Planetary Protection Overview

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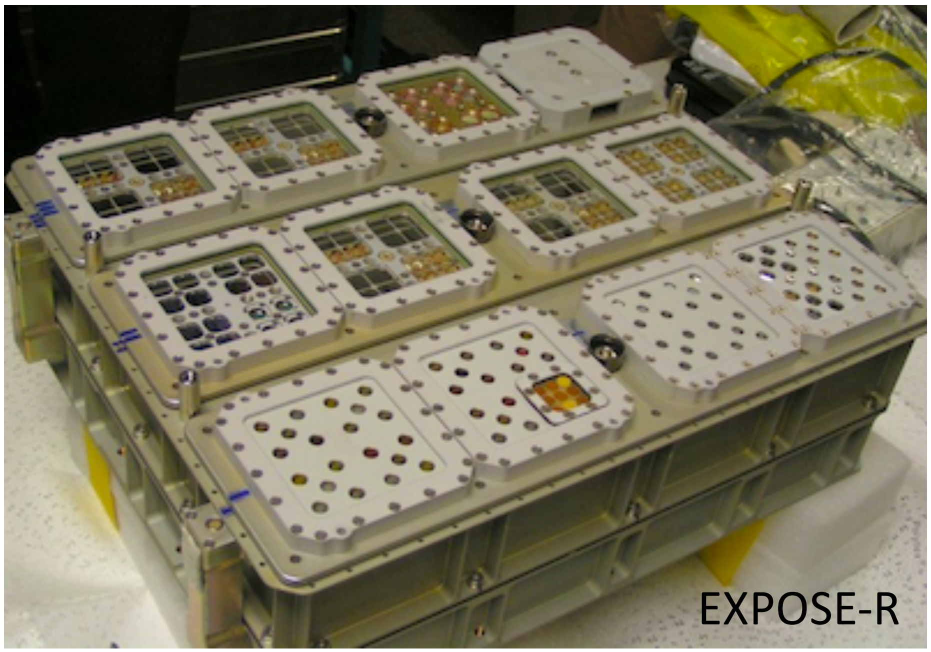
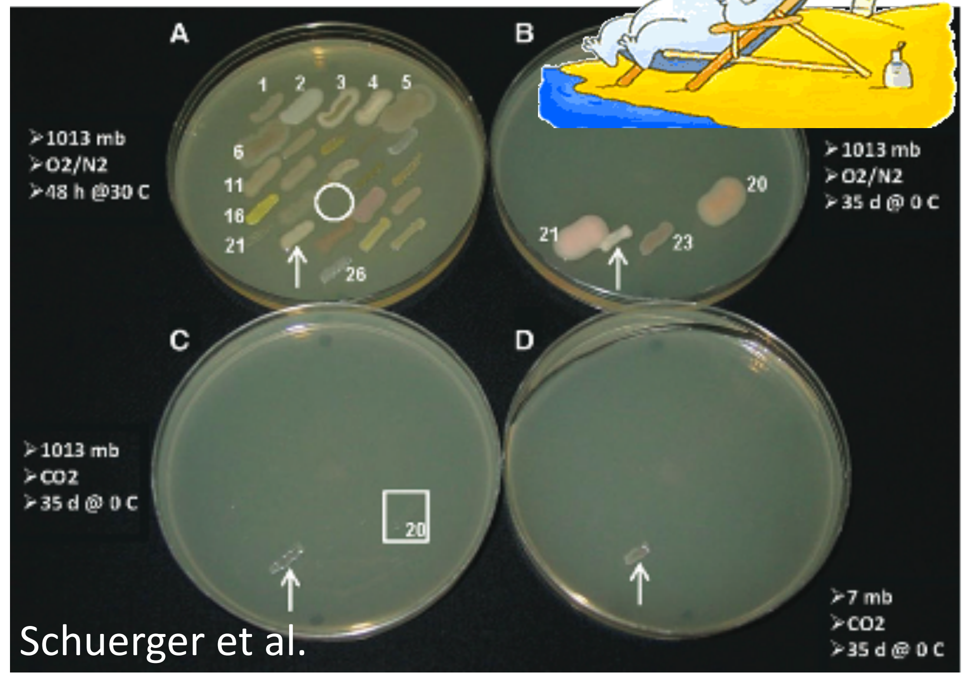
Astrobiology's Big Questions:
What are the origins, distribution, and future of life in the universe?

It's trivial to find life, if we bring it with us...

Extreme-tolerant microbes can survive spaceflight environments, and grow in Mars-like conditions

Cleanroom isolates can survive for years on the outside of the International Space Station





Microbes common on cheese can grow in a Mars chamber

All these observations confirm that planetary protection constraints, in place since the 1960s, are key to protecting science and other future human activities at Mars

International Framework for Planetary Protection

United Nations

Governing Body, via Outer Space Treaty, Article IX:

- *Avoid 'harmful contamination' of other planets*
- *Avoid 'adverse effects to the environment of the Earth'*

International Council for Science (ICSU)/COSPAR

- *Maintains international planetary protection policy, in support of UN*
- *COSPAR Panel on PP reviews NRC/ESF recommendations*
- *COSPAR Bureau & Council review and approve Panel on PP Consensus*

US National Academies *(for EU/ESA, this is ESF)*

- *Develops recommendations on policy and requirements*
- *Forwards to NASA and ICSU Committee Space Research (COSPAR)*

