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EXPLORING PLANERY SYSTEMS, IN THE SOLAR SYSTEM AND BEYOND. THE ENABLING POWER OF INTERNATIONAL COLLABORATION

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Abstract

How are planetary systems born out of the collapse of interstellar clouds? How does their evolution shape the assembly of planets, satellite systems and small bodies that they host? How may a few of these planets and moons become habitable and possibly host life? Addressing these key science questions from the “Planetary exploration, Horizon 2061” foresight exercise takes a convergence of scientific insight, technical know-how and resources that can be found only via international collaboration.

First of all, characterizing the huge diversity of exoplanets and of extrasolar planetary systems discovered in less than 30 years, and detecting a host of new ones, involves the design and operation of giant observatories, both in space and on the ground. In the Solar System itself, the huge diversity of objects (planets, small bodies, moons, rings, magnetospheres…) that populate it can be explored only via a share of targets and efforts at international level, using an equally broad diversity of in-situ or remote sensing measurement techniques paving the way to sample return missions from increasingly farther destinations. Beyond the reach of sample return, the ice giants Uranus and Neptune, the Dwarf planets and icy bodies that populate the Edgeworth-Kuiper belt are mostly unchartered territories. Beyond them, Humankind also needs to accomplish its first steps into the interstellar medium. This essential exploration of the outskirts of the Solar System will require a well-designed coordination of ambitious space missions and of giant Earth-based telescopes.

For such a share of targets and missions to produce the best possible science return, scientific data have to be freely distributed amongst all partners via world-class data infrastructures such as the Planetary Data System (https://pds.nasa.gov/) or the Planetary Science Archive (https://www.cosmos.esa.int/web/psa/psa-introduction). In the same spirit, rules for the curation and distribution of samples returned from the diverse destinations to the worldwide scientific community, currently under definition for the on-going Mars Sample Return campaign, will no doubt be applied to future sample return campaigns from Venus, asteroids, Trojans, comets and the icy satellites of the giant planets.

Finally, we wish the building of the cislunar gateway station by a consortium of space agencies, a prelude to the establishment of permanent robotic or human bases on the Moon and later Mars, to be only the first step towards an enhanced and sustainable international collaboration to better understand the fate of planetary systems, of the Solar System, and of our Mother Planet.

Keywords: Planetary science, solar system exploration, international collaboration

1. Introduction

"Planetary Exploration, Horizon 2061" (Blanc et al., 2021) [1] is a long-term foresight exercise initially proposed by the Air and Space Academy and led by scientists, engineers and technology experts who are heavily involved in the planetary sciences and Solar System exploration.

The ultimate objective of this exercise is to draw a long-term picture of **four pillars** supporting planetary exploration:

- Pillar 1: the major scientific questions concerning planetary systems;
- Pillar 2: the different types of space missions that aim to address these questions;
- Pillar 3: the key technologies needed to make these missions possible;
- Pillar 4: the ground- and space-based infrastructures and services needed to support these missions.

The year 2061 corresponds to the return of Halley's comet into the inner Solar System, to the centennial of the first human space flight and to the centennial of President Kennedy's Moon initiative. It is a symbolic representation of our intention to encompass both robotic and human exploration in the same perspective. This unusually distant horizon is located well beyond the limits of the typical planning exercises of space agencies to avoid any possible confusion with them. Most importantly, the Horizon 2061 exercise is intended to "free the imagination": free the imaginations of planetary scientists who were invited to share their visions of the most relevant and important scientific questions, independent of the existence of technical solutions to address them, and free the imaginations of engineers and technology experts who were invited to look for innovative technical solutions to enable the challenging space missions that will address these questions.

Four main objectives can be achieved via this important dialogue between scientists and engineers:

- Objective 1: identify the technologies and infrastructures needed to address major scientific questions;
- Objective 2: provide a broad spectrum of notional space missions of diverse sizes and complexity levels to explore these questions;
- Objective 3: inspire coordination and collaborations between the different players of planetary exploration to better meet technology challenges, maximize synergies between individual missions and increase the overall science return of space exploration;
- Objective 4: share the major scientific questions and technological challenges of planetary exploration with the public and public/private leaders.

