

# Plasma Propulsion Research at UCLA

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*University of California, Los Angeles*

**PlasmaFest**

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**UCLA**

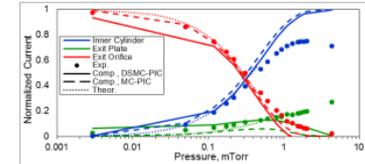
**PLASMA & SPACE PROPULSION  
LABORATORY**

# Activities

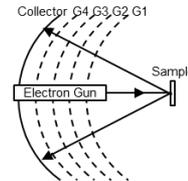


## EP Plasma Physics

### Canonical Experiments for Plasma Model Validation

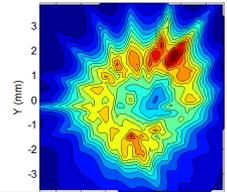
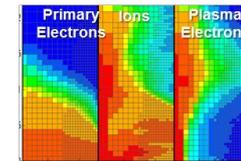


i-SEE  
e-SEE



## Applied Plasma Science

### $\mu$ -Cusp Confinement

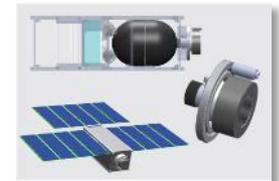


### Plasma-Material Interactions



## EP Technology

EP Thrusters and Cathodes



EP = "Electric Propulsion"

# Miniature Electric Propulsion "EP"



## Ion Thrusters

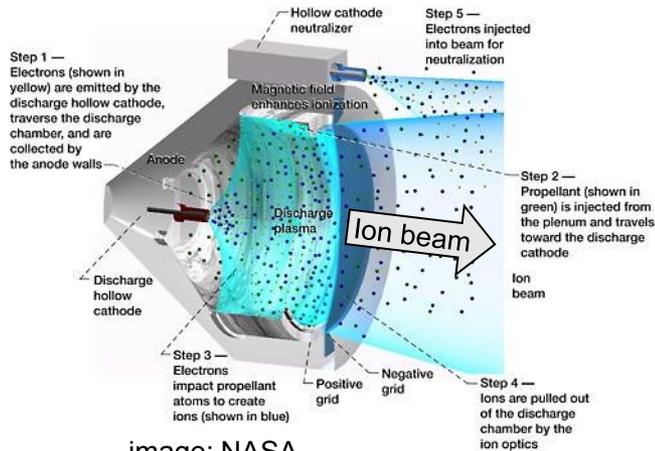
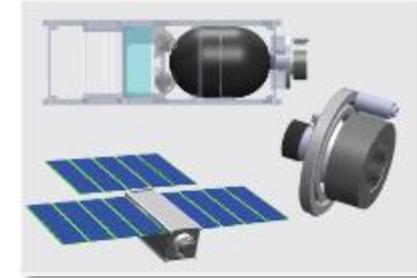
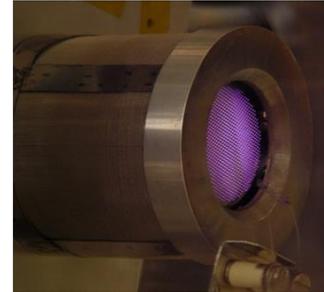


image: NASA

## (MiXI) Miniature Xenon Ion Thruster



Mao H-S., Wirz R.E., *Appl. Phys. Ltrs.*, 101, 2, 2012  
 Conversano R., Wirz R.E., *Journal of Spacecraft and Rockets*, 2013

