Small Scale Plasma Waves and Heating within Kelvin-Helmholtz Instabilities at Earth's Magnetopause

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Background and Motivation

Earth is protected from charged particles in the solar wind (SW) by its magnetic field, known as the magnetosphere (Figure 1).

Interactions between the SW and magnetosphere can have a wide range of consequences, but our understanding of those interactions is incomplete.

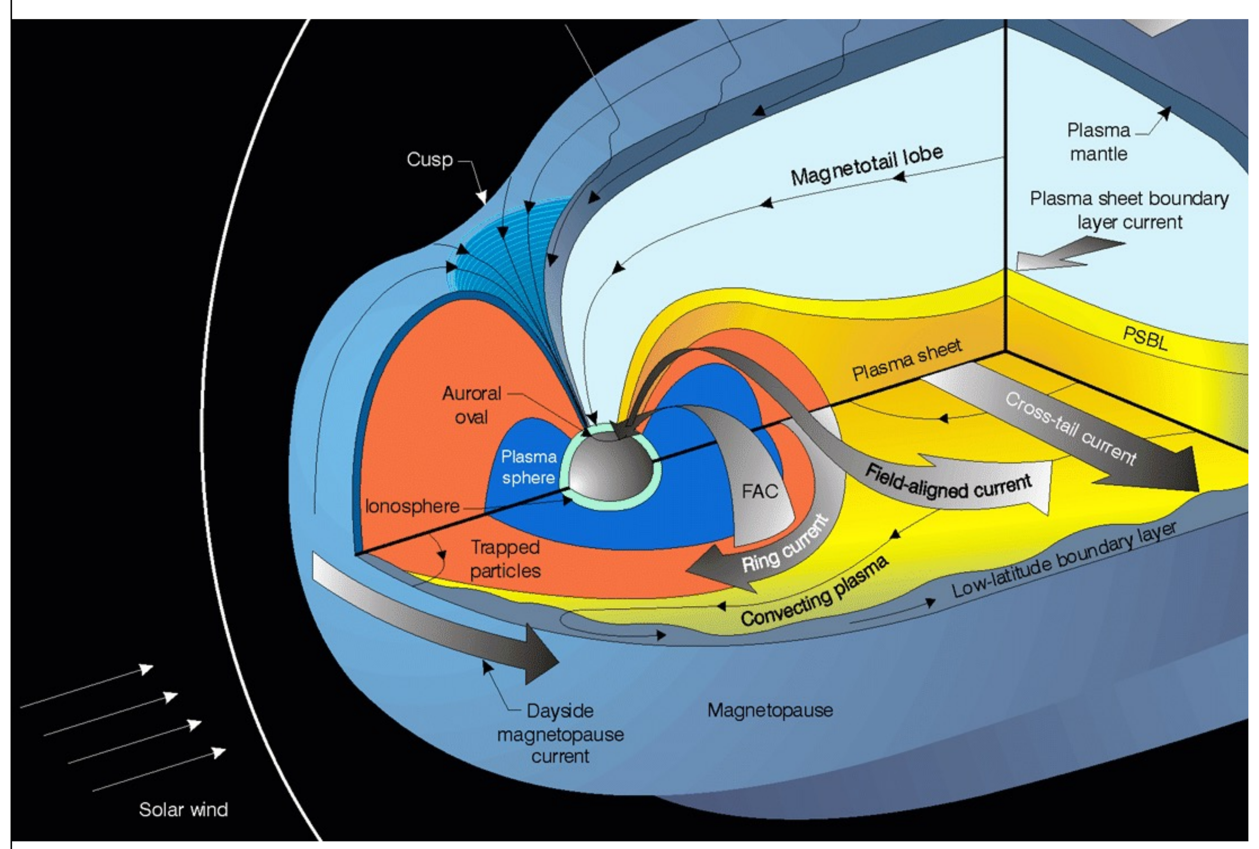

Figure 1: Earth's magnetic field forms a system of currents and plasma known as the magnetosphere which protects Earth from the SW (Pollock et al., *Space Science Reviews,* 2003).

The Kelvin-Helmholtz Instability

The Kelvin-Helmholtz Instability (KHI) develops at regions of large velocity shear, like the boundary between the magnetosphere and the SW (Figure 2), but can be stabilized by the magnetic field.

The KHI is known to drive secondary processes like magnetic reconnection and various wave modes which can contribute to heating SW plasma and transporting it into the magnetosphere.