The key relevant space missions and required technologies, supporting infrastructures and services to meet these objectives are presented in another complementary paper "Synthesis of the Planetary Exploration – Horizon 2061 – Foresight Exercise" by P.W. Bousquet et al[2].

2. The overarching science goal of planetary exploration

The scientific exploration of planetary systems attempts understand their cosmic evolution, from their formation as "by-products" of stellar formation, to the physical and chemical evolution of their objects, to the emergence of habitable worlds, and possibly of life. Thus for Horizon 2061, the overarching science goal is to:

explore and understand the evolution of planetary systems, from their formations to the possible emergence of habitable worlds and life.

This goal is then broken down into six key science questions (Figure 1):

- Question 1: How well do we understand the diversity of planetary system objects?
- Question 2: How well do we understand the diversity of planetary system architectures?
- Question 3: What are the origins and formation scenarios for planetary systems?
- Question 4: How do planetary systems work?
- Question 5: Do planetary systems host potential habitats?
- Question 6: Where and how to search for life?

When a new field or territory is explored, the quest starts with an inventory and characterization of the objects found in the field to understand their diversity, relative distributions, and interconnections. This is summarized by the first two questions:

Question 1: How well do we understand the diversity of planetary system objects?

Question 2: How well do we understand the diversity of planetary system architectures?

Then, the causes of the observed diversity are explored. Is the observed diversity a result of the initial conditions of their formation, or of the effects of the physical laws governing their evolution and interactions? This leads to the second set of questions:

Question 3: What are the origins and formation scenarios for planetary systems?

Question 4: How do planetary systems work?

Finally, the question of the origin of life, in the Solar System and elsewhere, drives the choice of the third pair of questions:

Question 5: Do planetary systems host potential habitats?

Question 6: Where and how to search for life?

Different instruments and space missions can be adopted in the search for answers to these fundamental scientific questions.

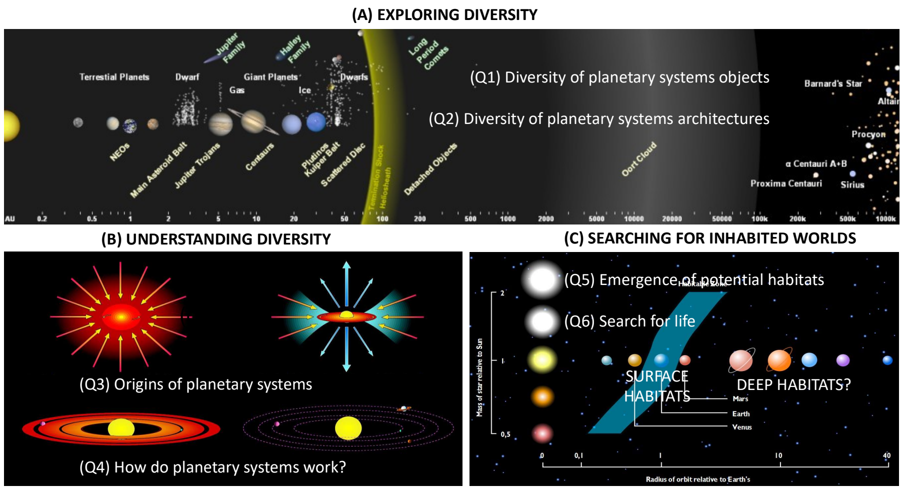

Figure 1. The six key science questions about planetary systems considered in the "Horizon 2061" foresight exercise

3. Scientific objectives versus mission destinations

The scientific questions are addressed in the "Planetary Exploration, Horizon 2061" by Rauer et al.[3] in the broader context of the exploration of all planetary systems. They show how synergies between exoplanet and Solar System research will play a key role in the elaboration of answers to these six questions, by placing Solar System exploration in the broader context of the study of extrasolar systems and of their objects[3]. Then the same science questions are addressed more specifically to the study of the solar system and its objects by Dehant et al.[4], who derive from their analysis specific scientific objectives and measurement requirements for the space study of solar system objects.

