Analysis of dynamics of loops in an active region associated with a small C-class flare

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Abstract: Analysis of dynamics of the magnetic loops before and during a X-ray C1.4 class flare in NOAA AR 10646 is presented using data of the *SOHO*/CDS spectrometer. The sit-and-stare observational mode of the *SOHO*/CDS was used to measure the temporal evolution of the spectral profiles of He I 584.33 Å (chromosphere), O V 629.73 Å (transition region) and Si XII 520.67 Å (corona). Several precursor events and main impulsive phase of the flare were detected at different positions along the CDS slit in all spectral lines. Analysis of the two selected chromospheric precursors with clear relation to the main impulsive phase and the main impulsive phase of the flare itself has shown time delays between chromospheric/transition region and coronal occurrence of events, significant upflows during precursor events and peaks of downflow and upflow velocities during main impulsive phase. These findings indicate that the chromospheric evaporation could be the driving mechanism responsible for the observed flare emission. Further investigation of remaining precursors and also analysis of the co-observations obtained by *TRACE* instrument and the *DOT*/LaPalma telescope is necessary for confirmation of this conclusion.

Introduction

The reconnection of magnetic field lines is the most accepted mechanism which can release magnetic energy during the flares. This energy is subsequently transformed to kinetic energy of non-thermal particles and to heat. The resulting accelerated beams of particles and/or thermal conduction fronts then propagate downward and heat the chromospheric plasma to coronal temperatures. As the chromospheric material heats, it expands upward into the corona. This process is known as ***chromospheric evaporation***. Observational evidence for chromospheric evaporation is therefore based mainly on detection of strong upflows ($\sim$300 km s^{-1}) in coronal emission lines (formed at temperatures higher than 10^7 K) during the flare impulsive phase (Antonucci & Dennis 1983; Doschek et al. 1996; Silva et al. 1997; Bornmann 1999).

Hydrodynamic simulations (Fisher at al. 1985a,b,c) of the response of upper chromosphere and the transition region to chromospheric evaporation revealed an energy threshold separating two different regimes of the discussed mechanism. ***Explosive evaporation*** occurs when the flare energy deposited to chromosphere is higher than the threshold energy and overpressure of the evaporated material drives plasma simultaneously upward towards the corona and downward into the chromosphere. Fisher et al. (1985b) predicted that the spectral lines formed at temperatures $\sim 10^5$ K should therefore exhibit downflow velocities of around 40 km s^{-1}. Energy fluxes less than the threshold value lead to the ***gentle evaporation*** when the transition region spectral lines should exhibit upflows of $\sim$20 km s^{-1} (Fisher et al. 1985b).

Fárník et al. (1996) revealed that at least 15% (at most 41%) of their flare sample show precursors, i.e. brightenings appearing near location of the main impulsive phase which are closely related with the flare. Brosius & Phillips (2004) pointed out that the precursors are probably results of the gentle evaporation while the main impulsive phase appears to be due to explosive evaporation.

We concentrate on analysis of the measurements of a X-ray C1.4 class flare observed in NOAA AR 10646 on July 15 2004 here (see Fig. 1). In particular, we discuss the properties of the two precursor events and the main impulsive phase (see Fig. 2).

Data

- instrument: CDS/NIS spectrometer (Harrison et al. 1995)
- spectral lines: He I 584.33 Å, O V 629.73 Å, Si XII 520.67 Å
- exposure time: 10 s; cadence: 15.1 s

Results

Precursor 1

- simultaneous occurrence in the He I and O V intensities
- duration: 11.8 min
- upflows of maximum velocities 20.8 km s^{-1} and 28.1 km s^{-1} detected in the He I and O V Doppler shifts, respectively
- no coronal counterpart visible in the Si XII spectral line

Precursor 2

- simultaneous occurrence in the He I and O V intensities
- latter occurrence in the Si XII intensity; time delay $\sim$2 min
- duration: 10.8 min
- upflows of maximum velocities 56.1 km s^{-1}, 55.7 km s^{-1} and 17.0 km s^{-1} detected in the He I, O V and Si XII Doppler shifts, respectively

Main impulsive phase 3

- simultaneous appearance of the rapid intensity rise in the He I and O V lines
- latter appearance of the rapid intensity rise in the Si XII line; time delay $\sim$45 s
- different duration of the intensity decline phase in selected lines
- peak of downflow velocities followed by upflows detected in the Doppler shifts of all spectral lines
- max. downflow velocities: He I = 37.2 km s^{-1}, O V = 53.3 km s^{-1}, Si XII = 19.6 km s^{-1}
- max. upflow velocities: He I = 23.6 km s^{-1}, O V = 31.2 km s^{-1}, Si XII = 6.3 km s^{-1}
- maximum downflow and upflow velocities achieved $\sim$45 s later in the Si XII Doppler shifts comparing to cooler lines

