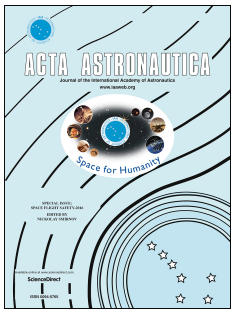

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Planetary Protection: updates and challenges for a sustainable space exploration

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Abstract

Planetary protection enables scientific return from solar system bodies investigations and at the same time protects life on Earth. As we continue to explore our solar system by landing machines and humans on other planets, we need to ascertain that we do not bring potentially dangerous material home to Earth or carry anything from Earth that may contaminate another planetary body and prevent scientific investigations.

A Planetary Protection Policy has been developed by the Committee on Space Research (COSPAR), which provides a forum for international consultation in the area of space research. The COSPAR Planetary Protection Policy, and its associated requirements, is not legally binding under international law but is an agreed standard with implementation guidelines for compliance with Article IX of the Outer Space Treaty. States Parties to the Outer Space Treaty are responsible for national space activities under Article VI, including the activities of governmental and non-governmental entities.

The current members of the COSPAR Panel on Planetary Protection are representatives from national space agencies and thematic experts from the science community of different countries (https://cosparhq.cnes.fr/scientific-structure/ppp). Other stakeholders, including the private sector, are invited to attend and present at the PPP meetings.

The COSPAR PPP maintains and updates the COSPAR Planetary Protection Policy regularly, always reviewing all available scientific knowledge leading to updates to the policy, in particular as concerns the outer solar system and

lunar exploration. Such updates are performed in a careful and balanced way to ensure that the right measures are envisaged to fulfil the rationales for planetary protection.

Keywords: (maximum 6 keywords) Planetary Protection; COSPAR Panel on Planetary Protection; Planetary Protection Policy; bioburden (reduction); space mission categories; contamination control

Submitted to Acta Astronautica
22 February 2022

1. Introduction: COSPAR and the Planetary Protection Policy

The exploration of the Solar System with machines and humans on the Moon has been occurring for more than six decades to date. As we investigate our neighbouring planetary bodies, we discover additional clues on the origin and evolution of our own planet and the emergence of life on Earth. For such investigations to remain possible and sustainable, we need to ensure that we do not harm the places that offer us the best opportunity to even better understand these processes and the possible habitats in the Solar System. It is an international responsibility to take care not to compromise the scientific investigations that can provide us with answers for such essential questions. This can only be achieved by not bringing potentially dangerous material back to Earth, or by carrying anything from Earth that may contaminate another planetary body. It is a responsibility we must take seriously. Planetary protection against harmful contamination is an international concern that is becoming even more essential in view of the emergence of new stakeholders and ever-increasing number of space missions planned to explore other planets and celestial bodies in our solar system and the growing involvement of private actors in these activities.

The legal basis for planetary protection is found in the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (the Outer Space Treaty) under Article IX, which states that "States 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 nations signatories of the treaty are therefore under an obligation to establish mechanisms that guarantee compliance with the treaty for any space exploration of the Moon and other planets or moons or asteroids. The term "harmful contamination" remains undefined in the treaty.

Several space agencies, such as the European Space Agency (ESA), the United States National Aeronautics and Space Administration (NASA), the Japanese Aerospace Exploration Agency (JAXA), the Russian Roscosmos, the Chinese CNSA, and the Indian ISRO, among others, build and operate different kinds of missions to explore space. Scientific goals are always a part of such endeavours.

Many countries at these times also have commercial or private sector activities in space, including to the Moon and other celestial bodies. Under Article VI of the Outer Space Treaty, States Parties bear international responsibility for their national activities in space exploration including the activities of governmental and non-governmental entities, with the activities of non-governmental entities specifically requiring authorization and continuing supervision by the appropriate State Party to the Treaty. States Parties to the Outer Space Treaty are responsible under articles VI and IX of the treaty for ensuring that their national activities in outer space, governmental or not, avoid harmful contamination of the Moon and other celestial bodies while preventing at the same time adverse changes in the environment of the Earth.

