The Curation of Cryogenic Samples

March 12, 2021

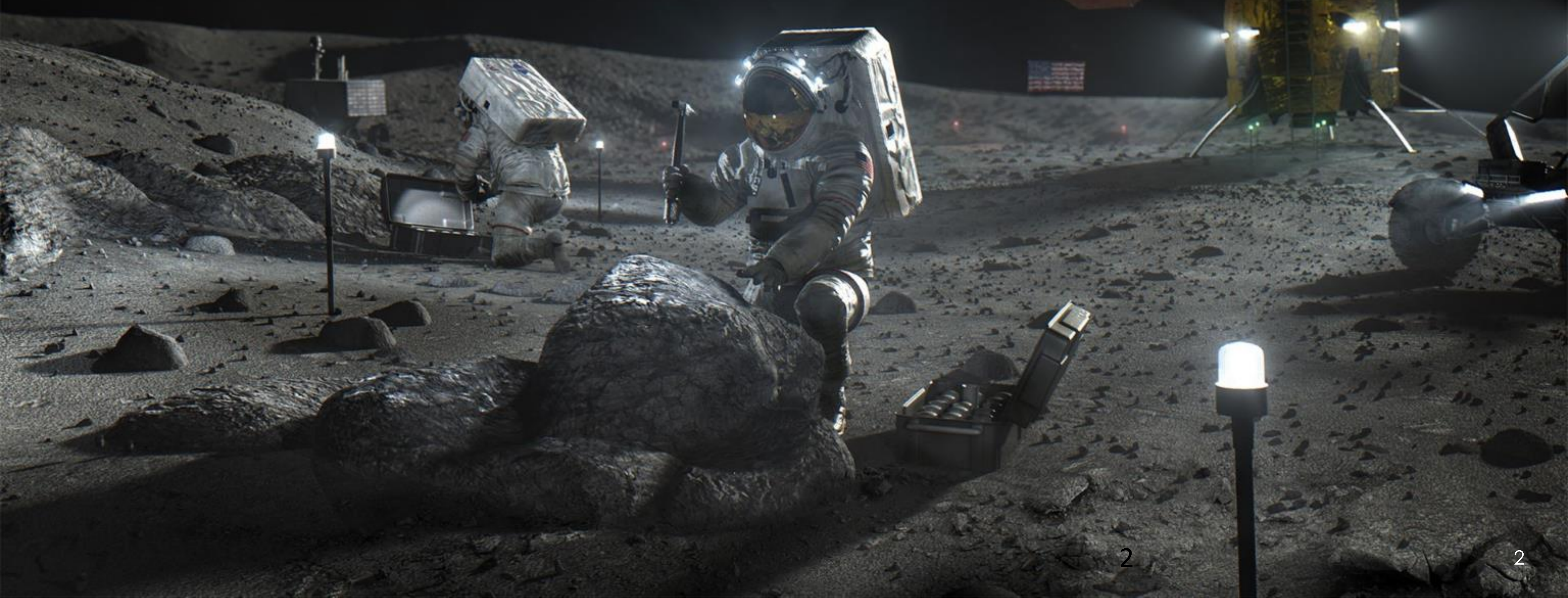
Julie Mitchell, PhD

Curator of Ices and Organics, Artemis Curation Lead

Why is cryogenic sample curation important?

How will it be executed?

What hardware and techniques will be used?



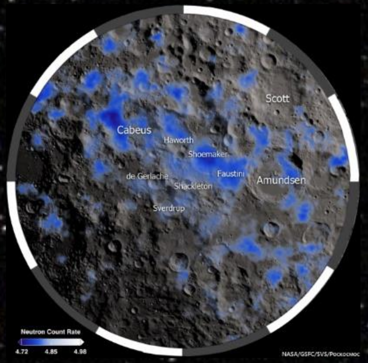
2

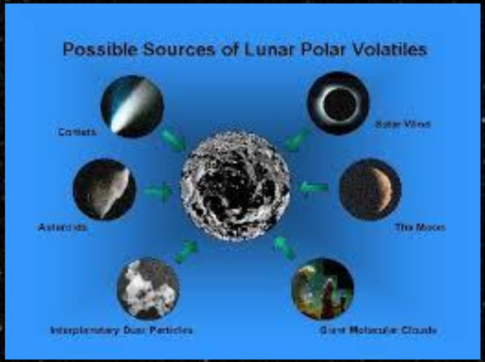
"Cryogenic sample return will increase the scientific fidelity of sample analyses of volatiles and ices."

