My Opinion / Recollections Regarding

The Perspective of the Planetary Protection Independent Review Board (PPIRB)

Christopher H. House

Outline

- PPIRB Background
- Origins of Planetary protection (PP) policies
- Interplay between PP policy, implementation, and exploration
- New discoveries with respect to bioload replication at Martian surface
    - Gullies and Recurring Slope Lineae
    - Deliquescence
- Other considerations
    - Induced special regions
    - Martian meteorites
    - Nature of microbial colonization
    - Nature of spacecraft bioload and relevant PP microorganisms
    - New modern and/or flexible approaches
- Summary and Questions

PPIRB Background

- Chartered: By NASA/SMD AA Zurbuchen.
- Charter Summary: “An assessment to include analysis of the scientific, engineering, industrial, legal, and program management aspects of planetary protection (PP). Results of the assessment will be documented in a non-consensus final report presentation.”
- Term: July-September 2019
- Membership: 12 planetary scientists, biologists, private & civil sector space reps.
- Meetings/Telecons: 4 in person multi-day meetings; 11 working telecons.
- Report: Reviewed within NASA prior to delivery. Released 18 Oct 2019.
- Briefed: SMD, NASA Administrator, EOP Staff, NAC, SSB, House Science Committee Staff, NAC Science Committee. JAXA, ESA, COSPAR, NAS

PPIRB Background

PPIRB Membership

Dr. Alan Stern, PPIRB Chair	Southwest Research Institute
Dr. Edward (Beau) Bierhaus	Lockheed Martin
Dr. Wendy Calvin	University of Nevada-Reno
Dr. Amanda Hendrix	Planetary Science Institute
Dr. Christopher H. House	Pennsylvania State University
Dr. Hernan Lorenzi	J. Craig Venter Institute
Mr. Tommy Sanford	Commercial Spaceflight Federation
Dr. Erika Wagner	Blue Origin
Dr. Andrew Westphal	University of California at Berkeley
Mr. Charles Whetsel	Jet Propulsion Laboratory
Mr. Paul Wooster	SpaceX
Dr. T. Jens Feeley, Study Manager	NASA Headquarters (Ex Officio)

PPIRB Report Overview

<u>Approximately 80 PP Findings and Recommendations, Including:</u>

- Clarifying and Streamlining Processes within NASA
- Advancing Protocols with More Modern Technology
- Reducing Burdens on Missions
- Advancing Policies for Private Sector Missions

<u>Sample Topics in the PPIRB Report:</u>

- Planetary Protection Categorization
- Human Spaceflight
- Private Sector Initiatives and Missions
- Robotic Mars Sample Return
- Ocean Worlds Exploration

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Most important findings and recommendations:

- PPIRB all agreed PP is important
  - Should enable exploration
  - NASA leads by example for all varieties of missions
- Establishment of a permanent board for PP (that’s you)

Selected Findings & Recs: Mars (Robotic)

Supporting Recommendation: For space activities without significant NASA involvement (including private sector robotic and human planetary missions), NASA should work with the Administration, the Congress, and private sector space stakeholders to identify the appropriate US Government agency to implement a PP regulatory framework.

Supporting Recommendation: The PPO should exploit new discoveries and new technologies to better categorize exploration targets, create better forward and backward PP implementation protocols, and lower PP cost and schedule impacts on projects.

