Current Issues in Planetary Protection

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25 May, 2012

2012 NASA Planetary Science Goals

Goal 2: Expand scientific understanding of the Earth and the universe in which we live.

2.3 Ascertain the content, origin, and evolution of the solar system and the potential for life elsewhere.

2.3.1 Inventory solar system objects and identify the processes active in and among them.

2.3.2 Improve understanding of how the Sun's family of planets, satellites, and minor bodies originated and evolved.

2.3.3 Improve understanding of the processes that determine the history and future of habitability of environments on Mars and other solar system bodies.

2.3.4 Improve understanding of the origin and evolution of Earth's life and biosphere to determine if there is or ever has been life elsewhere in the universe.

2.3.5 Identify and characterize small bodies and the properties of planetary environments that pose a threat to terrestrial life or exploration or provide potentially exploitable resources.

What are the origins, distribution, and future of life in the universe?

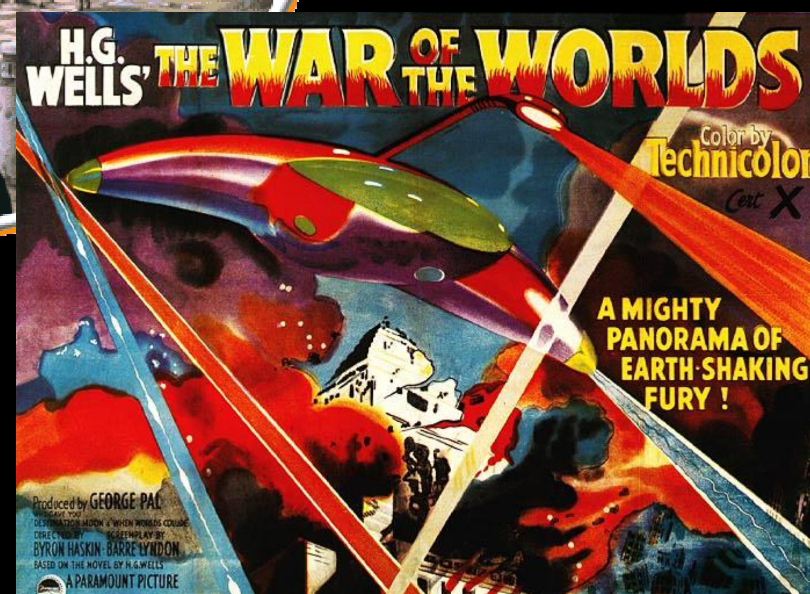
In a Nutshell...

H.G. Wells
1898

Orson Welles
1938

And scattered about...
were the Martians–dead!
–slain by the putrefactive
and disease bacteria against
which their systems were unpre-
pared; slain as the red weed was
being slain; slain, after all man's devices
had failed, by the humblest things that God,
in his wisdom, has put upon this earth.

...By virtue of this natural selection of our kind
we have developed resisting power; to no
germs do we succumb without a struggle...



Early Concerns: Protecting Science during Space Exploration

27 June 1958, Volume 127, Number 3313 SCIENCE

Moondust

The study of this covering layer by space vehicles may offer clues to the biochemical origin of life.

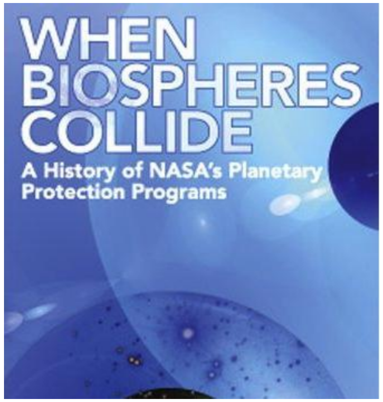
Joshua Lederberg and Dean B. Cowie

tions are very small, they are perhaps large enough to initiate the condensation. If this point is granted, it would then be necessary to examine the capture of a second atom of hydrogen or of carbon by the CH molecule. Because of the abundance of hydrogen, the first is more probable but the calculation of the probability of formation of the CH_2 molecule is very difficult. It is possible that some more hydrogen atoms attach themselves to the CH_2 molecule (CH_2 CH_3 CH_4 ?) but before long it is mainly atoms of much larger mass (C, N, O, . . .) which are captured because the large molecule

"…we urgently need to give some thought to the conservative measures needed to protect future scientific objectives on the moon and the planets"

Over 50 Years of International Effort

- 1956, Rome: International Astronautical Foundation meets to discuss lunar and planetary contamination
- Feb. 1958: International Council for Science (ICSU) forms committee on Contamination by ExtraTerrestrial EXploration



- June 1958: NAS establishes the SSB
- July 1958: Formation of NASA
- Oct. 1958: Formation of COSPAR by ICSU
- July 1958: Formation of UN-COPUOS
- 1959-1962: Publication of guidelines for preventing forward and backward contamination: US, USSR, COSPAR
- 1963: NASA acquires the first 'Planetary Quarantine Officer' – on loan from the Public Health Service

Preventing Contamination: A 'Probabilistic' Formulation

- In 1962, the SSB recommended to allow a 1×10^{-4} probability of contamination *per mission* – anticipating many missions

The number of microbes that could survive on a planetary object was based on the initial contamination level [N_0], and reduced by various factors:

$$N_{final} = N_{initial}\, F_1\, F_2\, F_3\, F_{...}$$

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
$F_{...}$—Additional factors as appropriate for the mission scenario

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

- Factors are organized in chronological order, with the understanding that iteration is necessary
- 'Probability of growth' on Mars, during Viking, was estimated to be 1×10^{-6} – we now know it's a lot closer to 1...

