Mon. Not. R. Astron. Soc. **387,** L69–L73 (2008) doi:10.1111/j.1745-3933.2008.00487.x

Co-spatial evolution of photospheric Doppler enhancements and Hα flare ribbons observed during the solar flare of 2003 October 28

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Accepted 2008 April 16. Received 2008 April 8; in original form 2007 July 13

ABSTRACT

The active region NOAA (National Oceanic and Atmospheric Administration) AR 10486 which appeared on the solar disc in 2003 October produced a lot of space weather related activity. Here, we report on the co-spatial evolution of the photospheric Doppler enhancements and the chromospheric Hα flare ribbons observed during the 4B/X17.2 class solar flare of 2003 October 28 in this active region. These velocity enhancements exactly match the Hα brightness enhancements in space, and are delayed by approximately 1 min in time. Hα brightness attains a maximum nearly at the same time as the peak seen in light curves in high-energy emission observed by *KORONAS* (Kuznetsov et al. 2006).

Key words: Sun: activity – Sun: atmospheric motions – Sun: flares – Sun: photosphere.

1 INTRODUCTION

Hα flare ribbons are sites of the impact of energetic particles on chromospheric material. The resulting chromospheric evaporation is manifested as a brightening in Hα. This brightening occurs because the ionization of H-atom by the particle beam impact is followed by recombination to various energy levels of the hydrogen atom, including 3rd level. The transition from level three to two results in Hα emission. The bremsstrahlung radiation generated by deceleration of the particles while striking the target produces hard X-ray emission (Brown 1971), while the gyrosynchrotron emission due to motion of charged particles along magnetic fields produces microwave radiation (Hudson 1972) and γ-rays. All these classic signatures of the particle beam impact were seen at enhanced levels in active region NOAA AR 10486 which appeared on the solar disc during 2003 October and produced a lot of space weather related activity (Gopalswamy et al. 2005). In addition, some interesting photospheric disturbances were also reported in this active region (Donea & Lindsey 2005; Kosovichev 2006; Kumar & Ravindra 2006; Zharkova & Zharkov 2007) as well as a post-impact enhancement of the amplitude of acoustic p-modes (Ambastha 2006). These seismic sources have been recently related to the momentum transferred to the photosphere by energetic γ-ray producing events (Zharkova & Zharkov 2007; hereafter ZZ07) and have been associated with down-flow events seen in Dopplergrams obtained from Michelson Doppler Imager (MDI; Scherrer et al. 1995) onboard the *Solar and Heliospheric Observatory* (*SOHO*; Domingo, Fleck & Poland 1995) after the main impulsive phase of 4B/X17.2 class flare of 2003 October 28. Kosovichev & Zharkova (1998) reported the first detection of 'solar quakes' inside the Sun observed during X2.6 flare of 1996 July 9 using *SOHO*/MDI Dopplergrams. In this Letter, we present yet another interesting phenomenon viz. the co-spatial evolution of localized velocity enhancements observed in *SOHO*/MDI Dopplergrams and Hα flare ribbons during the 4B/X17.2 class flare of 2003 October 28.

2 THE OBSERVATIONAL DATA

We chose data of the active region NOAA AR 10486 obtained on 2003 October 28 to study the effect of a major flare on velocity flows. This active region was one of the largest group of sunspots observed in declining phase of the solar cycle 23. It appeared on the east limb of the Sun on 2003 October 23 in southern hemisphere. This complex active region belonged to $\beta\gamma\delta$ class and produced several X- and M-class flares during its passage on the solar disc. On 2003 October 28, a major flare of 4B/X17.2 class occurred in this active region when it was located near the central meridian (S17E13). This was one of the largest flares of solar cycle 23, which occurred near the Sun's centre and produced extremely energetic emission almost at all wavelengths from γ-ray to radio waves. The flare was associated with a bright/fast-halo Earth directed CME (coronal mass ejection), strong type II, III and IV radio bursts, and an intense radio burst. This flare was observed with space-based solar observatories viz. *SOHO*, *TRACE* (Handy et al. 1999), *RHESSI* (Lin et al. 2002), *KORONAS* (Kuznetsov et al. 2006) and several other ground-based observatories viz. Udaipur Solar Observatory and Aryabhatta Research Institute of Observational Sciences (ARIES) in India in Hα wavelength (Ambastha 2006; Uddin, Chandra & Ali 2006).

