Ion Velocity in the Discharge Channel and Near-Field of the HERMeS Hall Thruster

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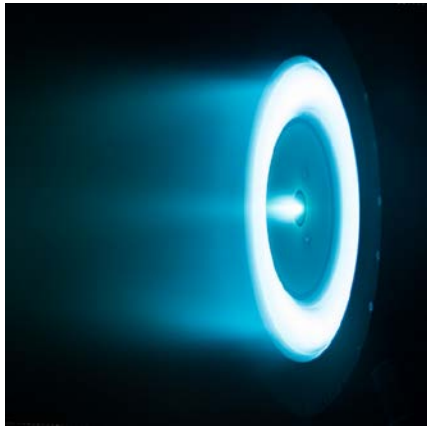
Outline

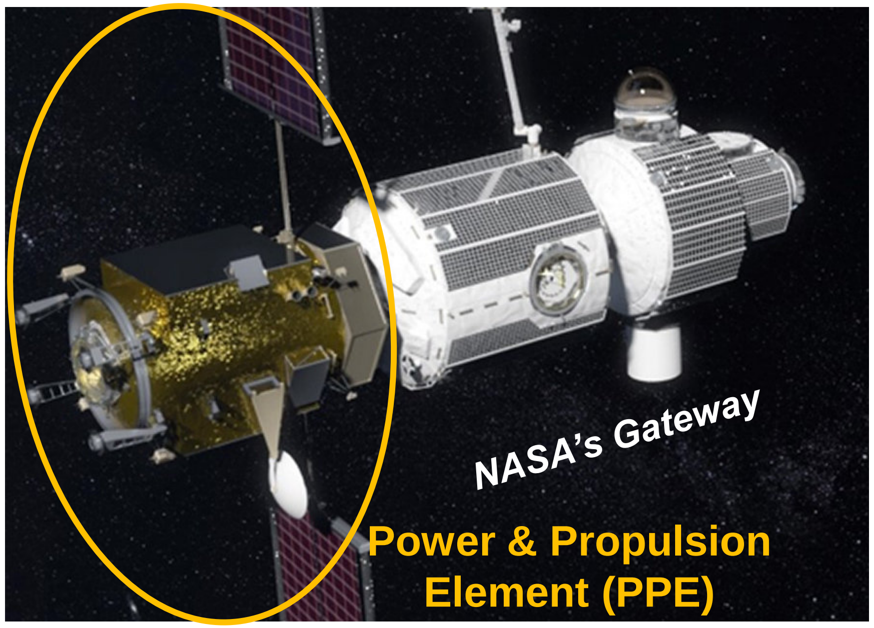
- Introduction
- Principles of LIF
- Experimental Setup
- Data analysis
- Results
  - Near the discharge channel
  - Downstream of pole covers
- Conclusion

Introduction

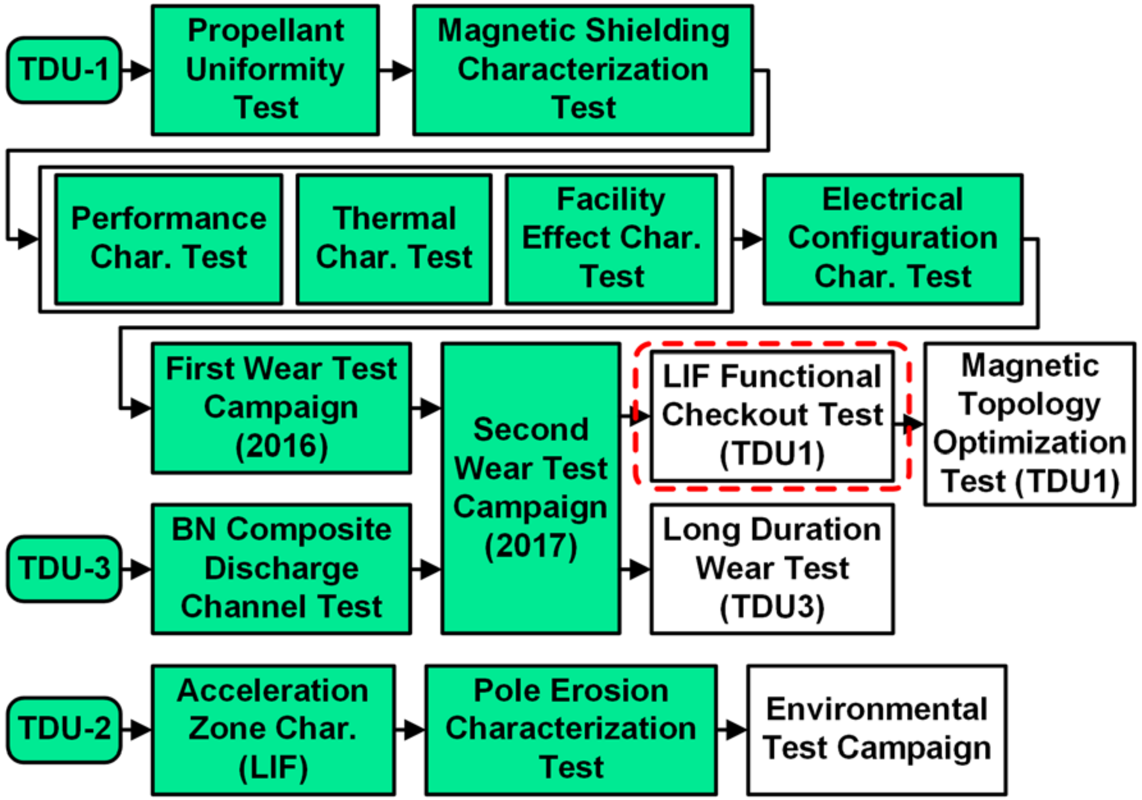
- A NASA GRC and JPL team developed a 12.5-kW, magnetically-shielded Hall thruster, called Hall Effect Rocket with Magnetic Shielding (HERMeS)
- Transitioned to commercial production under Aerojet Rocketdyne's Advanced Electric Propulsion System (AEPS)
- Candidate to provide propulsion for the Power and Propulsion Element, the first element of NASA's Gateway
- Continuing risk reduction activities using HERMeS
- Developing a related plasma diagnostics package called Plasma Interaction Sensors for Correlation with Environment Simulations (PISCES)



◄ HERMeS in operation



HERMeS Test Campaign Status



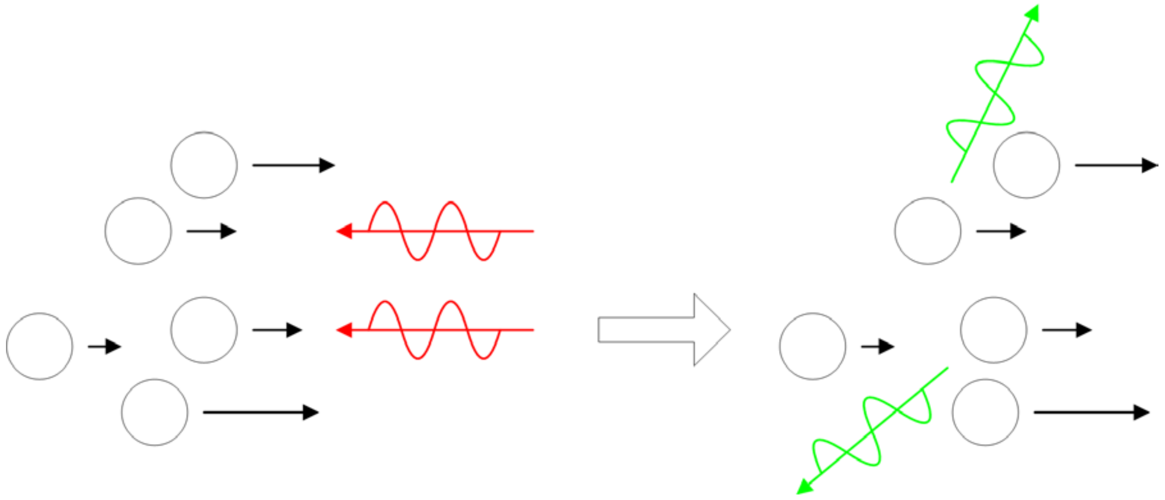
- Other JPC papers on AEPS and HERMeS
  - **Hall**, AEPS hollow cathode testing (EP3, Mon 9:30a)
  - **Benavides**, Thrust vector probe (EP8, Mon 3:30p)
  - **Mackey**, Uncertainty in thrust stand (EP8, Mon 4:30p)
  - **Frieman**, TDU long duration wear test (EP10, Tue 9:30a)
  - **Lobbia**, TDU environmental testing (EP10, Tue 10:00a)
  - **Lopez Ortega**, Modeling pole erosion (EP10, 10:30a)
  - **Lobbia**, Accelerated backsputter test (EP10, 11:00a)
  - **Kamhawi**, Magnetic topology optimization (EP14, 3:30p)
  - **Ahern**, In-situ wear assessment (EP14, 4:00p)
  - **Mikellides**, Cathode spot-to-plume mode simulation (EP14, 4:30p)
  - **Yeats**, 13 kW EP system architecture (EP14, 5:30p)
  - **Katz**, Accel region electron transport sim (EP17, 9:30a)
  - **Choi**, 3D electron fluid model for plume (EP17, 10:00a)
  - **Lopez Ortega**, First principles transport model (EP20, 3:30p)

