Knowledge Gaps for Biological Planetary Protection for Crewed Missions to the Moon and Mars

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Crewed Exploration Planetary Protection Comparison: Moon vs Mars

Moon

COSPAR Assessment: "of significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote chance that contamination carried by a spacecraft could compromise future investigations."

Categorization (Outbound):
II/IIa/IIb

Implication:
- Documentation

Categorization (Return):
V(unrestricted)

Implication:
- No further constraints

Mars

COSPAR Assessment: "a target body of chemical evolution and/or origin of life interest and for which scientific opinion provides a significant chance of contamination which could compromise future investigations."

Categorization (Outbound):
III/IVa/IVb/IVc

Implication:
- Documentation
- Avoidance of Impact and/or Cleanliness Requirements

Categorization (Return):
V(restricted)

Implication:
- Documentation
- Rigorous containment of unsterilized material to protect Earth's biosphere
- Quarantine of crew

Current COSPAR Policy: Human Exploration Planetary Protection Guidelines (Excerpts)

Specific implementation guidelines for human missions to Mars include:

- Human missions will carry microbial populations that will vary in both kind and quantity, and it will not be practicable to specify all aspects of an allowable microbial population or potential contaminants at launch. Once any baseline conditions for launch are established and met, continued monitoring and evaluation of microbes carried by human missions will be required to address both forward and backward contamination concerns.

- A quarantine capability for both the entire crew and for individual crew-members shall be provided during and after the mission, in case potential contact with a Martian life-form occurs.

- A comprehensive planetary protection protocol for human missions should be developed that encompasses both forward and backward contamination concerns and addresses the combined human and robotic aspects of the mission, including subsurface exploration, sample handling, and the return of the samples and crew to Earth.

Current COSPAR Policy: Human Exploration Planetary Protection Guidelines (Excerpts)

Specific implementation guidelines for human missions to Mars include:

- Neither robotic systems nor human activities should contaminate "Special Regions" on Mars, as defined by this COSPAR policy.
- Any uncharacterized Martian site should be evaluated by robotic precursors prior to crew access. Information may be obtained by either precursor robotic missions or a robotic component on a human mission. (see also the US NRC recommendations given in the 2002 Safe on Mars report: http://www.nap.edu/books/0309084261/html/)
- Any pristine samples or sampling components from any uncharacterized sites or Special Regions on Mars should be treated according to current planetary protection category V, restricted Earth return, with the proper handling and testing protocols.
- An onboard crewmember should be given primary responsibility for the implementation of planetary protection provisions affecting the crew during the mission.
- Planetary protection requirements for initial human missions should be based on a conservative approach consistent with a lack of knowledge of Martian environments and possible life, as well as the performance of human support systems in those environments. Planetary protection requirements for later missions should not be relaxed without scientific review, justification, and consensus.

Path to Closing Knowledge Gaps and Establishing PP Requirements

Workshops Timeline

2015	2016	2018	2018 & beyond
NASA Workshop at Ames	1st COSPAR Meeting at LPI	2nd COSPAR Meeting at LPI	COSPAR Working Meeting on Contamination Transport on Mars at LPI, May 2018 COSPAR Working Meeting on Microbial Monitoring & Health at LPI, May 2019 COSPAR Working Meetings on Spacecraft Systems (virtual) May 2020 and June 2022
Identification of Planetary Protection Knowledge Gaps for human missions to Mars	Refinement and prioritization of Planetary Protection Knowledge Gaps for human missions to Mars	Mission Opportunity identification for addressing Planetary Protection Knowledge Gaps for human missions to Mars	Measurements and Payload/Operation Concepts for addressing Planetary Protection Knowledge Gaps for human missions to Mars
What Knowledge Gaps…	…in what order…	…using what missions…	…to make what measurements…

1

2

3

4,5,6

(virtual:

- initial briefing,
- waste mgmt.,
- quarantine & sample handling)

…to establish the right quantitative and implementable planetary protection requirements for safe and sustainable exploration and utilization of Mars.

