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SPACE EXPLORATION: KEEPING THE MOMENTUM

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SUMMARY

From 10 to 12 May 2023, the Air and Space Academy (AAE), supported by the Associazione Italiana di Aeronautica e Astronautica (AIDAA), Space Generation Advisory Council (SGAC) and Politecnico di Torino, organised an international conference in Turin on "Space Exploration", focusing on motivations, missions and key technologies of Solar system exploration. The conference brought together over 350 people from 15 countries, including 75 speakers.

This opinion is a direct result of the conference.

Seven specific themes were addressed at the conference and are dealt with in this opinion: an analysis of the cultural motivations for automated and human space exploration; the encouragement of innovative ideas from the younger generation; lunar exploration and its environmental aspects; the use of "flying machines" on certain planets and moons; how to go faster... and further; the search for water and its possible use; and finally, cooperation between robotic resources and humans.

The keyword of this opinion is to **keep the momentum** of recent years. The "magic recipe" for achieving this clearly comprises a number of ingredients, including culture, public support, clarity of strategy, cost viability, the time needed to achieve the objective, technological efficiency, education, etc.

Space discovery, with its wealth of new scientific information made accessible to the layperson, fires the interest and involvement of citizens – and therefore, ultimately, their support. European agencies and governments should more openly address the philosophical and cultural bedrocks of space exploration, as well as its scientific, political and economic justifications and ethical context, in order to root it deeply in European culture and values and ensure such support in the long term.

An effective way of ensuring the continuity of intergenerational support for exploration would be to create a framework for implementation of cheaper, simpler missions to be carried out by small entities or universities and open to a large number of new, young contributors. Appropriate calls for proposals should be issued on a regular basis, enabling a generational fusion with the expertise of seniors.

Lunar exploration, and possibly exploitation (at least "*in situ*"), which has recently found its way back to the top of most agendas, makes a powerful contribution to all this, especially if proper concern is demonstrated for preserving the lunar environment. To this end, it is important to enhance our collective understanding of the Moon's environment, to make rational use of its resources and mitigate the impact of a robotic and/or human presence.

The question of water and organic carbon in the Solar system, in each of their potential physical and/or chemical states, is a scientific subject of major astrophysical interest, as well as a potential resource to be acquired. It is likely to be the starting point for a wide variety of space missions in decades to come, once again combining automated spacecraft and humans.

The momentum we are talking about here, at least for long-distance automated probes such as those destined for missions to the outer Solar system, also depends on the capacity to "go faster", and therefore the ability to develop the technical means to do so, starting with propulsion systems. Of course, going faster will also rely on faster, more efficient decision-making processes, including those governing mission selection and implementation.

Once probes have arrived at their destination, *in-situ* exploration means also need to be improved. This is why, for planets and moons with a certain atmosphere, Europe's space industry should make more systematic study of "flying machines" such as rotary wing aircraft, gliders and balloons.

International cooperation is omnipresent in all this, especially for Europe. However, the part we play in a partnership, i.e. the power we exercise, depends on the added value we contribute. It is therefore essential to build on Europe's strengths with a view to continuity before knocking on the doors of potential partners.

This cooperation should be seen as an end in itself, a political imperative for humanity, all the more so in times of geopolitical tension. Cooperation is a practice deeply rooted by nature in fundamental scientific communities, but space exploration which, one must reiterate, is of particular interest to all peoples, brings a specific value that goes far beyond the simple goal of sharing costs. With the arrival of new partners in the circle of global space players, a new era can begin, which is all the more important as humanity faces major geopolitical and environmental challenges. Indeed (geo)politics is – in the long term – the embodiment of deeper and more fundamental cultural and even civilizational issues. It is not only economic interests that are at play, but the interpenetration of cultures and their mutual sustenance. This is well worth remembering in these troubled times.


SPACE EXPLORATION:
KEEPING THE MOMENTUM

TABLE OF CONTENTS

FOREWORD

From 10 to 12 May 2023, the Air and Space Academy (AAE), supported by the Italian Association of Aeronautics and Astronautics (AIDAA), Space Generation Advisory Council (SGAC) and Politecnico di Torino, organized at PoliTo an international conference on "Space Exploration[1]", focused on motivations, missions and key technologies of Solar system exploration. The conference was attended by more than 350 people from 15 countries, including 75 speakers.

This Opinion, endorsed by the AAE general assembly, follows up on the conference, adopting the same structure in terms of topics/sessions, and taking into account subsequent internal exchanges within the programme committee.

It should be noted that, while the conference addressed both human and robotic missions, the specific matter of European human autonomous access to exploration was not addressed and will not be tackled in this Opinion. Another AAE Opinion ("Recommendations for an independent European capability for human spaceflight[2]"), prepared in parallel with the conference, is available on the AAE website.

Given the success of this conference, and the very lively, evolutive and dense context of space exploration worldwide, AAE will consider organising a similar event within a few years.

1. *The proceedings are available at the following address: https://academieairespace.com/documents-et-medias/space-exploration-conference-proceedings*
2. *https://academieairespace.com/publications/opinions/opinion-n16-recommendations-for-an-independent-european-capability-for-human-spaceflight/?lang=en*

INTRODUCTION

The purpose of the conference was not to reach a consensus on the issues discussed, but to encourage a diversity of participants from all over the world and from all generations, from pioneers to students, and thus benefit from their wide range of experiences and thoughts. An important milestone in open exchange, the event is expected to produce concrete results for exploration of the Solar system, taking advantage of the momentum which has been building up for several decades all over the world.

This is not the first time that such a momentum has been experienced, especially for lunar exploration – beginning with the "Moon race" in the 1960s – but after each event or declaration the momentum has been lost, for a variety of reasons and changing priorities, whether political, financial or scientific. Lessons learned from these past experiences were used to develop proposals to promote the long-term sustainability of space exploration.

The conference therefore followed two main principles:

- focusing content on issues insufficiently addressed in other congresses but key to sustaining the momentum of exploration: addressing motivations beyond the political ("all explorers"), taking account of the environment from start, reducing mission travel time, increasing the scope of each mission, using *in-situ* resources, coupling humans and robots;
- ensuring the active involvement of all generations, from pioneers to students, so as to build a "feedforward" momentum that can be maintained across generations.

These choices, which secured the success of the conference, as evidenced by the exchanges that continued after the event, are reflected in the present document, the main aim of which is to contribute to this process over the coming years.

