High-Energy Emission from a Solar Flare in Hard X-rays and Microwaves

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Abstract We investigate accelerated electron energy spectra for different sources in a large flare using simultaneous observations obtained with two instruments, the Nobeyama Radio Heliograph (NoRH) at 17 and 34 GHz, and the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) at hard X-rays. This flare is one of the few in which emission up to energies exceeding 200 keV can be imaged in hard X-rays. Furthermore, we can investigate the spectra of individual sources up to this energy. We discuss and compare the HXR and microwave spectra and morphology. Although the event overall appears to correspond to the standard scenario with magnetic reconnection under an eruptive filament, several of its features do not seem to be consistent with popular flare models. In particular we find that (1) microwave emissions might be optically thick at high frequencies despite a low peak frequency in the total flux radio spectrum, presumably due to the inhomogeneity of the emitting source; (2) magnetic fields in high-frequency radio sources might be stronger than sometimes assumed; (3) sources spread over a very large volume can show matching

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evolution in their hard X-ray spectra that may provide a challenge to acceleration models. Our results emphasize the importance of studies of sunspot-associated flares and total flux measurements of radio bursts in the millimeter range.

**Keywords** Flares, impulsive phase · Radio bursts, microwave (mm, cm) · X-ray bursts, hard

1. Introduction

Energetic electrons accelerated to energies of tens and hundreds of keV can be observed through microwave and hard X-ray (HXR) emissions from the solar corona. Imaging observations are important to study the origin of energetic electrons in large flare events, which in turn can be used to test flare models and other related theoretical issues. Two dedicated solar imaging instruments most important for studies of solar flares are at present available – one in X-rays and gamma-rays by the Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI, Lin et al., 2002) and the other in microwaves by the Nobeyama Radioheliograph (NoRH, Nakajima et al., 1994) at 17 and 34 GHz. NoRH is capable of imaging signatures of microwave-emitting electrons in flaring sources. At 17 GHz it measures both Stokes $I$ and $V$, and at 34 GHz Stokes $I$ alone, with good sensitivity and spatial resolution of $\approx 10''$ and $\approx 5''$, respectively at the two frequencies. Signatures of hard X-ray emitting electrons are mapped by RHESSI. RHESSI's primary objective is the study of energy release and particle acceleration in solar flares. This is accomplished by imaging spectroscopy of solar hard X-rays and gamma-rays over a 3 keV to 17 MeV energy range with energy resolution of $\approx 1$ keV, time resolution of $\approx 4$ s or better and spatial resolution as high as $2.3''$.

Non-thermal microwave emission during large solar flares is produced by the gyrosynchrotron mechanism which involves coronal magnetic fields of at least a few hundred gauss and electrons of hundreds of keV and higher energy. Hard X-ray emission, on the other hand, is mainly produced by bremsstrahlung from precipitating electrons of tens to hundreds of keV energies. The two different methods of mapping energetic flare electrons therefore complement each other, and provide good means of testing flare-related concepts which have been abundant in the recent literature. The major hard X-ray flux is emitted by precipitating electrons striking a thick target, whereas microwaves are emitted by electrons gyrating in magnetic fields, both precipitating and trapped in coronal magnetic tubes.

Several issues related to accelerated electrons in solar flares are debated in the literature. First, it is not clear if a single acceleration mechanism operates in a flare or different mechanisms contribute (see e.g., Wild, Smerd, and Weiss, 1963; Bogachev and Somov, 2001). Note that the possible presence of different “accelerators” does not necessarily show up in the shape of the electron spectrum (Bogachev and Somov, 2007). One cannot also rule out the possibility that in an event with repetitive acceleration/injection episodes part of an electron population accelerated in the previous episode undergoes an additional acceleration from basically the same mechanism.

One more question is related to the fact that the electron spectra inferred from microwave observations at frequencies believed to be optically thin appear to be harder than those inferred from HXR data as initially shown by Kundu et al. (1994) and repeatedly confirmed afterwards. Following the interpretation of Melnikov and Magun (1998), other researchers (see, e.g., Silva, Wang, and Gary, 2000; Lee, Gary, and Shibasaki, 2000; Takasaki et al., 2007) suggest that this fact can be explained by the collisional hardening of the electron spectra in magnetic traps.