



Planetary Exploration 2061

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

Final discussion

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and the Horizon 2061 team

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Observatoire Midi-Pyrénées

September 13th, 2019



REPORT TO COSPAR
On the occasion of its
August 2020 General Assembly, Sydney, Australia
TENTATIVE OUTLINE

EACH CHAPTER TO BE A BOOK CHAPTER + A STAND-ALONE PEER-REVIEWED ARTICLE
Book edited by SOC committee + Pascal Willis, Editor-in-chief of Adv. Space Res.

CHAPTER 1: Summary - Horizon 2061 rationale, objectives and main results

CHAPTER 2: Key Science Questions

CHAPTER 3: Representative space missions

CHAPTER 4: Enabling technologies

CHAPTER 5: Supporting infrastructures

CHAPTER 6: Implementation opportunities and the role of cooperation between actors in the future of Planetary Exploration



REPORT TO EPSC-DPS
Geneva, Sept. 19th and 20th, 2019

PLANETARY EXPLORATION, HORIZON 2061 session MIT4

Friday, 20 September 2019 | Moon (Room 15)

Chairperson: Jeremie Lasue

[An introduction to the Planetary Exploration, Horizon 2061 foresight exercise and to the preliminary conclusions of its synthesis workshop \(Toulouse, Sept. 11-13, 2019\)](#)

Michel Blanc and the [Scientific Organization Committee of H2061 Toulouse 2019](#)

08:40–08:50 |

[Report from Horizon 2061 Synthesis Workshop Pillar 1: From Science questions to representative space missions](#)

Véronique Dehant, Steve Mackwell, and Michel Blanc

08:50–09:00 |

[Report from Horizon 2061 Synthesis Workshop Pillar 2: From representative missions to technology requirements](#)

Ralph McNutt, Pierre Bousquet, Anil Bhardvadj, **Manuel Grande**, Oleg Korablev, Franck Montmessin, Olivier Hainaut, and Michel Blanc

09:00–09:10 |

[Report from Horizon 2061 Synthesis Workshop Pillar 3: Enabling technologies](#)

Wing Ip, Advenit Makava, Patricia Beauchamp, Brook Lakew, Jean Broquet, Linli Guo, Jorge Alves, and **Michel Blanc**

09:10–09:20 |

[Horizon 2061: Infrastructures, services & collaborative programs](#)

Bernard Foing and the [Horizon 2061 team contributors](#)

[On the Feasibility for Mining the Hydrogen Peroxide \(H₂O₂\) of Mars for Monopropellant Rocket Fuel](#)

Francisco J Arias and Salvador De Las Heras

09:30–09:40 |

[A New Mechanism to Make Mars Habitable](#)

Edwin Kite, Ramses Ramirez, and Martin Turbet

09:40–10:00

Panel and discussion with the community

PLANETARY EXPLORATION, HORIZON 2061 session MIT4

Poster contributions (Thursday evening)

Attendance time: Thursday, 19 September 2019, 17:15–18:45 | Level 1

L1.33 |

EPSC-DPS2019-292

[Surface Dating of Airless Bodies by Remote Sensing Luminescence](#)

Rita Schulz

L1.34 |

EPSC-DPS2019-341

[Solar and Hybrid Electric Propulsion Missions to the Outer Solar System](#)

Edgar Bering, Matthew Giambusso, Alex Parker, Mark Carter, Jared Squire, and Franklin Chang Diaz

L1.35 |

EPSC-DPS2019-730

[Smallsat Innovations for Planetary Science Missions](#)

Rebecca Schindhelm, Karen McConnell, David Osterman, Shane Roark, Reuben Rohrschneider, Jeffrey Van Cleve, Michael Veto, and Jonathan Weinberg

L1.36 |

EPSC-DPS2019-2001

[Report from Horizon 2061 Synthesis Workshop Session 3: foresight visions and programs from agencies and industry](#)

Doris Daou, Francis Rocard, Kyeong Ja Kim, Hélène Boithias, Maria Antonietta Perino, and Michel Blanc

