Landed Science at a Lunar Crustal Magnetic Anomaly

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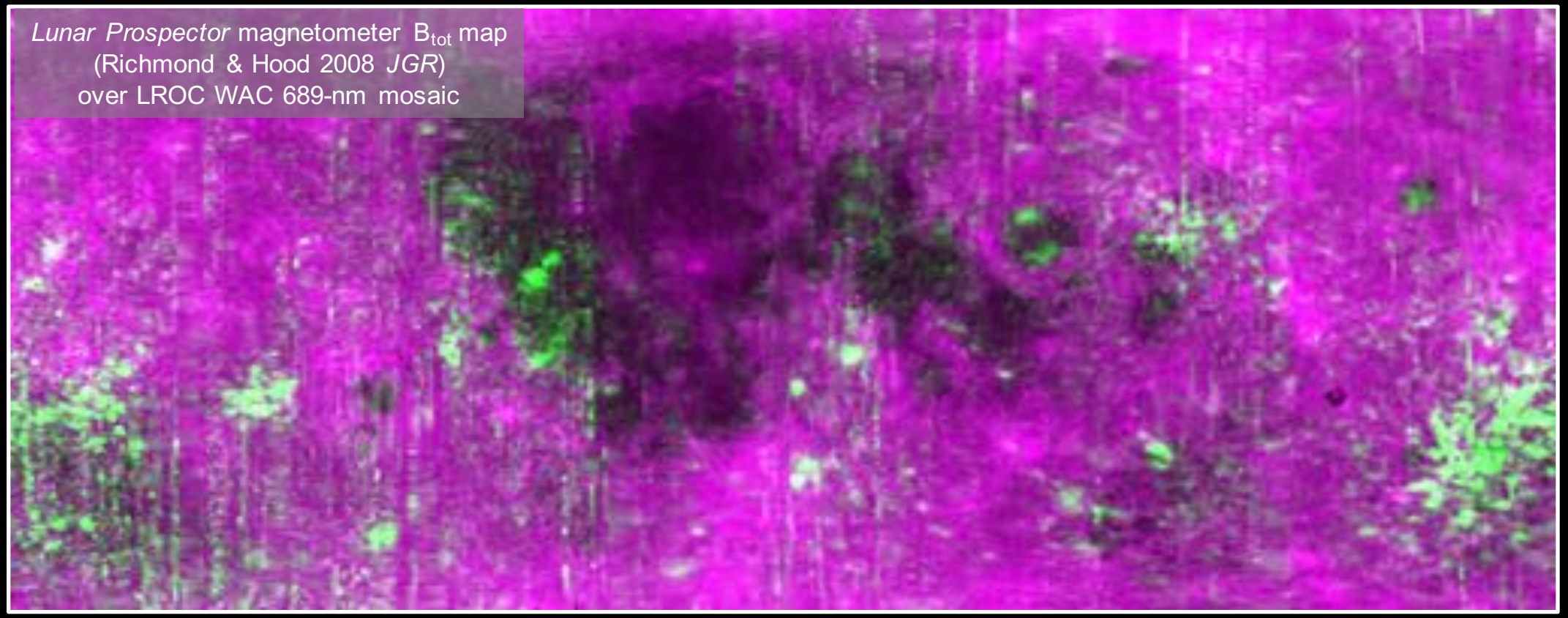
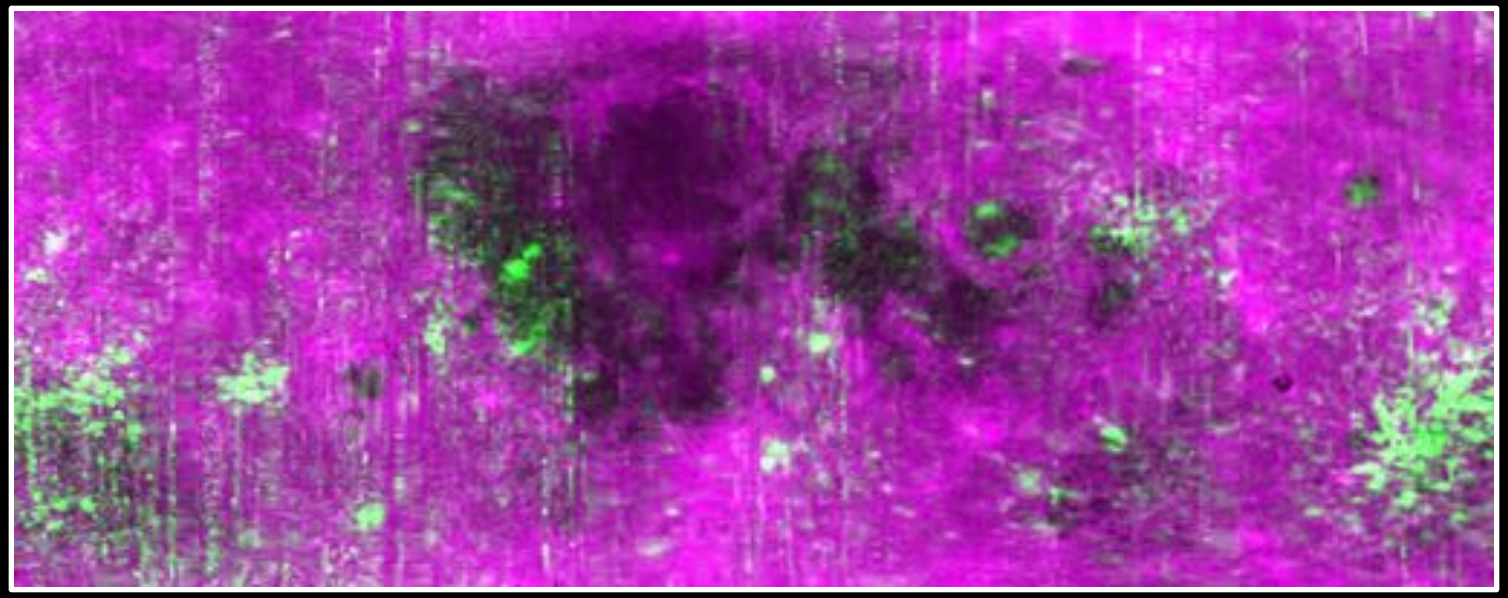
Lunar Magnetic Anomalies

- The lunar crust contains magnetized areas, a few tens to several hundred kilometers across, known as "magnetic anomalies".
- The crustal fields are appreciable: Strongest anomalies are ~10-20 nT at 30 km altitude, perhaps a few hundred to 1000 nT at the surface.



Lunar Magnetic Anomalies: Formation Hypotheses

- Magnetized basin ejecta: ambient fields amplified by compression as impact-generated plasma converged on the basin antipode (Hood and co-workers)



Lunar Prospector magnetometer B_{tot} (Richmond & Hood 2008 *JGR*) over LROC WAC 689-nm mosaic

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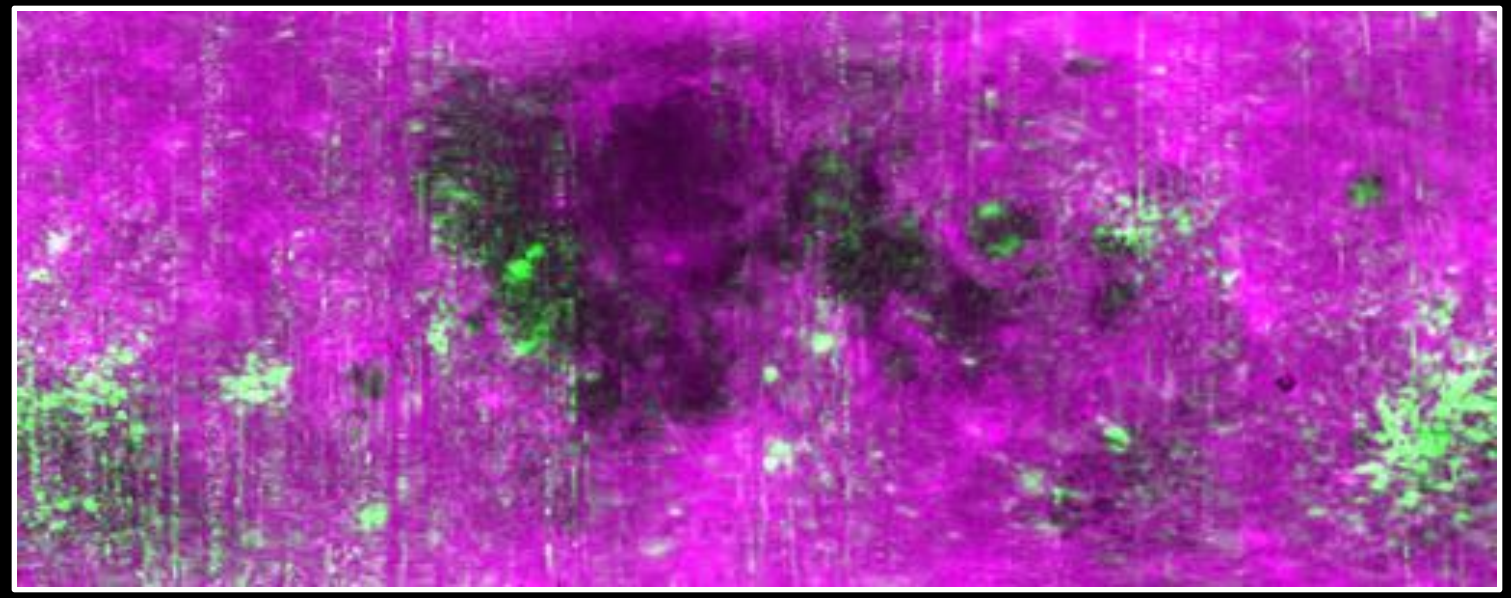
- Magnetic field impressed on the surface by plasma interactions when a cometary coma struck the Moon (Schultz)



