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Solar System

ROSETTA - PHILAE

Since the last COSPAR symposium, the ROSETTA mission has been the highlight of the second half of 2014. In January 2014, the probe came out of hibernation and arrived near the nucleus 6 months later. ROSETTA fired its engine three times in May-June and achieved a change in speed of approximately 800 m/s, to finally reach the vicinity of the nucleus on August 6, 2014. The probe's first task was to produce a map of the nucleus in order to identify possible landing sites for the small lander PHILAE. Between the end of August and the beginning of September, two intense working weekends were organized at the SONC[1] (at CNES in Toulouse) to bring together PHILAE scientists and engineers in charge of CNES and ESA navigation. The goal was to select the landing site among 10 proposals. In October, ESA selected the Agylkia site, located on the comet's small lobe. CNES conducted a billion simulations of PHILAE's descent trajectory to study the impact which the sensitivity of release parameters has on the final precision of the landing. The error ellipse calculated was of about one kilometer.

PHILAE was released on November 12. After a seven-hour ballistic descent, it made its first touchdown within 100 meters of the planned target, demonstrating the outstanding accuracy of trajectory calculations and drop maneuver. Unfortunately, neither the anchoring harpoons nor the anti-rebound cold gas thruster fired. PHILAE bounced for 2 hours and travelled more than 1 200 m across the surface before stopping in the shadows of the Abydos region. Thanks to the data from the French CONSERT radar and the magnetic sensor ROMAP, CNES reconstructed in detail PHILAE's bouncy path and demonstrated its mid-air collision and subsequent destabilization. CONSERT data revealed PHILAE's location at an accuracy of a few hundred meters. In the summer 2016, ROSETTA will fly close over the comet to locate PHILAE using the OSIRIS camera images and clarify its behavior and its immediate environment. PHILAE worked on the comet's surface for 57 hours, in accordance with the predictions given by the primary battery provided by CNES.

The First Sequence Science (FSS), which CNES had taken months to prepare, had to be modified due to PHILAE's non-nominal configuration. All instruments were successfully activated once. Only two of the 10 instruments did not work as expected because neither the drill nor the AXPS reached the comet's surface, which prevented any data recording. The eight other instruments provided original scientific results which were the subject of several articles in the July 2015 issue of *Science* magazine.

Since spring 2015, several attempts to communicate with PHILAE were made. Height communications links were established with the lander, but they were too short to enable any measurements to be commanded. No signal has been received since July 9, 2015. One reason for this is that the comet was moving closer to perihelion, forcing ROSETTA to retreat for safety reasons, preventing a good session for the communication with the lander.

The distance between the comet and the Sun is increasing over time, reducing the possibility of any communications with PHILAE, either because there is not enough energy available on board to power the transponder, or because the temperature has fallen below -50 °C, the threshold below which PHILAE can no longer operate. The Rosetta mission is scheduled to end in September 2016. By then, the orbiter must locate PHILAE on OSIRIS images and determine its attitude and environment in order to understand what went wrong in 2015, before and after perihelion.

MARS SCIENCE LABORATORY

The MSL CURIOSITY rover has been exploring the Red Planet since summer 2012. CNES is involved in the payload and in the operations. The IRAP[2] laboratory is co-responsible for the CHEMCAM instrument which analyzes Martian rocks using the LIBS method (Laser Induced Breakdown Spectroscopy). LATMOS[3] and LISA[4] provided the chromatography column subsystem for the SAM instrument. Lastly, CNES implemented the FIMOC[5], an operation center for the

Fig. 1: Artist's view of Philae's descent to Comet Churyumov-Gerasimenko. The background is a real picture taken by the Osiris-Nac camera. *© CNES/ESA/D.Ducros/Rosetta/MPS for OSIRIS Team/MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA*

CHEMCAM and SAM instruments in Toulouse. Both instruments are being operated alternatively by CNES and the American PI.

At the end of 2014, the loss of use of the laser diode that served for focusing CHEMCAM led to the installation of a new software restoring auto-focus capability to the instrument by optimizing contrast on CHEMCAM's camera images. At the end of 2015, CHEMCAM had fired more than 300 000 laser shots, allowing the analysis of more than 1 100 rocks on Mars. It is the most used instrument of CURIOSITY's payload, which shows that this remote sensing technology is highly effective (see next pages).

SEIS - INSIGHT

INSIGHT (Interior exploration using Seismic Investigations, Geodesy and Heat Transport)(6) is a geophysical mission to Mars submitted by the Jet Propulsion Laboratory (JPL) as part of NASA's "Discovery" program.

