ACE/Wind multispacecraft analysis of the magnetic correlation in the solar wind

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Abstract: The propagation of galactic and solar cosmic rays in the solar wind (SW) can be strongly influenced by the SW fluctuations properties. Magnetohydrodynamic (MHD) scale fluctuations in the solar wind are usually highly anisotropic, and have also been found to exhibit different properties in regions of high and low solar wind speed. Previous studies analyzed the anisotropy properties of the solar wind magnetic fluctuations at scales of the order of $(10^5 - 10^6)$ km (inertial range) from two-times/single-point (assuming the Taylor frozen-in hypothesis), and found that the fluctuations in the fast solar wind present a trend to having wave numbers with their parallel (to the mean magnetic field) larger than the perpendicular one, while the fluctuations in the slow wind present the opossite trend. In the present study we present a comparison of the self-magnetic correlation function in the solar wind between two-times/one-point observations (from a single spacecraft) and one-time/two-points observations (from simultaneous observations of two spacecrafts, observing the pure spatial structures). We compare also previous results of the anisotropy of the solar wind fluctuations, obtained from a single spacecraft, with our new multispacecraft analysis using combining observations of the spacecrafts ACE and Wind.

Introduction

Theories of scattering of energetic solar particles in the heliosphere [2] and solar modulation of galactic cosmic rays [9] require knowledge of turbulence parameters to express particle diffusion coefficients.

In particular several theories (as the quasi-linear theory [3]) need the correlation of the turbulent magnetic fields as an input that describe the cosmic-rays transport

It is known that the presence of a uniform 'direct current' (constant in space and time) magnetic field ($\mathbf{B_0}$) in a turbulent MHD system develops spectral anisotropies for isotropic initial conditions (e.g., [7, 10]): high wavenumbers components develop more readily perpendicular to $\mathbf{B_0}$ than those parallel to it.

Of the various descriptions of anisotropic wave and turbulence properties of the solar wind, the so-called 'Maltese cross' [5] illustrates level contours of the magnetic self correlation which are seen to have a cross-like pattern when plotted in a 2D plane where one of the axes is parallel to the magnetic field. There is a lobe along each axis. A suggestive but oversimplified interpretation is the presence of two components or populations: slab-like fluctuations (with wavevectors mainly parallel to the mean field) and quasi-2D-like fluctuations (having mainly perpendicular wave vectors).

Unidirectionally propagating Alfvén waves correspond to values of the normalized cross helicity (σ_c) equal to +1 or -1, depending of the sense of the propagation, while high levels of turbulence are usually accompanied by a value of σ_c close to zero (see, e.g., [11], and references therein). From an analysis of 5 years of solar wind data (one minute of time cadence) measured by the spacecraft ACE on the Sun-Earth line at 1AU, [6] shown that σ_c is roughly isotropic in the inertial range, a result plausible with similar levels of turbulence for the 'slab-like' population and for the 'quasi-2D-like' one. Using the same sample of solar wind data, [1] found that at scales of the order of $(10^5 - 10^6)$ km (i.e., the inertial range) the fluctuations in the fast (younger) solar wind present a trend to having wave numbers with their parallel (to the mean magnetic field) larger than the perpendicular one, while the fluctuations in the slow (older) wind present the opposite trend; these observations support the existence of an spectral transfer from wavevectors parallel to the perpendicular ones, during the evolution of the solar wind turbulence.

All these previous studies are based on single spacecraft (SSC, using two-times/one-point) observations. Because the solar wind speed is much larger than the local Alfvén/sound speeds, the spatial correlation function can be measured in the direction of the flow direction (i.e., the solar wind fluctuations are convected in the reference frame of the spacecraft in a short time compared with the characteristic time scale of the variation of the fluctuations).

Recently a few studies on the spatial dependence of the magnetic correlation function in the solar wind from two spacecrafts (TSC, using two-point/single-time) were done [4, 8, 12] using data from the Cluster fleet. However, comparison between the previous studies (using the single spacecrafts) and the new approach have not been done yet.

