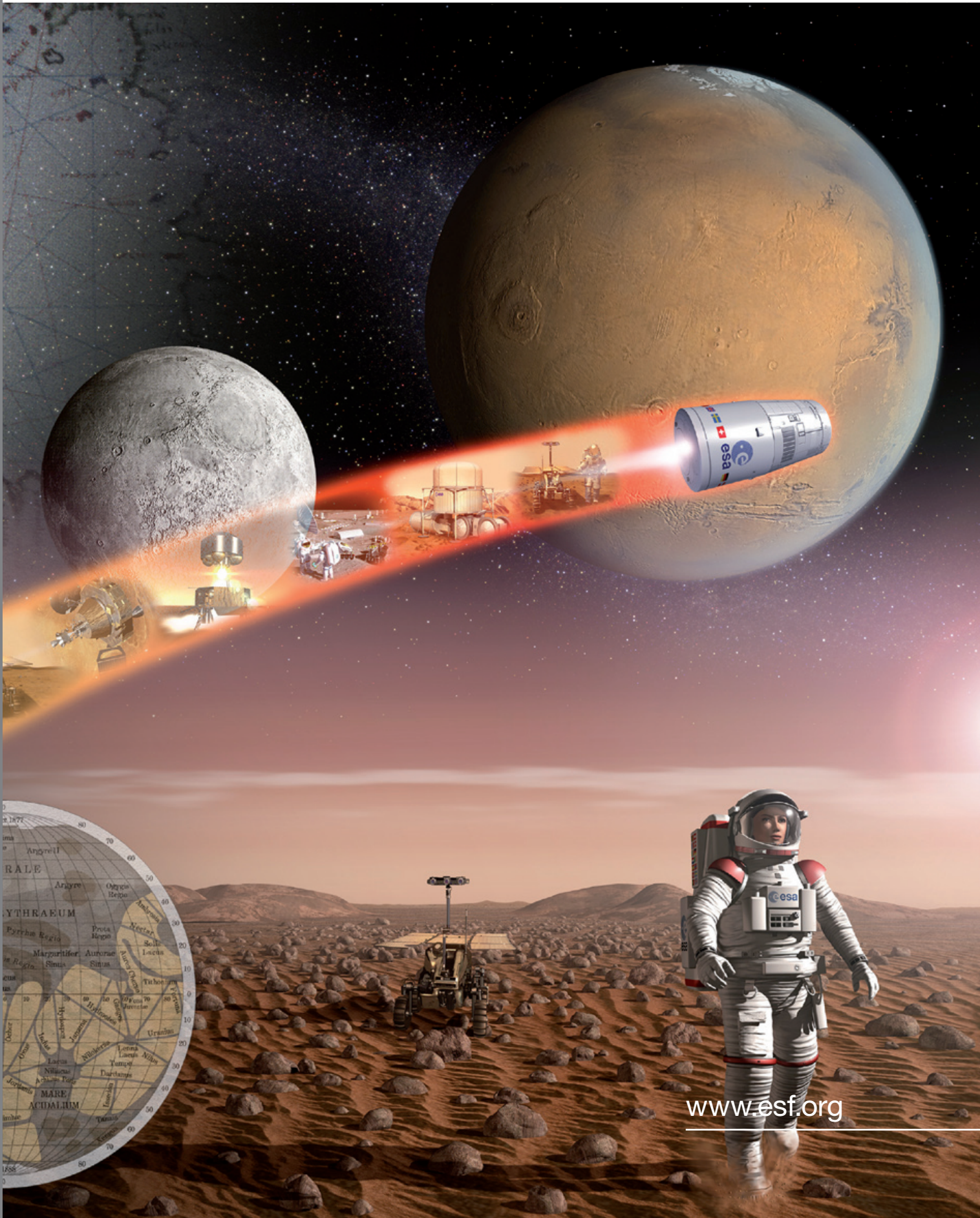


# Science-Driven Scenario for Space Exploration

Report from the European Space Sciences Committee (ESSC)



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The European Science Foundation (ESF) was established in 1974 to create a common European platform for cross-border cooperation in all aspects of scientific research.

With its emphasis on a multidisciplinary and pan-European approach, the Foundation provides the leadership necessary to open new frontiers in European science.

Its activities include providing science policy advice (Science Strategy); stimulating cooperation between researchers and organisations to explore new directions (Science Synergy); and the administration of externally funded programmes (Science Management). These take place in the following areas: Physical and engineering sciences; Medical sciences; Life, earth and environmental sciences; Humanities; Social sciences; Polar; Marine; Space; Radio astronomy frequencies; Nuclear physics. Headquartered in Strasbourg with offices in Brussels and Ostend, the ESF's membership comprises 77 national funding agencies, research performing agencies and academies from 30 European countries.

The Foundation's independence allows the ESF to objectively represent the priorities of all these members.

This work was carried out under ESA contract No. 21012

The European Space Sciences Committee (ESSC), established in 1975, grew out of the need for a collaborative effort that would ensure European space scientists made their voices heard on the other side of the Atlantic. More than 30 years later the ESSC has become even more relevant today as it acts as an interface with the European Space Agency (ESA), the European Commission, national space agencies, and ESF Member Organisations on space-related aspects. The mission of the ESSC is to provide an independent European voice on European space research and policy.

The ESSC is non-governmental and provides an independent forum for scientists to debate space sciences issues. The ESSC is represented ex officio in ESA's scientific advisory bodies, in ESA's High-level Science Policy Advisory Committee advising its Director General, in the EC's FP7 Space Advisory Group, and it holds an observer status in ESA's Ministerial Councils. At the international level, ESSC maintains strong relationships with the NRC's Space Studies Board in the U.S., and corresponding bodies in Japan and China.

# Foreword

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*“To explore is to adapt to situations you did not plan for”*  
Mike Horn, Earth explorer, November 2007

In 2005 the ESA Directorate for Human Spaceflight, Microgravity and Exploration (D-HME) commissioned a study from the ESF’s European Space Sciences Committee (ESSC) to examine the science aspects of the Aurora Programme in preparation for the December 2005 Ministerial Conference of ESA Member States, held in Berlin. A first interim report was presented to ESA at the second stakeholders meeting on 30 and 31 May 2005. A second draft report was made available at the time of the final science stakeholders meeting on 16 September 2005 in order for ESA to use its recommendations to prepare the Executive proposal to the Ministerial Conference. The final ESSC report on that activity came a few months after the Ministerial Conference (June 2006), and attempted to capture some elements of the new situation after Berlin, and in the context of the reduction in NASA’s budget that was taking place at that time; e.g. the postponement *sine die* of the Mars Sample Return mission.

At the time of this study, ESSC made it clear to ESA that the timeline imposed prior to the Berlin Conference had not allowed for a proper consultation of the relevant science community and that this should be corrected in the near future. In response to that recommendation, ESSC was asked again in the summer of 2006 to initiate a broad consultation to define a science-driven scenario for the Aurora Programme. This exercise ran between October 2006 and May 2007. ESA provided the funding for staff support, publication costs and costs related to meetings of a Steering Group, two meetings of a larger ad hoc group (7 and 8 December 2006 and 8 February 2007), and a final scientific workshop on 15 and 16 May 2007 in Athens. As a result of these meetings a draft report was produced and examined by the Ad Hoc Group. Following their endorsement of the report and its approval by the plenary meeting of the ESSC, the draft report was externally refereed, as is now normal practice with all ESSC-ESF reports, and amended accordingly.

The Ad Hoc Group defined overarching scientific goals for Europe’s exploration programme, 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. Mars was further recognised as the focus of that programme, with Mars sample return as the recognised primary goal; furthermore the report clearly states that Europe should position itself as a major actor in defining and leading Mars sample return missions.

We are glad to be able to provide this final report to ESA, European national space agencies and the space science community. We hope that it will help Europe better define its own challenging, albeit realistic, roadmap for the exploration of the solar system.

Finally we would like to thank gratefully Professor Gerhard Haerendel, who was chairing the ESSC-ESF during the most part of this evaluation and who contributed to a very large extent to its successful completion.