Planetary Protection Knowledge Gaps for Human Mars Missions

1st COSPAR Workshop (2016)

Each Group
Analyzed & Ranked
Knowledge Gaps (**KGs**)
by
Time Priority
& Mission Criticality

	Priority/Criticality	
GROUP 1: Microbial & Human Health Monitoring	TIME	MISSION
1A. Microbial Monitoring of Environment	H	
1B. Microbial Monitoring of Humans	H	
1C. Mitigation of Microbial Growth in Spacecraft Systems	H	
1D. Operational Guidelines for PP and Crew Health	L	
GROUP 2: Technology & Operations for Contamination Control		
2A. Bioburden/Transport/Ops during Short v. Long Stays	M	M
2B. Microbial/Organic Releases from humans and support systems	H	H
2C. Protocols (Decontam/Verific/Monitor) to Remediate Releases	M	H
2D. Design of Quaratine Facilities/Methods -for different phases	L	L
2E. How do Mars Env Conditions vary over time wrt growth of Earth mcirobes	L	H
2F. Res. needed to make ISRU & PP goals compatible	M	M
2G. "acceptable contam' of wastes left behind? Constraints on vented matls.	L	L
FORMER 2H. DELETED		
2 I. Approach to Achieve 'Break the Chain" Requirements?	L	L
2J. Global Distrib/Depth of subsurf. Ice-- and evidence of Extant life?	H	H
2K. Evolution of PP Reqmets/goals from robotic to Human Missions & zones?	H	M
GROUP 3: Natural Transport of Contamination on Mars	Time/Mission	
3A. Measurements/Models for Mars atm. transport of contaminants	H	
3B. Measurements/Models for subsurf. transport of contaminants	M	
3C. Effect of Biocidal Factors on surv./growth/adapt of microbes on Mars	H	
3D. Determine Acceptable Contam. Rates & Thresholds	H	
3E. Protection Mechanisms for organisms on Mars	M	
3F. Degradation of Landed Materials by martian envmt	M	
3G. Induced Env Conditiosn around Struture?	M	
3H. Sensitivity of non-culturable spp to biocidal factors	M	

Knowledge-Based Robotic to Crewed Transition Assumptions*

- Human spaceflight hardware leaks (in nominal and off-nominal operation), so the old robotic paradigm of managing a fixed bioload is inappropriate.

- The introduction of a maintained temperate terrestrial environment at the Martian surface affords the opportunity for many more organisms (in type and quantity) to escape into the Martian environment.

- This exploration is taking place in a post-Mars Sample Return (MSR) context where Martian life was NOT (yet?) discovered at the Martian surface/shallow subsurface in returned Mars material, but we know a lot more about Mars from those samples.

- Knowledge gaps need to be understood and preferably closed before launch to protect science return and the Earth.

* Developed as ground rules for the 2020 COSPAR "4th Workshop on Refining Planetary Protection Requirements for Human Missions" – see the Conference Documents section at https://sma.nasa.gov/sma-disciplines/planetary-protection

First Human Mars Mission Concept

Illustrating the minimum suite of elements needed for a “light exploration footprint”.

TRANSIT HABITAT AND TRANSPORTATION STAGE

Supports four crew on the two to three-year mission to Mars

Two crew remain in orbit while two crew visit the Mars surface

Planetary Protection Knowledge Gaps for Human Mars Missions

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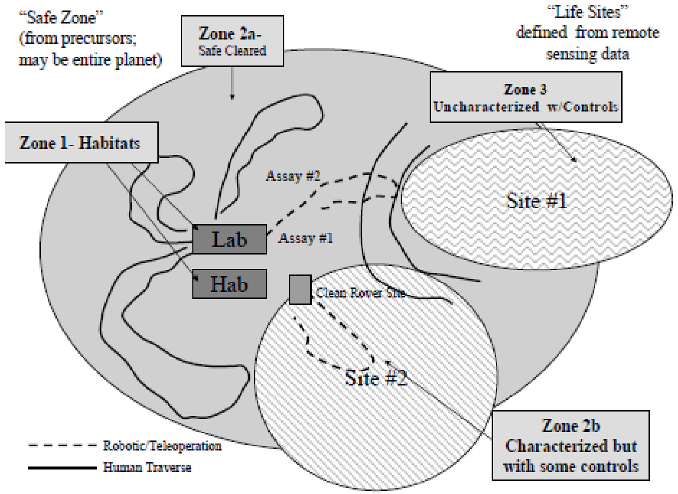
Contamination Transport – Findings & Recommendations

Knowledge about natural transport of terrestrial biological contamination (by e.g., windblown dust or ground water flow) on Mars is essential:

- to perform an informed partitioning of the Martian surface, i.e. operation zones for exploration and commercial activities, and
- to define requirements for flight systems and operation

Measurements on the surface of Mars acquiring high frequency meteorological data over at least a full Martian year at multiple fixed locations to develop, test and validate contamination transport models.

None of these measurements have been done at the necessary frequency and duration on any of the Mars surface missions in the past nor are they on any approved missions under preparation.