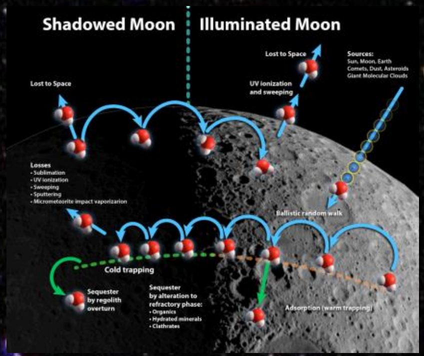
- Artemis III Science Definition Team (SDT) Report

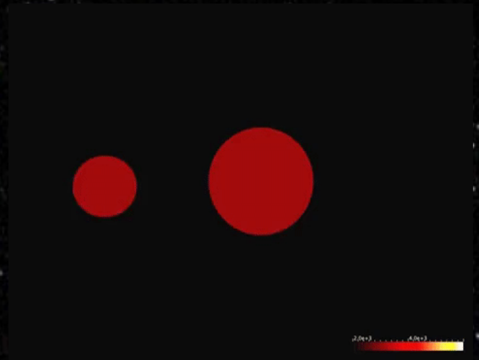
Science Enabled by Volatiles Samples

What is the current state of lunar polar volatiles?	What are the sources of lunar volatiles?	How and to what extent do volatiles migrate on the Moon?	What do volatiles tell us about lunar and solar history?
• Location • Compounds • Isotopes • Condensation state • Distribution on/sub-surface • Remote sensing accuracy	• Lunar Interior • Comets • Asteroids • Solar Wind • Interplanetary sources (e.g. IDPs)	• Sequestered (cold vs. adsorbed) vs. lost to space • Seasonal, diurnal, vs. latitudinal migration • Ballistic random transport • Altered due to radiation and impacts	• Ancient impacts • Solar Activity • Chronology of volatile migration and delivery • Lunar polar wander









