Microcavity Discharge (MCD) Thruster Basics and Conceptual Design

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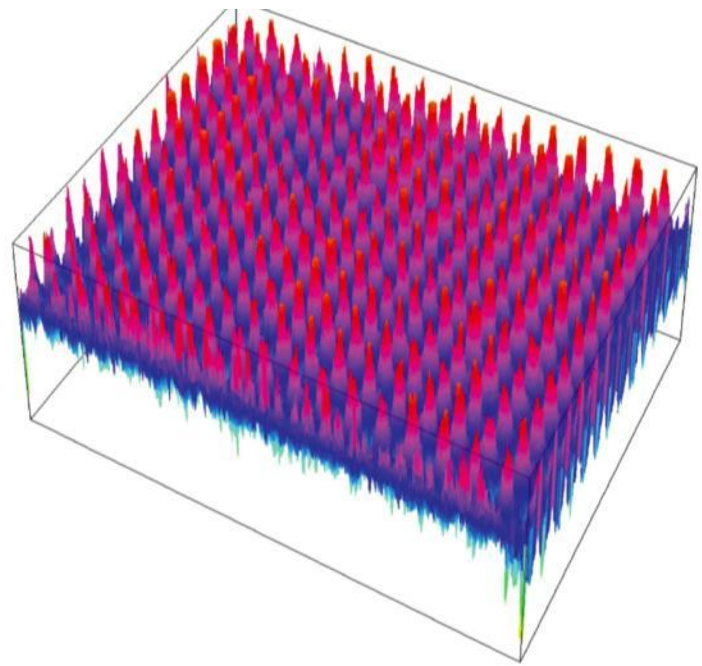
Outline

- Technology Background
- Preliminary MCD Data
- Preliminary CubeSat Notional Designs
- Summary

Micro-cavity Discharge (MCD) Thruster Background

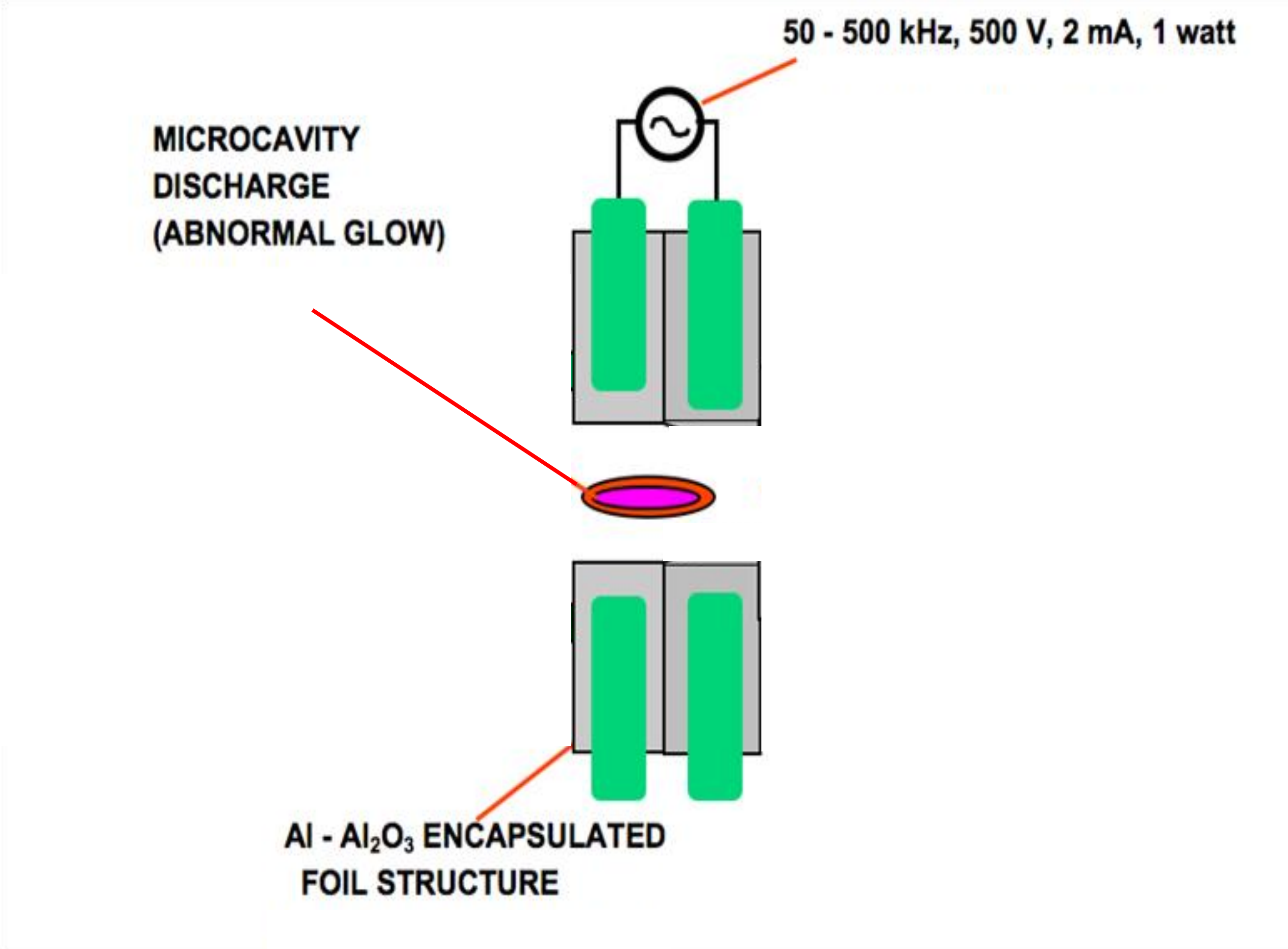
Microcavity Discharge (MCD) Thrusters

- Based on microcavity discharge
  - UIUC, 1999 - 2011
  - illumination, medical, other apps
  - thousands of hours life observed
- Parallel, stable cavities
- Electrothermal device
  - AC discharge, 20 - 500 kHz
  - choked supersonic nozzle
  - fast warm-up
  - constant thrust ~ p_o
- No auxiliary systems
  - no neutralizer, cathode, ignition system
- High thruster efficiency predicted
  - low heat, frozen flow, nozzle loss
- Long life with insulated electrodes



