National Aeronautics and Space Administration

Artemis Geology Tools

EVA Exploration Workshop

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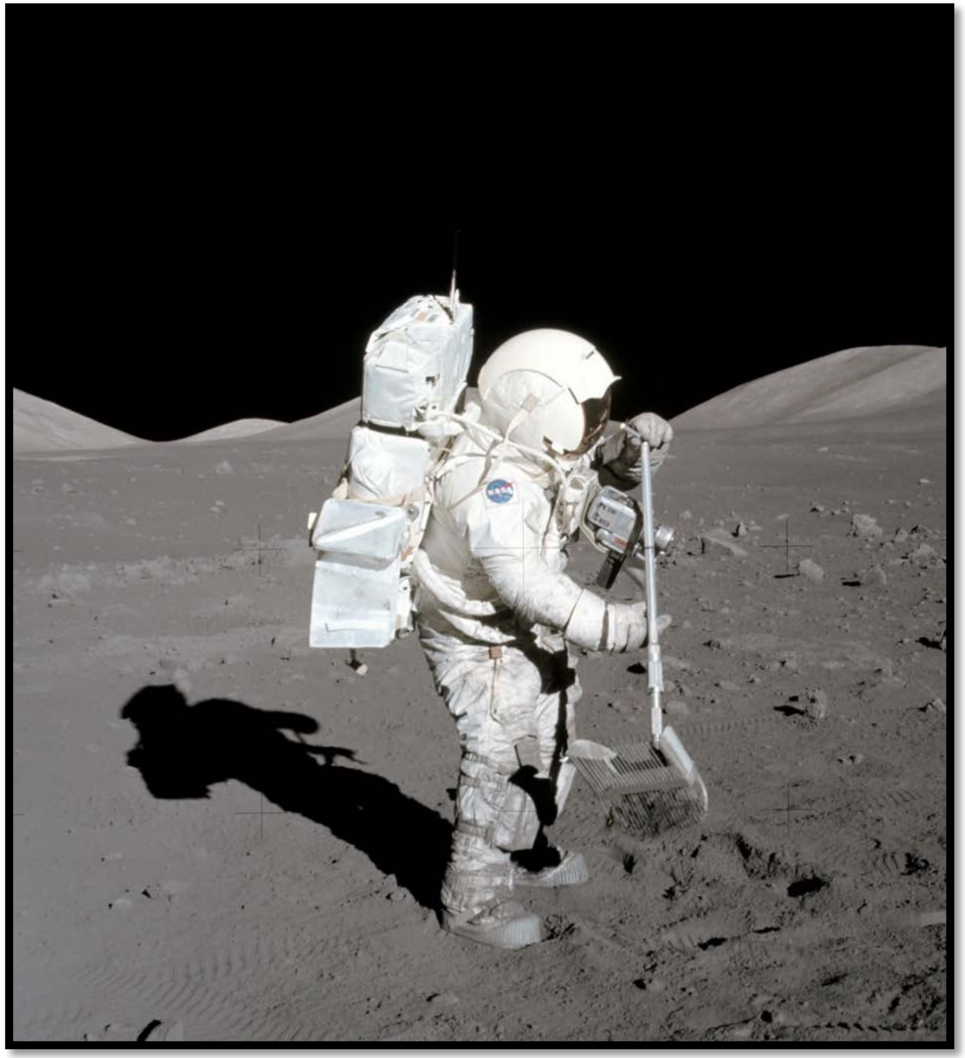
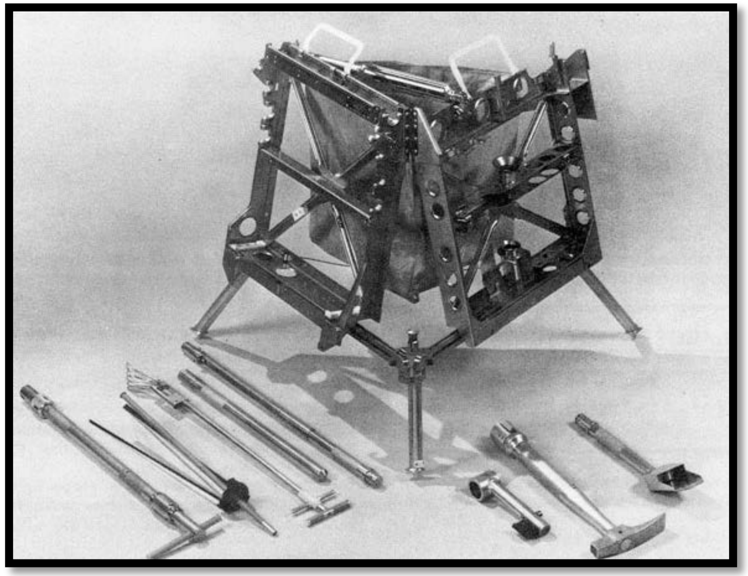
Purpose

- **Inform the community about:**
  - FY20 plan for beginning the development of Artemis geology tools.
  - The challenges associated with Artemis geology tools.



Current Tools Tasks

- The EVA Tools team will develop the next generation, flight-ready, baseline Artemis geology tool kit.
- The challenge is to get a baseline Artemis Geology Tool Kit to a Critical Design Review by the end of FY20.
- This kit is not meant to be all-inclusive, but allows the team to make substantial progress on tools with a high likelihood of future use.
- Current list of baseline Artemis Geology Tool Kit (9):
  - Hammer
  - Rake
  - Scoop
  - Tongs
  - Drive Tubes
  - Common Extension Handle
  - Contingency Sampler
  - Sample Return Container
  - Documented Sample Bag
- Development will begin from the Apollo 17 tool designs.

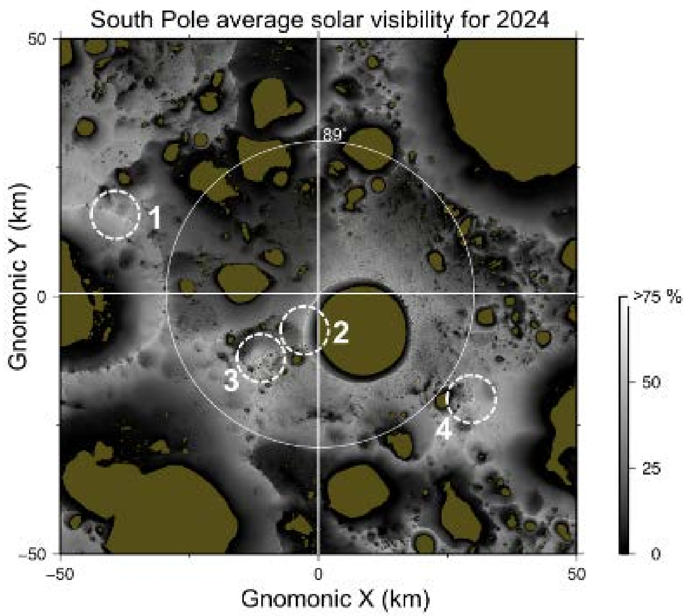


Apollo EVA Tools and Carrier

Apollo Videos

- ***Why aren't we just reusing the Apollo Tools?***
  - *Apollo tools were modified for almost every mission*

