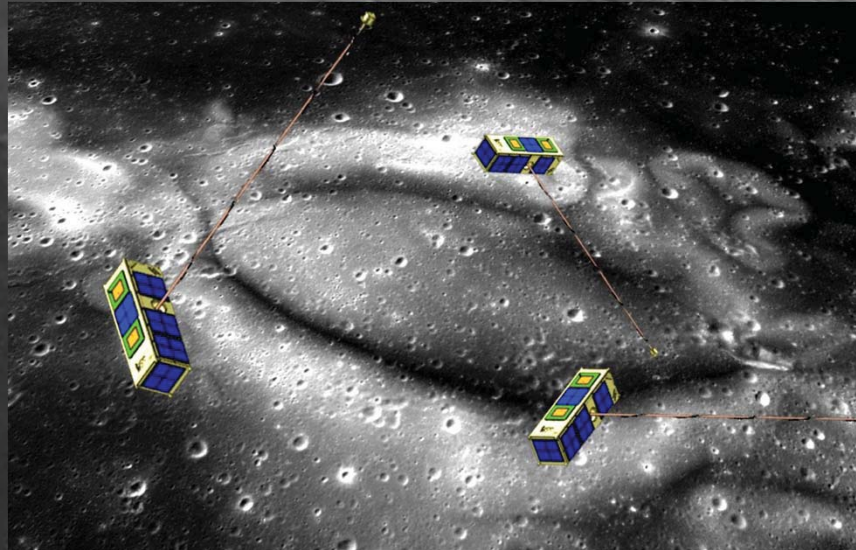


Lunar Impactor – Lunar science with a versatile cubesat platform



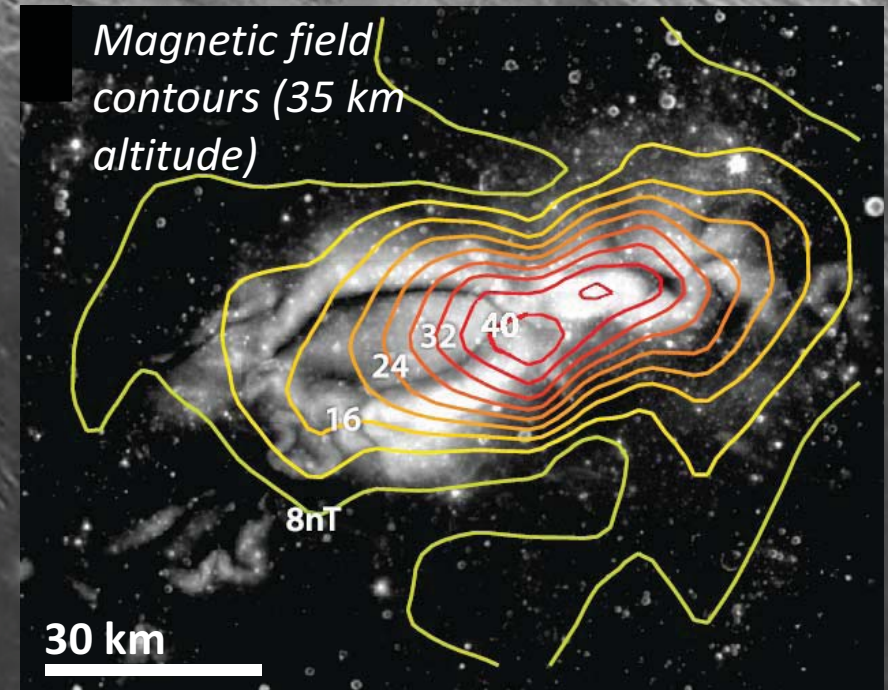
*Cubesat probes at
Reiner Gamma swirl*

I. Garrick-Bethell*, H. Sanchez, B. Jaroux, M. Bester, P. Brown, D. Cosgrove, M. Dougherty, J. Halekas, D. Hemingway, P. Lozano, F. Martel, C. Whitlock

*University of California, Santa Cruz
University of California, Berkeley
NASA Ames Research Center
Imperial College London
Massachusetts Institute of Technology
Jet Propulsion Laboratory

Lunar Swirls

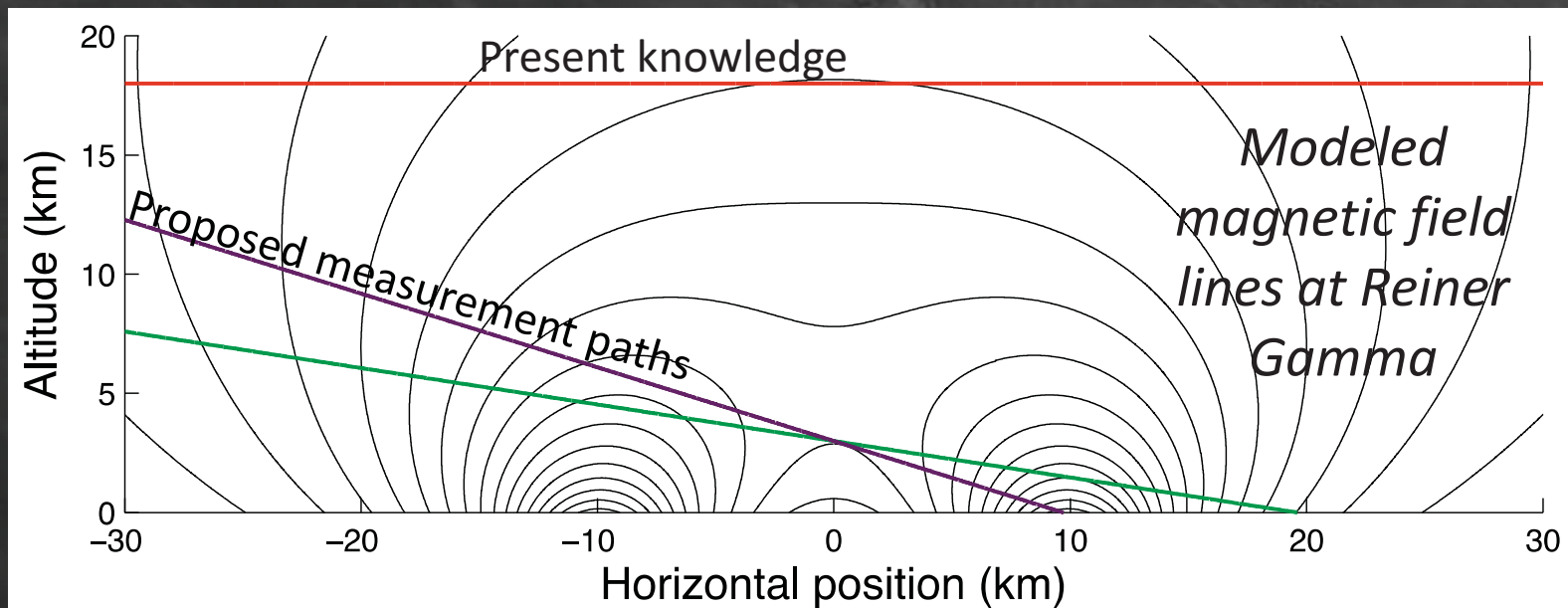
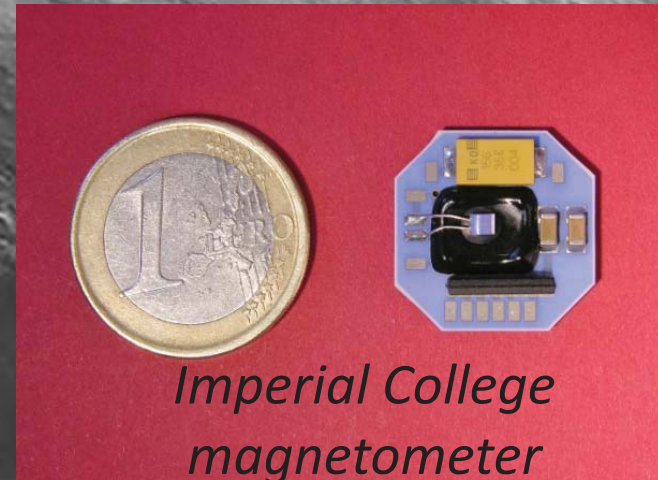
- Magnetized crust associated with unique surface markings.
- One of the most enigmatic features on the Moon.
- At the intersection of multiple science disciplines:
 - Lunar magnetism
 - Lunar surface water
 - Lunar dust
 - Lunar surface spectroscopy
 - Moon-plasma interactions
 - All priorities of 2007 National Academies lunar science report