The primary overall recommendation of this AAE Opinion is therefore to **keep the momentum**. The “magic recipe” by which to achieve this comprises several ingredients, including culture, public support, clarity of strategy, sustainability of costs, time to goal, effectiveness of technologies, education – in order to sustain the interest of the majority of “explorers”, decision-makers and dreamers.

In a world of communication, the space sector needs to base its communication around demonstrated reality: it must deliver *results* that open up new questions and generate excitement; it must design new missions to address these questions, with enhanced, innovative enabling technologies; it must take risks and learn from failures.

It also needs to reduce time and costs and stimulate a wide range of ideas and activities, encouraging competition to promote excellence, at the broadest scale possible, merging contributions from all institutions and companies, inciting new players to enter the game...

This competition, compulsory for the sake of efficiency and the emergence of new concepts and technologies, should not stand in the way of greater cooperation but, on the contrary, should be seen as one of its pillars. Indeed, the potential unleashed by **cooperation** must be seen as essential to the goal of “keeping the momentum”.

Despite its drawbacks, cooperation is an important factor of continuity and sustainability, as the European Space Agency (ESA) has demonstrated in several instances. It may be long and painful to start a new programme at ESA, but even more difficult to stop one! This makes Europe (at large) the most reliable space partner in the world – and also the “champion” of international cooperation, based on long and successful past experiences involving European states and organisations.

Space is a unique laboratory for cooperation at all levels, whether individuals, teams, institutes, industrial partners, or agencies and nations, right up to the planetary scale, bringing benefits for scientific activity and much more!

Space exploration, in particular, offers broad multi-dimensional modalities involving public and private actors, space and non-space companies and institutions, thereby opening up a large range of interactions and mutual benefits. It is exemplary in terms of the structural means that need to be put in place to serve a number of key societal activities in a highly constrained timeline, whilst at the same time facing the major planetary challenges ahead.

International cooperation should be seen as a goal in itself, a political imperative for humanity – all the more in periods of geopolitical tension.

Cooperation is a deeply embedded "*per natura*" practice of fundamental science communities. And space exploration, which inspires the keen interest of all peoples (especially when their respective flags are showcased), is one of the best possible areas for worldwide cooperation. In addition to working together to reduce costs for all players, cooperation in most, if not all programmes, has very good reasons to be structurally designed for "getting things done". In this respect, the European Union (EU) is uniquely placed to play a stimulating role, with its construction aimed to encourage partnership between its Member States (despite and because of their diversity).

Bearing these factors in mind, recommendations were drafted for each of the seven themes outlined below (addressed in more detail in the following chapters).

1. **Philosophy and motivations of exploration**. What are the profound motivations, in an anthropological sense, for automated and especially human exploration of space? Where does public interest in this endeavour stem from?

2. **Dream missions**. An important prerequisite for a sustainable future for space exploration is the involvement of the next generation of engineers, scientists, leaders. A competition open to young people to encourage out-of-the-box thinking led to four prizewinning projects for original missions that are presented here.

3. **Lunar environment**. A new wave of robotic and human exploration of the Moon is under way. In order to develop these activities safely, sustainably and symbiotically, their environmental impact must be systematically assessed and impact mitigation means carefully examined and tested. After a preliminary assessment of such impacts, different ways of preserving a clean lunar environment for future generations are explored.

4. **Going faster**. The timeline for exploration processes, from concept submission to data collection and exploitation, is very long. The purpose here is to review space propulsion technologies – whether

currently available or in the design or development stage – capable of accelerating future robotic and human missions to the different destinations of the Solar system. Potential gains in programme development time offered by international cooperation are also examined.

5. **Flying machines**. Solar system bodies with significant atmospheres have been explored using balloon or parachute probes. Future missions beyond the 2040s to explore these bodies by means of "flying machines" would require the development of various technologies and orbital infrastructures; e.g. gliders, drones, and motorized aerobots.

6. **Water**. The search for water in the Solar system is both a scientific and engineering issue. It requires better knowledge of the presence and specific properties of water, and new robotic space missions. *In-situ* water harvesting machines and sample return to Earth are discussed, in preparation for human exploration of the Moon and Mars, as well as the sustainability of water harvesting and its associated processing by advanced robotic means. The presence of water has been scientifically identified as a major step in understanding the formation of the Solar system and is key to questions of habitability and the potential development of life on other planetary worlds.

7. **Humans and robots**. Robotic missions and platforms and human missions are not in opposition. Humans and robots are and will be complementary, especially in their coverage of different destinations (no human mission inside the orbit of Venus or to the giant planets is planned for the foreseeable future). This theme examines how they can be combined and optimised.

1- PHILOSOPHY AND CULTURAL MOTIVATIONS FOR SPACE EXPLORATION[3]

While space exploration is first and foremost a fundamental science, it is clear that the sending of probes into the unknown, and particularly the sending of human beings into space, gives rise to expectations, ambitions and dreams of a very special kind. **Bearing this in mind, and acting accordingly, is a prerequisite for any sustainable, long-term, far-reaching exploration effort, anywhere in the world – and particularly in Europe – i.e. for "keeping the momentum", as strongly recommended in the introduction to this document.**

It is true that the main driving force behind the manned race to the Moon in the 1960s, and again today in a different context, was competition between different countries and political systems. But what are the cultural sources of this? Why do nations attach such prestige to these endeavours?

One of the reasons the Apollo adventure came to a premature end, for instance, is perhaps because it gave insufficient attention to such underlying roots – whilst making much of the immediate, political motivations. In the future, robust public and political support should be ensured by addressing these aspects more effectively.

It is thus necessary to characterize the collective imagination behind space exploration and its symbolic role in present and future civilisation – in what we might call the human adventure.

At the root of this collective imagination are religious myths, in particular that of Prometheus, who gave mankind not only fire, but knowledge, and moreover the

3. *A more detailed document on this matter, resulting from a 2-day workshop organised by AAE prior to the Turin conference, is available on the AAE website: https://academieairespace.com/documents-et-medias/philosophy-and-human-motivations-for-space-exploration/?lang=en*

desire for knowledge, then power… to the point of "*hubris*".

The myth of Prometheus has driven human adventure throughout the centuries, through successive cosmic models, and paradigms: Prometheus survived Aristotle and was still very much alive under Copernicus. And modern physicists, cosmologists, and later engineers who decipher, describe, and then use the laws of nature are making his legacy a reality.

Although Copernicus, Galileo, Giordano Bruno, cast the Earth, and with it humankind, out of its central role, twentieth-century space exploration has now instilled in us the feeling that the Earth is unique, our only sustainable Noah's Ark, which must be preserved at all costs. We have all heard about the famous "overview effect" felt by all astronauts, and have seen the beauty of our planet from space.

