Design and Characterization of an Adamantane Thruster

The Asteria Project

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Who We Are

ASPEN

Advanced Spacecraft Propulsion & Energy Lab

- Student-led organization, founded in 2018
- Focused on educating students in industry-applicable skills, introducing them to state-of-the-art propulsion technology, and performing cutting-edge research

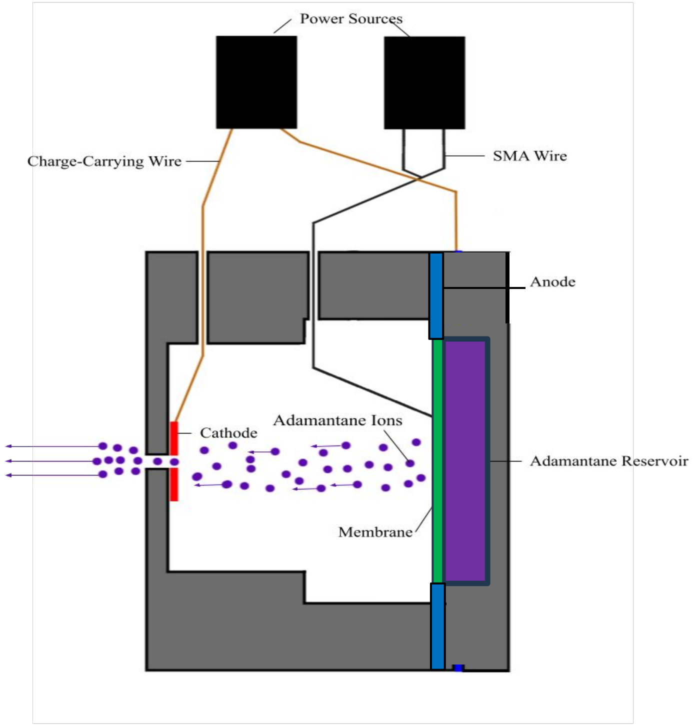
Motivation

- Increase usage of CubeSat for scientific missions (NASA CAPSTONE)
- Increased Legislation Regarding short windows for Satellite Deorbiting (NASA & ESA)
- Need to develop small modular thrusters for orbital maneuvers and decommissioning
    - Adamantane sublimes readily and allows for the compact, light weight design needed for CubeSats
    - Similar atomic mass to Xenon and higher ionization cross-section

Concept of Operation

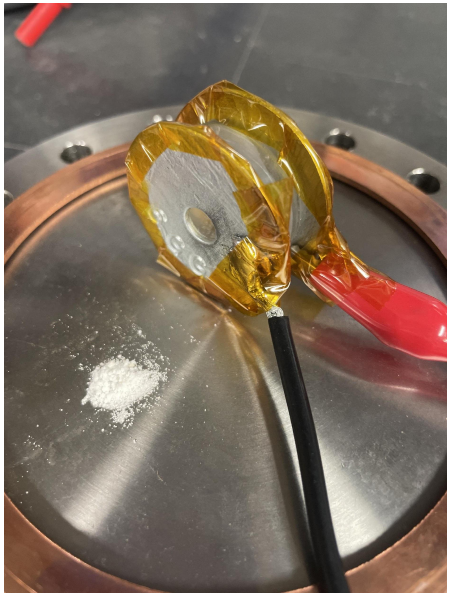
The Asteria Project

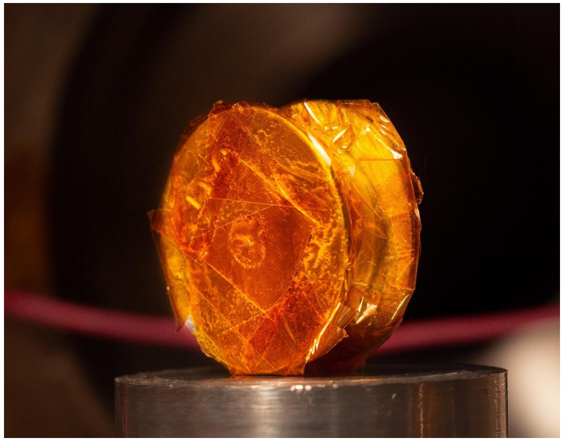
- Simple Ion Gun using a propellant that sublimates without the need for a heater and has a power usage under 10W



