Motivation and Challenges for Sampling the Moon's Giant South Pole-Aitken Basin

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Bradley L. Jolliff (bjolliff@wustl.edu)

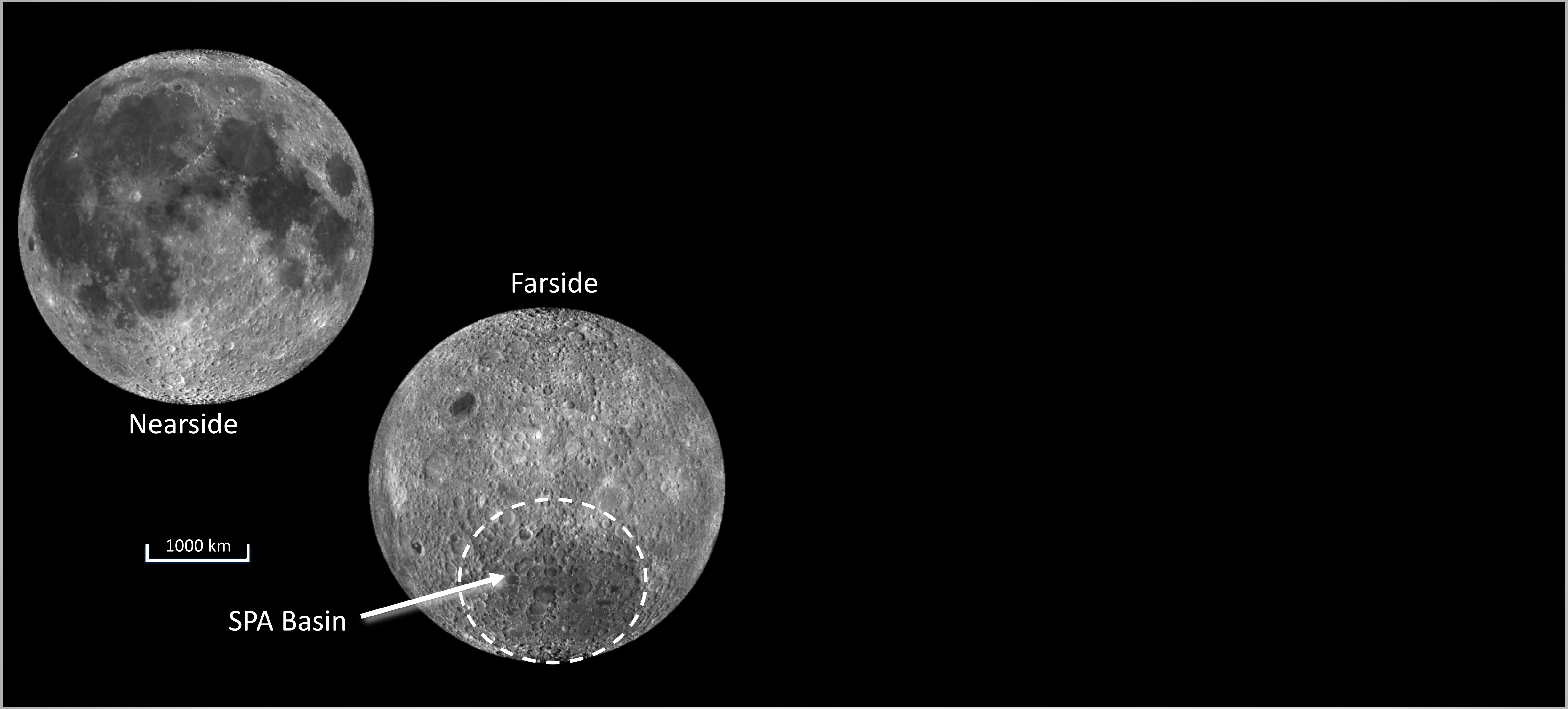
Department of Earth & Planetary Sciences and
The McDonnell Center for the Space Sciences

Washington University in St. Louis
St. Louis, MO 63130

Outline

- What is the South Pole – Aitken Basin and why is it important to explore it?
  - Why must we collect and analyze samples from it?
- An approach to robotic sampling: the MoonRise mission concept
  - Scientific challenges
  - Technical challenges
  - Programmatic challenges
- Exploring South Pole – Aitken Basin in an Artemis context
- Will CNSA sample the South Pole – Aitken Basin?

The South Pole – Aitken Basin is one of the largest impact features in the Solar System. Oldest & largest on the Moon.



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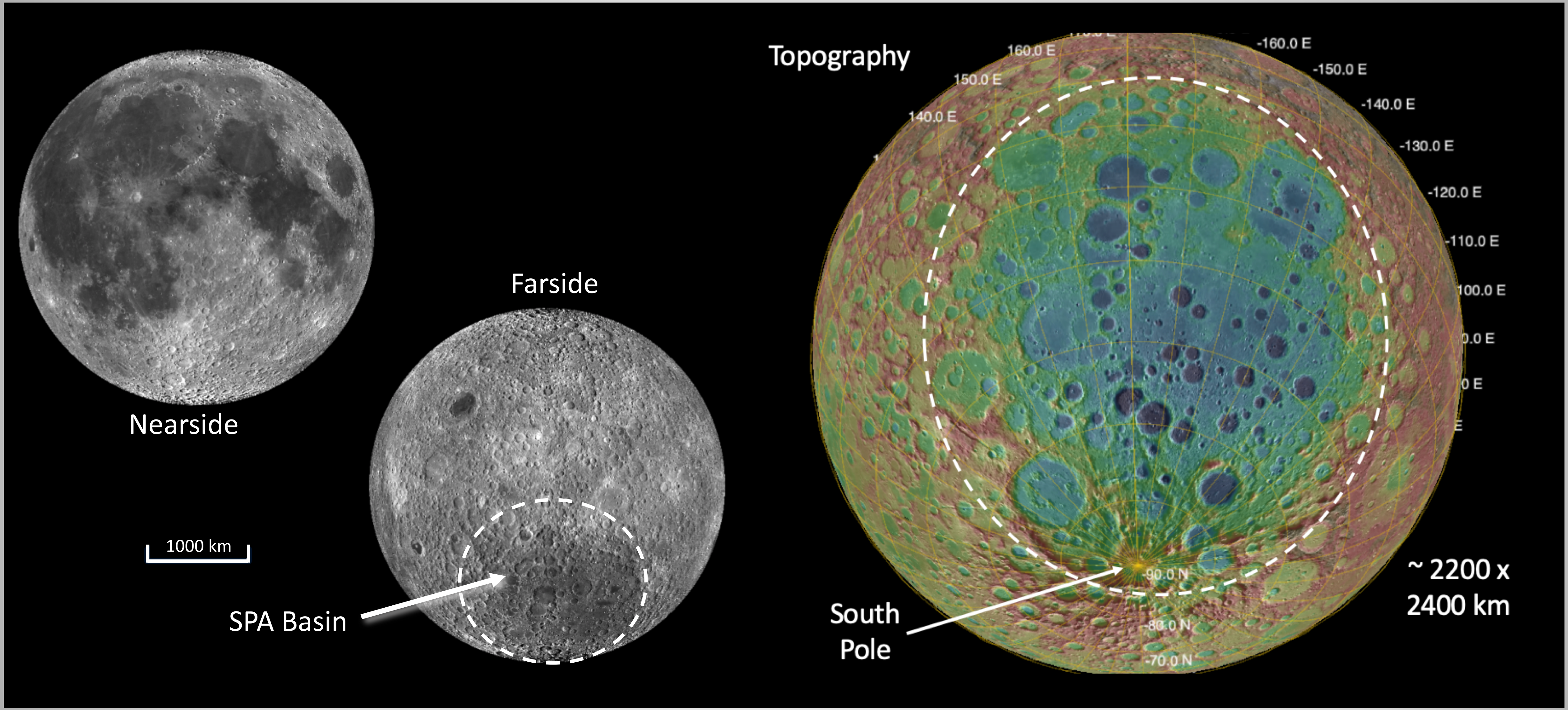
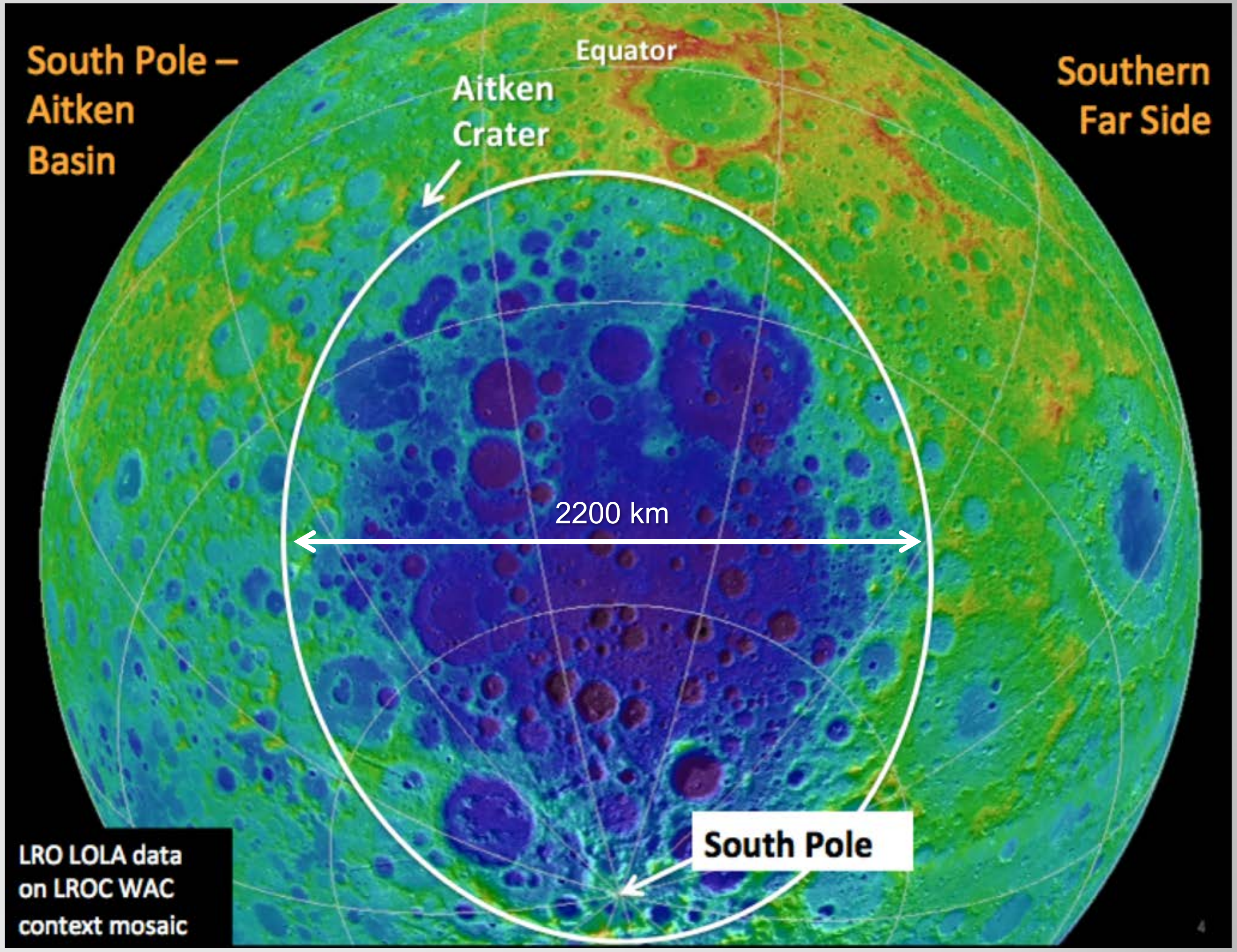


