Solar and Stellar Magnetic Fields: Origins and Manifestations
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Are there local dynamo in solar polar region?

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Abstract. Polar magnetic field, as a component produced by the global dynamo, is thought to be the remant of toroidal magnetic field transported poleward from Sun's active belt. With the improvement of instruments, more and more observations are challenging the viewpoint. Recently, we identify the bipolar magnetic emergences (BMEs) in the polar region, and find that the distribution of the magnetic axes for these BMEs shows random state, which does not follow the Joy's law of active region. The result implies the possible existence of local dynamo in the solar polar region.

Keywords. Sun: atmosphere, Sun: magnetic fields, Sun: photosphere, sunspots

1. Introduction

Observations of the magnetic field in solar polar region are very important in understanding the long-term variation and the origin of solar magnetism. The polar field was firstly observed by the ground-based magnetograms (Babcock & Babcock 1955): a general, predominantly dipolar field. The average flux density in the polar region is about several G (Babcock & Babcock 1955; Tang & Wang 1991; Deng *et al.* 1999; Tsuneta *et al.* 2008).

The vector magnetic field in the polar region was firstly quantitatively measured by Deng *et al.* (1999). It was found that the polar field is an inclined field, and deviate from the normal of the surface by about 40 degree. The result is confirmed by Sun *et al.* (2015) based on the SDO/HMI vector magnetic field observations in the polar region. The polar field contributes about 5.0e22 Mx flux (Deng *et al.* 1999). More observations with high spatial resolution and polarization sensitivity come from the SOT aboard Hinode. Many magnetic flux tubes with kilo-Gauss field strength is distributed in polar region, and they have same polarity, consistent with the global polarity in polar region (Tsuneta *et al.* 2008). The polar region is different from the quiet region of the Sun: a larger area of kilo-Gauss magnetic concentration in the polar region than those of the quiet Sun (Ito *et al.* 2010).

The magnetic field of polar region is thought to be the direct manifestation of the global poloidal field. It is the seed field of global dynamo, and produces the toroidal field which results in the formation of sunspot and active regions. The source of polar magnetic field is explained by the solar cycle model: with away from solar minimum, magnetic field of decaying active region dispersed into the polar region owing to differential rotation, meridional flow and turbulent diffusion (Wang *et al.* 1991; Sheeley 1992; Sheeley 2005) and finally makes the polarity of the polar region reverse near solar maximum. However, more and more observations have challenged the solar global dynamo models in explaining the magnetic origin for the polar region (Severny 1971; Lin 1994; Benevolenskaya 2004; Shiotaet *et al.* 2012; Jin *et al.* 2020).

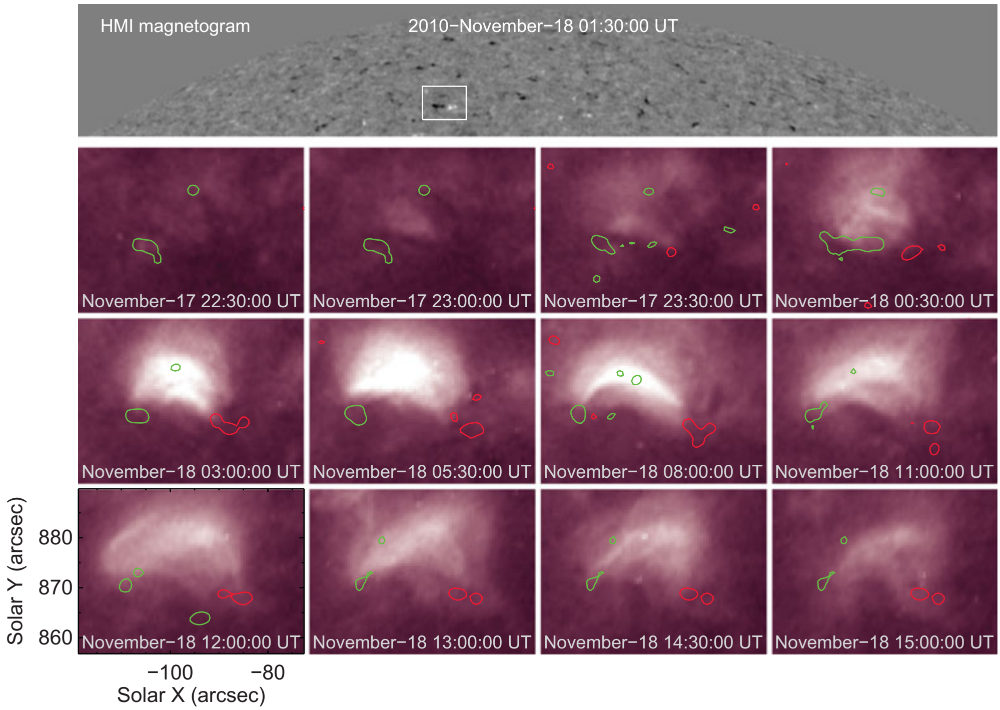

Figure 1. An identified BME example. Top panel: the HMI magnetic observation. Bottom panels: the atmospheric response in AIA 211 Å waveband during the evolution of BME. The green and red lines mean the −30 G and 30 G magnetic contours.