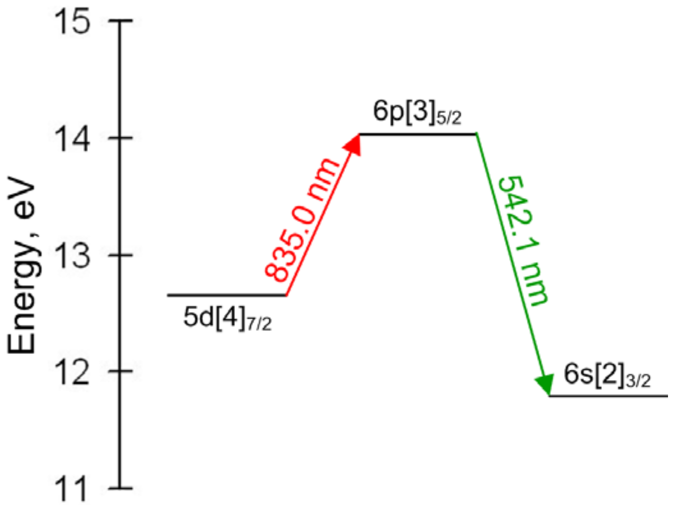
Why LIF?

- 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 and get reference TDU data in GRC VF6
  - EDU test in GRC VF5 at lowest achievable background pressure
  - Time resolved LIF at JPL Owens chamber
- Goals
  - Complete data set for model validation
  - Confirmation that EDU and TDU have the same discharge characteristics

How does LIF work?

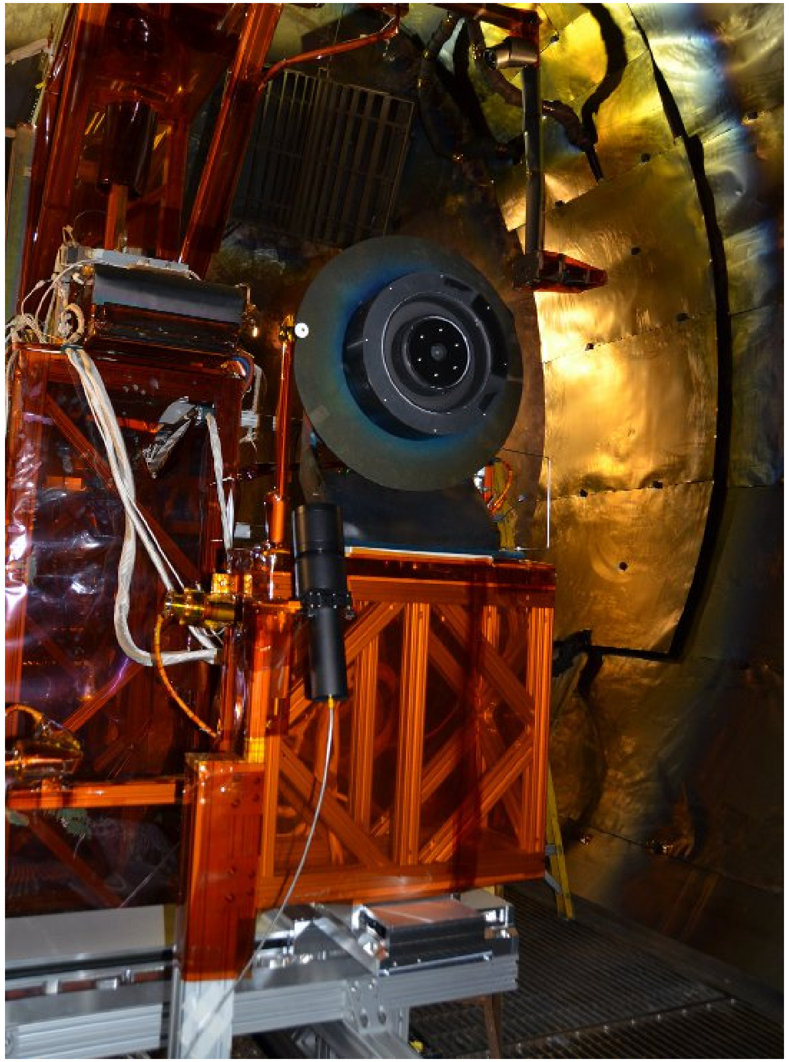
- Moving atoms absorb light at shifted frequency (Doppler effect)
- Collect emitted fluorescence while varying laser frequency to measure velocity distribution function (VDF)
- XE II 835.0 nm is easy to access with commercial diode laser
  - Metastable
  - Representative of bulk ion VDF
  - Fluoresce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