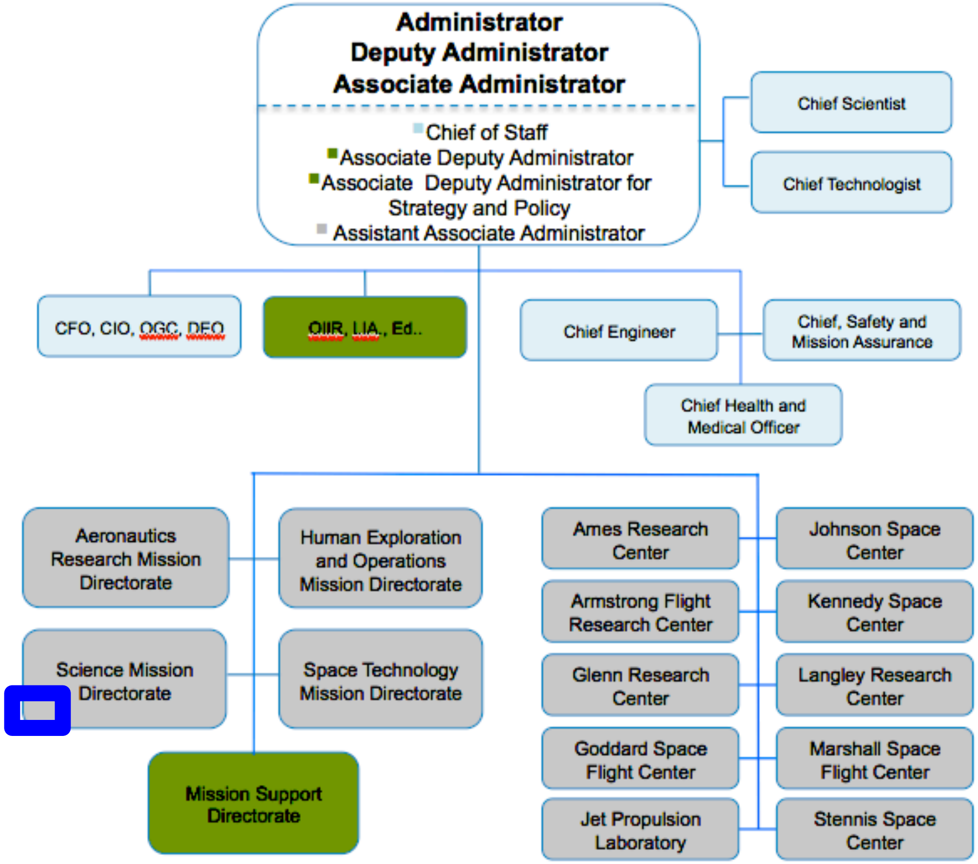
Office of Planetary Protection, NASA Headquarters

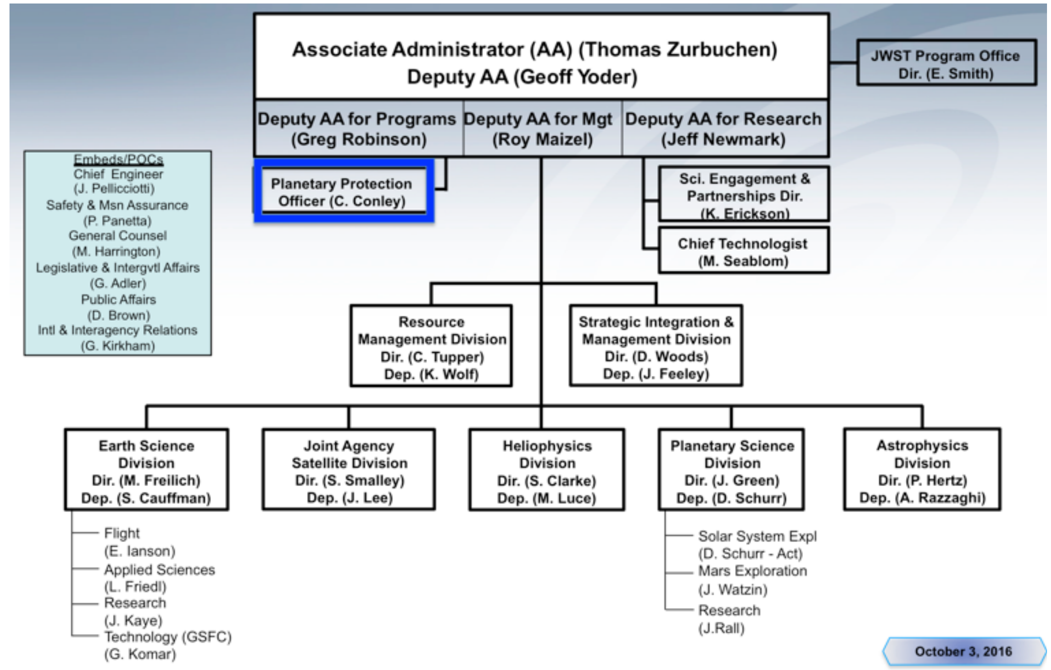
- *Enforces policy, including providing requirements to projects and auditing compliance, with advice from advisory bodies (NAC Planetary Protection Subcommittee; Space Studies Board)*

- ***Role of Projects/Missions:*** *Implement planetary protection requirements to ensure compliance with NASA policy and US treaty obligations*

- *Compliance with planetary protection on robotic missions to date has been self-enforcement by NASA, with advice by the NASA Advisory Council.*

NASA Planetary Protection Organizational Structure





PPO is responsible for oversight.

Mission Managers and Center Directors are responsible for implementation on projects.

NPD 8020.7: Planetary Protection Policy
- states NASA policy
- signed by the Administrator
- SMD AA responsible to administer policy
- PPO assigned as designee of SMD AA

NPR 8020.12: Reqts for Robotic Missions
- lists robotic mission requirements
- signed by the SMD AA

NPI 8020.7: Guidelines for Human Missions
- signed by AAs, SMD and HEO

Planetary Protection Policy

(from NPD 8020.7; near-verbatim from COSPAR)

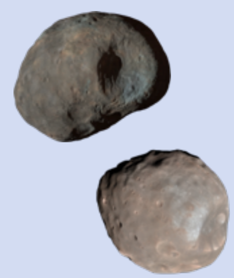
- "The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized."
  - Preserves science opportunities directly related to NASA's goals, and can support certain ethical considerations; originally recommended to NASA by the NAS in 1958
  - Preserves our investment in space exploration
  - Can preserve future habitability options
- "The Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from another planet."
  - Preserves Earth's biosphere, upon which we all depend...
- Assignment of categories for each specific mission/body is to "take into account current scientific knowledge" via recommendations from advisory groups, "most notably the Space Studies Board."

