HORIZON 2061

ABSTRACT BOOK

Planetary Exploration 2061

Step 3, Synthesis workshop

11 - 13 Septembre 2019 - IAS, Toulouse, FRANCE

Planetary Exploration HORIZON 2061 is a long-term foresight exercise initially proposed by the Air and Space Academy and led by scientists, engineers and technology experts heavily involved in planetary sciences and in the space exploration of the Solar System

TABLE OF CONTENTS

Abstracts - Day 3 - Sessions 6-7 100

SUMMARY OF STEPS 1 AND 2 AND WORKSHOP STRUCTURE

"Planetary Exploration, Horizon 2061" is a long-term foresight exercise initially proposed by the Air and Space Academy and led by scientists, engineers and technology experts heavily involved in planetary sciences and in the space exploration of the Solar System. Its ultimate objective is to draw up to the 2061 horizon a long-term picture of the four pillars of planetary exploration:

(1) our major scientific questions on planetary systems;
(2) the different types of space missions that we need to fly to address these questions;
(3) the key technologies we need to master to make these missions flyable;
(4) the ground-based and space-based infrastructures needed in support of these missions.

The year 2061 corresponds to the return of Halley's comet into the inner Solar System and to the centennial of the first human space flight and of President Kennedy's Moon initiative. It symbolically represents our intention to encompass both robotic and human exploration in the same perspective. Its distant horizon, located well beyond the usual horizons of the planning exercises of space agencies, avoids any possible confusion with them and is intended to « free the imaginations » : imaginations of planetary scientists, who are invited to formulate what they think are the most relevant and important scientific questions independently of the a priori technical feasibility of answering them ; imaginations of engineers and technology experts, who are invited to contribute to the exercise by looking for innovative technical solutions that will make it possible to fly the challenging space missions that will allow us to address these questions.

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

(1) Identify the technologies and infrastructures that will be needed to address our major scientific questions;
(2) provide a broad spectrum of notional space missions of diverse sizes and complexity levels all contributing to address these questions;
(3) inspire coordination and collaborations between the different players of planetary exploration to better meet technology challenges, stimulate complementary and synergies between individual missions and increase the overall science return of space exploration;
(4) share with the public and public/private leaders the major scientific questions and technological challenges of planetary exploration.

The « Horizon 2061 » exercise involves three successive steps. Its third step, the « Horizon 2061 synthesis workshop », will be hosted by the Institut Aéronautique et Spatial (IAS) in Toulouse from September 11th to 13th, 2019. Its tentative conclusions will be presented for discussion at the joint EPSC-DPS meeting in Geneva (September 15th to 20th, 2019), and later for discussion and final approval at the COSPAR General Assembly (Sydney, August 15th to 23rd, 2020).

Origin, context and motivations

The "Planetary Exploration, Horizon 2061" exercise was born from an initiative of the Air and Space Academy whose "GT 2061" working group was tasked to draw via a dialogue with the science and technology communities a long-term picture of the four pillars of planetary exploration at the 2061 horizon:
Pillar (1): our major scientific questions on planetary systems;
Pillar (2): the different types of space missions that we need to fly to address these questions;
Pillar (3): the key technologies we need to master to make these missions flyable;
Pillar (4): the ground-based and space-based infrastructures needed in support to these missions.

The choice of the year 2061, corresponding to the return of Halley's comet into the inner Solar System and to the centennial of the first human space flight and of President Kennedy's Moon initiative, symbolically represents our intention to encompass both robotic and human exploration in the same perspective. Its distant horizon, located well beyond the usual horizons of the planning exercises of space agencies and of their standing committees, which generally address shorter time scales, avoids any possible confusion with them and is intended to trigger a joint foresight thinking of the scientific and technology communities of planetary exploration that will « free the imaginations »:

- of the planetary scientists, who are invited to formulate what they think are the most relevant and important scientific questions independently of the a priori technical feasibility of answering them;
- of the engineers and technology experts, who are invited to explore innovative technical solutions that will make it possible to fly by 2061 the challenging space missions that will allow us to address these questions.

To build these four pillars, we use the method used to design science-driven space missions: we write a "Science Traceability Matrix" (STM) by which each science question and measurement objective can be translated into requirements on the scientific investigations and instruments needed, on the mission profile and on characteristics of the platforms. In the case of Horizon 2061, we write the STM, not of a single space mission, but of a "set of representative missions" whose combined science return will make it possible, by 2061, to address as comprehensively as possible six "key science questions".

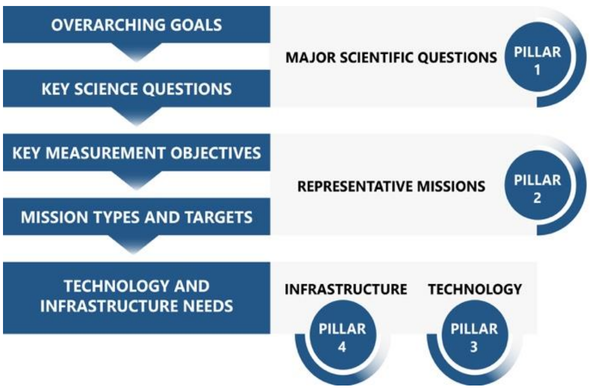

Figure 1:
To build the four "pillars" of planetary exploration, the Horizon 2061 exercise progressively fill the successive columns, from left (overarching goal) to right (technical requirements) of a set of representative missions whose combined science return will make it possible to address six "key science

Understanding Planetary Systems: from science questions to mission types and destinations.

We have chosen to place our Horizon 2061 exercise in the very important context of the current emergence of a unifying paradigm of planetary sciences: the concept of « planetary systems, a class of astrophysical objects which covers and links together the solar system, giant planets systems and extrasolar planetary systems. It is a "hard fact" that the solar system and its giant planets systems (5 "realizations" of planetary systems within our own) on one hand and extrasolar planetary systems on the other hand can be observed by different techniques and with important differences in measurement resolutions: whereas remote sensing using the variety of techniques of astronomy applies to all systems, only the solar system, in the XXIst century, is accessible to the powerful approaches of in situ investigations.
Despite this importance difference in their accessibility to our observations, there is no doubt that they form *one class of astrophysical objects*, as illustrated by the "cartoon" of Figure 2.
Studying them together in a comparative approach, from their formation in circumstellar disks to the potential emergence of habitable worlds and of life within them, will be a considerable source of new scientific insight, in the same way as what happened to Solar and stellar physics when they were finally considered as two different entries to the same scientific discipline.

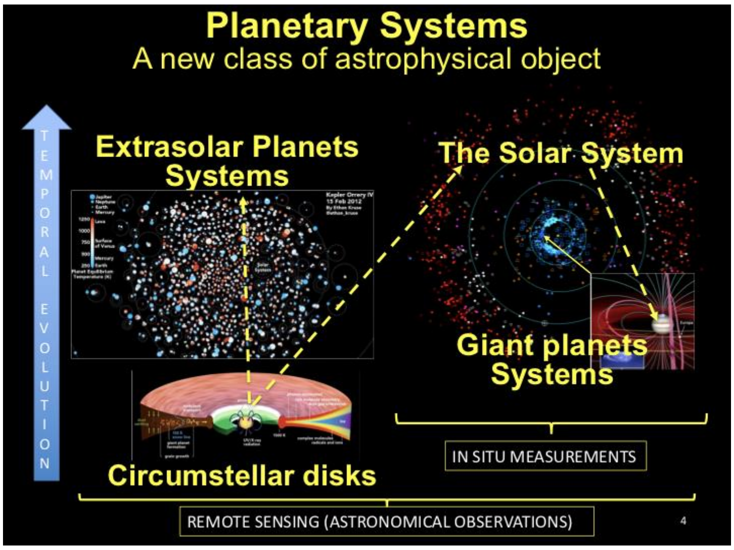

Figure 2: by studying Planetary Systems as a "new class" of astrophysical objects, in the perspective of their evolution, from their formation inside circumstellar disks to the possible emergence of habitable worlds within them, one can bridge the "observational gap" currently existing between disks, solar system objects and exoplanets and take advantage of considerable synergies to better address our "key questions" about them.

This is the challenge we propose for the development of our Horizon 2061 scientific foresight exercise: reach a more comprehensive understanding of how and under which conditions the formation and evolution of planetary systems can lead to the emergence of life, a question which we can formulate as our "overarching goal":
Study the formation and evolution processes leading to the growth of complexity, and ultimately to the possible emergence of life, through the diversity of planetary systems:
(1) the growth of molecular complexity, from the Interstellar medium (ISM) to planetary and moons environments;
(2) the growth of planetary environments complexity, and the conditions under which their evolutionary paths may lead them to become "habitable".

Developing this general goal into more specific questions addressing the different sequences of evolution of planetary systems and their coupling processes, we come up with the six "key science questions" presented in Figure 3 and in Table 1.

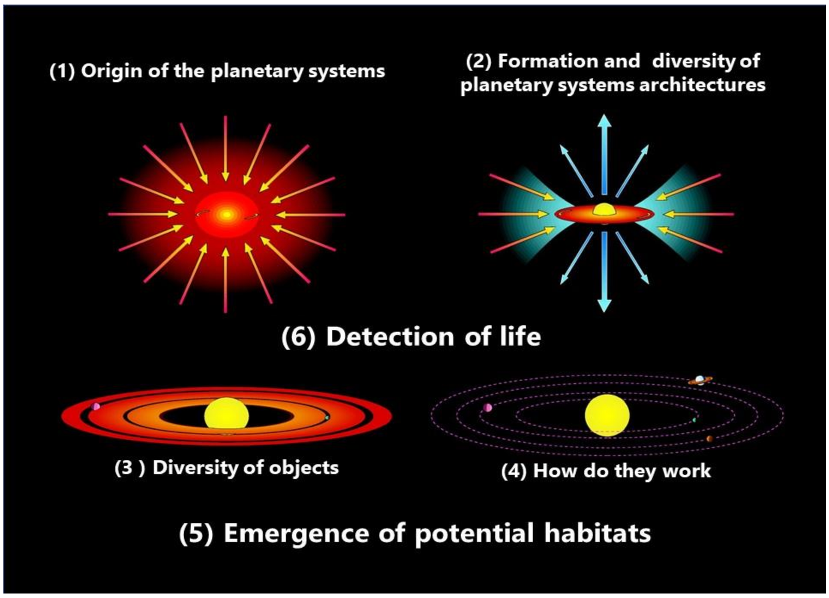

Figure3:
Six key science questions about planetary systems

Our chosen overarching goal is consistent with the current emergence of a unifying paradigm of planetary sciences: the concept of « planetary systems, a class of astrophysical objects which covers and links together the solar system, giant planets systems and extrasolar planetary systems in the quest for common answers to the major scientific questions just mentioned.

Table 1: Six science questions on Planetary Systems	
1. Origin of Planetary Systems	*4. Planetary Systems coupling mechanisms (= How do they work?)*
2. Formation and diversity of Planetary Systems architectures	*5. Emergence of potential habitats*
3. Diversity of objects	*6. Search for life*

In this approach, our foresight analysis of the major scientific questions and of the types of space missions to solar system destinations needed to address them that can be placed in the broader context of the scientific exploration of the fascinating worlds of extra-solar planetary systems. Then, starting from our six **major scientific questions** (figure 3), our Horizon 2061 foresight first identifies for each question the **key observations** that need to be performed and the destinations in the solar system where these measurements must be performed, and then the **types of space missions** that will need to be flown to these destinations by 2061 to perform these observations (figure 4).

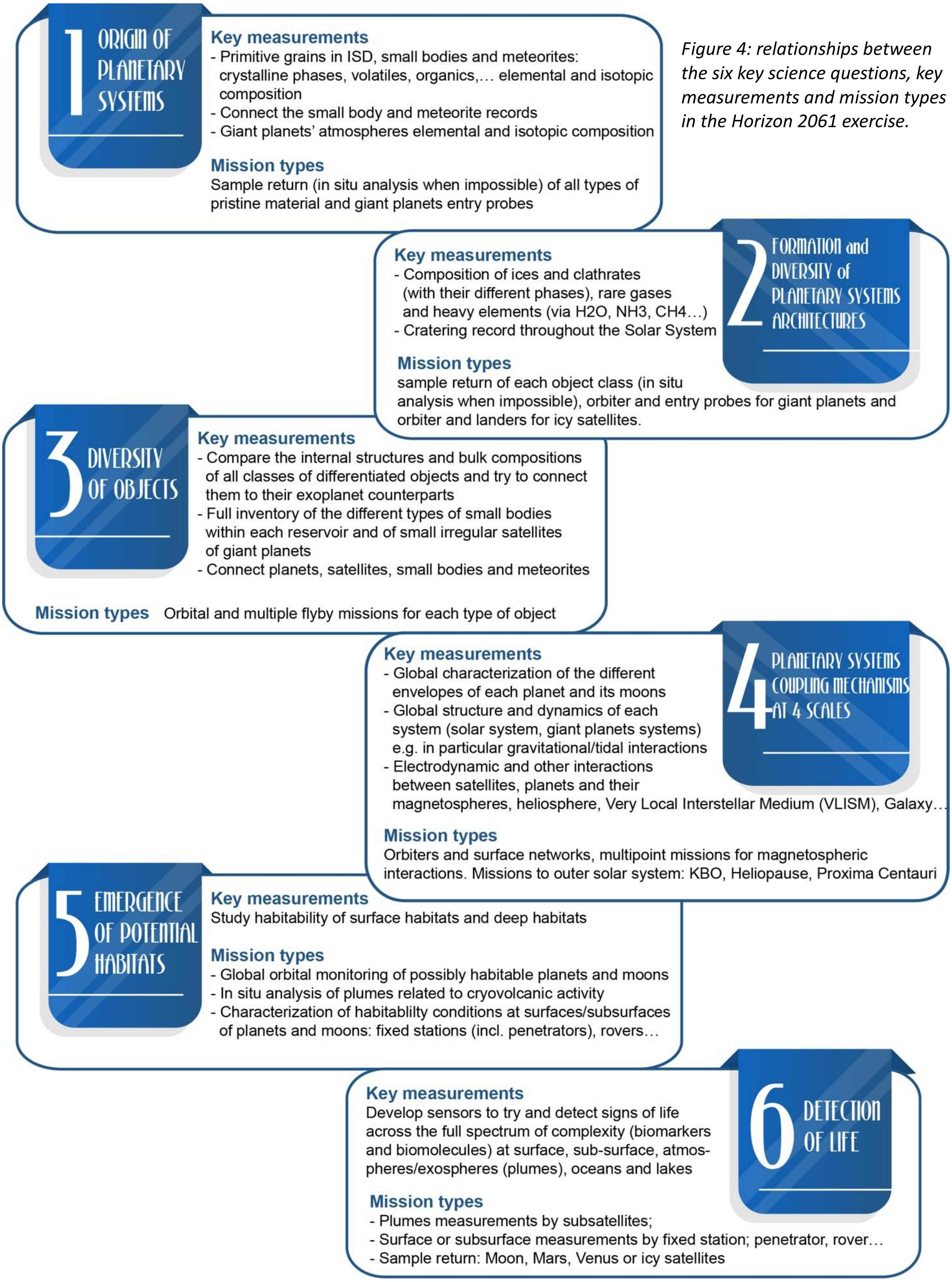

Figure 4: relationships between the six key science questions, key measurements and mission types in the Horizon 2061 exercise.

This analysis shows the large diversity of the destinations of our types of missions and its broad spatial spread towards deep space, from the Earth-Moon system up to the local interstellar medium beyond the heliopause, illustrated in Figure 5. By 2061, all the outer boundaries, or “frontiers”, of exploration should have moved dramatically outwards: human exploration might have reached Mars and perhaps the main asteroid belt; sample return missions should have reached, beyond the asteroid belt, the Trojan asteroids on the orbit of Jupiter and the icy moons of Jupiter and Saturn; *robotic exploration* should have reached the very local interstellar medium, well beyond the outer shock of the heliosphere, thus opening the very-long-term perspective of a new era: the onset of interstellar travel towards the closest stars and their planetary systems; and finally, the development of new giant telescopes on Earth or in orbit will provide unprecedented access to solar system small bodies, resolving them, spatially and/or spectrally, up to the distance of the Kuiper belt.

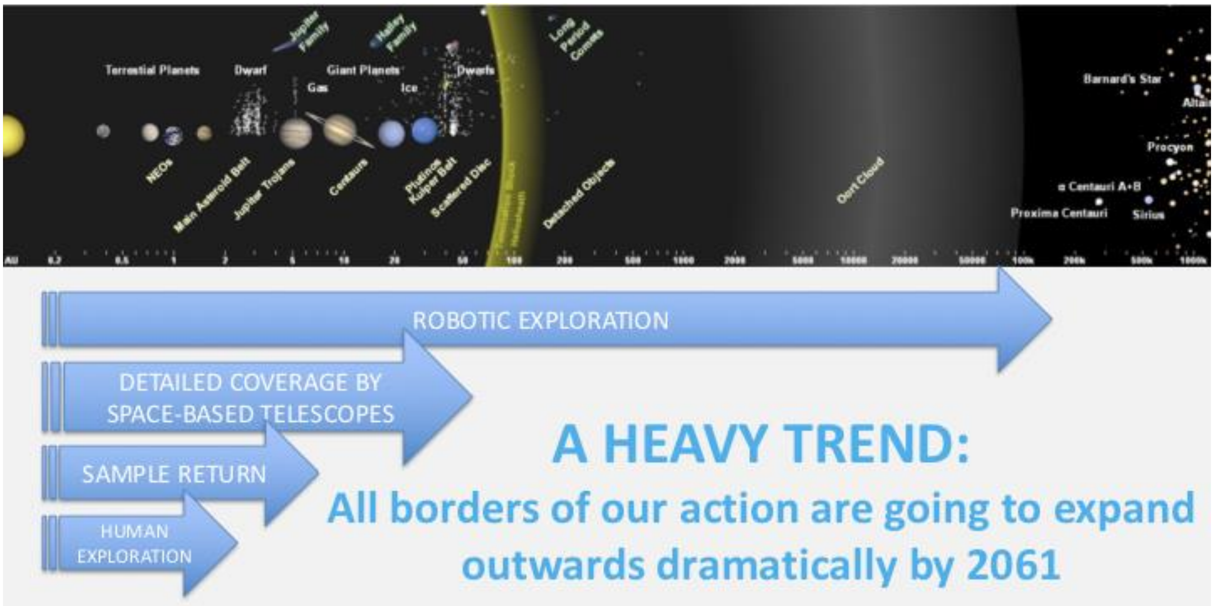

Figure 5: The outward expansion of the “frontiers” of our different ways of visiting and discovering the solar system should be one of the heavy trends of Humankind’s exploration endeavours by 2061.

From representative missions to enabling technologies.

One can classify for convenience our broad range of destinations into the six **provinces** listed in table 2. Each of these provinces can be visited by several "representative **missions"** chosen for their requirements on enabling technologies and support infrastructures: this is the link we need to establish to build the last two pillars of our exercise.

Table 2: The six "provinces" of Planetary Exploration	
1. Future giant observatories	*4. Giant planets systems*
2. The Earth-Moon system	*5. Small bodies*
3. Terrestrial planets	*6. Heliosphere, ISM and beyond*

Building on the presentations and exchanges of the Step 1 and 2 meetings in Bern and Lausanne, we have established a preliminary list of these "representative missions" and divided them into two sub-sets:

1. Missions that could/should reasonably be flown by 2040, using technologies that are or will be soon available either directly in the space activities sector, or in other domains from which they could be adapted to our needs;
2. An additional subset of missions that need to be flown during the following two decades (2041-2061) and will likely require novel technology developments and the design of infrastructures which will offer additional supporting capabilities and will enhance the overall science return of the exploration program, allowing better synergies between missions and stimulating international collaboration.

Then it is possible to connect each category of "representative missions" we have identified to the enabling technologies needed to fly these missions, based on the ouputs of the Lausanne workshop. With this additional link established, it was possible to draft figure 6, which summarizes the links between the representative missions that could be flown before or after 2040 and their enabling technologies.

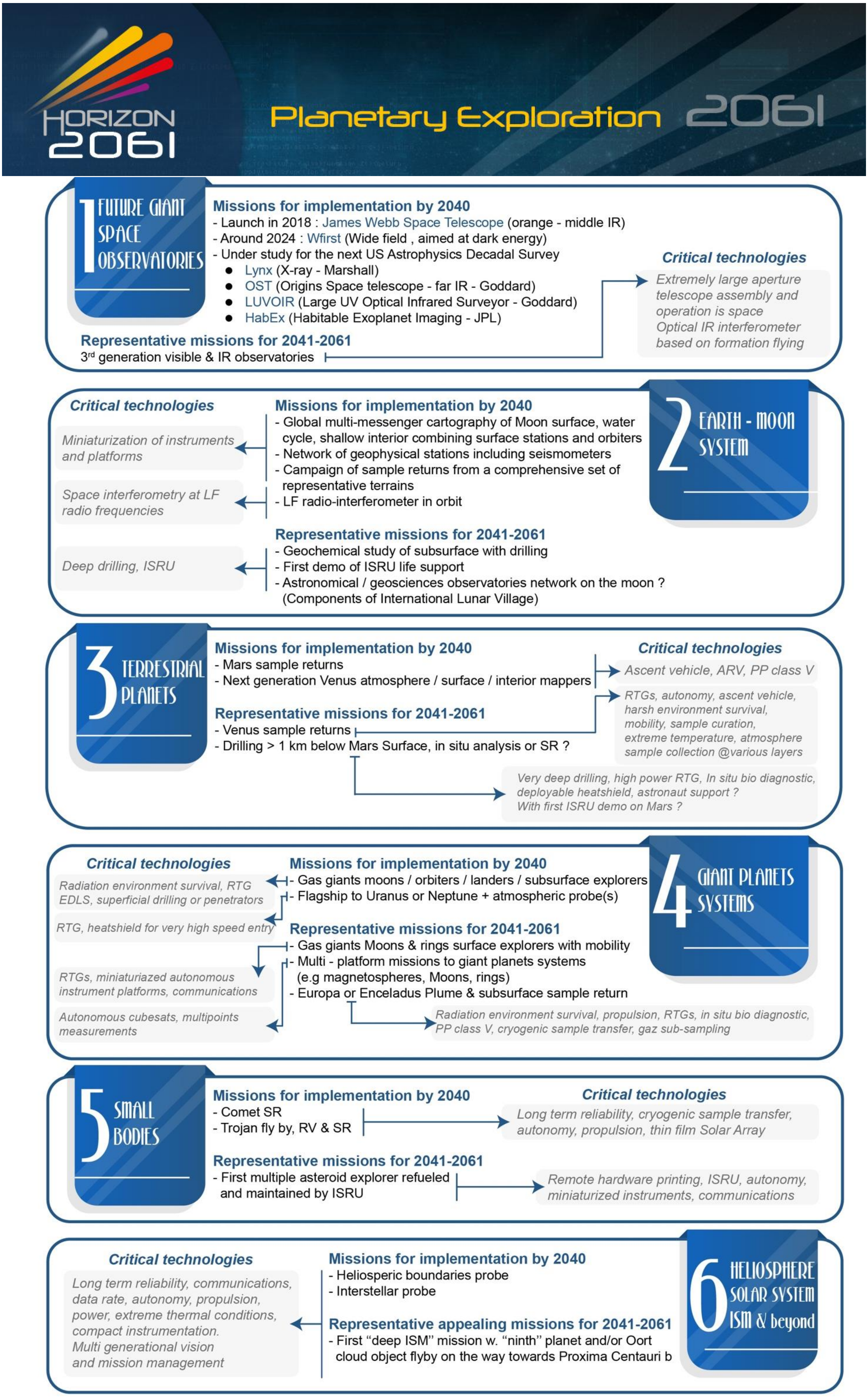

Figure 6: From representative missions to their enabling technologies

Critical technologies (pillar 3)

The **critical technologies** needed can be classified into six generic themes (Table 3) including critical technologies of dual use with manned space exploration.

Table 3: Six critical technological domains	
1. Science instrumentation	*4. Mission implementation- Overall system architectures*
2. Platform subsystems and enabling technologies	*5. Ground operations technologies and implementation*
3. System level technologies	*6. Advanced and breakthrough technologies*

1 Science Instrumentation

Remote sensing, In situ measurements, Seismometers
Life detection
In situ operations: Sample access (drilling, coring...) retrieval, selection/curation, encapsulation
Contamination control
Miniaturization, Printable instruments and electronics,
Sustainability in extreme environment
Autonomy (IA...) for operations, sample selection...

2 Platform subsystems and enabling technologies

Increased computer power, Data handling/data processing, Autonomy
Power, Energy storage,
Propulsion,
Structures, Thermal control
Communication, Navigation, Guidance and control,
Sustainability and performance in different severe environments (high radiation level, high or low temperature, high pressure, corrosive environment, adaptation to unknown events,)

3 System level technologies

Aerocapture, Aeroassistance, Entry, descent and landing
Mobility: Aerial, surface, subsurface
Hard landers and penetrators
In Situ Resource Utilization
Sample return (ascent, RV, orbital transfer...)
Intelligence in machines/Systems (IA,…)

4 Mission implementation- Overall system architectures

Multitarget missions, multi point measurements
Large S/C and collection of smallSats and probes, swarm of smallSats
Low cost and higher risk missions

Standardisation of S/C interface for flexible and collaborative missions
Large observatories based on Formation flying or on deployment of monolithic structures

5 Ground operations technologies and implementation
New technologies required for operations of outer solar system missions
Ground technologies related to the return of sample from space
Technologies and operations implementation aiming at cost reduction and efficiency improvement

6 Advanced and breakthrough technologies, *Technologies featuring low or very low TRL today, but large potential for science missions*

6.1 Advanced technologies for reducing the time of access to the outer solar system
Electric power generation (from radioisotope, nuclear reactor…)
High power electric propulsion, … other high efficiency, high thrust propulsion…

6.2 Breakthrough technologies (*very low TRL today)* e.g.:
Beamed energy propulsion: Electric sail/solar photonic propulsion
Quantum technologies: Quantum communication, Sensing and measurement in space
Collaborative systems or devices: collaborative swarms of Picosat (few 100g) or femptosat (few g), Collaborative swarms of small mobile...
Mobility: Extreme terrain mobility, microgravity mobility
Damage tolerant materials…

Shared infrastructures and facilities and international cooperative programs

While each mission, taken individually, requires enabling technologies and technical support equipments, considering all missions together in an international perspective makes it possible to create a considerable added value to an “international planetary exploration program:

- Some of the support equipments can be - and are - shared between different missions (e.g. DSN-type mission support);
- Some facilities, technical or scientific (data centers, extraterrestrial sample repositories, …) also serve much more than one mission, and facilitate “across-missions” science analysis;
- And finally, in some areas the best way of maximizing the science return from the exploration program is to define “international cooperative programs” within it: one of the best possible examples is given by the great perspectives offered by the upcoming phase of Lunar science exploration.

