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FRACTAL CHARACTERISTICS OF HELIOSPHERE PLASMA LAYER TRANSITIONS IN 2006

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Abstract. A detailed study of heliosphere plasma layer transitions was performed for the yearly interval of 2006 (the decline phase of solar activity). The list of sector structure transformations was constructed on the basis of ACE spacecraft data. Parameters of solar wind (SW) plasma and interplanetary magnetic field (IMF) in the near-Earth outer space (Wind data) were used in the analysis of the fractal dimension variations calculated for the intervals of these IMF polarity transformations. SOHO and LASCO data, representing the solar activity phenomena on the Sun, allow us to understand the solar prehistory of the SW flows, expanding to the Earth orbit. MDI magnetograms of the Sun give the opportunity to reconstruct the position of large unipolar regions in the equatorial belt of solar disk, which revealing in the sector structure of IMF parameters of SW flows after its expansion up to the Earth. The fractal characteristics of SW plasma and IMF show the fractal dimension fall down to ~1.5 in the regions of heliosphere plasma layer transition. The fractality of SW flows is discussed.

1. Introduction

The fractality of SW reflects the embedded structures in SW flows [Mogilevsky, 2001]. The investigation of the SW flow fractal structure [Val’chuk, 2006] was made on the basis of the Wind database, characterizing the near-Earth outer space, beyond the Earth's magnetosphere. In the beginning of the fractal dimension (FD) study we paid a special attention to the classification of the SW streams, connected with the different areas in the central region of solar disk. Moving in series across the central meridian of the Sun, specific regions imprint their characteristics in SW flows. Coronal holes, active regions with sporadic phenomena, such as flares and coronal mass ejections, co-rotating regions, eruptive prominences, quiet background areas of equatorial localization have there own characteristics in FD definition, calculated in the near-Earth space SW parameters. Solar wind streams from equatorial CHs are clearly detected in SW on the Earth's orbit. We know that CHs are projecting on the unipolar regions of the large-scale solar magnetic field. The sequential analysis of high speed SW flows from CHs with different polarity, existing in different phases of solar cycles, revealed the genetic similarity of these flows in a sense of numerical parameter fractal dimension. A coronal holes SW flow has the high fractal dimension D ~1.7-1.8 [Val'chuk et al., 2004], [Val'chuk et al., 2002]. It is the evidence in favor of the small size of these fractal structures in comparison with another origination SW flows: flare and coronal mass ejection (CME) flows and co-rotating regions (CIR) of SW. Now it is interesting to investigate the stationary phenomena of SW slow flows, connected with the heliosphere plasma sheet transition. This layer is known as interplanetary sector boundary, dividing the large scale flows of different polarities. Heliospheric plasma layer (HPL) was discovered in the 60-ies of the last century [Wilcox et al., 1965], this valuable finding resulted in a lot of studies [Wilcox et al., 1983], [Korzhov, 1977]. HPL is related to long live phenomena of solar activity. The HPL thickness at 1 AU was estimated to be ~ 700 000 km [Winterhalter et al., 1994]. The heliosphere current sheet (HCS), located inside HPL, is characterized by a field transition through about 180º in no more than 10's of minutes from one polarity to another [Lepping et al., 1996]. The location of HCS is a special problem in HPL study. This analysis needs the appropriate time discretization of data, much more detailed, than we are using in our calculations now. The transformation of the interplanetary magnetic field (IMF) sector structure, followed by the HPL transition, is reflected in many geophysical processes. There is a reason to believe, that the weather variation is connected implicitly with the sector structure IMF. The solar wind parameters in the vicinity of the heliospheric current layer were analyzed [Khvijusova, 2000], [Yermolaev, 1992], [Lepping at al., 1996], [Ivanov, 1998] in detail in many papers. Our analysis continues the FD study on the selected Wind data intervals of 2006, contained in the sector structure transitions [Val’chuk, 2006].

2. Available data

The existence of long and homogeny Wind data series with steady time digitization allows performing the fractal calculation for chosen intervals of HPL transitions in SW flows. The situation choice was made taking into consideration the following: 1) the ACE registration indicates the IMF polarity transition; 2) in SW flows near the Earth the presence of flares, coronal mass ejections, filament eruptions and other power solar activity phenomena was absent; 3) the magnetosphere disturbance (Ap index) was small, about several units. 29 intervals for calculating were treated, 49 HPL transitions were examined in 2006.

