Lunar Landing Sites Addressing NRC (2007) Objectives for the Scientific Exploration of the Moon

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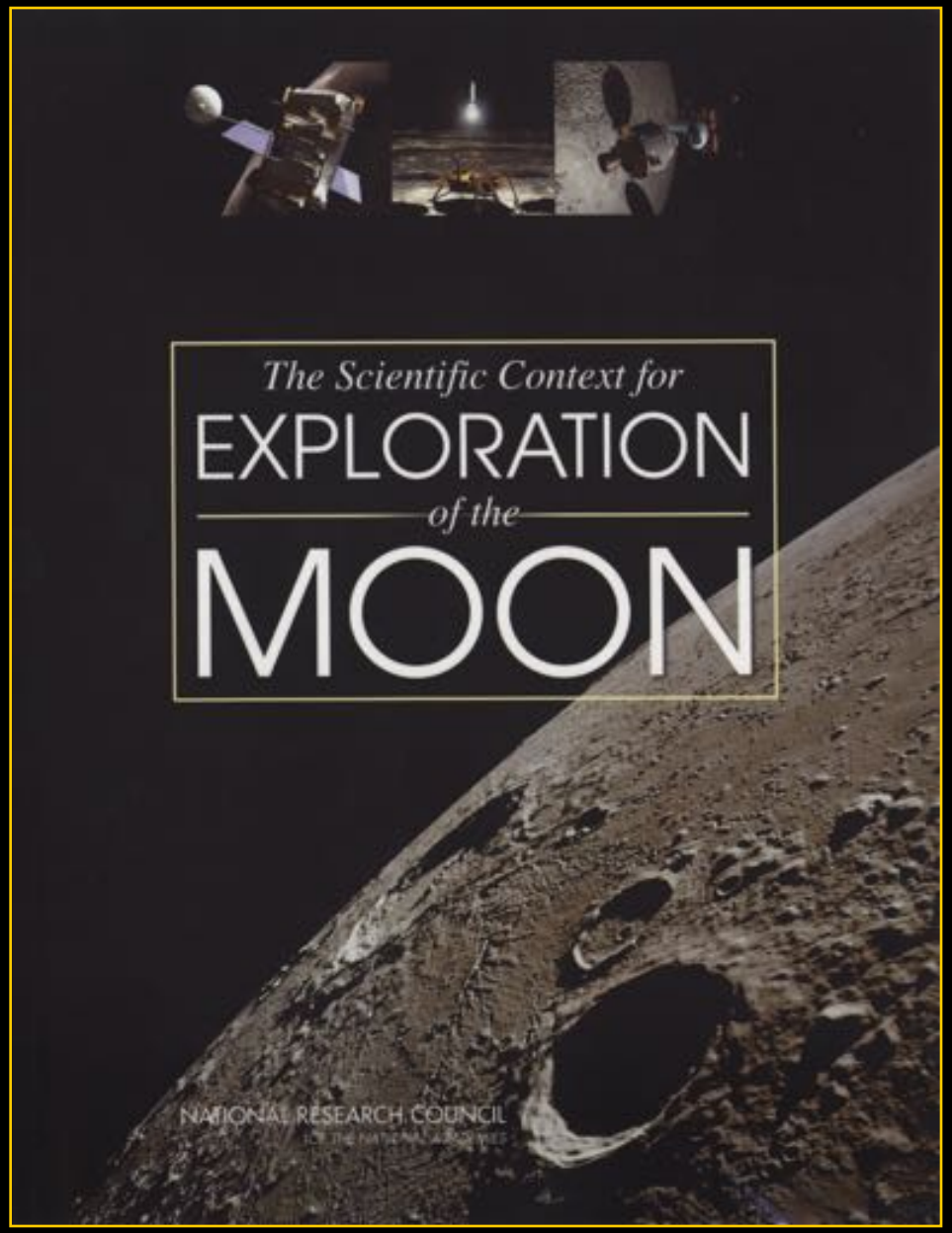


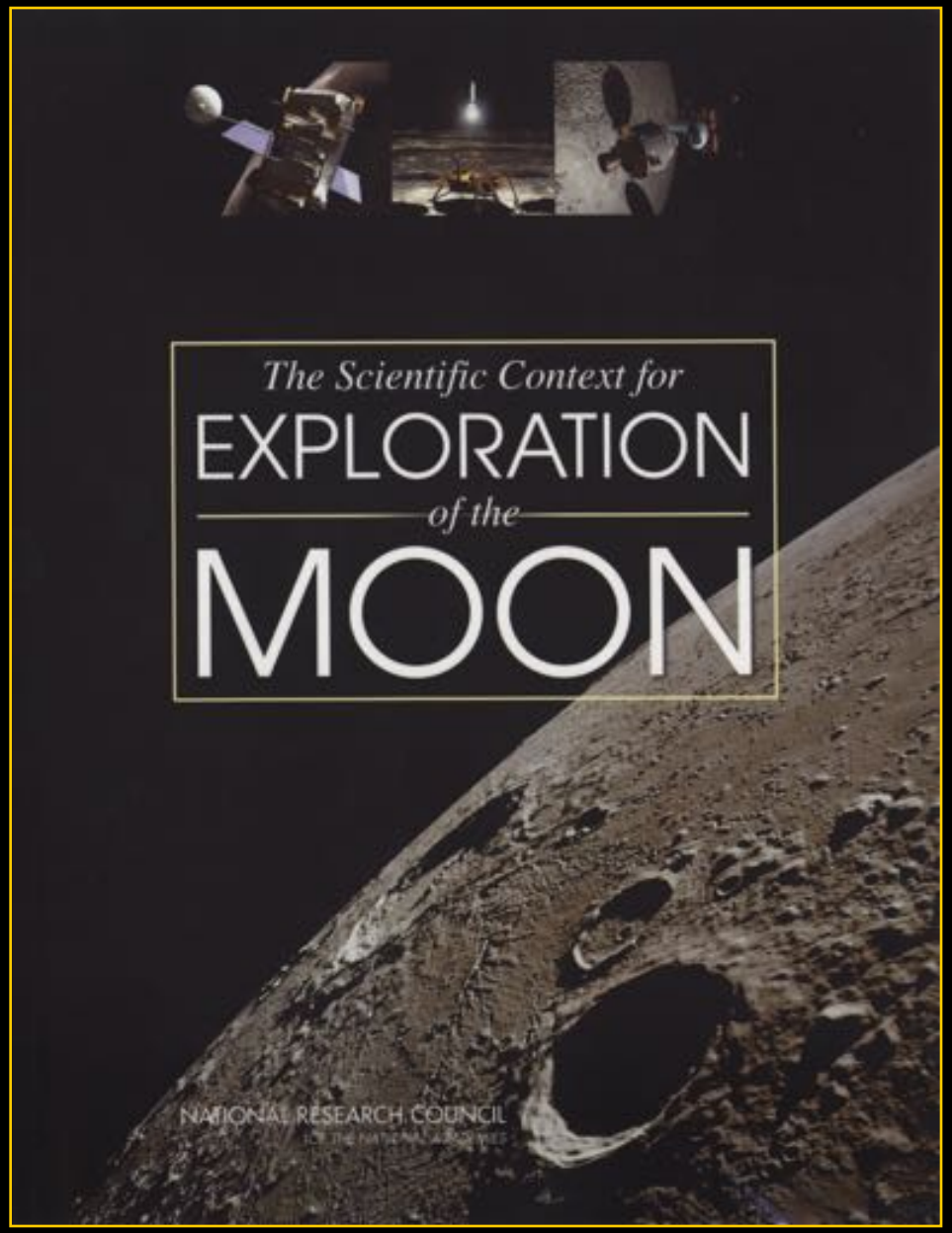
In 2007,

The National Research Council published a report called *The Scientific Context for Exploration of the Moon*, which provided NASA with scientific guidance for an enhanced exploration program that would provide global access to the lunar surface through an integrated robotic and human architecture.

The report identified 8 science concepts and, within those concepts, it

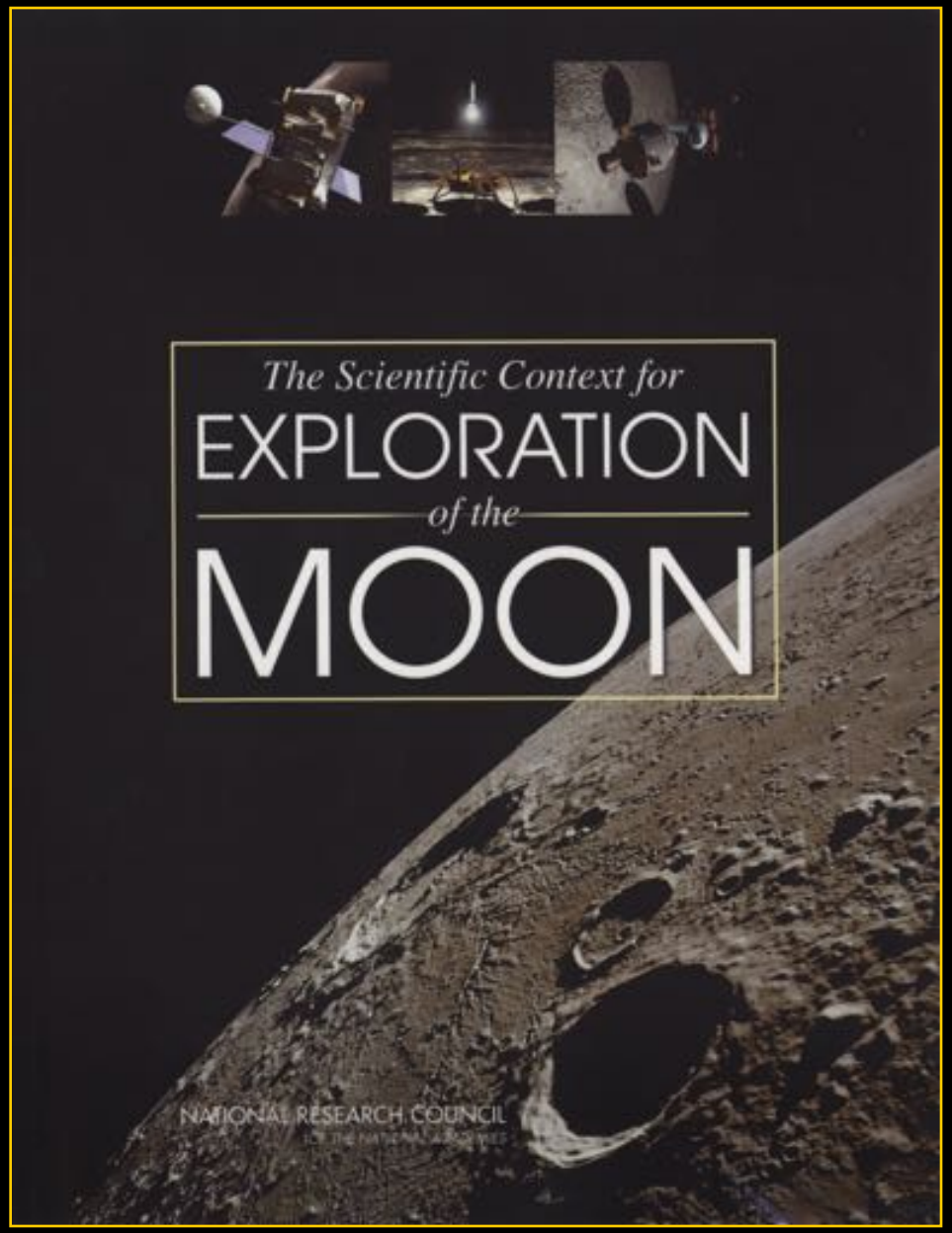
Identified 35 specific investigations

Importantly, the report also prioritized those investigations



Science concepts to be explored:

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 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 processes 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

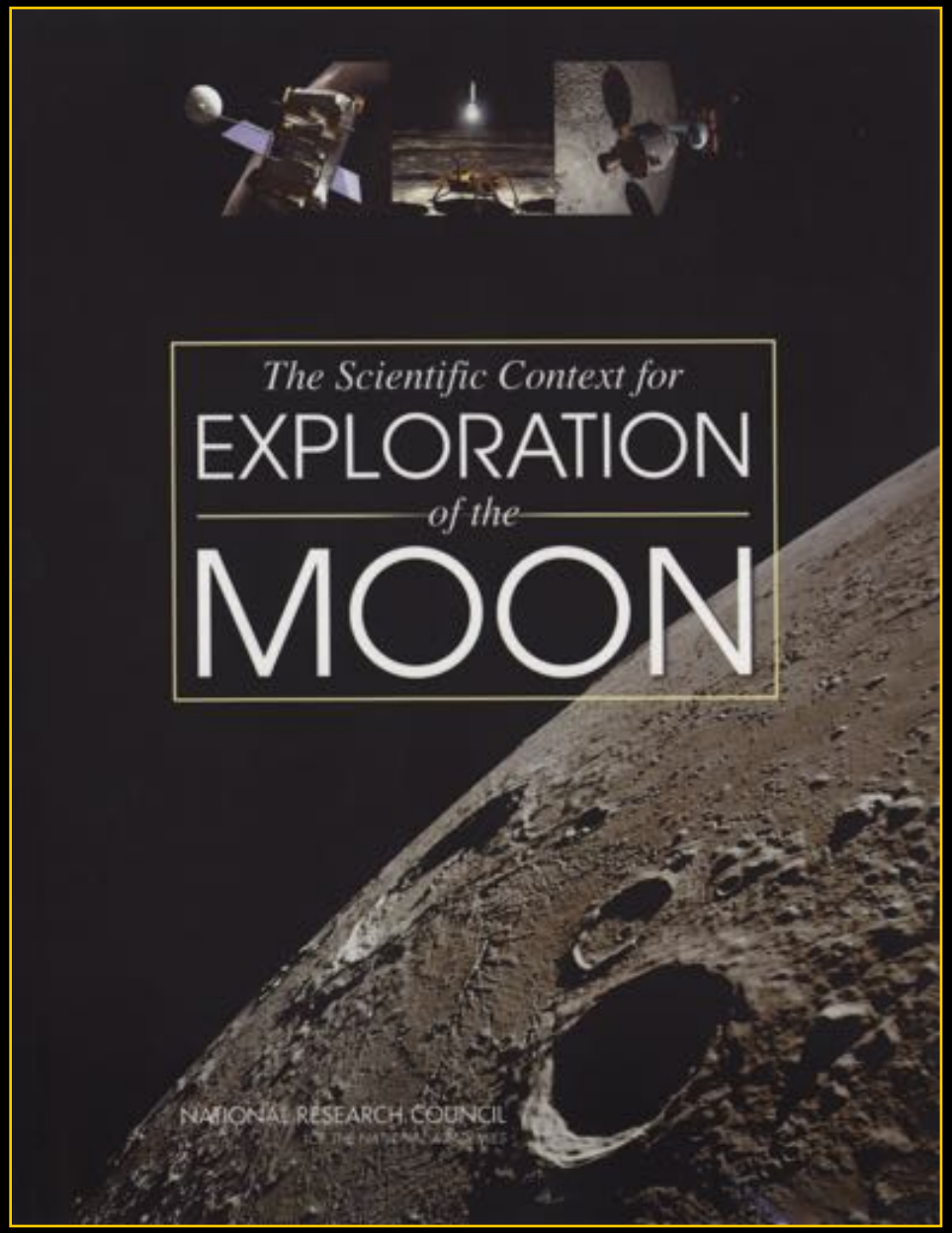


Landing Site Study

- The study addressed a simple question: Where on the lunar surface could the concepts and specific investigations be addressed?
- The goal is to identify all locations on the lunar surface where the issues could be addressed, producing a truly global assessment.
- This method has the potential of locating sites where multiple objectives could be addressed simultaneously; i.e., the scientifically-richest sites on the lunar surface.

