Planetary Protection Requirements on Missions Collecting Samples for Return to Earth from Mars: *id est* M2020

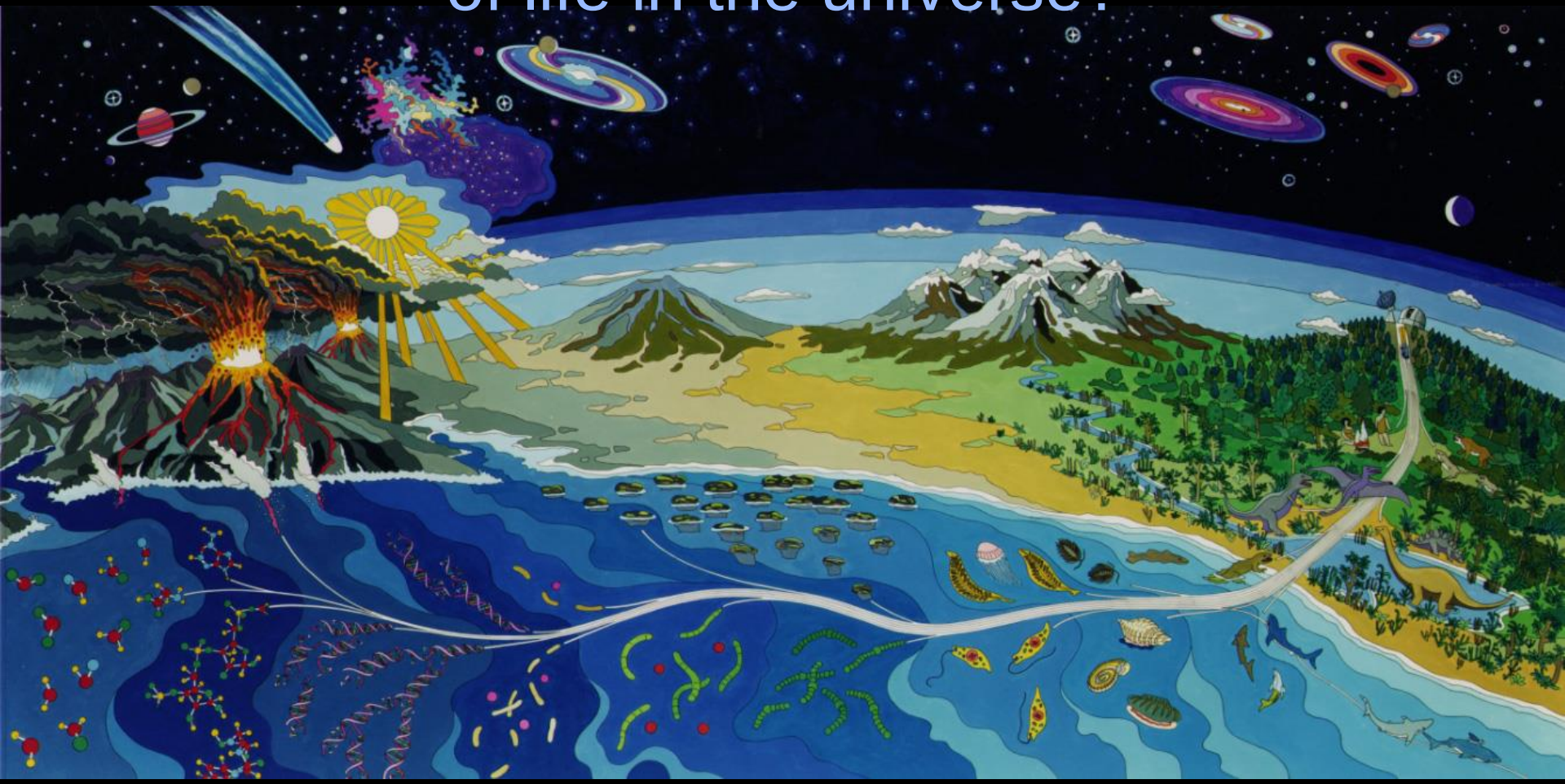
8 Dec. 2015

C. A. Conley, Ph.D.
Planetary Protection Officer
NASA Headquarters

Outline

- Background and Requirements
- Landing Site Issues
- Caching Requirements
- Restricted Earth Return

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...

