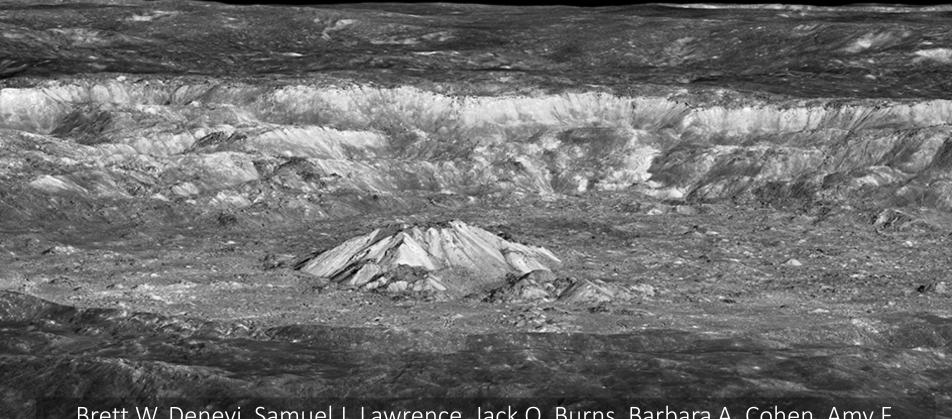
Advancing Science of the Moon Specific Action Team Report



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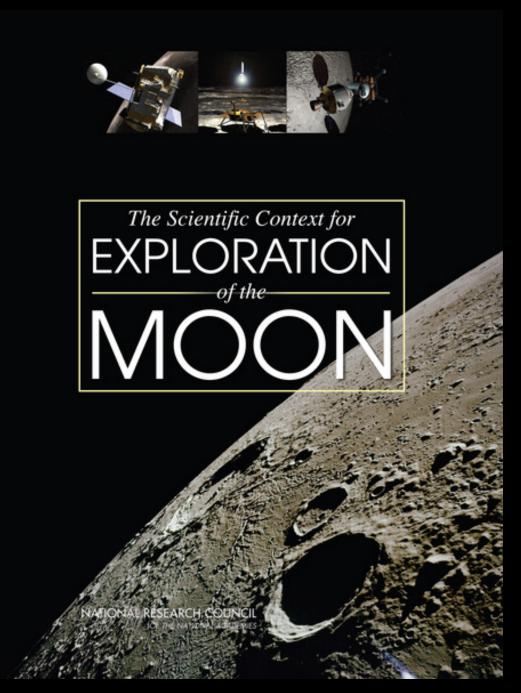
Advancing Science of the Moon Specific Action Team

The ASM SAT was requested by NASA Planetary Science Division and commissioned by LEAG; met last August in order to:

 Evaluate progress on lunar science goals since the 2007 Scientific Context for Exploration of the Moon report

2007 NRC report

- National Research Council study performed at the request of Associate Administrator of SMD
- Provide guidance on the science enabled by the newly established Vision for Space Exploration
- "NASA needs a comprehensive, wellvalidated, and prioritized set of scientific research objectives for a program of exploration of the Moon"



8 Prioritized Science Concepts

- 1: The bombardment history of the inner solar system is uniquely revealed on the Moon
- 2: The structure and composition of the lunar interior provide fundamental information on the evolution of a differentiated planetary body
- 3: Key planetary processes are manifested in the diversity of lunar crustal rocks
- 4: The lunar poles are special environments that may bear witness to the volatile flux over the latter part of solar system history
- 5: Lunar volcanism provides a window into the thermal and compositional evolution of the Moon
- 6: The Moon is an accessible laboratory for studying the impact process on planetary scales
- 7: The Moon is a natural laboratory for regolith processes and weathering on anhydrous airless bodies
- 8: Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state

Top 11 Goals

- 1a test cataclysm hypothesis
- 1b − age of SPA
- 1c precise lunar chronology
- 4a composition and distribution of polar volatiles
- 3a extent/composition of primary products of differentiation
- 2a thickness of crust, variability
- 2b stratification of the mantle
- 8a lunar atmosphere
- 2c size/composition/state of the core
- 3b variety/age/distribution/origin of lunar rock types
- 8b electrostatically transported dust

Advances in lunar science

- Since the SCEM report:
- Kaguya, Chang'e 1, Chandrayaan 1, LRO, LCROSS, Chang'e 2, GRAIL, LADEE, Chang'e 3
- Restoration and reexamination of older datasets
- Technological developments
- Advances in modeling
- New ideas

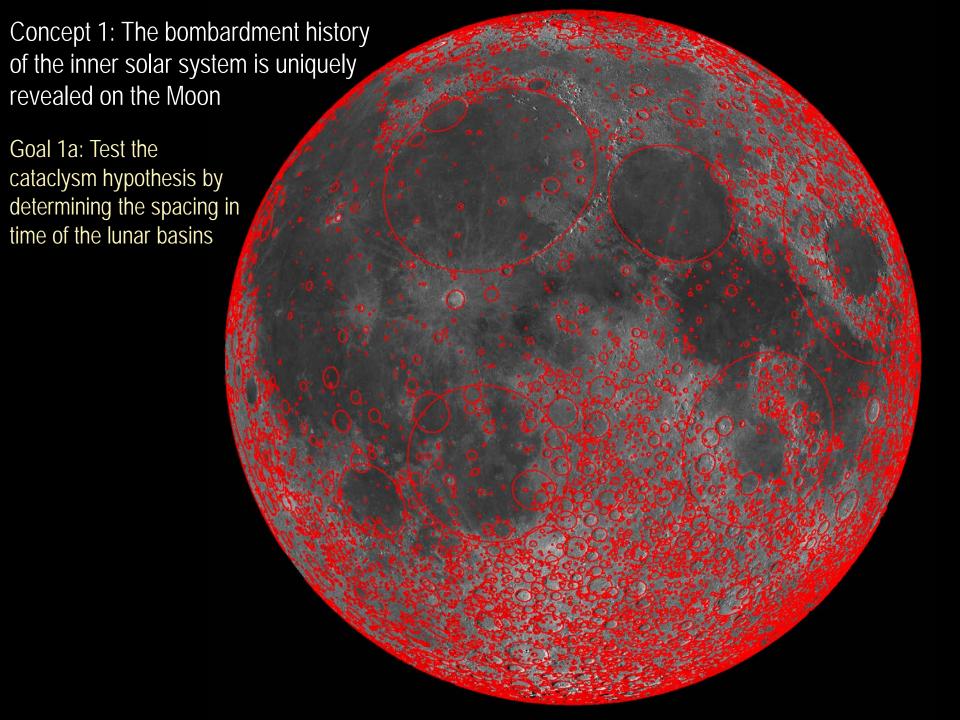




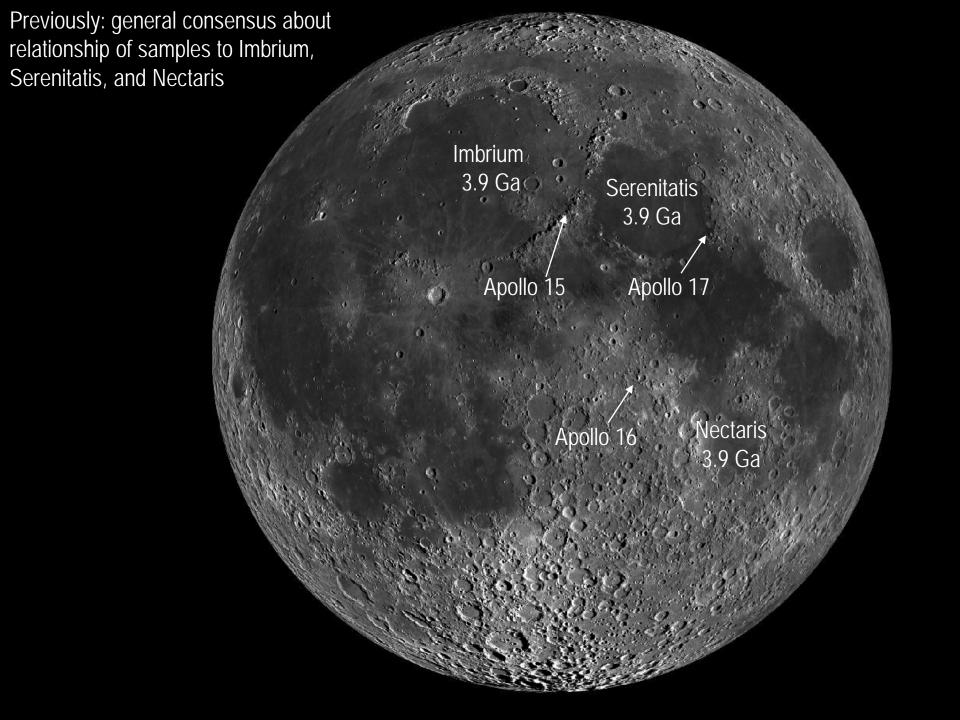
Advancing Science of the Moon Specific Action Team