We have used data from *SOHO*/MDI and ARIES for analysis of this event. The Hα data from ARIES remained nearly free from saturation effects due to the large dynamic range of CCD camera used in the observations and was therefore useful for the photometry of flare kernels. The details of the data are given as follows.

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2.1 *SOHO*/MDI data

We have used full-disc MDI Dopplergrams (spatial resolution of ∼1.9 arcsec pixel^{-1}) between 11:00 and 11:15 UT observed in Ni I 6768 Å line with a cadence of 60 s in order to examine the enhanced velocity signals in this active region during the aforesaid flare on 2003 October 28. The active region was tracked using heliographic coordinates in the full-disc Dopplergrams, which were interpolated to a 1 arcsec pixel size. We have also used the co-temporal white-light images and magnetograms from MDI for our study.

2.2 ARIES Hα data

Co-temporal Hα images from ARIES, Nainital, India, obtained with a cadence of 15 s have been used as a proxy for hard X-ray data. The ARIES observations were done using a 15 cm aperture, f/15 Coudé Solar Tower Telescope equipped with a Bernard Halle Hα filter and a Wright Instrument CCD camera system (16 bit, 385 × 576 pixel^2, pixel size = 22 μm^2). The image is magnified twice with the help of a Barlow lens so that a resolution of ∼1 arcsec pixel^{-1} is achieved. The observed filtergrams were corrected using dark current and flat-field images taken during the observations. All images were re-registered.

3 ANALYSIS AND RESULTS

The active region NOAA AR 10486 showed a complex morphology. In Fig. 1, we show the MDI white-light image of this active region overlaid with the contours of magnetic fields from a simultaneous MDI magnetogram. This picture clearly reveals the complex magnetic structure of the active region. Fig. 2 shows the temporal evolution of the flare in Hα during 11:02–11:07 UT on 2003 October 28. The 4B/X17.2 class flare produced in this active region on 2003 October 28 was the second largest flare event recorded during the solar cycle 23. The flare showed multi-ribbon structure in Hα. It consisted of two main parallel ribbons along the sigmoid filament in opposite magnetic-polarity regions. These parallel Hα ribbons moved apart with a very high speed ∼70 km s^{-1} as estimated from these observations. Details of the flare evolution in this active region are described in Uddin et al. (2006) using these observational data. The Hα flare ribbons evolve from initial localized brightenings called kernels which rapidly spread into elongated ribbons. The left-hand panel of Fig. 3 shows the location of three Hα flare kernels marked as K1, K2 and K3 for this flare event.

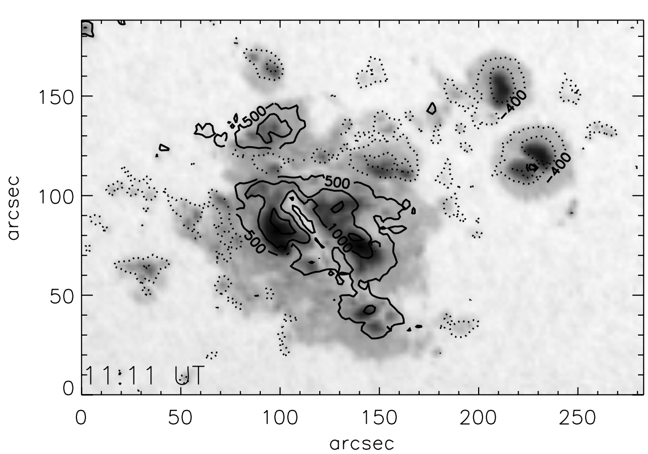

Figure 1. MDI white-light image of active region NOAA AR 10486 at 11:11 UT on 2003 October 28 overlaid with the contours of magnetic fields from the simultaneously observed magnetogram. The contours drawn with solid lines are for North polarity while that drawn with dotted lines depict South polarity.

A close inspection of Dopplergrams from MDI during impulsive phase of the flare (11:02–11:07 UT) revealed velocity enhancements co-spatial with the Hα flare ribbons. The morphology of these velocity enhancements is clearly visible when the sequences of Dopplergrams during 11:02–11:07 UT are subtracted from the Doppler image taken at 11:00 UT. The right-hand panel of Fig. 3 shows the observed velocity enhancements in the active region (patchy region with diminished velocity signals) during the flare, which appear similar to the Hα flare kernels (K1, K2 and K3) depicted in the left-hand panel of Fig. 3. Comparing these kernels with the morphology of the Doppler enhancements, we can see that these photospheric velocity enhancements are also arranged in three clusters (called R1, R2 and R3), which nearly coincide with the locations of K1, K2 and K3.