The payload is built jointly by CNES and the IPGP(7) – which provides the SEIS (Seismic Experiment for Interior Structure)(8) seismometer – and DLR(9) (German Space National Agency) which provides the HP3 heat flow probe. RISE, the third instrument (provided by the JPL(10) itself), is a transponder which will measure the precession and nutation of the Mars polar axis. A robotic arm and a camera will deploy SEIS and HP3 on the Martian surface.

The seismometer is the fruit of a significant investment from CNES (MARS-96, NETLANDER, EXOMARS, SELENE-2, etc.). Along with INSIGHT, it benefits from the best opportunity in the past fifteen years to be dropped on Mars, in an optimal configuration provided by its three long period VBB (Very Broad Band) sensors and thanks to which it will reconstruct the seismic signal in accordance with the three axes defined by each sensor.

SEIS is expected to determine crust thickness, core size, density and nature (solid or liquid), seismic activity and its spatial distribution and the regional impact rate of meteorites.

SEIS was built from autumn 2013 to the end of 2015 in a context constrained by schedule. Its delivery was initially scheduled in January 2015, but several technical issues postponed the date until January 2016. Significant efforts were deployed: the teams were increased, activities were carried out during the weekends by CNES, the IPGP, Sodern, the JPL and the Swiss, British and German partners. However, the instrument could not be delivered in time for a launch in spring 2016 because a leak was detected in the vacuum sphere containing the three seismometers. NASA initially canceled the launch, then ran a detailed risk analysis and cost assessment. It gave the green light for operations and a May 2018 launch. CNES and its partners are fully involved in the project to deliver the SEIS instrument in spring 2017.

BEPICOLOMBO

In the last COSPAR symposium, BEPICOLOMBO was scheduled for launch in July 2016. Since then, technical issues on the MPO (Mercury Planetary Orbiter) and MTM (Mercury Transfer Module) vehicles forced ESA to postpone the launch twice. It is now scheduled in April 2018 and orbit insertion around Mercury is planned for late 2024.

CNES manages the French contributions to the MPO and MMO (Mercury Magnetospheric Orbiter) payloads. The latter were delivered between June 2011 and May 2015. JAXA's MMO was delivered to ESA in June 2015.

LATMOS is in charge of providing the PHEBUS ultraviolet spectrometer which will study the planet's exosphere. Issues with the UV detector postponed the delivery of the flight model until April 2015. The Italian SIMBIO-SYS instrument, with its Visible and Infrared Hyperspectral Imager, was calibrated at the IAS(11) in spring 2015 and delivered in April – except for the Main Electronic (made by the IAS) delivered in May 2015.
All French instrument contributions have now been delivered.

HAYABUSA-2 - MASCOT

JAXA's(12) HAYABUSA-2 mission aims to land on a near-Earth asteroid in order to:
- perform remote characterization experiments, from the orbiting probe;
- perform in situ characterization experiments, via the MASCOT lander;
- collect samples before returning to Earth.

The target is the NEO (Near Earth Object) type C asteroid called 1999JU3, which measures about 1 km in diameter. The mission was launched on December 3, 2014. It is expected to reach the asteroid in mid-2018 and the return capsule will be back on Earth at the end of 2020.

The HAYABUSA-2 is the successor to HAYABUSA-1, which was launched in 2003 to the S-type asteroid Itokawa and successfully returned samples to Earth in June 2010.
The innovation of the HAYABUSA-2 mission is that it carries the MASCOT lander developed under DLR management, in partnership with CNES. MASCOT's main instrument is MICROMEGA, an imaging infrared spectrometer developed by the IAS. Its goal is to conduct in situ characterization of the asteroid, providing a determination of the mineralogical surface composition, down to its grain scale. To do so, MICROMEGA will perform a spectral analysis of surface samples in the near-infrared wavelength range, where the main minerals have characteristic signatures.
CNES contributions to MASCOT can be broken down into the following categories:

- On the platform: CNES contributes to telecommunications and power subsystems by providing:
  - primary batteries (inheritance from PHILAE/ROSETTA) and the centralized power converter;
  - communication antennas for which CNES was prime contractor;
- System engineering: CNES carries out:
  - the MASCOT mission analysis (separation, descent and landing phases)
  - the MASCOT/HAYABUSA-2 link budget.
- Support to operations: CNES and the IAS support DLR for the definition, preparation, checkout and implementation of operations during the cruise phase and MASCOT's mission.

The MICROMEGA instrument was delivered to DLR in February 2014 and MASCOT was delivered to JAXA four months later. The MASCOT mission will last 18 hours and will occur between the end of 2018 and spring 2019. HAYABUSA-2 will start its journey back to Earth at the end of 2019.