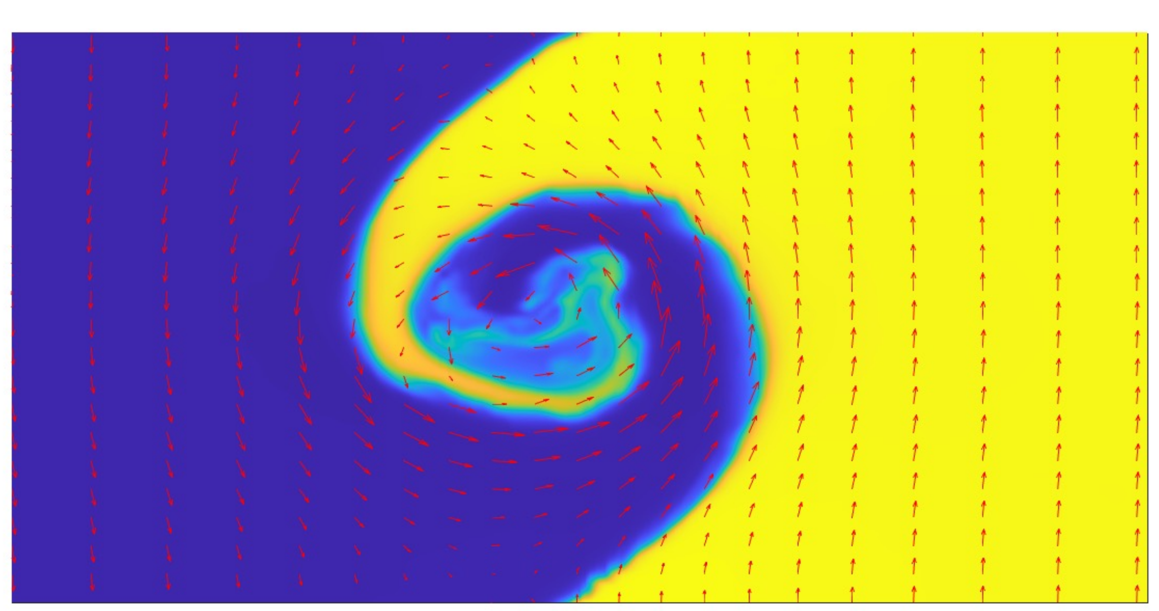

Figure 2: A simulation of the KHI shows a well-developed vortex which mixes plasma of different densities (color) at a velocity shear boundary (red arrows).

