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Study of EMIC Waves using Cluster Observations

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Electromagnetic ion cyclotron (EMIC) waves play a pivotal role in magnetospheric processes: they energize cold electron and ion populations, drive rapid pitch-angle scattering and loss of radiation-belt electrons, and precipitate ring-current ions [1]. EMIC wave power peaks near the plasmapause on the dusk flank during the main phase of geomagnetic storms. Moreover, in the inner magnetosphere—where a cold, dense plasma coexists with an energetic ion population—the conditions are particularly conducive to the preferential excitation of EMIC waves. When hot anisotropic ions $T_\perp > T_\parallel$ intrude into the cold dense plasmasphere, conditions become favorable for the generation of electromagnetic ion cyclotron (EMIC) waves [2]. In particular, plasmaspheric plume formations and intervals of enhanced solar-wind dynamic pressure constitute prime environments for EMIC wave excitation [3].

The investigation of plasma wave dynamics within space environments is fundamental to advancing our understanding of particle energization and energy transfer processes. This study focuses on a detailed analysis of observations of ion waves having low frequencies and their associated ion velocity distribution functions (VDFs) from Earth's magnetosphere and solar wind by the Cluster spacecraft during the recovery phase of the 18 July 2005 geomagnetic storm, particularly within a plasmaspheric plume. At the outer boundary of this plume, electromagnetic ion cyclotron (EMIC) waves were identified, resonantly scattering ring-current ions into the loss cone; a critical process in radiation belt dynamics.

It is essential to employ an observed VDF for superthermal protons in a multi-species plasma to gain deeper understanding of the EMIC instability by deriving real frequency and growth rates. In this study, we present the observed distribution using the Cluster data and fit it with the observed bi-Kappa distribution. We then employ the observed plasma parameters such as density, anisotropy, plasma beta and spectral index kappa to numerically calculate the real frequency and growth rate values.

We present in situ observations of Cluster satellite on July 18, 2005, when it crosses the plasmaspheric plume. It is observed by Cluster C1 that EMIC waves scatter the RC ions in the outer boundary of plasmaspheric plume. We choose a time period when the EMIC waves excited and observed the ion velocity distribution at the time when EMIC waves excitation is at the peak. In the figure below the observed distribution is shown (blue solid circles) which is modelled by the bi-kappa distribution (red solid line).

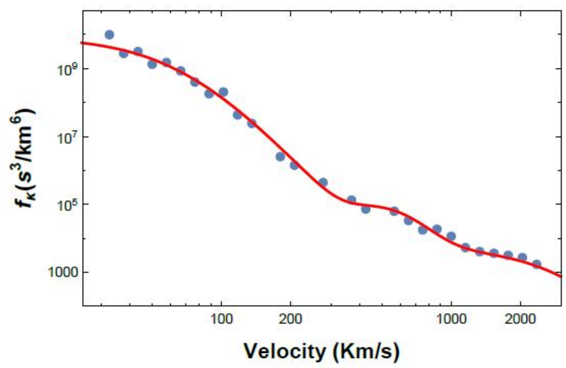

Figure 1: Fitting of the observed distribution with the kappa distribution.

Furthermore, we investigated the influence of realistic ion velocity distributions on EMIC wave growth rates. By directly utilizing observed non-Maxwellian distributions rather than idealized bi-Maxwellian assumptions, we found substantially stronger growth rates, emphasizing the necessity of employing realistic distribution functions in EMIC wave modeling. This work highlights the critical role of precise observational inputs in advancing the theoretical understanding of wave generation and particle dynamics in space plasmas. These observations provide a robust empirical basis for future kinetic simulations and theoretical studies, particularly using Particle-In-Cell (PIC) approaches to model EMIC wave behavior.

References

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