Lunar Exploration Summer Intern Program

Science Concept 1 (2008)	Science Concept 2 (2012)	Science Concept 3 (2010)	Science Concept 4 (2011)
Tomas Kohout Anna Losiak Katie O'Sullivan Kevin Thaisen Shoshana Weider	Jessica Barnes Renee French Joshua Garber Wil Poole Pillipa Holly Smith Yunsheng Tian	Jean-François Blanchette-Guertin Jessica Flahaut Christine Jilly Priyanka Sharma Audrey Souchon	David M. Blair Myriam Lemelin Daniela Nowka Carolyn E. Roberts Kirby D. Runyon
Science Concept 5 (2009)	**Science Concept 6 (2010)**	**Science Concept 7 (2011)**	**South Pole-Aitken Basin (2009)**
Daniel Eldridge Jarmo Korteniemi Trevelyn Lough Kaitlin Singer Lesley Werblin	Patrick Donohue Zachary Gallegos Noah Hammond Ross Potter	Sarah Crites Agata Przepiórka Stephanie Quintana Claudia Santiago Tiziana Trabucchi	Megan Ennis Amy Fagan James Pogue Simon Porter Joshua Snape



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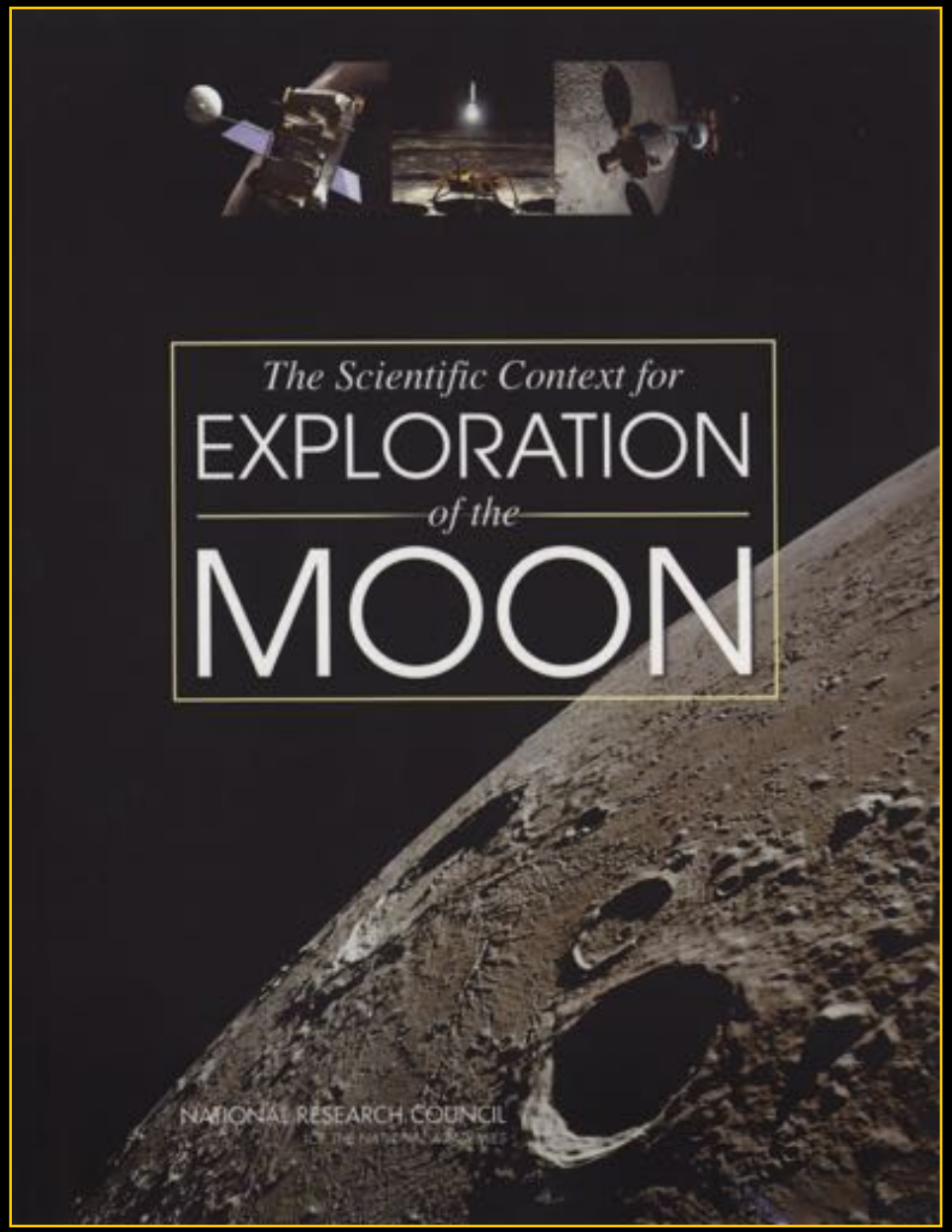
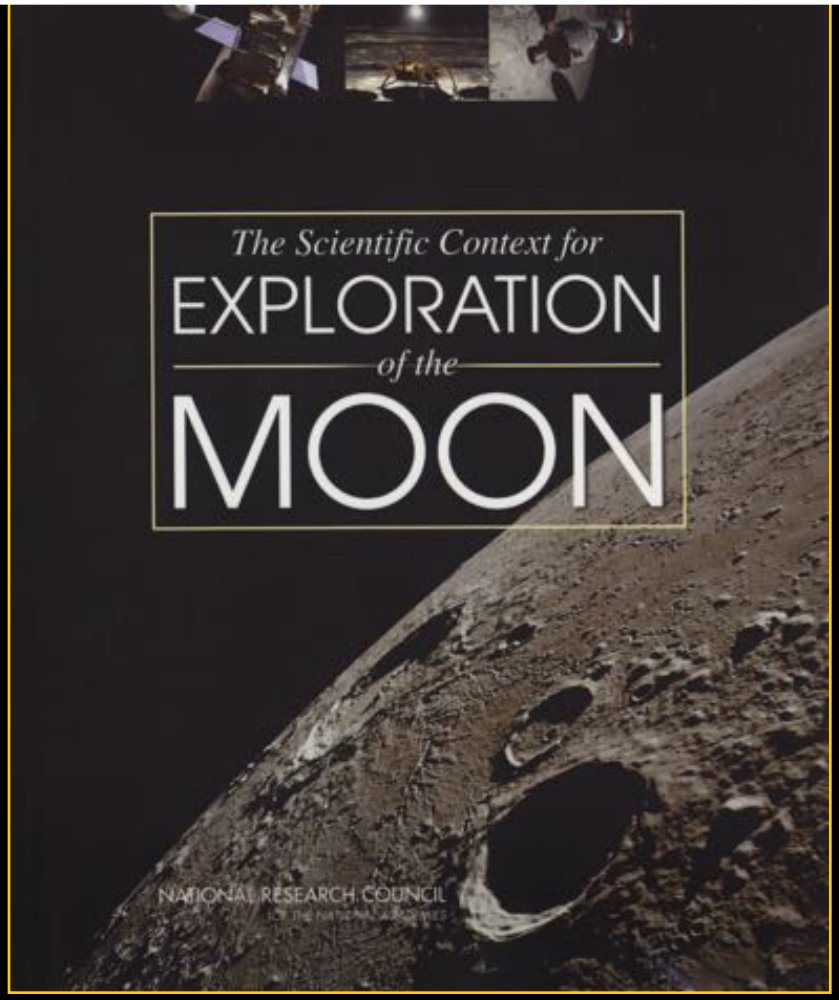


Number one science concept
& highest science priorities

1. The bombardment history of the inner solar system is uniquely revealed on the Moon
   a. Test the cataclysm hypothesis by determining the spacing in time of the creation of lunar basins
   b. Anchor the early Earth-Moon impact flux curve by determining the age of the oldest lunar basin (South Pole-Aitken Basin)
   c. Establish a precise absolute chronology *(by measuring ages of representative craters throughout the Moon's history)*
   d. Assess the recent impact flux

This is not just a story about the Earth and Moon, but one that is providing fundamental insights about the accretion and orbital evolution of planetary bodies throughout the solar system.



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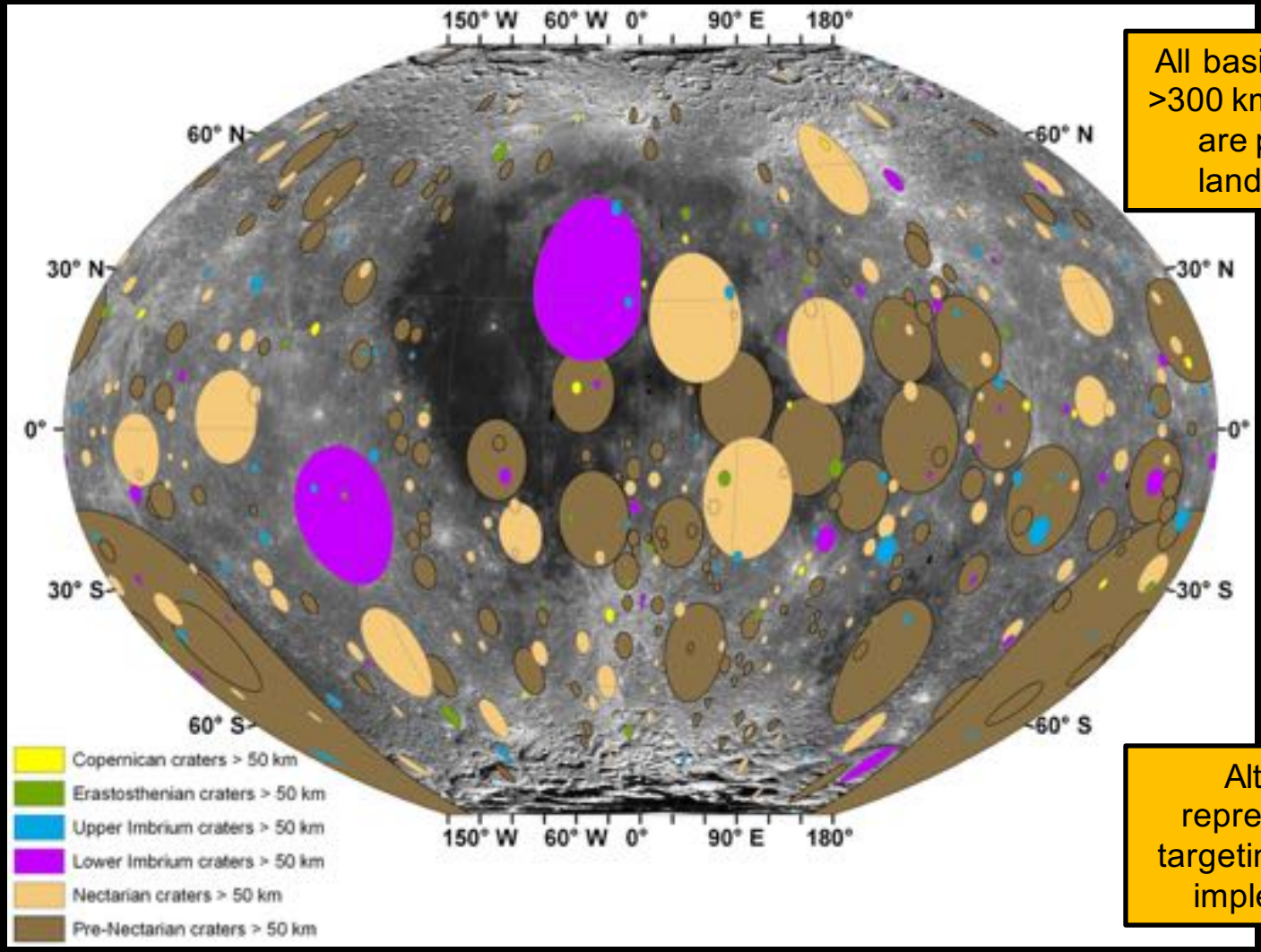
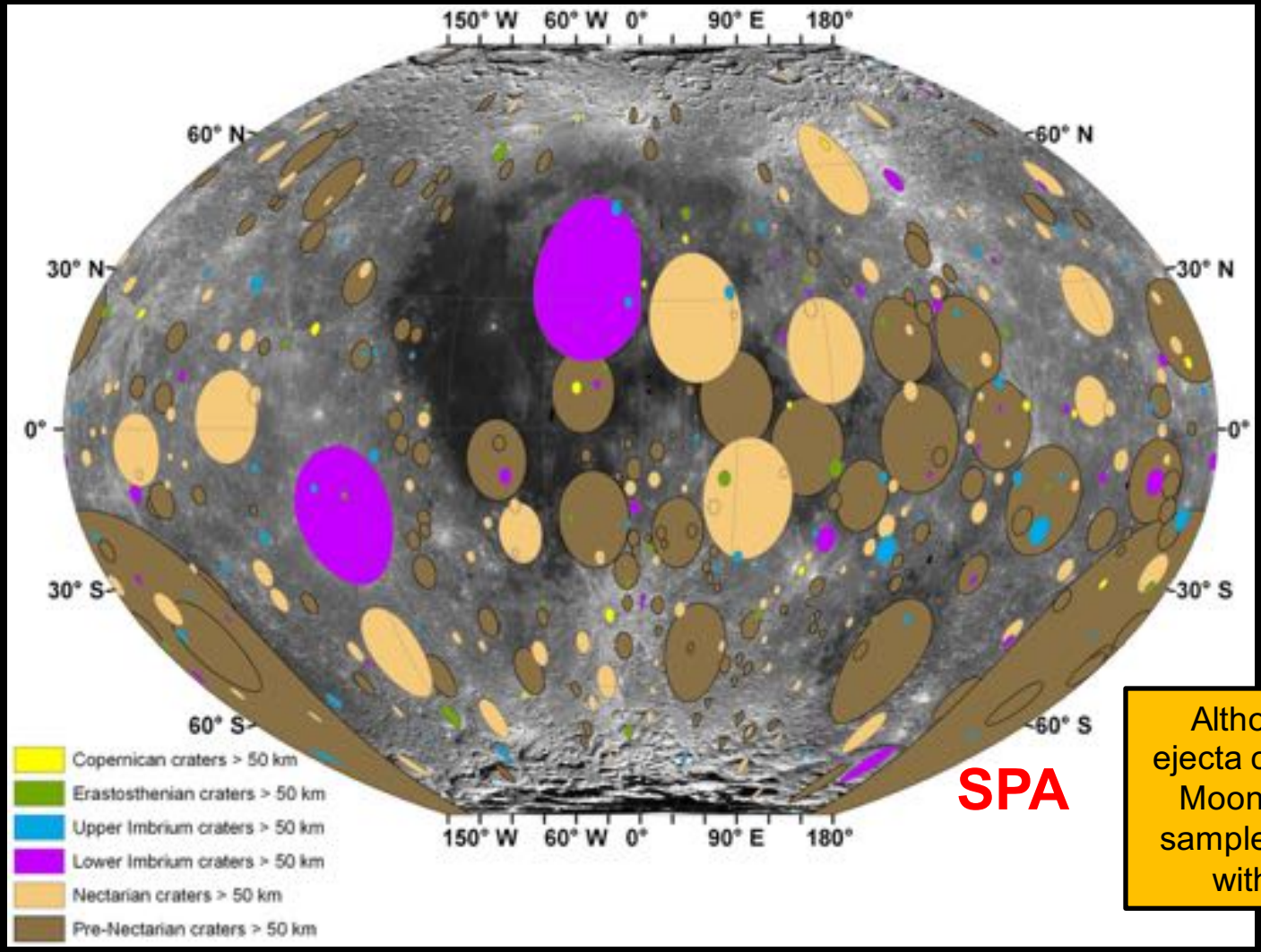
1a: Test the lunar cataclysm hypothesis