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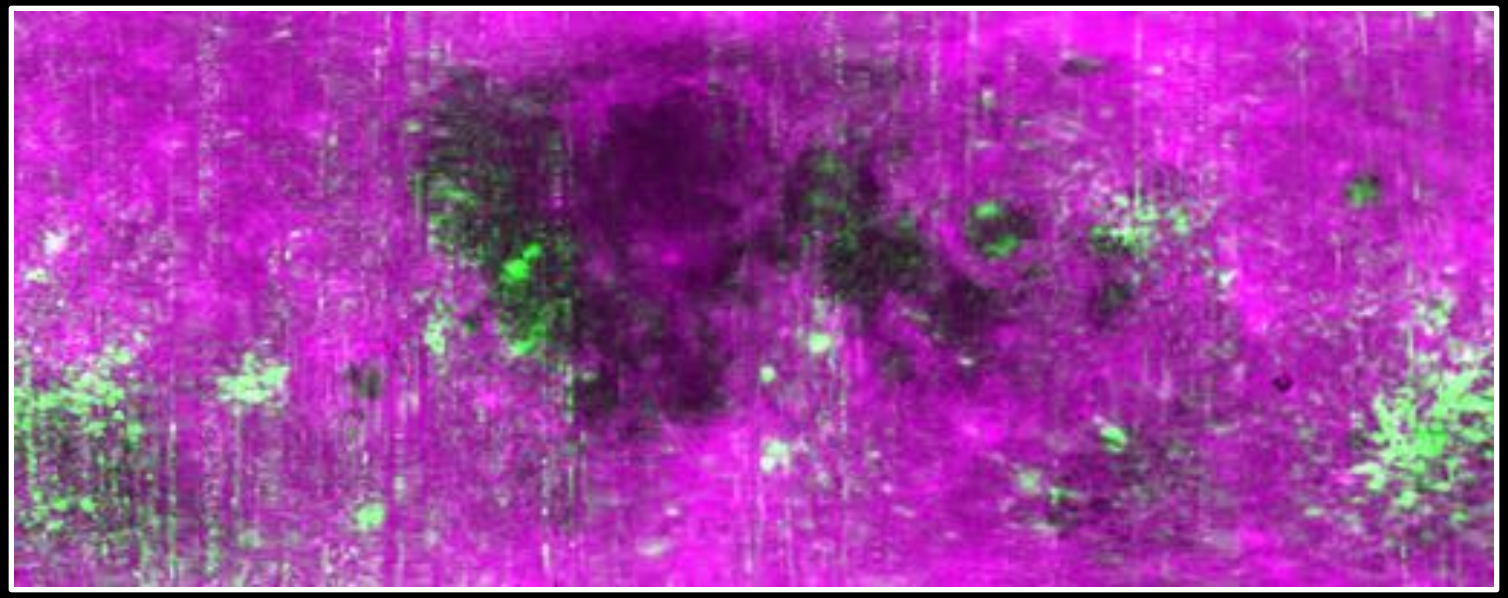
- Magmatic intrusion or impact melt magnetized in an early lunar dynamo field (e.g., Purucker et al. 2012; Hood, 2011)



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Lunar Prospector total field map

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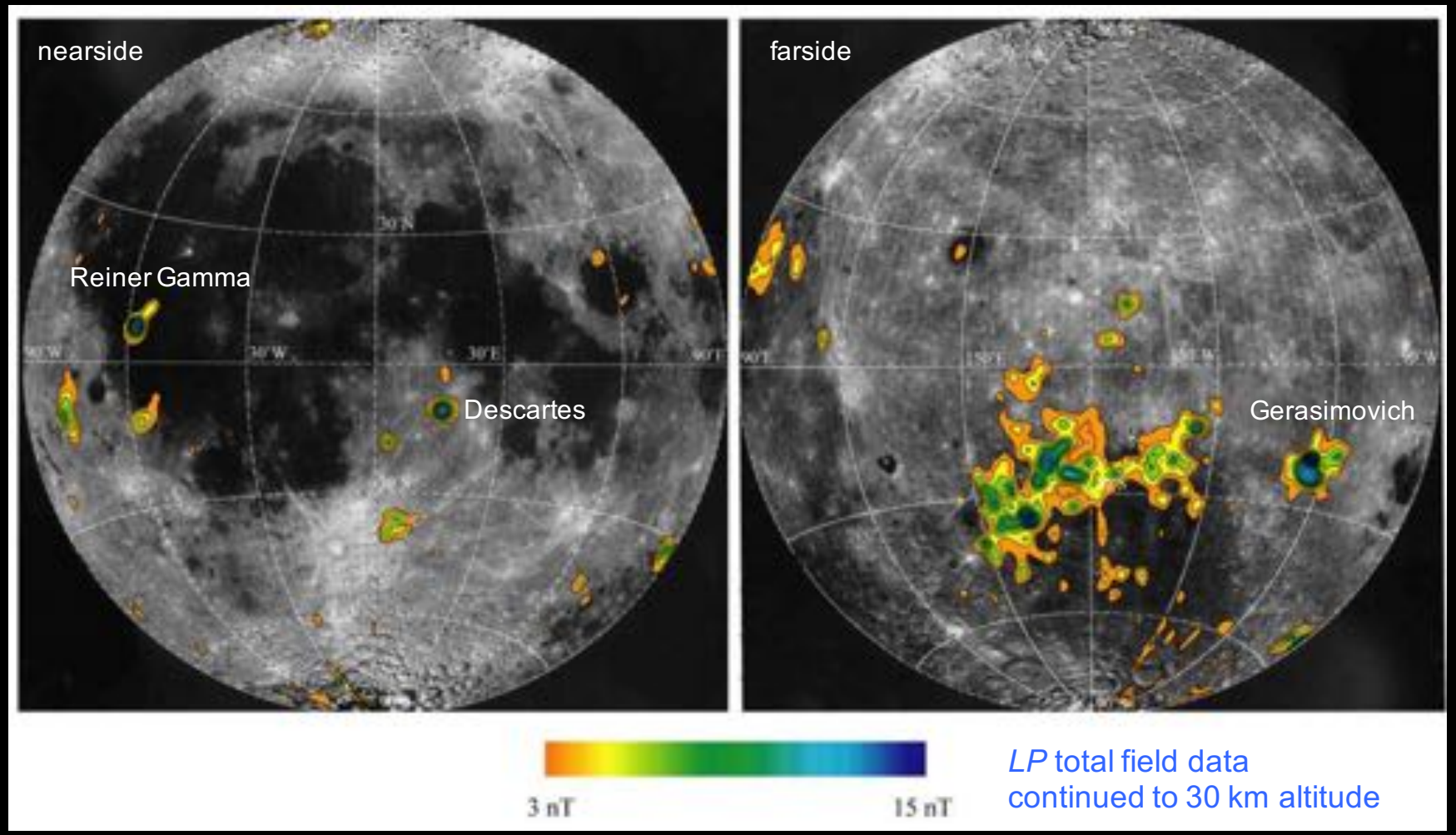
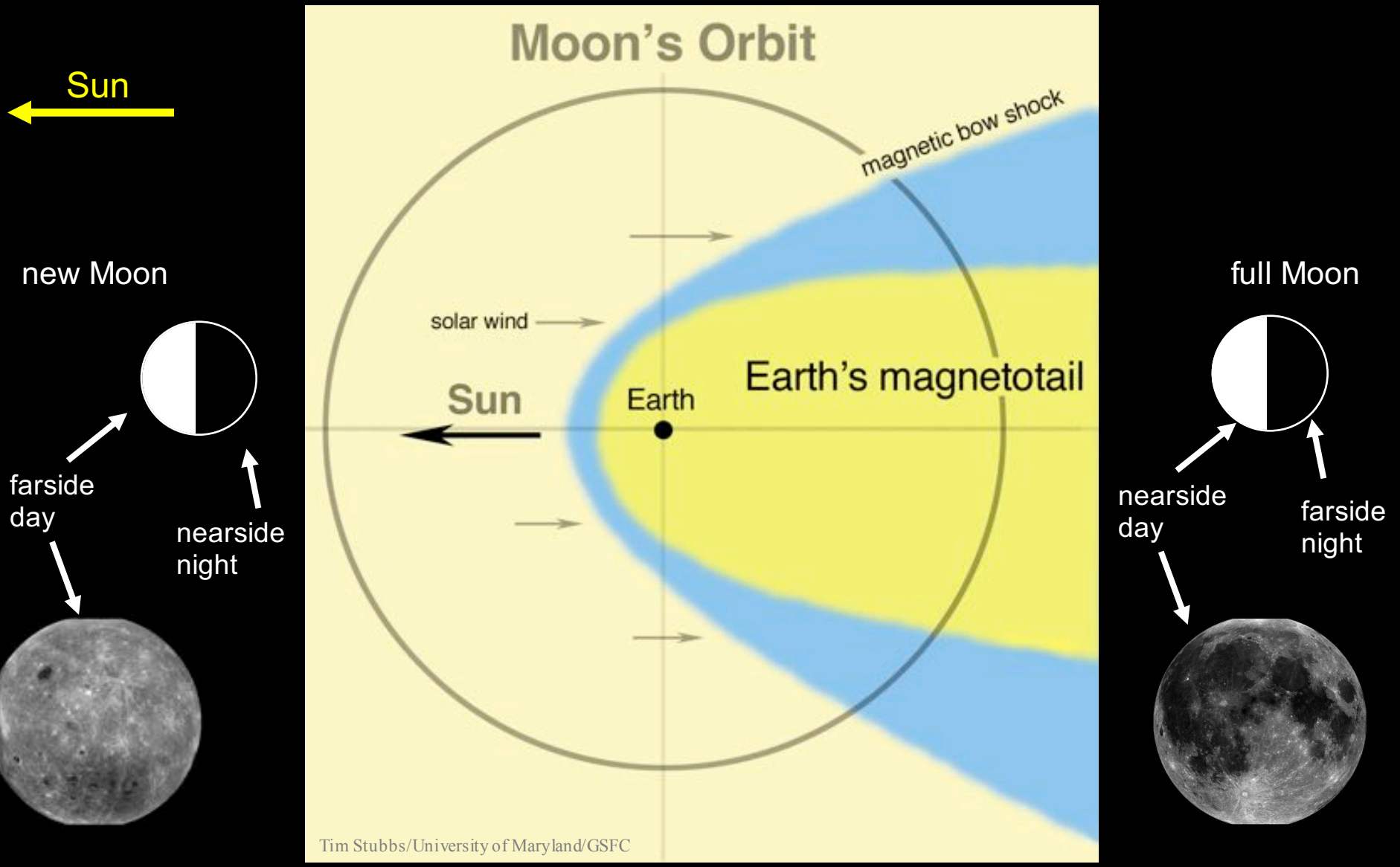