These three types of facilities and activities shared and coordinated at the international level “across missions” will not only save resources and maximize the fruit of investments, but will also produce a very significant additional science return. They can be broadly classified in the six categories listed in table 4.

In this approach, the sum of all missions will produce much more science return than would be the sum of the science return from each mission taken individually: an in-depth analysis of this exciting perspective will be our approach to build the "fourth pillar" of our Horizon 2061 exercise.
The different types of infrastructures and services can be classified into six categories, as summarized in Table 4.

Table 4: Six categories of support infrastructures	
1. Solar system space weather	*4. Overall capabilities, developed for manned missions, for In-space manufacturing, assembly and/or deployment of large structures*
2. Solar system wide infrastructure for communications, navigation and scientific observations	*5. Nascent commercial space services (orbital transfer, in situ resources ...)*
3. *Moon/Lunar platforms as laboratories and gateway*	*6 Overall Ground/Space infrastructures for sample analysis, contamination control, sample curation, planetary and Earth protection*

1 Solar system space weather

Synergy with services for ground/ Earth environment and space services for manned flights (moon, then Mars and asteroids…)

Environmental characterization

2 Solar system wide infrastructure for communications and navigation

Ground and space infrastructure, Synergy with other space missions (DSN upgrade/advancement and beyond)

3 Moon/Lunar platforms as laboratories and gateway

Lunar orbital platform gateway to ease access to the solar system and safe return of samples from the solar system (critical operation or final testing before sending payload to farther destination, …)

Human aided sample retrieval/return from the Moon

4 Overall capabilities, developed for manned missions, for In-space manufacturing, assembly and/or deployment of large structures

In space (potentially on the Moon) manufacturing (3D, others), assembly or deployment of large structures for different types of observatories or other needs

Utilisation of material from in situ resources

5 Nascent commercial space services (orbital transfer, in situ resources ...)

Launch, orbital transfer, access to the Moon

Utilisation of resources from the Moon or asteroids

Mining services

6 Overall Ground/Space infrastructures for sample analysis, contamination control, sample curation, planetary and Earth protection

Ground and space laboratory network

Earth protection and planetary protection against contamination,

Horizon 2061: who, for whom, for what objectives

The "Horizon 2061" foresight exercise has been designed to be led by scientists and engineers covering diverse components of the science and technology communities of planetary exploration and fed by their ideas and inputs at each of its steps. Its three-step format makes it possible to collect new ideas from the diverse disciplines contributing to this activity domain and to stimulate interdisciplinary dialogues as a central source of its foresight. Thanks to these foundations, Horizon 2061 can aim to achieve four main objectives:

1. Identify the technologies and infrastructures that need to be developed to fly the space missions that will make it possible to address the major questions of the science of planetary systems in the long term;
2. Provide, free of programmatic constraints, a broad variety of notional space mission concepts that have the potential to contribute to the progress of our understanding of planetary systems, from « small missions » that could be implemented by some of the new actors of planetary exploration, to the most complex and expensive ones that cannot be implemented by a single space agency and require international collaboration;
3. Inspire coordination and collaborations between the different players of planetary exploration to meet the technology challenges, develop the needed infrastructures and implement the missions that will best serve the progress of knowledge;
4. Share with the public and public/private leaders the major scientific questions and technological challenges of planetary exploration for the decades to come.

We regard the international cooperation aspects of Horizon 2061 as of the utmost importance in its approach, in line with the official support it has received from COSPAR under the auspices of the Air and Space Academy.

Development scheme of the H2061 exercise and elaboration of its conclusions.

The Horizon 2061 exercise is being developed in three steps, e.g. three meetings of international experts designed to progressively build the four pillars of planetary exploration.

The first step has been a joint ISSI-Europlanet forum (ISSI, Bern, september 13th to 15th, 2016) which led to formulate the six **major scientific questions** (pillar 1), to identify the **key observations** and where to perform these observations and initiated our exploration of the **critical technologies** needed.

The second step has been the community workshop "Technologies and Infrastructures for Planetary Exploration" hosted by the Ecole Polytechnique Fédérale de Lausanne (EPFL) from April 23rd to 25th, 2018, which laid the foundations of pillars 3 and 4 on the basis of a first inventory of the **mission types**.

The third step, devoted to the synthesis of the exercise, will be an international colloquium hosted by the Institut Aéronautique et Spatial, Toulouse, between September 11th and 13th, 2019. Its main organizers will be the Institut de Recherche en Astrophysique et Planétologie (IRAP) and the Observatoire Midi-Pyrénées (OMP). This colloquium, placed under the sponsorship of the Committee for Space Research (COSPAR), will complete the design of the four pillars and initiate the drafting of the final report, which will be edited and published under the auspices of COSPAR.

Format of the Toulouse synthesis colloquium.

The detailed program of the Toulouse synthesis colloquium, broadly inspired by the initial suggestions of the Air and Space Academy, has been defined by its Scientific Organizing committee (SOC).

Following a brief introduction which will present the objectives of the H2061 exercise and the results of its first two steps, session 1 will revisit the six **major scientific questions** and their related **key observations** and will present a first inventory of the different **types of missions** needed to perform these observations. Session 2, starting from this inventory, will focus on a small subset of these missions offering the most challenging technical requirements, e.g. those which will be seen as the best sources of inspiration for technology innovations. Its conclusions will connect us directly to session 3 on **critical technologies** and to session 4 on **shared infrastructures and facilities**. In conclusion, session 5 will discuss the **implementation schemes** for the most innovating missions and technical developments in the general context of « New Space », with a strong focus on the opportunities offered by international collaborations and public-private synergies. All the information concerning Horizon 2061 and the Toulouse synthesis workshop is posted on the Horizon 2061 website: https://h2061-tlse.sciencesconf.org

Proposed table of contents for the Horizon 2061 report.

The table of contents of the report on the findings and conclusions of our exercise, to be published under the auspices of COSPAR as a series of peer-reviewed thematic articles and/or a book of the COSPAR publications series, will follow closely the structure of the agenda of the Toulouse workshop. We will propose the following overall TOC to the examination of the Scientific Organization Committee (SOC):

Proposed title of the report:

Planetary exploration, Horizon 2061

From community vision to international perspectives

Table of contents

Executive summary

Feed-back to the communities, discussion of the conclusions and validation of the report.

The provisional conclusions of the Horizon 2061 exercise formulated at the end of its synthesis colloquium will be presented for discussion over the following year to the communities of planetary sciences and exploration, in order to prepare for the discussion and validation of the report at the General Assembly of COSPAR in Sydney (August 15th to 23rd, 2019). To this end we have organized a session dedicated to Horizon 2061 for the joint EPSC-DPS meeting (Geneva, September 15th to 20th, 2019). This “Horizon 2061” session will take place at the EPSC-DPS meeting in Geneva on Friday September 20th, 2019. The organization of similar sessions to the general assemblies of IAF and AOGS is also foreseen

Website: http://horizon2061.cnrs.fr/

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Horizon 2061 — Planetary Exploration 2061

Agenda - Program - Day 1

Wednesday, September 11th – Coriolis Room, Observatoire Midi-Pyrénées		
08:30	Registration and welcome coffee	
09:00	Welcome – introduction to workshop objectives - logistics	M. Toplis, Ph. Louarn, M. Blanc
Introductory talks: setting the stage		
Chairperson: Véronique Dehant		
09:30	Solar-system-exoplanet synergies - general approach and programmatic landscape	H. Rauer
09:50	Horizon 2061: from overarching science goal to specific science objectives	M. Blanc
Session 1 - From science questions to key measurements		
Chairperson: Michel Blanc		
10:10	Origin and early formation of planetary systems: link between disks and planetary systems architectures	C. Baruteau
10:30	*Coffee break*	
10:50	Composition and Interior structure of solar and extrasolar giant planets	N. Nettelmann, R. Helled
11:10	From the exploration of habitable worlds to the detection of life	F. Gomez Gomez (remote talk)
11:30	**KEYNOTE TALK:** The Exploration and Investigation of Solar System Formation and Evolution	Scott Bolton
11:50	Round-table discussion	Moderator: H. Rauer
12:20	*Lunch break*	
Session 2 - From representative missions to key technical requirements		
Chairpersons: Ralph McNutt, Pierre Bousquet		
14:00	Planetary science objectives for missions to the Earth-Moon system	B. Foing
14:15	Critical scientific space missions to Venus in the Horizon 2061 perspective - the role and feasibility of a sample return mission	G. Berger, E. Marcq, P. Pinet
14:30	Mars: Sample return and beyond	S. Maurice
14:45	Concept Study of Comets and Asteroids Exploration by Small Spacecraft: Towards Revisiting Comet Halley	N. Ozaki et al.
15:00	Sample return of primitive matter from the outer solar system	P. Vernazza, P. Beck
15:15	Direct Exploration of Outer Solar System using Solar Power Sail	O. Mori
15:30	*Coffee break*	
16:00	The heliosphere: Lessons learned from Voyager, Cassini, IBEX about our home in the galaxy	Merav Opher (remote)
16:20	Missions to characterize origin, habitability and search for life in gas giant systems	N. André, M. Blanc
16:35	Joint Europa Mission (JEM) A multiscale, multi-platform mission to characterize Europa's habitability and search for extant life	M. Blanc, O. Prieto-Ballesteros, N. André et al.
16:50	Missions to the Trans-Neptunian populations and interstellar objects	M. Bannister
17:05	Near-Term Interstellar Probe: The First Dedicated Step	R. McNuttet al.
17:20	Round-table discussion	Moderator: P. Bousquet
17:50	*Poster session and Horizon 2061 Icebreaker drinks*	
	Pathfinder for Solar flAre Monitoring Explorer (SAME-Pathfinder)	Y. Du
19:00	Adjourn	
20:00 – In-town public outreach lecture by Scott Bolton: « Exploration de Jupiter: les derniers résultats de la mission Juno » (English with french translation)		

Agenda - Program - Day 2

Thursday, September 12th – IRAP conference room, IRAP		
Session 3 - Foresight visions and programs from agencies and industry		
Chairpersons:		
08:30	JAXA's planetary exploration plan for the next decades	N. Ozaki, Y. Toukaku
08:45	Progress and Prospects of Unmanned Deep Space Exploration in China	LI Ming (CAST) Read by L. Guo
09:00	KIGAM's new direction for lunar science and exploration in conjunction with lunar and planetary ISRU	K.J. Kim
09:15	**KEYNOTE TALK:** Eurospace recommendations for Human Presence & Exploration	P. Lionnet, J-C. Treuet (remote)
09:30	OHB Planetary Exploration Enabling Technologies Involvements	M. Berg
09:45	The role of the Italian Space Agency in Solar System exploration and international collaboration	M. Antonietta Perino (remote)
10:00	Round-table discussion – session 3	Moderator: B. Foing
10:30	*Coffee break*	
11:00	Missions to the Ice Giants (contribution to session 2)	O. Mousis
Session 4 - Enabling technologies A- Scientific instrumentation for the future		
Chairpersons: Manuel Grande, Linli Guo		
11:15	**KEYNOTE TALK:** Results from the Chang'e 4 far-side Lunar lander: the plant growth experiment	G. Xie
11:30	Recent advances in in-situ miniaturized geochemical and Life Detection Instrumentation	J. Antonio Rodriguez Manfredi (remote)
11:45	Medium and long-term perspectives of radio sounding and radar instrumentation techniques for the study of the surfaces and sub-surfaces of solar system objects	A. Herique, W. Kofman and S. Zine
12:00	Medium and long-term perspectives of seismology for the study and characterization of planetary and satellite interiors	D. Mimoun, R. Garcia and P. Lognonné
12:15	Prospects of space geodesy and gravimetry for the future study of planetary and satellites interiors and geodynamics	A. Genova
12:30	*Lunch break*	
Session 4 - Enabling technologies A- Scientific instrumentation for the future (cont'd)		
14:00	The mid and long-term future of mass spectrometry in solar system exploration	H. Waite (given by S. Bolton)
Session 4 - Enabling technologies B – Platform and system level technologies		
Chairpersons: Manuel Grande, Linli Guo		
14:15	Exploration mission concepts based on miniaturized technologies, perspectives drawn from the LPCM 13 conference	P. Bousquet
14:30	Exploration technologies for advanced small platforms reaching to extreme environments	M. Blanc, L. Guo, J. Huang
14:45	The potential of electric propulsion: research at LPP and in the ANR industrial chair Poseidon	Bourdon A., P. Chabert
15 :00	In space manufacturing and assembly of large systems	C. Figus
15:15	Relevant technologies and validation assumptions for ISRU	M. Blanc, L. Guo
15:30	The role of on-board autonomy in future space exploration: ERGO's autonomous long traverse achievements in Morocco desert	M. Graziano (given by J.Martinez)
15:45	Architecture and technology challenges of the Comet Interceptor Mission	M. Bannister

Agenda - Program - Day 2

Thursday, September 12th – IRAP conference room, IRAP		
16 :00	*Coffee break*	
16 :15	Round-table discussion – session 4	Moderator: M. Grande
Session 5 - Infrastructures and services for the future – part 1		
Chairpersons:		
16:45	Exploring Space through Sample Return Missions: How, Where, and What Do We Do with the Rocks?	A. Hutzler
17 :00	Exploring Space through Sample Return Missions: Planetary Protection and Contamination Control and Knowledge.	A. Hutzler
17:15	Future infrastructures to study and monitor Solar-System-wide space weather	N. André
17:30	Planetary plasmas data systems: towards the future	V. Génot
17:45	Round-table discussion – session 5	Moderator: B. foing
18:05	*Break – transfer to ISAE*	
Session 5 - Infrastructures and services for the future – part 2 Lunar Exploration and Horizon 2061 special event at ISAE-Supaéro (18:30 – 21:00)		
18:30	From lunar outposts to the Moon Village	B. Foing
19:00	The cislunar gateway as an infrastructure for lunar and solar system exploration	S. Lizy-Destrez
19:30	Short reports on the four pillars of Planetary Exploration	Session rapporteurs
20:00	*Aperitif and informal discussions*	*All*
21:00	Adjourn	

Agenda - Program - Day 3

Friday, September 13th – Coriolis Room, Observatoire Midi-Pyrénées		
Session 6 – Students and early career professionals contributions		
Chairpersons:		
08:30	Towards an origami based compliant modular system for deep space exploration: the next generation of cubesat	S. Bonardi et al.
08:45	The Cathalus Mission Concept to Occator Crater at Ceres: Science, Operations and Systems Design	G. Acciarini et al.
09:00	TELEOP: Impact of confinement and isolation on crew performances during long-duration missions	V. Martin Estrana et al.
09:15	CaLIBSow: Chemical Analysis with LIBS for Ocean Worlds. An instrument concept for Outer Solar System subsurface oceans	B. Chide
09:30	Assessing the Habitability of an Active Ocean World: the Etna Mission Concept to Enceladus' Tiger Stripes	P. Panicucci et al.
09:45	Remote Localisation and Characterisation of Venus' Seismic and Volcanic Events through a Network of Balloon-Based Instruments	L. Martire et al.
10:00	Lunar Outpost Sustaining Human Space Exploration by Utilizing In-Situ Resources with a Focus on Propellant Production	P. Guardabasso, D. Gaudin et al. (ISAE)
10 :15	Sample Return Mission to Enceladus	Ignacio Albarran, E. Clavé et al.
10:30	*Coffee break*	
Session 7 – Implementation issues, international collaboration, workshop synthesis and reporting		
Chairpersons: Maria Teresa Capria; Ralph Mc. Nutt		
10:45	Splinter sessions for synthesis of the four pillars	Pillar raporteurs
11:30	**Keynote talk:** The enabling power and modalities of international collaboration	Eleonora Ammannito
12:00	Final round-table discussion	Moderator: M. T. Capria, R. Mc Nutt
13:00	*Lunch*	
14:00	End of meeting	

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ABSTRACTS
DAY 1
Sessions 1-2

Solar system-exoplanet synergies - general approach and programmatic landscape

Heike Rauer [1*]

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Until the detection of extrasolar planets around solar-like stars, the solar system was our only example to gain detailed insights into the processes of planet formation and their subsequent evolution. Today, some thousands of extrasolar planets are known. While they do not allow us to study them in situ, as we do in the solar system, they surprised us by the large diversity of planetary systems that exist. Yet, a planetary system similar to our own remains to be detected, including planets which harbor life. Future research on planet formation and evolution as well as the search for life needs to combine the detailed knowledge we have about the solar system with the statistical information we gain on extrasolar planets over a much wider parameter range in terms of planetary and stellar parameters. The talk will provide an overview of upcoming space missions for solar system and exoplanet research and which science goals will be addressed.

Horizon 2061: from overarching science goal to specific science objectives

Michel Blanc[1*]

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Since the first discovery of a planet orbiting a main-sequence star (Mayor and Queloz, 1995) studies of planetary objects have spectacularly broadened their scope, and planetary sciences experience the emergence of a new unifying paradigm: the concept of "planetary systems", a class of astrophysical objects which covers and links together the solar system, giant planets systems and extrasolar planetary systems.
The solar system and its giant planets systems (5 "realizations" of planetary systems within our own) on one hand and extrasolar planetary systems on the other hand are observed by different techniques which offer drastically important differences in measurement resolutions and types: whereas remote sensing using the variety of techniques of astronomy applies to all systems, only the solar system, in the XXIst century, is accessible to the powerful approaches of in situ investigations.

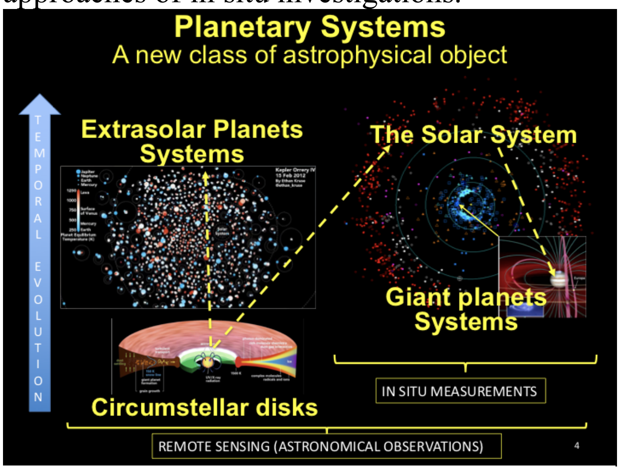

Figure 1: by studying Planetary Systems as a new class of astrophysical objects, in the perspective of their evolution, from their formation inside circumstellar disks to the possible emergence of habitable worlds within them, one can bridge the "observational gaps" currently existing between disks, solar system objects and exoplanets and take advantage of considerable synergies to better address key scientific questions about them.

Despite this importance difference in their accessibility to our observations, there is no doubt that they form *one class of astrophysical objects*, as illustrated by the "cartoon" of Figure 1. Studying all planetary objects and their systems together in a comparative approach will be a considerable source of new scientific insight, in the same way as what happened to solar and stellar physics when they were finally considered as two complementary entries to the same scientific discipline: stellar physics.

This outstanding source of synergies between solar system and other planetary systems does not solely apply to the diversity of objects and systems, illustrated in the upper part of Figure 1 (e.g., the "space domain"). With the spectacular progress made in telescope observations of circumstellar (e.g. protoplanetary) disks provided by the development and coming into operation of very large aperture telescopes equipped with high-resolution imaging, and of space-based and ground-based telescopes that provide altogether a broad spectral coverage from near-UV through visible, IR and submillimeter up to the millimeter domain, our knowledge of the spatial distribution and spectral characteristics of the gas and dust components of these disks has made and will continue to make spectacular progress in the coming decades. This opens serious hopes to access to the temporal evolution of these fascinating "planet factories", from the first phase of their formation inside collapsing proto-stellar clouds

to the period when planets form and sometimes open gaps within them. Hence, with the fantastic support of circumstellar disk studies, we can observe in our galactic neighborhood objects similar to the protosolar Nebula out of which all solar system planets formed. While retrieving their evolutionary sequences with the additional help of advanced simulation tools, one can also infer some critical information on how our own protoplanetary disk formed and gave birth to all solar system objects (see Blanc et al., Space Science Series of ISSI Volume 56 “From Disks to Planets – the making of planets and their early atmospheres”, 2018, and Lammer and Blanc, 2018 therein, for more).
Thus, building on the synergies between disks, exoplanet and solar system studies, one can gain a deeper insight into to the temporal evolution of planetary systems taken as a generic class of astrophysical objects (Figure 1), from their origin and formation, to the emergence of habitable worlds among their constituting objects, and lay the foundations for the search for alien life throughout the whole class of planetary systems, as has been proposed in the “Planetary Exploration, Horizon 2061” foresight exercise. See: (http://horizon2061.cnrs.fr/).
This general science goal can be formulated in the following concise way:

Study the formation and evolution processes leading to the growth of complexity, and ultimately to the possible emergence of life, through the diversity of planetary systems:
(1) the growth of molecular complexity, from the Interstellar medium (ISM) to planetary and moons environments;
(2) the growth of planetary environments complexity, and the conditions under which their evolutionary paths may lead them to become “habitable”.

Developing this general goal into more specific questions addressing the different sequences of planetary systems evolution including their current workings, one can come up along the “tree of evolution” of planetary systems with six key science questions illustrated by the cartoon of Figure 2, which can be applied in the same way to the solar system, giant planets systems and extrasolar planetary systems.

1. What is the origin of planetary systems?
2. How does their formation scenarios produce the diversity of their architectures?
3. How well do we understand the diversity of their constituting objects?
4. How do planets and planetary systems work?
5. Where and under which conditions does their evolution lead to the emergence of potentially habitable worlds?
6. How to search for and recognize life in these habitable worlds?

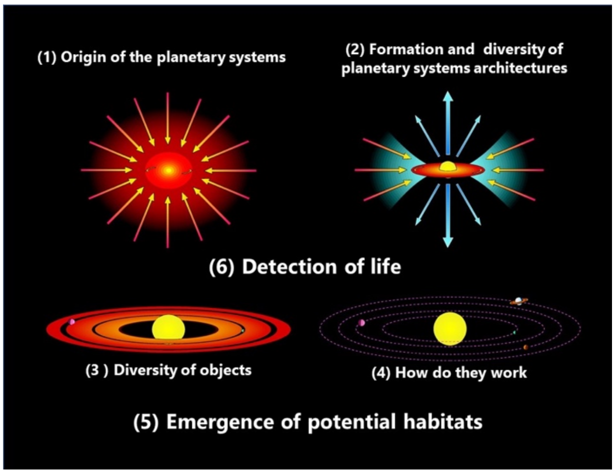

Figure 2:
Six key science questions about planetary systems

This theme of the “tree of evolution” of planetary systems, from origins and formation to the possible emergence of habitable worlds among their planets and satellites, has been chosen to form the science base of the first pillar, “science questions”, from which the three other pillars derive in our science-driven approach.

Formation and Orbital Evolution of Young Planetary Systems

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The growing body of observational data on exoplanets (Figure 1) and on protoplanetary discs (Figure 2) has stimulated intense research on planet formation and evolution in the past few years. The extremely diverse, sometimes unexpected physical and orbital characteristics of exoplanets lead to frequent updates on the mainstream scenarios for planet formation and evolution, but also to the exploration of alternative avenues. The aim of this communication is to give an overview of the classical pictures and new ideas on the formation and orbital evolution of planets, highlighting the key role of the protoplanetary disc in the various parts of the theory. We will discuss to what extent the early evolution of planets formed in their protoplanetary disc may account for the architecture of observed planetary systems, including our own.

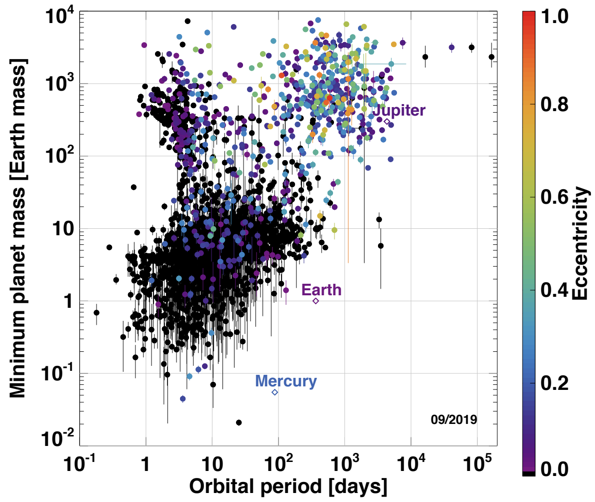

Figure 1: Mass, orbital period and eccentricity of the nearly 3200 exoplanets known so far. Data extracted from exoplanets.org. Figure adapted from [1].

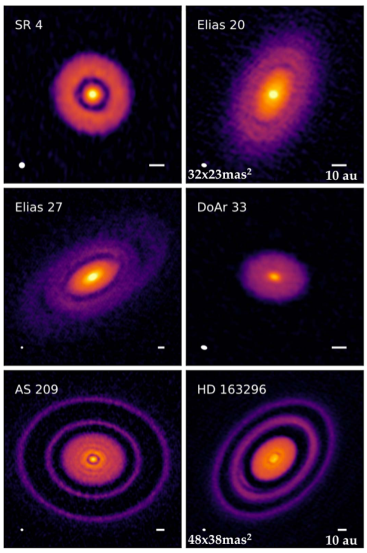

Figure 2: Dust ontinuum emission at 1.3 mm wavelength of several protoplanetary discs obtained by radio interferometry with ALMA. Figure adapted from [2].

References

[1] C. Baruteau, X.-N. Bai, C. Mordasini and P. Mollière, *Space Sci. Rev.* 2016, 205, 77
[2] S. Andrews et al., *ApJ* 2018, 869, L41

Composition and Interior structure of solar and extrasolar giant planets

Nadine Nettelmann[1*], Ravit Helled[2]

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[2]*University of Zurich, Switzerland*
[*]*Corresponding author e-mail adress: nadine.nettelmann@uni-rostock.de*

Planets in the Solar system and in extrasolar systems complement each other. For the former, numerous accurate observational constraints but only on few planets are available, spanning decades of observations. For exoplanets, hundreds to thousands of detected planetary objects allow for meaningful statistical analysis even if the observational uncertainties for a single planet can be quite large. In this talk I will give an overview on our current knowledge on the composition and internal structure of the giant planets in the solar system and put them into context to extrasolar giant planets. In particular, we will discuss the gravity field data obtained by the Juno spacecraft at Jupiter and the Love number k2 as an equivalent, emerging parameter for exoplanets. At present, the number of measured k2-values is equally partitioned at 2:2 between solar and extrasolar giant planets. I will show how a measured k2-value for Neptune could help to constrain its composition. Such observational data might be at the horizon by 2061.