NASA Planetary Protection Policy
(from NPD 8020.7; near-verbatim from COSPAR)

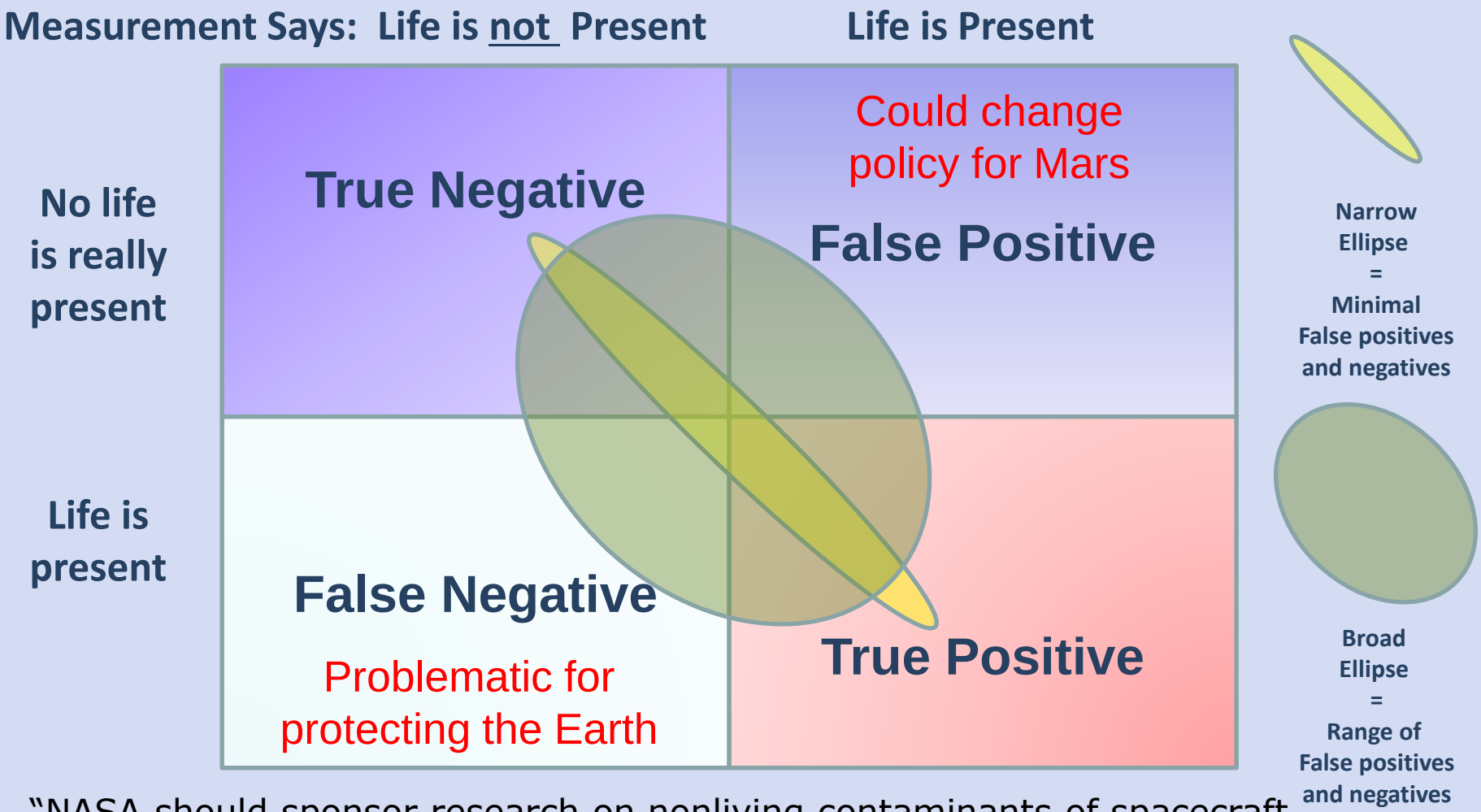
- "The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized."
  - Preserves science opportunities directly related to NASA's goals, and can support certain ethical considerations; originally recommended to NASA by the NAS in 1958
  - 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."

NASA/COSPAR Guidelines for Mars Sample Return

- "... the outbound leg of the mission shall meet Category IVb requirements..."
- "... the canister(s) holding the samples returned from Mars 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 Mars. ..."
- "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 MSR requirements are consistent with SSB recommendations from multiple reports on planetary protection considerations for Mars Sample Return

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

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.

Outline

- Background and Requirements
- Landing Site Issues
- Caching Requirements
- Restricted Earth Return

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 $<1x10^{-6}$ 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

Partial Categorization Letter, 05-2015

- ... due to the presence of a "returnable" sample cache including hardware that is intended in future to be returned to Earth, the M2020 mission represents the first element of a possible future Mars Sample Return campaign, and hereby receives a designation of Planetary Protection Category V Restricted Earth Return...

- ... the outbound leg of the M2020 mission shall be required to comply with requirements for Planetary Protection Category IVb implemented at subsystem level, as a mission to Mars that will not access Special Regions, but that will conduct "scientific investigations of possible extraterrestrial life forms, precursors, and remnants" ...