COSPAR, which was established in 1958, is the international scientific COmmittee for SPAce Research of the International Council for Science (https://cosparhq.cnes.fr/). The main objectives of COSPAR are to promote, at an international level, scientific research in space while promoting exchange of information and opinions. COSPAR's tasks include organising scientific assemblies, symposia and encouraging publications by providing a forum open to all scientists and stakeholders. COSPAR has a close relationship with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS).

One of the core activities of COSPAR has been to maintain, develop, and promote an international Policy on Planetary Protection and its associated requirements as the primary scientifically authoritative international reference standard guiding compliance with Article IX of the Outer Space Treaty. This Policy is the only internationally agreed planetary protection standard available for reference and use by all States that is based on the latest available scientific data. The COSPAR Planetary Protection Policy therefore reflects current scientific knowledge as concerns the potential harmful introduction of organic-constituent and biological contamination in space activities while exploring other solar system bodies.

2. The COSPAR Panel on Planetary Protection

Among the Commissions and Panels in the COSPAR structure is the Panel on Planetary Protection (PPP) established with as a primary goal to study, maintain, and update when necessary, the COSPAR policy and its associated requirements as a reference for spacefaring nations and to help guide States' compliance with the Outer Space Treaty, specifically with respect to protecting against the effects of forward and backward contamination.

The structure and composition of the PPP, as well as all recent documents related to the Panel's activities, can be found at [1]: https://cosparhq.cnes.fr/scientific-structure/ppp. The Panel was restructured in 2018 and has met regularly in open and closed sessions, executive meetings and assemblies several times a year since then.

2.1 Role of the COSPAR PPP

The Panel operates by reviewing all available scientific knowledge in the literature or by commissioning studies/consultations/evaluations performed by groups or committees of experts within or outside the Panel who review this scientific information and make recommendations to the Panel on whether a change to the policy is warranted. [1,2,3].

There are two primary goals of COSPAR's PPP. The first is to provide guidance to any spacefaring entities (governmental or not) so that they may ascertain that their space missions to targets that could be possible habitable environments in our solar system do not contaminate them with biological material from the Earth (forward contamination). The second goal of the Panel is to prevent any contamination of our biosphere from returned extra-terrestrial material, e.g., if the mission is designed to acquire samples to return to Earth for scientific analysis in different laboratories (backward contamination) [2,3].

COSPAR's PPP is thus concerned with possible biological interchange during exploration of the solar system and aims to ensure that the scientific research involved is not compromised by contamination. At the same time, precautionary measures help protect the Earth's biosphere from any potential hazards by spacecraft returning alien samples.

The planetary protection policy is regularly reviewed to consider the latest scientific results and to adapt as necessary. This has been the case recently in 2020 and 2021 [4,5].

The COSPAR Planetary Protection Policy and associated guidelines constitutes a voluntary non-legally binding standard through which the engineering solutions are to be determined at the discretion of either the governmental organization responsible for undertaking the planetary mission or the regulatory authority tasked with authorizing and supervising the planetary mission undertaken by a private sector entity within that State's jurisdiction. The Policy recommends that COSPAR members inform COSPAR when they are establishing planetary protections requirements at the national level. This open and transparent approach facilitates the sharing of information.

Furthermore, the Policy recommends that COSPAR members provide information about the procedures and computations used for planetary protection for each mission. These reports should include, among other things, the carried bioburden (that is, the number of microorganisms living on an unsterilized surface) and its probable composition, in some cases, at launch and the methods used to determine that bioburden for certain categories of missions. These reports should also include the methods used to control that bioburden, with the decontamination and/or sterilization procedures (Fig. 1). Organic inventory if greater than 1 kilogram for all spacecraft if the mission is to impact or land on a celestial body should also be included, whereas orbital parameters for non-landing missions should be provided. Finally, for end-of-mission reports, the disposition and approximate surface locations of the spacecraft and all its major components should be provided.