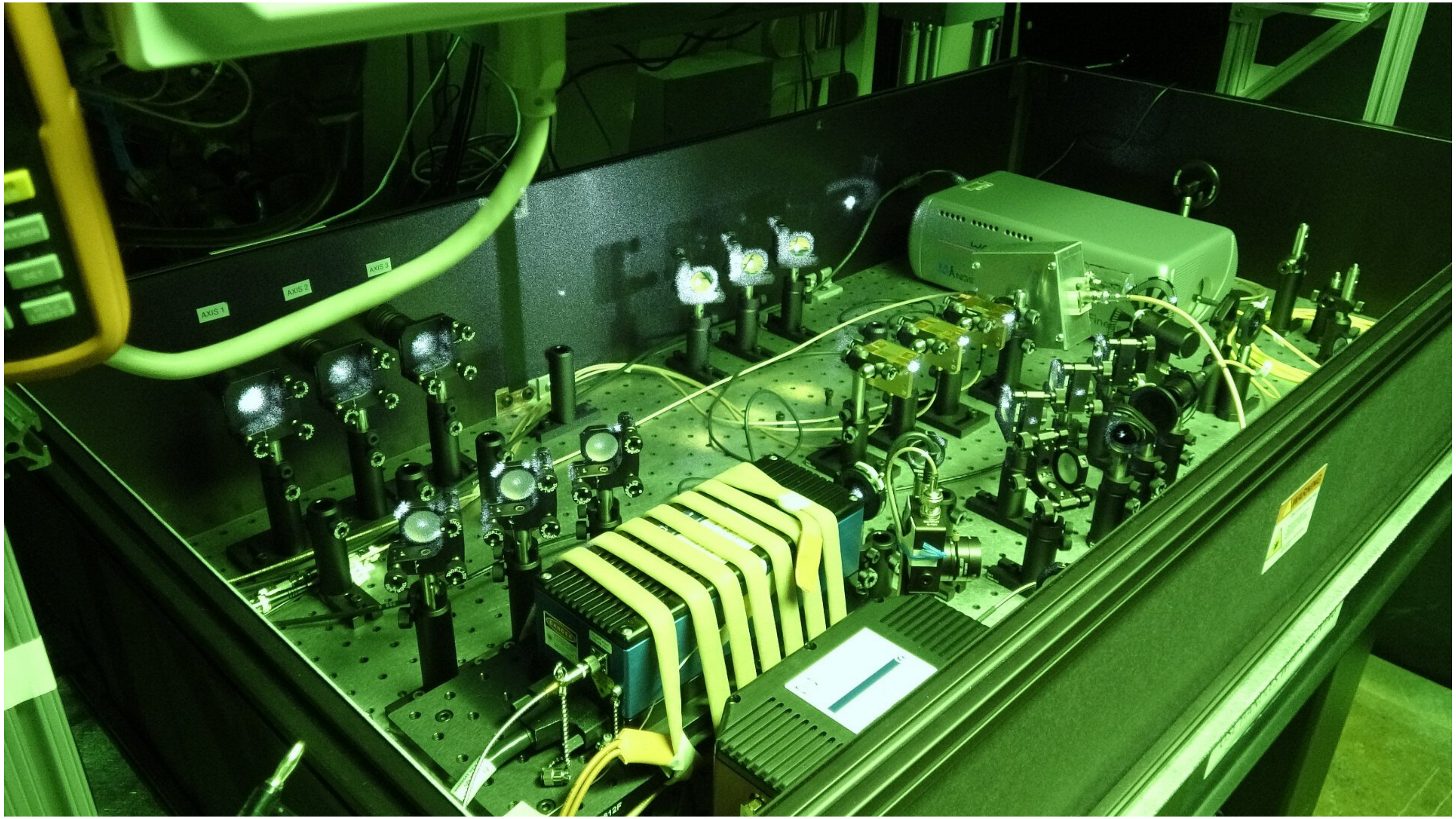


Experimental Setup – Test Article

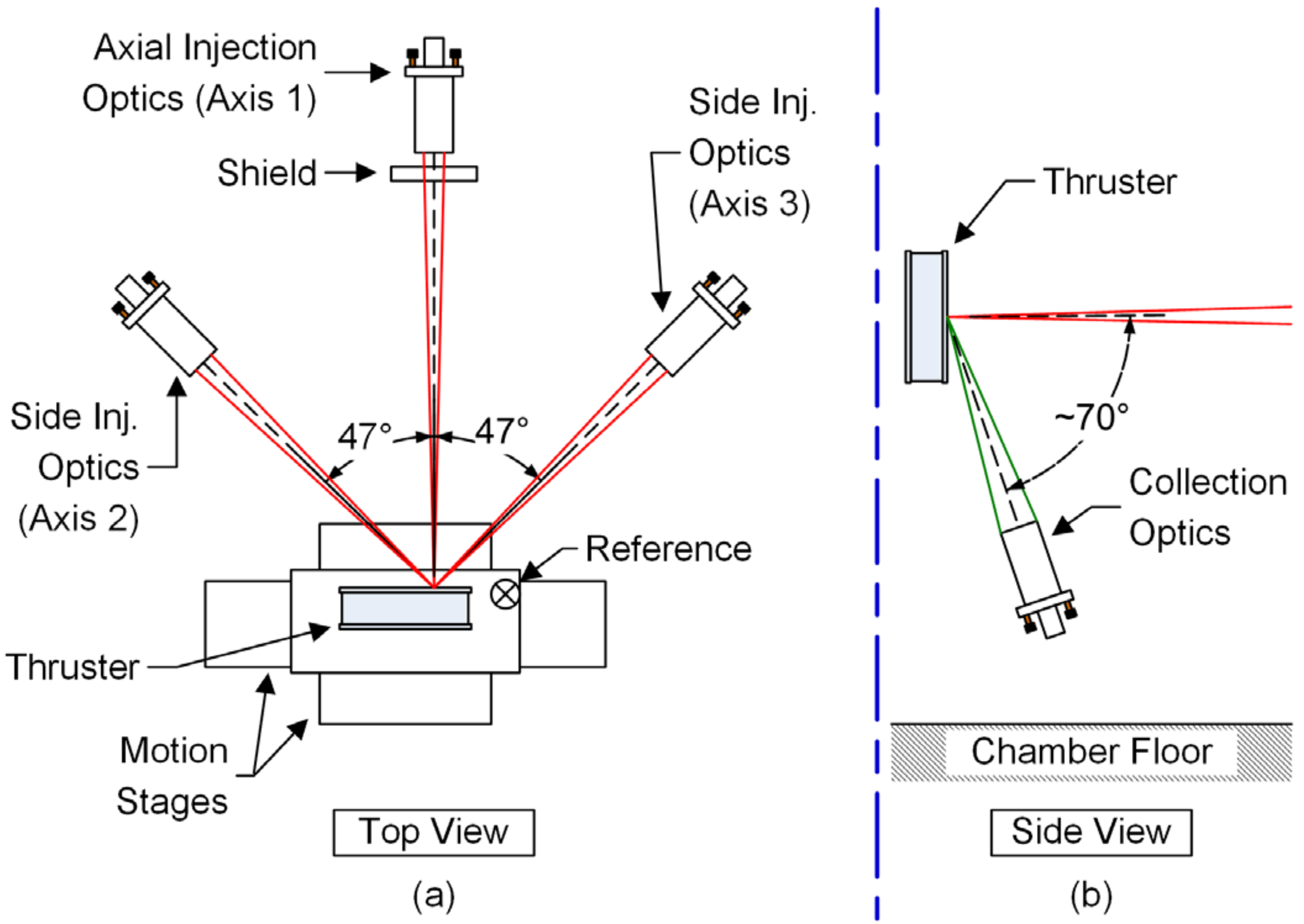
- HERMeS TDU1
  - Throttle range from 0.6 to 12.5 kW, 2000 to 3000 sec
  - Magnetic shielding topology
  - Centrally mounted cathode, 7% cathode flow fraction
  - Cathode tied to thruster body
  - Test was in VF6, ~1.2e-5 Torr near thruster
- This presentation will focus on:
  - 300, 400, 500, and 600 V conditions
  - Nominal magnetic field

