Planetary Protection of Icy Worlds

Discussion Primer CoPP April 2024

COSPAR Panel on Planetary Protection (PPP) Icy Worlds
Subcommittee: Peter Doran, LSU (chair), Alex Hayes, Olivier Grasset,
Olga Prieto-Ballesteros, Athena Coustenis and the PPP team.

Subcommittee formed to review Icy Worlds in the PP policy.

PPP discussed review and ideas generated at last 3 meetings.

Resulted in a number of recommendations outlined in this paper

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The COSPAR planetary protection policy for missions to Icy Worlds: A review of history, current scientific knowledge, and future directions

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Note: The paper discusses proposals for POTENTIAL changes to COSPAR PP policy for icy worlds

Note 2: As has been precedent, any eventual policy changes will not impact approved projects that are either already flying or in their final preparation stage

COSPAR POLICY ON PLANETARY PROTECTION

Prepared by the COSPAR Panel on Planetary Protection and approved by the COSPAR Bureau on 3 June 2021.

Based on a recommendation by PPOSS

5. Environmental conditions for replication Given current understanding, the physical environmental parameters in terms of water activity and temperature thresholds that must be satisfied <u>at the same time</u> to allow the replication of terrestrial microorganisms are (Ref: [11], [12]):

– Lower limit for water activity: 0.5

– Lower limit for temperature: -28˚C

Proposal

We propose to define new indices for use throughout the solar system based on the currently established limits of Earth Life with regards to temperature and water activity.

LLT = Lower Limit for Temperature (lower limit for replication).
Current record is -18^{o}C – 10^{o}C buffer)

LLAw = Lower Limit for Water Activity. Current record was 0.62 and a 0.12 buffer was added. Since the last assessment of the literature (Rummel et al. 2014) the record has become 0.585. New theoretical limit of 0.540 (Paris et al., 2023)
Also supported by reviews by a COSPAR Colloquium (Hipken and Kminek 2015) and U.S. National Academies/European Science Foundation joint panel (Rettberg et al. 2016)

Time for a new assessment! Will discuss in session at Inaugural International COSPAR Planetary Protection Week next month in the UK

New Definition for Icy Worlds in PP Policy

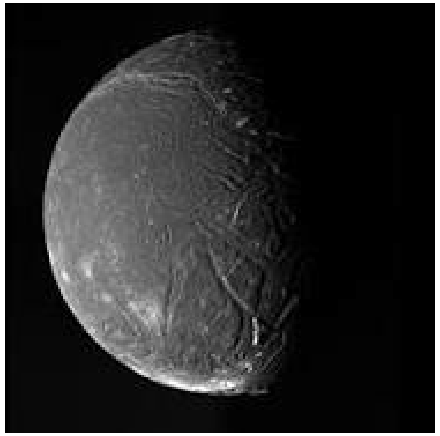
- *The committee prefers "Icy Worlds" over e.g. "Ocean Worlds" for the PP policy. You don't need an ocean for habitability. A body could have a slushy layer or just layer of warm ice and be potentially habitable to Earth life (forward contamination).*

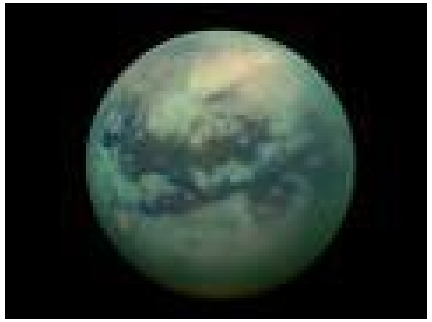
Currently only "Icy Moon(s)" appears in the policy. Not all bodies of concern are moons

Proposal

We propose a definition for Icy Worlds in the policy: ***"Icy Worlds in our Solar System are defined as all bodies with an outermost layer that is believed to be greater than 50% water ice by volume and have enough mass to assume a nearly round shape."***

