Motivation and Background

Damping of Alfvén waves is one of the most likely mechanisms for ion heating in the solar corona. Ion-neutral collisions have significant but poorly-understood effects on energy transfer and Alfvén wave propagation in partially ionized plasmas, such as those found in the solar chromosphere. The neutral density in HELIX varies strongly with radius, giving access to a wide range of Alfvén dynamics across the plasma column. The ratio of ion-cyclotron to Alfvén collision frequency in the solar atmosphere varies from 10-6 to 10, while in HELIX the ratio varies from about 0.02 to 0.5. With the use of a new internal wave-launching antenna close to the high-density core, a small-scale magnetic sensor coil probe, and time-resolved Laser-Induced Fluorescence (LIF) temperature measurements, the behavior of radially confined Alfvén waves is measured and characterized in argon.

Experimental Apparatus

LIF and Temperature Measurements

Wavelet-Based Time-Frequency Analysis

The phase difference between the measured fluctuation signal at the scanning frequency and the antenna current is averaged over 50 – 100 measurements using the real-time data acquisition system. The time-resolved LIF measurements are averaged over 100 pulses for each wave point (84 total) at each radial location.

Summary

- Time-resolved LIF measurements confirm a change in plasma behavior and temperature in the presence of the launched wave.
- Wave excitation lowers the plasma temperature. This effect is dependent on the local density and density gradient.
- Additional LIF measurements at other radii will give a more complete description of how the plasma wave interaction depends on the local density and density gradient.
- Wavelet analysis of B-dot probe signals indicates plasma turbulence when the wave is present.
- Finite frequency and perpendicular wavelength effects must be included to explain the measured parallel wavelengths of the excited wave.

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The measured wavelengths are in the kinetic Alfvén regime and the full wave dispersion relation becomes:

\[ \lambda_{\text{meas}} = \frac{B_0}{\sqrt{\rho_n c_s}} \left[ 1 + \sqrt{1 - \left( \frac{\rho_n c_s}{m_i n_i} \right)^2 \frac{q}{2}} \right] \]

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Shown above in green is the Alfvén wavelength predicted by the classic dispersion relation. The measured wavelengths with error bars (based on the standard deviation of the measured phase values) are also shown. Also shown are the wavelengths predicted by the kinetic Alfvén dispersion relation for several \( q / m_i n_i \) values (based on the size of the plasma core). The quantities for \( k = 12.6 \text{ cm}^{-1} \), a plasma core bounded at \( \rho = 0.5 \text{ cm} \) are consistent with the measured wavelengths and the measured size of the high-density plasma core.

The wavelet frequency peaks that portray for the plasma discharge are likely drift waves driven by the strong density gradient in the plasma core. The wave frequency peaks during the antenna pulse, broad spectral bands from 20 to 50 kHz appear in the high density core and outside of the location of the antenna. The broad frequency features during the antenna pulse suggest a turbulent spectrum of Alfvén waves are excited.

Measured and Predicted Wavelengths versus Radial Location