A Laser-Induced Fluorescence Diagnostic for HERMeS and High-Power Electric Propulsion

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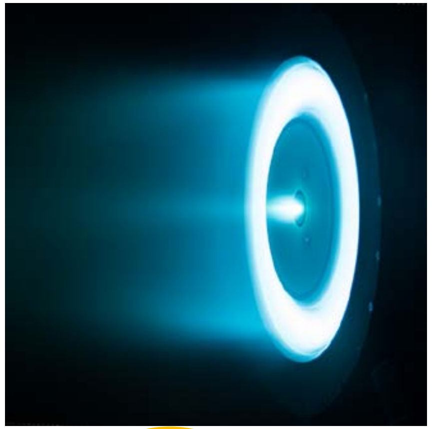
Outline

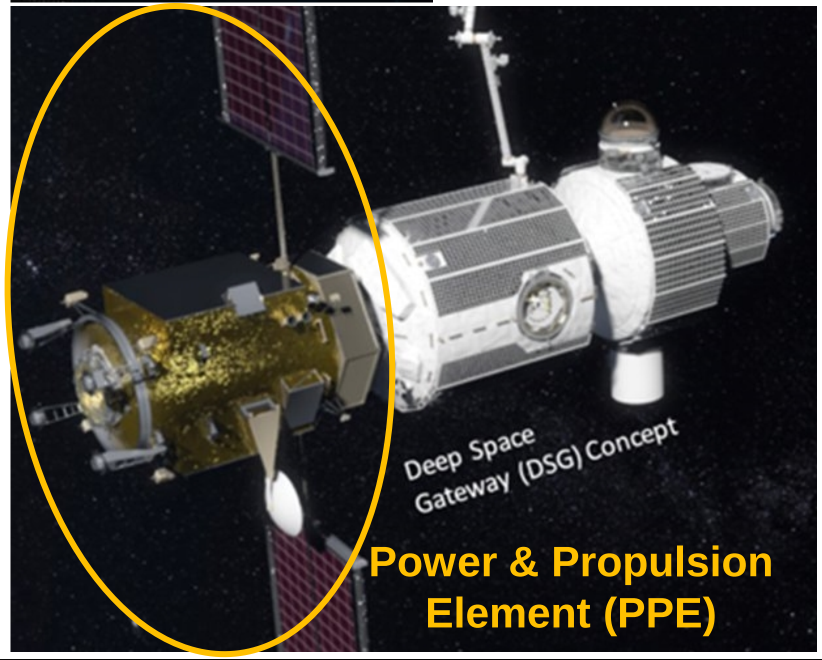
- Introduction
- Principles of LIF
- Experimental Setup
- Data analysis
- Preliminary results
- Conclusion

Introduction

- A NASA GRC and JPL team developed a 12.5-kW, magnetically-shielded Hall thruster, called Hall Effect Rocket with Magnetic Shielding (HERMeS)
- Transitioned to commercial production under Aerojet Rocketdyne's Advanced Electric Propulsion System (AEPS)
- Candidate to provide propulsion for the Power and Propulsion Element
- Continuing risk reduction activities using HERMeS

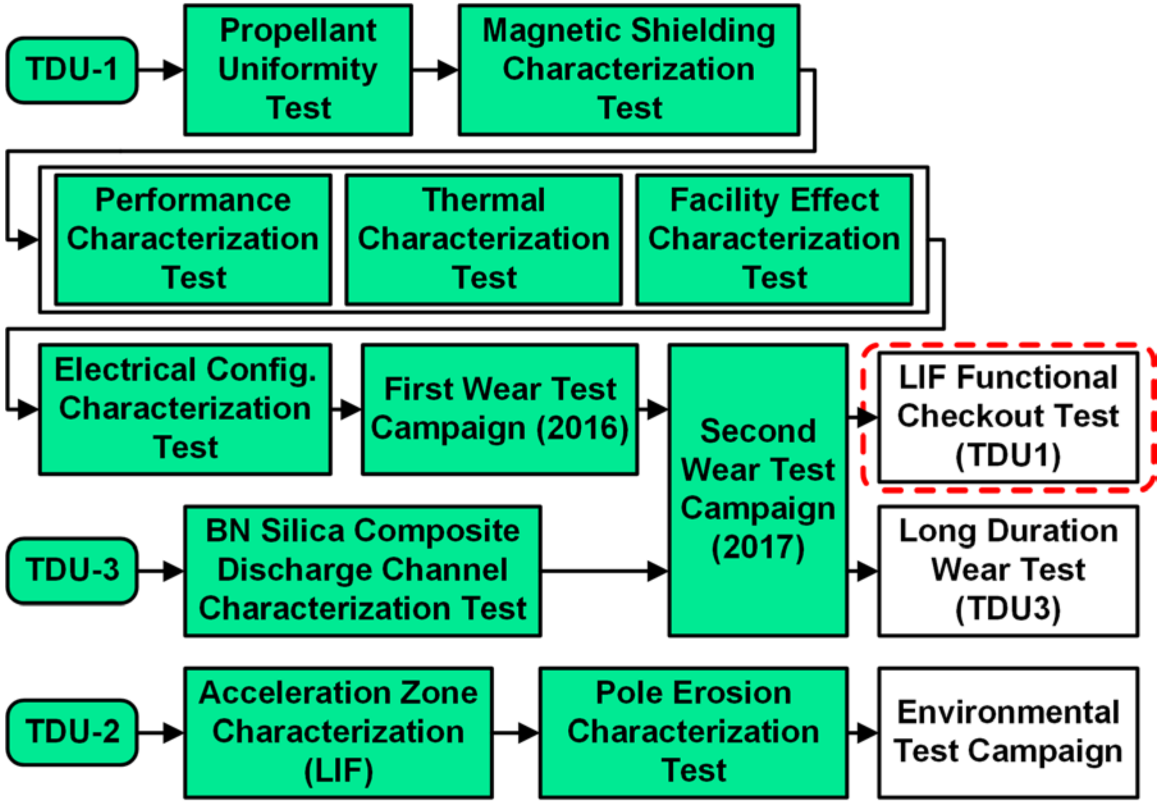


◄ HERMeS in operation



HERMeS Test Campaign Status

- Overview found in IEPC-2017-284 & 231
- Other JANNAF papers on HERMeS
  - **Kamhawi**, BN/Silica composite discharge channel test (2N, Tue 1:35p)
  - **Peterson**, long duration wear test (2N, Tue 2:05p)
  - **Xu**, AEPS early development results (2N, Tue 2:35p)
  - **Mackey**, evaluation of BN for Hall thruster discharge channel (2N, Tue 3:05p)
  - **Frieman**, cathode and keeper configuration on HERMeS (2N, Tue 4:05p)
  - **Williams**, HERMeS wear trends via optical emission spectroscopy (3B, 9:05a)
  - **Kamhawi**, magnetic optimization tests (3B, 10:05a)

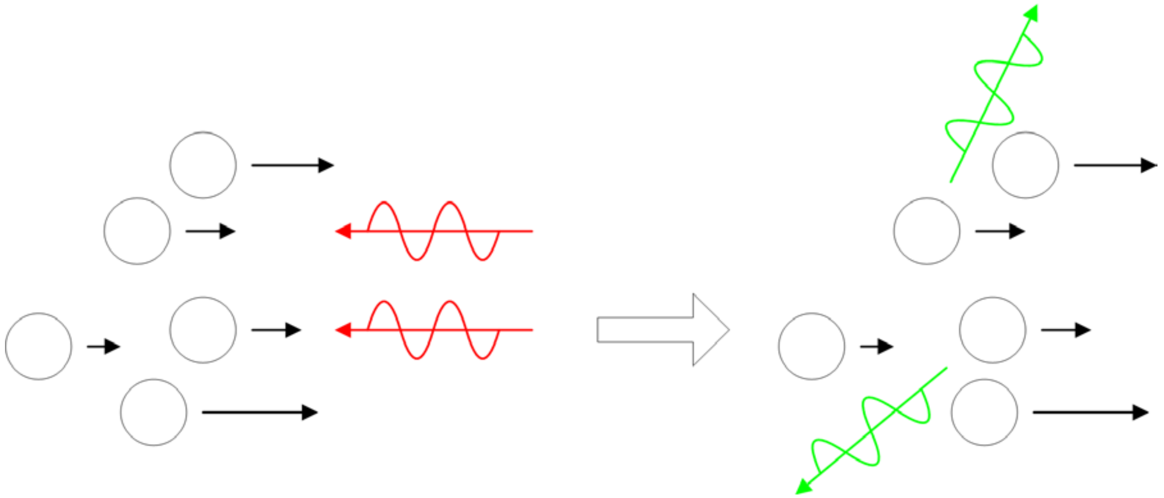


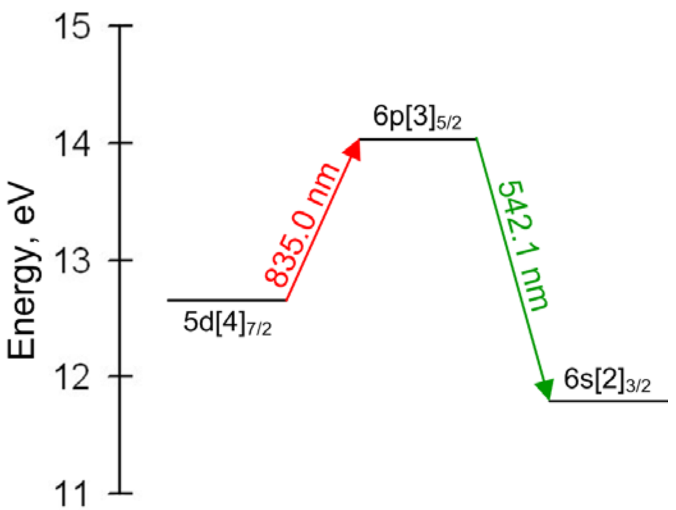
Why LIF?