Figure 1. NASA's Mars 2020 Rover in a clean room at NASA's Jet Propulsion Laboratory in Pasadena, USA. *Credit : NASA/JPL-Caltech*

The Panel also conducts, upon request, a thorough review and assessment of mission-specific planetary protection requirements in order to assist space mission teams and provide the best risk assessment of a mission as concerns planetary protection.

Recent updates to the Policy included revision of some parameters and definitions for icy moons of giant planets that were approved in June 2020 [4], while another one specific to the Moon requirements was published in June 2021 [5]. The COSPAR PPP currently has 25 members representing space agencies and experts from the scientific community, as well as ex-officio members from the US National Academy of Sciences, Engineering and Medicine (NASEM), the COSPAR Committee on Industry Relations, the Office for Outer Space Affairs, United Nations, Vienna, Austria. The PPP welcomes observers at their meetings [1,6,7].

2.2 Operating mode of the PPP

As said earlier, the PPP's primary objective is to develop and promulgate a clearly delineated policy and associated requirements to protect against the harmful effects of forward and backward contamination [6-8]. Again, it is not the purpose of the Panel to specify the means by which adherence to the COSPAR Planetary Protection Policy and associated guidelines is achieved; this is reserved to the engineering judgment of the organization responsible for the planetary mission [1].

The Panel endeavours, through workshops, meetings and at COSPAR Assemblies, to provide an international forum for the exchange of information on best practices for adhering to the COSPAR planetary protection requirements [8-10]. The international nature of the Panel allows for discussion (including holding an active dialogue with the private sector) and decisions to be made during the Panel's meetings and to arrive at recommendations on the Policy that are submitted to the COSPAR Bureau for validation prior to publication. Once the update to the Policy is made, the Panel informs the international community [e.g., 7, 8].

3. The COSPAR Policy on Planetary Protection

In this section we detail the current COSPAR Policy on Planetary protection, and the requirements as updated recently [4,5]. This policy must be based on the most current, peer-reviewed scientific knowledge, and is intended to enable exploration, not hinder it. Planetary protection requirements are not cast in stone and evolve over time as new information becomes available (updates to the Policy are published in COSPAR's bulletin *Space Research Today*).

Space exploration involves missions built by national or international space agencies and from the private sector. They are composed of orbiters or landers or a combination thereof. The data acquired will allow for scientific insights on the external environment, the surface and subsurface (sometimes searching for traces of life or precursors of life), or possibly the inner structure of those celestial bodies.

The main goal of the Policy is to ensure the sustainable and safe conduct of scientific searches for any extra-terrestrial life forms. This implies that no terrestrial biological material is introduced into the environments of the investigated bodies. This proposition holds that the introduction of such contaminating material would preclude the proper scientific investigations. In addition, the Earth must be protected from the potential hazard posed by extra-terrestrial samples carried by a returning spacecraft. Therefore, for certain space mission/target planet combinations, controls on contamination should be put in place by operating agencies or national regulatory authorities in accordance with issuances implementing this policy [4, 5].

Planetary protection standards are there to indicate technical requirements needed protect the integrity of scientific investigations by limiting biological and molecular contamination of solar system bodies and at the same time protecting the Earth from potentially harmful samples carried on returning missions. The main strategies were published in August 2022 in the Implementing Planetary Protection Requirements for Space Flight (https://standards.nasa.gov/standard/NASA/NASA-STD-871927):

a. Understand and control harmful contamination of other worlds by terrestrial organisms, organic materials, and organic volatile materials carried or released by spacecraft (referred to as forward contamination) in order to assure integrity in the search for evidence of extraterrestrial life and the study of prebiotic chemistry in the solar system for the appropriate period of biological exploration.

b. Prevent harmful biological contamination of the Earth-Moon system by potential extraterrestrial life and bioactive molecules in returned samples and spacecraft from a sensitive solar system body (referred to as backward contamination).

Standards have also been established by the European Cooperation for Space Standardization – ECSS), and published by ESA Requirements and Standards Division, in ECSS-Q-ST-70-53-58C (2008-2017). These discuss sterilization processes, cleaning flight hardware, microbial examination in cleanrooms (Fig. 1), bioburden reduction and more such essential processes.

