Advances in Lunar Science Over the Last Decade

Carlé M. Pieters

NRC Decadal Survey: Panel on Mercury and the Moon

January 29, 2021

Apollo

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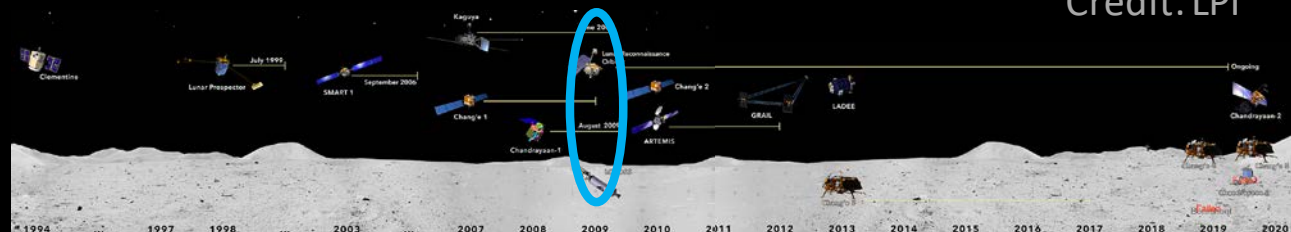
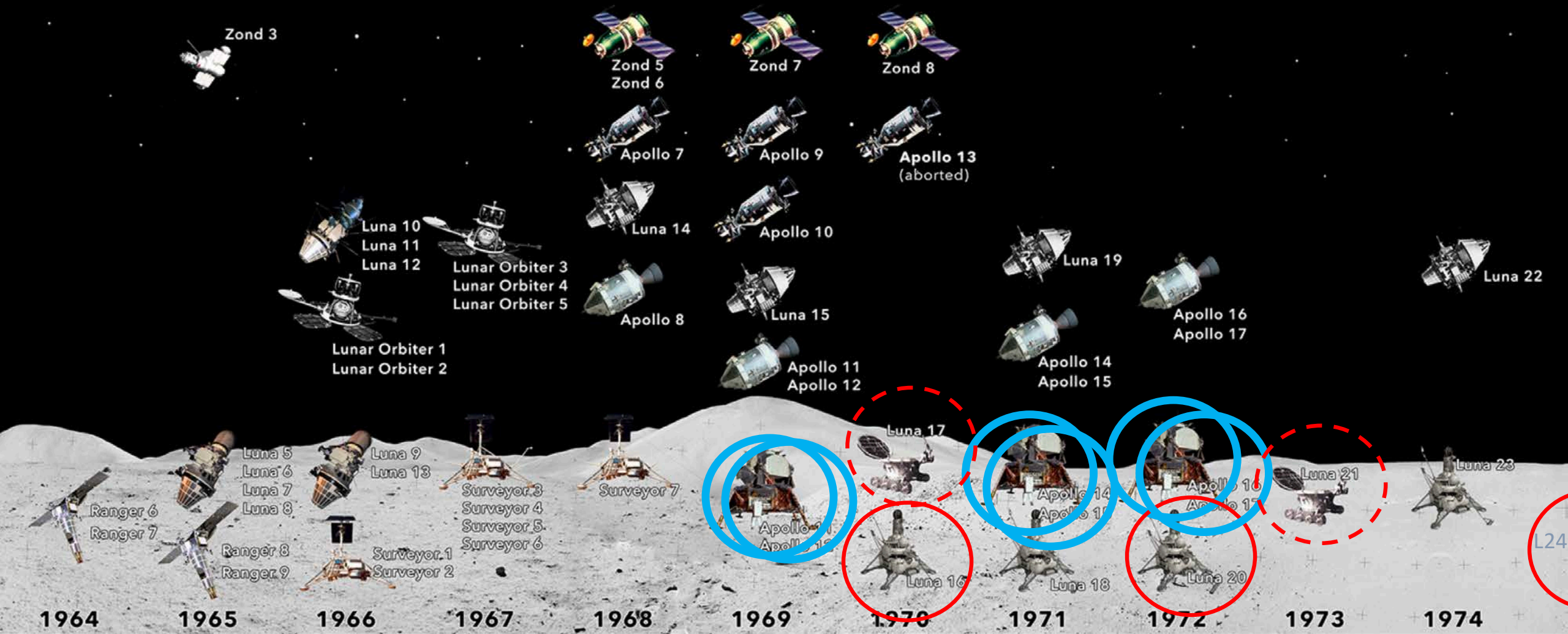
Decades Long Gap

Present



Credit: LPI

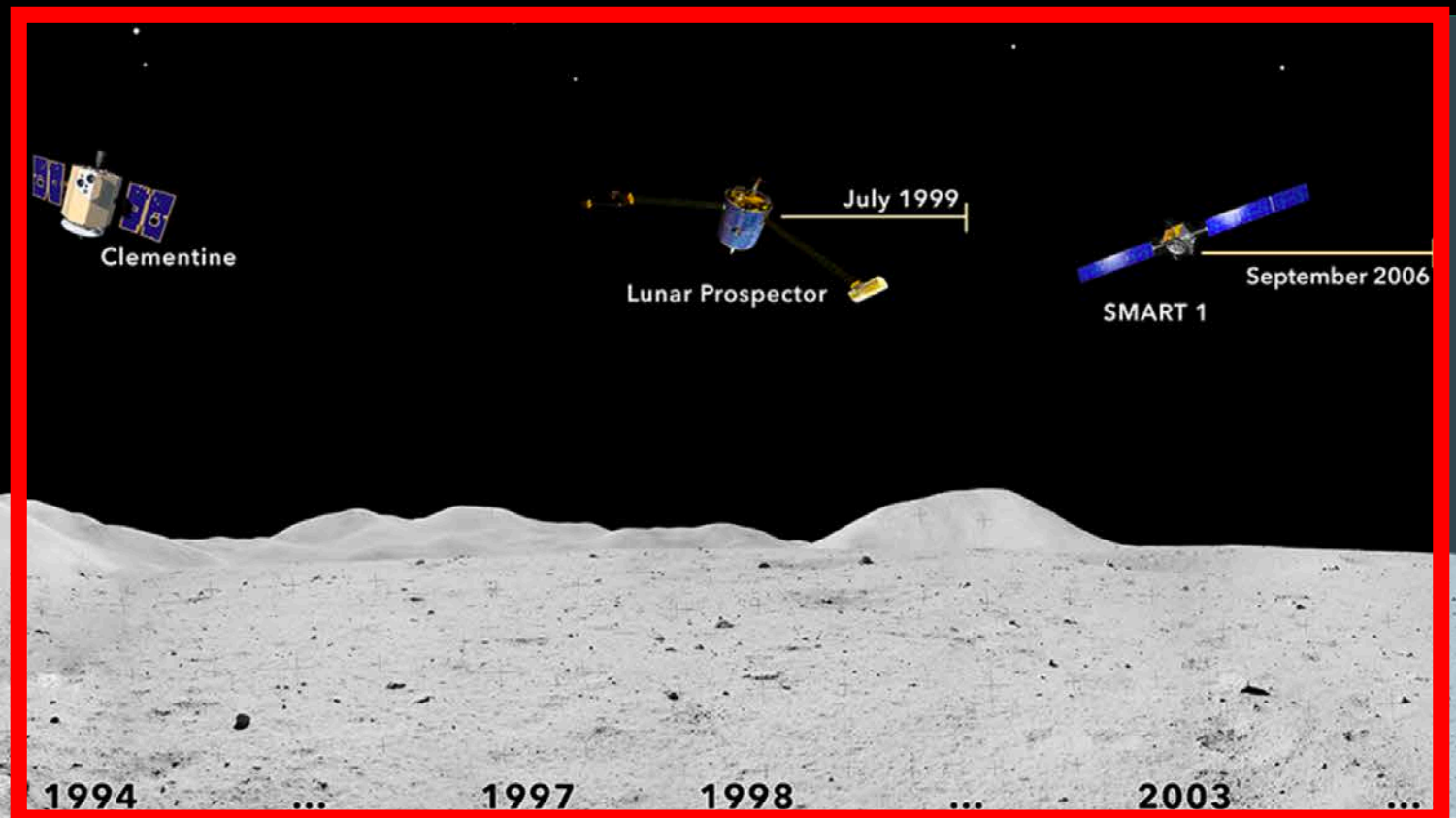
Apollo/Luna Era at the Moon

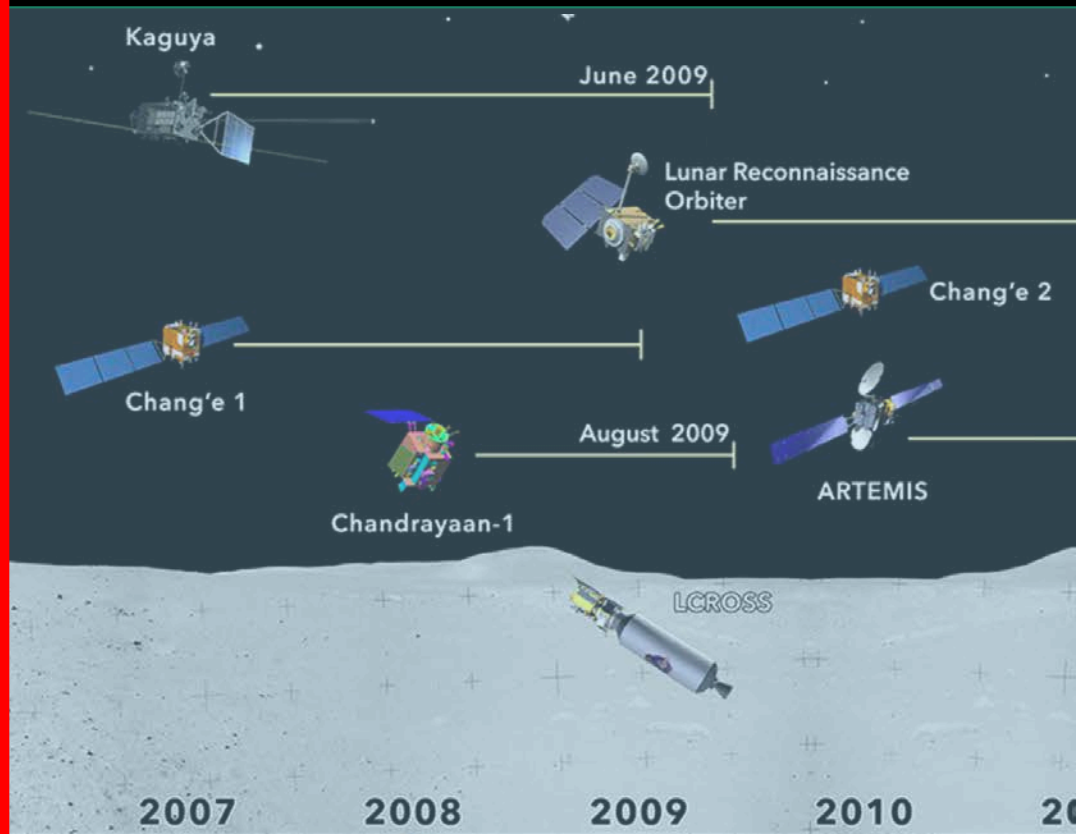


20 year Gap…..

