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TIME-EXTENDED ACCELERATION OF ENERGETIC PARTICLES IN THE CORONA DURING THE 19 OCTOBER 1989 GLE

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ABSTRACT

The broad injection cones and long durations of large solar energetic particle events (SEPs) have been recently considered as evidence for particle acceleration in the shock wave generated by a coronal mass ejection. Radio observations of an energetic flare on 19 Oct 1989 show that energetic electrons radiate both near the flare site and several tens of heliocentric degrees away. This is evidence for rapid particle propagation from the flare site or else for the simultaneous activation of widely separated sites of acceleration. At some places energetic electron signatures persist over at least several hours after the flare. We argue that even if the CME-associated shock wave may contribute to the acceleration, it competes with processes in the low and middle corona which may supply energetic particles to interplanetary space over several hours and with injection cones comparable with the width of CMEs.

INTRODUCTION

Long-lived populations of energetic particles are observed both in the corona and in interplanetary space: suprathermal subrelativistic electrons emit radio waves ("noise storms") during several hours or even days after flares or in the absence of flares. Recent γ-ray observations show that even relativistic electrons and protons above 200 MeV still exist in the corona hours after flares. Large particle events in interplanetary space may last several days. In the following, particle populations radiating in the corona will be referred to as "interacting", while those detected near 1 AU will be called "escaping" particles.

Long duration emission of energetic particles requires either prolonged storage or time-extended acceleration. Centimetre-to-decametre radio waves are emitted by electrons which radiate in dense structures of the low and middle corona. Since the energetic electrons have short ($\leq$1 min) lifetime, they must be accelerated over hours or days. The long-lasting and time-variable radio emission which accompanies at least the 15 Jun 1991 γ-ray event [1] argues in favour of the time-extended acceleration of both interacting electrons and protons also in such energetic events.

How interacting and escaping particle populations are related is presently not clear. It was generally considered that the particles escaping from the flaring active region get access to the interplanetary field line connected with the satellite either directly, if the acceleration occurs close to the field line on the Sun, or after diffusion in the corona and interplanetary space. Recently it has been argued, especially with respect to magnetically poorly connected events of long duration ($\gg$1 hr), that all or part of the escaping particles are accelerated by the shock wave created by a coronal mass ejection [2, 3, 4]. This mechanism decouples the acceleration of the escaping particles from the interacting particles.

In this contribution the sites and time evolution of the radio emission produced by electrons in

the corona below 1 $R_\odot$ above the photosphere are studied in the case of the energetic flare of 19 Oct 1989. We consider the electron signatures as representative of charged particles in general, including ions. This is a basically unproven, though to a certain extent plausible, hypothesis which we must make because there are no direct imaging diagnostics of proton acceleration in the solar atmosphere.

OBSERVATIONS

The 19 Oct 1989 event was observed throughout the electromagnetic spectrum, from radio to γ-rays. An X13 soft X-ray event started around 12:50 UT, attained its maximum at 12:55, and decayed over more than seven hours. Energetic protons and electrons were detected during several days at 1 AU, both by the GOES satellites *Solar Geophysical Data*, referred to as SGD in the following) and by neutron monitors. The associated optical flare of importance 3B occurred in AR 5747 near central meridian. It lasted several hours (S25E09, SGD).

