Planetary Protection and the Icy Moons of the Giant Planets

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Contents

Legal issues

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The Outer Space Treaty -1967-

- Treaty on principle governing the activities of states in the exploration and use of outer space, including the moon and other celestial bodies
  - Date opening for signature: January 27th, 1967
  - Date of entry into force: October 10th 1967
  - State parties : 98 (2003)

- Article IX of the « Outer Space Treaty » ref 610 UNTS 205:

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

- → signed and ratified by practically all Nations involved in Space activities since 1967 (including China, France, India, Japan, Russia, USA … ESA members statement to be checked)

The “Moon agreement” - 1979

- Agreement concerning the activities of States on the Moon and other celestial bodies
  - ref 1363 UNTS 3
  - DOS: December 18th 1979
  - DEF : July 11th , 1984
  - State parties 10 (2003)
- Article 7 of the « Moon Treaty »
- «…State parties shall take measures to prevent the disruption of the existing balance of its environment, whether by introducing adverse change in that environment, by its harmful contamination through the introduction of extra-environmental matter or otherwise. State parties shall also take measures to avoid harmfully affecting of the environment of the Earth through the introduction of extra-environmental matter or otherwise ».
- → signed and not ratified by France, neither signed nor ratified by USA, ESA members statement to be checked)

Comments on the UN Treaties

- The Outer Space Treaty is recognized as the solid base for the activities in the outer space. State parties include all space faring nations
- It applies with a legal force to the State parties and is recognised as establishing a customary international law
- The Article IX is opening the door of a large discussion about "harmful contamination" which is considered here as biological and leads to a side effect that the celestial bodies are better protected than the Earth (adverse changes).

COSPAR
planetary protection policy

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The COSPAR PP policy

- COSPAR PLANETARY PROTECTION POLICY (20 October 2002; Amended 24 March 2005)
- Statement of a scientific board
- It is not a binding law but might be considered as a soft law
- Five categories of mission have been defined

The COSPAR PP policy

Cat.	Type of Mission	Target Bodies	Recommendations
1	All	Sun, Mercury, Venus, Metamorphosed Asteroids	• Impact probability • Contamination passive control
2	All	Venus, Saturn, Uranus, Neptune, Comets, Jupiter, Chondritic Asteroids, some moon of the external planets, Pluto, Charon, Kuiper-Belt objects...	• Crash probability minimization • Passive control of the contamination
3	Flyby and orbiters	Mars, Europa...	▪Minimization of crash probability ▪Active control of the contamination
4 A	Contact probes ground or atmosphere	Mars, Europa … No Astrobiology in the payload	•Minimization of probability of off-nominal entry or landing • Active control of the contamination
4 B		Astrobiology in the payload (Mars)	• Same + Stringent active control of the contamination
4 C		Penetrating a special region (Mars)	• Same plus more stringent active control of the contamination
5 No R	Earth return	All	• No restriction
5 R		Mars, Europa, TBD	• Earth crash avoidance • Contact chain breaking • Sample quarantine

Implementation Guidelines on the Use of Clean-Room Technology for Outer-Planet Missions

- **COSPAR, *recommends* the use of the best available clean-room technology, comparable with that employed for the *Viking* mission, for all missions to the outer planets and their satellites.**
- **(COSPAR 1976)**
- **Numerical Implementation Guidelines for Forward Contamination Calculations**
- **To the degree that numerical guidelines are required to support the overall policy objectives of this document, and except where numerical requirements are otherwise specified, the guideline to be used is that the probability that a planetary body will be contaminated during the period of exploration should be no more than 1x10-3. The period of exploration can be assumed to be no less than 50 years after a Category III or IV mission arrives at its protected target. No specific format for probability of contamination calculations is specified.**

CATEGORY III/IV/V REQUIREMENTS FOR EUROPA

- **Missions to Europa**
  - Category III and IV. Requirements for Europa flybys, orbiters and landers, including bioburden reduction, shall be applied in order to reduce the probability of inadvertent contamination of an europan ocean to less than 1 x 10-4 per mission.
  - Preliminary calculations of the probability of contamination suggest that bioburden reduction will likely be necessary even for Europa orbiters (Category III) as well as for landers, requiring the use of cleanroom technology and the cleanliness of all parts before assembly, and the monitoring of spacecraft assembly facilities to understand the bioload and its microbial diversity, including specific problematic species.
  - Specific methods should be developed to eradicate problematic species. Methods of bioburden reduction should reflect the type of environments found on Europa, focusing on Earth extremophiles most likely to survive on Europa, such as cold and radiation tolerant organisms (SSB 2000).
- **Sample return from Europa : restricted Earth return**

CATEGORY REQUIREMENTS FOR SMALL SOLAR SYSTEM BODIES

- **Category I, II, III, or IV.**

The small bodies of the solar system (…) represent a very large class of objects. Imposing forward contamination controls on these missions is not warranted except on a case-by-case basis, so most such missions should reflect Categories I or II. Further elaboration of this requirement is anticipated.