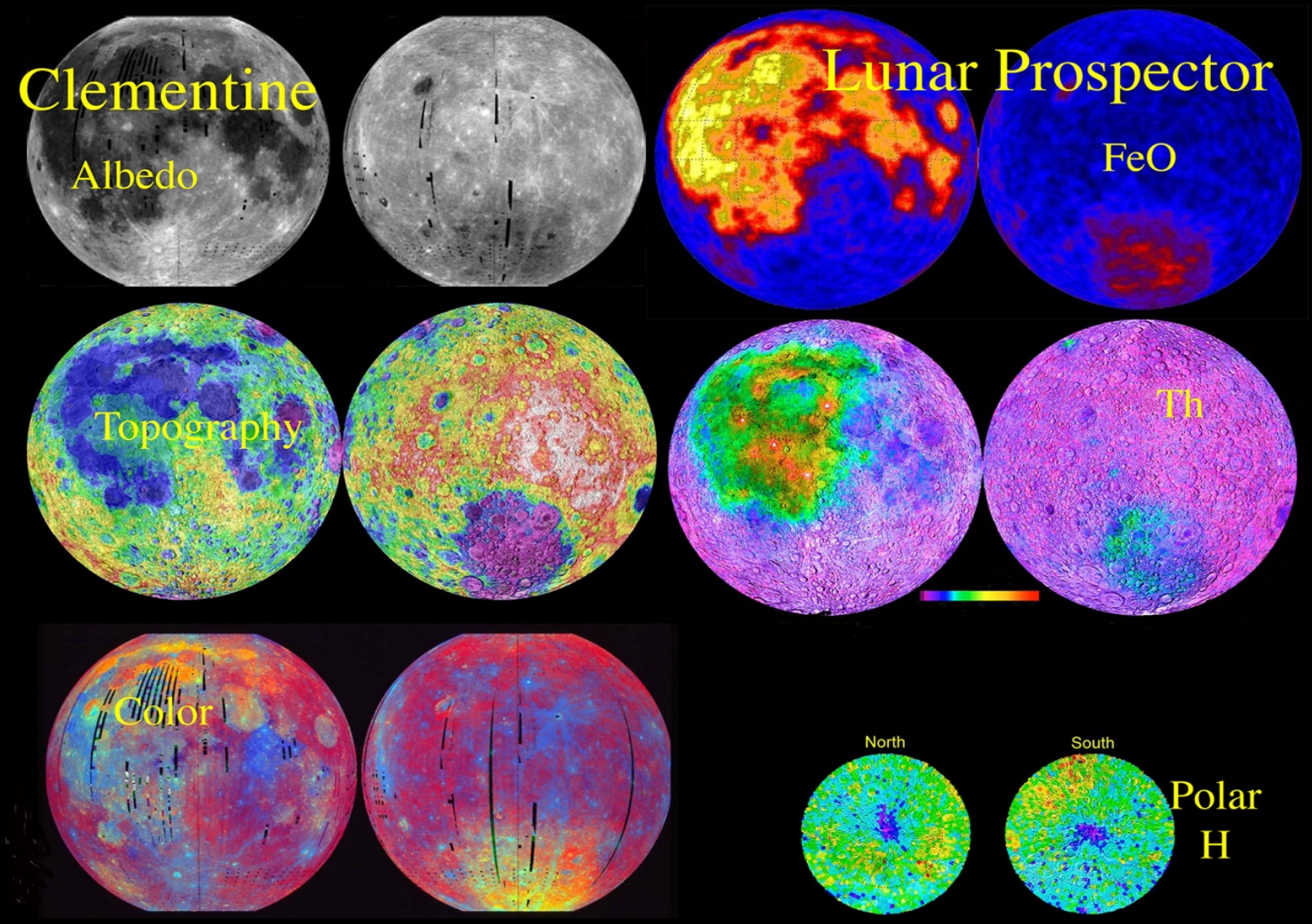
[only Earth-based Astronomy & Lunar Sample studies….]

Reawakening: New Views of the Moon





New Views of the Moon



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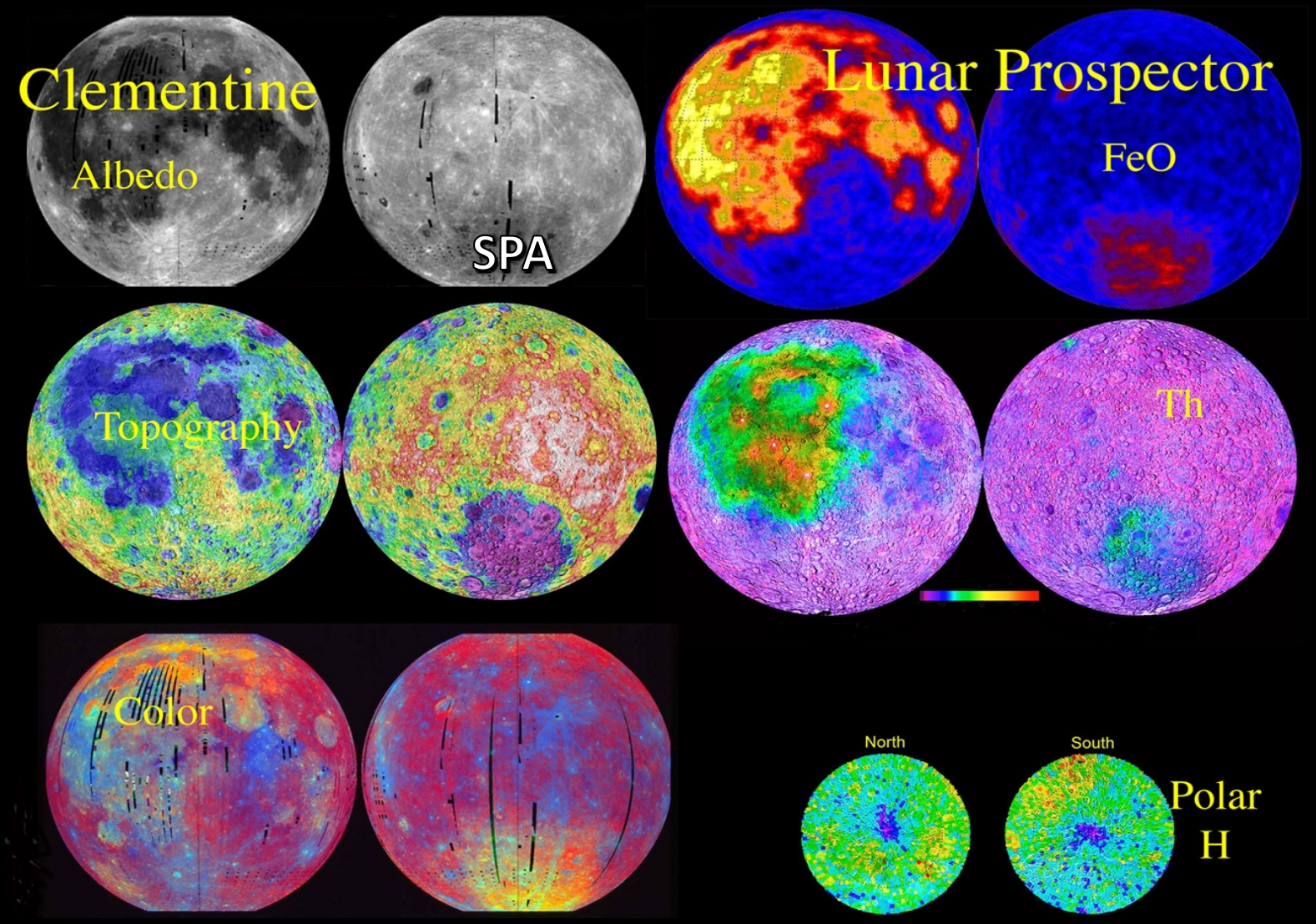

