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Sandia National Laboratories

Overview of low-density plasma diagnostics on Z

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National Diagnostics Working Group

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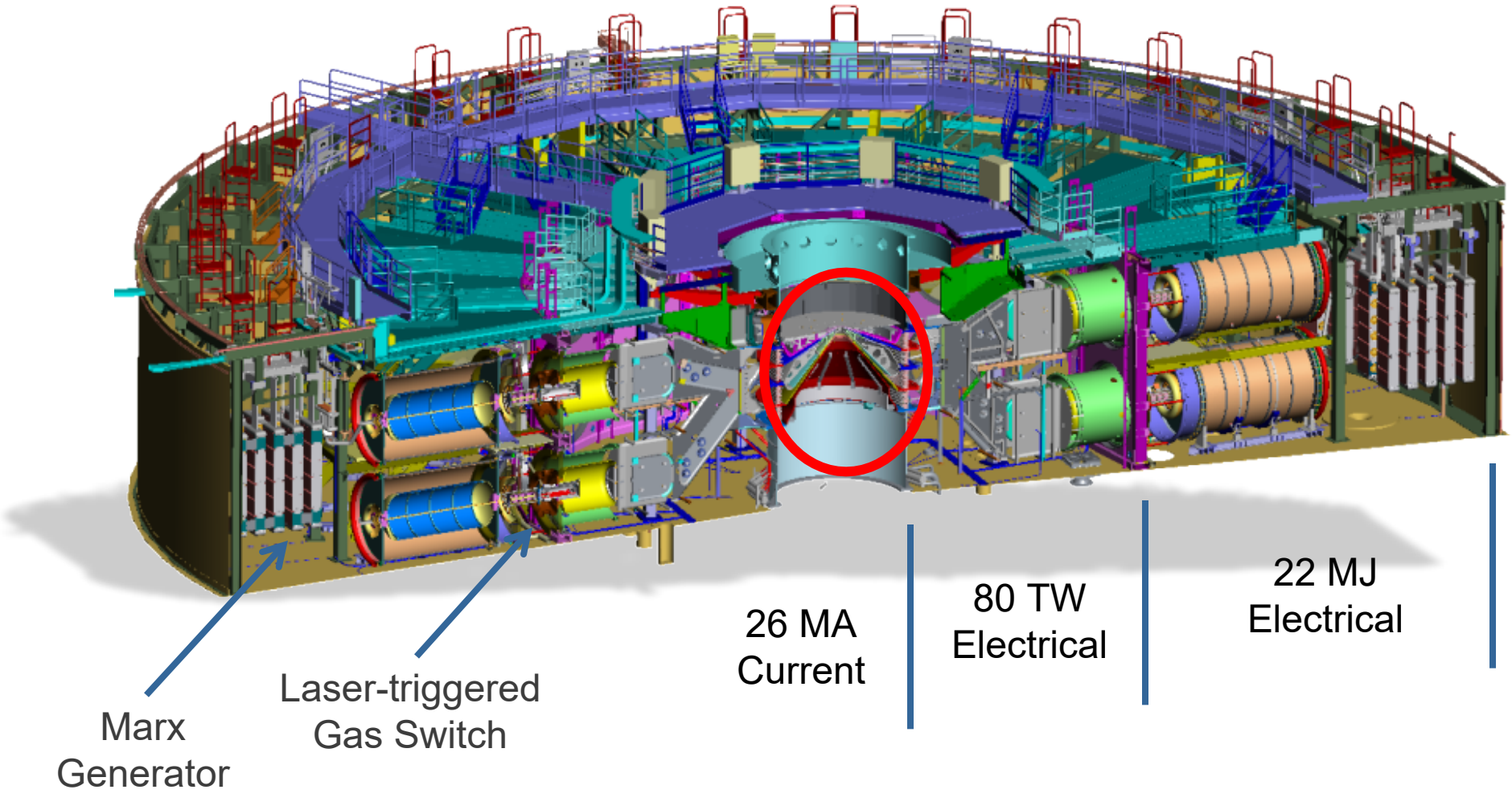
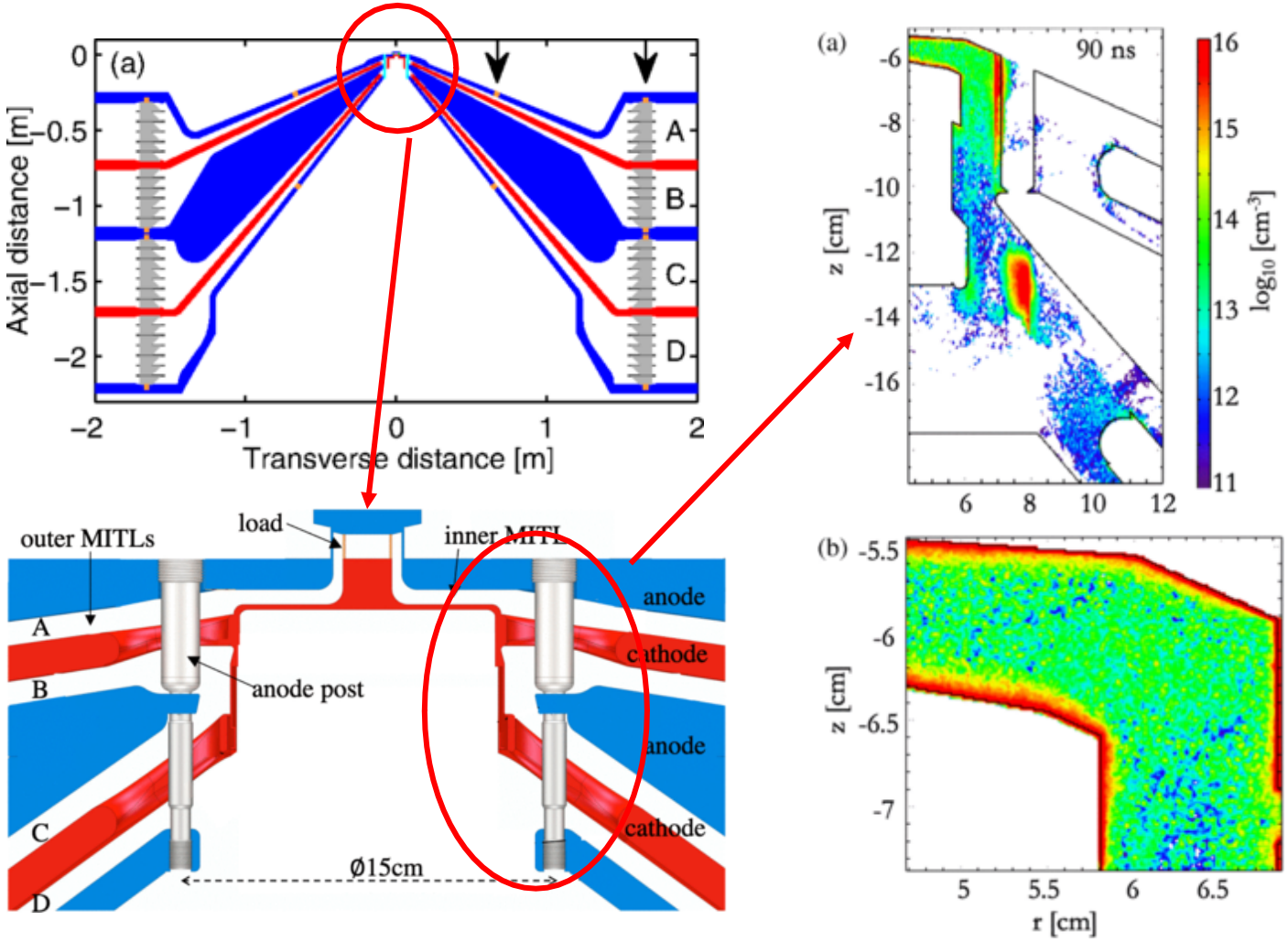
Z is the world's largest pulsed power machine, and compresses energy in space (>10^9 x) and time (>10^9 x) to generate high energy density conditions