JUICE

JUICE is the first Large-class science mission (L1) chosen in May 2012 as part of ESA's Cosmic Vision 2015-2025 program among three candidate missions (target envelope of 850 M€).
JUICE's scientific payload was selected in May 2013. CNES is the contracting authority of the French instrument contributions. The contributions to the scientific payload of the JUICE mission are detailed below:

- MAJIS (Moons And Jupiter Imaging Spectrometer):
  - The IAS is the instrument prime contractor and provides the command-control and power supply electronics, the proximity electronics of both VIS/NIR and IR spectral channels, and the focal planes of the VIS/NIR and IR channels.
  - LESIA contributes to the ground segment of the instrument.
  - Italy: the IAPS(13) provides the optical head, including optical and thermomechanical design.
  - Belgium: the CSL(14), the ORB(15), and the IASB(16) contribute to radiation testing activities on detectors.
- RPWI (Radio & Plasma Wave Instrument):
  - The LPP(17) provides the SCM (Search coil triaxial magnetometer).
  - The LPC2E(18) provides the MIME contribution (mutual impedance probe).
  - LESIA is Co-PI of RPWI.
- The SWI (Submillimeter Wave Instrument): LERMA(19) provides the frequency synthesizer; the frequency doubler at 280 GHz; a frequency distribution system (OCXO output); and an OCXO-type reference frequency.
- PEP (Particle Environment Package): IRAP provides the MCP (MicroChannel Plate) of the US JENI sensor; anticoincidence system: performance characterization tests on various PEP sensors in radiation environment.
- UVS (Ultraviolet Spectrograph): LATMOS provides the holographic diffraction grating for the instrument.

The end of MAJIS Phase A review took place in January and the PDR (Preliminary Design Review)(20) is planned for October. By then, the instrument design will be completed and the tradeoff will have been made.

MAVEN

The NASA MAVEN mission aims to study the mechanisms that led to the loss of Mars' atmosphere during its history. MAVEN will also provide qualitative and quantitative measurements of the current processes of atmosphere depletion.
IRAP provided the analyzer and front-end electronics (microchannel plates, anode, preamplifiers, and high voltage power supply of the SWEA (Solar Wind Electron Analyzer) spectrometer. This experiment examines the electron inflow of solar wind to determine the impact ionization rate from charge exchange, as well as the dynamic pressure of the solar wind.

The probe entered in orbit around Mars in September 2014 and started its scientific observations in November. The SWEA instrument provides high quality data. MAVEN successfully completed its first "Dip Deep" campaign from 10 to 18 February 2015, lowering the periapsis of the probe from 150 to 120 km. The SWEA results revealed the signature of the interaction between the incident electron populations and atmospheric CO_2. It resulted in a residual spectrum whose characteristics have been very well reproduced by a model taking into account the relevant cross sections of the main reactions involved. In November 2015, about fifty articles were published in *Science* and *Journal of Geophysical Research*; they highlight the main mechanism responsible for the Mars atmospheric loss. Several French IRAP and LATMOS scientists have co-authored these articles.

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(4) Laboratoire Interuniversitaire des Systèmes Atmosphériques, CNRS, Université Paris-Diderot, Université Paris-Est Créteil Val de Marne.

(5) French Instruments Mars Operation Center.

(6) Interior exploration using Seismic Investigations, Geodesy and Heat Transport

(7) Institut de Physique du Globe de Paris, CNRS, Université Paris-Diderot.

(8) Seismic Experiment for Interior Structure.

(9) Deutschen Zentrums für Luft- und Raumfahrt.

(10) Jet Propulsion Laboratory.

(11) Institut d'Astrophysique Spatiale, CNRS, Université Paris-Sud.

(12) Japan Aerospace Exploration Agency.

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(16) Institut royal d'Aéronomie Spatiale de Belgique.

(17) Laboratoire de Physique des Plasmas, CNRS, Ecole polytechnique, Observatoire de Paris, Université Paris-Sud, Université Pierre et Marie Curie.

(18) Laboratoire de Physique et Chimie de l'Environnement et de l'Espace, CNRS, Université d'Orléans.

(19) Laboratoire d'Etude du Rayonnement et de la Matière en Astrophysique et atmosphères, CNRS, Observatoire de Paris, Université Cergy-Pontoise, Université Pierre et Marie Curie, Ecole Normale Supérieure de Paris.

(20) Preliminary Design Review.

Fig. 2: This image is an unannotated version of the Photojournal Home Page graphic released in October 2007. This digital collage contains a highly stylized rendition of our solar system and points beyond. As this graphic was intended to be used as a navigation aid in searching for data within the Photojournal, certain artistic embellishments have been added (color, location, etc.). Several data sets from various planetary and astronomy missions were combined to create this image. *© NASA/JPL 2008-01-26*

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Solar System

The ROSETTA-PHILAE mission (ESA)

Fig. 1: Picture of Comet Churyumov-Gerasimenko taken by the Osiris instrument aboard the Rosetta satellite.

