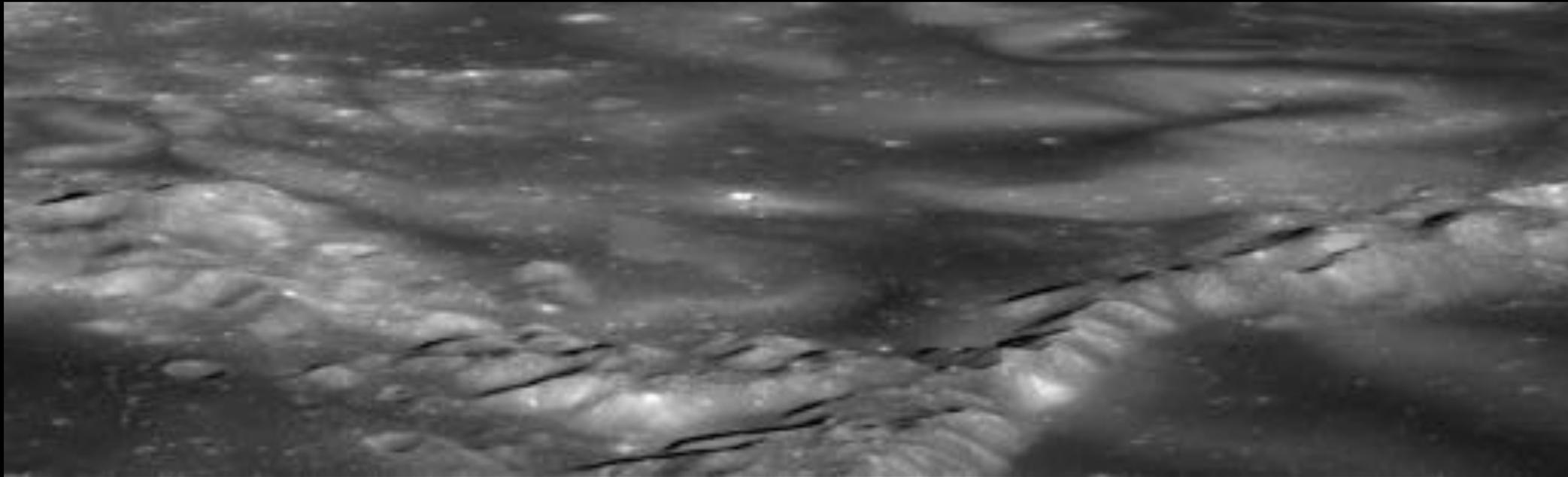


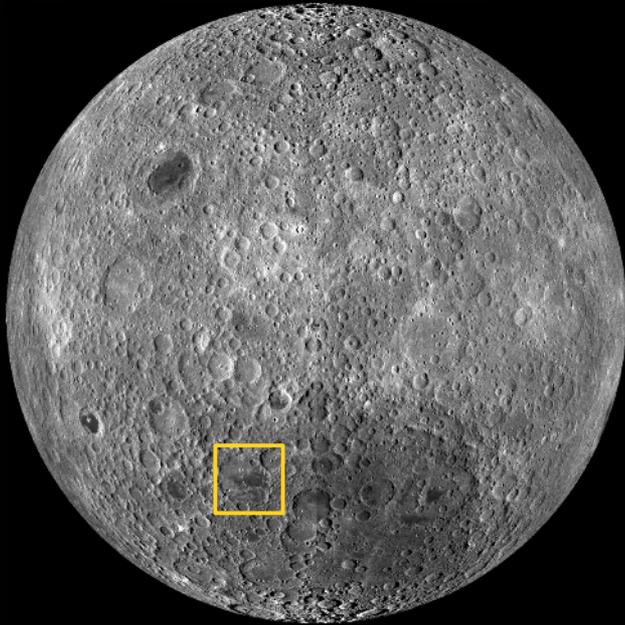
Priority Lunar  
Mission Target:      The Swirls at Ingenii



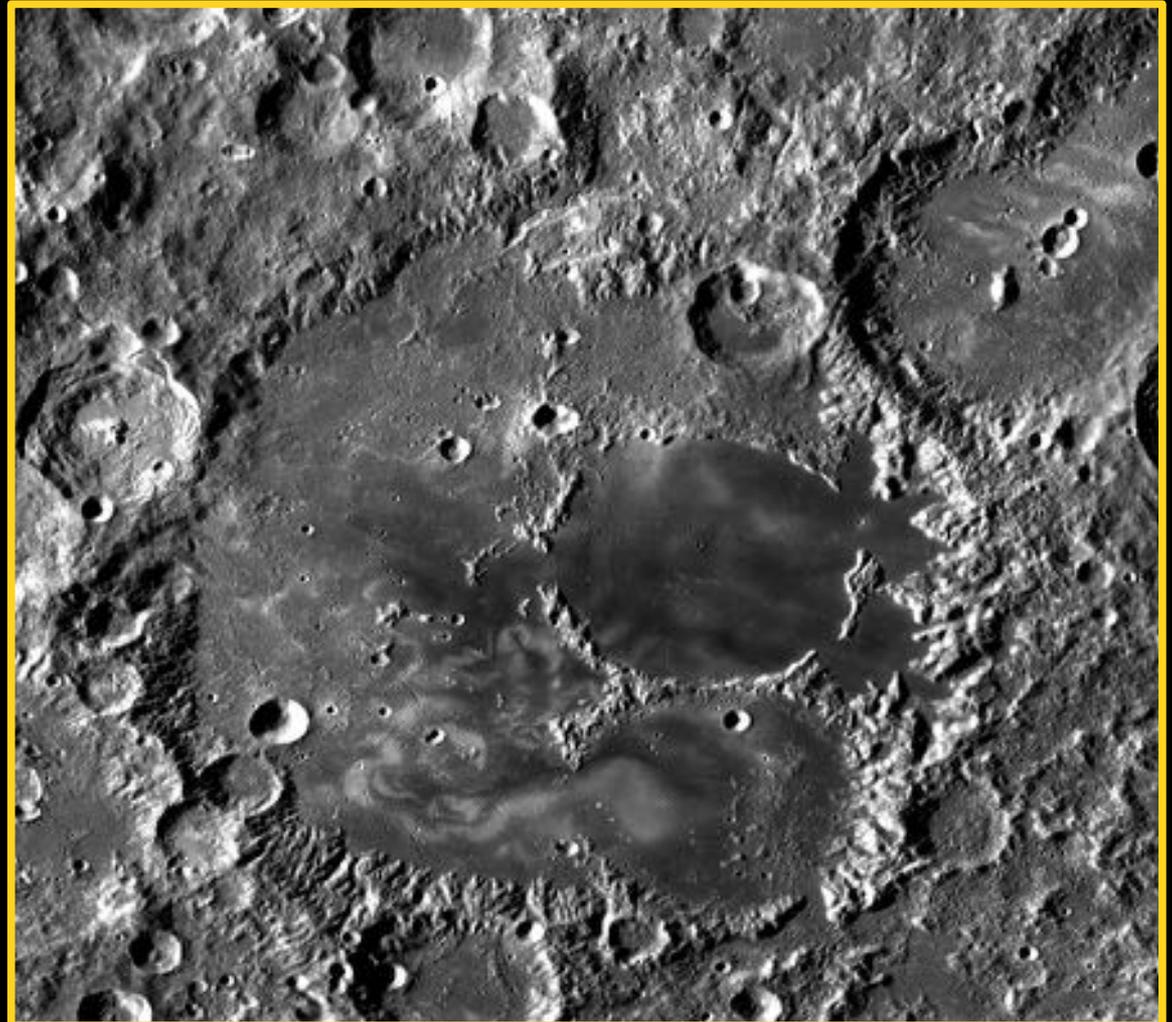
Georgiana Kramer  
Lunar & Planetary Institute