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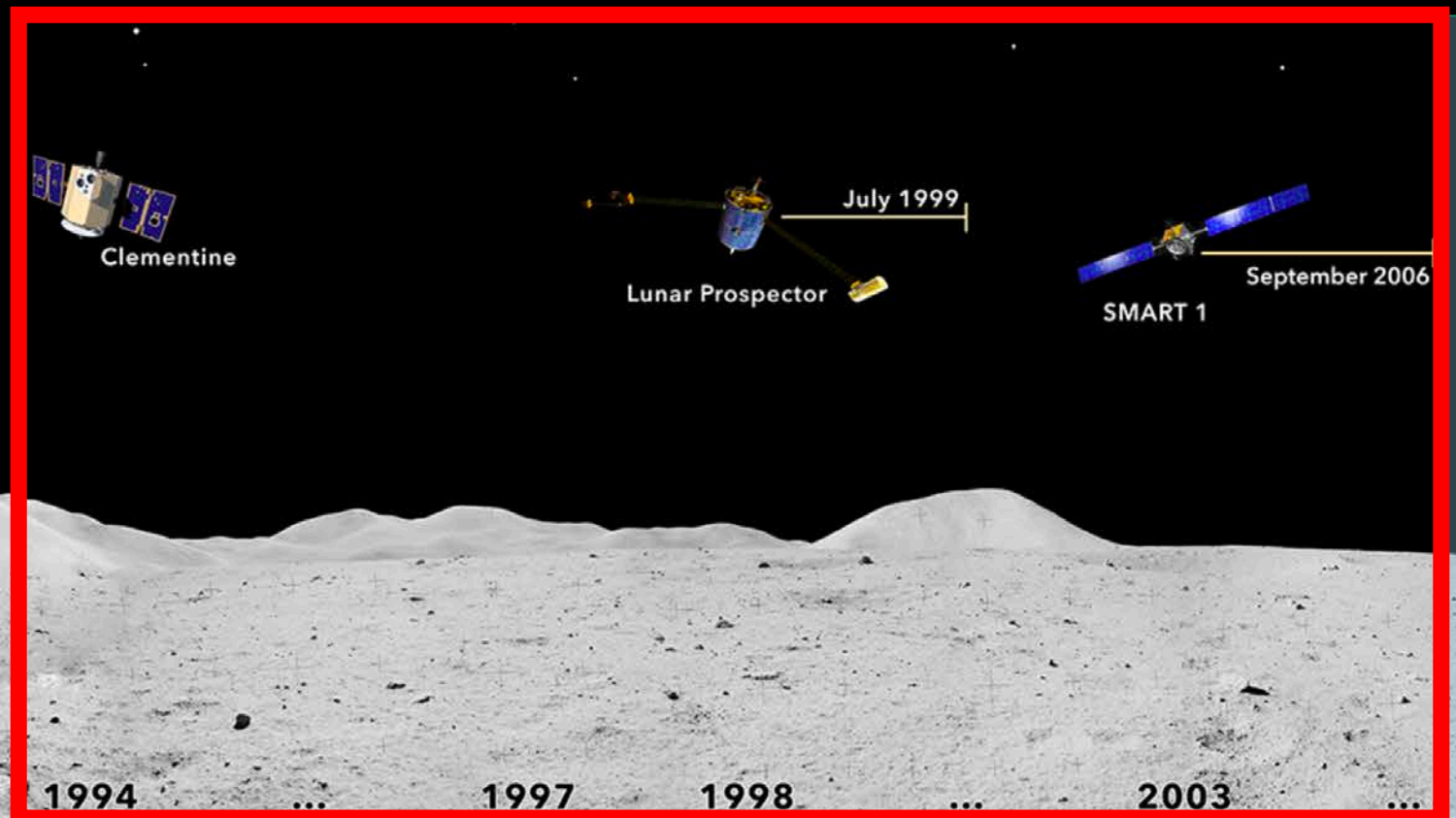
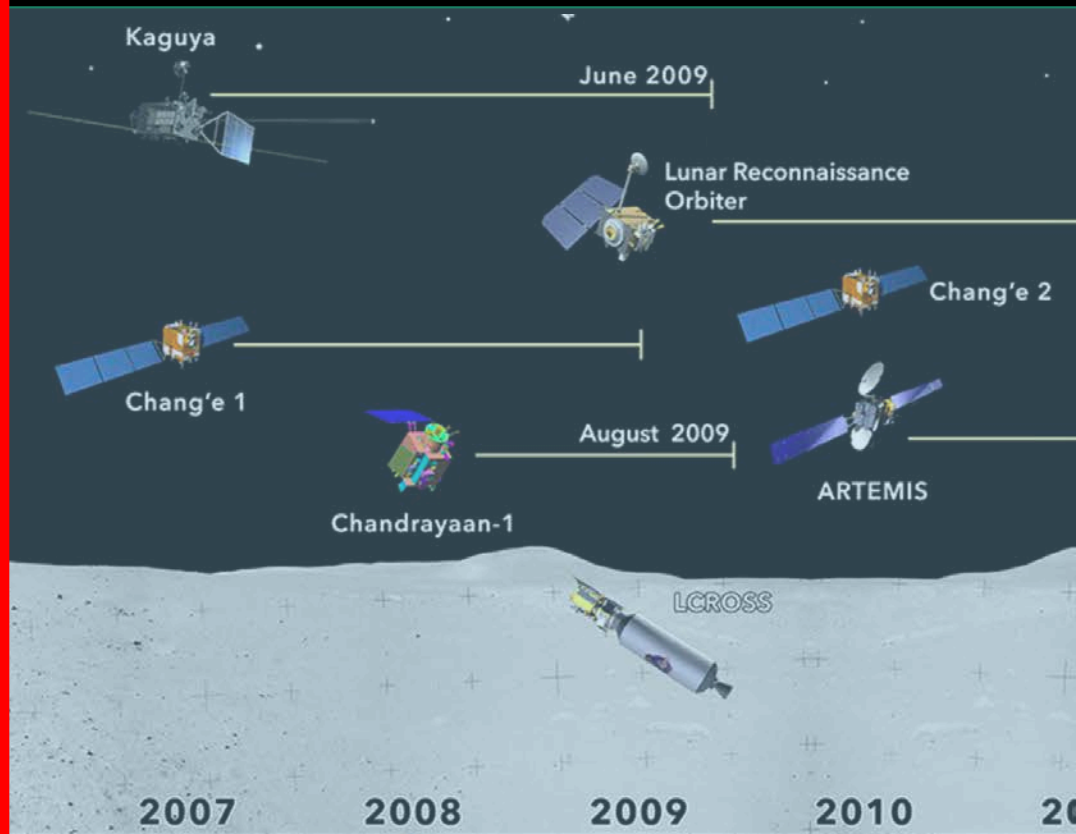
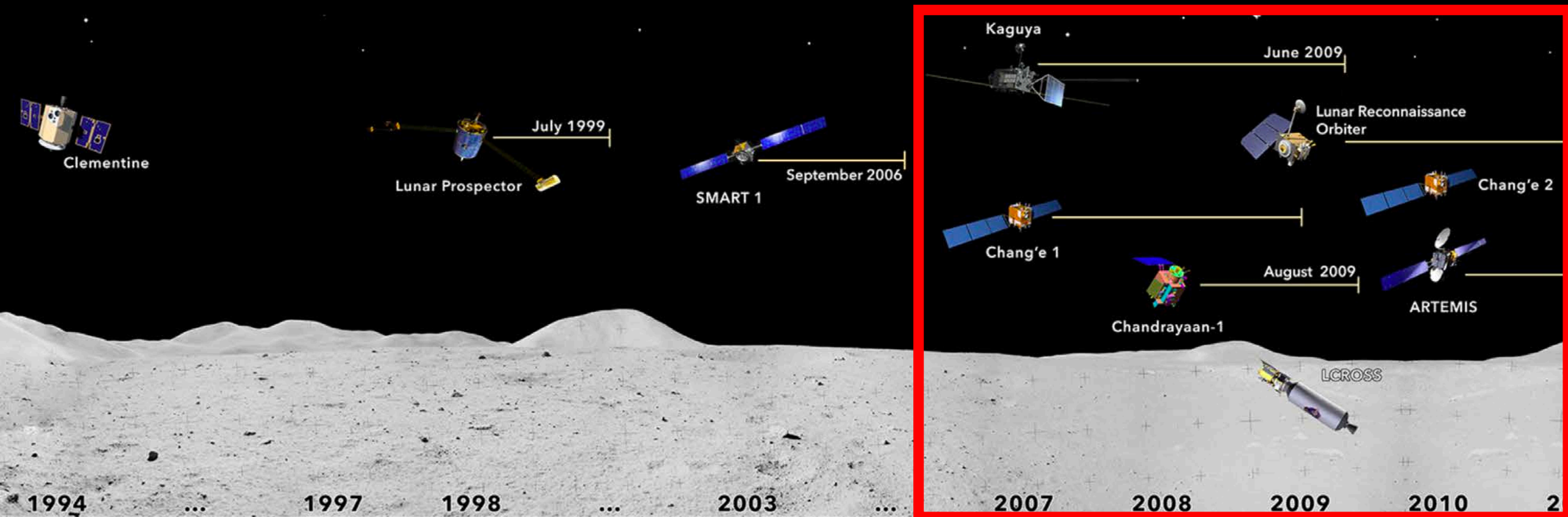




Renewed International Interest in the Moon

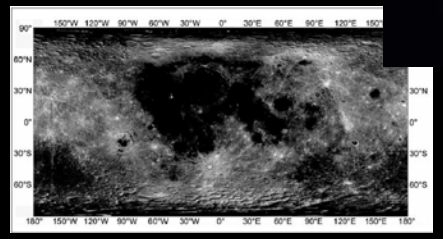
Japan, China, India, NASA…



At the time of the last Decadal Assessment…

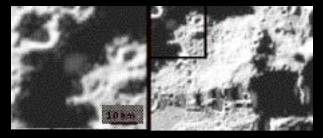
- A group of **small** orbital missions had been independently launched to the Moon by Japan, China, India, and USA (2007-2009), and valuable ***modern*** data was just beginning to be organized and analyzed across an international lunar science community:

  - JAXA's 2007/09 Kaguya
  - CNSA's 2007/09 Chang'e 1; 2010/11 Chang'e 2



  - ISRO's 2008/09 Chandrayaan-1 [+ M^3 (Discovery) and Mini-SAR (DoD)]

  - NASA's 2009 +11 LRO/LCROSS; 2010 ARTEMIS (redirect)



The Decade Since then….

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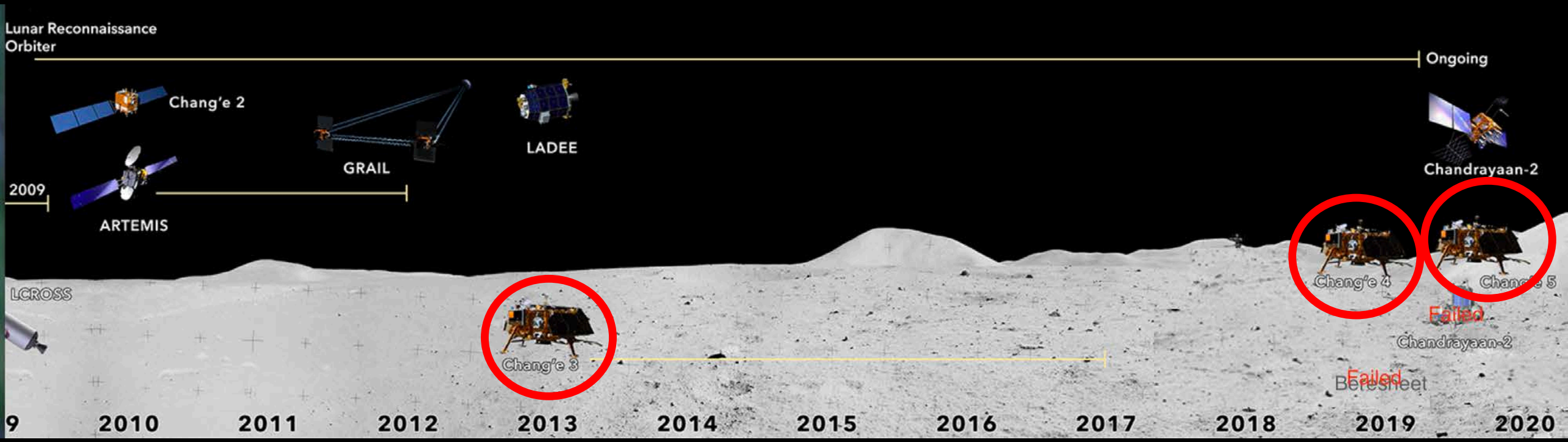

The Decade Since then….