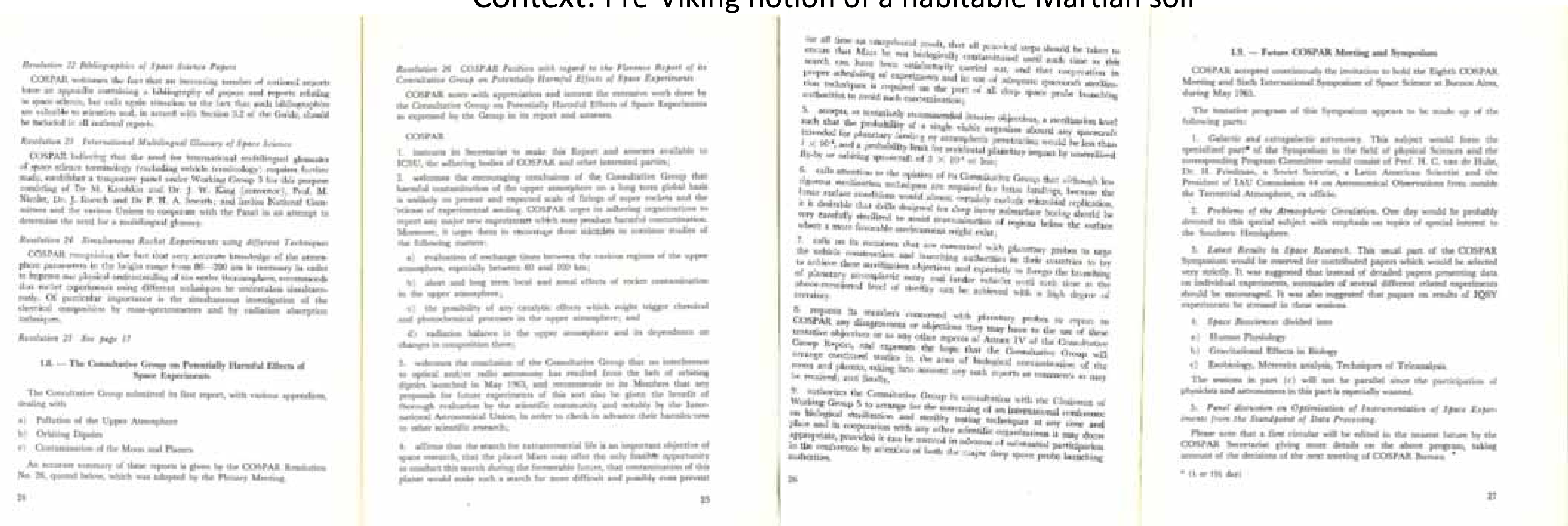
Major Recommendation: NASA should reconsider how much of the Martian surface and subsurface could be Category II vs. IV.

Category II missions comprise all types of missions to those target bodies where there is **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.

Major Recommendation: Planning for a Mars Sample Receiving Facility (MSRF) should be accelerated, and should be kept as pragmatic as possible so as not to unduly drive the cost or schedule of MSR.

Origins of PP policies

- 1964 COSPAR RESOLUTION
  - Establishes "interim" Planetary Protection probability goals for Mars
  - Notes that the Lunar surface is different than Mars because the conditions preclude microbial replication
  - Concept of a period of astrobiological exploration, followed by human exploration…
  - Context: Pre-Viking notion of a habitable Martian soil



COSPAR. COSPAR RESOLUTION 26.5, *COSPAR Information Bulletin* **20**, 25-26, 1964.

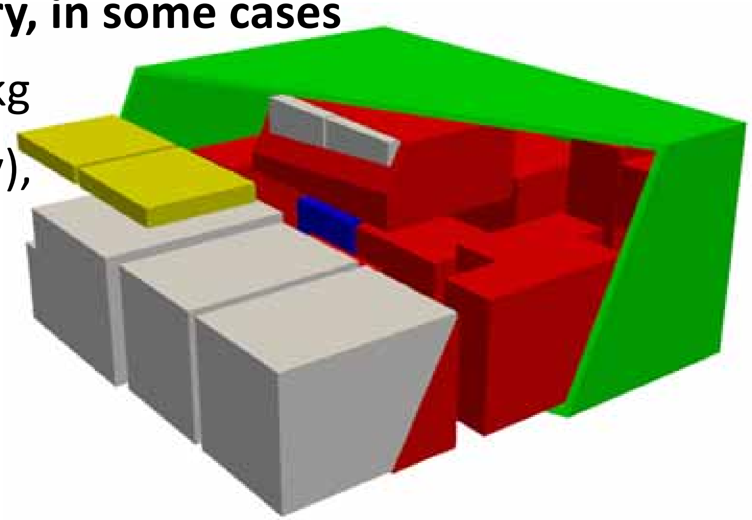
- Article IX of the 1967 UN Outer Space Treaty (a.k.a, the non-interference provision)
  - Establishes doctrine of peaceful, cooperative exploration of space
  - Not intended to hinder exploration