Z is an "engine of discovery" for stewardship and fundamental HED science

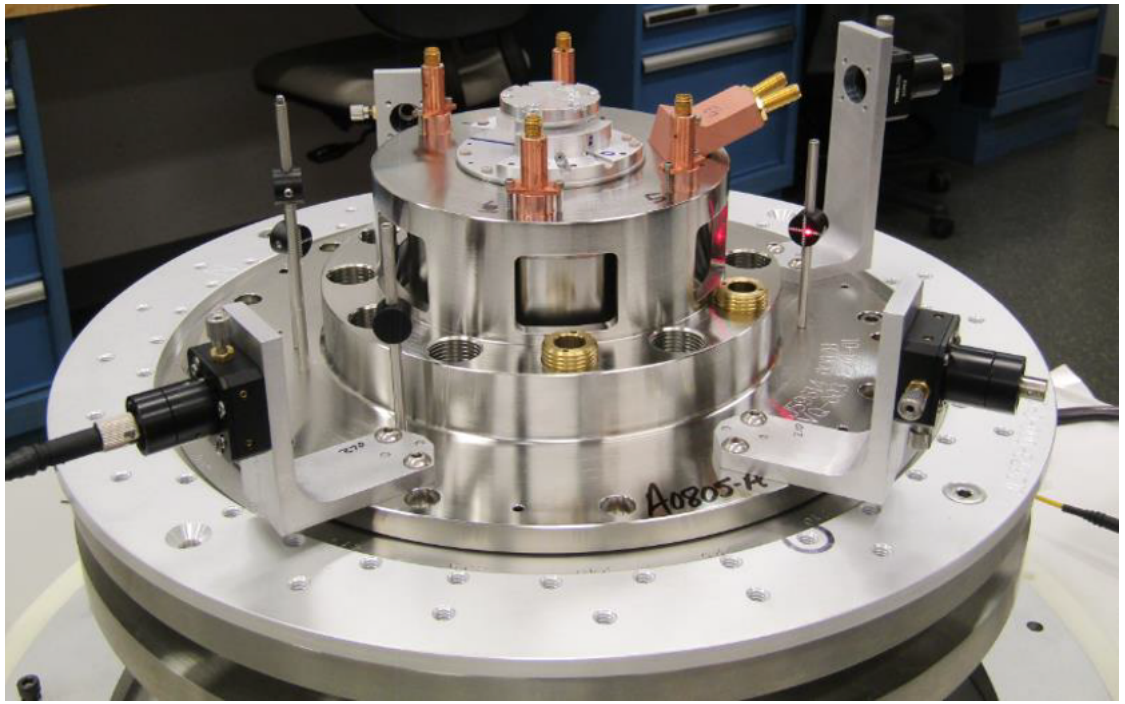
High energy density in the final power feed causes current losses due to plasma formation

- Understanding current losses can help better design experiments.
- Understanding of power flow is important as we look to a Next Generation Pulsed Power (NGPP) machine.
- Low plasma density measurements in the final feed can be compared to simulations and give insight into early plasma onset.

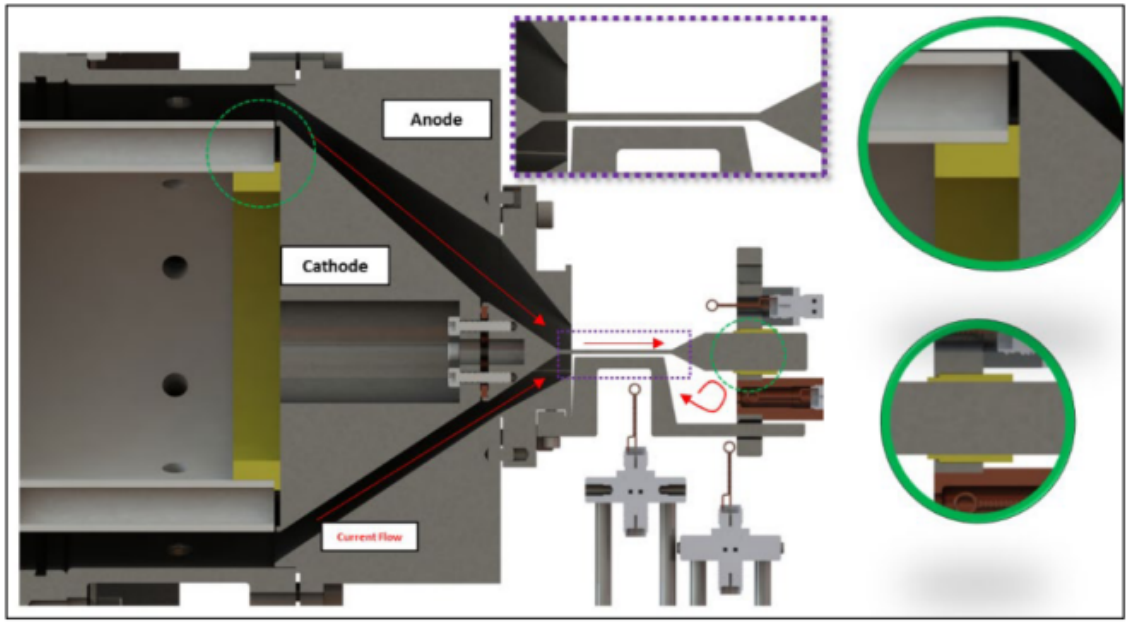


Gomez, M. R., et al. (2017). Physical Review Accelerators and Beams **20(1)**.
Bennett, N., et al. (2019). Physical Review Accelerators and Beams **22(12).**

