerated before the 10:29 UT, during the first 10 minutes after the type II radio burst started. In this time the extremely powerful CME was originated at the Sun, which revealed itself in a day as a exclusively geo-effective disturbance. There is no escape from the consideration also the more early onset of acceleration since, as it pointed out in Chertok et. al. (2001), the filament eruption in the active region started before the X-ray flare commencement. The acceleration seems probably to be occurred in the lowest part of the solar corona.

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