Accepted PP parameters

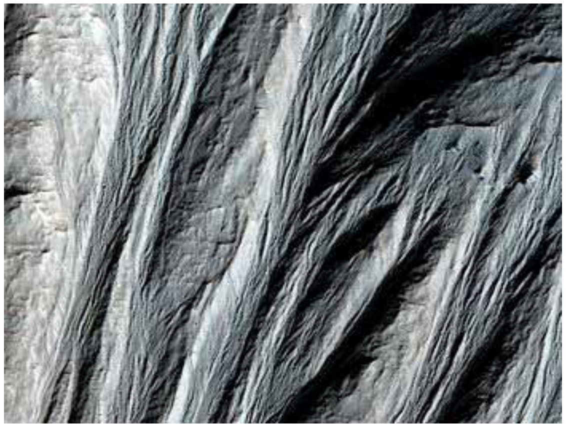
- **Forward Contamination** – The delivery of terrestrial biology from Earth to other celestial bodies, and specifically, as it relates to adversely affecting the future investigations.
- **Backward Contamination** – Harmful contact between terrestrial biology and pathogens or biology arriving on Earth from other celestial bodies, generally in the context of a mission returning materials from such a body to the Earth.
- Earth microbiota cell division has not been observed below -18°C (Rummel et al., 2014)
- Report of genome replication at -20°C (Tuorto et al., 2014)
- COSPAR recommendations that Special Regions be in part based on temperatures above -25°C

Interplay between PP policy, implementation, and exploration

- **Impossible to quantify cost of PP compliance (impact is not only in dollars)**
  - Engineering time on implementation and documentation
  - Exclusion of certain
  - Barrier to participation (perhaps, emerging instrument partners)?
  - Barrier to flying some off-the-shelf technologies?
  - Mission concepts never proposed (i.e., direct Cat 4c: <30 bacterial spores per lander)?
- **Potential for diminished science return or pace of discovery, in some cases**
  - Europa lander has a landed science payload of 42.5 kg
  - To end its mission (or react during a landing anomaly), it also has 11.8 kg of thermite incantatory material