Descartes is the strongest nearside anomaly.
Gerasimovich (Crisium antipode) is strongest overall.

Richmond and Hood (2008) *JGR*

Varying Plasma Environment



LROC WAC basemaps

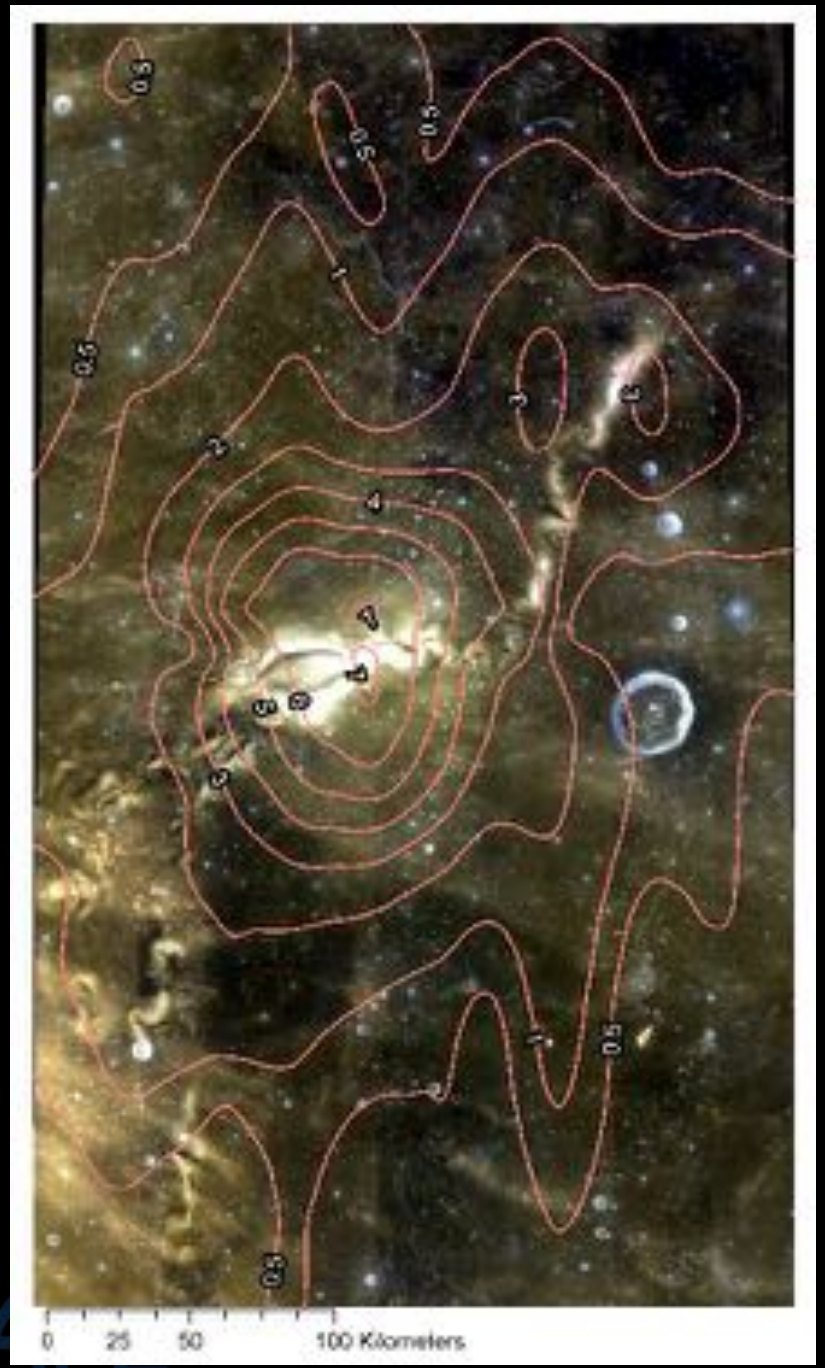
Effect on Solar Wind Flow

- Observations by *Lunar Prospector, Kaguya, Chandrayaan-1*, *ARTEMIS*, and *Chang'E-2* demonstrate that mini-magnetospheres exist over the stronger anomalies: measurements of reflected electrons, observation of solar wind flow, and reflected neutral atoms (e.g. Halekas et al. (2008 *PSS*), Lue et al. (2011 *GRL*), Vorburger et al. (2012 *JGR*), Wang et al. (2012 *ASR*)).

- Actual field structure at the surface in the magnetic anomalies is unknown.

Lunar Swirls

Reiner Gamma



- Magnetic anomalies are collocated with unusual albedo features called lunar swirls.
- Sinuous, high-reflectance markings. Especially distinctive in the UV.
- Dark lanes sometimes found within the bright portions.
- Found in both maria and highlands.
- Type example is Reiner Gamma, in Oceanus Procellarum.
- No topographic relief.
- Weaker OH absorptions than the surroundings.

Clementine pseudo true color composite, with contours of *LP* total field strength at 35.5 km altitude. Blewett et al. (2007) *GRL*

Hypotheses for the Origin of Swirls

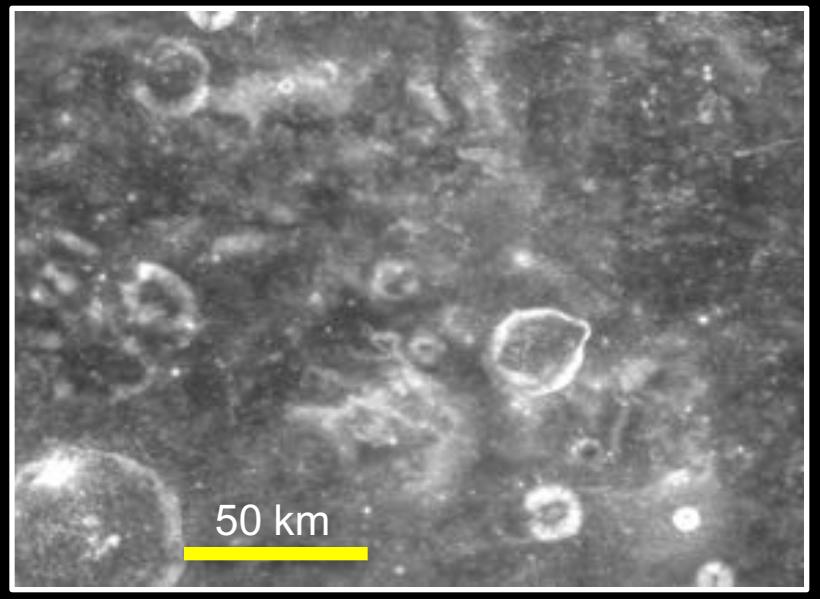
- Attenuated space weathering caused by solar-wind standoff (Hood)
- Recent impact by a comet or a meteoroid swarm (Schultz, Starukhina, Pinet)
- Electrostatic dust accumulation (Garrick-Bethell)
- Collapse of "fairy castle" uppermost soil structure (Pieters)