When presented with a given mission concept, the COSPAR PPP determines whether each mission is low risk or high risk. The five Categories of Planetary Protection outline the recommended measures that an agency should apply to each mission. See: https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/. The five categories for target body/mission type combinations and their respective suggested ranges of requirements can be found on the COSPAR PPP web page and were described in previous publications of the Policy (e.g. [5]).

Missions deemed to be of lowest risk (Category I) are those to a target not of direct interest for research into the process of chemical evolution/ prebiotic chemistry or the origin of life. These can include flyby, orbiter and lander missions but to destinations where no specific protections are required, e.g. the Moon, Venus, gas giants, some satellites. The lowest-risk missions are in COSPAR Policy Category I where any mission (flyby, orbiter, lander) is planned for bodies like undifferentiated, metamorphosed asteroids which are not of direct interest for understanding the process of chemical evolution or the origin of life.

4. Recent activities of the Panel

4.1. Updated category for lunar missions

In 2021 and in view of a renewed interest for lunar exploration with all the new robotic projects, which will hopefully allow for sustainable human presence in the future and return new scientific knowledge, we updated the Policy given the need to protect scientifically-interesting regions but recognizing the need for relaxation of some reporting requirements on the rest of the Moon [11,12]. This followed various actions and elements taken by the Panel such as a joint NASA-

COSPAR survey of the community, a thorough examination of all the existing studies and reports and literature findings.

The new Policy [5] stipulates that for all orbiters and flyby missions, there is now no need to compile the full organic inventory. The Moon remains in Category II, but with two new subcategories for *landed* missions on the Moon, such that:

- requirements were relaxed for missions to almost all places on the Moon with requested material inventory limited to organic products that may be released into the lunar environment by propulsion systems

- full organic inventory (solid and volatiles) is now only required for missions to the surface of the Moon whose nominal mission profile accesses Permanently Shaded Regions (PSRs) and the lunar poles, particularly at latitudes southwards of 79S and northwards of 86N. (Fig. 2).

A concern here is the possibility of indirect contamination resulting from release of volatile compounds migrating in the lunar exosphere and which could be trapped in the PSRs.

In general, *Category II* missions concern all types of missions (flyby, orbiter, lander) to those target bodies where there is significant interest relative to the process of chemical evolution and the origin of life, but where there is only a remote* chance that contamination carried by a spacecraft could compromise future investigations. The requirements are for simple documentation only and are based on short planetary protection plans established for these flight projects outlining impact targets, brief Pre- and Post-launch analyses detailing impact strategies, and a Post-encounter and End-of-Mission Report which provides the location of impact if such an event occurs.

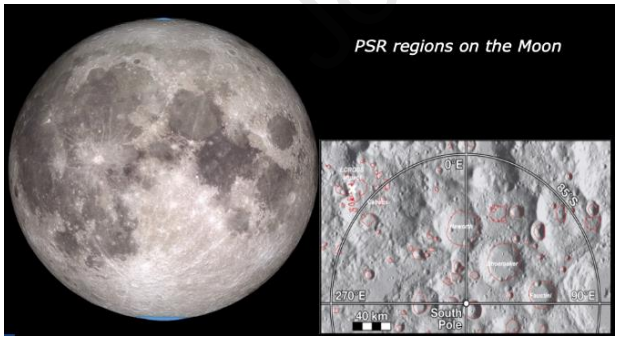

Figure 2. Right side, red features: PSRs at the Moon's south pole are further protected in the new Policy. Left side: fine blue caps concentrated at the poles are also protected while other regions have relaxed requirements. Credit: LRO/NASA.

It is important to note that landing on the Moon surface or access to any region on the Moon is still not prohibited by the updated Policy. Quite the opposite, COSPAR's Policy is there to enable future robotic and manned sustainable exploration of our satellite securing important scientific results.

4.2 Venus missions' policy

In view of recent scientific reports (e.g. [13] and references therein) and in the face of new plans from several space agencies, including NASA and ESA, to send new missions to Venus in the coming decades, the Panel tasked some of its expert members to look at findings and current knowledge on the possible habitability of Venusian clouds.