We are using dedicated Z experiments to study power flow



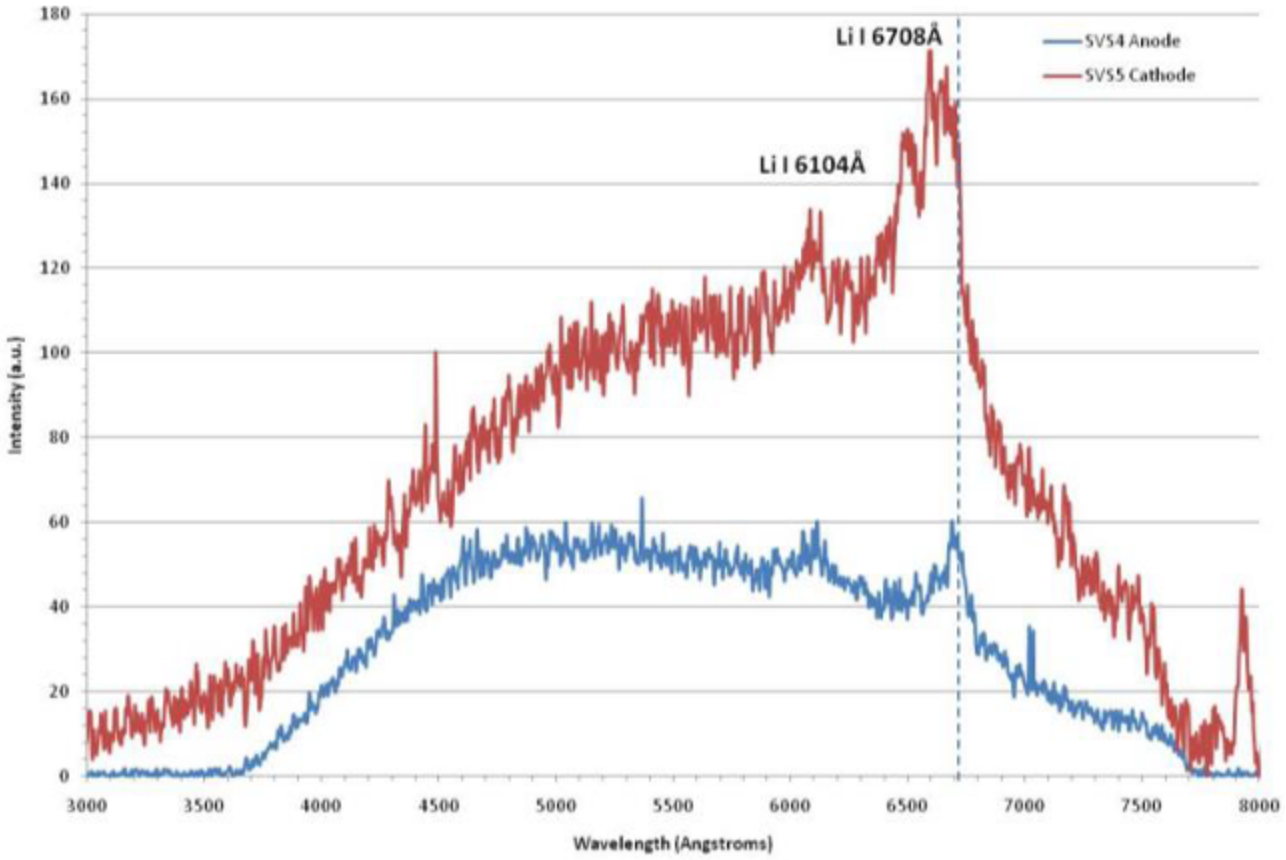
We use Mykonos to study Z relevant power flow at 700 kA



- LTD Machine.
- Load reaches current densities comparable to Z at 1.6 cm from the load.
- Is being used to test and develop various diagnostics talked about here.
- Also used to see the effects of cleaning the electrode surfaces.

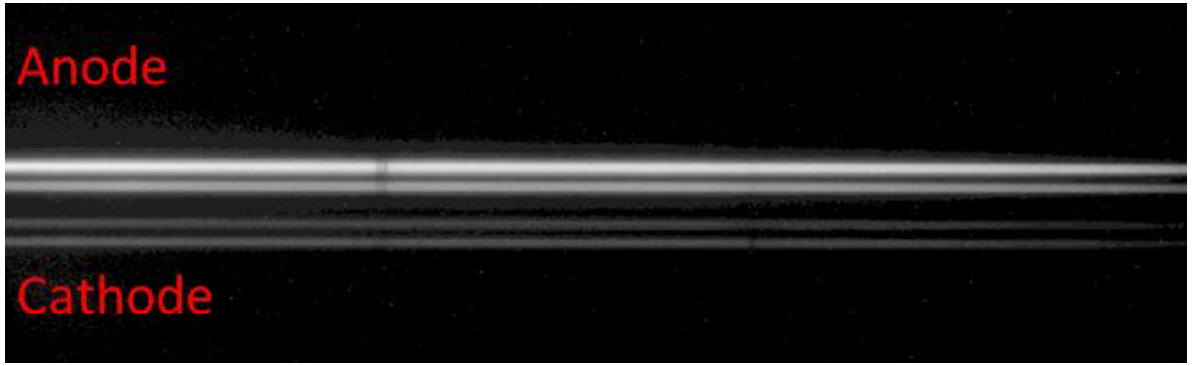
We employ Streaked Visible Spectroscopy (SVS) to make timed resolved measurements of plasma parameters

