Initial Experiments of a New Permanent Magnet Helicon Thruster

J. P. Sheehan[1], B. W. Longmier[1], I. M. Reese[2], T. A. Collard[1], F. H. Ebersohn[1], E. T. Dale[1], B. N. Wachs[1], and M. E. Ostermann[1]

[1]University of Michigan, Aerospace Engineering
[2]University of Michigan, Applied Physics

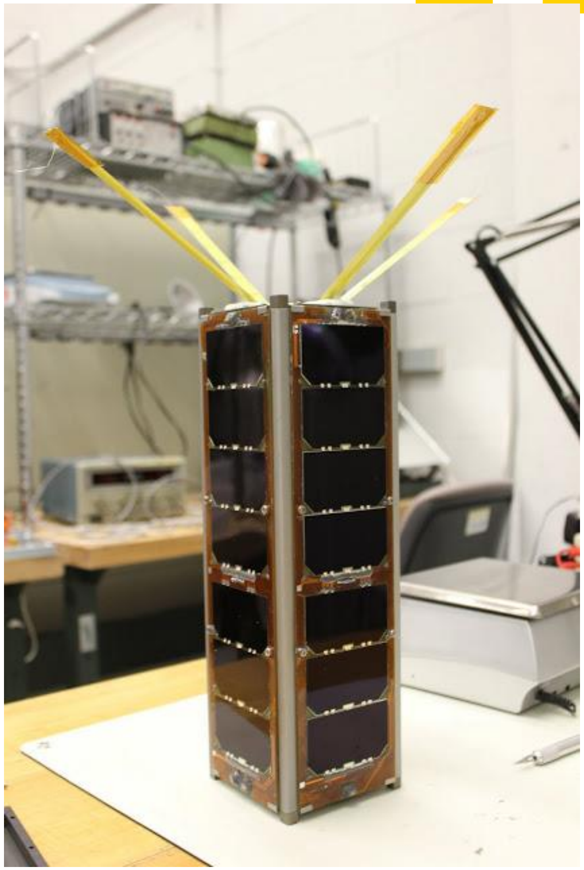
University of Michigan

Outline

- Nanosatellites and their possibilities
- The CubeSat Ambipolar Thruster (CAT)
  - Design
  - Magnetic field
  - Initial firing
- Particle-in-cell simulations in development
- Micronewton thrust stand
- Solid, liquid, and gaseous propellants

Nanosatellites: smaller, different mission capabilities

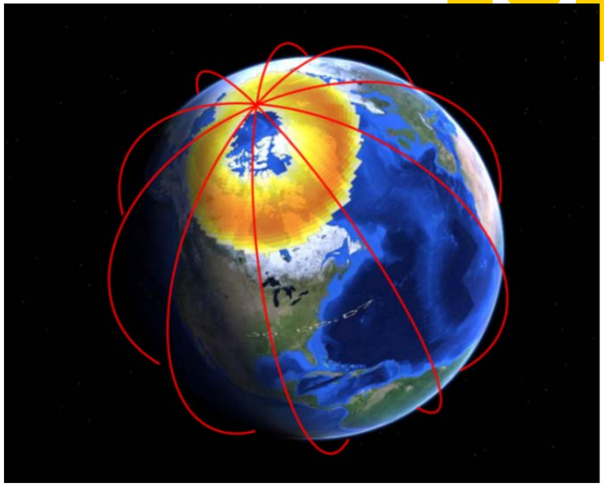
- CubeSat: a 10 cm based standardized form factor
- < 5 kg total mass
- Low cost: ~$1 million for an experimental satellite
- Enables university run satellite programs
- Politically more palatable
- Currently have no engine for significant Δv maneuvers