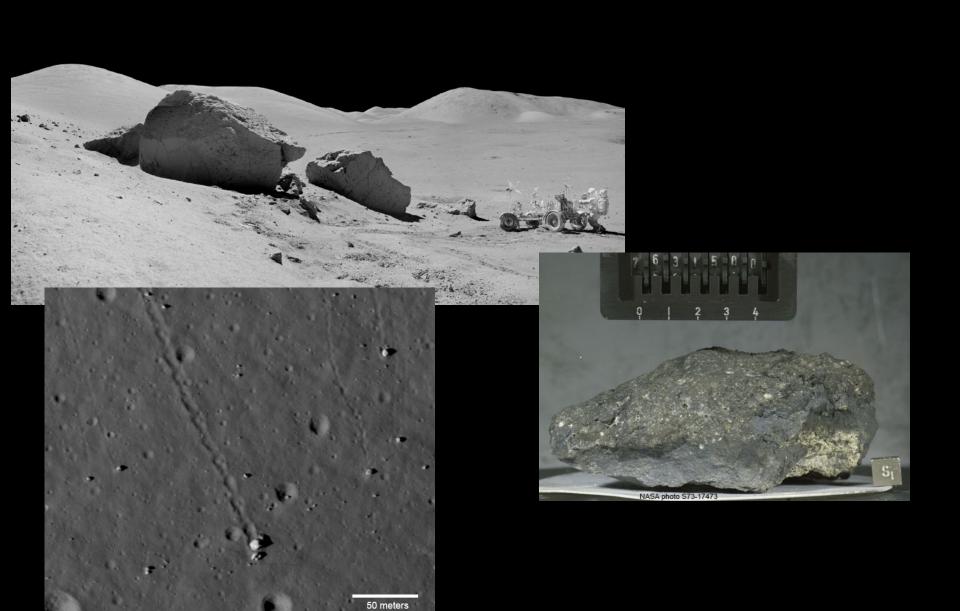
The ASM SAT was requested by Jim Green and commissioned by LEAG; met in August in order to:

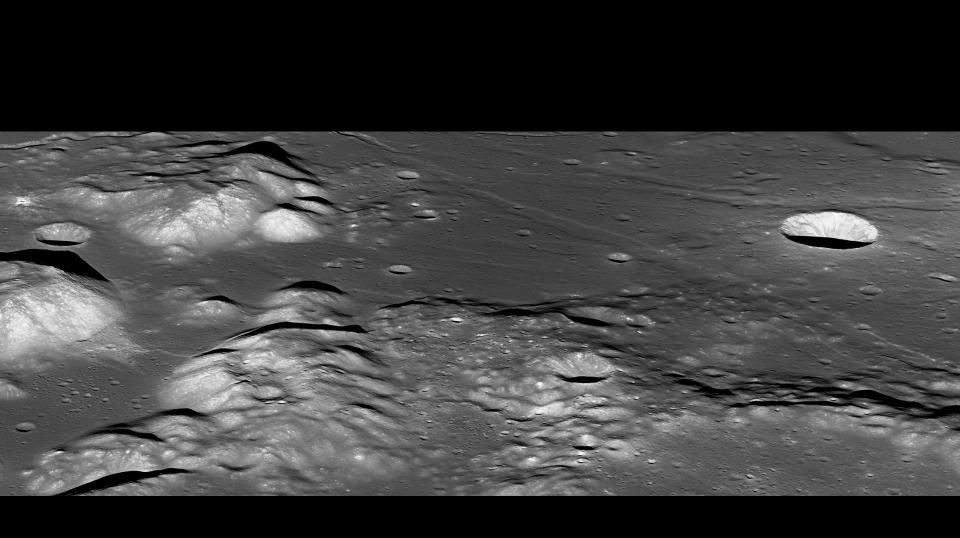
- Evaluate progress on lunar science goals since the 2007 Scientific Context for Exploration of the Moon report
- Consider concepts related to science implementation, as well as secondary science opportunities, outlined in the 2007 report
- Note any new lunar science concepts that have become apparent since 2007