Indeed, while extrasolar planetary systems are observed by a broad variety of astronomical techniques, the Solar System will keep its unique place in the future study of planetary systems for four main reasons:

- It will remain by far the system that can be observed with the highest spatial resolution: in situ, close-up investigations of its objects by space probes will combine with the enhanced resolving power of Earth-based telescopes to scrutinize even its most distant objects (giant planet systems, Trans-Neptunian objects…); it is also the only planetary system we can ever hope to sample in situ via descent probes and landers.
- Because the Solar System can be observed with this unique combination of orbiting spacecraft, in situ landers and probes, and giant ground- and space-based telescopes, it enables scrutiny of the broadest diversity of objects that a planetary system may be expected to host.
- The Solar System is, for the time being, the only planetary system where we can observe secondary systems within it, formed of an equally diverse collection of objects: numerous systems of satellites that vary in complexity, rings and plasma tori formed around its giant planets, and our Earth-Moon system where life is known to have evolved. Thus, studied together with the Solar System as a whole, these secondary systems provide us with unique insight into the diversity of planetary system architectures.
- Finally, the combination of space missions and telescope observations makes it possible to study in detail its interface with the local interstellar medium surrounding it, the heliopause, and offers the perspective that, very soon, we will take the first steps outside of our own home planetary system to explore its surroundings.

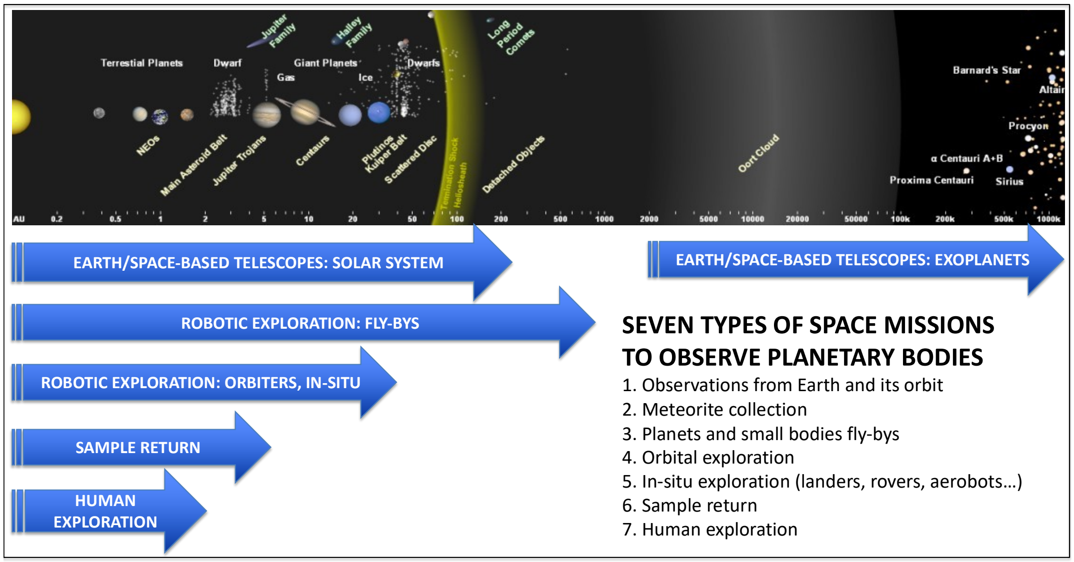

Figure 2. Observation techniques versus mission destinations

Astronomical observations from Earth or its orbit give access to most objects of the Solar System and to our Galactic environment, which contains many planetary systems. However, a gap in coverage exists in the very local interstellar medium surrounding the heliosphere. Robotic exploration can give access to all Solar System objects on a one-by-one basis and for limited amounts of time. In its simplest form, planetary fly-bys allow the first reconnaissance of an object or planet and are the way to start exploring the interstellar medium beyond the heliopause. Orbital exploration, often preceding different forms of in-situ exploration of atmospheres and surfaces, allows for a first characterization of the materials constituting each object, and can be foreseen for the Solar System's eight planets. The key tool for an in-depth characterization of an object is to collect and return samples to Earth laboratories. The power and accuracy of analytical tools available in these laboratories will surpass the limitations of in-situ or remote sensing space-borne instruments for some time. Finally, human exploration can bring the unique capabilities of scientists working directly on their observing sites with the support of large-scale infrastructures enabling their long-term presence and activities. The range of human exploration can probably extend to the asteroid belt and encompasses our Moon, Mars and Venus in the few decades to come.

