Dynamic properties along the neutral line of a delta spot inferred from high-resolution observations

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ABSTRACT

Delta (δ) spot are complex magnetic configurations of sunspots characterized by umbrae of opposite polarity sharing a common penumbra. Active regions (ARs) containing δ-configuration sunspots can evolve very rapidly giving rise to Space Weather effective events, such as solar flares and coronal mass ejections (CMEs). We carried out a study on the morphology, magnetic configuration and velocity field in the region separating the two magnetic polarities of a δ spot observed at the highest spatial resolution currently attainable (0".15) with available telescopes. We observed Active Region NOAA 11267 with the CRisp Imaging SpectroPolarimeter at the Swedish 1-m Solar Tower, on the 6th of August, 2011, from 09:00:05 UT to 09:37:37 UT. We analyzed full Stokes measurements along the Fe I profile at 630.25 nm, spectroscopic data over the Fe I line at 557.6 nm and filtergrams in the core and in the wide band of the Ca II H line at 396.8 nm. SDO/HMI observations have also been used in order to investigate the evolution of the AR. We found that the magnetic field along the neutral line is quite sheared and we observed upward and downnward plasma motions of about 3 km s^{-1} in the same region, in agreement with previous results presented in the literature. These steady, persistent and subsonic motions along the interface region between the two magnetic polarities of the δ spot can be interpreted as due to the Evershed flow occurring in the penumbral filaments wrapped around the umbra fragments.

OBSERVATIONS AND DATA REDUCTION

AR NOAA 11267 was observed on the 6th of August 2011, during an Observational Campaign carried out at the Observatorio del Roque de los Muchachos in La Palma (Canary Islands). The CRisp Imaging SpectroPolarimeter (CRISP) at the Swedish 1-m Solar Telescope (SST) acquired spectroscopic, spectropolarimetric and imaging data from 09:00:05 UT until 09:37:37 UT. These observations were complemented with Dopplergrams, Magnetograms and continuum images acquired by the Helioseismic and Magnetic Imager (HMI) on board the Solar Dynamic Observatory (SDO) covering three days of observations, from 00:10:24 UT of the 5th of August 2011, until 23:58:25 UT of the 7th of August 2011.

CRISP data:

- Full Stokes measurements of the Fe I line at 630.25 nm. CRISP acquired data every 4.4 pm at 15 line positions, from -30.7 pm to +30.7 pm with respect to the line center. Ten frames for each spectral points and for each polarization state of liquid crystals defining Stokes parameters were acquired. The temporal cadence of each complete scan of the Fe I line at 630.25 nm is ~28 s.
- Spectroscopic measurements along the profile of the Fe I line at 557.6 nm, with a step of 3 pm covering a spectral range of 20 spectral points, from -27 pm to +27 pm with respect to the line center. A spectral point in the continuum at +66 pm was also acquired. The temporal cadence of each complete scan of the Fe I line at 557.6 nm is ~28 s.
- Filtergrams in the core and wide band of the Ca II H line, with a temporal cadence of 9 s.

SDO/HMI data:

- Full-disk continuum filtegrams, longitudinal magnetiograms and Dopplergrams in the Fe I line at 617.3 nm with a resolution of 1'' and a temporal cadence of 12 minutes

The CRISP data were corrected using standard reduction for dark current and flat field. Then they were processed with the Multi-Object Multi-Frames Blind Deconvolution (MOMFBD) , obtaining near diffraction-limited resolution (0".15). All SDO/HMI have been aligned, taking into account solar differential rotation using the IDL *SolarSoft* package. Doppler velocities were deduced using a Gaussian fit to the Fe I line at 5576 Å, imposing that plasma in sunspot umbrae is globally at rest.AR

