OUTER HELIOSPHERE: A FIRST ATTEMPT OF MAGNETIC FIELD SPECTRA DETERMINATION FROM VOYAGERS DATA

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Summary The Voyager spacecrafts (V1-V2) are providing unique measurements of plasma and magnetic field at the helioshpere edge. We compare the magnetic field measured from the Voyagers inside the heliosheath (HS) (V1 years 2004-2012, V2 year 2007-). Observations of high variations of energetic particle fluxes at V2, recently suggested the existence of two regions with distinct magnetic field features: the SHS (sectored heliosheath), where the magnetic field alternates the polarity due to the current sheet flapping and piling up as the heliopause is approached, and the UHS (unipolar heliosheath) which extends outside the SHS, where the magnetic field polarity is constant. We present here the first magnetic field power spectra computation inside the heliosheath. The spectra differ in both anisotropy and inertial decay rate. The difference cannot be explained in terms of the different physics supposedly present in the sectored and unipolar regions.

Both the Voyagers have crossed the termination shock entering the heliosheath (V1 in December 2004 [13], V2 in August 2007 [10] . In this region, many observations are not completely understood [12, 8]. One of these is the difference observed by V1 and V2 in the flux of both energetic ions and electrons (ions: kinetic energy from about 40 KeV to >1 GeV (Galactic Cosmic Rays) and electrons: from about 50 KeV to >100 MeV) [6]. In particular, while particle fluxes time histories seen by V1 were almost constant in the period 2007-2012, those recorded by V2 showed variations with an amplitude 50 times larger. According to Hill et al. [6], possible physical interpretations to explain the enhancement or depression of energetic particle intensity are related to the Helioshperic Current Sheet (HCS) maximum latitudinal extensions. These northern and southern boundaries enclose the socalled sectored heliosheath region (SHS), where the magnetic field changes polarity as the HCS is crossed, according to the Parker spiral structure. At higher North and South latitudes, outside the sector region, the heliosheath is unipolar (UHS), see fig. 1. Traveling at a latitude of about 30° S, V2 is thought to have crossed different times the boundary of the SHS, and a correlation was found between the energetic particle flux at V2 and the alternation of unipolar and sectored zones crossed by V2. Different particle transport properties are expected in these regions. Opher et al. [9] suggested that in the SHS region the magnetic field was not laminar but disordered and turbulent, with the sector structure being replaced by a sea of nested magnetic islands. These bubbles would take origin from magnetic reconnection processes occurring near the heliopause, triggered by the compression of sectors and by the narrowing of the HCS (see Drake et al. [2]). Different scenarios may coexist, for instance the presence of magnetic reconnection or turbulence in the SHS can as well increase the ions and electrons transport.

We are here interested in analyzing the magnetic field fluctuations in the two different SHS and UHS heliosheath regions, see fig.1. We consider the highest resolution of recorded data (48-s averages) from this NASA mission [7] and we compute power spectra by exploiting a proper data gap treatment developed inside this group [5, 4]. The data gap problem arises from the fact that data can be lost due to telecommunication issues, noise, instrumental interferences and other reasons.

We consider four magnetic field ($\mathbf{B}$) datasets in the interval 2009-2012. In particular, for V1 we analyze the sequences 2009 DOY 1 - 2009 DOY 180 (A1) and 2010 DOY 180 - 2011 DOY 180 (B1). V1 is supposed to be in the SHS in this two periods, even if the constancy of polarity of $\mathbf{B}$ suggests that V1 remained within just one sector, see the azimuthal angle variations in fig 2a, and [1]. For V2, we choose the interval 2009 DOY 219 - 2010 DOY 180 (A2), when V2 was inside the unipolar region and measured a low flux of energetic particles, and the period 2010 DOY 255 - 2011 DOY 256 (B2), when V2 was in the SHS measuring an enhanced particles intensity. The power spectra of the magnetic energy and of the field components of $\mathbf{B}$ in the heliographic reference system for A1, A2, B1, B2, are shown in panels (c,d,e,f), respectively.

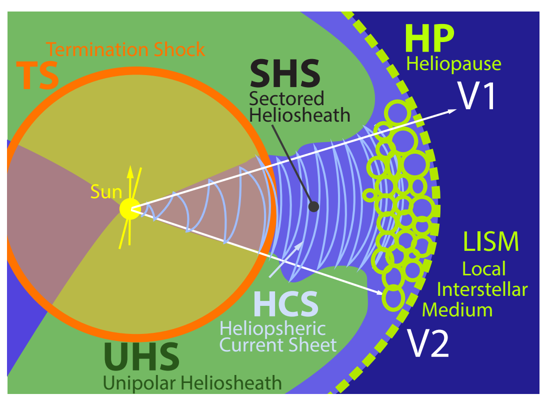

Figure 1: Qualitative scheme of the heliosphere

A few aspects are common to all spectra. They show a mild algebraic decay in the low-frequency range ($f < 10^{-5}$ Hz) a steeper algebraic decay in the intermediate range (about $10^{-5} < f < 3 \cdot 10^{-4}$ Hz) and a hi-frequency range ($3 \cdot 10^{-4} < f < 10^{-2}$ Hz) where the decay is likely affected by the accuracy of the magnetometers, which is around 0.03 nT. Concerning the magnetic energy fluctuation, in the low frequency range, spectral slopes are within