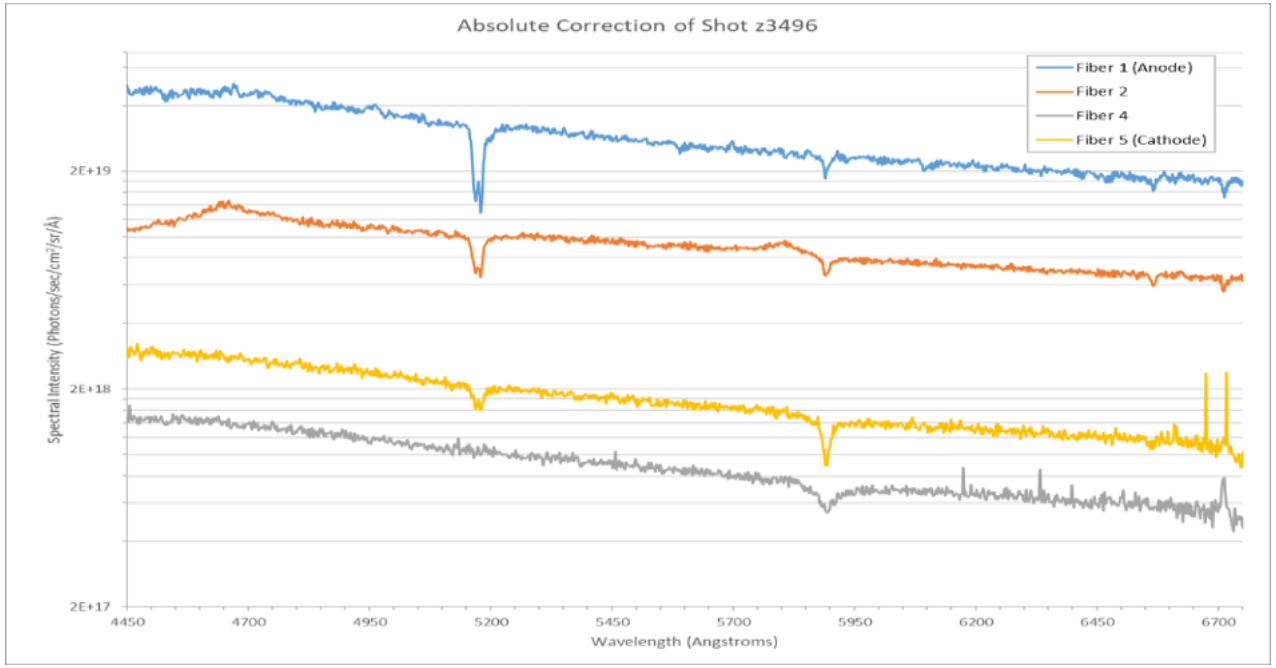
- 4 streaked visible spectroscopy systems.
- Sweep speeds from 25 ns – 2000 ns.
- Observe lines from species in the plasma.
  - Natural contaminates
  - Doped substances
- Measures parameters such as the T_e, n_e and B of the plasma.
- Example of Li dopant measurements.
  - Width gives densities of ~10^{18} cm^{-3}



Our gated visible spectroscopy capabilities have recently been expanded to include 2 new systems

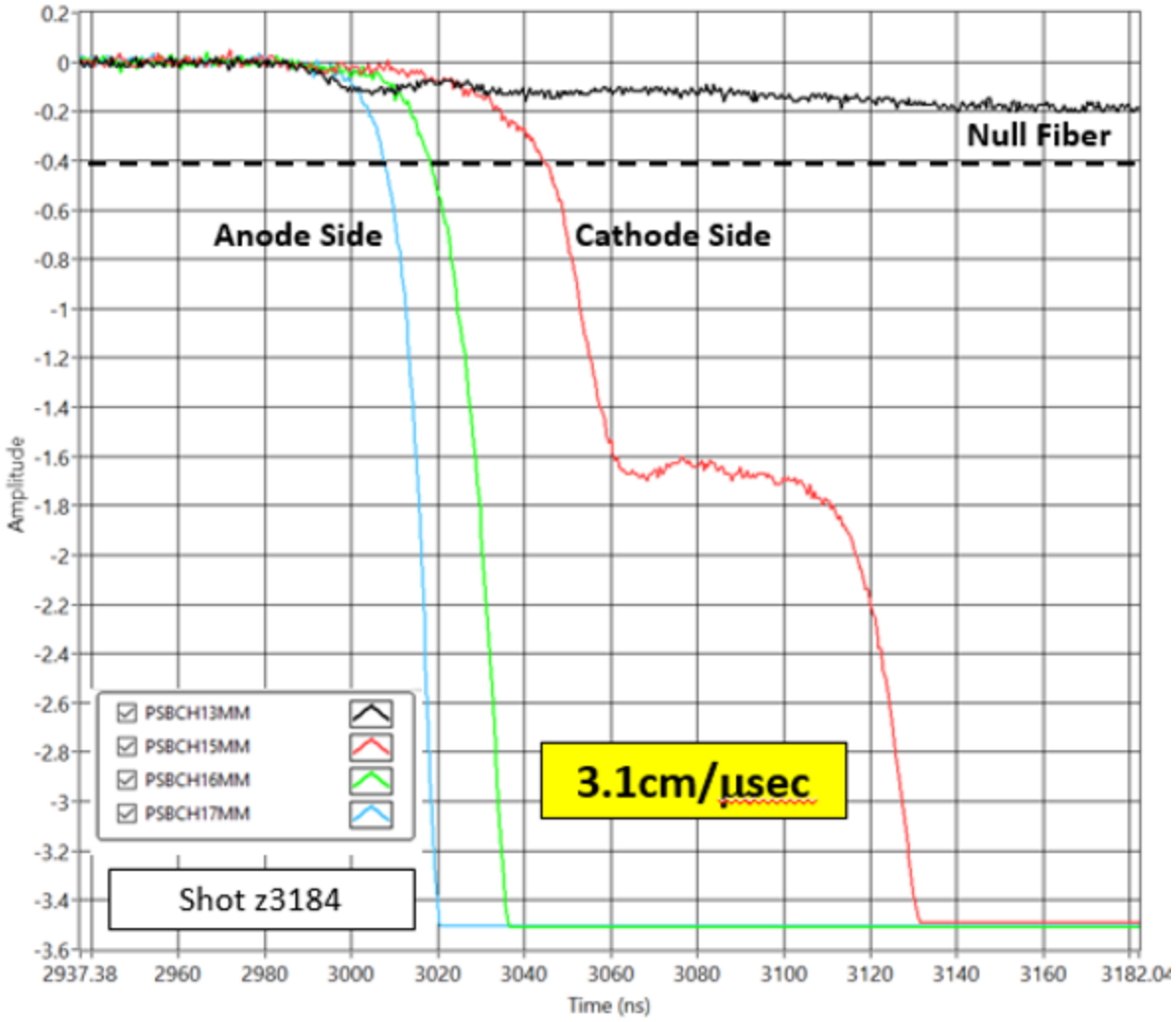
- 2 visible gated systems.
- Recent developments:
  - 8-frame gated system.
    - Minimum frame separation 250 ps.
  - UV gated system (down to 200 nm).
- Systems are typically fielded with a linear array of between 5-17 fibers.
- Minimum gate time is 2.5 - 7 ns.
- Shows differences in intensity across the anode cathode gap.



