Lunar Crustal Magnetic Fields and Effects of Their Interaction with the Solar Wind

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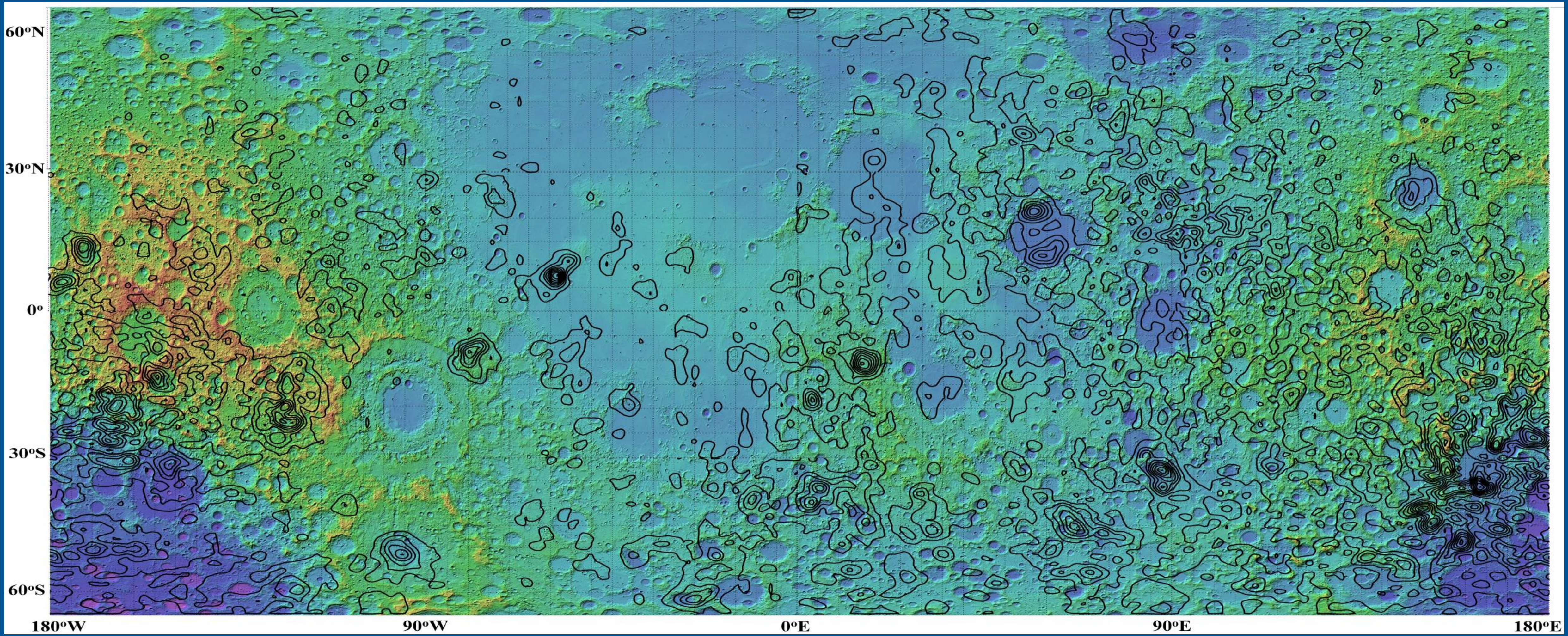
Key Non-Polar Destinations Across the Moon to Address Decadal-level Science Objectives with Human Explorers: National Academies Panel on Heliophysics, Physics, and Physical Science

Meeting No. 4
Tuesday, September 9, 2025
4 p.m. EDT

- ``The exact origin of lunar magnetic anomalies is one of the outstanding unresolved issues of lunar science'' according to a presentation by Renee Weber at a special session on 50 Years of Lunar Science held at the LPSC in 2019.

Large-scale Crustal Field Map at 30 km altitude (Hood et al., JGR, 2021)



Produced using Lunar Prospector and Kaguya orbital magnetometer data using an Equivalent Source Dipole Technique. Smoothed two-dimensionally to a resolution of about 3 degrees of latitude/longitude. Contour Interval: 1 nT.

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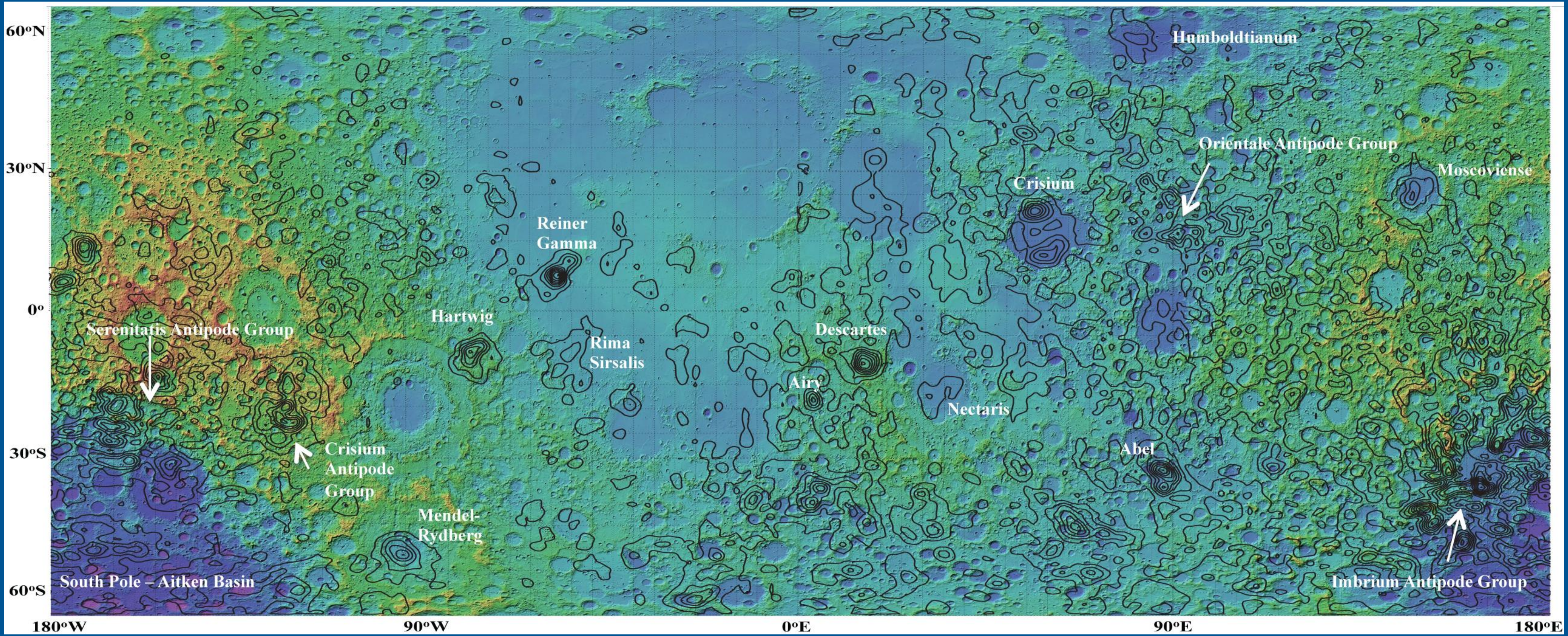

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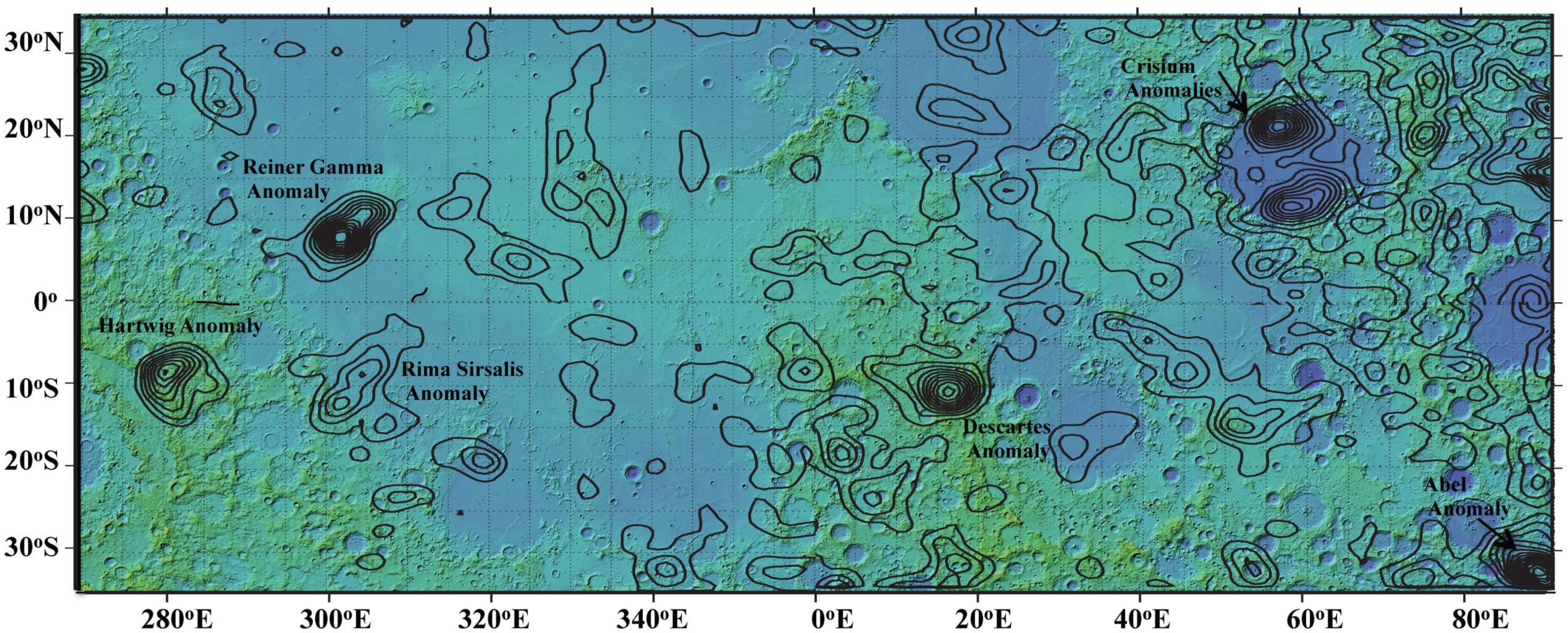

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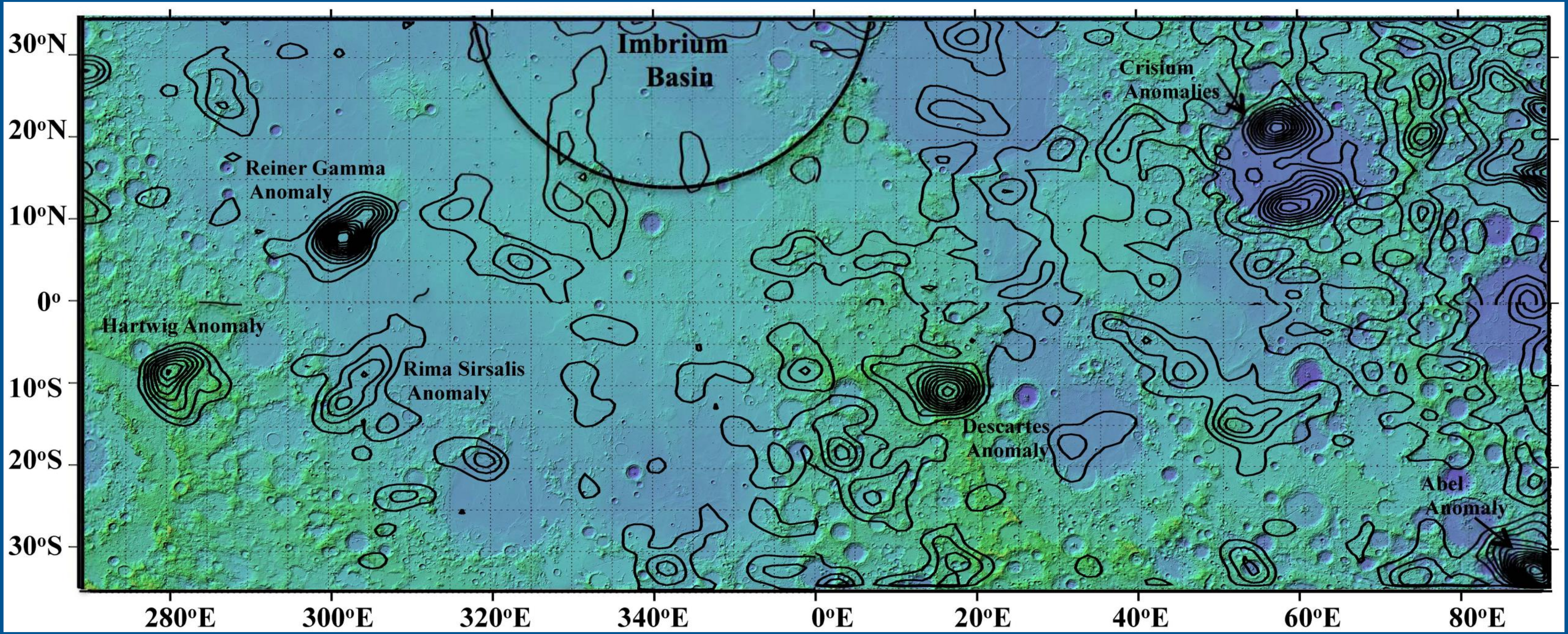

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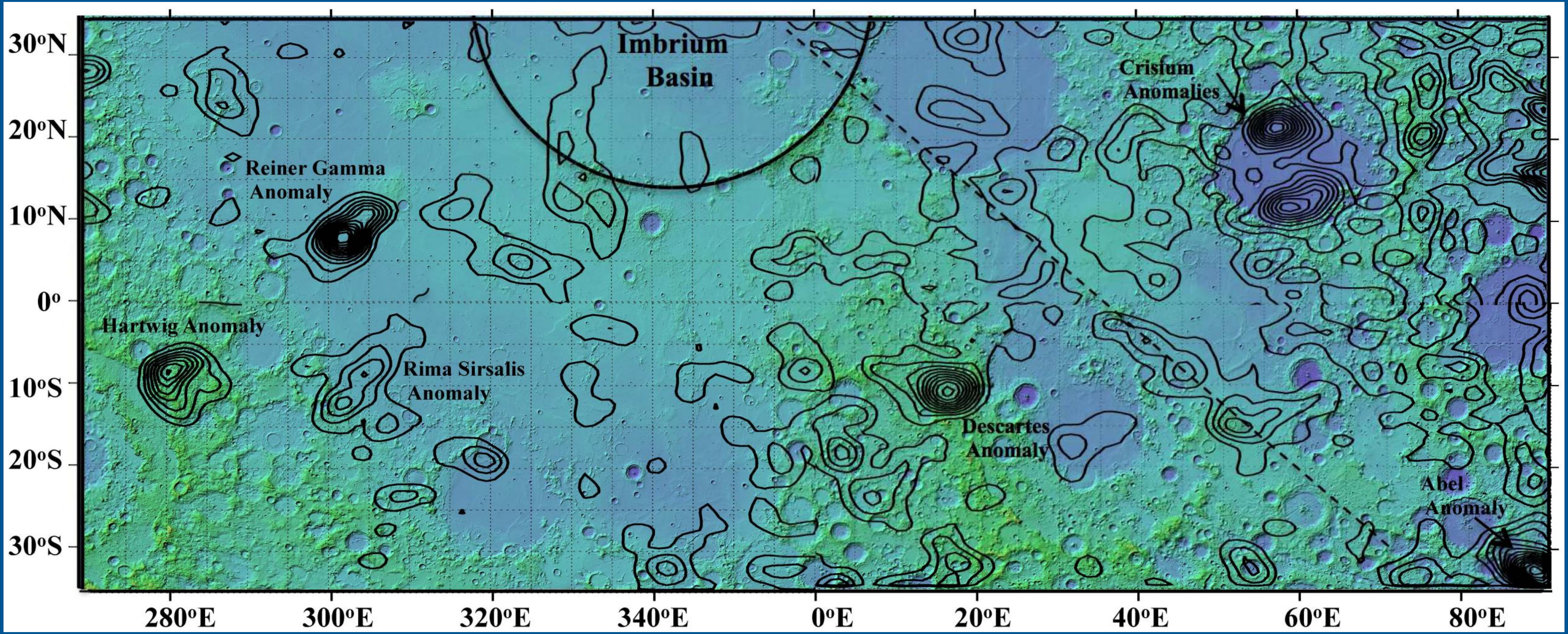