The South Pole – Aitken Basin is one of the largest impact features in the Solar System. Oldest & largest on the Moon.

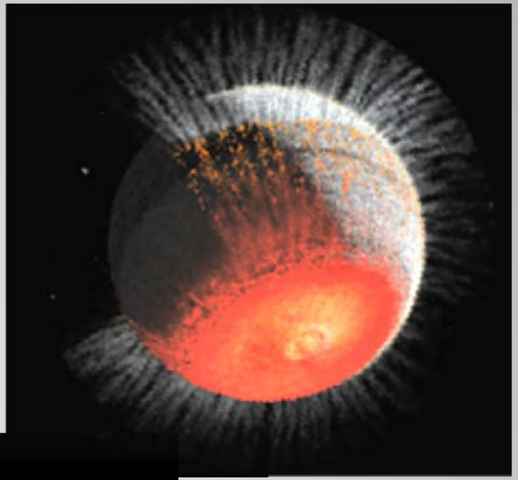
- **A unique location on the Moon and in the Solar System**
- SPA: largest and oldest clearly recognizable lunar impact basin
  - SPA event completely resurfaced large part of the Moon and reset ages over an enormous area.
  - As such, SPA *anchors the lunar impact chronology*.

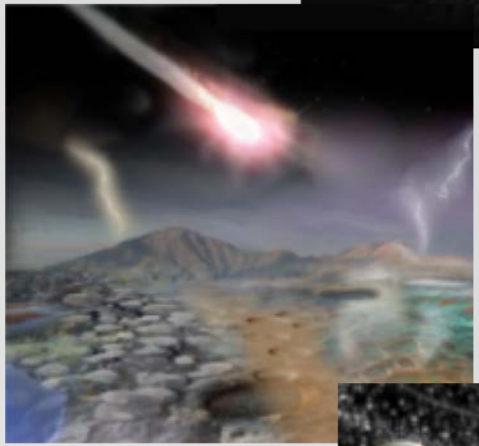
Critical Science is to determine the basin formation age and SPA chronology.

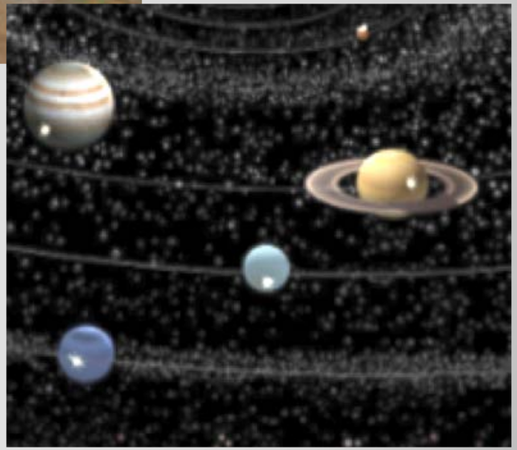


Compelling Science Questions

- What was the heavy bombardment history of the Moon?
  - *Was there a Cataclysm? What duration?*
- What are the implications for early Earth and the terrestrial planets?
  - *Critical time for early life on Earth (and elsewhere?)*
- What are the implications for early Solar System Dynamics?
  - *Nice, Grand Tack, Pebble Accretion, etc.*

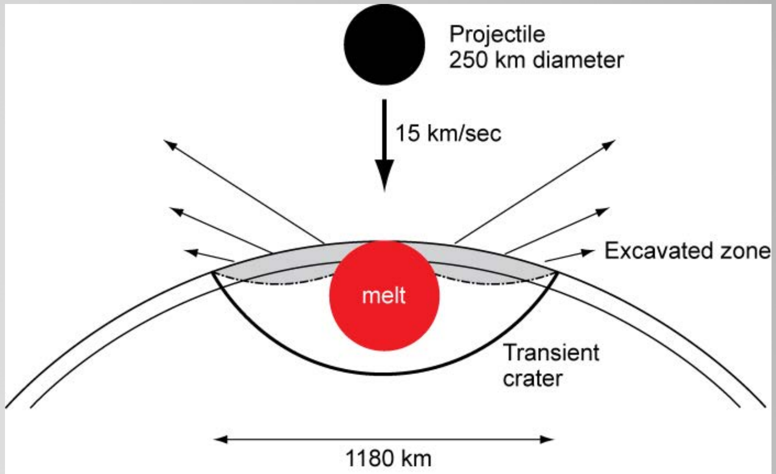


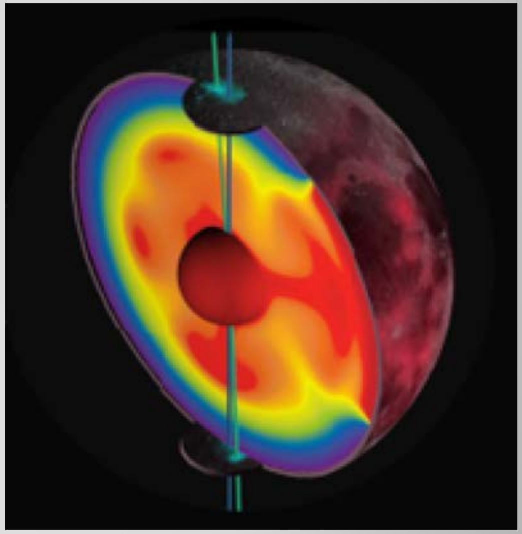




And more Compelling Science

- **Better understanding of the (very large) impact basin formation process**
  - How deep did SPA penetrate, how were the excavated materials distributed, how did the Moon's crust and mantle respond?
- **Elucidate Crust / Mantle / Core structure**
  - What are the processes that produced large-scale planetary heterogeneity and when was the core dynamo active?
- **Thermal Evolution of the Moon**
  - What is the distribution of heat-producing elements in the lunar interior and implications for thermal evolution?
- **Basalts as Probes of the Farside Mantle**
  - What is the heterogeneity of the farside vs. near-side mantle?

