Planetary Protection of Icy Worlds

Discussion Primer December 2023

Icy Worlds Subcommittee: Peter Doran (chair), Alex Hayes,
Olivier Grasset, Olga Prieto-Ballesteros, Athena Coustenis

Subcommittee formed to review Icy Worlds in the PP policy. PPP discussed review and ideas generated at last 3 meetings

Paper currently in review in *Life Sciences in Space Research*

The COSPAR Planetary Protection Policy for missions to Icy Worlds: A review of history, current scientific knowledge, and future directions

Doran, P.T.[a,*], Hayes, A.[b], Grasset, O.[c], Coustenis, A.[d], Prieto-Ballesteros, O[e], Hedman, N.[f], Al Shehhi, O.[g], Ammannito, E.[h], Fujimoto, M.[i], Groen, F.[j], Moores, J.E.[k], Mustin, C.[l], Olsson-Francis, K.[m], Peng, J.[n], , Praveenkumar. K.[o] Rettberg, P.[p], Sinibaldi, S.[q], Ilyin, V.[r], Raulin, F.[s], Suzuki, Y.[t], Xu, K.[u], Whyte, L.G.[v], Zaitsev, M.[w], Buffo, J.[x], Kminek, G.[q], Schmidt, B[b].

- Today is part of our community outreach for comment We have also presented/discussed
  - Twice at the NAS CoPP meeting
  - COSPAR 2022 general assembly ,
  - OPAG last week,
  - Will present at LPSC meeting in March. Discussion of proposals for POTENTIAL changes to COSPAR PP policy for icy worlds present in the paper.

Note: 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.

5**. Environmental conditions for replication**

Given current understanding, the physical environmental parameters in terms of water activity and temperature thresholds that must be satisfied at the same time to allow the replication of terrestrial microorganisms are:

− Lower limit for water activity: 0.5 (record was 0.62, now 0.585)

− Lower limit for temperature: -28˚C (10 degree buffer)

These numbers based on exhaustive literature review made by MEPAG SR-SAG2 (Rummel et al. 2014), with follow-on reviews by a COSPAR Colloquium (Hipken and Kminek 2015) and U.S. National Academies/European Science Foundation joint panel (Rettberg et al. 2016)

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.

Definitions

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 0.1 buffer was added.
Since the last assessment of the literature (Rummel et al. 2014) the record has become 0.585

Time for a new assessment!

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 habitable.*

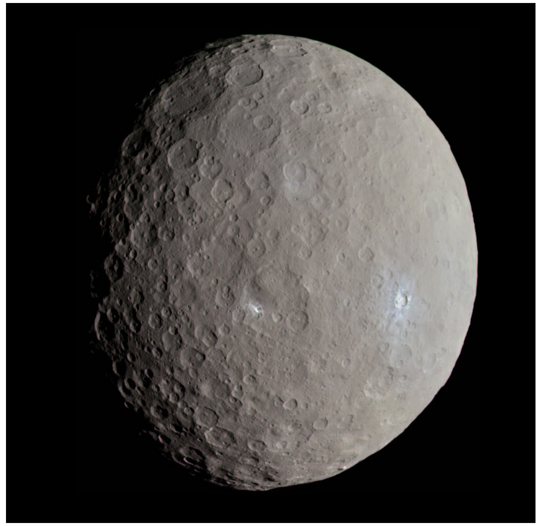
Currently only “Icy Moon(s)” appears in the policy. Not all bodies of concern are moons

Proposal

We propose a definition for Icy Worlds in the policy: ***“Icy Worlds in our Solar System are defined as all bodies with a crustal composition believed to be greater than 50% water ice by volume that 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),…

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]

