



NASA Human Spaceflight Opportunities for Continuum Robots

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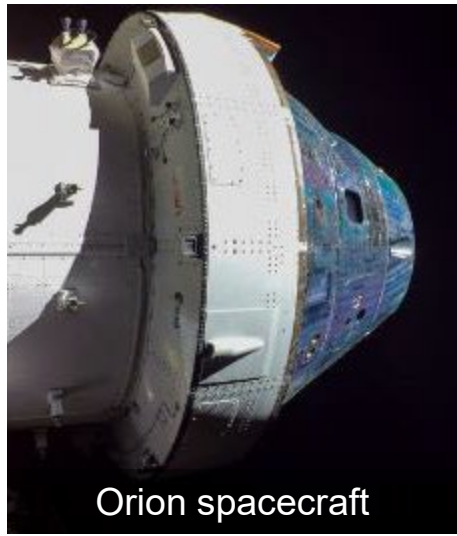
Agenda

- Introduce NASA's Artemis Missions
- Opportunities for Continuum Robotics
 - Gateway
 - Lunar Surface
- Encouraging Robotics Technology Adoption
- Ways to Contribute

Artemis: A Foundation for Deep Space Exploration



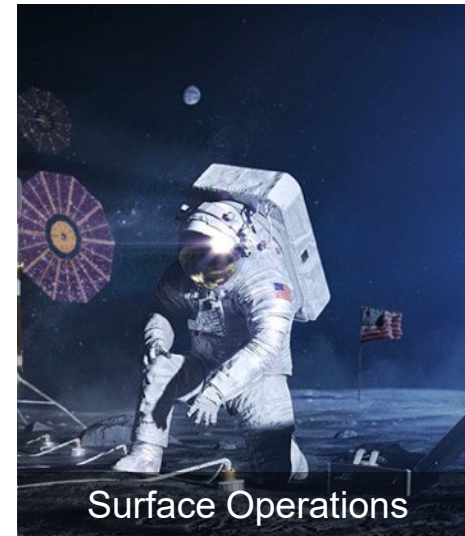
Space Launch System



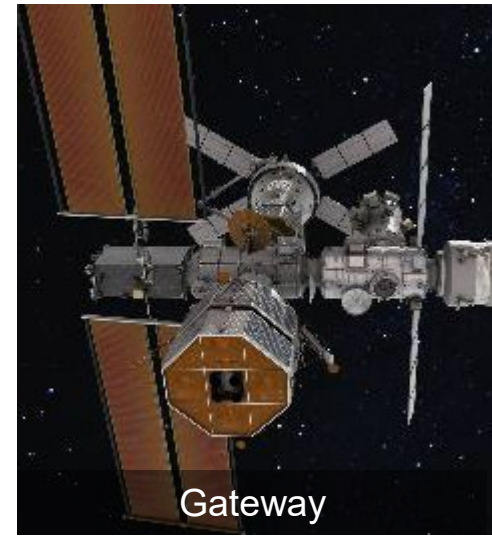
Orion spacecraft



Human Landing System



Surface Operations



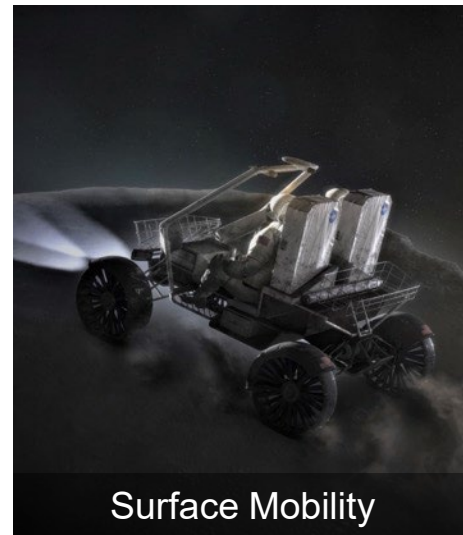
Gateway



Exploration Ground Systems



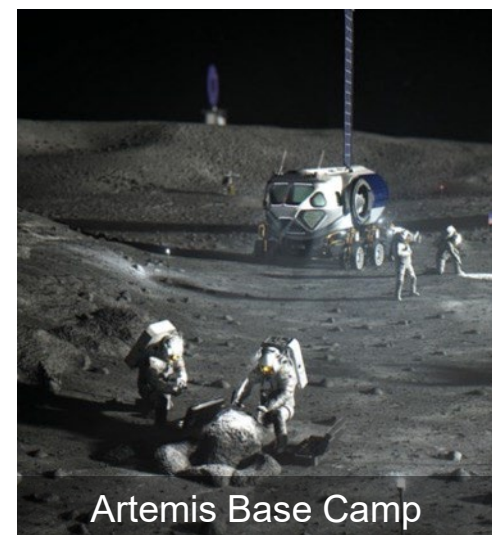
Space Communications
& Navigation



Surface Mobility

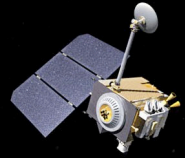


Spacesuits



Artemis Base Camp

Artemis: Landing Humans On the Moon



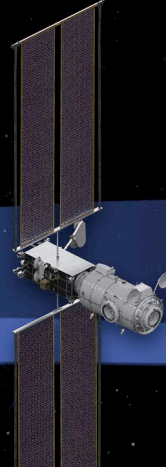
Lunar Reconnaissance Orbiter: Continued surface and landing site investigation



