Toward a Global Space Exploration Program: A Stepping Stone Approach

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Committee On Space Research (COSPAR)

COSPAR Panel on Exploration (PEX)

"All truths are easy to understand once they are discovered; the point is to discover them."

Galileo Galilei (1564 - 1642)

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Table of Contents

Toward a Global Space Exploration Program: A Stepping Stone Approach

COSPAR Panel on Exploration (PEX)

Executive Summary

Space exploration is a multifaceted endeavor and a "grand challenge" of the 21st century. The political agendas of a growing number of nations highlight space exploration as a goal and frame it as an international cooperative adventure. In response to the growing importance of space exploration, the objectives of the COSPAR Panel on Exploration (PEX) are to provide high quality, independent science input to **support the development of a global space exploration program** while working to **safeguard the scientific assets of solar system bodies**.

Science roadmaps and recommendations for planetary exploration have been produced by an acronym-rich array of national and international working groups. These include an IAA Cosmic Study (*Next Steps in Exploring Deep Space*) and reports by the US NRC, ILEWG, ESSC, LEAG, and MEPAG. Such studies highlight the most compelling aspects of fundamental and applied scientific imperatives related to the exploration of the Moon, Mars, and small bodies of the solar system, and together they comprise a touchstone for space exploration that can enable architectural studies for robotic and human exploration.

Several nations are currently engaging in, or planning for, space exploration programs that target the Moon, Mars and near-Earth asteroids, and propose voyages of exploration for robots and humans alike. These journeys can provide answers to some of the most fundamental scientific and philosophical questions - "How did our solar system and home planet form?" "Does life exist beyond the Earth?" and "What are the potential opportunities for humanity in our local space environment?" A shared scientific vision, grounded in these fundamental questions and focused on the theme of **"Origins and evolution of our solar system and life,"** has the power to unite space exploration stakeholders, challenge scientists, and capture the public imagination. With such a vision in hand, the science community can guide and accelerate the progress of robotic and human space exploration and share the benefits that these activities confer to society.

Building a new space infrastructure, transport systems, and space probes and creating a sustainable long-term space exploration program will require international cooperation. Accordingly, it will be essential to address the question "**How can the established space community cooperate on a truly international level while engaging newly emerging spacefaring nations in meaningful ways?"** The COSPAR Panel on Exploration proposes a stepwise approach to creating effective and efficient partnerships for future space exploration.

The following elements provide stepping stones along a pathway to help make a shared vision for space exploration a reality:

- Extreme environments on Earth can pose conditions analogous to those at potential landing/operation sites on the Moon and Mars. Expertise obtained from **Earth-based field research campaigns,** worldwide, should be exploited to generate **a coordinated international exploration testbed.** Such expeditions will allow different stakeholders (space and Earth scientists, engineers, entrepreneurs, journalists, etc.) from various cultures to advance related space exploration science and technology by working together to further mutual goals.

- The ISS is the best example of international cooperation in space exploration to date and represents a major milestone that will shape future international space partnerships, for exploration in particular. This achievement should be capitalized upon by **ensuring the science exploitation of the ISS enabling exploration,** during its extended lifetime. This activity would use recently integrated facilities and enhanced crew capabilities to advance our knowledge of living and working at LEO and beyond.

- As a means of effecting worldwide collaboration on small missions, **an international CubeSat program in support of exploration** can act as a model that could enable a new generation of light-weight, low-cost nanosatellites, suitable for "piggyback rides" to Moon and Mars. An international CubeSat program would be particularly interesting for less-advantaged partners, such as small space agencies and developing countries.

- In preparation for larger endeavors, **a system-of-systems approach** with small exploration missions, e.g., small orbiters and landers, as described in the **Global Robotic Village concept of ILEWG**, can initiate and enhance additional international collaborations, as well as science, commercial and public engagement opportunities.

- **Robotic sample return missions** to the Moon, near-Earth asteroids, and Mars have the highest priority for the science community. Such complex space missions will be much more affordable when conducted cooperatively, allowing worldwide expertise to be applied. **Multi-element sample return mission scenarios, implemented by the major space powers, provide opportunities for emerging countries to contribute** either payloads or manpower for a joint mission. Dedicated curation facilities, constructed and maintained within an international framework, can also foster extensive science and engineering collaborations.

- **A multinational consortium** based on the **Antarctic model** could be formed as an organizational approach **to coordinating the development and operation of national and international space outposts**, whether on the Moon, on Mars, or elsewhere in the solar system.

These stepping stones can transcend cross-cultural barriers, leading to the development of technical interfaces and shared legal frameworks and fostering coordination and cooperation on a broad front. Such advances can address scientific and technical prerequisites and provide a foundation for the creation of a successful global space exploration program. The long-term sustainability of a global space exploration program will benefit from the participation and support of a broader community outside of the current space industry, including their financial and logistical support, and the inclusion of the public through a variety of measures targeted at a non-specialist audience.

In cooperation with national and international science foundations and space-related organizations, COSPAR should adopt and advocate this stepping stone approach to prepare for future cooperative space exploration efforts. The involvement of existing, emerging, and developing space nations in such endeavors will both strengthen existing partnerships and foster new ones and bolster capacity building. COSPAR should promote the development of synergistic science programs with open data access, ensure retention of its leadership role in providing requirements for responsible space exploration, and support efforts to exploit synergies between Earth science and space exploration.

While science and technology are the heart, and often the drivers, for space exploration activities, other stakeholder communities should be more robustly integrated and involved than they have been to date. Long-term planning and development of major space architectures for exploration can only succeed when all stakeholders: **governments, space agencies, commercial space sector, space entrepreneurs, and the public** can work toward common, or at least compatible, goals at national and international levels.

A shared vision of how to proceed and progress on these stepping stones can be the basis for a successful global space exploration program. **Science has the power to act as a bridge between spacefaring nations and other stakeholders and the ability to engage society and promote participation while delivering direct benefits to the public**. An interchange of scientific insights can lead to the development of new, common exploration policies and the training of a new space generation that can sustain space exploration over decades.

The PEX, working with COSPAR Scientific Commissions and Panels, and with the international science foundations, the IAA, IAF, UN, and the IISL, will support science-driven national and international space exploration working groups as well as space agency groups such as ISECG that support the analysis and implementation of possible architectures in the new era of planetary exploration. COSPAR's input, as gathered by PEX, will be intended to express the consensus view of the international scientific community and should ultimately provide a series of guidelines to support future space exploration activities and cooperative efforts, **leading to outstanding scientific discoveries, opportunities for innovation, strategic partnerships, technology progression, and inspiration for people of all ages and cultures worldwide.**

1. Vision for the robotic and human scientific exploration of the Earth-Moon-Mars space

In this section we compile highlights from the science roadmaps and recommendations for planetary exploration from the International Academy of Astronautics (IAA) Cosmic Study *"Next Steps in Exploring Deep Space"*, National Research Council (NRC) reports, the International Lunar Exploration Working Group (ILEWG), the Lunar Exploration Analysis Group (LEAG) and the Mars Exploration Program Analysis Group (MEPAG) to create and exploit synergies between similar programs of national and international science working groups. The excellent science documents/roadmaps prepared by the afore-mentioned science and analysis working groups allow us to summarize compelling scientific imperatives that can be used to provide vision for space exploration and context for architectural studies for robotic and human exploration of the Earth-Moon-Mars space (see also Appendix B).

The content of several roadmaps, discussed below, includes elements of both applied and fundamental science. While science and technology represent the core and, often, the drivers for space exploration activities, several other disciplines and their stakeholders should be more robustly interlinked and involved than they have been to date. Successful long-term planning and development of major space architectures for exploration can only be implemented when all stakeholders - governments, space agencies, commercial space sector, space entrepreneurs, and the public - strive for common goals at both national and international levels (Ehrenfreund and Peter 2009). A shared vision is thus crucial to provide direction that enables new countries and stakeholders to join and engage in an overall effort supported by the public.

In 2007 the *"Global Exploration Strategy (GES): The Framework for Cooperation"* was released as the first product of an international coordination process among fourteen space agencies (GES 2007).[1] The International Space Exploration Coordination Group (ISECG) has been created to implement and coordinate the GES. ISECG supports the analysis and implementation of possible space exploration architectures in the new era of planetary exploration. In theme 1: *"New Knowledge in Science and Technology"* the GES acknowledges that systematic, science-driven space exploration reveals fundamental truths about the history of the solar system and the origin and nature of life and that both robotic and human exploration are necessary to answer the key questions.

The European Space Sciences Committee (ESSC) released in 2009 the *"Science-Driven Scenario for Space Exploration"* which defined overarching scientific goals for Europe's exploration program, dubbed *"Emergence and co-evolution of life with its planetary environments,"* focusing on those targets that can ultimately be reached by humans, *i.e.,* Mars, the Moon, and Near-Earth Objects (NEOs). A NEO technological demonstration mission was recommended as well as the active participation in a lunar robotic exploration program. Mars was recognized as the main exploration target and a Mars sample return mission as the primary goal.

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[1] http://www.globalspaceexploration.org/

The report also addressed human exploration and stressed that *"manned missions to Mars are expected to increase public awareness of science and expand funding and activities in many related scientific and technological field. This will lead to an increase in scientific knowledge and an expansion in the economy at a global level."* Furthermore the report clearly states that Europe should position itself as a major actor in defining and leading a Mars sample return mission (Worms et al. 2009).

In the following the consensus view of the international scientific community as summarized by the IAA Cosmic Study, ILEWG, LEAG and MEPAG is presented:

IAA Cosmic Study 2004 "Next Steps in Exploring Deep Space"

In 2004 the Cosmic Study undertaken by the IAA summarized a new vision for the *"Next Steps in Exploring Deep Space"* (Huntress et al. 2004). The study defined four key destinations as the most important targets: the Moon, Libration Points (gravitationally balanced locations that are ideal for maintaining spacecraft, telescopes, etc.) such as the one located away from the Sun and behind the Earth that is called "SEL2", Near-Earth Objects (NEOs) and the planet Mars. The following overarching science questions were defined as:

- Where did we come from?
- What will happen to us in the future?
- Are we alone in the Universe?

Investigations of the terrestrial planet environment allow us to gain knowledge on the formation and early history of our solar system. Investigating the Earth-Moon-Mars space, including NEOs, may answer long-standing questions about the origin and future destiny of the human race. In order to understand the origin of the Earth-Moon system and the processes on the young Earth that led to the origin of life, the Moon is a priceless target to be investigated with robots and humans.

The Moon and Lagrange points provide a unique platform to study the origins of our Universe and the formation of planetary systems. Investigating the physical properties and chemical processes on small bodies provides us with a glimpse into the earliest periods of our solar system. Mars, which has been extensively investigated for water and its mineralogy in the past, is the prime target in our solar system for discovering evidence of extinct life and possibly extant biosignatures. Any science breakthroughs on the search for life on Mars will have a strong impact on all future exploration missions.

Current missions that are planned to explore the Earth-Moon-Mars space in the next decade include lunar orbiters and landers, sample return missions to the Moon, Phobos and near-Earth asteroids, as well as orbiters, landers and rovers to explore the martian atmosphere, surface and subsurface, see Appendix A. A Mars Sample Return (MSR) mission to be conducted through international cooperation is planned for the next decade. The James Webb Space Telescope (JWST) will be transported to L2 in 2014. National roadmaps of the main spacefaring nations are listed in Appendix A.

1.1 Destination Moon

The Moon is a valuable and crucial target for planetary science: it represents a window through which to explore the origin of our solar system and the Earth-Moon system. Created by a destructive impact to Earth in the early history of our solar system, the Moon provides a unique platform to search for clues about the conditions of the primitive solar nebula and the formation of terrestrial planets.

In the early history of solar system formation, some 3.9 billion years ago, the destabilized solar nebula disk caused a massive delivery of planetesimals to the inner solar system. This so-called Late Heavy Bombardment (LHB) phase was likely triggered by rapid migration of giant planets. As a consequence, numerous small bodies including comets and asteroids and their fragments (meteorites and interplanetary dust particles), impacted on young planets (Gomes et al. 2005). The bombardment record is uniquely revealed by the Moon (see Figure 1), as the early record has been erased on Earth by plate tectonics and erosion. Evidence for water on the Moon was recently provided by four different spacecraft (Lunar Prospector, Chandrayaan-1, Lunar CRater Observation and Sensing Satellite LCROSS, and the Lunar Reconnaissance Orbiter LRO). Investigating the distribution of water on the Moon and searching for embedded molecules in polar ice deposits are exciting yet challenging avenues to pursue. Understanding the formation of the Moon, its internal structure and environment, and the impact history of the inner solar system are of particular importance in reconstructing the details of processes that occurred in the early solar system, and to shed light on the origin of life on Earth.

Results from recent Moon missions

Since the US Apollo and Soviet Union Luna missions, spacecraft from various countries have been sent to the Moon (see Neal 2009, for more details). However, after the last Soviet lunar lander in 1976 (Luna 24 – a robotic sample return mission from Mare Crisium), no new science missions were sent to the Moon until the US Clementine (launched 25 January 1994; Nozette et al. 1994) and Lunar Prospector (launched 7 January 1998; Binder 1998) orbital missions. These missions produced the most comprehensive lunar data sets to date, highlights of which include:

- Tantalizing data that supported the presence of H deposits at the lunar poles (Nozette et al. 1996; Feldman et al. 1998)
- Refinement of the pre-existing gravity model of Bills and Ferrari (1977) from Lunar Orbiter and Apollo 15 and 16 subsatellites on the basis of Clementine data (Zuber et al. 1994; Lemoine et al. 1997)
- Evidence for three new large ‘‘mascons’’ (mass concentrations - Muller and Sjogren 1968; Melosh 1978) on the nearside of the Moon as well as partially resolving four mascons on the farside (Konopliv et al. 1998, 2001).
- The most comprehensive lunar surface compositional maps to date (e.g., Lucey et al. 1995, 1998, 2000; Elphic et al. 1998, 2002; Lawrence et al. 1998; Gillis et al. 2003, 2004; Feldman et al. 2004a; Prettyman et al. 2006)

- The first lunar topographic map (e.g., Spudis et al. 1994)
- Compositional data on the central peaks of impact craters and possible exposed upper mantle at South Pole-Aitken basin (e.g., Pieters et al. 1997; Pieters and Tompkins 1999; Tompkins and Pieters 1999)
- Identification of a thorium-rich ‘‘hotspot’’ on the lunar nearside centered on Mare Imbrium (Lawrence et al. 1998, 2003, 2004, 2005; Haskin 1998; Haskin et al. 2000), which was hinted at by the Apollo gamma-ray spectrometer data (e.g., Metzger et al. 1977; Haines et al. 1978; Hawke and Bell 1981)
- Evidence for induced crustal magnetism at the antipodes of major impact basins (Lin et al. 1998; Halekas et al. 2003) as well as compositional evidence for antipodal ejecta deposits (e.g., Haskin et al. 2000)
- Evidence for the presence of a small iron-rich core with a radius of ~340 km (Hood et al. 1999)
- Definition of different terranes on the lunar surface by Jolliff et al. (2000) based on the data from the Clementine and Lunar Prospector missions, which included the Procellarum-KREEP Terrane, the Feldspathic Highlands Terrane, and the South Pole-Aitken Terrane

The next mission to the Moon was SMART-1 launched by the European Space Agency (ESA) on 27 September 2003, arriving at the Moon during March 2005 (see Foing et al. 2006).

Figure 1. One of the first images taken by the AMIE instrument (clear filter) onboard SMART-1 in December 2004 shows an area of the Moon featuring the Mouchez crater near to lunar zero longitude. *Image Credit: ESA/SMART-1/Space-X, Space Exploration Institute*

SMART-1 was launched as a solar ion propulsion drive technology demonstration, rather than a full science mission. SMART-1 carried seven instruments onboard performing various science and technology investigations. Among them were three remote sensing instruments: an X-ray spectrometer (D-CIXS), a lunar infrared spectrometer (SIR) and the smallest visual digital camera (AMIE Advanced Moon Imaging Experiment). SMART-1 provided advances in our understanding of the origin and evolution of the Moon by studying surface composition, bombardment history (see Figure 1), volcanism and the morphology of large basins (Foing et al. 2008). SMART-1 reported major element data of the lunar surface from the D-CIXS instrument (e.g., Grande et al. 2007, Swinyard et al. 2009), and multi-angular imagery of selected targets (e.g., Kaydash et al. 2009). A coordinated campaign permitted to observe the flash and debris from the SMART-1 controlled grazing impact in 2006 (Burchell et al. 2010). SMART-1 also studied the seasonal variations of illumination of polar areas, and pointed to potential sites of quasi-eternal light, that could be relevant for future robotic outposts and human bases.