In order to examine the co-spatial evolution of the Hα flare ribbons and the cluster of photospheric Doppler enhancements, we have co-aligned the MDI Doppler images with the Hα images between 11:02 and 11:07 UT. Fig. 4 shows the contours of Hα flare intensity drawn over the difference Doppler images (excess velocity over the Dopplergram obtained at 11:00 UT) for the period 11:02–11:07 UT. It is clearly seen that enhancements of velocity signals or Doppler sources clustered in the form of ribbons exactly match the location of Hα flare ribbons.

We can see from Fig. 3 that the three patches or portions of the Doppler ribbons forming three clusters of Doppler sources (R1, R2 and R3—bounded by Carrington longitude 282 and 294 as well as Carrington latitude −14.5 and −18.5) contain the seismic sources S1, S2 and S3, respectively, reported by ZZ07 (using time–distance diagrams) and most of the sources (X3, X1 and X4, respectively) reported by Donea & Lindsey (2005) (using holographic method) as presented in table 1 of ZZ07. A raster of 3 × 3 pixels is selected in the centroid of each of Hα flare kernels (K1, K2 and K3) to study the correlation between the variations of Hα flare intensity and photospheric velocity flows in these locations. The temporal evolution of Hα flare intensity and Doppler velocity averaged over 3 × 3 pixels at the centroid of the flare kernels (K1, K2 and K3) during 11:01–11:12 UT has been plotted in Fig. 5. This shows a 1 min delay of the peak time in velocity flows (∼11:05 UT) relative to the peak time of Hα flare intensity (∼11:04 UT) in all the aforesaid three flare kernels. A similar delay was reported between velocity and high-energy emission during this flare by ZZ07. However, the values of velocities are relatively higher in ZZ07 since our velocities are average values over a grid of 3 × 3 pixels at the centroid of the flare kernels (K1, K2 and K3). Moreover, the velocities reported by ZZ07 include other flows like contributions from granulation, meridional flows, line-of-sight component of solar rotation, etc. We have nearly eliminated the contributions from the aforesaid factors by subtracting from the Dopplergram at 11:00 UT. Thus, our velocity values are slightly different from those reported by ZZ07.

4 DISCUSSION AND CONCLUSIONS

There are two kinds of physical interpretation for the Doppler enhancements accompanying the Hα flare ribbons. A distortion of the line profile that is expected to accompany major flares is capable of influencing instruments like MDI (Qiu & Gary 2003). In the absence of line-profile information, we cannot make a definitive statement about this. The other kind of interpretation depends on