Apollo vs Artemis

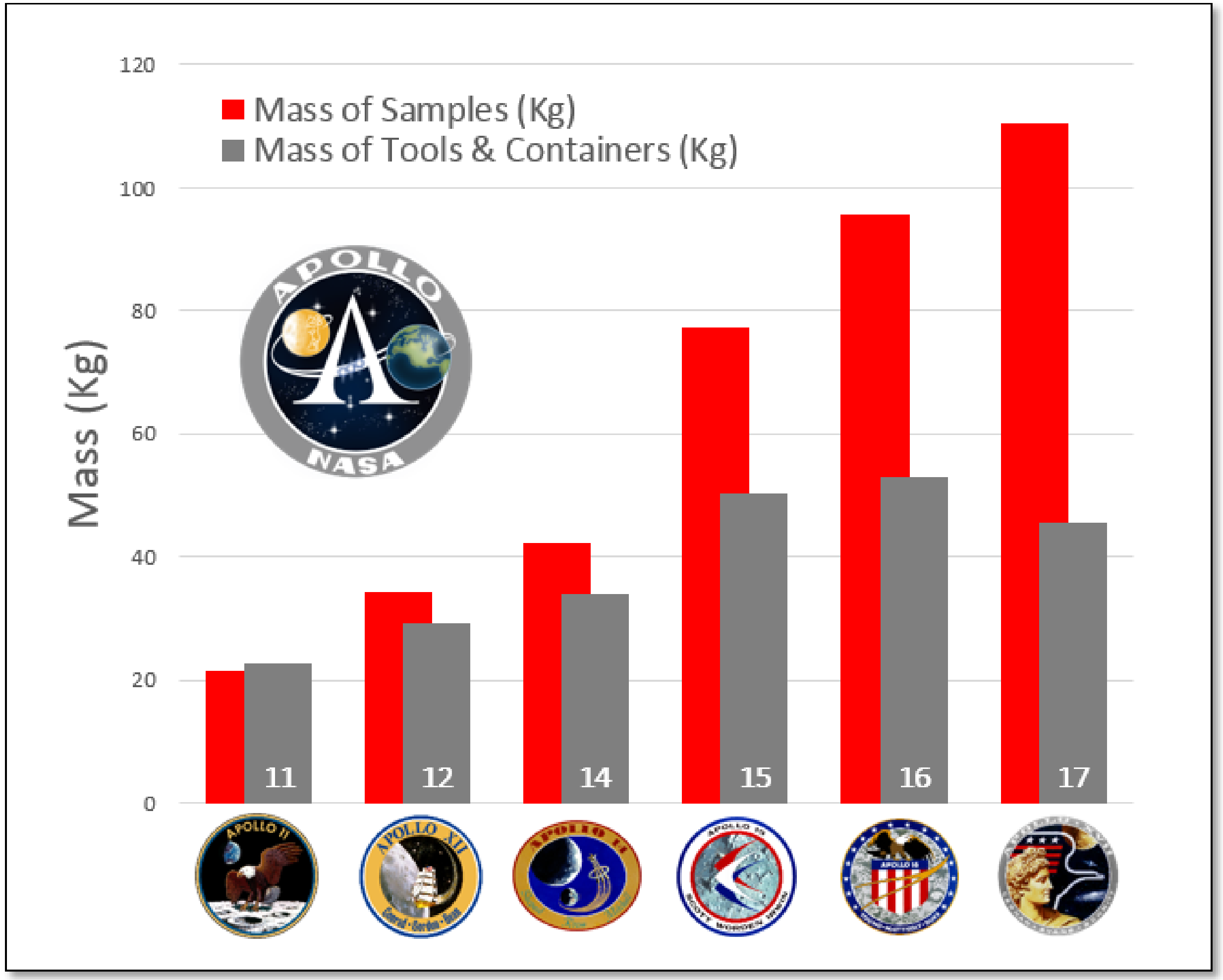


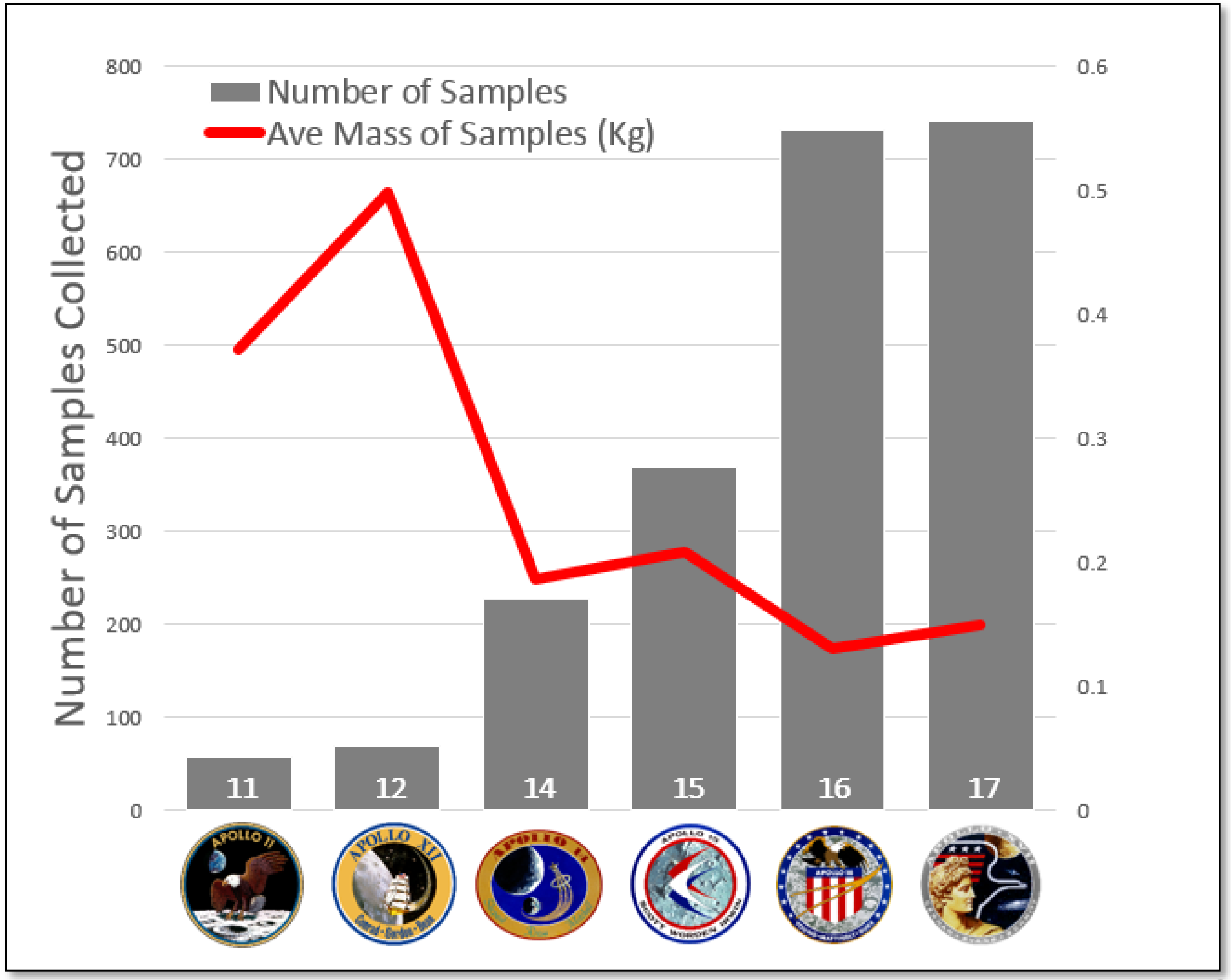
Four highly illuminated areas shown above:
1. De Gerlache Rim,
2. Shackleton Rim
3. Shackleton – De Gerlache Ridge
4. Plateau near Shackleton

- Environment
- Visibility/Shadowing
- Current manufacturing capabilities
- Hardware material availability

Apollo Tools Over Time

- Tools evolved, both as planned and in response to new knowledge
- On later missions, with increasing mobility, a greater number of samples with smaller average weights were collected (additionally representing more varied locales)

