CubeSat Ambipolar Thruster

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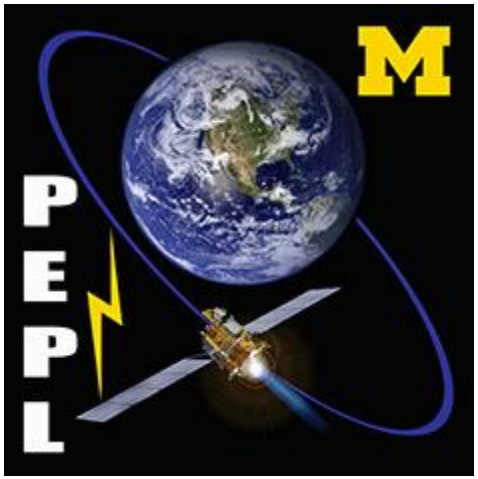
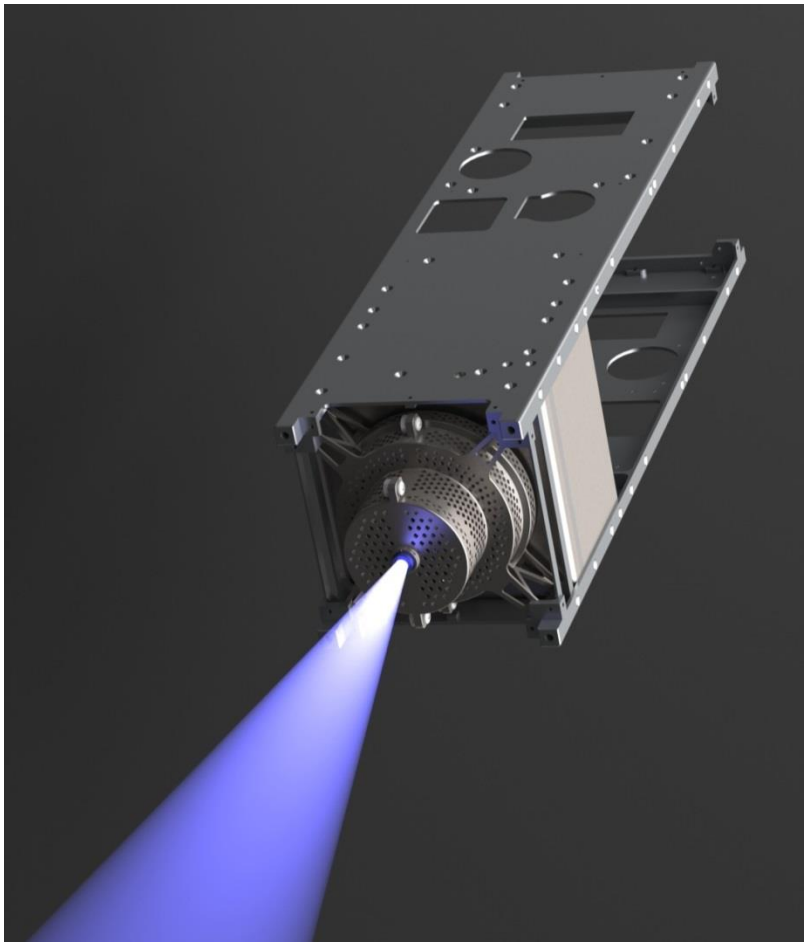
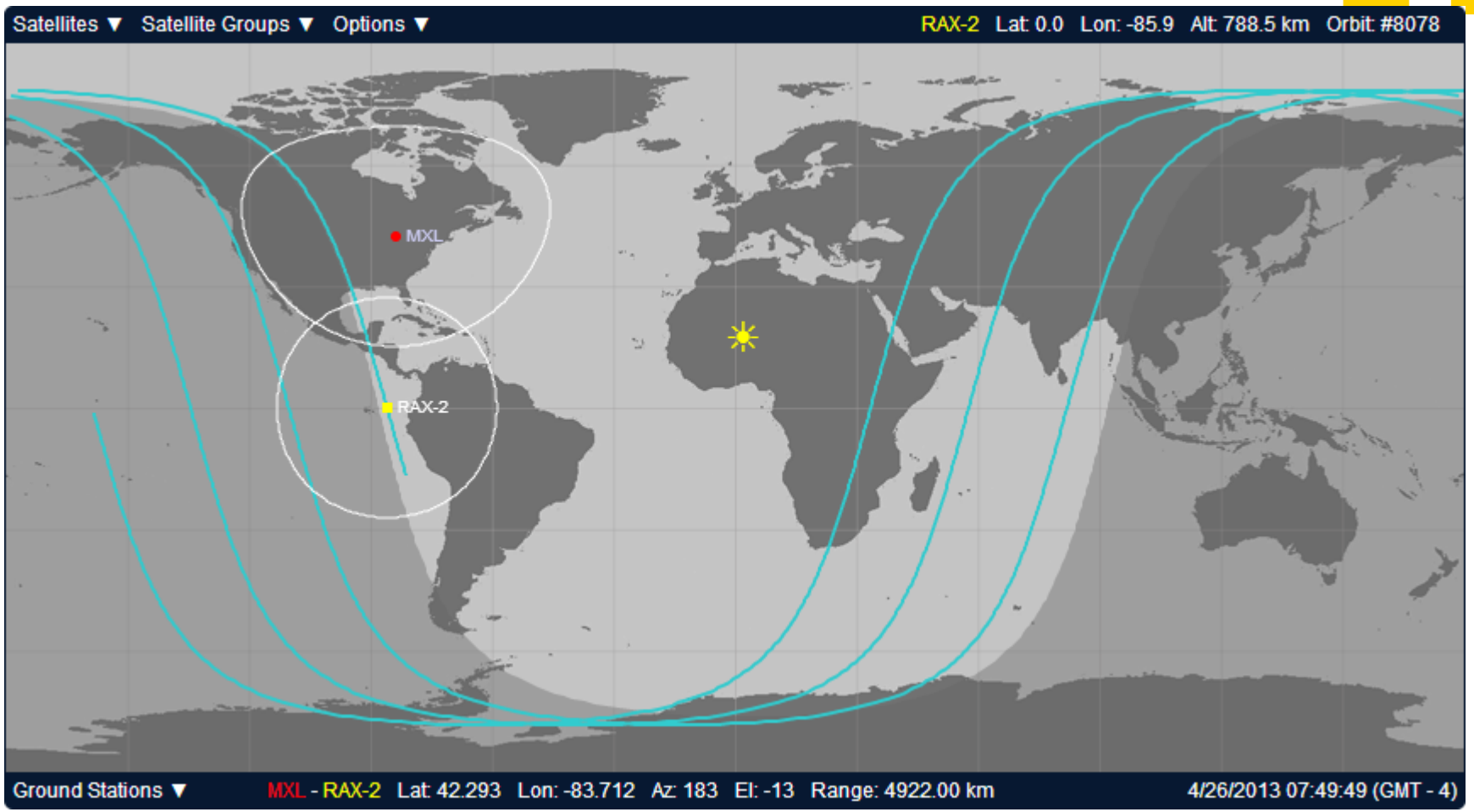


Outline

- CubeSat Ambipolar Thruster
  - Components
  - Performance
  - Modeling
- PATRIOT and future missions