Artemis I: First human spacecraft to the Moon in the 21st century



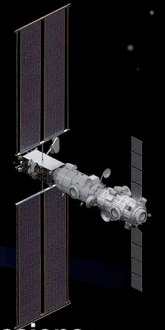
Artemis II: First humans to orbit the Moon and rendezvous in deep space in the 21st century



Gateway begins science operations with launch of Power and Propulsion Element and Habitation and Logistics Outpost



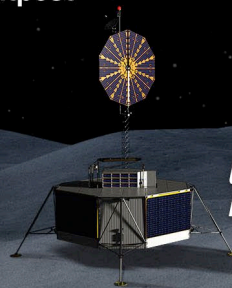
Artemis III-V: Deep space crew missions; cislunar buildup and initial crew demonstration landing with Human Landing System



Early South Pole Robotic Landings
Science and technology payloads delivered by Commercial Lunar Payload Services providers



Volatiles Investigating Polar Exploration Rover
First mobility-enhanced lunar volatiles survey



Uncrewed HLS Demonstration

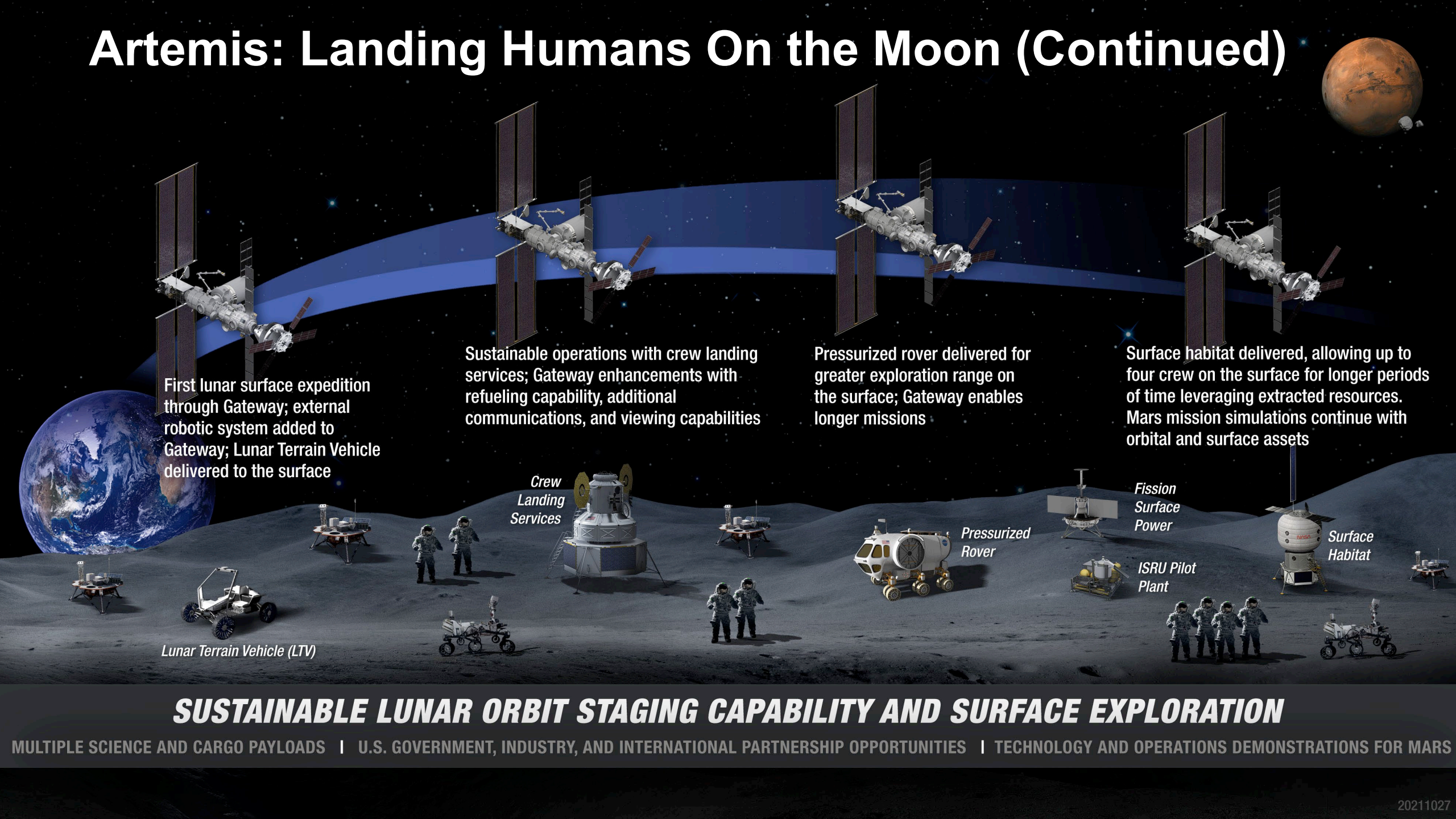


Humans on the Moon - 21st Century
First crew expedition to the lunar surface



LUNAR SOUTH POLE TARGET SITE

Artemis: Landing Humans On the Moon (Continued)

