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The Relationship between Coronal Bright Points as seen in He I λ10830 and the Evolution of the Photospheric Network Magnetic Fields*

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Abstract

Transient 'dark points' in He I λ10830 are found to be associated with small magnetic bipoles. The number of these dark points varies inversely with the sunspot number. Sampled over a solar cycle, about one-third of the dark points are associated with erupting magnetic flux (ephemeral regions) while the other two-thirds are associated with chance encounters of opposite magnetic polarity features. Since coronal bright points are associated with He I dark points, it is suggested that the inverse correlation of both of these events with the sunspot number results from the higher probability of chance encounters between magnetic network of opposite polarity (larger areas of mixed magnetic polarity) during low levels of solar activity.

1. Introduction

Coronal bright points, seen in soft X-ray and EUV spectroheliograms, are small-scale (15–30 arcsec) short-lived (2–48 hr) emission features that overlie small bipolar magnetic regions that have an average total magnetic flux of $(2–3)\times10^{19}$ Mx (1 Mx $\equiv$ 10^{-8} Wb) (Golub *et al.* 1977; Golub 1980). Golub *et al.* (1974, 1977) concluded that the magnetic bipoles co-spatial with X-ray bright points are ephemeral regions, i.e. small (10–20 arcsec) emerging magnetic regions having lifetimes of less than a day, an average total magnetic flux of $3\cdot3\times10^{19}$ Mx, and a similar latitude distribution as coronal bright points. As shown in Fig. 1, the number of ephemeral regions, however, varies nearly in phase with the solar cycle (Harvey *et al.* 1975*b*; Martin and Harvey 1979; Harvey 1984), while the number of X-ray bright points is anticorrelated with the solar cycle (Davis *et al.* 1977; Golub *et al.* 1979; Golub 1980; Davis 1983).

To try to resolve this contradiction, the evolution of the magnetic fields in the quiet Sun underlying coronal bright points has been explored using the daily full disc photospheric magnetic field observations and He I λ10830 spectroheliograms. Harvey *et al.* (1975*a*) found that X-ray bright points correspond to similar-sized dark structures observed in spectroheliograms of He I D_3 and He I λ10830. The results of the present study indicate that at least two-thirds of the He I 'dark points' are

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associated with magnetic bipoles that result from the 'chance' encounter of existing opposite polarities and one-third with erupting ephemeral regions. This result helps to explain the anticorrelation of coronal bright points with the solar cycle; Giovanelli (1982) found that the area of mixed polarity (and, hence, the probability of chance opposite polarity encounters) varies inversely with the sunspot cycle. It is conjectured that chance encounters of existing opposite polarity network may be a significant method of flux removal in the quiet Sun.

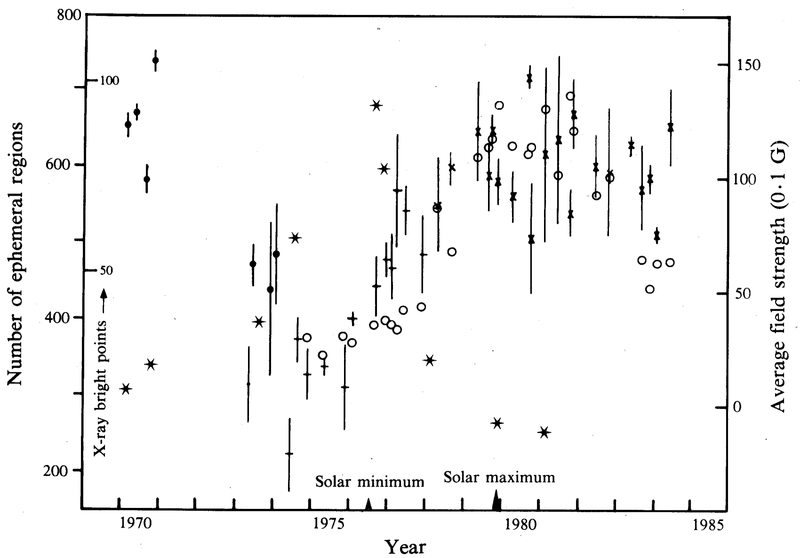

Fig. 1. Instantaneous number of ephemeral regions on the entire surface of the Sun from 1970 to mid-1984. These numbers are determined from counts of ephemeral regions using the full disc data corrected by a visibility function (Harvey *et al.* 1975*b*). Random errors were estimated by dividing the data into two subsets and are indicated by vertical lines. Data sources are the Kitt Peak magnetographs: 40-channel data (solid circles); and 512-channel, high gain (plusses) and low gain (crosses) data. Also shown are the observed number of X-ray bright points (stars) from Davis (1983) and the total magnetic flux (open circles) on the entire Sun (J. Harvey, personal communication).