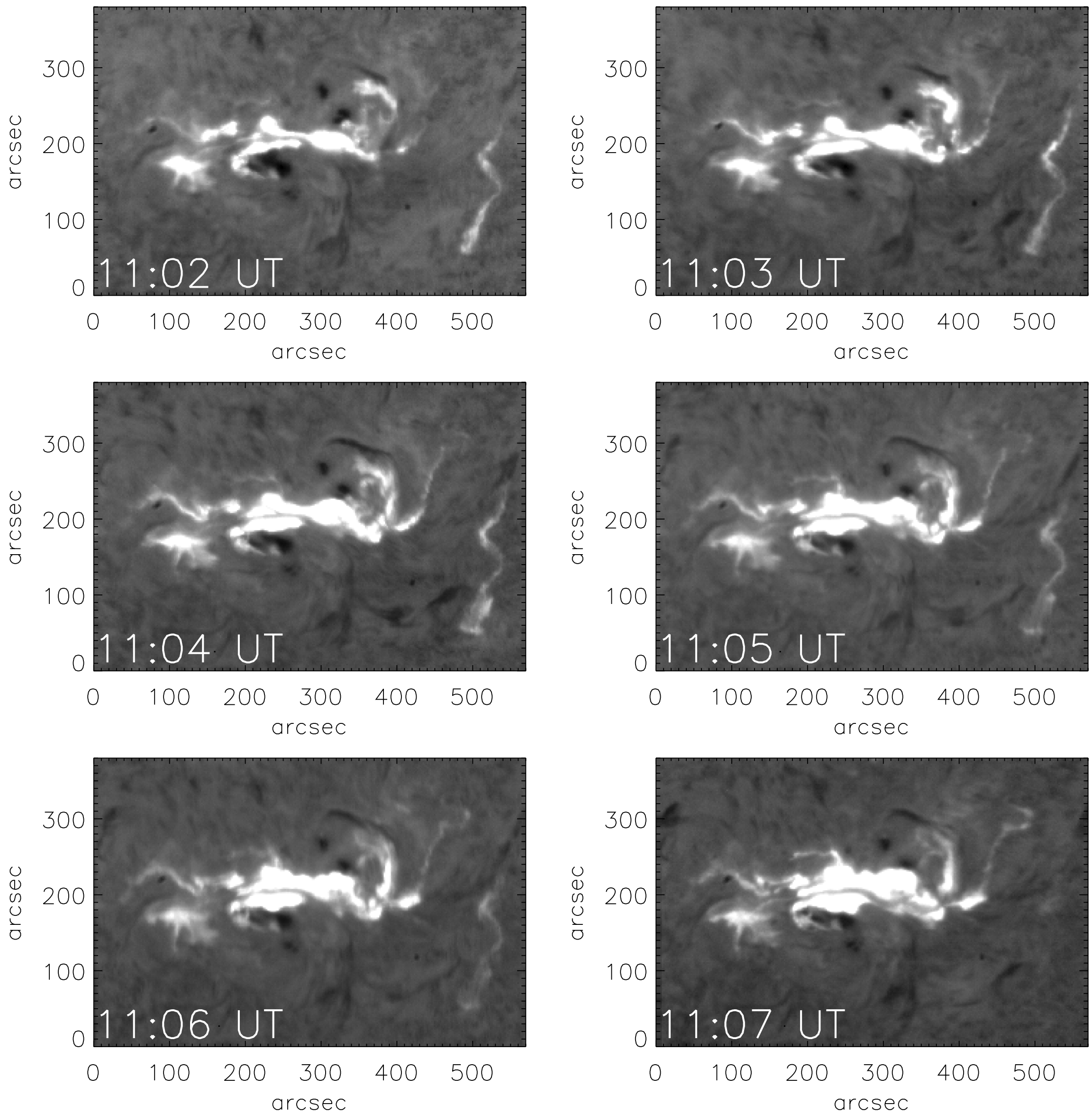

Figure 2. Sequence of Hα filtergrams observed at ARIES during 11:02–11:07 UT showing the temporal evolution of 4B flare in the active region NOAA AR 10486 on 2003 October 28.

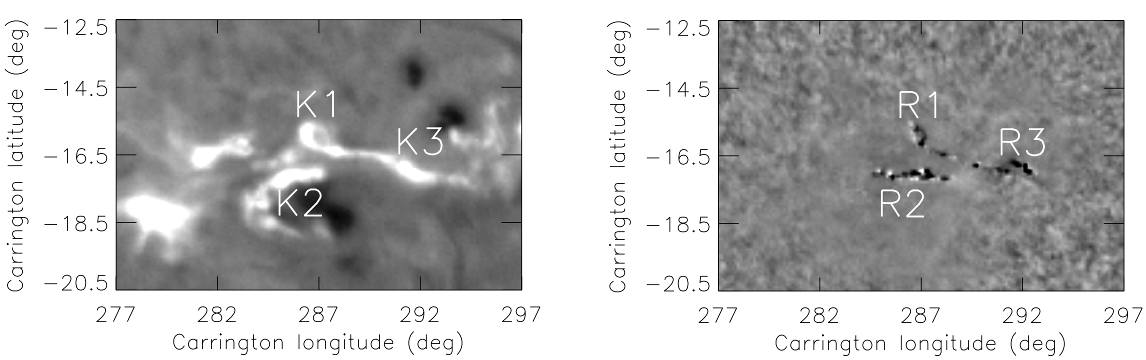

Figure 3. (Left-hand panel): Hα filtergram obtained at ARIES at 11:01 UT on 2003 October 28 showing the locations of the flare kernels (K1, K2 and K3) in the active region NOAA AR 10486 at the start of the flare. (Right-hand panel): The difference of MDI Dopplergram obtained at 11:03 and 11:00 UT. The patchy region bounded by Carrington longitude 282 & 294, as well as Carrington latitude −14.5 and −18.5 shows suppressed velocity signals as expected for active regions. However, the photospheric velocity enhancements above this background in the active region during the flare appear in the form of Doppler ribbons analogous to the Hα flare ribbons as seen in the patchy region. The locations of the cluster of Doppler sources R1, R2 and R3 at 11:03 UT are also shown in the image.

