An Enabling Low-Power Magnetically Shielded Hall Thruster for Interplanetary Smallsat Missions

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Jet Propulsion Laboratory
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Pasadena, California

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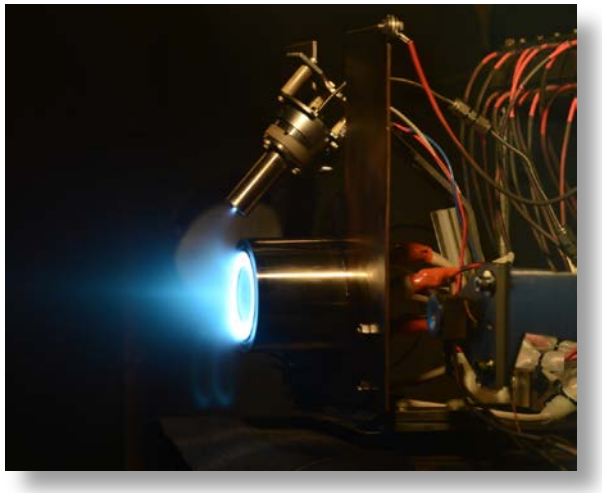
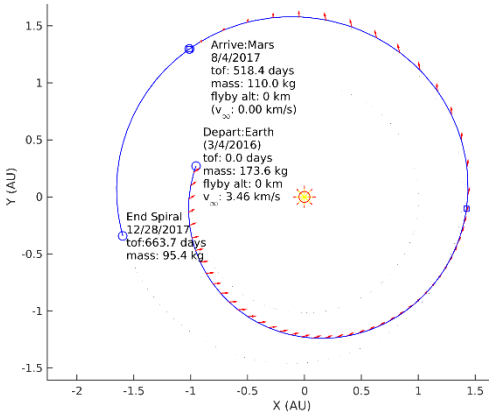
Overview

<u>Objective</u>: Explore the enabling capabilities of a small spacecraft employing an optimized, low-power, long life Hall thruster



- Introduction / Background - *Electric Propulsion, Hall Thrusters, and Magnetic Shielding*
- Motivation - *Why move to the miniature scale?*
- MaSMi-60 - *Performance of the current generation MaSMi Hall thruster*
- Mission Trajectory Studies – *Deimos orbit insertion and Uranus orbit insertion*
- Conclusion & Future Work



Electric Propulsion (EP) Overview

Rocket Equation

Juno Launch Vehicle
Ibtimes.com

$$m_p = m_0\left[1-\exp\left(-\frac{\Delta V}{I_{sp}g}\right)\right]$$

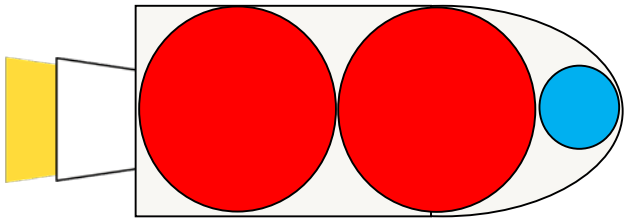
$$I_{sp}\uparrow \Rightarrow \Delta V\uparrow \quad \text{for fixed } m_p$$

$$I_{sp}\uparrow \Rightarrow m_p\downarrow \quad \text{for fixed } \Delta V$$

Chemical Propulsion

T ~ N - GN

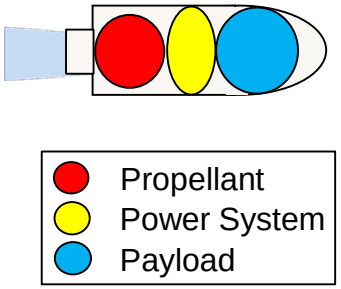
I_{sp} ~ 300 – 450 s



Electric Propulsion

T ~ 0.1 – 100's mN

I_{sp} ~ 2000 – 10,000+ s



"Next-Gen Ion Thruster"
foxnews.com

EP: The Good

- Lower spacecraft mass
- Smaller launch vehicle

Lower Mission Cost

EP: The Bad

- Lower thrust output
- Impulse = Thrust x Time

Longer Mission Time

Hall Thruster Operation and Magnetic Shielding (M.S.)