Based on published measurements, the level of water in the Venusian clouds is well below known limits for life on Earth, even though the temperatures in the clouds would support Earth life [14]. Based on these findings the following conclusion was made by [15] "Therefore, the COSPAR Panel on Planetary Protection concludes that without new measurements demonstrating water activity >0.5, Venus clouds are not a concern for planetary protection". We therefore did not request any updates to the current COSPAR Policy for Venus missions which are assigned Category II [14].

4.3 Mars Policy

Clearly, Mars has attracted much interest since the beginning of space exploration and this interest has increased over time. Mars has indeed a lot to offer in terms of knowledge on the origin and evolution of the inner solar system and the emergence of life therein.

In view of the extended and more sophisticated means employed for martian exploration (more and deeper drilling, more ancient regions, sample return projects, etc), it is important to ensure that such investigations take place with all the security and care possible in order to be sure that the scientific results are safeguarded and Earth's biosphere preserved.

The COSPAR PPP formed a subcommittee in 2021 to review the status of PP for missions to Mars based on the existing peer-reviewed literature on the possibility of habitable environments on Mars. The committee considered three areas of concern in the context of growing cells and proliferation: stability of water, biocidal effects in the martian environment and transport of spacecraft bioburden (Fig. 1). The subcommittee found that at present there is neither sufficient new evidence nor scientific community consensus to conclude that the bioburden recommendation for Mars needs to be changed at this point. Nevertheless, several knowledge gaps concerning atmosphere and dust, as well as biocidal effects, water vapour processes and content and transport processes on the martian surface were identified that will

* "Remote" here implies the absence of environments where terrestrial organisms could survive and replicate, or a very low likelihood of transfer to environments where terrestrial organisms could survive and replicate.

require new targeted research investigations before bioburden requirements can be relaxed. These findings and recommendations from our Panel are published in [16].

In addition, the COSPAR Sample Safety Assessment Framework (SSAF) was developed by a COSPAR appointed working group as a series of workshops aiming to assess whether samples returned from missions to Mars could be harmful for Earth's biosphere. The findings from these workshops were published by [17].

COSPAR is also mindful of future human missions to Mars for when that occurs. Human exploration is certainly cause for concern both for forward and backward contamination. A co-sponsored COSPAR-NASA series of workshops discussed the steps to be taken in order to address knowledge gaps in science and technology for planetary protection for future missions to Mars. These fall under three categories essentially: Microbial and human health monitoring; technology and operations for biological contamination control; Natural transport of biological contamination on Mars. Reports from these workshops were posted under Conference Documents at this link: https://sma.nasa.gov/sma-disciplines/planetary-protection/. The findings will be published in a report by Spry et al. (2023).

5. Future items for consideration by the PPP

In 2020 and 2021, the COSPAR PPP has published two updates of the Policy for Outer solar system bodies and the Moon and several articles on its related activities. But space exploration continues and so do our attempts to comply with our responsibility in planetary protection [18]. We thus will be further investigating (among other things) any additional considerations about martian robotic and human exploration and the exploration of the moons of giant planets to decide if there is need to update the Policy.

For missions of high risk (capable to potentially contaminate habitable environments), an important level of control needs to be applied to verify that the least possible bioburden is carried on board. Planetary protection technologies are always enhanced for cleaning and sterilizing spacecraft and for handling soil, rock and atmospheric samples. Such elements are always considered by the Panel.

5.1 Mars

The PPP will be regularly considering all new scientific findings leading to need for further considerations on the martian policy requirements for robotic as well as for manned missions. Of particular interest are returned data from space missions or ground-based observations.

