Moon Mineralogy Mapper:
Return to the Moon by way of India

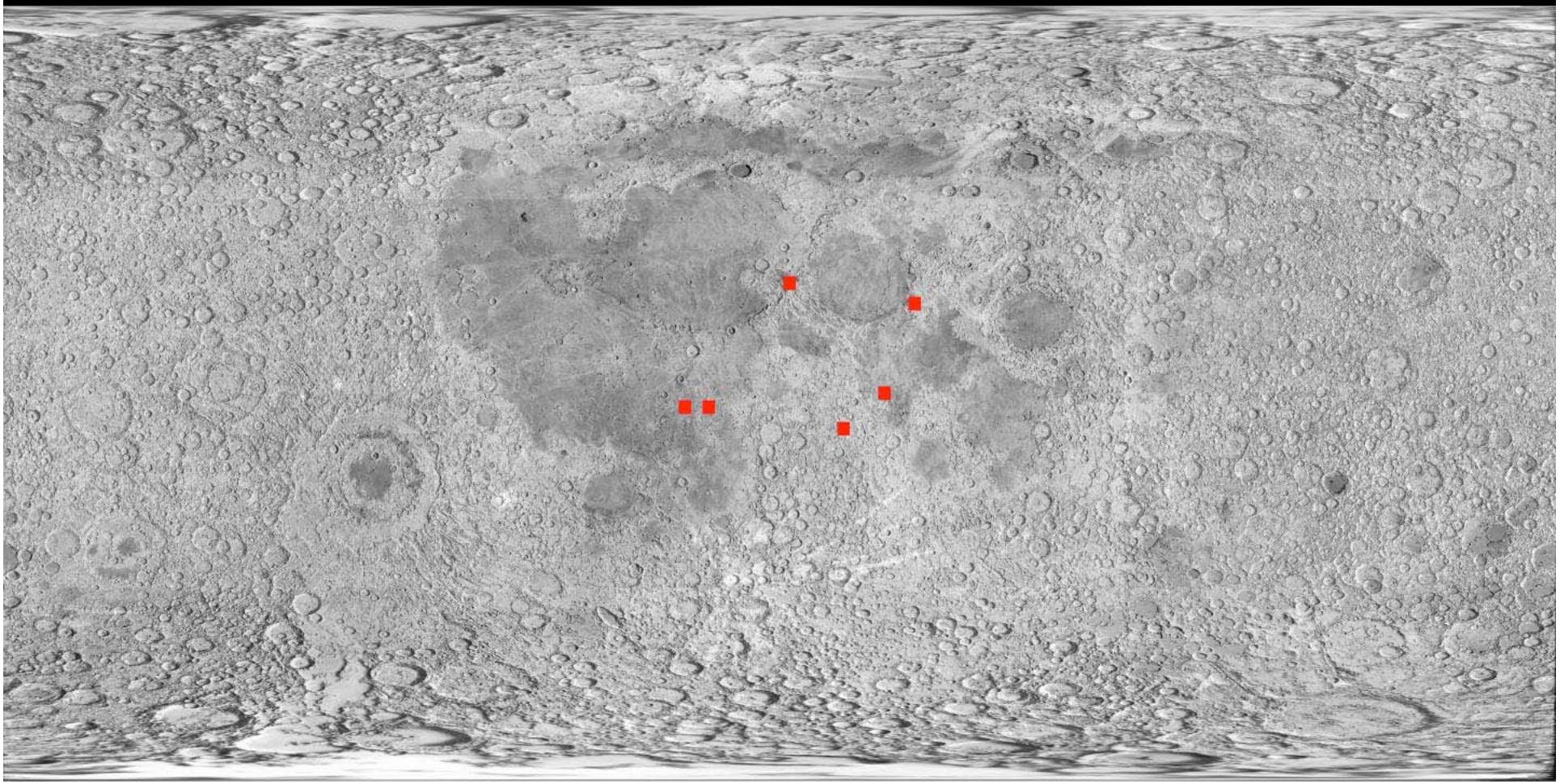
[M^3 or “M-cube”]

Carle Pieters, Principal Investigator

Brown University

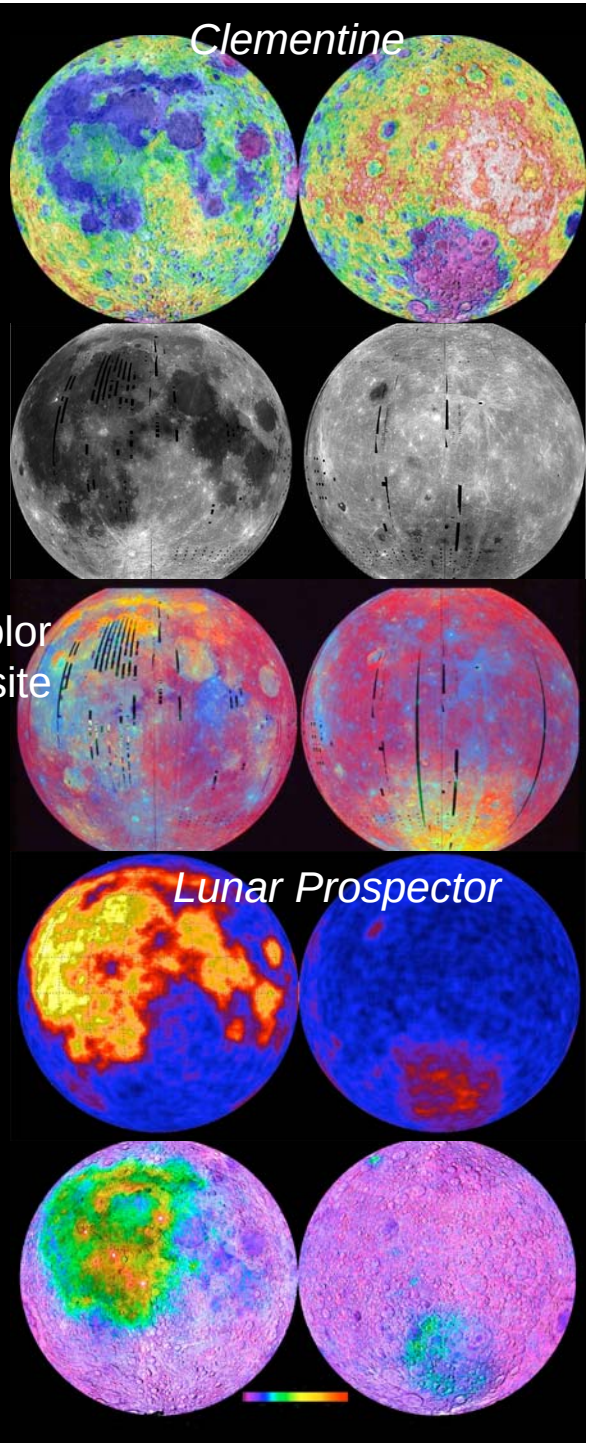
Apollo Exploration 1969 - 1972

- Landing sites are equatorial areas on the lunar near-side.



Paradigm Shifts
from two small missions 1994 &1998

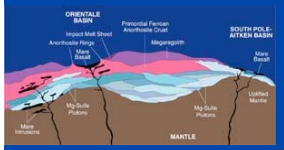
- The enormous South-Pole Aitken basin dominates the feldspathic farside of the Moon.
  - Largest and oldest lunar basin
  - Minor basalt fill
  - Iron-rich interior (lower crust/mantle)
- Heat producing elements were concentrated on the lunar nearside (Apollo sites) early in lunar history.
- The poles are unusual environments and may accumulate volatiles.