**John Marks**  
Chief Executive  
European Science  
Foundation

**Jean-Pierre Swings**  
Chairman  
European Space  
Sciences Committee

December 2007

# Acknowledgements

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This strategy report has been reviewed by individuals chosen for their diverse perspectives and expertise, in accordance with procedures used by the European Science Foundation (ESF). The purpose of this independent review was to provide additional critical comments to assist ESF and the European Space Sciences Committee's (ESSC) Ad Hoc Group in making the published report as sound as possible and to ensure that it meets standards for objectivity, evidence and responsiveness to the study charge. The contents of the review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their participation in the review of this report:

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**An anonymous reviewer**

The ESSC and the ESF are also very grateful to Professor Gerhard Haerendel, all Steering Committee members, Ad Hoc Group members, and participants to the Athens workshop, for their dedication and hard work in support of this evaluation activity. The contribution of Agustin Chicarro in compiling the table appearing in Appendix 1 of this report is gratefully acknowledged.

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# Science-Driven Scenario for Space Exploration

## 1. Introduction

The international space exploration programme foresees multiple robotic and human missions in the solar system in the coming decades. A global strategy is being developed jointly by a large number of space-faring nations and organisations. In Europe a major planning effort is ongoing in the framework of the ESA Aurora Programme, Europe's Exploration Programme (EEP) that envisages the launch of ExoMars in 2013 as a first step towards a robust and renewed effort for exploration.

A roadmap for Aurora started to be developed in 2001. Furthermore a strong heritage exists in Europe within both the mandatory programme, with several solar system missions having been launched, as well as the various ELIPS-funded research programmes. This allows Europe and ESA to face new explorative challenges making use of solid and successful experiences.

In view of the evolving international context, ESA has initiated further analysis and definition of Europe's potential role in the exploration initiative by identifying scientific, technological and societal priorities. For the science part ESA has asked the ESSC-ESF to conduct a broad consultation in support of the definition of a science-driven European scenario for space exploration. To this end the ESSC has appointed a Steering Committee to supervise the whole evaluation exercise and an Ad Hoc Group (AHG) to conduct the evaluation itself. The final report to ESA received the agreement of the AHG before it was approved by the ESSC and ESF. The AHG met twice, on 7 and 8 December 2006 and 8 February 2007. At their second meeting the AHG decided to split the work among five sub-groups: Near Earth Objects (NEOs), Mars robotic missions, Mars human missions, Moon robotic missions, and Moon human missions (Appendix 4).

In addition a workshop was organised by ESF to consult with the relevant scientific community. Eighty-eight scientists and national representatives from ESA Member States met in Athens on 15 and 16 May 2007 in a workshop organised by ESF and sponsored by ESA (Appendix 5).

This draft report features the recommendations from the AHG to ESA's Human Spaceflight, Microgravity and Exploration Directorate (D-HME), supplemented by the findings laid out by the participants in the Athens workshop. Part of this outcome has already been taken into account by ESA's D-HME as input to their architecture studies.

## 2. General scientific goals of Europe's Exploration Programme

Whether done robotically or with humans, or both, science and the search for knowledge are an essential part of exploration. Exploration without human spaceflight does lack an important societal and even scientific interest and perspective. Hence human spaceflight should be integrated in Europe's Exploration Programme (EEP) in a synergistic way at all stages of development of the programme. However the first phases of this programme should be robotic.

**A vision for Europe should therefore be to prepare for a long-term European participation in a global endeavour of human exploration of the solar system with a focus on Mars and the necessary intermediate steps, initiated by robotic exploration programmes with a strong scientific content.**

Drivers for human exploratory missions include science, technology, culture and economic aspects. Above all the search for habitability and, hence, for life beyond the Earth, has been considered as one of the intellectual driving forces in the endeavour to explore our solar system. This aspect was central in establishing the overarching science goal of the EEP.

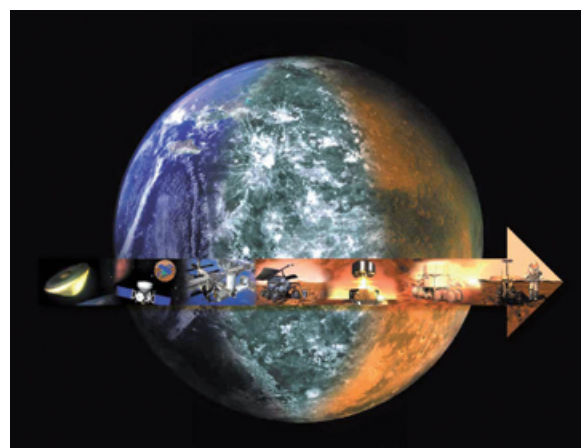


Figure 1: Artist's impression of the Aurora programme roadmap

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## General Recommendations

1. The overarching scientific goal of EEP should be called: 'Emergence and co-evolution of life with its planetary environments', with two sub-themes pertaining to the emergence of life, and to the co-evolution of life with their environments.
2. EEP should focus on targets that can ultimately be reached by humans.
3. The first steps of EEP should be done robotically.
4. International cooperation among agencies engaged in planetary exploration should be a major feature of EEP, realised by concrete joint ventures such as some of the elements mentioned in the 14 space agencies' Global Exploration Strategy document.
5. Mars is recognised as the focus of EEP, with Mars sample return as the driving programme; Europe should position itself as a major actor in defining and leading Mars sample return missions.
6. There is unique science to be done on, of and from the Moon and of/on Near Earth Objects or Asteroids (NEOs/NEAs). Therefore, if these bodies are to be used as a component of EEP, further science should be pursued; the Moon could thus be used as a component of a robust exploration programme, including among others: geological exploration, sample return and low-frequency radio astronomy, technology and protocol test-bed.
7. The role of humans as a unique tool in conducting research on the Moon and on Mars must be assessed in further detail.
8. Since EEP's ultimate goal is to send humans to Mars in the longer term, research on humans in a space environment must be strengthened. Beyond the necessary ongoing and planned biological research and human presence on, e.g. the international space station (ISS) or in Antarctica, opportunities to this end might also arise in the context of an international lunar exploration programme. ESA needs to ensure the continuity of the necessary expertise in the longer-term by supporting the relevant groups.
9. Europe should develop a sample reception and curation facility, of joint interest to ESA's science and exploration programmes. A sample distribution policy needs to be established between international partners early in the process.
10. Understanding the processes involved in the emergence of life in the solar system, e.g. through in-depth exploration of Mars, is crucial to understanding the habitability of exoplanets, and remains a high scientific priority that should be supported by ground-based laboratory studies and specific experiments in space.
11. Once EEP is funded and running it is suggested that a series of international science and technology exploration workshops be set up in the near future, which for Europe could be organised by ESF and the community and co-sponsored by ESA, in order to better define the mission concepts and technological choices relevant to the above goals as this multi-decadal programme develops.

## 3. European capabilities and achievements

In order to remain a key player with its unique expertise, Europe needs to maintain and further develop its independent capabilities for planetary exploration so that it can prepare independent access to planetary exploration. This should be done by developing its key enabling technologies and scientific domains of expertise. Niches already exist, e.g. for hardware development in the field of life sciences, geophysical sciences and planetary sciences. Europe has already developed scientific capabilities benefiting human spaceflight in human physiology, countermeasures and radiation health.

