Initial Results in Semiconductor Manufacturing Plasmas

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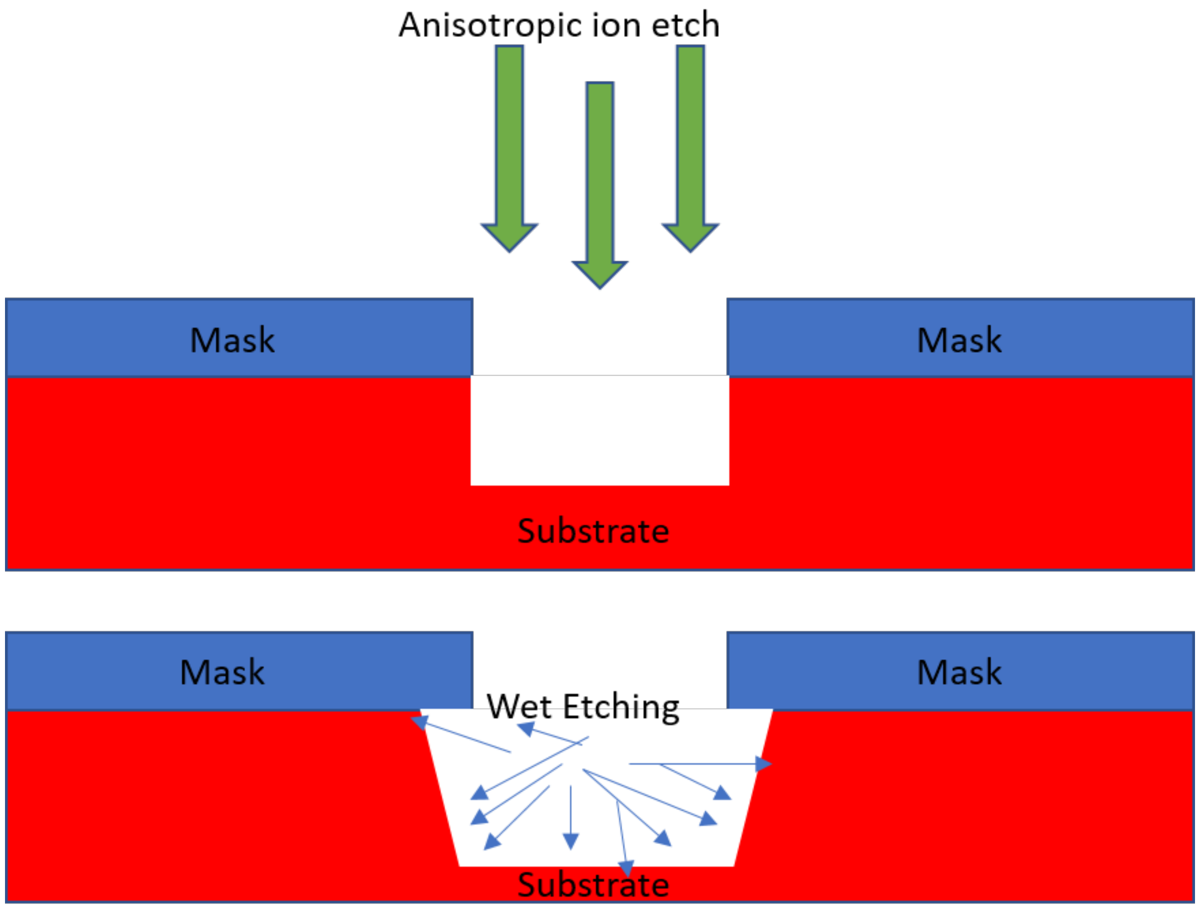
Princeton Plasma Physics Lab – Graduate Summer School

Industry Plasmas

- Plasma is used for semiconductor etching and doping.
- Provides more controllable, anisotropic etches compared with "wet" etching.
- Much more green, no need for harmful chemicals



Moore's Law

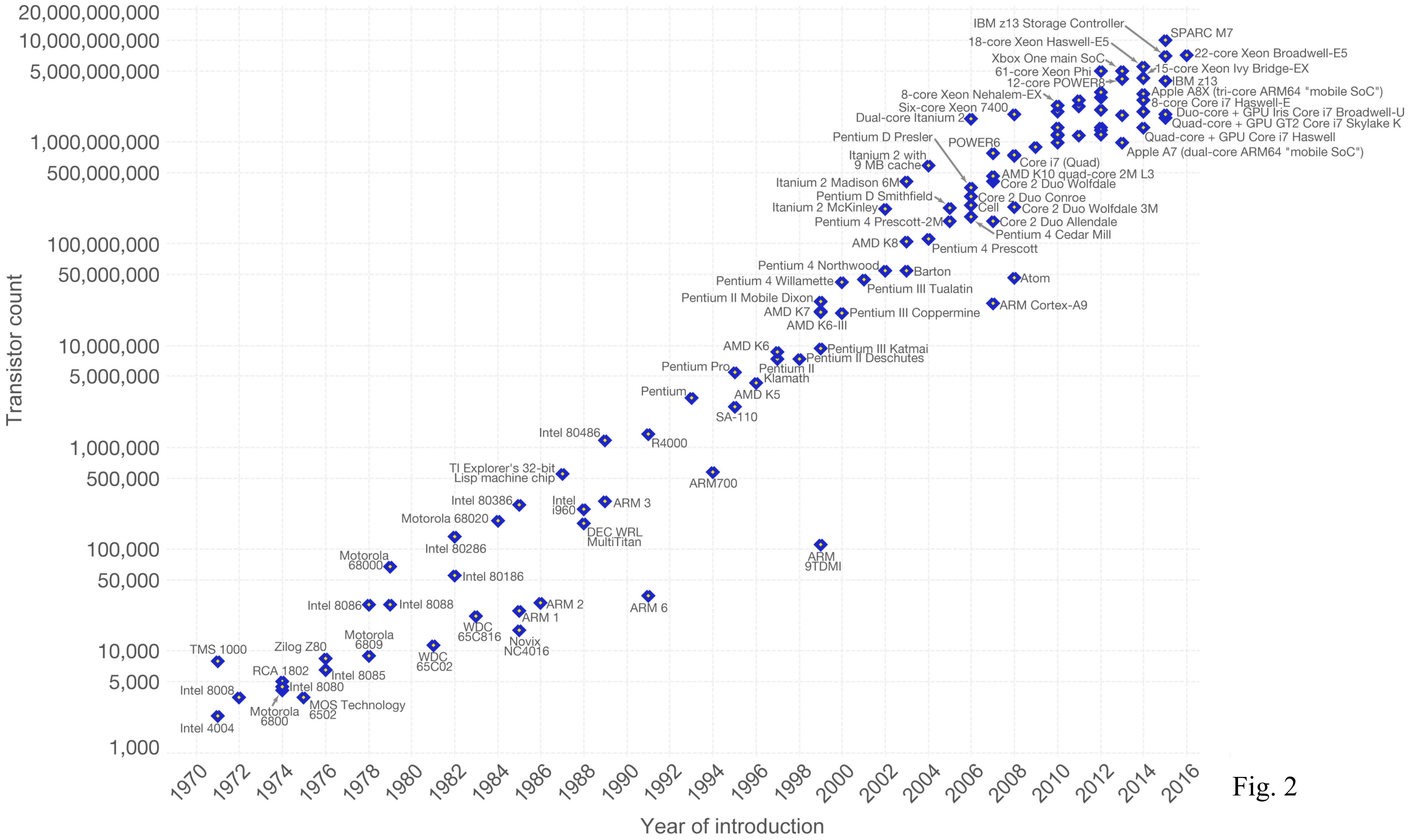


Fig. 2

Transistors

- Semiconductor features are reaching the nanoscale
- Silicon atoms are ~.2nm in diameter
  - We are reaching a natural limitation
- Smallest defect will greatly affect overall performance.

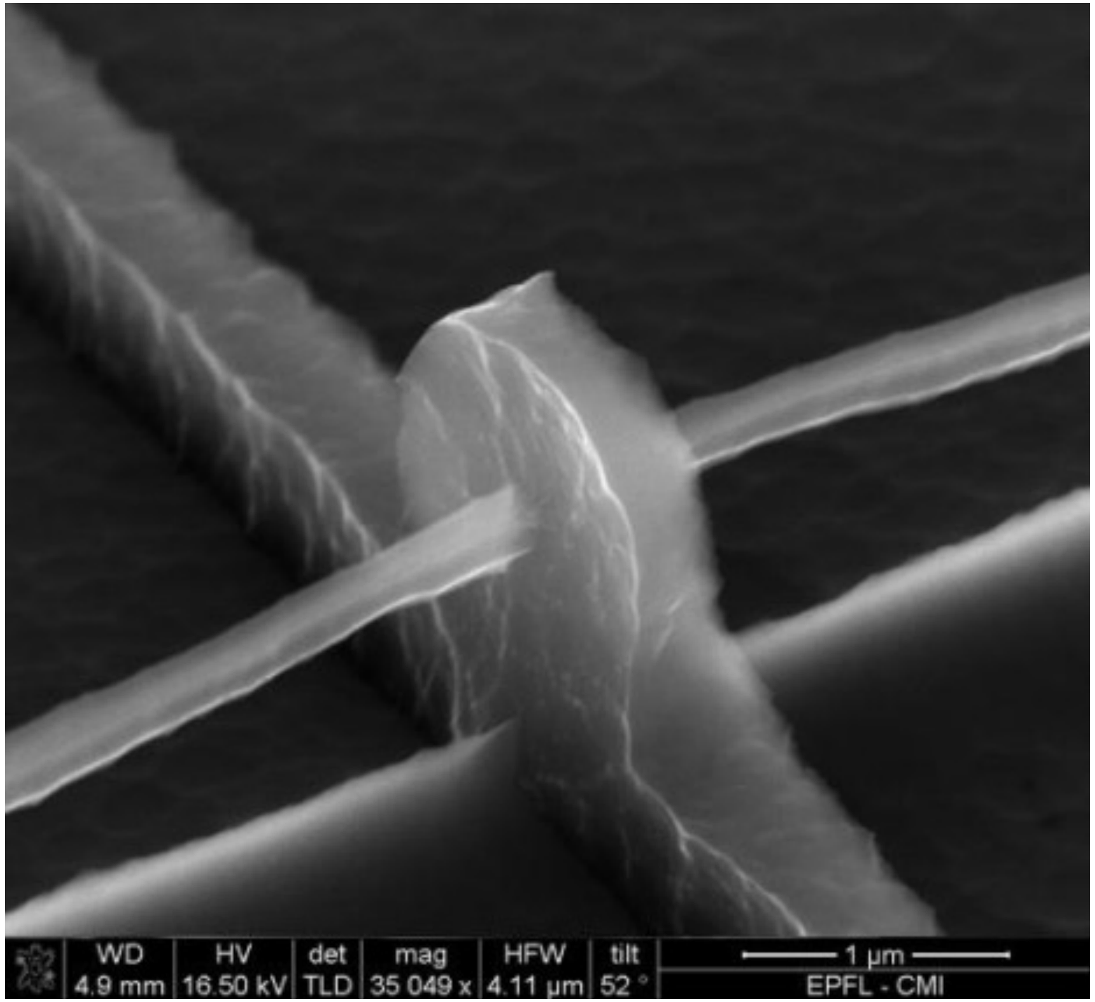


Fig. 3

Keep Moore's Law Alive

- We must find a way to keep increasing processing power

- Start building 3-dimensionally
  - Die-to-Die
  - Die-to-Wafer
  - Wafer-to-Wafer