- NASA's lunar initiatives produced excellent focused science
  - **LRO** has operated continuously for >11 years with major contributions and achievements
  - **GRAIL** [a Discovery selection] provided detailed information on global crustal properties
  - **LADEE** measured the tenuous lunar exosphere with time using modern instruments
  - **Lunar samples** (in modern laboratories) continue to build fundamental science
- **X-Prize** stimulated commercial interest in lunar landing; none were able to claim the prize, but many became ready for CLPS initiative
- China continued with a defined program involving additional launches and achieving several important milestones:
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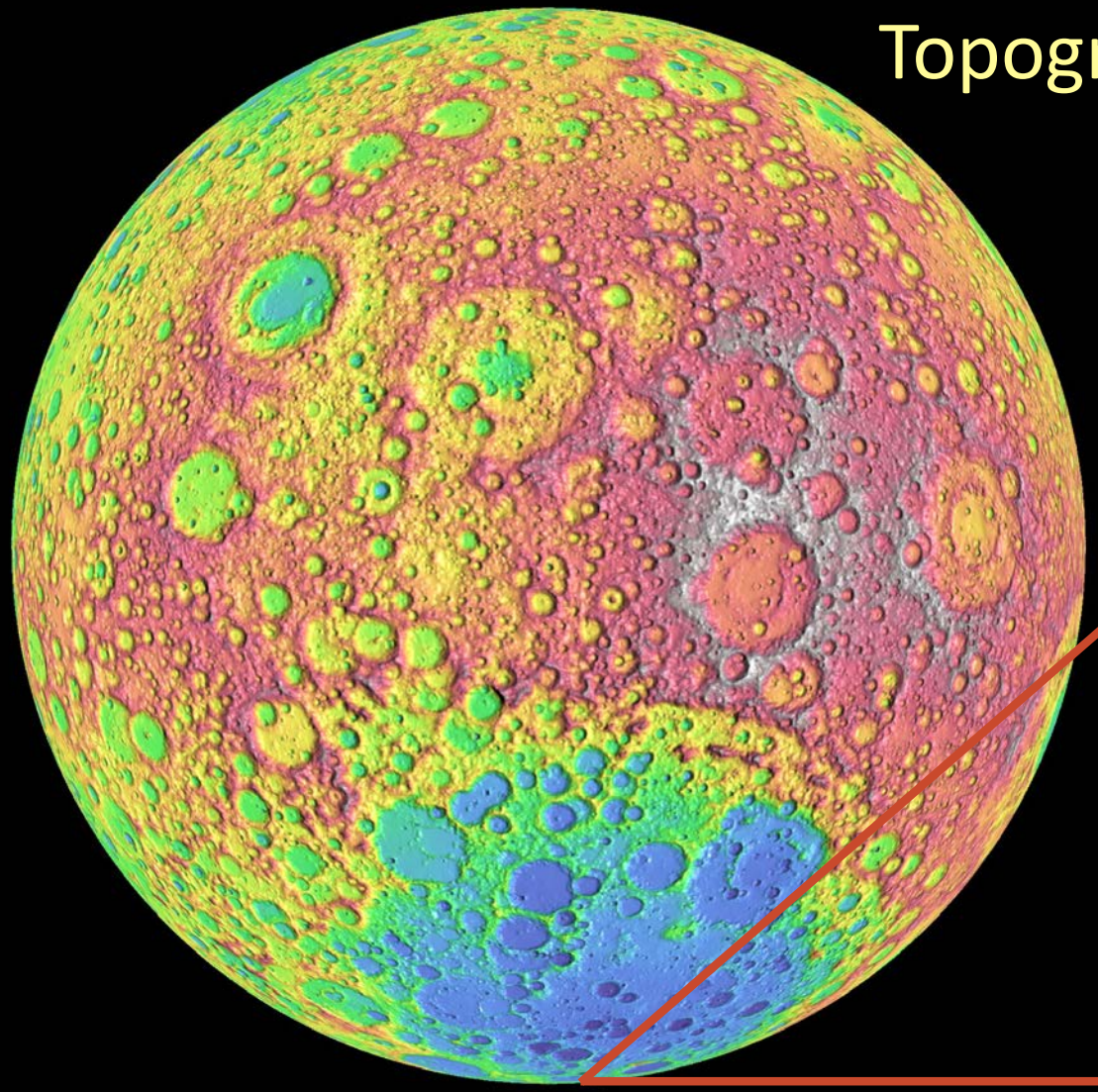
Example LRO Highlights….

LOLA
Diviner
LROC

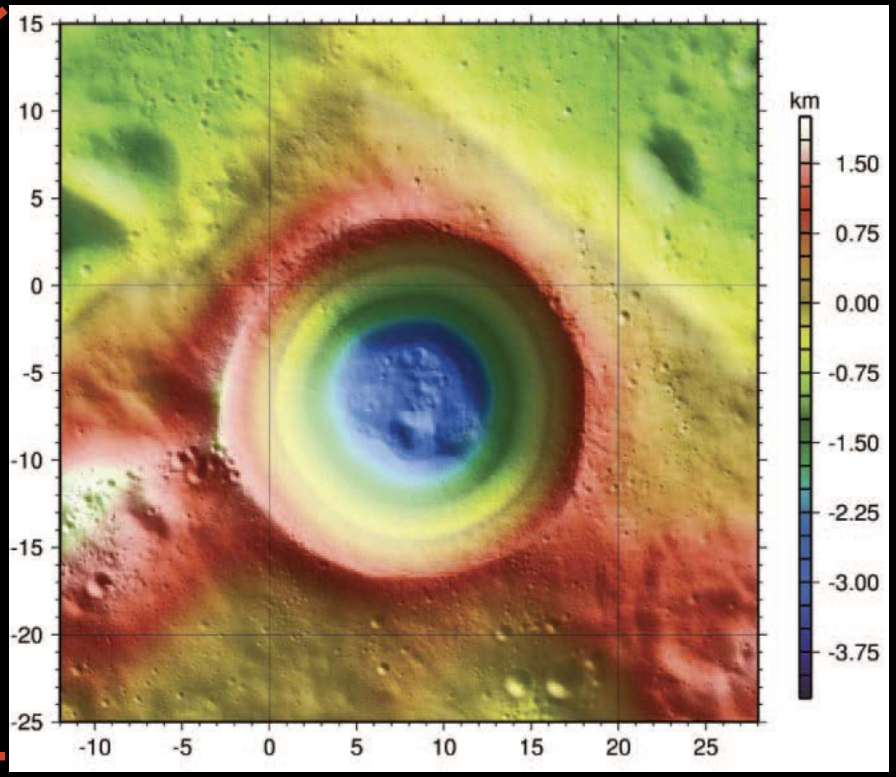
LOLA (Lunar Orbiter Laser Altimeter)

Topographic data with exceptional detail!

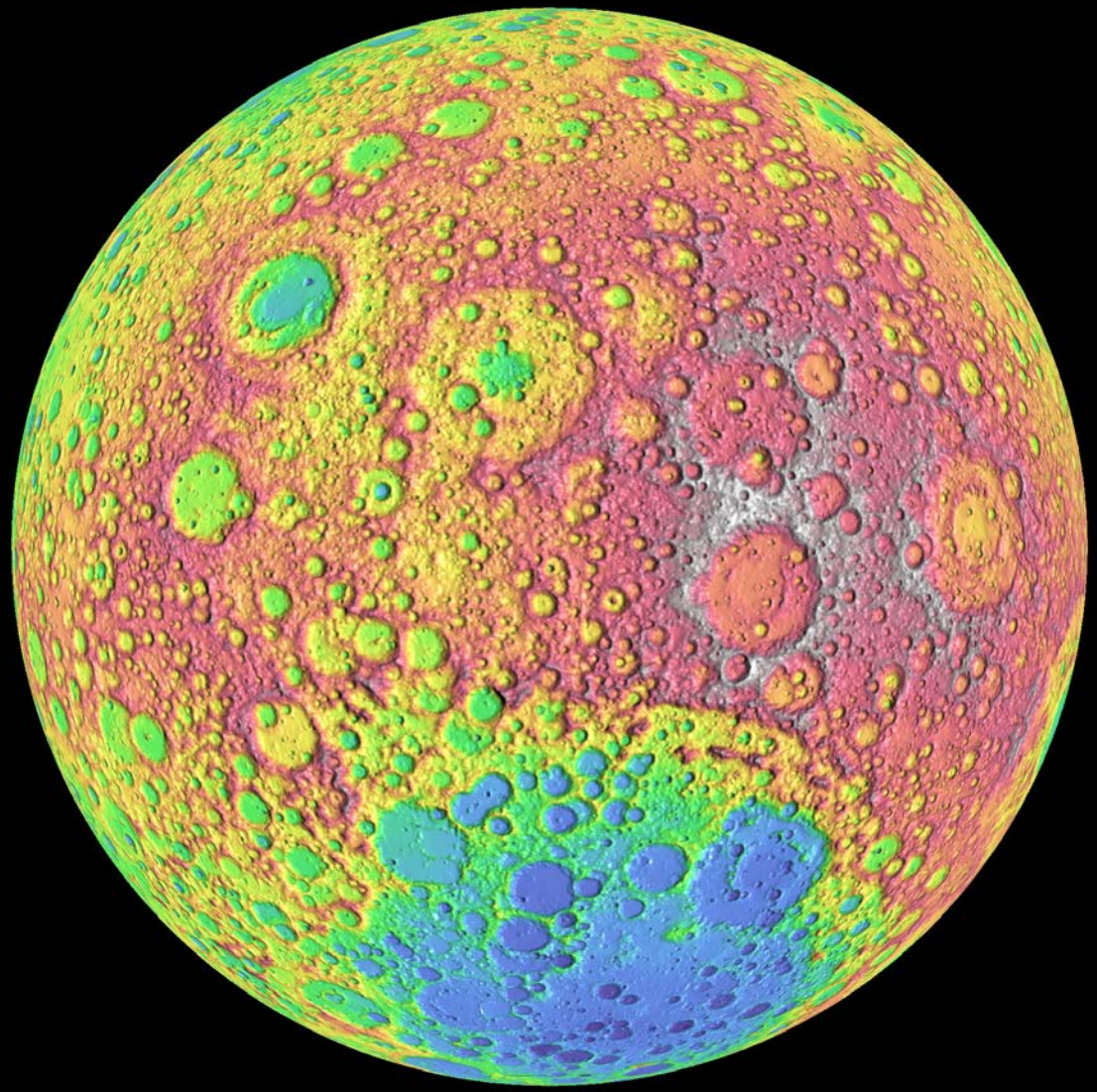


Inside Shackleton!

[Zuber et al., 2012 Nature]



LOLA (Lunar Orbiter Laser Altimeter)



- LRO measurements produced an accurate reference frame for the Moon.

LOLA data was essential for seleno-referencing M^3 data (Boardman et al., 2011, JGR)