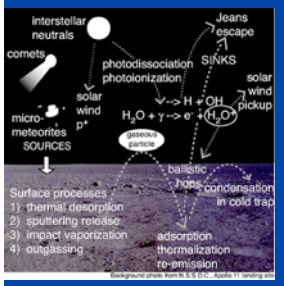


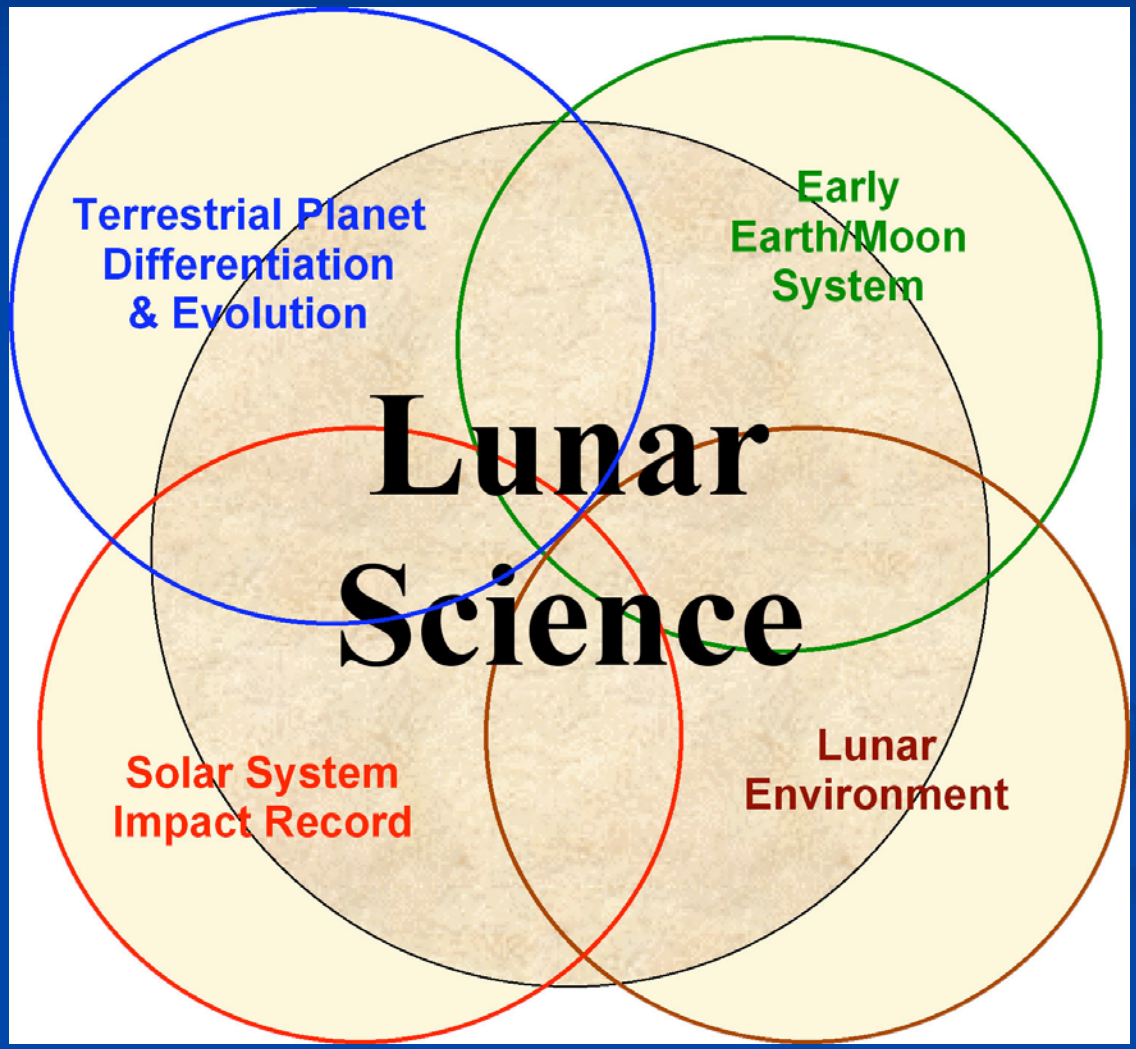
Overarching Science Themes

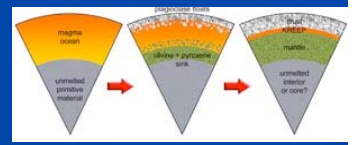
See NRC/NAS 2007 Report:

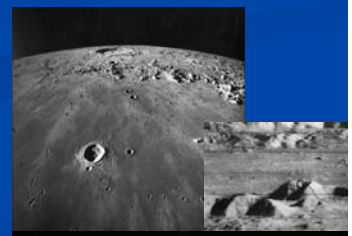
http://books.nap.edu/catalog.php?record_id=11954





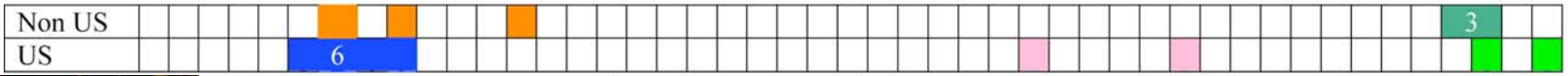


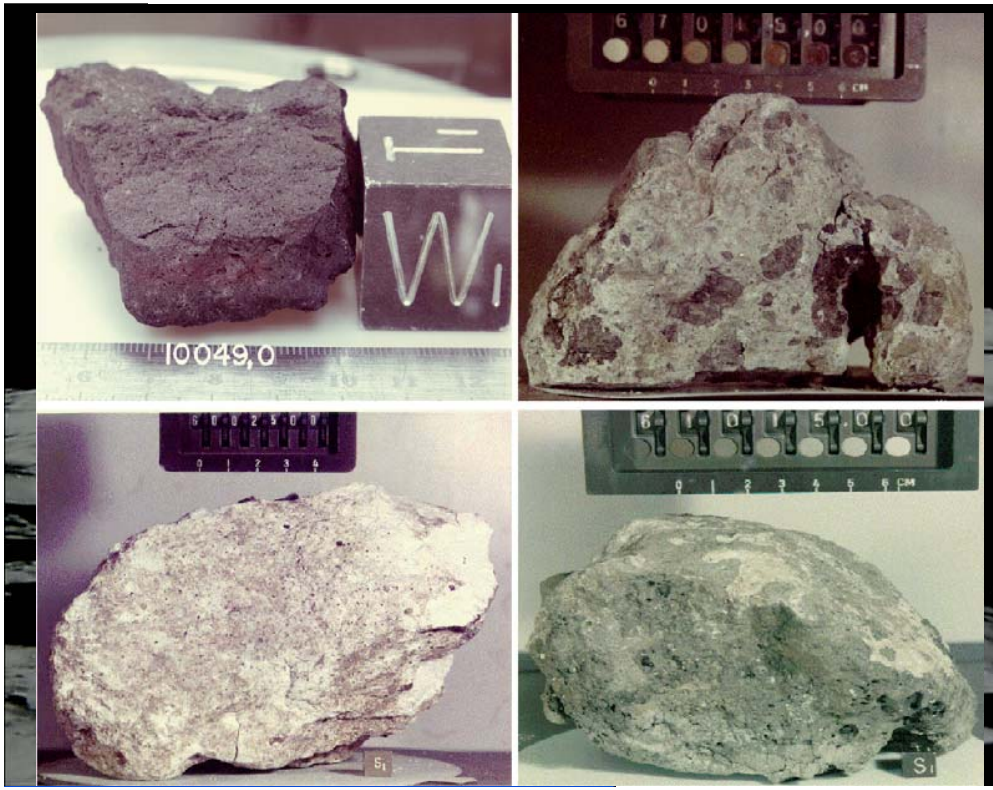




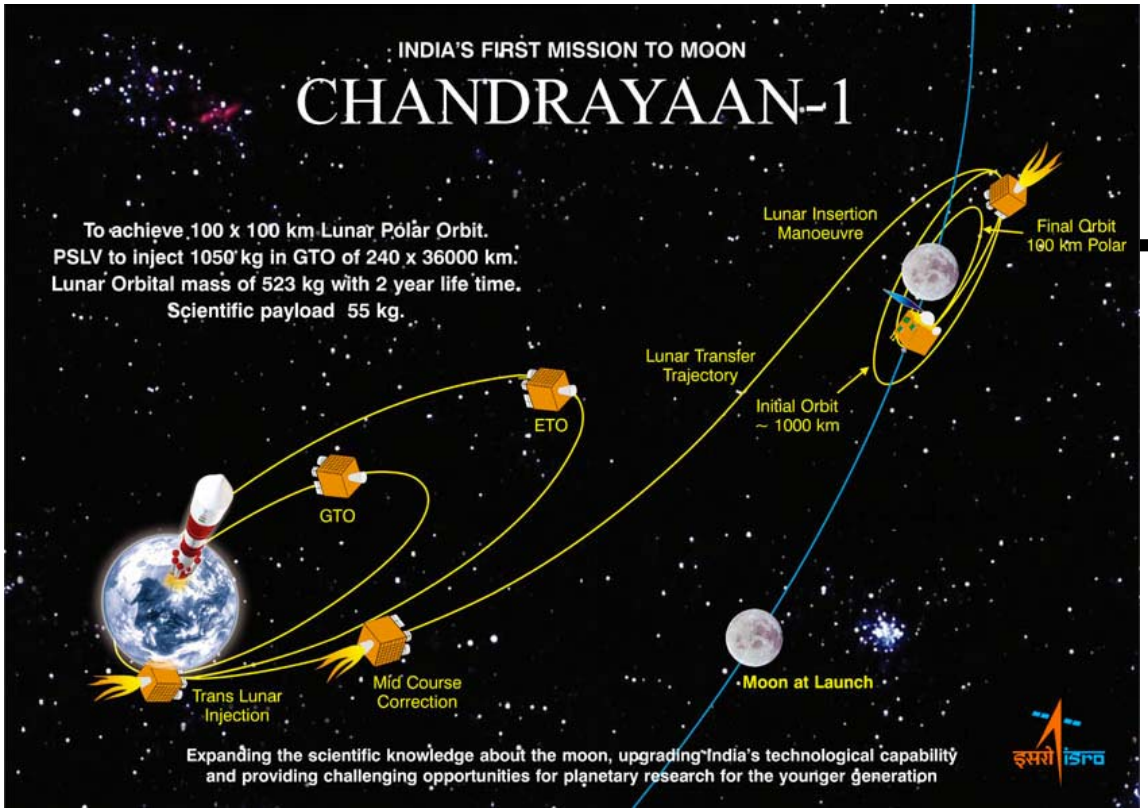
Lunar Exploration Timeline: Return after a long Drought

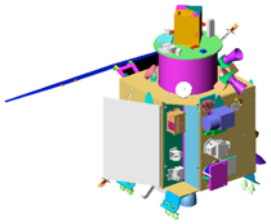
Sputnik
1957





- The Apollo/Luna samples brought new and fundamental understanding of planetary evolution (and the Earth-Moon system).
- After decades of neglect, two very small missions were sent to the Moon. The small pulse of new data sparked several paradigm shifts.
- A fleet of sophisticated modern sensors are now *at last* exploring the Moon.





