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Astrobiology and the exploration of the Solar System

Italian Space Agency contribution

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Abstract. Astrobiology is among the main themes supporting and contributing to the Solar System exploration. Here we present a list of the main activities funded or otherwise supported by the Italian Space Agency (ASI) with a specific focus on their relevance for astrobiological investigations.

Key words. Astrobiology – Solar System Exploration – Space Missions

1. Introduction

The fundamental questions on how life originated on the Earth, whether it originated also somewhere else within the Solar System, and which are going to be the future steps in the evolution of life are among the crucial scientific questions that today are behind the Space Exploration.

The first attempt to find signs of life beyond the Earth was done in the mid-70s of last century. With the arrival in 1976 of the two Viking landers on the surface of Mars, there was among the scientific community a great expectation on the findings of the experiments carried by the landers. Both the Viking landers were equipped with a biology package experiments to search for signs of microbial metabolism (Soffen 1977). The information on the characteristics of the Martian environment returned by the two Viking landers where impressive (Arvidson et al. 1989). As for the presence of life, however, the outcome was unclear. The immediate interpretation of the data returned seemed to imply the absence of biological activity in the present and past Mars (Klein 1978). Recently, however, the debate reopened also considering the finding of the other landers and rovers that NASA sent on the surface of Mars (Benner et al. 2000).

The ambiguity of the results from the Viking Program was a stimulus for the scientific community to further discuss a more reliable methodology for unambiguously detect life beyond the Earth. As a consequence of this discussion, it became clear that before a life detection experiment could be performed expecting a clean result, a better understanding of the Martian environment was needed (Schulze-Makuch et al. 2015). It then was implemented a new approach to Martian and planetary exploration where the focus was directed into the understanding of the evolution and current state of planetary objects. Most of these activities, however, can be considered as preparatory for a second attempt to directly detect biological activity on Mars and other planetary objects.

2. Past missions

We list here past space missions where the Italian Space Agency (ASI) funded a contribution of the Italian scientific community with a specific relevance for astrobiology-driven investigations. In Table 1 there is a summary of past missions mentioned in this paper with few relevant information.

2.1. Venus Express

There is a long standing hypotheses that terrestrial-type biology can survive within the clouds of Venus (e.g. Morowitz & Sagan (1967), Cockell (1999), Grinspoon & Bullock (2007)). The ESA mission Venus Express and in particular the Italian/French spectrometer VIRTIS provided a detailed view of Venus' atmosphere: its circulation, structure and composition in relation to altitude, and its interactions with the planet's surface and with the solar wind at altitude (e.g. Piccioni et al. (2007) and references therein). The question whether Venus is currently or did in the past host biological activity is still open but we now have more detailed information to be used to design the upcoming next generation of missions to Venus.

Italy contributed to the mission with the PI-ship of two instruments: VIRTIS (Visible and Infrared Thermal Imaging Spectrometer, an imaging spectrometer in the visible/close infrared spectrum, identical to the spectrometer in flight on the Rosetta mission, which supplies data relative to the atmosphere, surface and to their interactions; PFS (Planetary Fourier Spectrometer), which performs vertical scans of the atmosphere and is identical to the instrument in flight on the MarsExpress mission. Furthermore, there was a significant participation in manufacturing the ASPERA-4 (Analyzer of Space Plasmas and Energetic Atoms) instrument, which studies the interactions between the solar wind and the Venusian atmosphere and is identical to the instrument in flight on the MarsExpress mission.

2.2. Cassini

Looking through the thick atmosphere of Titan and studying the moon's surface, it has been possible to find lakes and seas filled with liquid hydrocarbons (e.g. Brown et al. (2008)). The implications of these findings are still under analysis in particular what these liquid hydrocarbons could mean for life's potential on Titan. Cassini-Huygens data also revealed that Titan could have reserves of liquid water, similar to those on Jupiter's moon Europa, trapped beneath its frigid surface (Iess et al. 2012). In particular this finding triggered opened to new possibilities for habitable environments within Titan. Cassini scientific instruments also witnessed icy plumes erupting from Saturn's small moon Enceladus. When flying through the plumes, the spacecraft found evidence of saltwater and organic chemicals (Waite et al. 2009). This finding raised questions about whether or not habitable environments could exist beneath the surface of Enceladus.