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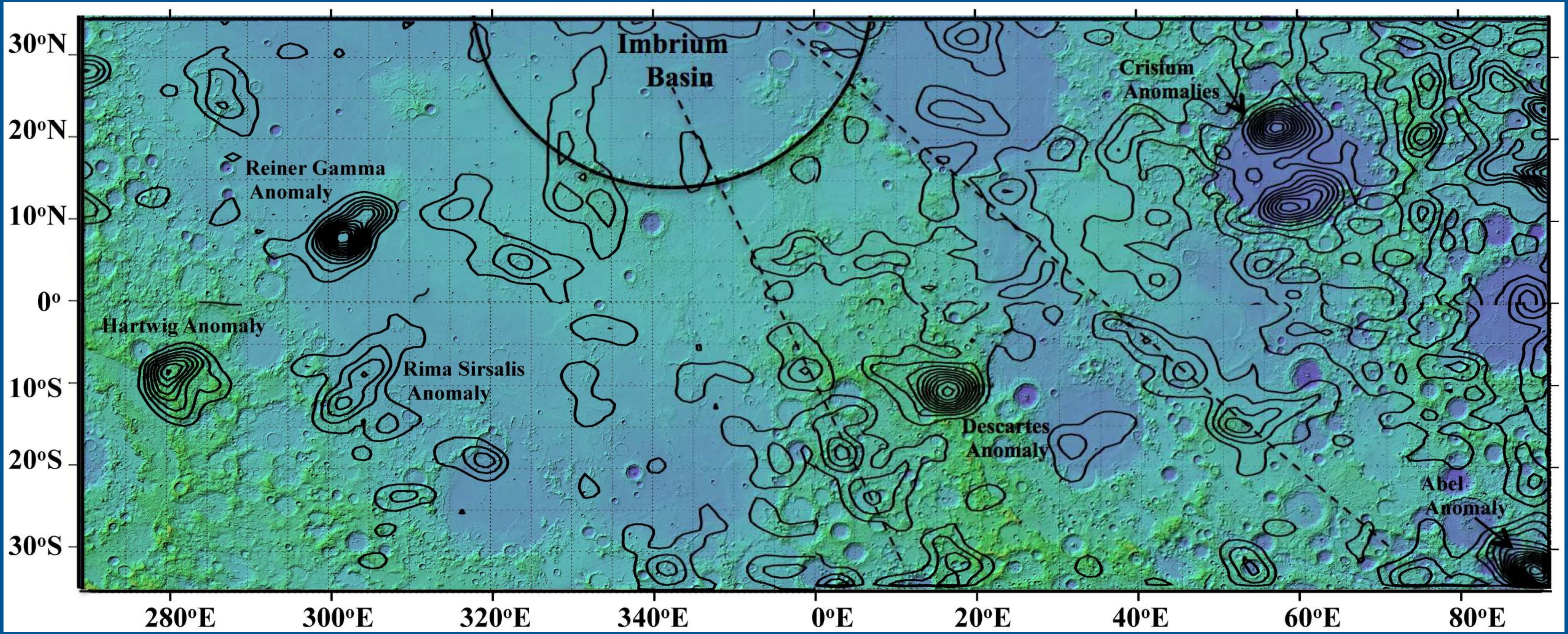

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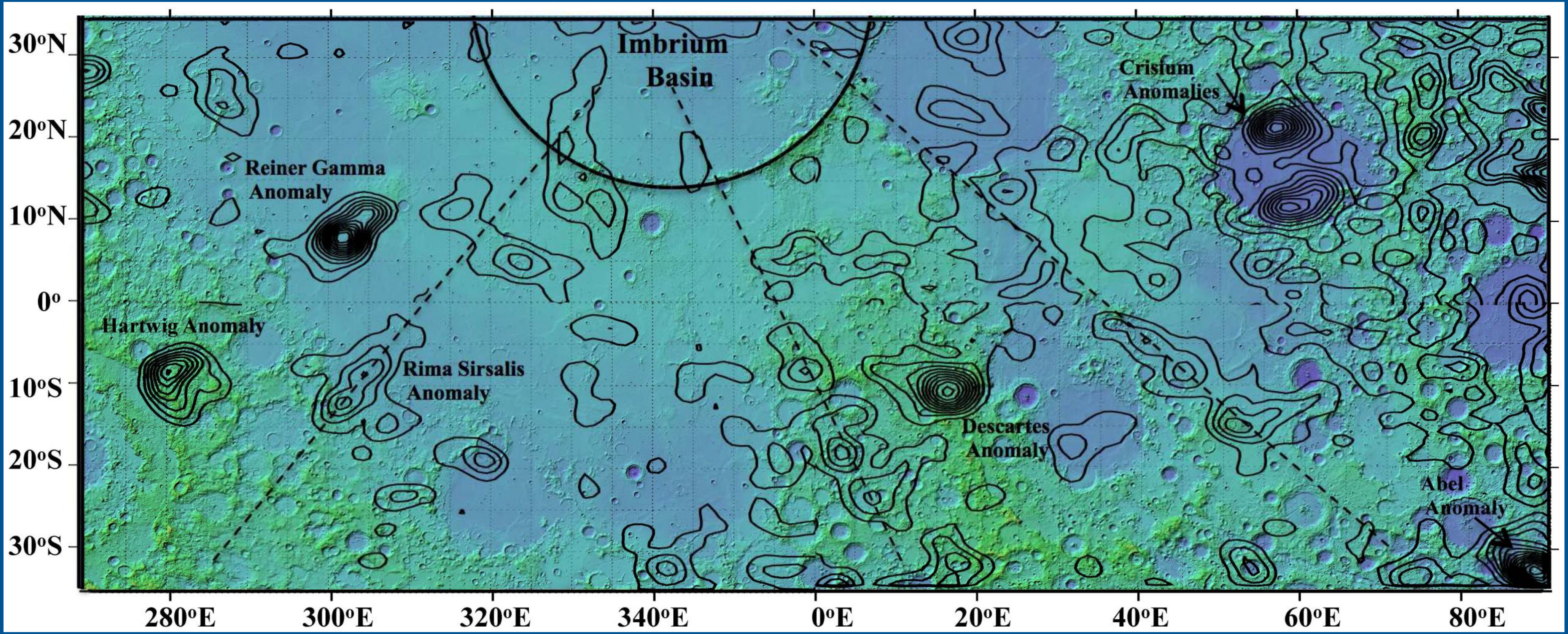

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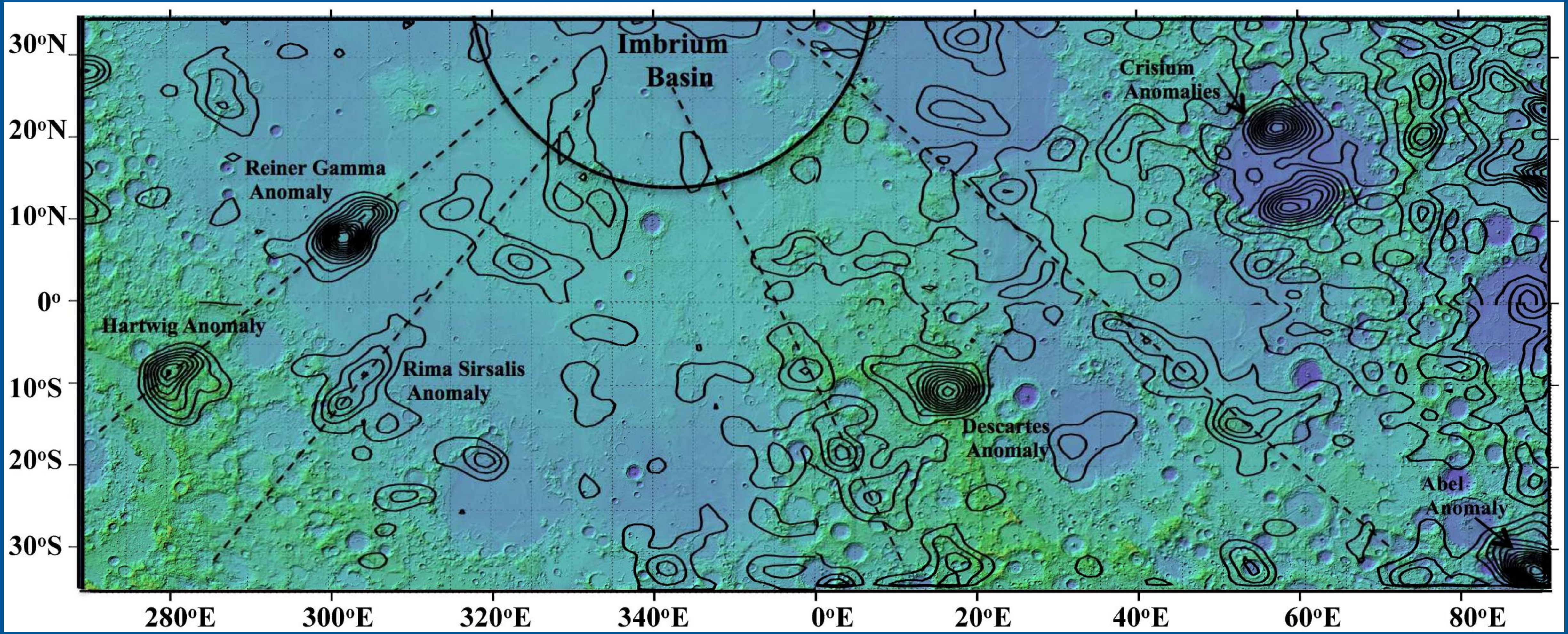

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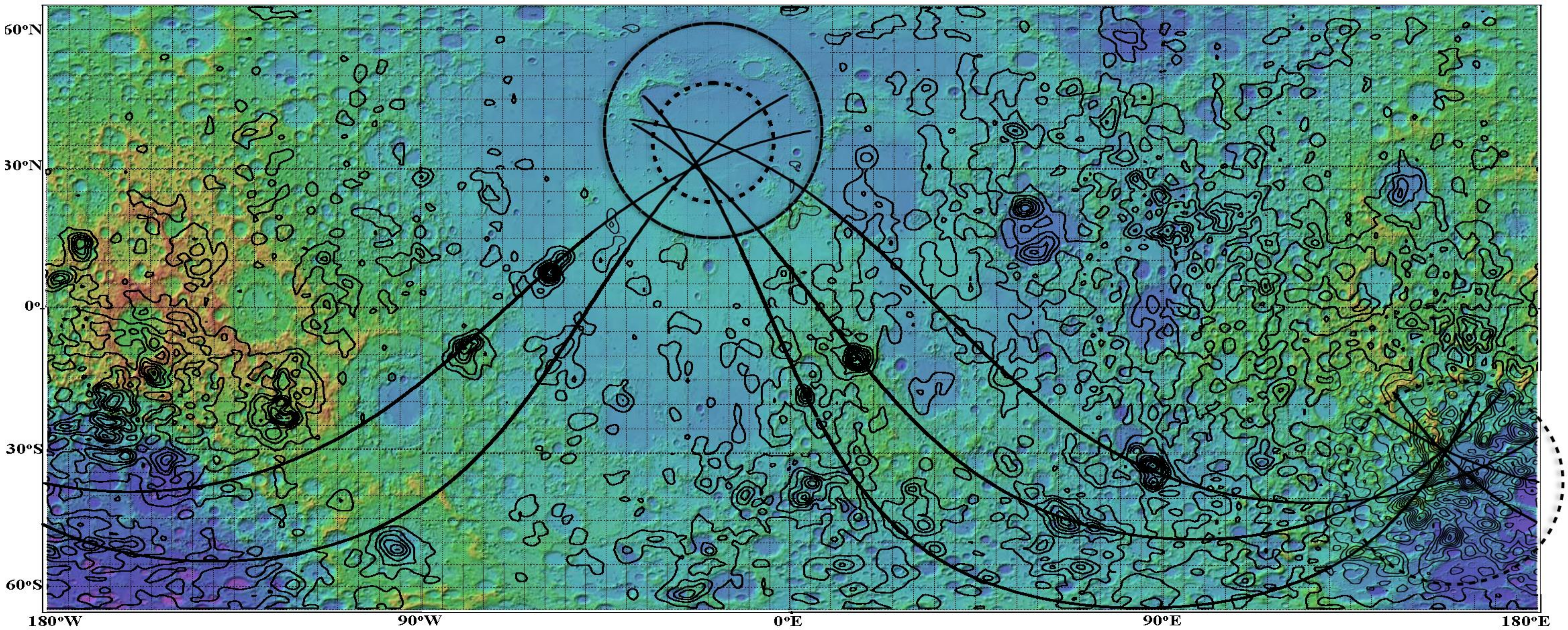
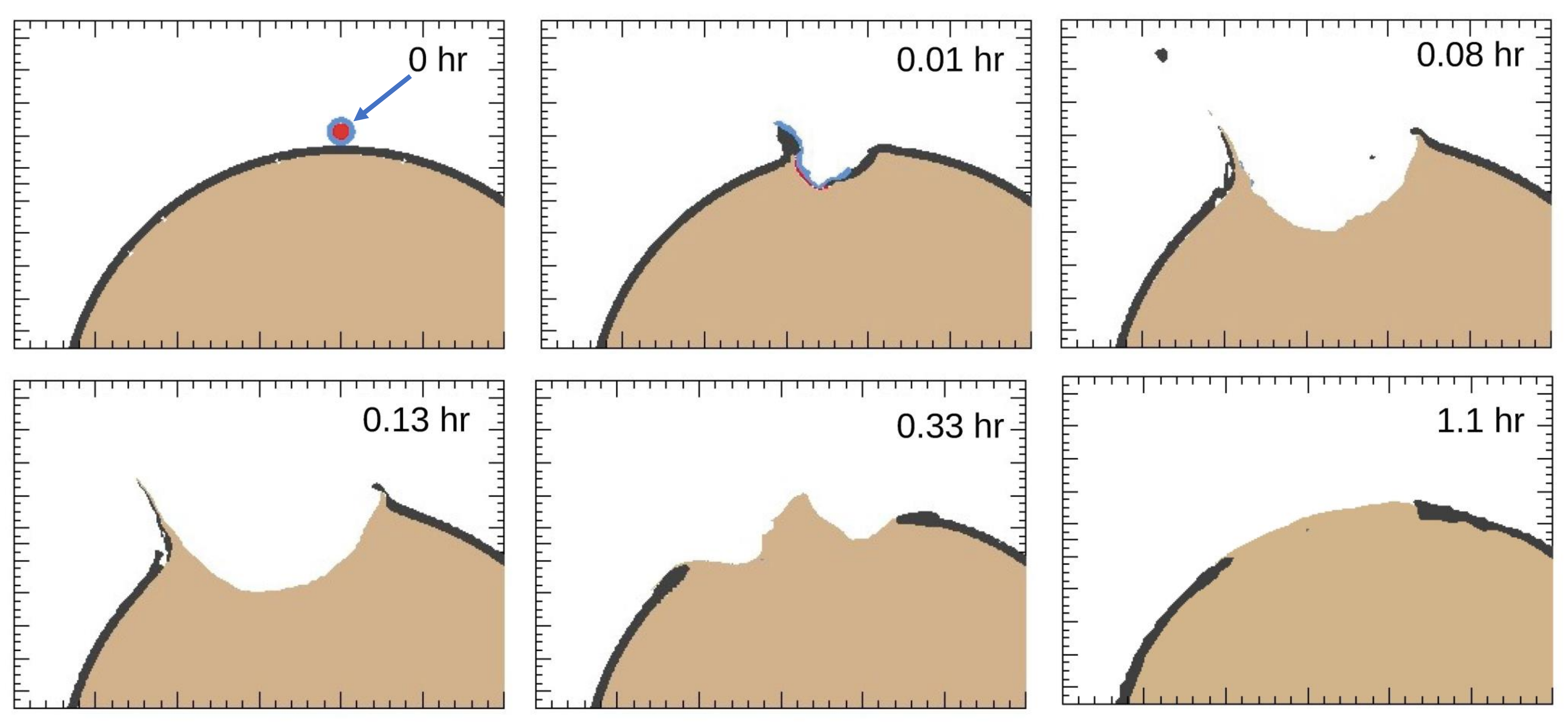


Great circle paths pass through several strong isolated anomalies and converge within the inner rim of Imbrium. They also necessarily intersect in the Imbrium antipodal zone where the strongest anomalies are found.

