Testing the hypothesis: ‘planetary protection is expensive’ from an ESA perspective

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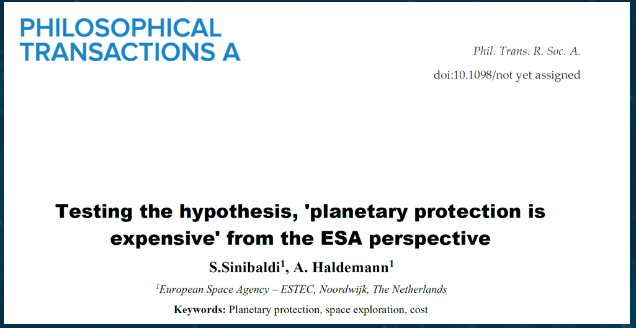
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Testing the hypothesis, 'planetary protection is expensive' from the ESA perspective

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→ THE EUROPEAN SPACE AGENCY

Motivations

The message

Planetary protection is about:

1 Enabling space exploration, protecting science and investment in space

2 Providing options and solutions in complex missions

3 Contributing to a more frequent and cheaper access to space

Motivations

Messina P, Gardini B, Sacotte D, di Pippo S. 2006 The Aurora Programme - Europe's framework for space exploration. In ESA Bulletin - European Space Agency 126, 10-15

Since the time of Aurora Programme (2006), there were numerous discussions within ESA and among its Member States on whether ESA should embark on planetary protection Category IV missions.

It was voiced that "PP is expensive" and it was requested that preliminary spacecraft design and development planning should evaluate planetary protection requirements

Planetary protection is often perceived as costly. This is partially due to the lack of understanding of what the discipline implies and how it is implemented.

Methods

Cost analysis and effort assessment made for all PP categories I-V

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 and IIb); comets; carbonaceous chondrite asteroids; Jupiter; Saturn; Uranus; Neptune; Ceres; [a]Icy Worlds; [a]Kuiper-belt objects that are not classified as Icy Worlds; others TBD
III	flyby, orbiter	Mars; Icy Worlds; Ceres; others TBD
IV	Landers	Mars (cat. IVa, IVb and IVc); Icy Worlds; Ceres; others TBD
V	Earth return	all Earth return missions

[a]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 environments that may exist beneath their surfaces (a probability of introducing a single viable terrestrial organism of less than 1 × 10−4), addressing both the existence of such environments and the prospects of accessing them.

Methods

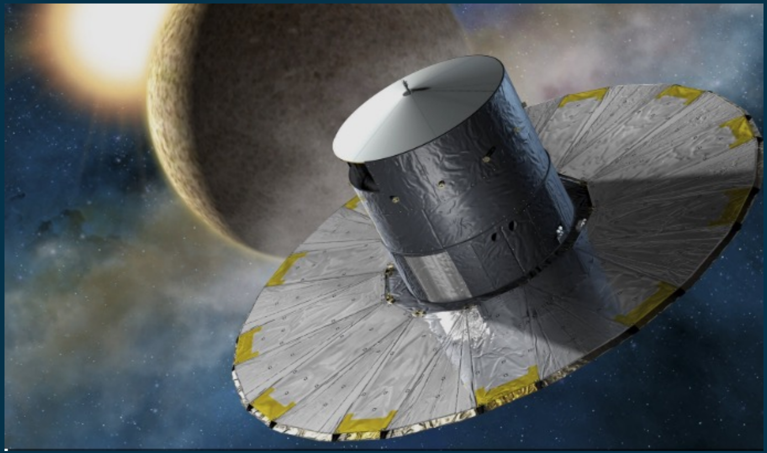
Analysis of the implementation strategies for ESA selected missions for each PP category, I-V
Interview mission teams, study relevant records/documents

Estimation of the effort for meeting final PP requirements considering the following

- Initial investments. This is a fixed cost to build and run (for the duration of the project) PP-related infrastructures. It includes bioburden-controlled cleanrooms, microbiological laboratories, but also computational tools used in probabilistic models to impact target bodies and/or to contaminate it (as applicable)
- Workforce allocated by mission teams for staff specifically working in planetary protection, either in the laboratory, or as project PP engineer or team leader. This is expressed in "full time equivalent" (FTE) number of persons per year
- Design and operational measures imposed to meet planetary protection requirements.
- Consumables used in PP-related infrastructures, for examples garments, wipes and swabs used for biological assays.

Note: ESA's contractual arrangements with the mission contractors limited reporting absolute costs directly in this paper

Missions Analysed – Category I



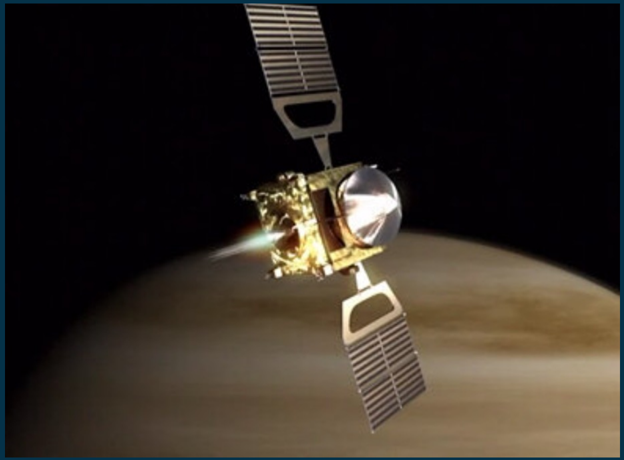
Category I missions: Smile, Euclid, Gaia, PLATO, ARIEL and LISA

Requirements: no protection is warranted, BUT:
ESA PP policy is levied to all missions leaving Earth orbit

Effort: probability of inadvertently impacting Mars (with both launcher and spacecraft) is within the applicable thresholds, and so is the probability of contaminating Europa or Enceladus

It can be simply met by demonstrating that the propulsive capability threshold is below certain limits

Missions Analysed – Category II



Category II missions: Giotto (1985), SMART-1 (Small Missions for Advanced Research in Technology) (2003), Venus Express (2005), Bepi Colombo (2018), Argonauts

Requirements: documentation only

Effort: limited to mission analysis, documentation, and, for landed missions, inventories of organic materials contained in the spacecraft.

Missions Analysed – Category III

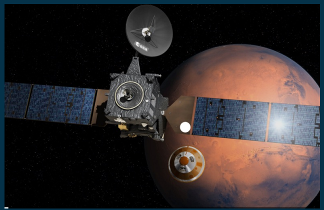
Rosetta 2004

Originally conceived as a sample return mission in cooperation with NASA and so in Category V

Re-planned as a comet orbiter and lander targeting comet 46P/Wirtanen, and requiring a flyby of Mars, which meant that Category III considerations applied

MEX (Mars Express) 2003

ESA's first mission to Mars, it has provided 3D views of Mars and mapped the chemical composition of the atmosphere, and it was instrumental to demonstrate the existence of environmental conditions that might have harboured life on the Red Planet. MEx has also observed Mars's innermost moon Phobos in great detail. "cheaper, faster and better"

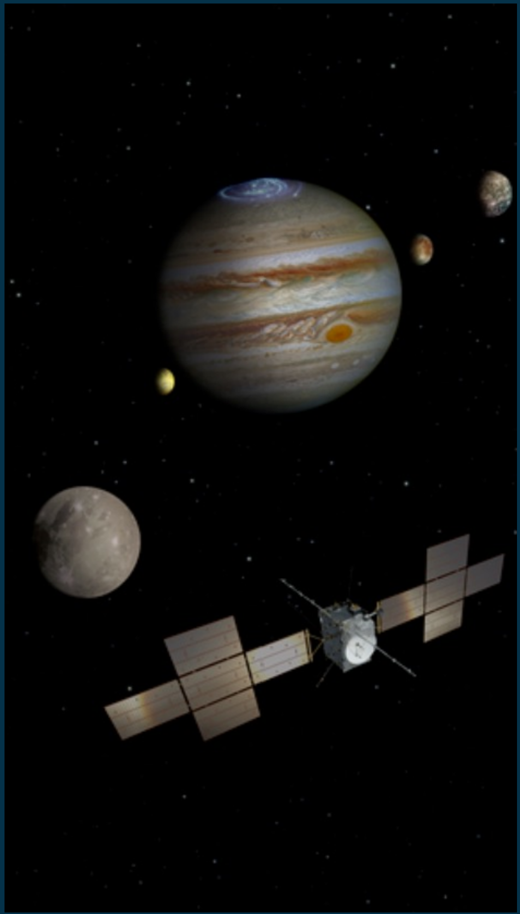


ExoMars Trace Gas Orbiter (TGO)

Understanding of methane and other gases present in small concentrations (less than 1%) in the martian atmosphere, and that could be evidence of potential biological or geological activities. Operating in a circular orbit at approximately 400 km altitude since 2018

PP effort: Probability of impacting Mars

Missions Analysed – Category III



JUICE – Jupiter Icy Moons Explorer 2023

The explorer is on its way to investigate the habitability of three Jupiter's Galilean satellites (Ganymede, Europa and Callisto), that are believed to harbour subsurface oceans. Cat III due to Europa fly-bys, as the spacecraft will be searching for organics and essential chemistry for life on Europa

Effort:
Analysis to demonstrate that the spacecraft would only have "remote" potential for contaminating Ganymede liquid-water environments with a multidisciplinary study

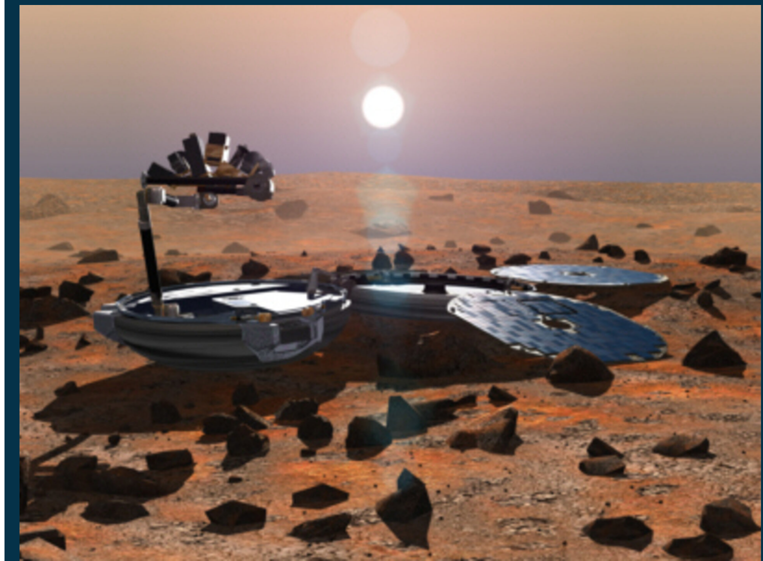
Use of collision avoidance (for both Mars, Europa and Ganymede)

Probability of impact analysis, considering reliability of the spacecraft and using Monte Carlo techniques, and agreed stopping conditions for the integration time (to meet the 1000 years period of biological exploration)

Spacecraft design: 1) locating electronic units inside "vaults", to shield them from both radiation and micrometeorites impacts, 2) fine managing of telecommand sequences, given interplanetary explorers cannot be operated real time (with JUICE having a turn round up to 45 minutes)

Biological sampling: culture-based assays, i.e. spore former organisms, oligotrophic, alkaliphilic, vegetative, anaerobic and fungi, and DNA based, molecular methods like 16s rRNA gene and shotgun metagenomics for biological knowledge

Missions Analysed – Category IV



Beagle 2 – 2003 IVa

limiting the total surface bioburden at launch to 3 x 10^5 spores, with a spore density no higher than 300 spores/m^2. Spore counts were assessed by culturing a heat shocked sample in accordance with ESA spore assay procedures current at the time

Additional requirement to catalogue chemical cleanliness, and to check compatibility of their instrument package with carbon analysis methodologies

Effort:

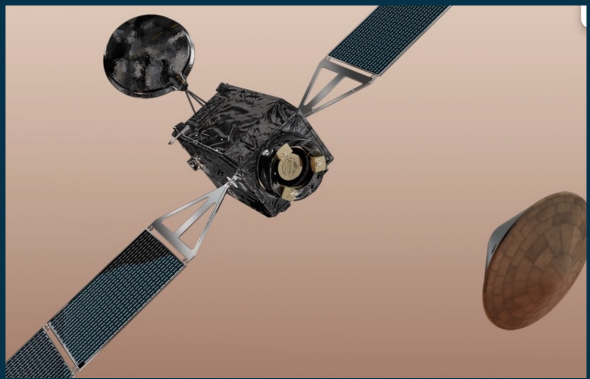
Use of aseptic assembly and sampling of space hardware, along with sterilisation processes mainly based on the use of dry heat microbial reduction

Part of the overall investment by Beagle 2's stakeholders (UK government as well as ESA and sponsors) was a cleanroom facility for the high-cleanliness lander assembly

Beagle 2's experience highlights the need for initial investments (fixed costs) in highly controlled cleanrooms, specialised facilities and laboratories to enable PP implementation with space hardware

A cautionary point however is that the cleanroom built for Beagle 2 was too small for the rover work on ExoMars, so it was decommissioned

Missions Analysed – Category IV



ExoMars 2016 – Schiapparelli IVa

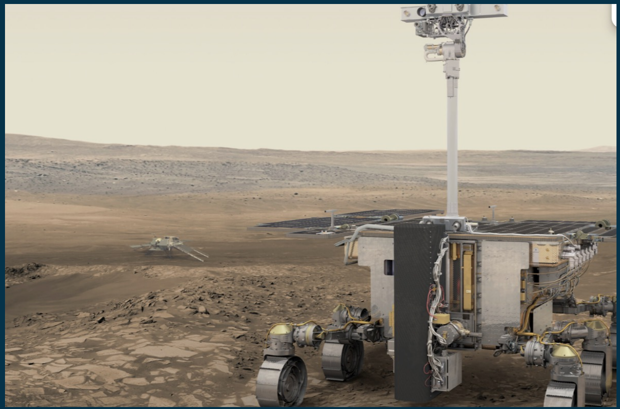
As part of the TGO mission launched in 2016, Schiaparelli was the Entry, Descent and Landing Demonstrator Module (EDM), addressing the ExoMars programme's first technology objective to land on Mars (technology demonstrator)

For EDM these included meeting a total bioburden of less than 5×10^5 bacterial spores. Lander: 3×10^5 bacterial spores, with an average surface bioburden density of less than 300 spores / m^2

Effort:

- Bioburden budget was created and an assay plan for each spacecraft item was established
- Certified microbiological laboratory, and certified personnel were needed to implement the assays
- Design and built ISO 7 and ISO 8 (highly controlled) cleanrooms with HEPA and carbon filters were used, monitored and maintained in service up to launch
- Portable tent to ensure the ISO7 environment was procured, commissioned and used both during integration activities at test facilities in Europe
- Personnel were trained to progressively more rigorous levels
- Recontamination prevention measures, to avoid cross-contamination between the TGO and the EDM
- The majority of the EDM equipment, except for electronic units, were sterilised with Dry Heat Microbial Reduction (DHMR)
- A total of 3236 spore assays were performed on the TGO and its Proton launcher. 7 planetary protection engineers and 6 laboratory technicians worked on the ExoMars 2016 mission (TGO plus Schiaparelli) during the different project development phases (A, B, C/D, E1

Missions Analysed – Category IV



Rosalind Franklin IVb

Search for life on the Red Planet (Oxia Planum)

Overall implementation strategy to meet final planetary protection requirements is designed to protect the scientific investigations from “false positives”

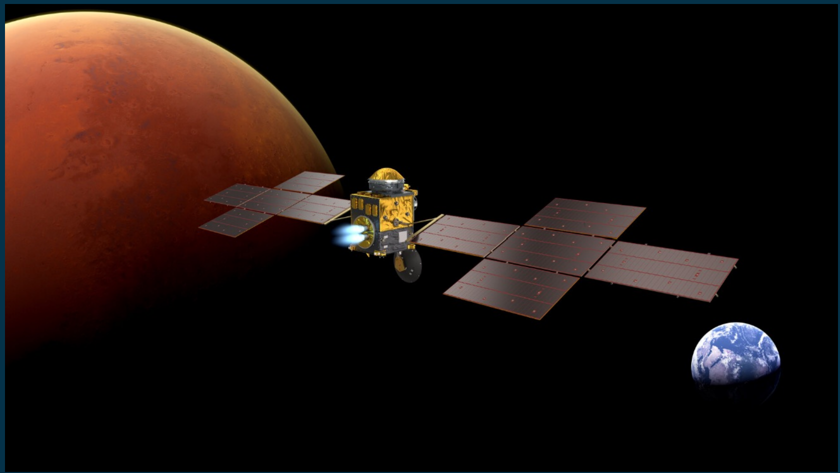
Bioburden contamination control and model-based break-up and burn-up analysis for the carrier module are used to meet the final spore count and density typical for Category IV-b missions (< 3×10^5 internal and external surface spores, and density of < 300 spores/m^2 spore density)

Stringent biological and organic thresholds for the so-called ultraclean zone (UCZ). Limit of 0.03 bacterial spores / m2 is established, and a total organic carbon limit was set in consultation with the instrument teams

Effort:

Initial investments due to use of biologically controlled environments, ad-hoc tents and microbiological labs (Italy, Germany, France and UK)
A total of approximately 12,205 assays were performed on both the rover and carrier modules. The total workforce supporting planetary protection for all the mission development phases (A, B, and C/D) has been around 9 planetary protection engineers/leads and 5 laboratory technicians.
Development of cleaning and sterilisation processes designed for different elements of the mission
Prevention of recontamination: design of the UCZ, Analytical Lab Drawer (ALD), - Mars Organic Molecular Analyser (MOMA)

Missions Analysed – Category V



Mars Sample Return – ERO (Earth Return Orbiter)

Restricted Earth Return mission (V-r)

Planetary protection strategies for both forward and backward contamination
Outbound phase very similar effort compared to other Cat. III missions
Inbound phase:

1. for the first 100 years after departure from Mars, a probability of less than 1 in a million of releasing an unsterilised particle of 50nm size or larger into Earth's biosphere
2. safety critical functions, i.e. those that can lead to the risk of releasing unsterilised material, designed to be 2-failure tolerant. In addition, ERO is required to perform an Earth-avoidance manoeuvre into a heliocentric orbit after releasing of the EES

Safety considerations with respect to the potential release of unsterilized material from flight hardware that has been exposed to Mars are an essential part of the design and operations of a Mars sample return mission

Planetary Protection Re-entry Safety (PPRS) panel that has independence from the ESA and the ERO project, has been created

Results

Categories I and II

For mission Categories I & II, minimal nominal effort is required by projects to comply with ESA and international planetary protection regulations, and additional investments or fixed costs are not needed.

For those missions meeting and verifying PP requirements is covered by normal project work activities, and no dedicated PP functions are needed. System or product assurance engineers can implement the planetary protection needs.

Results

Category III

JUICE

Category III orbiter mission to Icy Worlds (JUICE), planetary protection requirements influenced spacecraft design and operations

However, the majority of the measures used for planetary protection were, in any event, necessary to ensure that JUICE could survive the harsh radiation environment and performed its mission successfully

The total manpower for developing and validating the necessary computational tools and reach the required confidence levels was estimated to be an extra 0.8 FTE working in the project (8 months). Note: time to run the Monte Carlo simulations not considered
For future orbiter missions to Icy Worlds, the initial investment in terms of time and effort will be dramatically reduced

JUICE was one of the missions at ESA where the project benefitted from a planetary protection system level approach, with decision making processes that included engineering, safety, science and planetary protection functions in a coordinated way

The total cost impact of purely planetary protection tasks for JUICE compared with the total cost of the mission was well below 1%.

Results

Category III

MeX, TGO and Rosetta

Category III orbiter mission to Mars

The additional impact on cost to implement planetary protection measures based on mission analysis is a small portion of the normal work of mission analysis

The PP effort might increase for future missions to Mars where a lower altitude orbit (< 300 km) is selected to enable a prioritised scientific return.

Results

Category IV

Beagle 2, Schiapparelli and Rosalind Franklin

Category IV landers to Mars

Specific cost to meet planetary protection requirements has been estimated to be up to or around 5% of total mission cost

Largest portion of that cost (more than half) is due to the fixed-cost initial facilities investments and the development and qualification of new or bespoke methods

The facility cost may have been higher than 5% for Beagle 2 (perhaps 10-15%), but then that mission was Europe's first to establish a highly clean integration facility for a Mars lander.

Fixed cost for ExoMars for special accommodations mentioned earlier (a transportable clean tent for Schiaparelli and the GBT for the ALD in Rosalind Franklin) represented additional one-time investments approximately totalling to 8-10 FTE during Phase C.

Important:
Clean integration needs can arise due to scientific objectives, as was the case for Rosetta, Beagle 2, and Rosalind Franklin.
In those cases, meeting some or all of the PP requirements aligns with meeting instrument design and integration requirements, and represents a coordination between the instrument or spacecraft system engineers and the planetary protection engineers. Therefore some 'resource sharing' in the overall budget can be assumed.

Conclusions

Attempt to tackle a common assumption: “planetary protection is expensive at ESA”

Bound by ESA’s contractual arrangements with the mission contractors from reporting absolute costs directly in this paper

Estimation of planetary protection implementation was a complex activity in particular for those missions developed decades ago, given the difficulties to find relevant information and a level of “hidden” cost. Nevertheless, we have considered those uncertainties and calculated direct and indirect costs

Considered: total number of personnel working in the planetary protection function for the mission duration; initial investments for facilities and consumables; computational tools (as applicable); and measures imposed at design and operational level driven by planetary protection requirements.

For forward contamination, we have found that meeting planetary protection requirements is not a cost driver. It becomes a part of the integrated system engineering cost for a mission.

The cost is less than that of a scientific instrument. The planetary protection measures however contribute to ESA’s scientific and industrial return on investment

Conclusions

For backward contamination, based on the experience acquired on the ERO, where planetary protection is an integral concept of the overall mission objective, separating PP from other mission costs is not a useful exercise

Rather, we recognised that a Category V mission like ERO represents the culmination of ESA and European industry learning to integrate planetary protection as 'just another element' into the mission and spacecraft design

Planetary protection at ESA has become a system engineering activity, included throughout mission development from the early project phases through verification of requirements, launch, and mission operations

Planetary protection at ESA enables mission teams to explore the solar system in a sustainable and responsible manner. It will allow and contribute to a more frequent and cheaper access to target bodies, while fulfilling ESA obligations (Outer Space Treaty, Articles VI and IX) towards its Member States

Conclusions

We conclude that the overall cost to implement PP is not prohibitive to ESA's missions, but that it has required first-of-a-kind investments in generating new space know-how

New investment in modernising planetary protection toolkits will constitute a new round of fixed investment requirements (DNA-based technologies. PRA, etc). Essential to tackle the complexity of current European missions and support the ongoing shift at ESA from prescriptive to risk-informed decisions frameworks supporting the implementation of PP policies.

At most this should allow to maintain the PP efforts at or below the 5% of cost observed at ESA to date for Category IV missions. At best, a further reduction of cost for planetary protection could arise in the coming years, depending on how ESA addresses key knowledge gaps to better define the concept of harmful contamination


QUESTIONS?
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