But surely the beauty of the cosmos, the wonder, is also a fundamental part of the call of the deep. The wonder of infinity. Even if planetary travel, whether robotic or manned, cannot compare to the dimensions of the galaxy and the Universe.

The first great spacefaring nations did not, though, develop the philosophical foundations for space exploration and their own competition simply by remembering the classical myths and responding to the call of the infinite. The USA and the Soviet Union each had their own "*doxa*", the "Frontier" and "Manifest Destiny" for the former; and "Cosmism" for the latter – a mixture of spirituality and faith in science and progress close to today's transhumanism.

To this of course must be added literature. Science fiction, which may have anticipated some real achievements but, above all, has inspired many young people to dream of space. Although sometimes there is no science in "SF", where it crosses into "fantasy"… and this can have the opposite result, a kind of attraction for the magical.

The more it progressed, the more exploration showed not only the absence of life on other planetary surfaces (while leaving open the possibility of fossil traces or even of current oases), but also the extraordinary combination of circumstances that had allowed life to flourish on Earth, circumstances not yet found elsewhere, in the infinite variety of possibilities. We have moved on from Giordano Bruno's notion of a "plurality of worlds" (expected to have strong similarities with the Earth) to a notion of a "diversity of worlds". Of course, the laws of physics are universal, but evolution is not only mechanically guided by these laws, but also guided by the physical context, partly constructed by a succession of random events. We must consider this result to be the fruit of astrophysical observation on the one hand, and of exploration of the Solar system on the other – and of biology itself of course. This role played by exploration (and space science in general) deserves to be brought out more clearly.

The need to preserve our planet (this “pale blue dot”, to quote Carl Sagan at the time of Voyager), where life appeared and developed as a result of an extraordinary combination of circumstances – this need is all the greater.

We are earthlings before we are human.

However, let us hope that this recent awareness of the fragility of our planet, and the legitimate priority of preserving the environment, will not translate into any disinterest in the Universe... and that future generations will continue to “look up to the stars”, and not only “look down to the wellbeing of the Earth”. This uncertainty directly challenges the sustainability of exploration. For this, education is key.

When it comes to manned flight, this quest is borne by a handful of astronauts, sent by humanity so that every human being can feel represented in this collective adventure. Everyone explores – by delegation. The presence of the body, to quote the French philosopher Michel Serres, is essential.

Space tourism, also about physical presence, is a controversial issue, especially in Europe. Some consider that the development of very ambitious, far-reaching, privately-funded space tourism will *extend* this “overview effect” to thousands of earthlings and strongly contribute to the creation of a more unified humanity. This can be called the “enlightenment effect”: the famous Apollo VIII image of an Earthrise from a remote place (the Moon) changed the perception of humankind about the Earth and itself, with a limited impact however on human mentalities. The question is: would private flights flying billionaires to the Moon one day create the same feeling of “exploring by delegation” as do astronauts, whose role is clearly to represent at least their country, and more broadly humanity? Let’s leave this question open for the time being…

When it comes to the main human developments expected in the next decade, one might imagine that what is curiously called “virtual reality” will one day undermine this fascination for exploring by delegation. When people are immersed in the attraction of a "metaverse" and its wonders, will the physical presence of the body still be a matter of interest?

The exploitation of the resources of the Solar system (Moon, asteroids…), which is truly physical, could also be an answer to this question. But this is not necessarily the way to go. This too is an interesting debate from the point of view of philosophy and civilisation. While it may help to bring new resources to humanity and preserve our planet, it is also seen, by some, as a further manifestation of human excess (*hubris*), a return to colonisation. We are not there yet… but that is no reason not to think about it from an ethical point of view.

Clearly ethical questions are inherent to this reflection on exploration. Indeed, ethics has become an important subject for Europe in particular, sometimes giving the impression that we in Europe prefer to think about what to avoid rather than what to undertake.

But when Europe decides to move forward, it should do so in accordance with its fundamental principles, its "philosophy", in order to take the right direction, and maintain it in the long term. This also means that, from the outset, a fairly far-reaching, large-scale ethics about humanity's cosmic footprint should be considered.

Space exploration policy, when it comes to human exploration, should be the result of such European values, the result of the way Europe (EU and beyond) defines its own identity. It is also certain that a common, visible, ambitious space exploration endeavour should be a very effective cement for Europe: it works both ways…

If Europe wishes to be a leader, somewhere in space, it means first recognising that "Space culture" (exploration <u>and</u> exploitation) is or can become a European value, an expression of European flagship values such as humanism, curiosity, peace, responsibility, solidarity, diversity… as well as an expression of the politically agreed flagship programmes linked to the environment, climate, green and blue Earth, etc.

Above all, as already mentioned in the introduction to this document, *cooperation* is embedded in most of European space endeavours. Europe does cooperation better than any other country or region. This will undoubtedly be a strong feature of such a future policy, leading Europe to cooperate not only with its traditional partners but also with many others, including newcomers to space exploration. Such cooperative projects will involve, in addition to the usual scientific and technological exchanges, a dialogue of cultures and visions.

Designed in this way, cooperation will be – to some extent – a guarantee of long-term viability of the programmes concerned.

A “narrative” involving the people should be built – and this cannot be a simple communication operation, *ex-post*, once the decision has been taken, but rather the *ex-ante*, deep-rooted perspective of a forward march.

Philosophy and literature provide elements for reflection, not answers, and the debate remains open, perhaps forever… but participating in it throws a more intense light on future choices than a purely political or technocratic approach.

Recommendations

R1.1 European agencies and governments should more openly address the philosophical and cultural foundations of space exploration – as well as its scientific, political and economic justifications – in order to root it deeply in European culture and values and ensure long-term support from citizens. For this purpose, ESA should organize a dedicated reflection, involving philosophers, historians, sociologists, together with scientists, on the specificities, the meaning and the future of the space adventure, both automated and human.

R1.2 European governments should renew their efforts to promote space science and space adventure in a common educational platform for young people, as an unrivalled cement for a sense of belonging as well as a call for science and progress.

2- DREAMS FOR FAR-REACHING MISSIONS

One important aspect if we are to keep the momentum of space exploration and ensure a sustainable future for it is the involvement of the next generation of engineers, scientists, leaders and believers in Europe. As indicated by Didier Schmitt, Strategy and coordination group leader for robotic and human exploration at ESA, during the final round table at AAE's Space Exploration conference:

"*It is of great importance for the future of space exploration in Europe that the next generation will be a generation of leaders who are not scared of big challenges.*"

In fact, according to the Space Generation Advisory Council (SGAC), this generation is highly motivated and dreaming of a sustainable, diverse and equal future for space exploration in Europe.

