High-frequency Density Oscillations from a Plasma Source Used for Simulating Low-Earth Orbit Plasma Environment

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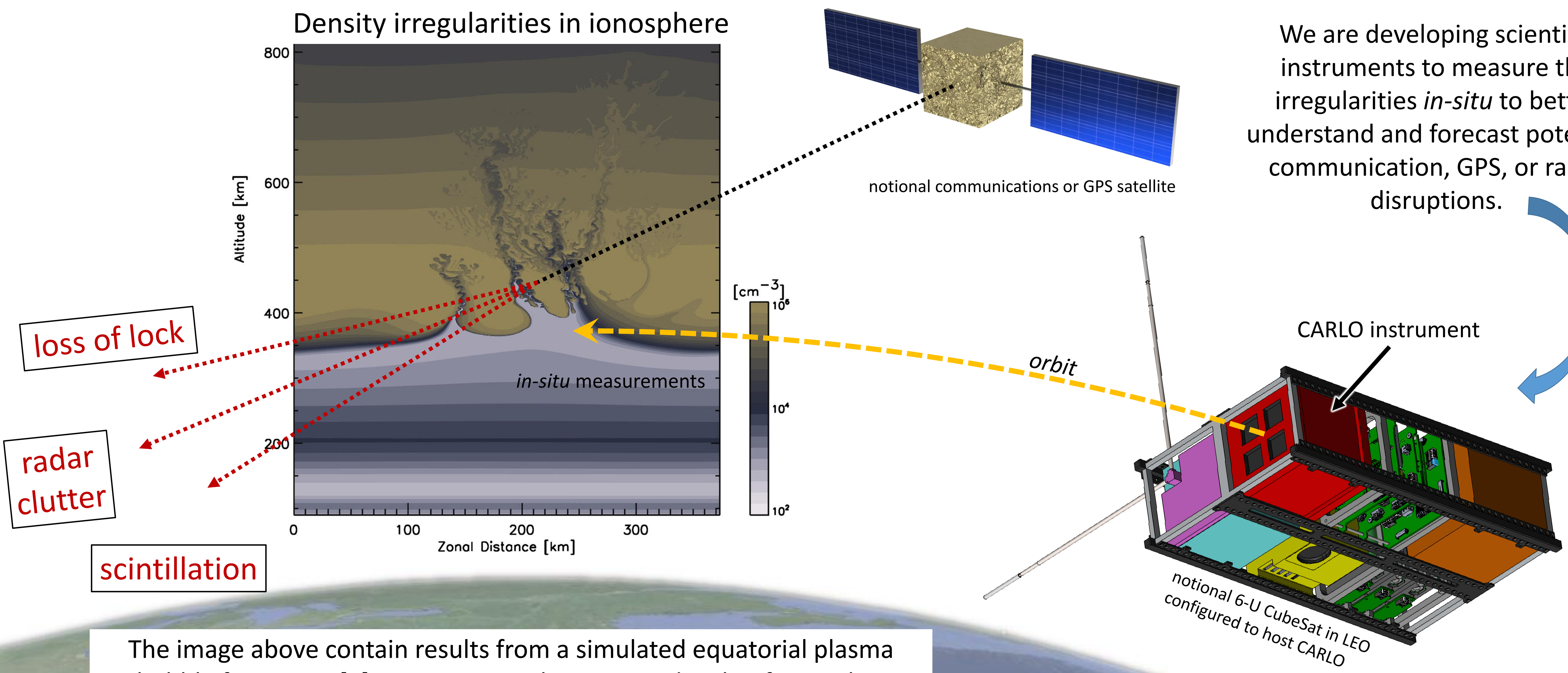
Abstract

We present data from ground-based, vacuum-chamber tests demonstrating the ability to modulate the output of a plasma source capable of producing a low-Earth orbit (LEO) type plasma. We obtained plasma oscillations up to 2.5 kHz impingent on stationary test equipment, which corresponds to meter-level ionospheric structures in LEO. This plasma source is, therefore, suitable for developing scientific instruments that measure the LEO plasma environment, *in situ*, with **meter-level spatial resolution**. Measurements were made using a fixed-bias collector and an electrometer sampling at 40 kHz. A mechanical aperture was established at the output of the plasma source via two concentric grids. The outer grid was free to rotate in the azimuthal direction with respect to the fixed inner grid. An identical, alternating hole pattern in the two grids resulted in a variable aperture that cycles through 90 open/close cycles per revolution. The frequency of the plasma oscillations is limited by the mechanism used to spin the grids and the bearing assembly on which the grids rotate. Higher frequencies are obtainable by upgrading the drive mechanism, allowing the possibility of **centimeter-level spatial resolution**.