New discoveries with respect to bioload replication at Martian surface

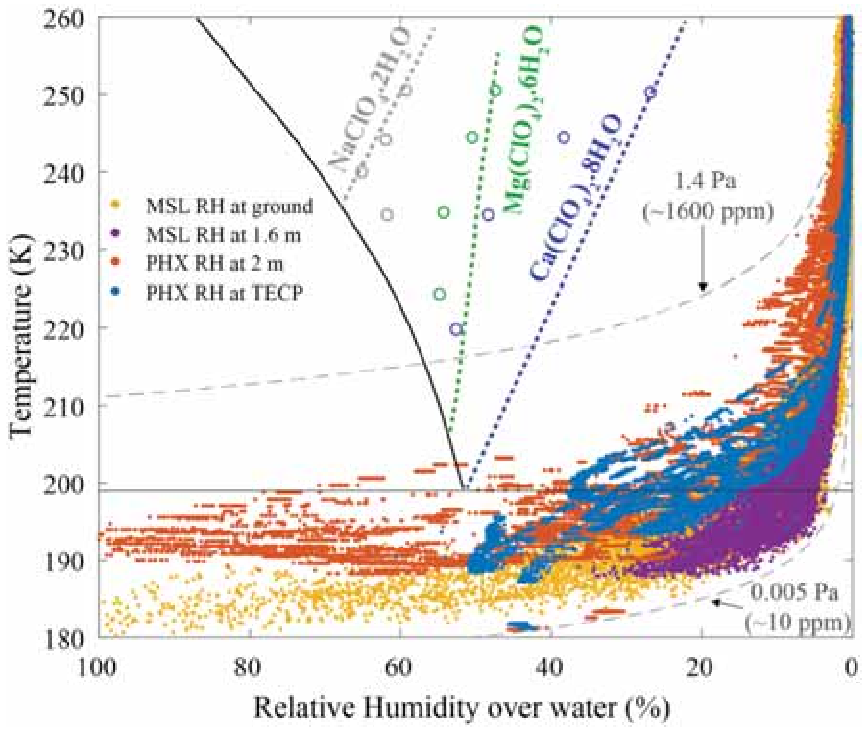


- Gullies and Recurring Slope Lineae (RSLs)
  - Flow features on steep slopes
    Gullies are on cold slopes (with CO_2 ice)
    RSLs are associated with warm slopes
  - Perchlorate in RSLs reported (Ojha et al., 2015).
  - Perchlorate detection is likely a CRISM artifact (Leask et al., 2018)
  - RSLs are landslide events on a dusty surface
  - Numerous RSLs following M34 global dust storm (McEwen et al., 2020)

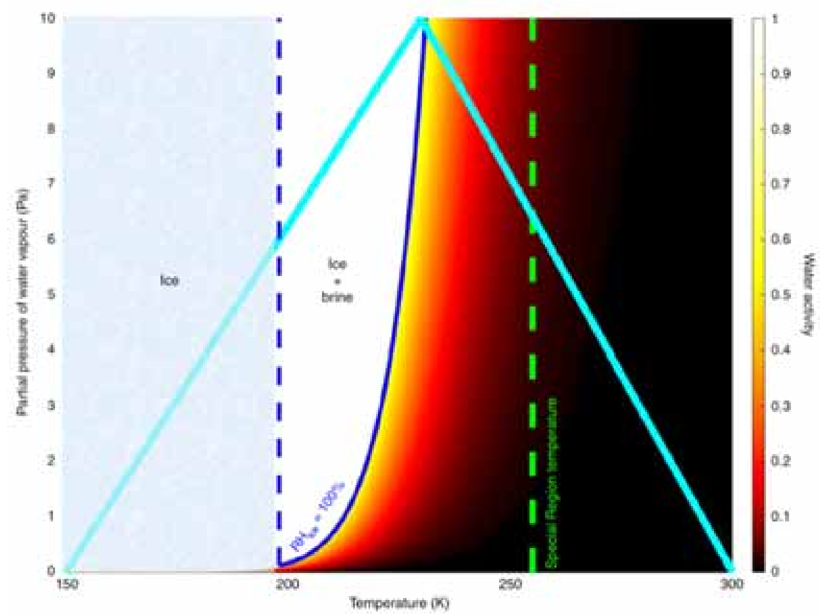
Deliquescence

	Can salt likely *hydrate* under REMS surface conditions?	Can salt likely *dehydrate* under REMS surface conditions?
$MgCl_2$	MAYBE	NO
$Ca(ClO_4)_2$	YES	NO
$CaCl_2$	NO	YES

"Sodium perchlorate does not hydrate from the anhydrous form even after several hours of low temperature, high humidity conditions that were theoretically predicted to result in formation of NaClO4•H2O." Gough et al., 2019



Fischer et al., 2019



"Our results indicate that (meta)stable brines on the Martian surface and its shallow subsurface (a few centimeters deep) are not habitable because their water activities and temperatures fall outside the known tolerances for terrestrial life." Rivera-Valentin et al., 2020

Report of the Joint Workshop on Induced Special Regions

Michael Meyer[a,*], Corien Bakermans[b], David Beaty[c], Douglas Bernard[d], Penelope Boston[e], Vincent Chevrier[f], Catharine Conley[a], Ingrid Feustel[g], Raina Gough[h], Timothy Glotch[i], Lindsay Hays[e], Karen Junge[j], Robert Lindberg[k], Michael Mellon[l], Michael Mischna[d], Clive R. Neal[m], Betsy Pugel[a], Richard Quinn[j], Francois Raulin[n], Nilton Rennó[o], John Rummel[p], Mitchell Schulte[a], Andrew Spry[p], Pericles Stabekis[q], Alian Wang[r], Nathan Yee[s]

Finding: While a spacecraft on the surface of Mars may not be permitted to explore a Special Region during the prime mission, the sterilizing environment that is the martian surface and near surface would progressively clean the exposed spacecraft surfaces so that such SR investigations could be proposed for later in the extended mission.

