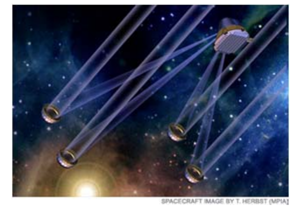
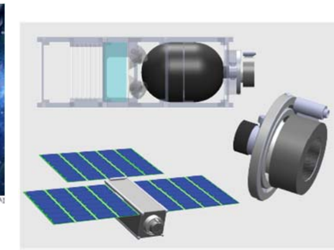
Motivation / Objectives

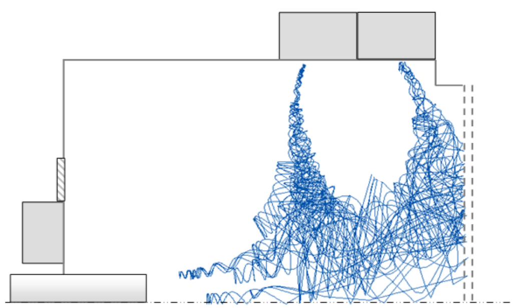
Motivation

- Ring cusp discharges provide highly efficient plasma thrusters
- Development of an efficient microdischarge (~1 cm)
  - large delta-V missions using small spacecraft
  - formation flying and control for larger spacecraft





Previous Work and Objectives



to secondary e^- (P_{ps}), to wall (P_{pw}), to ionization (P_{piz}), to ionization (P_{siz})

Mechanism	Primary Electron Losses				Secondary Electron Losses		
	P_{ps}	P_{pw}	P_{piz}	P_{px}	P_{sw}	P_{siz}	P_{sx}
3 cm → MiXI (mTH1)	20.9%	58.2%	12.1%	8.8%	20.6%	0.1%	0.2%
30 cm → NSTAR (TH15)	69.0%	0.7%	13.7%	16.6%	49.1%	7.5%	12.5%

Miniature discharge, MiXI (3cm)

- Overall impressive performance
- **Design bracketed by field strength:**
  - Efficiency: *requires high field strength*
  - Stability: *requires low field strength*
- Improved knowledge of near-surface cusp region needed for optimization

Microdischarges (~1 cm)

- *Increased surface area-to-volume ratio with smaller discharge*
- *Efficiency/stability balance*
- *Plasma volume is increasingly dominated by the magnetic cusp field at small scale*

Conversano R., Wirz R., "CubeSat Lunar Mission Using a Miniature Ion Thruster," AIAA-2011-6083

Wirz R., "Computational Modeling of a Miniature Ion Thruster Discharge," AIAA-2005-3887

Mao H. S., et al., "Plasma Structure of Miniature Ring-Cusp Ion Thruster Discharges," AIAA-2012-4021

Objectives

1) Investigate the behavior and structure of plasma for a single cusp
2) Develop an efficient multi-cusp microdischarge

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2012**	2. REPORT TYPE	3. DATES COVERED **00-00-2012 to 00-00-2012**
4. TITLE AND SUBTITLE **Near-Surface Cusp Confinement of Micro-Scale Plasma**		5a. CONTRACT NUMBER
		5b. GRANT NUMBER
		5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER
		5e. TASK NUMBER
		5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **University of California Los Angeles (UCLA),Engineering,Los Angeles ,CA,90095**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S)
		11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

