



The ISECG* Global Exploration Roadmap as Context for Robotic and Human Exploration Operations

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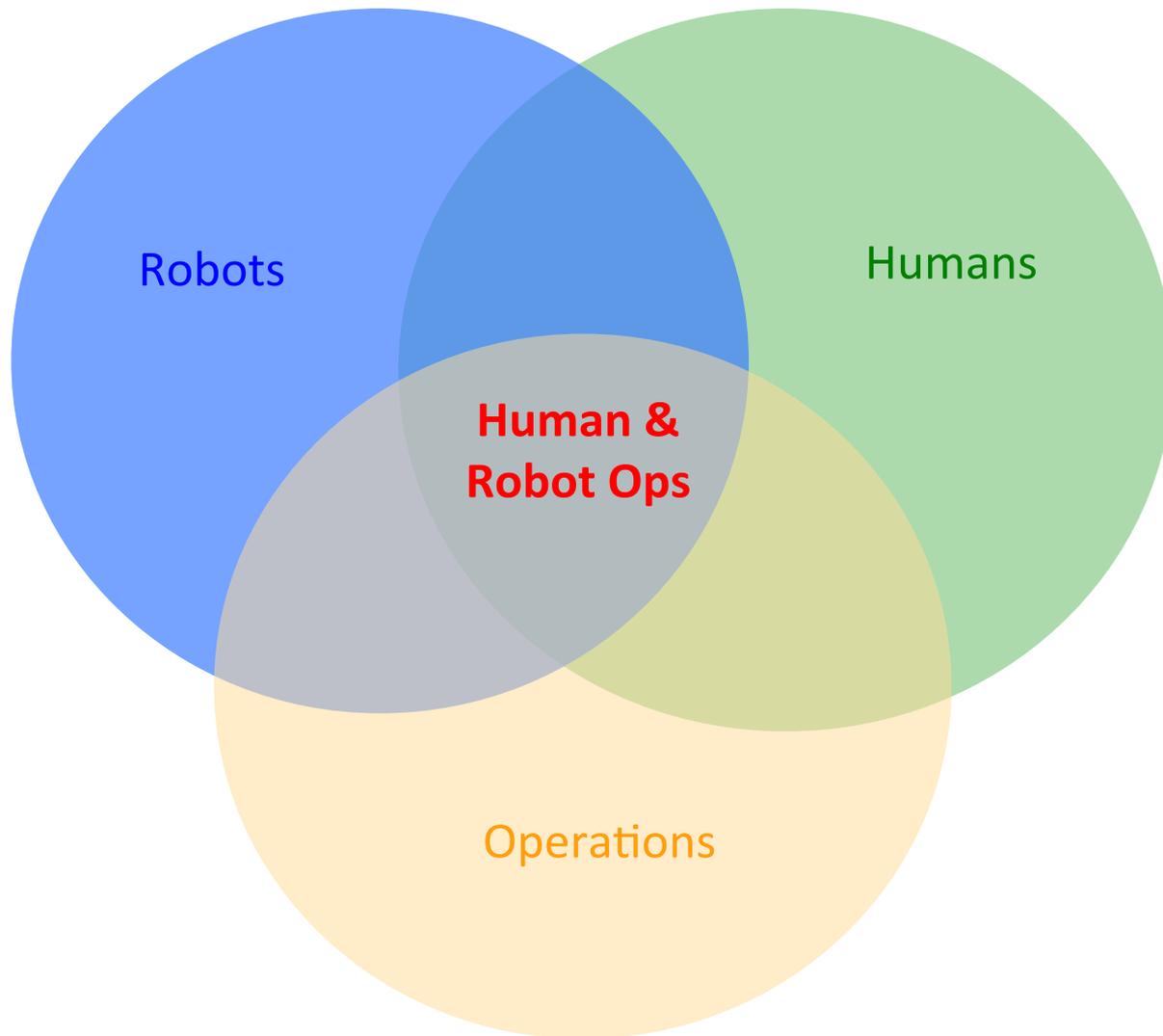
* ISECG = International Space Exploration Coordination Group



Presentation Overview

- Focus Areas
- Global Exploration Roadmap (GER) Overview
- Robotic & Human Operational Challenges and Associated Activities

General Area of Focus Within Context of GER





Areas of Focus

The following areas relate to the GER and reflect opportunities to work on how robotic and human operations enable each other:

- 1. Leveraging the International Space Station**
- 2. Planetary science robotic missions to potential human destinations**
- 3. Micro-g body proximity operations (e.g. asteroids)**
- 4. Autonomous operations**
- 5. High and low-latency telerobotics**
- 6. Human-assisted sample return**
- 7. Contamination control**

* Information System Architecting

- Big data
- ...



