Astroparticle Physics 100 (2018) 13–21

Contents lists available at ScienceDirect

Astroparticle Physics

journal homepage: www.elsevier.com/locate/astropartphys

The occurrence of non-uniformity of solar and plasma features throughout five solar cycles

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ARTICLE INFO

Article history:
Received 15 November 2017
Revised 1 February 2018
Accepted 19 February 2018
Available online 21 February 2018

ABSTRACT

Interplanetary magnetic field (IMF) magnitude, plasma and solar parameters recorded at 1 AU over a period of 50 years have been studied according to IMF polarity sense. Our results indicated that there is a symmetric in toward and away days which may depend slightly upon the magnetic state of the heliosphere. Statistically insignificant dependence between the magnetic field *B* and solar activity was deduced. The solar plasma speed (*SWS*) are faster by about 13 km/s for toward than for away polarity days during the solar cycle 21 and by 16 km/s for toward than for away polarity days during the solar activity cycle 22. In contrast, the *SWS* are faster by about 17.5 km/s for away than for toward polarity days during the solar activity cycle 23. In addition, the solar plasma was hotter during toward than away days during solar cycles 21, 22, and 24, while it was cooler during toward than away days during solar activity cycles 20 and 23 .Finally, the observed asymmetry phenomena can be used as an indicator for solar activity.

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1. Introduction

It is well known to the solar and space physics community that the heliospheric current sheet (HCS) separates the heliosphere into two regions of opposite magnetic polarity. During the positive magnetic polarity epochs (1971–1979 and 1991–1999), the solar magnetic field is directed away from the Sun above the HCS and toward the Sun below the HCS. In contrast, during negative magnetic polarity epochs (1981–1989 and 2001–2012), the direction of the magnetic field of the Sun is reversed. Earlier, Svalgaard and Wilcox [31] and King [14] used OMNI data showing positive–negative/negative–positive polarity asymmetries in the spiral interplanetary magnetic field (IMF) lines in the heliosphere, as well as they calculated the daily averages of the spiral IMF lines for all negative and positive polarity epochs. According to the Bieber [3] technique, the hourly field vector is considered to have negative polarity (or Toward) if its solar ecliptic azimuthal angle lies between 225° and 360° and between 0° and 45° and otherwise it is considered as Away (**A**) the Sun in geocentric solar ecliptic (GSE) coordinates, as shown in Fig. 1. Also, the contribution of non-alignment between the solar rotation axis and the normal to the ecliptic plane was eliminated.

Following the same manner for separating the hourly of the spiral IMF lines, Bieber [3] extended the analysis to cover the period 1965–1984. The results displayed that the average spiral angle above of HCS was more tightly wound by $3.1° \pm 1.1°$ than it was below of the HCS. A correlation between the north–south asymmetry in the spiral angle of IMF and the north–south asymmetry in the solar diurnal anisotropy of galactic cosmic rays have been studied (e.g., [5,27,32]) during negative solar polarity epochs (1965–1968 and 1981–1988), and from 1975 to 2013 by El-Borie et al., [8]. Following the same method for separating the IMF data, asymmetry in the spiral angle ($2.4° \pm 0.9°$) was found during the period 1965–1987 [30].

The north–south (N–S) asymmetries of several solar activity phenomena have been studied earlier. A study of several solar activity phenomena showed some configuration of N–S asymmetry of solar activity [38]. A study of asymmetrical distribution for major solar flares, type II radio bursts, and white light flares over three solar activity cycles (19–21), showed that the asymmetry occurred in the northern hemisphere during the cycles 19 and 20 while during cycle 21 the asymmetry favoured the southern hemisphere. After solar cycles 19 and 20 the asymmetry shifted from the northern to southern hemisphere (in cycle 21). The change in asymmetry from the northern to the southern hemisphere may be related with Sun's interior events [26]. Howard [11] examined the solar magnetic flux data from 1967 to 1973. The results showed that the magnetic flux of northern solar hemisphere exceeds the

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https://doi.org/10.1016/j.astropartphys.2018.02.007
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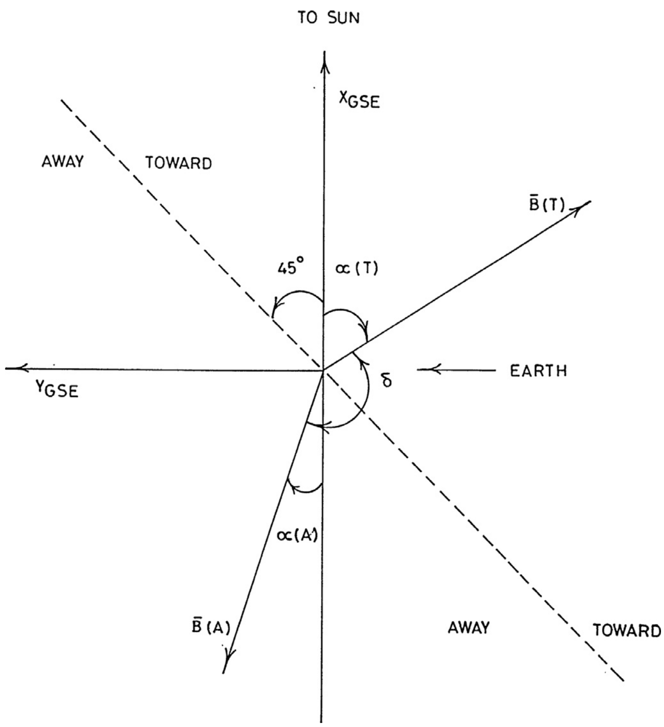

Fig. 1. Toward (T) and away (A) field polarities in geocentric solar ecliptic coordinates (GSE). Spiral angle α (T) if its solar ecliptic azimuthal angle lies between 225° and 360° and between 0° and 45° and otherwise it is considered α (A). The angle (δ) between the two vectors is also shown.

southern hemispheric flux by about 7%. Swinson et al. [33] studied the distribution of sunspot numbers and sunspot areas in solar hemispheres. Their analysis showed that the N–S asymmetry of sunspot numbers has northern hemispheric dominance during the period 1947–1984.