Hence Europe certainly does not start from scratch on this exploration programme. Examples of these niche developments and achievements are:

- Mars Express, which on the one hand has demonstrated Europe's technical capabilities to fly an independent planetary orbiter mission (Huygens and Rosetta lander are examples of landing devices), and on the other hand has provided ample information on the geology, mineralogy and atmosphere of Mars, which is important for its further exploration (Refs. 1-3).
- Concerning our understanding of the adaptation of the human body and its functions to the conditions of space flight, above all weightlessness, Europe has a leading role from studies in space as well as in long-term simulation experiments. This is also valid for psycho-physiological aspects of human space flight (Refs. 4, 5).
- Regarding our understanding of the regulations at the cellular and sub-cellular level (signal transduction and gene expression) and their responses to the gravity stimulus European researchers are very strong in this field (Refs. 6-8).
- There is a long heritage in Europe relating to the biological effects of cosmic radiation and its dosimetry. The first, and so far only, radiobiological experiments outside our magnetosphere were done with the European Biostack experiments during the Apollo missions (Refs. 9-11).
- European scientists have developed a prototype for a self-sustained bio-regenerative life support system (Melissa, Ref. 12).
- SMART-1, the first European mission to the Moon has demonstrated new technologies for propulsion, navigation and miniaturisation. It performed reconnaissance of geology, composition, polar regions and possible landing sites as a precursor to future international exploration (Ref. 13).
- Just as the International Space Station is a key element for some of these achievements, the French-

Italian Concordia base in Antarctica is an asset in preparatory studies on long-term isolation, water and waste recycling and other relevant aspects.

A very strong synergy will need to exist between Aurora and ELIPS, ESA's programme for life and physical sciences in space. ELIPS was reviewed, and its second phase was evaluated by the ESSC-ESF through a very large user consultation process, which took place in 2005 (Ref. 14). A similar exercise will take place in the first half of 2008.

Specific recommendations were made in the final report of that evaluation process, pertaining to the detection of signatures of life on other planets or bodies, and to the understanding of the limits of life on Earth.

**Several recommendations in that report address the core competences of Europe in that domain, and list specific contributions by the exo/astrobiology and planetary exploration communities, including:**

- development of life-support systems including bio-regenerative approaches
- early detection control and prevention of microbial contamination
- investigation of the radiation field in space and its biological effects

These studies require preparatory robotic space missions, supportive ground-based studies, and use of the ISS and Concordia.

## 4. The robotic exploration of Mars

The study of other planets has told us how Earth is unique. Clearly, life, even if it formed elsewhere in our solar system, has developed significantly only on Earth. Moreover, Earth presents a unique combination of geological characteristics: plate tectonics and a global magnetic field, an oxygen-rich atmosphere (for the last two billion years, produced by life itself) and a hydrosphere, and a satellite (the Moon) that stabilises the obliquity and thus the climate.

A habitable planet appears to be a complex and perhaps rare object. But how are geological evolution and habitability coupled? Will life interact with the host planet to make it all the more habitable? On Earth, life has interacted with global geological processes to make it habitable for large, multi-cellular life forms.

We may thus see life as a geological process. On Mars, it may have once appeared and eventually have lost the race against faster developing adverse geological processes. For instance, one hypothesis is that Mars had a warmer and wetter environment protected





Figure 2: ExoMars rover

by a magnetic field. But the protecting field died before life had significantly evolved and the atmosphere was eroded and went into a negative greenhouse cycle that resulted in the cold desert planet we see today<sup>1</sup>.

One may thus envisage Mars as a 'paleo-habitable' planet. What are the links between geology and life? Has Mars ever hosted life? If so, for how long, and under what conditions, was Mars able to sustain life? There is a deep need to understand how the geological evolution and habitability are coupled, and Mars offers a unique opportunity to investigate this crucial question on a second planet.

One of the most significant and important aims of robotic exploration of Mars is therefore to assess the habitability of Mars and its capability to have sustained life, if it ever emerged, and for how long. This in turn is crucial to understanding the habitability of exoplanets.

**Another essential aspect is to continue a relevant research on Earth to enable the determination of possible habitats, the mode of preservation of expected bio-signatures (differentiate traces of life from abiotic processes) in these habitats, and the unambiguous recognition of life beyond Earth. Indeed, characterising bio-signatures involves studies of early traces of life in the Precambrian Earth and taphonomy<sup>2</sup> of cells in various preservational environments of present Earth.**

The search for extinct and extant life on Mars refers to the 'Emergence of life' theme of EEP, whereas the search for extant life and characterisation of past and present habitability conditions deal with the 'Co-evolution of life with their environments' theme of EEP. If a robotic mission should discover traces of extinct or even extant life on Mars, this would stimulate the interest of scientists and of society at large for a continued human exploration of a second inhabited planet. Therefore, a further important goal of robotic exploration is its ability to demonstrate the necessity for a detailed human exploration of Mars in order to answer the question of whether or not there is extant life at various locations on Mars.

**Mars is recognised as the focus of EEP, which should first be led robotically, with sample return(s) from the red planet as its driving series of programmes; furthermore Europe should position itself as a major actor in defining and leading Mars sample return missions.**

Recent evaluations conducted with international partners are pointing towards the possibility of implementing a 'caching' system for future Mars landers, to be retrieved by MSR missions. Such a caching system could then be developed by Europe for ExoMars, which would then include samples obtained by drilling. This approach could both increase the science return from future Mars landers and also, spread over several missions and a longer period of time the technological risk attached to potential multiple point failures of a single mission. Hence one possible option would be for Europe to develop such a caching system for ExoMars. This option must be weighted, however, against the added complexity of the mission which could easily generate unacceptable delays and/or budget increase.

Beyond the experience gained with Mars Express a roadmap for EEP should articulate the following steps:

- Step 1: Exomars will be the first and therefore critical step in EEP; it will offer the European community a leading position, by exploring Mars with scientific objectives as diverse as exobiology, geology, environment and geophysics. Securing this mission for a 2013 launch must therefore be the top priority of Europe's robotic exploration programme
- Step 2: Mars sample return programme

1. Recent observations made by the OMEGA spectrometer of ESA's Mars Express probe seem to point to a quite different scenario, that Mars never had enough CO<sub>2</sub> and methane to generate such an effect. If confirmed this would mean that the red planet has always been cold and dry, even if major impacts could have modified this situation for brief periods of time (Ref. 15).

2. Study of a decaying organism over time.

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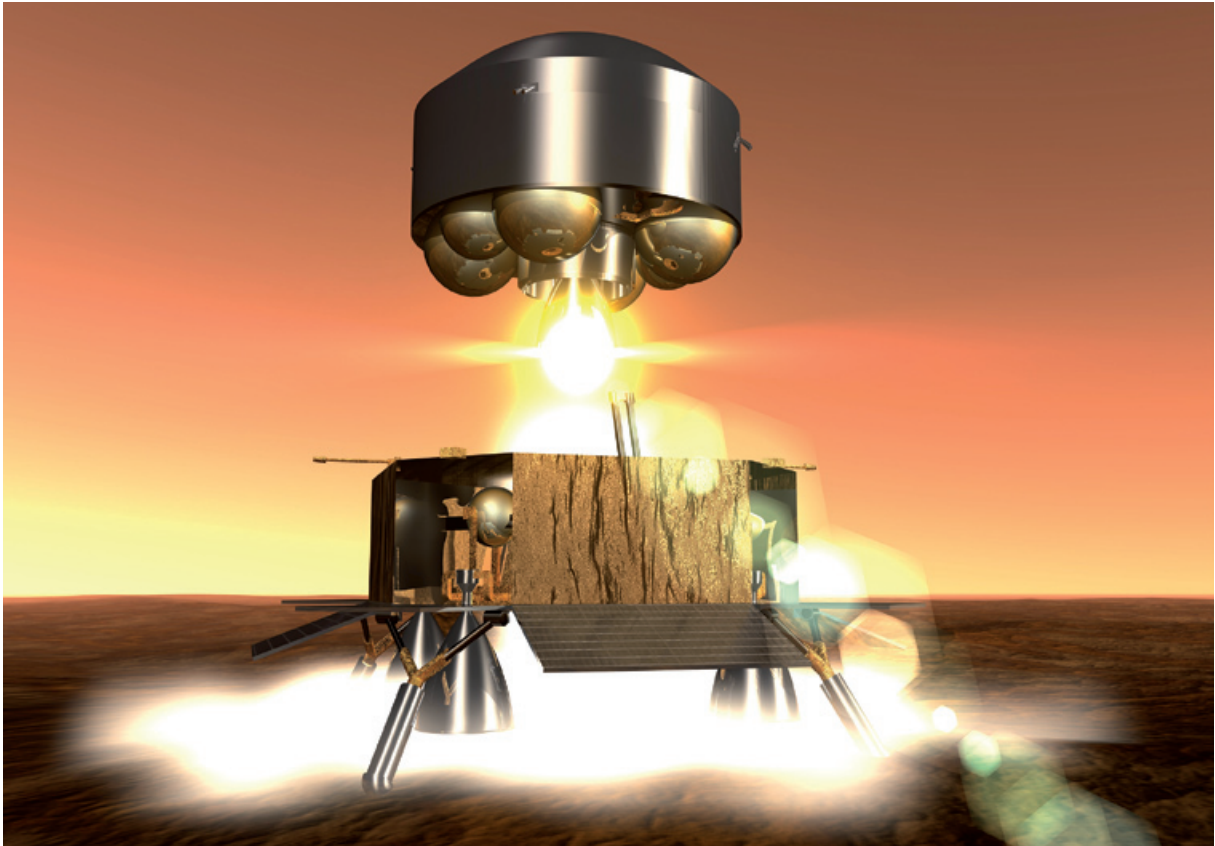