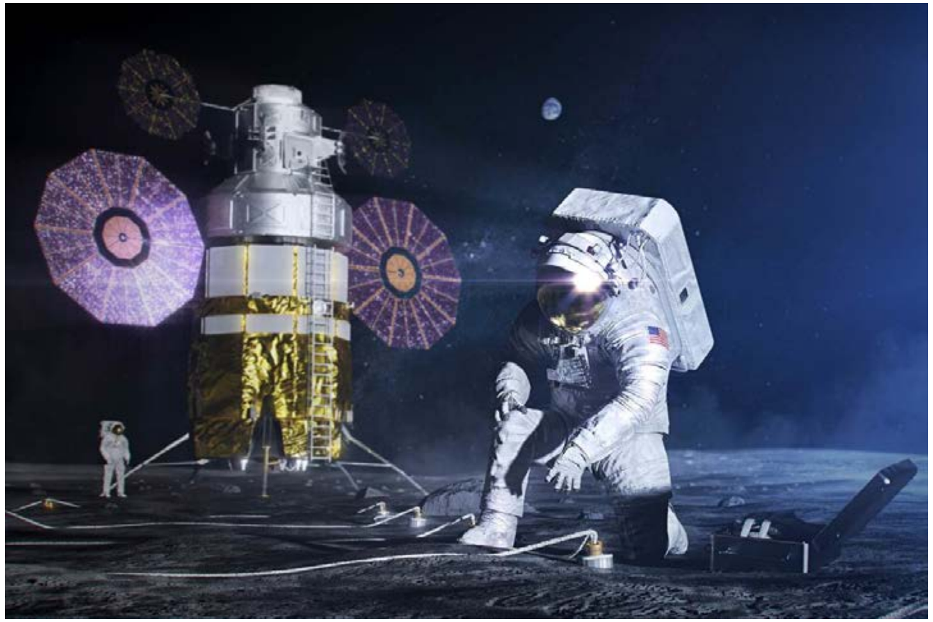




Adapted from the *Catalog of Apollo Lunar Surface Geological Sampling Tools and Containers* (Allton, 1989)

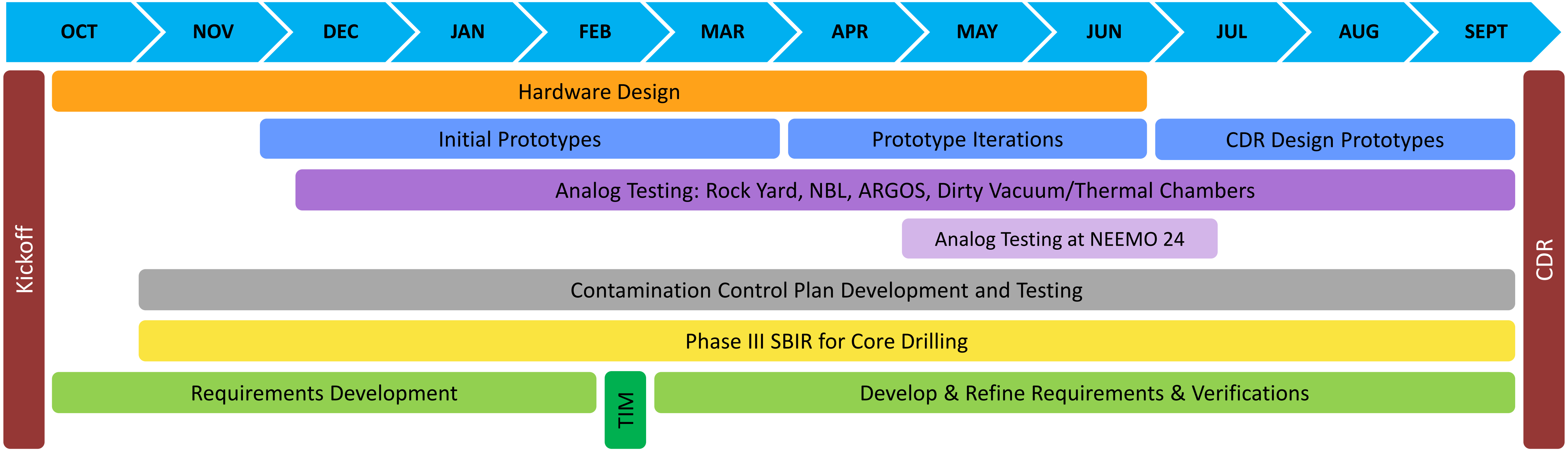
Notional Concept of Operations

- Tools will be transported to the lunar surface on an Ascent Module, Decent Module, Commercial Lunar Payload Services (CLPS) or a combination of these options.
- The Contingency Sampler will be used to take a sample as soon as possible during the first EVA.
- Crew may carry small tools on the xEMU.
- Tools will likely need to be transported across the lunar surface by a method other than carried by the crew or on the xEMU.
- Tools will be used to obtain samples and be placed into sample containers.
  - Plan to take samples in a Permanently Shaded Region (PSR)
- Sample baggies will be weighed prior to bringing back into Ascent Module.
- Samples will be placed into a bulk sample return container and transported back to Gateway, onto Orion, and back to Earth.
- To save up mass and enable the return of as many lunar samples as possible, all tools (minus sample return containers) will remain on lunar surface at conclusion of mission.
  - Potential to reuse tools on future missions.



Artemis Geology Tools FY20 Plan

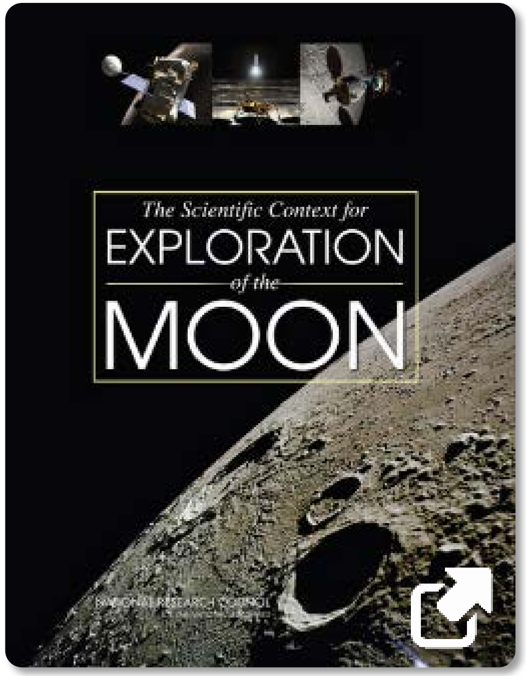
- Prototype early and often to get feedback from end users, especially crew.
- Take advantage of existing suited and unsuited testing in ARGOS, NBL, NEEMO, etc.
- Utilize JSC Rock Yard for quick trips with community.



* Planning for NASA JSC EC7 FY21 tasks to include the manufacturing, testing, & certification of this baseline geology tool kit.

Documents Guiding Science Questions

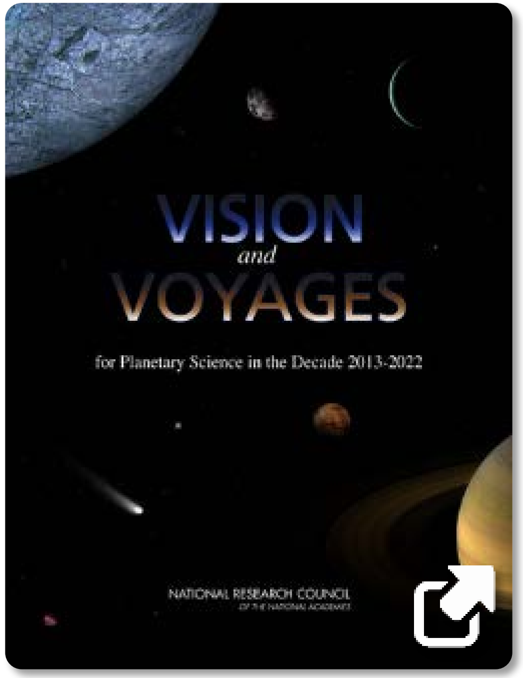
Scientific Context for the Exploration of the Moon (SCEM)



2007

- National Research Council
- Defines 8 prioritized science concepts and associated science goals
- 4 Overarching Themes: 1) Terrestrial Planet Differentiation, 2) Earth/Moon System, 3) Lunar Environment, 4) Solar System Impact Record