Between 2007 and 2009, four more orbital missions were launched to the Moon: Selene/Kaguya launched by Japan (JAXA) on 14 September 2007; Chang'E-1 launched by China (CNSA) on 24 October 2007 (Sun et al. 2005; Huixian et al. 2005); Chandrayaan-1 launched by India (ISRO) on 24 October 2008 (Bhandari 2005; Goswami 2010). The dual launch of the Lunar Reconnaissance Orbiter (LRO: Chin et al. 2007) and the Lunar Crater Observation and Sensing Satellite (LCROSS: Colaprete et al. 2010) was launched by the United States (NASA) on 18 June 2009. Data for these recent missions are still being collected, refined and interpreted, but a number of exciting new results have been published:

- All missions (except LCROSS) carried laser altimeters. These data increased the fidelity of the topography map produced using Clementine data and extended it to cover the entire Moon (e.g., Araki et al. 2009; Ping et al. 2009; Huang et al. 2010; Smith et al. 2010)
- The Selene/Kaguya mission carried subsatellites that were used to define the gravity field of the lunar farside (Namiki et al. 2009)
- Global temperature variation maps have been produced from the LRO instrument suite (e.g., Gladstone 2010; Paige et al. 2010)
- The lunar radiation environment is being quantified by the LRO mission (e.g., Spence et al. 2010)
- The presence of H_2O and hydroxyl species on the lunar surface well away from the permanently shadowed regions (PSRs) has been documented by the Chandrayaan-1 mission (e.g., Pieters et al. 2009), see Figure 2, and the Cassini mission (Clark 2009)
- Data also show the presence of volatile species in and around the polar PSRs (Mitrofanov et al. 2010; Bussey et al. 2010a; Heldmann et al. 2010; Hong et al. 2010; Spudis et al. 2010)
- Polar illumination has been tracked using Kaguya data (Bussey et al. 2010b)
- The first microwave emission map was produced from Chang'E-1 data (Jiang et al. 2010)

- New lunar lithologies, not represented in the sample return collection, have been discovered using orbital data (Ohtake et al. 2009; Sunshine et al. 2010; Pieters et al. 2010)
- Detailed images of the lunar surface have been collected that allow surface processes and potential hazards to be studied (e.g., Robinson et al. 2010)

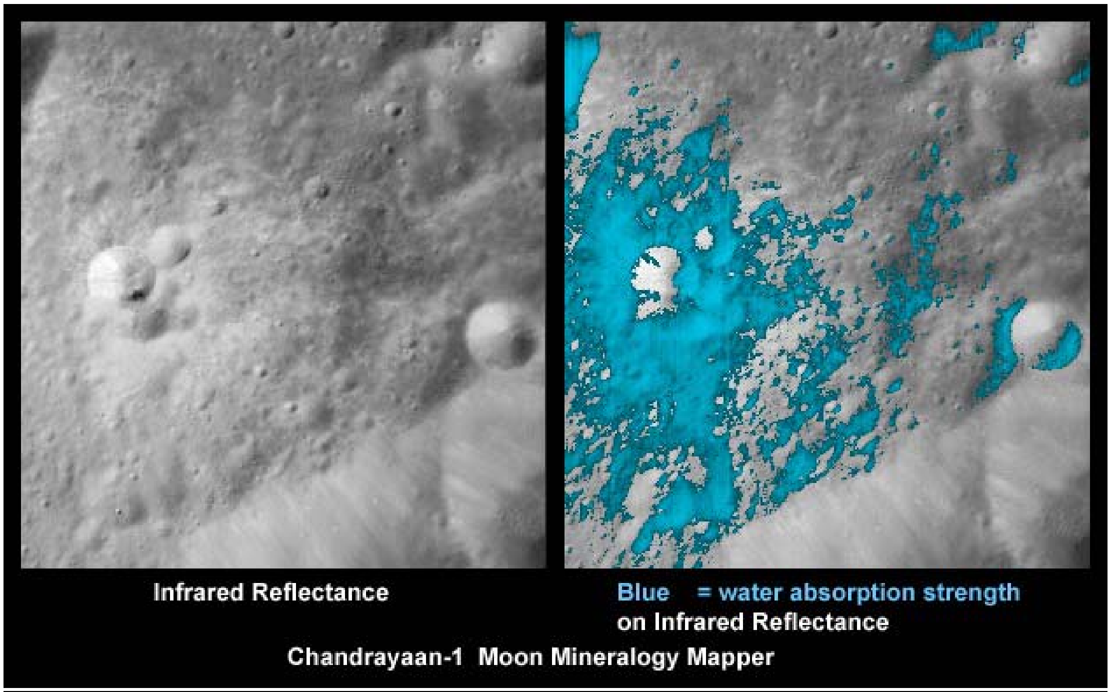

Figure 2. NASA's Moon Mineralogy Mapper on the Indian Space Research Organization's (ISRO) Chandrayaan-1 spacecraft shows a very young lunar crater on the side of the Moon that faces away from Earth. *Left:* image showing brightness at shorter infrared wavelengths. *Right:* the distribution of water-rich minerals (light blue) is shown around a small crater. Both water- and hydroxyl-rich materials were found to be associated with material ejected from the crater. *Image Credit: ISRO/NASA/JPL-Caltech/USGS/Brown U*

The data sets currently being collected will be used to advance lunar science and exploration, including location and study of potential hazards and resources, as well as characterization of the cratering process, polar volatiles, volcanism and space weathering, among others. NASA missions that are currently scheduled to visit the Moon include GRAIL and LADEE.

- The Gravity Recovery And Interior Laboratory (GRAIL): a mission to refine the total lunar gravity field that will, in essence, peer deep inside the Moon to reveal its internal structure and thermal history (Zuber et al. 2008)
- The Lunar Atmosphere and Dust Environment Explorer (LADEE); the mission is intended to explore the tenuous lunar exospheric species and dust above the Moon's surface (Leshin et al. 2008; Delory et al. 2010)

China's Chang'E-2 Moon orbiter will be launched in 2010 and Chang'E-3 Moon lander and rover are to be launched later in the decade. Japan plans to send two Moon orbiters Selene 2 and 3 during this decade. The Russian Luna-Glob mission (anticipated launch date in 2012/2013) consists of an orbiter and landing probe (either an exploration station or penetrators). Contact in-situ investigations in the lunar near-pole area are envisaged with the Luna Resource/1 mission composed of a Russian lunar lander and an Indian orbiter and mini-rover. A lunar multi-element mission (lander, rover, re-transmitting satellite), Luna Resource/2, is planned for later in the decade.

The interest of several nations to undertake lunar missions will continue to place the Moon at the forefront of science and exploration for the foreseeable future. In particular, there is substantial international interest in the development of an International Lunar Network (ILN), a lunar geophysical network whereby various nations contribute stations/nodes and/or instruments to explore the deep lunar interior to unlock the secrets of early planetary evolution (ILN 2008). Building on ILN, this strong focus on the Moon provides a unique opportunity for increased international collaboration in science, instruments, missions and exploration of the solar system, see Appendix A and B.

Many COSPAR Moon volumes (ASR 1994, 1996, 2002, 2004, 2006) and 10 ILEWG volumes have compiled information in the last two decades on what science can be done: *of, on and from the Moon*.[2] Among the more recent ambitions is to use the Moon for Earth sciences and to study fundamental solar system processes. NRC, LEAG and ILEWG have roadmaps on-line that outline fundamental and applied science concepts for Moon missions. The lunar farside, shielded from terrestrial radio emission, allows exploring the cosmos from the Moon.

NRC report 2007 "Scientific Context for the Exploration of the Moon"

This NRC report outlines what exciting research can be performed to decipher many important questions of rocky worlds (NRC 2007).

The overarching themes are the investigation of:

- The early Earth-Moon System
- Terrestrial planet differentiation and evolution
- Solar system impact record and
- The lunar environment

Eight science concepts and goals were defined that include:

- Investigation of the bombardment record of the Moon
- Moon interior structure
- Lunar crustal rocks
- Lunar poles

[2] http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=34125

- Lunar volcanism
- Impact processes
- Lunar regolith and
- Lunar dust and atmosphere environment

<u>International Lunar Exploration Working Group (ILEWG)</u>

Relevant science recommendations from ILEWG Conferences on Exploration and Utilisation of the Moon (ICEUM) include:

<u>Exploration4science:</u>

- What does the Moon tell us on processes that are shaping Earth-like planets (tectonics, volcanism, impact craters, erosion, space weathering, volatiles)?
- What is the present structure, composition and past evolution of the lunar interior?
- Did the Moon form in a giant impact and how? How was the Earth evolution and habitability affected by this violent event, and by lunar tidal forcing?
- How can we return samples from large impact basins as windows to the lunar interior, and as records of the early and late heavy bombardment?
- What can we learn on the delivery of water and organics by comets and asteroids from sampling cores of the lunar polar ice deposits? Are there prebiotic ingredients in lunar soil or ice?
- How to find and return samples ejected from the early Earth (and possibly the oldest fossils) now buried within the few meters of lunar regolith?
- How to use most effectively the Moon as a platform for astrophysics, cosmology and fundamental physics, compared to Earth or space-based laboratories?
- How to use a “Global Robotic Village” (as recommended by ILEWG) to provide the measurements to fulfill these scientific objectives?

<u>Among the recent ILEWG recommendations are:</u>

“Recognizing the importance of the geophysical studies of the interior of the Moon for understanding its formation and evolution, the necessity for a better monitoring of all natural hazards (radiation, meteorite impacts and shallow moonquakes) on the surface, and the series of landers planned by agencies in the period 2010-2015 as unique opportunity for setting up a geophysical network on the Moon, we recommend the creation of an international scientific working group for definition of a common standard for future Moon network instruments, in a way comparable to Earth seismology and magnetism networks. We encourage interested agencies and research organizations to study inclusion of network instruments in the Moon lander payload and also piggyback deployment of a Moon Geophysical and Environmental Suitcase (ICEUM 8, Beijing, 2006).”

“To address outstanding lunar science questions remaining to be resolved (relating to mineralogy, geochemistry, interior structure, gravity, topography, polar regions, volatiles, environment protection) as well as the scientific investigations that can be performed from the Moon as a platform (astrophysics, solar physics, Earth observations, life science) (ICEUM9, Sorrento, 2007).”

“We, the participants in the ILEWG/LEAG/SRR 2008 conference, reaffirm our commitment to international lunar exploration, from the analysis and integration of current lunar orbiter data, to the development of lunar landers and rovers, the build up of a “Global Robotic Village”, and the preparation for human settlements and international lunar bases (ICEUM10, Cape Canaveral, 2008).”

467 International Lunar Explorers, delegates from 26 countries, assembled at the Global Lunar Conference GLUC including the 11^{th} ILEWG Conference on Exploration and Utilisation of the Moon (ICEUM11) from 31 May to 3 June 2010, in Beijing. GLUC-ICEUM11 was a truly historical meeting that demonstrated the worldwide interest in lunar exploration, discovery, and science. The community feels strongly that joining the forces of spacefaring nations to explore the Moon should be seriously implemented, with the views of expanding a “Global Robotic Village” and building in the long run a Manned International Lunar Base. “We, the delegates of the GLUC-ICEUM11 conference, commit to an enhanced global cooperation toward international lunar exploration for the benefit of humankind (GLUC-ICEUM11, Beijing, 2010).”

The Lunar Exploration Analysis Group (LEAG)

The Lunar Exploration Analysis Group (LEAG) has constructed a Lunar Exploration Roadmap (LER), which is a hierarchical document that is comprised of three themes with subsequent goals, objectives, and investigations or initiatives.[3] The objectives and investigations/initiatives have been time phased using Early Stage, Middle Stage, and Late Stage. Definitions of these terms are:

- **Early**: Robotic precursors and up to the second human landing (≤1 lunar day)
- **Middle**: Initial outpost build-up to including stays of 1 lunar day and including part of the lunar night, as well as robotic missions
- **Late**: Outpost established, stays of >30 days, including robotic missions

For roadmapping efforts, the Early Stage has been subdivided into pre-Early (Robotic Precursor Missions) and Early (Robotic & Short Human Sortie ≤1 Lunar Day). Low, medium, and high prioritizations have been assigned by the LEAG roadmapping team to the objectives and investigations in terms of what is interpreted, through contact with leaders in the community, as general thinking of how particular science communities (i.e., Earth observing, heliophysics, and astrophysics) could best use the Moon.

[3] http://www.lpi.usra.edu/leag/ler_draft.shtml

For lunar science, LER defers to the NRC (2007) *"Scientific Context for the Exploration of the Moon"* report for prioritization of science concepts and goals, which specifically studied the issue of prioritization. The priorities are intended to help gauge, within the range of uses of the Moon that have been proposed over the years within these communities, which concepts appear to offer the most promise.

Low Priority:	Would be good to do, but is not essential for habitat/exploration development; would only give an incremental advance to our scientific knowledge; and/or could be conducted more efficiently elsewhere
Medium Priority:	Falls in between Low and High Priority; could be enabled with sufficient infrastructure investment
High Priority:	Is essential to do in order to make progress in habitat/exploration development; would facilitate a fundamental advance in our scientific knowledge; is facilitated by or should be facilitated by the Lunar Architecture; and/or is best done on the lunar surface

The Moon has been and will continue to be the scientific foundation for our knowledge of the early evolution and impact history of the terrestrial planets. Remotely sensed, geophysical, and sample data allow us to define investigations that test and refine models established for lunar origin and evolution. For example, documenting the diversity of crustal rock types and the composition of the shallow and deep lunar mantle will allow refinement of the lunar magma ocean hypothesis. Dating the formation of large impact basins will relate directly to the crustal evolution of all the terrestrial planets and, possibly, to the bombardment history of the outer solar system. Establishing a global lunar geophysical network will allow, for the first time, the deep lunar interior to be studied in detail. This is critical for understanding the early evolution of the terrestrial planets. The main themes within the LER are summarized below.

Science Theme: Pursue scientific activities to address fundamental questions about the solar system, the Universe, and our place in them.

This theme addresses four main goals along with objectives:

- Understand the formation, evolution and current state of the Moon (9 objectives, 36 investigations)
- Use the Moon as a "witness plate" for solar system evolution (2 objectives, 9 investigations)
- Use the Moon as a platform for astrophysics, heliophysics, and Earth-observation studies (3 objectives, 28 investigations)
- Use the unique lunar environment as a research tool [this goal is subdivided into combustion research (4 objectives, 11 investigations), fluid physics and heat transfer research (4 objectives, 11 investigations), materials processing research (3 objectives, 5 investigations), and life sciences research (11 objectives, 29 investigations)]

The LEAG roadmap describes how the Moon is a unique platform for fundamental astrophysical measurements of gravitation, the Sun, and the Universe. A number of high priority heliophysics investigations are defined in the LER. Long-term observations of the whole Earth disk from the Moon provide a broad picture of annual fluctuations in atmospheric composition and, over several years, can map trends in these fluctuations. The high priority Earth-observing investigations include: Monitor the variability of Earth's atmosphere; detect and examine infrared emission of the Earth; develop radar interferometry of Earth from the Moon.

Feed Forward Theme: Use the Moon to prepare for future missions to Mars and other destinations.

This theme will establish the Mars mission risk reduction technologies, systems and operational techniques that could be developed through a lunar exploration program. The following evaluation criteria will be used to evaluate candidate ideas:

- Mars Risk Reduction Value: How well do the candidates address the key risk reduction areas identified through NASA's robotic and human Mars mission planning studies
- Lunar Platform Value: Do candidates leverage the unique attributes of a lunar program to achieve success - or - would other platforms be more effective from a technical/cost perspective

There are two goals under this theme. One addresses hardware and the other operations:

- Identify and test technologies on the Moon to enable robotic and human solar system science and exploration (9 objectives and 38 investigations)
- Use the Moon as a testbed for mission operations and exploration techniques to reduce the risks and increase the productivity of future missions to Mars and beyond (3 objectives and 13 investigations)

Timing for individual investigations is driven by when the capability would be required for lunar applications since these technologies would be supporting lunar activities not done specifically as Mars technology demonstrations.

Sustainability Theme: Extend sustained human presence to the Moon to enable eventual settlement.

The fundamental purpose of activity involving the Moon is to enable humanity to do there permanently what we already value doing on Earth: science, to pursue new knowledge; exploration, to discover and reach new territories; commerce, to create wealth that satisfies human needs; settlement, to enable people to live out their lives there; and security, to guarantee peace and safety, both for settlers and for the home planet. Achieving permanent human presence depends on ensuring that profitable, economically self-sustaining commercial endeavors will develop wherever possible and ethically appropriate. Activities not within the commercial domain must define and produce value sufficient to justify continuing government and non-profit funding.

Initial human and robotic presence must lay a solid foundation in science and technology demonstrations, showing the value of extended and expanded presence, so that our opportunity to live and work on the Moon can be sustained. The "Sustainability theme" within the Lunar Exploration Roadmap has many dimensions that share the unifying notion that *sustained* lunar activities are only possible when they are *sustainable* through ongoing return of value, realized and anticipated, from those activities. The long-term objective of permanent human presence in the form of a self-sustained settlement is the titular purpose of the elements described in this theme, but such an objective is most readily defensible when strongly linked to the sister themes of "Science" and "Feed forward" of the lunar experience to the human exploration of other destinations in the solar system. Therefore, the direct mingling of science and exploration goals and objectives is explicitly made in this theme of the roadmap.

The role of commercial activity as an indispensible aspect of sustainability is self-evident in times when the limits of governmental support are so apparent, but the effective integrated phasing of initiatives across all the themes, goals and objectives is at the core of establishing a sustainable expansion of human presence away from Earth. The "Sustainability theme" is comprised of several goals:

- Maximize commercial activity (5 objectives, 19 initiatives)
- Enable and support the collaborative expansion of science and exploration (12 objectives, 77 initiatives)
- Enhance security, peace and safety on Earth (5 objectives, 9 initiatives)

The Lunar Exploration Roadmap is a ***living document*** that is updated annually to include new data and changing national and international political situations. For example, the 2010 review will include a revision of the "Science theme" to include results from recent missions, especially Chandrayaan-1, LCROSS, and LRO, expansion of the "Feed forward theme" to specifically include NEOs, review of the "Sustainability theme" and cross-integration of objectives between the themes.

1.2. Destination: Near-Earth Asteroids

The remaining planetesimals of the solar system formation process - those that were not integrated into planets - exist today as small bodies such as asteroids and comets. Most of the asteroids and comets are confined to stable orbits (such as the asteroid belt between Mars and Jupiter) or reservoirs in the outer solar system (such as the Kuiper Belt) or beyond our solar system (such as the Oort cloud). Icy planetesimals in the outer solar system occur as comets, Centaurs, and Kuiper-Belt objects. The investigation of comets and asteroids provides us with important insights into the original composition of the solar nebula from which the planets formed. Comets and asteroids and their fragments (meteorites and Interplanetary Dust Particles IDPs) frequently impacted the young planets in the early history of the solar system (Gomes et al. 2005). The large quantities of extraterrestrial material delivered to young terrestrial planetary surfaces during this period may have provided the material necessary for the emergence of life (Chyba et al. 1992; Ehrenfreund et al. 2002).

NRC report 1998 "Exploration of Near-Earth Objects"

Near-Earth Objects (NEOs) orbit in close proximity (< 1.3 AU[4]) of the Earth and may pose a hazard to life on Earth. The NRC report *"Exploration of Near-Earth Objects"* discusses that *"approximately 5% of NEOs are the most readily accessible extraterrestrial bodies for exploration by spacecraft"* (NRC 1998). The energy requirements to rendezvous with and land on these bodies are less than those to land on the surface of the Moon. The combination of the diversity and accessibility of these bodies presents new opportunities and challenges for space exploration and indicates a need for sufficient ground-based observations of NEOs to identify targets of highest scientific interest. Fundamental science questions to address are:

- How many objects are there?
- What are their size distribution and composition?
- How often do they strike Earth?

NEO Sample Return

The Japanese Hayabusa mission explored the asteroid Itokawa (Yano et al. 2006, Michikami et al. 2010), see Figure 3. Hayabusa is the first asteroid sample return mission to sample pristine early solar system material from a NEO. The sample return capsule was retrieved in Australia on 13 June 2010. The sample content will now be investigated in Earth laboratories and hopefully provide important clues to early solar nebula processes.

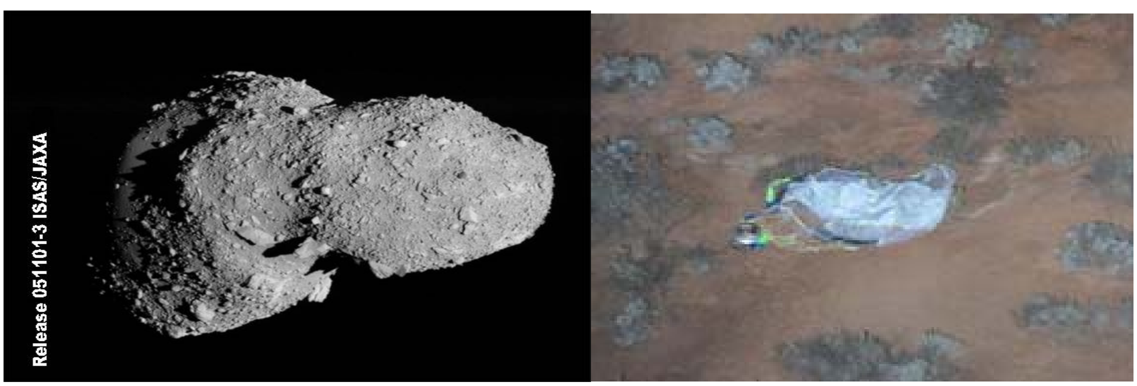

Figure 3. *Left:* The near-Earth asteroid Itokawa has been observed by the Hayabusa mission that confirmed an S-type composition. The image shows a surprising lack of impact craters but a very rough surface. *Right:* The sample return capsule was retrieved on 13 June 2010 in Australia. *Image Credit: JAXA*

Mission concepts for NEO sample return missions have been extensively studied by independent experienced teams in the US, Europe, and Japan.

