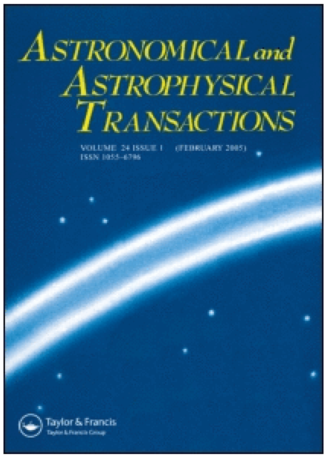

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ON THE ASYMMETRY OF THE SOLAR BIPOLAR ACTIVE REGIONS FROM THE PHENOMENON OF THE SIGN CHANGE OF THE MICROWAVE CIRCULAR POLARIZED EMISSION

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Using one-dimensional scans of the polarization distribution of the microwave emission in solar active regions, as obtained at the Siberian Solar Radio Telescope it is shown that the phenomenon of sign inversion of the circular polarization of the microwave emission at a wavelength of 5.2 cm from bipolar groups has a west asymmetry when the group passes the central meridian (CM) of the Sun. This probably means that the axis of the symmetry of the magnetic field for a typical bipolar group is inclined to the east limb of the Sun so that the following wing of each loop is more inclined with respect to the horizontal than the preceding wing. Analysis of 77 active regions showed that this phenomenon had a tendency to be symmetrical relative to the CM or to have an east asymmetry under an increasing level of X-ray activity.

Keywords: Solar active region; Circular polarization of the microwave emission; Symmetry

1 INTRODUCTION

The microwave polarized emission of solar active regions is produced by a thermal cyclotron mechanism in plasma trapped in strong magnetic fields arising from the subphotospheric layers in the corona (Cohen, 1960). In the terms of this mechanism the polarization of the S component (slow changing emission of local sources above spots) with the prevalence of the extraordinary wave is well explained (Zheleznyakov, 1997).

When the emitted radiation crosses a perpendicular magnetic field layer it is possible, depending on the characteristics of the layer, to have mode coupling, that is the ordinary and extraordinary modes leaving the quasitransverse (QT) region can be different from modes entering the layer (Zheleznyakov, 1997). When the coupling is weak, the ordinary and extraordinary modes are conserved during passage through the QT layer. However, since the direction of the magnetic field changes, the sense of polarization of the two modes is reversed (Fig. 1).

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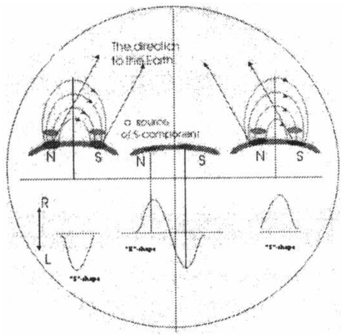

FIGURE 1 Not far from the central meridian (CM) both opposite peaks in the plot of polarized emission above spots of north and south magnetic polarities can be seen: the E shape. An S shape the plot of stokes' V parameter would be seen when the group is placed more off further from the CM and would mean that the sign of the left- or right-hand part of group is reversed and different in different hemispheres of the Sun divided by the CM.

As seen from Figure 2, according to one of the classical magnetic field models for a bipolar group of spots (Takakura, 1961) (where a is the depth of a horizontal dipole under the photosphere and d is the distance between spots) and the mode-coupling theory (Cohen, 1960; Zheleznyakov, 1964), radiation from the preceding spot passes through the region of QT propagation only in the case when the angle θ is less than zero (this means that the group is placed in the west hemisphere of the Sun). For radiation from the following spot the situation is reversed; it passes through the QT region when $\theta > 0$ (*i.e.* the group is localized in the east part of the solar disc). As the group approaches the CM ($|\theta|$ is decreased), the height of the QT field $H_\perp$ region is increased but ω_t (the critical frequency at which the coupling constant changes from weak to strong (Zheleznyakov, 1997, p. 160) is decreased (according to Zheleznyakov (1997, p. 311)) and the QT propagation condition is not realized. This would mean that, for microwave emission not far from the CM, one could see both opposite peaks in the plot of polarized emission above spots of north and south magnetic polarities: the E shape (see Fig. 1). The S shape in the plot of the Stokes V parameter would be seen when the group would be placed further from the CM and would mean that the sign of the left- or right-hand part of group is reversed and different in the different hemispheres of the Sun divided by the CM.

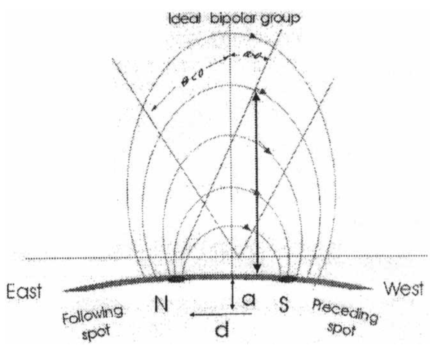

FIGURE 2 A bipolar group of spots where a is the depth of a horizontal dipole under the photosphere, and d is the distance between spots. The horizontal straight line indicates the level of the microwave emission, and the vertical straight line with arrows in the $H_\perp$–a region of the QT field in the model described by Takakura (1961).

