Evolution of helicity in NOAA 10923 over three consecutive solar rotations

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Summary. We have studied the evolution of magnetic helicity and chirality in an active region over three consecutive solar rotations. The region when it first appeared was named NOAA10923 and in subsequent rotations it was numbered NOAA 10930, 10935 and 10941. We compare the chirality of these regions at photospheric, chromospheric and coronal heights. The observations used for photospheric and chromospheric heights are taken from Solar Vector Magnetograph (SVM) and H-α imaging telescope of Udaipur Solar Observatory (USO), respectively. We discuss the chirality of the sunspots and associated H-α filaments in these regions. We find that the twistedness of superpenumbral filaments is maintained in the photospheric transverse field vectors also. We also compare the chirality at photospheric and chromospheric heights with the chirality of the associated coronal loops, as observed from the HINODE X-Ray Telescope.

Key words: Sun : helicity, chirality, super-penumbral whirls, sigmoids

1 Introduction

Magnetic fields exhibit chirality and is observed in most of the solar features like filament channels, filaments, sunspots, coronal loops, coronal X-Ray arcades and interplanetary magnetic clouds (IMCs) ([1], [2], [3] and the references therein). First of all G.E. Hale in 1925 ([4]) observed vortices in H-α around sunspots and he called these features as 'sunspot whirls'. He investigated the data extending over three solar cycles and found no relationship between the direction of these vortices and the polarity of the sunspots. Also, he found no reversal of the whirl direction together with the general reversal of the sunspot polarities with cycle. He found that about 80 % of sunspot whirls have counterclockwise orientation in the northern hemisphere and clockwise in

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the southern hemisphere, now known as the helicity hemispheric rule. Richardson ([5]) confirmed Hale’s results after doing the same type of investigation with the data for four solar cycles. Seeshafer ([1]) also found that the negative helicity is dominant in the northern hemisphere and positive in the southern hemisphere. This is known as the hemispheric helicity rule and is independent of the solar cycle. Since 90s the subject is highly taken into account by most of the researchers in the field. Pevtsov, Canfield and Metcalf ([2]) demonstrated the existence of chirality in the active regions, after analyzing vector magnetograms from Mees Solar Observatory. Although, the entire active region may not show the same type of chirality everywhere yet a dominant sense of chirality can be found for most of the active regions.

The chirality of the H-α filament can be directly recognized by looking at the filament barbs. If the orientation of the barbs is counterclockwise the chirality of the filament is known to be dextral and if it is clockwise the chirality is sinistral. Martin ([6]) mentioned that the chirality of the solar features can be used for resolving 180 degree azimuthal ambiguity in the solar vector magnetic field. It is believed that there is one-to-one correspondence between the filament chirality and the magnetic helicity sign. A right-handed twist and a clockwise rotation of the loops, when viewed from the above implies positive helicity or chirality and vice-versa. The magnetic helicity is a quantitative measure of the chiral properties of the solar magnetic structures ([7], [8]). It is given by a volume integral over the scalar product of the magnetic field \( B \) and its vector potential \( A \).

\[
H = \int A \cdot B dV.
\]

(1)

It is well known that the vector potential \( A \) is not unique. Thus the helicity can’t immediately be calculated from the above given equation. Seeshafer ([1]) pointed out that the helicity of magnetic field can best be characterized by force-free parameter \( \alpha \) also known as the helicity parameter. The force free condition is given as

\[
\nabla \times B = \alpha B.
\]

(2)

Taking the \( z \)-component of the magnetic field

\[
\alpha = (\nabla \times B)_z/B_z
\]

(3)

The magnetic helicity density can be given as

\[
H_m = B^2/\alpha
\]

(4)

but except for potential fields.