VIRTIS observes how comets work

Using data provided by the ESA probe ROSETTA on comet 67P/Churyumov-Gerasimenko, researchers (from LESIA and IPAG , among others), have provided the first observational proof of a daily water-ice cycle on the surface of the comet.

As sunlight heats a comet's frozen nucleus, the ice in it - mainly water ice, but also other "volatiles" – sublimates. The resulting gas migrates from the ground to the surface, carrying solid dust along. This gas and dust mixture is expelled in the form of powerful jets – gas velocity can reach 2 000 km/h – and forms the coma. As soon as the molecules are irradiated by ultraviolet photons from the Sun, they are dissociated and/or ionized. They are then carried by the magnetic field of the solar wind and form a thin and straight ion tail while heavier dust form a second tail, broader and curved.

One of the features investigated by comet experts is related to the physical processes that drive outgassing. The idea is to understand how water ice is extracted from the ground to replenish the coma with water vapor in a regular cycle.

As the comet rotates, taking just over 12 hours to complete a full revolution, the various regions undergo different illumination conditions.

Water ice on and a few centimeters below the surface "sublimates" when illuminated by sunlight, turning it into gas which then escapes into the coma. When the same region falls into darkness, the thin layer of the highly insulating surface rapidly cools again, whereas the underlying layers remain warm, and cool more slowly owing to the accumulated solar heat.

As a result, deep water ice continues sublimating and finding its way to the cold surface through the porous ground. As soon as this "underground" water vapor reaches the surface, it freezes again, creating a thin layer of fresh ice.

As the Sun rises again on the frozen surface, the newly formed ice sublimates immediately. This cyclical process is inevitably repeated because new ice keeps forming on the surface at night.

It was possible to estimate the relative abundance of water ice with respect to other material. Over the surveyed surface portion, water ice accounts for 10-15% in mass and it is well-mixed with the other ground constituents.

On a given region, the amount of surface water ice measured by VIRTIS over a thickness of several microns accounts for only 3% of the water vapor measured by MIRO in the microwave domain. We may therefore consider that ice sublimates daily over a few millimeters, which correspond to the insulating layer that freezes night after night [1].

Why does 67p have a head and a body ?

A scientific team from LESIA has participated in a study presented in the scientific journal *Nature*, based on data provided by the OSIRIS instrument on ESA's ROSETTA probe, which helps understand how this unusual body formed.
The factors shaping cometary nuclei are still largely unknown, but could be the result of concurrent effects of evolutionary and primordial processes.

When ROSETTA reached comet 67P/Churyumov-Gerasimenko in summer 2014, its peculiar bilobed shape stirred up surprise. Two hypotheses emerged to explain it. The core is either the result of the fusion of two objects that were once separate, or the result of a localized excavation by outgassing at the interface between the two lobes.

An argument in favor of the second hypothesis is that the "neck" is formed by localized outgassing. The heat that accumulates and radiates on both sides of the neck will tend to locally increase erosion and eventually form the observed structure. It may be compared to a toaster that simultaneously heats both sides of a piece of bread. The large crack – which extends to 100 meters in length and a few meters in width – located on the comet's neck, demonstrates that the comet is weakened in this region and may eventually break, which is a common phenomenon in comets. However, this fracture does not explain the shape of the nucleus.

The study brought the debate to an end by showing that the comet's major lobe is enveloped by a nearly continuous set of strata, up to 650 meters thick, which are gravitationally independent of a stratified envelope on the minor lobe. In other words, these layers only extend in local horizontal lines if the gravitational field is reconstructed to virtually cut the comet in two, considering only the major lobe.

67P/Churyumov-Gerasimenko is an accreted body of two distinct objects, initially roughly spherical and with "onion-like" stratification which formed long before they merged.

The authors also conclude that gentle, low-velocity collisions occurred in the early stages of the Solar System between two kilometer-size cometesimals. The impact between the comet's two components must have occurred at very low speed (a few meters per second), as this fragile comet would have been crushed if the shock had occurred at common speeds of about one kilometer per second.

Lastly, the composition and structural similarities between the two lobes of comet 67P indicate that these cometesimals experienced a highly primordial stratified accretion and a similar formation process, though they formed independently. We do not yet understand this unexpected primordial stratification. It constitutes an additional observational constraint for the Solar System constitutes formation models which will have to reconstruct the process that led to their formation [2].