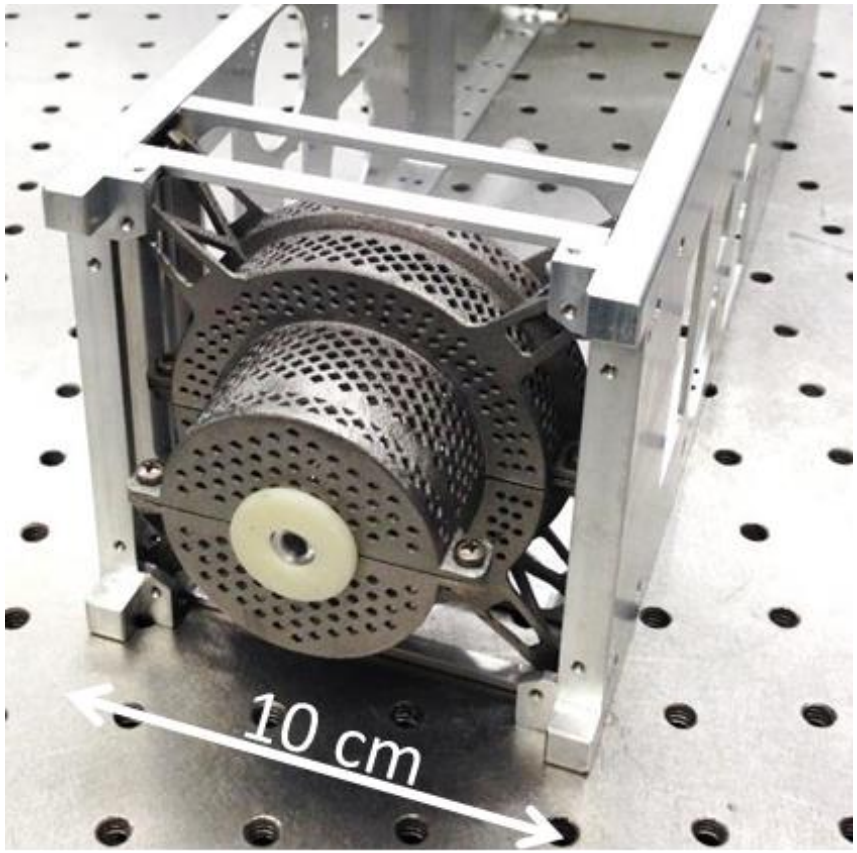


Without propulsion, CubeSats are stuck in their deployed orbit

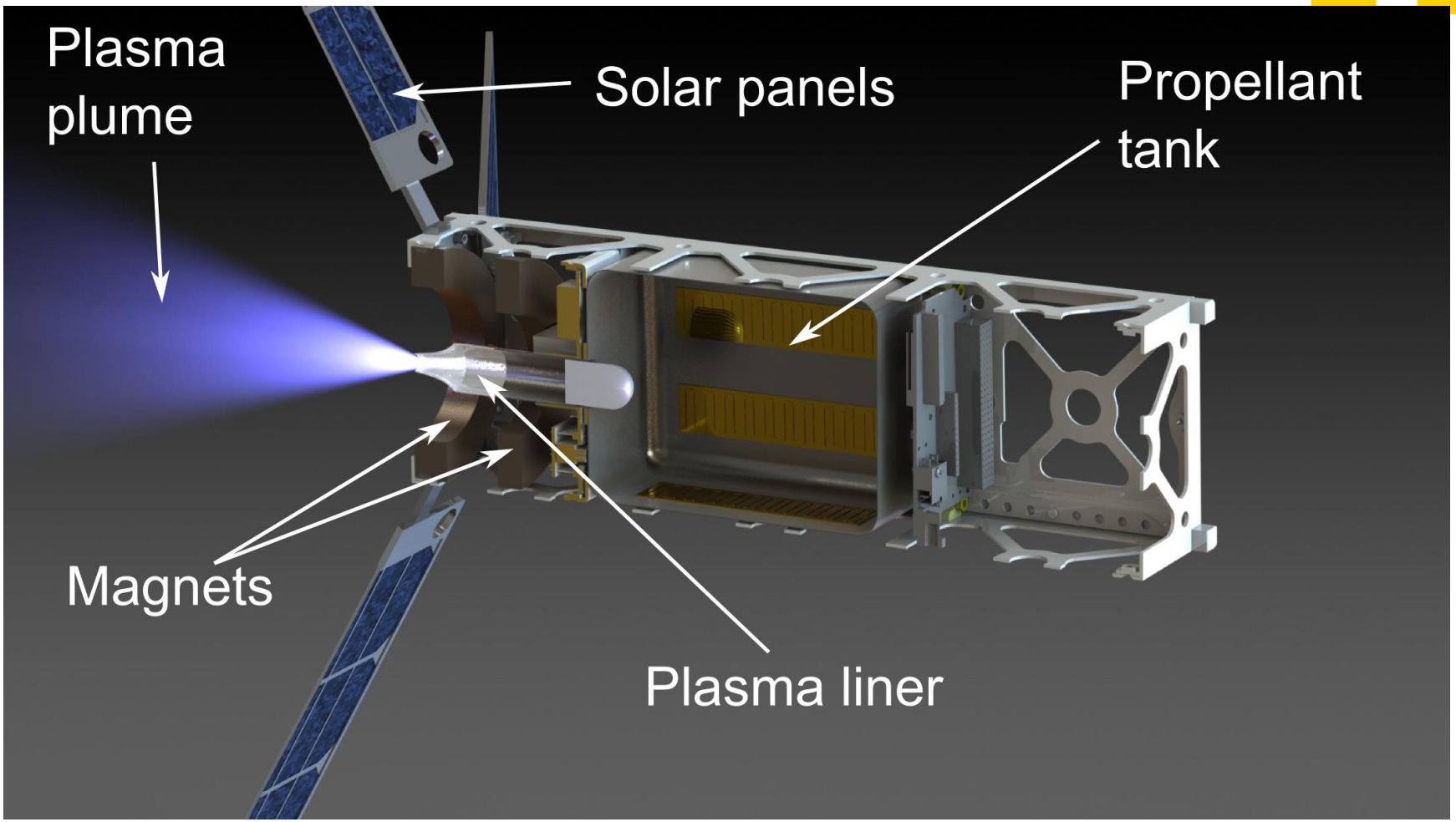


CubeSat Ambipolar Thruster (CAT)

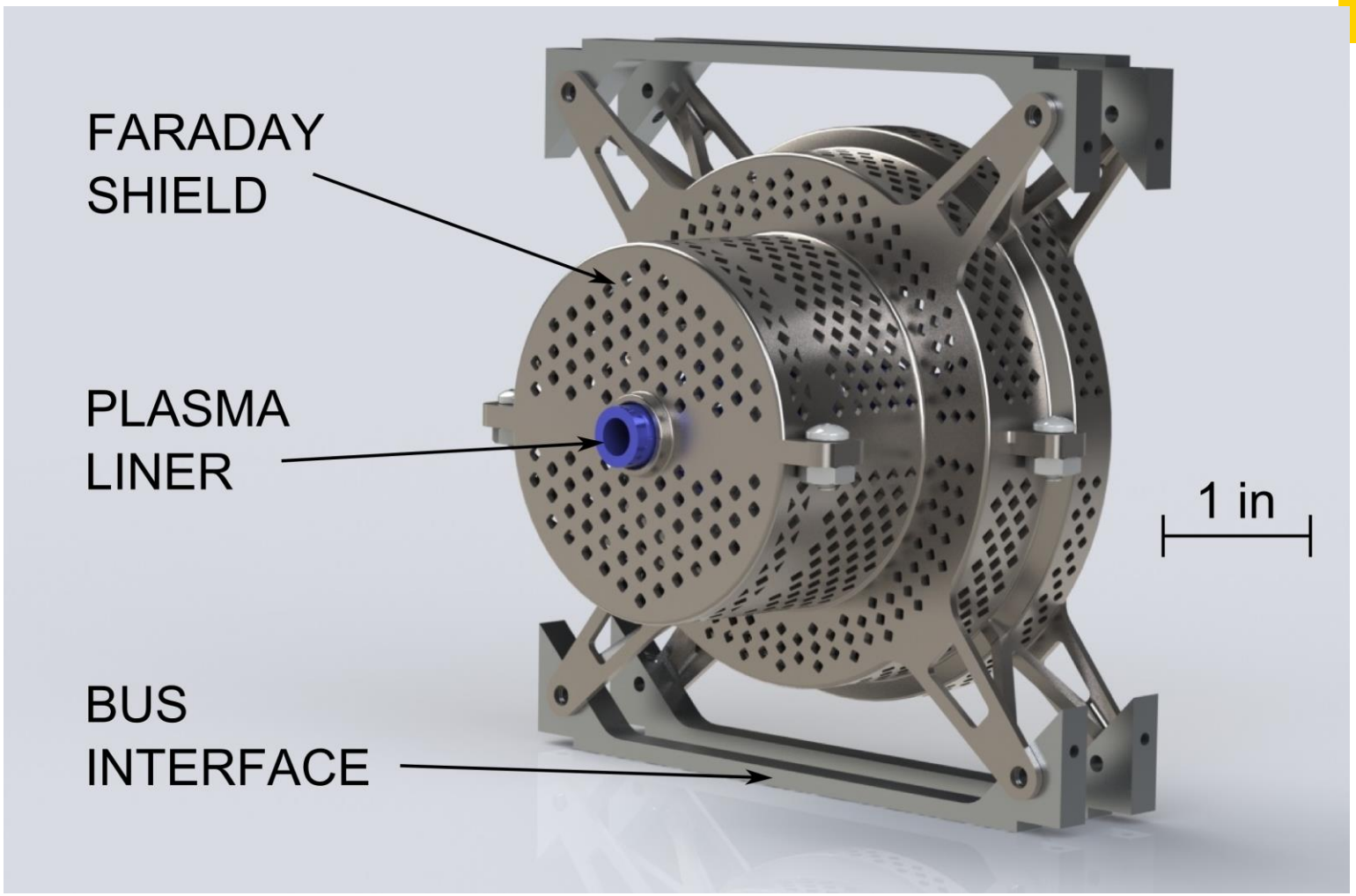
- Nominally designed for 3U
  - 6U thrust vectored version
- ~0.1U for thruster
- Mass: <1 kg
- 0.2U – 2.5U for propellant tank
- Uses “free” spring space
- 5V, 28V or 48V PPU
- 3 to 300 W, assisted by batteries
- Multiple propellants