From the exploration of habitable worlds to the detection of life

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Life detection is one of the priority objectives that future space missions will have. The discussion about the possible existence of life outside the planet Earth has given way to the development of adequate instrumentation to be able to determine the presence of life in a certain place without any ambiguity. The discovery of exoplanets [1] on the other hand has opened this debate not only in planetary bodies near the Earth but in remote places where the habitability conditions necessary for a possible existence of life could occur. Therefore, it has already begun with the development of adequate instrumentation for future missions that help us determine the presence of biosignatures as organic matter (extinct life) and even current life (extant life).

The detection of a living process will have to be done through some of its attributes. The measurable attributes of life are its complex physical and chemical structures and processes, among which we can highlight the sustainability through the obtaining of free energy and the production of biomass as the livelihood of life. Some techniques for biomass production (Fig. 1) are being developed for space exploration missions. The traces that a living process leaves in the environment are called biosignatures. One possible way to identify a living process is by identifying its biosignatures.

A biosignature can be the organic matter that has been produced by life, up to an isotopic, mineralogical, chemical pattern or evidence that requires the participation of a living process for its formation. We can also classify as biosignature those microscopic structures formed by biological processes [2], or those traces of reflectance produced by biological processes (carotenes, chlorophylls, ...) or the biological gases (Fig. 2) that can accumulate in an atmosphere of a planet.

During the presentation we will review the life identification techniques that could be used in planetary exploration.

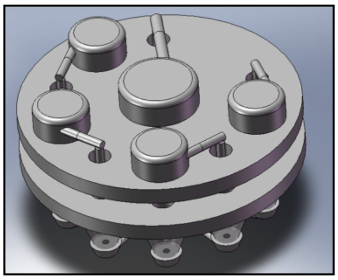

Figure 1: DTIVA prototype for extant life identification. The prototype consists in two modules: first one for life enrichment and second one for final identification using molecular biology techniques. FGomez ©

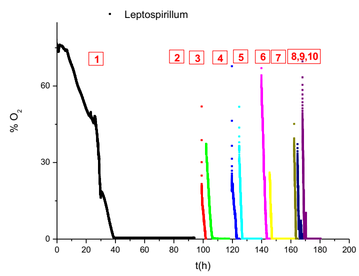

Figure 2: Leptospirullum oxigen production during its growing process

References

[1] "Habitable Exoplanets Catalog". University of Puerto Rico at Arecibo. 2015.
[2] Gómez et al., Scientific Reports 2019

The Exploration and Investigation of Solar System Formation and Evolution

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Retrieving the formation and evolution of the solar system has been one of the key goals of planetary exploration. This goal has recently taken on new importance with the discovery of exo-planets. Understandings from our solar system will be used to help relate exo-solar systems to ours, answering questions about how common systems like ours are and evaluating the probability of life existing in other star systems.

The exploration of our solar system's origin and evolution involves the understanding of all components, dynamically, structurally and compositionally. Small bodies including asteroids, comets, satellites, rings must be understood with respect to the similarities and differences between various reservoirs as well as the diversity within a reservoir. The comparative study of the planets is key to unraveling the puzzle and also helps us to address key questions. For instance, given the differences between the terrestrial planets, why is Earth the only one with a liquid water ocean?

The giant planets offer unique clues, especially with respect to origin. The interior structure, magnetic fields and composition are key descriminators for the theories of the early solar system ranging from the building of a planet to the potential role of planetary migration. An overview of mission results will be presented in the context of helping us define future directions and priorities in the coming decades to resolve fundamental questions regarding the origin and evolution of the solar system.

Planetary science Objectives for Missions to the Earth-Moon system

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[3] *ILEWG International Lunar Exploration Working Group* [*]*Bernard.Foing@esa.int*

Space exploration builds on international collaboration. COSPAR and its ILEWG International Lunar Exploration Working Group (created in 1994) have fostered collaboration between lunar missions towards future exploration and utilization of our 8th continent , the Moon [1-45]. A flotilla of lunar orbiters has flown in the last international lunar decade (SMART-1, Kaguya, Chang'Eal1 &2, Chandrayaan-1, LCROSS, LRO, GRAIL, LADEE). Chinese Chang'E 3 lander and Yutu rover. Other landers from 2019 (Chang'E 4 & 5, Chandrayaan-2 Vikram, Luna, commercial, LRP) will constitute a Robotic Village on the Moon, and provide opportunities for Planetary Science Objectives. We discuss the planetary science objectives, missions, challenges and roadmap of activities towards 2061.

I-Planetary Science questions include:

1- Science of the Earth-Moon & solar system
2- Science from the Moon: astrophysics & cosmology, stellar systems, SETI, Earth
3- Science on the Moon: materials & life 4
4- Moon Humans, Society, Culture & Arts

II- Key measurements include:

1-Remote science measurements
2-In-situ measurements
3-Strategic Knowledge Gaps
4-Multi-messenger science
5-Monitoring environment
6-Measure to understand
7-Measure to survive

III- Representative space missions:

1-Apollo
2-Technology missions (eg SMART-1)
3-cience & exploration (eg LRO)
4-Discovery class science missions
5-New lander missions
6-New commercial missions
7-Large cargo missions
8-Human precursor missions
9-Large human spaceliners

V- Complementarities and synergies with existing or planned space missions and/or ground-based facilities

1-Synergy with planetary robotic missions
2-Synergy with Mars missions
3-Synergy with space stations
4-Support ground based facilities
5-Moon based facilities 4 deep space expansion (launcher, ISRU, manufacturing, labs)

VI-Technology enablers & challenges

1-Launch, Rockets, Propulsion, Rendez-vous
2-Landers
3-Instrumentation, miniaturisation
4-Mobility & robotics
5-Complex systems
6-Communications & autonomy
7-Human –robotic partnerships, Use of AI
8-Biotechnologies
9-Medical & human performance technologies

VII- Critical technologies to address:

1. Science instrumentation
2. Platform subsystems and enabling technologies
3. System level technologies
4. Mission implementation- Overall system architectures
5. Ground operations technologies and implementation
6. Advanced and breakthrough technologies

VIII- New infrastructures & services needed

Earth based (Eye, Telescopic, Advanced, Earth orbit)
Flyby (cameras, spectrometers, particles, gravity)
Orbital (orbiter, small, swarm)
In situ (descent probe, impactors, station, mobile, network)
Available samples (Meteorites, Apollo, Luna, upcoming)
Future Sample Return Unexplored sites (young, polar, ice, farside, subsurface, early Earth & planets) & science targets
ISRU (Resource reconnaissance mapping, Extraction demo, Mining, Manufacturing, Export)
Astrophysics & science from the Moon (Earth, planets, sun, heliosphere, stars, galaxy, exoplanets, extragalactic, cosmology, SETI)
Astrobiology & Life (Organics, Microbial, Plants, Animals, Humans, mini-Biosphere, Cyborgs, Post-humans)
Moon Human Sustainable exploration (short missions, living off the land, sustainable base)
Lunar Societies (Earth-Moon Village, sustainable base, community growth, market economy, Moon cities, independent Moon Republic)

We look forward discussing the planetary science objectives, missions, challenges, synergies and roadmap of activities towards 2061.

Annex 1: COSPAR Pasadena Lunar Declaration 2018

Lunar, Planetary and Space Explorers attended the 13th ILEWG International Conference on Exploration and Utilisation of the Moon (ICEUM13) from 16 to 20 July 2018 at COSPAR 42nd Assembly in Pasadena, California. The ICEUM13 was co-organised by
the International Lunar Exploration Working Group (ILEWG) with support of COSPAR Panel on Exploration, COSPAR commissions B, E, F, and representatives from agencies, SSERVI and space research institutions.
COSPAR participants of ICEUM13A B3.3 session on Lunar science and Exploration:
- Appreciated great talks given at session showing lively ongoing research and projects
- Recognise the work from ILEWG, SSERVI partnerships
- Endorse ILD international lunar decade 2020-2030 proposal (submitted by the late David Dunlop)

- Recommend to consider astrophysics, heliophysics and radio science from the Moon
- Encourage to consider life sciences experiments on precursor robotic missions
- Call for studying opportunities from commercial landers and missions
- Endorse small and cubesats for lunar science and exploration
- Call for communication links infrastructures and services
- Reiterate guidelines for protection of environment and to keep the Moon farside radio quiet
- Request a study of opportunities of large cargos (Blue origins, Space X) by ILEWG/SSERVI
- Endorse the extension of B2 sub-commission tasks to "planetary maps, cartography, geodesy, reference frames & data management"

COSPAR participants of ICEUM13B PEX2 Human and Robotic Exploration of Moon, Mars and NEOs:
- Attended Interdisciplinary talks on science, technology, radiation, human spaceflight, habitats, life support
- Noted key aspects of radiation research, health risks, countermeasures, travel to Mars
- Noted the interest of MoonMarsNEOs in situ resources utilisation, sustainability for programme and links to UN Sustainable Development Goals (SDGs)
- Recognize the need for robotic MoonMars precursor missions, to address Strategic Knowledge Gaps, technology development, terrestrial analogues
- Recommend to ILEWG, IMEWG, SSERVI and partners to define Reference design scenarios for robotic village outposts and for Habitats on Moon, Mars and NEOs
- Urge to improve ways how to engage stakeholders, private funding, public and youth, to make progress and to ensure benefits
- Ask to discuss an effective mechanism for establishing priorities, and organising commercial partners to come in
- Recommend a Rational and multi-purpose driven programme
- Reiterate the need for protection of environments regarding science, utilisation and ethical considerations, and the establishment of a framework for planetary stewardship

There recommendations were endorsed unanimously by ICEUM13 participants and by COSPAR Moon B3 sub-commission and were presented at COSPAR commission B meeting.

For the ICEUM13-COSPAR2018 B3.3/PEX2 sessions Pasadena participants in Pasadena,

Prof Bernard Foing (ESA, ILEWG & VU Amsterdam), Main Science Organiser
Prof Carle Pieters (Brown U.), Dr Gregory Schmitt (SSERVI), Deputy Organisers

Annex 2 : Science & Technology for the MoonVillage

ILEWG MoonVillage team organized a series of workshop where different working groups have addressed issues with future lunar activities. The **Science and Technology** team has identified key technologies and possible major scientific disciplines for a Moon Village and ranked them by importance and by Technology Readiness Level (TRL). In terms of basic technologies and objectives, rover exploration, life support systems, navigation and surveying technologies resulted to have the highest importance and readiness. Technologies for the development of the habitats (materials, modules connections, power supply, alternative energy technologies and energy storage) ended up on having high importance with medium-low technology readiness. Technologies intended to help the astronauts or improve techniques had low-medium importance together with low-medium TRL (e.g. space lift to transfer resources, bio cybernetic augmentation “Exoskeleton”, jumping rover, telescope).
After brainstorming for required technologies, the focus was shifted to what kinds of science can be expected to be performed, once a functional and usable habitat would be available. The group has categorized studies of planetary formation and the Solar System as a highly important scientific discipline with a medium-high TRL. Scientific areas with high-medium importance, but low technological readiness, were found to be ISRU, psychological effects, adaptations of life to low gravity and plant cultivation. The physiological effects of low-gravity on the body were considered of medium importance and readiness.

The proposed establishment of the lunar base can be divided into 4 steps. First the primary base infrastructure is laid out through robotic missions, assisted by human tele-operations from Earth, from the lunar orbit, or via a human-tended gateway station in one of the Earth-Moon Lagrange points (EML-1/2). During the second phase, the first manned habitation module will be deployed. This module contains a bare minimum of functionality to support a small crew for a couple of months. During the third phase, additional modules with more dedicated functions will be sent to the Moon, in order to enhance functionality and to provide astronauts with more space and comfort for long-term missions. In the final phase of the lunar village, a new set of modules will be sent to the base in order to accommodate new arriving crew members.
To ensure crew safety, the landing site for supply vessels shall be located in safe distance to the base. Extensive utilization of autonomous or tele-operated robots further minimizes the risk for the crew. From the very beginning, quickly accessible emergency escape vehicles, as well as a heavily shielded ‘safe haven’ module to protect the crew from solar flares, shall be available.
Sustainable moon village development would require explorers to fully utilize and process in-situ resources, in order to manufacture necessary equipment and create new infrastructure. Mining activities would be performed by autonomous robotic systems and managed by colonists from the command center. Building upon the heritage of commercial mining activities on Earth the production would be divided into six stages: geological exploration and mapping, mine preparation, extraction of raw resources, processing of raw resources, separation of minerals, storage and utilization. Additional manufacturing techniques, such as forging, would also need to be explored so as not to limit the production capabilities. To facilitate the progress of the Moon Village initiative it is necessary to attract private industry investments. Potential sources range from technology testing in the moon environment and private R&D funding from science and academia fields, to space tourism, and more ambitious endeavors such as building a prototype launcher site as a ground segment for debris de-orbiting and satellite recycling activities.

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Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

Critical scientific space missions to Venus in the Horizon 2061 perspective - the role and feasibility of a sample return mission

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1- Science questions

Venus is a potential next target for in-situ robotic exploration. Since the Venera missions in the 70-80s, which provided in-situ analyses of few surface sites, space missions to Venus focused on its atmospheric composition (Venus Express, Akatsuki). Nevertheless, and despite its dense atmosphere, radar and infrared spectroscopy provided some hints about its surface composition at global scale, suggesting unidentified chemical reactions (highlands radar anomalies [1]) and possible differentiated rocks [2]). In addition to comprehensive morphologic observations (e.g., Pioneer Venus Orbiter, Venera 15 and 16, Magellan) suggesting a past active tectonics (tesserae, late resurfacing), the recent observations raise questions on the exact surface composition. Thermodynamic [3] and recent experimental studies depict the possible mineral reaction affecting, or having affected, the surface composition. These reactions are driven by redox reactions and are linked to the sulfur and carbon cycle. They also suggest the possible persistence of alteration features acquired under past wetter conditions.

Concerning the atmosphere, its complex stratification, ranging from a dense and immobile low atmosphere to a super-rotating high and light atmosphere also raises unsolved questions such as the nature of the UV absorber [5], missing reservoirs in atmospheric cycles and the conditions of coupling between topography and gravity waves breaking at cloud top level or giant structure [6]. In addition, the intermediate clouds may meet conditions propitious for the emergence and sustainability of life [7].

In the last decade, several projects of space missions to Venus orbit or even Venus surface have been evaluated, or are under evaluation, by the space agencies: SAGE, Veritas, Davinci, VICI (NASA), VeneraD (IKI), EnVision (ESA). This situation highlights the interest of the scientific community for this often called Earth's twin sister, although the two planets followed a different evolution path leading to a radically different environment today.

2- Measurement requirements and mission type:

The key measurements to be performed to address these issues encompassing the Venus geodynamics, atmospheric processes and biological potential are available in Earth's laboratories: microscopic observations and chemical analyses of rock samples; chromatography, mass spectrometry, NMR for gas/aerosols. For rock samples, the comparison of analytic data from low lands to high lands will also better constrain the possible elemental transfer at large scale through the atmosphere (radar anomalies).

Most of the required techniques have been space-qualified for in-situ measurement, mainly on Mars. However, the extreme conditions of the Venus surface and the density of its lower atmosphere constitute a serious limitation for any in-situ analyses (soil or atmosphere) and an alternative is a sample return mission for both surface rocks and atmosphere.

3- Technology challenges and synergies with existing or planned space missions:

Return sample mission is a challenge in space exploration even if it is sometimes envisaged in alternative to human spaceflight program. With the exception of cosmic dust (Stardust) and lunar samples (Apollo), no robotic or human return mission from distant terrestrial planet was carried out. The major obstacle is the energy required for the return fly and supposes advanced and breakthrough technologies. For Mars, a return mission is under evaluation by NASA and the next Mars2020 mission will prepare a selection of samples for a future sample return mission. It is clear that a Venus sample return mission will benefit from the Mars program. But in the case of Venus, still more several critical technical issues have to be overcome such as the electronic accommodation to in-situ high temperatures or the earth return vehicle and trajectory (once envisioned in 1986). In addition, for a successful scientific mission, multisite sampling at both the surface and the atmosphere would be envisaged.
Concerning the feasibility, the recent progress in high temperature electronics [8], the concept of aero-platforms [9] and the development project of gateways in the next future allowing the launch of vehicle at low gravity, as well as the development of propelled spacecraft (pulsed or thermal nuclear propulsion?) allow us to be optimistic.

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Mars: Sample return and beyond

S. Maurice, IRAP, Tooulouse, France

Concept Study of Comet Halley Revisiting Missions

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Comets and asteroids have been of interest for thousands of years. JAXA's first interplanetary mission, Sakigake, explored the Comet Halley in 1986, and JAXA opened a door to deep space exploration. One of the JAXA's strongest areas is an exploration by small spacecraft, such as PROCYON (Fig. 1), a world's first 50kg-class deep space mission [1]. In the Comet Interceptor mission [2], led by ESA and planned for a 2028 launch, JAXA will explore comets using its small spacecraft technology.

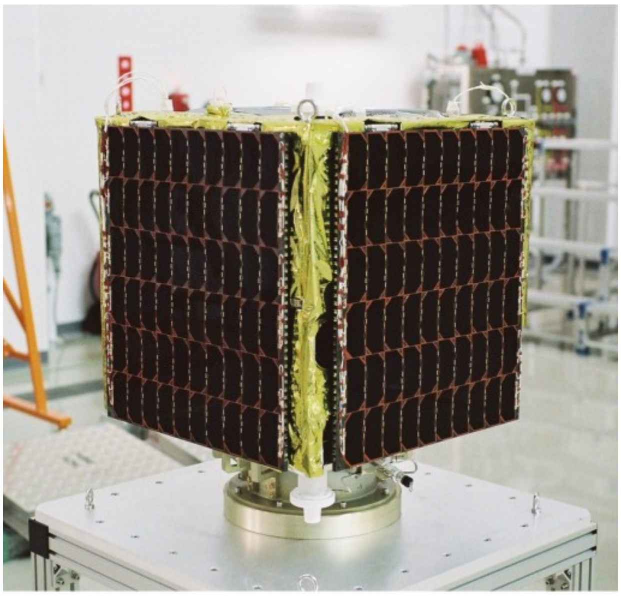

Figure 1: 50kg-class deep space mission PROCYON

Missions by small spacecraft has following advantages: 1) low-cost missions, 2) frequent missions (short-time development), 3) multi missions (broad area and simultaneous observation), 4) high-risk/ challenging missions. In the field of Earth orbiting satellites, small satellites are creating innovation using these advantages. After the advent of Lunar Orbital Platform-Gateway (LOP-G) in 2020s, the similar innovation can be accelerated in deep space exploration.

This talk presents the conceptual study of future small body explorations by small spacecraft, particularly the revisiting exploration to Comet Halley in 2061. In 40 years from now, we expect that humankind will own the bases on moon/Mars surface. Spacecraft is not a nonrepairable system anymore, and we can refuel the spacecraft in the stations. Using those advanced technologies, we can explore the Comet Halley by completely different mission scenario as shown in Fig. 2.

1) Massive cluster flybys
   This concept uses hundreds/thousands of small spacecrafts that sequentially flyby the comet. Although each flyby has one chance to observe the comets, this massive cluster flybys expand the observation duration.

2) Rendezvous with super high DV
   If we own the deep space station and can refuel the spacecraft in the station, we can gain super high DV by containing the fuel in a ultra-light inflatable tank. The concept may enable the spacecraft to rendezvous to the comets.

3) Flyby sample return
   In this concept, one spacecraft impacts on the surface of the comets, and the others collect the dusts and bring them back to the Earth or station.

4) Hitchhike[3]
   Instead of using comets for just a science, the spacecraft could hitchhike to the outer planet.

Towards the future, we discuss what are the key technologies to make them possible and how we should prepare.

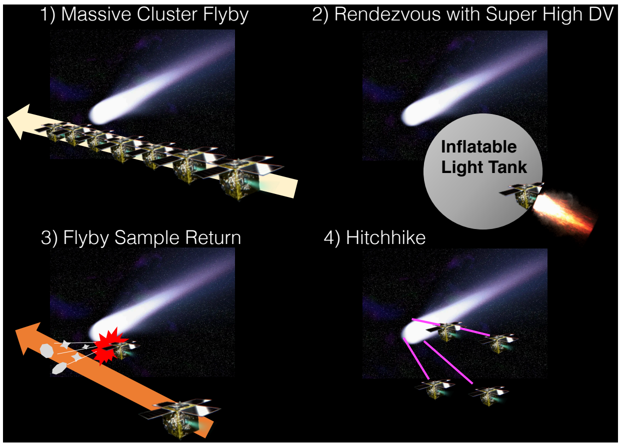

Figure 2: Mission Concept of Comet Halley Exploration

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TOULOUSE Horizon 2061 SYNTHESIS WORKSHOP

Session 2: From representative missions to technical requirements (pillar 2)

Title: Sample return of primitive matter from the outer solar system

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Destination(s):

Table 2: Six "destination provinces" of Planetary Exploration			
~~1. Observatories in Earth orbit~~		~~4. Giant planets systems~~	
~~2. Earth-Moon system~~		5. Small bodies	
~~3. Terrestrial planets~~		~~6. Heliosphere, ISM and beyond~~	

1- Science questions and corresponding measurement requirements

Constraints on the formation of a planetary system can be derived from observations of interstellar clouds, star-forming regions and exoplanets, enabling the characterization of the diversity of ingredients, processes, and products of stellar formation. The study of nascent extra-solar stellar systems and their planets is however limited by our inability to study the formation processes of a single system over the entire formation interval, which takes millions of years. In addition, since these are distant systems, it is not possible to examine all the processes, especially those that leave specific imprints in the chemical, isotopic, and structural makeup of dust and minerals, i.e., at micrometer- and submicrometer-scales (Messenger et al. 2006). The study of our Solar System provides the complementary information and in particular a complete chronology of the major events that shaped it. In the case of the Solar System, these events resulted in the formation of an inhabited planetary system. Confronting the astrophysical view of planet formation as observed across the Galaxy to that derived for the Solar System is of prime importance to assess whether the processes governing the formation of our planetary system were the exception or the rule.

For that purpose, extra-terrestrial samples, which date from the early stages of the Solar System, are of fundamental importance. As a matter of fact, the most detailed information on the processes, conditions, and timescales of the early history of the Solar System has so far come from the study of extra-terrestrial samples in Earth-based laboratories. Most of them are delivered naturally to Earth and occur in the form of rocks (meteorites), fragments (micrometeorites), or dust (interplanetary dusts particles, IDPs). This suite of samples is among the most studied in Earth and Planetary Science laboratories and has enabled us to probe some of the constituents of the solar accretion disk (chondrules, refractory inclusions, matrix, macromolecular organics), to examine in detail the first steps of planetesimal formation (agglomeration of dust, impacts, differentiation) and to determine the timing of different processes (absolute and relative).

However, cosmochemistry (the science of extra-terrestrial samples) is tied to the type of sample available for laboratory studies. The present day cosmochemical view of Solar System formation is limited by biases inherent to the fact that most samples are collected passively, at 1 astronomical unit. First, direct information on the origin of most samples within the Solar System is generally lost. Second, the Earth's atmosphere plays an important role in filtering out most of the fine-grained material (μ-meteorites and IDPs) against strongly lithified objects (meteorites). Last, the volatiles (ices) and most semi-volatile (salts) species are largely lost during the orbital transfer from the source region to the Earth.

The last thirty years of cosmochemistry and planetary science have shown that one major Solar System reservoir is vastly undersampled in the available suite of extra-terrestrial materials, namely small bodies that formed in the outer Solar System (>10AU). Because various dynamical evolutionary processes have modified their initial orbits (e.g., giant planet migration, resonances), these objects can be found today across the entire Solar System as P/D near-Earth and main-belt asteroids, Jupiter and Neptune Trojans, comets, Centaurs, and small (diameter <200km) trans-Neptunian objects. This reservoir is of tremendous interest, as it is recognized as the least processed since the dawn of the Solar System and thus the closest to the starting materials from which the Solar System formed. This is underlined by the extremely interesting results obtained by in-situ studies of isotopic compositions of matter from comet 67P/Churyumov-Gerasimenko by ESA's Rosetta mission (see Hoppe et al. 2018 for a review), and from laboratory studies of anhydrous chondritic porous interplanetary dust particles (CP-IDPs) (Ishii et al. 2008), ultra-carbonaceous Antarctic micrometeorites (UCCAMs) (Duprat et al. 2010), and matter from comet 81P/Wild 2 returned to Earth in 2006 by NASA's Stardust mission (Brownlee et al. 2006).

A collective brainstorming exercise between ground and space observers and astro/cosmochemists identified the following top-level science objectives that justify a sample return mission of a primitive small body:

- What is the path to an inhabited planetary system?
- What were the initial ingredients of the Solar System and how were these ingredients distributed around the young Sun?
- What is the fraction of presolar material that survived until today in outer Solar System bodies?
- How diverse was the origin of the starting materials and what was the environment of the pre-solar cloud core?
- What is the pathway of life-forming elements (C,H,N,O) from the interstellar medium to the Solar System?
- How and when did planetesimals accrete in the outer Solar System?

The next major breakthroughs in planetary science will come from studying outer Solar System samples in the laboratory, but this can only be achieved by an L-class mission that directly collects and returns to Earth materials from this reservoir. The proposed strategy consists in 1) a direct trajectory to the rendezvous target, 2) a reconnaissance of the terrain with an orbiter payload including an optical camera, a near-infrared spectrometer and a thermal infrared camera, 3) collection of surface/subsurface samples (at least two locations) that are volatile and dust rich and 4) return of the samples to Earth. The re-entry capsule must be able to conserve the samples at cryogenic temperature. The selected target should be as primitive as possible which might exclude near-Earth objects from the candidate list. Comets and P/D main belt asteroids including main belt comets would then appear as the most accessible and scientifically valuable targets, with comets being our preferred targets because of their activity that can be used to characterize the volatiles and also because their surface should be more "primitive".

2- Types of missions required to perform the key measurements

Our top-level science questions require a sample return mission of a small body whose surface composition is as primitive as possible. Key measurements to understand the nature and origin of outer solar system material require equipment, and most importantly sample preparation protocols that are technologically incompatible with in situ analysis by a space mission.