3. Classification of HPL transitions

Table 1, (-/+)

Table 1 contains 14 recurrent transitions from negative to positive polarity of IMF. The second column contains the first day (FD) of month (M) and the last day (LD) of month (M) of the recurrent interval Δ D. The mean value Δ D is sufficiently stable, ~ 27days.

N	FD, M LD,M	Transition	Δ D
01m	02.01 – 30.01	–/+	28
02m	31.01 – 26.02	–/+/–	27
03m	27.02 – 24.03	–/+	26
04m	25.03 – 18.04	–/+	25
05m	19.04 – 16.05	–/+	28
06m	17.05 – 13.06	+	28
07m	14.06 – 10.07	–/+	27
08m	11.07 – 06.08	–/+	27
09m	07.08 – 31.08	–/+	25
10m	01.09 – 30.09	–/+	30
11m	01.10 – 26.10	–/+/–	26
12m	27.10 – 21.11	–/+	26
13m	22.11 – 17.12	–/+	26
14m	18.12 –	–/+	

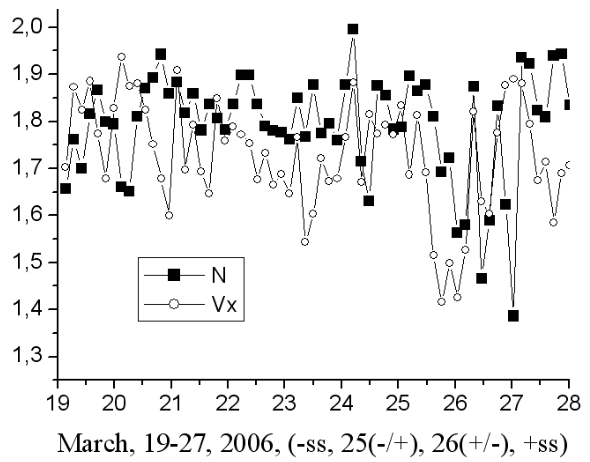

Fig.1. Double HPL transitions exist in March 25-26, 2006, geomagnetic activity was very quiet.

Tables 1-4 contain four lists of recurrent HPL transitions, classified according to the type of the changeover of one polarity to another. Among four series of HPL transitions we consider two basic ones: Table 1 contains (–/+) transitions, Table 2 contains (+/–) transitions, repeating all over the year in every ~27 days. These transitions have quiet geomagnetic conditions. The stable HPL repetition confirms the consistency of configuration of near-equatorial large scale magnetic fields of the Sun in solar minimum.

Examples of FD calculations are shown in Fig. 1-4. These are FD variations of SW plasma parameters: proton concentration N (squares) and SW speed component V_x in GSM co-ordinates (circles). Fig. 1-4 show typical variations of fractal dimension values in several day intervals, where HPL transitions are presented. The principal feature of HPL passing in surrounding background SW flows in Fig.1-4 are characterized as a sharp diminishing of FD values.

Table 2, (+/-)

The table 2 contains 13 recurrent transitions from positive to negative polarity IMF. ΔD~27 days

N	FD,M LD,M	Transition	ΔD
1p	23.01 – 18.02	+/–	26
2p	18.02 – 17.03	+/–	28
3p	18.03 – 12.04	+/–	26
4p	13.04 – 09.05	+/–	27
5p	10.05 – 05.06	+/–	27
6p	06.06 – 03.07	+/–	28
7p	04.07 – 30.07	+/–	27
8p	31.07 – 25.08	+/–	26
9p	26.08 – 22.09	+/–	28
10p	23.09 – 18.10	+/–	26
11p	19.10 – 13.11	+/–	26
12p	14.11 – 07.12	+/–	24
13p	08.12 –	+/–	

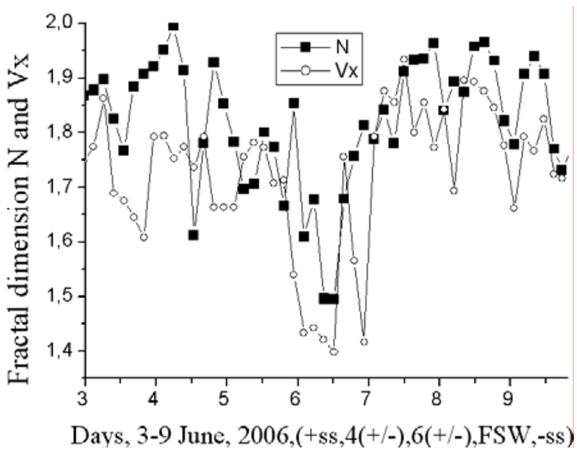

Fig.2. The transition from (+) to (-) polarity is successful in this interval only in the second situation of HPL passing, 6 June 2006. The day of 5 June 2006 has a positive polarity IMF.