All basins (craters >300 km diameter) are potential landing sites

Although representative targeting could be implemented

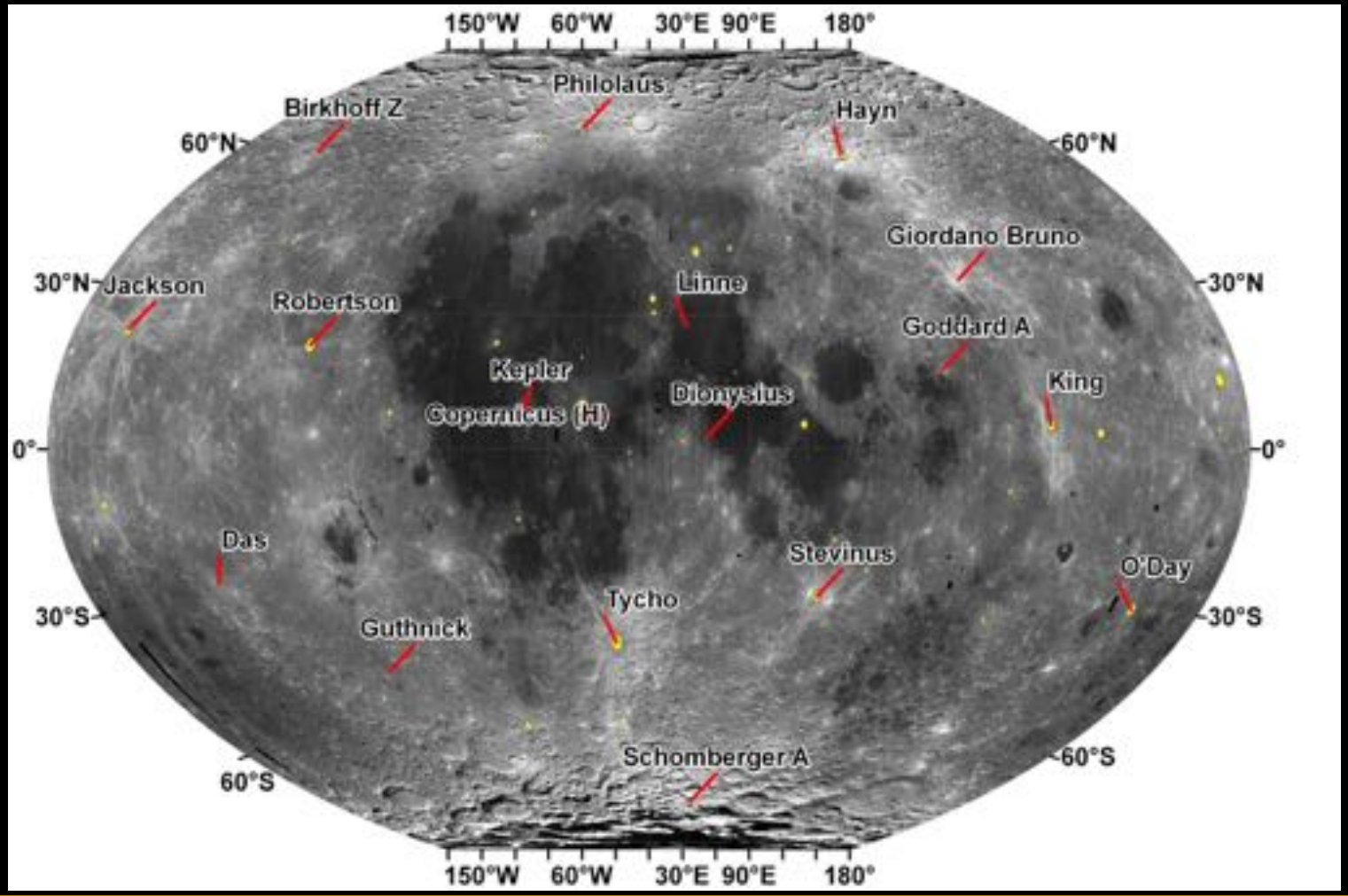
1b: Determine age of SPA to anchor basin-forming epoch



Although SPA ejecta covered the Moon, the best samples are from within SPA

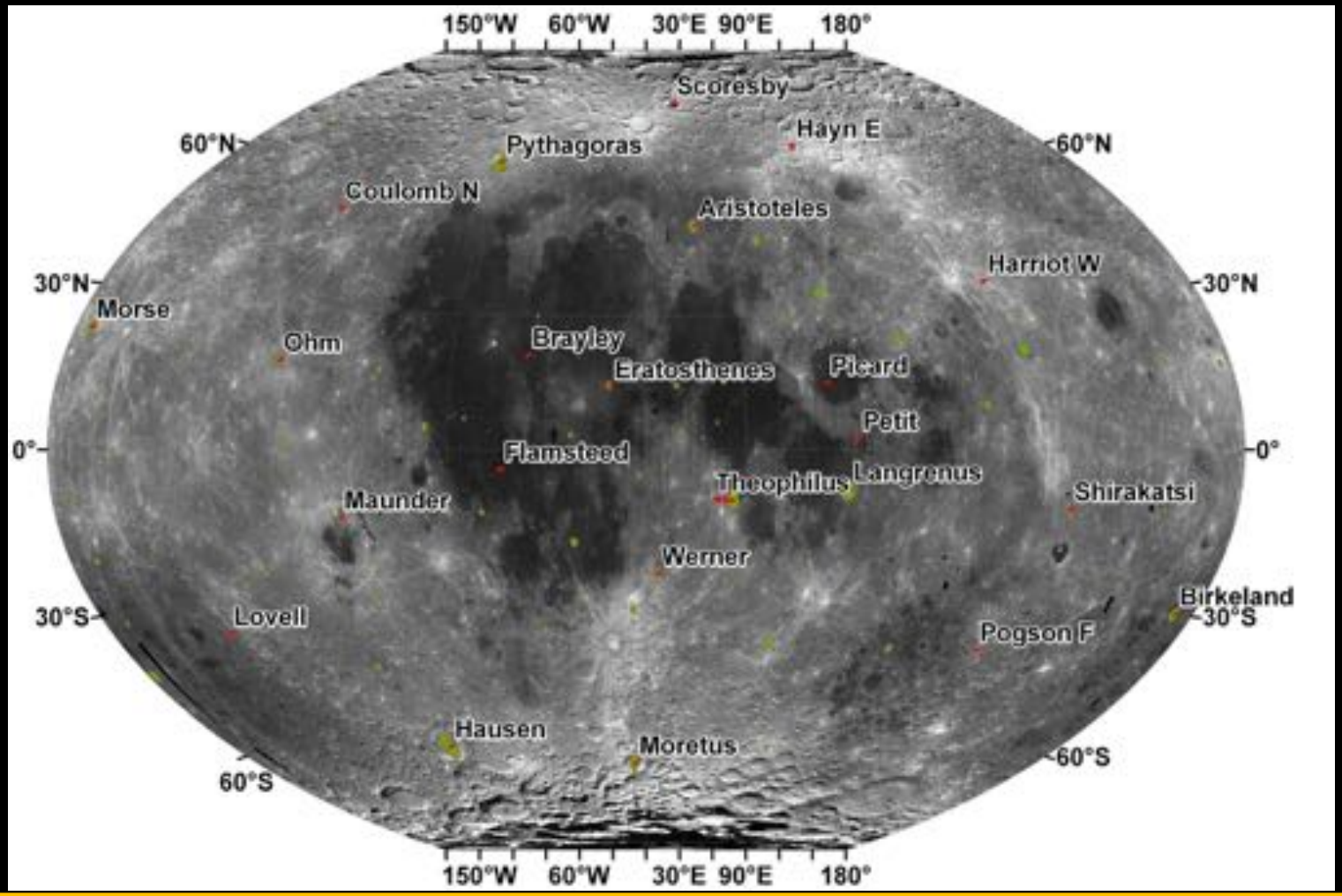
1c: Establish a precise absolute chronology

- Representative Copernican-age craters



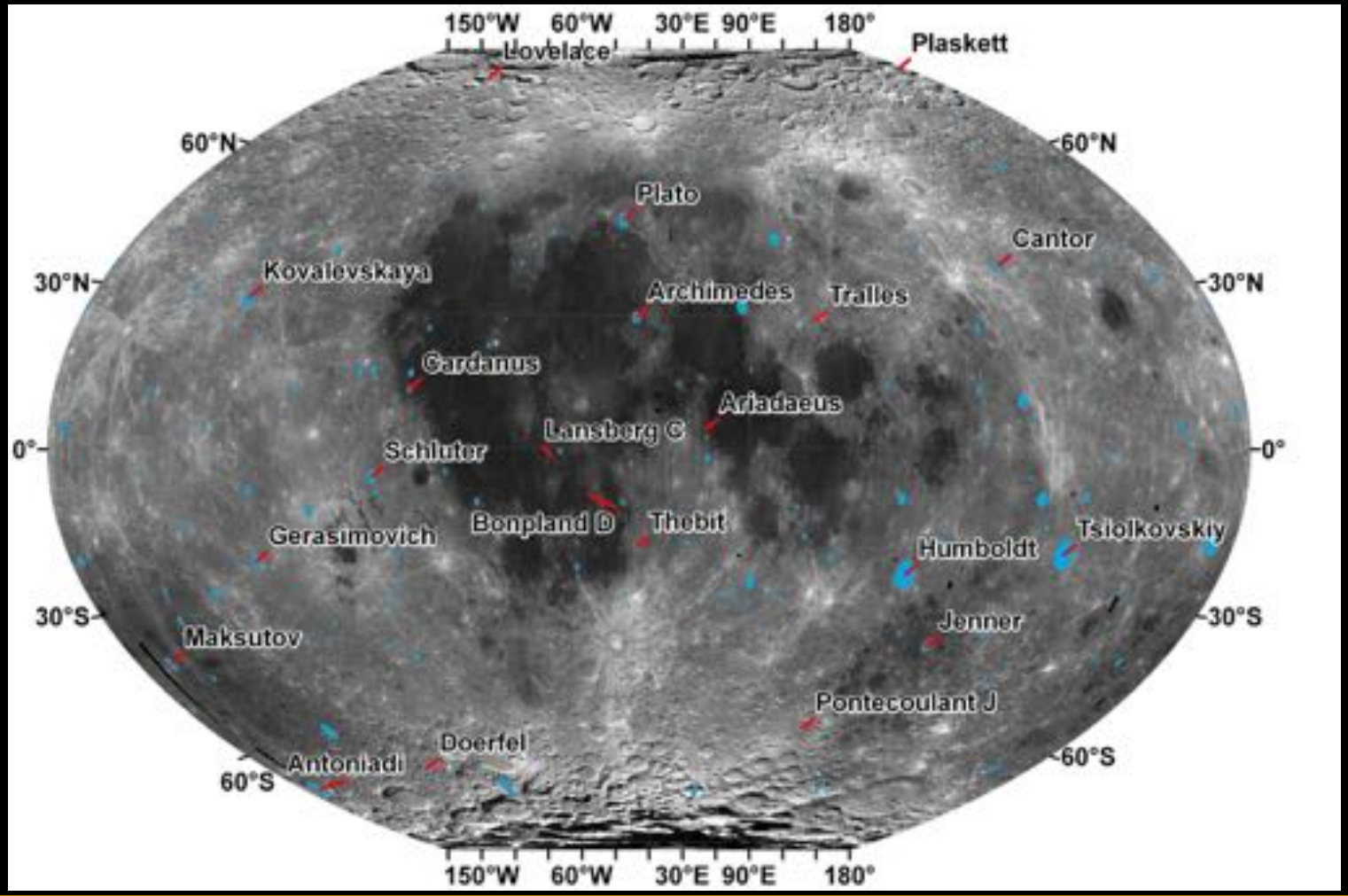
1c: Establish a precise absolute chronology

- Representative Eratosthenian-age craters



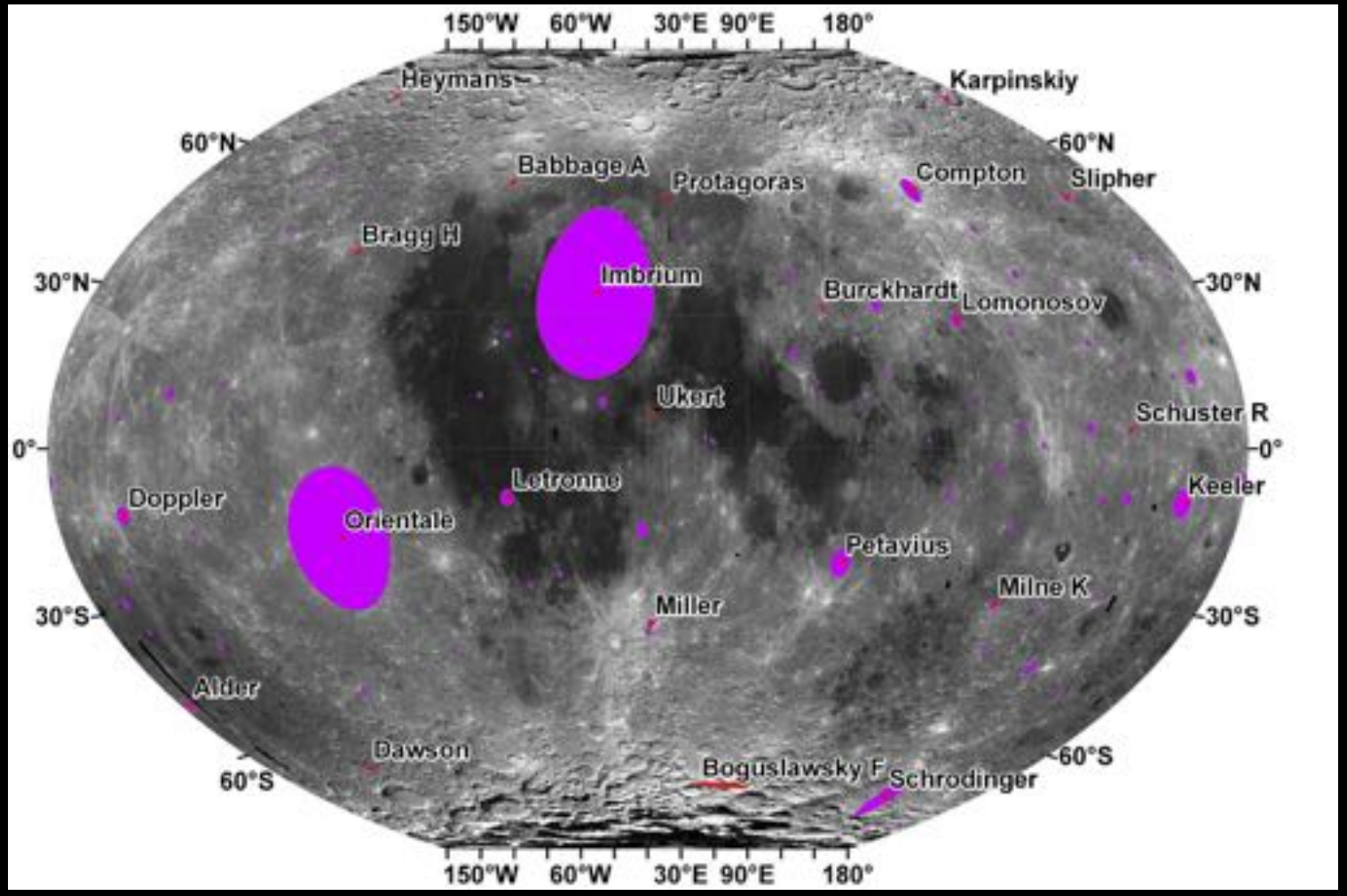
1c: Establish a precise absolute chronology