By primitive, we imply that the surface should not have witnessed any major alteration process including aqueous alteration, metamorphism and differentiation. The surface/subsurface should be volatile-rich and the refractory phase should be similar to CP IDPs. Currently, P/D asteroids, comets, Jupiter and Neptune Trojans, Centaurs and small (D<250 km) TNOs appear as suitable targets as their refractory phase is similar to CP IDPs. Among these populations, P/D asteroids and comets are being favored as they are the most accessible targets. Between these two populations (comets and P/D asteroids), comets are probably the most primitive bodies. The presence of volatiles at the surface and/or within the subsurface of P/D asteroids is not guaranteed, especially in the case of P/D near-Earth asteroids. One task during the study phase of the mission will be to properly evaluate whether near-Earth asteroids (NEAs) are meaningful targets for such a mission. Results from the OSIRIS-Rex and Hayabusa 2 sample return missions will be key in this respect. On the international scene, NASA has turned down the proposed comet surface sample return mission CAESAR, which was one of the two finalists for the next New Frontiers mission. This further postpones the analysis of a returned icy body sample but opens the opportunity for another space agency to take the lead on such a mission concept.

3- Complementarities and synergies with existing or planned space missions and/or ground-based facilities

The proposed mission will entirely complement – not duplicate – what has been achieved via the Rosetta mission and what will be achieved from Earth with JWST and the ELTs for the simple reason that these aforementioned tools provid(ed) mostly the general context whereas the proposed mission aims to study samples of the most primitive bodies in Earth laboratories, thereby allowing a characterization with unprecedented precision of the starting materials of our Solar System.

3- Enabling technologies and technology challenges

We have identified four key capabilities that a future mission needs to have in order to meet the science objectives.

1) Sample, preserve and return material at cryogenic temperatures in order to keep volatiles species, i.e., water ice in their solid form. The temperature of liquid nitrogen (77K) is sufficient to preserve both crystalline and amorphous ice over a mission time of 5 years. This capability is needed for any volatile and organic bearing targets, like asteroids, and is not limited to comet nuclei. To keep other volatiles such as CO and CO_2 and to retain heavy noble gases, a lower temperature (down to 10K) would be required.
2) Sample multiple locations on the target. Lessons from previous space missions have shown that small bodies are chemically, mineralogically and geologically heterogeneous, either due to their formation or evolution. The selection of the sampling locations should be driven by a detailed remote sensing reconnaissance of the target in a phase prior to sampling.
3) Sampling multiple lithologies, including loose regolith (if present), rootless pebble or rock, and a drill core. Obtaining a core down to around ten cm may allow probing below the thermal skin of the object and sample volatile rich material. It will also enable to study the effects of space weathering processes by micrometeoroids bombardments, as well as solar radiation induced fracturation and chemical processing of surface material.
4) A re-entry vehicle that prevents textural modification of the samples

4- New infrastructures and services needed

A sample return mission would also allow to maintain the currently high scientific level of the community working on extra-terrestrial samples in European laboratories while at the same time providing new challenges and exciting perspectives for developing new state of the art instruments and curation facilities. At present there are no official european sample curation facilities of extra-terrestrial samples. This has to be built, and such a facility would need to be able to host cryogenic samples.

Planetary Exploration 2061
HORIZON 2061
STEP 3 : Synthesis Workshop
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Direct Exploration of Outer Solar System using Solar Power Sail

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For missions with large solar distances, in the past Galileo, Cassini and New Horizons have relied on radio-isotope thermal generators (RTG) to generate the required electric power, while chemical propulsion was used to generate the required ΔV. As the performance of solar cells improved, Rosetta and Juno were able to instead rely on solar power even at these distances. Furthermore, Hayabusa and Hayabusa2 were able to generate enough power to operate their ion thrusters, generating enough ΔV for a return trip to small asteroids. It is key to note, however, that the power obtainable through solar panels reduce drastically beyond the asteroid belt, making the operation of ion thrusters challenging, while yet larger ΔV is required to reach these distances. These two factors make landing missions beyond the asteroid belt difficult with today's state of the art. NASA is currently considering exploring Jupiter trojan asteroids through the Lucy mission, however this mission aims to achieve multiple flybys over the target asteroids, and not landing.

The mission we propose uses the solar power sail-craft to explore the Jupiter trojan asteroids. Solar power sail-crafts are spacecraft equipped with a large number of thin-film solar cells attached on a solar sail with large surface area, generating enough power to operate high specific impulse (Isp) ion thrusters at Jovian distances and beyond. Solar power sails are distinct from solar sails in that the majority of the thrust is generated through the high-Isp ion thrusters, and not from the sail itself. The sail instead serves as an extremely large platform to mount the necessary number of solar cells for power generation.

Table 1 shows the current status of outer solar system exploration. Solar power sail-craft aims to extend the reach of sample return technology demonstrated by Hayabusa to beyond the asteroid belt. Potential target bodies can include the Jupiter trojan asteroids, as well as Saturnian moon Enceladus and Centaurs (Fig. 1). In addition, the large cargo capacities anticipated of solar power sails may be used to transport and deploy multiple lander and explorer nanosatellites, where the main spacecraft may serve as a mother spacecraft to relay the explorer probes' communications with the Earth.

In 2017 NASA has selected Lucy (multiple flybys for Jupiter trojan asteroids) The Lucy project is very similar to the solar sailing project proposed in 2005 by our solar sail working group to Jupiter trojan asteroid multiple flyby mission plus observation of Jupiter. This solar sailing project, unfortunately, was not selected, since key solar power sail technologies had not been demonstrated at that time. In order to demonstrate solar sail and solar power sail technologies for the first time in the world, the IKAROS mission was later proposed and selected, leading to its launch and technology demonstration in 2010. Following this success, we have now further developed the concept for the much larger H3 launch vehicle, to perform direct observation on Jupiter trojan asteroids [1]. Since Lucy is a flyby mission to these asteroids, combining its observations with the more detailed

observations of the solar power sail probe will maximize scientific output. In other words, the two projects are thoroughly complementary endeavors, and key members of the two projects are in agreement with this direction.
In addition to asteroid exploration, solar power sail-craft will take advantage of its cruise flight environment to perform deep-space scientific observations. For past exploration missions, long cruising phase has been seen in a negative light due to prolonged and costly operations, and hibernation periods were implemented. For our project on the other hand, we propose this as an advantage, by deeming the interplanetary cruising phase as 1) a laboratory for cutting edge space science which benefit from long-term scientific observations and experiments, and 2) an opportunity for rapid scientific return, where data can be expected immediately after launch.
Solar power sail-craft can lead the exploration of outer solar system, as well as provide breakthrough space astronomy as a new scientific field.

Table 1: Status of outer solar system exploration

	Jupiter zone	Saturn zone	Uranus	Neptune	Pluto, EKBO
Flyby	●U ■U:Lucy	●U	●U	●U	●U:New Horizons
Orbiter/ Rendezvous	●U:Galilleo, Juno ■E/J:Juice ■U:Europa Clipper	●U	■U		
Landing	●U ■J:Solar Power Sail-craft	●E:Cassini	■U		
Sample return	■J:Solar Power Sail-craft				

● Achievements
▲ Under operation
■ Under development / Under investigation

J = Japan;
U = USA;
E = ESA;

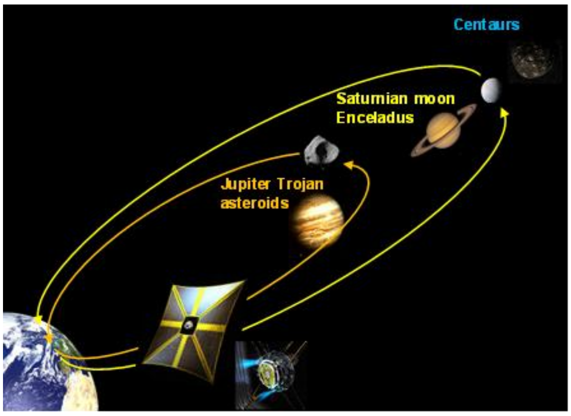

Figure 1: Several application opportunities of solar power sails

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The heliosphere: Lessons learned from Voyager, Cassini, IBEX about our home in the galaxy

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The heliosphere is a template for all other astrospheres, enabling predictions about the conditions necessary to create habitable planets. Space science is at a pivotal point in generating new understandings of the heliosphere due to the flood of new in situ data from the Voyager 1 (V1), Voyager 2 (V2), and New Horizon spacecraft, combined with the energetic neutral atom (ENA) maps generated by IBEX and Cassini.

The heliosphere is an immense shield that protects the solar system from harsh, galactic radiation. This radiation affects not only life on Earth, but human space exploration as well.

The data returned, however, prove to be a challenge to explain. Some of the puzzles are where the anomalous cosmic rays (ACRs) (energetic particles around 1MeV) are accelerated? The expectations were that the ACRs were accelerated at the Termination Shock (the largest shock in the heliosphere. This didn't turn out to be the case. Voyager 1 and 2 crossed that region with no sign that the ACRs were accelerated there. Not only that they were not accelerated at the Termination Shock, but their intensities kept increasing as the spacecraft moved deeper in the *heliosheath,* as if the source was ahead of the two spacecraft's. Another puzzle, among others, is the thickness of the heliosheath (the last layer of the heliosphere). None of the current standard global models predict the very thin *heliosheath* (~ 30-40 AU; (AU: astronomical unit)). Other observations not explained by current models are: the drastic different flows on Voyager 2 as compared to Voyager 1. Additionally, Voyager 1 measured a region (on the order of 10-15 AU) where the solar wind seem to stagnate before crossing into the interstellar medium. Finally, recently the very shape of the heliosphere is being challenged by modeling and energetic neutral measurements. To explain some of these challenging observations there have been several suggestions such as that plasma processes such as turbulence and reconnection (a process in which magnetic field are annihilated) may play a crucial role in the global structure of the heliosphere. It is hard to pin-down if these processes are indeed taking place because of the current instruments on board of Voyager 1 and 2.

As the Sun moves through the surrounding partially-ionized medium, neutral hydrogen atoms penetrate the heliosphere, and through charge-exchange with the supersonic solar wind, create a population of hot pick-up ions (PUIs). The Voyager 2 data demonstrated that the heliosheath pressure is dominated by PUIs. In particular, current instruments on Voyager 1 and 2 can only measure the thermal component (around eV of the solar wind) and suprathermal particles with energies above 30keV). This gap of data between eV and 30keV is crucial, since this is where the PUIs are, that are thought to carry most of the energy in the *heliosheath*. Additionally, the magnetometer cannot measure accurately the weak fields of the heliosheath.

I will review some of these challenging observations focusing on a more recent debate that it is the shape of the heliosphere.

The very shape of the heliosphere (Figure 1) is being challenged by these measurements and models as well as the realization that the heliosphere influences the local interstellar medium to distances far larger that its own.

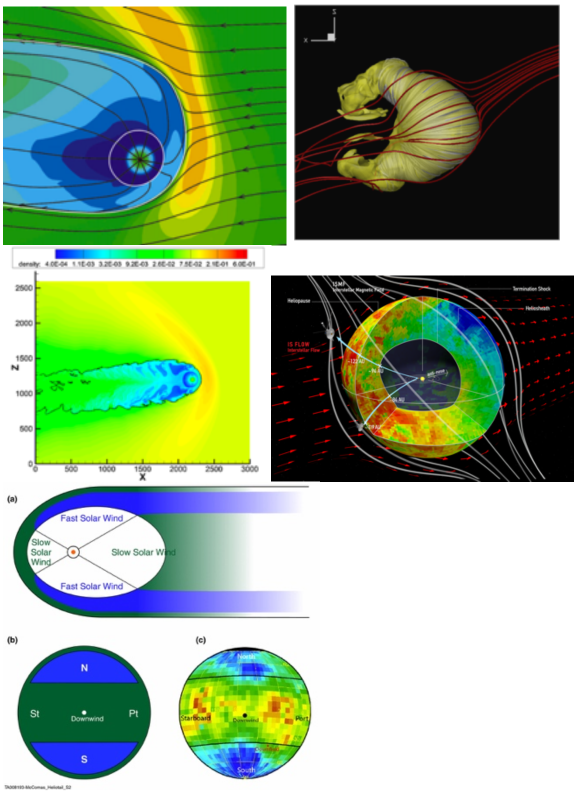

Figure 1: An on-going controversy: what is the shape of the heliosphere? Top row: Different numerical models (top row-left Izmodenov & Alexashov 2015; top row-right Opher et al. 2015; 2019; middle row left Pogorelov et al. 2015) give different shapes of the heliosphere. Middle row-right: observations from ENAs from Cassini (Dialynas et al. 2017) and (bottom –row) IBEX (McComas et al. 2013) infer different shapes.

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Missions to characterize origin, habitability and search for extant life in giant planets systems

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1- Science questions and corresponding measurement requirements

Finding traces of extant life beyond Earth in the Solar System would be a huge accomplishment showing us that the dominant paradigm of the origin of life (de Duve 1995) is correct: rather than being the result of a "one-off", freak process, life (biology) would be shown to be a simple continuum process taking advantage of every favorable condition (the so-called "habitability") to make progress towards ever increasing chemical complexity. To really understand life, we must relate its discovery to the habitability of its host planet (or satellite) and, moving backward in time, relate this habitability to the processes that have favored its emergence and preservation in its host planetary system.

Astrobiologists agree today that the conditions for habitability are directly related to the definition of life we can formulate on the basis of the only model of life we know, namely terrestrial life. From this standpoint, habitable environments must meet three basic requirements symbolically represented by the "Triangle of Habitability" (Westall et al., 2018): 1). The presence of liquid water, which is the best solvent known for inorganic and many small organic substances. The H_2O molecule has unique properties that are specifically useful for life, e.g. latent heat due to the chemical bonds, potential for high salt content due to its density, broad range of temperature and pressure stability, etc. 2) The availability of life-essential chemical elements, such as H, N, C, O, S, P, as well as transition metals that help provide structure to the biomolecules and provide nutrients to the organisms. Transition metals are made available through the dissolution of the minerals. 3) Energy sources available for life to maintain metabolism. In the absence of light, energy accessible for life is usually provided by chemical disequilibria sourced either by radiation, reactions activated by temperature, or by redox reactions. An additional key dimension to planetary habitability is time. We do not know how quickly life appeared on Earth. The process must have been sufficiently fast at the beginning to impede backward reaction, but the emergence of forms of increasing complexity likely needed longer time scales, thus implying the maintenance of habitability conditions over very long times.

Based on these considerations, Lammer et al. (2009) explored the variety of known configurations of planets and satellites to derive four classes of 'habitable worlds", or Habitats, as being the ones that meet partly the habitability conditions. Classes I and II relate to our terrestrial planets, and to the presence of liquid water at their surface. Classes III and IV correspond to objects where liquid water can be found, not at the surface, but in sub-surface oceans, which are found among the icy satellites of Jupiter and Saturn or at Titan: they are the "Ocean worlds".

The in-depth exploration of these Ocean worlds requires sampling og materials from the near-surface and their analysis in different phases. Space exploration considers distinct categories of bio-signatures since each one needs different analytical instrumentation and has different limitations of detection:

a) Generic biomolecules. They are biological monomers and polymers (like polysaccharides, lipids, proteins or some form of information-transmitting molecule similar to DNA) that may reveal a complex prebiotic chemistry or even active biochemistry.

b) Organic indicators of past or present life. As mentioned above, high radiation conditions on the Europan surface may degrade any material if it is exposed for any length of time. It is expected that biomolecules will break up and react, producing degraded organic compounds that can also be symptomatic of the presence of complex chemistry. It is critical to validate the biological origin of those degraded signatures.

c) Inorganic indicators of past and present life, such as biogenic stable isotope patterns in minerals and organic compounds, biogenic minerals, or coupling of certain atmospheric gases which would be a product of metabolism, which eventually could persist when the measurements are performed.

d) Morphological and textural indicators of life. This means any object or pattern indicating bio-organic molecular structures, cellular and extracellular morphologies, or biogenic fabric on rocks.

2- Types of missions required to perform the key measurements

Multiplatform missions (orbiters of ocean worlds, landers, atmospheric probes or balloons, sample return) are required in order to obtain a comprehensive understanding of the origins and habitability of the Jupiter and Saturn systems as well as search for extant life in the environments of their ocean worlds.

3- Complementarities and synergies with existing or planned space missions and/or ground-based facilities

The representative missions will follow the legacy of the Galileo, Juno and the future JUICE, and Europa Clipper missions at Jupiter, Europa, and Ganymede; and the legacy of Cassini-Huygens and the future DragonFly mission at Saturn and Titan.

4- Enabling technologies and technology challenges

The main technology challenges for these representative missions are the following:

- *Use of a heavy launcher*
- *Use of RTGs for outer solar system missions*
- *Planetary protection*
- *Radiation (especially at Jupiter)*
- *AI and smart technology for the landing sequence*
- Development of a smart bio-signature characterization package

5- New infrastructures and services needed

Describe, when relevant, which new infrastructures and scientific services, or significant additions to existing ones, will be desirable or required to:

- *Support an optimal operation of the missions and help meeting their science objectives;*
- *Contribute to provide and/or maximize the scientific return expected from the planetary exploration program, including its data analysis and interpretation component.*

Special mention will be made of the services to be provided by sample curation facilities, data centers and virtual observatories in the short and long-term future.

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Joint Europa Mission (JEM)
A multiscale, multi-platform mission to characterize Europa's habitability and search for extant life

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Europa, together with Enceladus, is the best possible destination to search for and possibly find life in the outer solar system. Strong indications that Europa may indeed be inhabited come from recent key discoveries: the Galileo discovery of a sub-surface ocean in contact with a silicate floor that could be a source of the key chemical species for biomolecules, the many indications that the icy crust is active and may be partly permeable to the transfer of materials, including elementary forms of life, and the identification of candidate thermal and chemical energy sources necessary to drive a metabolic activity. To understand how the Europa system works and whether it may have developed a biosphere under the effect of its proper evolution and of forcing by the other components of the Jupiter System we need to design and fly to this Ocean World a multi-scale, multi-platform, interdisciplinary mission that will perform combined orbiter and lander science investigations. Here we summarize the science and technology strategy of this proposed Joint Europa Mission (JEM), based on the NASA lander concept and on a novel ESA-designed platform which will carry and deliver the lander to its destination, relay its data back to Earth and will finally reach a low-altitude near-polar Europan orbit to perform orbital science operations for about three months. While the orbiter will perform an in-depth investigation of Europa's geophysics, ocean and habitability, investigations by the Europa lander will be focused on the search for bio-signatures in solid and liquid samples. The impacts of planetary fields, of plasma, neutrals and dust environment, and of Europa's internal structure on its habitability will be characterized by our described mission.

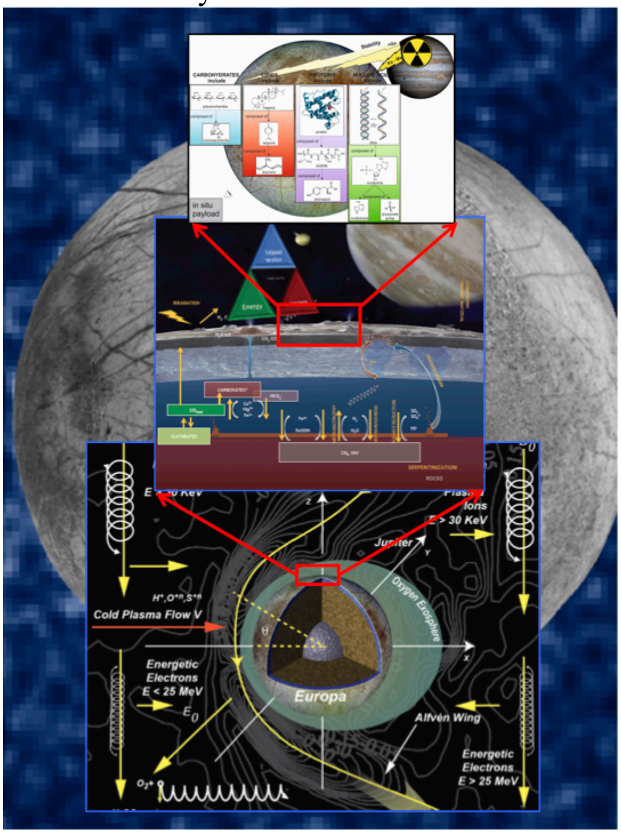

Figure 1: *This logical chart of our Science Plan shows the three successive scales investigated by JEM, from bottom upwards: (1) the global Europa, a complex system responding to the two main types of Jovian forcing, tidal forcing and magnetospheric forcing; (2) the scale of Europa's potential biosphere (median figure), at which we will more particularly characterize the ocean and ice sheet and (3) finally the local scale at which we will perform life detection experiments.*

Missions to the trans-Neptunian populations and interstellar objects

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Interest in future exploration of the trans-Neptunian region has never been higher among the planetary science community and the general public, spurred by the scientific returns from the wildly successful New Horizons mission. The trans-Neptunian objects (TNOs) are an extremely diverse population, key to understanding the past history and the present geology of our solar system. Planning for future missions by international agencies has begun to shift towards combined missions to Centaurs, the ice giant planets, and TNOs. Gravity assists from ice giants can be used for travel to distant TNOs, while at the same time returning valuable science on the ice giants and their ring and satellite systems. Trajectories to high-priority distant targets also include close approach opportunities to multiple TNOs en route, in addition to remote observations of nearby TNOs. The available target list and thus the scientific dividends of a future mission to the trans-Neptunian region are soon to be hugely enhanced by the tens of thousands of new TNO discoveries anticipated from LSST in the 2020s.

Near-Term Interstellar Probe: The First Dedicated Step

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From the beginning of the Space Age, our knowledge of the heliosphere, the "bubble" blown by our Sun's solar wind into the interstellar medium [1], and the bodies of the solar system therein have increased dramatically, but the outer solar system remains glimpsed only briefly. An Interstellar Probe outward from the Sun, escaping through and beyond the outer solar system, rapidly and beyond the Voyager spacecraft with new and modern observational techniques [2], would be a bold move in space exploration, complementing the new missions of the Parker Solar Probe and Solar Orbiter inward toward the Sun. It could enable (1) detailed and in situ new understanding of our global heliosphere, both as it affects us directly and in the context of astrospheres, the similar plasma environments of neighboring stars, (2) further discoveries in the unexplored Kuiper Belt, now seen for the first time in situ by New Horizons at the Pluto system and the primeval body MU69, and (3) the first observations of our circumsolar dust disk from the "outside" looking inward at our system, as if observing an exoplanetary system, and outward with a view no longer partially obscured by that dust [3]. These observations would offer insight into the evolution of our solar system and our understanding of exoplanetary systems and their capabilities for life. The question facing us today is the appropriate next step - a true first step - in negotiating the transition from past multiple studies to new-mission reality. This first step in actually reaching toward the stars will require the recognition of engineering limits, scientific trades, and compromises, but such actions are new neither in science nor in exploration. Such a step would be an "Interstellar Probe," for which we are now ready [4]. The time for that step has come.

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Pathfinder for Solar flAre Monitoring Explorer (SAME-Pathfinder)

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The high-time-spatial resolution multi-band monitoring of the solar burst events has extremely important scientific merits of scientific research and the application merits of space weather forecasting. Nowadays, many solar missions are operated in space, the Solar Dynamics Observatory is one of the most famous mission[1].

The solar radiation from the optical to X-ray bands is very strong, so the photon sieve membrane imager with an extremely narrow bandwidth, low focusing efficiency and high spatial resolution is especially suitable for solar narrow-band observation. It is proposed that a solar observation mission in a high-altitude dawn-to-dusk orbit: the SAME-Pathfinder, which carries three scientific instruments (payloads): a soft X-ray imager, a H_α photon sieve imager and an ultraviolet (UV) imager, which will be briefly introduced as follows.

(1) The soft X-ray imager uses a Wolter-I mirror with a diameter of ~200 mm. Its designed spatial resolution is 2 arcseconds, which is comparable to the performance index of the X-ray telescope onboard the Hinode satellite[2].

(2) In addition to high-energy observations, an optical telescope with a filter (656 nm) to observe the Hα line of the sun (visible light from the electronic transition of a hydrogen atom) is typically used to monitor solar flares either in ground or in space. Most solar observatories have Hα ground-based telescopes, such as the Big Bear Sun Observatory[3]. Some observatories monitor solar flares by capturing visible images of the sun every few seconds. Therefore, the Hα line in the visible light band is also an important way of observing the solar burst. The observation of the sun in space can better eliminate the influence of atmospheric turbulence on the imaging quality compared with the ground observation. The H_α photon sieve[4] imager has a membrane mirror with very low weight and a high-resolution diffraction-limited imaging. The photon sieve is made from the Fresnel zone plate with a lot of tiny holes which can focus the light via diffraction. The so-called H-alpha photon sieve telescope is first onboard the FalconSat-7 which was launched on 25 June 2019. The telescope has a field of view (FOV) of ~0.1^{o} and a spectral bandwidth of ~1 Å[5]. However, the H-alpha photon sieve imager of this mission has a FOV of 40 arcminutes and spectral bandwidth of ~ 0.2 Å.

(3) The UV imager is a single spectral channel (centered at 133.4 nm) instrument, which has two observation modes with a continuous zoom technology, one observation mode is low spatial resolution with a full-disk imaging and the other mode is a high spatial resolution imaging with a small FOV (~ 5 arcminutes). The observation sketch of the sun is shown in Figure 1, all the 3 payloads can image the sun simultaneously, once either the UV imager (with the full-disk observation mode) or X-ray imager catches a flare event autonomously in the orbit, then the UV imager quickly points to the flare region and monitor the flare in a high-resolution imaging mode. The time resolution is about 1-10 seconds for each imaging. In addition, all the 3 payloads require high-quality image stability systems to obtain clear images of the sun.

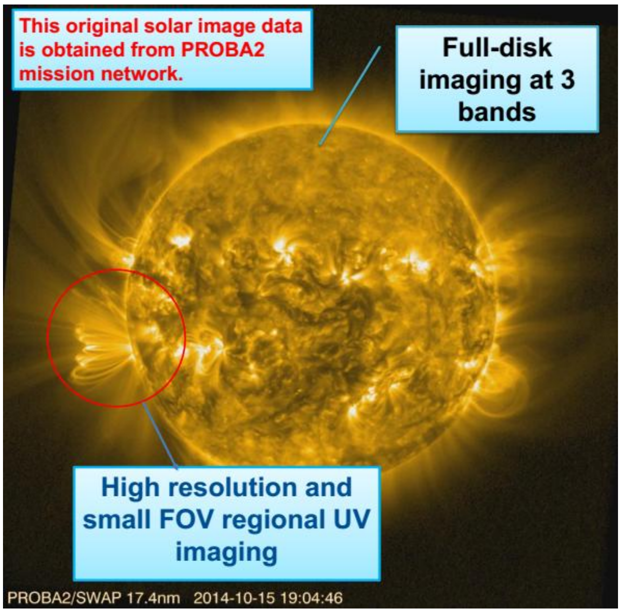

Figure 1: Solar observation diagram with the SAME/SAME-Pathfinder missions. The original figure of the solar flare are obtained from the data of PROBA2/SWAP[6].

