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Using a shell turbulence model to describe the evolution of the solar wind spectrum

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The solar wind is a key link in the Sun-Earth system, but neither the physics of its formation nor the physics of its evolution are yet completely clear. This fact was the main reason for the launch in 2018 of a special satellite mission, Parker Solar Probe (PSP), largely focused on the issue of solar wind research. Over the first five years of operation, this mission provided specialists with a huge influx of new data with high temporal resolution and large variations in heliocentric distances. In particular, it made it possible to study in detail the spectra of fluctuations of solar wind fields: the velocity field and the magnetic field, and to take a new look at the turbulent cascade formed in interplanetary plasma.

PSP data confirmed the previously discovered presence in the picture of the spectral density of magnetic field energy fluctuations of two breaks, the first of which is located near the subionic scale, the other at the left end of the inertial interval, that is, in the region of large-scale vortices. There is no consensus on the evolution of these markers yet, so at the moment, studying the dynamics of these kinks, which limit the inertial interval and determine the turbulent cascade, is key. And if to describe a near-dissipative fracture it seems necessary to use a kinetic approach, then the evolution of a large-scale fracture can apparently be described while remaining within the framework of the magnetohydrodynamic paradigm. In this paper, using PSP mission data as a basis, we describe the free evolution of a turbulent cascade using a shell isotropic MHD model and try to reproduce the actually observed evolution of the spectral break.

To describe the turbulent cascade, we use the shell model, or, in other words, the cascade model developed by F. Plunian and P.G. Freak. The class of shell models for hydrodynamic type systems is the Fourier images of a system of MHD equations, in which the images of nonlinear terms are approximated by the sum of quadratic nonlinearities in such a way that in the non-dissipative case the three-dimensional MHD conservation laws are satisfied: conservation of total energy, magnetic and cross helicity. In this case, the continuous spectral scale is replaced by a set of discrete spectral shells, and the nonlinear terms take into account the exchange of energy only between neighboring shells. In this approach, we use PSP data near the Sun as input and study, in the process of free evolution of the turbulent cascade, the possible evolution of the spectra and the dynamics of the motion of a large-scale break. The obtained results of cascade modeling are compared with PSP data on the Sun-Earth axis and, based on the comparison, a conclusion is drawn about the applicability of shell analysis and the free degeneracy hypothesis.

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