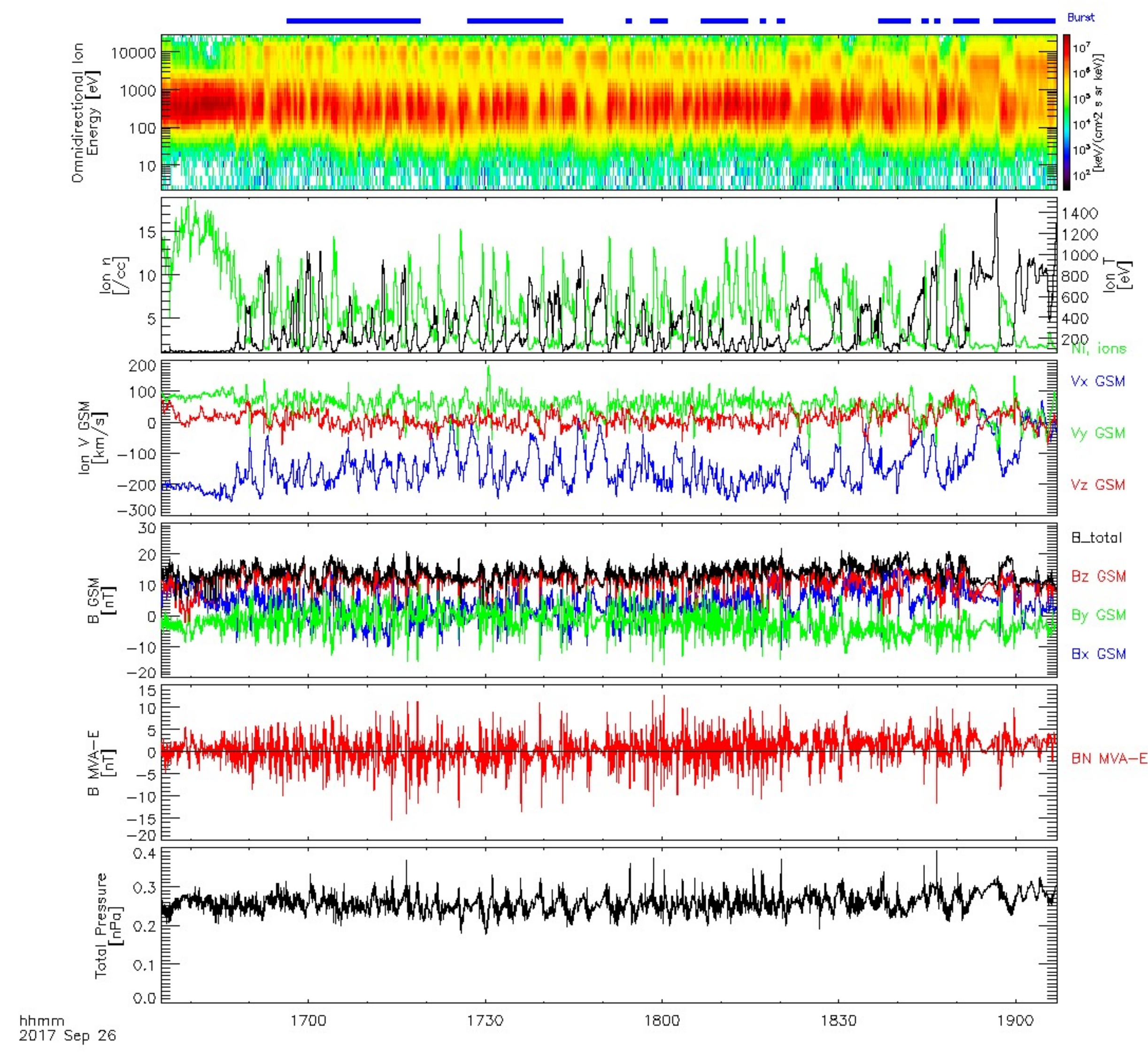

Figure 3: The KHI appears in MMS data as quasi-periodic fluctuations in ion energy, density and temperature, with large velocity shears, fluctuations in total magnetic field which appear as bipolar signatures in the normal component of the magnetic field, and decreases in total pressure corresponding to times when B_N is near 0.

Observations of KHI

The Magnetosphere Multiscale (MMS) mission allows us to study secondary processes within Kelvin-Helmholtz (KH) waves at unprecedently small scales.

MMS observed 45 KH wave events between its launch in 2015 and March 2020 (Figure 3) (Rice et al., *JGR,* Under Review).

We search the database of events for evidence of small-scale wave activity and heating.

Characteristic Heating Frequency

The frequency at which heating takes place is the ratio of Ohmic heating to plasma thermal energy density, which can be measured directly by MMS (with a few assumptions).

For most KHI events, heating frequency is low, sometimes less than 1% of the ion cyclotron frequency.

Heating frequency tends to increase during periods of small-scale wave activity (Figure 5).

Isolating Small Scale Waves

Power spectra of the electric and magnetic field show wave power at frequencies consistent with lower-hybrid waves. Band-pass filtered fields show clearly defined wave packets (Figure 4).

Ion cyclotron and Kinetic Alfvén waves both propagate near or below the ion cyclotron frequency and are left-handed circularly polarized. Hodograms of the magnetic field over the ion cyclotron period show evidence of such waves.

Lower-hybrid, ion cyclotron, and Kinetic Alfvén waves can all contribute to plasma heating across the magnetopause boundary.

