A 300 GHz Collective Scattering Diagnostic for Low Temperature Plasmas

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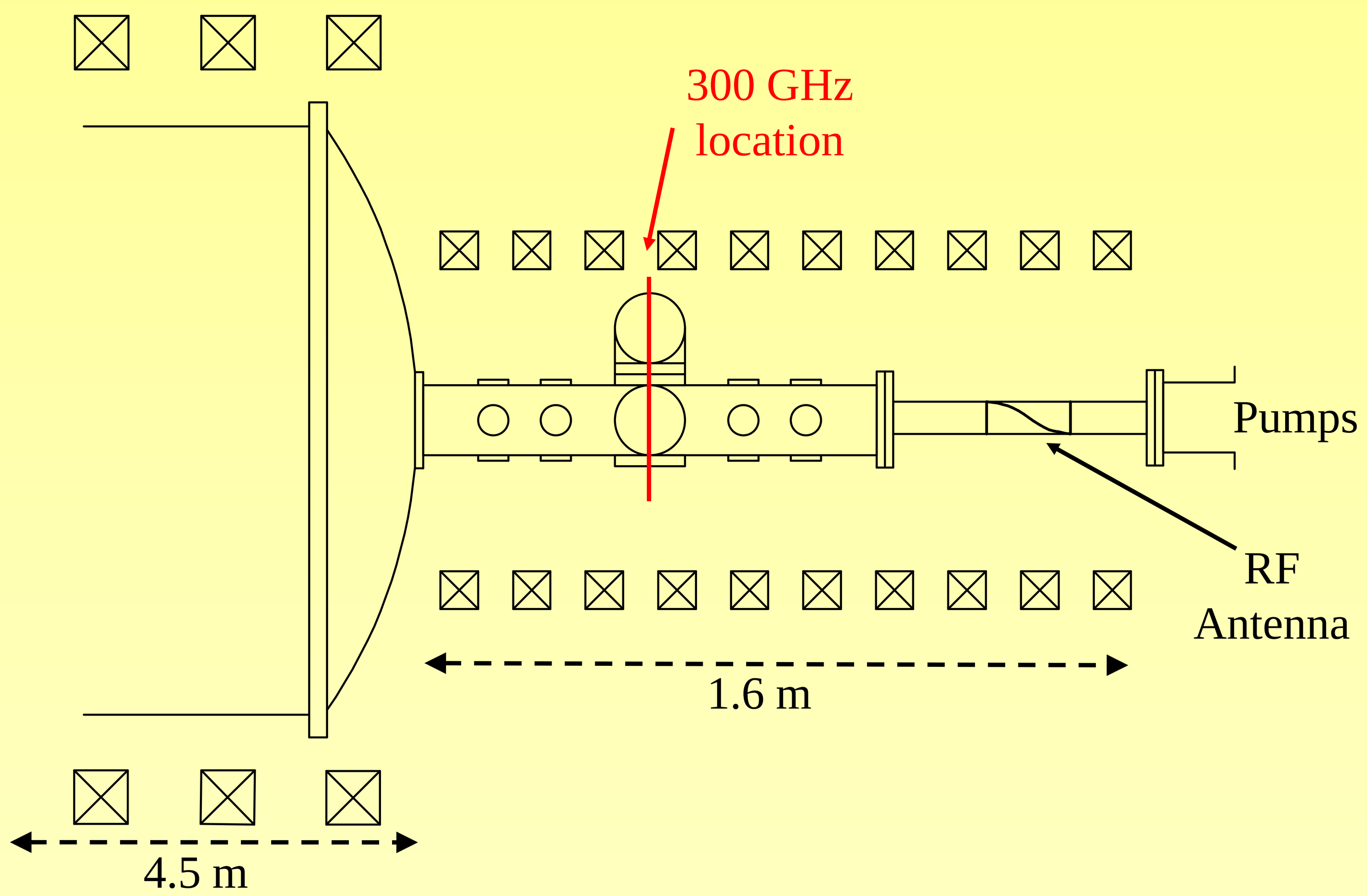
Motivation