Finding: While a buried RTG could produce an Induced Special Region, it would not pose a long-term contamination threat to Mars. One possible exception would be a migrating RTG in an icy deposit that reaches an existing natural Special Region.

Finding: Microbial transport away from subsurface Induced Special Regions is highly improbable.

Spacecraft-induced special region

FIG. 15. Schematic cross-section summarizing the fate of microbes that may potentially be in and around the thermal anomaly. See explanations in text (Section 8.3) for further details.

Shotwell, R. F., Hays, L. E., Beaty, D. W., Goreva, Y., Kieft, T. L., Mellon, M. T., ... & Spycher, N. (2019). Can an Off-Nominal Landing by an MMRTG-Powered Spacecraft Induce a Special Region on Mars When No Ice Is Present?. *Astrobiology*, *19*(11), 1315-1338.

Martian meteorites considered in MMX PP classification

Restricted Versus Unrestricted Earth Return

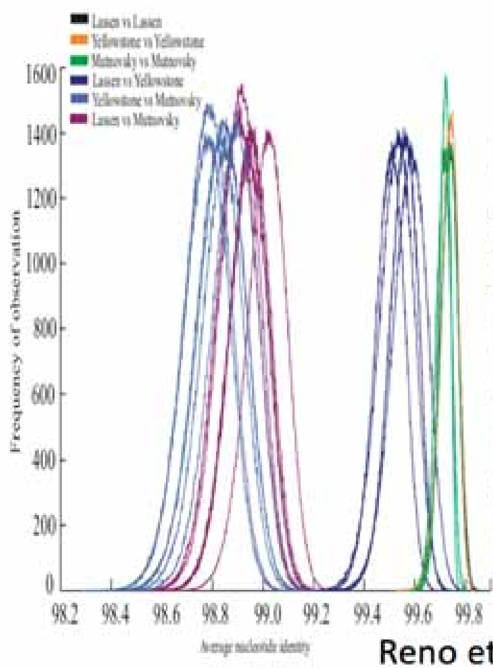
In determining whether samples returned from Phobos or Deimos should be classified as restricted or unrestricted Earth return, the committee considered the following factors:

- The work represented by the SterLim and JAXA teams can be considered as the state of the art, in regard to the modeling of the process of deposition of martian material on the surface of the martian moons. Nevertheless, significant deficiencies exist in understanding, and there remain experimental and computational challenges associated with the quantitative estimation of ejecta mass and temperature distributions. Even though issues still exist with the modeling work that was performed (see Chapter 2), the work is convincing in showing that there is significant sterilization introduced during the whole chain of events.
- The issue of desiccation on the surface of the martian moons for any present martian microbes was not considered. At temperatures above the freezing point of water, desiccation is bactericidal to even the most radiation-resistant microbes in a matter of months. (See "Sterilization by Radiation on Phobos/Deimos Surfaces," in Chapter 2.)
- The relative influx of martian microbes from the Phobos/Deimos sample versus the natural influx of direct Mars-to-Earth transfer can be shown to be smaller by several orders of magnitude.

Recommendation: After considering the body of work conducted by the SterLim and JAXA teams, the effect of desiccation on the surfaces of the martian moons, and the relative flux of meteorite- to spacecraft-mediated transfer to Earth, the committee recommends that samples returned from the martian moons be designated unrestricted Earth return.