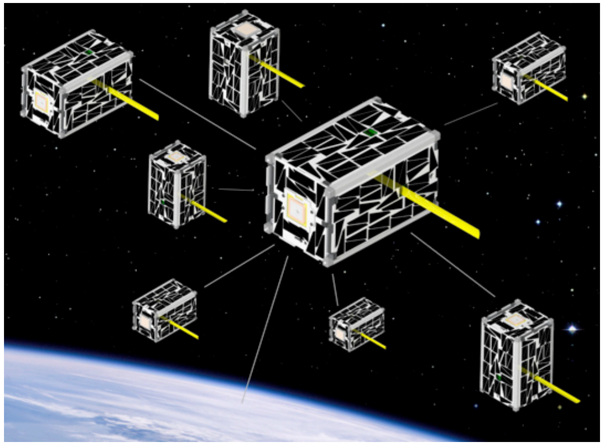


The Michigan Exploration Laboratory's RAX-2

Maneuverable CubeSats could enable many new missions

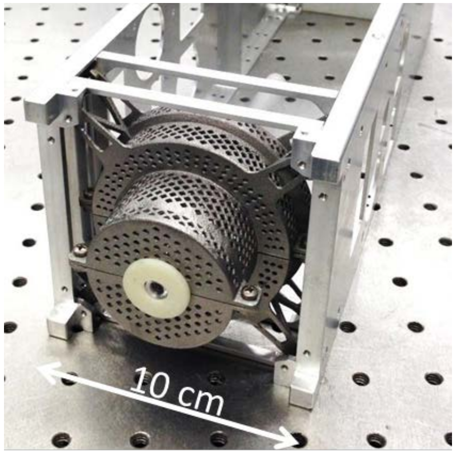
- Previously inaccessible orbits
  - Orbits that are not accessed by launch vehicle
  - Highly elliptical orbits
  - Geostationary orbits
  - Polar orbits
  - Earth-Moon, Earth-Sun Lagrange points
- Cluster formation flying
- Long-lived low altitude orbits



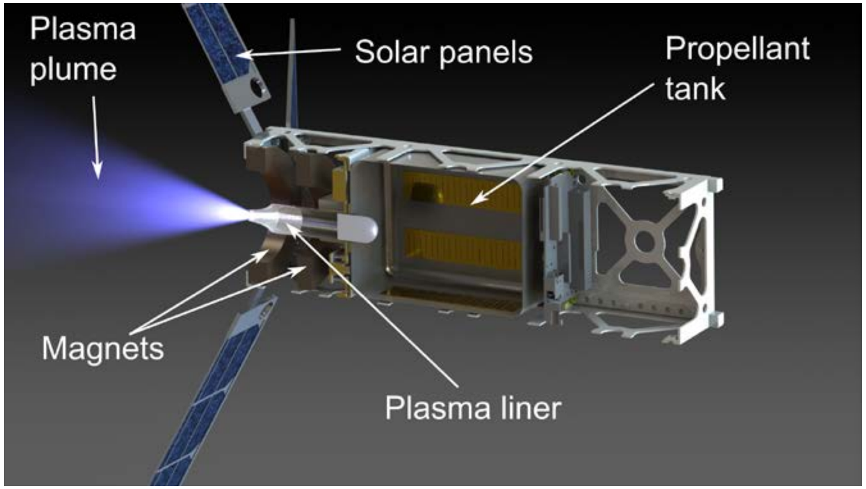


Credit: NASA

CubeSat Ambipolar Thruster (CAT)