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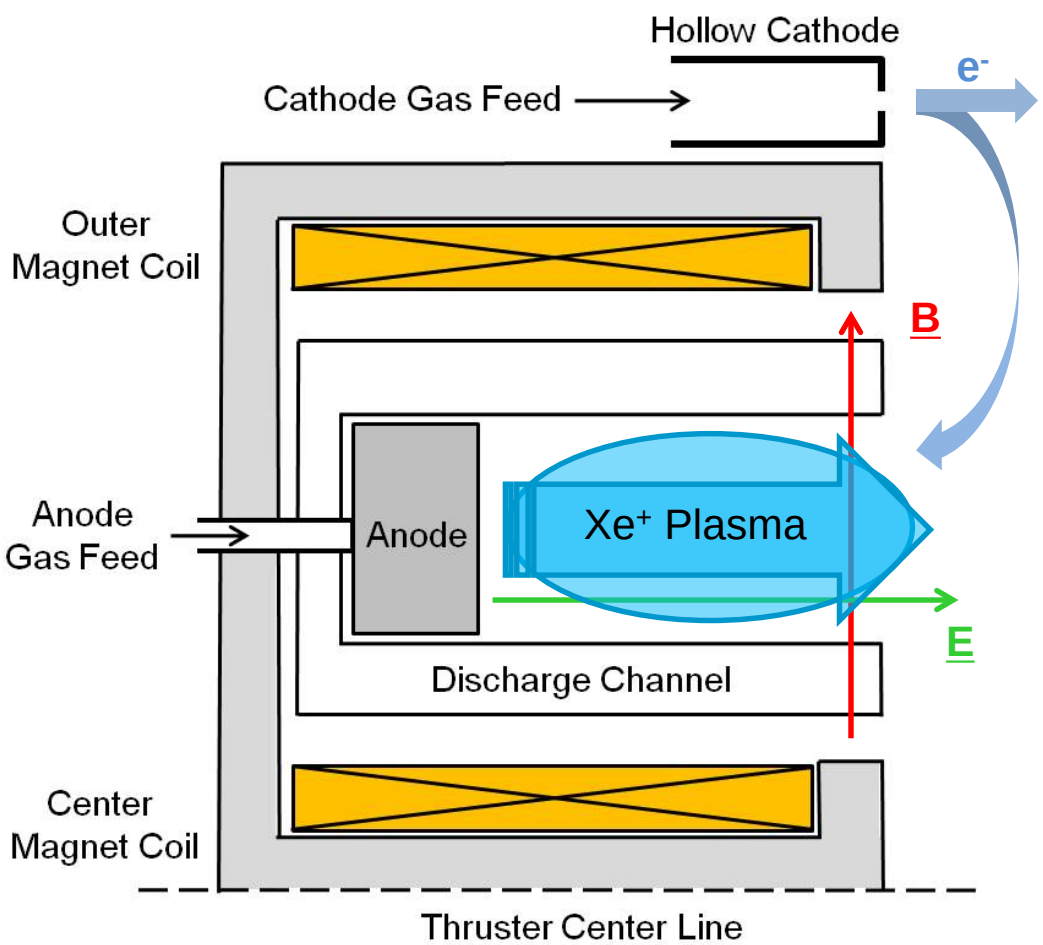
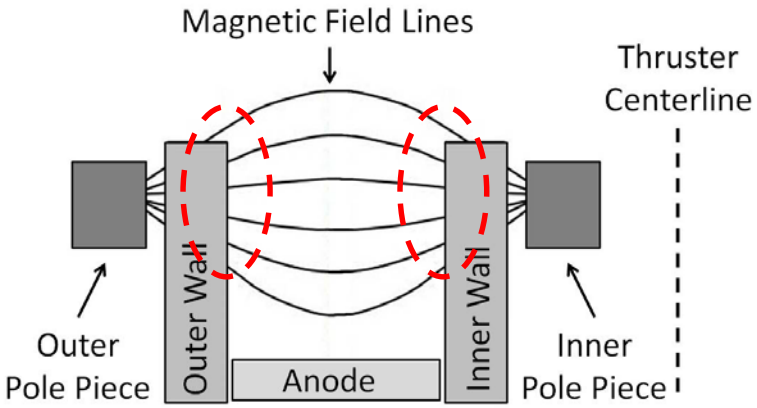
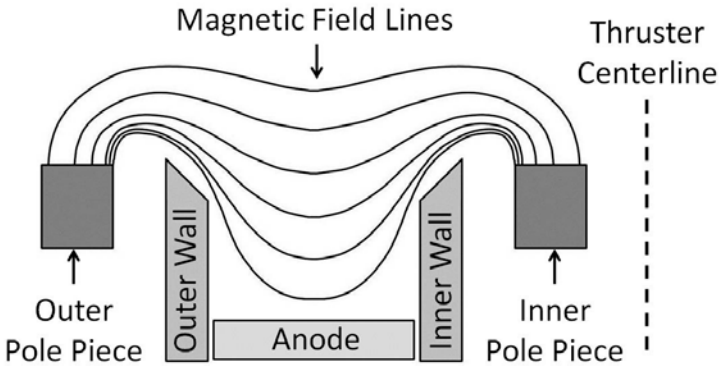
Basic Hall Thruster Operation