A compact and portable 300 GHz collective scattering diagnostic employing a homodyne detection scheme has been installed on the Hot hELIcon eXperiment (HELIX) at WVU. Recent experiments in helicon plasma sources by Krämer *et al*. and Kwak *et al*. have employed mm-wave technology to investigate electron densities in a pulsed source and density fluctuations due to ion-acoustic waves. A proof-of-principle technique for the homodyne detection scheme employs the insertion of a rotating aluminum wheel, similar to that as reported by Veron, to mechanically generate a Doppler shift in the interaction beam. The initial focus of the scattering experiments is to measure the so called “Trivelpiece-Gould” wave, or slow wave, which is believed to be responsible for the high rf absorption efficiency of helicon sources operating near the lower hybrid frequency. Experimental parameters observed to heat ions near the plasma edge in conjunction with theoretically calculated wave numbers associated with the slow wave, as seen in Kline *et al*., are examined for evidence of the slow wave using the mm-scattering diagnostic. With the current HELIX chamber geometry limiting the scattering-based wave number range from 62 cm-1 to 89 cm-1, artificially driven ion-acoustic waves are also used as a proof-of-principle test for the diagnostic system.

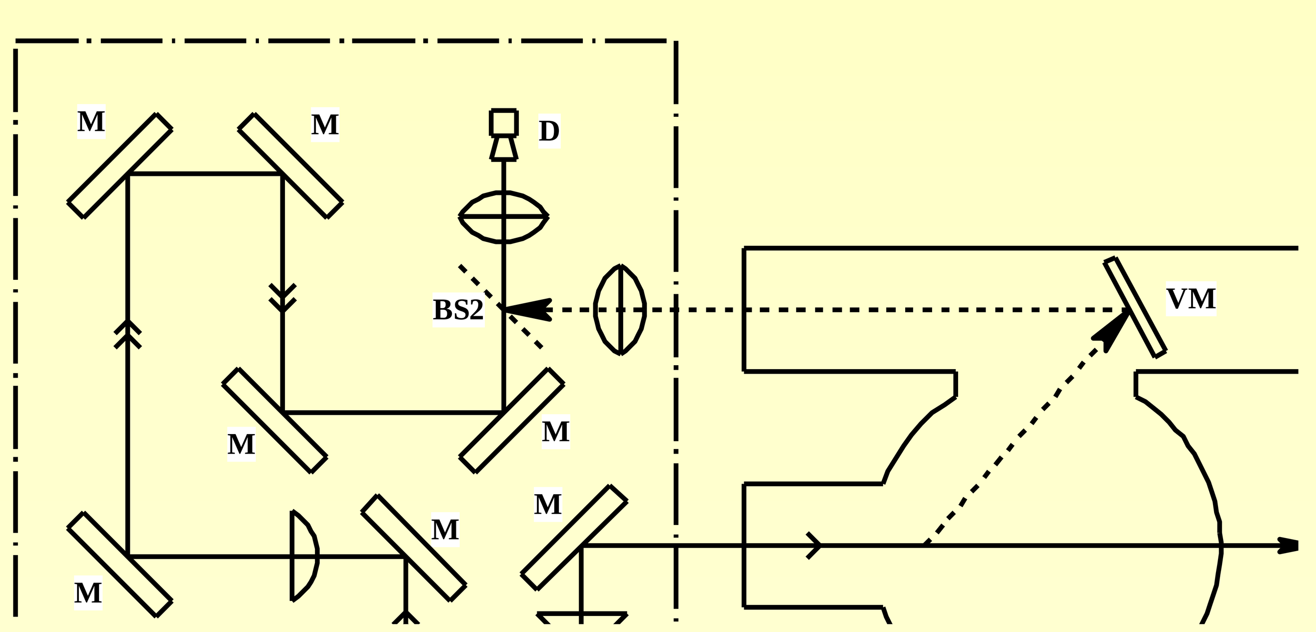
M. Krämer, B. Clarenbach, and W. Kaiser, Plasma Sources Sci. Technol. **15**, 332 (2006).
J.G. Kwak, S.J. Wang, S.K. Kim, and S. Cho, Phys. Plasmas **13**, 074503 (2006).
J.L. Kline, E.E. Scime, R.F. Boivin, A.M. Keesee, and X. Sun, Plasma Sources Sci. Technol. **11**, 413 (2002).