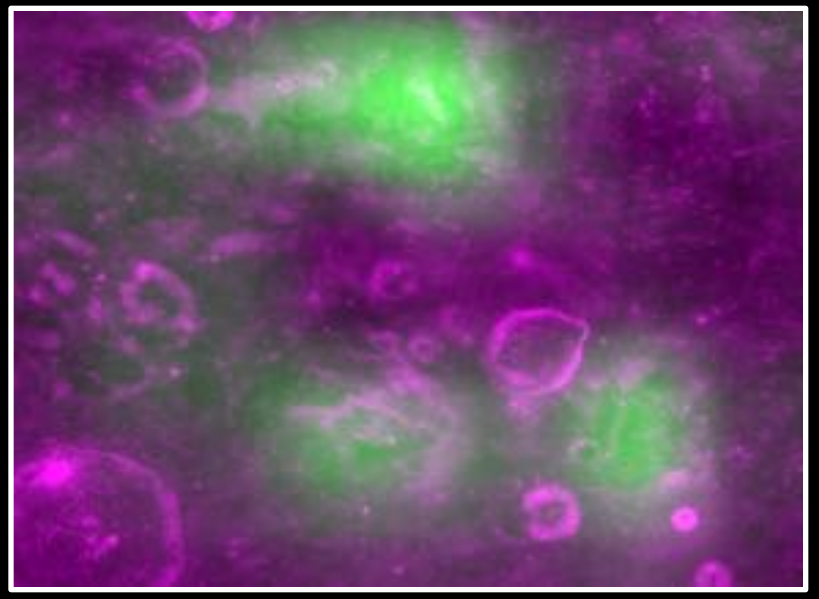
Farside swirls near crater Firsov.

Apollo 10 photo AS10-30-4365.

Magnetic Anomalies as Natural Laboratories

The magnetic anomalies offer a venue to examine sets of key questions in several major areas of planetary science.





The Gerasimovich highland magnetic anomaly and swirls, in the vicinity of the Crisium antipode.

Lunar Prospector total field strength at 30 km altitude on LROC WAC mosaic.

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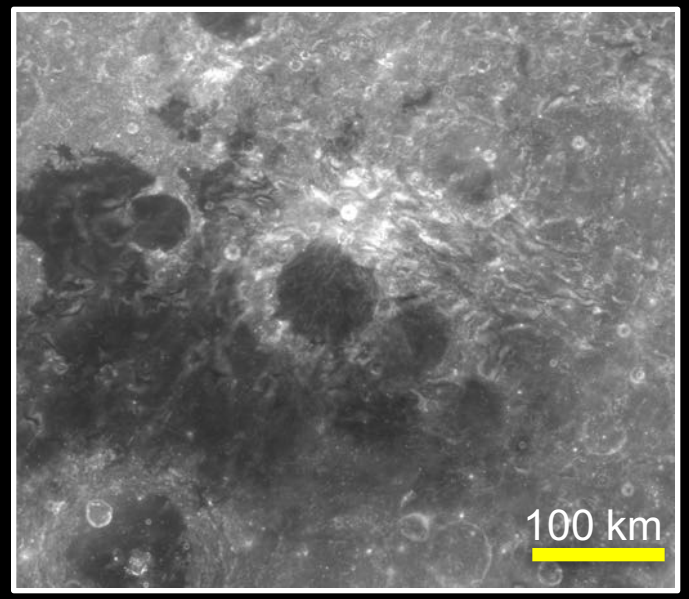
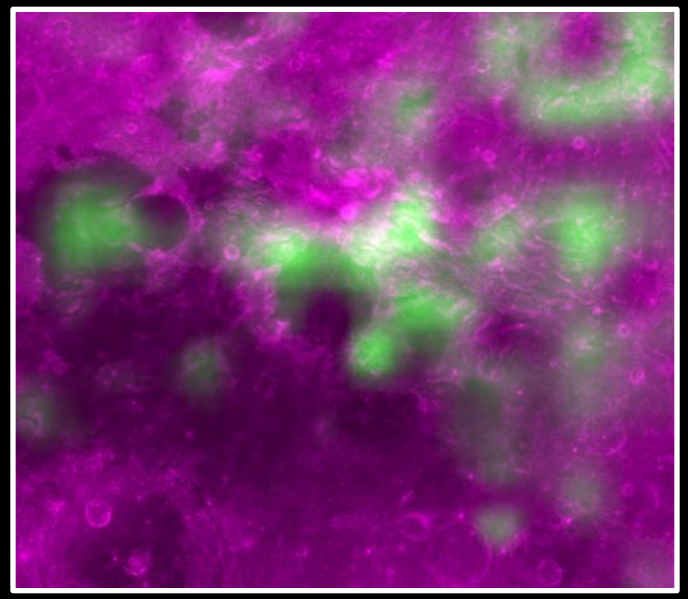
Compelling problems that bring together "sky science" (particles and fields) and geoscience.





The magnetic anomaly and swirl belt at Mare Marginis, in the vicinity of the Orientale antipode.

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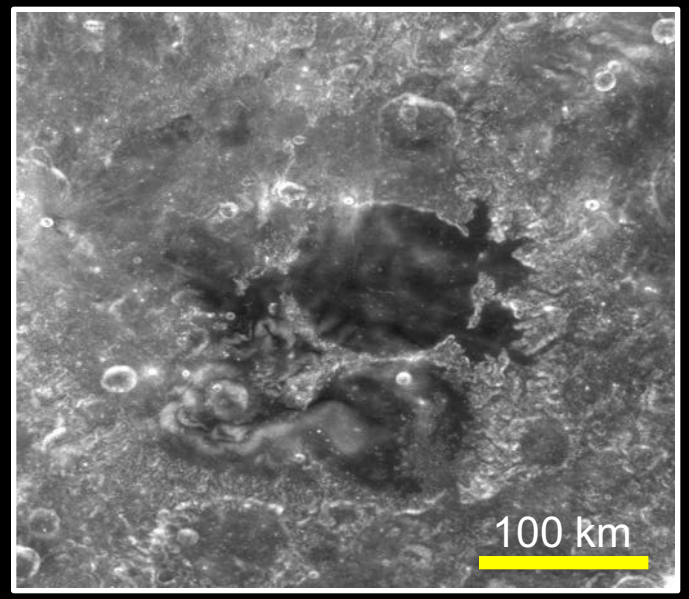
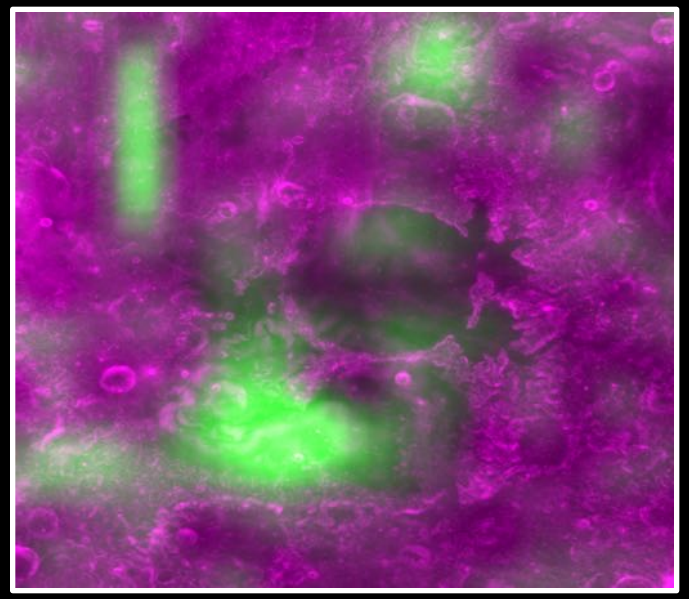
Magnetized region provides a control on one of the key variables: solar wind exposure (micrometeoroids not affected by magnetic field).