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[4] 1 AU = astronomical unit = 149.60×10^6 km

NASA's New Frontier program has pre-selected the Origins Spectral Interpretation Resource Identification Security Regolith Explorer spacecraft, called Osiris-Rex that is planned to rendezvous and orbit a primitive asteroid. An important goal for NEO sample return missions is the acquisition of samples together with known geologic context. Finally, thorough contamination control is essential to achieve the objective of returning a pristine sample. It is crucial to return an uncontaminated sample to Earth in an amount sufficient for molecular, organic, isotopic, and mineralogical analyses.

NEO science through robotic and human exploration

Many asteroids are primitive, having escaped high-temperature melting and differentiation. The chemical and physical nature, distribution, formation, and evolution of primitive asteroids are fundamental to understanding solar system evolution and planet formation. The analysis of carbon compounds in fragments of asteroid 2008 TC_3 revealed recently interesting insights into asteroid chemistry (Jenniskens et al. 2009), see Figure 4. Given our current technology and launch limitations, sample return from a carbonaceous near-Earth asteroid has been suggested to provide the highest science return with the lowest implementation risk (Lauretta et al. 2009).

A number of broad science themes can be identified for NEO science (NRC 1998):

- Measuring the physical characteristics of NEOs
- Understanding the mineralogical and chemical compositions of asteroids
- Deciphering the relationships among asteroids, comets, and meteorites
- Understanding the formation and geologic histories of NEOs

These science themes are usually associated with ground-based and robotic exploration but would be augmented by human exploration missions. In addition to addressing fundamental science questions, knowledge acquired during a human NEO mission would facilitate development of methods to mitigate their potential hazard. Near-Earth asteroids can closely approach the Earth and therefore present a threat to humans and life on Earth. However, these objects are mineral-rich and their close proximity make them interesting targets for the exploitation of raw materials and supporting interplanetary journeys.

Applied science goals include:

- Understanding the NEO surface physical properties so as to allow the design of systems that impact, or attach to these surfaces
- Understanding bulk properties of NEOs so as to allow modeling of their response to impacts, detonations or external forces
- Determining the diversity of objects within the NEO population with respect to mechanical and bulk properties
- Calibrating the ability of Earth-observations to remotely determine the essential physical properties of NEOs

The NASA space exploration roadmap envisages a visit by humans to an asteroid after 2025. For both, applied and fundamental science, a human NEO mission would produce a wealth of data, at the same time expanding our human spaceflight experience base beyond low-Earth orbit and the Earth-Moon system, proving space-qualified hardware directly applicable to lunar and Mars exploration, and providing a valuable and visible "milestone" akin to the impact of Apollo 8. An astronaut Extra Vehicular Activity (EVA) to the surface of a near-Earth asteroid would be of value to both the applied and fundamental science goals listed above as well as providing an important public outreach and demonstration relevant to hazard mitigation.

Figure 4. *Left:* A small NEA entered Earth's atmosphere on 7 October 2008 and exploded over the Nubian Desert of northern Sudan. Scientists expected that the asteroid 2008 TC_3 disintegrated into dust in the resulting high-altitude fireball. Image taken by cell phone of the contrail left by 2008 TC_3 during its decent. *Image Credit: Shaddad*
Right: Almahata Sitta meteorite number 15 (a remnant of asteroid 2008 TC_3) in-situ on the desert floor during its find on 8 December 2008. *Image Credit: P. Jenniskens, SETI Institute*

The statistical distribution of NEO orbits has been investigated by Chesley and Spahr (2004). In the most recent NRC report (2010) on *"Defending Planet Earth: Near-Earth Object Surveys and Hazard Mitigation Strategies"* a peer-reviewed, targeted research program in the area of impact hazard and mitigation of NEOs is recommended, that should encompass surveys, characterization and mitigation. The scope of the research program should include analysis, simulation as well as laboratory experiments. The role of ground- and space-based facilities in addressing NEO survey goals was investigated in detail. It was recommended that the US takes the lead in organizing and empowering a suitable international entity to participate in developing a detailed plan for dealing with the NEO hazard. Rendezvous spacecraft missions can help in the detailed characterization of NEOs and thus provide valuable information for the design and development of hazard mitigation. Finally it was recommended that any human mission to NEOs should maximize data obtained for NEO characterization (NRC 2010).

1.3 Destination: Mars

Mars continues to be an object of keen interest in the context of planetary evolution and extraterrestrial life. Its climate has changed profoundly over time and the planet's surface still retains physical and chemical evidence of early planetary and geologically more recent processes. A primary objective of future international planetary exploration programs is to implement a long-term plan for robotic and human exploration of Mars, and as part of these programs, to search for extinct or extant life on Mars. Although currently the surface of Mars may be uninhabitable by indigenous life, regions in the subsurface may still harbour life or remnants of past life. Recent missions, such as Mars Global Surveyor, Mars Odyssey, the Mars Exploration Rovers, Mars Express, Mars Reconnaissance Orbiter, and Phoenix, have added significantly to our knowledge of the history of water at the martian surface and the evolving role it has played in interacting with the crust, see Figure 5. The geological record indicates a diversity of water-modified environments, including promising ancient habitable environments.

The presence of methane gas suggests a dynamic system on Mars that couples its interior and atmosphere, even as its reported variability challenges our present understanding of atmospheric chemistry. In the coming decade, Mars is the only target addressing the search for life that, realistically, can be visited frequently by robotic spacecraft, paving the way for returned samples and human exploration. Finally, the consensus of the Mars science community is that the greatest progress in determining biological potential of Mars is through returning samples from the Mars surface to be analyzed in Earth laboratories (NRC Mars 2007).

<u>Results from recent Mars missions</u>

General

- Mars has benefited over the last decades from a fleet of orbital and landed spacecraft. Orbital remote sensing has revealed a complex geologic record that appears to span most of the history of the planet, and that formed in response to processes that include volcanism/plutonism, weathering/erosion, sedimentation, glaciation, polar ice cap processes, fluid/rock interactions, tectonism, and others. Example references include Christensen et al. (2003), Neukum et al. (2004), Hahn et al. (2007), Tanaka et al. (2005), Heldmann et al. (2007), Frey (2008), and many of the references listed below.

Ancient Mars

- On ancient Mars, water was persistent in shallow surface bodies, lakes, connected networks, and as groundwater near the surface, and Mars therefore likely had a very different climate than it does today (Malin et al. 2003; Hynek and Phillips 2003; Howard et al. 2005; Irwin et al. 2005; Squyres and Knoll 2005; Baker 2006; Jolliff et al. 2006; Knoll and Grotzinger 2006; Irwin et al. 2008; Squyres et al. 2009, Murchie et al. 2010).

- A diverse suite of minerals, including hydrated sulfates, phyllosilicates, and silica, produced by the action of water on martian crustal rocks has been identified both from orbit and from the martian surface (Poulet et al. 2005, 2009; Chevrier and Mathe 2007; Squyres et al. 2006a; Arvidson et al. 2008; Morris et al. 2008; Mustard et al. 2008; Squyres et al. 2008; Ehlmann et al. 2008, Hecht et al. 2009). The character and concentration of at least some of these minerals systematically change on a global scale over geologic time (Bibring et al. 2006), generally indicating more alteration by liquid water early in Mars history.
- The detailed processes of rock formation and weathering, and the influence of these two processes on mineralogy and morphology/texture has been established at two martian sites of very different geological character (e.g., Grotzinger et al. 2005; McLennan et al. 2005; Squyres and Knoll 2005; Squyres et al. 2006b; Squyres et al. 2007).
- Remnant magnetism in the ancient crust shows that there was a powerful global magnetic field that shut down early in Mars history, exposing the atmosphere to increased erosion by the solar wind (Connerny et al. 2001; Lillis et al. 2008) and perhaps triggering a profound change in climate and surface-atmosphere interaction (Bibring et al. 2006).
- Determination of the planetary figure and gravity fields (Neumann et al. 2004) provide key information on the distribution of mass and the degree of isostatic equilibrium.

Geologically Young Mars

- Layering in the polar caps and in sedimentary rock in many places, often with remarkably repetitive sequences of layer thicknesses, indicate cyclical processes (e.g., Laskar et al. 2002; Milkovich and Head 2005; Lewis et al. 2008).
- The north and south polar caps are different in many ways: the north appears younger and has no remnant summertime layer of CO_2. Layer thicknesses for the north have typical variations consistent with computed changes in the planet's obliquity and orbital eccentricity on time scales of several hundred thousand to a few million years (e.g., Phillips et al. 2008).
- An array of glacial and periglacial landforms, including debris covered shallow ice-deposits in mid-latitudes, pointing to massive transport of volatiles, especially water, from the polar reservoirs to lower latitudes, presumably in response to the cyclical changes of polar insolation (Head et al. 2003; Head et al. 2005; Holt et al. 2008; Plaut et al. 2009).

Modern Mars

- Ground ice extends over most of the high latitudes in the top meter of surface material. Its depth (therefore volume) is not known, but a subsurface cryosphere may today hold a significant fraction of ancient liquid water (Boynton et al. 2002; Feldman et al. 2004b; Smith et al. 2009).

- Surface change: Impact craters continue to be identified, helping to calibrate the crater-dating algorithms and providing insight into the material beneath the dust-covered surface. New gullies have been observed; whether dry avalanches or water-aided movement, they indicate a landscape that continues to change even today (Malin and Edgett 2000; Malin et al. 2006; McEwen et al. 2007).
- A multi-year record of the seasonal cycles of water, CO_2 and dust, including spectacular, episodic hemispheric and global dust events, has revealed processes which operate over much longer time scales (Smith 2004; 2008). Actively precipitating water ice clouds have now been observed (Whiteway et al. 2009).
- Earth-based observations, building on orbital indications, have detected methane in the atmosphere of Mars (e.g., Mumma et al. 2009). Its very presence suggests an active subsurface source. Reported variations in space and time, still controversial, are inconsistent with our present understanding of processes affecting the martian atmosphere. The all-important provenance of the methane, whether geochemical or biochemical, remains to be determined.

Future missions to Mars include the NASA's Mars Science Laboratory (MSL) that will be launched in 2011 and explore the martian surface with a rover carrying sophisticated instrumentation. NASA's Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft is scheduled for launch in late 2013. A long-term ESA-NASA cooperation for Mars exploration has been developed with the Exomars mission that will be conducted in two steps in 2016 and 2018, respectively. In 2016, ESA will provide a Mars Orbiter and a 600-kg Entry, Descent and Landing (EDL) Demonstrator launched by NASA. The Mars Trace Gas Orbiter will accommodate a suite of scientific instruments for the detection of atmospheric trace gases. The 2018 mission is NASA-led and includes the contribution of a rover from ESA. The ESA Rover Exomars will share the journey to Mars with the NASA rover Mars Astrobiology Explorer-Cacher (MAX-C). Both rovers will be integrated in the same aeroshell and will be delivered to the same site on Mars. The ESA Rover will carry a comprehensive suite of analytical instruments as well as a drill, dedicated to exobiology and geochemistry and the search for signs of past and present life. The NASA rover MAX-C will conduct high-priority in-situ science and make concrete steps toward the potential future return of samples to Earth. The Russian Phobos-Grunt mission will visit the martian moon Phobos in 2011 and return samples to Earth for scientific research. China will send the Yinghuo-1 (YH-1) orbiter "piggyback" on the Russian Phobos-Grunt mission, see Appendix A and B.

The Mars Exploration Program Analysis Group (MEPAG) Roadmap 2008/2009

The MEPAG Goals document summarizes a consensus-based list of broad scientific objectives organized into a four-tiered hierarchy: goals, objectives, investigations, and measurements. The goals have a very long-range character and are organized around major areas of scientific knowledge and highlight the overarching objectives of the Mars Exploration Program (Arvidson et al. 2006). MEPAG documents are regularly updated and available to the public, on-line at http://mepag.jpl.nasa.gov/.

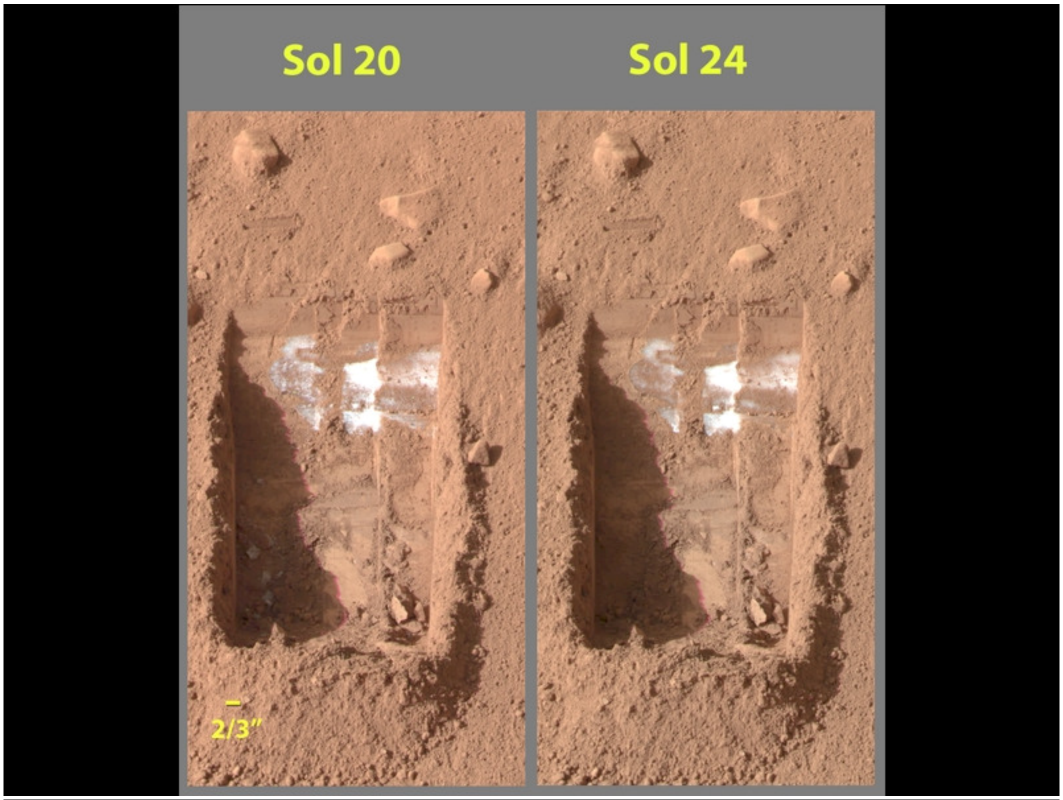

Figure 5. Color images acquired by NASA's Phoenix Mars Lander's Surface Stereo Imager on the 21st and 25th day of the mission (June 2008), or Sols 20 and 24 showing sublimation of ice in the trench informally called “Dodo-Goldilocks” over the course of four days. *Image Credit: NASA/JPL-Caltech/University of Arizona/Texas A&M University*

The goals of the MEPAG roadmap version 2008/2009 (MEPAG 2009) are listed below:

- Goal 1: Determine if life ever arose on Mars
- Goal 2: Understanding the processes and history of climate on Mars
- Goal 3: Determine the evolution of the surface and interior of Mars
- Goal 4: Prepare for human exploration

MEPAG has identified cross-cutting strategies that could be used to guide the present and future exploration of Mars:

- Follow the water
- Understand Mars as a system
- Seek habitable environments
- Seek signs of life

Most recently, MEPAG has considered the following science objectives for the next decade (Mustard et al. 2009):

- How does the planet interact with the space environment, and how has that affected its evolution?
- What is the diversity of aqueous geologic environments?
- Are reduced carbon compounds preserved and what geologic environments have these compounds?
- What is the complement of trace gases in the atmosphere and what are the processes that govern their origin, evolution, and fate?
- What is the detailed mineralogy of the diverse suite of geological units and what are their absolute ages?
- What is the record of climate change over the past 10, 100, and 1000 million years?
- What is the internal structure and activity?

Mars Sample Return

The return of martian samples to Earth has long been recognized to be an essential component of a cycle of exploration that begins with orbital reconnaissance and in-situ martian surface investigations. However, spacecraft instrumentation cannot perform critical measurements such as precise radiometric age dating, sophisticated stable isotopic analyses and definitive life-detection assays, and therefore the major questions about life, climate and geology require answers from state-of-the-art laboratories on Earth. Returned sample studies could respond radically to unexpected findings, and returned materials could be archived for study by future investigators with even more capable laboratories. Unlike martian meteorites, returned samples could be acquired with known context from selected sites on Mars according to the prioritized exploration goals and objectives (MEPAG ND-SAG 2008).[5]

The return of carefully selected samples even from a single well-chosen site would be the means to make the greatest progress at this point in planetary exploration. The recognized challenges of definitively detecting biosignatures, especially when attempted in-situ, has raised the priority of sample return for astrobiological studies (NRC Mars 2007) to the same high level given sample return for geochemistry, including geochronology. For both science areas, the return of samples would provide the opportunity for repeated experimentation with the latest analytic tools, including the all-important ability to follow-up on preliminary discoveries with new or revised analytic approaches. Knowledge of the samples' context on Mars, including detailed knowledge of the environment from which they were selected, would also be crucial for defining the laboratory analyses and interpreting their results (Mustard et al. 2009). In contrast to Earth, Mars still retains rocks from its very early history that provide clues to its ancient conditions and possible habitable environments. Several recent documents describe in detail sample return goals and scenarios (e.g., iMars 2008, MEPAG ND-SAG 2008).

[5] http://mepag.jpl.nasa.gov/reports/ndsag.html

The Mars community consensus holds that the search for life, geochemical studies and age dating, as well as climate and coupled atmosphere-surface-interior processes can be best studied with samples returned to Earth and analyzed in state-of-the-art laboratories. The field of life in extreme environments has strongly progressed in the last decade and some living species on Earth have been shown to survive under conditions of extreme radiation, subfreezing temperatures, high salinity, extremely high and low pH, and cycles of hydration to dehydration as present on Mars today.

Advances in the knowledge of environmental conditions on Mars today and in the past, combined with advances in understanding of the environmental limits of life, reinforce the possibility that living entities could be present in samples returned from Mars. The Next Decade Mars Sample Return Science Analysis Group (ND-MSR-SAG) formulated the 11 high-level scientific objectives that should allow for a balanced program to return samples from Mars (MEPAG ND-SAG 2008). A crucial element is to gather samples with a variety of geologic histories such as sedimentary material, hydrothermally altered rocks, low temperature altered rocks, igneous rocks, regolith samples, polar ice (if possible) as well as atmospheric gas.