M3: A Guest Instrument on Chandrayaan-1, ISRO's first mission to the Moon

ISRO: Indian Space Research Organization

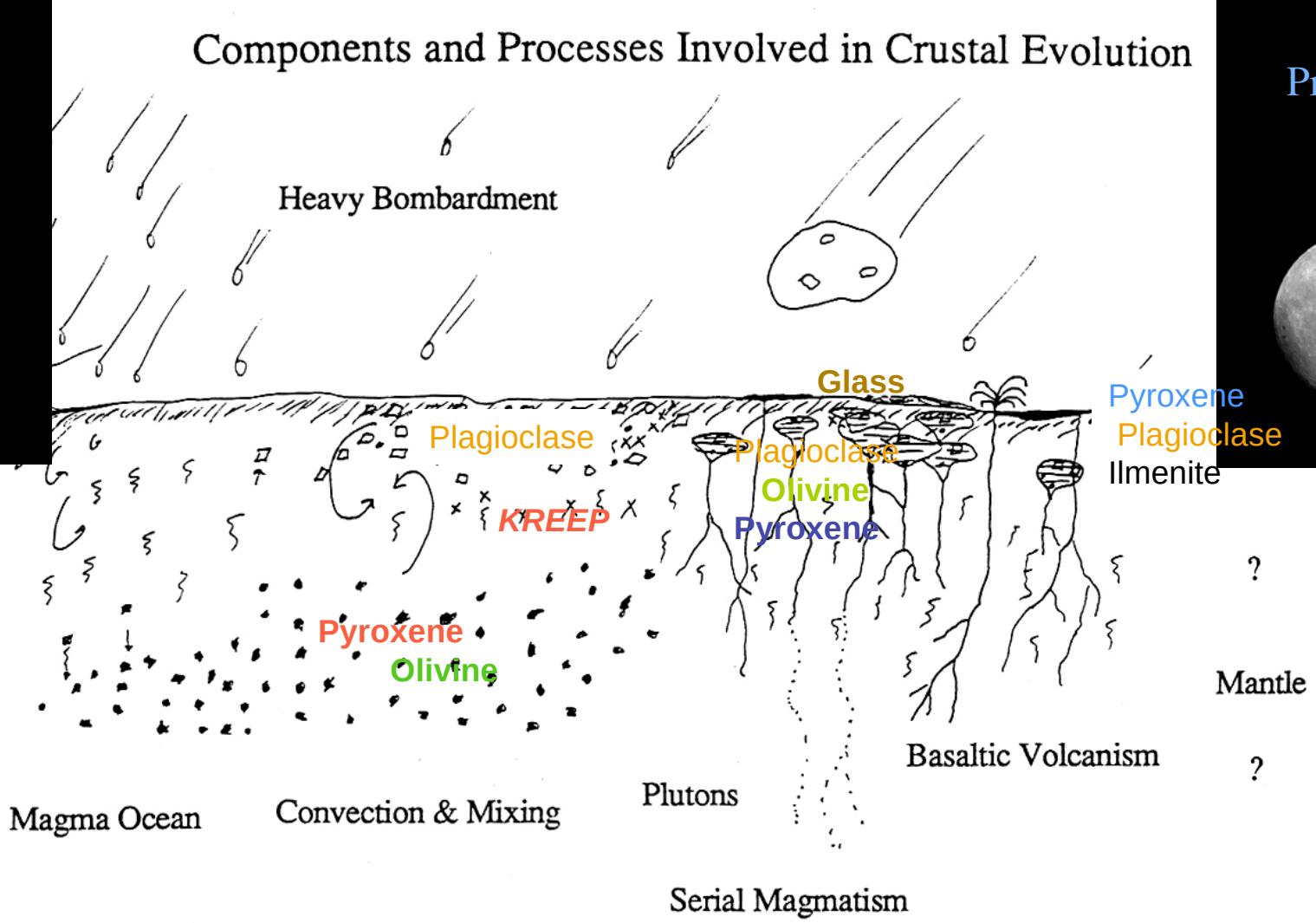
- What: Near-infrared imaging spectrometer to measure and map the mineral composition of the Moon at high resolution
- Why: Valuable science data to understand the evolution of the Moon.
- Selection: Summer 2004 selected by ISRO for foreign payload "short list"; Feb. 2005 selected for funding by NASA as a Discovery Mission of Opportunity after an extensive peer-review process; Confirmation 2/2006
- When: Deliver 2007, Launch middle 2008. Two-year operations at Moon

Lunar **Mineralogy** Reflects Early Geologic Evolution

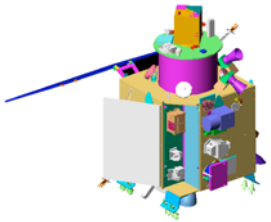
Keystone to the Terrestrial Planets

4.5 Gyr ago

Present



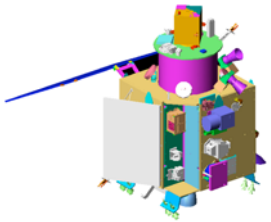
M3 Objectives



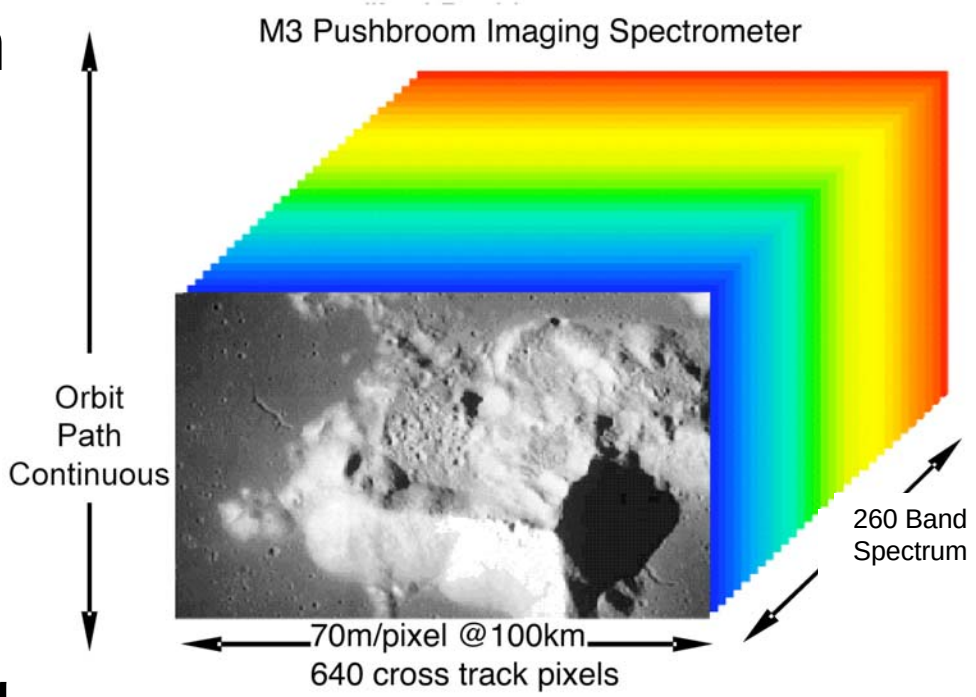
- Primary **Science** Goal: Characterize and map the lunar surface composition in the context of its geologic evolution. This translates into several science sub-topics to be addressed.

- Primary **Exploration** Goal: Assess and map the Moon mineral resources at high spatial resolution to support planning for future, targeted missions.

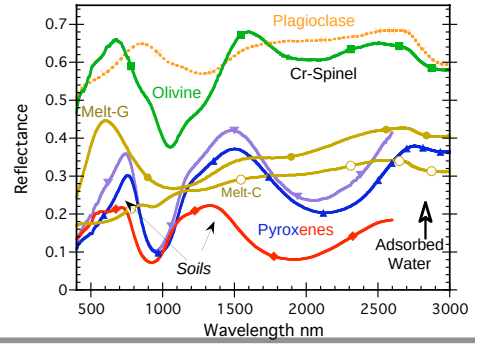
Moon Mineralogy Mapper (M3)



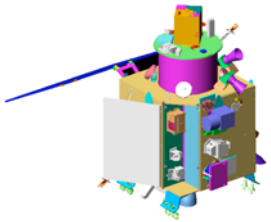
- Chandrayaan-1 launches in mid 2008 on an Indian spacecraft
  - 100 km circular polar Orbit
  - Two year mission duration
- M3 is a NASA Discovery "Mission of Opportunity"
  - Team led by PI: C. Pieters
  - Designed and built at JPL
- M3 is a pushbroom imaging spectrometer
  - Two spatial dimensions
  - One spectral dimension



M3 covers the spectral range where diagnostic features occur for all common rock-forming minerals **and** hydrous phases [0.43 to 3.0 μm].

