# THE HIGH-ENERGY GAMMA-RAY FLARE OF JUNE, 15, 1991: SOME EVIDENCE OF PROLONGED PARTICLE ACCELERATION AT THE POST-ERUPTION PHASE

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## Abstract

We compare the high-energy (up to 2 GeV) prolonged (at least 2 hours) gamma-ray emission, observed by the gamma-telescope GAMMA–1 in the June 15, 1991 flare , with microwave bursts and solar cosmic rays. The comparison testifies that the gamma-ray and radio emissions, observed well after the impulsive phase of the flare, appear to be initiated by prolonged nonstationary particle acceleration during the late phase of the flare rather than a long-term trapping of energetic electrons and protons accelerated at the onset of the flare. It is suggested that such an acceleration may be associated with a long post-eruption energy release following a coronal mass ejection.

## 1. Introduction

The 3B/X12 flare of June 15, 1991 was accompanied by a prolonged gamma-ray continuum up to 2 GeV and 0.8–8.1 MeV gamma-ray line emission (Akimov et al., 1991; Ryan et al., 1993). This paper continues an analysis of the flare by means of comparison of the gamma-ray emission with microwave bursts and solar cosmic rays. The main purpose is to discriminate between two models: a) a short particle acceleration at the impulsive phase of the flare, long trapping, and slow precipitation; b) a prolonged acceleration directly during the late phase of the flare and fast precipitation (see Mandzavidze and Ramaty (1992) and references therein).

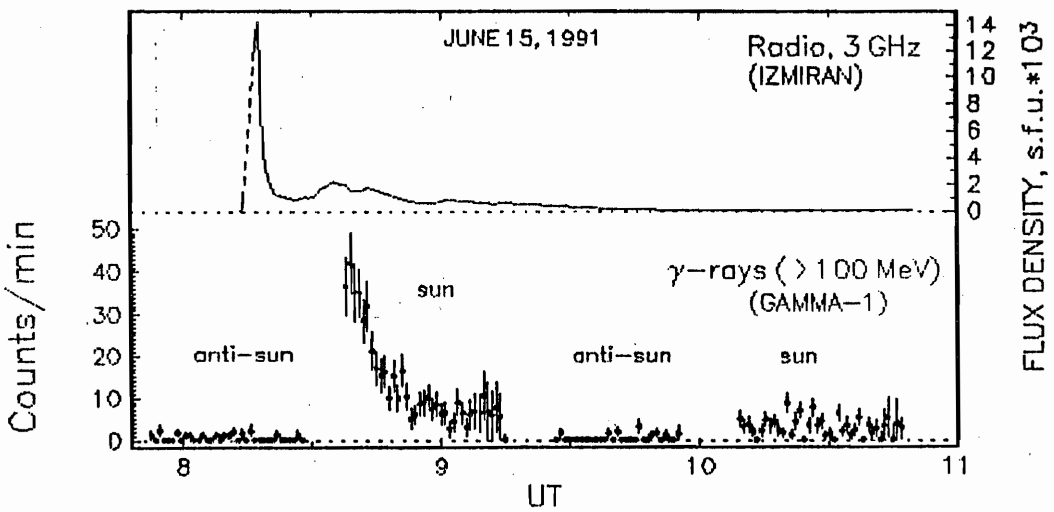


Fig. 1. Microwave and gamma-ray time profiles.

## 2. Observations and discussion

Figure 1 shows that according to radio data the energy release in this flare consists of a strong impulsive 10-min component with rather sharp decay followed in 15 min by a relatively weak but well visible delayed enhancement. The GAMMA–1 telescope was switched on in solar attitude at 08:37:22 UT at the time of delayed component maximum. Nevertheless, gamma-emission with energies up to 2 Gev was registered at the moment (Akimov et al., 1991). Then the gamma-ray flux decreased gradually during about half an hour in general accordance with a decay of the microwave flux density. In the next orbit (later 10:08 UT), the solar gamma-ray flux was yet well above the background. According to Leikov et al. (1993), the gamma-ray energy spectrum, in particular during the 08:37:22–09:00:14 UT interval, has a flattening bellow 100 MeV which indicates that most of photons were born in a neutral pion decay process.