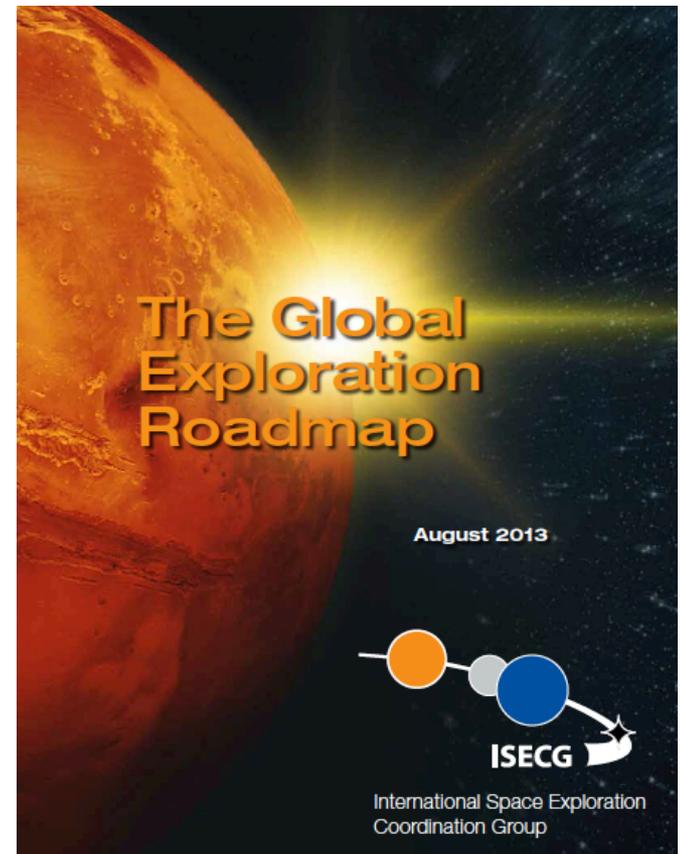
Global Exploration Roadmap (GER) Overview

Global Exploration Roadmap Overview

Introduction to the Global Exploration Roadmap

- **International Space Exploration Coordination Group**
 - Established 2007 after release of Global Exploration Strategy
 - 12 space agencies share exploration objectives and plans and advance concepts of mutual interest
 - The first iteration of the Global Exploration Roadmap (GER) was released by ISECG in September 2011
 - Second iteration in August 2013
- **Non-binding reference for agencies**
 - Informs stakeholder consultation
 - Informs near-term decisions

* *The GER reflects the international effort to collaboratively define technically feasible and programmatically implementable exploration mission scenarios with the common goal of humans on the surface of Mars*





Driving Principles

Principles Driving the Mission Scenario:

Affordability – Take into account budget constraints

Affordability of a complex exploration programme must be maintained over extended periods of time. Cost must be a consideration when formulating programmes and throughout programme execution. Innovations and integration of advanced technologies must be driven by the goal to reduce costs. Each agency's planned contributions must accommodate realistic expectations regarding cost and the future availability of funding.

Exploration Value – Generate public benefits and meet exploration objectives

Sustainable human space exploration must respond to exploration goals and objectives and deliver value to the public as well as to participating stakeholder communities, beginning early in the process and continuing throughout the journey.

International Partnerships – Provide early and sustained opportunities for diverse partners

Broad international cooperation is not only critical for enabling increasingly complex exploration missions, but also an important contributor to achieving exploration value. Mission scenarios must build on the competencies and long-term interests of each agency, large or small, allowing each to sustain and grow its aspirations for space exploration. Collaborations will be established at all levels (missions, capabilities, technologies), with various levels of interdependency among the partners. These collaborations should be set up to ensure resiliency of the programme against failures, delays or programmatic issues. In addition, opportunities for new partners should be available to strengthen robustness of the overall partnership.

Capability Evolution – Execute missions of increasing complexity based on the stepwise development of capabilities

Sustainable human exploration beyond low-Earth orbit, toward the long-term goal of human missions to Mars, requires building upon existing capabilities and competencies, increasing performance with each step. New technologies should be pursued and applied to address challenges. Exploration mission challenges necessitate advancing and demonstrating critical capabilities to manage risk.

Human/Robotic Partnership – Maximize synergy between human and robotic missions

Combine the unique and complementary capabilities of humans and robotic systems, enabling a greater set of goals to be met effectively, cost-efficiently and safely. Robotic precursor missions will prepare for human missions by acquiring strategic knowledge about future destinations and demonstrating critical technologies. Use of robots to assist and complement crew activities will also enhance the productivity and benefits of eventual human exploration missions to any given destination.