Inside CAT:
a compact plasma source

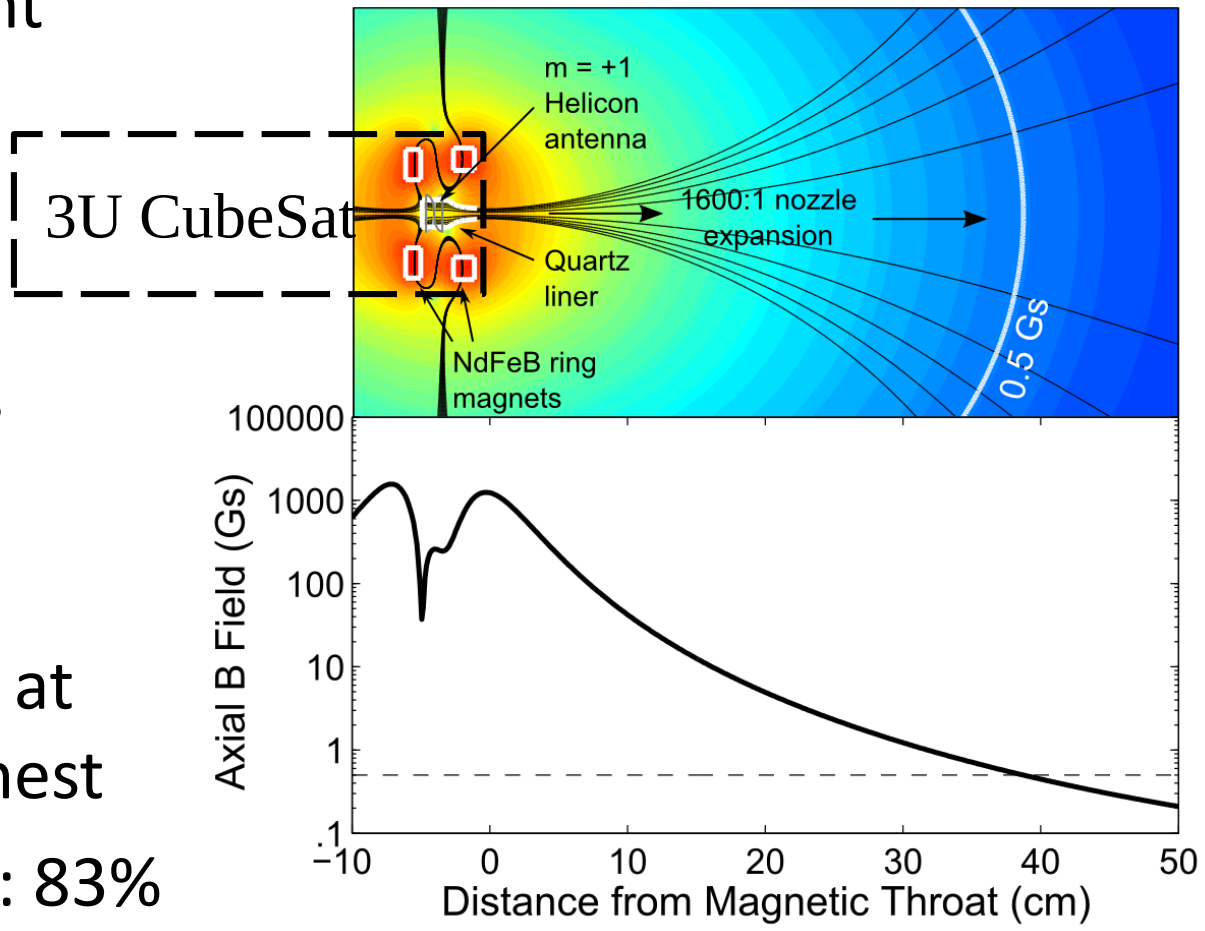


Fully assembled CAT engine



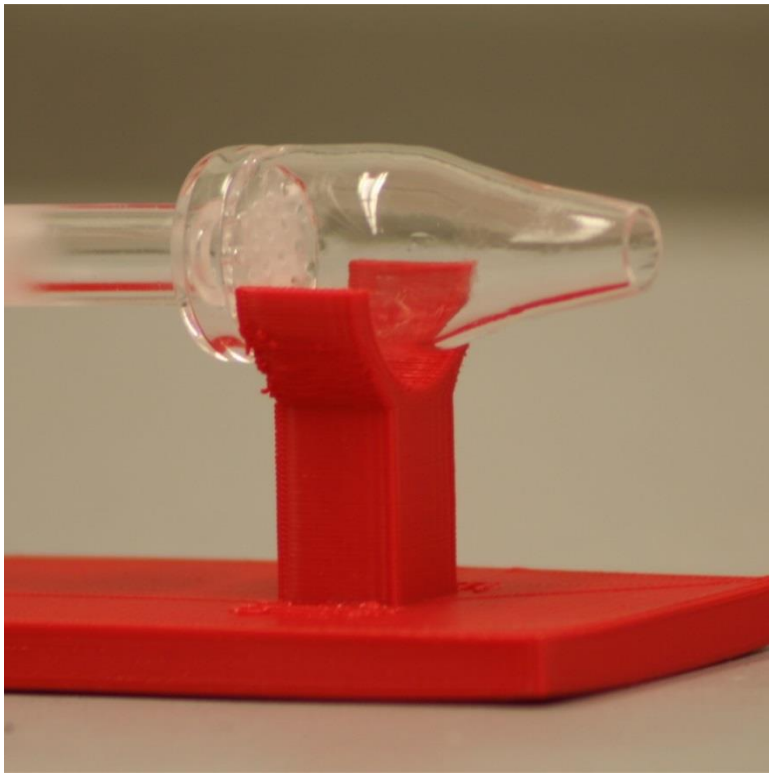
Magnets create converging-diverging magnetic field

- NdFeB permanent ring magnets
- Magnetic field at throat: 600G
- Decays to Earth's magnetic field in 40 cm
- Plasma detaches at 0.5 G at the furthest
- Nozzle efficiency: 83%



Plasma liner contains plasma, directs flow of gas

- Quartz tolerates high temperatures
- Showerhead disperses gas, protects downstream elements from plasma
- Physical nozzle follows magnetic nozzle

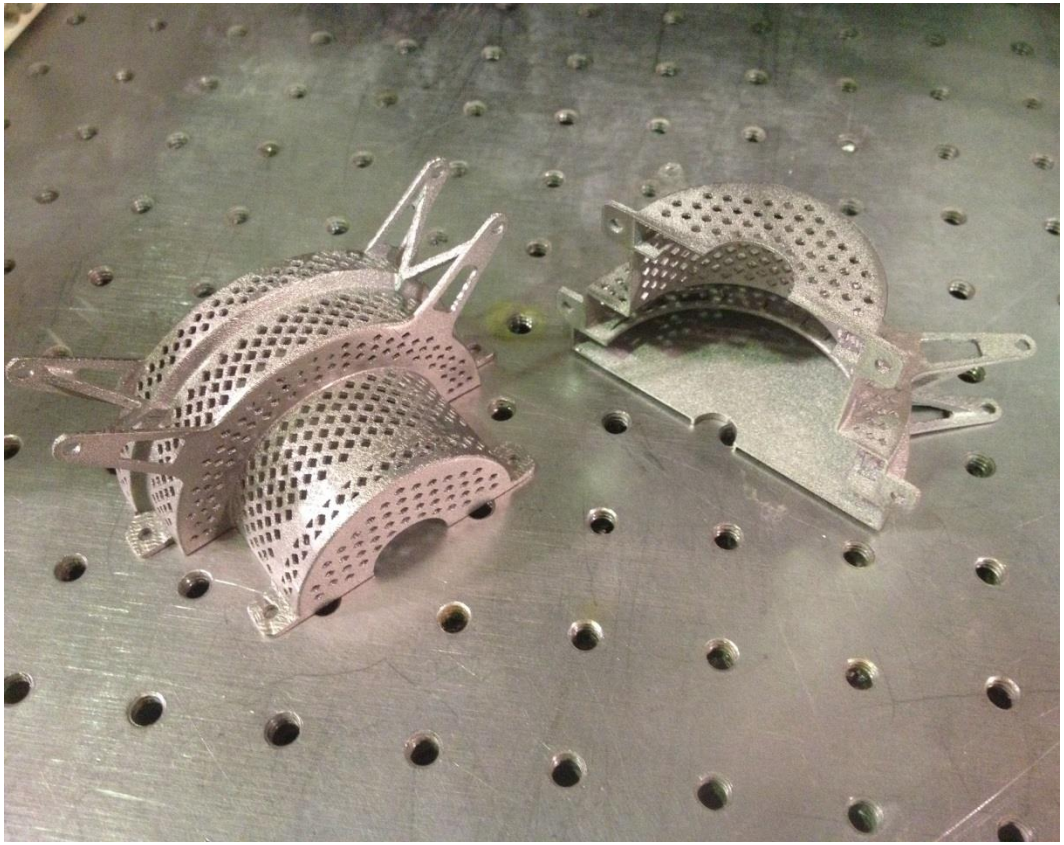


Antenna generates plasma, heats electrons

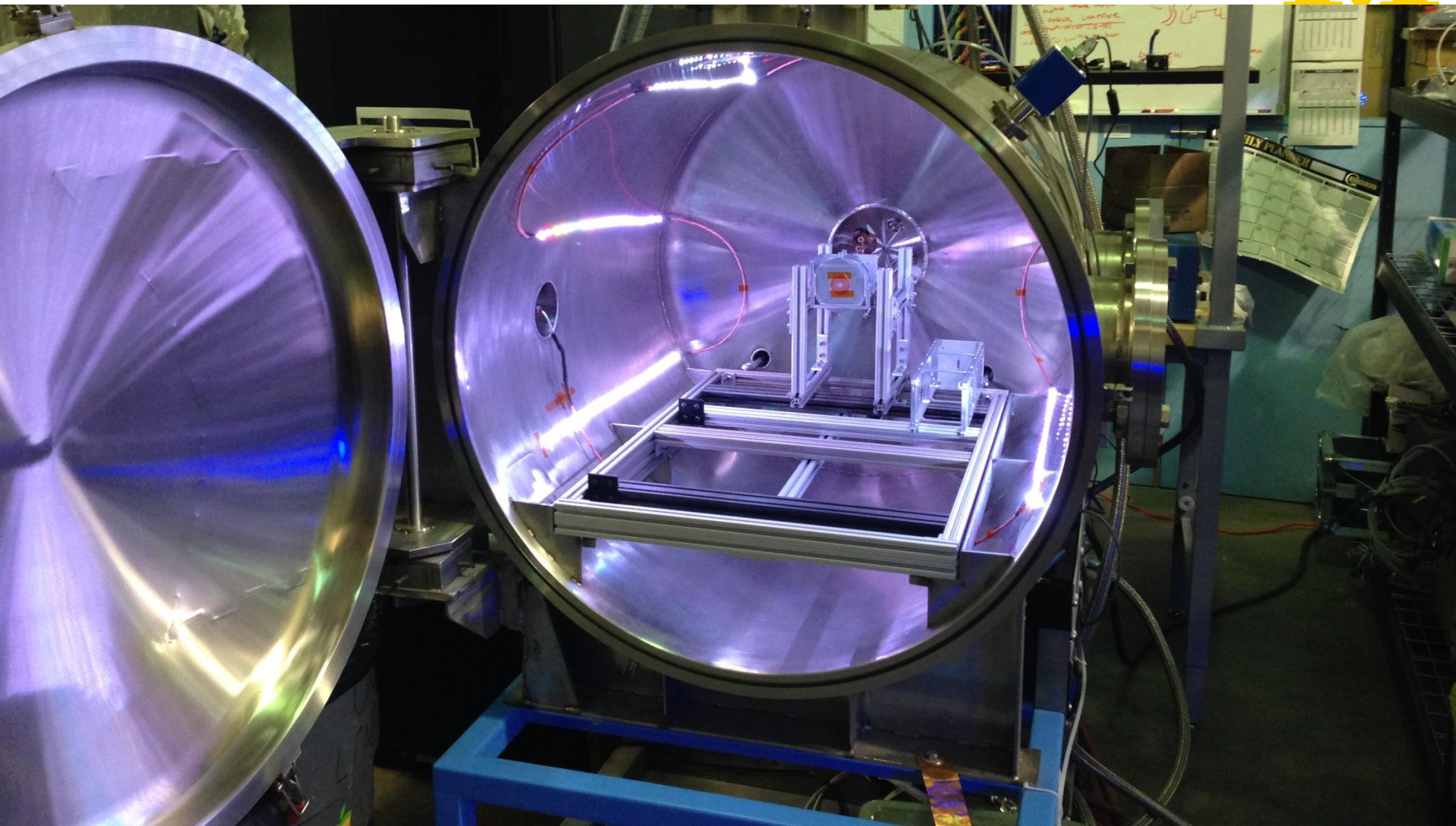
- 3D printed
  - Complex geometries possible
- Solid silver to maximize conductivity
- Helical half-twist
  - Ideal for launching helicon
- Power leads connect directly to RF source board
- Couples RF energy into electrons via helicon plasma wave