This definition includes dwarf planets like Pluto, but rejects small bodies including comets, trojans, irregular moons, TNOs (centaurs / KBOs),…





Body	Category	Current Classification
2002 MS$_4$	Dwarf Planet[2], Cubewano[3] (TNO)[4]	II
Ariel	Moon of Uranus	II
Callisto	Moon of Jupiter	II
Charon	Moon of Pluto	II*
Dione	Moon of Saturn	II
Enceladus	Moon of Saturn	III/IV
Eris	Dwarf Planet, Scattered Disk Object (TNO)	II
Europa	Moon of Jupiter	III/IV
Ganymede	Moon of Jupiter	II*
Gonggong	Dwarf Planet, Scattered Disk Object (TNO)	II
Haumea	Dwarf Planet, Haumeid (TNO)	II
Iapetus	Moon of Saturn	II
Makemake	Dwarf Planet, Cubewano (TNO)	II
Mimas	Moon of Saturn	II
Miranda	Moon of Uranus	II
Oberon	Moon of Uranus	II
Orcus	Dwarf Planet, Plutino (TNO)	II
Pluto	Dwarf Planet, Plutino (TNO)	II*
Quaoar	Dwarf Planet, Cubewano (TNO)	II
Rhea	Moon of Saturn	II
Salacia	Dwarf Planet, Cubewano (TNO)	II
Sedna	Dwarf Planet, Sednoid (TNO)	II
Tethys	Moon of Saturn	II
Titan	Moon of Saturn	II*
Titania	Moon of Uranus	II
Triton	Moon of Neptune	II*

[3]Classical Kuiper Belt Object
[4]Trans-Neptunian Object

Ceres

This definition does not capture Ceres

From our paper:

"While Ceres' crustal composition likely does not meet the >50% water ice requirement to be considered by the above definition, we include it in our policy discussions as it shares many of the characteristics and exploration objectives of the other Ocean Worlds (that are also Icy Worlds) "

10. Category III/IV/V requirements for Europa and Enceladus [15]

10.1. Missions to Europa and Enceladus (Ref: [15], [20], [21], [22], [23], [24])

Category III and IV. The biological exploration period for Europa and Enceladus is defined to be 1000 years; this period should start at the beginning of the 21st century. Requirements for Europa and Enceladus flybys, orbiters and landers, including bioburden reduction, shall be applied in order to reduce the probability of inadvertent contamination of Europan or Enceladan subsurface liquid water to less than $1x10^{-4}$ per mission. The probability of inadvertent contamination of a Europan or Enceladan ocean of $1x10^{-4}$ applies to all mission phases including the duration that spacecraft introduced terrestrial organisms remain viable and could reach a sub-surface liquid water environment. The calculation of this probability should include a conservative estimate of poorly known parameters, and address the following factors, at a minimum:

- Bioburden at launch
- Cruise survival for contaminating organisms
- Organism survival in the radiation environment adjacent to Europa or Enceladus
- Probability of landing on Europa or Enceladus
- The mechanisms and timescales of transport to a Europan or Enceladian subsurface liquid water environment
- Organism survival and proliferation before, during, and after subsurface transfer

- Current policy only refers to Europa and Enceladus
- Current policy identifies encountering liquid water as a trigger for concern, but cold brines below -28^{o}C should be uninhabitable to Earth life.
- Where we should start to be concerned is not when we reach detectable liquid water, but when the ice cap gets above -28^{o}C
- There is a well documented cryoecosystem on Earth in relatively warm ice.