- Representative Upper Imbrian-age craters



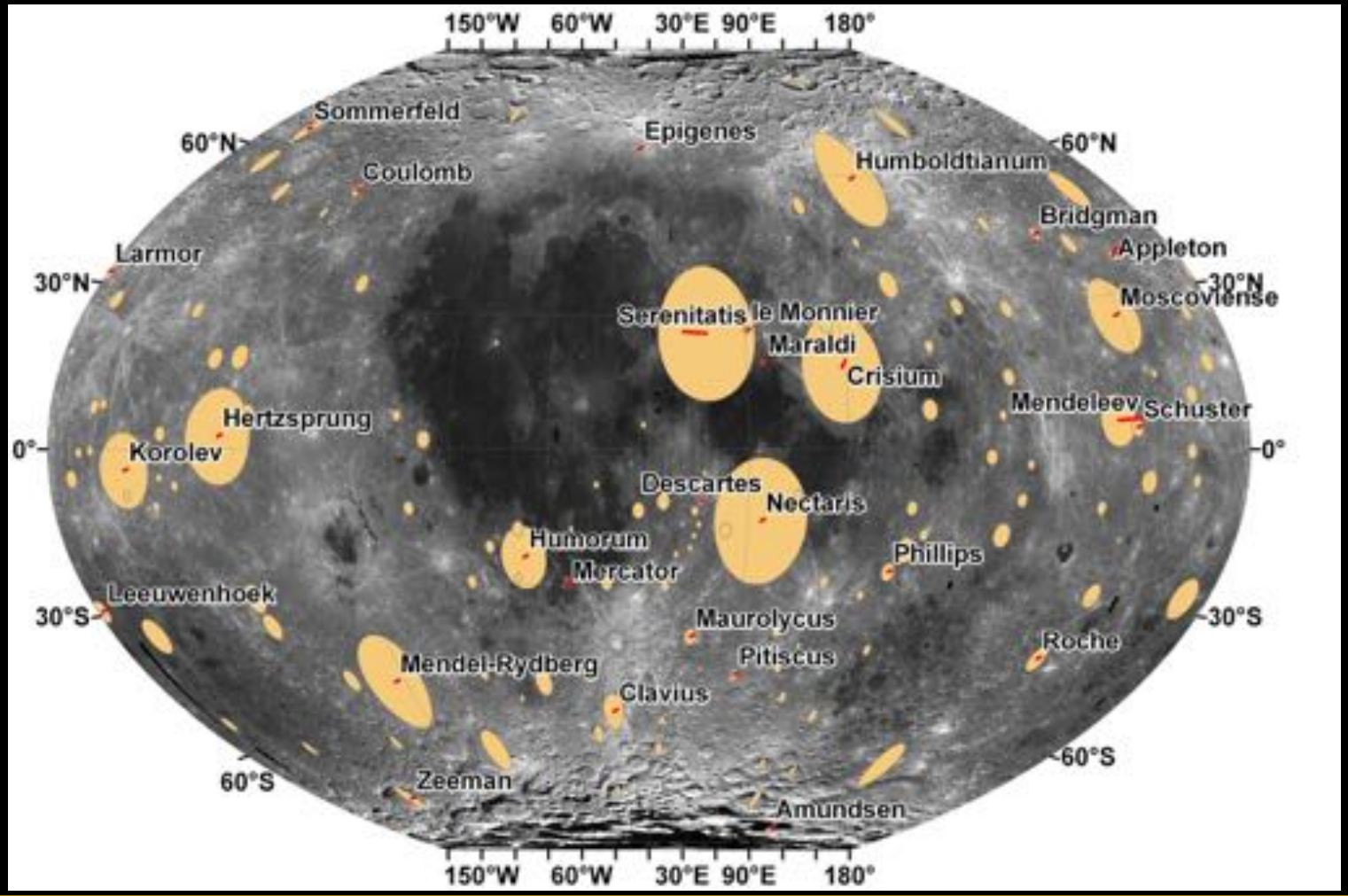
1c: Establish a precise absolute chronology

- Representative Lower Imbrian-age craters and basins



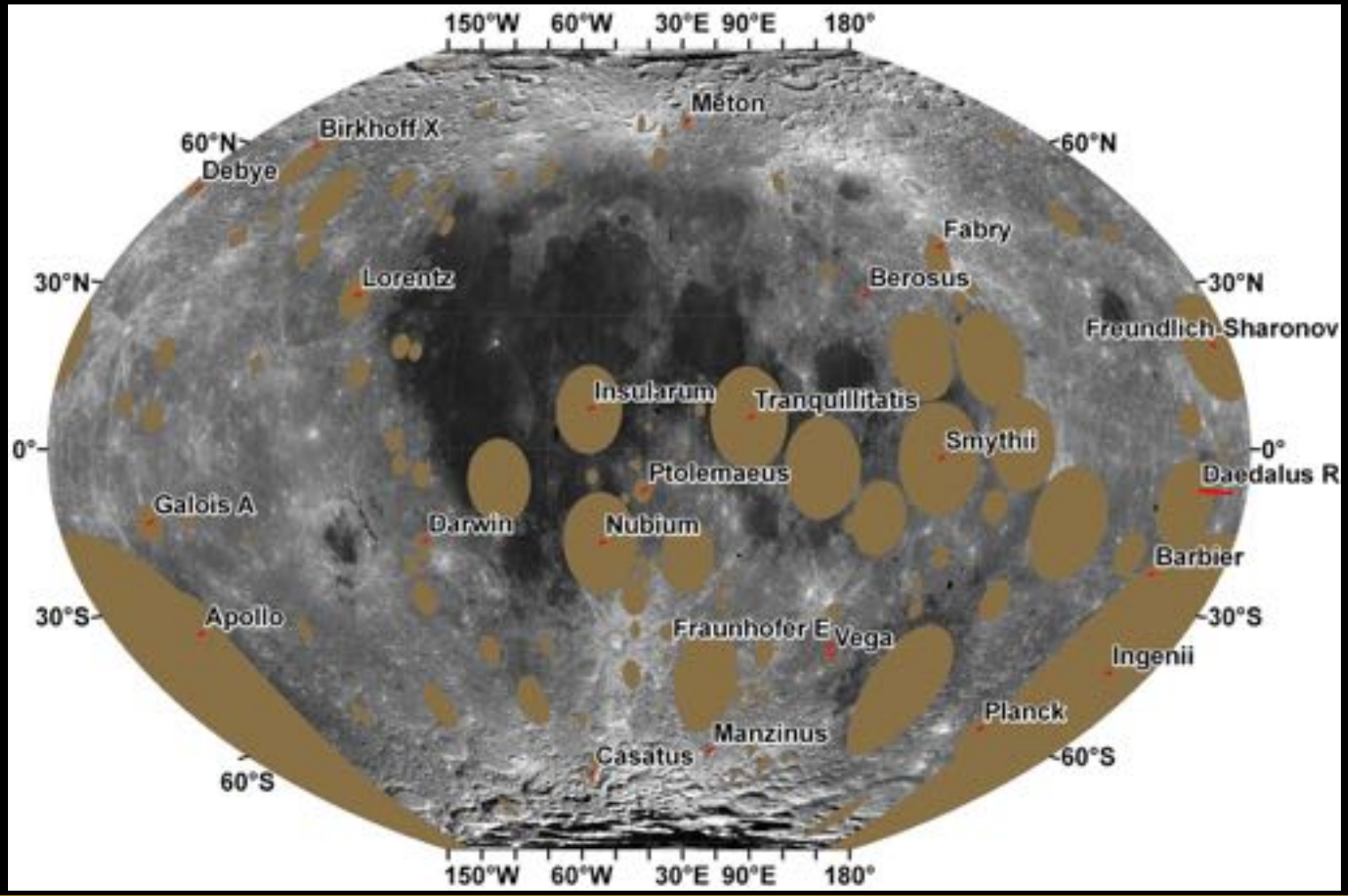
1c: Establish a precise absolute chronology

- Representative Nectarian-age craters and basins



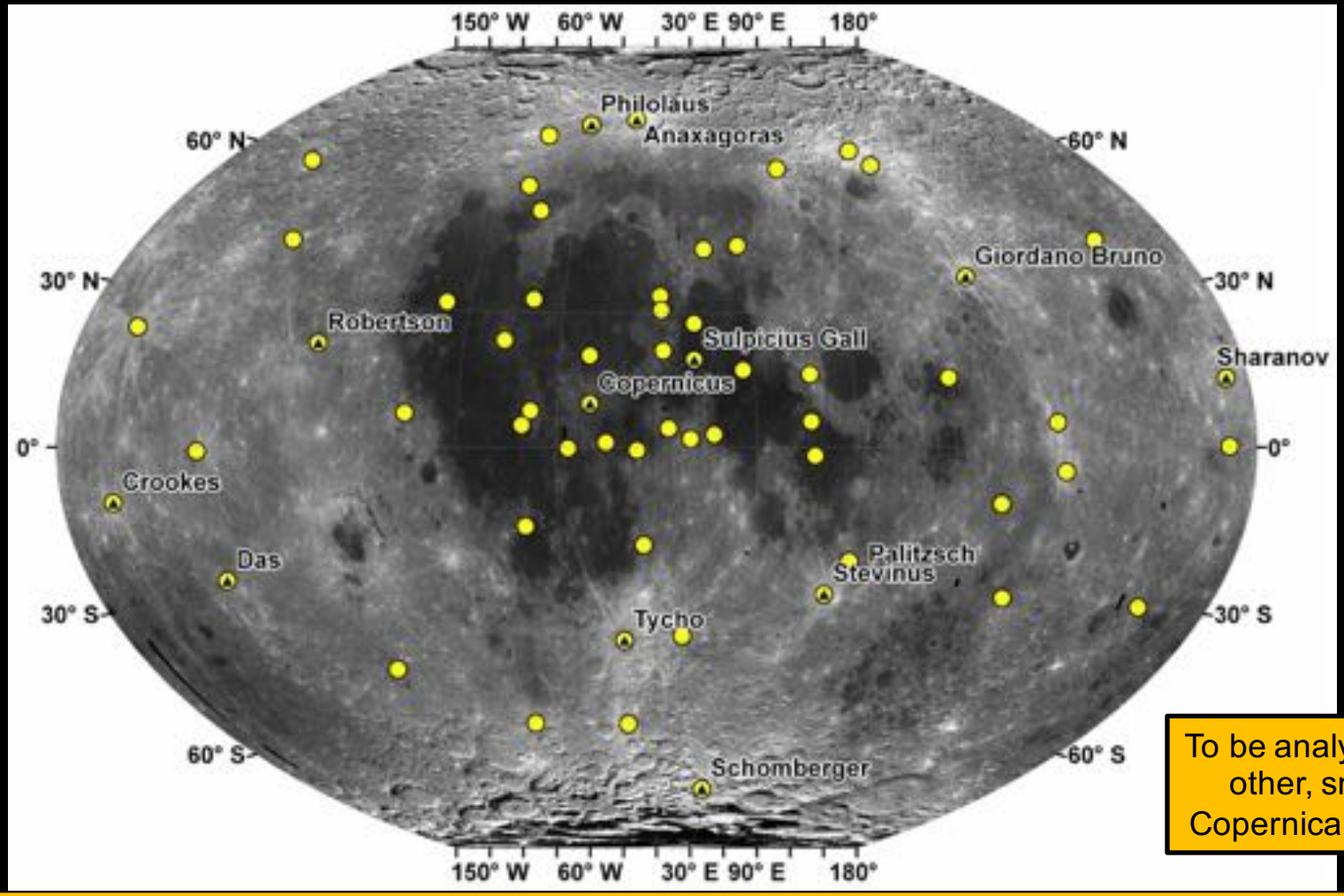
1c: Establish a precise absolute chronology

- Representative Pre-Nectarian-age craters and basins

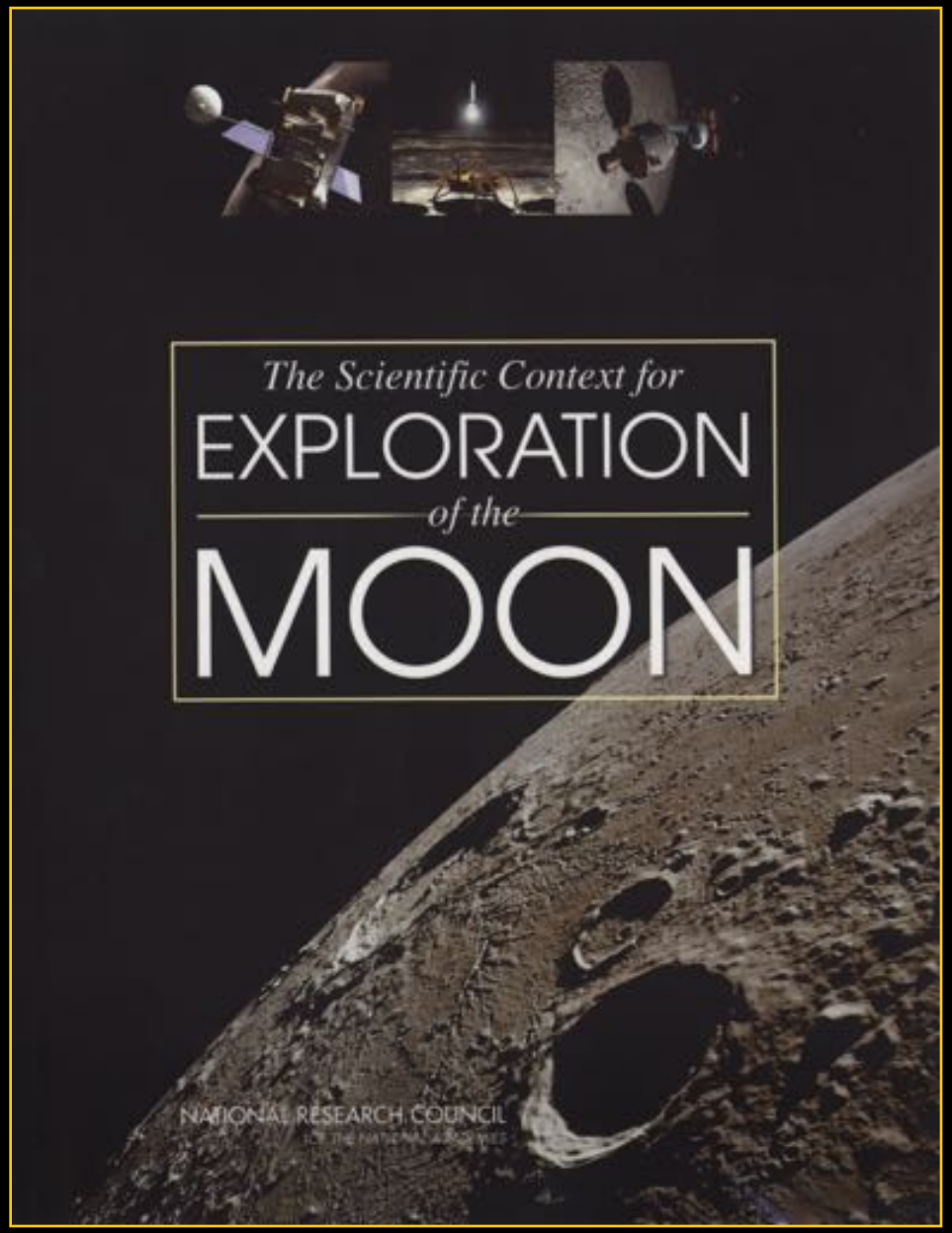


1d: Assess the recent impact flux

- All Copernican-age craters in Wilhelms (1987) – i.e., large examples



To be analyzed with other, smaller Copernican craters



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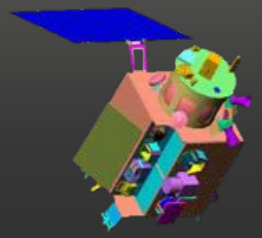
Input data