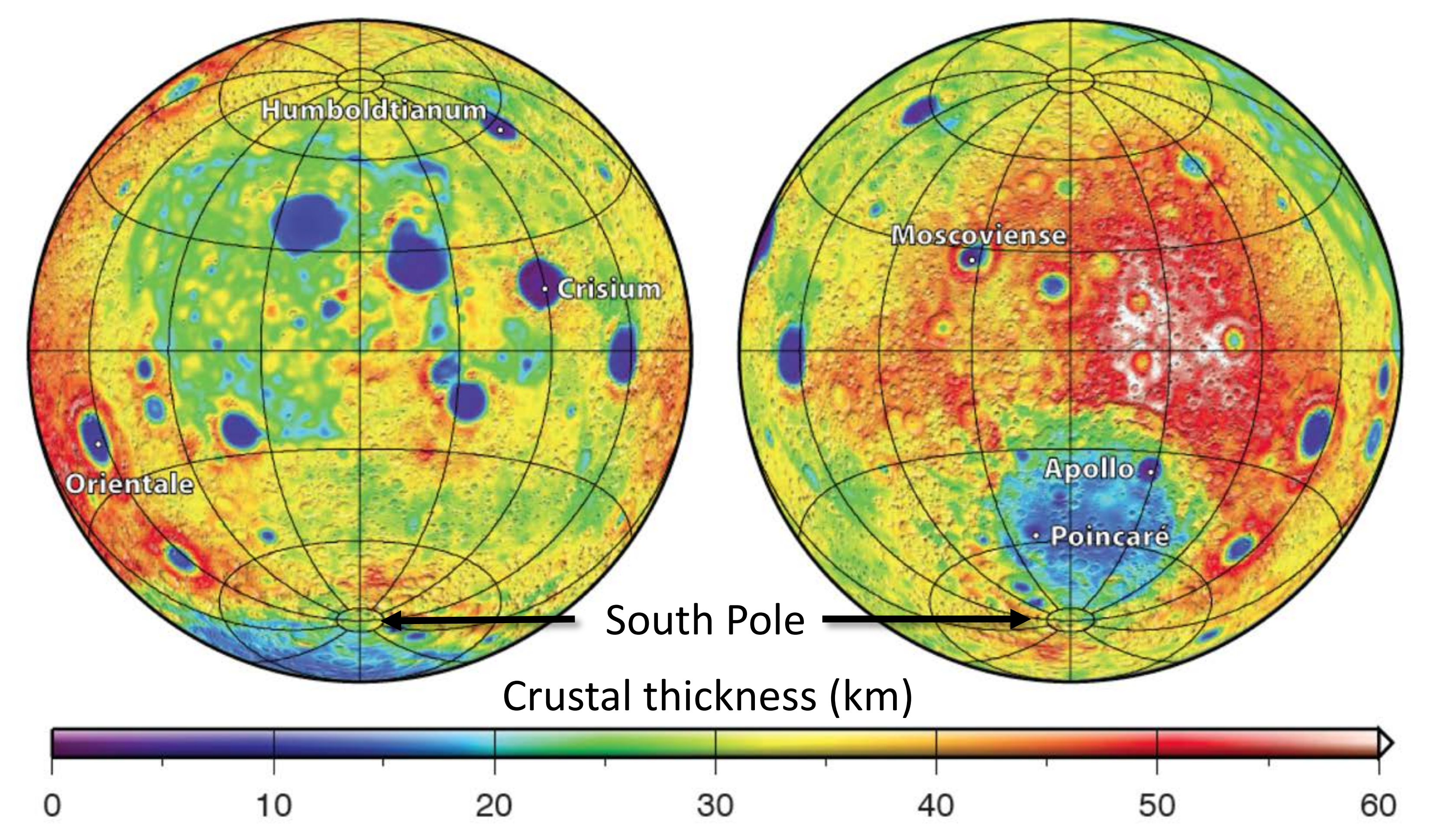




Geophysics – GRAIL (2011-2012)

- SPA Basin
  ~10-20 km crustal thickness (likely impact melt body)
- Low Porosity
  ~ 6%
- High Density
  ~ 2800 kg/m^3

➢ *Need to know the rock types!*

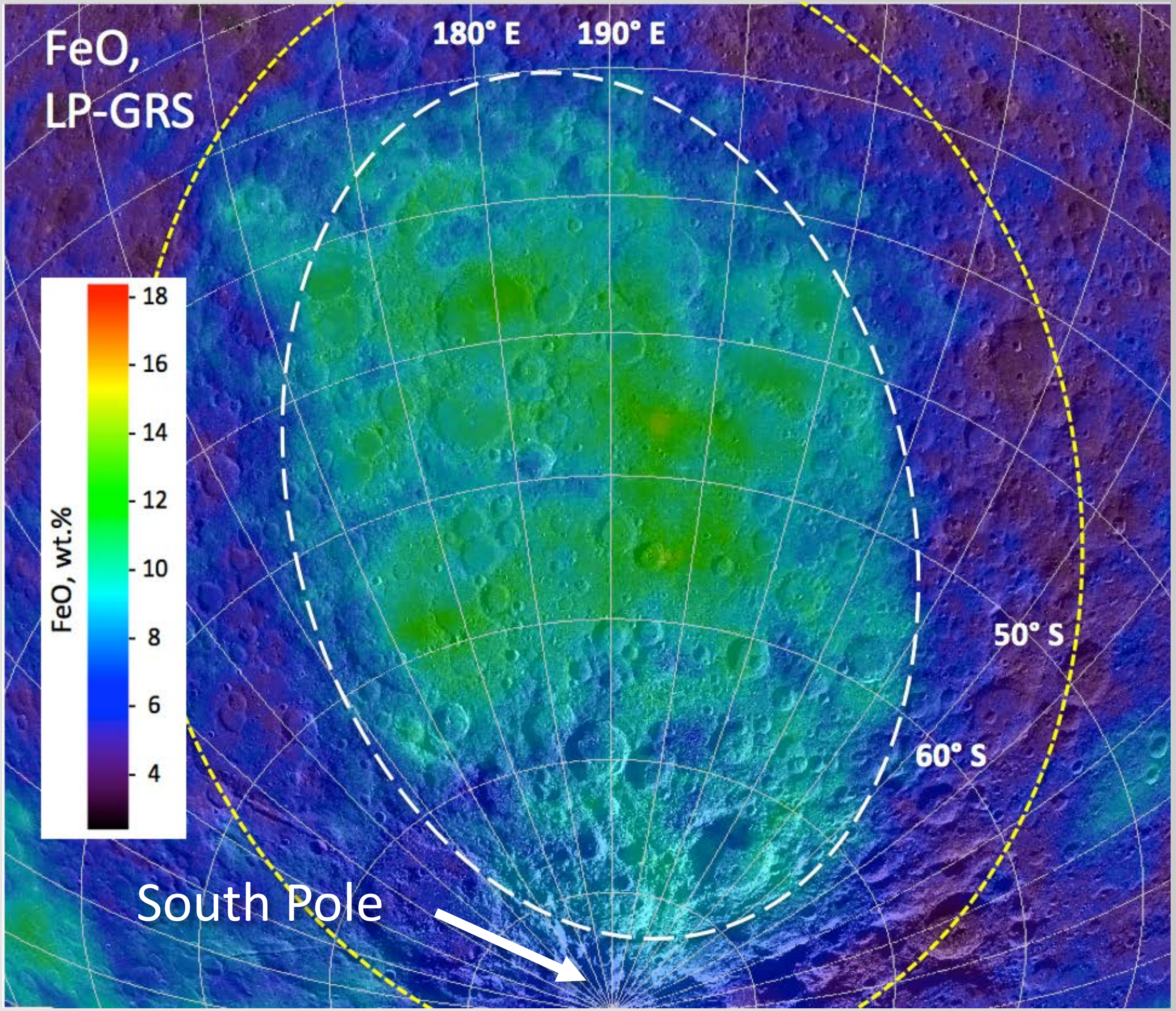


Crustal thickness superposed on topography. Model assumes crustal porosity of 12% and a mantle density of 3220 kgm^{-3}

Wieczorek et al (2013)

