# Gateway, Artemis and Other Opportunities for Biological Research in Deep Space Over the Next Decade


**Jeffrey D. Smith, Ph.D.**

Deputy Manager (Acting) NASA Deep Space Logistics


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# The Artemis Program

The primary mission objective of Artemis ***over the next decade*** is captured in the Program's unofficial motto:

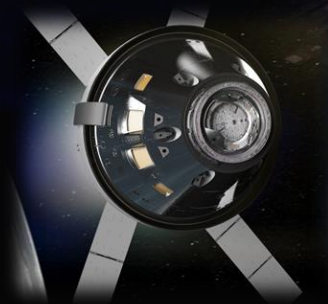

Artemis is the first step in the next era of human exploration

Together with com-mercial and international partners, NASA will establish a sustainable presence on the Moon to prepare for missions to Mars

https://www.nasa.gov/artemisprogram

ARTEMIS

Brings cross-cutting program elements together into one mission architecture



Orion

SLS

Gateway


HLS

LSP

CLPS

# Artemis and Other NASA Missions Over the Decade

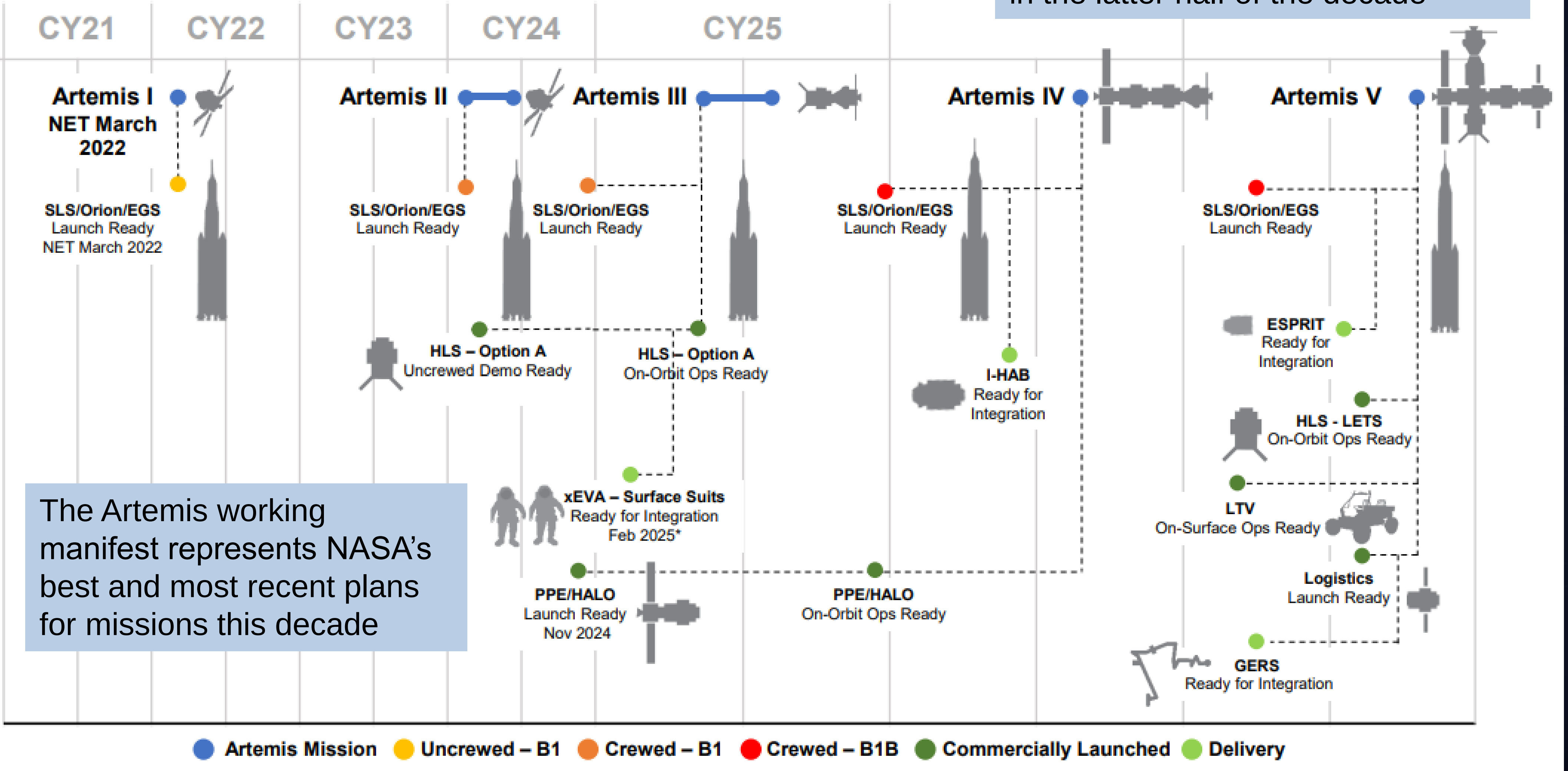
## Can, and Will, Deliver Crew and Payloads to Deep Space Destinations:

**Which missions offer real opportunities for Biological Research beyond LEO, and when will they fly?**

- **SLS/Orion**: starting with Artemis I, 2022 with subsequent crewed missions about once per year
- **Commercial Lunar Payload Services (CLPS):** six missions awarded to-date for small lunar landers starting in 2022/2023
- **Gateway:** commercial launch of first modules planned in 2024 with arrival to lunar orbit in 2025
- **Deep Space Logistics (DSL)**: large cargo supply missions supporting Gateway and Artemis with launch and delivery planned to support each crewed mission to the Gateway
- **Human Lander System (HLS)**: lunar landing demonstration mission (Option A) using SpaceX Starship on Artemis III, currently planned in 2025
- **Launch Services Program**: multiple missions planned to support Artemis and other science mission objectives with possible rideshare opportunities beyond LEO
- **Other Commercial or International**: missions may become available; schedule uncertain