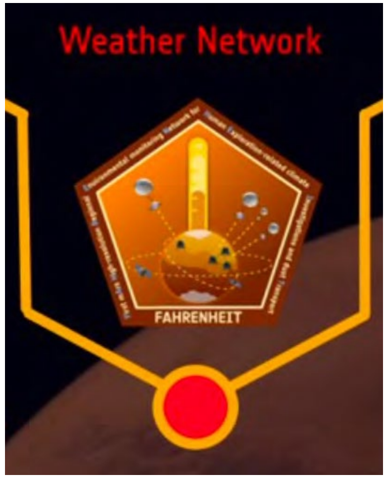


Criswell Report 2005

Prototype pressurized rover cabin

Contamination Transport - Measurements in Meteorology

Rover Environmental Monitoring Station (REMS) on Curiosity (NASA/JPL/Caltech)



FAHRENHEIT mission study included in ESA’s Terrae Novae 2030+ Strategy Roadmap

- Air pressure
- Air temperature
- Ground temperature
- Wind (vertical) – two or more heights for vertical flux
- Wind (horizontal)
- Dust particle concentration/mass flux (threshold stress for lofting)
- Total dust column opacity
- Humidity (surface-atmosphere exchange and vertical flux) diurnal cycle, better than 1% (or measure VMR directly) – Martinez 2017
- Solar flux (net radiative flux at the surface)
- Saltation layer depth?
- Sampling at 1 Hz
- Boom preferred for highest data fidelity

Planetary Protection Knowledge Gaps for Human Mars Missions

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Microbial and Human Health Monitoring – Findings and Recommendations

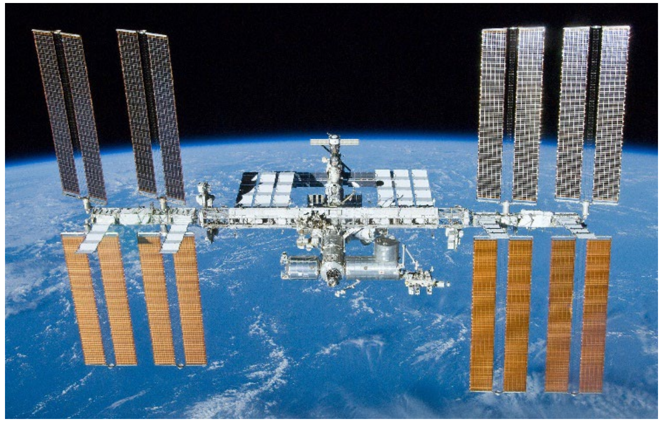
These knowledge gaps apply to both forward contamination (in combination with contamination transport models) and backward contamination

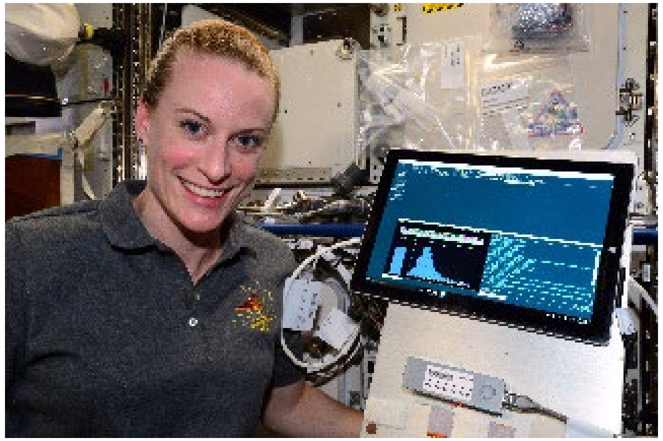
There are significant synergisms between the Earth safety (planetary protection) and issues relevant to assess the health status of astronauts on a mission to Mars and back (crew health)

ISS is the only useful existing test-bed to get long term and <u>statistically relevant</u> baseline data and trends

To close knowledge gap, there is a need for:

- Systematic microbial monitoring of a crewed flight system (ISS)
- Systematic microbial monitoring of crews (ISS)