- HERMeS/AEPS project need plasma data from inside the discharge channel for model validation
  - Injected probes (ex: HARP) are too perturbative (Jorns, AIAA-2015-4006)
- LIF can get ion velocity without perturbing plasma, which can be related back to electron mobility
- Concurrently conducting LIF studies at JPL (Chaplin, IEPC 2017-229) and GRC
  - Functional checkout test in VF6
  - Also get a complete set of TDU data for reference
  - EDU test in VF5 at lowest achievable background pressure
  - Time resolved LIF at JPL
- Goals
  - Complete data set for model validation
  - Confirmation that EDU and TDU have the same discharge characteristics

How does LIF work?

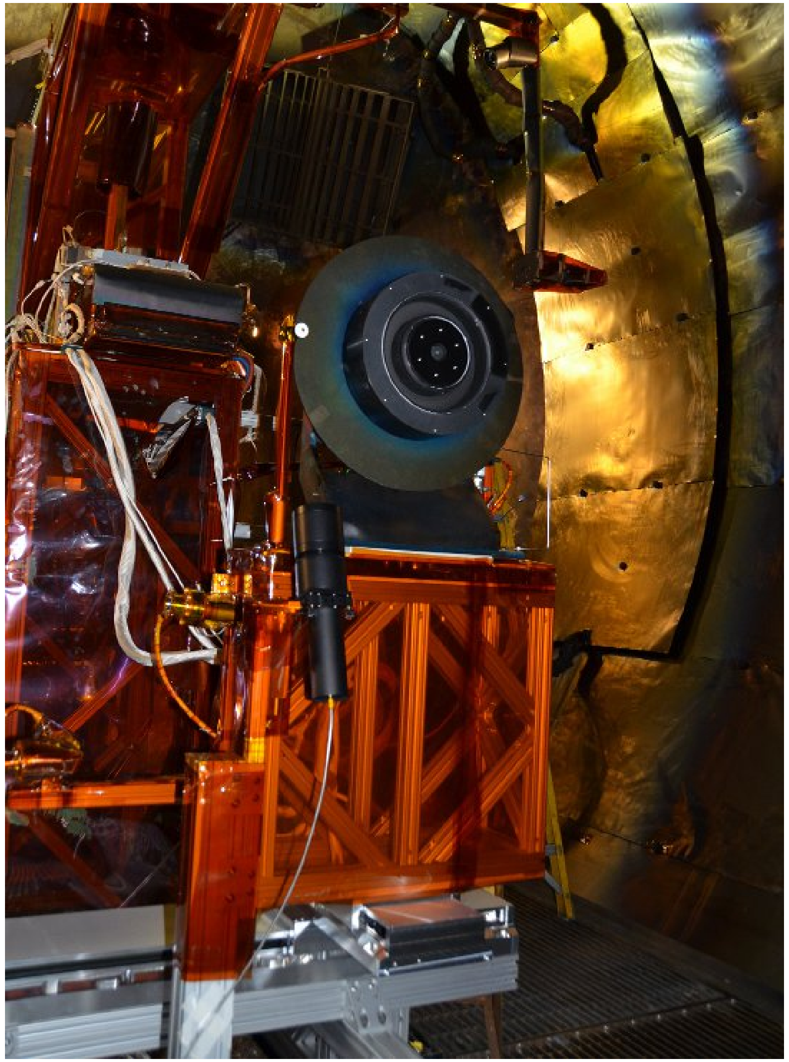
- Moving atoms absorb light at shifted frequency (Doppler effect)
- Collect emitted fluorescence while varying laser frequency to measure velocity distribution function (VDF)
- XE II 835.0 nm is easy to access with commercial diode laser
  - Metastable
  - Representative of bulk ion VDF
  - Fluoresce in green, 542.1 nm



