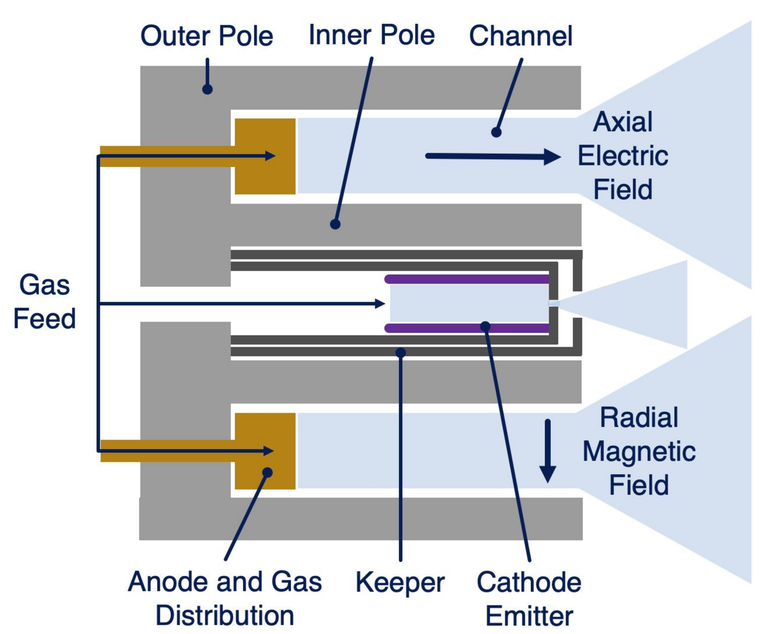
Performance of the Plume: The ACME Hall Thruster

STUDENT: Peter Thoreau

Plasmas and Hall Thruster Background

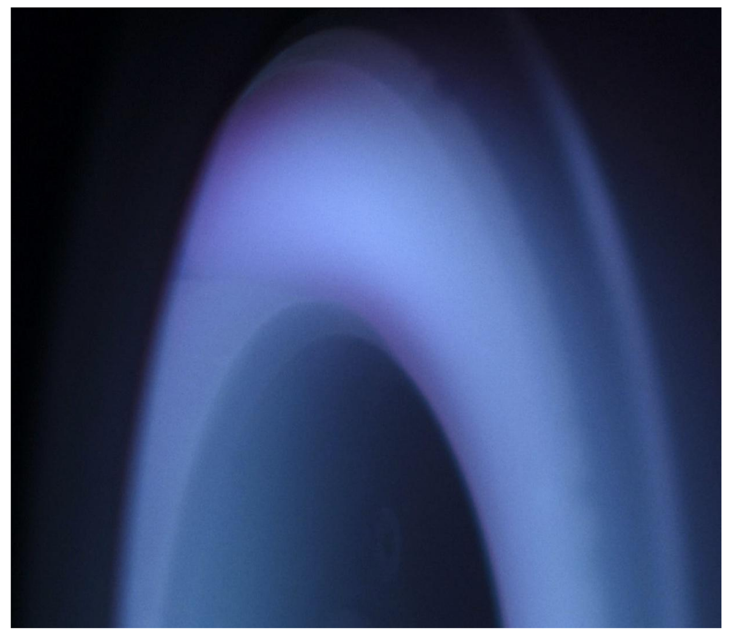
- Plasma, the 4th state of matter, consists of a quasi-neutral collection of charged particles exhibiting collective behavior
- Plasmas can be manipulated with the use of electric and magnetic fields

- Hall thrusters are a type of in-space propulsion system that utilizes plasma to generate thrust
- Ionized propellant is accelerated by an axial electric field
- The field is generated by a positively biased anode and a population of electrons trapped in the radial magnetic field near the exit plane
- These electrons drift in a circular path around the annular channel generating a Hall current