Potential Volatiles in Samples

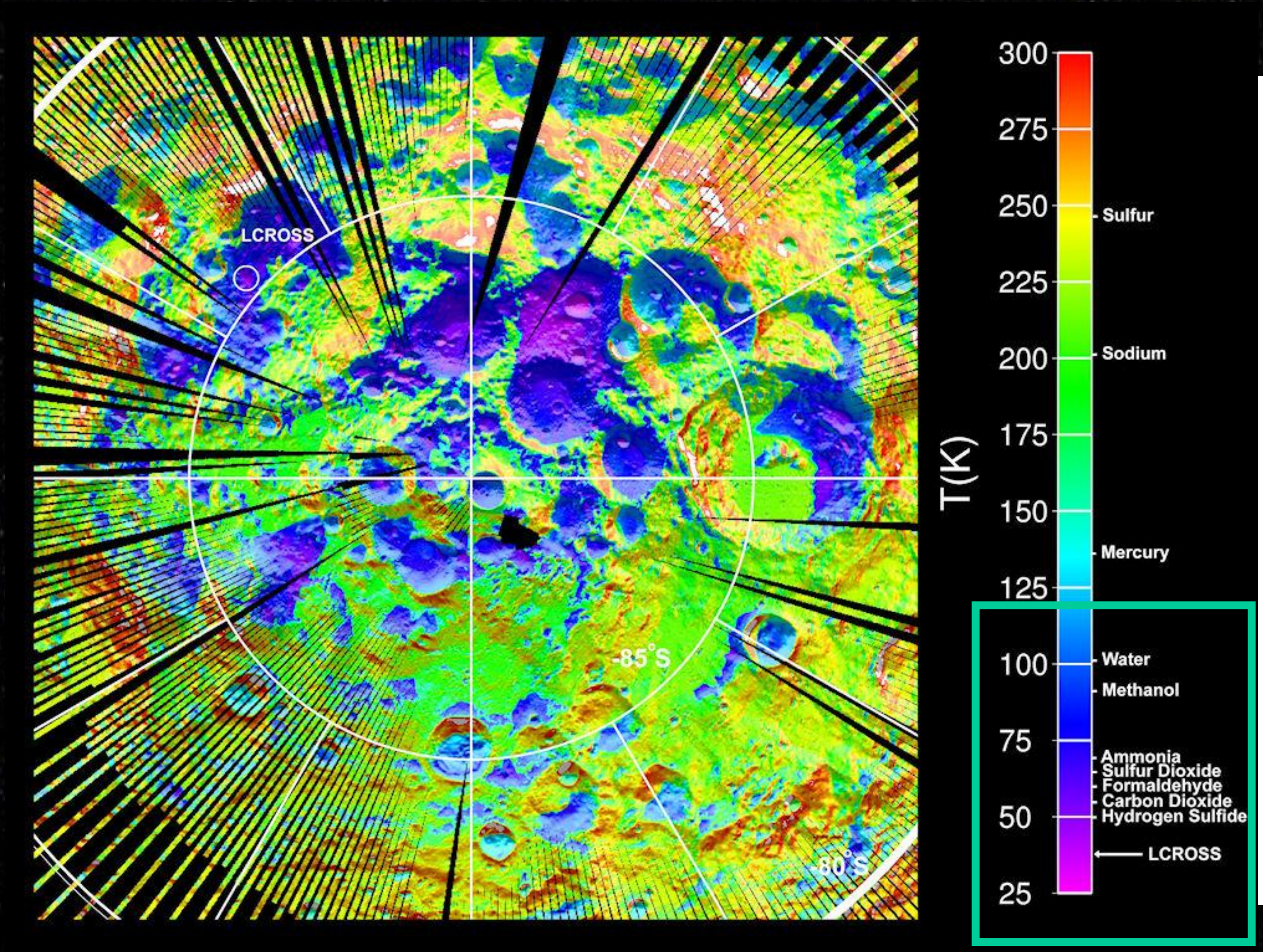


Image credit: UCLA/NASA/JPL/LDRE

