Low Frequency MHD Waves in the Magnetosheath-Magnetopause

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The primary focus of this proposal is to study low frequency waves at the magnetopause and magnetosheath. In particular, it is of interest to understand the nature of the waves and their role in transport processes at the magnetopause. One third of the funding of this proposal also is directed at understanding solar eruptive phenomena. Four topics are described below.

(I) Kinetic Alfvén Waves at the Magnetopause

Because ultra-low frequency (ULF) waves (with frequencies below 500 mHz) dominate the spectrum of nearly every magnetopause crossing, it is expected that those waves should play an important role in the transport processes that occur at the magnetopause boundary. In Figure 1 we show a typical magnetopause crossing with significant low frequency wave activity at the magnetopause which is characterized by a sharp transition in polarization.

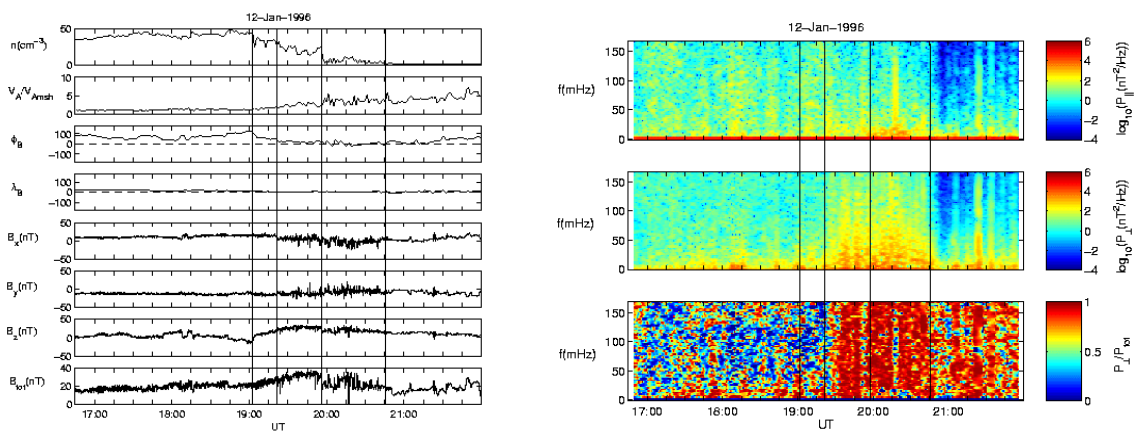

Figure 1. Data from a magnetopause crossing by the WIND satellite on Jan 12, 1996 from 19:20 UT to 19:55 UT. In the left panel, plasma and magnetic field data are shown (density, Alfvén velocity, and magnetic field). ϕ is the magnetic field vector angle in the LM plane and λ the angle between the magnetic field and magnetopause tangent plane for an LMN boundary normal system. The wave spectral power is shown in the right hand panel where $P_\perp$, $P_{||}$, and P_{tot} are the power spectral densities of $|\delta B_\perp|^2$, $|\delta B_{||}|^2$, and $|\delta \mathbf{B}|^2$. Also shown is the fraction of wave power in transverse waves.

Recently, we performed theory/data comparisons that suggest that ULF waves at the magnetopause result from a mode conversion process which transforms compressional MHD waves that originate in the magnetosheath into transverse kinetic Alfvén waves (KAWs) near a field-line resonance location. The mode conversion process can explain (a) a change in wave polarization at the magnetopause and (b) the amplification of the

transverse magnetic field component by an order of magnitude which is clearly seen in the second panel of Figure 1. Because the interplanetary magnetic field changes orientation regularly, it is possible to characterize the magnetopause wave activity as a function of magnetic shear (defined to be the angle between the magnetic field in the magnetosheath and the magnetic field on the magnetospheric side of the magnetopause). Because the mode conversion process exhibits a strong dependence on this magnetic field rotation theory/data comparisons of expected wave signatures can be used effectively as a test of the mode conversion process. Data for the comparison was taken from the ISEE1, ISEE2 and WIND spacecrafts. Thirteen magnetopause crossings were considered where sizeable compressional magnetic field fluctuations were found in the magnetosheath. These cases provided good coverage of the magnetic rotation angle from 0 to 180 degrees. Windowed magnetic power spectra were obtained for parallel and transverse magnetic fluctuations during each crossing. The magnetosheath and magnetopause spectra were compared for each crossing to quantify the wave amplification for each crossing. From the study, it was deduced that (1) the transverse wave component at the magnetopause is not significantly amplified below a threshold magnetic shear angle (approximately 50 degrees), (2) greatest amplification is for magnetic shear between 70 and 180 degrees, and (3) waves with higher frequencies are less amplified.