# Artemis I – V: Working Manifest for Technical Integration

Launch dates become less certain in the latter half of the decade




The Artemis working manifest represents NASA's best and most recent plans for missions this decade

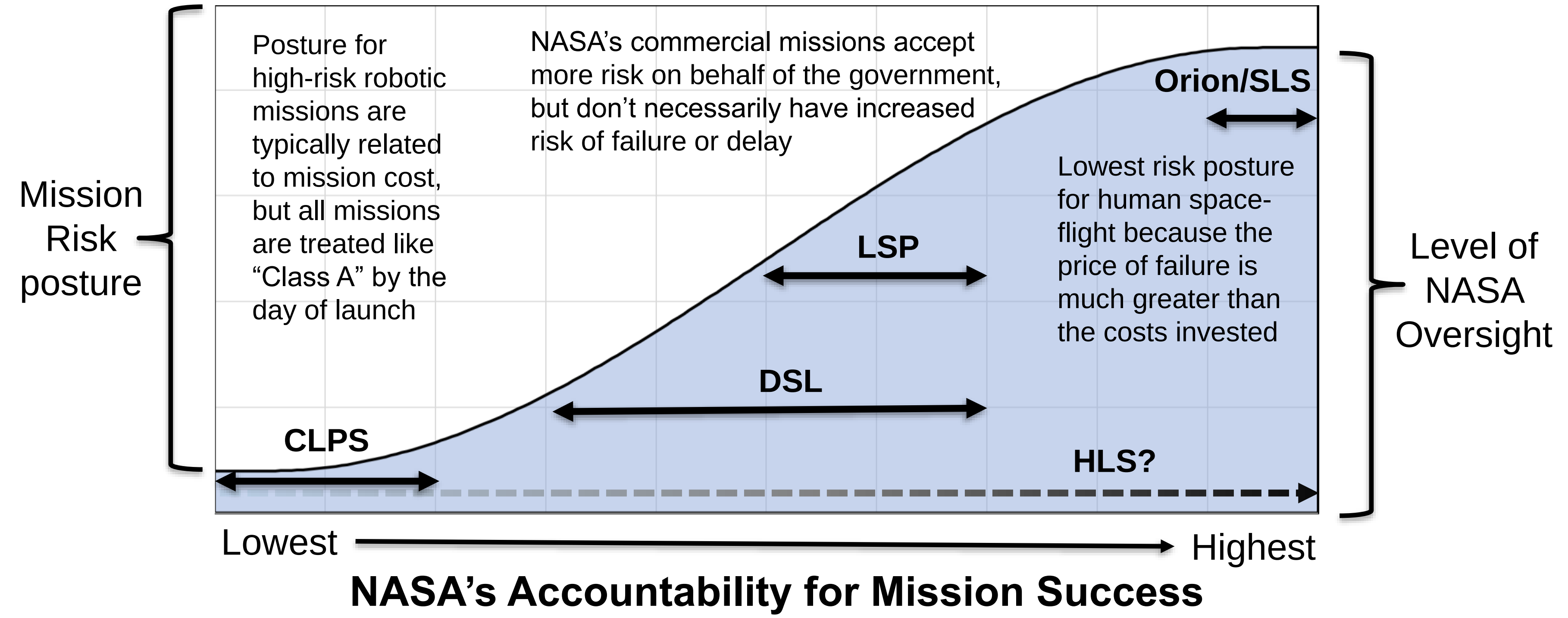
**Key Terminology:**

**B1:** Block 1 (SLS with ICPS)
**B1B:** Block 1B (SLS with EUS)
**EGS:** Exploration Ground Systems
**ESPRIT:** European System Providing Refueling, Infrastructure & Communications
**EUS:** Exploration Upper Stage
**GERS:** Gateway External Robotics System
**HALO:** Habitation and Logistics Outpost
**HLS:** Human Landing System
**ICPS:** Interim Cryo Propulsion Stage
**I-HAB:** International Habitat
**LETS:** Lunar Exploration Transportation Services
**LTV:** Lunar Terrain Vehicle
**PPE:** Power & Propulsion Element
**SLS:** Space Launch System
**xEVA:** Exploration Extravehicular Activity

***Date based on Government planning and estimates; not contract informed**

NASA Advisory Council HEO Committee Public Meeting, January 18, 2022: https://www.nasa.gov/directorates/heo/nac-heoc