Faraday shield contains RF, encases thruster

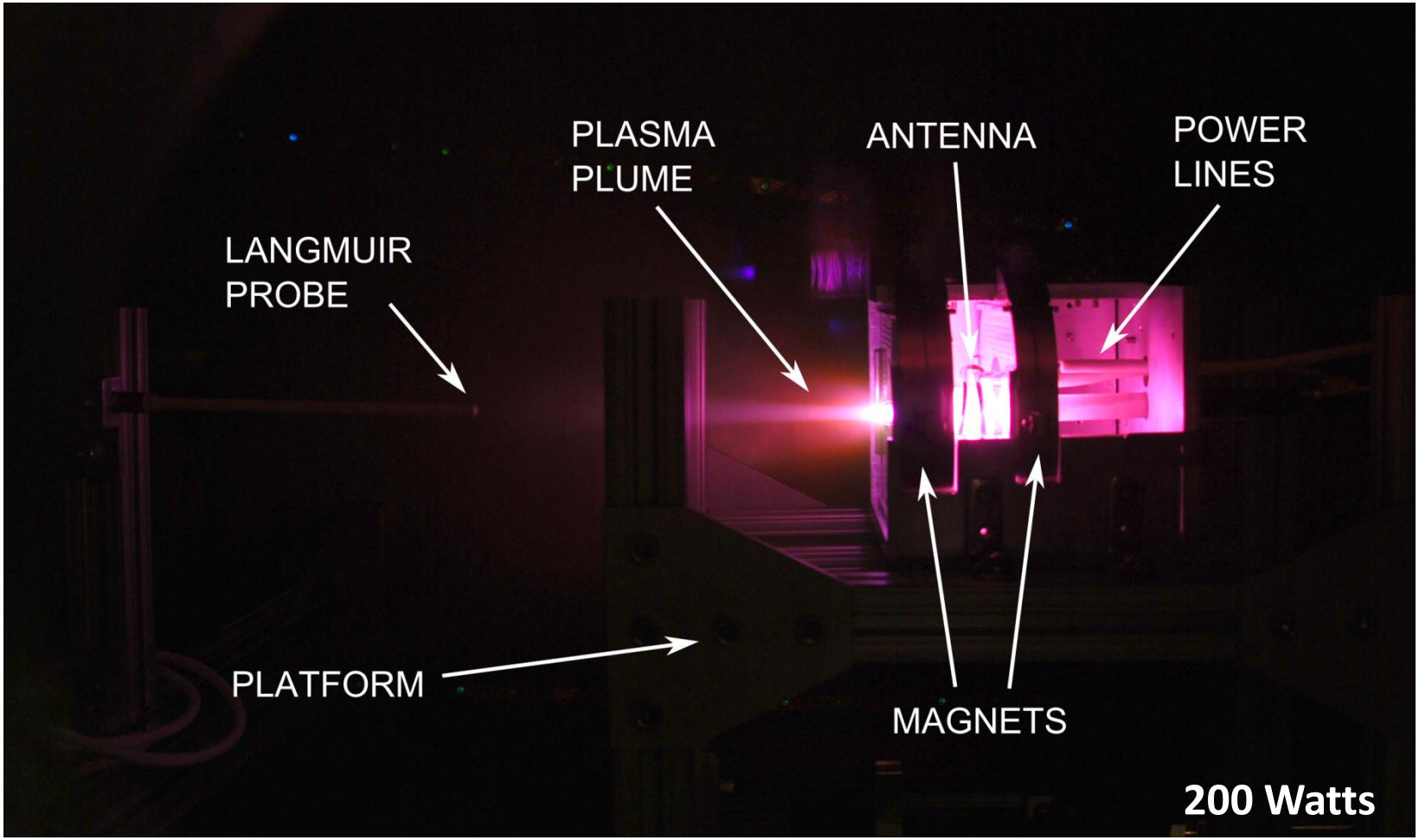
- 3D printed
  - Low cost
  - Rapid iteration
- Titanium
- Contains RF within thruster
- Structural support for liner, magnets



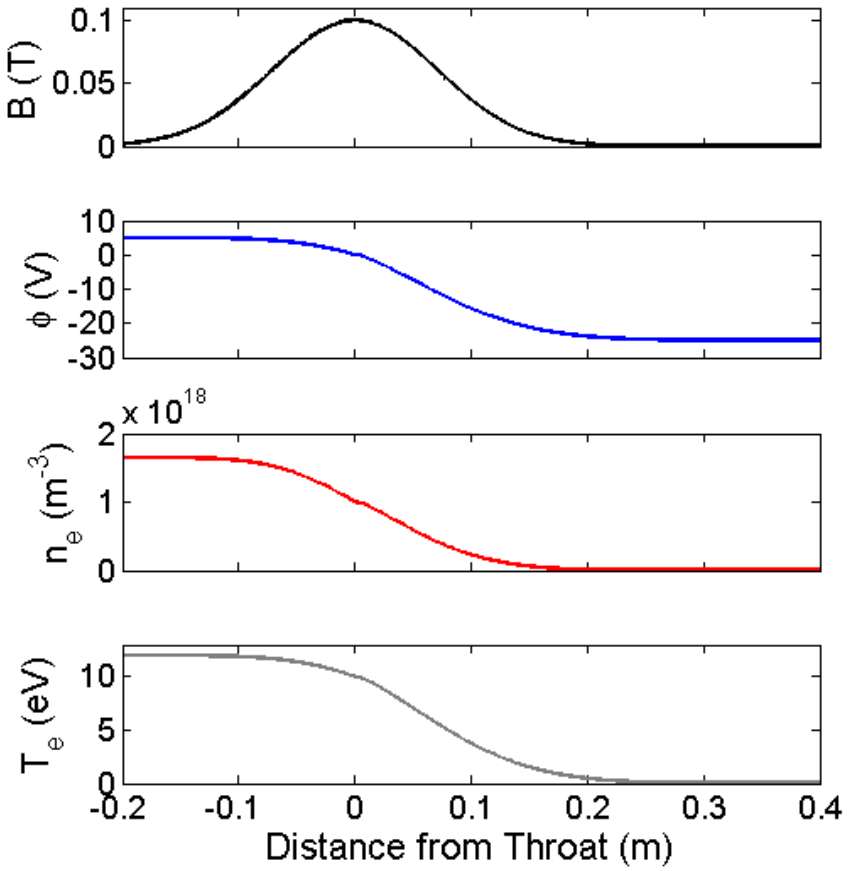
CubeSat testing chamber at PEPL within UMich



Xenon testing: plasma follows magnetic field lines



Ambipolar ion acceleration mechanism



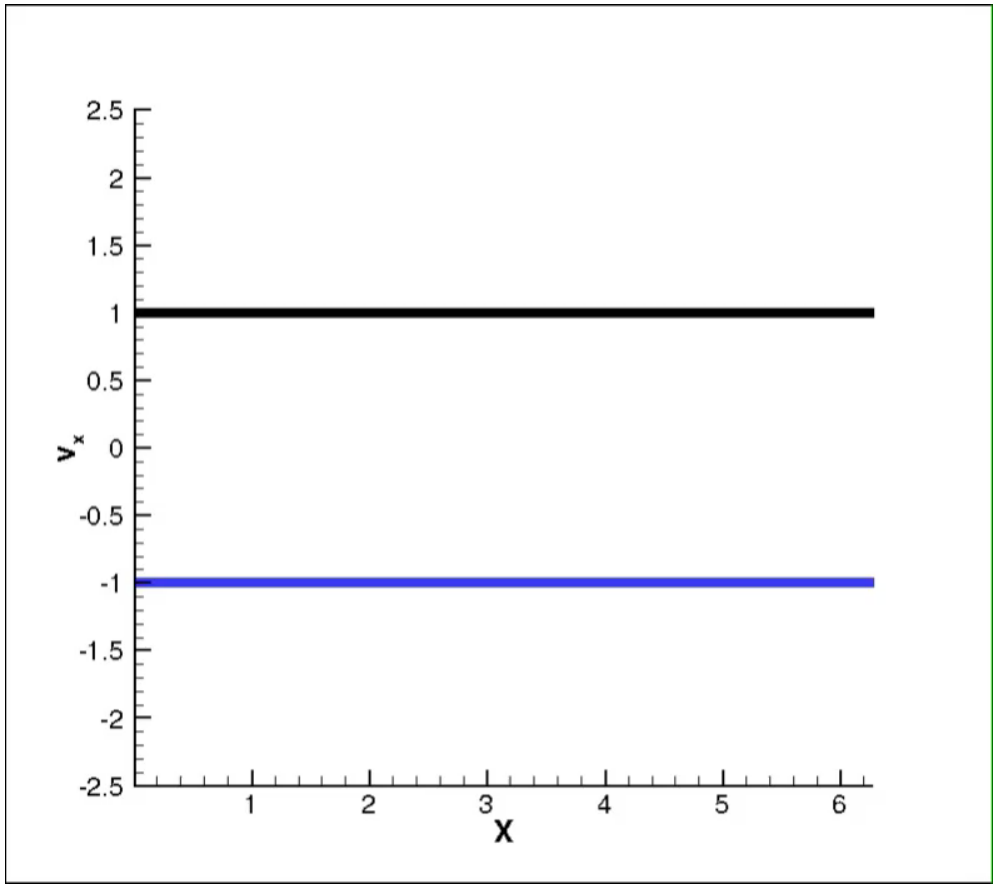
- Electrons heated by helicon wave
- Electrons rush out of nozzle
- Slow ions dragged along by Electric field
- Electrons lose thermal energy to ion kinetic energy
- Higher electron temperature → higher ion velocity
- Mechanism is critical for thrust, performance models