- We want a singular, 3-dimensional semiconductor

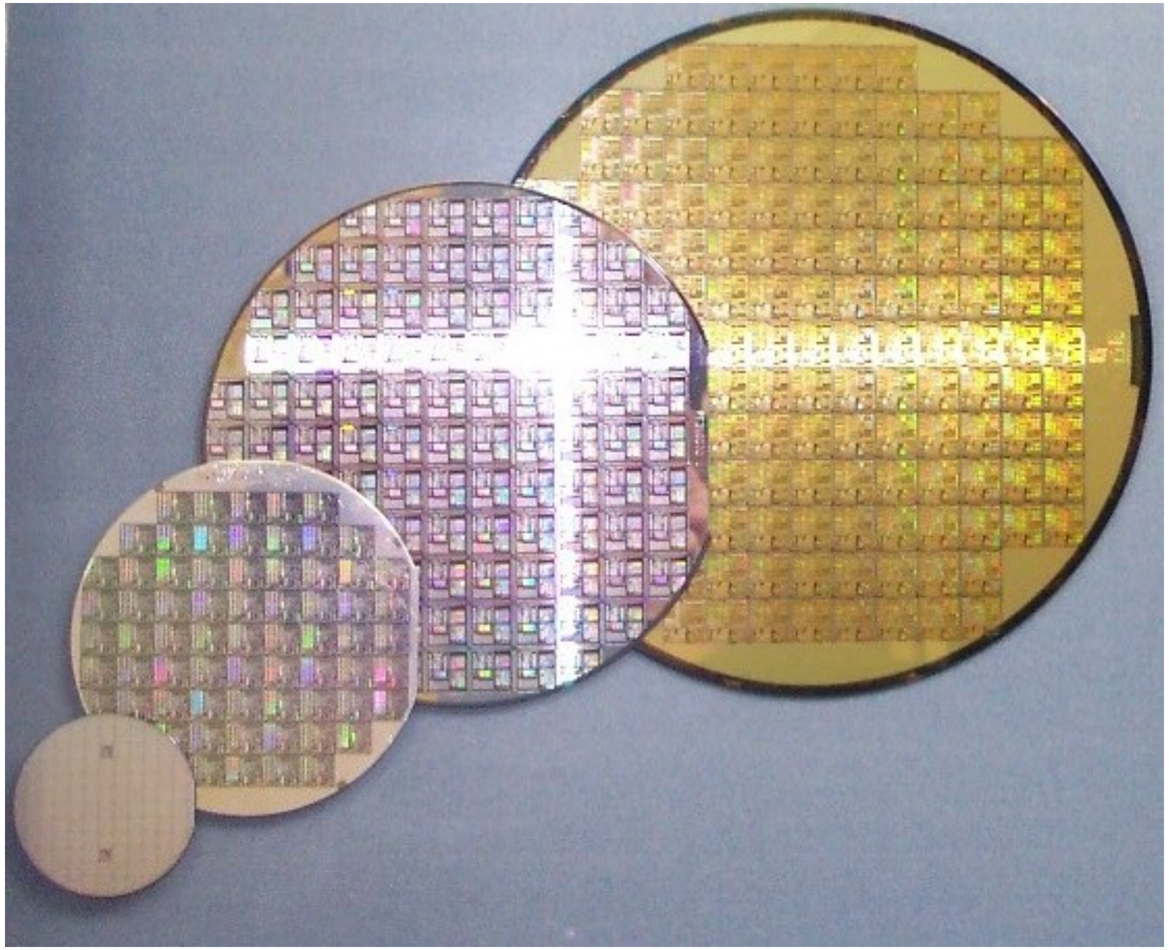
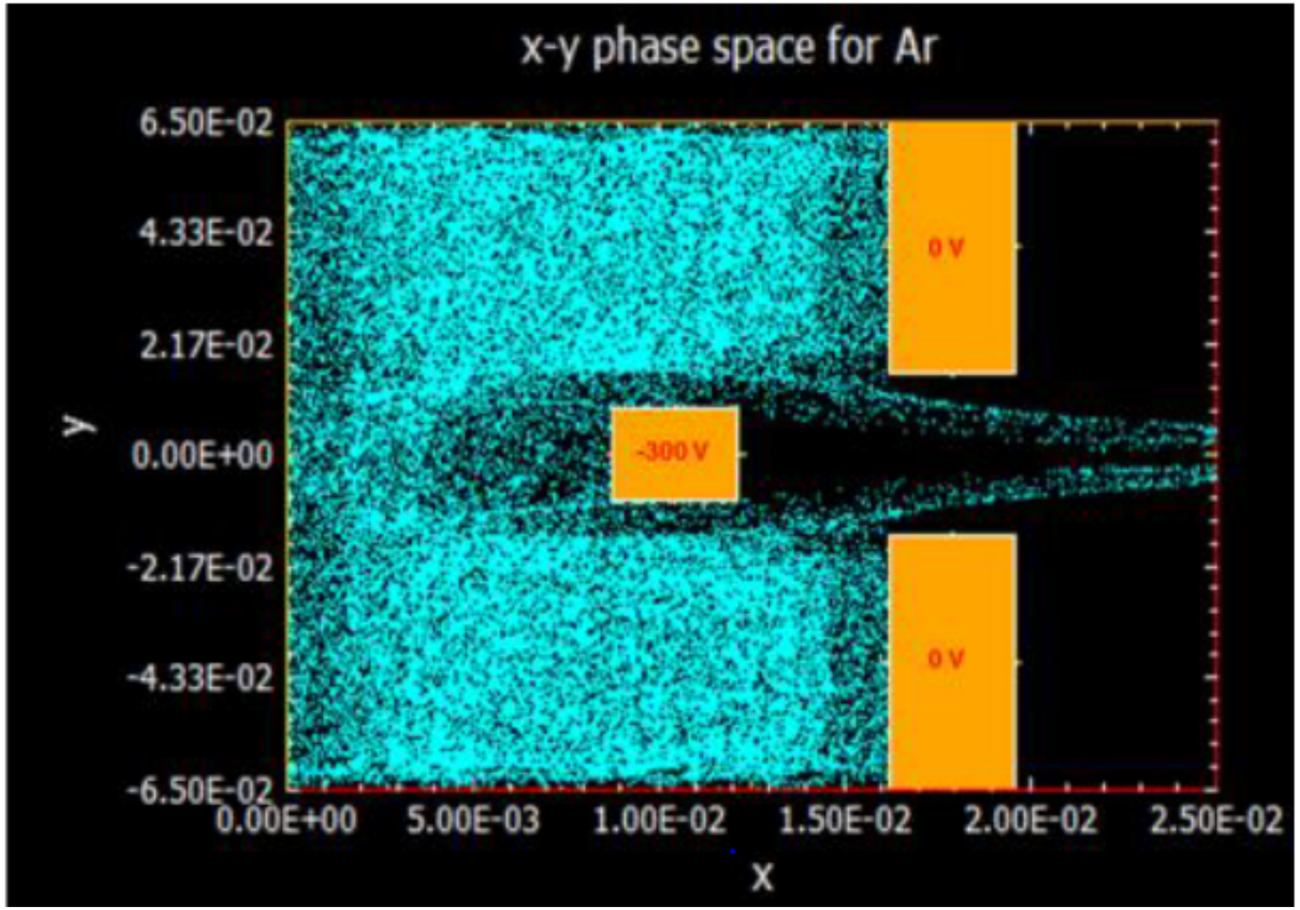


Fig. 4

Controllable Ion Beamlets

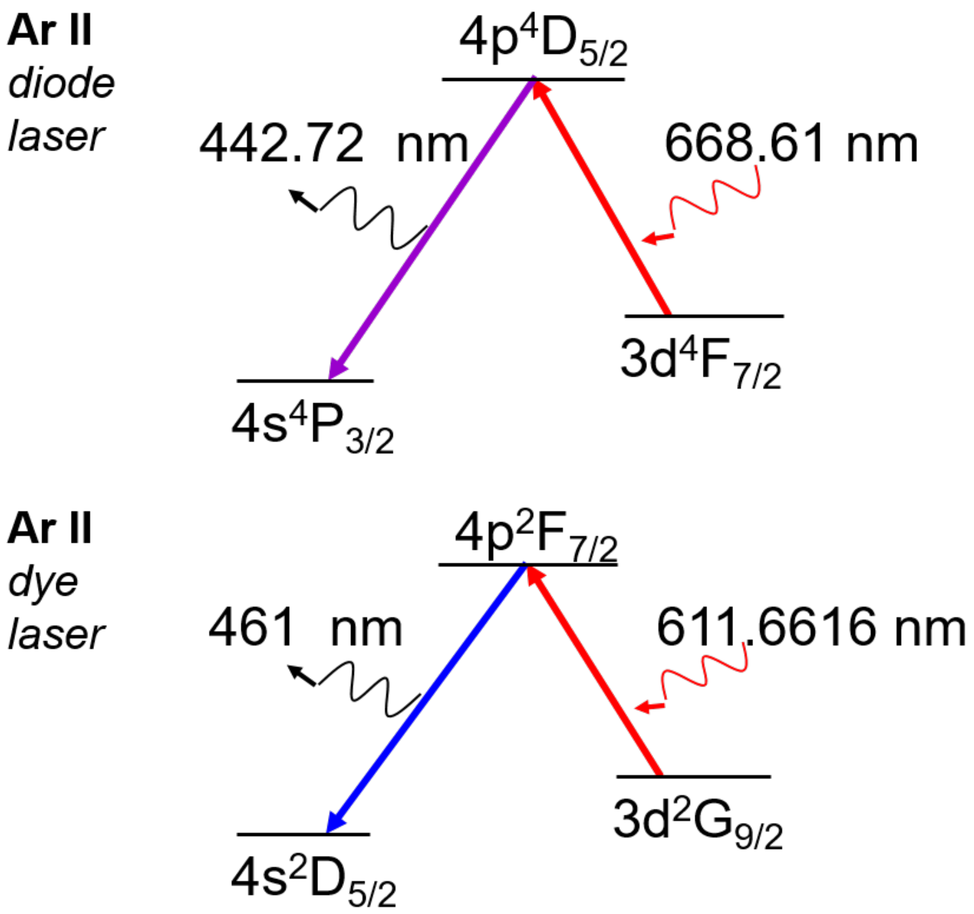
- NSF GOALIE Grant: **Optimization of Ion Beam Extraction – Enabling Technology For Advanced Semiconductor Fabrication**

- Use LIF to investigate ion velocities and angular distribution dependences on source parameters.



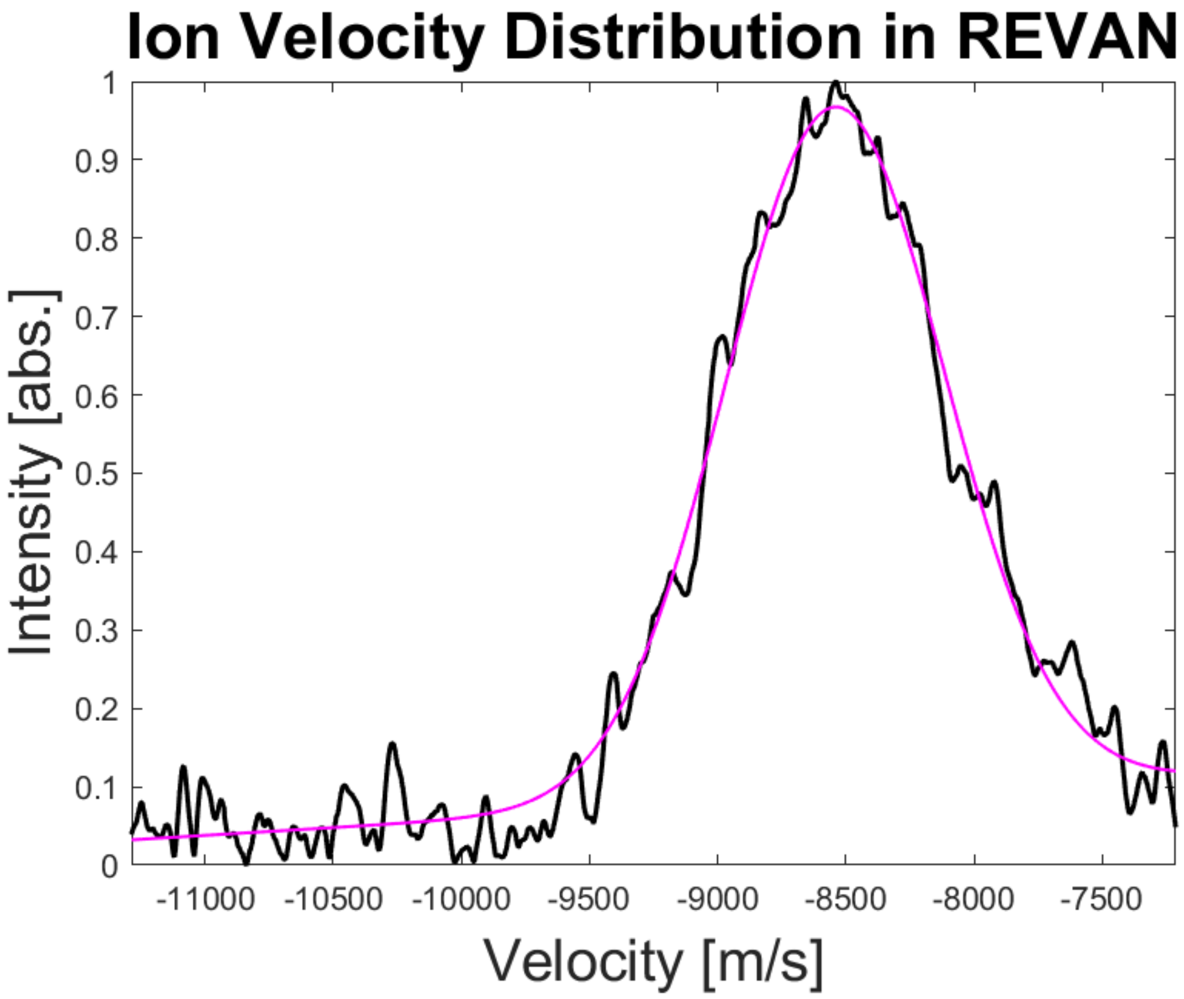
LIF

- Use laser to excite an electron to a higher state
- Collect emitted light when electron falls to more stable orbit
- Depending on velocity of ion it will "see" different wavelength of injected light
  - Can use this Doppler shift

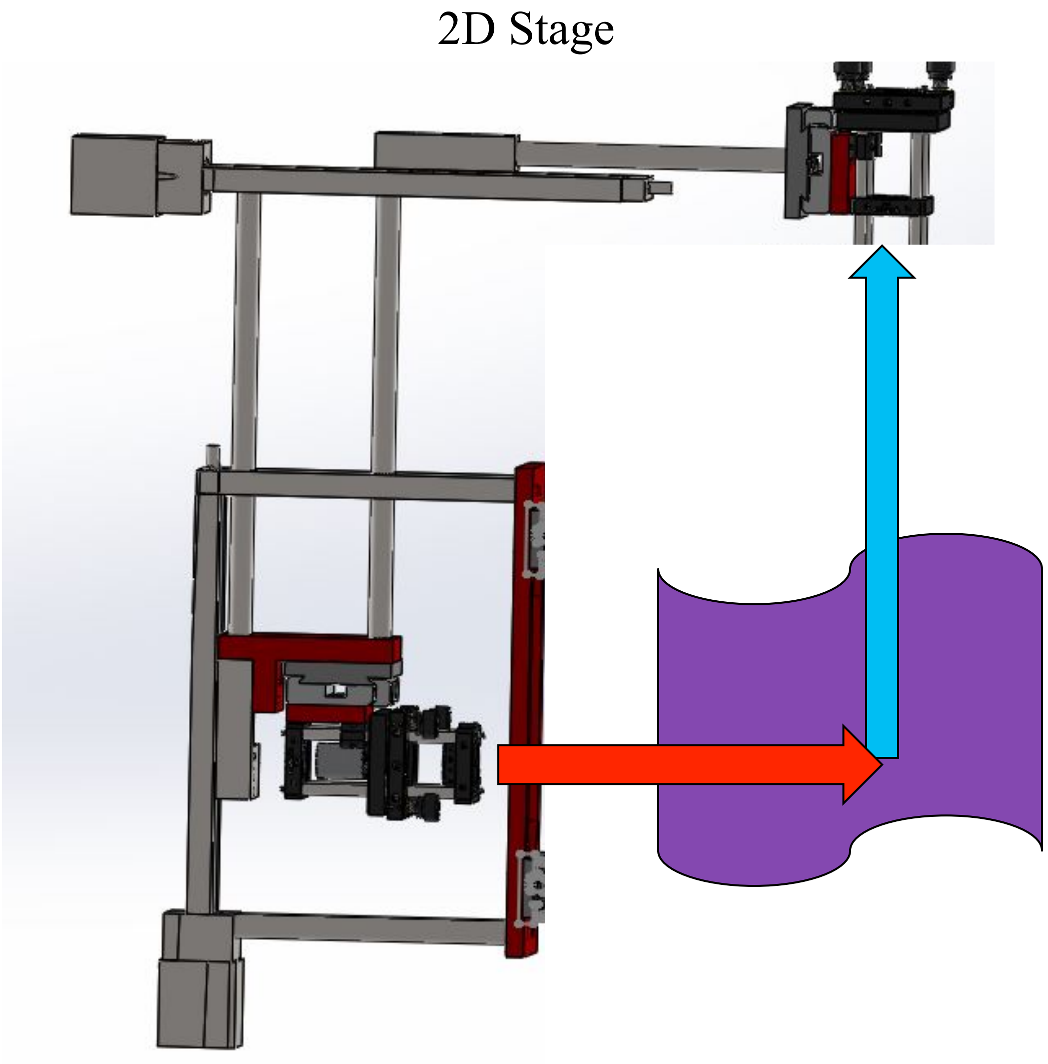


LIF

- Scan laser over frequency range
- Assume Maxwellian Distribution
- Fit Gaussian to IVDF
  - Area under curve → Density
  - Offset → Velocity
  - Width → Temperature