The scientific payloads can provide high-resolution multi-band video imaging of the Sun, monitoring its burst events, and have a crucial role in space weather forecasting and solar physics studies. Moreover, the SAME-Pathfinder mission can also verify the technologies of the two-mode remote sensing telescope with intelligent machine learning algorithms for the solar flares, high-FOV and narrow-bandpass photon sieve imaging payloads and high pointing stability satellite platforms. The SAME-Pathfinder mission will lay the foundation for the international collaboration mission, namely the SAME mission. The SAME mission is a solar panoramic stereoscopic monitoring flagship mission at the 3 Lagrangian points between the Sun and earth. It has three spacecrafts, which can be made by the Asia, Europe and America collaboratively. The SAME mission is planned for launching at around 2030s, and its sketch is presented in Figure 2. The SAME mission can also be a flyby mission for remote sensing observations of the Venus and Mercury, and its L3 spacecraft could also be an astrophysical satellite for observations of the exotic celestial objects behind the sun.

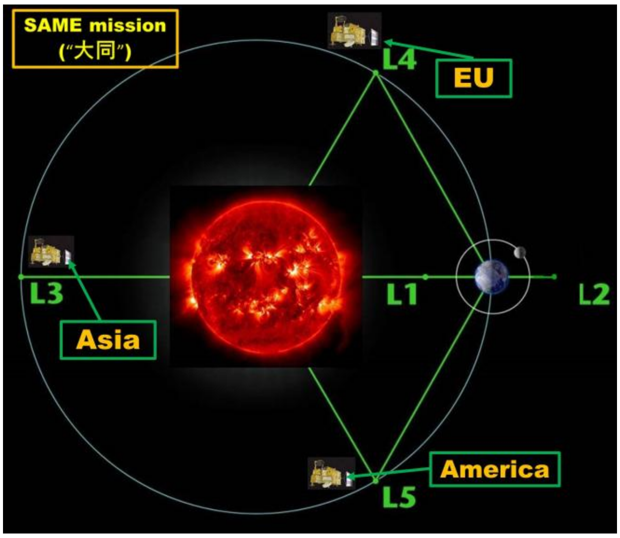

Figure 2: The diagram of the SAME missions: a solar panoramic stereoscopic monitoring flagship mission at the 3 Lagrangian points with collaborations of Asia, Europe and America.

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ABSTRACTS
DAY 2
Sessions 3-4-5

JAXA's Planetary Explorations

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Space exploration is the ultimate challenge of exploring new frontiers. ISAS/JAXA delivers various space assets to the planets from Mercury to Jupiter. A large data set integrating data from multiple probes will throw light to revealing a history of the solar system. This is a framework of ISAS/JAXA Deep Space Fleet.

The path of Japanese planetary exploration had begun with the space probe *Sakigake* (Pioneer in Japanese) launched in 1985[1]. As a part of the international mission namely "Halley Armada", with its twin spacecraft *Suisei*, *Sakigake* was sent to examine Halley's Comet during its sojourn in the inner Solar System [2].

Akatsuki, or the Venus Climate Orbiter, the world's first planetary meteorological satellite, was launched in May 2010. After the second attempt of orbit insertion in December 2015, *Akatsuki* has revealed mysterious characteristics of Venus atmosphere. [3]

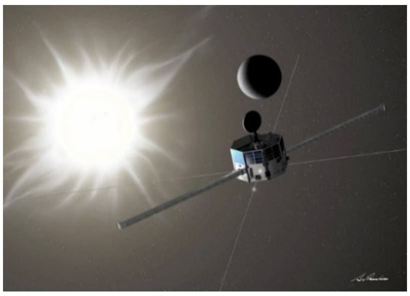

Figure 1: An artistic rendering of BepiColombo/MMO Mercury Magnetospheric Orbiter

BepiColombo, a joint mission of ESA and JAXA was launched in October 2018. The mission will conduct a comprehensive study of Mercury. Arrival at its orbit is in December 2025. [4]

In June 2010, *Hayabusa* spacecraft returned to Earth with the material of Stone type Asteroid *Itokawa* after 7-year journey. Leveraging this experience, *Hayabusa2* has arrived at the Carbon type Asteroid *Ryugu* this June. The mission is designed to return the samples to elucidate the origin and evolution of the solar system and to study primordial materials that would have led emergence of life. It is planned to be back on Earth in December 2020. [5]

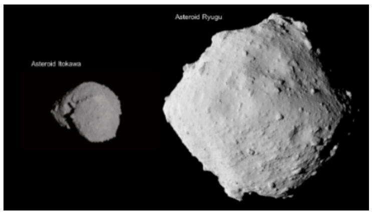

Figure 2: The actual images of asteroids *Itokawa* and *Ryugu* juxtaposed.

ISAS continues to promote planetary exploration in collaboration with JAXA Space Exploration Center (JSEC). Phobos and Deimos, two Martian Moons are the targets of Martian Moons Exploration (MMX) mission. Scheduled for launch in early 2020s, MMX will return a sample from one of these moons. [6][7] Applying experience from MMX, ISAS/JAXA will expedite exploration on Mars surface with international partners.

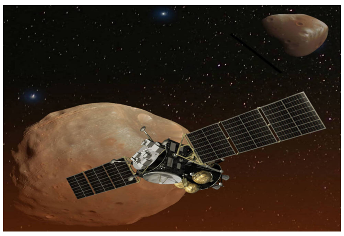

Figure 3: An artistic rendering of MMX, and Marian moons, Phobos and Deimos.

International cooperation and planetary exploration are inseparable. JAXA will supply hardware of observation instruments for ESA's Jupiter Icy Moons Explorer (JUICE) that will observe the Jupiter and three of its largest moons. [8]

Lunar exploration is continuing prospect of human endeavor. Smart Lander for Investigating Moon (SLIM) integrates the techniques that enable accurate landing and the demonstration of the technologies on the gravitational body. These innovations, if successful, will advance JAXA toward capabilities vital for future exploration programs in which multiple landings and sample returns are foreseen. SLIM is under development for launch toward Moon in 2022. [9]

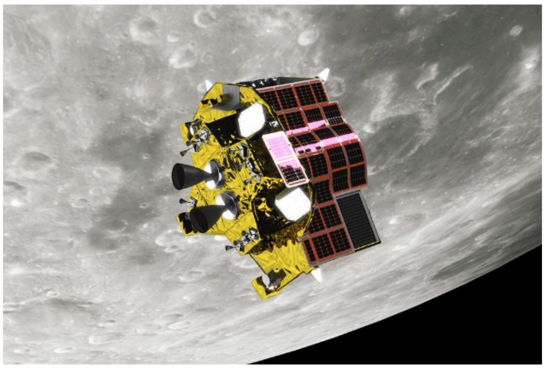

Figure 3: An artistic rendering of SLIM

JAXA is going to acquire critical technologies such as microsatellites, space transportation system, lunar and planetary exploration, and cryogenic cooling system, that are essential for future planetary exploration missions by stimulating research and development as well as technology demonstrations in small missions.
Front loading funds are applied for these research and development and technology demonstrations to focus efforts and cost in the earlier stages of the projects and to capitalize on strength of Japanese technologies. [10]

Acknowledgments: We are grateful of the successful 2nd touchdown by Hayabusa2 on asteroid *Ryugu* took place on July 11, 2019.

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Progress and Prospects of Unmanned Deep Space Exploration in China

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This presentation introduces the progress, prospects and opportunities of Chinese Lunar Mission and Planetary Mission. The presentation reviews CE-1, CE-2, CE-3 and CE-4 mission history first. The present development includes the status of CE-5 mission and Mars-1 mission. The major part of the presentation will introduce the future Chinese Lunar Mission and Planetary Mission, includng CE-6, CE-7 and CE-8 mission, also the Asteroids Mission, Mars Sample Returning Mission and Jovian Exploration Mission. The Mission concept, science objective, engineering configuration will be introduced for each mission according to the study result of CAST team.
All of the Chinese lunar and planetary exploration programs are open for international cooperation. Different kinds of possible aspects of cooperation are discussed. Detailed cooperation opportunities for the near term, CE-6 and Asteroids Mission, are also introduced.

Key word: deep space exploration, lunar mission, planetary exploration

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KIGAM's new direction for lunar science and exploration in conjunction with lunar and planetary ISRU

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As one of national research institutes of Korea, Korea Institute of Geoscience and Mineral Resources (KIGAM) leads innovative geo-technology to sustainable earth. KIGAM is the only research institute for geological resources in Korea and its mission is to create a bright future for the Korean peninsula and for the entire world [1]. KIGAM has been established since 1918 and its research areas are geo-research on land and ocean, geo-exploration on deep subsurface resources and utilization, new geo-technology on geo-hazards and global climate change.

KIGAM established a planetary geoscience research group in 2008 and for the past 10 years the research areas of this group were mostly limited to lunar geology and payload development for Korean lunar mission and associated studied. KIGAM is currently developing a gamma-ray spectrometer (GRS) onboard Korea Pathfinder Lunar Orbiter (KPLO) which is scheduled to be launched in 2021 and carry six instruments [2]. The KPLO GRS (KGRS) aims to obtain elemental information of the lunar surface composition using a $LaBr_3$ detector. The result of KGRS could be invaluable to measure low energy X-ray and gamma-rays below 100 keV as well as the upper energy range up to 10 MeV. Within this energy range, possibly elemental signature as lunar resources could be investigated.

Since the new tasks of human to go to Mars and Moon have been set within a few decades, global research interests have focused on in-situ lunar resource and utilization. Thus, KIGAM's new vision in lunar ISRU has been emphasized and the previous planetary research group has been under reformulating by including researchers who are expertized in resource refining and utilization on earth. Regarding lunar ISRU, KIGAM is interested in ISRU prospecting and utilization conducting internal research projects as well as national and international cooperative projects. Obtaining a detailed lunar resource map for prospective ISRU activities by human on the Moon is very important. As an example, KIGAM investigated prospective He-3 rich landing sites on the Moon [3]. It is a very important fact that KIGAM, as a national institute that focuses research associated with geological and resources, needs to develop its own research program should come first prior to commit on any international cooperative program. This effort is currently being established and soon KIGAM is ready for an international collaboration in planetary exploration for not only science and but also technical development toward research development for human's settlement goals on the Moon and Mars.

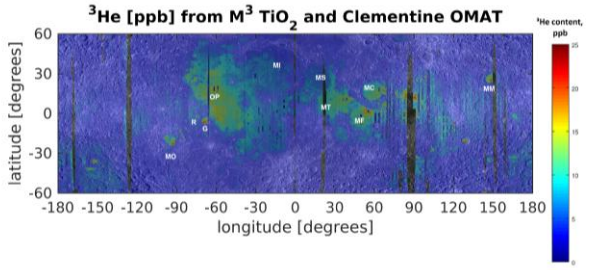

Figure 2: Recently published a global map of ^{3}He content at the surface of the Moon [3].

Near future international collaborations could be beneficial for Korea to conduct its planned missions successfully for both lunar surface and asteroid explorations [4].

Not like USA or several other counties, Korea does not have a space agency, and Ministry of Science and ICT together with Korea Aerospace Research Institute (KARI) have been acting the equivalent roles of a Korean space agency. At this point, the roles of KIGAM in international collaborations are limited to its role and responsibility (R&R) of the organization. This R&R of KIGAM allows active research programs in the fields of geology and resources both on Earth and extraterrestrial environments. Within this category, KIGAM's planetary research group is interested in developing collaborative planetary research and educational programs in near future.

Acknowledgments: This work has the support of the internal research project (19-7616) of KIGAM funded by the Ministry of Science and ICT of Korea.

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Eurospace recommendations for Human Presence & Exploration

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Drivers & challenges

Background

Robotic exploration missions open new horizons for planetary knowledge, and will also act as precursors for human exploration missions.

Human presence in space and exploration activities are proposed as one, due to their synergetic nature, from both technology and missions points of views. The proposals of the Human presence and exploration roadmap are made with a view of supporting an adequate level of European readiness within the frame of current programmatic decisions in these areas.

Activities proposed

Exploration programmes and Human presence in space programmes are being carried in the ESA frame mainly, but may/will open the way to global endeavours. The current status of European readiness, in view of the breadth of activity in planning is rather consistent, hence the narrow scope of technology proposals put forward by Eurospace in this roadmap.

The most of activities are focusing on automation and robotics (including crew/robot synergies and crew collaborative robotics, but also automatic docking aspects). Developments of large structures, also considering habitats are also in the roadmap, together with critical aspects related to propulsion and aerothermodynamics.

Technology and Policy drivers

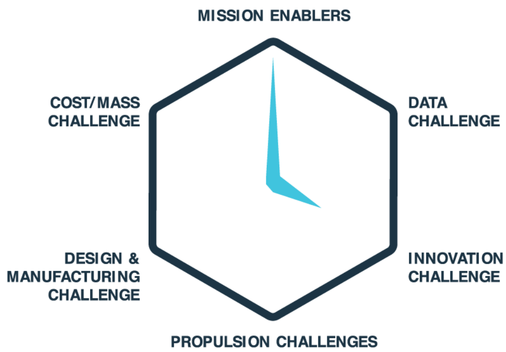

Figure 1: Technology drivers.

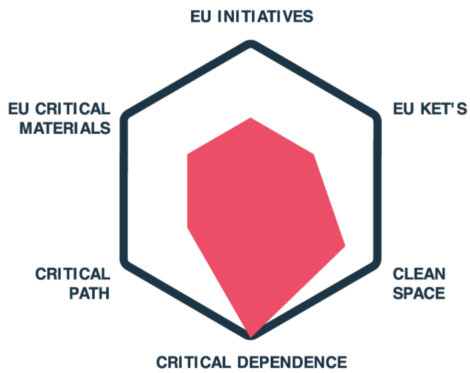

Figure 2: Policy and risks

Exploration & Human presence in space Recommendations

For Exploration: address long duration travel issues, increase readiness level for planetary activities.

For human exploration: investigate and develop synergies between crew and robotics, improve European readiness level on habitats.

Key areas for action

Robotics, automation/autonomy, habitats, planetary activities

- End to end automation/autonomy
- Flexible automation/autonomy

Long distance travel

- Propulsion systems (EP and Advanced concepts)
- Fuel and power aspects
- Large assemblies
- Communications
- Breakthrough concepts

Synergy between human and robotics

- Crew collaborative robotics
- Astronaut support

Life support

- ECLS
- Habitats

Safety and protection issues

- Radiation shielding
- Debris/micro-meteoroid/dust

Large structures

- Inflatables: outfitting the interior
- International cooperation

Planetary activities

- Atmospheric entry: Shielding
- Soft/precise landing: Propulsion aspects, mechanical aspects and GNC aspects
- Surface activities: Autonomy, range & mobility and drilling/manipulation requirements
- Planetary protection

Return mission

- Sample handling
- Contamination control

Acknowledgments: This work[1] has the support of the ASD-Eurospace members and has been prepared by Eurospace Space Research and Technology Committee (SRTC).

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OHB Planetary Exploration Enabling Technologies Involvements

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OHB is closely involved in exploration and space science via a wide range of different national and international projects, acting as both a components supplier and a principal contractor. As the largest German space technology company, OHB additionally takes the initiative and performs its own self-financed exploration and space science studies.

Exploration and space science involve a high degree of cross-disciplinary questions, thus creating new technological approaches and fresh opportunities for science, research and business.

This entails missions dedicated to planetary science, fundamental physics and astrophysics as well as the harnessing of extraterrestrial resources. These are supplemented by technology demonstration missions which are relevant for the areas mentioned above.

For example, OHB System is currently working on a two-part ExoMars mission, a flagship project within the ESA Aurora program in conjunction with the Russian space agency. This mission is currently concentrating on a scientific examination of Mars from orbit and on the surface to search for life on this planet.

The first sub-mission has already entered the implementation phase and is to be launched in 2016. This will be followed by the second mission in 2020, when the ExoMars rover is placed on the planet's surface.

Furthermore OHB is prime contractor for the PLATO (Planetary Transits and Oscillations of stars) scientific research mission of the European Space Agency (ESA), which is to be launched in 2026. PLATO is a satellite-based observatory for use in space to detect and conduct research into exoplanets orbiting in other solar systems.
In addition to OHB System is conducting further studies and projects for exploring the Moon, Mars and other celestial bodies such as Jupiter and asteroids.

In the frame of the Horizon 2061 initiative selected technologies will be presented, that are enabling those projects and missions.
It will include quantum technologies, enabling Quantum Cryptography. Air quality monitoring for permanent atmosphere monitoring of exploration habitats, which is demonstrated on the ISS. Xenon refueling in space for refueling of electrical propulsion systems to enable reusable and affordable systems for sustainable human exploration missions
Sustainable technologies for space exploration as Additive Manufacturing and In-Situ Resource Utilization using space-based resources for human missions in deep space.
Robotic technologies enabling the collection, analysis and transfer of samples, e.g. from the Mars surface.
Spacecraft technologies allowing a stable pointing for long duration observations enabling detection and characterization of terrestrial exoplanets around bright solar-type stars, with emphasis on planets orbiting in the habitable zone.

The role of the Italian Space Agency in Solar System exploration and international collaboration

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The Italian Space Agency (ASI) has a long tradition in Solar System exploration. Building up on this tradition, ASI is committed to provide scientific, programmatic and technical know-how in many international programmes and missions. In particular, an important aspect for the Italian scientific and industrial communities interested in planetary sciences is the development of new instrumentation for future space missions. To this end, ASI aims at motivating synergies between different science and industrial teams with interest in the field of planetary sciences and also to stimulate innovation and new mission concept development. As a result, ASI has a major role as the national Coordinator of the joint efforts among science community, industry, and interested private partners. In view of the establishment of such synergies, it is important to guarantee the existence of a fruitful and collaborative environment both national and international wise.

The overall outcome is the optimization of the Italian contribution to future international plans for the exploration of the Solar System and beyond.

In Situ Exploration of the Giant Planets:

a Horizon 2061 perspective

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Much of our understanding of the origin and evolution of the outer planets comes from remote sensing by necessity. However, the efficiency of this technique has limitations when used to study the bulk atmospheric composition that is crucial to the understanding of planetary origin, primarily due to degeneracies between the effects of temperatures, clouds and abundances on the emergent spectra, but also due to the limited vertical resolution. In addition, many of the most abundant elements are locked away in a condensed phase in the upper troposphere, hiding the main volatile reservoir from the reaches of remote sensing. It is only by penetrating below the "visible" weather layer that we can sample the deeper troposphere where those elements are well mixed. A remarkable example of the superiority of in situ probe measurements is illustrated by the exploration of Jupiter, where key measurements such as the determination of the abundances of noble gases and the precise measurement of the helium mixing ratio have only been possible through in situ measurements by the Galileo probe.

The Galileo probe measurements provided new insights into the formation of the solar system. For instance, they revealed the unexpected enrichments of Ar, Kr and Xe with respect to their solar abundances, which suggested that the planet accreted icy planetesimals formed at temperatures possibly below ~50 K to enable the trapping of these noble gases. Another remarkable result was the determination of the Jovian helium abundance using a dedicated instrument aboard the Galileo probe with an accuracy of 2%. Such an accuracy on the He/H_2 ratio is impossible to derive from remote sensing, irrespective of the giant planet being considered, and yet precise knowledge of this ratio is crucial for the understanding of giant planet interiors and thermal evolution. The Voyager mission has already shown that these ratios are far from being identical in the gas and icy giants, which presumably result from different thermal histories and internal processes at work. Another important result obtained by the mass spectrometer onboard the Galileo probe was the determination of the $^{14}N/^{15}N$ ratio, which suggested that nitrogen present in Jupiter today originated from the solar nebula essentially in the form of N_2. The Galileo science payload unfortunately could not probe to pressure levels deeper than 22 bar, precluding the determination of the H_2O abundance at levels representative of the bulk oxygen enrichment of the planet. Furthermore, the probe descended into a region depleted in volatiles and gases by unusual "hot spot" meteorology, and therefore its measurements are unlikely to represent the bulk planetary composition. Nevertheless, the Galileo probe measurements were a giant step forward in our understanding of Jupiter. However, with only a single example of a giant planet measurement, one must wonder to what extent from the measured pattern of elemental and isotopic enrichments, the chemical inventory and formation processes at work in our solar system are truly understood. In situ exploration of giant planets is the only way to firmly characterize their composition. In this context, one or several entry probes sent to the atmosphere of any of the other giant planets of our solar system is the next natural step beyond Galileo's in situ exploration of Jupiter, the remote investigation of its interior and gravity field by the Juno mission, and the Cassini spacecraft's orbital reconnaissance of Saturn.

An atmospheric entry probe targeting the 10-bar level would yield insight into two broad themes: i) the formation history of the giant planets and that of the Solar System, and ii) the processes at play in planetary atmospheres. Both themes have relevance far beyond the leap in understanding gained about an individual giant planet: the stochastic and positional variances produced within the solar nebula, the depth of the zonal winds, the propagation of atmospheric waves, the formation of clouds and hazes and disequilibrium processes of photochemistry and vertical mixing are common to all planetary atmospheres, from terrestrial planets to gas and ice giants and from brown dwarfs to hot exoplanets.The probe would descend under parachute to measure composition, structure, and dynamics, with data returned to Earth using a Carrier Relay Spacecraft as a relay station. An atmospheric probe could represent a significant ESA contribution to a future NASA New Frontiers or flagship mission to be launched toward Saturn, Uranus, and/or Neptune.

The First Green Leaf on the Moon: A Statement About The CE-4 Mission Biological Experiment Payload

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1 Introduction

On Jan 3, 2019, Chang'E-4 successfully landed on the pre-selected landing zone on the far side of the moon, which is located in the Theodore von Kármán Crater in the Aitken Basin of the South Pole. This is the first lunar landing on the far side of the moon. Chang'E-4 also conducted a biology science experiment in addition to the first lunar landing mission. In the biological experiment payload (BEP), six organisms were carried: potatoes, rapeseed, Arabidopsis, cotton, yeast and fruit flies. The objective was to be able to verify the growth of plants, animals and microbes on the moon.

2 Structures and Modules of BEP

The purpose of the biological experiment payload is to secure the relevant science experiment on the surface of the far side of the moon, which needs to be sealed under one atmospheric pressure. Considering the lunar high vacuum environment, the payload was designed as a pressure vessel with a cylindrical structure (Figure 1). The payload is designed to divide into two parts: the upper tank and the lower tank, and the insulating ring processed by the polyimide material is connected in the middle. The biological module, the camera, the water storage device were installed in the upper tank body and designed as a pressure vessel; the control module is installed in the lower tank body and is not designed as a pressure vessel.

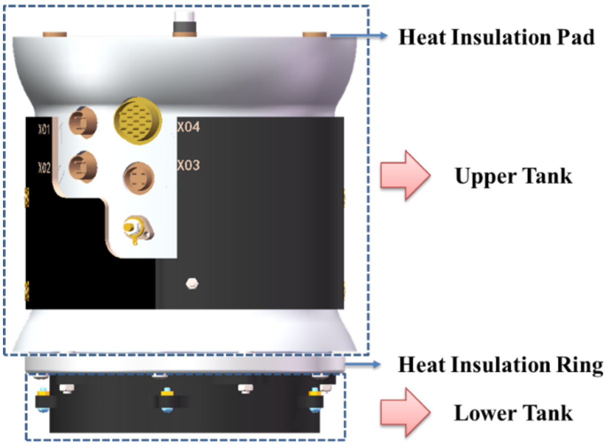

Figure 1: The engineering structure of the payload

The lower tank control module includes a power management circuit and a load control circuit. The lower tank lead wire is connected with the upper tank 37-chip connector for the data transmission between the upper and lower tanks. The outer surface of the tank and the outer surface of the heatsink are all blackened.

The payload is an independent whole unit without any accessory components, in which the line interface cooperates through the aerospace special socket form, including a control module, a thermal control module, a structural module, a light guiding module, and a biological module.

3 How It Works on Moon

The payload is a cylindrical structure with a weight of 2.608 kg, which meets the requirements of the Chang'E 4 probe. It is fixed on the top plate of the lander by bolt connection. The biological space is about 0.82 L, which contains plant seeds, insects and yeast, and constitutes a micro-ecosystem. The payload has a very tiny light-transmitting hole with diameter at Φ10. The natural sunlight of the moon surface is collected by the mirror to verify the photosynthesis of the plants under the lunar environment. The semiconductor cooling/ heating sheet is combined with the polyester film material and the aluminum foil to form a temperature control system and the temperature in the payload is maintained within a range of 25 to 35 ℃ to ensure the survival of the living organism. The photo collection is to facilitate observation of the activity of plants and animals in the micro-ecosystem. Independent control mode is adopted to realize thermal control, photo collection, data storage, data transmission and power management in the payload, while the energy supply is supported by the lander.

4 Experimental Results

An experimental photo sent back earlier this year showed a green leaf growing from the cotton seed inside the payload. It is the first green on the moon.

Recently, the team has used 3D reconstruction and data analysis to further process the image. It turns out that the green is actually made up of two leaves. The image also shows the roots of plants growing on the moon.

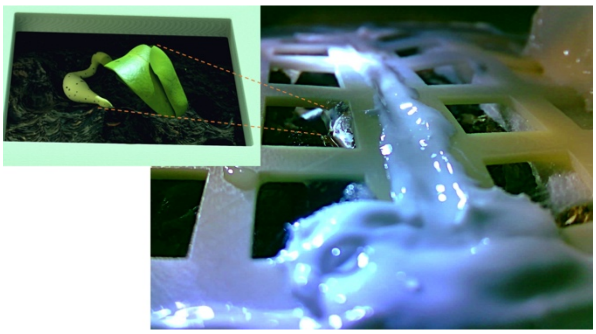

Figure 2: Cotton seeds sprout on the moon, the top left corner is data repair

The accumulated working time of the payload was 1300 hours, a total of 125 shots with 622 photos were received in 5 months, the experiment verified that photosynthesis and the respiratory action of plants work under low gravity and strong radiation conditions. Our biological experiment payload explored the growth and development of photosynthesis and photosynthesis effects on the lunar surface under low gravity, strong radiation and natural light.

Acknowledgments: This work has the support of the State Administration of Science, Technology and Industry for National Defence, PRC.

