Ion Heating Due to Low-Frequency Wave Propagation in Partially Ionized Plasmas With a Strong Density Gradient in the Hot Helicon Experiment (HELIX)

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Important Results-Alfvén Wave Propagation, Turbulence, and Heating

• Magnetic sense coil probe measurements are consistent with Alfvén Wave propagation in HELIX
• Langmuir probe measurements show electron heating
• LIF suggests metastable density depletion and ion heating
• Wavelet analysis shows plasma turbulence, where this spectra is broadest correlates with ion heating
Coronal Heating May Be Due To Alfvén Wave Turbulence and Energy Cascades

- Plasma motions in the chromosphere or photosphere launch transverse low-frequency waves
- Spatial variations in magnetic field and density cause reflection
- Counter-propagating wave interaction drives turbulence
- Energy transfer to smaller perpendicular scales provides efficient electron heating
- Dmitruk et al.* show that turbulence (and therefore, heating) can be sustained in the presence of counter-propagating low-frequency Alfvén waves


HELIX Diagnostics and Parameters

<table>
<thead>
<tr>
<th>Plasma Parameter</th>
<th>Value in HELIX</th>
<th>Value in Corona</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas Species</td>
<td>Argon</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>Magnetic Field (G)</td>
<td>800</td>
<td>10</td>
</tr>
<tr>
<td>Density (cm$^3$)</td>
<td>$\leq 3 \times 10^{13}$</td>
<td>$1 \times 10^8$</td>
</tr>
<tr>
<td>Ion Temperature (eV)</td>
<td>$\leq 1$</td>
<td>100</td>
</tr>
<tr>
<td>Electron Temperature (eV)</td>
<td>2-5</td>
<td>100</td>
</tr>
<tr>
<td>Ion Gyro-Radius (m)</td>
<td>$\sim 2.7 \times 10^{-3}$</td>
<td>1.02</td>
</tr>
<tr>
<td>Electron Gyro-Radius (m)</td>
<td>$\sim 0.04 \times 10^{-3}$</td>
<td>0.024</td>
</tr>
<tr>
<td>Electron Skin Depth (m)</td>
<td>0.0016</td>
<td>0.531</td>
</tr>
<tr>
<td>Ion Sound Gyro-Radius (m)</td>
<td>0.017</td>
<td>1.252</td>
</tr>
<tr>
<td>Ion Cyclotron Frequency (rad/s)</td>
<td>$1.9 \times 10^5$</td>
<td>$9.6 \times 10^4$</td>
</tr>
<tr>
<td>Electron Plasma Frequency (rad/s)</td>
<td>$2.52 \times 10^{11}$</td>
<td>$5.64 \times 10^8$</td>
</tr>
<tr>
<td>$\beta_e$</td>
<td>0.0005-0.0045</td>
<td>0.008</td>
</tr>
<tr>
<td>$\bar{\beta_e}$</td>
<td>40-300</td>
<td>14.6</td>
</tr>
<tr>
<td>$v_{Te}/v_A$</td>
<td>6-17</td>
<td>1.9</td>
</tr>
</tbody>
</table>
Density and Density Gradient Scale Length Dictate Wave Propagation Dynamics
Parallel Wavelength Measurements Are Consistent With the Collisionless Inertial Alfvén Wave Dispersion Relation even though $v_{Te}/v_A \approx 10$

$k_\perp$ obtained from $n(r)/\nabla n(r)$
$k_\perp$ is 10 times smaller than $n(r)/\nabla n(r)$
$T_e(r)$ from measurements

Inertial Dispersion Relation
Full Dispersion Relation (electron Landau damping, electron-ion collisions, finite frequency)
At $r = 0$ cm, Broad Spread in Wave Frequency is Observed When Wave is Excited.

- Frequency (kHz)
- Total Signal Amplitude (arb.)
- Drift Waves

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**Graph Details:**
- Y-axis: Frequency (kHz)
- X-axis: Time (ms)
- Graph shows a spread in wave frequency.
- Red ellipse highlights the region of interest.
Wavelet Analysis Shows Turbulence and Plasma Response Changes With Radius

Radius (cm)

Area Under the Curve (arb)
Electron Temperature Measurements Show Heating Due to Perturbation

Measurements Through the Perturbed Current Channel

Measurements Outside the Perturbed Current Channel
Normalized Electron Temperature Change Shows Radially-Dependent Heating

Measurements Through the Perturbed Current Channel
Measurements Outside the Perturbed Current Channel
At $r = 0$ cm, Ions are Heated During the Wave Perturbation, Density Does Not Change
At $r = 1$ cm, Metastable Density Drops, Signal-to-Noise is Too Low for Reliable Temperature Fitting.
Ion Heating is Suggested at \( r = 0 \) cm, metastable density decreases at larger radii.
Summary and Conclusions-Alfvén Wave Propagation, Turbulence, and Heating

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- Questions?