Lunar Polar Sample Return – An Opportunity to Unravel the History of Volatiles and Organics in the inner Solar System

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Outline

- The role of the Moon in Solar System exploration
- Volatiles in and on the Moon
- Unique environments at lunar poles
- Case for a Lunar Polar Sample Return (LPSR)
- Emerging opportunities and recommendations

The Moon as a subject & archive

- Moon is our nearest neighbour
- Facilitate further exploration of Solar System

National Research Council 2007 report

- Records bombardment history of the inner Solar System
- Structure and composition of the lunar interior
- Lunar poles may record flux of volatiles to the Moon
- Thermal and compositional evolution of the Moon
- Impact processes on airless bodies
- Regolith and weathering processes

Importance of lunar volatiles

- Water influences viscosity, melting temperatures, melt crystallisation etc…
- It is vital for development of life (as we know it)
- Implications for the formation and subsequent evolution of the Earth-Moon system
- Link between volatiles in the interior and on the surface of airless planetary bodies

Apollo era legacy

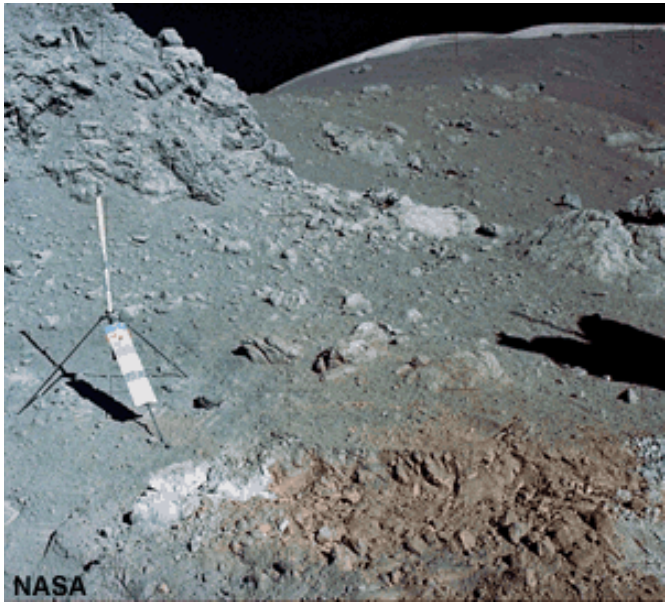
- Lack of hydrous minerals in Apollo and Luna samples
- Any water detected considered terrestrial contamination
- Lack of global remote sensing data

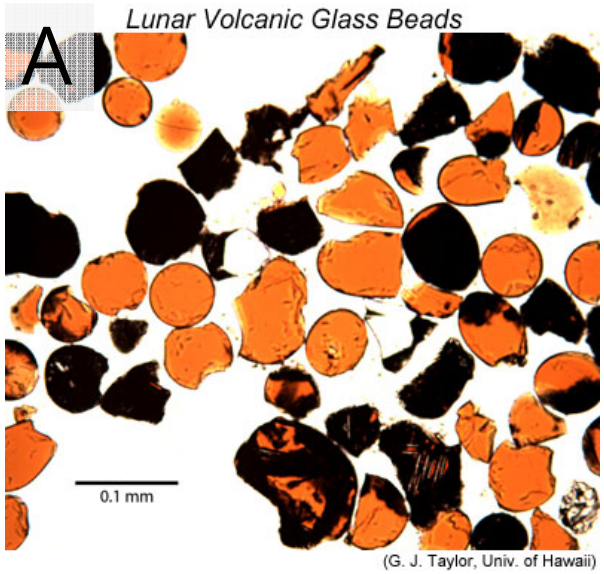
'an anhydrous Moon'

