Lower Hybrid Current Drive
Past, Present and Future

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Outline

- Overview of Lower Hybrid Current Drive Theory
- Comparison of 80 kW operations and current operations
- Indications of Lower Hybrid activity
  - Mode coil pickup
  - X-ray spectra
- Future/Potential Diagnostics
- Theoretical Modeling
- Open Questions
• "Lower Hybrid" Waves are waves launched between the cyclotron resonances
• Absorption occurs through Landau damping
  – Absorption has an asymmetry due to wave direction
Lower Hybrid Theory

- But there are Conflicting Mechanisms!
- Absorption Through Lower Hybrid resonance
- Landau Damping on thermal electrons
Recent History

- 80 kW operations allowed us to hone our engineering...
Recent History

- ...But the power just wasn’t high enough
Recent History

- 200+ kW operations are much better…
Recent History

- ...still not optimal however
Maybe - just maybe - we are close to a regime where we can see what we have done
Mode Coils

- Toroidal Array - 31 toroidally displaced coils used to measure mode activity at the plasma edge.
Mode Coil Pickup

- Mode coils pickup a very strong signal during lower hybrid on time.
- Extensive processing provides us with interesting data.
Mode Coil Pickup

- One mode coil (ϕ~90°) was hooked up to 800MHz power diagnostics
Hard X-Ray Spectra

- Hard X-Ray Spectra measured with HXR camera, placed on a box port flange at the same toroidal location as the antenna

Data/Plots courtesy of A. Almagri
Into the future

- 16 channel Radiometer for radiation in the range of 4-8 GHz
  - Electrons emit cyclotron radiation (~4GHz in MST)
  - Superthermal Electrons experience a Doppler shift

- Integrated Soft X-ray detectors for 1-10 keV region
  - Detectors can be gated to cut off low energies
  - Comparison of three gated detectors can give us two energy bins
  - Diagnose spectrum in the 10-20 $v_{in}$ region

- Ion/Electron Heating
  - Discover evidence of one of the “bad” absorption mechanisms
CQL3D...Now with fewer caveats!

Transport turned off (!)

\[ J_\parallel (\text{MA/m}^2) \]
\[
\begin{array}{cccc}
0.0 & 0.2 & 0.4 & 0.6 & 0.8 \\
\end{array}
\]

\[ r/a \]

\[ 1 \times 10^{11} \text{ cm}^{-3} \]
CQL3D…Now with fewer caveats!

\[ J_b (\text{MA/m}^2) \]

\[ r/a \]

\[ 0.0 \quad 0.2 \quad 0.4 \quad 0.6 \quad 0.8 \]

\[ 3 \quad 2 \quad 1 \]

\[ 5 \times 10^{11} \text{ cm}^{-3} \]
Open Questions

- Are we launching the spectrum we think we are launching?
  - Measurement of spectrum has not been done in plasma conditions
- Pondermotive effects?

\[ F = \frac{e^2}{2m} \cdot \frac{v^2}{r} \]

\[ \text{pondermotive effects?} \]
• Superthermal electrons, good! Warm electrons/ions, bad!
• Exciting new indications of presence of lower hybrid waves
• Even more exciting diagnostics on the horizon
• CQL3D Continues to tantalize, while at the same time puzzling.

Catch the thrilling conclusion at my prelim in a few months!