Plasma Propulsion
Research at UCLA

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University of California, Los Angeles

PlasmaFest
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Activities

**EP Plasma Physics**

**Applied Plasma Science**

**EP Technology**

EP = “Electric Propulsion”
Miniature Electric Propulsion “EP”

**Ion Thrusters**

1. Electrons (shown in yellow) are emitted by the discharge hollow cathode, traverse the discharge chamber, and are collected by the anode walls.
2. Positive ions (shown in blue) are emitted from the anode and out of the discharge chamber by the ion optics.

**Hall Thrusters**

- Electron Hall current
- Ions
- Plasma Jet
- Anode/Gas Distributor
- Hollow Cathode
- Electrons

**Miniature Xenon Ion Thruster (MiXI)**

- Image: NASA

**Magnetic Shielding (MaSMi)**

- Image: Rafael

References:
Cusp Confinement vs. Scale

Direct Current Ring-Cusp Ion Thruster Performance

<table>
<thead>
<tr>
<th>Energy Loss Mechanisms</th>
<th>Primary Electron</th>
<th>Plasma Electron</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Wall to Plasma e-</td>
<td>Wall Ionization</td>
</tr>
<tr>
<td>NSTAR (D=30cm)</td>
<td>0.7% 69%</td>
<td>49% 8%</td>
</tr>
<tr>
<td>MiXI (D=3cm)</td>
<td>58% 21%</td>
<td>21% 0.1%</td>
</tr>
</tbody>
</table>

Main Observations:
1. For direct current discharge, primary electron dominated due to poor cusp confinement ($\theta_{loss}$)
2. Increased losses at small scales ($B_{bulk}/B_{cusp}$)
3. Must improve understanding of cusp confinement for effective $\mu$-scale devices
MaSMi
(Magnetically Shielded Miniature) Hall Thruster

- First ever sub-500W demonstration of magnetically shielded Hall thruster

- Benefits:
  1. High efficiency
  2. Long life

**Canonical Experiments**

**Heavy Species Interactions**

- **Objective:** Examine heavy species (ion-neutral) collisions and the transport of electrons in a simplified experiment with well-characterized boundary and input conditions.
- **Modeling:** Collision and particle-induced emission DSMC-PIC.
  - Variable hard sphere model (low energy species)
  - Classical scattering with spin-orbit free potential function (high energy species)

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**Deflection plates**

**Lens**

**ExB filter**

**Test Cell**

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**“Test Cell”**

- **Inner Cylinder**
- **Exit Plate**
- **Exit Orifice**
- **Ion Beam**
- **Particle trajectories for “unbiased” condition (V=0)**
- **Normalized Electrode Current**

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**References**

R. E. Wirz et al. (2011) IEPC-2011-122
R. E. Wirz et al. PSST (submitted)
Scientific Challenge
• Conventional theory of magnetic cusp confinement and discharge design insufficient for micro-scale

Objectives
1. Improve understanding of the plasma behavior in the near-cusp region
2. Develop efficient and stable cusp-confined micro discharge (≤1 cm)
• Ridge structure caused by an axial drift at **upstream** cusp, not at the target cusp

• Small changes in upstream B-field dramatically change loss structure at target cusp

• **Discovery:** Loss behavior at cusp strongly influenced by upstream field conditions at $\mu$-scale

• **Improved Understanding:** Unique theoretical construct developed to describe primary electron confinement in cusp $\mu$-discharges

M Squared SolsTiS Ti:Sapphire Laser System

<table>
<thead>
<tr>
<th>Type</th>
<th>CW</th>
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<tbody>
<tr>
<td>Power @ 350-500 nm</td>
<td>200 - 700 mW</td>
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<tr>
<td>Power @ 700-1000 nm</td>
<td>0.5 - 2.3 W</td>
</tr>
<tr>
<td>Linewidth</td>
<td>&lt;50 kHz</td>
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<tr>
<td>Scan Range</td>
<td>&gt;25 GHz</td>
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<tr>
<td>Wavemeter Accuracy</td>
<td>60 MHz</td>
</tr>
<tr>
<td>Wavemeter Resolution</td>
<td>10 MHz</td>
</tr>
<tr>
<td>Chopper (Disk)</td>
<td>0 - 3 kHz</td>
</tr>
<tr>
<td>Chopper (AOM)</td>
<td>0 - 20 MHz</td>
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</tbody>
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- SRS Chopper
- Spectral Products Monochromator

Accessible Ground State Absorption Lines

<table>
<thead>
<tr>
<th>Elements</th>
<th>350</th>
<th>400</th>
<th>450</th>
<th>500</th>
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<tbody>
<tr>
<td>Ba</td>
<td>+</td>
<td>+</td>
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</table>
Small-scale plasma discharges require non-intrusive diagnostics

- Laser provides high spatial and frequency resolution (good control of state transitions)

### Applications

<table>
<thead>
<tr>
<th>Hall Thrusters</th>
<th>Cusps</th>
<th>Micro Discharges</th>
<th>Pi</th>
</tr>
</thead>
</table>

### Techniques

<table>
<thead>
<tr>
<th>Technique</th>
<th>Parameter</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>LIF</td>
<td>VDF</td>
<td>Neutrals and ions</td>
</tr>
<tr>
<td>Absorption</td>
<td>$n$, $T$</td>
<td>Noble gas metastable and sputterant ground states</td>
</tr>
<tr>
<td>LCIF</td>
<td>$n_e$, $T_e$</td>
<td>H, He, Ar; need CRM</td>
</tr>
<tr>
<td>LIF-dip</td>
<td>$E$</td>
<td>Separate pump and probe lasers</td>
</tr>
</tbody>
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Researchers/Collaborators/Funding

- **Fundamental EP Plasma Physics**
  - Marlene Patino, Dr. Taylor Matlock, Dr. Samuel Araki (AFRL), Dr. Lee Johnson (JPL)

- **μ-Cusp Confinement**
  - Ben Dankongkakul, Samuel Araki, Cesar Huerta

- **EP Thrusters and Cathodes**
  - Ben Dankongkakul, Dr. Taylor Matlock, Dr. Dan Goebel, Dr. Ryan Conversano (JPL)

- **Plasma Material Interactions**
  - Dr. Taylor Matlock, Chris Dodson, Gary Li, Cesar Huerta, Marlene Patino, Dr. Dan Goebel, Prof. Nasr Ghoniem

- New members/contributors: Lucas Garel, John Hayes, Matthew Miller, Cyril Nader, Stephen Samples

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