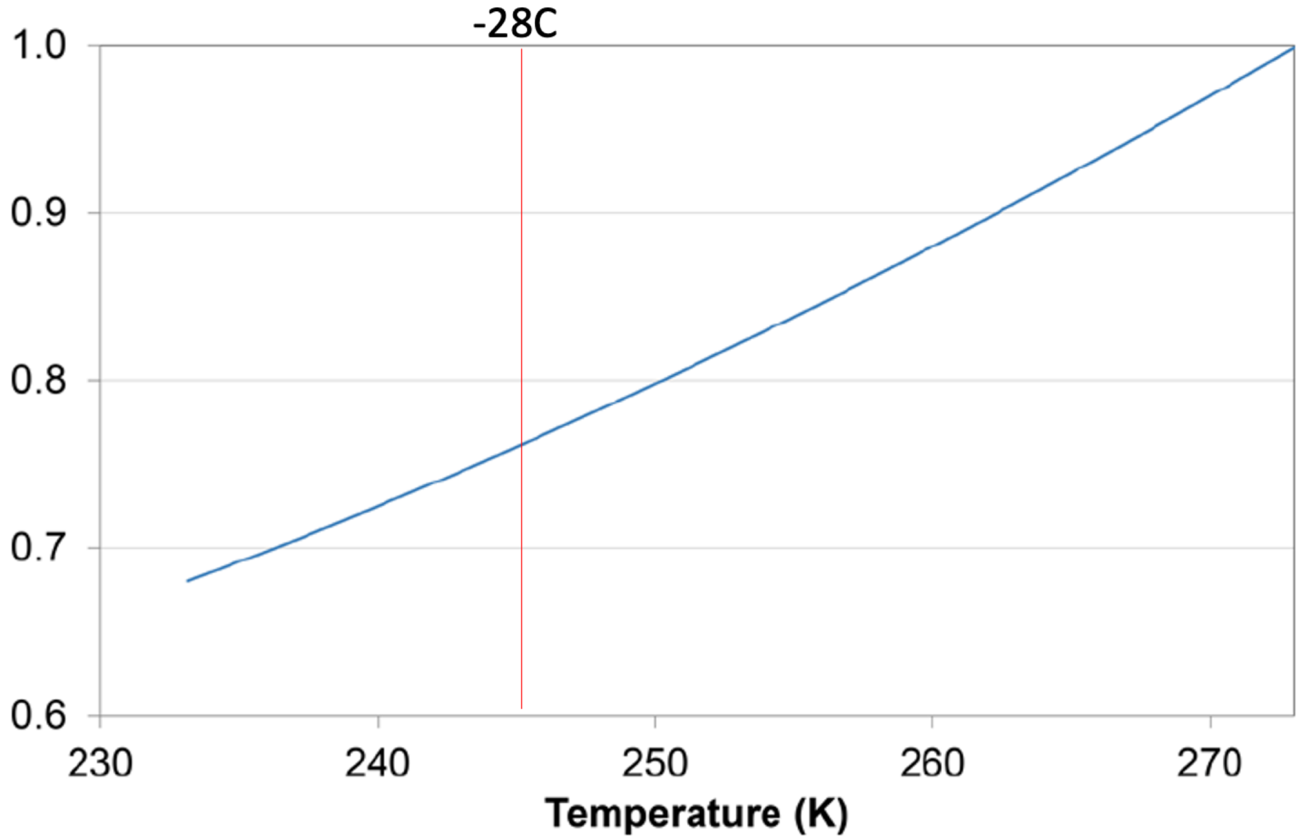
10.1. Missions to Europa and Enceladus (Ref: [15], [20], [21], [22], [23], [24])

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°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°C

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's all about 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)