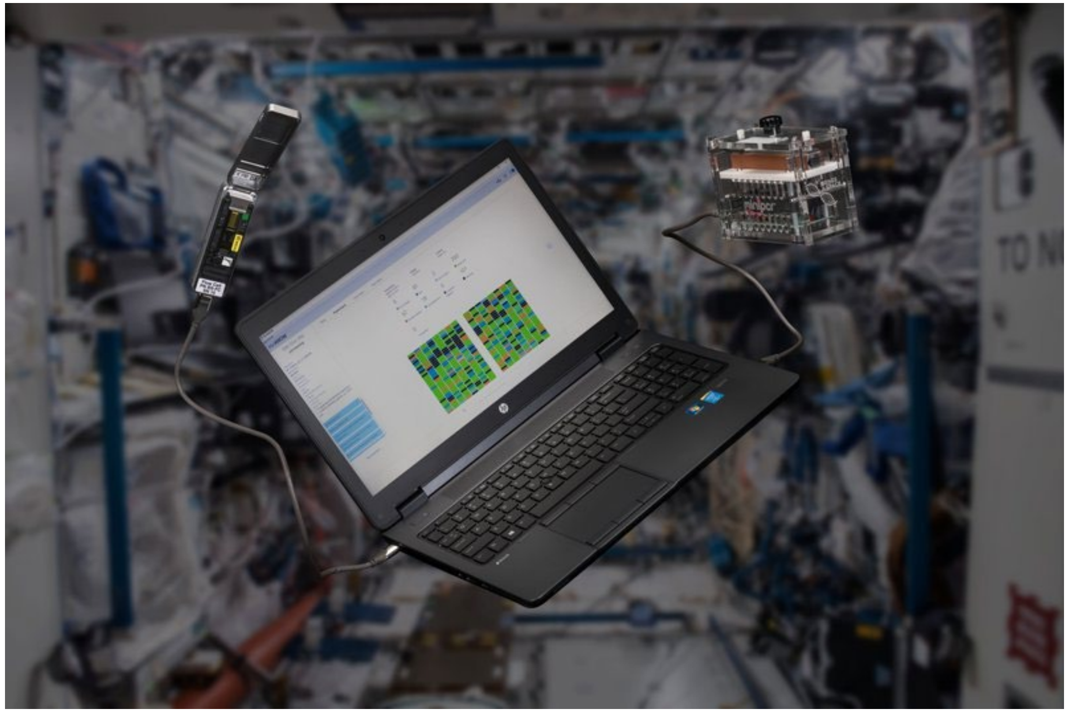




Microbial and Human Health Monitoring – Findings and Recommendations (2)

No need to invent something new here!

- MinION (Oxford Nanopore Technologies)
- Used on ISS on several flights by multiple astronauts
- Process, consumables and crew-time needs well understood



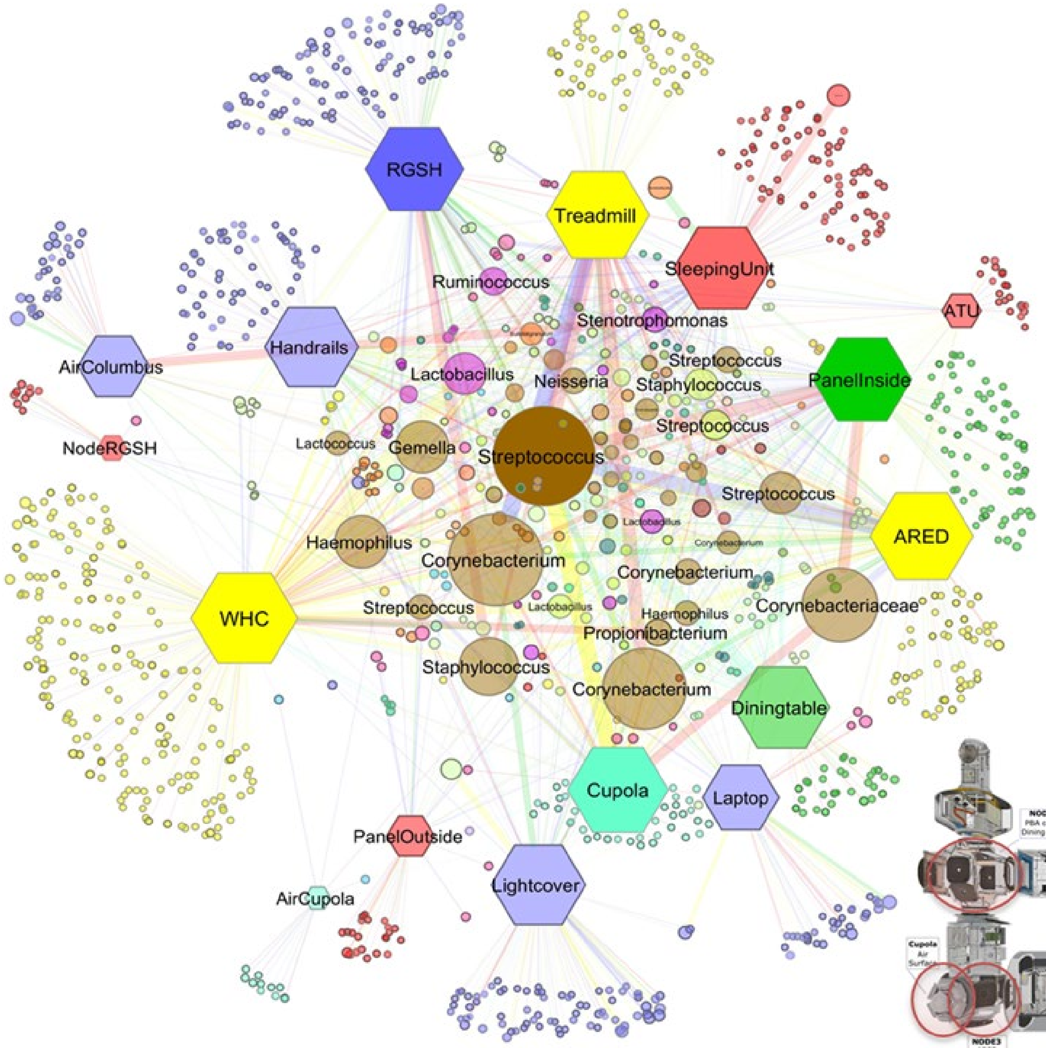
(MinION is *a* solution, not *the* solution.)

