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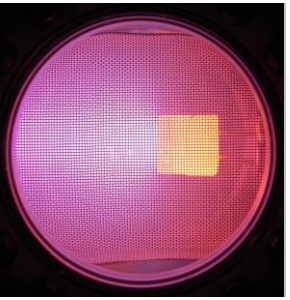

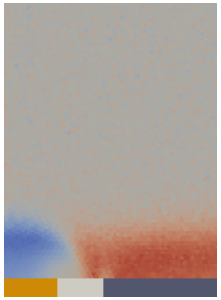

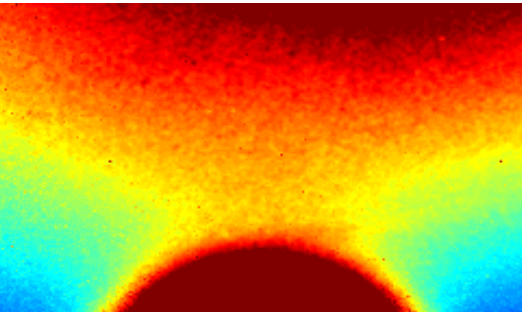

# Recent Studies of Low Temperature Plasma Boundaries

Ben T. Yee (1118)

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U.S. DEPARTMENT OF ENERGY

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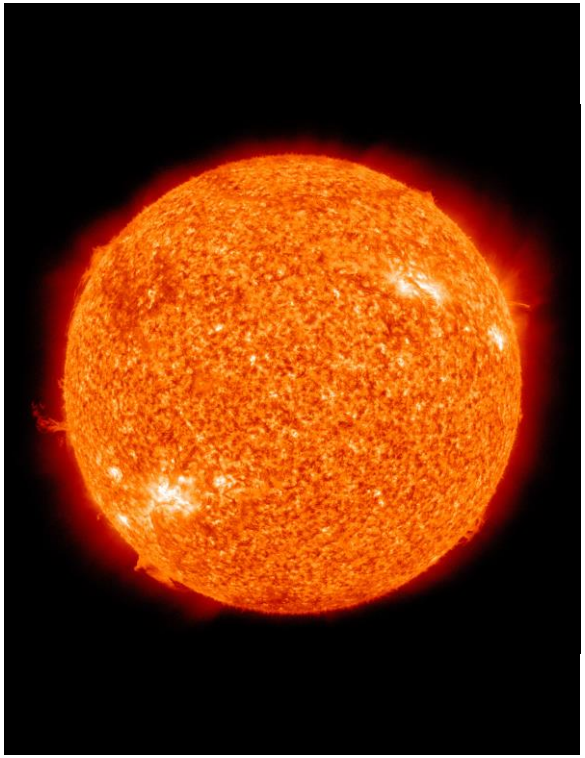
- Department of Energy's Office of Fusion Energy Science

# Outline

- Introduction to plasmas
- Basic plasma behavior at boundaries
- Contemporary topics in plasma sheaths
- New results in electron and structured sheaths

