Microwave and Hard X-ray Imaging Observations of Energetic Electrons in Solar Flares and Microflares

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INTRODUCTION

It has been known for a long time that flares occur in regions consisting of many magnetic loops and that a flare is caused by the interaction between loops. Evidence of interaction between newly emerging flux and overlying magnetic fields causing flares have been provided from optical observations and soft X-ray observations from Yohkoh have provided evidence ofinteractions between coronal loops. Radio evidence of interacting flaring loops is rather limited, primarily due to lack of good spatial resolution. In recent years, because of observations made with NoRH at 17 and 34 GHz, it has been possible to show evidence of interacting loops, although the spatial resolution was only of order 5"-10". Hanaoka [1] and Kundu et al. [2] have provided evidence that emerging flux appeared near one sunspot-dominated active region and argued that interactions between this emerging flux and the overlying loop resulted in the onset of flares and microflares. The main flare site in each case was the location of emerging flux which was also the site of soft X-ray and EUV brightening.

In this paper we discuss a normal solar flare with magnetic field topology suggestive of interacting loops. We also briefly discuss a microflare in hard X-rays and microwaves. We supplement the microwave imaging observations with HXR imaging observations of hard X-rays in the energy range 6-100 KeV.

HARD X-RAY AND MICROWAVE OBSERVATIONS OF A LARGE FLARE

We describe the RHESSI hard X-ray and Nobeyama microwave imaging observations of an X-class (X 2.7) event that was observed on Nov 3, 2003, 00:58:33 UT in AR 0488 (position N08W66), with a large peak at 01:15:25 UT and ending at 03:08:19 UT. The maximum fluxes at 17 and 34 GHz are respectively 678 and 536 SFU. Besides the peak at 01:15 there are two other peaks at approximately 01:20 and 01:32:30 UT. In NoRP (Nobeyama Radio Polarimeter) data the peak at 01:20 is the most dominant at frequencies 9.40, 3.75, 2.0 GHz. At 1.0 GHz the emission prior to this peak is fluctuating and a peak with fluctuations exists at around 01:05 UT. The third peak at 01:32:30 UT is spiky and it is nonthermal with a turnover frequency between 17 and 34 GHz. Figure 1 shows the RHESSI time profiles in different energy bands (left), and NoRH time profiles 35, 17, 9.4, 3.75, 2.0 and 1.0 GHz (right).

One significant property of the HXR emission (<12 keV) during the period 01:00-01:08 is that the preflare emission, in projection, lies close to and above the W-limb, although the associated microwave source is on the disk (Fig 2a). It is not clear how the two preflare sources are related: 12-25 KeV, and NoRH 17 and 34 GHz sources. The RHESSI HXR source seems to coincide in position with the EIT flaring source at its apex. The morphological structure seems to suggest that we are dealing with a loop top HXR source situated at the top of the EIT flaring loop as well as the flaring sources at 17 and 34 GHz, whose morphology suggests a complex flaring arcade structure.

During the period prior to 00:50 UT which we call the radio preflare phase, we see 17 GHz emission primarily gyro-resonance radiation from three sunspots. Fig.2 (b) shows EIT image along with RHESSI 12-25 keV, 17 and 34-GHz contours. The compact core of the 34-GHz source in the preflare phase coincides with the apex of the EIT loop. This may imply that the 34-GHz source is thermal in nature. Note that the loop showing the EIT and 34-GHz emission eventually becomes the main flaring loop.