Figure 3: Artist's view of the Mars sample return ascent module lifting off from Mars

- Step 3: Human mission programme, for which Europe needs to prepare itself to be a major partner

To participate in this endeavour with a major role, Europe has a number of assets but needs to develop or improve them, or identify the assets that international partners could contribute to its programme, such as:

- improving and expanding Europe's world-class instrumentation capability;
- Europe's industrial capability to build an infrastructure on Mars;
- international collaboration history of Europe;
- development in Europe of 5-10W radioisotope-based, long-lived (e.g. over 5 years) power devices to open new opportunities for European-led international collaboration.

There are two separate but equally important purposes for the exploration of Mars using robots. One purpose is science-driven, the achievement of specific goals that will aid in the understanding of the potential origin of life beyond Earth and the evolution of a

rocky planet. Another purpose is preparation, in terms of technology development and demonstration, for the human exploration of space. Scientific drivers for the exploration of Mars are:

- Is, or was, Mars inhabited? Were conditions for long-term life sustainability ever reached on Mars?
- How has Mars evolved as a planet? This will include origin and evolution of the Martian atmosphere, hydrosphere, cryosphere, lithosphere, magnetosphere and deep interior.
- To what extent are the present surface conditions of Mars supportive or hazardous to life (to putative indigenous or terrestrial life forms, including humans)?

To explore Mars with robots, the approach must consider both the science goals and human exploration requirements of any programme.

## a. Exploration of Mars from orbit

- High resolution imagery, spectroscopy and any other relevant techniques of remote sensing of planetary surfaces;

- Planetary geodesy and all relevant techniques of probing of planetary sub-surface and interior;
- Identification of potential landing sites (recent changes in morphology; landslips);
- Monitoring and measuring atmosphere, climate and weather (dust storms) over the solar (activity) cycle for reconstructing the evolution of the Martian atmosphere and early Martian environment.

#### b. Exploration of Mars with landers

- Probing of deep interior by seismology and other relevant techniques such as deep drilling (metres to tens of metres);
- Life detection;
- Ability to undertake direct imagery and any other relevant analysis of surface and sub-surface regions. This will require precision landing;
- Analysis of different rocks and ice. This will require the ability to move;
- Assessment of ISRU<sup>3</sup>: regolith composition, surface radiation levels, depth profile of radiation penetration, etc.
- Setting up a weather station network in conjunction with seismology stations.

#### c. Exploration of Mars with returned samples

- Very high precision analysis at sub-micron level;
- Enabling technology demonstration for human exploration.

Finally, the Ad Hoc Group has discussed limitations of exploring Mars with robots. Sections 6 and 7 address these aspects in more detail.

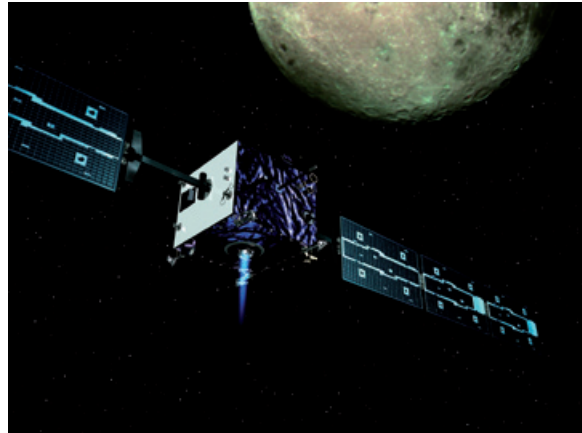


Figure 4: SMART-1 mission at the Moon

## 5. Robotic lunar exploration

Europe should actively participate in the manned exploration of the Moon and Mars. The first step is to continue with robotic missions and prepare for manned missions to Mars. An intermediate step could be to contribute to an international venture to establish a human base on the Moon; the third step would be to contribute to the implementation of manned missions to Mars and back to Earth again.

The Moon as a target for exploration missions offers a number of outstanding opportunities for science of, on and from, the Moon. The main objective would be the discovery, exploration, and use of the '8th continent' (Ref. 16), and the harvesting of unique information from the Moon as an archive of the formation and evolution of the solar system. Furthermore EEP should consider the use of the Moon as a large laboratory in free space.

While the Moon is geologically less active than Mars, its structure (core/mantle, chemical stratification) and geophysical processes are far from being understood and require in situ measurements (rover, seismic network, heat-flow probes etc.) at various locations.

**We also require in situ analysis and sample return for geochemical analyses of regions not yet sampled (e.g. South Pole Aitken basin, far-side high-**

3. In Situ Resource Utilisation

4. This statement must be qualified: from the Apollo seismic data, the Moon has more than 1 seismic event of body wave magnitude larger than 5 on the Richter scale. We also know that the Moon has a high Q and maximum ground movements that last between 10 and 60 minutes. Hence the Moon's surface is stable only insofar as such seismic events can be accounted for (Refs. 18-21).

# Science-Driven Scenario for Space Exploration

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lands, young basalts in Procellarum, far-side maria). Experience gained in developing precision landing, sample collection and return, and rover techniques for the Moon will be advantageous for subsequent Martian missions.

A particularly interesting aspect of the ‘science of the Moon’ is that lunar evolution is closely related to the evolution of the Earth. All external effects that have acted on life on Earth in the past will have acted on the Moon as well. Like a ‘museum’ the Moon has acted as a ‘witness plate’ of past meteorite bombardments of the Earth-Moon system and will harbour traces of past activity of the Sun (Ref. 17).

**Identifying promising locations for reading these archives/records could first be done robotically, although the full scientific exploitation of them is likely to require renewed human operations on the lunar surface.**

Robotic exploration of the Moon should also provide the prerequisite information for a safe presence of humans on the Moon. Important issues to be understood are the biological adaptation to reduced gravity, the assessment of radiation risks in missions outside the geomagnetic shield, the establishment of closed artificial ecosystems, and the development of technologies for the use of in situ resources. Because planetary protection policy considers the Moon as part of the Earth-Moon system, relevant studies on micro-organisms, plants and animals can be performed on the Moon without planetary protection restrictions.

Apart from being a research target itself, the Moon is also an ideal platform for a number of scientific experiments, especially in astrophysics, because of its large stable ground<sup>4</sup>, the absence of any significant atmosphere and its large mass for shielding against cosmic radiation and particles. A systematic lunar programme, with balanced contributions from science, exploration and technology demonstration, will include orbiters, landers (equipped with rovers, environment package, seismometers), sample return missions, life science experiments, precursors for human exploration and science investigations conducted with astronauts.

**There is a consensus among astrophysicists today that initially the Moon should be used only for projects uniquely requiring the Moon. A prime example of such a unique experiment is a digitally steered low-frequency radio interferometer consisting of an array of non-moving dipole antennas (Refs. 22-25). The low-frequency window to the universe has never been explored with imaging telescopes before because of the Earth’s ionosphere and the lack of any**

**lunar infrastructure; hence unique and novel science can be done. Scientific goals of a first explorative mission would be the local interstellar environment of the solar system, the solar-terrestrial relationship and the history thereof. Ultimately this technique can be developed into a large telescope for targeting precision measurements of the conditions in the early universe and its inflationary phase.**

In addition a number of space-based interferometers at other wavelengths (sub-millimetre, infrared, optical) have been proposed (Refs. 26-28). Should a realisation of these large interferometers as free-flyers prove to be technically or financially more difficult than expected, lunar options may be revisited. This too will require a detailed knowledge of lunar surface properties (dust, seismicity etc.) and potentially some actual astronomical site-testing. Site-testing would include the response of construction materials and lubricants to extreme temperature variations.