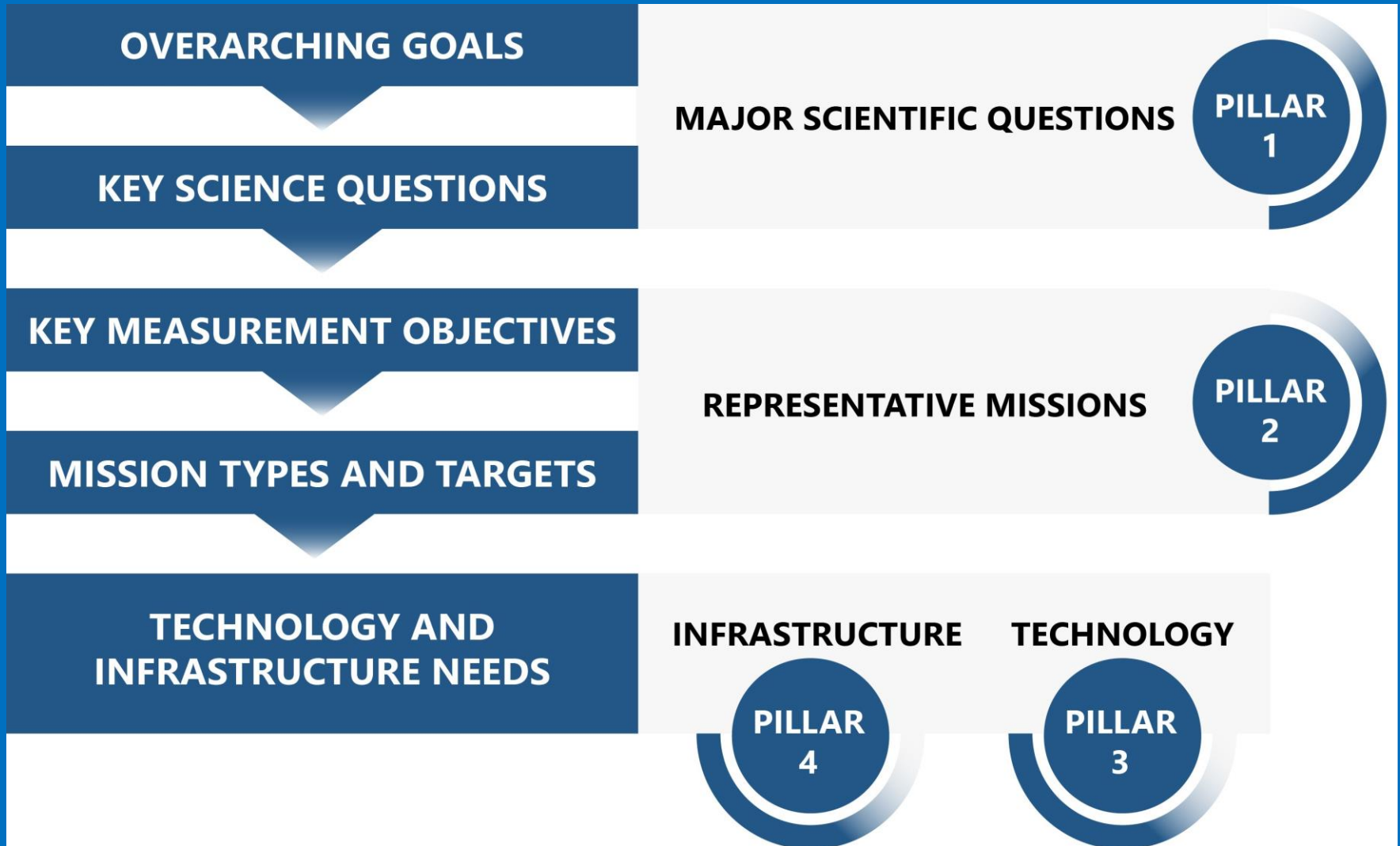


Special Horizon 2061 session
17th AOGS Annual Meeting 2020
South Korea

H2061 METHOD (1)

DESIGN AN

« **INTEGRATED SPACE SCIENCE MISSION TO PLANETARY SYSTEMS** »
BY BUILDING ITS **TRACEABILITY MATRIX**, WE WILL BUILD OUR « **FOUR PILLARS** »



METHOD (2)

Produce a 50-year foresight of

Planetary Systems Exploration (Solar System)

through a projection of its four « pillars »:

- (1) major scientific questions

Bern, Sept. 2016

- (2) representative planetary missions

- (3) enabling technologies

Lausanne, April 2018

- (4) supporting infrastructures

SYNTHESIS Toulouse, June 5-7 2019

Confront our long-term « science dreams »
with a projection of our technical capacities

Pillar (1)

Major scientific questions

OVERARCHING SCIENCE 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”.

Pillar (1)

Major scientific questions

- a. Origins of Planetary Systems**
- b. Formation and diversity of Planetary Systems architectures**
- c. Diversity of objects**
- d. Planetary Systems coupling mechanisms**
- e. Emergence of potential habitats**
- f. Detection of Life**

FROM KEY SCIENCE QUESTIONS TO KEY MEASUREMENTS AND TO MISSION TYPES

1 ORIGIN OF PLANETARY SYSTEMS

Key measurements

- Primitive grains in ISD, small bodies and meteorites: crystalline phases, volatiles, organics,... elemental and isotopic composition
- Connect the small body and meteorite records
- Giant planets' atmospheres elemental and isotopic composition

Mission types

Sample return (in situ analysis when impossible) of all types of pristine material and giant planets entry probes

2 FORMATION and DIVERSITY of PLANETARY SYSTEMS ARCHITECTURES

Key measurements

- Composition of ices and clathrates (with their different phases), rare gases and heavy elements (via H₂O, NH₃, CH₄...)
- Cratering record throughout the Solar System

Mission types

sample return of each object class (in situ analysis when impossible), orbiter and entry probes for giant planets and orbiter and landers for icy satellites.