- To ensure appropriate coordination and oversight by the PPO of project requirements relevant to planetary protection and possible future sample return, all changes to M2020 Project Level 1 requirements relevant to planetary protection, as well as lower-level derived requirements affecting planetary protection compliance that would normally come under project or program control, shall be submitted to the PPO for approval prior to acceptance or implementation by M2020.

in situ Biosignature Detection (05-15)

1. Clarification of NPR 8020.12D Section 5.3.2.2.b implemented at subsystem level, requirements for *in situ* instruments investigating 'precursors or remnants' of life:

1.1 The M2020 project shall prevent contamination by Earth compounds of Mars materials subjected to *in situ* analysis above the levels negotiated with instrument providers as part of instrument accommodations.

a) pre-launch cleanliness levels and post-launch operations necessary to ensure adequate contamination prevention shall be derived by the project and reported as part of implementing planetary protection requirements

b) compliance shall be monitored by the PPO in addition to project/program processes

Outline

- Overview of Requirements
- Landing Site Issues
- Caching Requirements
- Restricted Earth Return

Avoiding Special Regions (05/*07*-2015)

2. Clarification of NPR 8020.12D Sections 5.3.2.3.c and 5.3.2.5.c, requirements for avoiding access to or creation of spacecraft-induced special regions:

2.1 Due to the presence of a radiothermal generator (RTG) used to power the M2020 rover, the M2020 project shall ensure that candidate landing sites exclude the following from the post-parachute-opening 3-sigma landing ellipse:

a) locations with ice or hydrated minerals at depths of <5 meters (based on MSL impact calculations), for which exposure to an RTG could cause liquid to be liberated sufficient to mobilize a particle of <50nm in size

b) Special Regions as formally defined in NPR 8020.12D Section 5.3.2.5 or as modified by mutual agreement prior to launch, pending evaluation of the definition rendered by the 2014-15 MEPAG/SSB/ESF evaluations, and subject to review by the NASA Planetary Protection Subcommittee

c) transient Special Regions created by the presence of an RTG on the rover are included in these constraints: their absence shall be demonstrated by test and analysis

2.2 In addition to the standard reviews, the final candidate landing sites shall undergo an independent review, organized by the PPO, as part of the pre-launch landing site selection process and prior to the preparation and presentation of landing site options to the Science Mission Directorate Associate Administrator.

2.3 Later access to locations identified in 2.1, via either vertical or horizontal mobility of rover elements, shall be prohibited.

NPR 8020.12D: Special Regions Definition

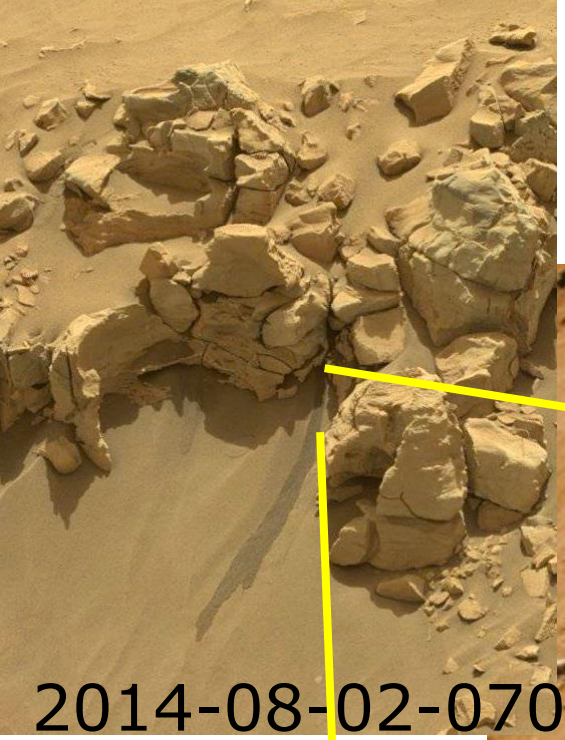
5.3.2.5 a. Given current understanding of terrestrial organisms, Special Regions are defined as areas or volumes within which sufficient water activity AND sufficiently warm temperatures to permit replication of Earth organisms may exist. The physical parameters delineating applicable water activity and temperature thresholds are given below:

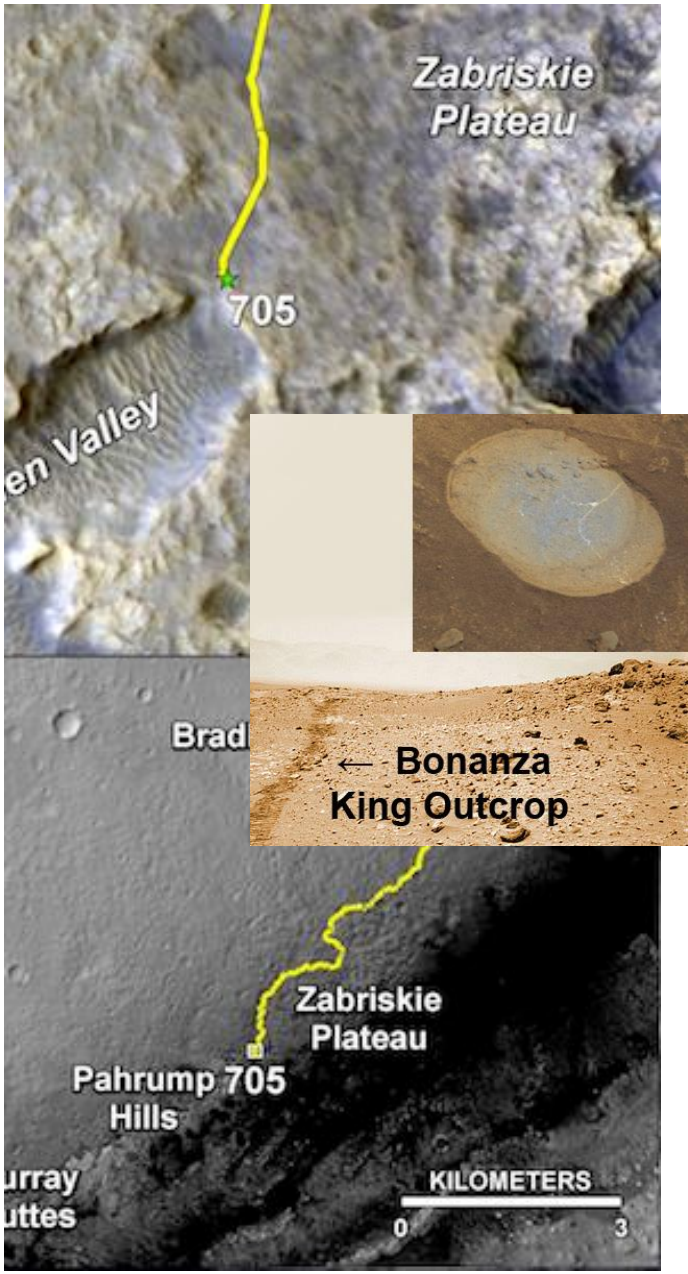
(1) Lower limit for water activity: 0.5 aw; Upper limit: 1.0 aw
(2) Lower limit for temperature: -25C (revised to -28C); No Upper limit defined
(3) Timescale over which limits apply: 500 years (short timescale TBD)

b. Observed features for which there is a significant (but still unknown) probability of association with liquid water and which should be classified as Special Regions:

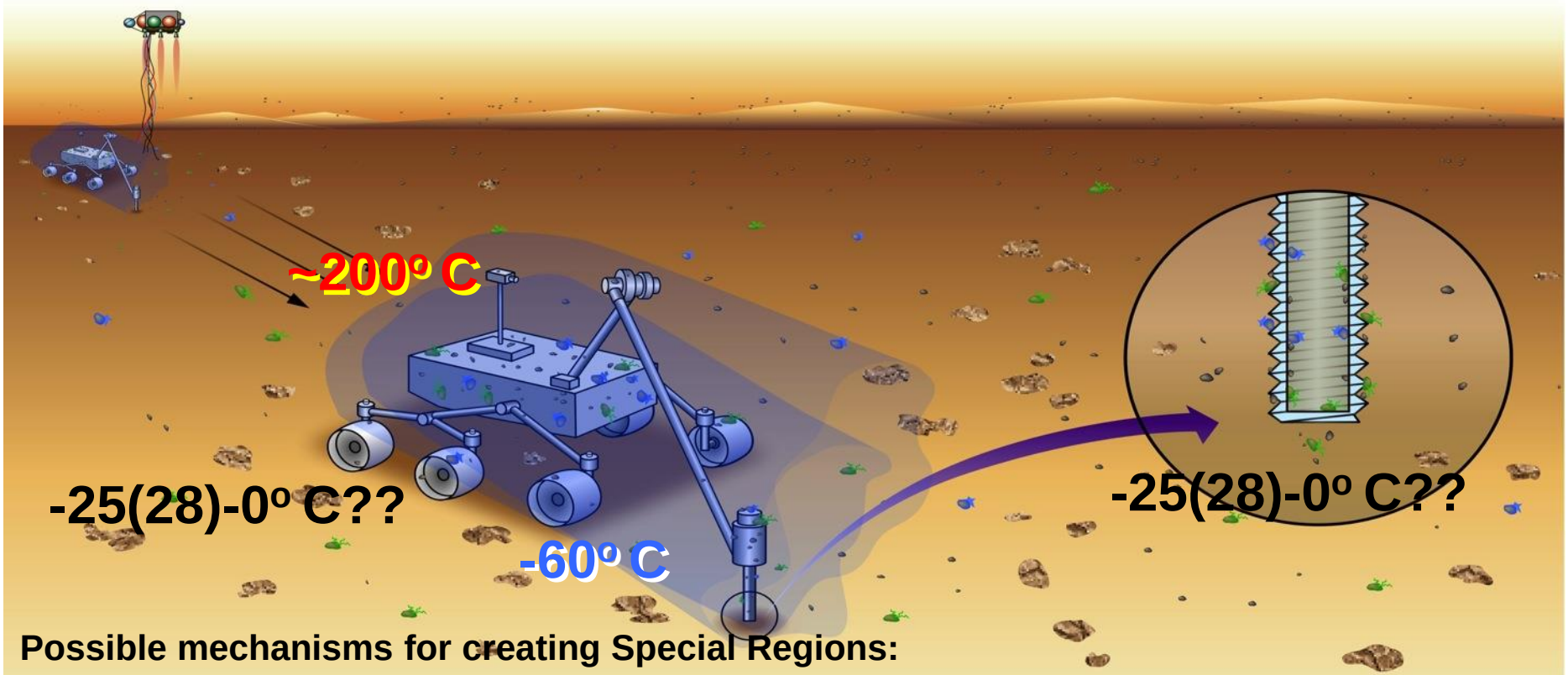
(1) Gullies and bright streaks associated with gullies
(2) Pasted-on terrains
(3) Subsurface below 5 meters
(4) Others, to be determined, **including dark streaks**, possible geothermal sites, fresh craters with hydrothermal activity, modern outflow channels, or sites of recent seismic activity.