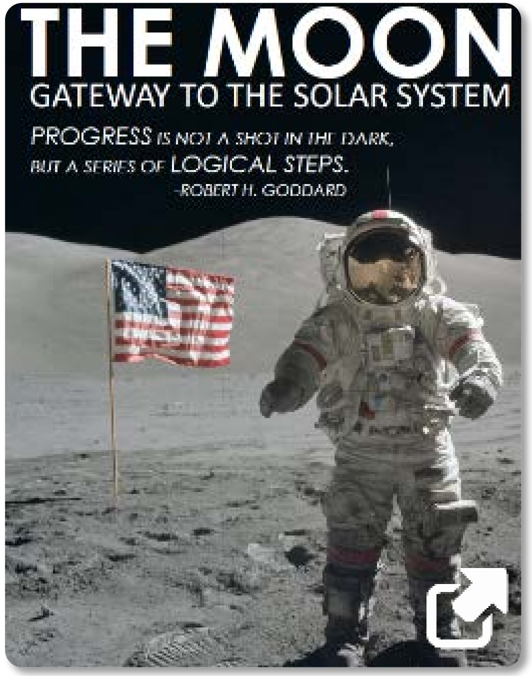
Vision and Voyages for Planetary Science in the Decade 2013-2022



2009

- National Research Council
- Identifies key questions facing planetary science and outlines recommendations for exploration
- Lunar components include Lunar South Pole-Aitken Basin Sample Return & Lunar Geophysical Network

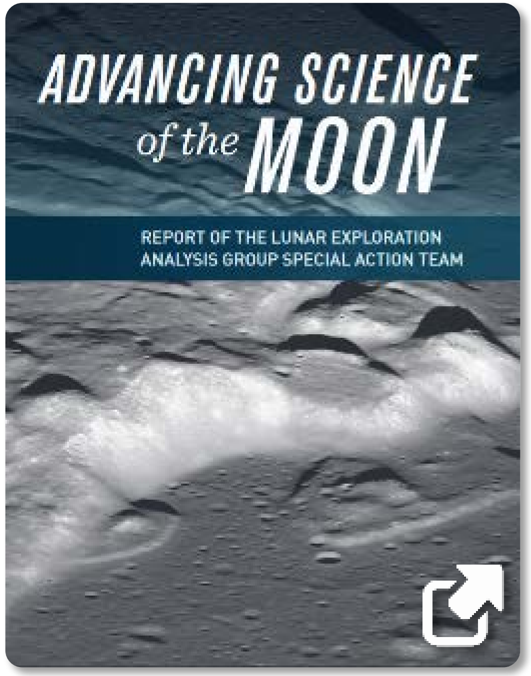
Lunar Exploration Roadmap (current version 1.3)



2016

- Lunar Exploration Analysis Group (LEAG)
- A living/updated document
- Intended to layout an integrated & sustainable plan for lunar exploration
- 3 Themes: 1) Science, 2) Feed Forward, 3) Sustainability

Advancing Science of the Moon: Report of the Specific Action Team



2017

- LEAG Specific Action Team Report
- Chartered to evaluation the progress towards achieving the goals of the 2007 SCEM Report
- Reviewed the 8 original SCEM concepts while adding 3 new concepts

Science Requirements

- Science goals are currently in development across the Artemis Programs, to include lunar surface EVA science objectives that are in work but have not been finalized.
- However, it is recognized that lunar sample return will be a critical objective and thus is the driver for beginning work on these sampling tools.
- In order to maintain the aggressive schedule the team is working the Astromaterials Research and Exploration Science (ARES) Division at JSC to develop notional geology sampling objectives and what tool requirements those drive.
- There is accepted risk that future decisions with regards to official science objectives will impact requirements and possibly tool design.

Artemis Geology Tool Kit Relevance

Sample Types

- **Float**
  - Rocks that are loosely adhered to the surface
- **Chip**
  - A piece of rock forcibly removed from a larger rock
- **Soil**
  - Loose regolith made up of small (below pea-sized grains)
- **Soil Core**
  - A cylindrical sample of regolith
- **Rock Core**
  - A cylindrical sample of a hard rock
- **Surface**
  - The top ~1mm of soil
- **Atmospheric sample**
  - A sample of the atmosphere of a planetary body

Not FY20 Focus

Baseline Artemis Geology Tools (FY20)

- **Tongs**
- **Rake**
- **Hammer**
- **Scoop**
- **Drive Tube**

(Tongs, Rake, Hammer, Scoop, Drive Tube:) Common Extension Handle

- **Contingency Sampler**
- **Documented Sample Bag**
- **Sample Return Container**

Support Tools

Testing

- The team has worked with colleagues across the Agency to utilize the appropriate testing facilities for each level of our EVA tool development.
- These tests have enable cross discipline knowledge sharing and early tool concepting.
- Current test environments
  - Neutral Buoyancy Laboratory (NBL)
  - Aquarius Habitat, Islamorada, FL
    - NEEMO 15, 16, 18, 19, 20, 21, 22, 23
    - SEATEST II
    - NEEMO NXT
  - Advanced Materials Lab (AML)
  - Thermal/Vacuum Chambers
  - Active Response Gravity Offload System (ARGOS)
- Previous test environment
  - Flagstaff, Arizona
    - Desert RATS 08, 09, 10, 11
  - Building 9, JSC
    - RATS 12

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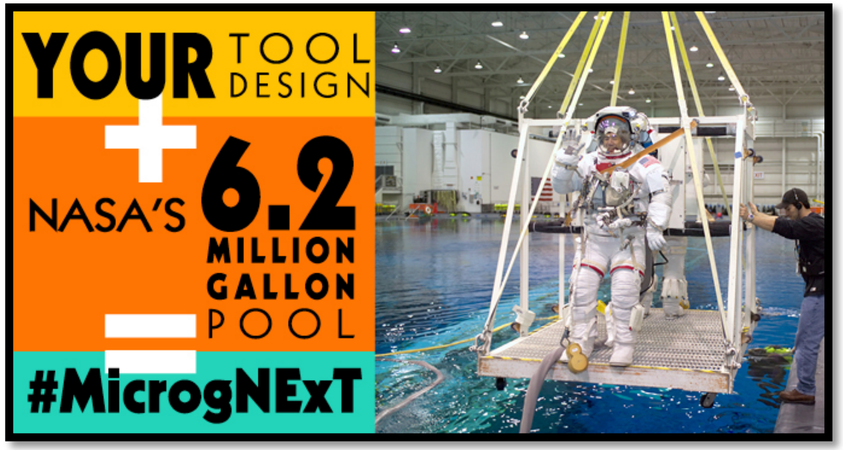
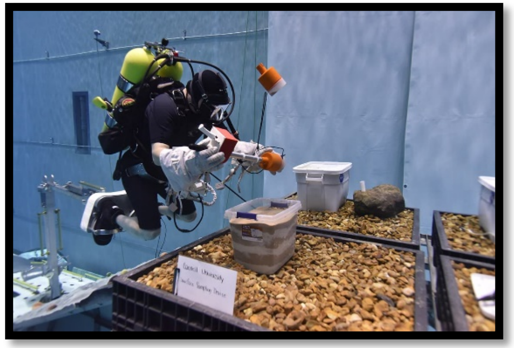
Micro-g NExT Program

- The Micro-g Neutral Buoyancy Experiment Design Teams (Micro-g NExT) Program challenges undergraduate students to propose, design, build, and test a tool that addresses an authentic, current space exploration problem.
- The JSC EVA Community supports the program by reviewing proposals and volunteering as team mentors.
- The EVA tools team has been involved since its beginning 5 years ago by submitting relevant design challenges for the students to choose from.
- The program enables the EVA tools team to crowdsource proposed tool concepts during the prototyping phase.
- The challenges submitted this year are Artemis focused: sample collection on the moon.
- 27 proposals were submitted in November 2019 for the current Micro-g NExT year, giving the team access to those unique tool designs now.



