Proof-of-principle measurements using the 300 GHz collective scattering diagnostic

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Abstract - Motivation
Experiments designed to provide a proof-of-principle measurement with the WVU 300 GHz collective scattering diagnostic continue. The collective scattering system, capable of measuring wave-numbers ranging from 62 to 89 cm⁻¹, is operated in conjunction with a new electrostatic double probe (with a measurable wave-number range up to ~50 cm⁻¹). To directly excite finite \(k\) electrostatic waves propagating perpendicular to the magnetic field that can be detected with this diagnostic, an internal antenna designed to launch electrostatic ion-cyclotron waves has been built and installed in HELIX. For the magnetic field strength of HELIX, the wave dispersion of such waves is essentially that of an ion-acoustic wave. Wave number measurements for naturally occurring and externally driven waves, using both the scattering system and electrostatic double probe, are presented.

Experimental Apparatus - HELIX

300 GHz location

Experimental Apparatus - 300 GHz diagnostic

- Incident and Collection beam waist (w) ~ 1.7 cm
- Observable scattering angle range: 60° to 90° \(\Delta k\) ~ 62 to 89 rad/cm
- \(\Delta k = 2\pi / w \approx 1.2\) rad/cm

Experimental Apparatus – Electrostatic double probe

- Tangent tips separated by ~ 0.61 cm
- Wave numbers measurable up to ~ \(k\) ~ 50 rad/cm

Plasma Characterization

Neutral Pressure ~ 8 mTorr
RF Power ~ 500 Watts

The electron temperature has an interesting peak at the same radial location where the fluctuation amplitudes are peaked.

Double Probe Fluctuation Observations and Analysis

Summing the range of spectral amplitudes in both frequency and wave number at each radial location for each of frequency and magnetic field indicates the fluctuations are peaked at the same radius as the electron temperature (\(r ~ 4.5\) cm).

Slices at 500 kHz and 9.5 MHz \(\pm 500\) kHz from the spectral density show that energy and momentum are NOT conserved as is generally assumed:

\[
k_{RF} \approx 0 \rightarrow k_1 \approx k_2
\]

\[
k_1 \equiv k_{RF} \approx 29 \quad k_2 \equiv k_{USB} \approx 14
\]

\[
k_2 \equiv k_{LSB} \approx 13
\]

Slices from the spectral density at several wave numbers suggest that the low frequency fluctuations are an ion-acoustic wave and the rf side band fluctuations are lower-hybrid waves. Although the ion-acoustic \(k_{1}\) gives an electron temperature of \(0.5\) eV (well below the LP measured temperature of \(3\) eV), inclusion of the radius of the probe tips in the total probe tip separation yields a dispersion consistent with a \(1\) eV electron temperature.

The phase speed of the lower-hybrid waves is comparable to the electron thermal velocity (\(V_T = 5\times10^3\) cm/s) at small wave number, which may explain the radially localized electron temperature peak at \(r ~ 4.5\) cm.

Summary:
- Electrostatic probe measurements indicate fluctuations that are radially localized and have been identified as ion-acoustic and lower-hybrid waves.
- Currently the mechanism generating the fluctuations is not fully understood, but because the energy and momentum appear not to be conserved, we believe they are not parametrically excited.
- Although near the calculated minimum detection threshold, scattered signal amplitudes having the same radial profile as the double probe indicate the first successful measurements with the scattering diagnostic.

Measured Spectral Amplitudes and Collective Scattering Observations

For the parameters that yielded the largest probe-measured fluctuation amplitudes (\(B \approx 650\) and 800 G and an of frequency of \(9.5\) MHz), the spectral amplitudes of the potential fluctuations as a function of wave number were examined to estimate the fluctuating density amplitude for wave numbers measurable with the scattering diagnostic. The steep spectral decay, a decay rate of \(\delta^{+}\), is inconsistent with an inertial range – suggestive of active damping of the waves.

For a magnetic field of 800 G, the scattering diagnostic was deployed to examine the fluctuations (\(r ~ 80\) rad/cm) as a function of radius. Measurements were obtained for the scattering diagnostic fully operational and with the injection beam block. The difference between the two measurements is shown below as a function of frequency.

The spectral amplitude differences for the scattering diagnostic as a function of radius for the signal amplitudes near 130 kHz indicate a radial profile the same as that obtained with the double probe. Although the frequency is lower than expected, particularly with a wave number of \(89\) rad/cm, this indicates the first successful measurement with the 300 GHz scattering diagnostic.