Sample Return Missions from Small Solar System Bodies

- Category V. Determination as to whether a mission is classified “Restricted Earth return” or not was proposed by a SSB study, Specifically, such a determination shall address the following six questions for each body intended to be sampled:
- Does the preponderance of scientific evidence
  - 1. indicate that there was never liquid water in or on the target body?
  - 2. indicate that metabolically useful energy sources were never present?
  - 3. indicate that there was never sufficient organic matter (or CO2 or carbonates and an appropriate source of reducing equivalents) in or on the target body to support life?
  - 4. indicate that subsequent to the disappearance of liquid water, the target body has been subjected to extreme temperatures (i.e., >160°C)?
  - 5. that there is or was sufficient radiation for biological sterilization of terrestrial life forms?
  - 6. 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?
- For containment procedures to be necessary (“Restricted Earth return”), an answer of "no" or “uncertain” needs to be returned to all six questions.

Category V. The Earth return mission is classified, “Restricted Earth return.” (Europa et al)

- The outbound leg of the mission shall meet the contamination control requirements given above.
- Unless the sample to be returned is subjected to an accepted and approved sterilization process, the sample container must be sealed after sample acquisition, and a redundant, fail-safe containment with a method for verification of its operation before Earth-return shall be required. For unsterilized samples, the integrity of the flight containment system shall be maintained until the sample is transferred to containment in an appropriate receiving facility.
- The mission and the spacecraft design must provide a method to “break the chain of contact” with Europa.
- Reviews and approval of the continuation of the flight mission shall be required at three stages: 1) prior to launch from Earth; 2) prior to leaving Europa for return to Earth; and 3) prior to commitment to Earth re-entry.
- 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 (SSB 1998).

Implementation in the space agencies

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Implementation of the PPP – USA-

- Nasa policy directive on biological contamination control for outbound and inbound planetary spacecraft
  - Source : NASA Policy Directive 8020.7G and Space Act 1958
  - Referring explicitly to “The Outer Space Treaty” and to COSPAR guidelines
  - Establishing the function of the Planetary Protection Officer reporting to the NASA administrator.

Implementation of the PPP – USA-

The PPSC

The Planetary Protection Subcommittee (PPS) is a standing subcommittee of the NASA Advisory Council's (the Council) Science Committee supporting the advisory needs of the Administrator, the Science Mission Directorate (SMD), the Exploration Systems Mission Directorates (ESMD), and other NASA Mission Directorates as required.

The Subcommittee will review and advise on appropriate planetary protection categorizations for all bodies of the solar system to which spacecraft will be sent.

Implementation of the PPP – ESA-

- Planetary Protection Working group
  - Gathering scientists and experts and advising the HME directorate
- Planetary Protection Officer
  - One DTEC at ESA
  - One in the SS directorate

In charge of insuring the compliance of the ESA missions with the COSPAR guidelines

Last News from ESA PP

- ESA began working on planetary issues for
  - Rosetta (science directorate)
  - Mars Express and Beagle 2 (science directorate)
  - Exomars (Human missions and Exploration directorate)
- ESA submitted a High level document for PP policy to the ESA council.

Based on the recommendation outlined above, the ECSS Q-70-53 Working Group and the ESA Planetary Protection Working Group (PPWG) recommends defining an "ESA Planetary Protection Policy" in a Council level document, with related technical standards in an Appendix.

