The *LUNAR COMPASS* Mission Concept: Rover Exploration of a Magnetic Anomaly

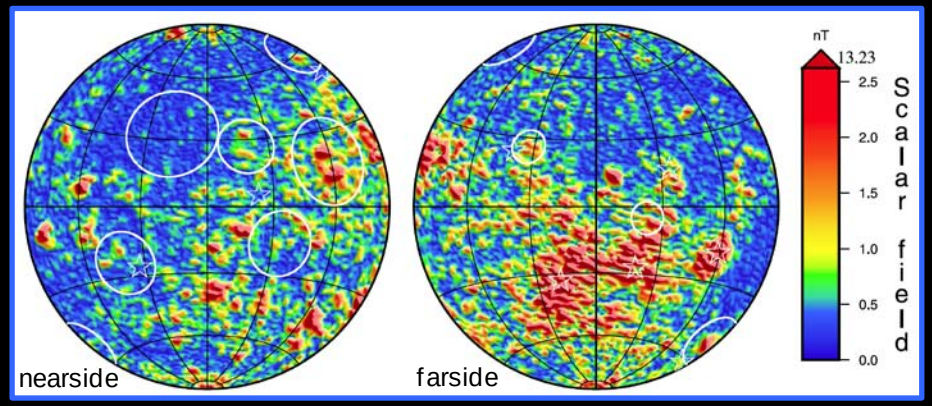
David T. Blewett, Dana M. Hurley, Brett W. Denevi,
Joshua T.S. Cahill, Rachel L. Klima, Jeffrey B. Plescia,
Christopher P. Paranicas, Benjamin T. Greenhagen,
Lauren Jozwiak, Brian A. Anderson, Haje Korth, George C. Ho,
Jorge I. Núñez, Michael I. Zimmerman, Pontus C. Brandt,
Sabine Stanley, Joseph H. Westlake, Edward W. Tunstel, and Jeffrey R. Johnson

Space Science Branch,
Johns Hopkins University Applied Physics Lab, USA

JOHNS HOPKINS
APPLIED PHYSICS LABORATORY

Lunar Magnetic Anomalies

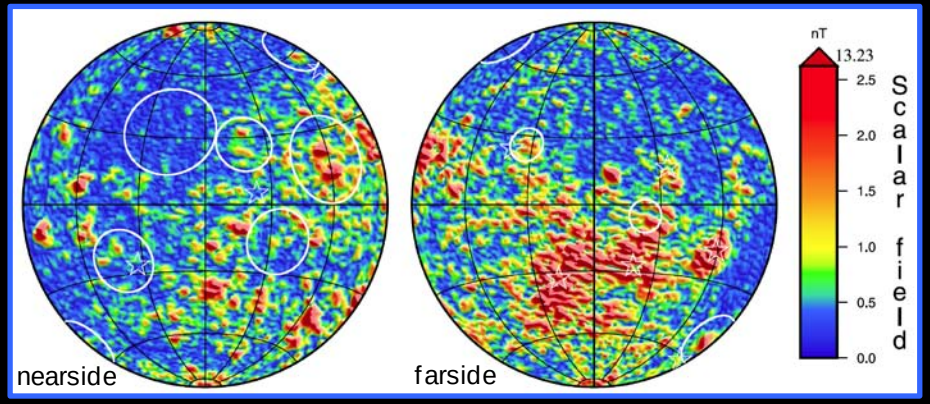
- The lunar crust contains magnetized areas, a few tens to several hundred kilometers across, known as "magnetic anomalies".
- The crustal fields are appreciable: Strongest anomalies are ~10-20 nT at 30 km altitude, perhaps a few hundred to 1000 nT at the surface.



Lunar Prospector magnetometer map
Purucker & Nicholas (2010 *Icarus*)

Lunar Magnetic Anomalies: Formation Hypotheses

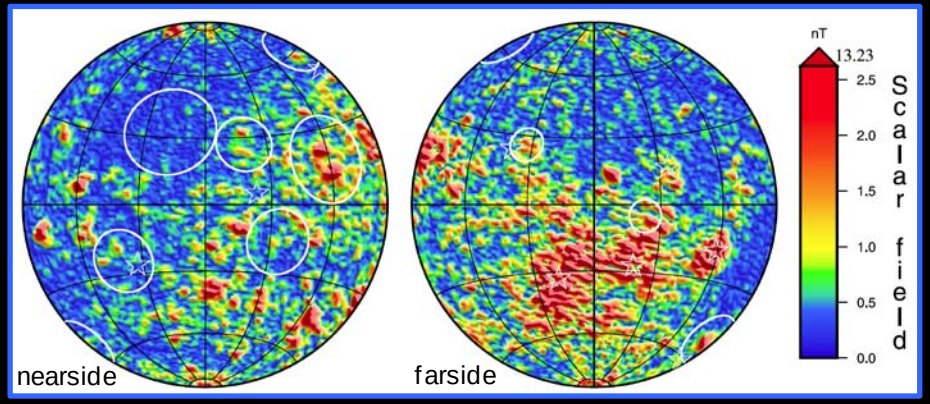
- Magnetized basin ejecta: ambient fields amplified by compression as impact-generated plasma converged on the basin antipode (Hood and co-workers)



Lunar Prospector magnetometer map
Purucker & Nicholas (2010 *Icarus*)