During the session "Dream missions", four students selected by SGAC from different parts of the world were invited to recount their dreams for space exploration. Via a competition that started in September 2022, 25 participants from all across the globe shared their dreams for space exploration, and worked their way through three selection rounds that included an essay, video presentations and interviews with the jury, composed of SGAC members assisted by AAE experts. The jury greatly admired the brave, innovative and multidisciplinary dreams that were presented, appreciating this insight into the topics the next generation is thinking about. Besides the four selected topics, they reviewed proposals that included space food production, mission design, and new launch technologies. The four selected presentations, ranging from deep space exploration programmes and proposals for legal organisations that ensure global cooperation for space exploration, comprised the following topics:

- a crewed return mission to Titan;
- a sample return mission to Europa to explore the oceanic environment;
- global space exploration collaboration: to turn a dream into reality;
- cryogenics for long-term space flight, raising the question of what needs to be solved in the legal system to allow these technologies to support human space exploration.

Of course, by definition, some of these topics are highly questionable. None involve any support from AAE at this stage. But dreaming about space exploration missions that touch on the border between sci-fi and space exploration challenges the technological developments for current space flights and increases the creativity to solve current problems. All space missions in the history of space once started as a dream, a crazy idea and/or a solution to a problem, and the space community needs to keep encouraging people to dream.

To ensure a long-term momentum for space exploration, the European space sector needs to create an environment where students and young professionals are encouraged to dream about space exploration, and to bring these dreams about. The question is not whether the next generation is sufficiently motivated to make an impact in the European space community, but how the next generation could be involved more. How do we create an environment for young people to start developing their leadership skills from early on in their careers and make them responsible for the future of space exploration in Europe?

With the open discussions and debates about the future of space exploration and the space sector in Europe happening over the next few years, it is a unique opportunity to start involving young people and encouraging them to share their visions and take responsibilities for the European space sector.

Recommendations

R2.1 A task force/committee at ESA should be established to produce recommendations for ESA and all players in the European space sector on how to better involve the next generation in space exploration discussions.

R2.2 ESA mission and operation teams should create student programmes where students from all across Europe could be invited to attend meetings/ conferences with observer status. This was successfully tested at NASA during INSIGHT missions and boosts career opportunities for many talented scientists and engineers in Europe.

R2.3 In order to foster dreaming about space missions, European space institutions, agencies and other organisations should collaborate with next generation organisations (e.g SGAC) to set up a platform for young professionals and students on a European scale to share their dreams and discuss them with experts all across the space industry.

3- ENVIRONMENTAL ASPECTS OF LUNAR EXPLORATION

The development of a new era of robotic and human exploration of the Moon which characterizes the current decade is in line with the objectives and strategy described initially in the "Global Exploration Road Map" in 2018 by a group of 15 space agencies and updated in 2022 by an enlarged group of 27 agencies. Lunar exploration is the first step towards future human missions to Mars and beyond, and has its proper mid-term objectives that mainly cover exploration, science and the utilisation of lunar resources. Lunar exploration currently plays an important role in the demonstration of new capacities and leadership by public and private players and offers new opportunities for innovative technology developments and basic and applied research over a broad spectrum of scientific disciplines.

On the Moon's surface as well as in cislunar orbits, the "Artemis" programme led by NASA, the "International Lunar Research Station" programme led by the Chinese space agency CNSA, other space agencies or private initiatives and integrative concepts such as the Moon Village will enable a broad diversity of activities: scientific research, exploitation of lunar resources, services to astronauts, up to perhaps small enterprise and tourism. These activities will rely on a large spectrum of facilities and operations: Earth-based launches, orbital support infrastructures, lunar landers and transportation vehicles, lunar habitats, logistics facilities for the production of power, structural material and life support systems... The objective of "keeping the momentum" for space exploration in general presented in the introduction of this document implies a safe, sustainable, and symbiotic development of these activities.

In an era of increased environmental awareness about our own planet, in which close monitoring of the impact of human activities will drive innovative mitigation solutions, the environmental impacts of the new era of lunar exploration must be systematically assessed and mitigation means carefully examined and tested. Indeed, the development of activities around and on the Moon may progressively change the pristine lunar environment into an "anthropized" environment. Assessing the threats of this transition to the lunar environment requires an understanding of:

- the scientific assets and cultural heritage of the present lunar environment;
- the nature, locations, and quantitative extent of potential lunar resources;
- the development of technological capabilities during the next decades.

A preliminary assessment of these threats leads to the identification of the most critical issues:

- waste management for the "lunar gateway" and Moon-based infrastructures;
- environmental impacts of power plants and water, oxygen, and mineral extraction facilities;
- proliferation of space debris around the Moon;
- impact of the development of Earth-Moon traffic on the Earth;
- and others…

Efficient and sustainable mitigation of these threats should focus on three priority areas:

- management of lunar orbits;
- management of resources and waste at the Moon's surface and in orbit;
- development of policies and norms in accordance with international space law[4].

Exploration of these different avenues towards preserving a clean lunar environment for future generations led to the recommendations formulated below.

Coordinated international efforts should aim at building a "virtuous circle of Moon exploration" in three complementary directions that will reinforce each other with time: "Understand", "Utilize" and "Mitigate". These are further elaborated below.

4. *Today, the conduct of activities on the Moon and other celestial bodies is regulated by the "Outer Space Treaty" (OST). Specific to lunar environmental protection, the key provision is Article IX OST, which only lays down the principles of no harmful contamination of celestial bodies and due regard for international consultation in case of potentially harmful interference.*

Understand

The natural lunar environment, its dynamics and its interaction with the space environment should be the subject of basic research and of general analyses of the potential impacts of robotic and human activities. The studies should include ways to preserve regions of potential astrobiology interest for scientific study and protect them from contamination by terrestrial extremophile organisms which might replicate in their environment.

A systematic inventory of the natural resources of the Moon, their locations and their limits, should be made in a complementary way through public and private missions.

Policies should be established for sharing information and data at the international level in the different areas related to the Moon, including scientific data obtained from institutional and commercial missions, and the nature, conduct and location of lunar activities.

A list of Moon locations (or specific orbits) of particular interest for scientific research should be identified for tentative preservation through international agreements. It could include for instance some of the “swirls”, or the “Dark Mantle Deposits” (DMDs), for their potential as rare resources, or as cultural heritage, under the umbrella of a scientific body like the Committee on Space Research (COSPAR), taking stock of the guidelines established by the COSPAR Panel on Planetary Protection. This identification of “preserved areas” should be progressive and evolve over time with the progress of scientific knowledge and projects.