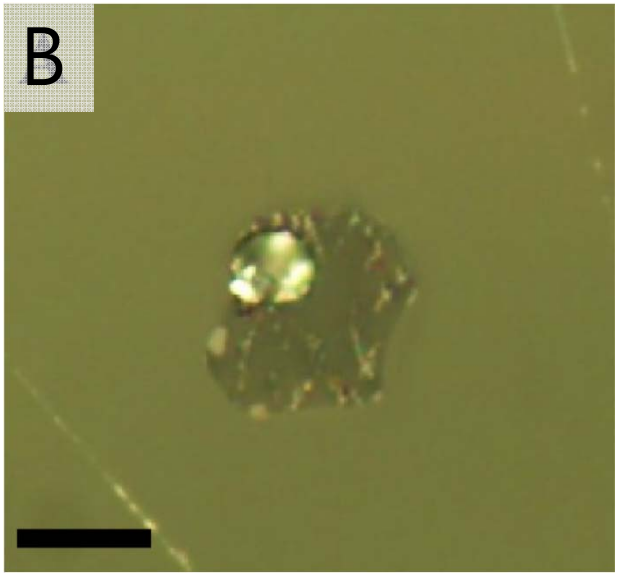
- Organics low levels detected (ppb range) deemed terrestrial contamination, hint of something indigenous?

Recent discoveries – interior volatiles

Glasses and melt inclusions data suggest a wet lunar interior with Earth's mantle-like abundances (up to 400 ppm H_2O)