Planetary Protection Considerations for Robotic and Human Missions

- Avoid contaminating target bodies that could host Earth life (e.g., Mars, Europa, Enceladus)
- Ensure biohazard containment of samples returned to Earth from bodies that could support native life (e.g., Mars and possibly moons, Europa, Enceladus)
- On human missions, characterize and monitor human health status and microbial populations (flight system microbiome) over the mission time, to support recognition of alterations caused by exposure to planetary materials

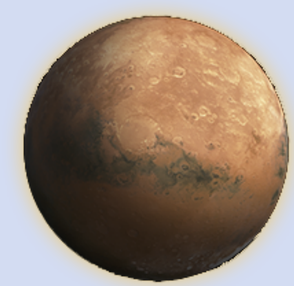
Earth's Moon, Most Solar System Bodies

Documentation only; No Operational Constraints on *in situ* activities or sample return



Phobos/Deimos

Document *in situ* activities; Possible return constraints



Mars, Europa, Enceladus

Documentation and operational restrictions to avoid introducing Earth life; Strict biohazard containment of returned samples

Preventing Contamination of Icy Moons: A Probabilistic Formulation

The number of microbes of type X that could survive on an icy body is based on the initial contamination level [N_{X0}] and various *independent* survival factors:

$$N_{final} = \sum_X N_{Xinitial} F_1 F_2 F_3 F_4 F_5 F_6 F_7$$

$P_{contamination}$ is set equal to N_{final}

- F_1—Total number of cells relative to assayed cells (N_{X0})
- F_2—Bioburden reduction survival fraction, when applied
- F_3—Cruise survival fraction
- F_4—Radiation survival fraction
- F_5—Probability of impacting a protected body, including spacecraft failure modes
- F_6—Probability that an organism survives impact
- F_7—Burial survival fraction

(Probability of growth given introduction is assumed to be 1)

- Where the organisms of type X are defined as:

  Type A: Typical, common microbes of all types (bacteria, fungi, etc.);

  Type B: Spores of microbes, which are known to be resistant to insults (e.g., desiccation, heat, radiation);

  Type C: Dormant microbes(e.g., spores) that are especially radiation-resistant; and

  Type D: Rare but highly radiation resistant non-spore microbes (e.g., *Deinococcus radiodurans*).

Preventing the Forward Contamination of Titan?

COSPAR Workshop Example Calculation of Contamination

The number of organisms that will survive on Titan is based on the initial contamination level [N_0] and various survival factors:

$$N_s = N_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7$$

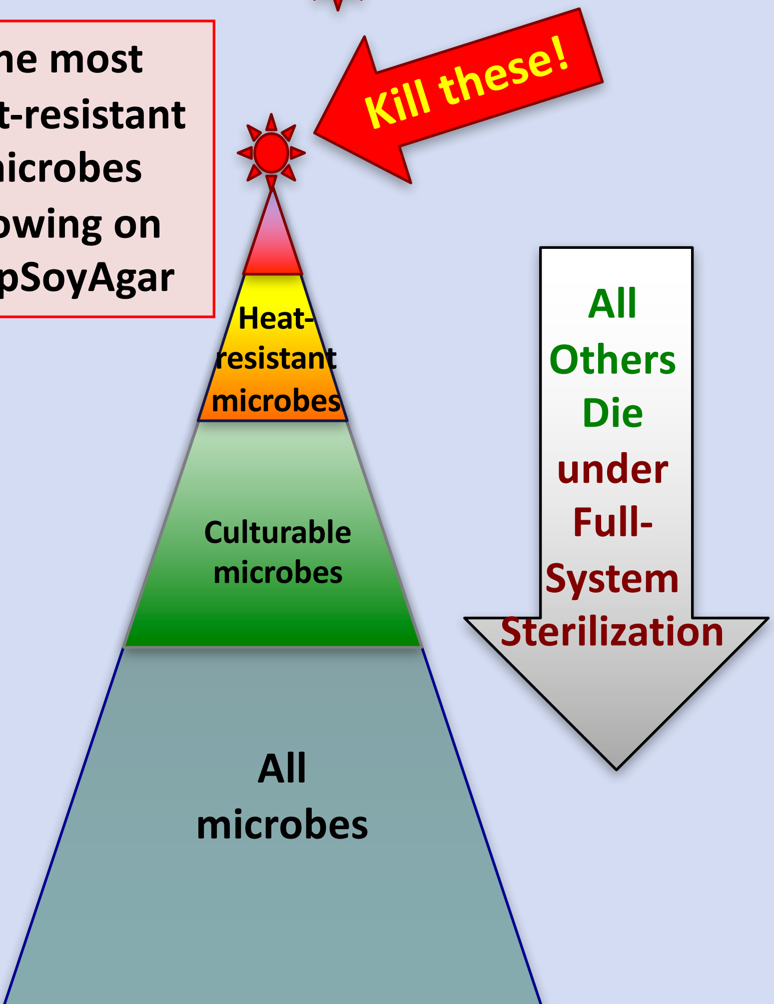
F_1	—Bioburden Reduction Treatment	1
F_2	—Cruise Survival Fraction	10^{-1}
F_3	—Radiation Survival in the Near-Surface/Orbital Environment	10^{-1}
F_4	—Probability of Landing at an Active Site	2×10^{-3}
F_5	—Burial Fraction (Below the “Cap”)	1×10^{-4}
F_6	—Probability of Getting “There” on the Conveyor	1×10^{-2}
N_0	One Million Microbes...or More	10^6+
N_s		2×10^{-5}

We need N_s to be less than 1×10^{-4}

Options for Microbial Reduction

What is a "spore" for planetary protection?