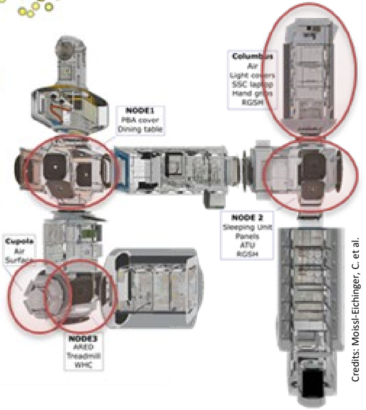
Microbial and Human Health Monitoring – Findings and Recommendations (3)

- Routine microbial monitoring today (2019) is only quarterly

- Routine microbial monitoring today is limited in scope (i.e., number of crew and locations on ISS) and depth (i.e., details of microbial population)

- Individual research activities carried out by NASA, JAXA and ESA are very detailed and comprehensive but not frequent enough and not always comparable (different methods)

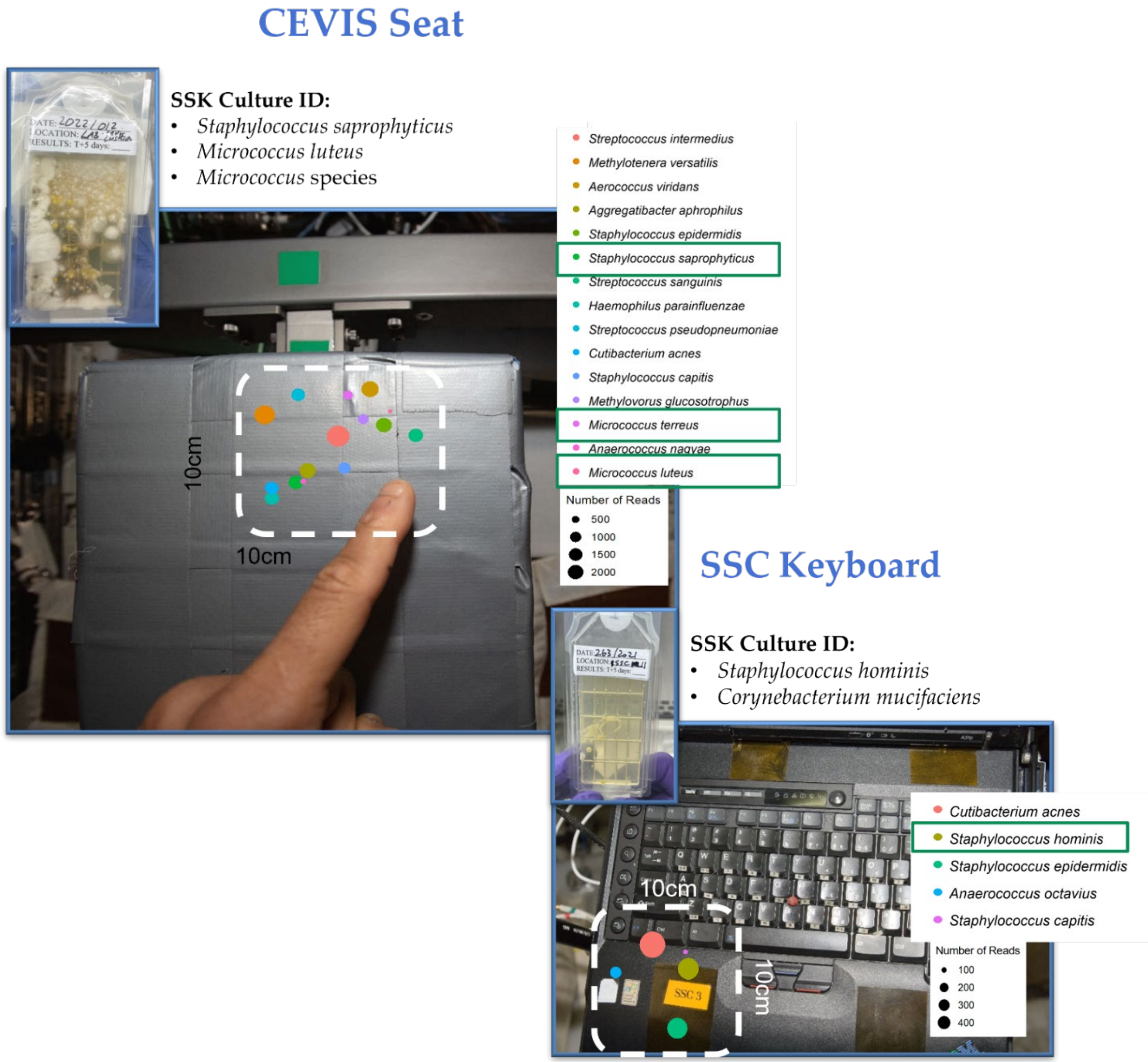




Credits: Moissl-Eichinger, C. et al.

BioMole: Surface Comparison

- **Lessons Learned from increased operational experience:**
  - 4 additional crew members performed 5 sampling sessions
  - Alterations to the cadence of the procedures to ensure science return
- **Data comparisons:**
  - Nanopore identifications were associated with:
    - Historical culture-based isolates from ISS air and surfaces
    - Human and environmental inhabitants
    - Previously published ISS molecular data
    - No obligate pathogens
  - Parallel data from the two methods
    - Increased diversity from nanopore data
    - Assessments in work to increase our understanding of the ISS microbiome
- **NASA risk assessment would not have been altered**



Microbial and Human Health Monitoring – Findings and Recommendations (4)

Proposed way forward:

- Data-mining activity of existing data to establish starting points for ISS sampling (frequency, number of samples)
- Establish a task group (e.g., in frame of ISLSWG International Space Life Sciences Working Group) to write sampling and analysis procedures using the MinION equipment (flight heritage)
- Integrate data-mining information and MinION procedure outputs to write a microbial monitoring plan for the ISS and crew that would address this knowledge gap
- Similar microbial monitoring beyond Earth orbit to study effects of the radiation environment (e.g., Gateway) and on a lifeless surface (e.g., Moon) were considered a must-have complementary data set, after gathering data on the ISS and before humans travel to Mars.