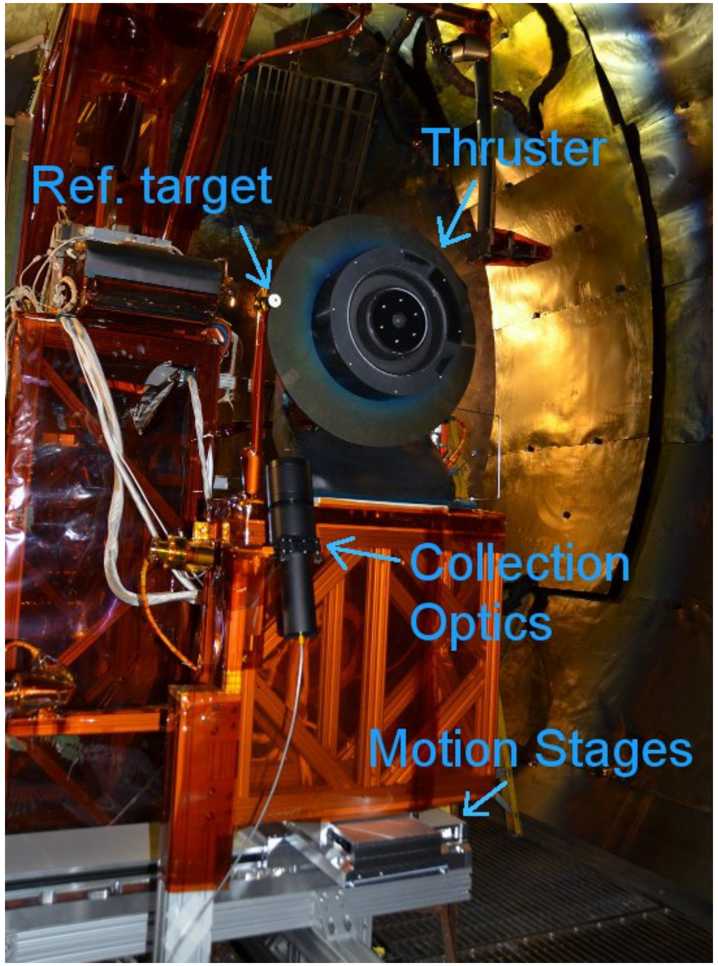


Experimental Setup – Air Side Injection Optics

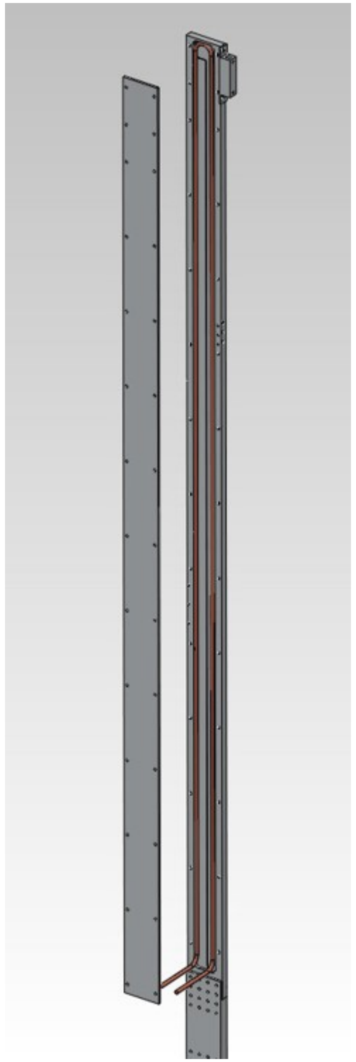


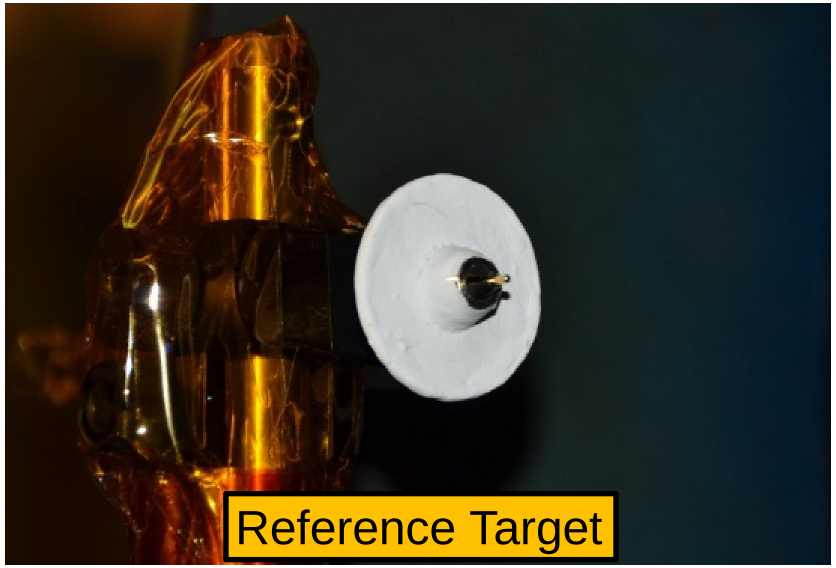
Experimental Setup – Vacuum Side Optics

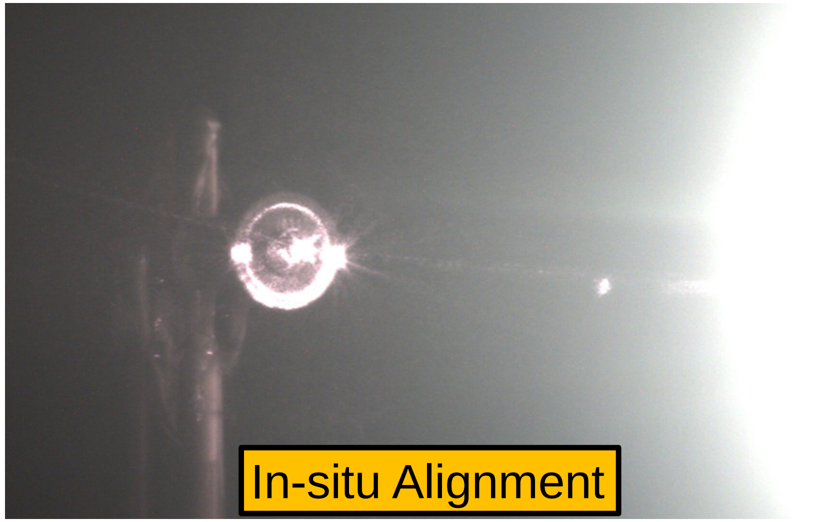




Experimental Setup – Tower Cooling and In-Situ Alignment





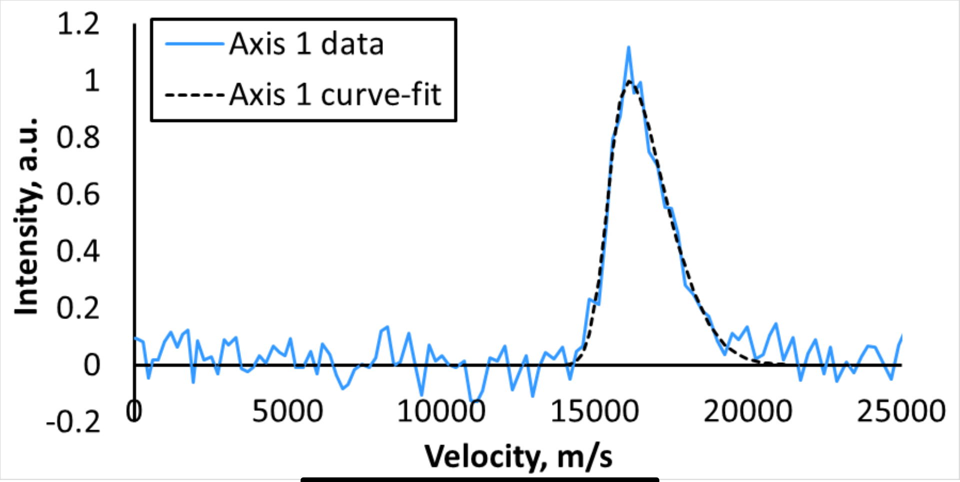


Experimental Setup – Air Side Collection

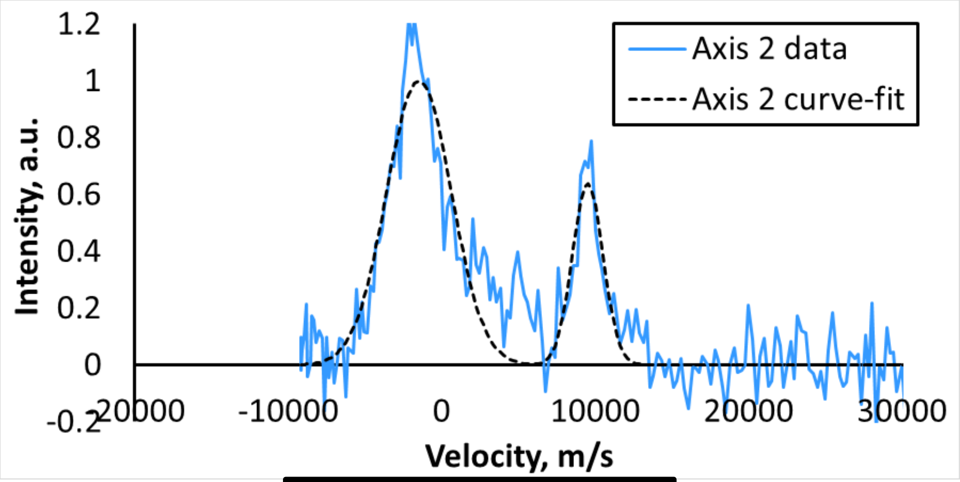
- Collected fluorescence > monochromator > photomultiplier > trans-impedance amplifier > lock-in amplifier > computer data
- Stationary reference signal > lock-in amplifier > computer data
- Computer
  - Control thruster motion stages
  - Control optics alignment motors
  - Read wavemeter
  - Read laser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

Data Analysis

- Saturation study was performed, broadening no more than 10% on narrowest VDFs
- Hyperfine structure and natural broadening small compared to the VDFs
- Zeeman effect uncorrected and will be treated in future analysis
- Data analysis steps:
  - Convert wavemeter and OG signal to velocity
  - Correct intensity by laser power variation
  - Apply curve-fits (Gaussian, skew-normal, twin Gaussian)
- Spatial uncertainty: 0.5 mm
- Velocity uncertainty: ±100 m/s typical (±600 m/s for noisiest scans)