## Hall Thrusters

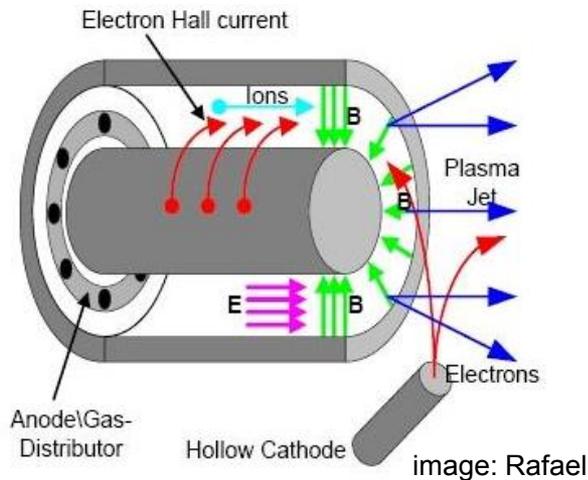
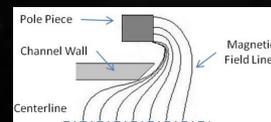


image: Rafael

## (MaSMi) Magnetically-Shielded Miniature Hall Thruster



Conversano R., Goebel D.M., Hofer R.,  
 Matlock T.S., Wirz R.E., *33rd IEPC*, 2013

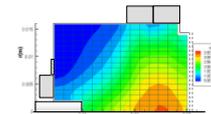
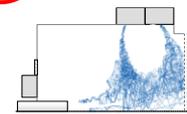
# Cusp Confinement vs. Scale



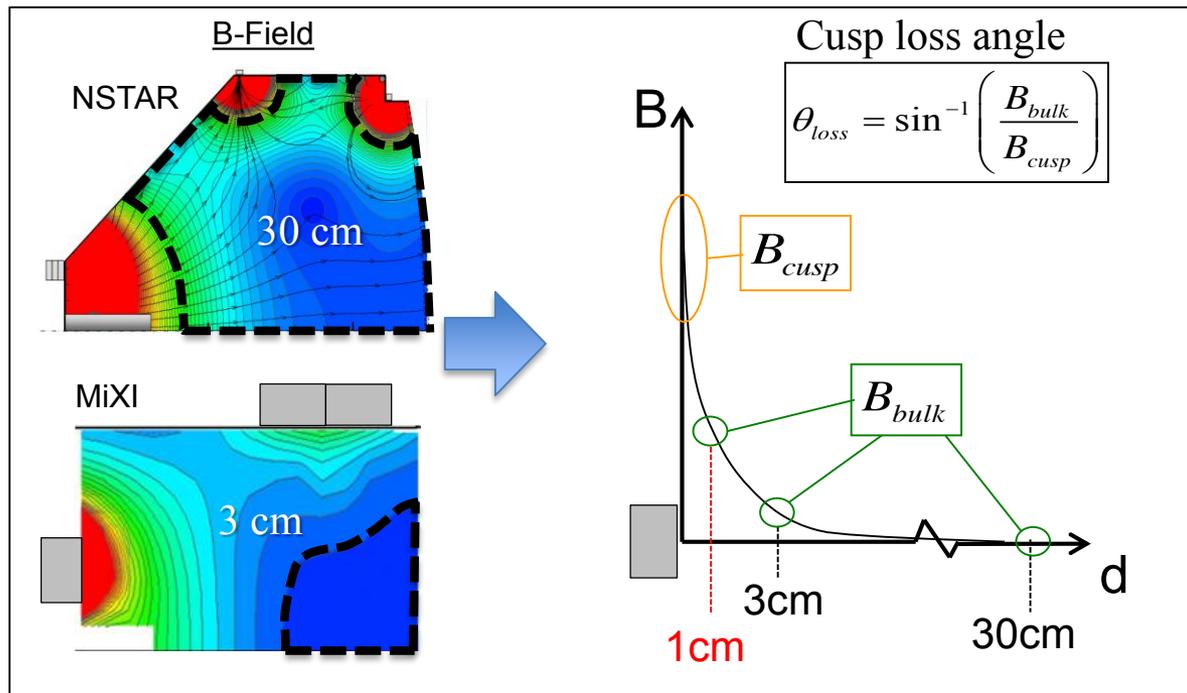
## Direct Current Ring-Cusp Ion Thruster Performance