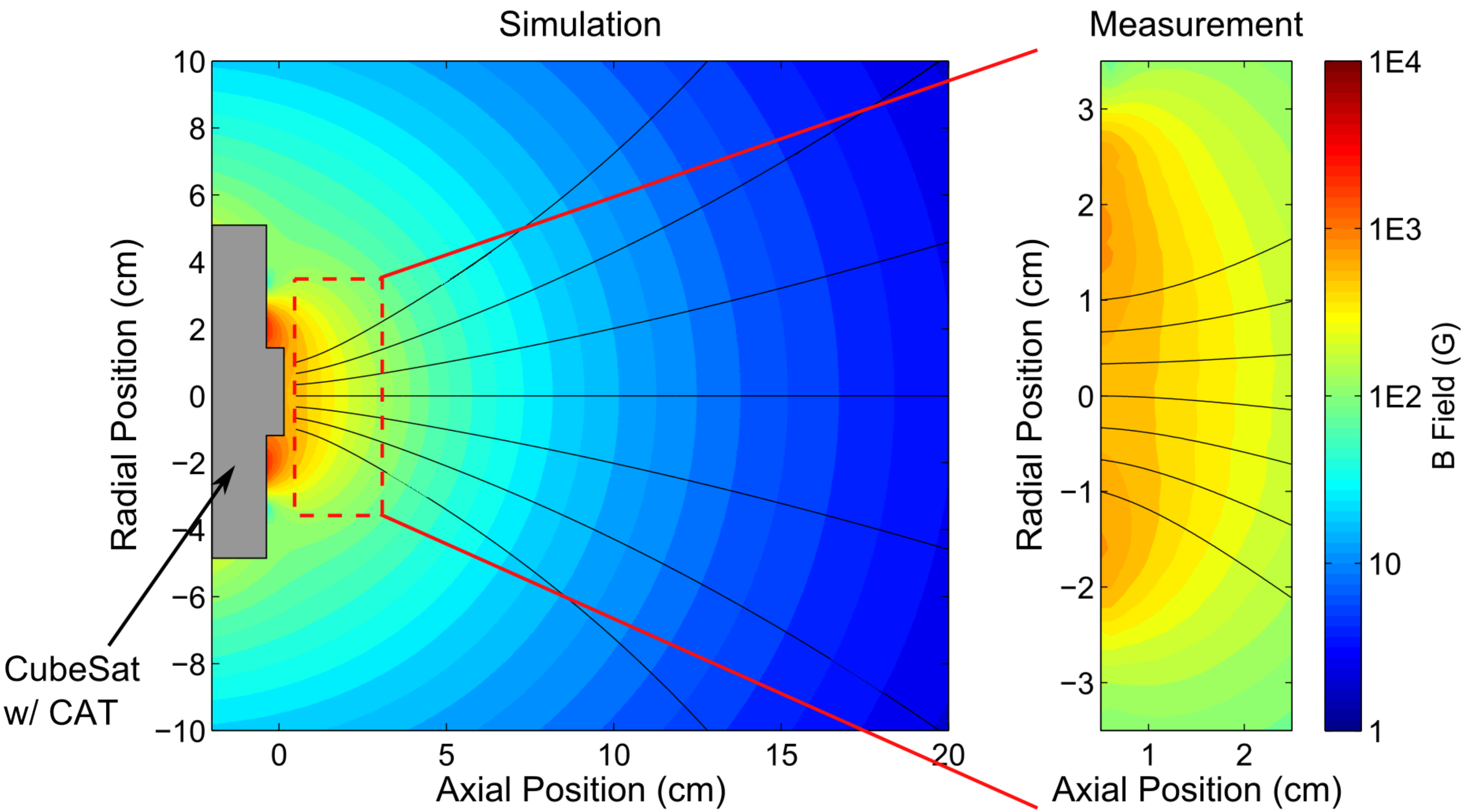


- ~0.6U for thruster
- Mass: <1 kg
- 0.4U – 0.9U for propellant tank
- Uses “free” spring space