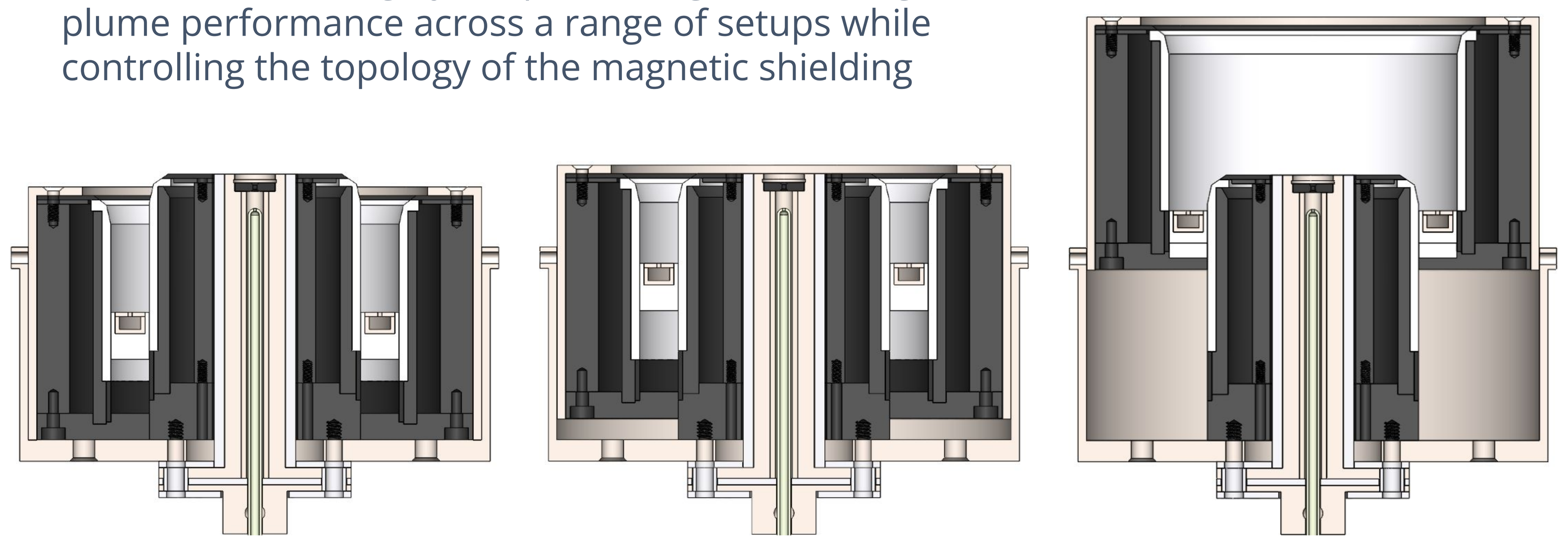
The ACME Hall Thruster

- Magnetic shielding is an evolution of Hall thruster design, enabling longer lifetimes by limiting the erosion of the walls
- The magnetic field lines of the thruster are contoured around the walls and pole caps at the exit plane
- The plasma of the Hall current, pictured right, is separated from the walls reducing both erosion and heating
- The **A**daptive-field **C**entral-cathode **M**agnetically-shielded **E**lectric thruster (ACME) is designed to investigate the effects of this field topology on the performance of the thruster