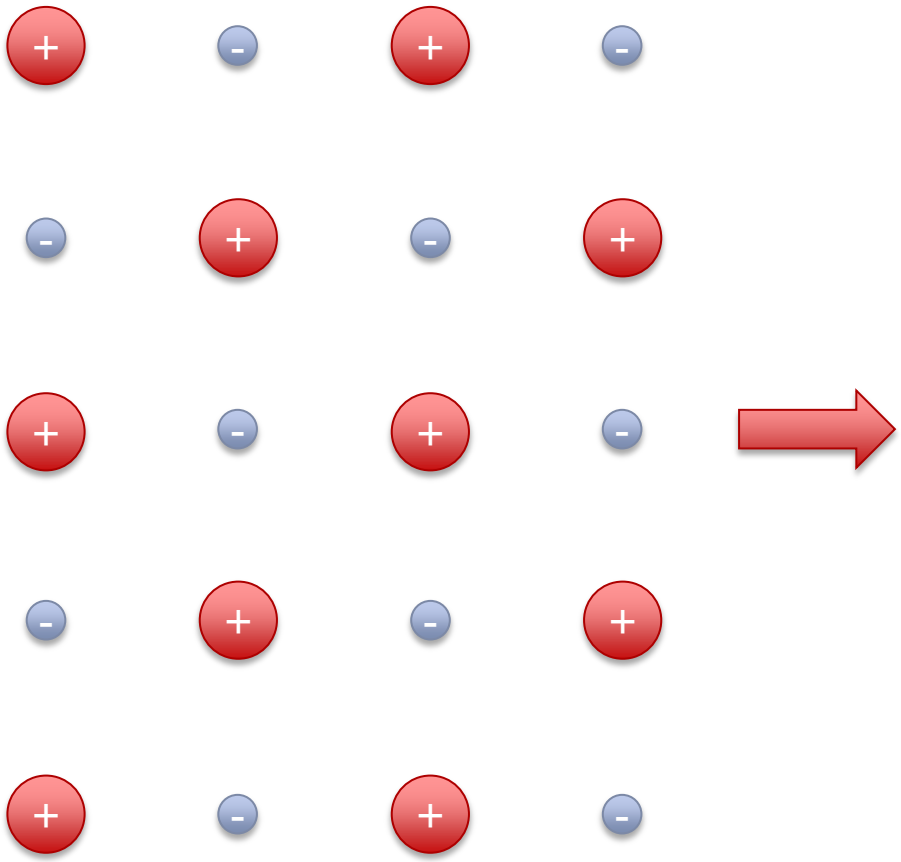
# What is a plasma?





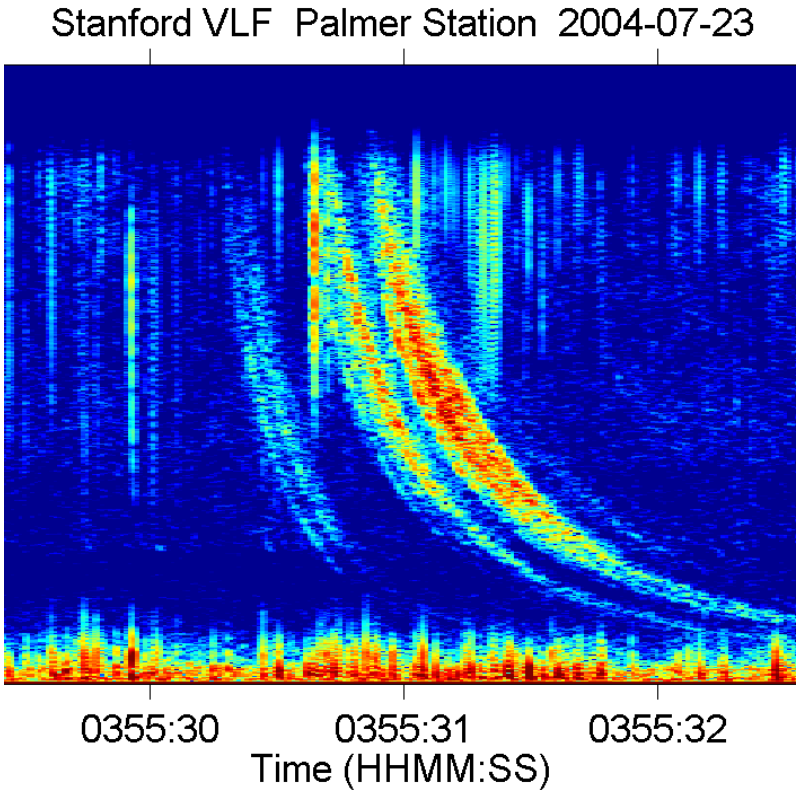
NASA/SDO (AIA), http://sdo.gsfc.nasa.gov/assets/img/browse/2010/08/19/20100819_003221_4096_0304.jpg.
Doug O'neill, "Lightning September 2014-2, " http://www.flickr.com/photos/dougtvl/15079086839/.
D-Kuru/Wikimedia Commons "Arc lamp-arc 2 PNr0030", https://commons.wikimedia.org/wiki/File:Arc_lamp-arc_2_PNr°0030.jpg