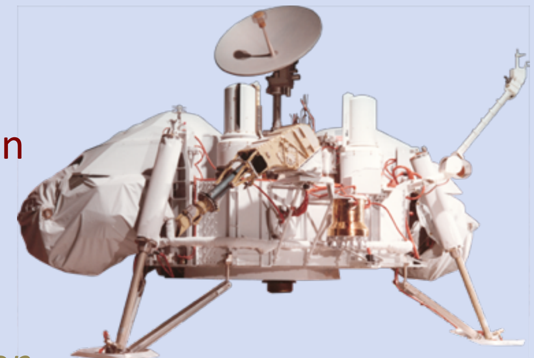
The most heat-resistant microbes growing on TrypSoyAgar



Similar approaches pertain to other microbial reduction processes

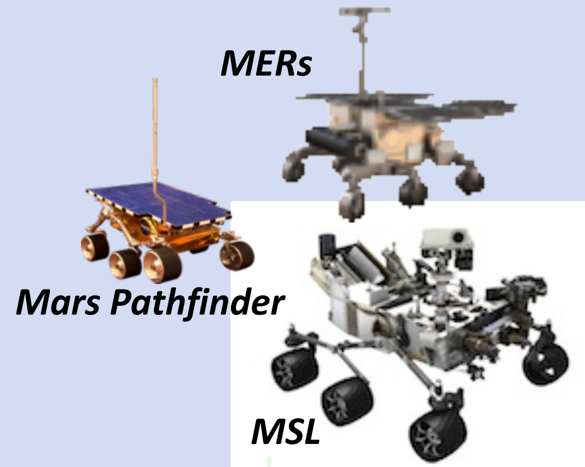
1970s

Surface Cleaning
Full-System Heat Reduction
Bioshield during Launch
Organic Cleanliness and Overpressure
Recontamination Prevention for MS



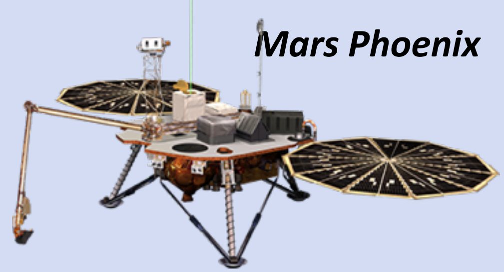
1990-2010s

Surface Cleaning



2000s

Surface Cleaning
Subsystem Reduction
Biobarrier for Arm



Contamination Mitigation and Verification (specifics on next slide)

Based on the Viking and ExoMars implementation, standard practice for IVb missions is: **(A) clean hardware and verify that it's clean pre-launch;** and then implement appropriate recontamination prevention approaches such that: **(B) sample processing at the target can be done without exceeding accepted limits on sample contamination.**

To accomplish this, from a systems engineering standpoint, one would **identify the potential/likely contamination sources**, both **during ATLO** on Earth and also **post-launch during cruise and operations** on Mars. Then **assemble the various cleaning and recontamination prevention strategies** that are available, and identify open issues.

Taking all the above as inputs to the design process, the goal is to:
Design hardware that survives starting at point A; then **Incorporate whatever approaches to recontamination prevention are needed to ensure attaining point B.**

The Viking Project set requirements on the criteria for A and B.

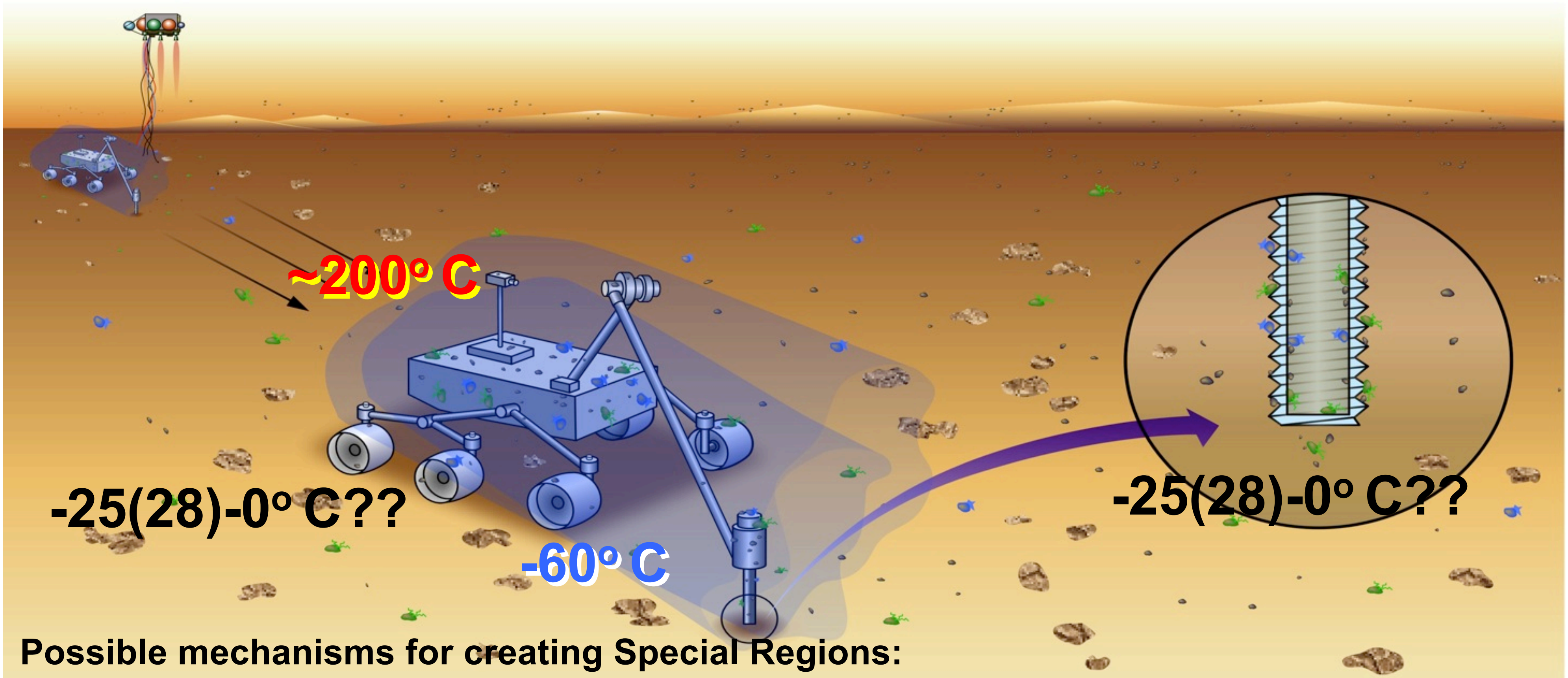
Following Viking, NASA policy set explicit requirements on pre-launch bioburden, to protect Mars: protecting scientific measurements is addressed by limiting contamination ‘driven by the nature and sensitivity of the life detection instruments’.