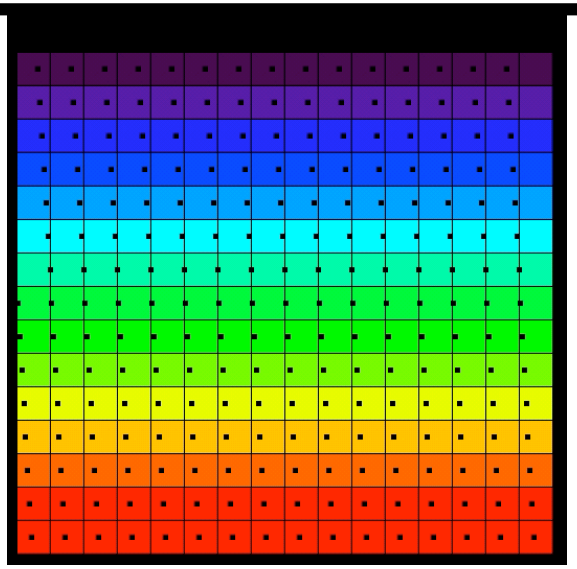


Unique Characteristics of M3 Spectrometer



M3 design provides spectral and spatial Uniformity:

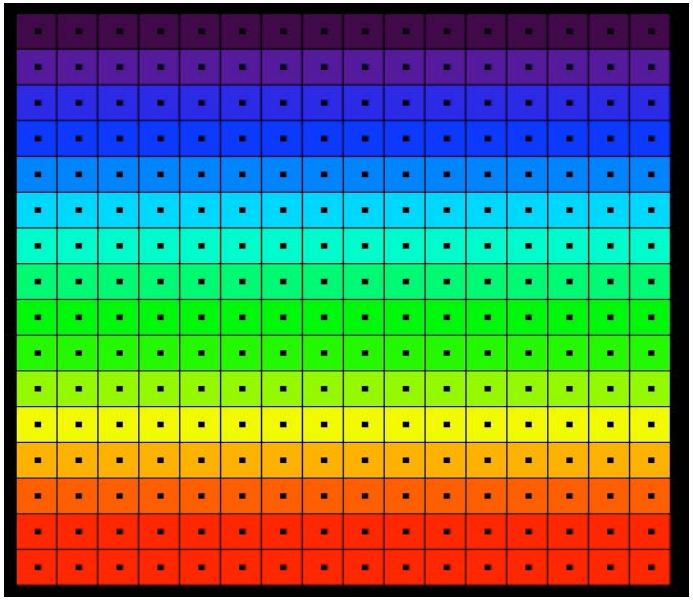
- <10% of a pixel across and along detector FOV.



IFOV Spatial Error along spectrum

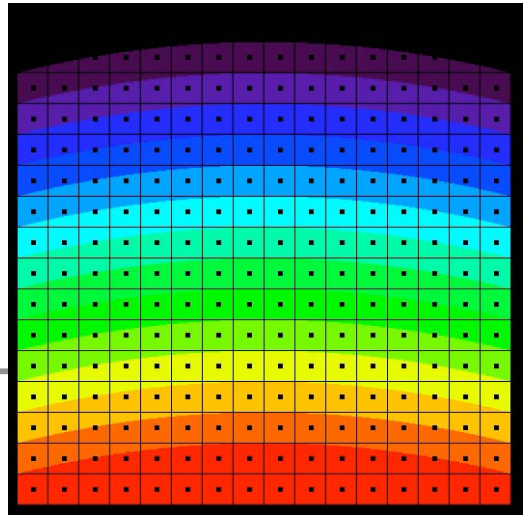
Common ***Problem*** Modes of other spectrometers

Wavelength

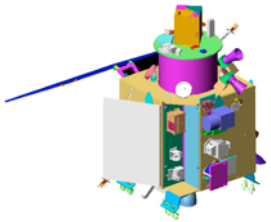


Spatial Cross Track Sample

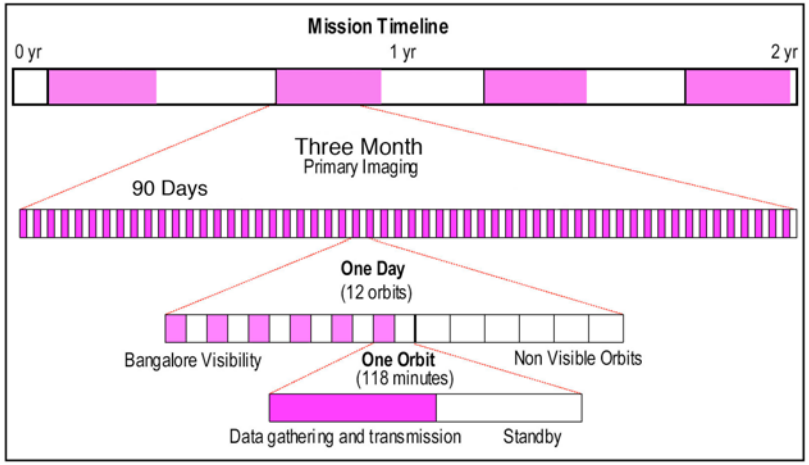
Spectral Error across FOV



M3 Measurements extend over Two Years



Chandrayaan-1 Two-year mission plan:
Four optical periods with high sun lighting



Data volume limited by downlink options.

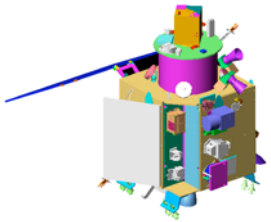
M3 Measurement plan:

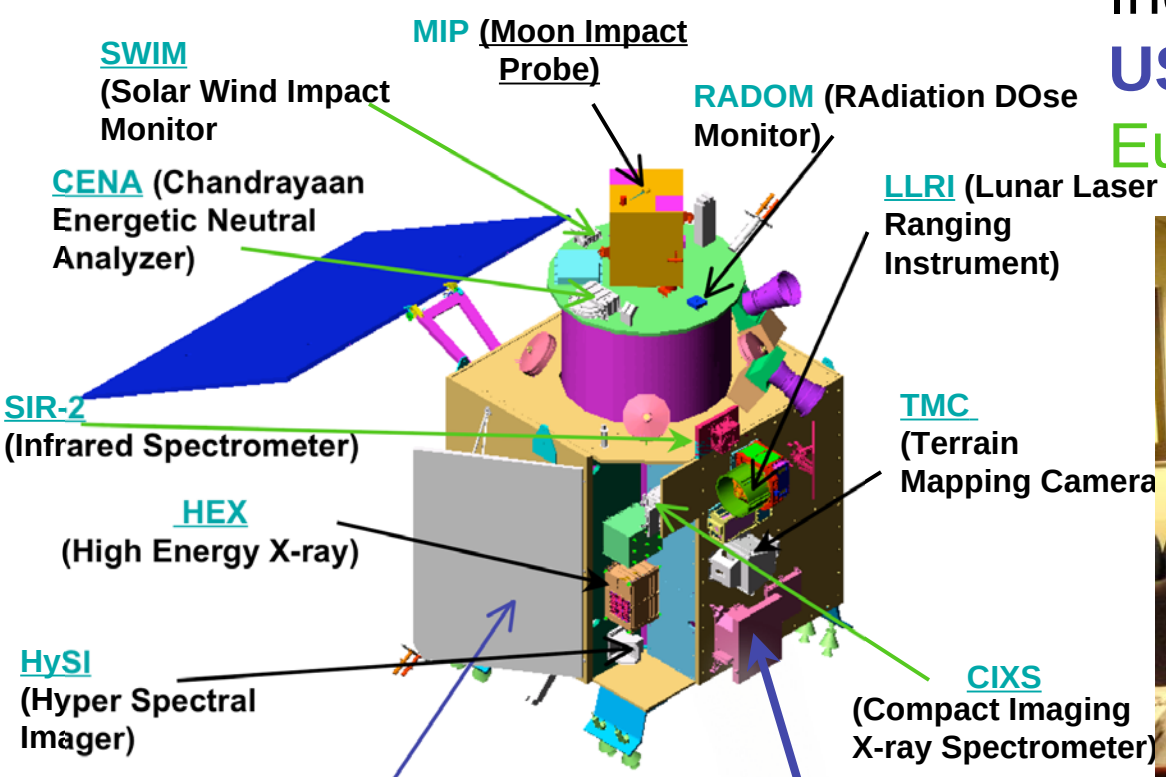
All M3 Reflectance Spectra

- 0.70 to 3.0 μm [0.43 to 3.0 μm achieved]
- 40 km FOV, contiguous orbits
- high SNR
- 1 Gbyte/orbit

