IAA Cosmic Study
2010

Protecting the Environment of Celestial Bodies

(PECB)

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Contents

I. Executive Summary

The study group tasked with producing this International Academy of Astronautics (IAA) ‘Cosmic Study’ on Protecting the Environment of Celestial Bodies was formed under the auspices of IAA Commission V (Space Policy, Law & Economy).

The members of the international, multidisciplinary team assembled to undertake the Study accept, as a premise, the Planetary Protection Policy guidelines developed by COSPAR, which differentiate the degree of protection according to the type of space activity and the celestial body under investigation (such that fly-by missions have less stringent requirements than lander missions, while Mars is ‘better protected’ than the Moon). However, this Study goes deliberately beyond the interpretation of ‘Planetary Protection’ as a set of methods for protecting the planets from biological contamination and extends consideration to the geophysical, industrial and cultural realms.

The Study concludes that, from the perspective of current and future activities in outer space, present measures aimed at protecting the space environment are insufficient. Deficiencies include a lack of suitable *in-situ* methods of chemical and biological detection and the absence of a systematic record of radioactive contaminants. Other issues identified by the Study include an insufficient legal framework, a shortage of effective economic tools and a lack of political will to address these concerns.

It is expected that new detection methods under development, and the resultant increase in microbiological knowledge of the planetary surfaces, will lead to changes in the COSPAR planetary protection guidelines and bioburden limits. It is important, however, that any new approaches should not hamper future exploration and exploitation of celestial bodies more than absolutely necessary. The Study addresses the need to find a balance between protection and freedom of action.

From a legal perspective, the Study concludes that a general consensus on protection of the environment of the Moon and other celestial bodies should be sought among spacefaring states, while the question of new laws and regulations should be deliberated in the UN and scientific organisations. In doing so, it is recommended that experience in formulating the Antarctic Treaty System and other terrestrial environmental accords should be taken into account.

In general terms, it is expected that the majority of space activities would remain untouched by any future policies and regulations, to ensure that space exploration and exploitation remains open to future generations. But this philosophy brings with it a responsibility to protect the freedoms of those future generations from the ill-conceived practices of the present. As a result, activities that threaten the environments of celestial bodies, and our cultural heritage, should be identified, mitigated and discouraged (either by policy or by law).

II. Foreword by Mahulena Hofmann

Space activities undoubtedly bring a wide range of benefits to humankind – in science, technology, economy and many other areas. Like all human activities, they leave *per se* more or less measurable traces in the space environment. Some significant forms of this phenomenon - the issue of space debris or the problem of biological contamination – have been analyzed in the space community already. Important studies have been devoted to other questions such as the issue of abandoned objects in planetary orbits or the environmental impact of planned planetary mining or human settlements. However, these issues require a systematic, international and multidisciplinary approach.

This IAA Study on Protecting the Environment of Celestial Bodies (PECB) aims at providing an overview of existing methods of planetary protection and their feasibility from the perspective of current and future needs – biological, chemical, legal, economical and other methods. By doing so, the study goes deliberately beyond the interpretation of "Planetary Protection" by COSPAR (Committee on Space Research), which is generally used as a set of methods for protecting the planets from *biological* contamination and avoiding compromising future astrobiological research. Because of the limits given by the planned volume of the study, it concentrates mainly on the Moon and Mars environments.

Its general goal has not necessarily been the draft of a new, formal international document. The ambition of the study is primarily to initiate an international discussion, to raise awareness of these issues and to deliberate how to organize this protection more efficiently on an international scale. The result is a set of recommendations on "how to avoid future damage to and pollution of the environment of celestial bodies" developed at the final stage of the project.

The interdisciplinary character of the study required research by a multidisciplinary team composed of Ivan Almar (Hungary), Charles S. Cockell (UK), Cassie Conley (USA), Gernot Groemer (Austria), Gerda Horneck (Germany), Francis Lyall (UK), Gulnara Omarova (Kazakhstan), Juldis Omarova (Kazakhstan), Annelie Schoenmaker (ESA), Patricia Sterns (USA), Kazuto Suzuki (Japan), Les Tennen (USA), Mark Williamson (UK), Vasilis Zervos (UK), chaired by Petra Rettberg (Germany) and Mahulena Hofmann (Czech Republic/Germany) and supported by Marc Haese (ESA) as rapporteur.

The study has been performed in several steps. It has been accepted by Commission V of the International Academy of Astronautics (IAA) and was approved by its Scientific Activity Committee (SAC) in spring 2007. The first step was the definition of key questions related to the protection of celestial bodies which took part mostly during the Kick-off Meeting at the 58th International Astronautical Congress in Hyderabad, India. After the distribution of the relevant themes among the potential authors, first drafting work for each chapter was started in spring 2008. Not only the 2008 Glasgow IAF Congress but also other international meetings served as a platform for presenting and discussing the very first results and the steps to follow. The present Cosmic Study is a result of these efforts.

The last issue deals with the time of publishing this study. To some, the deliberations aimed at improving the present system of planetary protection seem to be unnecessary, premature and pro-activist. The economic crisis of 2009, which has slowed many ambitious space programs, seems to some to be a decisive argument for abstaining from any serious attempt to analyze its deficiencies and suggesting new approaches. This situation, however, can be seen also from another, positive perspective. Without any haste, this period can be used for discussing measures to prevent the destruction of the environment of the Moon and more distant celestial bodies which will be ready for a time of more intense space exploration. A second argument for not losing time is the fact that the economic crisis did not hit all geographical areas with the same intensity. Very probably, even during an economic depression, courageous projects appear on the drafting boards of new spacefaring nations, including missions to the Moon and exploitation of its resources. The example of nuclear exploration shows that reaching a consensus with participating nations requires a very long period of trust building and negotiation.

Moreover, it is known that a significant amount of space debris has already contaminated the surface of the Moon, Venus and Mars. All research, especially in-situ research, produces a certain amount of pollution. The spacecraft populations in the orbital environments of the planetary bodies, notably the Moon and Mars, are already on the rise. Developing space based energy sources, including in-situ resource utilization for use in space or transfers to Earth, can affect the planetary environment detrimentally. Commercial space tourism is increasing and so is its environmental impact. Industrial activity, mining in particular, may destroy the original environment of smaller celestial bodies.

More planetary protection issues and risks will arise with the addition of the human component to planetary missions: neither space suits nor space habitats will be closed systems; cross contamination will be reduced, but not fully avoided – at least at the landing and habitat site. Any permanent base on a celestial body can be a source of pollutants which can destroy or degrade in-situ research. Colonization and terraforming would mean a large scale transformation of the environment – the reforming of the environment of a planet to accommodate human life. Polluting planetary space can have harmful effects also to astronomy. Space based weapons would be particularly damaging to the space environment.

The last but not least argument for publishing the study just at this moment is the example of Earth-bound environmental problems and their currently, hardly manageable, range. It shows how difficult it is to cope with the detrimental consequences of human activities in comparison with preventive measures to avoid them. Even if the precautionary steps might be expensive and time consuming, economy teaches that at a certain point in time they prove less demanding than retrospective clean-up measures.

Finally, the chairs would like to express their thanks to all participants and supporters of the study for their devotion to this fascinating subject, and their experience and collegiality.

III. Scope and Methodology by Mark Williamson

1. Scope of the Study

As with much of science and technology, the title of this study – Protecting the Environment of Celestial Bodies - represents an approximation, a compromise in terminology. For instance, because people have preconceived notions of what constitutes ‘an environment’, it appears to consider only the planetary bodies and their moons, but the space environment also includes the orbital space surrounding those bodies and the electromagnetic spectrum and particle environment that pervades space.

The title also refers to ‘protection’, which is arguably an emotive word and often misunderstood, perhaps because of the disagreeable connotations of ‘protectionism’. Alternatives might include preservation, conservation or safeguarding, but our use of the word protection reflects current usage as embodied in the term ‘planetary protection’. However, “planetary protection”, as it is understood among the space community, concentrates on biological protection from contamination, either in terms of forward contamination of planetary bodies or back contamination of the Earth. This study extends consideration of protection beyond this understandable prioritisation of biology to the geophysical, industrial and cultural realms.

As such, the study recognises that there are many reasons to consider protecting a part of the space environment: because it is scientifically interesting, for example, or because it provides a useful resource or asset. Alternatively, an area or feature of the environment may be unique in some way and considered culturally worthy of protection: the Apollo 11 landing site is a prime example.

Although many readers will find much that is new to them in this study, the issues encompassed within protection of the space environment are not new. As implied above, the subsidiary issues of planetary contamination and Earth orbit debris have been recognised for decades and now benefit from a regime of policies and mitigation measures. Other aspects with relevance to protection of the Earth’s orbital environment include the recognised fields of space traffic management, space situational awareness and space weather.

The present study, while recognising and applauding the advances made in these areas, extends the remit of protection *beyond* the parts of the space environment in use today, in an attempt to prepare for planned missions and promised developments. Our collective experience of terrestrial environmentalism has shown that leaving consideration of the issues until commercial and industrial developments are in place is too late. In publishing this study now, we are attempting to learn from experience.

Although a comprehensive list of potential threats to the space environment would be extremely long, it is worth highlighting, in general terms, the aspects already identified as under threat:

- Celestial bodies (including planets, moons and asteroids): planetary protection measures already cover contamination issues, but do not consider the scientific merit of geomorphological features which may be threatened by future (manned) exploration, industrial development and space tourism.

- Earth's orbital resources (including low, medium and high altitude orbits, equatorial and polar): the orbits currently at greatest risk are some LEOs and the geostationary orbit (because of its high commercial worth). It is also recognised that the GEO graveyard is not a long-term solution to geostationary overcrowding, because the satellites in the graveyard are uncontrolled.

- Lunar orbit and planetary orbits: an increase in the use of these orbits is likely to face the same issues as Earth orbit with regard to potential collisions, explosions and other fragmentations that will increase the orbital debris environment and threaten scientific and commercial missions.

- Cultural and Historic sites: the lunar surface and, to a lesser extent, Mars already have a number of historic exploration sites that are potentially under threat from future exploration and development, perhaps most urgently from remote space tourism (via teleoperated rovers), and later by actual tourists and prospectors.

In addressing these and other potential threats, it will be important to bear two aspects in mind: balance and sustainability. Acceptable progress in protection issues will not be made by simply banning access to the space environment. It will be necessary to strike a balance between preservation and controlled use of that environment. One way to engineer this balance is to adapt the environmental concept of sustainability and instil an 'ethic' of environmental awareness.

Although much has been written and published on the subject of protecting the space environment, the present study, being conducted under the auspices of the IAA, indicates that the issues are taken seriously by a respected professional body. It is our hope that this is the first step towards broader recognition among the international space community and the beginning of a formal process resulting in guidelines and policies (see recommendations, section VI).

2. Methodology: An Interdisciplinary Approach

The possibility of protecting various aspects and assets of the space environment has been discussed in some detail for many years (not least by this author), but proponents of protection have failed to engage the mainstream space community to any significant extent. As a result, any broad acceptance of guidelines or policies that might protect or preserve those assets has failed to appear.

The notable exception is the protection of Earth's orbital resources from a damaging increase in space debris, provided by guidelines proposed by the Inter-Agency Space Debris Coordination Committee (IADC)[1] and adopted by the UN General Assembly. Although there are limitations to the effectiveness of these guidelines, the process of proposing and gaining agreement at an international level provides a useful model for extension to other aspects of the space environment, in particular the celestial bodies.

In addition, the analogous efforts of the terrestrial environmental movement, and the resulting protective measures, indicate the advantage of an interdisciplinary approach.

2.1 Viewpoints

It is clear from previous work on this wide-ranging subject that there are many different viewpoints of the value of the space environment (Williamson, 2006): scientists, for example, regard it as a subject of study, either remotely or in situ, whereas commercial operators think of it as a resource or asset to be used for financial gain. For this reason, it would be unwise to allow a single interest-group, or user-group, to judge which parts of the space environment should be protected and which should not.

Unfortunately, the understandable need for scientists to specialise, in order to make an original contribution to their chosen field, has led researchers to concentrate on what is termed 'planetary protection'. And while this sounds sufficiently broad, it tends to concentrate on biological protection – both to protect potential lifeforms on the planetary bodies against contamination from spacecraft and to ensure that future astrobiological research is not compromised.. The topic is so complex and, admittedly, important as a precursor to science on those bodies that it has dominated the efforts of the relatively few expert practitioners in the field. It means, however, that other aspects of protection have been sidelined.

Although it is relatively easy to convince members of the space community that biological contamination is undesirable and that engineers must design spacecraft to be non-contaminating, it is more difficult to instil an ethic that accords protection to landforms and morphological features on a planetary body (including moons and other minor bodies). This is strange, because establishing sites of special scientific interest (SSSIs) or, on a larger scale, international parks could protect both physical features and potential lifeforms. The issue is that planetary exploration is so focused on discovering life, or the precursors to life, or 'following the water' that might support life, that biological contamination dominates the field of planetary protection.

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[1] IADC member agencies include ASI (Agenzia Spaziale Italiana), BNSC (British National Space Centre), CNES (Centre National d'Etudes Spatiales), CNSA (China National Space Administration), DLR (German Aerospace Center), ESA (European Space Agency), ISRO (Indian Space Research Organisation), JAXA (Japan Aerospace Exploration Agency), NASA (National Aeronautics and Space Administration), NSAU (National Space Agency of Ukraine), as well as ROSCOSMOS (Russian Federal Space Agency).

So, perhaps the interdisciplinary approach to protection of the space environment should start with the scientists who study that environment, encouraging those interested in biological protection to work more closely with those who have non-biological interests. Indeed, this should be the easiest segment of the space community to convince. Other segments have their own, differing professional views and their own vested interests.

For example, the engineers who design the spacecraft and launch vehicles that empower scientists to study the space environment are, in their professional roles, more concerned with how it relates to the spacecraft they design. While the space environment provides a useful set of locations - chiefly orbits and planetary surfaces - from which to operate the spacecraft, it also tends to damage and degrade those spacecraft. To the engineer, the space environment is both a useful resource and a set of problems to be solved.

It also represents a resource for commercial satellite operators, who form a majority among space users, in that it provides accommodation for their satellites. The space environment - specifically geostationary orbit - has provided this opportunity since the technology became available to place satellites in that orbit, in the 1960s. Since then, hundreds of geostationary satellites have generated a significant amount of income for satellite operators and their shareholders.

Other commercial users have come forward as space technology has developed. In the late 1990s, for example, the world of satellite-based Earth imaging entered a new, commercial phase, using high-resolution satellites in sun-synchronous orbits. Since then, advertisers have used the International Space Station to promote their wares by filming adverts there, and several fee-paying tourists have visited the station. Meanwhile, a number of companies intent on developing sub-orbital tourism have begun to build spacecraft, while others are developing orbital modules and the means to access them.

More and more, the space environment is becoming an extension of our terrestrial business and commercial environment, which is why those interested in protecting the space environment, must encourage an interdisciplinary approach.

2.2 Space Debris Community

Without attempting a detailed history of how the space debris community has developed, it is possible to summarise a few key points with relevance to environmental protection.

Firstly, it is important to realise that current space debris guidelines and practices were not the product of some government diktat or intergovernmental accord. Moreover, there was no collective realisation among those building and launching spacecraft that doing so without due regard to the orbital environment was detrimental to that environment (and if there was some realisation, there was little action).

Our current knowledge and understanding of the space debris environment originates, to a large extent, from the interest and perseverance of a handful of dedicated individuals. Although many of the key protagonists worked for space agencies in Europe and America, they were not originally employed at the initiative of those agencies to study the debris issue; the initiative was a personal one. Nor were those individuals 'de facto experts' in space debris, because it was not a recognised field of study or research. Their experience grew from a personal, professional interest in what was happening in Earth orbit, an interest developed by interaction with their peers at conferences such as the International Astronautical Congress (IAC).

Interestingly, the effort was not interdisciplinary by design, mainly because it was initiated by people with the necessary mathematical and analytical skills to appreciate orbital dynamics, atmospheric drag, impact probability and other technical aspects. It was not initiated by a panel formed by lawyers, policy experts and government officials, but by people with the technical background to recognise a problem and the expertise to formulate a solution. Moreover, those individuals had broad interests in the continuance of space exploration while having no particular vested interests in how exploration and development should be conducted.

As far as these 'initiators' are concerned, their interest in orbital debris dates back at least to the 1970s, when some of the earliest explosions of discarded rocket stages were noted, but important progress was made in 1980, when the International Astronautical Federation (IAF) issued a study, on behalf of the United Nations Outer Space Affairs Division, in which debris management in geostationary orbit was addressed (Bonnal & Flury, 2006).

Although NASA's subsequent, unilateral efforts to reduce the risk of launch vehicle fragmentations led to a policy of removing residual propellant from spent stages, it was 1993 before the IADC itself was established as a truly international debris mitigation forum. Thus, it can take decades for good ideas to become policy.

The potential threat of debris in Earth orbit has been highlighted in recent years by China's intentional destruction of its Feng-Yun 1C weather satellite, in January 2007, and the collision between the defunct Russian Cosmos 2251 and the operational Iridium 33 in February 2009.So, despite the relative maturity of the orbital debris issue and the adoption of mitigation guidelines, significant debris-producing events continue to occur.

Although the development of space debris mitigation methods provides a potential model for those interested in protection of the space environment, it has its limitations. Apart from any salutary warning that significant improvements may take a generation or more, it is important to note that even the space debris community is not broad enough in its remit because it confines itself to debris in Earth orbit.

There are valid reasons for this concentration on Earth orbital debris, but it risks reducing the space community's expectations: now that orbital debris is understood and mitigation measures are in place, some might say the job – at least in terms of education - is done. But this would ignore the orbital environments of the other planetary bodies, most notably the Moon and Mars, where spacecraft populations are already on the rise.

With current plans to return astronauts to the Moon, perhaps by 2020, and despatch crews to Mars thereafter, it is important to realise that the Moon and Mars will acquire an orbital infrastructure (of communications, navigation and imaging satellites) within a similar timeframe. Our experience of operations in Earth orbit suggests that orbital debris will increase as a result. Indeed, the concept of a lunar orbit infrastructure is not straightforward, because low altitude orbits are disrupted by mascons (mass concentrations beneath the lunar surface) and because a putative selenostationary orbit would be highly unstable. Moreover, in terms of satellite retirement, the Moon has no graveyard orbit analogous to that around the Earth, no atmosphere to incinerate old satellites and no oceans to dispose of unwanted hardware. The 'orbital debris issue' is far from solved.

Nevertheless, it is possible to draw several basic conclusions from the development of the space debris community:

- Governments, space agencies and other national and international bodies are unlikely to take the initiative in protecting the space environment.
- Commercial entities are unlikely to take the initiative (for fear of damaging an already uncertain financial return).
- The initiators are more likely to be independent space professionals with no vested interests.
- The process of highlighting the issues and convincing detractors will take time.
- The goal of those concerned with protection of the space environment must be to highlight the issues without alienating members of the community, which means that comments and recommendations must be fact-based and pragmatic (i.e. related initially to current uses of the space environment).

As far as the interdisciplinary nature of any environmental protection lobby is concerned, the space debris community model provides some guidance, but not the final answer. On the one hand, the debris community is now composed of engineers, scientists, lawyers and policy experts and could therefore be regarded as interdisciplinary; on the other hand, it lacks significant input from the more commercial space community (and has taken too long to reach the point of acceptance among that community).

If the space environment beyond Earth orbit is to be protected - for future generations of scientific investigators and commercial users alike – we must adopt a more proactive approach.

2.3 Terrestrial Environmental Movement

Those interested in protecting the space environment can learn from the terrestrial environmental movement, which, within a generation, has moved from the sidelines to centre stage in global society. Much has been written on the reasons for this transition, but in summary it would probably be fair to say that the move has been neither smooth nor voluntary for most of the world's populations. There has been, and continues to be, heated argument about the solutions to environmental degradation and, where governments *have* been convinced, most of those solutions have involved legislation. Unless the space community, including its commercial segment, suddenly experiences a collective epiphany, there will eventually have to be guidelines, policies, sanctions or laws to protect the space environment.

As long as we realise the limitations of analogy, it ought to be possible to mirror our terrestrial legislation in protecting the space environment, for example by holding the equivalent of the 1972 UN Conference on the Human Environment (Reijnen, 1989). Some 114 states and non-governmental organisations (NGOs) participated in the 1972 Stockholm conference, which among other things highlighted the concept of sustainable development and led to the establishment of the UN Environment Programme (UNEP).

This in turn led to the 1992 United Nations Conference on the Environment and Development (UNCED), held in Rio de Janeiro, and its Agenda 21, an action programme directed at sustainable development and the proper use and management of environmental resources. The Rio Conference reaffirmed the principle of sustainable development, which had been defined in the Brundtland Commission's Report of 1987 as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987). This is a pattern that could readily be adapted to the protection of the space environment.

It is clear that the success of the terrestrial environmental movement is closely linked with the rise of 'globalism' and that major international meetings have helped to 'globalise' the issue. Considering the Earth as a single entity – the 'one planet' philosophy – has thus helped, potentially, to save the planet. It is interesting, from a space community viewpoint, that it was photographs of the Earth taken from space which fuelled that philosophy.

The space community has an advantage, therefore: it is already globalised and, by its very nature, has what we might call a 'large-scale environment' within its remit. Whether that environment is Earth orbit, lunar orbit or the surface of a planetary body, the use and/or protection of that environment requires consideration on a broader scale than is normal here on Earth. Moreover, as the space environment has a far smaller 'user community' than the Earth's, it should be easier to engineer an interdisciplinary approach among the different user groups – as long as it is done before commercial space tourism becomes a reality.

2.4 The Way Forward

Although the space community is a tiny subset of the global community, its members habitually group themselves into ever smaller sub-groups dependent on their specific interests. It is for this reason that the space debris community developed from a small group of interested individuals.

What this means in practice is that there are many different camps within the space community - astronomers, satellite communications operators, space tourism entrepreneurs - all of which have different agendas and different needs. This makes it difficult to get them together; indeed, they are rarely within the same building. For this reason, the space community needs an overarching body to coordinate the various interest groups and their often-conflicting needs. In other words, it requires an interdisciplinary approach.

Indeed, the present IAA Cosmic Study has aspects in common with previous IAA Studies, such as the "Position Paper on Space Debris Mitigation and the "Cosmic Study on Space Traffic Management", both published in 2006. It is worth quoting the introduction to the latter, which states: "At first glance, the management of space traffic does not appear to be a pressing problem. On closer examination, this judgement has to be challenged" (Contant-Jorgenson et al, 2006). Surely, the same could be said for protection of the space environment.

Significantly, although the orbital debris issue now benefits from the IADC space debris mitigation guidelines of 2002, the problem has not been solved. Debris continues to be produced and some satellite operators continue to ignore the guidelines altogether.

In fact, the issues are interconnected in that space debris surveillance and traffic management both limit the production of further orbital debris, while the reduction of debris helps protect orbital assets for the future. Although current guidelines and enforcement mechanisms, to the extent that they exist, help protect the Earth's orbital environment, they do little to address the rest of the accessible space environment.

The present Study is, at its simplest, an extension of the current philosophy beyond Earth orbit. The challenge, of course, is to convince the space community that orbits around the Moon and Mars, and the surface environments of the planetary bodies, are also assets worth protecting.

Protecting the space environment is a significant and long-term task, but this does not mean that time is on our side. Once commercial endeavours begin, they can evolve very quickly. Although the Apollo lunar programme was politically rather than commercially driven, it showed what could be done, with political and financial support, in less than a decade.

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IV. Planetary Protection from the Perspective of the Natural Sciences

IV.1 COSPAR Planetary Protection Policy - Present Status by Cassie Conley and Petra Rettberg

Abstract

Most solar system exploration involves spacecraft either going near or physically contacting other planets and moons of our solar system. As such, this exploration must involve some level of risk that these locations may be contaminated by terrestrial substances or organisms carried on the spacecraft. The potential to damage scientific results by unintentionally imported material is significant, if contamination is not recognized and controlled. Moreover, samples brought back from other planets might carry materials with the potential to contaminate the Earth, by analogy with invasive species already transported between continents. The prevention of these eventualities is called Planetary Protection, and such considerations have been taken into account from the beginning of the space exploration era. The Committee on Space Research (COSPAR) has developed and maintains a planetary protection policy (PPP), which is regarded as the international consensus standard for biological contamination. Planetary protection categories have been defined depending on the nature of the mission and the target body to be studied. For each of the five categories, specific requirements are set for documentation, operational constraints, and in some cases biological contamination. The COSPAR policy is continually revised, following the most current scientific knowledge about the capabilities of Earth life and the environmental conditions on other planets and moons that might be suitable for life.

1. Introduction

If we wish to understand the potential for life to exist elsewhere in our solar system, we must take every necessary precaution to prevent Earthly organisms from contaminating the targets of our exploration. Likewise, as we return samples of extraterrestrial material to Earth, we must be even more cautious to avoid contaminating the Earth (and human explorers who plan on returning to Earth) with harmful organisms from elsewhere.

With these goals in mind, we can develop further what planetary protection might be, and what it is meant to prevent. The case of Earth organisms being taken to another solar system body where they might reproduce is known as “forward” contamination, while the case of alien microbes being brought to Earth is known as “backward” (or “back”) contamination. Avoiding forward contamination is necessary to preserve planetary conditions for future biological and organic constituent exploration, and potentially for significant ethical reasons. Avoiding backward contamination is simple prudence - a necessary step to protect Earth and its biosphere from potential extraterrestrial sources of contamination.

Preventing interplanetary cross-contamination may be conceptually simple, but the practical implementation is complicated by our ignorance about the three main aspects that govern the success or failure of planetary protection provisions. We don't currently understand the nature and ultimate capabilities of Earth life, nor the nature and extent of planetary environments that might be suitable for that life, and neither do we have an understanding of the extent of extraterrestrial life. Life on Earth survives everywhere we look, even in unexpected places, and laboratory-based experimentation gives only a limited idea of the different limits for survival versus growth. Planetary missions are just beginning to scratch the surface of other worlds, which means that our understanding of possible environments thereon is in its infancy.

Suggestively, as we explore our solar system, local environments on other planetary bodies are being identified that appear to be increasingly similar to environments known to be hospitable for life on Earth, much more so than was predicted even a few years ago. These include the subsurface oceans of Europa, Titan, and possibly Enceladus, and the subsurface, possibly near-surface, aquifers of Mars. Any number of these locations might have hosted an independent origin of life, and several may have suffered the earlier introduction of Earth organisms blasted there by large impact events which we know have been fairly common. Whether we can detect either form of life is questionable, but we do know that we won't be able to investigate the question at all if we allow invading modern Earth organisms to destroy the evidence, or be mistaken for naturally introduced relatives.

2. Planetary Protection Measures

For the most part, planetary exploration missions have adopted planetary protection considerations from their inception, with each mission taking precautions appropriate to the location being explored and to the intended operational parameters.

Current missions to target bodies thought not to have significant potential for providing information about organic materials in the solar system, such as missions to Mercury or Venus, assemble spacecraft in cleanrooms but take no more than basic precautions to limit the number of Earth organisms carried on those spacecraft (termed “bioburden”).

Missions to locations that may contain information about chemical evolution and the origins of life, but that are thought unlikely to provide habitats for Earth life, also are assembled in cleanrooms. Additionally, they provide documentation regarding mission operations and organic constituents of the spacecraft, and may perform operations to limit contamination. The Galileo mission to Jupiter fulfilled documentation requirements when it launched, but the discovery of a potential liquid water ocean beneath the surface of Europa raised concerns that habitats for Earth life could be present in the Jovian system. To prevent contamination of the icy moons, particularly Europa, when the spacecraft was near the end of its life, the Galileo mission was terminated by having the spacecraft deorbit into Jupiter. When the Cassini mission launched to Saturn, no potential habitats were known in that system, but with the discovery of water/ice geysers on Enceladus, Cassini will end its mission in an equivalent manner. Most likely, Cassini will target Saturn or another body to protect Enceladus and prevent a high-velocity impact of Titan.

Future missions to the Jovian and Saturnian systems, which are now recognized to contain potential habitats for Earth life, will take additional precautions to protect those habitats, similar to those routinely practiced when exploring places like Mars. Mars missions and others that target or encounter planetary bodies with significant potential to provide habitats for Earth life must take precautions either to avoid contact with those locations, or to reduce the bioburden carried by the spacecraft hardware to a level at which contamination is unlikely.

Mars is thought to have the greatest potential of any other solar system body to support Earth life, so the most care has been taken to developing approaches that protect it from biological contamination. Of the missions currently in orbit around Mars, ESA's Mars Express and NASA's Mars Odyssey orbiter missions are performing operations in such a way that they each have a low probability (<1%) of impacting Mars within 20 years, and < 5% chance of doing so within 50 years. For this reason no bioburden restrictions, other than cleanroom assembly, were imposed on these spacecraft. More recently, NASA's Mars Reconnaissance Orbiter performed “burn-up and break-up” analyses to show that, with entry heating, viable organisms would not reach the Martian surface when the spacecraft deorbits. In general, orbiter missions to Mars provide significant documentation and perform operations to minimize their impact probability both inbound to the planet and while in orbit. Mars orbiter missions that do not meet orbital lifetime requirements must also take precautions before launch to reduce their bioburden.

Landers to locations thought to have significant probability of providing habitats for Earth life must reduce the number of Earth organisms they carry to a level that is thought to be unlikely to produce contamination. Currently, Mars is the only planet for which such precautions have been taken since the Ranger lunar missions of the 1960s, but future missions to other bodies, such as Europa in the Jovian system or to Enceladus in the Saturnian system, will also follow bioburden reduction procedures. For example, NASA's Mars Exploration Rovers (MERs) were carefully assembled and cleaned before launch to ensure that there were fewer than 300 heat-resistant microbial organisms, colloquially called “spores,” per square meter of the spacecraft surface that would be exposed to the Martian environment. The MER missions were not expected to access directly more favorable environments for terrestrial microbes on or under the Martian surface.

In contrast, NASA's Phoenix spacecraft was equipped with a robotic arm that it used to dig beneath the Martian surface and contact subsurface ice - a location that is much more protected than the bare surface of Mars. Therefore the entire Phoenix spacecraft was cleaned to the same level as the MERs, and the arm itself was carefully sealed inside a “biobarrier” designed to be opened only after the spacecraft had landed on Mars. Before launch, this sealed package was baked under conditions known to kill 9,999 out of every 10,000 spores. Phoenix was the first spacecraft to use this “subsystem-level” biobarrier approach and it turned out to be successful. The next Mars landers, including ESA's ExoMars and NASA's

Mars Science Laboratory, also will use biobarrier technology in addition to careful cleaning, both to minimize the chance that hitchhiking Earth organisms could contaminate Mars and to protect the cleanliness of sensitive instruments designed to measure organic compounds that might be present in Martian samples.

3. COSPAR Guidelines on Planetary Protection

The implications of planetary protection were appreciated long before space travel was a reality, and an acknowledgement in the real world didn't take long. The post-Sputnik timeframe saw the introduction of quarantine standards by the International Council of Scientific Unions (ICSU; now called the International Council for Science) in 1958, as well as recommendations for non-contaminating spaceflight practices by the US National Academy of Sciences in their 1958-1960 studies. For a review of the early history, consult Dick (2008).

By 1967- prior to the first successful landing on a solar system body other than the Moon - there was general agreement among spacefaring nations that interplanetary contamination should be regulated. Article IX of the United Nations Outer Space Treaty that entered into force on October 10, 1967, reflected this agreement, placing obligations on spacefaring nations such that (see also chapter V.1, Lyall):

> …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.

In anticipation of a coming space age, in 1958 ICSU had formed an interdisciplinary Committee on Space Research (COSPAR), which from its inception was the focal point of much of the international discussion and consensus on planetary protection issues. Both COSPAR and the International Astronautical Federation consult with the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) on matters involving the Outer Space Treaty. COSPAR has developed and maintains a planetary protection policy, which is regarded as the international consensus standard for biological contamination under the Treaty (see also chapter IV.2, Almar).

Current COSPAR planetary protection policy, as well as NASA policy and ESA policy, is based on the concepts put forward in DeVincenzi et al. (1983), which described five different categories of space missions, depending on the nature of the mission and the target body to be studied. COSPAR's planetary protection policy continues to be revised on a regular basis, with several changes having been approved by the COSPAR Bureau and Council at the 2008 Assembly in Montreal, Canada (COSPAR, 2008).

The current version of the COSPAR planetary protection policy states that:

> The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from an interplanetary mission. Therefore, for certain space mission/target planet combinations, controls on contamination shall be imposed, in accordance with issuances implementing this policy.

Responding to the Outer Space Treaty and the initial COSPAR policy, in 1967 NASA established a Planetary Quarantine (now Planetary Protection) Officer who carries responsibility for the overall NASA program in this area. NASA's implementation of planetary protection provisions depends on current scientific knowledge, based on internal and external recommendations including those from the Planetary Protection Subcommittee of the NASA Advisory Council and most notably from the Space Studies Board of the National Academy of Sciences. ESA also has a Planetary Protection Officer and advisory committee, the Planetary Protection Working Group. Additionally, COSPAR policy provides for the COSPAR Panel on Planetary Protection to provide advice on the subject to launching nations upon request.

As solar system bodies are explored and become better studied, knowledge of the existence of environments that may contain life or that could be contaminated by Earth life is constantly refined. Also, the ability of mission personnel to characterize biological contamination has been revolutionized over the last several decades through the advent of molecular methods, so measurement of forward contamination and its sources has been markedly improved (see also chapter IV.3, Rettberg). Accordingly, planetary protection measures associated with specific missions and targets are subject to continual re-evaluation and change. To date, all spacefaring nations have agreed to follow, at minimum, the COSPAR guidelines on planetary protection, while any national space agency may impose additional restrictions on the missions for which they are responsible.

COSPAR policy specifies that missions should be assigned one of five categories, based on the type of mission (flyby, orbiter, or lander) and considering to what extent the specific planetary target body is of interest for understanding the origins and evolution of life (Table 1).

> Category I includes any mission to a body considered not of direct interest for understanding chemical evolution or the origins of life, and has no implementation requirements beyond the categorization itself.
>
> Category II includes any mission to a body of significant interest relative to chemical evolution but only a remote chance that contamination could jeopardize future exploration, and has implementation requirements of documentation only.
>
> Category III is assigned to any mission planning to fly by or orbit a body of significant interest relative to chemical evolution and the origins of life or for which contamination would jeopardize future exploration. Requirements imposed on Category III missions include significant documentation

including an archive of organic materials carried by the spacecraft, as well as cleanliness and/or orbital lifetime restrictions.

Category IV missions include landers and probes to the surfaces of planetary bodies of significant interest to chemical evolution and the origins of life, or for which contamination would jeopardize future exploration. Requirements for Category IV missions include thorough documentation, as well as cleanliness requirements designed to minimize biological contamination of the target body. All sample return missions are assigned Category V for the return leg, with the outbound leg assigned the appropriate category for that mission and target combination.

Category V missions are categorized as either “unrestricted Earth return,” for sampling from locations not of biological concern, in which case documentation is the only requirement, or “restricted Earth return” for samples from planetary bodies of biological concern. Sample-return missions assigned “restricted Earth return” are automatically considered hazardous to Earth until demonstrated otherwise by appropriate testing. For these returned samples, the highest possible containment is mandated that will protect both the Earth from the sample, as well as the sample from the Earth. Such containment will require the use of a facility operating at the equivalent of Biosafety Level 4, which is the most stringent containment available for highly infectious diseases like the smallpox or ebola viruses.

Each mission assigned to either Category III or Category IV may be required to meet specific constraints on spacecraft cleanliness before launch, as well as operations during the mission. However, the specific requirements that a mission must meet to minimize forward contamination depend on the target planetary body, and are determined based on COSPAR and national planetary protection policies and advice from the appropriate scientific advisory bodies. For example, missions to Europa must fulfill the requirement of maintaining a less than $1x10^{-4}$ probability of contaminating the Europan Ocean over the lifetime of the mission. In 2007, NASA was advised by its Planetary Protection Subcommittee to protect all icy bodies that might contain liquid water using a similar probabilistic approach.

In the case of Mars, requirements are based on those that were established for the Viking missions, which took an initial probabilistic contamination allowance and translated that into numerical limits on the number of heat-resistant 'spores' that would be allowed on the orbital and landed components. This metric was known at the time to provide an under-estimate of the total spacecraft bioburden, and is now recognized to detect only a small subset of the organisms present (see chapter IV.3, Rettberg). Nonetheless, it was chosen as a proxy for spacecraft cleanliness because the Viking spacecraft underwent a terminal sterilization process that used dry heat as the killing agent, and the spores in question were identified as being the most resistant organisms detectable. Even today, the Viking isolates include some of the most resistant organisms to heat sterilization yet identified.

The Viking analyses determined that, in order to meet the probabilistic contamination allotment and taking into account all events post-launch, the spacecraft could carry no more than 30 viable spores on all exposed surfaces, and only a few more additional viable spores embedded within spacecraft components. To reach these extremely low levels of contamination, the Viking project cleaned the spacecraft to a level of no more than 300 spores per square meter of spacecraft, no more than $3x10^5$ surface 'spores' total, and no more than an additional $2x10^5$ embedded. After achieving these levels of cleanliness the project packaged up the entire spacecraft inside a specially constructed “bioshield” and performed a Dry Heat Microbial Reduction step (DHMR) that has been determined to reduce the total number of viable spores by 10,000 times.

Today, by COSPAR guidelines, Category III missions to Mars that choose to meet bioburden limits are allowed to carry no more than $5x10^5$ spores in total. As an alternative, missions that will avoid impacting Mars for 25 years at a probability of 99% and for 50 years at a probability of 95% are not required to limit bioburden beyond clean-room assembly of the spacecraft - this includes flyby missions as well as nearly all orbiters.

Category IV landed missions to Mars are assigned one of three subcategories (IVa, IVb, and IVc) that have differing cleanliness requirements depending on the location of the landing site and the specific objectives of the mission. Landers to most locations on the surface of Mars are assigned Category IVa, and must meet numerical limits of $3x10^5$ spores on all exposed surfaces and ≤ 300 spores per square meter, equivalent to Viking pre-sterilization levels. Category IVb is assigned to landers carrying life-detection instruments, while IVc is assigned to missions accessing so-called “Special Regions” (see below). Both these mission Categories limit bioburden to 300 spores per square meter ($3x10^5$ surface 'spores' total) subsequently reduced by four orders of magnitude, equivalent to Viking post-sterilization levels.

Missions may choose to apply the strictest cleanliness requirements at the full system level, or only to subsystems that will interact with the surface areas of Mars to be protected or will contact samples to be studied for signs of life. For a subsystem implementation, the rest of the spacecraft must be clean at the level of 300 spores per square meter. Cruise stages and other hardware expected to impact Mars at high velocity are allowed to carry no more than $5x10^5$ spores in total, including exposed and mated surfaces as well as embedded bioburden.

4. Current Revisions

Recent changes in the COSPAR guidelines reflect the desire to incorporate the best scientific advice into planetary protection policy. Previous to the 2008 Montreal Assembly, COSPAR guidelines set Category I as providing a sufficient level of protection for both Venus and Earth's Moon. To accommodate an increasing understanding of and interest in the history of volatile compounds in the solar system and their contribution to the origins of life, both Venus and the Moon are now protected at the level of Category II, which requires documentation of mission operations, and for lunar missions an organic inventory as well.

Most of the surface of Mars is too cold and dry to allow Earth life to propagate, but some areas on the surface or in the subsurface may support conditions that could allow Earth organisms to reproduce - these locations are termed “Special Regions.” In Montreal, COSPAR accepted the advice of several committees and working groups to define Special Regions on the basis of the two parameters of temperature and water activity (COSPAR, 2008). Limits on these two parameters should be set such that it would be highly unlikely for Earth life to grow in places not designated as Special Regions. Based on a survey of available literature, the limits were set to define Special Regions as locations on Mars that could reach simultaneously both a water activity of between 0.5 and 1 *and* a temperature of -25^{o}C or greater, at some time within 500 years of the mission.

During deliberations, there was considerable debate among the biologists involved regarding appropriate numerical limits, because investigations to date on the cold and dry limits of Earth life are extremely sparse - indeed, some locations on Earth likely to harbor such life have never been investigated at all. Most of the referenced research on temperature was performed in polar locations, which attain very cold temperatures during the winter but warm up to near-freezing (or above) during the summer. High alpine locations, which never reach such warm temperatures, might be better environments in which to research the true cold limits for life on Earth. Unfortunately, so little data is available from alpine field sites that none was cited in any of the published workshop reports. Thus, further work on the limits of life may influence our understanding of the potential for life. The parameters by which Special Regions were set may be altered, depending on future discoveries.

Also in Montreal, for the first time COSPAR policy adopted measures that address planetary protection for human missions to Mars. These measures were derived from results of a series of workshops intended to develop preliminary guidelines for missions beyond the Earth-Moon system, specifically Mars missions that would include astronauts. However difficult it may be to clean and sterilize robots, it is trivial in comparison to cleaning humans. In recognition of this fact, COSPAR accepted the following four general principles regarding human exploration:

- Safeguarding the Earth from potential back contamination is the highest planetary protection priority in Mars exploration.
- The greater capability of human explorers can contribute to the astrobiological exploration of Mars only if human-associated contamination is controlled and understood.
- For a landed mission conducting surface operations, it will not be possible for all human-associated processes and mission operations to be conducted within entirely closed systems.
- Crewmembers exploring Mars, or their support systems, will inevitably be exposed to Martian materials.

With the acceptance of these general principles, a number of implementation guidelines were also accepted, and are available to be developed further within future iterations of the COSPAR planetary protection policy.

5. Recommendations

- The understanding of potential for life to exist elsewhere in our solar system requires taking every necessary precaution to prevent Earthly organisms from contaminating the targets of our exploration.
- Likewise, returning samples of extraterrestrial material to Earth requires avoiding contaminating the Earth (and human explorers who plan on returning to Earth) with harmful organisms from elsewhere.

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Table 1: COSPAR Planetary Protection Policy Categories

	Category I	Category II	Category III	Category IV	Category V
Type of Mission	Any but Earth Return	Any but Earth Return	No direct contact (flyby, some orbiters)	Direct Contact (lander, probe, some orbiter)	Earth Return
Target Body	See Appendix to PPP	See Appendix to PPP	See Appendix to PPP	See Appendix to PPP	See Appendix to PPP
Degree of Concern	None	Record of planned Impact probability and contamination control measures	Limit on impact probability Passive bioload control	Limit on probability of nonnominal impact Limit on bioload (active control)	If <u>restricted</u> Earth return: • No impact on Earth or Moon • Returned hardware sterile • Containment of any sample
Representative Range of Requirements	None	Documentation only (all brief) • PP plan • Pre-launch report • Post-launch report • Post-encounter report • End-of-mission report	Documentation (Category II) plus • Contamination control • Organics inventory (as necessary) Implement procedures such as • Trajectory basing • Cleanroom • Bioload reduction (as necessary)	Documentation (Category II) plus • P_C analysis plan • Microbial reduction plan • Microbial assay plan • Organics inventory Implement procedures such as • Trajectory basing • Cleanroom • Bioload reduction • Partial sterilization of containing hardware (as necessary) • Bioshield • Monitoring of bioload via bioassay	*Outbound* Same category as target body / outbound mission *Inbound* If <u>restricted</u> Earth return: • Documentation (Category II) plus • P_C analysis plan • Microbial reduction plan • Microbial assay plan • Trajectory plan • Sterile or contained returned hardware • Continual monitoring of project activities • Project advanced studies / research If <u>unrestricted</u> Earth return: • None

IV.2 New Concepts for an Advanced Planetary Protection Policy by Ivan Almár

Abstract

The Planetary Protection Policy of COSPAR concentrated traditionally only on the risk of forward and back contamination within the Solar System. But what kind of action is needed if we accept that the lifeless planetary environment has also some kind of intrinsic value? A preliminary classification of the planetary bodies, of the planned astronautical activities and of the potential protection levels is suggested. The recently revised COSPAR document is approaching the requirements of a generalized protection policy for the different constituents of our Solar System.

1. Introduction

COSPAR has a long tradition since 1964 in dealing with "planetary quarantine requirements". Revised and amended several times (1978, 2002, 2008), its Planetary Protection Policy has been accepted in order to prevent forward contamination and back contamination within the Solar System. Its practice, accepted by most space-faring countries, is based on a very pragmatic approach. The COSPAR planetary protection policy is, however, limited from the very beginning on the one hand to the protection of the surface of planetary bodies against terrestrial life forms and, on the other, to the protection of the Earth against back contamination of alien life forms, which might represent a danger. Only in some COSPAR resolutions accepted in 2008 does the concern for the safety of lifeless environments appear.

2. Value Problem

The main concern of the present planetary protection policy, in general, is to avoid harmful cross contamination of celestial bodies and thereby protect any (hypothetical) extraterrestrial life against contamination. There is no explicit mention of preservation of the existing lifeless surfaces of extraterrestrial bodies, even though some planetary transformation plans (in order to exploit hypothetical resources) were made public a long time ago. "But if we agree that the space environment is worthwhile and important as an asset or resource, and therefore has a value, we automatically raise the question of its protection." [Williamson 2006] The intention of a future planetary protection policy should be to make space exploration and the exploitation of resources a controlled and well-planned endeavor, without preventing the regulated commercial utilization of Solar System resources.

If planetary explorers do not fully address the environmental consequences of their activity and do not protect the pristine surface of celestial bodies, all essential *in situ* evidence on the origin and evolution of planets, asteroids and satellites will be denied to future generations of astronomers. The protection of the lifeless environment in the Solar System is, however, not only a scientific and a legal problem; it is equally important to convince society of its moral responsibility for the future destiny of the Solar System bodies. There has been a lot written on these ideas, but there is no consensus on this moral issue.

As presented already in 1989 in an IAF congress [Sterns et al. 1990, Almar et al. 1990]: "A balance must be found between the impact of any mission and the scientific results or other benefits which may be obtained thereby. Furthermore, certain activities may be sufficiently detrimental to the environment to require restrictions and prohibitions thereof, regardless of any benefits which otherwise may be realized."

The most important societal or philosophical question connected with the protection of the non-living planetary environment is probably formulated as follows [Callicott 1995]: “In addition to human beings, does nature (or some of nature’s parts) have intrinsic value? That is the central theoretical question in environmental ethics.” To evaluate in a realistic way the proper relationship of mankind to these basic categories of our cosmic environment, the necessity of putting together a fundamental or intrinsic value-system has been suggested [Lupisella 1997]. People usually accept a value-system of decreasing order, where the Earth and its immediate environment (e.g. the geostationary orbit) have a high, even commercial value, but the further the celestial body or territory is from us the smaller the value can be.

Is there any way to assess and measure such values objectively? Lupisella [1998] in his cosmocentric ethic system assigns a significant degree of intrinsic value to non-living entities like Valles Marineris or Olympus Mons, admitting that it would be very difficult to establish such a system by consensus.

The timeliness of initiating a profound professional discussion on the possible “ethical values” of the lifeless environment is undeniable. Recently the problem was formulated in the following way [York 2005], concentrating on the obvious cases of the Moon and Mars: “The probable absence of life on the Moon may dramatically downgrade ethical concerns about human exploration and settlement, but it does not eliminate them altogether. Even if one rejects the notion that a lifeless world possesses its own intrinsic worth, contamination of the lunar environment could hinder future scientific inquiry.” And “Further in terms of a land ethic, a landscape may deserve to be spared from our interference even if it is not a home to any life that we recognize. Perhaps it is time to think [about an object] like a Martian mountain. Perhaps it is time for a Martian land ethic and for a land ethic that extends to all other worlds.”

The conclusion is: “It may be objected that extending the land ethic to other worlds may inhibit space exploration. The potential inhibition of scientific inquiry by ethical standards is not unique to the proposal for an extraterrestrial ethic, however. Ethical restrictions about the use of humans in laboratory research, for example, also may serve to limit the expansion of knowledge, although such restrictions are widely accepted as appropriate. The extension of a land ethic to other worlds need not, however, undermine an aggressive space exploration program, although it would place certain restrictions on it.”

This ethical problem should be discussed in a more general way, since almost all bodies in the Solar System (except the Sun itself) are or will be targets of space probes and later of human explorers. This does not mean that all these celestial bodies are of equal importance in this respect. For example, Deep Impact, a NASA Discovery Program mission to fly by a comet and blow a relatively large crater into its surface, is also a precedent. Reaching Comet Tempel-1 on 4 July 2005 it released a 350 kg projectile which hit the cometary nucleus at a speed over 35,000 km/hr. The experiment demonstrated NASA's technological capability to cause significant changes on the surface of a pristine celestial body in the Solar System, yet environmental or ethical issues were not raised during deliberation.

There is a need to make a kind of generally accepted classification of the targets and of the different kinds of activities, as well as the necessary level of protection connected with each of them.

3. Classification

3.1 As supposed by the general public, our Solar System environment can be divided into four categories according to the level of protection:

- the Earth: our home planet. In an era of growing global consciousness the protection of the Earth is a global concern
- the environment of the Earth: although there are no strict rules, the protection of the immediate environment of the Earth (the upper atmosphere in particular) is already considered a problem (e.g. space debris)
- other celestial bodies: they seem to be far away and not exposed to any danger (at least this is the general opinion)
- outer space: seems to be infinitely large and not vulnerable at all.

3.2. Classification of the Surfaces of Planetary Bodies

But there is another important point to be considered: the age of the solid planetary surface. Some bodies have rapid or relatively fast rates of change. For example, Io, Jupiter's volcanic moon, has the youngest surface in the Solar System, while Europa, Earth, and several cometary nuclei show relatively fast changes on their surface.

Human interactions may be important for the future of a small celestial body (e.g. the nucleus of a comet as the target of an impacting rocket may fall into pieces), but on fast changing surfaces there is generally less danger that human interaction would destroy something which otherwise would stay unaltered for billions of years. In contrast, very old, non-variable surfaces such as the Moon, Mercury, and several satellites and asteroids, are absolutely vulnerable and their scientific value would be irrevocably damaged if a large-scale intervention occurs.

3.3 Classification of Activity

Activity in space can be classified under three headings:

- research: (also *in situ* research) produces a certain amount of pollution. There is a lot of space debris already on the surface of the Moon, Venus and Mars.
- industrial activity: mining, in particular, may destroy smaller celestial bodies. It can be clearly demonstrated how the surface of an entire celestial body can be modified and destroyed by a medium-sized surface mining activity. The small Martian moon Phobos is frequently considered an ideal base for such an activity; Phobos, with its special system of surface grooves, however, is probably unique in the Solar System. As terrestrial experience has shown, when exploration becomes exploitation the environment tends to suffer.
- colonization and terraforming: the result might be a large-scale transformation of the environment. Writing on the moral and ethical dilemma of terraforming Mars, Jakosky [1998] poses several difficult questions: "Does Mars as a planet have any intrinsic value in and of itself? Is there less intrinsic worth in a planet that is devoid of life than in one with an active biosphere? Should we access and use the resources that are available there or should we leave them as they are?"

The result of every kind of activity in these foreign environments will depend heavily on the strategy and legal regime of the endeavor. The worst possible scenario is *free-for-all*, i.e. whoever gets there first should have the right to do whatever they want. This could lead to destruction of entire celestial bodies preventing the possibility of its further investigation in the future. Enormous damage and danger could be caused by a free-for-all in space.

3.4 Classification of Protection Level

If a decision is made to act, then basically only two alternatives exist - the *complete protection* of all celestial bodies and interplanetary space, which is not a realistic requirement, or *the protection of selected bodies and regions* – which seems to be feasible. Some guidelines should be established to allow the selection of sites of special scientific interest.

What can be done now? The task of the present generation of planetary scientists would be to survey and evaluate all existing planetary environments with regard to their scientific value (or even uniqueness), sensitivity to artificial interference, difficulty or ease of access by planetary missions, etc. An important point would be, without any doubt, to estimate the probability of some kind of indigenous life in the territory in question. This survey should also make distinctions among the different forms of permitted activities: c*omplete protection*, which might imply remote sensing only; *robotic exploration only*, which might imply in-situ robotic exploration (perhaps with only a limited number of missions, and maybe sub-categories distinguishing between biological and non-biological experiments): c*ontrolled human exploration* (implying high levels of control over disturbance activities and contamination); or *uncontrolled human exploration* (suggesting little or no control of activities).

The first objective of such a classification project would certainly be to start a limited, well defined and organized initiative to select the highest scientific priority areas and objects and the kind of protection that is necessary in the case of each of the regions and celestial objects in question. There is a need for a dedicated effort of an international group or task force of experts to draft the necessary recommendations, serving as a basis of the legal discussions ahead. The societal or ethical considerations should be included in the deliberations as well.

4. Role of COSPAR

4.1 International Coordinator

COSPAR is probably the best-suited organization for this task. In the sixties it was charged to work on the planetary quarantine prescriptions. Based on such a survey, a list of the most important planetary environments should be compiled by a panel or a task force composed of space science experts. A classification scheme of territories with gradually decreasing interest for science should be established, making exploration and exploitation of resources on a number of planetary surfaces permissible.

It is important to note that many of the planetary environments in question have remained practically unchanged for aeons and the damage caused by human interaction would be irreversible (Almar, 2002). Such areas of special interest ought to be preserved, in spite of the fact that on the Earth our civilization has tried with mixed success to protect other vast wilderness areas, especially the Polar Regions and the seas. The opportunity to protect space wilderness is before us in the next few decades.

4.2 COSPAR Planetary Protection Policy

COSPAR Planetary Protection Policy states that "COSPAR maintains and promulgates this planetary protection policy for the reference of spacefaring nations, both as an international standard on procedures to avoid organic-constituents and biological contamination in space exploration and to provide accepted guidelines in this area to guide compliance with the wording of this UN Space Treaty and other relevant international agreements." Further, it accepts that for certain space mission/target body combinations, controls on contamination shall be imposed in accordance with a specific range of requirements." Within Category IVc, certain Martian special regions are defined "as a region within which terrestrial organisms are likely to propagate, or a region which is interpreted to have a high potential for the existence of extant Martian life forms." It also emphasizes as an important requirement "the continual monitoring of project activities".

COSPAR Planetary Protection Policy has a very pragmatic approach. The category requirements depend on target body and on mission type. Even special regions on Mars are selected with special requirements. Furthermore, continuous monitoring of the situation is carried out, requiring from time to time a new version of the COSPAR Planetary Protection Policy.

Recent revisions to the COSPAR Planetary Protection Policy, agreed upon in Montreal, July 2008 [Space Research Today, 2008], were discussed in the Panel on Planetary Protection (PPP). The definition of a 'Special Region' based on measurable parameters on Mars as developed in Rome was affirmed in Montreal and provided as a replacement for the initial broad definition from 2002. The Panel recommended that COSPAR sponsor a workshop on this topic (…ethical considerations related to biological planetary protection…), to be held in cooperation with other appropriate groups including the International Academy of Astronautics, the International institute for Space Law, and other national and international institutions.

The *Panel on Exploration (PEX)*, established in 2007 by the COSPAR Bureau, had its first formal meeting in Montreal 2008. Its terms of reference state that "the targets for this panel are realistically the Moon, Mars and near Earth objects – i.e. places which could be reached by human spaceflight". The issue of environmentally damaging activities (i.e., dust raising, vibration, radio contamination, nuclear power sources, etc.) which can adversely affect scientific activities (e.g. telescopic observations, fundamental physics, geological studies) should be where the Panel initially concentrates its activities. In contrast to PPP, which concerns itself with contamination by organics/volatiles, the PEX should aim to produce a set of guidelines on these topics which could then serve to guide policy makers, engineers, etc. in the development of strategies, architectures and missions.

This is definitely a new approach: here COSPAR is dealing with "the issue of environmentally damaging activities" and with "protecting the planetary environment for scientific research", and is even interested in discussing "ethical considerations" – although at the moment only with those "related to biological planetary protection", and not planetary protection in the broader sense of this term.[2]

COSPAR *Resolution No. 4/2008* concludes that "Neither robotic systems nor human activities should contaminate 'Special Regions' on Mars". "A Special Region is defined as a region within which terrestrial organisms are likely to replicate. Any region which is interpreted to have a high potential for the existence of extant Martian life forms is also defined as a Special Region."

It is also an important change to "assign Venus to Category II vice Category I" because of the interest in Venus as a potential site for complex clues related to the questions of organic molecules in the universe, and to "assign the Earth's Moon to Category II vice Category I because of the potential for missions to disrupt polar volatile deposits and contaminate or destroy lunar evidence of the organic molecules and other volatiles contributed to planetary environments by comets and other solar system bodies over the course of solar system evolution."

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[2] The full text of the last COSPAR Planetary Protection Policy is available at http://cosparhq.cnes.fr/Scistr/Scistr.htm#ppp including a section on principles and guidelines for Human Missions to Mars, Resolution No. 6/2008.

In summary, it can be stated that these are new concepts in COSPAR's planetary protection policy. It is dealing not only with biological contamination (and back contamination) between Earth and habitable planets – as defined by the terms of the PPP and fixed in the earlier forms of the Planetary Protection Policy – but also with such hostile environments on celestial bodies like Venus and Moon for the sake of scientific research in the future on these planetary surfaces. This is an important step towards a "cosmocentric" space policy or strategy.

Based on a survey of all known planetary environments, a list can now be compiled giving priorities to features or regions of high value for future scientific exploration. The list should also evaluate other circumstances, like its uniqueness, difficulty or ease of access by spacecraft, its role in the history of planetary exploration, etc. The list should be open for discussion by experts of different international bodies.

Finally, these internationally selected scientific preserves, planetary parks or wilderness areas, which would be open to scientific investigation but closed to the exploitation of extraterrestrial resources, should be legally protected within the frame of an international environment-protection treaty of the United Nations.

5. Recommendations

- Based on a similar classification, a COSPAR panel (PPP or PEX) should select the highest priority "special areas and objects" on and among different kinds of celestial bodies within the Solar System;
- A COSPAR, IAA, IAF joint commission should determine the level of protection needed in all relevant cases, taking into account its effect on future space exploration programs;
- IISL, UN COPUOS, IAA and COSPAR should cooperate to formulate the legal framework and define the steps needed to make it an accepted rule for future space exploration and exploitation;
- A permanent body should be established to monitor how these rules are respected and how the situation changes, due to our increasing knowledge of celestial bodies and also due to our increasing technical capabilities.

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IV.3 Prevention from Biological Contamination - Core of COSPAR Planetary Protection Policy by Petra Rettberg

Abstract

The actually applied methods for bioburden determination of spacecraft are based on culture-dependent microbiological techniques. However, the majority of known microorganisms cannot be cultured. New rapid methods that provide more accurate estimates of total viable bioburden and do not require the cultivation of microorganisms have to be developed and standardized for future space missions. The physiological potential of the microbial community on spacecraft and in cleanrooms has to be investigated in detail to be able to focus future bioassays on the detection of organisms that might contaminate e.g. the Mars environment or complicate planned life-detection measurements.

1. Introduction

The protection of planetary bodies against biological contamination is the most experienced and accepted form of protection. Activities have concentrated so far on the avoidance of contamination with viable organisms, but have also addressed contamination with organic/biochemical compounds. The aim of these planetary protection activities is exclusively the enabling of future scientific investigations of possible extraterrestrial life forms, precursors, and remnants without any environmental pollution resulting in the misleading interpretation of scientific results. They also protect the Earth-Moon system from potentially harmful agents in extraterrestrial samples brought back to Earth.

These planetary protection activities are organized by COSPAR which has formulated the present Planetary Protection Policy (http://cosparhq.cnes.fr/Scistr/Pppolicy.htm) "for the reference of spacefaring nations, both as an international standard on procedures to avoid organic-constituent and biological contamination in space exploration, and to provide accepted guidelines in this area to guide compliance with the wording of this UN Space Treaty and other relevant international agreements". The last amendment to the policy was adopted in July 2008. It embodies a set of detailed recommendations, implementation guidelines and category specifications (see chapter IV.1 for details).

2. General Planetary Protection Requirements

The general planetary protection requirements for fly-by, orbiter or lander missions encompass measures and activities on different levels including specific documentation depending on the mission type/target combination.

- Impact probability: The requirements range from a record of planned impact probability and contamination control measures for category II missions to limits on probability of non-nominal impact for category IV missions and a prohibition of any impact on the Earth-Moon system in the case of category V, restricted Earth return missions.

- Integration environment: The use of the best available cleanroom technology is recommended. In cleanrooms the number of particles per cubic metre represents the main controlled parameter. For category IV missions these cleanrooms also have to be bioburden controlled according to international standards.

- Cleaning/sterilization: Suitable sterilization methods to be used for materials, components, subsystems and whole spacecraft have to take into account the survival probability of the most resistant terrestrial microorganism in the environment concerned. Their efficiency has to be evaluated according to international standards.

- Microbial control: Regular microbial detection assays according to standard procedures have to be performed on flight hardware in order to verify that the contamination level is within the specification. If not, appropriate cleaning procedures have to be performed before further verification assays are carried out allowing the continuation of the assembly, integration and test activities.

- Recontamination prevention: Any recontamination of previously sterilized subsystems during spacecraft assembly, integration and testing has to be prevented. For this purpose bioshields, sterile on their internal surfaces, can be used for the protection of already sterile parts. These bioshields have to be removed during later stages of the whole mission, e.g. they may be ejected during cruise or before descent.

- Inventory of organic compounds: For certain missions, e.g. category IV missions, an organic inventory of compounds used in building the spacecraft has to be compiled and representative samples have to be archived.

3. Microbial Detection Assays

3.1 Cultivation-based Methods

Bioburden, or total viable cell count, refers to the number of microorganisms on or in a contaminated object. In the context of planetary protection the contamination on surfaces in cleanrooms, in cleanroom air, and on flight hardware has to be determined and controlled. However, the quantitative analysis of viable microorganisms in an environmental population is difficult. Only a small percentage of microorganisms can be cultivated (Amann et al., 1995). The majority (>99%) of microorganisms from the environment resist cultivation in the laboratory.

Two different types of microorganism belong to the uncultivable fraction in a population: species for which the selected cultivation conditions are not suitable or which have entered a temporarily nonculturable state, and species that have never been cultured before for lack of suitable methods. Nucleic acid analysis (ribosomal

RNA) suggests that uncultivated organisms are found in nearly every prokaryotic group, and several divisions have no known cultivable representatives.
The application of culture based methods for community studies of principally cultivable microorganisms introduces a strong bias and exhibits several drawbacks. Cultivation of a heterogeneous microbial sample is difficult since any medium or cultivation condition exerts an intrinsic selection pressure due to its specific composition and properties (Amann et al., 1995; Dobrovol'skaya et. al., 2001). Therefore, every time an environmental sample is cultivated a part of the present bacterial community will be favoured by the applied conditions and dominate the culture. Ultimately, once a cultivation step is included in the test setup, the total number of detected microorganisms and the number of different species identifiable will only be a fraction of the existing microbial diversity.

Cultivation on nutrient agar plates under defined conditions is frequently used for the quantification of active cells in environmental samples. Due to the necessity to select one or a few types of nutrient medium (composition, pH) and incubation conditions (aerobic, anaerobic, temperature, duration), the resulting numbers of colony forming units give only a rough proxy of the actual number of viable microorganisms in a sample. The advantage of cultivation based assays lies in their simplicity, the long-term experiences with these assays and the possibility of characterizing the physiological characteristics of the isolates in detail. One disadvantage, besides the bias in detection, is the duration of the bioassay which can range from a day to several weeks.

For planetary protection, NASA and ESA have established a planetary protection policy, which generally follows the COSPAR policy. Based on this policy, NASA and ECSS (European Cooperation for Space Standardization) have specified associated procedures (NASA NPR 5340.1D, ECSS-Q-ST-70-55C) to ensure compliance with it. In these documents detailed methods and procedures are defined for surface and air sampling and the detection of biological contaminants with swabs, wipes, contact plates, fall-out stripes and air samples, followed by cultivation for bioburden determination. These procedures are designed primarily for the detection and enumeration of heterotrophic, mesophilic, aerobic and anaerobic microorganisms in the case of the NASA procedures. The ESA procedures also include psychrotolerants and methods for non-culture based detection of microorganisms.

The COSPAR bioburden limits for the different planetary protection categories are based on bioburden to be measured with respect to the number of aerobic microorganisms that survive a heat shock of 80°C for 15 minutes (named "spores" in this context) and that can be cultured on TSA (a widely used rich medium for bacteria) at 32°C, giving macroscopically visible colonies after 72 hours. In between, microbiological investigations have shown that under the above mentioned culture conditions not only spore-forming bacterial species are selected and cultivated, but also other thermotolerant species (Rettberg, Midiv). The detection of extremotolerant bacteria (La Duc et al., 2007) and the presence of viable but yet to be cultivated bacteria (Moissl et al., 2007) from various spacecraft assembly facilities suggest the need to evaluate other potential microbial communities. Recently, archaea, a group of microorganisms separate from bacteria, has been detected in spacecraft assembly facilities (Moissl et al., 2008).

When the COSPAR bioburden limits based on a specific cultivation assay were defined (before the Viking missions to Mars), spores, metabolically inactive forms of certain bacteria (mainly bacilli), were thought to be the most robust forms of organisms which might survive in space and on other planets and which therefore might contaminate e.g. the Mars environment or confound planned life-detection measurements. The most important recent progress in environmental microbiology, however, was the discovery of the so-called extremophiles living in extreme environments where other life forms cannot survive. The great majority of extremophiles are single-celled microorganisms that are species of archaea, bacteria, or algae. The habitats where extremophiles are found may have extreme temperatures (hot or cold), extreme chemical conditions (acidic, alkaline, salty, or toxic), extreme pressures, or extreme dryness. Continuing discoveries of extremophile organisms have expanded the known size and diversity of the terrestrial biosphere. Some of these newly discovered extremophilic microorganisms might be able to survive and even multiply on other celestial bodies as well, but they cannot be detected with current bioburden assays used for planetary protection purposes.

3.2 Molecular-based Methods

Biodiversity is the abundance of different species found in a certain environment. Traditionally the identification of the environmental bacterial diversity was solely based on cultivation dependent microbiological methods. The isolated bacteria were subjected to several tests identifying an array of morphological, physiological and biochemical classification features. These data were used to construct a phylogenetic tree, showing the evolutionary relationships among various biological species that are believed to have a common ancestor.

Later on, with the advancement of analytical methods, cellular molecules were also used as indicators for evolutionary progression. The small subunit ribosome gene (16S rDNA) became the most used taxonomic bacterial marker gene. The start- and end-region of the gene are highly conserved across all bacterial and archaeal domains, offering the opportunity to amplify almost all the 16S rDNA genes by PCR (polymerase chain reaction, an *in vitro* method for DNA amplification). This setup is the basis for the cultivation-independent approach of environmental community studies. However, there are also disadvantages connected with this kind of technique, since broad range 16S rDNA PCR is a highly sensitive method and the chance of false positive results due to contamination of the working equipment needs to be addressed carefully.

Another disadvantage of molecular-based methods for bacterial community studies lies within the samples themselves. Environmental samples contain a high bacterial diversity where the relative quantity of single species (and by that rDNA sequences) can diverge over orders of magnitude. In addition, it is known that the copy number of the rDNA gene varies between bacteria (Coenye and Vandamme, 2003) and that minor variations can even be observed inside the same species (Candela et al., 2004).

Though it is theoretically possible to detect rare species by amplifying genes from the few original copies, the binding of the primers is not an actively guided process and, thereby, heavily influenced by the starting copy numbers of each 16S rDNA sequence. These variations will lead to a biased amplification and an inaccurate identification of the present bacterial species.

There is also a disadvantage with the PCR technique itself. The standard universal primers used to amplify all bacterial 16S rDNA do not exhibit “equal universal” properties. Depending on the species of 16S rDNA sequence, these universal primers will bind with different affinities to their DNA target. Therefore, in samples with multiple 16S rDNA’s, a taxa bias will be introduced during amplification due to the dissimilar affinity of the primers to the heterogeneous DNA sequences (Horz et al., 2005). Even though several methods have been established to minimize the bias of the amplification step, like the use of multiple primer pairs, or denatured primers, so far no totally unbiased DNA amplification with universal primers has been published.

4. Recommendations

- Only a very small subpopulation of a whole microbial community can be detected with the currently applied microbiological methods for planetary protection measurements, thereby prohibiting the accurate estimation of the total bioburden. New rapid methods that provide more accurate estimates of total viable bioburden and that do not require the cultivation of microorganisms have to be developed and standardized.
- The biodiversity in spacecraft assembly facilities has to be determined regularly in detail. If changes are observed, the potential reason has to be investigated.
- The physiological potential of the cultivable and uncultivable microbial communities in spacecraft assembly facilities are for the most part uncharacterized. More investigations on the survivability and resistance of different microorganisms under the environmental conditions of other solar system bodies, as well as metagenome analysis, have to be performed to be able to focus future bioassays on the detection of organisms that might contaminate e.g. the Mars environment or complicate planned life-detection measurements.
- The COSPAR planetary protection guidelines and bioburden limits have to be adapted to the increasing microbiological knowledge and the new developing detection methods.

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IV.4 Prevention from Chemical and Radioactive Contamination – A Significant Element of Planetary Protection by Francois Raulin

Abstract

For research activities on chemical evolution and the search for pre-biotic compounds, biomarkers and life on other planets and moons of our solar system chemical and radioactive contamination has to be avoided as far as possible, even if a certain amount of contamination will be inevitable. A systematic chemical contamination monitoring, the set up of a catalog of potential contaminants and the development of suitable methods for environmental cleaning are necessary. The designation of astrobiologically interesting areas as planetary parks which have to be kept pristine for future generations is suggested.

1. Introduction

There are several aspects concerning chemistry and the protection of the environment of celestial bodies. First, there are chemical compounds of scientific interest which can be searched for in a planetary environment, in particular in the frame of astrobiological investigations. The environments must be protected to avoid contamination of these compounds from human or robotic activities. In any case, space exploration of celestial bodies is an inescapable source of chemical contamination: in addition to maintaining such contaminations at the lowest possible level, it is also essential to develop a catalog of the potential contaminants and their level of concentration. Systematic chemical analysis of celestial bodies, by remote sensing, *in situ* and sample return techniques is a way to check and control the level of contamination. In certain cases, it may be necessary to clean specific areas of celestial bodies that have been chemically contaminated using dedicated techniques. This could allow, in particular, the selection and maintenance of clean areas, such as ‘planetary parks’ on specific celestial bodies.

2. The Chemicals of Interest

Scientific investigations on extraterrestrial bodies may require the search for and quantitative analysis of many chemicals. This is particularly the case with astrobiological investigations. Astrobiology, the study of life in the universe, includes the study of the origin, evolution, distribution and destiny of life, as well as processes and structures related to life. The study of exogenic and endogenic sources of organics of abiotic origin is thus of prime importance for these investigations, as well as the study of their evolution in the environment of the relevant celestial body. The same applies with the study of compounds of prebiotic interest, such as organic compounds involved in the prebiotic chemistry which allowed the emergence of life on Earth. All compounds which can be related to biological activity, organic and inorganic biomarkers, are also essential targets for astrobiology.

The following considerations concentrate on Mars as an example of a planet of our solar system which is of high astrobiological interest.

Exogenic sources of organics include all organic compounds found in carbonaceous meteorites, micrometeorites and comets, all small bodies including a noticeable fraction of organic matter, and which are potential impactors on a planetary surface. Carbonaceous chondrites such as The Tagish Lake or the Murchison meteorites include several percents of organic carbon. The main part of it is in the form of an insoluble organic polymer, kerogen-like macromolecular compound of still not very well known structure. The soluble part includes many chemical species:

- hydrocarbons (aliphatic, aromatic and polar)
- carboxylic, dicarboxylic, hydroxyl and amino acids
- dicarboximides, pyridine carboxylic acids
- sulfonic and phosphonic acids
- N-heterocycles (in particular purines)
- amines, amides
- alcohols (mainly polyols).

Cometary nuclei, although their chemical composition is not directly known, are supposed to be rich in organic compounds from the observation of their coma (Greenberg et al., 1995). Many organics have been identified in gas phase in the coma: low molecular weight aldehydes, alcohols, hydrocarbons, nitriles and isonitriles, and S-compounds. The analysis of cometary dust suggests that these compounds should be also present in the cometary nucleus, together with complex organics, such as amino acids, heterocyclic bases, hexamethylene tetramine (HMT) and various polymeric materials (polymer of formaldehyde – polyoxymethylene (POM) and hydrogen cyanide in particular). Some of these organics, once deposited on the surface of Mars, could evolve by photochemical or/and oxidative processes. Alcohols, aldehydes, and most of the hydrocarbons could be transformed into carboxylic acids and more precisely carboxylate salts, which are very resistant to the Martian conditions.

The surface and near-subsurface of Mars is supposed to be rich in strong oxidants, such as hydrogen peroxide, the presence of which may explain the behavior of organics in contact with the Martian soil, as observed during the Viking biology experiments in the late 1970’s (Oyama et al., 1978). It is thus of importance to determine the nature and concentration of these oxidants and their vertical profile in the sub-surface. The use of hydrogen peroxide as a sterilizer of Mars landers, rovers and payload may be a problem for such studies.

Organics on Mars may be also of endogenic origin, formed by abiotic processes, such as serpentinisation, a potential source of H_2, CH_4 and other light hydrocarbons, or released from methane or other simple alkane clathrates trapped in the deep layers of the planet (Lefèvre and Forget, 2009).

Organics may be of biological origin, indicating a past or even present biological activity on the planet. Organic biomarkers include amino acids and peptides, sugars, nucleotides and polynucleotides, as well as more stable compounds, particularly hopanoides. Simple organic compounds like CH_4 or C_2H_4, and inorganic compounds like H_2S or NH_3, can also be of biological origin. The knowledge of the C or S isotopic ratio is important in deriving their biotic origin.

Another point of crucial importance in confirming the biological origin of an organic compound, when it has a chiral center in its structure, is the presence of homochirality. Terrestrial contamination may transport homochiral amino acids and nucleotides to an extraterrestrial body. This would be a tremendous handicap for searching for traces of life on it!

3. Identification of Potential Terrestrial Chemical and Radioactive Contaminants

It would be of great interest to build a catalog of such potential contaminants (Debus, 2005), which could then be used as a database for discriminating non contaminants from contaminants in the extraterrestrial samples analyzed either *in situ* or in terrestrial laboratories.

The building of this catalog will be a difficult task, because the list may be very long. It will need regular updating and complementing. As examples, one can forecast the following materials:

- Fuels (in particular hydrazine) that may be a source of ammonia, the search for which is astrobiologically important on several planetary objects (such as Mars, Europa, Titan and Enceladus)
- Materials from RTG (radioisotope thermoelectric generator) or RHU (radioisotope heater unit)
- Materials from
  - parachutes, heatshields & airbags
  - lubricants of mobile parts of probes and orbiter equipments,
  - scientific payload parts and chemicals, especially from surface and atmosphere chemical analysis tools (e.g., carrier gas of GC-MS (gas chromatography-mass spectrometry), solvent of future LC-MS (liquid chromatography-mass spectrometry) space equipments, liquids from wet chemistry instruments, derivatization reagents).
- Dead microorganisms from sterilization procedures as a source of specific organic material, which is very often impossible to remove from spacecraft prior to launch.

In many cases, it should be essential to perform *in situ* chemical analysis of some sites in planetary environments, for survey, monitoring and alert, in case of important chemical contamination. This can be carried out using different physical-chemical techniques. Many of them have already been developed and are used, or will be used soon, in space in the frame of robotic planetary exploration missions, as indicated below by an (*):

- Organics and volatile inorganic compounds can be quantitatively analyzed by gas chromatography-mass spectrometry, eventually using chemical derivatization and/or pyrolysis (*), micro-electrophoresis (*) or liquid chromatography coupled to mass spectrometry
- Inorganic compounds can be quantitatively analyzed by atomic absorption spectroscopy (*), X-fluorescence (*), induced plasma - adsorption/emission

spectroscopy ICP-AES, (*), induced chemical plasma – mass spectroscopy (ICP-MS).

4. Environmental Cleaning

For some contaminated sites on other planets or moons it may be necessary to perform cleaning. Several methods can be followed to reach this goal:

Cleaning of chemicals
The procedures will depend on the nature of the chemical contaminant. In the case of organic compounds, the use of oxidants like hydrogen peroxide or ozone may be sufficient. However, the use of these oxidants may introduce an additional contamination. This could be an important problem, for instance for astrobiological research. In the case of Mars, where it is essential to understand the behavior of organics and their possible destruction by oxidants, such as H_2O_2, their use could jeopardize such astrobiological studies. Some specific chemical contaminants, to be identified, may require dedicated procedures, to be defined and studied.

Cleaning of radioactive samples
Procedures analogous to the ones used on Earth may be difficult to apply, because they require a large amount of solvents. A specific study on that kind of contamination is to be carried out.

Cleaning of biological contaminants
Methods for environmental cleaning from microorganisms commonly use oxidizing agents such as peroxides, ethylene oxide, chlorine and liquid bleach products containing sodium hypochlorite. As already pointed out for the similar cleaning procedures for organic chemical contaminants, the introduction of these agents may induce new contamination problems. In addition, the control of the effectiveness of the cleaning activities will require a sophisticated biological monitoring schedule. For the sterilization of materials, parts and components different materials can be used for which international standards like those from ECSS, the European Cooperation for Space Standardization, exist.

5. Chemically and Biologically Clean Planetary Parks

Planetary exploration, particularly in the case of manned missions, will inevitably introduce contamination. There are many different potential sources of contamination, including those directly associated with several decades of robotic planetary exploration (landers, rovers, balloons, atmospheric probes, crashed spacecraft/orbiters). With manned space missions, the level of contamination could be even more important. The future era of industrial activities in space will open a new source of chemical contamination (from mining in particular). Space tourism, which is expected to follow a large development in the mid- and long term future, will be another important source.

When manned space missions, for instance to the Moon and Mars, are developed it is likely that systematic cleaning of the whole contaminated places will be impossible to perform. A solution is to define dedicated places, which are kept clean. The main effort in term of cleaning and planetary protection will be concentrated on these “clean parks”. This requires performing the following steps:

- selection
- border control
- *in situ* cleaning and monitoring.[1]

6. Recommendations

- A database of potential chemical contaminants should be compiled to support the discrimination of terrestrial contaminants from natural components occurring on the planet or moon under investigation.
- Existing detection methods for chemical contaminants, as well as methods for environmental cleaning, should be adapted and new methods should be developed for application on other planets and moons.
- The designation of astrobiologically interesting areas as planetary parks which have to be kept pristine for future generations is suggested.

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[1] For more about planetary parks see chapter IV.5.

IV.5 Planetary Parks - Suggestion for a Targeted Planetary Protection Approach by Gerda Horneck and Charles S. Cockell

Abstract

International space exploration programs foresee robotic visits to a variety of Solar System bodies and finally the establishment of human settlements on the Moon and Mars. Strategies are required to consider ethical and environmental arguments beyond the currently used planetary protection policy established by COSPAR. In analogy to the National Park system existing on Earth, a planetary park system is proposed that incorporates the concepts of COSPAR's planetary protection, but extends the reasons for practical protection policies beyond the utilitarian protection of scientific resources emphasized by planetary protection, into other utilitarian and intrinsic value arguments. Such planetary park systems might still allow for the development of non-park areas by commercial enterprise.

1. Planetary Park System for the Moon

Activities associated with robotic and eventually human lunar missions will interact with the lunar environment in two reciprocal ways. The mission needs to be protected from the natural environmental elements that can be harmful to the equipment or to humans (Horneck et al. 2003); likewise some features or regions of this specific natural environment should be protected so that the Moon retains its value for scientific or other purposes (Vondrak and Horneck 1994). Increasing robotic visits and eventual human exploration and settlements threaten to have a significant environmental impact on scientifically important sites and sites of natural beauty in the form of contamination with microorganisms and spacecraft parts, or even pollution as a consequence of i*n-situ* resource utilization.

Interactions with the natural environment vary for the different successive phases of lunar exploration as follows:

- Transient lunar robotic exploration with temporary and local low impact on the lunar environment
- Permanent robotic presence with long-lasting, but local and low impact on the lunar environment
- First robotic in-situ resource utilization with temporary, local – or extended – and moderate impact on the lunar environment
- Lunar human outpost with persistent, local and moderate impact on the lunar environment
- Permanent lunar base with persistent, extended and high impact on the lunar environment.

This concern has already been reflected in the 1979 Moon Treaty: "The Agreement Governing the Activities of States on the Moon and Other Celestial Bodies" of the United Nations, which is a follow-on to the Outer Space Treaty of the UN (UN 2002). "*In exploring and using the Moon, States Parties shall take measures to prevent the disruption of the existing balance of its environment, whether by introducing adverse changes in that environment, by its harmful* *contamination through the introduction of extra-environmental matter or otherwise*". However, so far, the Moon Treaty has not been ratified by any nation which engages in self-launched human space programs or has plans to do so.

Planetary Protection guidelines as formulated by the Committee on Space Research (COSPAR) are based on the Outer Space Treaty of the United Nations and follow the objectives: on the one hand, to prevent contamination by terrestrial microorganisms if this might jeopardize scientific investigations of possible extraterrestrial life forms, precursors and remnants, and on the other hand to protect the Earth from the potential hazard posed by extraterrestrial material brought back to the Earth. As a consequence, they group exploratory missions according to the type of mission and target body in five different categories, requesting specific means of cleaning and sterilization (COSPAR 2005). The *Moon* has recently been moved from category I, which imposes no planetary protection requirements on the spacecraft and mission, to category II, which requires a planetary protection plan, pre- and post-launch analysis on impact probability and contamination control measures (Conley and Rummel, 2008).

In lunar exploration, a further complication is what we call the 'Environmentalist's Paradox' (Cockell and Horneck 2006). To protect an environment, we first need to understand it, so that we can define exactly what it is we seek to protect. This requires robotic or human exploration, and in the process this inevitably involves the introduction of waste and the spoiling of the very environment we seek to protect. One way out of the Environmentalist's Paradox is to protect *some* regions of planets, and thus prevent contamination and spoilage in the first place.

We propose - in analogy with Earth's wilderness parks - to establish a lunar park system as an area of the lunar surface untrammelled by people, where people are visitors who do not remain. The purpose of the proposed lunar park system is to preserve certain regions for the following reasons:

- To preserve regions for scientific interest and use
- To preserve regions of historic value
- To preserve regions of natural beauty
- To preserve regions for future generations.

1.1 Preservation of Regions for Scientific Interest and Use

The Moon lacks a substantial natural atmosphere. Modifications due to Apollo exploration were apparently local and short-lived. One environmental parameter of scientific interest is the natural transient release of lunar gases, which may provide information about the interior structure of the Moon. Such natural lunar exospheric components, e.g. gas and dust, may be detectable now, but may become difficult to detect in the presence of intense exploration. Furthermore, contamination of the lunar surface by biological material of terrestrial origin should be done in a controlled manner, because it may also disturb the fragile composition of the lunar exosphere. Another location of concern is the lunar far side, which is expected to be an excellent location for radio-wave astronomy facilities because it is shielded from terrestrial sources (Maccone 2005). Safeguards should be established to ensure the preservation of appropriate sites on the lunar far side for high sensitivity radio astronomy.

1.2 Preservation of Regions of Historic Value

Several locations on the lunar surface are of unique value because they are landing sites from the era of initial lunar exploration. Examples are the landing sites of Luna, Surveyor and Apollo missions, as well as instruments established on the surface of the moon, e.g. the lunar laser ranging retroreflector array that was installed by the astronauts of the Apollo 11 mission. Methods should be established for the preservation of sites for their historical importance.

1.3 Preservation of Regions of Natural Beauty

Even for a lifeless Moon, several locations may be geologically unique, like certain hills, craters, volcanoes or lunar maria. They earn preservation for their own intrinsic worth. Especially some permanently shadowed craters in the south polar region need to be protected, because of their natural beauty, but also because they have unique features of high scientific interest. Although most of the Moon's water supply should have evaporated and drifted off into space long ago, recent neutron spectrometry data from lunar orbiters has indicated evidence of enhanced hydrogen in the permanently shadowed floors of polar craters. They have been interpreted as a possible sign of water ice hiding in the permanent shadows of deep, cold craters, safe from vaporizing sunlight, and frozen solid. It appears that an area of approximately 6000 to 15,000 km² around the South Pole is permanently shadowed (Nozette et al. 1994). These Polar Regions are still lunar incognita, and it is critical to explore them and study their geological history.

1.4 Preservation of Regions for Future Generations

The ethical argument about whether we have responsibilities to future generations that are not in existence is one that has a long heritage. It is currently under discussion regarding global changes on our planet and utilization of Earth’s resources. The establishment of wilderness areas on the Moon expresses a respect for the options and choices of future people and allows them to make decisions about how they would use the lunar land. Maximizing those choices for future generations is a responsible environmental position to take.

Such a concept of a planetary park system developed for the Moon could be used to test out protocols for planetary parks for Martian application and elsewhere in the Solar System.

2. Extension of the Concept of Planetary Parks to Other Bodies of the Solar System

Whereas the future exploration of Solar System bodies will first be driven by research and scientific curiosity, it is to be expected that it will soon be followed by industrial activities, such as mining of in-situ resources. Eventually, some bodies may be colonized (Turner 1998) and may even be transformed by terraforming and/or ecopoisis (Haynes and McKay, 1992). These perspectives are not covered by the current COSPAR planetary protection policy, which is merely based on a scientific interpretation of the Outer Space Treaty. This is reflected by the statement: "*The conduct of scientific investigations of possible extraterrestrial life forms, precursors, and remnants must not be jeopardized. In addition, the Earth must be protected from the potential hazard posed by extraterrestrial matter carried by a spacecraft returning from an interplanetary mission*."

Several authors have proposed the preservation of specific regions in the Solar System beyond the COSPAR Planetary Protection Policy (Lupisella and Logsdon 1997, Almár 2002, Cockell and Horneck 2004, 2006). Arguments put forward have been of cosmo-ethical, astro-environmental or more practical nature. Applying an environmental ethic to the surface and subsurface of other planetary bodies requires the incorporation of principles of ethics into a practical land-use policy. Cockell and Horneck (2004, 2006) suggest the establishment of a planetary park system that provides a simple method for preserving and conserving regions of other planetary surfaces.

An example is given for a Planetary Park system on Mars (Cockell and Horneck 2006). Mars in an environmentally heterogeneous planet that possesses deserts, extinct shield volcanoes, canyons and polar ice-caps. It has been proposed to preserve representative portions of these features, both because this will provide a diversity of Planetary Parks with different features of outstanding beauty and intrinsic natural value, but also because of their scientific – geological and maybe even biological – worth.

Seven regions for possible Planetary Parks on Mars have been suggested: a Polar Park, Olympus Park, a Desert Park, a Historical Park, Marineris Park, a Southern Park and Hellas Park. Those regions fulfil at least one of the requirements formulated below:

- To preserve regions for scientific interest and use
- To preserve regions of historic value
- To preserve regions of natural beauty
- To preserve regions for future generations.

3. Summary and Outlook

- Within the 21st century, it is to be expected that the exploration of the planets, moons and small bodies of our Solar System will soon raise commercial interests, including utilization of resources, colonization and tourism and may finally lead to terraforming activities. As a consequence, conflicts between the scientific community and commercial groups may arise. In addition, there are ethical reasons for the planets, moons and small Solar System bodies to exist regardless of their robotic or human exploration or colonization.

- The concept of Planetary Park Systems, proposed in this study, helps us to solve this conflict and to incorporate both utilitarian and intrinsic value arguments. Its potential success is built on the fact that it is a simple extrapolation of the successful national park system on Earth, thereby allowing the protection of specific areas of Solar System bodies for different reasons, but under a single set of regulations and under one system (cf. Earth's National Park system).

- The protection of some regions of planetary surfaces might imply new regulations for non-park areas designed to encourage commercial exploration and settlement. As with parks on Earth, there will be many issues to be resolved. The discussion presented here is intended as part of an early discourse about the exact moral and legal definition of wilderness on other planetary bodies. Thereby Planetary Parks allow us to express a respect for another world, and create a fuller and nobler concept of 'civilization'.

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IV.6 Human Missions to Mars: a Challenge for Planetary Protection by Gernot Groemer

Abstract

In contrast to robotic missions, human space missions involve much larger spaceflight infrastructure and cannot be sterilized in the same manner as uncrewed systems. Therefore, the risk of unintentional transfer of bioloads is inherently larger. The exploration of Mars is the first foreseeable challenge of avoiding contamination in astrobiologically sensitive regions, but findings related to Mars missions can be transcribed to any other potential target body in the solar system, such as the icy Moons of Jupiter and Saturn.

However, the human exploration of the Red Planet is the best test case investigated so far in theoretical, laboratory and (simulated) field studies. Based on field simulations in terrestrial analogue environments, we postulate, that human physiology and psychology play a major role in assessing the likelihood of contamination, underpinning the need for very safe and robust countermeasures to avoid the transfer of bioloads.

1. Human Mars Missions and Astrobiology

There is considerable evidence that Mars' climate and its inventory of volatiles have changed greatly during the planet's history. The presence of liquid water beneath the Martian surface, combined with life's ability to live without sunlight, leads to the hypothesis that life might exist beneath the surface. If fossilized or extant life is present in the subsurface water ice repositories of the planet, it will require very sensitive instrumentation for detection.

These detection techniques will be vulnerable to even trace amounts of residual terrestrial biological contaminants, so any forward contamination may jeopardize the pristinity of the samples and, consequently, the scientific success of any mission. The challenge is amplified for human missions because of the higher bioload, higher mission complexity and human factor issues.

Contamination vectors during a crewed surface sojourn are not well known due to uncertainties in the exploration procedures, tools to be used and which areas are to be accessed by humans and/or robotic assistants, especially as long-range mobility will play a crucial role in the human exploration of the planet. Environmental impacts may include issues such as direct shedding of human substrata during the surface expeditions (e.g. enteric bacteria, skin particles), mechanical disturbances of the local environment, In-situ resource utilization infrastructure, airborne pollution (e.g. lander exhaust fumes) or life support systems biota. Probably the most challenging task in terms of planetary protection is a subsurface drill, as putative (extinct) life on the planet is commonly believed to reside in subsurface ecologies.

In addition to human metabolic output, there will be a significant amount of waste generated during the surface sojourn. It is currently unclear if these waste products may be left on the surface to reduce the launch mass of the return vehicle, leaving behind a potential source of future contamination.

2. Human Factors and Planetary Protection

The first human mission to Mars will face a significant level of risk, and many of the risk factors affect both mission/crew safety and PP issues, in particular regarding contamination issues. Crew safety, integrity of planetary protection and mission success are thus closely related overall goals.

Experiences from actual space flight missions and psychosocial research during Mars-analogue simulations indicate that human factors play a crucial role, especially during the long duration missions expected for a Mars expedition (Dawson, 2002). This includes protocol compliance (e.g. adhering to tedious decontamination procedures in airlocks after many weeks of daily Extra-Vehicular Activities (EVA)), and as such adds a critical element to the planetary protection considerations.

Human crews will also interact with their immediate landing areas, as they will have to set up peripheral structures (power sources, communication infrastructure, etc.) and will have multiple egress/ingress activities during their surface sojourn. Additionally, neither spacesuits nor space habitats will be closed systems: they either leak material by intentional venting of gases and fluids, or change the local environment (e.g. thermodynamically by heating the surface and hence releasing volatiles).

Because humans are hosts to a complex biological community related to digestion and many other human functions, all components of a human mission cannot be sterilized before launch and many PP issues and risks will arise with the addition of a human component to the mission. Hence, the amount of bioload transfer depends on the duration and number of EVAs, suit and equipment technology used and potential sterilization techniques.

Although it is likely that before the first EVAs there will be an adaptation period for humans to get used to the new environment, it is unlikely that this will last long enough to significantly recover from the changes in human physiology during the cruise phase. It is therefore likely that astronauts will face an increased risk of traumatic injuries. Hence, contingency situations will change the priorities of the mission when lives are at stake – rendering any planetary protection requirement irrelevant during a crisis.

Currently, there is a paradigm in place to not allow humans to access the astrobiologically most interesting regions in observance of the planetary protection measures set forth by the Committee for Space Research. At the same time, it is generally recognized, that limiting subsurface sampling activities only to robotic drilling systems puts severe constraints on the reachable soil depth and sample procurement (Smith and McKay, 2005). In addition to this, most current laboratory and polar drilling activities do not simulate the operational environments and human factors issues a crew will face on Mars. Ultimately, until the environmental impact of Earth contaminants can be addressed adequately, the number of areas that are visited by humans should be kept to a minimum.

This constitutes a dilemma where the best suited “system” for deep drilling, namely a properly equipped human crew, is not allowed to access the primary target sites to search for life. However, to our knowledge, the actual transfer of bioloads has never been measured in a high-fidelity astronautical setting.

3. Transfer of Bioloads in Spaceflight Environments – Laboratory Studies and Field Experience

Laboratory experiments show evidence that microorganisms may survive transits in interplanetary space and re-entry environments (e.g. through catastrophic transport mechanisms such as asteroid impacts). Furthermore, with the finding of still viable but not cultivable bacteria at an altitude of 41km in the Earth’s stratosphere, it has been speculated that eventually viable bacterial cells might be able to inoculate even other bodies in our solar system.

More recently, microbial habitats have been discovered in thin liquid films present in permafrost or in frost brine lenses (“cryopegs”) at temperatures around -20°C. Our knowledge about these microbial communities – sometimes residing in ice cores which have been isolated from their original environment for at least 120,000 years - is very limited. These unique terrestrial environments serve as model niches for potential extraterrestrial habitats.

The two Viking lander sites, which have been examined with an equipment suite suited to organic chemistries using gas chromatography, have not detected any signs of organics, having a detection threshold of 10^6 cells for the total sample (Klein 1978). This value is reached at various locations on the Earth, e.g. the Atacama desert.

Although this is a fairly obvious result to be expected on the surface of a lifeless planet, it still poses a mystery: the surface should not be totally devoid of organics. Estimates derived from interplanetary dust particle counts (e.g. in the Earth’s stratosphere), which should be comparable to the dust flux on Mars given the continuous production processes in the Solar System, indicate that the meteoritic infall should have delivered at least a mass flux of 2 $\mu g\ m^2\ yr^{-1}$. This equals several tons of carbon per year (Flynn 1996), which should result in several kg of carbon per m^2. Organic carbon is therefore systematically eradicated on the surface, probably due to the UV radiation (photolysis) and some lesser understood chemical reactions like oxidation. So even if (traces of) life is delivered onto the surface, it is likely to be destroyed within a short time frame if exposed to the local radiation and chemical environment.

However, the situation is clearly different in the subsurface regions, where Mars might offer conditions which are hospitable for terrestrial life when shielded from the UV flux. The Martian subsurface offers conditions where several extremophiles from the Earth might at least survive. Terrestrial microbial communities have been found to survive in the following ranges:

- Temperature: from -262 to 150°C (incubation time dependent) (Mars: -123 to +25 °C)
- Pressure: from 10^{-7} to more than 10^{8} Pa (Mars: 560 Pa)
- Salinity: organisms may survive in salt crystals (Mars has regionally high salinities)
- pH: 0-12.5 (Mars: unknown for subsurface adsorbent water, but probably on the acidic side).

If microbial communities are to survive interplanetary travel – be it natural or on man-made objects – they may therefore spread, for example. through dust born transportation. All landers, including the ones that crashed, are commonly believed to have contaminated only their immediate surroundings and hence represent a local source of contamination.

4. Using Terrestrial Analogues for Tracing and Reducing the Contamination

Developing a sound understanding of how and where contamination happens is an issue of high relevance to the search for life. Terrestrial models and experiments obtained during Antarctic ice coring contamination studies or robotic drilling experiments in the Canadian High Arctic and Spain have demonstrated that subsurface sampling can be conducted in a way so that forward contamination can be reduced below detection limits – by discarding the outermost layers of the drill core, for example.

Current terrestrial analogue research activities focus on three main areas: comparative planetary geology, astrobiology and exploration science, which includes instrument testing and development, astronaut training, and exploration-related activities (Osinski et al., 2006). In order to provide field test opportunities, terrestrial Mars analogues have been used for many expeditions. Examples of such terrestrial analogues include the NASA Haughton impact crater site in the high Canadian arctic, the underwater laboratory NEEMO south of the Florida keys and the Mars Desert Research Station (MDRS).

One of the earliest experiments used fluorescent microspherules as biological surrogates which can be clearly distinguished from natural organisms. These particles were applied during subsurface (ice) drills in the high Canadian Arctic in order to study the exogeneous contamination of core samples: 0.5 µm spherules were applied to the drilling equipment and a reliable transfer to the core sample was observed.

The MARTE project (Mars analogue research and technology experiment), in 2003, investigated hypothetical anaerobic subsurface ecospheres at the saline river Rio Tinto, Spain, which has mineral concentrations which might be comparable to ancient acidic Martian riverbeds with respect to their basaltic origin and hydrothermalism. The (remote) drilling procedure also involved the usage of DNA and protein microarray technologies to detect microorganisms. This experiment was primarily designed for relatively shallow (10m) surface robotic drilling, whereas many impact ejecta blankets easily reach these depths.

5. Recommendations

- Determine the validity of currently used microbiological proxies under simulated Martian conditions for both forward and backward contamination (this might include using cell fragments, DNA fragments, biologically precipitated minerals, etc., as model substances).
- Study the spatial distribution of contaminations spread by dust and wind in the vicinity of a Mars landing site.

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V. Planetary Protection from the Perspective of the Social Sciences

V.1 Planetary Protection from a Legal Perspective - General Issues by Francis Lyall

Abstract

Law has a number of roles to play in the protection of the environment of celestial bodies. In part it is prescriptive and in part it can set standards to be attained in the future. At present relevant space law is scattered, incoherent and incomplete. This paper summarises relevant law and identifies gaps and holes in its provisions. Principles of terrestrial environmental law are relevant since International Law applies in outer space. Basic principles for space are indicated in the Outer Space Treaty of 1967.The Moon Agreement, 1979, which applies not only to the Moon, contains sensible elements, but is not favoured by most states for reasons connected more with the concept of common heritage and an international regime to govern the exploitation of the Moon rather than its environmental aspects. Consideration should therefore be given to the codification of environmental law for celestial bodies into which more detailed agreement as to exploitative activities can later be slotted.

1. Law

Law may be prescriptive in detail as to conduct. It may also encapsulate aspirations to be attained over a period in particular activities. These elements are present in the use of law in the protection of the environment of celestial bodies. Both International Law and municipal (state) law can be involved, the importance of the latter lying in the implementation of international obligations, whether in the practice of states themselves or of those subject to their jurisdiction and control. The various legal and other provisions relevant to the protection of the environment of celestial bodies are not mutually consistent, coherent or comprehensive. Created in the interstices of law developed for other purposes, their codification will become necessary if that protection is to be fully attained.

2. International Law – General Issues

International law is the law that governs the relationship between states and lays down their rights and duties. In the last half-century, and building on previous more inchoate concepts, international negotiations and agreements have been developing a variety of principles regarding the terrestrial environment. The pollution, contamination and destruction of the natural environment has become a matter of concern for which legal controls and remedies have been created. While much of this relates to the use of state territory, increasing attention has been paid to terrestrial areas beyond national sovereignty. Article III of the Outer Space Treaty 1967 (see section 3) provides that the exploration and use of outer space is to be carried out in accordance with international law. The rapidly evolving terrestrial international environmental law is therefore relevant to the protection of the environment of celestial bodies in both principle and occasional detail (cf. Stockholm Declaration, 1972; Part XII, Arts. 192-237, UN Law of the Sea Convention, 1982; Rio Declarations, 1992).

3. Space Law as Part of International Law

3.1. Overview

The fundamental general international legal instrument as to the exploration and use of space is the Outer Space Treaty, 1967 (OST, 1967). For environmental purposes the Moon Agreement of 1979 (MA, 1979) may also be important (see 3.3 below). Other treaties relevant to the exploration and use of outer space (but with little or no environmental interest for this chapter) include the Agreement on Rescue and Return of Astronauts of 1968, the Liability Convention of 1972, and the Registration Agreement of 1976.

The instruments of the International Telecommunication Union (1992 ff) that deal with the use of radio frequencies are essential for space operations, and there is a further body of 'soft law' including UN Resolutions and Memoranda of Understanding between space agencies. Certain UN Resolutions set out principles which states should (but are not bound to) observe including principles as to the use of nuclear power sources.

One level below 'soft law' are inter-agency agreements and guidelines. However, as a matter of practice they are becoming of more importance than is generally realised. Their conversion into formal international law is thought by some to be needed, but to others the intrusion of technical enforceable legal obligation is unnecessary, not to say undesirable. A danger is that trust and cooperation between the space-active states might be eroded through disagreements over compliance with the law. Further, the imprecision of informality allows standards more easily to be raised as time goes on, the international negotiation of precise language being unnecessary. No matter one's stance on that argument, it is important that states should adopt their own laws to set and enforce standards.

3.2 Outer Space Treaty, 1967

As of 1 January 2008 the OST had been signed by 25 and ratified by 99 states including all the space-active states. Its fundamental provisions setting out general basic principles are now part of customary international law and therefore bind all states whether or not they are parties to the treaty.

OST Arts. VI and VII require states to license and continuously supervise their own activities in space and that of their nationals to ensure compliance with the requirements of international law.

OST Art. VIII provides that a state on whose registry an object launched into space is entered retains jurisdiction and control of that object. Ownership of an object launched into space, or landed or constructed on a celestial body, is not affected by its presence in space.

3.3 Moon Agreement, 1979

The Moon Agreement (MA, 1979) is in force, but as of 2008 had been signed by four and ratified by only 13 states, none of them majorly space active. The main objections made to it by the main space-active states are that it holds the Moon to be part of the Common Heritage of Mankind (a nebulous concept) and its consequent requirement that when exploitation of the Moon is imminent its parties will establish a regime to govern what is done (Art. 11.5). Most states are unwilling to allow their freedom to be thus fettered.

However, because its text was adopted by the UN General Assembly without vote, and because of the content of the debates and negotiations that led to the MA, its environmental provisions may be taken to express the international will on such matters. Many of them make good sense. Despite its short title, by its Art. I the Agreement applies to all celestial bodies in the solar system, not only to the Moon (except insofar as specific legal norms enter into force in respect of a particular celestial body).

4 Sovereignty and Jurisdiction in Space

It is important to recognise that under OST Art. II no state has or can have sovereign title in space or to a celestial body in whole or in part. This is repeated in MA Art. II.2, and MA Art. 11.3 spells out in further detail that no part of the Moon can be subject to a property right nor its use create such a right. It follows that no individual or corporate entity can have a property right in or to the whole or a part of a celestial body, because the rights of a non-state entity exist only within the legal system of a state.

However, it is also clear that samples of celestial bodies can be taken and that such samples are subject to property rights (MA Art. 6.2). Further legal developments will be needed when the exploitation (as opposed to the exploration) of celestial bodies is likely to begin (see section 7).

5 Exploration of Celestial Bodies

In the immediate future only the exploration of the Moon, Mars and perhaps some asteroids is likely: exploitation will come later. Under both the OST (Arts. I and IX) and MA (Arts. 4 and 6), such exploration is lawful even if to a limited degree contamination is caused. As noted above, both treaties prohibit ‘harmful’ contamination but without indicating the point at which contamination becomes harmful. Under the MA freedom of scientific investigation would include the collection and removal of samples (MA Art. 6.2) as has already occurred, notwithstanding the silence of the OST on such matters. Otherwise, moon bases, manned and unmanned, may be established (OST. Art. IX).

MA Art. 9.1 introduces further specification. Bases are to occupy a minimal area and be located so that free access by others to the area is not impeded (MA Arts. 9.1 and 2). No property title to the area occupied is created by such activities (MA Art. 11.3: cf. OST Art. II). By OST Art. XII and MA Art. 15.1 moon bases and facilities are to be open to inspection by other state parties, the latter provision indicating that the purpose of inspection is to ensure that parties are living up to their obligations under that Agreement.

6 Specific Environmental Law

6.1 Contamination.

OST Art. IX deals with contamination. Art. IX does not define 'contamination', thus arguably leaving it open to cover both non-biological and biological contamination. However, whether environmental pollution or degradation is covered is not clear.

Art. IX first requires states to avoid the 'back' contamination of the Earth from material being returned from space to Earth. In relation to 'forward' contamination of space from Earth, Art. IX requires states to study and explore outer space, including the Moon and other celestial bodies, in a manner that avoids their harmful contamination and where necessary to adopt measures appropriate for the purpose. The presence of the adjective 'harmful' modifying 'contamination' indicates that contamination is not *per se* prohibited. The meaning of 'harmful' is, however, not clear. Similarly, the modifier 'where necessary' blurs the parameters of the requirement. As enunciated in Art. IX the duty to avoid harmful contamination is general and aspirational. It leaves indefinite the circumstances when active measures are to be taken. This allows states progressively to raise the standards which they require of their licensees as situations and technologies develop.

Like OST Art. IX, MA Art. 7.1 first provides for the avoidance of back contamination of the Earth. Thereafter it sharpens the OST provisions requiring its parties to take measures to prevent the disruption of the environment of the Moon or other celestial bodies 'whether by introducing adverse changes in its environment, by harmful contamination through the introduction of extra-environmental matter or otherwise'. As in OST Art IX, what exactly constitutes 'harmful' contamination is unclear, but 'adverse changes' and the 'introduction of extra-environmental matter' are welcome if limited partial clarifications. The latter phrase can include non-biological matter. 'Or otherwise' leaves the door open for other contaminative possibilities which may emerge in the future.

Like terrestrial environmental law, prudence would indicate that the precautionary principle should be applied by the licensing requirements laid on space activities that potentially may contaminate celestial bodies and compliance with such requirements should be carefully monitored. As to the degradation of celestial bodies there is no legal bar to experiments involving the crashing of probes into various asteroids, comets or the Moon. Such are subject, however, to the COSPAR rules (see section 6.2).

Malfunctions during intended landing are not subject to any legal penalty. The 'exhaust' effects of landing or take-off (e.g. the Apollo missions) are not subject to control, although perhaps some attention could be given to ensuring that future engines do not cause 'harmful contamination'.

6.2 Biological Contamination: COSPAR Guidelines

In relation to biological contamination, the Committee on Space Research has set out a policy for planetary protection which is recommendatory, not legally binding (COSPAR 2005: see also Chapter IV.1). The Policy deals with both the protection of the Earth and of celestial bodies in five categories of classification, Category 5 involving the return of material to Earth being the most stringent. Categories 1-4 deal with outward interaction with celestial bodies in an increasing set of requirements depending on whether the body may be of interest in the understanding of chemical evolution or the origin of life. Category 3 comprises fly-by missions where the likelihood of collision with a celestial body is small but, in that event, there is a significant chance of contamination jeopardising future biological experiment. Accordingly 'clean room' procedures are required for the construction and handling of the probe. Category 4 involves planned landings and here the requirements are most stringent, involving the sterility of the intended lander (cf. NASA Policy Directives). Because the Policy is not legally binding, consideration should be given to the incorporation of some of its elements in a general instrument on the environment of celestial bodies, were such an agreement to be developed.

6.3 Objects

Exploratory vehicles and machinery remain the property of the state that launched them or licensed their building on a celestial body (OST Art. VIII; MA Art. 12.1-2) and therefore continue to be its responsibility whether they are in space or on celestial bodies. They cannot be abandoned in order to void or avoid the duties of their launching state.

OST Art. VIII provides for the return to the state of registry of objects found beyond the limits of another state party. This would include objects or debris found on a celestial body. MA Art. 13 provides for a state learning of a crash landing on a celestial body to notify the launching party (if discoverable) and the UN Secretary General. There is, however, nowhere a requirement to remove debris or disused equipment from a celestial body.

However, perhaps the 'contamination' provisions of the OST and MA should be extended to deal with such situations. The Google Lunar X-Prize may affect the natural environment of the Moon. Its justification is the stimulus of entrepreneurial activity. Some would debate whether this is a suitable measure to encourage scientific activity.

6.4 Nuclear Power

Long-range or long duration activities in space require more electrical power than is available through solar panels and photo-electrical devices that harness power from the Sun. Nuclear sources are required, both radioisotope thermoelectric generators (RTGs) and nuclear reactors being at present the devices acceptable for the purpose. One of the UN Space Principles resolutions deals with such questions in some detail (UN Nuclear Principles 1992). While the Principles cover the disposal of such devices when they have accomplished their function in Earth orbiting satellites (Pr. 3), they are silent as to the disposal of nuclear devices on or after use on celestial bodies. This question requires consideration and appropriate rules. MA Art. 7.2 requires the UN Secretary General to be informed of the placement and purpose of any nuclear materials on the moon or celestial bodies (cf. MA Art. 1).

7. Exploitation of Celestial Bodies

7.1. The exploitation of celestial bodies is further off in the future. When exploitation of celestial bodies occurs, major problems of contamination and environmental degradation will doubtless emerge. Terrestrial experience indicates that mining or other recovery of natural resources is contaminative of surrounding areas and damaging to the natural environment. If manufacturing or processing is carried out *in situ*, industrial processes would be involved with the import of materials foreign to the celestial body and the creation of unnatural waste might occur. Suitable licensing and enforcement regimes will be required.

MA Art. 11 is contentious. Under it the parties to that treaty have agreed that the Moon and its natural resources are part of the ‘common heritage of mankind’. Accordingly, when exploitation of the resources of the Moon is about to become feasible the parties are to agree an international regime to govern that exploitation (MA Art. 11.5). The purposes of such a regime include the safe and orderly development of the resources of the Moon, their rational management, the expansion of opportunities to use the resources and an equitable sharing by parties to the MA of the benefits secured (MA Art. II.7). The terrestrial parallel to such a regime is that dealing with the Area under the UN Law of the Sea Convention, 1982 (q.v.), which had to be significantly revised before becoming acceptable to many of the relevant states. The major relevant states had to be guaranteed positions on the regulatory body, and even so the US still has not ratified (it may in the near future). However, in relation to the Moon it seems very unlikely that space-competent states will be willing to surrender their discretion to authorise the exploitation of a celestial body, even to an international body on which they might have considerable influence.

Notwithstanding the difficulties of arriving at a suitable international arrangement, it is clearly desirable that a comprehensive agreement on some elements of the matter be attained before large-scale exploitation of the resources of the Moon or of any other celestial bodies occurs. Large-scale exploitation carried out by many states will likely require the participation of private capital, and may be carried out by private enterprise alone. In the absence of international agreement guaranteeing suitable arrangements for securing a profit on investment, private finance is unlikely to be forthcoming. The MA, suitably amended, could form the basis of such an agreement.

An international body would not authorise, license or approve a particular activity or derive any fees from it, but internationally a limited right to work in an area designated by the authorising state and to own materials mined or otherwise won from it would be recognised. Particular areas might also be set aside from exploitation (see section 7.3). The analogy here would be the control exercised over fishing in areas of the high seas, together with the rights of fisherman in relation to their catches. Some areas of the high seas are 'closed' to fishing by international agreement between the home states of the fishing boats. In such an agreement, measures could also be incorporated further to secure celestial bodies against harmful contamination, pollution and degradation through spoil heaps and disused equipment.

7.2 Military Uses of Celestial Bodies

All the space treaties and the UN Principles Resolutions provide that celestial bodies are to be used only for peaceful purposes (e.g. OST Art. IV; MA Art. 3).

Military manoeuvres on celestial bodies are specifically prohibited by OST Art. V para 2, although the use of military personnel in space exploration is permitted. This permission is understandable: only military personnel were likely to engage in space activities at the time the OST was drafted. Military bases on the Moon are prohibited by Art. V para 2, as is the testing of weapons and the stationing of nuclear weapons or weapons of mass destruction in space or on celestial bodies. Similar provision is made by MA Art. 3.

7.3 Special Sites on Celestial Bodies

Particular sites on the Moon and other celestial bodies may be considered to have historic importance and should therefore be preserved from further interference. Locations such as the Apollo landing sites on the Moon and the Mars lander areas should be considered for this special treatment although they may no longer be of particular scientific interest. Some formal international designation procedure is required similar to that which exists for World Heritage sites.

The setting aside on celestial bodies of sites of special scientific interest is contemplated in MA Art. 7.3. This could include the projected establishment of a radio-telescope facility on the lunar far-side (Maccone, 2005). Parks could be created to protect areas of celestial bodies from undue interference whether scientific or commercial (Cockell, 2006). In the designation of such areas the 'competent bodies' of the UN are to be consulted, but the actual procedures for designation are not yet established (MA Art. 7.3).

7.4 Planetary Defence

Notwithstanding the general prohibition of nuclear weapons and of nuclear explosions in space (OST Art. IV), consideration needs to be given to the possible requirements of planetary defence against asteroid impact with the Earth. While it is still not clear what kind of measures should be deployed to avoid the possibility of that eventuality, the legal background should be clarified.

8. Recommendations:

- A general agreement on the environment of the Moon and celestial bodies during exploration should be negotiated among the space-competent states, setting standards and fixing the extent of permissible contamination or degradation of sites. The contentious question of the control of the entrepreneurial exploitation of these bodies should be left aside for future negotiation.
- Any space activity involving the environment of the Moon or any other celestial body should, as part of its licensing process by the relevant state, be made subject of an environmental impact assessment. It should be open to interested parties, not only nationals of the licensing state, to contribute to the process and the assessment should be officially published.
- An analogue of the World Heritage Site listing should be developed for the protection of historic sites, such as the Apollo sites.

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V.2 Planetary Protection from a Legal Perspective: Due Diligence and National Legislation by Mahulena Hofmann

Abstract

The present international legal framework for the protection of the environment of celestial bodies can be characterized as insufficient, too general and fragmentary. The "province of mankind" rules are too general to impose concrete obligations on spacefaring nations to protect the space environment, whereas other binding provisions of international treaties cover only biological contamination. Special guidelines for pre– and post-flight measures are of recommendatory character only and therefore non-justiciable. A solution can be found in the extensive interpretation of the "due diligence principle" of Article IX OST connected with the harmonization of licensing procedures of national space activities.

1. Background of the Present Legal Situation

The general and fragmentary character of the international legal framework for the protection of the environment of celestial bodies is the consequence of the fact that the main instruments of international space law were drafted in the period of an intensive interest in the exploration of outer space, whereas less attention has been paid to environmental issues (Matte, 1989). In the meantime, the awareness of environmental problems has considerably increased: this can be documented by space laws issued by the majority of spacefaring nations which included environmental criteria in their licensing procedures. The reluctance to adopt an internationally binding instrument aimed at the prevention of damage or risks to the planetary environment can be explained only by an understanding that there is no necessity to limit the freedom of activities in outer space by additional environmental obligations. Measures preventing the environment of celestial bodies from turning into a situation characteristic of the environment in some parts of the present Antarctic may be considered as prohibitive and excessive by a part of the scientific and engineering community.

2. General Rules of International Space Law

The general provision resulting in a certain obligation to protect the environment of celestial bodies is Article IX OST (Lyall, 2005): the exploration and use of outer space is to be guided by the principle of "due regard to the corresponding interests" of all other Parties to the OST. This "due diligence" provision can be interpreted as creating an obligation to respect the interests of other States Parties not to endanger the environment both of outer space, including the celestial bodies, and of the Earth by space activities. This provision can even be considered as part of international customary law (Birnie, 2002). However, a consensus as to this interpretation is still in the process of development (Jasentuliyana, 1999).

Further rules capable of establishing an obligation not to cause harm to the environment of celestial bodies are Articles I OST and 4 (1) MA, both declaring the exploration and use of outer space, including the Moon and other celestial bodies, as the “province of all mankind”. This concept, although highly disputed in connection with the distribution of space assets, can be interpreted so as to include a common interest of all countries not to cause any harm to the existing space environment.

3. Special Rules of International Space Law

Article IX OST formulates the legally binding regime of minimizing the contamination of the Moon, other celestial bodies and the Earth during the studies and exploration of outer space (see Chapter V.1). Where necessary, the States are called upon to “adopt appropriate measures”. The limits of this regime consist in its concentration on the exploratory - and not the exploitatory - phase of space activities, the prevention of only “biological” contamination (Williamson, 1998) and the discretion of States to decide on the “necessity” and scope of any measures.

Article 7 MA has attempted to adapt the principles of the OST to the needs of the protection of the environment of celestial bodies. The decontamination regime has been extended to the exploitation phase of space activities, and the avoidance of biological contamination has been extended to the prohibition of any “disruption of the existing balance” of the environment of celestial bodies. The problem of this regime resides in the low number of States Parties to the Treaty, not including any spacefaring nation.

Other international space law treaties deal only to a limited extent with the damages occurring as a consequence of space activities. The 1968 Rescue Agreement´s obligation to return abandoned objects launched into outer space to the launching authority (Article 5 para 3) is based on the request of this authority; if no request has been expressed, most probably no measure can be taken by other States. Potentially relevant could be the provision connected with a hazardous nature of a space object (Article 5 para 4): in a case where a Contracting Party has discovered “elsewhere” a space object being of a hazardous or deleterious nature, the launching authority is obliged “immediately to take effective steps” to eliminate possible danger or harm.

The 1972 Liability Convention defines “damage”, inter alia, as damage to property of States or persons, natural or juridical, or property of international intergovernmental organizations. In order to evoke its provisions in connection with environmental damage, a courageous fiction would be necessary to interpret the “province of all mankind” principle as a basis for a special property title of “mankind” to outer space and environmental damage as damage “erga omnes” – a damage which touches the property of “everybody” or of “mankind”.

The 1975 Registration Convention did not include environmental data in the catalogue of information to be furnished obligatorily to the Secretary General of the United Nations (Article IV). The only provision dealing with space objects of a hazardous or deleterious nature concerns the assistance in the identification of the object; as in the Rescue Agreement, this assistance is dependent on a pertinent request by the launching State Party (Article VI).

4. National Rules and Standards

Several spacefaring states adopted national legislation which includes environmental provisions in the catalogue of criteria necessary for the licensing of space objects (Gerhard, 2005). The US national space law comprises, for example, the Commercial Space Launch Act of 1984, as well as the National Environmental Policy Act (42 U.S.C.4321. et seq) which have to be complied with by the missions (Hermida, 2004). The Russian 1993 Law on Space Activity requests all participants in space activities to take any necessary measures to avoid any threat to the environment. Environmental criteria are also part of the licensing procedures of the 1998 Australian Space Activities Act, the 1986 UK Act on Outer Space Activities and the 1996 Law on Space Activities of Ukraine. However, the scope and justiciability of these provisions are very heterogenous. They have been adopted by the Parliaments of the launching States without any serious harmonization or coordination procedure. Some of the national space acts, such the 1993 South African Space Affairs Act, do not include any environmental requirements.

5. Recommendatory Rules

A detailed set of guidelines and recommendations aimed at avoiding biological contamination of the Moon, other celestial bodies and the Earth has been developed by COSPAR. This entity is a committee of the International Council for Science (ICSU), an international NGO, and consist of two kinds of Members: National Scientific Institutions, as defined by ICSU, which are engaged in space research; and International Scientific Unions federated in ICSU which seek membership in COSPAR.

Two of its panels deal with planetary protection issues at present: the Panel on Planetary Protection (PPP), which elaborated the 2008 Planetary Protection Policy as a set of guidelines and recommendations based on Article IX of the Outer Space Treaty (approved by the Bureau and Council and by COSPAR 2008), and the Panel for Exploration (PEX). The list of its National Scientific Institution Members counts 44 institutions at present and includes, e.g. the University of Teheran, Israel Academy of Sciences and Humanities, Science Council of Japan, the Pakistan Space and Upper Atmosphere Research Commission, the Russian Academy of Sciences and the US National Academy of Sciences.

In the European sphere, these recommendations have been further implemented by the European Cooperation for Space Standardization (ECSS), an initiative established to develop a coherent single set of standards for use in all European space activities. These standards are jointly elaborated by European space agencies, aerospace companies and scientific and technical experts. Its 2008 set of recommendations is aimed at the prevention of forward contamination of other celestial bodies.[1]

There are also national systems which implement the general recommendations of COSPAR in the form of requirements that must be applied by actual project teams. Such national standards have been issued by NASA or CNES, for example.

6. The Gaps

The main gaps in the present legal framework of the PECB can be summarized as follows. There is a lack of awareness about the feasibility to extend present binding rules of international law beyond the scope of biological contamination. The “due diligence” principle has, until now, not had the opportunity to be interpreted in a concrete case concerning the environment of celestial bodies; its scope and contents remain unclear. The “province of all mankind” rule has a certain potential to be developed into a provision prohibiting the causing of damage in outer space; however, its disputed character in connection with the distribution of space assets makes international acceptance of this interpretation less probable – at least in the imminent future. Special rules of international space law link any rescue measures – including cases of an environmental hazard – with the request of the launching states concerned. The adoption of any national space legislation implementing international obligations is only voluntary. International recommendatory environmental rules are broadly respected by space agencies but are of a non-justiciable character.

7. Recommendation

- A solution can be found in the extensive interpretation of the “due diligence principle” of Article IX OST connected with the harmonization of licensing procedures of national space activities.

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V.3 International Regime of Antarctica as a Model for Planetary Protection by
Patricia Sterns and Les Tennen

Abstract

The exploration and use of both outer space and Antarctica present challenges to the pristine natural environments. The Antarctic continent contains small ice-free areas along the coast, which are home to diverse life forms, from the microscopic to birds, seals, and plants. The activities of man in these enclaves could have a considerable detrimental effect. Alternatively, the vast Antarctic ice sheet has an inherent buffering capacity by which the impact of mankind's presence can be absorbed and assimilated. Outer space may have examples of both of these environmental conditions, and the origins of the planetary protection policy were founded on the recognition that celestial environs must be protected and preserved from the impact of mankind on the possibility that there may be indigenous life forms or the precursors or remnants thereof.

1. Similarities between the Outer Space and the Antarctic Milieu

The apparent similarities between the outer space and Antarctic milieu are reflected in the legal regimes applicable to each. The Antarctic Treaty[1] entered into force almost a decade prior to the adoption of the Outer Space Treaty,[2] and the legal regulation of Antarctica articulated concepts which may have direct application to the exploration and use of outer space. Thus, the treaty regimes for outer space and Antarctica express similar legal precepts concerning, *inter alia*, peaceful purposes,[3] freedom of scientific investigation,[4] prohibitions on the assertion of claims of national sovereignty,[5] banning of nuclear weapons,[6] and the right of visitation of facilities *in situ*.[7]

The treaty regimes for Antarctica and outer space diverge in many important respects, including the protection of natural environments. The *Antarctic Treaty* does not contain any specific provision relating to the protection of the environment. The Outer Space Treaty, on the other hand, expressly requires states to avoid the harmful contamination of the Moon and other celestial bodies.[8] The only provision of the Antarctic Treaty which relates specifically to natural

1. Antarctic Treaty, opened for signature December 1, 1959, 12 U.S.T. 794, T.I.A.S. No. 4780, 420 U.N.T.S. 71.
2. Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, Including the Moon and Other Celestial Bodies, opened for signature January 27, 1967, art. VI, 18 U.S.T. 2410, T.I.A.S. No. 6347, 610 U.N.T.S. 205; see also Agreement Governing the Activities of States on the Moon and Other Celestial Bodies, entered into force July 11, 1984, 1363 U.N.T.S. 3.
3. Outer Space Treaty, art. IV; Antarctic Treaty, art. I.
4. Outer Space Treaty, art. I; Antarctic Treaty, art. II.
5. Outer Space Treaty, art. II; Antarctic Treaty, art. IV.
6. Outer Space Treaty, art. IV; Antarctic Treaty, art. V.
7. Outer Space Treaty, art. XII; Antarctic Treaty, art. VII.
8. Article IX.

environmental conditions is contained in article IX. Subsection (1) of this article provides that the parties to the Treaty shall meet periodically to consider measures to further the principles and objectives of the treaty, including, at sub-subsection (f), the preservation and conservation of living resources. This reference to living resources would include the flora and fauna of the continent, and perhaps extend to all other forms of life there, but would not appear to encompass the natural physical environment.

2. Antarctic Treaty System

The parties to the Antarctic Treaty have conducted numerous meetings in furtherance of the mandates of article IX, resulting in the adoption of additional international instruments, which together constitute the Antarctic Treaty System. The Antarctic Treaty System regulates the activities in the Antarctic *Treaty Area*, which is that area south of 60 degrees south latitude.

International instruments included in the Antarctic Treaty System, or otherwise relating to the protection of the Antarctic environment, are the Agreed Measures for the Conservation of Antarctic Fauna and Flora and associated Recommendations (effective from 1 November 1982),[9] the Convention for the Conservation of Antarctic Seals (entered into force 11 March 1978),[10] the Convention on the Conservation of Antarctic Marine Living Resources (entered into force 7 April 1982),[11] the Convention on the Regulation of Antarctic Mineral Resource Activities (concluded 2 June 1988, not yet entered into force),[12] Recommendations relating to the Antarctic Protected Area system concerning Specially Protected Areas, Sites of Special Scientific Interest and Historic Sites and Monuments (1989)[13], Code of Conduct for Antarctic Expeditions and Station Activities (effective from 16 December 1978)[14], the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (entered into force 5 May 1992) (Cohen, 2002), the Convention for the Prevention of Marine Pollution by the Dumping of Wastes and other Matter (entered into force 30 August 1985),[15] Arctic Shipping Guidelines (2002)[16] and the Protocol on Environmental Protection to the Antarctic Treaty (entered into force 14 January 1998).[17]

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9. ATCM III-VIII (Brussels, 1964).
10. Http://sedac.ciesin.org/entri/texts/antarctic.seals.1972.html.
11. Http://sedac.ciesin.org/entri/texts/antarctic.marine.resources.1980.html.
12. Http://sedac.ciesin.org/entri/texts/acrc/cramra.txt.html.
[13] ATCM XV-1 (Paris, 1989).
[14] ATCM VIII-11 (Oslo, 1975).
15. See http://www.imo.org/Conventions/mainframe.asp?topic_id=258&doc_id=681.
16. The International Maritime Organization approved Guidelines for ships operating in Arctic ice-covered waters, MSC/Circ.1056/MEPC/Circ.399, December 2002, http://www.imo.org/includes/blast DataOnly.asp/data_id%3D6629/1056-MEPC-Circ399.pdf.
17. Http://www.antarctica.ac.uk/about_antarctica/geopolitical/treaty/update_1991.php. The Protocol currently includes five Annexes concerning environmental impact assessment, conservation of fauna and flora, waste disposal and management, prevention of marine pollution, and area protection and management.

The recommendatory 1975 (78) *Code of Conduct for Antarctic Expeditions and Station Activities* sets forth guidelines for the management and disposal of waste in Antarctica. These guidelines specify the kind of waste, and the manner of disposal, much of which remains on site. For example, the Code of Conduct specifies that non-combustible, solid waste, including chemicals, but excluding batteries, are to be disposed of at sea, either in deep water, if possible, or at specified sites in shallow water. Batteries, waste containing radio-isotopes, and certain other materials including plastics and rubber, should be removed from the Antarctic Treaty Area. Combustible materials, in general, should be incinerated, and the ash disposed of at sea. Liquid waste, pursuant to the Code of Conduct, should be macerated and flushed into the sea. Field sites should use the facilities of their supporting station, while waste from inland stations should be concentrated in deep pits.

The Code of Conduct also establishes a procedure for the evaluation of proposed major operations in Antarctica. Specifically, the environmental impact of a proposed activity should be evaluated including an assessment of the potential benefits of the activity, the possible impact on the relevant ecosystems, and a consideration of alternative actions. Further environmental evaluations may be required unless the activity is likely to have only a "minor or transitory impact," although there is no agreement on the meaning of this phrase. Nevertheless, parties have an obligation to cooperate in the preparation of environmental assessments.[18]

The Code of Conduct incorporates Article IX of the 1964 (1982) recommendatory *Agreed Measures for the Conservation of Antarctic Fauna and Flora*, which concerns the introduction of non-indigenous species, parasites and diseases to Antarctica. This article prohibits bringing any non-indigenous species of plant or animal into the Treaty Area except in accordance with a permit, which shall be drawn in terms as specific as possible. Any such plant or animal which might cause harmful interference with the natural system shall be kept under controlled conditions, and ultimately be removed or destroyed. Special precautions shall be taken to prevent the accidental introduction of parasites and diseases into the Treaty Area.

The Agreed Measures for the Conservation of Antarctic Fauna and Flora introduced the practice of setting aside areas of special interest subject to different management regimes. The categories of areas of special interest proliferated into not less than seven different designations. Annex V to the 1991 binding Protocol on Environmental Protection to the Antarctic Treaty reduced the categories to only two defined protected areas: Antarctic Specially Protected Areas (ASPAs) and Antarctic Specially Managed Areas (ASMAs). The primary distinction between these two areas is that ASPAs are intended to protect environmental, scientific, historic, aesthetic or wilderness values, while the focus of ASMAs is to protect activities (Cohen 2002, 554). ASPAs and ASMAs are similar to special regions referenced in the COSPAR planetary protection policy, international scientific

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18. Protocol on Environmental Protection to the Antarctic Treaty, art. 6.

preserves provided in article 7.3 of the Moon Agreement, or the emerging concept of planetary parks.

The 1991 internationally binding *Protocol on Environmental Protection to the Antarctic Treaty* declares, in article 2, its overriding objective to be “the comprehensive protection of the Antarctic environment and dependent and associated ecosystems and [designates] Antarctica as a natural reserve, devoted to peace and science.” States participating in the Antarctic Treaty System seek to achieve this objective, *inter alia*, by planning and conducting activities in the Antarctic Treaty Area so as to avoid adverse effects on climate, weather patterns, air, or water quality; significant changes in the atmospheric, terrestrial (including aquatic), glacial or marine environments; detrimental changes in the distribution, abundance or populations of species of fauna and flora; or degradation of, or substantial risk to, areas of biological, scientific, historic, aesthetic or wilderness significance. Assessments of environmental impacts of proposed major operations are to consider not only the impact of the activity itself, but also the cumulative impact in combination with other activities. The assessment also should include consideration of whether the activity will detrimentally affect any other activity in the Antarctic Treaty Area.

The Protocol elaborates on the right of inspection established by article VII of the Antarctic Treaty. Article 14 of the Protocol requires that parties shall cooperate fully with observers undertaking inspections, who shall be permitted access to all parts of stations, installations, equipment, and vessels subject to inspection pursuant to the Antarctic Treaty, together with all records maintained thereon. Reports shall be furnished to the parties whose facilities or vessels were the subject of inspections, which parties have the opportunity to comment. The reports and any comments are circulated to all other parties, and made available to the public.

The parties to the Protocol have agreed to undertake to elaborate rules and procedures concerning liability for damages. In the meantime, however, the parties to the Protocol have committed to a process for the resolution of disputes, which includes consultations, negotiation, inquiry, mediation, conciliation, arbitration, judicial settlement or other peaceful means to which the parties to the dispute agree. Notwithstanding such commitment, each party, when signing, ratifying, accepting, approving or acceding to the Protocol, can designate that disputes shall be submitted to either the International Court of Justice, or an Arbitral Tribunal. The Protocol details the circumstances by which a dispute is submitted to either the ICJ or an Arbitral Tribunal, with a clear preference for the latter.[19]

3. Main Differences between the two Regimes

The Antarctic Treaty System has developed a far-reaching set of rules and procedures for the protection of the environment of the frozen continent, which may provide some guidance for the protection of extraterrestrial environments. The

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19. See generally arts. 16, 18, 19 and 20; see also Schedule to the Protocol on Arbitration.

primary focus of the Code of Conduct, for example, is on the management and disposal of waste materials. In the Antarctic Treaty Area, much of the waste is to be removed, and what remains is to be disposed of in a manner which is intended to lessen the impact on the environment. In the exploration and use of outer space, however, the practice of states has been simply to leave waste material and spent payloads on site, whether in orbit or on a celestial body (Williamson, 2006). Although removal of interplanetary spacecraft at the end of mission is impractical, it may be questioned whether sufficient consideration has been given during the planning stages of missions to the consequences of the deposition of terran based waste on an extraterrestrial environment (Williamson, 2006; Sterns, 2000).

The problem of debris in Earth orbit grows in significance with the multiplicity of objects launched into space. The international community has established the Inter-Agency Space Debris Coordination Committee (IADC) to address this issue, but the focus has been on the prevention of debris and not the removal of non-functional items already in orbit (Report, 2005). Efforts at removal of material to date have been limited to repositioning of satellites and to manned orbital missions where certain waste items have been accumulated for return to Earth. The repositioning of satellites to a disposal orbit, rather than de-orbiting the space object, may be illusory and ineffective as an environmental protection, as the accumulation of spent craft at any orbital location eventually could pose a hazard to or interfere with other spacecraft, missions, or other scientific or commercial endeavors.

The formal procedure for evaluating the environmental impact of activities in the Antarctic Treaty Area based on Annex I to the 1991 Protocol on Environmental Protection to the Antarctic Treaty has no counterpart in the law of outer space. A launching authority may disclose plans to conduct a mission, and seek international comment, on a voluntary basis, but there is no formal international procedure in place for an environmental impact assessment of activities sought to be conducted in space or on celestial bodies. However, if a state has reason to believe an activity planned by it or its nationals in outer space, including the Moon and other celestial bodies, would cause potentially harmful interference with the activities of another state, it shall undertake appropriate international consultations pursuant to article IX of the Outer Space Treaty.

The Antarctic Code of Conduct provides that the environmental impact assessment of activities should include consideration of the “potential benefits of the activity, the possible impact on the relevant ecosystems, and a consideration of alternative actions.” The Antarctic Environmental Protocol adds that the environmental impact assessment also must include consideration of the cumulative impact of the activity in combination with other activities. In regard to outer space, the planetary protection policy provides the only institutionalized method by which an assessment of the impact of a spacecraft on an extraterrestrial environment is conducted, although such is not comparable to the environmental impact assessment applicable to Antarctica. Nevertheless, the planetary protection policy does not currently include consideration of the concepts expressed in the Code of Conduct or the Protocol.

The present formulation of the planetary protection policy does not mention the cumulative impact of missions, which is a significant change from the original policy developed by COSPAR. The original policy, enunciated in 1964, was expressed as planetary quarantine requirements (PQR), which specifically considered the cumulative impact of all interplanetary exploratory missions anticipated to be launched over a thirty year period. The PQR required that decontamination techniques were to be employed to reduce the probability of contamination of a celestial environment by a single viable terrestrial organism aboard any spacecraft intended for planetary landing or atmospheric penetration to less than $1x10^{-4}$. The probability limit for an accidental planetary impact by an unsterilized fly-by or orbiting spacecraft was $3x10^{-5}$ or less.[20] These probability limits were cumulative, and were apportioned to the space-active states. These national allocations were further distributed among individual missions (NASA, 1973).

The Antarctic Environmental Protocol provides that States elaborate rules and procedures for liability for damages, although a detailed process is set forth in the instrument for the settlement of disputes. While a dispute resolution process is established in the law of outer space by the Liability Convention,[21] it is questionable whether the Convention applies to forward contamination or other damage to a celestial environment (Sterns, 2002). Nevertheless, in the event of contamination or environmental damage, monetary compensation would be insufficient to restore the *status quo ante*. Furthermore, the consequences of contamination of an alien environment would exceed the capacity of any one nation to remedy (de Cocca, 2000).

4. Recommendation

- The Antarctic Treaty System has developed a far-reaching set of rules and procedures for the protection of the environment of the frozen continent, which may provide some guidance for the protection of extraterrestrial environments. The primary focus of the Code of Conduct, for example, is on the management and disposal of waste materials. In the Antarctic Treaty Area, much of the waste is to be removed, and what remains is to be disposed of in a manner which is intended to lessen the impact on the environment. In the exploration and use of outer space, however, the practice of states has been simply to leave waste materials and spent payloads on site, whether in orbit or on a celestial body. Although removal of interplanetary spacecraft at the end of mission is impractical, it may be questioned whether more consideration should be given during the planning stages of missions to the consequences of the deposition of terran based waste on an extraterrestrial environment.

20. COSPAR Res. 26, 20 COSPAR Info. Bull. at Annex 4 (1964).
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V.4 Planetary Protection from a National Perspective - Example of Kazakhstan by Gulnara Omarova and Juldis Omarova

Abstract

The 1997 Intergovernment Agreement between the Republic of Kazakhstan and the Russian Federation covers the ecological issues of use of the Baikonur Cosmodrome. This agreement includes the obligation of the Russian party to provide ecological expertise of launchers and spacecraft in terms of their impact on the environment, as well as conducting measures on cleaning up after accidents, rocket fuel contaminations, and radioactive contaminations. However, harmful contamination of certain territories due to exploitation of the Baikonur Cosmodrome and its impact on the environment and human health remains a problem worth discussing and studying in all aspects at national and international levels. This would contribute to the development of models aimed at avoiding harmful contamination of the Moon and Mars.

1. Question of Sufficiency of Present Mechanisms of Protection of Environment of Celestial Bodies

The issue of protection of the environment of the celestial bodies is an inalienable part of space exploration. Legal aspects of space exploration of the Moon and other celestial bodies have received globally recognized importance through five United Nations general treaties, including the "Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, in particular, the Moon and Other Celestial Bodies" (Outer Space Treaty (OST)) and the "Agreement Governing the Activities of States on the Moon and Other Celestial Bodies" (Moon Agreement (MA)). These important instruments of the international law of outer space provide a basic legal framework and mechanisms for the exploration of the Moon and other celestial bodies.

These two international agreements include wording regarding general mechanisms of protection of the environment of the Moon and other celestial bodies. According to Article IX of the OST, in the exploration and use of outer space, 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. At the present time, COSPAR is implementing this mechanism with respect to biological contamination (see chapter IV.1).

According to Article VII of the MA, in exploring and using the Moon, States Parties shall take measures to prevent the disruption of the existing balance of its environment, whether by introducing adverse changes in that environment, by its harmful contamination through the introduction of extra-environmental matter, or otherwise. At the present time, the detailed mechanisms of how to prevent the disruption of the said balance are not yet formulated. Unfortunately, many spacefaring nations as well as emerging space nations have not ratified the Moon Agreement.

The existing international legal regime governing outer space has provided an indispensible basis for undertaking space activities, but does not adequately address many of the emerging issues of current and future activities in outer space. Today, the development of an international legal framework of goals and recommendations for the safety of planned and currently foreseeable space activities in outer space, in terms of protection of the environment of celestial bodies, is quite a challenge.

Apparently, the present mechanisms of protection of the environment of celestial bodies are not sufficient, but require the development of a specific legal framework. The building blocks of such specific legal framework, with a rational set of measures preventing the degradation of the environment of celestial bodies, should integrate the existing international legal regime governing outer space, the COSPAR 2002 Planetary Protection Policy recommendations, and outcomes of a wide range of studies, discussions and deliberations both at national and international levels.

2. Need to Change Present Approaches

The successfully prepared and executed robotic missions, such as NASA robotic missions to Mars (Spirit & Opportunity), and NASA and ESA robotic missions to Saturn's natural satellite Titan (Cassini/Huygens) have shown the feasibility of reaching other planets of the solar system. The next period of space exploration will be focused on continuing the study of universal processes in the solar system that affect interplanetary and space environmental conditions and their evolution. This would pave the way for safe human spaceflight to the Moon and other celestial bodies in the foreseeable future. The industrial phase of current space activities is expanding beyond Earth orbit towards the creation of a space-based industrial infrastructure, global space energy systems, a permanent lunar,mining infrastructure and colonization of the Moon and Mars.

The current legal framework is liberalism (Kerrest, 2006) and today it is challenging a very important problem posed by space exploration objectives. New space frontiers are bringing an increased number of jurisprudential issues related to the protection of the environment of celestial bodies of the Solar system, notably the Moon and Mars. A set of specific measures to prevent the disruption of the environment of celestial bodies should become an important component of international space law. The development of such measures should change present approaches, which are quite general and unfortunately ignorable by spacefaring countries, because there is a conflict between the two paradigms of space exploration – conquest of space on the one hand and the province of all mankind on another hand. A new strategy should be established to settle this conflict and to find a balance between space exploration and protection of the environment of celestial bodies as soon as possible based on a systematic, interdisciplinary and international approach.

3. Drafting New Binding Rules under Present Condition

The first years of the 21st century have been marked by a parade of new space strategies from the leading space nations of the post cold war world. Political leaders have announced long-term ambitions in space exploration, including manned spaceflights to the Moon and Mars. NASA, ESA and other largest space agencies have demonstrated their capability to implement their programs of exploration of the Moon, Mars and other celestial bodies quite independently and spontaneously, regardless of the MA and without any pragmatic general approach to and concept of the problem of protection of the environment of celestial bodies.

International space law has encountered quite sophisticated problems in light of the announced space strategies. One of them is the question of how to protect the environment of celestial bodies, which is not just a rhetorical question but a question of policy, requiring priority attention and practical solutions. 2009, as a year of global economic downturn, systemic financial collapse and growing deficits will undoubtedly decrease further investments in risky national and international space programs and projects. At the same time, it will increase the need for broader international cooperation and coordination of joint, cost-effective efforts in the exploration of the Moon and other celestial bodies, focusing on innovative and possibly environmentally friendly solutions. In this context, the political conditions very much allow and favor the drafting of new binding rules for protecting the environment of celestial bodies.

4. National Practice Exemplified by Kazakhstan's Approach

The environmental aspects of space activities are very significant and valuable for Kazakhstan due to environmental problems in exploitation of the Baikonur Cosmodrome. Since 1994, space activities from the Baikonur Cosmodrome have been legally covered by a rental agreement, signed by the governments of the Republic of Kazakhstan and the Russian Federation.

Today, the Baikonur Cosmodrome is a launching site for a large number of robotic and manned missions and commercial satellites and still has the potential to provide a significant part of global space services (Omarova, and Omarova, 2006). Launches from the Baikonur Cosmodrome are usually followed by the separation of launch vehicle stages which fall on certain areas of the territory of Kazakhstan, creating a kind of space debris on the Earth, and producing harmful contamination in Kazakhstan territory.

The 1997 Intergovernment Agreement between the Republic of Kazakhstan and the Russian Federation covers the ecological issues of use of the Baikonur Cosmodrome. This agreement includes the obligation of the Russian party to provide ecological expertise of launchers and spacecraft in terms of their impact on the environment, as well as conducting measures on cleaning up after accidents, rocket fuel contaminations, and radioactive contaminations. However, harmful contamination of certain territories due to exploitation of the Baikonur Cosmodrome and its impact on the environment and human health is a big problem worth discussing and studying in all aspects at national and international levels. This would contribute to the development of models aimed at avoiding future harmful contamination of the Moon and Mars.

In 1993, the National Aerospace Agency (NAA) was established with the aim of coordinating national space activities and establishing international cooperation in the field of peaceful uses of outer space. In 1994, the independent functions of the NAA were restricted due to the absence of a national space development strategy. Between 1994 and 2007, national space activities were coordinated by the Aerospace Committee affiliated to different ministries.

In 2007, the National Space Agency was established with the aim of building a fully-fledged space industry in Kazakhstan. One of the agency's main tasks is the licensing of national activities in outer space, which includes environmental criteria. Another task is the preparation of annual conclusions on launches planned by the Russian Federation from the Baikonur Cosmodrome.

One of the cornerstones of the national space strategy is the adherence to international agreements in the field of activities in outer space. The establishment in 2007 of the National Center for Space Science and Technology, which brings together three research institutes in the fields of astronomy, astrophysics, Earth's ionosphere and space research, represented a significant development in the field of fundamental and applied sciences, including the study of celestial bodies, near-Earth objects and space debris.

Kazakhstan, as one of a few emerging space nations, became a party to the five main United Nations Treaties in 1997. This is clear evidence of its full commitment to all binding provisions of the international treaties in the field of space exploration, including provisions related to the issue of the protection of environment of celestial bodies, and of its understanding that there is a necessity to limit the freedom of activities in outer space by additional environmental obligations.

Moreover, Kazakhstan has been active in implementing all five international agreements in its national space legislation and practicing all their provisions in cooperation with other countries on space-related issues. As a member of the UN Committee on the Peaceful Uses of Outer Space (COPUOS), Kazakhstan has promoted the efforts of the Committee towards strengthening the existing international legal regime governing outer space and developing a legal framework on specific problems arising in different stages of space exploration, including environmental issues.

5. Conclusion

Political conditions and the current situation in global activities in outer space show that the international space community now has an extraordinary opportunity to find new effective approaches to the problem of protection of the environment of celestial bodies. One possible way to attract the attention of all states to the issue of "Protecting the Environment of Celestial Bodies" is in the framework of implementation of objectives of the UNISPACE III Conference, namely "to provide a valuable forum for a critical evaluation of space activities and to increase awareness among the general public regarding the benefits of space technology".

A critical evaluation of space activities as one of its main elements should include the status of protection of the environment of celestial bodies in all aspects - including technical, political and legal - with a view to establishing a comprehensive, international regime for the protection of the space environment.

6. Recommendations

The following steps should be taken in protecting the environment of celestial bodies, using the available mechanisms of international cooperation and capability of international organizations and institutions:

- continue support to the study of the status and potential of the existing international legal regime governing outer space; assess whether international and national space legislations adequately address current and potential activities on the Moon and other celestial bodies; and assess the effectiveness of the current state of international law governing the prohibition of contamination of the environment of celestial bodies;
- draw greater attention to the problems of the use of nuclear power sources in outer space, Near-Earth objects, and space debris, connecting them broadly to the problem of protection of the environment of celestial bodies;
- consider the reasons for the low participation of states in the MA (General Assembly resolution 34/68, annex) and encourage states to become parties to the United Nations treaties on outer space, in particular, to the OST and MA, by providing information on adhering to the treaties and asking states parties to the MA to demonstrate the benefits;
- assess whether the main principles of international cooperation in the field of environment protection can be applied to the problem of the protection of the environment of celestial bodies (Krichevski, 2006);
- draft a set of measures preventing the destruction of the environment of the Moon, Mars and other celestial bodies and a code of conduct on “how to avoid future pollution of the environment of celestial bodies”
- space agencies and private companies should pay attention to the protection of the environment of celestial bodies in their activities in outer space, providing national and international environmental expertise (Krichevski, 2006) of planned space programs and matching goals of space exploration with environmental solutions.

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V.5 Economic Analysis: Precondition of Legal and Institutional Arrangements by Vasilis Zervos

Abstract

Institutional arrangements in space tend to follow, rather than precede technical developments. The use of economic analysis is outlined with the aim of pointing to sensible rules of the road for spacefaring nations in numerous cases starting from exploitation of resources and space colonization to near Earth object threats. The recommendations point towards the need for the development of a workable framework based on solid principles and economic analysis that will lead to low-ambiguity and high-practicality policies and legal institutional arrangements.

1. Introduction

Economics typically deals with scarcity of resources. Economics textbooks look at the Robinson-Crusoe framework of allocation of resources where, in contrast to a 'spaceship Earth' approach, there is isolation from the outside world. But this is considered to be a simplification, for there *is* an outside world and reaching it causes major changes. The finding of ice on Mars, which is a useful resource for colonization purposes, could easily result in a situation where the value of this resource is much higher for the competing spacefaring nations than gold was for the 18th century colonial powers. The Martian environment will inevitably suffer, but colonization could reverse negative effects in more mature, future stages, although this is dependent upon the level of cooperation, or competition among spacefaring nations.

The following sections discuss key economic concepts associated with different scenarios of human-related activities affecting celestial bodies:

- Exploration for raw materials on celestial bodies utilizing principles of cost-benefit analysis relating to the case of importing materials/hardware to Earth
- Strategic advantages for first-comer/colonizer in possible future resources which include security considerations.
- Non-strategic and non-exploitation security rationale related to the threat of celestial bodies to Earth (Near Earth Object (NEO) threats).

2. Impact of Resource Exploitation

The concept of non-appropriation of celestial bodies and the use of their resources for the benefit of all mankind are noble concepts, but arguably meaningless in the absence of the relevant capabilities and low-cost options for doing otherwise (Jurist et al, 2006). However, possible colonization of celestial bodies in the future will inevitably result in the need to refine and develop tools in order to apply such concepts. In the meantime, there is the issue of exploitation of resources.

Celestial bodies are hardly perceived today as the 'El-Dorados' of the future. With much of the Earth being relatively unexploited, the cost of access to space would have to drop significantly, or the benefits of such exploration would have to be substantially higher, for this process to begin. Cost is an obvious automatic mechanism for the protection of much of the environment here on Earth, or on celestial bodies.

The recent example of the Antarctic comes to mind: its predicted oil reserves have remained untapped, but given the rise of the price of oil and the 'warming' of the poles, this exploration becomes more likely and raises competition between the stakeholders in the area. In the case where there are significant benefits, and costs can be passed on to future generations, then exploitation occurs and the question is 'what happens with the social costs?'. In addition, the concept that in the future there will be more efficient use of resources also supports the non-exploitation principle, but only in the presence of cooperation of spacefaring nations. However, as more and more nations develop the relevant space capabilities for utilizing space resources, competition-in-colonization emerges as a realistic scenario. Cooperation becomes more difficult as the number of nations/agents increase, but also more necessary to avoid large-scale conflict.

In order to avoid the modern equivalent of the competition of colonial powers of the past centuries, the 'non-appropriation' principle of space alongside the 'principle of benefits of exploration for all of mankind' were introduced, although not generally accepted. The real danger, however, comes from the absence of the necessary 'tools' to apply such concepts, evident in recent efforts to develop 'rules of the road' for Earth orbits.

What is the mechanism to enforce and apply such concepts if a private vehicle by country X discovers a substantial amount of 'unobtainium' just under the surface of the Moon, or Mars? If some of this valuable material is brought to Earth, how would one would go about ensuring that this benefits all mankind? A simple mechanism is to examine the impact of this on the cost of production of different industries: if one industry became more efficient then this would lead to benefits, but how would they be spread over to everyone?

The discussion on the protection of such environments would transform into environmental-friendly mining, or sustainable exploration, meaning that future uses of the relevant body should not be hampered by such activities. There are, at this stage, more questions than answers and one can only suggest further research towards understanding the relevant implications and refinement of the *'rules of the road'* taking into consideration both economic and security factors applied via a functional legal framework.

3. Impact of Habitation

A more meaningful way that human activities can affect the environment of celestial bodies in the future is the introduction of a larger scale of human made machinery and/or humans than assumed in the previous section. One mode of this could be linked to colonization following exploitation for the extraction of resources.

Externalities (Buchanan and Stubblebine, 1969) relate to costs/benefits in the production/consumption of ‘product A’ that the respective market fails to take into account (external to market = externality). For example, factories dumping untreated pollutants in rivers lower their cost of production by passing some of their costs to the fishermen and casual users of the river. Pollution in this sense refers to externalities, as external markets are affected negatively. The social costs include the (lower) costs of the factory, but also the (higher) costs of the fishermen and casual users.

The intuition is simple, but the applications are less straightforward and there are many uncertainties on future costs by implications of pollution. This means that in the presence of such uncertainties it is hard to calculate the full impact of the externality.

One popular way to deal with the externality is to assign property rights of the affected resource to the affected people. This then could result in fishermen being compensated for their damages, but the factory could find it more cost-efficient to continue to pollute and compensate. The ‘polluter pays’ mechanism, which tends to gain popularity, could prove more efficient provided the payment is over the cost advantages the factory enjoys by polluting. It is clear, however, that uncertainties and risks make such mechanisms inefficient and subject to perverse incentives.

In the case of colonization of celestial bodies, costs of pollution beyond the colonial perimeter relate to increased costs of others to establish a colony there, or for the same colony to expand beyond some point. As these are only potential colonies we use the term pseudo-externality, as it is not presently affecting any other activity/market. The first colony would have the advantage of choosing suitable ground and also have little incentive to utilize clean technologies within a strategic setting. It is easy to see how this pseudo-externality can become real if others decide to colonize the area; their choices are restricted by the dumping grounds of the established colony. This example illustrates why the term ‘pseudo’ is only provisional.

Of course, this simple static framework neglects the dynamic element of colonial expansion, as often is the case for societies here on Earth. The cost in reality is imposed on potential future inhabitants. The cost per inhabitant of a colony is made lower by utilizing ‘dirty’ technologies that put a heavy burden on the inhabitation of the outside environment. As the number of inhabitants grows, the ‘outside environment’ becomes increasingly part of the colony (inside environment). At some point, it is more costly to first pollute and then clean up,, rather than utilizing clean technology to begin with. In this case, the pseudo-externality affects the colony itself, translating into real costs for the colony and future expansion plans. This then pushes for adoption of cleaner technology applications.

The futuristic development of in-situ resource utilization for supporting colonies on celestial bodies could, however, tip the scale on this cost mechanism, possibly making local resources more cost-effective to use than Earth-derived resources for the creation and maintenance of machine/human facilities. Simple examples, such as materials for insulation, would have minimal environmental impacts, as they would simply result in a rearrangement of the landscape and materials on the relevant celestial bodies. However, more extreme scenarios could include the introduction of more complex forms of populated establishments and purpose-made, genetically engineered bio-environments. Such colonies would result in interactions between environment and life-forms with the potential to affect the environment of the celestial bodies and Earth. Genetic modifications, either naturally augmented or engineered for the colony-specific environment, are likely to eventually cause changes within the bio-environment. The implications of such interactions with the Earth's bio-environment would need monitoring in order to nullify relevant dangers, but this is beyond the scope of this analysis.

With regards to pollution (Brock and Taylor, 2005; Tisdell, 2001), the early stages of development are characterized by rapidly expanding levels of pollution, unlike the mature levels of colonial activity, where standard of living takes precedence over growth. The later stages are characterized by habitation and development paradigms placing more emphasis on sustainability, rather than growth.

Colonization and the development of future bases on the Moon and other celestial bodies could result in peripheral garbage zones, owing to the minimization of disposal cost. A short-sighted cost-benefit analysis with relevant discount period and values would tend to favor litter in the early stages. The discovery of ice on the surface of Mars poses interesting questions for the relevant environment: the colonization of Mars would likely severely affect the surface, but could also result in a colonial rush for spacefaring nations to secure those, or other valuable and scarce resources.

It should be noted that levels of human activity associated with strategic advantages do not necessarily 'evolve' into mature colonies. Moon exploration can be seen as such an example, as its exploration carries scientific advantages, but also strategic advantages for further explorations of celestial bodies and security considerations for Earth. This is much of the reason why, as with space stations, collaboration for Moon bases is preferred, as competition is likely to result in inferior solutions for all involved.

4. Recommendations

The human nature to exploit, explore and develop can create problems for relevant future efforts. Taking such long-term concerns often requires an approach not in-line with the 'spirit' of pioneering and exploration. But as our capabilities increase so do our responsibilities. In this case, sustainability ensures future efforts are not handicapped by today's choices. Recommendations in line with this framework include:

- The need to perform economic analysis of outpost/colonization plans regarding impact on sustainability by examining both benefits and costs to future settlements

- Undertake economic analysis of NEO threat monitoring and actions focusing on the distribution of costs and an assessment of mechanisms of burden allocation that accounts for an optimal allocation of resources
- Regarding the resource-exploitation of celestial bodies: what are the problems with the current principles and what economic 'tools' of applicability and distribution of benefits and costs are needed?
- As space becomes increasingly a resource rather than a cold-war battleground the new institutional arrangements and agreements must take this into account by making meaningful and sensible use of economic and legal principles in order to precede developments and avoid ad-hoc solutions.

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V.6 Politics: Tool for Ensuring the Implementation of Planetary Protection by Kazuto Suzuki

Abstract

In order to understand the willingness of states to protect the environment of celestial bodies, political analysis of a state's behaviour is important. There are three theoretical frameworks for designing political institutions for international rules and regulations. The theory of hegemonic stability is not sufficient because there are several states which are capable of exploring celestial bodies. Liberal Institutionalism is also difficult to apply because there is a lack of coordination and convergence of interests. Thus, this chapter suggests a constructivist approach, where norm entrepreneurs establish a discourse of protecting the environment of celestial bodies and increase the legitimacy of the international rules and governance system.

1. Introduction

There are hundreds of ways to explain what politics is and what politics can do to change the behaviour of states and individuals. In general, politics is a process of people seeking and using power to realize their objectives. It is regulated by rules, laws, and procedures. If one seeks to limit the contamination of celestial bodies, there should be a person or entity with enough power to establish a rule or law for protecting the environment of celestial bodies.

However, people often violate rules and laws. If a person or an entity holds an interest in exploring a celestial body without complying with the rules and laws, the current international system has no effective recourse. In short, a legal solution is important for regulating the behaviour of a person or an entity, but it is not sufficient for ensuring the regulatory framework.

Thus, there should be a ways and means provided by the political process to improve the effectiveness of the regulatory framework. There are some assumptions in this argument. First, at the moment, there are a very limited number of states capable of exploring celestial bodies. The United States, Russia, China, Europe (either individual states or ESA), India and Japan are the possible candidates for exploring celestial bodies. These countries have the power to establish international standards.

The second assumption is that there is no current consensus or “normative understanding” among those states with space capabilities. These states may have their own standards for protecting celestial bodies, but that means that there are different interpretations of how to protect celestial bodies. If one of these standards is not fully protecting celestial bodies, it would undermine all the efforts that other states may take.

The third assumption is that there is no effective governing body of space activities, such as the WTO in the case of international trade. There are bodies such as UNCOPUOS and OOSA which might act as a governing body, but there is no power in these institutions for enforcing the rules.

2. Theory of Hegemonic Stability

If there is no effective governance system in international society, there should be some state willing to maintain international order and enforce certain regulations for the common good (Gilpin 1987, Grieco 1990). The role of the hegemonic state has become very important in this regard.

The hegemonic state is, first of all, a state with outstanding material power to enforce the rules and laws, and to punish the rule-breakers. It may use its military and economic power to sanction the rule-breakers, such that any state would have no incentive to break the rules.

Second, the hegemonic state would exercise its leadership in its favour, such that its national standard would become the international standard. For example, the rules of export control regimes, Nuclear Proliferation Treaty, international air traffic regulations, and many other international rules are made by a hegemonic state which has the capability to dominate certain domain of activities. It is likely that an international standard on protection of the environment of celestial bodies would be established by the state with the leading space capabilities.

Third, the hegemonic state cannot convince other states only by exercising its material power, but must also exercise moral authority. If the rules and standards are set by material forces, there will be an incentive for other states to violate the rules when the power of hegemonic state declines. But if the rules and standards are set with moral and ethical authority, they are unlikely to be violated, because the rules and standards are already accepted as a norm for other states as well.

Fourth, the hegemonic state needs to provide international “public goods” to facilitate international cooperation, and is expected to provide not only the international standard, but also the scientific data and infrastructures for the examination of biological and chemical contamination. This means that the hegemonic state would bear the cost of those infrastructures, and that other states would follow the rules set by the hegemonic state in exchange for saving the cost of developing their own infrastructure.

The theory of hegemonic stability seems to be a fine method for maintaining international order for protecting the environment of celestial bodies. However, it would be difficult to employ this theory because the most capable state, the United States, may not be able to exercise its hegemonic power over other capable states for exploring celestial bodies. The United States is no longer the sole provider of ideas and infrastructure for space exploration. Its attitude toward space exploration is not a cooperative one, but competitive and confrontational, and competition with countries such as China, India and Russia is one of the motivations for the US to invest for space exploration. Only if the United States reestablishes itself as the only country with capability and experience for planetary exploration would it be possible for the United States to behave as a hegemonic state.

3. Liberal Institutionalism

The theory of liberal institutionalism shares the same assumption that the state would behave rationally. However, it would emphasis the importance of international cooperation. It argues that if a state wants to maximize its interests, it would be better to avoid confrontation and friction with other countries. It would be in the interest of a state to comply with international rules because there will be unintended consequences if it breaks the rules (Keohane and Nye 1997, Keohane 1984, Krasner 1983).

However, one cannot assume that the states would comply with rules on which they are not agreed. Thus, it would be important for the rules to be established at an international level by an appropriate institution. In this case, it would be difficult to adopt a rule with consensus if the interests of parties involved were widely diversified.

The theory of liberal institutionalism depends heavily on the convergence of the interests of participating states, but there is no consensus among parties concerned and no effective organization for international governance, so that it would be difficult to apply this theory. However, the reason why there is no consensus is not because of confrontation of interests, but because of the lack of a coordinating effort. Thus, from this theory, it can be argued that if a certain international institution, such as UNCOPUOS, takes an initiative for coordinating national positions, there might be a possibility to establish a consensual rule, with the institution acting as guardian of the rule.

4. Constructivist Arguments

The third theoretical framework which might be applicable for understanding the possibility of politics for protecting the environment of celestial bodies is constructivism. Unlike theories of hegemonic stability and liberal institutionalism, constructivism focuses on the conceptual understanding of actors, whose behaviour depends on what they believe is “good” or “appropriate”. People follow the rules not only because they fear the punishment, but also because it is good and appropriate.

From the constructivist perspective, the ways in which states comply with international standards and rules are to make the norm as acceptable as possible for all the states involved in space exploration. Establishing a legal framework and clarifying the rules and procedures would be helpful for all states to follow and interpret the rules, but it is not sufficient for ensuring the compliance of all the states. Thus, the keywords for implementing international standards and rules are discourse and legitimacy.

Discourse originally means either written or spoken communication or debate or formal discussion. However, in the context of political science, “discourse” is considered to be an institutionalized way of thinking, a social boundary defining what can be said about a specific topic, or possible understandings. It is not mere rhetoric, but a set of words with certain values which can be accepted as a "truth" by society. For example, the discourses such as "landmines are against humanity" or "the death penalty is murder by state" are used to promote new international norms and institutions.

In this way, the protection of the environment of celestial bodies needs a certain "discourse" to convince all states capable of space exploration to refrain from using substances which might contaminate the environment of celestial bodies or to apply measures for reducing biological contamination.

Legitimacy is another key concept in the study of constructivism. "Legitimacy" is usually interpreted as a general acceptance of norms and systems. If the governing system is legitimate, that means that the system is accepted as a good system by the population that might be influenced by the system.

In the sphere of international relations, the question of legitimacy often attracts attention by scholars because there is no established governance mechanism in international society. Thus, it would be naïve to rely only on international governance to protect the environment of celestial bodies. It is, therefore, very important to establish legitimacy, i.e. the values and methods acceptable for all participating states, for protecting the environment of celestial bodies, with or without a legal structure.

5. Norm Entrepreneur

However, discourse does not come naturally. Someone needs to take the initiative and provide leadership for creating and distributing the discourse. This person or entity is called "norm entrepreneur".

For example, Henri Dunant was the norm entrepreneur for establishing the International Red Cross, Dag Hammarskjöld was the norm entrepreneur for establishing UN peacekeeping operations, the Intergovernmental Panel for Climate Change (IPCC) was the norm entrepreneur for the Kyoto Protocol, and the United Kingdom was the norm entrepreneur for abolishing slavery.

It is not yet clear who, or which state, should be the norm entrepreneur for protecting the environment of celestial bodies, but it is our expectation that International Academy of Astronautics (IAA) should take the leadership in establishing the norm, and that this Cosmic Study Report would be used as the foundation of the new norms.

6. Recommendation

- Political theory tells us that we need to establish a normative base for protecting the environment of celestial bodies. In order to do so, it is necessary to construct viable ideas and discourses which would convince all states to establish the legitimacy of new norms and an international governance system. This requires a norm entrepreneur that would devote itself to creating a new scheme for international coordination and standardization of the means to protect the environment of celestial bodies. It is suggested that this norm entrepreneur should be the International Academy of Astronautics (IAA).

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V.7 Education and Media: Raising Awareness of Planetary Protection by Annelie Schoenmaker

Abstract

Education and media are tools that are widely used in spacefaring nations to raise awareness, enthusiasm and pride amongst the citizens. Whereas the most visible missions benefit from wide media coverage, issues such as planetary protection are mostly ignored. This issue is, however, likely to interest a large fringe of the population if the parallel can be made between environmental issues on Earth and on other celestial bodies. Considering the exponential growth of space activities, the issue of planetary protection should be included in the concept of sustainable development. This would be achieved most effectively by communicating with active organizations outside the space community.

In addition to science, technology, legal and policy tools, education and media can also be of help for protecting the environment of celestial bodies. While education plays a decisive role in prevention and awareness raising, the media tends to have an effect during or after space operations. It is essential to educate the current and future space professionals about the dangers of forward contamination, but it might also be useful to target the general public.

1. Education

1.1 Categories

Three categories of target can be identified: the space sector, students and the public at large.

The first obvious target for education in planetary protection and especially in forward contamination is the space sector itself. Professionals targeted are naturally the engineers and scientists working directly on exploration missions, but also policy and legal specialists that work on these issues in the forum of COSPAR for example. An interdisciplinary approach to education in this field is therefore necessary for a common understanding and consistent reasoning on these issues.

Another target group for education in the planetary protection field is students working towards aerospace degrees. The students are the future professionals of the space sector and it is therefore essential to make them aware and familiar with the issue of contamination. This might be the most crucial level of education as it will develop reflexes in the new generation of space professionals. It also coincides with a general awareness and concern for environmental issues on Earth and is therefore even more likely to be received with natural interest by the students.

The public at large, even though less concerned by this issue at first glance, should also be educated on the issue, mainly because of the psychological factor involved with the word “contamination”. Exploration in general is quite a popular topic and environmental issues are likely to be raised in any case, as the concern about Earth's environment is growing. In this case, the goal is rather that of awareness raising than of operational knowledge. Although it does not impact their daily life, it can be introduced as an ethical issue. In the long run, if exploration goes to the next level and humans settle on other celestial bodies, the issue will become a lot more topical amongst the public at large and public opinion might impact political decisions. For this to happen in the future, the awareness raising process should start early.

1.2 Approach

Different target groups demand different approaches. For professionals, lectures and workshops can be organized to spread experience and knowledge amongst practitioners. These can be organized by space agencies, by universities or as professional development programs for industry partners. They can be national or international and the framework of international conferences can be used. For students, the issue can be included as an independent topic in a college education, but can also be addressed as part of other classes, such as an aspect of system engineering or policy-making in the space sector. For school pupils, it can be included in geography, biology and chemistry related classes. The idea of Earth as just another planet in the solar system should be addressed at an early age. This can benefit environmental, ecological and sustainable development awareness amongst children, and will then make the issue of planetary protection seem more familiar.

At older ages and in other non-space sectors, the topic of planetary protection and forward contamination can be used as an ethical or philosophical problem to be discussed in view of future developments in space exploration. Questions such as the exploitation of the Moon or Mars to the fullest as on Earth, with little concern about the impact on the planet's environment, should be discussed early so as to have a preventive action on the future exploration. Lessons learnt from Earth can be a way to make environmental protection associations take an interest in forward contamination and include it in their perimeter of action.

In the same line of thinking, the natural frame offered by national parks can be used for making the visitors aware of similar initiatives being developed for the Moon and Mars in view of protecting the already existing "heritage", such as the Apollo landing sites or the first human footprint on the Moon.

The most effective way of educating people about space in general, and planetary protection in particular, is to set up partnerships between the space sector and educational institutions. According to the NASA Office of Space Science (OSS): "By creating long-term partnerships between the education and space science community, we can make a substantial contribution to science, technology and mathematics education and literacy, to the public understanding of science and technology, and to broadening the participation in the space science program." (NASA 1995).

1.3 Existing Initiatives

Involvement of space actors in education is not new, and even in the field of planetary protection a number of initiatives have already started. NASA's and ESA's Planetary Protection Offices, for example, have established a course on planetary protection policies and practices to familiarize current and future practitioners with the COSPAR planetary protection policy and guidelines. The course provides theoretical and hands-on training on means to perform successful planetary protection measures.

On the communication side, NASA's Office of Planetary Protection has long recognized the importance of communications in accomplishing its goals and objectives and has a long-term initiative under way in communication research and planning. With solar system exploration missions advancing into the era of sample return and with the science of astrobiology changing assumptions about the nature and boundaries of life, the planetary protection office is expanding its communication planning efforts and taking the first steps toward implementation (Billings, 2004).

Other initiatives that can be mentioned as a possible source of inspiration are projects in the field of Earth Observation about the protection of the environment of planet Earth and our cultural heritage. UNESCO is a major player in this field and has initiated the "Open Initiative – Young Generation" project, in which UNESCO assists local conservation authorities to involve school children (age 12-15), from schools surrounding UNESCO Biosphere Reserves and World Heritage natural and cultural sites, in easy tasks of the field work required to support satellite image processing (UNESCO, website).

2. Media

2.1 Categories and Approach

The need to communicate the issues of planetary protection is thus real and the main space agencies of the world have already recognized it. The main question is now how to trigger the interest first of journalists and then of the public. In the same way as for education, the public targeted needs to be defined first, so as to be able to adapt the speech, the level of detail and take into account the respective interests.

The most obvious and most receptive target is specialized publications, such as *Space News* or *Advances in Space Research*, for example. These publications are read by the space community, mostly by engineers and scientists and, as they are already familiar with the topic, it can be of interest to them. Moreover, specialized journals can cover all the different disciplinary aspects of planetary protection and give more detailed analysis of specific issues.

General publications are harder to approach, for space in general and even more for such particular issues. To generate the interest of journalists and editors, it is best to have a topic that directly impacts society, and in that sense backward contamination would be more easily covered than forward contamination. Backward contamination carries an element of fear with it and the interest generated by Mars sample returns, for example, would give an appropriate media environment to discuss such issues.

However, forward contamination can make it into the news as well when a major event happens, such as the crashing of a spacecraft on a celestial body. One example is the end of NASA's Galileo mission to Jupiter. The plans were revised for the end of the mission to ensure that the spacecraft would burn up in the atmosphere of Jupiter. This was aimed at protecting Jovian moons where water might be found. Media coverage of the end of the Galileo mission generally acknowledged the planetary protection element of this event (Rummel, 2004).

Major newspapers and magazines do have science sections where such topics are susceptible of appearing, but it remains hard to enter those media circles.

The Internet is now such a widely used tool that virtually any topic can be (and is) discussed, analyzed, studied and covered on the web. But while it easy to publish news and articles on the Internet, it is not a guarantee of them being read or understood or even believed. The use of space agency and industry portals offers the most reliable and efficient access to the public, and this means is largely used, but again it is designed more for people already looking for it.

A means of accessing people not looking especially for space information is to start familiarizing environment protection agencies or associations, science institutes and even eco-tourism organizations about these issues. This would then create an expansion of information available on the web through non-space portals.

One of the most efficient media tools today is television. Documentaries about space science and astronomy, for example, could include a part on the topic of planetary protection. One can also imagine the making of a science fiction movi with that theme. These are usually very effective ways of making the public aware of dangers or ethical issues.

These tools should, however, always be used with a lot of caution and with the necessary involvement of space scientists, engineers and experts on the topic. The issue of backward contamination is especially sensitive as it triggers the imagination easily, and the difference between forward and backward contamination should always be carefully explained.

2.2 Effects of Media Coverage and Public Opinion

> "By their selection of newsworthy events, journalists identify pressing issues (…). By their focus on controversial issues (e.g. toxic dumps), they stimulate demands for accountability, forcing policy-makers to justify themselves to a larger public. By their use of images ("frontiers", "struggles") they help to create the judgmental biases that underlie public policy." (Nelkin, 1987).

This quote shows that media coverage and the way the message is conveyed may raise awareness, concern or fear in the public, and can stimulate the creation of strong public opinion, which can in turn influence public policy. Public opinion then becomes a powerful political tool and can help change the direction of the current if need be. A few examples come to mind, such as the Apollo missions, where the huge public interest faded quickly after a few missions until the program came completely to a standstill, or the sustainable development issue today, which suddenly has gained priority in the public opinion and contributes to changing public and corporate policies.

The process from being scientifically aware of a phenomenon that will certainly happen to acting accordingly takes a long time. Even if today no sample has been returned from Mars and lunar bases only exist on paper, discussion on the issue needs to start…and not only among the space community, if the public is ever to have an impact on the way exploration is conducted.

3. Recommendations: a Communication Plan

- Education and the media require different approaches but can also be complementary for raising awareness and concern on the topic of protecting the environment of celestial bodies. The way forward should include a few concrete initiatives to promote the results of this IAA study and the topic in general to make education and media coverage happen.

- First of all, the study can be advertised through the communication offices and planetary protection departments of the main space players and IAA partners, such as ESA, industry or national space agencies. Press conferences can be organized quite easily by taking advantage of their networks of journalists, their internet portals and other respective national media channels. The education offices of these space actors should also be addressed when advertising this study, to suggest they take this topic even more into account in the future.

- Some articles that describe the main issues addressed in this study and the way forward suggested can be prepared for specialized journals. Another broader and less detailed article on the topic should be prepared for issue in a general publication, such as a magazine or a newspaper.

- Nationally, contact should be taken up, at least in every spacefaring state, with associations, NGOs, industries and universities, either space or environment related, to familiarize them with the issue. Especially popular or widely disseminated associations such as Greenpeace can be targeted, to reach a large fringe of the population. Another strategy can be to suggest planetary protection related topics to university students, in a variety of different fields: engineering, sciences, law, policy, economics, cinema, art…

- Finally, finding famous personalities to support the cause, such as astronauts, politicians or artists, can be a worthwhile communication plan. Astronauts might be especially good ambassadors for the protection of planetary environments as they have had the opportunity to see the world from a different perspective. This can be a very powerful tool that strikes the imagination and sensitivity of people.

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VI. Conclusions and Recommendations

The following conclusions and recommendations have been derived from an analysis of the current status of protection of the environment of celestial bodies and from the identification of future needs and requirements:

I. In order to provide a reliable assessment of threats to the space environment, new, rapid and more accurate methods of estimating total viable bioburden should be developed and standardised. For manned missions, the physiological potential of spacecraft-associated microbial communities should be investigated in more detail. The validity of microbiological proxies under simulated Martian conditions for both forward and backward contamination should be determined.

II. A database of chemical and radioactive contaminants should be compiled to support the discrimination of terrestrial contaminants from natural components occurring on the planet or moon under investigation. Existing detection methods for chemical contaminants, as well as environmental cleaning methods, should be adapted and new methods should be developed.

III. A general consensus on the protection of the environment of the Moon and other celestial bodies should be sought among spacefaring states, setting standards and fixing the extent of permissible contamination or degradation of exploration sites. The contentious question of control of entrepreneurial exploitation of these bodies can be left for future negotiation, but space entrepreneurs and industrialists should be party to the general consensus.

IV. The question of new legal regulations to strengthen present planetary protection policies should be deliberated in the United Nations and among international scientific organisations. A nucleus of this legal instrument could be the due diligence provision of the Outer Space Treaty, which can be interpreted as an obligation to respect the interests of other State Parties and not endanger the environment of outer space, including celestial bodies.

V. Any space activity involving the environment of the Moon or any other celestial body should be subject to a comprehensive environmental impact assessment. This could be incorporated into domestic licensing processes or based on a system comparable to Annex I to the 1991 Protocol on Environmental Protection to the Antarctic Treaty. The UN Secretary General should be informed of measures taken to protect the environment of celestial bodies during space activities, and this information should be made public.

VI. The level of protection needed for different solar system bodies, and for specific locations of interest, should be determined by a new COSPAR/IAA/IAF joint commission. An affiliation of this body with the United Nations Committee on the Peaceful Uses of Outer Space (UN COPUOS), which has already taken an interest in space debris, should be reached.

VII. The proposed joint commission should establish a system of International Planetary Parks by defining the highest priority ‘special areas and objects’ within the solar system.

VIII. An analogue of the World Heritage Site listing should be developed for the protection of historic exploration sites, such as the Apollo sites. In establishing this system, the practice established by Annex V to the 1991 Protocol on Environmental Protection to the Antarctic Treaty should be taken into account.

IX. An international conference analogous to the 1972 UN Conference on the Human Environment should be organised to promulgate the ideas and ethics of protection of the space environment.

X. The proposed joint commission, in cooperation with space agencies and other space-related organisations, should actively promote and publicise this Study and the topic of space environmental protection in general.

VII. Appendix: Draft Legal Instrument

In recognition of the importance of an agreed policy and legal instrument for protection of the environment of celestial bodies, the following formal language is offered as a template for future deliberations.

States, recognising that:

- Outer Space, including celestial bodies, is the province of all mankind;
- Outer Space, including celestial bodies, has to be preserved for future generations;
- by exploration and exploitation of Outer Space, including celestial bodies, the principle of due diligence to the interests of others as embodied in Article IX of the Outer Space Treaty is of utmost significance,

acknowledge that:

1. States guarantee that persons under their jurisdiction comply with rules embodied in Article IX of the Outer Space Treaty; by doing so, they shall take into account the criteria developed by COSPAR.

2. States furnish the UN Secretary General the information on measures taken to protect the environment of celestial bodies during their space activities. This information shall be made public by the UN Secretary General.

3. States include measures for planetary protection among the conditions for licensing space objects according to their domestic law; they take into account practices on impact assessment embodied in the Antarctic Treaty.

4. States indicate, in co-operation with COSPAR and the UN Secretary General, areas on celestial bodies that deserve special protection according to Article VII.3 of the Moon Treaty.

VIII. Abbreviations

ASI	Agenzia Spaziale Italiana
CNES	Centre National d'Études Spatiales (French Space Agency)
CNSA	China National Space Administration
COSPAR	Committee on Space Research
DLR	Deutsches Zentrum für Luft- und Raumfahrt (German Aerospace Center (DLR))
ECSS	European Cooperation for Space Standardization
ESA	European Space Agency
IAA	International Academy of Astronautics
IADC	Inter-Agency Space Debris Coordination Committee
IAF	International Astronautical Federation
ICSU	International Council for Science (originally, International Council of Scientific Unions)
IISL	International Institute of Space Law
ISRO	Indian Space Research Organisation
ISRU	In-Situ Resource Utilisation
ISU	International Space University
JAXA	Japan Aerospace Exploration Agency
MA	Moon Agreement
NASA	National Aeronautics and Space Administration
NGO	Non-Governmental Organisation
NSAU	National Space Agency of Ukraine
OOSA	Office for Outer Space Affairs (UN)
OST	Outer Space Treaty
pH	Measure of the acidity of a solution
ROSCOSMOS	Russian Federal Space Agency
SAC	Scientific Activity Committee (IAA)
UN COPUOS	United Nations Committee on the Peaceful Uses of Outer Space
UNCED	UN Conference on the Environment and Development
UNEP	UN Environment Programme
WTO	World Trade Organisation

IX. Authors

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Gernot Groemer has a background in astronomy and astrobiology. He is working in the field of Mars analogue research, focusing on planetary surface exploration. He directed various field expeditions in planetary analogue environments as well as a parabolic flight and manages a multi-year development project for a spacesuit simulator programme of the Austrian Space Forum. His scientific focus is in the development of tracing methods for studying contamination vectors in human exploration environments.

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