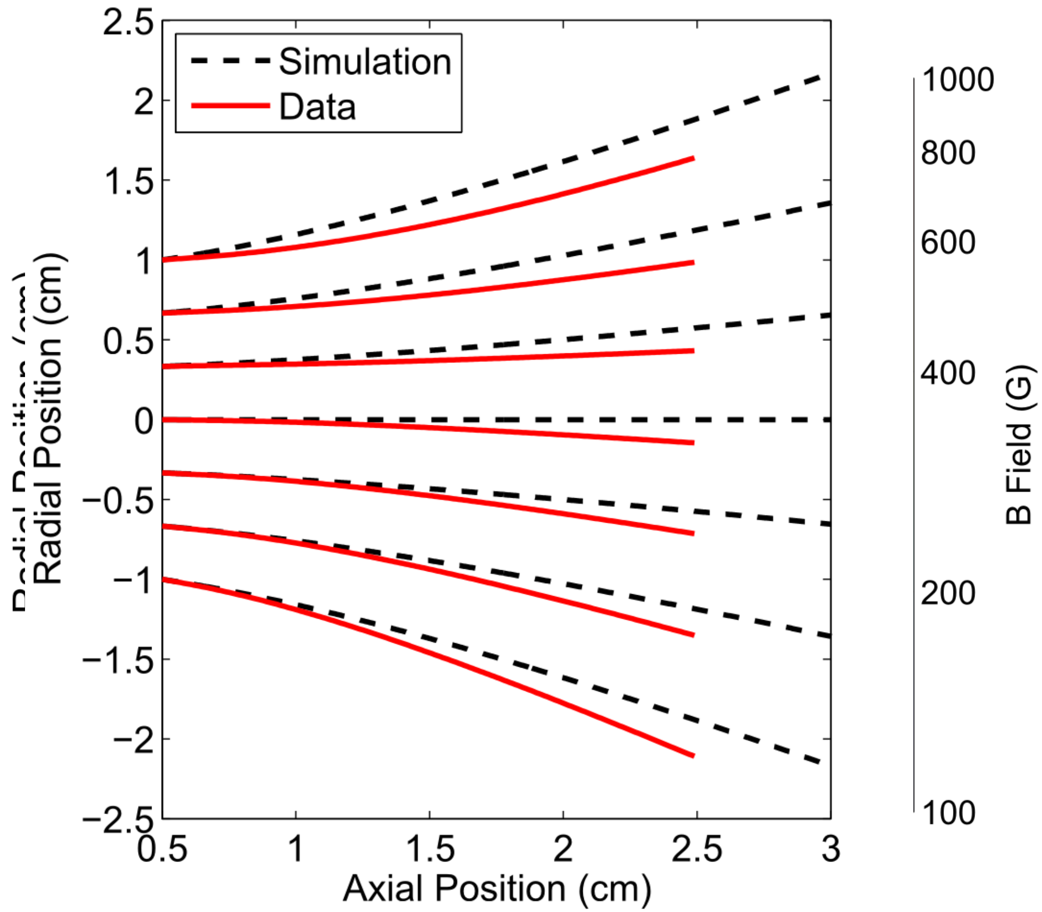
- ~1U for spacecraft controls
- 0.5U – 1.0U for instruments
- Powered by 10s of V
- 10 – 50 W, assisted by batteries