2. Data

The data used are daily full disc observations in Fe I λ8688 of the longitudinal photospheric magnetic fields and He I λ10830 spectroheliograms taken by the National Solar Observatory from 1975 to mid-1984. Magnetic field observations and the He I λ10830 spectroheliograms with an instrumental spatial resolution of 1 arcsec were made using the 512-channel magnetograph (Livingston *et al.* 1976) at the Vacuum Telescope located on Kitt Peak. Two 14–20 day periods of continuous, good quality magnetograms and He I λ10830 spectroheliograms were selected for analysis during each of the 11 years of the data set.

Analysis of the Magnetic Field Observations

Small-scale (<30 arcsec) magnetic bipoles seen in the full disc magnetograms were identified as either an ephemeral region, i.e. a bipole that has emerged since the previous day's observation, or as resulting from the 'chance' encounter of existing opposite polarity magnetic network, as follows: The 18-cm diameter images of the full disc magnetograms from two successive days were overlaid (with an estimated accuracy of 5–10 arcsec) and 'blinked'. Only areas of the Sun where the magnetic fields were visible on both days were examined. To assess the changes in the distribution of the network fields, magnetic bipoles, i.e. small (<30 arcsec) magnetic structures of adjacent poles of opposite polarity, were identified on the second magnetogram. The magnetic fields were examined on the previous day's magnetogram within a circle of radius ~ 60 arcsec (i.e. the distance network would travel at $0 \cdot 5\ \mathrm{km\,s^{-1}}$ during 24 hours) centred on the identified magnetic bipole. If within this area, magnetic network of opposite polarity was present and had approximately the same amount of flux as seen later in the bipole, the bipole was identified as resulting from a 'chance' encounter of that existing network (see, for example, the magnetic structure labelled 2 in Fig. 2). If, on the other hand, there was no opposite polarity network or the flux in the bipole was much greater than that visible within the area analysed, the bipole was identified as an ephemeral region (see, for example, the magnetic structure labelled 1). In Fig. 2, the boxes on 10 August indicate the identifications of ephemeral regions that emerged since the observation of 9 August; the arrowheads designate bipoles on 10 August that could be reasonably explained by the migration of existing flux observed on the previous day, i.e. 'chance' encounters of opposite polarity network.

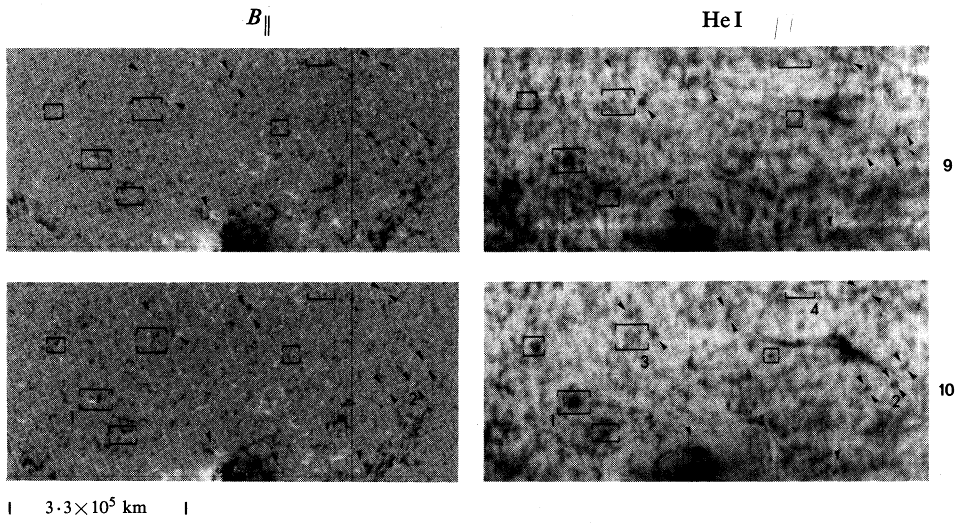

Fig. 2. Sections of the full disc photospheric magnetograms (*left*) and the corresponding He I λ10830 spectroheliograms (*right*) from two successive days, 9 and 10 August 1978, showing the identifications of newly emerged flux (indicated by brackets) and of encounters of existing opposite polarity network (indicated by arrowheads) and their associated He I structure on 10 August. The He I structures labelled 1 and 2 are what is defined as 'dark points', while structures 3 and 4 have the same intensity as the surrounding He I network.