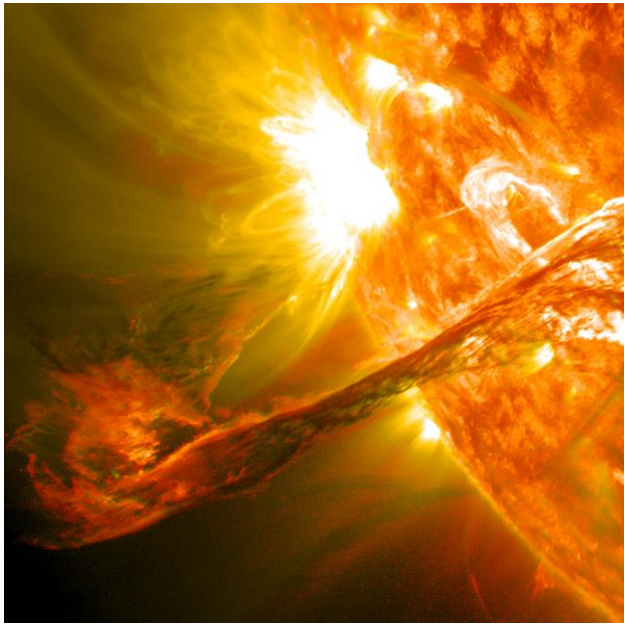
# It’s an ionized gas



- Electrically conductive
- Responds to magnetic fields
- Can manipulate or alter the propagation of light

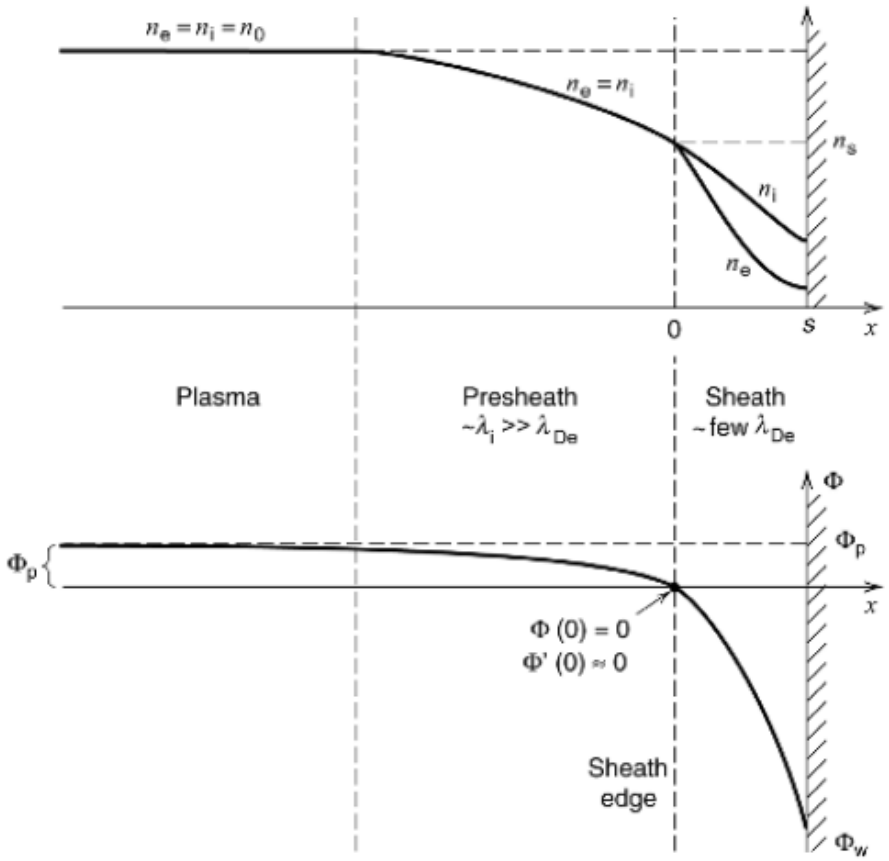
# It exhibits collective behavior



# Eventually, a plasma meets walls

- Simplest case:
  - Neutral bulk plasma
  - Conducting boundary (with nothing “special”)
  - Cold ions
  - Maxwellian electrons
  - No collisions within the sheath

