M. Viso, Exobiology Program Manager
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Exobiology

French scientific teams of astrobiologists contribute greatly to national and international activities, to the processing of data acquired during missions, and to the preparation of space experiments, of missions to explore target bodies for astrobiology and of relevant future space missions.

Planetary missions

CASSINI

The joint American-Italian CASSINI mission, extended until 2017, is still inspiring work on the chemical reactions in Titan's atmosphere based either on observations or laboratory work [1]. The continuation of the work on the organic aerosols produced in laboratory simulation allows the study of the optical properties of these tholins [2]. The chemical characterization, in close cooperation with an international team, is ongoing. At the same time, while the mission is progressing toward its end, the French scientists selected by NASA are preparing for the last legs of the operation.

EXOMARS

ESA's EXOMARS program kept science and technical teams busy for the past few years while preparing for both missions in 2016 and 2020.

EXOMARS 2016 is now on its way to Mars. The French contributions to the Trace Gas Orbiter's Russian payload and to the DLR-led technical experiment – to be implemented on the Entry, descent and landing Demonstration Module (EDM) – were delivered on time. As co-investigators of several instruments, the teams are preparing the processing of data from the CASSIS European Stereo Imager in order to continue the studies on surface features [3], and from the Russian Atmospheric Chemistry Suite to search for Mars' atmospheric trace gases. The contribution to the instruments on the SCHIAPARELLI module designed to demonstrate the ability to land softly on the surface will give a unique opportunity to investigate the upper, middle and low atmosphere.

In preparation of the second mission, now renamed EXOMARS 2020, teams are building the qualification and flight models of the instruments. Besides the engineering activities, the teams are developing the science activities related to each instrument [4, 5, 6]. They are also very collaborative which translates into activities to prepare future operations. For instance, to prepare the EXOMARS mission and the required teamwork, several ISAR samples were submitted to a "blind round robin test" of the EXOMARS 2020 mission instruments [7]. Several meetings were organized by ESA to strengthen the science objectives of EXOMARS and to select the potential landing sites. Finally, Meridiani Planum has been selected for the 2018 mission but the selection could be revised or confirmed for the 2020 launch.

Experiments in low Earth orbit

The results of the EXPOSE-R samples which were retrieved in 2011 have been published in a special issue of the "International Journal of Astrobiology" [8]. Over the past two years, the EXPOSE-R2 experiment has been performed and the samples have been shipped back to the laboratory (in early 2016). The new gas mixtures, the new exposed products and the dedicated samples mimicking the exposition of the Martian soil to the sunlight filtered by the Martian atmosphere will be analyzed in the next few months; the results will be useful to prepare future missions or discuss their outcomes.

From space to the laboratory and vice versa

Several laboratories are working on the relationships between cosmochemistry and the flow of organic molecules reaching planetary surfaces. They are irradiating various types of ice maintained at very low temperatures (50 to 90 K). They have described for several years this complex chemistry while using increasingly sophisticated tools [9, 10]. The variety of molecules [11, 12] and the deciphering of mechanisms underlying the reactions provide new insights into the possible contribution of this interstellar or interplanetary chemistry to the organic enrichment of planetary bodies [13]. Some teams are also studying the Insoluble Organic Matter of Chondrites as a proxy of what could be found on asteroids or other space bodies, and to understand the mechanisms of synthesis, isotopic enrichment and trapping of noble gas [14, 15].

The work performed on high-resolution mass spectrometer like Cosmorbitrap helps understand the data issued from space missions such as ROSETTA or HERSCHEL as it is also preparing future ambitious missions. The engineering work is complemented by practical studies using terrestrial analogs of various cosmochemistry or planetary and cometary reaction chains [16]. The light scattering properties of some of these analogs are also studied during parabolic flights with the PROGRA2 facility [17]. Such studies

Fig. 1: The US and French teams testing the Raman spectrometer of Supercam for MARS 2020 at the Los Alamos National laboratory. © *IRAP*

are also applied to track cosmic objects and to understand direct observation and measurements [18].

