National Aeronautics and Space Administration

Characterizing Plasma Oscillations Using Active Wave Injection

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Program: SURP

Project Objective:

The overall goal is to develop techniques to identify plasma instabilities in hollow cathode and plasma thruster discharges and characterize their growth rates using active wave injection (AWI). Plasma oscillations are responsible for two of the most important phenomena in plasma thrusters--electron transport from the hollow cathode to the anode and production of energetic ions that erode thruster surfaces--but are not well-understood. Both phenomena impact thruster life, which is the primary technical challenge in developing Hall thrusters for future missions.

FY16/17 Results:

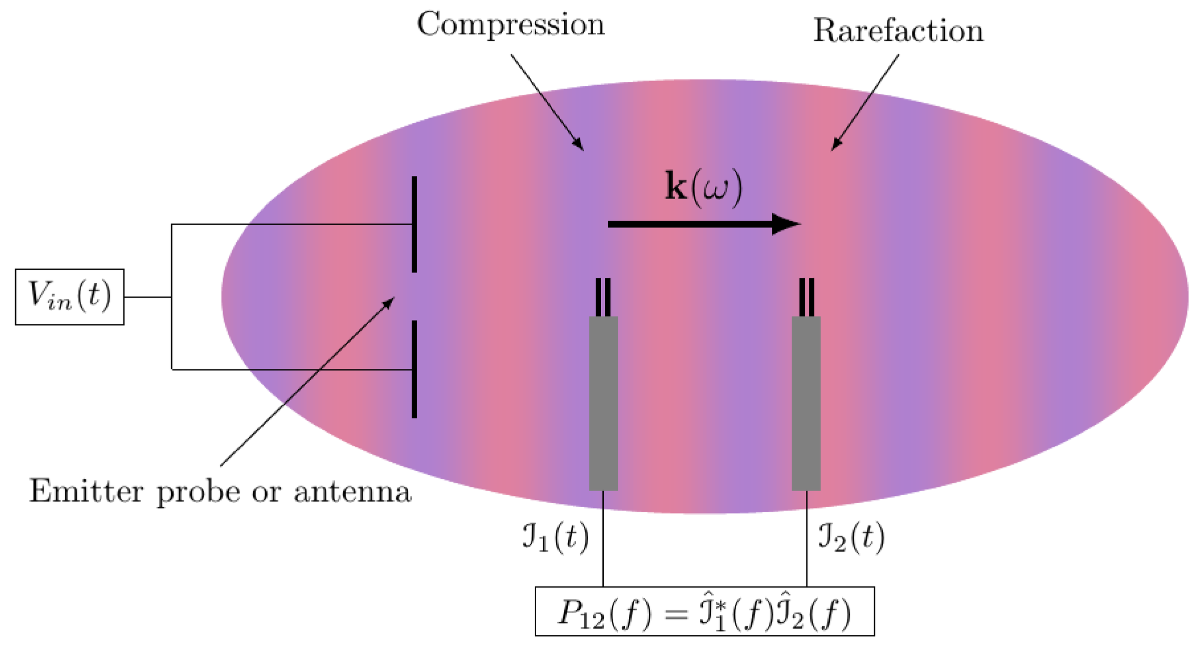
We developed a prototype version of the active wave injection diagnostic and implemented it in a magnetized RF argon plasma discharge to conduct dispersion relation measurements of electrostatic ion cyclotron (EIC) waves. Preliminary dispersion relation measurements with single-frequency injected waves made to provide a baseline measurement against which to compare results using harmonically rich exciting signals. Major accomplishments include

- Designed and manufactured probes and circuitry
- Developed signal analysis methodology and software for data processing
- Verified functionality of diagnostic in noisy RF plasma discharge

Benefits to NASA and JPL (or significance of results):