Utilize

Many development efforts should be made in the area of knowledge and tools (ISRU, *In-Situ* Resource Utilization) for robotic and human lunar activities. Joint programmes should be favoured between academia and industrial research, innovating SMEs and space industry in order to cover the full chain of production of know-how, from basic research to applied research, innovation and, in the longer run, market.

Particular attention should be paid to the development of systems with potential reuse on Earth, e.g. in the area of energy or closed-loop life-support systems (such as “Melissa[5]”).

5. *MELISSA (“Micro-Ecological Life Support System Alternative”) is an ESA project initiated more than 25 years ago in the field of life support systems for long duration missions (Moon, Mars…).*

Methodologies and standards should be agreed on and shared at the international level for maximum interoperability of lunar systems and infrastructures. The agreements should be extended as far as possible to mission architectures to enable win-win interactions between the different stakeholders of lunar exploration.

Key principles should be defined for a comprehensive system approach for the management of all elements brought to the lunar surface, considered as potential resources for lunar operations (maximum reuse or recycling)

Mitigate

As a complement to the general impact studies of robotic and human activities, case-by-case specific environmental impact studies should be performed on the lunar surface and in cislunar orbits. In particular, states should require impact assessments as part of their mission planning or licensing requirements, and coordinate at the international level to notify each other and consult in case of any possible issue.

The long-term natural evolution of the different types of lunar orbits which can be used for operational missions or as graveyard orbits shall be analysed to elaborate, as soon as possible, quantitative recommendations for managing the trajectories of end-of-life satellites.

R&D programmes on Logistics reduction technologies should be actively pursued with the objective of reducing residual waste on the Moon (final waste limitation).

Based upon the principles defined by the Outer Space Treaty, guidelines and rules for safe and sustainable lunar activities are under elaboration by international bodies such as COSPAR and the Inter-Agency Space Debris Coordination Committee (IADC). Several private dedicated multi-stakeholder platform(s) are also identifying priority areas and proposing related policies and standards. Such bodies can assist the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) working group on the Legal Aspects of Space Resource Activities in its task to develop guiding principles for the safe, peaceful, rational, and sustainable use of space resources. The focus should initially be on the elaboration of key ethical principles for responsible activities on the Moon, with special attention given to areas such as the far side or the permanently shadowed regions.

In the future, the scale, nature, and duration of activities in the exploration and use of the Moon resources will require a switch from "regulation" to "governance". The examples of terrestrial and space governance areas (e.g., Antarctica, the High Seas, telecommunications frequencies) should be used to promote a step-by-step and pragmatic approach for establishing a global multi-level governance of human activities on the Moon, and a regulatory system of space mining.

The above three areas of activity should promote the following key principles:

- develop joint efforts between the diverse components of the science and technology communities to meet the challenges of the new area of lunar exploration via broad and innovative interdisciplinary research;
- stimulate initiatives of SMEs, industry, and commercial operators to build an "economy of innovation" that will ultimately be deployed at the scale of the Earth-Moon system;
- incite national space agencies, international organizations and NGOs, eventually under the auspices of the UN, to jointly shape a balanced, equitable, and sustainable use of lunar resources that will preserve humankind's shared heritage on the Moon for future generations.

These points can be summarized through three synthetic recommendations, the purpose of which is to inspire the different stakeholders of lunar exploration and exploitation.

Recommendations

R3.1 The scientific community, international scientific bodies, space agencies and funding agencies, together with New Space actors and investors, should UNDERSTAND the Moon, its environment, its potential resources for science and exploitation, and the potential impact of human and robotic activities on the lunar environment, in particular thanks to global analyses, inventories and data sharing policies.

R3.2 Space agencies, space industries along with non-space industries for new types of space activities and investors should UTILIZE the Moon by ways of innovative approaches and tools (*In-Situ* Resource Utilization, ISRU) enabling maximum use of local resources and reuse of imported products, and as far as possible closed-loop systems for life support.

R3.3 Space agencies, industries and international organizations (UN, COSPAR, NGOs and working groups in the area of sustainability of activities on the Moon) should MITIGATE all impacts of human and robotic activities on the Moon in order to achieve a sustainable use of the scarce lunar resources based on the principles of international space law and a future governance regime for lunar exploration and utilization.

4- FLYING MACHINES

This theme is about *in-situ* exploration vehicles that "fly" in a planetary atmosphere as opposed to probes simply descending under a parachute (so far in Venus (many), Mars (many), Jupiter (1996) and Titan (2005)). In 1985, two Soviet Vega balloons on Venus became the first planetary probes to fly in an atmosphere of a planet other than Earth. Their mission was highly successful, providing unique measurements while drifting at an altitude of about 54 km for about 8 days. Venus, Mars, Titan and the giant planets are Solar system bodies whose atmosphere and/or surface can be explored with flying machines. Balloons to explore Mars were developed by the Soviets, but the mission Mars 96, then Mars 98, was cancelled in the late 90s. After an interval of almost 40 years, the Ingenuity Mars Helicopter beautifully demonstrated the new capability of such a flying machine – a helicopter – to fly around its base (Perseverance Rover) and explore different spots on the surface of Mars. Mars helicopters are now integrated into the architecture of the Mars Sample Return mission studies (currently planned in the early 2030s). The next planned flying machine is NASA's Dragonfly, expected to launch in 2027 and to arrive at Titan in 2034, and the NASA Davinci+ mission to Venus, planned to launch in the late 20s/early 30s.

Many studies of flying machines have been carried out in the past 20 years by several space agencies (NASA, ESA, CNES...) as part of future mission studies to Venus, Mars, Titan and the giant planets. Interestingly, aerobots and other types of flying machines are also now part of student project mission studies for Venus, Mars, and the outer planets (Uranus). Flying machines are true inspirational concepts for students. Helicopters and drones combine rechargeable batteries and a coupled energy source (currently solar panels for Mars, a radioisotope nuclear power system for Titan), thus providing the capability to make short flights in between landed surface phases for battery-recharging and scientific investigations on the surface. Descending to the surface and landing is not practicable (possible) on Venus, but long-lived aerobots are poised to be included in the next steps in the exploration of Venus, following the three missions under development by NASA (Davinci+, VERITAS), and ESA (Envision). A large number of different concepts of Venus aerobots are being studied especially by NASA at JPL Jet Propulsion Laboratory. Only a few, not well publicized studies, are being undertaken in Europe.