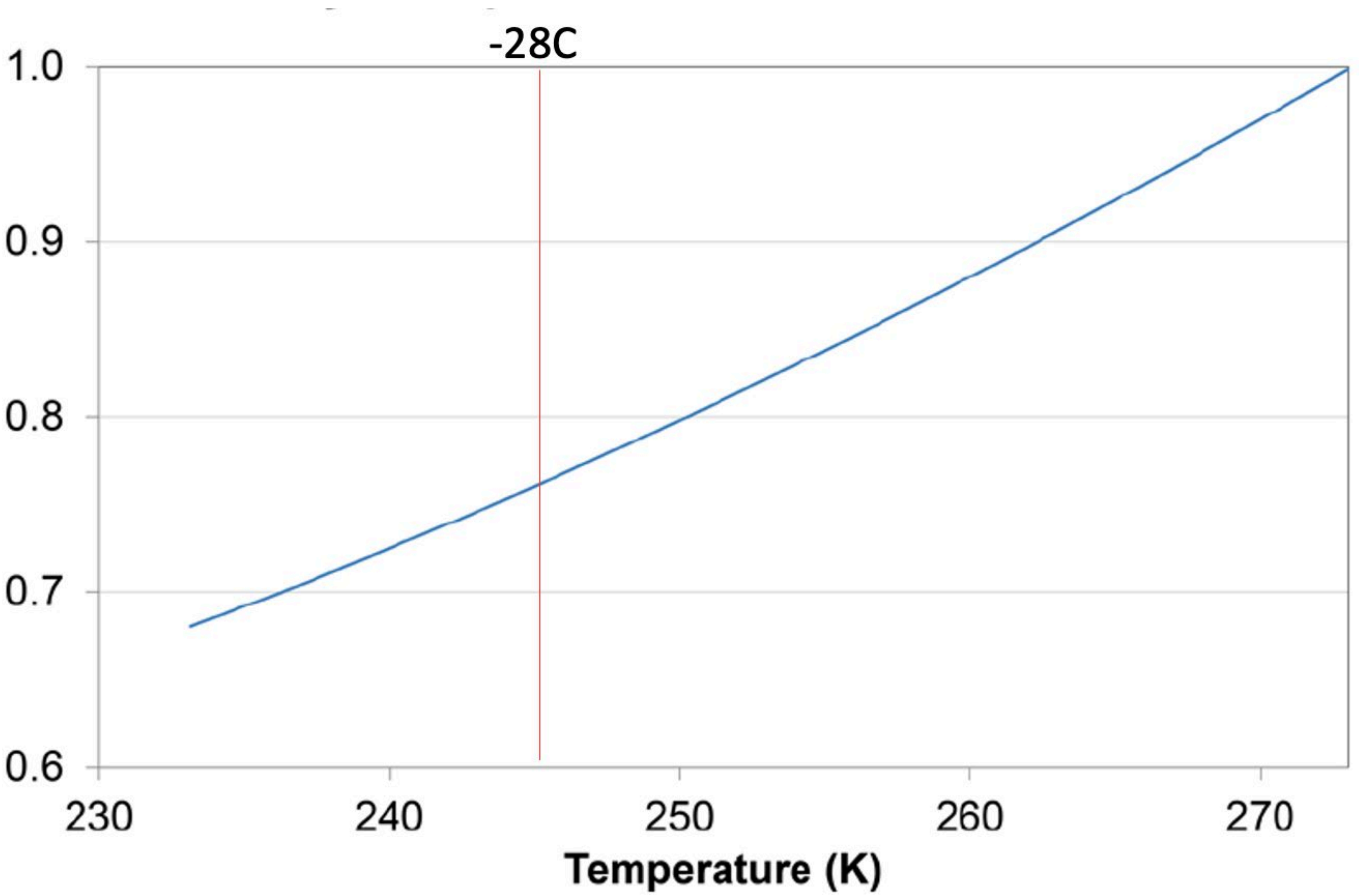
Where there's water there's life?

