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Multi-wavelength investigation of energy release and transport in the 16 August 2004 flare

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Abstract. The current contribution investigates the solar flare of 16th August 2004 with the multi-wavelength observations with high temporal resolution from RHESSI, Large Solar Vacuum Telescope (LSVT), Hiraiso Solar observatory, Nobeyama Radioheliograph (NoRH, 17 and 34 GHz) and Siberian Solar Radio Telescope (SSRT, 5.7 GHz), TRACE. The main flare was preceded by a pre-flare event with a very short energy release time. The observations of the main flare reveal a close temporal correlation between the Hα intensity observed with LSVT and those in hard and soft X-ray emissions observed with RHESSI, and in microwave fluxes observed with NoRH and SSRT. This close temporal correlation can be only associated with high-energy particles. The role of energetic particles in energy transport and non-thermal excitation and ionisation on Hα emission during the pre-flare and pre-flare event is investigated with full non-LTE approach and possible agents and scenarios of energy transport are discussed.

Keywords. waves, hydrodynamics, Sun: atmosphere, Sun: photosphere, Sun: chromosphere, Sun: Corona, Sun: flares, Sun: particle emission

1. Observations

We present investigation of the solar flare of 16th August 2004 based on the multi-wavelength observations- Hard X-ray by RHESSI (Lin *et al.*, 2002); Hα observations by Large Solar Vacuum Telescope (LSVT)(Skomorovsky & Firstova, 1996) and Hiraiso Solar observatory (http://sunbase.nict.go.jp/); microwave data by Nobeyama Radioheliograph (NoRH, 17 and 34 GHz)(Nakajima et al.1994) and Siberian Solar Radio Telescope (SSRT, 5.7 GHz)(Grechnev *et al.*, 2003); UV images by TRACE (Handy *et al.*, 1999); full disk magnetograms provided by the MDI/SOHO (Scherrer *et al.* 1995). The main flare consisted of two phases and was preceded by a pre-flare event with a very short energy release time (Fig 1). The locations of flare kernels are presented on Fig. 2. As can be seen on Fig 3, a delay between the HXR peak and the Hα peak at 03:37:54 UT is 24 seconds. Also the emission in the line centre trails those in a blue wing by a few seconds. This is likely to reflect the fact that the observed Hα emission is excited by a moving hydrodynamic shock and, thus, it appears first at the upper layers where blue wing emission origins and then propagates to the deeper layers of the line core formation.

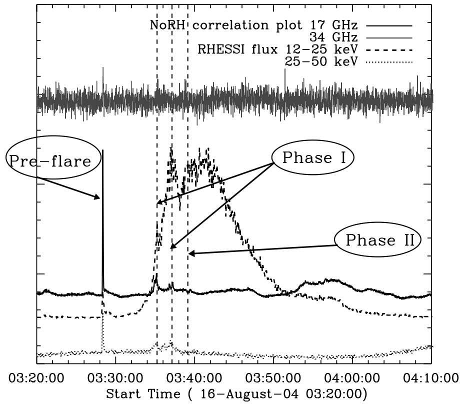

Figure 1. The evolution of microwave and HXR fluxes during the pre-flare and flare bursts according to RHESSI and NoRH data.

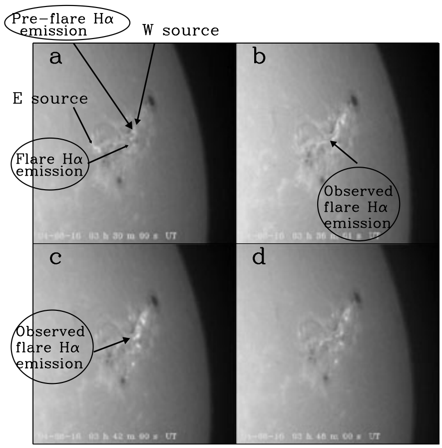

Figure 2. The images obtained in the Hα line center by Hiraiso observatory: a- 3:30:00 UT (nearest moment to pre-flare); b-3:36:01 UT; c-3:42:01UT ; d 3:48:00 UT. It can be noted that the pre-flare burst consist of the two main kernels located in the direction E-W. During the flare phase gradual emission appears in the kernels emerging in the direction N-S (compare the upper and lower rows).

2. Magnetic topology of the flare

All observed HXR sources are associated with magnetic sources of different polarities extracted by using a magnetic field comparison for nearest 20 pixels and extracting those whose value is higher at least by 100G than neighboring ones (Zharkova *et al.*, 2005a). As it is seen on panel a for the pre-flare phase, all the emission sources (HXR, microwave and Hα) are connected to the new emerging magnetic sources. The Hα and W microwave sources associated with the negative polarity and the E source is connected with the positive polarity. In the panel b, the HXR source at 6–12 keV is located on the loop top connecting the magnetic sources with positive and negative polarities. Also note that the northern part of the HXR source was connected with the new emerging magnetic sources which disappeared at the moment when the HXR emission started. There is an increase in a number of magnetic sources in the West with the HXR source shifting towards this location (compare the panels c and d).

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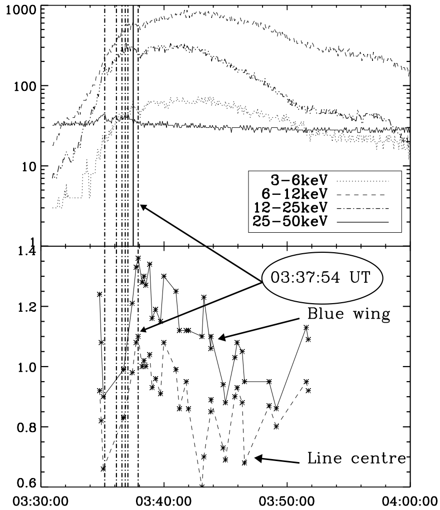

Figure 3. Time profiles of the HXR flux (top) and intensity in the Hα line center and blue wing (bottom). The moments of the flux peaks are marked by the dash-dotted lines. The solid line on the top plot corresponds to the HXR peak preceding the Hα one.

