24 Space Activities in Exo-Astrobiology

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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 proto-planetary disks around other stars and the detection of more than 50 exoplanets provides evidence that the formation of extrasolar systems may be a common process throughout the Universe. Biogenic elements such as C, H, O, N, 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 in 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, metabolizing 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, which is investigated by a great number of interdisciplinary scientists, well documented in the preceding chapters of this book. Exploration with astronomical telescopes, satellites and space missions contributes to the investigation of possible life habitats in our solar systems, the search for exoplanets 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, which will investigate astrobiological aspects during their operation phase.

24.1 Astrobiological Potential of Space Astronomy Missions

24.1.1 Infrared Spectroscopy of Cosmic Dust and Organics

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 extrasolar systems and for traces of past or present life. Fig. 24.1 shows a number of space missions, which investigate astrobiological perspectives, in particular by providing infrared (IR) and sub-mm data. The Infrared Space Observatory ISO, in operation between 1995-1998, has revolutionized 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, earlier called FIRST, is one of the Cornerstone missions of ESA's Horizons 2000 program and will be launched in 2007. The Herschel Space Observatory will be the only space facility ever developed covering the far infrared to submillimeter range of the spectrum (from 80 to 670 microns). The Herschel satellite is approximately 7 meters high and 4.3 meters wide, with a launch mass of around 3.25 tons. 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 multi-user 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 proto-planetary 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.

24.1.2 The Next Generation Space Telescope (NGST)

The next 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 extrasolar systems.

24.1.3 Exoplanets from Space: GAIA, COROT, EDDINGTON, KEPLER and 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 Earth's) during the 150 days continuous high precision simultaneous photometry of 5000 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 whether habitable or life-bearing planets exist around nearby stars are major questions 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 CH_4 and O_3 in the atmosphere of extrasolar planets in order to identify Earth-like planets capable of sustaining life. Most of the molecular oxygen in the Earth's atmosphere is thought to have been produced by bacterial activity in the last billion years. O_3 is a sensitive tracer of O_2, and its detection would give hint for formidable astrobiology developments.

24.1.4 Global Life Signatures on Earth?

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.

24.2 Astrobiological Potential of Planetary Missions

Figure 24.2 shows the most important space missions exploring our solar system in the near future.

24.2.1 CASSINI HUYGENS

CASSINI-HUYGENS was launched on October 15, 1997 and is on its journey to explore Saturn and its moon Titan in 2004. Before the CASSINI orbiter continues to explore Saturn, its moons, magnetosphere and rings, the European HUYGENS probe will be released and parachute through the atmosphere of Titan with an entry speed of 20 000 km/h, then allowing 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 of the young Earth. Recent high resolution images through the thick haze provide evidence of hydrocarbon oceans and continents on Titan's surface. CASSINI images and spectra will also give a penetrating view until the surface of Titan. Data of the Huygens probe 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.

Fig. 24.1 This figure summarizes space missions, which investigate astrobiological perspectives, in particular by providing infrared (IR) and sub-mm data. Among them are the infrared satellites ISO, SIRTF, and the airborne observatory SOFIA. ESA's cornerstone mission FIRST (HERSCHEL) will observe in the wavelength range between 80-670 micron and on the NGST a mid-IR facility is planned. IRSI-DARWIN will look for Earth-like planets and monitor their atmosphere in the IR.