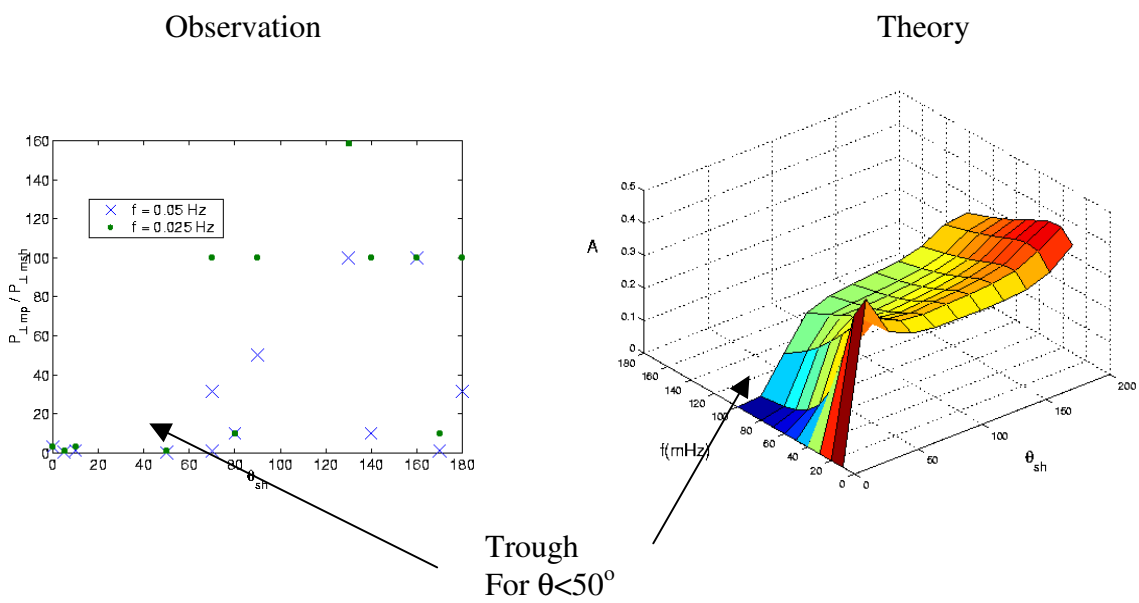

Figure 2. Comparison of observed wave amplification with theoretical prediction of mode conversion. The trough in amplification for small angle and larger amplification for smaller frequency waves provide a consistent link between theory and observation.

These observations were compared with theoretical calculations of wave solutions. Wave solutions were obtained by solving the kinetic-fluid equations (including finite Larmor radius effects and electron Landau damping) for a compressional wave scattering off a

gradient in the Alfvén velocity including magnetic field rotation. Magnetic field rotation at the magnetopause has a strong effect on the mode conversion process because it introduces new classes of waves which can either be transmitted through the magnetopause or excite localized kinetic Alfvén eigenmodes within the magnetopause boundary layer. To examine the wave structure at the magnetopause, an incident compressional wave spectrum was considered based on wave observations in the magnetosheath. The incident compressional waves scatter off of the magnetopause boundary layer, but in the process, part of the wave energy is converted into kinetic Alfvén waves. We compute the amount of wave energy converted to transverse waves based on the incident wave spectrum. Maximum energy conversion occurs at magnetic shear angles greater than approximately 50 degrees. For smaller angles, a trough in energy conversion is found which is broader for larger frequency. The wave absorption is a decreasing function of frequency for frequencies of interest. These properties are qualitatively consistent with the wave observations as seen in Figure 2.

These results imply that mode conversion of compressional MHD waves to kinetic Alfvén wavess occurs at the magnetopause. Moreover, based on previous studies the kinetic Alfvén waves are expected to provide significant particle transport and plasma heating at the magnetopause.