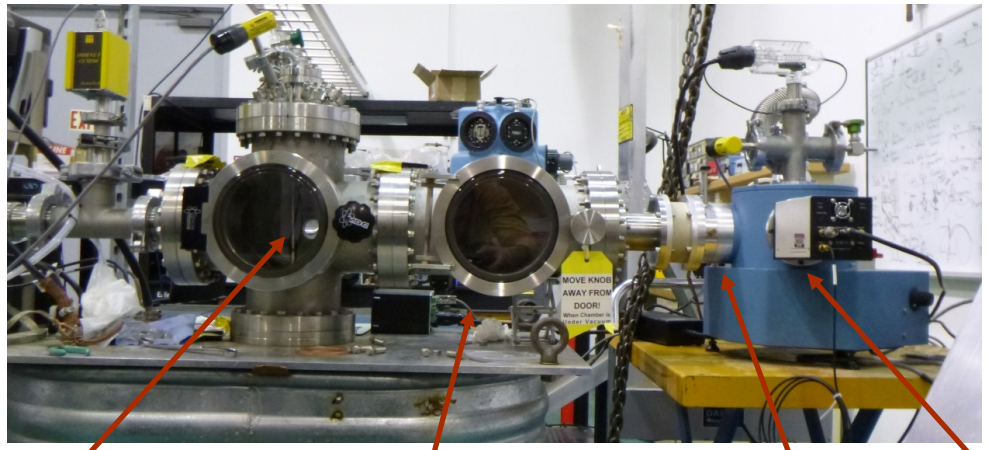


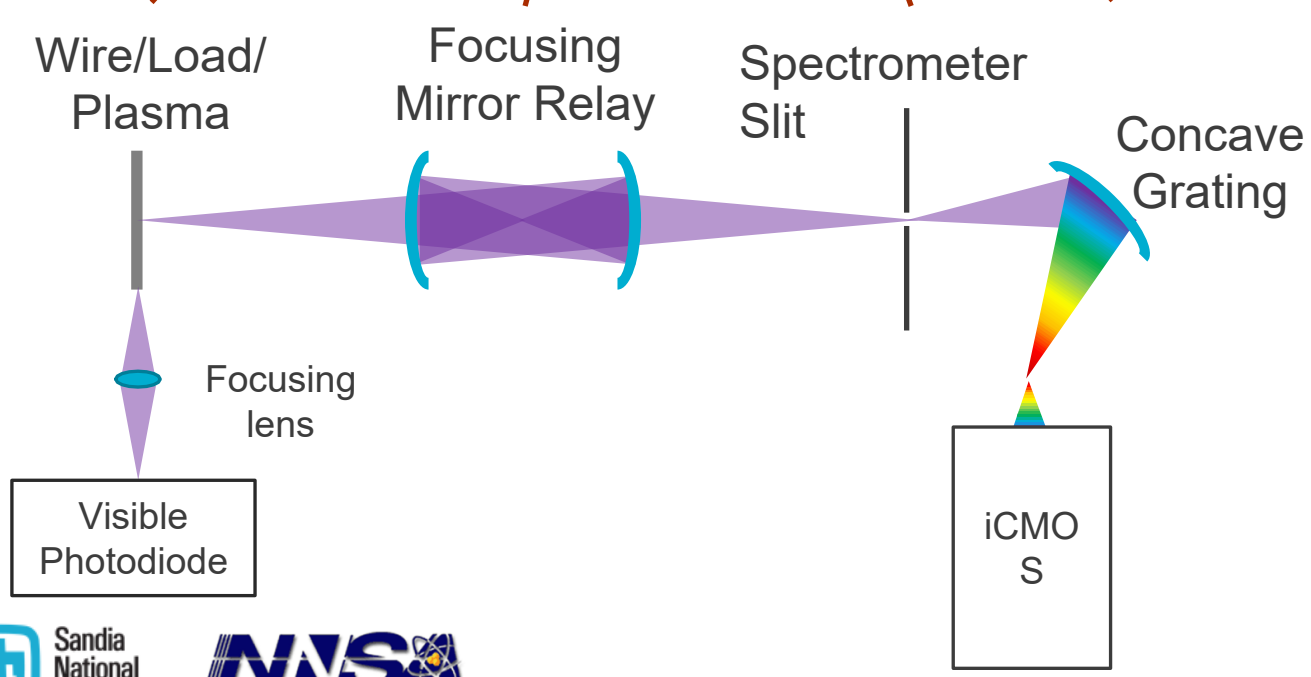
Avalanche Photo Diodes (APDs) can measure the location of plasma emission

- Look at several points across the AK-gap.
- Measures the velocity of the closure of the AK gap.
- Measured values show 3-5 cm/μs.
- This compares well with simulations predicting closure velocities between 2-4 cm/μs.



We are developing a VUV Spectrometer on a single wire pulser to look at desorption from electrode surfaces





McPherson 234/302 VUV Spectrometer

Optical Design: Aberration Corrected Seya-Namioka

f/#: f/4.5

Focal Length: 0.2 m

Gratings: 600, 1200, 2400 g/mm

Grating Coatings: Al + MgF2
- Pl for 2400 g/mm

Operating Wavelengths: > 40 nm

Required Vacuum: ~10^{-5} Torr

Linear Dispersion: 4 nm/mm

Slit Width: 0.1-3 mm

Photek iCMOS 160

Quantum Efficiency: 20-25% (100-300 nm)

