Radio Observations of the 20 January 2005 X-class Flare

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Abstract We present a multi-frequency and multi-instrument study of the 20 January 2005 event. We focus mainly on the complex radio signatures and their association with the active phenomena taking place: flares, CMEs, particle acceleration, and magnetic restructuring. As a variety of energetic-particle accelerators and sources of radio bursts are present, in the flare–ejecta combination, we investigate their relative importance in the progress of this event. The dynamic spectra of ARTEMIS-IV – Wind/Waves – HiRAS, with 2000 MHz – 20 kHz frequency coverage, were used to track the evolution of the event from the low corona to the interplanetary space; these were supplemented with SXR, HXR, and γ-ray recordings. The observations were compared with the expected radio signatures and energetic-particle populations envisaged by the Standard Flare – CME model and the recon-
nection outflow termination shock model. A proper combination of these mechanisms seems to provide an adequate model for the interpretation of the observational data.

Keywords Radio bursts · Dynamic spectrum · Type III · Type II · Type IV

1. Introduction

Solar flares and coronal mass ejections (CMEs) are the most energetic phenomena on the Sun. They can be envisaged as two different aspects of a common magnetic energy instability and release (see, e.g., Pick et al., 2006, and references therein), described by the standard CME—flare model, which combines the kinematics of the energy release of ejecta and flares. As the rising CME (or erupting filament or rising plasmoid) stretches and deforms the coronal magnetic-field lines, a vertical current sheet is formed, where reconnection explosively releases the free magnetic energy, stored in the corona (see e.g. Forbes and Lin, 2000; Forbes, 2003; Priest and Forbes, 2002); furthermore, CME acceleration profile and flare energy release are seen to evolve in a synchronized manner (Temmer et al., 2010). The energy, thus liberated, is divided over plasma heating, particle acceleration, kinetic energy of the eruption, and MHD shock waves.

The development, in the low corona, of large flare/CME events coincides with an extended opening of the magnetic field, accompanied by energetic-particle acceleration and injection into interplanetary space and shocks. These are detectable, at metric and longer waves, by their radio signatures (see, e.g., review by Pick and Vilmer, 2008).

The Type III burst radio emission is produced by non-thermal electrons streaming along coronal magnetic lines. In open field lines, they may escape into interplanetary space and may be detected in situ (see, e.g., Faindberg and Stone, 1970; Lin, Evans, and Fainberg, 1973; Kurt, Logachev, and Pissarenko, 1977; Klein et al., 2008). In closed magnetic structures, on the other hand, they eventually turn Sunwards, resulting in inverted U- or J-shaped bursts on the dynamic spectra (U or J bursts). Metric bursts of the Type III family generally consist of groups of individual bursts (see e.g. Goldman, 1983, and references within); on the reports they are marked as III G for fewer than ten occurrences and III GG for more.

The Type II bursts trace the propagation of MHD shocks in the corona and interplanetary space. It is, in general, accepted that Type II bursts at decametre and longer wavelengths are driven by CMEs, bow or flank (see, e.g., Vršnak and Cliver, 2008, for a review). The Type II bursts at metre wavelengths, however, are interpreted either as a flare blast wave (Vršnak, Magdalenić, and Aurass, 2001) or as a CME-driven shock (Kahler et al., 1984; Maia et al., 2000; Claßen and Aurass, 2002). A metric stationary Type II burst (a Type II burst with a very slow drift on the dynamic spectrum) has been identified, for the first time, by Aurass, Vršnak, and Mann (2002); it was interpreted as the radio signature of fast-mode termination shocks by Aurass et al. (2006). The proposed formation process included a pair of counterstreaming outflow jets moving upwards and downwards from the reconnection site, encountering the rear of the CME and the top of the post-flare loop, respectively, resulting in termination shocks (Mann, Aurass, and Warmuth, 2006; Mann, Warmuth, and Aurass, 2009; Warmuth, Mann, and Aurass, 2009).

The continua during periods of activity represent the radiation of energetic electrons trapped within magnetic structures and plasmoids, and they are known under the names of Type IV bursts and “Flare Continua” (Robinson, 1978a, 1985). The stationary Type IV (IV mB) bursts emanate from magnetic structures usually located above active regions; they often exhibit significant fine structure. The moving Type IV bursts (Robinson, 1978b)