The large-scaled picture shown in Figure 2 reveals that the post-burst microwave enhancement has a complex profile with a number of sub-bursts in the time scale T≤200 s. Besides, definite similarity takes place between the general trends (and perhaps between some details) of the temporal profiles of the >100 MeV gamma-rays and microwave burst on the decay stage of the delayed component. In addition, the 0.8–8.1 gamma-rays and radio burst have approximately the same decay time.

Thus the features outlined above are direct indicators of the presence of electrons with energies from few hundred of keV to at least several MeV as well as of protons with energies from some tens of MeV up to several GeV at the flare region during many tens of minutes well after the impulsive phase of the flare. Our data provide some evidences of the prolonged multiple particle acceleration during the late phase of the flare rather than the long-term trapping of energetic electrons and protons accelerated at the impulsive phase. The main argument is that no trap model can provide the same life-time for so different kinds of particles as the 500 keV–8 MeV electrons, 30 MeV and 1 GeV protons. Moreover, it is obvious that the precipitation should be sufficiently fast (the time of the pitch-angle diffusion T≤200 s) in order to secure the variability of radio profile.

The energetic particle fluxes registered after this flare on the IMP–8, GOES–6, 7

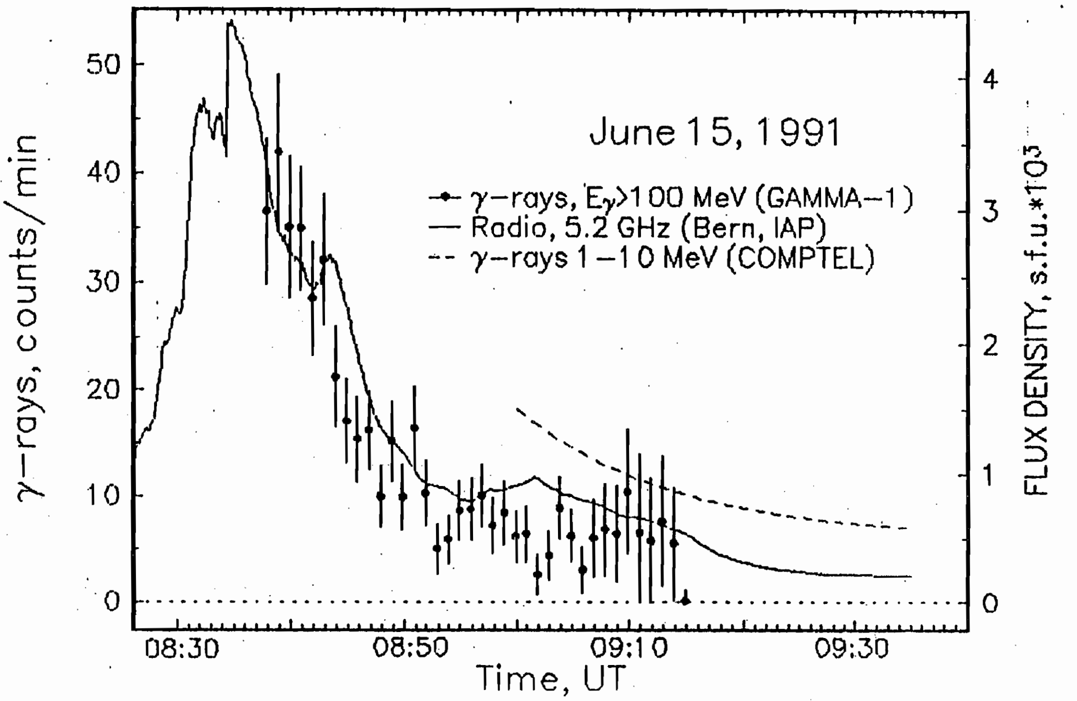


Fig. 2. Enlarged time profiles of the delayed component.

satellites, and neutron monitor network reveal unusual features which could support the assumption of the prolonged acceleration. In particular, the analysis shows that protons with energies <500 MeV exhibit normal dispersion of the onset and maximum times of the enhancement while protons of higher energies (as well as relativistic electrons) do not show such dispersion and arrive to the Earth about 10–15 min later than low-energy protons. It can be added that the registered energy spectra of the >500 MeV protons have not been softening during 2 hours after the maximum. Perhaps the high-energy protons were escaping into the interplanetary space for a long time and started later than low energy particles.