Lunar Magnetic Anomalies: Formation Hypotheses

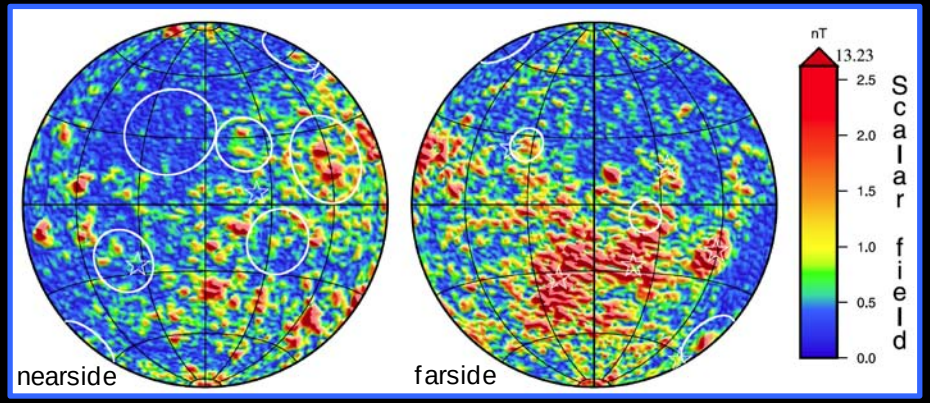
- Magnetized basin ejecta: ambient fields amplified by compression as impact-generated plasma converged on the basin antipode (Hood and co-workers)
- Magnetic field impressed on the surface by plasma interactions when a cometary coma struck the Moon (Schultz)



Lunar Prospector magnetometer map
Purucker & Nicholas (2010 *Icarus*)

Lunar Magnetic Anomalies: Formation Hypotheses

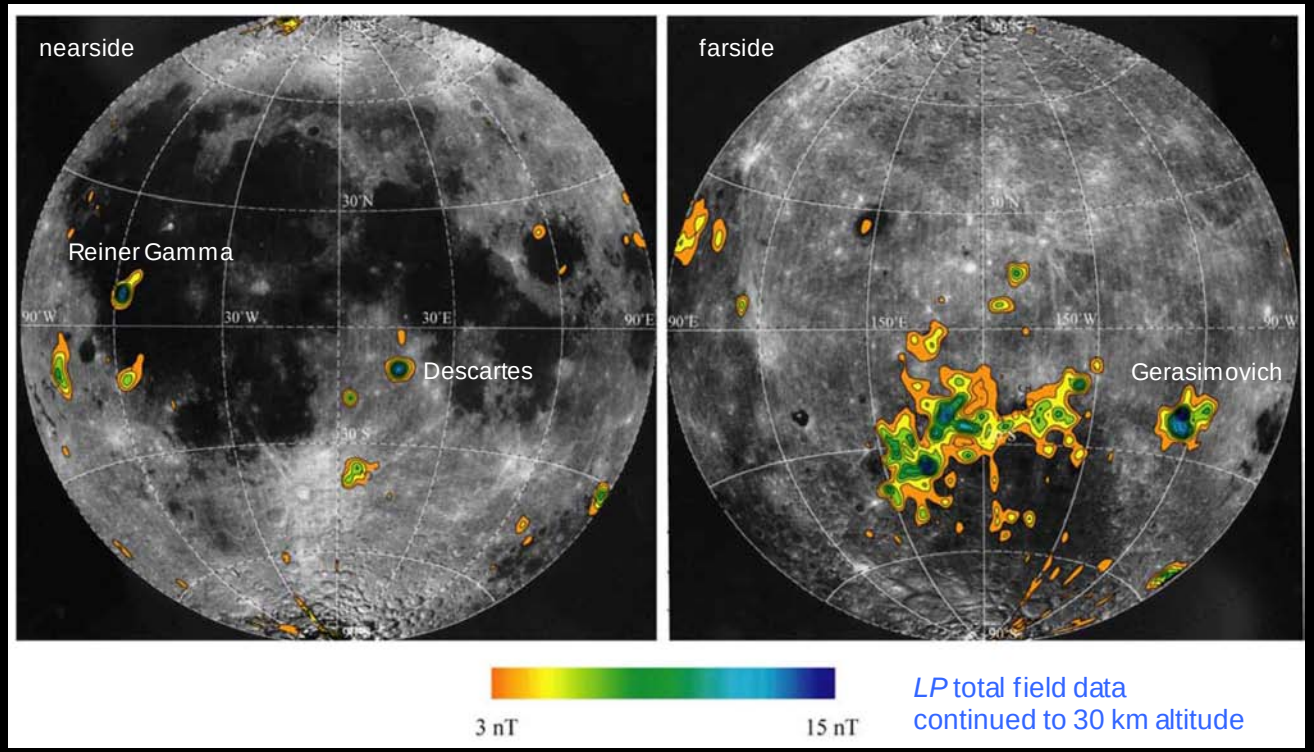
- Magnetized basin ejecta: ambient fields amplified by compression as impact-generated plasma converged on the basin antipode (Hood and co-workers)
- Magnetic field impressed on the surface by plasma interactions when a cometary coma struck the Moon (Schultz)
- Magmatic intrusion or impact melt magnetized in an early lunar dynamo field (e.g., Purucker et al. 2012; Hood, 2011)