2 EXPERIMENTAL DATA

The reversal of polarization when active regions cross the solar disc has been known for many years (Peterova and Ahmedov, 1973; Kundu and Alissandrakis, 1984; Maximov and Bakunina, 1991).

We investigated this phenomenon using a large data archive for the period 1982–1993 with the best angular resolution (17–30) reported by Peterova and Ahmedov (1973) in the one-dimensional mode of scanning the Sun at a wavelength of 5.2 cm on the (the Siberian Solar Radio Telescope (SSRT) (http://ssrt.iszf.irk.ru). For each day of observation of the active region the noon (05:00 universal time) scan of Stokes parameter V was used to mark the type of polarization distribution; a sketch of the sunspot group was made from data obtained at the Sayan Solar Observatory and data from bulletins *Solar Data* and *Solar Geophysical Data*. The cases when a few groups simultaneously were seen by the radio beam were excluded from investigation; groups with compact or closed configuration of the magnetic field (class C under the classification of Mackintosh) that have space between the preceding and following parts of a group filled with many spots of different polarities and groups that had a strong evolution were also excluded.

3 RESULTS

According to Peterova and Ahmedov (1973), Kundu and Alessandrakis (1984) and Maximov and Bakunina (1991), most bipolar groups (70% at a wavelength of 5.2 cm; 40 bipolar groups of the 54 investigated for the period 1982–1988) demonstrated the phenomenon of polarization reversal.

These characteristics of polarization sign reversal (t_{begin}, the day before or after crossing the CM when the E shape first appears in the polarization distribution (see Fig. 1); Δt duration of existence of the E shape) are collected together in Table I using the data from the studies by Peterova and Ahmedov (1973) and Maximov and Bakunina (1991). In Table I the $+$ sign means after the group has crossed the CM, and the $-$ sign means before group has crossed the CM. An E shape of the polarization distribution means that one can see two opposite peaks in a V scan (see Fig. 1).

This phenomenon for a wavelength of 5.2 cm begins on average 1 day before the active region crosses the CM and lasts for 4–5 days. Obviously the phenomenon of polarization sign reversal exists in the most cases when microwave emission of bipolar active regions is recorded, at least for wavelengths of 5.2 and 9.0 cm. This phenomenon shows west, asymmetry not only at 5.2 cm but also at wavelengths of 3.2 and 4.4 cm. It most probably means that magnetic loops above spots, which have axies of symmetry in the same direction in which the ordinary and extraordinary wave are removed from the Sun's surface at a minimal

TABLE I Characteristics of Polarization Sign Reversal.

λ (cm)	*Number of cases of polarization sign reversal (% of common amount)*	t_{begin} *(days)*	*Δt (days)*
3.2	50	+(2–3)	2–3
4.4		+(1–2)	2–3
5.2	74	−1	4–5
9.0	70	−(1–2)	3–4

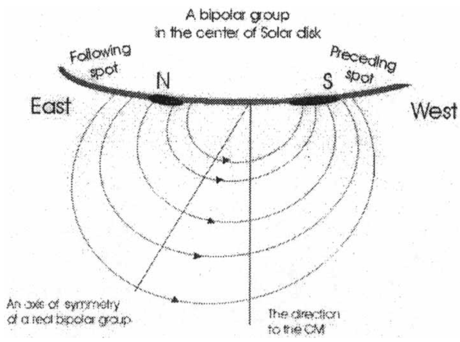

FIGURE 3 Real magnetic loop of a bipolar group with the following wing which is more inclined with respect to the horizontal than in the preceding wing, as seen in the centre of the solar disc.

distance, are inclined towards the east limb of the Sun; this means that the following wing of the each loop is more inclined with respect to the horizontal than is the preceding wing (Fig. 3).

In the east hemisphere for such a loop, $H_{\perp}$ (the height of the QT region) is lower than in the west hemisphere; so the conditions for crossing the QT region for microwave radiation are better and the S shape of the polarization distribution would last longer than in the west hemisphere, where $H_{\perp}$ is higher and propagation through the QT layer will be reached when the active region is at a larger distance from the CM. Then we would see the E shape on a V scan lasting longer in the west part of the solar disc, so the west asymmetry of this phenomenon is simply explained.

For 77 active regions which demonstrated the phenomenon of polarization reversal when crossing the CM for 1988–1993 the coefficient κ of asymmetry was calculated:

$$\kappa = \frac{t_1 + t_2}{t_2 - t_1 + 1},$$

Where t_1 is the day when the polarization sign reversal begins (the first day when the V scan demonstrates two opposite peaks in the polarization distribution *i.e.* the E shape) and t_2 is the day when this phenomenon ends (the last day when we can see the E shape in the V scan while the group crosses the solar disc).