Magnetic nozzle replaces physical rocket nozzle

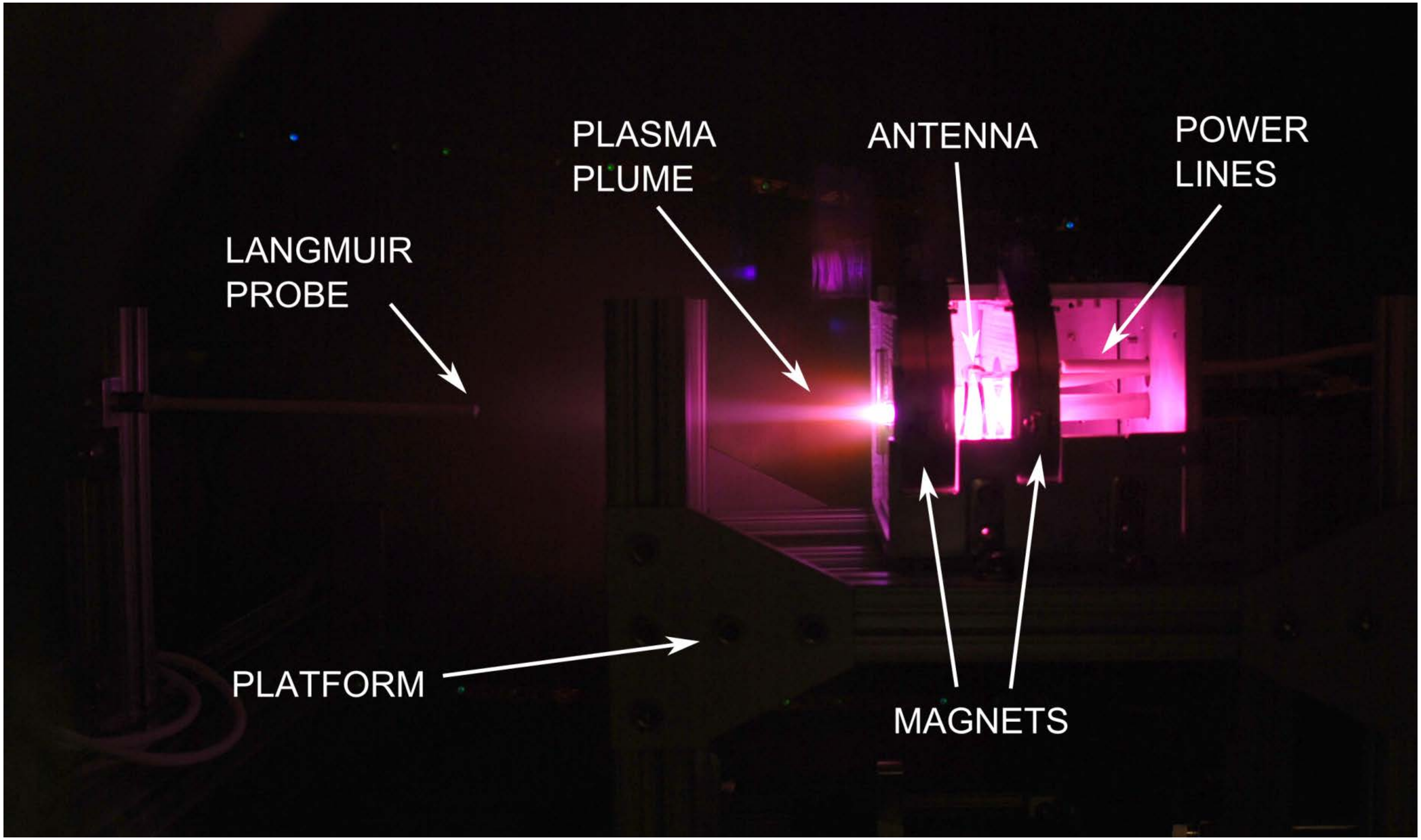


Near-field measurements match simulations to within 10%

- Permanent magnets
  - No power requirements
  - Currently NdFeB
  - SamCo for higher Curie temperature
- Maximum strength in device of 600 G
- Net dipole moment of 55 A·m^2
  - Dipole cancelation designs
- Differences due to uncertainty in thruster placement



