Three dimensional power spectra in the solar wind at 1AU

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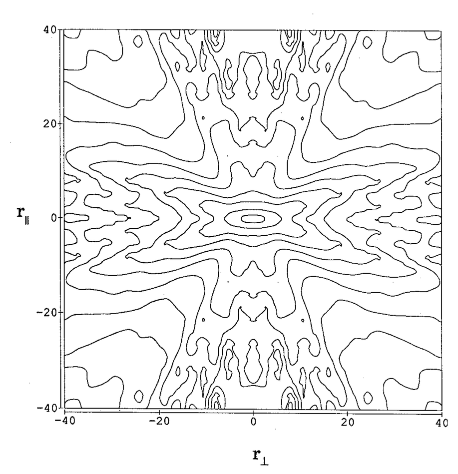
Abstract

Observations and theory motivate the study of possible anisotropy in the turbulent fluctuations of the solar wind, with respect to the large-scale magnetic field. We analize data from the ACE specraft, at 1AU, essentially in the ecliptic plane. We present an analysis of reduced spectra for the helicity, velocity, magnetic and Elsasser fluctuations, at different orientations with respect to the mean magnetic field. The implications to standard models of the solar wind fluctuations are briefly discussed. This work was in part supported by the NASA grants NNG04GA54G and NAG5-11603, Argentinean UBA grant UBACyT X329, Argentinean CONICET grants PIP 2693 and PIP 2388, and FONCyT-ANPCyT grant PICT 12187. S.D. is a member of the Carrera del Investigador Científico, CONICET.

Motivation



On the left, the maltese-cross diagram for magnetic self-correlations (Matthaeus et.al. JGR 1990), suggesting a 2 component ("slab" + "⊥ turbulent") structure. Our goal is to understand:

- Spectral anisotropy in solar wind turbulence.
- Co-existance of "parallel-waves" and "perpendicular-turbulence"

The Data

- We use ACE data (ecliptic plane 1AU).
- 1 minute cadence values for velocity and magnetic fields.
- Range of time analyzed: from 23-Jan-1998 to 30-Jun-2002.

The Technique

- We group our data in 4 days intervals.
- In each interval we define fluctuations as follows:

$$\frac{\mathbf{B}}{\sqrt{4\pi\rho}} = \mathbf{V}_A + \delta\mathbf{b}, \qquad \mathbf{v} = \mathbf{U}_0 + \delta\mathbf{v}, \qquad \mathbf{z}^{\pm} = \delta\mathbf{v} \pm \delta\mathbf{b}$$

where $\mathbf{U}_0$ and $\mathbf{V}_A$ are the linear trends for a given interval, except to the radial (from the Sun) component of the velocity, where $\mathbf{U}_0$ is the cubic trend.

- We define correlation functions as usual. For example:

$$R_{vv}(r) = \langle \mathbf{v}(\mathbf{x}) \cdot \mathbf{v}(\mathbf{x} + \mathbf{r}) \rangle \qquad (1)$$

Analogous definitions hold for R_{bb}, R_{++} and R_{--}.

Data Analysis - Angular Average

- $\mathbf{V_0}$ gives the direction of the lag $\mathbf{r}$. In order to analyze the anisotropy of the fluctuations, we select each interval according to the value of the angle (θ) between $\mathbf{B_0}$ and $\mathbf{V_0}$. Thus, we can carry out conditioned averages for those intervals which correspond to a given range of θ.
- We normalize $R(r)$ in each interval as $R(r) \longrightarrow \tilde{R}(r) = R(r)/R(r=0)$, so that $\tilde{R}(r=0) = 1$.
- The maximum lag taken, when $R(r)$ is calculated, corresponds to two days.
- For each interval we obtain a particular correlation function; making averages of these functions, selecting them according θ, we obtain conditioned means for $R(r)$.
- In each interval, we determine whether $\mathbf{z}^+$ is "incident" and $\mathbf{z}^-$ is "outgoing", or the other way around. We then average all the "incident" correlation functions together, (and all the "outgoing" together as well), and determine the average R_{++} and R_{--}.
- We define $R_{vb} = (R_{out} - R_{in})/4$.