ASI and the Italian planetary science community contributed to this fantastic endeavor as one of the partners of the Cassini mission. ASI developed the high-gain antenna with an integrated low-gain antenna (guaranteeing telecommunication with Earth for the entire duration of the mission), the VIMS spectrometer, the radio science subsystem (RSIS) and the radar, that also uses the high-gain antenna. Furthermore, ASI developed the HASI instrument for the Huygens probe, which measured the physical properties of the atmosphere and of Titan's surface.

2.3. Rosetta

Thanks to Rosetta mission, we know for sure that chemicals living in our own DNA, proteins, and cell membranes can be found in comets. Therefore, comets are possible candidates as carriers that introduced the basic components of life to Earth and possibly to Mars and the moons Enceladus and Europa. VIRTIS, the Italian-French VIS-IR imaging spectrometer on Rosetta, in addition to water ice cycle (De Sanctis et al. 2015) and or-

Table 1. Past missions

	Venus Express	Cassini	Rosetta	Dawn
Launch Date	9 November 2005	14 October 1997	2 March 2004	27 September 2007
Arrival Date	11 April 2006	14 January 2005	6 August 2014	1 July 2011
End Date	18 January 2015	15 September 2017	30 September 2016	1 November 2018
Mission Type	Orbiter	Orbiter-Lander	Orbiter-Lander	Orbiter
Target	Venus	Saturn System	Comet 67/P	Vesta-Ceres
Leading Agency	ESA	NASA	ESA	NASA

ganics (Capaccioni et al. (2015), Raponi et al. (2020)), also detected ammonium salts (Poch et al. 2020) which are thought to be the starting point for far more complex compounds (urea and glycine) that are known to be precursors to life as we know it on Earth.

The Italian participation in mission, besides from supplying manpower to the Lander Project Team, involved both the orbiter and the lander. In the first case, three Italian instruments made the journey: VIRTIS (Visual InfraRed and Thermal Imaging Spectrometer); GIADA (Grain Impact Analyser and Dust Accumulator); the WAC (Wide Angle Camera) of the OSIRIS instrument. The sample acquisition and distribution system (SDS) and the subsystem of solar panels.

2.4. Dawn

Vesta and Ceres are remnants of the early Solar System. Studying these objects can help astrobiologists understand how our System evolved to become the only known system to support an inhabited planet – the Earth. After Dawn exploration of Ceres - mainly thanks to the Italian VIR spectrometer - we know that it hosts water ice (Combe et al. 2016) and aliphatic compounds (De Sanctis et al. 2017). Vesta on the other hand had been extensively bombarded by OH rich carbonaceous material (De Sanctis et al. 2012).

The Italian participation in the mission consists in providing an imaging spectrometer operating in the visible region and in the near infrared with a high spatial and spectral resolution, to carry out the hyperspectral mapping of asteroids: the VIR-MS “Visible-IR Mapping Spectrometer”, derived from the VIRTIS instrument aboard the Rosetta mission, was built by the Selex Es in Florence. Furthermore, Italy provided manpower to the Dawn Project Team at the JPL/UCLA for in-flight operations.

3. Current missions

We list here on going space missions where the Italian Space Agency (ASI) funded a contribution of the Italian scientific community with a specific relevance for astrobiology-driven investigations. In Table 2 there is a summary of the current missions mentioned in this paper with few relevant information while in Table 3 there is a summary of the current sample return missions.

3.1. Mars Reconnaissance Orbiter (MRO)

MRO is essential to study the potential for habitable environments on past and present Mars. MRO also provides invaluable data used in selecting landing sites for future Mars missions. Data from MRO is important in building climate models for Mars, and for use in comparative planetology studies performed astrobiologists who study the potential habitability of exoplanets that orbit distant stars.