LIF

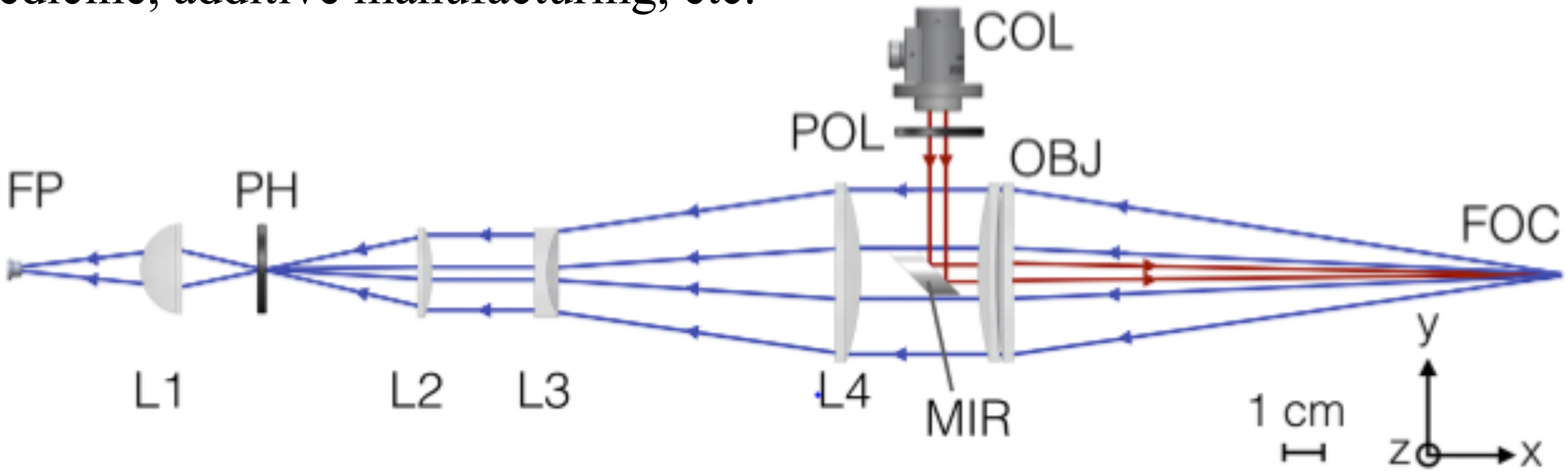


- Standard LIF needs two points of optical access
- Inject collimated beam to excite ions
- Collected with a focused optics to give localized measurement in plasma
- With enough optical access we can map the density, velocity, and temperature of the whole plasma

LIF

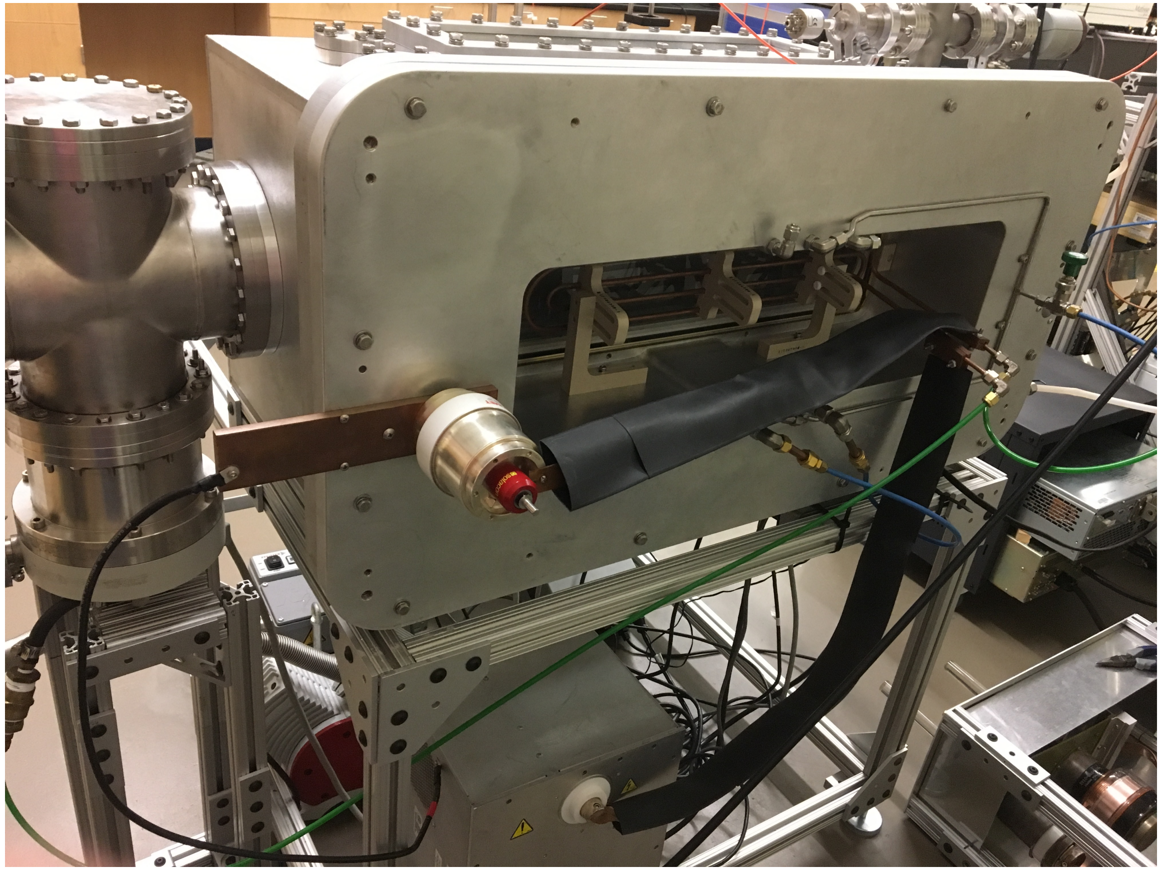
- Developed at WVU
- Allows for collection and injection along the same optical path
- Lets us measure previously forbidden regions of plasmas such as in antenna
- Many applications outside of plasma physics
  - Medicine, additive manufacturing, etc.

Confocal LIF



D.S. Thompson (2017)

Ribbon Experiment for Velocity and Angular distribution (REVAN)

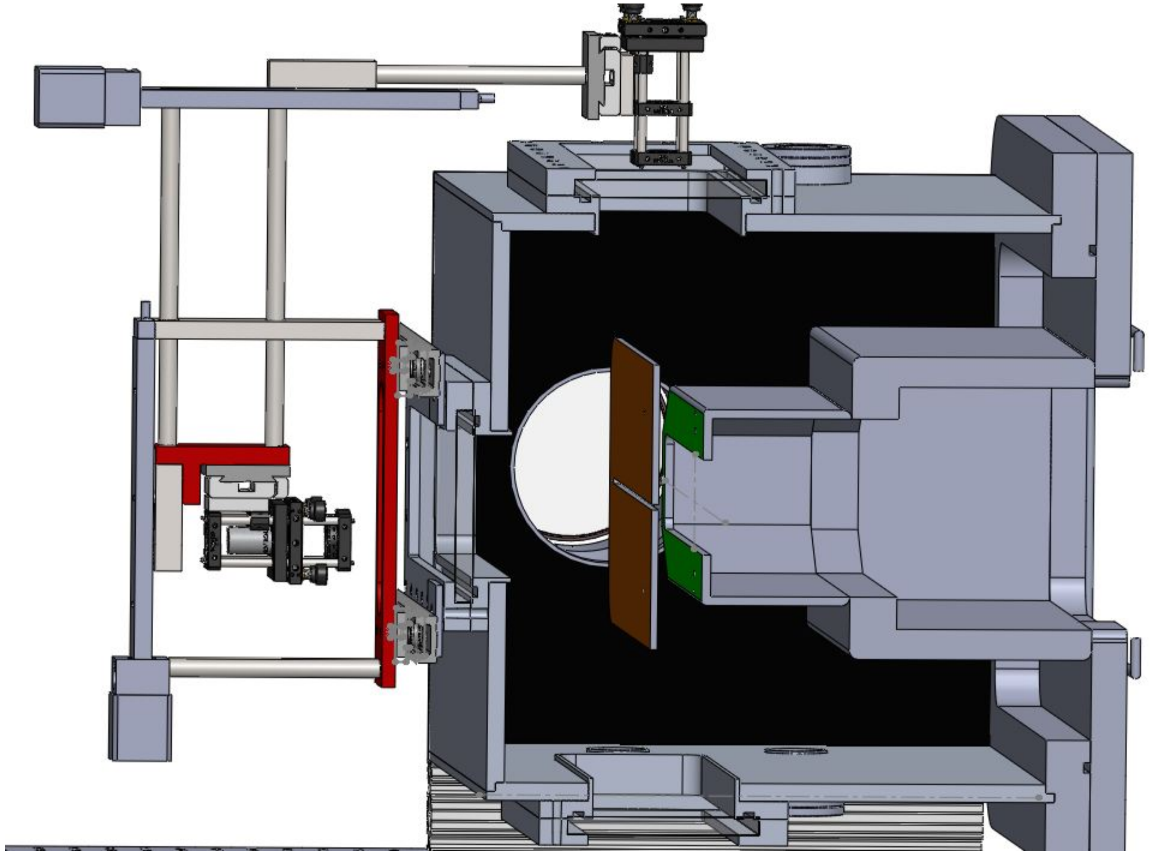


REVAN

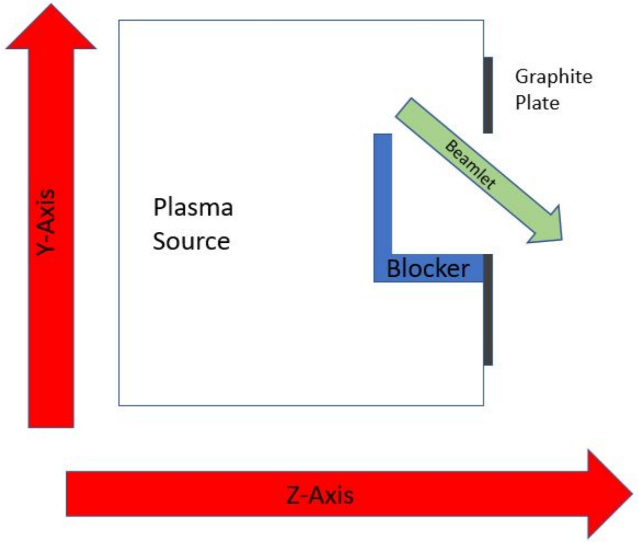
- Orange plate mimics silicon wafer
  - Biased relative to plasma source

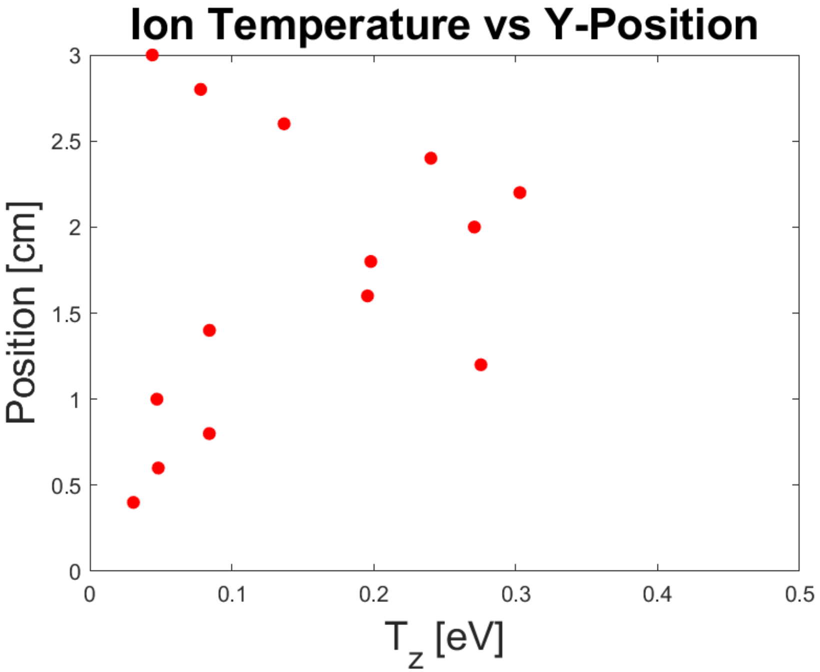
- Green marks exchangeable extraction optics
  - Different blocker geometry can create a double or single beamlet