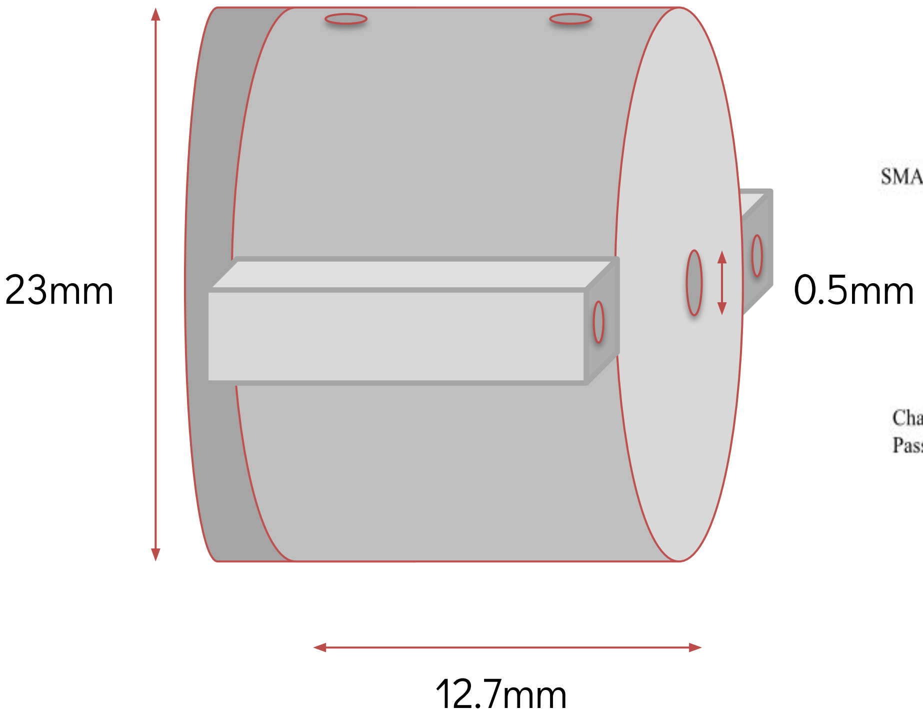
Initial Design

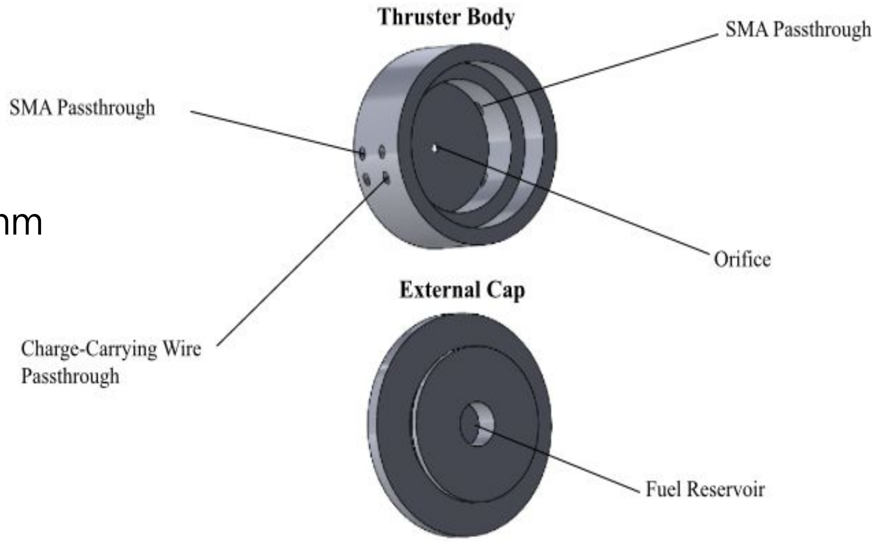
- Made of off-the-self components (washers and clear tubing)
- Slightly larger design with no separation of propellant revisor from ionization chamber