Lunar Prospector

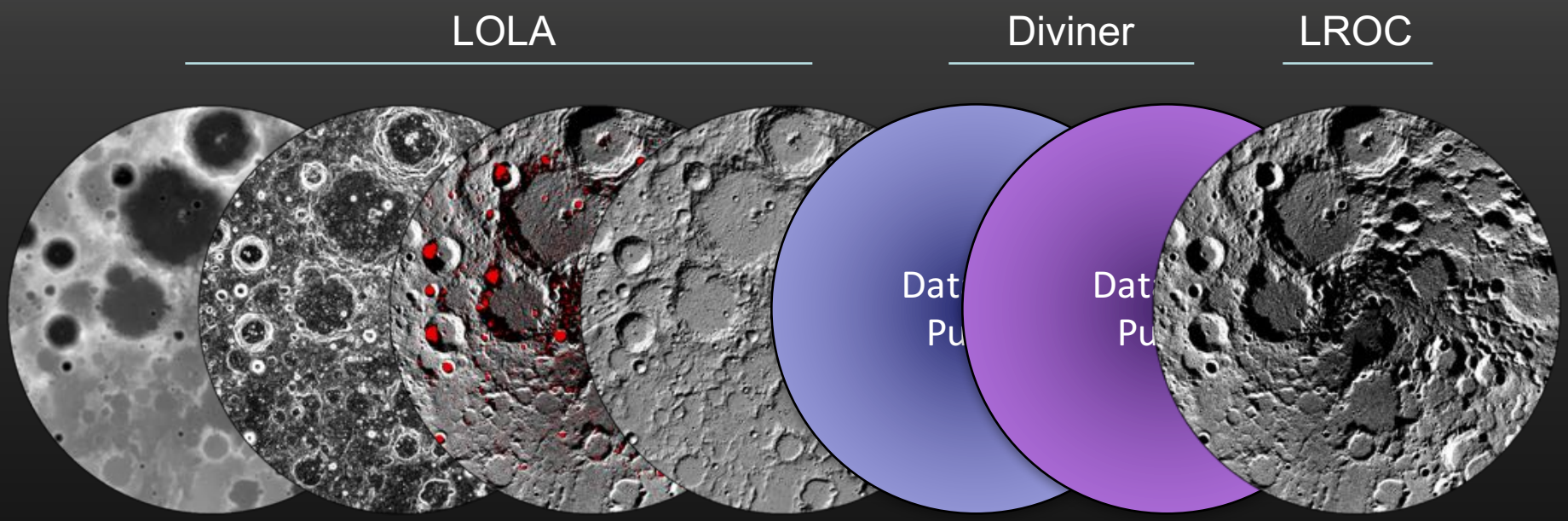
Chandrayaan-1



Lunar Reconnaissance Orbiter

Input data

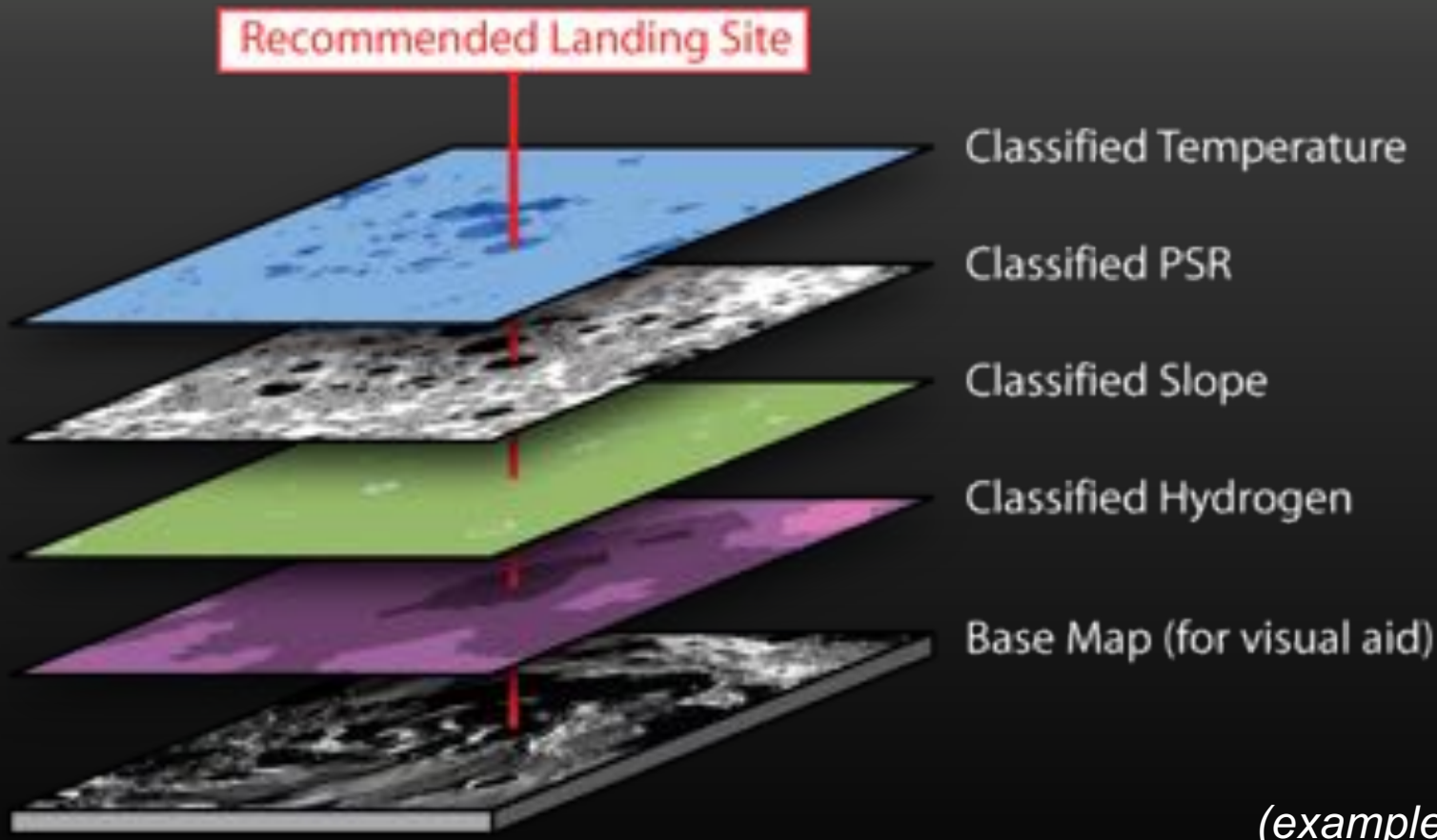
Lunar Reconnaissance Orbiter (LRO)



DEM	Slope	PSRs	Relief	Max Temp	Min Temp	WAC
120 m	*120 m*	*240 m*	*240 m*	*240 m*	*240 m*	*100 m*
> ±60˚	*> ±60˚*	*> ±80˚*	*> ±75˚*	*> ±80˚*	*> ±80˚*	*> ±60˚*

Methodology

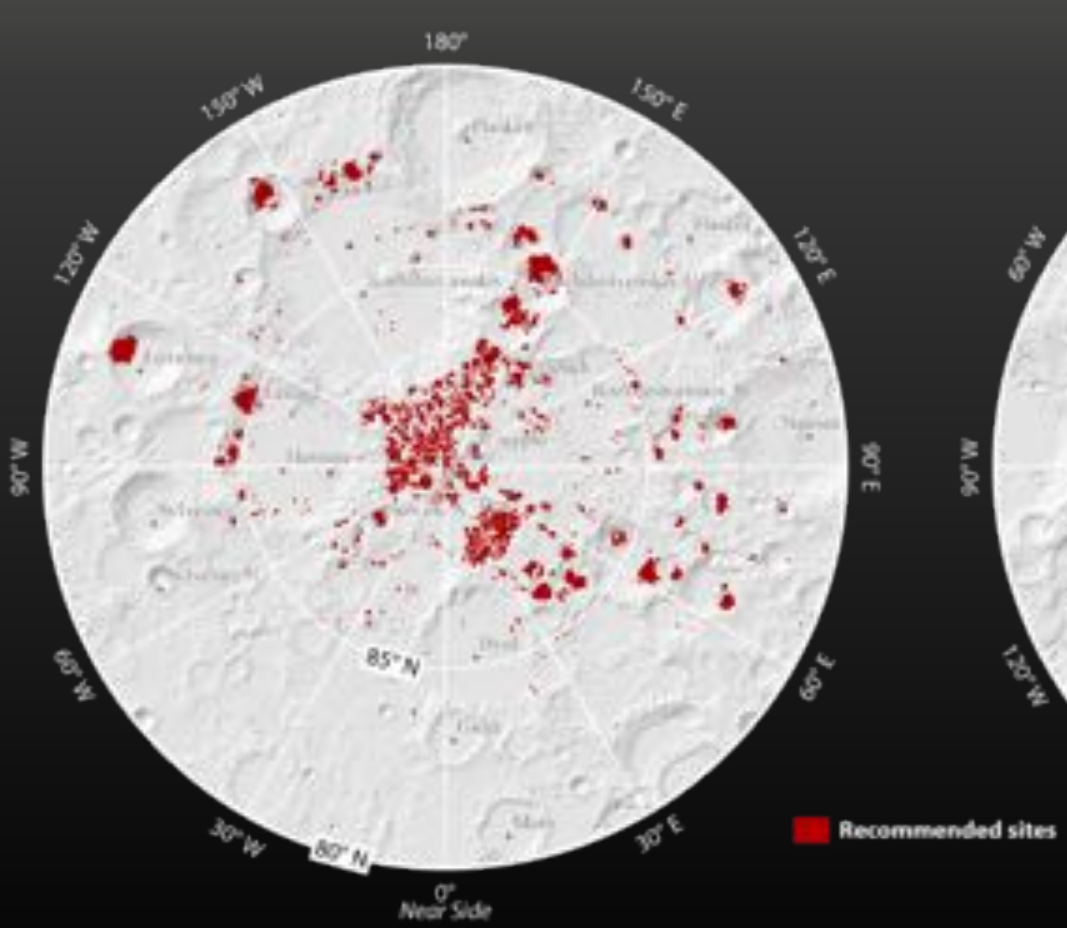
Classification and weighting in ArcMap



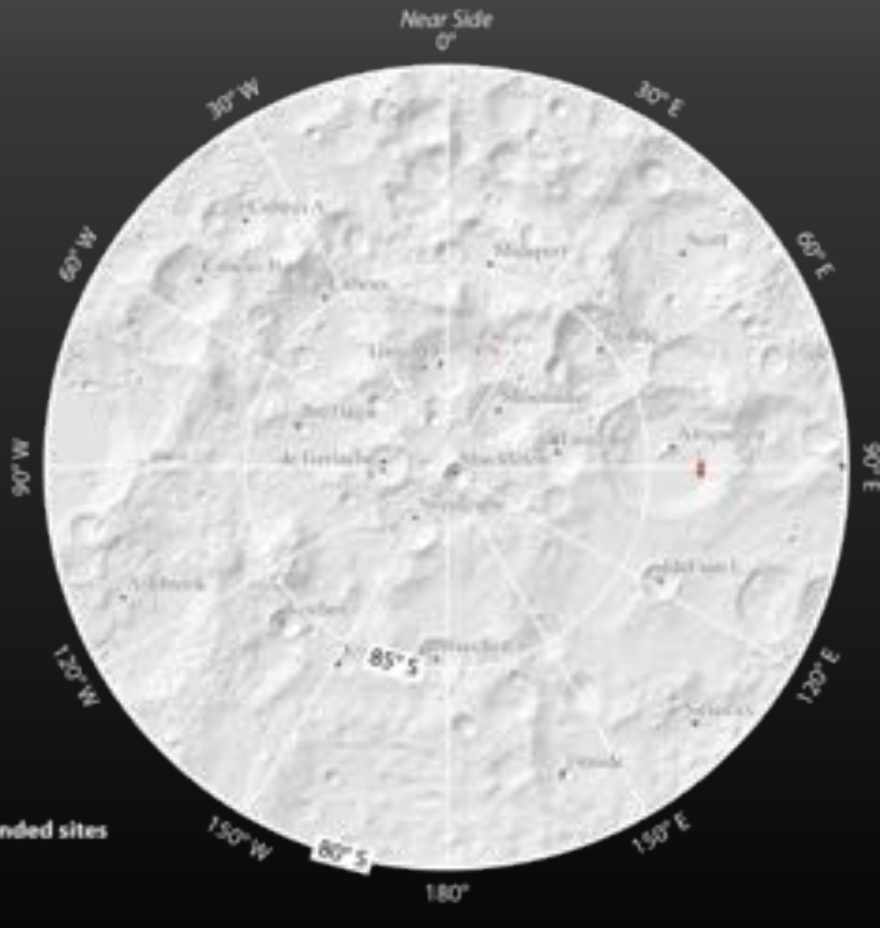
(example for 4a)

4a: State and distribution of polar volatiles

- Post-classification result (favoring highest ranking areas)



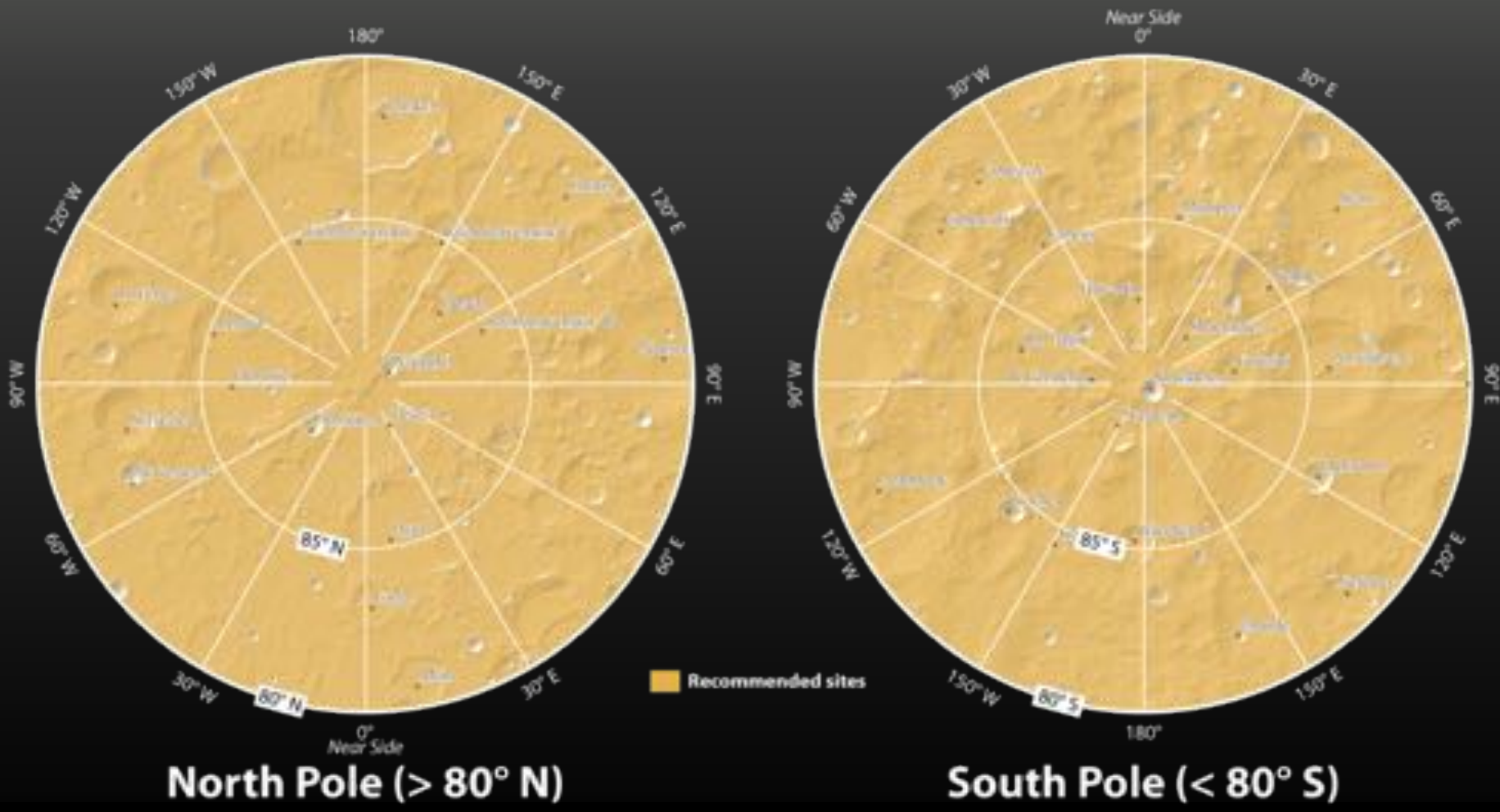
North Pole (> 80° N)