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



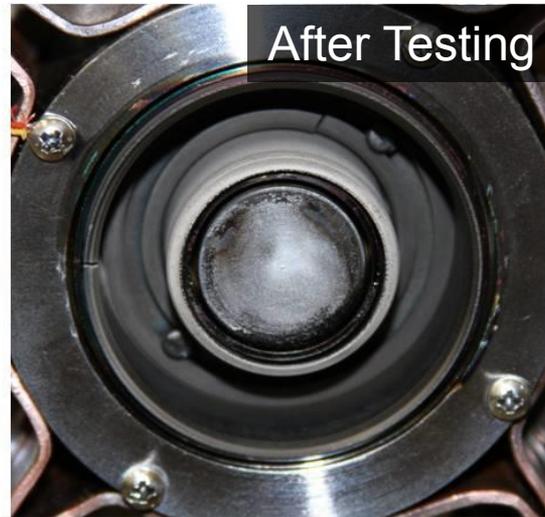
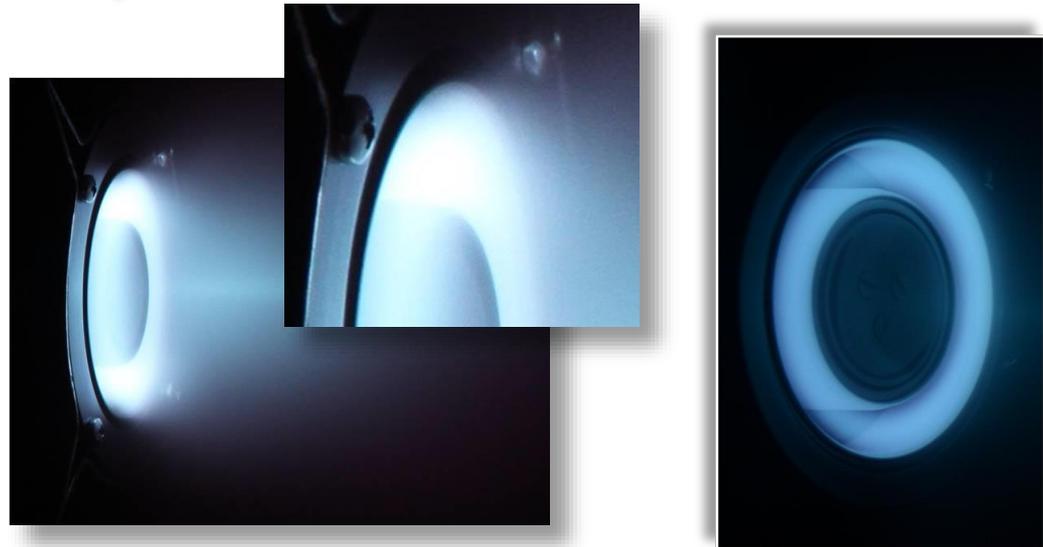
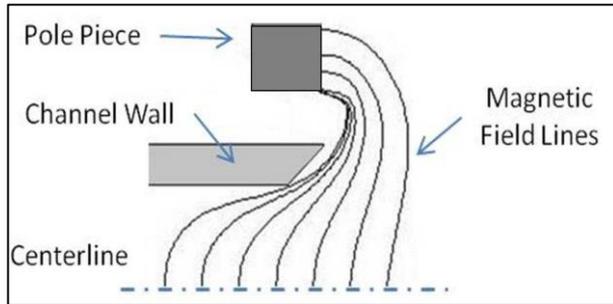
Wirz R.E., AIAA 2005-3887



### 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*

### Magnetic Shielding



- First ever sub-500W demonstration of magnetically shielded Hall thruster
- Benefits:
  1. High efficiency
  2. Long life