Robustness – Provide for resilience to programmatic and technical challenges

A robust human space exploration programme will have sufficient flexibility to cope with unplanned changes or crisis situations, whether they are due to catastrophic events, changes in the partnership structure, adjustments in available funding or evolution of the exploration goals and objectives. To achieve robustness, dissimilar redundancies of critical functions should be applied early, where practicable.

Common GER Goals

1. Search for Life
2. Extend Human Presence
3. Perform Space, Earth, and Applied Science
4. Perform Science to Support Human Exploration
5. Develop Exploration Technologies and Capabilities
6. Stimulate Economic Expansion
7. Enhance Earth Safety
8. Engage the Public in Exploration

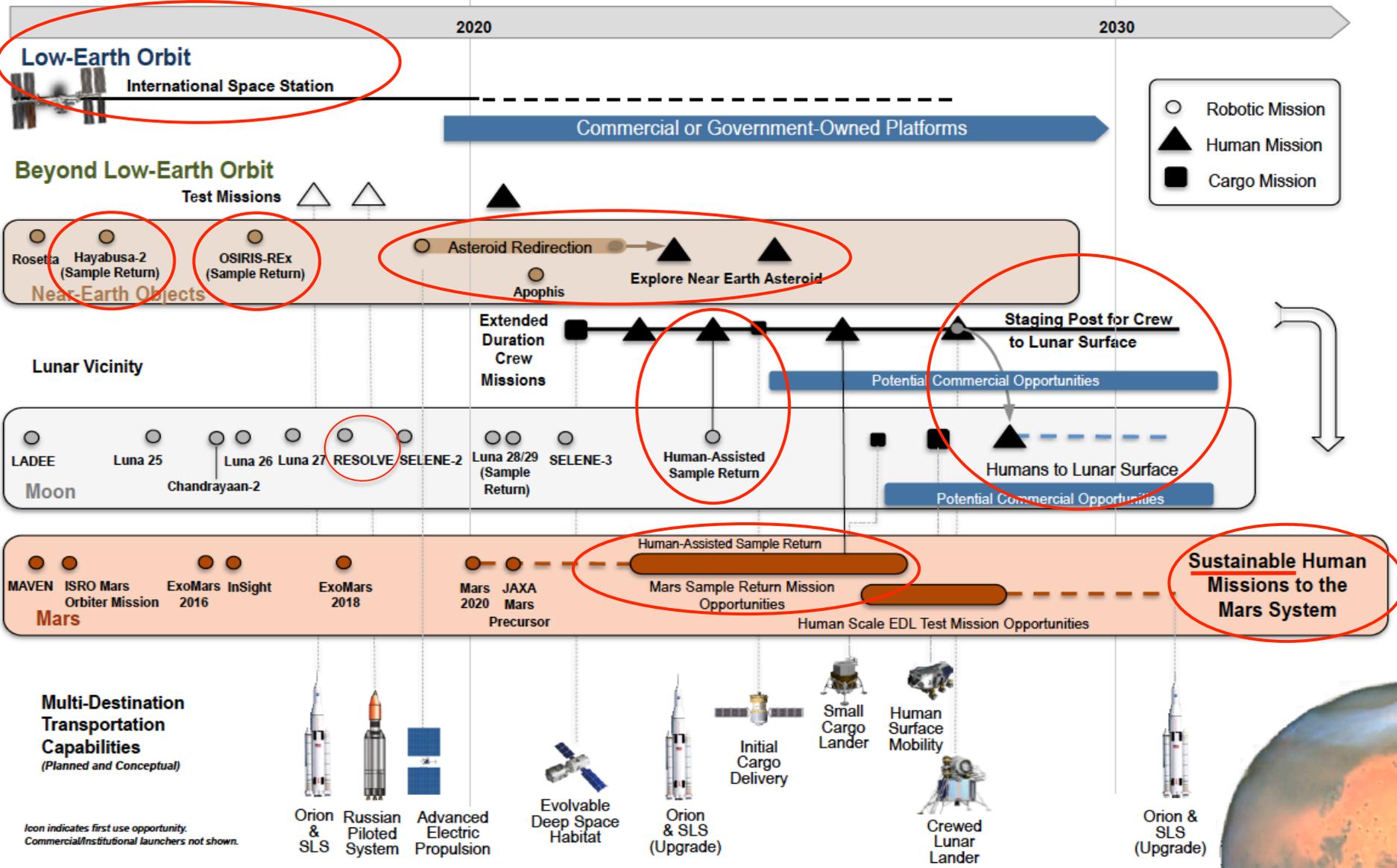


GER Goals & Objects

Goal	Objective
Search for Life	✓ Find evidence of past or present life.
	✓ Explore the past or present potential of solar system destinations to sustain life.
Extend Human Presence	Explore new destinations.
	Increase opportunities for astronauts from all partner countries to engage in exploration.
	✓ Increase the self-sufficiency of humans in space.
Develop Exploration Technologies and Capabilities	Test countermeasures and techniques to maintain crew health and performance, and radiation mitigation technologies and strategies.
	Demonstrate and test power generation and storage systems.
	✓ Develop and test high-performance mobility, extravehicular activity, life support, and habitation capabilities.
	✓ Demonstrate the use of robots to explore autonomously and to supplement astronauts' exploration activities.
	Develop and validate tools, technologies, and systems that extract, process, and utilize resources to enable exploration missions.
	Demonstrate launch and advanced in-space propulsion capabilities.
	Develop thermal management systems, including cryogenic fluid management capabilities.
	✓ Learn how to best perform basic working tasks and develop protocols for operations.
	Test and demonstrate advanced entry-decent-landing technologies.
	✓ Test automated rendezvous and docking, on-orbit assembly, and satellite servicing capabilities.
	✓ Develop and demonstrate technologies to support scientific investigation.
	✓ Develop space communications and navigation capabilities.
Perform Science to Support Human Exploration	Evaluate human health in the space environment.
	Monitor and predict radiation in the space environment.