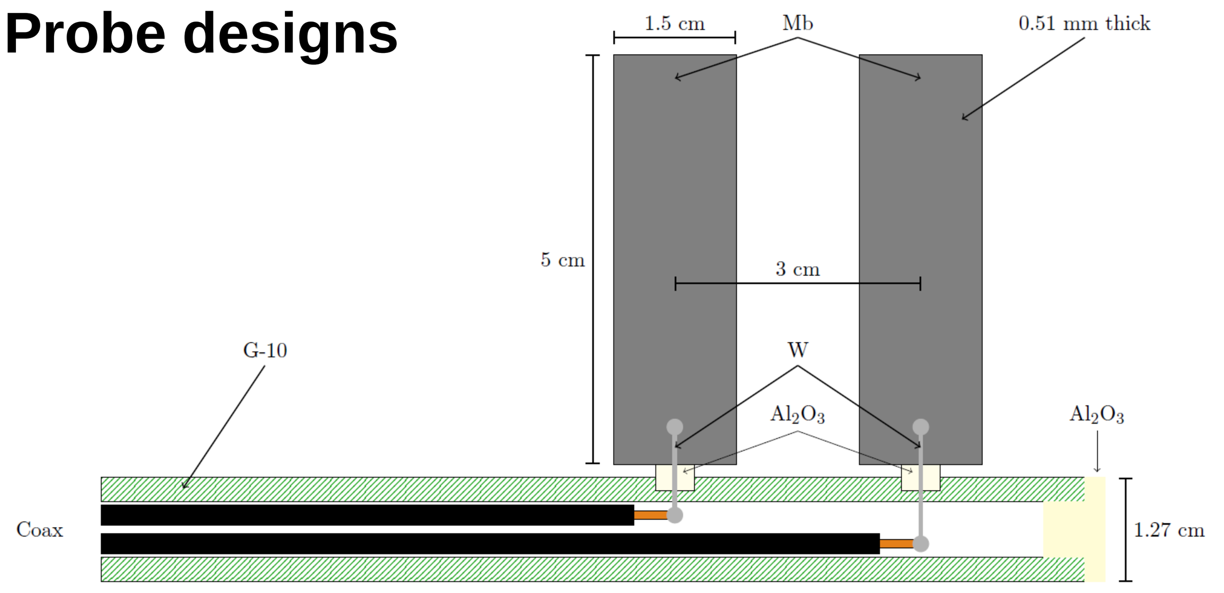
This research will impact JPL's competitiveness for applications such as future Discovery and New Frontiers mission proposals that would use Hall thrusters. These mission concepts could require thruster burn times of tens of thousands of hours and rely on physics-based models of thruster operation to validate their lifetime and reliability. An improved understanding of the effect of plasma oscillations on electron transport and high-energy ion formation, two key processes that drive thruster lifetime, will reduce mission risk. The tools developed here will also be used in designing advanced thrusters with improved lifetime and performance.