Curiosity at Bonanza King Outcrop





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

RH: ??%

Outline

- Overview of Requirements
- Landing Site Issues
- Caching Requirements
- Restricted Earth Return

Sample Caching System Hardware (12-15)

1.2 Hardware subsystems that are involved in the acquisition, delivery, and storage of samples intended for future return to Earth shall be cleaned to a level of <300 heat resistant 'spores' per m2 of hardware surface and also cleaned to levels of organic cleanliness derived as described in section 3.1.a of this letter, enclosed in a physical biobarrier that is not subsequently opened until operations at Mars, and subjected to a validated biological reduction process (e.g. Dry Heat Microbial Reduction) that achieves at least four orders of magnitude of microbial reduction.

1.3 Recontamination shall be prevented as described under section 3 of this letter.

1.4 Pre-launch hardware cleanliness shall be verified by test:

a) verification of biological cleanliness shall be performed following NASA-standard processes

b) a similar level of verification shall be performed for organic cleanliness, following validated processes

c) a microbial inventory containing at least 99% (demonstrated by rarefaction curve) of nucleic acid sequences in subsystem hardware assembly environments shall be provided in the M2020 Post-Launch Report

d) typical PPO audit activities, as described for biological cleanliness in NPR 8020.12, shall be accommodated for both biological and organic cleanliness

Deviations from IVb Implementation (12-15)

The project has indicated that they plan to submit requests to deviate from the formal requirements given in in NPR 8020.12D for missions implementing Planetary Protection Category IVb at subsystem level.

Requests for deviation from formal requirements must be supported by documentation sufficient to demonstrate that the project-proposed implementation will achieve results equivalent to NPR 8020.12D.

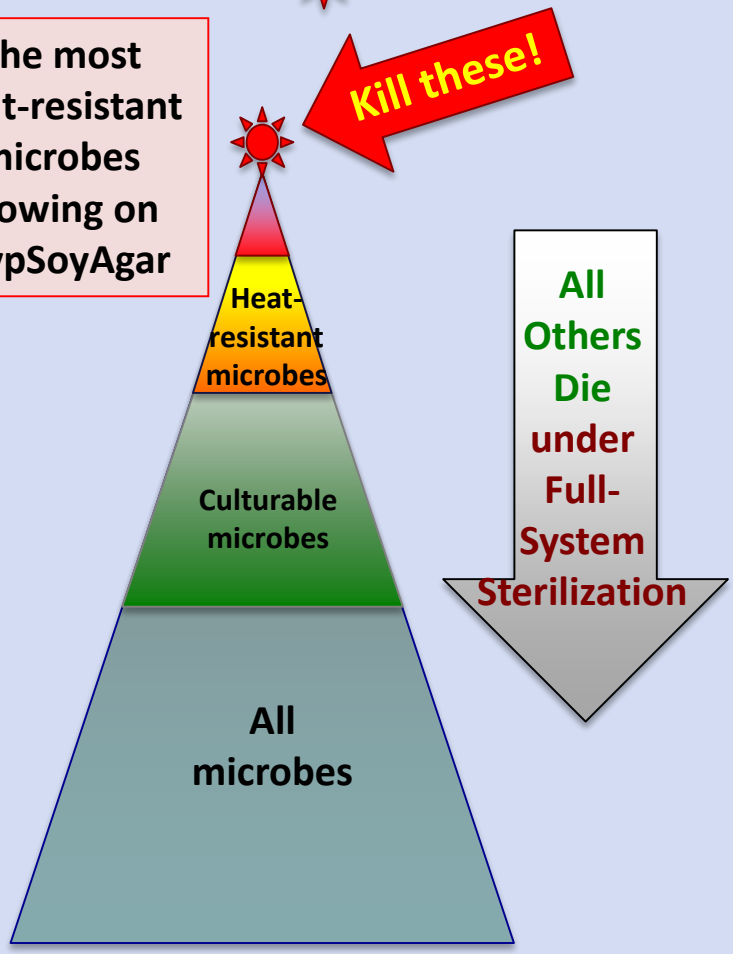
The Categorization Letter addresses this issue as follows:

“ Requests for deviations from standard NASA requirements shall follow the formal deviation process that has been provided to the project by the PPO. All deviation requests shall be supported by sufficient documentation to demonstrate equivalent readiness to TRL-6 for hardware systems, and also demonstrate process validation that meets accepted US or international standards (e.g., FDA QSR 820.75, ISO 13485 7.5.2) for any processes not currently accepted by the NASA PPO.”

Options for Microbial Reduction

What is a "spore" for planetary protection?

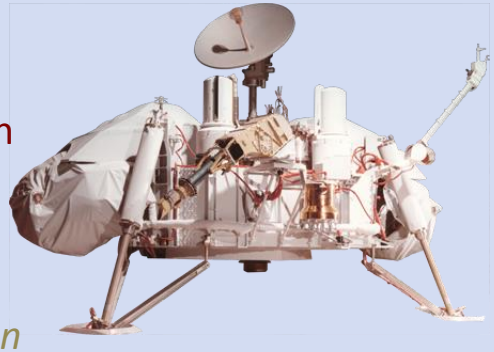
The most heat-resistant microbes growing on TrypSoyAgar



Similar approaches pertain to other microbial reduction processes

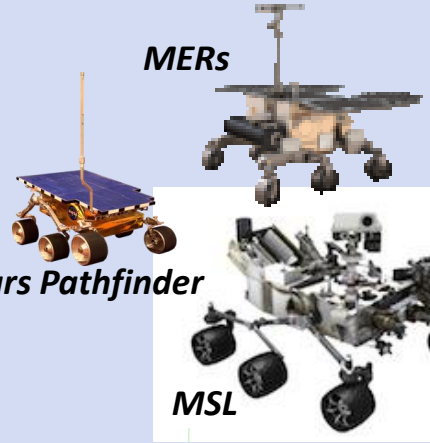
1970s

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



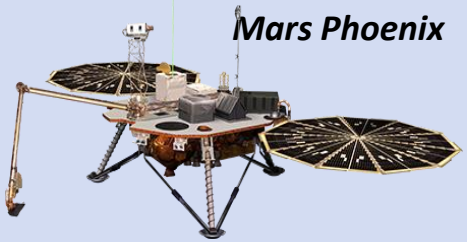
1990-2010s

Surface Cleaning

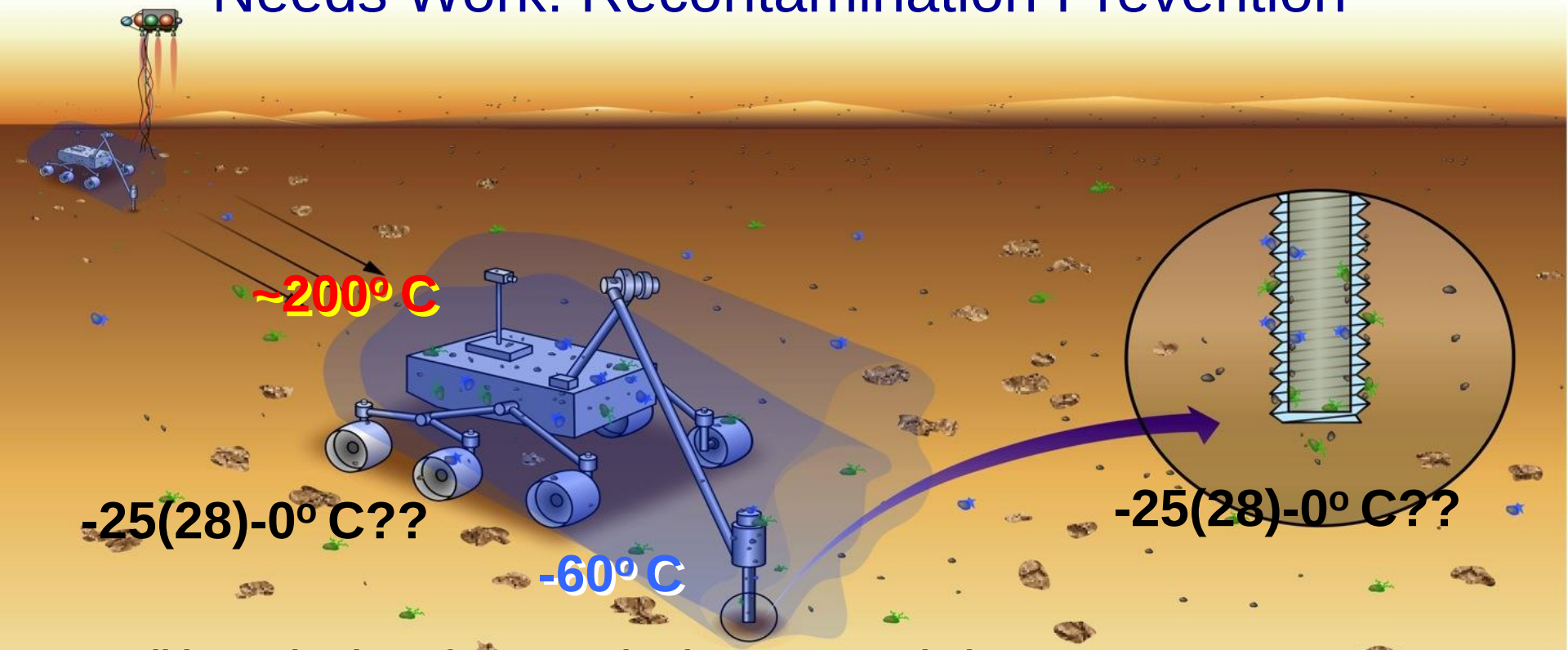


2000s

Surface Cleaning
Subsystem Reduction
Biobarrier for Arm



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

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

Outline

- Overview of Requirements
- Landing Site Issues
- Caching Requirements
- Restricted Earth Return

Restricted Earth Return (05-15)

3. Clarification of NPR 8020.12D Sections 5.3.3.2 and 5.3.2.7, requirements for Category V Restricted Earth Return:

3.1 The M2020 project shall ensure that Mars samples intended for possible future return are not contaminated by terrestrial organic compounds or viable organisms at levels above those specified below, through final deposition of sample tubes on Mars:

a) the probability that a single viable organism is introduced into each sample shall be less than the limit obtained by multiplying the internal surface area of a sealed sample tube, in m2, by the Viking post-sterilization surface bioburden limit of 0.03 viable organisms per m2

b) terrestrial organic contamination shall be limited to levels below < 1 ppb of any Tier 1 organic compound per sample; < 10 ppb Total Organic Carbon per sample (reference: draft Project L1 requirements and the 2014 MEP Organic Contamination Panel output)

3.2 Sample tubes shall be designed for opening after return to Earth in a manner that prevents additional contamination of samples during extraction.