Verma [37] presented studies on solar plasma parameters (temperature, wind speed and density) showing greater values above the HCS than below it during the negative magnetic polarity epoch (1981–1987). In addition, the solar plasma was denser above the HCS than below it during the negative solar magnetic polarity epoch [6]. The solar magnetic activity is generally believed to be initiated by a hydro-magnetic dynamo operating either in or at the base of the convection zone of the Sun. Dynamo models predict the possibility of mixed parity solutions where the solar magnetic field has both dipole and quadrupole moments. Such fields should be asymmetric with respect to the solar equator. In fact, there is evidence that the Sun's magnetic field was highly asymmetric as it emerged from the Maunder minimum [24].

In the present work, we make a detailed study of N–S asymmetries on the interplanetary field magnitude (B), solar plasma parameters (ion density N, temperature T, dynamic (ram) pressure nV^2, and speed SWS) and compare these with the observed results of asymmetries in the solar features (sunspot number R_Z and solar radio flux SF). Section 2 shows the asymmetry between northern and southern IMF vectors. Sections 3 and 4 represent a detailed analysis of N–S asymmetry of the considered parameters during the considered time period (1967–2016). Section 5 contains the discussion and summarized conclusions.

2. The asymmetry between northern and southern solar magnetic field vectors

The long-term variation of north–south asymmetry in the solar activity and its physical interpretation is an essential problem and also has not been given clearly so far. Fig. 2 displays the relative annual number of days for toward (T) and away (A) IMF groups over the period 1967–2016, expressed by T/(T + A). Above the central line more T days than A days. Years of minimum (denoted by dash lines) and maximum of solar activity (denoted by solid lines) are added. Epochs of reversals of Sun's polar magnetic field are also expressed. The A + epochs (or A−) represent the positive (or the negative) magnetic polarity states in the solar northern hemisphere.

Fig. 2 shows that there is enough evidence for symmetry in toward and away days. This symmetry may depend slightly upon the magnetic state of the heliosphere. Nearly equal T and A days have been observed around the years of maxima and minima solar activity (1970, 1972, 1977, 1979, 1980, 1982, 1984, 1991, 1994–1998, 2000, 2001, 2003, 2005, 2007, and 2013). On the other hand, during the four solar magnetic epochs, there exist more A days than T days (below the central line) during the periods 1971–1979 (occurred in 1975, 1976, and 1979) and 1991–1999 (in 1992, 1993, and 1999). In contrast, there are more T days than A days (above the central line), during the periods 1981–1989 (in 1983, 1985, 1986, 1988, and 1989) and 2001–2011 (in 2004 and 2008–2012). These results indicate that, in general, when the IMF was pointed toward the northern solar hemisphere (A−) above the HCS, there exist more T days than A days. While on the average, the asymmetry observations signified more A days than T days when the IMF was away from the Sun on the northern solar hemisphere (A+) above the HCS. It will be good to note that the shape of the current sheet results from the influence of the Sun's rotating magnetic field on the solar wind plasma in the interplanetary medium. The influence of the spiral-shaped magnetic field lines (A+/A− in 1980/1981 and 2000/2001 or A−/A+ in 1990/1991 and 2013/2014) on the interplanetary medium (solar wind) creates the largest complicated structure in the heliospheric current sheet. It warps into a wavy spiral shape. The asymmetry observations of the opposite polarity configurations also reported before [6,9,33]. They have shown that when the HCS was displaced below the Earth (on average) and when the IMF pointed toward the Sun above the HCS, more T days than A days on the Earth can be predicted, while the reverse is true when the IMF pointed away from the Sun on the northern hemisphere. Therefore, we notice form Fig. 2, that more **A** than **T** days during the epochs of positive solar polarity when the northern solar hemisphere was more active than the southern one. In contrast, when the southern solar hemisphere was active during the epochs of negative magnetic polarity; there were more days of toward IMF polarity. However, these activities tend to shift from northern hemisphere to southern hemisphere. Hence, these asymmetries in the number of away and toward days of IMF are connected with the asymmetries in the solar magnetic activity [7,13,28]. Note that, in the present work only days of well-defined IMF direction have been used over the considered period (1967–2016), and in many situations the IMF data were not recorded. So, in few years we have only used 250 days or less and the difference between T and A groups was about a few days.

3. The north–south asymmetry of the field magnitude and plasma parameters

We have used the daily averages of interplanetary magnetic field (field magnitude ***B***), as well as plasma and solar parameters, (sunspot number ***Rz***, solar flux ***SF***, solar plasma speed ***SWS***, ion plasma density ***N***, temperature ***T*** and the plasma flow pressure ***P***) recorded near 1 AU over the period 1967–2016 (taken from NASA's space physics data facility as an OMNI data). The IMF direction is determined on the hourly basis in the GSE coordinates. The field directions are sorted into two polarities; away (A) polarity days if the solar ecliptic azimuthal angle of the IMF daily averages lies be-

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