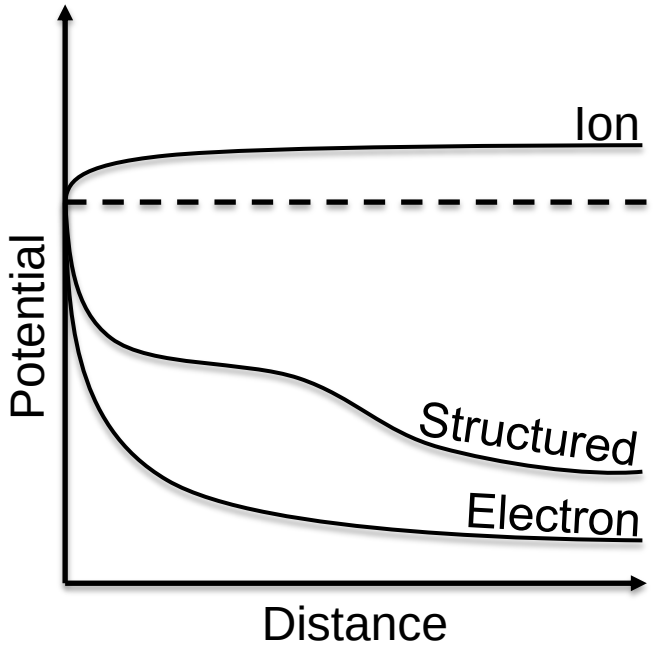





M. A. Lieberman and A. J. Lichtenberg, *Principles of Plasma Discharges and Materials Processing*, 2nd ed. Hoboken, NJ, USA: John Wiley & Sons, Inc., 2005.

# Sheaths: they're complicated

- Electron-emitting surfaces
  - Compensates for electrons leaving
- Multiple ion species
  - Changes the Bohm criterion
- Collisions in the sheath
  - Extend region of quasineutrality
  - Scatters particles back into plasma
- Magnetic fields




→ **Electron-rich sheaths**

→ **Structured sheaths**



S. D. Baalrud, N. Hershkowitz, and B. Longmier, *Phys. Plasmas*, vol. 14, no. 4, p. 042109, 2007.
S. D. Baalrud, B. Longmier, and N. Hershkowitz, *Plasma Sources Sci. Technol.*, vol. 18, no. 3, p. 035002, Aug. 2009.

# Reaching a better understanding

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**Simulation**

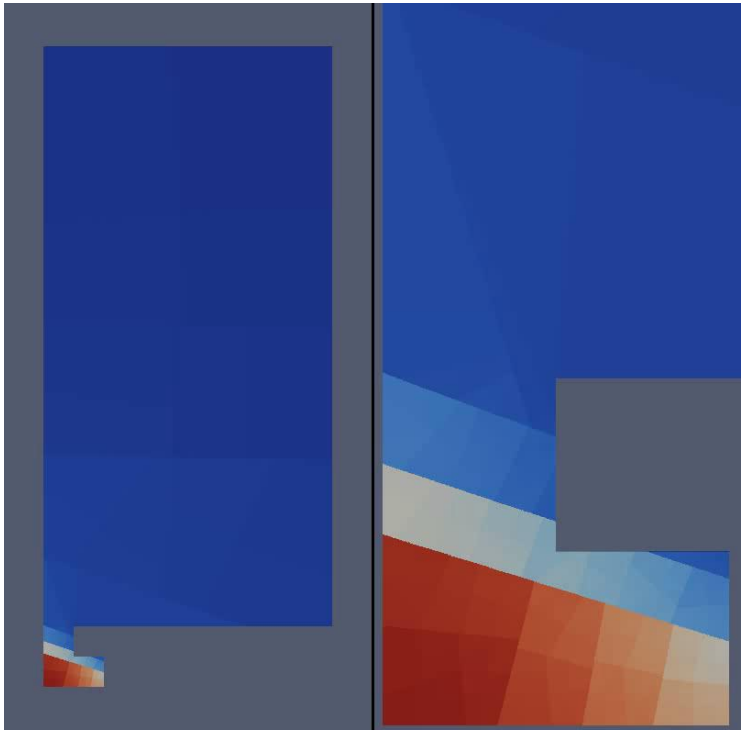
- Short time scales
- Small spatial scale
- Selectable physics
- Low cost changes