Motivation

Density irregularities in ionosphere



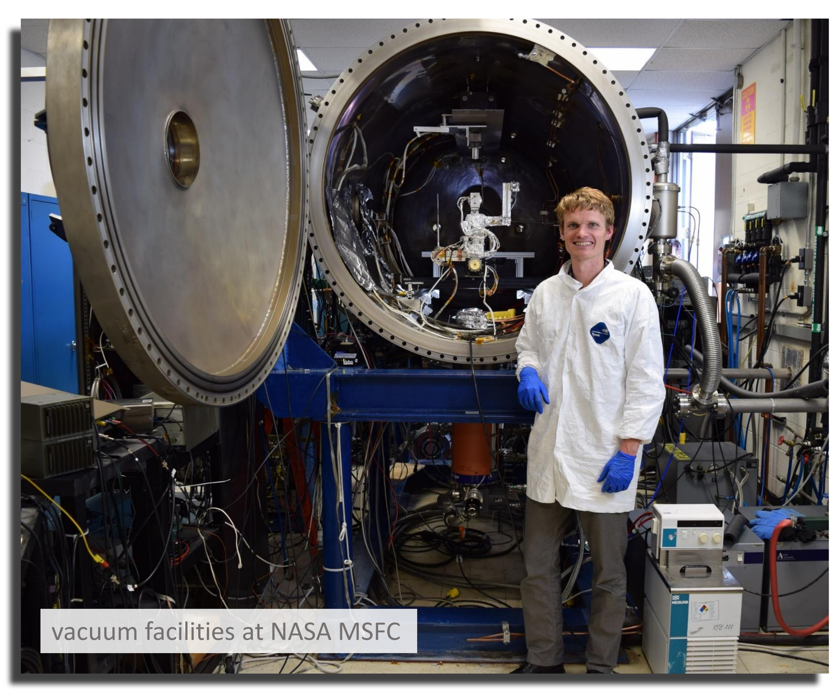
We are developing scientific instruments to measure the irregularities *in-situ* to better understand and forecast potential communication, GPS, or radar disruptions.

The image above contain results from a simulated equatorial plasma bubble formation [1]. Density irregularities can develop from other phenomena such as space weather or ground-based artificial heaters. The wavelength of radio communication affected is proportional to the characteristic length of the irregularity.

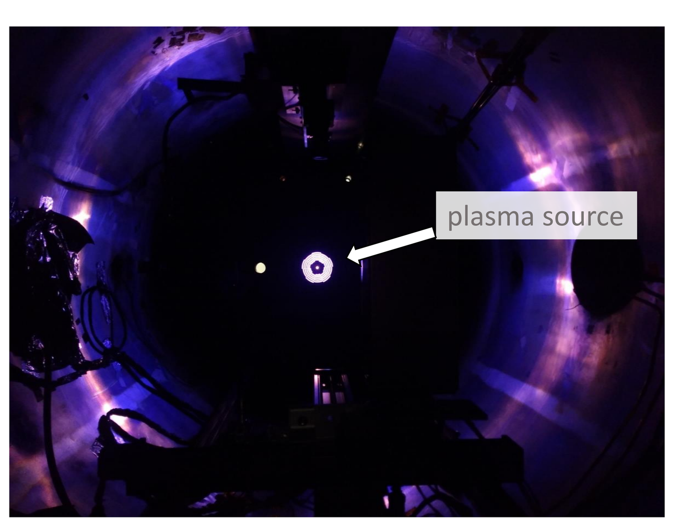
[1] Yokoyama T, Jin H, Shinagawa H (2015) West wall structuring of equatorial plasma bubbles simulated by three-dimensional HIRB model. *J Geophys Res Space Physics* 120:8810–8816.

Image of Earth from Google.