Active wave injection diagnostic

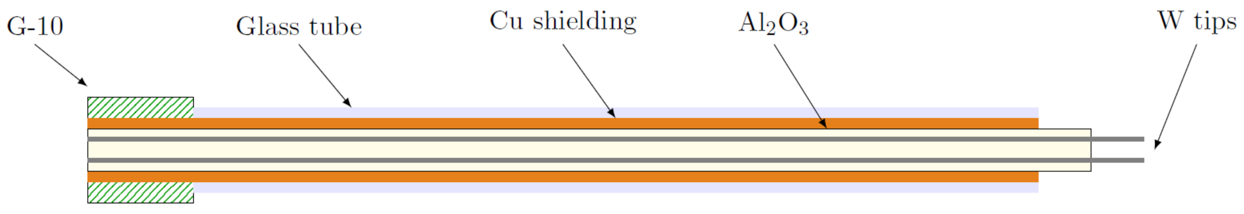


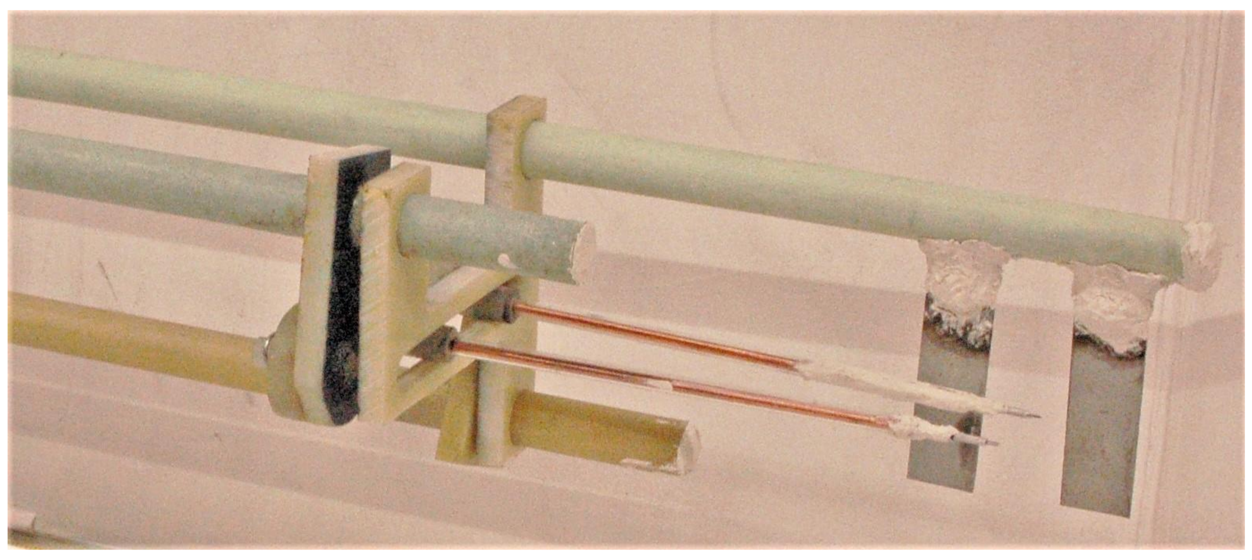
The diagnostic consist of an emitting probe and two receiver probes. A driving voltage $V_{in}(t)$ with customizable harmonic content sent to the emitting probe excites electrostatic waves in the plasma. The traveling plasma compressions and rarefactions cause time-varying voltage and ion-saturation-current signals which two receiver probes record. Fourier interferometric analysis of the receiver probe traces yields information about the traveling wave.

Probe designs



A two plate molybdenum antenna (above) along with a pair of double Langmuir probes (below) constitute the diagnostic.





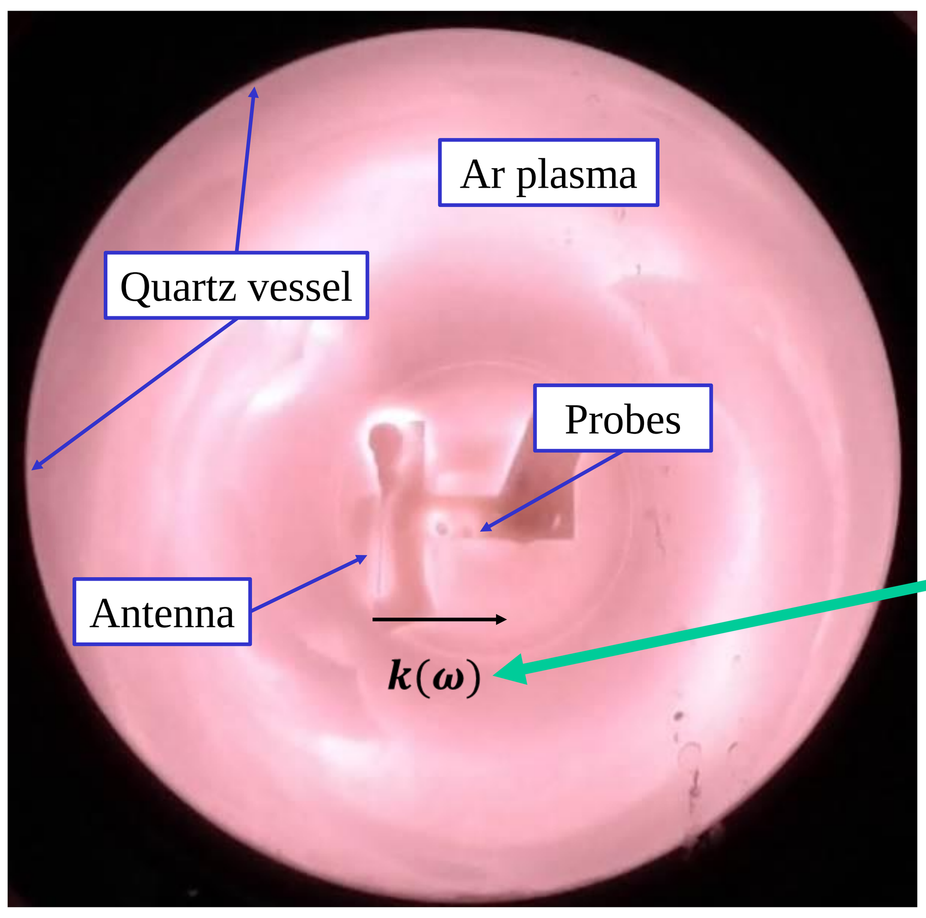
The diagnostic assembled for input into a magnetized RF argon plasma discharge. The probes can move relative to the antenna and to each other to conduct measurements at various spatial positions.