A detailed illustration of the Artemis mission timeline. At the top, four Orion spacecraft are shown in a curved blue band representing lunar orbit. Below them, the lunar surface is depicted with various assets and astronauts. The Earth is visible on the left, and Mars is in the top right corner. The timeline progresses from left to right, showing the sequence of events from the first expedition to sustained operations and Mars mission simulations.

First lunar surface expedition through Gateway; external robotic system added to Gateway; Lunar Terrain Vehicle delivered to the surface

Sustainable operations with crew landing services; Gateway enhancements with refueling capability, additional communications, and viewing capabilities

Pressurized rover delivered for greater exploration range on the surface; Gateway enables longer missions

Surface habitat delivered, allowing up to four crew on the surface for longer periods of time leveraging extracted resources. Mars mission simulations continue with orbital and surface assets

Lunar Terrain Vehicle (LTV)

Crew
Landing
Services

Pressurized
Rover

Fission
Surface
Power

ISRU Pilot
Plant

Surface
Habitat

SUSTAINABLE LUNAR ORBIT STAGING CAPABILITY AND SURFACE EXPLORATION

MULTIPLE SCIENCE AND CARGO PAYLOADS | U.S. GOVERNMENT, INDUSTRY, AND INTERNATIONAL PARTNERSHIP OPPORTUNITIES | TECHNOLOGY AND OPERATIONS DEMONSTRATIONS FOR MARS