Particle-in-cell simulations

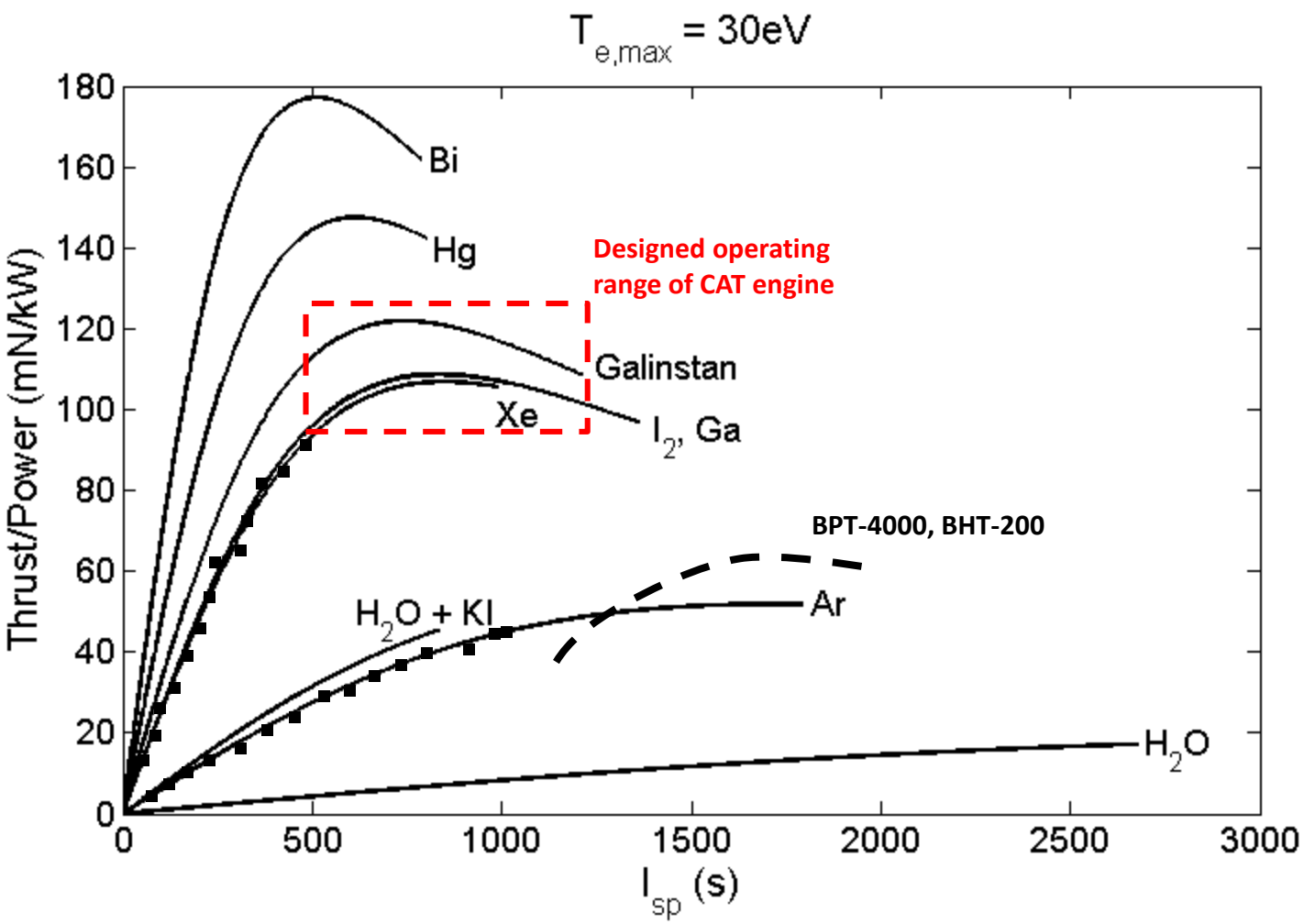
- Quasi-1D model
- Constant magnetic moment captures mirror effects

$$F_z = qE_z - \mu\nabla|B|$$

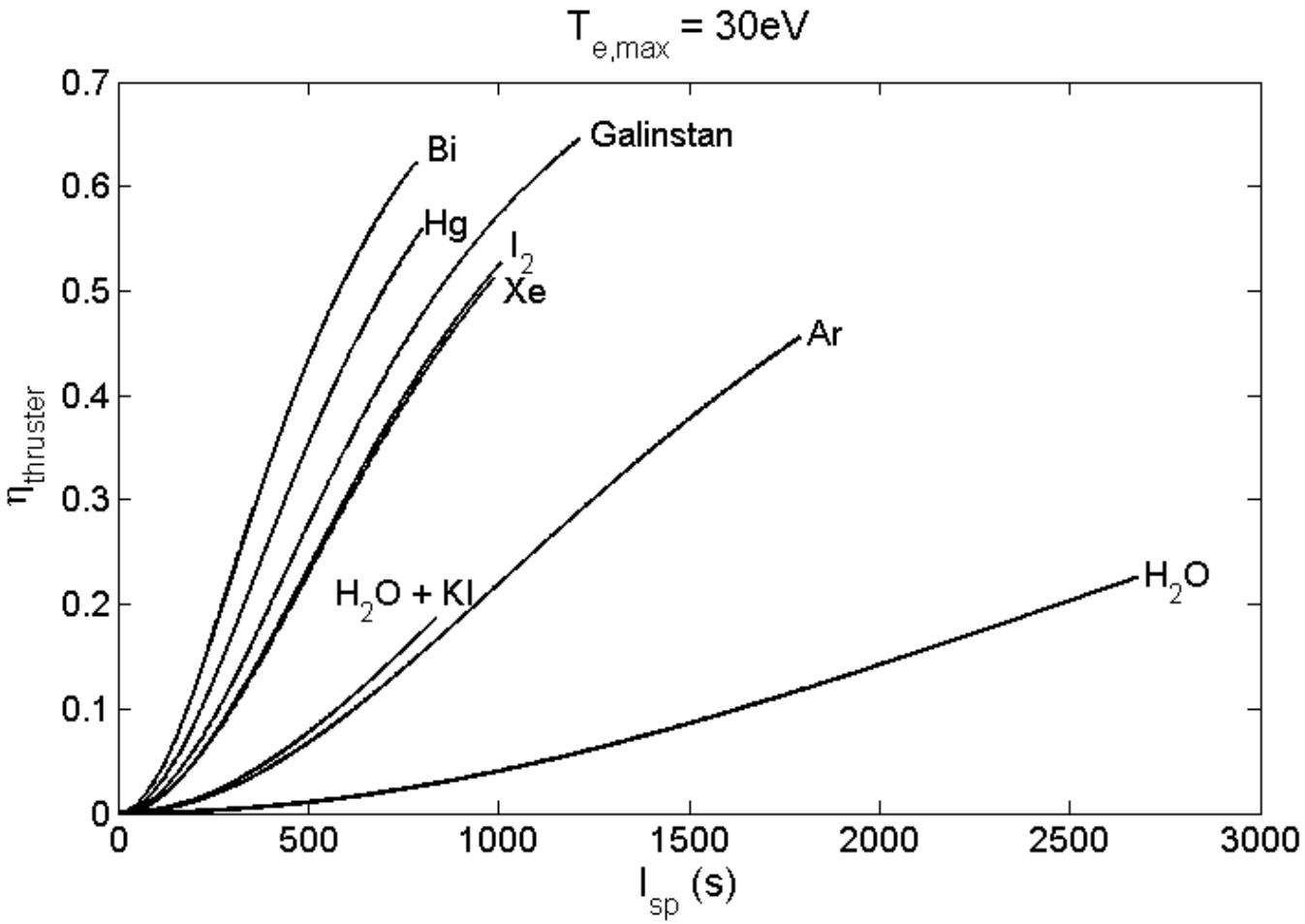
- 2 particle model will capture instabilities
- Insight into analytical model



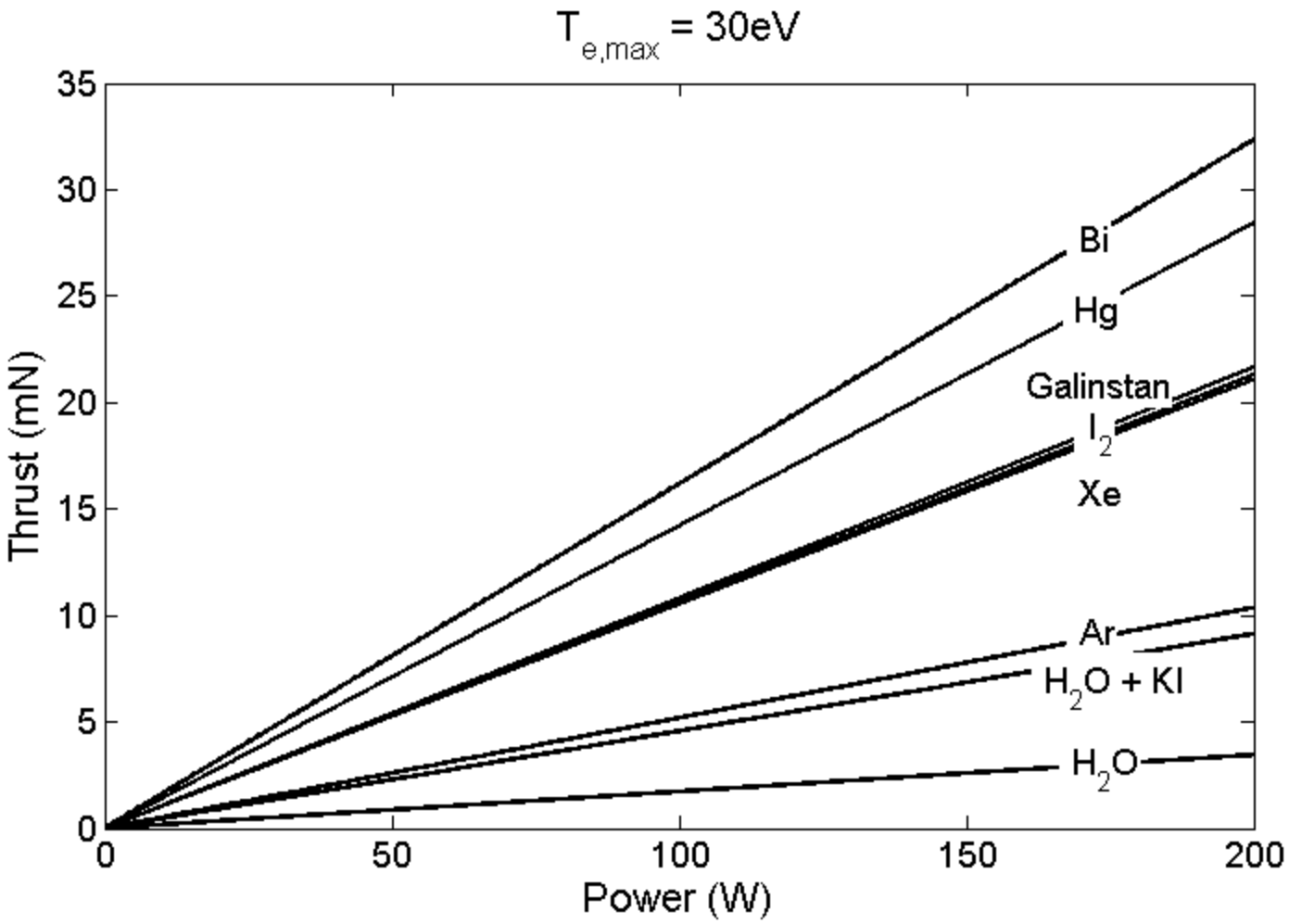
CAT design focused on high thrust to power