There are a number of enabling technologies to realise this roadmap, such as air-less entry and descent, hazard avoidance control, precise point landing, generic soft-landing platform, instrument development, context and environment characterisation, sample acquisition and screening (robotics), intelligent rover sample fetcher and permanent robotic assets deployment, planetary protection demonstration, lunar ascent rocket, rendezvous, Earth re-entry, Earth descent and landing, sample curation, radioisotope power sources development.

In summary a European roadmap for lunar exploration would include:

- SMART 1 exploitation and orbiter follow-up
- Surface missions-mobile laboratory
- Sample return
- Contribution to a human-tended science laboratory
- Low-frequency radio astronomy, especially from the far side

## 6. The case for human missions to Mars and the Moon

Science is driven by rationality, excitement, curiosity, cooperation, competition and boldness. What is more exciting than to send human beings to Mars and bring them safely back to Earth again? What stimulates our curiosity more than to explore, whether there can be or has ever been life on a planet other than Earth? What is bolder than to test whether humans can sustain the environment of long-term spaceflight in the solar system and live on another planet?

Manned missions to the Moon and Mars are the natural next steps to explore the conditions for the origin and evolution of life, and how it has interacted with its planetary environment(s).

**Thus, missions to Mars, and especially those involving humans are, from an exploration, science and technology perspective, an extremely exciting challenge of our time. A broad range of scientific disciplines from physics, chemistry and geology to biology and medicine will benefit from it by addressing the following questions:**

Can Mars sustain life? Are there any signs of past or present forms of life on Mars, and could it be made habitable? Only by sending human-made instruments (robots) there with, at some stage, a human presence to fully expand their capability, will we be able to answer these questions.

Without sample return and humans on Mars at an appropriate stage, the scientific and technological return will be incomplete and the confirmation of the hypothesis that life exists or has existed in some form on Mars will remain open.

Specifically, a human presence will greatly facilitate the following:

- Deep (100m to km) drilling through the cryosphere to seek possible habitable environments in Martian aquifers – probably the most likely environments for extant life on Mars today.
- Searches for microfossils in Martian sedimentary materials. Experience on Earth shows that large quantities of materials from carefully selected locations will need to be searched with microscopes. Shipping the required quantities of Martian materials to Earth for analysis is probably out of the question, so in situ studies by human specialists would be desirable.

How does gravity affect life from molecules to integrated physiology, and what is the significance of the gravitational environment for evolution? To explore these issues, biological material from molecules and

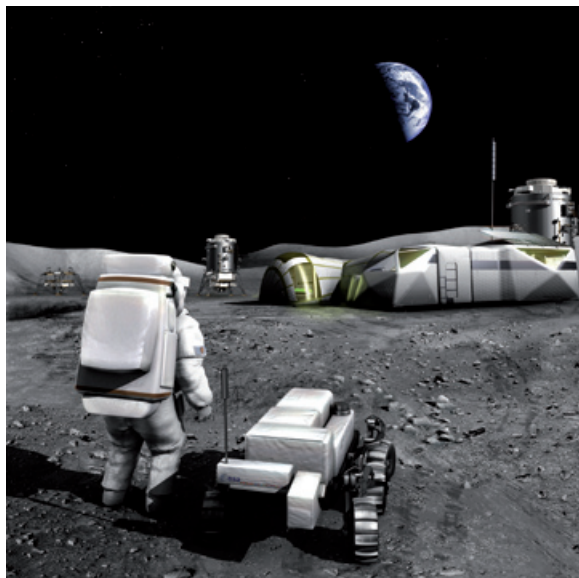


Figure 5: Artist's impression of the Aurora Moon base

cells to organisms should be subjected to long-term variations in exposure to gravitational stress (g) such as 0 g (spaceflight, e.g. on the ISS), 0,17 g (Moon) and 0,38 g (Mars).

**In addition to answering these questions, manned missions to Mars are expected to increase public awareness of science and expand funding and activities in many related scientific and technological fields. This will lead to an increase in scientific knowledge and an expansion in the economy at a global level.**

Prior to manned missions to Mars, appropriate guidelines need to be developed to protect the planet from human activities that may be harmful to its environment, and also to protect human explorers from the environment (i.e. that of the spaceflight and that of Mars). Finally, we need to protect the Earth from potentially harmful agents brought back from Mars with the return of the explorers. Answers to these issues concerning planetary protection and countermeasures against the effects on humans of weightlessness, radiation and the planetary environment need to be available well ahead of manned missions to Mars. Section 7 deals with this issue in more details.

The human exploration of the Moon would be an obvious means of developing techniques for later exploration of Mars and would add greatly to our knowledge of the early history of the inner solar system. Specifically, human lunar exploration would have the following scientific advantages:

# Science-Driven Scenario for Space Exploration

- Much more efficient collection of a more diverse range of samples from larger geographical areas than is possible by tele-operated robotic exploration;
- Facilitation of large-scale exploratory activities such as deep (approximately 100m) drilling to determine geological details of the surface of the Moon (e.g. paleo-regolith deposits);
- Facilitation of landing much more complex geophysical and other equipment than is likely to be feasible robotically;
- Increase of opportunities for serendipitous discoveries;
- Gaining operational experience on a planetary surface that will be of value for later exploration of Mars;
- Facilitation of a number of other, non-planetary science activities on the Moon such as life sciences investigations under reduced gravity conditions, and maintenance and upgrading of astronomical instruments placed on the lunar surface.

It can be noted that human versatility is such that a number of these objectives can be met simultaneously.

For European scientists to continue exploring the frontiers of new research, Europe should actively participate in the manned exploration of the Moon and Mars. The first step is to continue with robotic missions and prepare for manned missions to Mars. An intermediate step could be to contribute to an international venture to establish a human base on the Moon; the third step would be to contribute to the implementation of manned missions to Mars and back to Earth again.

Therefore, this programme should start as soon as possible with a dual-track roadmap: (1) robotic and non-manned missions to Mars and, in parallel, (2) the continued biological research and human presence on the ISS, in Antarctica, atmospheric balloons, etc. in preparation for the manned missions to the Moon and, eventually, Mars.



Figure 6: Inspection of a STAR DUST canister and sample collector

## 7. Planetary protection

Whereas from the planetary protection point of view, the Moon is considered as part of the Earth-Moon system and therefore no special planetary protection measures are required for lunar missions, Mars on the other hand is a target of special concern with regard to possible forward, as well as backward, contamination, as laid down in the planetary protection guidelines of COSPAR. (Refs. 29, 30).

**ESA is encouraged to continue the development and adoption of its own Planetary Protection policy in compliance with the COSPAR guidelines. European involvement must be investigated further, for example with respect to Mars sample return missions, defining the role that Europe should play in developing Earth-based quarantined sample curation facilities. A sample distribution policy also needs to be established between international partners early in the process.**

With this involvement in planetary protection activities, Europe will develop further competence to be able to actively contribute to the planetary protection discussions with regard to human exploratory missions that are just starting.

As already indicated, prior to manned missions to Mars, appropriate guidelines need to be developed:

- to protect the planet from human activities that may be harmful to its environment; this includes preventing the introduction of biological agents and human microbes that could hamper the search for indigenous Martian life;
- to protect the Earth from potentially harmful agents brought back from Mars or even sample return missions upon return of the explorers.

Answers to these planetary protection issues need to be available well ahead of manned missions to Mars, e.g. by testing this protocol and guidelines during lunar missions.