While ESA nearly cancelled the ICAPS instrument dedicated to the study of optical properties or grains in space, the teams are working with their European colleagues to achieve the scientific objectives using different means.

New intruments for new missions

In July 2014, NASA announced the selection of the instrument suite for the MARS 2020 mission. SUPERCAM, a US-led instrument with a very significant contribution of French laboratories, was selected. This new instrument is based on the CHEMCAM heritage. It has worked aboard CURIOSITY since 2012, giving key mineralogical information on the habitability of Gale Crater (latest reference [19]). SUPERCAM will be more powerful with the addition of an IR spectrometer, a Raman Spectrometer and a color camera. The technical and science work is proceeding at full speed to be ready for a 2020 launch.

Several other projects are organized with national or international consortia to prepare future science or exploration missions. For instance, with the study phase of VITRINE, a suite of new "nano-payloads" is being prepared; they require limited-capability room, energy and data links from a platform. Those "nano-payloads" are designed to be hosted by nanosatellites, space stations or other satellites or probes, in order to expose samples – solid compounds, gaseous mixtures and extemporaneously produced cosmic ices – to space radiations, including sunlight. The design is based on specifications from the science experimental findings described in the chapter about cosmochemistry in laboratory.

Outreach

The agency supported an annual astrobiology course organized by Dr. Muriel Gargaud, the University Paris XII and the University of Bordeaux, dedicated to PhD students (RED, *Rencontres d'Exobiologie pour Doctorants*). Lastly, thanks to the support of the agency as well as several other institutions in Europe and Canada, the scientific community was able to finalize the second edition of the "Encyclopedia of Astrobiology" [20].
The astrobiology science community is involved in the international organization – European Astrobiology Network Association – and in the national *Société Française d'Exobiologie*; it contributes to organizing an annual congress and a dedicated workshop. The latest, held at CNES in May 2016, gathered more than 80 scientists and was entitled "From space molecular diversity to the homochirality of living bodies".

REFERENCES

[1] Carrasco, N., *et al.* (2015), The AMINO experiment: methane photolysis under Solar VUV irradiation on the EXPOSE-R facility of the International Space Station, *International Journal of Astrobiology*, **14(1)**, 79–87.

[2] Brasse, C., *et al.* (2015), Optical constants of Titan aerosols and their tholins analogs: Experimental results and modeling/observational data, *Planetary and Space Science*, **109–110**,159-174.

[3] Pilloried, C., *et al.* (2016), Formation of gullies on Mars by debris flows triggered by CO2 sublimation, *Nature Geoscience*, **9**, 65-69.

[4] Westall, F., *et al.* (2015a), Biosignatures on Mars: what, where and how? Implications for the search for Martian life, *Astrobiology*, **15(11)**, 998-1029.

[5] Westall, F., *et al.* (2015b), Archean (3.33 Ga) microbe-sediment systems were diverse and flourished in a hydrothermal context, *Geology*, **43(7)**, 615-618.

[6] Ciarletti, V., *et al.* (2015), Bistatic sounding of the deep subsurface with a Ground Penetrating Radar - Experimental validation, *Planetary and Space Science*, **117**, 177-183.

[7] Bost, N., *et al.* (2015), Testing the ability of the EXOMARS 2018 payload to document geological context and potential habitability on Mars, *Planetary and Space Science*, **108**, 87-97.

[8] *International Journal of Astrobiology*, (2015), **14(1)**, 142.

[9] Vinogradoff, V., *et al.* (2015), Carbon Dioxide Influence on the Thermal Formation of Complex Organic Molecules in Interstellar Ice Analogs, *Astrophysical Journal Letters*, **809**, L18.

[10] Fresneau, A., *et al.* (2015), Ice chemistry of acetaldehyde reveals competitive reactions in the first step of the Strecker synthesis of alanine: formation of HO-CH(CH3)-NH2 vs. HO-CH(CH3)-CN, *Monthly Notices of the Royal Astronomical Society*, **451**, 1649–1660.

[11] Meinert, C., (2016), Ribose and related sugars from ultraviolet irradiation of interstellar ice analogs, *Science*, **352**, 208-212.