The following factors that would affect our ability to achieve MSR's scientific objectives have been identified:

- Sample size
- Number of samples
- Sample encapsulation
- Diversity of the returned collection
- In-situ measurements for sample selection and documentation of field context
- Surface operations
- Sample acquisition system
- Sample temperature
- Planning considerations involving the MAX-C caches
- Planetary protection
- Contamination control

Driven by the emergence of a diverse landscape, both morphologically and compositionally, the scenario now under consideration for Mars Sample Return (MSR) involves a sequence of mission elements referred to as the MSR campaign spanning multiple launch opportunities. An initial mission element in the multi-mission scenario would be the Mars Astrobiology Explorer-Cacher (MAX-C) currently under development by NASA. MAX-C can cache samples that could be picked up by a future mission (Hayati et al. 2009). Subsequently, a potential future MSR rover element utilizes a flexible rover to recover the cached samples, which would be launched from Mars with a Mars Ascent Vehicle (MAV) into orbit. A Mars Sample Return Orbiter (Sample capture and Earth Entry Vehicle) would rendezvous with the orbiting sample container and return the samples to Earth. The returned samples would be handled in a Sample Receiving Facility (SRF) and sample curation facility, the two ground segments of MSR.

The SRF is particularly important, because it must assess biohazards while at the same time avoiding damaging contamination of the samples. This multi-element MSR concept readily accommodates international cooperation, see Figure 6. A major challenge is to select a site where significantly diverse regions can be sampled during one mission. Another challenge is to preserve sample integrity upon re-entry and transfer to a SRF (Pratt et al. 2009).

Figure 6. Artist's concept of the Mars Sample Return mission showing the ascent phase from the martian surface. Once the sample container reaches Mars orbit it will rendezvous with a Mars Sample Return Orbiter that returns the collected samples to Earth. *Image Credit: Jet Propulsion Laboratory*

The pursuit of the proposed sample return campaign in a step-by-step approach now appears to be within the international community's grasp, both scientifically and technically. Orbital reconnaissance, experience with surface operations and the development of the MSL Entry/Descent/Landing system have reduced both the scientific and technical risks of sample return, in accordance with the NRC recommendations (NRC 2003, NRC Mars 2007) so that NASA and other space agencies can take steps to implement a sample return mission as soon as possible.

The next mission steps in the proposed sample return campaign would be:

- Collection of appropriate samples and caching them at an appropriate site
- Acquisition of the cache and launch of it into Mars orbit
- Rendezvous with the cache in Mars orbit and return to Earth

The activities for the next decade with regard to the proposed sample return are:

- Identification of the sample return site
- Deployment of a caching rover, preferably launched in the 2018 opportunity
- Initiation of a technology development program for the proposed sample return cacher, Mars ascent vehicle, and Earth-return orbiter
- Planning for sample handling and analysis facilities for returned samples

MSR development would likely advance readiness and reduce risks for future human missions through knowledge gained about hazards and resources and by demonstrating scaled versions of key technologies such as In-Situ Resource Utilization (ISRU) (Stetson et al. 2009).

The following goals for the period 2016-2025 related to preparing for human exploration are listed in the NASA Roadmap 2005.[6] Many of these are still active, others have shifted as priorities and budgets have evolved:

- Laboratory study of Mars samples
- Intensive search for life
- Subsurface exploration
- Understand potential Mars hazards - toxicity, biohazards
- Scalable demos of key capabilities (ISRU, EDL) and dress rehearsal
- Expand Mars telecom infrastructure
- Human habitation and operation validation on Moon
- Select and validate human Mars architecture
- Select site for robotic outpost
- Commit to timetable for human Mars exploration

MEPAG is in the process of updating its Goal IV (Prepare for Human Exploration) objectives and investigations. Some highlights of those follow:

- Determine the aspects of the atmospheric state that affect aerocapture, EDL and surface operations, including launch from the surface of Mars
- Determine properties of the martian surface and whether that could affect surface operations by humans on Mars
- Determine if the martian environments to be contacted by humans are reasonably free of biohazards to humans on Mars or Earth
- Characterize potential sources of water and other materials as a resource (ISRU) for human missions

Human exploration of Mars is likely several decades away but in-situ exploration by humans could lead to a deeper understanding of the evolution of the solar system and the origin and evolution of life.

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[6] http://images.spaceref.com/news/2005/srm2_mars_rdmp_final.pdf

2. Stepping stones toward a global space exploration program

As outlined in the previous chapter the major spacefaring nations have developed plans for ambitious space exploration programs to explore the Earth-Moon-Mars space in the new millennium. Appendix A lists space exploration capabilities and planned exploration missions for this decade. National exploration programs are developed under different political realities and follow different interests, but are also subject to different authority and influences from the various space exploration stakeholders. Therefore it will require many steps to reach a united space exploration governance structure. In the transition period toward a truly global endeavor robust stepping stones in preparation of global space exploration can unite key stakeholders already in an early phase (Ehrenfreund and Peter 2009; Ansdell et al. 2010). Stepping stones can improve and ease technology transfer rights or other regulations as well as the development of interfaces which are all major prerequisites and building-blocks for a future global space exploration program. Different initiatives providing clear milestones, as illustrated in Table 1, could be used as intermediary steps to support joint research, foster transnational alliances, and educate and inspire a new generation of researchers.

Table 1. Potential near-term international initiatives in space exploration
(adapted from Ehrenfreund and Peter 2009)

Initiatives	**Potential specific missions**	**Participants**
Preparation for future robotic and human planetary exploration missions	International Earth-based field research program	Current and emerging spacefaring nations, developing countries, private sector
Joint program for international research activities	Science exploitation of the ISS enabling exploration	ISS partners and potential new space partners
Cooperation on low-cost missions accessible to emerging spacefaring nations	International CubeSat program in support of space exploration	Current and emerging spacefaring nations, developing countries, private sector
System-of-systems approach: small orbiters and landers	Global Robotic Village (ILEWG model)	Current and emerging spacefaring nations, developing countries, private sector
Joint exploration missions	Moon, NEO, Mars sample return mission	Current and emerging spacefaring nations, developing countries, private sector
Concept studies for an international space infrastructure	International lunar base or post-ISS infrastructure	Current and emerging spacefaring nations, developing countries, private sector

2.1 International Earth-based field research program

Extreme environments on Earth can pose conditions analogous to those at potential landing/operation sites on the Moon and Mars. By increasing our knowledge of the geology and biology of terrestrial analogues, our understanding of other planetary bodies and the limits/adaptability of life can be ultimately enhanced. Moreover, the technologies required for scientific investigations in extreme environments on Earth are similar to those needed for operations in space (Chung et al. 2010, Osinski et al. 2010). Thus, analogue studies in extreme environments also provide a unique opportunity to foster collaboration between the Earth science and space exploration communities. Testing related technologies and protocols and training science and operations teams in extreme environments will be beneficial for interpreting and validating information from orbiter and rover missions on extraterrestrial bodies (Léveillé 2009).

International cooperation on terrestrial analogue activities is a logical first step to implementing international Moon-Mars missions. This is an ideal time for such partnerships as many countries are embarking on ambitious space exploration activities beyond their budgetary means. It provides a unique opportunity to establish international cooperation at an early stage that will evolve into a truly integrated space exploration program designed to share costs and reduce risks.

Field research in support of planetary exploration include in general: the investigation of geological and geochemical context; drilling of cores and sampling; remote controlled field rovers; cameras; instruments; evaluation of crew operations; simulations and Extra Vehicular Activities (EVAs) and many other aspects. Numerous programs are currently undertaken worldwide that include various stakeholders (Ansdell et al. 2010). Among the most international oriented programs are:

Concordia: Concordia Station is a permanently inhabited research facility in Antarctica for conducting scientific research in the fields of glaciology, atmospheric sciences, astronomy and astrophysics, Earth sciences, and human biology and medicine. Currently there are 13 people living in the station. The station is impossible to leave and reach during the winter months. The European Space Agency (ESA) cooperates on aspects of human exploration and sends regularly crew members to the station.

CAREX: The European Commission has initiated within its “7th Framework” a program called CAREX (Coordination Action for Research Activities on life in Extreme Environments), that coordinates and sets scientific priorities for research of life in extreme environment. CAREX endorses cross-sector interests in microbes, plants, and animals evolving in diverse marine, polar, and terrestrial extreme environment as well as outer space (CAREX 2008).

MDRS/F-MARS: The Mars Society operates two simulated Mars habitats, the Flashline Mars Arctic Research Station (F-MARS) on Devon Island and the Mars Desert Research Station (MDRS) in Utah. MDRS is a societal endeavor that engages public applicants.

ILEWG field tests: ILEWG has developed with tasks groups on "Technology" and "Lunar Base", technical pilot projects that organized and coordinated field GeoMoonMars campaigns in the Utah desert research station (see Figure 7), at Eifel volcanic park, Rio Tinto, and other sites, in collaboration with ESA, NASA and academic/industrial partners. The goals of ILEWG field campaigns include: 1) testing instruments, rovers, landers, EVA technologies, habitat and field laboratory; 2) performing field research in geology, sample analysis, exobiology; 3) studying human factors and crew aspects; 4) outreach and student training.

Figure 7. ILEWG-ESA-NASA Mars Desert Research Station MDRS Crew #77, testing sampling procedures, instrumentation, in-situ analysis and human exploration aspects in Utah, February 2009. *Image Credit: ILEWG/MDRS*

PISCES: The Pacific International Space Center for Exploration Systems (PISCES) is located in Hawaii in Hilo (UH-Hilo) and dedicated to the development of new technologies needed to sustain life on the Moon and beyond. PISCES was conceived by the Japan-US Science, Technology and Space Application Program (JUSTSAP) and established as an official center at Hilo in 2007 (PISCES 2007). The Pacific International Space Alliance (PISA) will be the international expansion of PISCES. PISA intends to engage governments, universities, industry, and non-governmental organizations in PISCES-like activities in Hawaii.

Mars500: On 3rd June 2010, a crew of six men (from Russia, Europe and China) started a simulated mission to Mars. The simulation will total 520 days (250-day trip to Mars, 30-day stay on the surface, and 240-day return journey). The crew lives and works in a sealed facility in Moscow to investigate the psychological and medical aspects of long-duration space missions. Efforts to reproduce a real trip to Mars include limiting supplies and imposing an artificial 20-minute delay in communications each way. The isolation study will be conducted under the auspices of ESA and the Russian Institute for Biomedical Problems (IBMP).

The large number of existing and planned terrestrial analogue programs shows the importance of these activities and provides foundations upon which cross-disciplinary expeditions can be initiated under the auspices of both developed and emerging space nations (Ansdell et al. 2010). Although there are many terrestrial analogue field sites currently in operation around the world, no integrated program exists to date to bring together these common efforts. Consequently there is no common focus, database, nor roadmap.

The European Commission (EC) supported through its "7th Framework Programme" the Coordination Action for Research Activities on life in Extreme Environments (CAREX) project.[7] This project has been active for two years in delineating a multidisciplinary scientific community and has established a comprehensive roadmap for research on life in extreme environment through working meetings and field trips. The approach proposed as one of this roadmap's core themes: *"Life and Habitability"* could serve as a model for an international research program that prepares for future robotic and human exploration of the Earth-Moon Mars space and that combines efforts to exploit synergies between Earth science and space exploration. Understanding and protecting life on Earth requires similar concepts that are needed for the exploration of environments and possible life beyond Earth (Chung et al. 2010).

Successful transnational cooperation in this research area will stimulate sharing expertise and resources and will encourage the establishment of common standards, methodologies and frameworks. An *"International Earth-based field research program"* as stepping stone for global space exploration, supported by national science foundations and executing a roadmap that has been established in consensus with many international partners, will provide sustainability and a stimulus for emerging countries to join such an international effort (Ansdell et al. 2010, Nordheim et al. 2010). Such a program has strong synergies with experiments and science investigations conducted on the ISS that investigate, for example, human physiology in microgravity. Improved coordination of terrestrial analog research (including isolation studies), ISS based research as well as experiments from supporting parabolic flights can provide an important base of knowledge for long-duration missions, see section 2.2. A database of the various aspects of robotic and human exploration simulations will be crucial to perform more complex integrated studies that prepare for challenging human exploration missions visiting the Moon, Mars and NEOs.

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[7] www.carex-eu.org

2.2 Science exploitation of the ISS enabling exploration

Research on the international Space Station (ISS) delivers increasing science return. Over 400 experiments have been performed in the last 10 years on topics including human life science, biological science, human physiology, physical science, material science, Earth and space science that are summarized in the publication: *"International Space Station Science Research: Accomplishments during the assembly years: An Analysis of Results from 2000-2008"* (Evans et al. 2008).

The European Programme for Life and Physical Science in Space: ELIPS makes Europe the largest scientific user of the ISS. Among the future ESA research objectives on the ISS is the*"Preparation of Human Exploration of Space."*

ELIPS 3 conducts studies on:

- Radiation biology and physiology
- Health care and human performance under extreme conditions
- Life-support and thermal control systems
- Food production in space
- Fluid handling and processing in space
- Material exposure and advanced materials
- Contamination and planetary protection studies

A Decadal survey conducted by the US National Research Council (NRC) on *"Biological and Physical Sciences in Space"* is currently investigating research objectives that define and align life and physical sciences research to meet the needs of exploration missions. The survey investigates what life and physical science experiments have to be conducted to meet the multidisciplinary science and engineering challenges of future human exploration activities.

More facilities, a larger crew, better equipped laboratories that are used in international cooperation offer an environment that can be used to prepare for robotic and human exploration. Below we describe in more detail a few of the national ISS facilities that are particularly suited for exploration science (see also Figure 8):

Laboratories like MISSE (Materials International Space Station Experiment) test spacecraft materials in the environment of atomic oxygen, vacuum, solar radiation, charged particle radiation, micrometeorites, thermal cycling etc. Testing of new materials is necessary to determine the durability of materials in space and to improve the design of stronger, more durable spacecraft components.

The Japanese Experiment Module Kibo provides a laboratory that enables experiments for space medicine, biology, Earth observations, material production, biotechnology and communications research. The Remote Manipulator System (RMS) connects the pressurized laboratory to the Exposed Facility, a platform that can hold up to 10 experiment payloads.

The Russian greenhouse LADA from Roskosmos studies fundamental plant biology and in particular the growth of sweet peas, wheat, tomatoes, lettuce in microgravity, and provides an important contribution to research related food safety issues.

The Canadian OSTEO (Osteoporosis Experiments in Orbit) Bone Culture System enables the growth of bone cells in microgravity. OSTEO has been used successfully on US Space Shuttle and Russian Foton recoverable orbital flights and is also available for use on the ISS.

The European Laboratory Columbus harbors several facilities that provide a testbed for exploration, such as the Biolab (for experiments on micro-organisms, cells and tissue cultures, plants in microgravity), the European Physiology Modules Facility (EPM) that tests effects of long-duration spaceflight on the human body, the Fluid Science Laboratory (FSL) that investigates the weightless liquids, the European Drawer Rack (EDR), the European Transport Carrier (ETC) and the Microgravity Glove Box (MGB) as a support for experiment activities in Columbus and its external facilities EuTEF and SOLAR. EXPOSE as part of EuTEF tested the effect of solar radiation and space vacuum on biological and organic material and SOLAR provides measurements of the solar spectral irradiance throughout virtually the whole electromagnetic spectrum. Additional ISS research capabilities are outlined in the recent booklet "Research in Space". [8]

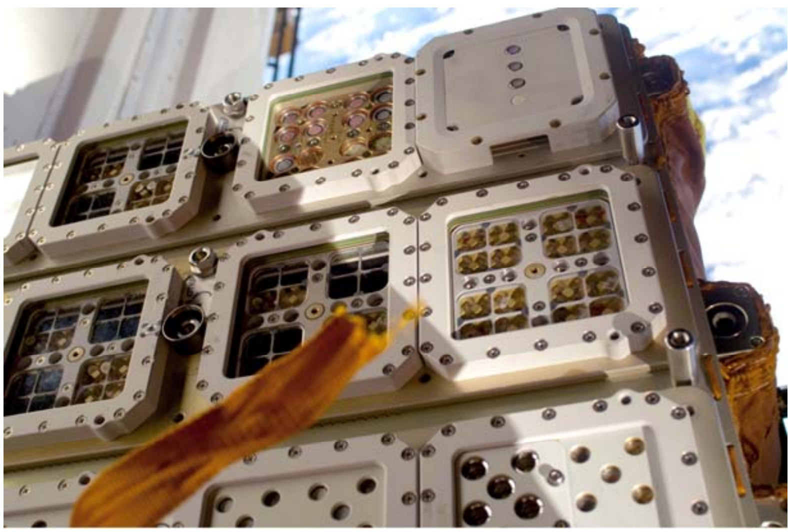

Figure 8. The external exposure facility EXPOSE-R is currently operational on the ISS since March 2010. EXPOSE-R is a multi-user facility that accommodates biological and biochemical experiments. It is attached to an external platform URM-D on the Russian segment and investigates the effects of space radiation on biological material. The research conducted on this facility provides a model for successful European-US-Russian collaboration. *Image Credit: ESA*

[8] http://www1.nasa.gov/pdf/393789main_iss_utilization_brochure.pdf

Supporting non-ISS projects that involve bedrest and isolation campaigns, parabolic flights and drop tower campaigns as well as sounding rocket experiments are important as they represent crucial elements in the preparation phase for space exploration. A recent study by the International Space University (ISU) investigated in detail analog studies for the preparation of human missions to Moon and Mars that proposed to establish a metric to enhance cooperation, ease standardization and to exploit sufficiently datasets of analog studies worldwide (Nordheim et al. 2010, Ansdell et al. 2010), see section 2.1.

All current roadmaps of national and international space exploration working groups (as well as ISS partners) recognize the importance of the *"Science exploitation of the ISS enabling exploration"*. Expanding international cooperation to non-ISS partners (such as China and India) is essential for future global space exploration. A long-term science program utilizing modular payload racks may be suited to involve developing countries supported by United Nations (UN) bodies.

2.3 International CubeSat program in support of exploration

Development of the smallest of the small satellites, the "nano" and "pico" categories in which so-called CubeSats belong, was pioneered by universities, where they were recognized some twenty years ago for their potential as highly effective educational vehicles. Conventional satellite development for the most part is a capital- and expertise-intensive endeavor requiring multi-year development and large professional teams, severely limiting opportunities for science and engineering students to participate. Recognizing the need for student access to aerospace development programs, Jordi Puig-Suari of California Polytechnic Institute (CalPoly) and Robert Twiggs of Stanford University co-developed the CubeSat specification.

Though pioneered in universities, the potential impact of small satellite technology was not lost on governmental space and research agencies, e.g., NASA, NSF and ESA. NASA's O/OREOS CubeSat to be launched in September 2010 is depicted in Figure 9. In addition to governmental programs, CubeSats have spawned significant commercial activity, including numerous commercial entities spun off from academic institutions. The United Nations (UN) have formally recognized the benefits small satellites provide to developing and emerging nations. The utility CubeSats for science and technology as research platforms is now recognized (Woellert et al. 2010) and providers are responding by providing affordable instrumentation normally seen only for larger satellites. CubeSats are able to capitalize on the latest technology to fly instruments that truly are "state of the art" and can address the latest high priority issues. A new initiative within the framework of the UN, the UN Basic Space Technology Initiative (UNBSTI) plans to act as information broker and interface between stakeholders (Balogh and Haubold 2009).