Thruster performance

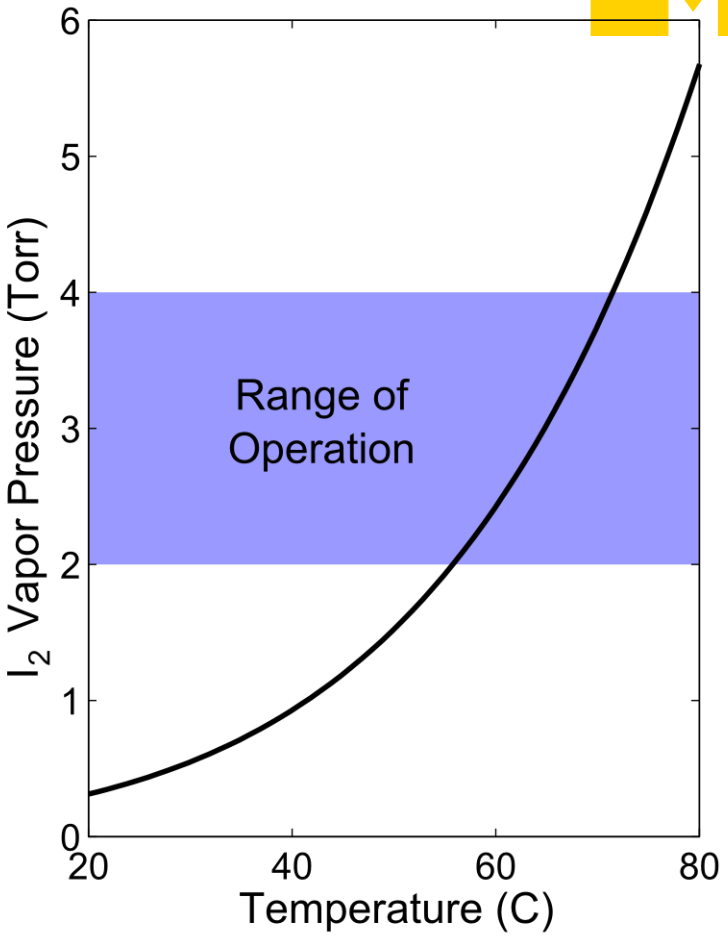


CAT design accommodates 3U CubeSat up to 100 kg class satellites

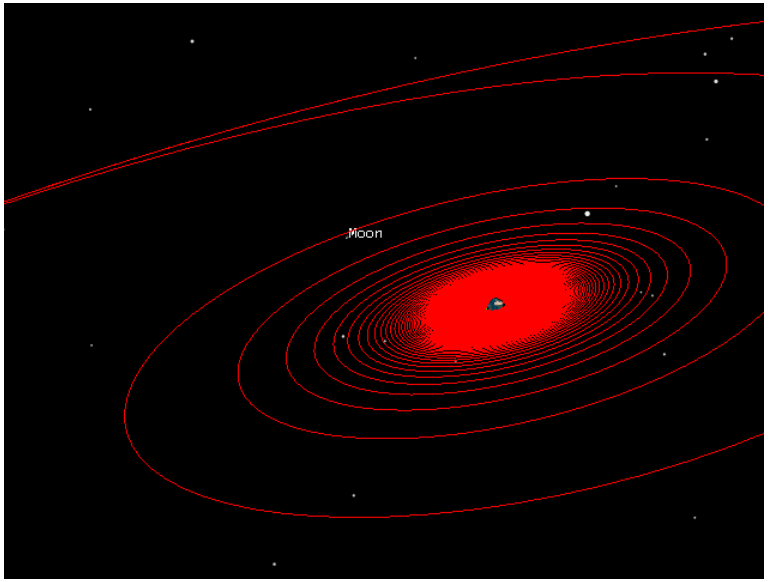


Liquid/Solid storable propellants greatly reduce volume requirements

- No onboard pressure vessel
- Solid/liquid propellants
  - Water
  - Galinstan
  - ~~Mercury~~
  - **Iodine**
- Iodine propellant system
  - Solid storable
  - Heat to control vapor pressure/mass flow rate



PATRIOT mission will test CAT on orbit

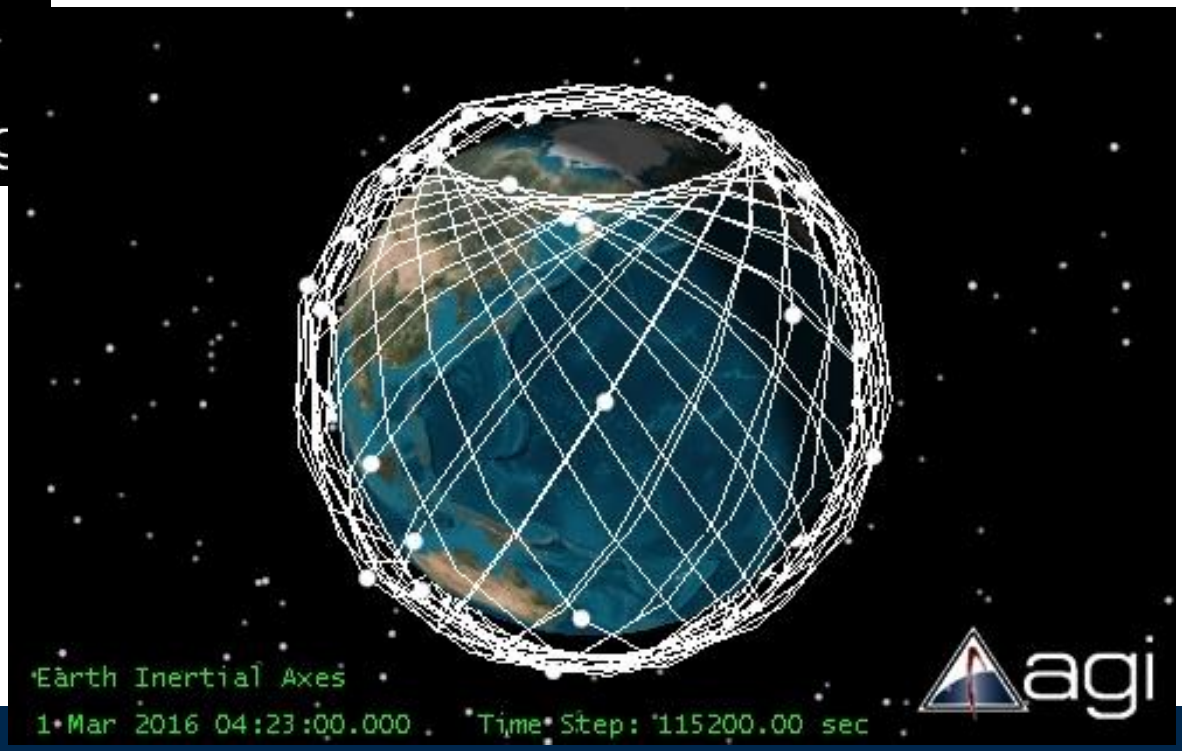


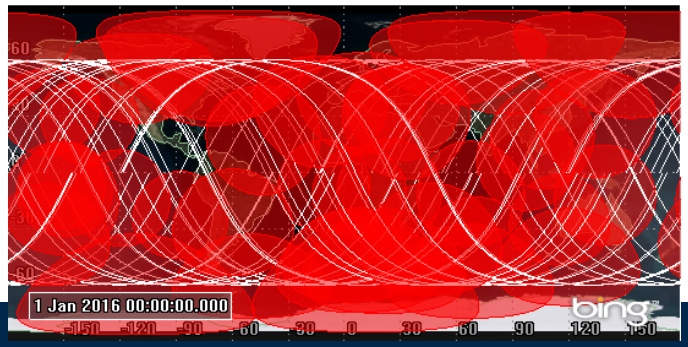
- Objectives
  - Turn CAT on
  - 2 measurements of thrust
  - Observable orbit change
  - Earth escape attempt
- Multiple flights
- Non-propulsion requirements
  - Long range communications
  - Power systems
  - Attitude control
  - RF shielding
  - Radiation shielding w/ spiral orbit

Global constellation deployment and maintenance with large delta-V capable smallsats