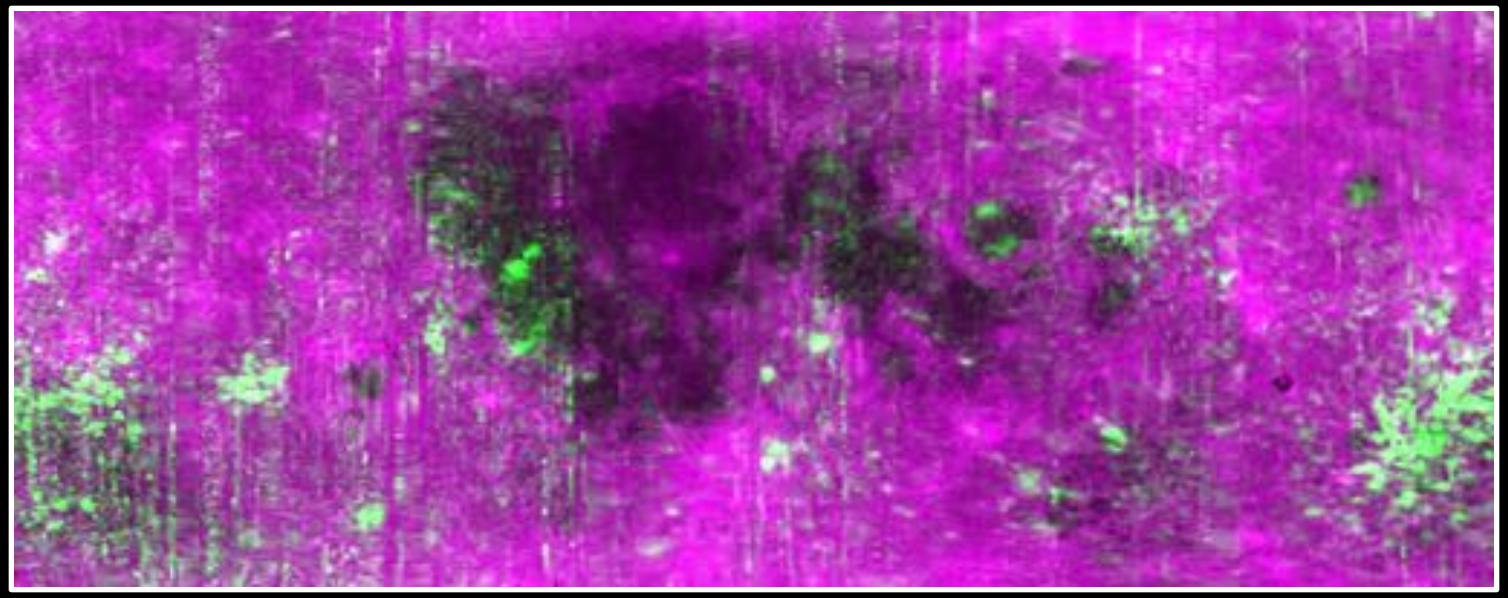


The Mare Ingenii magnetic anomaly and swirls, in the vicinity of the Imbrium antipode.

Lunar Prospector total field strength at 30 km altitude on LROC WAC mosaic.

Lunar Magnetic Anomalies

- Unique opportunities that touch on a broad range of key problems in planetary science –
  - Geophysics: the nature and origin of the magnetized crust (ancient dynamo, magmatic intrusion, magnetized basin ejecta, comet impact)



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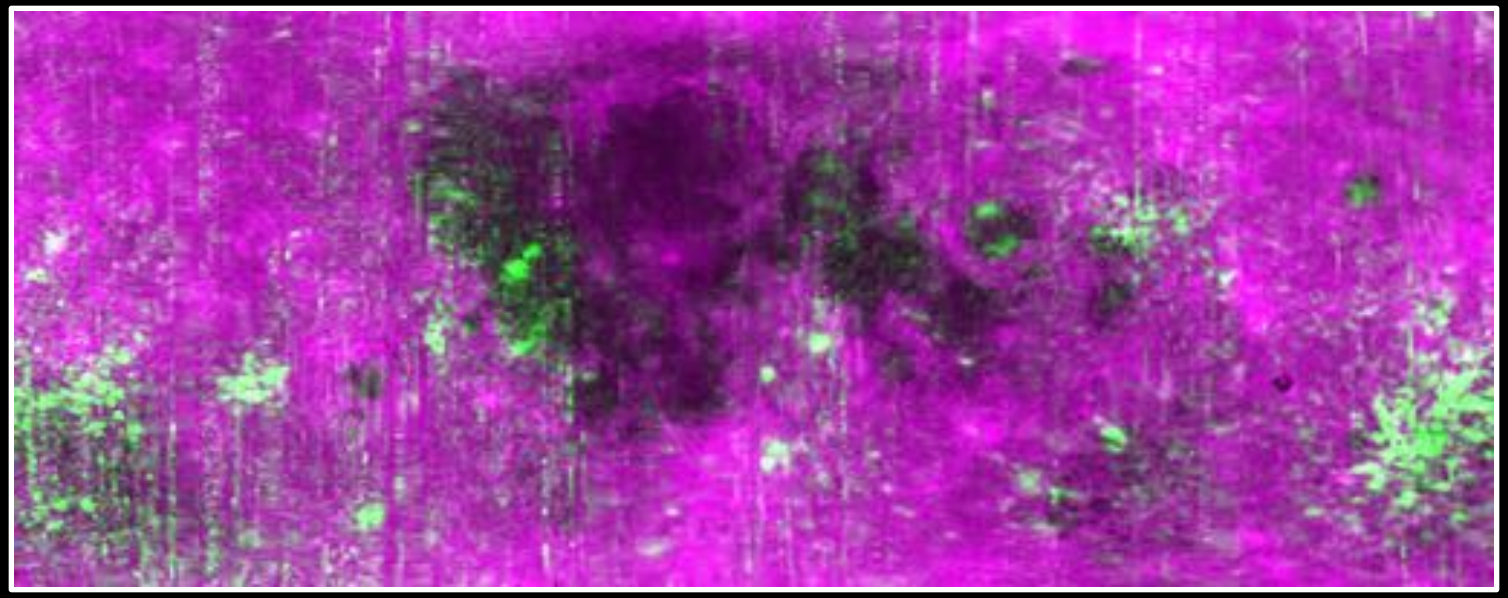

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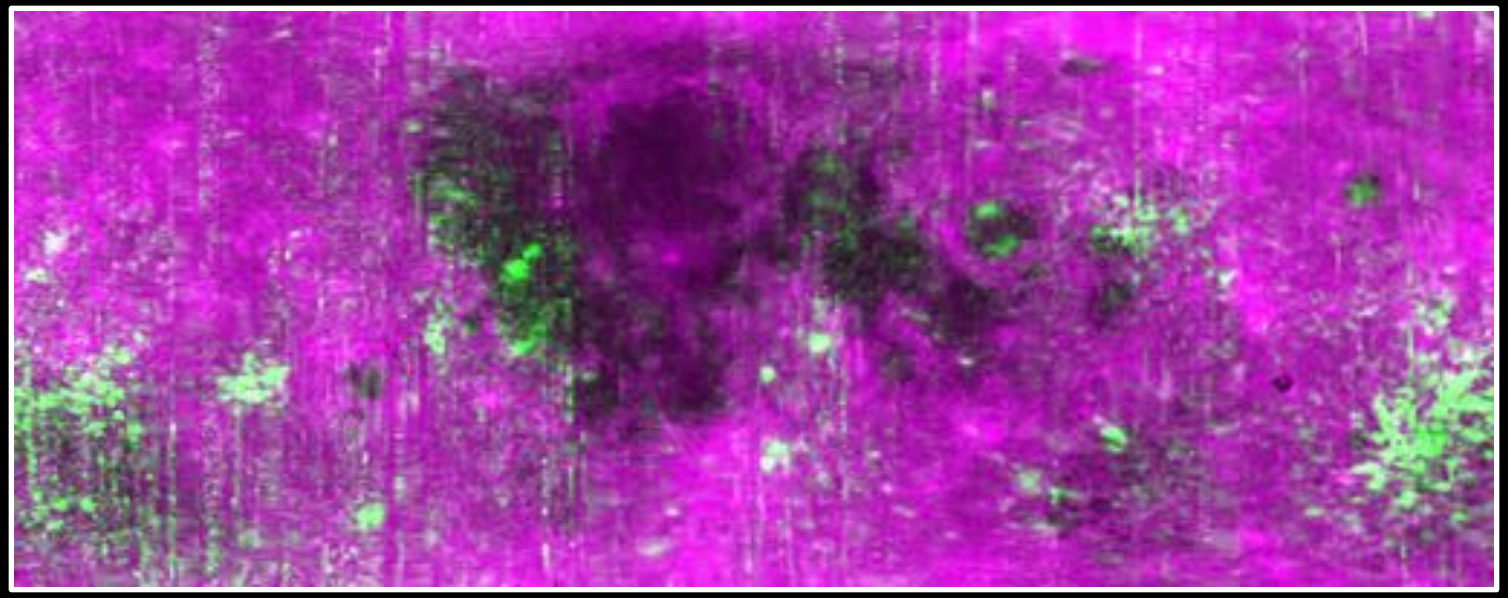
  - Space Plasma Physics: formation of mini-magnetospheres/standoff region, fluxes by energy/species that reach the surface, changes with time of lunar day
  - Geology/Surface Processes: space weathering, solar-wind implantation and sputtering, origin of swirls, lunar water cycle/hydration, dust motion and accumulation, comet impact



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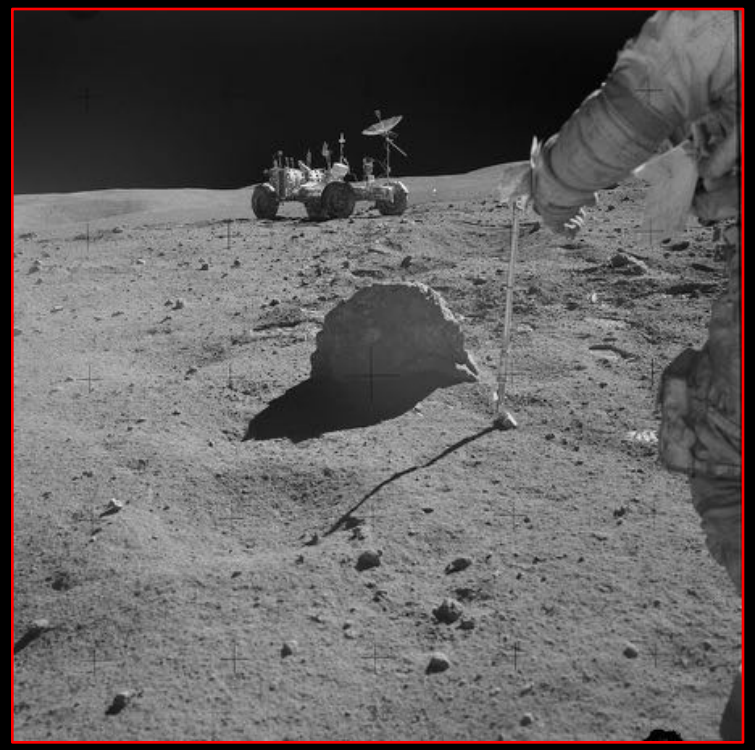
Lunar Magnetic Anomalies

- Address human exploration Strategic Knowledge Gaps (SKGs)
  - Theme I, Resource Potential: I-D, temporal variability and movement dynamics of surface-correlated OH and H_2O.
  - Theme II, Lunar Environment: II-B, radiation at the lunar surface.
  - Theme III, Living & Working on the Lunar Surface: III-B-1, lunar geodetic control. III-C-2, lunar surface trafficability. III-E, near-surface plasma environment.