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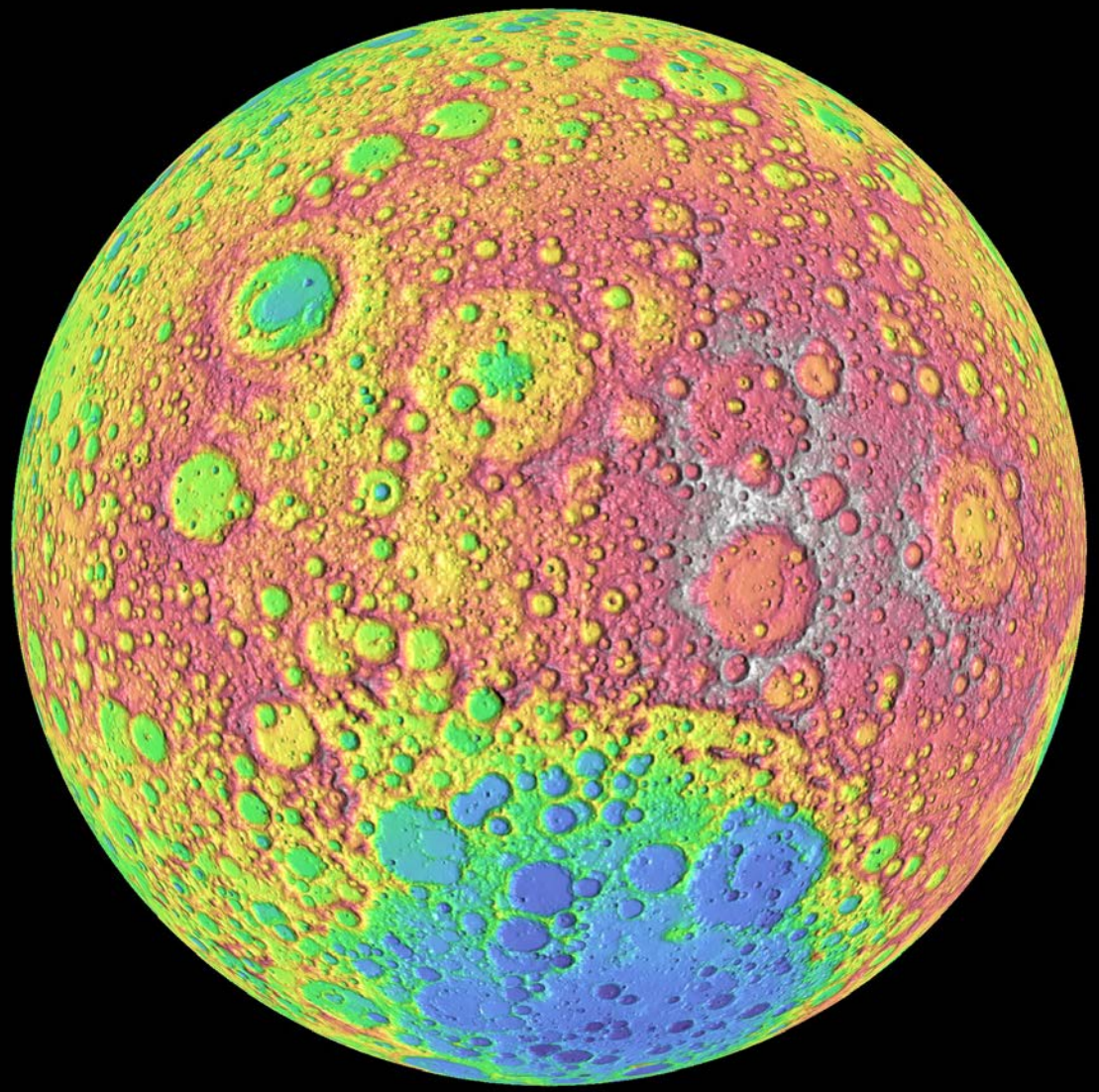
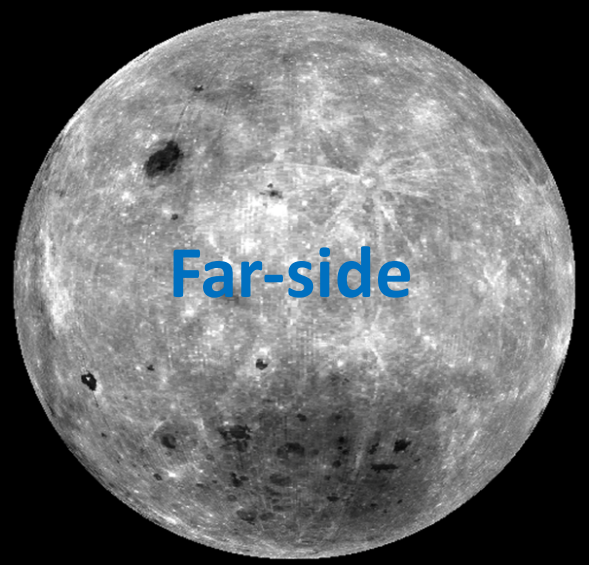
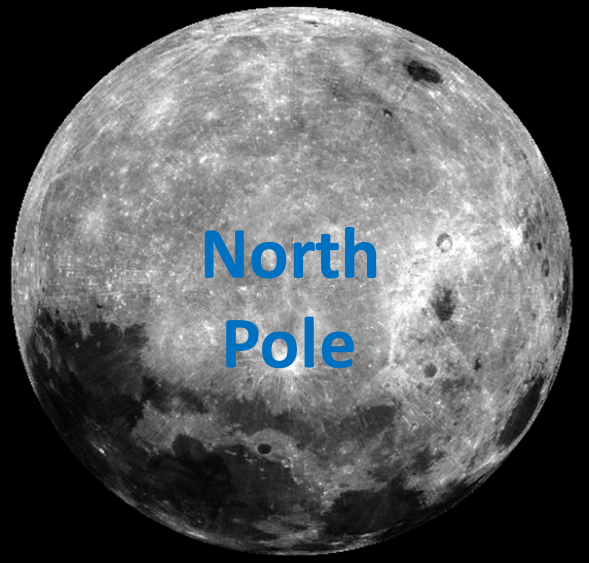
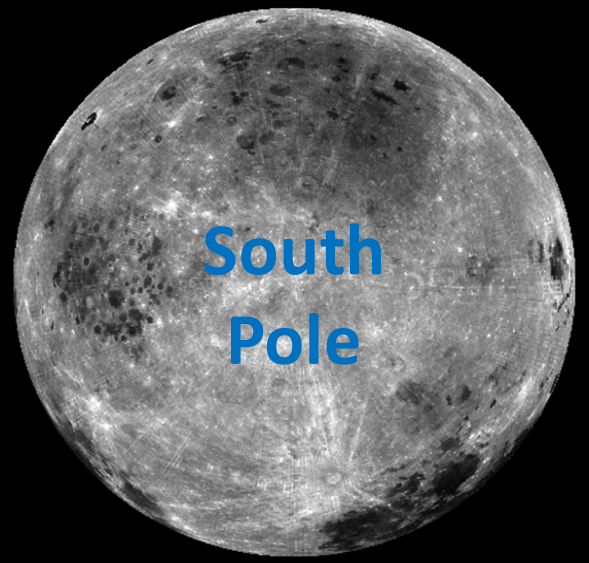




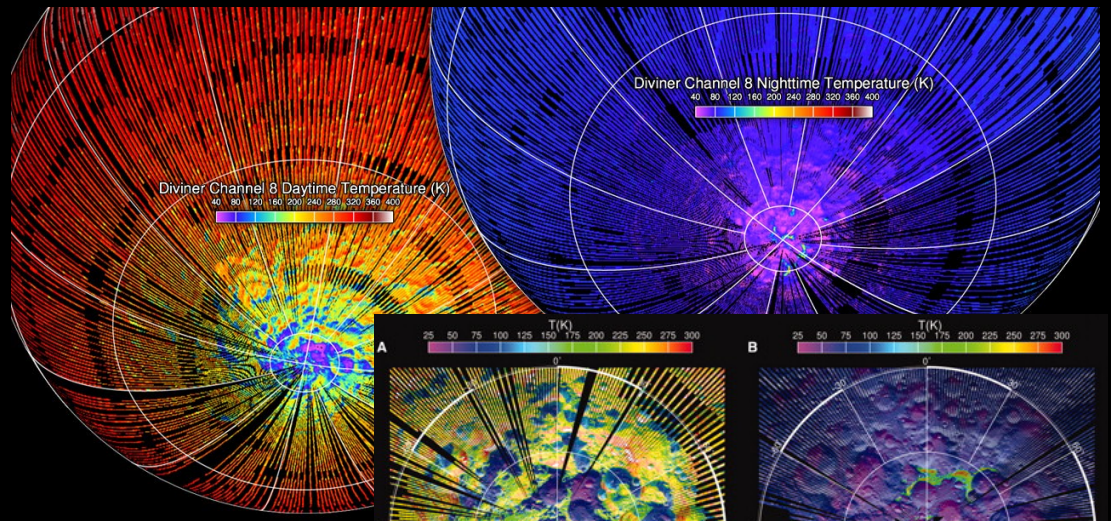
LOLA **Albedo**: Lucey et al., 2014, JGR-P