Lunar Science for Landed Missions Workshop  
January 12, 2018

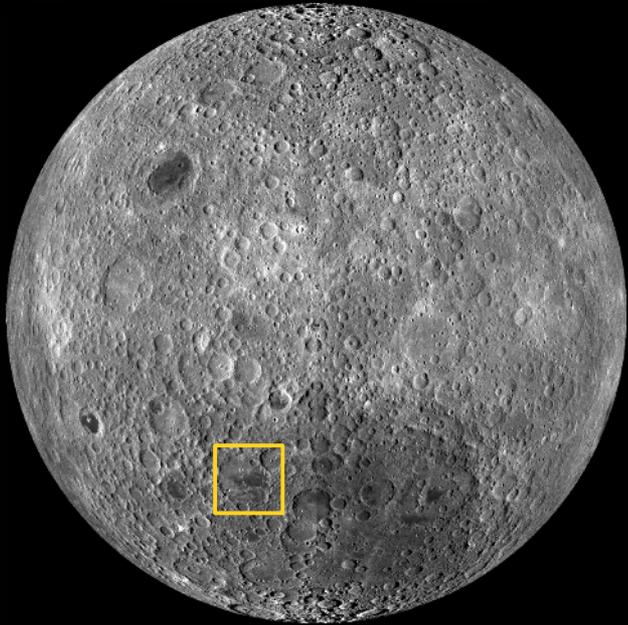
# Introduction



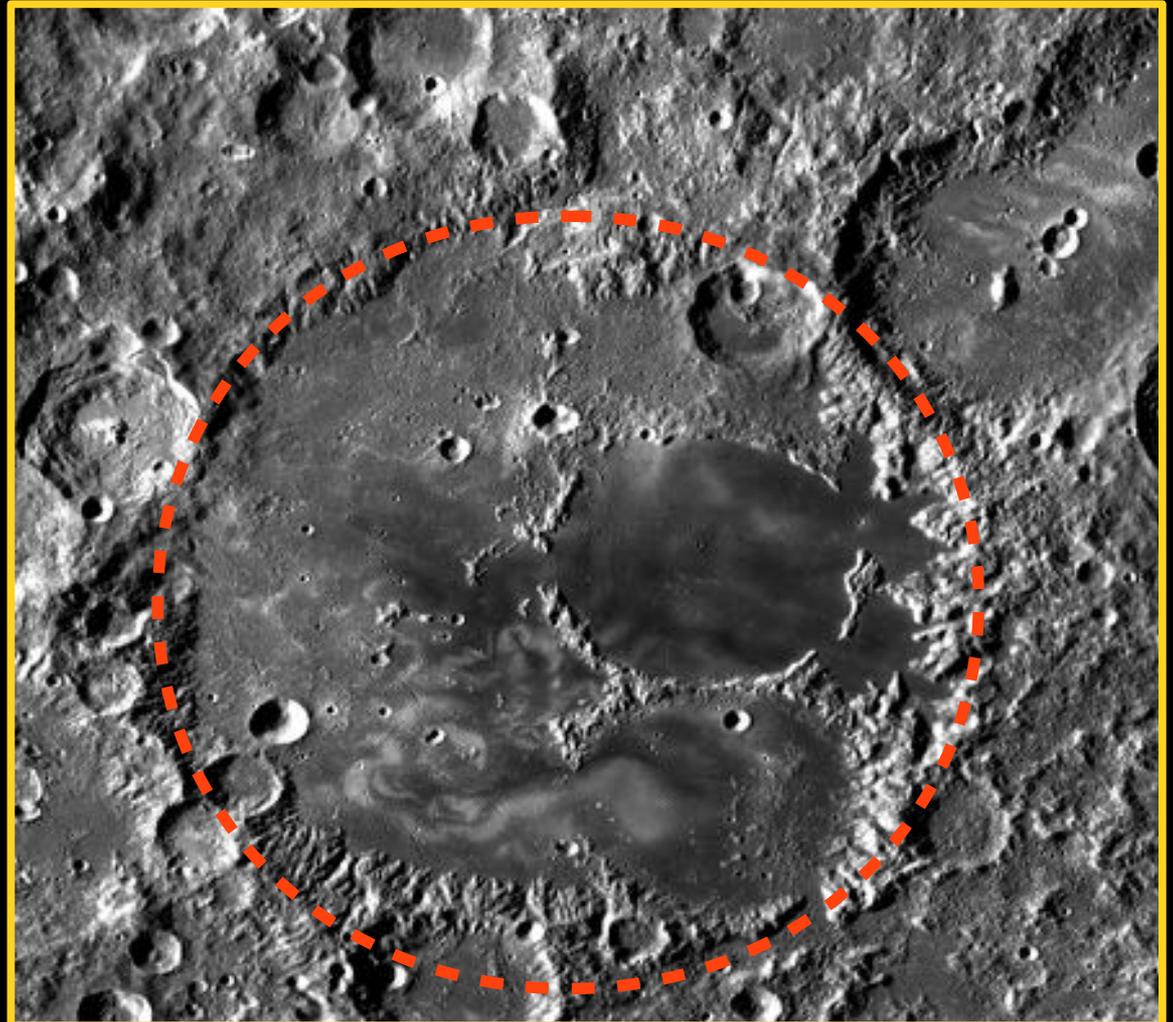
- Location: 33.25 S, 164.83 E



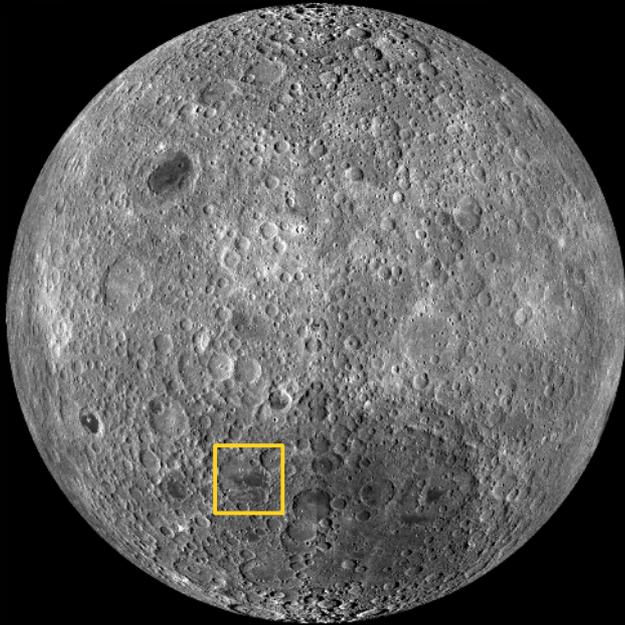
# Introduction



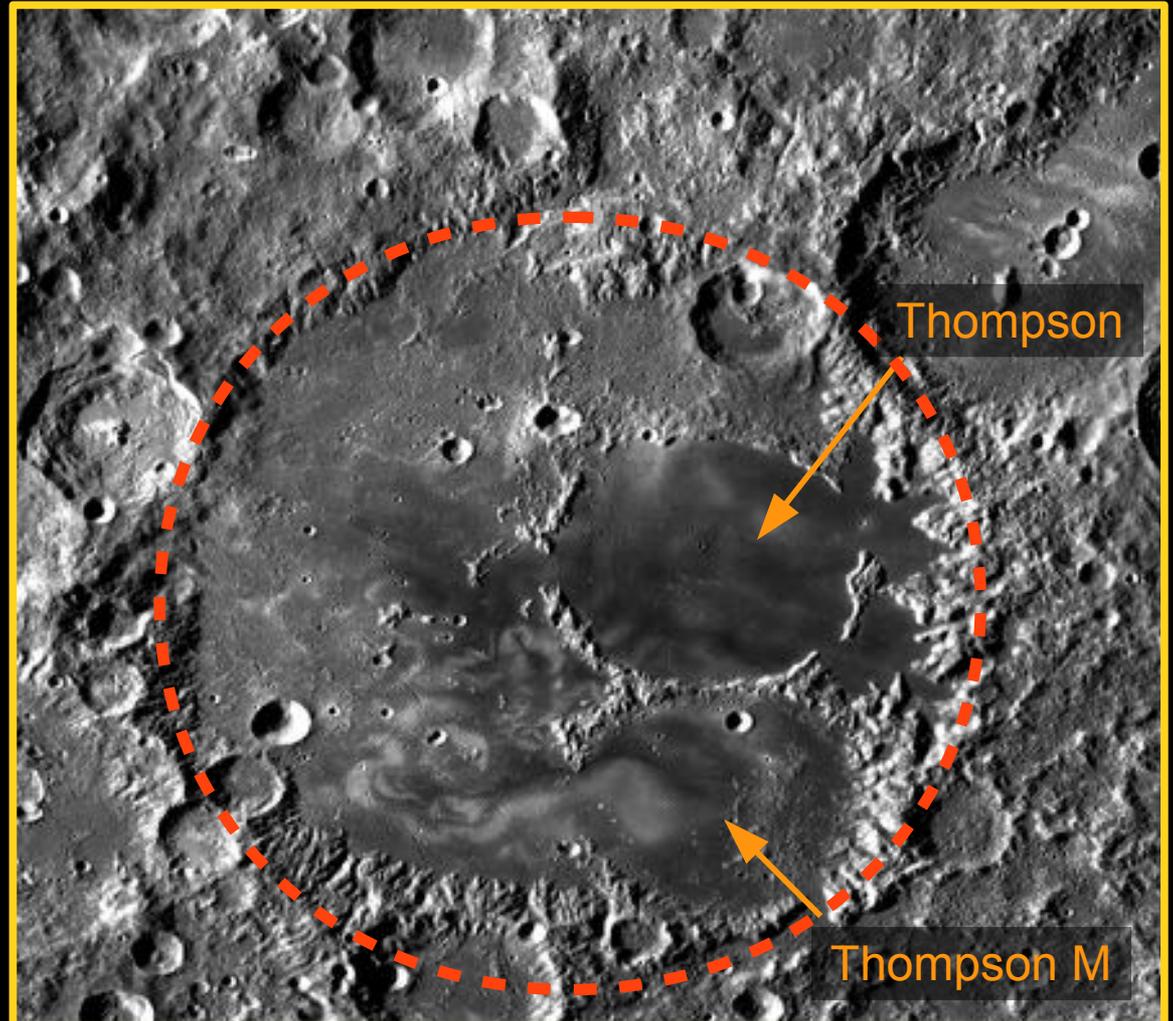
- Location: 33.25 S, 164.83 E
- Rim = 325 km



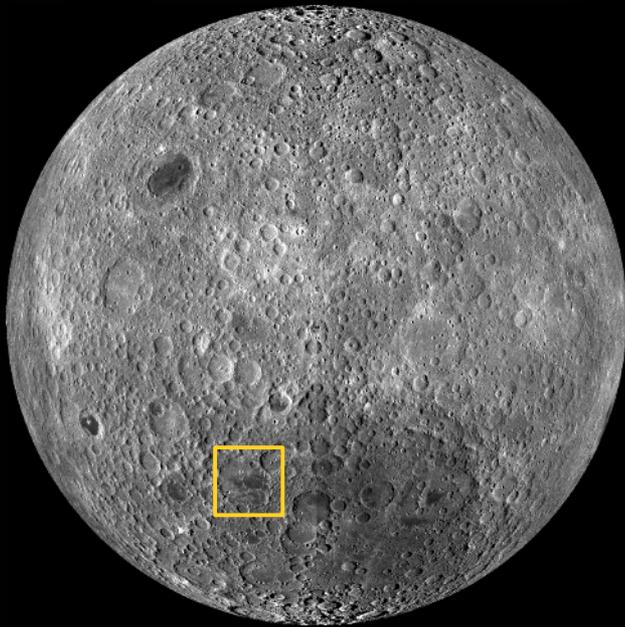
# Introduction



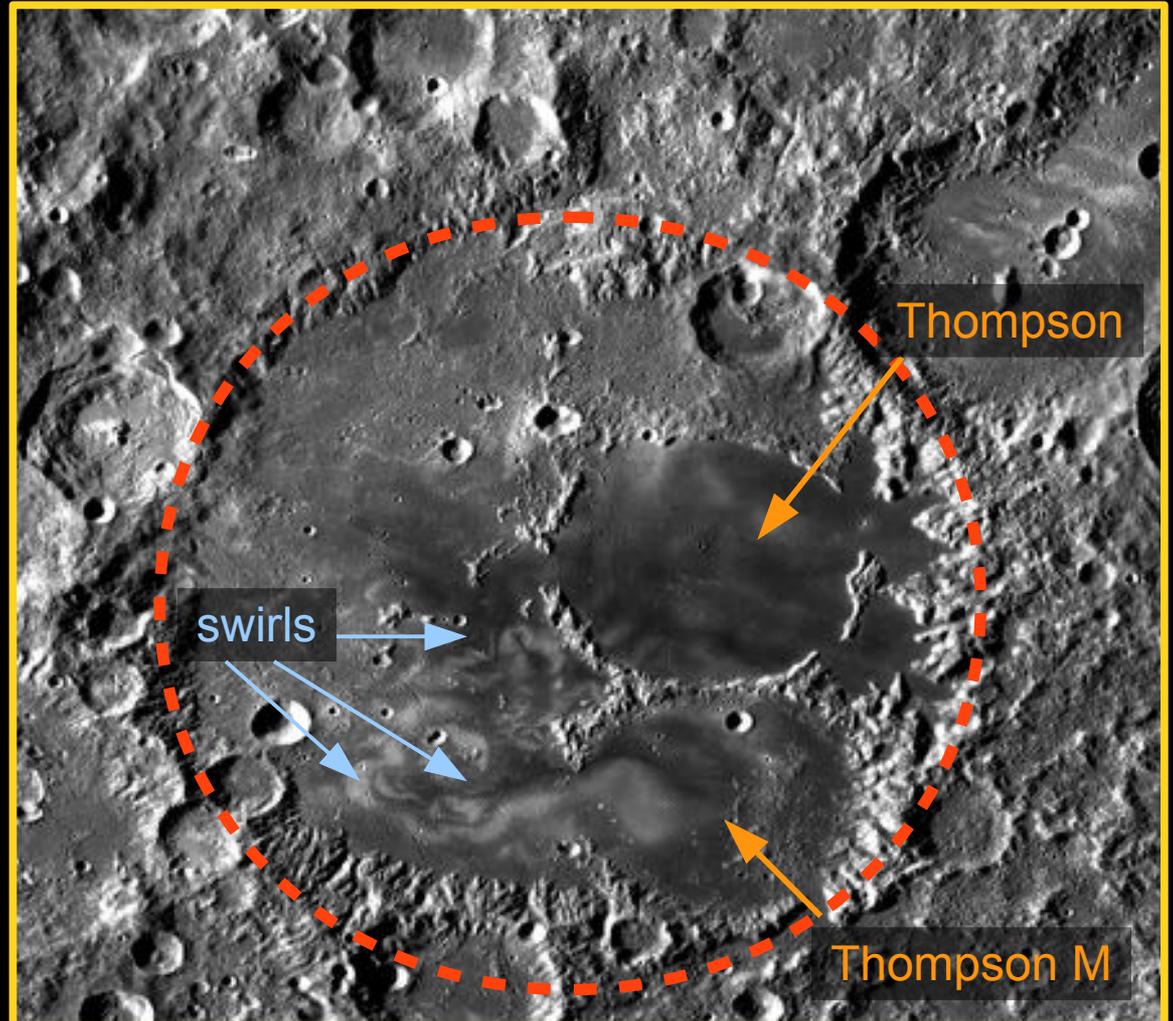
- Location: 33.25 S, 164.83 E
- Rim = 325 km
- 2 mare-filled craters within Ingenii basin
  - Thompson, ~120 km
  - Thompson M, ~100 km