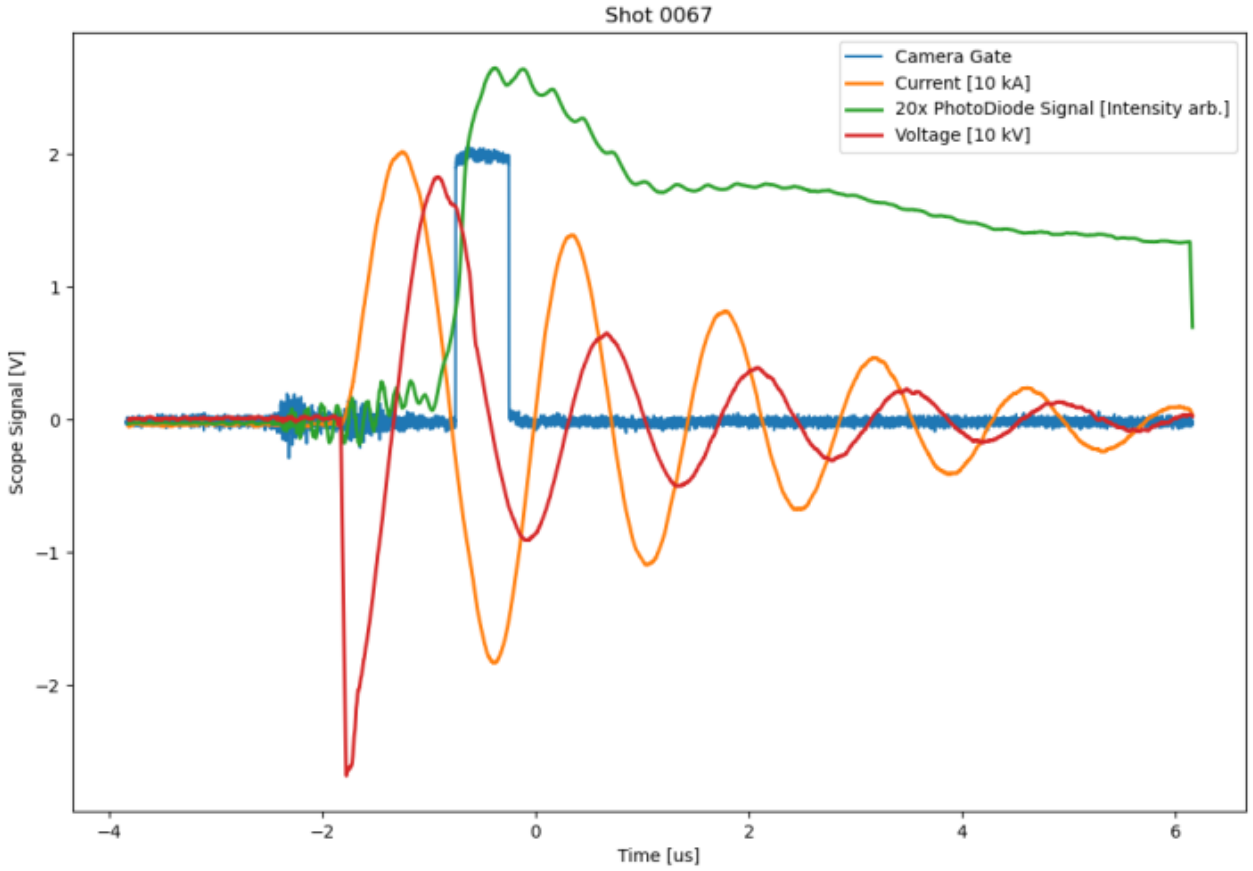
Gate Width: > 3 ns

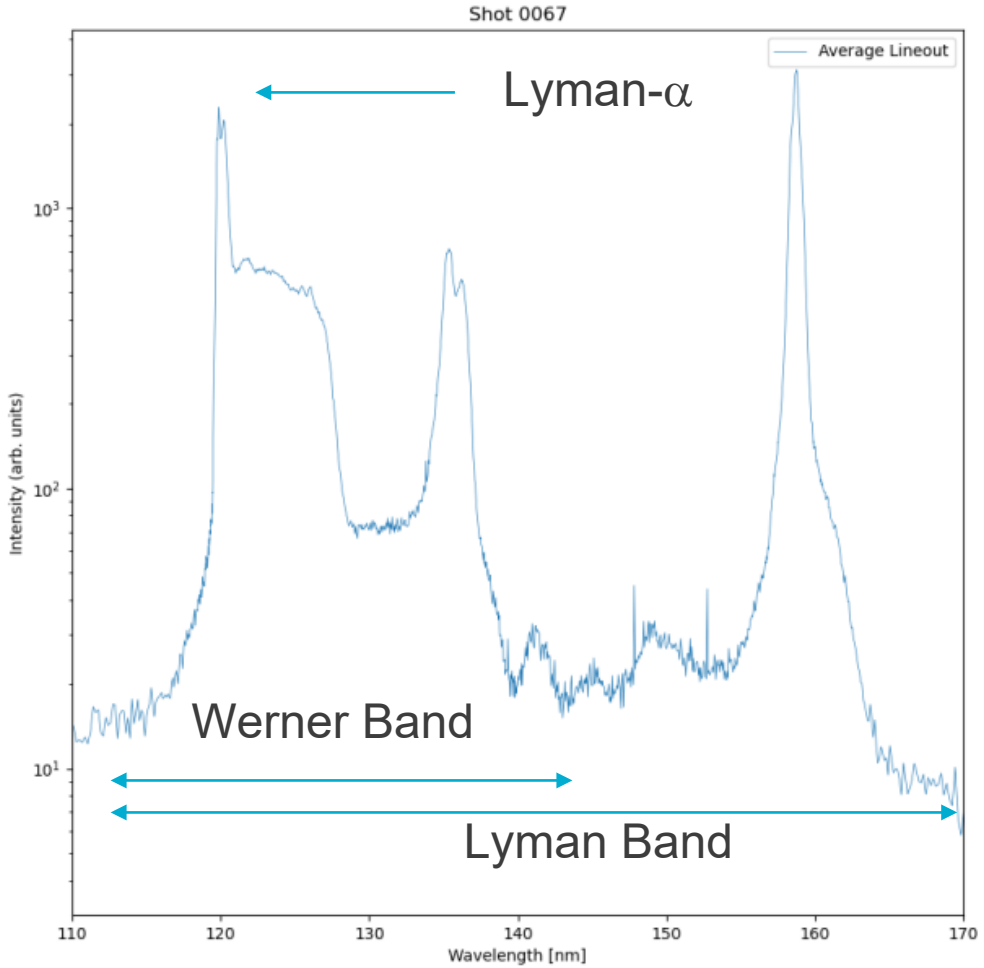
Window Size: 25mm, 1920x1200 pixels

Pixel Size: 13.3 µm

Window Material: MgF_2

First VUV Spectra show both atomic and molecular H lines





Taken using:

