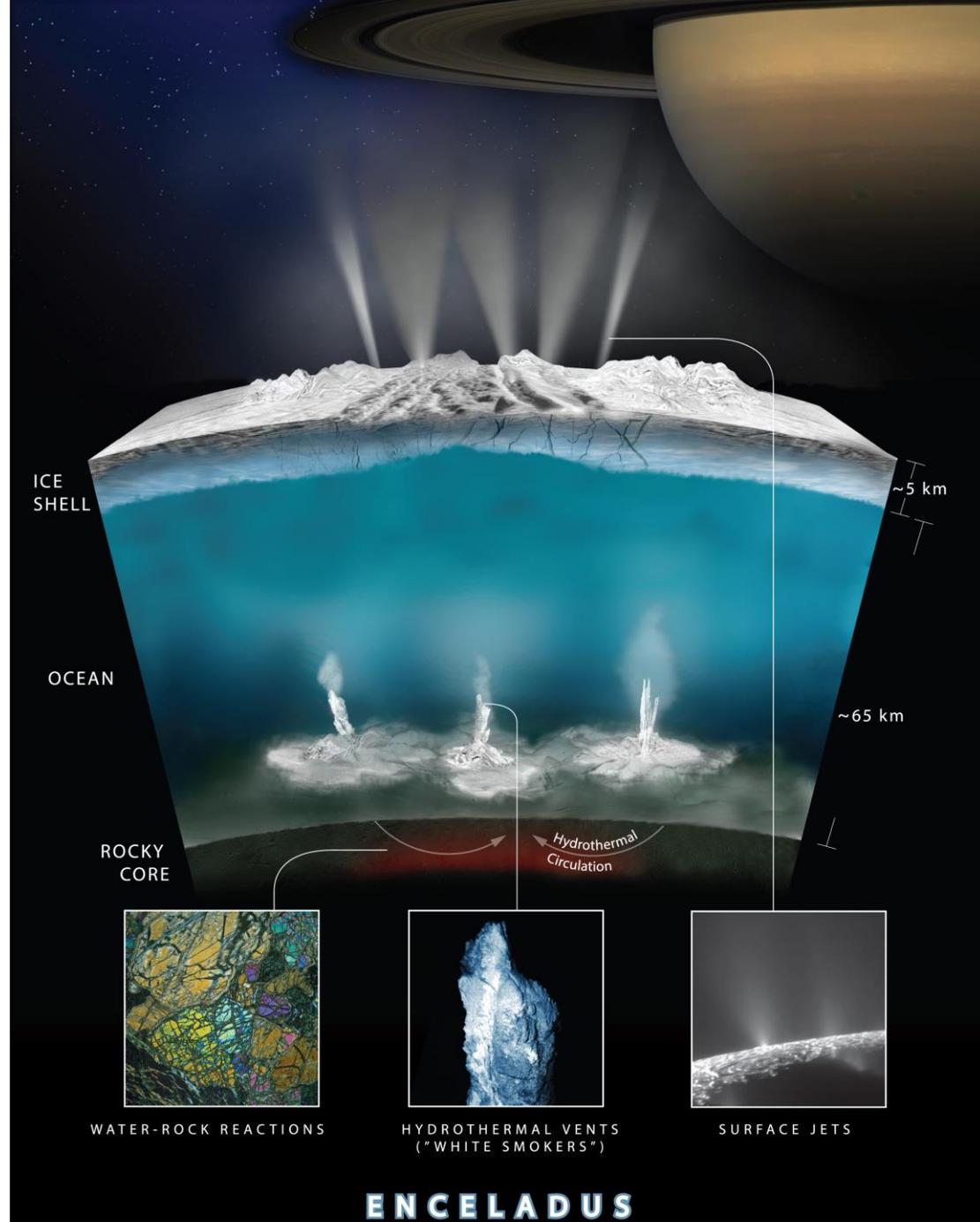


Should We Reconsider the Forward-Contamination Requirement for Ocean World Exploration?