Mission Needs Drive Design

LOW EARTH RETURN

3 HOURS

3,000°F

17,500 MPH

250 MILES



LUNAR RETURN

3 DAYS

5,200°F

24,700 MPH

240,000 MILES



MARS RETURN

9 MONTHS

6,200°F

26,800 MPH

39,000,000 MILES



**Numbers are averages*



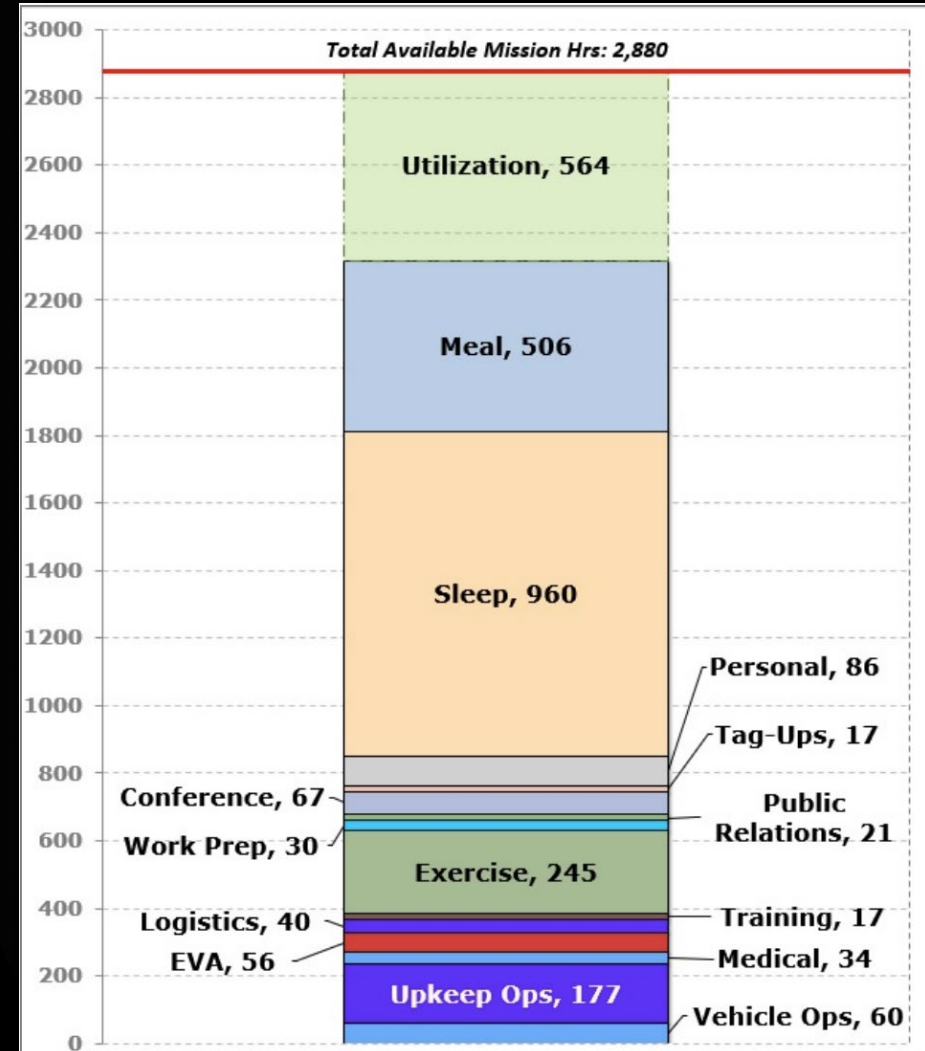
GATEWAY



Crew Time Is Valuable – a Gateway Example

- Crew time is highly planned during a mission
- The chart at right estimates time allocations based on historical ISS crew time usage and assumptions about Gateway operations
 - Crewmembers: 4
 - Mission duration: 30d
- Utilization is a major objective for human spaceflight, but secondary to crew health and spacecraft caretaking
- Robots have an opportunity to maximize crew time
 - Upkeep ops: housekeeping, work prep, system/consumable management, organization, etc.
 - Utilization: scientific research tasks
 - Caretaking and preparations for crew arrival

On the Lunar Surface, crew time will be similarly precious, especially on EVAs



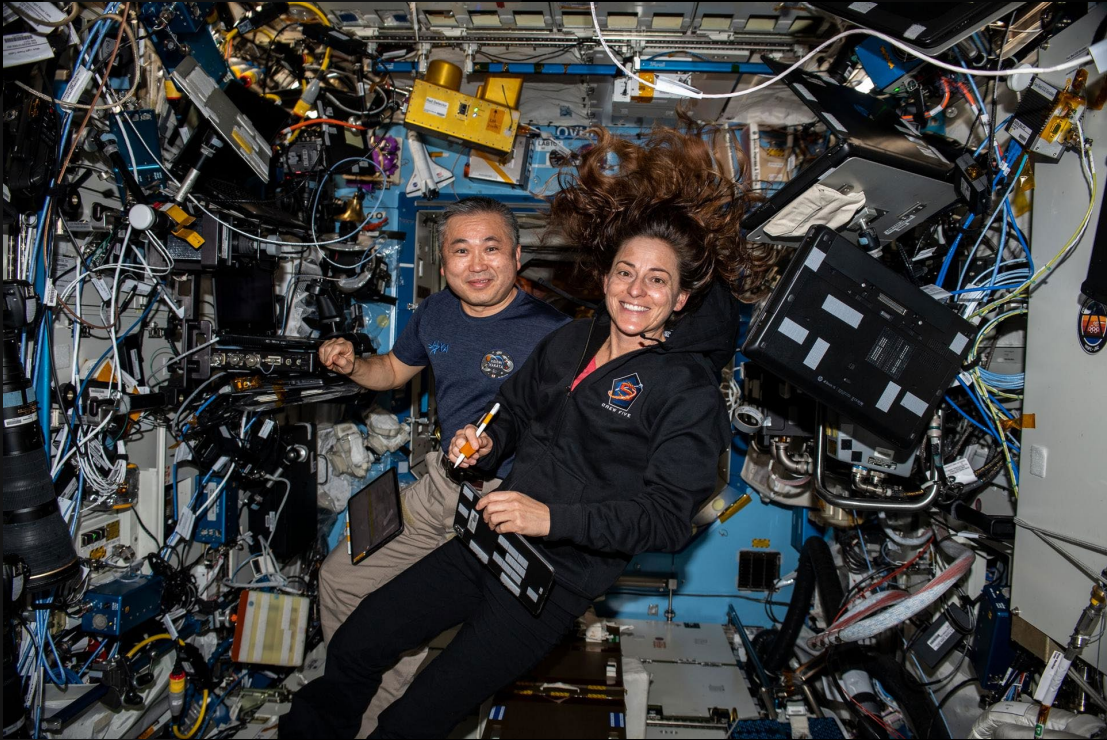


How Can Continuum Manipulators Help?