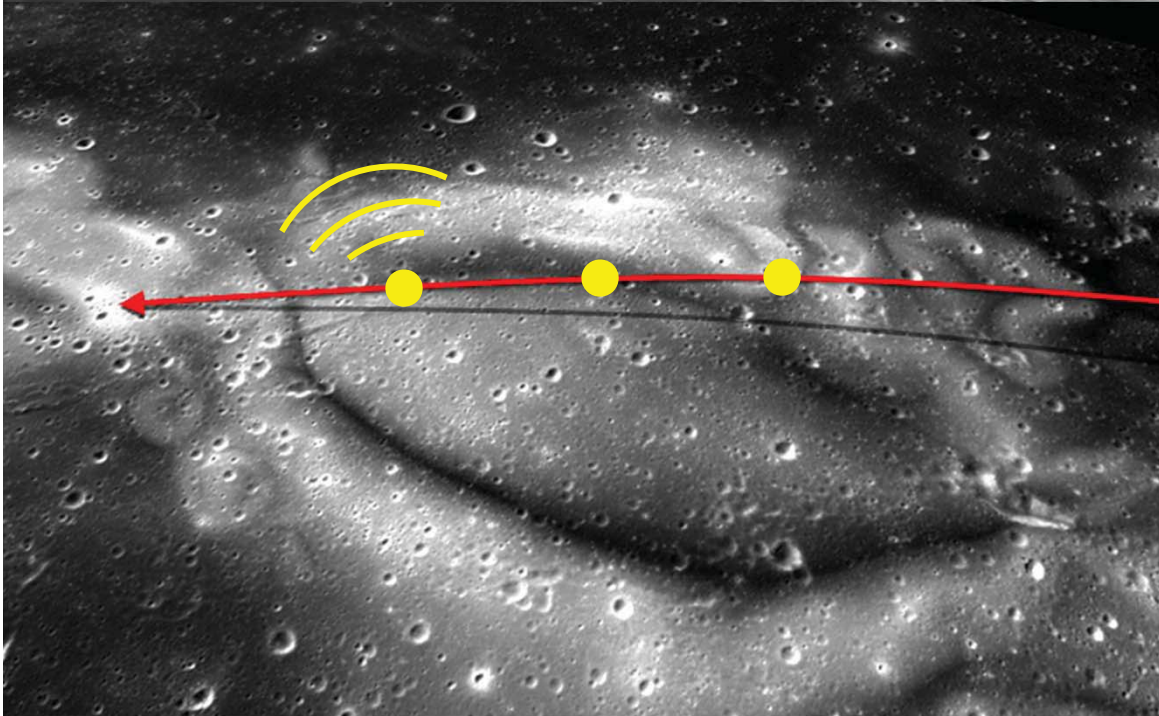
Reiner Gamma swirl
(visible with binoculars)

Objective: Near-surface measurements

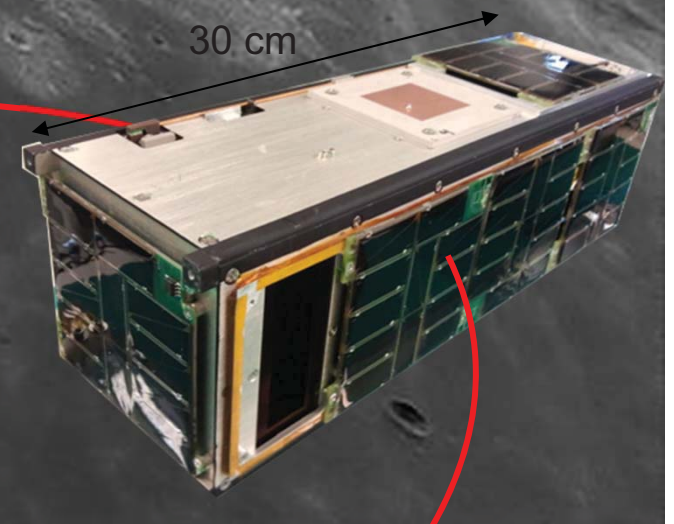
- Fly a 3-axis magnetometer into the heart of Reiner Gamma.
- Provides insight into all science questions.
- Other instruments also possible.



Getting to the Moon: Option 1



Navigation
(JPL)