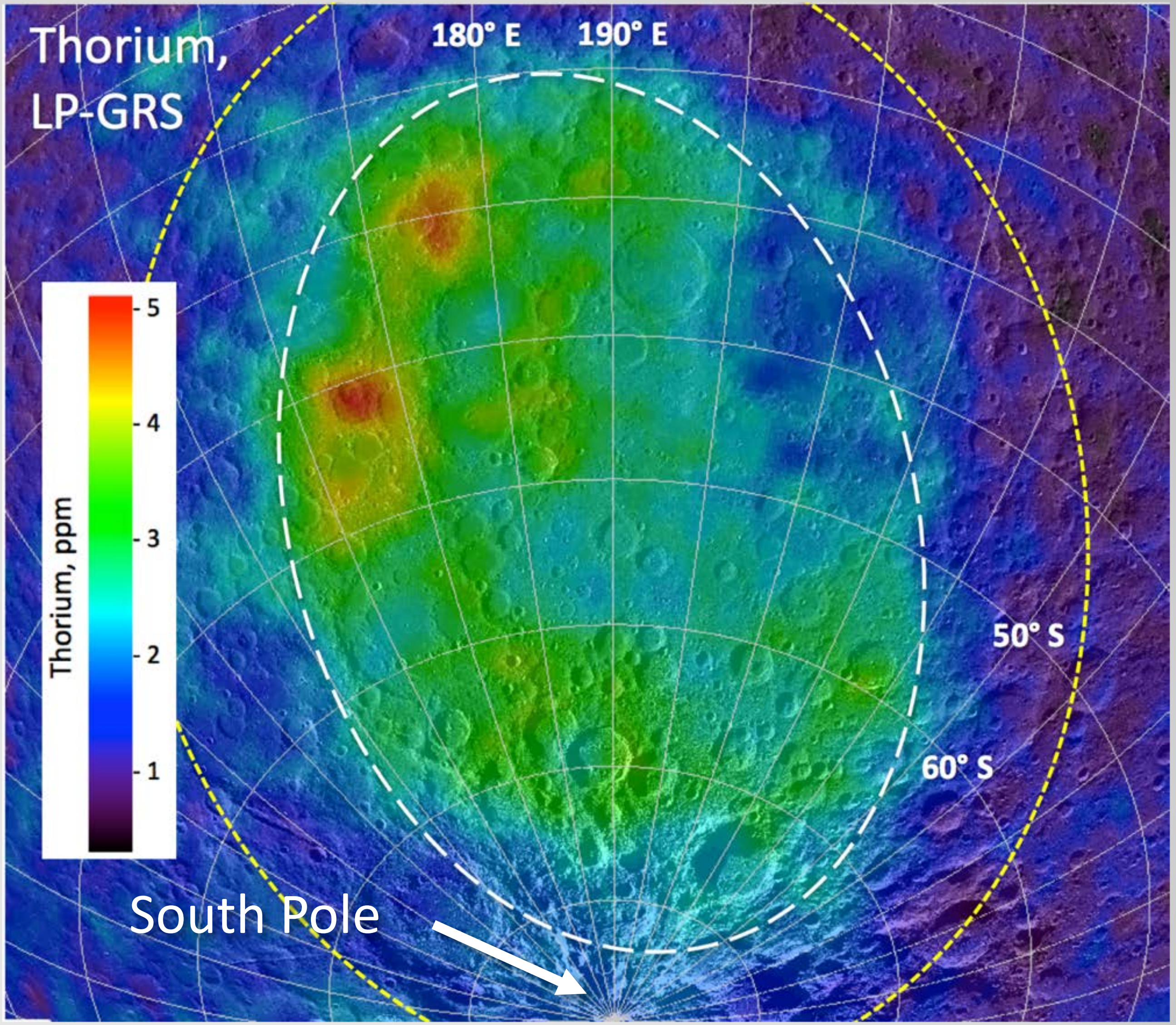
Lunar Prospector gamma-ray Spec FeO

- LP-GRS FeO map reflects compositional signature of the SPA basin interior.
    - Range: 8-16 wt.% FeO
- Basalt ponds have high FeO, but many areas are significantly mafic without mare basalts.
- Consistent with high proportion of SPA impact-melt materials, including deep mantle materials.



Lunar Prospector gamma-ray Spec Thorium

- LP-GRS Th map also reflects compositional signature of the SPA basin interior.
  - Range: 2-4 ppm (generally)
  - >5 ppm (hotspots)
- Thorium anomaly does not extend to the South Pole
  - SPA materials present at So. Pole as ejecta, but diluted by feldspathic highlands components

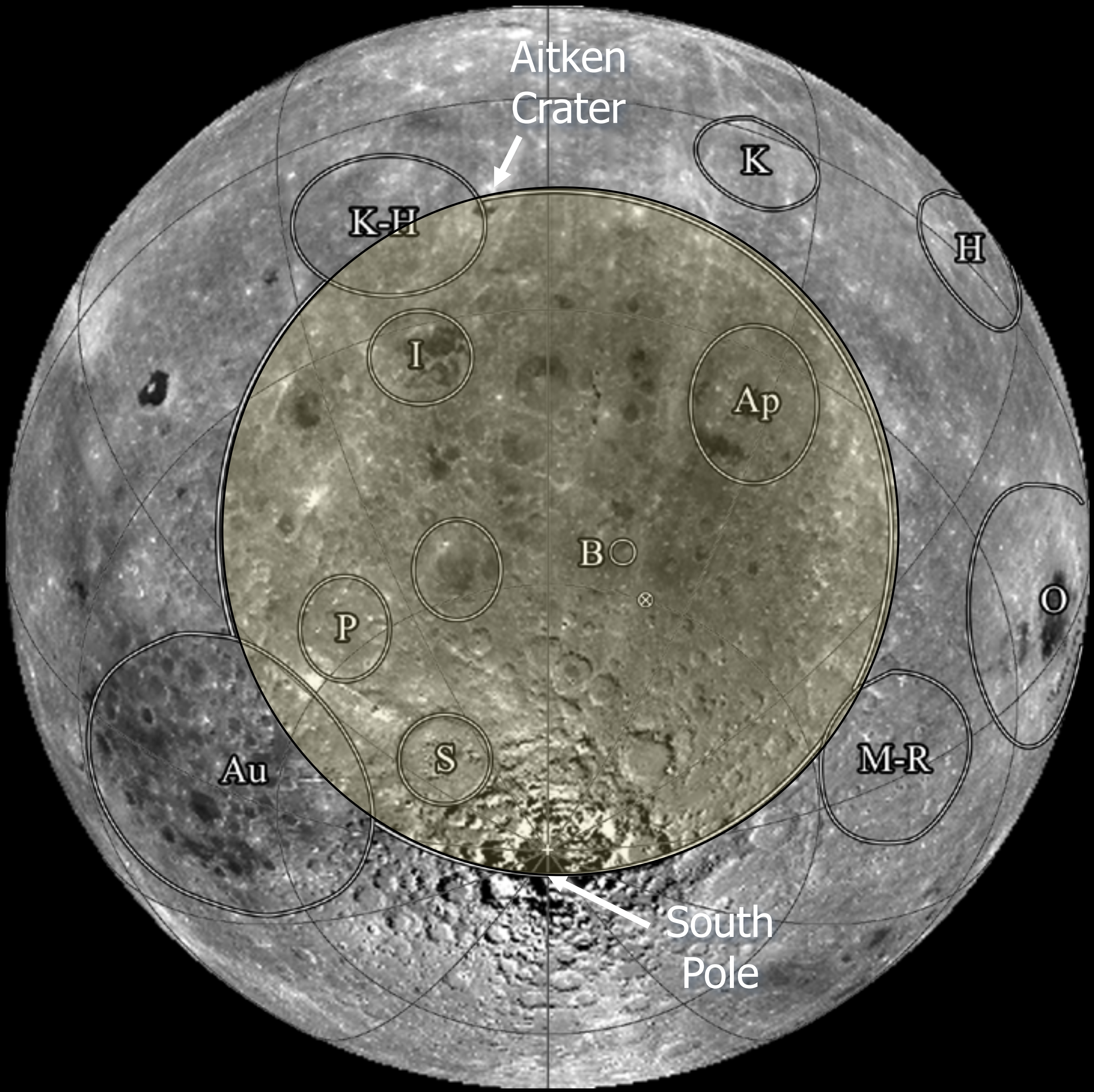


In summary: South Pole - Aitken Basin:

Window to the deep Crust and upper Mantle of the Moon

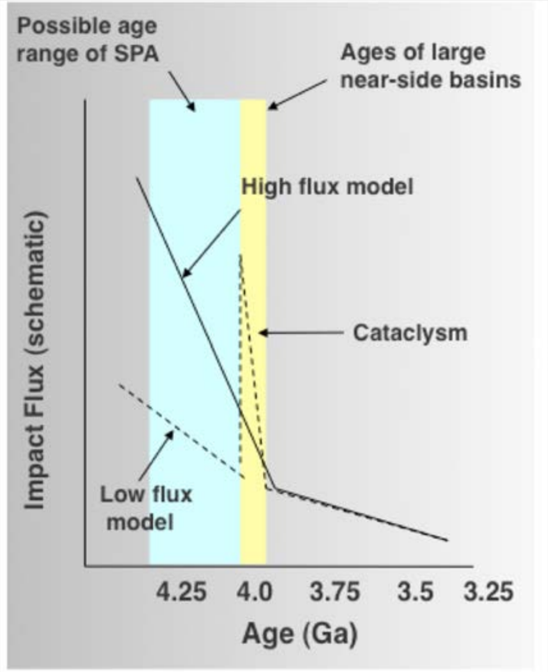
Window to early Solar System History

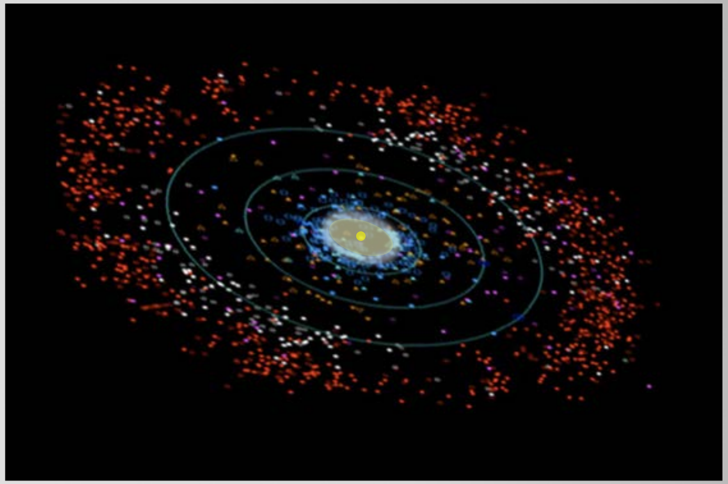
Scientifically compelling

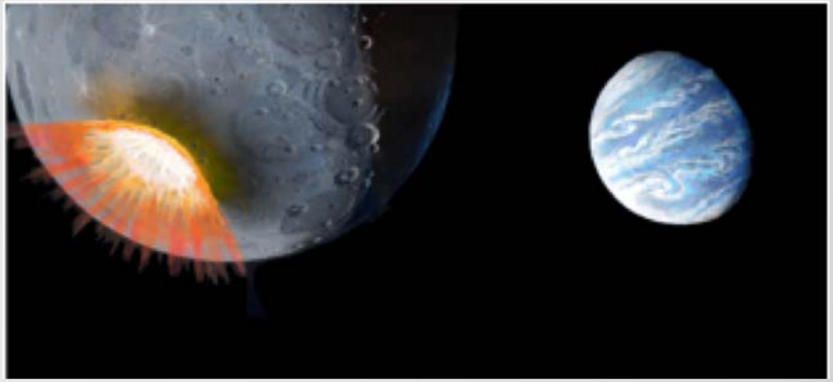


SPA sample return addresses key Solar System Science

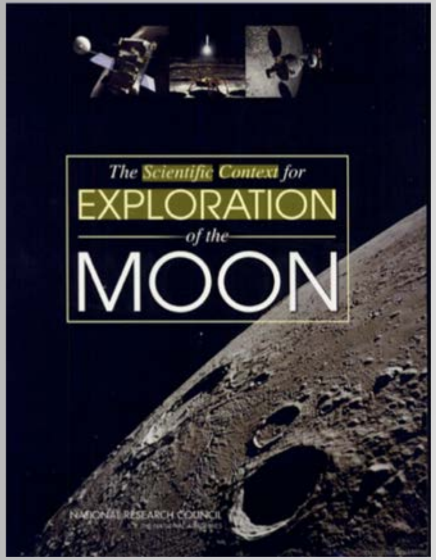
- **SPA samples will enable a critical test of the "Cataclysm" hypothesis that is indicated by Apollo samples.**
    - **Significance for early Solar System orbital dynamics**
        - **Significance for:**
          Earth-Moon System
          - Impact chronology
          - Implications for evolution of early Earth
            - Continental growth
            - Atmospheric evolution
            - Origin of life