3 DIVERSITY OF OBJECTS

Key measurements

- Compare the internal structures and bulk compositions of all classes of differentiated objects and try to connect them to their exoplanet counterparts
- Full inventory of the different types of small bodies within each reservoir and of small irregular satellites of giant planets
- Connect planets, satellites, small bodies and meteorites

Mission types Orbital and multiple flyby missions for each type of object

4 PLANETARY SYSTEMS COUPLING MECHANISMS AT 4 SCALES

Key measurements

- Global characterization of the different envelopes of each planet and its moons
- Global structure and dynamics of each system (solar system, giant planets systems) e.g. in particular gravitational/tidal interactions
- Electrodynamic and other interactions between satellites, planets and their magnetospheres, heliosphere, Very Local Interstellar Medium (VLISM), Galaxy...

Mission types

Orbiters and surface networks, multipoint missions for magnetospheric interactions. Missions to outer solar system: KBO, Heliopause, Proxima Centauri

5 EMERGENCE OF POTENTIAL HABITATS

Key measurements

Study habitability of surface habitats and deep habitats

Mission types

- Global orbital monitoring of possibly habitable planets and moons
- In situ analysis of plumes related to cryovolcanic activity
- Characterization of habitability conditions at surfaces/subsurfaces of planets and moons: fixed stations (incl. penetrators), rovers...

6 DETECTION OF LIFE

Key measurements

Develop sensors to try and detect signs of life across the full spectrum of complexity (biomarkers and biomolecules) at surface, sub-surface, atmospheres/exospheres (plumes), oceans and lakes

Mission types

- Plumes measurements by subsatellites;
- Surface or subsurface measurements by fixed station; penetrator, rover...
- Sample return: Moon, Mars, Venus or icy satellites

Pillar (2)

Representative space missions

Tentative contents

- 1. Future Giant Space Observatories**
- 2. The Earth-Moon System**
- 3. Terrestrial planets**
- 4. Giant planets and their systems**
- 5. Small bodies**
- 6. Heliosphere, Solar System, ISM and beyond**

FROM KEY MEASUREMENTS AND MISSION TYPES TO CRITICAL TECHNOLOGIES

1 FUTURE GIANT SPACE OBSERVATORIES

Missions for implementation by 2040

- Launch in 2018 : James Webb Space Telescope (orange - middle IR)
- Around 2024 : WFIRST (Wide field , aimed at dark energy)
- Under study for the next US Astrophysics Decadal Survey
 - Lynx (X-ray - Marshall)
 - OST (Origins Space telescope - far IR - Goddard)
 - LUVVOIR (Large UV Optical Infrared Surveyor - Goddard)
 - HabEx (Habitable Exoplanet Imaging - JPL)

Critical technologies

Extremely large aperture telescope assembly and operation in space
Optical IR interferometer based on formation flying

Representative missions for 2041-2061
3rd generation visible & IR observatories

Critical technologies

Miniaturization of instruments and platforms

Space interferometry at LF radio frequencies

Deep drilling, ISRU

Missions for implementation by 2040

- Global multi-messenger cartography of Moon surface, water cycle, shallow interior combining surface stations and orbiters
- Network of geophysical stations including seismometers
- Campaign of sample returns from a comprehensive set of representative terrains
- LF radio-interferometer in orbit

Representative missions for 2041-2061

- Geochemical study of subsurface with drilling
- First demo of ISRU life support
- Astronomical / geosciences observatories network on the moon ? (Components of International Lunar Village)

2 EARTH - MOON SYSTEM

3 TERRESTRIAL PLANETS

Missions for implementation by 2040

- Mars sample returns
- Next generation Venus atmosphere / surface / interior mappers

Representative missions for 2041-2061

- Venus sample returns
- Drilling > 1 km below Mars Surface, in situ analysis or SR ?

Critical technologies

Ascent vehicle, ARV, PP class V

RTGs, autonomy, ascent vehicle, harsh environment survival, mobility, sample curation, extreme temperature, atmosphere sample collection @ various layers

Very deep drilling, high power RTG, In situ bio diagnostic, deployable heatshield, astronaut support ?
With first ISRU demo on Mars ?