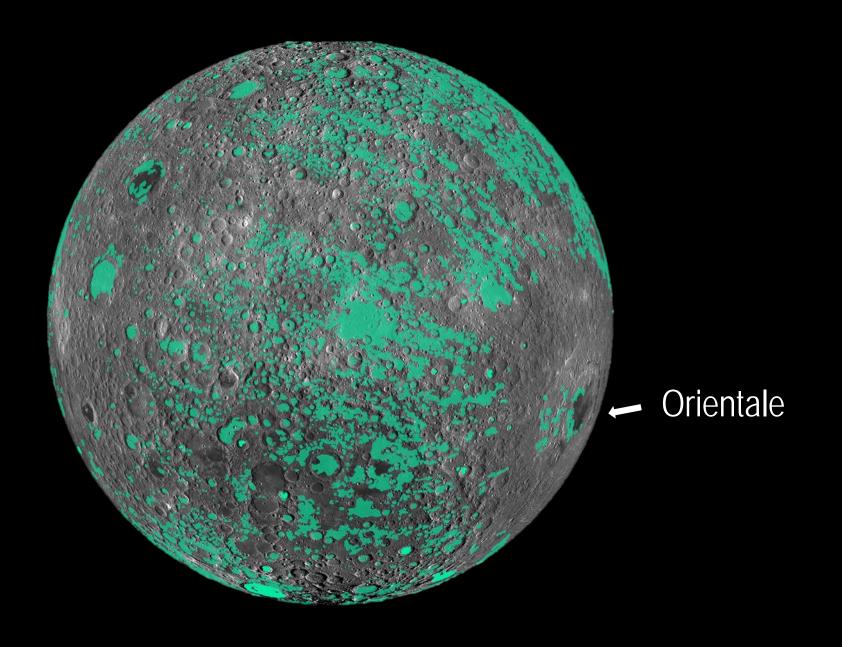


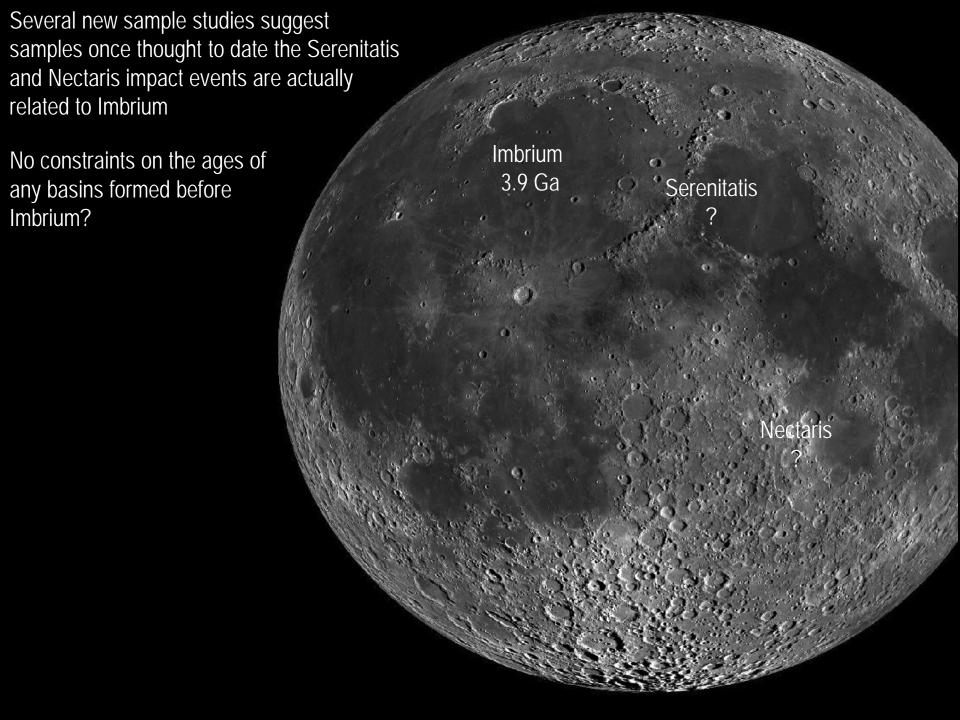


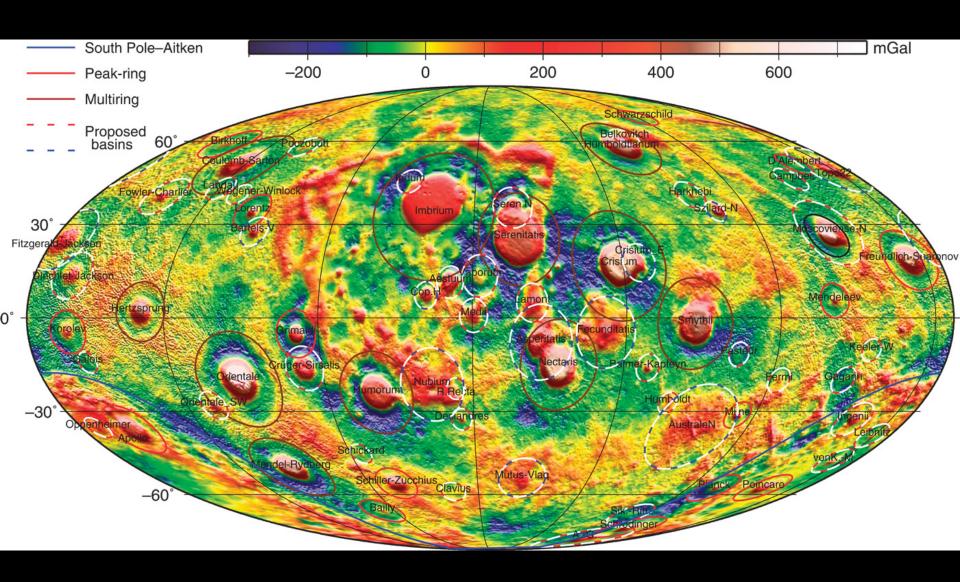


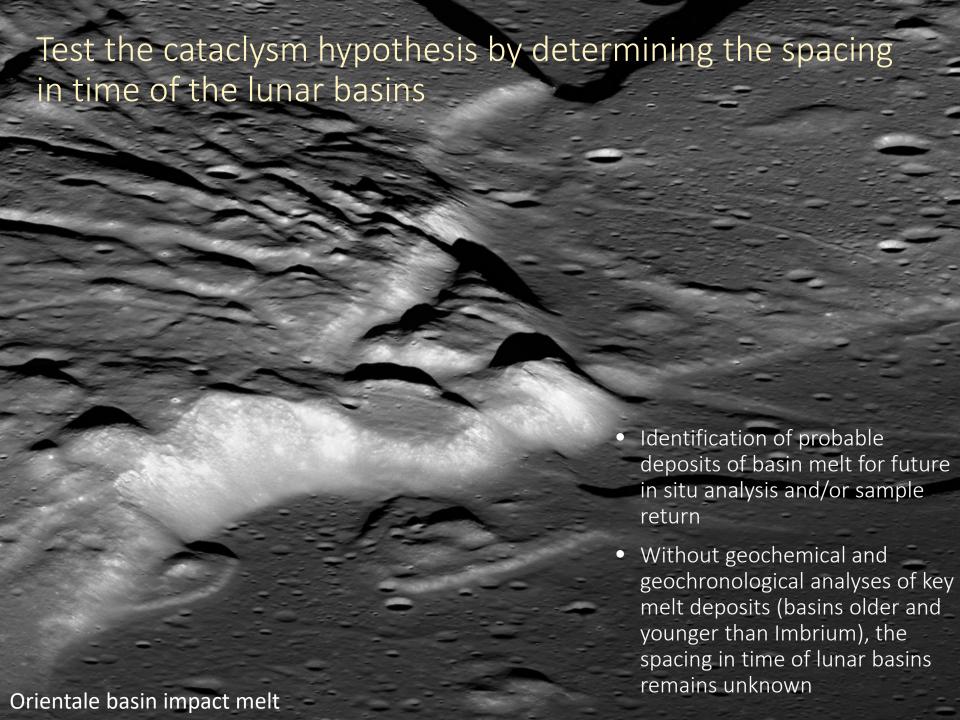




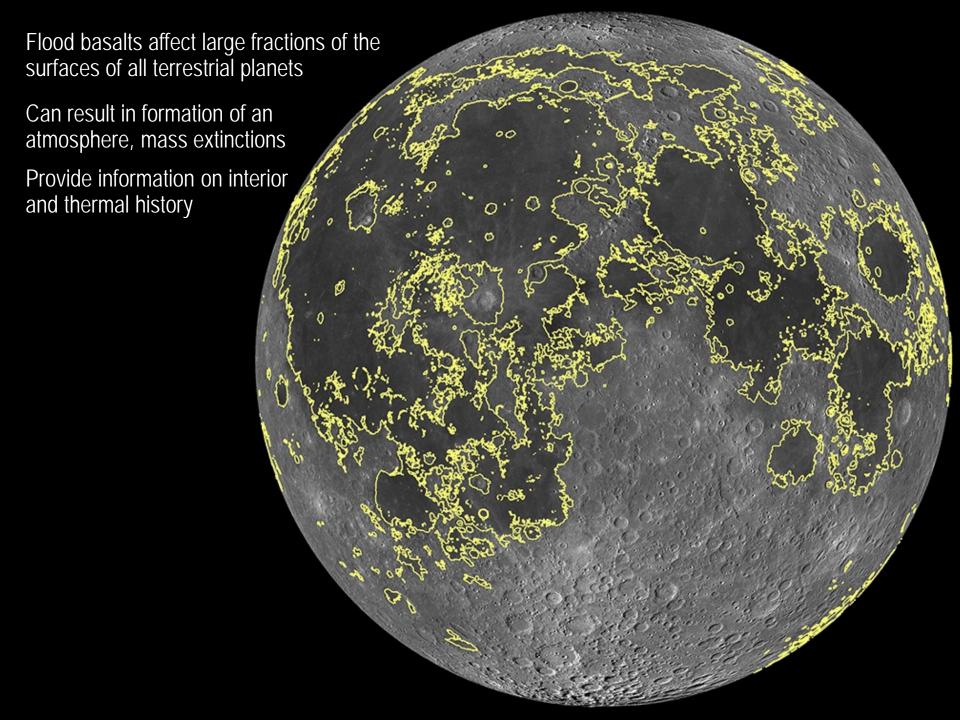






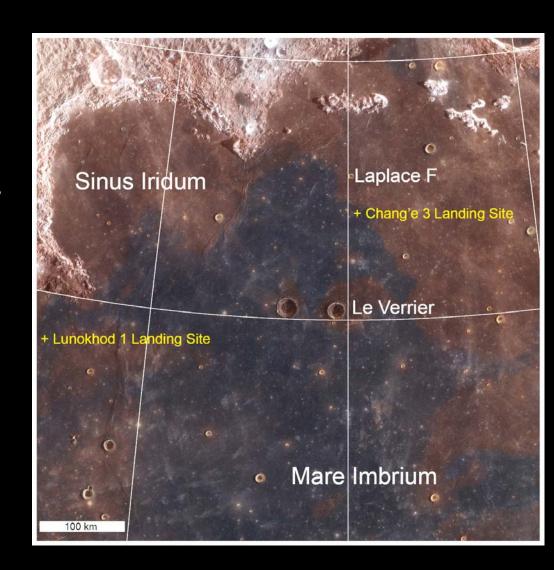


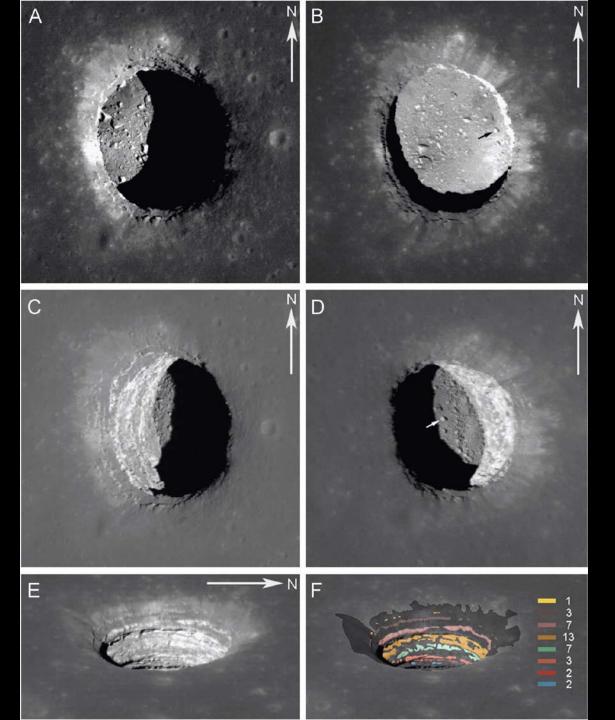


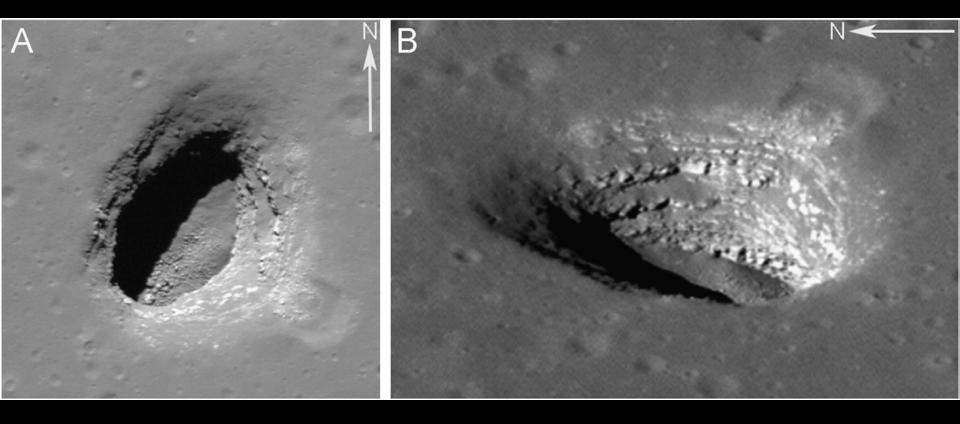


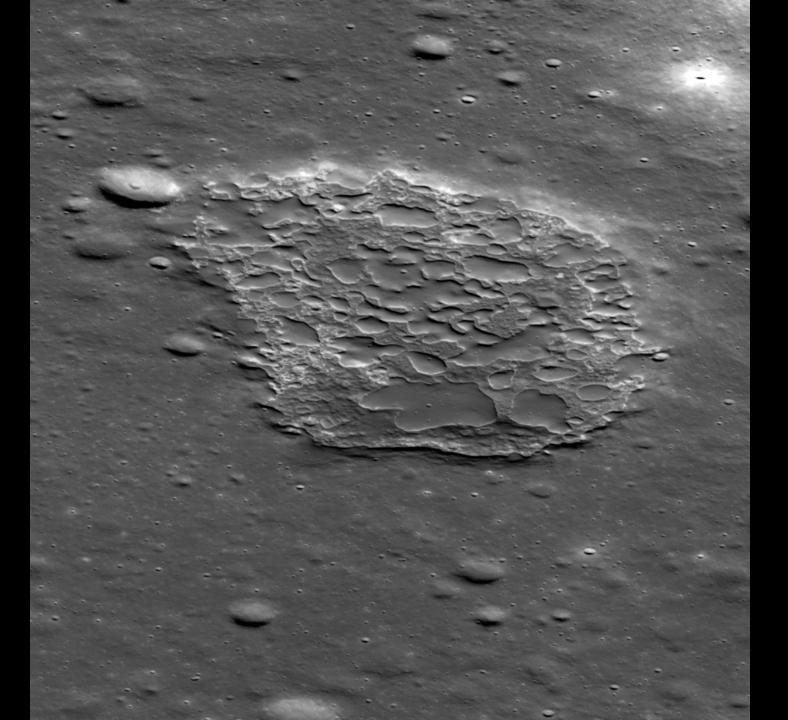
Compositions

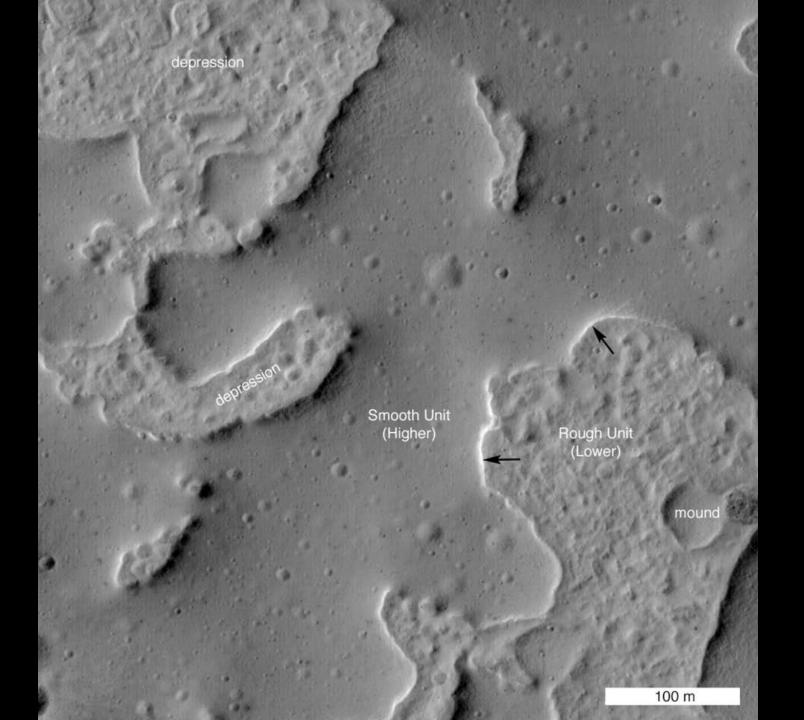
- Incremental progress on compositional variability of mare basalts through analysis of remote sensing observations, new lunar meteorites, Chang'e 3 data, isotopic studies of lunar materials
 - Compositional ranges beyond Apollo samples
 - Source region origin from primordial differentiation or secondary event that affected nearside
 - No volcanic samples from known locations on the far side, cannot compare compositional and source region differences with the near side

