Strong Blue Asymmetry in Hα Line as a Preflare Activity

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Abstract Chromospheric activities before solar flares provide important clues to the mechanisms that initiate solar flares, but are as yet poorly understood. We report a significant and rapid Hα line broadening before the solar flare SOL2011-09-29T18:08 that was detected using the unprecedented high-resolution Hα imaging spectroscopy with the Fast Imaging Solar Spectrograph (FISS) installed on the 1.6 m New Solar Telescope (NST) at Big Bear Solar Observatory. The strong Hα broadening extends as a blue excursion up to −4.5 Å and as a red excursion up to 2.0 Å, which implies a mixture of velocities in the range of −130 km s−1 to 38 km s−1 derived by applying the cloud model, comparable to the highest chromospheric motions reported before. The Hα blueshifted broadening lasts for about six minutes and is temporally and spatially correlated with the start of a rising filament, which is later associated with the main phase of the flare as detected by the Atmosphere Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). The potential importance of this Hα blueshifted broadening as a preflare chromospheric activity is briefly discussed within the context of the two-step eruption model.

Keywords Flares, pre-flare phenomena · Heating, in flares · Spectrum, visible
1. Introduction

The preflare phase refers to the early stage of the flare development process, generally before the impulsive hard X-ray emission (Benz, 2002). Since the first report of Bumba and Krivský (1959), the preflare phase has been regarded as a key subject for understanding the triggering mechanism of flares. The preflare phase is observed as local transient brightenings. A preflare brightening is smaller than a flare kernel, typically a few dozen arcseconds (e.g., Joshi et al. 2011). It is mostly located in the vicinity of emerging flux regions (Sterling, Harra, and Moore, 2007), eruptive filaments (Chifor et al., 2007), or canceling magnetic features (Moon et al., 2004; Sterling, Moore, and Freeland, 2011), which are roughly cospatial with flare kernels that occur later. The typical timescale of a preflare brightening is a few dozen minutes, which is shorter than the main flare duration (e.g., Sterling, Moore, and Freeland 2011). These spatial and temporal characteristics of the brightenings were interpreted as heating through localized and short-lived magnetic reconnection (Joshi et al., 2013).

Chromospheric motions can also be an important element for defining the preflare activity. Many studies have reported rising motions (e.g., Kundu et al. 1985, Sterling, Moore, and Freeland 2011) and oscillatory motions (e.g., Malville and Schindler 1981, Bocchialini et al. 2011) within filaments before the flare occurrence. However, only a few spectroscopic studies on the preflare chromospheric motions have been reported. Canfield et al. (1990) observed a Hα blueshifted absorption feature that was clearly associated with an erupting preflare filament. Alikaeva and Chornogor (2004) found a chromospheric upflow with speeds higher than 10 km s$^{-1}$ in their preflare Hα spectra that were obtained with the ATSU-26 solar telescope. They also found two crossing Hα loops interacting before the flare, after which the velocities were redistributed in both the chromosphere and photosphere. Cauzzi et al. (1996) reported an upward motion a few seconds before the impulsive phase of the flare determined from lines originating in high chromospheric layers (Ca II K and Hβ) and from metallic lines (Si I 3905, Fe I multiplets four and five). These motions together with a simultaneous strong emission were interpreted as implying early chromospheric heating before flares. Most recently, Leiko and Kondrashova (2015) studied a microflare using the Hα spectrograph of the solar telescope, Télescope Héliographique pour l’Etude du Magnétisme et des InstabilitéS Solaires (THEMIS), to find strong temporal variations of the line-of-sight (LOS) velocity in the chromosphere. The Hα Doppler velocity changed from $-25$ km s$^{-1}$ at about 13 min before the microflare maximum to $5$ km s$^{-1}$ at the maximum. The result suggests that there might be considerable mixing in both magnitude and direction of the chromospheric motions.