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Precis

- Today's 10^{-4} requirement deserves reconsideration
- It is foundational, yet is a capability-driven value codified before the modern science of microbial life and ocean worlds
- FC is a hazard unlike other low-probability, high-consequence risks
- The topic is not circumscribed by only technical considerations. The ethical implications justify broad stakeholder discussion.
- This open conversation would be timely now: in this century we will explore multiple ocean worlds

Fixed threshold, bound by treaty

For ocean worlds, limit to 10^{-4} the probability of any mission introducing a single viable Earth organism into a “potential habitat”

- Potential habitat = liquid water or warm ice
- Applies to any mission, by any enterprise
- Adopted by international consensus (COSPAR), governed by treaty (1967 Outer Space Treaty), enforced by states who are party to the treaty

Pedigree of the current 10^{-4} requirement

See Melzer, M., *When Biospheres Collide: A History of NASA's Planetary Protection Programs*. 2011, NASA: Washington, DC. p. 78-84.

- 1958 10^{-6} discussed by West Coast Committee on Extraterrestrial Life (WESTEX), led by Lederberg. Microbial contamination models from cannery sterility assurance, with the goal of eliminating *Clostridium* spores.
- 1962 10^{-4} recommended by L. Jaffe (JPL) as both achievable and appropriate for Mars exploration
- Keep the chance of contamination low, compared to the chance of obtaining no useful biological data from Mars for other reasons
 - Keep the chance of contaminating Mars in the course of unmanned exploration low, compared to the chance of contaminating it the first time a manned landing occurs
- 1964 10^{-4} ratified by COSPAR based on a probabilistic framework
A sterilization level such that the probability of a single viable organism aboard any spacecraft intended for planetary landing or atmospheric penetration be less than 10^{-4}
- 1966 $\leq 10^{-3}$ limit for contaminating a planet of biological interest within the period of biological exploration. Adoption by all states engaging in the exploration of space.
COSPAR suballocated the 10^{-3} overall limit:
- 4.4×10^{-4} each for the US and USSR; 1.2×10^{-4} for other spacefaring nations
 - For Viking, integrated probability was suballocated in 7.2×10^{-5} pieces
 - But because Mariner succeeded, each Viking lander was augmented to 10^{-4}
- 1967 NASA directive NPD 8020.10 (now NPR 8020.12) harmonizes with COSPAR requirement

Why reconsider the requirement?

Statistical approach adopted from other industries

...capability-based

...half-century old science

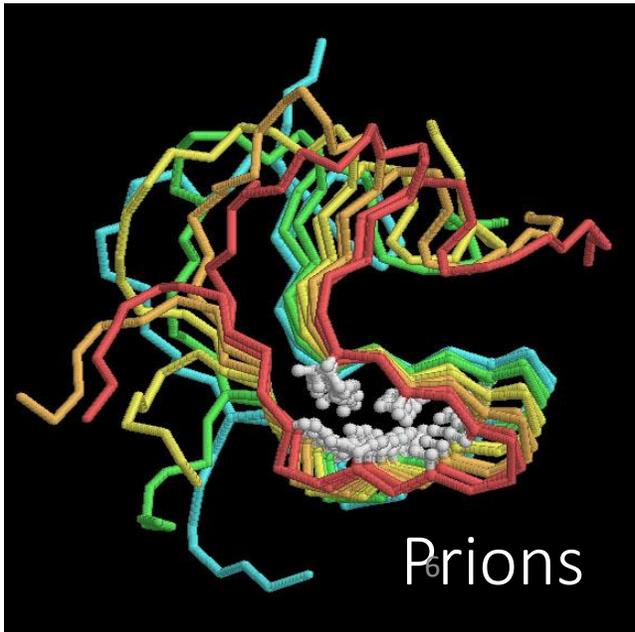
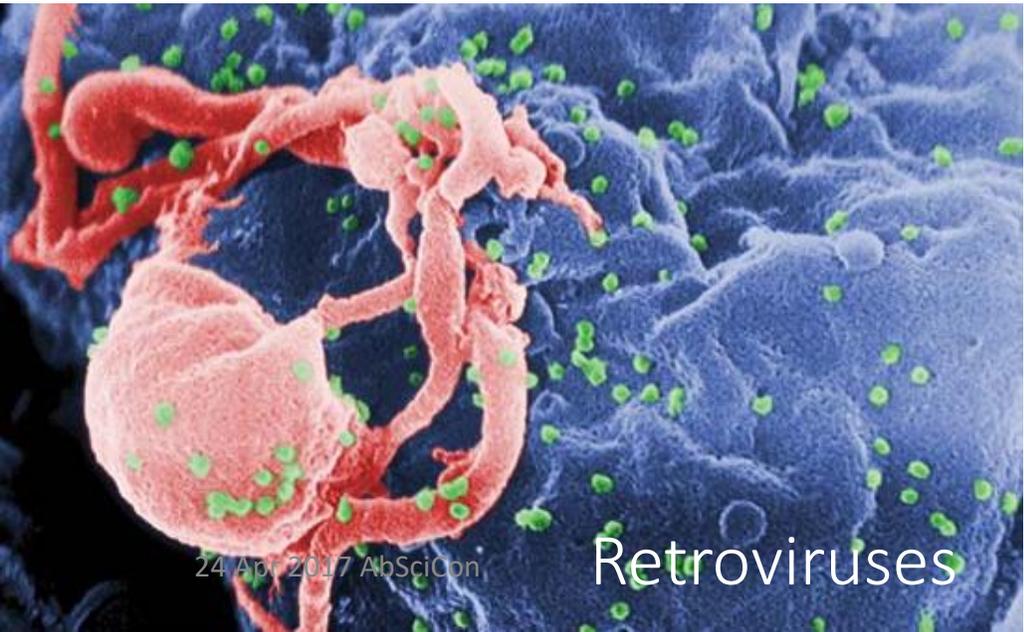
...not originally conceived as a per-mission threshold