Experiment Setup

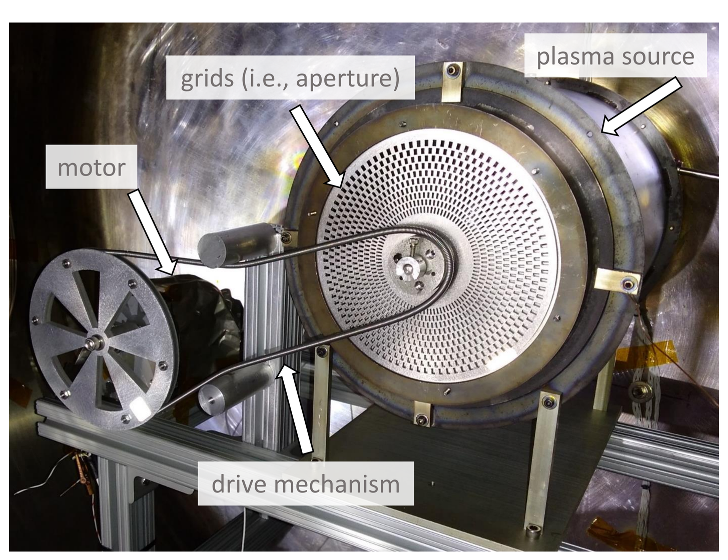


The author stands next to a cylindrical vacuum chamber at NASA MSFC, which is 122 cm in diameter and 241 cm in length. The chamber is equipped with a plasma source capable of producing the LEO environment.

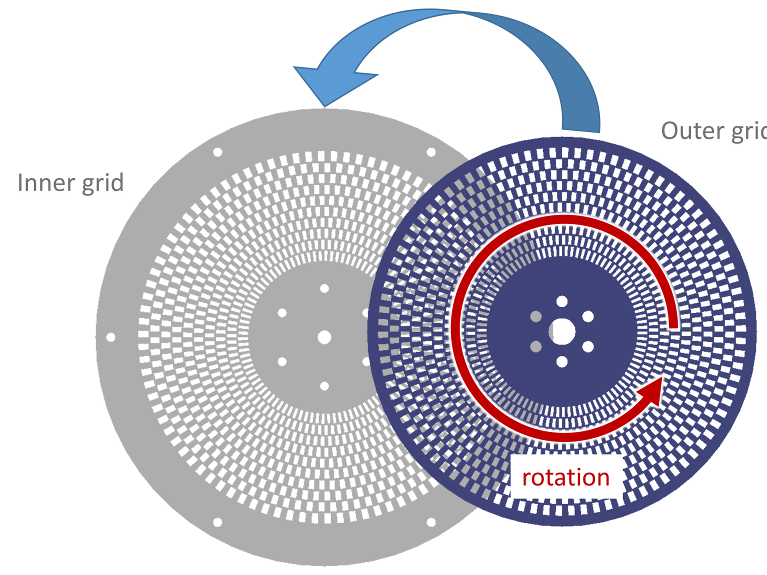


The purple glow of an argon plasma is visible through a viewport in the vacuum chamber. The source is capable of producing streaming ions of approximately 2–4 eV and thermal electrons of approximately 0.1 eV.

Plasma Source

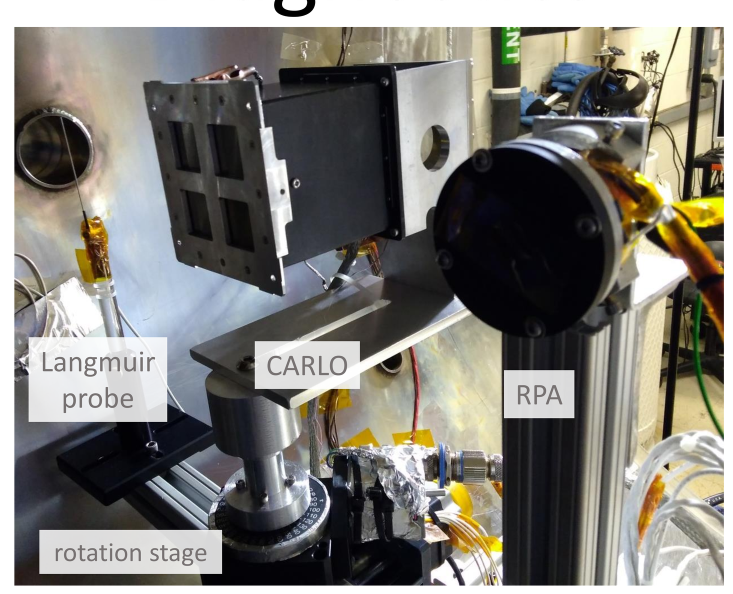


The plasma source has a variable-aperture output grid enabling real-time control of the plasma density.