HORIZON 2061
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Recent advances in in-situ miniaturized [*Environmental,*] Geochemical and Life Detection Instrumentation

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The characterization of the local environment, the search for evidence of ancient climates or extinct life, or the determination of potential habitats for extant life and the presence of chemical precursors in environments such as Mars have been challenges that, in a way, are already assimilated.

However, when we set those same scientific objectives in environments characterized by extremes of temperatures, pressures, high radiation, long dormant periods in transit, gravity, high-g impact forces or vibrations, those same developments become tremendously complex.

If we also add the requirement of a dramatic size reduction, tending towards a high level of miniaturization, if these developments were already complex, now they become almost a chimera.

Nevertheless, over the last years important developments of new essential technologies and innovative approaches that bring these objectives closer together are being carried out. These are enabling new development studies that are advancing the technology for a wide range of instrumentation applications. We will have the opportunity to comment on some of these recent developments, aimed at exploring some of the targets of most astrobiological interest: Mars, Outer Solar System bodies, comets,…

Additionally, in that same context, it is also important to emphasize the relevance of convenient field testing campaigns, focused not only on improving the robustness and utility of the techniques or instrumentation, and understand performances and capabilities, but also to develop and enhance the remote operation strategies required to get the most out of the developed instrumentation.

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Medium and long-term perspectives of radio sounding and radar instrumentation techniques for the study of the surfaces and subsurfaces of solar system objects

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After some missions, the penetrating radar is becoming a classic method to probe the subsurface and internal structure of solar system's bodies: In the past decades MARSIS onboard Mex (ESA) [1] and SHARAD onboard MRO (NASA) [2] have imaged Martian subsurface structures especially its ice caps, offering constraint on its composition. More than 30 years after ALSE onboard Apollo 17 (NASA), LRS on board Selene-Kaguya (JAXA) [3] have probed the Moon regolith, and more recently, CONSERT onboard ROSETTA (ESA) [4] have fathomed a limited part of the 67P/ Churyumov–Gerasimenko comet nucleus. Finally, RIME [5] and REASON [6] are under implementation for JUICE (ESA) end EUROPA Clipper (NASA) respectively to the Jovian satellites. This panorama would not be complete without mentioning Ground Penetrating Radar on board rovers such as the Chang'e 3 GPR (CNSA) [7]; WISDOM onboard Exomars Rover (ESA) [8] and RIMFAX onboard M2020 (NASA) [9].

Scientific returns of such missions show the radar as a unique opportunity to access the third dimension, by providing a direct measurement of the bodies' interior thanks to kilometers-deep penetration kilometers allowing the context of remote measurements of surfaces and the stratigraphic connection of the observed terrain units. Nevertheless, radar instrument design remains challenging: instrument performances in term of investigation depth, sensitivity and resolution are highly dependent on the considered wave frequency band - and in this respect on the composition and the structure of the fathomed bodies, which are generally unknown. Performances are also strongly dependent on the geometry of observation: incidence angles, measurement obits arcs, multi-sensor geometry… Therefore, instruments have to be significantly revisited for each mission with major trade-offs related to antenna accommodation, data flow and potentially available power. Orbits configuration, relative speed, altitudes are then so different between planets and small bodies than radar instrument concept and design could significantly differs for both families of bodies [10].

Radar for planets and major satellites would be similar to Earth observation instrument. After Nadir-looking configuration, next instrument generation would consist in slant looking P Band Polarimetric radars [11] benefiting from increased telemetry system performances to image geological structure of the first hundred meters and to identify hidden geological features. Such radars would also benefits from increased electronics integrations and induced mass reduction.

Radar for icy and rocky small bodies requires specific development with a large versatility in term of operation range and observation angle, which is made possible by a low relative speed (lower than few tens of meters per second). The next generation of instruments [10] would focus first on fathoming small bodies' regolith at higher resolution to understand bodies' evolution processes, and also in probing the deep interior with lower frequency radar to better model accretion/reaccretion processes.

For both planets and small bodies, small platform like CubeSat is also an opportunity to develop bistatic or multi sensor measurement to increase sensitivity and performances.

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Medium and long-term perspectives of seismology for the study and characterization of planetary and satellite interiors

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On November 26th, 2018, the InSight probe [1] landed successfully on Mars, carrying a complete geophysical suite including SEIS, a very broad band seismometer [2], HP3, a temperature probe [3], a magnetometer, a micro-barometer, a wind sensor [4] and RAD, a surface radiometer [3]. This landing and the successful subsequent science operations closed the gap of nearly 36 years without a seismometer operating at the surface of another planet: the Viking lander had stopped working in 1982 [5]. It is therefore appropriate to try to project us in the future of planetary seismology for the next 40 years, which can result, on a broader perspective, to enlarge the scope of planetary seismology potential applications.

Step 1 : New generation of ALSEP and Seismology as a tool for ISRU

The Moon holds a particular place on this prospective exercise, including with the context of human mission. Establishing a seismic network operating several years on the Moon must be the first priority, with the development of a new generation of Artemis Lunar Surface module. Beside of the completion of the Moon structure understanding, which may be done in the next few years thanks to the effort of US and (or) China [11], we expect the seismology to become also (as it is on Earth) a standard tool for In Situ Resources Utilization (ISRU), for mining water ice of other minerals of interest. This will be also true for small bodies, where private companies will look for resources for a commercial utilization of space (space factories or refueling stations)

Step 2: “finish the job” and reveal the solar systems **rocky planets interior structure**.

One of the declared objectives of planetary seismology is comparative planetology [6]. The underlying science question can be formulated as this: can we understand the difference in the various rocky planets’ evolution and the impact of this evolution on habitability? Earth, Mars and Venus, born at the same time in a relatively small zone of the primitive solar system nebula have witnessed very different fates. After completion of the understanding of Mars internal structure (maybe with a network, although an increase of seismometer sensitivity might also be required), the natural target for a geophysical mission is Venus: the knowledge of its interior may hold the key to the understanding of its unique properties, such as its dense and hot carbon dioxide atmosphere and apparent lack of plate tectonics [7]. However, the temperature (400°C) and pressure (90 atm) at the Venus surface are not compatible with the state of the art of planetary seismometer; therefore, several options are open, from orbital measurements to a flotilla of autonomous aerobots [8]. Mercury and its expected big internal core seem in that respect a relatively easier target (once landed!) thanks to its absence of atmosphere. For planets with atmosphere, such as Mars or Venus, the experience gained on InSight leads us to recommend the use of a 6-DOF measurement (linear plus rotation) to compensate for the tilt effect due to the atmospheric tides [12,15]

Step 3: Ocean worlds internal structure

After the selection of DragonFly [9], the UAV for Titan, one can say that seismic exploration of the Ocean Worlds (Europa, Titan, Ganymede, Enceladus …) has already started. (The Dragonfly lander encloses a short period seismometer on one of its feet). However, if installing seismic networks on these distant moons seems unlikely, even in a 40 year time span, we can expect that strawman payloads recommended for in-situ probes will include seismometers, such as in [10] ; within a short time, key properties of the moon structure, such as the ice sheet thickness and the ocean depth can be retrieved. Designing the instrumentation for these planetary targets enclose however specific difficulties, such as the need to be highly tolerant to radiation to survive the encounter with the planetary giant's particle belts.

Step 4 : Long term

. Another use of the understanding of small bodies seismology is also planetary defense; by helping to determine the internal structure of potentially hazardous asteroids (PHAs), seismic techniques can help evaluate the threat and the potential efficiency of a planned mitigation action [12]. A systematic survey of PHAs (as soon as they are discovered) with small CubeSat size probes including a seismometer a gyroscopic payload and a beacon to precisely track their location would definitely be a part of a planetary wide defense system.

In the previous sections, we have considered the use of seismic techniques with a performance level close to what has already been achieved for Apollo or Insight (typically 10^{-10} $m/s^2/\sqrt{Hz}$). Improving the detector performance by several orders of magnitude -which is technically possible with optical interferometry techniques [13]- would enable the measurement of gravitational waves – on a planetary scale. All planets without atmosphere can be the place of remote sensing long period seismology, if very precise ranging (below nm) can be made between slow orbiting S/C and surface reflectors. Such a technique can be developed for the future with the expected LISA technology. Of course this would require a quiet, airless planet- such as the Moon, but one can imagine that a planetary-scale network of gravitational-wave level detectors would provide an extremely efficient tool to explore the cosmos, by measuring gravitational events, but also to detect high energy particles with macroscopic energies [14].

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HORIZON 2061
Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

Mid- and Long-Term Perspectives in the Evolution of Cutting-Edge Geodesy and Gravimetry Techniques for the Characterization of Planetary and Moon Interiors

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Geodetic investigations onboard space missions provided unprecedented insight into the internal structure of several celestial bodies. Knowledge of planets and moons interior is essential to understanding the formation and evolution of the Solar System. Highly accurate measurements of planetary and moons gravity fields yield unique information on the internal structure of those celestial bodies.

The future of space exploration will need extremely high quality geodetic data to enhance our knowledge of terrestrial planets (*i.e.*, Mars and Venus) and gas giants (*i.e.*, Jupiter and Saturn) and to survey poorly explored worlds as icy moons (*e.g.*, Europa, Ganymede, Titan), dwarf planets (*e.g.*, Ceres, Pluto) and ice giants (*i.e.*, Uranus and Neptune). To accomplish these outstanding scientific goals, sophisticated radio science instrumentations will be designed and used onboard future spacecraft.

1. Introduction

Space robotic missions of international space agencies have conducted gravity investigations by using telecommunications systems for Telemetry, Tracking & Command (TT&C) routine functions or dedicated instrumentations (*e.g.*, high-gain antenna, transponder) for radio science. The accuracies of the acquired geodetic data rely significantly on the system configuration onboard spacecraft and landers. The inclusion of extra-elements enabled important enhancements in the quality of the radio tracking data. On the other hand, a more sophisticated radio science system may augment mass and power budgets of a space mission.

The successful missions Gravity Recovery and Climate Experiment (GRACE) **[1]** and GRAvity Recovery and Interior Laboratory (GRAIL) **[2]** provided the most accurate measurements of Earth and Moon gravity fields, respectively. However, these missions were fully dedicated to the gravity investigation since the radio science system was the only payload onboard. Future space robotic missions will require radio tracking data with accuracies similar to GRACE and GRAIL missions for geodetic experiments and to include other scientific payloads for a comprehensive understanding of planets and moons. We present here mid- and long-term perspectives in the design and development of cutting-edge technologies of radio science instruments for deep space telecommunications and inter-satellite tracking.

2. Radio Science System

Gravimetry techniques can be distinguished into two main categories that are based on the measurement of gravity forces through a gradiometer (*e.g.*, ESA mission Gravity field and steady-state Ocean Circulation Explorer, GOCE) or the indirect measurement of gravity accelerations by determining the spacecraft orbit with radio tracking data. The second approach has been mainly used because of its simpler configuration and the possibility to host other instrumentations onboard the spacecraft. Radio science investigations enabled highly accurate measurements of the gravity field of the planets Mercury **[3]**, Mars **[4]**, Jupiter **[5]**, and Saturn **[6]** with radio tracking data acquired by the Deep Space Network (DSN) stations. High-resolution gravity anomaly maps of the Earth and the Moon were the results of the dual-spacecraft GRACE and GRAIL missions, respectively, that collected extremely precise inter-satellite radio tracking data **[7]**.

Deep space radio tracking and inter-satellite measurements will play a major role in planetary geodesy through significant enhancements to data quality and instrument design.

3. Deep Space Radio Tracking System

Deep space tracking systems onboard interplanetary spacecraftinclude a Deep Space Transponder (DST) that supports X-band frequencies (72-8.4 GHz). The radio tracking data collected from the Earth's DSN stations are significantly affected by the solar plasma. Radio science data acquired by tracking spacecraft in proximity of superior solar conjunctions do not provide significant information for the gravity investigation because of the high level of noise. These unfavorable orbit configurations can last few months leading to lose a large amount of data. X-band range and range-rate data accuracies for large solar elongation angles (*i.e.*, not close to superior solar conjunctions) are ~1 m and ~0.1 mm s^{-1} @60 s, respectively.

By adding an additional transponder that operates in Ka-band (32-34 GHz), three radio links (X/X, X/Ka, and Ka/Ka) are used to calibrate the plasma noise enabling extremely accurate radio tracking data (~20-30 cm range and 0.012-0.025 mm s^{-1} @60s). This instrument scheme has been used for the gravity experiments of the ESA missions BepiColombo **[8]** and JUICE **[9]**, and it will be well-suited for geodetic investigations of planets and icy moons in the Solar System.

4. Inter-Satellite Tracking System

The measurement of high-resolution gravity anomaly maps of planets and moons will be possible through dedicated dual- or multi-spacecraft missions. GRACE and GRAIL demonstrated the benefits to using inter-satellite tracking data. The radio science systems of these NASA missions utilized a dual-one-way ranging (DOWR) observation to precisely measure the relative motion between the two orbiters. This configuration required that the twin-spacecraft hosted identical sophisticated radio science instrumentations.

Future developments of the telecommunications technologies will enable the design of radio science system with comparable data quality and a simpler instrumentation architecture compared to the GRACE and GRAIL missions.

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HORIZON 2061
Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

THE IMPORTANCE OF MASS SPECTROMETRY IN THE HORIZON 2061 PROGRAM

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Introduction and historical overview. Mass spectrometry (MS) exploits differences in the mass-to-charge ratio of ionized compounds and fragments resulting from ionization or collision processes to aid in molecular identification. This technique is standard in many laboratories, and optimization of ionization techniques, separation methods, and other parameters can be used to address specific challenges such as analysis of high-mass compounds or discrimination of similar masses.

MS has been successfully applied in numerous extraterrestrial environments, including the atmospheres of Venus [1], Earth, the Moon, Mars [2], Jupiter [3], and Saturn [4], as well as cometary comae [5] and satellite exospheres and plumes [6]. These investigations provided critical insight into the chemistry of these diverse environments, including identification of organics or volatiles as well as isotopic and noble gas measurements in some cases.

Early MS in planetary exploration typically covered a relatively narrow mass range with unit mass resolution. While groundbreaking, these datasets leave many open questions. For example, the Cassini Ion Neutral Mass Spectrometer, which was in orbit around Saturn from 2004 to 2017, identified the presence of organic compounds at Enceladus, Titan, and from the rings, as well as signal at 28 u. With the exception of 28 u at Titan, which is dominated by atmospheric N_2, unambiguous identification of mass 28 species via MS requires a front-end gas chromatograph or higher mass resolving capabilities.

Near future. As scientific investigations of these environments, including the search for life, become more focused, more sophisticated analytical tools will be required. The mass spectrometers of the future will provide higher mass resolution and higher sensitivity. The Europa Clipper MASPEX instrument provides one example of how these technological advancements can be achieved within the constraints of a deep space mission.

MASPEX achieves high mass resolution (up to 34,000 FWHM) via its multi-bounce time-of-flight configuration. In time-of-flight MS, ions are given the same kinetic energy during extraction from the ion source into the drift tube. Since KE = ½ mv^2, molecules with different masses will travel at different velocities through the drift tube. This difference in velocity leads to earlier arrival of lighter masses at the microchannel plate detector, and later arrival of heavier masses. The time difference depends on the length of the drift tube, with longer distances providing greater time separation. To increase the overall path length of the drift tube while maintaining a footprint compatible with spacecraft resources, MASPEX uses reflectrons at the ends of the drift tube to bounce the ions back and forth. The resulting high mass resolution can be used to distinguish between compounds with very similar masses (e.g., CO and N_2), or to separate isobaric species with different isotopic compositions (e.g., $^{13}CH_4$ from CH_3D).

To aid in the search for trace organics which may include biosignatures, MASPEX uses a two-pronged approach: (1) a storage source, which results in higher ion fluxes through the instrument, decreasing the detection time required for quantifying trace constituents; and (2) a cryotrap that adsorbs ambient gases at closest approach, and then releases them at a higher effective pressure into the source when the Clipper spacecraft is outside the intense radiation environment near Europa.

Looking further ahead. To address fundamental questions on the origin and evolution of the solar system, and the possible presence of life on other worlds in the solar system, the next generations of MS will require sophisticated sample handling and separation techniques prior to introduction of analytes into the MS, preceding the ability to manipulate ions via mass filtration and fragmentation.

To introduce non-volatile compounds into the MS, sample preparation such as pyrolysis may be necessary. Some compounds of great astrobiological interest, such as amino acids, require derivatization or other manipulation (e.g., electrospray) before introduction into the MS. Development of sample delivery systems that can be automated in different extraterrestrial environments will be key to next-generation MS measurements.

The complexity of natural mixtures makes concrete identification of compounds and their precise isotopic signatures challenging or, in some cases, highly uncertain. For example, MS measurements of natural gas mixtures containing CH_4, C_2H_6, and C_3H_8 produce spectra with unresolvable interferences due to formation by all three compounds of identical dissociative fragments. In this simple example, the spectra can be deconvolved by forward modeling. However, in more complex spectra, the large number of possible contributors to commonly formed fragments hinders the ability to obtain unambiguous information about certain species, unless a robust separation technique, such as GC×GC, is also used.

In the search for extraterrestrial life, discrimination between biotic and abiotic molecular origins is paramount. Position specific isotopic analyses (PSIA), which measure the isotopic ratios of a given atomic position within the compound of interest, are emerging as a promising technique for tracing molecular formation pathways. Measurement of PSIA by MS requires precise manipulation of analyte ions, including use of a mass filter prior to detection as well as the ability to isolate and fragment ions in a controlled manner. PSIA on other worlds may be enabled by future developments that combine a high resolution MS for selection of ions at the front-end, with fragmentation in a collision cell to interrogate specific atomic positions, and final detection by a high sensitivity, ultra-high mass resolution instrument such as the Orbitrap.

Conclusions. MS has historically provided groundbreaking insights into the nature of environments in the solar system and the chemical processes that shape them. Moving forward, this instrumentation will be an increasingly useful analytical tool in detailed investigations of the solar system. Near-term advances include development of high mass resolution and high sensitivity instruments such as MASPEX. Advancements in future MS generations that will enable revolutionary science include sample handling and separation techniques, as well as high resolution mass filtering and controlled fragmentation.

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Exploration mission concepts based on miniaturized technologies, perspectives drawn from the LCPM 13 conference.

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The 13th International Academy of Astronautics (IAA) Low-Cost Planetary Missions Conference, LCPM 13, was held at the Université Paul Sabatier in Toulouse from June 3rd to June 5th, 2019. This conference is a forum for planetary scientists, technologists, engineers, project managers and agency officials to gather for the exchange of information and ideas for making this class of robotic mission richer scientifically while remaining affordably low-cost. The most remarkable trend towards affordable missions comes from the recent availability of miniaturized instruments and spacecraft such as cubesats. Based on the presentations received at LCPM 13, we will present how small spacecraft (typically below 100 kg) can credibly conduct high quality planetary science missions, and the various programs currently engaged under this format by the main Space Agencies across the world. The critical question of affordable access to Deep Space will also be addressed, together with the emergence of commercial services in support to planetary exploration such as transportation, navigation and communication.

In line with the long term timeframe of the Horizon 2061 exercise, we will then focus on the advanced technologies that emerged at LCPM 13, such as instrumental concepts for the characterization of planetary or asteroid surfaces and sub-surfaces, and new concepts of compact instruments dedicated to the characterization of the plasma environment of planetary objects. In the area of spacecraft and system design, the most striking development involved the adaptation of low-cost space technologies developed in a low-Earth orbit (LEO) context to lunar and inter-planetary missions, deep space navigation and autonomy, and novel and advanced forms of spacecraft orbit and attitude control. Finally, we will present the innovative mission concept that will be deployed over the next decades. In this respect, the affordability of small spacecraft should enable:

- the exploration of a large number of small bodies,
- high risk / high rewards missions to hazardous environment,
- the repetition of missions needing to observe the variability of parameters over the long term,
- multi point measurements, particularly in the field of radio-science, and of atmospheric and magnetosphere studies,
- distributed systems based of formation flying.

Reference

Website of LCPM 13 at http://lcpm.iaaweb.org/

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Exploration technologies for advanced small platforms reaching to extreme environments

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The overarching research goal of this paper will be to address and provide practical solutions to the technical challenges of all types incurred along the chain of space data by the application of *low-cost* ***advanced small platforms (ASPs)*** to deep space exploration missions meeting scientific objectives.

1.Advanced Small Spacecraft Platform faced to extreme environments in the future missions

1) High and low temperature extremes tolerant systems
2) High temperature electronics
3) High pressure and low pressure operations
4) High levels of radiation tolerant systems
5) High corrosive environment tolerant systems
6) The ocean environment

So, the *low-cost* ASPs systems must be designed for unknowns in the environment of future deep space mission.

2. Advanded technologies for advanced small platforms

① Science Instrumentation

- New tools and methods used in Life detection
- Advanced sample handling systems
- Subsystems for In situ measurements, miniaturization
- Sample retrieval and handling, such as tools, systems, encapsulation and return, scooping and digging, sampling on slopes ， melting subsurface ice
- Better spectra, better resolution remote sensing instruments

② ASPs system design

- Mother-daughter spacecraft, Networking and formation flying technologies of ASPs or swarm spacecraft systems
- Networking and assembly modes of ASPs with other exploration platforms；
- Multi-target mission architectures, such as carrying ASP probes to be dropped off at various locations;
- SmallSats，CubeSats, ChipSats/FemtoSats, distributed sensors, multi-point measurements, Increase of efficiency；
- Modular/standard spacecraft with standard interfaces/volumes for customized instruments , in order to lower costs.

③ Task planning technology of autonomous deep space

- Leveraging flying technology,
- quantum computer,
- big data processing,
- advanced online signal processing technology

④ Autonomous Navigation and control technology

- Ubiquitous intelligence in machines
- Autonomous network detection and formation flying technology
- Optimize science collection via autonomy

⑤ intelligent health management technology

- Fault diagnosis and health management technology for energy propulsion and thermal management systems

⑥ Advanced propulsion and energy technology

- Propulsion technology for faster access to the outer planets, heliospheric boundaries and beyond, Electric propulsion, Nuclear propulsion，laser propulsion…
- Energy storage (all-temperature), Surface power systems,

3.Another research for advanced small platforms

1) The use of international cooperation opportunities to fly deep space missions;
2) Special opportunities of small satellite launch verification technologies, the potentialities of using new launch or deployment opportunites;
3) Long-term environment monitoring, understanding and characterizing pristine to evolved environmental conditions in planetary worlds;
4) Advanced manufacturing technology;
5) Modeling and simulation system;
6) Ground Launch Measurement and Control System;
7) Scientific data processing and analysis.

HORIZON 2061
Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

The potential of electric propulsion : research at LPP and in the ANR industrial chair Poseidon

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Space propulsion includes the propulsion technologies required to reach space, as well as the ones that can be used to maneuver when in space. Although, these technologies may be significantly different, they are all based on the same principle, namely creating a force on the object by changing its momentum. This change is achieved by expelling mass, and the force is given by the rate of change of the spacecraft mass times the velocity of the ejected mass. Electric Propulsion (EP) makes use of electrical power to ionize and accelerate a propellant to velocities up to twenty times larger than those of chemical thrusters. The higher exhaust velocity of electric thrusters reduces the mass needed to provide a given impulse leading to reduction in launch mass and substantial cost savings. For example, to maintain a 3 ton satellite on a geostationary orbit for 15 years, a propellant mass consumption of about 100 kg is needed with an exhaust velocity of 20 km s^{-1} for an electric thruster, while nearly 1000 kg would be required with an exhaust velocity of 2 km s^{-1} for a chemical thruster [1]. This translates into a significant cost reduction, or possibilities to embark more payload. The thrust of electric thrusters is lower than that of chemical thrusters but a combination of low thrust and high specific impulse (defined as impulse per propellant mass unit) is sought for orbit insertion, attitude control and drag compensation. In current electric thrusters, the electric power used is of the order or below a few kilowatts and the thrust from the order of one to hundreds of millinewtons.

There are two new very promising trends for the development of electric propulsion in coming years: First, the need for high power (several tens of kilowatts) electric propulsion systems for full orbit raising and orbit transfer, there the required thrust is in the order of Newtons. Advances in solar power generation systems are increasing the total amount of available on-board power, and EP-based orbit transfers using 50kW or more of electric power are becoming realistic. Space electronics components are now becoming so powerful that the satellite can pass the Van Allen radiation belt during a longer period of time, making electric propulsion viable for orbit raising. Second, the need for low power (1-500W) electric propulsion systems for the exploding and disruptive market of small satellites, where the thrust level is in the order of microNewtons. This trend is driven by an extreme cost reduction and the possibility for mass production via for example the use of the standardized CubeSat technology, traded against quality and long lifetimes.

Among the different electric propulsion systems, Hall effect Thrusters are developed in France by SAFRAN Aircraft Engines, the industrial partner of the POSEIDON chair, and pioneer of electric propulsion systems in Europe Hall effect thrusters have been extensively studied since their invention in the 1960s. However, the physics of magnetized plasmas typical of these thrusters is complex; several plasma processes that have direct relevance to the thruster performance and lifetime are still poorly understood. Today, the design and development of Hall effect Thrusters is still semi empirical with long and expensive life tests. The final objective of the POSEIDON Chair is to develop a new experimental/numerical methodology to reduce the number of experimental tests in the development of future Hall effect thrusters.

A significant effort in the project is put on the development of state-of-the art parallelized simulation codes for magnetized low-pressure plasmas encountered in Hall effect thrusters. At LPP, the “Particle-In-Cell”, fluid and hybrid codes have been developed to carry out simple geometries and academic test-cases. They also serve as reference for benchmarking the 3D hybrid code AVIP developed at CERFACS (Toulouse) on academic test cases. Then the AVIP code will be used to simulate the complex 3D geometry of a real Hall effect thruster.

If this talk, we will present the way we combine in the POSEIDON chair fundamental and applied research activities, for both experimental and numerical studies, to better understand crucial plasma processes occurring in Hall effect thrusters: electron transport, interaction with walls and erosion, and address the question of alternative propellants. Detailed scientific results can be found in [2-9].

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In space manufacturing and assembly of large systems

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Why In Space Manufacturing and assembly?
Even if Launch capacities have significantly progressed since last 10 years, launchers will always be the bottleneck of Space Business. The Space access costs, the size limitation, the launch loads or even the launch opportunities have lead the Space business model to over-quality (failure is not an option), customized design, significant structural mass (and cost) and long time to market.

The New Space requires new paradigm in order to make it real! Airbus as a Mature Space company initiated several years ago a complete re-thinking of the future of Space business taking into account the different technology breakthrough as Robotic, Artificial Intelligence, Digitalization, Additive Manufacturing and Autonomy.

