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Global coronal waves: implications for HESSI

H. S. Hudson

SPRC/ISAS, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229, Japan

M. Karlický

Astronomical Institute, 251 65 Ondřejov, Czech Republic

Abstract. Recent observations from SOHO/EIT have shown in detail how large-scale waves propagate in the solar corona. Such waves, closely associated with flares and coronal mass ejections, have long been known more indirectly via meter-wave Type II bursts and chromospheric Moreton waves. This paper discusses *Yohkoh* X-ray observations and radio spectra of a related global wave of May 6, 1998 in the context of HESSI observations.

1. Introduction

To judge from meter-wave radio observations, the solar corona consists entirely of non-thermal particles, often electrons of keV and MeV energies. In principle these electrons should also emit bremsstrahlung hard X-rays, so that in an ideal world one could study them with an imaging spectrometer such as HESSI. In practice, of course, the bremsstrahlung is so weak that most of the phenomena have remained undetected. Instead, the strongest solar hard X-ray sources normally result from thick-target interactions at the footpoints of coronal loops. Coronal observations do exist, however: most recently the "Masuda flare" (Masuda et al., 1994, and papers in these proceedings) phenomena. We can also cite the over-the-limb hard X-ray bursts observed from OSO-5 (Frost and Dennis, 1971) and OSO-7 (Hudson, 1978; see Hudson and Ryan, 1994, for a review), as well as the *Hinotori* observation of an unusual coronal source (Kawabata et al., 1983). Over-the-limb flares also have been observed in γ-rays (Vestrand and Forrest, 1993). These observations differ in their interpretations, so it seems likely that several distinct physical processes are at work. Thus all in all we can anticipate interesting coronal observations from HESSI.

The purpose of this note is to examine an event of May 6, 1998, which produced a global wave probably observed directly in soft X-rays by *Yohkoh*/SXT. See Hudson et al. (2000) for a fuller description. This brief paper emphasizes the relationship of the radio dynamic spectrum to the X-ray observations. Unfortunately, we have no radioheliograph observations of this event, and space limits preclude much discussion of the X-ray data.

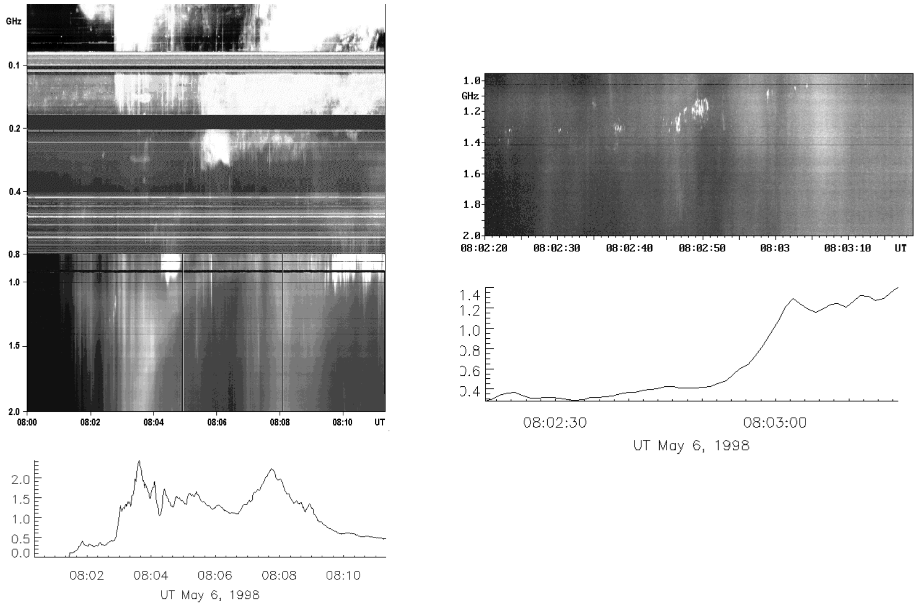

Figure 1. The 0.04-2.0 GHz dynamic spectrum (left), showing the drifting feature at decimeter wavelengths that we attribute to the origin of the global wave. The spectrum on the right shows only the 1-2 GHz range to emphasize the observation of negatively drifting spike bursts. The lower panels show the BATSE 25-50 keV hard X-ray counting rates. Hudson et al. (2000) suggest that the Type II waves originated with the small hard X-ray burst at 08:01:50 UT.