Lunar Crustal Magnetization Sourced via the Delivery of Iron-rich Ejecta from Basin-forming Impacts

R. I. Citron[1], L. L. Hood[2], and S. T. Stewart[3] 2025

The Planetary Science Journal, 6:158 (18pp), 2025 July



175 km diameter differentiated impactor with ~ 100 km diameter iron core at an impact velocity of 20 km/s, 45^{o} from vertical

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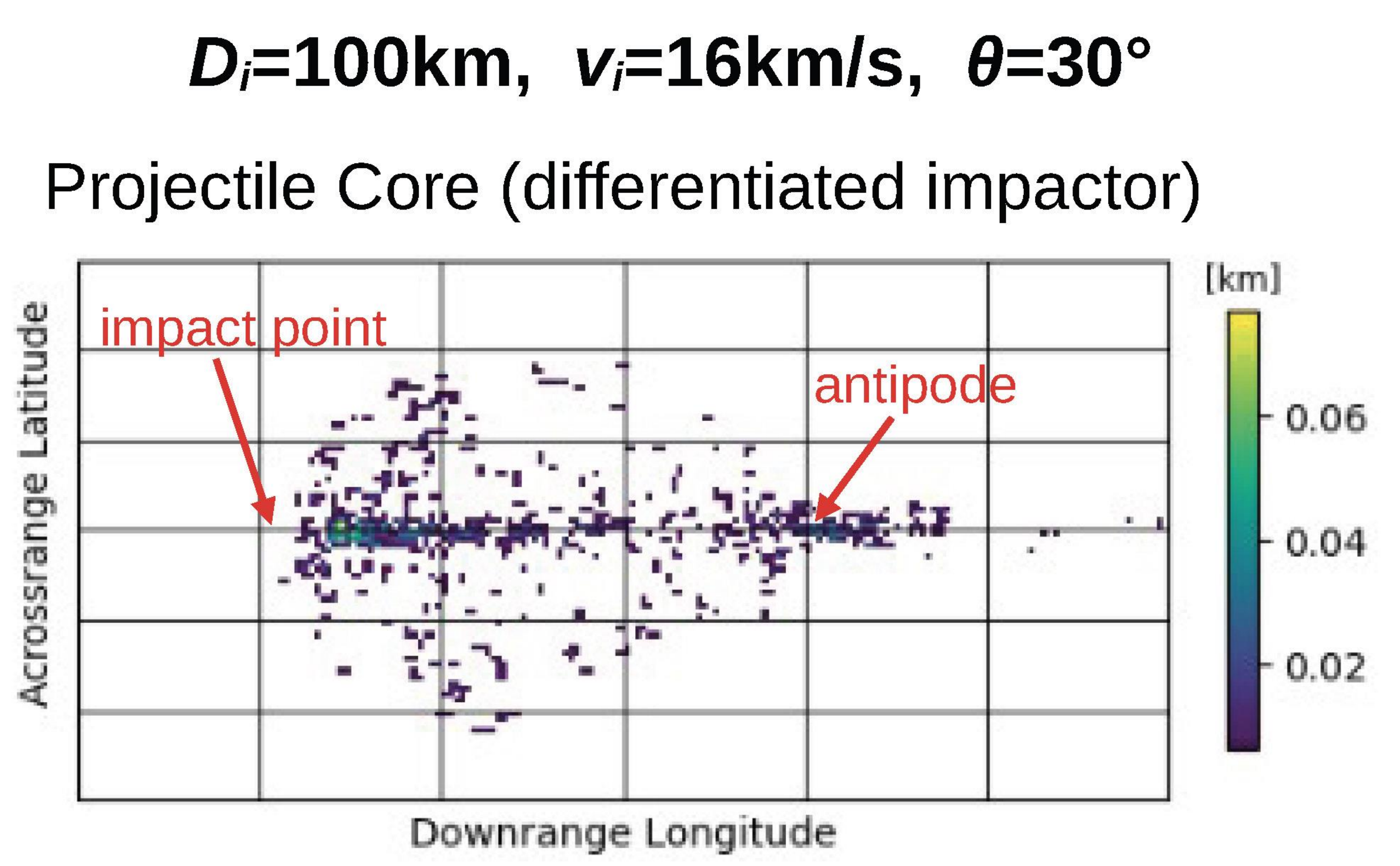


Supported by prior work of Wieczorek et al. (2012) and Wakita et al. (2021)

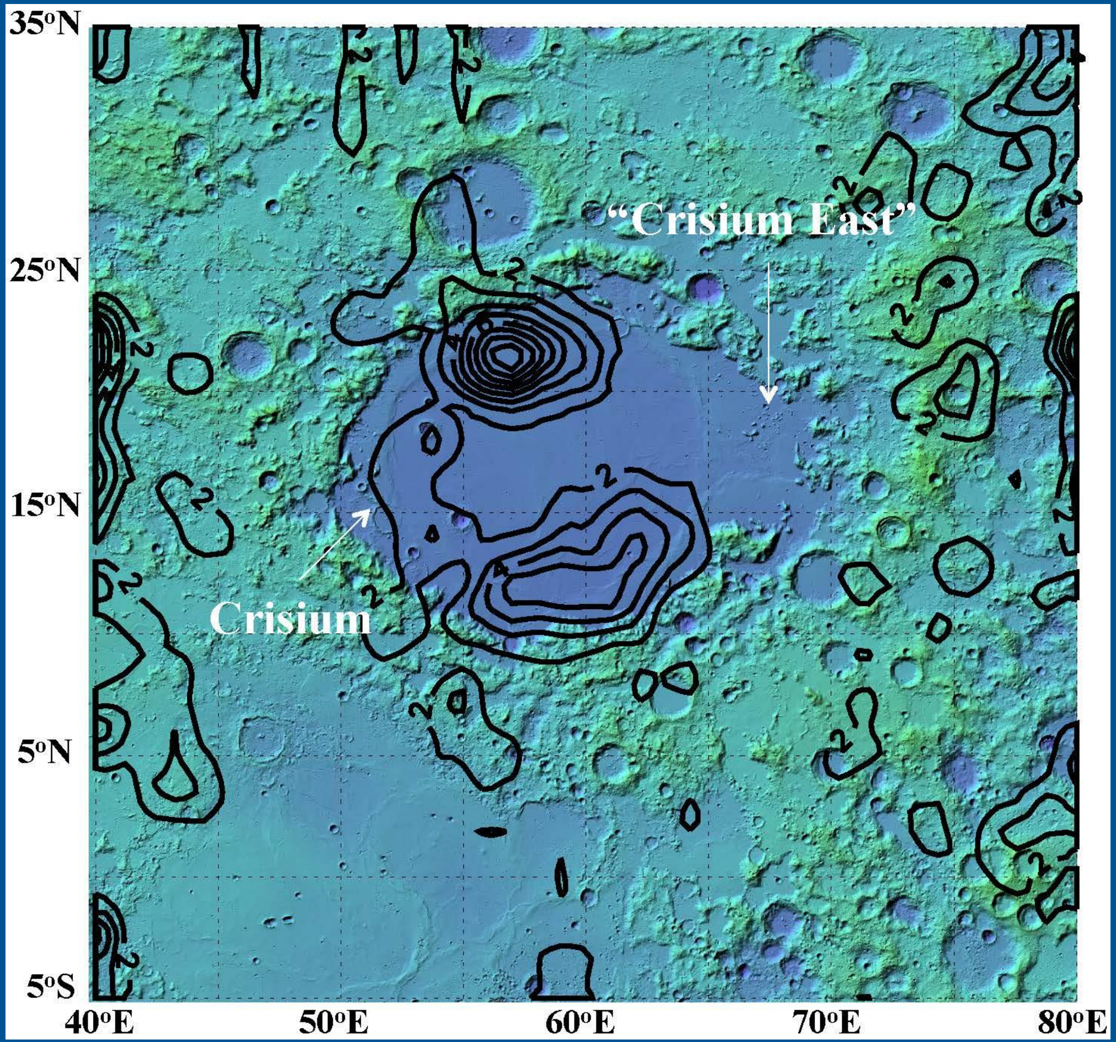
100 km diameter differentiated impactor with ~ 57 km diameter iron core at an impact velocity of 16 km/s, 30^o from vertical

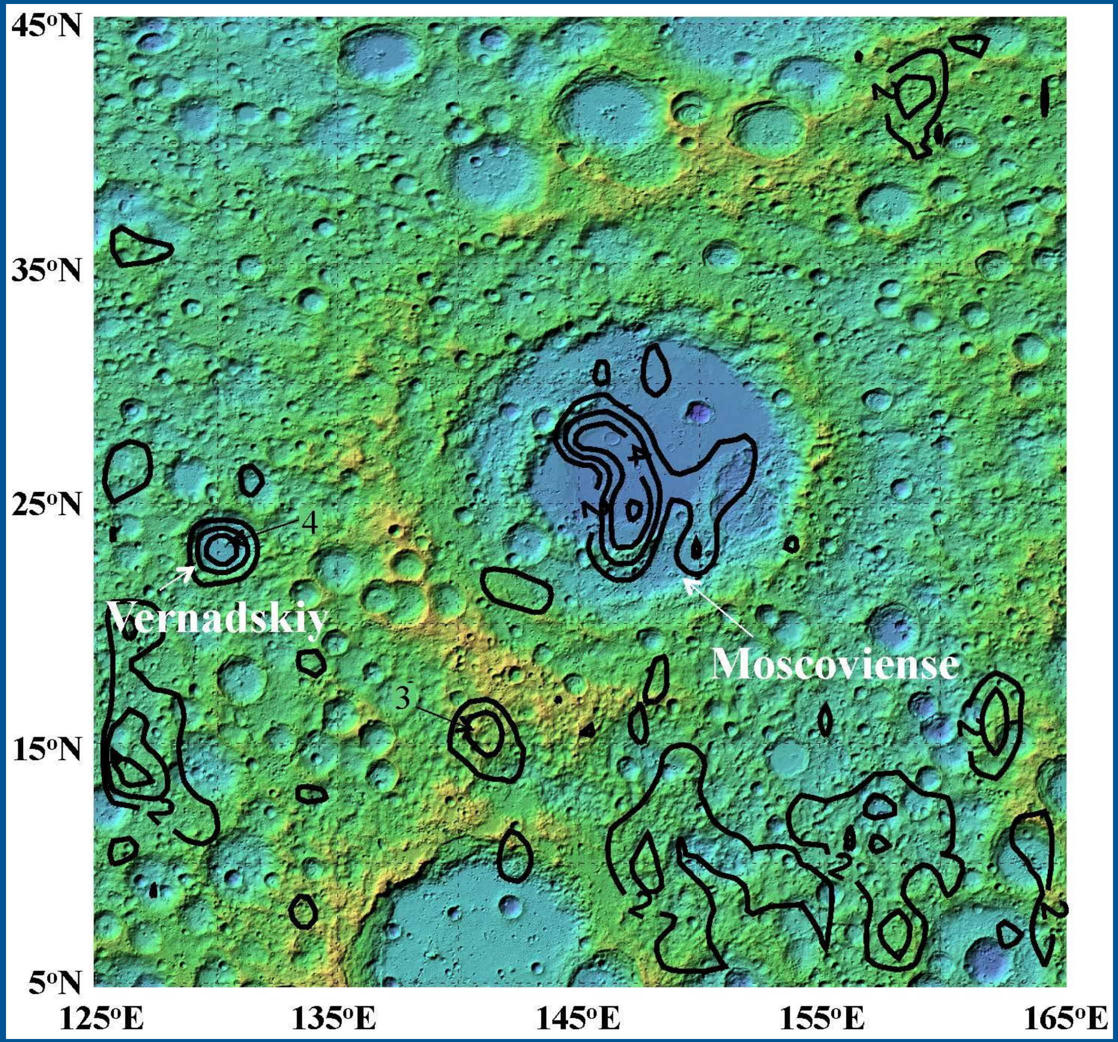
Lunar impact melt breccias (e.g., the boulder at right) are composed of welded-together material from lunar basin-forming impacts. They contain ~ 1-2 wt% macroscopic metallic iron that was derived from the cores of differentiated planetesimals that impacted the Moon, producing basins such as Imbrium [Korotev, 1987; 2000].

Astronaut shadow

Boulder photographed and sampled near the Apollo 15 landing site (Credit: Apollo 15 Preliminary Science Report)

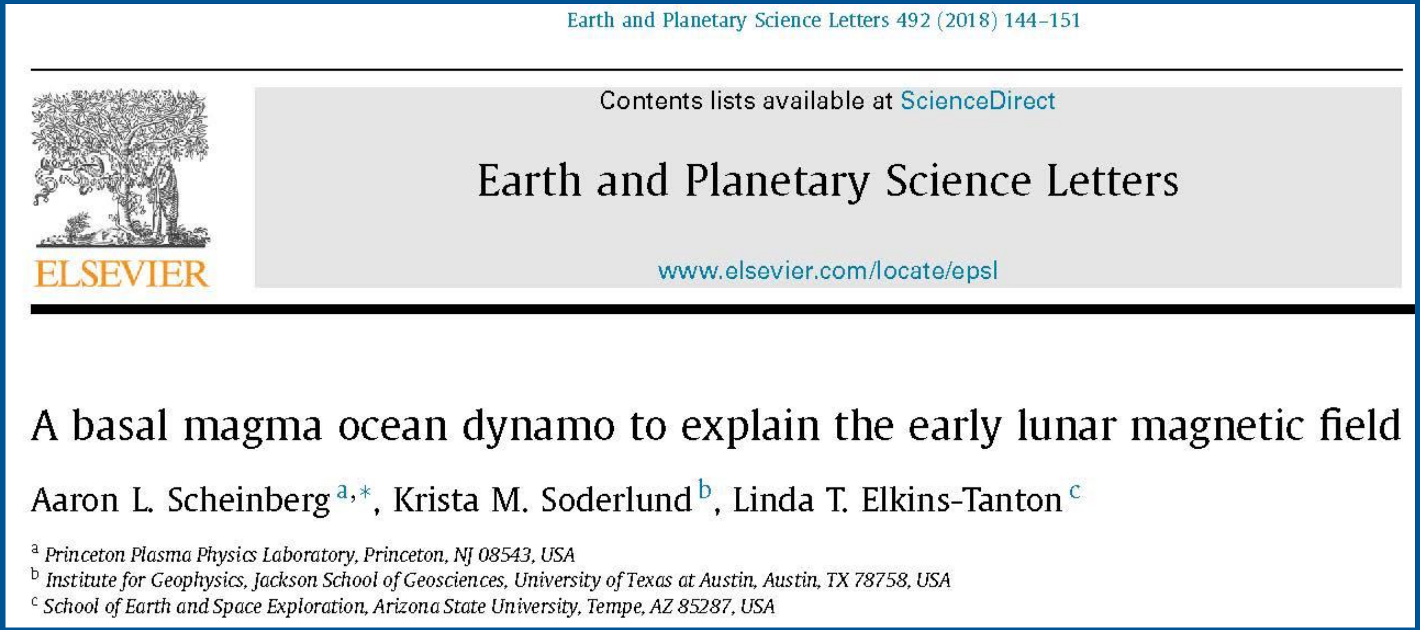
There evidence from orbital data for a former steady, internally generated lunar magnetic field, presumably an internal dynamo: Central magnetic anomalies in Nectarian-aged impact basins





Hood et al., JGR, 2021b

The small size of the lunar core has led to proposals of alternate sources of the lunar internal magnetic field, e.g., a basal magma ocean dynamo:


Earth and Planetary Science Letters 492 (2018) 144–151

Contents lists available at ScienceDirect

Earth and Planetary Science Letters

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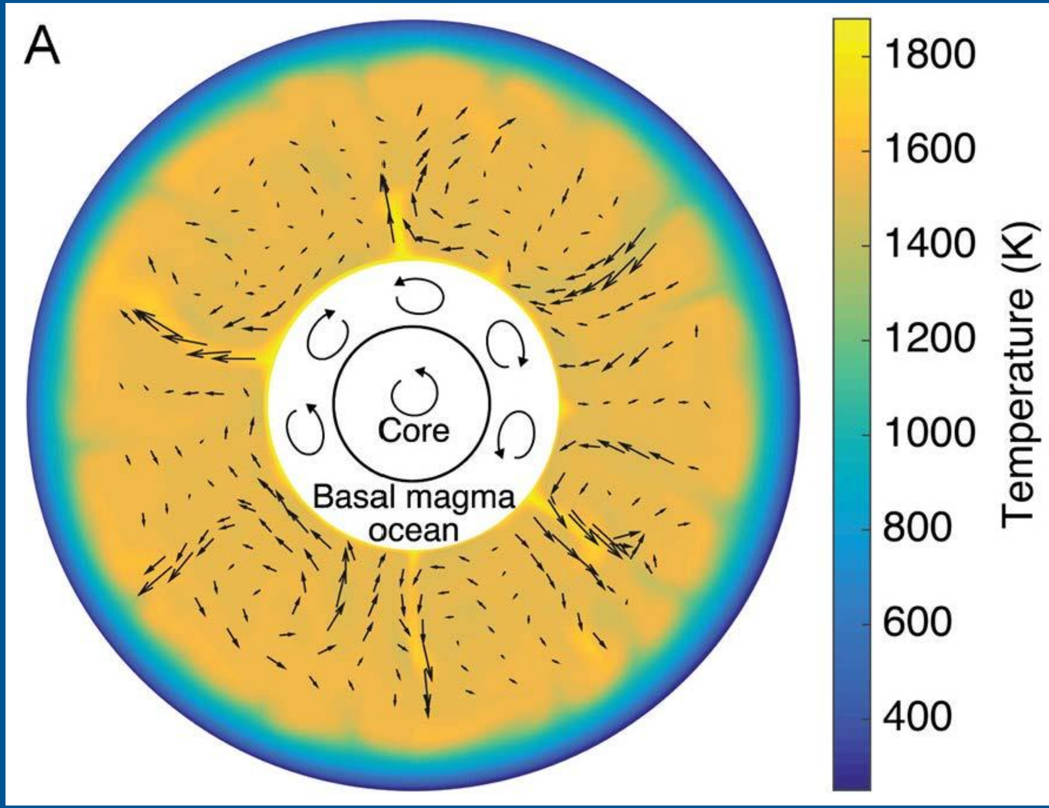
A basal magma ocean dynamo to explain the early lunar magnetic field