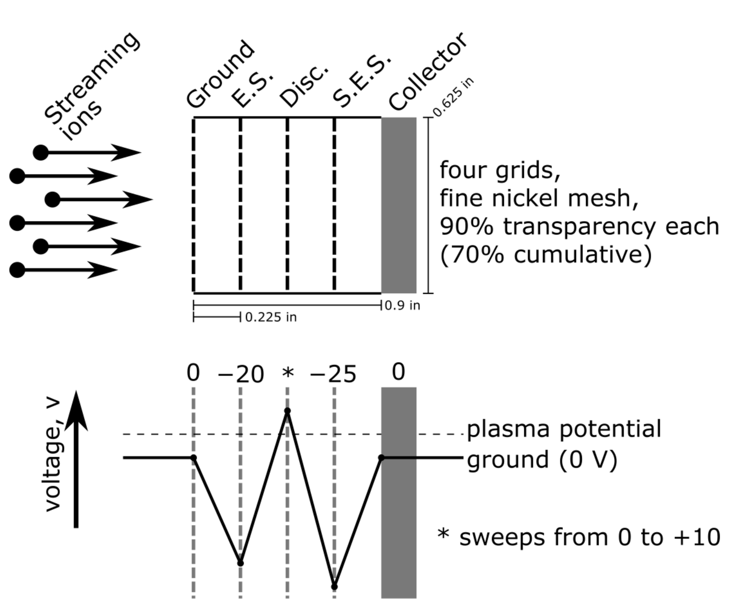


Two concentric grids with alternating hole patterns enable 90 open/close cycles per revolution. The smaller, outer grid (blue) is free to rotate azimuthally with respect to the fixed inner grid (gray).

Plasma Diagnostics

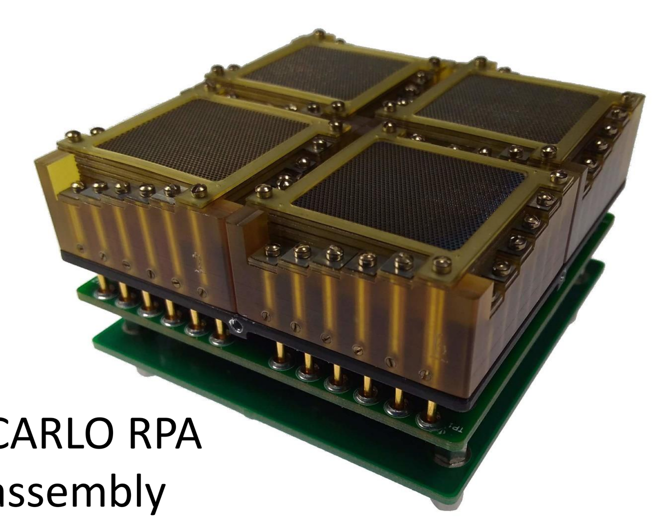


A Langmuir probe and retarding potential analyzer (RPA) are used to determine the plasma properties.

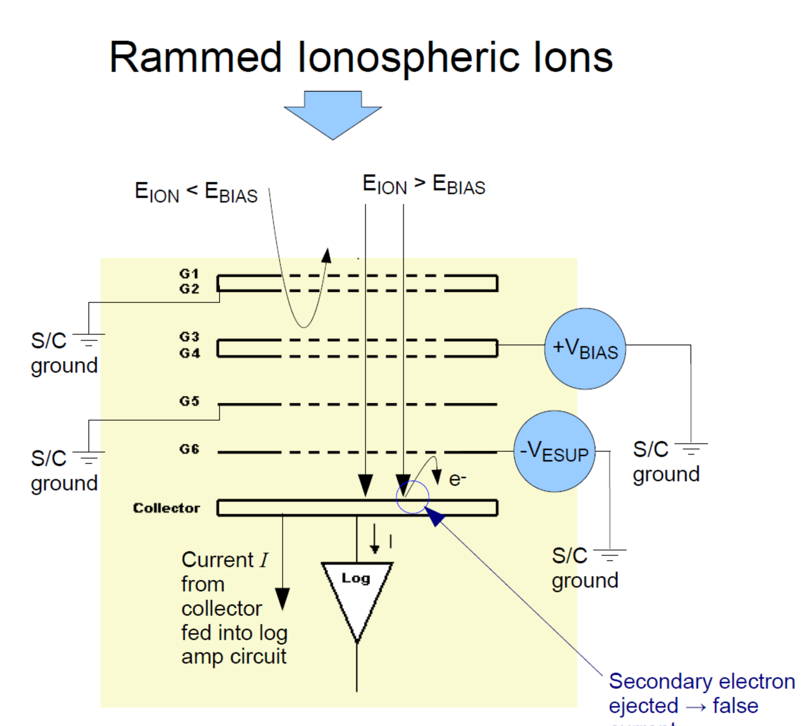


A RPA utilizes electrostatic potentials to filter out particles of a particular energy. The energy spectrum of impingent ions can be determined by varying the potential.