Micro-G NExT

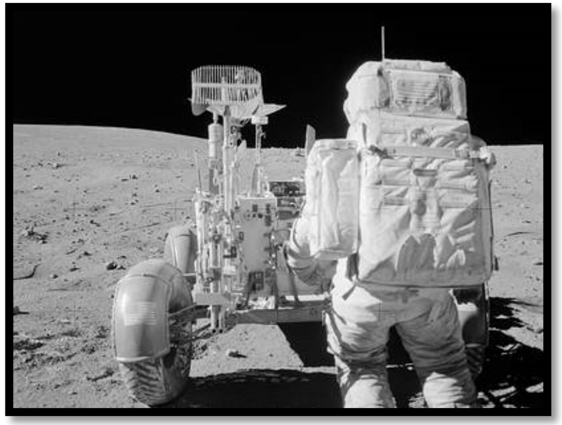
Previous years of Micro-g NExT have focused on microgravity environments (asteroids, LEO). The tools were tested in the Neutral Buoyancy Laboratory (NBL) in a simulated micro-g environment.

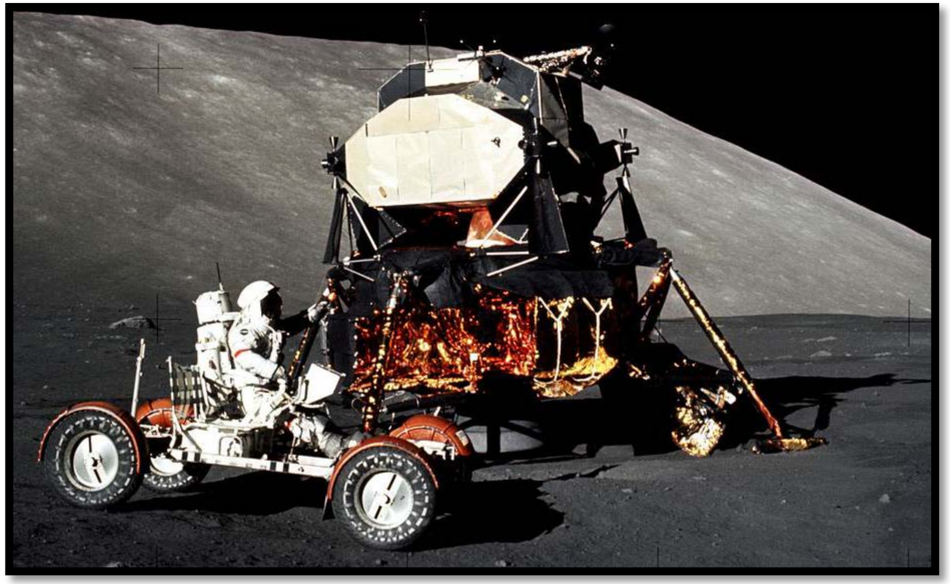


The current year is all Artemis-focused challenges that will be tested in the NBL with surface supply diving operations (similar to NEEMO) in a simulated 1/6-g environment.

Interfaces

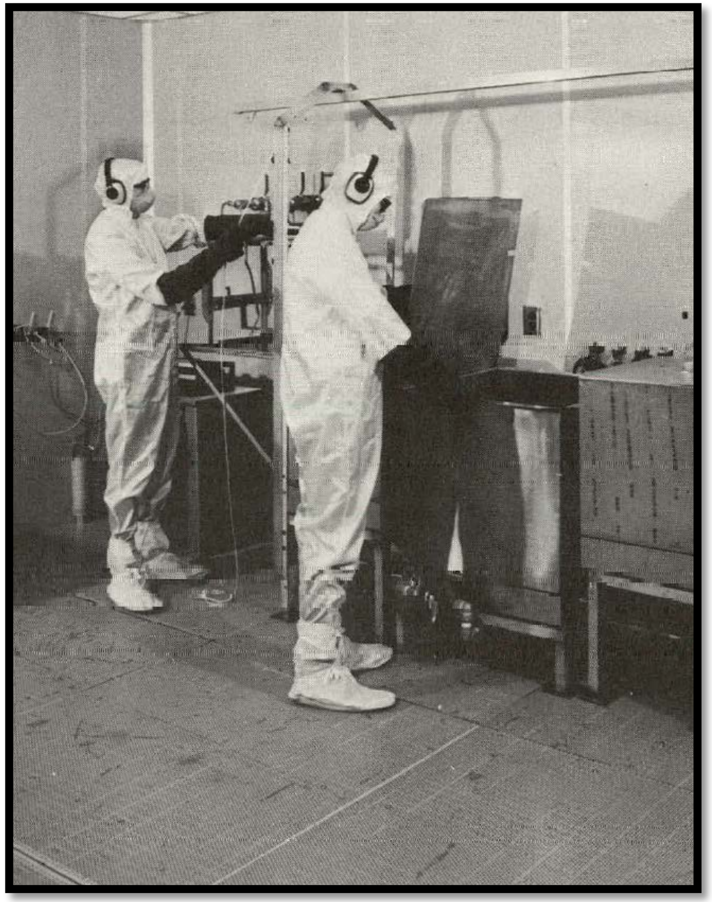
- **Launch Vehicle**
  - TBD
- **Gateway**
- **Descent Vehicle Interior**
  - Location to stow tools for launch
  - Location to stow Sample Return Container and other sample bags for return.
- **Descent Vehicle Exterior**
  - Potential to stow tools here like in Apollo.
- **CLPS Lander**
  - Potential to launch/land on CLPS mission.
- **Unpressurized/Pressurized Rovers**
  - Tool stowage area needed on these vehicles.
- **Crew member in xEMU**
- **Orion**
  - Sample Return Container with samples.
- **Freezer Hardware**
  - Some samples may have cold stowage requirements.





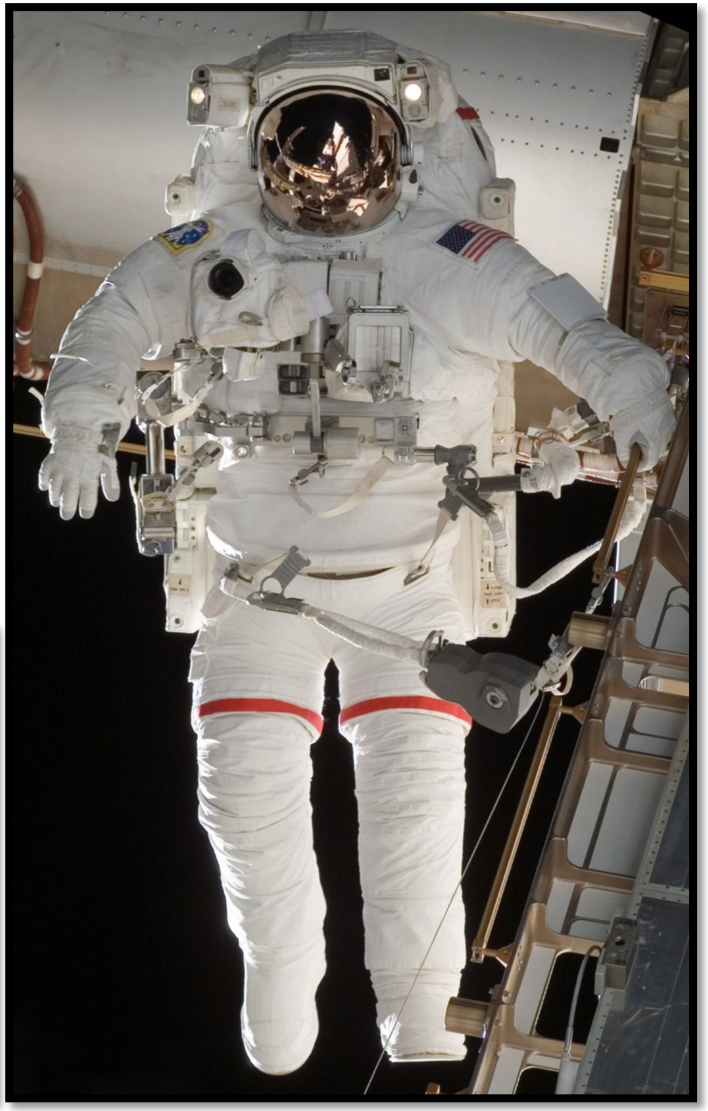
Contamination Control

- Lunar samples will need to be kept as pristine as possible for study by scientists on Earth through controlling contaminants.
  - Contaminant: any material, substance or energy that is unwanted or adversely affects the sample/contaminee.
- Contamination control is the “planning, organization and implementation of all activities needed to determine, achieve, and maintain a required cleanliness level in, on or around the contaminee”.
- Impacts material selection, precision cleaning needs, ground handling.
- Types of sample contamination:
  - Organic contaminants
  - Manufacturing, handling, & cleanliness contaminants
  - Tool material contaminants
  - Tool reuse from one sample location to another
- This will be new for the EVA Tools Team and will require leveraging experience of others who have more recent practice in this subject matter.
  - ARES, JPL, etc.