And the current helicity density will be given in terms of \( \alpha \) as

\[
H_c = B^2 \alpha
\]

(5)

In this paper, we identify the chirality of a sunspot in an active region named NOAA 10923 when it first appeared and NOAA 10930, 10935, 10941
in successive rotations. The associated H-α filaments in the three consecutive solar rotations were obtained from the Udaipur Solar Observatory (USO) high resolution H-α data. We have calculated the helicity parameter of the sunspots NOAA 10935 and NOAA 10941 and we found that the value of helicity parameter has increased after one solar rotation. These active regions are not following the helicity hemispheric rule. There are theories ([9], [10], [11]) which discuss about the ‘wrong’ sign of helicity in the beginning of the solar cycle. Sokoloff et al ([12]) observes a significant excess of active regions with the ‘wrong’ sign of helicity just at the beginning of the cycle. But there is no discussion found about the ‘wrong’ sign of helicity during the end of the solar cycle. The sign of helicity is supposed to follow the helicity hemispheric rule which our result doesn’t show. We compare the helicity of the active regions with the sign of associated sigmoids obtained from the Hinode.

2 Data and Instruments used

We use high resolution H-α images taken from Udaipur Solar Observatory (USO) from Spar Telescope and the vector magnetograms from the USO Solar Vector Magnetograph (SVM) ([13], [14]). The Spar Telescope uses 1392×1024 ccd with the pixel resolution of 0.395 arcsec and the SVM has 1024×1024 ccd with pixel resolution of 0.98 arcsec. Our H-α observations, after the monsoon break, started on 23rd November 2006. So we don’t have USO H-α image of the NOAA 10923 in its first appearance. After one rotation we observe the same sunspot in the name of NOAA 10930 on Dec 11 2006. And in other two consecutive rotations we have observed the same sunspot in the name of NOAA 10935 on 09 Jan 2007 and NOAA 10941 on 06 Feb 2007. We use the available vector magnetograms of NOAA 10935 (09 Jan 07) and NOAA 10941 (06 Feb 07) and compare the vectors with the whirls of the sunspot images taken in H-α wavelength.

The Spar Telescope has f/15 doublet lens with focal length of 2.25 meters and objective 0.15 meters. It uses a H-α Halle lyot type filter with FWHM of 500 mA operating at the wavelength of 6563 Å. The telescope utilizes a 1392×1024 CCD with the pixel size of 6.45 µm. The pixel resolution of the CCD is 0.395 arc-sec and the field of view it covers is 9 arc-min × 7 arc-min. The H-alpha images of the active regions NOAA 10930, NOAA 10935 and NOAA 10941 are shown in the Figure 1.

The magnetograms are taken from Solar Vector Magnetograph (SVM), which has recently become operational at USO. SVM is basically an instrument which makes two-dimensional spatial maps of solar active regions in the Zeeman induced polarized light of the solar spectral lines. SVM has the following main components : a Schmidt-Cassegrain telescope tube, rotating wave-plate polarimeter, tunable narrow-band Fabry-Perot filter, calcite analyzer (Savart plate) and a cooled CCD camera. The primary imaging is done by using a Celestron C-8 (TM) Schmidt-Cassegrain telescope of 8 inch aper-
Fig. 1. USO H-alpha images

Fig. 2. USO solar vector magnetograms (09Jan07 and 06Feb07 respectively)
tate. The focal length of the telescope is 2032 mm and the resulting output beam is a f/10 beam. The telescope has a pre-filter in front with a 15nm pass-band centered at 630nm wavelength. A circular aperture of 2 arc-min diameter selects the field of view (FOV) at the prime focus. This FOV is then modulated by the rotating waveplates of the polarimeter. The modulated beam is now collimated by a 180mm focal length lens. This modulated and collimated beam now enters the Fabry-Perot etalon and order sorting pre-filter. Now the re-imaging lens makes the image on the CCD camera. Just before the CCD camera a combination of two crossed calcite beam-displacing crystals is placed for the analysis of polarization. So we get two orthogonal polarized images of the selected FOV onto the CCD camera. The vector magnetograms of the two active regions NOAA 10935 and NOAA 10941 are shown in the Figure - 2. We have taken the Hinode (XRT)\cite{15} data for looking at the sigmoidal structure of corresponding active regions.