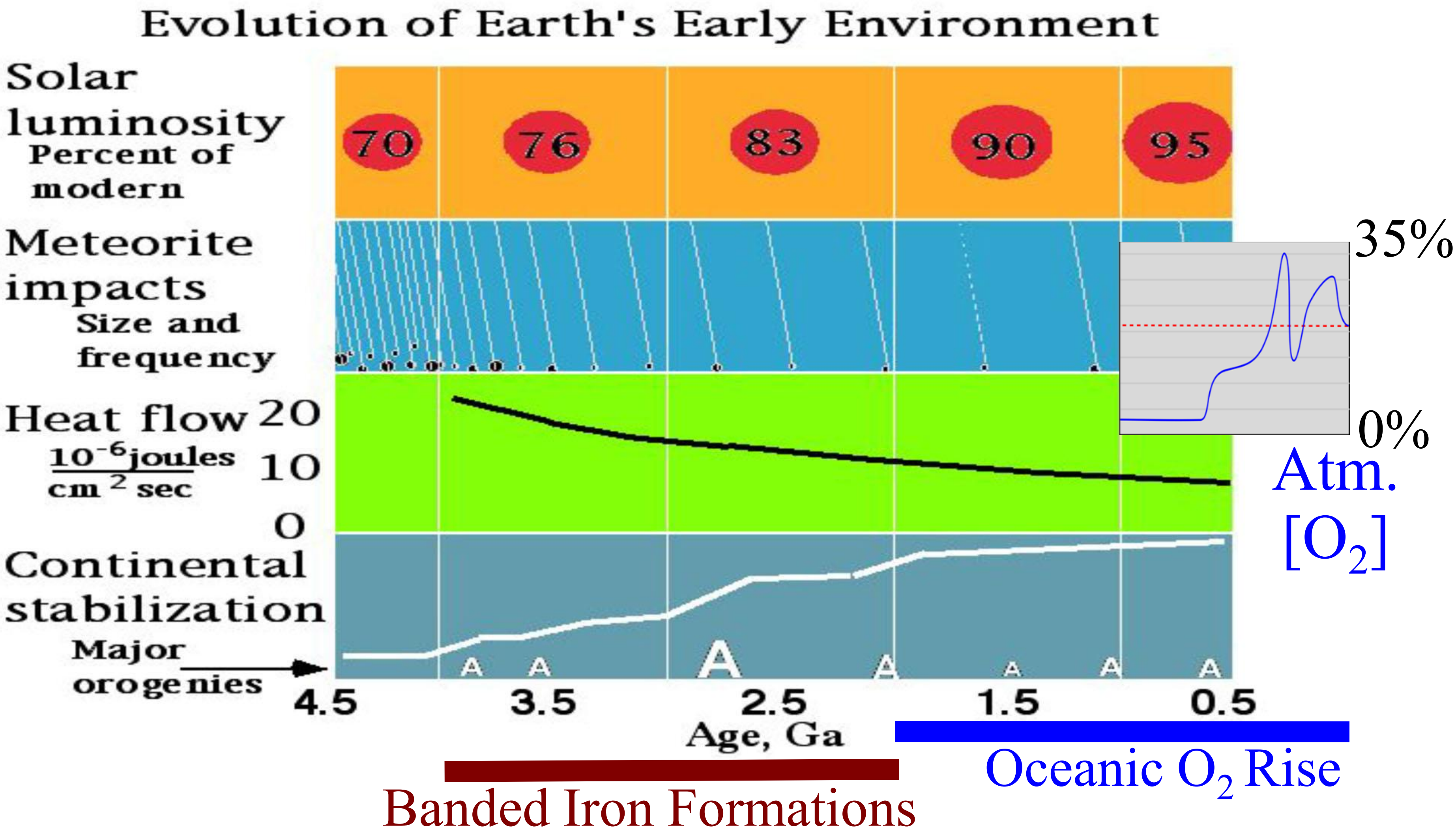
Current International Framework

- The Outer Space Treaty of 1967
  - Proposed to the UN in 1966; Signed in January 1967
  - Ratified by the USSR and US Senate by May, 1967
  - Article IX of the Treaty states that:

    "...parties to the Treaty shall pursue studies of outer space including the Moon and other celestial bodies, and conduct exploration of them so as to avoid their harmful contamination and also adverse changes in the environment of the Earth resulting from the introduction of extraterrestrial matter and, where necessary, shall adopt appropriate measures for this purpose..."

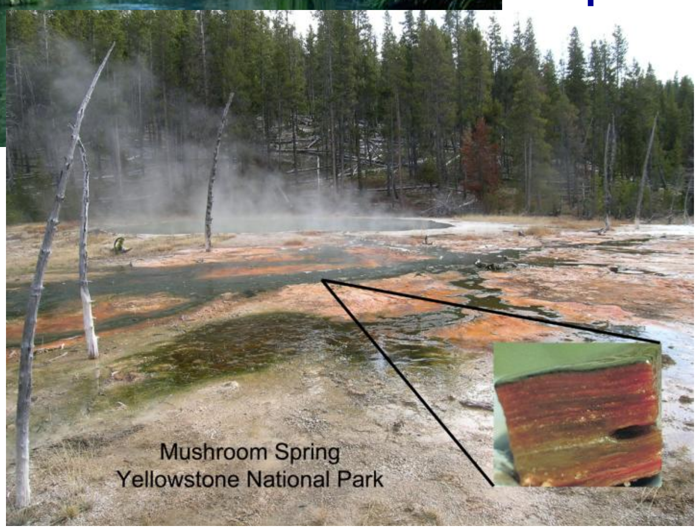
- The Committee on Space Research of the International Council for Science maintains an international consensus policy on planetary protection
  - COSPAR policy represents an international scientific consensus, based on advice from national scientific members, including the US Space Studies Board
  - COSPAR is consultative with the UN (through UN COPUOS and the Office of Outer Space Affairs) on measures to avoid contamination and protect the Earth
  - NASA and ESA policies specify that international robotic missions with agency participation must follow COSPAR policy, as a consensus basis for requirements

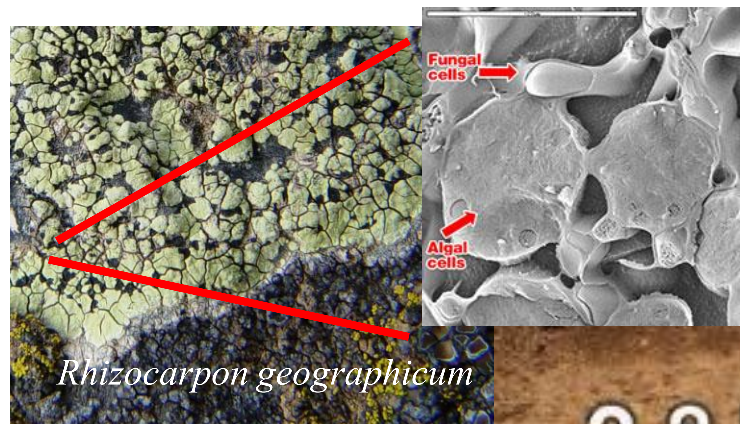
Life Affects the Evolution of Planets



Microbes are Everywhere on Earth

Most organisms live in fairly complex communities, in which members share resources and improve community survival