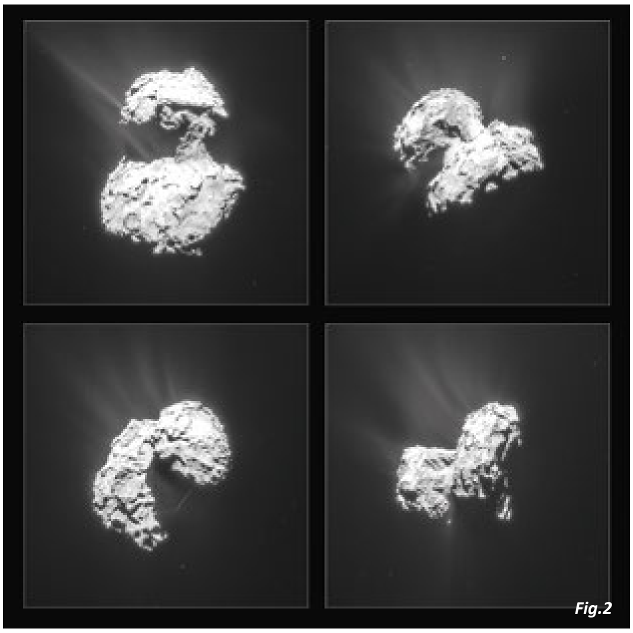

Fig. 2: These four images of Comet 67P Churyumov-Gerasimenko were taken by Rosetta's navigation camera in February 2015. The pictures were taken on February 25 (top left-hand corner), February 26 (top right) and February 27 (bottom left and right). They have been processed to bring out details of the comet's activity. Exposure time for each image: two seconds. *© ESA/Rosetta/NAVCAM/, 2015*

Fig. 3: Image of Rosetta and Philae made for the cover of the journal Science (issue 349) by Alex Torres (CNES) and David Ducros (Active Design) using images from Jean-Pierre Bibring's CIVA camera (IAS) (published on July 31, 2015). *© CNES/A.Torres - IAS/JP. Bibring - Illustration D. Ducros, 2015*

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Solar System

The Mars Science Laboratory mission (NASA)

CHEMCAM finds traces of a primitive continental crust on Mars

So far, we believed that Mars was almost entirely covered with basaltic rocks – dark rocks which form the Earth's oceanic crust. However, the walls of Gale crater, where CURIOSITY landed, contain very old (about 4 billion years old) and lighter rock fragments, which the CHEMCAM laser instrument has revealed the composition. French and US scientists have analyzed images and the chemical makeup of these 22 rock fragments. They have discovered that these light-toned rocks contain a high amount of feldspar and some traces of quartz, which makes them similar to Earth's granitic continental crust. These primitive Martian crustal components look very much like the TTG (Tonalite-Trondhjemite-Granodiorite), rocks that predominated in the terrestrial crust in the Archean era (over 2.5 billion years ago). This is the first evidence for continental crust on Mars.

This discovery has been possible because Gale crater, formed 3.61 billion years ago within older terrain, opens a new window on the Red Planet's primitive rocks. The crater walls provide a natural geological cut-away view 2-3 kilometers down into the crust, while the spectrometers of orbiting probes only analyze the surface to several tens of micrometers (millionths of a meter). [1]

Organic molecules in Martian mudstone

The SAM (Sample Analysis at Mars) instrument aboard the CURIOSITY rover is designed to analyze organic and inorganic compounds in the atmosphere, the surface regolith and rocks to evaluate the past and present habitability potential of Mars at Gale crater. Central to this task is the development of an inventory of the organic molecules present to elucidate the processes associated with their origin, their concentration and long-term preservation.

In this context, SAM identified unambiguously chlorobenzene (150–300 parts per billion by weight (ppbw)), and C_2 to C_4 dichloroalkanes (up to 70 ppbw) with the SAM Gas Chromatograph Mass Spectrometer (GCMS) and detection of chlorobenzene in the Evolved Gas Analysis (EGA) mode, in multiple portions of the fines from the Cumberland drill hole in the Sheepbed mudstone at Yellowknife Bay.