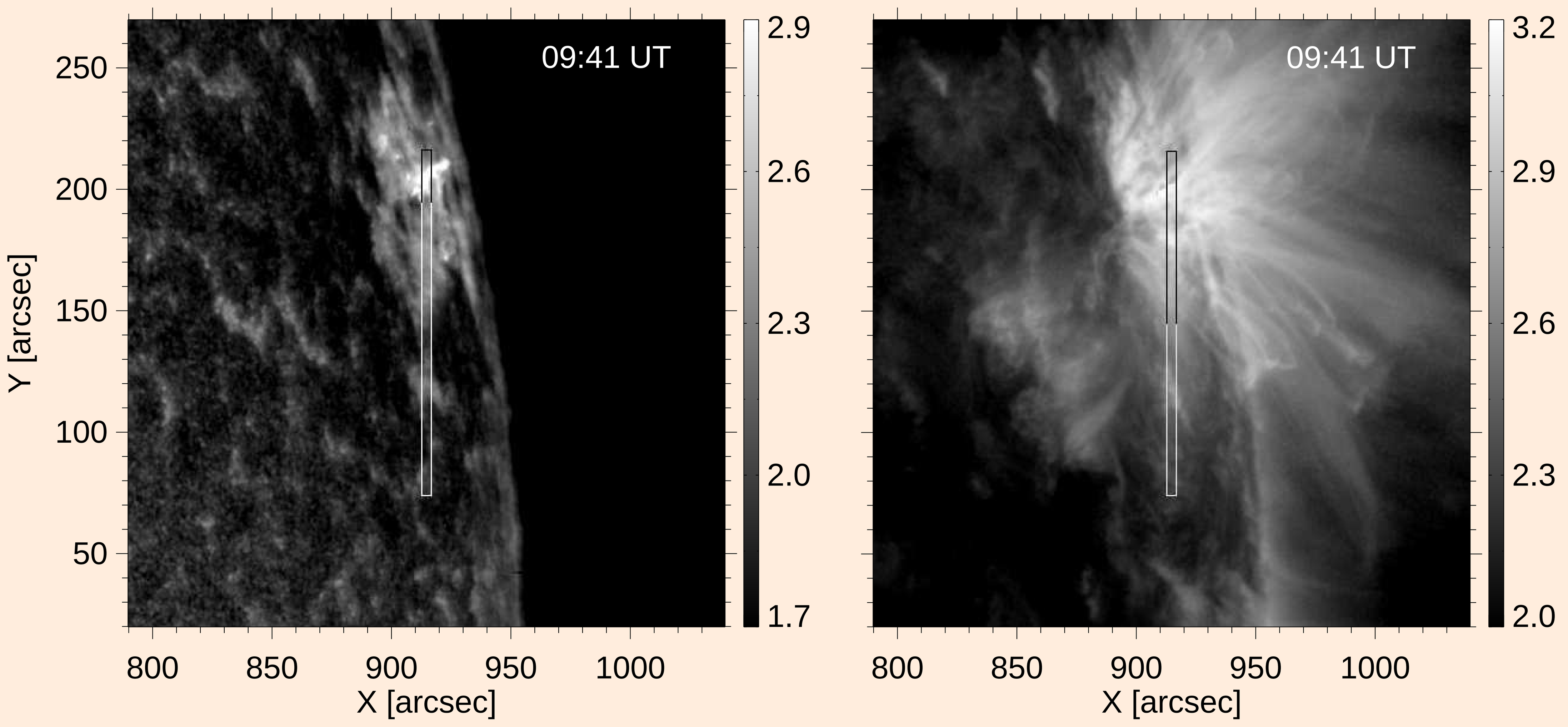

Fig. 1. TRACE 1600 Å (left) and 171 Å (right) filtergrams showing location of the CDS slit within NOAA AR 10646. The images were taken during the main impulsive phase of the flare under study. Spectral data described and discussed here were detected between 191.1 arcsec and 214.9 arcsec along the slit. Solar north is up, and west is to the right. The intensity values in counts s^{-1} are displayed in logarithmic scale.