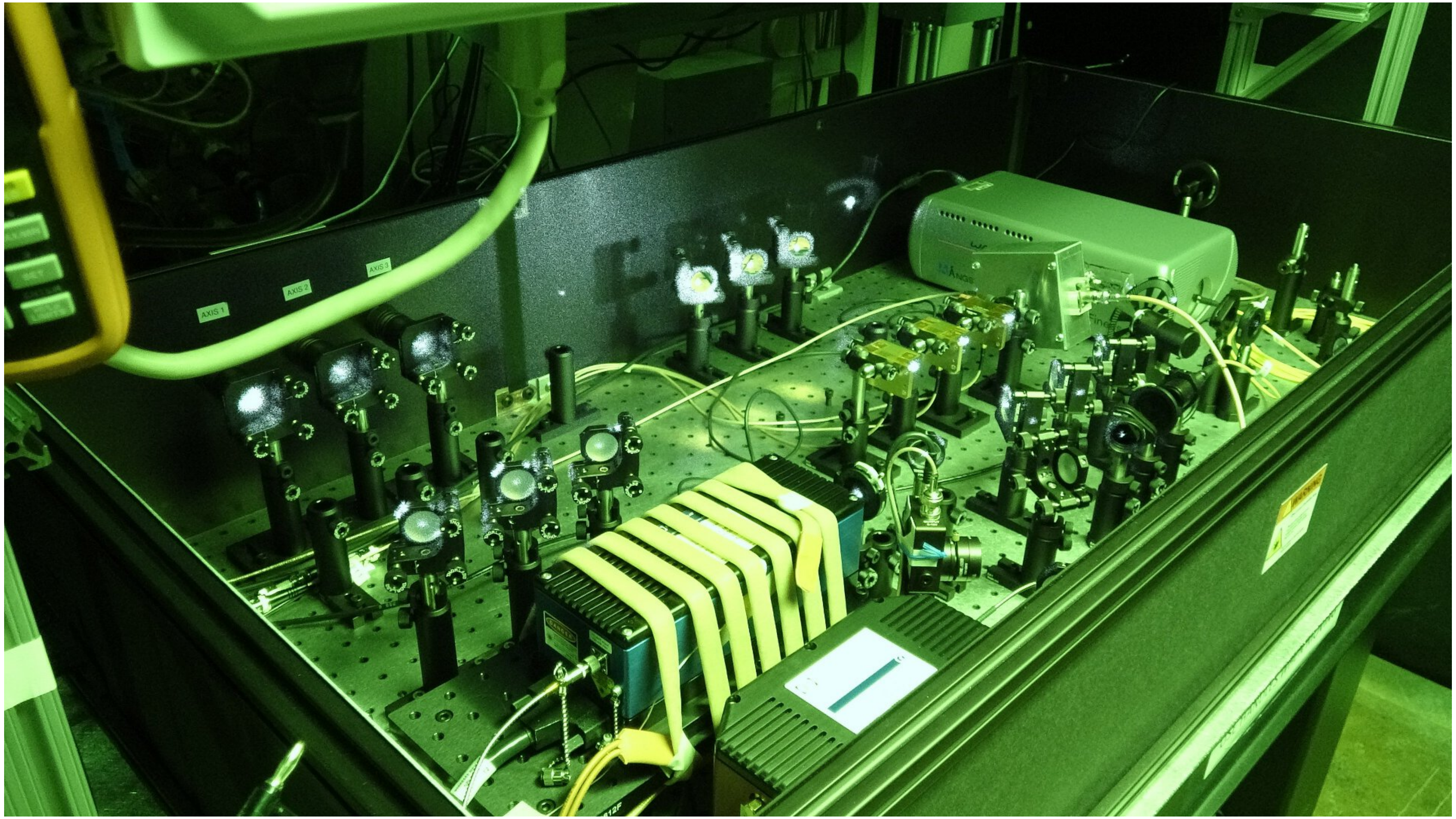


Experimental Setup – Test Article

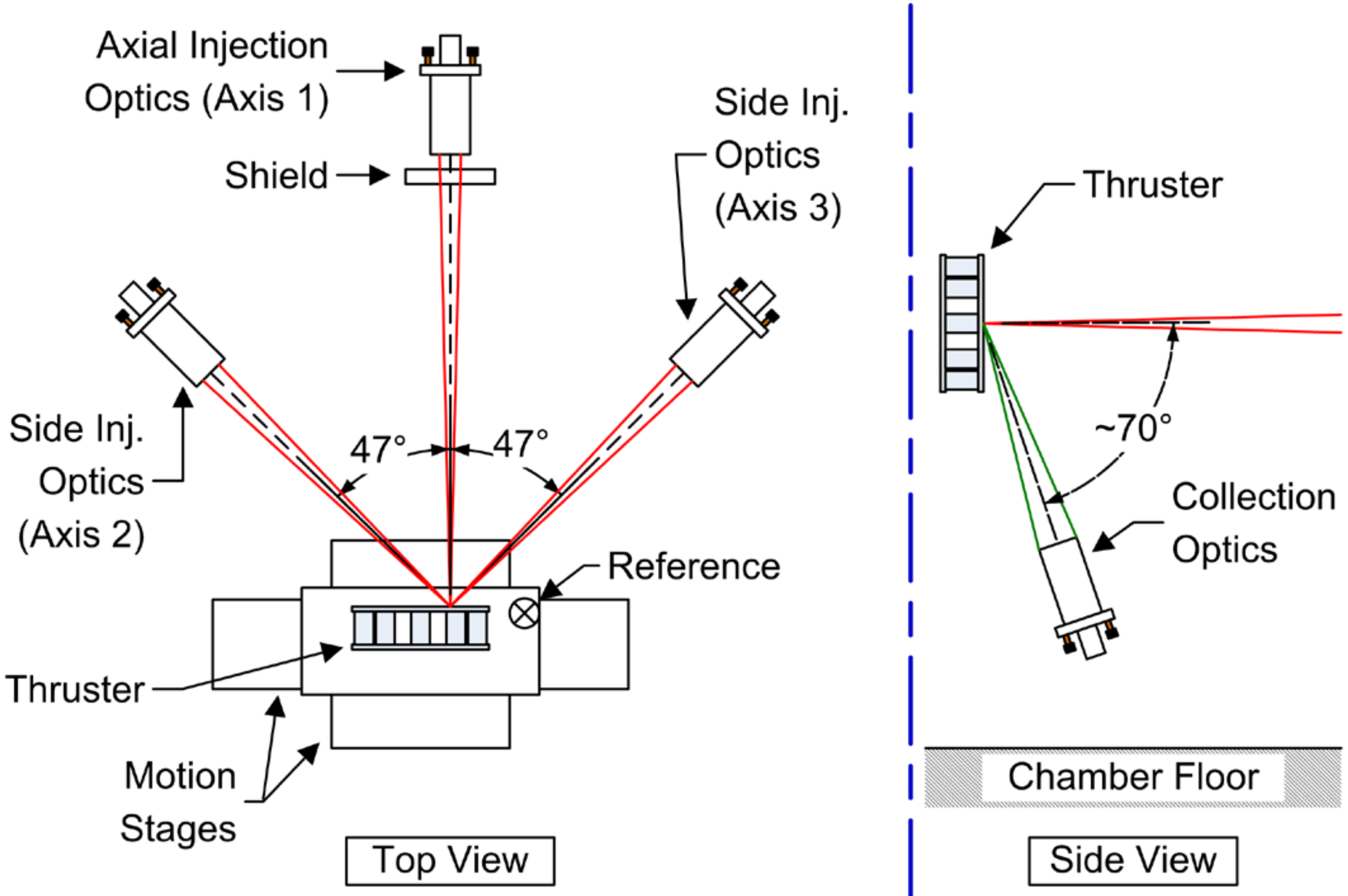
- HERMeS TDU1
  - Throttle range from 0.6 to 12.5 kW, 2000 to 3000 sec
  - Magnetic shielding topology
  - Centrally mounted cathode, 7% cathode flow fraction
  - Test was in VF6, ~1.2e-5 Torr near thruster
- Test points include:
  - 300 to 600 V
  - Nominal and off-nominal magnetic field
  - Different background pressure
  - Only showing 300 V, 6.25 kW and 600 V, 12.5 kW nominal magnetic field data



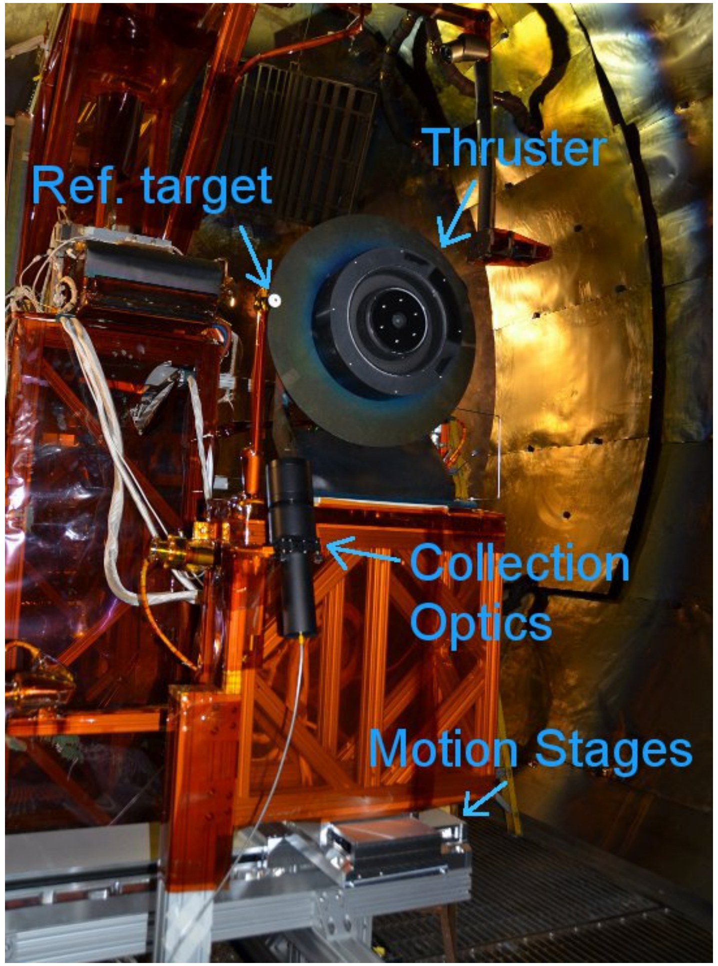
Experimental Setup – Air Side Injection Optics



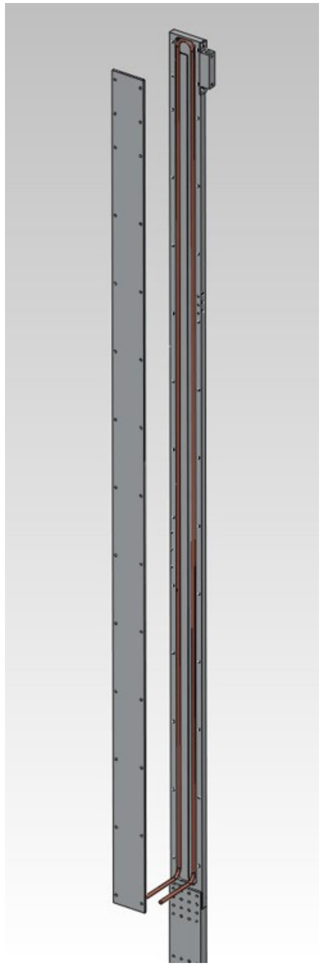
Experimental Setup – Vacuum Side Optics

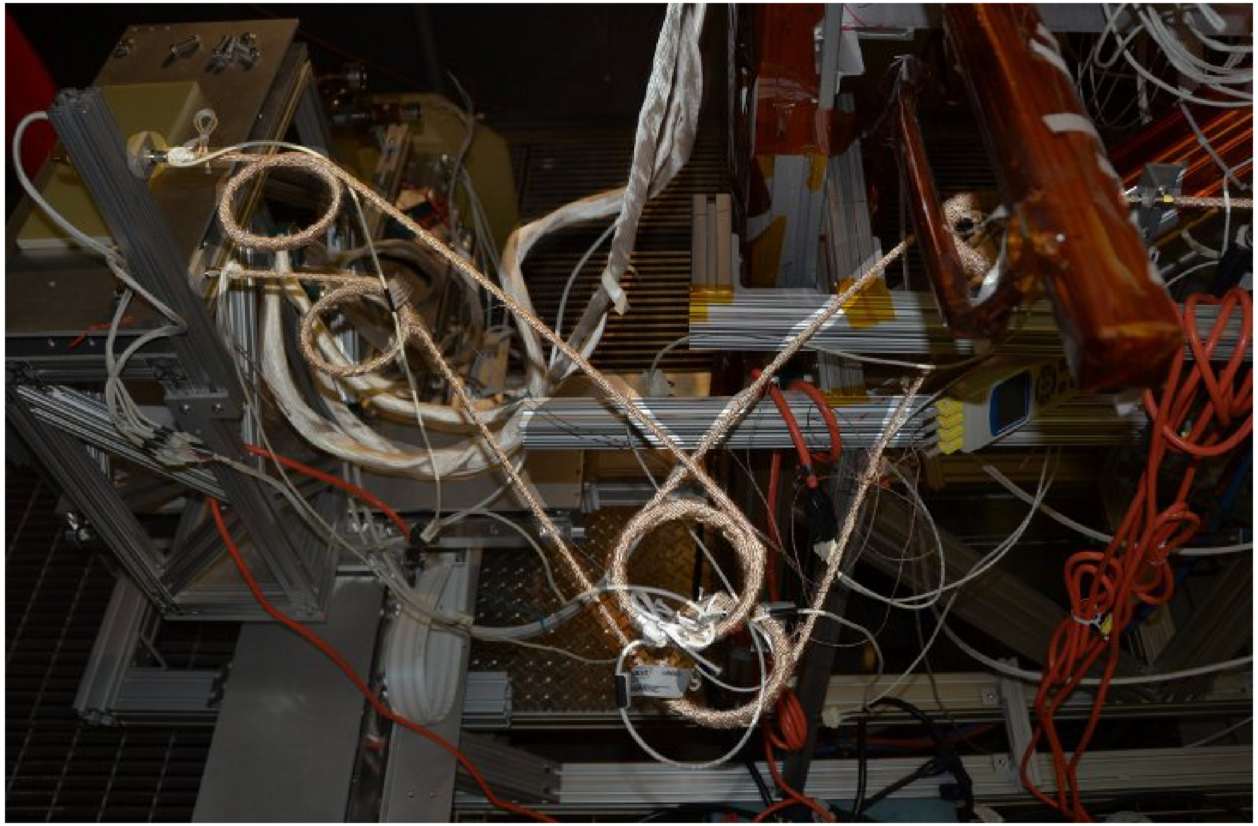


(a) (b)