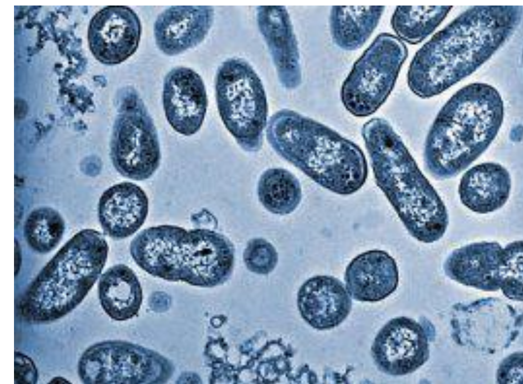
Lichen survives space exposure

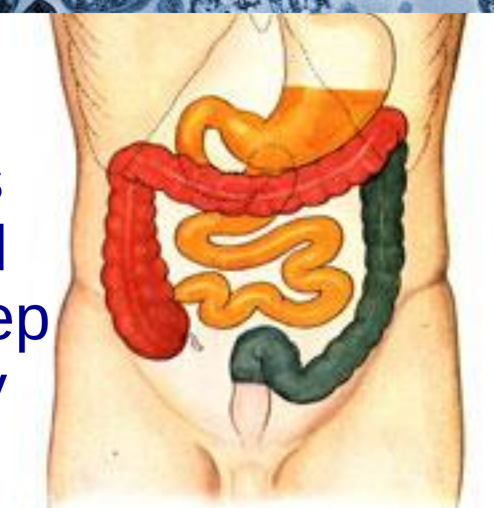
Some communities are made up of small numbers of species: frequently found in more ‘extreme’ environments

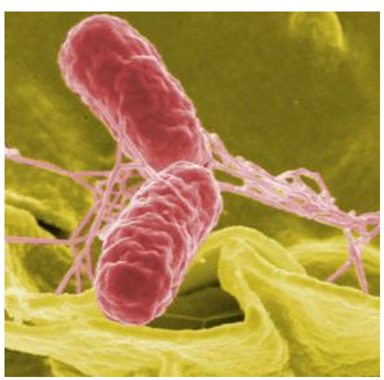
Introduced Organisms Can Have Ecological Impacts

Most stable communities are resistant to invasion by novel species

Salmonella typhimurium express more virulence genes after cultured growth in space







However, sometimes organisms with novel capabilities can sweep through a community

Life on Earth Keeps Spreading

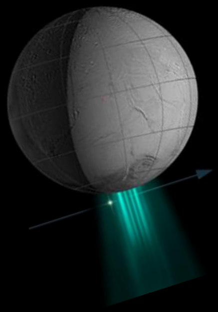
- Before *Deinococcus radiodurans,* we thought we knew how much radiation organisms could tolerate
- Before *Desulforudis audaxviator* (and their nematode predators), we thought we knew where organisms could live
- Organisms making do in 58 Million year old subsea sediments seem to wait around for a rather long time....
- What is the actual range (and duration) of conditions under which Earth Life can grow? Can tolerate? Can survive?
- Given that we know we keep learning more about life on Earth, how do we ensure that other planets are protected?

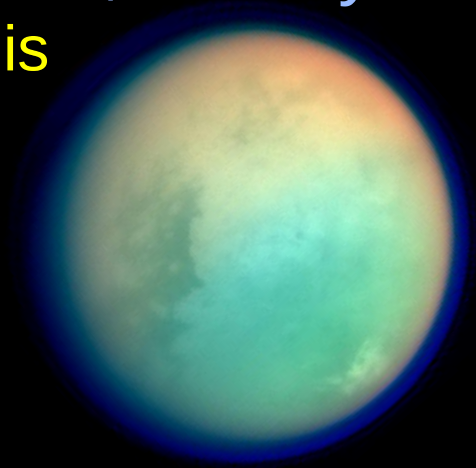
How do we compensate for what we *don't* know?

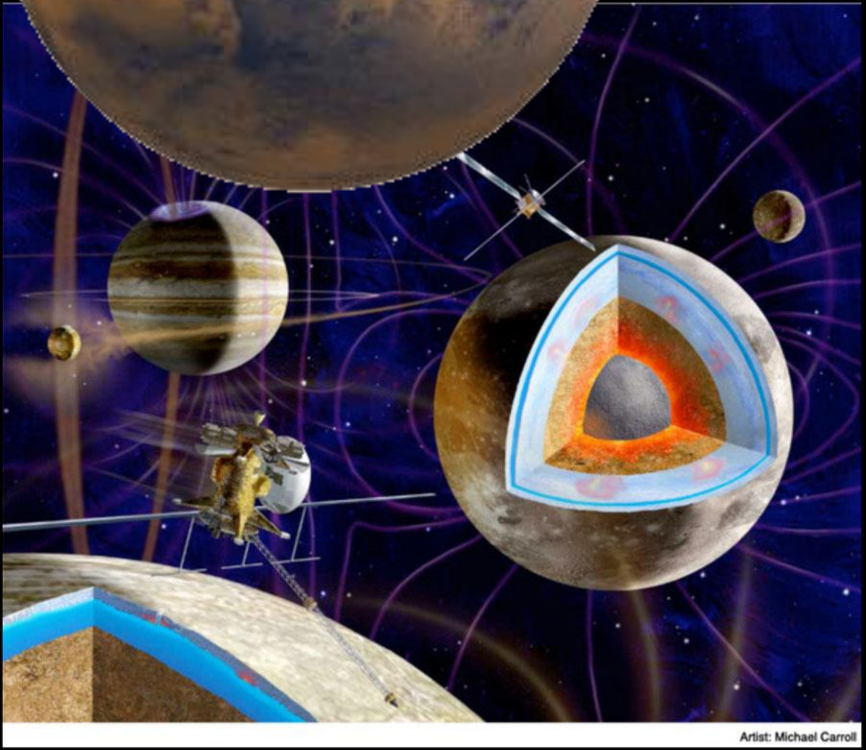
Planetary Environments are Diverse

The unaltered surfaces of most planets are cold, and by being cold, are dry

- spacecraft can change this







Interior environments may be more similar to Earth:

- possible subsurface oceans, both hot and cold
- subsurface rock, similar (?) to inhabited Earth rocks

Planetary Protection Mission Categories

PLANET PRIORITIES		MISSION TYPE	MISSION CATEGORY
A	Not of direct interest for understanding the process of chemical evolution. No protection of such planets is warranted.	Any	I
B	Of significant interest relative to the process of chemical evolution, but only a remote chance that contamination by spacecraft could compromise future investigations. Documentation is required.	Any	II
C	Of significant interest relative to the process of chemical evolution and/or the origin of life and for which scientific opinion provides a significant chance that contamination could compromise future investigations. Substantial documentation and mitigation is required.	Flyby, Orbiter	III
		Lander, Probe	IV
All	Any Solar System Body	Earth-Return *"restricted" or "unrestricted"*	V

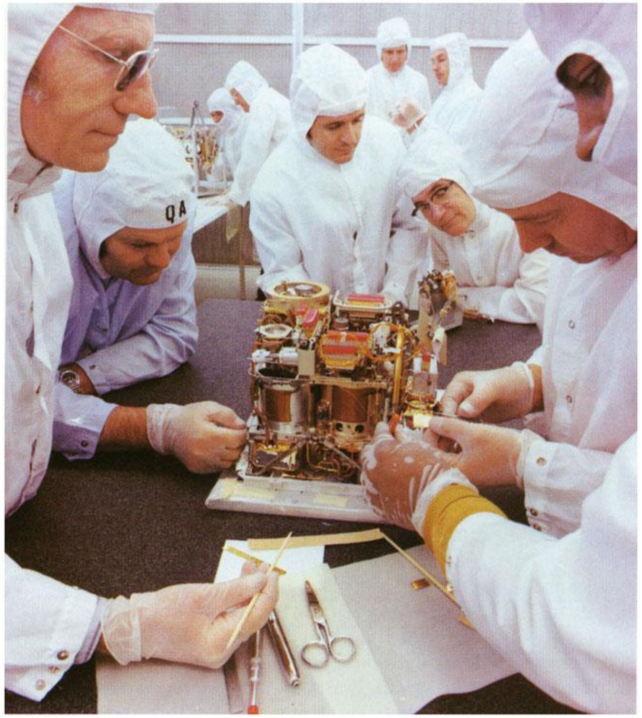
Planetary Protection Mission Constraints

- Depend on the nature of the mission and on the target planet
- Assignment of categories for each specific mission/body is to take into account current scientific knowledge based on recommendations from scientific advisory groups
- Examples of specific measures include:
  - Constraints on spacecraft operating procedures
  - Spacecraft organic inventory and restrictions
  - Reduction of spacecraft biological contamination
  - Restrictions on the handling of returned samples
  - Documentation of spacecraft trajectories and spacecraft material archiving

W. Peet, 1967

Cleaning Spacecraft Right: Viking

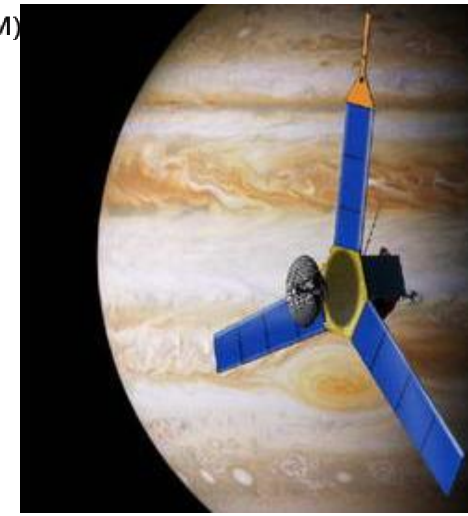
The Inquisition approach...



Dry Heat Microbial Reduction works

– The Viking Landers were estimated to carry ~30 viable spores
– This means they *needed* 10^{-6} in post-launch factors to meet the probability of contamination requirement

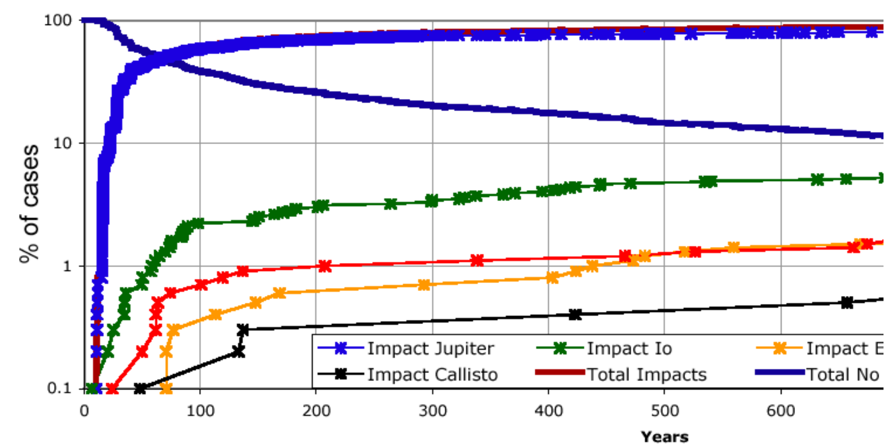
Juno Implementation Approach



Juno proposed to meet planetary protection requirements by avoiding impact with Europa (and other Galilean satellites) via an End-of-Mission Deorbit Maneuver.

To document a $1x10^{-4}$ probability of contamination, Juno considered a range of factors:

- How reliable is the spacecraft, over the mission phases during which Europa is in jeopardy?
- How long will organisms survive?
  - Bioburden at launch
  - Survival of contaminating organisms
- How likely is an Europa encounter?
- Can organisms survive the impact?