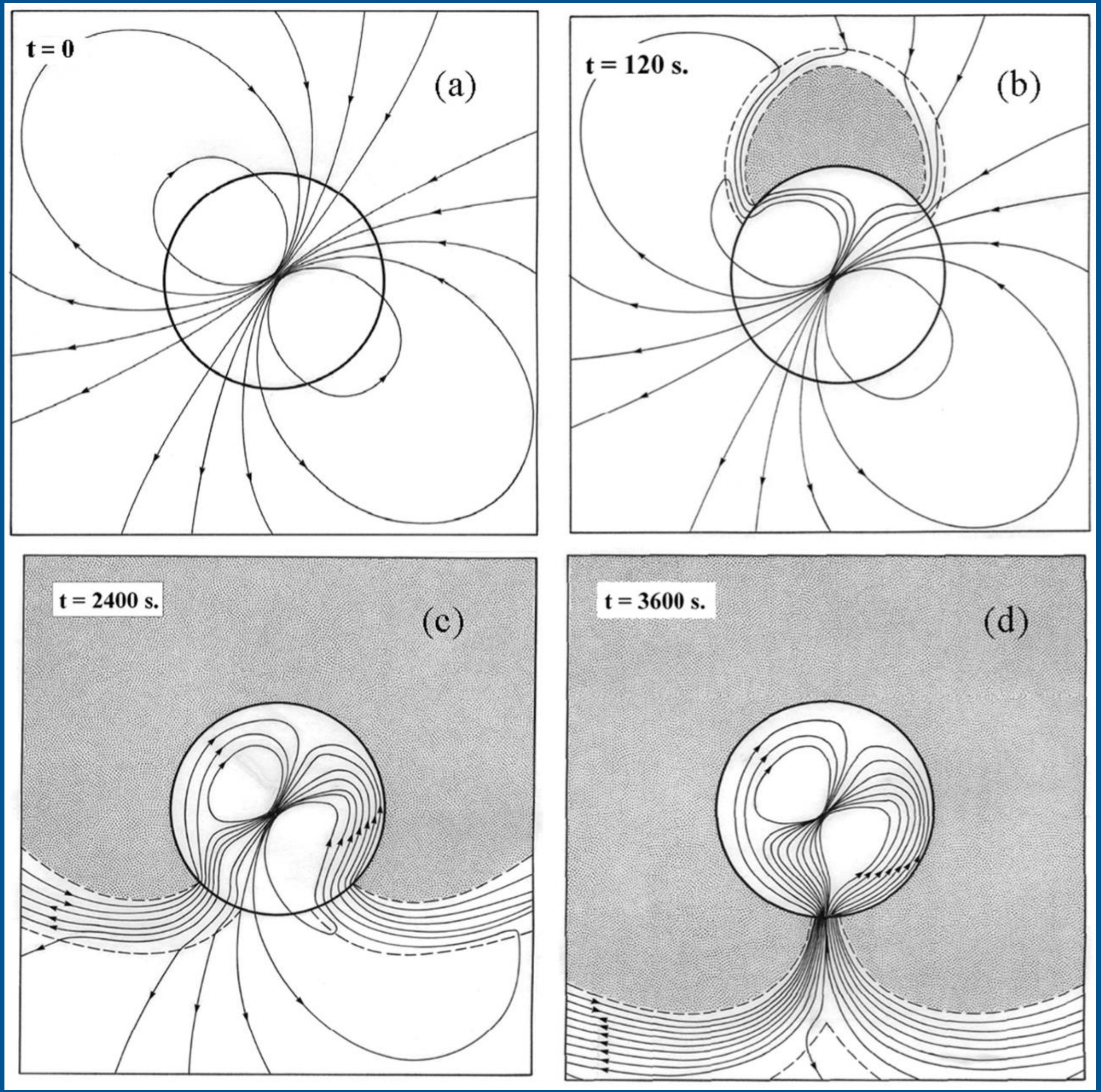
Aaron L. Scheinberg [a,*], Krista M. Soderlund [b], Linda T. Elkins-Tanton [c]

[a] *Princeton Plasma Physics Laboratory, Princeton, NJ 08543, USA*
[b] *Institute for Geophysics, Jackson School of Geosciences, University of Texas at Austin, Austin, TX 78758, USA*
[c] *School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287, USA*



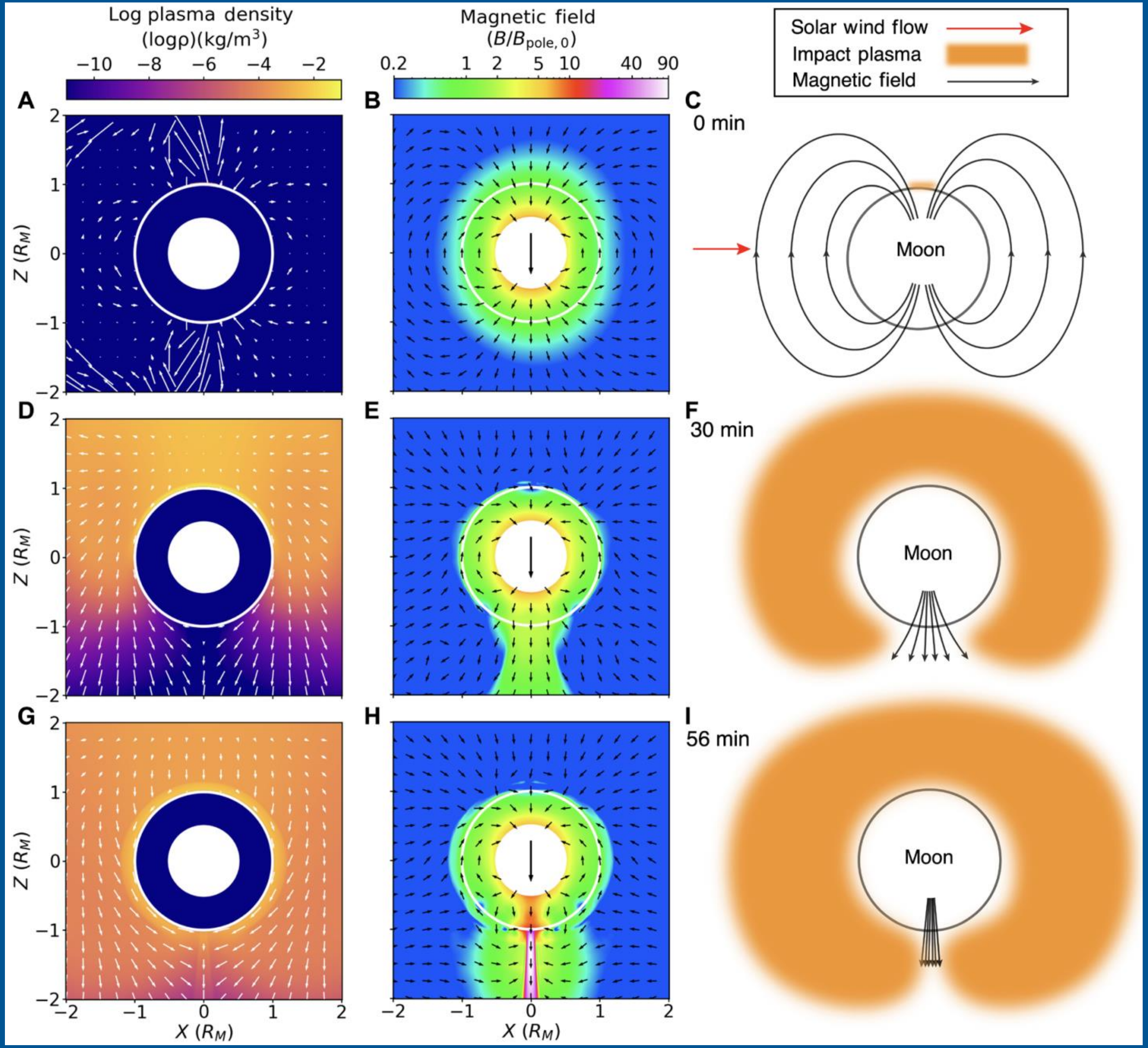
Scheinberg et al., EPSL, 2018

Qualitative sketch of the effect of a partially ionized impact vapor cloud on an internally generated dipolar magnetic field.



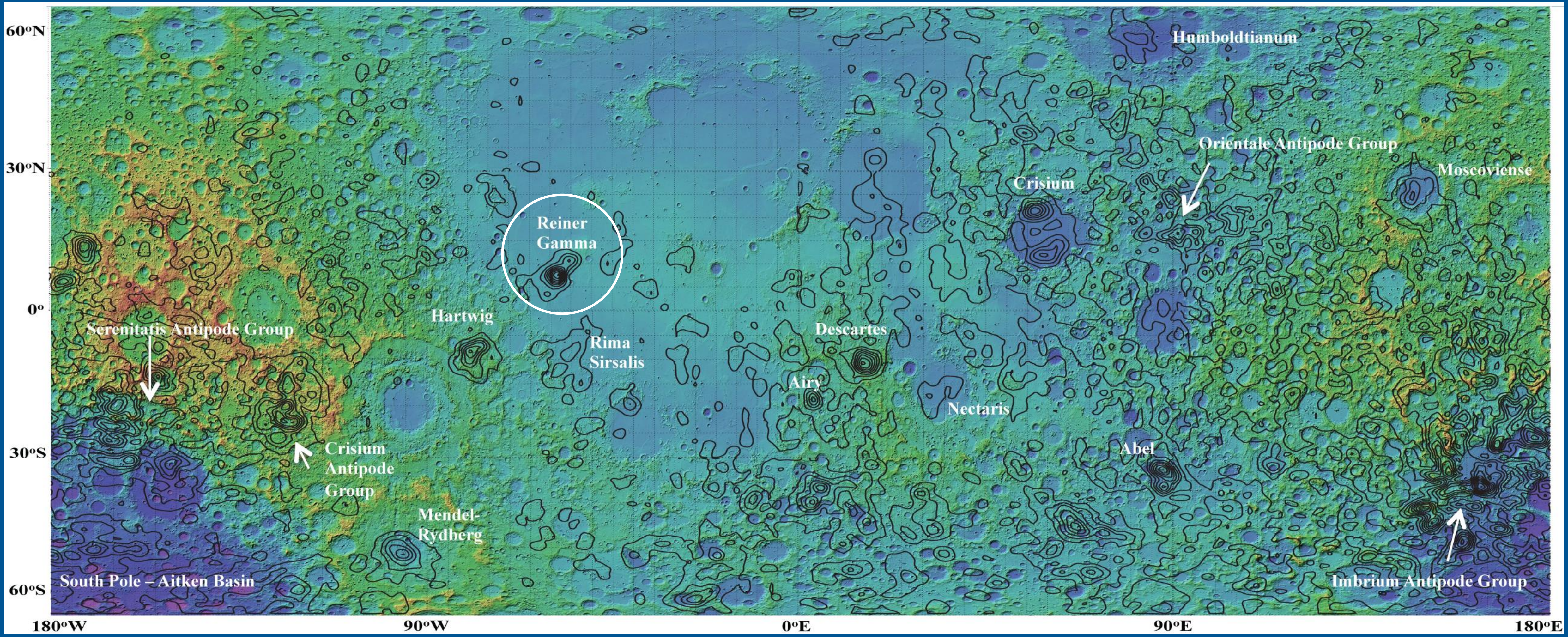
Hood & Artemieva, Icarus, 2008

Numerical impact simulations combined with MHD plasma codes have recently confirmed that an ambient magnetic field (e.g., a weak internal dynamo field) can be transiently amplified at the antipode of a basin-forming lunar impact.



Isaac Narrett et al., Science Advances, May, 2025

Large-scale Crustal Field Map at 30 km altitude (Hood et al., 2021)



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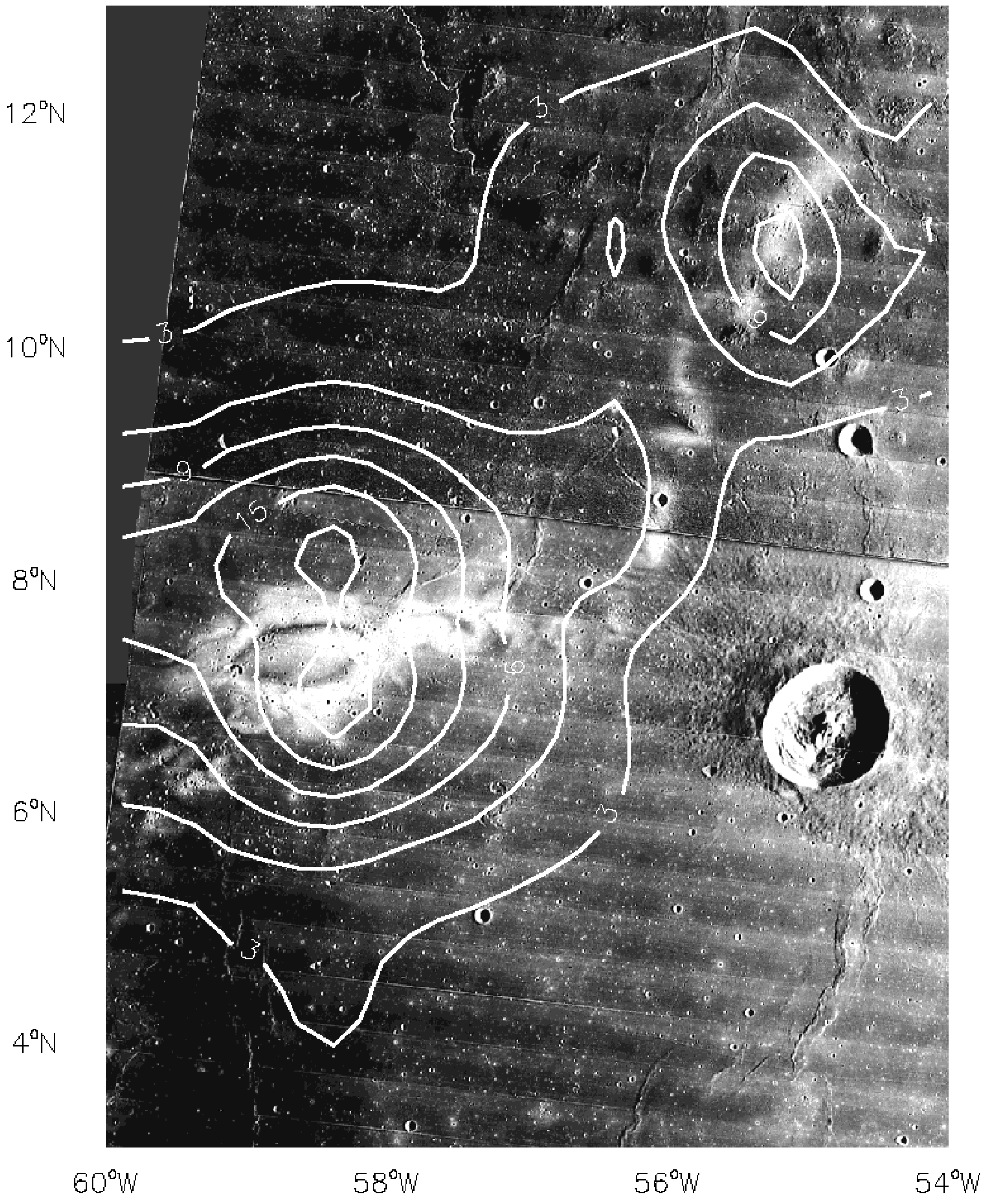
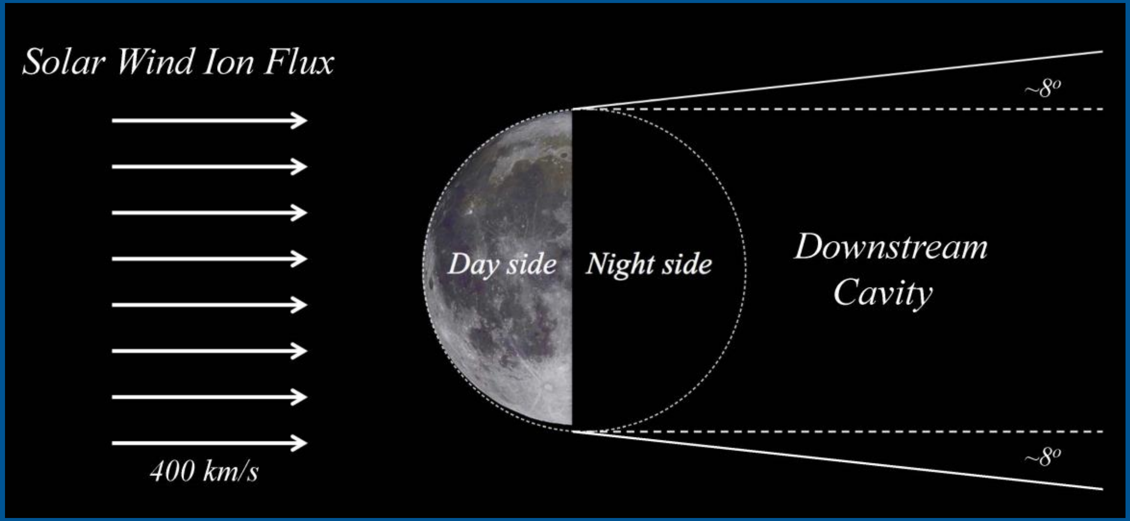
Superposition of a field magnitude map at 19 km altitude produced from Lunar Prospector orbital magnetometer data