A: Prelaunch Cleaning & Verification	Recontamination Vectors & Concerns	B: Acceptable Sample Contamination
NASA policy specifies 3-step protocol, based on Viking: 1) Clean to 300 'spores'/m^2 2) Apply 4-log process reduction 3) Protect from recontamination Hardware design must permit cleaning and reduction processes, and also ensure post-cleaning prevention of contamination	Viable organisms are (carried on) particles Dead ones are just organic contaminants	<1 viable Earth organism per cached sample Baseline/threshhold not specified, because organisms grow **Viable organisms**
Prelaunch organic cleaning/verification protocols not specified in NASA policy, but: Viking used precision cleaning with final post-assembly hot-gas purge; Cleanliness verified by measuring volatile organics in purge effluent using mass spectrometry Overpressure from hot-gas purge also ensured protection from external recontamination post-cleaning	Particles carry organic compounds, possibly at high local concentration Volatile organic compounds outgas/offgas from materials and redistribute easily 'Adventitious carbon' deposits from atmosphere: exposure to smaller volumes, times, and/or cleaner atmosphere reduces deposition	Tier 1&2 compounds 10ppb TOC baseline 40ppb TOC threshhold Local maximum concentration not yet defined **Organic Compounds**

Planetary protection policy is informed by science

High confidence in scientific results is essential to ensure policy is effective

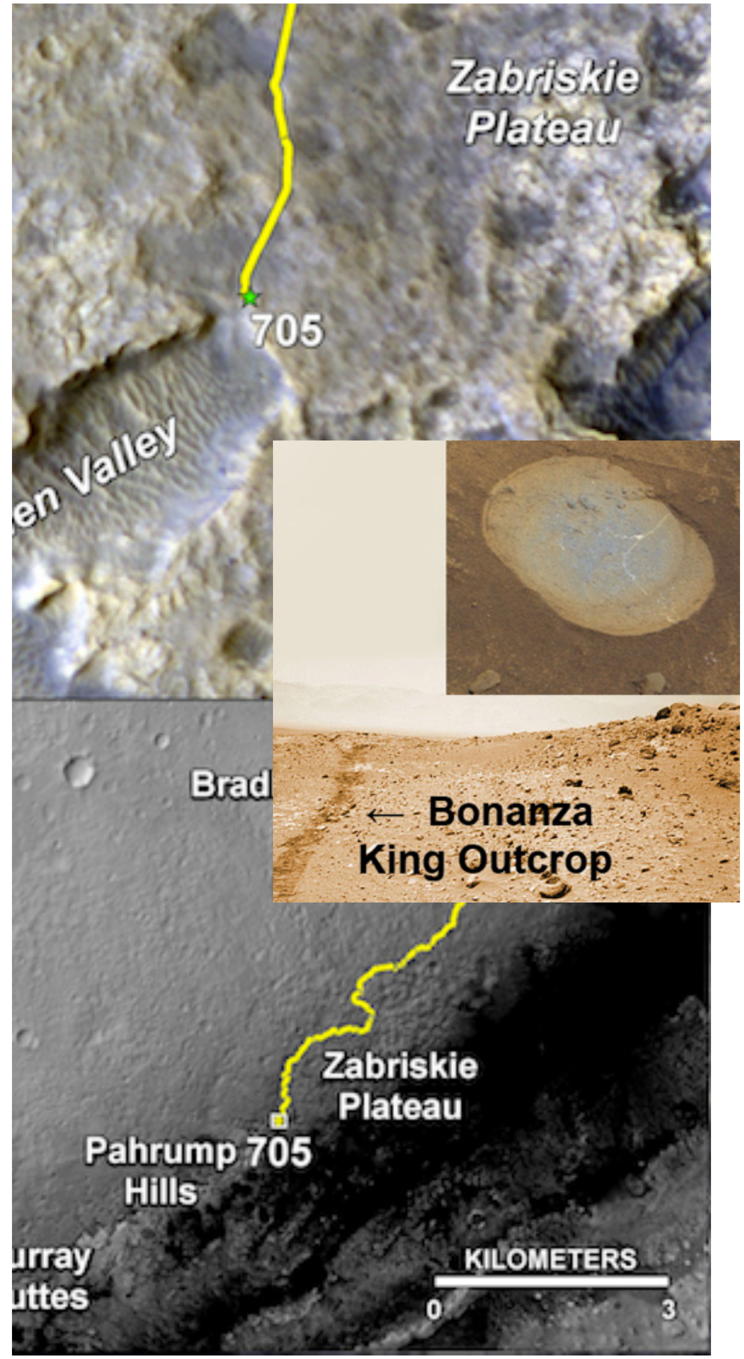
Needs Work: Spacecraft-Induced Special Regions