There are also other types of chromospheric motions not limited to the preflare activity. Most widely studied are the chromospheric motions during the main phase of flares (see Falchi, Teriaca, and Maltagliati, 2006 and references therein). Švestka, Kopecký, and Blaha (1962), Ichimoto and Kurokawa (1984), and others have revealed the red asymmetry of the Hα line profiles in the initial phase of flares interpreted as chromospheric downflows with velocities of tens of km s$^{-1}$. Keys et al. (2011) measured LOS Doppler velocities of a C-class flare using the Solar Optical Universal Polarimeter (SOUP) that provides two-dimensional spectral information across the Hα line profile at seven wavelength positions. The first frame exhibited a redshifted velocity of 6 km s$^{-1}$ and the subsequent frame showed a blueshifted velocity of $-15$ km s$^{-1}$ at the same position. Rouppe van der Voort et al. (2009) studied the Hα spectrogram of the quiet Sun to find a phenomenon called rapid blue excursions (RBE), which appears in absorption at a wide range of wavelengths from the line center to the far blue wing, typically extending up to $-2$ Å or $-90$ km s$^{-1}$. These results suggest that LOS velocity appears in various settings, and strong Doppler blueshifts indicative of violent
upflows are observed as frequently as the redshifts, indicating down-streaming of material from the corona.

In this article we present spectroscopic observation of preflare activities in the chromosphere preceding the solar flare SOL2011-09-29T18:08, which shows a very strong blueshifted component in the Hβ spectra. We have to note that the GOES data have a gap between 18:01 UT and 18:08 UT in which the flare maximum occurred, and the solar flare identifier refers to the time of resuming GOES measurement in the declining phase. Its soft X-ray class, C5.6, should therefore be regarded as an underestimation of its true strength. The spectroscopic imaging observation was made using the Fast Imaging Solar Spectrograph (FISS) of the 1.6 meter New Solar Telescope (NST) at Big Bear Solar Observatory and the Atmosphere Imaging Assembly (AIA) onboard the Solar Dynamics Observatory (SDO). This combination of instruments allows us to investigate not only the spectral properties but also spatial and temporal properties of the chromospheric motions with higher precision.

2. Observations

The FISS produced four-dimensional (spectral, temporal, and two spatial dimensions) Hα and Ca II 8542 Å data simultaneously in every scan. The details of the FISS instrument and data processing were described by Chae et al. (2013b). The FISS data that we took have a field of view (FOV) of 40″ × 60″ and a cadence of 66 seconds. The spectral profile for the Hα line is measured at 512 spectral positions and the spectral sampling is 0.019 Å. For the Ca II line, 502 spectral positions are used and the spectral sampling is 0.026 Å. The wavelength calibration is based on the two lines HI 6562.817 Å and Ti II 6559.580 Å in the quiet region average profiles. We have used FISS observations from 17:12 UT to 18:40 UT, fully covering the flare including the preflare phase.

We also analyzed the data taken by the AIA (Lemen et al., 2012) and the Helioseismic and Magnetic Imager (HMI, Schou et al. 2012) onboard the SDO. The time sequence of the 304 Å images from the SDO/AIA and of the LOS vector magnetogram from the SDO/HMI were used to check the chromospheric and the photospheric features and their dynamics. We employed a time-distance map to measure the transverse motion and brightenings. We constructed the time-distance map of the SDO/AIA 304 Å images along the line that is oriented in the direction clearly displaying the initial movement of the chromospheric feature. The SDO/AIA 171 Å images were also used to investigate the configuration and the temporal variation of the coronal magnetic field lines.

The Reuven Ramaty High Energy Solar Spectroscopic Imager (RHESSI) hard X-ray data are missing for this time period. The Fermi Gamma-ray Burst Monitor (GBM) data are available and show the impulsive X-ray count flux from the solar flare up to 100 keV that occurs around 18:03 UT. The GOES flare strength (C5.6) is certainly underestimated as a result of the missing GOES flux during the maximum phase. Small GBM peaks are found from 17:50 UT to 17:54 UT, which are not considered solar signals (not shown here). Presumably, they occurred at the time of a charged particle peak, and another group of peaks with a similar shape reappears at 18:32 UT, possibly in association with the Fermi orbit (Brian Dennis 2015, private communication).