Last News from ESA PP

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- ESA produced a high level document for PP policy submitted to the ESA council.
- ESA is setting standard widely based on former work done by NASA in order to prepare Exomars

Discussion

- The Outer Space Treaty is binding the state parties
- These state parties are responsible of the activities done in and from their territory
- If the activity is conducted by a private entity, the state of nationality of this entity will be responsible
- COSPAR emits recommendation but they could be considered as a soft law
- The baseline for Planetary Protection is responsibility and wide consensus

The gold standard

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“Viking”: the gold standard

- Spacecrafts designed to land on Mars and to investigate extant Martian life: Category IVb
- Need to minimize the probability of contamination of the surface and to have false positive results
- Policy set up by NASA according with COSPAR recommendation included :
  - Clean room assembly (Class 100 000)
  - Bioburden reduction by dry heat sterilization of the entire Spacecraft

"Viking": The gold standard

- Pre-sterilization : 300 spore/m^2 and 5 $x10^5$ spore total spacecraft load
- Post-sterilisation : 30 spores on the entire spacecraft
- This was obtained by :
  - Cleaning all the instrument and surfaces (Isopropylic alcohol),
  - Placing the landers in a sealed tight bioshield
  - "Cooking" the Viking landers at 111,7°C for 30 hours

View from the Engineers

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A view from the Engineers

- Further missions have not been "cooked" after integration (Mars 96, Beagle2, Mars pathfinder, MERs…)
- Bioburden levels have been obtained by
  - Component sterilisation (heat, chemical, radiation)
  - Sterile assembly in Clean rooms (class 100 000, 1000, 100 or better)
  - Surface cleaning using wipes and IPA
  - Packing in a bioshield

A view from the Engineers

- Planetary protection requirements could lead for Categories IV and V to a Bioload reduction
- This impacts the choice of the components and the Assembly, Integration and Tests (AIT) procedures
- This impact the cost of the mission

SO

PP requires careful consideration very early in such projects

A view from the Scientists

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A view from the scientists

- Search for life is the main driver for astrobiology
- Biological contamination could impair scientific results of the considered mission or even of further missions
- The sensibility of the instruments is dramatically increasing every year
- Before returning a sample it will be almost impossible to distinguish terrestrial contamination from the discovery of a possible extant Martian (Europan) life. This implies a strict decontamination of the spacecraft and of the instruments.
- Discussion are ongoing about the possibility for some terrestrial organisms to multiply on Mars or to find an ecological niche in the possible ocean of Europa

A view from the Management

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A tentative view from the management

- Planetary protection consideration is mandatory for state parties of the Outer Space Treaty
- PP Policy implementation is the responsibility of the space agencies
- Certification and launch authorization is the responsibility of the governments
- Problems could arise along the course of international missions
- Planetary protection requirements are more and more stringent as missions are more and more ambitious and complex and rare.

⇒ Costs increase

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A case for Europa

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A specific Case for Europa

Preventing the Forward Contamination of Europa

Task Group on the Forward Contamination of Europa
Space Studies Board
Commission on Physical Sciences, Mathematics, and Applications
National Research Council

A specific Case for Europa

- Requirements for Europa flybys, orbiters and landers, including bioburden reduction, shall be applied in order to reduce the probability of inadvertent contamination of an europan ocean to less than 1×10^{-4} per mission.
- The SSB from NRC in the United States proposed a first “magic” evaluation formula

$$Nx_s = Nx_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7.$$

A specific Case for Europa

$$Nx_s = Nx_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7$$

- **Defining 5 types of microorganism (X)**

Type A—Typical, common microorganisms of all types (bacteria, fungi, etc.);

Type B—Spores of microorganisms that are known to be resistant to environmental insults (such as desiccation, heat, and radiation);

Type C—Spores that are especially radiation-resistant; and

Type D—Rare but highly radiation-resistant non spore forming microorganisms

- (e.g., Deinococcus radiodurans).

Explaining the factors $Nx_s = Nx_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7$

- **F1—Total Number of Cells Relative to Cultured Cells**
  - the task group assumed conservatively that laboratory cultivation underestimates actual microbial abundance by a factor of 1,000, for each type of microbial subpopulation.
- **F2—Bioburden Reduction Treatment**
  - For this sample calculation, no special treatments are assumed, so no credit for bioload reduction can be taken and this factor must be set to 1.0.

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Explaining the factors $Nx_s = Nx_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7$

- **F3—Cruise Survival Fraction**
  - No credit is taken for cruise as a remediating factor for organisms of Type B and C (i.e., F3 = 1.0). Type A, are often susceptible to inactivation by extreme vacuum, so the task group took a value of 0.1. Hence, for Type D cells the task group assumed a survival fraction of 0.5.
- **F4—Radiation Survival**
  - Once impact occurred, spacecraft debris would be exposed to radiation on the surface at a dose rate of 10 to 100 Mrad per month (see Figure 2.3 in Chapter 2). Microorganisms exhibit exponential declines in survival at high doses of ionizing radiation according to the following relationship:
  - $N = No \exp(-D/Do)$
  - where No = the initial cell number, N = the number of survivors that form colonies, D = the radiation dose, and Do = the D37 dose (at which 37 percent of the population survives). This equation indicates that increasing the dose by a factor 10 decrease the survival rate by 22 000.