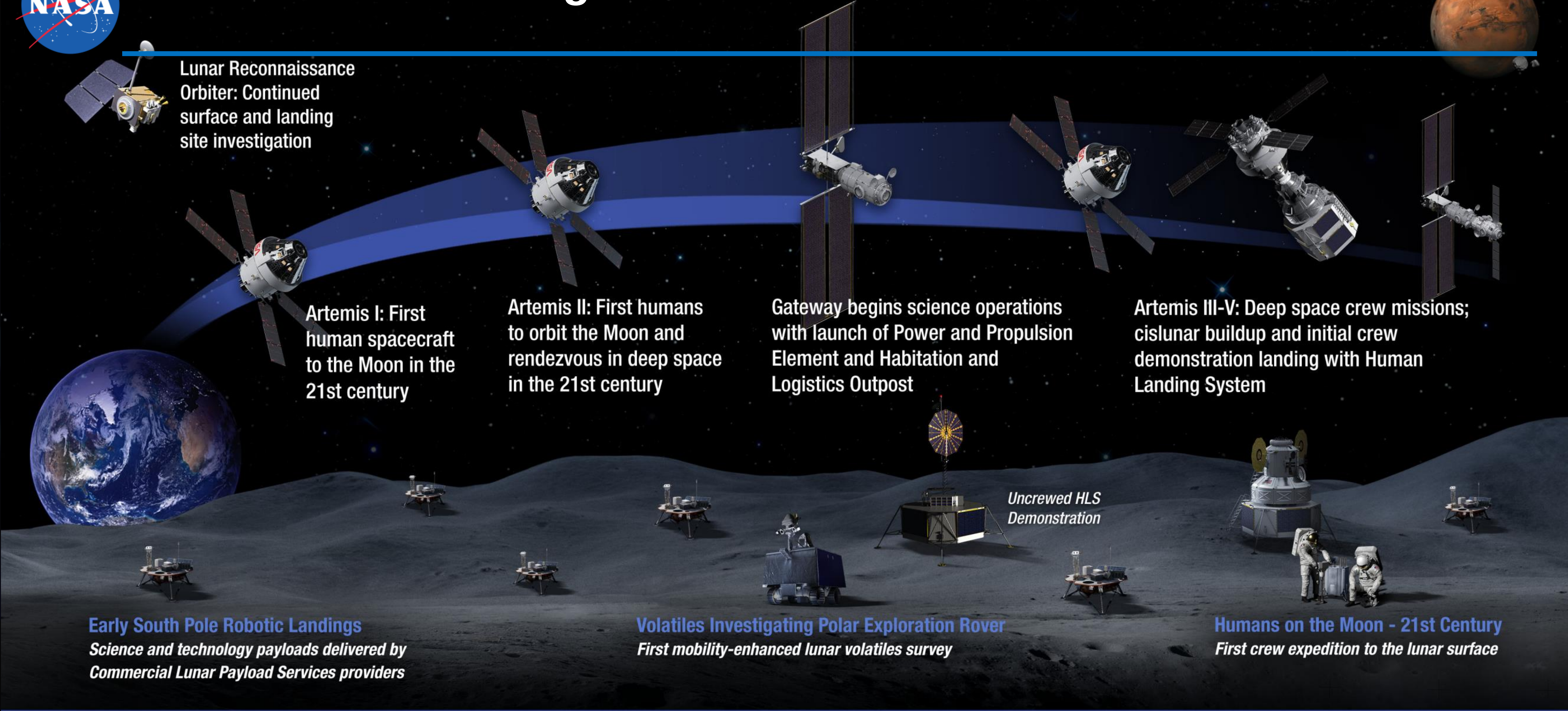
# Launch uncertainty depends a lot on mission risk posture




Notional relationship between mission risk posture, level of NASA oversight and NASA's accountability for mission success

- Many factors are at play when considering mission risk posture (e.g. use of flight heritage systems; new technology development; industry's risk of losing future business)
- Launch vehicle, spacecraft and payload can each have a different risk posture
- Understanding overall mission risk posture provides valuable insight when predicting launch dates

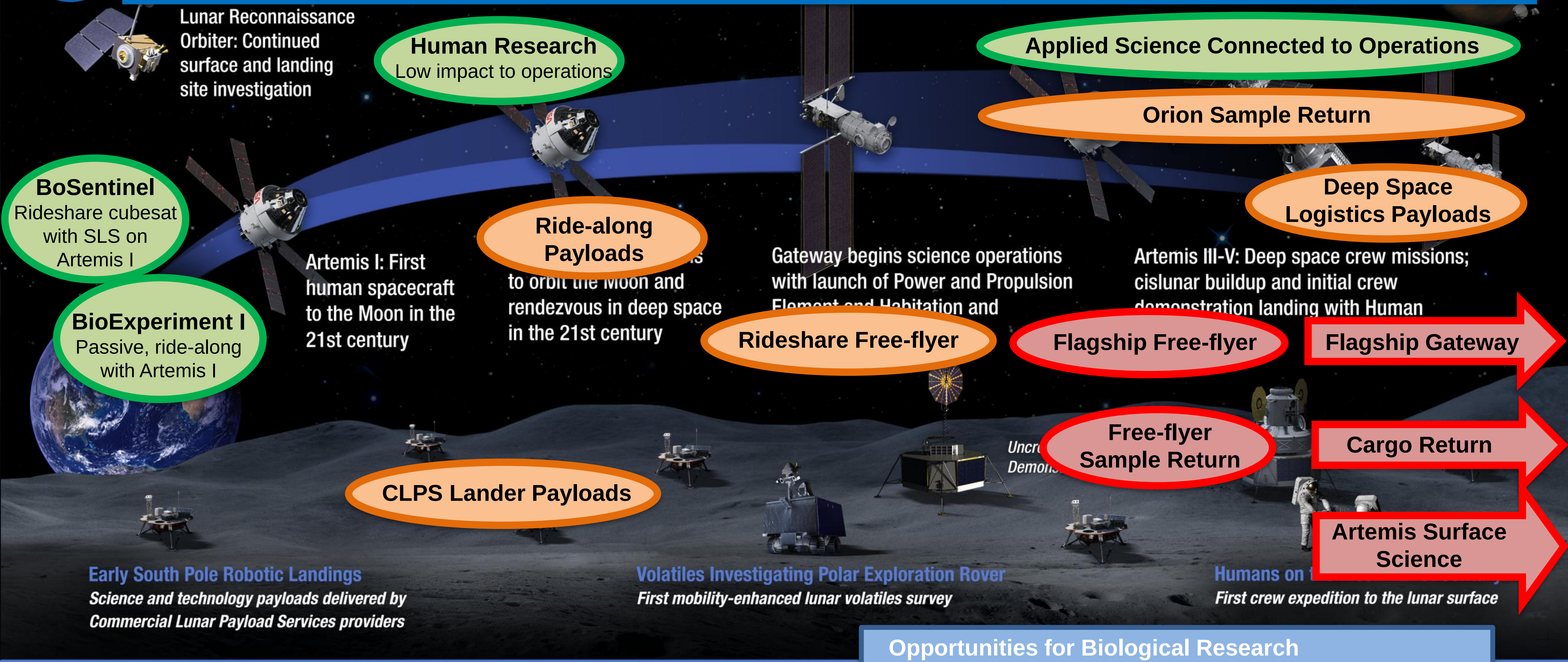
# Artemis I-V: Landing Humans On the Moon