Since five years Airbus Defence and Space is preparing the future with the development of all relevant technologies in order to manufacture and assemble in Space. After a review of the future benefits and applications, on-going developments will be presented.

The Metal3D development in collaboration with ESA deals with the first metallic 3D printer that will be delivered early 2020 and fly onboard the ISS.

The DEMETRA development: a full digital manufacturing factory designed for manufacturing and assembly in Space with robots.

In few years the maturity of both developments has significantly improved and the way forward is clear: We will fly!

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Relevant Technologies and Validation Assumptions for ISRU

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The Lunar ISRU(in-situ resource utilization) technology is the core key technology to realize the exploitation and utilization of extraterrestrial celestial resources, which has been widely concerned by aerospace engineers all over the world. In this report, our in-situ resources concepts refer not only to the natural resources on the moon, but also to the abandoned spacecraft resources launched by human beings on the moon.

1.The Value of ISRU Technology

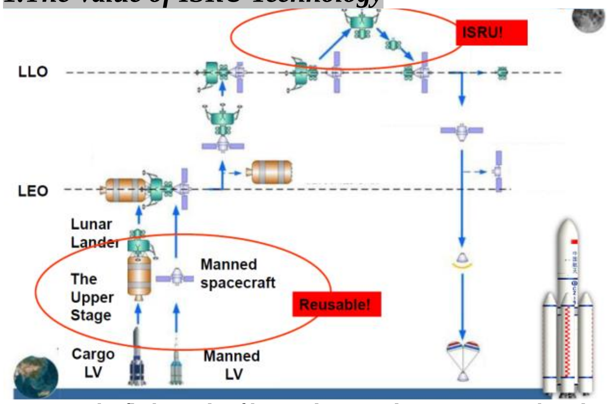

Figure1: The flight mode of human lunar exploration mission based on ISRU

For human lunar exploration mission, the value of ISRU technology is to reduce the weight of cargo that must be sent to the lunar surface by utilizing the natural resources of the moon, such as making oxygen from lunar soil and building materials, and making water from lunar water ice in permanent shadow pits on the lunar Antarctica.

For human Mars exploration mission, ISRU technology on Mars is indispensable, because of the high cost of life-support consumables supplied to humans from the Earth. ISRU technology can be used not only to produce life-saving consumables and building materials such as oxygen and water on the surface of Mars, but also to produce propellants such as liquid oxygen and methane (LOM) for Mars upgrade engines using the Martian atmosphere.

ISRU technology can significant reduce the number of launch vehicles and the cost of launches.

2. The Relevant Technologies of ISRU

①Exploration of Lunar or Mars Resources

The three-dimensional mapping of the lunar or Mars resources is completed by using microsatellites and their constellations, and the resource maps that can be further developed and utilized are drawn.

②Production of Oxygen and Water

Using lunar soil or carbon dioxide from Mars atmosphere to produce oxygen, or using water ice to produce water all requires high temperature heating, which requires high temperature resistance of equipment materials and oxidation resistance of electrode materials.

③Production of Building Materials

Making building materials from lunar soil or water ice involves 3D printing technology.

④Production of Propellant for Ascent Lander Engine

Whether liquid hydrogen and oxygen(LHO) propellant or liquid oxygen methane(LOM) propellant, zero Boil-off (ZBO) control technology of cryogenic propellant is needed for storage and transportation, as well as on-orbit injection technology of propellant.

⑤Sustainable high-power energy technology

In the ground test of using lunar soil to produce oxygen, we found that the consumption of power energy is huge, which means that the sustainable high-power energy must be guaranteed. These include technologies such as putting nuclear power on the surface of the moon or Mars, or putting solar power plants in orbit for wireless energy transmission.

⑥ Recycling of Lunar or Mars Resources and Environment Protection

If human beings want to survive on the moon for a long time, we must consider the recycling of resources and environmental protection. Including the transportation and storage of waste, pollution control and so on.

3. Tentative Idea of Technical Verification by Chang'e Lander

China will complete the lunar sampling and return mission of Chang'e-5 next year, and is currently conducting demonstration work at the lunar research station.

In this paper, a scheme of making oxygen from lunar soil by Chang'e lunar lander is proposed. It is assumed that on the basis of Chang'e 3 and 4 lunar landers, a high temperature reactor will be placed. The lunar soil will be sampled by the machine arm, heated by high-power solar panels at high temperature, and the oxygen generated will be collected and stored. Oxygen production was verified by mass spectrometer.

If this project can be implemented in Chang'e 6 or 7 or 8 missions, China will rapidly promote the development of ISRU technology and lay a technical foundation for the eventual establishment of a long-term habitable lunar base.

THE ROLE OF ON-BOARD AUTONOMY IN FUTURE SPACE EXPLORATION: ERGO’S AUTONOMOUS LONG TRAVERSE ACHIEVEMENTS IN MOROCCO DESERT

From early 2016 till mid December 2018, GMV has been leading a team of seven European partners (GMV UK, DFKI, Airbus, Scissys, UGA, Basel University, King’s College, and Ellidiss) working in the design, development and validation of the European Robotic Goal-Oriented Autonomous Controller (ERGO) system (http://www.h2020-ergo.eu/).

ERGO is one of the six space robotic building blocks developed in the frame of the PERASPERA project part of first call of the European Commission’s Horizon 2020; Space Robotics Technologies Strategic Research Cluster (SRC),

ERGO, is a goal oriented autonomy system framework suitable for application to different space robots operating in harsh environments, both space (orbital and surface) and terrestrial (i.e. nuclear, oil & gas, underwater and mines)

The ERGO framework has been tested in an orbital (in orbit service application) and a planetary (Martian surface exploration) scenarios. In both scenarios, the used robotic means, robotic arm and rover respectively, have been commanded via high level goals uploaded from ground.

The proposed presentation will discuss about the role of on-board autonomy in future space exploration while addressing the results achieved during the ERGO field tests that took place December 2018 at Moroccan desert (Gare Meduar), a Mars-like environment. The rover platform used was the SherpaTT Rover from DFKI. SHERPA TT is a 200 kg robotic platform that had demonstrated previously its high performances in earlier tests conducted in the Utah desert.

A large team of engineers performed dedicated tests to demonstrate the ERGO capabilities to achieve autonomous long traverses, nominal on-board planning, and dynamic re-planning on-board based on new high level goals sent from ground and opportunistic science. During this challenging test campaign, the rover was able to traverse autonomously 1.4 km during 8.5 hours continuous working through the Moroccan desert.

Thanks to the ERGO system, the rover has been capable of to elaborate its own plan to fulfil the designated goals. This plan has been autonomously dynamically changed on board, when the circumstances required so.

The original injected high-level goals were finding targets of interest autonomously on a given area, performing autonomously long traverses to a destination point, picking or dropping samples at a designated position, or taking images from a designated point.

The presentation will discuss the performances obtained and will offer an overview of the problems found during these tests. The paper will be completed by a video that will resume the tests performed in Morocco showing the effectiveness of ERGO to autonomously explore unknown surfaces.

Architecture and technology challenges of the Comet Interceptor mission

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The Comet Interceptor mission was selected in ESA's Fast-class call in June 2019 and is currently under detailed study by ESA, for a 2028 launch to the L2 Lagrange point. Comet Interceptor is a compact, agile set of three spacecraft that will visit a pristine comet that is entering the inner Solar System for the first time and is potentially unchanged from its formation. The sub-spacecraft will detach and allow a three-point measurement of the comet and its solar wind interaction. Remarkably, the mission target is yet to be discovered. A new generation of powerful survey telescopes, in particular the Large Synoptic Survey Telescope are discovering comets far from the Sun on their long inward approaches, providing years of lead time so they can be targeted by space missions. Although far rarer than long-period comets, Comet Interceptor will also have the capability to encounter an interstellar object passing through our Solar System, if one of these drifting worlds from another star is found on a suitable trajectory.

Exploring Space through Sample Return Missions: How, Where, and What Do We Do with the Rocks?

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Current scientific exploration of planetary bodies is dominated by Earth-based remote observations and robotic exploration. Scientific return from these endeavors, while highly valuable, is often incomplete. Samples directly returned from celestial bodies are needed to more fully answer the driving questions in planetary science. Sophisticated analyses such as high-precision elemental and isotopic composition, detailed identification of organic compounds or high-resolution petrographic analysis cannot be done with robotic missions. In addition, robotic missions cannot be equipped with the latest instruments for a variety of reasons, while the analytical Earth-based scientific equipment advances rapidly. However, studying returned samples over the long term involves keeping the samples as pristine as possible. Curation activities include aspects of the mission requirements and architecture, recovering the sample canister after returning to Earth, opening and characterizing the samples, storing and allocating them to the scientific community.

The NASA Johnson Space Center (JSC) Astromaterials Acquisition and Curation Office (AACO) has been a pioneer for sample curation over the past 50 years, currently with seven collections. In the following, we review sample curation at NASA JSC, describe the upcoming sample return missions and discuss how NASA and the global community are getting ready for them. We then review some of the challenges of bringing back samples and keeping them safely on Earth.

Current sample curation at NASA JSC: All collections are stored and processed in cleanroom laboratories ranging from ISO Class 4 to ISO Class 7: Lunar soils and rocks (ISO Class 6), Antarctic Meteorites (ISO Class 6), Cosmic Dust (ISO Class 5), Microparticle Impact (ISO Class 5), Genesis Solar Wind (ISO Class 4), Stardust Comet/Interstellar particles (ISO Class 5), and Hayabusa asteroid particles (ISO Class 5). Housekeeping protocols as well as cleanroom gowning apparel (garments, gloves, etc.) are adapted to each collection. Integrity of the samples is maintained by handling the samples in specifically designed cleanrooms, with a limited number of carefully selected materials. Most of the samples are handled and stored under dry inert gas (usually nitrogen) at ambient temperature.

New needs in sample curation: Apollo Next Generation Sample Analysis Program (ANGSA) is a prime example of how sample return can yield returns over several decades. In the fall of 2019, unopened vacuum-sealed Apollo samples, frozen Apollo samples and Apollo samples stored in Helium are going to be opened and processed for the first time, after being saved 50 years ago for this purpose. Even though Lunar samples are currently being handled and stored in dry nitrogen at room temperature, specific gloveboxes have been designed for the ANGSA samples, featuring cold handling, and handling under Helium.

NASA is currently awaiting two sample returns in the next five years: Hayabusa2 (led by JAXA) and OSIRIS-Rex (Origins Spectral Interpretation Resource Identification Security Regolith Explorer). Both missions are set to sample organic-rich asteroids, which will require curation facilities tailored for these samples. In March 2019, the NASA JSC AACO began construction of six new curation cleanroom laboratories by remodeling over 560 m^2 of existing space inside JSC Building 31, current home to all of NASA's extraterrestrial sample collections. On top of accommodating the main collection of OSIRIS-REx mission and a subset of material from JAXA's Hayabusa2 mission, half of these facilities will be dedicated to advanced curation and advanced cleaning research. Cleanrooms will be ISO 5 to ISO 7 and designed to reduce organic outgassing products and total organic carbon.

What is next? In the next decade, NASA is planning to get new samples from the Moon (Artemis) and from Mars (Mars 2020 and following missions, [1]). JAXA should launch the Martian Moons eXploration (MMX) mission in 2024 to return samples from Phobos. The recently proposed CAESAR (Comet Astrobiology Exploration SAmple Return) was designed to retrieve samples from comet 67P and was listed as a high priority in the 2013-2022 Planetary Science decadal survey [2]. The planetary science community has also been calling for sample return missions from less traditional bodies, such as Venus or Mercury [3]. In addition, there is increased interest in ocean worlds (Europa, Ganymede, Enceladus, Triton, etc.) as life-harboring bodies. All these bodies would require advance in mission technology, as well as development in curation [4].

Challenges in mission technology: Missions to bring a spacecraft to any planetary body are inherently challenging. In the case of sample return, the spacecraft needs to have capabilities to sample the body, then to return and land on Earth while protecting the sample as much as possible. Most of the past sample return missions have been robotic and have returned a small weight of sample. Human-based sample return missions like Apollo have yielded a much larger set of samples. This stems from several reasons: human exploration of space has been limited so far to our closest neighbor, the Moon; for further targets, energy restrictions limit the amount of mass sent to, and returned from, these bodies; finally, robotic sampling devices lack adaptability relative to human explorers. Another hurdle in sample return technology is protecting samples on the trip to Earth from heat [5], radiation or shock.

Challenges in curation needs: The next decades will hold a variety of challenges for new types of collections. A sample return from a comet requires that the samples be kept at sub-freezing or even cryogenic temperatures. A potential return from the Venusian atmosphere generates challenges concerning the long-term curation of gases. Samples from Mercury are extremely reduced and should not be put in contact with any oxidant. Another challenge is to curate potentially life-harboring samples from restricted bodies (Mars, Europa, etc.), by containing the samples while keeping them pristine and available to the scientific community. New curation protocols, potentially including robotic handling will be needed to address the myriad of future astromaterials curation challenges.

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Exploring Space through Sample Return Missions: Planetary Protection and Contamination Control and Knowledge

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Sample return missions, in cooperation with remote observations and in-situ robotic exploration, are needed to provide a complete understanding of a planetary body in space. When kept pristine, returned samples yield scientific results for decades after their return and serve as a fantastic tool for public engagement. To keep the samples pristine, it is important to reduce and track potential contaminants while acquiring samples, transporting them back to Earth, and on Earth during curation. Curation activities include receiving and characterizing the samples to storing and preparing samples for allocation. Contamination can occur in various forms, including particulate, inorganic, organic, biological, molecular, etc. Mission designs incorporate requirements to limit specific types of contamination to levels deemed acceptable by the scientific community. Once on Earth, samples should be curated in dedicated cleanrooms. However, a cleanroom by itself won't ensure cleanliness, as contaminants come from many sources, both outside and inside of the cleanroom. Therefore, it is vital to maintain a strict Contamination Control and Knowledge (CCK) protocol. Since all contaminants cannot be eliminated, it is mandatory to understand the identity and abundance of compounds that could affect the samples. If a contaminant is deemed to be unacceptable, or shows levels higher than usual, a plan for mitigation should be devised and applied [1].

Contamination Control and Knowledge is an evolving field where the needs are dictated by advances in instrumentation, scientific constraints and type of samples. Past sample return missions have primarily brought back rocks and soils that mostly need inorganic CCK. The scientific community has been calling for sample return missions from other celestial targets, including organic-rich bodies, and has been considering the needs and challenges of CCK for these targets.

In the following, we will describe how the NASA Johnson Space Center (JSC) Astromaterials Acquisition and Curation Office (AACO) is dealing with these challenges for its current sample collections, while getting ready for the future.

Contamination control in current collections: The current collections at NASA JSC (Lunar rocks, Antarctic meteorites, Stardust comet particles, etc) handle rocks, soils and dust that are low or devoid of organic matter. Cleanliness is maintained through strict protocols, limited materials in contact with the samples (mostly stainless steel, aluminum, glass), and routine monitoring of the cleanroom itself. Rigorous sample handling and staff gowning protocol, as well as advanced laboratory and tool cleaning ensure that overall contamination is kept to a minimum. Particle counts (along with temperature and humidity) are currently taken on a weekly basis to ensure particle load is within the cleanroom parameters. We have recently started localized constant particle counts, to assess the variability of particle load over time, and link it to activities and potential other parameters.

Upcoming challenges with organic contamination: Apart from sporadic studies on organic contamination over the past 50 years [2], the main concern for current collections is inorganic contamination. However, the next two sample return missions, OSIRIS-REx and Hayabusa2, have targeted organic rich carbonaceous asteroids. The OSIRIS-REx mission design set a requirement limiting total organic matter for the sample containers [3]. In preparation for the increased organic limits for OSIRIS-REx and Hayabusa2, AACO is acquiring organic compound measurements in existing curation cleanrooms before and during the construction of new curation facilities dedicated to these new collections. This effort aims at establishing a list of all contaminants found even temporarily in existing ARES cleanrooms that might impact future scientific discoveries and gather best practices for future construction work. Airborne and surface molecular contamination monitoring is mostly performed using wafers and air sampling tubes provided by Balazs NanoAnalysis, to measure molecular organics and molecular inorganic compounds. Identification of particles larger than 1µm has also been developed, to understand sources of contamination affecting curation cleanrooms.

Biological contamination and Planetary Protection: Planetary Protection (PP) addresses a specific type of contamination: biological contamination. The Committee on Space Research (COSPAR) has the mandate from the United Nations to maintain and promulgate the planetary protection policy [4]. COSPAR defines five PP categories based on type and risk, and classifies samples returned from potentially life-bearing target bodies (Mars, Europa, Enceladus, Triton, etc.) as restricted category V. Planetary Protection is two-fold, forward and backward. Forward PP is essential to preserve our ability to study the organically- and astrobiologically-interesting celestial bodies by preventing contamination with terrestrial micro-organism or organics and thus removing the possibility of false-positive results. Backward PP aims to protect the Earth's biosphere from extra-terrestrial agents, which might be harmful if released into the Earth environment. Both aspects must be considered, forward PP on samples collected and then returned, and backward PP during transport and curation phases. On the forward side, Contamination Knowledge (CK) witness plates must be extensively acquired during mission preparation: the Astromaterials Acquisition and Curation Office is curating the ever-growing CK collection for Mars 2020. On the backward side, various studies have been generating design for curation facilities encompassing both aspects of cleanliness and containment [EURO-CARES]. Biological contamination has been monitored in the NASA JSC curation cleanrooms over the past year [5] and a mitigation effort is planned to understand how to reduce bio load in the cleanrooms.

Contamination, whether organic, inorganic or biological has to be minimized, monitored and mitigated if necessary. Current CCK has been focusing mostly on inorganic elements and overall particles. With upcoming and future sample returns from carbonaceous asteroids and Mars to cite but a few, a more ambitious CCK is being developed through a common effort of the engineering, research and curation communities.

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Planetary Space Weather For Planetary Systems

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Space weather has become a mature discipline for the Earth space environment. With increasing efforts in space exploration, it is becoming more and more necessary to understand the space environments of bodies other than Earth (Lilensten, J., 2014). The study of planetary space weather considers different cross-disciplinary topics, such as the interaction of solar wind and of magnetospheric plasmas with planetary and satellite surfaces, atmospheres, and ionospheres; the variability of the planetary magnetospheres under different external conditions (solar or non-solar driven); the interactions of planetary radiation belts with atmospheres, satellites and rings (Plainaki et al., 2018). Planetary space weather will be of increasing importance for future planetary missions. We will discuss future scientific and technological perspectives of the discipline in the coming decades.

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Planetary plasmas data systems: towards the future

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For more than 20 years the Centre de Données de la Physique des Plasmas (CDPP) [1] is actively archiving space physics data, proposing innovative analysis tools [2], and promoting science among students and confirmed scientists altogether. In this presentation I shall discuss recent additions to the CDPP tools in relation to various space missions (Rosetta, Parker Solar Probe, JUICE, etc). These recent developments will be discussed and quickly demoed before putting in perspective the next evolutions of the Centre in the broader perspective of international initiatives for advancing planetary plasmas data systems [3].

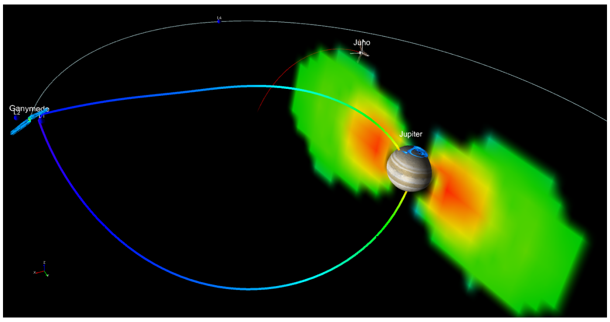

Figure 1: 3D visualization of the Jovian system with the CDPP/3DView tool. The features shown are: a model of radiation belts (Salammbo), a model of magnetic field (JRM09), the mapping of an HST aurora on Jupiter, together with hybrid model at Ganymede and the Juno orbit.

Acknowledgments: This work has the support of CNES and CNRS.

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From Lunar Outposts to the Moon Village

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Why a Moon Village? Multiple goals of the Moon Village include planetary science, life sciences, astronomy, fundamental research, resources utilisation, human spaceflight, peaceful cooperation, economic development, inspiration, training & capacity building.

How did the Moon Village start? The original concept of MoonVillage was discussed in the last decade. Space exploration builds on international collaboration. COSPAR and its ILEWG International Lunar Exploration Working Group (created in 1994) have fostered collaboration between lunar missions [1-23]. A flotilla of lunar orbiters has flown in the last international lunar decade (SMART-1, Kaguya, Chang'E 1 &2, Chandrayaan-1, LCROSS, LRO, GRAIL, LADEE), together with the Chinese Chang'E 3 lander and Yutu rover. Other landers from 2019 (Chang'E 4 & 5, Chandrayaan-2 Vikram, Luna, commercial, LRP) will constitute a Robotic Village on the Moon.

Figure 1: Milestone for MoonVillage Human Outpost after inflatable deployment, 3D printing protection with regolith, before human & robotic sustainable operations

MoonVillage preparation activities:
The community has developed a number of workshops, projects and research initiatives (10-53). Recently, a MoonBase is now operational by the International Moonbase Alliance (IMA), on a most Moon-like volcano.

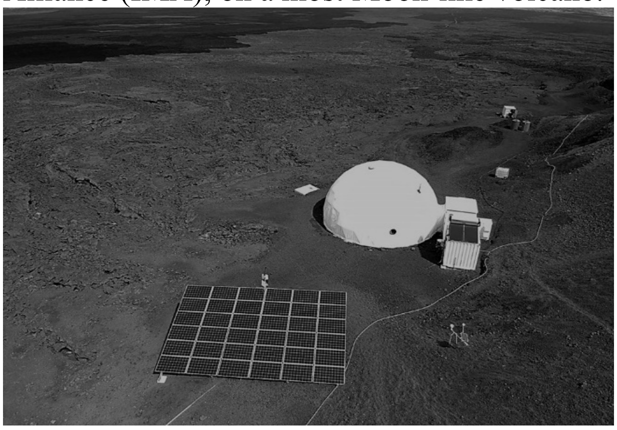

Figure 2: MoonBase outpost during EMMIHS 2019 (EuroMoonMars - International MoonBase- HiSeas)

Lunar missions have been conducted to learn how to live and work in this Moonbase. Starting on February 2019 at Hawai'i Space Exploration Analog and Simulation (HI-SEAS) habitat on the slopes of Mauna Loa on Hawai'i Big Island, the EMMIHS campaign was organized and operated by IMA, ILEWG, ESTEC, VU Amsterdam & partners.

Figure 3: EVA research activities on surface and inside lavatubes during EMMIHS 2019

The Igluna project, organized by ESA_Lab and

Swiss space centre has built a habitat in a glacier for a campaign in June 2019 in Zermatt, Switzerland, with participation of ILEWG & students from 15 universities as a simulation for future ice habitats on the Moon or Mars.

"The Moon Village will rely both on automatic, robotic and human-tendered structures to achieve sustainable moon surface operations serving multiple purposes on an open-architecture basis." The Moon Habitat Design group identified that the lunar base design is strongly driven by the lunar environment, which is characterized by high radiation, meteoroids, abrasive dust particles, low gravity and vacuum. The base location is recommended to be near the poles to provide optimized illumination conditions for power generation, permanent communication to Earth, moderate temperature gradients at the surface and interesting subjects to scientific investigations. The abundance of nearby available resources, especially ice at the dark bottoms of craters, can be exploited in terms of In-Situ Resources Utilization (ISRU).
The identified infrastructural requirements include a navigation, data- & commlink network, storage facilities and sustainable use of resources. This involves a high degree of recycling, closed-loop life support and use of 3D-printing technology, which are all technologies with great potential for terrestrial spin-off applications. We shall report on the roadmap for development, and on infrastructures and services for the future.

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The cislunar gateway as an infrastructure for lunar and solar system exploration

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Space exploration takes an active part in the Humanity evolution, as an answer to the human desire for discovery and conquest. Setting up human missions for new space exploration of the solar system will be an ambitious challenge for the entire humanity. Human and robotic exploration of the Moon, Near Earth Objects (NEOs), and Mars will strengthen and enrich humanity's future, bringing nations together for a common cause, revealing new knowledge, inspiring people, and stimulating technical and commercial innovation. These are the substantial benefits delivered to society. In this context, the International Space Exploration Coordination Group (ISEGC) [1] has identified several mission scenarios beyond Low Earth Orbit (LEO) as significant landmarks.

operating, with the collaboration of all main international space agencies, a Lunar Orbital Platform - G) as an outpost, located about one of the Earth-Moon Lagrangian points.

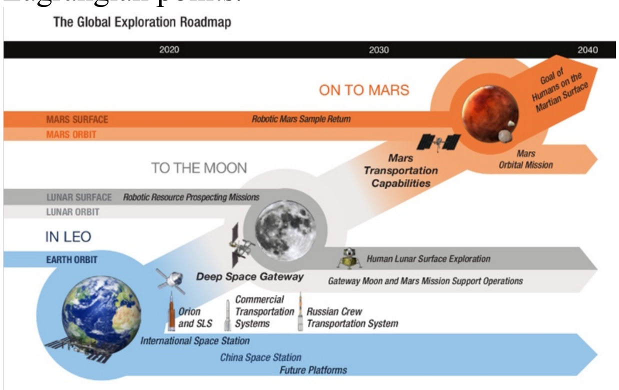

Figure 1: ISEGC roadmap [1]

After a description of the particular dynamics in the cislunar realm, this paper will present a synthesis of the infrastructure planned to be deployed in this region and will discuss the challenges and the perspectives for new space activities in the Earth-Moon system and beyond.

1- The cislunar realm

The Earth-Moon system can be modeled by the circular restricted 3-body problem (CR3PB) in which five equilibrium or Lagrangian points exists where gravitational pulls and centrifugal

Lagrange in 1772 [2]. Those libration points are interesting, as final locations or waypoint on the road to further destinations, since they required low energy to be reached and to maintain the orbit in their vicinity. Among the many orbits of the CR3PB, the Lyapunov orbits, Lissajous orbits, Halo orbits and Quasi-Halo orbits are most interesting. According to [3], Near Rectilinear Halo Orbits (NRHO) have been identified as suitable locations for the Gateway.

