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Observational Signature of Tilt Quenching of Bipolar Magnetic Regions in the Sun

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Abstract. It is believed that the tilt in the bipolar magnetic regions (BMRs) is produced due to a torque induced by the Coriolis force, acting on the diverging flow from the apex of the rising flux tube of the toroidal field in the solar convection zone (SCZ).The BMRs with a strong magnetic field are expected to have reduced tilt as they rise very quickly in the SCZ. This effect can provide the required nonlinear quenching mechanism to suppress the growth of magnetic filed in the dynamo models. Here, we use the magnetograms of the Michelson Doppler Imager (1996–2011) and Helioseismic and Magnetic Imager (2010–2018) to automatically detect the BMRs and look for the signature of tilt quenching. Based on the Bayesian inference method, our results show that the posterior distribution of quenching parameters is Gaussian, and the mean of this distribution agrees with the earlier findings.

Keywords. Sun: magnetic fields, (Sun:) sunspots, Sun: photosphere, methods: statistical

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1. Introduction

In the thin flux tube model, a rising flux tube experiences Coriolis force in the SCZ, appearing as a tilted Bipolar Magnetic Region (BMR) on the photosphere. Hale et al. (1919) observed that the tilt (γ) of BMRs depends on the latitude (λ) and given as $\gamma = \gamma_0 \sin\lambda$, which is know as the Joy's law. These tilted BMRs play a vital role in the Babcock–Leighton process (Babcock 1961; Leighton 1964) for the generation of the poloidal field (Mordvinov et al. 2022). In the kinematic dynamo models such as the Babcock-Leighton type, the saturation of the magnetic field is a big concern, and most of the modelers take an ad-hock nonlinear quenching of type

$$\gamma = \frac{\gamma_0 \sin\lambda}{1 + \left(\frac{B}{B_0}\right)^n} \tag{1.1}$$

to suppress the growth of magnetic field (Lemerle & Charbonneau 2017; Karak & Miesch 2017, 2018, with $n = 2$). Here B_0 is the magnetic field limit, beyond which we can expect the effect of tilt quenching. In contrast with the findings of Stenflo & Kosovichev (2012), Jha et al. (2020) reported an indication of tilt quenching and estimated the value of B_0 and n. Here in this proceedings, we have extended the work of Jha et al. (2020) and used Bayesian inference to better estimate these parameters.

2. Data and Method

We use the MDI (1996 − 2011) and HMI (2010 − 2018) magnetogram data and detected the BMRs using the same automatic technique as Jha et al. (2020) and

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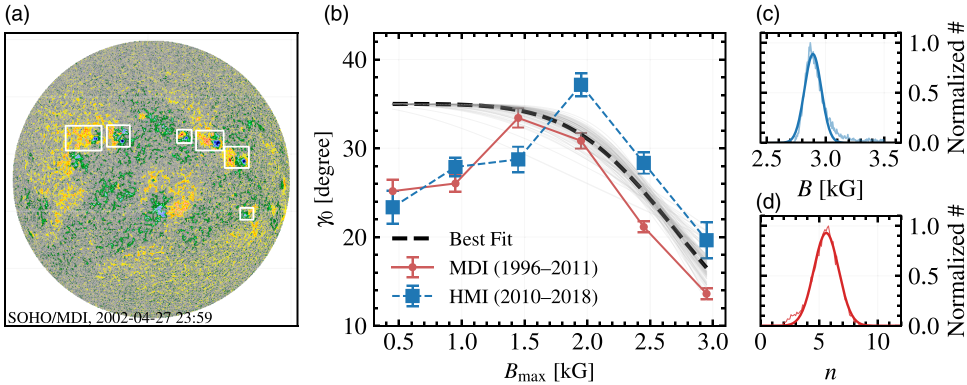

Figure 1. (a) An example showing the identified BMRs from MDI data. (B) Variation of γ_0 as a function of $B_{\max}$, light grey and dashed black lines shows Equation 1.1 based on the 500 randomly selected parameters from the distribution and the mean of the distribution. (c) and (d) show the posterior distribution of $B_{\max}$ and n.

Stenflo & Kosovichev (2012). A representative example of BMR detection is shown in Figure 1a.

3. Results and Conclusion

In Figure 1, we plot the γ_0 as a function of $B_{\max}$ for both data set (MDI and HMI), where we can see a signature of tilt quenching in high field regime ($B_{\max} > 2$ KG) similar to findings of Jha et al. (2020). We use the observed data as prior information to estimate model parameters (B_0 and n), called posterior distribution, using the Bayesian inference method. Assuming Gaussian likelihood and uniform prior distribution, we calculated the posterior distribution for these two parameters (B_0 and n), which is shown in Figure 1c and 1d. In Figure 1b, we plot Equation 1.1 using randomly selected 500 parameter sets from the distribution (light grey lines) and the mean of the distribution based on Gaussian fitting (dashed black line). The mean values, $\overline{B}_0 = 2893 \pm 73$ G and $\overline{n} = 5.6 \pm 1.1$, agree with the findings of Jha et al. (2020) based on least-square fit and indicate an even more substantial quenching effect. Readers may go through this YouTube link to watch the details about this work.

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