2. Event of May 6, 1998

The EUV observations from SOHO has shown the common occurrence of global waves (Thompson et al., 1998), but curiously enough the wave signature have been extremely difficult to recognize in soft X-ray imaging from *Yohkoh* SXT. The event of May 6, 1998, gave the first probable wave detection (Hudson et al., 2000; see this paper for a discussion of the reasons for the lack of an earlier detection). However SXT has observed numerous events associated with Type II bursts and with EIT waves; the former (Klassen et al., 1999; Klein et al, 1999) almost invariably show rapid material ejections from the cores of the soft X-ray flare structure. Please see Hudson et al. (2000) for fuller details regarding the X-ray observations of the event discussed here.

We can use these observations to assess the physical conditions near the apparent origin of the wave. One hypothesis is that a sudden "magnetic explosion" caused motion perpendicular to the magnetic field, resulting in a piston action that launched a fast-mode MHD shock wave (Uchida, 1968). In the May 6 case the wave moved to the north, whereas loop-like ejections occurred later and predominantly to the west, consistent with the radially outward direction. The piston must therefore have moved approximately tangentially to the surface of the Sun, consistent with a perpendicular shock. Note that the CME resulting from this event, however, appeared to originate in transequatorial interconnecting loops lying to the north of this southern-hemisphere flare (Khan and Hudson, 2000). We thus observed a complicated series of events. Among them the near-vertical eruption from the flare appears to have driven a "piston" structure horizontally. The "piston" consisted of loops previously existing in the active region, and lying about 2×10^4 km from the flare core.

From the observations we cannot unambigously state that the "piston" structure actually provided the motion responsible for the wave, or whether it merely participated in both the wave and the eruption; the observations of the region between the "piston" and the flare core do not show any connection, but this may only reflect the limitations of image dynamic range and resolution in the SXT instrument. We note that bright flare loops seldom show transverse motions on scales observable by SXT. Karlický (1998) suggests an "evaporation shock" as the origin of the drifting microwave source, which would suggest that the wave exciter actually occured in the flare core region, rather than what we have called the "piston." In this case the essentially vertical motion of the evaporation front might be accompanied by a small transverse inflation of the flux tube. This could also launch a fast-mode shock wave.

Figure 1 shows details of the relationship between hard X-rays and the radio spectral observations not discussed in detail by Hudson et al. (2000), but quite relevant for HESSI. The two panels of the Figure show the bulk of the impulsive phase over the full spectral range covered by the Potsdam-Tremsdorf (0.04-0.8 MHz, courtesy Dr. H. Aurass) and Ondřejov (0.8-2.0 GHz) spectrographs. The hard X-ray light curves both come from the BATSE 25-50 keV channel. From the longer-wavelength data, we confirm that the initial peak in hard X-rays at 08:01:50.7 UT, as identified by Hudson et al. (2000) from the "piston" disappearance, could have in fact launched the wave. The much more energetic bursts at 08:03:30 UT would be a more plausible candidate in the evaporation-shock scenario, assuming that the strength of the evaporation shock scales with the hard X-ray flux. Karlický and Odstrčil (1994) suggest that high-frequency bursts (as seen in the right panel of Figure 1) could show the acceleration of downward electron beams simultaneously with MHD waves responsible for igniting the shock front. In general Figure 1 shows strong X-ray/radio correlations (both at longer and shorter wavelengths), but with much variability that does not match in detail. Presumably this results at least partly from the complicated propagation conditions (optical depth effects) throughout the spectrum.

3. Implications for HESSI

The participation of a relatively dense structure (the "piston") in the launch of the coronal wave is consistent with the presence of a drifting microwave feature at about 1 GHz (Figure 1), as is the existence of the evaporative flow in the flare core. Would the non-thermal electrons responsible for the Type II emission and its radio precursors produce enough bremsstrahlung in a structure of the piston type to be visible to HESSI? We cannot answer this question directly, but the product of the observed spatial scale of the piston and its inferred density gives a stopping distance for a fast electron of a particular energy in a marginally thick target (Wheatland and Melrose, 1995). At such energies, HESSI (thanks to its low-energy absorber system) may well be able to make images at the appropriate energy with sufficient image dynamic range. If so, we should be able to compare the acceleration mechanism for the electrons of a Type II burst (shock acceleration) and make a more direct comparison with the impulsive-phase particle acceleration.

An alternative HESSI observation might involve the trapping of non-thermal electrons in a mirror geometry. Such a geometry might explain the OSO-5, OSO-7, and *Hinotori* observations of long-lived non-thermal coronal sources, or even the Masuda flare phenomenon (eg Metcalf and Alexander, these Proceedings). Fletcher and Martens (1999) have carried out extensive simulations of the hard X-ray emissivity of coronal structures capable of trapping non-thermal electrons. We suspect that the passage of a global wave through existing coronal loops (not "restructured" by the flare, but only excited) could produce this trapped population via shock acceleration (Bai et al., 1983).

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