Also, the need to close knowledge gaps, in particular for manned missions, is crucial to future exploration. In that respect, COSPAR has co-sponsored with NASA a series of interdisciplinary workshops on Planetary Protection for Human Missions to Mars. Reports from these workshops are posted under Conference Documents at https://sma.nasa.gov/sma-disciplines/planetary-protection/ and a publication is prepared (Spry et al., 2023)

5.2 Icy moons

The icy moons of the giant planets are considered as possible habitable environments in view of a series of recent findings indicating the existence of liquid undersurface water oceans, organic chemistry and energy sources co-existing in some cases as for Europa, Enceladus and Titan. The COSPAR PPP has already overseen updates of the policy requirements and definitions for the icy moons (especially Europa and Enceladus, Fig. 3). There are several projects for future space missions to the icy moons of Jupiter (JUICE, Europa Clipper) and Saturn (Dragonfly) already selected and even close to launch. Several other agencies have plans to continue such investigations and exploration.

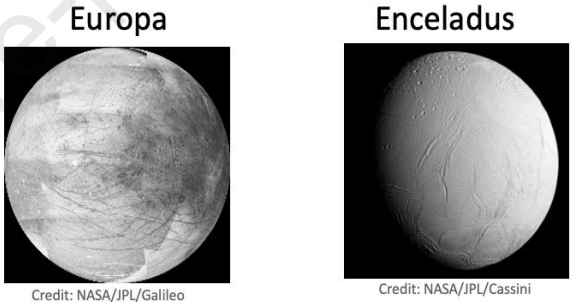

Fig. 3. New Policy considerations were implemented for icy moons, like Jupiter's moon Europa and Saturn's moon Enceladus

The COSPAR Policy has already accommodated several updates as concerns the icy moons Europa and Enceladus (Fig. 3) mission requirements following a study funded by the European Commission and led by the European Science Foundation (called PPOSS for Planetary Protection of the Outer Solar System). The PPP will be gathering community input to acquire consensus on changes that can be made to the protocols for visiting icy bodies in our solar system. The PPOSS recommendations were presented to the ESA Planetary Protection Working Group (PPWG) and to COSPAR in 2019 [19] and taken on board in the updated Policy [5].

5.3 Special cases

The COSPAR PPP operates in different modes. Among other, a special categorization was recently issued by the PPP for an unrestricted Earth return from Mars' moon Phobos by the JAXA MMX mission (https://www.mmx.jaxa.jp/en/), as studies showed that

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samples would not pose a threat for our biosphere after careful handling [COSPAR Panel meeting, 2019 and ([19], Fig. 4)].

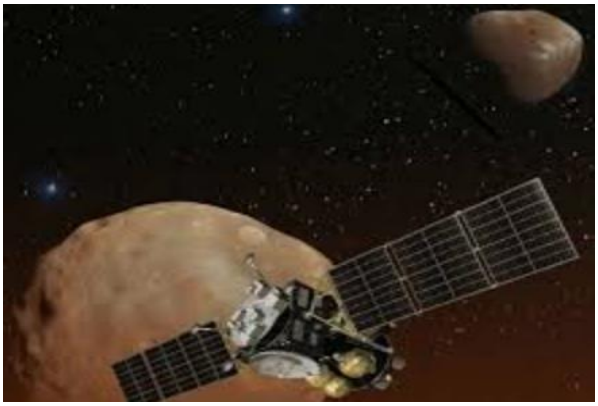

Fig. 4. The Martian Moons Explorer mission to Phobos and Deimos (Credit: JAXA)

The Panel is further discussing items related to evaluation of risk management-based approach, as well as how best to integrate the opportunities and caution represented by the private sector endeavors. The open sessions during the PPP meetings offer the possibility for all interested parties in space exploration to attend and propose issues of concern.

In the meantime, there is need for community input on science findings and anything relevant to the PPP recent reports and future considerations. This could happen via studies, surveys, Workshops, focused conferences and more.

6. Conclusions and outlook

Planetary protection guidelines have been developed to enable safe scientific space exploration and to ensure the protection of our planet. Securing sustainable robotic and human investigations in space relies upon compliance with the Planetary Protection Policy, which should be consulted at the start of new space projects by all stakeholders. Planetary protection technologies for cleaning and sterilizing spacecraft are improving around the world (Figs. 1, 5) and new measures are being taken to protect the Earth from any potential risk upon the return of samples from other planets.