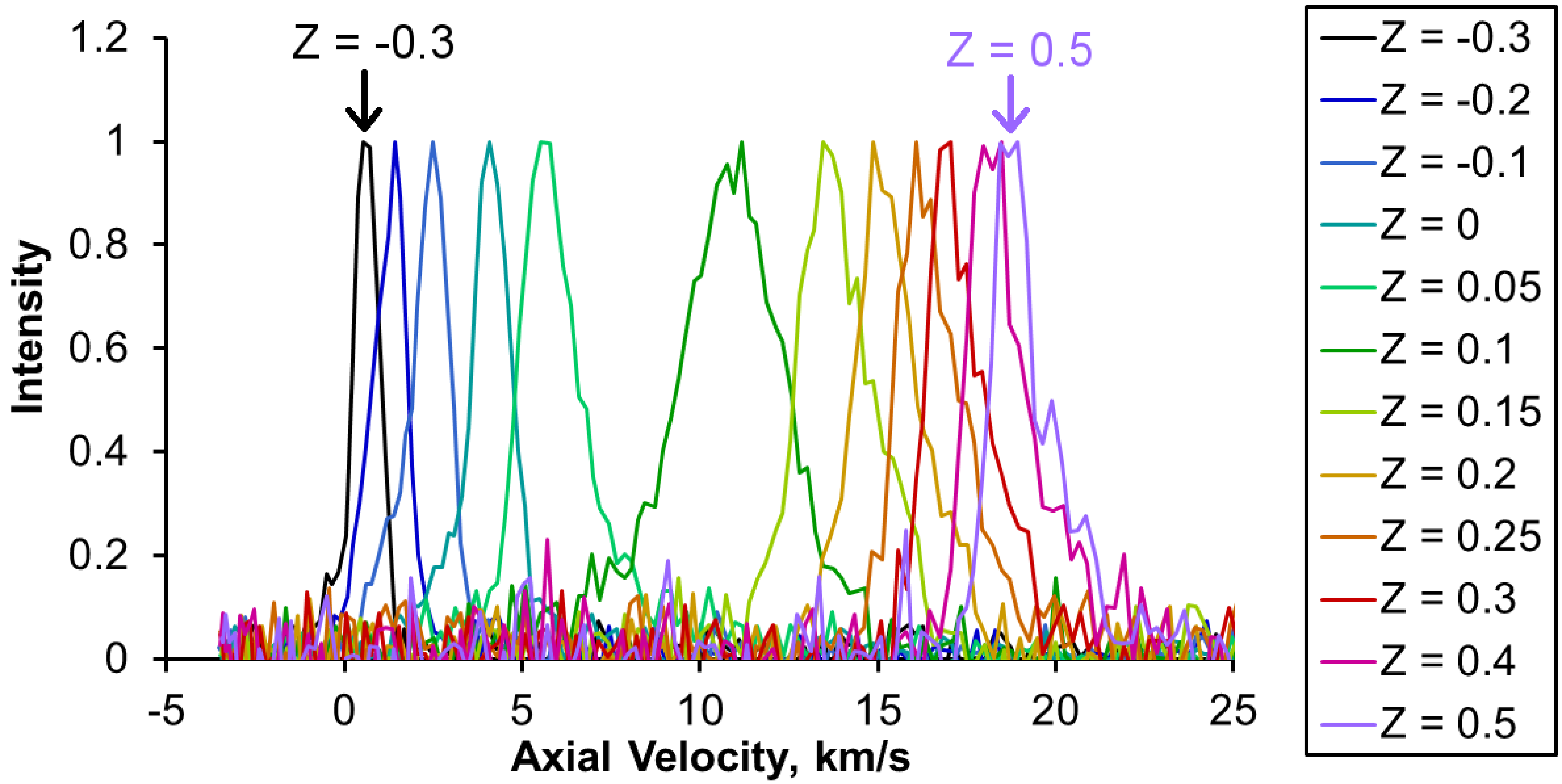


Skew-normal fit

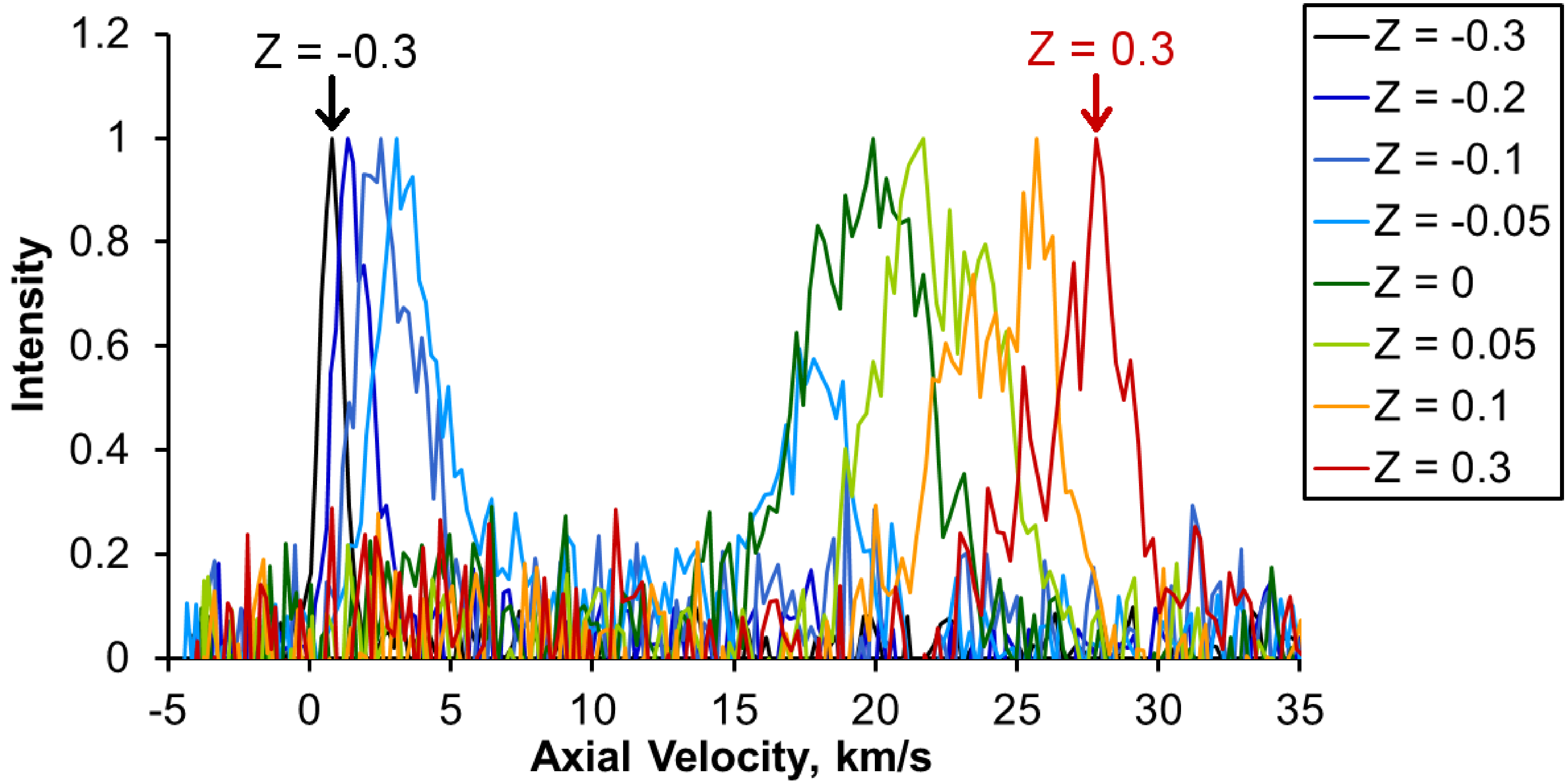


Twin Gaussian fit

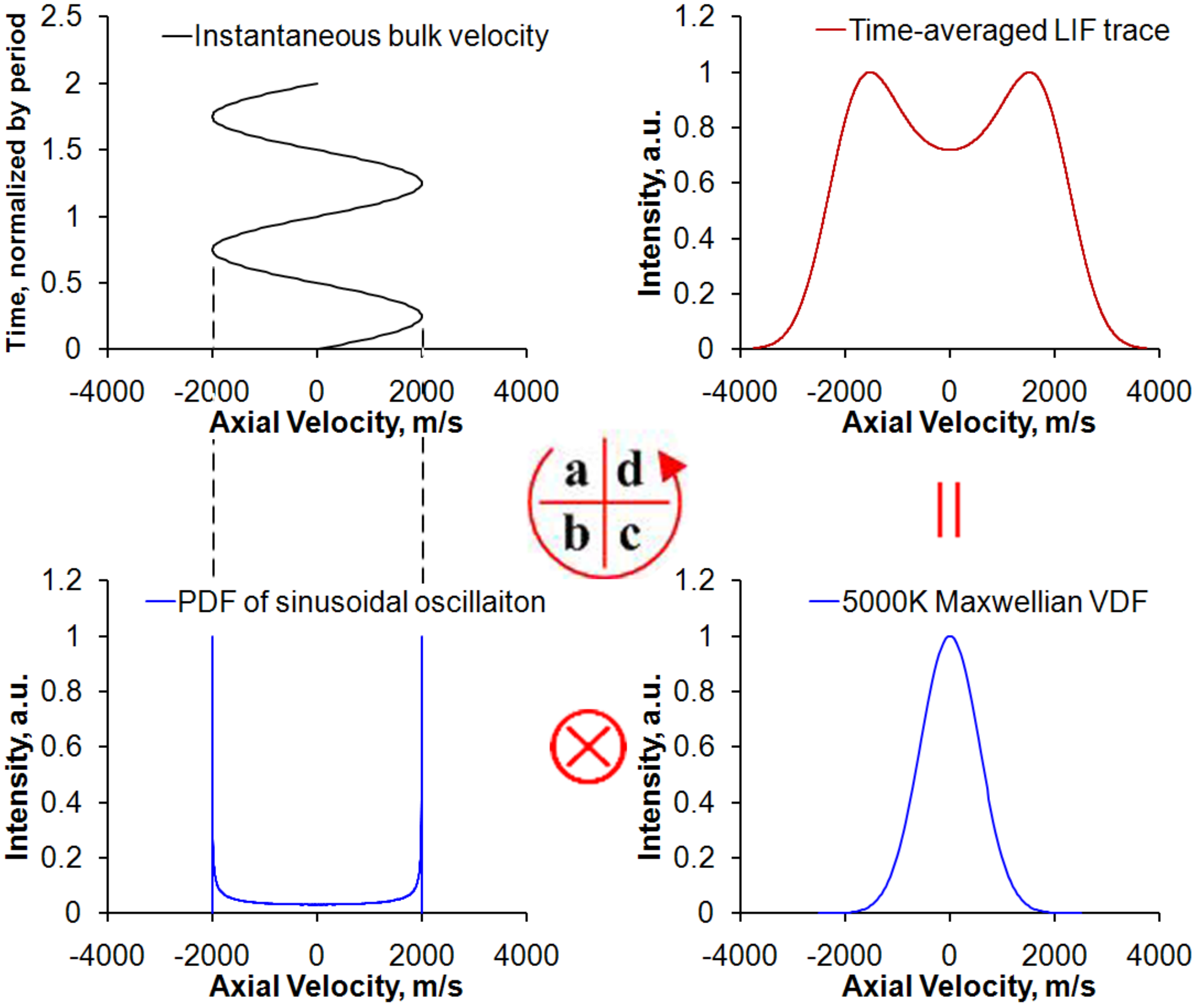
Channel Centerline VDFs: 300 V, 6.3 kW