[12] de Marcellus, P., *et al.* (2015), Aldehydes and sugars from evolved precometary ice analogs: Importance of ices in astrochemical and prebiotic evolution, *PNAS*, **112**, 965.

[13] Martins, Z., *et al.* (2015), Amino acids and organic compounds in the Paris meteorite: the most primitive CM2 chondrite, *MPS*, Accepted.

[14] Biron K., *et al.* (2015), Towards an experimental synthesis of the chondritic insoluble organic matter, *Meteoritics and Planetary Science*, **50**, 1408-1422.

[15] Chakraborty, S., *et al.* (2014), Massive isotopic effect in vacuum UV photodissociation of N2 and implications for meteorite data, *Proc. Nat. Acad. Sci.*, **111**, 14704.

[16] Somogyi, A., *et al.*, The Role of Ultrahigh Resolution Fourier Transform Mass Spectrometry (FT-MS) in Astrobiology-Related Research: Analysis of Meteorites and Tholins, *International Journal of Molecular Spectroscopy*, In press.

[17] Levasseur-Regourd, A.C., *et al.* (2015), Laboratory studies relevant to linear polarization (Chapter 5), in: Polarization of stars and planetary systems, *eds, Cambridge University Press, 62-80.*

[18] E. Hadamcik, E., *et al.* (2016), Imaging polarimetry of comet 73/Schwassmann-Wachmann 3 main fragments during its 2006 apparition, *Planet & Space Sci.*, **123**, 51-62.

[19] Jackson, R.S., *et al.* (2016), ChemCam Investigation of the John Klein and Cumberland Drill Holes and Tailings, Gale Crater, Mars, *Icarus.*

[20] Gargaud, M., *et al.* (2015), (Eds.); *Encyclopedia of Astrobiology, second edition*, XLV, Springer, 2737.