Is 10^{-4} per mission too loose?

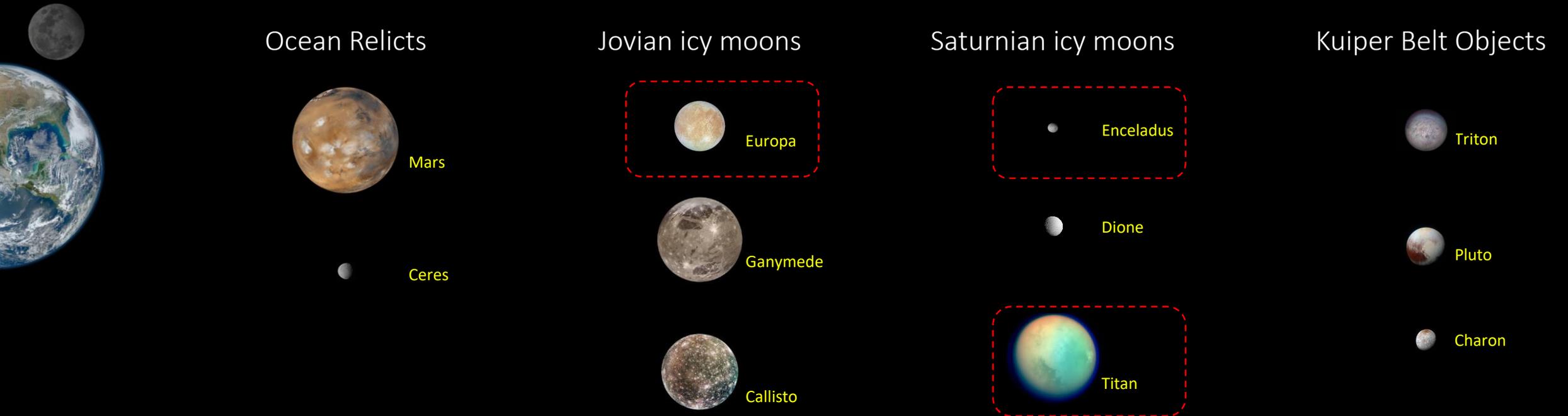
Too stringent? How can we know?



Life is more diverse and tenacious than we used to think



Originally just Mars...now, many ocean worlds



Are there lessons from the Risk Management field?

- Is FC like other Low-Probability, High-Consequence hazards?