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## 8. Impact of human presence on the scientific exploration of Mars

In the endeavour to search for signatures of life on Mars, it is expected that several robotic missions will and have to precede any human landing on Mars. Overall, human and robotic missions should be complementary. Finally, astrobiology can immensely benefit from a human presence on Mars. The advantages of human presence include:

- the adaptability and dexterity of humans, thereby providing a better capacity in dealing with the unpredictable;
- possibility of carrying out field geology, such as deep-drilling (metres to tens, or even hundreds, of metres), critical in situ inspection and decision-taking, and long-term in situ analysis of a wide variety

of samples (rocks, ice, atmosphere), thereby also enabling a skilful pre-selection of samples to be returned to Earth;

- remote control of on-site robotic activities, such as search for life in special regions;
- adaptability and flexibility of the research experiment portfolio;
- in situ repair of explorative and analytical facilities and instruments, as has already been demonstrated with the Hubble Space Telescope repair by astronauts.

On the other hand, one should bear in mind that human involvement may also impede the scientific exploration of the planet.

Those cases where human presence could become an impediment pertain to the following areas:



Figure 7: Artist's impression of a base on Mars

- **Science:** planetary protection requirements might hinder access of humans to astrobiologically interesting sites. Bearing these constraints in mind a rigorous sequence of events must be established well in advance, e.g. by testing them on the Moon. In addition it may become necessary to establish 'human-free' areas on Mars;
- **Human health issues:** a detailed environmental risk assessment is required before humans are sent to Mars;
- **Technology:** human presence requires much higher demands on reliability of the mission than robotic missions; there are additional requirements with regard to life support and safety;
- **Economics:** high costs of a human mission;
- **Societal issues:** risk of potential back-contamination when returning to the Earth.

Therefore, a careful planning of the overall scenario of the EEP is required to make maximum use of the synergy between robotic and human exploration of Mars. Adequate guidelines, both scientific/technological and legal, will need to be established with the different stakeholders involved.



Figure 9: Asteroid 243 Ida & Dactyl

© NASA/JPL-Caltech

## 9. The case for NEO sample return missions

Small bodies, as primitive leftover building blocks of the solar system formation process, offer clues to the chemical mixture from which the planets formed some 4.6 billion years ago. Near Earth Objects (NEOs) representative of the population of asteroids and dead comets are thought to be similar in many ways to the ancient planetesimal swarms that accreted to form the planets. NEOs are interesting and highly accessible targets for scientific research.

The chemical investigation of NEOs having primitive characteristics is thus essential in the understanding of the planetary formation. They carry records of the solar system's birth and early phases and the geological evolution of small bodies in the interplanetary regions. Moreover, collisions of NEOs with Earth pose a possible hazard to present life and, additionally, they could have been one of the major deliverers of water and organic molecules on the primitive Earth. Characterisation of multiple small bodies is important in that context for threat evaluation, mitigation and, potentially in the long-term, for identification of resources.

**For all these reasons the exploration of NEOs is particularly interesting, urgent and compelling. The main goal is to set, for the first time, strong constraints on the link between asteroids and meteorites, to achieve insight on the processes of planetary accretion and on the origin of life on Earth and its distribution in the solar system. In the short term, and after flyby and landing missions on NEOs (ca. 2014), the next goal should be sample return, enabling a detailed investigation of primitive and organic matter from one selected, small body.**



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A sample return mission to an NEO can be a precursor, low-cost mission to Mars sample return missions, and it is possible with a short planning phase (before 2020). Priority shall be given to pristine small bodies; e.g. C or D-type asteroids or comets.

It is generally agreed that NEOs are among the most accessible bodies of the solar system and that some of them could even turn out to be more accessible than the Moon. A sample return mission to an NEO could be realised with new technological developments.

Based on the present knowledge of the NEO population, it is possible to find 320 objects, reachable with a  $\Delta V < 7\text{km/s}$ , and about 180 with a  $\Delta V < 6\text{km/s}$  (Ref. 31; see also Refs. 32, 33). Target selection strategy must take into account both compositional properties and  $\Delta V$ .

At a later stage, the diversity of objects should be investigated by missions to different types of objects. Finally, characterisation of potentially hazardous objects is considered vital.

**Europe should implement an NEO technological demonstration mission, where the cosmogonical and exobiological contexts would be explored.**

The leading aim is to answer the following fundamental questions:

- What are the initial conditions and evolutionary history of the solar nebula?
- What are the properties of the building blocks of the terrestrial planets?
- How have major events (e.g. agglomeration, heating, aqueous alteration, solar wind etc.) influenced the history of planetesimals?
- What are the elemental and mineralogical properties of NEO samples and how do they vary with geological context on the surface?
- Do primitive classes of NEOs contain pre-solar material yet unknown in meteoritic samples?
- How did NEO and meteorite classes form and acquire their present properties?

Furthermore, sample return missions on primitive NEOs will give insights into major scientific questions related to exobiology, such as:

- What are the nature and origin of organic compounds on an asteroid?
- How can asteroids shed light on the origin of organic molecules necessary for life?
- What is the role of asteroid impact for the origin and evolution of life on Earth?

Although challenged by several recent articles one important observation to date is the chiral asymmetry in organics such as amino acids in meteorites. It has

been suggested that this left-handedness may be related to the left-handedness that is the signature of life on Earth (Refs. 34, 35). The planets of the inner solar system experienced an intense influx of cometary and asteroidal material for several hundred million years after they formed.

The earliest evidence for life on Earth coincides with the decline of this enhanced bombardment. The fact that the influx contained vast amounts of complex organic material offers a tantalising possibility that it may be related to the origin of life.

A detailed study of the material at the surface or sub-surface of an asteroid is therefore needed. The information that is required demands complex pre-analysis processing and very high levels of analytical precision.

**Therefore, it is essential that the sample is returned to Earth for detailed laboratory investigations where the range of analytical tools, their spatial resolution and analytical precision are generally orders of magnitude superior to what can be achieved from remote sensing or in situ analyses.**

Such information can be achieved only by large, complex instruments; e.g. high mass resolution instruments (large magnets, high voltage), bright sources (e.g. synchrotron) and usually requires multi-approach studies in order to understand the nature and history of specific components.

In summary, a mission with sample return to a primitive NEO of C or D type will help in understanding the chemical and biological aspect of the formation and the evolution of our and other planetary systems.

**Such an innovative mission will be very important:**

- **to test new technology developments: precision landing, autonomous sampling (sample transfer, containment, drilling), advanced propulsion, Earth re-entry capsule, in-orbit docking, telecommunication, in situ energy, planetary protection;**
- **to prepare new adequate laboratory facilities for extraterrestrial sample analysis;**
- **for scientists, and particularly young scientists, for a programmatic vision of exploration, huge scientific interest, large interest for the media and European citizens.**

Moreover, robotic sample return mission to NEOs can serve as pathfinders for sample returns from high gravity bodies, e.g. Mars and, much later on, for human missions that might use asteroid resources to facilitate human exploration and the development of space.

## 10. International cooperation

All space agencies agree that international cooperation will be essential to accomplish advanced missions such as Mars sample returns. One of Europe's strengths is its collection of member states, making it naturally open to international cooperation. Apart from a prioritised mission list, Europe's exploration programme could have two components. One is architecture for Mars: if one agrees to concentrate on Mars sample return missions, this architecture could be based on telecom & navigation ('GPS on Mars'). The other one – bolder – is to engage other partners to join Europe in developing instruments or other aspects and coordinating their approach.

Indeed the current situation sees duplication of similar initiatives by various international partners; e.g. Moon missions by India, China, Japan etc. It has been argued that an IACG<sup>5</sup> with a renewed mandate, for instance on an international exploration programme, would greatly facilitate this coordination of efforts. There are two ways to international collaboration: multilateral or bilateral; in the latter there is a minor partner, which is rarely a satisfactory option. ITAR<sup>6</sup> rules are also very detrimental to international cooperation.

Therefore we propose:

- to give a strong international cooperation side to the EEP, identifying relevant partners for each building block of the programme;
- to base this cooperation on 'planetary assets' that partners can bring in: systems deployed on planetary bodies to be used by everybody; e.g. GPS on Mars.

