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 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

- Axial Injection Optics (Axis 1)
- Shield
- Side Inj. Optics (Axis 2)
- Side Inj. Optics (Axis 3)
- Thruster
- Motion Stages
- Reference

- Thruster
- Collection Optics
- Chamber Floor
- Side View
- Ref. target
- Motion Stages
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)
Channel Centerline VDFs: 300 V, 6.3 kW
Channel Centerline VDFs: 600 V, 12.5 kW

- $Z = -0.3$
- $Z = -0.2$
- $Z = -0.1$
- $Z = -0.05$
- $Z = 0$
- $Z = 0.05$
- $Z = 0.1$
- $Z = 0.3$

Intensity vs. Axial Velocity, km/s
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

30 km/s = 612 eV
Discharge Channel Ion Velocity Vector: 600 V, 12.5 kW

30 km/s = 612 eV
Pole Cover Ion Velocity Vector

5 km/s = 17 eV

IFPC, 300 V, 6.3 kW

15 km/s = 153 eV

OFPC, 300 V, 6.3 kW

IFPC, 600 V, 12.5 kW

OFPC, 500 V, 10.4 kW

IFPC = Inner Front Pole Cover, OFPC = Outer Front Pole Cover
Preliminary Results for Energy of Ions Bombarding Pole Covers

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

*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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