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# Coherent lateral motion of Penumbral Filaments during X-class Flare of 13 December 2006

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Abstract. The high-resolution pictures of the solar photosphere from space based 50 cm Solar Optical Telescope (SOT) onboard Hinode spacecraft, are now routinely observed. Such images of a δ-sunspot in NOAA 10930 were obtained by Hinode during 13 December 2006 while a X-class flare occurred in this active region. Two bright ribbons were visible even in white light and G-band images apart from chromospheric Ca II H images. We register the sunspot globally using cross-correlation technique and analyse local effects during flare interval. We find that during flare the penumbral filaments show lateral motion. Also, we locate two patches, one in either polarity, which show converging motion towards the polarity inversion line (PIL). In Ca II H images we find kernel with pre-flare brightening which lie along the PIL.

## 1. Introduction

The flares in the solar corona are believed to be due to sudden restructuring of the stressed magnetic field. The energy is released in the form of thermal as well as non-thermal radiation and energetic charged particles. In powerful flares the energetic particles can penetrate the dense chromosphere to reach down to the photosphere where they heat-up the photosphere leading to white-light flares. It has been observed that photospheric changes are accompanied during these highly energetic events in the form of: (i) change in morphology, (ii) change in magnetic flux, (iii) change in magnetic shear angle (the angle between observed field azimuth and potential field azimuth) and (iv) proper motion.

Here we focus on the local changes, i.e., changes seen in small-scale features like penumbral filaments during flares. Such studies require seeing-free high-resolution observations at a high-cadence. This is possible with the 50 cm Solar Optical Telescope (SOT) onboard Hinode spacecraft (Kosugi et al. 2007; Tsuneta et al. 2008; Ichimoto et al. 2008; Suematsu et al. 2008). Here, we present the observations of a  $\delta$ -sunspot in active region NOAA 10930 during a X-class flare on 13 December 2006 at 02:20 UT by Hinode. The two ribbons could be seen in G-band and Fe I 630.2 nm Stokes-I and V images (Isobe et al. 2007). Earlier, we had reported the lateral motion of penumbral filaments during the flare interval (Gosain et al. 2009). Here, we present the converging motion of the two patches, one in either polarity, located on either side of the PIL. Also, the pre-flare brightening in kernels located along the PIL as seen in Ca II H line, is discussed.

## 2. Observations and Data Analysis

The X-class flare of 13 December 2006 occurred in an active region numbered NOAA 10930 during 02:20 UT. The region consisted of a  $\delta$ -sunspot with almost N-S orientation of the bipole. The high-resolution filtergrams in G-band (430.5 nm), Fe I 630.2 nm and Ca II H (396.8 nm) wavelengths were obtained by Filtergraph (FG) instrument onboard *Hinode* Solar Optical Telescope (SOT). The images were sampled spatially with 0.1 arc-sec per pixel and temporally with one image every two minutes. The filtergrams were calibrated for dark current, flat field and bad pixels using the standard SolarSoft IDL libraries. A time sequence of filtergrams was selected between 02:00 and 03:00 UT for analysis. The images were aligned globally by choosing a large field-of-view for registration. The registration procedure for the sunspot in Hinode filtergrams has been described elsewhere in detail (Gosain et al. 2009).

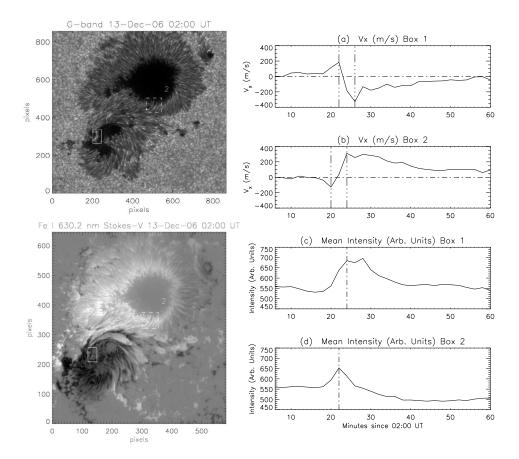


Figure 1. The top and bottom panels on the left show the G-band intensity and Fe I Stokes-V images, respectively. Boxes '1' and '2' mark the location of the two patches where the velocity  $V_x$  and G-band intensity are tracked during the flare interval. These are plotted in panels (a)-(d) on the right.