For reasons stated above, it is very important to report to COSPAR. Reports should include information on the estimated bioburden at launch and its composition for Category IV missions, and for Category V "restricted Earth return" missions, on decontamination and sterilization methods employed, on the mission trajectory, orbital parameters and end-of-mission spacecraft disposition, and on the organic inventory for landed or impacting missions.

The open sessions during the PPP meetings offer the possibility for all interested parties in space exploration to attend and discuss issues of concern, as well as proposed solutions. Scientists, engineers but also space agencies and the private sector representatives are encouraged to participate and exchange at these meetings. The Panel will pursue its efforts to envisage any new needs for updates in the Policy with regard to new possibilities of exploration that might entail contamination (forward or backward) and will keep the community informed and aware of these changes.

Fig. 5. Planetary Protection measures against contamination by spacecraft, here ExoMars assembled and tested under planetary protection constraints. Credit: ESA ExoMars Program/Thales Alenia Space.

It is important to understand that planetary protection guidelines are there to ensure that scientific space exploration is safeguarded and to that the Earth is protected. For this, compliance with the Planetary Protection Policy is required, and the Policy can and should be consulted at the start of any new space projects.

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References

[1] The COSPAR panel on Planetary Protection https://cosparhq.cnes.fr/scientific-structure/panels/panel-on-planetary-protection-ppp/

[2] Coustenis, A., Kminek, G., Hedman, N., 06/2019. The challenge of planetary protection. *ROOM Journal #2(20)*

[3] Coustenis, A., Kminek, G., Hedman, N., Ammanito, E., Deshevaya, E., Doran, P.T., Grasset, O., Green, J., Hayes, A., Lei, L., Nakamura, A., Prieto-Ballesteros, O., Raulin, F., Rettberg, P., Sreekumar, P., Tsuneta, S., Viso, M., Zaitsev, M., Zorzano-Mier, M.-P., 2019. The COSPAR Panel on Planetary Protection role, structure and activities. *Space Res. Today* 205, DOI:10.1016/j.srt.2019.06.013.

[4] Fisk, L., Worms, J-C., Coustenis, A., Hedman, N., Kminek, G., the COSPAR Panel on Planetary Protection, 2020. Introduction to the new COSPAR Policy on Planetary Protection and the updated Policy. *Space Research Today* 208, August 2020, pp. 10-22. DOI: 10.1016/j.srt.2020.07.009.

[5] Fisk, L., Worms, J-C., Coustenis, A., Hedman, N., Kminek, G., the COSPAR Panel on Planetary Protection, 2021. Updated COSPAR Policy on Planetary Protection with introductory note. *Space Research Today* 211, August 2021. doi.org/10.1016/j.srt.2021.07.009

[6] Worms, J-C. and the COSPAR Panel on Planetary Protection, 2020. « Planetary Protection Policy: For sustainable space exploration and to safeguard our biosphere ». *Research Outreach* 118, 126-129. DOI: 10.32907/RO-118-126129.

[7] Coustenis, A., Hedman, N., Kminek, G., The COSPAR Panel on Planetary Protection, 2021. "To boldly go where no germs will follow: the role of the COSPAR Panel on Planetary Protection" *OpenAccessGovernment*, July 2021

[8] Coustenis, A., Hedman, N., Kminek, G., & the COSPAR Panel on Planetary Protection, 2021. "The COSPAR Panel on Planetary Protection: Recent Activities". *Global Space Exploration (GLEX)*, 14-18 June, St Petersbourg, Russia.

[9] Coustenis, A., Hedman, N., and Kminek, G., 2022e. Recent updates in the COSPAR Planetary Protection Policy. *44th COSPAR Scientific Assembly*, Athens, Greece, 16-24 July. https://www.cosparathens2022.org/. Abstract PPP.1-0001-22.

[10] Hedman, N., et al., 2022. The COSPAR planetary protection policy: ensuring the sustainability of scientific investigations in space. *United Nations/China 2nd Global Partnership Workshop on Space Exploration and Innovation*, 21-24 November.