Conventional B-Field



Magnetically Shielded B-Field



At miniature scale, M.S. improves **LIFE** & **EFFICIENCY**

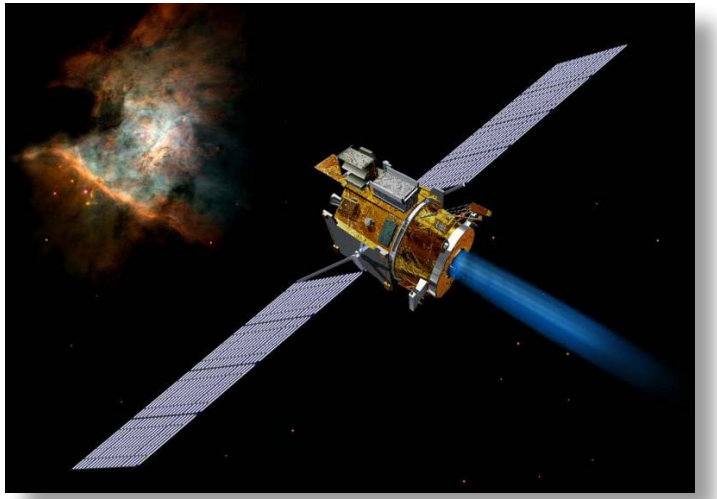
Motivation: Why Pursue Low-Power Magnetic Shielding?

- Changing Requirements for Future Missions
  - Lower spacecraft mass: *~200 kg vs. 1000+ kg*
  - Lower available power: *~1 kW solar array*
  - Demanding trajectories: ΔV *~ 5 km/s*

www.uzay.tubitak.gov.tr

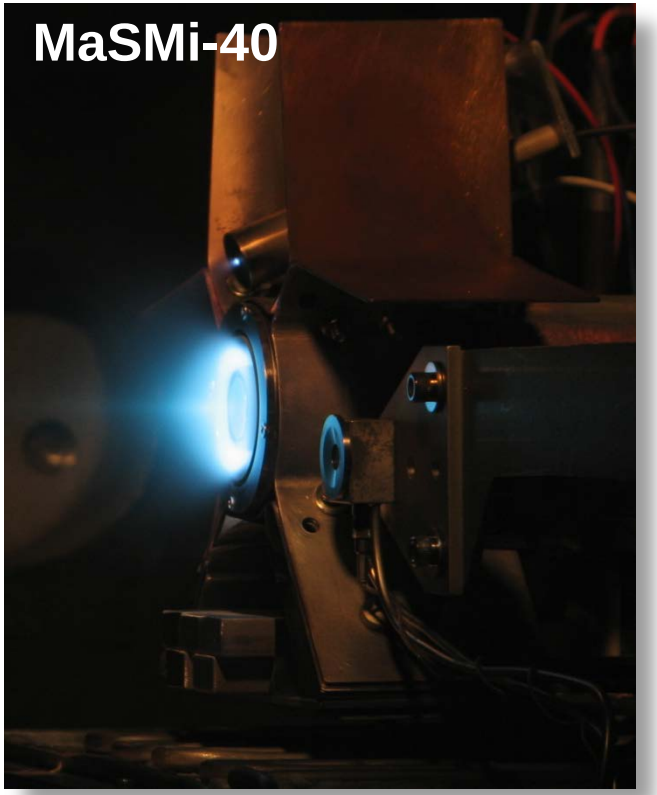
- Hall Thruster State of the Art
  - Miniature: short lifetime (~1000 hrs)
    moderate efficiency (~40%)
  - Long-Life (MS): high-power (~4+ kW)