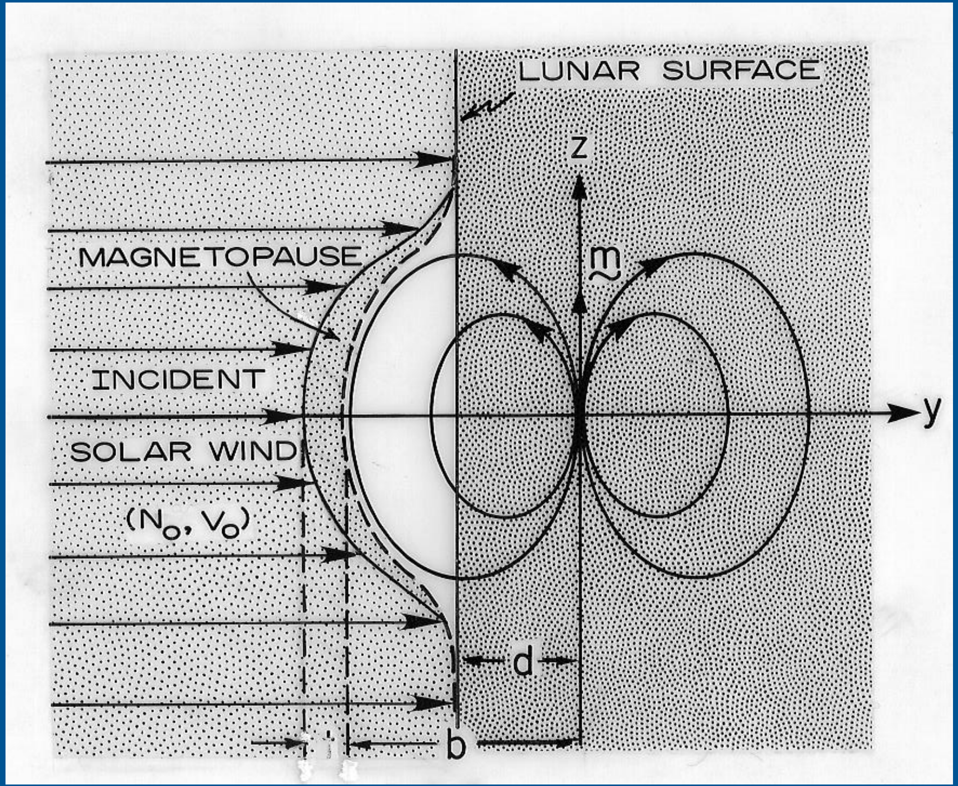


From Hood et al. (2001)

Low-altitude Lunar Orbiter photo of Reiner Gamma. Topography is < 200 m from comparisons with nearby mare wrinkle ridges.

<u>A Partial Explanation for Albedo Effects of Crustal Magnetic Fields</u>: The solar wind ion bombardment contributes to the darkening of the lunar surface with time (e.g., the disappearance of young crater rays). The strongest lunar anomalies are capable of shielding local areas of the surface from the solar wind.

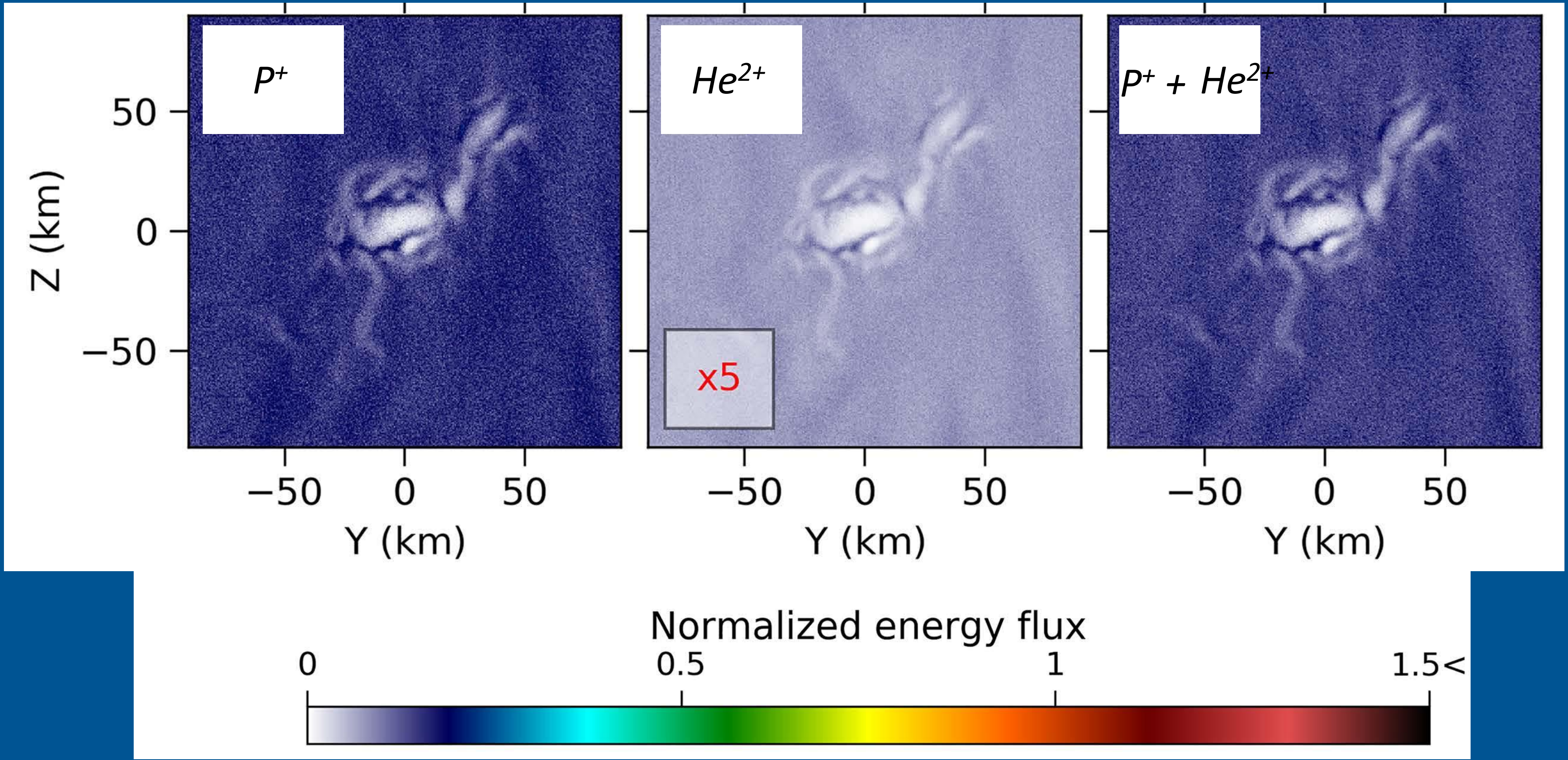




Hood and Schubert, Science, 1980

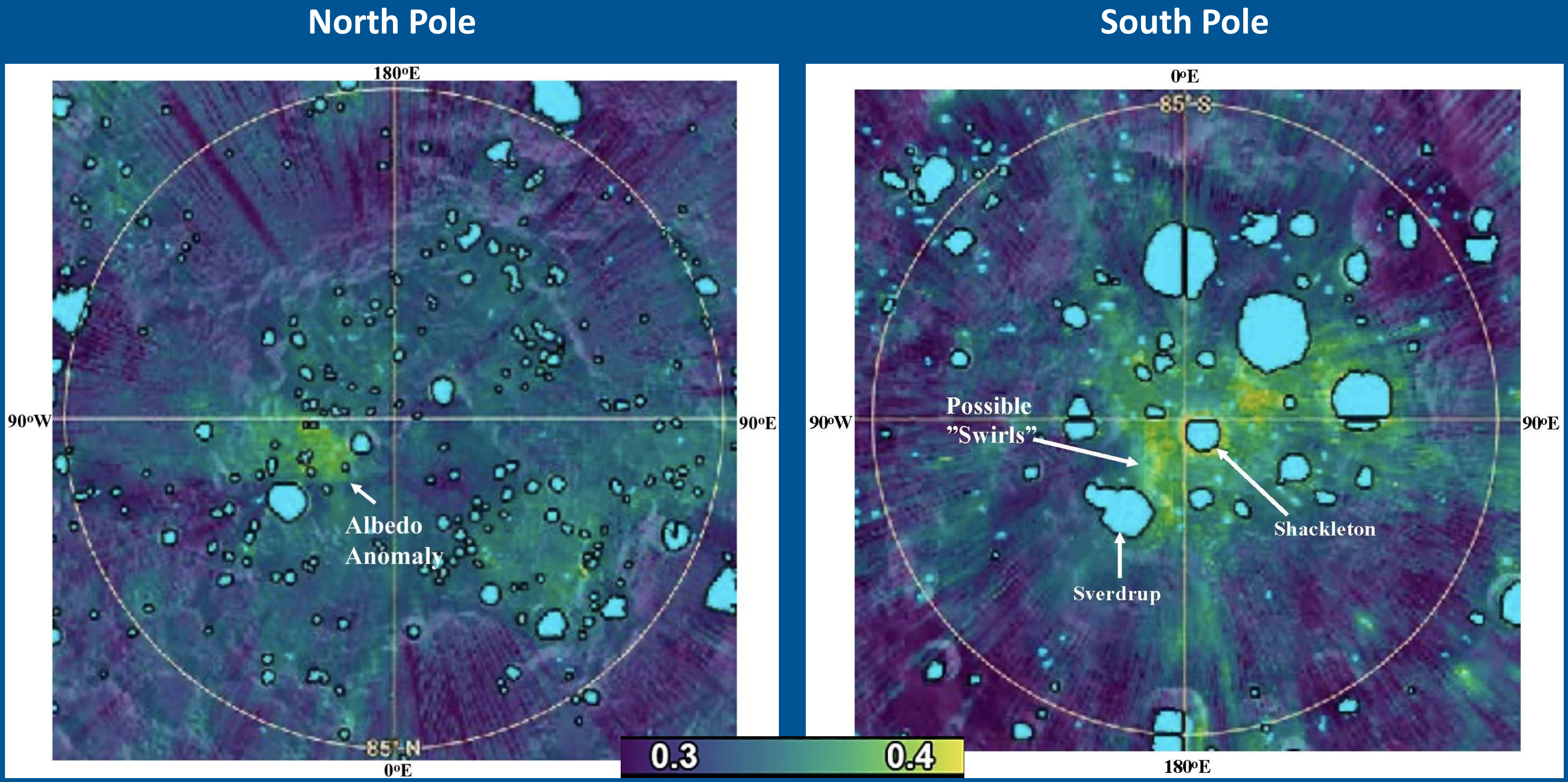
Example simulation of solar wind energy flux onto the Reiner Gamma anomaly :

Uses the 3-D fully kinetic, electromagnetic particle-in-cell code (Markidis et al., 2010) and the crustal magnetic field model of Tsunakawa et al. (2015).



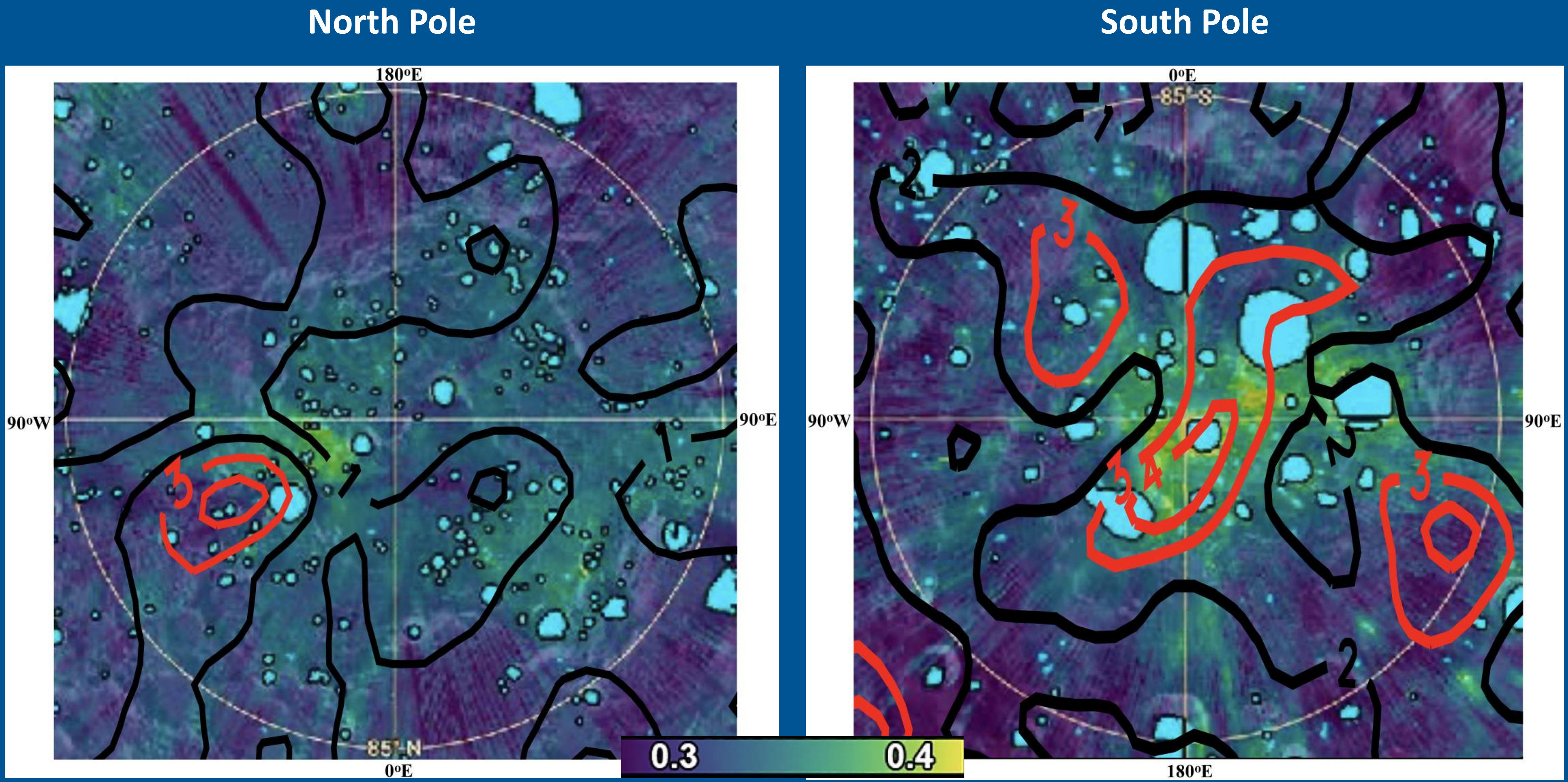
Deca et al., JGR, 2020

Surface Albedo at the Lunar Poles (Moriarty et al., 2024):



Based on Data from the Lunar Orbiter Laser Altimeter (LOLA) on the Lunar Reconnaissance Orbiter Spacecraft (Smith et al., 2010)