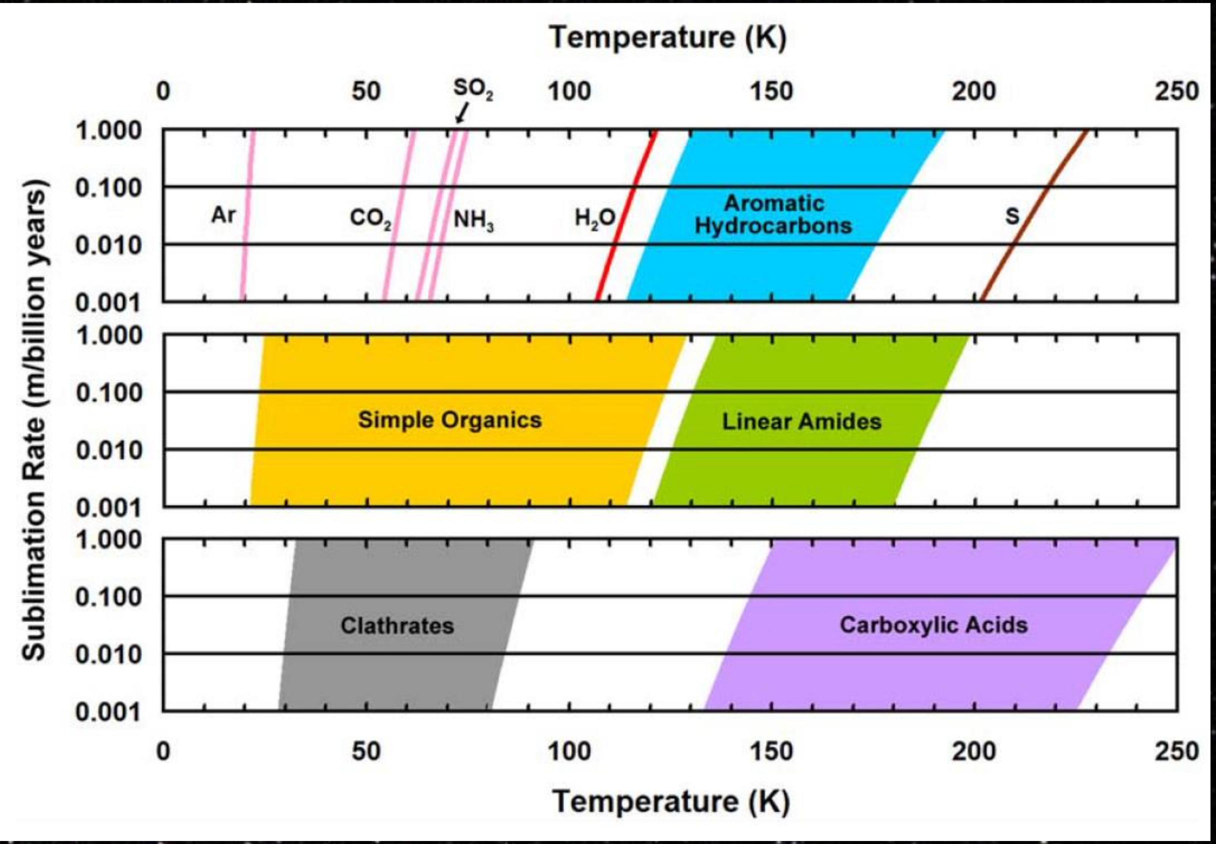
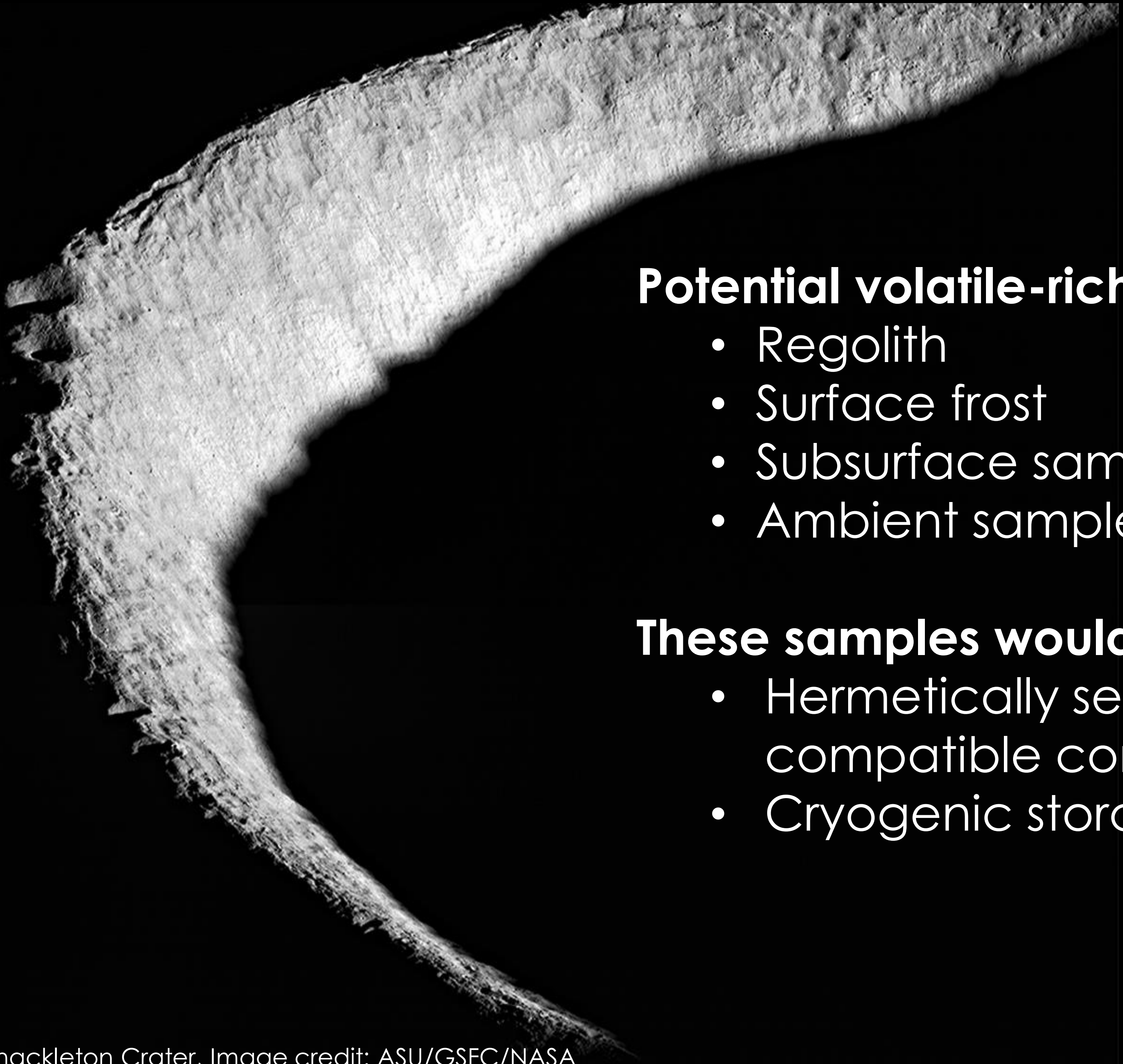