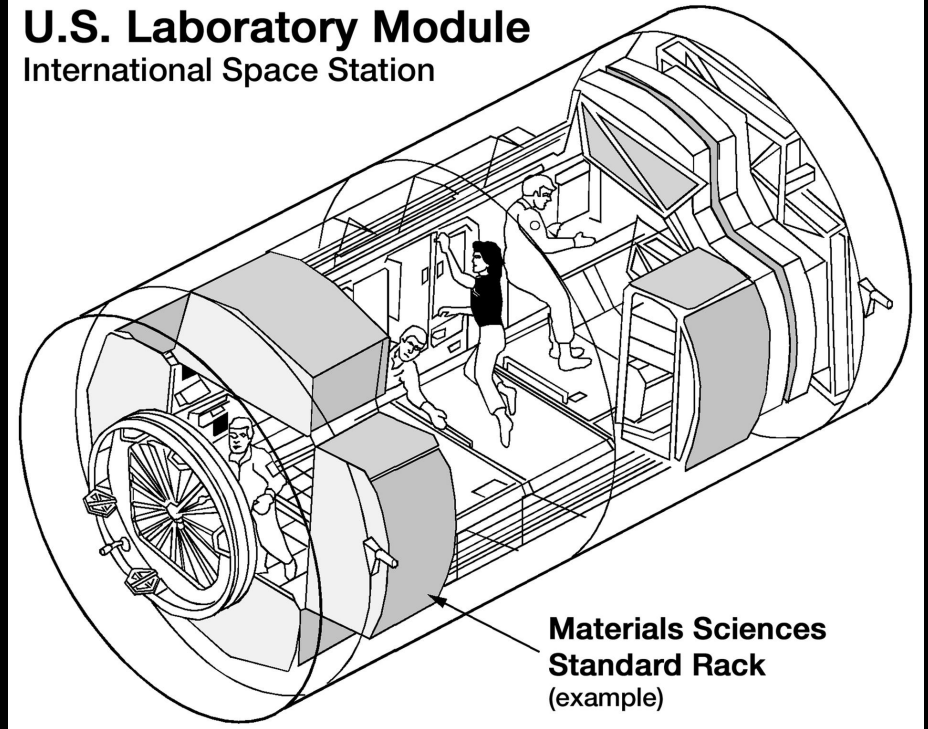
- Gateway is smaller than ISS but will have many heritage features and influences
- We can lean on ISS experience for ideas
- Inspection and surveying of inaccessible or difficult to reach areas
 - A recent troubleshooting activity for crew exercise equipment required rotating a rack.
 - Excluding the work on the anomalous component, this took 6h 10m to prepare and reset the rack. An additional crewmember was needed to assist in the physical rotation due to its mass and size.



