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Three-wave synthetic nature of turbulence from ion-scales down to sub-electron scales in the magnetosheath

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The nature of plasma turbulence remains unclear at kinetic scales, especially sub electron scales. We simultaneously investigate spectra of magnetic and electric fields from proton scales ($\sim$1 Hz) down to sub-electron scales ($\sim$1 kHz) using MMS1 measurements in the magnetosheath turbulence. We find that magnetic field spectra exhibit identical behavior between ion characteristic scales and electron inertial scale, while bifurcate at about 30 Hz (around electron inertial scale) and then aggregate around 1 kHz (around electron gyrofrequency). Kinetic Alfvén waves (KAWs) are identified in the range from 1 Hz to 30 Hz: (1) the power spectral indices of PSD(B) and PSD(E) are about -3 and -1; (2) parallel magnetic and electric fluctuations are present but subdominant. Magnetic field spectra downstream the quasi-perpendicular bow shock show a clear spectral enhancement, which is identified as quasi-parallel whistler waves (WWs). Electric field spectra present a wide bulge around 800Hz, which is also seen as island-like patterns in the time-period wavelet spectra. The electric field spectral enhancement is dominated by field-parallel fluctuations and is, therefore, diagnosed as ion acoustic waves (IAWs). We also perform a quantitative analysis of the multiple mode types using polarization predictions from two-fluid theory. We obtain the energy partition of electromagnetic fields for different wave modes and successfully reproduce the observed PSDs of $B\perp$,$B\parallel$, $E\perp$, and $E\parallel$. We conclude that: (1) PSD($B\perp$) is mainly related to KAWs and WWs at frequencies below and above 30 Hz; (2) PSD($B\parallel$) is primarily determined by KAWs throughout the investigated frequency range; (3) PSD($E\perp$) is mainly determined by KAWs with a secondary contribution from WWs in the full frequency range; (4) PSD($E\parallel$) is mainly determined by IAWs with a secondary contribution from KAWs. Our findings suggest that the magnetosheath turbulence consists of a mixture of multiple wave modes (KAW, WW, and IAW) in the range from sub-ion scales to sub-electron scales.