Responsible Space Exploration and Use: Balancing Stakeholder Interests

Pascale Ehrenfreund,[1] Margaret Race,[2] and David Labdon[1]

[1]Space Policy Institute, George Washington University, Washington, District of Columbia.
[2]SETI Institute, Mountain View, California.

ABSTRACT

Despite the worldwide economic downturn, many space-faring nations are planning space missions and architectures to explore the Moon, near-Earth asteroids (NEAs), and Mars in the coming decades. Most of these plans are focused on robotic exploration, but some also include human endeavors extending beyond the International Space Station and low Earth orbit. Looking ahead, the space exploration arena is clearly changing. In the not-too-distant future, space activities are likely to include a significant increase in numbers of nations, partnerships, and commercial and private ventures planning missions that go beyond traditional exploration. Already, space entrepreneurs have announced ambitious plans such as roving and mining on the Moon; harvesting resources on NEAs; and preparing for human travel and establishing outposts on the Moon and Mars. This raises questions of how to ensure that exploration and use are conducted in responsible and balanced ways. There is a growing need to establish more comprehensive regulations governing these activities. In this article, we discuss and compare the main international treaties that govern Antarctica, the oceans, and celestial bodies, as well as the physical, institutional, and ethical concerns raised by various stakeholders. We analyze terrestrial environmental management strategies of the Antarctic Treaty System and the United Nations Convention on the Law of the Sea and highlight their implications for considering ways to deal with increased exploration and commercial ventures that target the use of celestial bodies. The pathway toward the adoption of an international environmental regime for space exploration will be undoubtedly a stepwise approach as the current ambitions and plans of governments, commercial ventures, and the private sector materialize and diversify.

INTRODUCTION

Despite the worldwide economic downturn, many space-faring nations are planning space missions and architectures to explore the Moon, near-Earth asteroids (NEAs), and Mars in the coming decade. The anticipated spacecraft launches for the next decade involve an impressive array of nations, target bodies, and mission types that may translate to another active period of space exploration. For example, upcoming lunar missions include a mix of orbiters, landers, and rovers planned by NASA, European Space Agency, China, Japan, Russia, and India. Both the United States and Japan have planned missions to NEAs and small moons, while NASA, Russia, and Europe have announced a variety of future Mars missions.[1] The ambitious plans of space entrepreneurs include the exploration of resources on the Moon and NEAs as well as sending humans to the Moon and Mars.* The increasing interest in both robotic and human missions beyond Earth orbit by multiple nations and stakeholders raises questions of how to ensure that exploration, use of resources, and exploitation are done in responsible and balanced ways. In short, there is an increasing need to clarify policies governing these activities.

To date, all missions planned and launched by national space agencies to the Moon and other celestial bodies have adhered to planetary protection rules for limiting biological contamination,† as outlined by the Committee of Space Research (COSPAR), ‡ consistent with the Outer Space Treaty (OST). However, in recent years, a number of reports and studies have noted the need to proactively develop a responsible environmental regime that encompasses physical, institutional, and ethical concerns raised by various stakeholders. It is recognized that the environments of planetary bodies targeted by robotic and human mission exploration can easily be disturbed in ways that may compromise their pristine conditions. For example, an NRC report on the scientific exploration of the Moon[2] argues that human lunar exploration that encompasses landings, lift-offs, and extravehicular activity (EVA) will inject tons of non-native gas into the atmosphere and transform the Moon's pristine environment. Environmental disturbances and destruction from dust raising, seismic disturbance, site destruction, electromagnetic interference, and radioactive and biological contamination have been evaluated as well.[1–4]

Because of its proximity to Earth, the Moon has received the largest amount of attention in regard to space activities conducted on

*Twenty-six international Google Lunar X-Prize competitors (GLXP) are trying to land on the Moon by 2015; Planetary Resources Inc. has announced plans to mine near-Earth asteroids; Space X is planning both robotic and human missions to Mars in the coming decade; and the Dutch venture Mars One has announced its plans for a one-way human mission to Mars to be supported in part by television revenues.

†Planetary protection constraints are imposed on missions to avoid the harmful contamination of planetary bodies during exploration and to safeguard the Earth from extraterrestrial contamination or life forms returned on samples, equipment, or even crew. No type of Earth-orbiting mission is constrained by planetary protection control measures that impact hardware, operations, or activities in outer space.

‡http://cosparhq.cnes.fr/

DOI: 10.1089/space.2013.0007

and around a celestial body. For example, following the discovery of helium-3 in the lunar regolith in 1985, some scientists suggested the prospect of large-scale mining of this element as a fuel for nuclear fusion reactors.[5] Others have proposed that the Moon could be a destination for regular flights to deliver cargo, emplace science experiments, develop initial infrastructure, and even bring tourists to the lunar surface. Despite the fact that these types of ventures are unlikely in the near term, some have questioned whether they represent justifiable and responsible activities on the lunar surface. Various researchers and groups have begun to consider what kind of environmental protections and ethical approaches are warranted on and near other celestial bodies.[6–12]

Recently, the International Academy of Astronautics (IAA) Cosmic Study on "Protecting the Environment of Celestial Bodies" examined the status of planetary protection controls for avoiding biological contamination and considered whether and how protection might extend to geophysical, industrial, and cultural realms. Similarly, a COSPAR workshop on Ethics and Planetary Protection deliberated on the advisability of extending planetary protection considerations beyond science exploration *per se* and recommended the need to examine and develop alternative approaches for protection and management of planetary bodies in anticipation of the growing interest in exploration and use of space.[13,14] A subsequent COSPAR workshop opened dialog on the future direction of planetary protection mechanisms given the changing elements of political, technical, commercial, and legal aspects of space exploration.[15] Not surprisingly, no single approach has been identified as ideal, with proposals ranging from the creation of international scientific preserves or planetary parks to the designation of special management areas, requirements for environmental impact assessments, development of a space code of conduct, and coordinated dialog among stakeholders with interests in future space activities.

As future space plans introduce disturbances beyond those created by past activities, it would be prudent to clarify and complement the legal regime currently regulating the exploration of the Moon and other celestial bodies. What is needed now is a framework that proactively deals with environmental stewardship and mitigates the potential damage caused by activities that aim to use and exploit planetary bodies and their resources. In essence, the international space community is currently lacking guidance for how to balance both exploration and use in settings intended for the peaceful benefit of humankind in locations without national sovereignty or jurisdictional control.

In this article, we examine the many concerns about scientific and commercial impacts in the coming era resulting from increased robotic and human space activities. We compare major treaties and legal frameworks that govern "international space" to identify their strengths and shortcomings in dealing with matters of governance, access, use, and dispute resolution. Building on the cumulative decades of experience with international treaties (see sections on Overview of Major International Treaties), we examine features that could be instructive for ensuring environmental stewardship, guiding responsible use, and balancing stakeholder interests beyond Earth—scientific and otherwise. We assumed that the foundational principles of the OST will remain untouched during deliberations about responsible exploration and use beyond Earth orbit.[§] In addition to considering treaty provisions or processes that have been useful for addressing activities in Earth orbit, we also drew from relevant environmental management approaches used for Earth-based environments.[**] Our aim is to determine whether and how different legal approaches and features that deal with "international space" may be useful for balancing interests of multiple stakeholders, while providing a reasonable and responsible framework for guiding exploration and use of space beyond Earth orbit in the coming decades.