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Explaining the factors $Nx_s = Nx_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7$

- **F5—Probability of Landing at an Active Site**
  - The factor represents the likelihood of landing at a geologically active site on the europan surface. F5 is the probability that the spacecraft will land at a site where burial to a depth of significantly more than 1 meter will occur in less than 7,000 years. Extrusive volcanic activity could bury the spacecraft. The task group assigned the very conservative value of 0.1 to factor F5, the probability of landing at a site where activity might bury the spacecraft or a significant part of it within 7,000 years, allowing eventual access to a global ocean.
- **F6—Burial Fraction**
  - For example, if a portion of the spacecraft is buried to 10 cm, it will take only 90 years to accumulate 7 Mrad of dose, but if it is buried to 1 meter the time to 7 Mrad will be 7,000 years. For this illustrative calculation, 50 percent of the spacecraft was assumed to be protected by being buried in ice to a depth of 1 meter or more.

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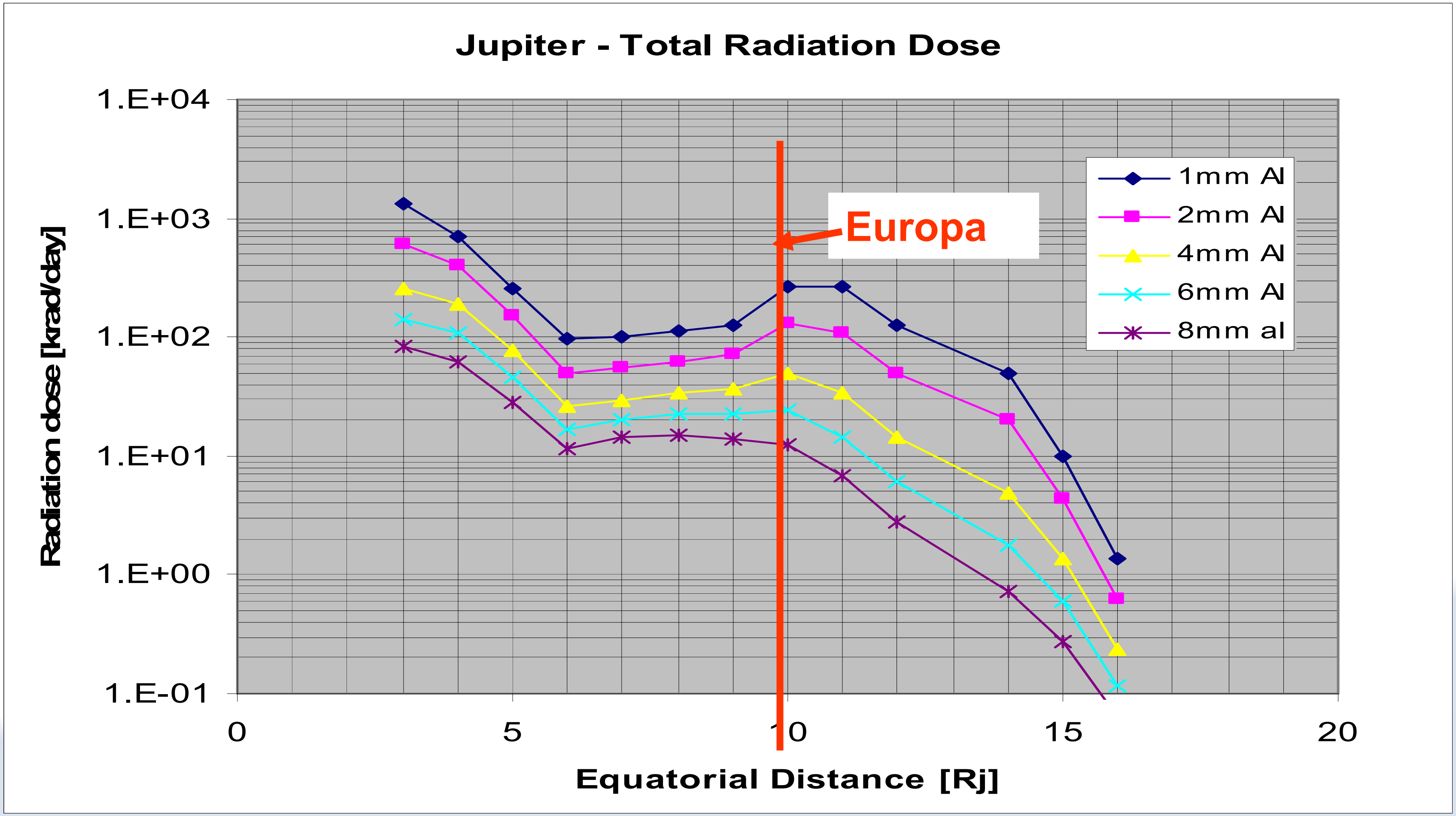
Jupiter Radiation dose as a function of distance from planet



