EXO-ASTROBIOLOGY WITH ESA SPACE SCIENCE MISSIONS

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ABSTRACT

Key questions of astrobiology can be addressed by several space missions from the ESA Science Horizons 2000 Programme, such as:

- How do solar and stellar systems form? (with ISO, FIRST, SMART-1, Rosetta, Colombo, Gaia)
- Geological evolution of terrestrial planets (with Living planet, Mars-express, SMART-1, Bepi-Colombo to Mercury)
- Interstellar Complex organic chemistry (with ISO, ISS/EXPOSE, FIRST, Rosetta)
- Co-evolution of Earth-Moon, impacts life frustration (with SMART-1, Bepi-Colombo)
- How to detect other solar systems and habitable zones (with space photometry, COROT, Eddington, Gaia, IRSI-Darwin)
- Early Earth and alternative environments (Huygens/Cassini and Mars-express)
- Signature of biosphere, global biomarkers and photosynthesis evolution (living Planet missions, Darwin)
- Water and exobiology on Mars (with orbiter instruments and Beagle-2 lander on Mars Express)
- Study of biomarkers and delivery of organics (with Mars-express and future missions)

We shall review the Exo-Astrobiology potential from these ESA missions.

Key words: Astrobiology, Exobiology, Astrochemistry, Astronomy, Planets, Comets, Meteorites, Origin of Life.

1. INTRODUCTION

The origin of stars and planetary systems, life in our solar system and possibly elsewhere in the Universe are research topics which have attracted great interest among scientists. The discoveries of protoplanetary disks around other stars and the detection of more than 50 exo-planets provides evidence that the formation of extra-solar systems may be a common process throughout the Universe. Biogenic elements such as H, C, N, O, S, and P are known to be widespread in our Galaxy and beyond. The search for organic molecules in interstellar and circumstellar environments, their incorporation into potential planet-forming disks and subsequently into solar system material has been successfully investigated within the last decade. The origin of life on planet Earth might have proceeded from simple precursor molecules to more complex self-replicating, metabolising structures, evolving into primitive life. Extraterrestrial delivery of organic matter and water by comets and asteroids shortly after planetary formation may have triggered the emergence of life on Earth and possibly on Mars. The common interest on the origin and distribution of life in the Universe led to a new discipline, named Astrobiology. Exploration with astronomical telescopes, satellites and space missions contributes to the investigation of possible life habitats in our solar system, the search for exo-planets and the link between infalling extraterrestrial matter and the jump-start of life on Earth. In this respect, Astrobiology will benefit from and determine a number of space exploration programs in the future. In the following a brief overview is given about astronomical and planetary space missions (with emphasis on ESA missions) which will investigate astrobiological aspects during their operation phase.

2. ASTROBIOLOGY WITH SPACE ASTRONOMY

2.1. Infrared: ISO, SOFIA, HERSCHEL

Several space missions are in progress, or are well into the planning stage, that have key objectives concerning the nature of extraterrestrial organic chemistry, the search for extra-solar systems and for traces of past or present life. Figure 1 shows a number of space missions which investigate astrobiological per-
spectives, in particular by providing infrared (IR) and sub-mm data.

The Infrared Space Observatory ISO, in operation between 1995-1998, has revolutionised our understanding of gas and dust in interstellar and circumstellar space by monitoring the distribution of organic molecules in such regions. The exploitation of ISO data will remain a major effort of the infrared community in the following decade. In the meantime the next infrared satellite (SIRTF, US mission) is already on the start ramp. The airborne observatory SOFIA will be launched in the near future and will be able to observe parts of the near infrared spectrum. Herschel is one of the Cornerstone missions of ESA’s Horizons 2000 programme and will be launched in 2007.

The Herschel Space Observatory will be the only space facility ever developed covering the far infrared to submillimetre range of the spectrum (from 80 to 670 microns). The Herschel satellite is approximately 7 metres high and 4.3 metres wide, with a launch mass of around 3.25 tonnes. It will carry the infrared telescope and three scientific instruments and will be located 1.5 million km away from Earth. Herschel has an operational lifetime of three years minimum. It potentially offers about 7,000 hours of science time per year. It is a multiuser observatory accessible to astronomers from all over the world. The key science goals that Herschel will achieve concern the formation of galaxies in the early universe, and how stars form. Herschel will contribute to astrobiological studies by studying the processes by which stars, their surrounding protoplanetary disks and planets themselves are made. Also ground-based IR facilities and (sub)millimeter interferometers, such as VLT, KECK and ALMA, will be important in the astrobiological context, since they will allow the detection of complex molecules with abundances almost a factor of a hundred below current detection limits.