3. Spatial Structure

Figure 1 shows that the observed active region is the trailing part of a larger-scale bipolar structure. The active region was connected to another active region (NOAA 11302) located
Figure 1 Large FOV images of the source active region, NOAA 11305. Top: SDO/AIA 171 Å image before the flare. Red (blue) contours represent positive (negative) polarity magnetic field, and the contour levels are in ±100, ±1000 G, respectively, from the SDO/HMI magnetogram. The same contour levels are used for magnetic fields in all other figures. The black box indicates the FOV of the panels displayed in Figure 2. Bottom: SDO/AIA 304 Å negative images before (left) and after (right) the main flare occurrence. The dashed green ellipse represents the remote flare kernels.

about 300 Mm east of it by high-lying coronal loops clearly visible in SDO/AIA 171 Å images. The main polarity of the active region is negative and that of its leading partner is positive. The flare caused disturbances in some of these coronal loops, but did not permanently disrupt them. There was no report of a coronal mass ejection (CME) associated with this flare. From the SDO/AIA 304 Å images, we also found that the remote flare kernels appeared 150 Mm southeast of the active region when the flare occurred. Even though the flare affected a large volume, we found that the main dynamical processes occurred inside a part of the active region that we indicate by black boxes in Figure 1.

Figure 2 shows the C5.6 main flare itself and its preflare visible in the SDO/AIA 304 Å images. The preflare started at 17:49 UT in between the positive and negative poles of the moat region. Its brightness increased for about five minutes, then diminished. The impulsive phase of the main flare started at 18:01 UT. The 304 Å flare kernel was cospatial with
Figure 2 Time sequence of the SDO/AIA 304 Å images. The white arrows indicate the rising filament. The dashed green line indicates the slit for constructing the time-distance map (Figure 8c). The yellow box corresponds to the FOV of the FISS.

the positive and negative poles in the moat region and a part of the large negative-polarity sunspot. The most noteworthy feature seen in the 304 Å images is the filament that is indicated by the white arrows. This filament connects the negative and positive poles of the moat region and has an apparent length of 18 Mm and an apparent width of 1 Mm. It stayed stable until the preflare occurred near the middle of it. During the preflare activity, the filament slowly moved westward and accelerated, which likely reflects the projected component of the upward motion. After the main flare took place, the filament was no longer visible.

4. Spectral Properties

The Hα counterpart of the filament appears in the raster images constructed at several wavelengths from the FISS data as shown in Figure 3. It also appears as a filament clearly visible at the center of the Hα and Ca II 8542 Å lines. Like the 304 Å filament, this Hα filament was stable before the preflare and began a dynamical change when the preflare started. The dynamic change is characterized by very strong blueshift, as can be inferred from the appearance of the elongated absorption feature at the far blue wing (−1.5 Å) of the Hα line (surrounded by the dashed blue ellipses in Figure 3). The feature, Hα blueshifted broadening, had a width comparable to that of the rising filament and lasted for a few minutes. We note that the evolution of the filament seen in the Ca II 8452 Å line differs from that seen at the Hα line. In the Hα line center images, for instance, the filament is discernible throughout the preflare phase, while the filament soon vanishes in the Ca II 8452 Å line images.

The spectrograms of Hα and Ca II 8542 Å lines are shown in Figure 4, where we mark the blueshifted broadening feature with dashed ovals. We note that this feature in the Hα
Figure 3  Time sequences of the FISS Hα (brown) and Ca II 8542 Å (green) raster images at three wavelengths for each spectral line. In the top panel, the dashed blue ellipses mark the Hα blueshifted broadening. The white arrows indicate the rising filament. The dashed cyan box is the region over which the intensity is integrated to produce the light curve in Figure 8a. The dashed green lines mark the slit position used for constructing the spectrograms displayed in Figure 4. The crosses indicate the P1 – P4 positions used for local spectra shown in Figure 5.