The solar disk characteristics (MDI magnetograms, the SOHO images in FeXV line in the prehistory of even HPL situation were analyzed accurately. Using the radial component of SW velocity (Wind data), it may be necessary to return to the solar disk and to identify the region of SW generating sufficiently to be sure. We have to take into account the solar rotation, when we carry out the rear projection.

Geomagnetic disturbance in 2006 was sufficiently quiet. Only one geomagnetic storm (14-15 December, 2006) with sudden commencement had the level G4.

This great geomagnetic storm was generated by X-flare (X3.4/2B, 13 December, 2006). Another 19 geomagnetic storms had small geomagnetic disturbance, they had the level G1-G2.

Table 3, (+/-)
The third chain of recurrent transitions represents the leading boundary of the new (-) sector. The mean value is ΔD~27 days.

N	FD,M LD,M	Transition	Δ D
I	12.01 – 05.02	–, +/–	25
II	06.02 – 05.03	+/–, –	28
III	06.03 – 04.04	+/–, –	30
IV	05.04 – 01.05	+/–/+	27
V	02.05 – 24.05	+/–, –	23
VI	25.05 – 20.06	+/–, –	27
VII	21.06 – 19.07	+/–	29
VIII	20.07 – 14.08	+/–/+	26
IX	15.08 – 06.09	+/–,–/+	23
X	07.09 – 05.10	+/–, –	29
XI	06.10 – 01.11	+/–, –	26
XII	01.11 – 28.11	+/–, –	28
XIII	29.11 – 26.12	+/–, –/+/–	28
XIV	27.12 –	+/-	

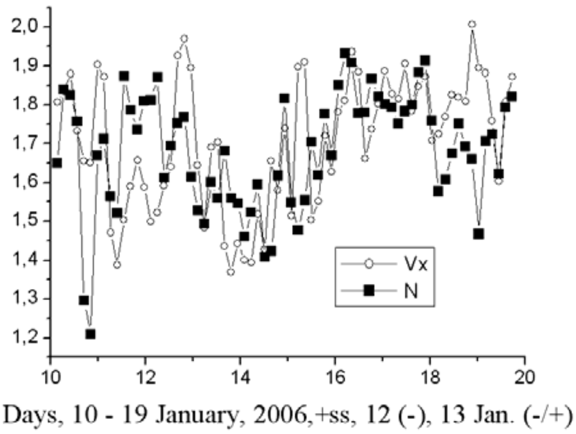

Fig.3 The appearance of (-) polarity is observed in the very low geomagnetic disturbance.

Table 3 represents the generation of the new negative polarity sector. Fig.3 show the first touch of the HPL: the wide diminishing of FD appears in the negative sector generation. In Wind data N density has the extreme values ~25 from 11 to 15 May with sharp variations of this parameter. Very low geomagnetic activity is observed over the period. Appearing in January 2006, this sector formed the trailing boundary twice in May. It is seen at first in the beginning of this month, and then – in the end of May 2006 only, see Table 4. Since on May 6, 2006 the geomagnetic disturbance has the level of a weak geomagnetic storm, Table 4 begins from 31 May 2006. Fig.4 shows the HPL transition obviously, interplanetary magnetic field has the characteristic variation. It may be assumed, that HPL arrived on May 30, 2006. The surrounding background FD values amount to ~1.7-1.9. The next trailing boundaries are repeated with recurrent 27-day interval up to the end of year. The treated data allows us to choose the general characteristic of HPL transitions and to evaluate sporadic phenomena, which exist in the solar minimum phase too.