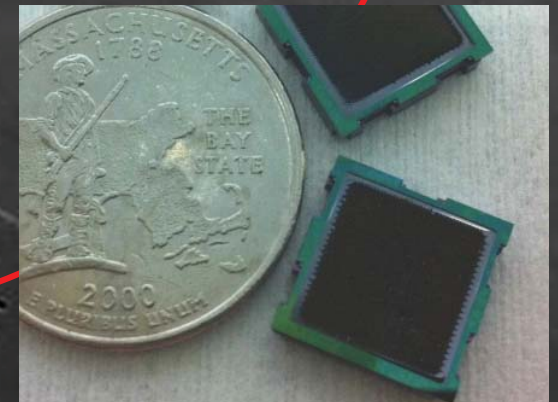


30 cm

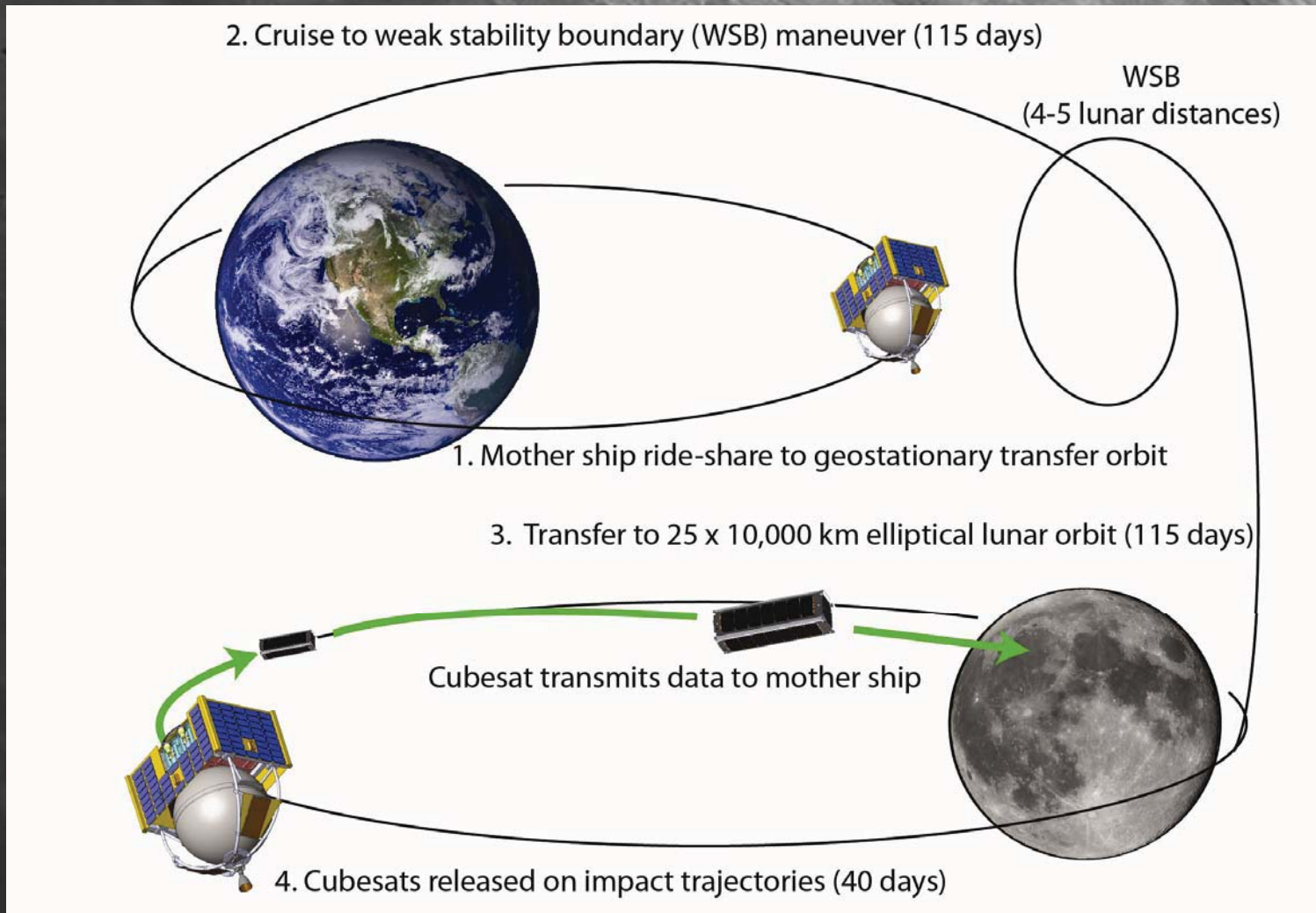
Spiral to the
Moon out of
geosynchronous
orbit



Propulsion (MIT)



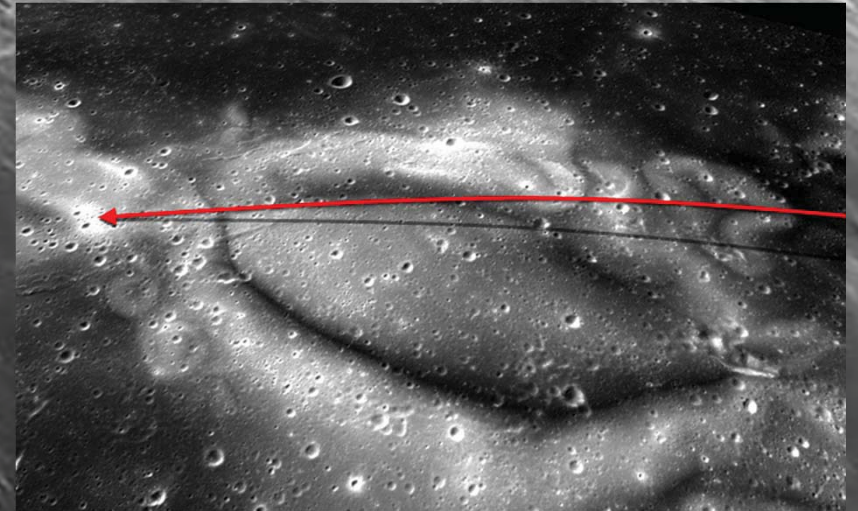
Getting to the Moon: Option 2



→ Planetary Hitch Hiker enables other mother-daughter architectures.

Conclusions

- Cubesats enable first-of-a-kind measurements of the Moon.
- Architecture enables future near-Earth missions, such as small asteroid targets.
- Cubesats are an exciting technology that engages students and the general public.



Extra Slides

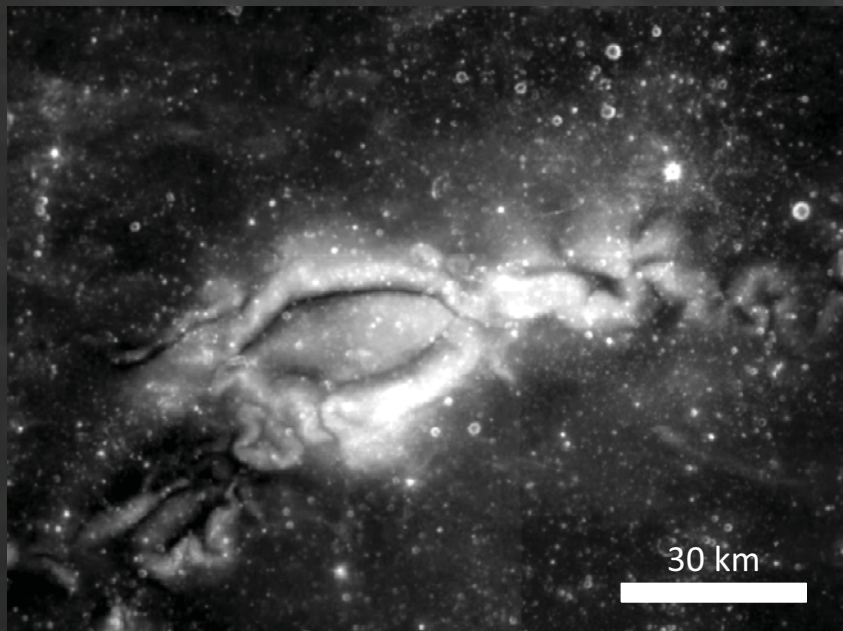
Acknowledgments and Partners

- UC Berkeley – Science and Mission Operations
- NASA Ames – Mission Planning
- MIT – Propulsion and Trajectory Planning
- Imperial College London – Magnetometer
- Jet Propulsion Laboratory – Transponder
- Open to other interested partners

Lunar surface water

- Surface hydroxyl/water abundances are anti-correlated with bright parts of lunar swirls.