- Exception on Earth is almost always associated with brines with high salinity/low water activity.
- These brines can also be liquid, or be a mixture of ice/liquid down to very cold temperatures (<-40C)

$CaCl_2$ in Don Juan Pond, Antarctica

$MgCl_2$ in Lake Gounter, Western Australia

In ice, A_w is well above the limit when temperature is at -28C, so we can focus on just temperature as limiting



Sippola and Taskinen 2018, Activity of Supercooled Water on the Ice Curve and Other Thermodynamic Properties of Liquid Water up to the Boiling Point at Standard Pressure. Journal of Chemical & Engineering

It all simplifies to temperature and connectivity

- Europa (Jupiter) clear evidence of connection on some timescale to fluids beneath
  T_{surf}=-143^{o}C (midday at equator, colder toward poles / other times)

- Enceladus (Saturn) plumes indicating connection
  T_{surf}=-193^{o}C (midday at equator, colder toward poles / other times)

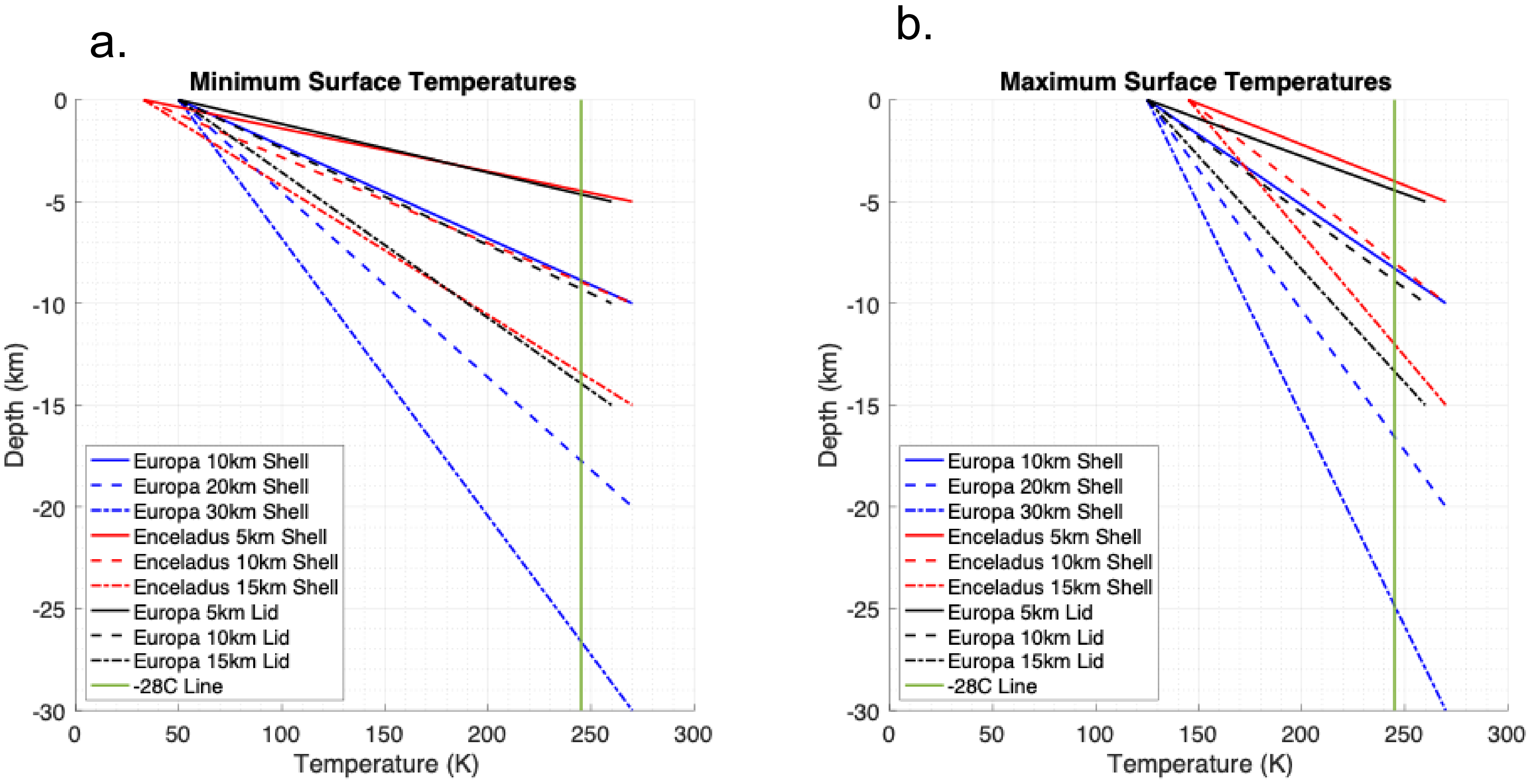
- Ganymede (Jupiter) internal ocean ~3 X larger than Europa, but lacks clear evidence of a connection
  T_{surf}=-113^{o}C (midday at equator, colder toward poles / other times)