The spectrogram looks somewhat similar to the rapid blue excursions (RBE) studied in detail by Rouppe van der Voort et al. (2009) in that it appears in absorption at a wide range of wavelengths from the line center to the far blue wing. Our observed feature is physically different from the quiet-Sun RBEs of Rouppe van der Voort et al. (2009) in some aspects, however. Most of all, it extends much farther blueward, up to $-4.5 \text{ Å}$, than these well-known RBEs that typically extend blueward roughly up to $-2 \text{ Å}$. We also note that the region of strong upward Doppler motion, the feature marked by the blue dashed ellipse in the top row of Figure 3, takes an elongated ellipse shape. The major axis of the ellipse must be along the
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Figure 4  Examples of the FISS Hα (left column) and Ca II 8542 Å (right column) spectrograms. The zero wavelength in the left (right) panels represents Hα 6562.817 Å (Ca II 8542.09 Å). Each spectrogram was taken at the slit position marked by the green line in Figure 3 at each time. The vertical axis indicates the distance from right lower end of the dashed green line in Figure 3. The dashed blue ellipses indicate the Hα blueshifted broadening.

filament axis, and the minor axis of the ellipse is comparable with the filament thickness. On the other hand, an RBE often exhibits a linear motion within a narrower width because it represents a mass flow along a spicule. This also differs from the rapid red excursions (RREs), which again show jet-like features but in the downward motion (e.g. Sekse et al. 2013). Finally, we find that not only blue excursions, but also red excursions, up to 2 Å, occur either nearby (at 17:53:22 UT) or at the same location (at 17:54:28 UT), composing a dynamically complex structure between 0 and 10 Mm in Figure 4.

Another important feature is that this broadening event is prominent only in the Hα line and not clearly visible in the Ca II 8542 Å line. In the Ca II 8542 Å line, there is only a small change at the far blue wing. This means that the upward-moving Hα material is almost transparent to the Ca II 8542 Å line so that the observed Ca II 8542 Å spectrum mostly comes from the unperturbed chromosphere below. This occurs when the upflow is heated to a temperature where the Ca II 8542 Å line opacity no longer exists. There is no such clear-cut temperature, but here we give a rough estimate based on the literature. For instance, Figure 8.9 of Carroll and Ostlie (2007) shows that the Ca II line forms at temperatures between 3000 K and $10^4$ K, whereas Hα forms in a much wider range from 5000 K to $5 \times 10^4$ K. We therefore assume that the Hα brightening region is heated to a temperature...
above $10^4$ K. Furthermore, this plasma probably coexists with an even hotter plasma with a temperature $\geq 5 \times 10^4$ K to account for the He II 304 Å brightening.

Figure 5 shows spatially resolved Hα spectra at four time intervals from the top to bottom panels. The first four columns show spectra determined at single locations, P1 – P4. These locations are separated by 0.86″, and each separation extends to 5.4 pixels. The rightmost column shows the average line profiles integrated over the box that covers the flaring area (the dashed cyan box in Figure 3). This strong blueshift broadening is confined to a narrow
Figure 6  Temporal and spatial variation of the FISS Ca II 8542 Å spectra. The panels follow the same format as Figure 5. The zero wavelength represents the Ca II 8542 Å line center at 8542.09 Å.

region (P1 – P2) over a short time interval (∼6 min). The strong blueshifted broadening could not have been recognized in the spatially averaged spectrum (right-most column). This phenomenon is therefore hardly observable without high spatial and temporal resolution and spectral coverage. In Figure 6 we plot the Ca II 8542 Å line profiles in the same manner as in Figure 5. Unlike the Hα spectrum, the Ca II 8542 Å line spectrum does not clearly show the blueshifted absorption feature. As mentioned, this is probably due to the temperature, which is higher than 10⁴ K.

In Figure 7 we compare the Hα Doppler velocity and the SDO/AIA 304 Å intensity map. The top two panels show the spatial distributions of Hα Doppler velocity as contours on top...
Figure 7  Spatial distributions of Hα upward Doppler velocity. In the top panels the Doppler velocity maps (contours) are superposed on the SDO/AIA 304 Å images at two instants of the preflare phase. The white arrows indicate the rising filament. The bottom panels show the Doppler velocity maps only at the corresponding times.

of the SDO/AIA 304 Å images at two instants of the preflare phase. The bottom panels show the Doppler maps as grayscale images at the corresponding times. The Hα explosive event was co-spatial with the preflare brightening and the rising filament.