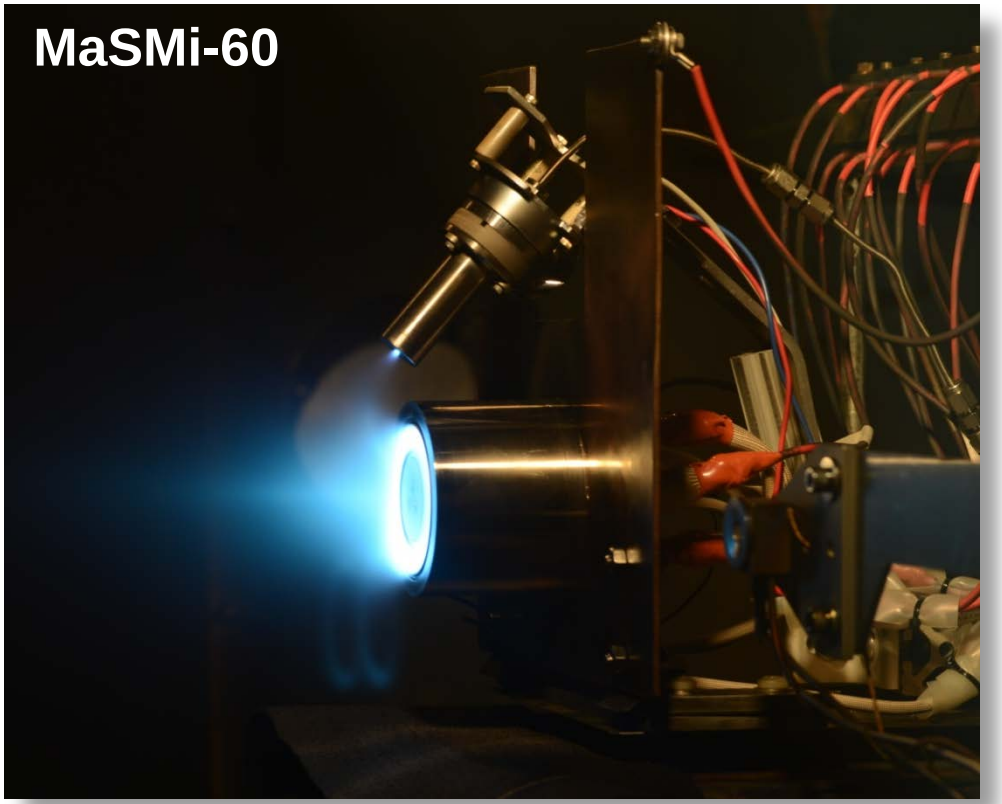
- Current Hall Thruster Technology Gap
  - No thruster currently demonstrates
    - Low-power (sub-500 W)
    - Long operational lifetime (~10,000+ hrs)
    - High efficiency (>40%)



www.sciecnedaily.com

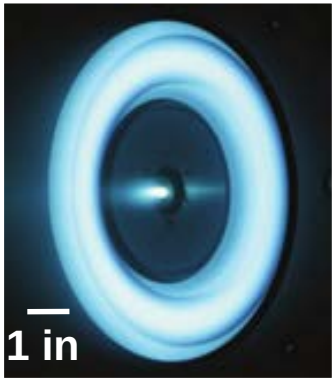
MaSMi-60: 2nd Design Iteration of the MaSMi Hall Thruster





- Designed & fabricated a second prototype MaSMi Hall thruster
- Increased magnetic circuit radial dimensions to **prevent magnetic saturation**
- Improved magnetic circuit geometry to **shield inner and outer channel walls**
- Improved thermal design to **lower operating temperatures**