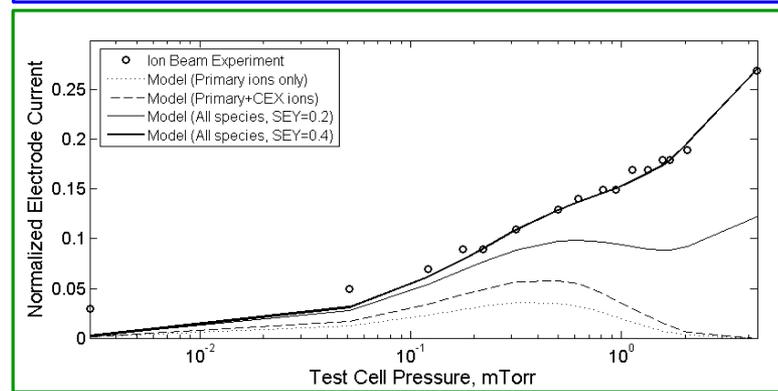
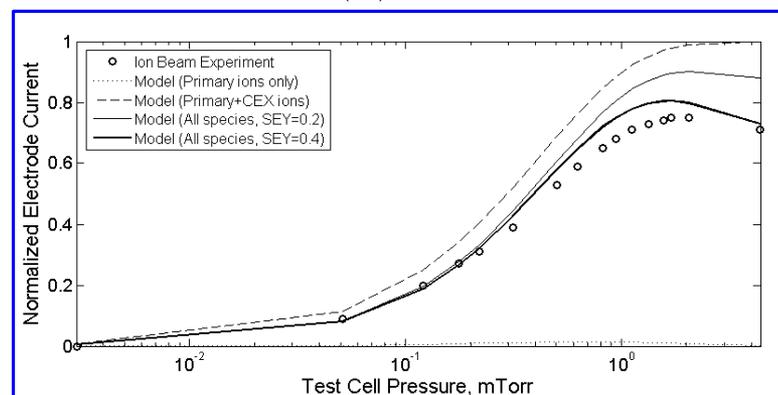
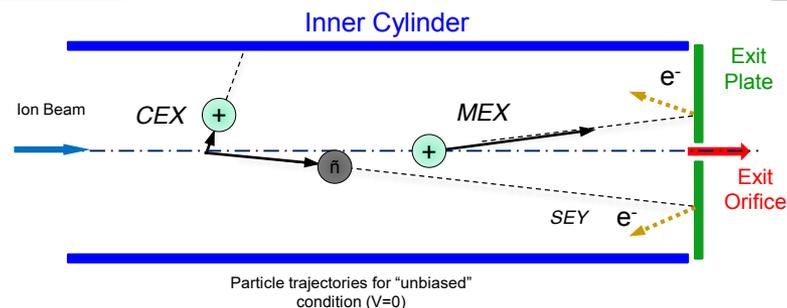
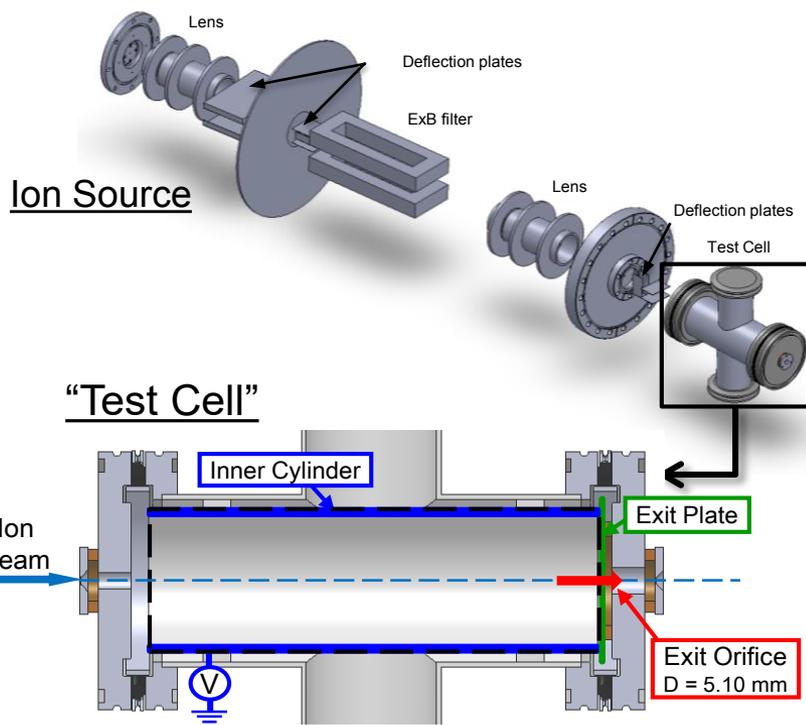
Conversano R., Goebel D.M., Hofer R.R., Matlock T.S., Wirz R.E., *Plasma Science, IEEE Transactions on*, (2014)

