MULTI-WAVELENGTH ANALYSIS OF PLASMA FLOWS DURING SOLAR FLARES

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ABSTRACT

Flows of plasma are common phenomena observed during solar flares. In case of flares located close to the solar disk centre, the spectral analysis of line shifts or asymmetries is an important tool to understand the mechanisms of vertical flows in flaring layers. These flows are associated with evaporation processes driven by non-thermal electron flux or thermal conduction heating. The disturbances of line profiles occur in chromospheric lines emitted by cool plasma, as well as in hotter transition region or coronal lines observed in the EUV or X-ray ranges. In order to understand flows of cool chromospheric plasma, we use the non-LTE radiative transfer code. This code allows us to calculate different models of the chromosphere and find a velocity field. SOHO/CDS instrument provides an information about the flows in transition region and coronal parts of flares. We analyse the spatially resolved flows seen in the flare atmosphere by using spectroscopic diagnostics during the impulsive and gradual phase of flares.

Key words: flares; line profiles; evaporation.

1. INTRODUCTION

It is well known that during solar flares various asymmetrical profiles of different spectral lines are frequently observed. These asymmetries or line shifts observed in X-rays, extreme-ultraviolet (EUV) as well as in chromospheric lines are caused by vertical mass motions in flaring layers. It is also widely accepted that during chromospheric flares the plasma is evaporated into the corona (Kopp & Pneuman 1976; Antiochos & Sturrock 1978). Such evaporation should produce blue-shifted line profiles for the flares located close to the disk centre. For the hot plasma at temperatures of several MK this blue-shifted component, observed mainly during the impulsive phase, was detected in the X-ray spectra of many flares observed by the Yohkoh/BCS instrument (Doschek et al. 1994; Wülser et al. 1994; Berlicki et al. 2002). Plasma velocities deduced from Doppler-shift analysis are of the order of a few hundred km s\(^{-1}\). This high-velocity explosive evaporation is considered to be driven mainly by heating of the chromosphere by non-thermal electrons accelerated during the primary energy release (Antonucci et al. 1984; Fisher 1987).

When the non-thermal electrons heat the chromosphere the rapid temperature increase produces an enhanced pressure in the heated region. This overpressure, besides the evaporation, also drives downward-moving cool and dense chromospheric condensations (Fisher et al. 1985) which seem to be responsible for red-shifts of the Ha line profiles reported by many authors (Švestka 1978; Ichimoto & Kurokawa 1984). Another mechanism which can drive the explosive evaporation during the impulsive phase of flares is thermal conduction, however the role of this mechanism is still debated.
A different situation occurs when the flux associated with non-thermal electrons is very low. Then only a weak chromospheric evaporation takes place. This kind of evaporation is referred to as gentle evaporation (Antiochos & Sturrock 1978; Schmieder et al. 1987; Schmieder et al. 1990) and it can be observed in chromospheric spectral lines like Hα, Ca II (8542 Å) or in the EUV lines. This evaporation could be driven by the large conductive heat flux from a high-temperature flare plasma contained in magnetic tubes above the chromosphere. Such physical conditions may appear during the gradual phase of solar flares, when there is no significant flux of non-thermal electrons.

In this paper we present an analysis and interpretation of flows during several flares for which the spectroscopic observations in different spectral ranges were available for the impulsive as well as for gradual phase.

2. FLOWS OF FLARE PLASMA

We present several examples of flares for which the vertical flows of plasma was observed.

2.1. October 20, 2003 flare - impulsive phase

The flare on October 20, 2003 occurred in NOAA 10484, one of the three active regions which appeared in late October 2003 and produced many flares. In Figure 1 we present the X-ray fluxes observed with GOES and RHESSI. Optical observations of this are were made by THEMIS in the Canary Island, and Multi-channel Infrared Solar Spectrograph (MISS) at Purple Mountain Observatory (PMO). Slit-jaw Hα images obtained by MISS are shown in Figure 2. From these images, we clearly see two Hα flare ribbons that correspond to R1, R2, and partly R3 of the EUV 304 Å ribbons. We can follow some points of interest by carefully coaligning the MISS slit-jaw Hα image using the SOHO/MDI intensity image. In order to investigate the time evolution of chromospheric and X-ray emission in all the MISS observations, we selected spectra corresponding to the ribbon emission.

In Figure 3 we present a sample set of the Hα, Ca II 8542 Å, and He I 10830 Å profiles at this point observed by MISS in the impulsive phase at 07:11:14 UT. In this Figure the solid lines is for the profiles in the flaring region and dotted lines for those in a nearby quiet-sun region. Figure 3 also shows that the profiles in all three lines display red-asymmetry.

This asymmetry can be interpreted in terms of chromospheric condensations (Ichimoto & Kurokawa 1984; Fisher et al. 1985). The asymmetry of the Hα line correspond to the downflow of plasma with velocity of about 50 km s⁻¹. For this flare we do not have information about the velocity of hot plasma - there is no spectral data for hot lines.

The slowly-varying time profiles of chromospheric emission of the flare in Hα, Ca II 8542 Å, and He I 10830 Å lines (Figure 4) suggests that the heating of the chromosphere is mainly by continuous heat flux from the hot corona or trapped particles. However, the spectral analysis of X-ray emission observed by RHESSI suggests that thermal conduction is dominant (Li et al. 2005)
2.2. October 22, 2002 flare - gradual phase

An M1.0 flare was observed in the active region NOAA 0162 on October 22, 2002, close to the solar disk centre. This active region was a target during a coordinated observational campaign (Berlicki et al. 2004). Ha observations were performed using the MSDP (Multichannel Subtractive Double Pass) spectrograph coupled to the VTT telescope working at the Teide Observatory (Tenerife, Canary Islands).

For the analysis of flows we use Ha line profiles observed in several areas within the flare ribbons. The black crosses marked in the MSDP image in Figure 5 - left panel are the centres of the corresponding areas. These profiles were observed at six different times (Figure 5 - right panel). For each Ha profiles observed in the analysed areas of the flare, using the non-LTE code developed by Heinzel (1995) we found the best fit between observed and synthetic profiles (Berlicki et al. 2005). In this way we found the velocity of plasma (Figure 6).

In most of the analysed areas and at most of the times the velocities obtained from the modelling exhibit negative values which means upward flows. We interpret the upflows found in the flare ribbons in terms of the Antiochos and Sturrock (1978) model for gentle evaporation. This process may occur during the gradual phase of solar flares (Schmieder et al. 1987) and it can be driven by conductive heat flux from the high-temperature flare plasma contained in magnetic flux tubes above the photosphere.

2.3. October 28, 2003 flare - gradual phase

This extreme big (X17+) flare occurred in NOAA 10486 and it was very energetic and accompanied by less energetic pre-events. The overall morphology of this event fill the standard picture of a two-ribbon flare with arcades of loops emitting at different temperatures. The footpoints of these loops are well observed in Ha, and form the ribbons (Figure 7). During the gradual phase the loops evolve and the ribbons moves away with high speeds.

SOHO/CDS observed during the whole day providing the scans of the active region before and during the flare. We present the observation of one fast NIS raster, that is designed to cover a wide range of temperatures. This raster was recorded during the gradual phase of the flare (12:28-12:52 UT). The
ACKNOWLEDGMENTS

This work was supported by the European Commission through the RTN programme (European Solar Magnetism Network, contract HPRN-CT-2002-00313).

REFERENCES


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