Experimental Setup – Tower Cooling and Propellant Delivery

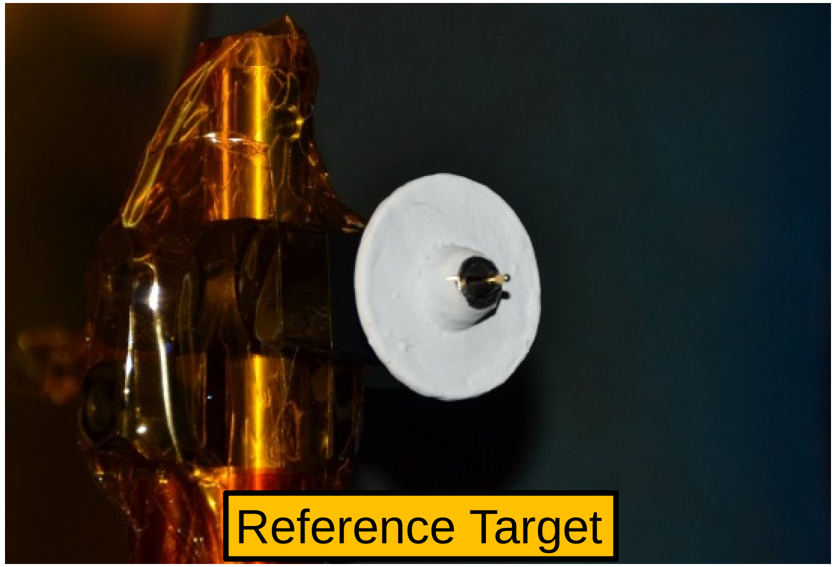




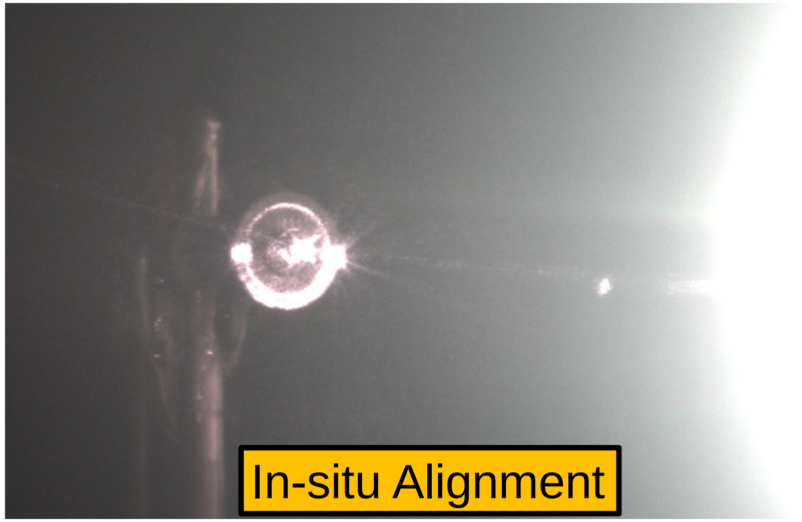
Experimental Setup – Air Side Collection

- Collected fluorescence > monochromator > photomultiplier > trans-impedance amplifier > lock-in amplifier > computer data
- Stationary reference signal > lock-in amplifier > computer data
- Computer
  - Control thruster motion stages
  - Control optics alignment motors
  - Read wavemeter
  - Read laser power monitor
  - Read lock-in amplifier outputs