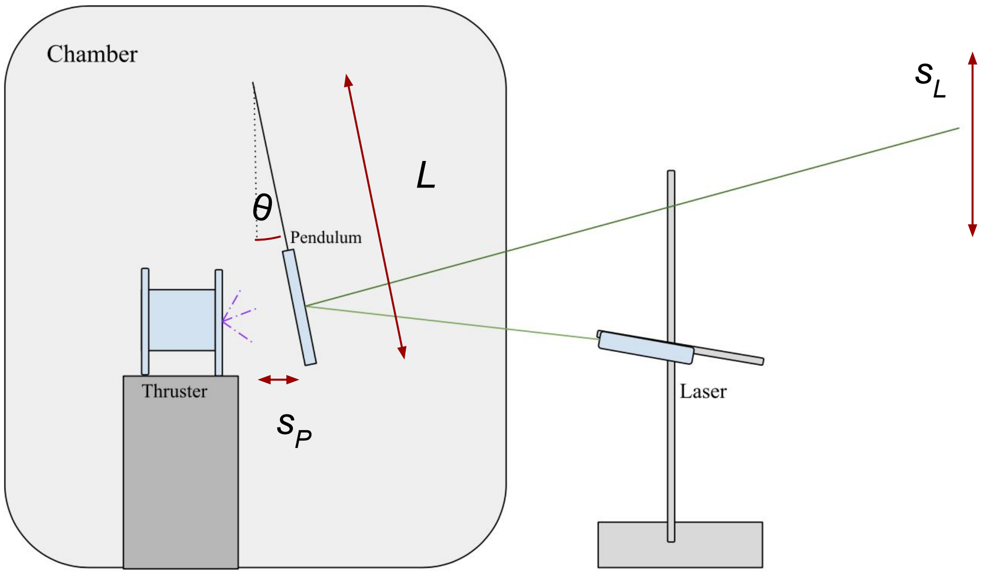
Current Thruster Design





Thrust Measurement

- Indirect thrust measurement with simple pendulum
- Horizontal displacement of the pendulum converted to vertical displacement of a laser
- Tested at both rough and high vacuum
- Grounded pendulum and chamber