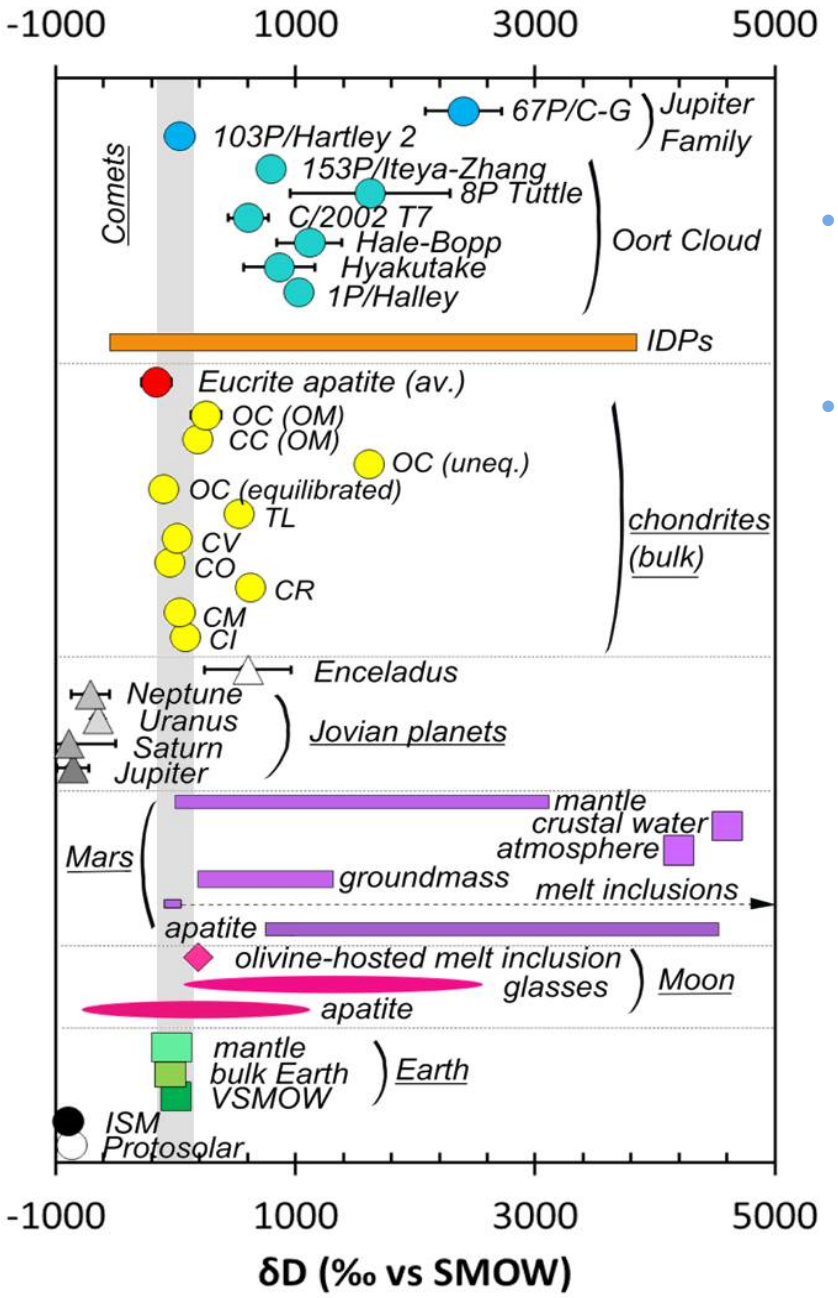






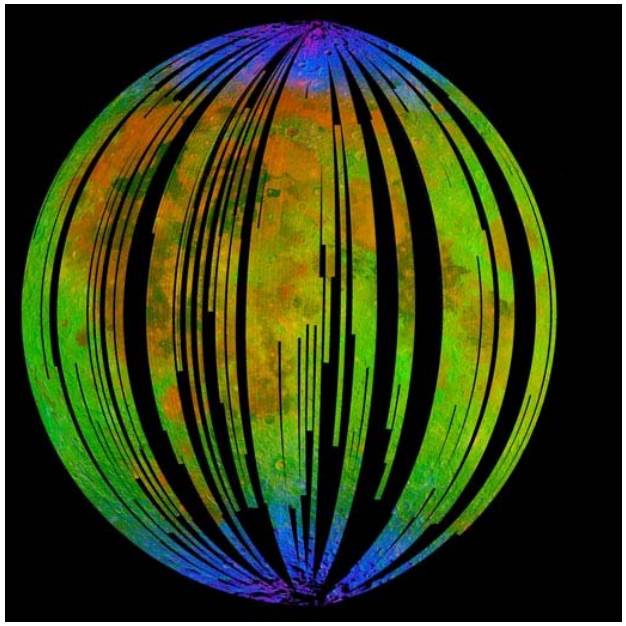
A: 74220 glasses analysed by Saal *et al.* (2008) Science (image credit NASA)
B: Olivine melt inclusion in glass bead (Hauri *et al.* (2011) Science)

Source(s) of interior lunar water



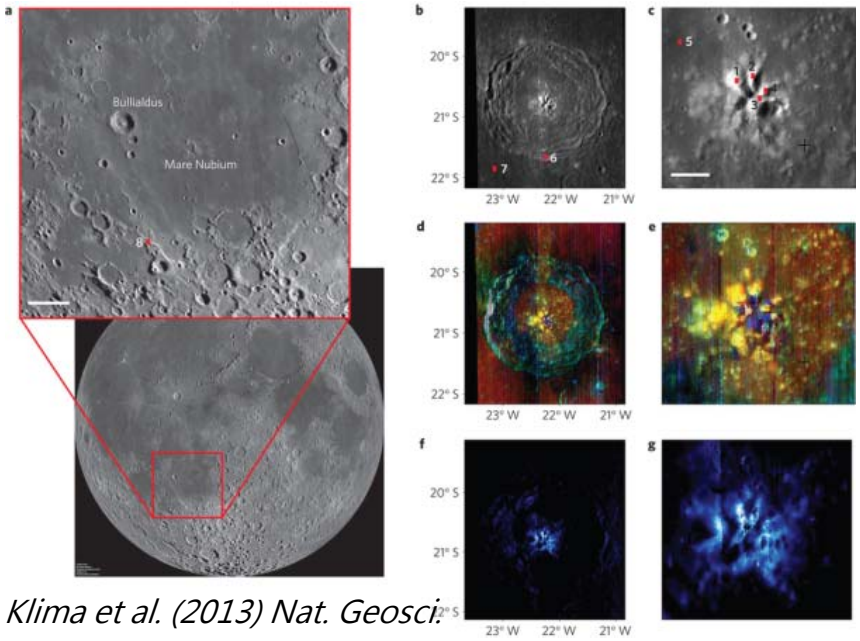
- Can assess the source(s) of volatiles from the H-isotopic composition of the water
- Lunar mantle characterised by a δD value of ~-200 to +200 ‰
  - **Cometary** (Greenwood *et al.* (2011) Nat. Geosci.)
  - **Asteroids** - Carbonaceous chondrites (e.g. Tartèse *et al.* (2013) GCA; Saal *et al.* (2013) Science)
  - **Common origin** (Saal *et al.* (2013) Science; Barnes *et al.* (2014) EPSL)