OVERVIEW OF MAJOR INTERNATIONAL TREATIES

In general, current legal arrangements to deal with international space are limited to just three major regions and resources on Earth—Antarctica, the world's oceans, and outer space—all of which are beyond the reach of the legal and political jurisdictions of individual members of international society, and each of which is linked with international treaties that differ in the ways they deal with matters of governance, access, and use of their respective common resources.[16]

In this section, we briefly review the key features and implementation frameworks for each of the major treaties governing international space and examine how they have been modified over time in response to changing science and technology and issues of access and use. Because these treaties involve different approaches to balancing the interests of a diverse set of stakeholders and activities, an examination of their comparative frameworks is useful in considering possible future approaches for managing exploration and use of space beyond Earth orbit. Basic information and key features of each treaty are described briefly in the sections below and summarized in *Tables 1–3*.

The Antarctic Treaty System

The Antarctic environment is among the most remote, untouched, and hostile expanses in the world, largely untouched by human activity. It covers an area of 13.7 million km^2, is covered by an ice sheet 4 km deep, and harbors a wide array of flora and fauna. The Antarctic Treaty was established to govern this unique continent. It represents a significant milestone in the establishment of an international legal framework for effectively governing and managing environments

§For example, no changes to prohibitions about sovereignty or staking claim to resources; strict limitations on military activities; no nuclear weapons or weapons of mass destruction; peaceful, beneficial uses for all mankind; and continuation of states being responsible for their national activities.

**For example, such features as rules of access to areas and resources; institutional bodies for oversight or jurisdictional authority; definitions/designations of special areas, zones, or assets; avoidance of harmful contamination or pollution; guidelines for waste disposal; criteria for responsible treatment of biological, physical, and other features; codes of conduct; and processes for input of updated scientific findings or understanding about environmental resources and processes.

Table 1. Basic Information on the Treaties Discussed in the Section Overview of Major International Treaties

	Antarctic Treaty	Outer Space Treaty	Moon Treaty	UNCLOS
Parties	49	100	17	162 (and EU)
Effective	06/23/61	10/10/67	07/11/84	11/16/94
Notable Absentees	None	None	All major space powers	United States

EU, European Union; UNCLOS, UN Convention on the Law of the Sea.

Table 2. Legal Status of Each Treaty by Individual Space Powers

	Antarctic Treaty	UN Outer Space Treaty	UN Moon Treaty	UNCLOS
China	✓	✓	×	✓
Russia	✓	✓	×	✓
United States	✓	✓	×	Signed, not ratified
Japan	✓	✓	×	✓
India	✓	✓	Signed, not ratified	✓
European Union	×	×	×	✓
France	✓	✓	Signed, not ratified	✓
United Kingdom	✓	✓	×	✓
Germany	✓	✓	×	✓
Italy	✓	✓	×	✓

✓, ratified; ×, not ratified.

and resources for peaceful purposes in the interests of humankind. The Antarctic Treaty's development benefited from a wide array of scientific studies conducted during the International Geophysical Year (IGY) in 1957–1958 and was initially signed in 1959 by 12 countries, some of which set aside rights to sovereign and/or territorial claims in parts of the Antarctic continent.[††]

In a geopolitical sense, the most significant of the treaty's 14 initial articles are those that stipulate exclusively peaceful uses for mankind; strict limitations on military activities and bases; no sovereign claims; no nuclear explosives or waste disposal; and peaceful settlement of controversial issues.[17] Equally important was the fact that the international community agreed to designate the continent as a preserve for science investigation and exploration, with cooperative sharing of information, freedom of access and observation, and established consultative meetings, amendment provisions, and accession procedures.[17] Under the treaty, jurisdiction and responsibility for national activities rest with the signatory parties. Coordination of scientific research in Antarctica is assigned to The Scientific Committee on Antarctic Research (SCAR), which also provides international, independent scientific advice to the Antarctic Treaty System (ATS) and other bodies. SCAR is an interdisciplinary committee of the International Council for Science, which in turn is a nongovernmental body made up of national scientific members and international scientific unions.[18]

The initial Antarctic Treaty (which is not a UN treaty) has been supplemented over the decades by some 200 agreements and measures (collectively referred to as the Antarctic Treaty System [ATS]) that have been developed and ratified via the Antarctic Treaty Consultative Meetings (ATCM) process. In practice, the treaty allows for a flexible, incremental system that can be supplemented with additional measures that become binding upon the parties after their acceptance, without the need to amend the treaty itself.

Over the years, addenda to the treaty through the ATCM process have addressed a wide variety of topics, such as conservation of biota and ecosystems, development of a comprehensive environmental protection protocol, waste management and pollution control measures, designation of specially managed and protected areas, environmental impact assessments, and a moratorium on mineral extraction activities.[19] This latter provision was adopted after rejection of the 1988 Convention on the Regulation of Antarctic Mineral Resource Activities (CRAMRA), which suggested that mining for nonscientific purposes be subject to control and taxation by an international organization. At the 1991 Madrid Antarctica Treaty Conference, a 50-year moratorium on mineral exploration and mining was approved, meaning that decisions about future nonscientific mining in Antarctica will not be reviewed again until 2041.

Additions, amendments, and modifications to the ATS can only be worked out by those nations that have active interest in Antarctica as demonstrated by conducting substantial research activity there. Currently, there are 31 countries that actively pursue scientific research programs in Antarctica. Thus, cooperative involvement in

[††]Original signatories of the Antarctic Treaty were Argentina, Australia, Belgium, Chile, France, Japan, New Zealand, Norway, South Africa, the Soviet Union, the United Kingdom, and the United States. In 1991, the Consultative Parties (*i.e.*, the most interested parties with regard to these claims) decided to refrain from mining Antarctica and to "commit themselves to the comprehensive protection of the Antarctic environment and dependent and associated ecosystems and hereby designate Antarctica as a natural reserve, devoted to peace and science." The mineral resources of Antarctica have not been declared the "Common Heritage of Mankind" (*The Antarctic Treaty*, Secretariat of the Antarctic Treaty, www.ats.aq/e/ats.htm).

Table 3. Comparison of Key Provisions Among the Four Treaties	Antarctic Treaty	UN Outer Space Treaty	UN Moon Treaty	UNCLOS
Peaceful Use	✓	✓	✓	✓
Ban on military activity	✓	✓	✓	×
Ban on claims on sovereignty	✓	✓	✓	✓
Ban on nuclear weapons	✓	✓	✓	×
Amendment procedure	✓	×	✓	✓
Use of phrase "common heritage of mankind"	×	✓ ("Province of all mankind")[§§§§§§]	✓	✓
Independent organiz. for exploitation of resources	×	×	✓	✓
Ban on private property	×	×	✓	×
Exclusive Economic Zones	×	×	×	✓

✓, yes; ×, no.
[§§§§§§]The "province of all mankind" provision contained in the Outer Space Treaty refers to "activities (exploration and use)" and that the "common heritage" provision as contained in the Moon Treaty refers to "material objects"— that is, the former relates to, but is not the same as, the latter. In: SPI and SWF, 2012. *Guide to Space Law Terms*, 2012. www.gwu.edu/%7Espi/assets/docs/AGuidetoSpaceLawTerms.pdf

modification of the ATS is also an incentive for countries that participate in the conduct of scientific research on the continent.

Countries that do not operate in Antarctica are justifiably excluded from altering the treaties that govern the region. The ATS currently has 49 signatory countries. Since ratification, the ATS has facilitated the continued preservation, exploration, and use of the marine and terrestrial wilderness associated with the continent, focusing almost exclusively on peaceful, scientific purposes in an international setting. The notable exception to exclusively scientific activities on the continent is that of commercial tourism. Antarctic tourism includes both sea and air tourism, and has been a presence in Antarctica continually since 1966.[‡‡] It is managed by International Association of Antarctica Tour Operations, an industry-based group that has developed for over 40 years its own voluntary standards, policies, and procedures for conducting tourism and providing safe operations of vessels in polar seas. Many of the research outposts, bases, and stations operated by states allow use of their facilities for tourism and equipment.[§§]

Even before the treaty was fully ratified, it was recognized as an important instrument in encouraging international cooperation in an era of Cold War animosity. Indeed, former U.S. president Dwight D. Eisenhower urged that the Antarctic Treaty be used as a model for governance of other international space, notably in outer space, the high seas, and the seabed.[17]

The Outer Space Treaty and Associated Legal Instruments

The OST, which constitutes the basis of international space law, came into force as a UN treaty in 1967.[***] Like the Antarctic Treaty, it was also an outgrowth of the IGY and Cold War concerns about governance of international space. One hundred countries have ratified the treaty to date, among them all the major space powers. The 17 articles of OST address similar important geopolitical concerns as the ATS.