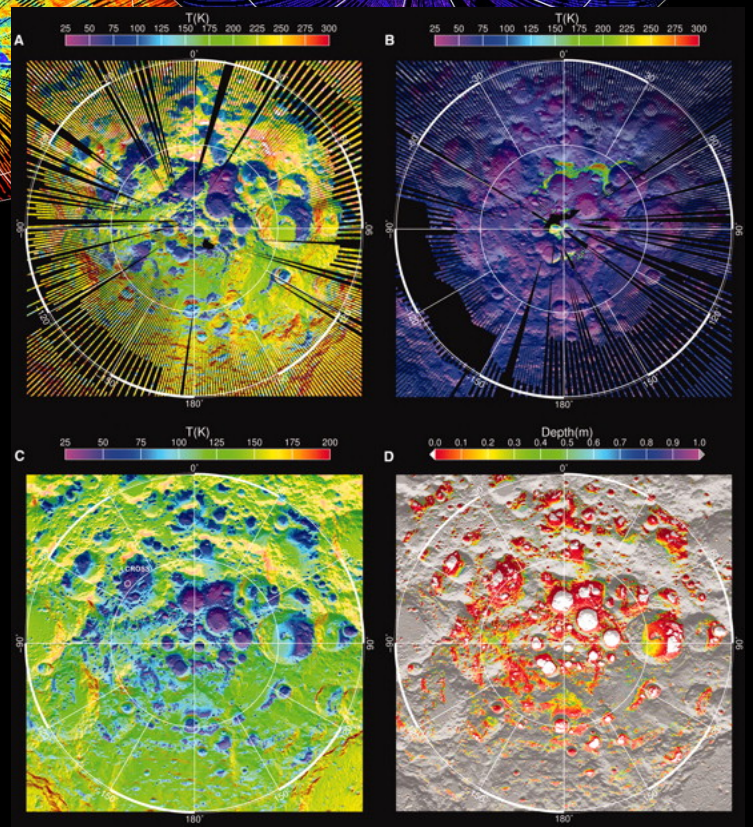




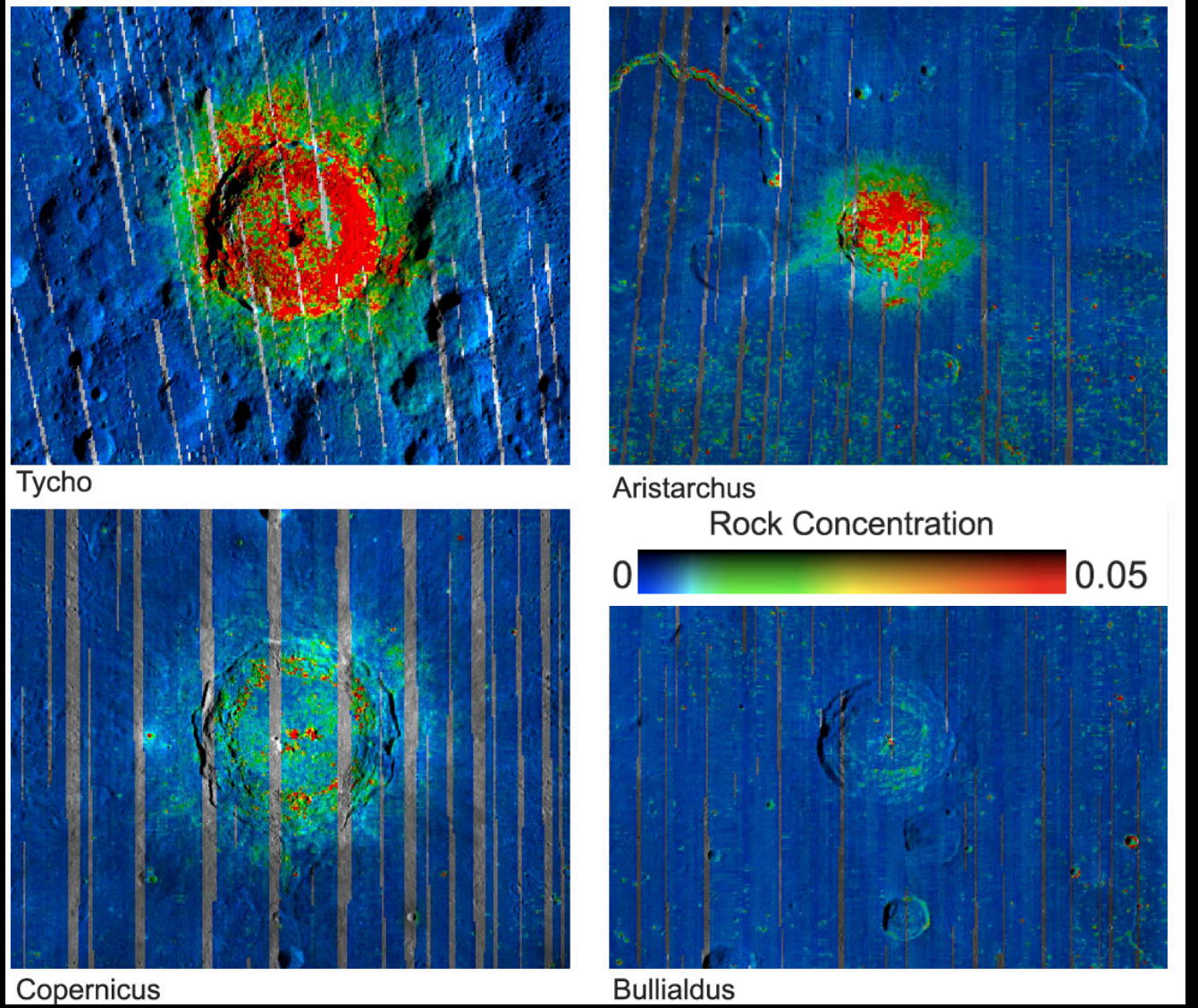
Diviner Thermal Global Data

Bandfield et al., 2011, JGR



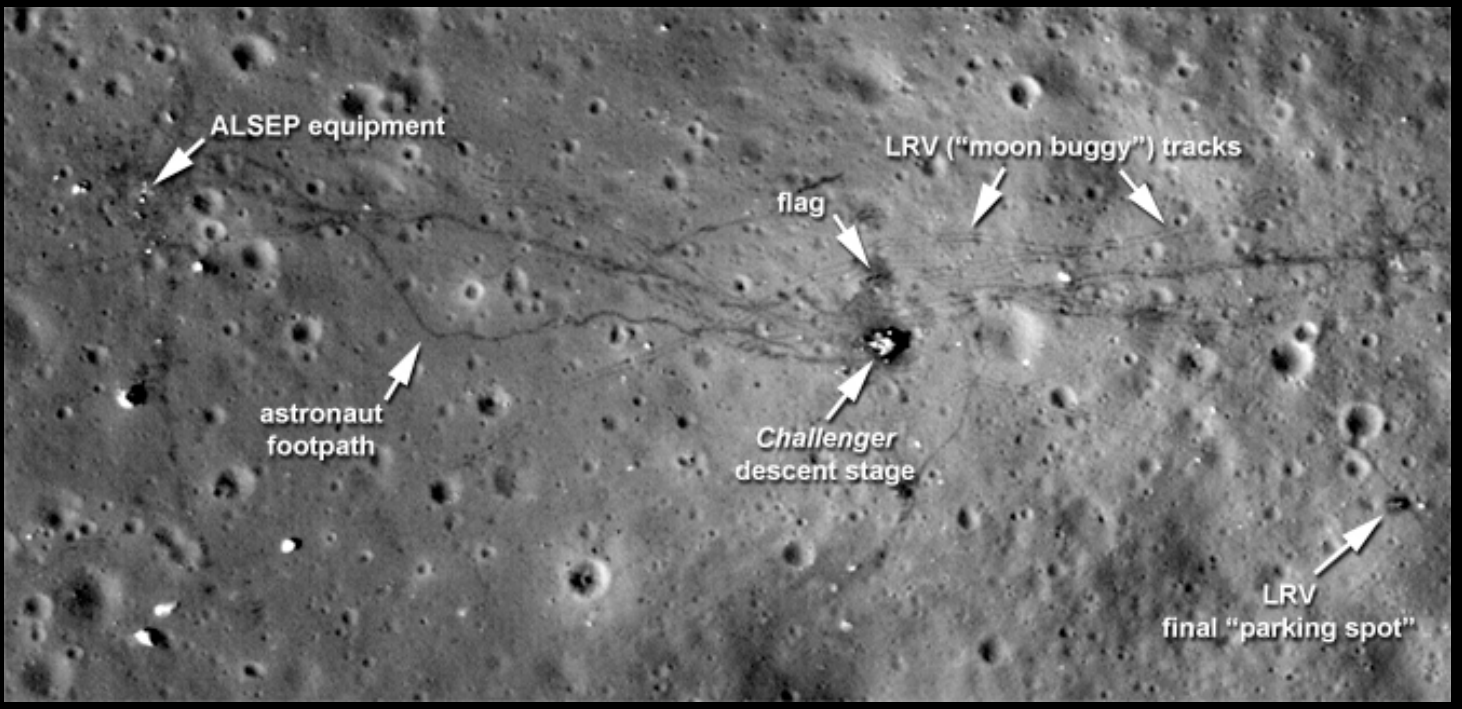


Paige et al.
Science 2010

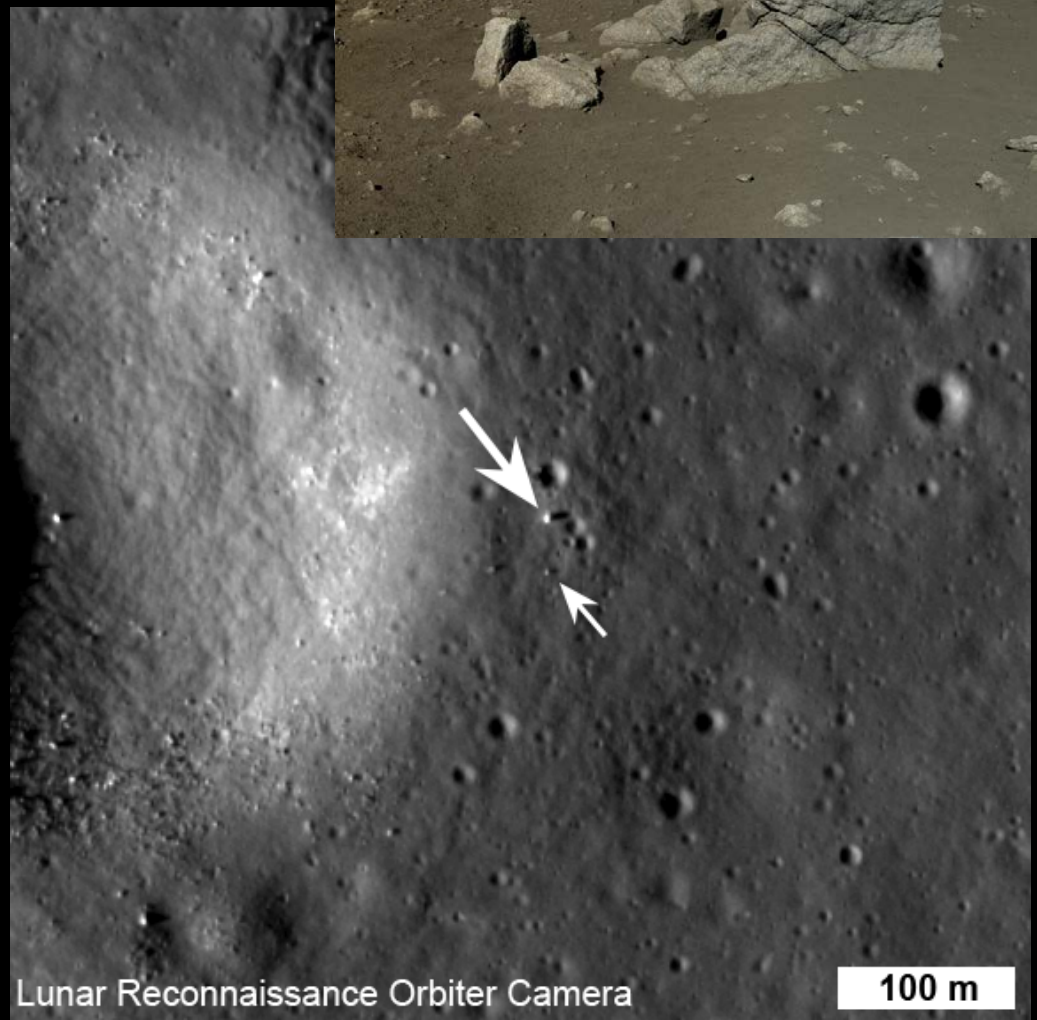


LROC NAC imaging over 11 + years in orbit

Apollo 17



Chang'e 3



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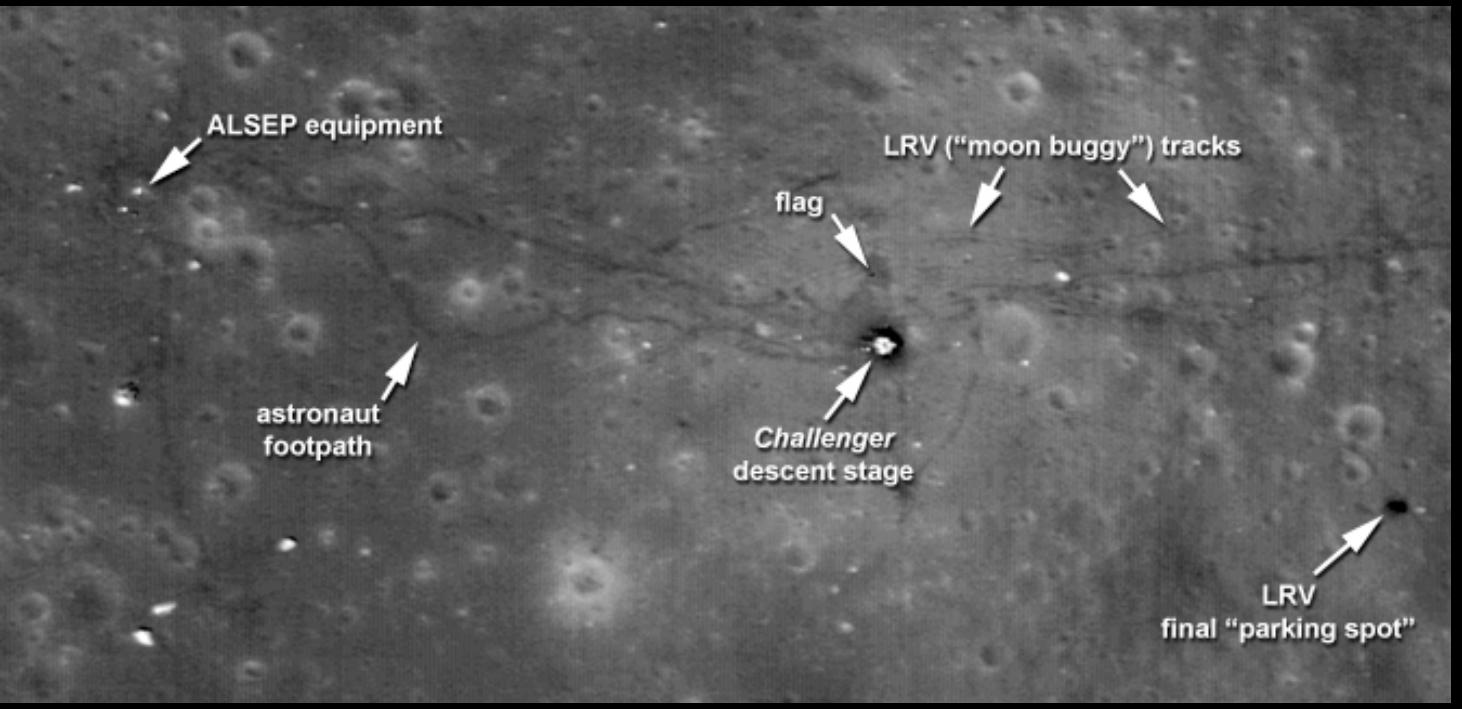