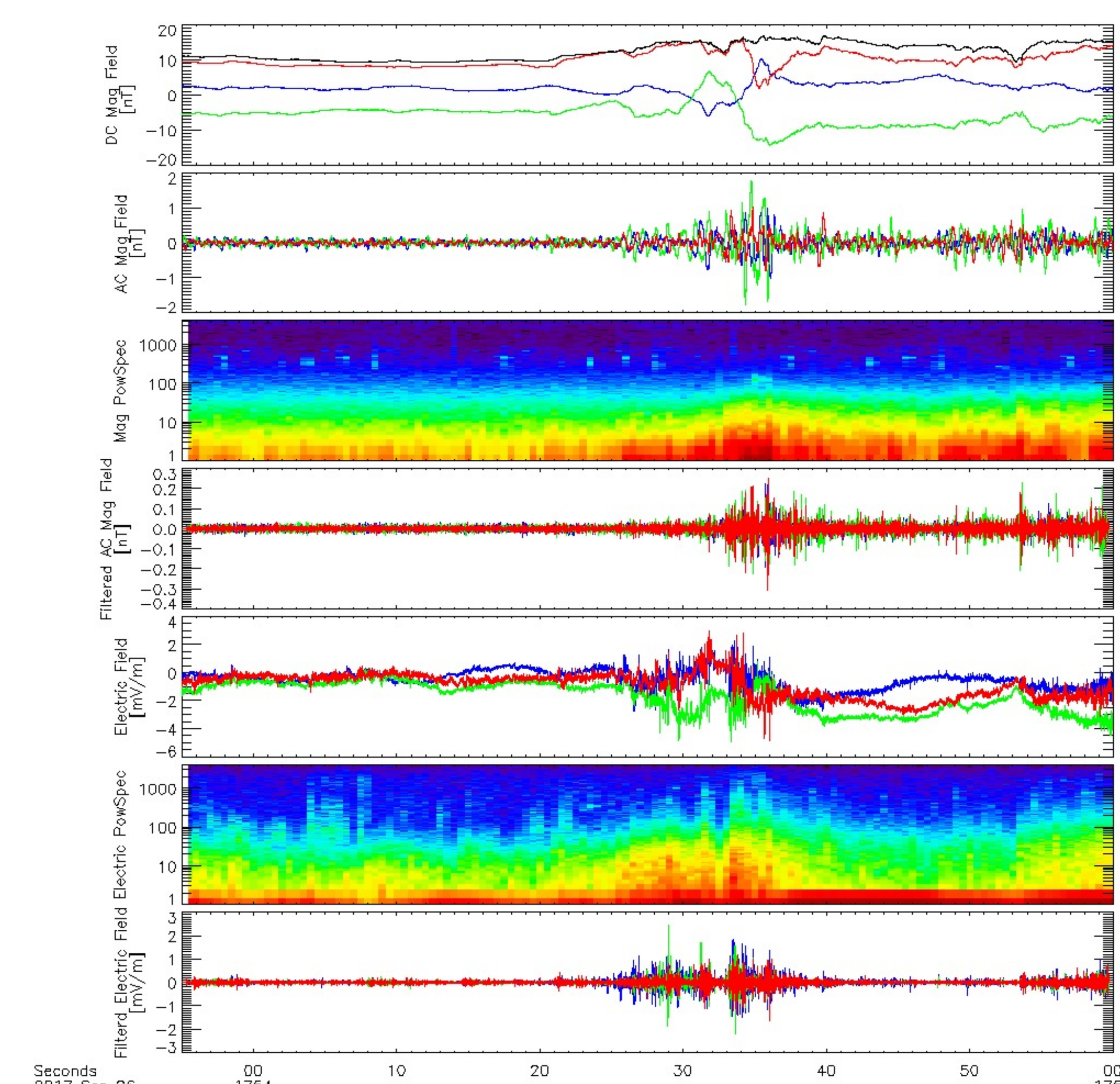

Figure 4: Within a KH wave, we see evidence of smaller scale waves in the magnetic and electric fields and their respective power spectra. Band-pass filtering reveals clear wave packets in the lower-hybrid frequency range.

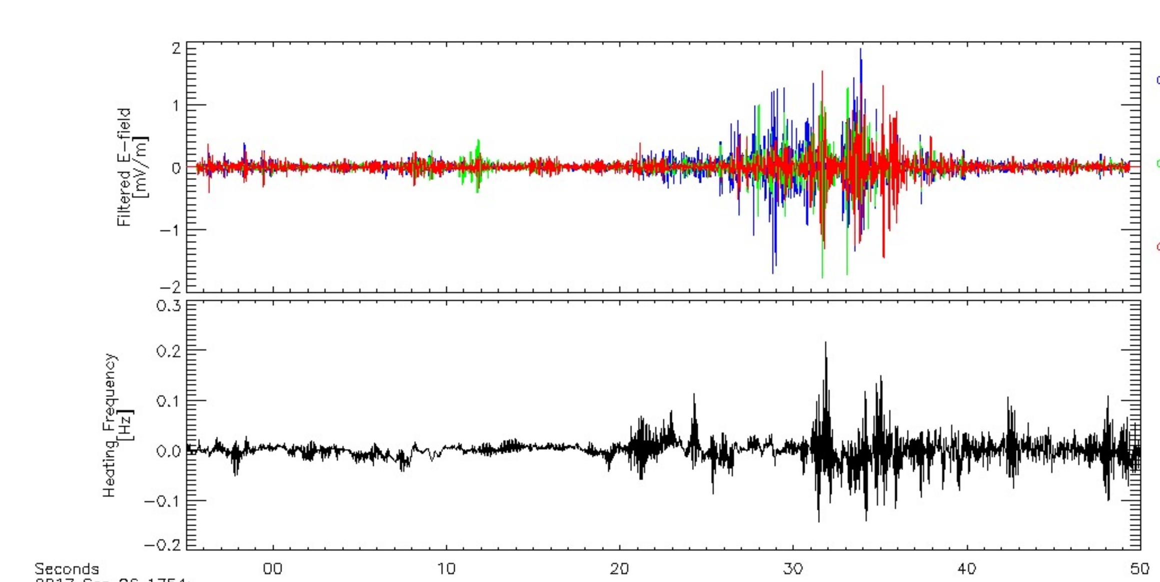

Figure 5: Characteristic heating frequency tends to increase during periods of small-scale wave activity.