# Introduction

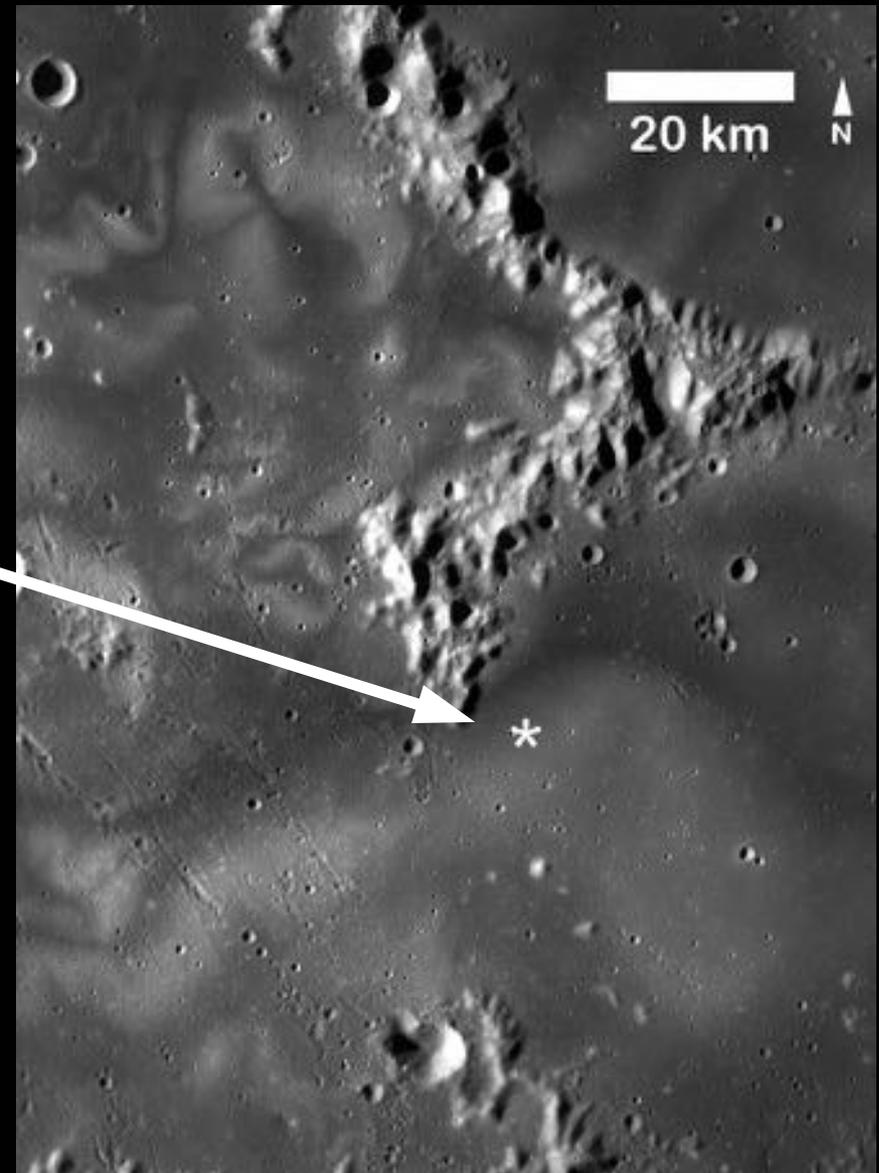


- Location: 33.25 S, 164.83 E
- Rim = 325 km
- 2 mare-filled craters within Ingenii basin
  - Thompson, ~120 km
  - Thompson M, ~100 km
- Swirls



# Already Considered

- Mare Ingenii was selected as a Constellation region of interest.



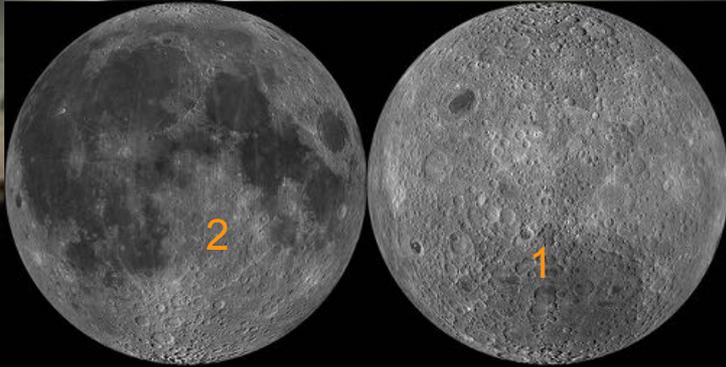


# What's a Lunar Swirl?

- 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



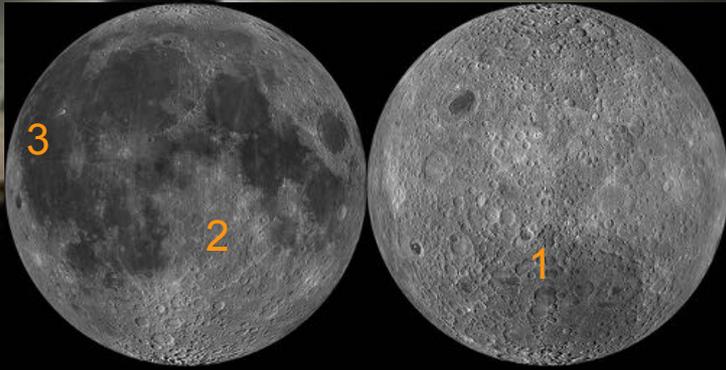
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1.  
Ingenii



2. Airy - Clementine simulated true color



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1.  
Ingenii

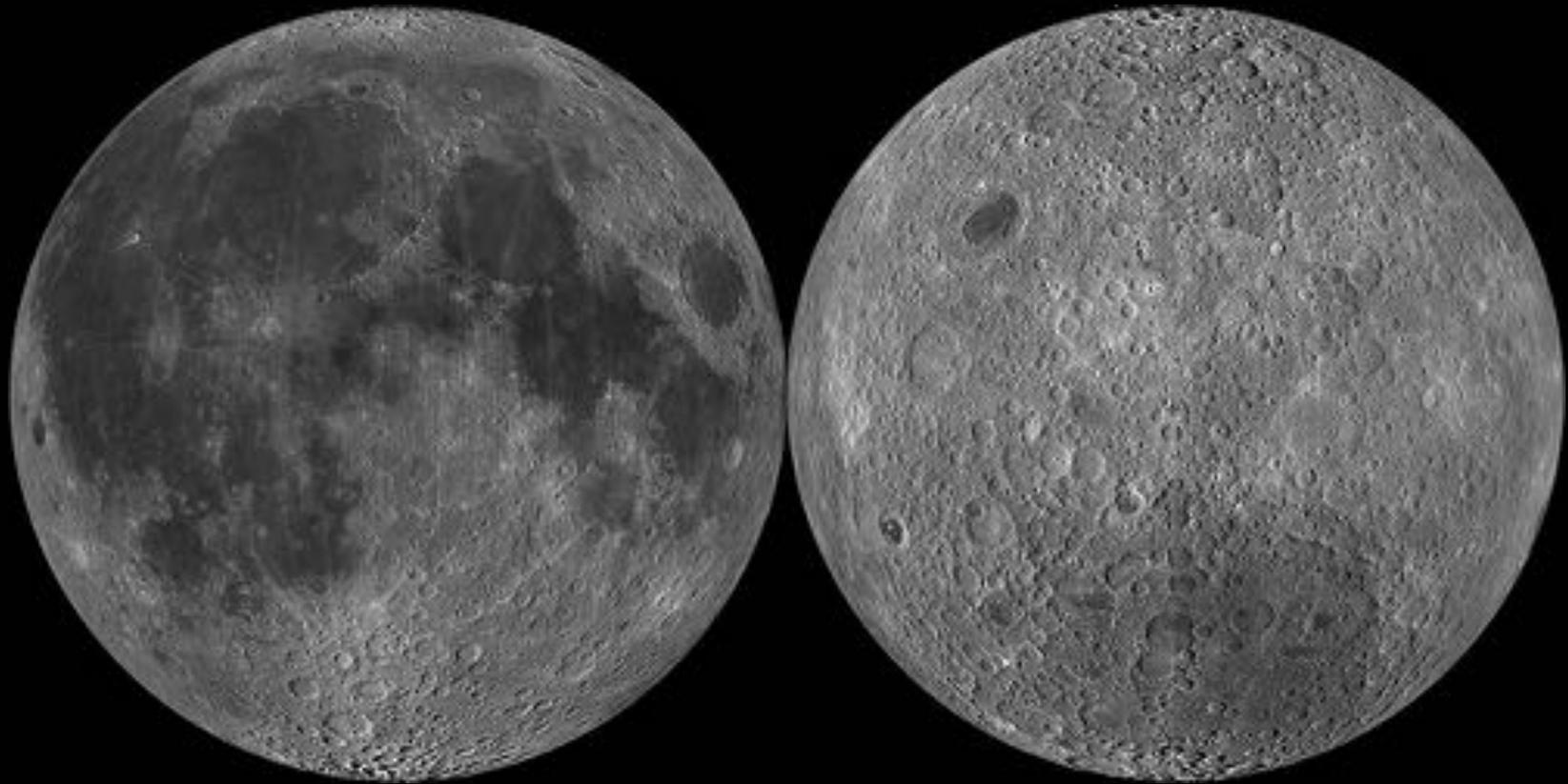


2. Airy



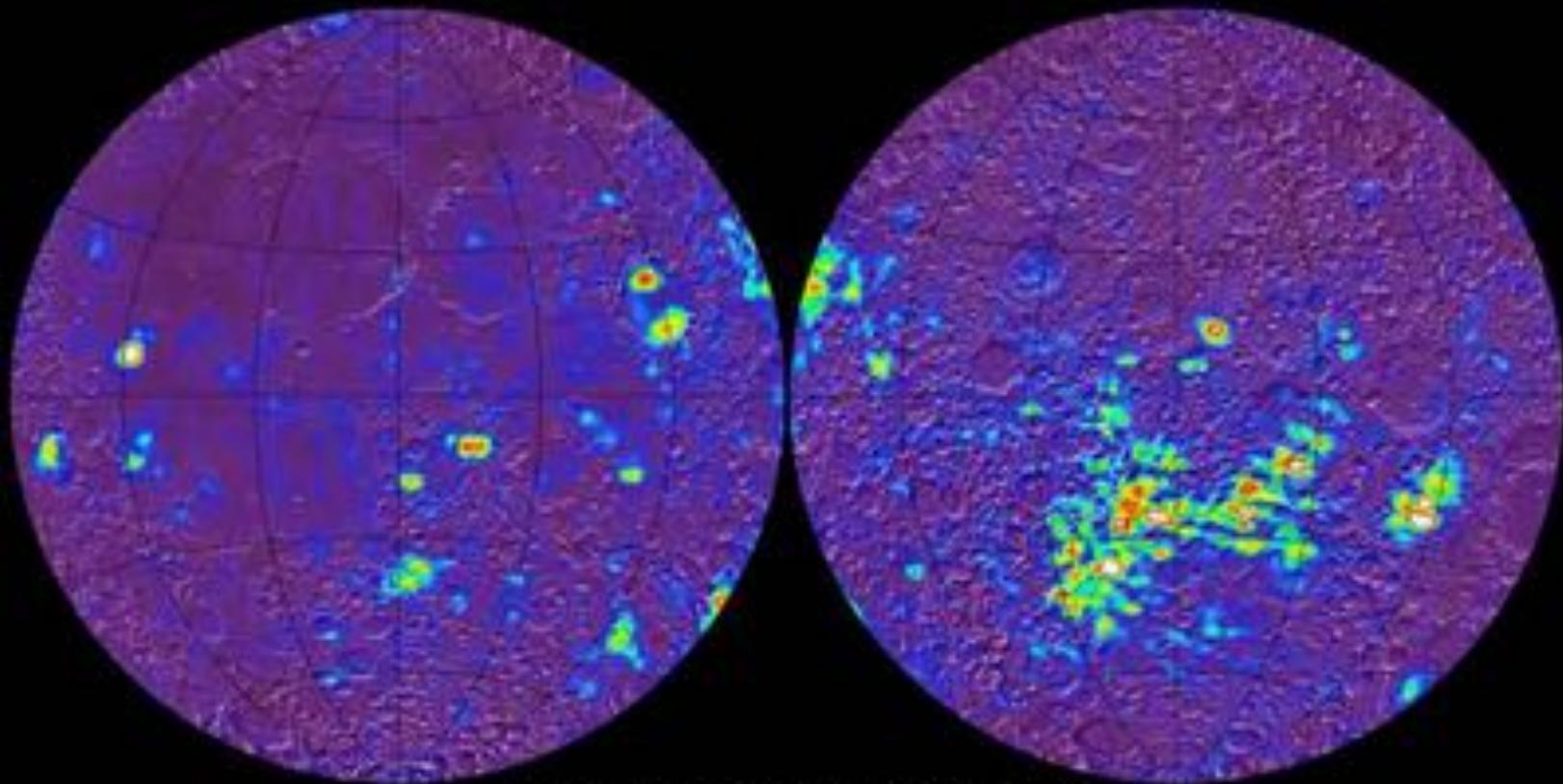
3. Reiner Gamma  
- Clementine simulated true color