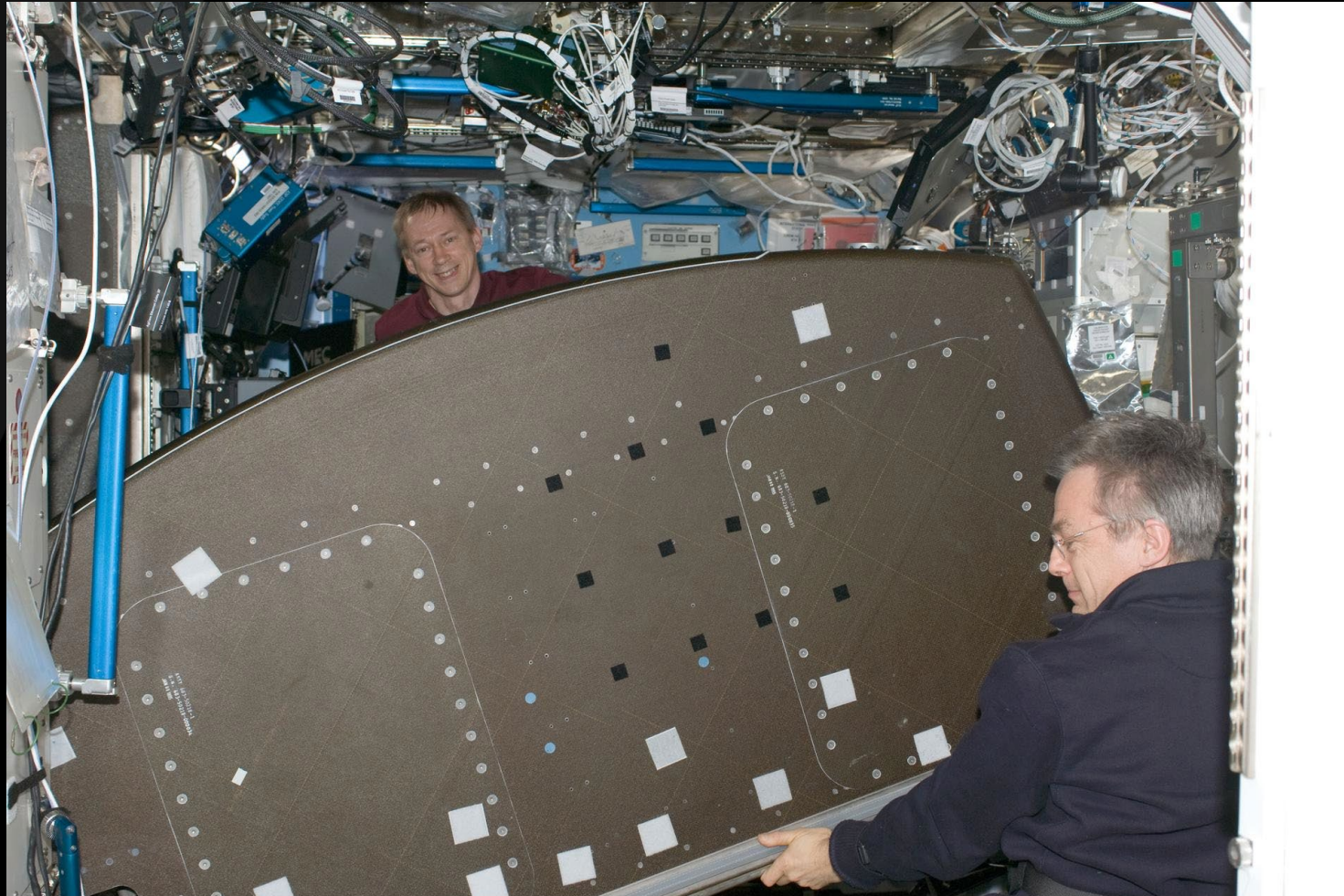
ISS Interior



U.S. Laboratory Module
International Space Station



A Rotated ISS Rack



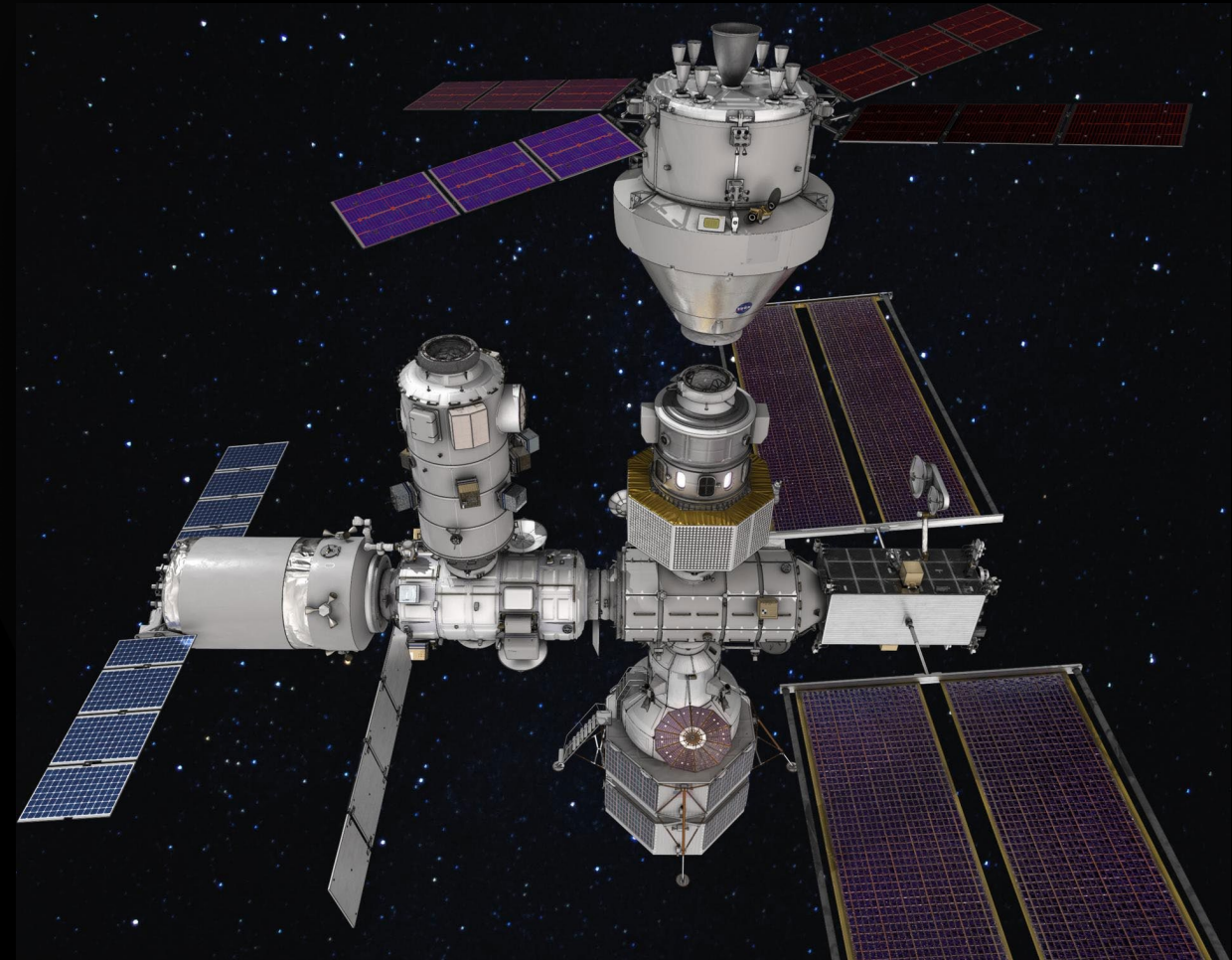
ISS020E030661



Looking to Gateway Intravehicular Robotics

- Gateway System Managers are interested in general purpose robots, but realize they don't do it all
 - It might also be useful to have a limited number of specialized robots, [Dr. Julia] Badger says. "For example, if there was a reason to get behind a rack, *you may want a snake-type of robot for that.*"
- Other use case candidates include searching for leaks, assessing equipment, fire alarm response

Note: Gateway has initial provisions for intravehicular robotics, but no systems are yet baselined.