- Targeted Mode: Optimum
  - Resolution (100 km orbit):
    - 70 m/pixel spatial
    - 10 nm spectral [260 bands]
  - 3 optical periods [20 - 50% coverage]
    - 10 to 12 deg latitude/orbit
- Low Resolution Mode: Global Coverage
  - Resolution (100 km orbit):
    - 140 m/pixel spatial
    - 20 & 40 nm selected (86 bands, ~3x spectral averaging)
  - 1 optical period [~100%]

M3 is Part of a Highly International Exploration Mission



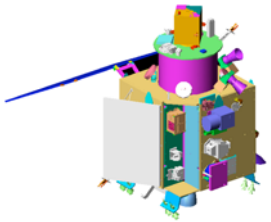


Indian

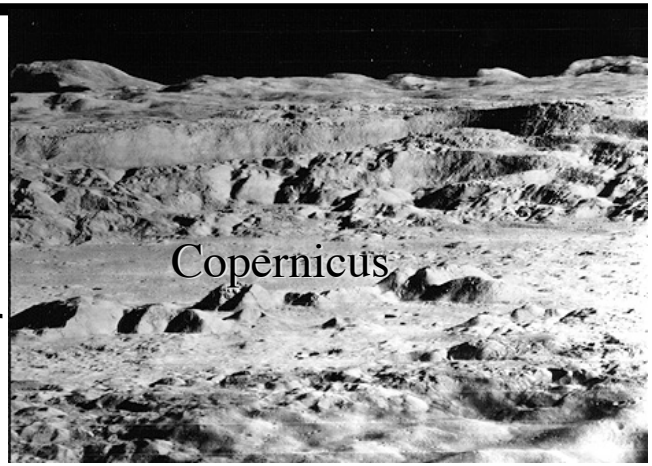
US

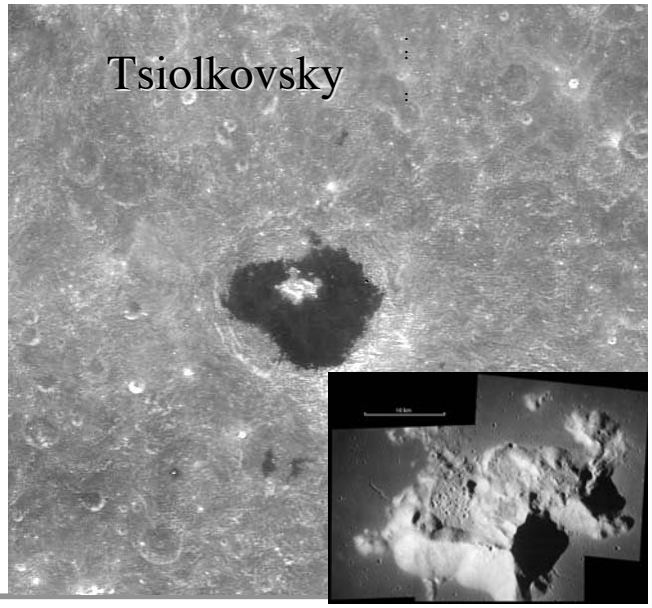
European

M3 Science Goals Address Planetary Science Issues

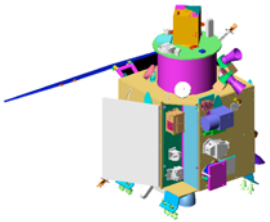


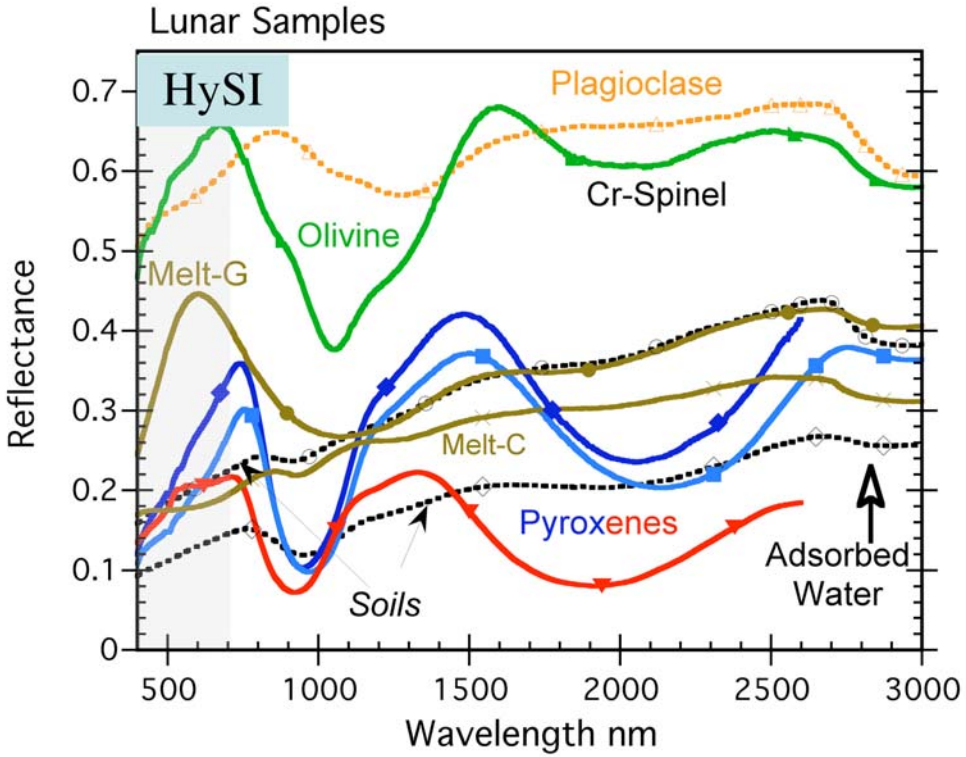
- Origin and Evolution of the lunar crust and mantle.
  - Evaluate primary crustal components and their distribution across the highlands.
  - Characterize the diversity and extent of different types of basaltic volcanism.
  - Map fresh craters [probes to the interior; impact record].
- Identify and assess deposits containing volatiles.
- Identify and evaluate concentrations of unusual/unexpected minerals.





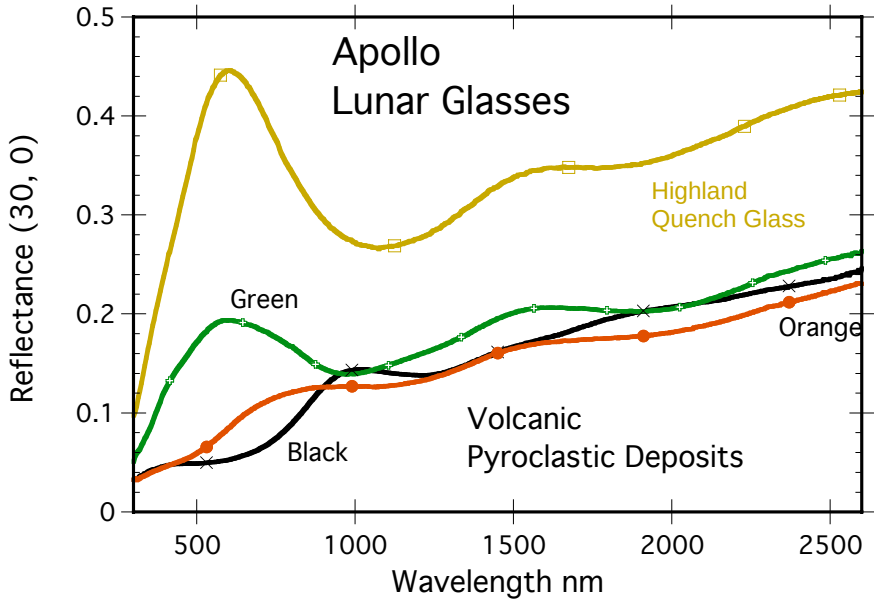
Minerals Exhibit
Highly Diagnostic Absorption Bands