Recent discoveries – surface volatiles

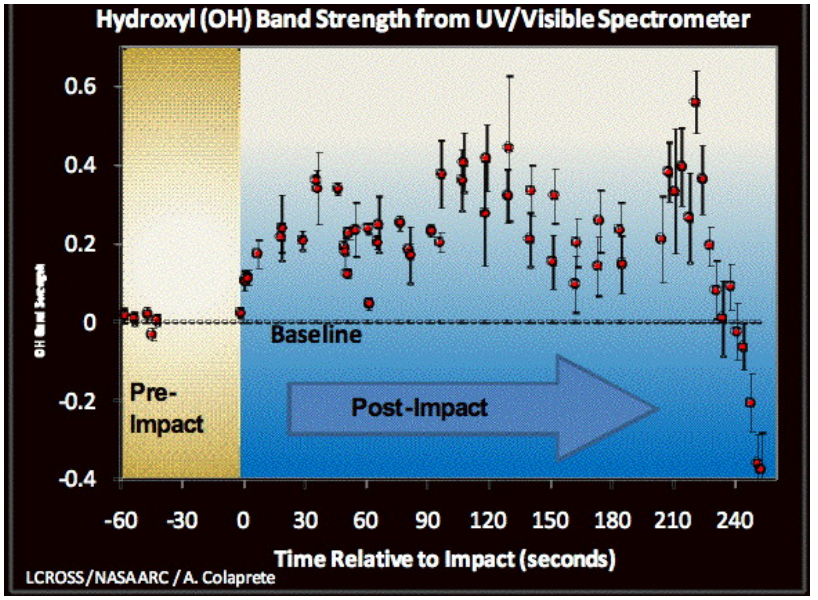


M³ instrument: ISRO/NASA/JPL-Caltech/Brown Univ./USGS

LCROSS impact experiment



Klima et al. (2013) Nat. Geosci.



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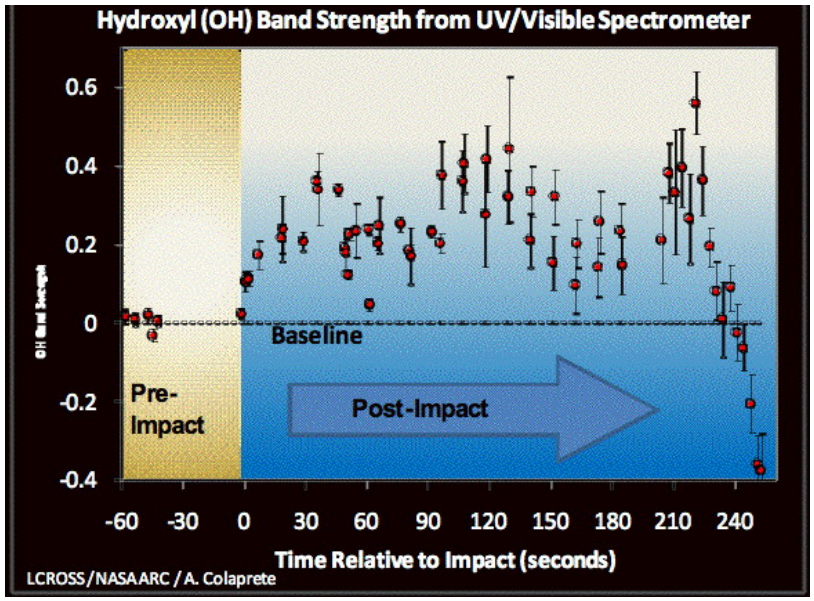

- Target – Cabeus crater, near south pole
- Detection of H_2, H_2O, NH_3, CH_4, CO_2, N_2, etc
- ~5 ± 2 % water by mass (Colaprete *et al.* (2010) Science

Sample studies - results

- Surface organics from lunar soil studies
- Contribution by Solar Wind (Liu *et al.*, (2012) *Nat. Geosci.*) to H inventory of soils
- Cosmogenic contribution based on N studies (e.g., Mortimer *et al.* 2015 Icarus)
- Organics: recent analysis of lunar regolith suggest low levels of organics from exogenous sources (Matthewman *et al.* (2015) Astrobiology; Elsila *et al.* (2015) GCA).