Superposition of the Crustal field Maps onto the LOLA Albedo Maps



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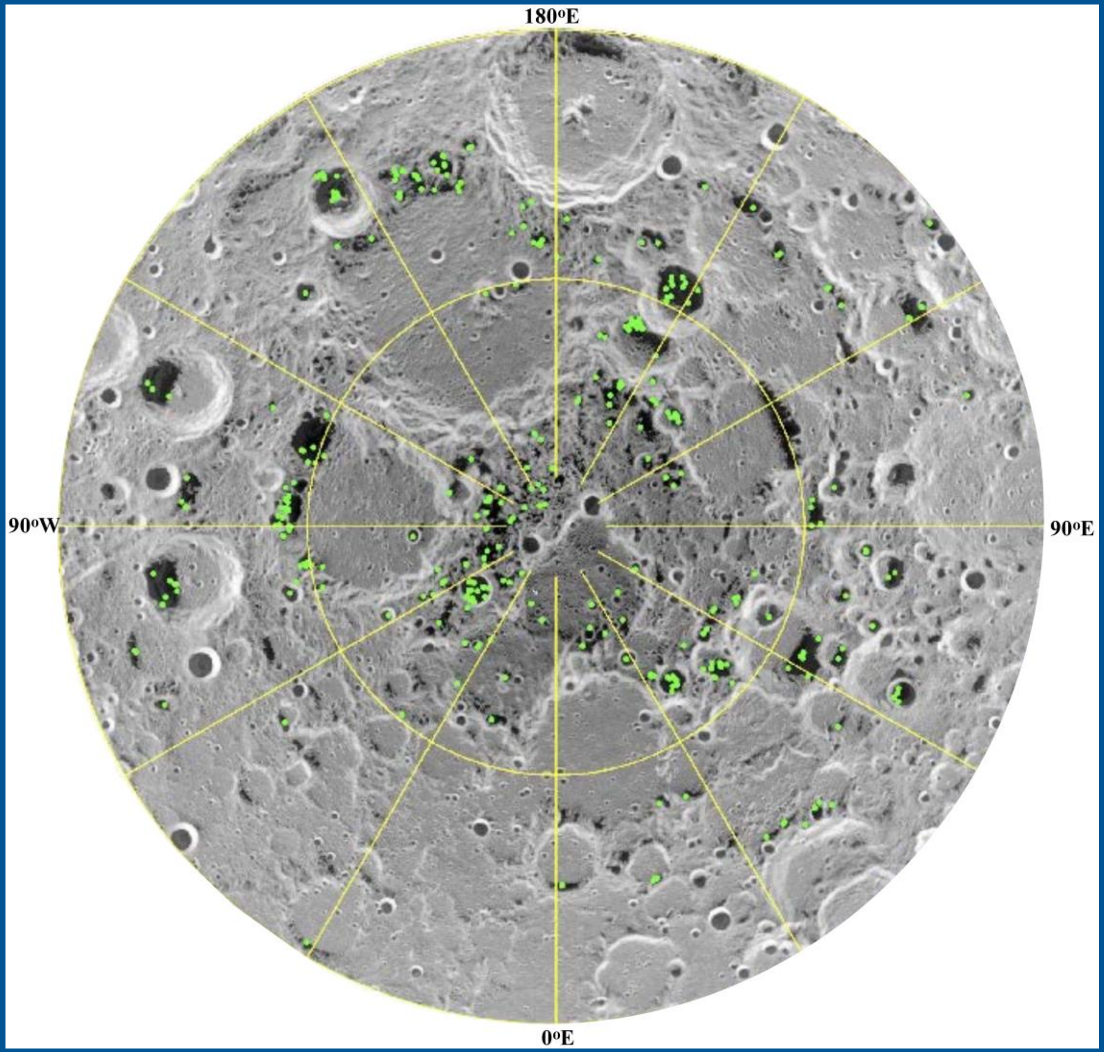
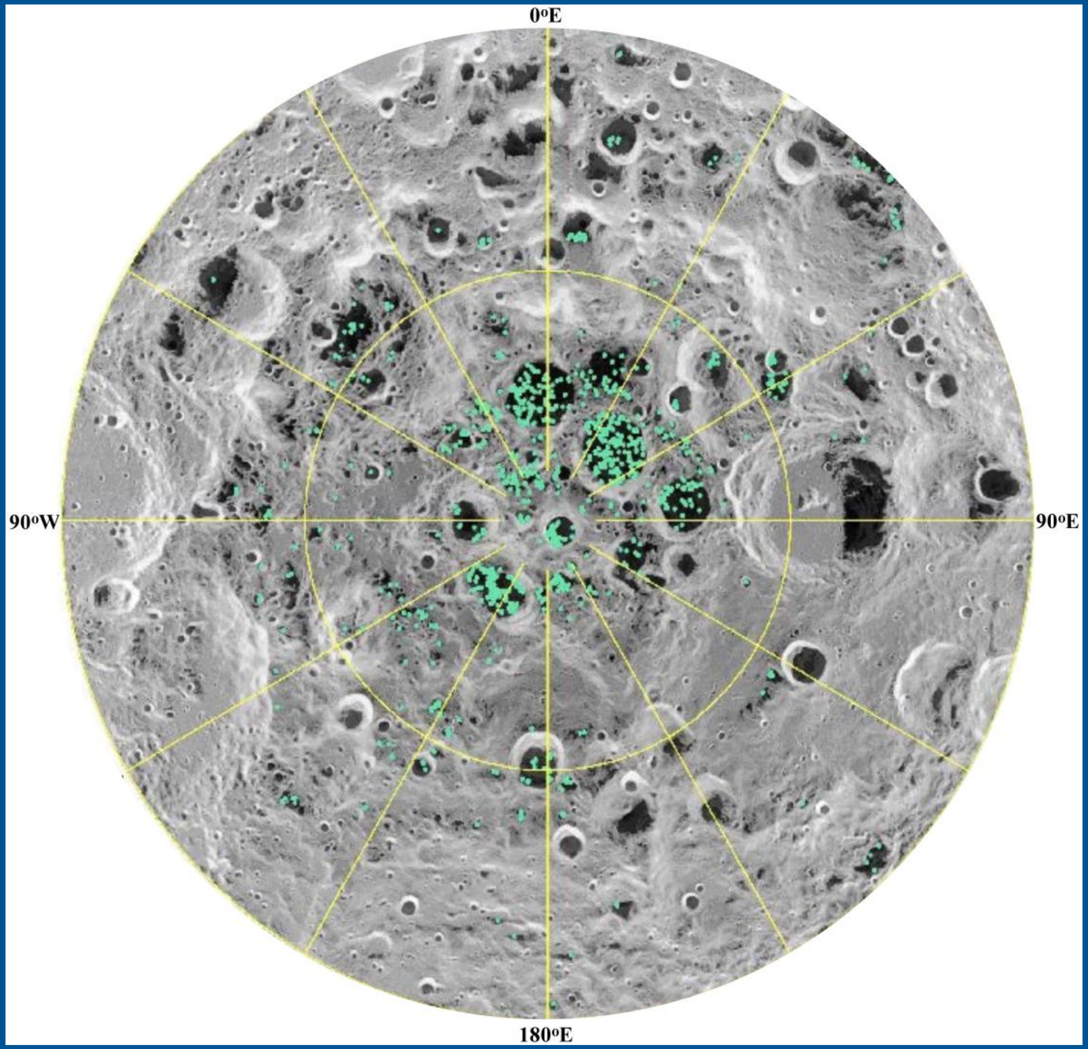
Inferred Water Ice Distribution at the Lunar Poles (Li et al., 2018):

North Pole



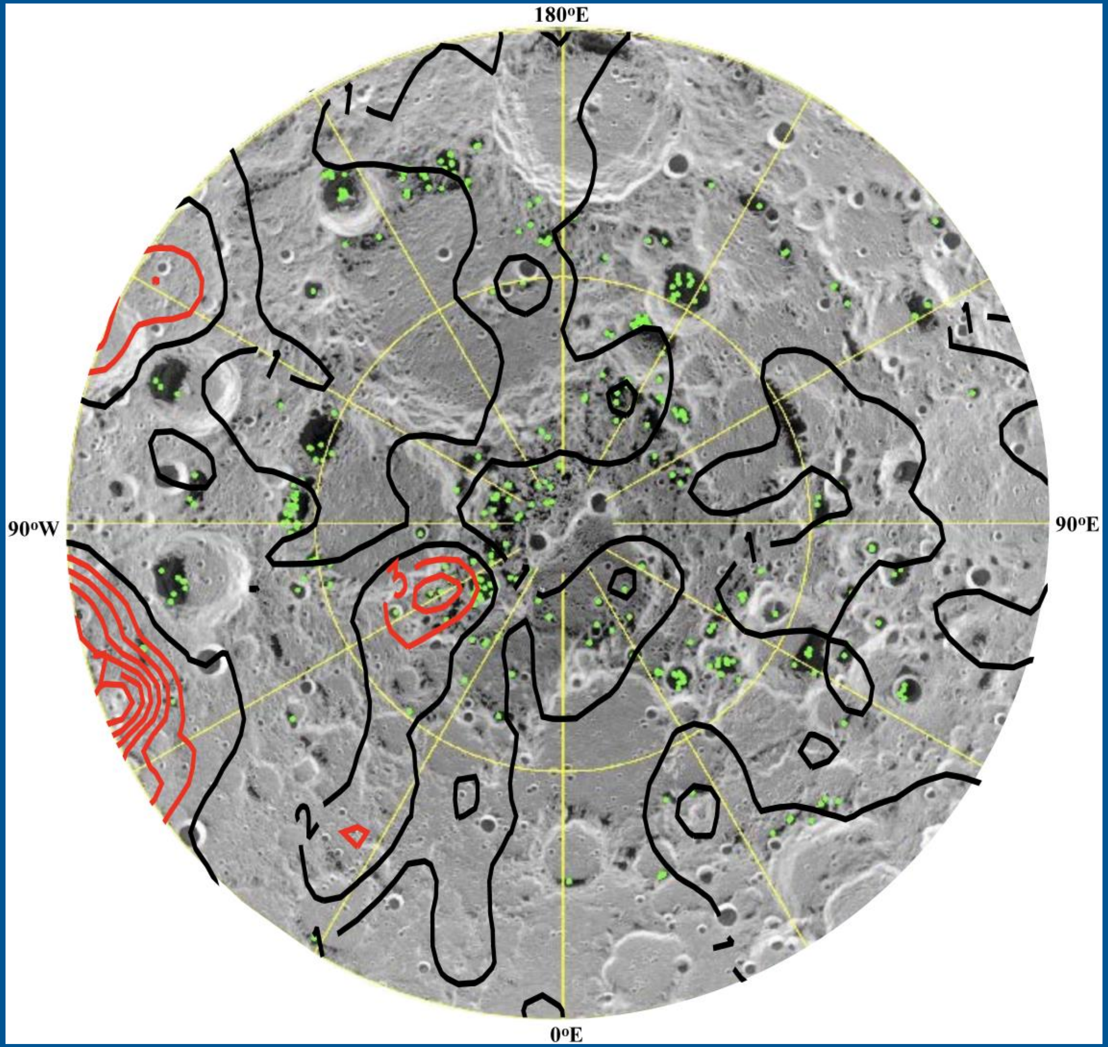
South Pole



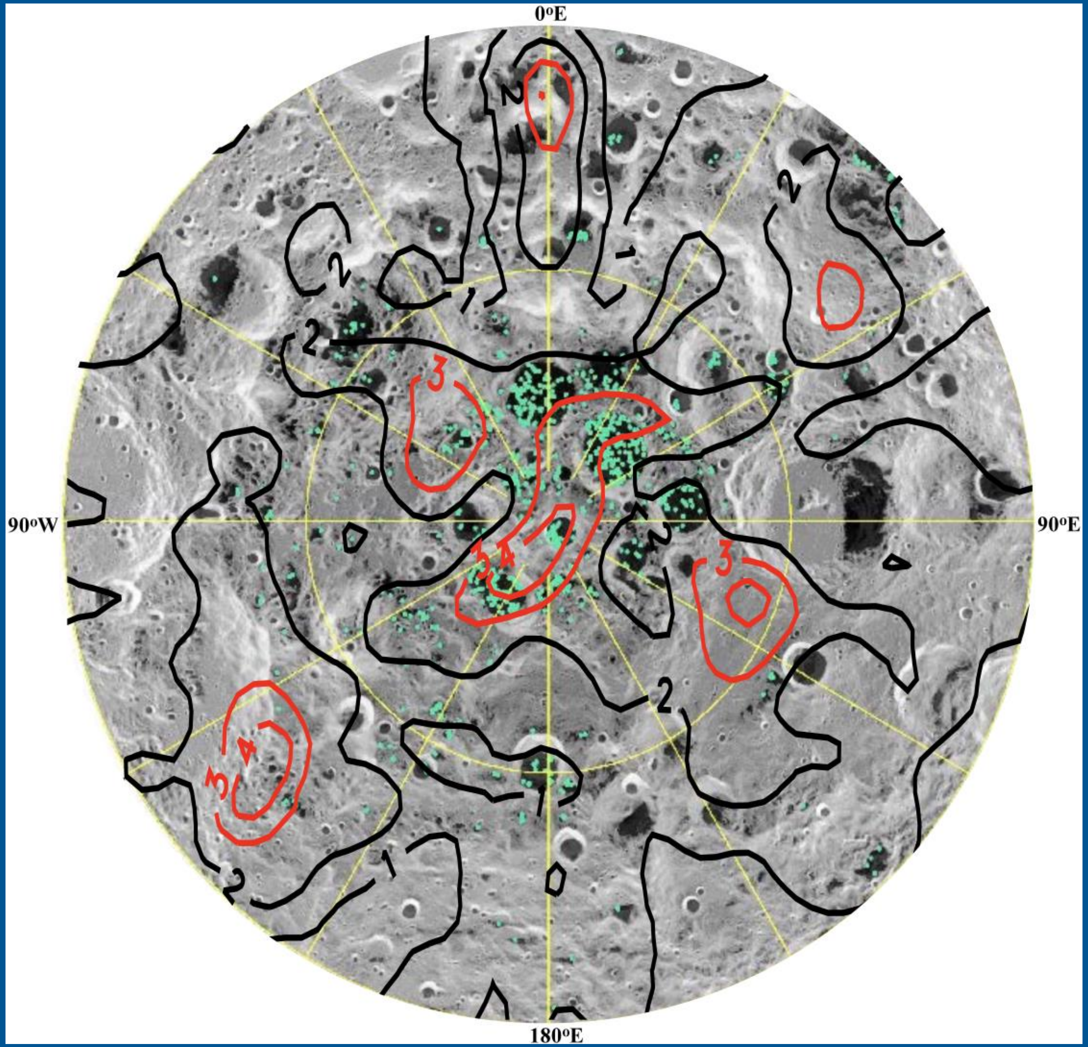
Inferred distributions based on Chandrayaan-1 Moon Mineralogy Mapper (M^3) data

Crustal Magnetic Field at 20 km Altitude Superposed on Inferred Water Ice:

North Pole

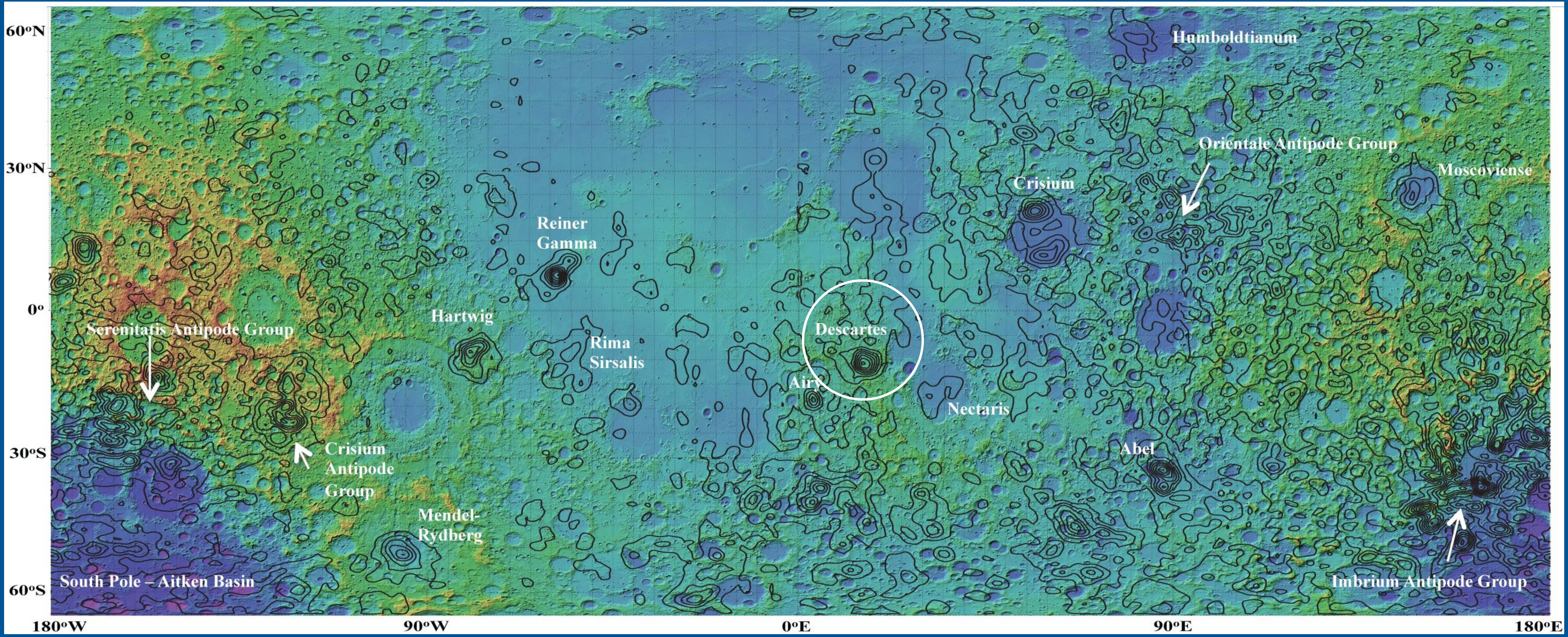


South Pole



Crustal Field based on Lunar Prospector & Kaguya Orbital Magnetometer data

Where is a good *non-polar* place for a manned mission to resolve these issues?