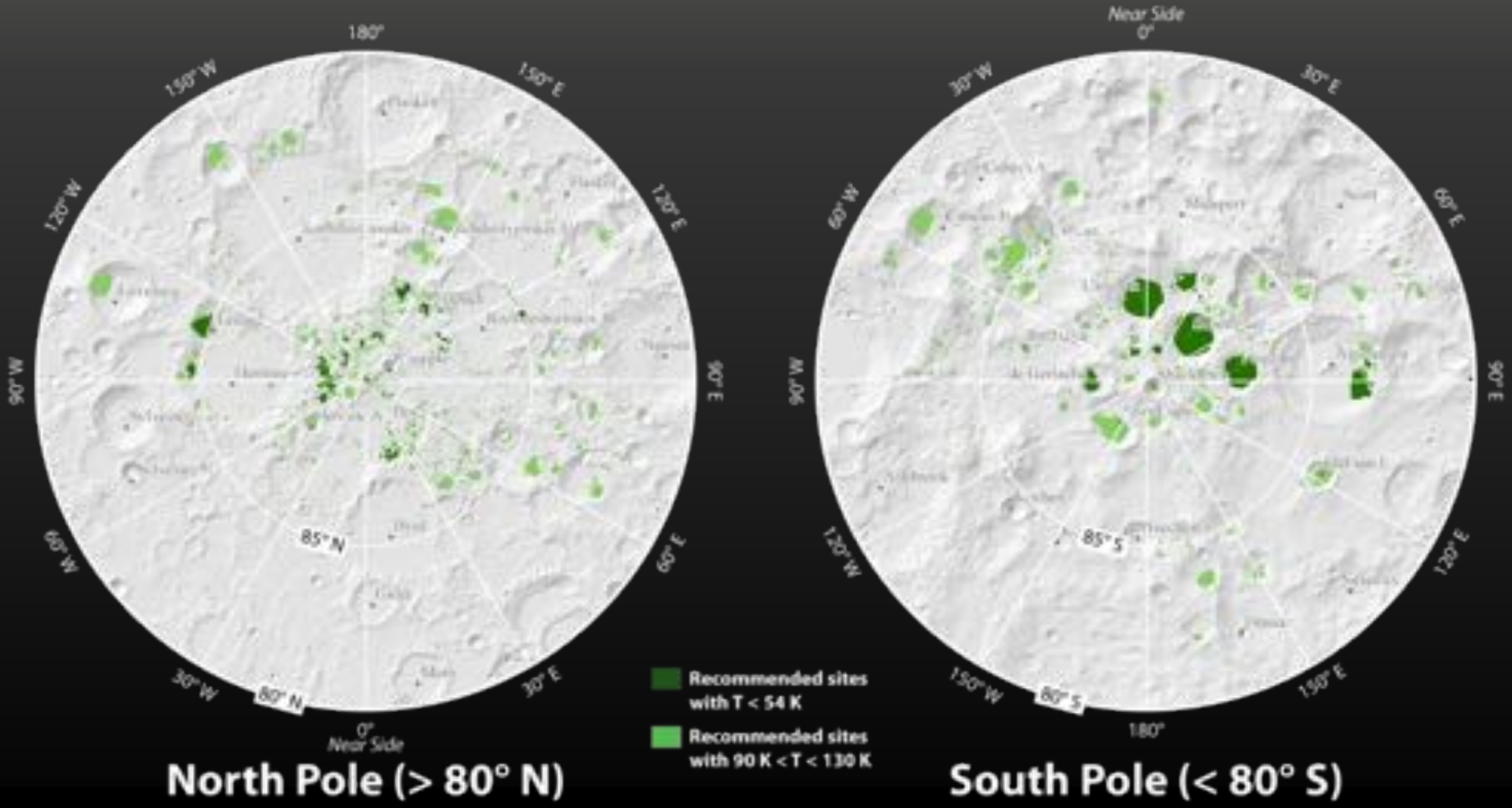
South Pole (< 80° S)

4b: Sources of polar volatiles

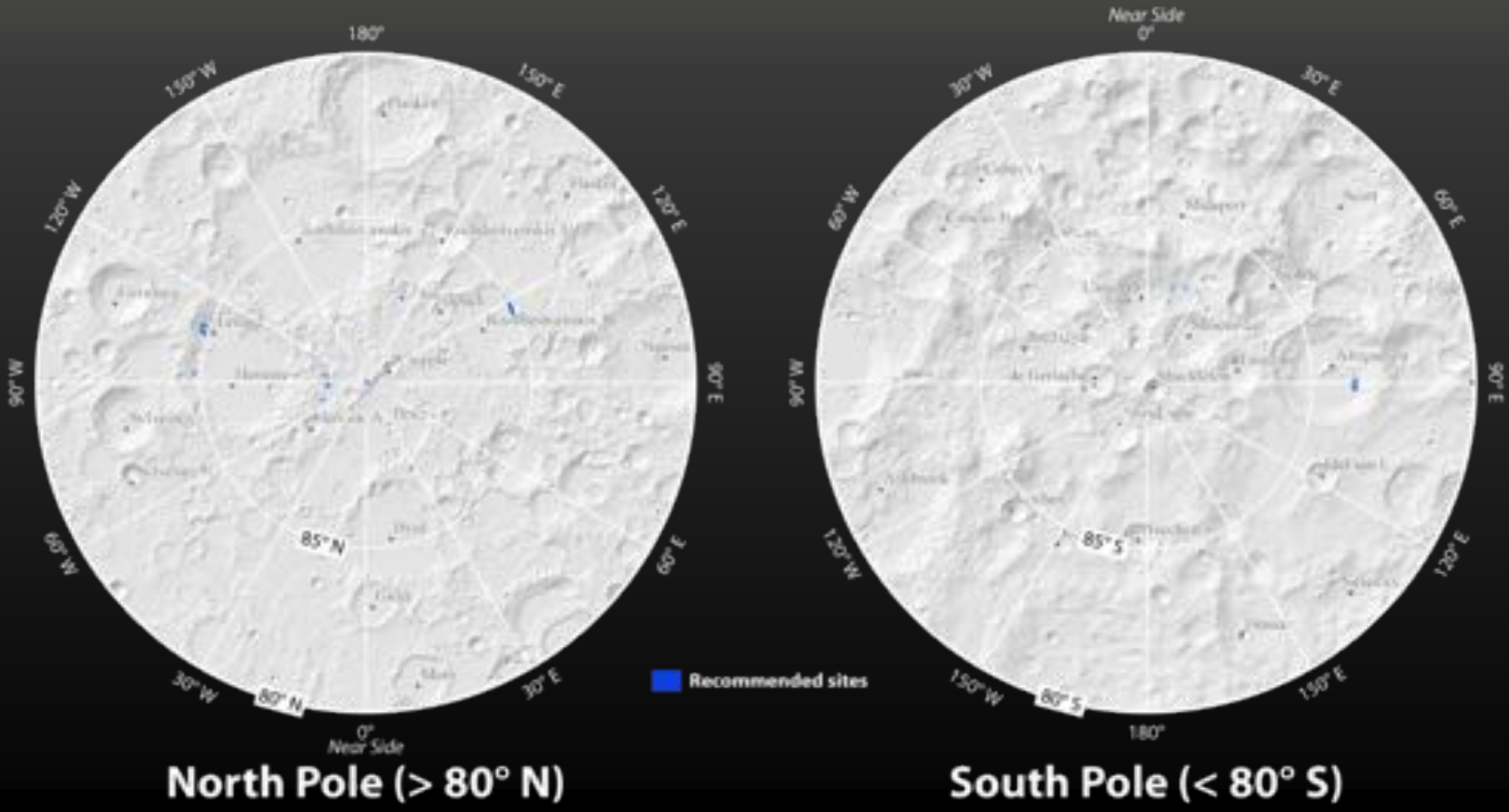
- This is not a selection driver for landing sites



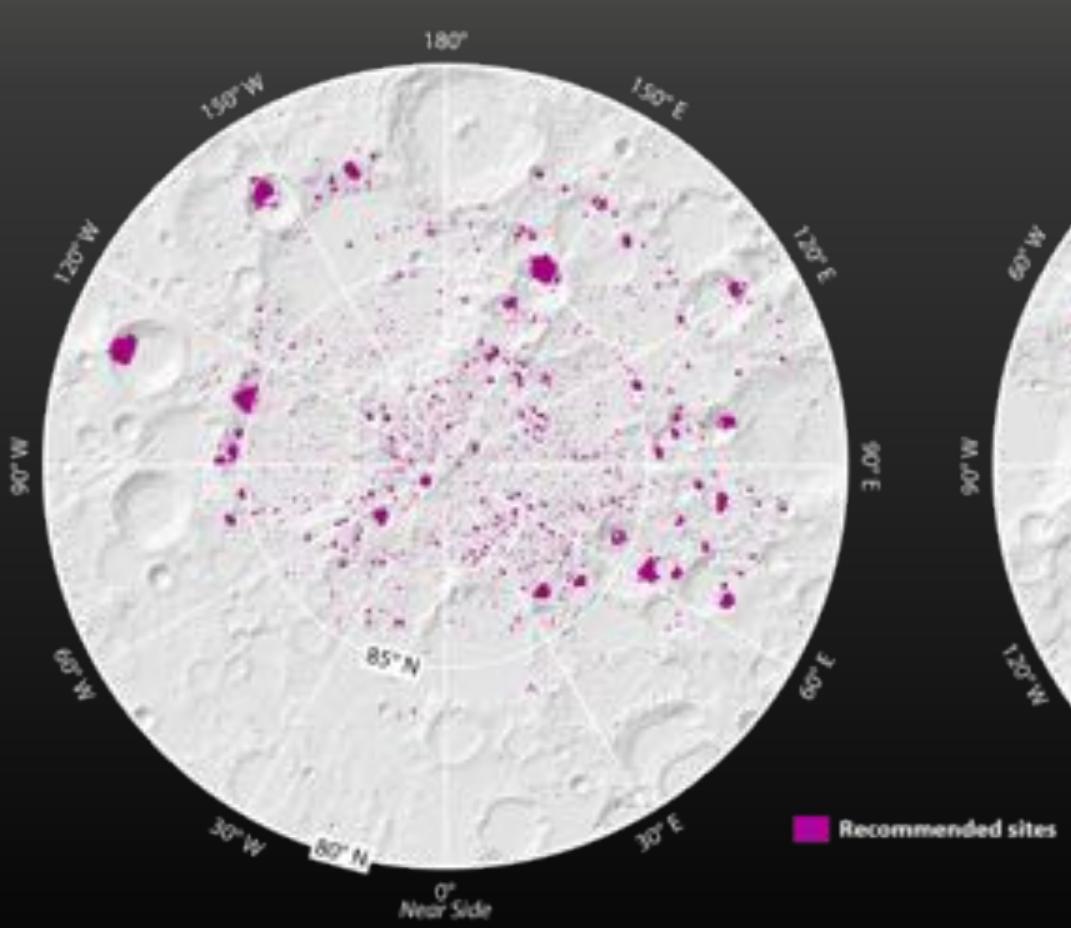
4c: Transport, retention, alteration, and loss processes



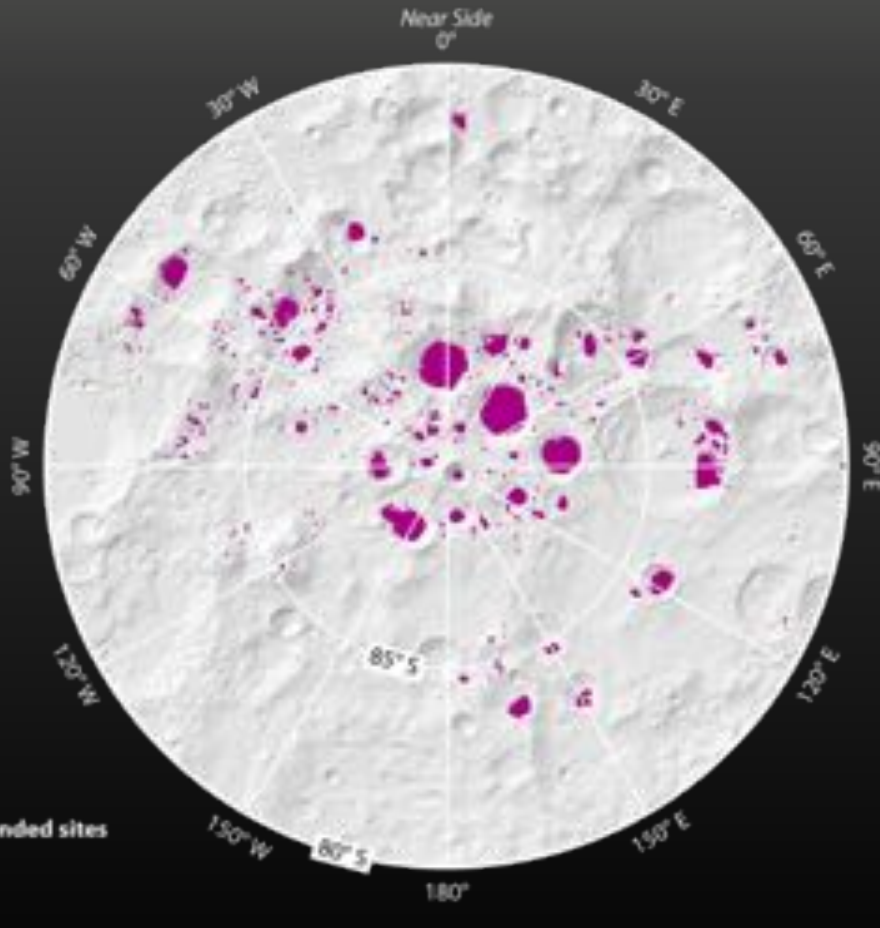
4d: Physical properties of extremely cold regolith