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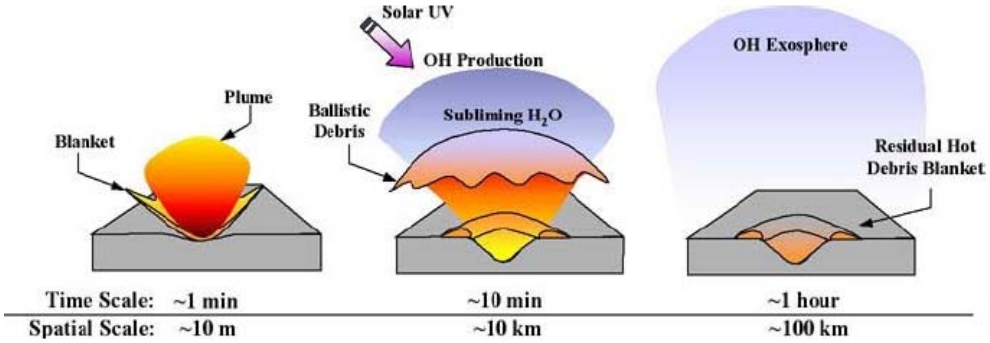

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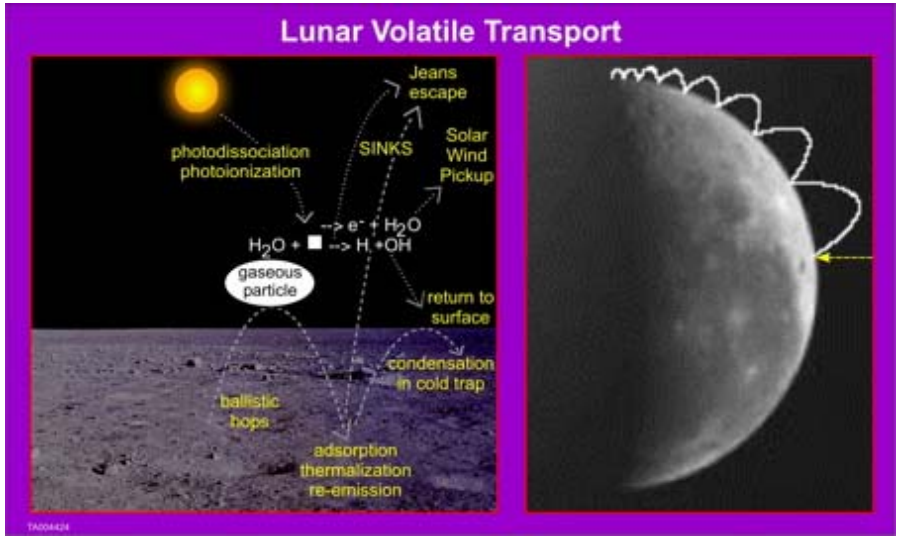
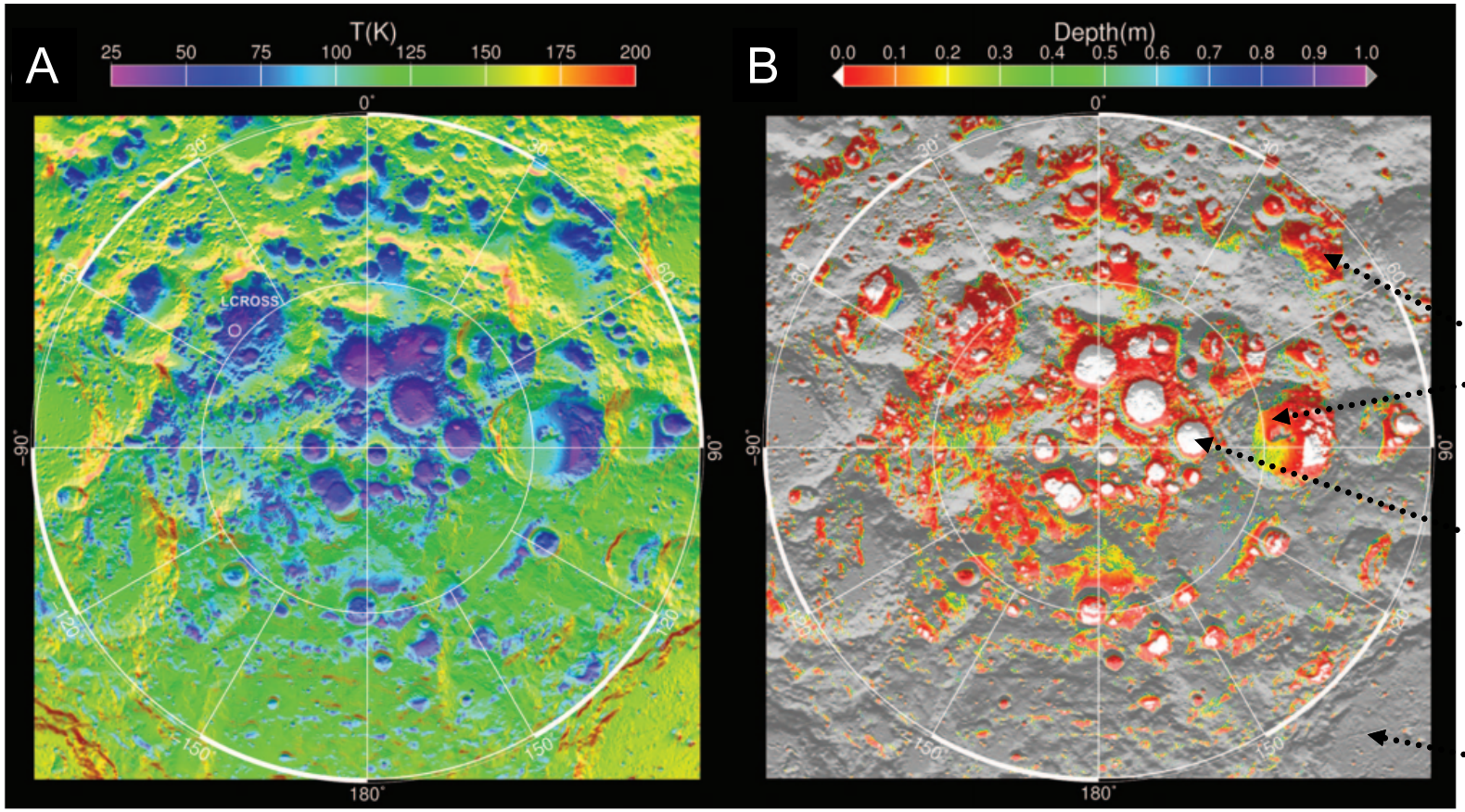