As small-satellite technologies begin to facilitate bona fide science experiments, their comparatively low-cost and the ubiquitous opportunities to deliver them to space will make it possible to replicate experiments across multiple space flights. The rapid evolution of capable instruments for CubeSats promotes them as possible hitch-hikers on Moon and Mars orbiters.

An *"International CubeSat program in support of exploration"* could perform interesting research in biology, atmospheric science, space weather, material processing and other areas that are relevant for space exploration (Ansdell et al. 2010). For emerging countries that are not able to contribute to rovers and orbiters such a program would allow them to participate and form and educate a space generation (Woellert et al. 2010).

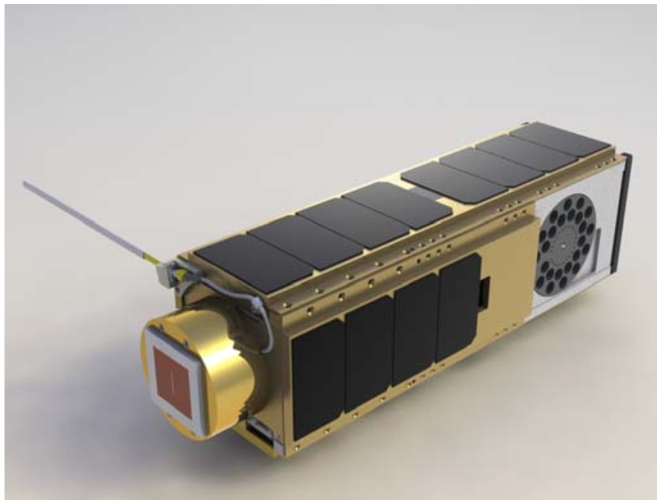

Figure 9. NASA's Organism/Organic Exposure to Orbital Stresses, or O/OREOS nanosatellite, is a triple CubeSat that weighs approximately 5 kg and includes two separate science payload instruments testing the stability of organic material and micro-organisms in Low Earth Orbit (LEO), respectively. *Image Credit: NASA Ames Small Spacecraft Office*

CubeBots as low-cost robotic surface component

Extending the concept of traditional CubeSats in orbit, exceptionally small, CubeSat class mobile surface systems may also provide affordable, high-value opportunities for broad-based participation and scientific discovery in future exploration missions. During the past decade, exceptionally small robotic systems have become practical. Figure 10 provides an illustration of one such concept, a small surface robot in the 5-kg class.

These systems, which could range from 1-100 kg, can leverage advances in computing and electronics, imaging, actuators, etc. and enable very low-cost candidate payloads for future surface missions. It is evident that these systems have several critical limitations, primarily in the functional areas of 1) safe and precise transportation to lunar or planetary surfaces, 2) communication, and 3) power and (especially) thermal management. However, each of these challenges could be dealt with through collaboration with more traditional space programs and missions or employing distributed and networked operations paradigms. For example, multiple "CubeBots" from various sources might readily be deployed as a single payload with much larger landers - scattering autonomously at a surface site to collect useful data from highly hazardous but scientifically interesting sites.

In addition, the challenge of delivering data from such robots could readily be accomplished in several ways. For example, a number of such "CubeBots" could be ganged together in a wireless network to transfer data via successive line-of-site links from a remote location back on the lander from which they were deployed.

Figure 10. A small surface robot in the 5-kg class. *Image Credit: Jet Propulsion Laboratory*

Alternatively, multiple "CubeBots" might be merged into a single synthetic aperture using a simple retro-directive phased array technique to provide data to an orbiter directly. Also, the challenge of thermal management – particularly providing heat during extreme environmental conditions – could be provided by a "nesting" approach. For example, after two weeks of exploration on the Moon, any surviving "CubeBots" could attempt to return to the system that deployed them (i.e., a lander). This system would then provide the needed heating to enable the smaller "Bots" to survive the extended lunar night and resume exploration the next day. Overall, the integration of multiple small CubeSat-class robots with large surface systems could dramatically extend the potential for participation in surface exploration activities, as well as the reach of more traditional systems into scientifically promising, but potentially risky environments. Combining multiple such "CubeBots" together and linking them to larger systems on the surface or in orbit could readily expand the data returned from these novel, low-cost exploration systems and involve a large community of scientists worldwide.

2.4 Global Robotic Village (model ILEWG)

The ILEWG community recommended a sequence of technology, exploration and commercial missions on the road to human Moon presence, see Figure 11. ILEWG supports the cooperation of a series of missions including polar orbiters and landers and network missions. Robotic engineering precursors for in-situ resource utilization and deployment of infrastructures preparing for human-tended operations are recommended (ICEUM 5-5, Hawaii, 2003).

"The community recognized that the lunar exploration program must later include advanced orbital instruments as well as in-situ analyses from several surface stations and targeted sample return, and urged broad and open discussion and coordination for selections of landing sites to optimize the science return and benefit for exploration (ICEUM 6-5, Udaipur, 2004)."

ILEWG supports the goals of a comprehensive series of surface elements including landers and rovers at the poles and other key sites. The model envisages the deployment of landers from different countries that are developed and operated in coordination. The rovers should perform complementary cooperative robotics and exploration tasks, and demonstrate enabling technologies. Such a program will initiate and enhance international collaboration, as well as science, commercial and public engagement opportunities. Various infrastructure assets such as telecom, power generation, can be shared by the international partners. "The planning and development of a Global Lunar Robotic Village will encourage and stimulate the peaceful and progressive development to investigate the Moon, and foster international cooperation between nations, space agencies and private companies (ICEUM7-9, Toronto, 2005)."

The rationale for and possible implementation of a lunar Global Robotic Village have been discussed by the ILEWG community, with a phased approach with orbital reconnaissance, small landers, a network of landers for science (of, on and from the Moon) and exploration. Then advanced robotic precursors to human missions with deployment of large infrastructures, resource utilization, would conduct operations imminent to human arrival, during and between human early missions, see Figure 11. Possible elements of the Global Robotic Village are discussed in ILEWG volumes (ICEUM4 2000 pp. 219-263, pp. 385-391, ICEUM9 2007 pp. 82-190). ILEWG developed a research pilot project called "ExoGeoLab" supported by ESA, NASA and partners to test a lander, with rovers and instruments, and cooperative Robotic Village operations, see section 2.1.

Google Lunar X Prize and other entrepreneurial efforts

Exciting precursors to the proposed ILEWG Global Robotic Village will be emplaced by 2013 benefiting from the Google Lunar X Prize competition. In the domain of robotic exploration the X PRIZE Foundation and Google announced in 2007 a new cash prize competition, the Google Lunar X PRIZE with 30 million US dollars in incentives. The goal of the new prize is to land a privately funded robotic rover on the Moon that is capable of completing several mission objectives.[9] The new era of space exploration provides ample opportunities for the commercial sector (Ehrenfreund and Peter 2009). The commercial space sector and space entrepreneurs will support operations and infrastructures to enable the government sector to engage in exploration activities, but will also take independently the lead in certain exploration endeavors. The recent successful launch of the Falcon 9 rocket (Space X) was a first step toward the goal of using private contractors to deliver people and cargo to the International Space Station.

[9] http://www.googlelunarxprize.org/

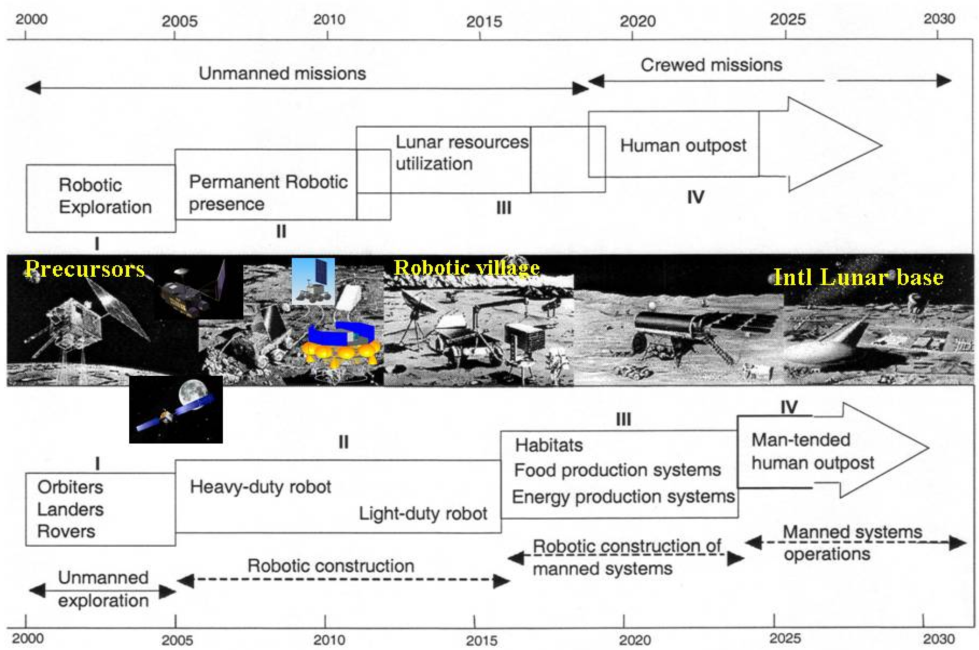

Figure 11. The ILEWG roadmap: from precursor missions via a Global Robotic Village to Human Outposts. *Credit: ILEWG*

2.5 International Sample Return missions from Moon, NEOs and Mars

The analytical precision and accuracy obtainable in modern Earth-based laboratories exceeds that of any in-situ instrument onboard spacecraft, due to limited resources of power and sample preparation. As discussed in section 1 sample return missions to Moon, NEOs, Phobos and Mars have highest priority for the science community.

The Russian planetary exploration mission Phobos-Grunt will visit the martian moon Phobos in 2011. Phobos-Grunt will return samples from Phobos to Earth for scientific research and study the Mars environment concerning atmosphere, dust storms, plasma and radiation. China will send the Yinghuo-1 (YH-1) orbiter piggyback on the Russian Phobos-Grunt mission to conduct space-environment, atmospheric, gravity, and surface-imaging studies of Mars, see Figure 12.

NASA's New Frontiers program has pre-selected two sample return missions: MoonRise, a lunar South Pole-Aitken Basin sample return mission would place a lander in a giant basin near the Moon's South Pole and return approximately 1 kg of lunar materials to Earth laboratories. The Origins Spectral Interpretation Resource Identification Security Regolith Explorer spacecraft, called Osiris-Rex, would rendezvous and orbit a primitive asteroid. After characterizing the target, instruments would collect material from the asteroid surface for return to Earth.

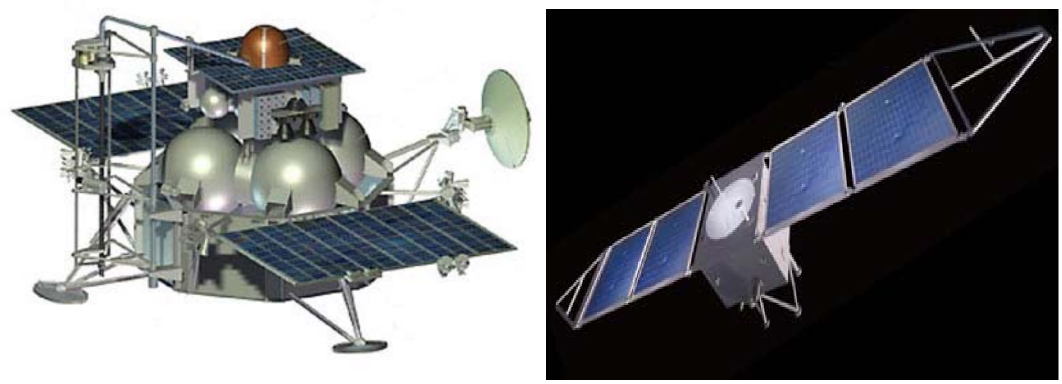

Figure 12. *Left:* Mars' moon Phobos will be visited by the Russian mission Phobos-Grunt that will return samples to Earth for scientific research. *Right:* China will send the Yinghuo-1 (YH-1) orbiter piggyback on the Russian mission. *Image Credit: Roskosmos, CNSA*

The Chinese Chang'E program foresees a lunar sample return mission by 2017. A Japanese NEO sample return mission Hayabusa-2 is under discussion. A general concept for a Mars Sample Return mission is discussed in detail in section 1.3.

The Moon's proximity to Earth allows lunar sample return to act as a testbed for robotic technologies enabling sample return from more distant planetary bodies. Between 1969 and 1972 the six Apollo missions that landed astronauts on the Moon returned a collection of over 2,000 soil samples (in total, 382 kg). However, Apollo samples were collected from a relatively small, equatorial area of the Moon that consists of conditions that are atypically for the Moon as a whole. Therefore many follow-on lunar sample return options have been evaluated in the last decade to bring back samples from other locations on the Moon, and take them into terrestrial laboratories to perform a full suite of investigations such as mineralogical, lithological, geochemical and geo-chronological analyses that are not possible to conduct via in-situ exploration.

The rationale for lunar sample return is described in (ICEUM1 1994 pp. 51-63, ICEUM9 1007 pp. 59-60, 81). Priority areas include the South Pole Aitken Basin impact melts (as a probe of lower crust and upper mantle material, and a constraint on the chronology of early bombardment), samples of polar volatiles, and from the youngest lunar volcanic units in Procellarum. Lunar samples can be returned with automatic missions such as MoonRise and Chang'E-3 or from future human missions to the surface.

Touch and go and surface-collection missions to the Moon have been investigated by the *Curation and Analysis Planning Team for Extraterrestrial Material (CAPTEM)*. Current mass estimates for a sample collection lander for Moon (or Mars) are in the range of 1000-1500 kg, and sample-return operations are complex.

Indeed, sample return technology is highlighted as the closest simulation for human exploration missions. Enabling technologies have been defined that can be used for many sample acquisition types and sample return mission scenarios, and include: sample acquisition methods; sample transfer mechanisms; sample container technology; low mass lander/ascent vehicle infrastructure; development of cold/cryogenic curation and storage protocols; development of non-silicate aerogel for dust sampling and environmental monitoring (CAPTEM 2007).

Sample return missions from asteroids are technically simpler as they require docking, rather than descent and ascent vehicles. Those automated sample returns will make use of curatorial and sample distribution facilities and methodologies developed for lunar samples, with potential added complexity imposed by planetary protection and contamination requirements.

Sample return missions will be much more affordable when conducted in cooperation and when worldwide expertise can be exploited. As seen for the Mars Sample Return mission, a multi-element mission scenario (discussed in detail in section 1.3) is currently anticipated that would provide opportunity for other nations to join and develop one of the elements. Cooperation with space powers that build major hardware (space probes, descent modules, ascent modules, etc.) and provide launchers can be augmented by other current and emerging spacefaring nations that provide either payload or manpower for joint missions. An Earth-based challenge is the curation of returned samples. Dedicated curation laboratories will need to be designed and constructed, and there may be specialized requirements for long-term preservation of ice samples and other volatiles, which would require storage and manipulation of such samples at sub-freezing temperatures. Building such a facility in international cooperation could foster extensive science and engineering collaboration in support of future international sample return missions.

2.6 International Lunar Base

Planetary science stands to be a major beneficiary of human space exploration. Human exploration of the Moon facilitates landing, operating and maintaining massive and complex scientific equipment as well as large-scale exploratory activities such as drilling. Human exploration can enable the intelligent and efficient collection of samples in large quantities, covering different locations and wider geographical areas (Cockell 2005, Crawford et al. 2009). Human exploration of the Moon allows for increased opportunities for serendipitous discoveries. Furthermore, it takes advantage of the fact that human beings can work intelligently and quickly, make sense of complexity and are able to troubleshoot unforeseen problems with inherent flexibility. Whereas robots are expendable, environmentally robust, continuously present, and characterized by physical durability, they suffer from limited intellectual capability, a slow data rate and power constraints. Overall, however, robotic exploration is comparatively cheap - both in terms of cost and risk. Humans, in turn, are mechanically flexible, able to communicate and can handle difficult terrain.

Humans can easily adapt to different situations, are intellectually flexible, but they require life support, and need to sleep and eat. Overall, human exploration is expensive. In order to make the best use of each system's advantages, a sensible long-term exploration roadmap should envision that robots and humans explore in synergistic partnership (Huntress et al. 2004; Cockell 2005; Hubbard 2005; Worms et al. 2009; Stetson et al. 2009; LEAG and ILEWG roadmaps).

Different enabling technologies that are needed to prepare for human exploration:

- Soft and precision landing
- Ascent and return capability
- Surface mobility
- Samples collection and in-situ analysis
- Advanced life support systems
- Radiation protection
- In-situ resource utilization (ISRU)
- Habitats as living and working area
- Energy production and storage
- Advanced robotic tools
- Astronaut assisted drilling
- Laboratory facilities

An international lunar base design requires the knowledge of many different disciplines, e.g., scientists, engineers, architects, industrial designers and medical personnel, see Figure 13. The vision for space exploration introduced by US President G. Bush envisaged the return of humans to the Moon by 2020.[10] ILEWG and LEAG have worked for more than a decade on concepts for a lunar base as an important milestone in their roadmap. The International Astronautical Federation (IAF)/International Academy of Astronautics (IAA) Lunar Development Forum acts as an informal group of world citizens in the development of space travel. They observe and participate in public discussions of current and future activities to the Moon and beyond, and have been publishing a newsletter "Lunar Base Quarterly" since 1990. In 2003 ESA's Human Spaceflight Vision Group has identified a Moon Base programme as a "societal project" and "an ideal stepping stone to another world that will open the door to future exploration of the solar system".[11] From a political point of view, the development of a lunar base as an example for international cooperation has been identified by the Beijing Declaration 2008.[12] A recent ESA-NASA architecture study[13] offered a unique possibility to discuss the requirements and implementation aspects of human lunar exploration missions by sharing capabilities. A *"Reference Architecture for Human Lunar Exploration"* has been completed by the International Space Exploration Coordination Group (ISECG), that includes 3 scenarios: Polar Lunar Outpost Scenario; Lunar Sortie Mission Scenario; and an Extended-Stay Mission Scenario, see also Appendix B.