Clementine 750 nm reflectance



H₂O/OH abundance derived from M³



Kramer et al., 2011

Global Magnetic Field Map

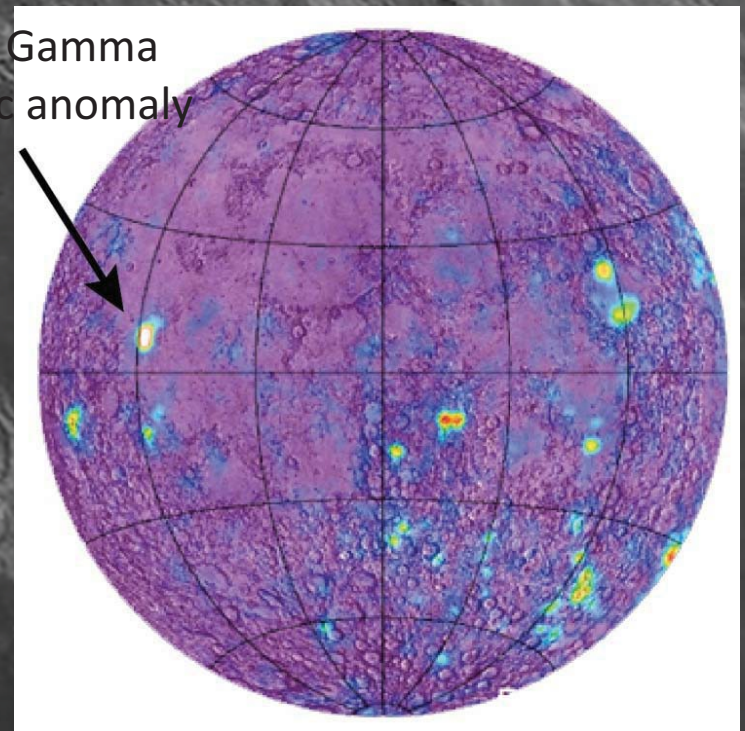
- Lunar Prospector: global map of magnetic fields.
- Origins of the Moon's magnetic field still debated:
 - A past lunar dynamo?
 - Or impact processes?

→ Next step:

Magnetic field measurements near the surface would constrain their origin.

Other swirls exist throughout the Moon

Reiner Gamma magnetic anomaly



1998: Lunar Prospector magnetic field strength at 30 km (0-30 nT)

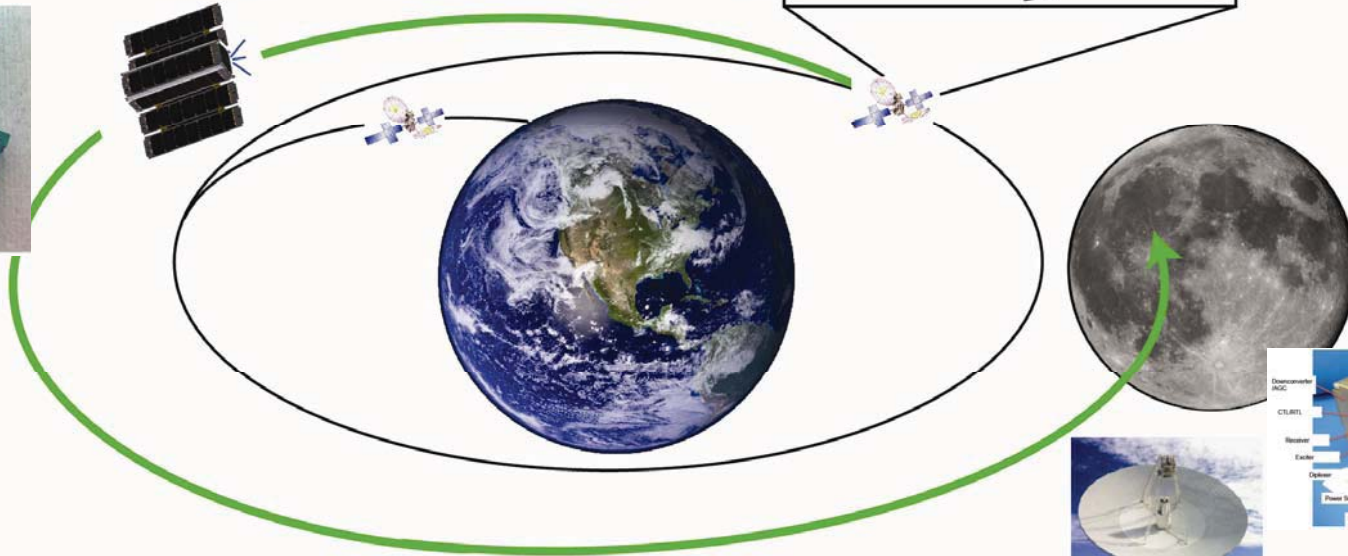
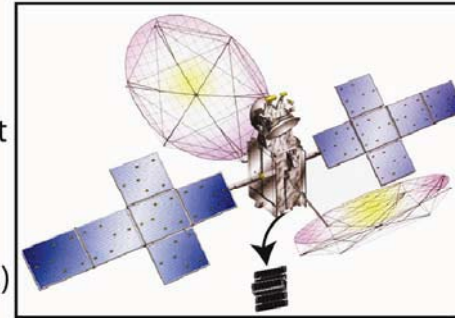
Status/Challenges Ahead

- Challenges for a cubesat-only approach:
 - Long-duration testing of propulsion system.
 - Relatively high power (~ 30 W)
 - Approaches to radiation protection/mitigation.