# Planetary Magnetic Fields

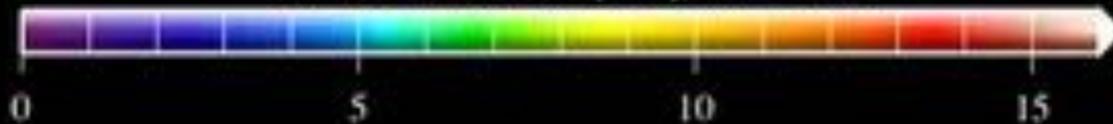


... on a planetary body that has no global magnetic field

# Magnetic Anomalies



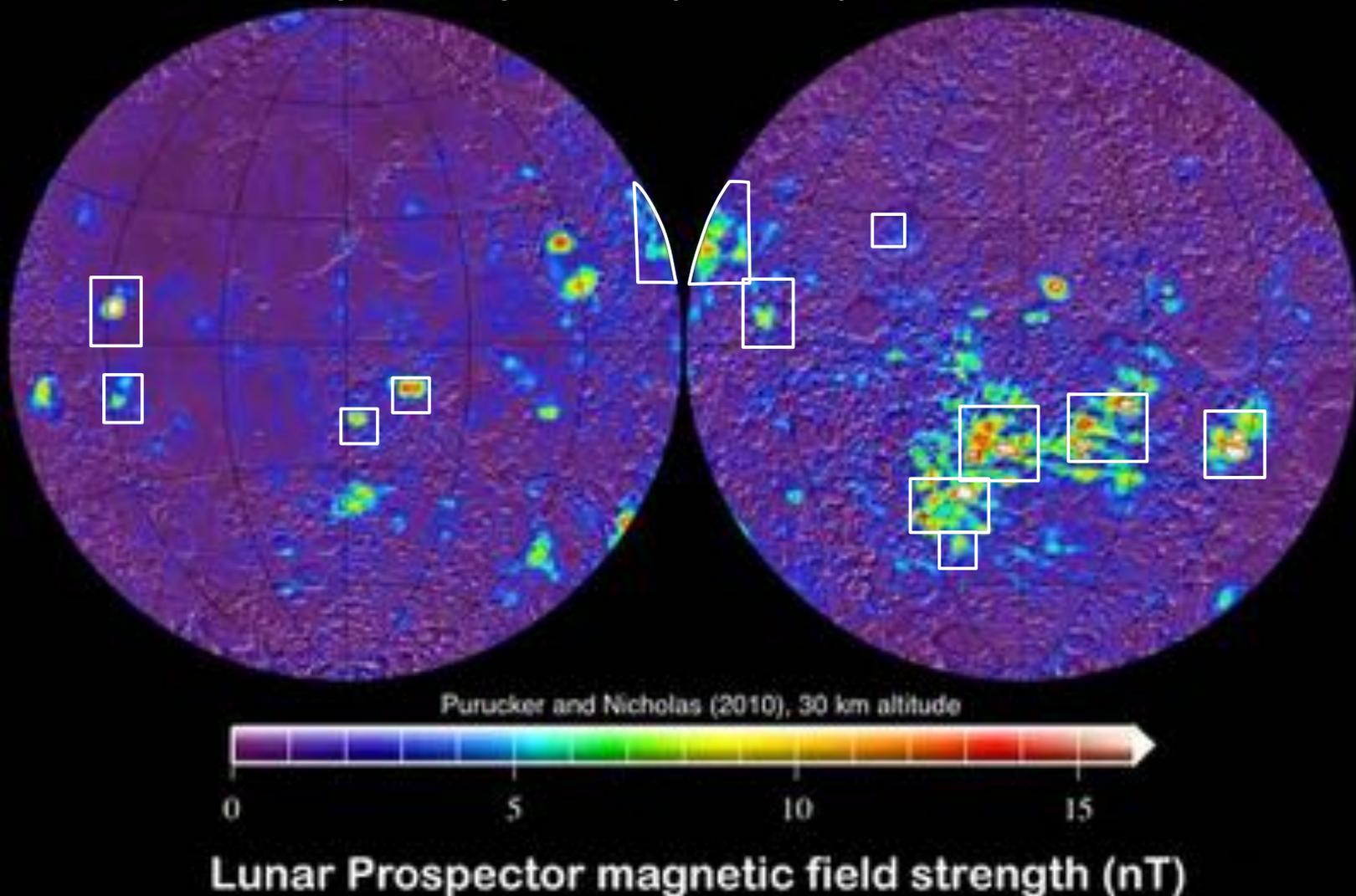
Purucker and Nicholas (2010), 30 km altitude



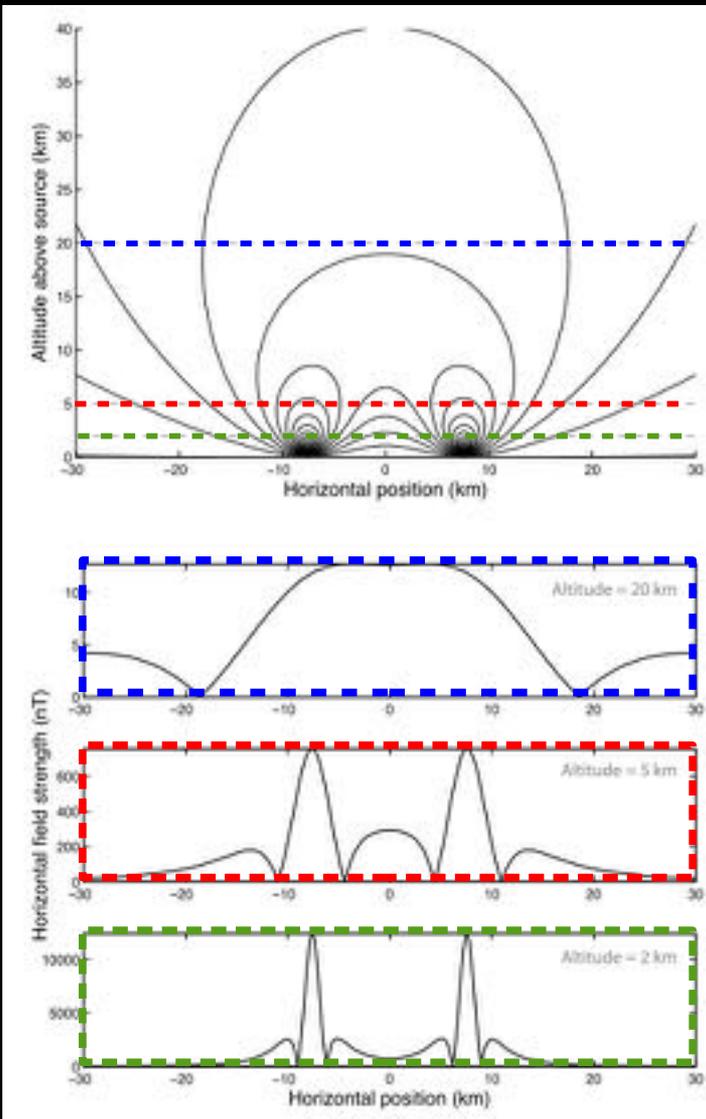
Lunar Prospector magnetic field strength (nT)

# Magnetic Bubbles

- All lunar swirls are associated with a magnetic anomaly
  - But not every anomaly has an (identified) swirl



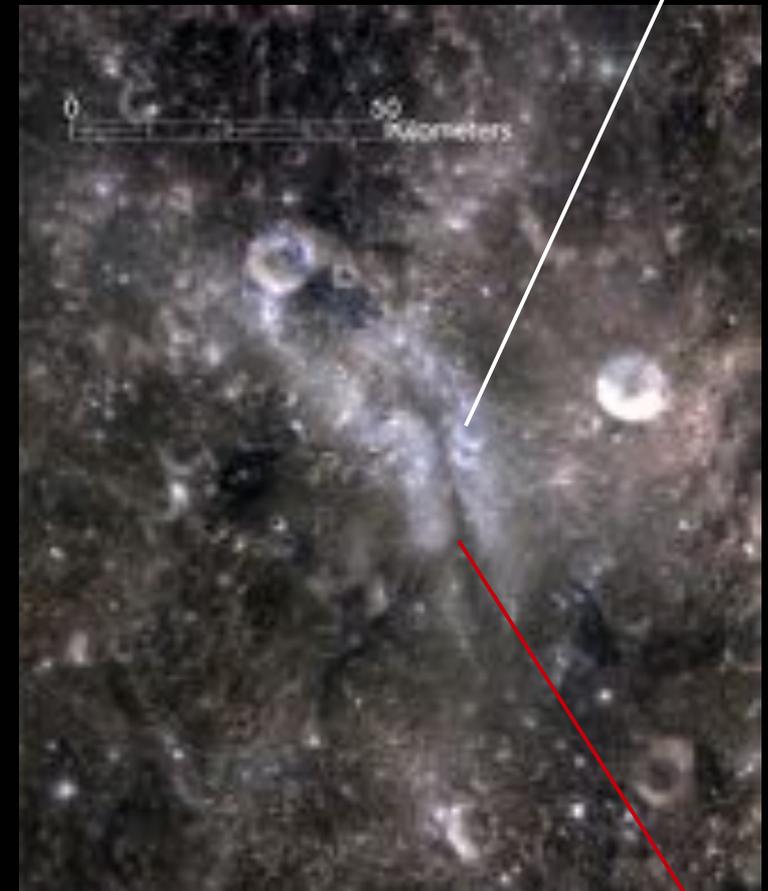
# Topology of the Magnetic Field



- 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.