$$F_T = mg\sin\theta$$

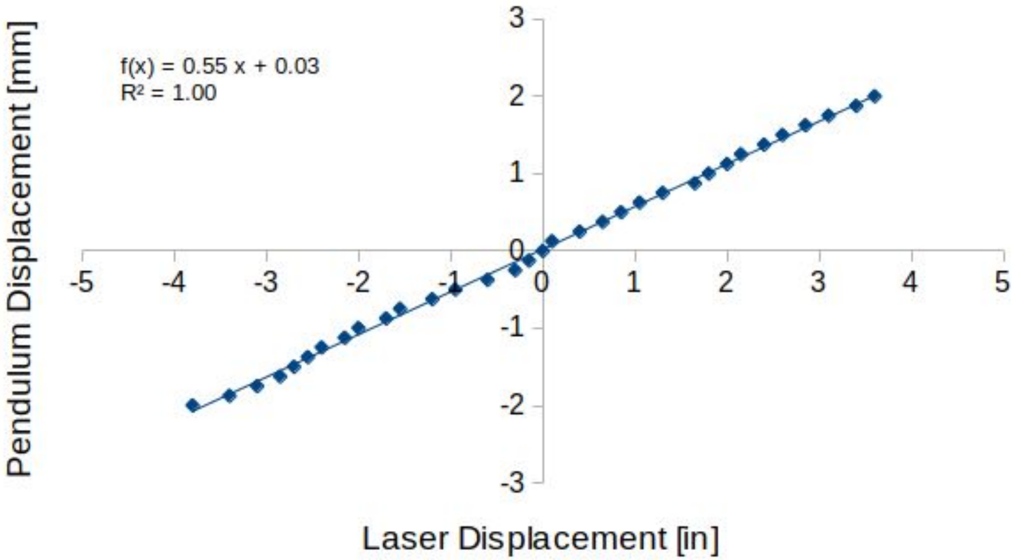
$$F_T = \frac{mg s_P}{L}$$

$$s_P = C s_L$$

$$\boxed{F_T = \frac{mgC s_L}{L}}$$

Calibration

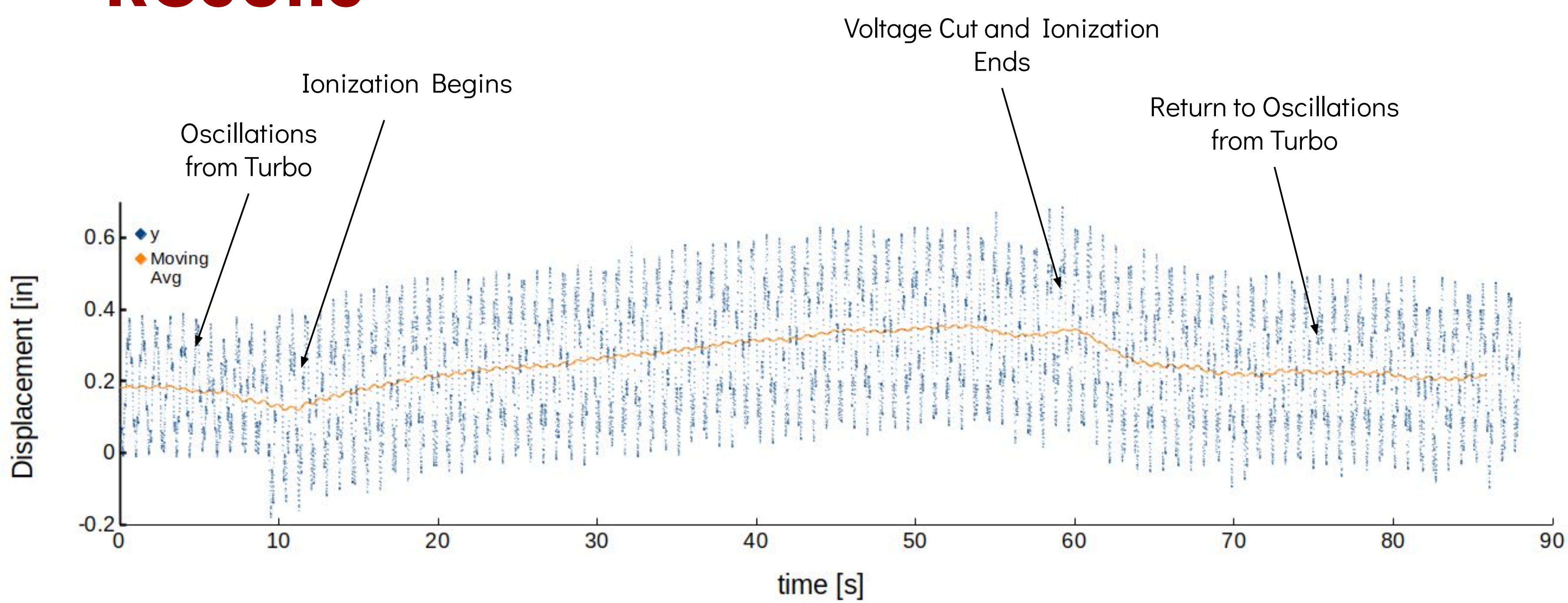
- Laser position is calibrated using a micrometer to displace the pendulum
- 1/16 mm horizontal displacement of the pendulum