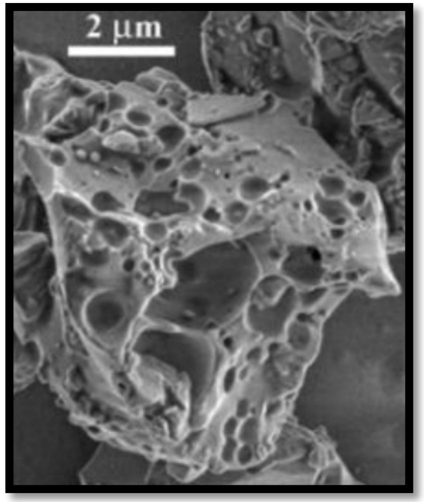
Designing Tools for Astronauts in a Spacesuit

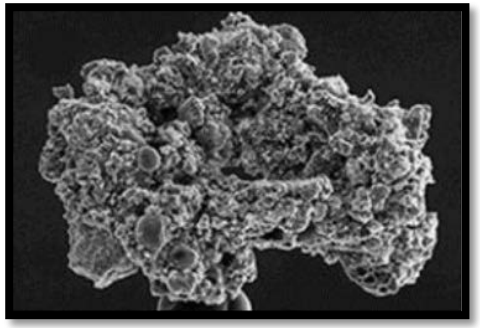
- **There are unique challenges in designing tools that can be used by astronauts in spacesuits.**
  - Sharp edges
  - Touch temperatures
  - Work envelope
  - Hand fatigue
  - Loads

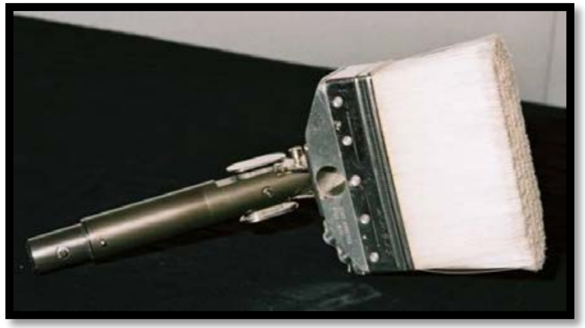


Dust Mitigation

- Lunar regolith is the layer of unconsolidated rock that covers lunar bedrock.
- Lunar “soil” is arbitrarily defined as the less than 1 mm portion of the regolith.
- Furthermore, the term lunar “dust” tends to represent the under 10-20 μm size fraction though “dust” is used loosely to describe particles up to ~100 μm.
- Highly cohesive/adhesive due to geometry and electrostatic charge.
- Three stages where the presence and impact of lunar dust can be minimized
  - Prevent dust from adhering to hardware reentering the lander
  - Minimize dust entry into the lunar lander
  - Maximize clean up of dust
- How can tools minimize dust entry?
  - Tools that could be useful
    - Existing tools: Apollo & ISS brushes, connector cleaners, wipes,
    - Possible future tools: tape roller, boot scrubber, “mud room” tarp
  - Testing of tools
    - Benchtop, lab grade lunar regolith simulant removal test
    - Glovebox testing, high grade lunar simulant removal test
      - Vacuum? Thermal? Electrostatically charged?







Challenges & Questions

- **Will likely need to use a non-metallic other than Teflon**
  - Only approved non-metallic during Apollo was Teflon, but the Artemis landing location and PSRs will likely be too cold to use Teflon. Teflon was used for the Documented Sample Bags as well as a bushings and
  - Currently looking into PEEK, Vespel, & and Kapton Film

- **What materials can we use to collect samples in a PSR?**
  - The volatiles in a PSR include hydrogen sulfide (H_2S) and a few other unfriendly compounds which will react with some of the metals on the Apollo material list.
  - The PSRs are significantly colder than sunlit areas. Materials may need to be altered to protect against embrittlement at cold.

- **Do a majority of the samples need to be vacuum-sealed for the return flight?**
  - Assuming PSR samples will need to be in vacuum-sealed containers. Also assuming there will be other “special” samples that need to be vacuum-sealed.
  - But if majority of samples don’t, that could save a lot of mass by allowing us to put the min a softgoods bag and bring back more samples.
  - There were some issues with things getting stuck in the seals of the vacuum-sealed boxes on Apollo, ruining the seals.

Challenges & Questions

- **Will the tools that are left on the lunar surface pick up a plasma charge in between EVAs or Artemis missions?**
  - How can that be prevented or discharged?
  - How mush of a charge can the suit protect the crew from?

- **Can we reuse tools that are left on the lunar surface without negatively impacting the geology?**
  - A return mission to the same landing site would not necessarily mean a return to the same sample collecting areas. The tools used in collecting from the first sample area could contaminate the samples in the second area with the materials from the first.

- **How and where will Acceptance Testing be performed?**
  - Contamination Control requirements will drive tool cleanliness to be maintained not just up until assembly, but through testing and integration on the launch vehicle.
  - Assumed Acceptance Testing could include vibration, shock, thermal, all of which would need to be done in a clean room.
  - Do facilities with these capabilities exist?

Schedule and Deliverables FY20

- **Kickoff Meeting:** Oct 2019 - COMPLETE
- **Requirements Review:** Feb 2020
- **Initial lunar dust mitigation tools assessment –** July 2020
- **Critical Design Review:** Sept 2020