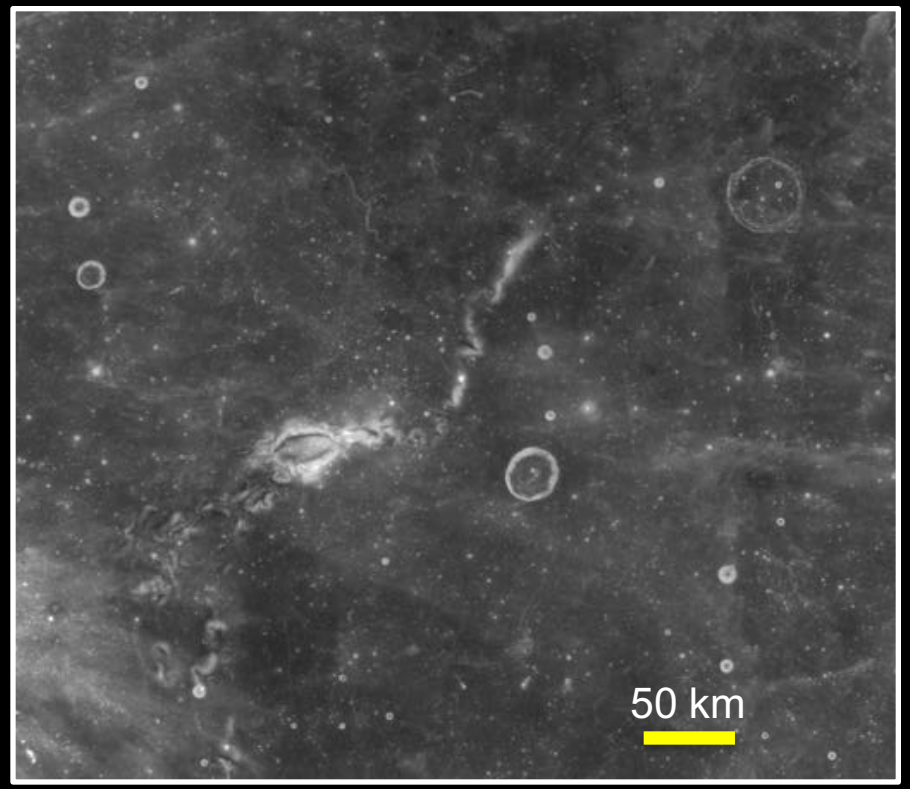


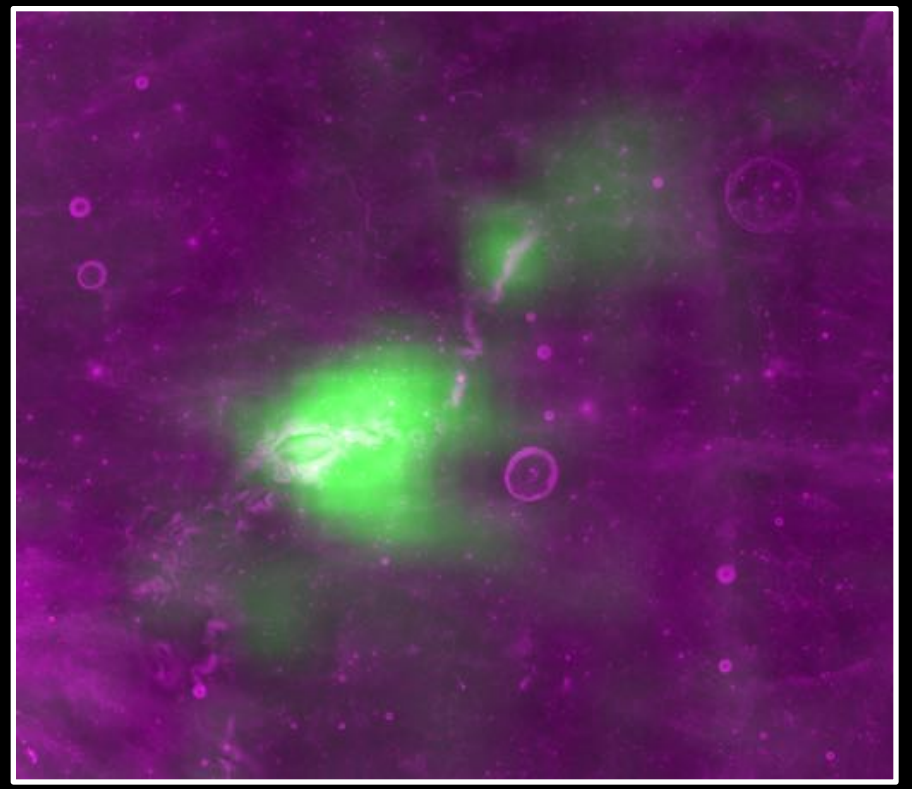
AS16-108-17741

D. Blewett et al.: lunar magnetic anomaly rover

Landed mission target: Reiner Gamma

- Choose nearside location for ease of communications.
- A longitude >45° from sub-Earth maximizes time out of magnetosphere.
- Reiner Gamma (7.5° N, 59° W) is ideal.





The Reiner Gamma magnetic anomaly and swirl, in Oceanus Procellarum.

Lunar Prospector total field strength at 30 km altitude on LROC WAC mosaic.

Landed mission target: Reiner Gamma

Reiner Gamma. LROC WAC basemap

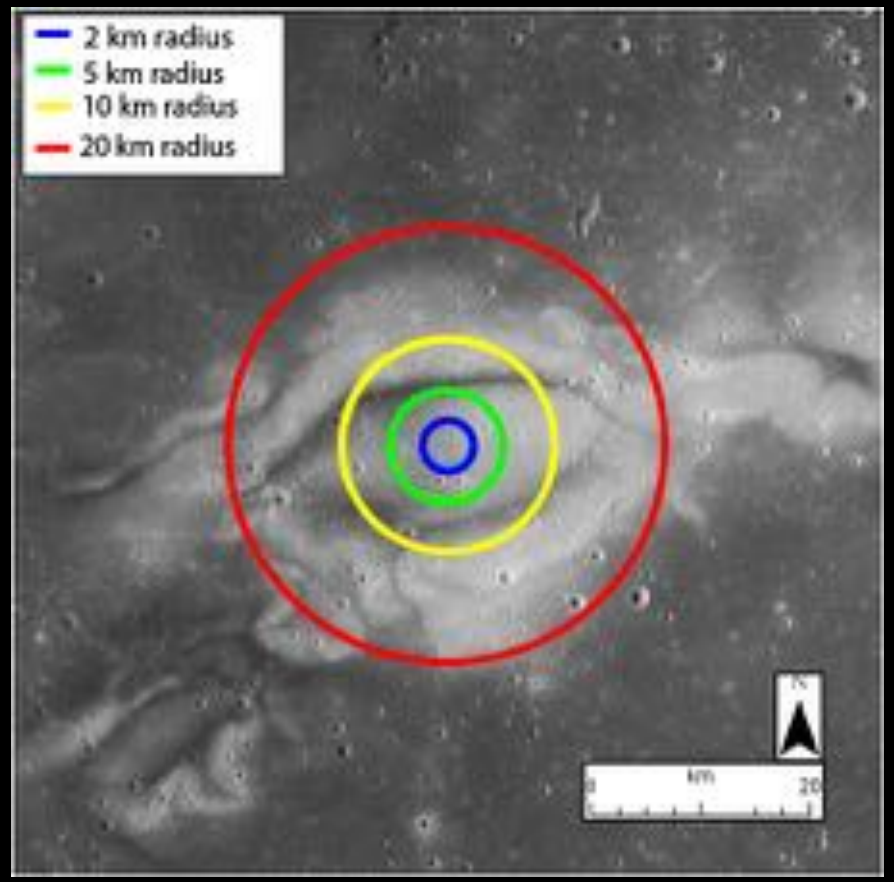
Measurements at multiple locations are needed to fully characterize

- Magnetic field strength, direction
- Solar wind access to surface
- Regolith properties and dust environment
- OH/H_2O production
- Time variability

Thus, a rover is preferred over a static lander.