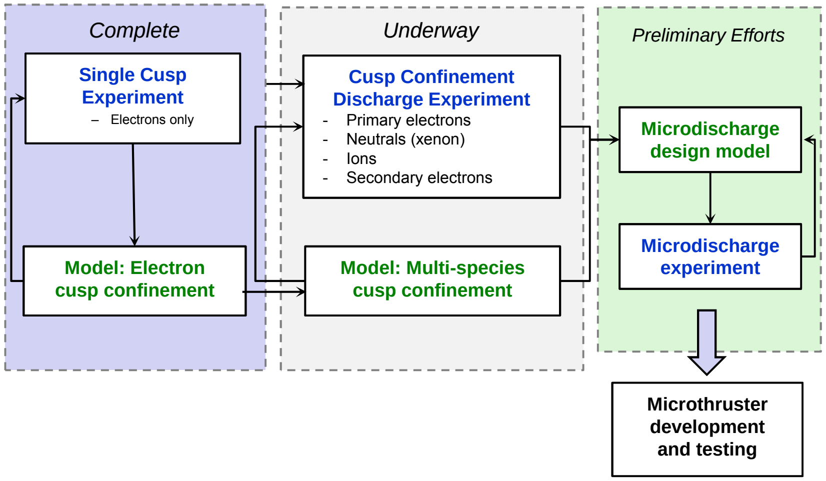
13. SUPPLEMENTARY NOTES
Presented at the 2012 AFOSR Space Propulsion and Power Program Review held 10-13 September in Arlington, VA. U.S. Government or Federal Rights License

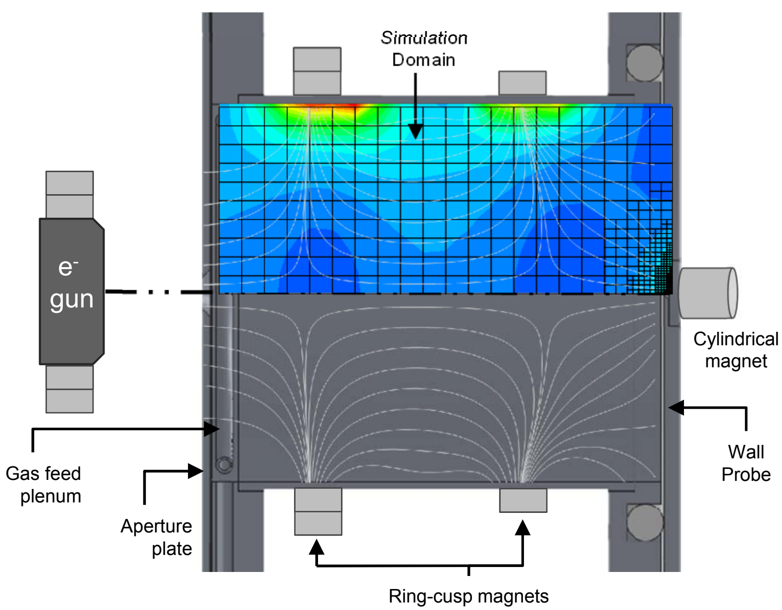
14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**4**	

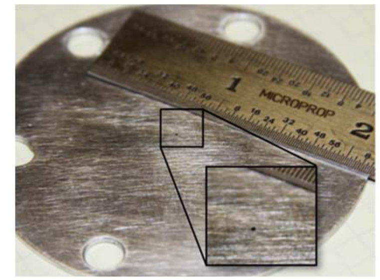
Approach

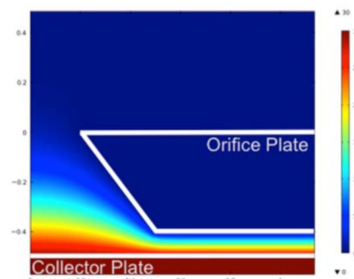




Cusp Confinement Discharge Experiment

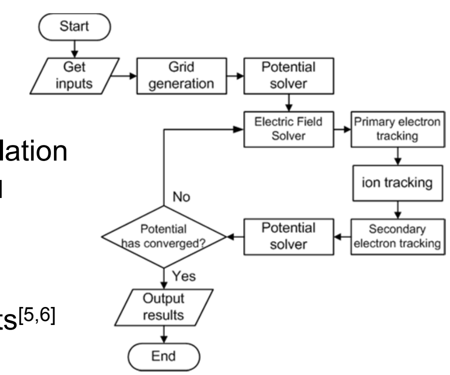
- Measure particle flux for single cusp
- Ring cusps upstream for improve primary electron confinement
- Ring plenum gas injection upstream
- E-gun supplies 50 μA of 25 eV electrons
- Wall Probe embedded into sliding downstream plate
  - Non-invasive planer scans of cusp
  - 400 μm diameter effective area
  - Orifice design behaves at RPA