The OST bans placing nuclear weapons or weapons of mass destruction in Earth orbit or on any other celestial body, and establishes that the exploration and use of space be conducted in a free, peaceful, and collectively beneficial manner. The OST also bans claims of sovereignty in space and on any celestial body by any state and assigns jurisdiction and responsibility for national activities (whether governmental or nongovernmental) to signatory parties. The OST asserts that space is "the province of all mankind" and stipulates freedom of access, open sharing of information on science and activities, and consultation to resolve practical questions. Additionally, the articles of the OST address concerns about avoidance of harmful contamination of celestial bodies and adverse changes to the Earth.

[‡‡]Tourism Overview. International Association of Antarctica Tour Operators. N.p., 2012. http://iaato.org/tourism-overview

[§§]The Antarctic Treaty—Background Information. British Antarctic Survey. N.p., 2007. www.antarctica.ac.uk/about_antarctica/geopolitical/treaty/

[***]Treaty on principles governing the activities of states in the exploration and use of outer space, including the Moon and other celestial bodies. United Nations Office of Outer Space Affairs. www.unoosa.org/oosa/en/SpaceLaw/treatyprep/ost/index.html

Although not referred to as a treaty system, the OST likewise has added a succession of other legal instruments and agreements over the decades relating to the rescue and return of astronauts, liability for damage by space objects, jurisdictional control and ownership of launched hardware, use of orbits and frequencies, activities on the Moon and other celestial bodies, Earth remote sensing, use of nuclear power sources in space, space debris mitigation, and cooperation for the needs of developing countries.[19,20]

The governance framework for the treaty is via the UN Committee on the Peaceful Uses of Outer Space (COPUOS) and the UN Office of Outer Space Affairs. The COSPAR, established in 1958 as an independent nongovernmental scientific organization, is the international policy-making institution on planetary protection and serves as a consultative body to UN COPUOS.[21]

Perhaps one of the most controversial additional agreements to the original treaty is The Moon Treaty (signed 1979), which attempted to extend the success of the OST in anticipation of increased human activity in space. The Moon Treaty asserts that the Moon and its resources (which are not explicitly defined) are the "common heritage of mankind"[†††] and forbids the exploitation of those resources except when sanctioned by an international organization that would be established in the future. The Moon Treaty was ratified by 13 states, all of which were non–space-faring.[‡‡‡] It has not been ratified by any major space power, including the United States, Russia, China, Japan, and numerous European states. Although it technically entered into force in 1984, the Moon Treaty remains a *de facto* failure because of the absence of ratification by all space powers.

A return to the Moon in the near future will likely prompt renewed deliberations about what agreements are needed regarding human activities and use of resources beyond Earth orbit. Although there are numerous legal agreements for commercialization and use of outer space in low Earth and geostationary orbits, currently there are no widely accepted agreements about commercial exploitation or use of resources on the Moon, Mars, asteroids, or other celestial bodies, and no environmental management framework, debris or waste control guidelines, or contamination avoidance policies, except regarding planetary protection (which has been applied only to science exploration to date).

The UN Convention on the Law of the Seas

Although humans have been exploring and using the seas for centuries, technological advances in the past century have highlighted the need for international agreements that balance territorial sovereignty, use of resources, freedom of the high seas, and notions of shared governance. From 1930 through 1960, a number of major attempts were made to codify questions of ocean law and governance (*e.g.*, League of Nations, 1930; national proclamations on continental shelves and resources; UN Convention on the Law of the Sea [UNCLOS][§§§] I & II), but for various reasons they were each unsuccessful.[22] Today's international legal regime over the ocean is rooted in the UNCLOS III (begun in 1973), which focused on issues related to the deep seabed and mining, the extent of the territorial seas, and the preservation of the marine environment and scientific research. Drafting the treaty took 9 years, with the final UNCLOS document signed in 1982 and entering into force in 1994.

Today, 163 states and the European Union have ratified the 1982 Law of the Sea Convention (or UNCLOS), which is the major international framework governing the use of the seas and the most widely ratified treaty on any subject. In a broad sense, UNCLOS provides clear jurisdictional allocations and boundaries, foundational principles of conduct, and a system of mandatory dispute resolution for states and the international community. Through its more than 320 Articles and 9 Annexes, UNCLOS provides a global framework for the law of the seas as well as specific agreements on shipping, safety, fishing, ocean dumping, and environmental protection.

The UNCLOS designates the seas as the common heritage of mankind, defining and allocating authority over important maritime zones (*e.g.*, territorial seas; contiguous zones; exclusive economic zones; High Seas; continental shelves; and the deep seabed). The treaty addresses the limits of territorial seas, passage on and under the sea, international navigation and transit through various zones, and conservation and management of living resources. UNCLOS also includes a code of conduct focused on protection of resources, use for peaceful purposes, responsibilities for compliance, cooperation and technical assistance, and liability for damages. In essence, jurisdictional control of large parts of the oceans is allocated by the treaty to coastal states, which are required to govern in ways that ensure the environmental integrity and optimum utilization of living resources of the oceans. Signatories are also required to submit any disagreements to mandatory dispute resolutions via a selected tribunal or court.

Implementation of the treaty is accomplished through use of multiple international organizations that deal with different multilateral arrangements. For example, the International Maritime Organization addresses issues involving ships and offshore oil platforms, safety and pollution, as well as dumping of wastes at sea. The Food and Agriculture Organization deals with fisheries conservation, and the UN Environmental Programme facilitates consideration of oceanic environmental questions. In addition, there is a Regional Sea program that involves some 140 states worldwide on issues specific to various areas of the globe.[22]

Interestingly, UNCLOS, like the Moon Treaty, contains a provision establishing an independent organization with power to regulate the use of marine resources. Article XI of the Convention established the International Seabed Authority, which can establish an

†††*Agreement Governing the Activities of States on the Moon and Other Celestial Bodies*, United Nations Office of Outer Space Affairs.

‡‡‡Among the 13 original signatories, subsequently, France and India have become launching nations.

§§§www.un.org/Depts/los/convention_agreements/texts/unclos/unclos_e.pdf

"Enterprise"[****] to act as an independent mining operator in international waters. The basis for the U.S. objection to the convention is that the "Enterprise"[††††] would necessitate a "transfer of technology to the Enterprise and to developing States with regard to activities in the area, including, inter alia, facilitating the access of the Enterprise and of developing States to the relevant technology, under fair and reasonable terms and conditions." Concerns were also raised that industrialized countries would have to pay pollution fees (essentially like royalties) to developing nations for profits made while exploiting international resources.[‡‡‡‡] In 1994, negotiators made modifications to two key articles relating to mandatory technology transfer and limitations of seabed productions and removed them from the treaty.[23] Even now, debates among U.S. congressional and military officials continue over the advisability of ratifying the treaty. Some have even argued that the treaty imposes a type of wealth redistribution that "could become a precedent for the resources of outer space."[§§§§] Despite the nation's refusal to ratify it, the United States observes much of the convention in practice, even as the Obama administration continues its efforts to persuade the Senate to approve UNCLOS.