In the present work we present a comparison of magnetic correlation functions in the solar wind obtained from a SSC with those obtained from TSC. We also present some preliminary results from the analysis of the anisotropy of the magnetic fluctuations at the inertial range scales ($\sim 10^5 - 10^6$ km).

Data analysis, results, and preliminary conclusions

We analyze observations of the magnetic field measured by the Advanced Composition Explorer (ACE) and Wind spacecrafts, using the same samples (intervals of one day of duration, with a time cadence of one minute) than those used by [4]. Thus, we analyze here the solar wind observations that correspond to a distance of ~ 1 AU from the Sun, and essentially on the ecliptic plane.

Our main goal is to compute two-point correlations of the form

$$R_b(\mathbf{r}) = < \mathbf{b}(\mathbf{0}, t) \cdot \mathbf{b}(\mathbf{r}, t) > \qquad (1)$$

Note that Equation 1 is the trace of the usual two-point correlation tensor for the magnetic field, where spatial and temporal translation symmetries were assumed. $\mathbf{b}$ represents the fluctuating magnetic field, and we will study the variance-normalized correlations, with the normalization factor as: $R_b^{norm}(0) = < \mathbf{b} \cdot \mathbf{b} >$, as done in [6, 1, 4]. For simplicity of notation, we omit the "$norm$" label hereafter. The SSC correlations were computed as described in [6, 1], while the TSC correlations as described in [4].

In this preliminary work we compare Rb obtained from SSC and MSC for the interval having the minimum angle (α) between the relative positions between ACE and Wind, and the Sun-Earth line (to can compare the spatial correlation in the same direction of the spatial lag from SSC and TSC), which for the analyzed interval is $\alpha = 3°$. This interval corresponds to the full day of Oct 4, 1999. The separation distance between the ACE and Wind is $199 R_E$ ($R_E = 6378$km, is the Earth radius).

Figure 1 shows a comparison of Rb using ACE-SSC (solid line), Wind-SSC (dashed line), and both ACE/Wind-TSC (asterisk). The mean value of the two SSC observations ($Rb_{ACE-SSC}$ and $Rb_{ACE-SCS}$) at a separation of $199 R_E$ (the separation between ACE and Wind) resulted 0.16, while $Rb_{ACE/Wind-TSC} = 0.23$; that means that the TSC-SSC ratio, at spatial scales of $\sim 200 R_E \sim 10^6$km, is $Rb_{TSC}/Rb_{SSC} \sim 30\%$.

In order to analyze the anisotropy of Rb, we split the full set of analyzed intervals according with three angular channels for the angle (θ) between the direction of the spatial lag, given by the relative positions between ACE and Wind, and the mean magnetic field (B_0): $0^0 \leq \theta_1 < 25^0$, $40^0 \leq \theta_2 < 50^0$, and $65^0 \leq \theta_3 < 90^0$.

ICRC 2007 Proceedings - Pre-Conference Edition

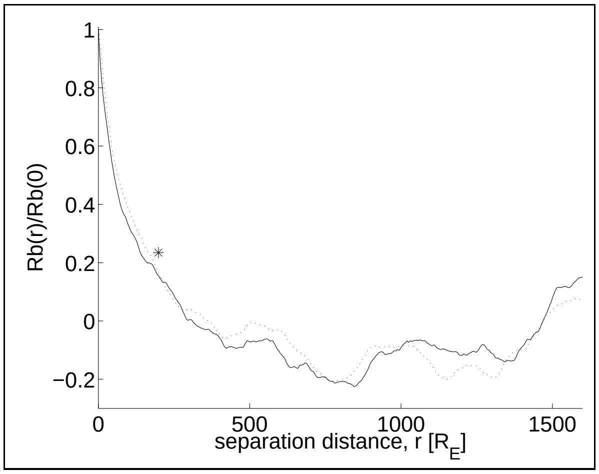

Figure 1: Comparison of Rb from ACE-SSC (solid line), Wind-SSC (dashed line), and ACE/Wind-TSC (asterisk).