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[10] http://www.nasa.gov/pdf/55583main_vision_space_exploration2.pdf
[11] http://esamultimedia.esa.int/docs/exploration/StakeholderConsultations/Moon_The_8th_Continent.pdf
[12] http://iaaweb.org/iaa/Scientific%20Activity/declaration.pdf
[13] http://www.nasa.gov/pdf/259237main_NASA_ESA_CAA-Report.pdf

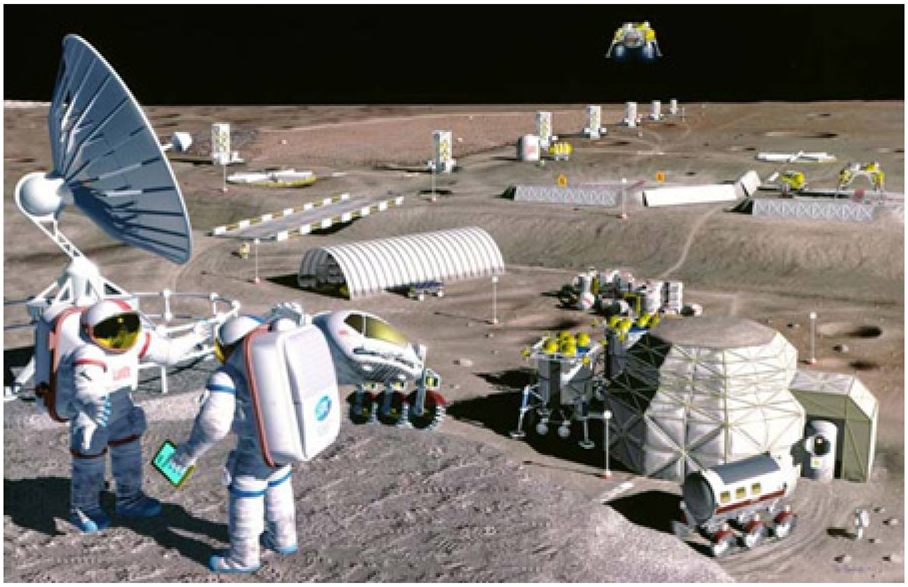

Figure 13. An artist's concept of a lunar outpost. *Image Credit: NASA GRC*

Considerations about the preparation for a human lunar base are described in ILEWG volumes (ICEUM4 2000 pp. 265-329, ICEUM9 pp. 192-223, ICEUM10 online) including transportation, architecture, power, life support systems, support technologies and robotics, operations, research and crew aspects.

The participants of ICEUM10/LEAG/ Space Resources Roundtable in 2008 addressed relevant key questions (see ICEUM10 Cape Canaveral declaration 2008, and presentations online at http://sci.esa.int/iceum10):

- What technologies need to be developed now for human return to the Moon?
- What are the critical elements for robotic development, habitats and hazard prevention?
- What is the current state of ISRU development?
- What are logical architectures and open implementation to allow effective integration of international elements?
- What opportunities are afforded within the current architecture for commercial on-ramps and how can these be facilitated?
- What are the needs/advantages of robotic missions for advancing lunar science and benefiting human exploration?
- What technology developments in robotic exploration are being conducted by various countries and agencies?
- How can human-robotic partnerships be used to develop and build a long-term presence on the Moon? What are the drilling challenges on planetary surfaces and how can they be addressed?
- How can future lunar surface activities be optimized?
- What precursor lunar surface experiments are of highest priority for space settlement/ commercial development?

An important element for lunar outpost architecture is the habitation module. Its configuration is an important element of the outpost architecture definition, and it is a function of the environmental requirements, of the radiation shielding approach, of the transportation/operation constraints and of the distribution of functions between habitat elements (separated or integrated in the habitation core). Looking at the different solutions analyzed in the past and at the several trade-offs performed on the radiation protection options, the cylindrical module option provides advantages. Additional deployable volumes will allow extending the internal volumes with limited impacts in mass and in transportation volumes. Radiation protection can be provided by bags filled with regolith.

The Center for Strategic and International Studies (CSIS) has made a cost estimate for a lunar base based on available concepts and publications. Costs for such an endeavour would be about $ 35 billion for a 4 people crew, with additional operating costs of about $ 7.35 billion assuming no ISRU (all material supplied from Earth; CSIS 2009).

Comprehensive studies and multidisciplinary analyses are needed to optimize the design of the human lunar outpost, the delivery of cargo logistics, and to develop evolutionary concepts for making use of local resources to enable sustainable human presence and fruitful operations on the surface of Moon and Mars. Concerning our understanding of the adaptation of the human body and its functions to the conditions of spaceflight, above all weightlessness, Europe has a leading role (e.g., Worms et al. 2009, HUMEX study[14]). Someday, larger lunar outposts may serve as a backup for civilization in case of a global catastrophe, like an asteroid impact or a pandemic. Requirements and implementation of human missions and space habitats throughout the solar system including an economic analysis have been recently compiled and analyzed (McNutt et al. 2010).

2.7 Antarctic bases as analogues for Moon and Mars

The US South Pole station is the model for a research base on the Moon or Mars. Antarctica, like the Moon or Mars is of scientific interest and is also an international arena where nations compete and cooperate with each other. The US constructed the base at South Pole over 50 years ago and continues to operate it. The US Antarctic Program has the biggest bases on that continent and does the most scientific exploration of any nation. Also like the Moon and Mars, Antarctica is a place where humans cannot live without technology providing life support. Antarctica is the only continent that did not have native people. The first base was emplaced by Argentina in 1904. The Scientific Committee on Antarctic Research (SCAR) is charged with the coordination of scientific research in Antarctica.[15] SCAR also provides international, independent scientific advice to the Antarctic Treaty system and other bodies. 31 countries pursue active scientific research programs in Antarctica and joined SCAR as full member.

[14] http://esamultimedia.esa.int/docs/gsp/completed/comp_sc_00_S55.pdf
[15] http://www.scar.org/about/

Looking at why and how the US South Pole station is operated is a way to see why and how we will operate a base on the Moon. The why traces back to competition and cooperation between nations. No nation may have any interest in “owning the Moon” but many space nations will certainly want to have a major say in any treaties or agreements that involve the Moon, for both scientific and commercial purposes. In the Antarctic, only nations that have active bases have a say in the treaties and agreements. While geopolitics may be what ultimately motivates the US program in Antarctica, the activities conducted at the South Pole station are all related to scientific exploration, see Figure 14. Commercial activities such as tourism are not supported by the US-operated infrastructure.

On the Moon as well, science will be what the astronauts do, although (due to the potential for commercial synergies) commercial activity may be conducted nearby, as well as in support of scientific research. Although the South Pole station has been in continuous operation since 1956 it is not a “settlement” or a “colony”. Scientists and support staff go to the station for a definite work period usually less than 1 year at a time. The crews change in an out so there is always someone at the station. This may also be how a Moon base is operated: crews coming in, going out. Like Antarctica, initial efforts will yield research bases, and not colonies or settlements - at least not right away.

Figure 14. *Left:* The Amundsen-Scott South Pole Station (US Antarctic Program) constructed in 1956 is continually inhabited by rotating crews. *Right:* The Belgium Princess Elisabeth Antarctica station is in use since 2009 and was constructed with eco-friendly construction materials. *Image Credit: NSF/USAP photo, International Polar Foundation/René Robert*

Another way that Antarctica is a model for the Moon is time. The South Pole station and the other US bases in Antarctica are over 50 years old and going strong. New discoveries are being made and students continue to flock to Antarctica to do their research. The US just opened a new base at the South Pole with a design lifetime of more than 30 years. Plans for a Moon base should also be built with this sort of long-term stay in mind. Like Antarctica, the more we study the Moon the more new questions will arise. We can only guess at what we might learn. All of this also applies to Mars. Long term research bases with rotating crews doing scientific exploration can be planned for > 100 years.

In Antarctica we have made long-term scientific exploration a reality. The US Antarctic Program has maintained a continuous research program in Antarctica for over 50 years. Scientists and other federal agencies propose research programs to the Office of Polar Programs OPP (NSF) ranging from astronomy to zoology. There are special programs for teachers, writers and artists, and news reporters. All aspects of the Antarctic Program, both logistics and science, are managed from the same office at NSF, which maintains a liaison and cooperative activities with the Antarctic programs of other nations working under the Antarctic Treaty System. On the national level, or if a multinational consortium were formed, this organizational approach could be used for a Moon/Mars program.

3. Protecting the lunar and martian environments for scientific research

It has been long recognized that the environments of the bodies most likely to be the targets of intense robotic and human exploration in the coming decades, namely the Moon and Mars, possess a degree of fragility and can easily be degraded if appropriate actions are not taken by the spacefaring nations. As an example, the total mass of the lunar atmosphere is ~ 100 tons, 90% of the molecular composition of which is still unidentified. The risks are various. According to the "Science Goal 8" of the NRC report (NRC 2007): *"Processes involved with the atmosphere and dust environment of the Moon are accessible for scientific study while the environment remains in a pristine state"* human lunar exploration that encompasses landings, lift-offs, and EVA's will inject tons of non-native gas into the atmosphere and transform the pristine environment. On the purely scientific level, we risk losing the ability to measure and understand the subtle pristine conditions of these bodies before they are irrevocably altered by human-induced activity. At the other end of the spectrum, we risk undertaking activities which may compromise non-scientific activities through environmental disturbance and modification.

Amongst the environmental factors that are relevant here are issues such as dust raising, seismic disturbance, biological contamination, site destruction, electromagnetic interference and radioactive contamination. The importance of these issues varies depending on the target body (Moon, Mars, asteroid, etc.), the disturbing activity (e.g., construction, in-situ resource exploitation, large scale human activities, power generation, communications infrastructure, etc.) and the potential activity which may be compromised (i.e., scientific, exploration, operations, etc.). However, all are likely to be of some significance on all target bodies.

It is instructive to mention some specific examples. The lunar farside has long been recognized as a scientifically valuable resource. It can provide a site for the location of low frequency radio telescopes for the exploitation of one of the few parts of the electromagnetic spectrum so far not accessed. This may provide insights into the cosmologically significant "epoch of re-ionization". The lunar farside provides shielding from terrestrial man-made and natural radio interference, and partial shielding from strong solar radio emission.

However, this unique location would clearly be compromised by inappropriate emplacement of lunar navigation and communication infrastructures. The IAA Cosmic Study on “the Protected Antipode Circle PAC” discusses that the farside of the Moon should be kept free from man-made Radio Frequency Interference (RFI) (Maccone 2008).

Some of the planetary protection issues are already quite well-covered by other bodies. In this category is the topic of biological contamination which has been extensively considered by the COSPAR Panel on Planetary Protection (PPP) and has resulted in the internationally recognized regulations to which most of the spacefaring nations adhere and which have been in place for 40 years. Other bodies which have an interest in these issues include the United Nations Committee on the Peaceful Uses of Outer Space (UN-COPUOS), the International Academy of Astronautics (IAA) and the International Astronomical Union (IAU), as well as individual space agencies. However, it seems that it would be of significant value to provide a focus in one place for all of these activities and in particular to give consideration to the impact on scientific research of these potentially deleterious activities. This may be particularly important at the present time when decisions taken in the US, still the largest individual nation in terms of space activities, mean that a great emphasis will be placed on the provision of space services by non-governmental, commercial interests. This may well mean that there is an even greater need than previously for highlighting the need for environmental protection in space as commercial pressures might relegate such considerations to a lower priority than previously, when space activities were the remit of only non-commercial interests.

The IAA Cosmic Study on “Protecting the Environment of Celestial Bodies” (PECB, currently in progress) examines current planetary protection controls for avoiding biological contamination and considers whether and how protection might extend to geophysical, industrial and cultural realms (Hofmann et al. 2010). In this context the establishment of planetary parks have been proposed by Cockell and Horneck (2006). The PECB Study report identified a variety of problems related to environmental protection, including the lack of suitable detection methodologies and an insufficient legal framework, a paucity of economic analytical tools, and a shortage of the political will to address the issues ahead (Hoffman et al. 2010; Race 2010).

The activities of COSPAR’s PEX should include at the very least the identification of the environmental contamination issues and where possible the quantification of their effects on science (and other) activities, legal aspects, and the identification of entities (both within and outside COSPAR) which have an interest and work already undertaken. It may well be that some irreversible degradation of these delicate environments is unavoidable. In this case, one of the duties of PEX will be to identify these and provide the impetus for the relevant scientific measurements to be made while they still can be done. A June 2010 Workshop on *"Ethical considerations for planetary protection in space exploration"* organized by COSPAR's Panel on Planetary Protection (PPP) advocated that COSPAR (PPP and PEX) and other bodies consider positive steps toward environmental stewardship for solar system bodies in addition to currently accepted regulations on planetary contamination.

4. Legal aspects of planetary exploration

The current legal regime governing Moon exploration is laid down in the UN Space treaties, specifically the 1967 Outer Space Treaty (OST) and the 1979 Moon Agreement (MA).[16,17] The former has been ratified by 100 states and parts of it could be said to apply even to non-parties on the basis of having become customary international law. The latter only has 13 state-parties, none of which are space powers (Australia, Austria, Belgium, Chile, Kazakhstan, Lebanon, Mexico, Morocco, the Netherlands, Pakistan, Peru, the Philippines, Uruguay). The OST applies to outer space, including the Moon and other celestial bodies. The MA applies to the Moon and other celestial bodies in the solar system other than the Earth, and reference to the Moon includes orbits around, or other trajectories to or around it. It does not apply to extraterrestrial materials that reach the surface of the Earth by natural means.

During the past four decades, neither the OST nor any of the subsequent treaties have established specific rules for activities related to the commercialization, exploitation, or use of natural resources of the Moon or other celestial bodies by either public or private entities. It should be noted that exploitation of lunar resources is a different topic, the "next step", and mainly the reason why the MA has remained of limited influence. The MA is the only of the five UN space treaties that explicitly addresses exploitation, and discussions about the meaning of Article 11, declaring the Moon and its natural resources the *"Common Heritage of Mankind"*, have sparked heated debate.

The MA prescribes that an international regime be set up to govern such exploitation, "as such exploitation is about to become feasible", and in relation herewith the question of the review of the MA is foreseen ten years after its entry into force. The MA entered into force in 1984, but no decision about review was taken since - perhaps because exploitation is still not "about to become feasible", but more likely because it did not provide for stable and predictable regulations on commercial, economic activity by either private interests or states parties. Currently attempts are being undertaken to "revive" the MA. Lunar exploration will benefit when new regulations encompass and balance a diverse set of stakeholder interests such as the protection of sensitive scientific areas on the Moon and commercial exploitation.

As regards to the important topic of the protection of the environment of celestial bodies, Art. IX OST provides a general obligation to protect the celestial bodies, including the Earth, from harmful contamination, which is not defined further. Article IX stipulates avoidance of harmful contamination, protection of exploration, and prevention of "adverse" changes on Earth from the return of extraterrestrial materials. The implementation of Article IX has resulted in a long and successful history of planetary protection (from living or organic contamination) of celestial bodies during space exploration.

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[16] http://www.unoosa.org/oosa/en/SpaceLaw/gares/html/gares_21_2222.html
[17] http://www.unoosa.org/oosa/en/SpaceLaw/gares/html/gares_34_0068.html

General (OST) principles governing Moon exploration include:

- Freedom of scientific investigation
- Province of all mankind
- Non-appropriation
- Compliance with international law including the UN Charter
- Prohibition of nuclear weapons and weapons of mass destruction (not defined)
- International cooperation and mutual assistance
- Non-interference with activities of other states
- International (state) responsibility and liability, also for activities carried out by private entities (which require "authorization and continuing supervision")

The MA adds on to this, including for instance:

- Use for exclusively peaceful purposes
- Prohibition of threats and hostile acts
- Prohibition of military and weapons-related activities
- Sharing of information on mission and its results
- Report to UN if discovery of organic life or phenomena endangering human life / health
- Notification of placement or use of radio-active materials on celestial bodies
- Any person on the Moon is considered an astronaut; refuge to be offered in case of distress
- Non-interference and consultations for surface and underground activities / settlements
- (Parts of) the surface or subsurface of the Moon, or natural resources "in place" may not become property of a state, Inter-Governmental Organization (IGO), Non-Governmental Organization (NGO), national organization, or natural person
- Samples may be collected and removed for scientific purposes, appropriate quantities may be used to support missions
- Moon and its resources are the *"Common Heritage of Mankind"* and an international regime is to be established when exploitation of resources is about to become feasible

A similar provision is contained in Art. 7 MA, but it qualifies such contamination as taking place "through the introduction of extra-environmental matter or otherwise". There is no prohibition of abandoning space objects on, or under, the surface of the Moon or on its trajectories. The IAA Cosmic Study on this subject will come up with new proposals, such as a differentiation of space activities and areas of the Moon, a new interpretation of the term "due diligence", the creation of "planetary parks" and a model for licensing procedures (Hofmann et al. 2010). Art. 7 also states the possibility of creating international scientific preserves for areas of the Moon having special scientific interests, thus providing a means for protecting parts of the lunar environment for scientific research.

Noteworthy is the 2008 *"Joint Statement"* in the UN-COPUOS Legal Subcommittee by the states parties, attempting to convince other states to ratify the Treaty by highlighting its advantages, pointing out that in conjunction with the OST, the MA is helpful for rejecting "idle claims to property rights" that have surfaced in recent years. Also, the International Institute of Space Law (IISL) has issued two statements, in 2004 and 2008, about claims to private property rights in space. The 2008 statement says: "International Law establishes a number of unambiguous principles, according to which the exploration and use of outer space, including the Moon and other celestial bodies, is permitted for the benefit of mankind, but any purported attempt to claim ownership of any part of outer space, including the Moon and other celestial bodies, or authorization of such claims by national legislation, is forbidden as following from the explicit prohibition of appropriation, and consequently is prohibited and unlawful."

Parallels for the regime governing the exploration and exploitation of the Moon can be found in the Law of the Sea (LOS) regime[18] and in the Antarctica regime.[19] The LOS regime also contains the term *"Common Heritage of Mankind"* with regard to resources of the deep seabed. Subsequent amendments have attempted to bring the system more in line with political and economic realities, and thus more readily acceptable by all states.

Antarctica and outer space have a lot in common. Both are hostile environments for humans, both are viewed with the potential for extensive and valuable resources of different types, and both are of intense interest for scientific research and exploration. As far as the Antarctic regime is concerned, the situation is somewhat different as several states have claimed sovereign rights over the area, which have subsequently been "frozen" but which are still "around" (this is not the case for the celestial bodies or parts thereof).

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 system is different from the legal regulation of outer space. The initial 1959 Antarctic Treaty has been supplemented by some 200 agreements and measures that have been developed and ratified via the ATCM process (Antarctic Treaty Consultative Meetings). Contrary to the OST, this provides for a flexible system that can easily be supplemented with additional measures that become binding upon the parties after their acceptance, without the need to amend the Treaty itself.

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18 http://www.un.org/Depts/los/index.htm
19 http://www.ats.aq/documents/ats/treaty_original.pdf

Contrary to the Antarctic Treaty System, the OST has not developed a comprehensive framework of mandated environmental protections similar to that afforded by the Antarctic Treaty System. Part of the difference is based on the lack of scientific information available about Earth versus outer space. Therefore the implementation of the OST's *"no harmful contamination"* article has focused on biological contamination avoidance, rather than on environmental protection, per se.

Although an understanding of Antarctic microbes and ecosystems has only recently developed, our understanding about flora, fauna, and environments on Earth is extensive, and can be applied to Antarctica for developing environmental and resource protections. Our limited knowledge about planetary environments, possible associated biota and dependent ecosystems in outer space makes it more difficult to establish appropriate levels of protection drawn directly from scientific analogies or legal precedents on Earth. It thus seems that the Antarctic Treaty framework is currently better prepared to tackle future challenges such as the growing interest in bioprospecting, increasing demand for tourism, and continued interest in mineral exploitation, oil and gas extraction, and expansion of economic activities (Race 2010).