In addition to dealing with complex geopolitical issues, UNCLOS faces additional serious and growing challenges not previously experienced at any time in history, such as fishery collapses, coastal dead zones, land-based pollution, ocean acidification, and other problems linked to climate change.[22] Although UNCLOS provides a strong framework for governance and ocean management, these and other complex issues will undoubtedly require special attention in order to maintain healthy, productive, and accessible ocean resources in coming decades.

LESSONS LEARNED FROM EXPERIENCE

Clearly, the OST has been a strong and effective legal instrument for nearly five decades, facilitating the exploration and use of space in both low Earth and geostationary orbits for the peaceful benefit of mankind. It has also guided the scientific exploration of the Moon, solar system bodies, and beyond in ways that have increased our understanding of the dynamic universe.

Over the past five decades, the international space community—comprised of numerous governmental, scientific, commercial, private, and even military stakeholders—has gradually developed a complex framework that balances exploration and use of assets and resources in Earth orbit. The same cannot be said for space environments beyond Earth. Since the beginning of the Space Age, only government space agencies, scientists, and technologists have been involved in missions to the Moon and other celestial bodies. As the UN COPUOS deals with issues of space debris and long-term sustainability of space activities, it is an appropriate time to also think proactively about stewardship of the environments and resources beyond Earth orbit. Plans to guide human activities and ensure balanced exploration and use of space beyond Earth are best formulated before increasing demands for access, exploration, and exploitation are beyond control.

The questions are similar to many we experience on Earth.[24] What guidelines or approaches can be used to deal with proposed activities that collectively aim to explore and exploit planetary environments, and may in the process cause significant disturbances or adverse impacts? For space environments beyond Earth orbit, the challenge is to develop a workable regime or framework within the existing OST that balances diverse stakeholder interests and access with responsible stewardship of landscapes, abiotic and physical assets, possible biotic resources, potentially habitable areas, and other important features.[*****] It is instructive to examine the different approaches to environmental stewardship that have evolved under various treaties and assess their comparative strengths and shortcomings for guiding activities in international space—particularly in the face of new environmental findings and potential threats.

Evolution of the ATS

From an environmental management perspective, the ATS provides arguably the most effective model of a strong, comprehensive, and adaptable approach to international environmental stewardship and resource management. The ATS has been updated over time through modest reforms, not significant legal changes, incorporating strong provisions for environmental management and use, particularly with the addition of its Protocol on Environment Protection and associated annexes in the 1990s.[†††††] The protocol articulated a position on environment stewardship, and was soon joined by additional annexes that included a process for environmental impact assessments, requirements for waste management and marine pollution control, and designation of special protected and managed areas based on up-to-date scientific findings.

International deliberations also led to recommendations for developing a consensus-based management plan for the exploration of subglacial aquatic areas, aiming to maintain their environmental integrity and scientific value while allowing exploration to proceed with special precautions. For example, the U.S. National Research Council has argued that the existence of microbial life in Lake

[****]United Nations Convention on the Law of the Sea. United Nations Division for Ocean Affairs and the Law of the Sea. www.un.org/depts/los/convention_agreements/texts/unclos/UNCLOS-TOC.htm

[††††]The Enterprise does not yet exist, and there are no plans to implement it.

[‡‡‡‡]In fact, any royalty fees collected would go into a fund for distribution to parties of the Convention, not to the UN general funds (APS, June 2012).

[§§§§]www.washingtontimes.com/news/2012/jun/14/rumsfeld-hits-law-of-sea-treaty/

[*****]"Other" resources or features typically fall into categories such as cultural, historic, aesthetic, scientific, and human built, but in the case of space may also include assets like orbital access, telecommunications frequencies, *etc.*

[†††††]The Protocol was enacted after rejection of CRAMRA, which attempted to allow, control, and tax mining for nonscientific purposes. Subsequently, a 50-year moratorium was placed on commercial mineral extraction. This is one way that the ATS is not a model for resolving issues related to mining in space—since the OST is for the both exploration and use by multiple entities.

Vostok, currently under investigation, should be assumed, in order to protect it, and other such subglacial environments from contamination.[‡‡‡‡‡] In 2012, the project Whillans Ice Stream Subglacial Access Research Drilling (WISSARD) recovered water and sediment samples from the subglacial Lake Whillians that showed clear signs of life.[§§§§§] Microbial life at $-13°C$ was recently detected in the ice cover of Lake Vida that encapsulates a cryogenic brine ecosystem.[25] The strong framework and review process initiated along with the Protocol on Environmental Protection subsequently demonstrated that the ATS can readily adapt to new scientific findings, even the discovery of previously unknown ecosystems.

Admittedly, the ATS designates the Antarctic as a "science preserve" and allows only limited nonscientific access and uses. Aside from maritime activities and fishing in its continental shelf areas (addressed in other ocean and maritime treaties), the single notable nonscientific activity in Antarctica involves commercial tourism, which has had access since the early days of the ATS, conducting activities with essentially minor and transitory environmental impacts at most. With the growing interest in tourism and the changing nature of the tourism industry, questions have arisen over the advisability of continued industry-based oversight of its own activities, and whether Antarctic Treaty parties, national governments, or other regulatory bodies may be needed in the future to resolve concerns about the increasing number of incidents and problems linked with the tourism industry.[26]

Likewise, the ATS has had to deal with questions about access to and use of its physical resources. *In situ* resource utilization (ISRU) has not yet been a viable approach for providing needed resources for the bases in Antarctica (*e.g.*, fuel for transport and electrical power).[26] In addition, commercial interest in drilling and exploration for mineral resources on the continent resulted in rejection of CRAMRA and a subsequent moratorium on drilling except for science exploration (see The Antarctic Treaty System section). As Earth's population continues to grow, and as more countries' economies develop, there will be undoubtedly increased demand for access to natural resources worldwide, which may in turn produce fundamental shifts in perspectives about the use of Antarctica resources and surrounding areas. Already today growing commercial whaling and fishing competition off the shores of Antarctica have led to political conflicts. Antarctica's ice shelf and glaciers harbor substantial fresh water reserves, and climate change may release fresh-water drift ice in the future. It has been argued that a "global increase in demand for fresh-water may eventually lead to scavenging of Antarctic ice followed by further exploitation of its mineral-fuel resources."[******]

Although the ATS is a model approach for environmental management of remote international space, its practical applicability to outer space situations has serious limitations, including the fact that only nations with active Antarctic research programs can be involved in decision making or major changes to regulations and policies. Nonetheless, the ATS has demonstrated the advisability of addressing potential threats and environmental changes proactively to maintain healthy, sustainable conditions for the long-term.

Evolution of the UN Convention of the Law of the Sea

The ATS and OST are both products of the mid-20th century, and each had the advantage of starting with essentially clean slates regarding management of their environments and resources. In contrast, the UNCLOS was developed in the context of centuries of complex legal agreements related to the oceans, their resources, diverse users and technologies, as well as emerging environmental challenges. Even so, the UNCLOS has been acknowledged as the world's "constitution for the oceans," a foundational document providing order, stability, predictability, and security, all based on the rule of law.[27] UNCLOS provisions have been accepted by almost the entire world, despite the resistance of the United States and several key countries to ratify the treaty.[††††††] While it continues to cope with lingering questions of rights, resource use, and territorial claims, the UNCLOS must also deal with pressing environmental management issues of how to reduce impacts upon resources in the face of increasing user demands, technological advances, and a lack of enforcement capabilities.