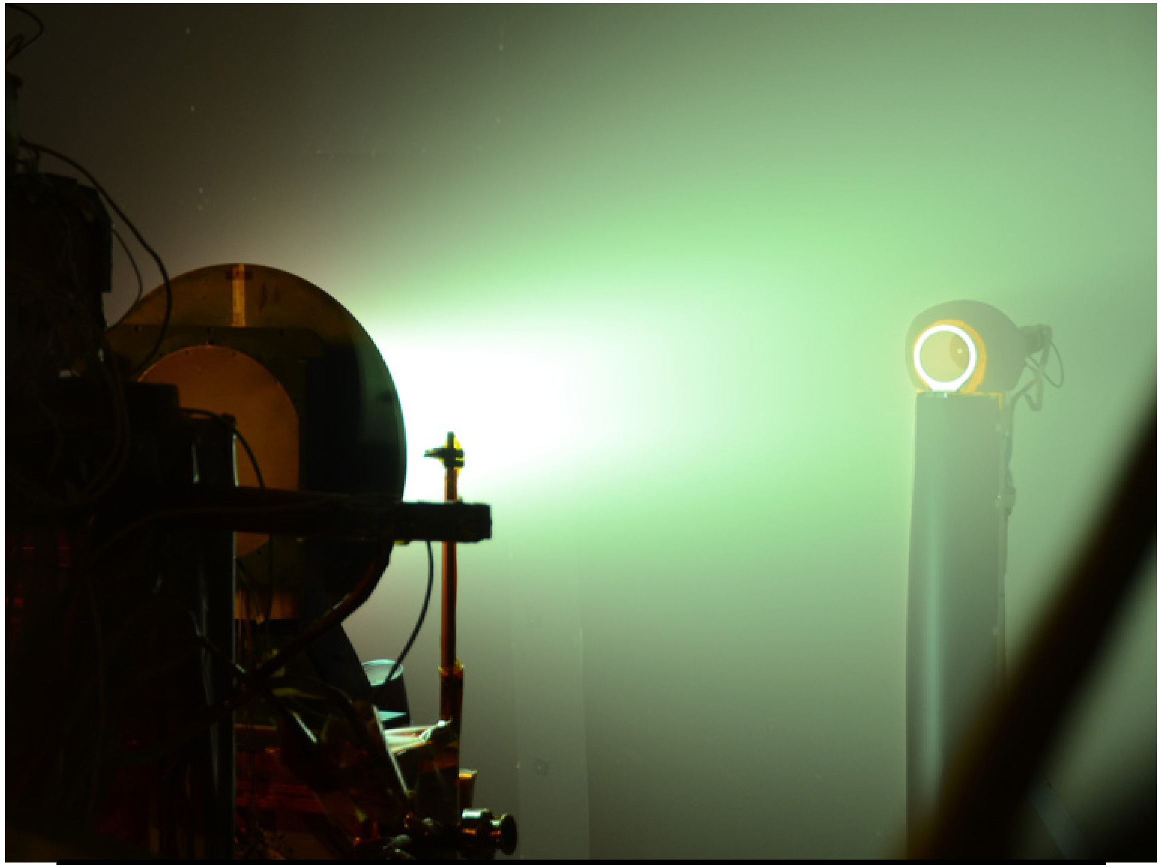
In-Situ Alignment



Reference Target



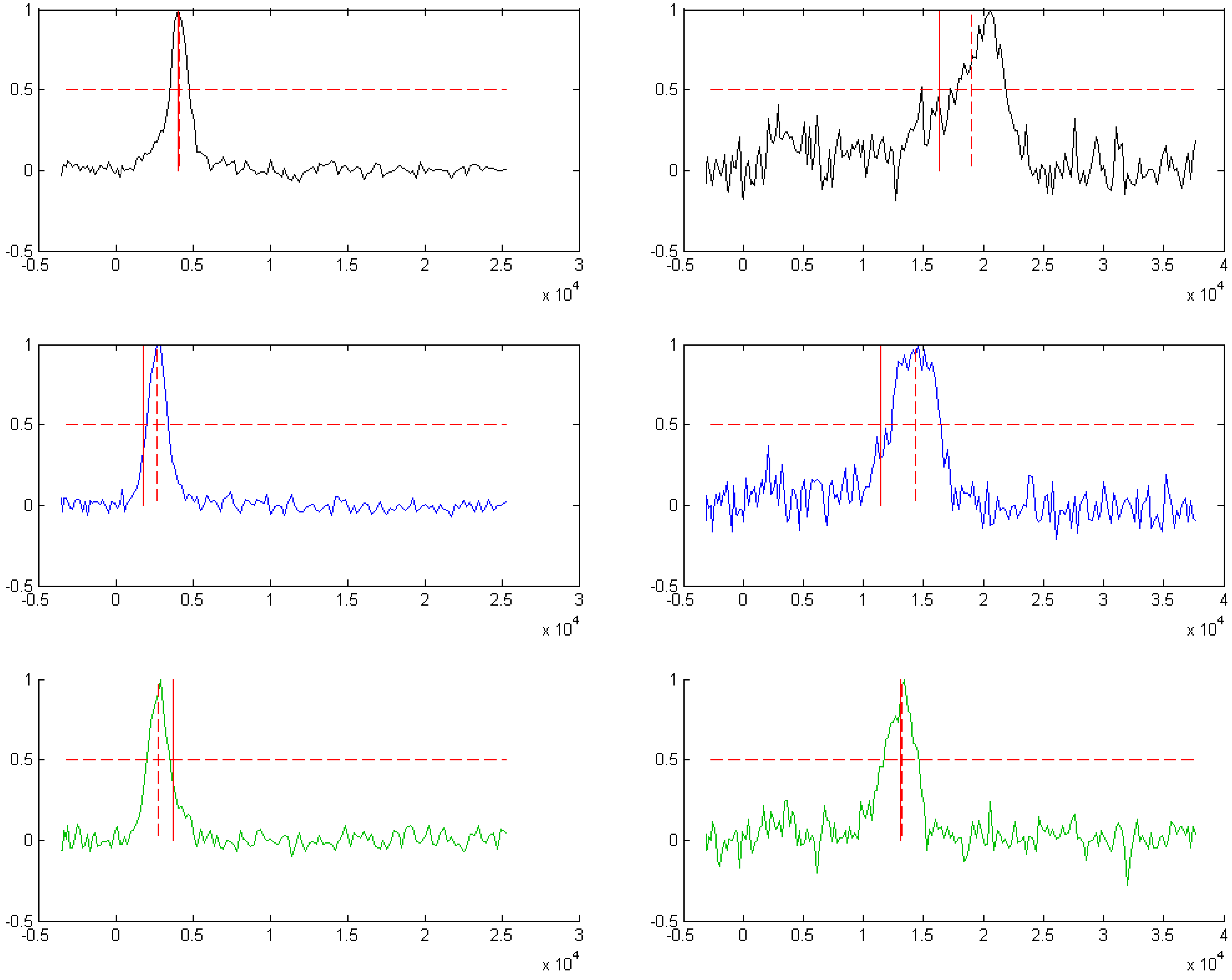
In-situ Alignment



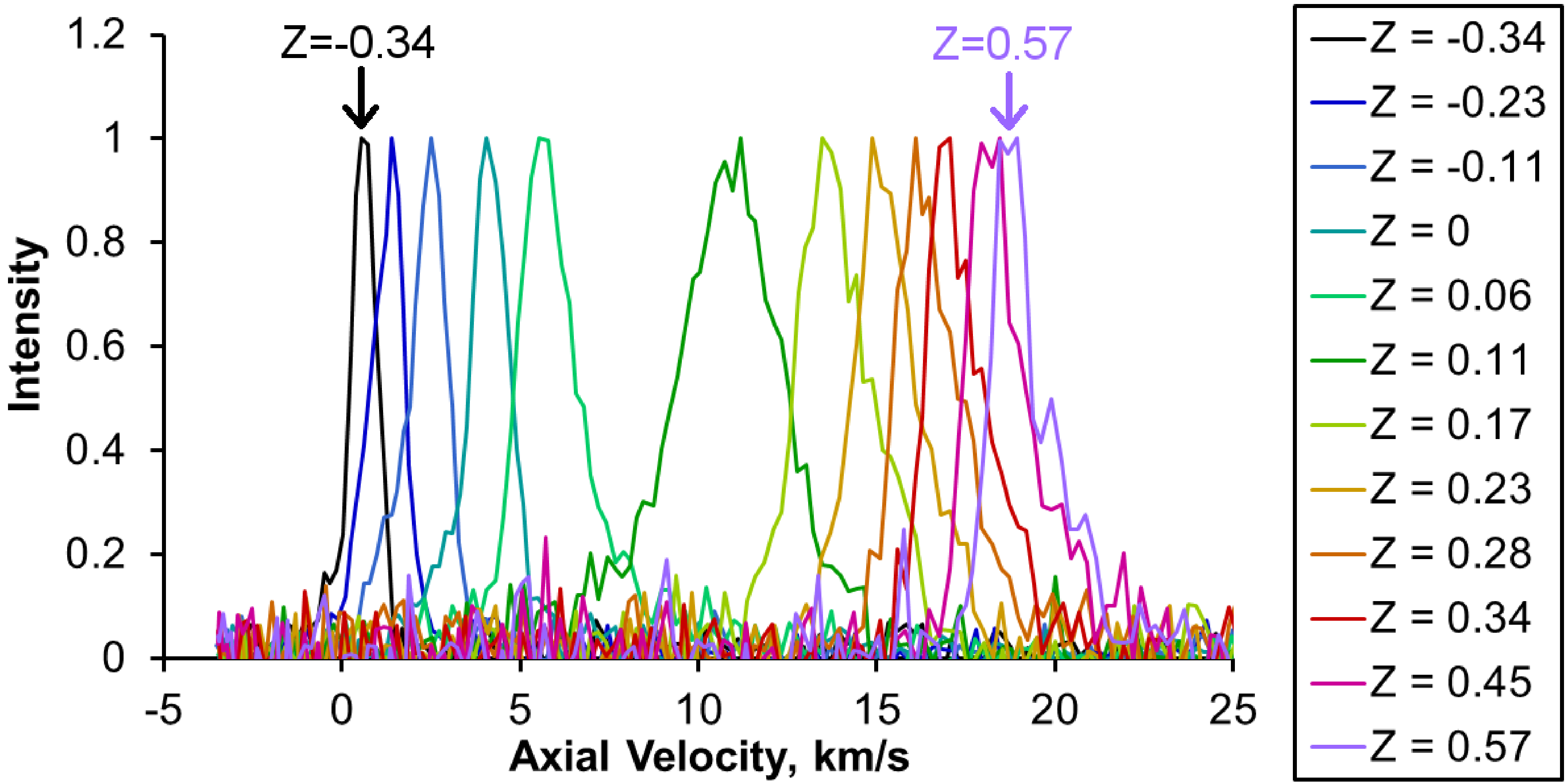
View through a laser-safe window (green tinted)

Data Analysis

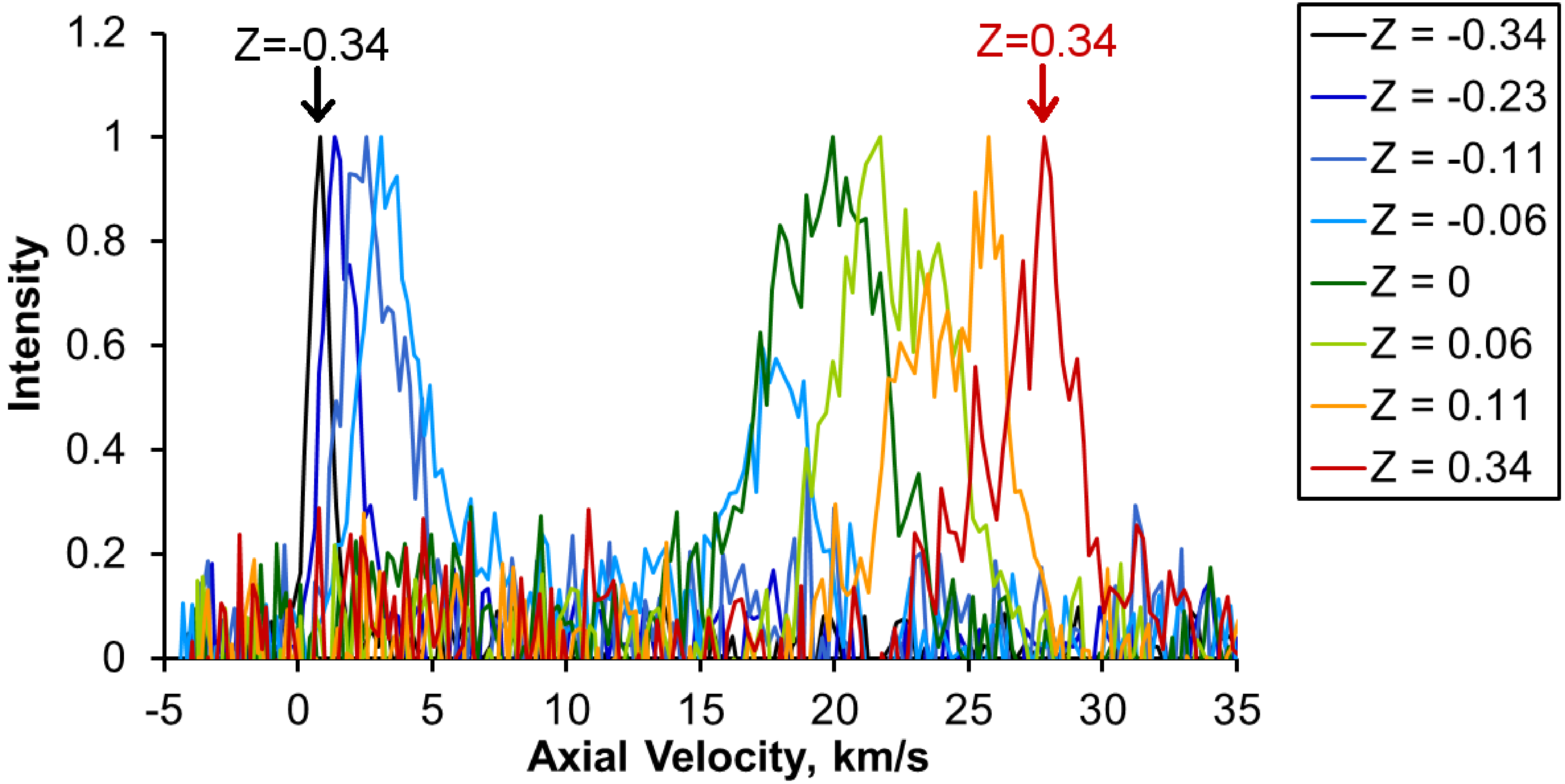
- Saturation study was performed, broadening no more than 10% on narrowest VDFs
- Preliminary analysis steps:
  1. Convert wavemeter and OG signal to velocity
  2. Correct intensity by laser power variation
  3. Apply 50%-of-maximum threshold-based averaging
- Spatial uncertainty: 0.5 mm
- Velocity uncertainty: ±100 m/s typical (±1000 m/s for noisiest scans)
- Will calculate uncertainty for each data point in later analysis