To determine the Doppler velocity in this figure, we used the bisector method (Deubner, Waldschik, and Steffens, 1996; Chae et al., 2013a). In this method, we typically select a level of the spectral line at which the bisector is taken as the measure of the Doppler shift. In the present case, we chose the 60% level of the quiet region continuum intensity, at which the blueshifted absorption feature of interest is well represented. Because we used the bisector method, the Doppler velocities shown in the figure might be underestimated compared to those inferred from the blue ends of the excursions.

5. Temporal Evolution

Figure 8 presents the temporal variation of the Hα blueshifted broadening in comparison with the development of the other features. The Hα and SDO/AIA 304 Å light curves are
Figure 8 (a) Time profiles of Hα and SDO/AIA 304 Å measured inside the dashed sky blue box in Figure 3. (b) Time variations of the Hα peak LOS velocity (dotted line) and the GOES X-ray 1.0–8.0 Å flux (thin solid line) overplotted on the radio dynamic spectrum from the GBSRBS (background image). The LOS velocities were determined by the bisector method applied to the FISS Hα spectra for each time. The gap between 18:01 UT and 18:09 UT of the GOES X-ray is due to absence of data. (c) The time-distance map from SDO/AIA 304 Å image. The vertical axis indicates the distance from the left end of the dashed green line in Figure 2. The white arrow indicates the location of the filament.

represented in Figure 8a. In Figure 8b the radio dynamic spectrum from the Green Bank Solar Radio Burst Spectrometer (GBSRBS) is shown as background image, and the maximum value of the Hα Doppler velocity map at each time is plotted as symbols connected by the dotted line. We also show with the white curve the GOES soft X-ray light curve, which has a data gap during the maximum phase of the flare. Figure 8c shows the time-distance map constructed from time series of the SDO/AIA 304 Å data along the slit defined in Figure 3 (the dashed green line).

The Hα and SDO/AIA 304 Å light curves in Figure 8a clearly show that this preflare activity started about six minutes before the main phase of the flare. The sizable LOS velocity of about $-10$ km s$^{-1}$ first appeared at 17:49 UT (Figure 8b), coinciding with the start of the preflare in Figure 8a. The peak Doppler value increased to about $-60$ km s$^{-1}$ in about six minutes, which is during the period of the preflare activity of Hα and 304 Å. The Hα blueshifted broadening lasted about six minutes during the preflare phase. Another noticeable property is that neither soft X-rays nor radio flux are enhanced during the period of the Hα blueshifted broadening. Although hard X-ray data were unavailable for this event, the radio signals were detected in the main flare phase, which are of a type III burst, indicating high-energy electrons escaping along open field lines. Therefore the data obtained in soft X-ray and radio wavelengths indicate that this blueshift event is not associated with energetic electrons accelerated in the corona, although it is associated with plasma heating.

Figure 8c shows the temporal variation of the transverse displacement of the 304 Å rising filament. This filament is clearly visible in absorption at about 17:40 UT (the white arrow in Figure 8c). About ten minutes later, it suddenly begins an oscillating motion. This instant corresponds to the time when the 304 Å preflare started and the Hα blueshifted broadening
first appeared. When the Hα blueshifted broadening disappeared, the filament started to rise at noticeable transverse speeds of about 10 km s$^{-1}$. This slow-speed rise phase lasted about six minutes, and then the filament rapidly moved out of the field of view. The instant of transition from the slow to fast rise phase is very close to the start time of the main flare.

6. Discussions

We focus on the nature and the role of the Hα blueshifted broadening in the preflare stage because this is the main result of this study.