Image SWRI, Dr. Kurt Retherford

Lunar poles – unique environments



Images from Paige *et al.* (2010) *Science*

Upper surface of lunar ice permafrost boundary.

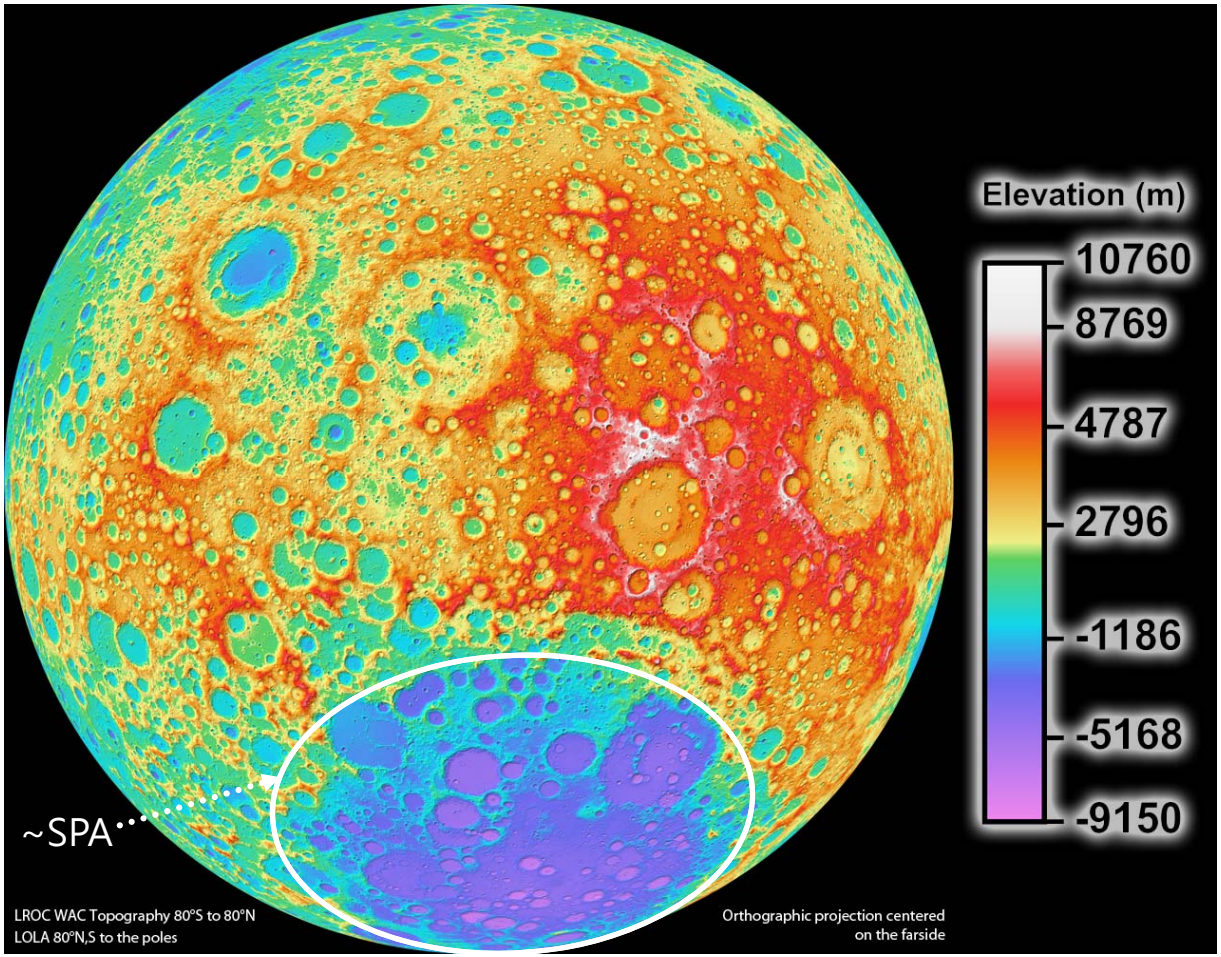
Water-ice thermally stable at the surface.

Subsurface temperatures too warm for cold-trapping of water ice within 1 m of the surface

South lunar polar region: locations more likely for preserving volatiles and organics than locations in lunar equatorial regions.

Diviner data: A) Model-calculated annual average near surface temperatures and B) Model-calculated depths at which water ice would be lost to sublimation at a rate of less than 1 kg m^{-2} per billion years.

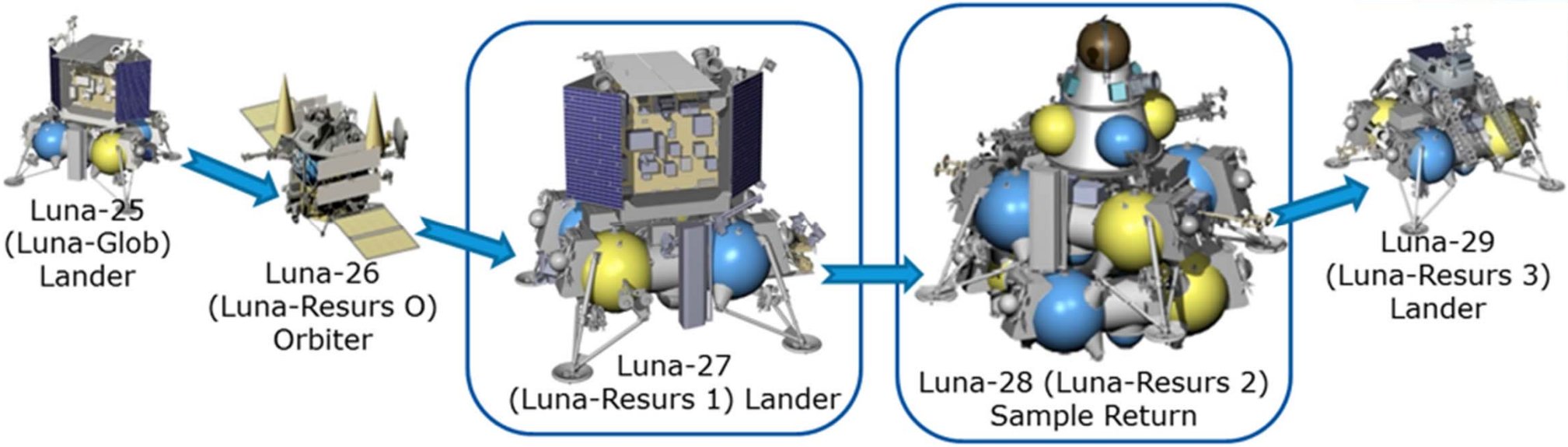
Other science drivers for LPSR



LROC WAC color shaded relief of the lunar farside. Credit: NASA's Goddard Space Flight Center/DLR/ASU.