JUNO Allocations and Estimates

Item	Current Best Estimate	Requirement Allocation
Failure Risk Analysis: Probability that spacecraft failure prevents deorbit burn	0.045	≤ 0.1
Mission Design: Probability of impact of a non-sterile spacecraft (L3 Mission System)	0.005	≤ 0.015
Spacecraft/Europa Impact Analysis: Probability of contamination in the event of an impact	<0.04	0.06
Probability of contamination of the Europan Ocean	$<9x10^{-6}$	$9x10^{-5}$
Requirement	$<1x10^{-4}$	

Each individual factor was in the range of percent – all together, they reached 10^{-5}

Preventing Contamination: Flexibility within a Framework

- Each mission scenario is unique, and small factors can play a significant role in compliance
- The ability to tailor reduction factors *appropriately* allows increased resolution when aspects of compliance are more challenging
- Assessing reduction factors in the context of mission phases provides independence in time
- Detailed analysis progressing from early to late mission phases ensures that ‘margin’ is not wasted
- ‘Probability of Growth’ is the last factor to consider – we’ve been wrong too many times before

Current View: SSB Icy Bodies Report

Alles sollte so einfach wie möglich gemacht werden, aber nicht einfacher.

Albert Einstein

Everything should be made as simple as possible, but not simpler.

Current and Upcoming Missions

- Several missions in operation and in preparation have planetary protection considerations to watch
  - The Dawn asteroid orbiter mission must avoid possible contamination of Ceres
  - Each of the Discovery selection competitors have planetary protection implementation challenges, but they are well-understood
  - The OSIRIS-REx asteroid sample return mission faces organic contamination constraints driven by science, but relevant to future planetary protection implementation concerns
  - The MAVEN Mars orbiter mission plans to implement the bioburden control option to meet planetary protection requirements: analysis currently under review

New Frontiers Program

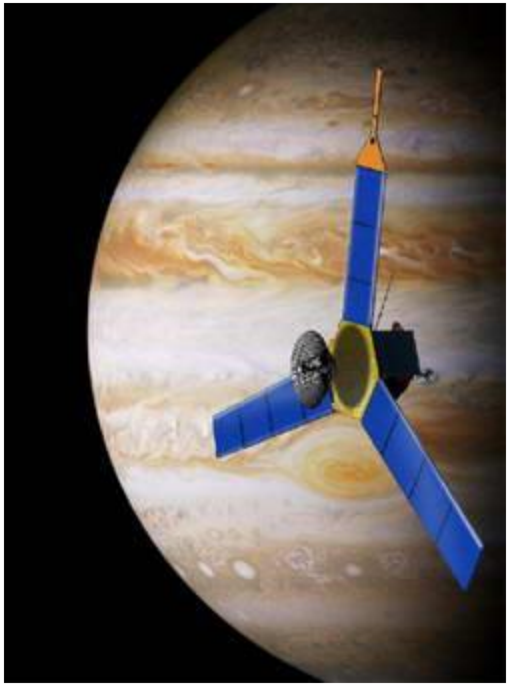
1st NF mission
New Horizons:

Pluto-Kuiper Belt Mission

Launched January 2006
Arrival July 2015

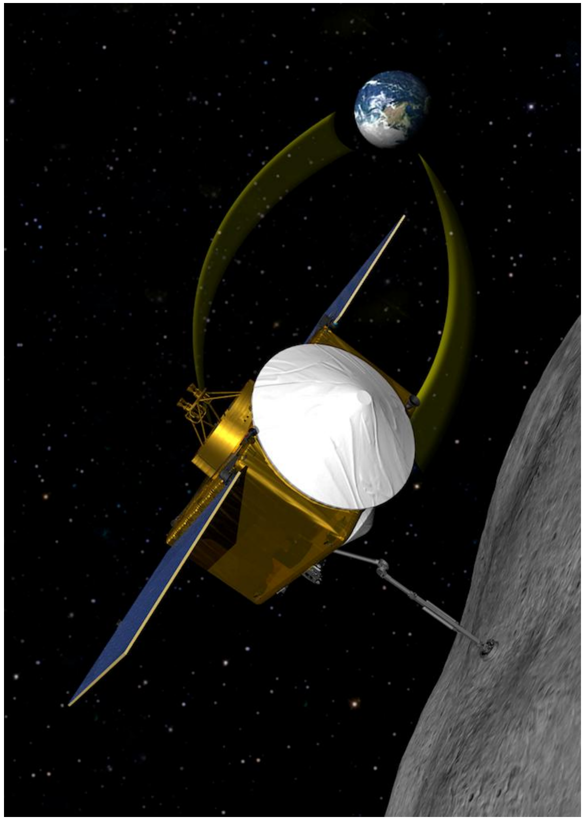
2nd NF mission
JUNO:

Jupiter Polar Orbiter Mission



August 2011 Launch
Arrival 2017

3rd NF mission
OSIRIS-REx
Asteroid Sample Return



September 2016 Launch
Arrival 2019

Discovery: Operating Planetary Missions

MESSEnGER:

GRAIL:

Dawn:

If Dawn finds water at Ceres, the project must take precautions

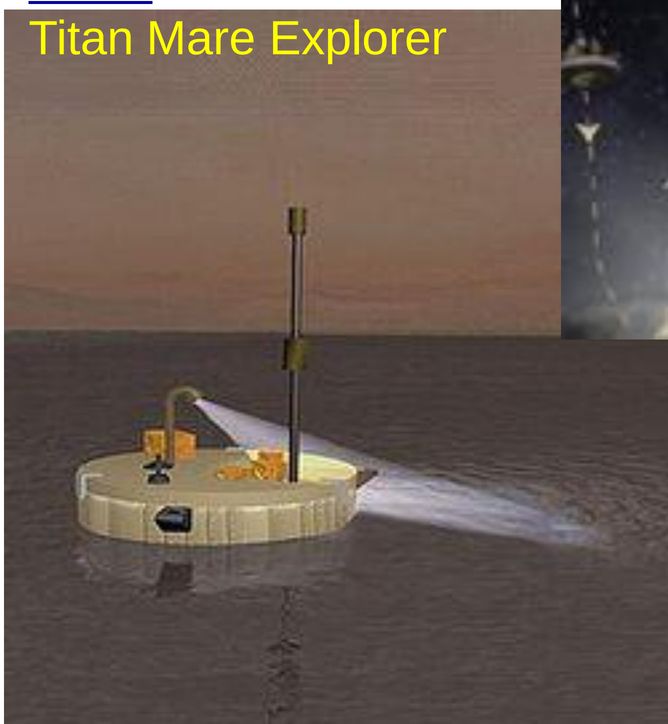
Current Discovery Competition:

CHopper:

Comet Hopper

TiME:

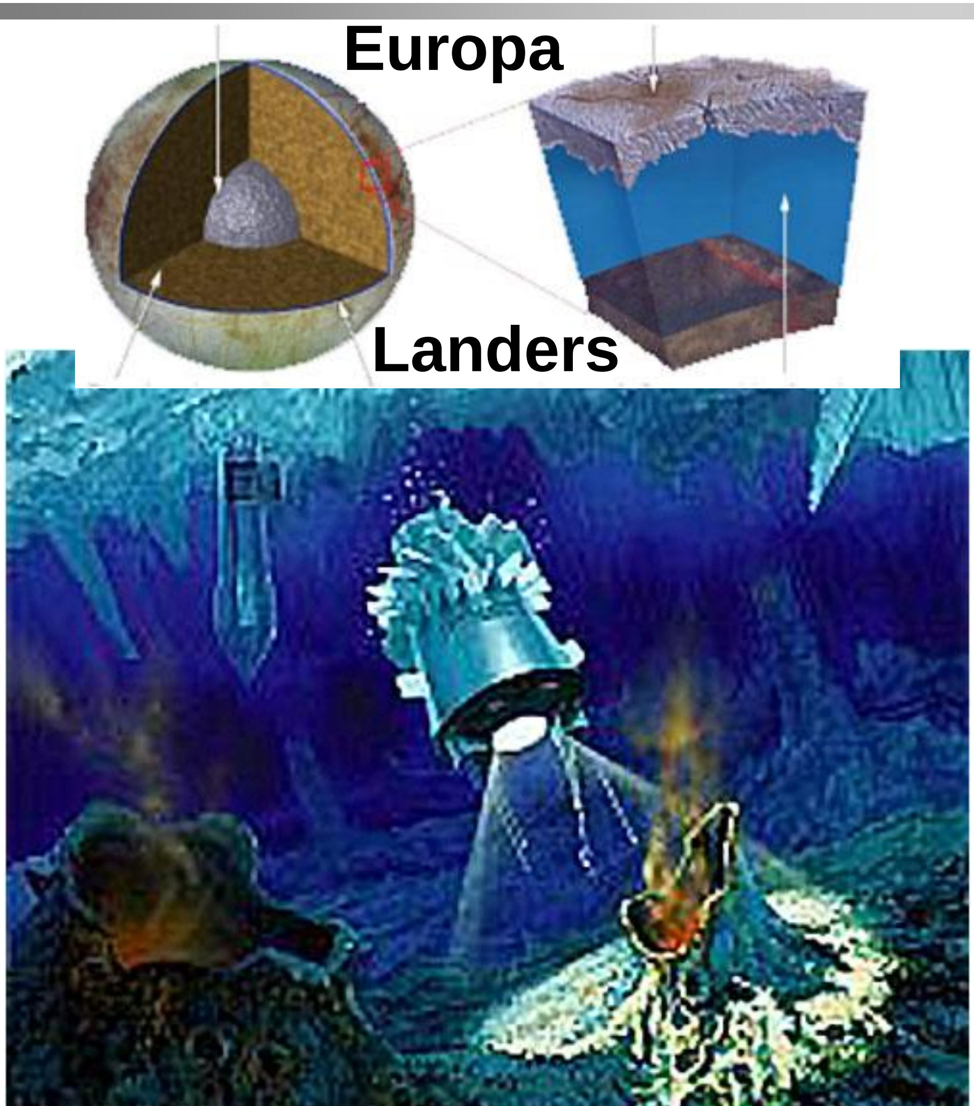
Titan Mare Explorer

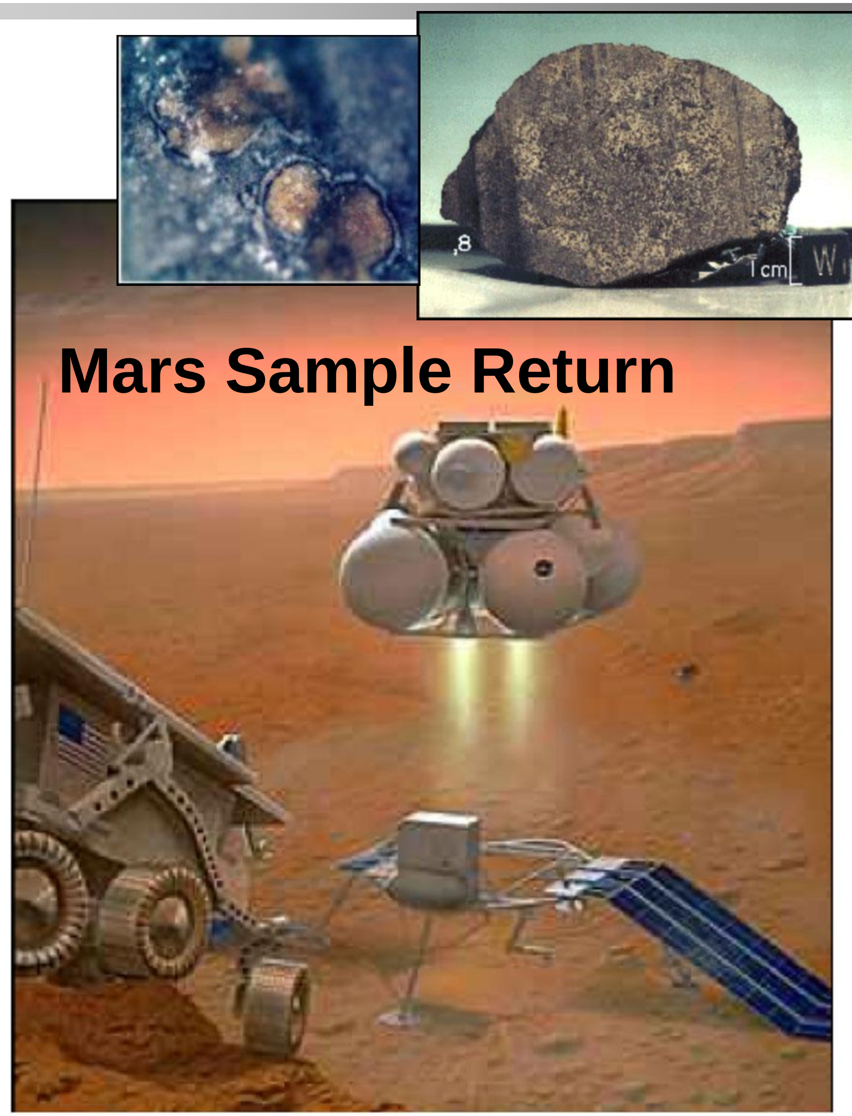


InSIGHT:

Mars Interior Mapping

Future Missions Have Significant Constraints





Technologies Keep Changing

- What technology developments can facilitate compliance with planetary protection requirements?
- Are new developments needed? In what areas?
- How can NASA ensure that spacecraft and instrument developers understand design issues associated with planetary protection?
- What can be done to ensure that NASA's technology investments are compatible with these needs?

Planetary protection works much better when included from the start

Planetary Protection Research

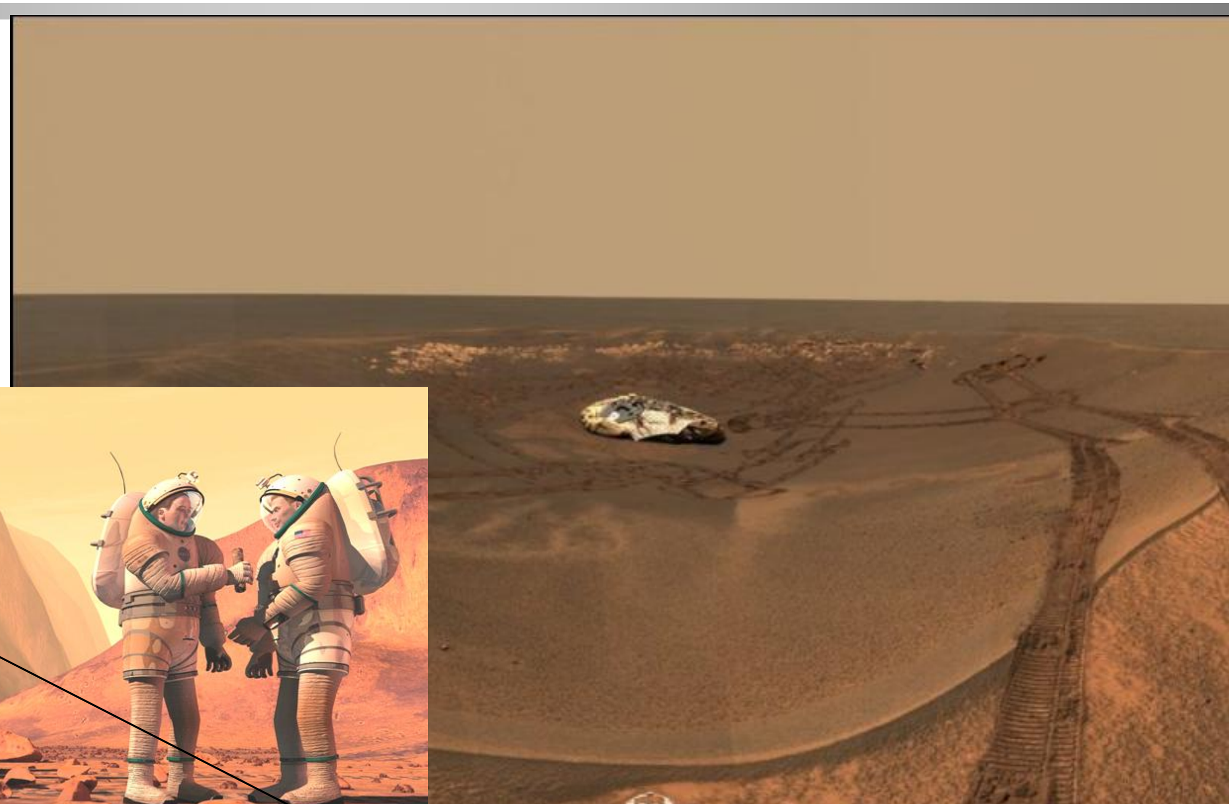
- Element of SMD ROSES call; solicits research that isn't covered by Astrobiology in these areas (13 grants total)
  - Characterizing the limits of life in laboratory simulations of planetary environments or in appropriate Earth analogs, particularly studies of the potential, distribution and dynamics of organism[s]   (4 grants)
  - Modeling of planetary environmental conditions and transport processes that could permit mobilization of spacecraft-associated contaminants (2 grants)
  - Development or adaptation of modern molecular analytical methods to rapidly detect, classify, and/or enumerate the widest possible spectrum of Earth microbes ... and (4 grants)
  - New or improved methods, technologies, and procedures for spacecraft sterilization (3 grants)