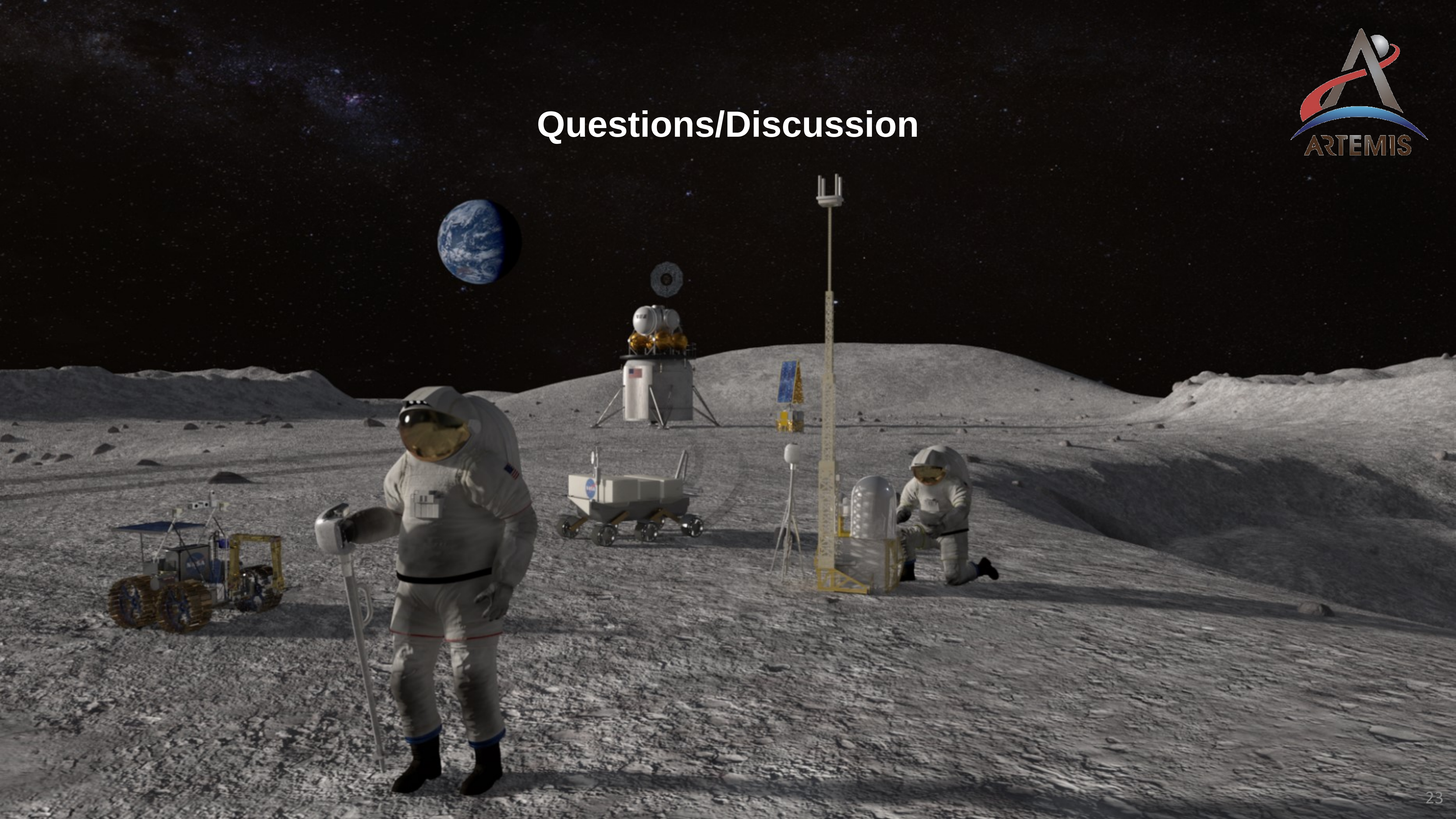
- The plan is to deliver multiple sets of these 9 tools for evaluations by multiple users in various testing facilities by end of Fiscal Year (Sept 30).

Gen 0 Tool Kit (2017)

Future Plans

- **There are numerous other EVA Tools and Equipment that need to be developed in future years to support a mission in 2024 and beyond:**
  - Tool carrier/s
  - Dust mitigation tools
  - Additional sample containers
  - Volatile sampling system
  - Powered core drill
  - Scale
  - Gnomon
  - Geotechnical tools
  - Field portable instruments
  - Incapacitated crew rescue hardware
  - Generic tools (pliers, crescent wrench, sockets, ratchet, compound cutters, etc.)
  - Deployable science payloads
  - Portable lighting
  - …

Questions/Discussion



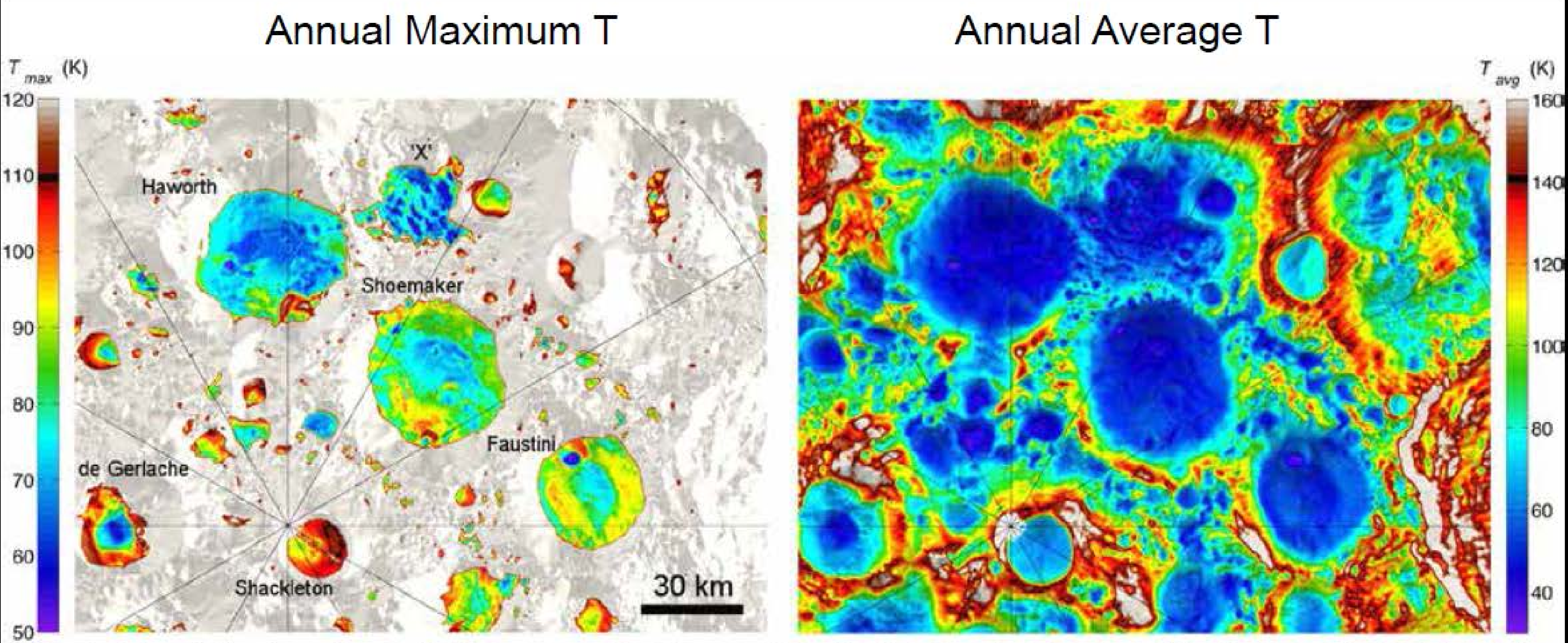
PSR Volatiles

Table 2. Abundances derived from spectral fits shown in Fig. 3. The uncertainty in each derived abundance is shown in parenthesis [e.g., for H_2O: 5.1(1.4)E19 = $5.1 \pm 1.4 \times 10^{19}$ cm^{-2}] and was derived from the residual error in the fit and the uncertainty in the radiance at the appropriate band center.

Compound	Molecules cm^{-2}	% Relative to $H_2O(g)$*
H_2O	5.1(1.4)E19	100.00%
H_2S	8.5(0.9)E18	16.75%
NH_3	3.1(1.5)E18	6.03%
SO_2	1.6(0.4)E18	3.19%
C_2H_4	1.6(1.7)E18	3.12%
CO_2	1.1(1.0)E18	2.17%
CH_3OH	7.8(42)E17	1.55%
CH_4	3.3(3.0)E17	0.65%
OH	1.7(0.4)E16	0.03%