These different observation techniques, with the addition of meteorite collection at Earth's surface, are listed in Figure 2 as seven types of missions to the following destinations:

- the Earth-Moon system
- Venus
- Mars
- Mercury
- Gas Giant planets and their systems
- Ice Giant planets and their systems,
- Small bodies: asteroids, comets, Trojans, Trans-Neptunian Objects
- the "frontier regions" of the Solar System, extending from the Trans-Neptunian Solar System to the interstellar medium

For each of these destinations, Lasue et al.[5] have first summarized the expected contributions of their exploration to an improved understanding of the Solar System. They have then successively described the missions that will fly in the 2021-2040 time-scale, most of which are already defined and in preparation, and a new set of notional missions that should fly in the 2041-2061 period to address the six science questions of the Horizon 2061 exercise.

As a synthesis, Table 1 lists horizontally the specific technology requirements associated with the different types of mission listed vertically. M. Grande et al.[6] elaborate a projection of future technology developments in response to these requirements. Foing et al.[7] build up the corresponding projection for future necessary infrastructures.

The very demanding nature of these missions, both from a technology and from a cost point of view, claims for international collaboration to accomplish these ambitious exploration plans.

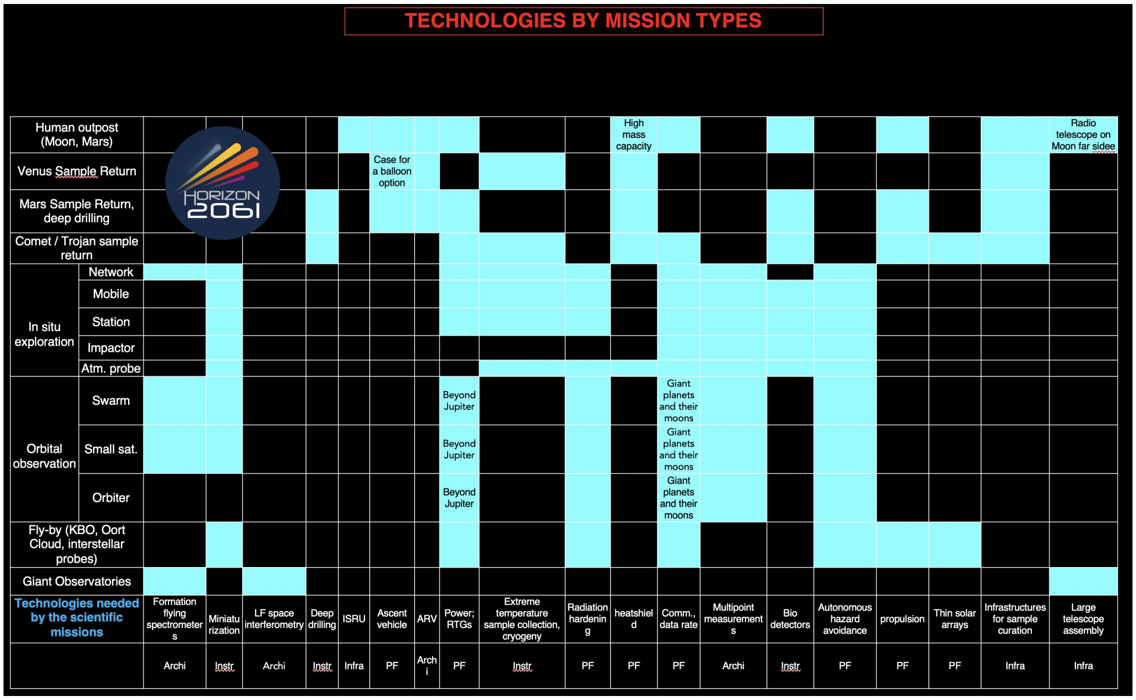

Table 1: Summary of the critical technologies that will be required to fly future missions in the 2061 timeframe

4. The Space Race

Today, international cooperation represents an important approach to sustain the space exploration framework, particularly given the demanding character of the foreseen missions[8]. However, cooperation is not how the endeavor of space exploration started. The onset of space exploration was a political and technological competition, the so-called Space Race, that started in the mid-1950s as one of the battle fields of the Cold War between the USA and USSR. Because most of the technologies used in those years were derived from military sectors, the first attempts to access the Earth's outer space were not open to international cooperation.