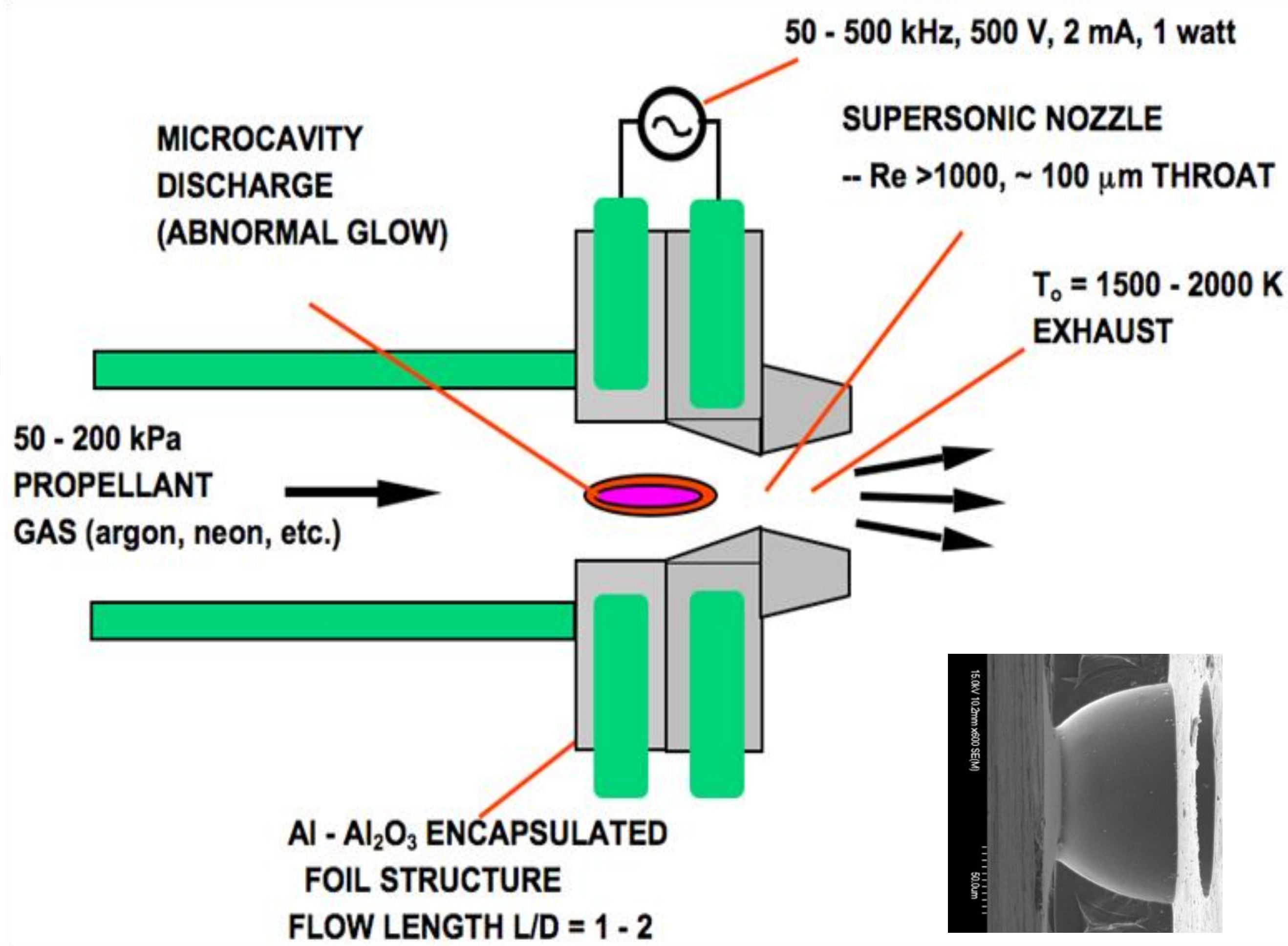
MCD Basics

- RF power supply
- Plasma created in microcavity between foils



MCD Thruster Basics

- Gaseous propellant
- RF power supply
- Plasma created in microcavity between foils
- Integral nozzle
- Cavity electric field strength ~10^7 V/m
- Predicted η ~ 60%

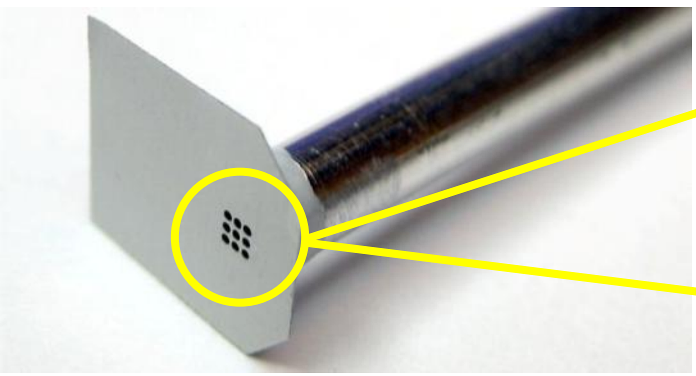


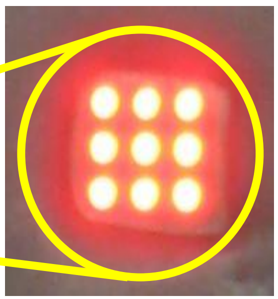
MCD Thruster Losses

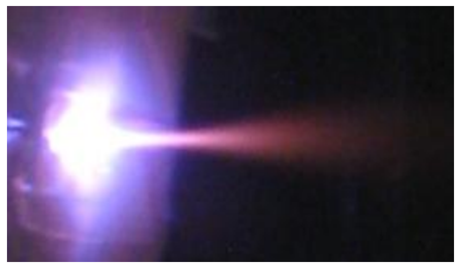
Loss	Description	Prediction
power processor	DC-AC converter+kHz stepup transformer	5%
feed system	pressurized tank	<1%
thruster auxiliaries	none	0%
gas utilization	unaccelerated propellant	0%
ionization loss	ion. fraction is 10^{-3} - 10^{-5}, ϕ = 15.9 eV	<1%
wall heat loss	subsonic wall heat transfer	5 - 10%
dielectric loss	AC heating of AL_2O_3	10%
nozzle expansion	supersonic boundary layer, low area ratio	10 - 15%
radiation	argon excitation	0 - 1%
ablation	insulator ablation low based on MCD	long life
Total Losses	MCD Thruster + PPU	30 - 40%
System Efficiency	**MCD Thruster + PPU**	**60 - 70%**