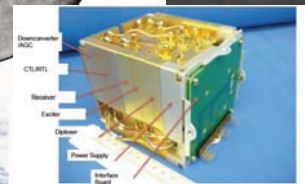
Getting to the Moon: Option 1

1. Cubesat ride-share to geosynchronous orbit

2. Spiral to Moon using electrospray propulsion (~120 days)



Cubesat communication and navigation via Deep Space Network

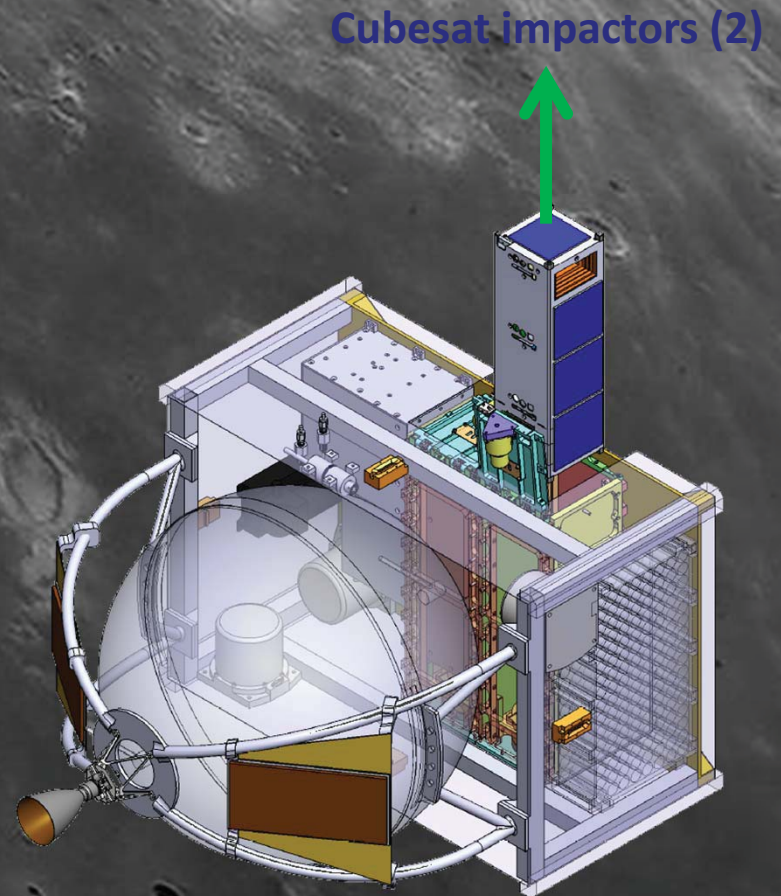


→ Enables frequent cubesat access to the Moon via release in geosynchronous orbit.

Planetary HitchHiker

- 2012 KARI-NASA Ames collaboration with university partners
 - Kyung Hee University
 - UC Berkeley
 - UC Santa Cruz.

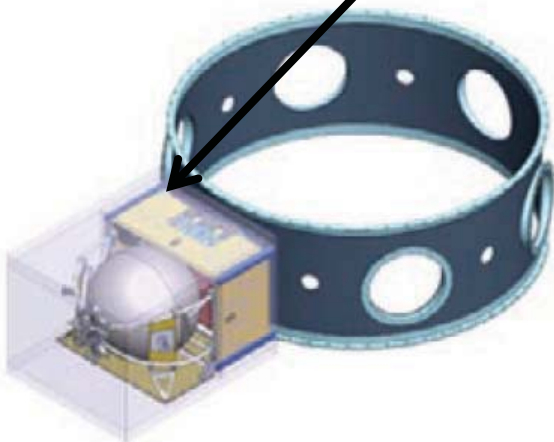
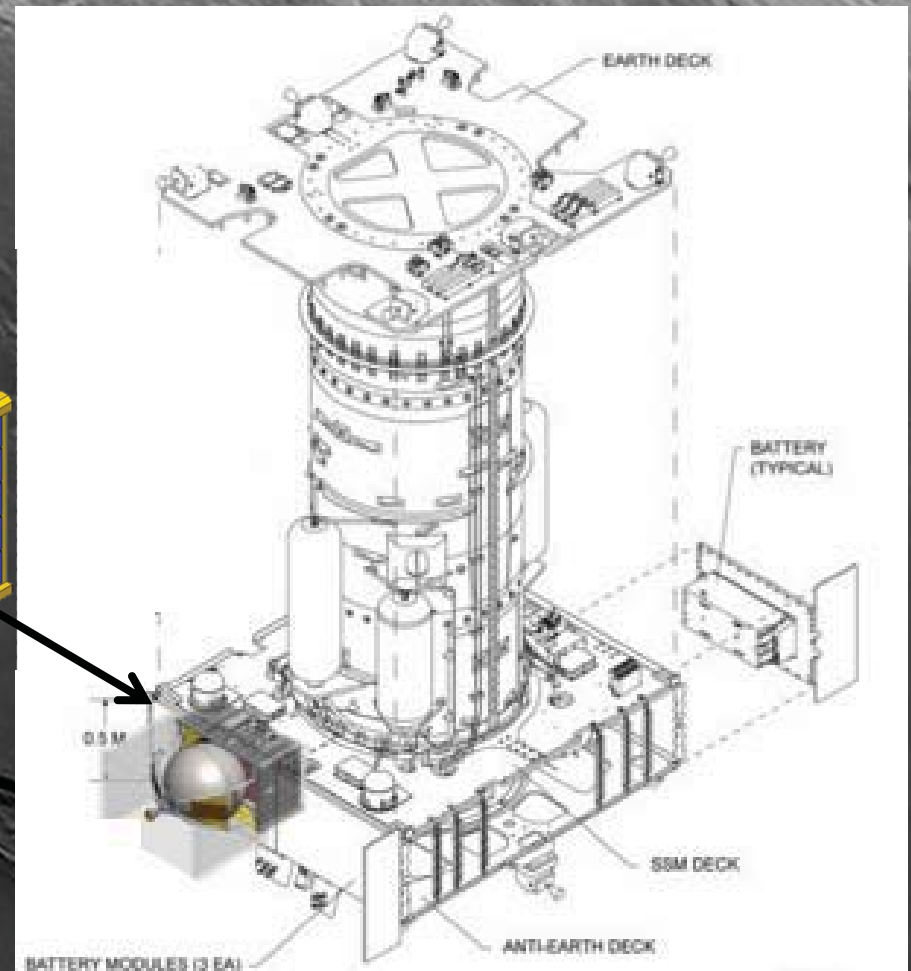
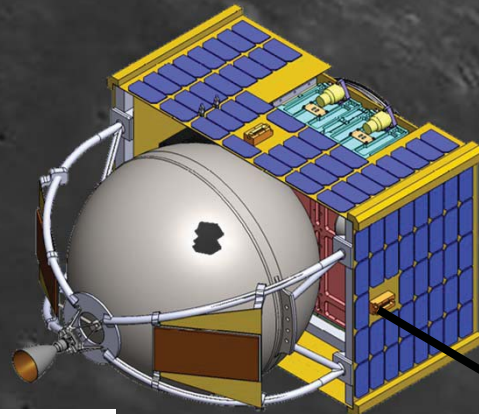
**Orbiting mother ship
< 100 kg
Carries two probes.**



Piggyback ride to GTO

SS/Loral Comm Sat GTO
Deployment

- Max Mass: 140 kg
- Max Volume: 80cm(W) x 50cm(H) x 40cm (D)