***Lunar South Pole Target Site***

# Artemis I-V: Landing Humans On the Moon

## And Opportunities for Biological Research in Deep Space Over the Next Decade




***Lunar South Pole Target Site***

**Opportunities for Biological Research**

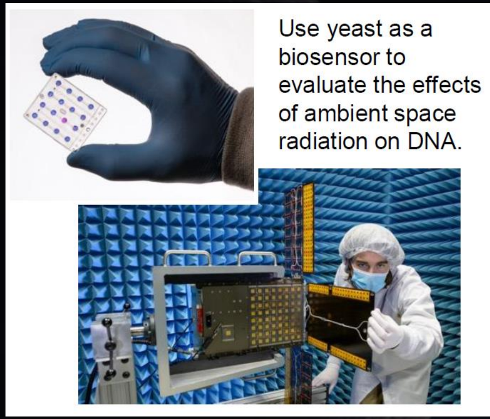
Planned | Probable | Possible

# Planned Missions Artemis I - V

# Build on LEO Science and Capabilities; Offer Collaboration with Operations

## Artemis I: Biological and Physical Sciences

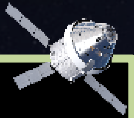
### BioSentinel




### Bio-Experiment 1


## Artemis II-IV: Human Research Program

Orion/Artemis II



1. Dry Saliva Books
2. Crew/Team Perf. Measures
3. Actigraphy

Operations Research

- Cabin imagery system
- Flywheel exercise device collaborations
- Food System Trade Study
- Microbial Monitoring
- Acceleration requirements
- Emergency $CO_2$ limits
- In-suit Nutrition Requirements

Gateway/Artemis IV

1. Crew/Team Perf Measures
2. Actigraphy, Cognition, Sleep Questionnaires
3. Dry Saliva Books
4. Blood Analysis (TBD)
5. Ultrasound
6. Pharm Samples
7. Ophthalmic Measurements
8. IN-SITU (ESA/ASI led)
9. Thermosensor (ESA/DLR led)
10. TIME (ESA led)
11. EveryWear application (ESA/CNES led)

## Planned Payloads Offer Insight for the Future

- **Non-interference with Primary Artemis Mission**: payloads are small and don't need a lot of upmass that could compete with other, higher priority, flight hardware needed for Artemis
- **Low/No Mission Resources Required**: payloads don't require power or data connections and only use crew in an unobtrusive way as part of their normal operational workload
- **In-Situ Data Collection/Almost No Downmass:** science data is collected in space and transmitted to Earth; downmass on Orion is very limited
- **Years in the making**: new science on new vehicles with new payload hardware has taken years to integrate with a new Artemis program

**Artemis Goal for HRP**: advance knowledge to support safe, productive human space travel, and perform systems testing to reduce risks for future human exploration

## Probable Missions Artemis II - V

## Offer a continuation of current/planned science and mission capabilities:

- **Ride-along Payloads:** a limited number of payloads, similar in size, scope and capabilities with Bio-Experiment 1 and/or HRP Early Artemis Mission Payloads are expected on each Orion flight; BPS and HRP are actively engaged in science definition and flight manifest for these payloads
- **CLPS Lander Payloads:** BPS is engaged in science and flight payload mission definition and development for future CLPS landers (LEIA and PRISM solicitations)
- **Rideshare Free-flyer:** smallsat/cubesat mission(s) that take advantage of heritage flight hardware (such as BioSentinel) are being considered by BPS for Beyond LEO Free-flyer Platforms including rideshare opportunities with SLS or with other commercial NASA launches such as LSP
- **Orion Sample Return**: science payloads on Orion, Gateway and early HLS landers only have a small amount of downmass available on Orion which will focus primarily on return of lunar surface samples during early Artemis missions

If they are to fly in the next decade, these mission opportunities will be reliant on heritage flight hardware/methods and subject to similar mission constraints as those that are currently planned

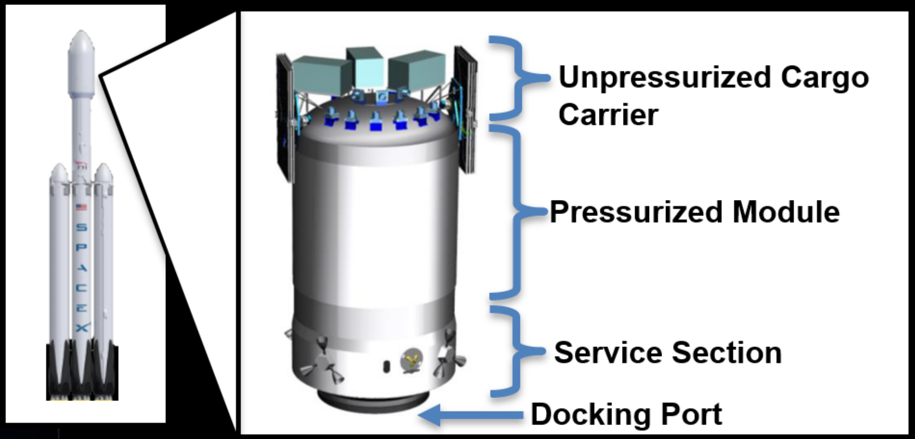
- Non-interference with primary Artemis mission
- In-Situ Data Collection/Almost No Downmass
- Low/No mission resources required
- Years needed to develop and integrate new science and flight hardware capabilities

# Probable Missions Artemis IV – V

# Opportunities for Deep Space Logistics Payloads

Launch Vehicle: Falcon Heavy
Space Vehicle: Dragon XL

## SPACEX System Overview




- SpaceX selected as the first U.S. commercial provider under the Deep Space Logistics Services contract to deliver cargo, experiments, and other supplies to the agency's Gateway in lunar orbit

