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Observing MHD turbulence in the solar wind

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Abstract. Solar wind MHD turbulence can be described as a mixture of inward and outward stochastic Alfvénic fluctuations, including also convected structures, dominated by an excess of magnetic energy. This study focuses on the role that magnetically dominated fluctuations have within the solar wind turbulence. This kind of fluctuations can be interpreted as non-propagating structures, advected by the wind during its expansion. In particular, observations performed in the ecliptic revealed a clear radial dependence of these magnetic structures within fast wind, but not within slow wind. At short heliocentric distances (0.3AU), the turbulent population is largely dominated by Alfvénic fluctuations characterised by high values of normalised cross-helicity and a remarkable level of energy equipartition. However, as the wind expands, another population, characterised by lower values of Alfvénicity and a clear imbalance in favour of magnetic energy becomes visible and clearly distinguishable from the Alfvénic population.

Key words. Solar wind: turbulence – Solar wind: Alfvénic fluctuations – Solar wind: magnetic structures

1. Introduction

Belcher & Davis (1971) introduced, for the first time, the concept that propagating Alfvén modes could be intermixed with static structures advected by the solar wind. This idea came out from the observational evidence that Alfvénic correlations were less pure within slow velocity regions compared to high velocity streams. Detailed studies performed by Matthaeus et al. (1990) on the two-dimensional correlation function of solar wind fluctuations at 1AU showed that interplanetary turbulence was made of two primary ingredients, namely slab (Alfvénic) fluctuations (mostly coming from fast wind) and 2-D turbulence (coming from slow wind). Tu & Marsch (1993) suggested the possibility of an interplanetary turbulence mainly

Send offprint requests to: R. D'Amicis made of outwardly propagating Alfvén waves and advected structures represented by the so called Magnetic Field Directional Turnings (MFDTs).

2. Statistical studies on solar wind MHD turbulence

The first statistical studies on magnetically dominated structures, based on high latitude Ulysses observations, were presented by Bavassano et al. (1998). These authors used the normalised cross-helicity $\sigma_C = (e^+ - e^-)/(e^+ + e^-)$ and the normalised residual energy $\sigma_R = (e^v - e^b)/(e^v + e^b)$ as statistical tools, where e^+, e^- are the energy associated to z^+ and z^- modes respectively, while e^v and e^b are the kinetic and magnetic energies, respectively. In principle, for Alfvénic fluctuations we expect to find $\sigma_C = 1$ because of the δv-δb alignment and $\sigma_R = 0$, because of equipartition. These authors found that the MHD scales are mainly made of outward Alfvénic modes and fluctuations characterised by a magnetic energy excess and low Alfvénicity.

Successively, Bruno et al. (2007) studied the radial evolution of solar wind MHD turbulence and found that magnetically dominated structures represent a remarkable component of the interplanetary MHD fluctuations. Observations in the ecliptic and out of the ecliptic showed that these advected, mostly uncompressive structures are ubiquitous in the heliosphere and can be found in both fast and slow wind while, as we know from literature (see review by Bruno & Carbone 2005), Alfvénic fluctuations outwardly propagating strongly characterise fast wind but are rather negligible in slow wind. In particular, Helios 2 observations revealed a clear radial dependence of these magnetic structures within fast wind, but not within slow wind. At short heliocentric distances (0.3 AU), the turbulent population is largely dominated by Alfvénic fluctuations characterised by high values of σ_C and a rather good level of energy equipartition ($\sigma_R \sim 0$). However, as the wind expands, another population, characterised by lower values of σ_C and higher negative values of σ_R becomes visible. Helios observations show that a new peak, located at $\sigma_C \sim 0$ and $\sigma_R \sim -1$, clearly appears in the distribution by the time the s/c reaches 1 AU. It has been suggested that these structures might be a signature of the crossing of the border between adjacent flux tubes (Bruno et al. 2001; Bruno & Carbone 2005). It is possible the these advected structures are already present in the fast wind, close to the sun, but they are masked by large amplitude Alfvénic fluctuations which dominate fast wind fluctuations at short heliocentric distances.

In any case, we cannot judge whether these convected structures reflect the complicated magnetic topology observed at the sun's surface or can be considered as a by-product of turbulent phenomena (Chang et al. 2004) which develops during the wind expansion. It might be possible that solar and local origin can coexist in the interplanetary space, but this would be established only when new space missions like Solar-Orbiter will allow us to disentangle spatial from temporal effects. In conclusion, we like to point out that the possibility of a solar origin of the coherent component of solar wind turbulence underlines intrinsic differences between MHD turbulence in the solar wind and the phenomenology of homogeneous, isotropic, fully developed turbulence in neutral fluids, where the non-linear dynamics itself is the only source of coherent structures.

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