Experimental Setup - HELIX



Experimental Setup – 300 GHz diagnostic

M = mirror, VM = Vacuum Mirror, BS = Beam Splitter, S = Source, D = Detector



- **Incident and Collection beam waist (w) ~ 1.7 cm**
- **Observable scattering angle range: 60°to 90°→ k_{fl} ~ 62 to 89 rad/cm**
- **$\Delta k \approx 2/w$ → $\Delta k = \pm 1.2$ rad/cm**

Homodyne detection scheme proof-of-principle test

A technique for testing the homodyne detection scheme is the insertion of a rotating aluminum wheel to produce a Doppler frequency shift of the incident beam similar to that reported by Veron [XXX]. The wheel yielded two diffraction orders (m = 1 and 2), producing Doppler shifts ranging from 10 to 40 KHz dependant on the wheels rotation frequency and diffraction order. This test demonstrates that the system is optically aligned, the mixer is functioning as intended, and that the system was ready to be installed on the HELIX plasma source.

Wheel description:

Radius (R) = 3 inches

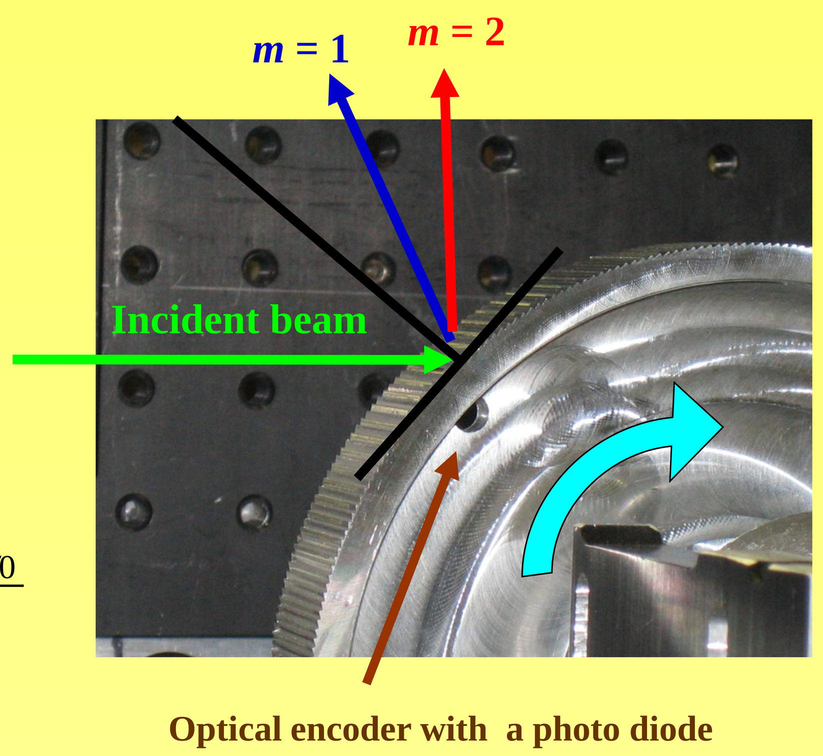
Grating Spacing (d) = 1.49 mm

Number of triangular teeth = 320

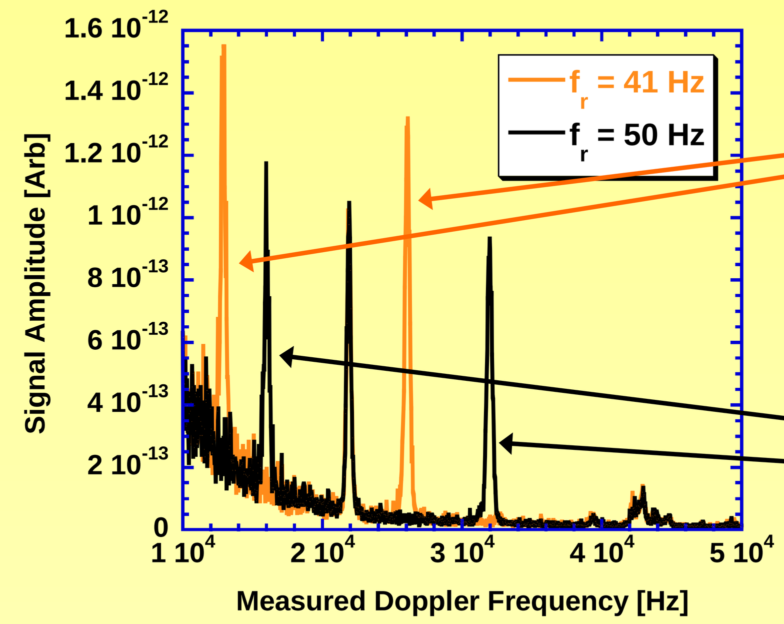
Maximum Rotation Frequency = 133 Hz

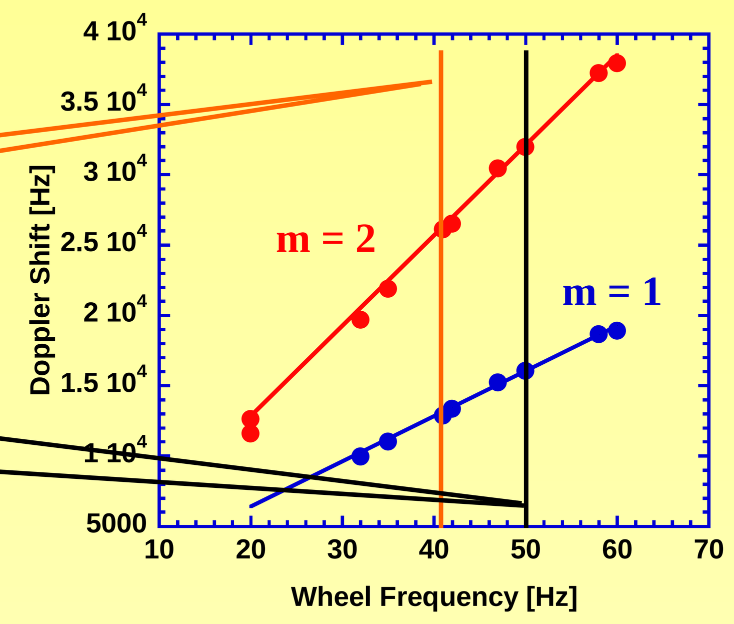
Diffraction Equation: $$\sin(\theta_m)+\sin(\theta_i)=\frac{m\lambda_0}{d}$$

Doppler Shift Equation: $$\nu_m=\frac{2\pi m f_r R}{d}$$



Optical encoder with a photo diode allows for measuring the rotational frequency (f_r) of the wheel





Calculation of density fluctuation amplitude needed for a measureable scattered signal