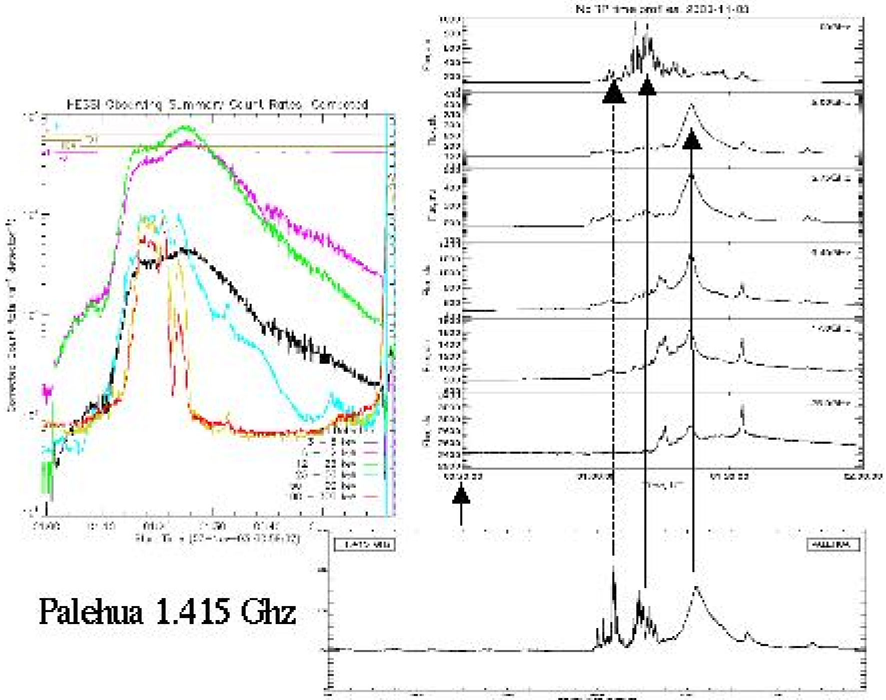


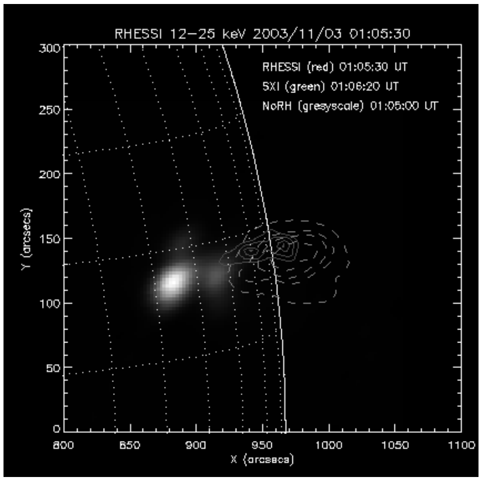
Fig. 1 - RHESSI Time profiles in different energy bands (left). NoRH Time profiles at 35, 17, 9.4, 3.75, 2.0, and 1.0 GHz (right).

One sees clearly the RHESSI source coinciding in position with the EIT flaring source at its apex (Fig.2b). The morphological structure seems to suggest that we are dealing with a loop-top HXR source situated at the top of the EIT flaring loop as well as the flaring sources at 17 and 34 GHz, whose morphology suggests a flaring loop structure.

Different features in the radio images show different light curves: the Main and Upper sources are very similar, others are less similar (Fig.4). This argues that this is not a simple connected loop but a more complex geometry.

One sees clearly the RHESSI source coinciding in position with the EIT flaring source at its apex (Fig.3). The morphological structure seems to suggest that we are dealing with a loop top HXR source situated at the top of the EIT flaring loop as well as the flaring sources at 17 and 34 GHz, whose morphology suggests a flaring loop structure.

Difference images (Fig. 4) during a late radio spike (01:32:30) show a double-ribbon-like morphology (in projection) that looks different from the rest of the event even though it comes from the same general location.



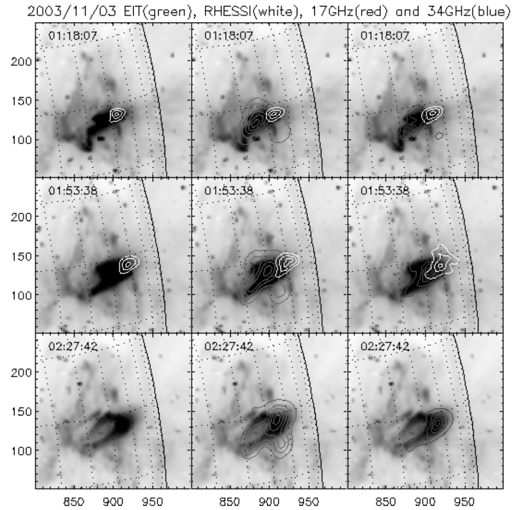


Fig. 2 (a). RHESSI (red) & SXI (green) pre-flare source, and 17-GHz flare (grayscale). Note the upward displacement of the X-ray sources.