Analysis of the He I λ 10830 Spectroheliograms

He I λ10830 is a chromospheric absorption line produced by transitions of the He I triplet from the 2^3S to the 2^3P energy levels. It is formed about 1500 km above the photosphere (the same height as the Hα and Ca K lines) at a temperature of about

7000 K. The He I triplet has a higher population than expected from chromospheric temperatures. Goldberg (1939) suggested that this excessive population is produced by recombination following photo-ionization of He I by coronal EUV radiation with $\lambda < 500$ Å. In regions of the corona where there is a depletion of EUV emission there will be a corresponding decrease in λ10830 absorption. Conversely, in regions where coronal EUV emission is enhanced, increased absorption is observed. Thus, in a He I 10830 Å spectroheliogram, coronal holes appear bright, while active regions and network appear dark. The He I 10830 Å line, as with D_3, appears in emission only in energetic flare kernels. Harvey *et al.* (1975*a*) found that X-ray bright points correspond to similar-sized, but dark structures in He I D_3 and He I λ10830. The He I 'dark points' are thought to result from the excitation by the overlying EUV/X-ray emission in coronal bright points.

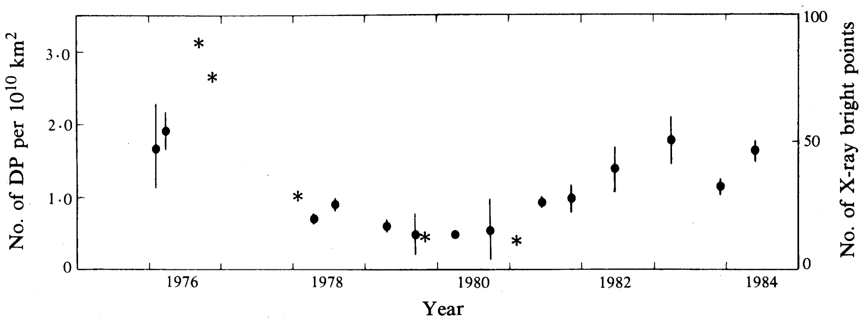

Fig. 3. Areal density of He I λ10830 'dark points' (solid circles) in areas of the quiet Sun counted within $0{\cdot}4R_\odot$ of disc centre as a function of time, compared with the counts of X-ray bright points (stars) from Golub *et al.* (1979) and Davis (1983).

The daily He I λ10830 spectroheliograms during the selected periods from 1975 to mid-1984 were analysed in the quiet Sun and in coronal holes located within 0·4 of a radius ($R_\odot$) from the centre of the Sun's disc. This distance restriction allowed the more accurate determination of the underlying magnetic field characteristics that are more strongly affected by geometric and spectral line effects at greater distances from the Sun's centre. The He I structures were selected as 'dark points' if their intensity was darker than the surrounding network by at least 15% and their size was 5–30 arcsec (for example, the structures labelled 1 and 2 in Fig. 2). Fig. 3 shows that the solar cycle variation of the number of He I 'dark points' is similar to that of X-ray bright points, although the magnitude of the decrease from 1976 to 1979–80 in the dark point counts (solid circles) appears to be less than is seen in the X-ray data (stars).

3. Association of He I 'Dark Points' with the Evolution of the Magnetic Field

The locations of the identified He I 'dark points' were compared with the magnetic field observations. A total of 13% of the dark points were found to occur either in a filament channel (and are probably misidentified small fragments of filament) or were co-spatial with unipolar network (although a new bipole may have emerged in the approximately 1–1·5 hr period between the magnetic field and He I observations). All of the remaining 87% of the He I dark points were associated with small bipolar magnetic regions.

