PLANETARY EXPLORATION, HORIZON 2061: A JOINT ISSI-EUROPLANET COMMUNITY FORESIGHT EXERCISE. Michel Blanc[1], Ari-Matti Hari[2], Rafael Rodrigo[1], Norbert Krupp[2], Karoly Szego[2], John Zarnecki[1], the H2061 W.G., Air and Spaee Academy[4] and the Planetary Exploration Horizon 2061 team[3]. [1](International Space Science Institute, Bern, Switzerland, blanc@issibern.ch), [2](Europlanet Research Infrastructure), [3](http://www.issibern.ch/forum/europlanetforum/), [4](http://www.academie-air-espace.com/).

Introduction: We present the preliminary results of a foresight exercise initiated by the Air and Space Academy (Toulouse, France) and jointly implemented by the Europlanet Research Infrastructure project of the European Union and by the International Space Science Institute (ISSI). The objective of this exercise is to produce a community Vision of Planetary Exploration up to the 2061 horizon, which we will name H2061 for short. 2061 was chosen as a symbolic date corresponding to the return of Halley's comet into the inner Solar System and to the centennial of the first Human space flight: this date connects particularly well science and exploration. This Vision will be built on a concurrent analysis of the four "pillars" of planetary exploration:

(1) The **key priority questions** to be addressed in Solar System science;

(2) The **representative planetary missions** that need to be flown to address and hopefully answer these questions;

(3) The **enabling technologies** that will need to be available to fly this set of ambitious missions;

(4) The **supporting infrastructures,** both space-based and ground-based, to be made available.

In this fully science-driven approach, we will build our Horizon 2061 Vision in three following steps. In step 1, **an international community forum convened in Bern, Switzerland on September 13th to 15th, 2016 by ISSI and Europlanet identified the first two pillars: key questions and representative planetary missions**. In this forum, over 35 selected international planetary science experts met during two days with 9 international technology experts from space agencies and major industrial groups to identify the contents of these two pillars. The outputs of step 1 will be used as inputs to step 2, an open community meeting focusing on the identification of pillars 3 and 4 which will take place around the end of the year 2017. Finally, the four pillars identified by steps 1 and 2 will be discussed and compared in the "synthesis" meeting of step 3, which will take place in Toulouse, France, on the occasion of the European Open Science Forum 2018 (ESOF 2018). In this contribution we report solely, and for the first time, on the preliminary results of step 1.

Planetary Exploration Horizon 2061: scientific approach. Since 1995 and the discovery of the first exoplanet orbiting a main sequence star, we are living a revolution in planetary science: as of today, over 3000 exoplanets have been identified by a diversity of techniques, first by ground-based telescopes and more recently by space missions like Corot and Kepler. Many more are to come in the few decades ahead of us, bringing to our knowledge an ever larger number of exoplanets. Outstanding progress is expected not only in their detection, but also in their characterization. The continuously expanding sample of exoplanets to which we have access from our Earth-based observing point contains today more than 500 exoplanetary systems (e.g., systems displaying at least 2 exoplanets). This figure can be compared to the number of planetary systems we can explore in our Solar System: one can count five, one being the Solar System as a whole, and four others being the satellite systems of our giant planets, which are sort of "small solar systems in the large one". While the "exploration" of exoplanetary systems will remain the privilege of space-based telescopes and remote sensing techniques for a long time, space exploration opens a far more detailed access to a far more limited number of systems and of constituting objects in the Solar System. Linking these two uniquely complementary lines of research lays the foundations of a new type of comparative science: the science of planetary systems. Our foresight exercise is a contribution to this perspective.

Overarching goal of the study of planetary systems. We propose the following overarching goal to the comparative science of planetary systems and to the associated set of space missions:

Study the formation and evolution processes leading to the growth of complexity, and ultimately to the possible emergence of life, across the diversity of planetary systems.

More explicitly, we propose to study the emergence of life as a "close encounter of the most important kind" between (1) the growth of molecular complexity, from the Interstellar medium (ISM) to planetary and moon environments, and (2) the growth in complexity of planetary environments themselves, and the conditions under which their evolunationary paths may lead them to enter the "triangle of habitability"and to become "habitable".

Top research objectives. To address this goal, we propose to identify five complementary objectives: (a) study the initial conditions of planetary systems formation (in the ISM and during star and proto-planetary disk formation); (b) retrieve the different formation and evolution scenarios leading to the presently observed architectures of planetary systems, and particularly the formation of the different categories of objects (giant planets, terrestrial planets, small bodies/debris disk objects) and the resulting architecture; (c) develop a comprehensive study of the coupling mechanisms operating between the central object(s) and the different planets/satellites: gravitational/tidal interactions and their effects on the long-term evolution of the interiors and orbits of planets and satellites, electrodynamic interactions and their effects on planetary environments, with a special emphasis on the role of magnetic field and coupling processes at the level of astrospheres and magnetospheres; (d) study the respective effects of the intrinsic properties of planetary bodies and of their forcing by the planetary system coupling processes (just described) on the emergence of habitable zones and potential habitats; (e) implement strategies for the detection of life in the diversity of candidate habitats: surface habitats (e.g. on Earth-like planets in habitable zones) and deep habitats (e.g. in the sub-surface oceans of icy moons).

Setting the stage for exploration: the exoplanet context. The main objective of our H2061 foresight exercise will be to develop an implementation plan to address our five top objectives in the Solar System. We will do it by first placing Solar System exploration in the broader context of the comparative science of planetary systems. We will summarize the perspectives of exoplanet research for the coming decades and how they will address our five top objectives: from the initial focus on detection of new objects, exoplanet research will develop and use a diversity of techniques of increasing complexity to characterize planets to higher and higher degrees of detail, from "simple" estimates of their masses and radii to sophisticated diagnostics of their physical and chemical properties. Along this line the characterization of their atmospheres will benefit first from the spectacular on-going progress of high-resolution and multi-wavelength spectroscopy, while a characterization of their surfaces will wait for the emergence of new imaging techniques giving access to the needed very-high angular resolutions.

From research objectives and detailed measurement objectives: Solar System exploration. Space exploration offers a unique diversity of measurement techniques to address our five top objectives at three complementary hierarchical levels: individual objects, giant planets systems, and finally the Solar System itself with its gravitational mechanisms (overall system dynamics) and its electrodynamic mechanisms (heliospheric and magnetospheric interactions). We will tentatively identify the different measurement objectives to be assigned to an ideally coherent suite of planetary missions:

- critical measurements providing improved constraints on the origin and formation scenarios of the System and its components;
- measurements or suites of measurements leading to a detailed characterization of the structure and dynamics of the surfaces and interiors of planetary bodies;
- their counterparts for the characterization of their fluid and plasma envelopes ;
- critical measurements leading to the characterisation of surface or sub-surface habitats, with a focus on terrestrial planets and Ocean Worlds;
- and finally, strategies for the detection of extinct or extant life in these habitats.

Drawing the contours of a strategic framework for Solar System exploration. Space exploration tools offer to us a rich diversity of mission scenarios to perform these key measurements. In order of increasing complexity, one can identify the following "elementary" mission types:

- planetary and/or satellite fly-bys;
- planetary and/or satellite orbital reconnaissance;
- atmospheric descent probes and surface scientific stations;
- mobile vehicles at planetary surfaces;
- sample return missions.

We will conclude our study by associating these different types of missions to the requirements generated by the different measurement objectives: the result will be the description of the "left-hand-side columns" of a simplified Traceability Matrix describing an integrated framework for a science-driven approach to planetary exploration, up to the 2061 Horizon.

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