This is a different philosophy, not one guided by nationalism, but one of cooperation which should appeal more to European citizens. In addition the Global Exploration Strategy Group composed of 14 space agencies has met a number of times in the past year and a half to try and better coordinate the exploration goals and objectives of the various space agencies, including NASA, ESA and a number of European partners (Ref. 36).

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5. Inter-Agency Consultative Group.

6. International Traffic in Arms Regulations.

# Appendix 1

## Science goals for the scientific exploration of Mars and the Moon

The following table summarises the remaining science goals for future European exploration of the Moon and Mars, after ExoMars and before and in preparation of Mars sample return. Thus, the table attempts to answer the following question: In view of past international scientific missions to Mars, what are the remaining major investigations for the planet and what type of missions would enable them to be carried out, in preparation for Mars sample return missions and, one day, human exploration?

The table does not address new technologies to be tested in those missions. It will be the responsibility of ESA to identify useful mission technologies in preparation for Mars sample return missions, such as sample collection and handling, orbital rendezvous, capsule return to Earth, etc. In the long term, the establishment of international assets (such as GPS) through international collaboration is a necessary endeavour.

Planet	MARS							MOON	EARTH
Mission	Network Science	Mapping Orbiter	Geophysics Orbiter	Super Rover	Deep Drilling	Balloons, Zeppelin	Sample Return		Sample Analysis
<b>Interior</b>									
Internal structure and activity	x		(x)		(x)			x	
State of the core and dynamo's history	x		x					x	
Mapping of magnetic anomalies in crust	x		x			x			
Geodesy and gravity anomalies	x		x			x		x	
Volcanic activity at present	x	(x)				x		x	
Thermal gradient and evolution	x				x			x	
Ground-penetrating radar	x	x	x	x		x		x	
<b>Surface</b>									
Characterisation of most geological units	x	x	(x)	x		x			
Calibration of cratering curve with in situ absolute dating	x			x			x	x	
Very hi-resolution imaging and spectroscopy		x				x		x	
Detailed history of water on Mars (inventory, alteration)	x	x	x	x	x	x	x		x
Bio/chemical rock and soil sample analysis	x			x			x	x	x
In situ Ar/K isotopic age measurements	x			x			x	x	x
Sample curation for analysis on Earth									x

# Appendix 1

Planet	MARS							MOON	EARTH
Mission	Network Science	Mapping Orbiter	Geophysics Orbiter	Super Rover	Deep Drilling	Balloons, Zeppelin	Sample Return		Sample Analysis
<b>Atmosphere</b>									
Meteorological monitoring (surface & orbit)	x		x			x			
Global & local circulation (dust storms, dust devils)	x		x			x			
Link climate and rotation (obliquity, nutation, etc)	x		x						
Trigger of atmospheric change 3.8 Ga ago			x						
Coupling of solar cycle and atmospheric density	x		x			x			
Monitoring atmospheric escape (thermal & non-thermal) as function of solar activity			x						
<b>Ionosphere</b>									
Link atmospheric escape to crust magnetism	x		x						
Space weather			x						
<b>Astrobiology</b>									
Identify astrobiological niches (surface and at depth)	x	x		x	x				
Establish environmental limits of life	x			x					
Coupling of geological evolution and habitability	x								
In situ carbon isotopic measurements	x			x			x		x
Detailed environmental hazards (dust, radiation, internal activity)	x					x			
Connection between evolution of martian atmosphere/early magnetic dynamo and terrestrial exoplanets	x		x						

## Appendix 2

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### Steering Committee composition

**Angioletta Coradini**, IFSI-CNR  
**Pascale Ehrenfreund**, Universiteit Leiden  
**Monica Grady**, Open University  
**Gerhard Haerendel**, MPE Garching,  
ESSC former Chairman  
**John Zarnecki**, Open University  
**Jean-Claude Worms**, ESSC-ESF

## Appendix 3

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### Ad Hoc Group composition

**Antonella Barucci**, LESIA Meudon  
**Reta Beebe**, University of New Mexico  
**Jean-Pierre Bibring**, IAS  
**Jacques Blamont**, CNES  
**Michel Blanc**, CESR  
**Roger Bonnet**, ISSI  
**John R. Brucato**, Osservatorio Capodimonte  
**Eric Chassefière**, IPSL  
**Angioletta Coradini**, IFSI-CNR  
**Ian Crawford**, Birkbeck College  
**Pascale Ehrenfreund**, Universiteit Leiden  
**Heino Falcke**, ASTRON  
**Rupert Gerzer**, DLR  
**Monica Grady**, Open University  
**Manuel Grande**, University of Wales  
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**Bernhard Koch**, DLR  
**Helmut Lammer**, SRI  
**Andreï Lobanov**, MPI  
**José J. Lopez-Moreno**, IAA-CSIC  
**Roberto Marco**, University of Madrid  
**Peter Norsk**, University of Copenhagen  
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**Cam Tropea**, Technische Universität Darmstadt  
**Stephan Ulamec**, DLR  
**Frances Westall**, LPCE-CNRS  
**John Zarnecki**, Open University  
**Jean-Claude Worms**, ESSC-ESF

## Appendix 4

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### Ad Hoc Group thematic sub-groups

**Robotic exploration of Mars**  
Monica Grady, Jean-Pierre Bibring,  
Helmut Lammer, Eric Chassefière

**Robotic lunar exploration**  
Ian Crawford, Heino Falcke,  
Dave Rothery, Jean-Pierre Swings

**Human missions to Mars and the Moon**  
Ian Crawford, Heino Falcke, Gerda Horneck,  
Bernhard Koch, Roberto Marco, Peter Norsk,  
Dave Rothery, Jean-Pierre Swings

**Impact of human presence on science  
exploration of Mars**  
Gerda Horneck, Jean-Claude Worms

**NEO sample return missions**  
Antonella Barucci, John R. Brucato,  
Monica Grady, José J. Lopez-Moreno

**Planetary protection**  
Gerda Horneck, Jean-Claude Worms

**International cooperation**  
Jacques E. Blamont, Gerhard Haerendel,  
Jean-Claude Worms

# Appendix 5

## The Athens Declaration

Eighty-eight scientists and national representatives from ESA Member States met in Athens on 15 and 16 May 2007 in a workshop organised by ESF and sponsored by ESA, with the aim of establishing recommendations to ESA's Directorate for Human Spaceflight, Microgravity and Exploration on a science-driven scenario for space exploration. The discussion was initiated by the ESSC-ESF Ad Hoc Group on exploration, and concentrated on a series of science goals and mission concepts for the short term (up to 2020), medium term (2020-2030), and long term (after 2030).

The workshop participants met in plenary and splinter sessions to refine the findings of the Ad Hoc Group report for the three target bodies: Mars, Moon and NEOs. The workshop participants agreed on a set of recommendations and findings that form the core of this Athens declaration.

### Commonalities

- The overarching scientific goal of EEP should be called: 'Emergence and co-evolution of life with its planetary environments', with two sub-themes pertaining to the emergence of life, and to the co-evolution of life with their environments.
- EEP should focus on targets that can ultimately be reached by humans.
- Mars is recognised as the focus of EEP, with Mars sample return as the driving programme; furthermore Europe should position itself as a major actor in defining and driving Mars sample return missions.
- There is unique science to be done on, of and from the Moon and of/on Near Earth Objects or asteroids (NEOs or NEAs). Therefore, if these bodies are to be used as a component of EEP, further science should be pursued; the Moon could thus be used as a component of a robust exploration programme, including among others: geological exploration, sample return and low-frequency radio astronomy.
- The first steps of EEP should be done robotically.
- Since EEP's ultimate goal is to send humans to Mars in the longer term, research for humans in a space environment must be strengthened. Beyond the necessary ongoing and planned biological research and human presence on, e.g. the ISS or in Antarctica, opportunities to this end might also arise in the context of an international lunar exploration programme.
- The role of humans as a unique tool in conducting research on the Moon and on Mars must be assessed in further detail.
- Europe should develop a sample reception and curation facility, of joint interest for ESA's science and exploration programmes.
- Understanding the processes involved in the emer-

gence of life in the solar system, e.g. through in-depth exploration of Mars, is crucial to understanding the habitability of exoplanets.