# 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)



single collision regime

multi-collision regime

R. E. Wirz et al. (2011) IEPC-2011-122

R. E. Wirz et al. PSSST (submitted)

S. J. Araki and R. E. Wirz (2011) AIAA-2011-3740

S. J. Araki and R. E. Wirz (2013) IEEE Trans. Plasma Sci., 41, 3

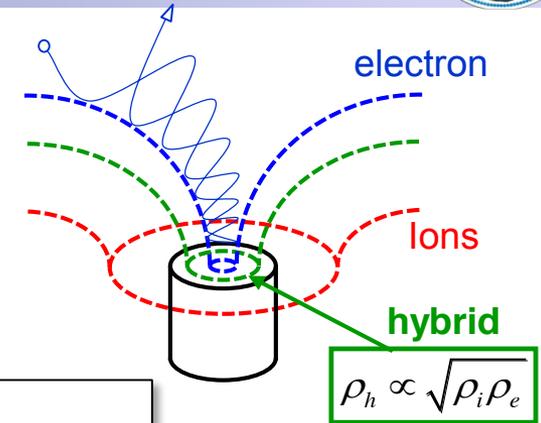
M. I. Patino, L. E. Chu, and R. E. Wirz (2012) AIAA-2012-4119

P. N. Giuliano and I. D. Boyd, (2013) Phys. Plasmas, 20

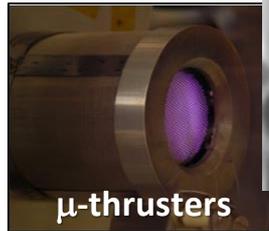
P. N. Giuliano and I. D. Boyd, (2013) J. Appl. Phys., 113, 11

## Scientific Challenge

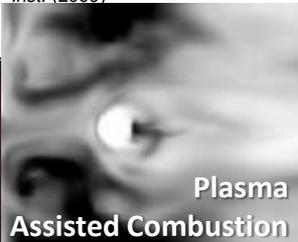
- Conventional theory of magnetic cusp confinement and discharge design insufficient for micro-scale



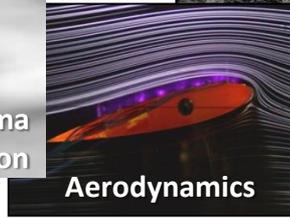
## Applications



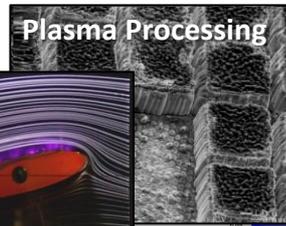
Wirz, R.E., *AIAA* (2005)



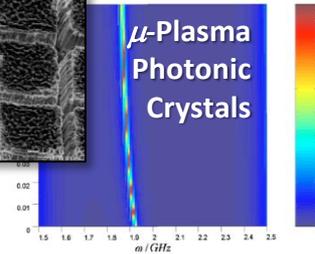
Miki, Schulz, Menon, *Proc. Comb. Inst.* (2009)



Mohan *UT, Knox* (2004)