M. Viso, Exobiology Program Manager
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Exobiology

EXOMARS: looking for a proof of concept

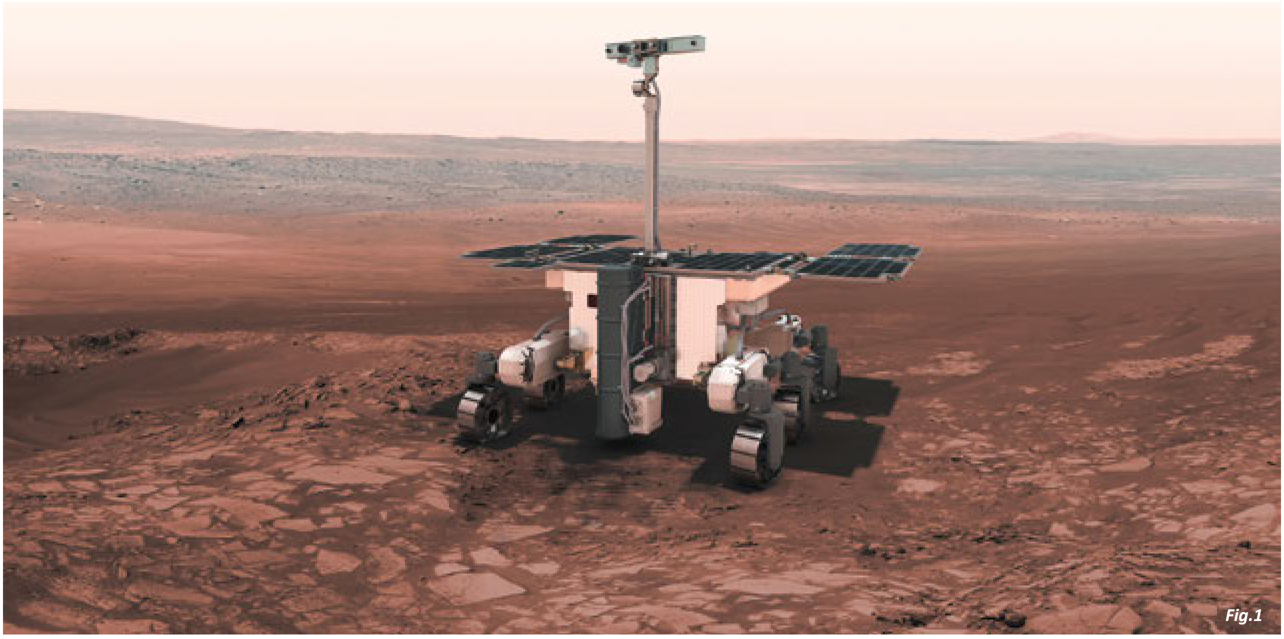


Fig.1

The EXOMARS program was proposed by the European Space Agency (ESA) in 2003 and adopted and subscribed by the ESA Member States in 2005. From then on, the concepts were subjected to several variations before reaching the current configuration. EXOMARS is an ambitious program now shared with the Russian space agency (ROSCOSMOS). This technological program aims to demonstrate the capability of Europe to land softly on the surface of Mars, to remotely operate a vehicle on the surface, to drill the ground up to two meters and to analyze selected samples. To achieve these goals, two missions are launched to the Red Planet. The EXOMARS 2016 mission was launched on March 14 and is on track to arrive at Mars on October 19. Its spacecraft, the Trace Gas Orbiter (TGO), will act first as a remote sensing satellite and then as a relay between the Earth and the Martian surface. It carries the Entry, descent and landing Demonstrator Module (EDM) for entering the Martian atmosphere, called “SCHIAPARELLI”. In 2020, a second mission will be launched atop a Proton rocket from the Baikonur Cosmodrome. This mission will deliver a Russian science platform and a European vehicle to the Martian surface. Both have a suite of instruments. On the vehicle, the complex suite of instruments requires a coordinated interpretation of the geological and chemical data. The development has now reached a sufficient level to have a proof of concept using terrestrial samples as references to train scientists to this new way for collaborative work.

The future EXOMARS rover mission (ESA/ROSCOSMOS), to be launched in 2020, will investigate the habitability of the Martian surface and near subsurface, and search for traces of past life in the form of textural biosignatures and organic molecules embedded in the geological record.

The EXOMARS rover is equipped with a suite of instruments developed across Europe by laboratory consortia and in Russia. The first instrument suite is dedicated to the contextual study using several cameras including a visible panoramic and stereo imaging camera (PanCam) coupled with a high-resolution camera (HRC), and an infrared spectrometer (ISEM) to identify hydrated minerals, and more generally, to characterize the composition of Martian surface materials (minerals and rocks) in the thin uppermost layer. This suite is complemented with a ground penetrating radar (WISDOM) to decipher the subsurface structure within the first meters (up to five meters). The observations will be completed with mea-

Fig. 1: ESA's ExoMars Rover provides key mission capabilities: surface mobility, subsurface drilling and automatic sample collection, processing, and distribution to instruments. It hosts a suite of instruments, known as the Pasteur payload, dedicated to exobiology and geochemistry research. *© ESA*

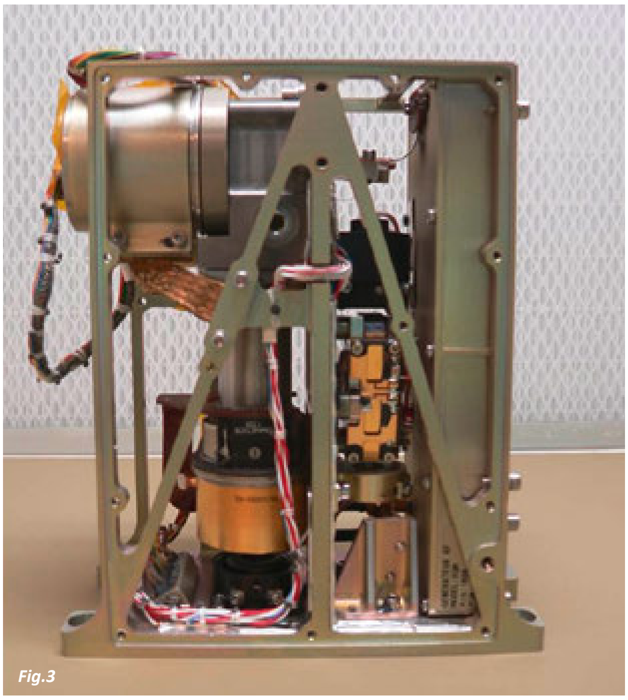
Fig. 2: Kitty's Gap Chert, a ~3.5 billion-year old volcanic sediment deposited in an infilling tidal channel on an early Earth characterized by environmental conditions similar to those found locally on early Mars, was used in a blind test of the ExoMars instrument payload. It is in these kinds of sediments that the landing site of ExoMars will be chosen. *© CBM*