4e: Ancient solar history



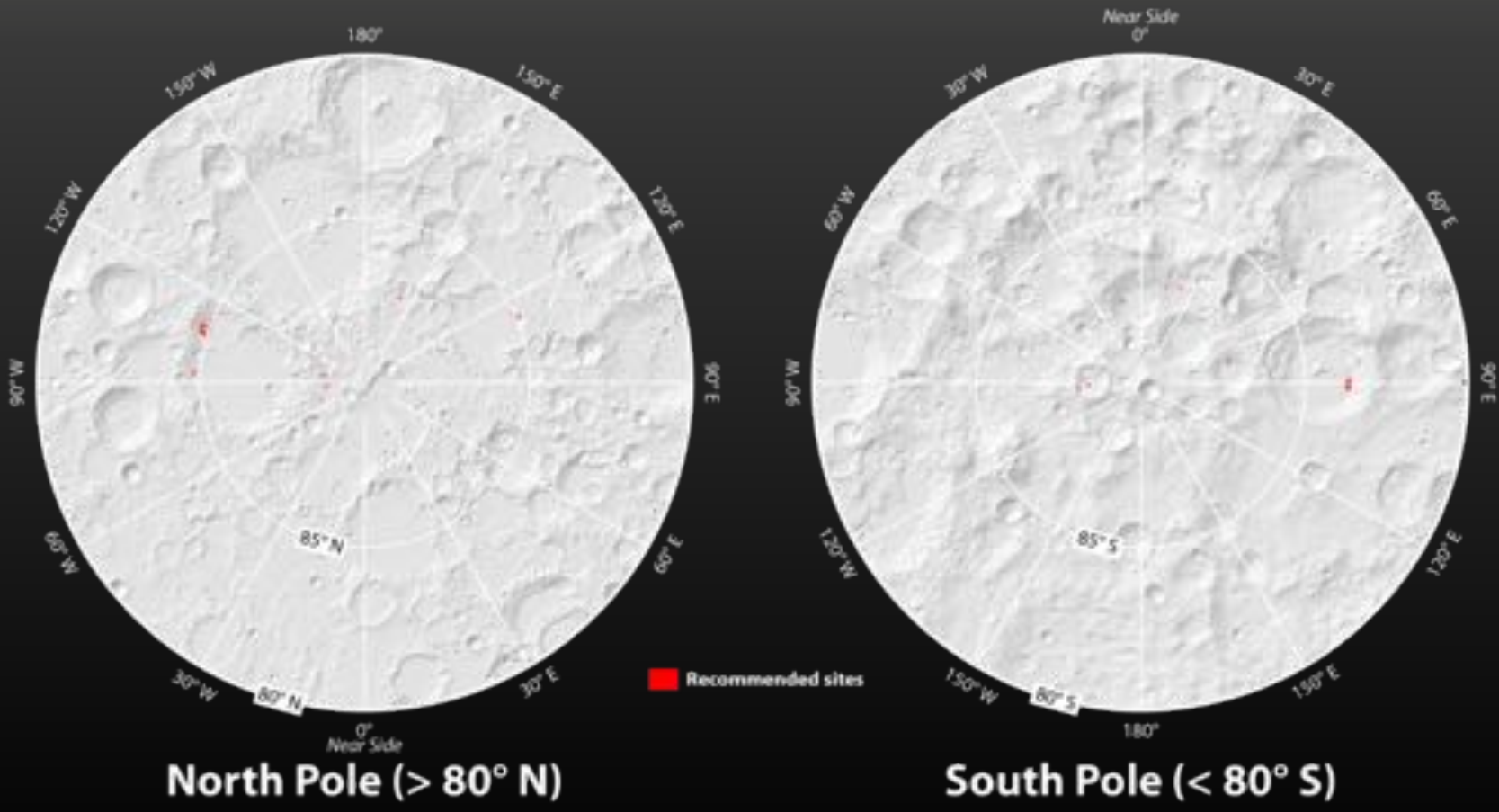
North Pole (> 80° N)



South Pole (< 80° S)

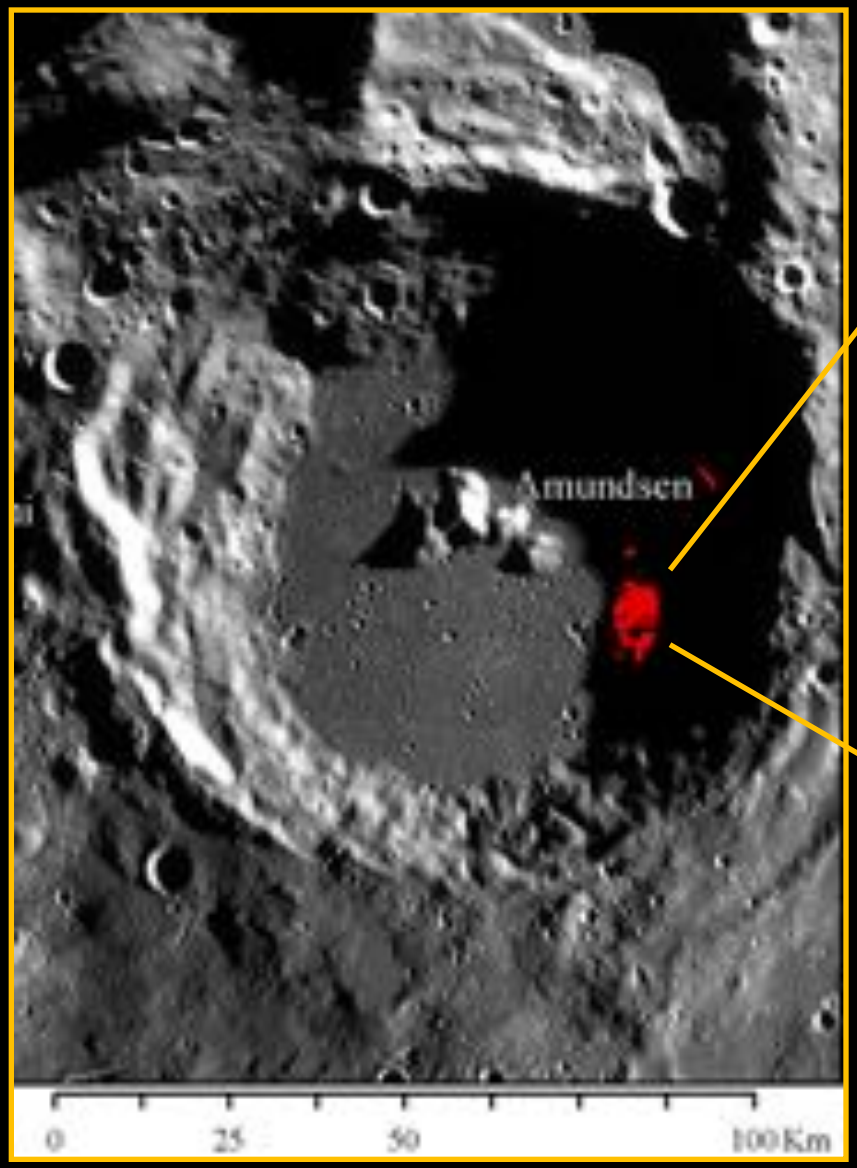
Overlap sites

- Where all five Concept 4 objectives can be addressed

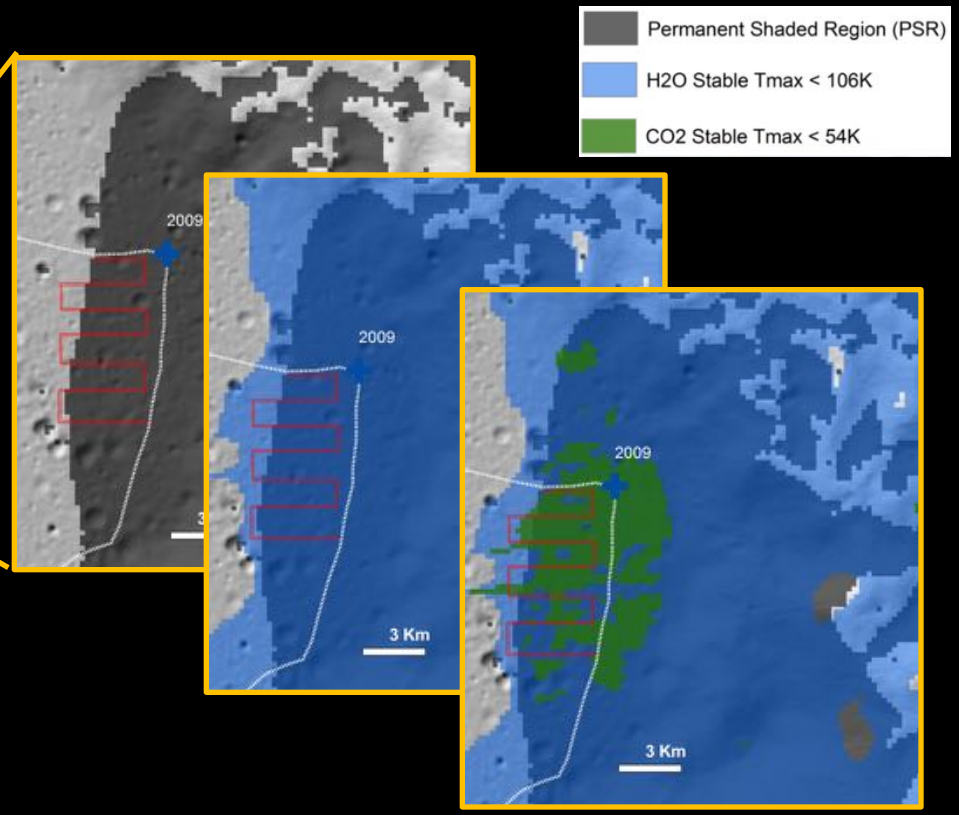


North Pole (> 80° N)

South Pole (< 80° S)



Amundsen Crater
Investigating Lunar Volatiles

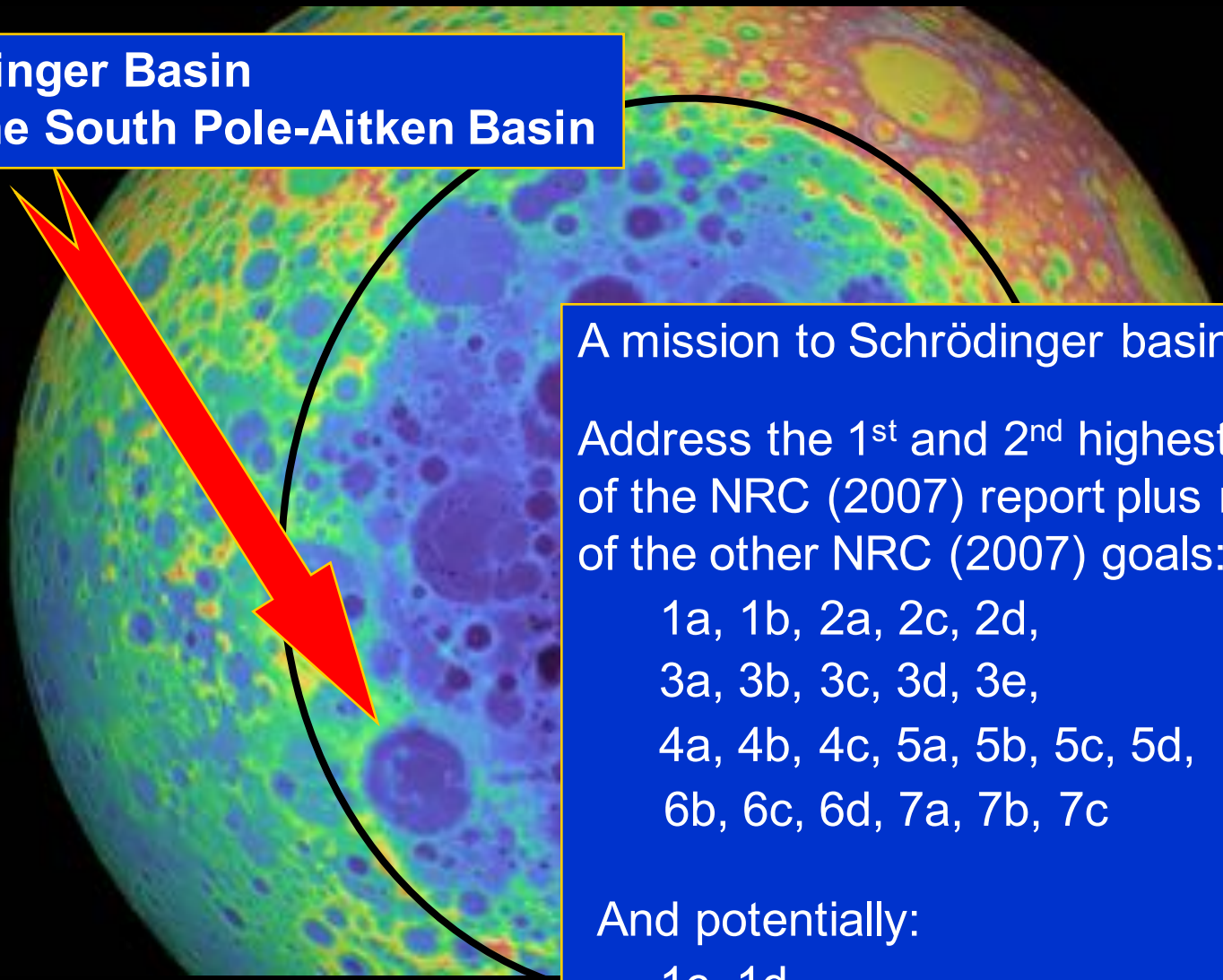


Within Amundsen Crater
GRP & NS survey of volatiles

Where to begin?

- Studies of Concept 1 (above) and several other concepts identified the Schrödinger Basin on the lunar far side as an excellent place to address the NRC (2007) objectives

The Earth-Moon System ~4 billion years ago



Schrödinger Basin
w/i the South Pole-Aitken Basin

A mission to Schrödinger basin can:

Address the 1st and 2nd highest priorities of the NRC (2007) report plus many more of the other NRC (2007) goals:

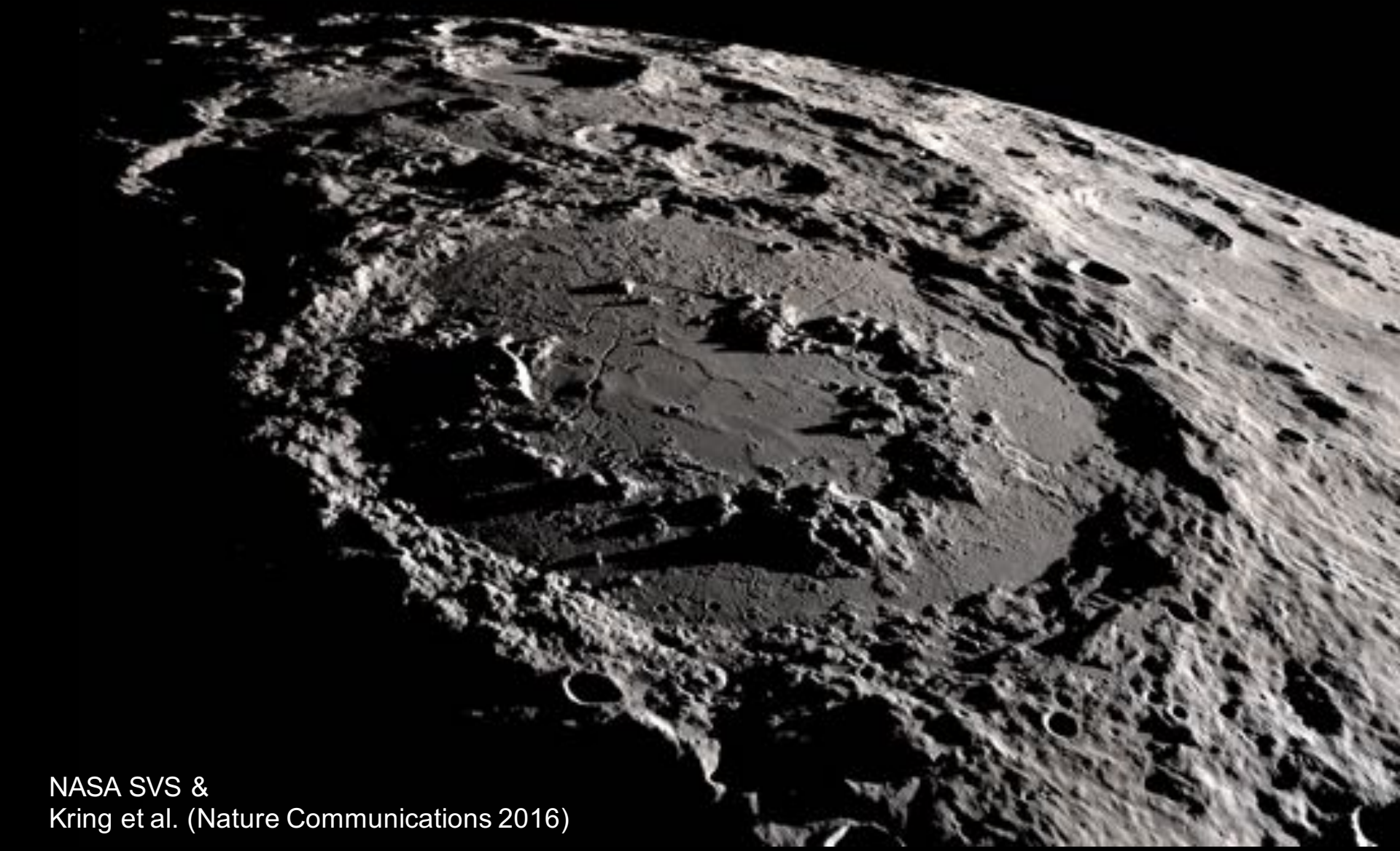
1a, 1b, 2a, 2c, 2d,
3a, 3b, 3c, 3d, 3e,
4a, 4b, 4c, 5a, 5b, 5c, 5d,
6b, 6c, 6d, 7a, 7b, 7c