Xenon testing: plasma follows magnetic field lines

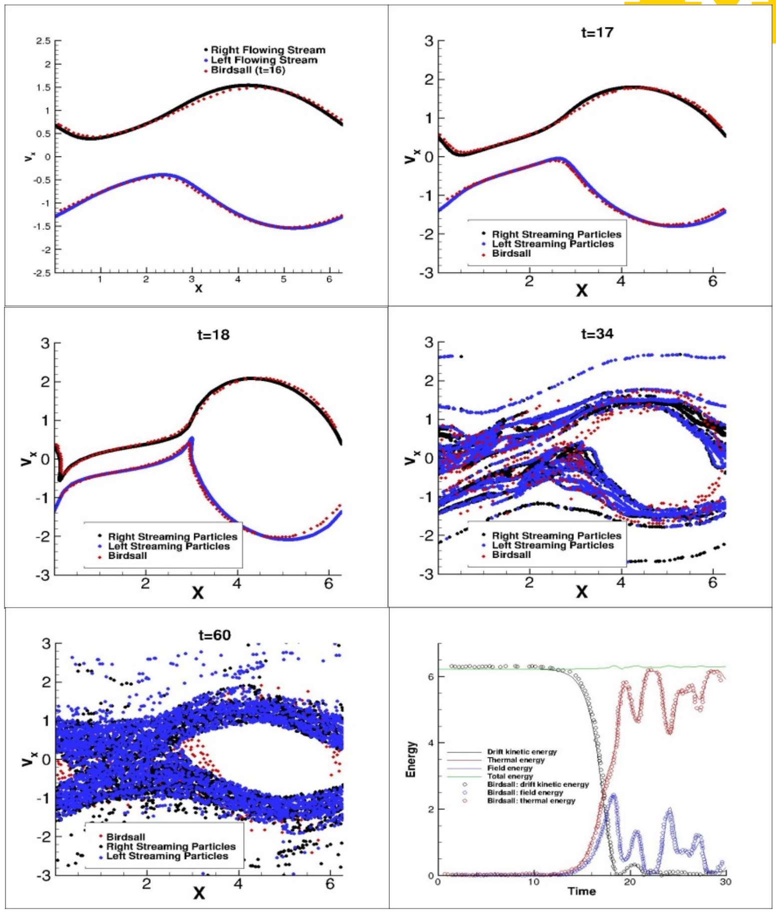


Quasi-1d3v particle-in-cell simulations in development

- Axial spatial dimension
- Axisymmetric
- Magnetic mirror forces accounted for

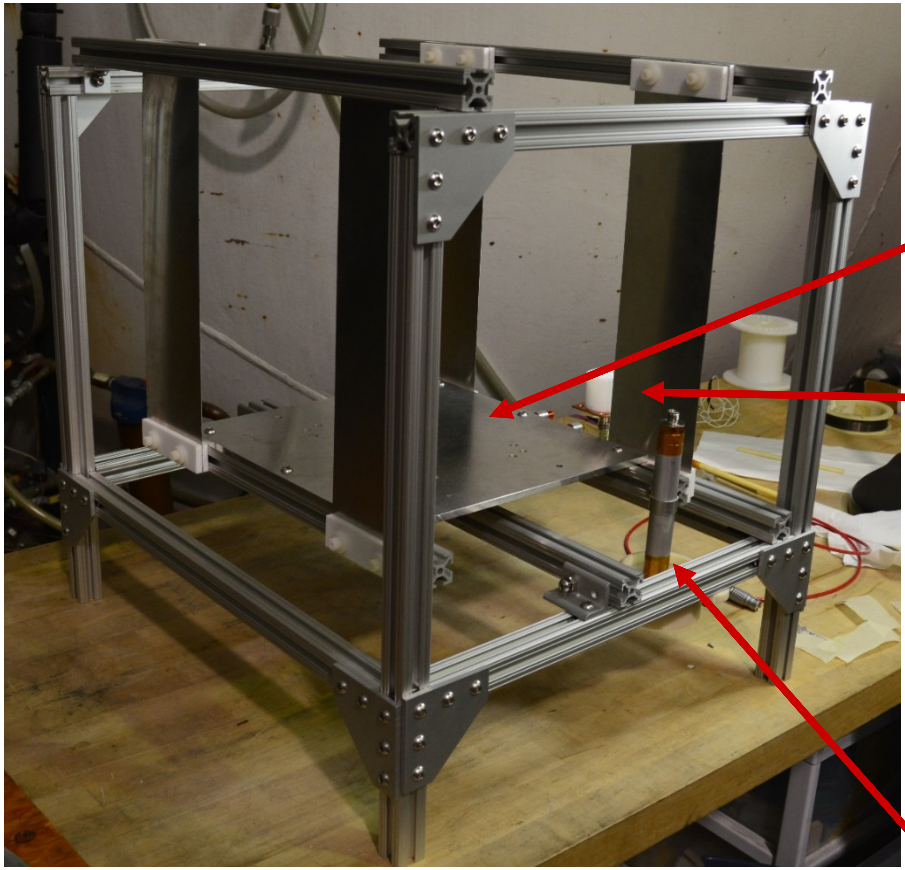
$$B_r = -\frac{r_L}{2}\frac{\partial B_z}{\partial z}$$

- Modified semi-implicit Boris algorithm particle mover
- Verification campaign nearly completed
  - Two-stream instability (right)
  - Sheath
  - Magnetic mirror