Rover mission to Reiner Gamma

Land in central RG magnetic anomaly.
Traverse across the dark lane.



Reiner Gamma. LROC WAC basemap

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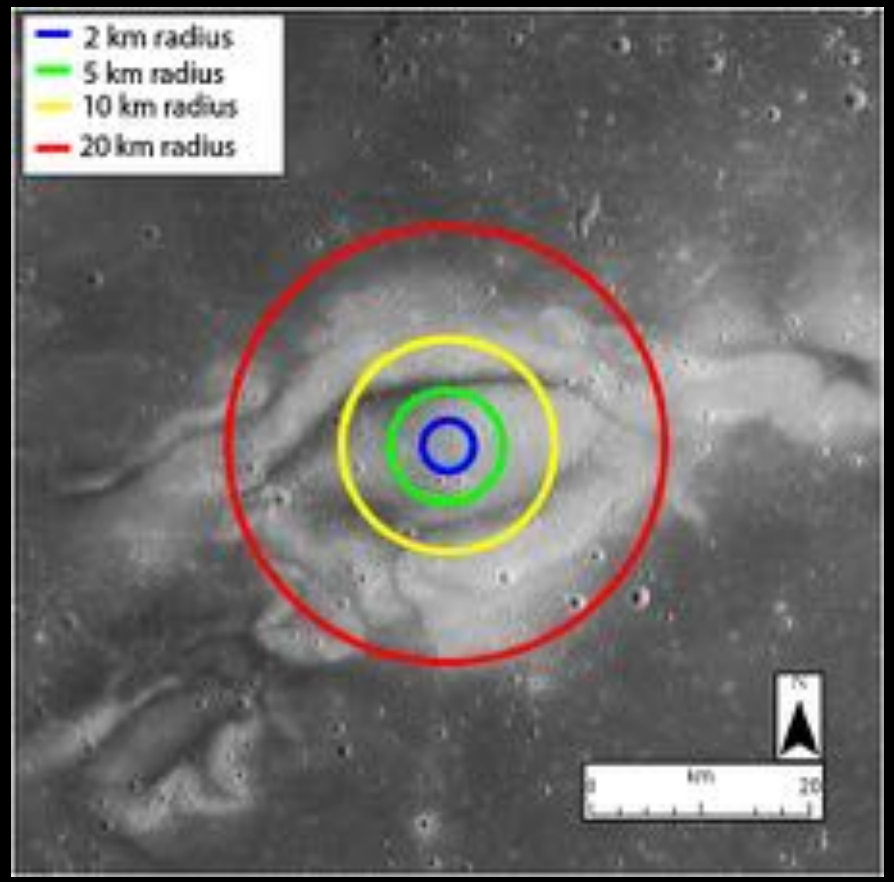
Soviet *Lunokhod* rover max distance was 37 km

Mars –
Curiosity, 17 km
Opportunity, 45 km



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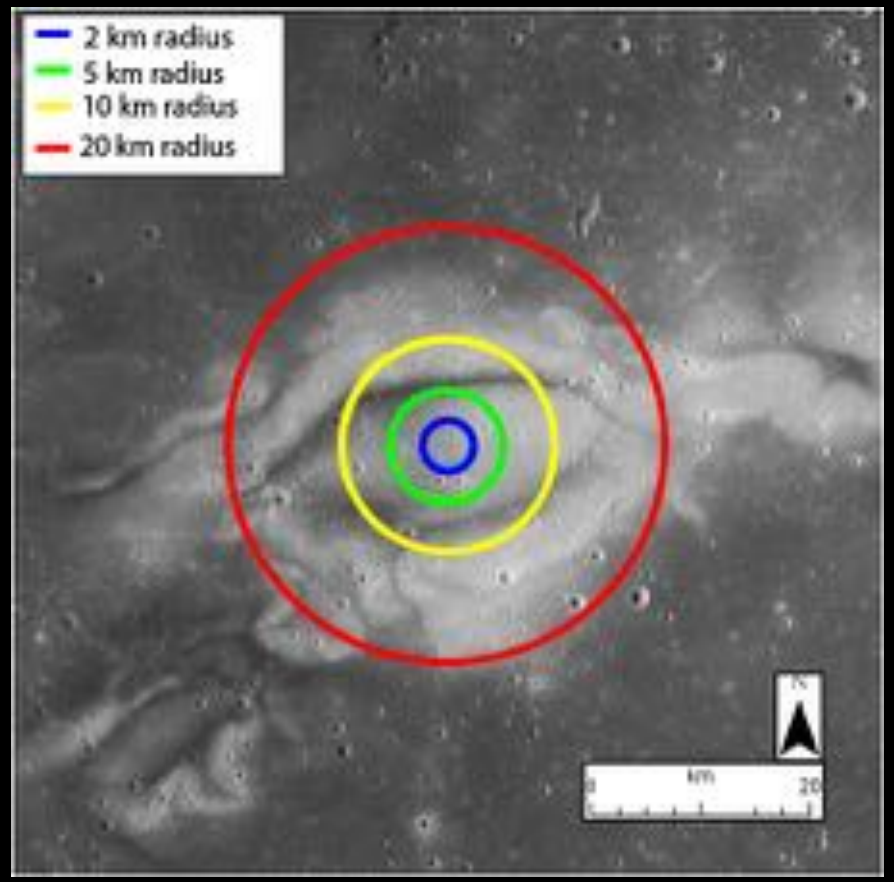

Reiner Gamma. LROC WAC basemap

At 1 cm/s, can cover 7 km in 8 days.

Potentially could do baseline mission in one lunar day.

A rover that could survive night would enable the rover to extend the linear traverse to areal coverage.

Magnetic Anomaly Rover: Instruments

- Particles and Fields
  - Solar-wind spectrometer (protons, alphas, electrons)
  - Vector Magnetometer
- Mast: Surroundings / Geology
  - Stereo camera
  - Vis-NIR spectrometer – mineralogy, OH-H_2O
- Arm instrument: Regolith
  - Multispectral micro-imager

Magnetic Anomaly Rover: Instruments

- Potential payload enhancements
  - XRF-XRD or APXS for elemental abundance
  - Mossbauer spectrometer to measure nanosize iron abundance
  - Scraper to make shallow trenches
  - Detector for slow-moving dust
  - Traverse gravimeter
  - Electric field probe
  - Laser retroreflector

Xiao et al. (2014 *Nature Geosci.*)

Chang'E-3 / Yutu rover image of boulders on rim of 450-m crater in Mare Imbrium.

Lunar Magnetic Anomaly Rover: Conclusions

- The special environment of the magnetic anomalies provides a natural laboratory for study of a wide variety of planetary processes.
- Mission will address key Decadal and SCEM questions in major sub-disciplines of planetary science including space plasma physics, geophysics, planetary geology.

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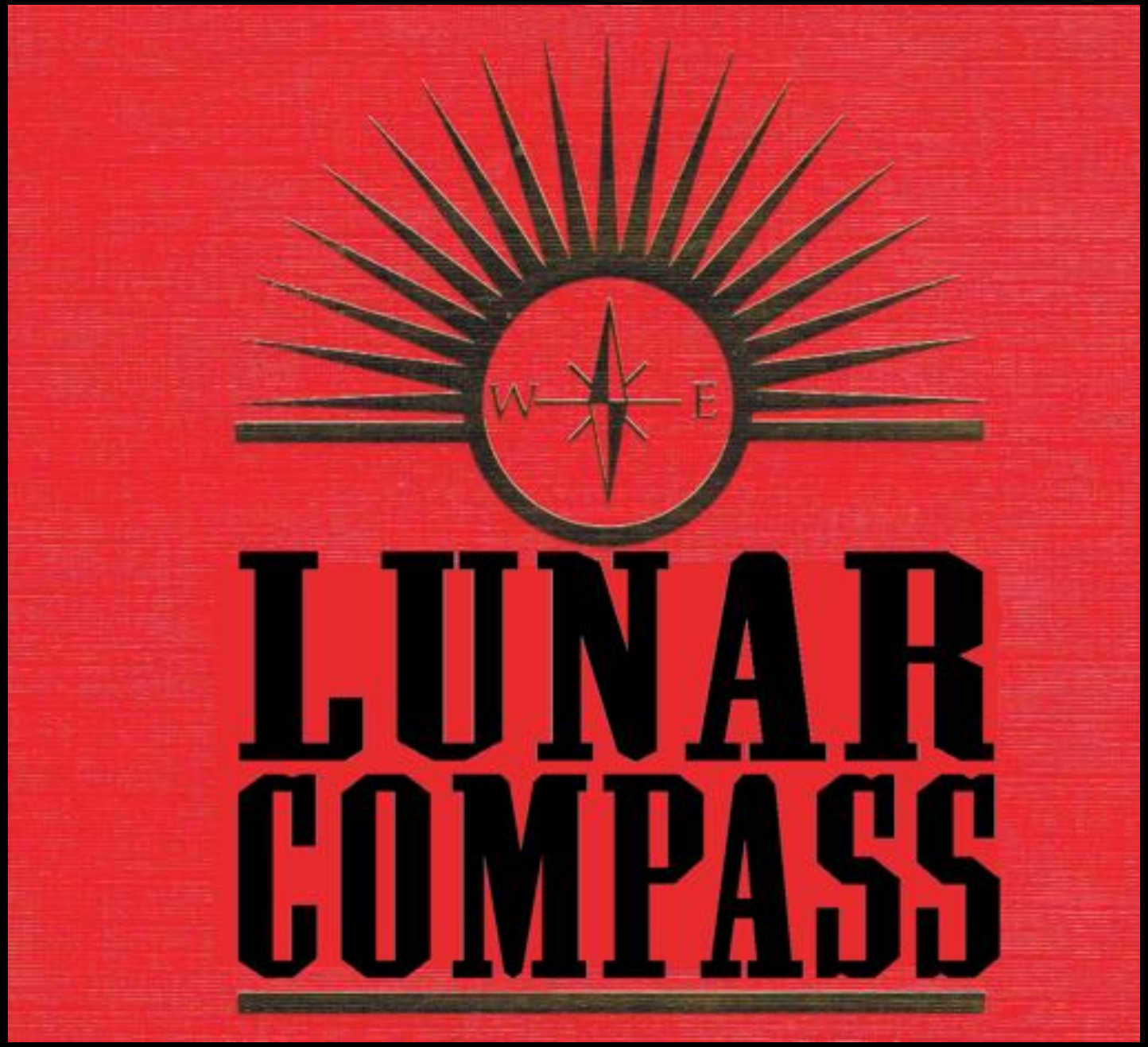
We plan to continue to develop the concept for the next Discovery round or other opportunities.