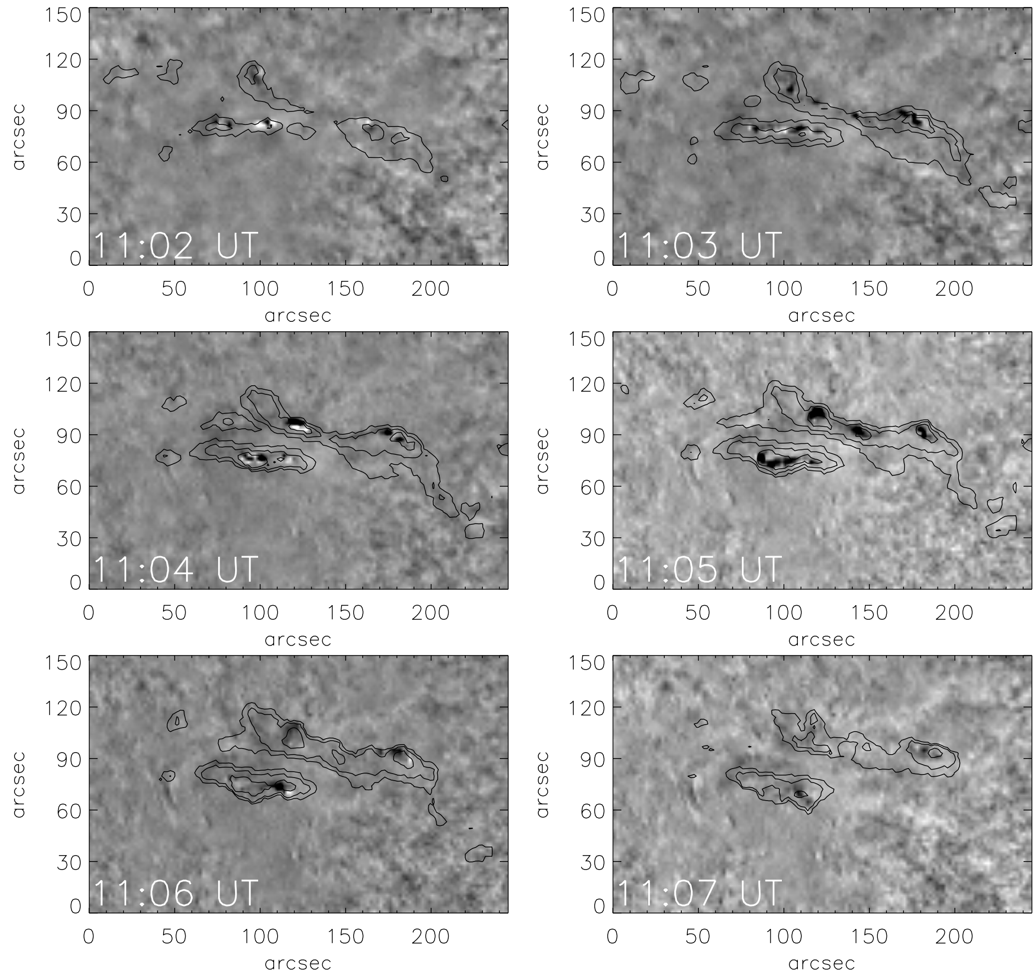

Figure 4. Sequence of MDI Dopplergrams overlaid with the Hα flare intensity contours observed during 11:02–11:07 UT. The contours are drawn at levels of 40, 60 and 80 per cent of the peak value in Hα intensity. The photospheric velocity enhancements in the active region during the flare exactly match the location of Hα flare ribbons.