However, given the wide variety of different environments found in outer space, notions like environmental stewardship, sustainability, preservation, resource use, exploitation, or adverse impacts on, under or above celestial bodies have yet to be defined and discussed in detail, because in many cases hostile space environments are incapable of sustaining life. Accordingly, there are no general guidelines for how to address the protection of lifeless environments in the solar system (Race 2010).

Many of the ideas identified as ways to move forward in outer space bear striking similarities to elements of the Antarctic Treaty's framework for environmental management, such as the designation of special management areas or protected zones, the development of a comprehensive environmental protection protocol, or the establishment of code(s) of conduct appropriate for different types of celestial bodies and environments and an elaboration of how these may apply to various categories of activities and different sectors (Race 2010).

It is necessary to clarify and complement the legal regime currently regulating the exploration of the Moon and other celestial bodies. The broad principles that were adopted in the 60s and 70s remain valuable today and the delicate balance reached at that time should be maintained. However, additional regulation to implement the treaties is necessary to ensure valuable, safe, economic, and broadly-based space exploration that will benefit both current and future generations. The possibility provided by Art. 7 MA to create international scientific preserves may be an interesting option to reach a similar situation as the one that was agreed for Antarctica, which has an initial focus on science, but still allows for commercial activity (e.g., tourism, support and supply operations) while controlling irreversible contamination of sensitive environments.

5. Synergies and Recommendations

Solar system exploration in robotic/human synergy will spur scientific discoveries, strategic partnerships, technology progress, and public inspiration. Broad engagement of all stakeholders (**governments, space agencies, commercial space sector, space entrepreneurs, and public constituencies**) will be required to create a sustainable global space exploration platform (Ehrenfreund and Peter 2009). A global space exploration program will aid in the development of sufficient capability to implement an innovative long-term roadmap that will allow new countries to join, and, become engaged in an overall effort that can unite all stakeholders, see Figure 15.

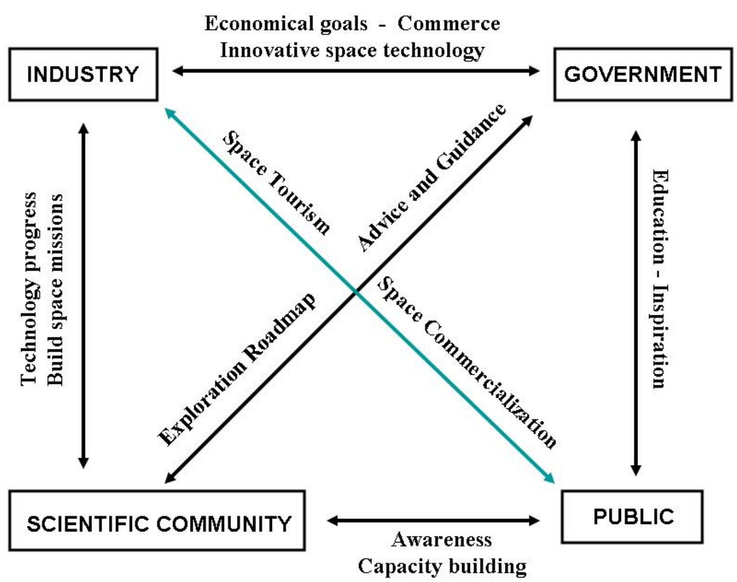

Figure 15. Relationships of the main stakeholders in global space exploration (Ehrenfreund and Peter 2009).

It is important to note that national and international science and analysis working groups have already invested considerable effort in developing science roadmaps, mission planning and mission scenarios (see sections 1 and 2, Appendices). Future planning of space exploration should build on this substantial body of work, taking into account the latest scientific discoveries, technological development and the geopolitical context. For each exploration mission a minimum science payload should be considered.

Vision:

Efforts have to be made to reiterate and reinforce the role of the scientific community in defining and fulfilling robotic and human space exploration goals: exploring the Moon, Mars and near-Earth asteroids. Exploration of the Earth-Moon-Mars-space can provide answers to **key questions of our existence: how our solar system formed, whether life exists beyond Earth, and what our future prospects may be**.

The roadmaps of the national and international working groups discussed in section 1 show a reoccurring theme, namely to explore the

"Origins and evolution of our solar system and life"

The study of this theme encompasses the integrated investigation of:

- The Earth-Moon system
- The bombardment record on the Moon
- The most primitive asteroid material in the solar system
- Possible life on Mars (past or present)
- Human endeavors to visit the Earth-Moon-Mars-space

Focusing on this theme can provide a clear and credible vision for a global planetary exploration science roadmap. **A shared vision is crucial to give overall direction, and to unite stakeholders in sustaining a global space exploration program.** The focus should be complementary to existing programs of robotic exploration of the solar system.

Synergies of robotic/human exploration:
Planetary exploration calls for the development of an integrated human/robotic science strategy. Robotic precursor missions in support of human exploration are proposed by several exploration stakeholders and spacefaring nations. Such missions can test engineering capabilities, identify hazards, probe resource utilization and scout future destinations. Robotic precursor missions are also needed to perform technology and flight system demonstrations, and to deploy infrastructure to support future human exploration activities. **Human-robotic partnerships will increase productivity, reduce costs and mitigate risks.** For example the Moon is an excellent place to develop capabilities for minimally-contaminating equipment, facilities, and human support, as well as a location to build and test capabilities that will be required for future exploration. NEOs represent both a rich future resource for space exploration and a threat to humankind. These objects are pathfinders for missions to bodies with higher gravity. Mars has been the subject of intense fascination to the public and is accessible to spacecraft launched from Earth every 26 months. **Forging a partnership between robotic science and human exploration can help provide a unified long-range vision for planetary exploration** (e.g., Huntress et al. 2004; Stetson et al. 2009). Clearly there is no conceptual separation between human and robotic exploration; rather the distinction is a result of bureaucratic structures within the national space agencies. Improved organizational development within space agencies should ensure ways to better work around this divide in order to realize a more effective, synergistic and sustainable space exploration program.

Synergies of Earth science and space exploration:
Oceans represent the largest ecosystem on Earth, but less than 5 % of the water column and less than 2 % of the ocean floor are currently explored. Twelve humans have walked on the Moon, but only 2 scientists have visited the deep part of the ocean. **Efforts should continue in order to exploit synergies of Earth science and space exploration.**

It is clear that protecting life on Earth requires similar concepts and information as investigations of life beyond Earth. Instrumentation and data handling, and the technology to probe the surface and subsurface likewise require similar methods. Recently, a network has been proposed to enable interchange of scientific insights involving both these communities, leading to the development of new common policies (Chung et al. 2010 and references therein). Others have argued for recognition of the potential of Mars exploration to contribute to the understanding of global climate change on Earth by investigating synergies of martian climate history and the emergence (or lack) of life on Mars (Stetson et al. 2009). Furthermore, Earth observation programs from the ISS or from the lunar surface have been on the agenda of space agencies and science working groups (see section 1).

Planetary protection of planetary scientific assets and related legal frameworks:
There is currently a need to consider environmental protection in space as commercial plans introduce new pressures beyond those experienced with past activities by exclusively non-commercial interests. As space activities diversify, it is necessary to clarify and complement the legal regime currently regulating the exploration of the Moon and other celestial bodies. The interest of society, and even future commercial activities, must be balanced against the temptation to proceed without restraints for the purposes of immediate gain, only to find that great knowledge and great value have been displaced by unrestrained contamination or uncontrolled alteration of valuable solar system environments. **Additional regulations need to be elaborated to ensure valuable, safe, economic, and broadly-based exploration that encompass and balance a diverse set of stakeholder interests and will benefit both current and future generations.** The creation of international scientific preserves similar to the ones agreed for Antarctica may be one facet of such regulations. Recently, a COSPAR international workshop on planetary protection undertook the first organized discussion on the diverse environmental management, legal, and ethical considerations that are involved. It was concluded that COSPAR and other bodies **should consider environmental stewardship** for solar system bodies additionally to accepted regulations for planetary contaminations.

Participatory exploration:
In order to achieve highly ambitious space exploration goals for exploring the inner solar system both robotically and with humans, space agencies must improve and expand their efforts to inform the public about what they are doing, and why. Various public surveys suggest that the part of society that supports the space program and believes that space exploration is a noble endeavor does not necessarily agree that governments should allocate substantial financial resources to achieve those exciting space missions. **To attain long-term support for a sustainable space exploration program, it is advisable to adopt new participatory communication techniques aimed at informing and engaging the public, as well as reaching the younger generation** in particular (Ehrenfreund et al. 2010b). The International Space University (ISU), for example is active in raising cultural awareness in the space domain, representing an environment of intercultural spirit through its “3I” approach (International, Interdisciplinary, Intercultural dimensions).

The ESSC report *"Humans in Outer Space"* discussed recently how space activities worldwide are now entering an era where the contribution of the humanities is crucial besides political, industrial and scientific considerations to nurture public constituencies for long-term space exploration (ESSC 2008). **It is necessary to engage public stakeholders in the planning and the process of space exploration.** Consultation, collaboration and consensus building with public stakeholders will help to ensure sustainability of a long-term space exploration program and foster aspirations for exploring the unknown.

Stepping stones toward a global space exploration program:

How can the space exploration community learn to cooperate on truly international level while engaging newly emerging spacefaring nations in a meaningful way? Small steps to perform preparatory research for exploration as described in section 3 can improve and ease technology transfer and cultural competition issues while ensuring the development of effective interfaces that must form the major prerequisites and building-blocks for a future global space exploration program. For example, **COSPAR can take a leadership role in supporting a stepwise approach to this new era of cooperation in space exploration** and help create effective and efficient partnerships for the future.

Expertise obtained from an Earth-based field research program could serve as a foundation to create a truly terrestrial international exploration testbed - where established and emerging space actors (scientists, engineers, space entrepreneurs etc.) from many different cultures and nations can learn to work together. In cooperation with ESF, NSF, and science foundations of other spacefaring nations, an **"International Earth-based field research program"** is an ideal stepping stone toward global space exploration when built on the execution of a consensus roadmap established by many international partners. Similarly, COSPAR should support the **"Science exploitation of the International Space Station enabling exploration"** which should be accomplished during its prolonged lifetime (beyond 2020). Scientific contributions to the ISS from China and India have been discussed, and could strengthen existing partnerships while fostering new ones. The science participation of developing countries in ISS research is supported by UN bodies. Collaborating on small missions, such as an **"International CubeSat program in support of exploration"**, can enable a new generation of low-cost payload opportunities for "piggyback rides" to Moon and Mars. CubeBots can serve as low-cost complementary surface components on planetary surfaces. Both, CubeSats and CubeBots can address preparatory research supporting exploration missions (e.g., concerning human exploration risks, planetary protection etc.). These new payloads can provide ample opportunities for developing countries that are financially limited in their participation to a global space exploration program while enabling mature space actors to tap into a global robotics talent pool.

In preparation for larger endeavors, a system-of-systems approach with small exploration missions (e.g., small orbiters and landers as described in the "**Robotic Village concept of ILEWG"**), will initiate and enhance international collaboration, as well as science, commercial and public engagement opportunities.

Sample return missions to the Moon, near-Earth asteroids and Mars will be much more affordable when conducted in international cooperation. Multi-element mission scenarios provide opportunities for several spacefaring nations to join and develop one of the elements. International sample curation facilities will foster extensive science and engineering collaboration and exploit worldwide expertise. The Antarctic Program, which involves both logistics and science, is managed by the effective liaison and cooperation between Antarctic programs of a number of nations working under the Antarctic Treaty System. **An organizational approach based on the Antarctic Program could be used as a model for international Moon and Mars bases.**

In the preparation phase toward a global space exploration program, COSPAR should promote the **development of synergistic science programs with open and full access to each others' data**. Several active systems are already available: NASA's Planetary Data System (PDS) archives[20], the Analyst's Notebook (a tool for accessing a number of PDS-compliant archives that demonstrates the value of creating standards-compliant archives to support cross-instrument and cross-mission data searches)[21], and ESA's Planetary Science Archive (PSA)[22] (compatible with PDS). The International Planetary Data Alliance (IPDA)[23] is recognized by COSPAR as the official body for definition of planetary science archive standards. All those efforts could play an important role in **standardization and construction of interoperable systems** for a future global space exploration program.

6. Conclusion

The year 2010 will lead to important decisions for a future global space exploration program. The US NRC Decadal surveys on *"Planetary Science"* and *"Biological and Physical Sciences in Space"* will provide science directions for space exploration in the next decade.[24,25] In October 2010 the EU-ESA consultation process on space exploration will be completed with a high-level conference in Brussels. This conference will further define Europe's future in space exploration and its position within the international space exploration community. Japan's space policy and JAXA's exploration roadmap are currently under review. The Canadian Space Agency CSA is implementing its new space plan to participate in human and scientific exploration of the Moon, Mars and asteroids. All space partners involved in the International Space Station are engaging in new programs that prepare for ISS research during its prolonged lifetime. Finally, the International Academy of Astronautics IAA, which is celebrating its 50th anniversary, is preparing for a "Space Agency Summit" in November 2010 that will address 4 key areas; among them are "Human Space Flight" and "Planetary Robotic Exploration." The attempt is to reach broad consensus on international cooperation in order to consider new concrete initiatives.

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[20] http://pds.nasa.gov/
[21] http://an.rsl.wustl.edu/
[22] http://www.rssd.esa.int/index.php?project=PSA
[23] http://planetarydata.org/
[24] http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_050845
[25] http://sites.nationalacademies.org/SSB/CurrentProjects/ssb_052412

The objective of the COSPAR Panel on Exploration (PEX) is to provide the best, independent science input to support the development of a global space exploration program and to safeguard the scientific assets of solar system objects. PEX will engage with COSPAR Commissions and Panels, ESF, NSF, and other science foundations, IAA, IAF, UN bodies, and IISL to support in particular national and international space exploration working groups and the new era of planetary exploration.

<u>PEX will take specific actions to:</u>

- Support an *"International Earth-based field research program"*
- Support the *"Science exploitation of the ISS enabling exploration"*
- Support an *"International CubeSat program in support of exploration"* for developed and developing countries
- Support the ILEWG *"Global Robotic Village"*
- Support studies and precursor activities toward *"International human bases"* (Moon, Mars) using research activities in Antarctica as a model
- Support *"Synergies between space exploration and Earth science"*
- Support the COSPAR Panel on Planetary Protection in *"Protecting the lunar and martian environments for scientific research"*
- Support *"Environmental stewardship"* to protect the Earth-Moon Mars space
- Support *"Activities in capacity building"* for space exploration
- Involve and *"Engage the public stakeholder"* and youth in participatory ways

These PEX activities will contribute to fostering a global space exploration program that stimulates scientists in current and emerging spacefaring nations as well as developing countries to participate in research aimed at answering outstanding questions about the origins and evolution of our solar system and life on Earth and possibly elsewhere.

"The only thing that will redeem mankind is cooperation."

Bertrand Russell (1872-1970)

COSPAR Panel on Exploration, June 2010

APPENDICES

A. Individual roadmaps of national Space Agencies
B. Roadmaps of national and international Science and Analysis Working Groups: ILEWG, LEAG, ILN, LSI, MEPAG, NAR, IMEWG, ISECG

A. Individual roadmaps of national Space Agencies

In the new millennium major spacefaring countries have developed plans for ambitious space exploration programs to explore the Earth-Moon-Mars space.

	United States	Russia	Europe	Japan	China	India
Launch System	D	D	D	D	D	D
Human Transport Capabilities	D until 2011 then UD	D	NE	NE	D	UD
Astronaut Corps	D	D	D	D	D	UD
Satellite Manufacturing Capabilities	D	D	D	D	D	D
Deep Space Network	D	D	D	D	UD	UD
Moon Missions	D	D	D	D	D	D
Mars Missions	D	D	D	D	UD	UD
Other Planetary and NEO Missions	D	D	D	D	NE	NE
ISS Participation	D	D	D	D	NE	NE
IMEWG, ILEWG, GES Participation	D	D	D	D	D	D

	United States	Russia	Europe	Japan	China	India	Launch
Moon Orbiters	 GRAIL LADEE		 ESMO	 Selene 2 Selene 3	Chang'E-2	 Chand- rayaan-2	2010 2011 2012 2013 >2015
Moon Landers and/or Rovers		Luna-Glob Luna-Res./1 Luna-Res./2	 Polar lander		 Chang'E-3		2012 2013 >2015 2018
Small Moons and NEO Missions		Phobos-Grunt					2011
Martian Orbiters	 MAVEN Exomars		 Exomars		Yinghou-1		2011 2013 2016
Martian Landers	Exomars						2016
Martian Rovers	Exomars		Exomars				2018
Mars Sample Return	planned		planned				>2020

Table 1. *Top:* Overview of space exploration capabilities of the major space actors (adapted from Ehrenfreund et al. 2010a). D: developed; UD: under development; NE: not existent. *Bottom:* Future planned space exploration missions and approximate launch dates are listed (as per June 2010). Hayabusa, the first asteroid sample return mission returned to Earth in June 2010. The Google Lunar X-Prize lander(s) are anticipated in 2013. The Exomars mission is conducted in NASA/ESA collaboration in 2016 and 2018, respectively.

NASA/US: In February 2010, US President Barack Obama proposed, amid the economic crisis and overall freeze on discretionary spending, a five-year $100 billion budget request for NASA. This plan for fiscal years 2011-2015 calls for cancelling the Bush administration's Constellation program and pursuing a new "flexible path" strategy that focuses on technology development and on creating opportunities for the commercial sector to enable more ambitious exploration endeavors, including human space flight (Augustine Report 2009). This new plan would send "robotic precursor missions to the Moon, Mars and its moons, Lagrange points and nearby asteroids to scout targets for future human activities and identify the hazards and resources that will determine the course of human expansion into space." The new US space exploration roadmap includes a visit to an asteroid after 2025 and reaching Mars orbit by the mid-2030's. President Obama indicated that he plans to support the utilisation of the International Space Station (ISS) until at least 2020. NASA will construct a stripped-down version of the Orion crew capsule that would be launched unmanned to ISS by around 2013 to carry astronauts home in an emergency (lifeboat for the ISS). Plans for a new heavy-lift vehicle that can carry crew capsules and supplies needed to reach deep space will be finalized until 2015.