Lunar Prospector magnetometer map
Purucker & Nicholas (2010 *Icarus*)

Lunar Prospector total field map

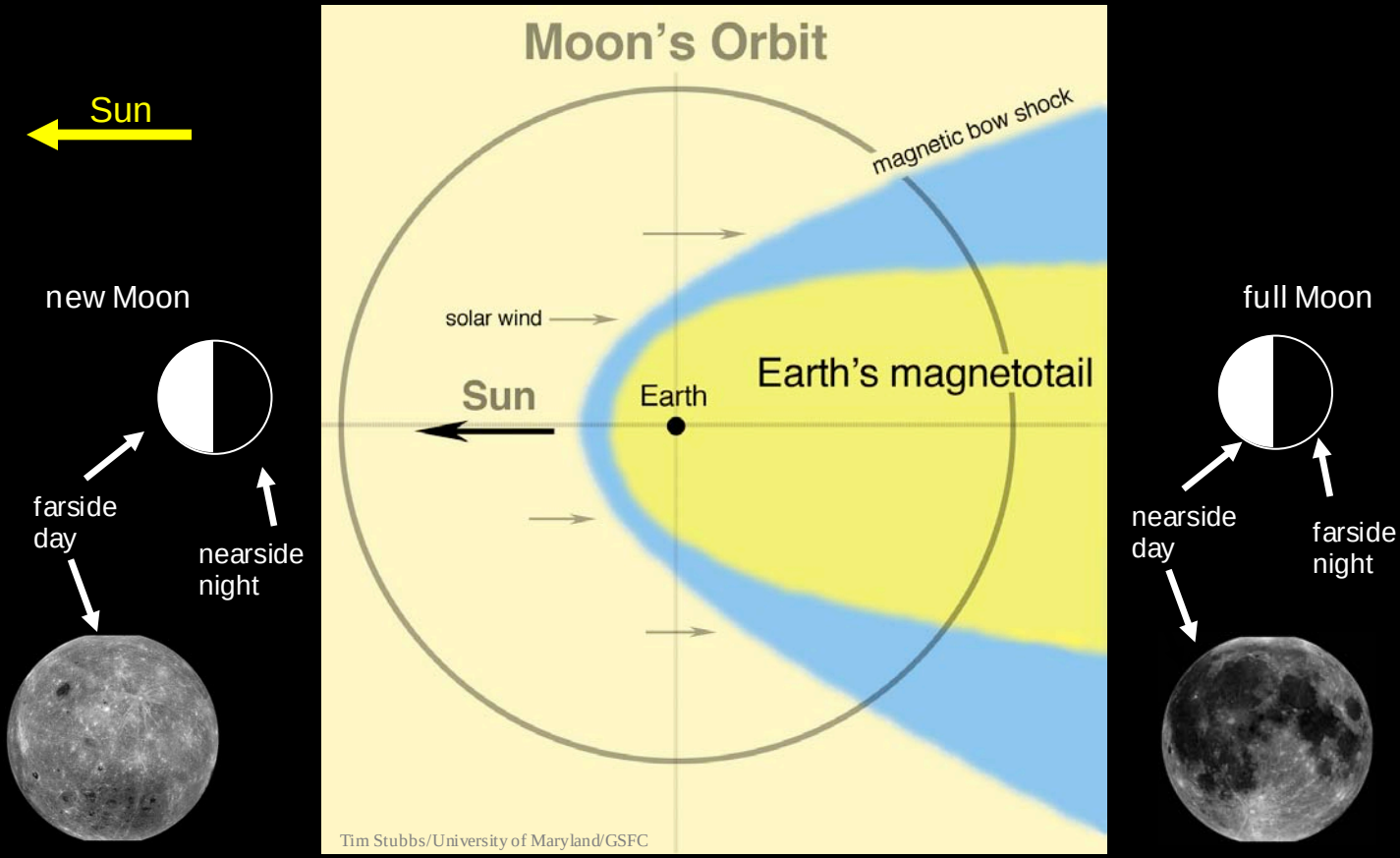
Strongest anomalies are ~20 nT at 30 km, perhaps 100s-1000 nT at surface.