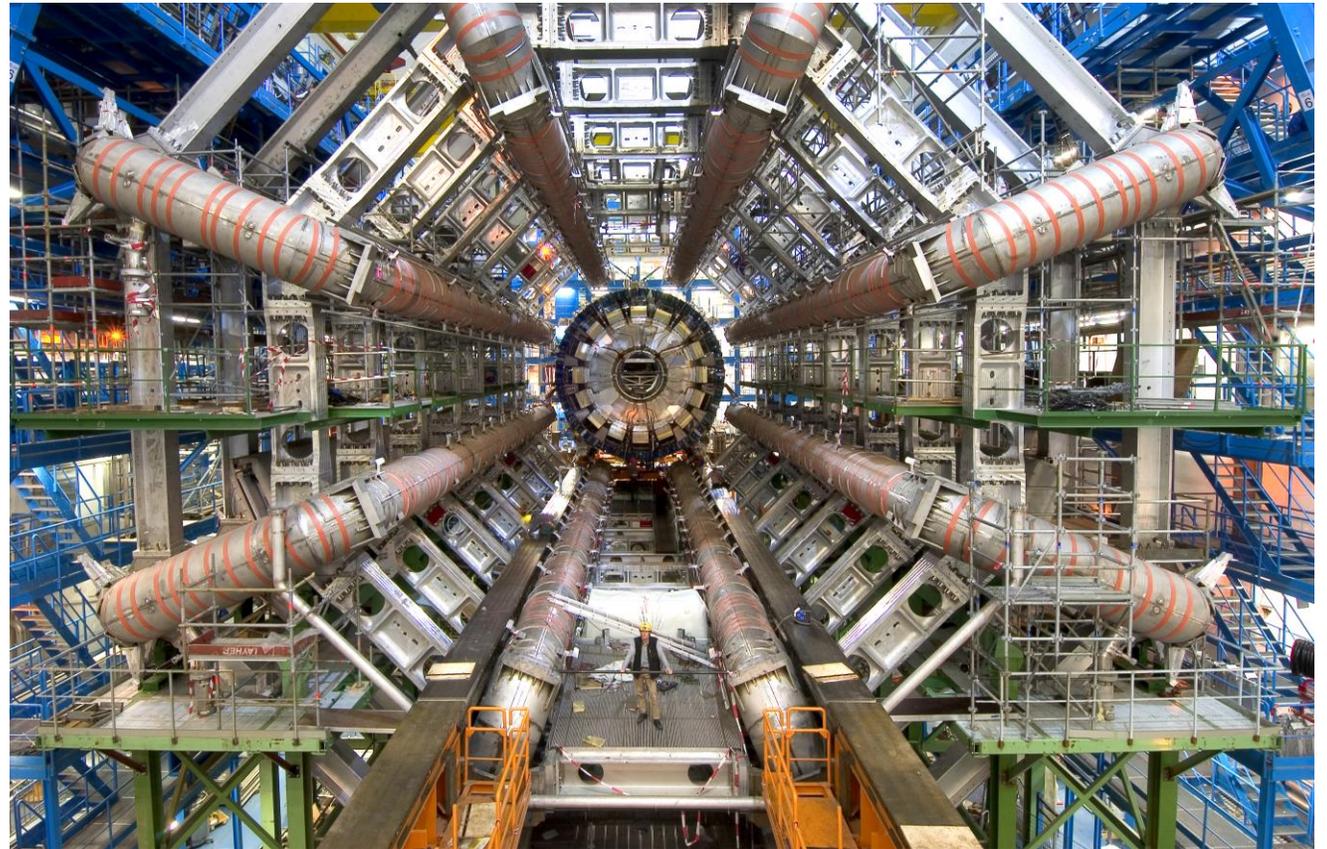
(See N. Pidgeon, C. Hood, D. Jones, B. Turner, R. Gibson, 1992. Risk Perception, in *Risk: Analysis, Perception & Management*, ISBN 0 85403 4676. Royal Society)

- LPHC hazards are psychological-social, not just technical, problems
- Quantitative risk assessment toolkit has limited utility
- ...and risk decisions are strongly affected by perception bias

However, successful precedents exist for social process solutions

Public risk management field is dominated by spectacular hazards

- Vehicular accidents
- Bridge and dam collapses
- Catastrophic chemical spills
- Radiation breaches from nuclear power plants
- Collateral damage from genetic modification of species
- Accidental triggering of nuclear war
- Ignition of Earth's atmosphere by thermonuclear detonations
- Destruction of Earth by creation of a black hole in particle-accelerators
- Runaway climate change
- Devastating asteroid impact