Sharad (Shallow radar), funded by ASI, looks for geologic boundaries and ice beneath

Table 2. Current missions

	MRO	Mars Express	Juno	ExoMars2016
Launch Date	12 August 2005	2 June 2003	5 August 2011	14 March 2016
Arrival Date	10 March 2006	25 December 2003	4 July 2016	19 October 2016
Mission Type	Orbiter	Orbiter	Orbiter	Orbiter-Lander
Target	Mars	Mars	Jupiter	Mars
Leading Agency	NASA	ESA	NASA	ESA

Table 3. Sample Return missions

	Osiris Rex	Hayabusa-2
Launch Date	8 September 2016	3 December 2014
Arrival Date	3 December 2018	June 2018
Return to Earth	24 September 2023	6 December 2020
Mission Type	Orbiter-Sample Return	Sample Return
Target	Asteroid Bennu	Asteroid Ryugu
Leading Agency	NASA	JAXA

the surface (Stuurman et al. 2016). The instrument was developed in Italy and provided to the NASA by the ASI as Facility Instrument, with the scientific guidance of a Principal Investigator selected by the ASI following a tender, in the person of Dr. Roberto Seu from the INFOCOM Department of the Sapienza University of Rome. The company in charge of the industrial development is Alenia Spazio, currently Thales Alenia Space, from Rome, which strengthened its know-how in the industry.

3.2. Mars Express

The Mars Express s/c is addressing the issue of astrobiology on Mars both directly and indirectly. The instruments are looking for indications of favorable conditions to the existence of life, either at present or during the planet's past, and in particular for traces of liquid, solid or gaseous water. Methane was detected by the Italian spectrometer PFS (Formisano et al. 2004), it is still debated whether its origin is biological or not. MARSIS, the radar provided by ASI, detected in 2018 and then confirmed in 2020 the presence of liquid water (Orosei et al. (2018), Lauro et al. (2021)).

Among the instruments aboard the probe, the ASI provided two instruments with a national PI: the Fourier PFS spectrometer to study the atmosphere and the MARSIS (Mars Advanced Radar for Subsurface and Ionosphere Sounding) subsurface radar, manufactured with the contribution of the NASA/JPL. Furthermore, the visible part (VNIR) of the OMEGA spectrometer (with a French PI) and the electronics of the ASPERA imaging instrument for energetic neutral atoms are part of the Italian contribution. One of the interdisciplinary scientists (IDS) is Italian too, and there are Italian scientists also within the HRSC (high-resolution stereo camera) team.

3.3. ExoMars2016

ExoMars is a program divided in two stages. During the first mission, launched on March

14th, 2016, the (TGO) probe reached the orbit of Mars after seven months of journey to start a long phase of investigations on the presence of methane and other natural gases in the atmosphere, but also to detect traces of the presence of active life. This stage also involved landing on the Red Planet – in a location named Meridiani Planum - a descent module (EDM), named Schiaparelli in honor of the Italian astronomer Giovanni V. Schiaparelli, the first person to draw an accurate map of the planet. In fact, the EDM separated from the probe on October 16th, 2016 and performed nominally all the predicted operations, up to the last stage of the descent – On October 19th – when, due to an anomaly in one of the control systems, the module crashed on Mars.

The TGO on-board camera, named CaSSIS (Colour and Stereo Scientific Imaging System), is designed and manufactured at the University of Berna with the contribution of the INAF – Astronomical Observatory of Padua and the Italian Space Agency. CaSSIS provides high-resolution, colour stereo pairs of accurately selected regions. Furthermore, it supports the other instruments aboard the TGO in its search for gases that can be important from a biological point of view, such as methane gas. NOMAD (an acronym for Nadir and Occultation for Mars Discovery) is a set of high-resolution spectrometers, capable of analysing in detail the gases in the atmosphere of Mars. It will also be able to detect the compounds in the atmosphere, even in very low concentrations. DREAMS (Dust Characterization, Risk Assessment and Environment Analyser on the Martian Surface), aboard the Schiaparelli probe, is a detector suite which measures weather parameters (pressure, temperature, humidity, speed and direction of wind, solar radiation) and the atmospheric electrical field in proximity to Mars' surface. It is the result of the cooperation between the ASI, the INAF – Astronomical Observatory of Naples and the CISAS of Padua. AMELIA (Atmospheric Mars Entry and Landing Investigation and Analysis) is a modelling of the Martian atmosphere, which uses the data collected by the detectors during the descent of the Schiaparelli lander on the Martian surface. In cooperation with the CISAS of Padua.