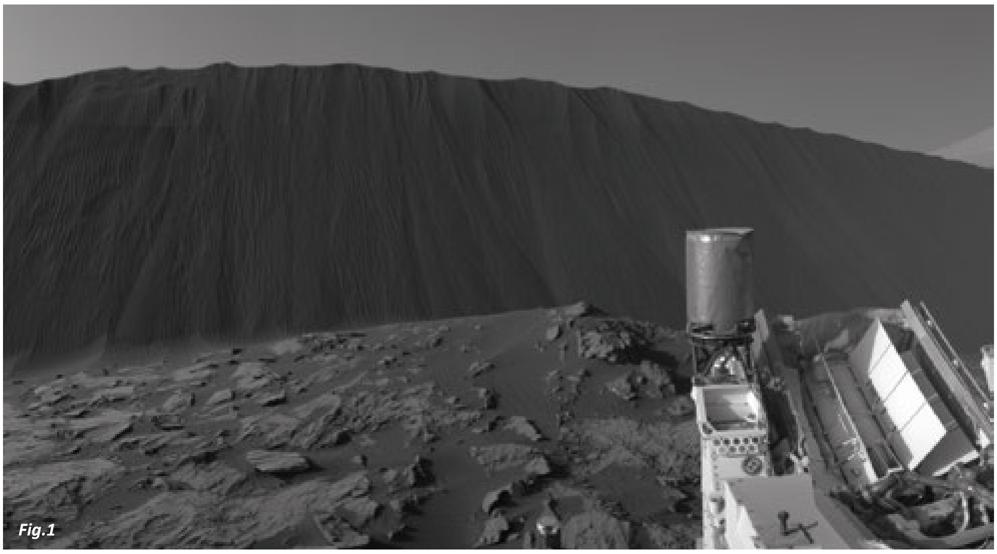
When combined with GCMS and EGA data from multiple scooped and drilled samples, blank runs and supporting laboratory analog studies, the elevated levels of chlorobenzene and the dichloroalkanes cannot be solely explained by instrument background sources known to be present in the SAM instrument. These chlorinated hydrocarbons are the reaction products of Martian chlorine and organic carbon derived from Martian sources (e.g. igneous, hydrothermal, atmospheric, or biological) or exogenous sources such as meteorites, comets, or interplanetary dust particles.

Further analysis will be needed to understand the origin of these Martian organic molecules. These results were obtained thanks to the participation of LATMOS[1] and LISA[2] ; the first author is a French postdoctoral researcher currently working at the Goddard Laboratories, which is responsible for the SAM instrument [2].

SAM discovers methane on Mars

French teams from LATMOS, LISA and IRAP contributed to the discovery of methane emissions in the Martian atmosphere that vary over monthly time scales. These results have defied explanation to date. In situ measurements made over a 20-month period by the TLS (Tunable Laser Spectrometer) of the SAM instrument on CURIOSITY at Gale crater detected the presence of methane in the atmosphere. TLS measured a background level of about 0.7 ± 0.25 ppbv (parts per billion by volume). This abundance is lower than model estimates of ultraviolet degradation of accreted interplanetary dust particles or carbonaceous chondrite meteorites. Additionally, in four measurements spanning a 2-month period, TLS observed elevated levels of methane of 7.2 ± 2.1 ppbv, implying that Mars is episodically producing methane from an unknown source so far.

Various hypotheses of geological or biological origin emerged. The SAM instrument continues to regularly measure methane in Gale crater to identify diurnal or seasonal cycles and if possible, determine methane source location(s). There is no doubt that the EXOMARS Trace Gas Orbiter (TGO) will provide additional data relevant to understanding and confirming the presence of this gas in the Martian atmosphere [3].