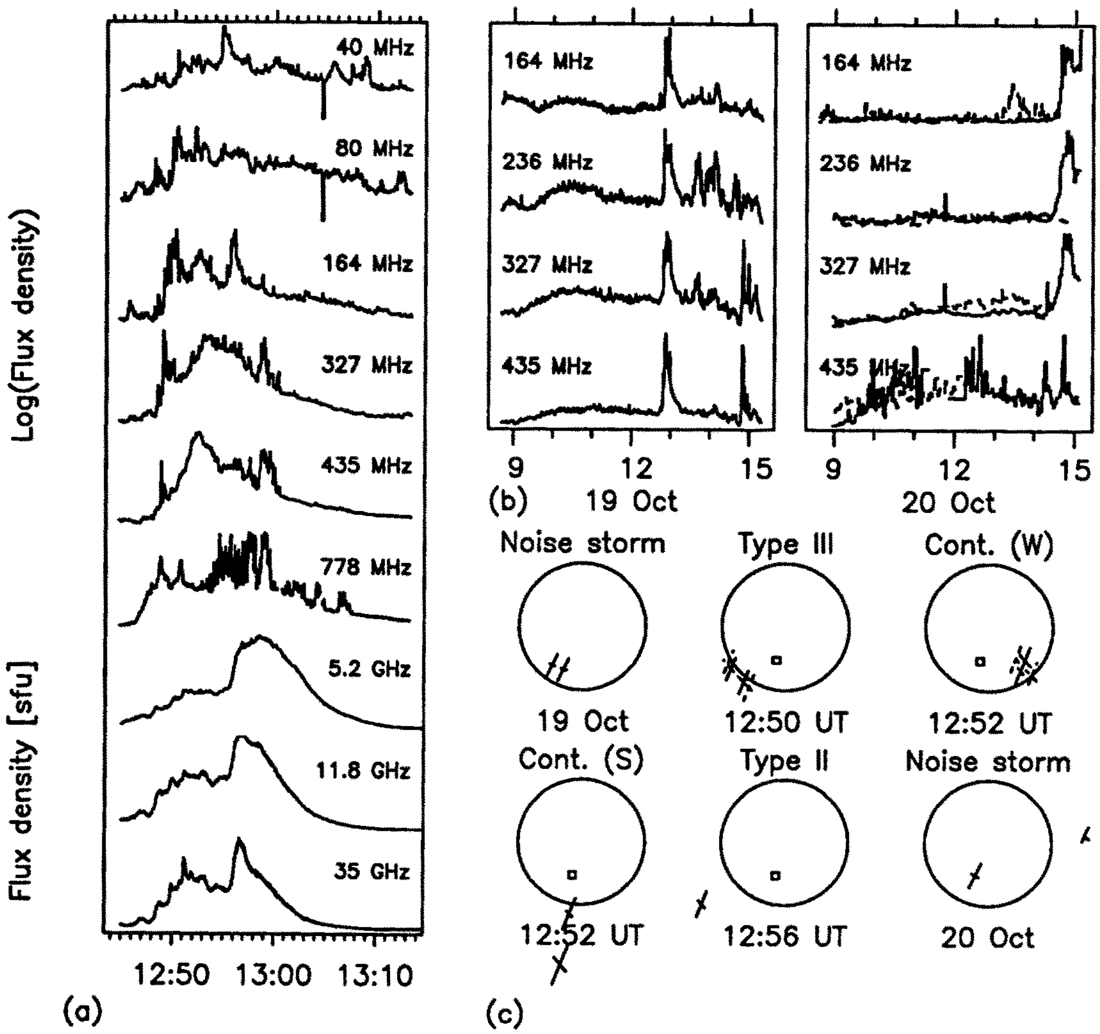

Figure 1: a.: Flux density during the main phase of the 19 Oct 1989 event at cm-m-wavelengths (Tremsdorf spectrograph, Bern polarimeter, Nançay RH). b.: Time history of the dm-m-λ emission during 19 (log-scale) and 20 Oct 1989 (lin. scale, the dashed and solid lines correspond to the western and eastern source plotted in (c), respectively. c.: Selected source configurations at 164 MHz: position and half-widths of radio sources are plotted as crosses, the Hα flare position by the open square.

The main phase of the bright radio emission at cm-to-Dm-wavelengths is shown in Figure 1.a. The dynamic spectrum (Artemis spectrograph, Space Res. Dept. of Paris Observatory, courtesy M. Poquérusse) detects type III bursts (12:48–12:51 UT), followed by a broadband continuum (12:51–12:56) which at its end is accompanied by a type II burst (brightening between 12:55 and 12:57 UT at 164 MHz, Figure 1.a).

The source configuration during different periods of the event, as well as the positions of noise storms on 19 and 20 Oct 1989, are shown in Figure 1.c at 164 MHz (Nançay Radioheliograph, henceforth called NRH). The sources are scattered over the southern hemisphere of the Sun: Prior to the flare a noise storm is located above AR 5747. The flare-associated radio emission starts with type III bursts from different sites at the south-eastern limb. The sources overlie an active filament east of the flaring active region. Continuum emission comes from two source complexes, one near central meridian, in association with the flaring active region, and a second one in the south-western quadrant, above AR 5740 (S17W31), at a heliocentric distance of 38 deg from AR 5747. No Hα flare is reported there (SGD). The following type II emission is located high above the south-eastern limb. The decimetric sources, for which only one-dimensional spatial information is available, are associated with the flaring active region.