## 3. Conclusion

Comparison of the emissions at different ranges imposes strong restrictions on the models associated with a long capture of particles in the trap. The shock wave acceleration appears to be not suitable for the interpretation of the delayed component of the gamma-ray and microwave emissions, because the shock was too far in the corona at the time of the delayed component.

We suppose that the prolonged energy release following the coronal mass ejection (CME) may be a source of particle acceleration up to high energies at the late stage of the flare (Figure 3). During this post-eruptive phase, the magnetic field above the active region, strongly disturbed by the CME eruption, relaxes to its initial state through the magnetic reconnection in a vertical current sheet accompanied by effective particle acceleration, generation of delayed microwave and X-ray components, formation of the post-flare loop system, and other remarkable phenomena (Kopp and Pneuman, 1976; Cliver, 1983; Kai et al.,1986). Estimations

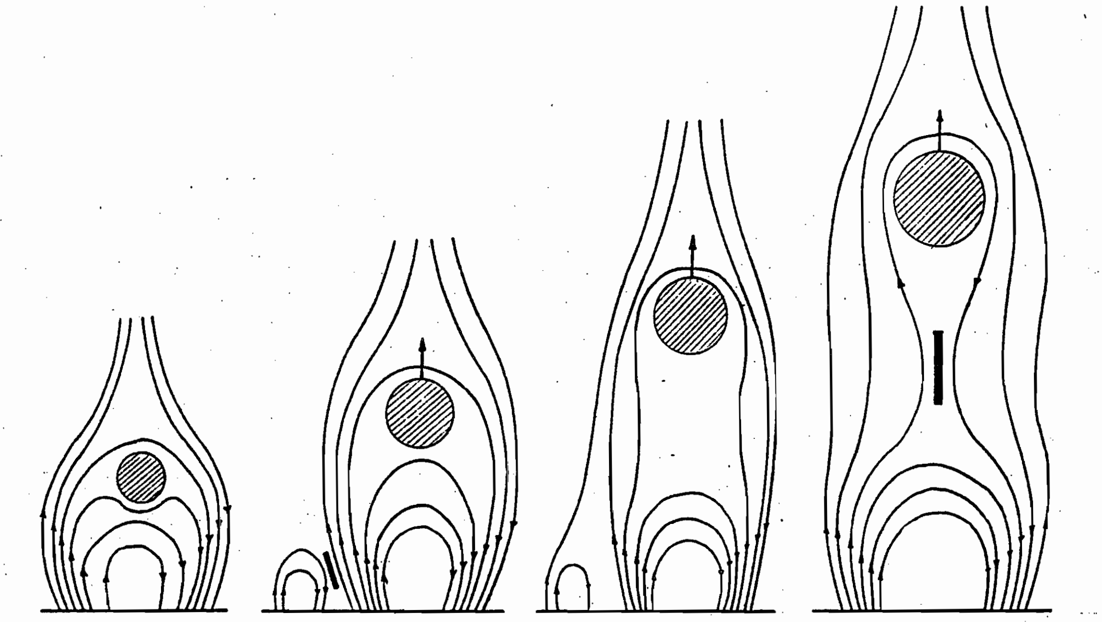


Fig. 3. A schematic illustration of the post-eruption energy release.

of Martens (1988) show that this process can result in a direct electric field acceleration of particles with a power-law spectrum, in particular, of protons up to 20 GeV.

Probably, the scenario outlined above is typical for other flares with high-energy gamma-ray emission because similar microwave bursts with analogous delayed components also were observed in these events.

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