Nature of microbial colonization

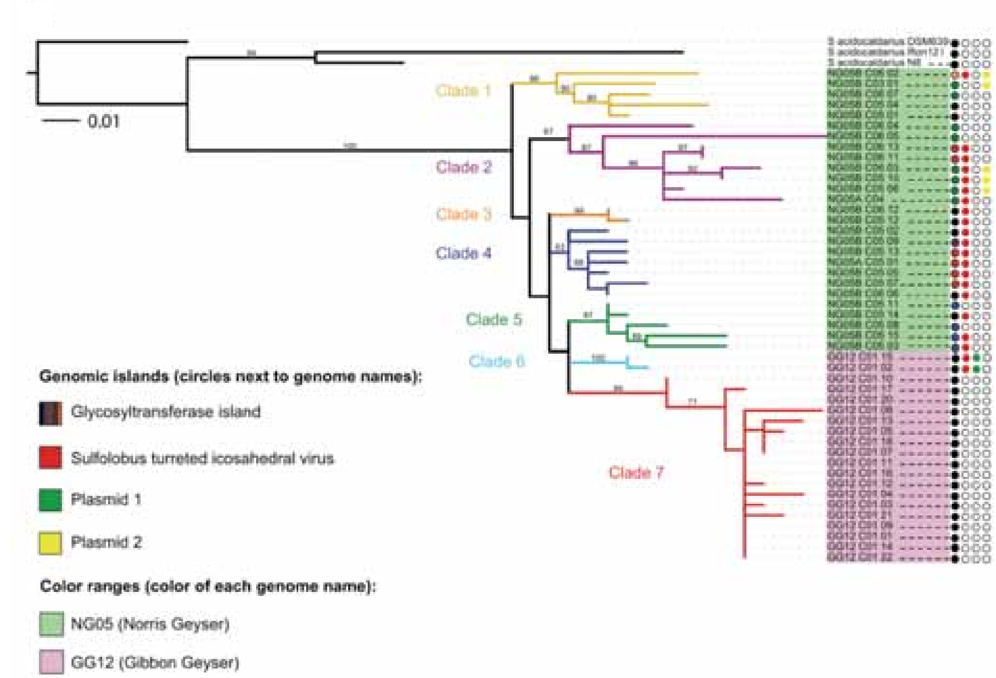
- **There are mechanisms for global transport of microbes on Earth**
- **There appear to be significant barriers to replacement of endemic strains**
  - **- Microbial specialization to specific fine-scale geochemistry**
  - **- Endemic microbial populations are large compared to new arrivals**



Divergence dates for *Sulolobus islandicus* from 910,000 years ago for the North American and Mutnovsky (Kamchatka) populations.
140,000 years ago for divergences within the Mutnovsky volcanic complex.

