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The last decade of planetary science discoveries in perspective and the implications for the engineering challenges of the future planetary space missions

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Abstract

The first decade of this century has seen a considerable increase in the knowledge related to planetary science. Paradigm shifts are on going as consequences of recent discoveries, whether on Solar System dynamics, on the population of planetary bodies, on their activity or differentiation state, on new potential microbial habitats or with exoplanets characterization. For engineers involved in the exploration of our system and in the observation of extrasolar systems, the resulting scientific expectations call for a closer look at the concrete implications on the designs of future missions and on spacecraft. Solutions have to be found to address the multitude of targets, the increase in the average distance of the exploration targets in our own system and the observation of ever fainter exoplanets.

1. Planetary science advances

This century has begun with a first decade of accelerated acquisition of knowledge thanks to the remarkable findings of both spacecraft and ground-based telescopes, combined with major advances in modelling. The presentation includes up-to-date statistics to ensure the objective character of this perception.

1.1 In our solar system

In our own solar system, the number of bodies known to mankind has been multiplied by more than seven, with the number of bodies larger than 500km multiplied by two. The dynamic history has been retraced with scenarios such as the "Nice model" to quote only one. New classes of planetary bodies have been defined with the controversial demotion of Pluto. Many bodies thought dead have been inferred or demonstrated as active, with Enceladus geysers epitomizing this trend. The number of bodies thought to be differentiated has also rocketed thanks to probe measurements and increasingly comprehensive modelling of planetary evolution spanning over the entire age of the Solar System. Water ice has been confirmed below the dry surfaces of the Moon and Mars. Sub-surface oceans of liquid water are now more and more often considered, thus providing for a growing list of potential habitats for simple life forms "as-we-know-it". Exotic life forms could even be theorized on the newly discovered bodies of liquid hydrocarbons on Titan.

1.2 Beyond our solar system

Exoplanetary systems have been discovered at a steadily increasing pace. The ever larger number of known systems bring the ability to make statistics and also its lot of counter-examples to theories once thought un-attackable. From hot Jupiters to Super-Earths to retrograde planets, the planetary zoo diversifies itself.

2. Paradigm shifts

Paradigm shifts are being experienced in all fields as a result of those discoveries. We review them briefly.

2.1 Knowledge of the systems

The scientists studying the formation and dynamics of systems (dynamicists), try to answer the question "how does the system work?". They are contemplating major shifts in their field:

- from "planetary orbits are established at the formation of the system, which is stable" to "planetary orbits are extremely dynamic and the system stability is marginal"
- from "nine solar planets" to "eight dominant solar planets plus tens of dwarf planets"

- from a study-able Solar System stopping at Pluto to objects with orbits up to several hundreds of AU
- from “planetary systems have a central star” to “planetary systems have different sorts of central objects: pulsars, brown dwarves, no star at all…”
- from “terrestrial planets close to the star, gas giants further away” to “no rule”
- from “orbits should be mostly circular and prograde” to “no rule”

2.2 Knowledge of the planetary bodies

Astrogeologists seek an answer to “how do planetary form and evolve?”. They are also experiencing shifts:

- from “most bodies are geologically dead” to “most large bodies have activity in some form”
- from “only bodies larger than 5000km tend to be differentiated” to “most bodies larger than 500km tend to be differentiated to some extent”
- new types of planets (between Jupiter and a star, between Neptune and Jupiter, between Earth and Neptune), which can be located at any distance from the star and therefore enjoy extremely diverse thermal conditions.

2.3 Conditions for life

Astrobiologists study “how/where/when does life appear”. The recent years have seen a departure from the post-Viking pessimistic view of “Solar System as a set of barren worlds”. In particular the previous notion of a narrow habitable zone at 1AU has given place to the realization that many habitats are possible in all parts of the solar system. Moreover, the exoplanetary science now aims at identifying bio-markers in the atmospheres of exoplanets.

3. Will Engineering meet the challenge?

Considerable engineering challenges are induced by those scientific paradigm shifts when it comes to address the new needs of planetary science. We discuss them along with ways-out.

3.1 The multiplication of targets

How to efficiently address the multiplication of targets by several orders of magnitude, with constant budgetary resources? The commonality of basic planetary science needs should enable to address the multiplicity of targets in a cost-efficient way by decreasing the non-recurring costs of spacecraft. The introduction of nanotechnologies in the space sector is an opportunity to increase the mass-efficiency and decrease the launch cost. This latter is also fortunately being slashed by the arrival of COTS launchers on the market.

3.2 Exploring in-situ more and more distant targets

As most Solar System planetary bodies lie in the Outer System, how to control the challenges brought by the large average distance to the Earth, whether for propulsion, mission lifetime, energy production or communications? Here again nanotechnologies promise to change the game both in terms of use of scarce resources on board and of use of local resources on planetary surfaces. In-situ resource utilisation, in general, will soon become a must. Optical communications will partially mitigate the increased distance, while maintaining or even increasing the amount of data transferred to the Earth. Some degree of artificial intelligence will have to be accepted to improve the autonomy of spacecraft at several light-hours from the control station. Fly-by missions can see their science return enhanced by using ancillaries. Improving the specific power of nuclear generators will become mandatory to have more than fly-by missions.

3.3 Observing ever fainter targets

How to observe exoplanets without being blinded by the central star? When one wants to go beyond the transit detection experienced by CoRoT and Kepler and considered for Plato, characterization technologies are to be considered. Many are being pondered, from interferometry to coronagraphy. All those techniques require though in-orbit demonstration and none of them can be associated to low costs at that stage. The ultimate goal, the characterization of an exo-Earth, will require the second generation of such space observatories. Mastering the huge induced size of a stand-alone spacecraft, or of the detector/coronagraph pair, or of a Darwin-like multi-spacecraft formation-flying constellation will call for a steady progress in the on-going developments, so that such a mission materializes one day.