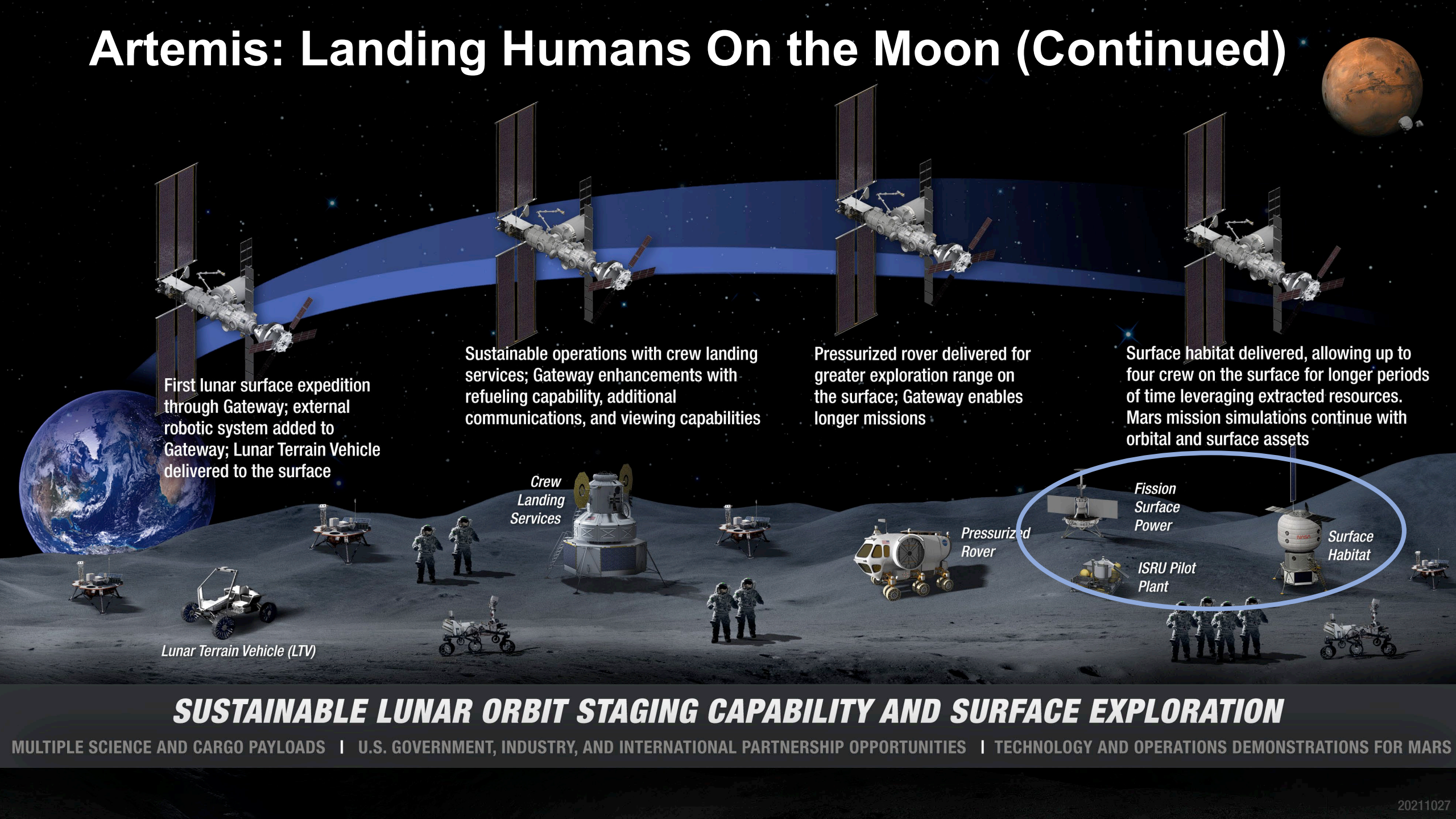
Quote Source: Ackerman, Evan. "Meet the Lunar Gateway's Robot Caretakers" <https://spectrum.ieee.org/lunar-gateway-robots>. 2022-04-07.

Image source: https://images.nasa.gov/details/Gateway-Telephoto-IAC7-Set-4k-BG_5



LUNAR SURFACE

Artemis: Landing Humans On the Moon (Continued)

A detailed illustration of the Artemis mission timeline. At the top, four Orion spacecraft are shown in a curved blue orbital path around the Moon. Below the orbit, the lunar surface is depicted with various assets: a Lunar Terrain Vehicle (LTV) on the left, two astronauts near a Crew Landing Services module, a Pressurized Rover, and a blue circle highlighting a Fission Surface Power unit, an ISRU Pilot Plant, and a Surface Habitat. A group of four astronauts stands near the habitat. The Earth is visible on the left, and Mars is in the top right corner.