Image credit: Zhang and Paige, 2009



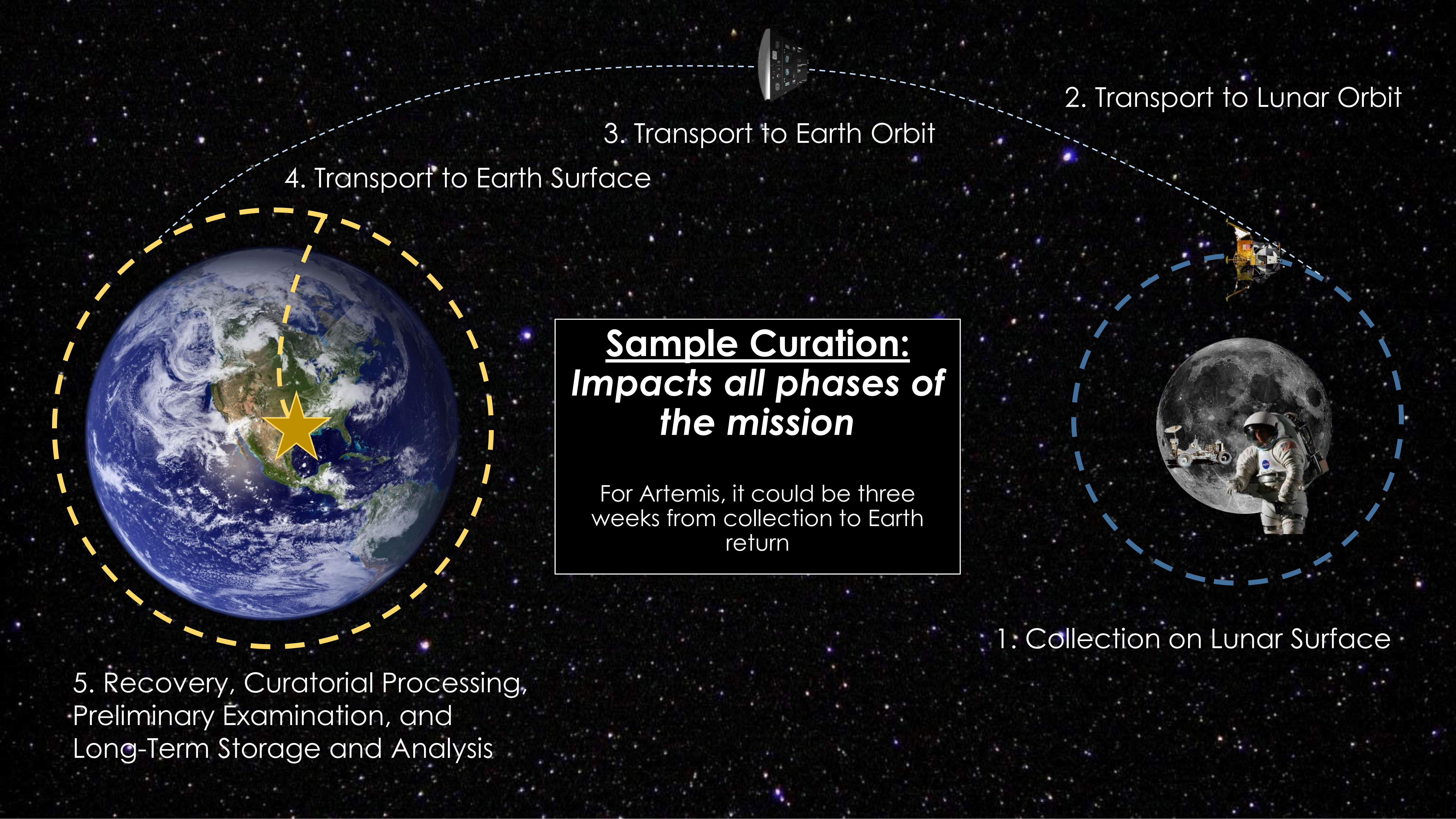
Potential volatile-rich samples include:

- Regolith
- Surface frost
- Subsurface samples containing volatiles
- Ambient samples for gas-phase species

These samples would best be preserved via:

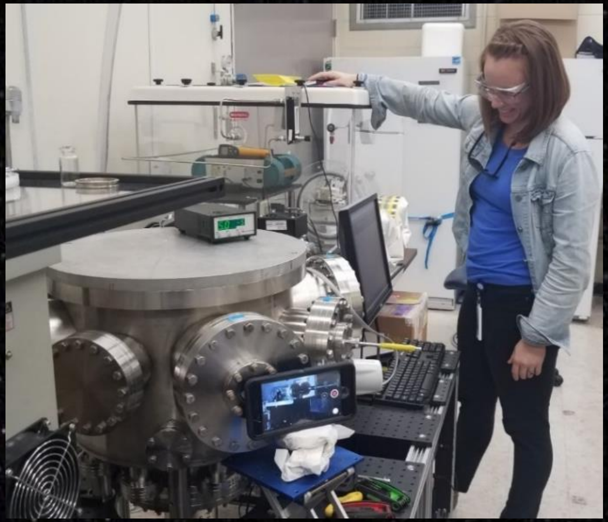
- Hermetically sealed, chemically compatible containers
- Cryogenic storage in-flight and after return

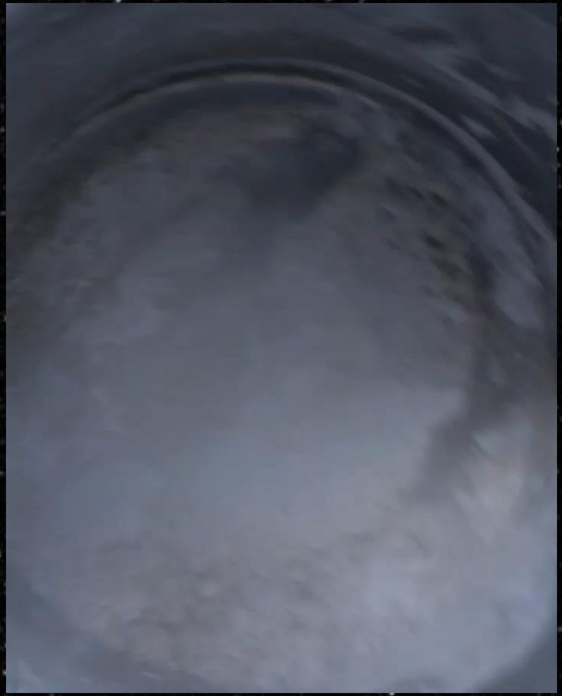
Shackleton Crater, Image credit: ASU/GSFC/NASA


