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Kinetic generation of whistler waves in the turbulent magnetosheath

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Whistler waves, right-hand polarized waves with frequencies below the electron cyclotron frequency, are common in many space plasma regions such as the Earth's magnetosheath. They can be generated by electron temperature anisotropy, in which case the instability grows through cyclotron resonance. A common way to determine the stability of an electron distribution function is to compare the parallel and perpendicular temperature (with respect to the background magnetic field) to stability thresholds. However, such an approach based on the moments of the distribution function can potentially leave out some properties of the distribution which are important for wave generation.

In this work, we investigate the features of the electron distribution functions measured by MMS in the turbulent magnetosheath downstream of a quasi-parallel shock. We show that even though statistically whistler waves tend to occur close to the regions where the stability threshold is exceeded, they are also observed in regions predicted to be stable to wave generation. For such waves we observe that the electron pitch angle distribution often has the so-called butterfly shape (with minima in both the parallel and perpendicular directions) and is located in magnetic field minima. Using a linear numerical dispersion solver (WHAMP), we show that the butterfly distribution is unstable to whistler wave generation even though the instability threshold based on the associated moments is not exceeded. Comparison between the numerical results and waves measured by the MMS spacecraft indicate that the observed whistler waves are generated by the butterfly distribution. This phenomenon has previously been observed in mirror modes and large scale magnetic holes. Our findings show that it also occurs on smaller scales (~1 ion inertial length) in more turbulent environments, such as the quasi-parallel magnetosheath.