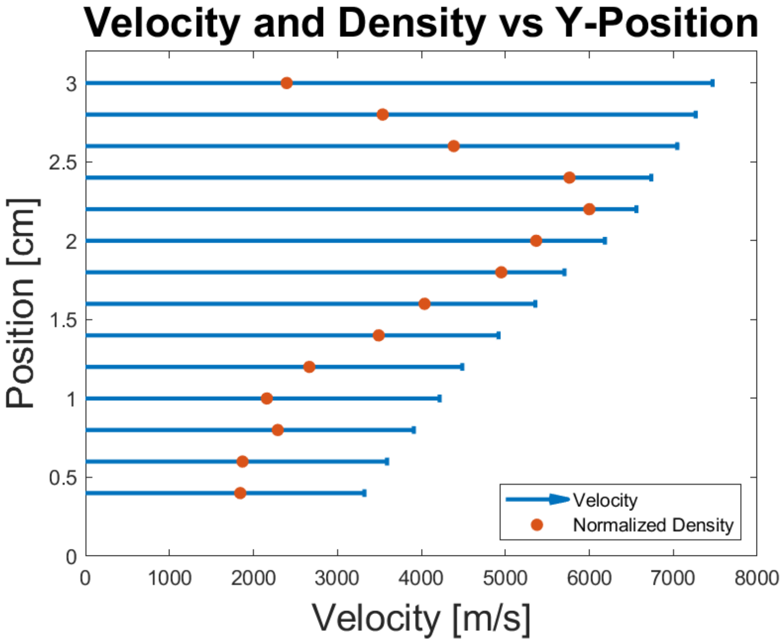
- Source parameters:
  - Pressure
  - Power
  - Extraction Voltage