	✓ Characterize the geology, topography, and conditions at destinations.
	✓ Characterize available resources at destinations.
	✓ Evaluate the impacts of the surface, near-surface, and atmospheric environment on exploration systems.
Stimulate Economic Expansion	✓ Provide opportunities for the integration of commercial transportation elements into the exploration architecture.
	✓ Provide opportunities for the integration of commercial surface and orbital elements into the exploration architecture.
	✓ Evaluate potential for commercial goods and services at destinations, including markets for discovered resources.
Perform Space, Earth, and Applied Science	Perform Earth observation, heliophysics, and astrophysics from space.
	Gather scientific knowledge of destinations.
	Gather scientific knowledge of solar system evolution.
	Perform applied research.
Engage the Public in Exploration	✓ Use interactive hands-on communications tools to provide virtual experiences using real and live exploration data.
	✓ Enlist amateur/citizen scientists to contribute to exploration-related knowledge collection.
Enhance Earth Safety	✓ Characterize potential near-Earth asteroid collision threats.
	✓ Test techniques to mitigate the risk of asteroid collisions with Earth.
	Manage orbital debris around the Earth.

ISECG Mission Scenario

ISECG Mission Scenario





Near-Term Opportunities for Cooperation

- **International coordination areas have been identified**
 - Use of ISS for Exploration
 - Space Systems and Infrastructure Development
 - Robotic Precursor Missions
 - Advanced Technologies
 - Analog Activities
 - Human Health and Performance Risk Mitigation

Operational Challenges & Associated Activities

1. Leveraging ISS

➤ Key Ops Challenge

- Achieving sufficient operational test fidelity for useful feed-forward results

➤ Activities

- Long durations
 - Year long study underway
 - Twin studies
 - ...
- Carefully mimic mission scenario details
 - Crew autonomy tests underway
 - Low-latency teleoperations (e.g. LLT science from ISS to ground)
 - ...
- ...



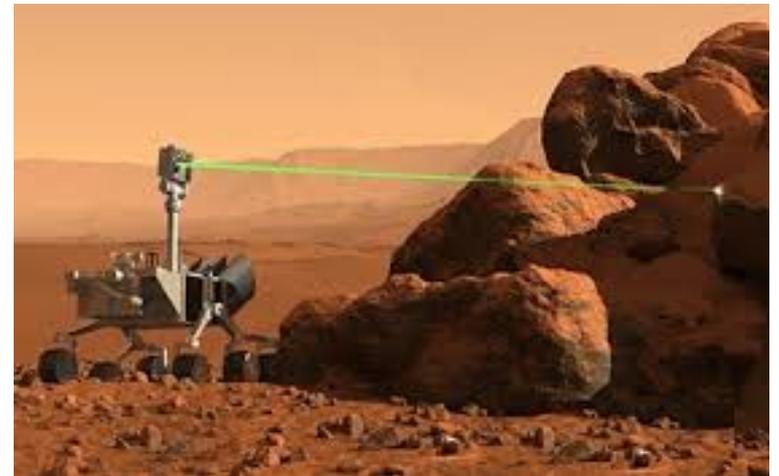
2. Planetary Science Missions

➤ Key Ops Challenges

- Sample acquisition
- Sample quantity & density
- Sample integrity & quality

➤ Activities

- Asteroid Ops
 - Osiris-Rex
 - Asteroid Redirection Mission
- Lunar Ops
 - RESOLVE
 - Low-latency teleoperations
 - Human-Assisted Sample Return
- Mars Ops
 - Low-latency teleoperations
 - Human-Assisted Sample Return