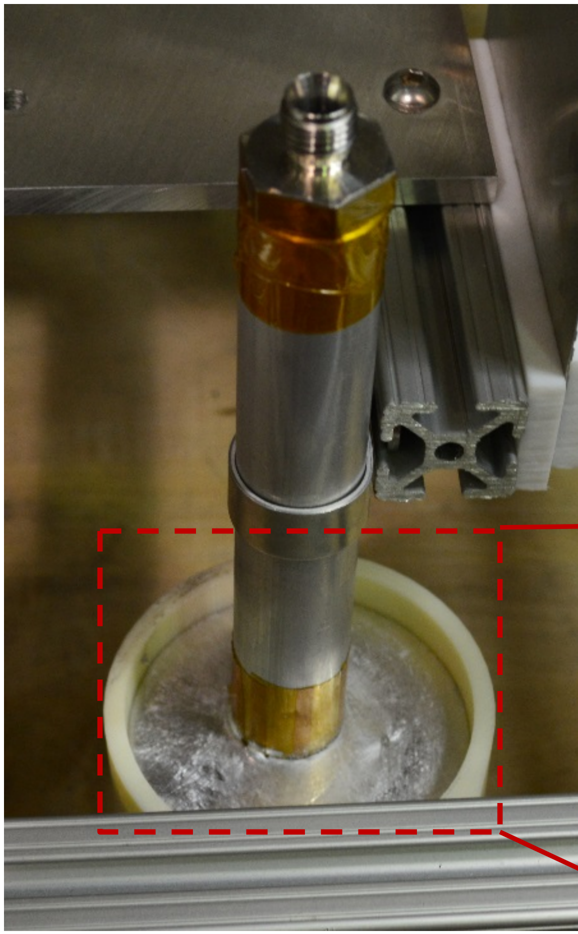
see poster 3P-44

Beam-deflection micronewton thrust stand

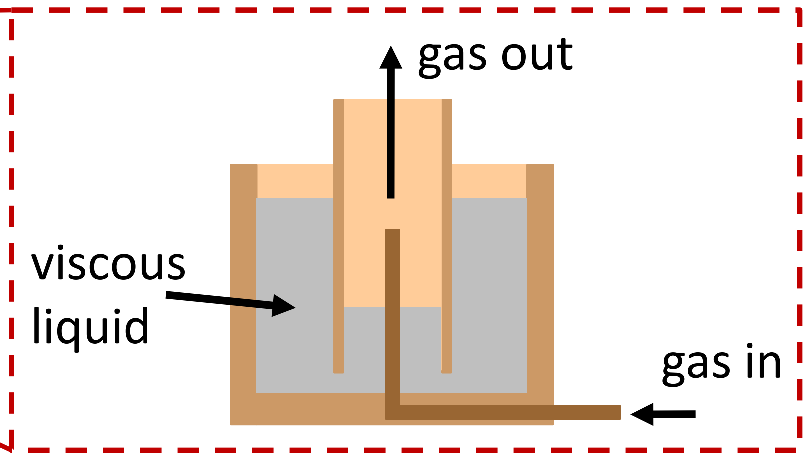


- Measure 10s mN, resolution 10s μN
- Thruster supported on mount plate
- Thrust moves plate, deflects thin beams
  - Euler-Bernoulli beam theory
- Deflection measured by optical displacement sensor (obscured)
- Tensionless gas feed system

Tensionless gas connector

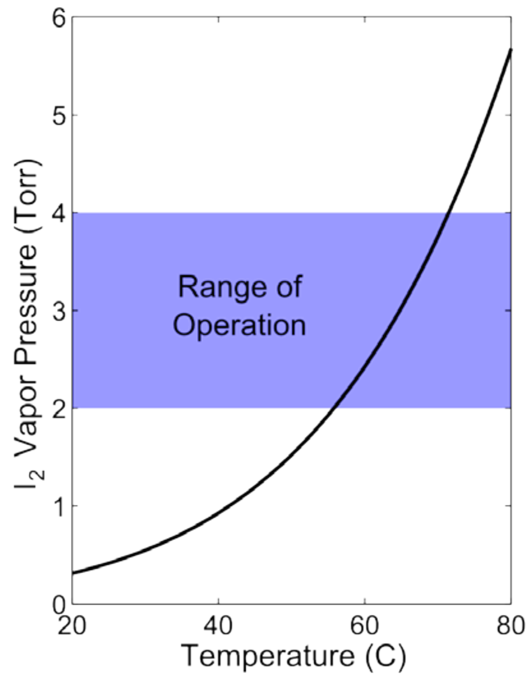


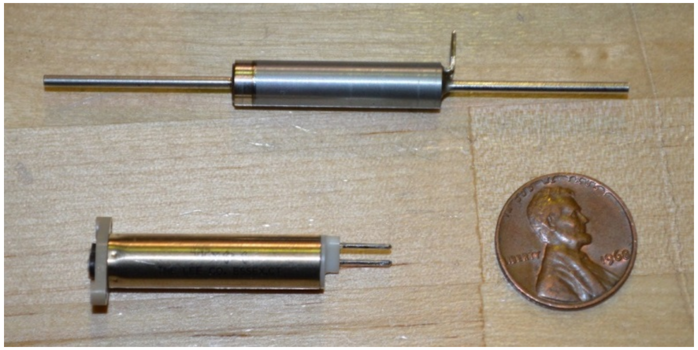
- Deliver gas without restricting motion
- Coaxial feed design
- Viscous, non-volatile liquid
  - Galinstan: eutectic metal
- Liquid damps oscillations
- Similar design in development for RF



Solid storable propellants greatly reduce volume requirements

- Gases: xenon, krypton, argon
  - Benchmark testing
  - Flight certified hardware
  - Miniature flow systems
- Solids and liquids: no pressure vessel
- Solid/liquid propellants
  - Water
  - Galinstan
  - ~~Mercury~~
  - Iodine
- Iodine propellant system
  - Solid storable
  - Heat to control vapor pressure/mass flow rate





Conclusions

- CAT's magnetic field is consistent with predictions to within 10%
- Inductive discharge achieved in prototype device
- Novel thrust stand in development
- Wide variety of propellants being explored