Critical technologies

Radiation environment survival, RTG EDLS, superficial drilling or penetrators

RTG, heatshield for very high speed entry

RTGs, miniaturized autonomous instrument platforms, communications

Autonomous cubesats, multipoints measurements

Missions for implementation by 2040

- Gas giants moons / orbiters / landers / subsurface explorers
- Flagship to Uranus or Neptune + atmospheric probe(s)

Representative missions for 2041-2061

- Gas giants Moons & rings surface explorers with mobility
- Multi - platform missions to giant planets systems (e.g magnetospheres, Moons, rings)
- Europa or Enceladus Plume & subsurface sample return

Radiation environment survival, propulsion, RTGs, in situ bio diagnostic, PP class V, cryogenic sample transfer, gaz sub-sampling

4 GIANT PLANETS SYSTEMS

5 SMALL BODIES

Missions for implementation by 2040

- Comet SR
- Trojan fly by, RV & SR

Representative missions for 2041-2061

- First multiple asteroid explorer refueled and maintained by ISRU

Critical technologies

Long term reliability, cryogenic sample transfer, autonomy, propulsion, thin film Solar Array

Remote hardware printing, ISRU, autonomy, miniaturized instruments, communications

Critical technologies

Long term reliability, communications, data rate, autonomy, propulsion, power, extreme thermal conditions, compact instrumentation, Multi generational vision and mission management

Missions for implementation by 2040

- Heliospheric boundaries probe
- Interstellar probe

Representative appealing missions for 2041-2061

- First "deep ISM" mission w. "ninth" planet and/or Oort cloud object flyby on the way towards Proxima Centauri b

6 HELIOSPHERE SOLAR SYSTEM ISM & beyond

Pillar (3)

Enabling technologies

Tentative contents

- 1. Exploration platforms of the future**
- 2. Platforms subsystems and enabling technologies**
- 3. Reaching out to challenging destinations**
- 4. New sensors and new sensor technologies for an expanding spectrum of science themes and disciplines**
- 5. Meet the challenges of Sample Return**
- 6. Disruptive technologies**

Pillar (4)

Supporting infrastructures

6 main themes

- 1. Earth-Moon system gateways to the Solar System and beyond**
- 2. Navigation and communication infrastructures**
- 3. Solar System Space Weather**
- 4. In-Situ Resources Utilisation facilities**
- 5. Sample Return, Curation and Analysis facilities**
- 6. Solar-System-Scale Observatories:**
 - 1. Space-based global observatories**
 - 2. Virtual Observatories**

**Additional contributions to the four
pillars:
Visions from Agencies and industry**

Session 3 - Foresight visions and programs from agencies and industry

Chairpersons: K. J. Kim, Michel Blanc

15'	JAXA's planetary exploration plan for the next decades	N. Ozaki, Y. Toukaku
15'	Progress and Prospects of Unmanned Deep Space Exploration in China	LI Ming (CAST) Read by L. GUO
15'	KIGAM's new direction for lunar science and exploration in conjunction with lunar and planetary ISRU	K.J. Kim
15'	KEYNOTE TALK: Eurospace recommendations for Human Presence & Exploration	Laura Gatti
15'	OHB Planetary Exploration Enabling Technologies Involvements	Marco Berg
15'	The view from TAS	Maria Antonietta Perino
20'	Round-table discussion – session 3	Moderator: Bernard Foing

Additional contributions to the four pillars: Students and early career professionals contributions

Session 6 – Students and early career professionals contributions

Chairpersons: Gengxin XIE, David Mimoun

15'	Towards an origami based compliant modular system for deep space exploration: the next generation of cubesat	S. Bonardi et al.	
15'	The Calathus Mission Concept to Occator Crater at Ceres: Science, Operations and Systems Design	G. Acciarini et al.	
15'	The Calathus Mission Concept to Occator Crater at Ceres: Science, Operations and Systems Design	P. Panicucci et al.	
15'	CaLIBSow: Chemical Analysis with LIBS for Ocean Worlds. An instrument concept for Outer Solar System subsurface oceans	B. Chide	
15'	Assessing the Habitability of an Active Ocean World: the Etna Mission Concept to Enceladus' Tiger Stripes	P. Panicucci et al.	
15'	Remote Localisation and Characterisation of Venus' Seismic and Volcanic Events through a Network of Balloon-Based Instruments	L. Martire et al.	
15'	Lunar Outpost Sustaining Human Space Exploration by Utilizing In-Situ Resources with a Focus on Propellant Production	P. Guardabasso,..., D. Gaudin et al. (ISAE)	
15'	Sample Return Mission to Enceladus	Ignacio Albarran,.. E. Clavé et al.	

Session 7 – Implementation, international collaboration, workshop synthesis and reporting

Chairpersons: Maria Teresa Capria, R. Mc Nutt

20'	Keynote talk: The role of the Italian Space Agency in Solar System exploration and international collaboration	Eleonora Ammannito	
	Final round-table discussion	Moderators : M. T. Capria, R. Mc Nutt	