Restricted Earth Return (05/*12*-15)

3.3 The M2020 project shall ensure that hardware is maintained at cleanliness levels necessary to comply with organic compound and viable organism contamination requirements. Specifically, the project shall:

a) derive the levels of hardware cleanliness necessary to ensure compliance, taking into account the potential for volatile and particulate recontamination at each phase of the mission
b) demonstrate, by analysis and test, that recontamination prevention approaches ensure maintenance of required sample cleanliness during all nominal rover operations through final deposition of sample tubes on Mars
c) develop cleanliness verification strategies to document compliance with pre-launch hardware cleanliness derived requirements
d) submit the above to OPP for review, acceptance, and subsequent compliance auditing

3.4 Documentation of relevant information about the M2020 mission, including detailed information about operations at Mars, and also information on interfaces between the M2020 project and future elements of a Mars Sample Return Campaign, shall be provided to the PPO in the form of a draft/partial Earth Safety Analysis Plan.

Documentation for Earth Safety Analysis

NPR 8020.12D, Section 2.7.2 F. PP Category V missions certified as "Restricted Earth return" require:

(1) A Planetary Protection Plan, including outbound phase requirements, if any, and an Earth Safety Analysis Plan.

(2) A Planetary Protection Implementation Plan and Return Implementation Plan that details the project's implementation of the Planetary Protection Plan.

...

(5) After sample collection, a report analogous to the outbound phase prelaunch reports: i.e., an Earth Pre-Launch Report.

(6) An Earth Pre-Entry Report demonstrating readiness to enter the Earth's atmosphere in compliance with planetary protection requirements.

(7) An End-of-Mission Report to address compliance with requirements for the protection of the Earth's biosphere and detailing the transfer of the samples to an appropriate containment facility.

(8) A Sample Pre-Release Report to provide verification of sample analysis procedures subsequent to the End-of-Mission and demonstrating that any planned sample release will not harm the Earth's biosphere.