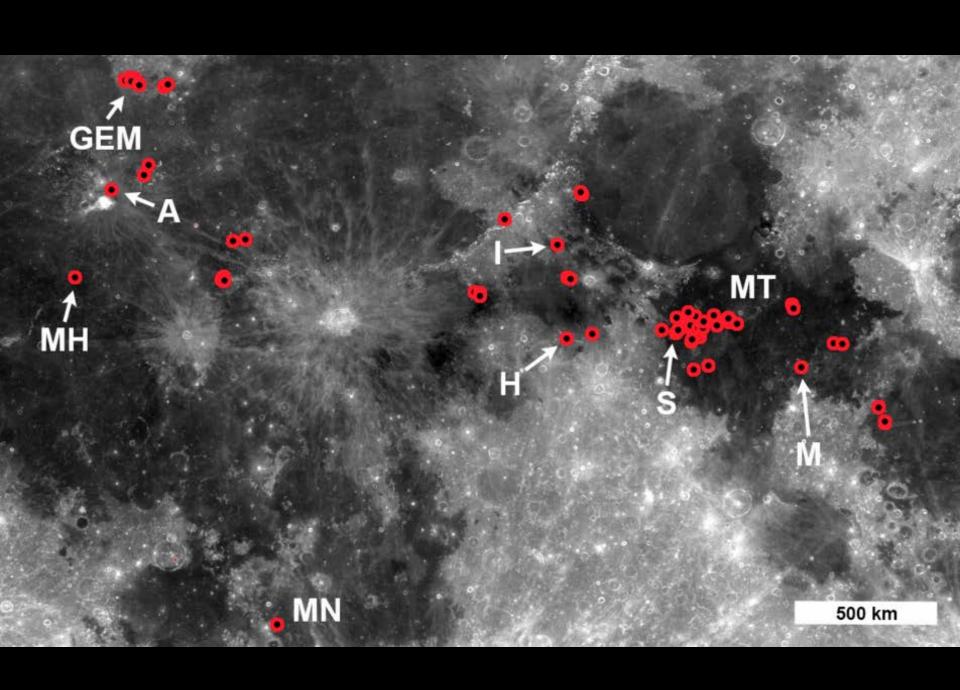


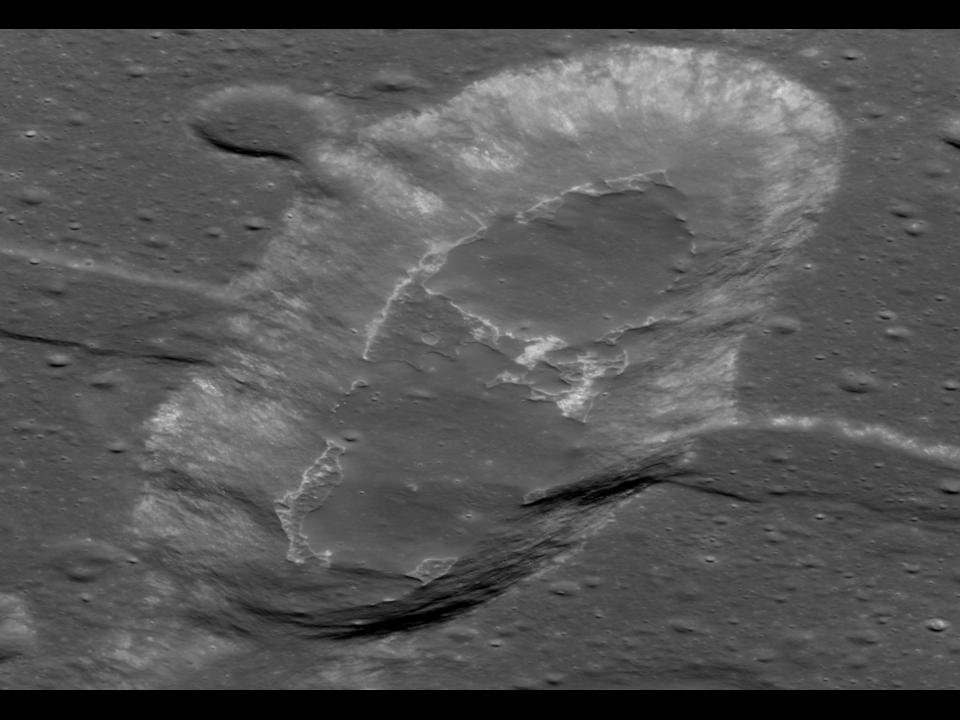


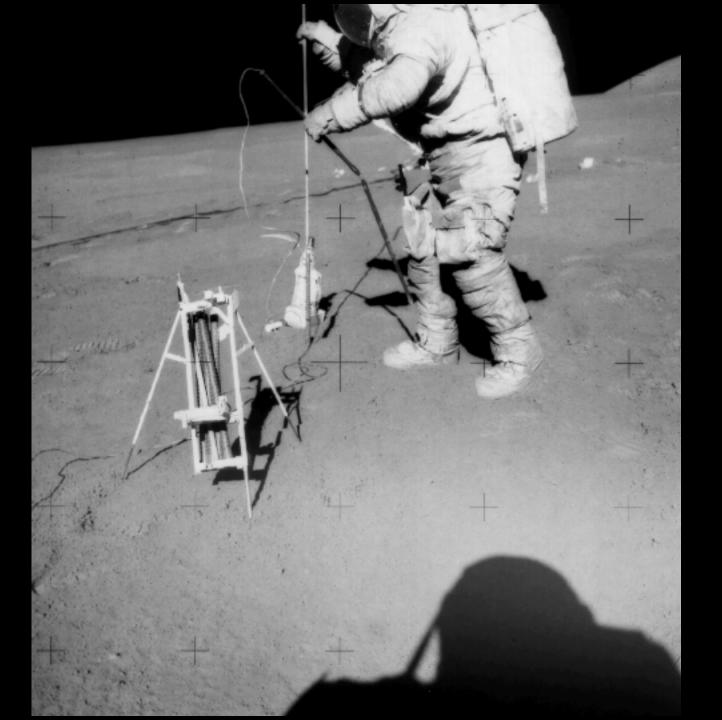












Determine the origin and variability of lunar basalts

Emphasis going forward should include understanding the composition, eruption styles, and variability of lunar volcanism

Sample return (for the youngest and oldest basalts, benchmark basalts), in situ elemental and mineralogical analyses with investigation of geologic context, and astronaut field work that could include core drilling, active subsurface sounding, and sampling of a complete sequence of basalt flows

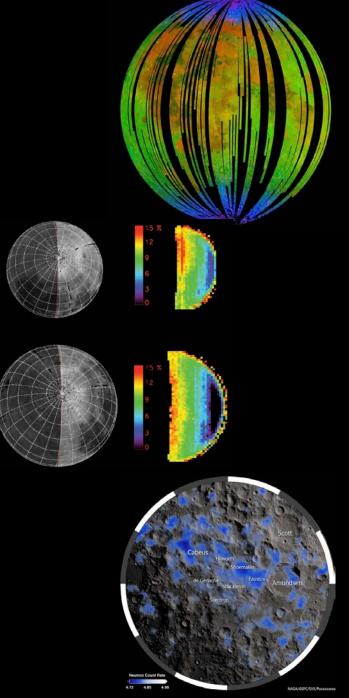
Oceanus Procellarum and Gruithuisen Gamma

New Goals and Concepts

- Several topics have risen in importance in the last decade that were either not covered in the original report, or were scattered throughout such that they were not sufficiently emphasized:
 - The lunar volatile cycle
 - The origin of the Moon
 - Lunar Tectonism and seismicity

The lunar volatile cycle

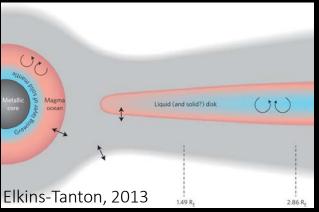
- Volatiles scattered across four Concepts of SCEM report
- Work from the last decade points to cycle with three components:
 - Primordial (interior) water
 - Surficial water (linked to solar wind)
 - Polar water (sequestered)
- Identify and characterize these lunar volatile reservoirs and evaluate their interrelations
 - Composition and variability of endogenous volatiles entrained in volcanic products
 - Sources of mid-latitude surface hydroxyl and water, determine how it migrates
 - Determine source(s) of polar volatiles