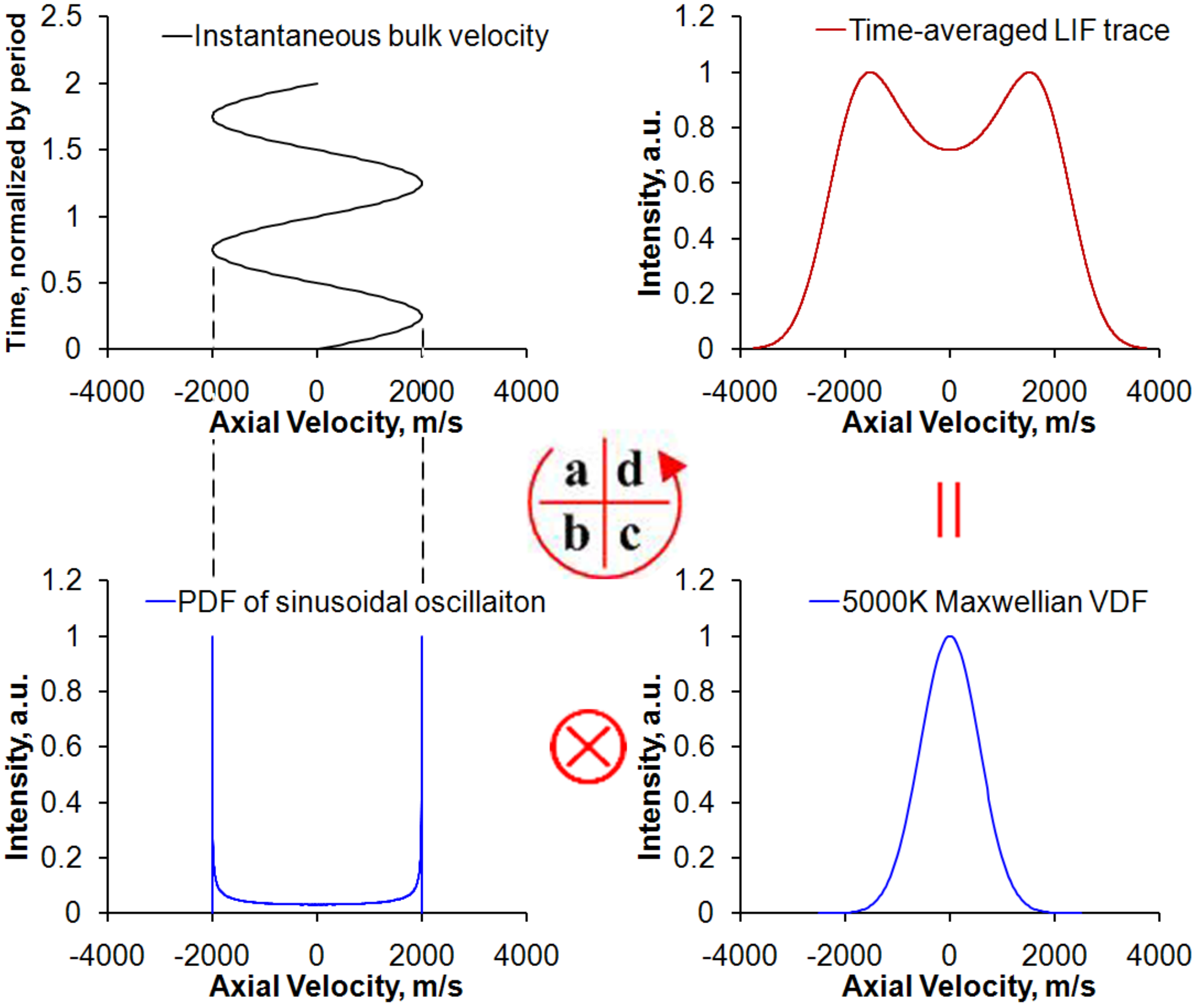
Preliminary Results: 300 V, 6.25 kW



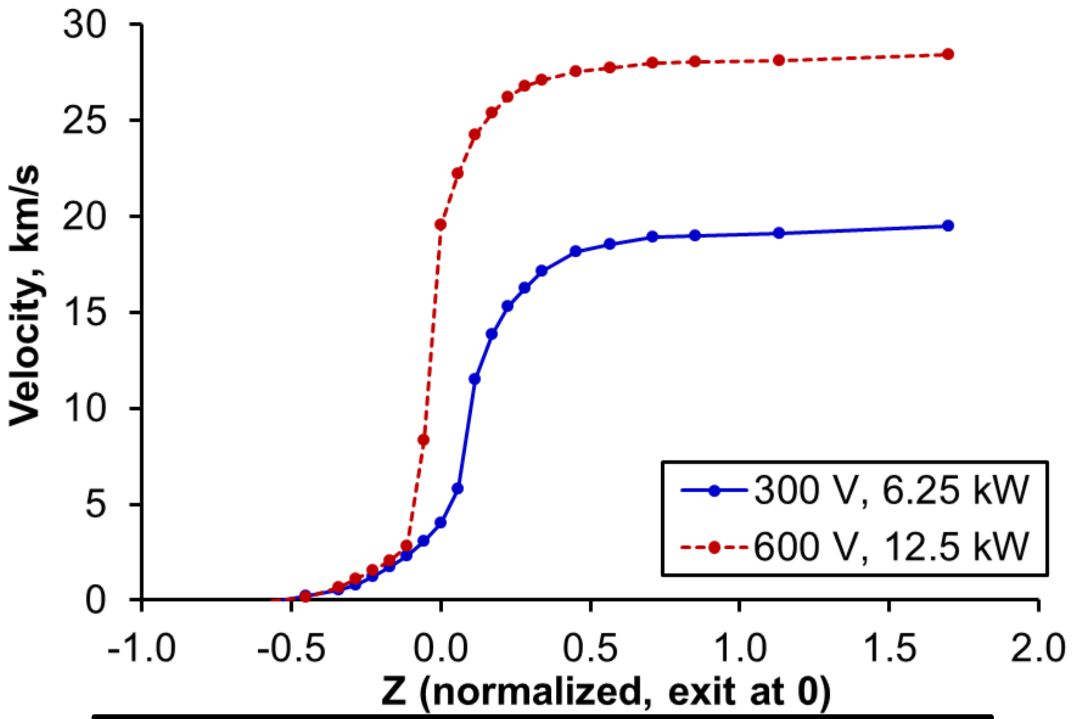
Preliminary Results: 600 V, 12.5 kW



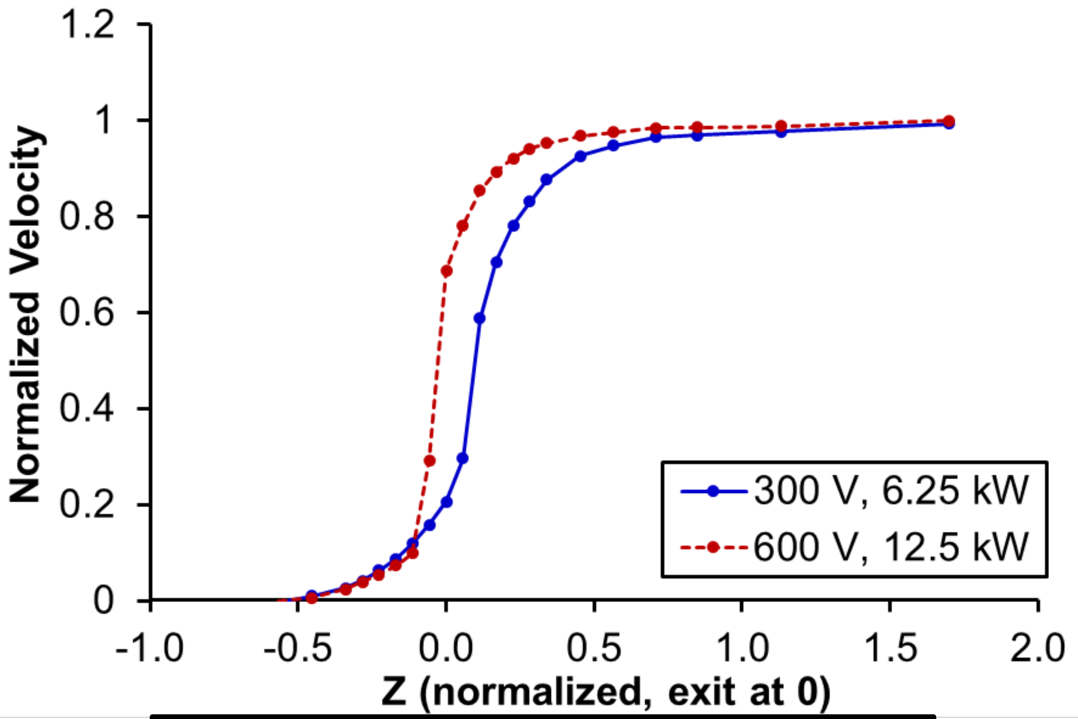
Why sinusoidal spatial oscillation appears as twin peak structure in time-averaged LIF