Table 1. Associations (in %) of He I dark points (DP), ephemeral regions (ER) and chance encounters of opposite polarity network fields (CE)

Arrows designate 'associated with'

	DP → ER	DP → CE	ER → DP	CE → DP
Quiet Sun				
Time sequence data	12	52	31	59
Once-per-day data	37	63	42	—
Coronal hole				
Time sequence data	17	52	19	45
Once-per-day data	23	77	70	—

Table 2. Intensity of He I structures associated with ephemeral regions relative to the surrounding network

He I structure	Number of ER	
Darker than surrounding network	638	(42·1%)
Same intensity as network	659	(43·5%)
Lighter than network	127	(8·4%)
No feature detected	91	(6·0%)
In emission	0	

Association of He I Dark Points and Ephemeral Regions

Restricting the analysis to the sample of dark points associated with bipolar regions, we find that only 37% of the He I dark points in the quiet Sun correspond to identified ephemeral regions (see Table 1). This is somewhat less than the ~50% overlap found between X-ray bright points and ephemeral regions by Golub *et al.* (1977). To determine if the association of dark points with ephemeral regions is affected by the prevalent and variable He I chromospheric network, He I dark points were identified within the boundaries of a total of 61 coronal holes during the three days of their central meridian passage and compared with the magnetic field data. (Coronal holes are easily identified in the He I λ10830 spectroheliograms as brighter areas showing little or no network and having predominately unipolar magnetic fields.) A total of 23% of the dark points in coronal holes (Table 1) are co-spatial with identified ephemeral regions, suggesting that regardless of the surrounding network structures only one-third or less of the dark points are associated with ephemeral regions.

The reverse correlation between ephemeral regions and dark points has also been considered; i.e., what are the characteristics in He I λ10830 overlying ephemeral regions? For each of the ephemeral regions within $0 \cdot 4 R_{\odot}$ of disc centre (a total of 1515), the intensity characteristics of co-spatial He I λ10830 structures were studied and grouped into five levels as follows: The intensity of the He I structure was (1) darker than the surrounding network by more than 15%, (2) the same as the network, (3) at least 15% lighter than network elements, (4) no feature could be detected, and (5) in emission. The results, summarized in Table 2, indicate that 42% of the ephemeral regions are associated with dark structures in He I; these structures tended to extend over a larger area than the magnetic bipole. A total of 58% of