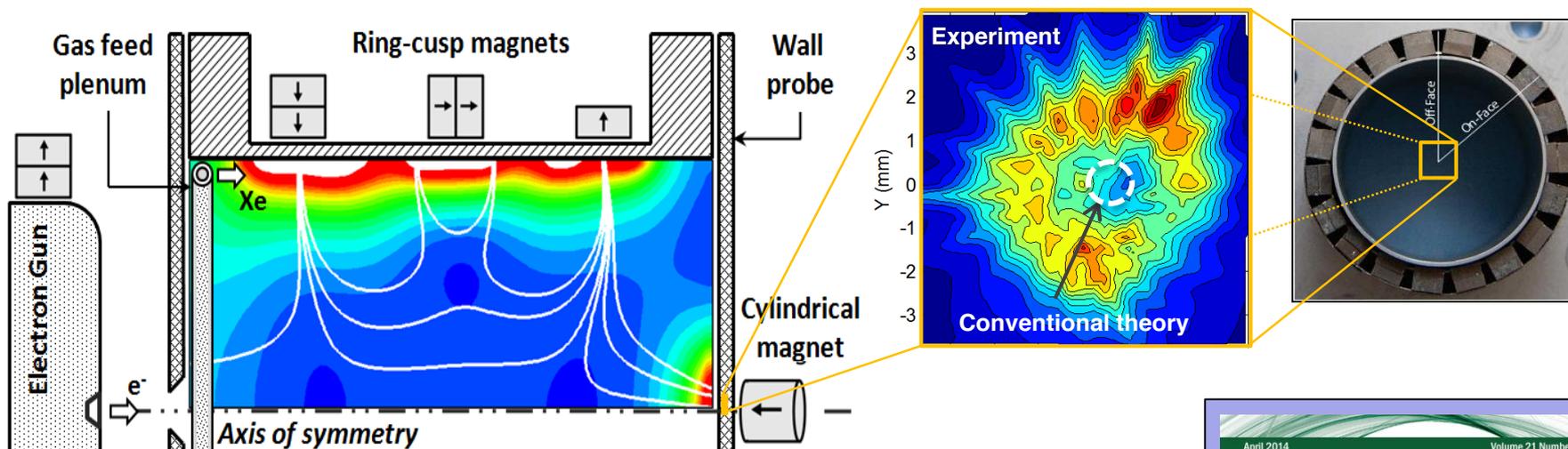
Yang, Hopwood, *J. Appl. Phys.* (2004)



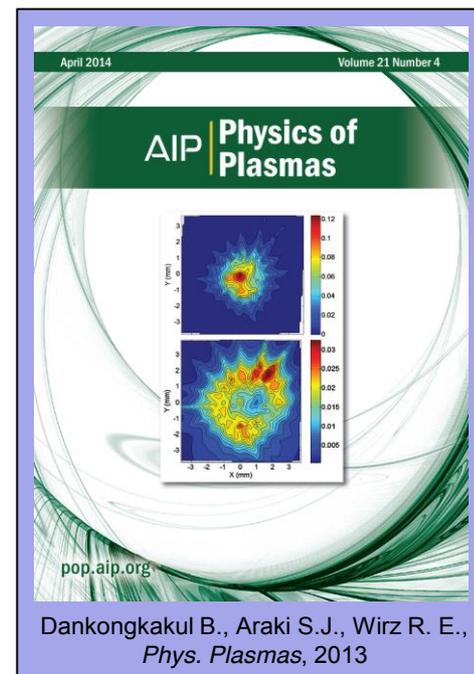
## Objectives

1. Improve understanding of the plasma behavior in the near-cusp region
2. Develop efficient and stable cusp-confined micro discharge ( $\leq 1$  cm)