Preliminary Results: Velocity Profile

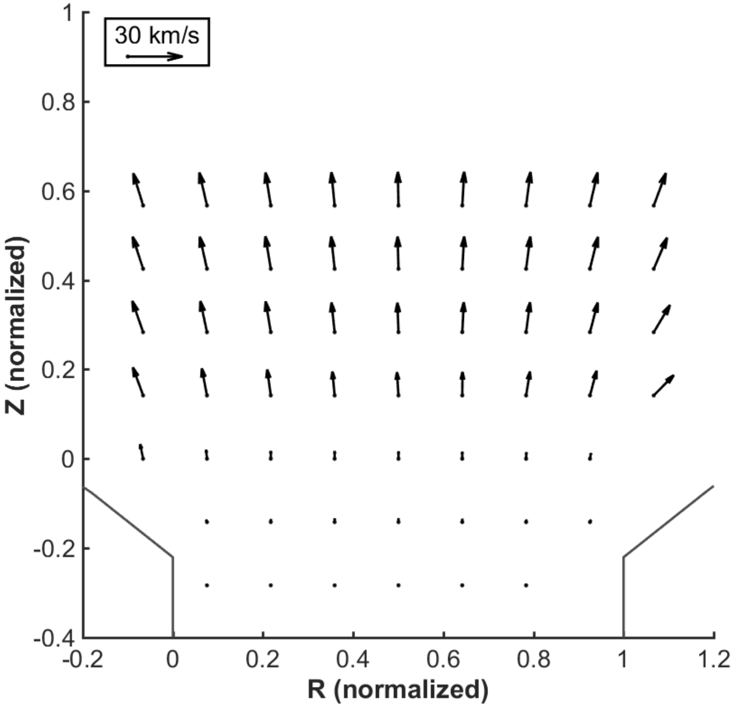


Averaged XEII velocity along channel CL

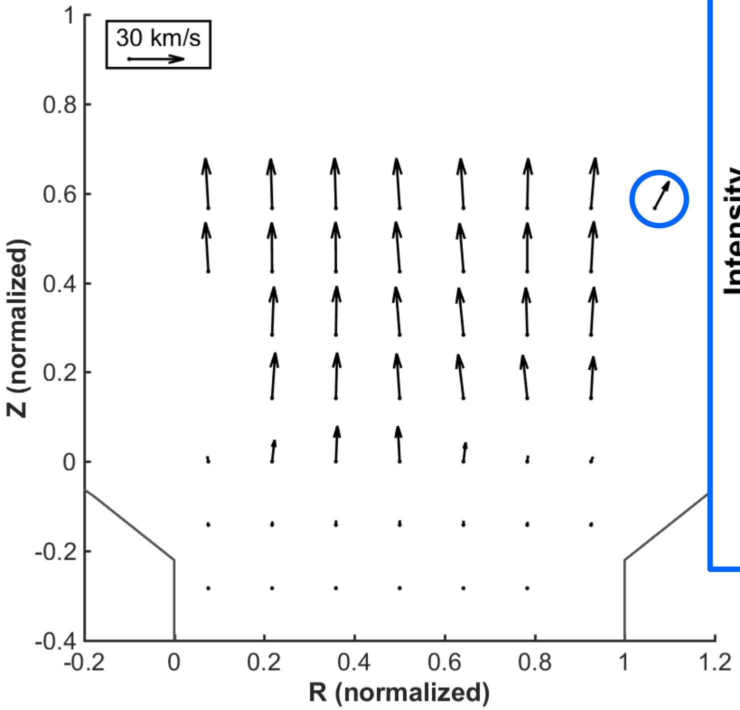


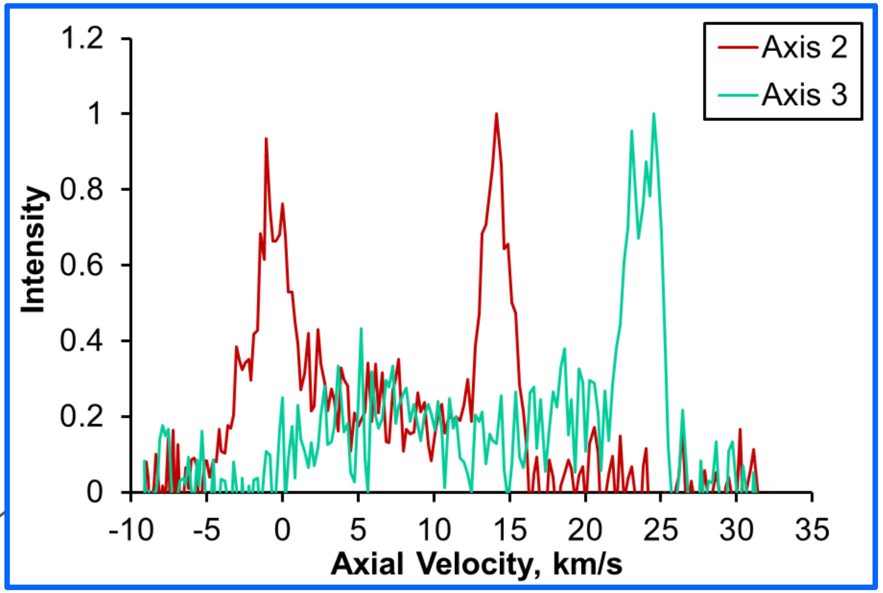
Velocity normalized by max velocity

Preliminary Results: Velocity Vectors



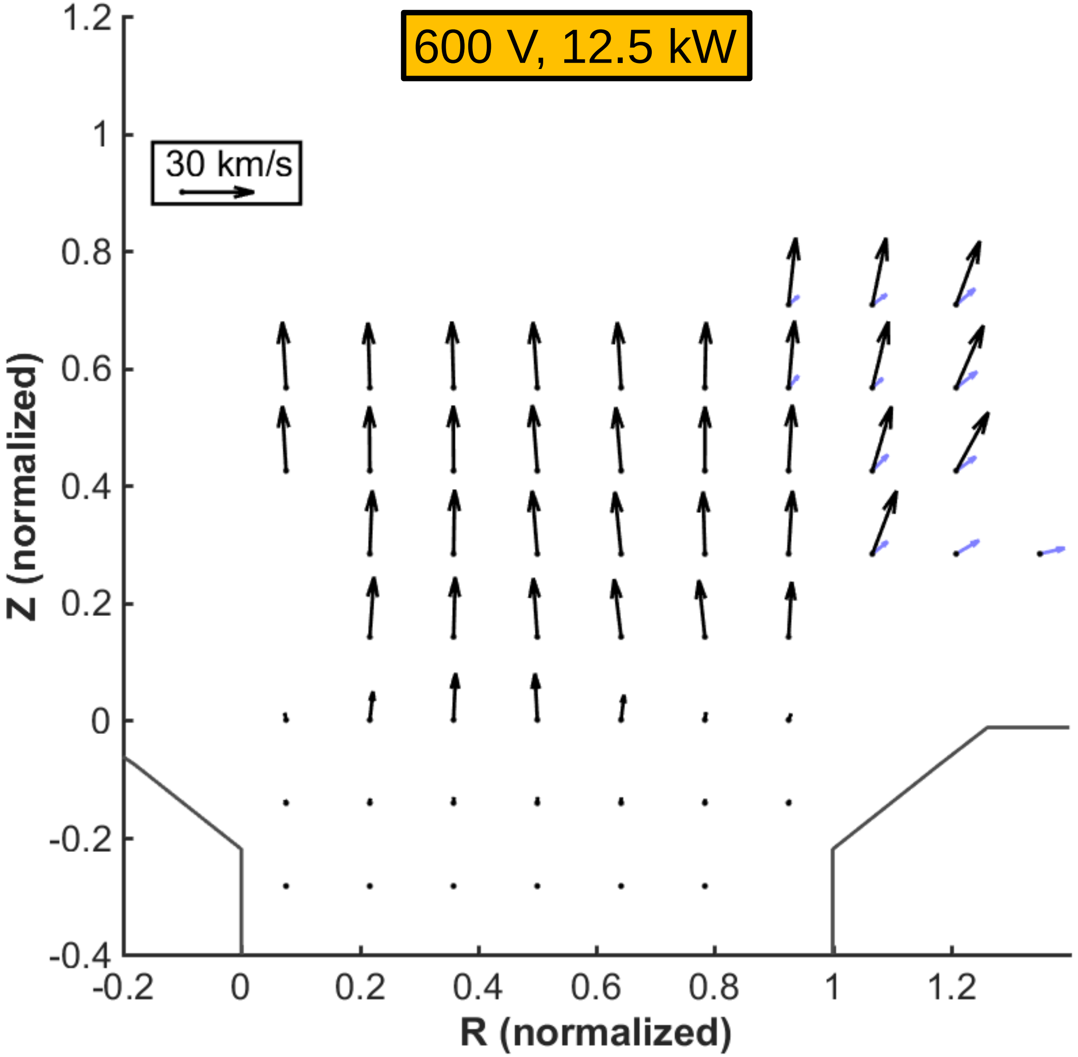
300 V, 6.25 kW

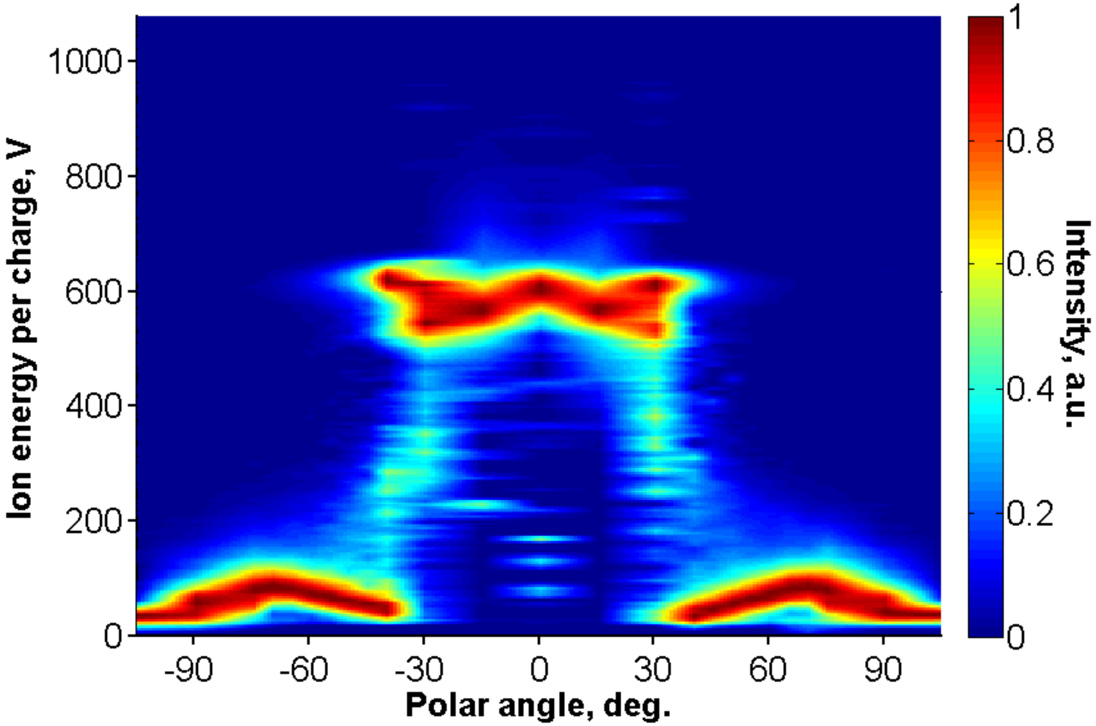




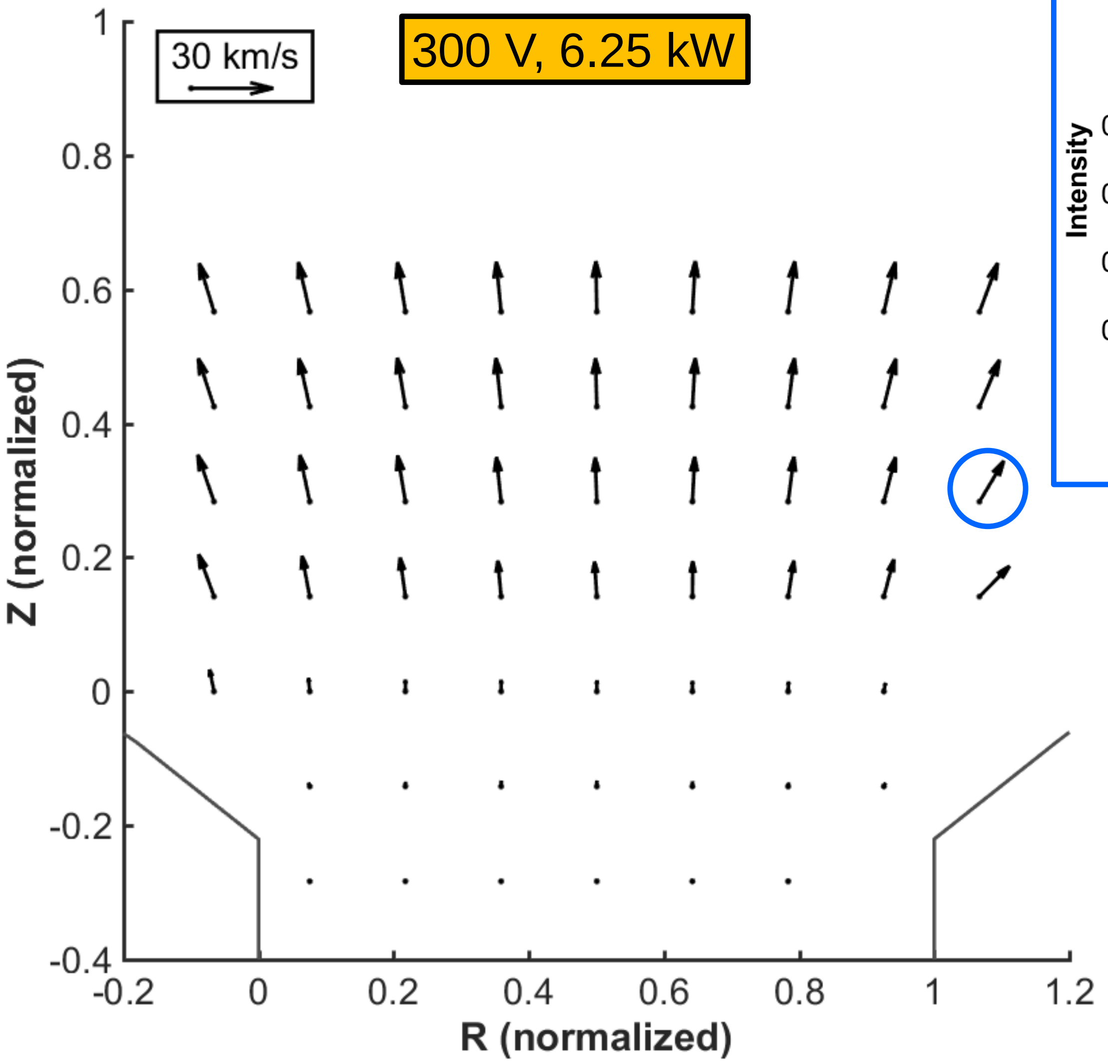
600 V, 12.5 kW

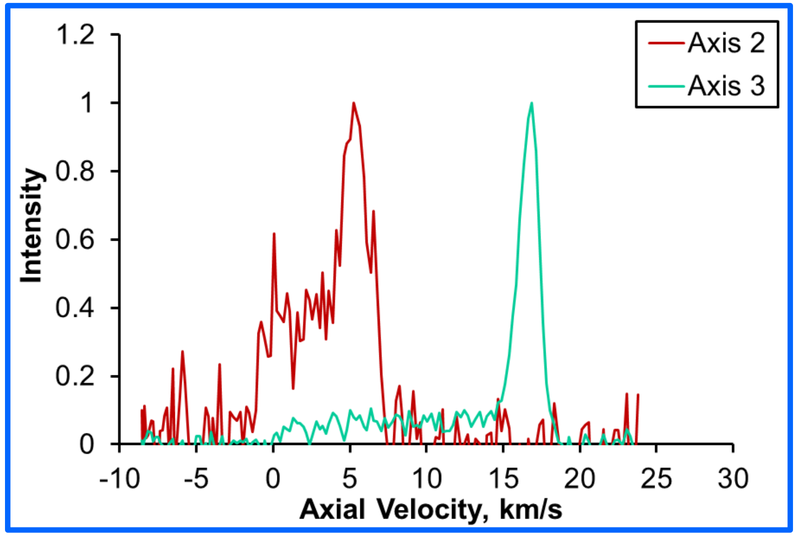
Preliminary Results: Extended Map