Initial launch vehicle orbit

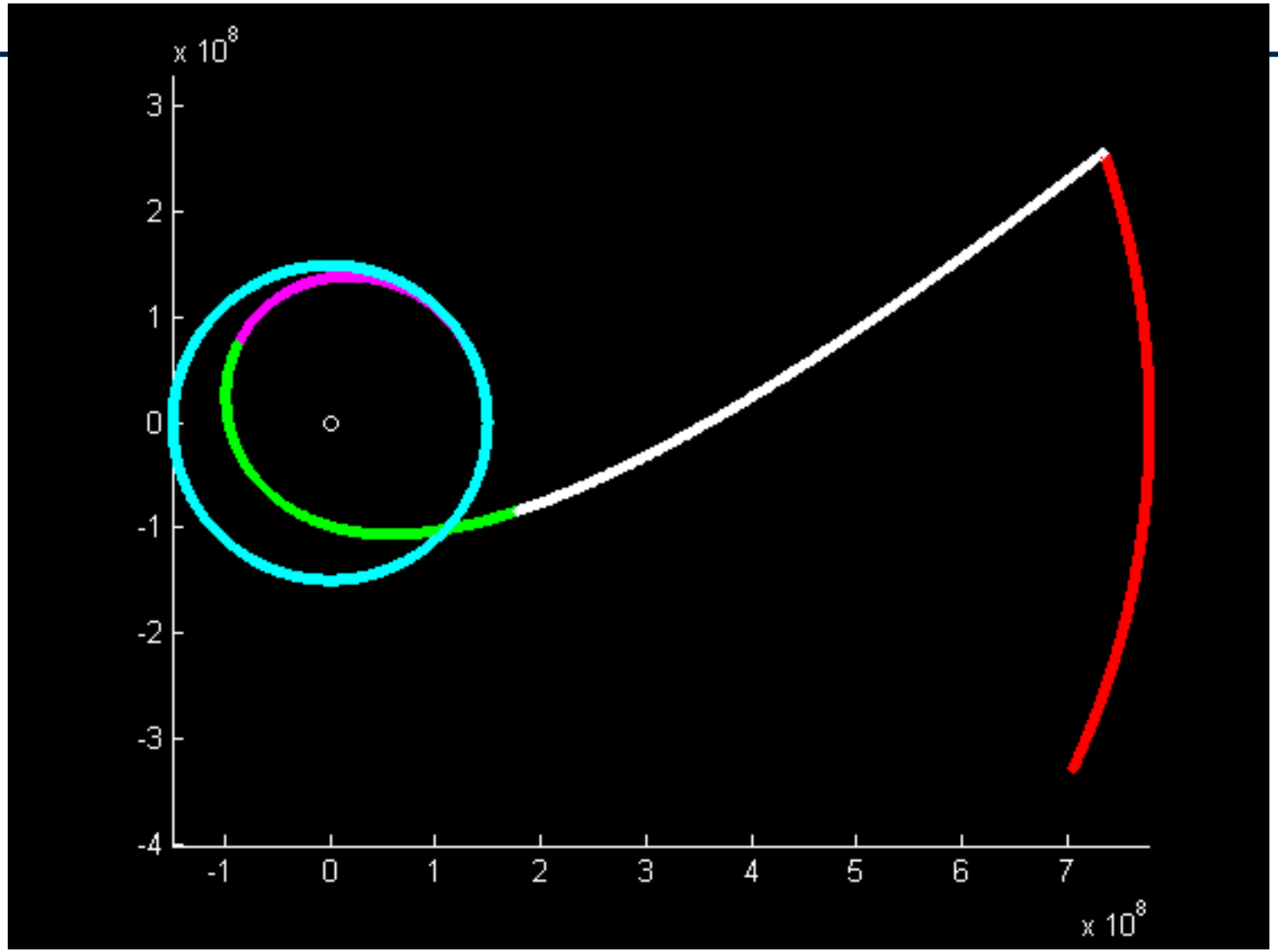
38 sats after 9mo



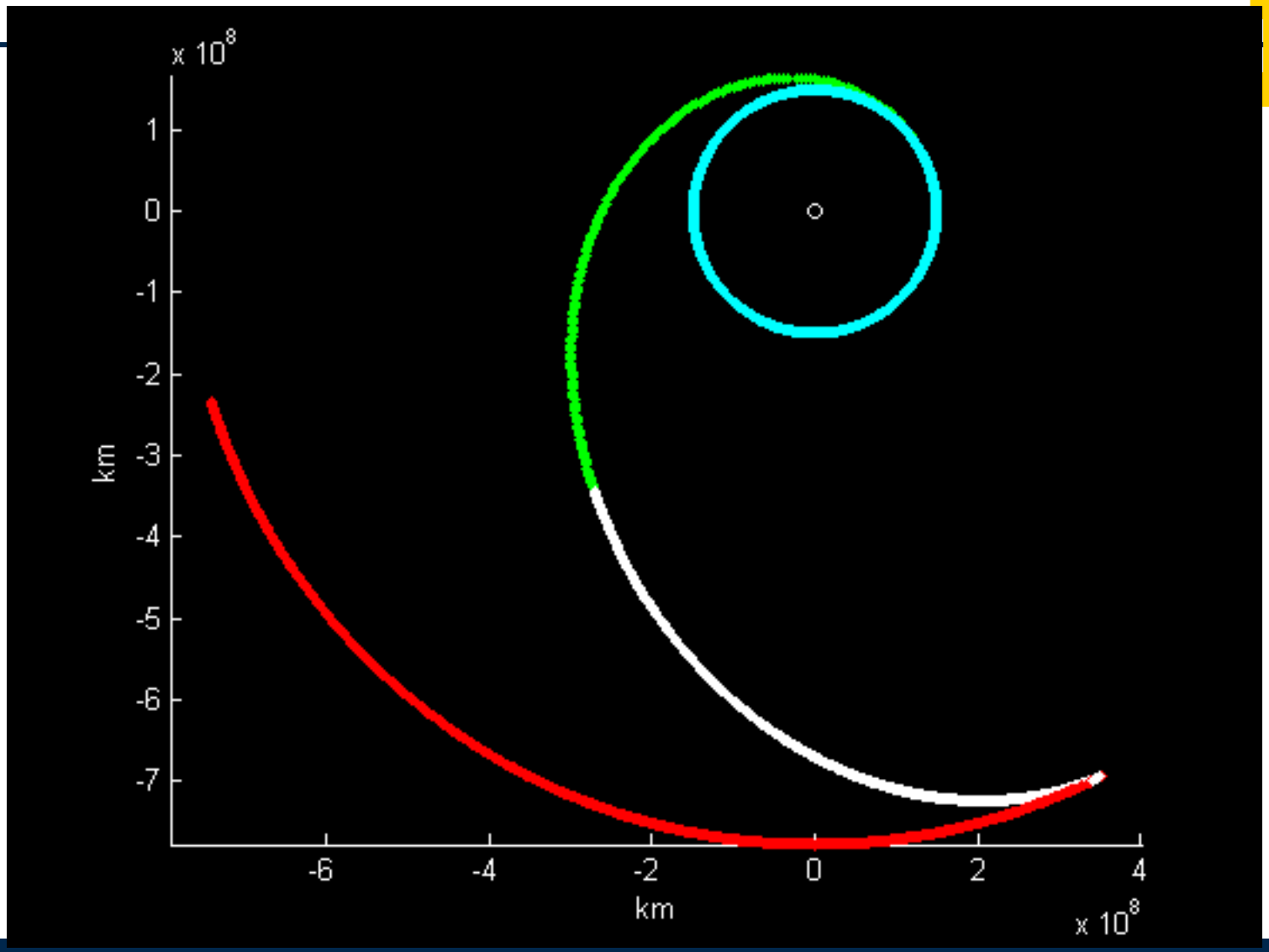


Interplanetary concept

16 month Jupiter fly-by mission. All solar powered. After Jupiter fly-by, the spacecraft would escape the solar system

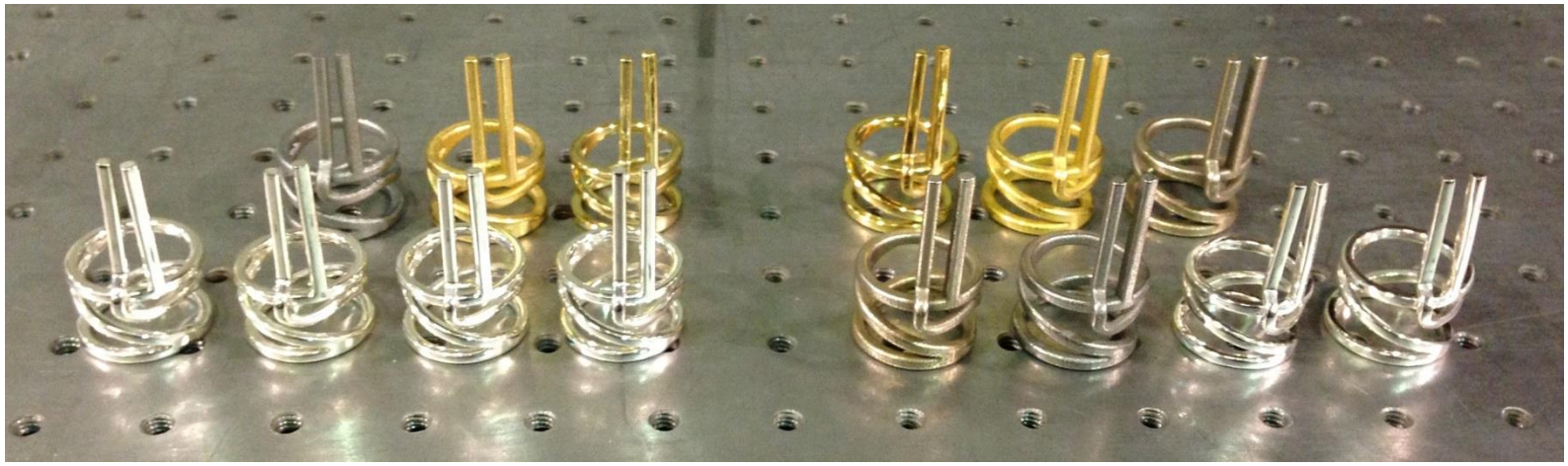


3 yr Jupiter rendezvous mission (7kg payload to Jupiter/Europa).
All solar powered mission.