Despite these contentious beginnings, the scientific community's interest in new and unprecedented data about the upper atmosphere and the open space environment helped to open limited, but important, opportunities for international cooperation. The International Geophysical Year (IGY), an 18-month period between July 1957 and December 1958, coordinated 67 countries in a series of terrestrial scientific studies, including the USA and USSR. In addition to the positive influence over the investigations on the Earth, the IGY enhanced the potential scientific use of the emerging space activities and, in that context, both the USA and USSR were encouraged to direct their efforts toward the scientific exploration of space.

During the IGY, the first artificial satellites, Sputnik-1 and -2 by the Soviet Union and Explorer-1 by the USA, were successfully launched marking the beginning of the Space Race. However, despite the political tension, science was not completely overshadowed as Explorer-1's scientific payload provided the first evidence for the bands of charged particles around the Earth that became known as the Van Allen radiation belts.

In December of 1958, understanding the potential benefits and possible threats of competition in space, the General Assembly of the United Nations discussed the Question on the Peaceful Uses of Outer Space. A resolution to establish the ad-hoc Committee on the Peaceful Uses of Outer Space (COPUOS) was adopted to avoid the expansion of national rivalries into the field of outer space, and to ensure that the exploration and exploitation of outer space would be done for the benefit of mankind (https://www.unoosa.org/pdf/gares/ARES_13_1348E.pdf).

The dual use of space activities, strategic and scientific, continued throughout the Space Race and generated some opportunities for international cooperation related to the development of scientific payloads. One of the most important examples is the Solar Wind Composition Experiment (SWC), a Swiss experiment that flew with the scientific payload of the otherwise all-American Apollo missions. The SWC was deployed on the lunar surface during each of the Apollo landings and exposed to the solar wind for several hours before being brought back to Earth for analysis (https://www.hq.nasa.gov/alsj/RP-1994-1317.pdf).

In 1966, the Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies, also known as the Outer Space Treaty, was adopted by the United Nations. Signed by many different countries, and acting as a booster for multilateral international cooperation, the Outer Space Treaty mainly identified general principles for cooperation that had to be complemented by ad-hoc agreements for specific projects.

Then, in 1972, with the end of the Space Race and the beginning of a more favorable international political scene, the United States and Soviet Union signed the Agreement Concerning Cooperation in the Exploration and Use of Outer Space for Peaceful Purposes. This allowed for the development of several joint space exploration projects and programs between the two countries, like the Apollo Soyuz Test Project (ASTP) for the development of a standard docking systems that was used in 1975 for the successful docking of the Apollo and Soyuz spacecraft.

The ASTP was a crucial milestone in international cooperation and served as trigger for the bilateral exchanges that eventually led to the development of the International Space Station (ISS).

The ISS Cooperation is governed by a complex, three-tier legal framework. The first tier is the Inter-Governmental Agreement (IGA) which was signed in January 1998 and stipulates that UN conventions governing space activities apply to ISS Cooperation. The second tier consists of four Memoranda of Understanding (MOUs) between NASA and each of the other four Cooperating Agencies: the European Space Agency (ESA), Canadian Space Agency (CSA), Russian Federal Space Agency (Roscosmos), and Japan Aerospace Exploration Agency (JAXA). The third tier regulates specific activities and interactions through various bilateral implementing arrangements between NASA and other cooperating agencies. Each partner state has jurisdiction over the elements they are providing as well as their personnel. Utilization rights are defined between partners who can barter or sell these rights to other partners or non-member entities.

Despite its high level of legal complexity, the ISS has proven to be a virtuous example of multinational cooperation. In more than twenty years in operation, it has generated incalculable benefits to humankind in various fields including human health, Earth observation, astronomy and astrophysics, and

For these reasons, a free and effective exchange of scientific information between all countries and all national communities is vital to efficiently address the key science questions about planetary systems. The cooperative dialogue between scientists at an

technology innovation. It has also been fundamental for education and as a source of inspiration for the new generation[9].