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Explaining the factors $Nx_s = Nx_0 F_1 F_2 F_3 F_4 F_5 F_6 F_7$

- **F7—Probability That an Organism Survives and Proliferates**
  - **F7a—Survivability of Exposure Environments**

    pH, ionic strength, toxic ions, cold temperatures throughout the ocean, and the high pressures at depth. For this calculation, 20 percent of organisms are assumed to survive.
  - **F7b—Availability of Nutrients**

    Elemental nutrients are needed by organisms to synthesize key biomolecules. The task group took the probability that the entire suite of needed components are present as 50 percent.
  - **F7c—Suitability of Energy Sources**

    The probability that for any given assembly of organisms found on a spacecraft there will be a species that is capable of utilizing the exact energy couples available in the europan ocean is, of course, small.This factor is taken as 0.001.
  - **F7d—Suitability for Active Growth**

    For this sample calculation, the task group took the likelihood of a suitable organism to be no more than 1 percent of the organisms that are preadapted to the other environmental factors given previously.

Protecting Europa (ctd)

TABLE A.3 Probability of Contamination

	Type D	Type C	Type B	Type A
Number of Culturable Organisms on Spacecraft	1.5×10^5	3.0×10^3	3.0×10^6	1.5×10^8
F_1—Total cells/CFUs	1.0×10^3	1.0×10^3	1.0×10^3	1.0×10^3
F_2—Bioburden reduction treatment	1.0	1.0	1.0	1.0
F_3—Cruise survival fraction	0.50	1.0	1.0	0.10
F_4—Radiation survival fraction*	1.0×10^{-5}	1.0×10^{-10}	1.0×10^{-10}	1.0×10^{-10}
F_5—Probability of landing at an active site	0.10	0.10	0.10	0.10
F_6—Fraction buried under more than 1 m of ice	0.50	0.50	0.50	0.50
F_7—Probability of survival and proliferation	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}	1.0×10^{-6}
Product of Factors and Organisms	3.8×10^{-5}	1.5×10^{-11}	1.5×10^{-8}	7.5×10^{-8}
Sum	3.8×10^{-5}			

* Values for 7-Mrad dose

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Evolution and conclusions

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What about Icy moons.

- Icy moons deserve specific consideration
- Europa is probably the best template for further work on icy moons
- Knowledge about Icy moons is improving rapidly and must be considered accordingly
- Range of parameters of the environment to which terrestrial micro-organisms are found adapted is widening continuously

Workshop on Planetary Protection for Outer Planets' Satellites

- Timing and place : April 15th to 17th, 2009, in Vienna
- Sponsored by Panel on Planetary Protection, Sub commission F and Sub commission B
- Inputs include ESA PPWG studies, ESA/NASA Outer Planet Studies, current information on extremophiles, etc.
- Update knowledge of parameters implicit in the COSPAR Europa planetary protection policy (using the Sagan-Coleman formulation) for terrestrial life and each satellite
- Use updated parameterization to segregate icy satellites into "bodies of concern" and "bodies not requiring further protection"
- Organized by
  - Catharine Conley, NASA
    Gerhard Kminek, ESA
    François Raulin, U. of Paris-12
    Pascale Ehrenfreund, George Washington U. (Editor)

Final consideration

- COSPAR is maintaining a planetary protection policy since almost 40 years.
- General categorization can be assessed from the scientific goals, the experiments and the target body
- PP constraints must be considered as soon as possible in the development of a project
- Specific measures have to be implemented according with the available knowledge
- Each mission would be evaluated by an appropriate advisory body under the responsibility of the leading agency and/or party

To conclude

- Pristine celestial bodies are a Mankind asset and planetary protection is the only way to conduct sounding research and exploration in the future
- Early cooperation on planetary protection issues is the only way to build up a wide consensus protecting this asset for the future generations.