MaSMi-60 Performance Assessment



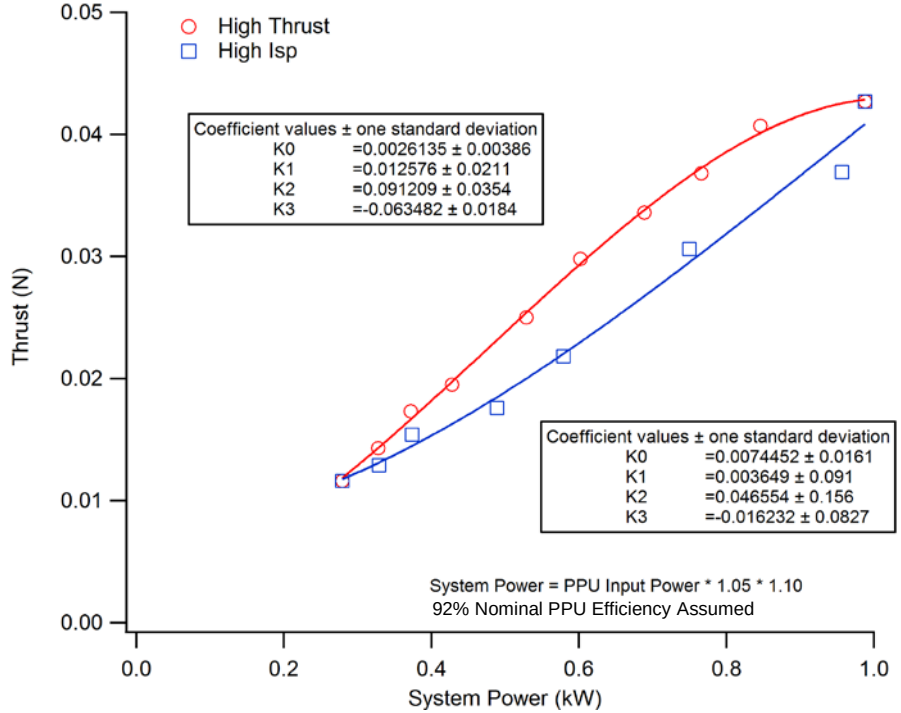
H6MS
6 kW

Magnetic Shielding Effectiveness

- ***>10 – 100x increase in channel lifetime*** based on QCM carbon backsputter measurements

Performance Measurements & Modeling

- Direct thrust stand measurements for thrust, I_{sp}, etc.
- Optimization cycle underway on current generation thruster to improve performance



MaSMi Compared to the State of the Art

Thruster	Disch. Power	Thrust	I_{sp}	Efficiency	Throughput
BHT-200	100 – 200 W	12 mN	1,400 s	42%	6 kg (demo)
BHT-600	200 – 800 W	39 mN	1,530 s	39%	37 kg (claim)
SPT-50	350 – 500 W	30 mN	2,000 s	40%	20 kg (demo)
SPT-70	700 W	40 mN	1,500 s	42%	32 kg (demo)
MaSMi	**Min: < 150 W Max: > 800 W**	**~ 40 mN**	**~ 1,500 s**	**~ 40%**	**~ 100 kg**