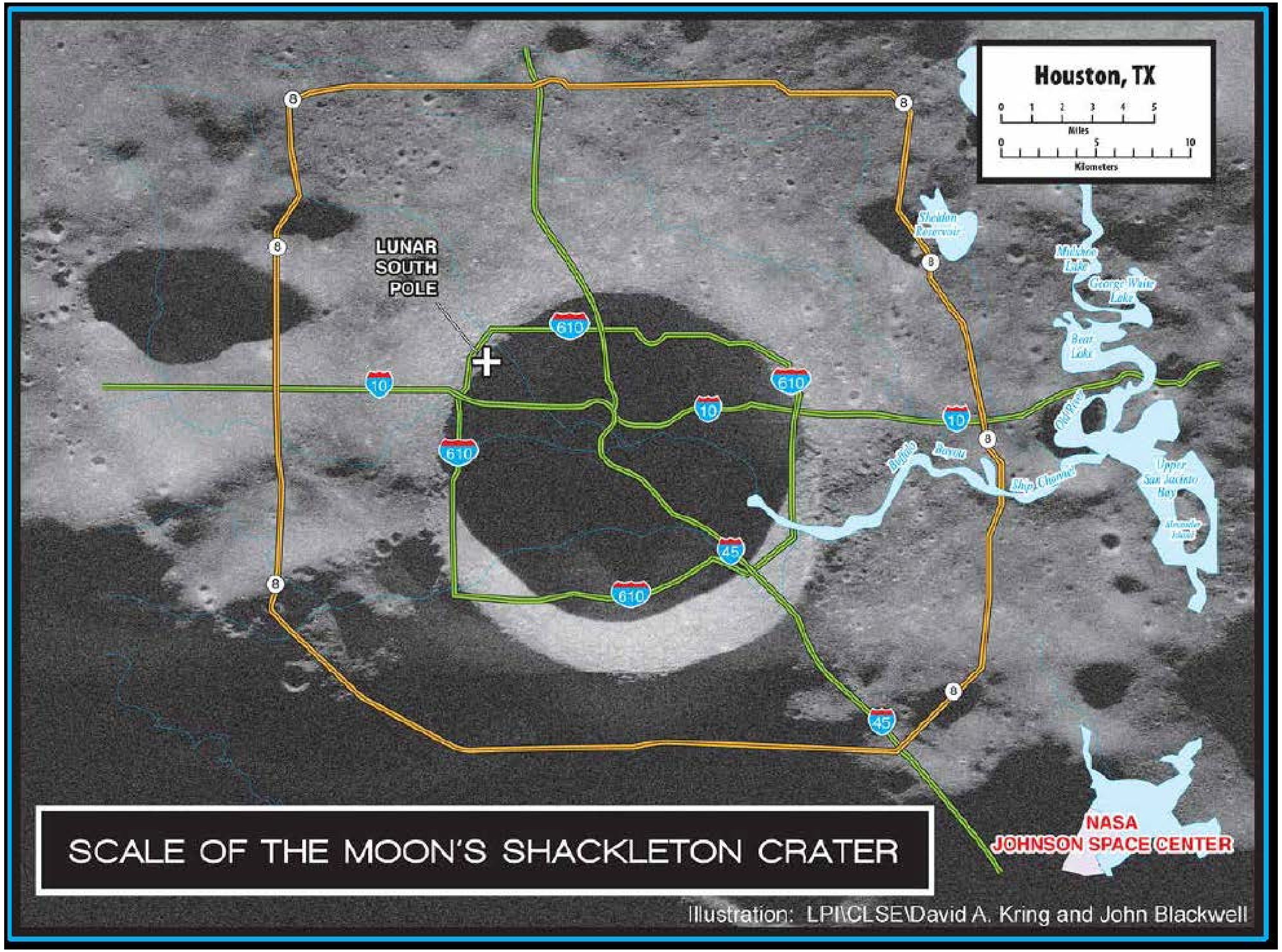
*Abundance as described in text for fit in Fig. 3C.

Temperatures in South Polar Region

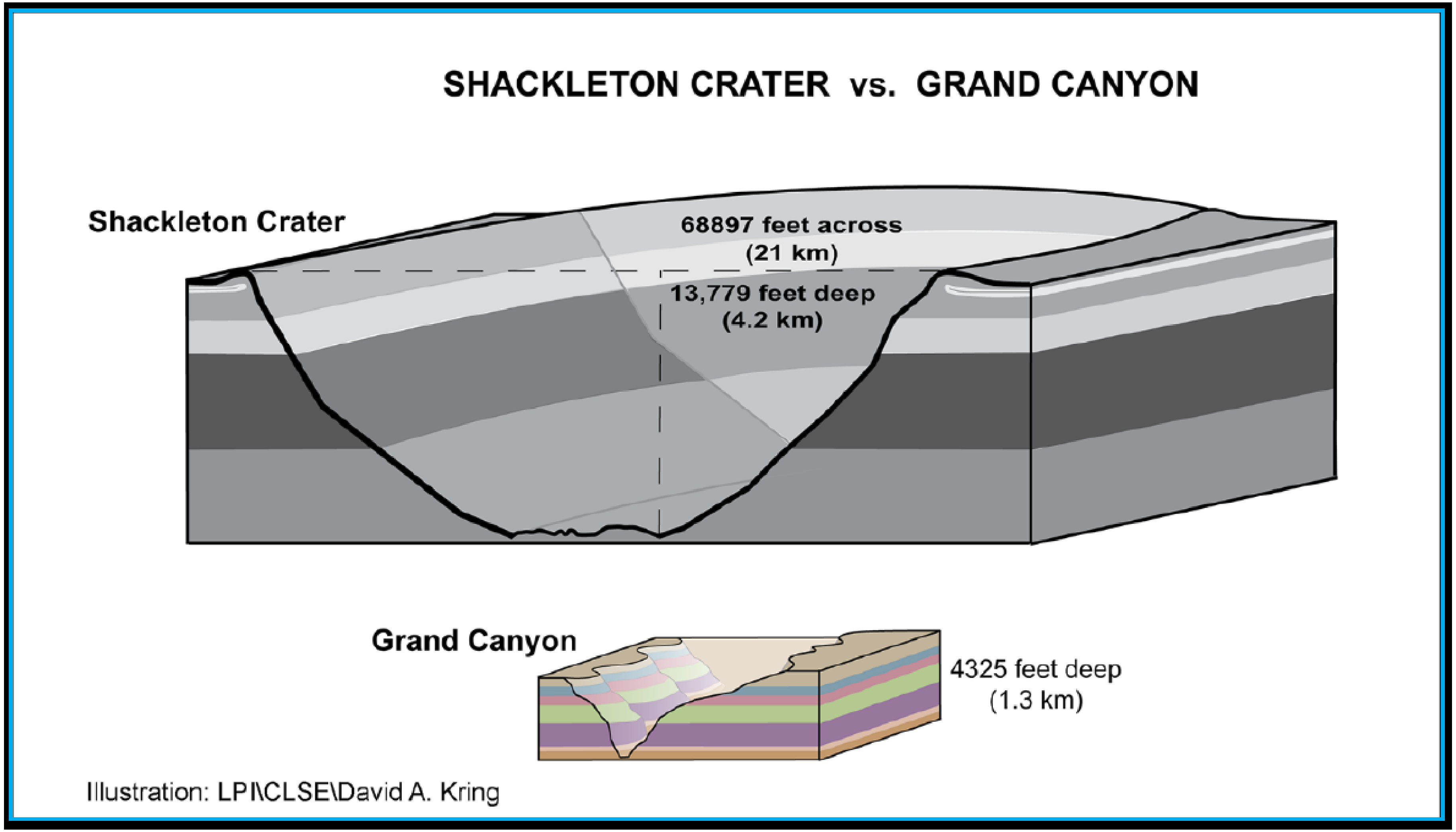


Annual maximum (left) and annual average (right) temperatures near the lunar South Pole. The black bar on the color scales indicates the chosen thermal stability criteria for surface water frost (Tmax<110K) and subsurface water ice (Tavg<140K), per Schorghofer (2008). Source: Hayne et al. (2015).

Hayne et al. (2015)



Houston, TX
0 1 2 3 4 5
Miles
0 5 10
Kilometers
LUNAR
SOUTH
POLE
8
10
610
45
NASA
JOHNSON SPACE CENTER
SCALE OF THE MOON'S SHACKLETON CRATER
Illustration: LPI\CLSE\David A. Kring and John Blackwell


SHACKLETON CRATER vs. GRAND CANYON
Shackleton Crater
68897 feet across
(21 km)
13,779 feet deep
(4.2 km)
Grand Canyon
4325 feet deep
(1.3 km)
Illustration: LPI\CLSE\David A. Kring