- Multiple supply missions planned in which the cargo spacecraft will stay at the Gateway for six to 12 months at a time
  - Cargo and Payload Delivery
  - Trash removal
  - Automated RPOD (docking/undocking)

| System Performance to NRHO | |
|---|---|
| Total Cargo Delivery | **> 5,000 kg** |
| Unpressurized Cargo Delivery | **> 1,000 kg** |
| Total Pressurized Volume | **> 50 m³** |
| Volume Available for Unpress. Cargo | **> 14 m³** |
| Late Load for Press. Cargo | **< L-7 days** |
| Payload Power | **≥ 1.8 kW** |
| Payload up/downlink | **Once per day** |
| Payload Interfaces: **Gateway and ISS Heritage Compatibility** | |

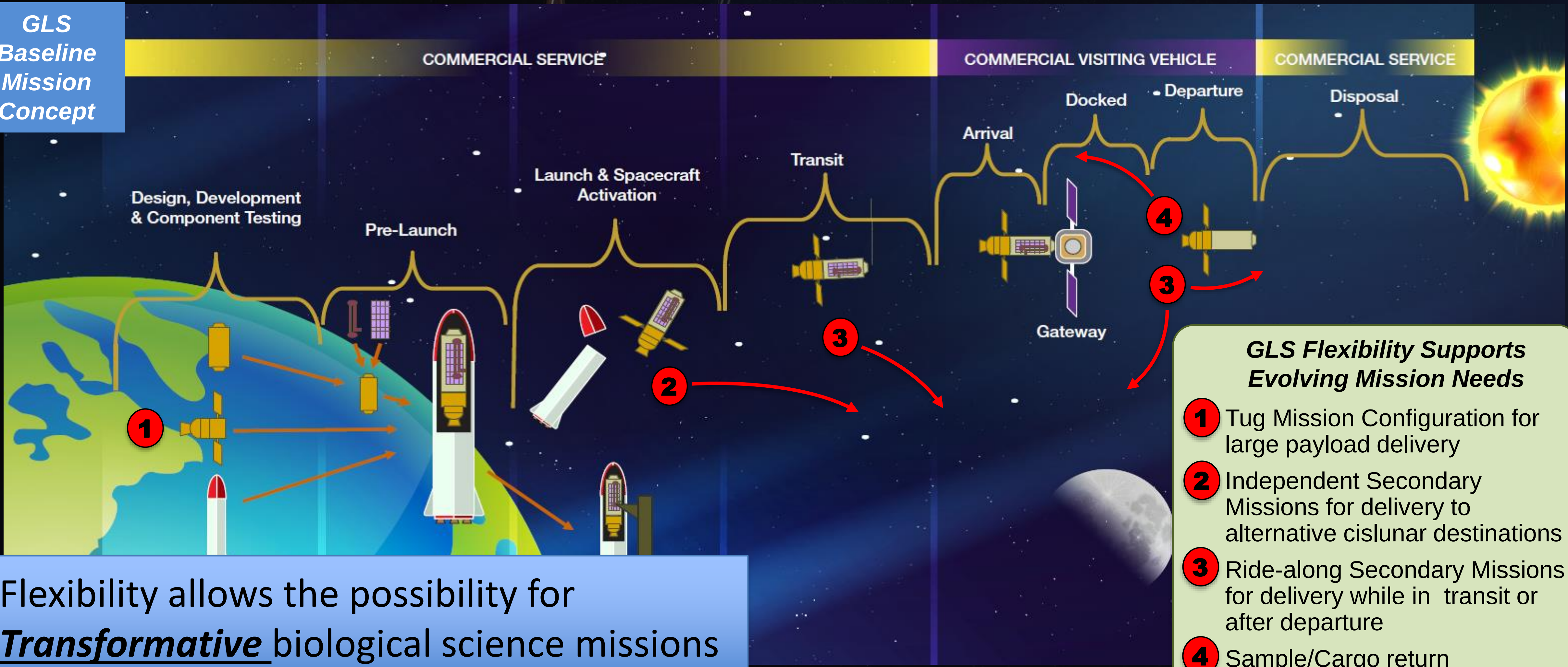
Probable Missions
Artemis IV – V

# Opportunities for Deep Space Logistics Payloads

- **DSL missions will have significant science payload capabilities available**
  - External payloads may be compatible with CSA EVR system, for transfer to Gateway, or permanently mounted on the Logistics Vehicle
  - During transit, payloads may be powered or passive, hard-mounted or soft-stowed
  - After docking, payloads may be transferred to Gateway or remain on the Logistics Vehicle
  - Remote operation, uplink and downlink are available for payloads during transit and while docked during crewed and uncrewed periods
  - Payloads may operate on the Logistics Vehicle after departure, which may include secondary mission(s) to other destination(s)
- **Opportunities for DSL science payloads are expected to be limited for early missions**
  - Some “Utilization” upmass will be planned for each mission; but the amount is highly dependent on other operational needs that will take priority for Boots on the Moon
  - Crew time for tending to science will be limited and highly dependent on other needs that take priority for Boots on the Moon

# Deep Space Logistics has a Flexible Delivery Architecture to Meet Evolving Gateway and Artemis Mission Needs

***GLS Baseline Mission Concept***




Flexibility allows the possibility for ***<u>Transformative</u>*** biological science missions in deep space over the next decade