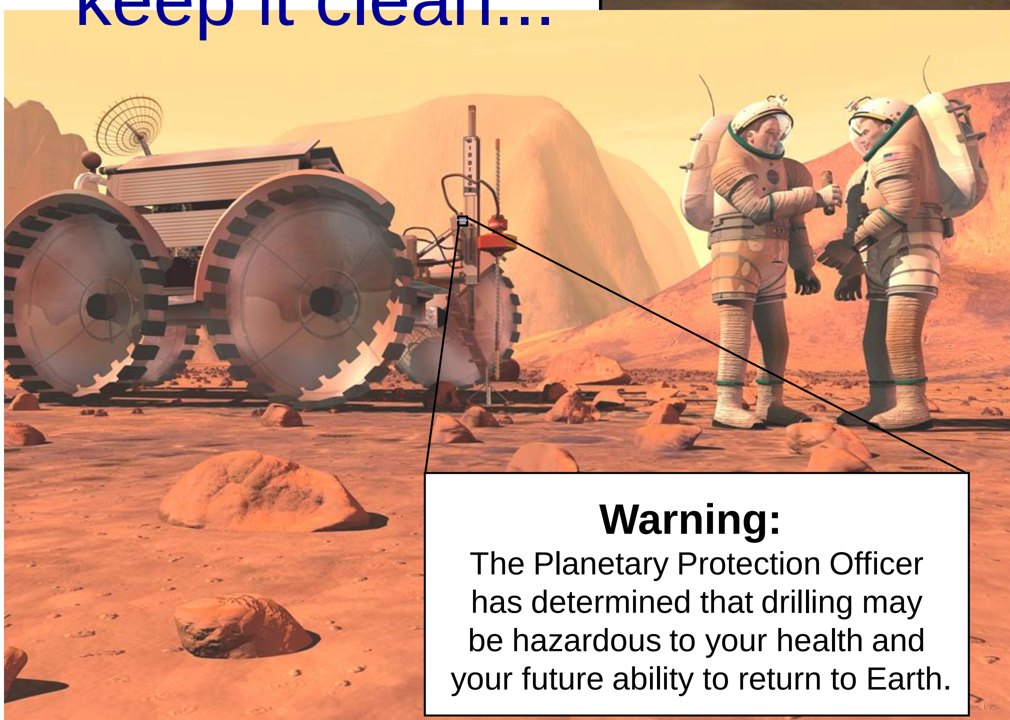
Programmatic Concerns

- An increasing number of mission concepts target locations of concern for planetary protection, both Mars and Outer Planets
  - Technology development for planetary protection, beyond basic research, has historically been left to missions: better coordination in planetary protection technology development would facilitate efficient use of resources (PPR is not enough...)
  - Ongoing planning for human spaceflight beyond Earth orbit highlights the need to elaborate, at the level of NASA policy, the guidelines for human exploration that were accepted by COSPAR in 2008
  - Increasing interest in exploration activities by multiple national and private organizations raises a range of concerns: e.g., international cooperation, commercial exploration, and historical/environmental protection

Human Missions to Mars

Planetary protection goals remain the same:
keep it clean...





Warning:
The Planetary Protection Officer has determined that drilling may be hazardous to your health and your future ability to return to Earth.

But humans will carry microbes to Mars – what do we do when astronauts get sick?

Planetary Protection and Commercial Spaceflight

Application of planetary protection policy to non-governmental entities is still being developed. Examples include:

The Google Lunar X-Prize will be awarded for the successful completion of the first privately-led mission to the Moon

- Space-X would like to send Dragon to Mars...

CONGRATULATIONS!

Facilitating International Cooperation

- Planetary protection preparation for upcoming international mission concepts is ongoing – ESA and NASA continue working together on planetary protection technology and requirements development
  - Joint development of specific needs (DHMR, VHP, etc.)
  - Multi-year effort to update the Life Detection Protocol
  - Coordination of agency advisory committee activities
  - Integrated activities for categorization and monitoring of joint missions as they develop

Protecting the Earth *must* be an international endeavour...

Overview and Summary of Life Detection Protocol Update Workshop

C. Conley
G. Kminek

1 May 2012

Development Strategy

Public **Conference** encouraged discussion of what it means to 'detect life' and develop a community consensus regarding what is required for a credible claim of life detection.

By-invitation **Workshop** addressed the potential for measurements that address broader scientific questions to be used also for planetary protection purposes to meet criteria for release of samples from containment, which could minimize use of scarce samples and duplication of effort.

Workshop Objectives:

- Evaluate current and possible scientific investigations that could identify signs of viable, extant life in samples returned from Mars
- Assess the state-of-the-art of available technologies and identify areas that require future work
- Discuss efficient phasing of planetary protection measurements in the context of proposed scientific analyses, to maximize efficient use of resources
- Identify needed improvements in sample preparation, detection technologies, and controls/blanks that would increase confidence in the results

Inputs from Conference

Assumptions: looking for life based on carbon chemistry that happens at Mars-surface temperature and pressure, on human-detectable timescales (i.e., water soluble).

Information addressing the properties of life as defined above might be found by measuring:

1) Structure and morphology of samples, at macro and micro scales
2) Chemical composition and heterogeneity of samples
3) Environmental and thermodynamic context of samples and interesting features within

Two competing hypothesis should be tested:

1) There is no life in the samples.
2) There is Mars life in the samples.

DATA will be collected: interpretation could provide 'strong biosignatures,' 'possible biosignatures,' 'indicators of abiotic processes,' or 'indicators of Earth contamination' – depending on which hypotheses the data support or refute.

Conclusions/ Future Directions

Testing competing ‘null’ hypotheses is an effective strategy to address both scientific and planetary protection interests. Hypotheses are:

1) There is no life in the samples.
2) There is Mars life in the samples.

Data will be collected: these data may be equally relevant to ‘science’ and ‘planetary protection.’ ***Interpretation*** of collected data will guide policy decisions regarding sample safety and subsequent handling, as well as inform scientific research.

Characterization of measurements as 'strong biosignatures,' 'possible biosignatures,' 'indicators of abiotic processes,' or 'indicators of Earth contamination' could be useful

A decision analysis strategy based on Bayesian statistics could be used to direct sequences of investigations to increase confidence in conclusions as input to policy

Sample handling and containment are key technology needs:

1) Non-destructive imaging should be used to identify subsamples for further analysis
2) Significant improvements in clean subsampling capabilities are needed
3) Remote micromanipulation could greatly facilitate clean sample handling

More Players in the Game...

- The landscape of space exploration is changing rapidly – more countries are interested in space exploration, and private corporations have improving capabilities
- What additional concerns are raised by the participation of more and non-governmental entities?
- How can these be mitigated? Used advantageously?
- To what extent can existing national and international frameworks be used to address issues?
- What can be done to ensure that relevant perspectives are collected and, to the extent possible, addressed?

The goals of planetary protection remain to protect science and the Earth

The Basic Rationale for Planetary Protection Precautions

(as written by Bart Simpson, Dec. 17, 2000, “Skinner’s Sense of Snow”)

Science class should not end in tragedy....
Science class should not end in tragedy....
Science class should not end in tragedy....
Science class should not end in tragedy....
Science class should not