Alternative: ESPA ring ride share

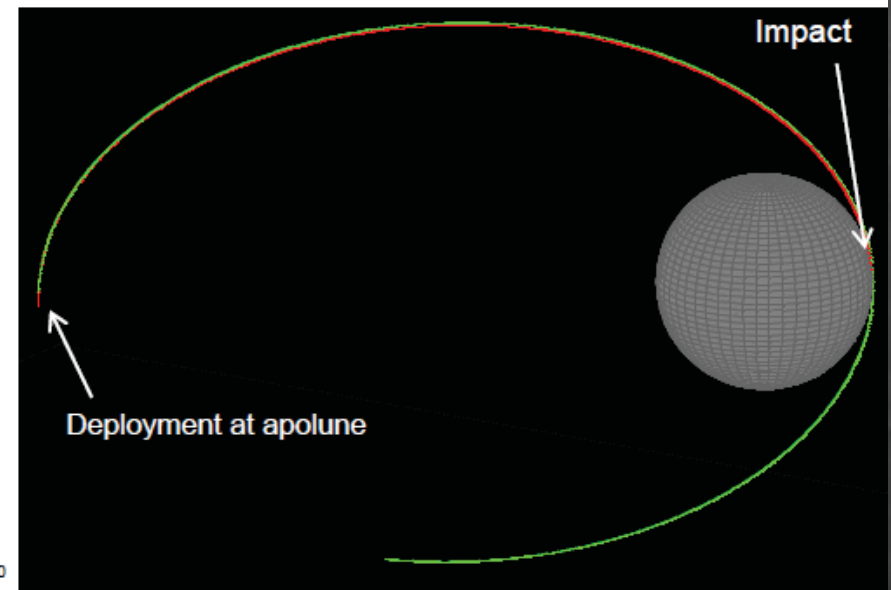
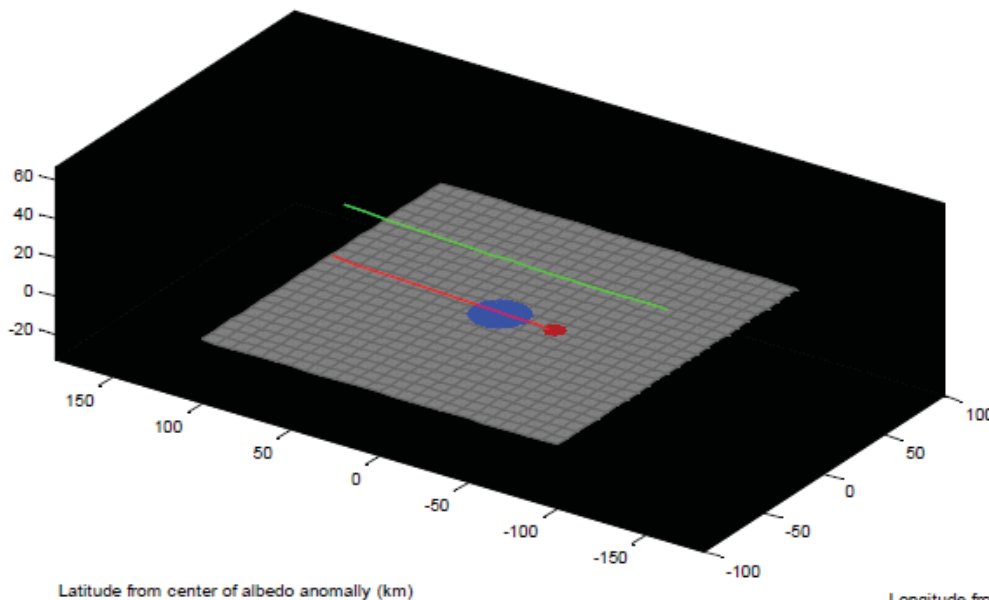
Trajectory and Targeting Studies

Baseline impact trajectory:

- Impacting angle: 4.3 degs
- Mother-Daughter range at Impact: 224 km
- Impact target diameter: 10 km
- Nominal deployment DV: 3.2 m/s
- DV magnitude error tolerance: 3 cm/s
- DV pointing error tolerance: 5 degs
- Impact speed: 2219 m/s
- Time spent travelling through anomaly: ~13.5 s

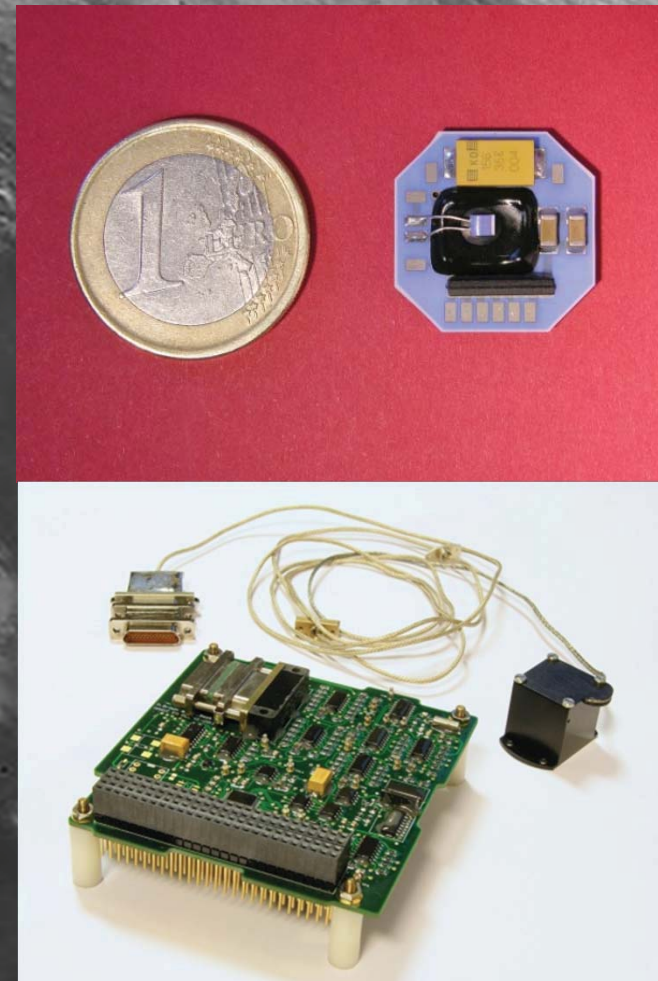
→ Picked to minimize impacting angle but maintaining reasonable daughtership deployment tolerances.

- Daughter impacts moon near Reiner-Gamma (red trajectory)
- Mothership flies overhead (green trajectory)
- Reiner-Gamma anomaly 1 deg or 30 km in diameter (blue disc)
- Impact error ellipse 10 km in diameter (red disc)



CINEMA Magnetometer - 1

- Anisotropic magneto-resistance (AMR).
- Three Honeywell HMC1001 sensors
- PC104 board-based
- Two three-axis assemblies, one on a 1-meter boom
- < 2 nT sensitivity
- 112 grams total, one board
- Half-board possible with FPGA electronics
- Current model ~ 50 grams.
- Measurement frequency of 200 Hz possible.