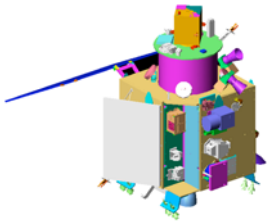


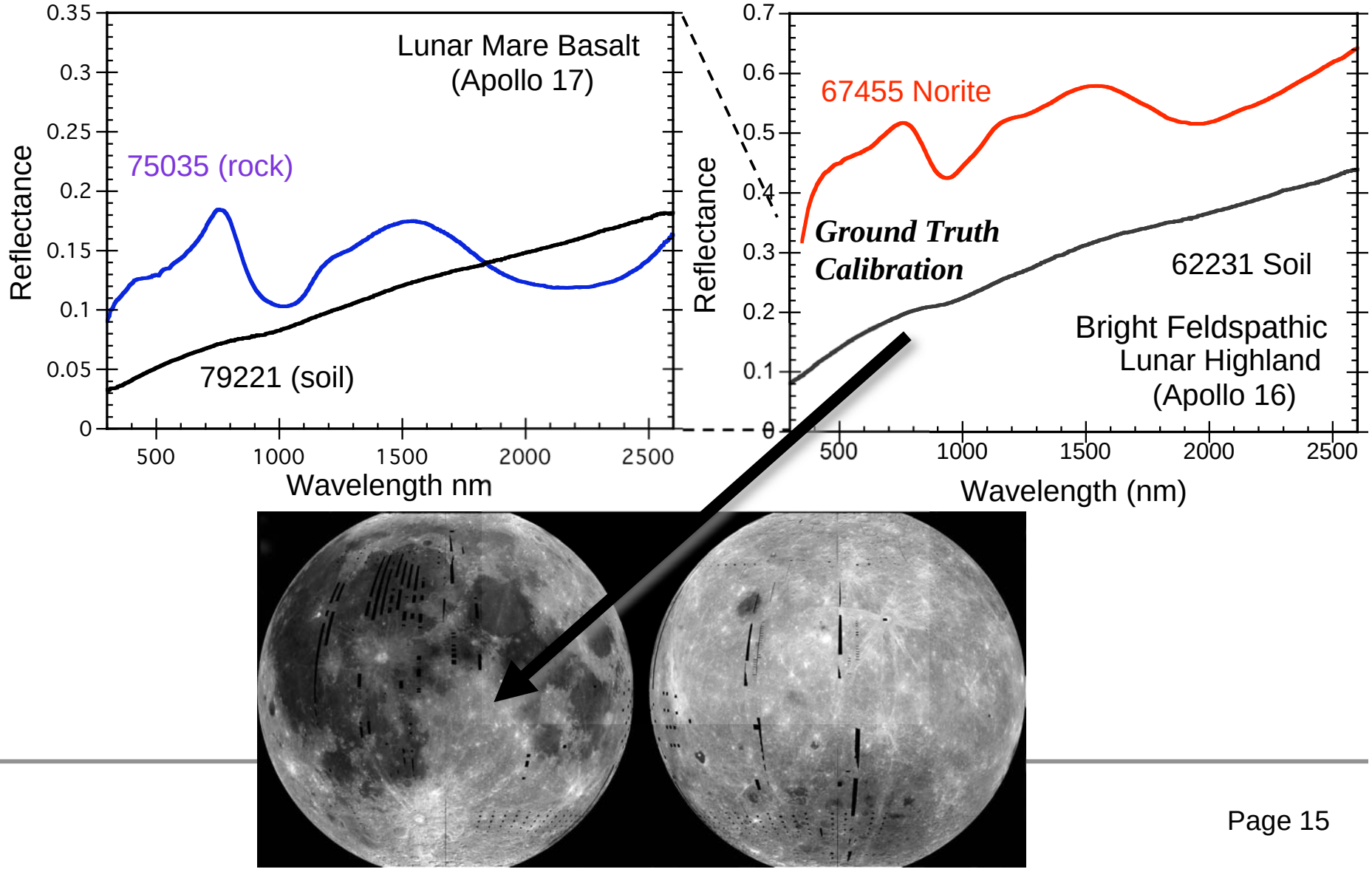
Samples from the Moon measured in Earth-based laboratories.

High spectral resolution reflectance spectra across the near-infrared are required to capture characteristic absorptions of lunar materials.