Electrostatic ion cyclotron wave experiment

We use the AWI diagnostic to measure the dispersion relation of electrostatic ion cyclotron (EIC) waves in an RF plasma discharge. These waves are described by the general electrostatic dispersion relation for an isothermal, magnetized plasma, but a simplified fluid model gives the approximate relation

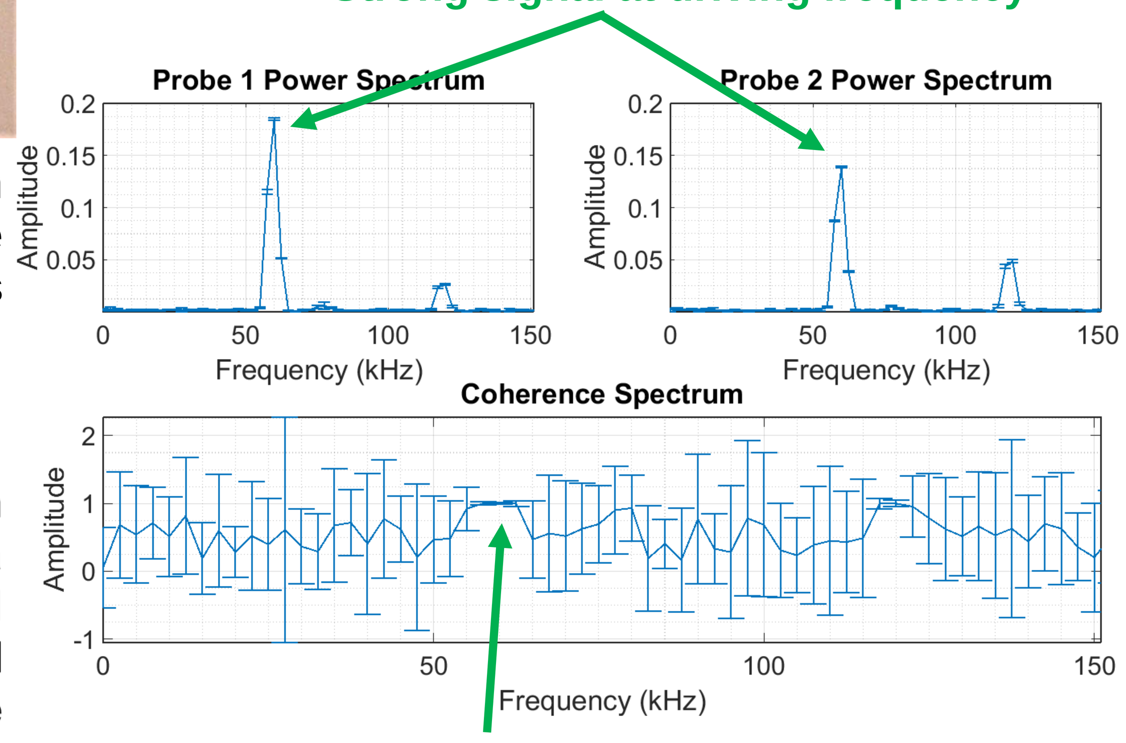
$$\omega^2 \approx \omega_{c,\mathrm{i}}^2 + k_\perp^2 c_S^2$$