Results

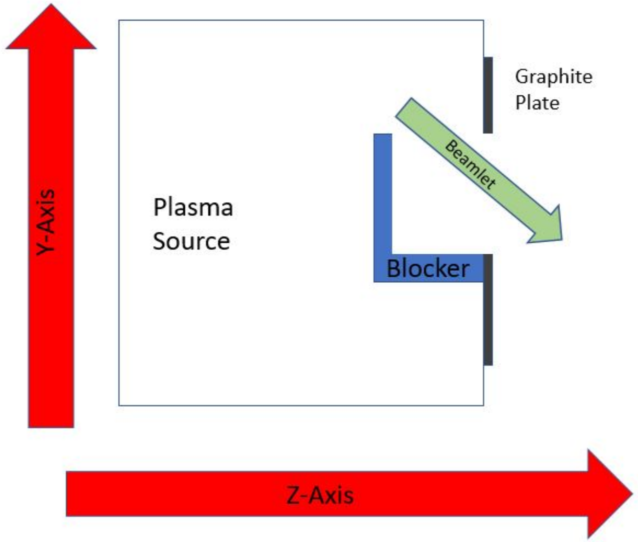


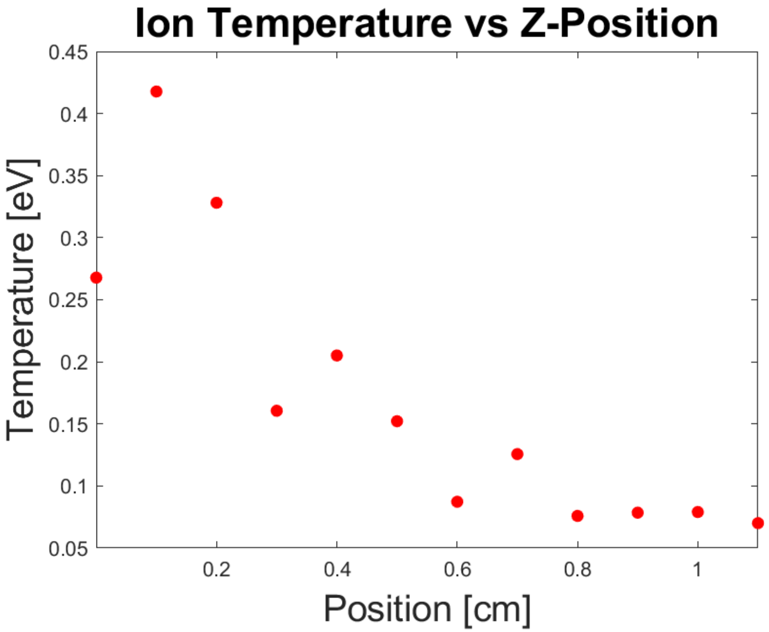


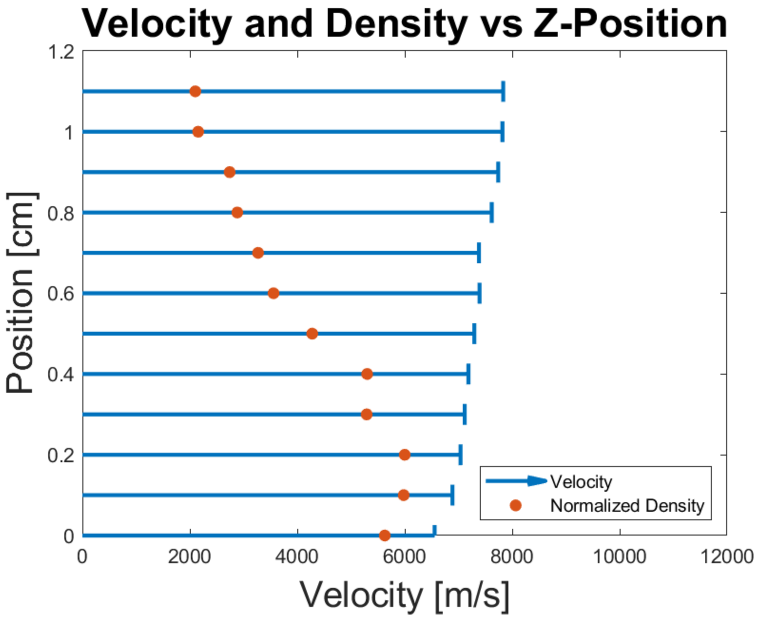


- Held source parameters constant
- Looked "up and down" for beamlet

Results

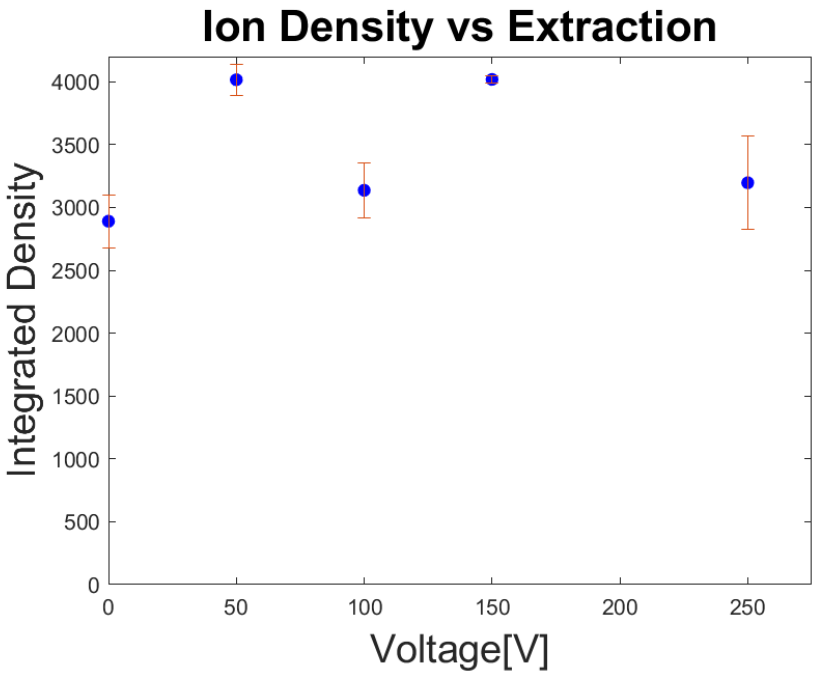


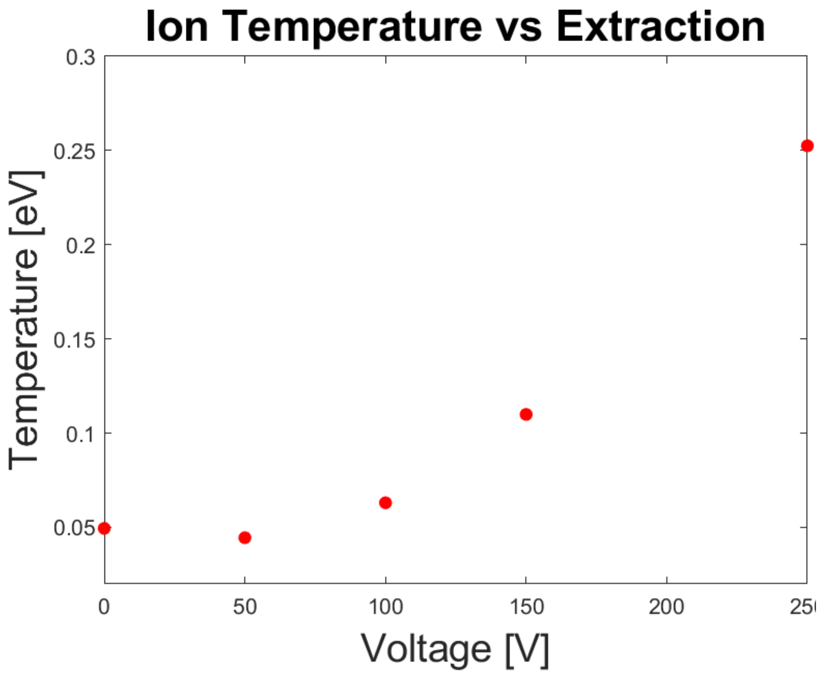


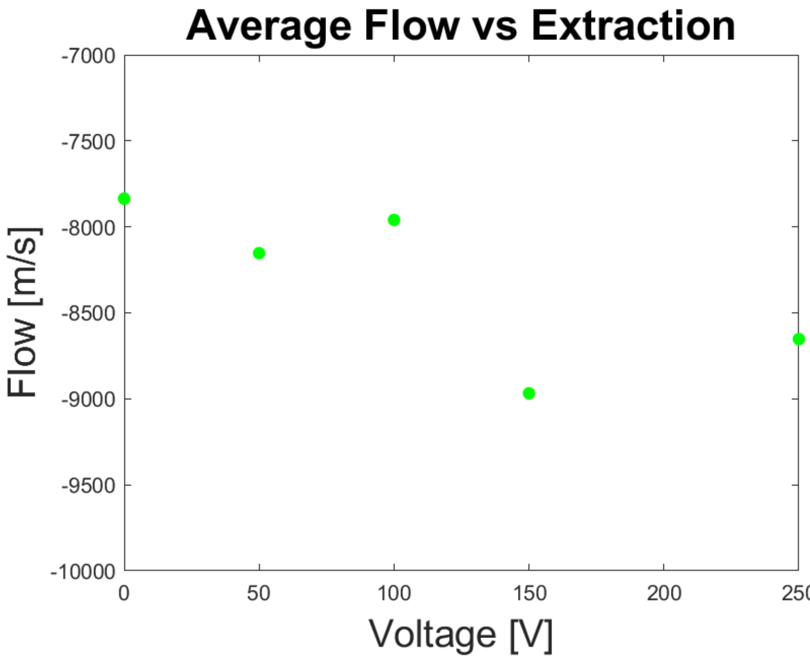


- Held source parameters constant
- Looked “left and right” for beamlet

Extraction





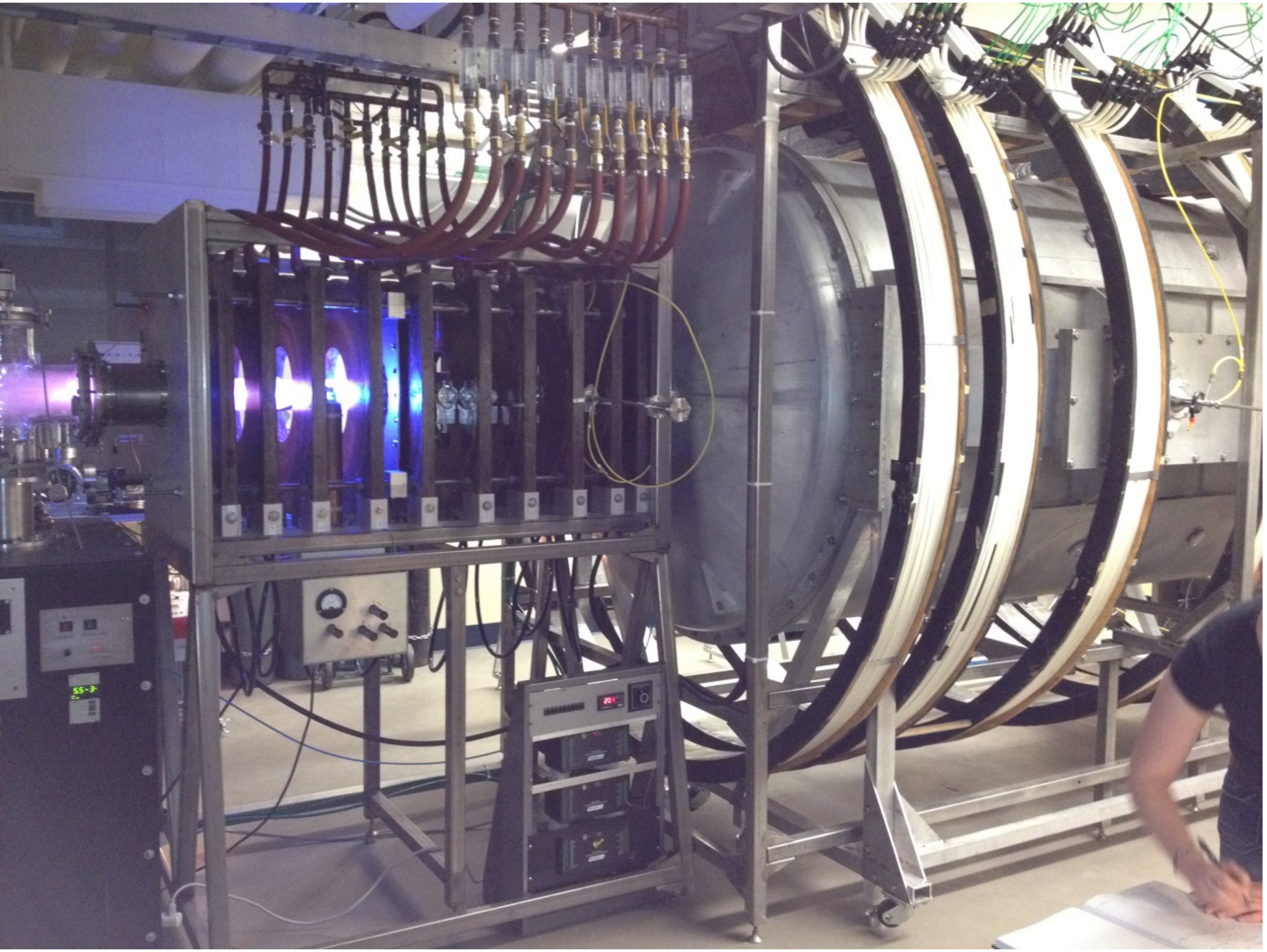


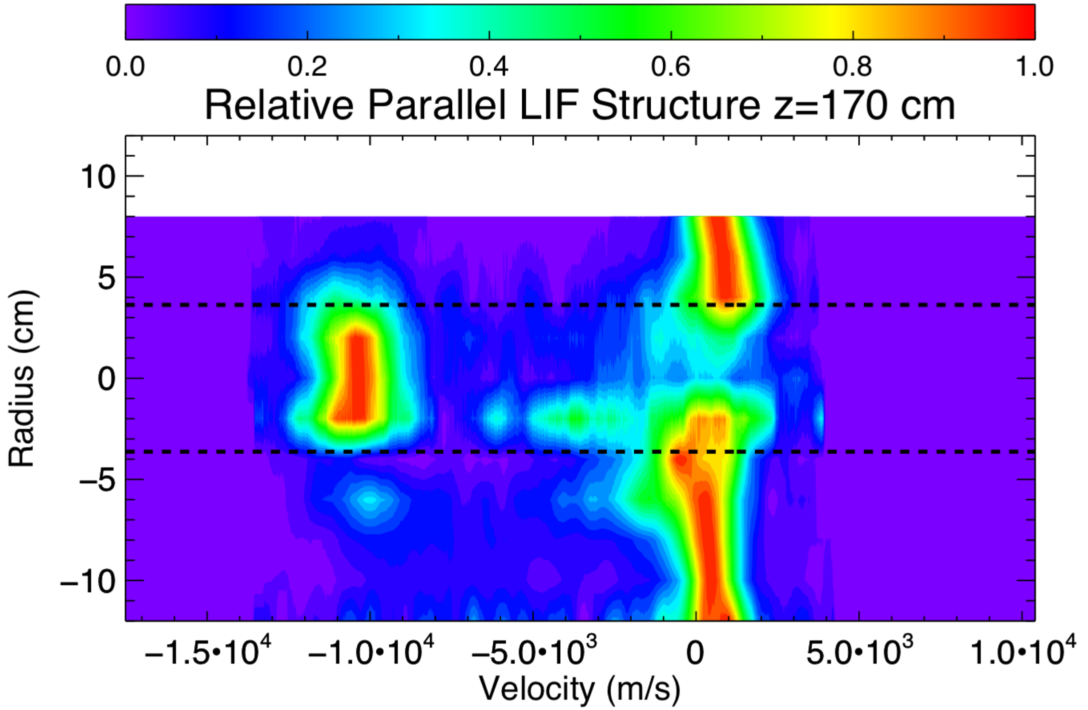
- Pressure, Power and Position are held constant
- Varied the bias on the “wafer”

Results and Looking Forward

- We have confirmed the existence of an ion beamlet in REVAN
- Failed to see velocity increase with extraction voltage
  - Most likely not in "wafer" sheath
- Improve ion signal
- Create an ion density map of the beamlet
- Investigate new biased "wafer" structure

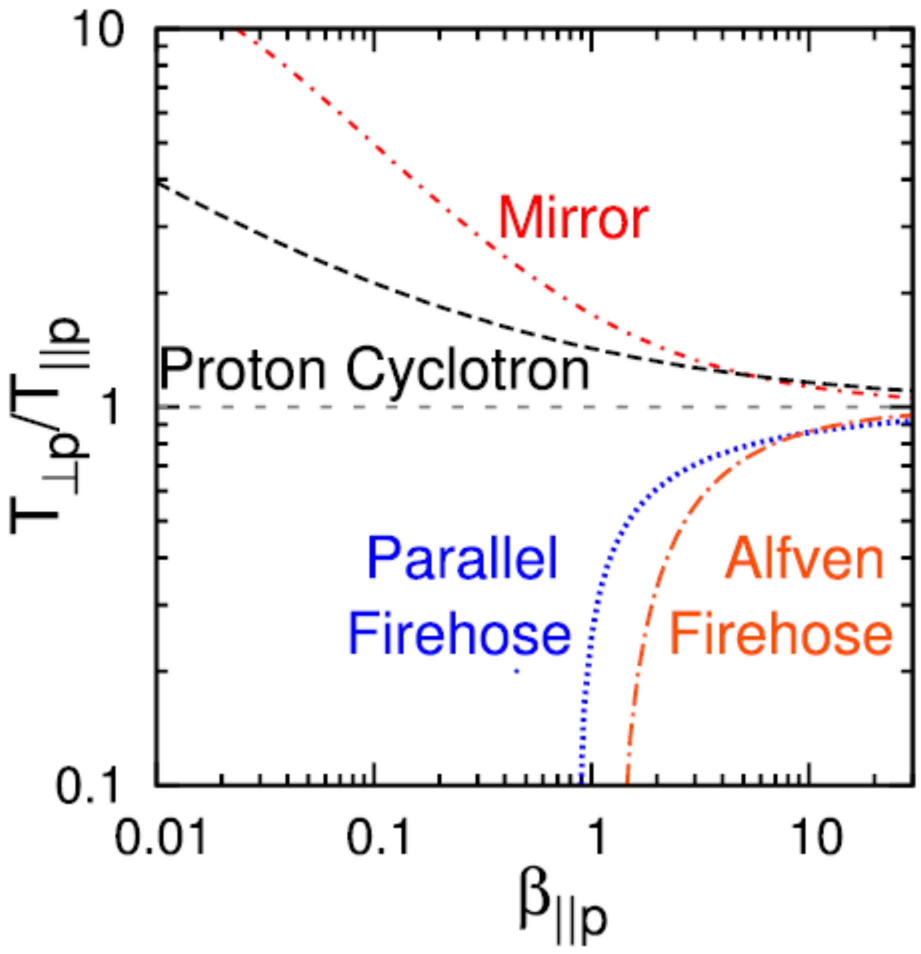
Current Projects – Double Layers





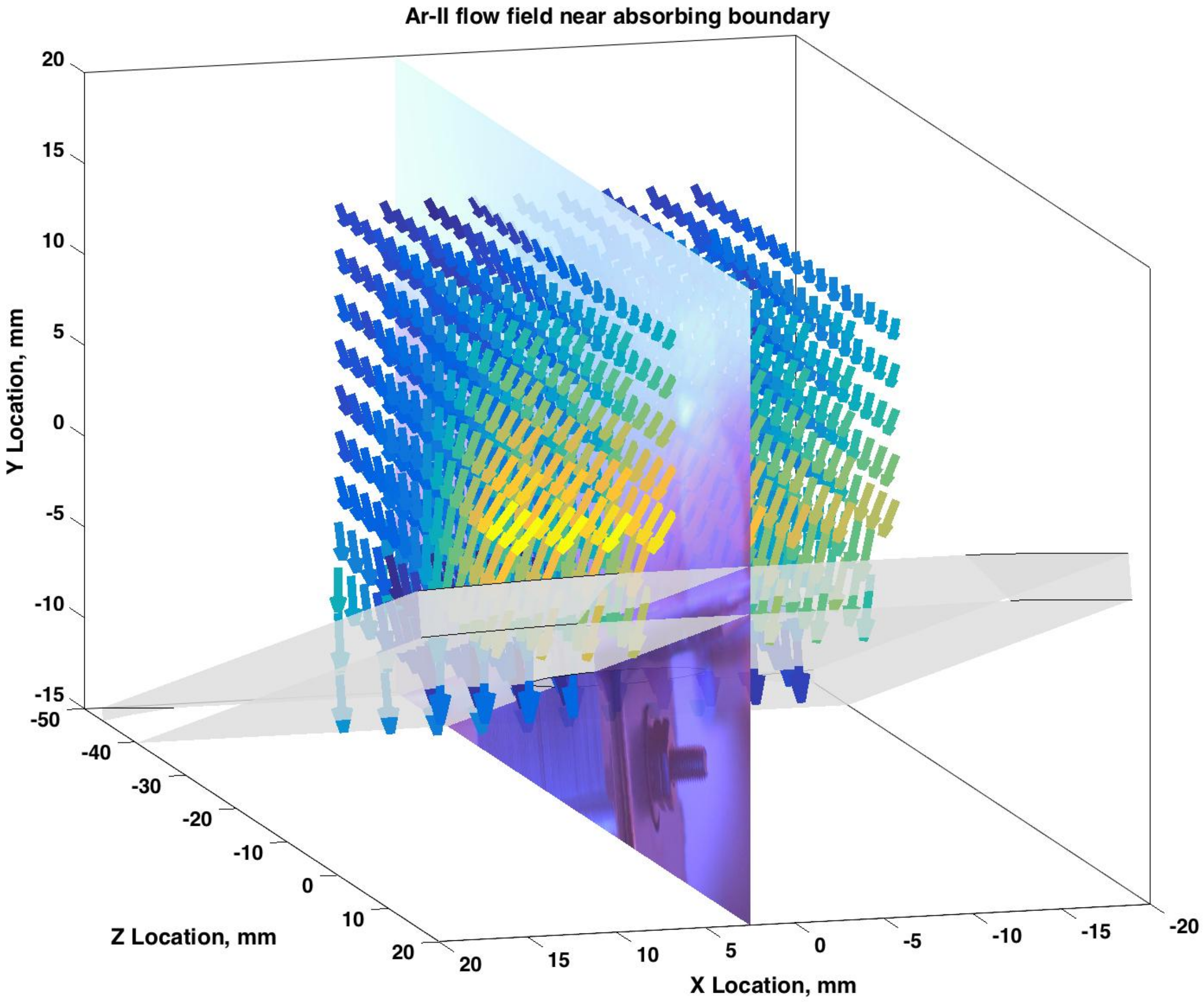
Current Projects – Solar Anisotropic Instabilities

- Look at ion temperature in solar winds
- Whenever particles enter the instability regions their energy gets redirected or they are ejected in a loss cone
- Investigate if this holds for low beta plasmas with LIF and B-Dot probe



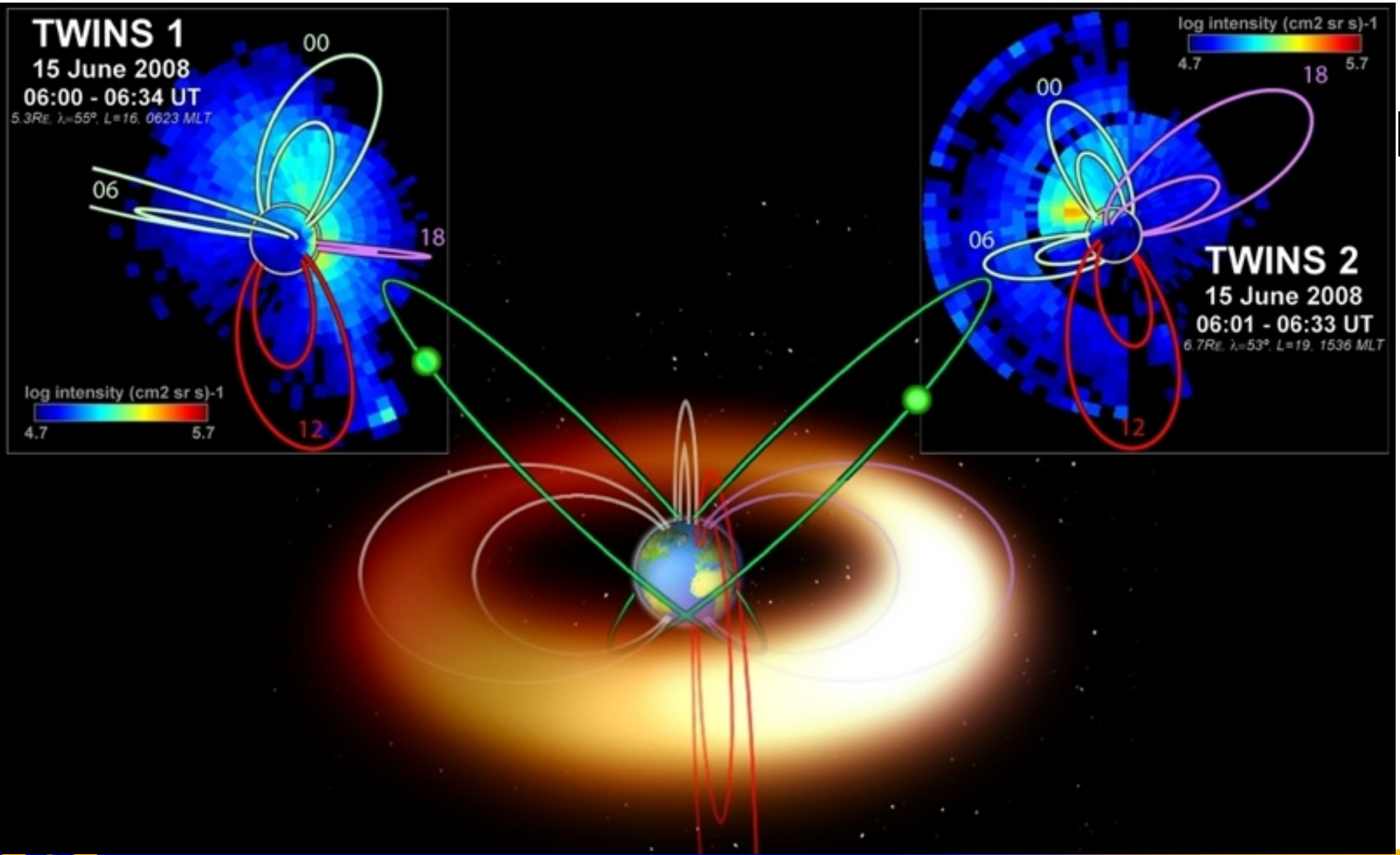
K.G. Klein (2015)