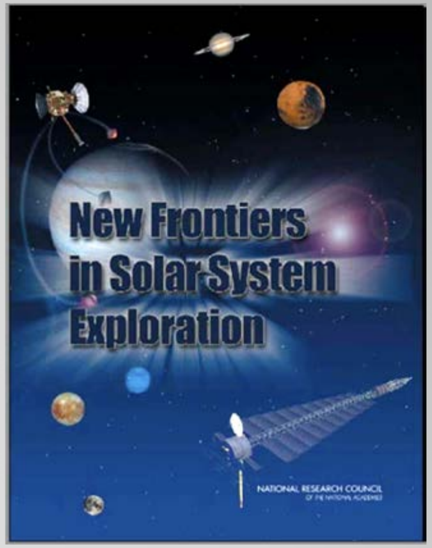


SPA Sample Return: Basis for High Priority



New Frontiers in the Solar System, an Integrated Exploration Strategy. ***US National Academy of Science Decadal Survey, Solar System Exploration*****, NRC, 2003.**

- Established sample return from South Pole-Aitken Basin as a top priority for exploration of the inner Solar System

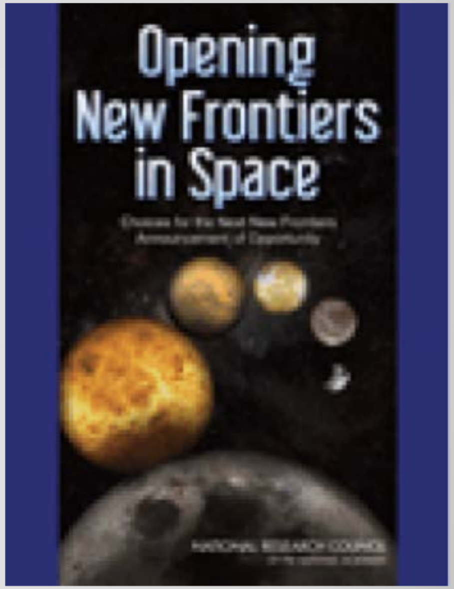


Report on The Scientific Context for Exploration of the Moon (SCEM), NRC, 2007

- Reaffirmed importance of SPA for lunar and Solar System science.

New Opportunities for Solar System Exploration (NOSSE), NRC, March 2008

- Validated the Planetary Science Decadal Survey and listed five science goals for the (SPA-SR) mission.



Why are samples needed?

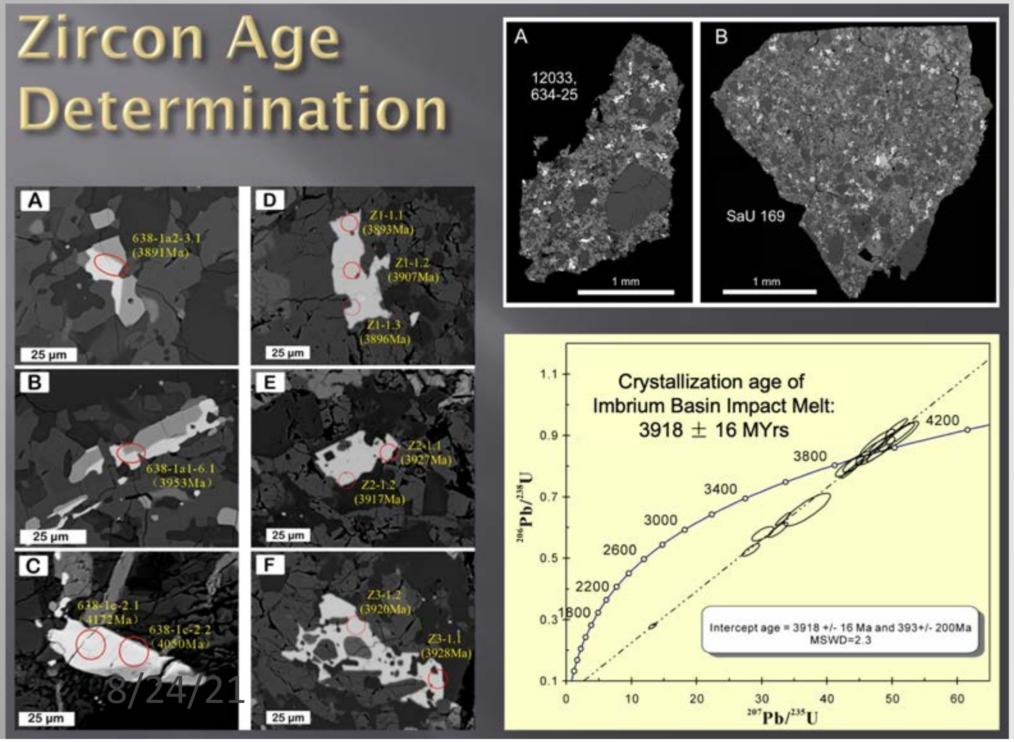
1. *Rocks are needed for chronology (age dating)*

Chronology includes U-Th-Pb, Rb-Sr, Sm-Nd, Ar(40/39), Lu-Hf, Hf-W

Analytical methods include bulk analysis and spot analysis (SIMS microbeam (secondary ion mass spectrometry), laser heating and laser ablation ICP-MS – inductively-coupled-plasma mass spectrometry)

The needed precision requires sample return and analysis in best labs on Earth. Cannot be done adequately using in-situ analysis on the lunar surface.

Liu et al., 2012 EPSL 319-320



Photos rom Dimitri Papanastassiou

Why are samples needed?

1. *Rocks are needed for chronology (age dating)*

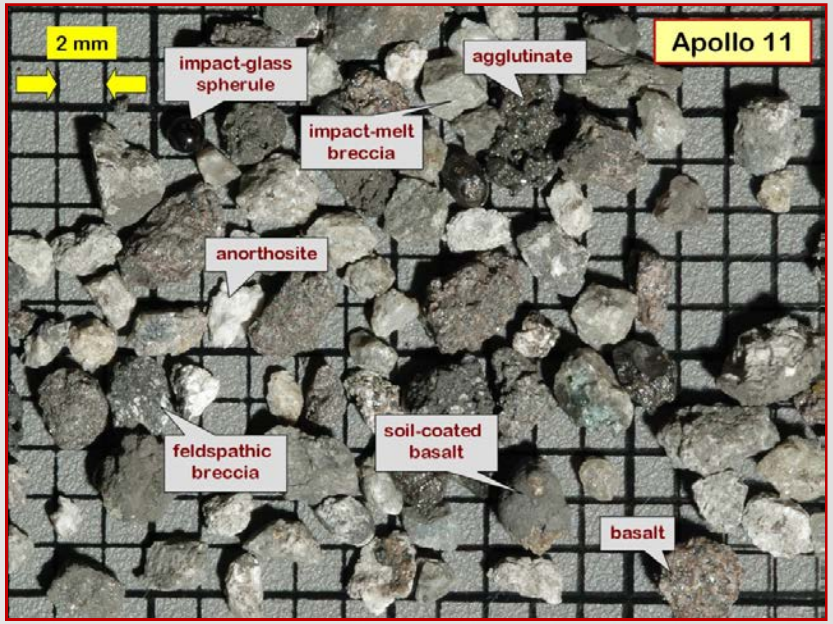
2. *Rock types: impact-melt breccias (Apollo examples) and igneous rocks*

Desired materials:

Some large rocks (hand sample),
Many small rocks (>4 mm; rake and sieve)

Troctolite 155 g, Apollo 17 rake sample

14321 Clast-rich, impact-melt breccia, 9 kg



Rock fragments, 2-4 mm, sieved from Apollo 11 regolith

What kind of samples are needed?

1. *Rocks are needed for chronology (age dating)*

2. *Rock types: impact-melt breccias (Apollo examples) and igneous rocks*

3. *Need diversity*

- large rocks from different locations

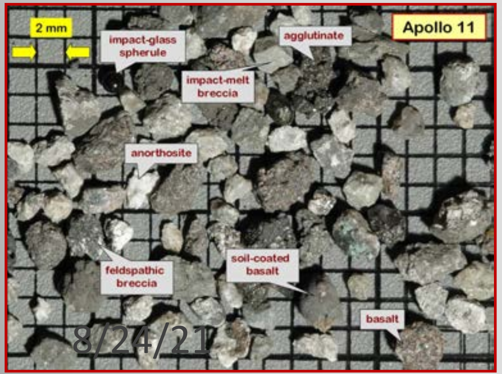
- small rocks in regolith

Impact process yields diverse suite of small rocks in regolith.