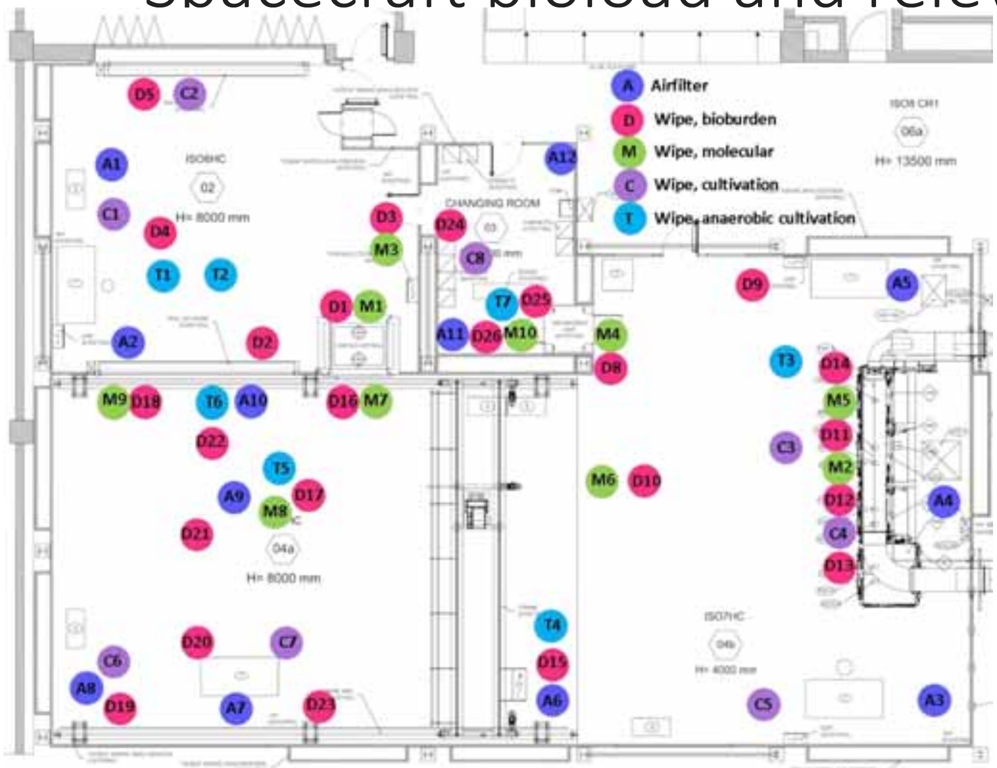
Reno et al., 2009

Fig. 1. Pairwise bANI for the 7 *S. islandicus* genomes. Comparisons between LNP (Lassen) strains (black), YNP (Yellowstone) strains (orange), and Mutnovsky strains (green) yield an average identity of 99.73%. Comparisons between North American strains (LNP vs. YNP, dark blue) give an average identity of 99.54%, whereas comparisons between each North American and Mutnovsky strain (magenta and light blue) yield an average identity of 98.89%.



At Yellowstone National Park, *Sulfolobus acidocaldarius* shows rare genomic events common in Norris Geyser field, but absent in nearly all Gibbon Geyser strains

Spacecraft bioload and relevant PP microorganisms



- Bioload is mostly inside instrument electronics
- Spore counts is one approach to bioload quantification
- Molecular approaches provide insight into the metabolic capabilities of a bioload
- Modern planetary protection could leverage the genomic revolution to focus on microorganism potentially relevant to the planetary mission target
- Molecular biology provides means to differentiate Earth life from non-Earth life

Microbial biodiversity assessment of the European Space Agency's ExoMars 2016 mission

Kaisa Koskinen, Petra Rettberg, Rüdiger Pukall, Anna Auerbach, Lisa Wink, Simon Barczyk, Alexandra Perras, Alexander Mahnert, Diana Margheritis, Gerhard Kminek & Christine Moissl-Eichinger

Koskinen et al., 2017

New modern and/or flexible approaches

- Genetic and genomic approaches to focus on what is in a bioload
  (less of a focus on the size of the bioload)
- Flexibility in PP implementation
  - Traditional approaches (clean rooms, heat reduction, and IPA wipes)
  - Hydrogen peroxide vapor
  - UV LEDs
  - Consideration of bioload reduction during transit
  - Checklist or probability assessment or bioload reduction

Summary

- PP is important and should enable exploration
- Planetary protection is a responsibility due to the non-interference provision and is intended to facilitate peaceful cooperative space exploration
- Bioload amplification is not possible in Mars Gullies and Recurring Slope Lineae
- Deliquescence at the Mars surface does not meet the criteria for bioload growth
- Induced special regions are likely transient
- Martian meteorites suggest the past transport of Earth microbes to Mars
- Microbial replacement of an endemic ecosystem requires **>**1 cell
- A modern exploration strategy can leverage genetic and genomics
- Flexible approaches to PP implementation best enable exploration

Backup slides…

Selected Findings & Recs: Mars (Humans)

Major Finding: Human missions to Mars will inevitably introduce orders of magnitude more terrestrial micro-organisms to Mars than robotic missions have done or will do.

Major Finding: Human missions to Mars will create new opportunities for science and exploration.

Major Finding: NASA's current policies for robotic Category V Restricted Earth Return from Mars appear to be unachievable for human missions returning from Mars.

Major Recommendation: NASA should invest in developing more informed, backward contamination PP criteria.

Selected Findings & Recs: Mars (Humans)

Major Finding: PP planning for human missions to Mars and the communication of those plans to the public are presently immature.

Major Recommendation: NASA should begin, sooner rather than later, preparing for the public communication of all aspects of PP planning for human missions to Mars, and should pay special attention to public PP concerns, similar to NASA's proactive treatment of NASA missions involving radioisotope power systems.