On a positive note, UNCLOS has worked over the years with numerous commercial user groups to develop and refine guidelines (for fisheries, shipping, offshore drilling, *etc.*), but serious problems of governance remain because of looming environmental changes and resource depletion. In fact, Part XII of the UNCLOS addressed the issue of marine environmental conservation by imposing a general obligation on states to protect and preserve the marine environment. Although UNCLOS established the basis for discussions on environmental protection in the international maritime world, many critics assert that the issues have been inadequately addressed.[‡‡‡‡‡‡]

As the human footprint on the ocean has expanded, the rules, regulations, and institutional governance structures for the conservation and sustainable use of marine biodiversity have not kept pace with changing developments. Indeed, the management challenges relating to ocean resources have evolved in ways that never could have been imagined when UNCLOS was negotiated in the 1970s. In December 2011, the UN General Assembly agreed to convene a process to ensure that the legal framework under UNCLOS effectively addresses the conservation and sustainable use of marine

‡‡‡‡‡*Exploration of Antarctic Subglacial Aquatic Environments: Environmental and Scientific Stewardship*. The National Academy of Sciences, 2007.

§§§§§www.wissard.org/

******http://gatewayhouse.in/publication/gateway-house/features/who-will-control-antarctic

††††††U.S. supporters have been pushing congress to ratify UNCLOS, and former Secretary of State H. Clinton had declared ratification of UNCLOS as one of her priorities in the State Department. However, the United States continues to resist efforts to ratify UNCLOS in particular because of the restrictions on the exploitation of the seabed, notably the establishment of the "Enterprise" system of management.

‡‡‡‡‡‡http://globalsolutions.org/files/public/documents/LOS_Factsheet.pdf

biodiversity in areas beyond national jurisdiction.[§§§§§§] One way forward is the negotiation of a multilateral agreement under UNCLOS, a so-called Implementing Agreement to "address conservation and sustainable use of marine biodiversity through area-based management tools such as designation of special protected areas, environmental impact assessments, and capacity building and technology transfer, among others."

In August 2012, a new Oceans Compact initiative was proposed by the UN Secretary General to mobilize and enhance the UN's capacity to support action by governments while promoting the engagement of intergovernmental and nongovernmental organizations, scientists, the private sector, and industry to tackle challenges to ocean health and productivity for the benefit of present and future generations."[28] The Oceans Compact aims to provide a platform for all stakeholders to collaborate and accelerate progress in the achievement of the common goal of "Healthy Oceans for Prosperity."

The intent is to address the cumulative impacts of sectoral activities on the marine environment, including consideration of using ecosystem approaches and precautionary principles as part of its environmental management approaches. Implementing the Oceans Compact plans will involve the creation of an oceans advisory group comprising the executive heads of the relevant UN organizations, high-level policymakers, scientists, leading ocean experts, as well as representatives of the private sector, nongovernmental organizations, and civil society.

Although ocean and space resources are considerably different, many of the future ventures and activities involve similar human aims. Thus, the UNCLOS and its approach to environmental management can be instructive in various ways, even if only in highlighting problematic issues, ones that the space community should strive to avoid.

Implications for Celestial Objects

Compared with Antarctica and the oceans, exploration and use of outer space beyond Earth orbit are still in the early stages, with no real categorization or designation of significant areas, boundaries, or resources. While the features of major bodies are known at the gross level (physical features and atmospheric conditions of planets, moons, asteroids, *etc.*), detailed information about distinct areas and potentially valuable resources (scientific or otherwise) are still in the descriptive stages for most bodies, even for well-studied ones like the Moon and Mars. In addition, there are no biological resources yet identified, only bodies or areas with biological potential. Thus, at least initially, the discussions about resources, environments, and their use will focus on mainly abiotic and physical features, landscapes, and other, mainly human associated values, including science.

The prospects for practical environmental management approaches for outer space and environments beyond Earth can be viewed as somewhere between the ATS (with its pristine environments, designation as a science preserve, and limitations on non-science users) and the UNCLOS (with vast and diverse resource and environmental types, historical precedent for extensive exploitation, and gradual recognition of significant impacts and changes in environmental conditions ahead). There is a need to plan for both exploration and use of outer space while also having guidelines to protect environments from major or cumulative impacts that could be disruptive in unknown ways. As a first step, it is useful to consider important distinctions between nearby celestial bodies and areas that missions will likely visit in the coming decades—the Moon, Mars, NEAs, and outer solar system regions.

Moon. The Moon, for all intents and purposes, is a dead body. There is very little geological activity, a practically nonexistent atmosphere, and no evidence of the possibility of environments that may harbor life. However, regions on the Moon provide a window to the origin of our solar system and the Earth. Outstanding scientific findings about our origins are expected from further investigating the cratering record, lunar soils, icy polar regions, and the exosphere, to name a few. Despite the Moon's seemingly dead nature, physical disruption of the surface by frequent landings and launches may compromise the potential to gather scientific information.[2] In addition to disruptions from landings and lift-offs, activities like EVAs, site destruction through human activities, dust raising, atmosphere contamination, vibration, radio contamination, and use of nuclear power sources can adversely affect scientific research. Thus, environmental preservation of the Moon will be concerned with avoiding significant destructive impacts upon its physical/abiotic features as well as safeguarding or preserving other values such as historical, scientific, or even aesthetic features, similar to the principles used in the ATS. Recently, NASA used such an approach in developing proposed guidelines to preserve the integrity of lunar heritage sites and adjacent areas during international robotic missions by Google Lunar X Prize (GLXP) competitors.[4] Otherwise, there has been little concern for the mainly minor and transitory impacts of most lunar missions, but some have questioned the impacts on future scientific observations that could be caused by missions that involve deliberate lunar impacts.

Mars. Mars is regarded as one of the best candidates for the potential to harbor life because of its similarity to Earth in many respects and past widespread existence of surface water. As such, exploration missions to Mars are generally intensive and raise the most concern on issues of environmental degradation and contamination. Numerous landers and rovers have been sent to the Martian surface, with many more planned. The search for extinct or extant life on Mars or organic material is one of the main goals of future lander and rover missions developed during this decade, paving the way for returned samples and human exploration. Currently, NASA's rover *Curiosity* is operating on the surface, hopefully followed by the European Exomars mission (2018) and NASA's Mars 2020 mission. A multielement Mars sample return mission is still envisaged in the international context. Human

[§§§§§§]www.un.org/depts/los/biodiversityworkinggroup/webpage_legal%20and%20policy.pdf exploration is not likely before the 2030s, although several non-governmental ventures have announced plans for missions to Mars in the next decade. It is considered of utmost importance that any landing spacecraft comply with COSPAR planetary protection policies and guidelines in order to avoid biological contamination of Mars by terrestrial microbes, in particular in the so-called special regions, that may harbor water-rich terrain.[29,30]

Near-Earth asteroids. NEAs often pass closely the Earth and represent a potential threat to humankind and life on Earth. However, these objects also hold clues to our understanding of the early solar system and the impact history of the young Earth. Their proximity makes them interesting targets for the exploration of raw materials and supporting interplanetary journeys. The first successful Japanese asteroid sample return mission Hayabusa brought back a sample from the asteroid Itokawa in 2010, which was extensively analyzed in Earth laboratories.[31] Several missions are planned to explore more such pristine objects and return samples in the order of ~100 g.

NEAs have been extensively discussed in the press because of the recent Chelyabinsk meteor event in February 2013. Numerous proposals have been announced by commercial ventures to exploit water and minerals from asteroids, but for at least a decade the main emphasis will probably be on scouting prospective objects. Ultimately, exploration and exploitation of asteroids will not need environmental management guidelines of the type envisioned for planets and the Moon, but issues of property rights, ownership, and other legal matters will likely arise and need to be addressed.