- International cooperation among agencies engaged in planetary exploration should be a major feature of EEP, realised by concrete joint ventures.
- Once EEP is funded and running it is further suggested that in the near future a series of international science and technology exploration workshops be set up, which for Europe could be organised by ESF with the science community and co-sponsored by ESA, in order to better define the mission concepts and technological choices relevant to the above goals as this multi-decadal programme develops.

### 1. Robotic exploration of Mars

Mars is recognised as the focus of EEP which should first be led robotically, with sample return from the red planet as its driving series of programmes; furthermore Europe should position itself as a major actor in defining and driving Mars sample return missions.

Beyond the experience gained with Mars Express a roadmap for EEP should articulate the following steps:

- Step 1: ExoMars will be the first and therefore critical step in EEP; it will offer the European community a leading position, by exploring Mars with scientific objectives as diverse as exobiology, geology, environment and geophysics. Securing this mission for a 2013 launch must therefore be the top priority of Europe's robotic exploration programme
- Step 2: Mars sample return programme
- Step 3: Human mission programme, for which Europe needs to prepare itself to be a major partner

An essential goal is to understand the details of planetary evolution: why did the Earth become so unique, as compared to Mars or Venus? Understanding the issue of habitability of planets (Mars in particular) and the co-evolution of life within its planetary environments is therefore our major goal. This in turn is crucial to understanding the habitability of exoplanets.

Another essential aspect is to continue relevant research on Earth to enable the determination of possible habitats, the mode of preservation of expected bio-signatures (differentiate traces of life from abiotic processes) in these habitats, and the unambiguous recognition of life beyond Earth. Indeed, characterising bio-signatures involves studies of early traces of life in the Precambrian Earth and taphonomy<sup>1</sup> of cells in various preservational environments of present Earth.

1. Study of a decaying organism over time.

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To participate in this endeavour with a major role, Europe has a number of assets but needs to develop or improve them, or identify those assets that international partners could contribute to its programme, such as:

- maintaining Europe's world-class instrumentation capability
- Europe's industrial capability to build an infrastructure on Mars
- International collaboration history of Europe
- the development in Europe of 5-10W radioisotope-based devices would open new opportunities to European-led international collaboration

## 2. Robotic exploration of the Moon

The main objective would be the discovery, exploration, and use of the '8<sup>th</sup> continent', and the harvesting of unique information from the Moon as an archive of the formation and evolution of the solar system. Furthermore EEP should consider the use of the Moon as a large laboratory in free space.

A European roadmap for lunar exploration would include:

- SMART 1 exploitation and orbiter follow-up
- Surface missions-mobile laboratory
- Sample return
- Contribution to human-tended science laboratory
- Low-frequency radio astronomy, especially from the far side

Sample return missions can in particular address samples from the South Pole Aitken Basin (window to lunar interior), from Procellarum (youngest volcanism), from poles, from paleo-regolith, extraterrestrial samples, regolith samples of the solar wind history, samples of ice cometary deposits in the last billion years, samples from Mars and asteroids (and Venus?), and lunar samples of the Early Earth.

Prototype radio astronomy experiments could initially be realised at one of the poles with the desire to move towards the far side thereafter. The usefulness of the Moon as a potential site for telescopes at other wavelengths needs to be further assessed by in situ exploration.

There are a number of enabling technologies to realise this roadmap, such as: air-less entry and descent, hazard avoidance control, precise point landing, generic soft landing platform, instrument development, context and environment characterisation, sample acquisition and screening (robotics), intelligent rover sample fetcher and permanent robotic assets deployment, planetary protection demonstration, lunar ascent rocket, rendezvous, Earth re-entry, Earth descent and landing, sample curation, radioisotope power sources development.

## 3. Near Earth Object sample return

In the short term, and after flyby and landing missions on NEOs (ca. 2014), the next goal should be sample return, enabling a detailed investigation of primitive and organic matter from one selected, small body. Priority shall be given to pristine small bodies, e.g. C or D-type asteroids or comets.

At a later stage, the diversity of objects should be investigated by missions to different types of objects. Finally, characterisation of potentially hazardous objects is considered vital. The following relevant technologies should start to be developed by Europe:

- precision landing
- autonomous sampling (sample transfer; containment; drilling)
- advanced propulsion
- Earth re-entry
- in-orbit docking
- sample treatment on Earth

Europe should implement a technological demonstration mission, which could be fairly cheaper than Mars or Moon sample return missions, and where the cosmogonical and exobiological contexts would be explored.

Characterisation of multiple small bodies is important in that context for threat evaluation, mitigation and, potentially in the longer term, for identification of resources.

In the context of the preparation of Mars sample return the development of technologies for NEO sample environment monitoring and control during cruise, and sample storage on the ground, are relevant to addressing planetary protection issues for future Martian missions.

## 4. Human exploration of Mars and the Moon

A driver of exploration programmes is to advance human presence in space. Future manned missions should make use of humans as intelligent tools in the exploration initiative, with the following specific scientific goals:

- reach a better understanding of the role of gravity in biological processes and in the evolution of organisms at large
- determine the physical and chemical limits of life (from microorganisms to humans)
- determine the strategies of life adaptation to extreme environments
- acquire the knowledge required for a safe and ef-

## Appendix 5

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efficient human presence in outer space (from the International Space Station via Moon to Mars)

Specifically, human exploration would have the following scientific advantages:

- Much more efficient collection of a more diverse range of samples from larger geographical areas than is possible robotically
- Facilitation of large-scale exploratory activities such as deep (approximately 100m) drilling to determine geological details of the surface of the Moon (e.g. paleo-regolith deposits) or to seek possible habitable environments in Martian aquifers
- Facilitation of landing much more complex geophysical and other equipment than is likely to be feasible robotically
- Increase of opportunities for serendipitous discoveries
- Facilitation of a number of other, non-planetary, science activities on the Moon such as life sciences investigations under reduced gravity conditions, and also maintenance and upgrading of astronomical instruments placed on the lunar surface

In terms of the enabling science and technology needed to reach these goals, further knowledge is required to enable a safe and efficient human presence in outer space:

- responses of the human body to parameters of spaceflight (weightlessness, radiation, isolation, etc.) and development of countermeasures
- responses of the human body to surface conditions on Mars and on the Moon, and protection measures
- development of efficient life support systems including bio-regenerative systems which can be done on Earth conditions, to be further adapted to specific mission conditions; in this context support to a Moon mission as an intermediate step towards a Mars mission could become relevant
- development of a habitat providing a living and working area on Mars and the Moon

To reach these goals experiments must be supported to better understand the role of gravity on biological processes on the International Space Station (multi-generation experiments in microgravity and long-term adaptation of humans to microgravity), on the Moon (multigeneration experiments at 0,17 g and long-term adaptation of humans to low gravity), and on Earth (multigeneration experiments under hypo- and hyper-gravity).

Furthermore the limits of life and its strategies of adaptation to extreme environments must be further studied through experiments on the International Space Station, the Moon and on Earth. More specifically the

programme should aim at determining the climate and environmental parameters of potential hazard to humans, i.e. on the Moon: dust, radiation, 0,17 g, seismic activities, and micro-meteorites; on Mars: dust, radiation, atmospheric traces, temperature variation, seasons, 0,38 g.

Knowledge acquired by the abovementioned experiments will enable human health and working efficiency in space and planetary environments. It is a sine qua non before the involvement of humans in exploratory missions to Moon and Mars, which then will benefit significantly from their presence.

Finally, guidelines for planetary protection need to be elaborated with international partners concerning forward and backward contamination, and Europe must play an influential role in that context by continuing the development and adoption of its own planetary protection policy, in compliance with the COSPAR guidelines.

### Concluding summary

These four components of EEP illustrate the overarching science goal 'Emergence and co-evolution of life with its planetary environments' which should structure Europe's approach, along with the framework recommendations presented in the commonalities section. This declaration is a complement to the more detailed report of the ESSC Ad Hoc Group, which took into account and incorporated the discussions arising at the Athens workshop.



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