Looking for partnerships:

- Rover, arm
- Instruments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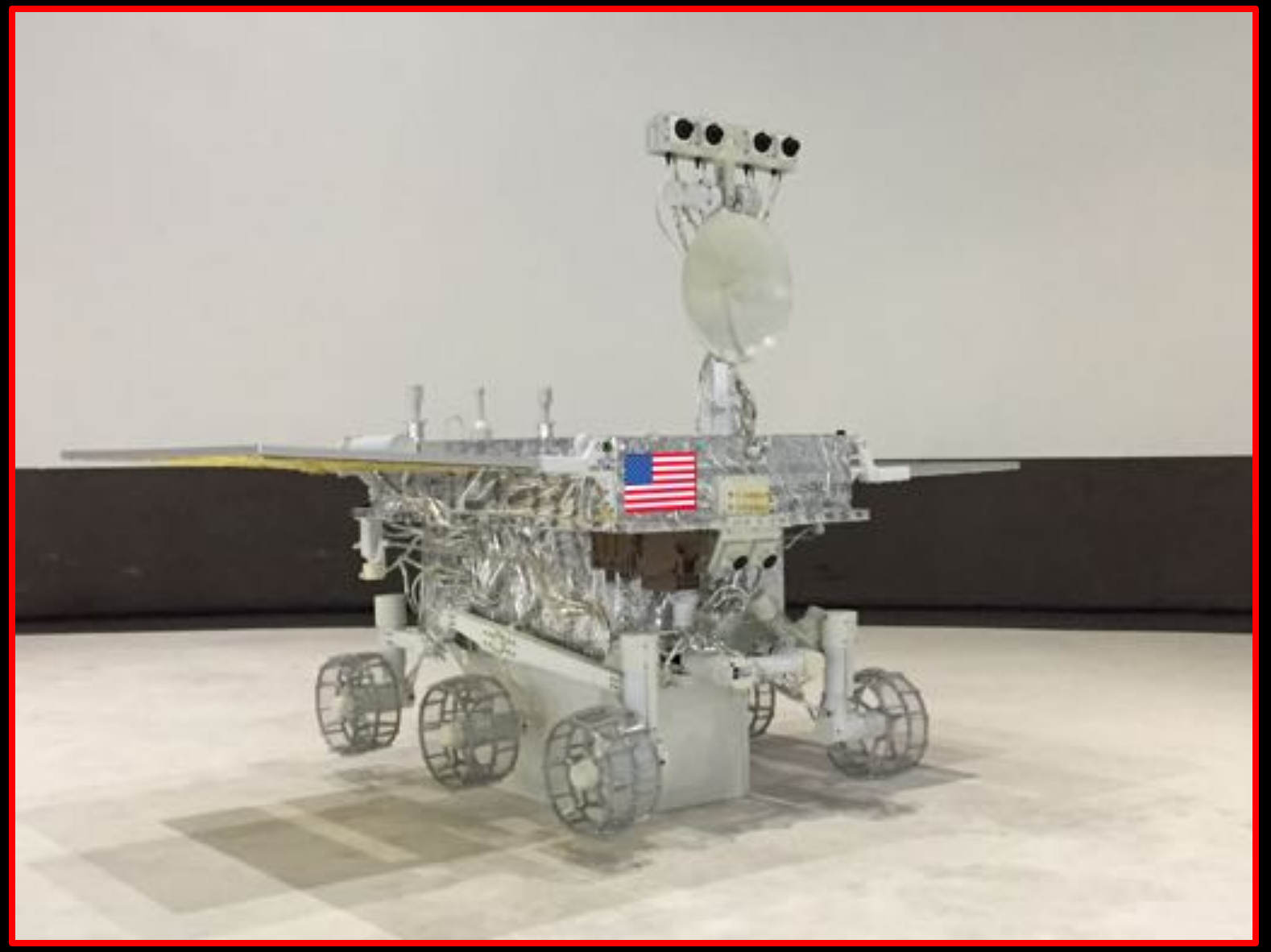
Rover: Engineering Model



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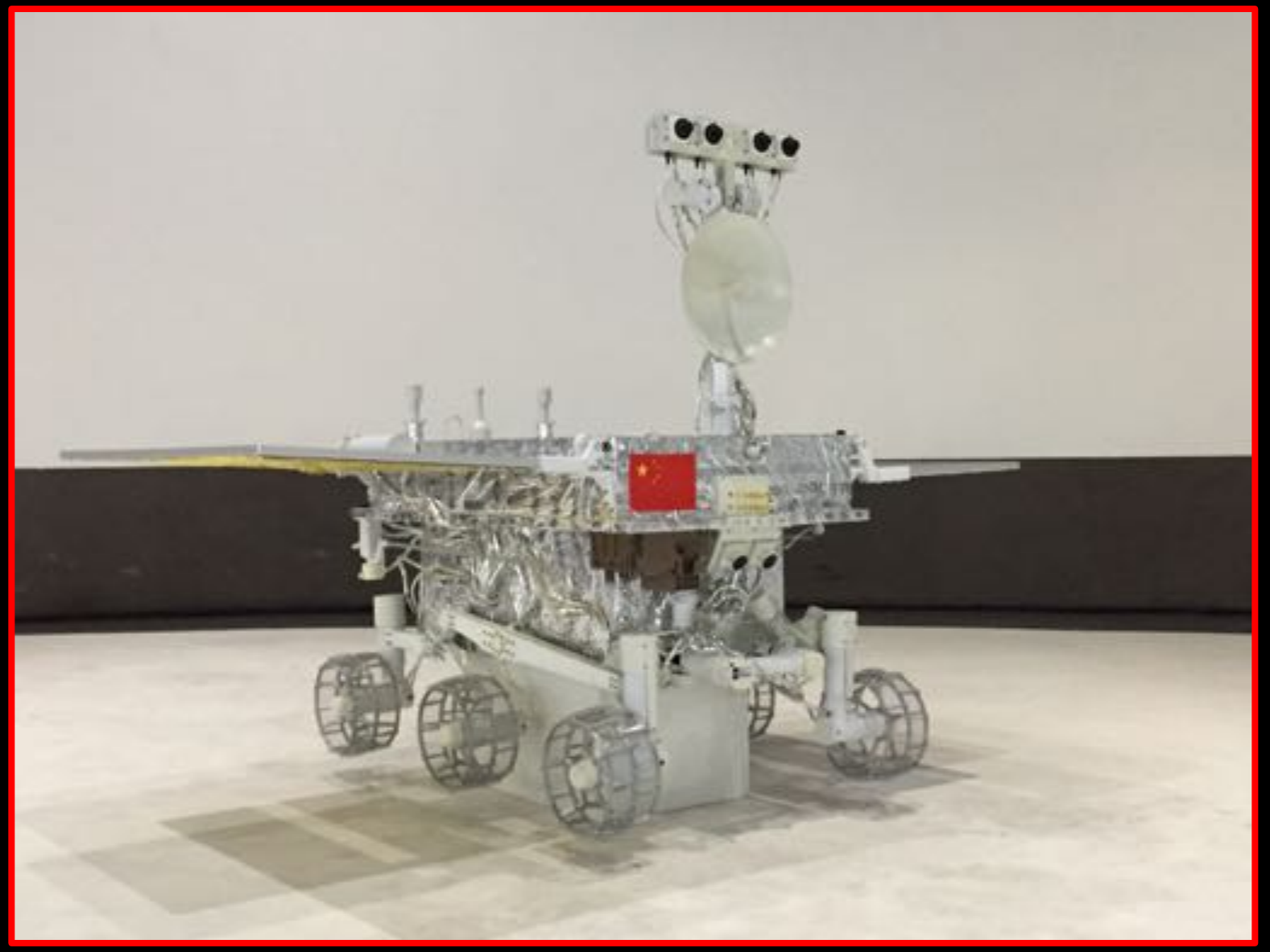

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