Current and near-future lunar missions include the Lunar Reconnaissance Orbiter (LRO) in orbit since June 2009. In 2011 the Gravity Recovery and Interior Laboratory (GRAIL) will fly twin spacecraft in tandem orbits around the Moon for several months to measure its gravity field in unprecedented detail. The Lunar Atmosphere and Dust Environment Explorer (LADEE) is a mission that will orbit the Moon in 2012 and determine global density, composition and time variability of the highly tenuous atmosphere and dust environment. Participation to the International Lunar Network (ILN) for geophysical studies is in the development phase for the period > 2015. Mars is also a main target of US exploration activities. The Mars Science Laboratory (MSL) to be launched in 2011 will explore the martian surface, followed by the Mars Atmosphere and Volatile EvolutioN (MAVEN) spacecraft, scheduled for launch in late 2013. A long-term ESA-NASA cooperation on the exploration of Mars has been developed with the Exomars mission that will be conducted in 2016 and 2018, respectively. The 2016 mission is ESA-led and launched by NASA. ESA will provide a Mars Orbiter and a 600-kg Entry, Descent and Landing (EDL) Demonstrator. The Orbiter will accommodate scientific instruments for the detection of atmospheric trace gases. The 2018 mission is NASA-led and includes the ESA Rover Exomars that will share the journey to Mars with the NASA rover Mars Astrobiology Explorer-Cacher (MAX-C). Both rovers will be integrated in the same aeroshell and will be delivered to the same site on Mars, see section 1.3. A number of Exploration Precursor Robotic Missions are planned in this decade that would enable human exploration in the next. The US NRC Decadal surveys on *"Planetary Science"* and *"Biological and Physical Sciences in Space"* will provide science directions for robotic space exploration and exploitation of the ISS in the next decade.

Europe: Europe (defined as the European Space Agency ESA and its member States) has a long-standing tradition of space exploration, and has participated with great success in many activities on its own and in partnership with other spacefaring countries. It has made significant contributions to robotics missions and human spaceflight.

ESA expanded its robotic presence in the solar system with the visit of several bodies including Mars (Mars Express) and the Moon (SMART-1, European instruments on Chandrayaan-1). SMART-1, Europe first lunar mission demonstrated technologies for future science and exploration missions. ESA has contributed 3 European instruments (C1XS, SIR2 and SARA) for the Indian lunar Chandrayaan-1 mission and a ground station control and data reception and collaboration for the Chinese lunar Chang'E-1 mission. ESMO, the European lunar science Moon orbiter, is developed as education and inspiration activity with a network of universities for launch in 2013. ESA has conducted a set of generic lunar studies, and design concepts for lunar landers (LEDA, EuroMoon, Lunar Exploration Study LES3, Moon-NEXT). It is now performing industrial studies for a mid-class lunar lander. ESA and NASA have conducted a comparative lunar architecture assignment with a focus on the development of a European logistic cargo lander launched on Ariane. ESA has recently developed a long-term cooperation with NASA to use all opportunities to go to Mars, starting with Exomars in 2016 and 2018, see NASA/US.

Europe has recently demonstrated its willingness and capability to provide essential contributions to the International Space Station (ISS) through the Columbus orbital laboratory, the Automated Transfer Vehicle (ATV), and other ISS infrastructures (Node 2, Node 3). The political dimensions of space exploration and its economic and strategic applications are in the process of being fully acknowledged in Europe (Horneck et al. 2010). Several steps and milestones have been completed since the first European Space Policy adopted in 2007 by 29 EU/ESA Member States, illustrating the growing political awareness of space exploration in Europe. In particular following the 1st EU-ESA International Conference on Human Space Exploration held in Prague on 23 October 2009 a one year political process has been initiated to develop a European approach to space exploration. The EU jointly with ESA launched a consultation process of various stakeholder communities (scientific, industry, national agencies) in spring 2010 with three workshops that will lead to the second high-level conference on exploration in October 2010 in Brussels. The workshop on "Science and Education in Space Exploration" (March 2010) identified areas of European leadership and concluded that space exploration can sustain European identity and integration. ESA is also developing technical scenarios for exploration relying on a modular approach based on different building blocks.

Roskosmos/Russia: The Russian government adopted several years ago a new Federal Space Program (2006-2015). The 10-year plan includes as major goal the development and maintenance of orbital space constellations in the interest of Russia's socio-economic benefits. Russia's Security Council approved also a draft space policy for the period until 2020. This policy aims at retaining Russia's status as a leading space power. The Phobos-Grunt mission that will visit the martian moon Phobos in 2011 will mark a revival of the Russian planetary exploration program. Phobos-Grunt will return samples from Phobos to Earth for scientific research and study the Mars environment concerning atmosphere, dust storms, plasma and radiation.

The Russian lunar program encompasses Luna-Glob (a Moon orbiter and landing probe) in 2012/2013, and further in the decade Luna Resource/1 (a lunar lander in combination with the Indian Chandrayaan-2 orbiter and mini-rover), and the Luna Resource/2 mission that is currently defined as a multi-element mission (lander, rover, re-transmitting satellite). Following the decision of the US to terminate shuttle operations in 2010, and the existence of a gap before the entry into operation of the next US, Chinese or commercial human space flight vehicle, Russia will play a crucial role in providing support to the ISS.

JAXA/Japan: In the document "Basic Plan for Space Policy" released in June 2009, it is stated that the government will continue to achieve world-leading scientific results, such as probes of Venus and Mercury and the astronomical observations by X-rays and strengthen cooperation in space science. Japan launched its lunar probe (Selene/Kaguya) that impacted on the Moon after successful operation in June 2009. The Japanese Hayabusa mission explored the near-Earth asteroid Itokawa and returned to Earth in June 2010. Moon orbiter Selene 2 and 3 are planned for this decade. Scientific investigation of the Moon remains a high Japanese priority. Japan's participation to the ISS focuses on the development and exploitation of the Japanese Experiment Module Kibo. There is currently a debate within Japan on whether to participate in the extension of ISS utilization until at least 2020. Japan's space organization and policy is currently under review by the new Japanese government.

CNSA/China: China is currently building up a space program with high ambitions. Among the main targets are a robotic program for exploring the Moon and human spaceflight. In 2007, China launched its first lunar probe, Chang'E-1, as the first mission of the China Lunar Exploration Program (CLEP), with participation of ESA for mission support and ground station control and data collection. Chang'E-2 orbiter as the first mission within in the Phase II of the overall Chinese Lunar Exploration Program will be launched in 2010, aiming to have a more detailed survey on the elected landing site at the same time all other scientific payloads are remaining the same as Chang'E-1. The core mission of the second phase of CLEP is Chang'E-3, which is a lander and rover. It is currently under development and will be launched 2012-2013. Phase III of the CLEP is a sample return mission, which is planned for launch in 2017-2018. In addition to their lunar-focused activities, the Chinese intend to send the Yinghou-1 (YH-1) orbiter with the Russian Phobos-Grunt mission in 2011 to conduct space-environment, atmospheric, gravity, and surface-imaging studies of Mars.

A taikonaut in 2008 performed China's first extravehicular activity (EVA). Further missions on manned spaceflight include the breakthrough of the rendezvous and docking technology followed by the space lab mission. The ultimate goal of Chinese manned space flight program of this stage is to build up a permanent space station. In 2011, China will launch Tiangong-1, the first space lab module, followed with an unmanned Shenzhou-8 to dock with it. China has, on at least two occasions, publicly announced desires to join the International Space Station (ISS) program.

The Chinese Shenzhou spacecraft, launching atop a Long March 2F rocket provides a man-rated option as an alternate means of transportation and a second capability (apart from Soyuz) for manned access to the ISS in the next decade. Currently, there is no official announcement of any Chinese manned lunar mission, but it is believed that this topic is under discussion within the space community and space scientists in China. Recently, China has announced that two female taikonauts have already been selected.

ISRO/India: India is embarking into new space endeavors that include space exploration and human spaceflight. ISRO, which previously had focused on space application efforts has developed new scientific programs and launched Chandrayaan-1 in 2008 to the Moon, as the first Indian planetary mission. International instruments on this mission include C1XS, SIR2 and SARA delivered by ESA, M3, mini-SAR by NASA, and RADOM from Bulgaria. A second robotic lunar mission in collaboration with Russia is in the planning stage for 2012. ISRO would contribute an orbiter - Chandrayaan-2 - and a mini-rover to the Russian mission. The combined mission Luna Resource/2 will be launched with an Indian rocket. Recent technological studies on human spaceflight scenarios have led to a proposal to the Indian government for a first manned mission in the 2016 timeframe and an ambitious program of human spaceflight to follow. The government has not yet accepted this proposal.

CSA/Canada: Canada is an active ISS partner and trains an astronaut corps. Canada has been involved in space exploration for more than 25 years with its robotics, science and astronaut corps contributions. As part of its space plan, the CSA objectives are to ensure full utilization of the ISS, to be active in on-orbit robotics servicing, to be a partner in the Mars Sample Return series of missions, to participate in human and scientific exploration of the Moon, Mars and asteroids. Canada views space exploration as a collaborative endeavour and aims at contributing key technologies and science expertise to international missions. These contributions should be critical, welcome and as much as possible visible. Canada contributes to the world space effort especially with NASA (i.e., participation to NASA's Phoenix mission) and ESA but also with other space agencies. In addition, the CSA is an active participant to international groups such as the International Space Exploration Coordination Group (ISECG) and the International Mars Exploration Working Group (IMEWG) and sees these groups as essential to engage the dialogue amongst spacefaring nations.

KARI/South Korea: Even though it started later than its Asian counterparts, Korea is making notable investment and progress in its indigenous space capability. It continues to prepare for a successful launch of the Korea Space Launch Vehicle-1 in cooperation with Russia. Korea also plans to send spacecraft to the Moon including a lunar lander. Korea's first astronaut, Yi So-yeon went to the ISS aboard a Russian Soyuz in April 2008.

B. Roadmaps of national and international Science and Analysis Working Groups:

1. ILEWG - The International Lunar Exploration Working Group

ILEWG is a public forum sponsored by the world's space agencies to support "international cooperation towards a world strategy for the exploration and utilization of the Moon - our natural satellite" *(International Lunar Workshop, Beatenberg (CH), June 1994).*

The Forum is intended to serve three relevant groups:

1. Actual members of the ILEWG, e.g., delegates and representatives of the participating space agencies and organizations - allowing them to discuss and possibly harmonize their draft concepts and plans in the spirit of the Beatenberg Declaration
2. Team members of the relevant space projects - allowing them to coordinate their internal work according to the guidelines provided by the charter of the ILEWG
3. Members of the general public and of the Lunar Explorer's Society who are interested and wish to be informed on the progress of the Moon projects and possibly contribute their own ideas

ILEWG has several task groups that advance work in the areas of lunar science exploration, living and working on the Moon, key technologies, utilization of lunar resources, infrastructure of lunar bases, surface operations, society, law, policy and commerce, public outreach, education and also supports the Young Lunar Explorers. Regular declarations of ILEWG summarize findings and give recommendations that are summarized by a large community (ILEWG 2009). ILEWG logical and progressive roadmap was defined in 1995 and is de facto implemented with the recent fleet of orbiter precursors for science, technology and reconnaissance. The second phase with number of coordinated surface elements supported its orbital assets will constitute the "Global Robotic Village". The third phase will see the deployment of large systems in preparation for astronauts. The fourth phase will see the transition from short missions to permanent human presence at international bases.

Working areas of ILEWG:

- Science of, on, and from the Moon
- Living and working on the Moon
- Key technologies
- Utilization of lunar resources
- Infrastructures for lunar bases
- Surface operations
- Society, law, policy, and commerce
- Public outreach, education, multicultural aspects; and
- Young Lunar Explorers.

Website: http://sci.esa.int/science-e/www/object/index.cfm?fobjectid=34125

2. LEAG - The Lunar Exploration Analysis Group

The Lunar Exploration Analysis Group (LEAG) is responsible for analyzing scientific, technical, commercial, and operational issues associated with lunar exploration in response to requests by NASA. The LEAG serves as a community-based, interdisciplinary forum for future exploration and provides analysis in support of lunar exploration objectives and their implications for lunar architecture planning and activity prioritization. It provides findings and analysis to NASA through the NASA Advisory Council within which the LEAG Chair is a member of the Planetary Science Subcommittee (PSS). LEAG has published in 2009 an extended document that incorporates previous efforts into an integrated plan for sustained lunar exploration. The Lunar Exploration Roadmap LER includes many investigations divided into 3 subthemes:

SCIENCE:	Pursue scientific activities to address fundamental questions about our solar system
FEED FORWARD:	Use the Moon to prepare for potential future missions to Mars and other destinations
SUSTAINABILITY:	Extend sustained human presence to the Moon to enable eventual settlement

Overall the roadmap is intended to layout an *integrated* and *sustainable plan* for lunar exploration that will allow NASA to transition from the Moon to Mars (and beyond) without abandoning the lunar assets built up using tax payer dollars.

Website: http://www.lpi.usra.edu/leag/

3. ILN International Lunar Network

The International Lunar Network (ILN), aims to provide an organizing theme for all landed science missions in this decade by involving each landed station as a node in a geophysical network. 8-10 or more nodes are under discussion.
In the ILN concept, each node would include some number of "core" capabilities (e.g., seismic, heat flow, laser retro-reflectors) that would be extant on each station, reflecting prioritized lunar science goals articulated in the National Research Council's study (NRC 2007). Individual nodes could and likely would carry additional, unique experiments to study local or global lunar science. Such experiments might include atmospheric and dust instruments, plasma physics investigations, astronomical instruments, electromagnetic profiling of lunar regolith and crust, local geochemistry, and in-situ resource utilization demonstrations. A lunar communications relay satellite is under discussion to support activities on the lunar farside.

Website: http://iln.arc.nasa.gov/

4. LSI - The Lunar Science Institute

The Mission of the NASA Lunar Science Institute LSI and its member investigators is to advance the field of lunar science by:

- Carrying out and supporting collaborative research in lunar science, investigating the Moon itself and using the Moon as a unique platform for other investigations

- Providing scientific and technical perspectives to NASA on its lunar research programs, including developing investigations for current and future space missions

- Supporting development of the lunar science community and training the next generation of lunar science researchers; and

- Supporting Education and Public Outreach by providing scientific content for K-14 education programs, and communicating directly with the public.

The NASA LSI has assembled 7 science teams in order to advance the field of lunar science. It does so by developing a partnership program with international science organizations (currently involved are Canada, South Korea and UK).

Website: http://lunarscience.arc.nasa.gov/

5. MEPAG - Mars Exploration Program Analysis Group

MEPAG is NASA's community-based forum designed to provide science input for planning and prioritizing Mars future exploration activities for the next several decades. It is chartered by NASA's Lead Scientist for Mars Exploration at NASA HQ, and reports its findings at FACA-sanctioned meetings of the Planetary Science Subcommittee of the NASA Advisory Council (NAC). Open to all interested members of the Mars exploration community, MEPAG conducts analyses of planning questions that are presented to it. MEPAG regularly evaluates Mars exploration goals, objectives, investigations and priorities on the basis of the widest possible community outreach. NASA's Mars Program Office, located at JPL, has been directed to manage the logistics associated with the operations of MEPAG on behalf of NASA's Space Science Enterprise. MEPAG holds open townhall-style meetings approximately twice per year. MEPAG's analysis efforts are discussed at regular meetings that are held approximately twice per year, and the results are documented in reports that are posted on the MEPAG web site. The cost of operating MEPAG is managed by the Mars Program Office at JPL. MEPAG is managed by an Executive Committee consisting of the past and present Chairs, NASA's Lead Scientist for Mars Exploration, two Mars Chief Scientists, the chair of the MEPAG Goals Committee (the only standing committee currently maintained by MEPAG), and an ESA Mars liason.

MEPAG additionally maintains a mailing list of all currently active Mars scientists, and that mailing list is used to convey information about Mars-themed conferences and workshops, and other announcements of relevance to the community. As of February 2010, this mailing list had about 2000 names.

Website: http://mepag.jpl.nasa.gov/

6. The NASA Astrobiology Roadmap

The NASA Astrobiology Roadmap provides guidance for research and technology development across the NASA programs in space, Earth, and biological sciences. This roadmap, updated approximately every five years, is prepared by scientists and technologists from government, academia, and the private sector. Research goals and objectives detailed in the roadmap address three basic questions: 1) How does life begin and evolve? 2) Does life exist elsewhere in the Universe? And 3) What is the future of life on Earth and beyond? Science goals in this roadmap identify key paths of research: understanding the nature and distribution of habitable environments in the Universe, exploring for habitable environments and life in our own solar system, understanding the emergence of life, determining how early life on Earth interacted and evolved with its changing environment, understanding the evolutionary mechanisms and environmental limits of life, determining the principles that will shape future life, and recognizing signatures of life on other worlds and on early Earth. Science objectives outlined in the roadmap identify high-priority efforts for the next three to five years. The roadmap identifies four basic principles that are fundamental to implementing NASA's astrobiology program: 1) Astrobiology is multidisciplinary in content and interdisciplinary in execution; 2) Astrobiology encourages planetary stewardship through an emphasis on planetary protection; 3) Astrobiology recognizes broad societal interest in its endeavors; and (4) Public interest in astrobiology warrants a strong emphasis on communication, education, and public outreach. Astrobiology is an important and growing focus of planetary exploration

Website: http://astrobiology.nasa.gov/

7. IMEWG - International Mars Exploration Working Group

The International Mars Exploration Working Group (IMEWG) has representatives from all space agencies and major institutions participating in Mars Exploration. The IMEWG was conceived at a meeting at Wiesbaden, Germany, May 1993, and since then has met two times a year to discuss the general strategy for the exploration of Mars.

The present charter of the IMEWG (approved in 1996) is as follows:

- Produce and maintain an international strategy for the exploration of Mars
- Provide a forum for the coordination of Mars exploration missions
- Examine the possibilities for the next steps beyond the currently defined missions

The intent of IMEWG is to lay out a broad long-range strategy for Mars exploration. The strategy must be sufficiently specific that intermediate and long-range goals can be identified, and yet sufficiently flexible that the means and schedule for achieving the goals can accommodate to programmatic and fiscal realities. The strategy must also be consistent with missions already funded or planned. The recommendations issued by IMEWG have been well met in various space organizations and led to actions that improve the complementarity of the planned and approved mission scenarios.

Website: http://www.atmos.washington.edu/~mars/IMEWG_strategy.html

8. ISECG - The International Space Exploration Coordination Group

The International Space Exploration Coordination Group (ISECG) was established in response to *"The Global Exploration Strategy: The Framework for Coordination"* (GES 2007) developed by fourteen space agencies and released in May 2007. This GES Framework Document articulated a shared vision of coordinated human and robotic space exploration focused on solar system destinations where humans may one day live and work. Among the many Framework Document findings was the need to establish a voluntary, non-binding international coordination mechanism through which individual agencies may exchange information regarding their interests, plans and activities in space exploration, and to work together on means of strengthening both individual exploration programs as well as the collective effort.

The goals of ISECG are: 1) to establish a voluntary, nonbinding international coordination mechanism that enhances information exchange concerning interests, objectives, and plans in space exploration; and 2) to strengthen both individual exploration programs and the collective effort (ISECG 2008). The ISECG promotes and transmits non-binding findings and recommendations. Toward this end, the ISECG has established several dedicated working groups such as the International Space Exploration Coordination Tool INTERSECT which facilitates cooperation (ISECG 2009) by integrating mission and capabilities information provided by participating agencies. The ISECG International Architecture Working Group is also nearing completion of a Reference Architecture for Human Lunar Exploration. Future efforts will focus on risk reduction strategies and the creation of a global exploration roadmap. These activities represent a useful first step toward globally coordinated exploration.

Website: http://www.globalspaceexploration.org/

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