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HXR and Hα emission sources observed during the impulsive phase of a solar flare

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Abstract. We present here results of simultaneous observations of hard X-ray radiation (HXR) sources and Hα brightenings recorded during the impulsive phase of a solar flare. Using high cadence observations we analyzed relationships of localizations as well as intensity variations of the sources observed in both wavelength domains. The visible data taken in the Hα line (2D spectra-images) were collected with the Multi-Channel Subtractive Double Pass spectrograph and Solar Eclipse Coronal Imaging System at the Białków Observatory (the University of Wrocław, Poland) with high time resolution (up to 40 ms). The HXR images were reconstructed using Reuven Ramaty High Energy Solar Spectroscopic Imager observations. We found good spatial agreement between HXR non-thermal and Hα thermal emission sources, confirming our earlier results showing a very fast radiative response of the solar chromosphere in Hα to energy deposited by non-thermal electrons during the impulsive phase of solar flares.

Key words: Sun – solar flares – high cadence – HXR – RHESSI – MSDP

1. Introduction

Solar flares have been investigated for many tens of years, nevertheless numerous important questions still remain without answers. One of them is a problem of very fast heating of a relatively dense and cold chromospheric plasma by charged particles streaming down along flaring loops from primary energy sources located somewhere close to the tops of the loops and - to some extent - by conduction and electromagnetic radiation. The accelerated particles travel with relativistic speeds and collide with the chromosphere in fractions of seconds after their release. Satellite-born hard X-ray (HXR) observations clearly reveal primary regions of the magnetic energy conversion located high in the corona. Secondary hard X-ray sources located near the feet of the flaring loops (so-called foot-point HXR sources) are also observed. The simultaneous observations made in visible wavelengths (like the hydrogen Hα line 6563 Å) give an opportunity to investigate relative localization of the bright compact and extended Hα emission sources localized in the vicinity of the foot-point HXR sources. We investigated relative localizations of hard X-ray radiation sources and Hα impulsive brightenings recorded simultaneously during one solar flare that occurred in NOAA

10786 on July 12, 2005. Using high cadence observations we analyzed temporal relationships and intensity variations of the non-thermal HXR and thermal Hα sources.

2. Observations and data reduction

Optical data (so-called Hα spectra-images) of the flaring kernels were collected with the Large Coronagraph (LC) equipped with the Multi-Channel Subtractive Double Pass spectrograph (MSDP) and the Solar Eclipse Coronal Imaging System (SECIS) at the Białków Observatory of the University of Wrocław. LC has a 53 cm diameter main objective and its effective focal length is equal to 1450 cm. Spatial resolution of the instrument, usually limited by seeing conditions, is about 1 arcsec. We also used the smaller Horizontal Telescope (HT) having compact Jensch-type coelostat with 30 cm mirrors and the main 15 cm objective with the focal length equal to 5 m. The MSDP spectrograph has a rectangular (2D) entrance window, which covers an equivalent area of $325 \times 41\,\mathrm{arcsec}^2$ on the Sun during observations in mode LC-MSDP (Mein, 1991; Rompolt *et al.*, 1994). The spectrograph has a nine-channel "prism-box", enabling restoration of the Hα line profiles in the range ± 1.2 Å from the line center with a spectral resolution of 0.4 Å. For each observed flare in a fast mode at the Białków Observatory we recorded 10 000 or 20 000 spectra-images with a time resolution between 0.04 s (25 images per second) and 0.075 s (slightly more than 13 images per second) - depending on the intensity of the light beam. More detailed information concerning MSDP-SECIS system and data reduction is available in: Radziszewski *et al.* (2006, 2007). A complete list of fast cadence observations of solar flares recorded at the Białków Observatory in years 2003 – 2005 will be published in Astronomy and Astrophysics journal (paper in review).

As a result of the data reduction for particular flare we obtained a series of 10 or 20 thousand data-cubes consisting of thirteen two-dimensional, quasi-monochromatic (band-width equal to 0.06 Å) images, separated in wavelengths by 0.2 Å (up to ± 1.2 Å from the Hα line center). Using these data-cubes we were also able to restore the Hα line profiles for each pixel inside the field of view. The collected data allow us to investigate local temporal variations of the Hα emission. The obtained Hα data were compared with HXR images reconstructed from Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) observations, using the PIXON method (Lin *et al.*, 2002; Hurford *et al.*, 2002). HXR light curves with a 0.25 s temporal resolution were obtained by a demodulation of the observed light-curves using software prepared by G. Hurford. From among almost fifty events observed with LC-MSDP-SECIS (or HT-MSDP-SECIS) system during the observational seasons 2003 – 2005 we have chosen for an analysis few medium GOES class solar flares, well observed in both HXR and Hα ranges within their impulsive phase. In this paper we present one example of the solar flare having a very good spatial correlation of the HXR and Hα sources - the