## 3. Results

## 3.1. Converging Motion of Opposite Polarity Pacthes

The figure 1 shows the G-band filtergram of the  $\delta$ -sunspot taken during 13 December 2006 at 02:00 UT. The two boxes marked '1' and '2' correspond to patches located in the two spots of opposite polarity. Within the two patches we tracked the relative shifts between two subsequent frames during the interval 02:06 to 03:00 UT. This shift  $\Delta x$  within time interval  $\Delta t$  gives velocity  $V_x$ . The panels (a) and (b) of figure 2, show the time profile of  $V_x$  corresponding to the patches within the boxes '1' and '2'.

It may be noticed that: (i) First signatures of motion begin at 02:18 UT which is about two minutes earlier than the peak of the flare seen in microwave observations of Zhang et al. (2008). (ii) For both patches '1' and '2' there are two phases of motion, initially in one direction and after about four minutes in the opposite direction. The peak velocity of these two phases of motions are represented by two vertical lines which are separated by about four minutes. (iii) The motion in the two boxes are in opposite direction in both phases. Initially, the motion in two boxes is away from each other and later it is towards each other, like a converging motion. (iv) The motion in box '2', which is closer to the neutral line, starts earlier than motion in box '1' by about four minutes. (v) The second phase of motion, i.e., converging motion, continues for long duration lasting more than 40 minutes.

The panels (c) and (d) of figure 2, show the mean G-band intensity within the two boxes. The two ribbons during the flare are visible in G-band images. Therefore, the enhancement in G-band intensity (marked by vertical lines) in panels (c) and (d) of figure 2, correspond to the instant when the ribbons move across these boxes. Here also, we notice that the intensity in box '2', which is located closer to the neutral line, peaks four minutes earlier than intensity in box '1', which may explain why motion in box '2' starts earlier than motion in box '1' by about four minutes.

## 3.2. Pre-flare Brightening along PIL in Ca II H

The figure 3 shows the Ca II H filtergrams of the sunspot during 13 December 2006 at 02:04, 02:08, 02:14 and 02:20 UT. We notice that although the flare onset time is 02:20 UT according to microwave flux observations, initial brightenings can be noticed in Ca II H filtergrams as early as 02:04 UT in panel (a). The location of this brightening is marked by a rectangular box. Further, it may be noticed that the brightening is located along the neutral line, and in subsequent panels (a)-(c) the length of the brightening increases along the neutral line. Finally, the flare develops into a two ribbon flare as seen in panel (d).

#### 4. Discussion and Conclusions

We have studied the evolution of small scale features in a flaring sunspot using high resolution space based observations. The fine structure of the sunspot penumbra as seen in high resolution G-band images is believed to outline the magnetic field lines. Using the penumbral filaments as a proxy for magnetic

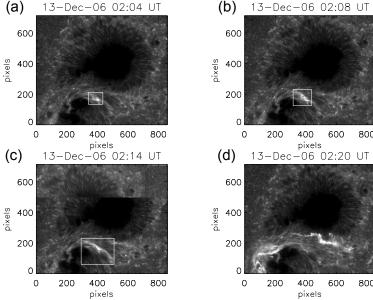


Figure 2. The panels (a)-(c) show the Ca II H filtergrams during pre-flare phase. The boxes mark the location of pre-flare brightening along neutral line. The panel (d) shows the filtergram at 02:20 UT.

field structure of the sunspot we study the changes in the structure during X-class flare of 13 December 2006. A two phased motion is seen in patches of either poalrity, i.e., boxes '1' and '2'. First phase of motion lasts for about four minutes, directed away from the neutral line, and another phase of motion lasts for more than 40 minutes, directed towards neutral line, i.e., converging.

Further, we notice that in Ca II H images the pre-flare brightening is clearly visible in elongated kernels, located along the PIL. This brightening is seen as early as 16 minutes prior to the flare onset.

To understand the changes in magnetic field configuration during flares one requires high-cadence vector magnetograms obtained with high-resolution which are expected from upcoming space missions like Helioseismic and Magnetic Imager (HMI) and Solar Orbiter.

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