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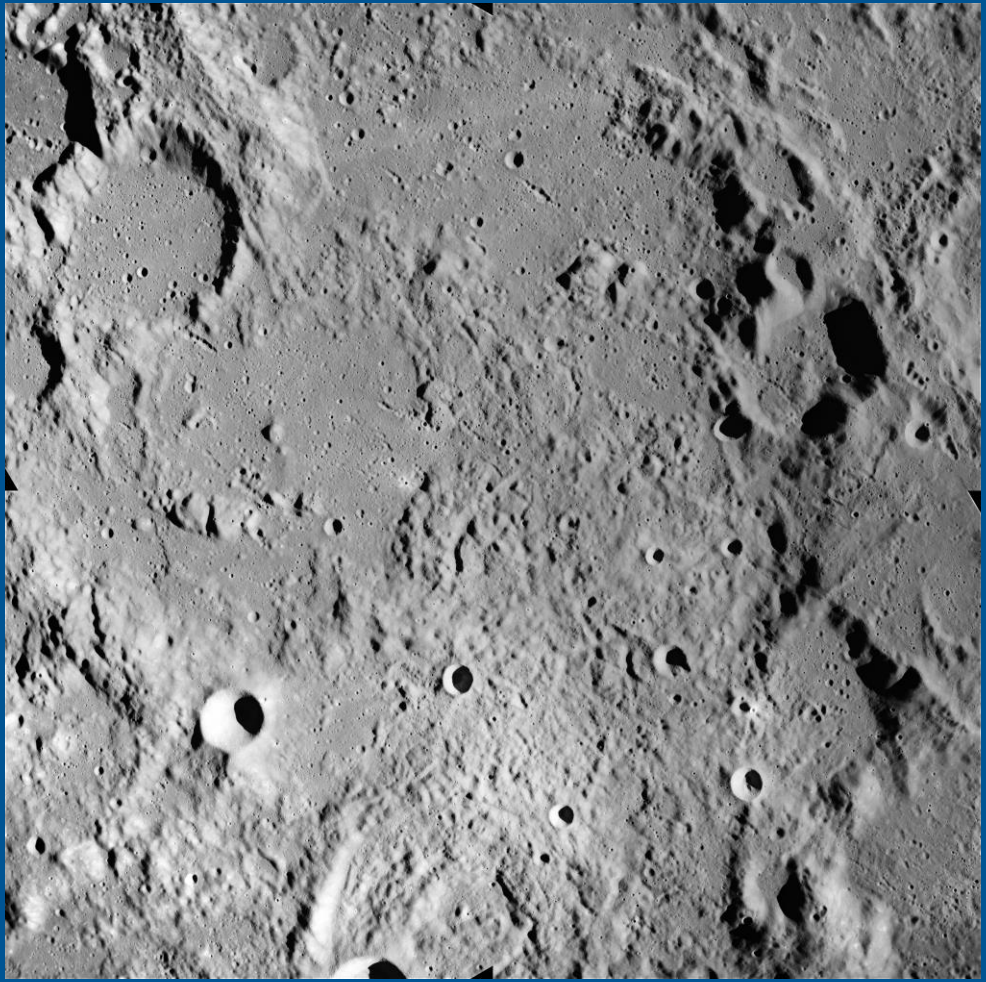
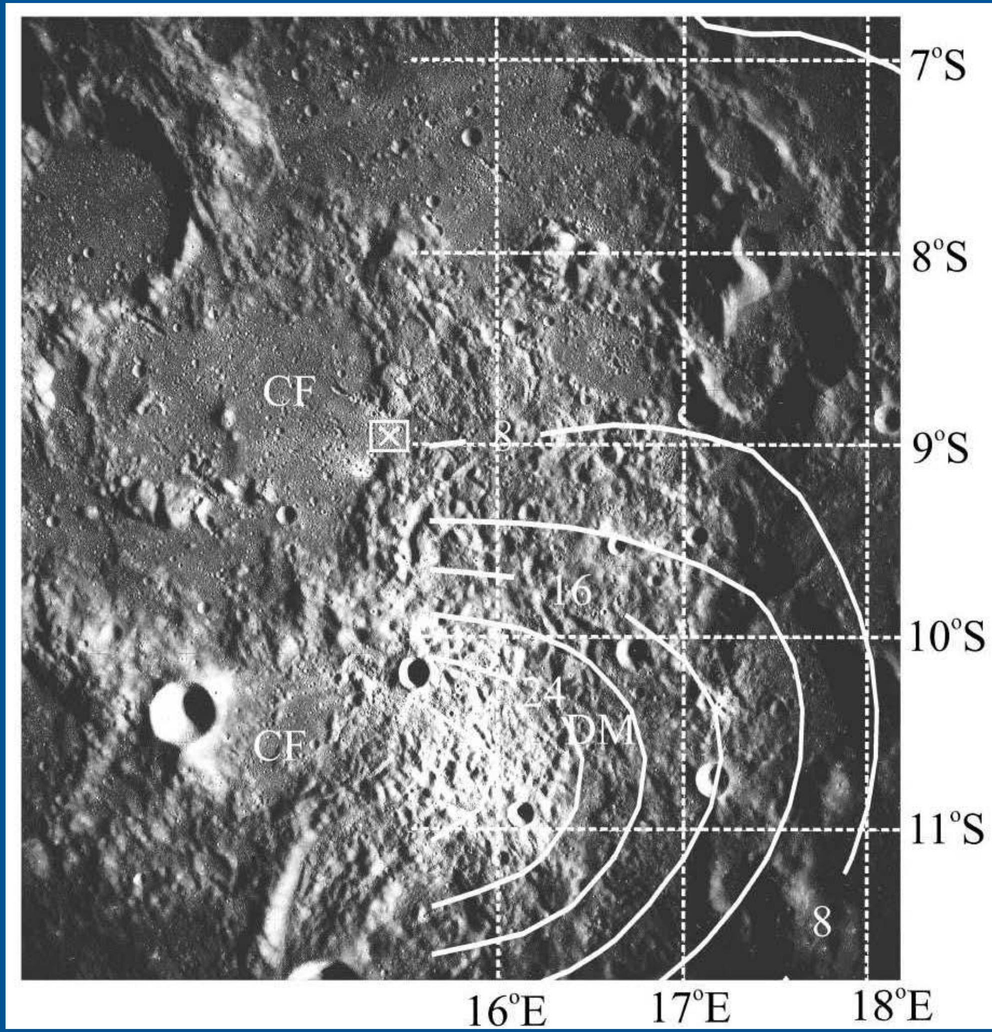
The Descartes Anomaly: A good candidate:



Apollo 16 Mapping Camera Frame 161



Richmond et al., GRL, 2003

One of the strongest anomalies on the near side correlates with a high albedo region in the Descartes mountains near the Apollo 16 landing site (X).

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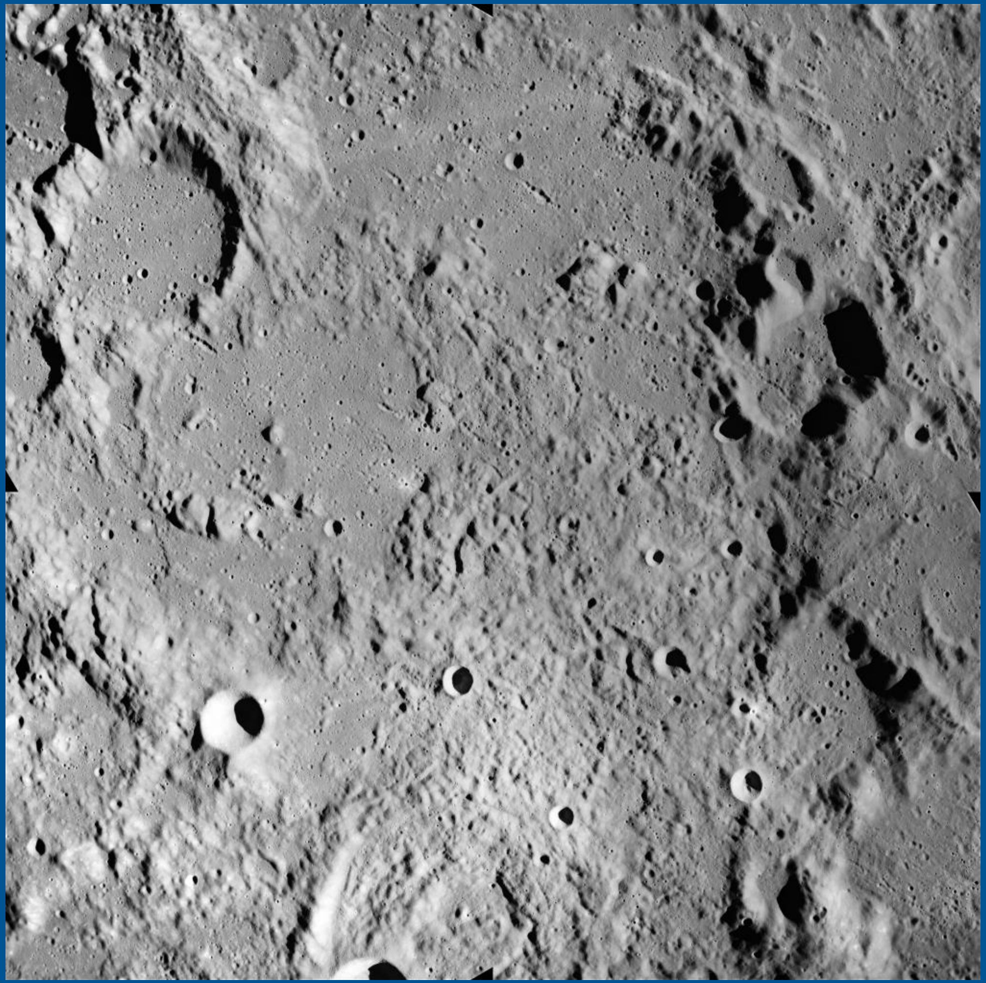

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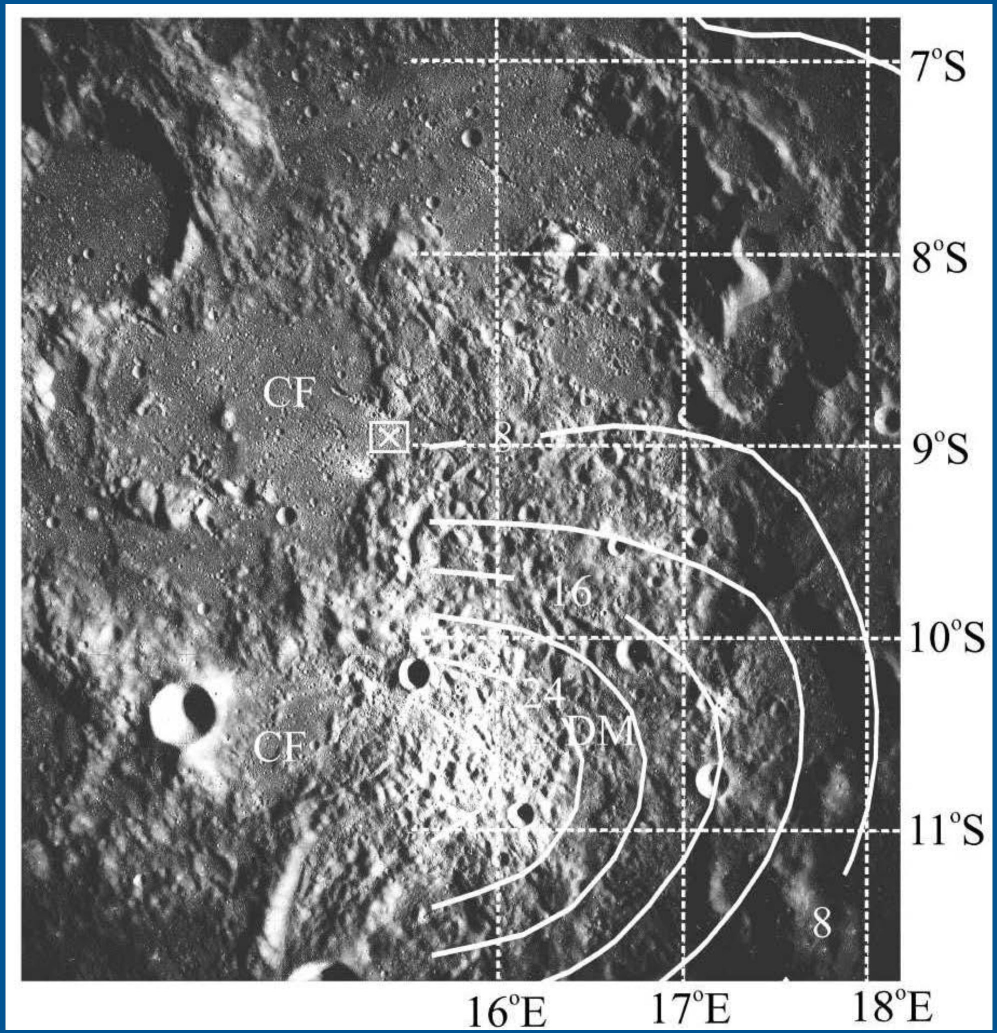
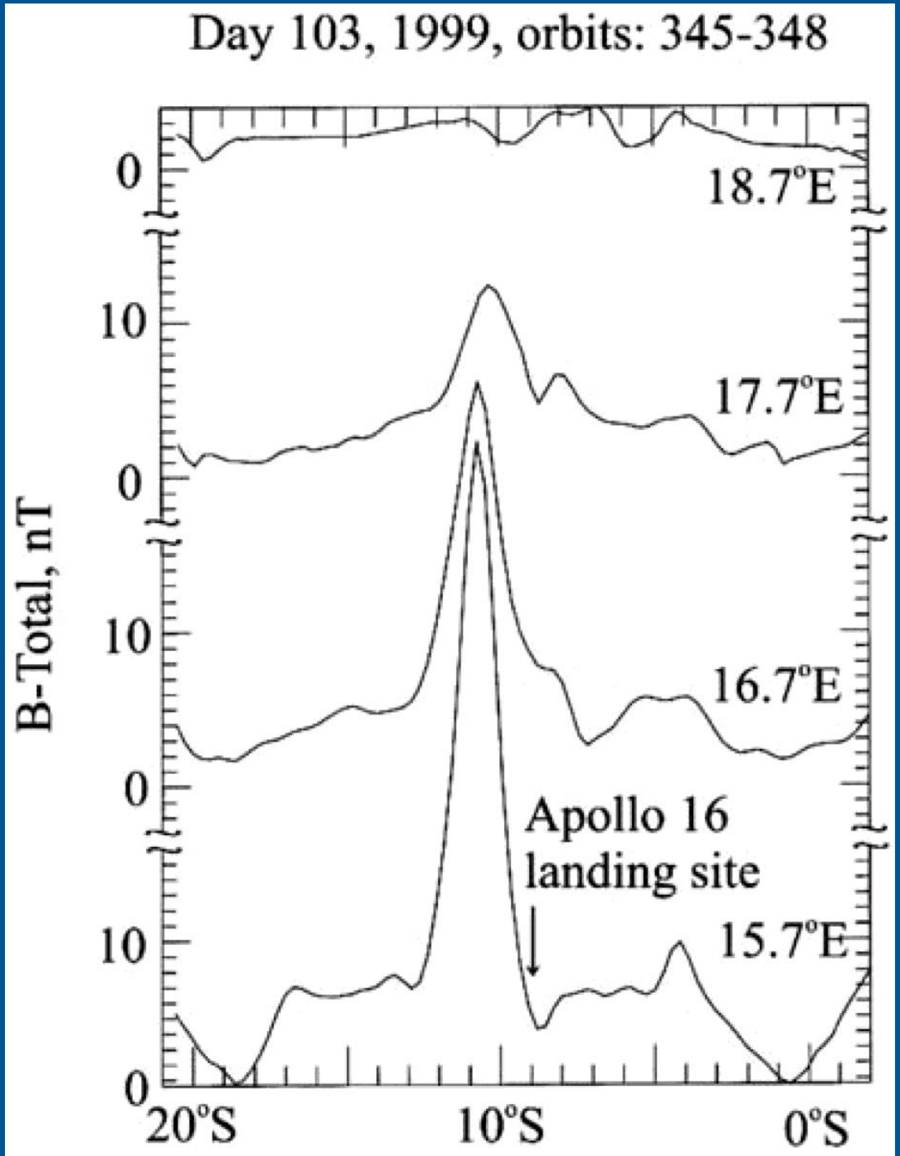