- Titan (Saturn) internal ammonia-rich water but at ~-100C. Possible connection, but perhaps only one-way
  T_{surf}=-179^{o}C

- Calisto (Jupiter), possible deep (100 km) subsurface ocean.
  T_{surf}=-110^{o}C (midday at equator, colder toward poles / other times)

- Triton (Neptune), may (?) have an internal ocean about 100-150 km ice shell
  T_{surf}=-235^{o}C

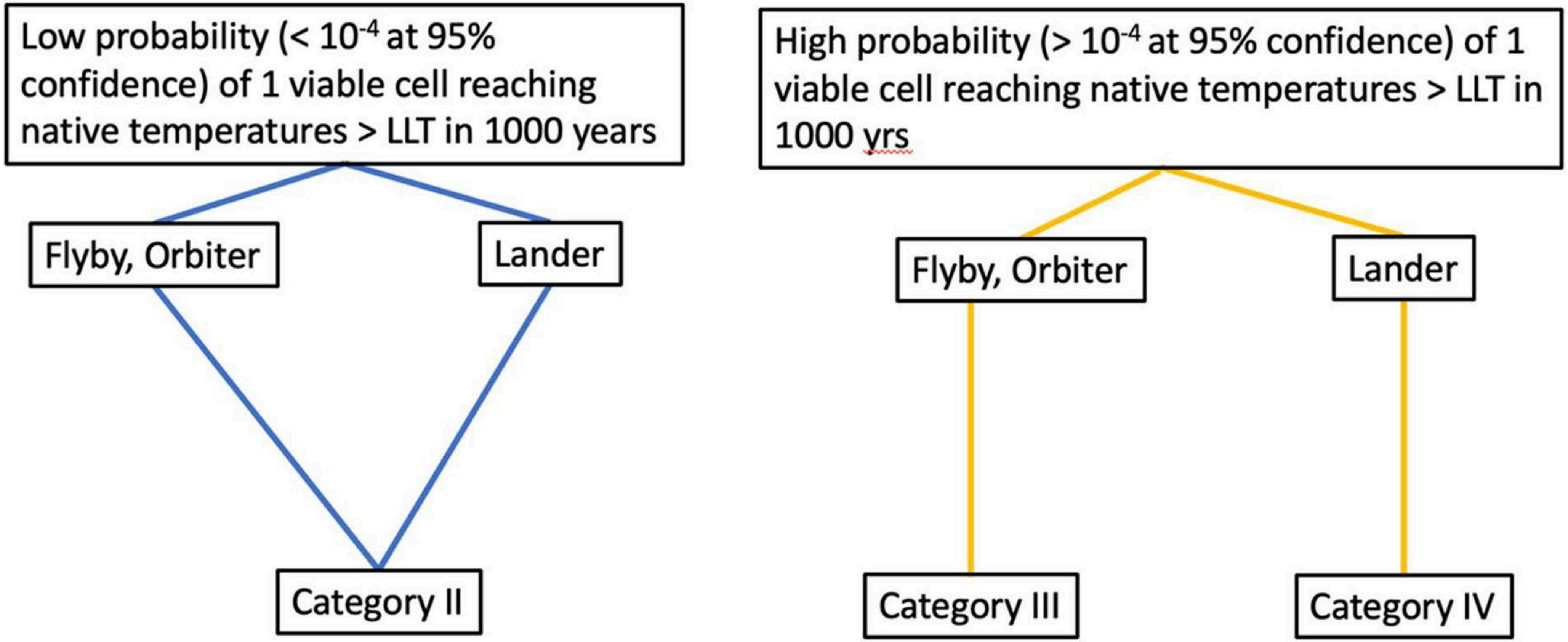
THIS IS JUST AN EXAMPLE OF THE TYPE OF MODELING A MISSION MIGHT USE



"The shallowest depth which sustains a temperature of -28°C is 4 km beneath the surface of a 5 km thick Enceladean ice shell when we assume the maximum surface temperature (solid red line of right plot)"

Courtesy Britney Schmidt and Jacob Buffo

Proposal
We propose to Categorize missions to icy worlds by the likelihood that the mission will connect with temperatures >-28C (LLT) within 1000 years (PBE).



LLT = Lower Limit for Temperature
(currently -28˚C)

What to do with Cat II*?

7. Category-specific listing of target body/mission types

Category I: Flyby, Orbiter, Lander: Undifferentiated, metamorphosed asteroids; Io; others to-be-defined (TBD)

Category II: Flyby, Orbiter, Lander: Venus; Moon; Comets; Carbonaceous Chondrite Asteroids; Jupiter; Saturn; Uranus; Neptune; Ganymede*; Callisto; Titan*; Triton*; Pluto/Charon*; Ceres; Kuiper-belt objects > ½ the size of Pluto*; Kuiper-belt objects < ½ the size of Pluto; others TBD

*The mission-specific assignment of these bodies to Category II must be supported by an analysis of the "remote" potential for contamination of the liquid-water environments that may exist beneath their surfaces (a probability of introducing a single viable terrestrial organism of $< 1 \times 10^{-4}$), addressing both the existence of such environments and the prospects of accessing them.

1) Leave the KBOs > ½ the size of Pluto as the only II* bodies remaining in the Policy, 2) Add KBOs > ½ the size of Pluto to our definition of an Icy World, or 3) Assume the larger KBOs will be sufficiently captured by our Icy World definition and leave KBOs in Category II only as "KBO's that cannot be classified as Icy Worlds". The first option leaves II* in the policy; the second and third removes II* entirely. How we deal with Category II* needs further discussion and community input.