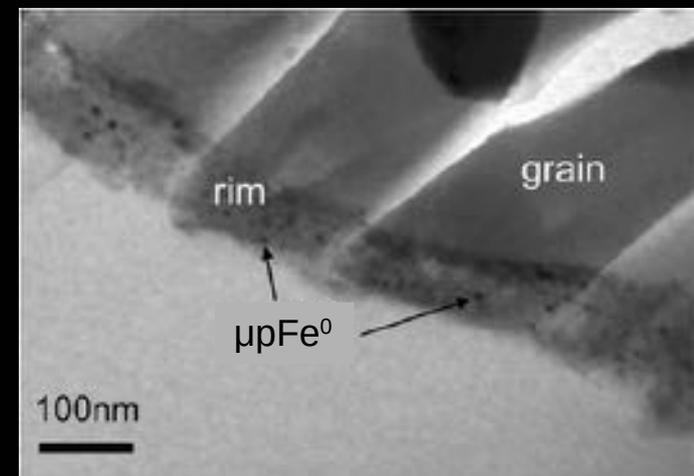
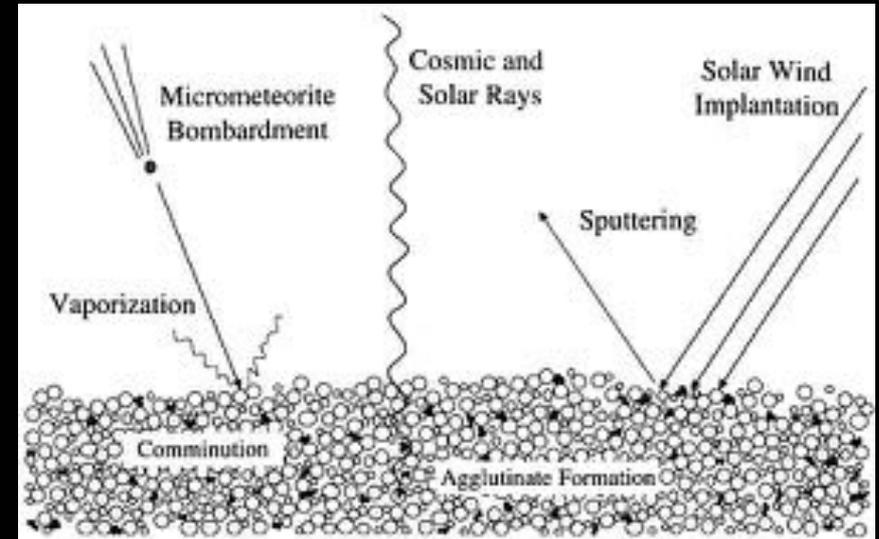
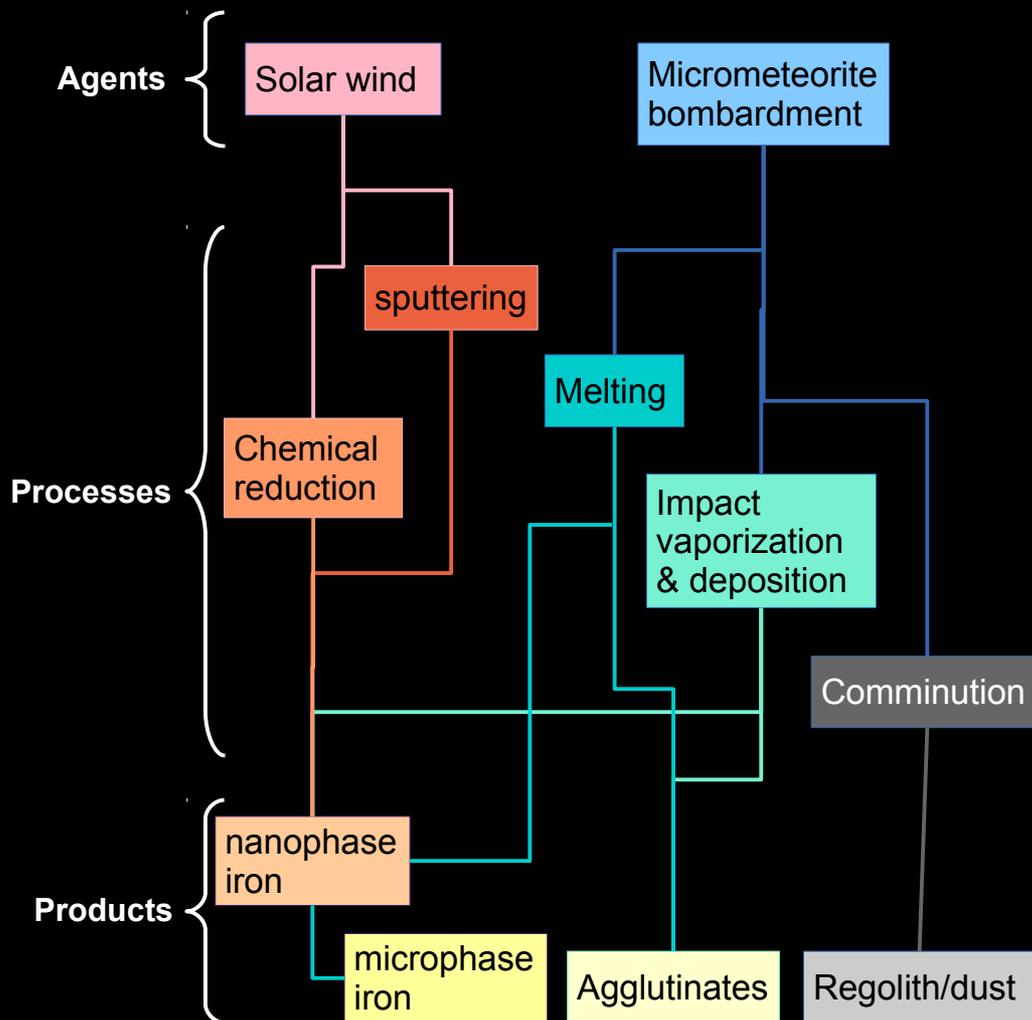
Horizontal surface fields  
= bright swirls



Vertical surface fields  
= dark lanes

# Space Weathering

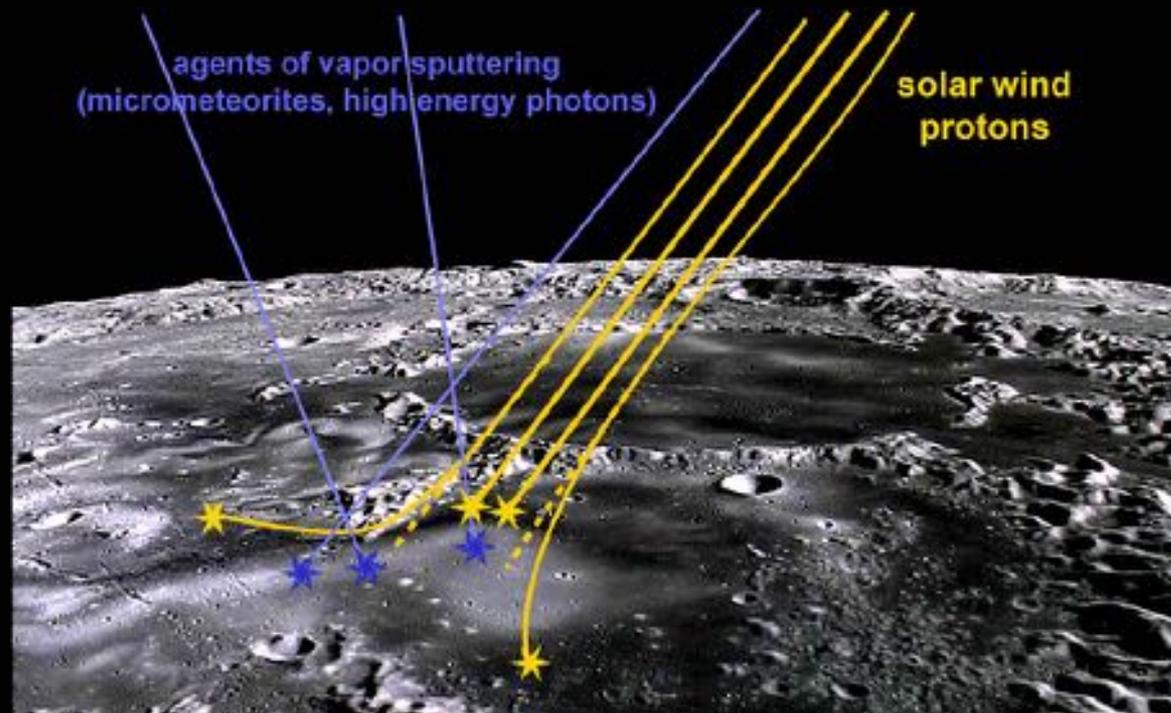
Processes that alter the surface of a planetary body that lacks an atmosphere to protect its surface.



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.

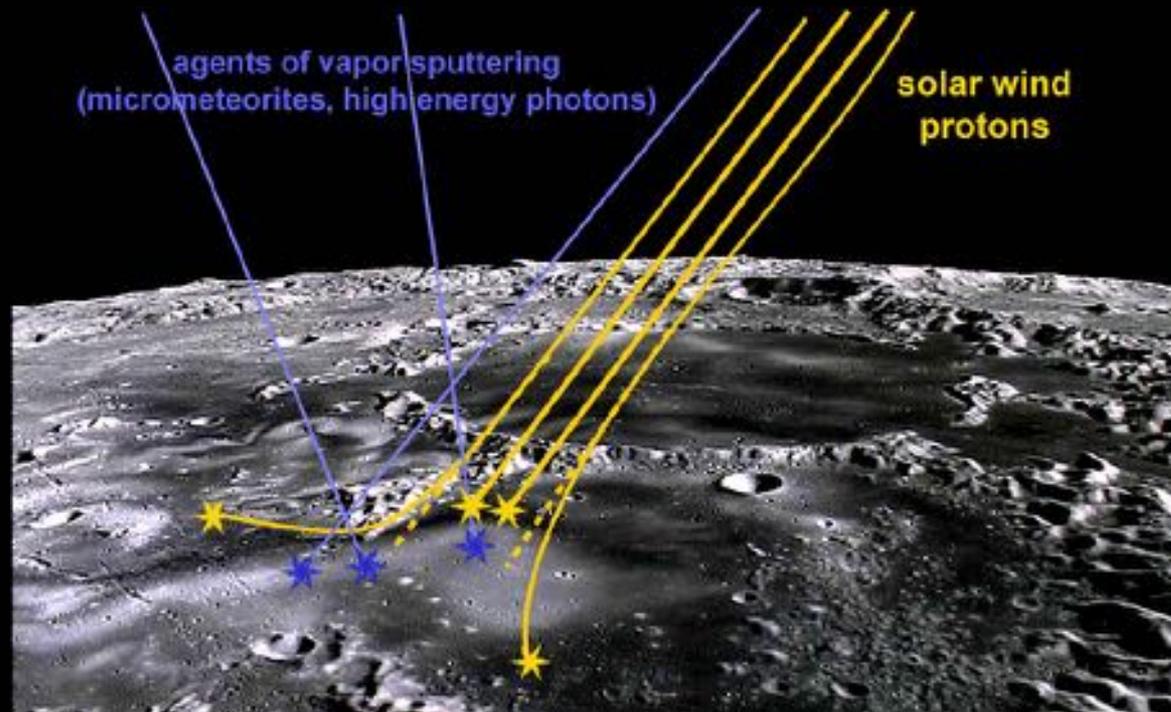


# Understanding Space Weathering

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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.