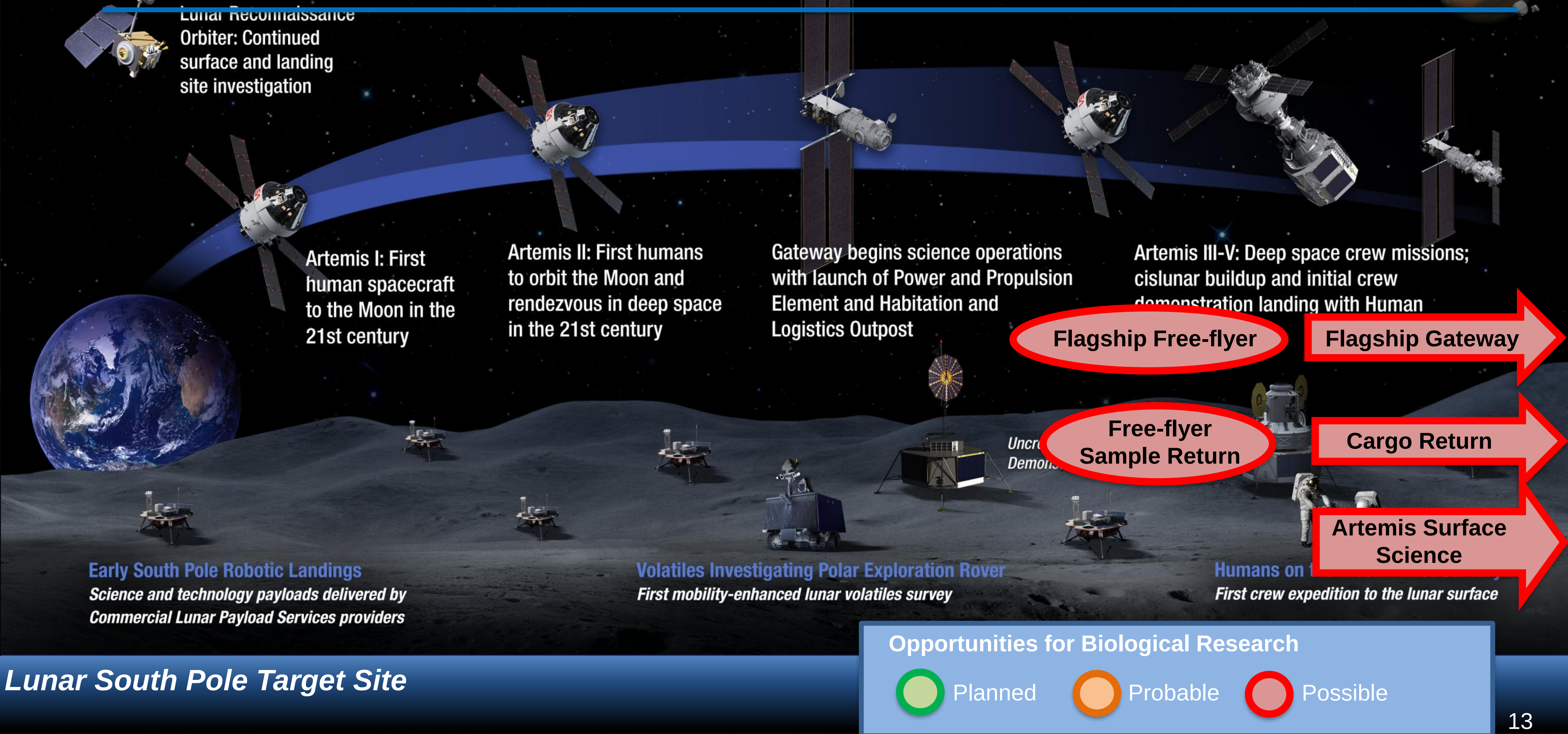
***GLS Flexibility Supports Evolving Mission Needs***

1. Tug Mission Configuration for large payload delivery
2. Independent Secondary Missions for delivery to alternative cislunar destinations
3. Ride-along Secondary Missions for delivery while in transit or after departure
4. Sample/Cargo return

# Possible Missions Artemis IV and out

# Artemis: Landing Humans On the Moon

## Opportunities for ***Transformative*** Biological Science in Deep Space




**Opportunities for Biological Research**

Planned Probable Possible

# Past Examples of Transformative Biological Science in Space:

Flagship missions with big science goals and big mission commitments (mostly)

## Free-flyers

### Biosatellite (1967-69)

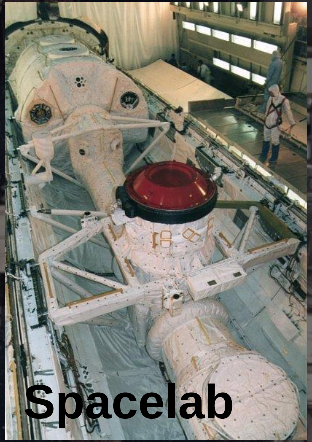
Three missions (1967-69) dedicated to biological research in LEO, ranging from 8-30 days

### Bion M-1 & M-2 (2013 & 2022)

Collaborative Missions with the Russian Space Agency and the Russian Institute for Biomedical Problems (IMBP). Bion M-1 flew in 2013 and M-2 is planned for 2022. Teams of US scientists work with IMBP scientists

## Shuttle

### Neurolab (1998)

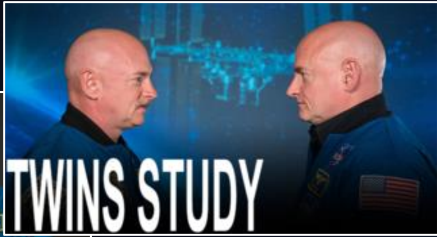



Two-week mission (STS-90) with the ESA Spacelab, dedicated to microgravity research of the nervous system. Involved 26 experiments, teams of scientists and international cooperation with Europe, Japan, and Canada.

## ISS

### GeneLab (2013- )

Open Science for Life in Space. Data repository includes over 350 omics-focused data sets from multiple spaceflight and related ground-based research.