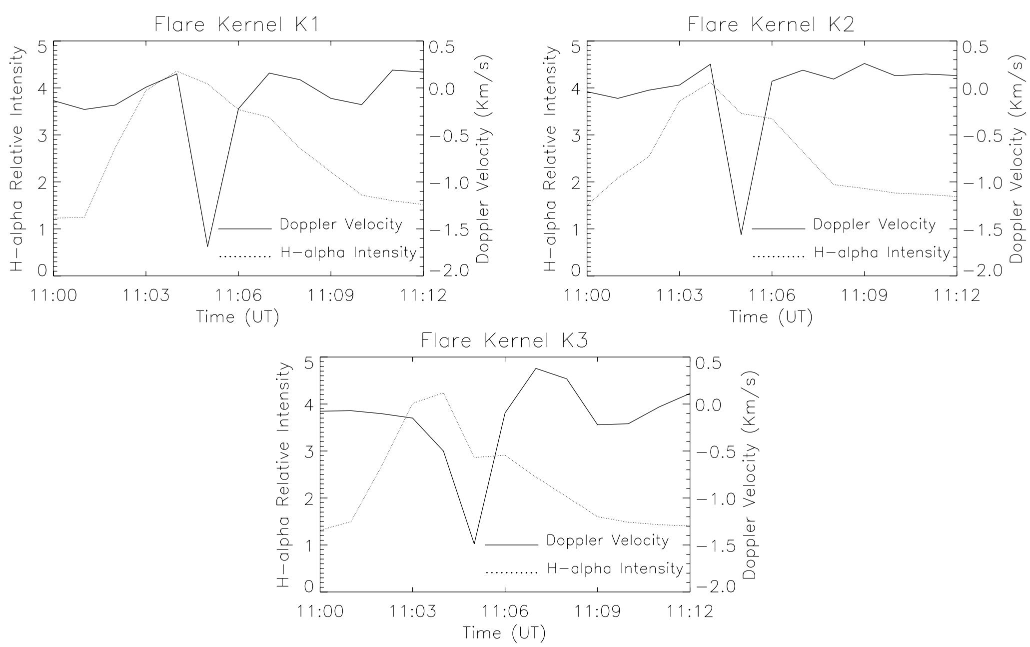

Figure 5. Plots of Doppler velocity and Hα relative intensity averaged over 3 × 3 pixels at the centroid of the flare kernels (K1, K2 and K3) depicted in Fig. 3. It is seen that the peak time of velocity enhancement (∼11:05 UT) follows the peak time in Hα intensity (∼11:04 UT).

the impact of a shock wave on the Ni I line-producing region. This shock wave has been demonstrated in simulations of the response of particle beams impacting the solar atmosphere (ZZ07). These simulations showed that a proton beam penetrates deeper in the atmosphere and explains 1 min delay between high-energy emission and peak of velocity enhancement. Our study using Hα observations confirms the findings of ZZ07, albeit with a better spatial resolution compared to the high-energy observations. As a result of this better spatial resolution of the sites of particle beam impact, we are able to discern the 'ribbon' like clustering of the Doppler sources or velocity enhancements and their co-spatial evolution with Hα flare ribbons. Improvement in photometric accuracy, spatial resolution and temporal cadence of Hα observations along with more accurate photospheric Doppler measurements during major flares can facilitate more sensitive observational investigations of the photospheric hydrodynamic response to the impact of particle beams in the solar atmosphere.

ACKNOWLEDGMENTS

We are very much thankful to the *SOHO*/MDI team for providing the data used in this work. We also thank the observing staff of ARIES for taking the simultaneous Hα observations. We would like to thank the anonymous referee for important suggestions, which improved the presentation of this Letter.

REFERENCES

Ambastha A., 2006, JA&A, 27, 255
Brown J. C., 1971, Sol. Phys., 18, 489
Domingo V., Fleck B., Poland A. I., 1995, Sol. Phys., 162, 1
Donea A.-C., Lindsey C., 2005, ApJ, 630, 1168
Gopalswamy N. et al., 2005, J. Geophys. Res. A, 110, 09S00, (doi:10.1029/2005JA011268)
Handy B. N. et al., 1999, Sol. Phys., 187, 229
Hudson H. S., 1972, Sol. Phys., 24, 414
Kosovichev A. G., Zharkova V. V., 1998, Nat, 393, 317
Kosovichev A. G., 2006, Sol. Phys., 238, 1
Kumar B., Ravindra B., 2006, JA&A, 27, 425
Kuznetsov S. N., Kurt V. G., Myagkova I. N., Yushukov B., Kudela K., 2006, Sol. Syst. Res., 40, 104
Lin R. P. et al., 2002, Sol. Phys., 210, 3
Qiu J., Gary D. E., 2003, ApJ, 599, 615
Scherrer P. H. et al., 1995, Sol. Phys., 162, 129
Uddin W., Chandra R., Ali S. S., 2006, JA&A, 27, 267
Zharkova V. V., Zharkov S. I., 2007, ApJ, 664, 573

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