Fig. 3: The qualification model of Micromega which was used in the round robin blind test. *© IAS*

surements of subsurface hydrogen content using a neutron spectrometer (ADRON). The second set of instruments is designed to drill and collect soil and rock samples (DRILL) while characterizing the various layers by spectrometry (MA_MISS). The fines produced during the drill and the collected samples will be characterized by an imager (CLUPI) prior to being processed by a crushing station. The resulting powder will be analyzed by the third set of instruments in the analytical laboratory. The visible and infrared spectro-imager (MICROMEGA) coupled with the Raman laser spectrometer will determine the interest of the sample in order to be processed and analyzed by the gas chromatograph-mass spectrometer (MOMA) searching for organic molecules.

This sophisticated suite of instruments on the European rover will provide a wealth of data to be analyzed by several teams of specialists with different science backgrounds. To prepare this operational and scientific analysis, at the initiative of the "Centre de Biologie Moléculaire" (Orléans, France), various teams are part of a round-robin sample analysis. The main goal is to coordinate and integrate the data and findings from different instruments and teams into the same two well-known reference samples.

In support of this mission, a selection of relevant Mars analogue materials has been characterized and stored for several years in the International Space Analogue Rockstore (ISAR), hosted in Orléans, France. Two ISAR samples were analyzed by prototypes of the EXOMARS rover instruments used for a petrographic study. The objective was to determine whether a full interpretation of the rocks could be achieved on the basis of the data obtained by the EXOMARS visible-IR imager and spectrometer (MicrOmega), the close-up imager (CLUPI), the drill mounted infrared spectrometer (MA_MISS) and the Raman spec-



trometer (RLS), first separately then in their entirety. In order not to influence the initial instrumental interpretation, the samples were sent to the different teams without any additional information. This first step was called the "Blind Test" phase. The data obtained by the instruments were then complemented with photography of the relevant outcrops (as would be available during the EXOMARS mission) and presented to two geologists tasked with the interpretation. The context data and photography of the outcrops and of the samples were sufficient for the geologists to identify the rocks. This initial identification was crucial for the subsequent iterative interpretation of the spectroscopic data. The data from the various spectrometers was, thus, cross-calibrated against the photographic interpretations and against each other. In this way, important mineralogical details, such as evidence of aqueous alteration of the rocks, provided relevant information concerning potential habitable conditions. The final conclusion from this test is that, when processed together, the EXOMARS payload instruments produce complementary data allowing reliable interpretation of the geological context and potential for habitable environments. This background information is fundamental for the analysis and interpretation of organics in the processed Martian rocks.

REFERENCES

[1] Bost, R., *et al.* (2015), Testing the ability of the EXOMARS 2018 payload to document geological context and potential habitability on Mars, *Planetary and Space Science,* Elsevier, **108**, 87-97. doi.org/10.1016/j.pss.2015.01.006

M. Viso, Exobiology Program Manager
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Exobiology

EXPOSE-R: Chemistry in the sunlight

Several experiments have been conducted outside Earth orbiting spacecraft since the beginning of the space station era. French astrobiology scientists have been involved in these space experiments since the early phase of space stations. Various instruments have been sent several times aboard the Soviet space station MIR. Numerous experiments have been conducted simultaneously, including the exposure of amino acids or other chemical or biological compounds. The results highlighted here deal with the effect of sunlight – understood as the full range of electromagnetic radiations emitted by the Sun – on methane. The effects of the sunlight could imitate some of the chemical reactions initiated on the upper layer of the atmosphere of Titan, one of Saturn's satellites. The EXPOSE-R2 experiment stayed on board the ISS for about two years.