BHT-200

BHT-600

SPT-Series

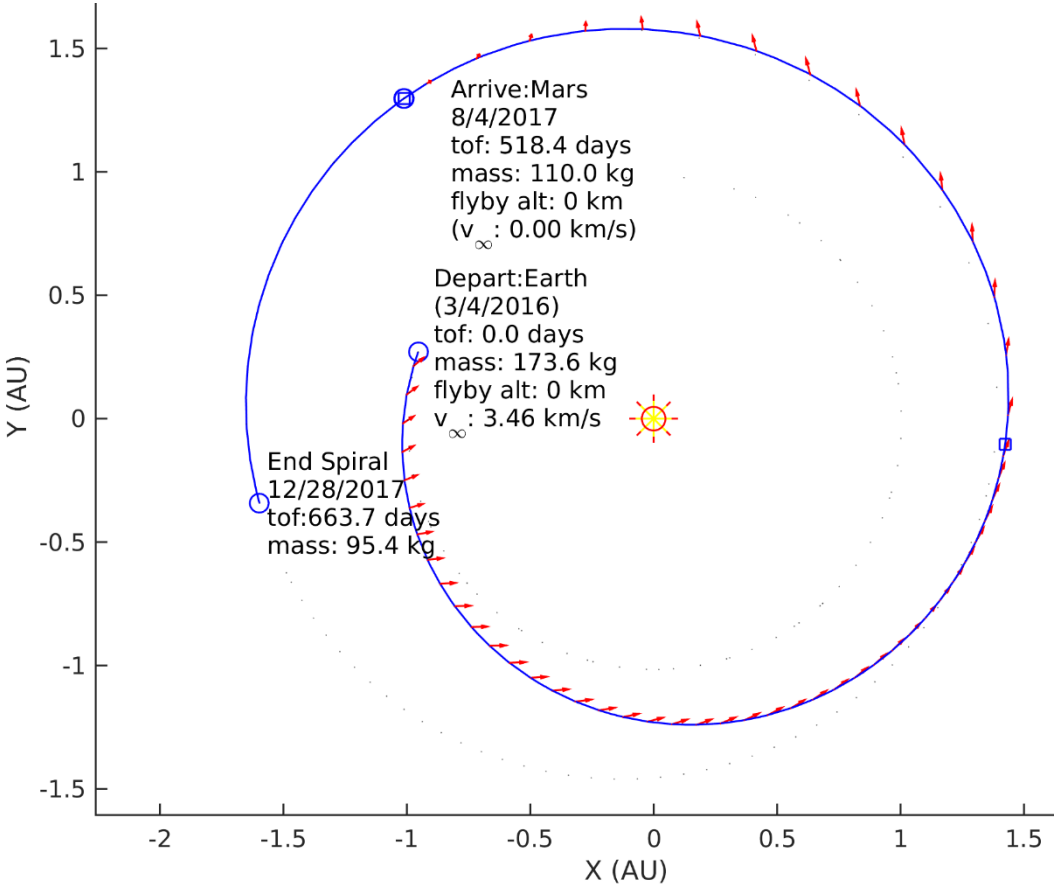
MaSMi-60

Mission Study 1:
Earth to Deimos Orbit Insertion

ASSUMPTIONS

- SmallSat SC, Solar Electric Propulsion (SEP) based mission
- Launch as piggy-back to Insight mission

Mission Parameter	Value
Thruster Duty Cycle	95%
Missed Thrust Margin	10%
BOL Power @ 1 AU	1.1 kW
TOF to Mars	518.4 days = 1.4 years
TOF to Deimos (Spiral)	146 days = 0.4 years
Propellant Mass	78.2 kg Xe