Sample return from Icy Worlds – needs further discussion

LLT can not be used to help with sample return, because the limits of life evolved on icy worlds and its ability to preserve in ice and remain viable are unknowable before its discovery.

Given the lack of knowledge and the risk of warming of any returned material we recommend a conservative approach is warranted and all icy world sample return should be restricted earth return.

<u>OR</u>

The questions in the policy for sample return from small bodies could be used and would almost certainly trigger a restricted earth return for all of our listed Icy Worlds

Sample return questions derived from NRC (1998) and currently in policy for "Sample Return from Small Solar System Bodies"

For containment procedures to be necessary, an answer of "no" needs to be returned to all six questions

1. Does the preponderance of scientific evidence indicate that there was never liquid water in or on the target body?
2. Does the preponderance of scientific evidence indicate that metabolically useful energy sources were never present?
3. Does the preponderance of scientific evidence indicate that there was never sufficient organic matter (or CO_2 or carbonates *and* an appropriate source of reducing equivalents)[1] in or on the target body to support life?
4. Does the preponderance of scientific evidence indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e., >160 °C)?
5. Does the preponderance of scientific evidence indicate that there is or was sufficient radiation for biological sterilization of terrestrial life forms?
6. Does the preponderance of scientific evidence indicate that there has been a natural influx to Earth, e.g., via meteorites, of material equivalent to a sample returned from the target body?

NRC. 1998. Evaluating the Biological Potential in Samples Returned from Planetary Satellites and Small Solar System Bodies: Framework for Decision Making. Washington, DC: The National Academies Press. https://doi.org/10.17226/6281.