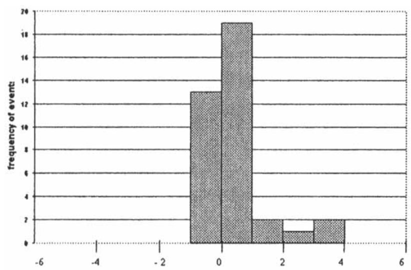

FIGURE 4 Histogram of the κ distribution for a weak level of X-ray activity. The vertical axis shows the frequency of events; the horizontal axis shows the coefficient of asymmetry of the phenomenon of polarization reversal when the bipolar group crosses the CM.

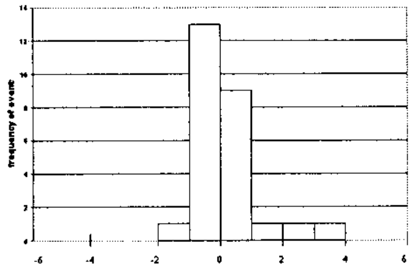

FIGURE 5 Histogram of the κ distribution for a moderate level of X-ray activity. The vertical axis shows the frequency of events; the horizontal axis shows the coefficient of asymmetry of the phenomenon of polarization reversal when the bipolar group crosses the CM.

The moments when the group of spots passes through the CM is considered as day 0; so t_1 and t_2 are the distances (in days) from the CM with the $-$ sign if the appearance of the E shape is fixed in the east hemisphere and with the $+$ sign if it is in the west.

Because of quite good correlation between the level of microwave emission and X-ray flares, the spheres of X-ray activity were chosen to demonstrate the level of flare activity of each investigated group. For each active region the summary sphere of X-ray activity for all the times when the group passed the visual part of the solar disc was calculated (using *Solar Geophysical Data*). These data were divided into three groups.

(i) *Groups with a weak level of X-ray activity* ($P_{\text{X-ray}} < 100 \times 10^{-6}\,\mathrm{W\,m^{-2}}$). These 37 active regions gave X-ray flares of sphere C while they crossed the solar disc; the histograms of the κ distribution is demonstrate in Figure 4.

(ii) *Groups with a moderate level of X-ray activity* ($100 \times 10^{-6}\,\mathrm{W\,m^{-2}} < P_{\text{X-ray}} < 500 \times 10^{-6}\,\mathrm{W\,m^{-2}}$). These 27 active regions gave X-ray flare of sphere M while they crossed the solar disc; the histogram of the κ distribution is demonstrated in Figure 5.

(iii) *Groups with a high level of X-ray activity* ($100 \times 10^{-6}\,\mathrm{W\,m^{-2}} < P_{\text{X-ray}} < 4000 \times 10^{-6}\,\mathrm{W\,m^{-2}}$). These 13 active regions gave X-ray flares of sphere X while they crossed the solar disc; the histogram of the κ distribution is demonstrated in Figure 6.

We can see west asymmetry for κ in the first group of data and a tendency to be symmetrical or to have east asymmetry for the second and third groups.

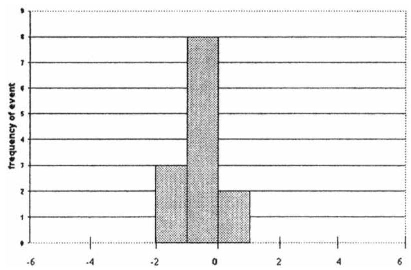

FIGURE 6 Histogram of the κ distribution for a high level of X-ray activity. The vertical axis shows the frequency of events; the horizontal axis shows the coefficient of asymmetry of the phenomenon of polarization reversal when the bipolar group crosses the CM.

4 DISCUSSION AND CONCLUSIONS

A well-known observation property of bipolar active regions is the asymmetry between the preceding and following spots.

The theory of wave propagation and coupling together with our investigation of the phenomenon of sign inversion of the circular polarization of the microwave emission at a wavelength of 5.2 cm demonstrates the east–west asymmetry of the coronal magnetic loops, which is in accordance with the conclusion made in work drawn by Ferris-Mas and Schussler (1998). They discussed this type of asymmetry of real magnetic loops using an analytical approach to the origin of the asymmetry between the preceding and following parts of active regions on the assumption that the fields giving rise to active regions are originally located in a layer of overshooting convection between the convective zone and radiative region. That asymmetry results from the effects of the Coriolis force on the buoyancy instability as a natural consequence of angular momentum conservation. The asymmetry in the pertubed path can only appear in the case of an unstable flux tube in the presence of stellar rotation. This property is preserved throughout the convection zone and gives rise to the observed asymmetries of active regions.

So the usual conditions of the rotating Sun such that the asymmetry with the eastward-inclined wing of a magnetic loop above a following spot in bipolar groups may be considered to be its normal state. Perhaps, as may be seen from Figures 5 and 6, if loops are symmetrical or have asymmetry of the opposite sense it could mean an unusual state of magnetic fields in active regions and, as a consequence, a higher level of flare activity. However, the results of this work allow us to make only a qualitative assumption about this.

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