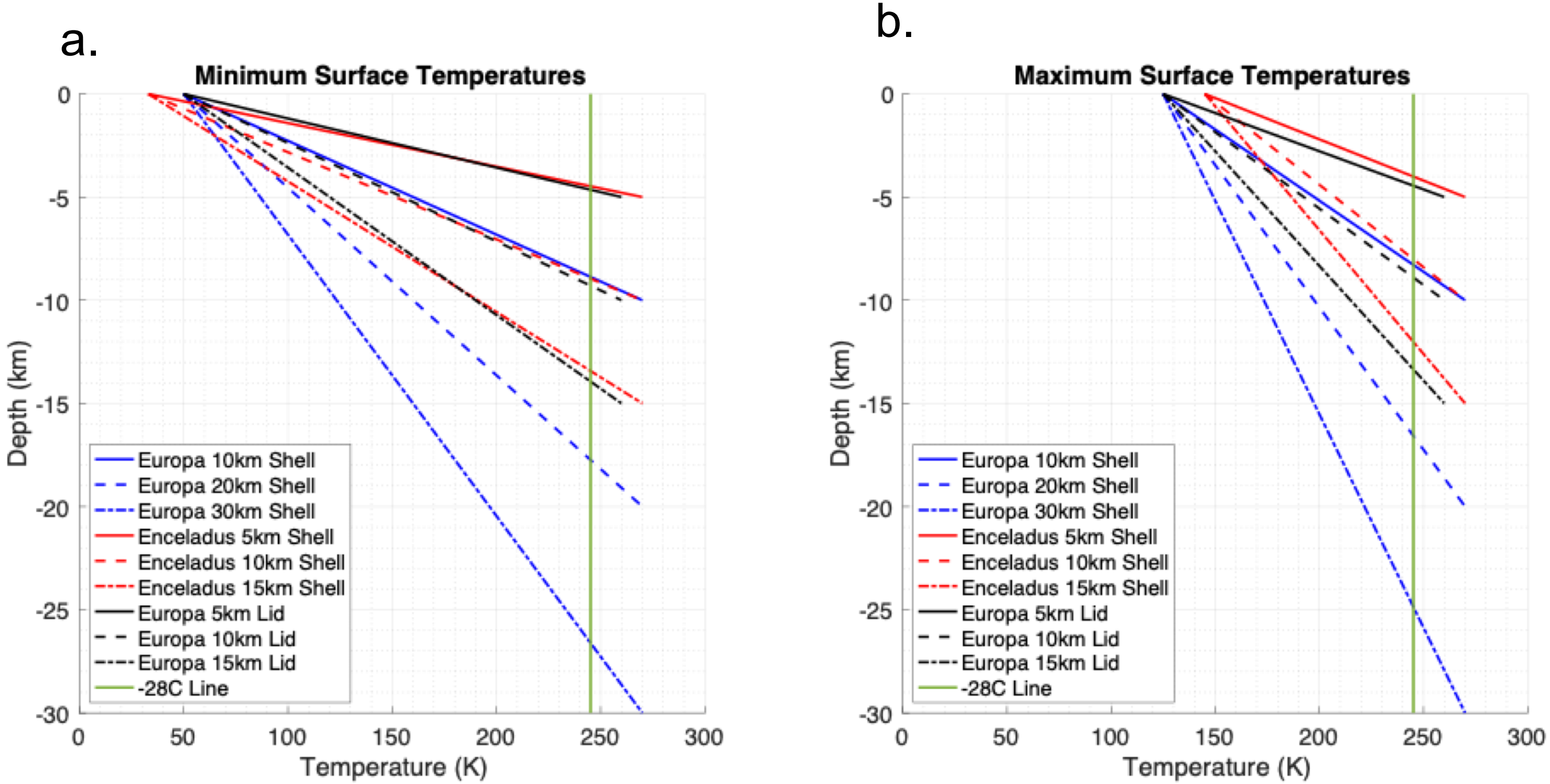
- Ganymede (Jupiter) internal ocean ~3 X larger than Europa, but lacks clear evidence of a connection
  T_{surf}=-113^{o}C (midday at equator, colder toward poles / other times)