Summary:

1) Establish a new definition of Icy Worlds for use in Planetary Protection: "***Icy Worlds in our Solar System are defined as all bodies with an outermost layer that is believed to be greater than 50% water ice by volume and have enough mass to assume a nearly round shape***"
2) Establish indices for the lower limits of Earth life with regards to water activity (LLAw) and temperature (LLT) and apply them into all areas of the COSPAR Planetary Protection Policy (currently 0.5 and -28^{o}C, respectively).
3) Establish LLT as a parameter to assign categorization for Icy Worlds missions (subject to 1000-year period of biological exploration).
4) Have all missions consider the possibility of impact.
5) Restructure or remove Category II* from the policy.
6) Establish any sample return from an Icy World as Category V restricted Earth return OR include Icy Worlds in questions for small bodies.

Today contributes to our community outreach for comment.

We have also presented/discussed

- Twice previously at the NAS CoPP meeting
- COSPAR 2022 general assembly in Athens ,
- OPAG in Fall 2023,
- LPSC meeting last week.

Will have further discussion at the Inaugural International COSPAR Planetary Protection Week in the UK next month and at COSPAR 2024 in Busan, Korea in August

Panel Discussion

- Backup slides

Example only. Policy changes have not been discussed by the PPP

Calculation for inadvertent contamination of an icy world

- Bioburden at launch
- Cruise survival for contaminating organisms
- Organism survival in the radiation environment adjacent to ~~Europa or Enceladus~~ the target
- Probability of landing on ~~Europa or Enceladus~~ the target
- *Probability of contaminating organisms surviving landing/impact on the target*
- The mechanisms and timescales of transport to an environment where temperatures exceed -28°C ~~Europan or Enceladian subsurface liquid water environment~~
- Organism survival and proliferation before, during, and after subsurface transfer

Proposal

We propose to add to the probability calculation for icy world contamination

"Probability of contaminating organisms surviving landing/impact on the target"

Example only. Policy changes have not been discussed by the PPP

Category	Mission Type	Target Body
I	Flyby, Orbiter, Lander	Undifferentiated, metamorphosed asteroids; Io; others to-be-defined (TBD)
II	Flyby, Orbiter, Lander	Venus; Moon (Cat. II, IIa & IIb); Comets; Carbonaceous Chondrite Asteroids; Jupiter; Saturn; Uranus; Neptune; ~~Ganymede*; Callisto; Titan*; Triton*; Pluto/Charon*;~~ Ceres; Icy Worlds < LLT*; Kuiper-belt objects ~~> ½ the size of Pluto*; Kuiper-belt objects < ½ the size of Pluto~~that cannot be classified as Icy Worlds; others TBD
III	Flyby, Orbiters	Mars; ~~Europa; Enceladus~~Icy Worlds; others TBD
IV	Landers	Mars (Cat. IVa, IVb, & IVc); ~~Europa; Enceladus~~Icy Worlds; others TBD
V “Restricted Earth return”	-	Mars; ~~Europa; Enceladus~~Small Solar System Bodies including Icy Worlds with an answer of “yes” to any of the 6 questions in section 6.6.2; others TBD
V “Unrestricted Earth return”	-	Venus, Moon; Small Solar System Bodies including Icy Worlds with an answer of “no” to all 6 questions in section 6.6.2 others TBD

* Assignment of Icy Worlds to Category II must ~~The mission-specific assignment of these bodies to Category II should~~ be supported by an analysis of the ~~“remote”~~ potential for contamination of the ~~liquid-water~~>LLT (see definitions in section 4.2) environments that may exist near and beneath their surfaces ~~(a probability of introducing a single viable terrestrial organism of < 1 x 10^{-4})~~, addressing both the existence of such environments and the prospects of accessing them~~.~~ within the PBE of 1000 years. In cases where that analysis produces a probability of > 1 x 10^{-4} that a single viable terrestrial organism