Xenon plasma at the exit plane of ACME demonstrating the magnetic shielding

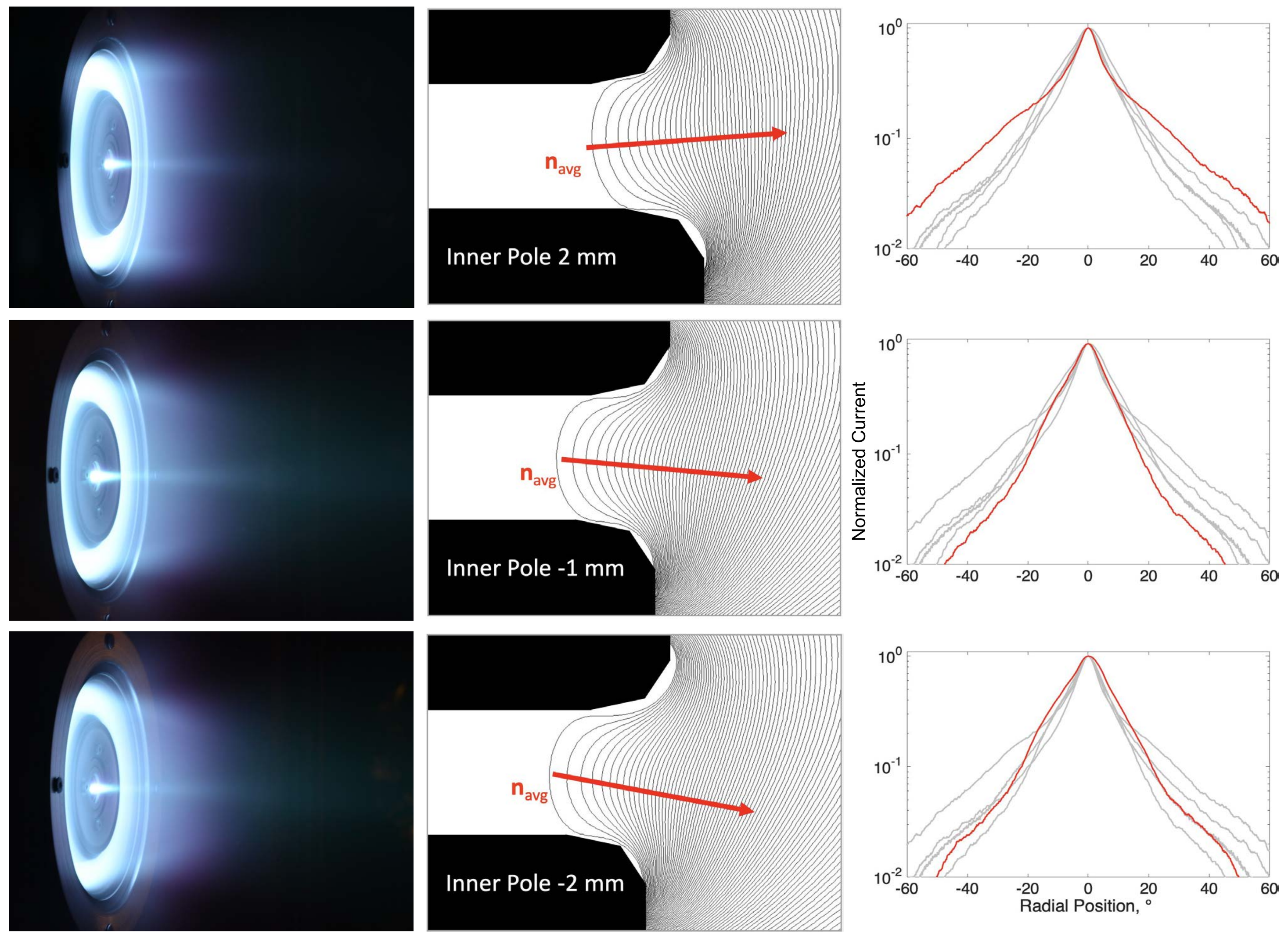
- ACME can reposition the inner and outer poles of the magnetic circuit, along with the anode, and cathode
- This allows for a highly adaptive design to investigate plume performance across a range of setups while controlling the topology of the magnetic shielding



The full range of inner pole positions ACME can operate in: Left: +5 mm, Center: 0 mm, Right: -35 mm

Focusing the Plume – Experiments on Xenon

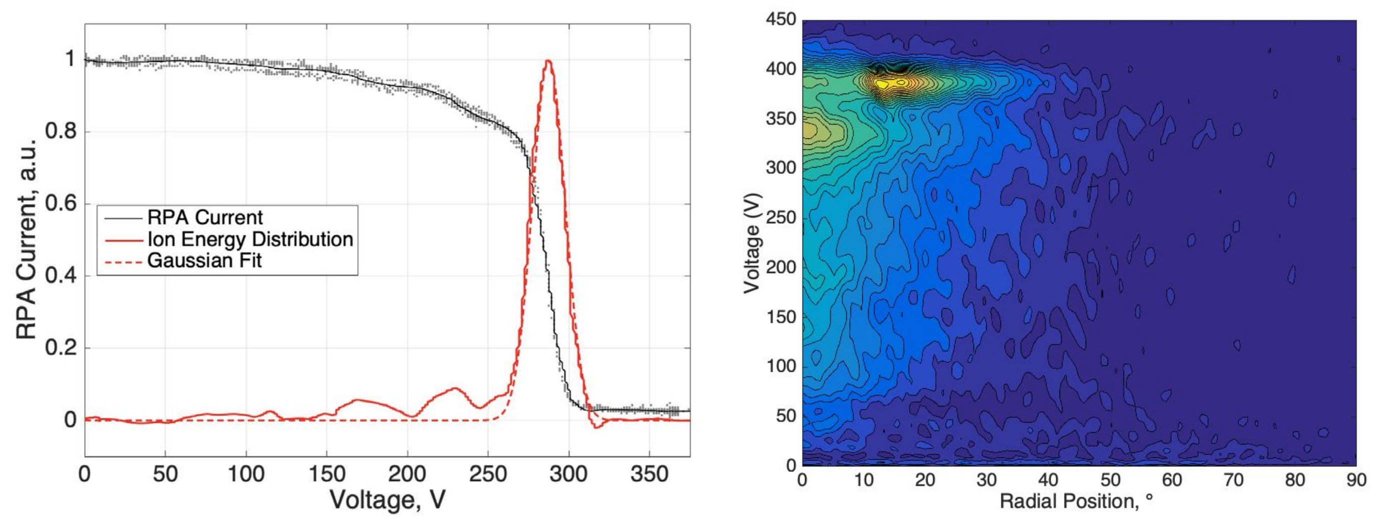
- Aim: To investigate the effects of pole position on the divergence of the plume
- Inner pole positions from +2, to –2 mm were tested at 300 V, 400 W
- The adjustable pole positions were able to change the field angle while maintaining the shielded geometry and produced a range of plume divergences from wide to over-focused.
- Swept Faraday probe measurements showed an maxima in the divergence utilization efficiency at the -1 mm pole position