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

Richmond and Hood (2008) *JGR*

Varying Plasma Environment



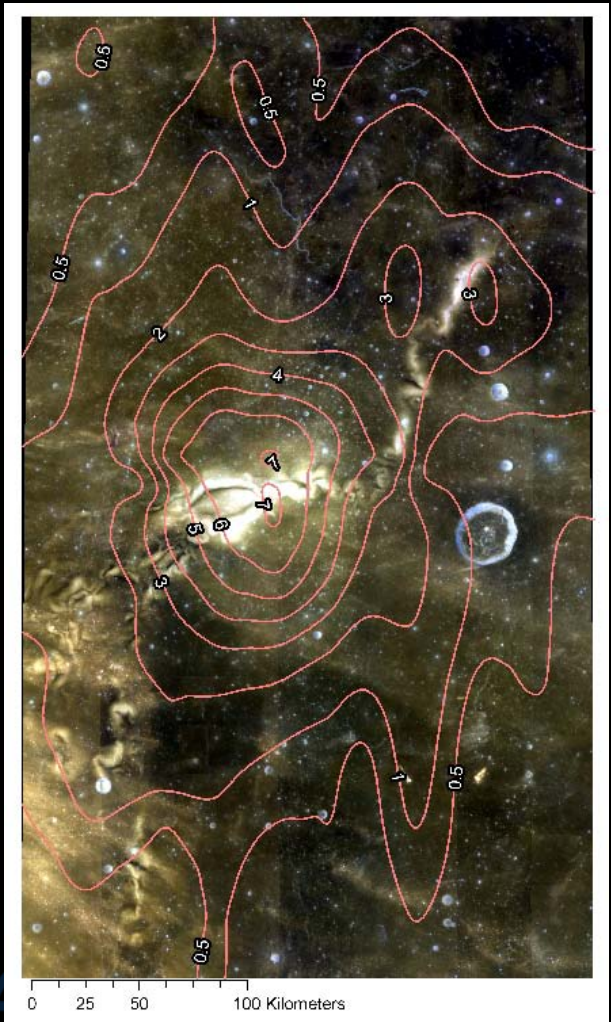
Effect on Solar Wind Flow

- 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 poorly known.

Lunar Swirls

Reiner Gamma



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

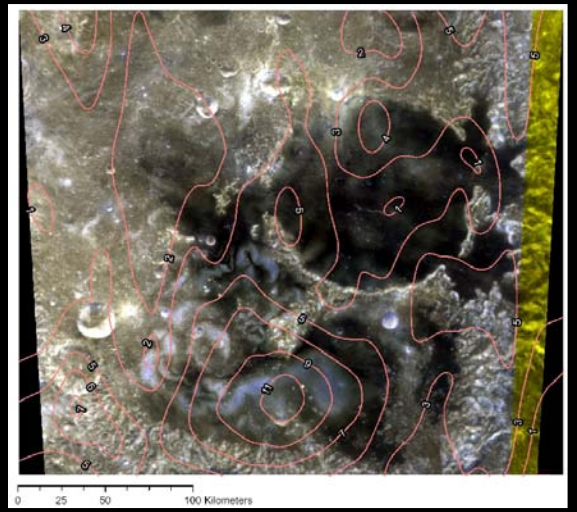
Clementine pseudo true color composite, with contours of *LP* total field strength at 35.5 km altitude. Blewett et al. (2007) *GRL*

Hypotheses for the Origin of Swirls

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

Magnetic Anomalies as Natural Laboratories

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



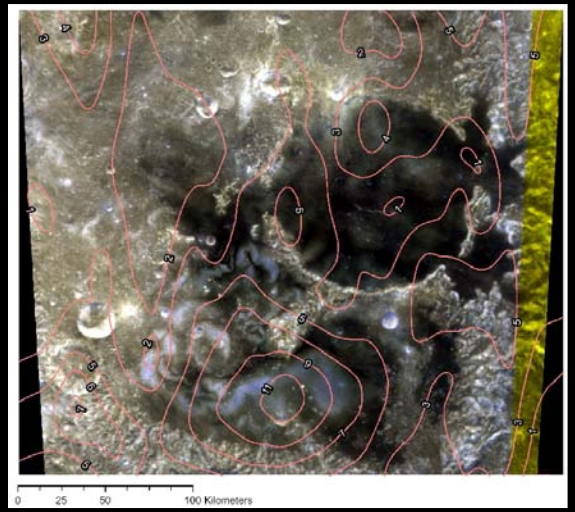
Mare Ingenii (Imbrium antipode) magnetic anomaly and swirls.

Lunar Prospector total field strength contours at 35.5 km altitude on *Clementine* color mosaic.

Magnetic Anomalies as Natural Laboratories

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

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



Mare Ingenii (Imbrium antipode) magnetic anomaly and swirls.

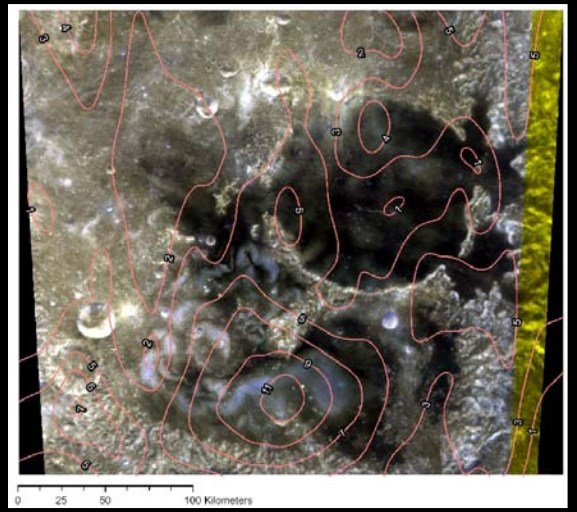
Lunar Prospector total field strength contours at 35.5 km altitude on *Clementine* color mosaic.