# Multi-Cusp Experiment/Modeling

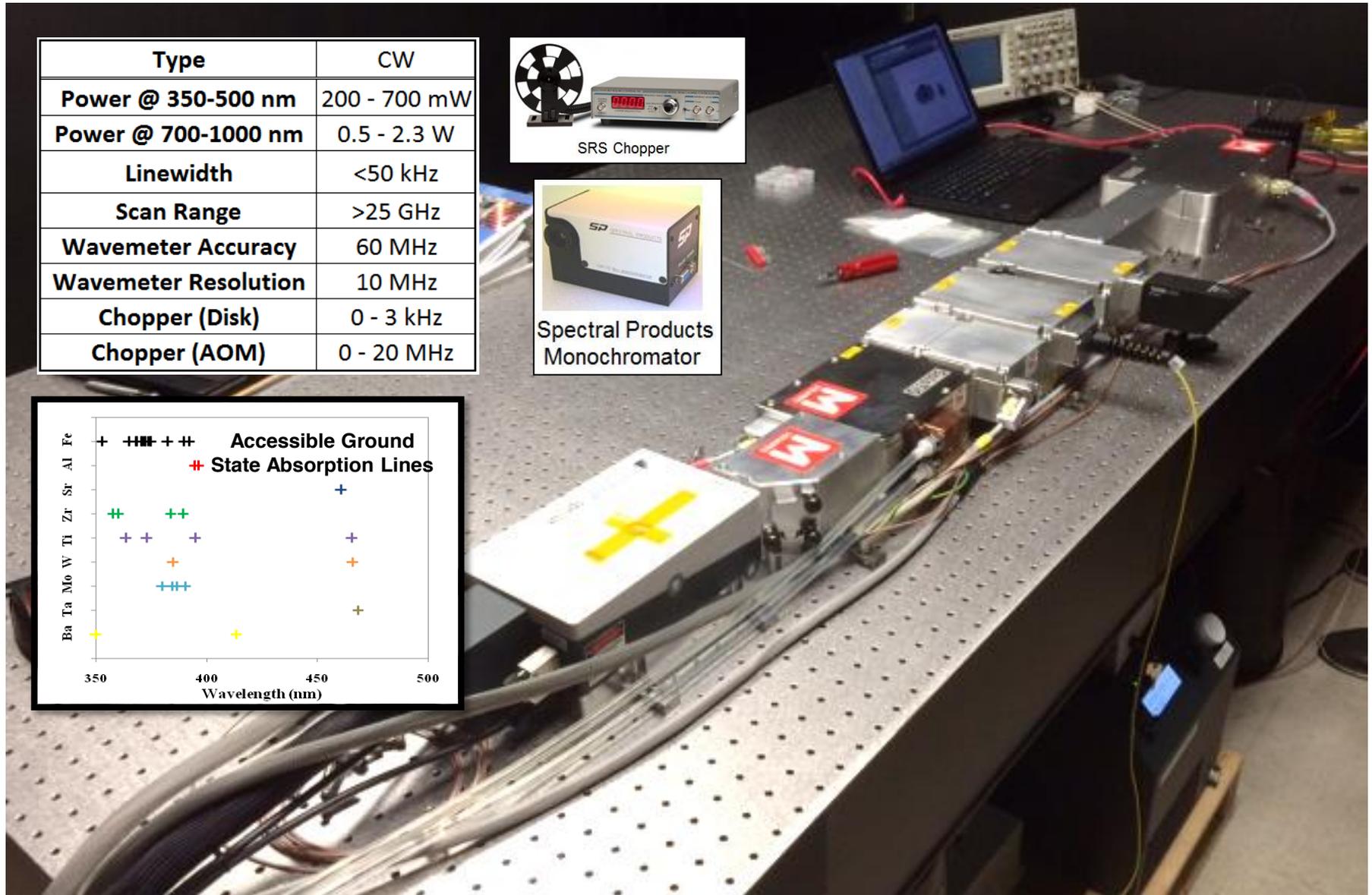
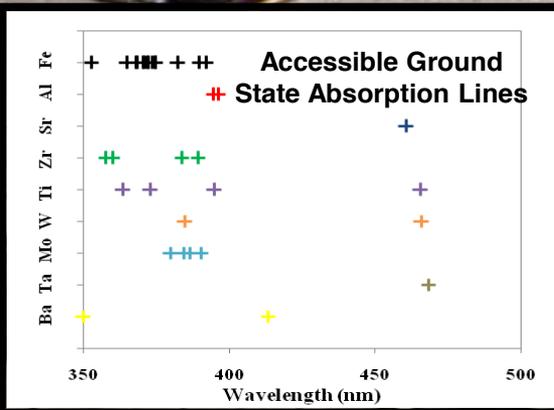