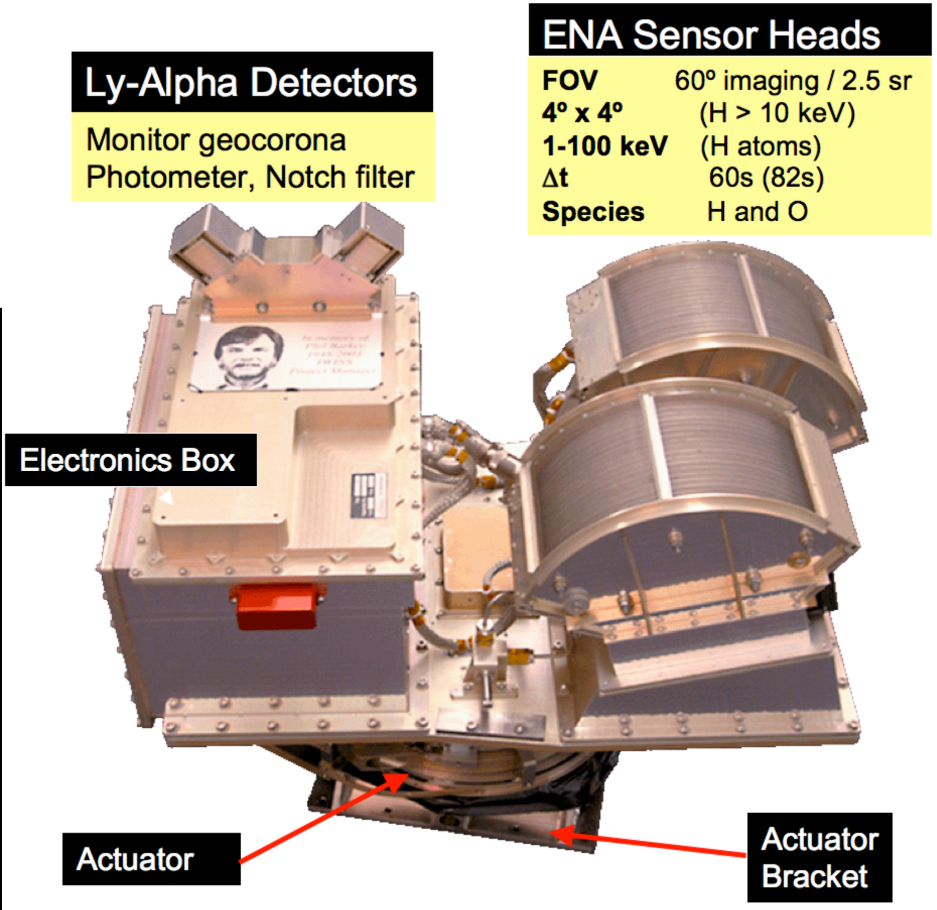
Current Projects – Magnetized sheaths



In collaboration with UIUC – measurements of the full 3D flow field in a 3D volume to investigate the physics of magnetized sheaths for fusion wall and Hall thruster fundamental science.

CURRENT PROJECTS – SPACE IMAGING

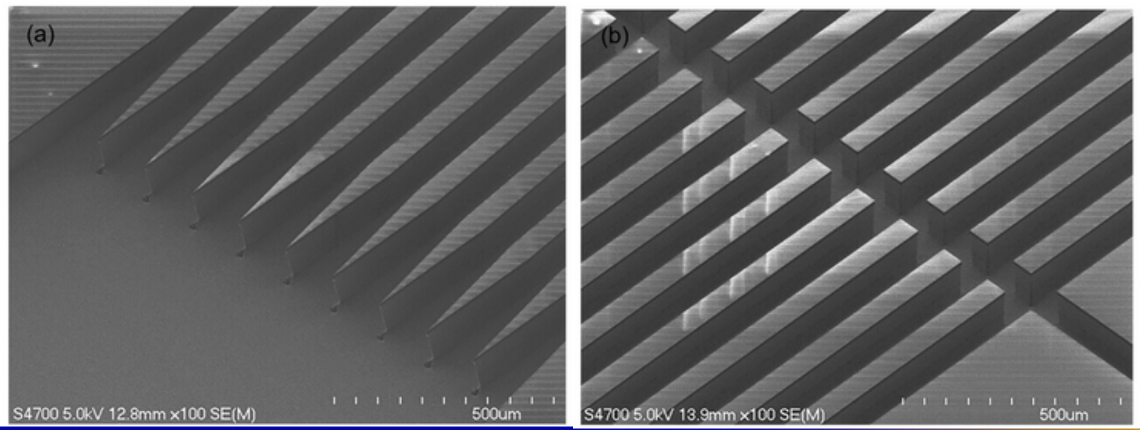


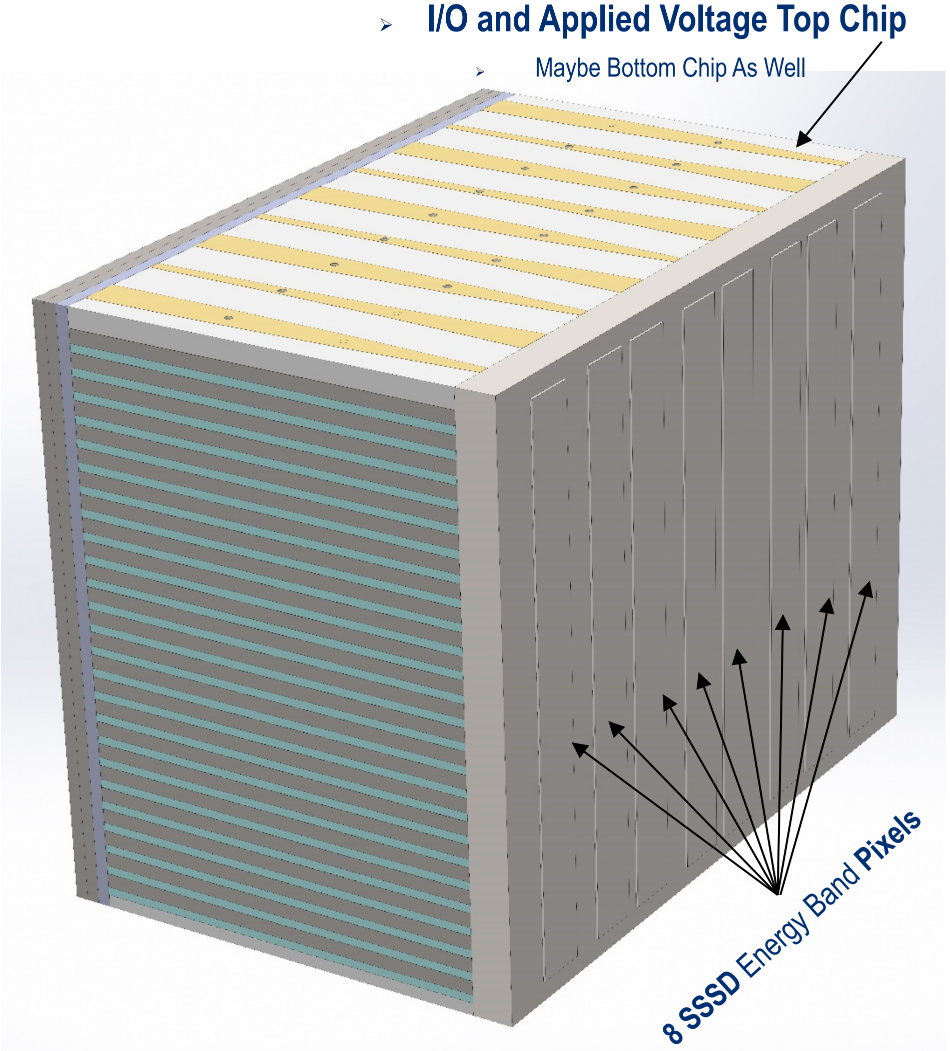


Look at the Earth's magnetosphere by imaging charge exchange of neutral atoms (~1-100 keV)

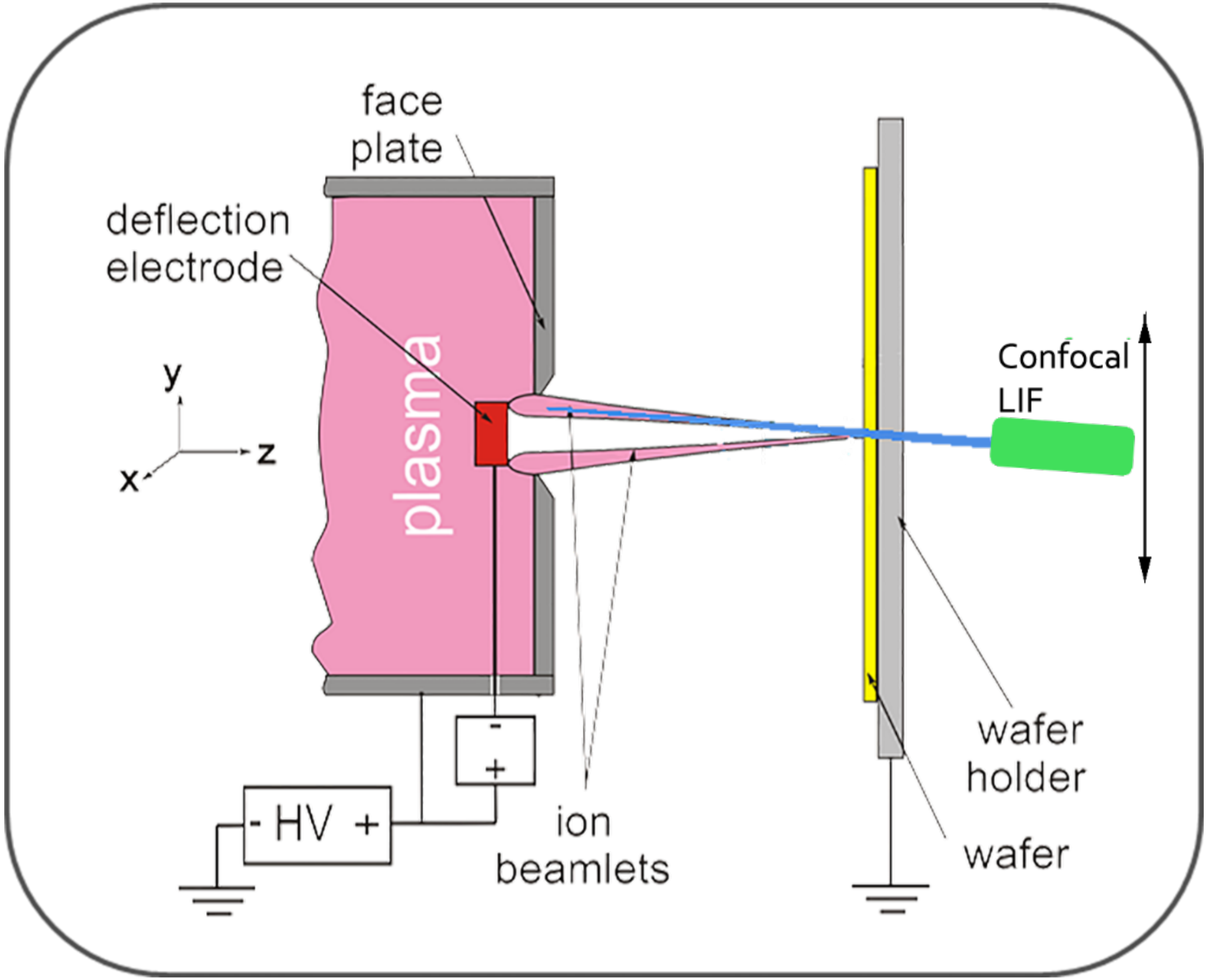
Current Projects- ultra compact plasma spectrometer

- In situ probes that can make direct, spatially resolved measurements of the ion energy spectra in the edge of tokamak.
- Must be easily replaced and requiring minimal resources.
- The ion spectrometers will consist of a combined collimator and energy analyzer fabricated from silicon
- Published results as of yesterday: A. M. Keesee, et al. (2018)