- 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

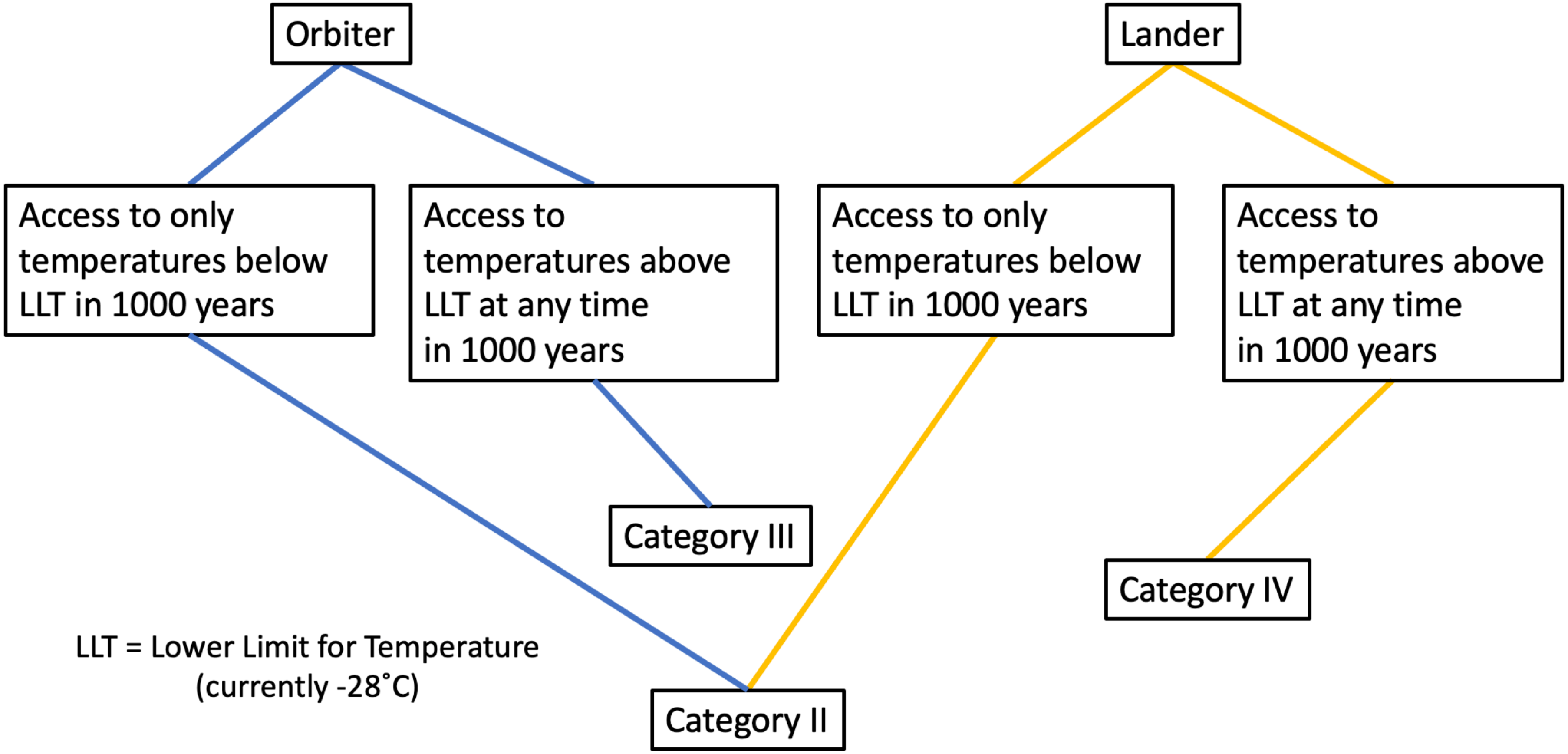
THIS IS JUST AN EXAMPLE OF THE TYPE OF MODELING A MISSION MIGHT USE



"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 (LRT) within 1000 years (PBE).



- Establish an Icy World (not just Europa and Enceladus) categorization that is based on the modeled depth to the LLT and the likelihood of a connection from the surface to that depth. For an orbiting mission, if the probability of accessing the depth to the LLT inadvertently is less than 10^{-4} in 1000 years, that mission would be classified as Category II. This would essentially treat regions where there is a possibility within 1000 years of a single microbe accessing temperatures higher than the LLT as "special regions" and would require making that language more general to include Icy Worlds in Category IVc. Note that we also propose to use a PBE of 1000 years for all Icy Worlds as was intended by the National Research Council (2012).
- All missions should consider the possibility of impact. Transient thermal anomalies caused by impact would be acceptable so long as there is less than 10^{-4} probability of a single microbe reaching deeper permanent regions >LLT in the PBE.

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

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

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 a crustal composition believed to be greater than 50% water ice by volume that 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.

Notable recent community input

CoPP October 2023:

- Has there been extensive research on microbes living in these exotic brines?
- What are the implications for exploring plumes?