The outer solar system. Jupiter's moon Europa and Saturn's moon Enceladus appear to have large, subsurface water oceans. These oceans are considered by many scientists to represent the greatest possibility of harboring life elsewhere in the solar system. Based on new evidence from Jupiter's moon Europa, material from the liquid ocean bubbles up and reaches the frozen surface. Enceladus harbors an ocean below the ice that likewise reaches the surface and vents complex organic compounds in plumes into space, a mechanism known a cryo-volcanism. Another recently explored outer solar system objects, Saturn's moon Titan, revealed the presence of liquid hydrocarbon oceans and river deltas, apart from complex organic molecules on the surface and in its dense atmosphere. The outer solar system may harbor still unexplored treasures on one of dozens of icy moons. Planetary protection guidelines have been elaborated recently, assessing the potential to introduce terrestrial organisms carried by spacecraft into habitable environments of the outer solar system that could jeopardize future biological investigations.[32,*******] However, because of these objects' great distances from Earth and infrequent space missions, no detailed environmental regime has been established.

The space community should avoid the need to develop protocols and guidelines retroactively and incrementally in response to obvious damage or looming threats. Better to be proactive in thinking about how to respond to increased pressures on resource and environmental usage and thereby avoid concerns about significant environmental degradation. Undoubtedly, the foundational principles of the OST (like those of the ATS) should remain untouched during deliberations about responsible exploration and use by multiple stakeholders beyond Earth orbit.[†††††††] As commercial and private stakeholders in space focus on increasing future uses and new technologies beyond Earth orbit, it will be critical that all stakeholders find ways to work collaboratively to minimize the types of escalating problems seen in ocean use and governance. Even though most of the resources in space are nonbiological, it is useful to consider whether discussions about environmental use and management could be initiated based on comprehensive, accurate understanding of space resources, potential impacts upon them, consideration of relevant time periods, and acknowledgement of diverse stakeholder interests.

FUTURE PERSPECTIVES: A STEPWISE APPROACH

We face novel questions and issues as our activities in Earth orbit and beyond expand significantly. A recent COSPAR workshop opened dialog on the future direction of planetary and environmental protection mechanisms given the changing elements of political, technical, commercial, and legal aspects of space exploration.[15] Despite having multiple agencies overseeing activities in Earth orbit, there is no clear understanding of which agency or agencies might coordinate the responsibility of providing certainty, safety, and transparency to new exploration in space beyond Earth orbit.

The question now is how should we prepare to deal with the anticipated mix of proposals seeking to undertake activities that both explore and use planetary environments and may in the process cause significant disturbances or adverse impacts? Developing the appropriate guidance and oversight framework is now a challenge for nations and international organizations. Drawing from experiences with ATS and UNCLOS, it is likely that it will take many years, if not decades, to develop an internationally agreed-upon framework for environmental stewardship beyond Earth orbit. Presumably, in the near term, both science and nonscience activities on the Moon and Mars will be essentially pilot-scale activities with minor or transitory impacts.

Before the numbers and types of ventures increase greatly, there is a need for a uniform, stable, and scientifically justified set of guidelines for environmental protection and stewardship, for both the Moon and Mars. As an initial step, it is appropriate to gather and analyze relevant information as input to those future international deliberations. In particular, the following steps and informational needs have been suggested.

*******www.gwu.edu/~spi/COSPAR_OP_PP_Workshop_final_Aug2009.pdf

†††††††For example, no changes to prohibitions about sovereignty or staking claim to resources; strict limitations on military activities; no nuclear weapons or weapons of mass destruction; peaceful, beneficial uses for all mankind; and states responsible for their national activities.

Gather Information on All Possible Stakeholders

The international space community is comprised of governmental, scientific, commercial, private, and even military stakeholders. Stakeholders who are likely to be involved in near-term endeavors beyond Earth orbit need to become aware of relevant OST policies on planetary protection and be included in ongoing discussions about responsible stewardship for mission activities. Presumably, current national and international science and analysis working groups[‡‡‡‡‡‡‡] already represent essential elements of information and oversight for existing and new stakeholders depending on their target bodies and planned activities. Many stakeholders, scientific and otherwise, are already involved in discussions about future roadmaps for robotic and human exploration of celestial bodies. Building on this information as a base, it will be possible to identify new stakeholder groups and keep them informed about the impact of existing planetary protection policies on biological contamination avoidance on their mission plans—as well as the ongoing discussions about developing responsible environmental stewardship guidelines for new activities on planetary surfaces.

Establish an Environmental Database for Celestial Objects

The assembly and dissemination of new findings in planetary science provide a crucial basis for establishing a new framework of environmental stewardship. The science community bridges national boundaries and the numerous international science and analysis working groups (mentioned above) that excel in compiling data into reports and organizing international conferences will play an essential role in informing the stakeholders on planetary processes and conditions. Scientists worldwide need to be encouraged to contribute to a database on environmental assets and resources of celestial target bodies such as the Moon, Mars, NEAs, and outer solar system moons. Additionally, environmentally damaging activities (from landing, liftoff, EVAs, dust raising, atmosphere contamination, vibration, radio contamination, nuclear power sources, site destruction through human activities, *etc.*) that affect scientific activities (telescopic observations, fundamental physics, geological studies, *etc.*) should be categorized. The first steps toward a future balanced stakeholder approach for the exploration of celestial bodies will be information exchange of planetary data and how environmental damage can be avoided using reasonable engineering and operational approaches.

Develop a Timeline for Space Endeavors

Currently, commercial ventures with near-term mission plans are limited to GLXP competitors intending to land small robotic rovers or hoppers on the lunar surface, and two proposed human missions to Mars. In the same timeframe, ongoing science missions continue to focus on lunar and Mars exploration to study processes associated with solar system formation, habitability, and the search for life. Plans for human missions to Mars by space agencies are presumably at least a decade or more in the future. Planetary protection controls for biological contamination are well categorized and monitored through COSPAR guidelines and will continue to apply to all missions in the coming years (especially to Mars). However, no detailed regulations exist for environmental disturbances. Until internationally agreed-upon policies are developed for environmental access and use by nonscience missions, it will be important to continue the incremental approach—such as that used for GLXP—to examine proposed activities in advance and offer working guidelines for avoiding environmental or other disruptions so that they can be incorporated into mission plans. Protecting environment and life on Earth requires similar concepts as does exploring other celestial bodies, including the expansion of human presence in space.[24] The timescale of any of these ambitious ventures to materialize will be strongly influenced by economic conditions worldwide and may not be as imminent and optimistic as currently announced. However, over the coming decades, frameworks will be needed to consider the consequences of potentially more disruptive activities (mining, deliberate impact missions, ISRU, establishment of outposts and settlements, construction of infrastructure, one-way missions to Mars, waste disposal, *etc.*). While early human missions beyond Earth orbit (1 to 2 decades hence) will access and exploit new areas and deploy pilot-scale or minor technology developments, mid- to long-term mission plans (2 to 4 decades) are likely to involve potentially more disruptive activities over larger areas. Serious discussions should be undertaken on practical approaches that balance both use and exploration for future ventures and times.[11,13–15]

Disseminate Information and Start a Coordinated Dialog

In addition to establishing and maintaining a list of stakeholders planning robotic and human exploration endeavors within different timeframes, it will be important to share information on recent planetary science results, information on anticipated stakeholder activities, and their implications for serious or avoidable environmental impacts. All stakeholders should share the same starting information about environmental concerns as they begin a dialog on future guidelines and requirements for environmental use. International science and analysis groups such as COSPAR supported by its commissions and panels, in collaboration with other national and international organizations (IAA, International Astronautical Federation, International Institute of Space Law, International Lunar Exploration Working Group, International Mars Exploration Working Group, International Primitive Body Exploration Working Group, International Space Exploration Coordination Group, Lunar Exploration Analysis Group, Mars Exploration Program Analysis Group, and others), can initiate such a process. In discussions with relevant stakeholders, the data exchange will enable the formulation of draft statements about responsible activities and environmental stewardship beyond Earth orbit. Those draft agreements

[‡‡‡‡‡‡‡] For example, the Committee on Space Research, International Academy of Astronautics, International Astronautical Federation, International Lunar Exploration Working Group, International Mars Exploration Working Group, International Primitive Body Exploration Working Group, International Space Exploration Coordination Group, Lunar Exploration Analysis Group, Mars Exploration and Program Analysis Group, and others.

and recommendations representing a consensus of national and international space stakeholders can be translated into legal frameworks by appropriate institutions. Considering the anticipated near-term timeline for lunar missions for both ongoing science exploration and new commercial ventures, developing a draft lunar environmental protocol should be a priority to fill the gap in current policy guidelines.