**Experiment**

- Long time scales
- Large spatial scales
- “Perfect” physics
- Easy iteration

**Simulations and experiments need to inform each other and play off each other’s strengths.**

# Aleph: HPC plasma simulations



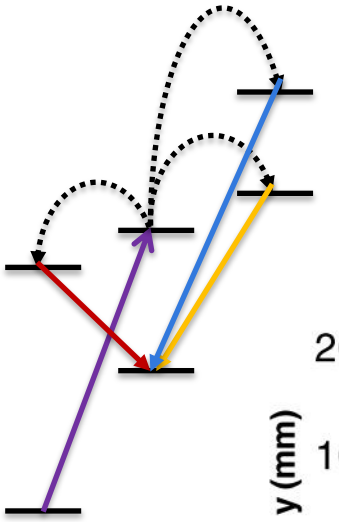
- Hybrid particle-in-cell and direct simulation Monte Carlo
- 1D-2D-3D with unstructured mesh
- Variety of particle interactions
- Massively parallel

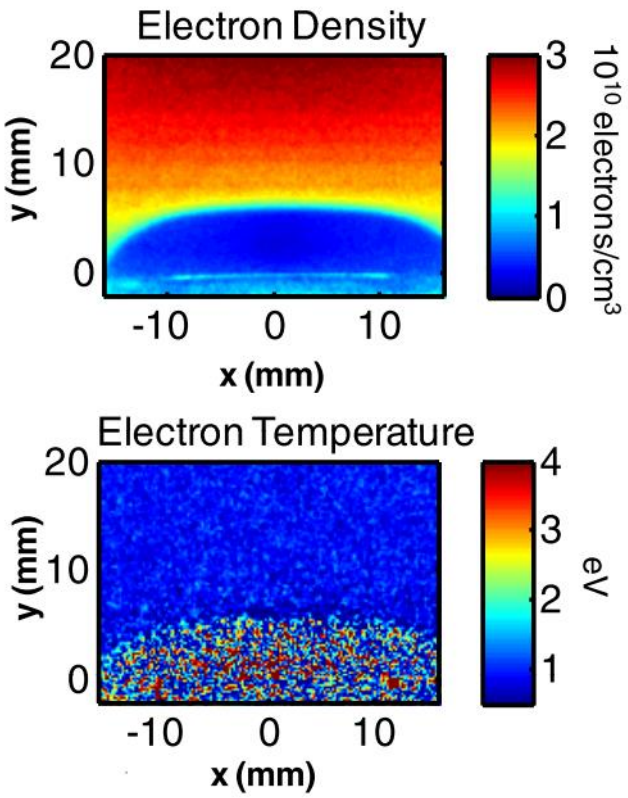


P.S. Crozier, J.J. Boerner, T.P. Hughes, and M.M. Hopkins, "Arc Simulations using Aleph a DSMC/PIC code," SAND2009-4930P

# LCIF and plasma tomography

- Probe measurements
  - Tedious
  - Perturbing
  - Error-prone
  - Limited spatial/temporal res.
- Laser collision-induced fluorescence
  - Fast (< 1 us)
  - Detailed (< 100 um)
  - Non-perturbing
  - Accurate








E. V. Barnat and K. Frederickson, "Two-dimensional mapping of electron densities and temperatures using laser-collisional induced fluorescence," *Plasma Sources Sci. Technol.*, vol. 19, no. 5, p. 055015, Oct. 2010.