Documentation for Earth Safety Analysis

NPR 8020.12 D Section 2.7.4.1 The Earth Safety Analysis Plan ... shall include

A. General
- (1) Identification
- (2) Rationale and Assumptions

B. Potential Contaminating Sources
- (1) Sample Containment Approach
- (2) Decontamination Approach (if required)
- (3) Earth Entry Plan

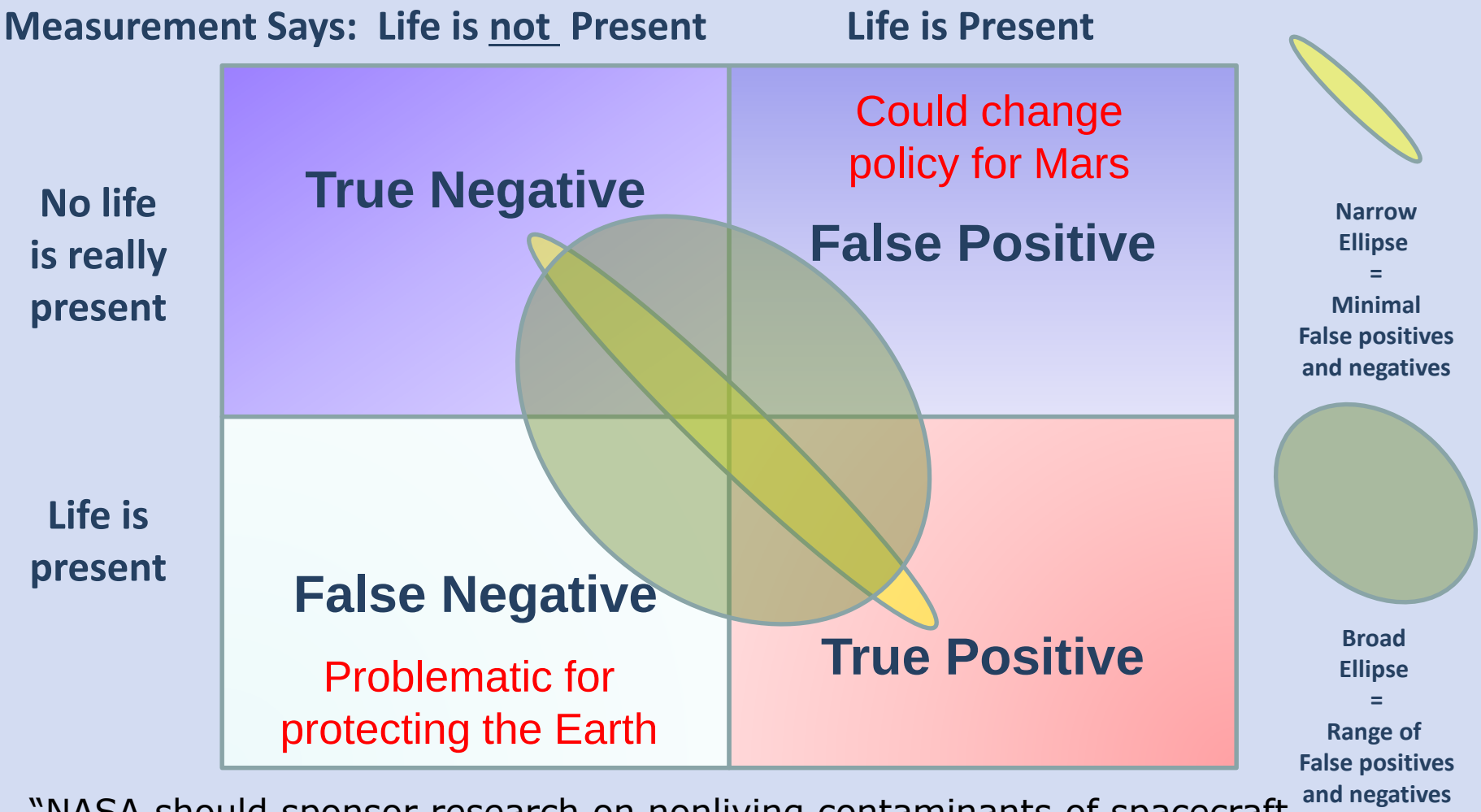
C. Probability of Contamination Model
- (1) Mission Probability of Contamination Equation
- (2) Critical Parameters
- (3) Contamination Sources Analysis
- a. Analytical Techniques
- b. Assumptions
- c. Substantiation of Parameter Values
- (4) Probability of Contamination Allocation Model
- a. Level of Risk (provided to the Project by the PPO)
- b. System Allocations (Return Capsule, Return Vehicle, etc.)

D. Analysis Documentation

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

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

Do we want those neighbors?