2.2. HST and NGST

The Hubble Space Telescope (HST) has provided first optical and near Infrared images of circumstellar disks around young forming stars. The new generation Space Telescope NGST will be able to penetrate the dusty envelopes around new-born stars and take a closer look at the stars themselves by using the infrared part of the spectrum. NGST will also have the sensitivity to study very small objects that are not massive enough to become stars. These objects - brown dwarfs and Jupiter-sized planets - will become targets for intensive study with NGST. The high resolution of NGST will also make it possible to see how other planetary systems form, and in this way enable us to study the origin of extra-solar systems.

2.3. EXOPLANETS FROM SPACE: GAIA, COROT, EDDINGTON & DARWIN

Milestones are expected in the search for extrasolar planets. Some 50 Jupiter type planets have now been detected from ground based velocity monitoring. With the GAIA astrometric mission, we should be able to measure the stellar reflex motion to detect tens of thousands of Jovian planets. The COROT mission will be able to detect the transit of giant planets, but also the presence of terrestrial planets (super Earths) during the 150 days continuous high precision simultaneous photometry of 3000 stars. The ESA Eddington and NASA Discovery mission KEPLER will have the capability to detect transits by Earth size planets in the habitable zones. How planetary systems form and evolve and to determine whether habitable or life-bearing planets exist around nearby stars are major objectives to be studied with DARWIN after 2010. With the help of nulling interferometers in the thermal infrared to remove the parent star light, IRSI-DARWIN will search for the spectral signature of gases such as CH₄ and O₃ in the atmosphere of extra-solar planets in order to identify Earth-like planets capable of sustaining life.

2.4. GLOBAL BIOMARKERS

Most of the molecular oxygen in the Earth’s atmosphere is thought to have been produced by bacterial activity in the last billion years. O₃ is a sensitive tracer of O₂, and its detection would give hint for formidable astrobiology developments. In this context one should recall that the remote signature of life is common practice with Earth remote sensing of vegetation by spectral imagery (for instance with ERS or ENVISAT). However this is diluted in the global abiotic spectral signature of the planet, as witnessed with the analysis of Galileo Earth flyby observations (cf. Sagan: Life on Earth? Maybe).

3. ASTROBIOLOGY WITH PLANETARY MISSIONS

3.1. CASSINI-HUYGENS

Figure 2 shows the most important space missions exploring our solar system in the near future. CASSINI-HUYGENS was launched on October 15, 1997 and is on its journey to explore Saturn and its moon Titan in 2004. While the CASSINI orbiter continues to explore Saturn and its rings, the European HUYGENS probe will be released and parachute through the atmosphere of Titan with an entry speed of 20,000 km/h. Aerobraking will allow a 2.5-hour descent of the probe. During this period six instruments will measure the properties of Titan’s atmosphere, which is known to contain organic molecules and nitriles and thought to resemble that.
ASTRONOMY SPACE MISSIONS SUPPORTING ASTROBIOLOGY


NGST  IRSI–DARWIN  GAIA

Figure 1. Astrobiology with space astronomy: ISO revolutionised our understanding of gas, ices, dust and organics in interstellar and circumstellar space. SOFIA and HERSCHEL will unveil processes for star and planetary formation, and search for large molecules as ingredients for life. NGST will penetrate and map the envelopes and circumstellar disks around newborn stars. By measuring stellar reflex motions, GAIA should detect tens of thousands of Jovian exoplanets, while COROT and Eddington will search for transits by terrestrial exoplanets. The IRSI–DARWIN interferometer will search for the signature of atmospheric carbon dioxyde, methane, water vapour and ozone biomarker.
of the young Earth. Recent high resolution images through the thick haze provide evidence of hydrocarbon oceans and continents on Titan's surface. Data of the Huygens sonde, before its impact with an unknown surface, will be of particular interest for astrobiology and deliver information on the prebiotic conditions of the second largest moon in our solar system.

3.2. STARDUST

The US space mission STARDUST was launched in 1999 and is currently on the route to rendezvous comet Wild-2. One of the main tasks of this mission is to capture comet dust and volatiles by impact into an ultra-low-density aerogel at a low speed of 6.1 km/s. The encounter distance will be approximately 150 km away from the nucleus. The collected material will be dropped off in a re-entry capsule that will parachute to Earth in 2006. This will represent the first cometary material to be analysed in Earth laboratories.

3.3. ROSETTA

The ROSETTA comet rendezvous mission will be launched in 2003 with the Ariane 5 rocket for a rendezvous maneuver with comet 46P/Wirtanen in 2011-2013. More than 20 instruments on the orbiter and the lander will obtain data on cometary origin and the interstellar-comet connection, which will broaden our insight into the origin of our solar system. ROSETTA will study comets Wirtanen's nucleus and its environment in great detail for nearly 2 years with far-observation activities, leading ultimately to close observations (~1 km distance). Comets are the relics of the planet-formation process in our own solar system and are thought to contain the most pristine chemical record, since they have spent most of their life in the cold outer part far from the Sun. Knowledge on their composition is a key astrobiological objective in order to investigate what material was delivered to the early planets during cometary impacts in their early history.