6.1. Preflare Heating in the Chromosphere

The strong Hα Doppler broadening can be caused by either heating or nonthermal velocity, $\xi$, of the plasma, or both. To determine these two quantities, we analyzed the Hα spectrum of P2 at 17:54:28 UT, using the classical cloud model (Beckers, 1964; Yang et al., 2013). As a result, we obtained that the central wavelength of the absorption profile is displaced by $-0.97$ Å and the Doppler broadening of the line is $\Delta \lambda_D \approx 1.84$ Å. The latter quantity is related to the temperature and nonthermal motion by $\Delta \lambda_D/\lambda = \sqrt{2k_B T/m} + \xi^2/c$, where $k_B$ is the Boltzmann constant and $m$ is the mass of the hydrogen atom. If we attribute this Hα broadening entirely to thermal broadening (i.e., $\xi = 0$), the temperature would be as high as $T \approx 4.3 \times 10^5$ K. At this temperature hydrogen atoms must be all ionized. It thus follows that the Hα line broadening would be dominated by plasma motion. Of course, there must be plasma heating to some extent including the temperatures for Hα and 304 Å line formation. Since the He II 304 Å line forms at $5 \times 10^4$ K, the preflare brightening observed in the He II 304 Å line indicates the presence of plasma at this temperature or higher. To explain the Hα signature, a lower temperature plasma should coexist, but the absence of a significant change in the Ca II 8542 Å line requires the temperature to be above $10^4$ K. Another constraint is the absence of X-rays and microwaves during the preflare phase. This implies that the strong Doppler event is not accompanied by energetic electrons accelerated in the high corona, and the temperature should not exceed the typical coronal value. We also checked SDO/AIA data for a bright feature at 131 Å, but no significant counterpart at 94 Å ($\log T \approx 6.8$) was found for the same region. We therefore estimate that this preflare heating is mild and the plasma temperature is in the range $10^4$ K $< T < 10^6$ K.

6.2. Nature of the Hα Blueshifted Broadening

When we adopt a reasonable temperature $T = 10^4$ K in the cloud model, the observed Hα broadening up to 1.84 Å should indicate the presence of nonthermal motion of about $\pm 83$ km s$^{-1}$. Since the displacement of the central wavelength of the absorption profile is $-0.97$ Å or equivalently, $-45$ km s$^{-1}$, the whole motion lies in a wide velocity range from $-130$ km s$^{-1}$ to 38 km s$^{-1}$. These values are comparable to the highest speeds of other similar chromospheric phenomena as a preflare activity, for instance, a blueshifted velocity of $-140$ km s$^{-1}$ (Canfield et al., 1990), limb observation of flow motions with speeds of 100 km s$^{-1}$ (Sterling, Moore, and Freeland, 2011), and a filament speed of $\approx 600$ km s$^{-1}$ from the Si iv line in the transition region (Kleint et al., 2015).

We interpret this strong Hα broadening as an explosive Hα event. The bulk motion itself is not so strong because the core of the line profile shifts only by $\approx 0.5$ Å (Figure 5). The broadening is strong, however, and implies the presence of velocities in a wide range
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from −130 to 38 km s\(^{-1}\), implying an explosive event resulting in random motion with a large velocity dispersion. An alternative mechanism that might cause Hα broadening without any explosion is a chromospheric condensation in which the steep velocity gradients in the flaring chromosphere can modify the wavelength of the central reversal in the Hα line profile, and the blue asymmetry could be generated as the maximum opacity shifts to shorter wavelengths (e.g., Gan, Rieger, and Fang 1993, Heinzel et al. 1994). We note, however, that the blue asymmetry in the latter model is due to the shift of an emission peak to shorter wavelengths, whereas this event shows absorption feature shifts to shorter wavelengths.

We note that the velocities determined from the bisector method carry an uncertainty for a flaring atmosphere. The bisector attributes the changes in the absorption line profiles intensities to the line width and LOS velocities alone, while intensity changes of the flaring atmosphere are highly dependent on the density, opacity, and the source function. For instance, a recent radiative hydrodynamic code (RADYN) simulation of the flare Hα line shows that an asymmetric line profile with a deformed blue wing is not necessarily associated with plasma upflow (Kuridze et al., 2015). The same uncertainty may apply to the present event, although the preflare activity is much weaker than for the M1.1 flare that was targeted by the RADYN simulation. It is important that the line asymmetry significantly changes with time and space, as shown in Figure 5. The characteristic scale of such spectral variation is about the width of the filament, and we assume that this explosive event occurred within the filament.

