Coherent Structures and Complexity-Entropy in Intermittent Plasma Turbulence

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The solar wind is a natural laboratory for the study of turbulence in plasmas. The power spectrum of magnetic field fluctuations in the interplanetary solar wind displays an inertial subrange with power-law scaling and spectral index of -5/3, which is indicative of a turbulent state. The magnetic field turbulence displays intermittency evidenced by probability distribution functions that become non-Gaussian with decreasing scale (Sorriso-Valvo et al., 2001; Koga et al., 2007; Chian and Miranda, 2009). The intermittent nature of the turbulent magnetic field is also responsible for the departure from self-similarity of magnetic field fluctuations (Carbone et al., 1995; Chian and Miranda, 2009; Miranda et al., 2013), and amplitude-phase synchronization among scales (Chian and Miranda, 2009; Chian et al., 2016). Intermittency within the inertial subrange is due to the presence of coherent structures which dominate the statistics of fluctuations at small scales. In addition, turbulence in plasma is intrinsically related to magnetic reconnection, in which magnetic energy is converted into kinetic and thermal energy in a complex manner, resulting in a change of topology in the magnetic field lines (Yamada et al., 2010).

The Jensen-Shannon (J-S) complexity-entropy index is a statistical tool that allows to distinguish noise from chaos in a time series (Rosso et al., 2007). The J-S index of interplanetary magnetic field data displays high entropy and low complexity, similar to stochastic signals (Weck et al., 2015; Weygand & Kivelson, 2019). Here we demonstrate that coherent structures are responsible for the decrease of disorder and the increase of complexity in turbulent plasmas. We apply the Jensen-Shannon entropy-complexity index of magnetic field data within reconnection exhausts detected in the solar wind at 1 AU (Miranda et al., 2021). We also compute the normalized Shannon entropy to the spatiotemporal patterns of the magnetic field obtained from numerical simulations of a three-dimensional incompressible MHD model of Keplerian shear flows (Miranda et al., 2015). Our results show that coherent structures are responsible for decreasing entropy and increasing complexity in turbulent plasmas.

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