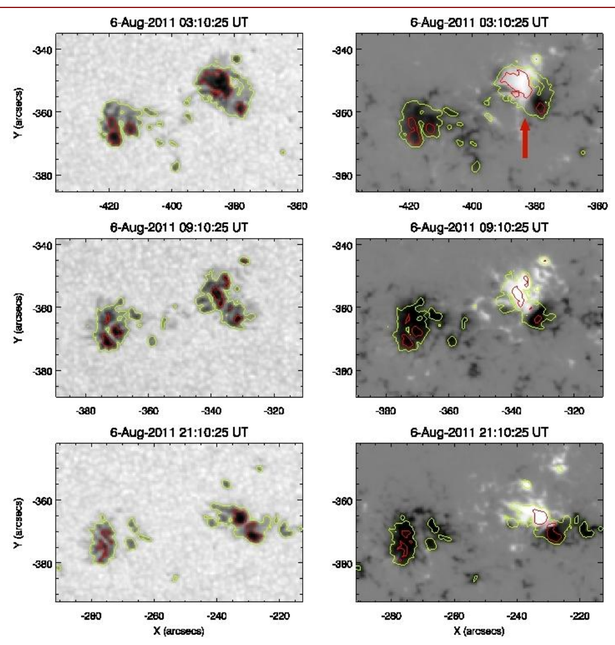

Figure 1: Sequence of SDO/HMI continuum images (*left panel*) and magnetograms *(right panel*) showing the evolution of the analyzed AR from 03:10:25 UT until 21:10:25 UT of the 6th of August 2011, with overplotted the contours of umbrae (I_c=0.55, red) and penumbrae (I_c=0.85, yellow), at different observational times. The red arrow points the δ spot.

HMI/SDO DATA ANALYSIS

AR NOAA 11267 was characterized by two main sunspots of opposite polarity, with the western, preceding one showing a δ configuration. Both main sunspots developed light bridges (LBs) during their evolution. The δ spot formed at 03:10:25 UT, as indicated by an arrow in the magnetogram of Fig. 1. The structure persisted during the selected time interval shown in Fig. 1.

Fig. 2 reports the Dopplergrams and magnetograms derived from SDO/HMI data. In the left column, blue (red) indicates upward (downward) motions. In the right column, the contours of downward and upward motions in the δ spot are overplotted on the corresponding HMI line of sight magnetograms, with values between -0.75 and -1.5 km s^{-1} for upflows (blue) and 0.75 - 1.5 km s^{-1} for downflows (red). Upward and downward motions along the polarity inversion line (PIL) of the δ spot persist for ~15 hours at least. The proximity of upflows and downflows along the PIL separating the two opposite polarities of the δ spot is clearly visible in these images. We also highlight that motions of this order of magnitude were not observed in LBs crossing the single-polarity areas of the two main sunspot.

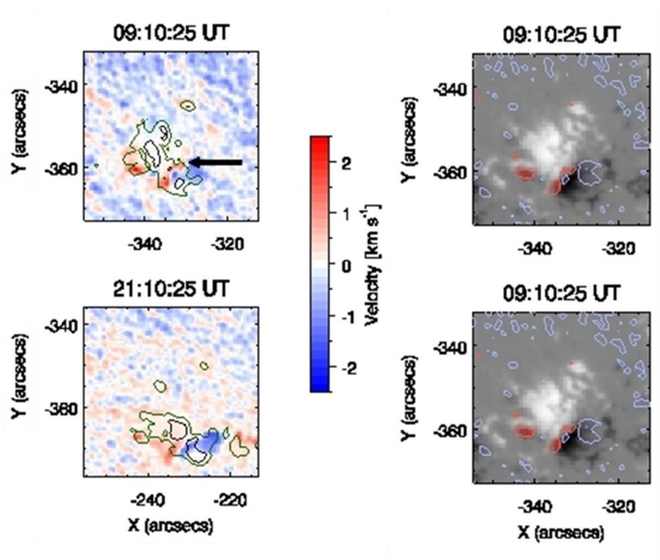

Figure 2: Sequence of SDO/HMI Dopplergrams (left column) and magnetograms (right column) relevant to 09:10:25 UT and 21:10:25 UT, during the 6th of August 2011. The black arrow indicates the location of the neutral line separating the two opposite polarities of the δ spot.

ANALYSIS AND *SIR* INVERSION OF *CRISP* DATA

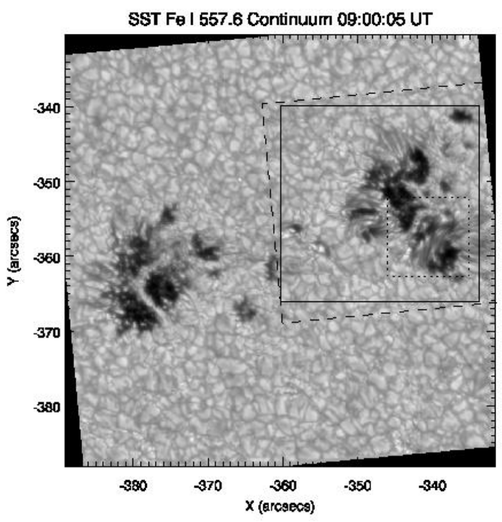

Figure 3: AR NOAA 11267 observed by the SST in the continuum of the Fe I at 557.6 nm. The dashed line square indicates the part of the SST FoV selected for the SIR inversion; the solid line square indicates the FoV used to investigate the velocity fields (both horizontal and along the line of sight); the dotted line box indicates the FoV of the zoomed regions displayed in Fig. 4.