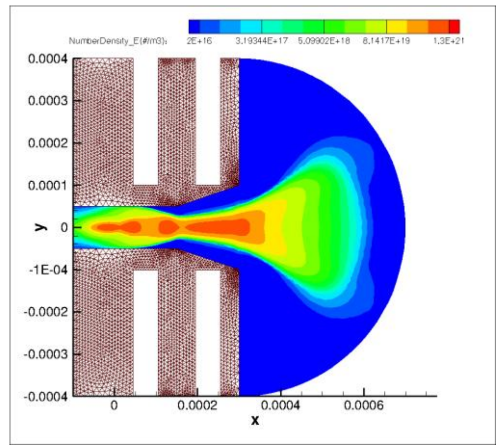
AFOSR Program Examined Scientific Challenges

- **Obtained an understanding of the basic physics & chemistry of 100 μm MCD region to achieve efficient volumetric heating and acceleration of flowing plasma with minimal losses**
- **Foil variation was not robust…**
  - ***CUA used IR&D funds to create robust variation***

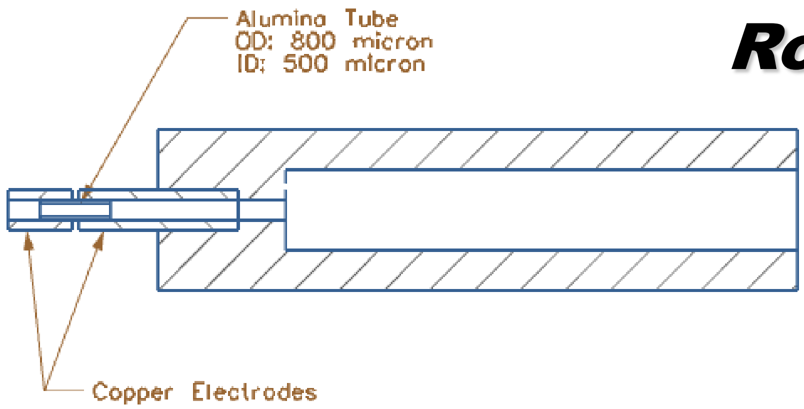




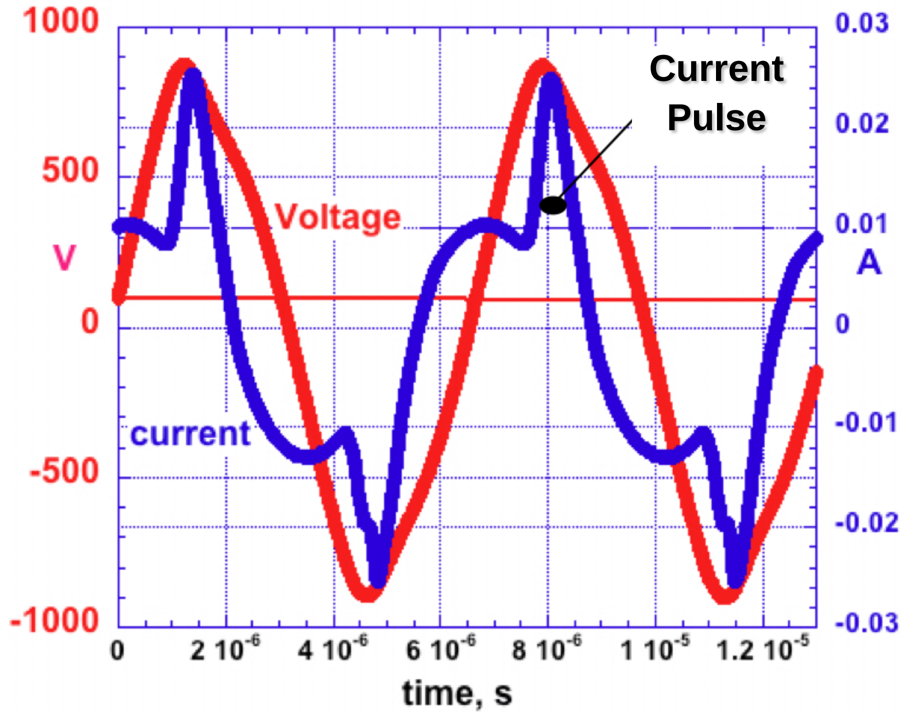




Robust MCD Thruster: V-I Characteristic

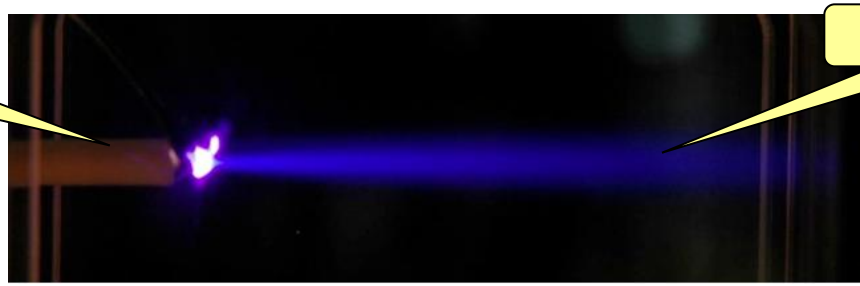


Robust variation of MCD thruster tested by CU Aerospace



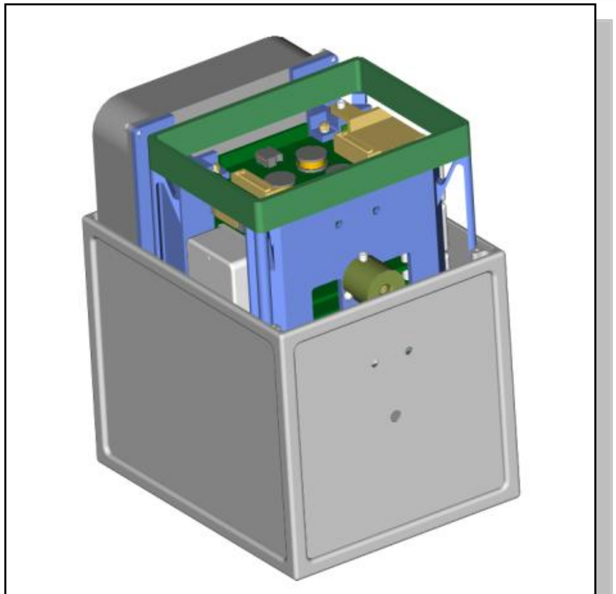
- Initial test w/ robust MCD thruster using EP-13 propellant
  - *Measured pressure rise at constant flow rate → 723 K*
  - *≈ 30% thrust enhancement*
  - *No degradation of hardware*
- Very low erosion found during testing
  - *"Electrodeless" → low erosion*