Richmond et al., GRL, 2003

The Descartes mountains are interpreted by lunar geologists as impact basin ejecta from either Imbrium or Nectaris. CF = Cayley Formation

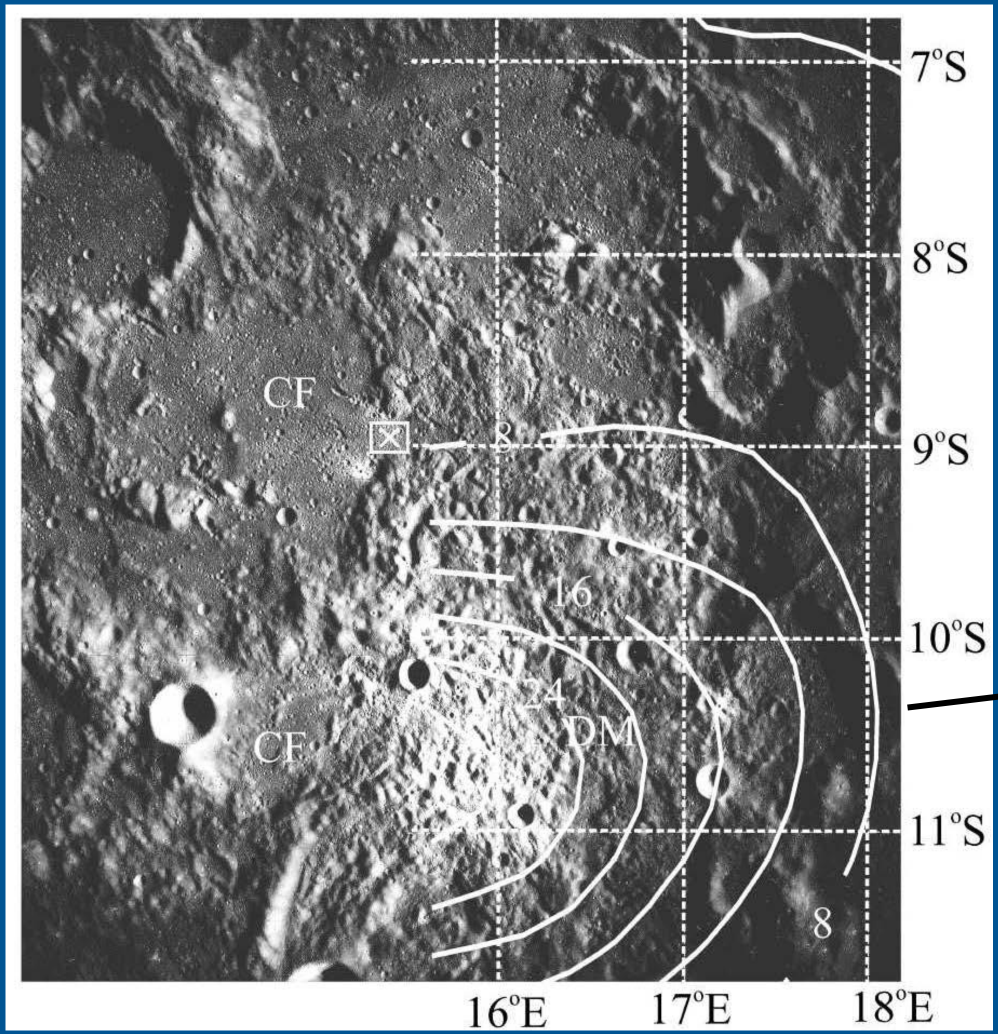
A Field of 42 nT at 19 km altitude was measured over the Descartes Anomaly:

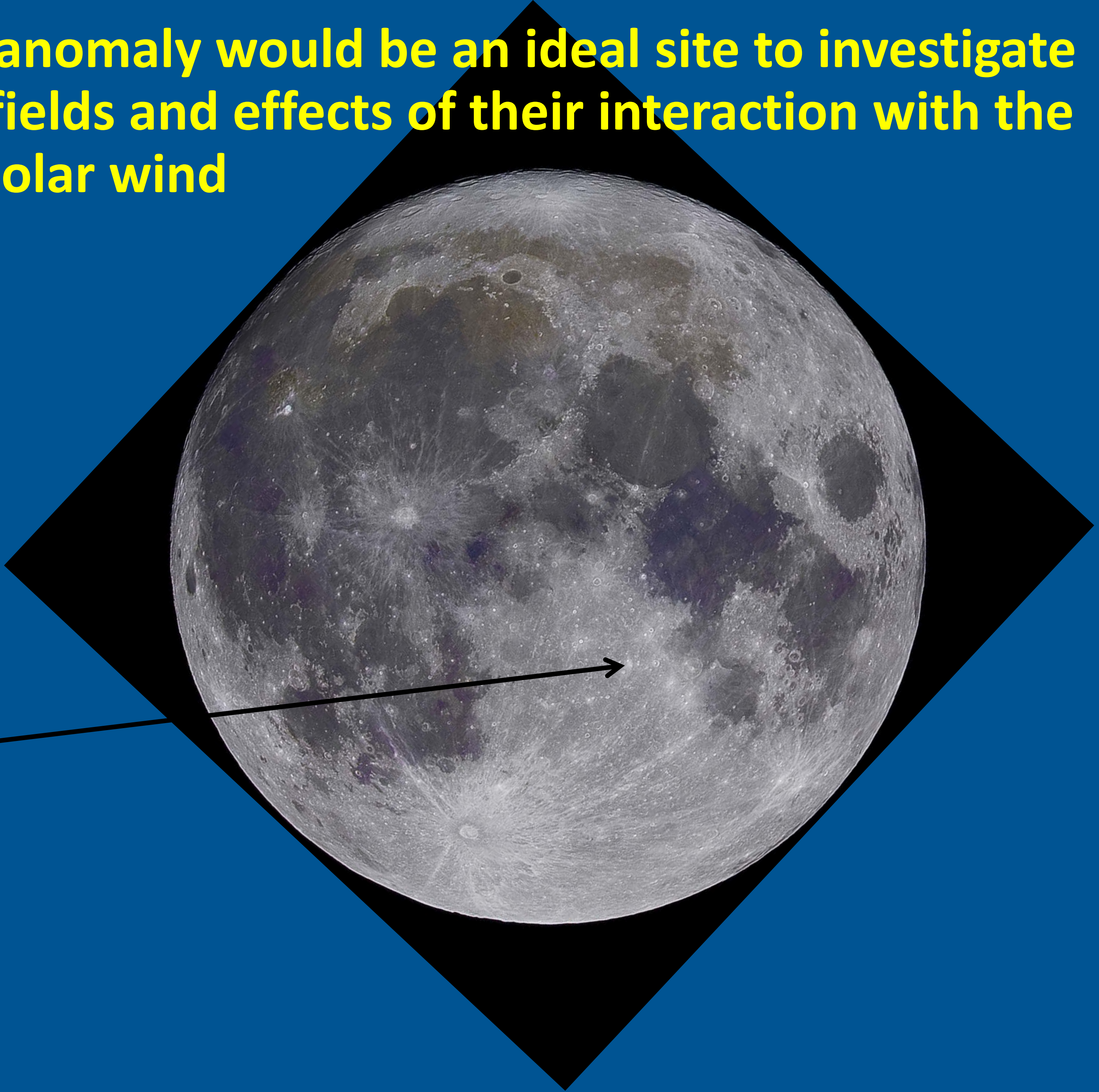


In contrast, fields over the Apollo 16 landing site were relatively weak

Richmond et al., GRL, 2003

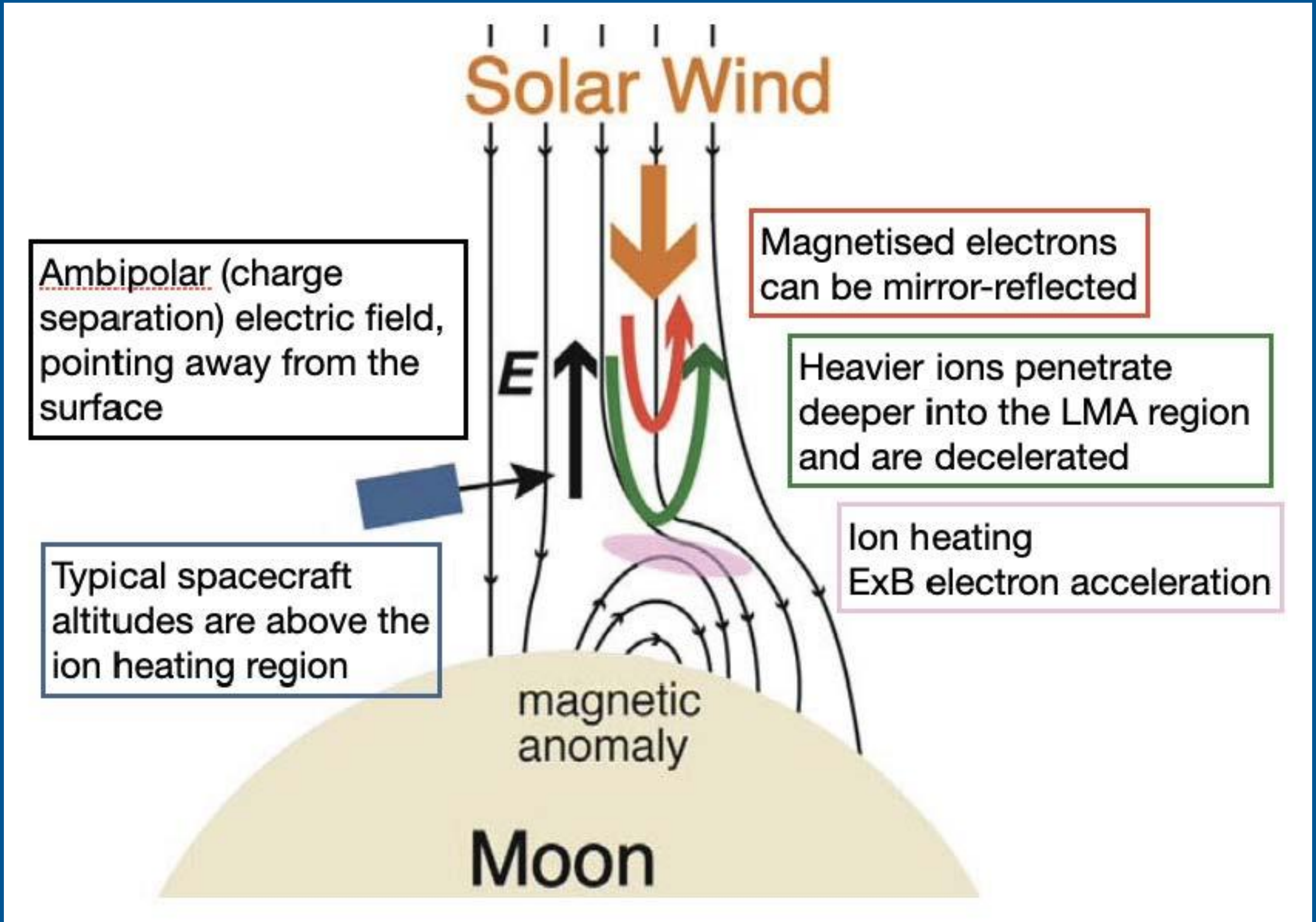
The Descartes magnetic and albedo anomaly would be an ideal site to investigate the origin of lunar crustal magnetic fields and effects of their interaction with the solar wind





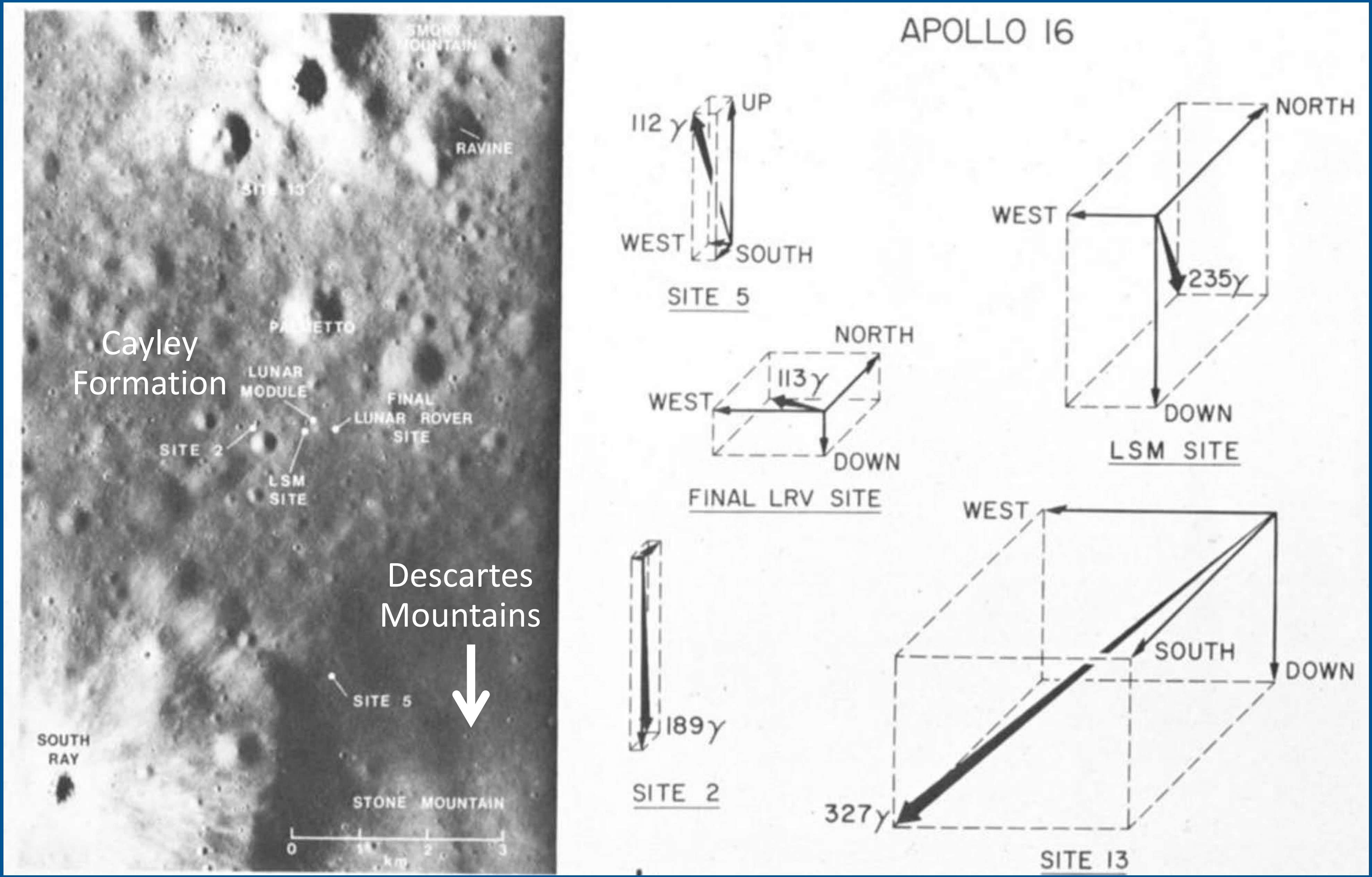
Extra Slides

Basic physics of the solar wind interaction with a crustal magnetic anomaly.



Credit: Jan Deca

Surface Fields up to 327 nT were measured nearby by the Apollo 16 astronauts



Dyal et al., Rev. Geophys., 1974