More recently, an important set of players have joined a new space race: private companies are propelling the sector forward more vigorously and swiftly than has been the case through governmental efforts alone. A profound transformation of the space sector is occurring, and it is being integrated further into both society and the economy. Investors are willing to fund technology development for space exploration because they are beginning to see promising profit opportunities over the medium- and long-term time frames. While these new players have added some level of complexity, primarily because the international legal framework is not currently adequate concerning private enterprise, their new perspectives, capabilities and needs are generating a boost to the space sector and a renewed momentum for space exploration.

Despite all the challenges, the Planetary Exploration, Horizon 2061 exercise demonstrates that international cooperation is paramount when it comes to expanding the horizon of space exploration. Collaboration provides for a fruitful platform whereby science objectives and methodologies are discussed and agreed upon, and where differences are overcome through constructive dialogues among the various parties involved.

5. The international dimension of the four pillars of planetary exploration

The "Planetary Exploration, Horizon 2061 foresight exercise" identifies four pillars that underlie the scientific exploration of planetary systems: 1) the major scientific questions concerning planetary systems; 2) the different types of space missions that aim to address these questions; 3) the key technologies needed to make these missions possible; and 4) the ground- and space-based infrastructures and services needed to support these missions

A broad diversity of measurement techniques is needed to satisfactorily answer the six key questions by the 2061 horizon such as in-situ measurements, remote sensing, chemical and composition analysis, geophysical measurements and deep remote sensing, as well as atmosphere, heliosphere and magnetic field analysis, and more. The diversity of provinces and objects to be visited is equally broad and include the terrestrial planets, gas giants, ice giants, small bodies (asteroids, comets, Trojans and TNOs), the heliopause and the interstellar medium.
international level, stimulated by many international exchange platforms, such as COSPAR, IUGG and IAU, and with the support of open, regional or national platforms (EGU, AGU, AOGS, EPSC and others) must be complemented by a continuous and proactive

collaboration among space agencies. This collaboration should also imply free access to planetary mission data as soon as possible after their in-flight acquisition.

International collaborations are already the backbone of the current era of space exploration with many space missions being developed by two or more space agencies, especially with respect to the on-board payload capabilities. These international collaborations will become even more important in the next decades to sustain more demanding programs targeting specific sample returns or more distant destinations. Only missions combining the best international payload instruments with the support of the most efficient and reliable international space technologies, will be successful in providing the answers to the science questions driving space exploration.

This approach not only benefits from the sharing of the financial costs and risks between the involved parties, but also from the technological excellence developed at an international level. For such an architecture to work successfully, scientific data must be freely distributed between all partners and, subsequently, be made freely available to the public. This is already the case for American and European space missions with data repositories such as the Planetary Data System (https://pds.nasa.gov/) or the Planetary Science Archive (https://www.cosmos.esa.int/web/psa/psa-introduction) which distribute data from all past and current NASA and ESA space missions.

A significant example of multinational collaboration that will be implemented in the next decade is the Mars Sample Return campaign that started successfully with the landing of NASA's Perseverance rover in February 2021. The campaign will make use of two rovers, Perseverance for collecting the samples, and a small, agile rover provided by ESA to fetch the sample canisters. Then, the samples will be placed in a Mars Ascent Vehicle in development by NASA, launched into Mars' orbit and collected by the Earth Return Orbiter provided by ESA for a safe return to Earth. This decade-long campaign will take full advantage of the technology developments of both partners.

The human return to the Moon, and the possible human exploration of Mars, will offer outstanding, and likely essential, opportunities for international collaborations in the near future. The on-going development of the cis-lunar gateway station by a consortium of space agencies (NASA, Roscosmos, ESA, JAXA, ASC) may lay the foundations of an enhanced and sustainable era of international collaboration for the human exploration of deep space.

Table 2 summarizes for each of the Solar System destinations (left-hand-side column) the scientific benefits expected from international collaboration (central column), and the most promising modes of foreseen cooperation (right-hand-side column).