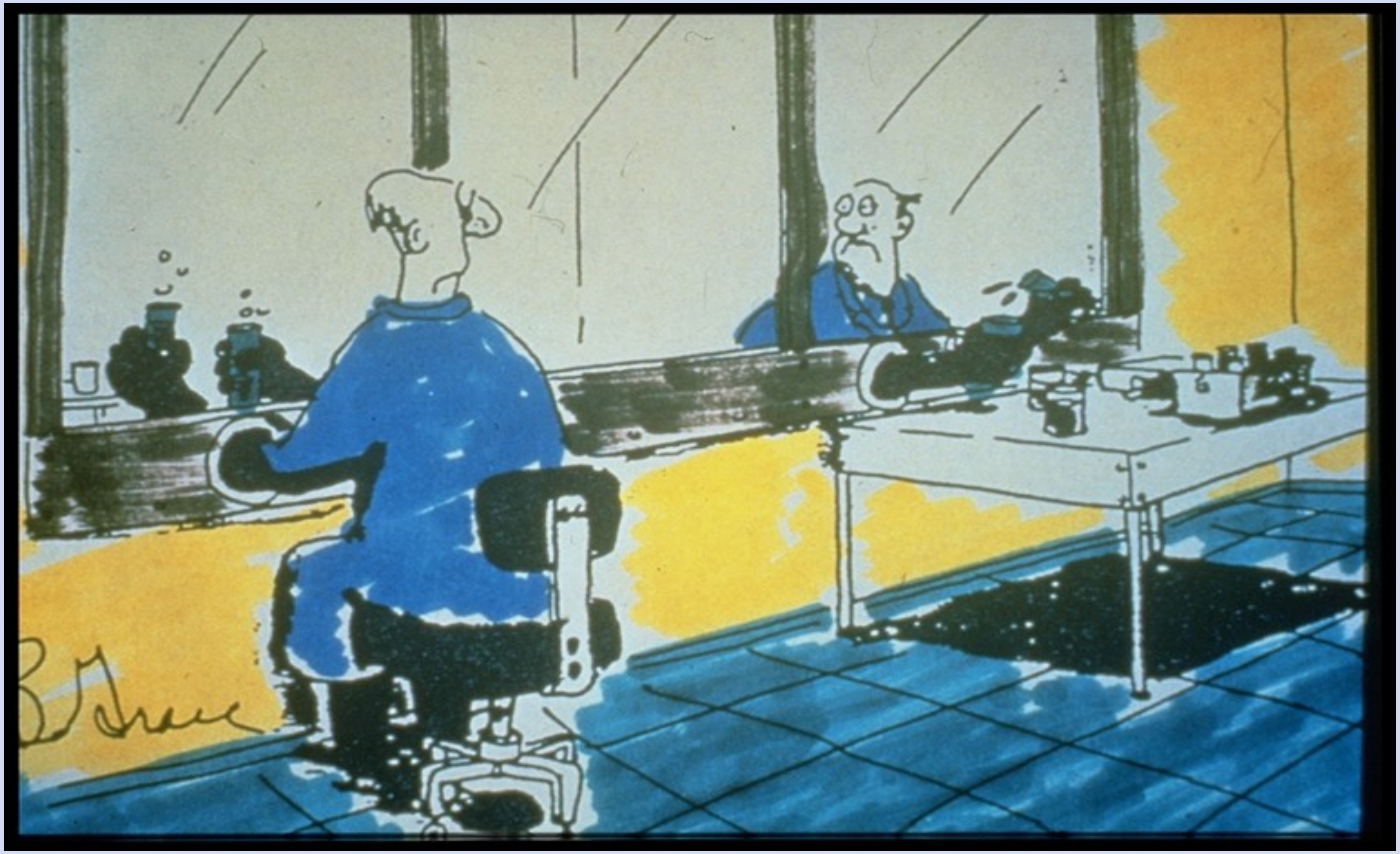
Possible mechanisms for creating Special Regions:

– Off-nominal impact delivers RTG to surface: MSL scenario
– Rover heats ground during nominal operations, inducing hydrated minerals to release water vapor into a closed environment: the Teakettle Problem
– Temperature gradient on rover from RTG to unheated surfaces creates special region when 100% relative humidity air condenses at night

