Priority Lunar Mission Target: The Swirls at Ingenii

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Introduction

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- 2 mare-filled craters within Ingenii basin
  - Thompson, ∼120 km
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- Swirls
Already Considered

- Mare Ingenii was selected as a Constellation region of interest.
What's a Lunar Swirl?

- High albedo
- Sinuous shape & interweaving dark lanes
- Associated with magnetic anomalies
- Impart no topography
  - i.e., they drape existing topography
- Optically immature

1. Ingenii – Clementine simulated true color
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1. Ingenii

2. Airy - Clementine simulated true color
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Planetary Magnetic Fields

... on a planetary body that has no global magnetic field
Magnetic Anomalies

Lunar Prospector magnetic field strength (nT)

Purucker and Nicholas (2010), 30 km altitude
Magnetic Bubbles

- All lunar swirls are associated with a magnetic anomaly
  - But not every anomaly has an (identified) swirl
Topology of the Magnetic Field

- Magnetic field lines of a pair of dipoles separated by 15 km and oriented horizontally.

- Profiles of the horizontal component of the magnetic field
  - at the various altitudes represented by colored dashed lines in figure above.

From Hemingway & Garrick-Bethell, 2012

Horizontal surface fields = bright swirls

Vertical surface fields = dark lanes
Space Weathering

Processes that alter the surface of a planetary body that lacks an atmosphere to protect its surface.

**Agents**
- Solar wind
- Micrometeorite bombardment
- Impact vaporization & deposition
- Sputtering
- Solar wind implantation
- Cosmic and Solar Rays

**Processes**
- Chemical reduction
- Melting
- Impact vaporization & deposition
- Comminution

**Products**
- Nanoparticle iron
- Microphase iron
- Agglutinates
- Regolith/dust

From Noble et al. (2005)
Understanding Space Weathering

- Retarded maturation on the swirls indicates the solar wind is the dominant form of weathering at the Earth-Moon distance.
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Weathering by the solar wind "turned off" at swirls.

- magnetic field deflects solar wind protons, so weathering on the swirls occurs almost exclusively by micrometeorite bombardment.
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- Dark lanes and regions adjacent to swirls receive normal solar wind flux + deflected ions.
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- Flux of solar wind particles less at distance of Asteroid Belt. Micrometeorites may dominate weathering process.

- Magnetic field deflects solar wind protons, so weathering on the swirls occurs almost exclusively by micrometeorite bombardment. Dark lanes and regions adjacent to swirls receive normal solar wind flux + deflected ions.
Sampling Fresh Material

Lunar swirls are kept fresher, longer.

Sample materials of the same age ...

- Petrologically formed at the same time
- Exposed by impact gardening at the same time
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... but different maturities
Lunar Swirls & Space Dew

M³ true color mosaic of Ingenii

- Swirls are easily identified where they occur on maria.
- Swirls are difficult to distinguish in the highlands.
Swirls as a Water Diviner

Hydroxyl (OH) parameter map derived from M³ data depicts variation in depth of 2.82µm band.

- The swirls appear dark
  - indicates swirls are *depleted* in OH relative to their surroundings.

- Due to deflected solar wind protons

- Deflected protons may mean over saturated dark lanes have increased OH abundances.
Heliophysics & Solar Evolution

- Instruments placed at the swirls can be used to measure the efficacy of the magnetic fields in deflecting particles of different mass.
  - As well as the existence or importance of the hypothesized charge-separated electric field effect.

- If the magnetic anomalies formed early in lunar history, and have been protecting the surfaces from the solar wind ever since, the swirls may be a great location to sample the ancient solar wind.
Plasma Physics

- The swirls are a place to observe charged particle interactions with a magnetic field involving complex geometries.

  - In particular, the swirls provide a unique scale for studying these interactions - larger than a vacuum chamber, yet smaller than a global magnetic field.
You are interested in energy resources during a mission

An electric field, generated as a consequence of charge separation by the magnetic field, may control space weathering by the solar wind.

- The restriction of positive ions in a plasma wake can lead to a buildup of negative static electricity on an astronaut's suit or
  - possible danger to astronaut or sensitive instrumentation.

Bamford et al., 2012
Energy Resources

- The strength of such an electric field is related to the local gradient in the magnetic field strength.
- The geometry of the magnetic anomalies may control the electric field useful ways
  - Protection
  - Energy resource

Bamford et al., 2012
The swirls have no topography - they simply drape over any existing topography.

The surface and subsurface roughness of swirls is no different than their surroundings.

- So no need to worry about uneven surfaces when landing on a swirl/dark lane interface
South Pole-Aitken

- Testing the terminal cataclysm hypothesis with SPA impact melt.
  - Especially if all you're sending is a robotic lander, you want to get the freshest sample possible.
Ingenii Basin is antipodal to Imbrium Basin.

- Ingenii Basin is surrounded by unusual furrowed terrain, which is attributed to the convergence of seismic waves.
- Some of these blocks may be uplifted portions of the SPA differentiated melt sheet.
Utilizing a Skylight

- One of the few locations where a collapsed pit, or skylight, has been identified.
- Skylights can be used as a habitat for a sustained human presence
  - protect astronauts from solar storms and prolonged exposure to cosmic rays.