$$P_s=\frac{1}{4}P_0\lambda_0^2 r_e^2 L_V^2\tilde{n}^2$$

Applying WVU parameters

$$\tilde{n}[cm^{-3}]=2.0\times10^{16}\sqrt{P_s[W]}$$

Detector Sensitivity = 600 mV/mW

Measured noise floor voltage = 450 nV

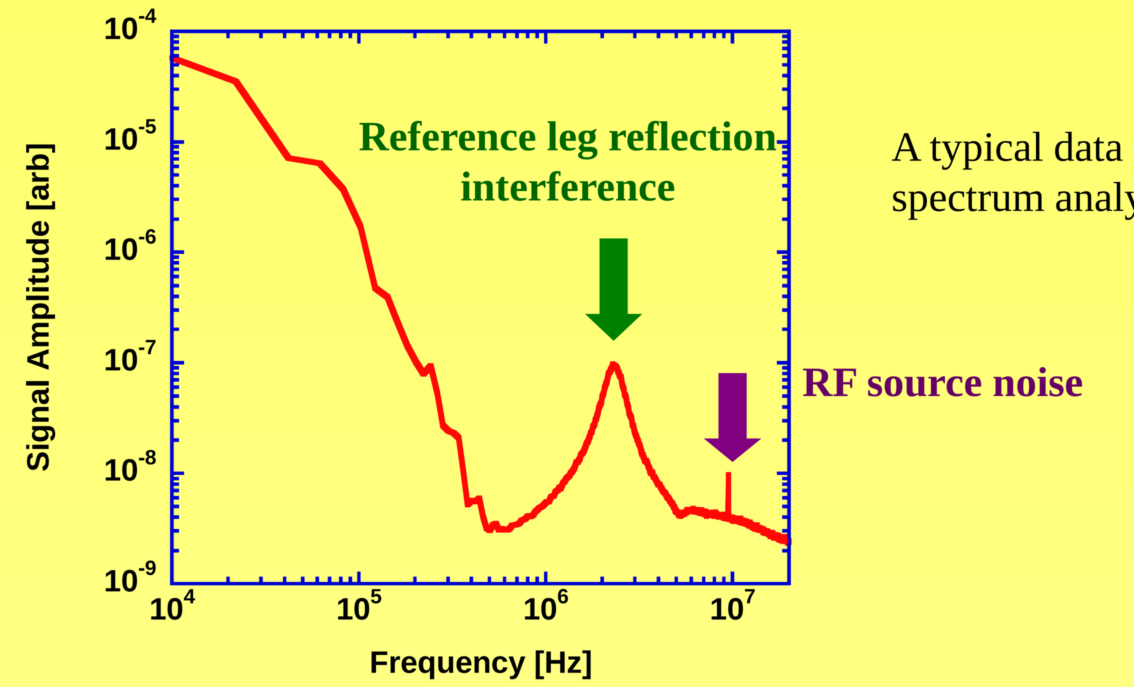
Minimum scattered power = 7.5×10^{-10} W

$$\tilde{n}=5.5\times10^{11}cm^{-3}$$

$$\frac{\tilde{n}}{n_0}=\frac{5.5\times10^{11}}{1\times10^{13}}\approx5\%$$

With the current detector sensitivity, a density fluctuation of ~ 5×10^{11} cm^{-3} is required to obtain a measureable signal above the noise floor. With a typical peak density of 10^{13} cm^{-3}, this would correspond to needing a density fluctuation on the order of 5%. With the slow wave expected near the edge, and densities typically an order of magnitude lower, that would require a 50% density fluctuation for a scattering measurement.

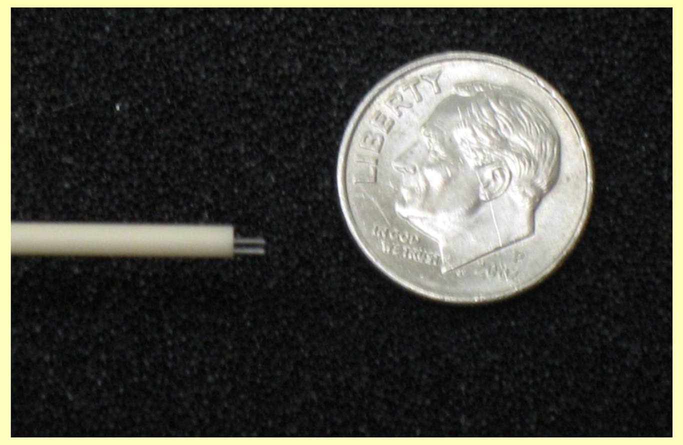
Experiments have yet to yield a scattered signal



A typical data set using a HP3585A spectrum analyzer.

- Experimental parameters similar to those in Kline *et al*. have been examined with the scattering diagnostic, but no scattered signals at the rf frequency above the noise have been observed.
- Large broadband noise has been observed (as seen above), and has been attributed to reflections in the reference leg of the diagnostic.

Experiments using a new wave launching antenna are currently underway



- Currently the antenna is undergoing initial tests to determine the launching efficiency.
- A new double probe, capable of measuring wave numbers up to ~ 50 rad/cm, is used in conjunction with the antenna to determine the driven wave characteristics.
- The antenna offers us an alternate proof-of-principle test, in the event the slow wave does not have the right wave number matching conditions.
- The antenna will also allow for better calibration of the system, since we will have more direct control over the wave characteristics.
- The waves will be launched directly across the 300 GHz diagnostic beam path.

Summary:
- **A proof-of-principle test of the homodyne detection scheme using a mechanically driven Doppler shift was successful.**
- **First tests of the scattering system were performed at parameters believed to excite of the slow wave in the Kline *et al*. experiments. No slow waves were observed.**
- **A new wave launching antenna is being implemented. The antenna will provide an external source of short wavelength electrostatic waves**