Lunar Magnetic Field Measurements with a Cubesat Impactor

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Lunar Magnetism: A 53 Year Old Problem

- 1959 Soviet Luna-1: Moon has no global magnetic field.
- 1970s: Local (~100 km) magnetic anomalies discovered - origins still debated.
  - A past lunar dynamo?
  - Or impact processes?

→ Magnetic field measurements near the surface would constrain their origin.
Lunar Swirls

• Anomalous color markings.
• Three different hypotheses for their formation.
• Solar wind processes: Shielding by the magnetic field?
  – Solar wind protons are normally a darkening agent.

Magnetic field at 18 km at Reiner Gamma

*Hemingway and Garrick-Bethell (2012)*

(Visible with binoculars)
Swirl Formation Hypothesis

Hood and Schubert (1980)

Hemingway and Garrick-Bethell (2012)
Swirl Formation Hypothesis

Hood and Schubert (1980)

→ Require near-surface particle flux and magnetic field measurements.

Hemingway and Garrick-Bethell (2012)
Lunar Surface Water

• The Moon is covered in very small amounts of surface water/hydroxyl (OH) (Pieters et al. *Science* 2009).

• Swirls are anti-correlated with water/OH.

• Understanding the origin of swirls would help understand lunar surface water processes and space weathering.

OH concentrations at Reiner Gamma. *Kramer et al.* (2011)
Field at the surface and altitude

- Fine structure emerges with altitude.
  - Cusp regions correlated with dark central features?
  - Goal: < 20 degree impact angle
Lunar Cubesat Impactor Concept

- Measure magnetic field and particle flux down to < 100 meters altitude.
Lunar Cubesat Impactor Concept

- Measure magnetic field and particle flux down to < 100 meters altitude.

Berkeley SSL CINEMA cubesat (in orbit now) NSF-funded, ~$1M, Korea Partner
How can we realize this mission with a 3U cubesat?

Enabling new technology:
1) Instrument (magnetometer)
2) Propulsion and navigation
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
- Measurement frequency of 200 Hz possible.
CINEMA Magnetometer - 2

- 1-meter boom

UC Berkeley Space Sciences Lab
Communication and Navigation

- JPL cubesat transponder.
  - Flying on INSPIRE
  - Doppler + range
- Deep Space Network 34-meter dish required to close links for telemetry, science data, and ranging.
  - Expensive, but necessary.
- Berkeley 11-meter dish also available.

Cubesat transponder (JPL)
Link Budget

- 20 kbps required during lunar impact.
- Use of Berkeley 11-meter dish for telemetry (4 kbps).
- UCB mission operations can perform entire mission.
Getting to the Moon

1. Cubesat ride-share to geosynchronous orbit

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

Cubesat communication and navigation via Deep Space Network
Propulsion - 1

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

Liquid salt: 1-ethyl-3-methylimidazolium bis(triuroomethylsulfonyl)imide
Propulsion - 2

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

MIT Space Propulsion Laboratory
Propulsion - 3

- Three-axis control, and:
- 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 in <1 year.
• Assumption: 30 W available power.
  – Body fixed panels.
• Spiral to lunar from GEO impact takes ~105 days, 1.9 km/s delta-v.
• Requires ~400 grams of propellant.
  – 0.7U of volume
Trajectory Simulations - 2

- Impact of the Moon, as seen from the Earth.
- Challenge: impacting at low (<20°) angles.
Challenges Ahead

• Challenges:
  – Long-duration testing of propulsion system.
  – Approaches to radiation exposure.
Conclusions

• A fully independent, 3-axis controlled cubesat capable of traveling to the Moon with >2 km/s delta-v capability will be possible in the next 1-2 years.

• Unique platform capable of other near-Earth space measurements.

• Paper available at: http://people.ucsc.edu/~igarrick
Extra Slides
Looking Ahead: Asteroid Interceptor

- Mass, density, magnetic field.
- Physical properties through impact.
- Ability to alter asteroid course
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
Extra slides
Technical Advantages

• A lunar cubesat would be the smallest spacecraft to ever leave the Earth.
  – Lots of public interest.

• Small mass = low launch cost.
  – Low cost enables more frequent missions.

• Cubesats enable university access to space and student training.

• A platform capable of reaching the Moon would have lots of other applications.
Key Technologies Required for a Lunar Cubesat

• Two key enabling technologies are being built or will be tested in 2013:
  – 1) Propulsion system that can provide high delta-v for GTO to lunar impact or possibly even lunar orbit. (0.5 U volume)
  – 2) Transponder and radio to provide communications and navigation via NASA’s Deep Space Network (DSN). (0.5 U volume)
• High power (~30 W) from solar panels is also required for the propulsion system, but this is not a major challenge for cubesats.
• Radiation for some orbits a serious concern.
1) Propulsion

• MIT’s nano-fabricated electrospray propulsion system offers high specific impulse (>2500 s) ion propulsion with no moving parts or plasma. Thrust scales linearly with power input.
• Modular ~1 cm square units provide main propulsion and attitude control.
• Time to lunar impact for 3U cubesat, from GTO (30 W power): 120 days. Total propulsion system volume: 0.5U.
• Testing underway at MIT. 1U LEO demo planned for launch in 2013.
• UCSC/Ames collaborating with MIT.
• MIT graduate student planning trajectories from GTO to Moon.

(Francois Martel/Paulo Lozano MIT)
2) Navigation

- JPL X-band (7.2 GHz up and 8.4 GHz down) radio and transponder capable of providing Doppler and range information via NASA’s Deep Space Network.
- Design review of improved version: Feb. 2013. Fits into 0.5 U volume.
- Cost: <$100k.
- Users can either work with JPL/DSN to obtain data, or communicate with their own large X-band capable ground station.
- UCB SSL experience: comm and nav with the DSN/JPL for ARTEMIS now in lunar orbit. Data rate: 0.5 Mbps (using a different transponder and 70 m dish).
- UCSC/UCB communicating with JPL on use of their system in a lunar cubesat mission.
Some Remaining Key Challenges

• 1) These technologies are almost ready, but not space qualified. User would have to accept some risk in using them, or wait another 1-2 years until they are fully qualified.
  – Some risk is probably acceptable for low cost cubesat missions.
• 2) The radiation environment at GTO is substantially worse than in LEO, due to periodic radiation belt passage.
  – Radiation tolerant hardware, radiation shielding, and radiation tolerant software designs are being considered. Motivation is very high, due to number of GTO opportunities.
  – Geosynchronous orbit greatly preferred, but probably fewer opportunities for cubesats.
  – Any shared ride beyond GTO would work. Example: Orion human space capsule test a possibility in 2014-2015. NASA is considering ride shares on Orion.
Future Work

• Design work for a 3U lunar cubesat is ongoing at UCSC/UCB/NASA Ames.

• Propulsion system: long-duration testing underway at MIT. 1U demonstration in LEO should launch in 2013.
  – Lunar trajectory work ongoing at MIT.

• Navigation system: awaiting results of Feb. 2013 design review at JPL.
  – Working with NASA Ames, UCB and JPL on navigation and Deep Space Network scheduling requirements.

• Radiation concerns: working with industry partner in early 2013 to discuss mitigation techniques.

• General feeling that the mission is possible and a design will converge.
  – Always seeking partners.

• Somebody will be the first to send a cubesat to the Moon, who will it be?