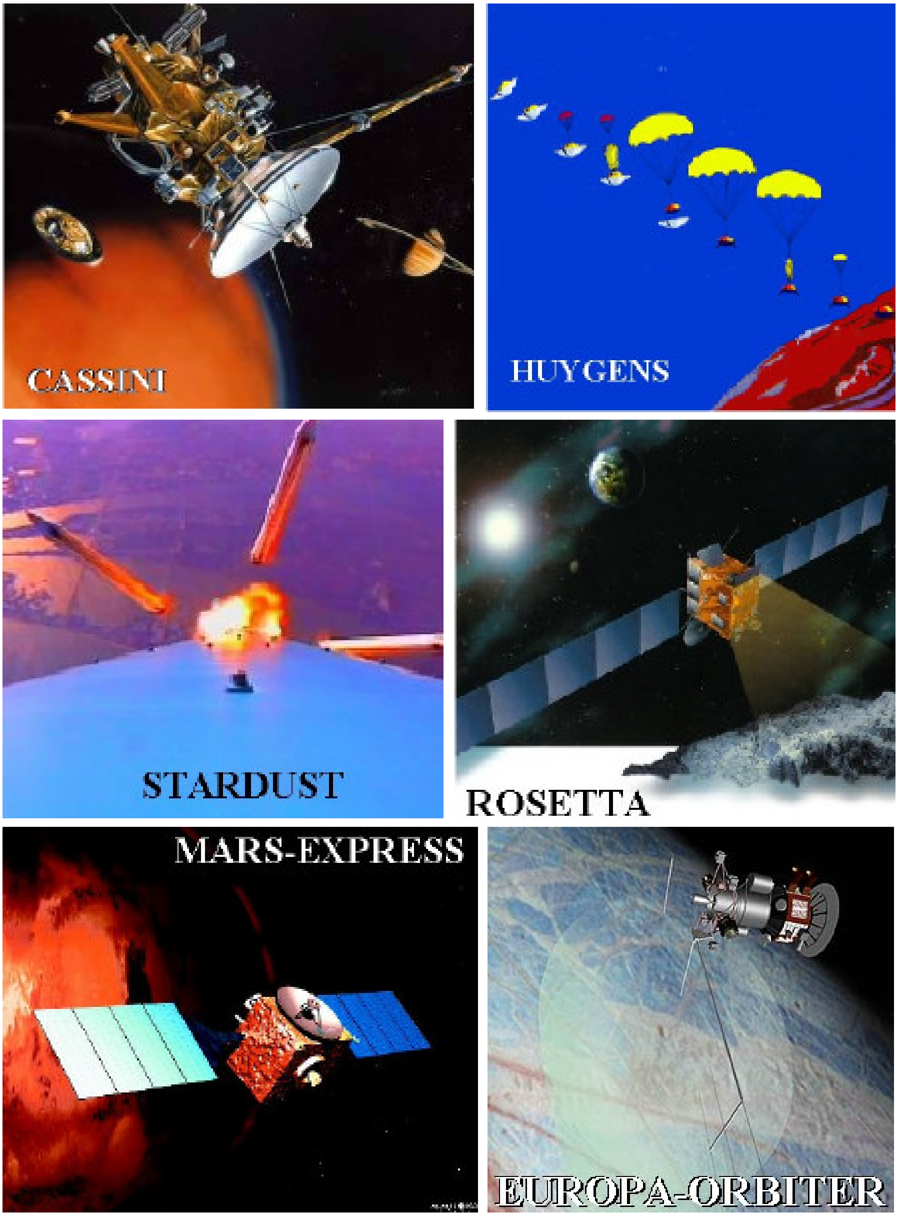

Fig. 24.2 This figure shows the most important space missions exploring our solar system in the near future with astrobiology relevance. Among them are CASSINI-HUYGENS, a mission to Saturn and Titan and the US mission STARDUST on its way to meet comet Wild-2. The ESA missions ROSETTA to rendezvous comet Wirtanen and MARS-EXPRESS/Beagle2 for Mars exploration, respectively are both launched in 2003. Planned for the future are missions to Jupiters's moon Europa to investigate its ice crust and possible subsurface oceans.

24.2.2 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 analyzed in Earth laboratories.

24.2.3 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) and to unprecedented measurements from the ROSETTA lander.

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.

24.2.4 MARS-EXPRESS and Future Mars Missions

In the search for life in our solar system the planet Mars represents the main target and will be visited by many spacecrafts in the next two decades. Also a Mars Sample Return mission is envisaged in the time frame 2009-2014, preceded by a series of automatic missions in orbit and on the surface with in situ analysis. 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 orbiter 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 the planet Mars. MARS-EXPRESS spectrometers will measure water in the atmosphere, while the radar will look at the surface. Just before its orbit insertion MARS-EXPRESS will jettison 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 and investigate rocks. The small robotic arm of Beagle 2 will carry sensors for analysis of rock fragments for the presence of organic matter, water and minerals. Beagle 2 will also deploy a mole capable of crawling short distances beneath 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 remain near the landing site. Preparation for this mission and future space missions to Mars are supported by the ground-based research of life under extreme conditions (such as permafrost, hydro-thermal vents or salt crystals).