The origin of the Moon

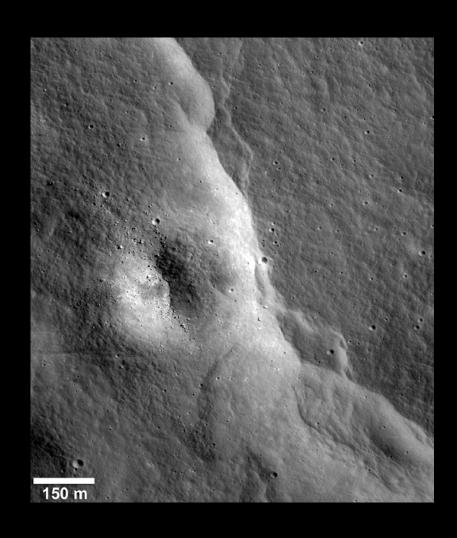
- A key goal of studying the Moon: better understand the origin and accretion of planets
- Moon's deep interior is a vault containing critical information about its initial composition during and immediately after accretion
- Specific goals:
 - timing of the collision
 - mechanisms, timing, extent of volatile depletion in the Moon
 - composition of the impactor
 - conditions and processes in the protolunar disk
 - conditions and processes at the surface of the lunar magma ocean, composition and longevity of an early atmosphere





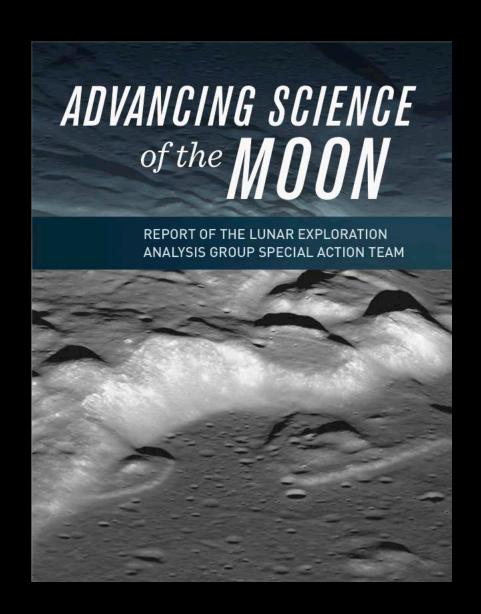
Lunar tectonism and seismicity

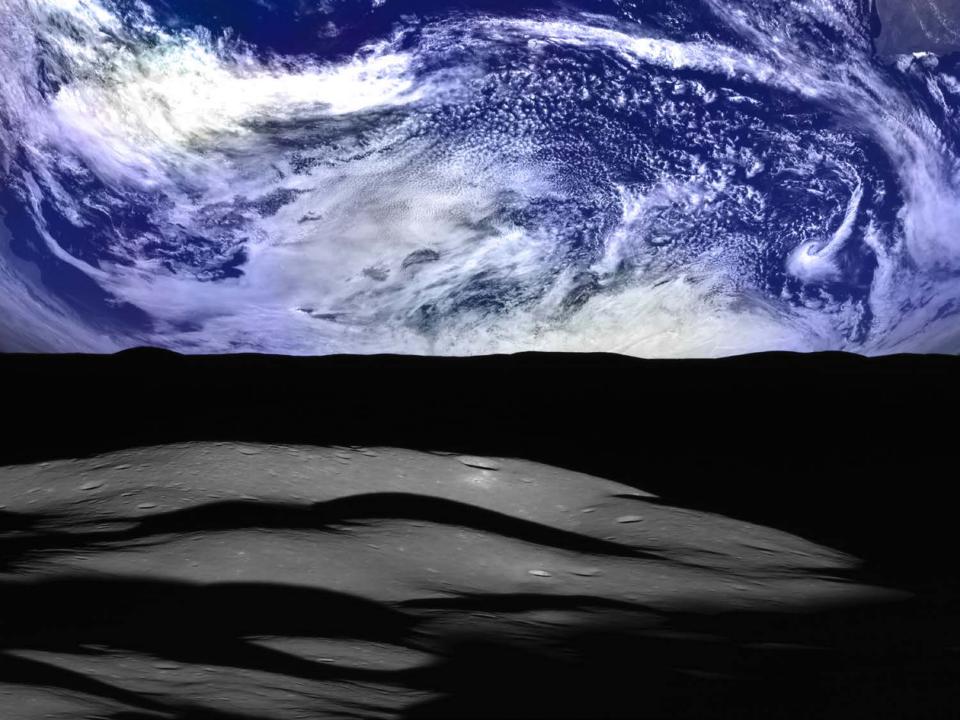
- Greatly expanded high-res imaging led to discovery of abundance of lobate scarps
- Without plate tectonics: number, distribution, level of seismicity of lobate scarps, provide information on Moon's interior structure, thermal history, and mechanism(s) of heat loss
- In addition to global contraction, may be due to stresses from tides and recession – active today
 - Lobate scarps explain shallow moonquakes?
 - If so, regions with active scarps would be targeted for seismic analyses, but avoided for landed assets such as outposts

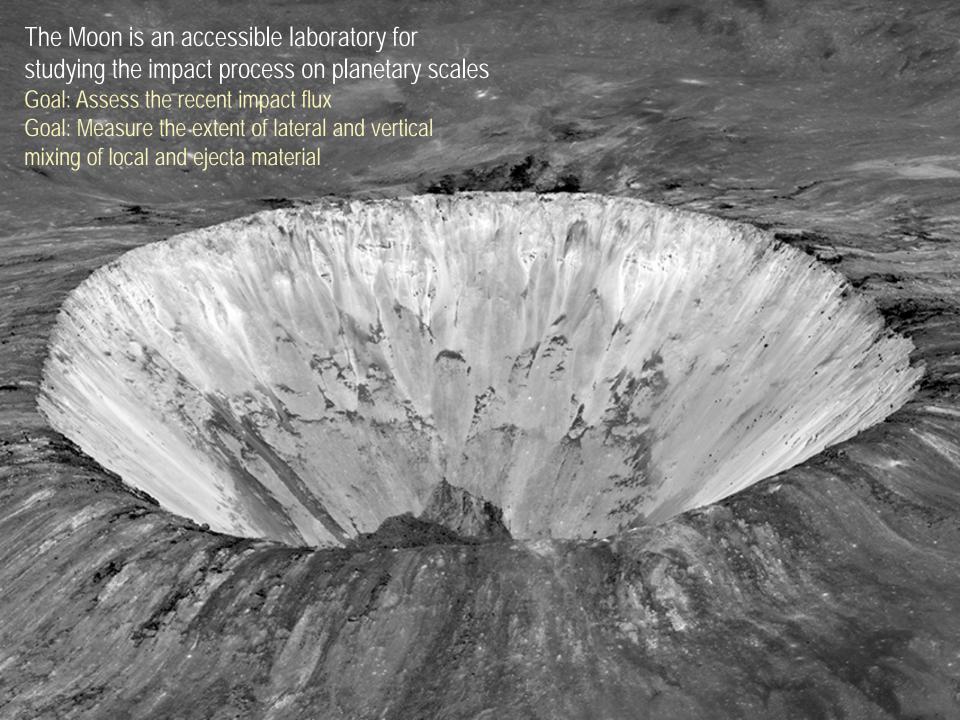


ASM SAT Conclusions

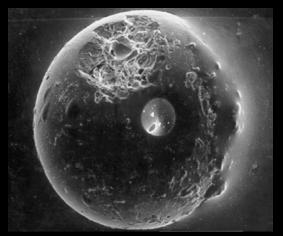
- Concepts and goals outlined in the 2007 NRC report remain important and relevant after a decade of progress in lunar science
 - Nearly all had at least some progress; none were "done"
- New concepts and goals have emerged
- While there is still real progress to be made from orbital missions, the advancement of many of these goals requires landed missions
- We are now in a much stronger position to take advantage of missions and identify ideal landing sites to address these goals