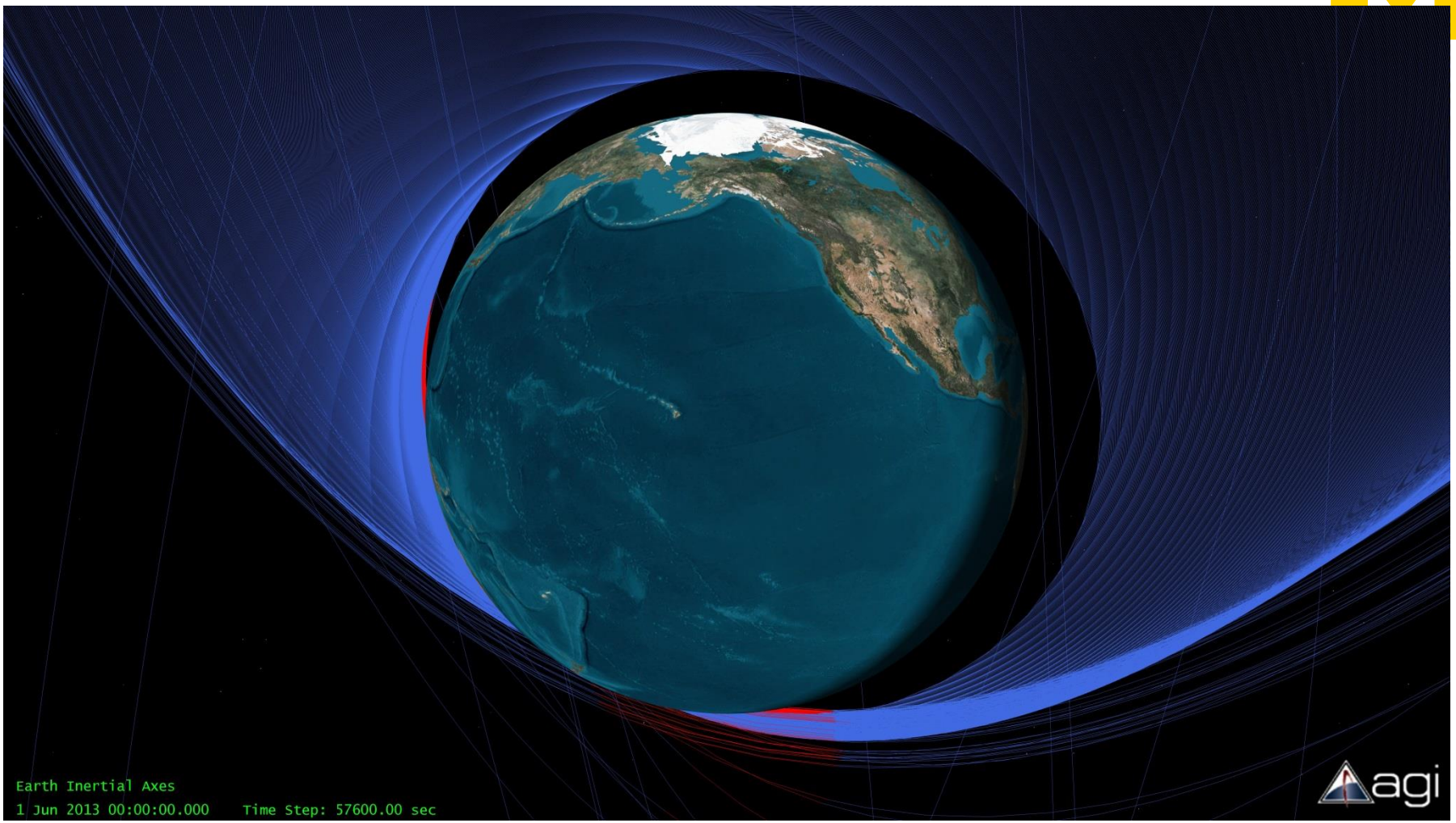


Conclusions

- CubeSats need meaningful Δv to fully realize potential
- CAT to provide 1 to 7 km/s delta-V
- CAT is versatile, highly efficient with multiple propellants
- PATRIOT mission will begin to explore new mission space



Earth escape from LEO firing from perigee



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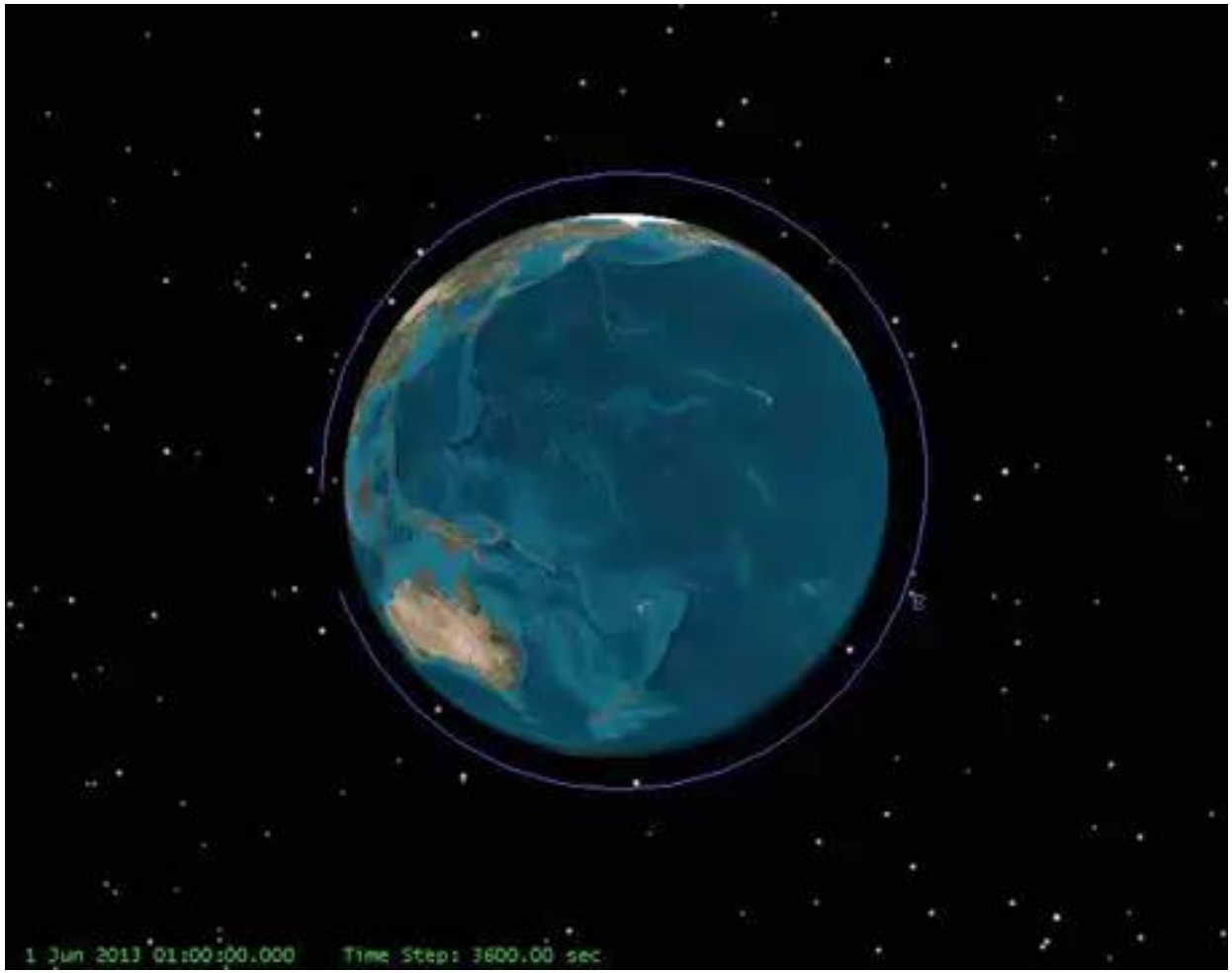
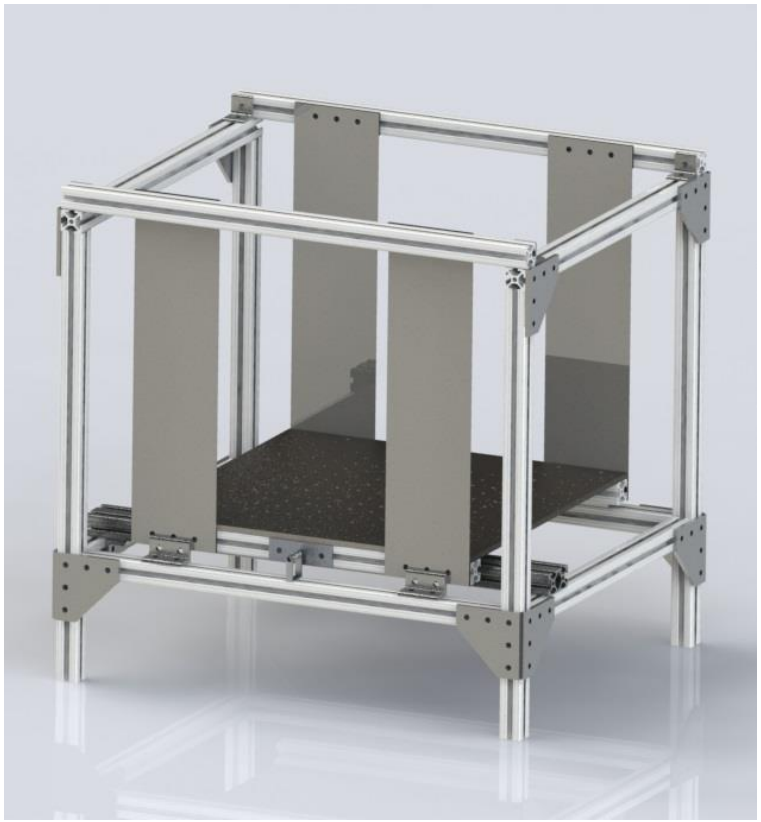
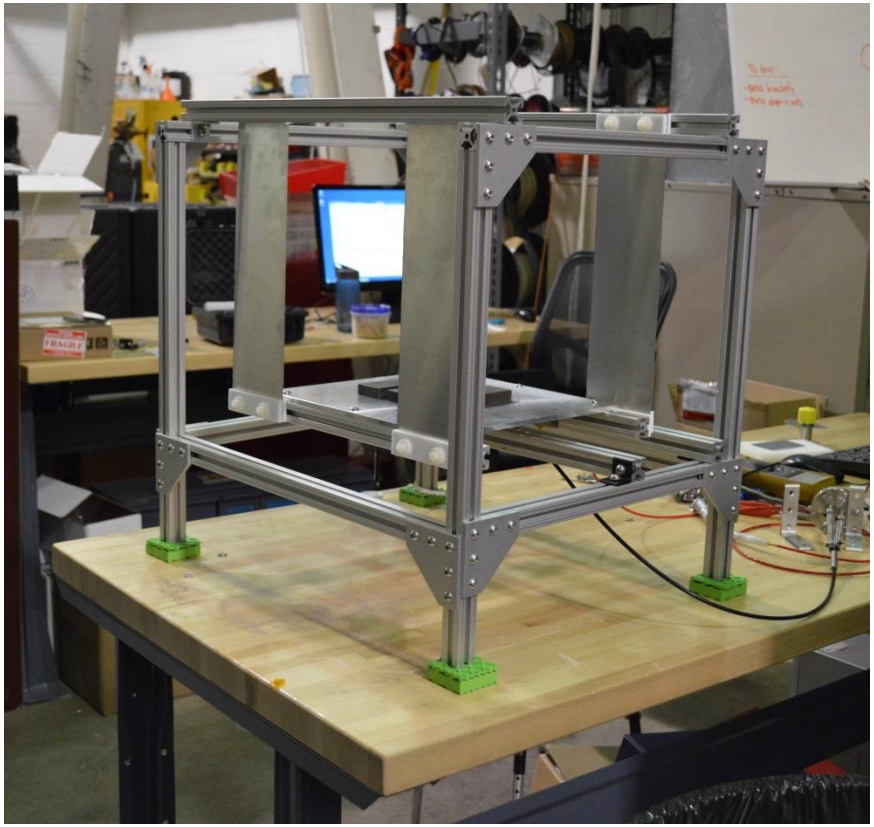


Thrust stand for micronewton force measurements





Mission to Europa:
6U CubeSat, double CATs