Curiosity at Bonanza King Outcrop



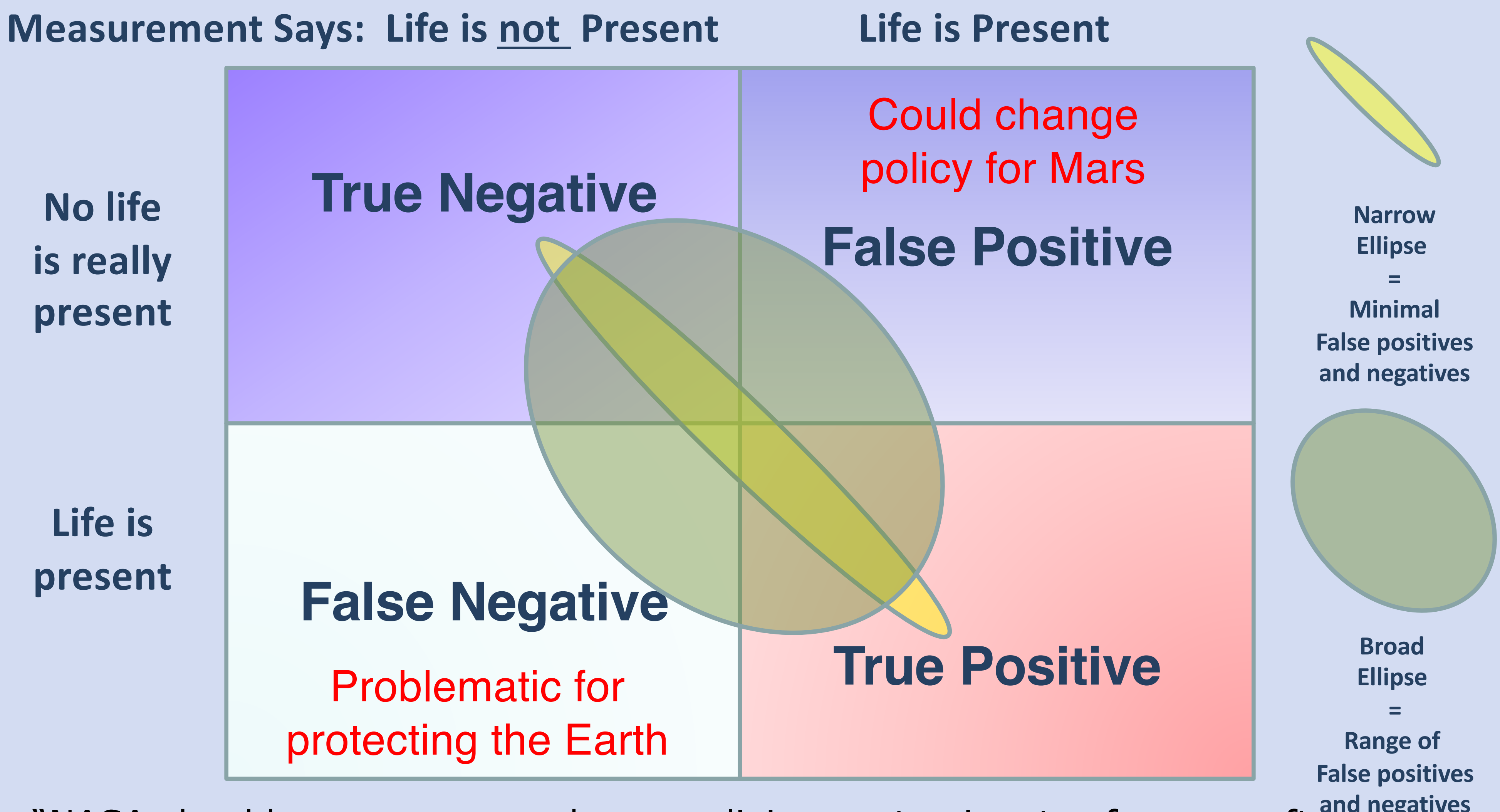
Returned Samples: Release from Containment?



Protecting the Earth and performing science have many clear synergisms – however:

The highest priority when studying extraterrestrial samples is to prevent harm to the Earth

Organic Contamination and Life Detection



"NASA should sponsor research on nonliving contaminants of spacecraft ... and their potential to confound scientific investigations or the interpretation of scientific measurements, especially those that involve the search for life."

-- SSB, 2006

NASA/COSPAR Guidelines for Restricted Earth Return

- "... the outbound leg of the mission shall meet Category IVb requirements..."
- "... the canister(s) holding the samples returned from [target] shall be closed, with an appropriate verification process, and the samples shall remain contained ... transport to a receiving facility ... opened under containment."
- "The mission and the spacecraft design must provide a method to "break the chain of contact" with [target]. ..."
- "Reviews and approval of the continuation of the flight mission shall be required ..."
- "For unsterilized samples returned to Earth, a program of life detection and biohazard testing, or a proven sterilization process, shall be undertaken as an absolute precondition for the controlled distribution of any portion of the sample."

All requirements are consistent with SSB recommendations from multiple reports on planetary protection considerations for Restricted Earth Return

PD/NSC-25: Scientific or Technological Experiments with Possible Large-scale Adverse Environmental Effects ...

- Applies to "all experiments that might have major and protracted effects on the physical or biological environment, or other areas of public or private interest ... even though the sponsoring agency feels confident that such allegations would in fact prove to be be unfounded."
- Federal Agencies' experiments must comply with PD/NSC-25 procedures independent of NEPA compliance

  1) Agency Head must report proposed experiments to OSTP Director sufficiently early to conduct appropriate reviews.

  2) Agency must provide a detailed evaluation of the experiments' importance, and possible direct or indirect environmental effects.

  ...

  6) In the case of experiments with potential global adverse effects, the Secretary of State will be consulted. The US National Academy of Sciences and international scientific bodies and intergovernmental organizations may be consulted.

  7) Experiments that may involve particularly serious or protracted adverse effects will not be conducted without approval of the President, and the head of the Agency involved, with advice of other concerned agencies.

