SF2A 2008
C. Charbonnel, F. Combes and R. Samadi (eds)

TURBULENCE IN ANISOTROPIC HELIOSPHERIC PLASMAS

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Abstract.
An alternative approach to Direct Numerical Simulations (DNS) of Magnetohydrodynamics (MHD) is presented, providing insight into the statistical properties of highly-turbulent, intermittent, anisotropic MHD turbulence: a set of shell-models coupled by Alfvén waves travelling along the axial magnetic field and which interact non-linearly, producing perpendicular fluctuations of the fields at small scales. This model can be applied to different physical situations; we present the cases of heating in solar coronal loops, and of turbulence in open coronal regions at the base of the solar wind.

1 Introduction

Because of the complexity of the nonlinear physics of MHD, and the very wide range of scales involved in MHD turbulence at the large Reynolds numbers found in space plasmas, direct numerical simulations meet strong limitations due to their computational cost: they have a low resolution (unable to describe the full range of scales) and they are very slow. For this reason, alternative approaches of numerical modelling must be sought, such as cellular automata (e.g., Lu & Hamilton 1991; see Buchlin et al. 2003 for an application to solar coronal loops) and shell-models. In shell-models (Gledzer 1973; Giuliani & Carbone 1998), the nonlinear terms of MHD are simplified by assuming local triad interactions between modes, which are scalar values for the velocity and magnetic fields in concentric shells in Fourier space. They allow to simulate MHD at high Reynolds numbers ($> 10^6$) while retaining the full dynamics of the evolution of the turbulent spectra. Using shell-models, we have developed a model of MHD turbulence that can be applied to different anisotropic plasmas, such as coronal loops and the solar wind.

2 Case of a coronal loop

In this model which is fully described in Buchlin & Velli (2007), shell-models for MHD in two dimensions are piled up along the axial magnetic field of a coronal loop. The boundary conditions are given as a velocity field imposed at the photosphere, and Alfvén waves travel along the loop. The turbulent cascade transports the energy (which is injected at large scales) towards the small scales, where it is dissipated intermittently (Fig. 1); the average power of dissipation is of the order of 10^2 to $10^3\ \mathrm{W \cdot m^{-2}}$, which is enough to heat a loop, and it is concentrated near the footpoints if the expansion of the loop with altitude is considered.

3 Case of a coronal hole and the solar wind

In order to model magnetically open regions such as coronal holes and the solar wind, several modifications of the coronal loop model have been performed: one of the boundaries is now open, the incoming waves are only produced by a reflection of the outgoing waves by Alfvén speed gradients, a wind (imposed) advects the waves, and the computing grid is non-uniform (allowing to extend the computation to 50 solar radii). We get the amplitudes of Alfvén waves, the power of heating (Fig. 2), and the spectra of turbulent fluctuations, as a function of position.

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4 Conclusion

These models, which provide results unattainable by direct numerical simulations, show that heating following a MHD turbulent cascade is a viable mechanism for heating coronal loops. In coronal holes, this heating could provide a contribution to the acceleration of solar wind.

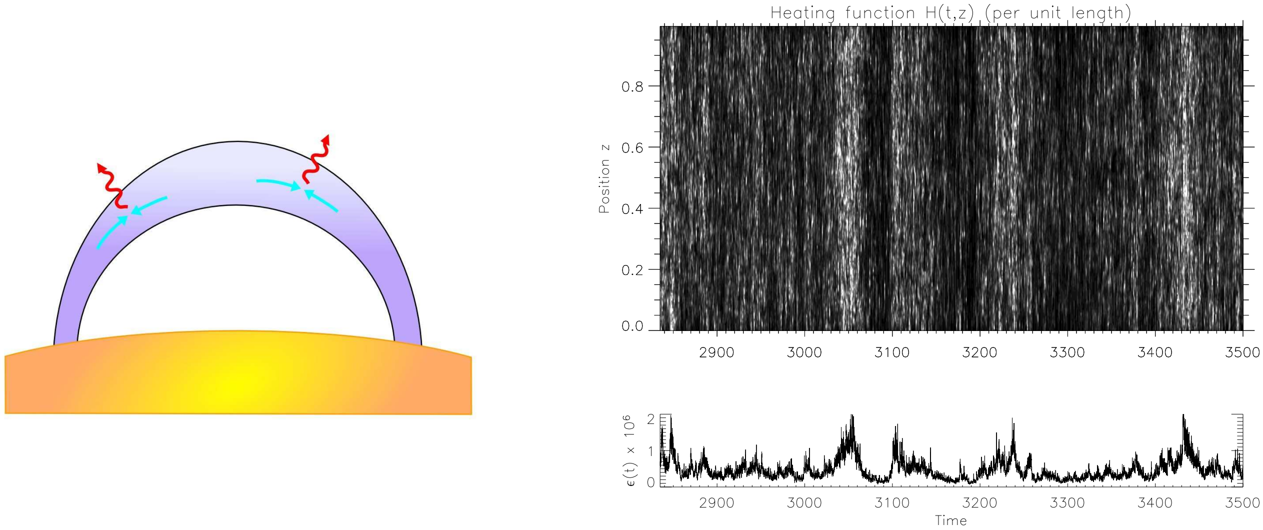

Fig. 1. Left: geometry of a coronal loop. Right: heating in a as a function of time (in seconds) and position along the loop (with the loop length of 10 Mm as unit).

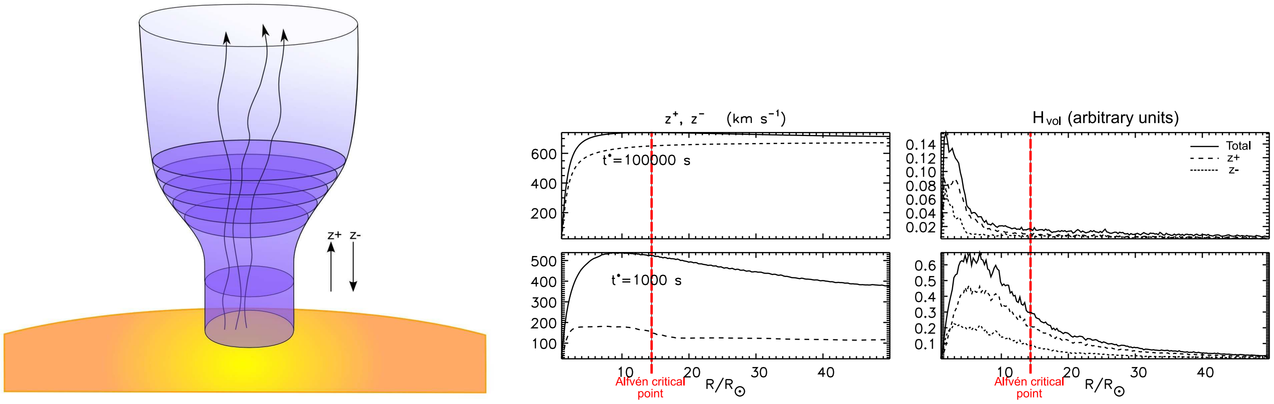

Fig. 2. Left: geometry of a coronal hole. Right: average amplitude of the waves and power of heating as a function of position.

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