DESTINATION	EXAMPLES OF SCIENTIFIC BENEFITS OF INTERNATIONAL COLLABORATION	MODES AND OPPORTUNITIES OF INTERNATIONAL COLLABORATION
Moon	• SAMPLE THE DIVERSITY OF TERRAINS • UNDERSTAND MOON FORMATION AND INTERIOR • EXPLORE LUNAR RESOURCES	INTERNATIONAL COORDINATION ILEWG, LOPG, MOON VILLAGE, ILRS… LUNAR GATEWAY, GEOPHYSICAL NETWORKS, LUNAR BASES AND OBSERVATORIES
Terrestrial Planets	• SAMPLE THE DIVERSITY OF MARTIAN GEOLOGICAL PROVINCES AND MINERAL/WATER RESOURCES • RETRIEVE MARS INTERNAL STRUCTURE AND METEOROLOGY • SEARCH FOR A MARTIAN LIFE • COMPARE MARS AND VENUS WITH OUR EARTH	DEPLOYMENT OF GEOPHYSICAL AND METEOROLOGICAL NETWORKS MARS SAMPLE RETURN CAMPAIGN VENUS SAMPLE RETURN MISSION FUTURE MARS BASES…
Giant Planets Systems	• EXPLORE THE DIVERSITY OF GIANT PLANETS SYSTEMS MOONS, OCEAN WORLDS, RINGS AND MAGNETOSPHERES • UNDERSTAND THEIR COSMIC EVOLUTION, FROM FORMATION TO HABITABILITY	INTERNATIONAL COORDINATION OF MISSIONS TO THE DIFFERENT SYSTEMS AND THEIR OBJECTS COMPLEX MULTI-PLATFORM MISSIONS: COMBINED ORBITER/PROBE MISSIONS, EXPLORATION OF ICE GIANTS, ASTROBIOLOGY LANDERS …
Small Bodies	• CONTRIBUTE TO A COMPREHENSIVE INVENTORY OF THE DIFFERENT CLASSES OF SMALL BODIES • CHARACTERIZE THE "BUILDING BLOCKS" OF PLANETS: ASTEROIDS, TNOs, COMETS…	INTERNATIONAL COORDINATION OF MISSIONS TO VISIT THE DIFFERENT CLASSES OF OBJECTS COMPLEX INTEGRATED MISSIONS WITH ORBITERS AND SAMPLE RETURN
From Heliopause to Interstellar Medium	• ESTABLISH THE 3-D STRUCTURE OF THE HELIOSPHERE • EXPLORE THE INTERSTELLAR MEDIUM IN DIFFERENT DIRECTIONS	INTERNATIONAL COORDINATION OF MISSIONS TO EXPLORE THE HELIPAUSE AND VERY LOCAL INTERSTELLAR MEDIUM IN DIFFERENT DIRECTIONS
Exoplanets	• INVENTORY OF EXOPLANETS AND PLANETARY SYSTEMS USING THE DIVERSITY OF TECHNIQUES • SEARCH FOR HABITABILITY AND BIOSIGNATURES ON EARTH-LIKE PLANETS IN HABITABLE ZONES	INTERNATIONAL COORDINATION OF MISSIONS TO DETECT AND CHARACTERIZE EXOPLANETS WORLD-CLASS GIANT TELESCOPE MISSIONS WITH HIGH SPECTRAL AND SPATIAL RESOLUTION

Table 2. Scientific opportunities and benefits for planetary exploration by destination

6. International collaboration towards 2061: ISECG, COSPAR and ILEWG as examples of fruitful international collaboration

In the last few decades, different working groups have formed involving scientists, industries and space agencies to carry out discussions about common objectives and interests related to exploration underlining the importance that international cooperation plays in the implementation of the identified exploration missions

Founded in 2007, the International Space Exploration Coordination Group (ISECG) is a non-binding forum in which participating space agencies share information about their space exploration plans, objectives, and interests with the goal of strengthening individual agency exploration programs and the collective effort. ISECG was established in response to "The Global Exploration Strategy: The Framework for Coordination," developed by 14 space agencies and released in May 2007. This GES Framework Document articulated a shared vision of coordinated human and robotic space exploration focused on Solar System destinations where humans may one day live and work (https://www.nasa.gov/exploration/about/isecg).