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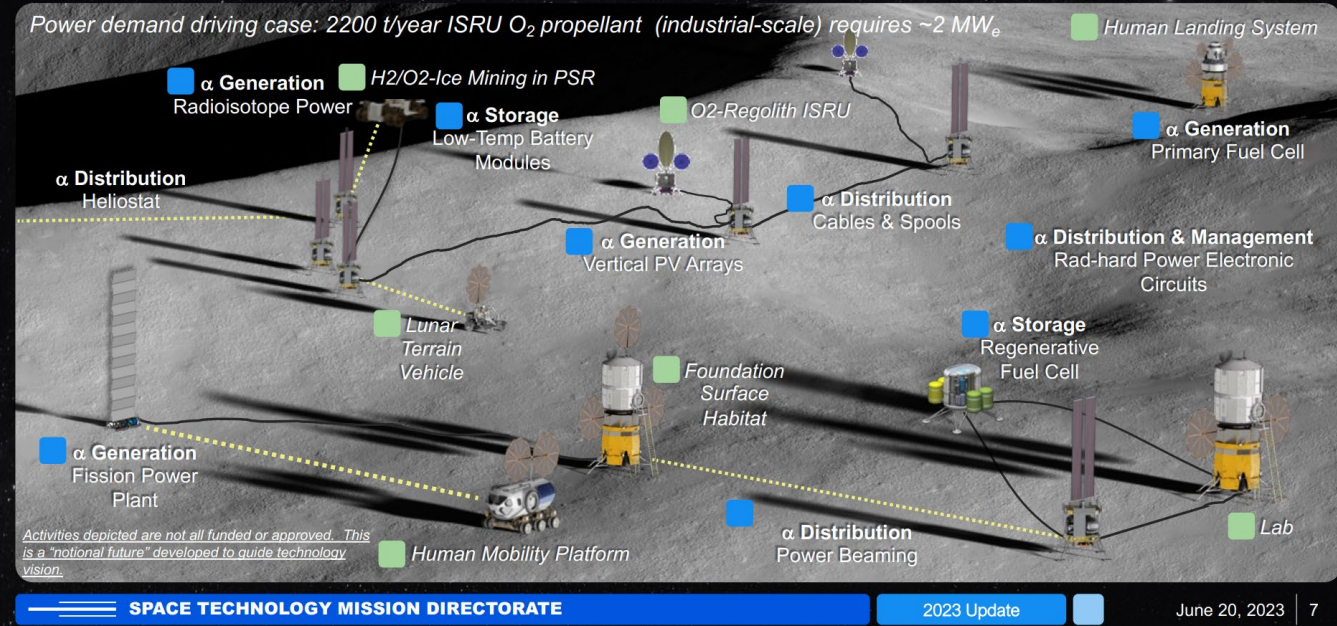
Lunar Surface Opportunities



- Surface power distribution
 - Power generation may be located at a distance from the loads, connected via cables
 - Are crewmembers the wisest choice for making connections?
 - A continuum robot integrated into a cable could make connections, inspect physical connectors for dust/debris
 - Is a continuum robot part of a mobility system to unspool cables?
- Habitats and other elements are likely to have external fluid connections, data cables, etc.
- Inspection of landers prior to ascent
- Intravehicular tasks onboard a habitat or pressurized rover may be suited for continuum robotics, like aboard Gateway
- These architectures are in work and can be influenced with new capabilities

Power Architecture Building Blocks

Phase α South Pole Facilities: Handoff from Artemis Base Camp to Industry (~2030+)



Source: NASA STMD Envisioned Future Priority for Power and Energy Storage Systems

<https://techport.nasa.gov/strategy>



Keys to Encouraging Adoption

- Technology maturation
 - Envisioned future priorities and technology roadmaps
 - Gaps and technology shortfalls are opportunities for funding
- Sensors to provide valuable insights and data
 - Camera and lighting
 - Multispectral (IR) imaging
 - Ultrasonic (leak detection)
 - Smoke/fire detection
- Control methodologies
 - Integration with ROS and SpaceROS
 - Localizing the position of a sensor and FoV
 - Efficient transmission of data from a robot to a human controller (astronaut or ground controller) or autonomous system manager



An Incomplete List of Opportunities

Funding:

- University
 - Early Career Faculty
 - NASA Space Technology Graduate Research Opportunities
 - Space Technology Research Institutes
 - Small Business Technology Transfer
- Small Business
 - Small Business Innovation Research
- All Business
 - Tipping Point
 - Announcement of Collaboration Opportunity (ACO)
 - NASA Innovative Advanced Concepts
- Team with prime contractors to improve services to NASA
- Payloads on CLPS landers

Collaboration:

- Space Act Agreements (including International)
- iMETRO facility at JSC for integration testing
- COSMIC
 - Consortium for Space Mobility and ISAM Capabilities
 - Membership is U.S. only
- LSIC
 - Lunar Surface Innovation Consortium

<https://www.nasa.gov/stmd-solicitations-and-opportunities/>



Key Messages

- Future human spacecraft have long uncrewed periods
 - Caretaking while crews are away will be greatly improved by the presence of robots
 - Robotic inspections and maintenance can help ensure very costly and irreplaceable mission elements are long-lasting
- Crew time can be maximized for science and exploration objectives with robotic support before, during, and after a mission
- Demonstrating and communicating what continuum robotics bring to the trade space allows for more informed architecture decisions



Questions and Discussion