2- Infrastructure about Earth-Moon Lagrangian points

Placing humans in space for a long duration mission beyond Earth's neighborhood implies the design of a highly complex system to travel, live and work safely in the hostile environment of deep space. Thanks to lessons learned acquired since the Apollo missions, robotics missions towards Mars or asteroids, and exploitation of the International Space Station (ISS), a next step might be to set up a permanent outpost near the Moon. This new station will be used as a strategic platform and a logistic hub for human missions in cis-lunar space, including the lunar surface and even further destinations like Mars or asteroids. Moreover, innovative technologies could be tested onboard, taking benefit of a unique environment. At this time, such an option is likely to rely on the NASA/ESA Orion Multi-Purpose Crew Vehicle (MPCV) and a heavy launcher, like the Space Launch System (SLS). Thus, Rendezvous and Docking (RVD) operational activities become mandatory and critical for the deployment and utilization of the LOP-G (such as station assembly, crew rotations, cargo delivery, and lunar sample return). As the next space station will be a gateway for future exploration missions, various rendezvous missions may be performed, including logistics flight and crew transportation missions from Low Earth Orbit (LEO), Geostationary (GEO) or Lunar Low Orbit (LLO), so as to reach Near Rectilinear Halo Orbit (NRHO), Distant Retrograde Orbit (DRO) or Halo Orbits. As the capacity to rendezvous in the vicinity of the Earth-Moon Lagrangian Points is by nature necessary, its analysis becomes fundamental [4].

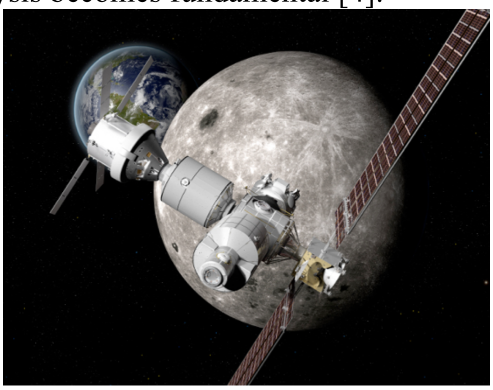

Figure 2: Artistic view of LOP-G – credits: NASA.

3- The space network: space activities on the Moon surface and about the Earth

The Lunar gateway has to be seen as one node of a large network, encompassing infrastructures in Earth LEO and GEO, with space tugs offering services between the Earth and the Lagrangian points, with basements on the Moon surface (like the Moon village [5] or LUPO for lunar resources exploitation [6]) and reusable launchers between lunar surface and EML1/2. As the Lunar Gateway will pave the way for cislunar operations, the red planet is one of the main target of space agencies. Exploring and sending humans to Mars will call for cargo missions to deliver experiment and robotic devices and eventually build a permanent base. Human and robotic missions beyond Earth orbit will not only be a prerogative of agencies and organizations, as new actors such as commercial companies will take more central roles in the exploration and exploitation of space. The future of space relies in its potential for economic growth that will in turn involve an increasing number of partners that will stimulate new, emerging markets. This new economy will require the setting of a large network of systems working restlessly and ensuring a constant presence of humankind in space.

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ABSTRACTS
DAY 3
Sessions 6-7

Towards an origami based compliant modular system for deep space exploration: the next generation of cubesat

S. Bonardi

Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

The Calathus Mission Concept to Occator Crater at Ceres: Science, Operations and Systems Design

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This work was initially developed during the 42nd edition of the Alpbach Summer School (SSA) and subsequently during the Post-Alpbach Summer School Event 2018 (PASSE), both co-organized by the Austrian Research Promotion Agency (FFG) and the European Space Agency (ESA). All authors, in alphabetical order, met and worked on a mission proposal under the theme "Sample return Mission from small solar system bodies".

Introduction: Ceres, the most massive body of the main asteroid belt [1], was observed as a low density body with stratified mantles and a silicate core [2, 3] and albedo features localized on the surface. The Dawn mission [4] has confirmed this complex picture. The Dawn gravity experiment [5] showed a hydrostatic celestial body with two or three crustal layers and a low surface density which implies high surface water content [6]. The albedo features revealed to be bright spots, or feculae, distributed on the surface of the body. The In particular, Occator's bright regions, the most extended feculae, are composed of salt-rich carbonates, younger than 2 Myr [7], believed to be the solid residues of brines erupted from a cryomagma chamber [8]. Planetary evolution models suggest an ocean may have once existed at shallow depths [7], which may still be present as localized brine reservoirs [9].

From the Dawn mission there is evidence for the presence of organics [10] in Occator's bright material. A precise sample analysis can only be achieved on Earth with bulky instrumentation. This would allow unraveling the crater exact composition and its interior, to evaluate the role of the possible aqueous and thermal processes and to better understand the crater evolution. A sample return from Occator Crater would provide invaluable insight to understand the Ceres' origin and evolution in the Solar System, to characterize its composition, and its past habitability.

Science Questions: The questions opened from the Dawn mission are divided into astrobiology and Ceres' origin and evolution.

To unveil the astrobiologic potential of Ceres, Calathus will answer: (1) "What is the nature of the bright material at the Occator's feculae?", (2) "Were the ingredients for life present in the subsurface of Ceres?", and (3) "What role do cryospheres play in the search for life?".

To characterize the origin of Ceres in the Solar system and its evolution, Calathus will answer: (1) “What is the nature of Ceres’ carbonaceous material?”, (2) “Where did Ceres and other C-type asteroids form?”, and (3) “Did C-type small bodies like Ceres contribute to the delivery of Earth’s water?”.

Mission Payload: The mission payload will consist of 7 instruments, split between an orbiter and a lander, based on the Calathus scientific objectives and dedicated to answering the scientific questions.

Instrument	Question 1	Question 2
Orbiter Mapping Camera	✓	
Subsurface radar	✓	
Thermal infrared mapper	✓	
Lander Sample	✓	✓
Lander Mapping Camera	✓	
Mass Spectrometer	✓	✓
Sampling Module	✓	✓

Table 1: Summary of instruments and questions choice.

Orbiter instruments build context for further analysis for the returned sample. In order to ensure the science margin, a preliminary compositional analysis is performed in-situ.

Systems design: To design a sample return mission a system engineering approach has been used by employing the concurrent design software OCDT from ESA [11].

The Orbiter: The spacecraft (Fig. 1) has been designed to use low-thrust ion engines during the interplanetary inbound and outbound trajectories. All the spacecraft subsystems have been designed by taking into account the high TRL required for interplanetary missions and the possible interfaced with other subsystems.

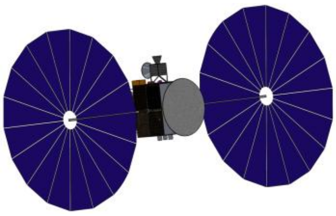

Fig. 1. The Calathus orbiter.

The Lander: The lander (Fig. 2) will be released from low altitude and perform a controlled descent and landing. On the ground, an Earth-in-the-loop process will decide the relevant sampling sites and the lander will perform: the sampling site cleaning, the sampling procedure, and sample storing. The sample canister is then put on orbit thanks to the ascending module.

Two critical subsystems have been identified and designed: (1) the sampling subsystem that is composed of a manipulator arm with camera, a grinding device and a hammering drill with 5 sample holding bits, and (2) the on-orbit catching subsystem that aims at relative navigation between the spacecrafts.

Fig. 2. Calathus lander. In details, the scientific module on the right and the ascending module on the left

Planetary protection: Ceres is a class V restricted body, implying forward and backward protection actions need to be taken. The sample will be curated in the EURO-CARES facility to remove chance of contamination.

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Planetary Exploration 2061
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TELEOP: Impact of confinement and isolation on crew performances during long-duration missions

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In the last decades, most space agencies have been focusing on manned flight missions. Therefore, to ensure the success of long-term space mission, new factors like confinement and isolation need to be studied. The TELEOP project investigates these effects on crew's performance during Human-Robot Interactions (HRI), such as cargo docking operations or remote control of a rover for surface exploration of the Moon or Mars.

Confinement implies living in narrow spaces with limited privacy, those conditions mostly characterize human space missions. In order to study its impact, TELEOP has conducted several analog mission campaigns, MDRS-189 and MDRS-206 (Utah desert) and ARES III (in Lunares, Poland). The subsequent mission has been carried out in the IBMP (Institute of Bio-Medical Problems of Moscow) NEK (In Russia) facility during SIRIUS-19 campaign, with the collaboration of NASA. In the following years, the aim is to run the experiment in more realistic and confined environments: the ISS and the Concordia station in Antarctica.

In order to assess confinement and isolation and their impact on teleoperation performance, an innovative protocol has been designed. This enables us to have a complete overview on factors linked to teleoperation performance (execution time and accuracy), such as participant's personality, physiological and psychological traits.

Teleoperation performance was evaluated for the guidance of a rover, a task that was performed by each crew member several times per mission. During the task, physiological activity was recorded using an ECG (Electrocardiogram) , whereas assessment of both physiological and personality aspects were performed using questionnaires. The latter two intended to assess the mood, motivation, confinement feeling and subjective effort.

As a result of the analysis of the data gathered during both the MDRS-189 and Ares-II missions, important results were uncovered. The main finding demonstrated a dependency between motivation and positive feelings or personality and confinement. Moreover, the outcomes showed a strict link of relatedness with confinement and teleoperation performance.

Thanks to this unique approach in studying the impact of confinement in such realistic environments, TELEOP allows us to learn more about this unexplored field and consequently to better prepare for future missions to Mars and to the Moon.

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CaLIBSow: Chemical Analysis with LIBS for Ocean World. An instrument concept for Outer Solar System subsurface oceans

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Introduction: 'Ocean Worlds' of the outer solar system are fascinating bodies from an astrobiology point of view: Europa, Enceladus and Titan are known to harbor a subsurface liquid water ocean, essential ingredient for life as we know it ([1] for a detailed review on the current understanding on these objects).

Magnetometric measurements from the Galilleo spacecraft [2] and geologic ground-base and orbital measurement [3] confirmed independently the presence of a liquid layer beneath a <100 km thick surface ice layer. Libration measurements of Enceladus from the Cassini spacecraft [4] showed that an ~31km deep ocean lies between a ~25km thick ice shell, even considerably thinner in the south polar region [~10km, [5]]. As for Titan, tidal response [6] comforts the hypothesis of a liquid ocean under a <100 km shell. For now, no in-situ measurement has been performed in this ocean as there is almost no direct access. Even though plumes were detected on Europa [7], they were never probed and our knowledge of the composition of the ocean only relies on models and experimental data [8]. Enceladus plumes of the South Polar Region [9] provided Cassini spacecraft a unique access to the composition of the subsurface ocean: it might by a salty Na-Cl-CO_3 alkali ocean [10], with organic species [11] and hydrothermal activity [12]. That's why they represent major targets for the search for habitability and potential present life. Missions are currently under development to study Europa from the orbit JUICE [13] and Europa Clipper, [14] and the Titan atmosphere in-situ (Dragonfly [15]) with a science return that would start as early as 2025 for Europa and 2034 for Titan.

Initiatives to go beyond and program an Ocean World exploration roadmap are rising up [16] and the first timeline forecast only a plume sample return by the end of the 2050's [17]. In-situ submarine exploration is seen as the most ambitious project but is goes far beyond our technology [18].

Several techniques are currently under investigation to penetrate the ice shell of Jovian moons: ice melting with heated probe [19], laser drilling [20], surface impactor [21]. By Horizon 2061 it is likely that an integrated submarine mission such as [22] would be ready for space flight. The LIBS underwater instrument proposed here will be ideally suited for this exploration program.

LIBS for Ocean World: The Laser-Induced Breakdown Spectroscopy (LIBS) technique offers a rapid analysis, no sample preparation, in situ and remote capabilities [23,24]. Therefore, it is ideal for hostile and/or fragile environments. It has been applied on Earth for radioactive environments [25], in metallurgy industry [26, 27, 28], but also for cultural heritage [29], where the objects of interest cannot be moved, and often not accessible by humans or under difficult conditions.

The ChemCam instrument [30, 31] is onboard the Curiosity rover, which landed on Mars in August 2012. It is using the LIBS technique for the first time in planetary science, and has shown that this is a powerful tool to get the chemistry of the analyzed samples. For 7 years now, ChemCam is acquiring an average of 600 spectra everyday (2 rocks of 10 points, 30 shots), and constitutes the biggest database of rocks and soils chemistry on Mars. All the major elements can be detected and quantified with a good accuracy [32, 33], along with several minor and trace elements [34,35].

The LIBS technique is also used in deep oceans, where the pressure is high. It fulfills different purposes such as investigating the composition of archeological sank objects [36,37], but also in oceanography, to detect analytes in bulk liquids in deep oceans such as around the mid-ocean ridge hydrothermal vents [38], where the composition of water can be affected by volcanic activities. LIBS is developed as well as a rapid tool to investigate the tap water quality. For all these purposes, LIBS technique is already well developed for underwater worlds with high pressure. Compared to LIBS analysis in air, the plasma that forms in liquid will decay more rapidly. [39] introduced therefore the concept of double-pulse LIBS (DP-LIBS), in order to get a good signal even in bulk liquid. The first laser pulse will generate a bubble at the focus position as it breaks down the water (due to high plasma temperature and pressure, creating a thermal expansion of the plasma, which forms a vapor bubble [40]. The second pulse, with a laser focused at the same position, will excite the existing plasma. In that case the second pulse will be isolated from quenching and will have more energy for excitation of the plasma as the vaporization stage is already done, resulting in an enhanced signal. The vapor bubble formed by the first pulse will collapse in a short amount of time due to water pressure, and therefore the delay between the first and second pulse have to be chosen carefully, between few hundreds a few ns and few microseconds. It has been shown that using this technique, the LIBS under water is very efficient for pressures up to 50 bar [41]. Alkali elements as well as few metallic ones have been easily detected.

CaLIBSow concept instrument: This proposed instrument will provide LIBS investigation supported by an infrared double-pulse laser. The spectrometer range will go from UV to VNIR enable the detection of major elements including alkali as well as CHNOPS and chlorine: Si, Al, Mg, Ca and Na (589.16 nm and 818.55 nm), K (766.7 and 770.1 nm), Cl (837.8 nm). This payload will retrieve the chemical composition of the ocean enabling the quantification of the salt content for a better understanding of the rock/water interaction and the search for biosignatures.

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HORIZON 2061
Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

Assessing the Habitability of an Active Ocean World: the Etna Mission Concept to Enceladus' Tiger Stripes

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This work was developed during the 5th edition of the Caltech Space Challenge. All authors developed a mission proposal under the theme “Encelanders: Assess whether Enceladus provides the conditions necessary (or sufficient) to sustain biotic or pre-biotic chemistry”.

Introduction: Enceladus, one of Saturn's moons, initially became a compelling target when the Voyager spacecraft [1] revealed it to be our Solar System's most reflective body, suggesting that the surface is composed entirely of fresh snow or ice [2-4]. The Cassini spacecraft subsequently imaged active plumes erupting material sourced from beneath the moon's south polar crust and expelling it tens of kilometers into the atmosphere [5] revealing Enceladus as an active world, likely to be driven by subsurface geothermal activity [6].
Furthermore, Cassini’s mass spectrometer detected four important biogenic elements that are coincident with the building blocks of terrestrial life: H, C, O and N. However, P and S, the two additional key biomarkers of Earth-based life, were not detected due to the intrument limited resolution [7], and these two are critical in assessing astrobiological potential. Thus, questions remain related to the habitability of Enceladus.
Overall, the coincident presence of an energy source, a catalyst for life, and the building blocks of Earth-like life promotes Enceladus as a paramount target to study the origin and evolution of life throughout our Solar System. Among all the other active ocean worlds in our Solar System, Enceladus is the only body that provides direct access to its ocean.

Science Return and Questions: The primary scientific goal of Etna is to understand how Enceladus provides habitable conditions.
To accomplish this goal, Etna will: (1) constrain the dynamics of the energy sources that drive surface and subsurface interactions, (2) assess the bulk composition and chemistry of the subsurface and (3) analyze periodicity and lifetime of habitable conditions.
The second scientific goal is to investigate the biotic and abiotic signatures of Enceladus. Specifically, Etna will: (1) characterize the composition, structure, and ratio of subsurface molecules, (2) visually determine the presence of bio-signatures and (3) determine how H, C, O, and N are produced.

Instrumentation: The mission payload consists of ten instruments (Tab. 1), split between an orbiter and a lander, selected to fulfill the scientific goals of the mission.

Instrument	Goal 1	Goal 2	Operation
Ice Penetrating RADAR for Enceladus Assessment and Sounding (IPREAS)	✓		O
Ultra-Violet Imaging Spectrograph (ALICE)	✓		O
Optical and Infrared Imaging Camera (OICAM)	✓		O
Radio-Science Investigation (RSI)	✓		O
In-orbit Magnetometer (iMag)	✓		O
High Resolution Mass Spectrometer Suite (AROMA-MOMA)	✓	✓	F, L
Grain Impact Analyser and Particle Accumulator (GIAPA)	✓	✓	F, L
DIstributed Seismology and Acoustic Investigation (DISEAI)	✓		L
Enceladus Infrared Analyzer (EVA)		✓	L
Air Temperature and Ground Temperature Sensor (ATS-GTS)	✓		L

Table 1: Payload. F = Fly-by, O = Orbiter, L = Lander.

Mission systems: The Etna mission architecture is composed of a single orbiter, a single lander, and three surface probes.

The Orbiter: The orbiter (Fig. 1) will perform flybys to conduct remote science, select the landing location and relay data from the landed assets back to Earth. The orbiter incorporates a variety of subsystems with high TRL components, a Juno-heritage propulsion system, and three conventional RTGs to provide power. All equipment is attached to the central bus, with the exception of a large foldable truss structure used for the IPREAS. Some complexity is introduced from the lander attachment and release mechanism.

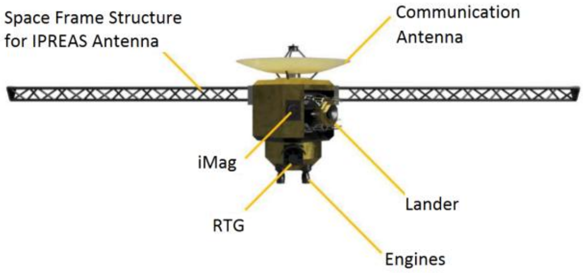

Fig. 1. The Etna orbiter housing the lander and probes.

The Lander: Etna includes a lander (Fig. 2), that is radiation tolerant. Design drivers for the lander include the need for a soft and upright landing, the need to use the same instrument package (AROMA-MOMA and GIAPA) both in-orbit and on the surface, and the need to deploy the probes during descent to the surface.

Fig. 2. The Etna lander

The Probes: The DISEAI probes (Fig. 3) are spin-stabilized and released from the orbiter during descent. Shock absorbers mitigate damages during surface contact. If the ground is covered in soft snow, the probe will burrow itself into it, and if the ground is hard ice, the shock absorber will mitigate the impact of the landing. Once landed, DISEAI extends its Storable Tubular Extendible Member (STEM) into the surface until contact is made with a hard surface. This allows the seismic vibrations otherwise damped out by the snow to be observed by the probe. From the top end of the probe, the Telescopic Tubular Mast (TTM) is deployed. This 1.5-m antenna will clear the surface to allow communication with the orbiter, even during precipitation events. Temperature control of the instruments is managed by an insulating layer of aerogel and an internal resistive heater. Two batteries are used as power sources and provide sufficient power for one week operational life.

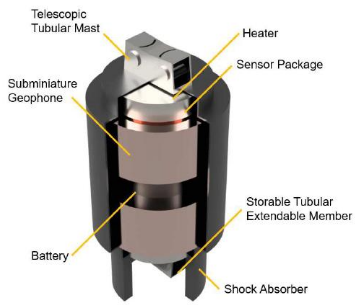

Fig. 3. The Etna surface probes

Planetary protection: Standardized procedures prevent the forward contamination of Enceladus by adhering to planetary protection protocol [8, 9].

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HORIZON 2061
Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

Remote Localisation and Characterisation of Venus' Seismic and Volcanic Events through a Network of Balloon-Based Instruments

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The Magellan mission mapped Venus *via* radar down to a resolution of 75 m/pixel [18], revealing several either seismic (intraplate faulting) or volcanic [7, 8] structures. The origin of those structures remained however a controversy, since Venus seems younger than Mars or the Moon. Since then, several studies have tried to detect active volcanoes [22] or infer seismicity [11, Sec. 3.1]. The study of Venus' interior may thus yield new elements useful for the comprehension of the formation of telluric planets.

However, conditions at the surface of Venus are often considered too harsh (*e.g.*, T~735 K) to hope for instruments to last long enough to measure seismic or volcanic activity. In that scope, [23] presents a feasibility study about the investigation of Venus' interior through various seismological techniques, one of those being using atmospheric free-floating balloons.

The prospective of balloon-based seismology is currently under way, and many preliminary studies and Earth-based demonstrators show promising results. Studies demonstrated that infrasound due to Rayleigh waves can be detected as far up as in orbit [12]. Simulations show that vertically polarised surface waves can produce infrasonic plane waves [13], whose geometric attenuation is minimal. Latest results based on a field experiment, which will be presented, yield promising results in determining the direction of incoming infrasonic waves. Furthermore, it is known that for the same quake magnitude, subsequent infrasound on Venus will have amplitudes about 600 times larger than those recorded on Earth [6]. Balloon instrumentation, and subsequent signal processing, are also thoroughly investigated [9].

The present work proposes to extend the current one-balloon prospective to a network of balloons in the stratosphere of Venus. Equipped with infrasound sensors and inertial measurement units (IMUs), each balloon can yield both a vector direction and a scalar amplitude of incoming infrasound. Combining those recordings across several balloons could enable to infer the localisation of the source, and possibly information on the source (*e.g.*, volcanic or seismic) and sub-surface structure. Additionally, these flying instruments may help characterise the thunderstorms and/or lightning possibly occurring in the cloud layer [10, 19, 21, 16, 17].

Some technologies are still lacking today, even to send only one such balloon to Venus. For example, attaching IMUs on the balloon envelope while still providing them with battery power seems a difficult problem. Moreover, deploying one infrasound sensor below the balloon remains a dangerous task ; deploying two would be even better scientifically, but the needed separation between both (>50 m) appears even more complicated. Hardware for communication with Earth must also be engineered. Finally, the balloons' life expectancy and manoeuvrability must be assessed, and improved as much as possible. Those are aspects of such a mission that will need to be secured.

However, localisation algorithms seem already in good shape. Generic implementations based on networks of sensors exist (*e.g.*, [20]), and may benefit from an additional directional input. Furthermore, GNSS algorithms use simple scalar inputs to determine a user's position [3, 2, 15]. Even if - in some cases - the classical plane-wave assumption fails [5], circular wave fronts could be considered [1]. Finally, as an illustration of this potential, [4] managed to geolocalise a chemical explosion using four balloons, each equipped with only one microphone. Thanks to those already-existing methods, localisation using vector and scalar data from numerous free-flying balloons will be possible.

Eventually, the network could be made autonomous by making use of machine learning capabilities. Such implementations are already used in the scope of detection and classification in seismology (*e.g.*, [14]), and could be extended to our prospective balloon network.

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Planetary Exploration 2061
STEP 3 : Synthesis Workshop
11-13 September 2019 - Toulouse, France

Lunar Outpost Sustaining Human Space Exploration by Utilizing In-Situ Resources with a Focus on Propellant Production

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Space exploration has recently witnessed a surge of renewed interest, in particular, the concept of a human mission to the Moon is increasingly being discussed by national agencies and private enterprises alike. A lunar base is commonly regarded as a good first step for humanity's expansion beyond Earth. This paper proposes a pre-phase A study about infrastructure on the Moon surface with the capability of sustaining future human space exploration. The outpost will be relying on In-Situ Resources Utilization (ISRU) and on the support of the orbiting Lunar Orbital Platform - Gateway (LOP-G), in line with the current ISECG exploration roadmap. In this context, precursor robotic missions, such as the concept proposed in the ESA-led Heracles study, and related activities on the Moon surface are considered as sources of insight and technology validation. The incremental steps necessary for setting up the lunar outpost are discussed and analysed, both for surface and on-orbit missions. A feasibility and sustainability study is carried out for a propellant production plant, the primary purpose of which is to provide the capability of refuelling space vehicles. The design of the overall mission revolves around four main building blocks, which are analysed in detail: crew habitats, a large pressurized crew rover, ISRU facilities and a lunar spaceport. The overall mission scenario has been derived from a set of trade-off analyses that have been performed to choose the mission architecture and operations that satisfy the stakeholder expectations: the most important features of these analyses and their results are described within the paper. Regarding the timeframe, the analysed mission is expected to take place after robotic precursor expeditions, which are scheduled to launch in the 2020s. The first manned mission shall follow before 2030 with the purpose of setting up the propellant production facility, which shall be operational by 2035. The study is carried out by the 10th edition of the Specializing Master programme in SpacE Exploration and Development Systems (SEEDS) of 2017/18 at Politecnico di Torino (Italy). This work was performed in cooperation with students from ISAE-Supaero (France) and University of Leicester (UK). The project is supported by Thales Alenia Space Italy, the European Space Agency and the Italian Space Agency.

Keywords: Moon, ISRU, Propellant, SEEDS, Water

Sample Return Mission to Enceladus

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Considering the technological progress and future missions planned in the next decades, it seems the 2060s will witness sample return missions from the icy moons of the giant planets. Among these, Enceladus is particularly attractive. Previous missions to the Saturnian systems identified geysers in the South Pole, where material from the subsurface ocean emerges from the ice cap. Organic compounds were detected in these plumes, highlighting the unique potential for life present in Enceladus' ocean. It is therefore thought that all conditions for the apparition of life are met in Enceladus ocean, and that, should it happen, living organisms could be detected in the material ejected through the plumes, by precise analysis in Earth laboratories.

Two different modules will be employed: one to collect the samples, the other to carry them back to the Earth. Moreover, to reach Enceladus, planetary flybys in the inner solar system as well as a tour of Saturn's moons is planned. This will allow for further scientific investigations. The estimated mission duration is 25 years, with a total Delta V close to 5 km/s. It should be launched by next generation heavy launcher (like the Space launch System) to put the 13 tonnes bi-modules spacecraft on an escape trajectory. Three mechanisms of sampling will be used to guarantee sample return from different sources (two samplers for plumes and surface material and one for material from the E ring and Titan atmosphere). The sampling will rely on an important pre-analysis of Enceladus' south pole region by instruments and an AI on board system. All the additive scientific data will be relayed to Earth through Lander-Carrier & Carrier-Earth links using optic communication. While the Carrier will be powered by solar panels, the Lander will embark a radioisotope system with a Stirling generator.

We thus identified several key technologies which will have to be developed to enable this mission. The most problematic phase of the mission remains the landing on the South Pole of the moon, due to major uncertainties regarding the properties of the surface and the distribution of active geysers.

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