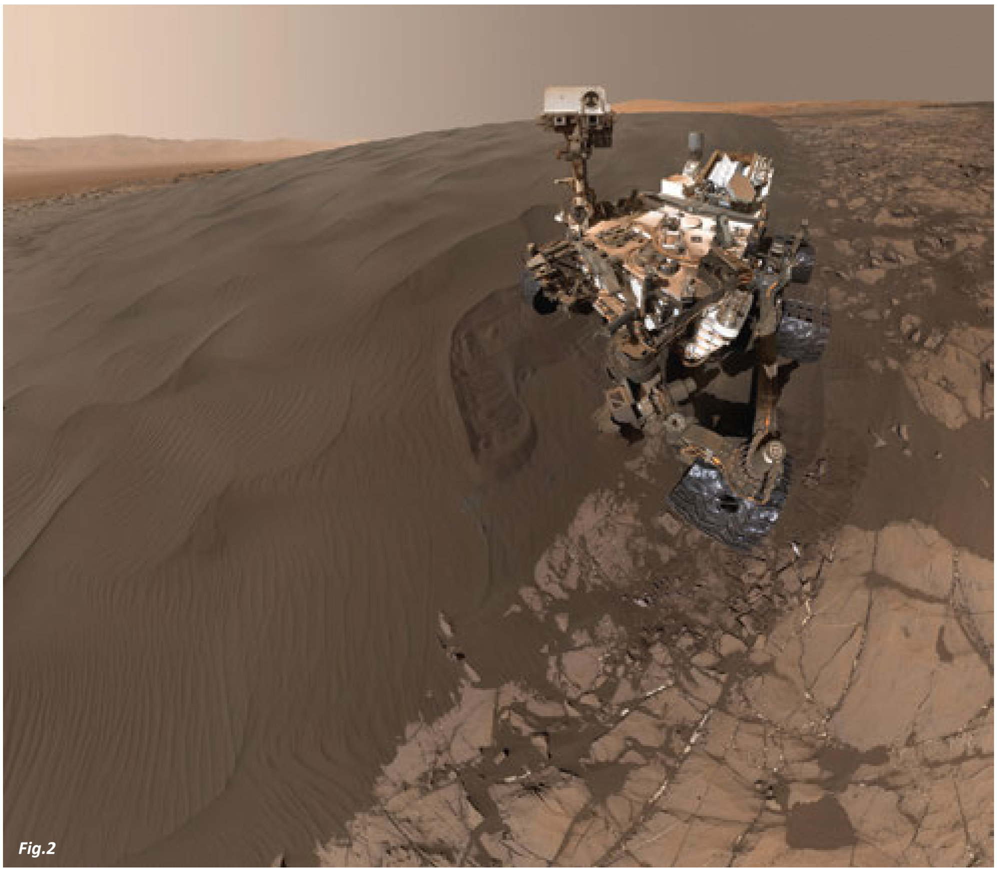


Fig. 1: This view from NASA's Curiosity Mars Rover shows the downwind side of "Namib Dune", which stands about 13 feet (four meters) high. The site is part of Bagnold Dunes, a band of dark sand dunes along the northwestern flank of Mars' Mount Sharp. The component images stitched together into this scene were taken with Curiosity's Navigation Camera (Navcam) on Dec. 17, 2015, during the 1,196th Martian day, or sol, of the rover's work on Mars. Since late 2015, Curiosity has been conducting the first upclose studies ever made of active sand dunes anywhere but on Earth. Under the influence of Martian wind, the Bagnold Dunes are migrating up to about one yard or meter per Earth year. The view spans from westward on the left to east-southeastward on the right. It is presented as a cylindrical perspective projection. *© NASA/JPL-Caltech*

Fig. 2: This self-portrait of NASA's Curiosity Mars rover shows the vehicle at "Namib Dune", where the rover's activities included scuffing into the dune with a wheel and scooping samples of sand for laboratory analysis. The scene combines 57 images taken on Jan. 19, 2016, during the 1,228th Martian day, or sol, of Curiosity's work on Mars. The camera used for this is the Mars Hand Lens Imager (MAHLI) at the end of the rover's robotic arm. *© NASA/JPL-Caltech/MSSS*

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Solar System

The CASSINI-HUYGENS mission (NASA-ESA)

Titan dunes created by tropical storms

The equatorial regions of Titan, Saturn's largest moon, are covered by a wide range of linear dunes that propagate eastward. This direction is opposite to that of the winds predicted by climate models, and poses one of Titan's greatest mysteries.

A Franco(1)-American team combined the results of a regional model of methane clouds with those of the Titan global climate model. It showed that dune formation was controlled by rare tropical methane storms, producing strong gusts blowing eastward and dominating sediment transport. These results explain the shape, dune orientation and propagation and provide information on the origin of its sand [1].

Mega-yardangs on Titan

Saturn's largest moon Titan is the only satellite in the Solar System with a dense atmosphere. Repeated flybys of this moon by the Cassini radar led to the discovery of several linear and strongly scattering structures, at mid-latitude, around 40° N. Their form is similar to that of mega-yardangs on Earth. Terrestrial yardangs are formed by aeolian erosion of loose layered sediments, often formed by former lake beds.

Thanks to the comparison of radiometric signatures of terrestrial structures with those of the structures present on the surface, we may conclude that there are two types of linear dunes in Titan's Belet Sand Sea and that the bright linear structures observed at 40° N latitude during the T64 and T83 flybys are very likely to be mega-yardangs.

The discovery, led by LAB(2), of mega yardangs on Titan's surface raises hypotheses about this moon's climate history: these structures might be the remnants of ancient lake basins, located at lower latitude than current lakes and seas, and formed at a time when liquid methane was not only found in polar regions. [2]

An ocean below Titan's surface measured by HUYGENS

One of the most astonishing findings of ESA's HUYGENS mission was the detection of an unusual source of electrical excitation in Titan's atmosphere.

To explain the unique pattern of these signals, scientists have suggested that Titan's atmosphere behaves like a giant electrical circuit, which is generated in the ionosphere when it interacts with Saturn's magnetosphere.