Low-Probability but High-Consequence

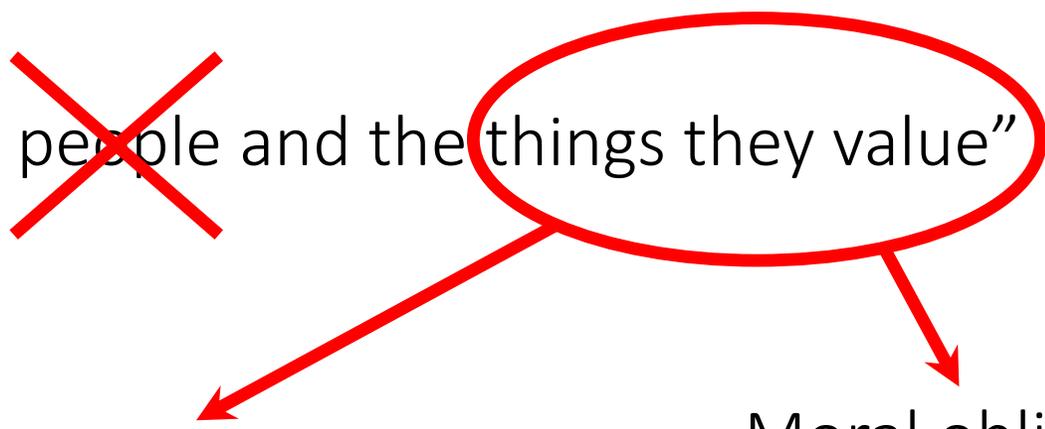
Risk perception and risk management

- Objective risk is illusory – no risk judgment is absolute
- Hazards are technical, but risk is psycho-social
- Psychometric model of LPHC risk finds three principal components
 - Dread risk** – involuntary, inequitable, uncontrollable, catastrophic
 - Unknown risk** – unobservable, not understood, delayed consequence
 - Societal risk** – size of exposed population
- Risk tolerance = “the willingness to live with a risk to secure certain benefits”

Forward contamination: **Unknown** and **Societal**, but hardly **Dread**

What is the forward-contamination risk?

Hazard = “a threat to people and the things they value”



Scientific integrity

Avoid destroying or irreversibly complicating the opportunity for future scientific analysis of a potential habitat

A soft cost

Moral obligation

Avoid interfering with a living system or habitat upon first contact

The Prime Directive

Identifying risk tolerance requires stakeholder – including public – dialogue

Individuals' value perceptions are likely labile



Case 1 – Non-habitable environment

- Many such environments are already being explored
- Little controversy likely. “Pristine preservation” view?

Hmm...

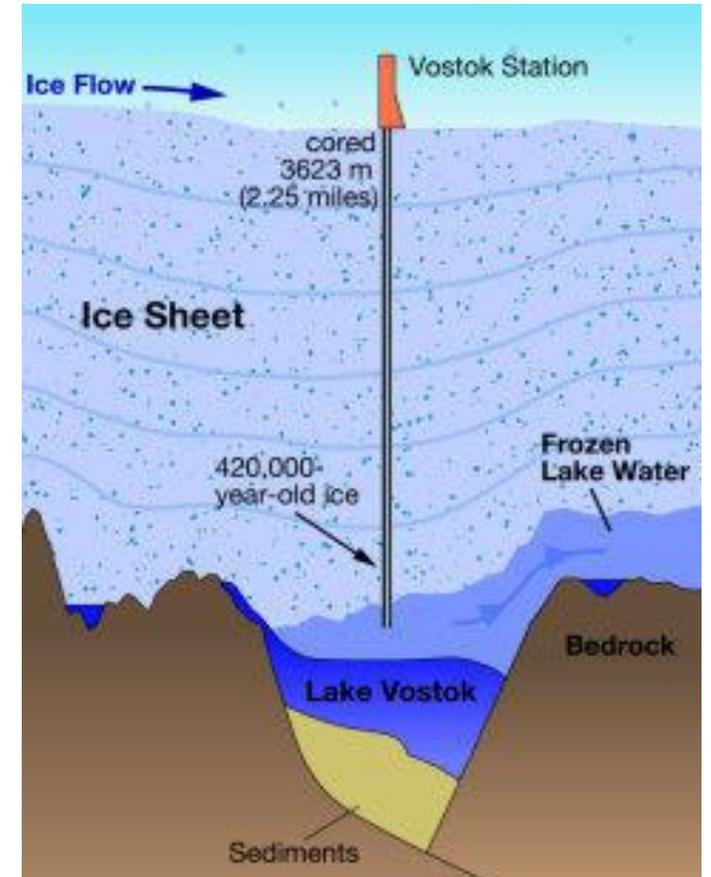
Case 2 – Habitable and possibly inhabited

- Most likely, a consensus to take care
- Lessons from Lake Vostok



Case 3 – Habitable but uninhabited environment

- The most ethically interesting case
- Leave it be?