OPAG last week:

- Use of the term Crust

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

Replace "a crustal composition" with "an outermost layer"

- Backup slides

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^{o}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 of change in policy

7. Definition of Icy Worlds

Icy Worlds in our solar system are defined as all bodies with a crustal composition believed to be greater than 50% water ice by volume that have enough mass to assume a nearly round shape (see Appendix A).

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

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

Will add appendix listing known icy worlds.

This is the wording used for the definition of a dwarf planet by the IAU. It will include bodies like ceres and Pluto, while simultaneously excluding comets, trojans, and TNOs (Centaurs / KBOs).

8. 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; Icy Worlds* others TBD

Category III: Flyby, Orbiters: Mars; Icy Worlds*

Category IV: Lander Missions: Mars; Icy Worlds*

Category V: Any Earth-return mission

"Restricted Earth return": Mars; Europa; Enceladus others TBD

"Unrestricted Earth return": Venus, Moon; others TBD

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Deleted: Ganymede*; Callisto; Titan*; Triton*; Pluto/ Charon*; Ceres; Kuiper-belt objects > ½ the size of Pluto*; Kuiper-belt objects < ½ the size of Pluto;

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*The mission-specific assignment of these bodies to Categories II, III or IV must be supported by an analysis of the potential for contamination described in Section 11.

9. Category II requirements for missions to the Moon

9.1 Orbiter and fly-by missions to the Moon [13]

Category II. Orbiter and fly-by missions to the Moon shall provide the planetary protection documentation described in Table 1. There is no need to provide an organic inventory.

8.2. Lander missions to the Moon [13]

Category II for the Moon is subdivided into IIa and Iib:

Category III. Orbiter systems shall meet one of the following conditions (Ref: [11], [12], [15]:

- The probability of impact on Mars by any part of a spacecraft assembled and maintained in ISO class 8 conditions, or better, is $\leq 1x10^{-2}$ for the first 20 years after launch, and $\leq 5x10^{-2}$ for the time period from 20 to 50 years after launch for nominal and non-nominal flight conditions.
- The total bioburden of the spacecraft on Mars, including surface, mated, and encapsulated bio-burden, is $\leq 5x10^{5}$ bacterial spores.

This is not only applicable to orbiter missions around Mars but also for Mars fly-by and Mars gravity assist maneuvers

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those environments. Planetary protection requirements for later missions should not be relaxed without scientific review, justification, and consensus.

11. Category II/III/IV/V requirements for Icy Worlds [15]

10.1. Missions to Icy Worlds (Ref: [15], [20], [21], [22], [23], [24])

Category II, III and IV. The Period of Biological Exploration (PBE) for icy worlds is defined to be 1000 years; this period should start at the beginning of the 21st century. Planetary protection requirements for flybys, orbiters and landers, including bioburden reduction, shall be applied in order to reduce the probability of inadvertent contamination of icy world subsurface environments beyond depths where maximum temperatures are > -28°C to < $1x10^{-4}$ per mission (water activity of ice is ~0.78 at -28°C and increases with temperature [ref], so we only use temperature as a limit to life in ice). The probability of inadvertent contamination of an icy world > -28°C subsurface of $1x10^{-4}$ applies to all mission phases including the duration that spacecraft

