Location of Decimetric Pulsations in Solar Flares

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Abstract This work investigates the spatial relation between coronal X-ray sources and coherent radio emissions, both generally thought to be signatures of particle acceleration. Two limb events were selected during which the radio emission was well correlated in time with hard X-rays. The radio emissions were of the type of decimetric pulsations as determined from the spectrogram observed by Phoenix-2 of ETH Zurich. The radio positions were measured from observations with the Nançay Radioheliograph between 236 and 432 MHz and compared to the position of the coronal X-ray source imaged with RHESSI. The radio pulsations originated at least 30 – 240 Mm above the coronal hard X-ray source. The altitude of the radio emission increases generally with lower frequency. The average positions at different frequencies are on a line pointing approximately to the coronal hard X-ray source. Thus, the pulsations cannot be caused by electrons trapped in the flare loops, but are consistent with emission from a current sheet above the coronal source.

1. Introduction

Does the very process of particle acceleration in solar flares directly produce coherent radio emission? Waves such as proposed for current instabilities and stochastic acceler-
ation may couple into radio waves (Benz and Wentzel, 1981; Karlický and Bártá, 2005; Li and Fleishman, 2009). Alternatively, instabilities produced by non-stochastically accelerated electrons having a non-Maxwellian velocity distribution may be observed by their coherent radio emission within the acceleration site.

In the impulsive phase of flares, very intense radio emissions are often observed. At decimeter wavelengths the peak flux density can reach $10^6$ solar flux units ($10^{10}$ Jy, Benz, 2009). Coherent emissions are most intense and to be distinguished from incoherent radio emissions, such as synchrotron or thermal radiation, not studied here (e.g. Nindos et al., 2008). There are several types of coherent emission processes. Most intense and very frequent are broadband radiations pulsating at irregular intervals on the time scale of one second. As the emission appears to be a non-thermal process, such decimetric pulsations are generally assumed to be tracers of non-thermal electrons and their acceleration.

Radio ‘outbursts’ at decimeter wavelength during flares have been detected very early with single frequency instruments (Lehany and Yabsley, 1948). These authors even remarked the coincidence with an ionospheric radio fadeout, caused by solar flare soft X-ray emission. Covington (1951) noticed occasional high circular polarization of bursts at 10.7 cm. De Feiter, Fokker, and Roosen (1959) reported an association of 545 MHz bursts with Hα flares increasing with flare importance. First spectral observations in the decimeter range were reported to consist of 90% of a ‘generalized class of fast-drift bursts’ (Young et al., 1961; Kundu et al., 1961). Some of these appear to be the decimetric continuation of meterwave type III bursts, but many others had a different nature, occurring in large groups and showing an ‘immeasurably’ high drift in frequency. Decimetric emission has also been named ‘flare associated continuum’ (Pick, 1986). Thompson and Maxwell (1962) refer to them as pulsating structures. This notation or simply ‘pulsations’ has established itself in the literature and will be used here.

The regularity of the pulsations has been noted early. Gotwols (1972) reports a quasi-periodic pulsation over most of the observed band from 600 – 1000 MHz. Remarkably regular pulses at 1.0 s period from 300 – 350 MHz were the basis of the theory of Roberts, Edwin, and Benz (1984) on magnetohydrodynamic (MHD) oscillations in the corona. In their catalogues, Güdel and Benz (1988) and Isliker and Benz (1994) characterize pulsations in the decimeter range between ‘almost periodic’ and ‘irregular’ with pulse separations of 0.1 to 1 second. Some complex cases may be the superposition of several pulsations with different periods (Mészárosóvá, Rybák, and Karlický, 2011). Ultra-rapid pulsations have been reported by Magdalenic et al. (2003) and Fleishman, Stepanov, and Yurovsky (1994). Pulsations have better defined upper and lower bounds in frequency than type III bursts and higher drift rates by a factor of 3 on average (Aschwanden and Benz, 1986). Contrary to type III bursts, pulsations are highly circularly polarized, except when occurring near the limb (Aschwanden, 1986, 2006).

The frequency range of pulsations extends from meter to centimeter wavelengths, but their character changes. At meter waves, McLean et al. (1971) observed about 50 strikingly regular pulses with periods increasing from 2.5 s to 2.7 s in time. Pulsations above about 300 MHz are less regular. The highest frequency pulsations reported extend beyond 4 GHz (Saint-Hilaire and Benz, 2003; Tan et al., 2010) and consist of irregular pulses.

The emission process of pulsations is unclear. It is often associated with some velocity space instability of non-thermal electrons, such as a loss-cone instability or plasma emission by beams (Benz, 1980; Fleishman, Stepanov, and Yurovsky, 1994). The frequency of such emissions is at the plasma frequency $\nu_p$, the electron gyrofrequency $\nu_e$, the upper hybrid frequency $(\nu_p^2 + \nu_e^2)^{1/2}$, or at twice these characteristic frequencies (review by Benz, 2002). For the driver of such a pulsating instability, electrons trapped in flare loops have been evoked.