Calibration Constant, C = 5.5×10^{-4}

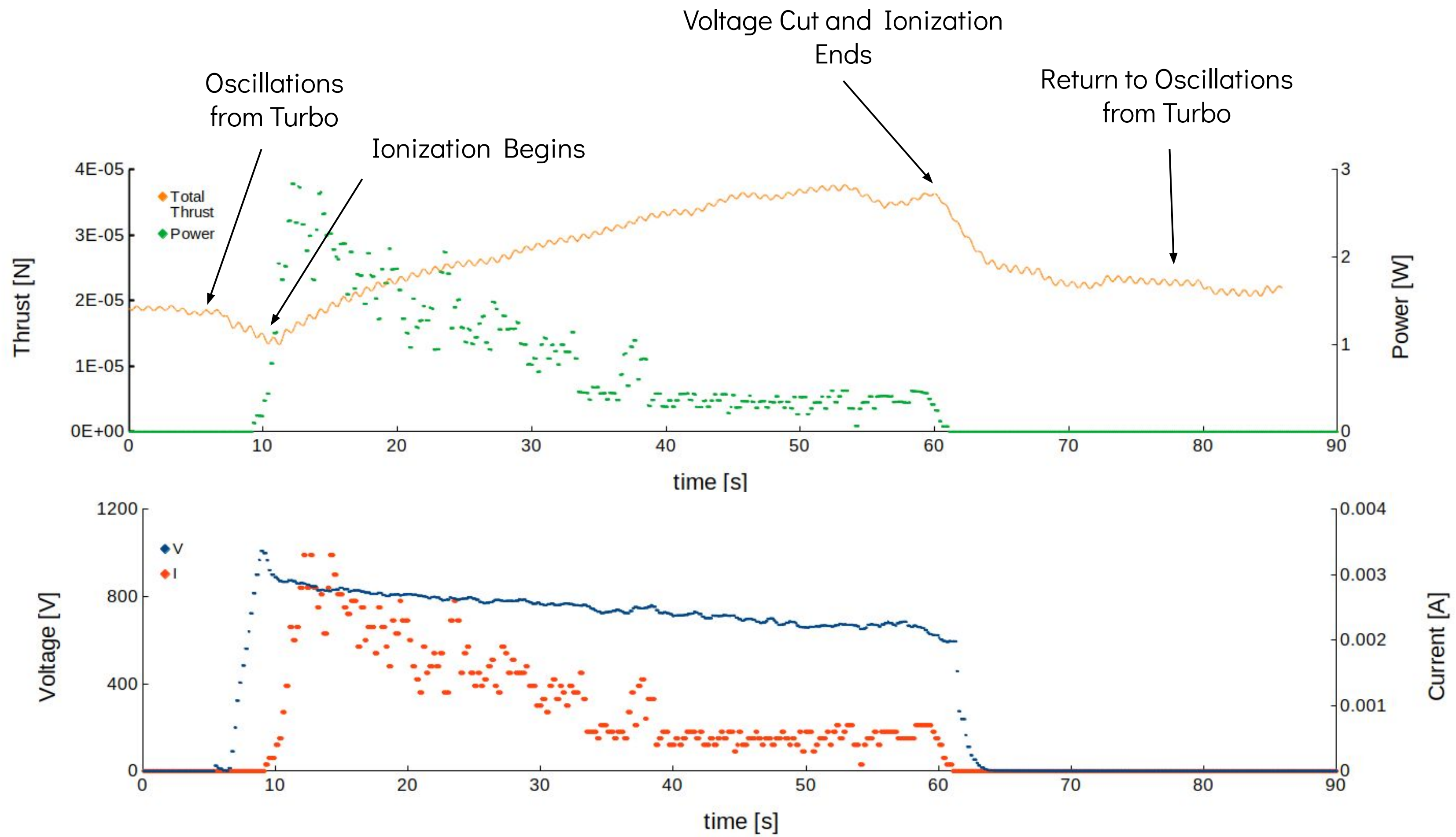
~50x Signal Amplification

Results



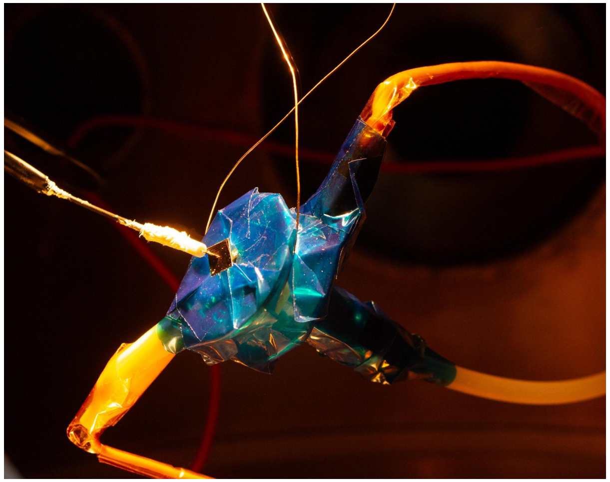
average thrust value was calculated at 29 μN, in comparison to 18 μN when operating unpowered and in a cold gas mode

Results



Voltage Cut and Ionization Ends
Oscillations from Turbo
Ionization Begins
Return to Oscillations from Turbo
Total Thrust
Power
Thrust [N]
Power [W]
4E-05
3E-05
2E-05
1E-05
0E+00
0
1
2
3
0
10
20
30
40
50
60
70
80
90
time [s]
V
I
Voltage [V]
Current [A]
1200
800
400
0
0.004
0.003
0.002
0.001
0
time [s]