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Spacecraft Systems (Waste Management) – Findings and Recommendations

- Surface disposal is preferred.
- Consensus was that waste containment should be designed to be effective for 50+yr.
- Trash etc. “sterilization” requirement is TBD: Effective containment may be sufficient.
- There was broad agreement that multiple layers of containment (at least two, potentially three) should be used, with the outer layer being a larger container that was resistant to the Mars environment.
- Option to sealing or to have closure but with venting through a HEPA filter (and potentially also a molecular scrubber)
- Some degree of microbial tracking is required, in the sense of understanding the initial bioload so that the risk can be assessed.
- Recommended that a single site adjacent to the landing site be used

Spacecraft Systems (Discharge Management) – Findings and Recommendations

- Participants addressed acceptability of gas/liquid/microbial discharges for spacecraft systems (suits, habitats/rovers) in nominal and non-nominal (spill) scenarios.
- Presumed that microbes (not chemistry) were the concern.
- Discussion reflected that, at the very least, for atmosphere/surfaces in the airlock ought to be bioburden reduced during egress (with acceptable levels TBD).
- Discussion also reflected that, as long as it has not been determined whether Mars is an abode of current life, steps need to be taken to minimize the opportunity for potential Martian biota to encroach into the interior of crewed systems, so processing of tools, suits etc. would be needed prior to ingress.
- One of the groups highlighted the need for a separate airlock (or other pathway) for tool egress and ingress from the pressurized volume, compared to crew.
- No consensus was reached on how much contamination is too much, or the degree/frequency of monitoring required.

Spacecraft Systems (Quarantine and Sample Containment) – Findings and Recommendations

The Knowledge Gaps around Quarantine of the crew and related assumptions/questions:
2D - What considerations should go into the design of quarantine facilities and methods for use on Mars, returning from Mars, and in the Earth-Moon system?