- Remote sensing: Different sample composition to existing sample suite.
- Impact history/dynamics of the early Solar System.
- Potential to sample ejecta from South Pole Aitken basin largest impact structure in the (inner) Solar System.
  - SPA ~2500 km diameter.

The ESA/Roscosmos Cooperation



- Preparatory collaborative programme between ESA and Roscosmos.
- ESA planning to contribute PROSPECT and PILOT package (on Luna 27) - approved for Phase B+ in December 2014.
- Next mission in Russia's proposed sequence is for polar sample return (Luna 28).
- Sample return is mid-2020s, with planning at an early stage.
- Pre-phase A/Phase-A studies for potential ESA contributions ongoing via European industry.

Polar volatiles

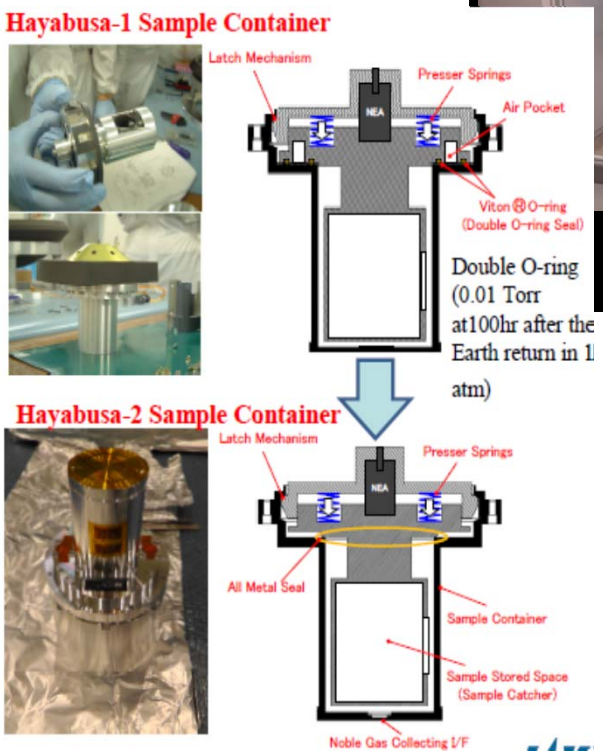
in-situ measurements and sample return

- Evidence from new data that ice/volatiles may be present at depth (up to few m).
- May also be accessible to drilling in a semi-permanent shaded region.
- This would allow sampling of the volatile history of the inner Solar system (rocks, soils, ices).
- New samples from previously unsampled/unique region of the Moon.
- Implications for sample curation (planning and preparation).

A European sample curation facility

- LPSR could be an opportunity for a European curation facility.
- ESA are cooperating with EuroCARES consortium (H2020 project with pan-European involvement).
- Cold and cryogenic curation well established for astromaterials (e.g. ice cores).
- Involvement in mission design and contamination control strategy essential early on.

Class 1000 clean anteroom, with door to freezer (at left)



Cold room for curation of the Tagish Lake meteorite (image: Chris Herd, Univ. Alberta).

Hayabusa 2 capsule (image: JAXA)

Summary

- ESA cooperating with Russia on Lunar Exploration.
- Russian programme defines a sequence of mission including LPSR in mid 2020's
- Planning for Lunar Polar Sample return is in an early stage.
  - Pre-PhaseA/Phase A studies in progress.
- Exceptional science return: addressing key questions on the source(s) of volatiles and organics in the Earth-Moon system
- Samples from new and unique region(s) of the Moon: window into impact bombardment history of the inner Solar System.
- Technological demonstration for sample return from other destinations and preparation for human missions.
- Contribution towards developing a sample curation facility in Europe for returned planetary samples.
- Good fit with the Global Exploration Roadmap.

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