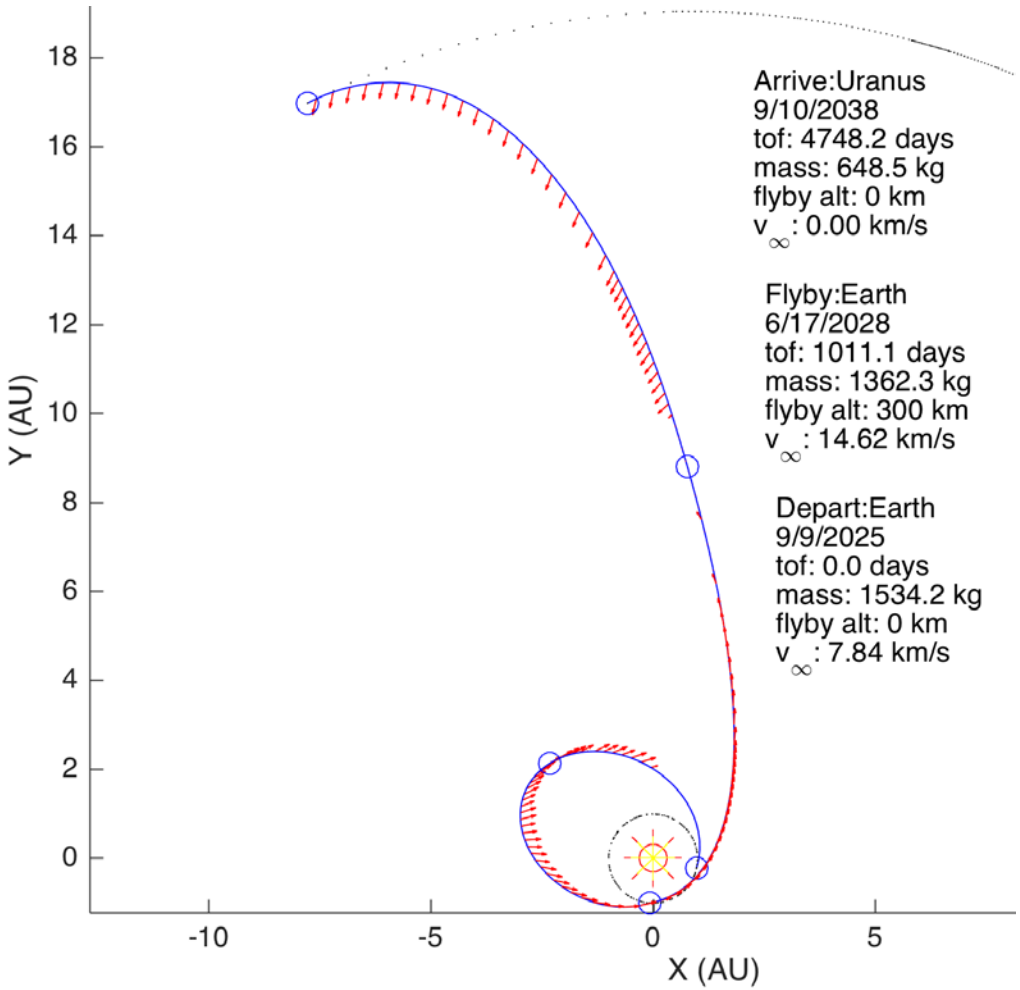


Mission Study 2:
Earth to Uranus Orbit Insertion

ASSUMPTIONS

- Radioisotope Thermal Generator (RTG) based mission
- Arrive at Uranus with $V_\infty = 0$ to enable orbit insertion flexibility
- Example of capabilities

Mission Parameter	Value
Launch Vehicle	Atlas V 551
Thruster Duty Cycle	95%
Missed Thrust Margin	10%
BOL Power @ 1 AU	1.1 kW
TOF to Uranus	518.4 days = 1.4 years
Propellant Mass	886 kg Xe

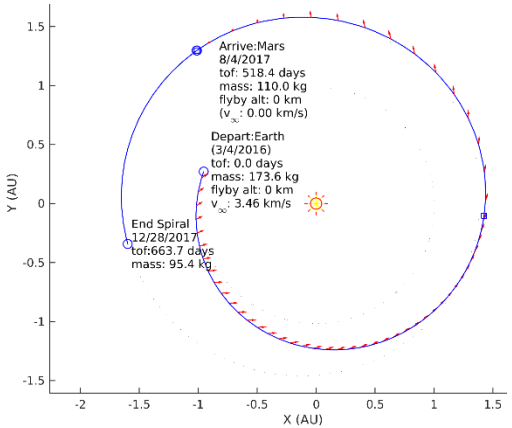


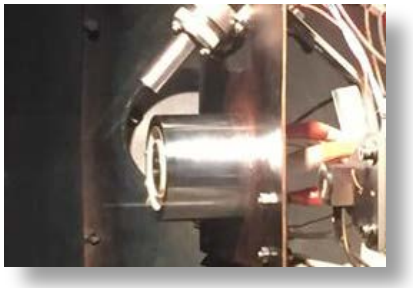
Conclusion and Future Work

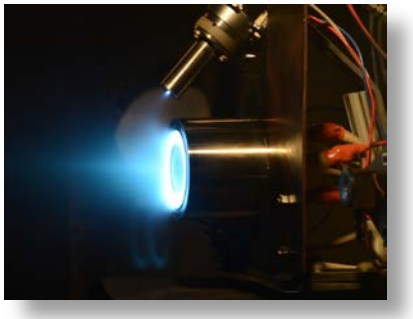
Small spacecraft + low-power, long life Hall thruster