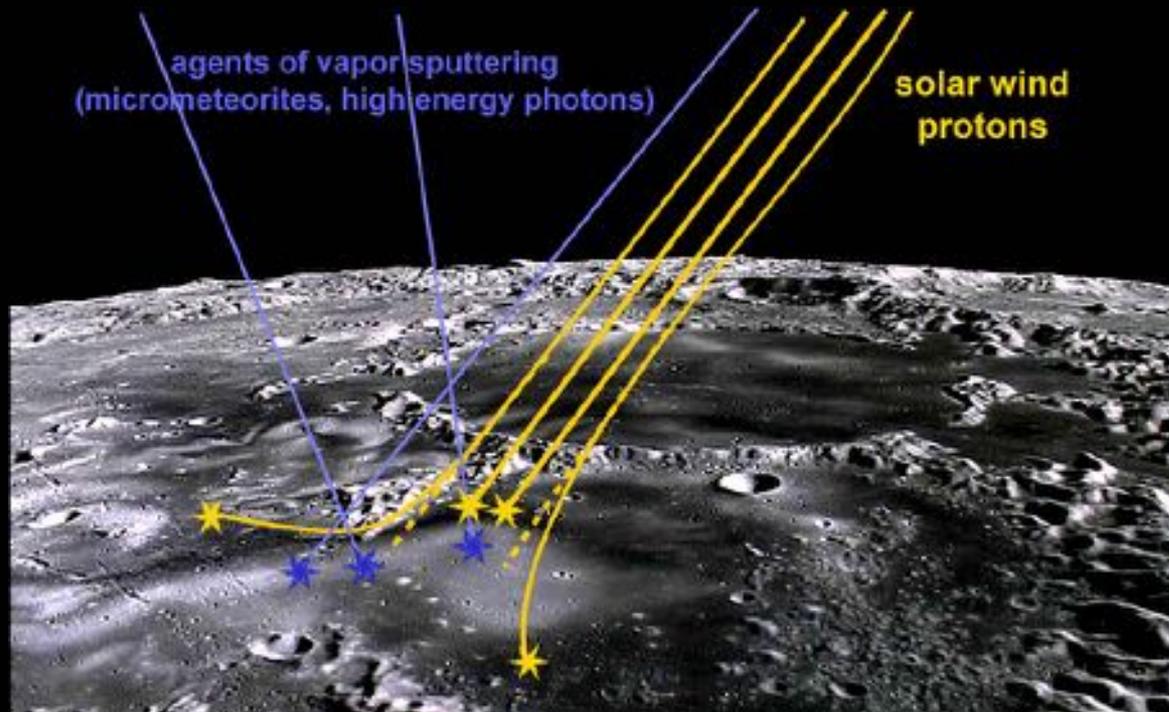
# Understanding Space Weathering

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- dark lanes and regions adjacent to swirls receive normal solar wind flux + deflected ions.

# Understanding Space Weathering

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*Weathering by the solar wind "turned off" at swirls.*

*Weathering by the solar wind is "turned up" at dark lanes.*

• Flux of solar wind particles less at distance of Asteroid Belt.

– micrometeorites may dominate weathering process

dark lanes and regions adjacent to swirls receive normal solar wind flux + deflected ions.



– magnetic field deflects solar wind protons so weathering on the swirls occurs almost exclusively by micrometeorite bombardment.

# 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



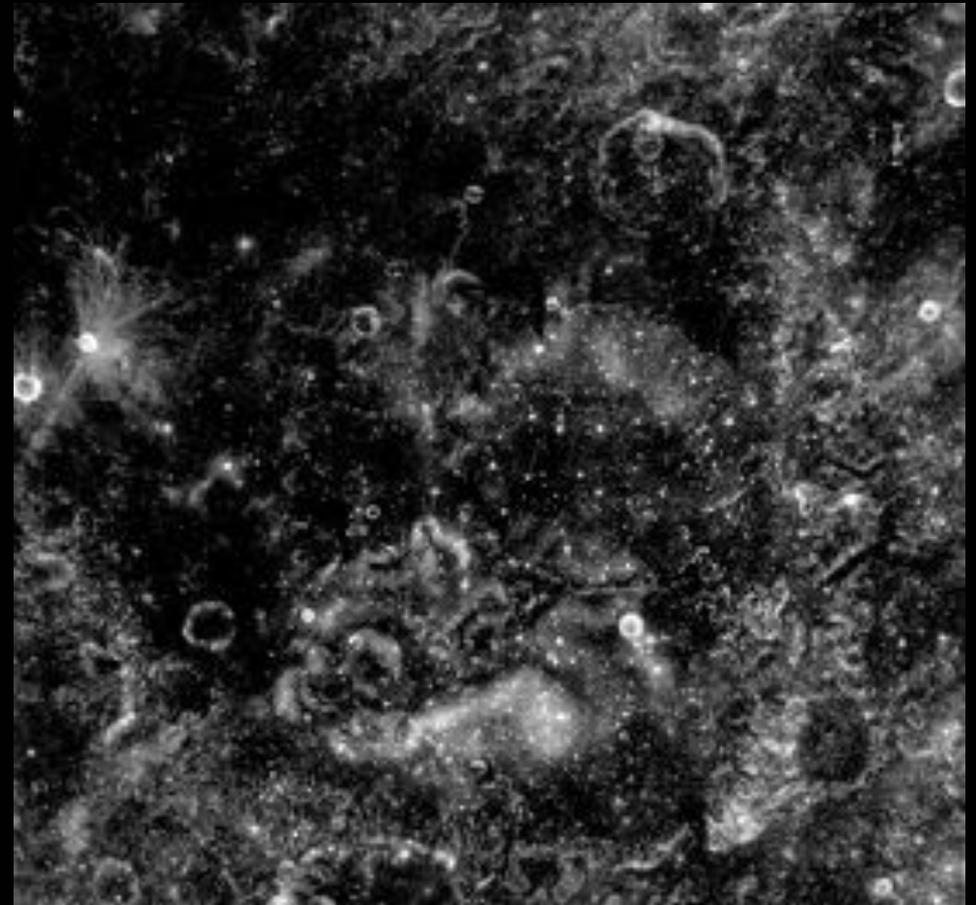
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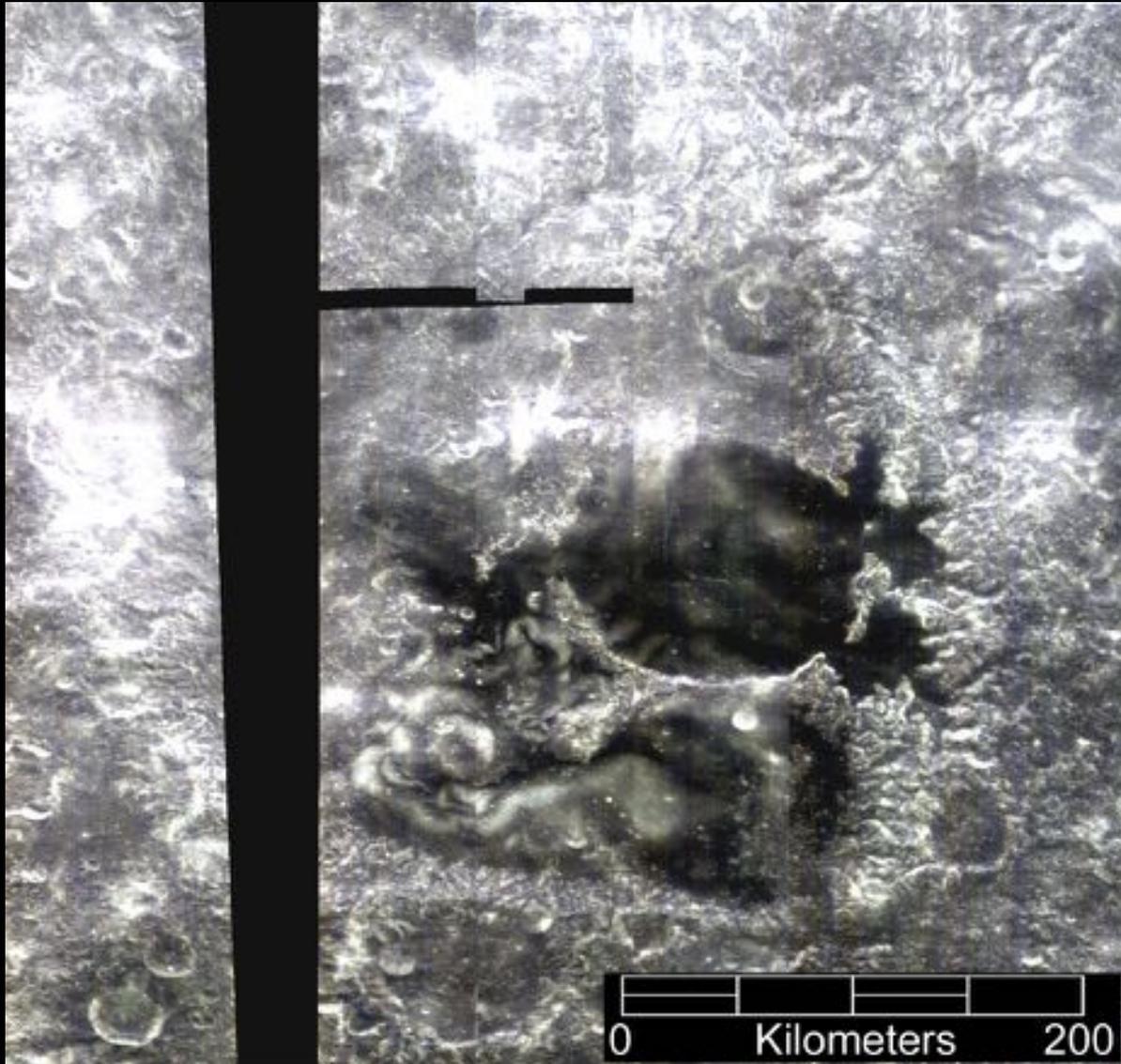
Sample materials of the same age ...

- Petrologically formed at the same time
- Exposed by impact gardening at the same time

... but different maturities



# Lunar Swirls & Space Dew



M<sup>3</sup> 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 M<sup>3</sup> data depicts variation in depth of 2.82 $\mu$ m 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.