# The setups

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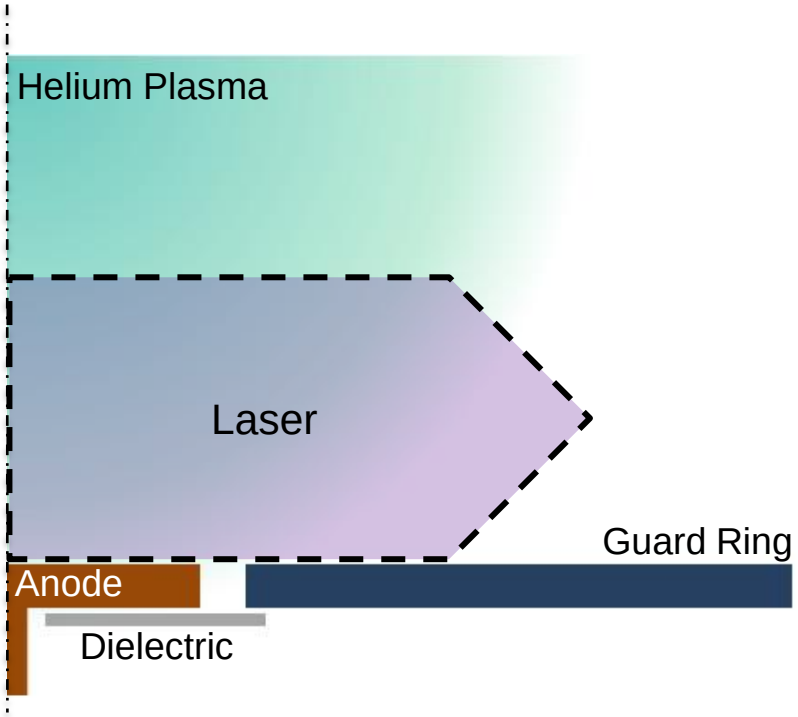
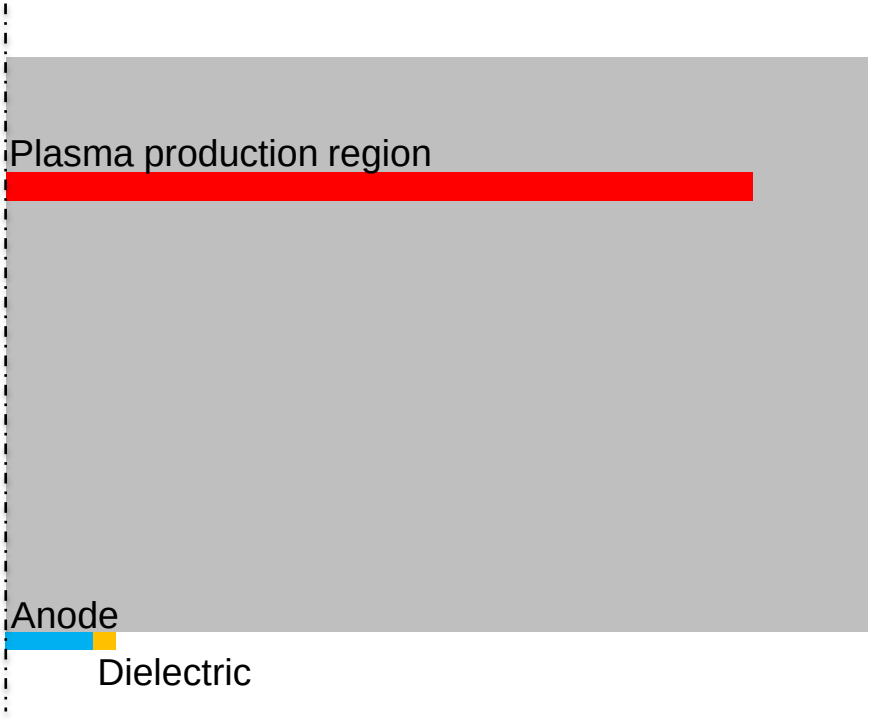
Experiment