(2015-16)

Astronaut Scott Kelly and Cosmonaut Mikhail Kornienko performed collaborative investigations using Standard Measures in space, while Scott's twin brother, Mark, participated in omics-focused research to evaluate changes between ground and flight

### Veg-01 (2015)

Astronauts eat lettuce grown in space. Veggie 01 experiment: opening a new avenue of plant research in space

# Benefits and Challenges for Flagship and Missions Of Opportunity (MOO)

| | Flagship Mission | | Mission of Opportunity |
|---|---|---|---|
| **Benefits** | • High mission momentum<br>• High visibility inside NASA and out<br>• High control as primary mission<br>• High participation<br>• High science impact<br>• High potential for partnerships to leverage investment | | • Adaptable to changing mission<br>• Rapid readiness<br>• Low impact to primary mission (power, mass, volume, crew time, integration…)<br>• Affordable cost |
| | | | |
| **Challenges** | • High cost<br>• Long lead time<br>• High complexity & Management | | • Dependence on primary mission<br>• Low priority to primary mission<br>• Potential long wait time to execute |

# Possible Missions Artemis IV and out

# Deep Space Free-flyers

## Free-flyer and Reentry Capabilities Have Matured Over the Last Decade

Commercial Cargo & Crew for ISS

DRAGON
CREW & CARGO

STARLINER

DREAMCHASER

- Returning >1 mt payload/mission
- Reentry at 7.6 km/sec

Deep Space Return

STARDUST
OSIRIS-REX (2023)

GENESIS

ORION

- Returning samples and crew
- Reentry at 11+ km/sec

Government-funded and Commercially-developed Systems can be adapted to support dedicated BPS mission objectives

**Flagship Free-flyer**

**A Deep Space Flagship Free-flyer Mission is possible for Biological Science within the next Decade**

- Single orbit, similar to Artemis I-II
- 2-4 week duration
- DSL is an option to provide

**Free-flyer Sample Return**

**Sample return from Gateway to augment Orion is possible for Biological Science within the next Decade**

- Small/Medium class satellite
- Delivery to Gateway with DSL
- Return to Earth as a free-flyer

Free-flyer missions in the coming decade will set up capabilities for larger Artemis cargo return missions in the next decade

**Cargo Return**

Free-flyer Sample Return

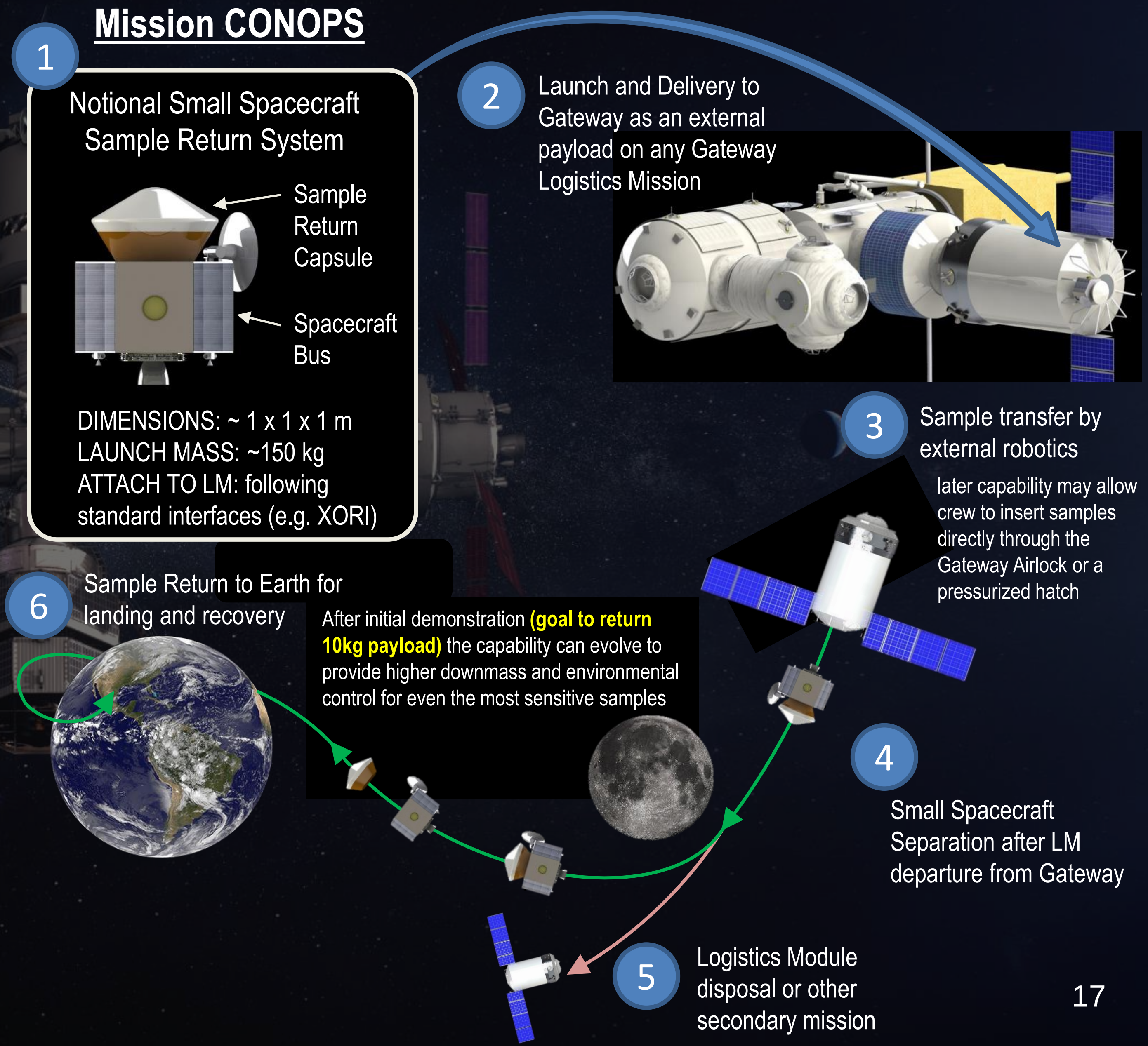
# Small Spacecraft Sample Return Concept to Enhance Gateway Utilization