From Draft Agreements to Guidelines and a Legal Regime

As human activity in space continues to expand, international law will need to keep up in order to prevent dispute and conflict among various parties. Working draft agreements that have been developed through a multi-stakeholder approach will need to be formulated eventually into a set of agreements or regulations under the context of the OST framework. In the meantime, in order to establish an effective working "code of conduct" to address a variety of future space activities and stakeholders, a flexible system will need to be implemented that enables the accommodation of new science and technology development.

Without amending current treaties, we should, however, learn from experience and revisit the successful measures that have worked well in the past. The relative ease by which the ATS can change or modify itself has demonstrated an immensely successful system of international law.[33]

It is noteworthy that the inclusion of an independent, international organization tasked with regulation of resources as described in the Moon Treaty and UNCLOS was a major obstacle to ratification for many parties. Expanding commercial and governmental interest in extraterrestrial resources for both scientific and commercial purposes necessitates a better solution. We acknowledge that space is not a science preserve but rather an expansive international space that humans will explore and utilize in diverse ways, in the near- and long-term. A stepwise approach to establish an environmental regime for celestial bodies must ensure the possible adaptation to a changing exploration context over time. Whether or not a legal entity is eventually established (such as an Enterprise institution), there is a pressing need to develop practical guidelines and control regulations in the meantime that balance stakeholder interests and are respected worldwide.

RECOMMENDATIONS

- Science is an important and essential contributor to the deliberations about space with respect to life, technology, and activities. International science and analysis working groups (such as COSPAR) should be involved as advising agencies in the process of establishing an international environmental regime for space exploration and use.
- It is of vital importance that unrestrained contamination or uncontrolled and irreversible alteration of valuable environments on solar system bodies is avoided. New planetary findings and information on potential environmental threats or impacts should be integrated into guidelines as appropriate.
- A dialog among space stakeholders should prepare for a flexible approach that balances the interests of multiple stakeholders with regulations that are respected and adhered to by many nations.
- It is advisable to have an administrative process that can flexibly integrate data about new findings or environmental threats as they arise and clearly articulate how various institutions or entities will be involved in reviews and decision making over time.
- Policy and regulatory approaches practiced through the ATS and UNCLOS may be partly applicable to planetary bodies beyond Earth. The flexibility of these treaties may be helpful to develop a framework for the high diversity of space exploration activities.
- A Lunar Environmental Protocol should be developed to guide the combined activities of science researchers and nonscience ventures to the Moon in the coming years. The existing GLXP guidelines that outlined ways to avoid disruption and protect historical/scientific and other resources of interest to humans are a good example of a stepwise process for building an environmental regime for celestial bodies.
- Mars and outer solar system targets that may harbor extinct or extant life are currently protected against biological contaminations under the existing nonbinding COSPAR planetary protection policy and guidelines. Those measures should be reinforced and refined in the face of increasing numbers of proposed nonscience ventures to Mars. COSPAR and other international organizations should continue to articulate detailed operational guidelines for mission planners of human missions to Mars.

CONCLUSIONS

It is evident that the OST has been a strong and effective legal instrument for nearly five decades, facilitating the exploration and use of space for the peaceful benefit of mankind. During this time, the treaty has had a dual implementation of sorts. The majority of the treaty's legal provisions have been applied to activities involving exploration and uses in Earth orbit by diverse countries and organizations. In contrast, the predominant concerns *beyond* Earth orbit have centered on the conduct of scientific exploration and the control of harmful contamination as guided by the planetary protection provisions in Article IX.[§§§§§§§]

With the marked increase in plans by launching nations, commercial ventures, and private entities beyond Earth orbit, it is clear that important changes in implementation lie ahead—particularly for human activities. Until now, the Moon and other celestial bodies have

[§§§§§§§] When the *Apollo* astronauts went to the Moon, extensive planetary protection controls were reviewed by an International Committee on Back Contamination to ensure that quarantine and testing of both returning astronauts and lunar samples were imposed to avoid harmful contamination. Since the end of the *Apollo* program, all human space activities have occurred exclusively in Earth orbit, where no planetary protection controls apply. In that same time, all robotic missions to locations on the Moon and other celestial bodies have been reviewed for compliance with Outer Space Treaty controls against harmful contamination, depending on the celestial body visited and the types of activities conducted.

been managed as *de facto* science preserves since scientific exploration activities are typically without major environmental impacts or conflicts among users. The international space community will soon need to address issues that involve multiple stakeholders and potential use conflicts that are beyond its collective experiences in orbit near Earth. Already, questions have been raised about how to oversee or guide activities such as long-duration human missions to planetary surfaces (both one way and round trip), delivery and installment of instrumentation and infrastructure, mining and ISRU, tourism, human settlement, and even astroburials—all occurring in outer space beyond Earth orbit in locations with no sovereign control or enforcement capabilities.

Further exploration of the Moon, Mars, and other bodies in the solar system will continue to draw comparison to relevant terrestrial analogs. Successful implementation of strategies for environmental management in the ATS and the UNCLOS can both be considered in part for future systems governing the use of the Moon and other celestial bodies. Drawing on both ATS and UNCLOS experiences, it is clear that features important for maintaining effective environmental protection and meeting contemporary challenges include the following: making modest reforms that do not include significant legal changes; inviting collaboration and participation by important strategic partners and alliances related to the resources in question (including commercial and private ventures); planning to manage risks on a proactive basis; and readdressing issues related to enforcement so as to provide more effective governance and oversight in the coming decades.

For the next decade, the most obvious need for developing guidelines will be for activities on the Moon. The Moon—closest to Earth—harbors the most commercial interest at present, but no guidelines for environmental stewardship and responsible use exist today apart from the recent guidelines to preserve the *Apollo* landing sites. A critical step will be to draft a Lunar Environmental Protocol that identifies and protects environmental landscape features and historical/scientific or other lunar resources of interest to humans. Such a framework could later be used as a model for other celestial bodies such as Mars.

The pathway toward the adoption of an international environmental regime for space exploration will be undoubtedly a stepwise approach as the current ambitions and plans of governments and the private sector materialize and diversify. Sound scientific information along with current planetary protection standards and policies to avoid biological contamination will provide important foundational information for starting the discussions. In addition, there will be need to investigate and develop appropriate new frameworks for areas involving policy gaps or lack of precedent, such as establishment of national outposts, settlements, extensive drilling and mining, and property rights and claims.[34] In order to be prepared for future space activities, a balanced stakeholder approach and continuous dialog must be ensured. Fortunately, some policy areas may borrow from other successful approaches in international space—including those used for decades in Earth orbit as well through the ATS and UNCLOS treaties.

ACKNOWLEDGMENTS

The authors would like to thank the NASA Astrobiology Institute and the Elliott School of International Affairs, George Washington University, for their support.

AUTHOR DISCLOSURE STATEMENT

No competing financial interests exist.