Magnetic Anomalies as Natural Laboratories

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

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

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

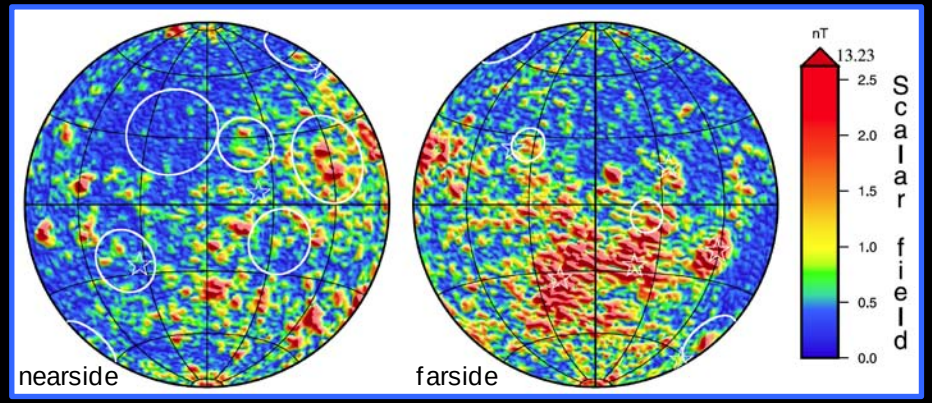


Mare Ingenii (Imbrium antipode) magnetic anomaly and swirls.

Lunar Prospector total field strength contours at 35.5 km altitude on *Clementine* color mosaic.

Lunar Magnetic Anomalies

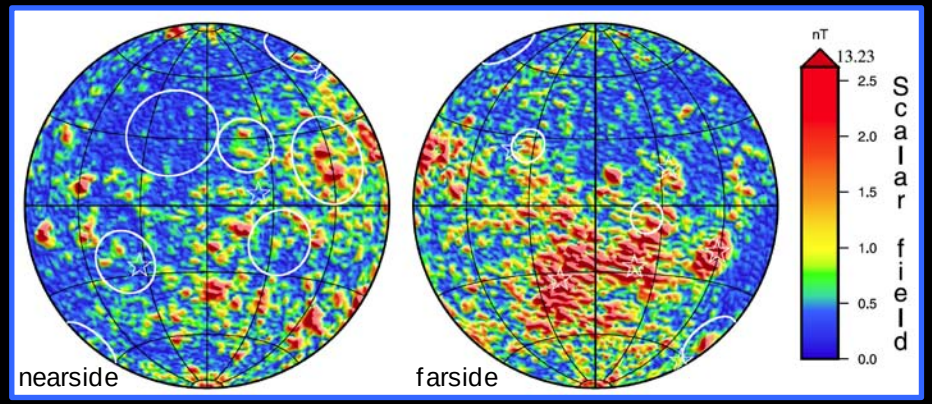
- Unique opportunities that touch on a broad range of key problems in planetary science –
  - Geophysics: the nature and origin of the magnetized crust (ancient dynamo, magmatic intrusion, magnetized basin ejecta, comet impact)



Lunar Prospector magnetometer map
Purucker & Nicholas (2010 *Icarus*)

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)
  - Space Plasma Physics: formation of mini-magnetospheres/standoff region, fluxes by energy/species that reach the surface, changes with time of lunar day

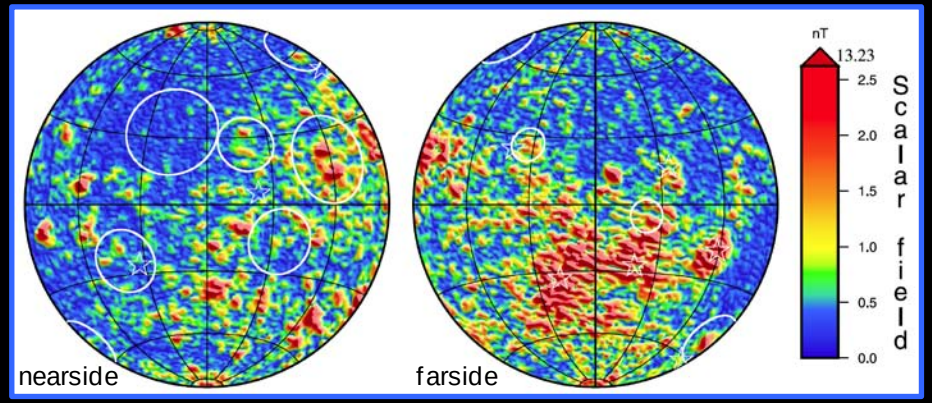


Lunar Prospector magnetometer map
Purucker & Nicholas (2010 *Icarus*)

D. Blewett et al.: lunar magnetic anomaly rover

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)
  - 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



Lunar Prospector magnetometer map
Purucker & Nicholas (2010 *Icarus*)

Lunar Magnetic Anomalies

- Address human exploration Strategic Knowledge Gaps (SKG)
  - 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