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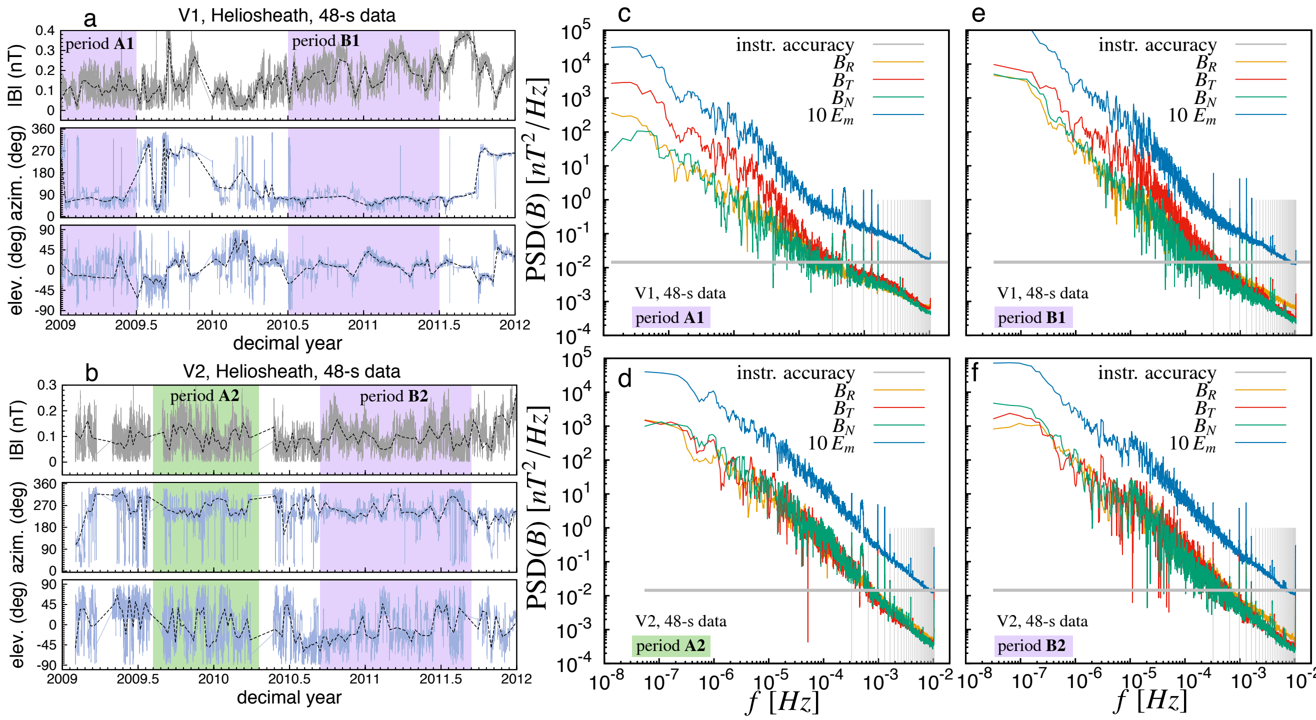

Figure 2: (**a**,**b**) Magnetic field module, azimuthal angle and elevation angle for V1 (top) and V2 (bottom). SHS periods are highlighted in purple (A1, B1, B2) and UHS periods in green (A2). (**c**,**d**) Magnetic field components and energy spectra during A1 and A2. All the spectra have been computed with the *compressed sensing* methodology, already tested in [4]. Vertical grey lines indicate probably instrumental-related peaks, harmonics of $2.3 \cdot 10^{-4}$ Hz. (**e**,**f**) Magnetic field spectra during the periods B1 and B2.

-1.24 ± 0.2 for both crafts and all the periods observed. However, in the portion of inertial range $10^{-5} < f < 3 \cdot 10^{-4}$ Hz, V1 and V2 show important differences which at this stage of knowledge seem associated to the different structures of the fluctuation of the field orientation. In particular, for the Voyager 1, either when located at the boundary between UHS and SHS or inside one single sector, the fluctuations level of the azimuthal and elevation angles is very low and their 48-s averages are constant. For V2 instead, both inside the unipolar period A2 and in sectored period B2 the orientation fluctuation is much more intense. These signal differences are reflected in a different structure of the spectra: the slope for V1 is 2.0 ± 0.19 while V2 shows a spectral decay of 1.68 ± 0.2, closer to the Kolmogorov value. By looking at the components, high anisotropy is observed by V1, where the tangential component is dominant and decays much faster than the radial and normal components a fact which is not observed by V2. In particular, the anisotropy can be observed in fig. 2a (B signal) and in fig. 2 c,e (power spectra). The anisotropy level in 2009 was $\sigma^2_{B_T}/\sigma^2_{B_R} = 10.5$, $\sigma^2_{B_T}/\sigma^2_{B_N} = 11.6$ while in 2011-2012 it reduced to 4.6 and 4, respectively. Spectrally this anisotropy is highlighted by the different decays showed by the normal and radial components (~ -1.5) and the tangential component (~ -2), see fig.2 c,e. By contrast, confer in fig. 2d,f, the nearly isotropic behavior as sensed by V2. It should be noted, in conclusion, that the highly different magnetic field structure we obtain by observing the solar wind along the Voyager different paths cannot be simply explained from being in or out the sectored heliosheath. For example, the V2 path seems to enter the unipolar region (A2) first and then the sectored region (B2), however, the signal and related spectra remain alike.

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