We also note that this blueshifted event differs from the RBE, small-scale jets observed on the disk in the quiet Sun (Rouppe van der Voort et al., 2009). Their typical width is around 250 km and the length is around 4 Mm. Their Doppler velocities are estimated as \(\approx 30−40\) km s\(^{-1}\). The present blueshifted event is spectrally wider than RBE and occurs in the pre-flare stage. Since this Hα blueshifted broadening occurred adjacent to the regions of the EUV brightening, it is possible that the local pressure was impulsively enhanced in the 304 Å brightening region, resulting in the explosive motion of Hα material with a large velocity dispersion within the hot region.

6.3. Relation to Other Flare Signatures

Apparently, the blueshifted Hα broadening is temporally and spatially coincident with the start of the slow rise motion of a filament. It is, however, common in flare observations that these two phenomena occur together, and we cannot determine which phenomenon triggers the other. If any increases in the X-ray or microwave fluxes were found at \(\approx 17:50\) UT, we might conclude that both of them were triggered by the energy deposition into the chromosphere and subsequent heating by energetic electrons accelerated in the corona. As mentioned in Section 2, there was no X-ray counterpart detected by the RHESSI for this event. It is certain that the slow rise motion (\(\approx 10\) km s\(^{-1}\)) of the filament started after the Hα blueshifted broadening, and it led to the main flare (Figure 8c). In this sense, we compare this event to the two-stage eruption pattern for flares (Wang and Shi, 1993) in which the preflare brightening represents the first magnetic reconnection in the lower atmosphere, resulting in the Hα blueshifted broadening, and the second reconnection responsible for the main phase of the flare occurs in the corona. We cannot provide evidence for a causal relationship between the two stages with the current data alone, however.

7. Summary

We have analyzed Hα blueshifted broadening associated with the preflare activity of the solar flare SOL2011-09-29T18:08, exploiting the Hα spectrographic observations with the
FISS along with the corresponding SDO/AIA EUV images. We find unusually strong Hα blueshifted broadening in the preflare stage using the Hα line profile measured at 512 spectral positions with spectral sampling of 0.019 Å on maps of spatial intervals of 0.16′′ per pixel. Our results are summarized as follows:

i) The foremost preflare activity was the brightening at 304 Å around a filament that started from 17:49 UT. The Hα brightness distribution resembles that of 304 Å. There was no counterpart in X-rays and radio bursts, and no significant change in Ca II line spectrum. From these, we estimate the temperature range of this preflare heating to be $10^4 < T < 10^6$ K.

ii) The preflare Hα brightening is simultaneous and cospatial with the 304 Å brightening. The spectral shape of the Hα broadening indicates a mixture of random velocities in a wide range between $-130$ km s$^{-1}$ and 38 km s$^{-1}$ at the maximum time 17:54 UT.

iii) The strong Hα upflow lasted about six minutes, while the EUV brightening continued in the low chromosphere. It was at the maximum of the Hα blueshifted broadening when the filament slowly started to rise ($\approx 10$ km s$^{-1}$). Because of the temporal and spatial coincidence, we interpret this event as the impulsive increase of local pressure in the 304 Å brightening region, resulting in the explosive motion of Hα materials with a large velocity dispersion within the hot region.

iv) The filament rises from the low chromosphere at a low speed of $\approx 10$ km s$^{-1}$ until it reaches a certain coronal height to further accelerate at the start of the main phase of the flare (18:01 UT). This pattern is a familiar feature of the two-step eruption model, where the slow rise followed by fast eruption occurs under a rapid change of magnetic field in the corona.

In this interpretation, we expect that FISS observations of preflare Hα blueshifted broadening will continue to be important for finding clues to the early activation of solar flares.

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