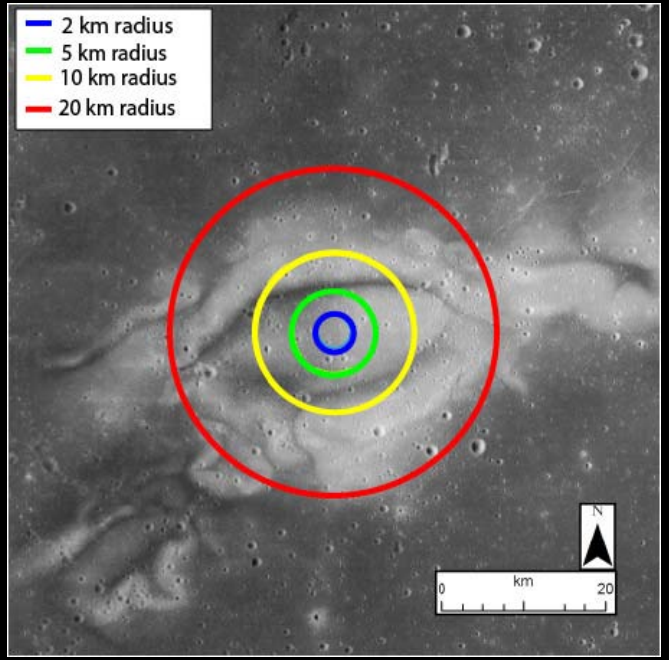
Rover mission: *Lunar Compass*

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

Reiner Gamma. LROC WAC basemap

Rover mission: *Lunar Compass*

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



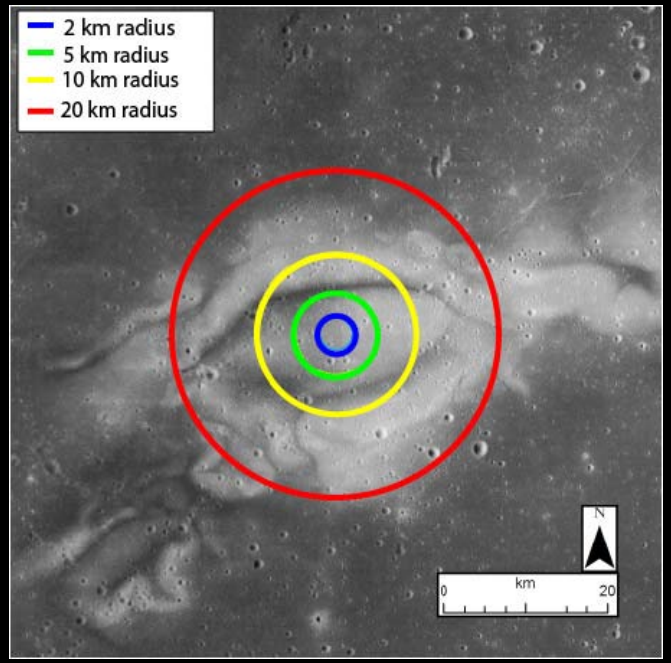
Reiner Gamma. LROC WAC basemap

Rover mission: *Lunar Compass*

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

Soviet *Lunokhod* rover max distance was 37 km

Mars –
Curiosity, 17 km
Opportunity, 45 km



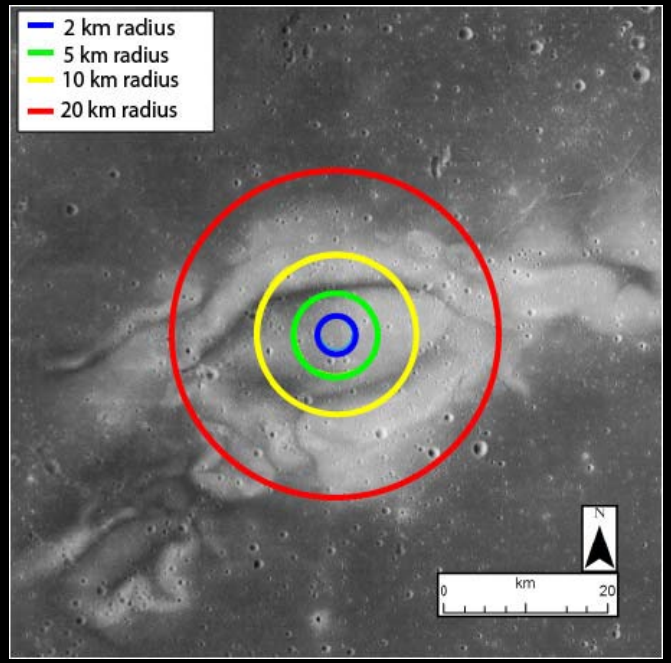
Reiner Gamma. LROC WAC basemap

Rover mission: *Lunar Compass*

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

Soviet *Lunokhod* rover max distance was 37 km

Mars –
Curiosity, 17 km
Opportunity, 45 km



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

Potentially could do baseline mission in one lunar day.

Reiner Gamma. LROC WAC basemap

Rover Instruments

- Particles and Fields
  - Solar-wind spectrometer (protons, alphas, electrons)
  - Vector Magnetometer
- Mast: Surroundings / Geology
  - Stereo multispectral camera
  - Vis-NIR spot spectrometer – mineralogy, OH-H_2O
- Arm instrument: Regolith
  - Multispectral microimager (AMIM - Núñez et al.)