Sample Curation:
Impacts all phases of the mission
For Artemis, it could be three weeks from collection to Earth return
1. Collection on Lunar Surface
2. Transport to Lunar Orbit
3. Transport to Earth Orbit
4. Transport to Earth Surface
5. Recovery, Curatorial Processing, Preliminary Examination, and Long-Term Storage and Analysis

Storage and Preservation Requirements

- Storage T requirement
  - Major outstanding question
  - Will be cryo, based on expected compounds
  - Will determine empirically
- Materials compatibility
  - Sample tools
  - Sample containers
  - Space suit materials
- Sample Handling
  - Cold/cryogenic materials
  - Hazardous/toxic volatiles
  - Clean room curation ops





Cold Stowage In-Flight

"Minimizing the mass penalty for cryogenic sample return results in increased scientific yield of the mission because more mass can be allocated to the lunar samples instead of the sampling hardware." – Artemis III SDT Report

Therefore, in addition to meeting temperature, materials, and handling requirements, a cold stowage system (freezer) should be as small and low-mass as possible.

Storage and Preservation Technologies

- ISS freezer options
  - Several existing systems designed specifically for ISS
  - For planned lunar vehicles, the ISS systems are too large, massive, and power intensive
  - May not reach the needed temperatures (TBD)
- Working with ISS Cold Stowage engineers to assess options via NASA and industry

MELFI, -95 °C

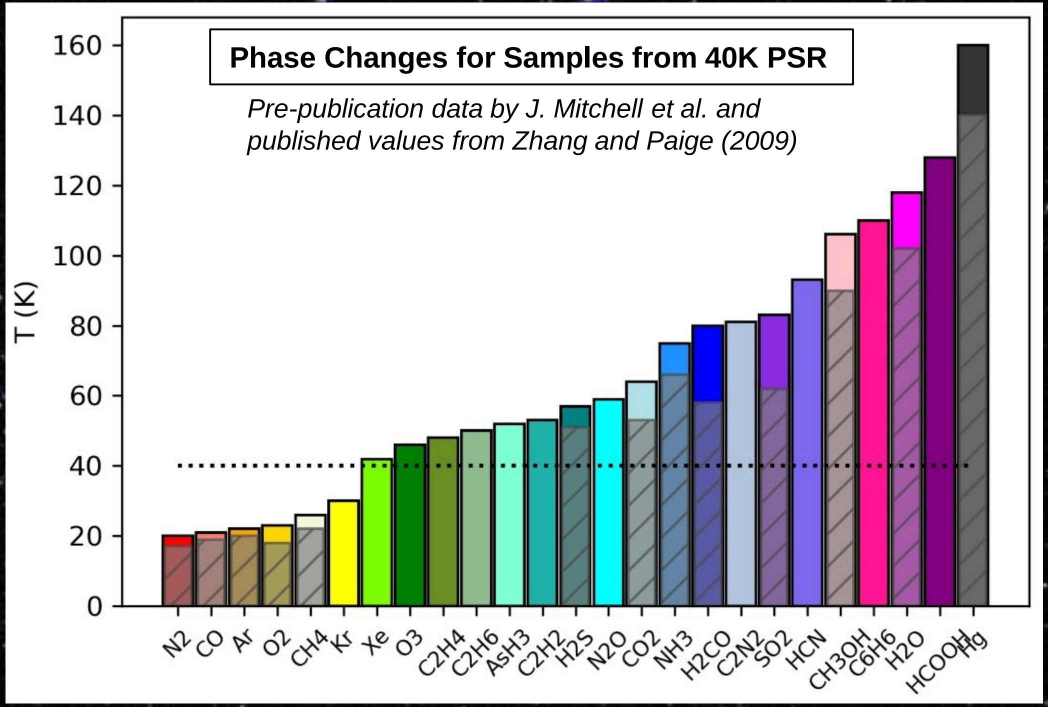
Cold Bag/Ice Bricks

GLACIER, -95 to -160°C

Polar, -95°C

Implications for No Cold/Cryo Stowage

- As T increases from lunar ambient, we expect sample alteration to increase:
  - Phase changes
  - Chemical reactions
  - Pressure increase
  - Loss of science
- Preliminary modeling shows a variety of alteration effects (right)
- The effects of increasing T will also be characterized empirically



