ABSTRACT

The exploration and colonization of the outer space represents a foreseeable future for the Humanity. This endeavour involves deepening our knowledge about the formation and evolution of the solar system, of other planetary systems, emergence of life (and its prospects once it exists), the interaction between Earth and Space (particularly with its Sun) and the impact of space conditions (radiation, gravity, etc.) on Earth-borne organisms. Materialization of this exploration and colonization currently drives technological developments in several fronts as optics, electronics and sensors just to mention a few. Other aspects as well law & ethics, psychology, biology, etc., cannot be discarded.

KEYWORDS

solar system bodies | artificial intelligence | energy supply | life | extremophiles | biochemistry | protoplanetary disks | (exo)planetary systems | geophysics | space weather | paleoclimate | climate change | the sun | impact hazards | extra-terrestrial human settlements | biology | psychology | health | altered gravity | radiation

OUR FUTURE? SPACE COLONIZATION AND EXPLORATION

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EXECUTIVE SUMMARY

Humanity undoubtedly feels the need to explore and discover. On the metaphysical side, there are no boundaries to knowledge and science endeavour is thus endless. On the physical side, however, there are few places on Earth that cannot be reached, and Humanity has naturally set its eyes to the ultimate boundary: Space. Infinite, mostly unknown, utterly challenging, it has fascinated Humanity since its very beginning.

In what Space Science is concerned, CSIC is in a good position to tackle some of the most interesting challenges. The wide variety of its research institutes and the efficiency of its personnel are strong assets for such a multidisciplinary goal. That being said, any prospective attempt in the identification and definition of Challenges and Global Objectives for the near future, as well as for long-term, must have in mind that Spain is an active member of the European Space Agency (ESA) contributing to its policies and strategies of research. Even in practical terms, access to space and/or ground-based facilities is unavoidably mediated and facilitated by ESA or by other space Agencies through international collaboration.

In an effort to organize the huge diversity of research lines involved in Space Science, this document gathers 6 main challenges. Each of them puts the light on a specific section of that big picture but should, by no means, be considered a watertight compartment.

The use of space resources for exploration, in particular the **In Situ Resource Utilization** (ISRU) may be possible thanks to recent advances in knowledge of the Moon, Mars and near Earth asteroids, and the emergence of new technologies and increased participation of private sector in space activities. By 2030, the potential of lunar resources will have been established and space resources will be used to obtain water, oxygen, metals and other materials from ice stored in the polar caps and regolith on the surface of the Moon. New technologies for this will have been developed and demonstrated. Human presence at the Moon, sustained by local resources is expected by 2040.

In addition to Mars and the Moon which are clear targets for Human exploration, other bodies will be the destination of unmanned **Voyages to the Solar System**. Venus is our closest neighbour in the Solar System. Despite its similarity with Earth in size and mass, its atmosphere is radically different which makes it an objective of choice for planetary modelling. Icy moons, like for instance Europa, Ganymede or Titan are also quite different from rocky bodies like Earth. Some have been proven to shelter deep oceans under an icy crust providing some of the key elements (water, heat and chemical elements) for extra-terrestrial life to emerge and be sustained. Characterizing geological activity and phenomena like cryomagmatism or tidal heating, is of particular importance. Deciphering the origin of the solar system is a goal sustained by these space missions but also by the study of terrestrial analogues.

Earth, as every body of the Solar System, strongly interacts with its environment. **Space-Earth interaction** produces threats and opportunities for our Society. Space Weather is a discipline whose goal is to forecast the effects of ionizing particles coming from Space (mostly from the Sun but also from deep space). Such effects could be very deleterious to our modern technology. Radiation from the Sun and from the outer space (as the galactic cosmic rays) also induce atmospheric changes that can have relevant Climate effects. Increasing our understanding of these phenomena involves considerable observational and modelling challenges of the Sun, the Atmosphere and the magnetic fields that mediate these interactions. In addition, monitoring and detection of potentially hazardous asteroids is another topic addressed by this challenge: not only because of the collision risk but also because asteroids are a worthwhile object of study per-se as they are remnants of the early phases of the solar system, the building blocks of the planets and the source of the water (essential for the emergence of life) on our planet.

Sustaining Human life in Space is a requirement for long-term exploration and extra-terrestrial human settlements. Space is a harsh environment that can have strong consequences on health. Gravity and radiation can impact tissues, brain development, the reproduction function, aging processes etc. Understanding these impacts and finding proper countermeasures is thus fundamental. As well, sustainable food is also of utmost importance. Basic food sources, both vegetal and animal, have to be adapted from Earth. The same can be said for microorganisms that perform a set of valuable functions: sewage, food fermentation, soil adaptation... Most of these aspects will require thorough molecular biology studies. This enormous amount of -omics (genomic, epigenomics, proteomic, etc.) information shall be gathered in a structured database.

The challenge entitled "**In search of Life**" addresses several aspects from the most fundamental to the most practical ones. The question of the origin of life in the universe is closely related to the development of molecular complexity (see Volume 9 of this series), and this challenge focuses mostly on the emergence of biological precursors. The search of Life beyond the solar system is mostly based on the study of exoplanets and the characterization of their habitability conditions. A deeper knowledge of extremophiles and Earth analogues allows to refine the boundaries of these habitability conditions, though the search of life forms should also envisage the possibility of evolution of life based on silicon, ammonia, and sulphur. Finally, the search for extinct and extant life in the solar system can rely on direct exploration missions, closely related to the second challenge described above. It is an ambitious and pluri-disciplinary approach that involves expertise in different fields: astrobiology, astrophysics, biophysics, (astro)chemistry, geology, mineralogy, geobiology, palaeontology, microbiology, lichenology, phycology, botany, and mycology, among other.

The purpose of the last challenge is to assess how to contribute with breakthrough materials and components to the new challenges imposed by the future space programs. Taking into account CSIC global mission and its internal strengths, we identified research axes where CSIC could significantly contribute to **push the limits of several space technologies**, thus enabling novel space-related studies and missions. These challenges are i) increasing the sensing and detection ranges, ii) ensuring functional safety in the data storage and analysis on-board systems, iii) optimizing the energy generation and management, iv) controlling the radiation impact on personal and equipment. To address these challenges, we need to coordinate multidisciplinary teams specialized in materials science, optics, high energy physics, micro-nanoelectronics, biophysics or astrophysics. These challenges also require the industry to actively participate in a collaborative frame and not only in the commercial one.