One of my favourite cartoon borrowed from John Rummel, chaiman of te COSPAR planetary protection panel and former NASA Planetary protection officer.

The Basic Rationale for Planetary Protection Precautions

(as written by Bart Simpson, 17 Dec. 2000)

Science class should not end in tragedy....
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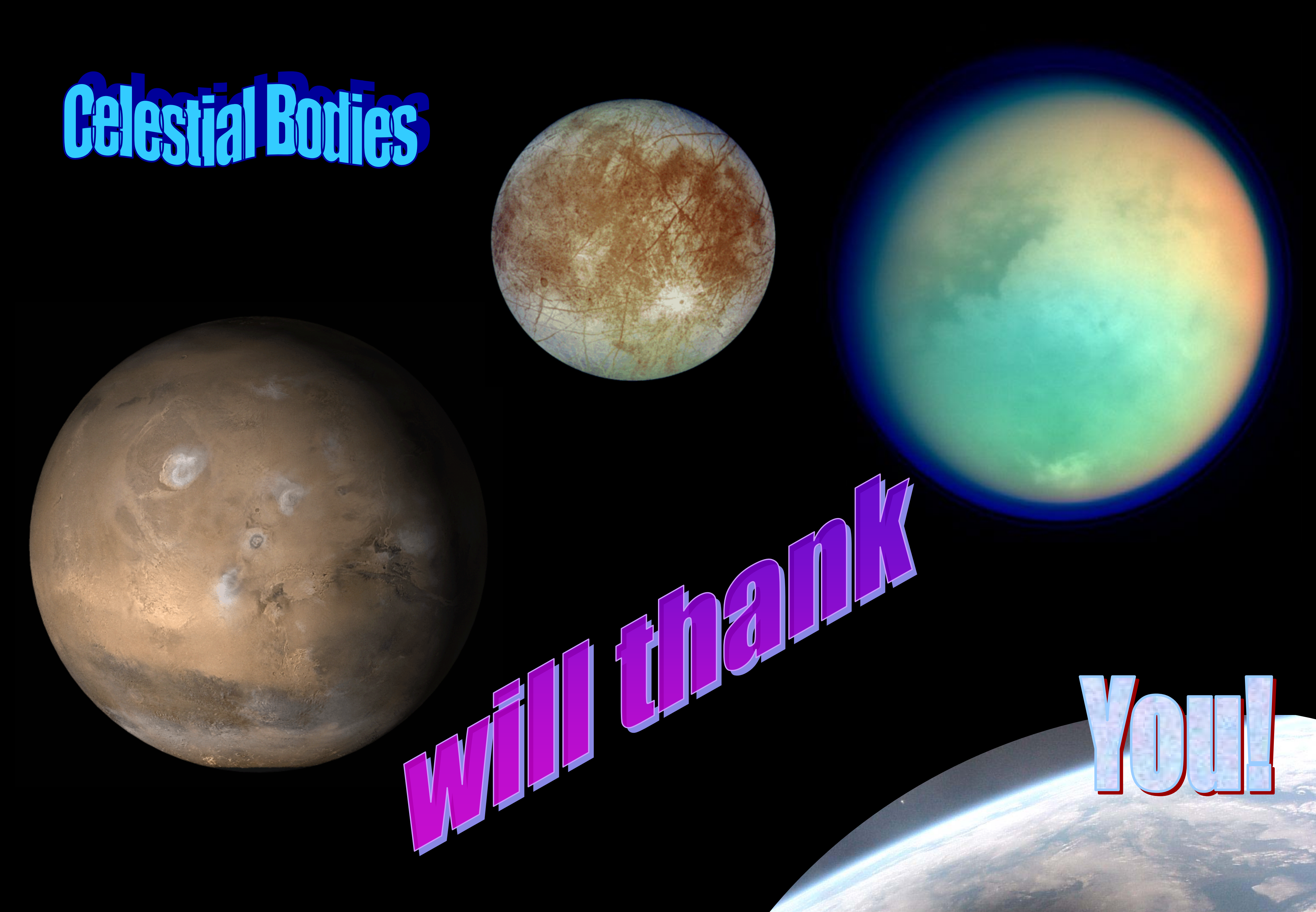
Celestial Bodies
will thank
You!