Finding: Isolation of individuals is not practicable; crew should be quarantined as a unit; quarantine on return despite in-space pseudo isolation.

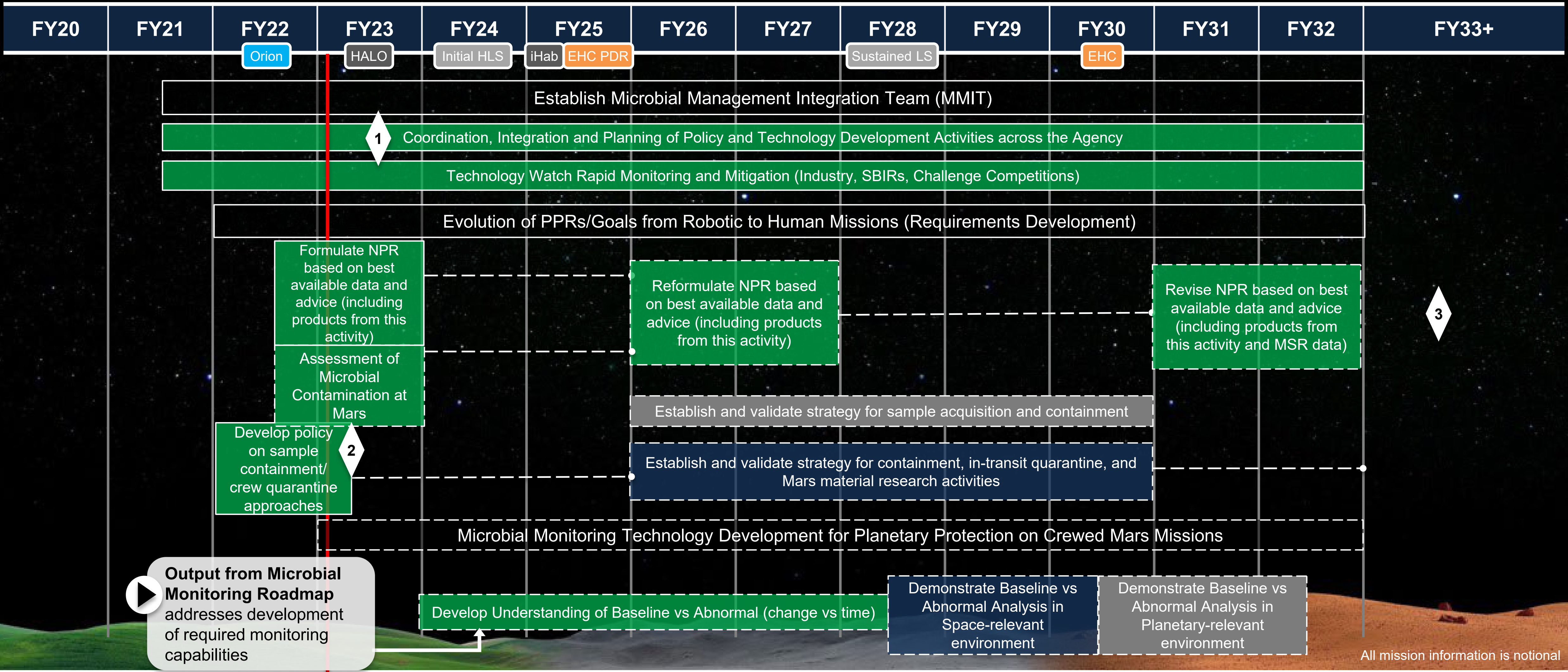
The Knowledge Gaps around how to handle the samples that would be taken during the mission, and upon the return:
2I - What approach should be taken to achieve the requirements to "Break the Chain of Contact" with the Martian environment for human missions?

Finding: Containment of all Mars samples should be maintained until samples are demonstrated to be “safe”, even if i) MSR shows no life, and ii) crew are previously exposed.

Planetary Protection Strategic Roadmap Coordination Activity for HEOMD (Artemis, Moon to Mars)

POC(s): Andy Spry/Bette Siegel
Revised: 04/15/2022

Develop Planetary Protection Capability for Crewed Missions to Mars (Slide 1 of 2)



- Ground Activity
- ISS / LEO
- Orion
- Gateway
- Lunar Surface
- Mars Transit
- Mars Surface
- Events/Milestones
- Decision Point