REFERENCES

1. Ehrenfreund P, McKay C, Rummel J, et al. Toward a global space exploration program: A stepping stone approach. Adv Space Res. 2012;49:2–48.
2. National Research Council Report: Scientific Context for Exploration of the Moon. Washington DC: The National Academies Press, 2007.
3. Maccone C. Protected antipode circle on the farside of the Moon. Acta Astronaut. 2008;63:110–118.
4. NASA's Recommendations to Space-Faring Entities: How to Protect and Preserve the Historic and Scientific Value of U.S. Government Lunar Artifacts. Release July 20, 2011.
5. Schmitt HH. Return to the Moon: Exploration, Enterprise, and Energy in the Human Settlement of Space. New York: Springer, 2005.
6. Lupisella M and Logsdon J. Do we need a cosmocentric ethic? International Astronautical Congress, F9.2.09, Turin, 1997. http://academia.edu/266597/Do_We_Need_a_Cosmocentric_Ethic (Last accessed on June 27, 2013).
7. Williamson M. Space: The Fragile Frontier. Reston, VA: American Institute of Aeronautics and Astronautics, 2006.
8. Cockell CS and Horneck G. Planetary parks–formulating a wilderness policy for planetary bodies. Space Policy 2006;22:256–261.
9. Sterns PM and Tennen LI. Ethics and the Conquest of Space: From Peenemunde to Mars and Beyond. IAF Paper. In Proceedings of the 50th Colloquium on the Law of Outer Space. IAC-07-E6.5.08. Reston, VA: The American Institute of Aeronautics and Astronautics, 2007.
10. Masson-Zwann T. Lunar exploration and exploitation as a special case of planetary exploration—legal issues. In: The Contemporary Problems of International Space Law. Kapustin A and Zhukov G (eds.). Moscow: Peoples' Friendship University of Russia, 2008, pp. 159–169.
11. Hofmann M, Rettberg P, and Williamson W. Protecting the Environment of Celestial Bodies (PECB). Cosmic Study of the International Academy of Astronautics, 2011.
12. Landfester U, Remuss N, Schrogl KU, and Worms JC (eds.). Humans in Outer Space—Interdisciplinary Perspectives. Studies in Space Policy (Volume 5). Wien: Springer, 2011.
13. Rummel J, Race M, and Horneck G. (eds.). COSPAR Workshop on Ethical Considerations for Planetary Protection in Space Exploration. COSPAR, Paris, 2011. https://cosparhq.cnes.fr/sites/default/files/ppp_workshop_report_ethical_considerations_princeton_final_v1a_7nov2012.pdf (Last accessed on June 27, 2013).
14. Rummel JD, Race M, Horneck G, and Workshop Participants. Ethical considerations for planetary protection in space exploration: A workshop. Astrobiology 2012;12(10):1017–1023.
15. Ehrenfreund P, Hertzfeld H, Howells K, and workshop participants. COSPAR Workshop on Developing a Responsible Environmental Regime for Celestial Bodies report, Paris, 2013. www.gwu.edu/~spi/assets/docs/PEX_WorkshopReport_ES_March14_Web%20(1).pdf (Last accessed on June 27, 2013).
16. Young OR. Governing international spaces: Antarctica and beyond. In: Science Diplomacy: Antarctica, Science and the Goverance of International Spaces. Berkman PA, Land MA, Walton D, and Yound OR (eds.). Washington, DC: Smithsonian Institution Scholarly Press, 2011, pp. 287–294.
17. Berkman PA, Land MA, Walton D, and Yound OR (eds.). Science Diplomacy: Antarctica, Science and the Goverance of International Spaces. Washington, DC: Smithsonian Institution Scholarly Press, 2011.

18. Cohen H. Public participation in Antarctica: The role of nongovernmental and intergovernmental organizations. In: Science Diplomacy: Antarctica, Science and the Goverance of International Spaces. Berkman PA, Land MA, Walton D, and Yound OR (eds.). Washington, DC: Smithsonian Institution Scholarly Press, 2011, pp. 271–276.
19. Race M. Policies for scientific exploration and environmental protection: Comparison of the Antarctic and outer space treaties. In: Science Diplomacy: Antarctica, Science and the Goverance of International Spaces. Berkman PA, Land MA, Walton D, and Yound OR (eds.). Washington, DC: Smithsonian Institution Scholarly Press, 2011, pp. 143–152.
20. Kerrest A. Outer space as international space: Lessons from Antarctica. In: Science Diplomacy: Antarctica, Science and the Goverance of International Spaces. Berkman PA, Land MA, Walton D, and Yound OR (eds.). Washington, DC: Smithsonian Institution Scholarly Press, 2011, pp. 133–142.
21. COSPAR Planetary Protection Policy. 2005. https://cosparhq.cnes.fr/sites/default/files/pppolicy.pdf (Last accessed on June 27, 2013).
22. Caron D. Negotiating our future with the oceans. In: A Planet for Life 2011—Oceans: The New Frontier. Tubiana L, Jacquet P, and Pachauri RK (eds.), 2011, pp. 25–34.
23. Law of the Sea: Separating Fact from Fiction, American Security Project. 2012. http://americansecurityproject.org/featured-items/2012/fact-sheet-law-of-the-sea-seperating-fact-from-fiction/ (Last accessed on June 27, 2013).
24. Chung S, Ehrenfreund P, Rummel J, and Peter N. Synergies of space exploration and Earth science? Adv Space Res. 2012;45:155–168.
25. Murray AE, Kenig F, and Fritsen CH. Microbial life at $-13°C$ in the brine of an ice-sealed Antarctic lake. PNAS. 2012;109(50):20626–20631.
26. Landau D. International cooperation and management of tourism: A world within a world. In: Science Diplomacy: Antarctica, Science and the Goverance of International Spaces. Berkman PA, Land MA, Walton D, and Yound OR (eds.). Washington, DC: Smithsonian Institution Scholarly Press, 2011, pp. 241–244.
27. Ban K. Secretary-General's remarks at 30th anniversary of the UN Convention on the Law of the Sea, United Nations, New York, 2012. www.un.org/sg/statements/index.asp?nid=6495 (Last accessed on June 27, 2013).
28. Ocean Compact: Healthy Oceans for Prosperity—An Initiative of the Secretary-General. United Nations, New York, The Oceans Compact Secretary General, 2012. www.un.org/Depts/los/ocean_compact/SGs%20OCEAN%20COMPACT%202012-EN-low%20res.pdf (Last accessed on June 27, 2013).
29. MEPAG SR-SAG. Findings of the Mars Special Regions Science Analysis Group, Unpublished white paper, 76 p., posted June 2006 by the Mars Exploration Program Analysis Group (MEPAG). http://mepag.jpl.nasa.gov/reports/index.html (Last accessed on June 27, 2013).
30. Report from the ESF-ESSC Study Group on MSR Planetary Protection Requirements. Mars Sample Return Backward Contamination: Strategic Advice and Requirements, 2012. www.esf.org/fileadmin/Public_documents/Publications/MarsSampleReturn.pdf (Last accessed on June 27, 2013).
31. Tsuchyjama A, Uesugi M, Matsushima T, et al. Three dimensional structure of Hayabusa samples: origin and evolution of Itokawa regolith. Science 2011;333: 1125–1128.
32. National Research Council Report. Assessment of Planetary Protection Requirements for Spacecraft Missions to Icy Solar System Bodies. Washington DC: The National Academies Press, 2012.
33. Triggs G. The Antarctic Treaty System: A model of legal creativity and cooperation. In: Science Diplomacy: Antarctica, Science and the Goverance of International Spaces. Berkman PA, Land MA, Walton D, and Yound OR (eds.). Washington, DC: Smithsonian Institution Scholarly Press, 2011, pp. 39–49.
34. Simberg R. Homesteading the Final Frontier: A Practical Proposal for Securing Property Rights in Space. 2012. http://cei.org/issue-analysis/homesteading-final-frontier (Last accessed on June 27, 2013).

Address correspondence to:
Pascale Ehrenfreund, PhD
Space Policy Institute
Elliott School of International Affairs
George Washington University
1957 E Street NW, Suite 403
Washington, DC 20052

E-mail: pehren@gwu.edu