Correlation Function Iso-Contours

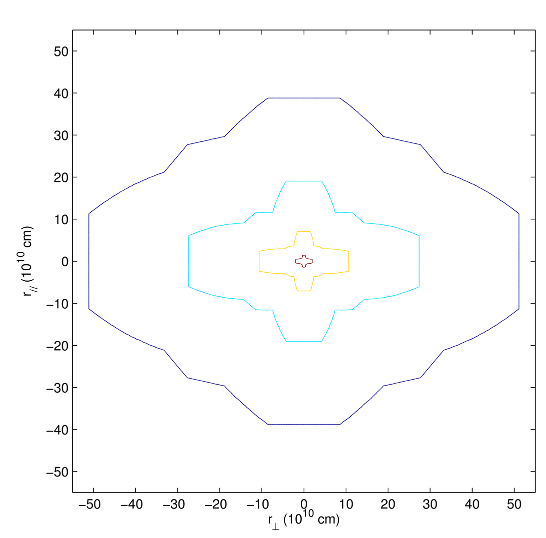


Figure 1: Velocity self-correlations levels at [1,1.5,2,2.5] 10^3 km^2/s^2.

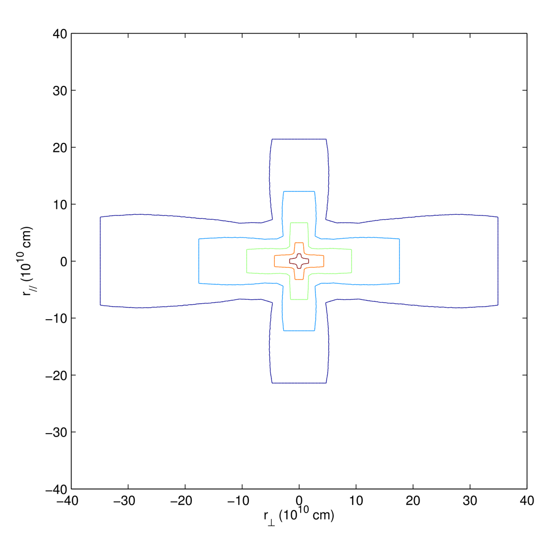


Figure 2: Cross helicity self-correlations, levels at [2,3,4,5,6] 10^2 km^2/s^2.

The magnetic self correlations, not shown here, are very similar to the cross helicity correlations. The important result is that *the cross helicity also has a Maltese-cross structure.*

Alfvén Ratio & Normalized Cross Helicity Spectra

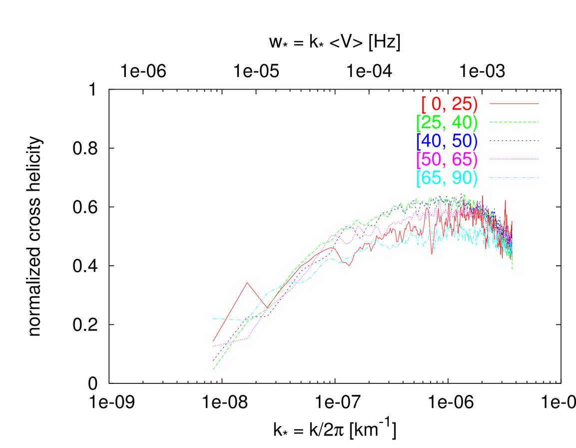


Figure 3: The normalized cross-helicity, $H_c(k)/4E(k)$.

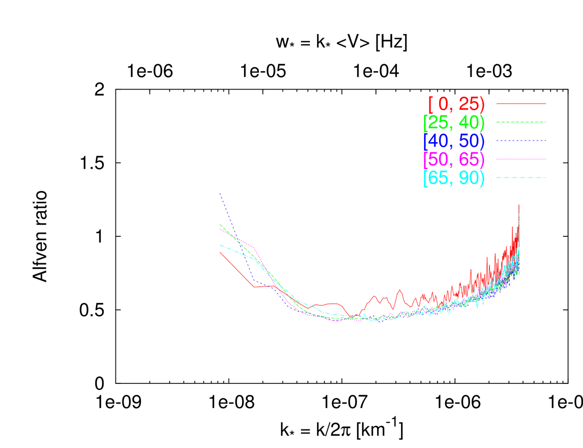


Figure 4: The Alfvén ratio $E^v(k)/E^b(k)$

These figures suggest that *the strength of the non-linearities is important in all directions in wave-vector space.*

Conclusions

- The magnetic self correlations are consistent with Matthaeus et al 1990.
- The cross helicity too is highly anisotropic, and in almost exactly the same way.
- Somewhat remarkably, the normalized Alfvénic correlation, is about equally present in all the analyzed spectral components.
- This observational result rules out any model in which the Alfvénic correlation is concentrated in a particular angular part of the spectrum – such as either the wave-like or quasi-2D component separately.
- *Our results imply a strong coupling between parallel ("wave") and perpendicular ("turbulence") components.*
- While a component description may be useful for some applications, it seems clear that at a fundamental level solar wind turbulence is acting like a single entity.