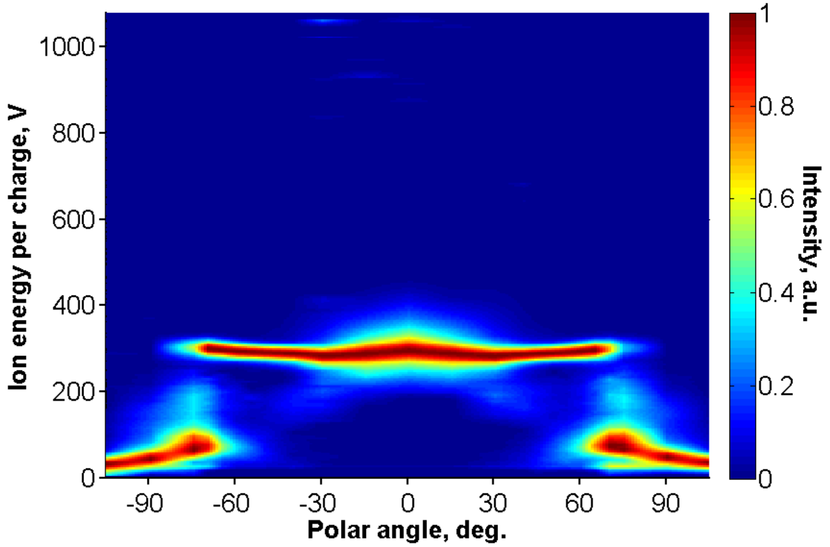




Near-Field LIF Correlates Well with Far-Field RPA Data







Conclusion

- New LIF capability for characterizing high-power EP devices at GRC
  - Compatible with engineering hardware
- Completed functional checkout and collected TDU data
- Extended spatial maps revealed a secondary, low-energy population that is likely to be CEX ions
- Energy and direction of high-energy and low-energy ions are in excellent agreement with far-field RPA data