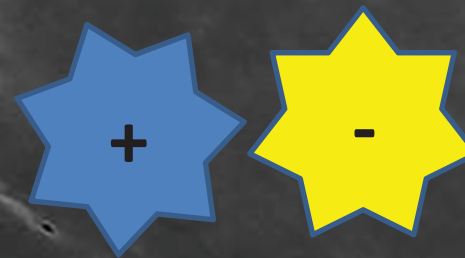
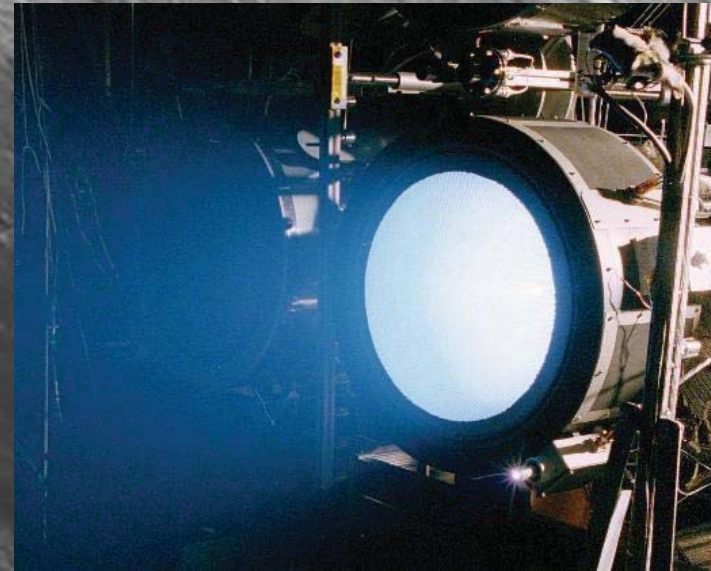
CINEMA Magnetometer (ICL)

Propulsion - 1

- Plasma propulsion – complex but efficient.
- Large molecule liquid salt – “plasma” in a liquid state.
 - Extract ions, accelerate them.



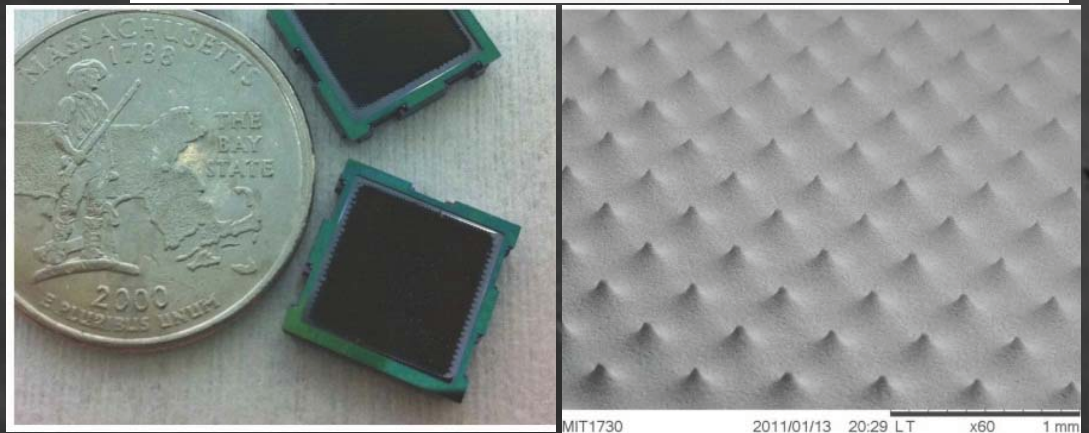
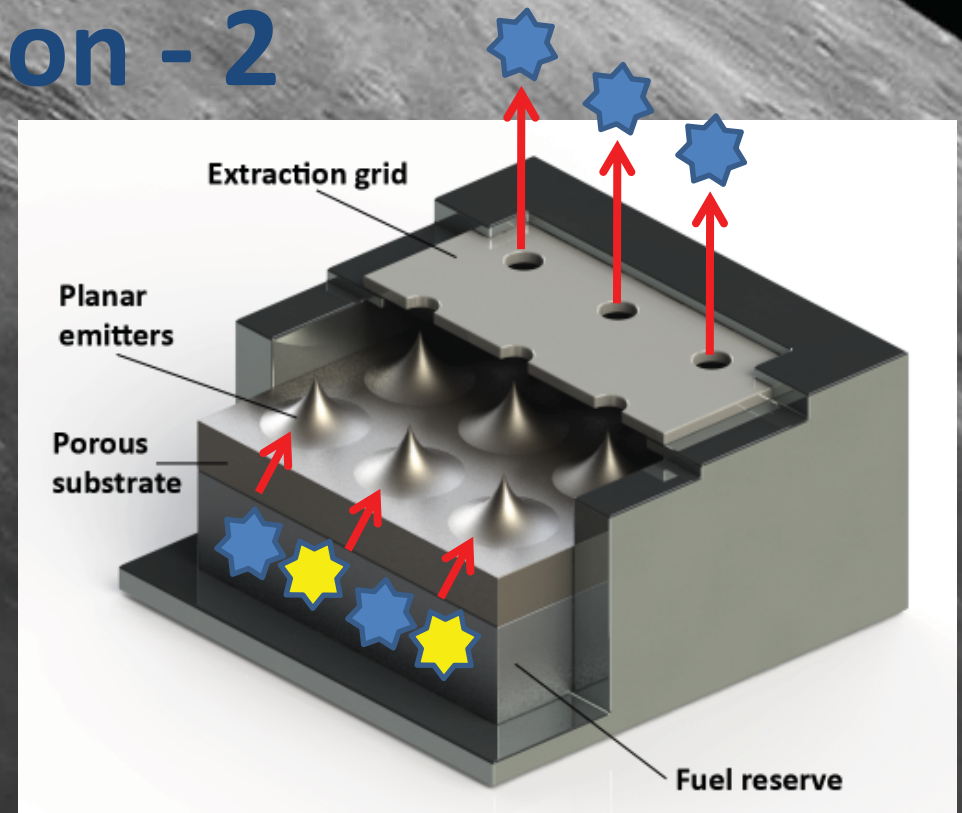
Solid salt



Liquid salt: 1-ethyl-3-methylimidazolium
bis(trifluoromethylsulfonyl)imide

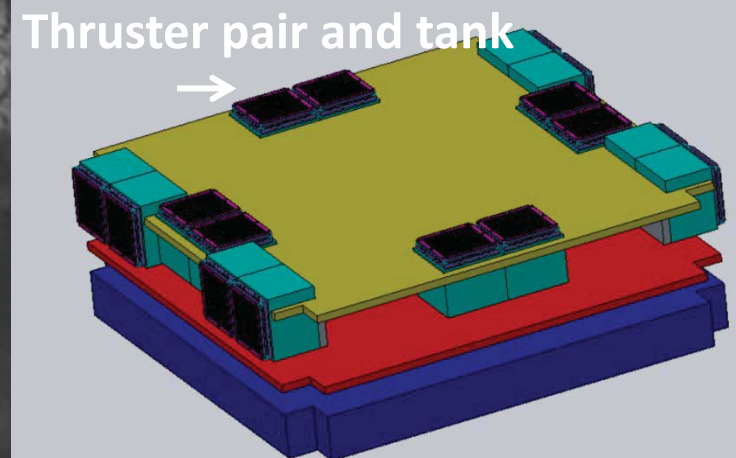
Propulsion - 2

- Micro-fabricated emitters.
- Porous metal tank wicks salt to emitter head by capillary action.
- Accelerated by extraction grid.