Computational Model

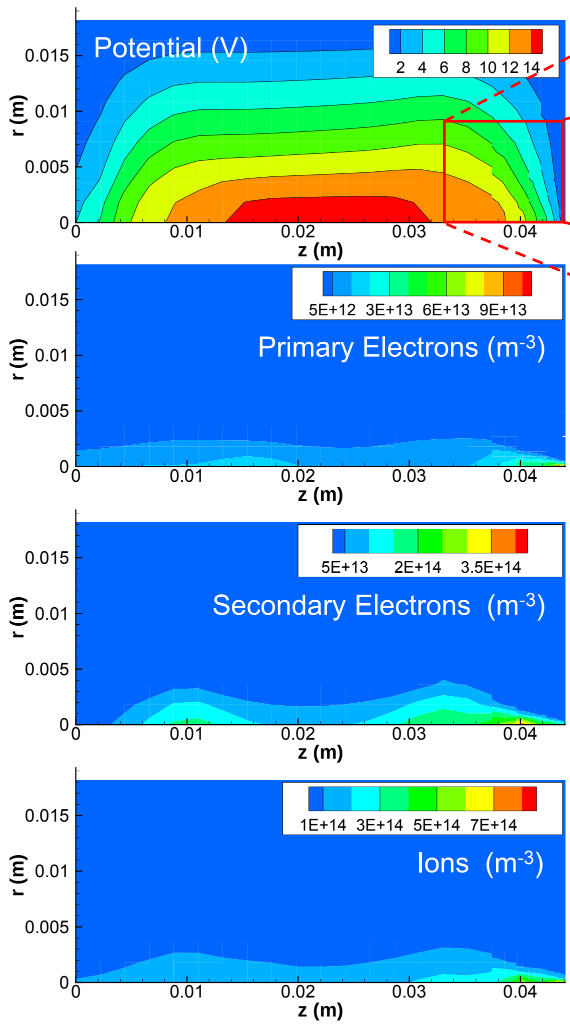
- 2.5D PIC-MCC model
- Adaptive Cartesian mesh
- 2nd order electric potential[1] and field calculation
- Modified Boris particle pushing technique[2]
- Generalized weighting scheme[3]
- Anisotropic elastic scattering of electrons[4]
- Analytical equations for permanent magnets[5,6]

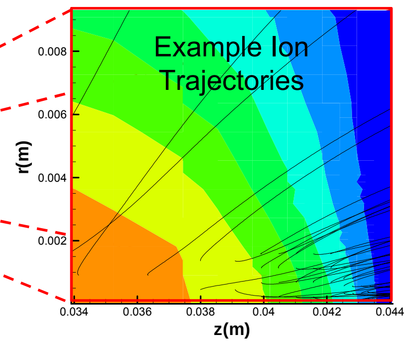


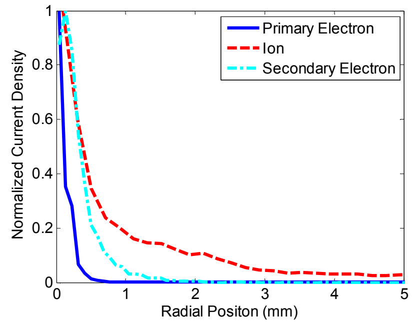
[1] Fox J. M., Ph.D. Dissertation, Aeronautics and Astronautics Dept., MIT, 2007
[2] Wirz R., Katz I., AIAA-2004-4115
[3] Verboncoeur J., *J. Comput. Phys.*, 174 (2001) 421–427
[4] Okhrimovskyy A., Bogaerts A., and Gijbels R., *Phys. Rev. E*, 65, 037402 (2002)
[5] Engel-Herbert R. and Hesjedal T, *J. Appl. Phys.*, 97, 074504 (2005)
[6] Babic S. I., Akyel C., *Progress In Electromagnetics Research C*, 5 (2008), 71-82