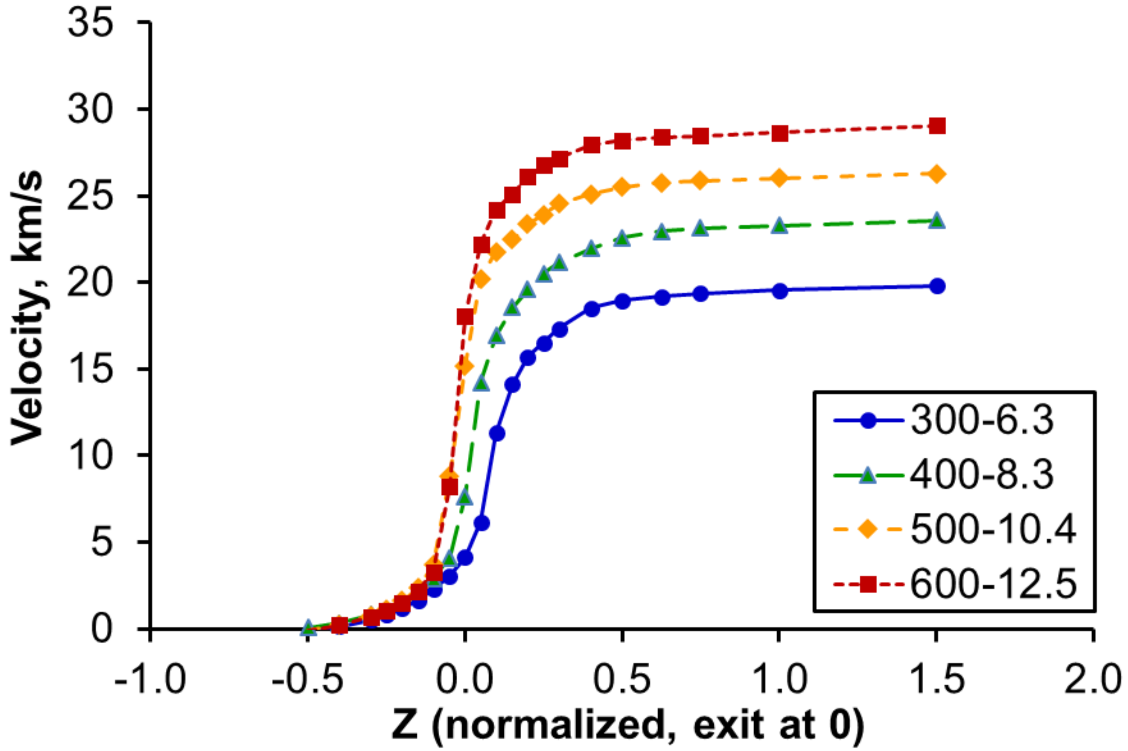
Channel Centerline VDFs: 600 V, 12.5 kW



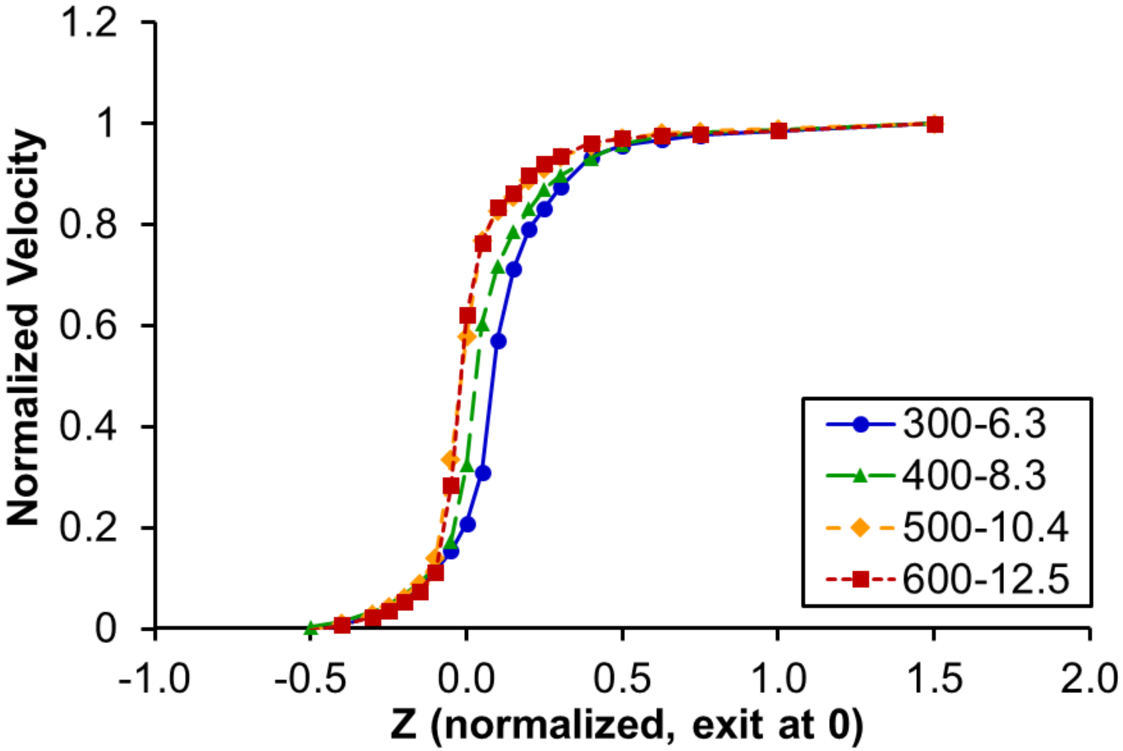
Why sinusoidal spatial oscillation appears as twin peak structure in time-averaged LIF



