5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Observational quantification of three-dimensional anisotropies and scaling of kinetic Alfven turbulence

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The energy distribution in wave number space is known to be anisotropic in many turbulent space plasmas environments, featuring $k_\perp > k_\parallel$ with respect to the background magnetic field $\boldsymbol{B}_0$. For kinetic scale turbulence, the standard kinetic Alfven turbulence model predicted a scaling of $k_\parallel \propto k_\perp^{1/3}$, whereas recent models suggested different relations (i.e. $k_\parallel \propto k_\perp^{2/3}$ and $k_\parallel \propto k_\perp^{3/3}$) by considering the effects of intermittency, tearing instability, and magnetic reconnection (i.e., Boldyrev & Perez 2012; Boldyrev & Loureiro 2019). Great attention was devoted to this issue in the latest numerical simulations. For example, Cerri et al. 2019 obtained a converging result of $k_\parallel \propto k_\perp^{2/3}$ based on analysis of five-point structure functions (SFs). As compared with two-point SFs, the five-point SFs have been proved to be more accurate in describing the anisotropy in recent simulations.

Utilizing similar five-point SFs method, a statistical survey of turbulence anisotropy at sub-ion scales (1-100 km) is conducted in the Earth's magnetosheath based on Magnetospheric Multiscale measurements during 2015-2020. By equating the SFs at three directions defined with respect to $\boldsymbol{B}_0$, abundant evidence of 3D anisotropy has been revealed, where the characteristic lengths of the 'statistical eddies' exhibit $l_\parallel > L_\perp > l_\perp$ signatures. Furthermore, the empirical anisotropy relations for the total, perpendicular, and parallel magnetic field fluctuations are fitted as $l_\parallel \sim l_\perp^{0.71\pm0.03}$, $L_\perp \sim l_\perp^{1.08\pm0.01}$; $l_\parallel \sim l_\perp^{0.69\pm0.03}$, $L_\perp \sim l_\perp^{1.13\pm0.02}$; $l_\parallel \sim l_\perp^{0.69\pm0.04}$, $L_\perp \sim l_\perp^{1.01\pm0.01}$ at scales within [0.1, 1] ion inertial lengths. Over 30% of the events in the data set exhibit scaling relations close to $l_\parallel \propto l_\perp^{2/3}$ (see Figure 1).

Applying the same methods to data from Parker Solar Probe, the anisotropy of solar wind turbulence in the inner heliosphere is investigated in a following study. The observational anisotropy relation is obtained as $l_\parallel \sim l_\perp^{0.71\pm0.17}$ in the transition range and changes to $l_\parallel \sim l_\perp^{0.38\pm0.09}$ in the kinetic range (see Figure 2).

These results provide new observational constraints to be further compared with phenomenological models and numerical simulations, which may enrich our knowledge of spectral anisotropy in kinetic Alfven turbulence.

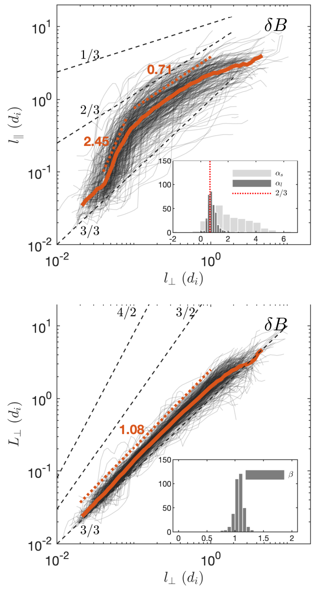

Figure 1. Statistical result of the wavevector anisotropy in the magnetosheath turbulence.

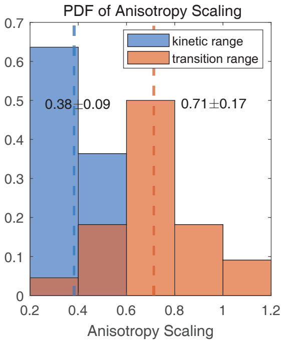

Figure 2. Statistical result of the wavevector anisotropy in the solar wind turbulence.

References

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