Table 4, (-/+)
The new (-) sector is generated in solar wind. The table contains 8 (-/+) trailing transitions from negative to positive polarity. The recurrent interval ΔD is sufficiently stable, ~ 27 days

N	FD,M LD,M	Transition	Δ D
1n	31.05 – 26.06	–/+	27
2n	27.06 – 23.07	–/+	27
3n	24.07 – 18.08	–/+	26
4n	19.08 – 15.09	–/+	28
5n	16.09 – 11.10	–/+	26
6n	11.10 – 07.11	–/+	27
7n	08.11 – 04.12	–/+	27
8n	05.12	–/+	

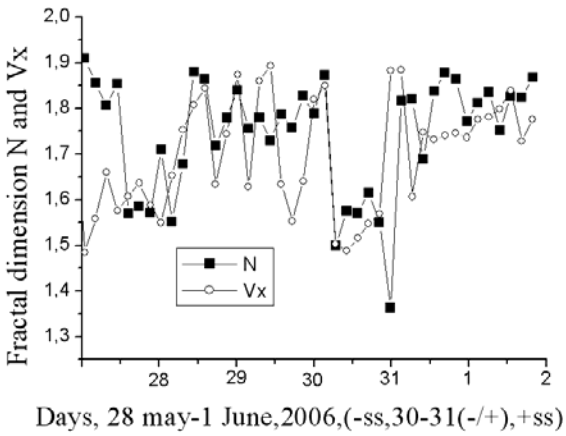

Fig.4. HPL transition had the beginning 30 June 2006 (ACE date of transition (-/+) – 31 June 2006).

4. FD calculations and its characteristics

The method by Higuchi [Higuchi, 1988] was used for FD calculations. This method is suitable for treating the physical parameter series; it gives the opportunity to make FD calculations for sufficiently long individual data intervals. Such intervals should have a steady time resolution without the gap of data absence. The computational procedure was described in our paper [Val'chuk et al., 2004]. The time series of SW parameters N and V_x were treated in the same way: one point calculation window equals to 6 hours (220 parameter measurements), the step is one half of the window and it equals to 3 hours.
The first situation in Fig.1 is characterized with the high-speed stream, followed by the double HPL transition. In the high speed stream of 19-23 March 2005 FD has high values ~1.7-1.9. In the situation of HPL transition FD falls to 1.4-1.5, showing a sharp diminishing of FD. During the interpreting of the second situation in Fig.2 we take into account, that HPL 1 (4 June 2006) do not have the authentic

transition. There was a little intrusion of negative polarity in (+) IMF sector. The second transition (6 June 2006) was true, the polarity changed from (+) to (-). The third situation in Fig.3 presents the first appearance of (–) IMF polarity in the initial phase. Fig.4 shows the case of HPL transition followed by SW high-speed stream.

5. Discussion and conclusion

The Sun as a physical object has the known hierarchic system of magnetic fields, transforming continuously in the solar atmosphere. Layers of solar atmosphere (photosphere, chromosphere, transition layer and corona) represent the plasma medium, which is available for wide-ranging observations in different wavelengths in space projects ACE, SOHO, Yohkoh, TRACE, CORONAS, LASCO and other. The upper hierarchic magnetic fields of the solar corona present a system of arcades and arcs, which contain the high temperature coronal plasma. Coronal holes (CH) are valuable long-lived phenomena, producing high-speed streams of solar wind (SW). Sporadic short-lived phenomena of solar activity (flares, coronal mass ejections, filament eruptions) introduce to the picture of long-lived phenomena (solar spots, active regions, background fields, CHs, heliospheric plasma layers) ancillary complexity during diagnostics of solar wind variations. Radial escaping of solar wind with interplanetary magnetic field beyond 10 R_{Sun} all over the space of the heliosphere is the manifestation of open solar magnetosphere. The fractal method is widely adapted to the investigation of solar atmosphere phenomena (sunspots, flares). Solar magnetosphere characteristics may be studied by means of fractal dimension calculations of plasma and IMF parameters of solar wind near the Earth. In our early papers we performed calculations of fractal dimension of high speed SW flows from equatorial and trans-equatorial CHs. That fractal dimension value equals ~ 1.7-1.9.

In the present paper we choose the heliosphere plasma layer as a subject of investigations. Fractal characteristics of HPL were calculated in the minimum of solar cycle 23. The transition of heliosphere plasma layer is revealed as the deep FD fall down to 1.5 in the most cases. The sharp decrease of the FD is the feature of another fractal structure in HPL region.

It may be concluded, that FD values reflected the HPL transition in the characteristic manner. If the geophysical disturbance is not valuable, the FD pictures are similar to each other, showing the FD falls, connected with HPL transition. SW plasma is the fractal medium, reflecting in FD the sector structure transitions.

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