After 13:00 UT the radio emission decays from its very high previous level. Broadband fluctuations at microwave frequencies persist without interruption until 15:30 UT and fade afterwards (SGD). At dm/m-wavelengths similar fluctuations are observed (Figure 1.b) in a bright source above the flaring active region. A new brightening, with similar flux densities as the main maximum, occurs at decimetric wavelengths near 15 UT. The dynamic spectrum (Artemis) shows various types of fast-drift bursts, including ordinary and reverse-drift type III bursts (due to upward and downward propagating electron beams).

On 20 Oct 1989 two noise storm sources are identified by the NRH (Figure 1.c): one above AR 5747, which already existed before the flare on 19 Oct; the other one above the western limb, presumably associated with AR 5736 (N13W68) or with active regions behind the limb. The noise storms demonstrate the continued acceleration of electrons. The western noise storm is in an appropriate position to supply particles to the vicinity of the Earth. A pronounced intensity increase of the western noise storm occurs around 13 UT on 20 Oct (Figure 1.b, dashed linec), near the time of a rapid rise in the energetic particle fluxes observed by GOES. It is not sure that the two enhancements are physically related, because a shock wave is observed to reach the Earth at that time.

DISCUSSION

The radio observations of the 19 Oct 1989 event provide further evidence that particle acceleration occurs in the corona during several hours after the flare starts. The coronal sites where the radio emission is generated are widely scattered over one solar hemisphere.

The brightening of a metre-wave source far west of the flaring active region implies that electrons either propagate along large-scale coronal loops from the flare site or are accelerated at the remote site, which happens to be closer than the flare to the region magnetically well connected with the Earth. Particles at this site can reach the Earth rapidly and explain the rapid initial rise and fall observed at the start of the SEP at 1 AU. This rapid rise would not be easily understood if the particles were only released at the flare site [5, 6].

If the observed radio signatures in the western hemisphere reveal remote sites of acceleration, the timing of the emission does not contradict acceleration by a CME, provided particles can escape both downward to the radio source in the middle corona and towards interplanetary space: the source in the western hemisphere brightens 3-4 minutes after the impulsive phase of the event. Given a distance of about 40 deg to the flare site, the disturbance would have to travel at $\sim$ 2000 km/s. As a CME may start before a flare, this is an upper limit which is within the observed range of CME speeds. We stress, however, that the rapidly rising initial signal detected by GOES and some neutron monitors argues in favour of a more localized acceleration than implied by the extended bow shock of a CME. Rather than directly accelerate the particles, the CME, if it plays any role, may trigger these localized acceleration processes.

From a pure timing consideration the radio emission in the western hemisphere and the type II emission some minutes later above the south-eastern limb can be due to the same propagating disturbance. The type II burst occurs very late in the event and at a site from which particles cannot easily escape towards Earth. The region of the extended shock wave where the type II emitting electrons are accelerated is hence not a well-suited site for the acceleration of escaping particles. This is in line with former conclusions that the type II related shock wave is not an efficient accelerator in the late phase of flares [7, 8].

The particle acceleration persists during at least 3 hours after the main phase. The radio source is located above the flaring active region. It emits over a broad band from centimetric to metric waves. The broadband centimetric fluctuations suggest that electrons up to at least 100 keV are accelerated. Given that this emission is spatially confined, the acceleration is probably due to local processes in the middle or low corona. This is consistent with the prolonged occurrence of typically impulsive acceleration signatures, such as fast-drift bursts due to electron beams propagating upward and downward through the corona. An influence of the CME which by that time has travelled far away from the active region can be excluded. The acceleration of low-energy electrons ($\sim$20 keV) is still visible on 20 Oct, in noise storm sources above AR 5747 and above the western limb.

The 19 Oct 1989 event appears remarkable by the wide spatial extent of its metric radio sources. However, it is not unique since it is well known that metric radio emission associated with energetic flares and the development of major coronal disturbances does involve widely spaced sources (e.g. [7, 9]). Time-extended particle acceleration after flares, as observed in the corona at radio wavelengths [7, 10] and more recently at γ-rays [1], is generally neglected as a viable particle source of SEP events. At least for electrons, the radio observations of the event under discussion and of two other GLEs of cycle 22 (12 Aug and 29 Sep 1989) do not lend support to this view, but demonstrate that acceleration occurs over a prolonged duration. Even if the CME-associated shock wave cannot be ruled out as an accelerator, the observations presented here demonstrate that time-extended coronal acceleration may supply energetic electrons, and likely also protons, to interplanetary space. A comprehensive study of the radio emission from the three GLEs is underway.

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