ELECTROMAGNETIC INSTABILITIES DRIVEN BY ION THERMAL ANISOTROPY IN HELICON PLASMAS

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ABSTRACT

Temperature anisotropies provide a source of free energy for instability growth in space and laboratory plasmas. The growth of electromagnetic ion temperature anisotropy driven instabilities is dependent on the anisotropy $T_i/T_e$ and the local plasma $eta$. These instabilities reduce the ion temperature anisotropy by inducing velocity-space diffusion, resulting in a limit on the ion temperature anisotropy that scales with plasma $\beta$. Here we report measurements of the spectra and parameter dependence of magnetic fluctuations in a helicon plasma source where the RF antenna responsible for plasma creation is amplitude modulated at the ion cyclotron frequency to increase the perpendicular ion temperature and thereby increase the ion temperature anisotropy. Magnetic fluctuation spectra up to 500 kHz, parallel and perpendicular to the magnetic field, are reported as a function of ion temperature anisotropy. Ion velocity distribution functions in the same region, measured by laser induced fluorescence, provide direct measurements of the ion temperatures parallel and perpendicular to the magnetic field.

THERMAL ANISOTROPY DRIVES INSTABILITIES

In magnetized, weakly-collimated and collimated plasmas, anisotropy in the temperature $T_i/T_e = 1$ may arise due to ion heating preferentially in one direction relative to the magnetic field. Electromagnetic instabilities arise in the plasma and work to isotropize the plasma. These instabilities include the Ion Firehose, Ion Cyclotron, and Mirr instability. As the plasma $\beta$ (plasma pressure relative to magnetic pressure) increases, the instabilities are triggered at lower levels of anisotropy.

In PHARMA, a new experiment at WVU, we intend to measure the ion thermal anisotropy and $\beta$ throughout an expanding plasma plume while simultaneously measuring the amplitude and angular number of subharmonic electromagnetic fluctuations. The measurements will be completed for the widest range of anisotropies and $\beta$ achievable in PHARMA and compared to the linear instability theory. A suitable means to determine if the anisotropy is constrained by the mirror mode threshold will be determined. Here we present the first preliminary results to determine if the instability is constrained by the mirror mode threshold even though the ion cyclotron threshold is predicted to be weaker for a given $\beta$.

In these experiments, we have returned to earlier (~1990) experiments that demonstrated a clear inverse scaling between ion temperature anisotropy and plasma $\beta$ (see Figure 1 below) in helicon source plasmas. Similar scalings have been reported in magnetotrophic and heliotechnic plasmas (see Figure 2 below).

The two magnetic sense coils were then placed between the Helmholtz coils. The Helmholtz coils were then driven by a function generator at low frequencies (~200 Hz to 200 kHz) and a Pearson Current Monitor measured the amplitude of current applied to the Helmholtz coils. All signals were observed through a LeCroy oscilloscope. Plots of the effective coil area response versus frequency for each magnetic sense coil. We can rearrange equation (2) to form relationship between the effective coil area and frequency:

$$A_{ef}f = \frac{V}{B_0 \pi N^2}$$

Axial coil $N=100$ Turns

Radial coil $N=28$ Turns

B DOT PROBE DESIGN

1. 9-pin vacuum feedthrough to be connected to twin-axial differential amplifier.
2. Ultra-torr connector for adjusting probe location.
3. Pressure hoses attached to roughing pump for vacuum seal, 4. probe tip.

The probe tip contains a two magnetic induction coils supported by a high-temperature resistant MACOR ceramic. Coil A measures fluctuations in the radial direction with $N=100$ turns; coil B measures fluctuations in the axial direction with $N=28$ turns. The assembly is vacuum sealed and protected by glass. The wires are fed through the center of the ceramic and into the metal housing to reach the D-sub electrical connections.

B DOT PROBE PHYSICS

Magnetic induction probes (B-dot probes) are small cylindrical coils that collects an induced voltage when placed in a time-varying magnetic field. From application of Faraday’s Law,

$$\mathbf{\dot{B}} \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

we can derive Faraday’s law of magnetic induction, which states that:

$$\mathbf{V} = \frac{\partial \mathbf{B}}{\partial t} = \frac{\partial \mathbf{B}}{\partial t} \otimes N \otimes A$$

where $\Phi$ is the magnetic flux, $N$ is the number of coil turns, and $A$ is the area of the wire loops. If we let $\mathbf{B} = B_0 \sin(2\pi f t)$, we can measure the signal from the oscillating magnetic field at the ion cyclotron frequency to understand how temperature is heated in perpendicular directions to the background magnetic field.

MAGNETIC SENSE COIL CALIBRATION

DC current was run through Helmholtz coils and its magnetic field was measured using a Lakeshore Hall probe. The linear fit was used to determine the magnetic field per amp for calibrating the magnetic sense coils.

PLASMA SOURCE WITH ION HEATING ANTENNA

Radial coil $N=28$ Turns

Magnetic probe measurements

Ion heating location

Plasma source with ion heating antenna.

Key Results

- Heating wave signature overwhelmed by intrinsic plasma fluctuations.
- Frequency spectra suggest drift waves excited near plasma edge – frequency consistent with drift wave calculations.
- Broadband electromagnetic turbulence observed at boundary of “blue core” plasma.
- Coherent electromagnetic modes observed inside “blue core” plasma.
- No effect on instabilities observed during initial ion heating experiments.

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