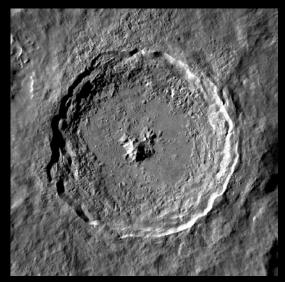


Current impact rate



Impact crater on 0.25 mm grain

- Small impactor rate (<1 mm) well known from Long Duration Exposure Facility
- Large impactor rate (>140 m) well known from NEO population
- Middle size range not well known

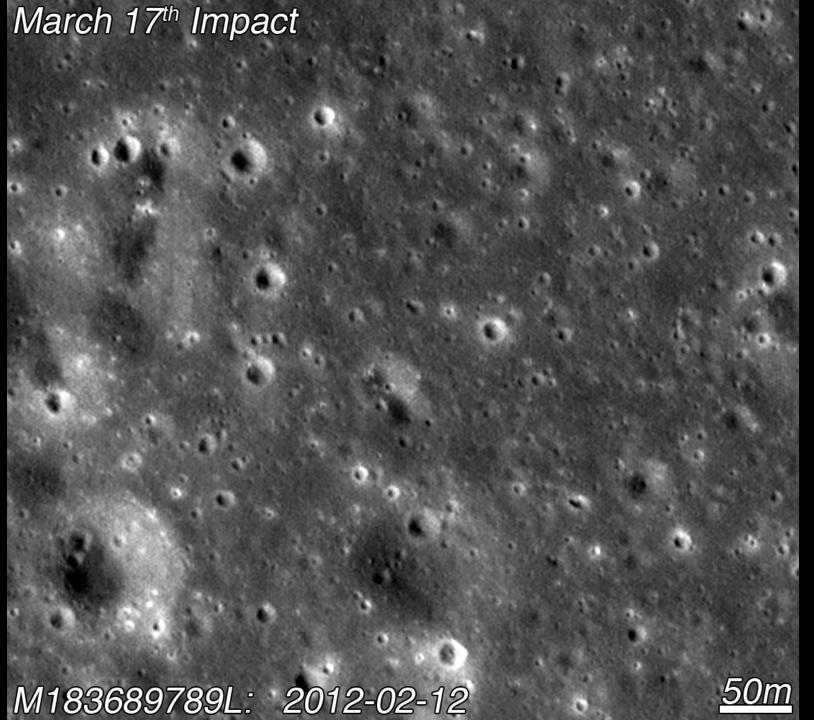


Tycho crater, 85 km across



Chelyabinsk – 20-m impactor

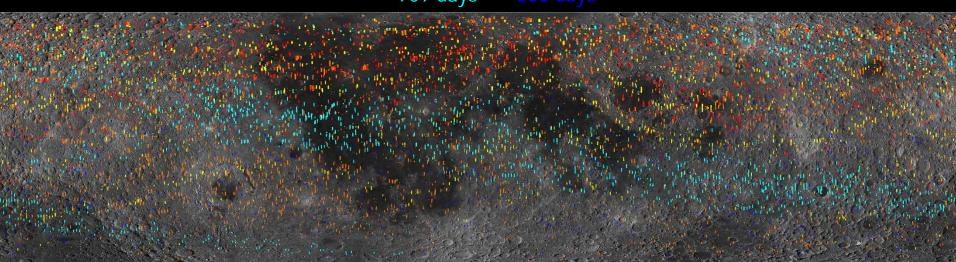