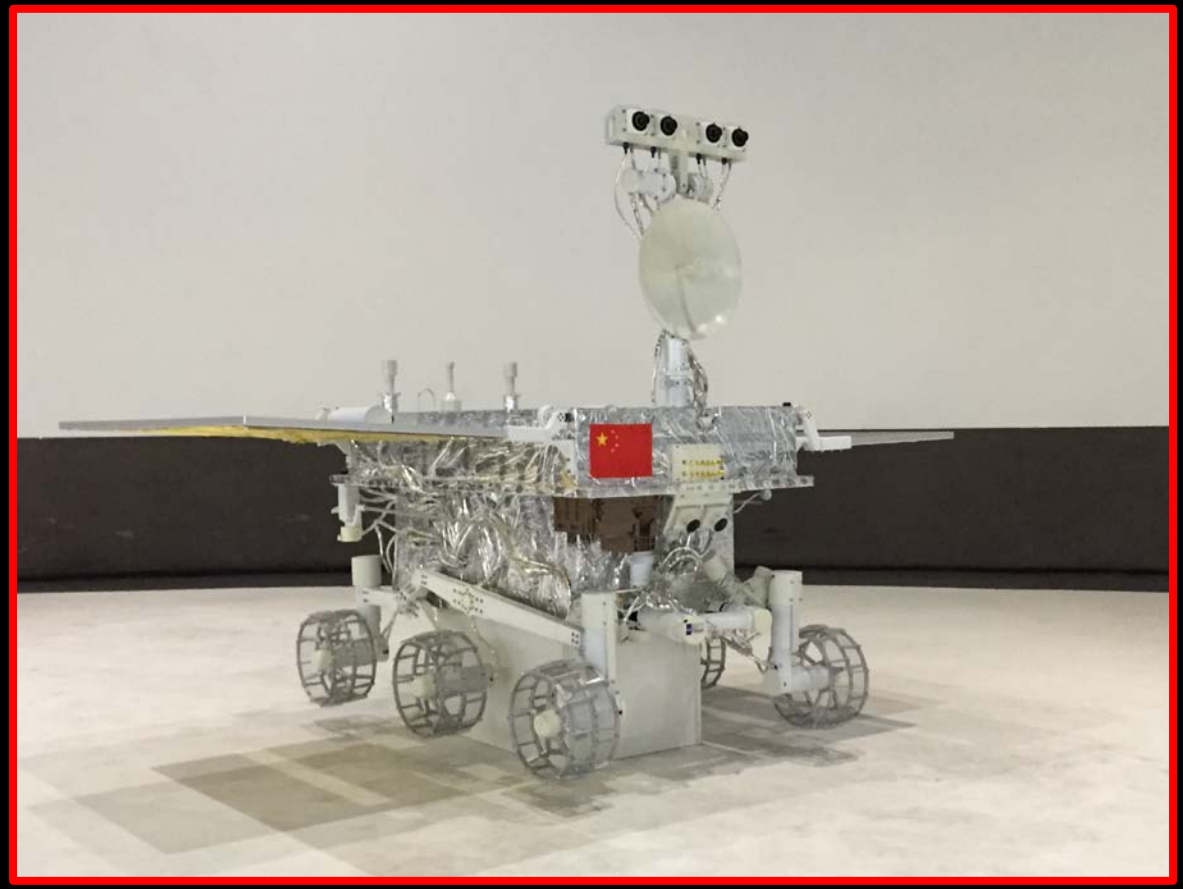
Rover Instruments

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

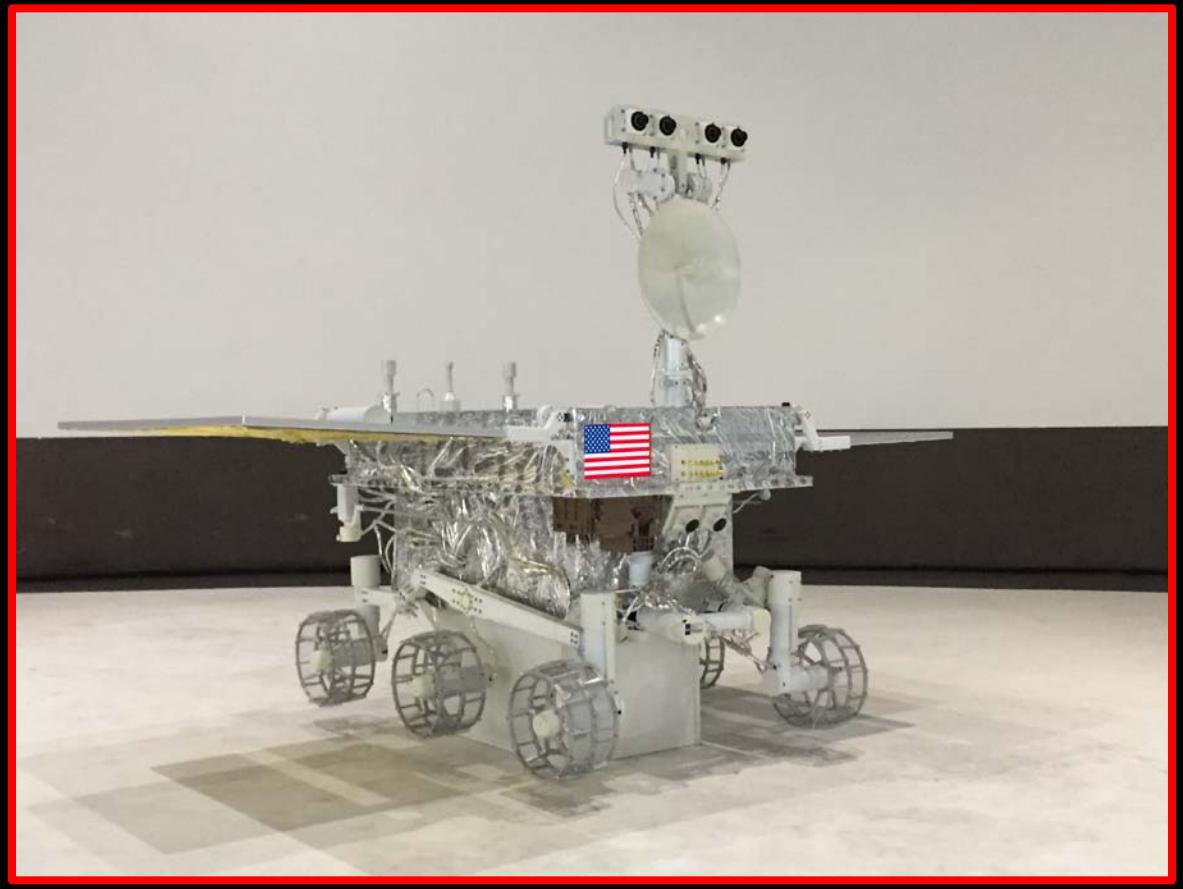
Xiao et al. (2014 *Nature Geosci.*)