Small rocks pieces typically make up 5-10% of regolith. Rake and sieve to increase scientific value of rock material.

Collect thousands (e.g., kg size bulk sample, ideally at several locations to assess representativeness)

Also must collect unsieved regolith. Apollo 11 sample 10084 (3.8 kg) among the most valuable geologic samples ever collected. It's the haystack and the needle is in there. *And we know how to find it.*



Apollo 16, John Young with rake

Challenges for SPA Sample Return

- Scientific
  - Where to go to get the “right” samples?
  - How do we know when we have the right samples?
  - Will the samples be too complex to unravel SPA history?
- Technical
  - Must ensure a safe landing: crater and boulder hazards
  - Complexity of sample collection and transfer to sample return capsule
  - Risk associated with a complex mission and multiple spacecraft components
- Programmatic
  - Will Artemis accomplish SPA sample return and science objectives?
  - Will CNSA or another entity do the mission first?

SPA Basin is a vast, continent-sized area

Where to sample?

Oblique view of central South Pole-Aitken basin along day-night terminator derived from Lunar Reconnaissance Orbiter data
NASA/GSFC/ASU (Ernie Wright, GSFC SVS)

Challenges for SPA Sample Return

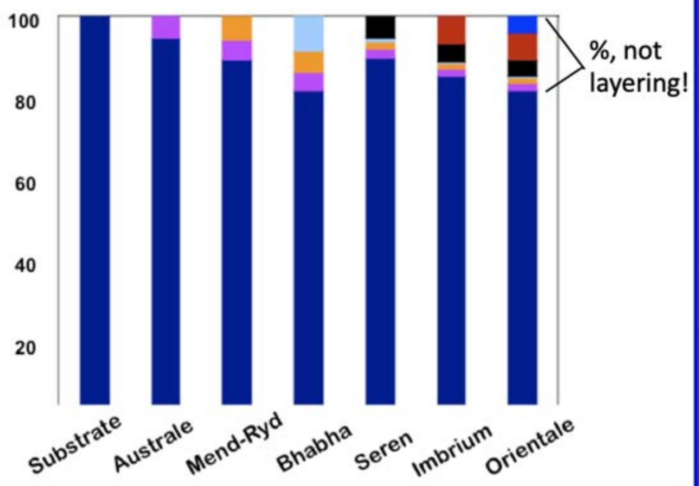
- Scientific
  - Where to go to get the “right” samples?

Leverage the impact process; impacts deliver the samples.

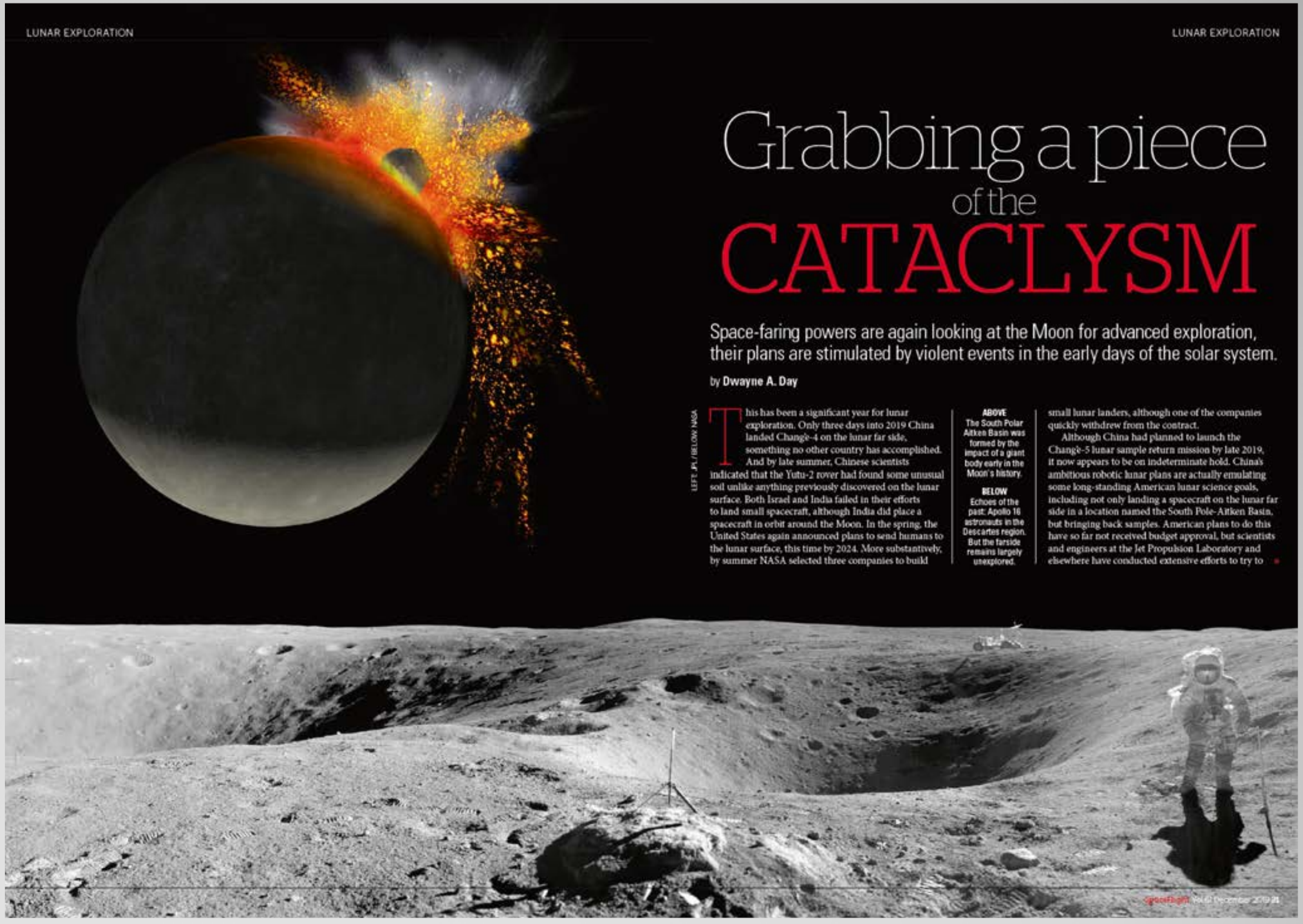
<u>MoonRise solution</u>

- Sample anywhere in the basin to achieve science objective (determine SPA age & chronology).
- Impact cratering process excavates and mixes materials to form regolith. We sample the regolith.
- Impacts within SPA and subsequent to its formation simply excavate and mix SPA “substrate”
- Use orbital remote sensing to select “most favorable” locations for landing and sample collection.

Modeling ballistic impact ejecta deposits; example for the interior of SPA basin.



Percent basin source of material in ejecta deposits. Example is for SPA *interior site* beginning with SPA basin fill (“substrate”). *From Haskin et al., 2003.*



LUNAR EXPLORATION

Grabbing a piece of the CATACLYSM

Space-faring powers are again looking at the Moon for advanced exploration, their plans are stimulated by violent events in the early days of the solar system.

by Dwayne A. Day

LEFT: JPL / BELOW: NASA

This has been a significant year for lunar exploration. Only three days into 2019 China landed Chang'e-4 on the lunar far side, something no other country has accomplished. And by late summer, Chinese scientists indicated that the Yutu-2 rover had found some unusual soil unlike anything previously discovered on the lunar surface. Both Israel and India failed in their efforts to land small spacecraft, although India did place a spacecraft in orbit around the Moon. In the spring, the United States again announced plans to send humans to the lunar surface, this time by 2024. More substantively, by summer NASA selected three companies to build small lunar landers, although one of the companies quickly withdrew from the contract.

Although China had planned to launch the Chang'e-5 lunar sample return mission by late 2019, it now appears to be on indeterminate hold. China's ambitious robotic lunar plans are actually emulating some long-standing American lunar science goals, including not only landing a spacecraft on the lunar far side in a location named the South Pole-Aitken Basin, but bringing back samples. American plans to do this have so far not received budget approval, but scientists and engineers at the Jet Propulsion Laboratory and elsewhere have conducted extensive efforts to try to

ABOVE The South Polar Aitken Basin was formed by the impact of a giant body early in the Moon's history.

BELOW Echoes of the past: Apollo 16 astronauts in the Descartes region. But the farside remains largely unexplored.

Grabbing a piece of the Cataclysm
Dwayne A. Day presents an in-depth study of various proposals, past and present, for returning lunar samples to Earth from a particularly violent impact experienced by the Moon during the early days of its formation.

Image on left is one of the MoonRise New Frontiers Mission proposal graphics.

Challenges for SPA Sample Return

- Scientific
  - How do we know when we have the right samples?