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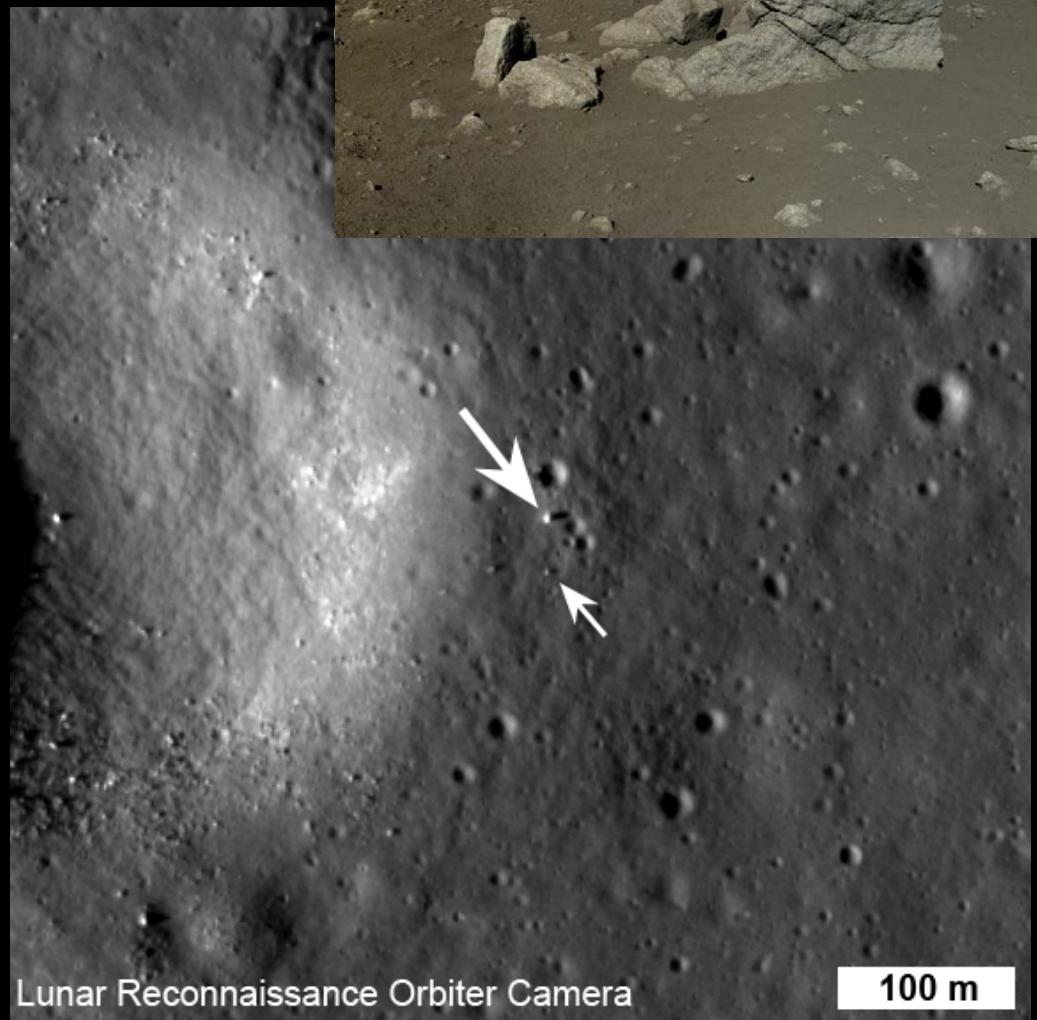

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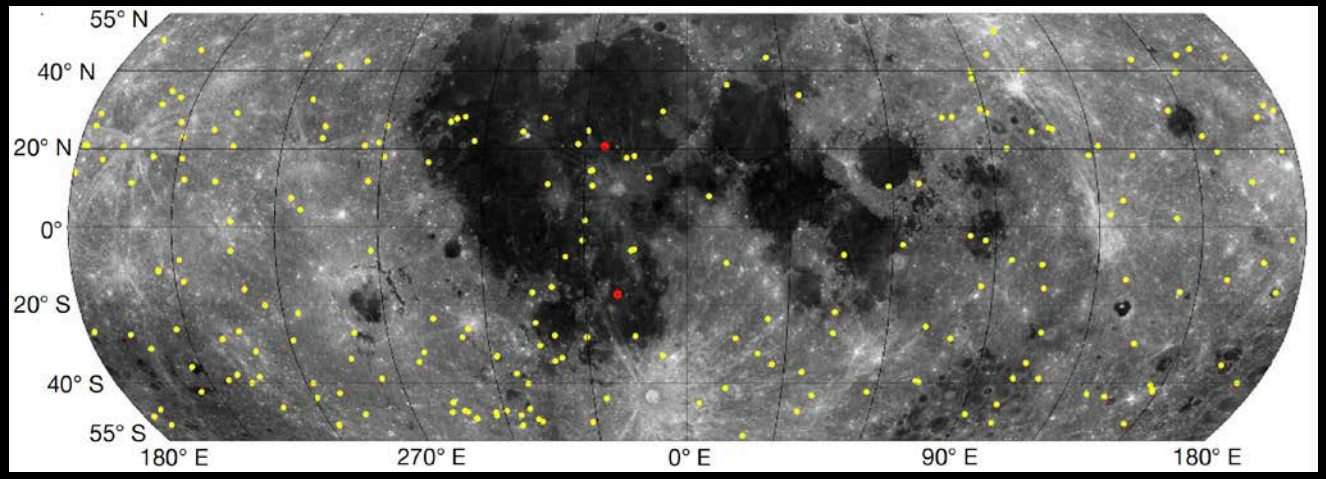
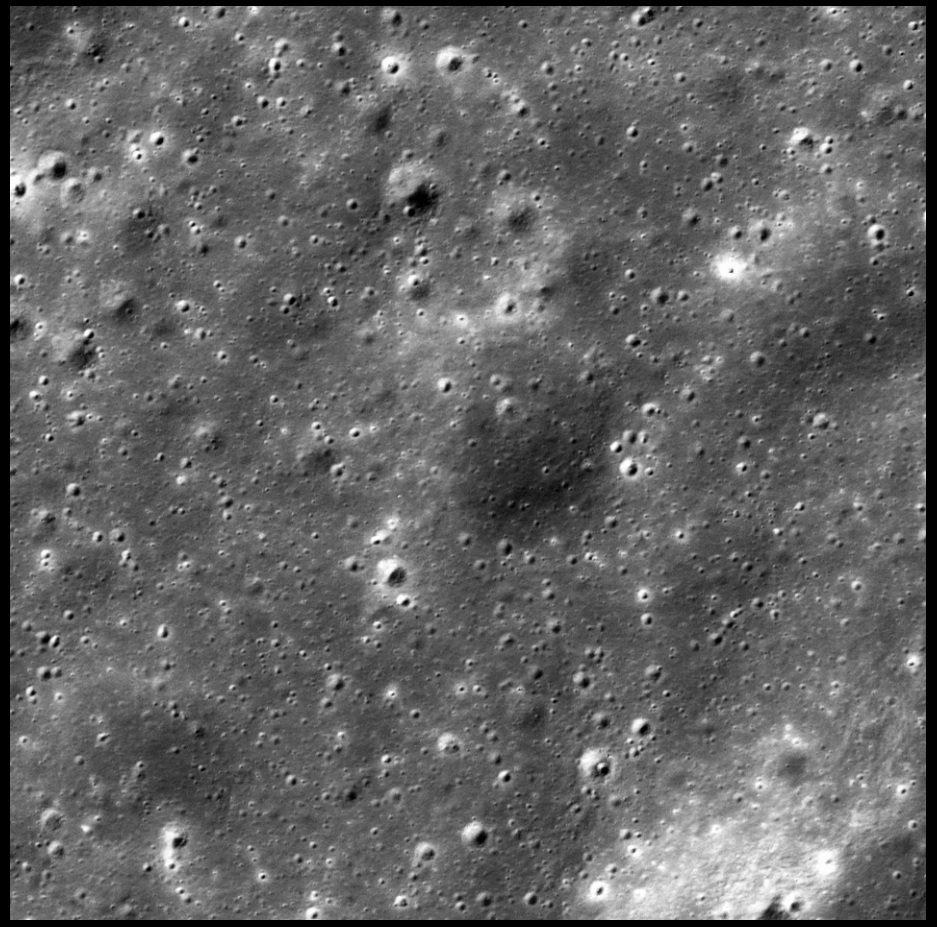
LRO: 11 years of operating at the Moon
2016: 222 craters (Speyerer et al, Nature)
2020: 400+…..