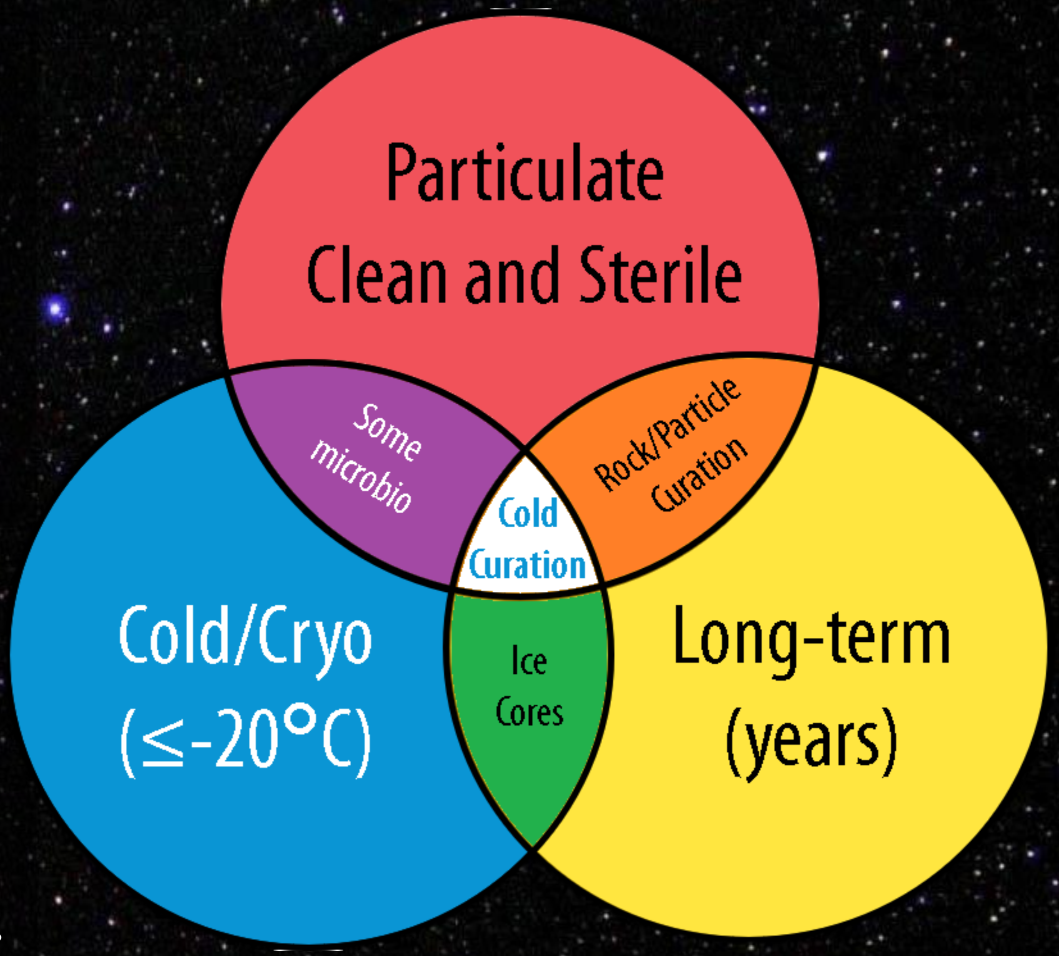
Potential Reaction
CH3OH(g) → CO(g) +2H2(g)
2CH3OH(g) → CH3OCH3(g) + H2O(l)
CH3OH(g) + H2O(g) → CO2(g) + 3H2(g)
CH3OH(g) + 3/2O2(g) → CO2(g) + 2H2O(g)
2CH3OH(g) + O2(g) → 2HCHO(g) + 2H2O(g)
CH3OH(g) + C2H4(g) → CH3CH2OCH3(g)

***Chemical Reaction Example:* Methanol**

Calculations by C Amick/JSC

Cryogenic Curation after Sample Return

- Sample processing
  - Initial Characterization
  - Catalog Development
- Long-term storage
- Sample allocation and transport



NASA Curation has successfully implemented this sequence for rock/particle samples for decades.