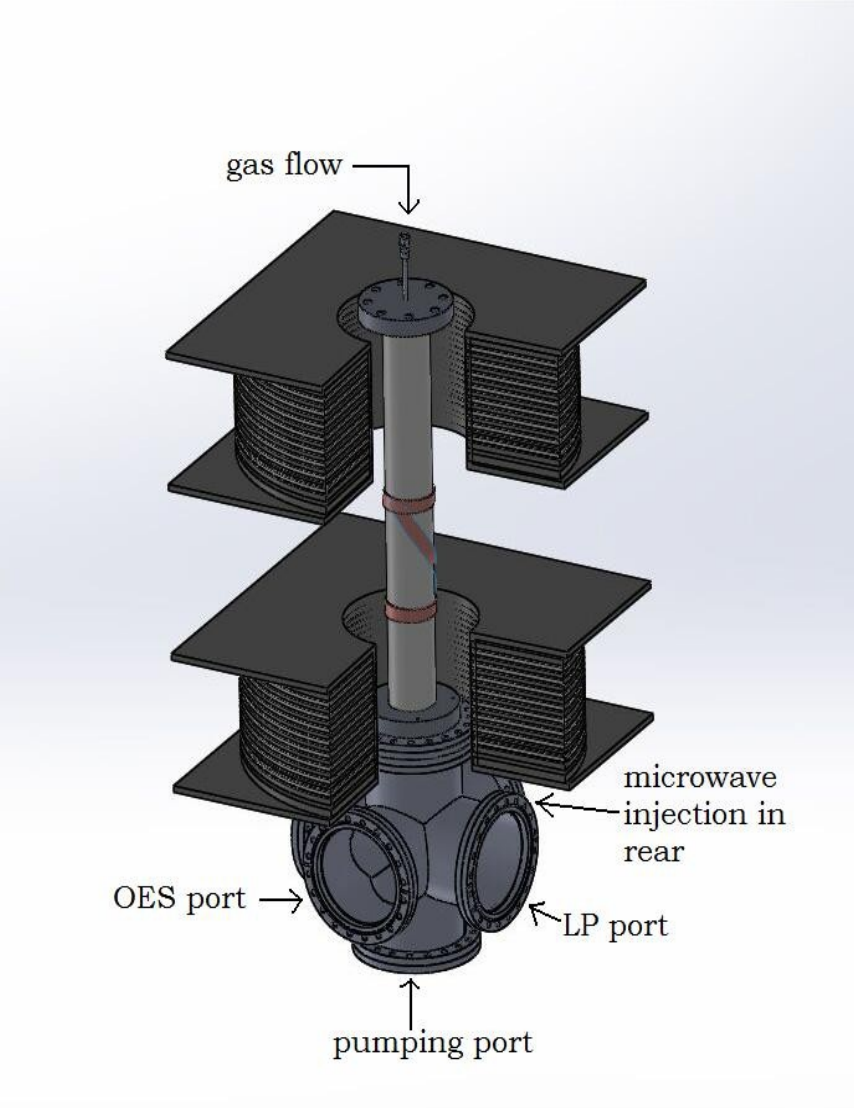


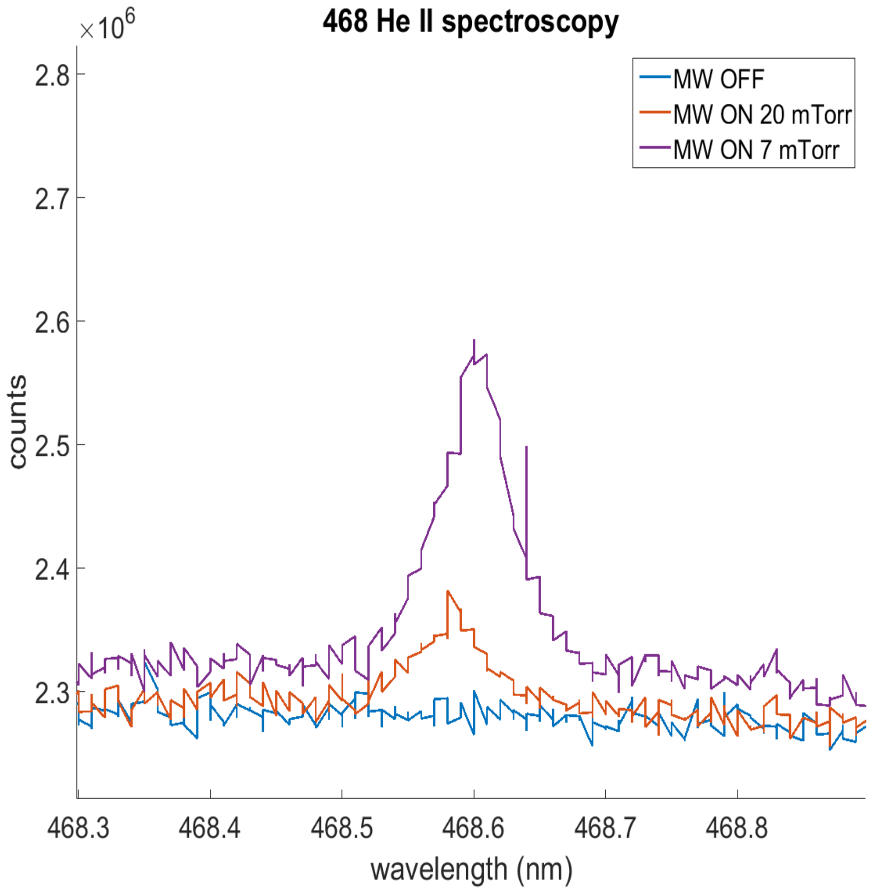


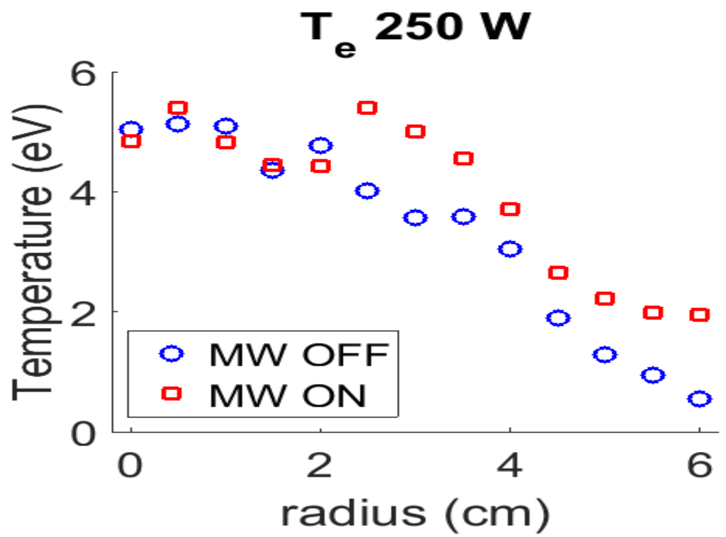
Current Projects – Plasma Etching and Deposition



Current Projects – Electron Cyclotron Heating

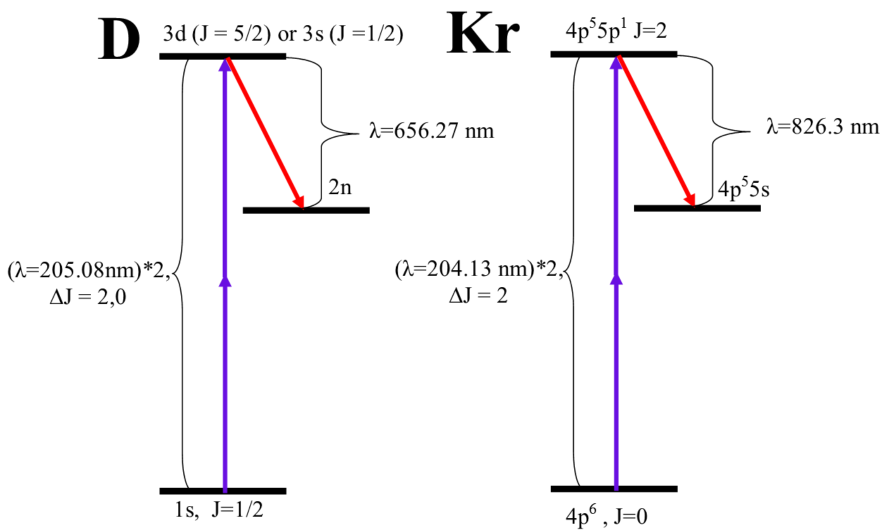


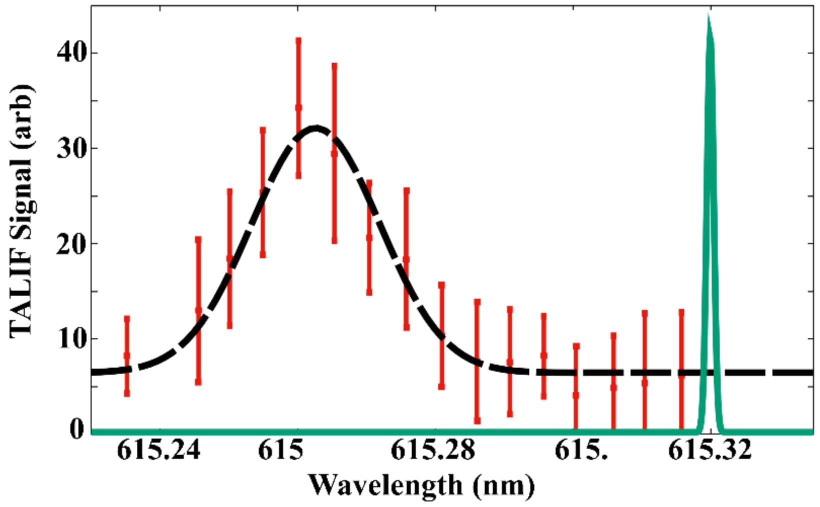


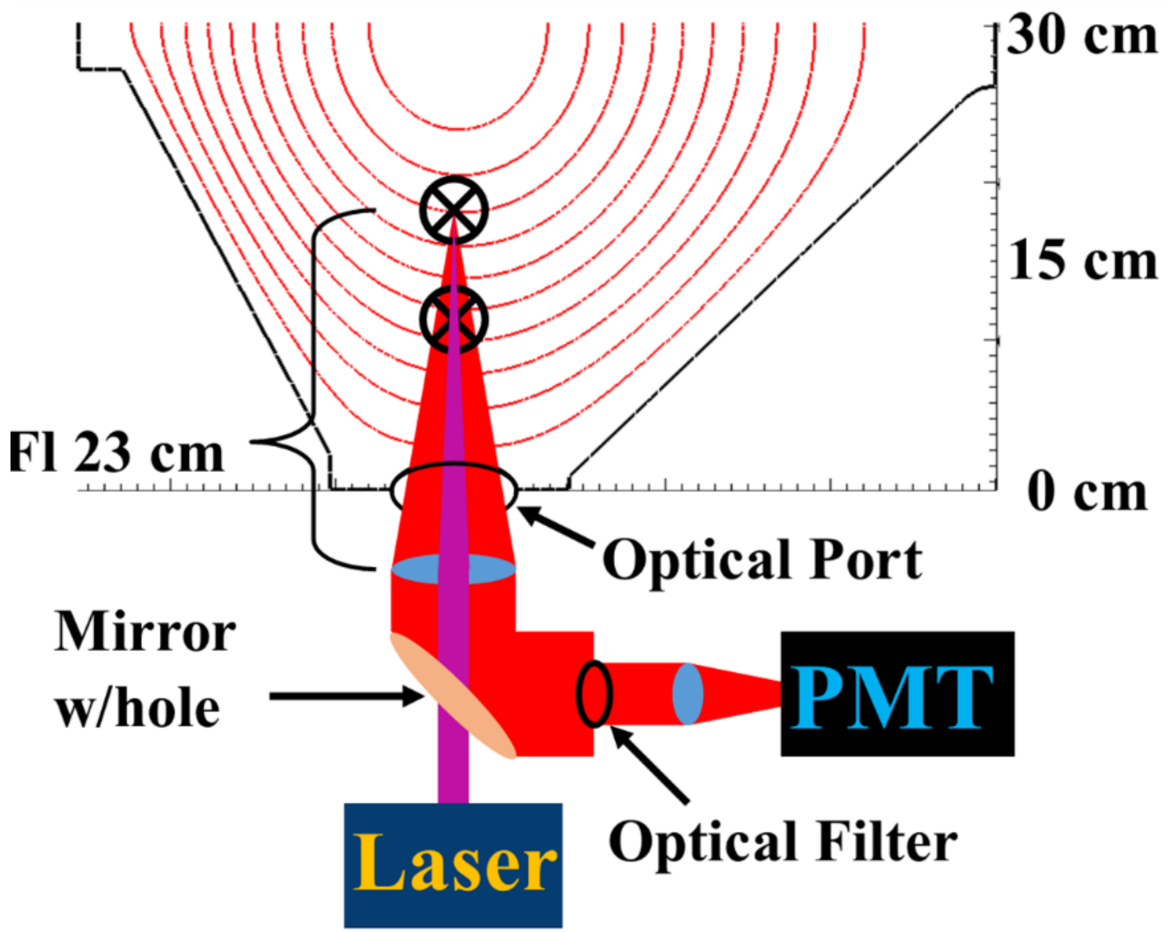


- Wanted to see if x-rays could excite electrons in He plasma to higher energy states
- Langmuir measurements and OES confirmed that the electron gained energy and were excited has high as n = 6