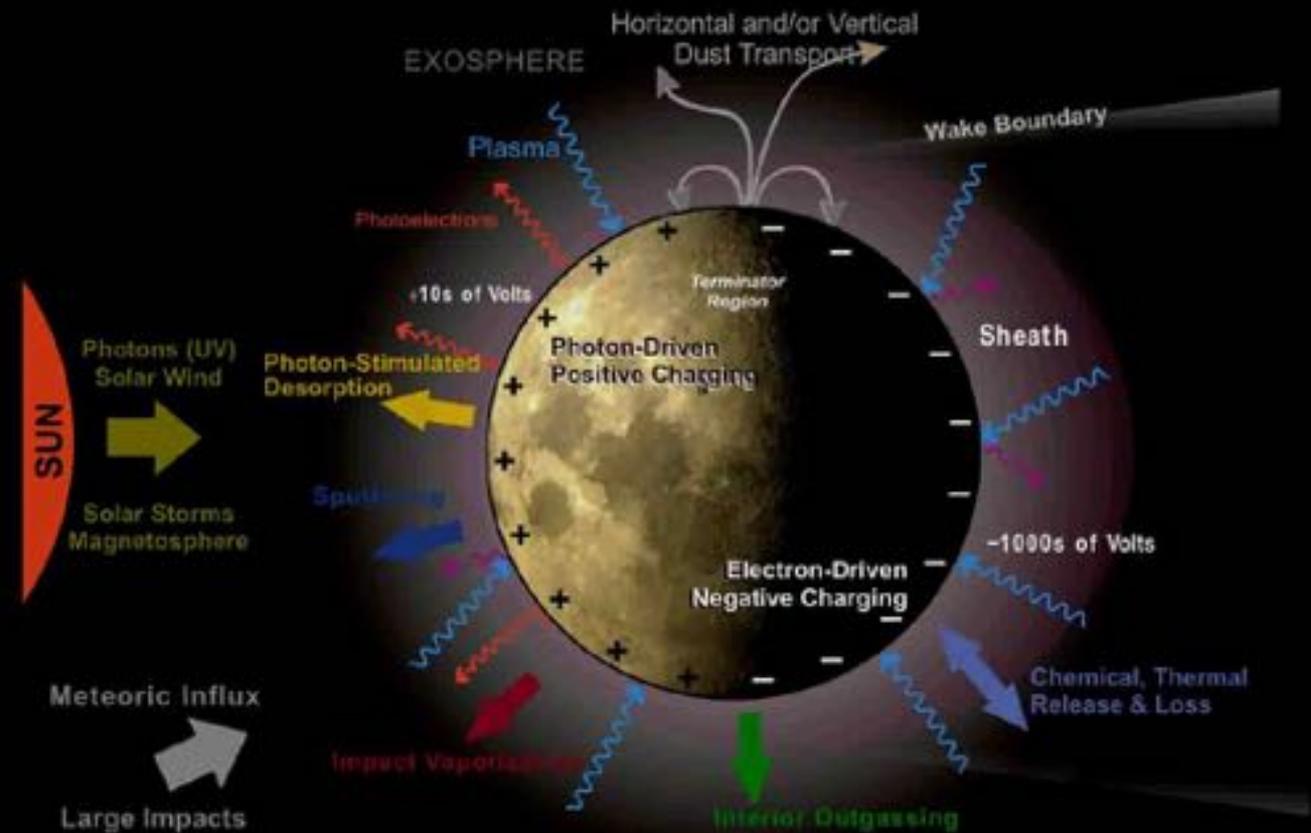
# Heliophysics & Solar Evolution

- 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.

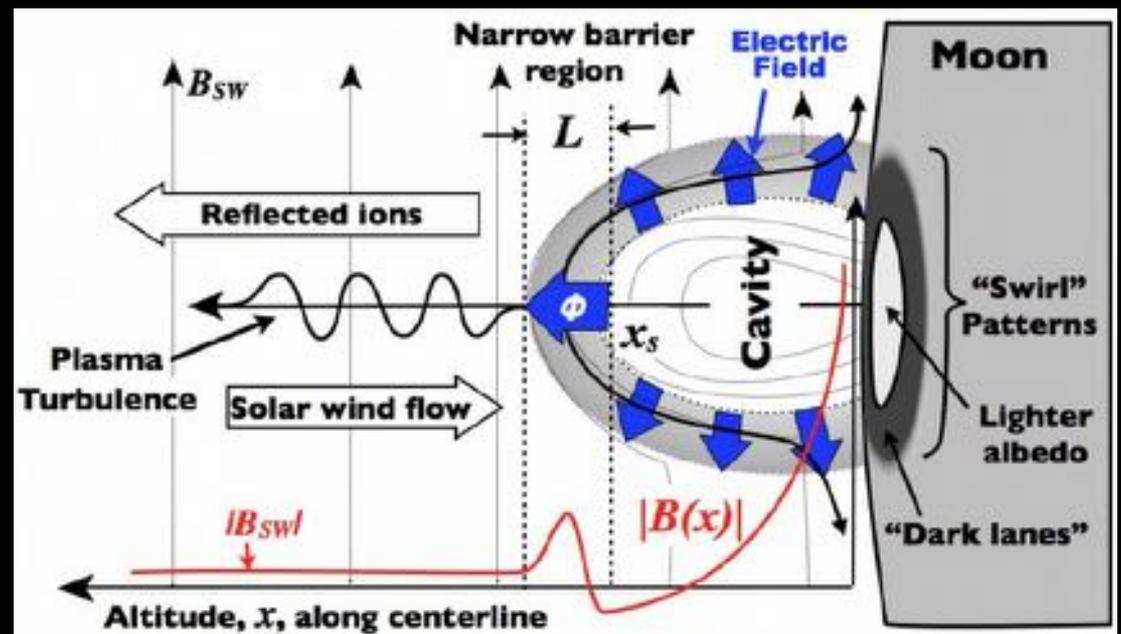
- In particular, the swirls provide a unique scale for studying these interactions - larger than a vacuum chamber, yet smaller than a global magnetic field.



# You are interested in energy resources during a mission

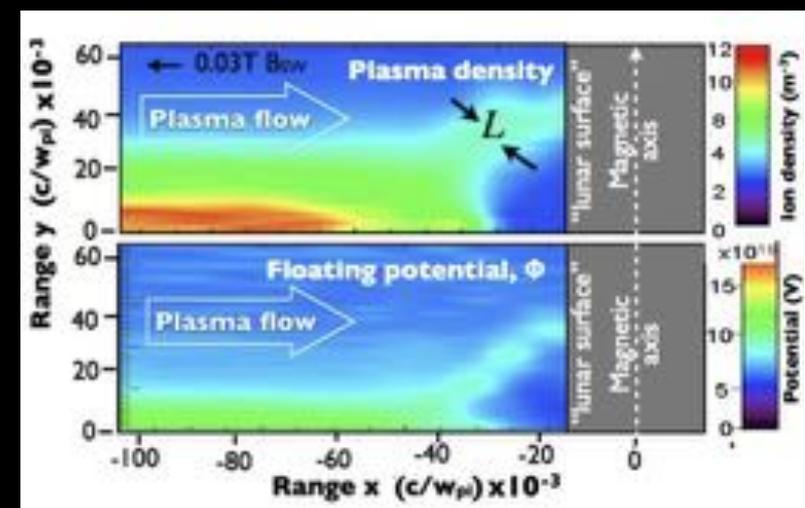
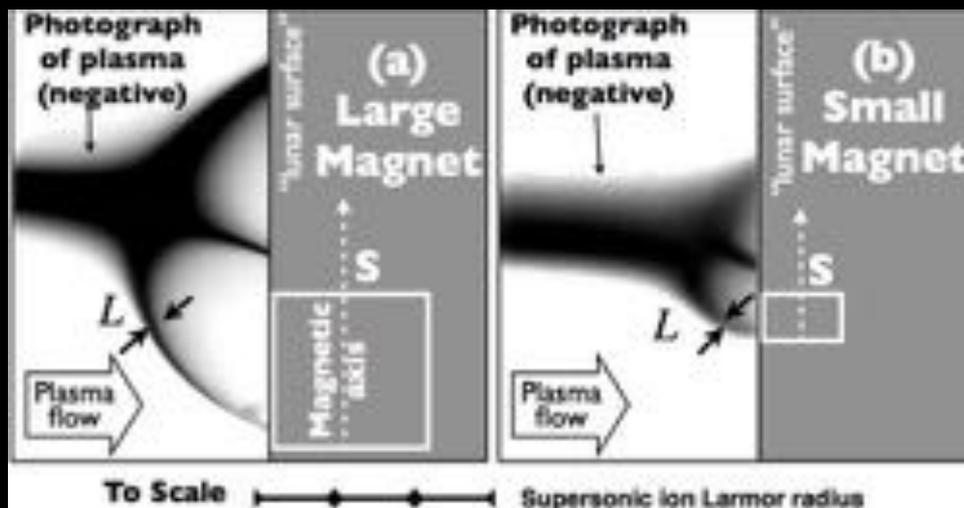
An electric field, generated as a consequence of charge separation by the magnetic field, may control space weathering by the solar wind.

- 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.

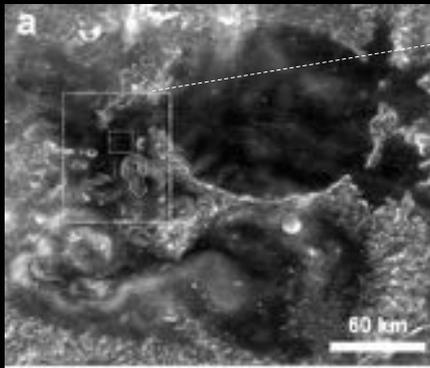


# Energy Resources

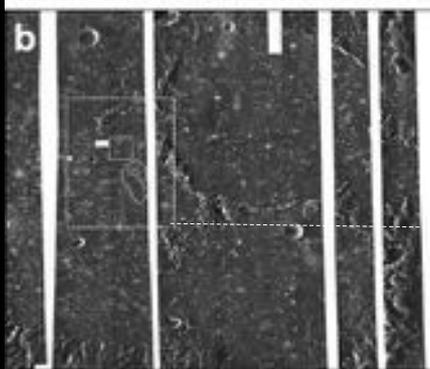
- The strength of such an electric field is related to the local gradient in the magnetic field strength.
- The geometry of the magnetic anomalies may control the electric field useful ways
  - Protection
  - Energy resource



# A Flat Place to Land

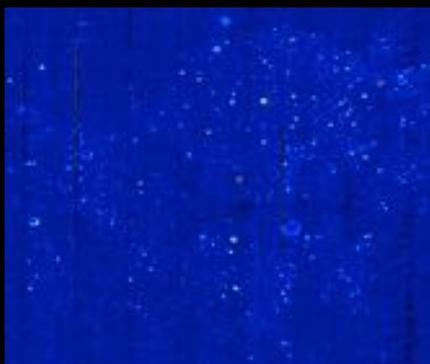


Clementine  
750 nm  
albedo



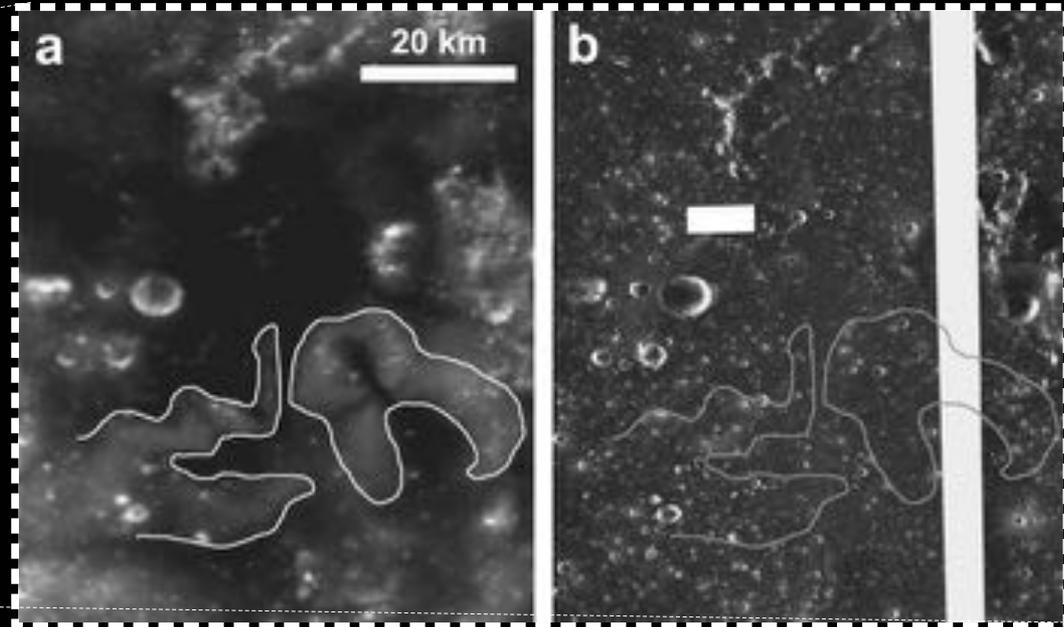
Mini-RF  
S-band  
backscatter

Neish et al., 2011



Diviner  
Rock  
abundance

Bandfield et al., 2011

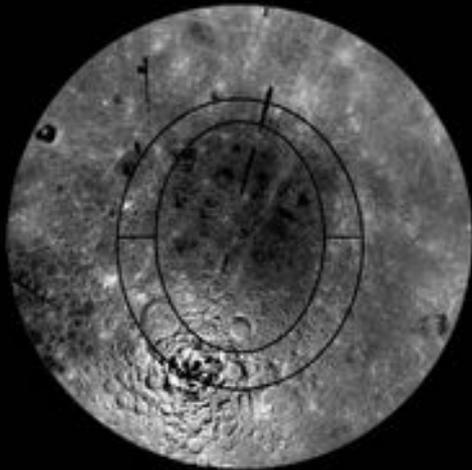


Neish et al., 2011

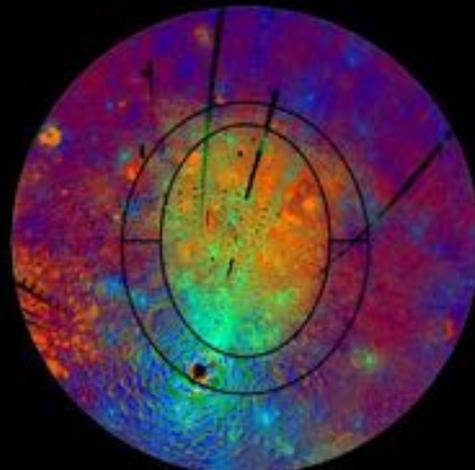
- The swirls have no topography - they simply drape over any existing topography.
- The surface and subsurface roughness of swirls is no different than their surroundings.
  - So no need to worry about uneven surfaces when landing on a swirl/dark lane interface