Fig. 2 (b). EIT flaring source (green) along with 12-25 keV RHESSI source (white contours), and NoRH 17 and 34 GHz maps (red contours).

SOME CONCLUDING REMARKS

The radio images of this event show great complexity during the brightest emission with a number of nonthermal sources having differing time profiles. Yet the later stages of the event in EIT look like a simple arcade with reconnection taking place at the top of the arcade. This argues that the event evolved from a complex morphology in the early stages to a simpler morphology later on.

The simple “Y-type reconnection at the top of an arcade” scenario appears to work for the late stages but does not describe the main part of the flare. We believe that there may exist more than one reconnection region in this complex event. The appearance of a new region with opposite polarity in close proximity to the pre-existing microwave region near the onset times of the rising phases of the flare peaks is significant and may be evidence of reconnection at this point.

.ACKNOWLEDGEMENTS

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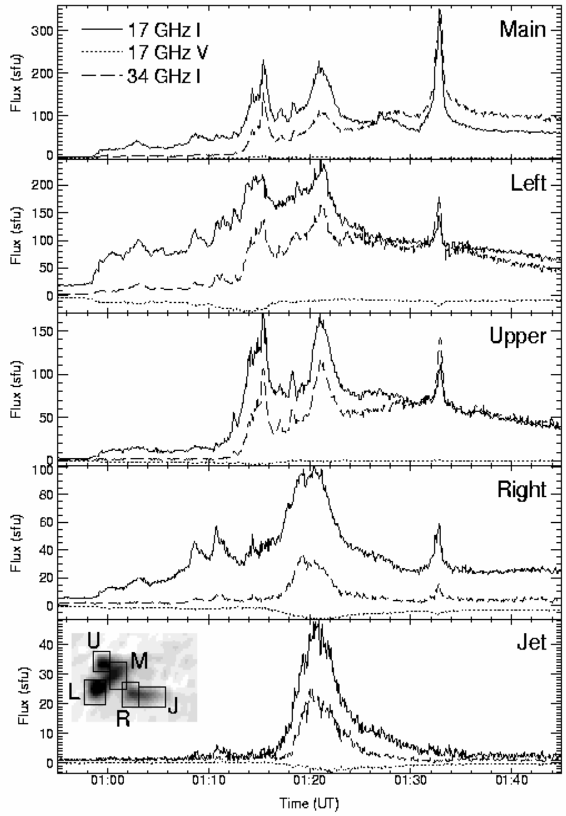

Fig. 3. Different features in the radio images show different light curves: the Main and Upper sources are very similar, others are less similar.

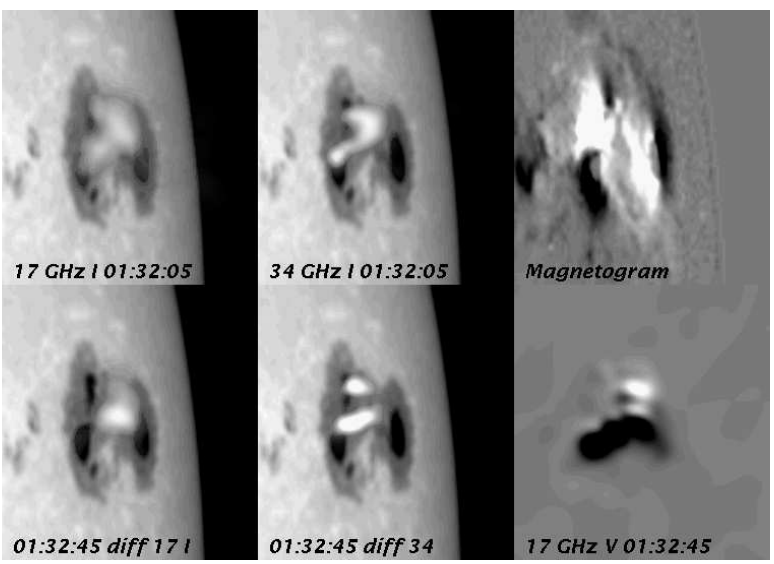

Fig. 4. Difference images during late radio spike (01:32:30) show a “double-ribbon” (in projection) morphology that looks different from the rest of the event even though it comes from the same general location.