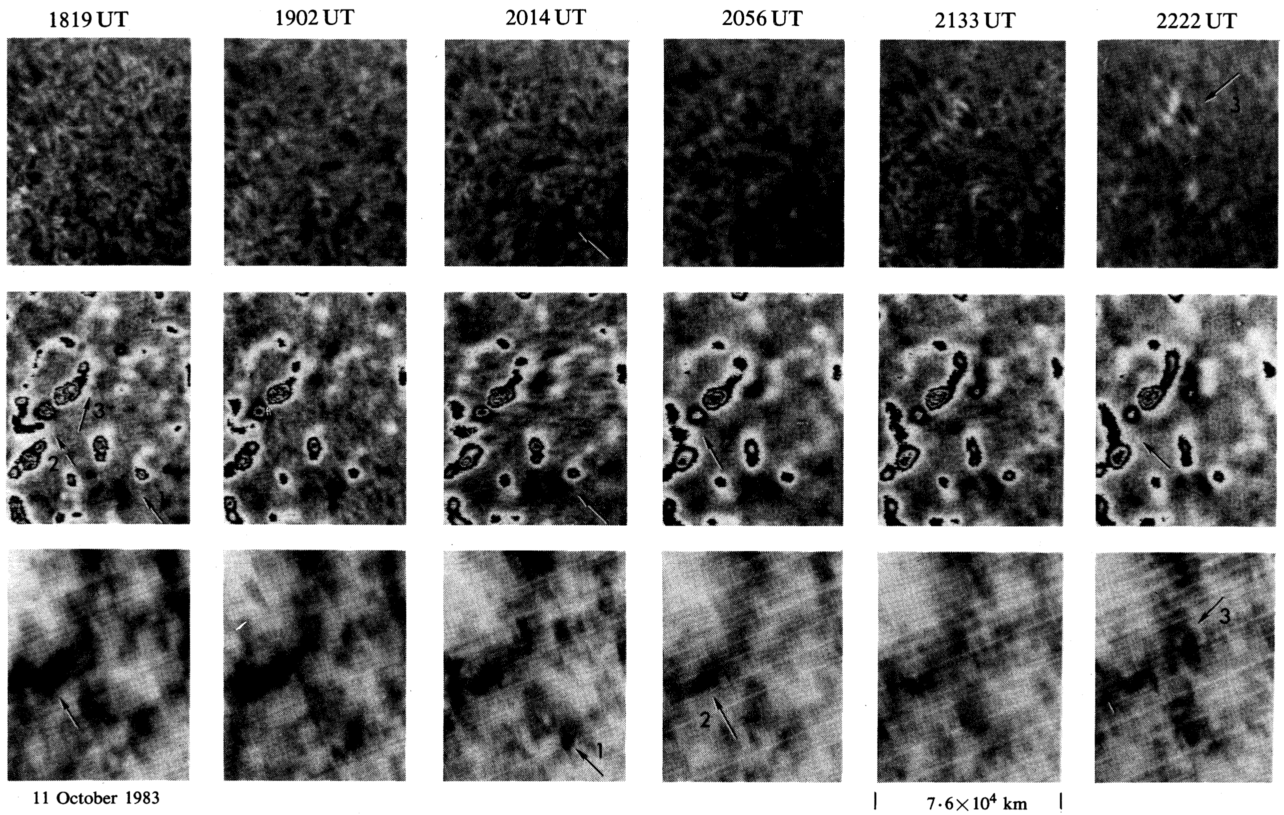

Fig. 4. A time sequence of Hα filtergrams (*top*), the photospheric magnetic fields (*middle*) and He I λ10830 spectroheliograms (*bottom*) of an area of quiet Sun. The Hα and magnetic field data were taken at the Big Bear Solar Observatory (by courtesy of F. Tang). The concentric alternating pattern of black and white in the magnetic field observations indicates saturation in the data with longer integrations; the polarity of the field is defined by the outermost shade (black represents negative polarity and white positive polarity). In the lower portion of the pictures and indicated by the arrow 1, two opposite polarity network elements approach each other and merge. Fibril loops connecting the two poles can be seen in Hα at 2014 UT along with a He I 'dark point', which fluctuates substantially in intensity. At arrow 2, a portion of positive network adjacent to the negative pole of an ephemeral region disappears and is associated with a He I dark point. Tang *et al.* (1983) found bright points in C IV to be associated with similar magnetic configurations. An ephemeral region (at arrow 3) can be seen emerging just above the centre of the pictures and is associated with an arch filament system (Hα) and a darkening in He I λ10830 late in this observational sequence.

the ephemeral regions have no recognizable structure in He I λ10830 that clearly distinguishes them from the surrounding quiet Sun network. In coronal holes, a higher percentage (70%) of the ephemeral regions are found to correspond to He I dark structures (Table 1); however, 30% showed no darkening in He I. While these results depend to some extent on the stage of evolution of the ephemeral regions and of the He I λ10830 structures at the time of the once-per-day observations, it does indicate that some ephemeral regions are not associated with significant enhancements in He I.

Dark Points and 'Chance' Encounters of Opposite Polarity Network

What is the nature of the magnetic bipoles that correspond to dark points in He I and are not identified as ephemeral regions? A total of 63% of the dark points in the quiet Sun and 77% in coronal holes are co-spatial with bipoles that appear to result from the 'chance' encounter of apparently unrelated, previously existing magnetic network of opposite polarities. While this result is based on an interpretation of the motions of magnetic flux observed once-per-day, recent time-sequence observations of the quiet Sun support the conclusion that many He I dark points occur with the approach and encounter of existing network flux of opposite polarities.