Channel Centerline Velocity Profiles

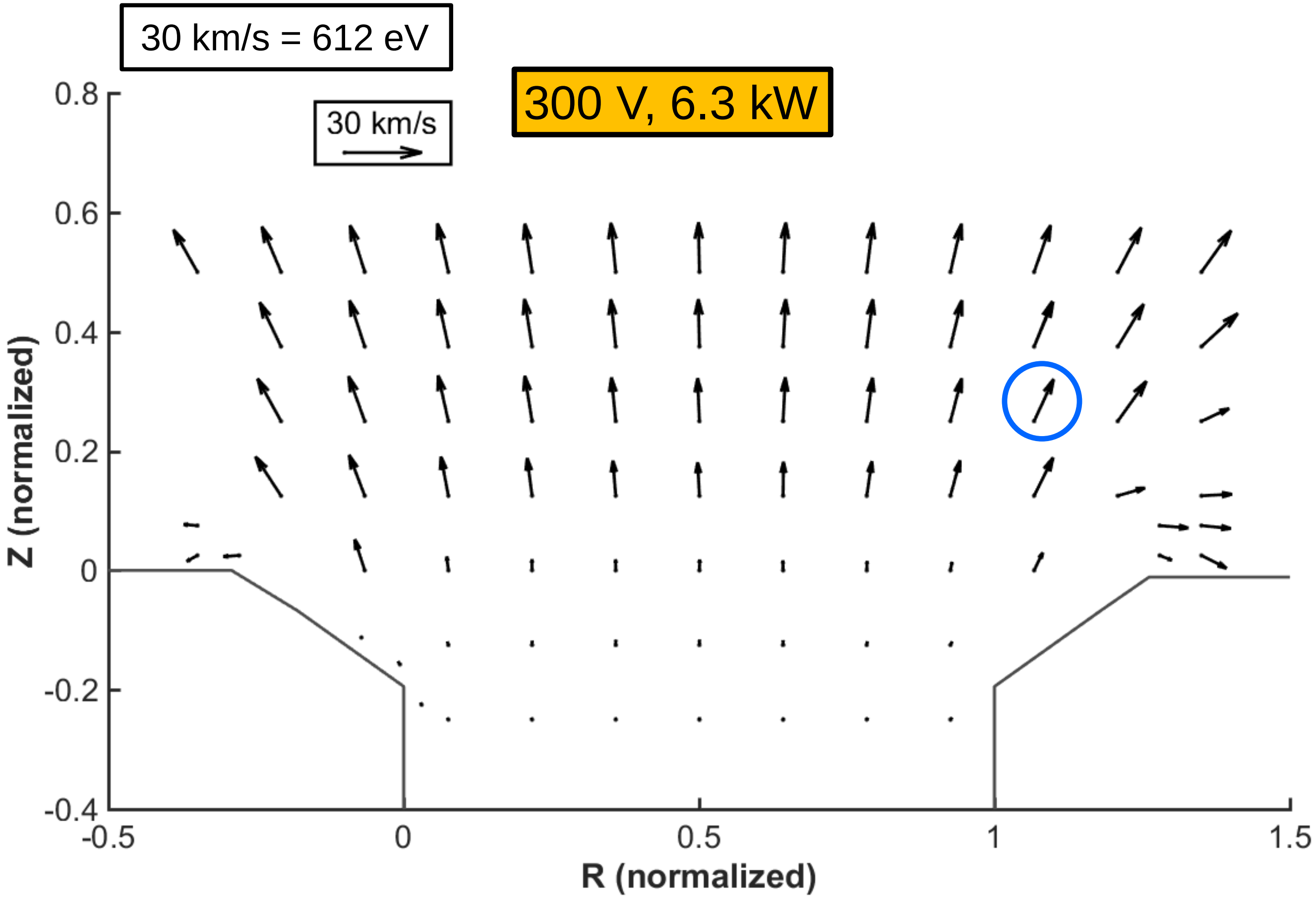


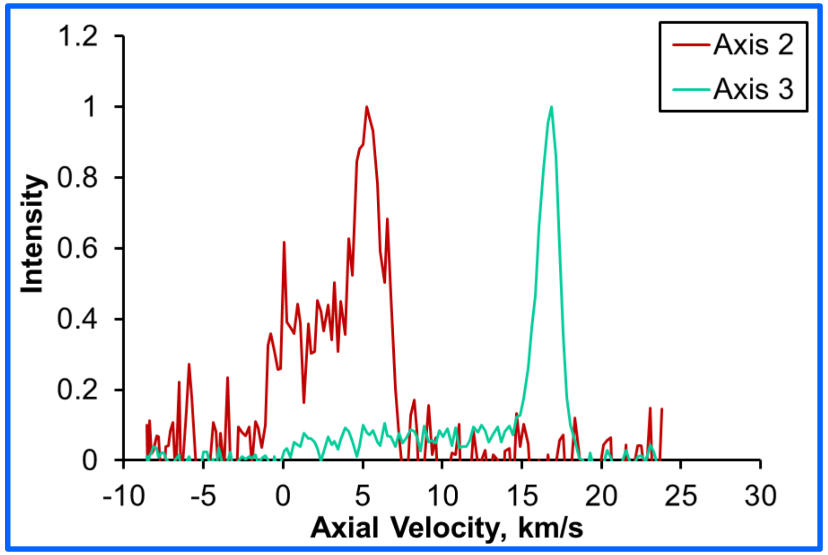
Averaged XEII velocity along channel CL

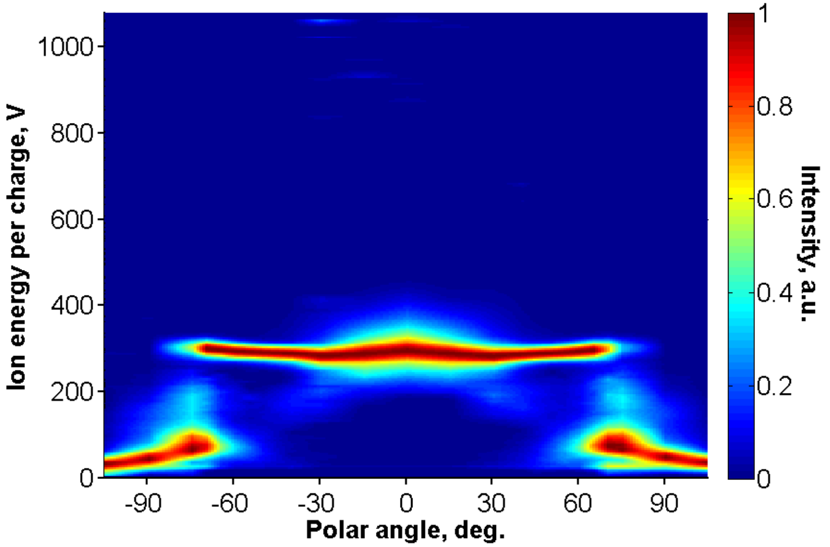


Velocity normalized by max velocity

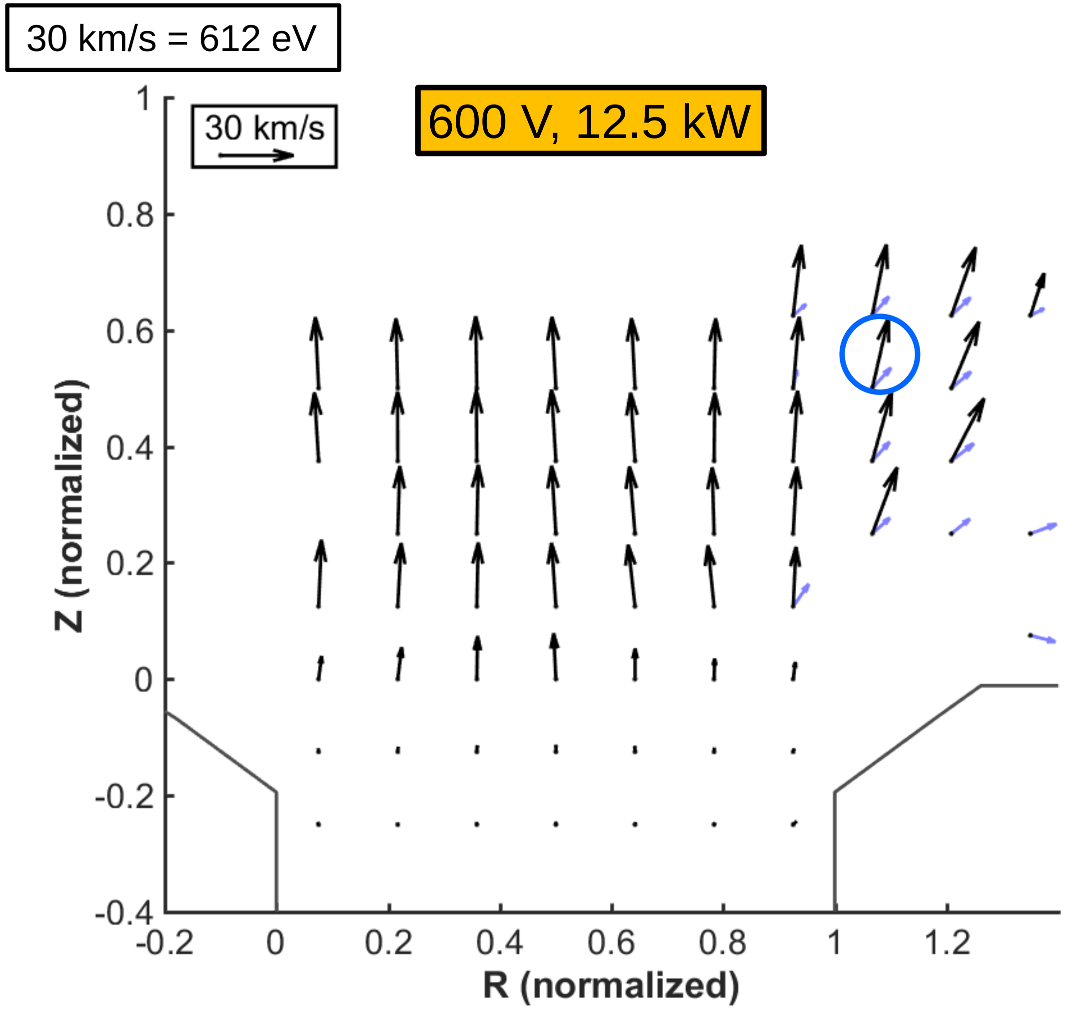
Discharge Channel Ion Velocity Vector: 300 V, 6.3 kW