Reference Design – MCD Thruster



Micro-Propulsion System (MiPS) Background: Cold Gas Technology

CubeSat Propulsion Design Challenges



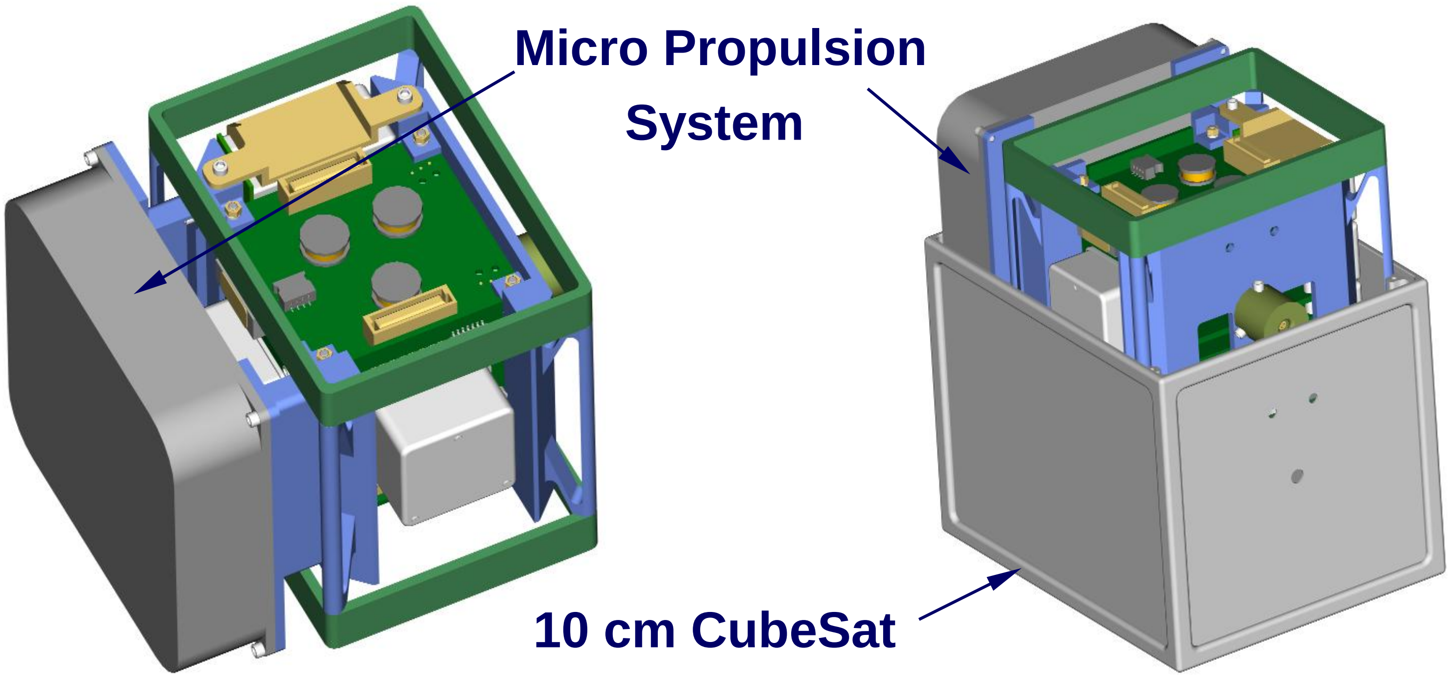
Packaging - Extremely Limited Volume:
- Liquid Propellant for Max Storage Density
- Propulsion System Doubles as Structure
- Pressurization System Eliminated
- Electrical Components Immersed in Propellant

Reliability = Value:
- All-Welded, Titanium Construction
- Elimination of Tubing Connections
- Frictionless Valves
- Self-Pressurizing Propellant

Electrical Power is Limited:
- Reserve Available Power for Payload
- High-Efficiency Micro Latch Valves
- Piezoelectrically Actuated Micro Valves

Thermal Management:
- Propulsion System Acts as Heat Sink
- Symbiotic Relationship with Propellant

MEPSI Micro Propulsion System



0.25U Propulsion System

Micro-Propulsion System Capability

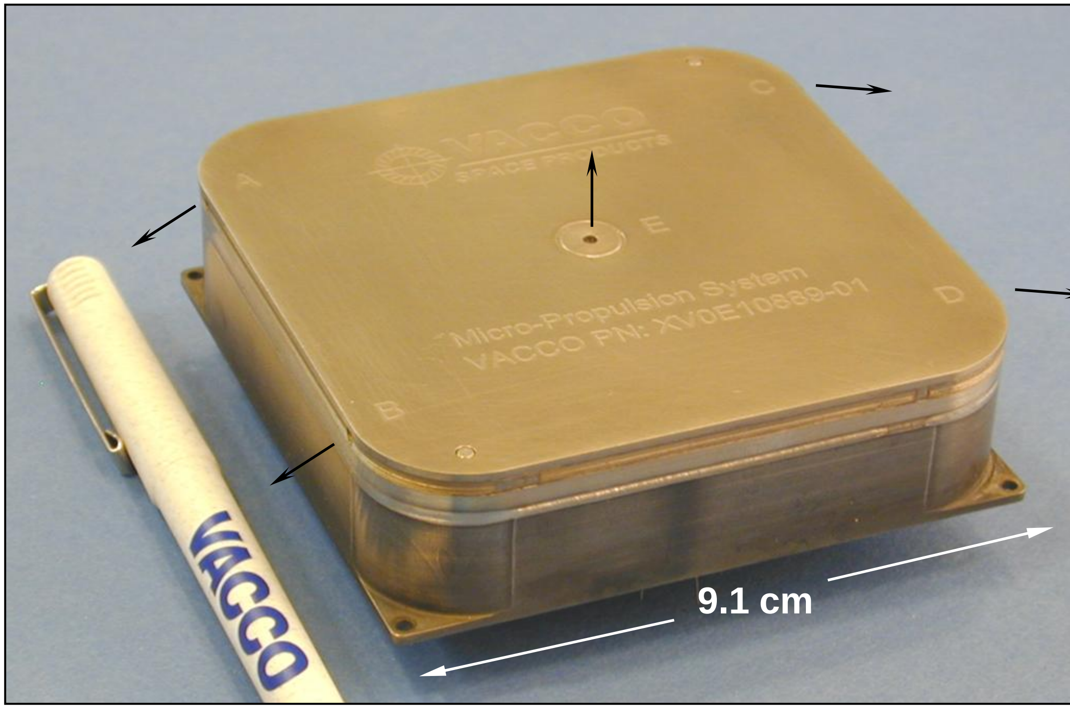
Thrust:

55 mN (40 psia Plenum Pressure)

Propulsion System Mass: 509 g

Dry Mass: 456 g

Propellant Mass: 53 g (liquid)



Thrust / Propulsion Wt.:

0.108 to 0.120 N/Kg

66 N-Sec/Kg

Number of thrust cycles:

Up to 61,000 Minimum Impulse Bit Firings

Total Impulse: 34 N-Sec

MEPSI Mass: 1.0 Kg

Total ΔV: 34 m/s

26 m/s (–Z)

1 m/s (+Z)

3 m/s Pitch/Yaw

4 m/s Roll & Un-Spin Reaction Wheels

Preliminary Warm Gas Design for CubeSats

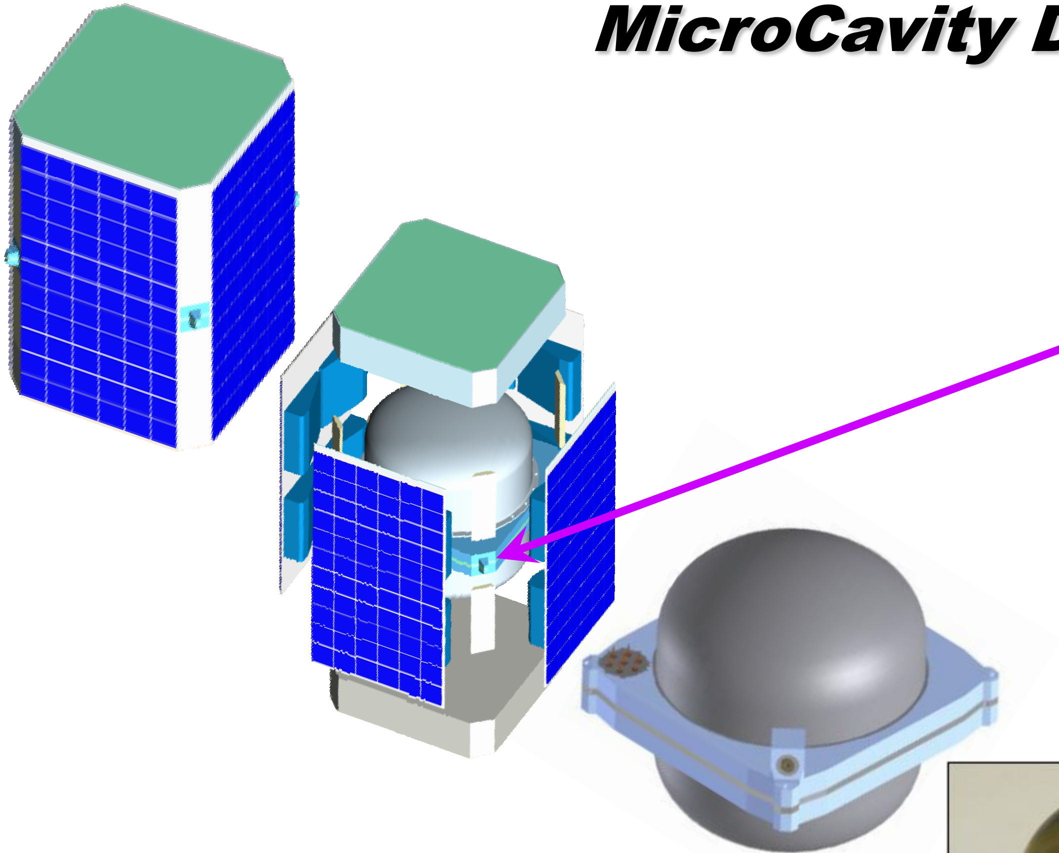
Basic Concept

MCD technology + MEPSI/MiPS technology