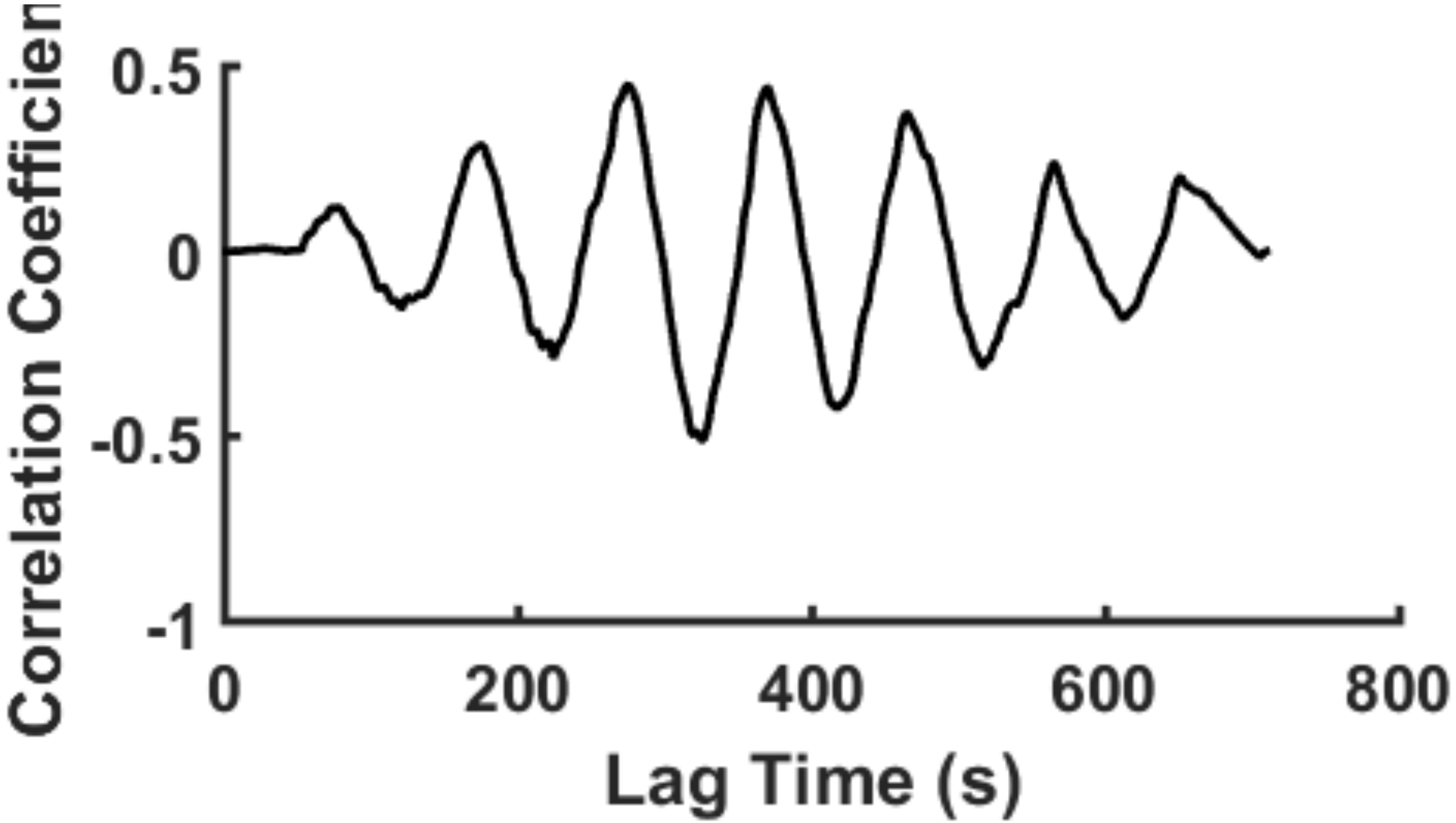
Current Projects – Two Photon Fluorescence



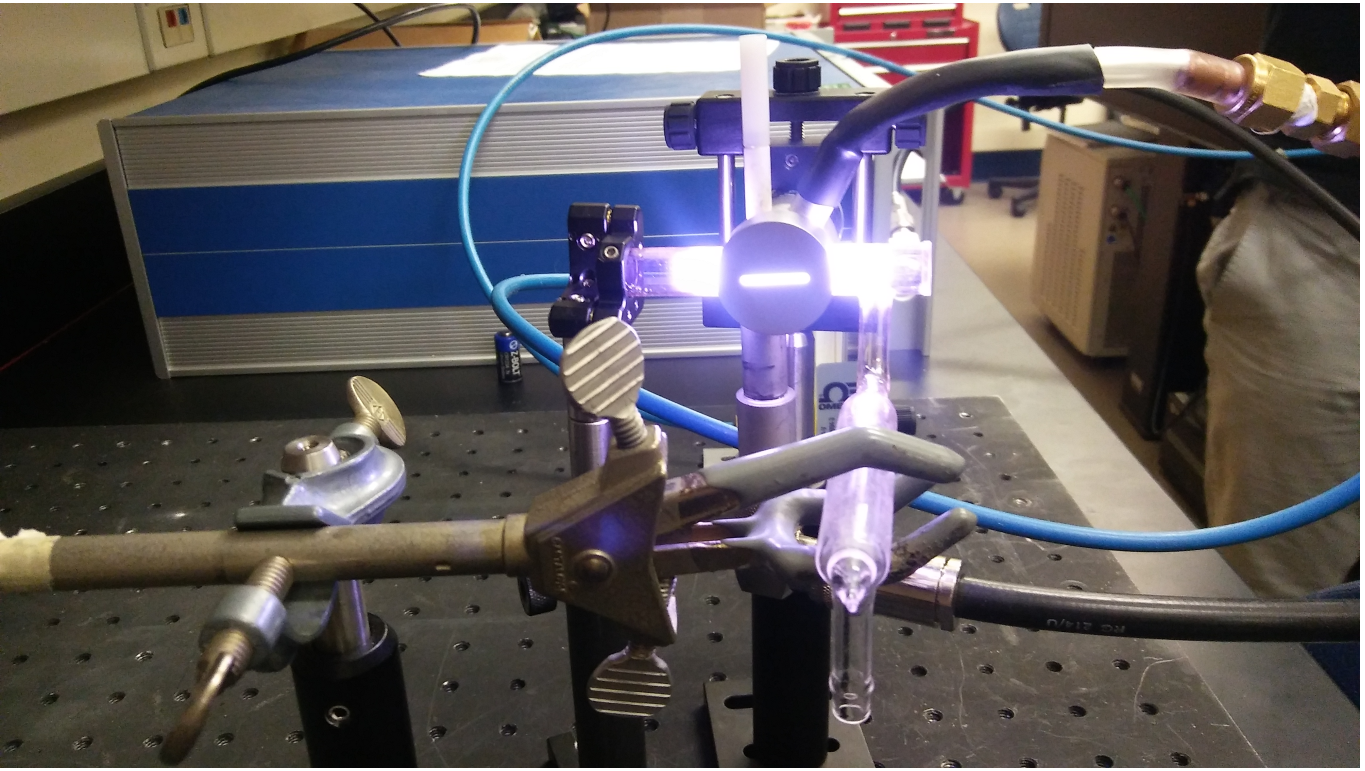


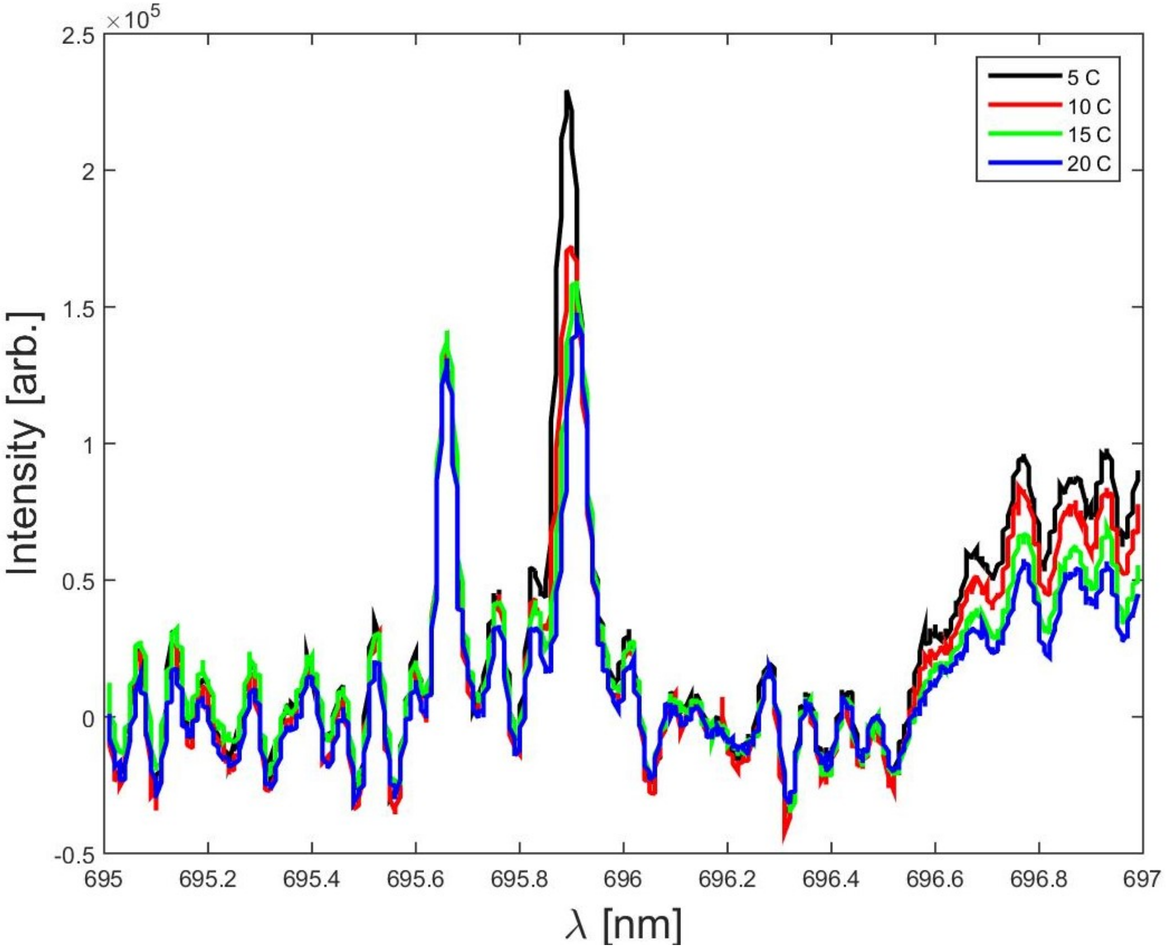


Current Projects – Moth Olfactory Systems



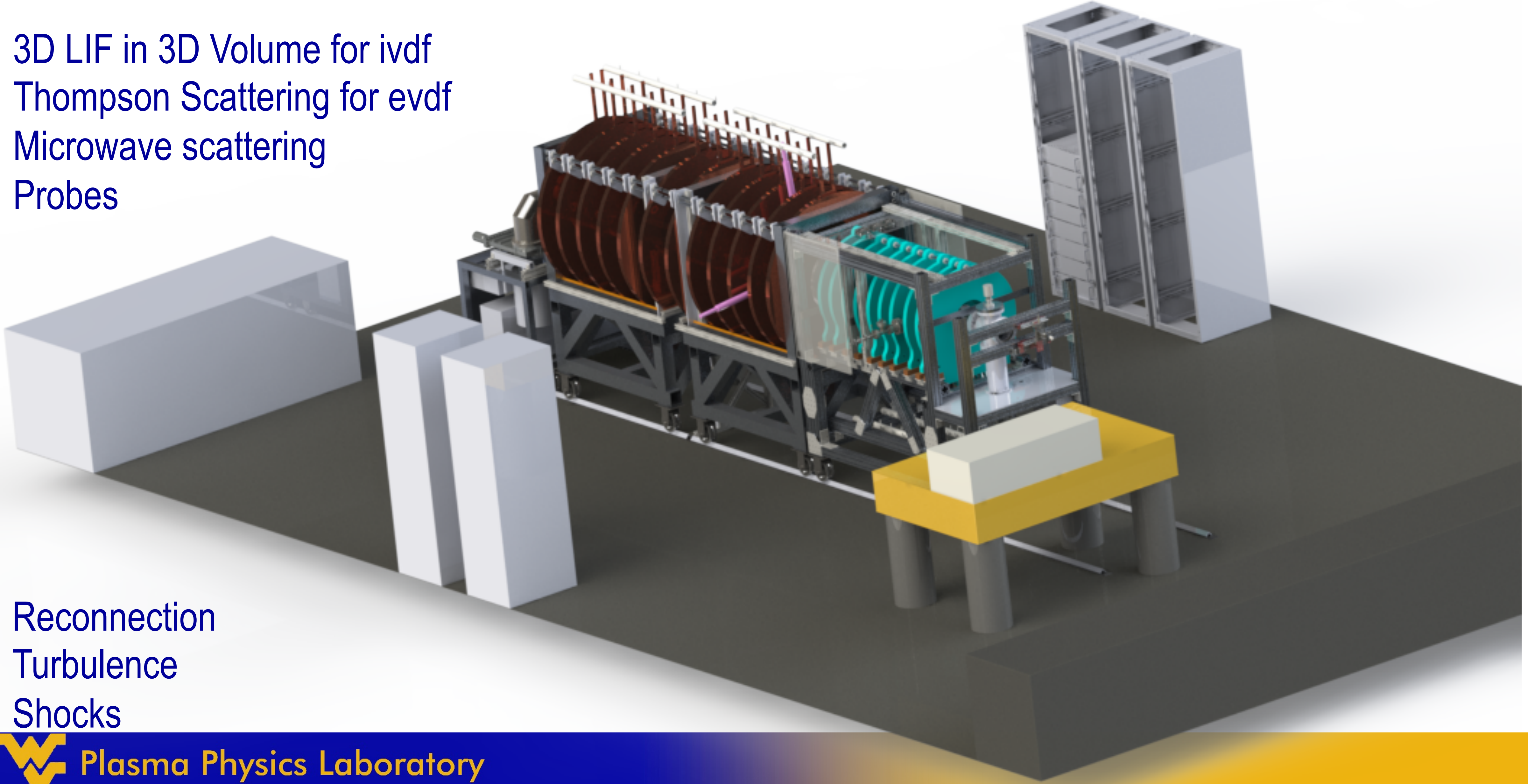
Current Projects – Iodine Electric Propulsion





PHAse Space MeAsurements (PHASMA)

3D LIF in 3D Volume for ivdf
Thompson Scattering for evdf
Microwave scattering
Probes



Reconnection
Turbulence
Shocks

Acknowledgements

- Scime Group:

  Dr. Derek Thompson, Thomas Steinberger, John McKee, Miguel Henriquez, Jacob McLaughlin, Andrew Jemiolo, Dr. Earl Scime

- Arturo Dominguez

References

Figure 2: By Author: ourworldindata.org - Original text : Data source: https://en.wikipedia.org/wiki/Transistor_countURL: https://ourworldindata.org/wp-content/uploads/2013/05/Transistor-Count-over-time.pngArticle: https://ourworldindata.org/technological progress), CC BY-SA 4.0, https://commons.wikimedia.org/w/index.php?curid=71553709

Figure 3: Davide Sacchetto, Design Aspects of Carry Lookahead Adders with Vertically-Stacked Nanowire Transistors

Figure 4: By German Wikipediabiatch, original upload 7. Okt 2004 by Stahlkocher de:Bild:Wafer 2 Zoll bis 8Zoll.jpg, CC BY-SA 3.https://commons.wikimedia.org/w/index.php?curid=928106