Propulsion - 3

- Three-axis control.
- Primary propulsion for transit to the Moon.
- Specific impulse > 2000 s.
 - Thrust and I_{sp} scale with input power and voltage.
- Currently, undergoing long-duration testing.
- 1U cubesat demo next year.
- Rad hard parts available.



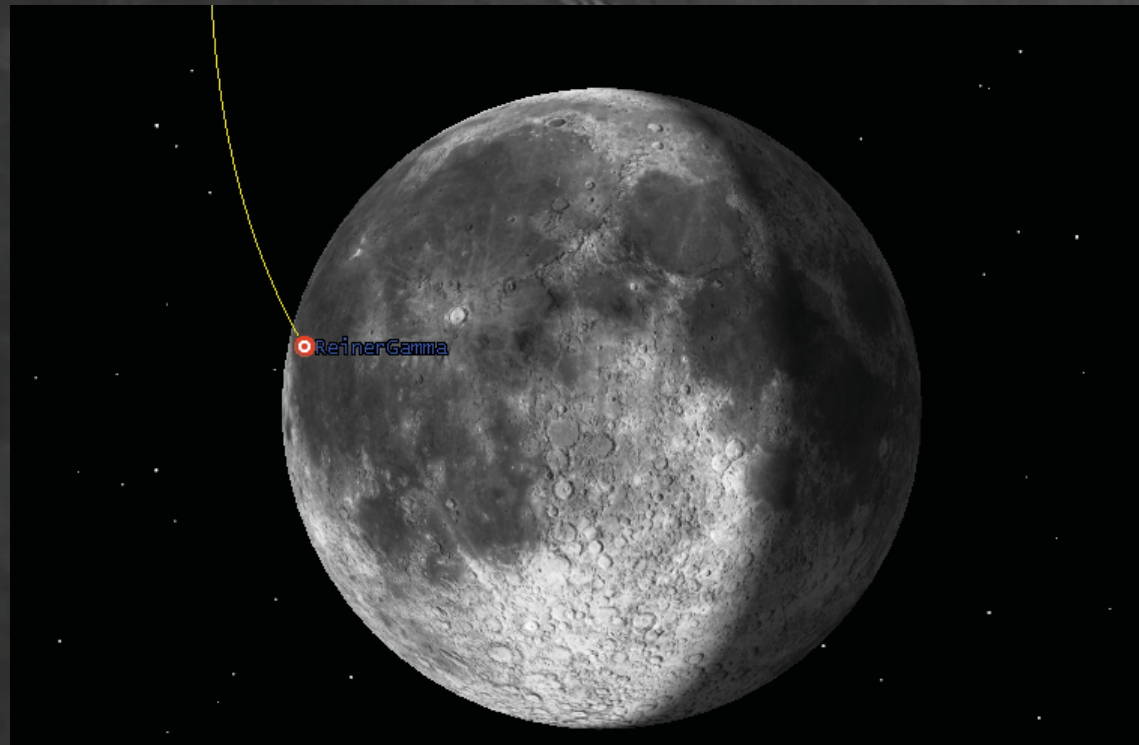
Trajectory Simulations - 1

- Assumption: 30 W available power.
 - Body fixed panels & one-time deployment
- Spiral to lunar from GEO impact takes ~ 120 days, 2 km/s delta-v.
- Requires ~ 400 grams of propellant.



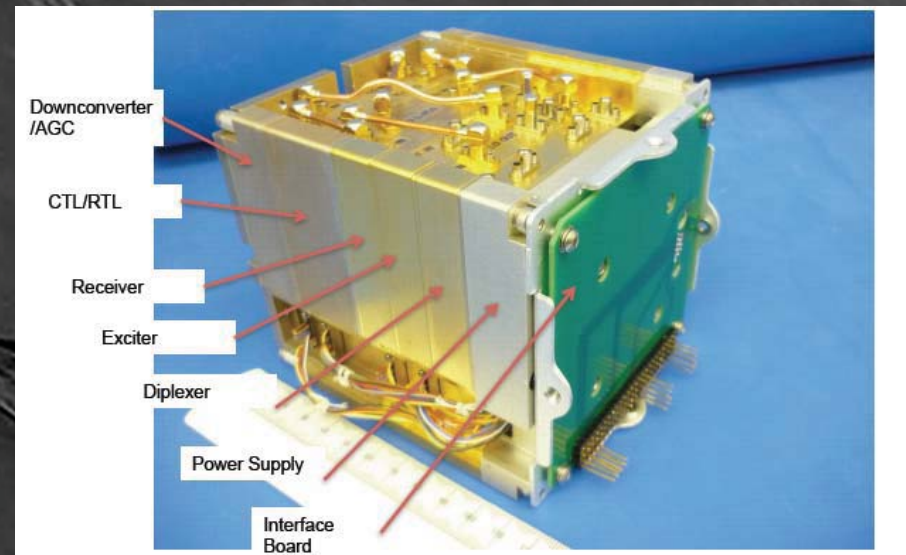
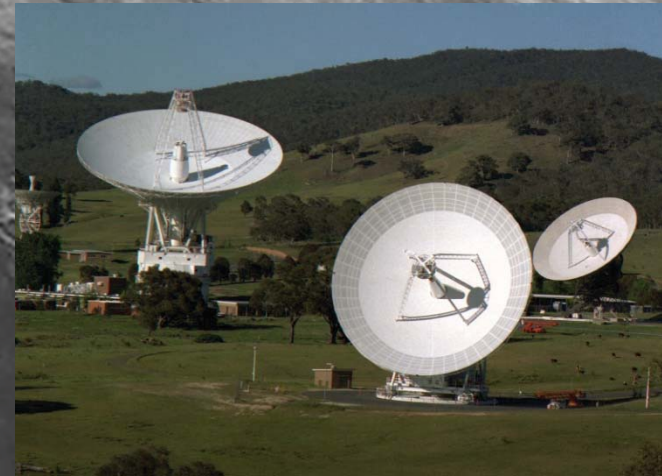
Spiral from Earth Trajectory Simulations

- Impact of the Moon, as seen from the Earth.
- Challenge: impacting at low ($<20^\circ$) angles.



Communication and Navigation

- JPL cubesat transponder (LMRsat).
 - Digital version available in early 2014.
 - Doppler + range.
 - X-band 2 W omni output.
- Deep Space Network 34-meter dish required to close links for telemetry, science data, and ranging.
 - Expensive, ~\$1000/hr, but necessary.
- Berkeley 11-meter dish also available.



DSN compatible cubesat transponder (JPL)

CINEMA Magnetometer - 2

0.9 meter boom