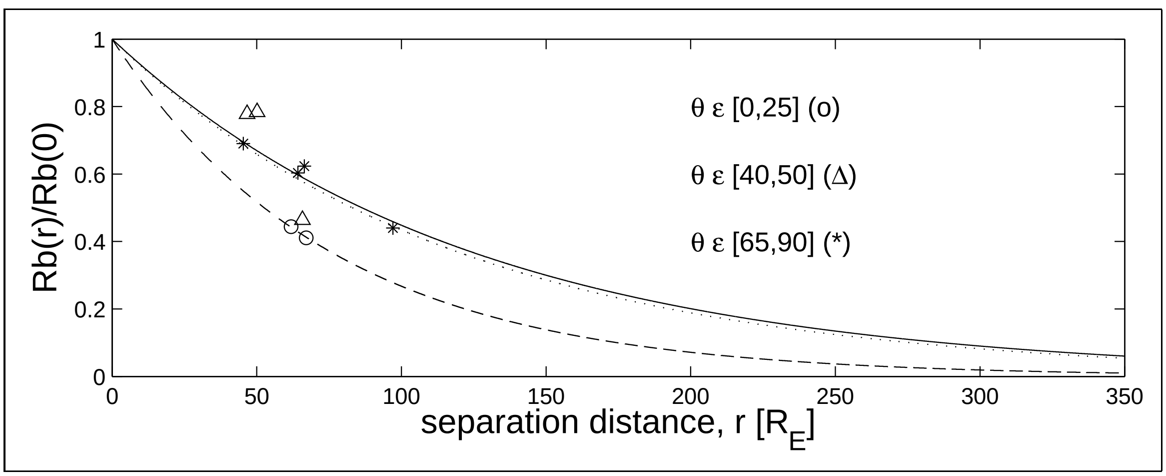

Figure 2: Observations of Rb from ACE/Wind-TSC for fast solar wind for different angular channels between the spatial lag direction and B_0. Exponential fit is included to each angular channel (dashed line for θ_1, dotted line for θ_2, and solid line for θ_3).

Because from SSC in previous studies there were only a few intervals for fast solar wind, in this first stage of the study, we select only faster solar wind intervals ($V_{SW} > 470$ km/sec). Figure 2 shows the normalized Rb, only from TSC for fast solar wind and for different angular channels: symbol *o* to represent θ_1 (spatial lag parallel to the mean field B_0), symbol Δ to represent θ_2 (spatial lag at intermediate angles respect to B_0), and symbol $*$ to represent θ_3 (spatial lag perpendicular to B_0). It is possible to observe that Rb for θ_1 is significantly lower than the value obtained for the other two directions, a result consistent with a fast solar wind having a more important population of 'slab-like' fluctuations than 'quasi-2D-like' ones.

We also compute the correlations lengths (λ^c) (computed as in [6, 1]) to Rb, considering each of the angular channels. We obtained $\lambda_1^c = 4.8 \times 10^5$km, $\lambda_2^c = 7.7 \times 10^5$km, and $\lambda_3^c = 8.0 \times 10^5$km. Thus, our result is consistent with the correlation scales obtained previously for the mixed solar wind (all angular channels and all speeds) by [4] ($\lambda^c \sim 10^6$km).

We presented here a preliminary analysis that compares Rb from SSC and TSC, and using only TSC we analyzed the anisotropy of the fast solar wind fluctuations. We resist to the temptation of drawing any major conclusion from the anisotropy study because it is necessary to make an analysis of more samples, ranging a larger angular set of bins. We plan to extend our research and publish our final results elsewhere. In the meantime, we believe that the physics involved in this research project will help to achieve a better understanding of the solar wind fluctuations and its influence on the cosmic rays propagation in the heliosphere.

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