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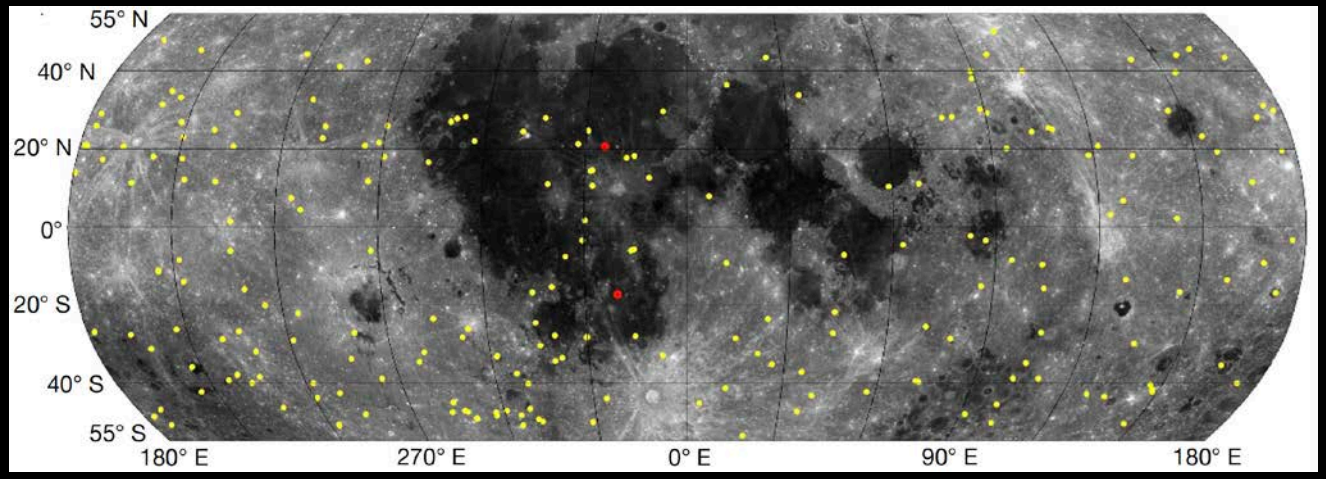

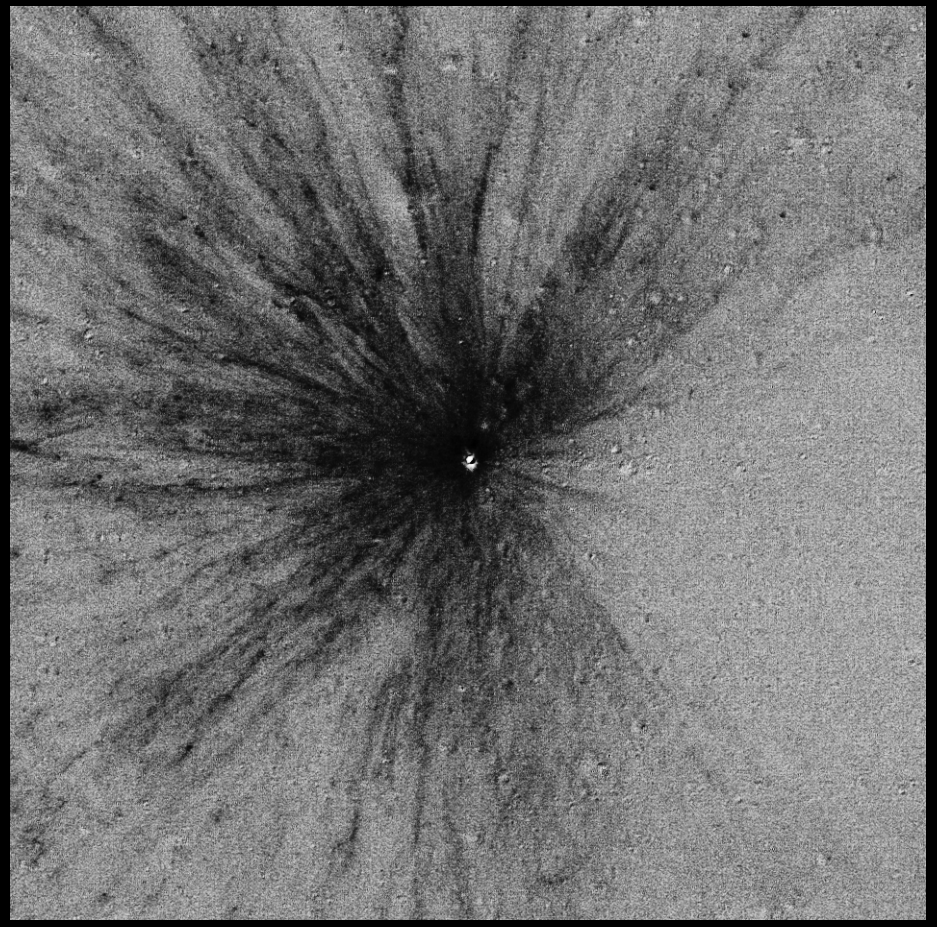

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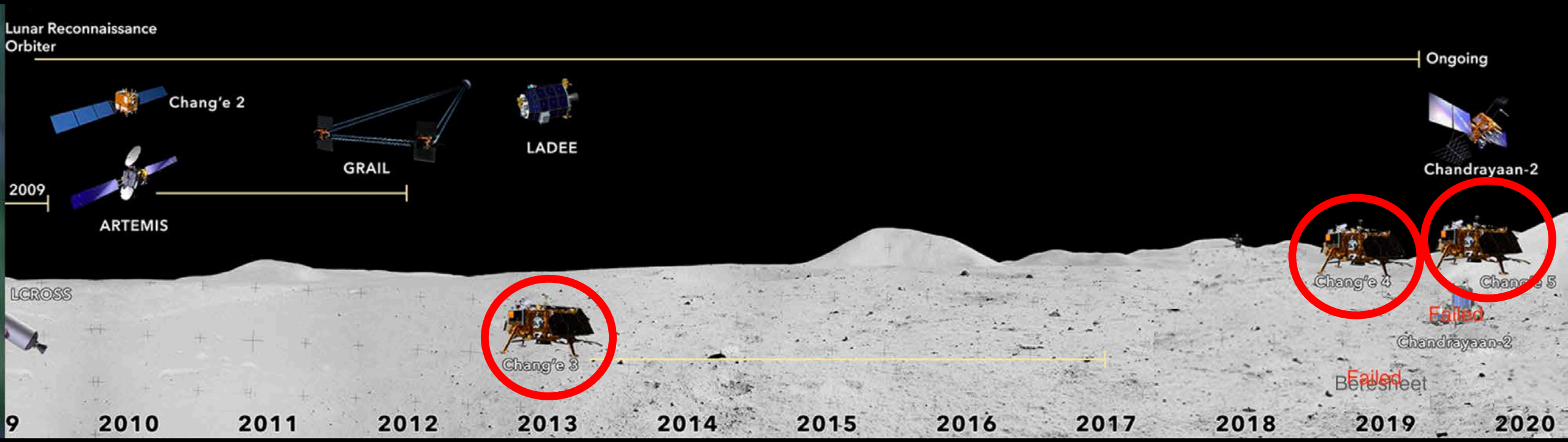

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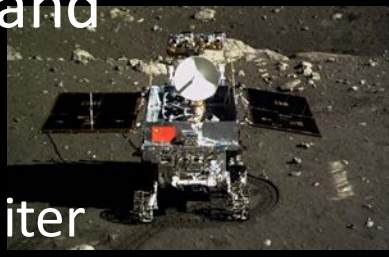


Future lunar activities in the decade ahead….

- **Russia** and **ESA**: Luna 25 – 29 landers and orbiters
- China: additional sample return, ***etc***. ….
- NASA:
  - Small Sats (ride-share): Ice Cube, Flashlight, Trailblazer (SIMPLEX), ….
  - Commercial Lunar Payload Services (CLPS) will deliver small payloads* to surface
    [See Needam presentation Nov 20: South Pole, Reiner Gamma, Shrödinger Basin, ….]
  - VIP-ER: long-lived polar rover investigating volatiles (CLPS delivery) [see Colaprete]
  - *Artemis III*

Artemis III Lunar Polar Science

Artemis III Lunar Polar Science

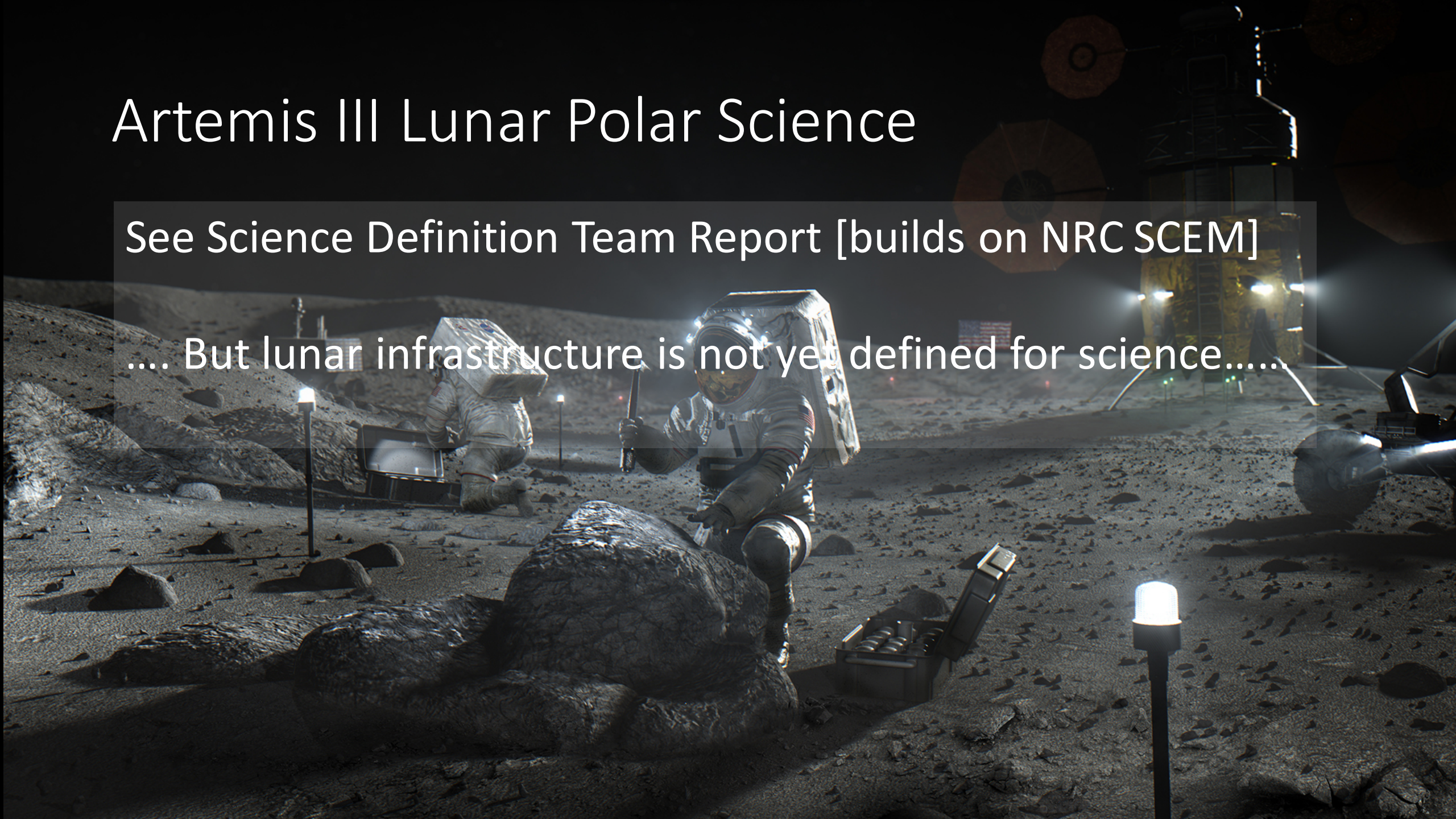
See Science Definition Team Report [builds on NRC SCEM]

https://www.nasa.gov/sites/default/files/atoms/files/artemis-iii-science-definition-report-12042020c.pdf

Artemis III Lunar Polar Science

See Science Definition Team Report [builds on NRC SCEM]

…. But lunar infrastructure is not yet defined for science……



Artemis III Lunar Polar Science

Human-Robotic Partnership

is key for long-term scientific exploration.