Recommendations

R4.1 Flying machine technology: significant new technologies should be developed in Europe for Mars helicopters and aerobots, Venus aerobots and Titan flying machines (drones, pressurized and hot air balloons) to provide opportunities for stand-alone European missions and international collaboration on future missions to these bodies for the 2040s and beyond.

R4.2 Deep planetary probes and gliders: the benefits of in-depth *in-situ* science exploration of planetary atmospheres should be further investigated in Europe pushing through limitations imposed by current technology (10 bars, vertical descent under parachute). Balloons are not viable in the atmosphere of the giant planets, while gliders may be. For the giant planets, technologies to be developed should make possible *in-situ* exploration by flying machines other than parachuted shallow probes (for which the technology is well advanced in Europe); this would involve deep probes and gliders down to perhaps 100 bars (such a high-pressure level to be justified scientifically).

5- GOING FASTER AND FURTHER

Keeping the momentum of exploration also means improving time-to-mission and time-to-results. Today, especially for outer planets or some small bodies, it can take decades from concept study to data collection – not to mention analysis – for an experiment on board a planetary probe. To maintain and increase interest (not only of the scientists, but also of the public and hence the political and financial decision-makers) we need to move faster. Certainly, this should include (wherever possible) more efficient, shorter selection processes, but it is also about improving space travel technologies.

Early missions to the outer planets were launched on a direct transfer trajectory to Jupiter (Pioneer 10 and 11, Voyager 1 and 2). Later, the continuation of the Voyager missions and the Galileo missions to Jupiter used the then new technique of a sequence of Gravity Assist (GA) manoeuvres at different planets (Venus, Earth, Jupiter, Saturn, Uranus). GA manoeuvres were used by later missions (e.g. Cassini-Huygens to Saturn, Rosetta to Comet 67P (also used on Mars), Bepi-Colombo to Mercury) and are to be used by the recently launched Juice mission to Jupiter. Planetary swingbys are propellant-free manoeuvres that make it possible to reach planets that would be otherwise inaccessibly directly by chemical and/or electrical propulsion alone, but they significantly increase transfer time to the destination. Going faster and further to the outer Solar system requires the use of new propulsion techniques beyond chemical propulsion, solar electrical propulsion, and gravity assist.

In-space propulsion systems have been improving over the last few decades and new concepts such as nuclear propulsion or propellant-free propulsion such as solar sailing are being introduced. But how far can we go? Can we go further and faster by pushing all known propulsion systems to their limits? It turns out that this will require significant advances or really clever new ideas. But, as history has taught us, this is a matter of time and may be just around the corner.

Solar sails, a slowly maturing technology, have the potential to significantly redefine deep space exploration by providing an alternative and efficient propulsion system based on the transfer of *momentum* from sunlight rather than traditional chemical or electrical propulsion methods. Once demonstrated and validated, this technology would have a significant impact on the future of deep space exploration, although its relatively low thrust capacity limits its potential.

In the same vein, the innovative, but not yet flight-demonstrated, electric solar wind sail (E-sail) uses the solar wind protons for propulsion, by means of long, thin conducting tethers charged to a high voltage e.g. +20 kV. A sheath forms around the tether. The electric field of the charged tether scatters the solar wind ions from their original straight trajectories, thus tapping momentum from them. When moving outward from the Sun, the thrust decays as 1/r (as opposed to 1/r**2 for solar sail) because the increase of the plasma Debye length (hence the cross-section of the sheath around the tether) partially compensates for the decay of the solar wind dynamic pressure.

Electric propulsion, which currently uses electrical energy provided by solar panels, can only be used efficiently (alone or combined with chemical propulsion) relatively close to the Sun (up to a few astronomical units?). At the beginning of this decade, space exploration is at an unprecedented crossroads, with the dawn of a new era of ambitious and exciting robotic and human exploration missions for which the use of Radioisotope-fuelled power systems (RTGs) will not be sufficient. More powerful energy sources based on nuclear fission systems will be required to enable the sustainability-driven missions of the coming decades. Advanced, efficient and reliable in-space propulsion will be needed for transporting exploration systems and accessing deep-space destinations such as NEAs and Mars and, beyond, to the planets in the outer solar systems. Programmes are underway to develop such nuclear fission systems: nuclear microreactors to provide surface power on the Moon or to power robotic probes; nuclear thermal propulsion engines and nuclear electric propulsion systems to provide efficient thrust for reusable in-space vehicles for cis-lunar and interplanetary transportation of humans, cargo, and instrumentation.

But going faster to the target planet will require slowing down (braking) more effectively upon arrival. Aerocapture and Aerogravity Assist technologies may provide a solution.

Aerocapture is an atmospheric manoeuvre that uses aerodynamic forces to transfer a spacecraft from a hypersonic orbit to the target capture orbit. Aerocapture provides large mass benefits over the all-propulsion manoeuvres typically used to enter capture orbits, because the vehicle is slowed down by the aerodynamic forces of the vehicle in an atmosphere, rather than by propellant. Aerocapture has mission-enabling potential for at least two classes of planetary missions:

1. SmallSat orbital insertion systems, a new paradigm for future planetary missions;
2. mission-enabling manoeuvres for orbiters to the Ice Giants (Uranus, Neptune) and Titan. It may also offer new capabilities for manned missions to Mars.

Aerogravity Assist, where the atmospheric drag and the gravity of a planet-sized body are used to provide the ΔV and turn angle needed for orbit insertion about another celestial body, would be highly suitable for missions to the Saturnian system, especially for an Enceladus mission. Past studies have considered Titan as the planetary body whose atmosphere and gravity could be used to decrease the velocity of the interplanetary trajectory to achieve a Saturn capture orbit, to be followed by flybys to study Enceladus, although a Saturn-based aerocapture could achieve similar results.

International collaboration may take several approaches, e.g. Cassini-Huygens, Juice and Europa Clipper, DART and HERA, Mars Sample Return. International collaboration beyond flagship class missions, especially with NASA on PI-type missions (New Frontiers and Discovery), would offer more flight opportunities for the European scientific community with the Space Science Exploration Programme; such collaborations, among others, should be facilitated. We will return to this in more detail in our conclusion.

Recommendations

R5.1 In-space propulsion: propellant-free in-space propulsion technologies (solar sailing and e-sailing) and advanced nuclear power systems and nuclear propulsion are key enabling technologies for future human and/or robotic exploration missions. Their development should be strongly supported by European space agencies and industry.