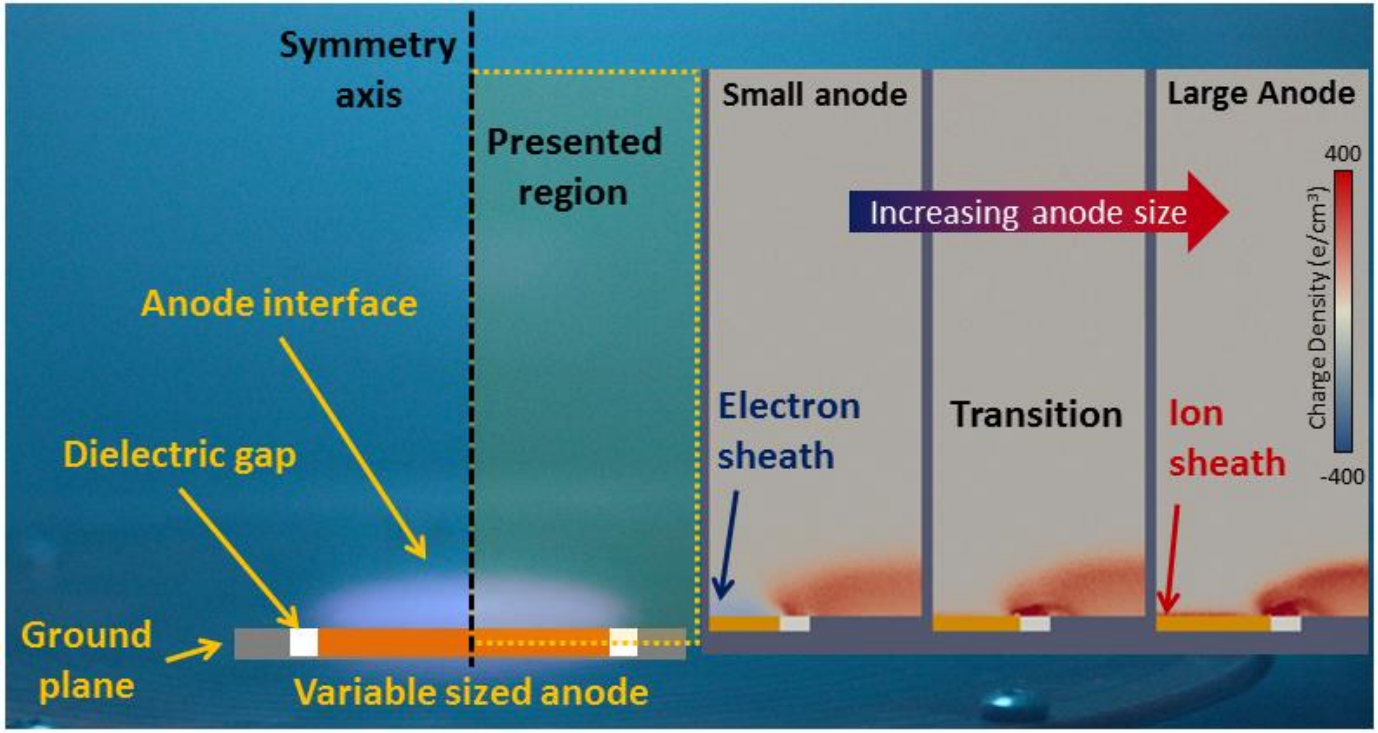

- Helium plasma
- Adjustable anode area
- LCIF along diameter

Simulation




- 2D, nearly full scale
- Same anode/cathode ratios

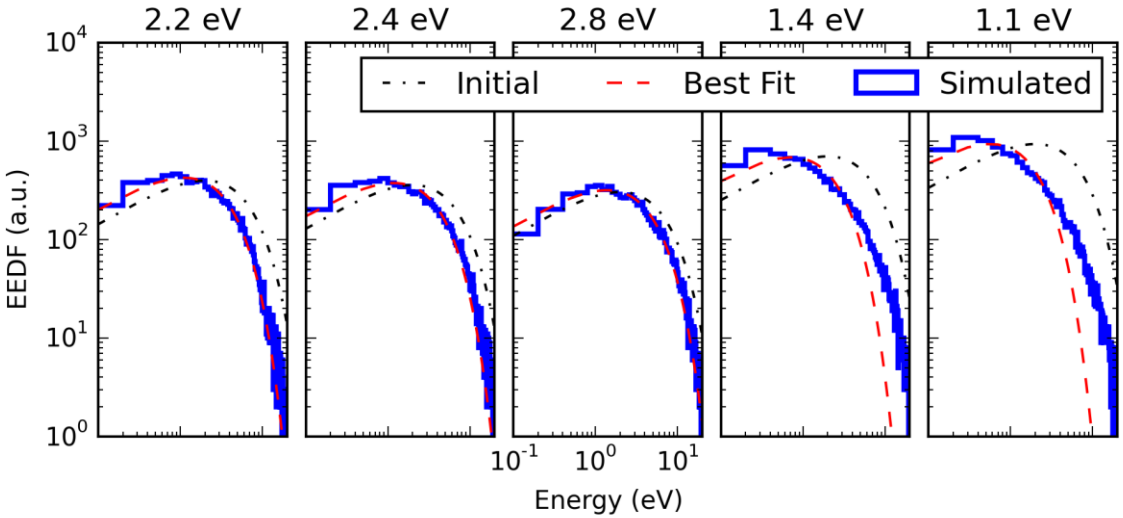
# Transitions between sheath types




- First simulations of transition between sheaths
- Found potential reason for absence of structured sheath
- Bridged conceptual gap between experiment and theory

# The sheath affects the bulk

Increasing anode size →

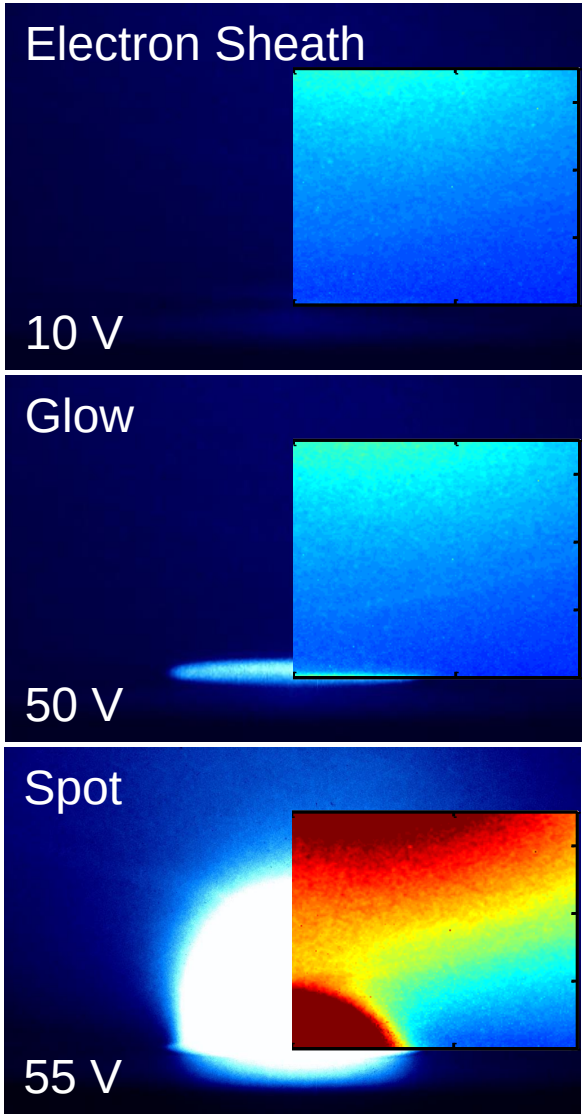



Electron sheath → Ion sheath

- Bulk plasma changes with sheath
- Plasma cools and density increase for ion sheath
- Anomalous high energy tail of electrons

# Anode glows and spots

- Clear experimental evidence of structured sheaths
- Sudden mode change observed between glow and spot
- Ideally placed to examine with simulation and experiment



# Future work

- Use ion LIF to develop charge density maps
- Employ unique simulation and diagnostic capabilities to examine glow-to-spot dynamics
- Search for instabilities in the sheath
- Investigate anode spot oscillations
- Address the impact of ion and electron flow on sheaths

**Further elucidate effects of sheath on bulk**

# Questions

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