The plume divergence across a subset of pole positions. (a) Photos at 105mm f/16 1/10" ISO200. (b) The simulated magnetic field with a calculated centerline acceleration vector (c) Normalized current density measurements

Plume Mapping – New Methodologies

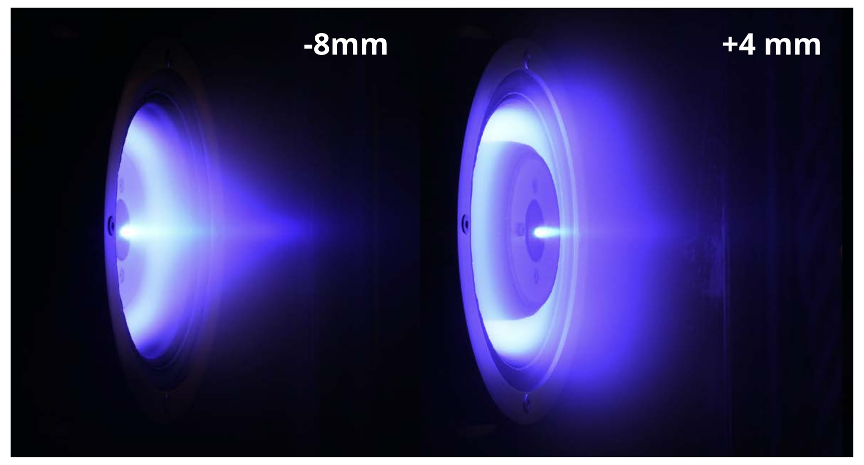
- Standard voltage utilization measurements are taken on thruster centerline using a Retarding Potential Analyzer (RPA)
- Taking a swept measurement allows the IEDF to capture the high energy ions in the plume as the beam diverges from the centerline



Left: A single RPA measurement taken on centerline showing the Ion Energy Distribution Function (IEDF). Right: A swept RPA showing how the IEDF varies by radial position

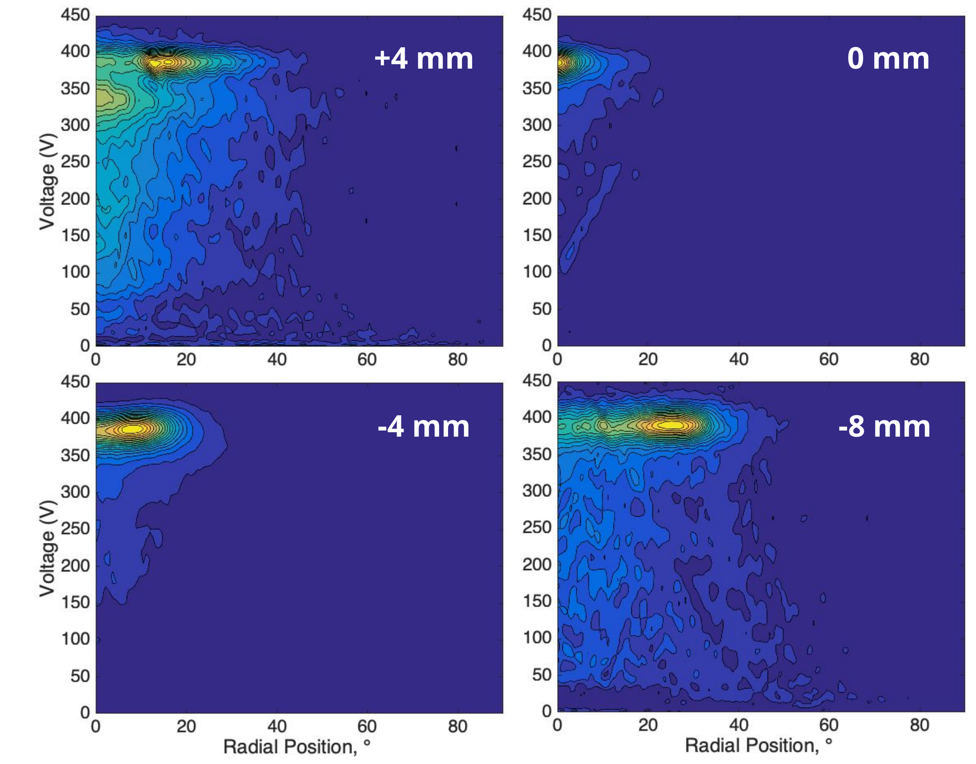
Mapping the Plume – Experiments on Krypton

