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Coherent structures and complexity-entropy in space plasma turbulence

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Solar wind is a natural laboratory for the study of fully-developed space plasma turbulence and magnetic reconnection. Turbulence in fluids and plasmas can be regarded as a complex distribution of coherent structures coexisting with random fluctuations. The magnetic-field turbulence in the solar wind is characterized by power spectra with power-law scaling and spectral index nearly -5/3, non-Gaussian fluctuations at small scales, and amplitude-phase synchronization among scales.

Magnetic reconnection in plasmas refers to the process in which magnetic energy is converted to particle kinetic and thermal energy, resulting in a change of topology of the magnetic-field lines [1, 2, 3]. The study of magnetic reconnection is key to understand the dynamics of solar flares, coronal mass ejections, rope-rope magnetic reconnection in the solar wind, and the interaction between solar wind and planetary magnetospheres. Magnetic reconnection, turbulence, and intermittency in plasmas are intrinsically related in a complex manner, and innovative analysis techniques developed for complex systems can provide important insights for understanding space plasmas [4].

We analyze observational data of magnetic-field fluctuations within a magnetic reconnection exhaust detected in the solar wind at 1 AU. The interplanetary magnetic field is decomposed into the LMN coordinates using the hybrid minimum variance technique. By computing the Jensen-Shannon complexity-entropy index, we show that coherent structures are responsible for an increase of intermittency, decrease of entropy, and increase of complexity. Moreover, the L component of the magnetic field displays a higher degree of intermittency, lower entropy, and higher complexity than the M and the N components. Our results confirm that magnetic-field turbulence within reconnection exhausts is intermittent with various levels of multifractality in different directions, suggesting that nontrivial coherent structures are responsible for varying degrees of entropy and complexity [5].

In addition, we study numerical simulations of a simplified model of turbulence induced by drift waves in plasmas. Depending on the value of a control parameter related to adiabaticity, the spatiotemporal patterns display a transition from a vortex-dominated regime to a regime dominated by a large-scale coherent structure. We analyze the spatiotemporal patterns based on the Jensen-Shannon index implemented using shearlets, which is a multiscale resolution analysis, and demonstrate that the large-scale coherent structure leads to a decrease of entropy and increase of complexity, in agreement with our observational results.

The detection of coherent structures such as vortices in turbulent fluids and plasmas can contribute for the understanding of the dynamics of space plasmas [6]. We apply geodesic theory to detect objective Lagrangian vortices in a simplified model of resistive drift-wave turbulence in plasmas. and analyze their contribution to the total kinetic energy and enstrophy. These results can contribute to our understanding of the role of coherent structures in intermittent space plasma turbulence.

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