Simultaneous time-sequence He I λ10830 spectroheliograms (using the 512-channel magnetograph at the Vacuum Telescope on Kitt Peak) and photospheric magnetograms (with the videomagnetograph at Big Bear Solar Observatory in collaboration with F. Tang) were obtained of the quiet Sun on 10–11 October 1983 and of a coronal hole on 12 October 1983 (see Fig. 4). During a total of 17·1 hours, 131 ephemeral regions emerged and 132 encounters of opposite polarity magnetic network occurred within an observed area of $2{\cdot}2\times10^{10}$ km^2. The comparisons between the occurrence of dark points, ephemeral regions and chance encounters (details will be published separately) are summarized and compared with the once-per-day results in Table 1. It is apparent from these data that not every emerging bipole (19–31%) nor encounter of existing network flux (45–59%) will result in a darkening in He I λ10830. However, the higher association (by a factor of 2–4) of He I dark points forming with the convergence of opposite polarity network than with ephemeral regions confirms the conclusion reached with the full disc once-per-day observations. Fig. 4 shows a section of the magnetic field, Hα and He I time-sequence data obtained on 11 October 1983 illustrating the development of He I dark points in association with (1) the encounter of apparently unrelated but existing opposite polarity network, (2) the interaction of an ephemeral region and adjacent network, and (3) the emergence of an ephemeral region.

4. Discussion

To explain the anticorrelation between the solar cycle variation of ephemeral regions and X-ray bright points, an investigation was made of He I λ10830 chromospheric counterparts of coronal bright points and the underlying photospheric magnetic fields. It was found that He I 'dark points' occur with the emergence of some ephemeral regions, but more often (by at least a factor of 2) with the encounter of existing network elements of opposite polarities. This conclusion, based on once-per-day data sampled over an 11-year period, is supported by time-sequence observations of the development of He I λ10830 dark points when apparently unrelated opposite polarity network elements approach and/or merge. The occurrence of He I dark points at such sites may be indicative of reconnection taking place in the corona resulting in heating. Since much of the magnetic flux at these sites disappears during these encounters, 'chance' encounters of opposite polarity magnetic network may be an important mechanism for the removal of flux in the quiet Sun.

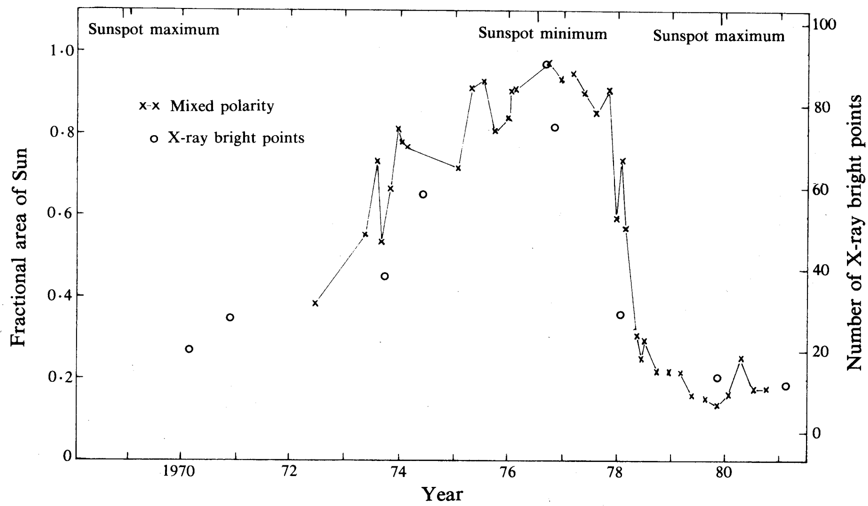

Fig. 5. Area of mixed polarity on the Sun (crosses) between ±60° latitude from Giovanelli (1982) compared with the number of X-ray bright points (open circles) from Golub *et al.* (1979) and Davis (1983).

However, does the better association of He I dark points with chance encounters of opposite polarity magnetic network than with ephemeral regions offer an explanation of the anticorrelation of coronal bright points with the solar cycle? The probability that 'chance' encounters will occur between network elements of opposite polarities depends on the degree of mixing between the positive and negative fields, i.e. on the area of mixed polarity on the Sun. Giovanelli (1982) measured the fractional area of mixed polarities on the Sun between latitudes ±60° from 1972 to 1981 and found that the area of mixed polarity varies inversely with the solar cycle. When the number of X-ray bright points is compared with the area of mixed polarity from 1973 to 1981, as shown in Fig. 5, a good correlation is found between the variation of X-ray bright points and the area of mixed polarity. This suggests that the anticorrelation of coronal bright points with the sunspot cycle (and He I dark points which also show a similar solar cycle variation, see Fig. 3) may indeed be explained by a close association with 'chance' encounters of existing network of opposite polarities.

Acknowledgments

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