Prior Cold Curation Experience

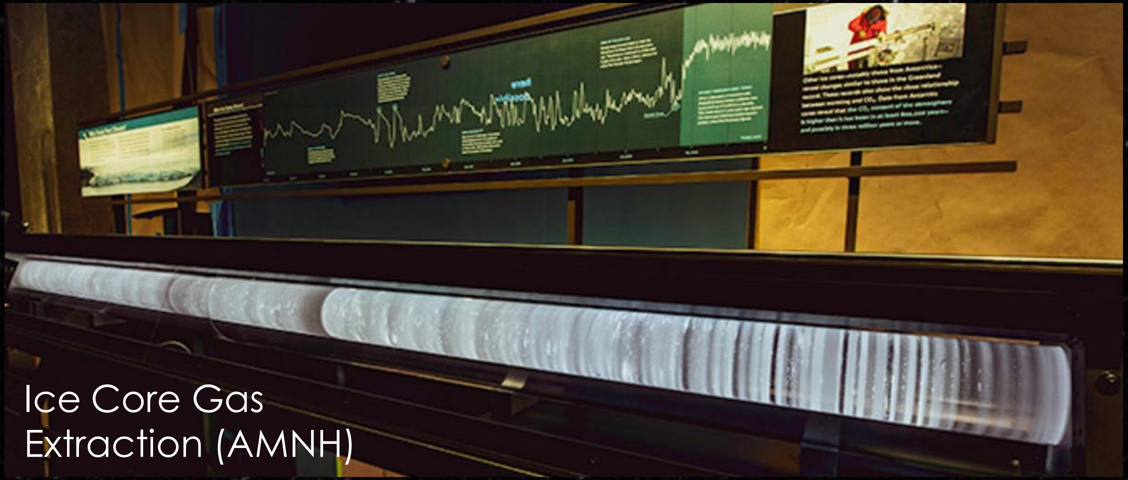
Antarctic Search
for Meteorites

Apollo Cold-
Curated Samples
(in preparation)

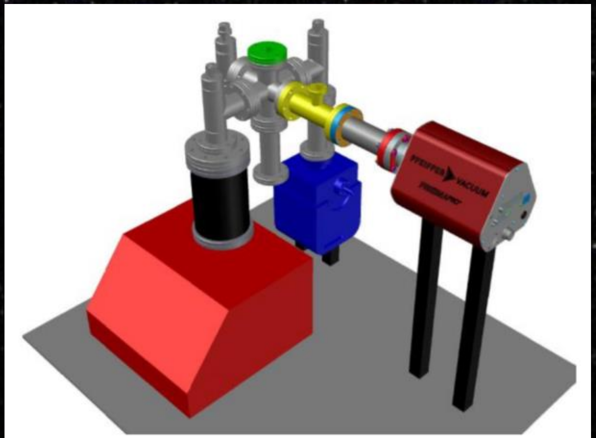
Sub-Zero Facility
for Curation of
Astromaterials

Volatile Extraction and Handling

- Lunar cryogenic samples will most likely be returned as a mixture of volatiles and regolith/rock
- Outstanding question:
  - Keep volatiles and regolith together or
  - Separate immediately after return?
- Gas extraction precedent (right)
- Notional plan is to separate volatiles and rock components as soon as possible to:
  - Mitigate sample alteration
  - Facilitate studies of regolith without worrying about escaping gases
- Need to do tests to determine what is best for the sample



Ice Core Gas Extraction (AMNH)



Apollo Gas Sampling Manifold (Pardi, et al. 2021)

Hayabusa2 Gas Sampling (JAXA)

Sample Characterization (notional)

	Documentation	Quantity	Classification	Identification
Rock/Particle  Apollo Sample 64435	*<u>Technique:</u>* *Photographs* *<u>Hardware:</u>* *Camera, microscope*	*<u>Technique:</u>* *Weighing, counting clasts and particles* *<u>Hardware:</u>* *Scale, microscope*	*<u>General rock type:</u>* *Basalt, breccia, crustal/anorthosite, soil, etc.* *<u>Method:</u>* *Visual observation*	*Sample and subsample numbers*
Volatiles  Lunar Volatile Simulant	*<u>Technique:</u>* *Photographs, spectroscopy* *<u>Hardware:</u>* *Camera, CRDS (gas), FTIR (solid)*	*<u>Technique:</u>* *Total/partial P (gas), weighing (solid)* *<u>Hardware:</u>* *P gauge, scale*	*<u>Specific volatiles:</u>* *E.g., H_2O-bearing, CO_2-bearing, NH_3-bearing, etc.* *<u>Method:</u>* *Spectral features*	*Original sample container and aliquot subsample numbers*

Long-Term Storage and Allocation

- Long-term storage aims to facilitate future analyses (e.g., ANGSA Program)
- Long-term storage must take into account:
  - Facility requirements for working with gases and ices
  - Evaluating long-term preservation using simulants
  - Storage requirements (temperature, materials, etc.)
  - Design of storage containers and vessels
  - Sample handling protocols and processes
  - Sample and environmental monitoring techniques
- Many of the techniques for long-term storage are already being investigated
- A dedicated facility for lunar cryogenic curation will be needed in the future

ANGSA Sample Processing at JSC

Questions?

Julie Mitchell, PhD
Julie.L.Mitchell@nasa.gov