24.2.5 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 are currently strongly debated.

A future mission currently in the planning stage for launch by US after 2006 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.

24.2.6 Moon, Mercury, Formation of Planets and the Early Frustration of Life

Future Mercury missions (MESSENGER, BEPICOLOMBO) and lunar missions (SMART1, SELENE) will give information of telluric planets in the inner solar system. They 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. Comparative planetology studies will give a better understanding on geological conditions on Early Earth, when life emerged.

24.2.7 Space Exposure Experiments

The International Space Station ISS also offers facilities, which investigate issues relevant for Astrobiology. On the SEBA/EXPOSE exposure facility on the ISS EXPRESS-PALLET 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.

Table 24.1. Space Roadmap for Experimenting Life in the Universe

	Now	**2003**		**2010**		**2020**
Limits of Life						
Extremophiles	In-situ					
Survival conditions on Earth		Active experiments				
Limits of life under Mars conditions			Mars missions			
Exoplanets and Habitability						
Exoplanets						
Exo-Jupiters	Ground-Based				GAIA	
Terrestrial Super Earths		COROT				
Earth-like habitable				Eddington or Kepler		
Atmospheric imprint of life					IRSI Darwin	
Habitability						
Water	MGS	Mars-Express				
Climate		Mars Climate Missions				
Frustration of life by impacts		SMART-1		Bepi Colombo		
Signatures of Life						
Biomarkers in solar systems						
Meteorites						
Instrumentation for life		Mars-Express				
characterization		Mars landers				
Biomarkers in exoplanets						
Atmospheric O_2-O_3				IRSI-Darwin		
Chlorophyll	Earth					?
Artefacts of civilisations				IR		
Radio bio-signals	SETI			lunar far-side		
Life in Solar Systems						
Mars						
Water	MGS	Mars Express				
Exobiology		Beagle 2				
Rovers	US Mars 2003					
Exobiology Mars Facility			EMF			
10 m cores				**X**		
In-situ				Robotic outpost		
Search for life					Sample return	
Man assisted research						
Europa						
Ocean surface	Galileo					
Ocean and liquid niches			Orbiter radar			
Search for liquid life					Penetrator	

Table 24.2. Space Roadmap for Expanding Life in the Solar System

Future of Life	**1980**		**Now**	**2005**		**2010**		**2020**		
Earth and Earth Orbit										
Ecosystems Response on human timescale				Living planet						
Earth long term habitability										
Hazards to Earth life					NEO watch					
Life in Earth orbit			ISS ---------------------				ISS			
Terrestrial life in space		X								
Planetary protection										
Terrestrial life on extraterrestrial outposts					X					
Evolving extraterrestrial life						X				
Moon										
First organisms	Luna Ranger									
first humans	Apollo									
Robotic precursors		Prospector								
			SMART-1							
Landers				Lunar-A						
				SELENE-B						
Virtual telepresence					X					
Robotic Outposts						X				
Ecosystem experiments						Femme				
						Melissa				
Vegetal, animals					X					
Resource utilisation					X					
Life support systems						X				
Evolving life on the Moon						X				
Robotic villages							X			
Humans and Lunar bases								X		
Expansion									X	
Colonisation										X
Mars										
Precursor	Viking									
Orbiters		MGS		Mars express						
Landers		Pathfinder								
Virtual telepresence					X					
Robotic outposts							X			
Resource utilisation								X		
Evolving life on Mars									X	
Manned expedition										X
Live off the land										X
Colonisation										
Terraforming										

24.3 Conclusion: Roadmap for Astrobiology and Long-Term Space Exploration

24.3.1 Experimenting for Life in the Universe

As a perspective we should mention other areas where space research can contribute to Astrobiology. This is namely in 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. A road map is indicated including the space missions identified (see Table 24.1.).

24.3.2 Expanding Life in the Solar System

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. As the space missions for this exploration program are still being defined, we propose a road map for these investigations, concentrating on the next 30 years (see Table 24.2.).

Acknowledgements. The following web-sites have plenty of information and supply the reader with recent highlights on astrobiological space research: http://sci.esa.int; http://www.astrobiology.com/; and http://origins.jpl.nasa.gov/.