MSR Campaign-Level Planetary Protection Requirements

- Campaign level categorization and individual mission-phase requirements:
  - All flight elements of a Mars Sample Return effort that contact or contain materials or hardware that have been exposed to the martian environment to be returned to Earth are designated "Planetary Protection Category V, Restricted Earth Return"
  - Landed elements must adhere to requirements equivalent to Planetary Protection Category IVb Mars missions, or Planetary Protection Category IVc should the landed element be intended to access a 'special region'
  - Orbital elements, including hardware launched from Mars, must meet requirements equivalent to Planetary Protection Category III Mars mission

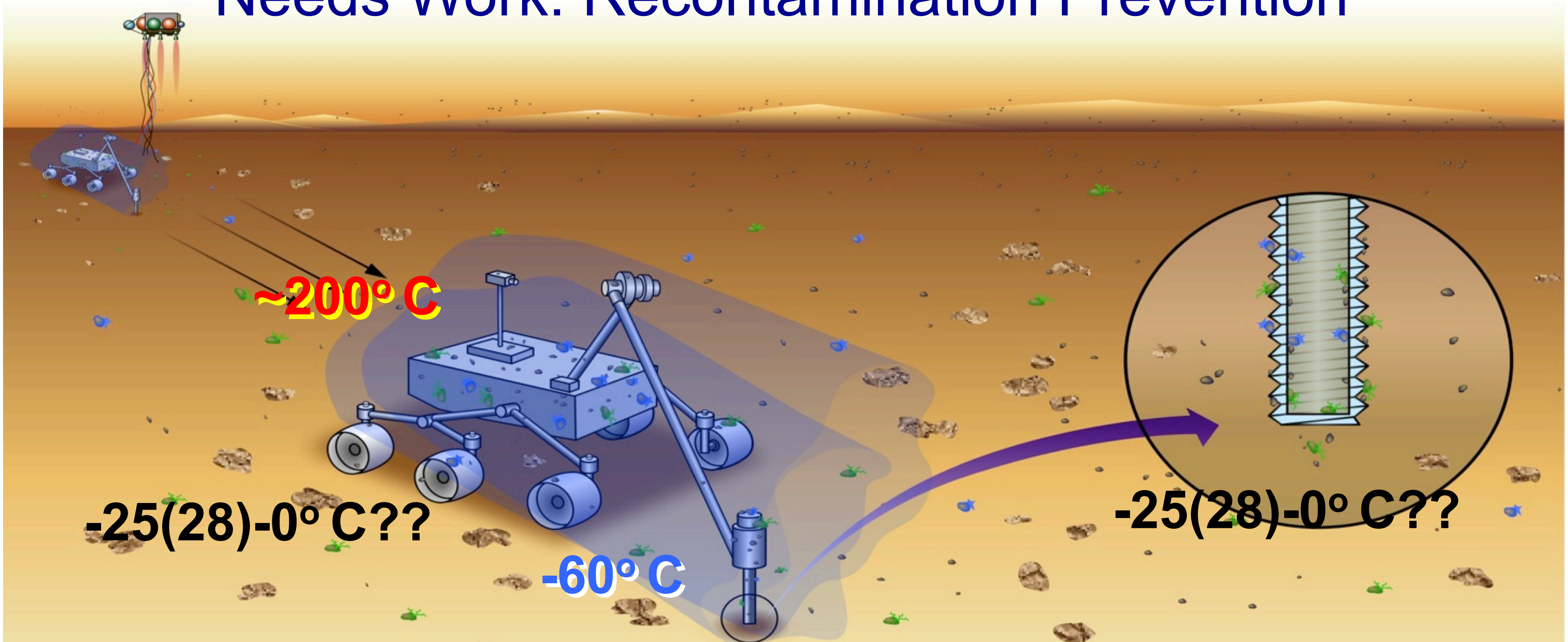
MSR Campaign-Level Life Detection Considerations

- Campaign level requirements:
  - all items returned from Mars shall be treated as potentially hazardous until demonstrated otherwise: *avoid adherent dust from atmosphere*
  - release of unsterilized martian material shall be prohibited: <10nm particle at <1×10^{-6} probability: *ESF study input to COSPAR*
  - subsystems sterilized/cleaned to levels driven by the nature and sensitivity of life-detection experiments and the planetary protection test protocol: *Viking/ExoMars organic cleanliness with IVb subsystem bioburden control, and recontamination prevention through return*
  - life-detection measurements dictate limits on contamination/recontamination of the samples: *assume instrumentation at least as sensitive as today*
  - need methods for preventing recontamination of the sterilized and cleaned subsystems and returned material: *technology development*
  - presence of a long-term heat source (RTG) would impose additional landing site restrictions to prevent both nominal and off-nominal spacecraft-induced "special regions":

Current Capabilities Will Improve...

- Instrumentation used on returned Mars samples will be at least as sensitive as today's instrumentation
- Detection of organic material on surfaces can attain femtomolar/attomolar sensitivity over micron-scale spots (e.g., LDMS; other desorption techniques)
- Detection of organic material in bulk samples can attain parts-per-billion sensitivity (ng/g)
- Capabilities to verify pre-launch organic/biological cleanliness may constrain requirements in practice
- Provisional guidance can be derived from past and current life detection missions, but additional work is necessary to assess current capabilities and extrapolate future needs

Needs Work: Recontamination Prevention



Possible mechanisms for contamination transport during operations

- Redistribution of contaminants (volatile and particulate) during cruise & EDL
- Generation and redistribution of contaminants during operations on Mars: moving parts; active temperature cycling of hardware
- Temperature gradient on rover from RTG to unheated surfaces creates potential for cyclical redistribution due to diurnal temperature/pressure cycling

Earth Safety Analysis: Open Issues

- Statistical confidence needed to permit samples to be returned?
  - Policy guidance (SSB report and ESF study evaluated by COSPAR)
  - Technology development activities to assess/improve reliability of spacecraft systems are ongoing but relatively independent
- How confident are we that life can be detected, if there?
  - Statistical approaches needed to inform sub-sampling of returned samples, for both physical and biological heterogeneity
  - Instrumentation to make measurements that detect life
  - Field tests to demonstrate adequate performance
- What material will go to destructive testing for planetary protection?
  - Address only safety issues not covered by measurements useful to both science and planetary protection: *NOT a flat "10%"*
- What criteria allow release of unsterilized samples from containment?
  - A defined protocol for life detection, with appropriate decision trees for investigation branch-points, will inform policy: open-ended 'know it when we see it' approaches may be inadequate to permit release
  - Statistics of Risk Assessment/Decision Analysis will be key

Do we want those neighbors?