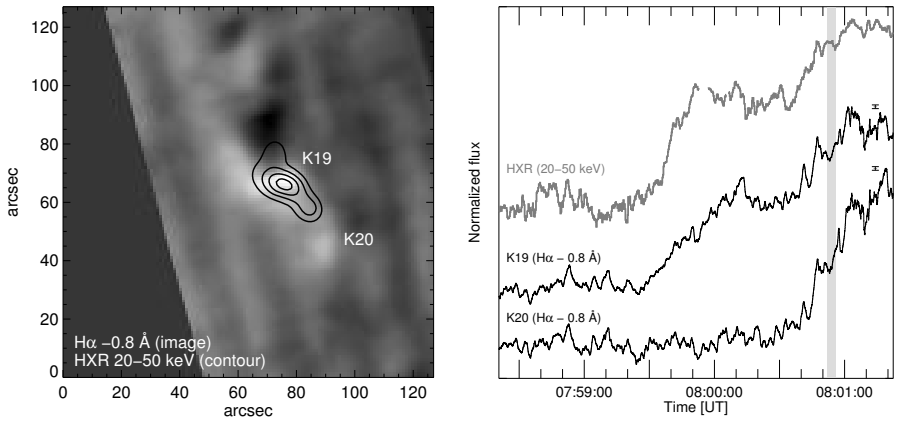

Figure 1. RHESSI X-ray and MSDP Hα emission (at -0.8 Å from the line center) of the solar flare in NOAA 10786 on July 12, 2005. The HXR source is located over Hα K19 source. The Hα light curve of the K19 kernel is well correlated with HXR light-curve. The Hα image was taken at 08:00:54 UT, $\mathrm{FOV}_{\mathrm{H}\alpha} = 128 \times 128\,\mathrm{arcsec}^2$, 1 px corresponds to 1 arcsec. The error bars indicate the standard deviations calculated for Hα light curves. Contours: RHESSI integration time: 08:00:52 – 08:00:56 UT (the vertical gray strip); $E = 20 - 50$ keV; detectors: 3F, 4F, 5F, 6F, 8F, 9F; method: PIXON, $\mathrm{FOV}_{\mathrm{HXR}} = 128 \times 128\,\mathrm{arcsec}^2$; isophotes: 30 %, 50 %, 70 %, and 90 % of $F_{\mathrm{HXR(max)}}$.

C8.3 flare in NOAA 10786 observed on July 12, 2005 (Fig. 1). Also for many other analyzed by us flares (from our data base) the spatial agreement of sources localizations was very good - particularly during the impulsive phase when both (HXR and Hα) light curves were excellently correlated in time.

3. Results and conclusion

After standard photometrical and geometrical processing of the MSDP data collected at the Białków Observatory we established locations and brightness of the flaring kernels observed in the Hα line (in range ± 1.2 Å) as well as the locations of the HXR flaring kernels recorded by RHESSI and presented on images restored using the PIXON method. The HXR and Hα flaring kernels, showing a very high temporal correlation of the light curves recorded in both spectral domains, have the same position on the solar disk with an accuracy of a couple of arcseconds.

For a C8.3 GOES class solar flare observed on 12 July 2005 the cross-correlation of the HXR ($20 - 50$ keV) and Hα (K19 kernel) light curves for the time interval 08:00:39 – 08:00:53 UT was equal to 0.96 (see Fig. 2), while both sources had the same position on the solar disk (Fig. 1). Good spatial agreement

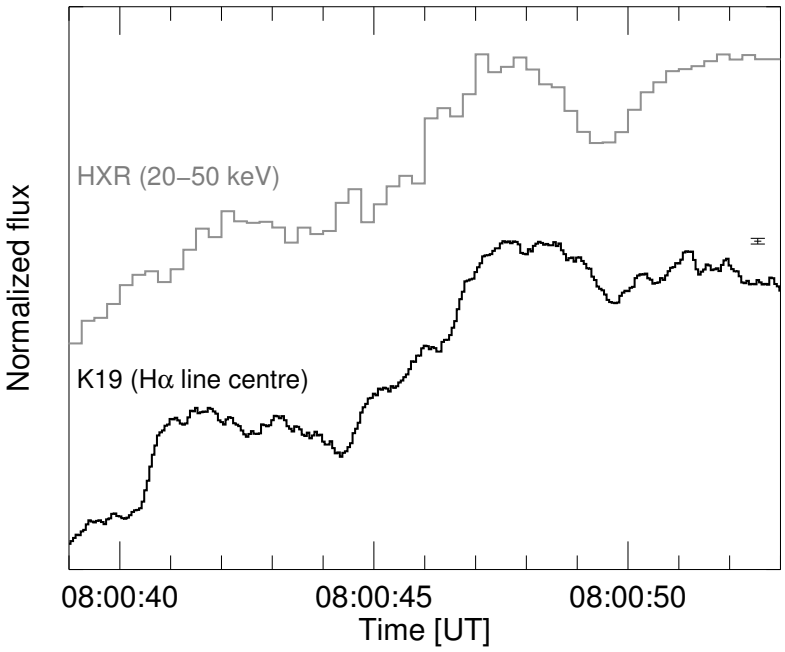

Figure 2. The HXR 20 – 50 keV and Hα line center light curves of the K19 kernel recorded during the C8.3 flare on 12 July 2005 at 08:00:39 – 08:00:53 UT. The cross correlation coefficient for this time interval is equal to 0.96.

of the HXR non-thermal and Hα thermal emission sources, having also well correlated light curves, indicates very fast radiative response of the chromosphere in the Hα range during an impulsive phase of solar flares. The presented results are consistent with our early study concerning fast changes of emission intensities recorded in both Hα and HXR ranges, observed during the impulsive phase of solar flares (Radziszewski *et al.*, 2007).

A more extensive analysis of the light curves (HXR and Hα) as well as localizations of both kinds of the emission sources will be continued. Also an analysis of the sizes of the sources (measured in HXR and various parts of the Hα line in range of ± 1.2 Å from the line center) as well as their changes in time, studied earlier (Radziszewski and Rudawy, 2008), will be continued.

The exceptional property of the MSDP spectrograph and its ability to provide high cadence spectral-images give us a unique opportunity to study fast changes of intensities and localizations of Hα emission in many wavelengths (covering the whole Hα line profile in the range ± 1.2 Å from the line center) simultaneously.

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