Fig. 3 shows the presence of a LB in the eastern, negative sunspot. The LB has the typical central, dark lane and chains of small-scale bright granules at its side (i.e. the so called segmented LB). The preceding sunspot also shows segmented LBs separating some areas with the same magnetic polarity; however the interface region between the opposite polarities of the δ spot is characterized by the presence of a bunch of sheared dark filaments interspersed with bright zones, lying almost tangentially to both opposite polarity umbra fragments.

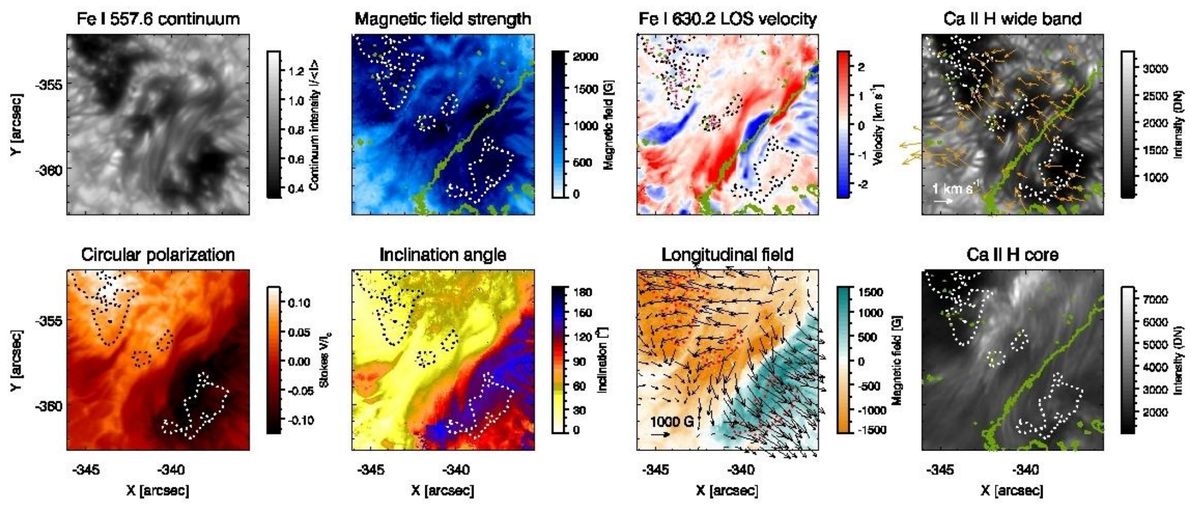

Figure 4 : Sequence of zoomed images of the region hosting the δ spot PIL. From top to bottom and from left to right: photospheric continuum intensity, magnetic field strenght, LOS velocity, wide band Ca II H line intensity with overplotted horizontal velocities, circular polarization signal, inclination angle of vector magnetic field, longitudinal magnetic field with overplotted the transverse magnetic field, chromospheric Ca II H line intensity. The green contours indicate the PIL; the dotted contours show the location of the umbrae.

CONCLUSIONS

The region of interface between the opposite polarities of the δ spot in AR NOAA 11267 showed the presence of dark filaments wrapped around the two umbra fragments. It was also characterized by upward and downward subsonic motions of ~3 km s^{-1} . The results obtained in our study suggest that the regions with lower brightness intensity in the δ spot do not show the typical characteristics of segmented LBs. This finding would have important consequences on the understanding of the processes that occur during the formation of LBs. Moreover, in the δ spot considered in our study, the plasma motions take place along curved filaments which are almost tangential to the opposite polarity umbral fragments. This situation gives rise to the complex LOS velocity patterns we observe which may be due to the Evershed flow in this region. Finally, it is worthwhile to highlight that δ configuration sunspots are often site of violent flares, likely due to a non-potential magnetic field topology and to a sheared PIL that is site of the energy release. Therefore, identification of peculiar properties of plasma and magnetic fields along the PIL of δ spot may help finding out precursors of effective Space Weather events.

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