The study of the evolution of organic matter subjected to space conditions, and more specifically to Solar photons in the vacuum ultraviolet range (120–200 nm) has been implemented on the ISS. Recently published papers summarize the first results extracted from the samples which were retrieved from space and from reference ground experiments. The photochemistry experiment called AMINO [1] has been conducted during 22 months between November 2008 and January 2011 on the EXPOSE-R ESA facility, outside the ISS. Defined chemical mixtures with relevance to astrobiology (connected to comets, carbonaceous meteorites and micrometeorites, the atmosphere of Titan and RNA world hypothesis) have been selected and exposed to space environment.

The EXPOSE facility, ordered by ESA, was built by an industrial consortium and designed to accommodate three trays. Each tray is able to support four sample holders. Those holders are customized for each type of experiment or samples. CNES sponsored several experiments whose samples have been accommodated in small cylinders made of stainless steel and closed by magnesium fluoride windows (MgF2). Magnesium fluoride is transparent over wavelengths from the vacuum ultraviolet (115 nm) up to the mid-infrared (mid IR) (10 µm). These characteristics allow the use of the same window for exposure (VUV) and analysis of the organic compounds (mid IR).

The methane experiment (see [2]) used closed cells whose body was made of two half-cylinders screwed into each other and closed at the distal end with magnesium fluoride windows. The long-term tightness was ensured by a brazing of the windows on each half cylinder and the soldering of the cylinders after filling and closing the cells. A first set of cells (Titan 1) was filled with a mixture of methane, di-nitrogen and helium (33.3%, 53.3%, 13.4%). The second set was filled with a mixture of methane, di-nitrogen, carbon dioxide and helium (33.3%, 46.7%, 6.7%, 13.4%). The total pressure in each cell was of 1.5×10^5 Pa.

The design of the experiment was such that while a sample was facing out, a twin reference sample was screwed underneath to prevent its exposure to sunlight, though it was submitted to the same conditions. During mission preparation, several reference samples were also prepared to be kept on the ground at the German Aerospace Agency (DLR) facility in Cologne. One was submitted to a temperature cycling like the flight experiment; the other was kept at 278K.

After the recovery of EXPOSE-R2, brown stains were displayed on the facility and a thin absorbing film was detected on the windows. Results showed that methane consumption was lower than expected, carbon dioxide did not decreased and there was ethane, propane, iso-butane and a few traces of n-pentane in the irradiated cells. The presence of carbon dioxide did not change the rate of methane consumption. When the chain was longer, the concentration of the various compounds was lower and decreased by a factor 5 for each one-carbon-atom elongation of the chain. A thin film of solid deposit was also detected onto the inside face of the exposed cells. This organic thin deposit displayed traces of N-H bonds. On the one hand, this result is surprising because magnesium fluoride prevents the direct photo-dissociation of di-nitrogen. However, the high pressure of the various compounds in the cell could explain the appearance of this nitrogenated deposit and the deviation, compared to Titan's atmosphere, in the ratio between the five produced carbon chains and the lack of unsaturated species (such as ethylene and butylene) or benzene.

Fig.1

REFERENCES

[1] Cottin, H., *et al.* (2015), The AMINO experiment: a laboratory for astro-chemistry and astrobiology on the Expose-R facility of the International Space Station, *International Journal of Astrobiology*, **14** (01), 67-77. DOI: http://dx.doi.org/10.1017/S1473550414000500 (About DOI), Published online: 03 November 2014.

(2) Carrasco, N., *et al.* (2015), The AMINO experiment: methane photolysis under Solar VUV irradiation on the Expose-R facility of the International Space Station, *International Journal of Astrobiology*, **14** (01), 79-87. DOI: http://dx.doi.org/10.1017/S1473550414000238 (About DOI), Published online: 18 July 2014.

Fig.2

Fig. 1: Partial view of Expose-R facility outside the ZARYA module of the ISS. © *ESA*

Fig. 2: A CNES engineer certifying the samples for “Amino” to be loaded on Expose R. © *UPEC / Nicolas Darphin*