3 Analysis

We observed the sunspot NOAA 10923 (Nov 06) which sustains in the three consecutive solar rotation in the name of NOAA 10930 (Dec 06), NOAA 10935 (Jan 07) and NOAA 10941 (Feb 07). There was no major activity associated with the active region NOAA 10923. Looking at the NOAA 10930 in H-Alpha (Fig(1)) we ensure that there is no particular orientation of the whirls and we can’t recognize the helicity of the sunspot. There was no filament seen associated with this active region. There were X3.4 (at 02:00 UT) and X1.5 (at 21:07 UT) class flares as well as strong CMEs associated with the active region

Fig. 3. XRT (Hinode) data reverse-S sigmoid showing the dextral chirality in comparison with that of photospheric and chromospheric data.
NOAA 10930 on 13 December 2006. After next rotation the same sunspot is found in the name of NOAA 10935 (Jan 07) (Fig(1)). We now observe the whirls with counter-clockwise orientation are dominating. A filament associated with the active region is observed. The end of this active region filament is curving towards the sunspot with counter-clockwise whirls and according to Rust and Martin ([16]) it should (not necessarily) be dextral. Still in the image here the orientation of the filament barbs are not clearly recognized to be dextral. There was not any major event associated with this active region.

![Image of sunspots and magnetic fields](image)

**Fig. 4.** Plot of vector magnetic fields of the sunspots upon the respective H-alpha images. In the lower part of the image blue arrows show the radial direction and the red arrows show the actual vector field direction. We can see the shear of the field.

In the next rotation we are able to recognize clearly the orientation of the filament barbs. The active region NOAA 10941 (Feb 07) has come in its third consecutive rotation of the sun. It has the barbs with counter-clockwise orientation close to filament and this type of chirality is dominating in the whole active region. The associated filament is dextral is clear now. No event was observed associated with this active region. We calculated the helicity parameter for the sunspots NOAA 10935 and NOAA 10941 which comes out to be $-1.1 \pm 0.12 \times 10^{-9} \text{ m}^{-1}$ and $-3.77 \pm 2.14 \times 10^{-8} \text{ m}^{-1}$ respectively. The
value of helicity has increased after next rotation which can also verified by directly looking at the H-alpha images. The helicity sign doesn’t support the helicity hemispheric rule. Both the active regions are found in the southern hemisphere and should bear positive chirality. For the calculation of helicity we have calculated the helicity parameter alpha best which will give one value of the alpha for the whole sunspot instead of the value at each pixel. It reduces the noise in the data. We use our SVM data to plot the transverse field upon the associated H-α image. First of all, the H-α data is re-binned according to the size of SVM data and then the related vector field is plotted over the H-α image. The 180 degree azimuthal ambiguity has been resolved by using acute angle method. We can see in Figure - 2 that the direction of H-α super-penumbra whirls show the same chirality as the photospheric transverse field vectors. So, by combining the photospheric and chromospheric data one can use the method of chirality to resolve 180 degree azimuthal ambiguity. Also by looking at the HINODE (XRT) data we find the reverse-S structure in the sigmoids associated with the active regions.

4 Conclusion and Discussion

We find that the active region NOAA 10923 in its different appearances doesn’t follow the hemispheric helicity rule, neither its associated filaments. But their association in the terms of chirality follow the well known result of Rust and Martin ([16]). We calculated the helicity parameter which was found to be negative as expected from the sunspot with dextral whirls. The helicity increases in the last appearance but there was no major activity observed associated with the active region in its last appearance. Hinode (XRT) images also show the same type of chirality in the associated sigmoids. Thus the sign of helicity derived from photosphere, chromosphere and corona are strongly correlated. Figure - 3 shows the vector fields plotted over the associated active regions in the chromospheric H-α observations. We find the good matching of the vectors with the super-penumbral whirls of the active regions. By combining the photospheric and chromospheric data the axial field direction at neutral line can be derived and this method can be used to resolve 180 degree azimuthal ambiguity. Sara F. Martin et al ([16]) has already mentioned that the 180 degree azimuthal ambiguity can be resolved by using this method of chirality.

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