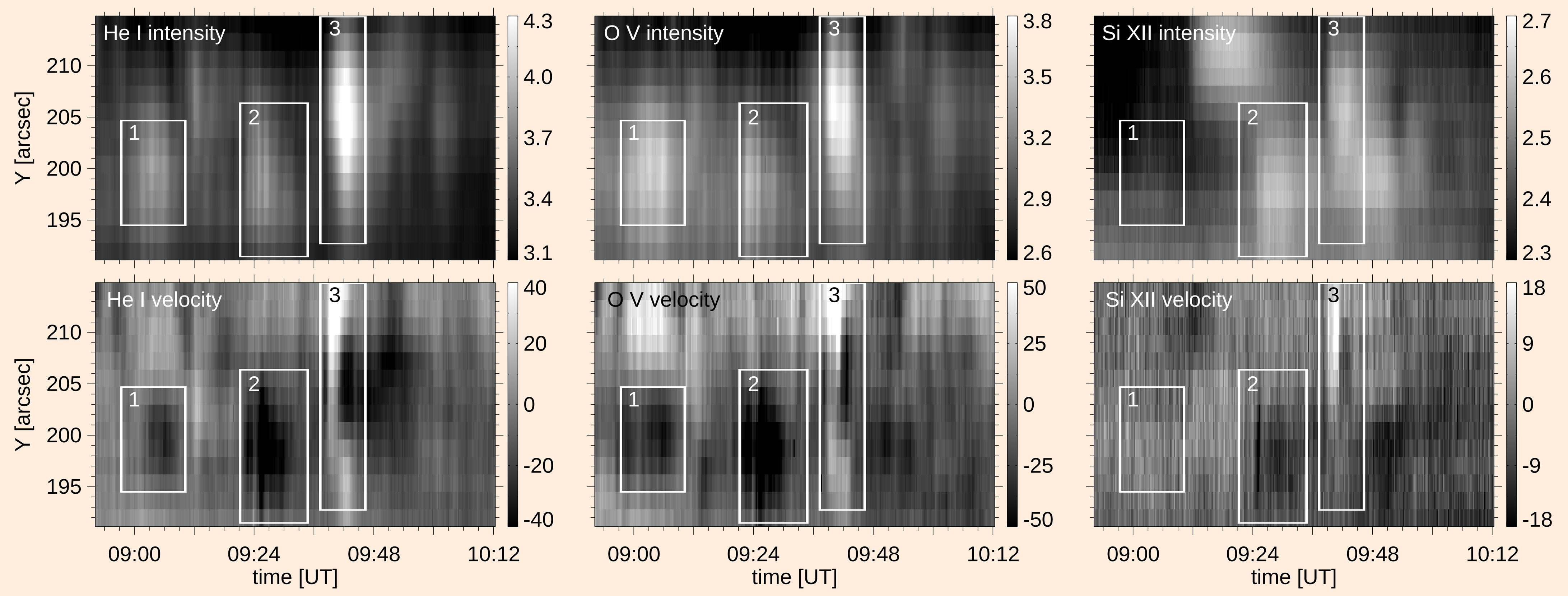

Fig. 2. Time-space maps of the He I, O V and Si XII intensities (upper row) and the Doppler shifts (lower row). The analyzed precursor events (1, 2) and main impulsive phase (3) of the flare are circumscribed by rectangles. The intensity values in erg cm^{-2}s^{-1}sr^{-1}Å^{-1} are displayed in logarithmic scale. The Doppler shifts are in km s^{-1}. Positive Doppler shifts correspond to downflows.

Discussion and conclusion

- the chromospheric/transition region occurrence of all events discussed here precedes their occurrence in the corona → particle beams preferred as the mechanism responsible for the energy transfer and chromospheric heating during observed flare
  - if the thermal conduction dominated → events would be seen in coronal line first
- strong upflows during precursor events → gentle evaporation
- downflow velocities followed by upflows during the main impulsive phase → explosive evaporation consequently changed to gentle evaporation (probably caused by decrease of the energy of particle beams)

⇒ chromospheric evaporation of different scales occurs during the precursor events and the main impulsive phase of the flare

Outlook

- analysis of the coronal precursor visible in the Si XII intensity which has no chromospheric/transition region counterpart (Fig. 2; *time* = 09:12 – 09:24 UT, *Y* = 204.7 – 214.9 arcsec)
- analysis of the strong downflow (occurred without any significant intensity enhancement) detected in the O V Doppler shifts (Fig. 2; *time* = 08:58 – 09:06 UT, *Y* = 206.4 – 214.9 arcsec)
- multicomponent fitting of the spectral profiles
- analysis of the co-observations obtained by *TRACE* instrument in 171 Å and 1600 Å channels and by *DOT* telescope in Ca II H spectral line
- estimation of the inclination of magnetic loops → determination of the velocities along the loops
- determination of the strength of coronal magnetic field from the Doppler shift oscillations

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