Heating in Wave Intervals

The KHI can be broken into periods where wave activity is well polarized. Poynting flux, wave power, and dE/dB ratios can be calculated for those well-defined wave intervals (Figure 6).

Comparison with wave intervals when KHI is not active will be required to fully quantify the small-scale wave heating during KHI.

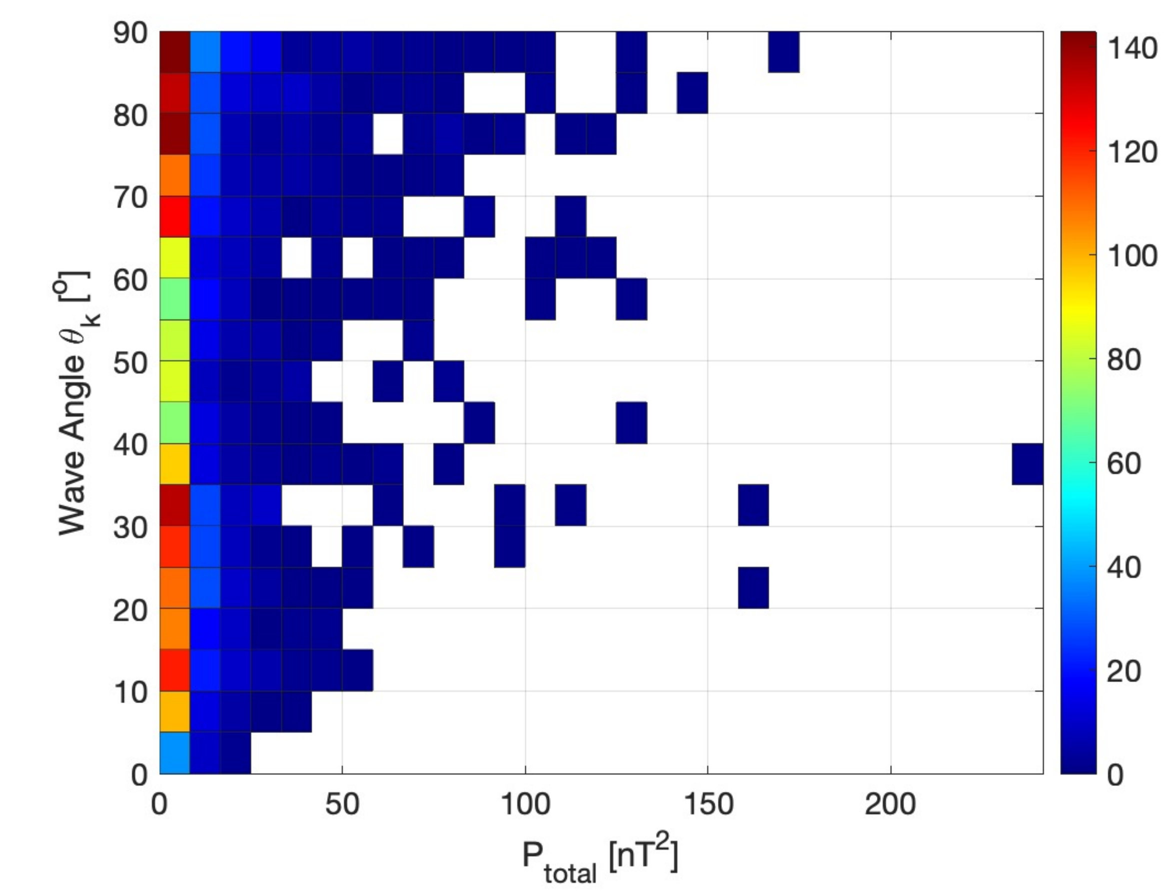

Figure 6: Mean wave power during wave intervals as a function of wave angle. Low power waves dominate, and most often propagate below 30° or above 70° from the background magnetic field.

Conclusions and Forward Work

We see evidence of small-scale waves within KHI at Earth's magnetopause that can contribute to heating SW plasma.

For the event shown here, there is evidence of heating with increased efficiency during small-scale wave activity.

We will extend the analysis of heating within small-scale wave intervals to all 45 KHI events in the database.

Comparison of the heating and wave activity during KHI and times without KHI can quantify the KHI's contribution to heating across the magnetopause.

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