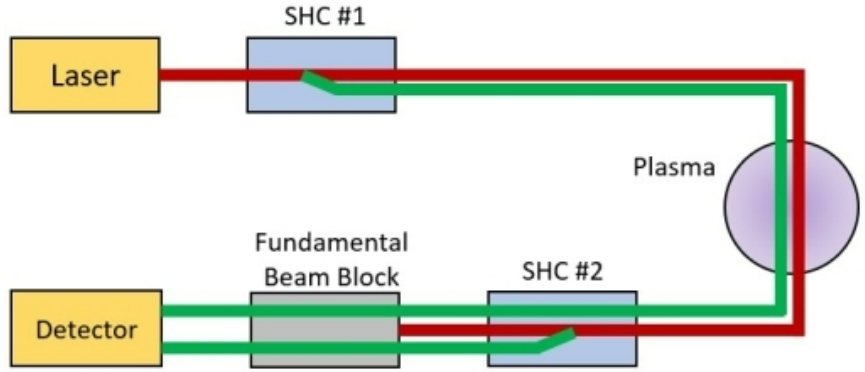
- 50 um slit width
- 500-ns gate width

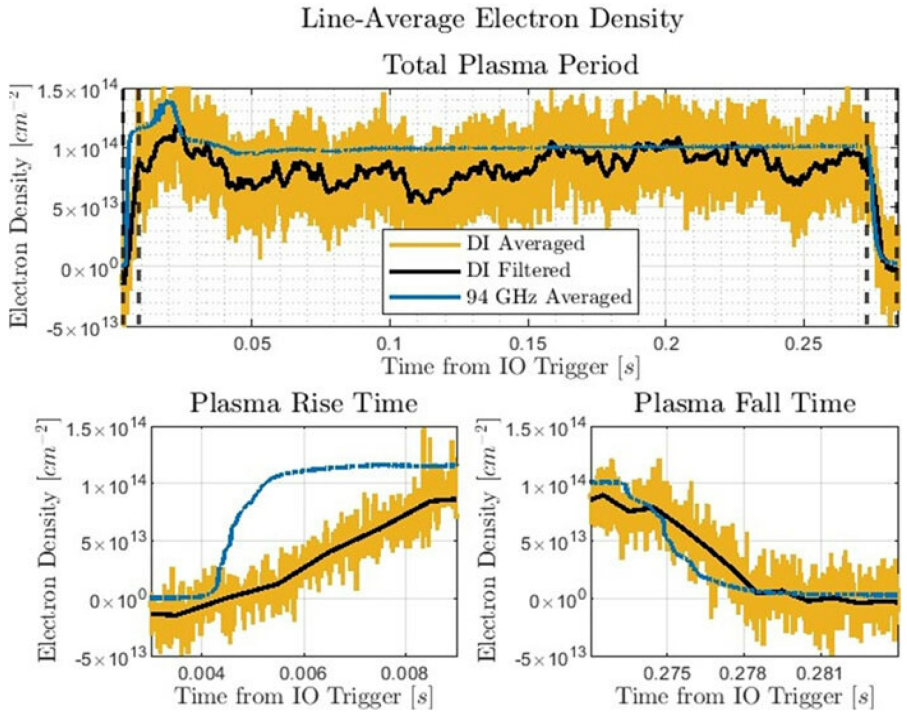
- <1.5x10-4 Torr Vacuum
- Spectra collected during breakdown

- Camera - 12 bit, 5 gain

A Dispersion Interferometer is currently commissioned to detect line averaged densities down to 10^{13} cm^{-2}

- Compares the phase difference between two collinear beams of the same frequency.
- Initial measurements performed on the HelCat RF plasma source at UNM.
- Currently being fielded on the Mykonos pulsed power machine.
- Future plans to field on Z.

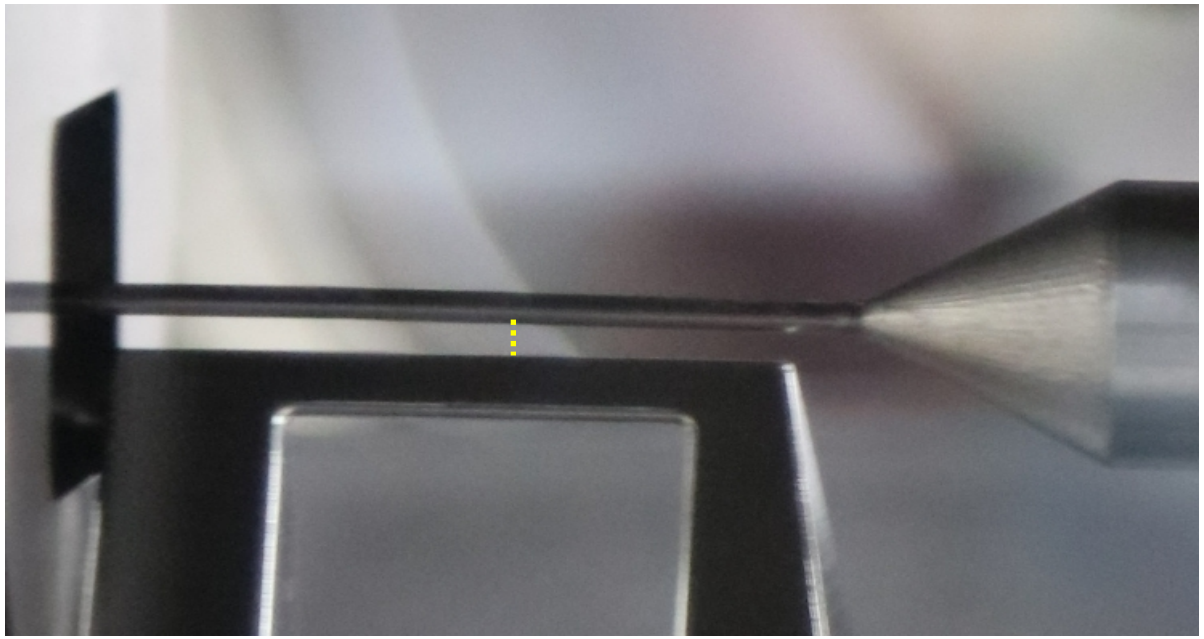




Hines, N. R., et al. (2022). Review of Scientific Instruments **93(11).**

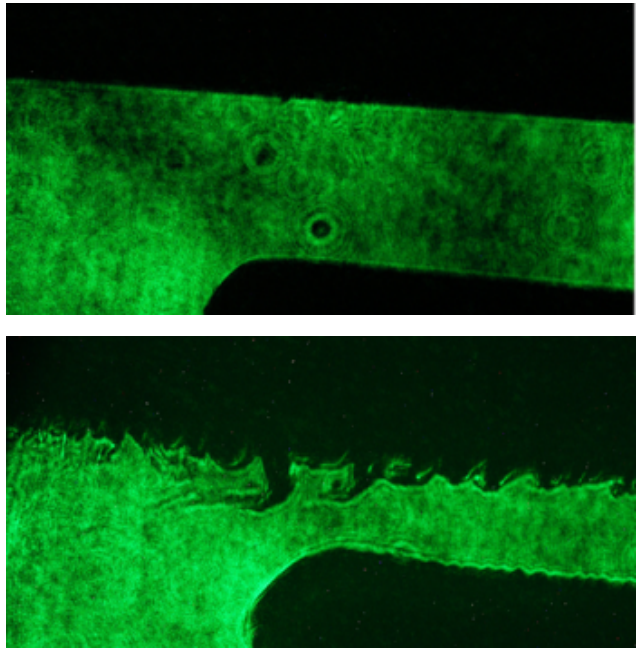
Photon Doppler Velocimetry (PDV) Interferometry is being developed to temporally and spatially resolve plasma density