R5.2 Aerocapture: going faster means slowing down quickly on arrival at the target body. The development of aerocapture and aerogravity assist technologies should be boosted in Europe. As it is unlikely that such new technologies would be used prior to validation, validation on near-Earth planets (Venus, Earth, Mars) should be considered.

6- THE SEARCH FOR WATER

The search for water is an essential matter, but one which raises many questions, whether as a scientific target across the Solar system, or as regards its technical uses in the future. Here we aim to throw light on some of these issues and identify possible ways forward for Europe in its search for water in space in its different forms.

Targets presented

The Juice mission is key, with special attention to the Ganymede and Europa moons which have liquid oceans under very thick ice crusts. Faults and fractures on the surface of the moons may reveal more, including possible water surface phenomena as discovered on Saturn's moon Enceladus. Hidden oases or not? In a few years from now, Juice's scientific instruments will provide a wealth of data to reveal more on the icy moons' features, many of which are in close interaction with Jupiter's enormous gravitational and magnetic fields.

Water is also clearly one of the main targets of Lunar exploration (addressed in Chapter 3) and part of NASA's ISRU planning. What kind of *in-situ* resources are we looking at for a first permanent habitat on Earth's moon with a view to preparing human exploration of Mars? Oxygen from mined minerals, water from ice traces, diversified byproducts from regolith processing? It is a fascinating new space world of research activities involving dozens of universities and industrial newcomers.

Chasing comets should also add to the information gained by the Rosetta-Philae mission about the composition of ice and associated elements, which could reveal prebiotic organic compositions.

Technology

From a technical point of view, the use of long-wave radar techniques to determine what lies beneath the surface of planets and moons is essential. Several missions have done so as regards the Mars subsurface, clearly identifying the presence of ice in various regions. The Juice mission will carry such a radar instrument to track water inside the Jovian moons Ganymede and Europa.

Drilling is another necessary means. The ExoMars Orbiter science package already provided interesting data but the ExoMars 2 mission aimed for much more data by landing a rover equipped with a drill. Drilling to a depth of two meters in potential permafrost terrain to access ice was a major objective. A recovery of the mission, halted by the termination of Russian partnership in 2022, was approved for launch in 2028 at the last ESA council ministerial meeting.

Commonality of interest and objectives

The search for water in the Solar system is stimulating progress on many in-depth questions:

- How did the Solar system develop and why is the presence and diversity of water (isotopic ratio, salt composition, potential organic molecules) a good indicator of its evolution?
- Are there "oases" present in other bodies than the Earth, the only one with liquid water on its surface (habitability and exobiology)?
- Could human space exploration be facilitated by using *in-situ* water resources where present? This is one of the many challenges of setting up temporary or permanent crewed stations on the Moon and Mars.

Future exploration possibilities

What can we reasonably accomplish to build on past and present achievements in terms of space exploration and acquiring knowledge? Here are some suggestions:

- Manned and robotic Moon visits with sample return in large quantities.
- Fly-by missions to all planets, often with orbiting phase (Mercury soon, Venus, Mars, Jupiter and Saturn).
- New comet encounters after successful first close monitoring of "Chury" 67P/TG comet nucleus.
- Visits to a number of asteroids with sample return.
- Robotic missions to Mars, planned with the MSR project aiming to return samples collected by the Perseverance robot mission.
- Crewed mission return and longer presence on the lunar surface, planned in the present decade.

Enriching the water theme with each of these mission suggestions is a crucial quest for progress in space exploration of the Solar system.

Role for Europe

The question here is twofold:

- What should Europe envisage in order to advance the water theme with space missions?
- What can Europe undertake in this field combining science research and potential *in-situ* water recovery and processing needed for crew missions?

The first question can be dealt with on the basis of already demonstrated European capabilities; the second depends on an ESA vision in its commitment to manned missions.

Opportunities for Europe, ESA and national space agencies should be considered according to several categories of possibilities, as illustrated in the table below.

Type of mission	Where	Values for mission prospects
Fly-by / Landing	Asteroid belt	Expand knowledge with fly-by, land where appropriate and perform sample return (presence of ice and/or water content in rocky areas).
Orbiting	Jovian & Saturnian icy moons	After well-known fly-by missions including Juice, it would be valuable to monitor icy moons with potential ice sublimation more closely. A return to the Enceladus and Saturn rings is attractive once more.
Chasing / Landing	Comets	Europe has demonstrated its skill with the Rosetta Philae mission and aims to prepare for another Intercept mission by placing a probe in orbit at the L2 position. A more ambitious soft landing could be attempted on a comet nucleus with *in-situ* analysis if not sample return.
Land exploration	Moon / Mars	Access icy surface or subsurface sources and perform *in-situ* analysis. Science must naturally be associated, in mixed missions, with ISRU early trailblazing steps. Exomars rover development invites potential adaptation to show European presence when all other qualified space nations are already present on the Moon and also aiming at Mars planet surface landing.

Concluding remarks

When considering future missions, opportunities for cooperation should not be neglected: it is of paramount importance to provide the European scientific community with the exploration data needed to pursue research at the highest level. However, such fruitful opportunities cannot be considered as sufficient to satisfy European ambitions in space exploration.

Potential missions for water, as shown in the above table, are affordable given Europe's capabilities. All that is required is a willingness to act and to fill some technical gaps that Europe needs to tackle.

Recommendations

R6.1 European agencies should seek to access the Moon and Mars by means of soft-landing robotic missions without mandatory support from major international partners.

R6.2 European agencies and industry should acquire the techniques for sample collection and return to Earth, learning from the amazing successes of Japanese, Chinese and US missions.

R6.3 European agencies should improve their ability to launch probes far from Earth by being more creative in their launch capabilities. For instance, the in-orbit rendez-vous technique could be used to assemble propulsion stages in LEO orbit in order to provide enhanced capabilities for exploration spacecraft, making them better able to reach their objectives quickly.

R6.4 European agencies and industry should focus on the development of equipment based on the energy of radioisotopes such as RTG (Radioisotope Thermoelectric Generator) and RHU (Radioisotope Heater Unit), to facilitate exploration missions beyond Jupiter.

R6.5 Europe should take the lead in planning one or more exploration missions dealing with the search for and capture of water in the Solar system. One clear expectation is the pursuit of the previous Exomars goal of penetrating Mars permafrost but other such missions should be considered, beginning with visiting ice deposits on the Moon.

7- HUMANS AND ROBOTS

Human-robotic collaboration is not unique to space. It is encountered whenever the objective is to push the boundaries of our knowledge and mastery of an extreme environment. “Exploration” on Earth, whether underwater or aeronautical, carries many useful lessons for space exploration. The crucial complementarity of the human-robotic collaboration is essential when it comes to safety, science, and bold objectives. More than ever before, the progress of technology is paving the way to unlocking human possibilities. It is our best option to serve the interests of science and inspire new generations.