- Aims: To investigate the effects of pole position on the performance of the thruster measured with a nested inverted pendulum thrust stand at 400 V, 600 W
- To investigate each component of the efficiency from: an ExB probe, a swept Faraday probe, and a swept RPA probe

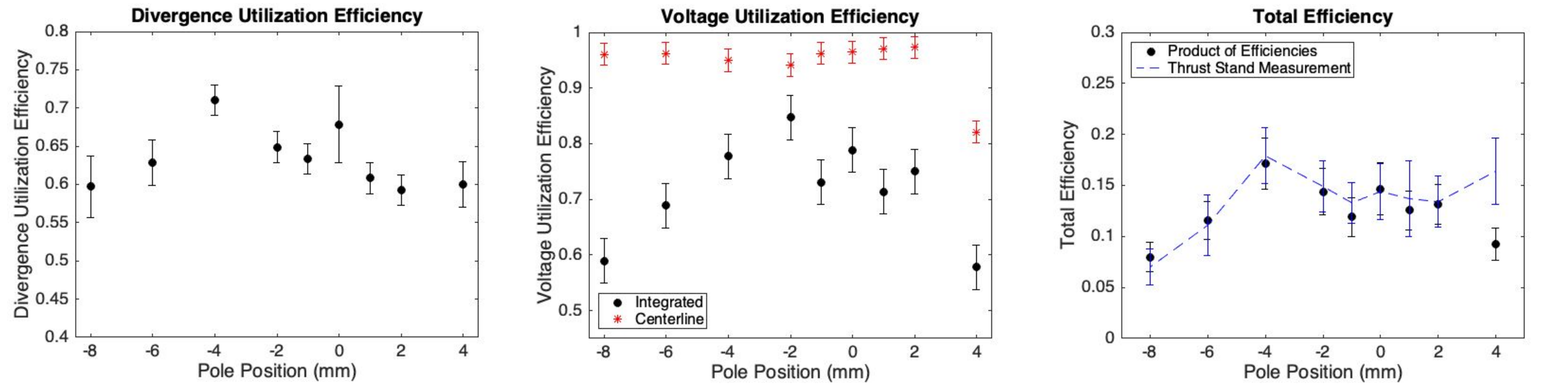


Plume photos at the extremes of positions tested on Kr

- ACME demonstrated consistent magnetic shielding across the range of pole positions tested
- The performance of the thruster shows a significant dependence on the pole positions
- IEDFs generated from the swept RPA show the improvements from the new measurement technique
- Overestimation of the voltage utilization efficiency from standard centerline measurement ranged from 9% at -2 mm, to 65 % at the -8 mm position



IEDFs of the thruster plume at +4, 0, -4, and -8 mm pole positions



- Mass and charge utilization efficiencies remained relatively consistent across the range of pole positions
- Current utilization monotonically decreased with more negative pole positions
- Both the divergence and voltage utilization efficiencies had local maxima at -4, and -2 mm respectively
- The product of the five efficiencies had good agreement with the thrust stand measurement at all but +4 mm, adding confidence to the performance analysis

Future Work

- Automated optimization of Hall thruster operating conditions using machine learning
- Updated anode design focusing on: even gas distribution, varied azimuthal injection, and water-cooling. Lead graduate student: Danny Roberts
- Lightweight and alternative propellants analysis

WILLIAM E. BOEING
DEPARTMENT OF AERONAUTICS & ASTRONAUTICS

ADVISER: Justin Little

Space Propulsion and Advanced Concepts Engineering (SPACE) Lab