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The wave characteristics of kinetic-scale solar wind turbulence and their impact on the spectra: PSP observations

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Kinetic-scale solar wind turbulence is believed to play a crucial role in the turbulent energy dissipation, and identifying the dissipation processes at work requires unraveling the plasma wave modes dominating the cascade. Using the reduced (fluctuating) magnetic helicity diagnostic, we discovered that the solar wind observed by the Parker Solar Probe (PSP) in the inner heliosphere usually exhibits coexisting kinetic Alfvén waves (KAWs) and Alfvén ion cyclotron waves (ACWs) at kinetic scales.[1] Figure 1 exhibits the statistical joint distribution of the reduced magnetic helicity σ_m in $f-\theta_{RB}$ space, here θ_{RB} measures the directions of the local magnetic field. The signatures of quasi-parallel left-handed polarization ACWs ($\sigma_m > 0$ at $\theta_{RB} > 150°$) and quasi-perpendicular right-handed polarization KAWs ($\sigma_m < 0$ at $60° < \theta_{RB} < 130°$) can be clearly identified at frequencies near the ion characteristic frequencies.

Further analysis reveals that for solar wind in the inner heliosphere, the magnetic spectra at kinetic scales often exhibits an exceptionally steep transition range, with spectral indices varying between −5.7 and −3, which are significantly steeper than those observed at ion-to-electron scales (−2.8 to −2.4).[2] Moreover, the turbulent energy transfer demonstrates distinctly different anisotropic scaling laws in the transition range compared to ion-to-electron scales.[3] While across both scale ranges, the spectra of parallel magnetic field fluctuations always exhibit a steeper slope compared to their perpendicular counterpart.

By integrating diagnostics of turbulent wave modes and anisotropy, we find that the anisotropic characteristics of kinetic-scale solar wind turbulence are likely to be controlled by the nature wave modes that carry the cascade. [4] As shown in Figure 2, compared with the trend of the spectral index and σ_m, one can see that the positive magnetic helicities are always accompanied by steeper spectra. In contrast, the negative magnetic helicities correspond to smaller spectral indices. This suggests a correlation between the presence of quasi-parallel left-handed (ACW) fluctuations and the steep spectra at kinetic scales, while flatter ones seem to correlate with quasi-perpendicular right-handed (KAW) fluctuations.

References
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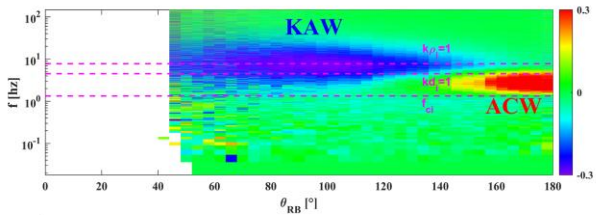

Figure 1. The distributions of the reduced magnetic helicity σ_m in the $f-\theta_{RB}$ space.[1]

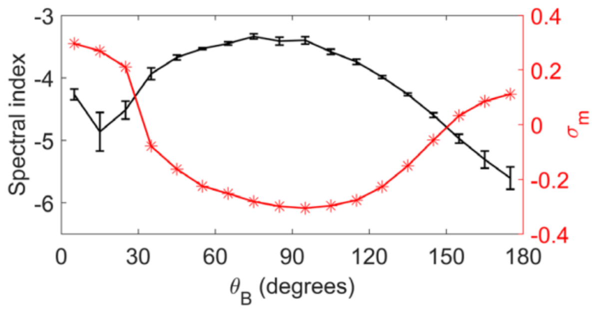

Figure 2. Angular variations of the spectral index (black curves) and the reduced magnetic helicity σ_m (red curves) at kinetic scales.[4]