A continuous driver of human and robotic exploration is scientific progress and the creation of knowledge. Being part of the quest to find our place in the Universe is a noble task. It can be achieved in the first instance by robots as surrogate scouts to places where it is unsafe or unrealistic today to send people. On-site human ingenuity, where possible, is however very valuable.

Even if no astronauts are accompanying robotic missions beyond Mars, for example to visit small bodies, robots and humans still form a team. A degree of autonomy is necessary and desirable for flight operations, but some human control is still essential, especially for payload operations. The trade-off between maintaining human control and reducing turn-around times through automation is a constant balance to be improved. The contribution of smallsats, including cubesats, to future exploration of small bodies is another current topic of interest for the human-robot “relationship” in small body exploration. With current developments in artificial intelligence, we may advance towards more fully “self-flying” spacecraft, including on-board adoption of payload operations, with on-board data processing, to the point of downlinking “results” instead of images or spectra.

Mars is a very intriguing place and while human missions to Mars are not yet within reach, the most challenging robotic surface missions are under preparation, requiring long-term build-up of broad technology and innovation capabilities. Local autonomy rather than centralized dependency is essential, much as it is on Earth. Research and development in this area is driving inventions with spin-offs in daily life in many sectors, such as autonomous vehicles or AI-driven collaborative robotics.

Landing and staying on the Moon is an unequivocal global goal. It is necessary to find the right balance between preserving the pristine status of an untouched location and the need for a human presence to study it further. The proximity of the Moon allows for an assessment of human robotic partnerships/ synergies in a harsh planetary environment. A synergistic approach between robots and humans will be a key factor in the efficient exploration of the Moon. It will pave the way and set the standard for human robotic exploration of Mars, asteroids, and other locations in the Solar system.

Today, sending women and men to low Earth orbit has become routine, even for non-professional “astronauts”. The maintenance of space facilities in Earth orbit was (and still is on the ISS) carried out by humans (e.g. Hubble Space Telescope, ISS). For large applications, the long-term maintenance of infrastructure may require fully robotic operations. The required technologies have been validated over the years on the ISS, including robotic delivery and assembly in space.

The increasingly important role of telerobotic is a cross-cutting theme across destinations. Over the last decade, telerobotic experiment missions have been conducted between the International Space Station (ISS) and Earth combining different modes of command of robotic assets on the planetary surface to provide an immersive user experience through visual feedback and force reflection, or to manage the robotic team as intelligent coworkers through task-level command. These teleoperation technologies and concepts have also been brought down to Earth into our homes and factories.

CONCLUDING COMMENTS: KEEPING THE MOMENTUM AND COOPERATING

In the introduction to this document, we emphasized two general issues: how to keep the momentum going and how to make international cooperation a structural (backbone-type) practice. How realistic are these objectives in the light of the seven themes reviewed above?

Concerning the momentum recently gained by the exploration adventure – and in particular, by human exploration – we have seen how it should be rooted more explicitly and more firmly in philosophical motivations; space discovery would then be essential to attract, maintain and improve the necessary public interest, excitement and involvement – and thus ultimately its support. We also stressed that lunar exploration, and possibly exploitation (at least at the ISRU level), which has recently returned to the top of most political agendas, should, by its very nature, preserve the lunar environment. We emphasized the need to establish an appropriate legal framework.

A specific driving theme is related to the question of water and organic carbon in the Solar system, in each of their potential physical and/or chemical states. This is a scientific topic of major astrophysical interest, a potential resource to be acquired and a “technical” issue (or an answer to a technical issue). It is likely to drive a wide variety of space missions for decades to come: no momentum should be lost, as each new discovery will in turn strengthen the global momentum of space exploration.

It has been emphasized that this momentum, at least for automated, long-distance probes, such as those for outer solar system missions, also depends on the ability to “go faster”, in order to obtain a reasonable time lapse for return of results for scientific investigators, to facilitate knowledge maintenance through missions, and integrate such programmes into a general, shared vision and endeavour. Indeed, planetary exploration should combine long-term automated ("flagship") missions and manned missions (such as to the Moon) in a strategically linked and complementary way. Of course, "going faster" should also include more effective, faster decision-making processes, including mission selection and implementation.

An efficient way to ensure the continuity of inter-generational support for exploration would be to create a framework for the implementation of cheaper and simpler missions, while maintaining an outstanding scientific and/or technological interest: these could be performed by small entities or universities, largely open to young ("fresh") contributors. Appropriate calls for proposals should be regularly released, with capped budgets enabling a sequential selection process: such an activity would constitute an optimized educational "generational" merge with senior expertise.

Cooperation may appear to be a first practical solution to the scarcity of flight opportunities. The scarcity of calls for space instruments threatens the maintenance and improvement of skills acquired over the past decades, particularly in Europe where the sustainability of a vibrant scientific instrument community built up in most, if not all, domains of technology is becoming highly fragile.

Moreover, partnership means that the share you have, i.e. the power you have, depends on the value you bring to the partnership. Increasing Europe's assets is therefore a must before knocking on the door of potential partners if Europe and its space industry is to remain as a space leader. The continuity of space exploration is an important part of this.

In addition to cooperation between NASA and the European national space agencies, NASA/ESA collaboration programmes should be developed beyond flagship missions, with sufficiently rapid selection processes.

Looking further, with the arrival of new partners in the space arena around the world, a new era of space exploration is at hand, offering an exciting future by replacing the previous era of confrontation with an expanded new type of cooperation. Each partner will bring its own expertise, will and passion, far beyond the simple goal of reducing the cost of missions. Space exploration is indeed exemplary of a societal practice in which international cooperation plays a prime role: as such, it can and will assume a central position this century when humanity is facing major planetary challenges.

It should be emphasized that cooperation as opposed to confrontation does not exclude competition, if developed in a peaceful context, for the sole sake of global efficiency.

This international cooperation for space exploration involves politics. But politics is – in the long run – the concretization of deeper, more fundamental cultural and even civilizational issues. It is not only economic interests that are involved, but also the inter-penetration of cultures and their mutual nourishment, for the benefit of peace and education.

Space exploration is an unrivalled area for the expression of such motivations, shared not only by decision-makers but also (and above all) by the people, the citizens – a prerequisite for robustness, efficiency and continued momentum, which would express the best of humanity.

ANNEX 1
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ANNEX 2
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