Results: Cusp Confinement Discharge

Computational Model

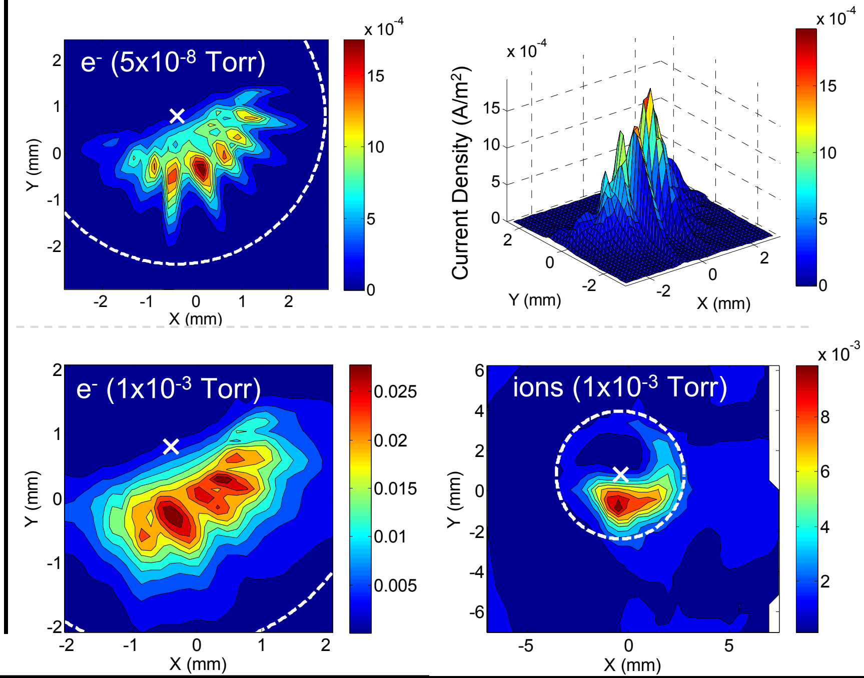






Wirz R., Araki S., Dankongkakul B., “Near-Surface Cusp Confinement for Weakly Ionized Plasma,” AIAA-2012-3948

Experiment



Observations

- Ionization due to primaries near the cusp causes high local ion density
- Ions are directed axially toward wall by electrostatic force
- Near-surface confinement behavior highly dependent on upstream B-field structure
- Plasma distribution affected by e-gun misalignment

“Leak radius”: r_l

Hybrid gyroradius: ρ_h

$$r_l \approx \rho_h = \sqrt{\rho_e \rho_i}$$

$$\rho_{e,i} = \frac{mv_\perp}{|q|B}$$

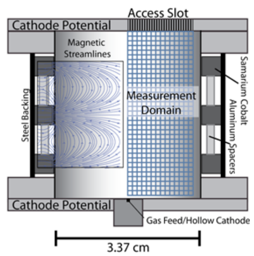
Units (mm)	Primary Electrons	Ions	Secondary Electrons
Leak Radius (Experiment)	0.62	0.77	0.59
Leak Radius (Model)	0.08	0.35	0.30
Gyroradius [b]	0.14	2.5	0.055
Hybrid Gyroradius	0.59	0.59 / 0.37	0.37