The current Global Exploration Roadmap reaffirms the interest of its members to expand the human presence into the Solar System, with the surface of Mars as a common driving goal. It reflects a coordinated international effort to prepare for space exploration missions beginning with the International Space Station and continuing to the lunar vicinity, the lunar surface, then on to Mars.

Responding to concerns raised in the scientific community that spaceflight missions to the Moon and other celestial bodies might compromise their future scientific exploration, in 1958 the International Council of Scientific Unions (ICSU) established an ad-hoc Committee on Contamination by Extraterrestrial Exploration (CETEX) to provide advice on these issues. In the next year, this mandate was transferred to the newly founded Committee on Space Research (COSPAR), that has provided an international forum to discuss such matters under the terms “planetary quarantine” and later “planetary protection”, and has formulated a COSPAR planetary protection policy with associated implementation requirements as an international standard to protect against interplanetary biological and organic contamination, and after 1967 as a guide to compliance with Article IX of the United Nations Outer Space Treaty in that area[10].

Among COSPAR's objectives are the promotion of scientific research in space on an international level, with emphasis on the free exchange of results, information, and opinions, and providing a forum, open to all scientists, for the discussion of problems that may affect space research.

The International Lunar Exploration Working Group (ILEWG) is a public forum reporting to COSPAR and the world's space agencies to support "international cooperation towards a world strategy for the exploration and utilization of the Moon - our natural satellite" (International Lunar Workshop, Beatenberg (CH), June 1994). ILEWG was founded by several space agencies: ASA, ASI, BNSC, CNES, DARA, ESA, ISAS, NASA, NASDA,RSA (https://en.wikipedia.org/wiki/International_Lunar_Exploration_Working_Group).

Since 1994 ILEWG has been organizing the ICEUM International Conferences on Exploration & Utilization of the Moon with published proceedings, and where community declarations have been prepared and endorsed by community participants. ILEWG has defined a roadmap towards future exploration, utilization and settlement of the Moon, and has been coordinating international cooperation opportunities including the use of lunar data, ground station support, the contribution of international payload on lunar missions, the definition and development of joint missions, and the preparation for robotic village and human base activities.

5. Conclusions

The humankind’s unremitting endeavour in planetary exploration, which shall be carried out for the benefit and in the interests of all countries, is a forward-looking and challenging process. International cooperation is an important enabling power of planetary missions, which represent the primary means to push the boundaries of humankind’s knowledge on the solar system.

International cooperation can make long-term visions, such as the Horizon 2061 foresight, come true. Realization of the diverse and challenging set of missions envisioned in Pillar 2 to address our major questions about the fate of planetary systems needs vast amount of resources, which include, among others, technologies, infrastructures, financial and human resources. No single space agency or nation has the ability to provide all the resources needed. Even if one single agency or nation had the ability, it would not be feasible for the agency or nation to invest so many resources to implement all these missions. Only by pooling together resources of all countries can these missions be made possible by 2061.

International cooperation can enable best use of limited resources available for planetary exploration missions. Duplication could be avoided through international coordination. By feeding contributions of all countries into a single planetary exploration plan, missions could be arranged in a manner to enable optimization of each one’s achievements and thus maximize the overall outputs of planetary exploration in a long timeline.

International cooperation is an enabler of sustainable development of planetary exploration. Planetary exploration can be carried out in a coordinated way through international cooperation, which would be based on generally recognized rules including, inter alia, the principles enshrined in the outer space treaties. These rules will certainly enable global partnerships and enhance the peaceful uses of outer space, which can contribute to sustainable development of planetary exploration. International cooperation is also an essential way for transparency and confidence building, which would in return enhance cooperation among nations.

International cooperation can enable capacity building and awareness-raising of planetary exploration in countries around the world, in particular developing countries. Open and inclusive international cooperation will enable emerging and developing countries to get access to opportunities that otherwise wouldn't be available for them, such as in-orbit demonstration of instruments, scientific analysis of lunar or Martian samples and so on. These opportunities will certainly enhance space capacity building and make people in the countries more aware of benefits of planetary exploration. That will eventually enhance the capacity of the humankind as a whole in planetary exploration and thus enable more future missions.

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