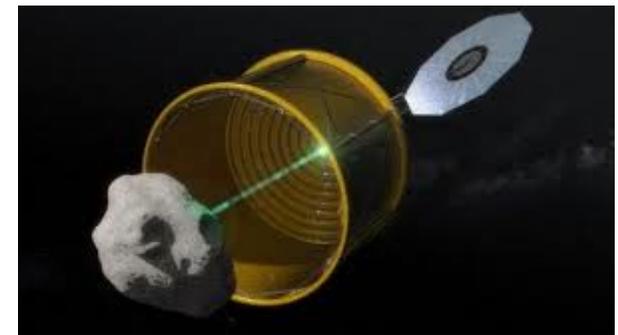
3. Micro-g Proximity Operations

➤ Key Ops Challenges

- Navigation near small body
- Dust
- Unknown body composition and regolith dynamics

➤ Activities

- Asteroid Ops
 - Osiris-Rex
 - Asteroid Redirection
 - Low-latency teleops
- Mars Moons
 - Phobos robotic precursor
 - Low-latency teleoperations – “stand off prox ops”
 - ...
- ...



4. Autonomous Operations

➤ Key Ops Challenges

- Operational confidence in robotic and other assets
- Crew autonomy
 - Effective quick decision-making
 - Science ops
 - Scheduling

➤ Activities

- ISS
- Asteroid Ops
 - Asteroid Redirection
- Lunar Ops
 - Far-side ops
 - Low-latency teleoperations

* *Need to create high fidelity autonomy tests*



5. Teleoperations

➤ Key Ops Challenges

- Manipulation
- Balance between autonomy and crew control
- Balance between high and low latency (e.g. Earth vs. Mars vicinity)
- Rapid teleops
 - Dynamic science (e.g. atmospheric, biology)

➤ Activities

- ISS tests to ground – e.g. LLT science
- Asteroid Ops
 - LLT stand-off prox ops at redirected asteroid
- Lunar Ops
 - LLT of sample search and acquisition for
 - LLT of RESOLVE follow-on for ISRU?
 - Landing site recon and prep
- Mars
 - Landing site recon & prep
 - ISRU and refuel
 - LLT science – could address planetary protection concerns



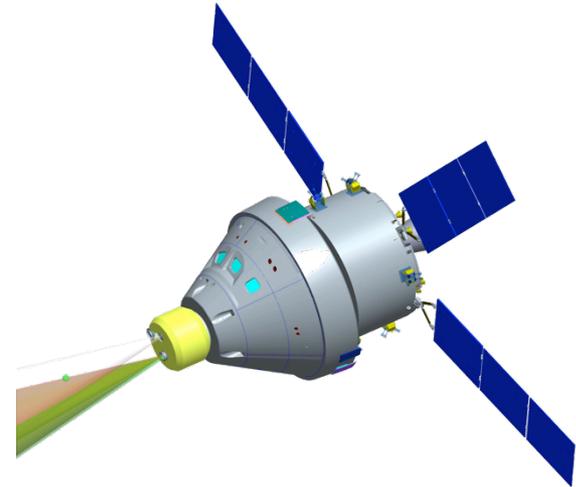
6. Human-Assisted Sample Return

➤ Key Ops Challenges

- In-space acquisition
- Sample integrity and containment
- Crew safety

➤ Activities

- Lunar Ops
 - Lunar sample acquisition in free space (pre-delivered by other party)
 - Lunar farside LLT sample acquisition on surface and pick-up in free space
 - Sample containment assurance
- Mars Ops
 - Cis-lunar free space acquisition
 - Mars orbit sample acquisition
 - LLT surface sample acquisition followed by Mars orbit pick up



7. Contamination Control

➤ Key Ops Challenges

- Crew biohazards
- Forward contamination
- Back contamination

➤ Activities

- ISS tests
 - Vent sampling underway
- Analog testing
 - Arctic soil sampling for microbial dispersal underway
- Low-latency teleops from sufficient distance for special regions
- Human-assisted lunar sample can test protocols for Mars sample and crew return to earth