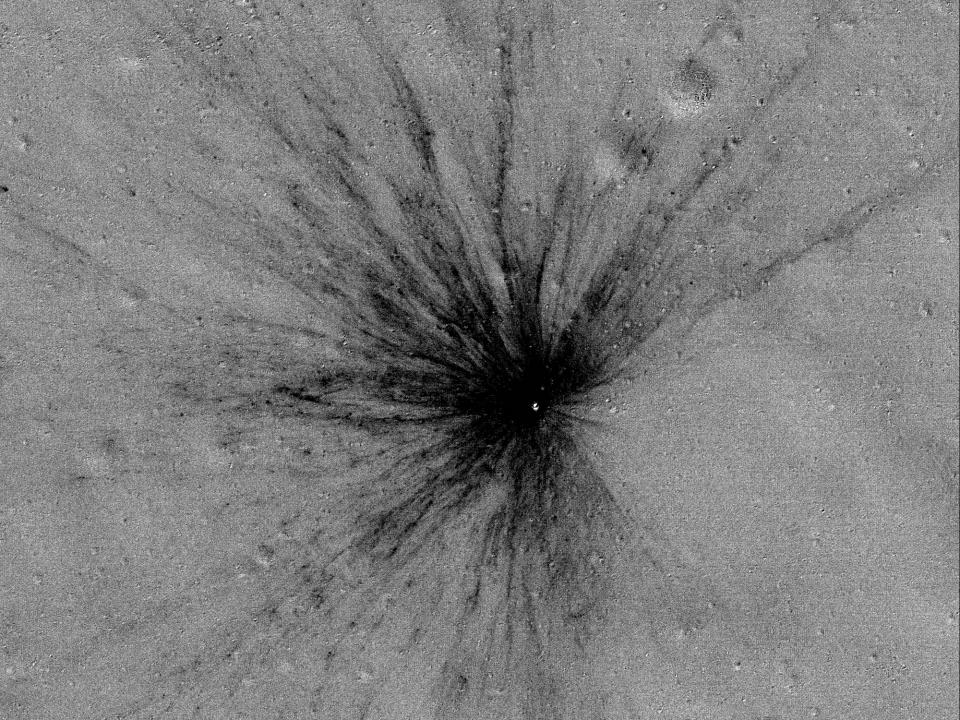
Repeat imaging from LROC

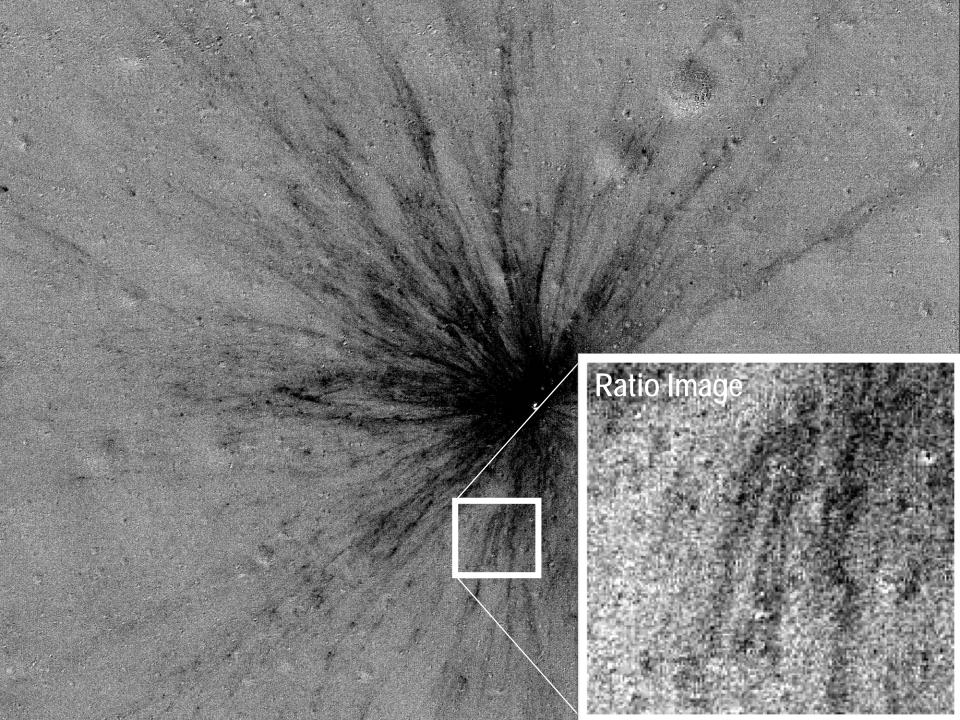
Temporal Image Pairs

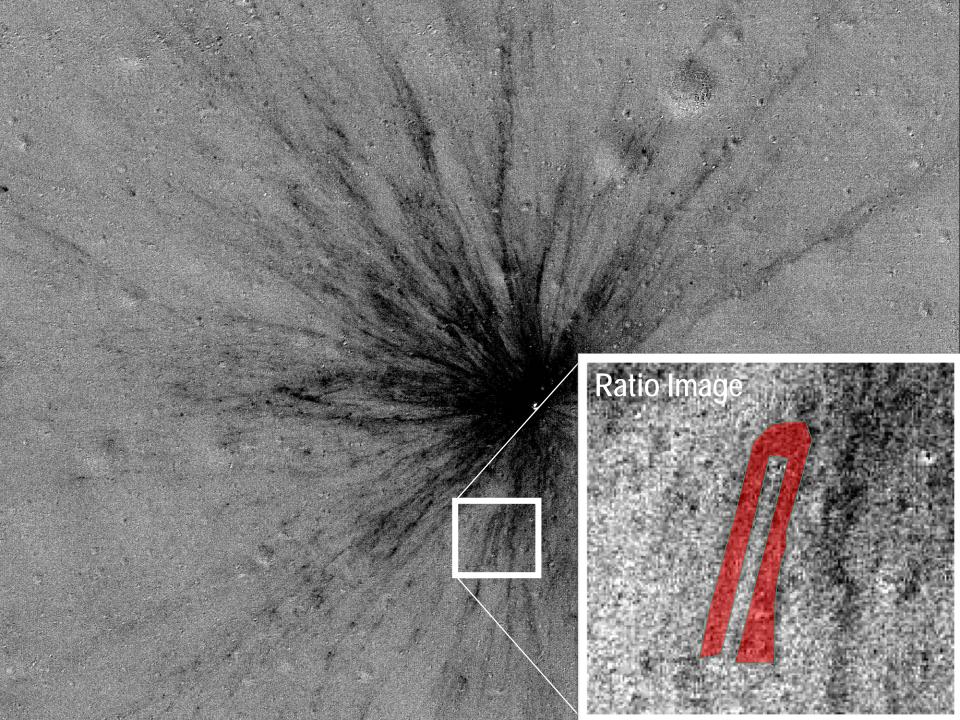
177 days 354 days 531 days 709 days >886 days

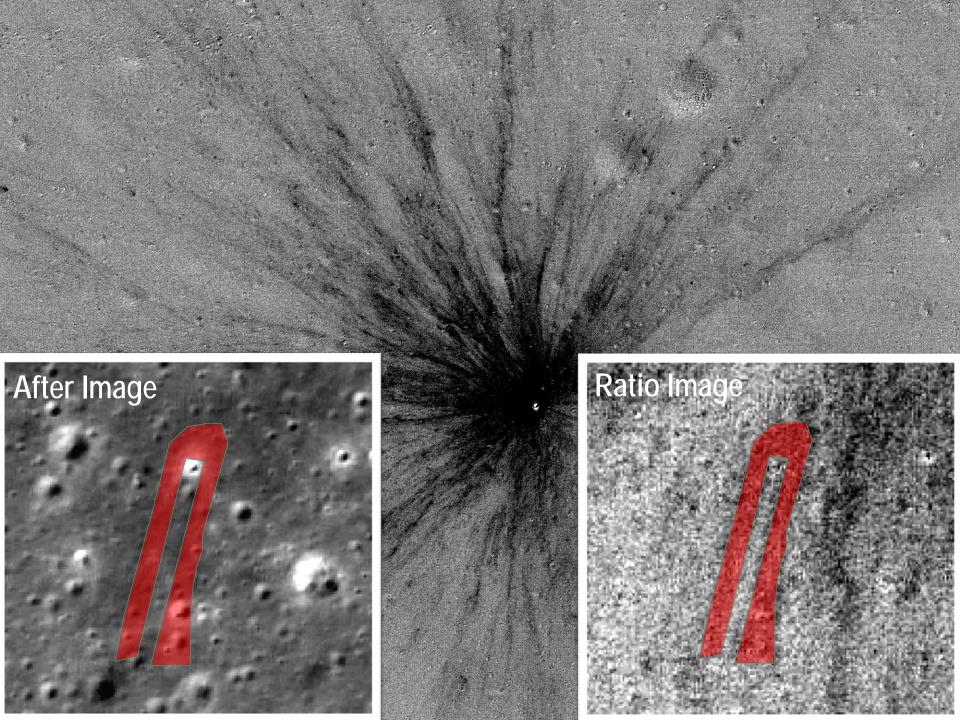


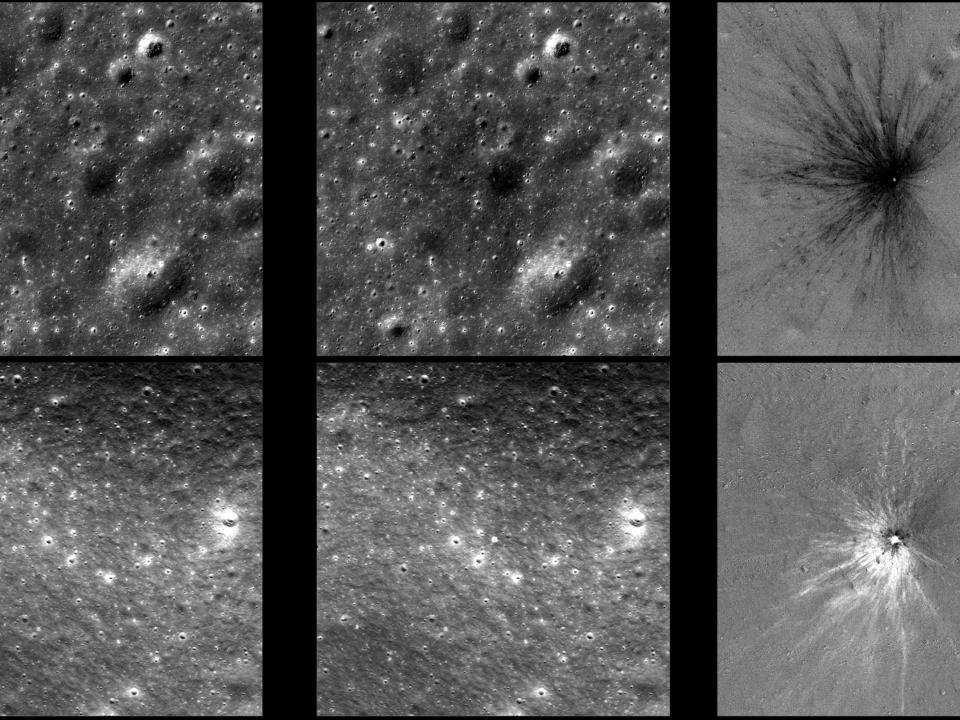


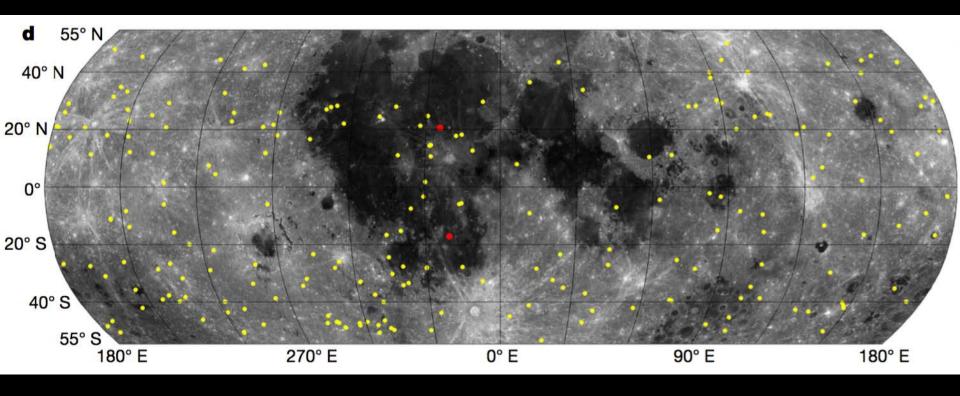












Hundreds of new resolved impact craters Tens of thousands of new surface changes