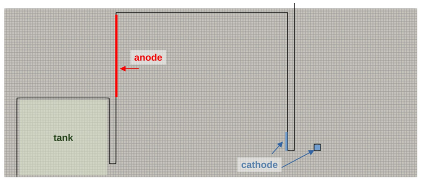
Characterization of Plasma



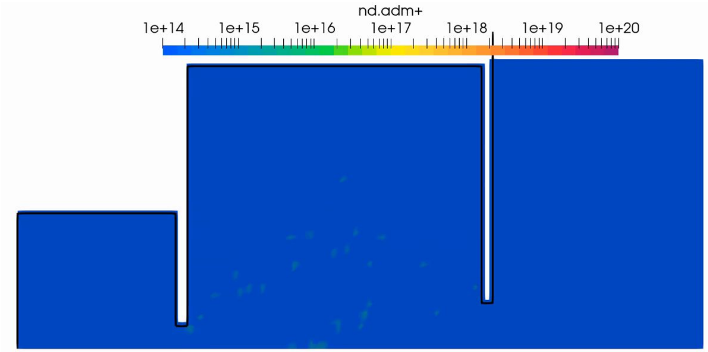
Property	Ambient Plasma	Propellant Flow
Electron density (n_e), m^{-3}	4.17*10^17 +/- 10.9%	5.79*10^17 +/- 11.9%
Electron temperature (T_e), eV	2.9 +/- 22%	5.68 +/- 18.1%
Plasma potential (Φ_p), V	12.63 +/- 2.3%	12.32 +/- 5.1%
Floating potential (Φ_f), V	9. 90 +/- 6.4%	5.39 +/- 30.5%

2D ES-PIC Simulations

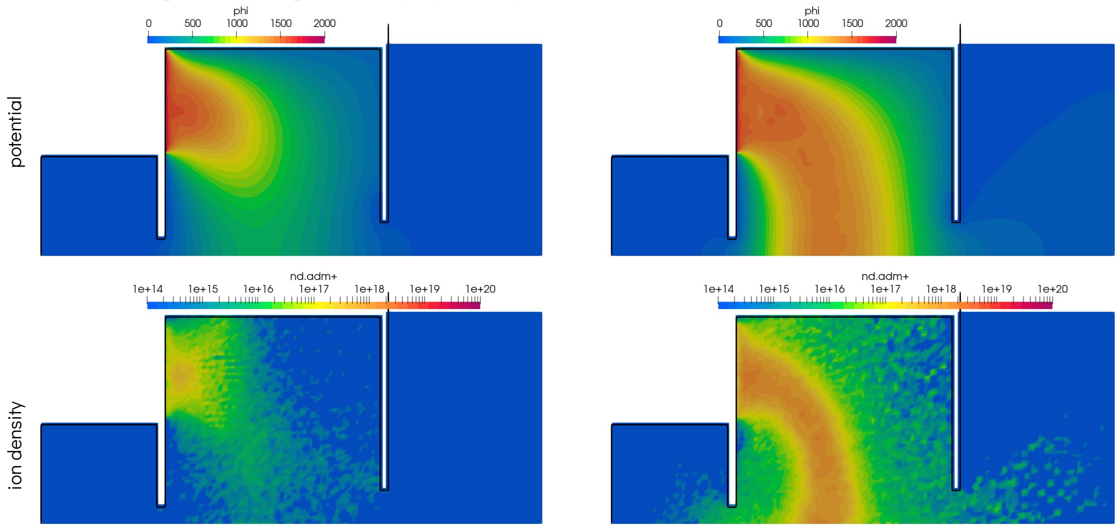
- Performed numerical simulations of several thruster design: nominal, external cathode, big anode, back anode, and cone
  - No significant difference, besides ionization starting in propellant tank with “back anode”. External cathode does not seem to play a noticeable role.
- ES-PIC method, all species represented by particles.
  - Simulation begins by a neutral-only run.
  - Electrons injected from the cathode, ionization modeled with MCC
  - Using a merging algorithm to reduce the number of simulation particles
- Ionization begins near the anode. A radial electric field then establishes.
  - Electrons then “leak out” to the propellant tank, leading to formation of dense plasma.
  - The simulation mesh is not sized appropriately to resolve the resulting Debye length, leading to non-physical potential values here (future work)