3.4. Juno

Jupiter is the largest planet in the Solar System and, as such, played a major role in our planetary system's formation and evolution. Studying Jupiter and its history can help astrobiologists understand the conditions that led Earth to become habitable for life as we know it. Jupiter also has many moons that are targets of astrobiology research, in particular the icy world Europa and Ganymede. The latter has been observed by JIRAM, the Italian spectrometer on-board the Juno spacecraft. JIRAM found evidences for water ice and organic molecules as well as reginal variations of these compounds (Mura et al. 2020).

The Italian participation in the mission is based on the now established experience in the field of spectrometers, optical cameras and radio science. In particular, Italy provided two instruments: the JIRAM infrared imaging spectrometer (Jovian InfraRed Auroral Mapper, PI Dr. Alberto Adriani from the INAF-IAPS, manufactured by Leonardo-Finmeccanica's Avionics Division) and the KaT radio science instrument (Ka-Band Translator, PI Prof. Luciano Iess from the Sapienza University of Rome, manufactured by Thales Alenia Space-I), representing the Ka-band portion of the gravity experiment. Both instruments take advantage of important synergies with the similar instruments under development for the BepiColombo mission, optimizing costs and increasing both the scientific and technological role of Italy.

3.5. Osiris Rex

OSIRIS-Rex (Origins Spectral Interpretation Resource Identification Security Regolith Explorer) is a space mission developed by the NASA, aimed at exploring asteroid Bennu. As the leftover debris from the solar system formation process that began over four billion years ago, small asteroids can provide important information about the history of the Sun and planetary objects. OSIRIS-REx is currently orbiting Bennu, a carbon-rich asteroid that records the earliest history of our Solar System, and will be bringing a piece of it back to Earth. Bennu may contain the molecular precursors to the origin of life and the Earth's oceans (Hamilton et al. 2019). Bennu is also a potentially hazardous asteroid that has a relatively high probability of impacting the Earth late in the 22nd century.

Italian scientists are funded by ASI to participate to the analysis of the data acquired by the orbiter and to analyze the samples once thay will be returned on the Earth.

3.6. Hayabusa-2

Hayabusa 2 is a Japanese mission launched in December 2014 on a six-year mission to study the asteroid Ryugu and to collect samples to bring to Earth for analysis. The spacecraft deployed two rovers and a small lander onto the surface. Hayabusa 2 fired an impactor into the asteroid in February 2019 to create an artificial crater. This allowed the spacecraft to collect a sample from beneath the surface of the asteroid. Samples were returned to Earth on December 2020 and are currently being analyzed by the scientists. It is anticipated that the samples will enable the analysis of terrestrially uncontaminated organic matter and minerals. Such analyses are in turn expected to elucidate the evolution of organic matter through Solar System history, including the origination and processing of biogenically important molecules, which could have been utilized by the first organisms on Earth (Potiszil et al. 2020)

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4. Future missions

4.1. ExoMars2022

The science objectives of the Rosalind Franklin rover have direct relevance to astrobiology. A major goal of the mission is to look for organics in samples collected by the rover's drilling efforts. After pristine material is gathered from beneath the Martian surface, samples of particular scientific interest will be placed in the MOMA ovens. Vapor released from heated samples will be analyzed with gas chromatography for traces of organic compounds. Organic compounds are chemicals that contain carbon, and are not themselves a sign of life. However, certain specific organic molecules are found in cells and, if discovered, might provide clues about the potential for life on Mars.

An onboard laboratory will process samples and deliver them to three instruments. Minerals will be characterized by the MicrOmega instrument; a Raman spectrometer will provide data concerning mineralogical composition; and part of the Mars Organics Molecule Analyser (MOMA) will study and identify soil chemistry.