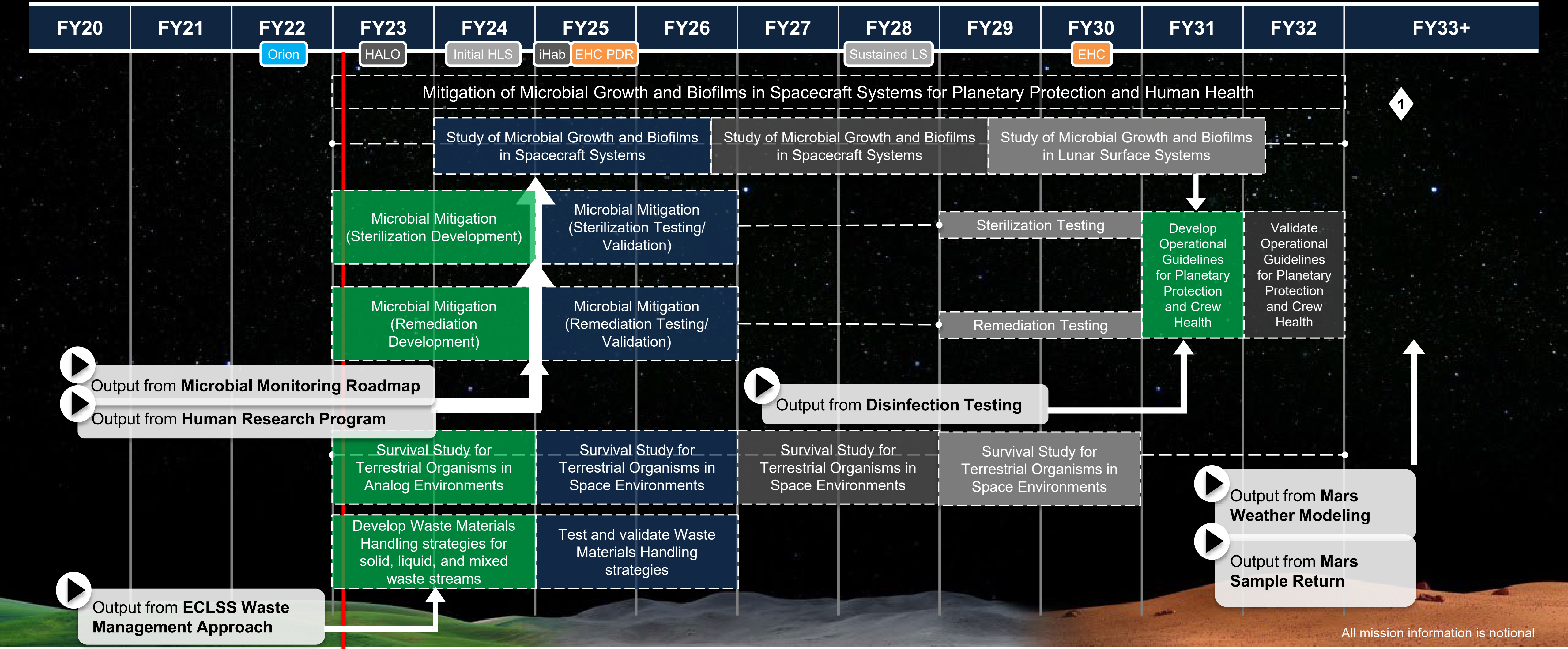
HLS = Human Landing System
EHC = Expanded Habitation Capability
HALO = Habitation and Logistics Outpost

(1) Recommendation on FY24 activities
(2) Determine approach on containment/quarantine policy approach
(3) Program decision on PP Implementation for first crewed Mars mission

Planetary Protection Strategic Roadmap Coordination Activity for HEOMD (Artemis, Moon to Mars)

Develop Planetary Protection Capability for Crewed Missions to Mars (Slide 2 of 2)

POC(s): Andy Spry/Bette Siegel
Revised: 04/15/2021



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(1) Determine Acceptable Levels of Microbial/Organic Releases from Humans and Support Systems

Summary and Future Options

- Progression of COSPAR Workshops has produced incremental progress in making Planetary Protection for crewed missions tractable as an issue.
- Paths to knowledge gap closure:
  - Measurements on the surface of Mars to support the development, test and validation of contamination transport models
  - A systematic microbial monitoring of ISS crew and ISS environment using the existing MinION system
  - Acceptance of numeric limits on waste management, sample containment, crew quarantine constraints and sterilization protocols
- More work remains in establishing “how much is too much” from a contamination release perspective.
- Workshop study reports and the participant communities remain as resources for updating agency and COSPAR policy and guidelines for the current era.

Summary and Future Options Continued

- Timely flow down of Agency level Planetary Protection requirements and adoption into spacecraft design/architecture requirements for the first crewed Mars mission can then occur.

- NASA recognizes that new investments are essential to close these knowledge gaps

Questions?