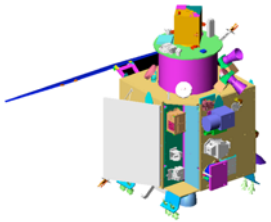


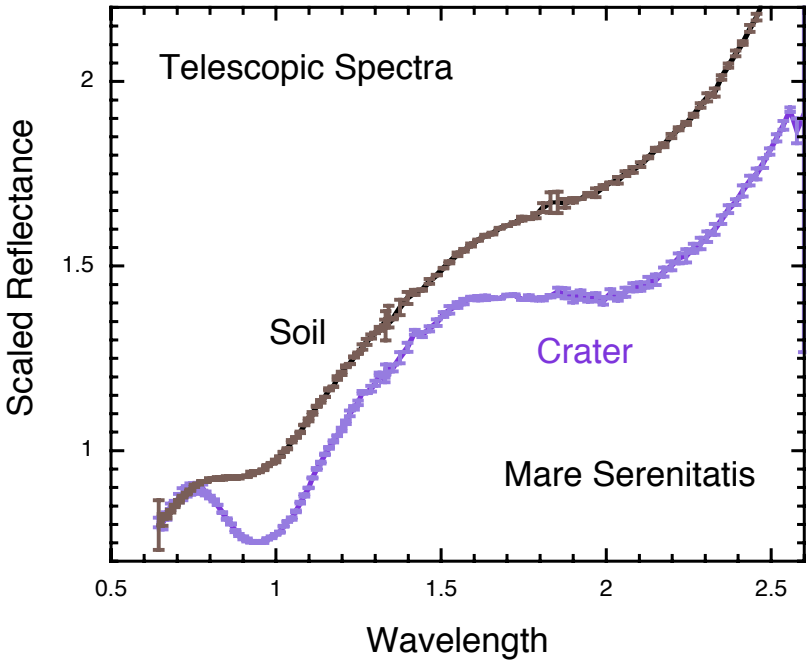
Lunar Samples Provide Ground Truth

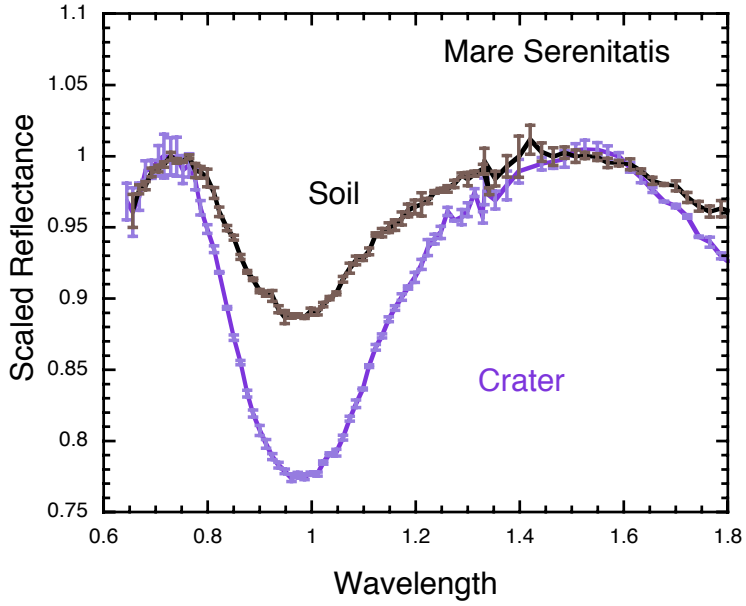


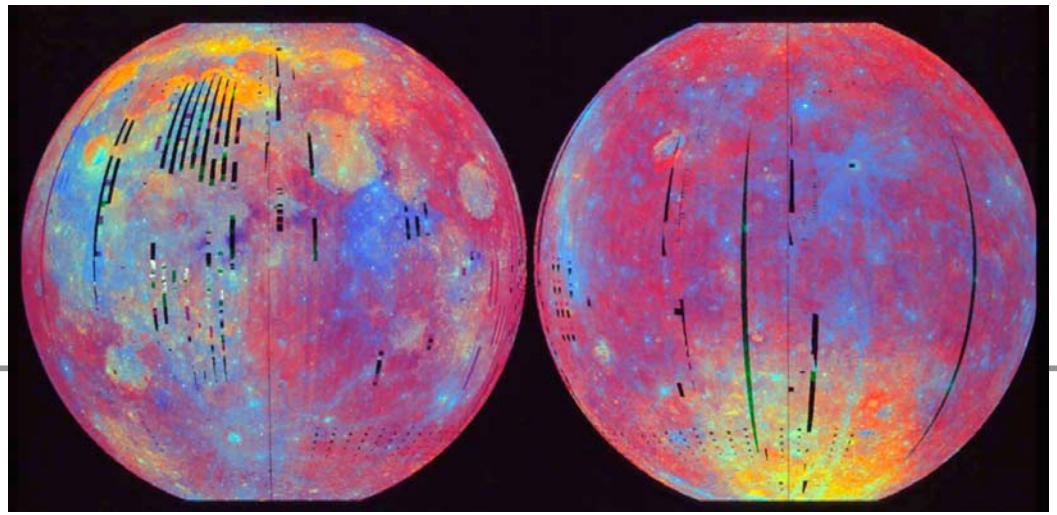


Mineral Characteristics are Weaker in Well-developed (mature) Soils



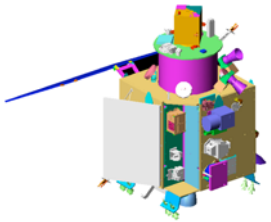


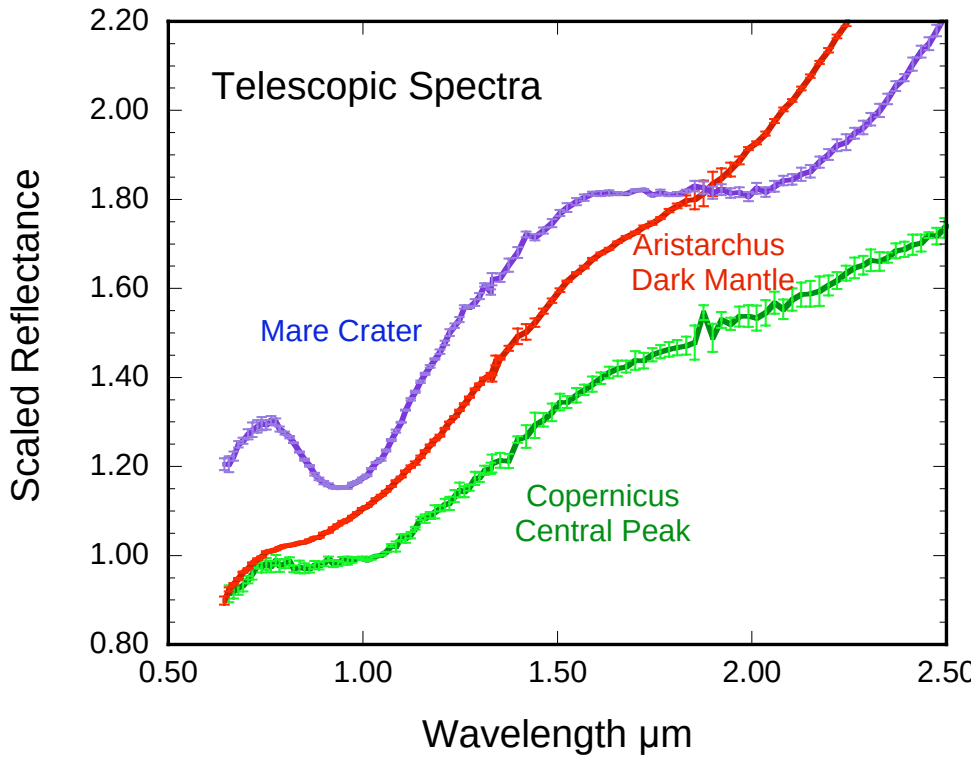


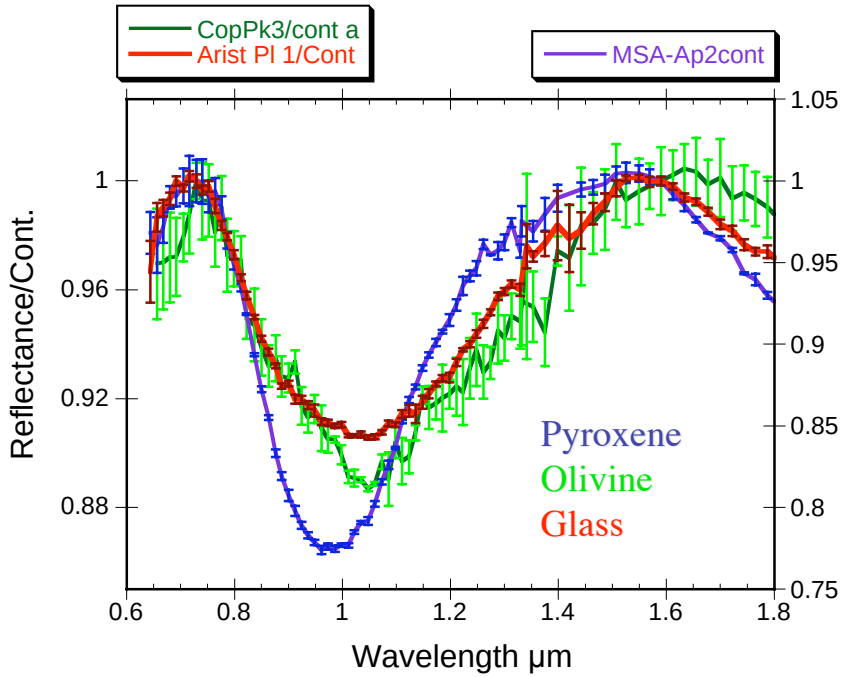


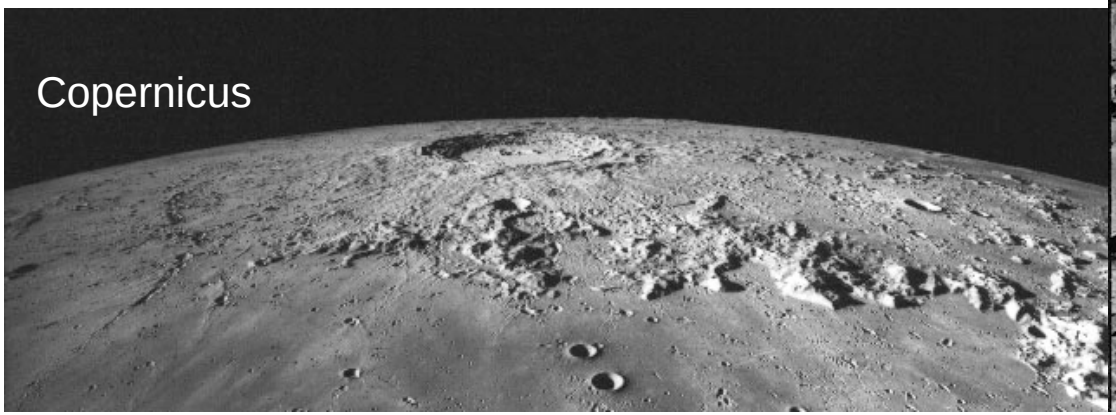
Clementine
Color Composite
R: 750/415
G: 750/950
B: 415/750

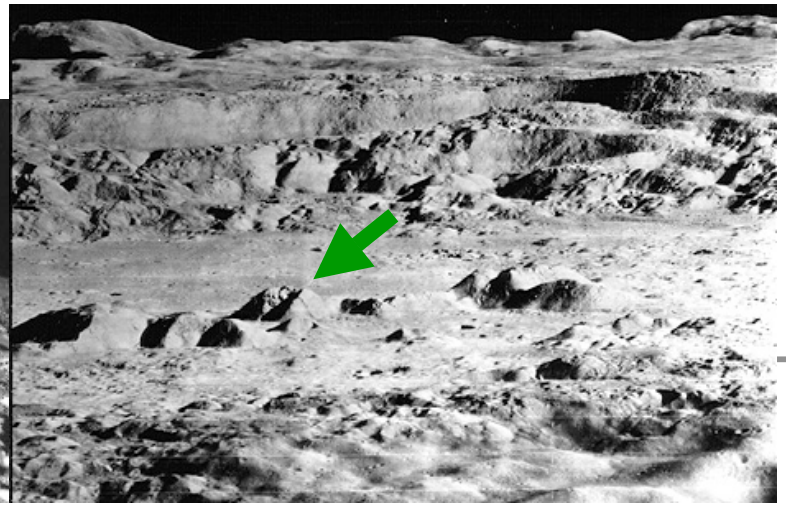
Mineral Characterization Requires High Spectral Resolution







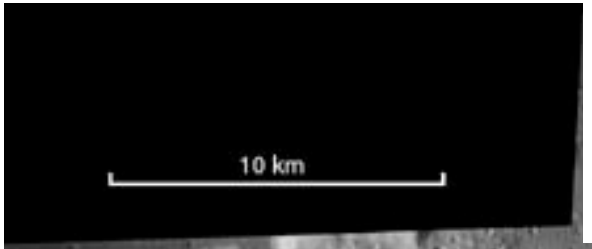




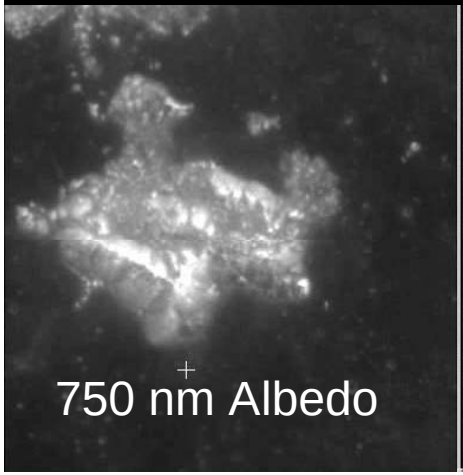
Mineralogy + Spatial information is Key.

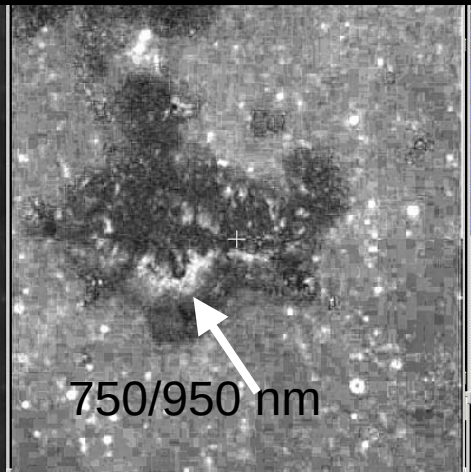
Tsiolkovsky: A Farside Pluton?