To collect and characterize the samples before entering into the onboard laboratory, the rover is equipped with an integrated Drill+Ma_MISS (Mars Multispectral Imager for Subsurface Studies) subsystem. Ma_MISS (De Sanctis et al. 2017), funded by ASI, is a spectrometer which analyses the geological and biological evolution of the Martian subsoil. It is inserted within the Drill and will allow to analyse the structure of the internal surface of the drilling performed by the Drill. Ma_MISS main objectives are: (1) Determining the presence of ice or water at the drilling site; (2) Documenting the mineral distribution and composition, and identifying the nature of local geology and chemistry; (3) Study the samples in their geological context; (4) Study the mineralogy of the subsoil

4.2. JUICE

The JUpiter ICy moons Explorer (JUICE) is a European Space Agency designed to spend at least three years collecting data at Jupiter, and will observe three of the planet's icy moons: Ganymede, Callisto, and Europa.

Relevance to Astrobiology JUICE will help astrobiologists understand how habitable worlds might emerge around gas giant plan-

Table 4. Future missions

	ExoMars2022	JUICE	Comet Interceptor	ABCS
Launch Date	Aug-Oct 2022	September 2022	2028	2021
Arrival Date	Feb-Apr 2023	2031	TBD	2021
Mission Type	Lander-Rover	Orbiter	Fly-by	Orbiter
Target	Mars	Jupiter System	TBD	Earth
Leading Agency	ESA	ESA	ESA	ASI

ets. The icy moons of Jupiter are also primary targets for astrobiology research in the Solar System. Moons like Europa are believed to harbor oceans of liquid water beneath their icy surfaces, and it is possible that these oceans could be habitable for life as we know it.

The choice of JUICE was the culmination of a process started in 2004, the year when the ESA began to widely consult with the scientific community, with the purpose of identifying the goals of the European planetary exploration in the following decade. Italy, and in particular the ASI, is widely involved in this mission, where highly-technological proposals deriving from the intense scientific activity carried out so far will find its space. The Italian Space Agency will be accompanied by the national scientific community, other research institutions and the academic world.

4.3. Comet Interceptor

Comet Interceptor will target a comet visiting the inner Solar System for the first time – perhaps from the vast Oort cloud (Snodgrass & Jones 2019). As such, the comet will contain material that has not undergone thermal processing before. Another potential target is an interstellar interloper from another star system, like the famed 'Oumuamua that flew past our Sun on a highly inclined orbit in 2017. Studying an interstellar object would offer the chance to explore how comet-like bodies form and evolve in other star systems.

For the first time a pristine comet coming from the most external regions of the Solar System will be explored. Everything we will discover on the original composition of the comets will help understanding the early phases of the evolution of the Solar System including the circulation of water and organic molecules.

The Italian community is contributing to the DFP (Dust, Field and Plasma package) with the DISC (Dust Impact Sensor and Counter) and to the all-sky multispectral and polarimetric imager EnVisS (Entire Visible Sky).

4.4. ABCS

AstroBio CubeSat (ABCS) is a 3U CubeSat (100×100×340 mm) selected by European Space Agency (ESA) to be launched on fall 2020 with the Vega C qualification maiden flight, as piggy back of the ASI LARES2 satellite. ABCS will be deployed in an approximately circular orbit at 5900 km altitude and 70° of inclination spending a significant amount of the orbital period within the harsh internal Van Allen belt, close to its maximum (Brucato et al. 2020). ABCS will host a mini laboratory payload based on an innovative lab-on chip technology suitable for research in astrobiology. The objective is to test in space environments an automatic laboratory able to provide a highly integrated in-situ multi-parameter platform that uses immunoassay tests exploiting chemiluminescence detection. The experiment will consist in a set of lateral flow immunoassays (LFIA) on nitrocellulose support where target bio-molecules are immobilized in specific test areas. Mission Goals are (1) to perform the functional tests of the system - delivery of reagents, mixing of chemicals (2) characterize the lab-on-chip device - detection of emitted photons, noise evaluate the stability of chemicals and biomolecules

5. Conclusions

We presented here the main activities that ASI is supporting and funding focusing on their relevance for astrobiology.

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