2. Challenge of global dynamo explaining polar magnetic origin

In low-resolution magnetogram, the polar region may appear unipolar, but the polar magnetic field is dominated by small-scale magnetic elements with mixed polarities (Severny 1971). Lin (1994) found that during sunspot maximum period, the polar regions were occupied by about equal numbers of positive and negative magnetic elements. Jin & Wang (2011) study the vector magnetic field in a polar region during solar minimum years, and they pointed that the ratio of magnetic flux in the minority polarity to the dominant polarity reaches 0.5, i.e., the mixed-polarities magnetic elements provides about 2/3 unsigned magnetic flux in the polar region.

Based on the magnetic observations during the maximum and decreasing phase of cycle 22, i.e., from early 1991 to mid-1993, Lin (1994) found that as the solar cycle develops toward sunspot minimum, the average magnetic field of the dominant polarity in the polar region increases, and the average magnetic field of the minority polarity decreases. However, Benevolenskaya (2004) uses the observations from the SOHO/MDI in 1996–2003, and reveals an interesting results that the total polar magnetic flux does not change during the polarity reversal in both hemispheres, but the positive and negative parts of the total flux change. By detecting the magnetic flux per patch in the solar polar region, Shiotaet *et al.* (2012) found that almost all large patches (⩾1.0e18 Mx) have the same polarity, while smaller patches have a balance of both polarities. During the increasing phase of cycle 24, the net magnetic flux of the polar region clearly decreases, while the total magnetic flux of these smaller patches (<1.0e18 Mx) does not change.

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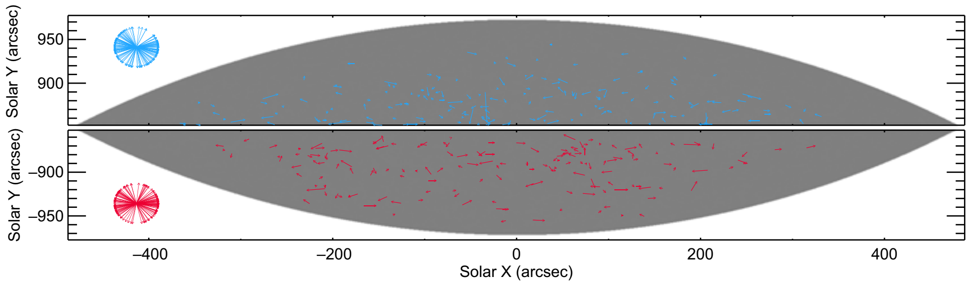

Figure 2. The distribution of BMEs magnetic axes in the polar region. The length and direction of each arrow in the polar region means the maximum separation and the magnetic axis direction for each BME. The arrows of the concentric circle in the top left and bottom left corners display the magnetic axis distribution of BMEs with the same distance of the opposite polarities in the corresponding polar region.

3. Random distribution of BME magnetic axis in the polar region

In our recent study, we try to explore the bipolar magnetic emergences (BMEs) in the polar region by considering the simultaneous magnetic evolutions and imaging observations in extreme ultraviolet waveband in the interval from 2010 June to 2011 May. More than 300 BMEs are definitely identified by two criterions. Firstly, a pair of emerging flux with opposite polarities in the LOS magnetogram appears quasi-instantaneously in the solar surface. Secondly, the brightening loop in extreme ultraviolet images between the opposite polarities appears with the increasing magnetic flux. An example of identified BME is shown in Figure 1. According to the Joy's law of active region, if these BMEs come from the global dynamo, their magnetic tilt should be consistent with the Joy's law of active region. We determine the magnetic barycenter position of both polarities for each BME, and obtain the direction of BME tilt. The distribution of magnetic tilt is shown in Figure 2. It can be found that the direction of magnetic tilt for BMEs is random either in the southern or northern polar regions, and does not obey the Joy's law of active regions (Jin *et al.* 2020).

Our observation result confirmed the possible existence of local dynamo in the solar polar region besides global dynamo. More careful and serious efforts need to be made to further explore the magnetic origin of polar magnetic field.

Acknowledgements

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