for wave propagation parallel to the background magnetic field. Here $\omega_{c,\mathrm{i}}$ is the ion cyclotron frequency, $k_\perp$ the parallel wavenumber, and c_S the ion sound speed.



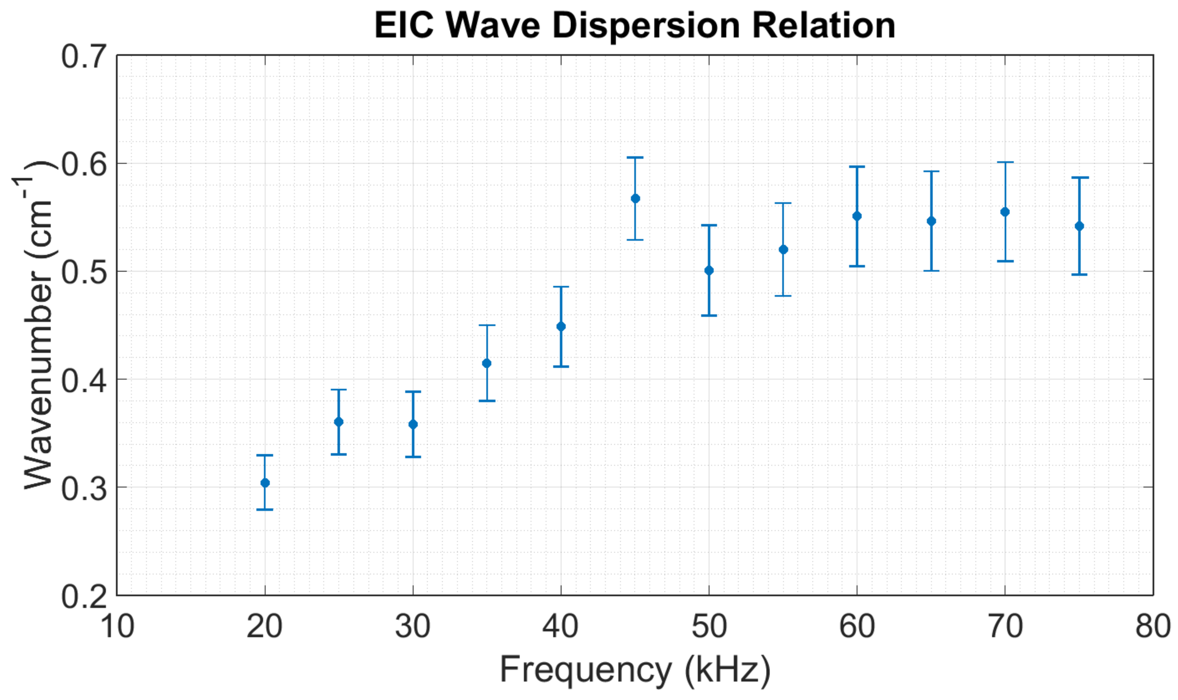
Probe signal analysis

We Fourier transform the probe time traces and analyze them in the frequency domain. Example probe power spectra and combined coherence spectrum below indicate the presence of traveling waves at 60kHz, which was the fundamental driving frequency of the antenna.



Preliminary dispersion relation

Below is an initial dispersion relation measurement of the EIC waves using several single-frequency (purely sinusoidal) driving signals to the antenna. Harmonically rich signals, such as square or saw tooth waveforms, are currently being investigated to reliably reproduce this measurement in fewer shots.



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