= High performance CubeSat propulsion system

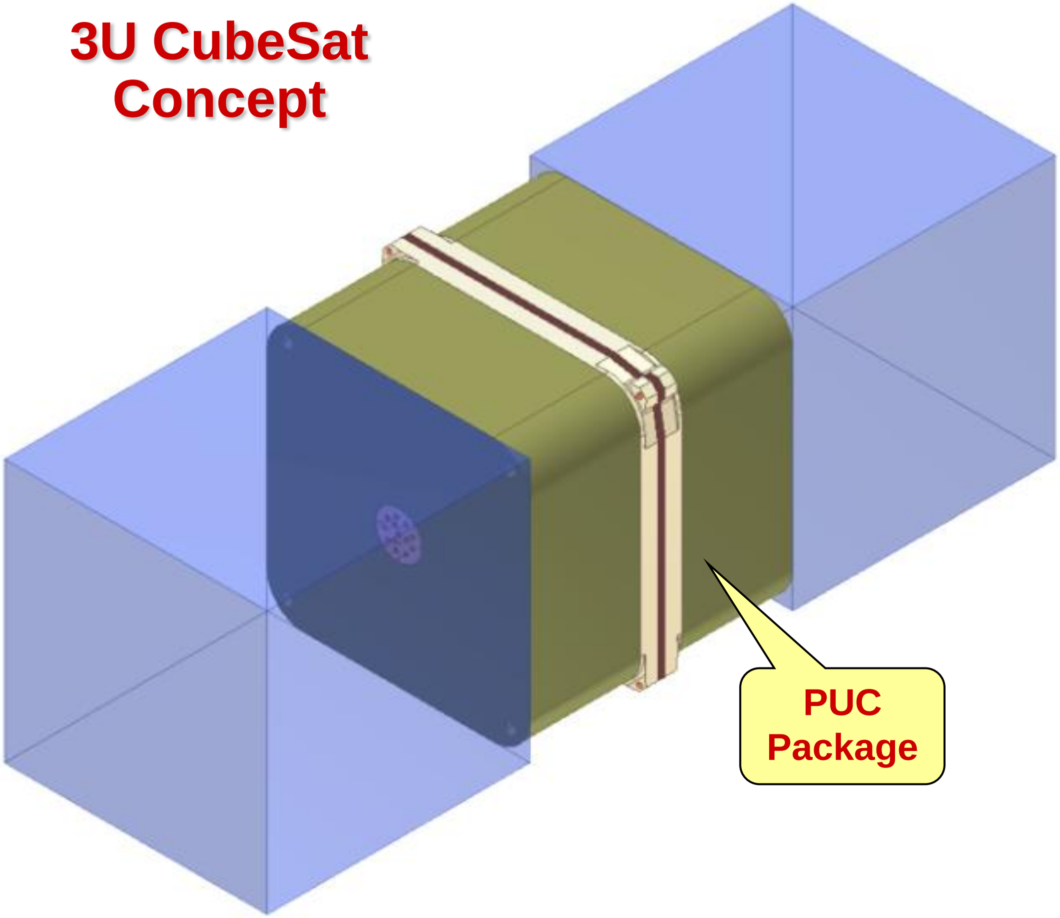
MCD / MiPS Hybrid System

MicroCavity Discharge (MCD) thruster tested by CU Aerospace

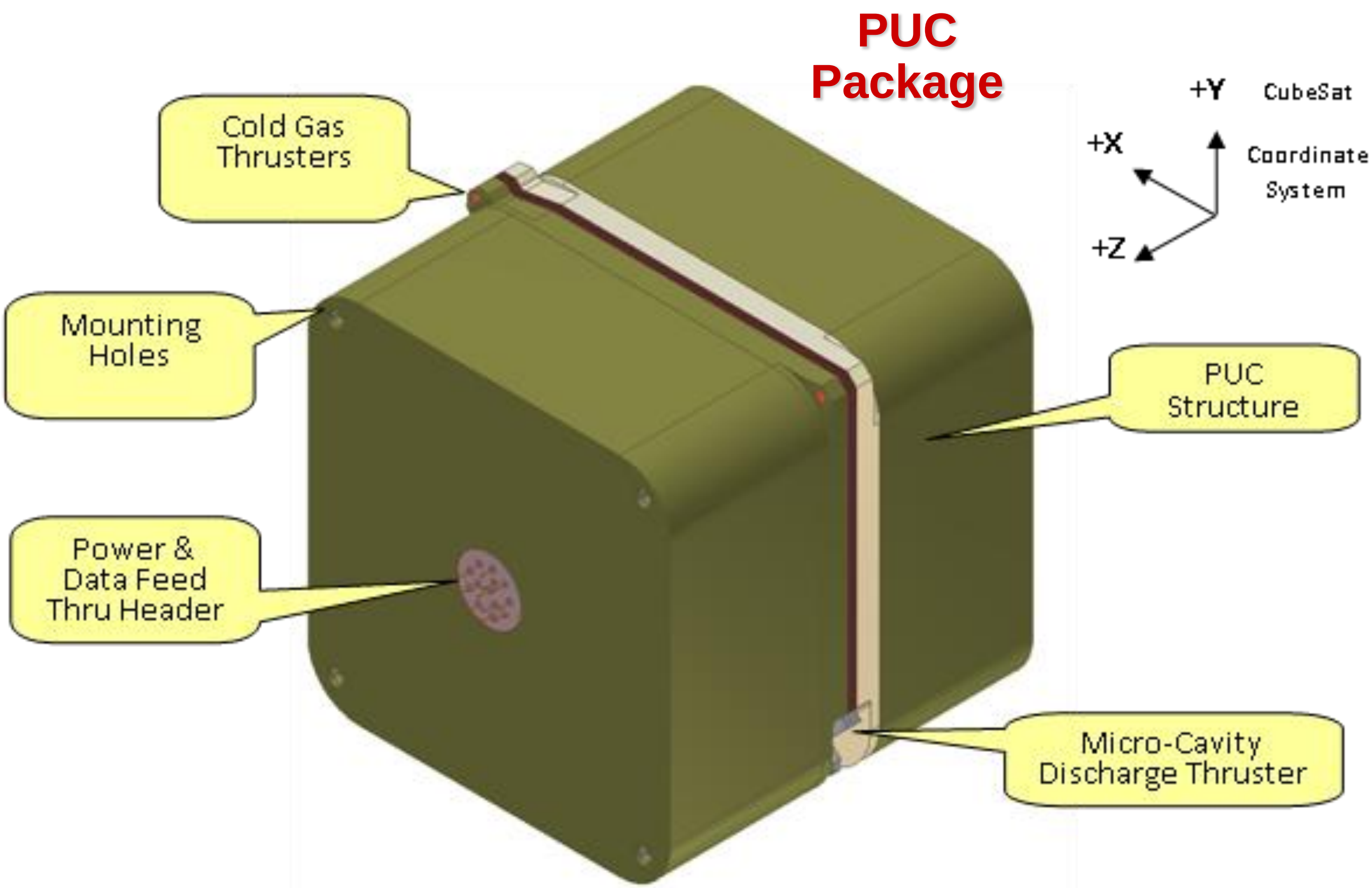


Heritage VACCO Micro Propulsion System tested at AFRL

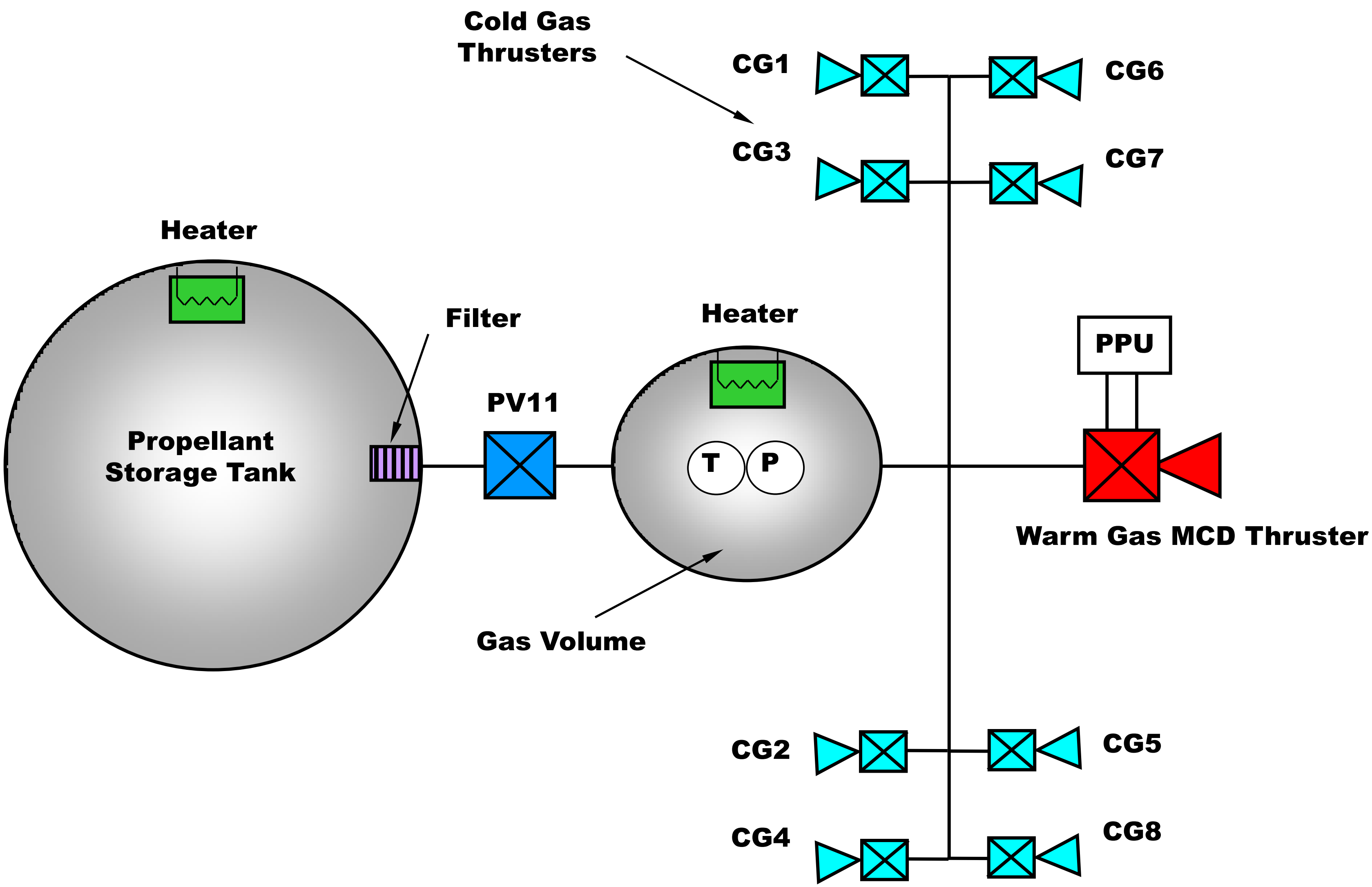
ACS+Delta-V Reference Design



Propulsion Unit Package

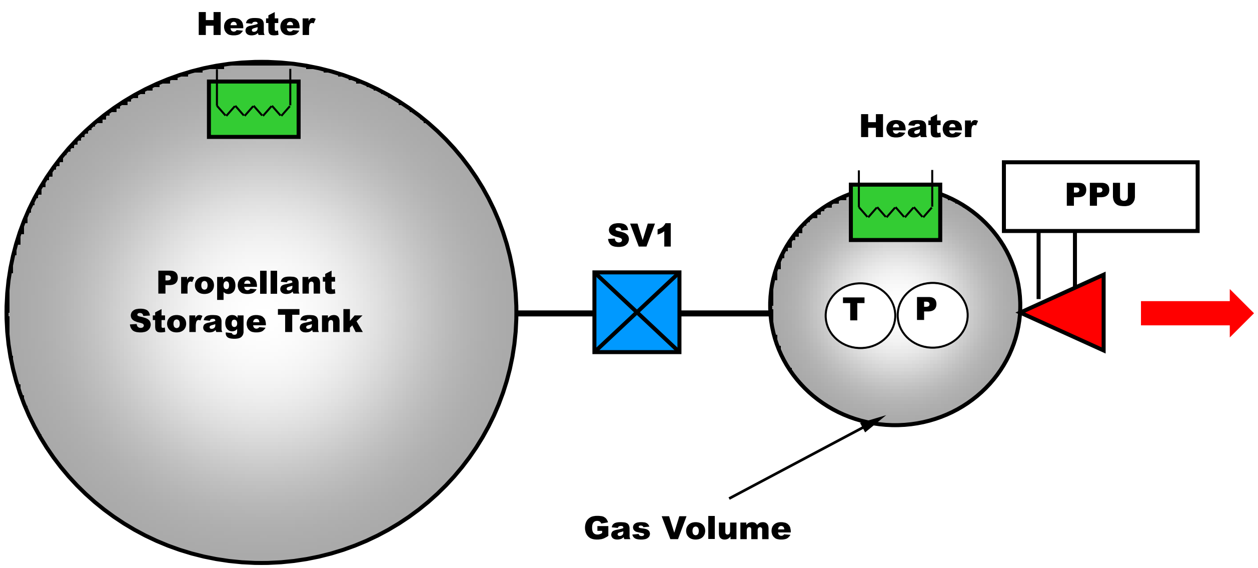


ACS+Delta-V System Schematic

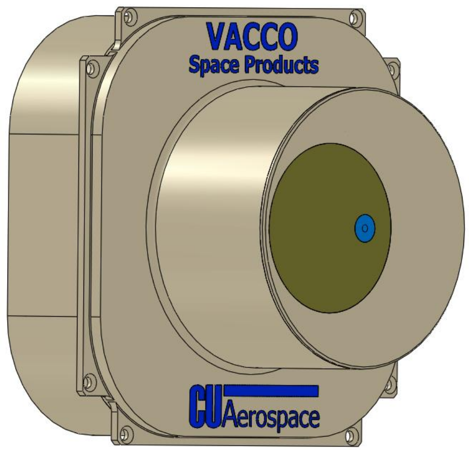


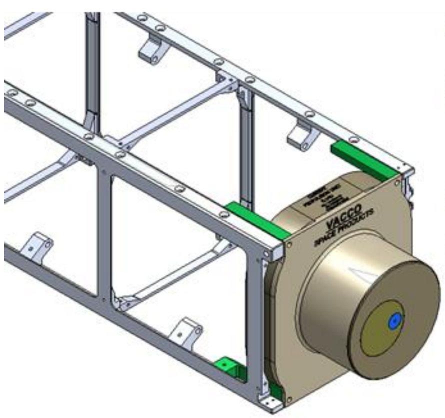
Simplified System Schematic