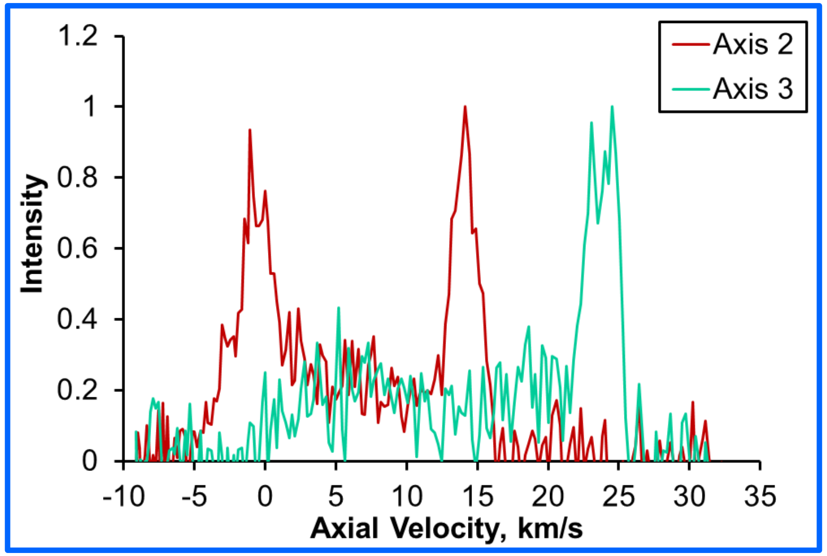


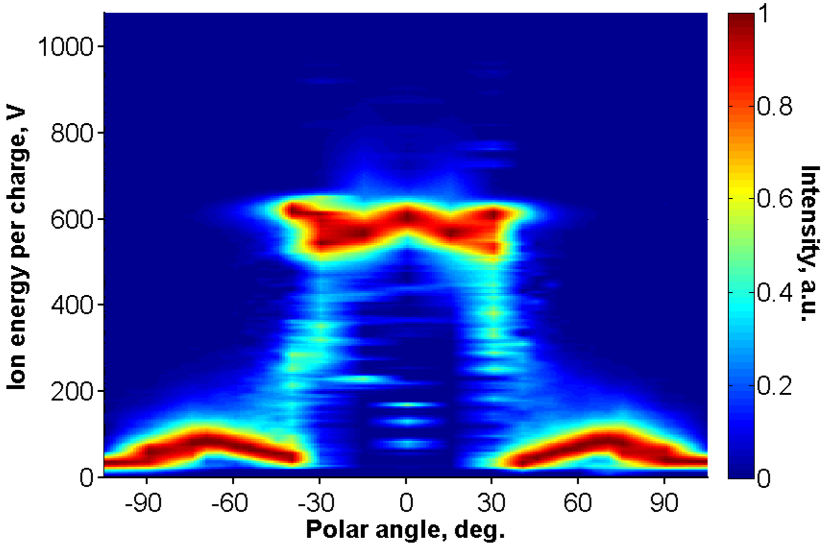




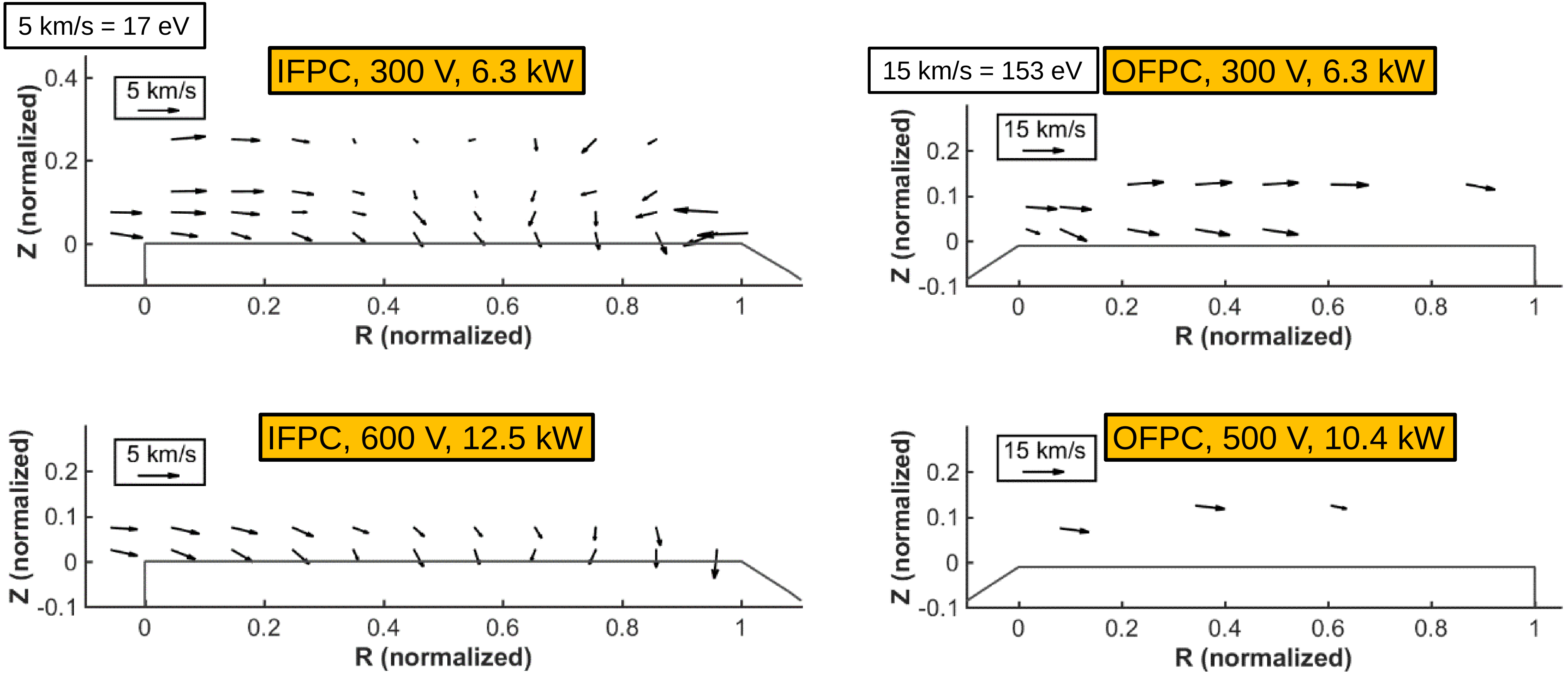
Discharge Channel Ion Velocity Vector: 600 V, 12.5 kW







Pole Cover Ion Velocity Vector



IFPC = Inner Front Pole Cover, OFPC = Outer Front Pole Cover

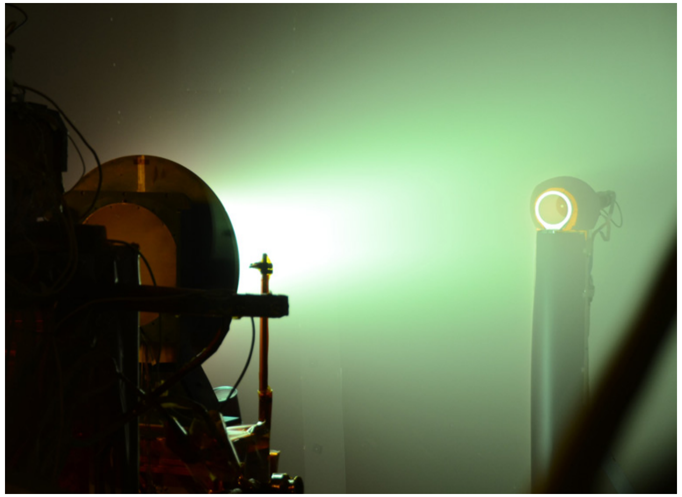
Preliminary Results for Energy of Ions Bombarding Pole Covers

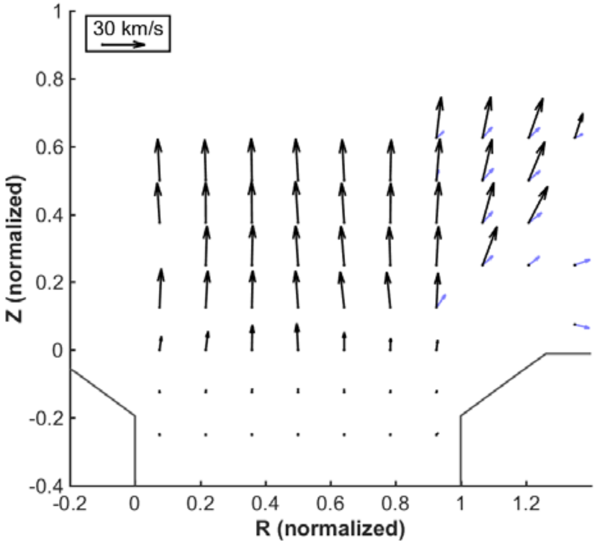
Operating condition	Average ion energy, IFPC, eV	FWHM energy, IFPC eV*	Average ion energy, OFPC, eV	FWHM energy, OFPC, eV*
300-6.3	0 to 20	25 to 72	81 to 119	33 to 91
400-8.3	3 to 7	19 to 74	77 to 99	97 to 145
500-10.4	2 to 5	26 to 46	75 to 77	102 to 155
600-12.5	2 to 15	20 to 48	Low signal	

*Full-width-at-half-maximum value of the ion energy distribution. FWHM energy near IFPC were artificially broadened by Zeeman effect.

Conclusion

- New LIF capability for characterizing high-power EP devices at GRC
  - Compatible with engineering hardware
- Completed functional checkout and collected TDU data
- Presence of low-energy population near discharge channel, likely to be CEX ions
  - Energy and direction of high-energy and low-energy ions in excellent agreement with far-field RPA data
- Ions near IFPC have low average energy while ions near OFPC have high average energy; pole ions have large spread in energy





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