Ethical approaches 1. Scope

- Define the affected parties
 - Possible life-forms on planets that humans explore
 - Science as an abstract ideal
- Historical context
 - Protecting human life against microbial contamination
 - Human survival, generally

Ethical approaches 2. Ethics 101

Why is this an ethical problem?

- Usually, costs measured against the cost of protecting human life
- But FC is measured against the costs of sterilizing spacecraft

A decision becomes an ethical problem when two (or more) positive values are weighed against each other

- No alternatives, no ethical problem
- No positive values, no ethical problem

Ethical approaches 3. Forward contamination

“Positive values” are diffuse for forward planetary protection

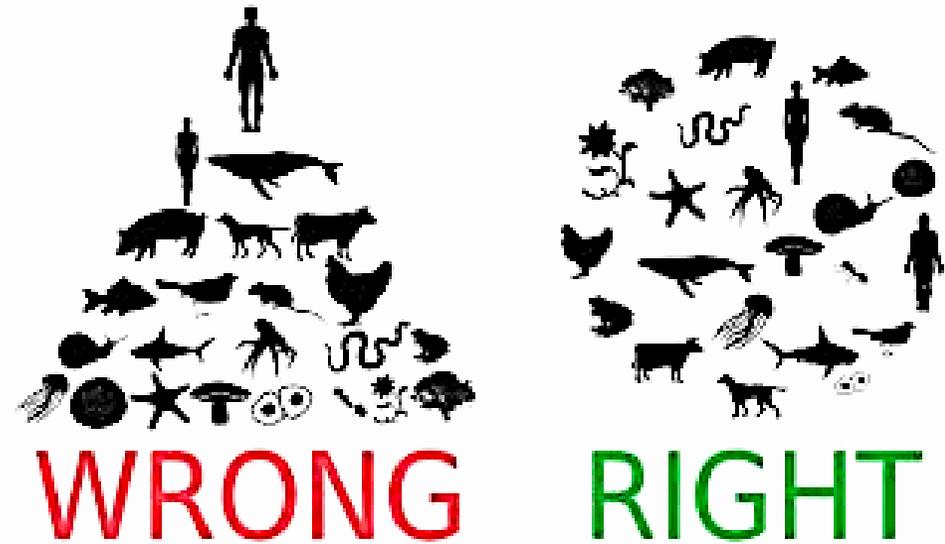
- The value of research in an uncontaminated pristine environment
- A possible human obligation toward extraterrestrial life
- Value of untouched environments in themselves
(planetary protection as a kind of environmental protection)

Ethicists might solve this by ascribing value from the outside

- Value of science as pure research
- Value of life itself
- Value of environments on a cosmic scale

Possible solution framework: biocentric perspective

- Biocentrism and anthropocentrism can encompass each other
- Anthropocentrism is vitally concerned with caring for life (including itself)
- ...and is then logically obligated to keep life diverse in the universe
- ...and to protect life from other life as far as possible



**Do/can/should different forms of life and environments
have different value?**

Developing requirements in practice

- Robotic exploration of active ocean worlds is imminent
- Ensure that stakeholders participate in decision meetings

Who are they?

What is the decision process?

- Key questions to address

Probability of contamination within the period of biological exploration

- What is the period of biological investigation for an ocean world?
- How many ocean-world missions might occur during this period?

In the 1960s, 10^{-4} was the lowest attainable probability of contamination

- What would be today's capability-driven requirements for instruments and missions?
- What can we learn from current research in hospital sterility?

(e.g., 10^{-6} vs 10^{-3} equipment biocontamination yield equal surgical lethality outcome)

Srun, S., et al., *Medical device SALs and surgical site infections: a mathematical model*. Biomedical Instrumentation & Technology, 2012. **46**(3): p. 230-7.

Successful management of social risks

Case studies from 1945, 1999, and 2008 show it can be done

Who should have a voice in the conversation?

How should the risk be assessed?

Who should specify the risk-management approach?

Who should determine the risk tolerance level?

Uncontrollability and *dread* are less important drivers than “distrust of the professional expert, and, by extension, distrust of the process of identifying and dealing with risks.”

Four recommended conversations

1. Is forward contamination a high-consequence hazard for human society, or something else?
2. How well-known outside the PP community is the understanding of how this hazard is managed today?
3. What is the most appropriate risk-management approach for this type of irreversible hazard...e.g., arbitrary threshold values or an adaptive process?
4. What requirements should be levied on projects?

How can our community foster these meaningful conversations?