<u>MoonRise solution</u>

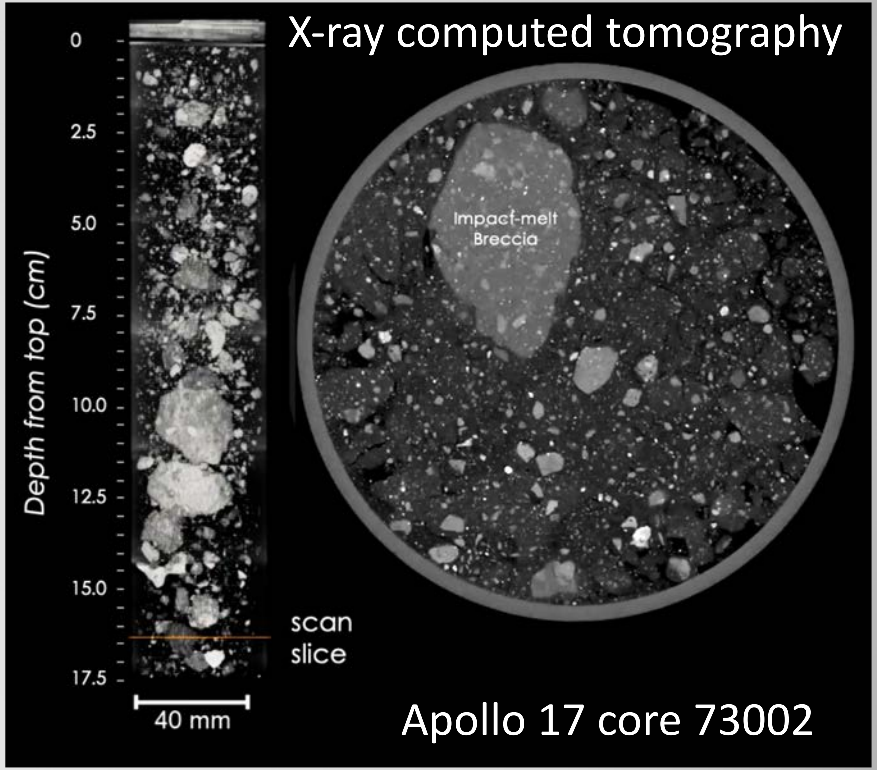
- Sieve the regolith to extract rock fragments.
  (rock fragments needed for age determinations)
- Rock fragments ~ 5-10% of regolith, so sieving to collect mainly rock fragments increases yield of sample by 10-20 times.
- Collect 2 kg mass, thousands of rock fragments
- Apollo, Luna, and lunar meteorite analytical experience

Challenges for SPA Sample Return

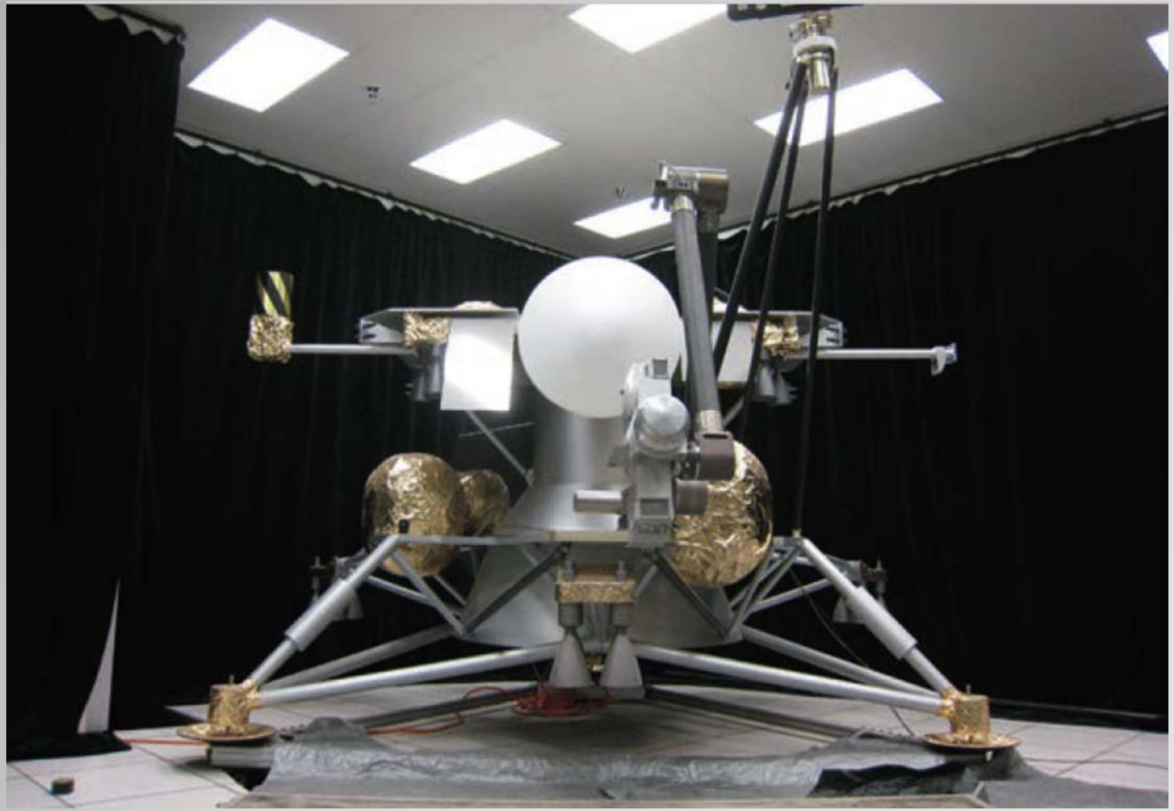
- Scientific
  - Will the samples be too complex to unravel SPA history?

<u>MoonRise (or any modern mission) solution</u>

- Modern analytical tools are greatly advanced compared to Apollo era. E.g., next-gen sample analysis (ANGSA)
- Small sample analysis – Genesis, Stardust, Hayabusa
- Leverage integration with recent state-of-the-art remote sensing (LRO, GRAIL, international missions)



Technical: Complexity of sample collection?



Mockup of the MoonRise lander, sample acquisition system, sample return canister, and ascent module at JPL, 2011, as part of the New Frontiers Phase A study.

Below: test box in front of lander is filled with lunar simulant for sample acquisition testing and demonstration. *Image credit: NASA/JPL*

“The technology is mature for a robotic sample return mission from the South Pole-Aitken Basin”

Dr. Leon Alkalai, JPL, MoonRise capture lead

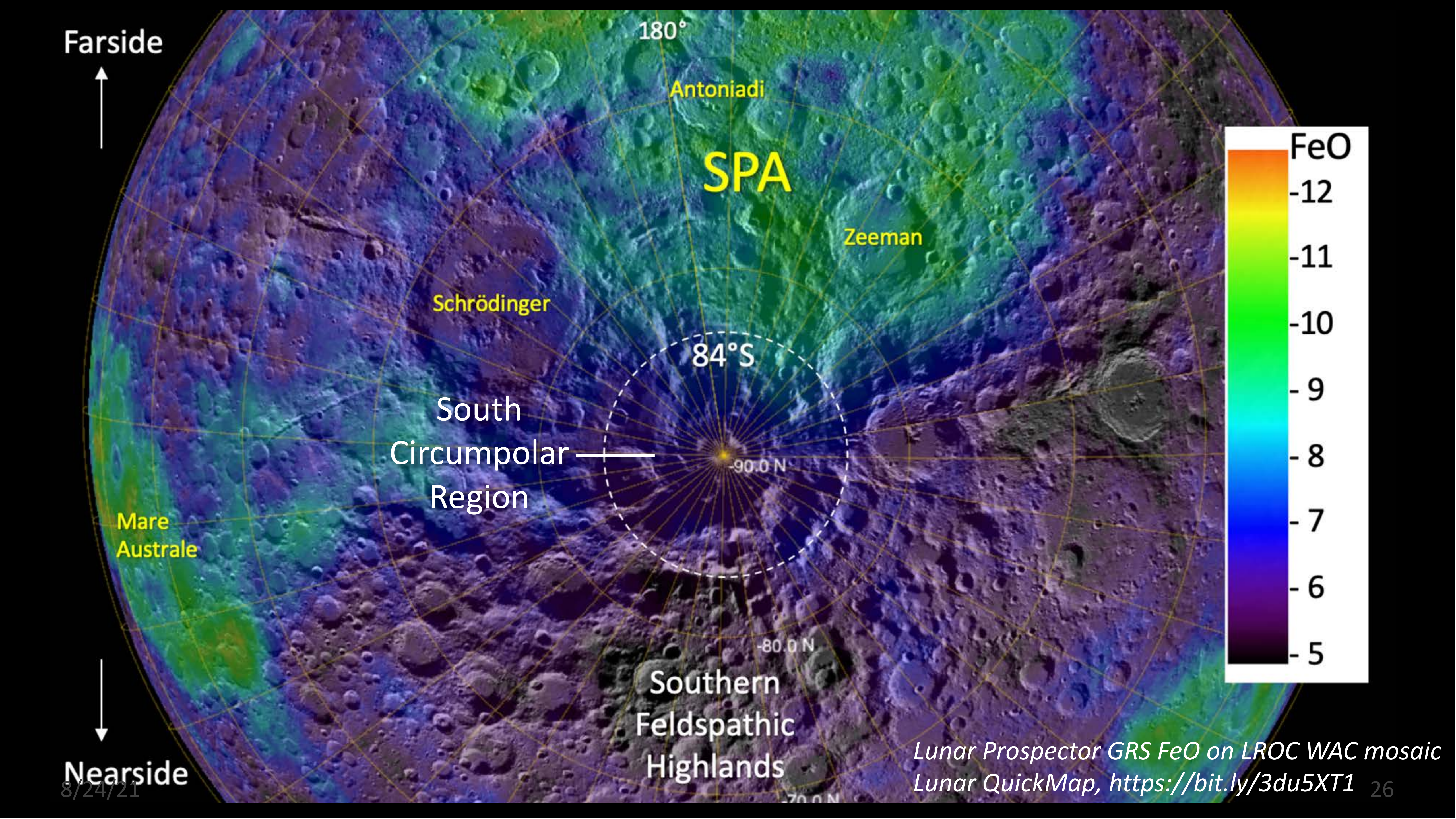
Challenges for SPA Sample Return

- Technical
  - Must ensure a safe landing: crater and boulder hazards
    - LRO systems (LROC, LOLA, Diviner) provide ample data to land safely anywhere on the Moon
    - Boulders: LROC can spot to <1 m *and* we know where they tend to occur.
  - Complexity of sample collection and transfer to sample return capsule
    - Testing and careful engineering; redundancy; KISS
  - Risk associated with a complex mission and multiple spacecraft components
    - Testing and careful engineering; redundancy; heritage (e.g., Stardust SRC)
    - CNSA has just completed such a mission successfully (Dec. 2020)

Challenges for SPA Sample Return

- Programmatic
  - Will Artemis accomplish SPA sample return and science objectives?
    - SPA southernmost rim passes close to the Moon's South Pole.
    - Materials ejected from the SPA basin along its southern rim were deposited within the south circumpolar region.
    - Subsequent impact history and ballistic mixing of deposits over 4+ billion years have diluted the southern SPA rim deposits, but some portion of the SPA rim deposit 'substrate' is still present in the south circumpolar region.