= LOW COST SCIENTIFIC MISSIONS

- *Low initial mass*
  - Reduced dedicated launch vehicle costs
  - Shared launch / multiple S/C launch options
- *Low cost enables higher acceptable risk*
  - Deep space science missions
  - Technology demonstration S/C architecture





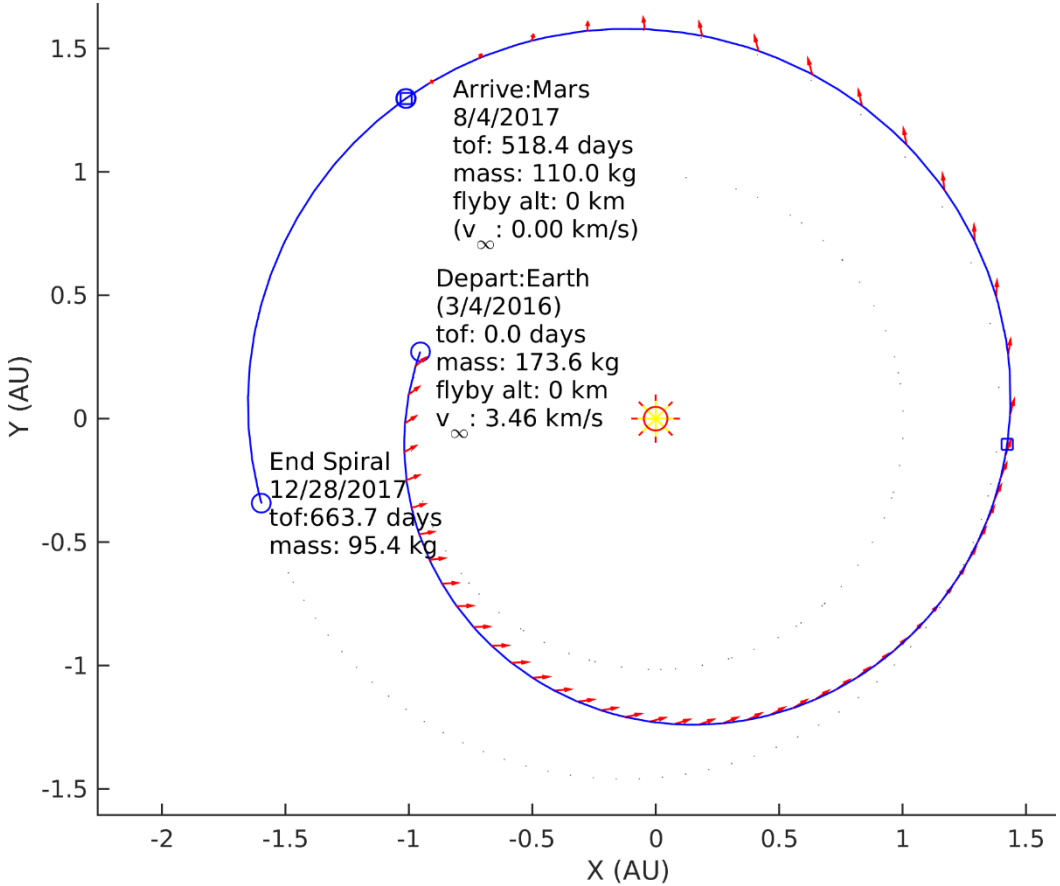


Future mission studies under investigation

- *Small spacecraft using MaSMi:* rendezvous with Jovian moons, NEA human precursor missions, etc.
- *Conventional spacecraft using MaSMi:* optimized Neptune & Uranus rendezvous, extended mobility for SEP mission to Saturn, etc.

THANK YOU FOR YOUR ATTENTION

QUESTIONS?

Mission Study 1 (Earth to Deimos) MEL

Mass Equipment List (kg)	
Attitude Control	0.7
Avionics	0.2
Power	7.5
Propulsion	20.1
Structure	12.2
Thermal	1.8
Telecom	4.0
Available Payload	13.5
Spacecraft Bus Mass (CBE)	60.0
System Contingency	35.6
Spacecraft Dry Mass	95.5
Propellant	78.2
Total Launch Mass	**173.7**