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

Rover: Engineering Model



Rover: Engineering Model



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 generate interest and support from major sub-disciplines of planetary science including space plasma physics, geophysics, planetary geology.

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 generate interest and support from major sub-disciplines of planetary science including space plasma physics, geophysics, planetary geology.
- Contribute to closing human exploration SKGs.

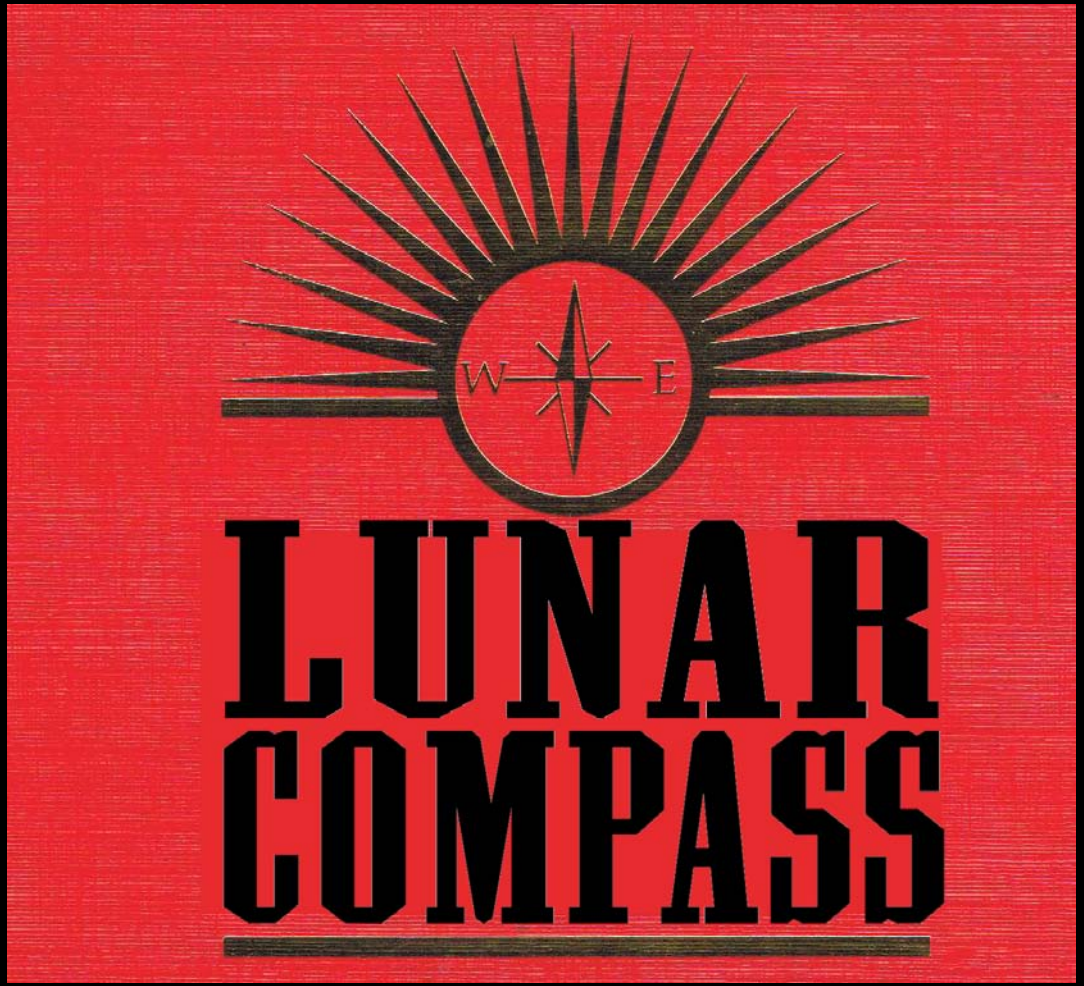
Lunar Magnetic Anomaly Rover: Conclusions

- The special environment of the magnetic anomalies provides a natural laboratory for study of a wide variety of planetary processes.
- Mission will generate interest and support from major sub-disciplines of planetary science including space plasma physics, geophysics, planetary geology.
- Contribute to closing human exploration SKGs.

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

Looking for partnerships:

- Rover, arm
- Instruments


W
E
LUNAR
COMPASS