** These (SPA) materials should be found among comprehensive samples collected at the Artemis III landing site.*



Lunar Prospector GRS FeO on LROC WAC mosaic
Lunar QuickMap, https://bit.ly/3du5XT1

Artemis: SPA sample return

- Will there be SPA material in deposits at the south circumpolar region (poleward of 84 deg S latitude?
  - Yes! Non-trivial, on order of 20% on average.

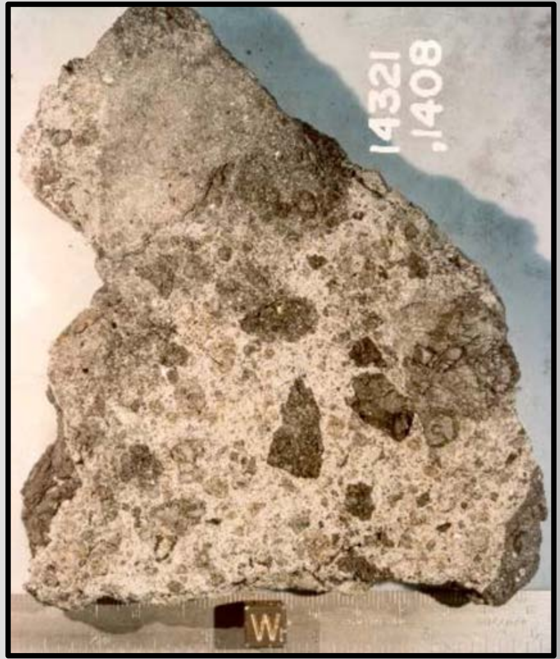
- Will this material be easy to find?
  - Not necessarily. Will require many samples, careful analysis, and age determinations.
  - Will likely be as - or in - complex breccias - - - ->

- Sampling for Artemis III *must* include "comprehensive" samples, e.g., systematic kg+ regolith samples and sieved or rake samples to collect hundreds of small rocks (and a few big ones!)

- *SPA science will be enhanced enormously by a separate (robotic) sample collection from the interior of SPA.*

Might just look like this!

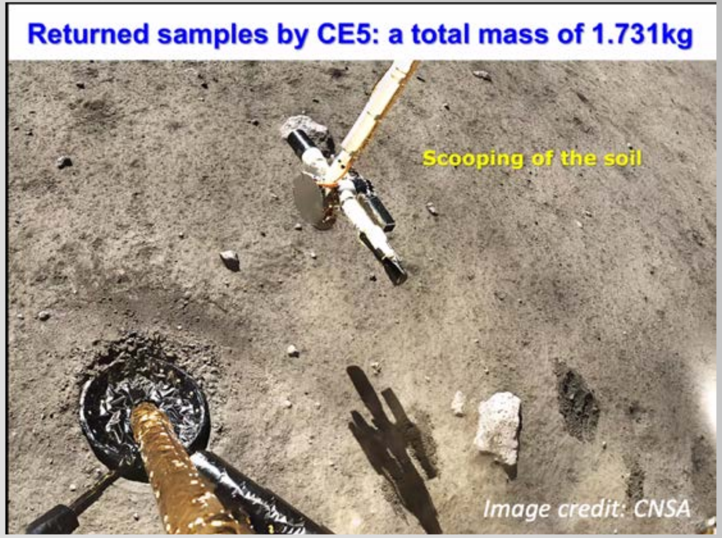
Apollo 14 breccia 14321

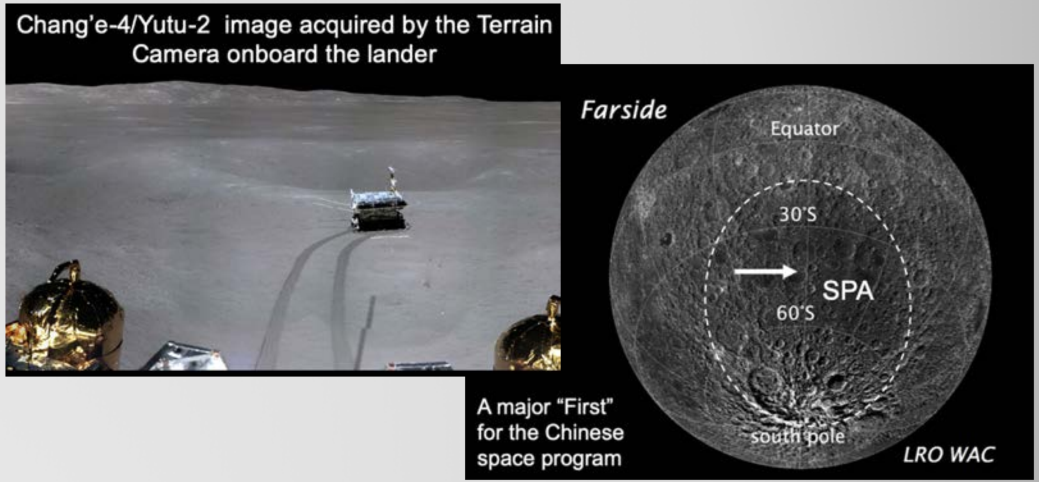


Challenges for (US) SPA Sample Return

Will CNSA or another entity do the mission first?

- China has just completed a robotic sample return mission, CE-5 (Dec. 2020).
- 1.73 kg of regolith scoop and core samples returned.
- Many rock fragments, suitable for age determination.
- China has already landed a rover mission inside SPA (CE-4).
- China has a backup to CE-5 that may be used for SPA or south polar sample return.





SPA Sample Return still a decadal survey science priority

White paper: Primary Author: Brad Jolliff, Washington University in Saint Louis, bjolliff@wustl.edu

Co-Authors

Noah Petro, NASA GSFC
Daniel Moriarty, NASA GSFC
Ryan Watkins, Planetary Sci. Inst.
Sarah Valencia, NASA GSFC
Kelsey Young, NASA GSFC
James Tuttle Keane, Caltech/JPL
Heather Meyer, APL

Maria Banks, GSFC
Mini Wadhwa, ASU
Nicole Schmitz, DLR
Cass Runyon, Coll of Charleston
Juliane Gross, JSC/Rutgers University
Trevor Graff, NASA JSC
Stephen Elardo, University of Florida

Sara Mazrouei, University of Toronto
Matt Siegler, Planetary Sci. Inst.
Kris Zacny, Honeybee Robotics,
Michele Faragalli, Carleton University
Daniel Glavin, NASA GSFC
Ross Potter, Brown University
R. Aileen Yingst, Planetary Science Inst.

Donald Barker, NASA
Csilla Orgel, ESA-ESTEC
Jessica Flahaut, CNRS/CRPG Nancy
Georgiana Kramer, Planetary Sci. Inst.
Alan Cassell, NASA Ames Res. Center
Kerri Donaldson Hanna, Univ. Central Florida
Tomas Magna, Czech Geol. Survey, Prague

White Paper Topics

Significance at level of New Frontiers Science: Chronology of lunar basin-sized impacts; Test of Cataclysm Hypothesis; and relevance for early Solar System orbital dynamics

Significance for early evolution of the Moon; formation of secondary crust; possible driver of major igneous & volcanic activity on Moon at time of formation

Test of hypotheses: SPA as a source of ancient igneous rocks such as 76535
Test CSFD analysis for age of SPA; anchoring lunar chronology

Giant impact basin theory; determine depth of excavation via composition of returned samples and investigate differentiation of thick melt body and GRAIL model for SPA crustal thickness

Volcanism in SPA: determine timing of volcanism (mare, nonmare cryptomare) and test models of mantle composition and heterogeneity

Remote sensing of SPA mineralogy and composition; providing ground truth via samples and extending knowledge from sample site to entire SPA basin
Enable recognition and interpretation of lunar meteorites that may come from SPA

South Polar deposits: ejecta from SPA and polar volatile deposits may be possible in one sample return from a well-selected site

Geology of SPA basin; where and how best to sample?

SPA-SR in the Age of Artemis and relevance for CLPS, PRISM programs

Recommendation: *Sample return from SPA remains a high priority for Solar System and Lunar Science, even more so now than in the past two decades.*