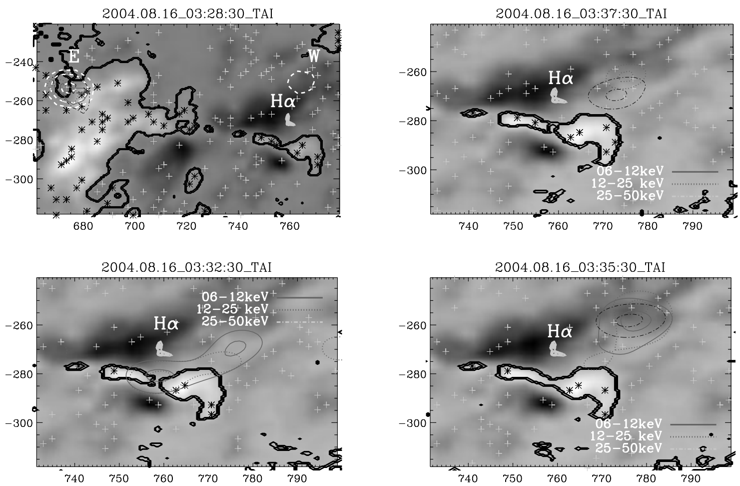

Figure 4. The MDI magnetograms of AR corresponding to different phases of the flare evolution: pre-flare(top–left); phase I (bottom); phase II (top-right). The solid line shows the magnetic inversion (neutral) line. The plus sings denote the negative magnetic sources higher than -200 G, the asterisks refer to the similar positive ones. The black contours mark HXR sources , the grey contour the Hα pre-flare kernel location. The white dashed contours on the top–left panel mark the microwave source locations (50% and 90%).

3. Results and Discussion

As can be seen in Fig. 4, the Hα kernel of the flare itself does not coincide with the location of the pre-flare kernel. The flare kernel is located close to a positive magnetic source while the location of the HXR source belongs to the negative one. This allows to assume that the N–S loop is reconnecting with the E-W one. Then the observed emission reflects acceleration processes in the primary energy release site and then a particle transport into the footpoints.

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The microwave source is located in one reconnecting loop between the eastern (E) and western (W) HXR and magnetic sources that with a high probability is located on the loop top connecting these E and W sources. This E–W loop is also associated with the sources of HXR emission. A location of the pre-flare H-alpha kernel that is not associated with any HXR sources, seems to belong to the southern footpoint of the another reconnecting loop elongated in N-S direction.

The pre-flare seems to occur on the loop top owing to the acceleration by an "electric field" drifted into a reconnecting region (Zharkova and Gordovskyy, 2004, 2005b; Dalla and Browning, 2005), then the first HXR and the microwave source "E" show this primary energy release site. The observed source of Hα emission orientated in the N-S loop not linked with HXR source is likely to be caused by non-thermal excitation by a proton beam precipitating into the N-S loop.

The other HXR sources appeared in the Phase I in W and E footpoints of the E-W loop show precipitation of the electrons and, possibly, their secondary stochastic acceleration in western footpoint appearing, for example, due to two beam instability caused by the precipitating beam and the returning beam of return current. This HXR source lasts for another two minutes that can be caused by a lower dissipation rate of this plasma turbulence. The electron beam precipitation time is less then 1 second but the observed Hα emission kernel arose with 24-second delay.

According to simulations by Zharkova and Gordovskyy (2004) assuming a length of the loop of 10^7 m, the proton beam precipitation time is a factor of about 10 s, which is a lower limit of the possible delay between separate precipitation of protons and electrons into the opposite legs. The proton velocities from the calculation by Zharkova and Gordovskyy (2004) are about 10^6 m/s for are connecting current sheet (RCS) with a thickness of 10 m and $2.4 \cdot 10^5$ m/s for the RCS with a thickness of 1 m. On the other hand, a distance between the observed Hα kernel and HXR source corresponding to the peak is about 30 arcseconds and the loop height could not be less then about $3 \cdot 10^7$ m. The estimation of a precipitation time of protons in the latter loop is closer to the simulations for the RCS with a 1 m thickness. This agreement assumes proton beams as the agents in the N-S loop while electron ones - in the E-W loop.

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References

Dalla, S. & Browning, P., 2005, *A* A , 436, 1103.
Grechnev, V.V. *et al.*, 2003, *Solar Phys.* 216, 239.
Handy, B. N., *et al.*, 1999, *Solar Phys.*, 187, 229.
Lin, R. P., *et al.*, 2002, *Solar Phys.*, 210, 3.
Nakajima *et al.*, 1994, "The Nobeyama Radioheliograph", Proc. of the IEEE, 82, 705.
Scherrer, P. H., *et al.*, 1995, *Solar Phys.* 162, 129.
Skomorovsky, V.I. & Firstova, N.M., 1996, *Sol. Phys.*, 163, 209.
Zharkova, V.V. & Gordovskyy M., 2004, *A*strophys.J, 604, 884.
Zharkova, V.V., Zharkov, S.I., Ipson, S.S. and Benkhalil, 2005, *JGR.*, 110 N A8, doi:10.1029/2004JA010934, p.104-128.
Zharkova, V.V. & Gordovskyy M., 2005, *M*NRAS, 356, 1107.