And potentially:

1c, 1d

Background SPA image: LRO-LOLA/NASA GSFC SVS

SCHRÖDINGER BASIN AND THE SOUTH POLE

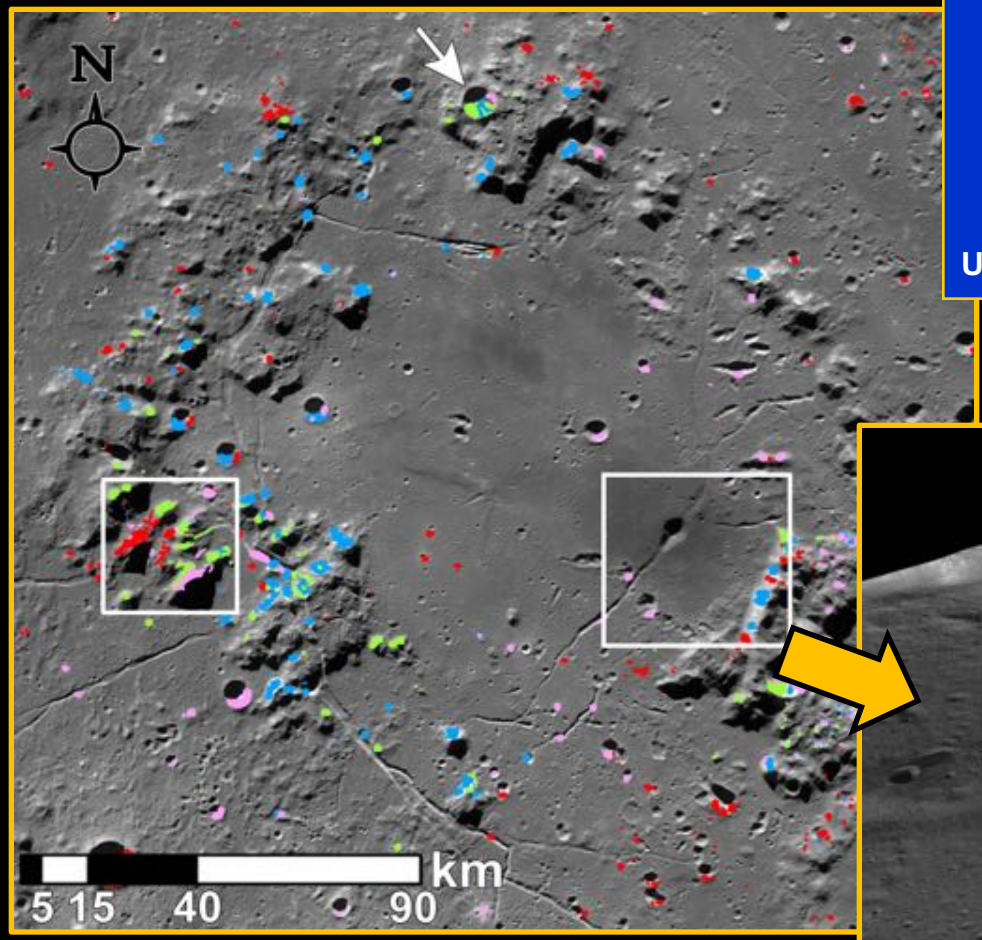


NASA SVS &
Kring et al. (Nature Communications 2016)

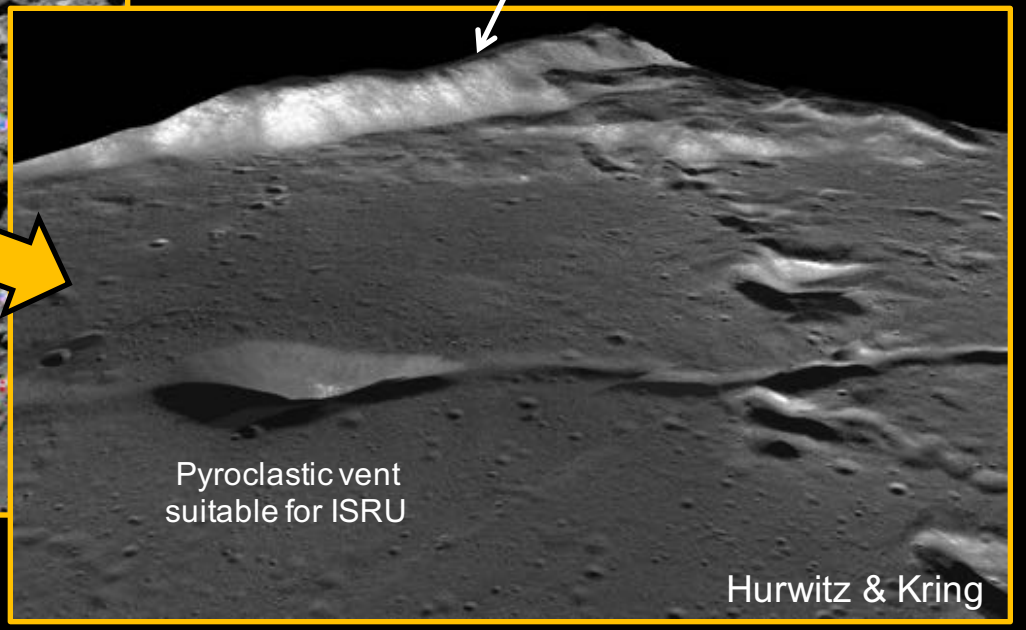
Schrödinger Basin w/i the South Pole-Aitken Basin

Detailed studies by:
- Kramer, Kring, Nahm, & Pieters (Icarus 2013)
- Kumar et al. (JGR 2013)
- Burns et al. (ASR 2013)
- Pratt et al. (IAC 2014)
- Potts et al. (ASR 2015)
- Hurwitz & Kring (EPSL 2015)
- Kumar et al. (JGR 2016)
- Steenstra et al. (ASR 2016)
- Kring et al. (Nature Communications 2016)
- Kring et al. (2016-submitted)

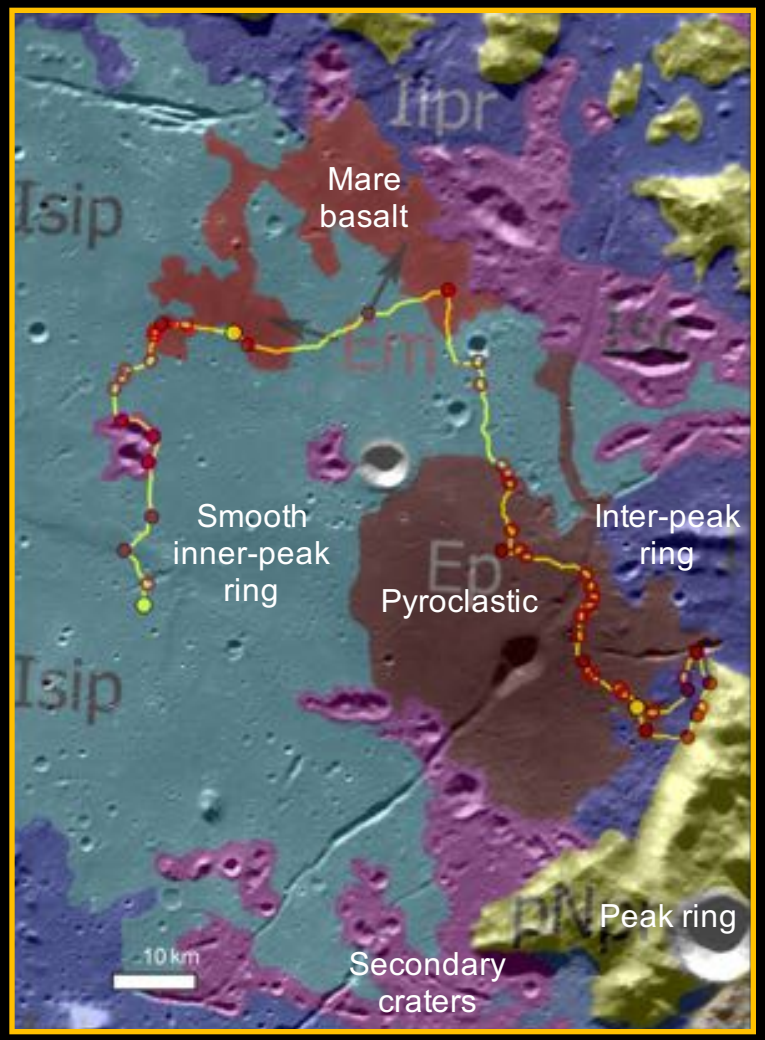
Using M^3 data, LOLA data, and LROC data.



Peak ring exposures of anorthositic, noritic, and troctolitic rocks



SHORTEST DISTANCE TRAVERSE



Traverse length: ~207 km
(Notional traverse extended by 45 km)

Total duration: 13 months (large margin)

- ~100 days at stations
- ~198 days traversing

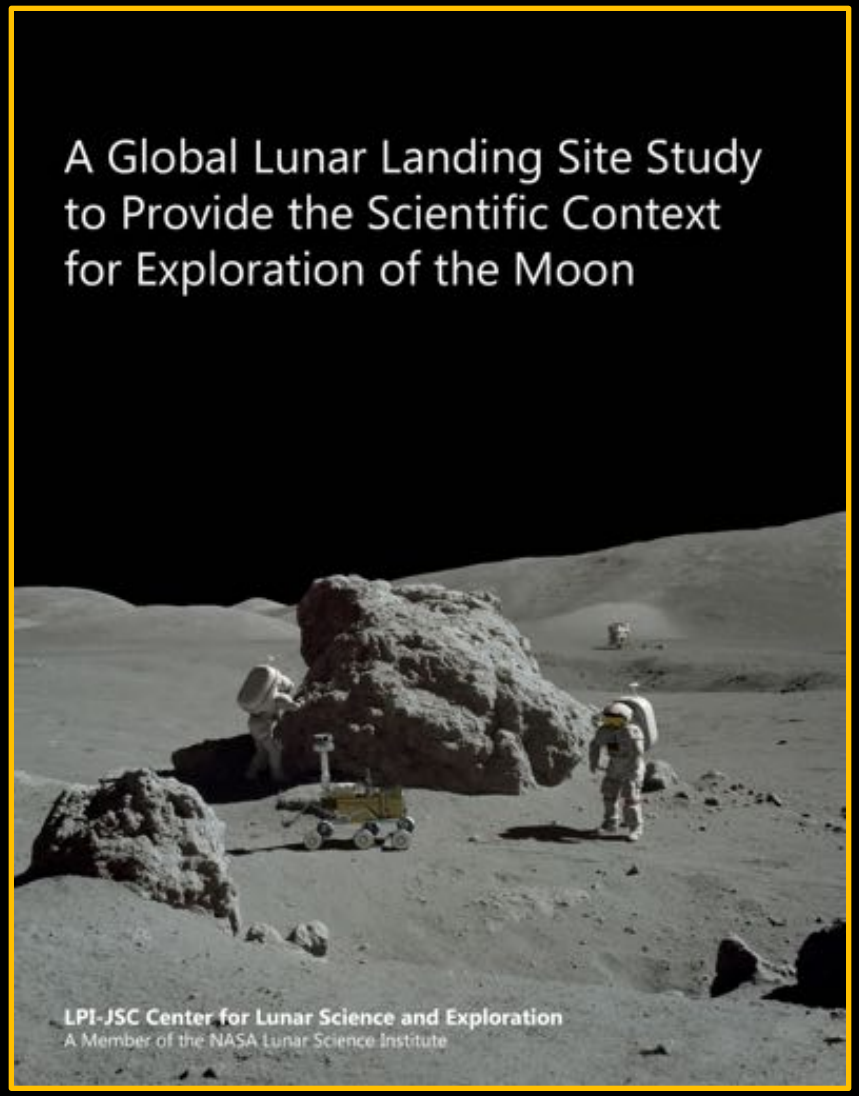
Traverses 6 geologic terrains

3 lander sites (yellow circles)

50 stations selected for imaging and *in-situ* analysis (red circles)

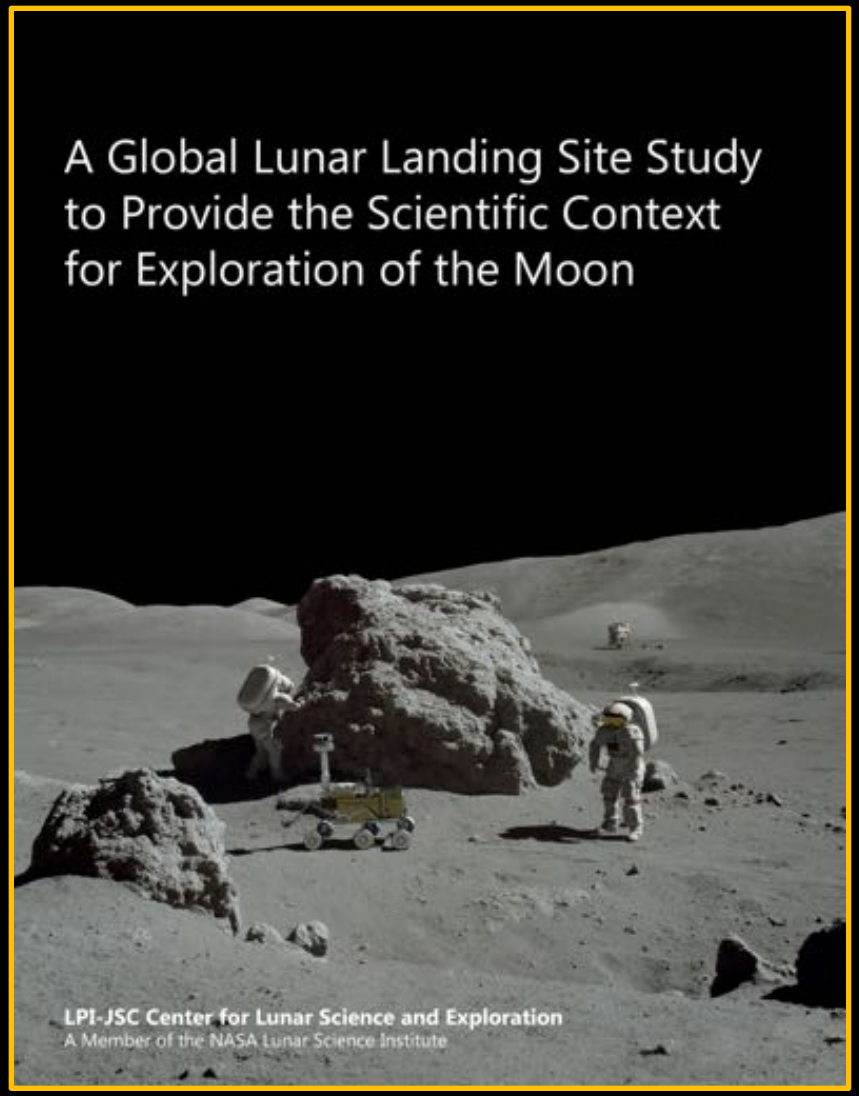
18 of the 50 stations are sampling sites (filled red circles)

In this study, speed reduced from 1 km/s to 0.36 km/s.



Some highlights

- Schrödinger basin on the lunar far side, within the South Pole-Aitken basin, is the location where the largest range of objectives can be addressed.
- For studies of polar volatiles, Amundsen crater may be a better target than Shackleton crater.
- Most of the NRC (2007) objectives can be addressed within the South Pole-Aitken basin on the lunar far side,
- But to truly resolve all of the NRC (2007) objectives, global access to the Moon is required



Thank you.

Roll the Video.