Instrument Development

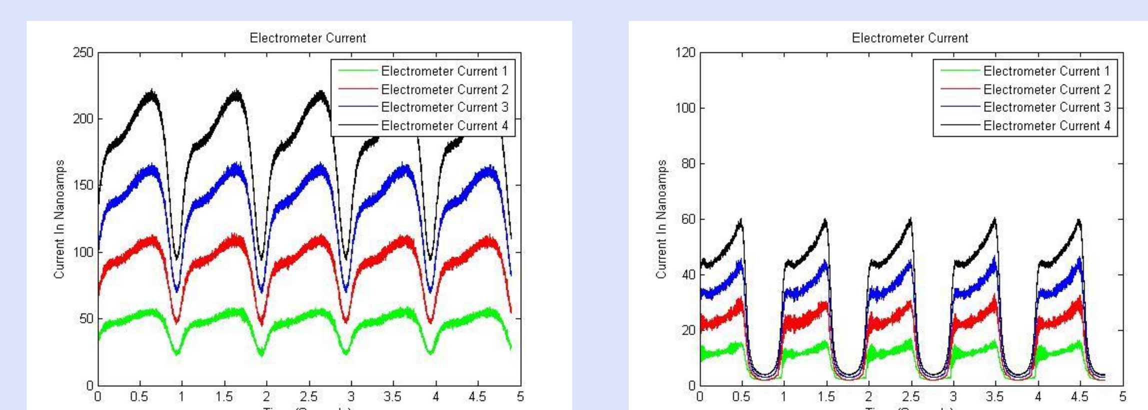


Charge Analyzer Responsive to Local Oscillations (CARLO) is a frequency-domain ion spectrum analyzer designed to measure the distributions of ionospheric turbulence from 1 Hz to 10 kHz (i.e., spatial scales from a few kilometers down to a few centimeters).

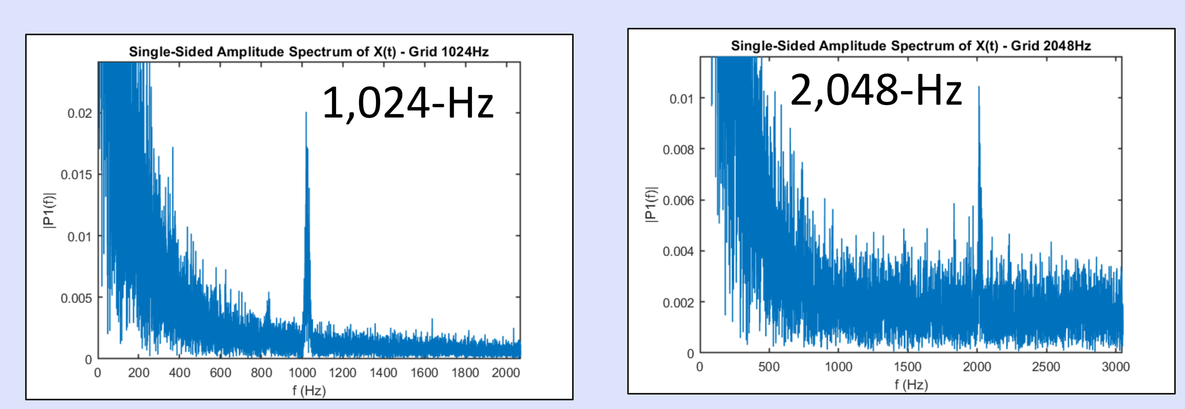


Results

- Established test setup capable of producing a LEO-like plasma with density fluctuations up to 2.5 kHz (equivalent to meter-level ionospheric structures)
- Verified that CARLO is able to detect plasma fluctuation up to 2 kHz
- Higher frequency is achievable with an upgraded drive mechanism to the grids (centimeter-level ionospheric structures)



CARLO instrument sampling at 1000 Hz while plasma source was modulated at 1 Hz.



Fourier analysis from CARLO operating in fixed-bias mode while the grids were spinning shows strong signals corresponding to the expected plasma oscillations. Grid speeds were confirmed via a tachometer.