# South Pole-Aitken

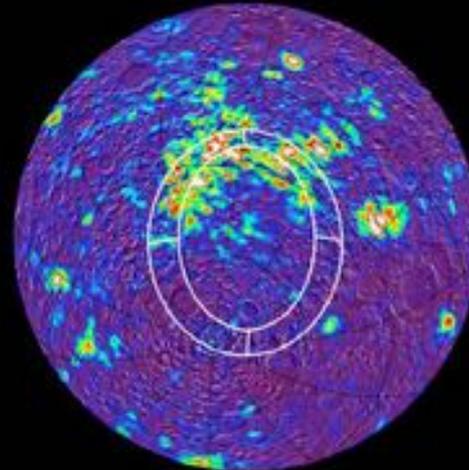
- Testing the terminal cataclysm hypothesis with SPA impact melt.
  - Especially if all you're sending is a robotic lander, you want to get the freshest sample possible.



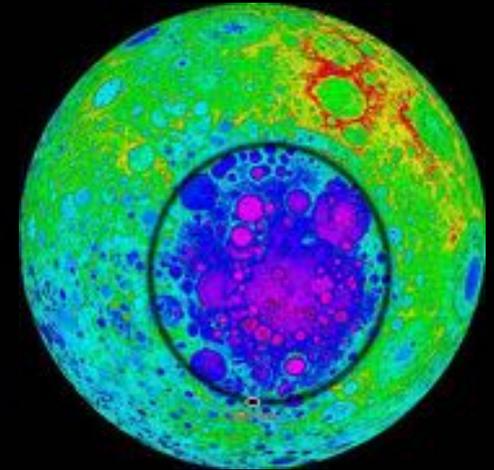
Clementine  
750 nm albedo



Clementine  
color-ratio



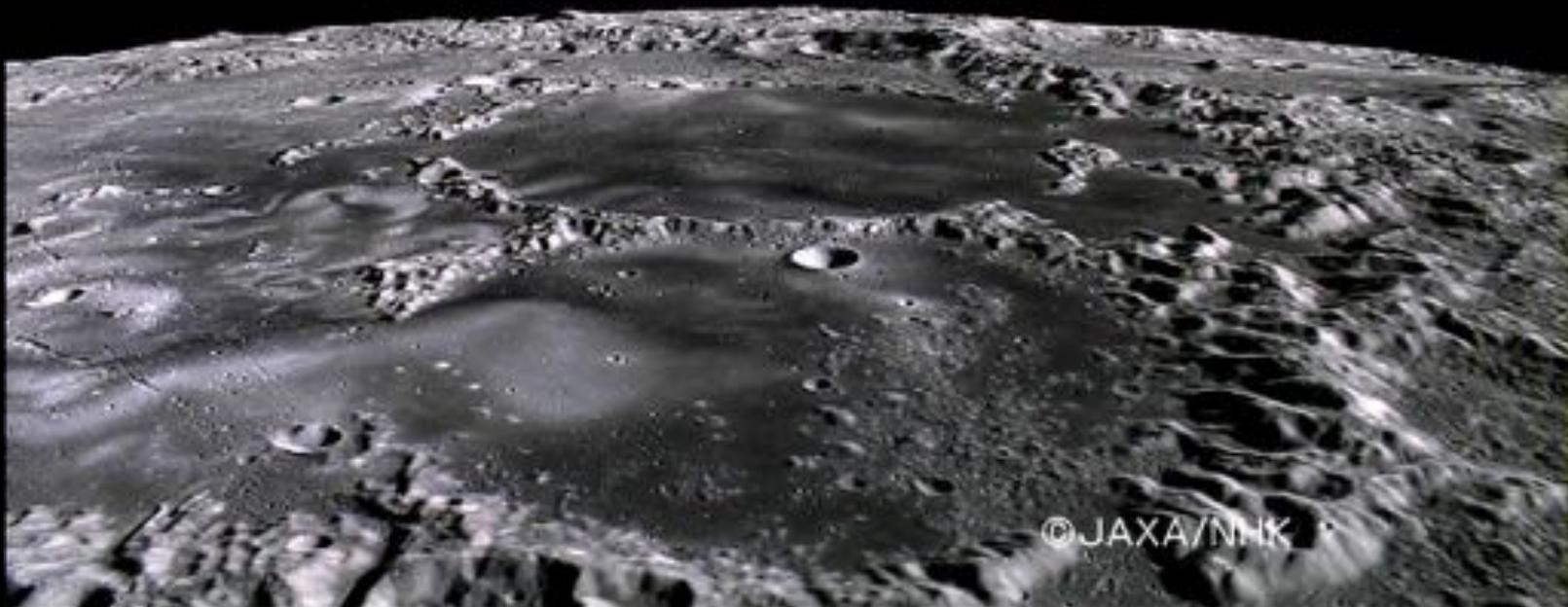
Lunar Prospector  
magnetic field



Kaguya  
topography

# Basin Antipode Effects

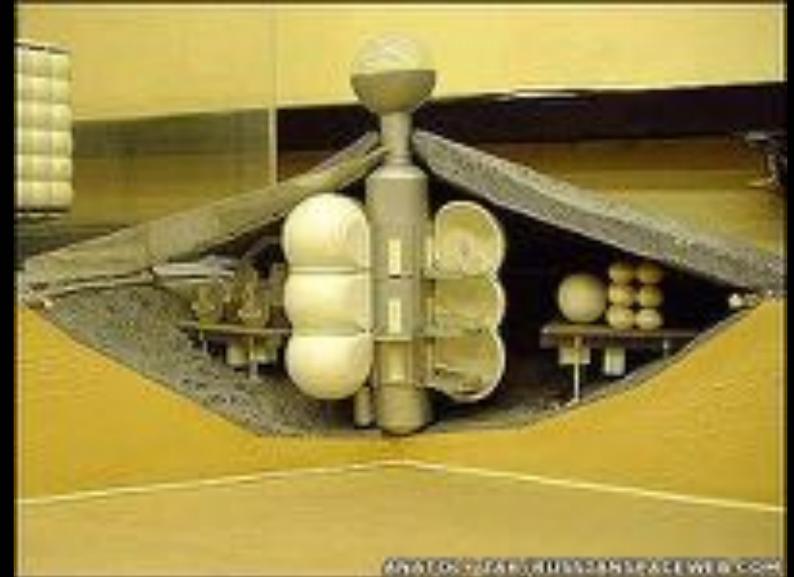
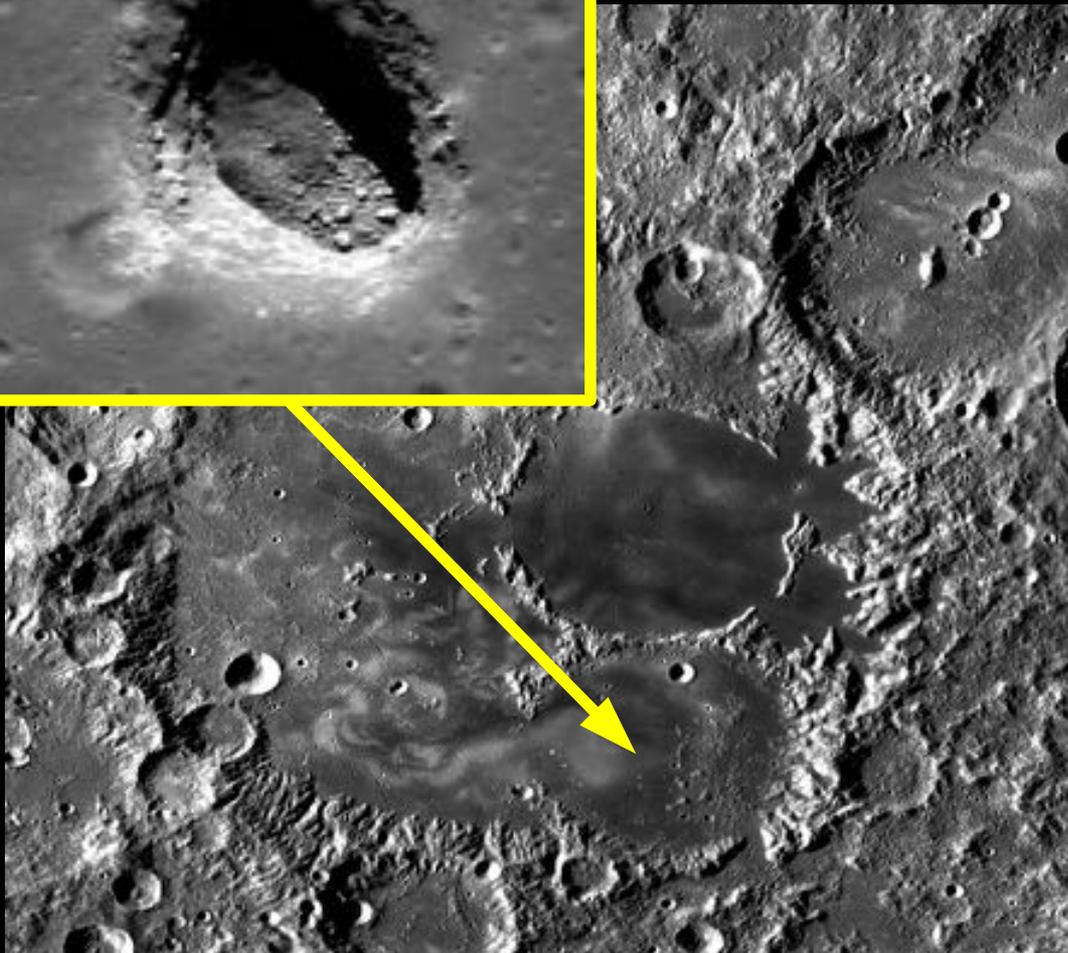
- Ingenii Basin is antipodal to Imbrium Basin.
  - Ingenii Basin is surrounded by unusual *furrowed* terrain, which is attributed to the convergence of seismic waves.
  - Some of these blocks may be uplifted portions of the SPA differentiated melt sheet.



Mare  
Ingenii  
(oblique)  
from  
Kaguya  
Terrain  
Camera

©JAXA/NNK

# 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.