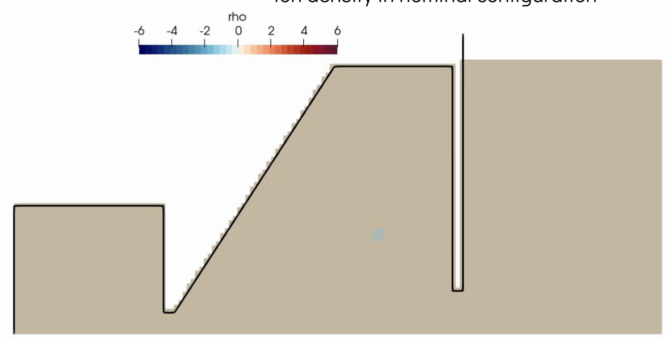
computational domain



ion density in nominal configuration

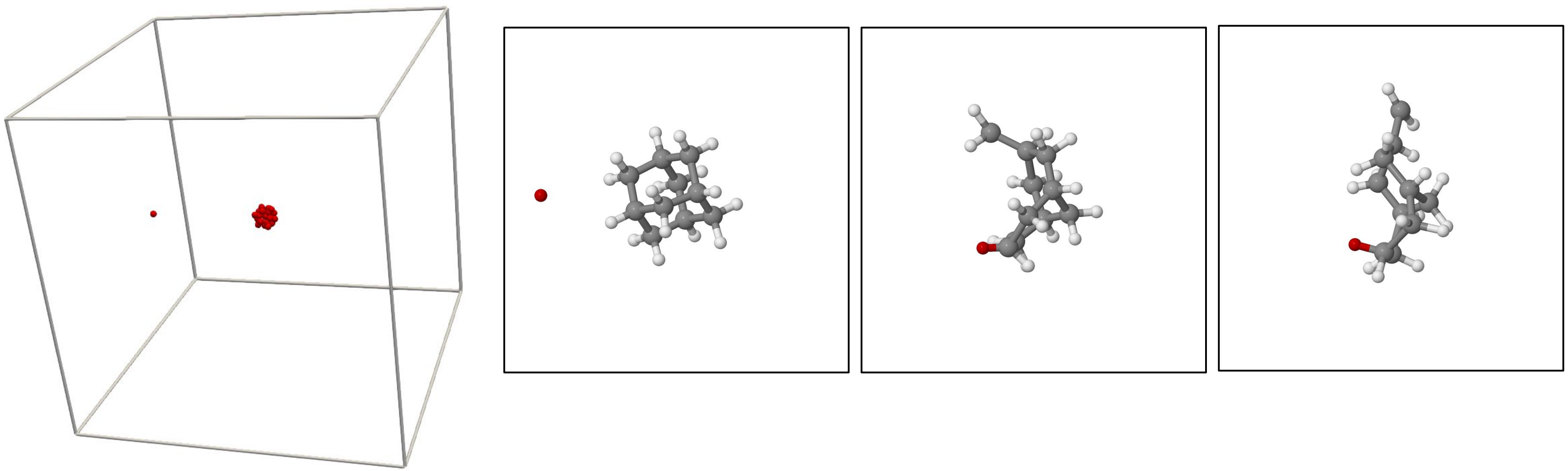


time step 12,500 time step 30,000



charge density for conical configuration

MD Simulations



- Molecular dynamics simulations were conducted to predict species produced during fragmentation
- The reactive force field method was used in LAMMPS to characterize bond breakage between atoms
- Considered electron (modeled as energetic hydrogen) and ion (neutral molecule) impact behavior
- Results showing fragmentation and in some instances, bonding of the incident particle to the molecules
- Currently running more simulations to characterize species probabilities

Future Work

- Thrust Stand Improvements
  - Direct thrust measurement with inverted pendulum
- Improved Instrumentation for V(t) and I(t)
- Full system design for integration on CubeSat with ability to collect thruster data from ground (long term)
  - Miniaturization
  - Integrated power supply
  - Multi-thruster design
  - Improved Hot wire filament for neutralization source
  - Valve/membrane for fuel storage

Conclusion

- Developing a small modular thruster with no need for a heater, large external propellant tanks, or complex controls
- Our simplistic and low power design utilizes a solid propellant that has similar atomic mass as Xenon and sublimates readily

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BLUE ORIGIN

USC Viterbi School of Engineering

BOEING