Primary propulsion only

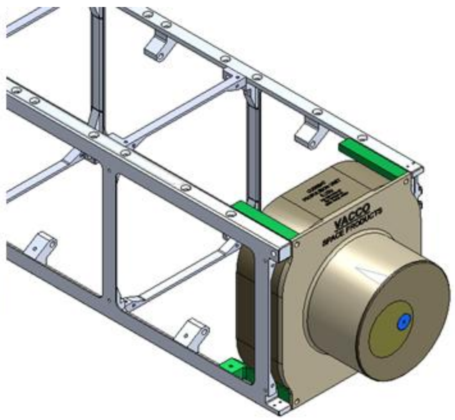


Family of MCD CubeSat Thrusters

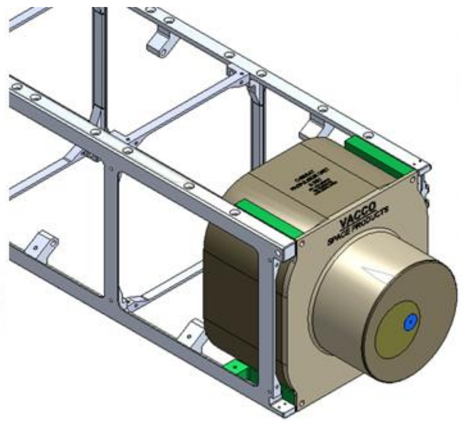




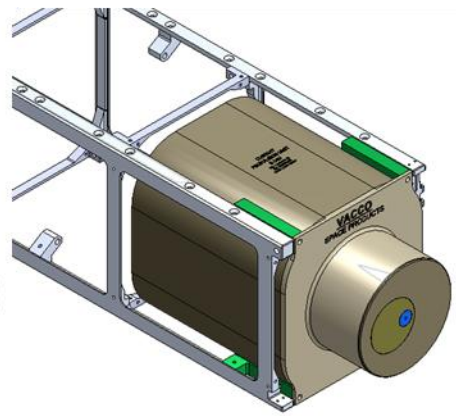
0.14U



0.25U



0.5U



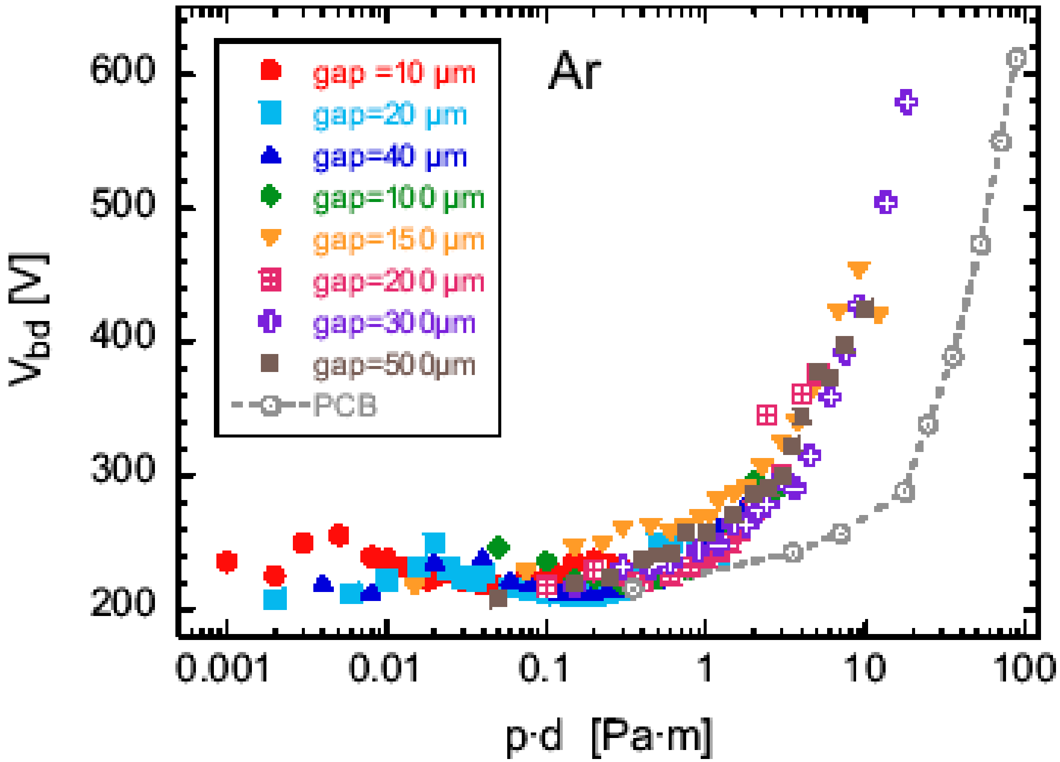
1.0U

Summary

- A robust microcavity discharge (MCD) thruster geometry was demonstrated by CU Aerospace
  - No auxiliary systems
    - no neutralizer or ignition system
  - High thruster efficiency predicted
    - low heat, frozen flow, and nozzle losses
  - Long life with insulated electrodes
- Merge MCD technology with MEPSI/MiPS technology to provide compact, high performance propulsion system
- CU Aerospace and VACCO Industries are rapidly advancing the technology on a Propulsion Unit for CubeSats (PUC) program funded by AFRL

Backup Slides

Paschen Breakdown in Small Gaps



V_{bd} versus the product p·d measured in Ar on devices with gap spacing ranging from 10 up to 500 μm.

Result: relevant gap spacing is electrode spacing (not discharge diameter) allowing E-fields > 10^7 V/m

[Carazetti and Shea, 2009]