- Ridge structure caused by an axial drift at upstream cusp, not at the target cusp
- Small changes in upstream B-field dramatically change loss structure at target cusp
- **Discovery:** Loss behavior at cusp strongly influenced by upstream field conditions at  $\mu$ -scale
- **Improved Understanding:** Unique theoretical construct developed to describe primary electron confinement in cusp  $\mu$ -discharges



# M Squared SolS Ti:Sapphire Laser System

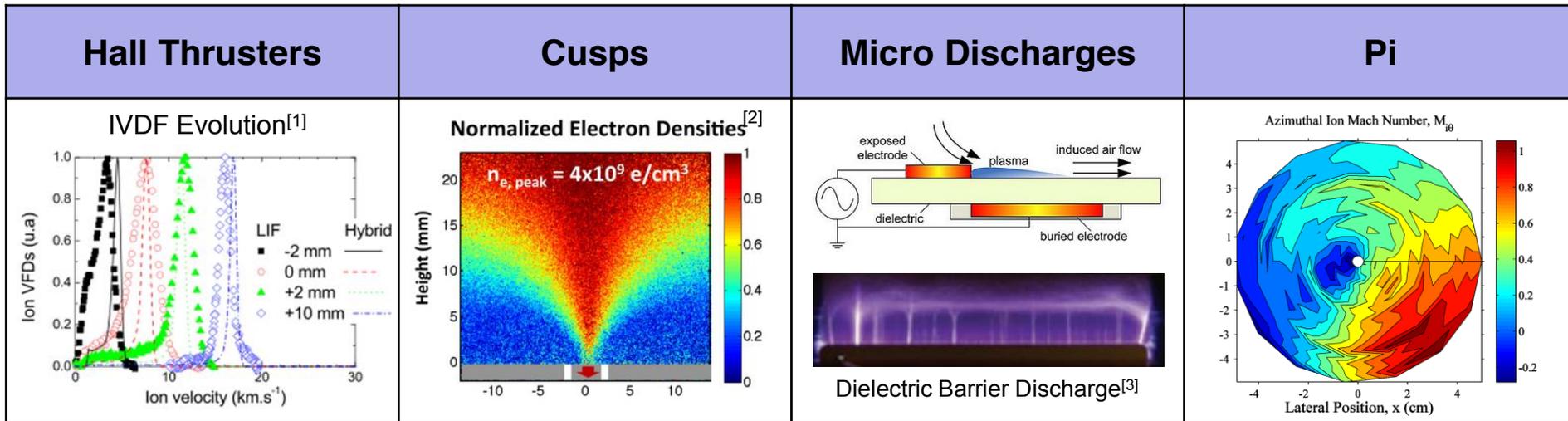
Type	CW
Power @ 350-500 nm	200 - 700 mW
Power @ 700-1000 nm	0.5 - 2.3 W
Linewidth	<50 kHz
Scan Range	>25 GHz
Wavemeter Accuracy	60 MHz
Wavemeter Resolution	10 MHz
Chopper (Disk)	0 - 3 kHz
Chopper (AOM)	0 - 20 MHz



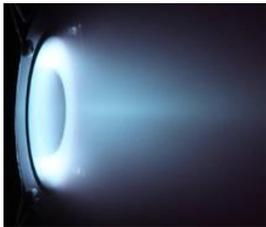
## Small-scale plasma discharges require non-intrusive diagnostics

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

### Applications



### Techniques



Technique	Parameter	Notes
LIF	VDF	Neutrals and ions
Absorption	$n, T$	Noble gas metastable and sputterant ground states
LCIF	$n_e, T_e$	H, He, Ar; need CRM
LIF-dip	E	Separate pump and probe lasers

Pi = Plasma Interactions



[1] L. Garrigues, *J. Appl. Phys.*, vol. 111, no. 11, pp. 0–8, 2012. [2] Barnat, E V, *PSST*, 19 (2010). [3] Corke, Thomas C., *Annual Review of Fluid Mechanics*, 42 (2010), 505–29.

# Researchers/Collaborators/Funding



## PLASMA & SPACE PROPULSION LABORATORY

UCLA

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