**Deep Space Logistics Gap for Gateway Sample Return:** samples returned from Artemis missions will have very high science & technology value, but sample return from Gateway will be no more than 100 kg on Orion (in contrast to thousands of kg returned from ISS each year)

**Near-term Mission Solution**: as Gateway operations develop and integrate with Lunar surface and CisLunar activities, small spacecraft sample return can significantly advance scientific research & technology development and provide additional returned mass capability

**Deep Space Logistics (KSC) and NASA Ames:** are partnered to explore on-demand sample return capability, and develop a plan to demonstrate and evolve Gateway sample return, engaging government and commercial partners, with the goals to

1) accelerate cis-Lunar commerce development,
2) increase downmass opportunities and
3) **lower the cost ($/returned kg)** of bringing back valuable science and technology payloads from deep space



# Gateway Sample Return: Possible Use Cases

- LUNAR SURFACE: return lunar regolith samples for scientific analysis on Earth. Temperature control would allow for return of samples containing volatile compounds. Synergy with robotic-based exploration at sites away from Artemis Base Camp (presumably the Lunar South Pole).

- PHYSICAL SCIENCES: return material samples that have been exposed to the deep space environment which advance exploration technology and future long-term missions into deep space (e.g- MISSE). In-space manufacturing, fluid physics, combustion, and dust mitigation could significantly benefit.

- HUMAN RESEARCH: return stabilized samples from crew or other model systems to understand and help mitigate the long-term effects of deep space exploration on the human body (synergistic effects of radiation, microgravity, loads, etc.). Temperature control will be necessary. Ability to maintain frozen samples would be exceptionally valuable.

- SPACE BIOLOGY: return stabilized samples from microbiology, cell, plant or animal research for high-throughput “omics” analysis. Temperature control will be necessary and would allow live & stabilized samples to be returned. Ability to maintain frozen samples would be exceptionally valuable.

PREPARATION FOR BASE CAMP

ROBOTIC EXPLORATION

LONG TERM EXPOSURE


IN-SPACE MANUFACTURING

HUMAN RESEARCH-
Develop best methods and technologies to support safe, productive human space travel using Gateway as a Mars Transit analogue.

BIOLOGICAL SCIENCE- crew health monitoring, detailed investigations of cosmic conditions on astronauts and other organisms. Detailed ‘OMICS’ research to develop therapies and mitigations to long-term human exploration of deep space.

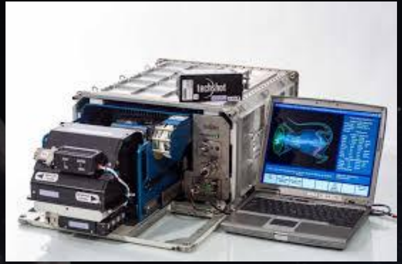
# Possible Missions Beyond the Decade

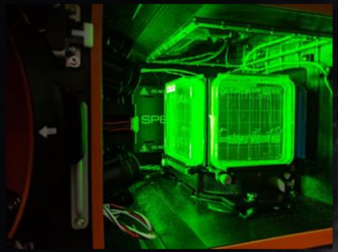
# Flagship Gateway and Artemis Surface Science

Opportunities for ***Transformative*** Biological Science in Deep Space

Flagship Gateway

## Flagship Gateway Science



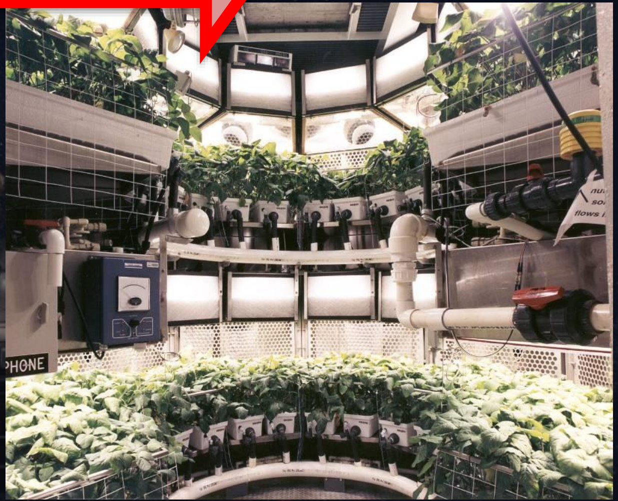



*Habitats & analytical tools for research*

Development of payloads, facilities and equipment to support dedicated science missions at the ***Gateway or Lunar surface***

Artemis Surface Science

## Growing Plants on the Moon



Develop a dedicated plant growth facility on the lunar surface as a future part of the ***Artemis Base Camp***

Flight hardware development and precursor science is required in the coming decade to lay the enabling groundwork for ***Transformative*** BPS missions in the decade beyond

# Opportunities this Decade for Biological Research in Deep Space

- **Execute Missions of Opportunity:** as free-flyers, ride-shares or integrated payloads, that fly with other human and robotic explorations into deep space, including government, private, and international ventures
- **Establish a Flagship Mission(s):** to be launched near the end of this decade or early in the next, that will be dedicated to transformational science in deep space, and benefit from the advantages a flagship mission can contribute to other NASA missions (e.g. Artemis)
- **Leverage and Collaborate:** with the Human Research Program and other NASA Programs that share objectives with Biological sciences to increase flight opportunities, leverage existing/heritage flight hardware, and share in the successes that biological research in deep space will bring to those Programs
- **Amplify the Impact of Limited Flight Opportunities:** with science teaming arrangements, bio-specimen sharing and open science to maximize participation and science return on investment
- **Don’t Wait, Develop Now:** it takes years, not months, to advocate for and establish flight opportunities and, in parallel, to develop and integrate biological science into robust and heavily automated flight hardware for highly-constrained, near-term, deep space missions. Science and flight systems developed in the coming decade will lay the groundwork for transformational science and missions beyond

# Questions

## References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