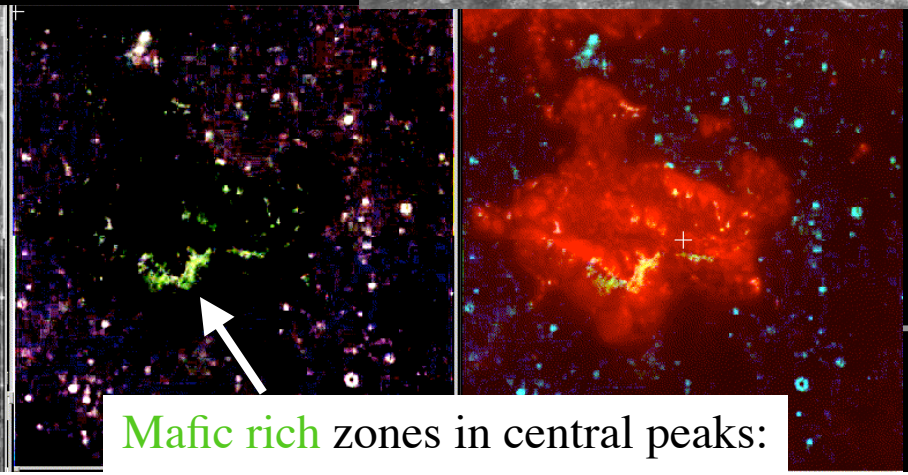
Olivine? + Anorthosite Central Peaks



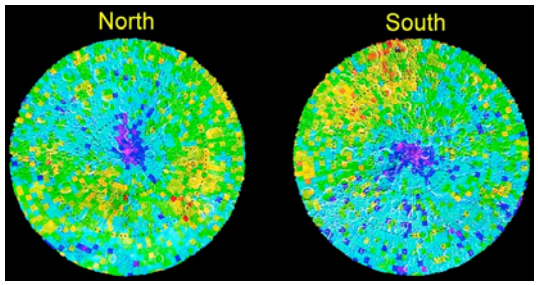
Pieters and Tompkins
1999 JGR





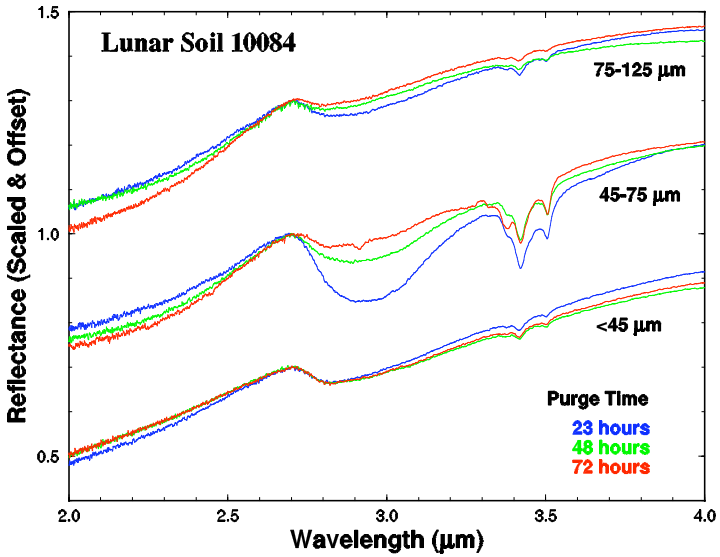


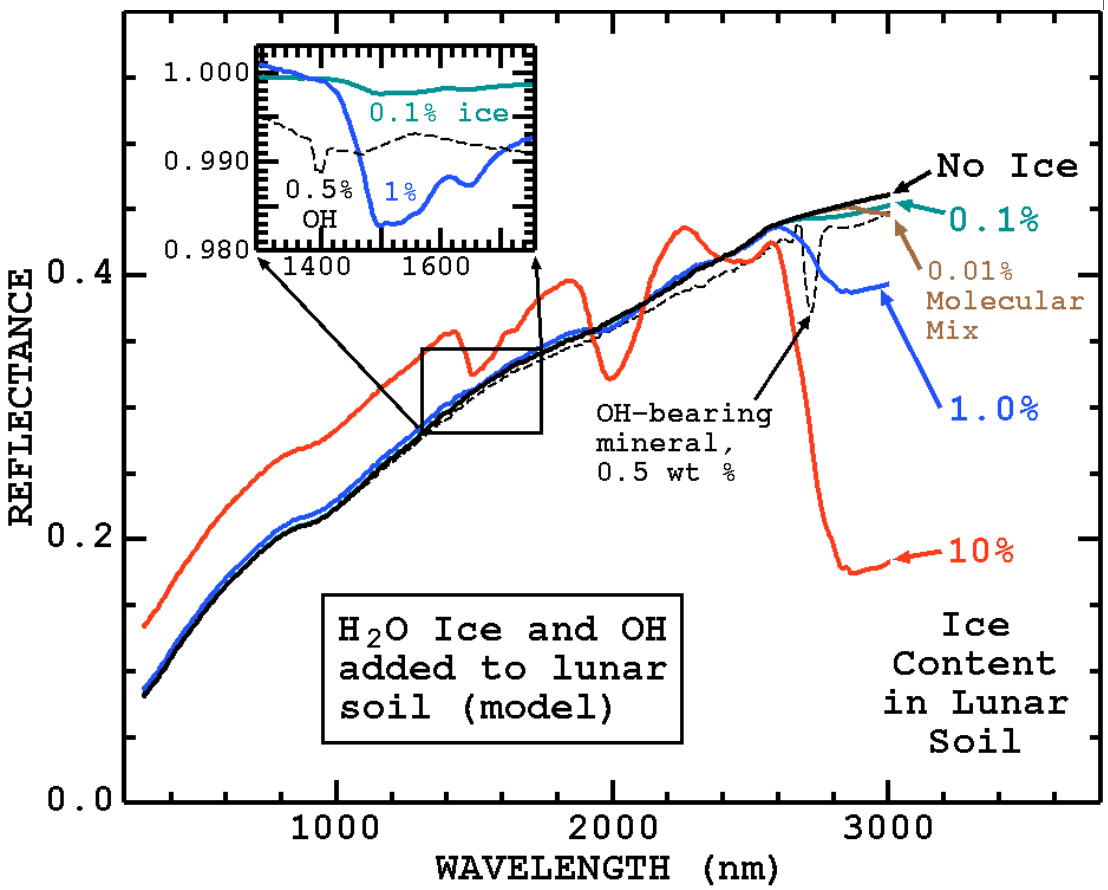
Mafic rich zones in central peaks:



Lunar Prospector
Hydrogen at the poles
Water ice?

Anhydrous lunar soils do not give up adsorbed water easily.

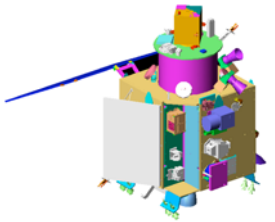




M3 Near-IR+ spectroscopy can uniquely identify the presence of small amounts of OH or H2O

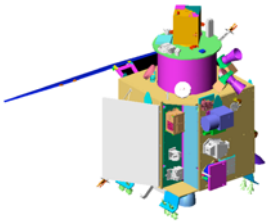
(surface scattered solar radiation).

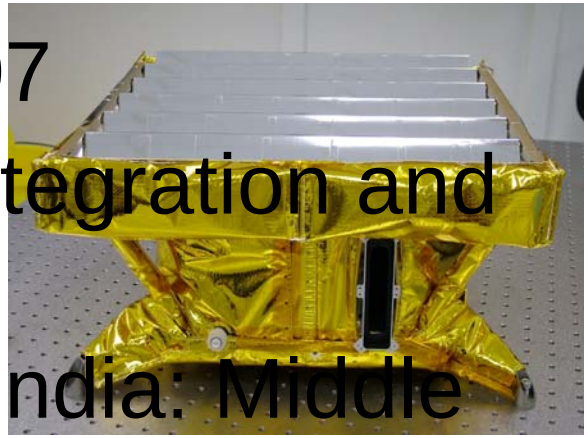
M3 January 2007



- Last viewing before radiator and thermal blankets attached
- Preparation for final thermal vacuum testing and calibration

Milestones





- M3 ship to India: August 2007
- Chandrayaan-1 instrument integration and testing: Fall-Winter 2007
- Chandrayaan-1 launch from India: Middle 2008
- Chandrayaan-1 operations at the Moon: few weeks later!
- Initial science report: late 2008
- ***Continue science analyses for 2 years.***


MOON MINERALOGY MAPPER
CHANDRAYAAN-1
M3
BROWN UNIVERSITY ISRO JPL NASA
May 2006