- Phase change from density appears as an apparent velocity.
- Measure the density at 4 points across a 1 mm AK-gap on Mykonos.
- Measures densities down to 10^{16} cm^{-3}.



Shadowgraphy has been fielded to explore gap closure on Mykonos

- David Yager just talk about the many recent advances of optical imaging on Z.
- These diagnostics are very useful to studying of power flow.
- Have also been used on Mykonos to measure gap closure.



Summary

Diagnostic	Highlights
Streaked spectroscopy	Time resolved spectrum form 400-700 nm
Gated spectroscopy	Spatially resolved spectrum over 5-17 points 8 frame camera and capabilities to go down to 200 nm
APD	Spatially resolved emission from the plasma
VUV spectroscopy	Looking at the Lyman-α line of surface desorption
Dispersion interferometer	Densities down to 10^{13} cm^{-2}
PDV interferometer	Densities down to 10^{16} cm^{-3} at 4 points over 1 mm.
Optical imaging	Various methods to observe plasma in the optical regime.

- Are there better ways or other diagnostics we can use to continue to study power flow plasmas relevant to Z and NGPP?
- Reminder: there will be a breakout this afternoon to discuss low density plasma diagnostics on Z.

THANK YOU

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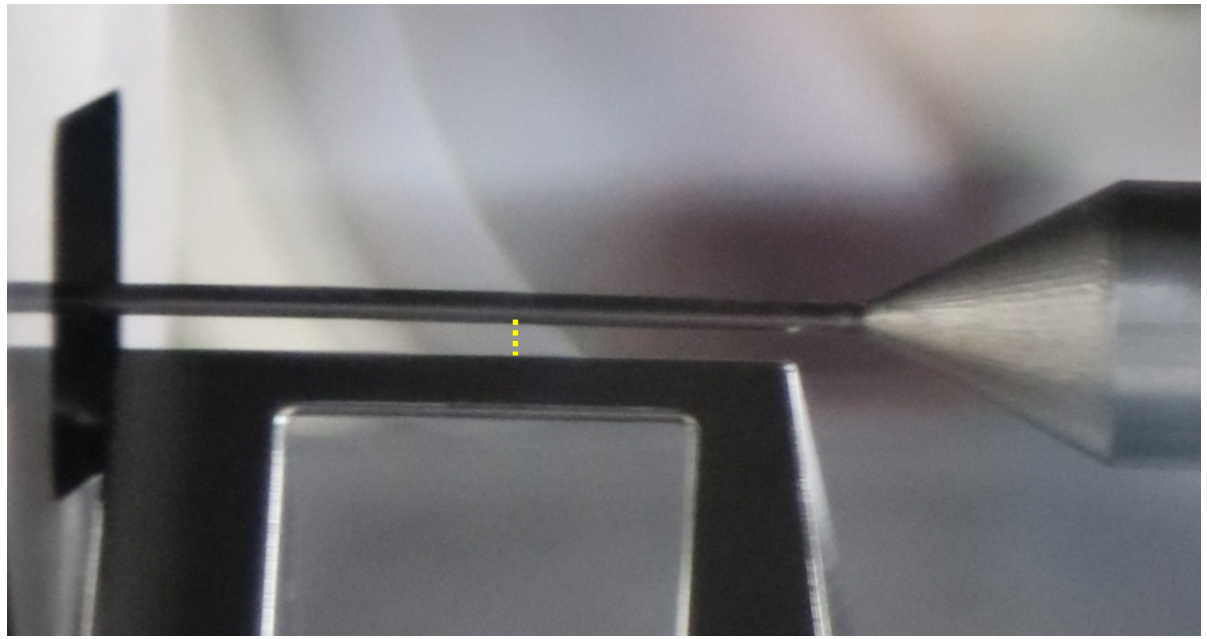

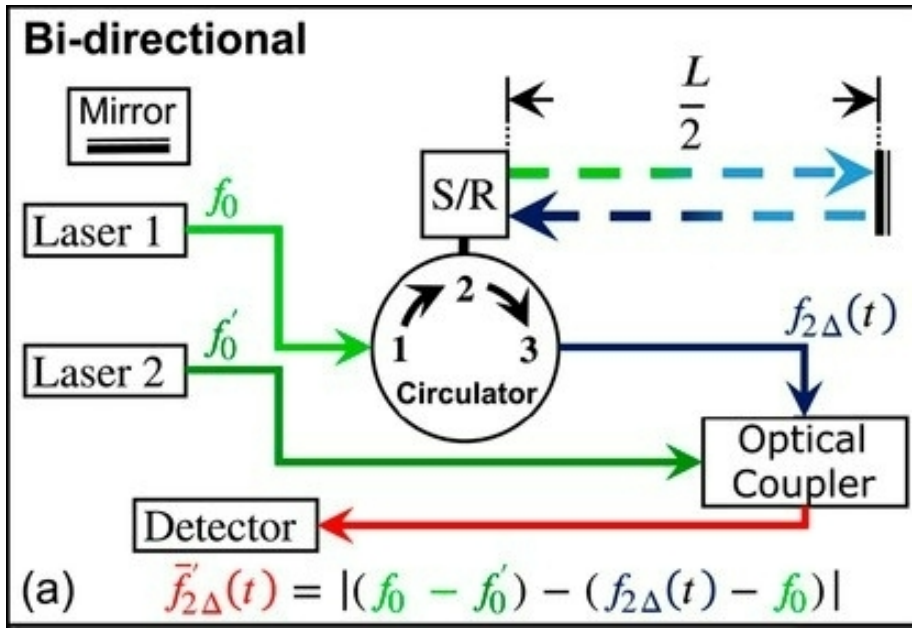

Swanson, K. J., et al. (2022). Rev Sci Instrum **93(4): 043502.**