3.4. MARS-EXPRESS AND FUTURE MARS MISSIONS

In the search for life in our the solar system planet Mars represents the main target and will be visited by many spacecraft in the next two decades. Also a Mars Sample Return mission is envisaged. The main goal of the European MARS-EXPRESS mission, to be launched in 2003, will be the search for water as well as for ancient and present life on Mars. The spacecraft will carry eight instruments, all of which will make a contribution to solving the mystery of the missing water. The current Mars environment is too cold (and the atmosphere is too thin) to retain liquid water on its surface. However, data from the Mars Pathfinder, which landed successfully on Mars in July 1997, suggested widespread flowing water in the previous history of Mars. Water could also be trapped as underground ice on planet Mars. Just before its arrival MARS-EXPRESS will jettison one module, a lander called Beagle 2, which will head for the Martian surface where it will take in situ measurements of rocks and soil. The Mars Express Beagle 2 lander will carry a variety of scientific instruments, such as panoramic and wide field cameras and a microscope which will look closely investigate rocks. The small robotic arm of Beagle 2 will analyse rock fragments for the presence of organic matter, water and minerals. Beagle 2 will also deploy a mole capable of crawling short distances across the surface to collect soil samples for a gas analysis system. The primary aim of these experiments will be to see if any evidence of past life processes near the landing site remains. Preparation for this and future space missions to Mars are supported by the ground-based research of life under extreme conditions (such as permafrost, hydrothermal vents or salt crystals).

3.5. EUROPA MISSIONS

Jupiter's moon Europa probably hosts a subsurface water ocean beneath its outer ice crust. What geological processes create the ice rafts and other ice-tectonic processes that are at the origin of prominent surface features on Europa? A future mission currently in the planning stage is to visit Jupiter's moon Europa in order to study the properties of the ice crust with radar measurements. Europa seems to have an internal energy source provided by tidal friction through its interaction with Jupiter which could keep water in liquid state below the crust. Europa provides therefore key ingredients for life (water, energy and possibly organic molecules) and will certainly be a future target for several space missions.

3.6. MOON, MERCURY AND THE IMPACT FRUSTRATION OF LIFE

Future Mercury missions (MESSENGER, BEPICOLOMBO) and lunar missions (SMART1, SELENE) will also investigate the presence of ice deposits (and eventually organics) in the permanently shadowed polar areas, they will quantify the early bombardment history in the inner solar system, with relevance to the frustration, selection and evolution of life. Missions to terrestrial planets and Moons will also constrain models of geological evolution, including in the phase when life emerged on Early Earth.

3.7. SPACE EXPOSURE EXPERIMENTS

The International Space Station ISS also offers facilities which investigate issues relevant for Astrobiology. On the EXPOSE exposure facility on the
PLANETARY SPACE MISSIONS SUPPORTING ASTROBIOLOGY

CASSINI  HUYGENS  SMART-1

ROSETTA  MARS-EXPRESS  BEPI-COLOMBO

Figure 2. Astrobiology with planetary missions: while Cassini will study Saturn, its moons, rings and magnetosphere, the ESA Huygens probe will be released for a 2.5 hour descent, and will analyse physico-chemical properties of the cold atmosphere of this early-Earth analogue. Rosetta cometary orbiter and lander will study the nucleus and environment of comet Wirtanen, as a clue to the formation and evolution of our solar system. SMART-1 to the Moon, and Bepi-Colombo to Mercury will constrain studies of geological evolution of Earth and terrestrial planets, and the bombardment of the inner solar system. In addition to its geoscience objectives, Mars-Express will study also the history and cycle of water in all forms on Mars, and will deploy the Exobiology lander Beagle-2. This will prepare for future missions searching for life on Mars.
ISS EXPRESS-PALLET (or its precursor experiment BIOPAN), the radiation stability of organic molecules and primitive organisms are tested in the context of extraterrestrial delivery and panspermia. The STONE facility allows to simulate the impact of material and studies the survival and evolution of minerals, organics and spores during atmospheric entry.

4. CONCLUSION: ASTROBIOLOGY AND LONG TERM SPACE EXPLORATION

As a perspective we should mention other areas that space research can contribute to Astrobiology. This includes the experimentation of the limits of life, the conditions of habitability on other planets, the search for signatures of life in the solar system and elsewhere in the Universe. We indicated a road map including the space missions identified (see Foing 2001, Table 1).

Another aspect of Astrobiology where space research will play a key role, concerns the future of life on Earth, in Earth orbit, on the Moon, Mars, and after 2020 in the solar system and beyond (Foing and Perry 2000, Ip, Foing, Masson 1999). As the space missions for this exploration programme are still being defined, we proposed a road map for these investigations, concentrating on the next 30 years (see Foing 2001, Table 2).

Please visit http://sci.esa.int for information and news on ESA space science missions.

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