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HORIZON 2061

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

IMAGINE TOGETHER THE FUTURE OF PLANETARY EXPLORATION



WHY HORIZON 2061?

2061 will be the centennial of the first human space flight...



... and of President Kennedy's Moon address to Congress

2061 will see the return of comet P/Halley in the inner solar system, reminding us of the international fleet of spacecraft which flew by it in 1986!



**THUS, 2061 IS A SYMBOLIC DATE CHOICE
WHICH ALLOWS US TO CONNECT ROBOTIC AND MANNED EXPLORATION
IN THE SAME, SINGLE PERSPECTIVE!**



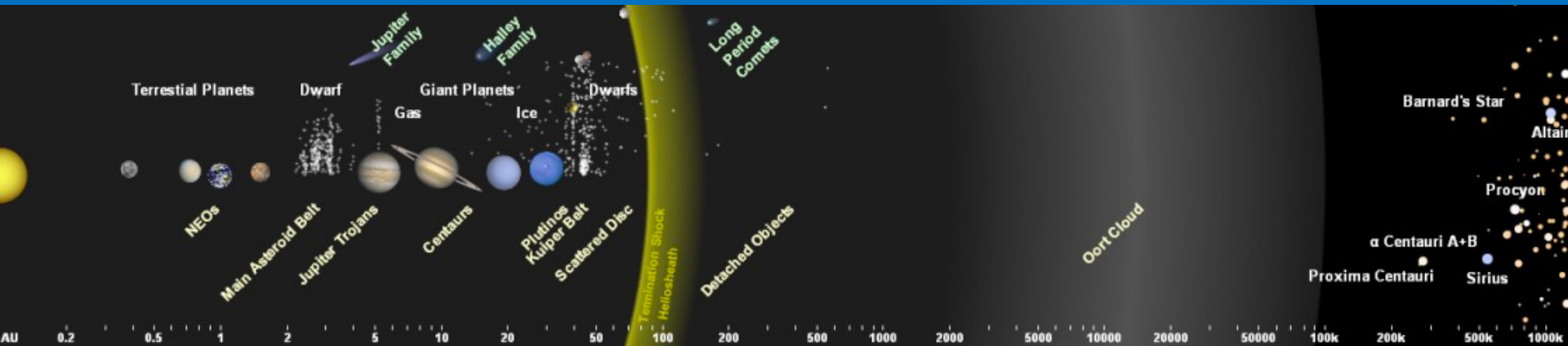
HORIZON 2061

MOTIVATIONS AND OBJECTIVES



1. HORIZON 2061 IS **NOT A ROAD-MAP BUILDING ACTIVITY** ! (No selection of priority themes, no selection of a « short list » of missions.
2. HORIZON 2061 IS AN INTELLECTUAL EXERCISE, LED BY THE COMMUNITIES OF PLANETARY SCIENCE AND EXPLORATION AND FED BY THEIR FREE IMAGINATIONS, WHICH AIMS AT **ELABORATING AN « INTEGRATIVE » (NON-SELECTIVE) MULTI-DECADAL SCIENCE-DRIVEN VISION OF THE FOUR PILLARS OF PLANETARY EXPLORATION, BUILDING UPON THE UNIFYING PARADYGM OF « PLANETARY SYSTEMS »**
3. IT IS BUILT ACROSS SCIENTIFIC AND TECHNICAL BOUNDARIES:
 - BETWEEN SOLAR SYSTEM AND EXTRASOLAR PLANETARY SYSTEMS SCIENCES
 - ACROSS THE LIMITATIONS OF THE DIFFERENT OBSERVATION TECHNIQUES (IN SITU VS. REMOTE SENSING)
 - ACROSS SCIENTIFIC AND TECHNICAL DISCIPLINES
 - BETWEEN SCIENTISTS, ENGINEERS AND MANAGERS
 - CONNECTING THE PUBLIC AND PRIVATE SPHERES**TO STIMULATE INTERDISCIPLINARY SYNERGIES FOR THE BENEFIT OF THE PROGRESS OF SCIENTIFIC KNOWLEDGE AND TECHNOLOGICAL CAPACITIES**
4. **THE REPORT OF THE HORIZON 2061 EXERCISE WILL BE PUBLISHED AS A MULTI-AUTHORS, MULTI-CHAPTERS BOOK BY ELSEVIER. EACH INDIVIDUAL CHAPTER WILL BE PEER-REVIEWED AND PUBLISHED ELECTRONICALLY ON-LINE AS A ScienceDirect article. IT WILL BE PRESENTED TO THE GENERAL ASSEMBLY OF COSPAR IN SYDNEY IN AUGUST 2020.**

Horizon 2061 perspective of Solar System Exploration, today and tomorrow



ROBOTIC EXPLORATION

DETAILED COVERAGE BY
SPACE-BASED TELESCOPES

SAMPLE RETURN

HUMAN
EXPLORATION

H2061 METHOD

DESIGN AN

« **INTEGRATED SPACE SCIENCE MISSION TO PLANETARY SYSTEMS** »

BY BUILDING ITS **TRACEABILITY MATRIX**, WE WILL BUILD OUR « **FOUR PILLARS** »

OVERARCHING GOALS

MAJOR SCIENTIFIC QUESTIONS

PILLAR
1

KEY SCIENCE QUESTIONS

KEY MEASUREMENT OBJECTIVES

REPRESENTATIVE MISSIONS

PILLAR
2

MISSION TYPES AND TARGETS

TECHNOLOGY AND
INFRASTRUCTURE NEEDS

INFRASTRUCTURE

TECHNOLOGY

PILLAR
4

PILLAR
3

METHOD

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, SEPT. 11-13, 2019

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

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
- Electrodynamical 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, Helioopause, 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