[11] The COSPAR Panel on Planetary Protection: "Fly me to the moon: Securing potential lunar water sites for research", 2021. *OpenAccessGovernment*, Sept. 2021. https://www.openaccessgovernment.org/lunar-water/119679/

[12] Coustenis, A., Hedman, N., Kminek, G., The COSPAR Panel on Planetary Protection, 2021. "The COSPAR Panel on Planetary Protection: Recent Activities". *Lunar and Planetary Science Conference no 52*, 15-19 March.

[13] Cordiner, M. A., Villanueva, G. L., Wiesemeyer H., et al. 2022. Phosphine in the Venusian Atmosphere: A Strict Upper Limit From SOFIA GREAT Observations. *Geophysical Research Letters*, 49 (22), https://doi.org/10.1029/2022GL101055.

[14] Hallsworth et al., Nature Astronomy 5, pages 665–675 (2021)

[15] Zorzano, M-P., Olsson-Francis, K., Doran, P. T., Rettberg, P., Coustenis, A., Ilyin, V., Raulin, F., Shehhi, O. A., Groen, F., Grasset, O., Nakamura, A., Prieto-Ballesteros, O., Sinibaldi, S., Suzuki, Y., Kumar, P., Kminek, G., Hedman, N., Fujimoto, M., Zaitsev, M., Hayes, A., Peng, J., Ammannito, E, Mustin, C., and Xu, K., 2023. The COSPAR planetary protection requirements for space missions to Venus. *Life Sci. Space Res.*, 37:18-24. doi.org/10.1016/j.lssr.2023.02.001

[16] Olsson-Francis, K., Doran, P., Ilyin, V., Raulin, F., Rettberg, P., Kminek, G., Mier, M.-P. Zorzano, Coustenis, A., Hedman, N., Al Shehhi, O., Ammannito, E., Bernardini, J., Fujimoto, M., Grasset, O., Groen, F., Hayes, A., Gallagher, S., Kumar K, P., Mustin, C., Nakamura, A., Seasly, E., Suzuki, Y., Peng, J., Prieto-Ballesteros, O., Sinibaldi, S., Xu, K., and Zaitsev, M., 2023. The COSPAR Planetary Protection Policy for missions to Mars: ways forward based on current science and knowledge gaps. *Life Sci. Space Res.*, 36:27-35. DOI: 10.1016/j.lssr.2022.12.001

[17] Kminek, G., J. N. Benardini, F. E. Brenker, T. Brooks, A. S. Burton, S. Dhaniyala, J. P. Dworkin, J. L. Fortman, M. Glamoclija, M. M. Grady, H. V. Graham, J. Haruyama, T. L. Kieft, M. Koopmans, F. M. McCubbin, M. A. Meyer, C. Mustin, T. C. Onstott, N. Pearce, L. M. Pratt, M. A. Sephton, S. Siljeström, H. Sugahara, S. Suzuki, Y. Suzuki, M. van Zuilen, and M. Viso, 2022. COSPAR Sample Safety Assessment Framework (SSAF). *Astrobiology*, S-186-S-216. http://doi.org/10.1089/ast.2022.0017

[18] Kminek, G., Fellous, J.-L., Rettberg, P., Moissl-Eichinger, C., Sephton, M., Royle, S., Spry, J., Yano, H., Chujo, T., Margheritis, D., Brucato, J., and Haddaji, A., 2019. The International Planetary Protection Handbook. An online-only supplement to *Space Res. Today*, 205, e1-e120. 10.1016/j.srt.2019.09.001.

[19] Raulin, F., Coustenis, A., Kminek, G., Hedman, N., 2019. Preface and special issue "Planetary protection: New aspects of policy and requirements". *Life Sci. Space Res.* 23, 1-2.

Highlights

- Planetary protection enables scientific space exploration and protects the Earth
- A Planetary Protection Policy has been developed by the Committee on Space Research
- It is an agreed international standard with guidelines for compliance with the OS Treaty
- It is based on the most recent scientific knowledge
- A COSPAR Panel maintains and promotes updates the Planetary Protection Policy

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: