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Electron spikes, type III radio bursts and EUV jets on 22 February 2010

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Abstract The Solar Electron Proton Telescope on board the twin STEREO spacecraft measures electrons and ions in the energy range from 30 to above 400 keV with an energy resolution better than 10%. On 22 February 2010 during a short interval of 100 minutes, a sequence of impulsive energetic electron events in the range below 120 keV was observed with the STEREO-A/SEPT instrument. Each of the four events was associated with a type III radio burst and a narrow EUV jet. All the events show nearly symmetric "spike"-like time profiles with very short durations $\simeq$ 5 min. The estimated electron injection time for each individual event shows a small time delay between the electron spike and the corresponding type III radio emission and a close coincidence with an EUV jet. These observations reveal the existence of spike-like electron events showing nearly "scatter-free" propagation from the Sun to STEREO-A. From the time coincidence we infer that the mildly relativistic electrons are accelerated at the same time and at the same location as the accompanying type III emitting electrons and coronal EUV jets. The characteristics of the spikes reflect the injection and acceleration profiles in the corona rather than the interplanetary propagation effects.

Keywords: Flares, Dynamics; Energetic Particles, Electrons; Radio Bursts, Type III; Jets

1. Introduction

Solar impulsive near-relativistic (> 30 keV) electron events are usually flare-related and show a strong association with type III radio emission (Lin 1985; Kahler et al., 2007). It is well established that type III radio bursts are generated by low energy electrons (< 30 keV) propagating through the solar corona and the interplanetary (IP) medium (e.g. Suzuki and Dulk, 1985).

The impulsiveness of electron events is normally defined by their rise time, the time between the onset and the intensity maximum. That time is basically below 10-20 minutes. In contrast, the decay time is usually much longer than the

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rise time. An additional important property of impulsive events is the presence of velocity dispersion. The low energy electrons need more time to arrive at the satellite from the Sun than the higher energy electrons (Krucker et al., 1999).

Haggerty and Roelof (2009) introduced three broad categories of impulsive beam-like electron events using their time profiles: 1) Spikes (rapid and equal rise and decay), 2) Pulses (rapid rise, slower decay); 3) Ramps (rapid rise followed by a plateau). This classification could be useful for a better understanding of the relationship between energetic particle events and the related solar activity phenomena: flares, CMEs, shocks, X-Ray and EUV jets etc. It should be mentioned that the first spike-like particle event observation was already reported in the 1970s (e.g. Lin, 1974).

Aurass, Klein, and Martens (1994) and Raulin et al. (1996) using radiospectrographic and imaging observations with the Nançay Radioheliograph found out close temporal and spatial coincidences between type III bursts and X-Ray jets.

The close association between impulsive electron events and type III bursts is well known since the 70s, however the relation between *in-situ* electrons and jets (X-ray, or EUV) has been discussed mainly in the last decade. Wang, Pick, and Mason (2006) and Nitta et al. (2006) investigated the association between EUV jets, ^{3}He-rich events and impulsive Solar Energetic Particles (SEP) and they concluded "jets associated with type III bursts to be an important observable for impulsive SEP events. They represent flaring that involves open field lines" (Nitta et al, 2006).

In this study, a sequence of four electron spikes detected during a short time interval of 100 minutes by the Solar Electron and Proton Telescope (SEPT) on the STEREO-A spacecraft is presented. We focus on the relationship between spikes, type III radio bursts and EUV coronal jets and discuss the common origin of all mentioned phenomena.

2. Instruments and data selection

The observations were carried out using the Solar Electron and Proton Telescope (SEPT) part of the Solar Energetic Particle (SEP) suite of the STEREO IMPACT investigation. SEPT consists of two dual double-ended magnet/foil particle telescopes which separate and measure electrons in the energy range 30–400 keV and ions from 60 to 7000 keV (Müller-Mellin et al., 2008). The energy range is divided into 32 logarithmically spaced channels with an energy resolution of $\simeq 10\%$ in the range ≤ 1200 keV.

Anisotropy information on the non-spinning spacecraft is provided by two separate telescopes: SEPT-E looking in the ecliptic plane along the Parker spiral magnetic field (i.e. 45° west of the spacecraft – Sun line) both towards and away from the Sun, and SEPT-NS looking perpendicular to the ecliptic plane towards North and South. The dual set-up refers to two adjacent sensor apertures for each of the four view directions: one for protons, one for electrons. The double-ended set-up refers to the detector stack with view cones in two opposite directions: one side (electron side) is covered by a thin foil, the other side (proton side) is surrounded by a magnet. The foil leaves the electron spectrum essentially unchanged but stops protons up to 400 keV. The magnet sweeps away electrons but lets ions pass. The geometry factor for each electron and proton telescope is 0.13 $cm^2\cdot$ sr and 0.17 $cm^2\cdot$ sr, respectively. The SEPT time resolution is 1 minute and the field of view (FOV) is 52°.

Complementary solar wind data, radio emission spectra and EUV images were obtained from PLASTIC (Galvin et al., 2008), SWAVES (Bougeret, J.L. et al., 2008) and SECCHI-EUVI (Howard et al., 2008) instruments on board STEREO-A. EUVI observes the solar atmosphere in four spectral channels (He II 304 Å: T $\simeq$ 80 000 K, Fe IX 171 Å: T $\simeq$ 1.3 MK, Fe XII 195 Å: T $\simeq$ 1.6 MK, Fe XV 284 Å: T $\simeq$ 2.0 MK). SWAVES provides radio observations in the frequency range between 2.5 kHz and 16 MHz.

3. Observations

On 22 February 2010 STEREO-A was at a distance of 0.96 AU from the Sun and 70° ahead the Earth on its orbit, detecting with SEPT a sequence of four electron spikes during a period of only 100 minutes from 04:50 until 06:30 UT.

Figure 1 shows the SWAVES dynamic radio spectrum in the range 16 - 0.03 MHz with a series of type III bursts (top), and the time profile of a sequence of electron spikes in the range 35-65 keV (middle). The bottom panel presents the SEPT dynamic energy spectrum in the range 35-1000 keV. The time axis for electrons is shifted so that it gives the arrival time in UT minus 13 min. The 13 min difference removes the prolonged travel time of ($\simeq$21 min) electrons (35 - 65 keV) from the Sun to the spacecraft along the Parker magnetic field spiral with respect to the propagation time of the type III radio emission (8 min). The length of the nominal Parker spiral is 1.04 AU and was calculated using the solar wind speed of 550 km s^{-1} as observed by the STEREO-A/PLASTIC instrument. The vertical dashed lines pointing at the onset times of type IIIs show the relative delay between the *in-situ* detected electron bursts and the type III radio emission. It is evident that these delays are smaller than six minutes which could be mainly explained if we take into account the intrinsic velocity dispersion in the range 35-65 keV and the background level, which can partly mask the true onset. An enlarged Parker spiral in comparison to the calculated ideal length of 1.04 AU could also contribute to the observed delays listed in Table 1. Note that the particles streaming along the Parker spiral were detected only in the sunward detector indicating very low scattering in interplanetary medium.

Numbers 1-4 in Figure 1 indicate the consecutive spikes. Evidently the spikes with number 1 and 3 exhibit double peaks seen in time profiles as well as in the dynamic spectrum. It means there are two individual sub-spikes in each event. Indeed, in spike 1 they partly overlap each other, but in spike 3 the double structure appears distinctely, see dynamic energy spectrum (Figure 1, bottom panel). All spikes were detected only at energies below 120 keV. They exhibit velocity dispersion and durations at Full Width at Half Maximum (FWHM) shorter than 5 min. Such short durations are very unusual for most of the particle events observed in-situ at 1 AU.

The promt rising peaks and the intrinsic electron velocity dispersion of about 5-6 min in the channel 35-65 keV set an upper limit on the duration of the electron injection into the IP medium of $\leq$ 1 min. That is much shorter than the observed 5 min duration and comparable with the duration of the type III radio bursts.
In Table 1 we summarize the spike characteristics and associated radio and EUV emissions.

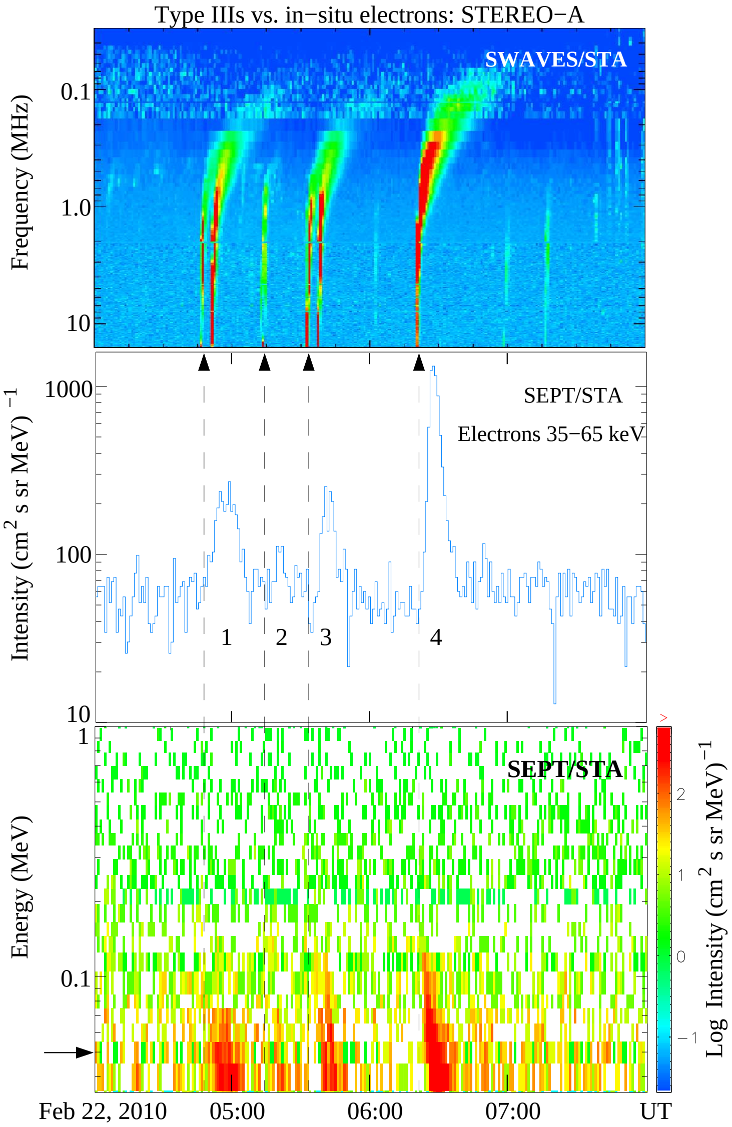

Figure 1. (Top) Dynamic radio spectrum of type III bursts on 22 February 2010 (SWAVES/STA). Middle, time profile of the sequence of electron events in the range 35-65 keV (SEPT/STA). The vertical lines indicate the onset of type IIIs relative to in-situ electron spikes. Bottom, the dynamic energy spectrum of electrons in the range 35 - 1000 keV (SEPT/STA). The time axis for electrons is shifted (middle and bottom panels) and gives the arrival time minus 13 min. The 13 min difference removes the prolonged travel time of electrons along the IP magnetic field with respect to the propagation time of the type III radio emission. The arrow on the left indicates the 35 - 65 keV energy channel.

Obviously the series of type III bursts observed with SWAVES were one to one coincident with the sequence of electron spikes appearing in the same time interval. Each type III burst was associated with an electron spike. Furthermore, the double

Table 1. Spike characteristics

Event	1 (double spike)	2	3 (double spike)	4
Type III onset, UT	04:46 & 04:51	05:12	05:32 & 05:37	06:20
Jet onset, UT	04:46 & 04:51	05:11	05:33 & 05:37	06:16-06:26
Spike onset [a]	04:52 & 04:55	05:17	05:37 & 05:40	06:23
– duration [b], min	11^c (2 x 5.5)	3	7^c (2 x 3.5)	4
– velocity dispersion	poor	poor	yes	yes
– energy range, keV	35-75	35-75	35-120	35-120
– time delay vs. type III, min	6 & 4	5	5 & 3	3

[a] – onset time = observation time UT - propagation time + 8 min, [b] – duration at FWHM in energy range 35-65 keV, [c] – total duration of both spikes together.

type IIIs at 04:46 - 04:51 UT and at 05:32 - 05:37 UT which occur only 5 min apart from each other, were in coincidence with the double electron spikes (numbers 1 and 3 in Figure 1).

Moreover, all individual type III bursts and electron spikes were temporally associated with coronal EUV jets as shown in Figure 2 and Table 1. For each event we present a difference image taken during the jet and a few minutes earlier using the EUVI lines He II (304 Å) or Fe IX (171 Å). The image cadence for the jets associated with spikes N 1-3 was 1.5 - 2.5 min. Only for event 4 the images were taken 10 min apart. It is evident that each type III burst and the accompanying electron spike occur together with a jet.

Figure 2 (leftmost top image) shows the direct 171 Å image of the active region and the location where all jets appear (indicated by an arrow). The other three images on the top panel show the running difference images in 304 Å corresponding to the times of spikes number 1, 2, and 4. For the double spike 1 only one jet at 04:51:15 UT is presented. The jet for the first sub-spike at 04:46 UT (Table 1) was very faint and difficult to discern, for this reason it has not been included in Figure 2. In the bottom panel, we present the sequence of 171 Å difference images between 05:33:30 and 05:38:30 UT during the times of the second double type III burst and the corresponding double spike 3. The two pairs of images, in which two different recurrent jets can be identified, clearly show the appearance, the decay and the propagation of both jets from the same location towards the west limb.