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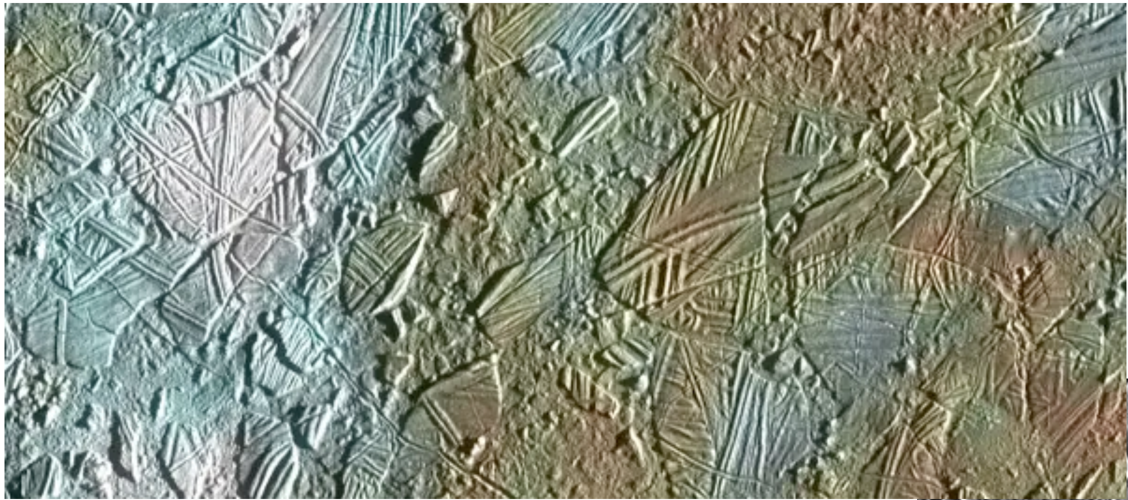
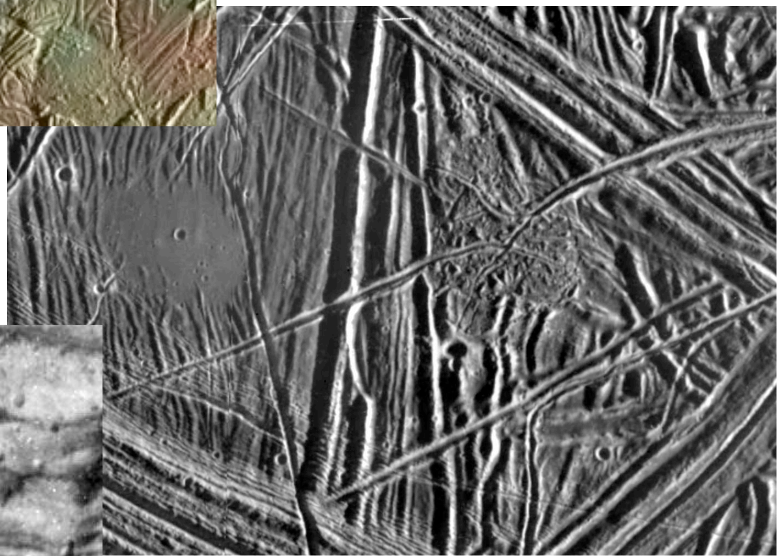
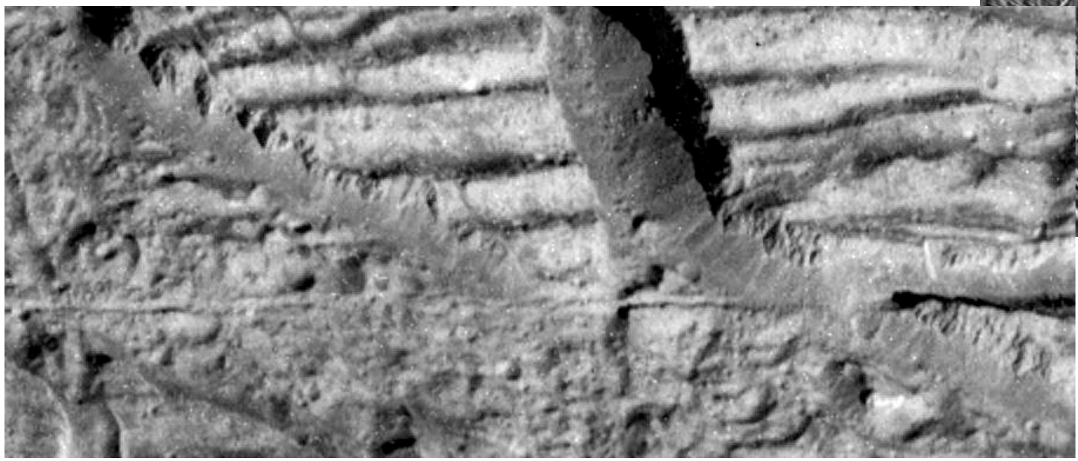


44x19 miles



7x10 miles

Europa and Enceladus are too cold in the top several kms to support terrestrial life (WHETHER THERE IS LIQUID THERE OR NOT).



1x2.5 miles