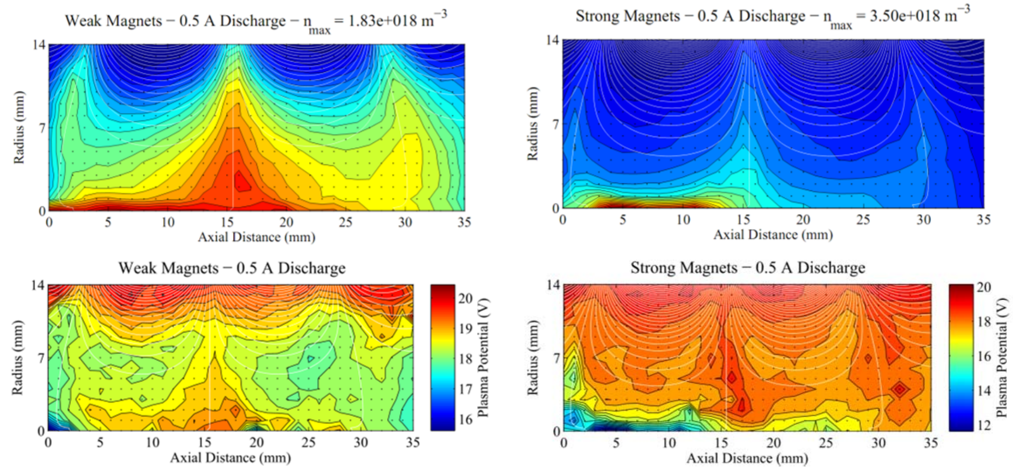
Microdischarge Analysis and Design

Miniature Discharge (3 cm) Analysis

- Plasma properties dominated by magnetic field structure and invariant to discharge power
- Strong magnets pinches down plasma volume, leading to poor volumetric utilization
- Confirms computational/theoretical analysis that strong magnets and high discharge currents can lead to the onset of instability

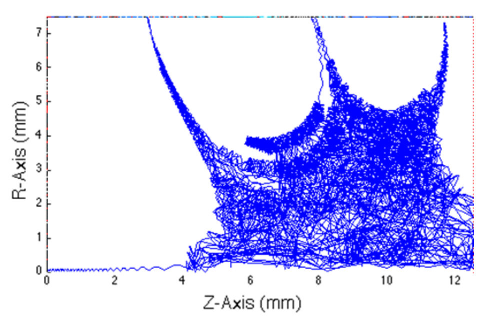
Mao H. S., Goebel D., Wirz R., "Plasma Structure of Miniature Ring-Cusp Ion Thruster Discharges," AIAA-2012-4021

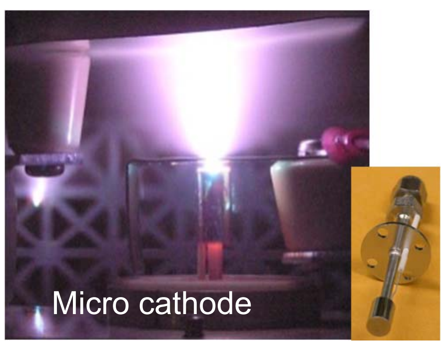




Microdischarge Design (*preliminary efforts*)

- Objectives: large plasma volume, desirable cusp strength, stability
  - Considering unconventional discharge designs
- Primary confinement efficiency on order of larger discharges (~25%)
  - Two-fluid plasma model (e^- and ions) needed
- Micro cathode design and testing underway





Concluding Remarks / Future Work

- Important insight derived from exp/comp single cusp effort for near-surface and volumetric confinement
- Future Work
  - Experiment: weakly ionized plasma analysis for single cusp and microdischarge
  - Continue to use semi-analytical tools for microdischarge design exploration
  - Comp Efforts: Detailed design: 2.5-D hybrid PIC model for weakly ionized plasma microdischarge design and analysis

- Acknowledgements:
  - AFOSR YIP and Dr. Mitat Birkan
    - Grant FA9550-11-1-0029
  - Students: Sam J. Araki, Ben Dankongkakul, Hann Mao