It is obvious that all very collimated jets originate at the same position and propagate in the same direction, suggesting a recurrent ejection along open magnetic field lines. The measured jet propagation speed in projection, determined only for the very distinct jet 3 at 05:37:15-05:38:30 UT, is about 500 km s^{-1}. For the other events the image time cadence was not good enough to estimate the jets speed. The lengths of the jets were in the range 40 000 - 70 000 km and only slightly different from event to event.

The EUV jet re-occurred on the periphery of the AR 11046 at W49N23 close to its eastern boundary and to a small Coronal Hole (CH) or CH-like dark bay (Figure 2, the direct 171 Å image at 05:38:30 UT). Such a CH/bay suggests that there were open magnetic field lines in the vicinity of closed active region magnetic field lines (Rust et al., 2008). The coordinates are given for the STEREO-A field of view. A few days

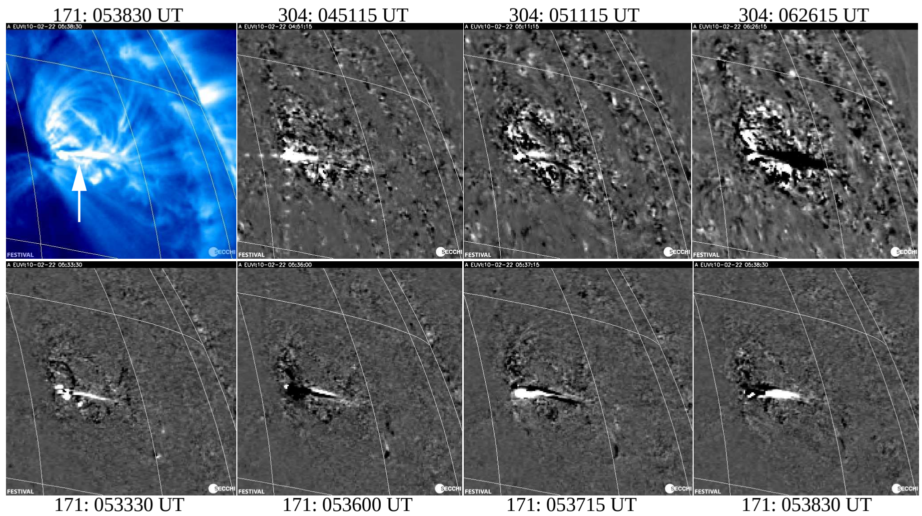

Figure 2. (Top) The leftmost panel shows an EUVI 171 Å image of the active region and the location of all jets (arrow). The rest shows the running difference images of the jets sequence in 304 Å corresponding to the spikes number 1, 2, and 4. Bottom, sequence of EUV 171 Å running difference images showing two consecutive jets in the time interval 05:33-05:38 UT coincident with the double type III burst and electron spike (number 3 in Figure 1). North is on top, west is to the right. Regions appear white (dark) when the emission has increased (decreased) between two consecutive images.

before on 17 February the AR 11046 was close to the west solar limb as observed from SOHO, showing only a few small spots and pores. In following days (18-20 February) the spots disappear and the region rotates spotless behind the west limb. Therefore the observations of X-ray emission were not available for the jet times, because the AR was already 25° behind the solar limb as seen from RHESSI and GOES.

4. Summary and conclusion

We confirm and extend previous observations suggesting very close association between impulsive electron events, type III radio bursts and EUV jets. The investigated sequence of short-lived energetic electron spikes is an excellent example showing its close association with the sequence of type III radio bursts and EUV coronal jets. Such a close association suggests the common origin of these phenomena due to recurrent magnetic reconnection process occurring at the same location in the corona (e.g. Chifor et al., 2008) or due to electron acceleration in front of propagating coronal jets (Miteva et al., 2007). Moreover, since all spikes show similar profiles, the propagation conditions in the interplanetary medium should be the same during the whole interval of 100 min, revealing nearly scatter-free electron propagation from the Sun to STEREO-A.

The main results are summarized as follows:

i) A sequence of four spikes occur during a short time interval of 100 min and show almost symmetric time profiles with durations below 5 min.

ii) All electron spikes were temporally coincident with type III radio bursts and very collimated recurrent EUV coronal jets, appearing in the same location and showing the same trajectory.

iii) The sharp spike - like profiles and the observed durations between three and five minutes set an upper limit on the duration of the electron injection into the interplanetary medium of ≤ 1 min, comparable with the durations of type III radio bursts.

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