During descent, HUYGENS measured the "Schumann resonances" of Titan. On Earth, there is a very low frequency electromagnetic field that propagates in the atmosphere and bounces between two conductive layers, *i.e.*, oceans, in the bottom, and the ionized part of the atmosphere above. This resonance is maintained by storm lightning. There are no storms on Titan: resonance is due to currents induced by Saturn's magnetic field. The LPC2E(3) team has demonstrated that this resonance is trapped between the ionized part of the atmosphere and a conductive layer between 50 and 80 kilometers below the surface. Since ice is not conductive, this layer is probably made of liquid water. This discovery, combined with the measurement of tidal effects on Titan, reinforces the hypothesis of the presence of an ocean underneath Titan's surface. [3]

Titan's lakes are connected by an underground labyrinth

In 2007, images taken by the ESA HUYGENS probe revealed large liquid areas spread across the polar regions of Titan's icy surface. These lakes are not filled with water but with hydrocarbons, a form of organic compound that is also found naturally on Earth and whose origin on Titan comes mainly from precipitation associated with the presence of clouds in its atmosphere.

Due to its changing morphology, scientists suspect that Titan's crust is porous and contains a large amount of liquid hydrocarbons. However, Titan's hydrocarbon cycle, which links their presence in its subsurface and surface to their atmospheric emissions, remains relatively unknown. A new study led by the LAM(4) laboratory modeled the possible interplay between Titan's seas and its underground lake network, to which they might be linked. This phenomenon is expected to be visible from the surface of Titan. The lakes fed by subsurface reservoirs would show the same kind of composition, whereas those fed by rainfall would be different and contain methane, nitrogen and traces of argon and carbon monoxide. This means that if we are able to measure the composition of surface lakes, we would learn more about what is happening underground.

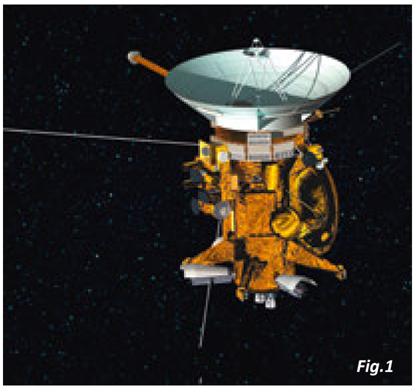
Fig.1

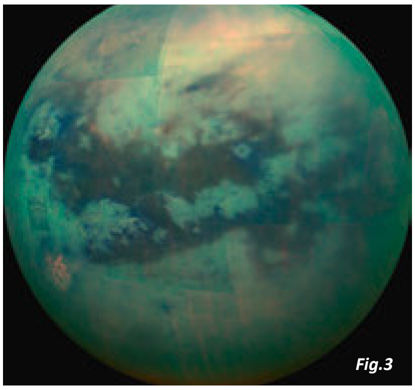
Fig.3

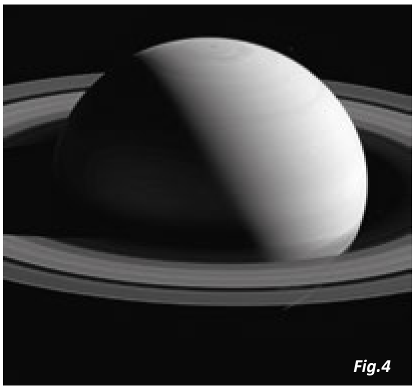
Fig.4

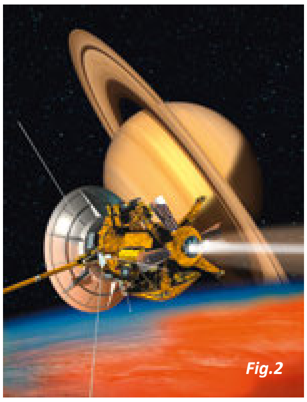
Fig.2

Fig. 1 and 2: Artist's view of the Cassini-Huygens probe flying toward Saturn and Titan. *© CNES/ill.David Ducros*

Fig. 3: This composite image shows an infrared view of Saturn's moon Titan from NASA's Cassini spacecraft, acquired during the mission's "T-114" flyby on Nov. 13, 2015. The spacecraft's visual and infrared mapping spectrometer (VIMS) instrument made these observations, in which blue represents wavelengths centered at 1.3 microns, green represents 2.0 microns, and red represents 5.0 microns. A view at visible wavelengths (centered around 0.5 microns) would show only Titan's hazy atmosphere (as in PIA14909). The near-infrared wavelengths in this image allow Cassini's vision to penetrate the haze and reveal the moon's surface. *© NASA/JPL/University of Arizona/University of Idaho*

Fig. 4: From a distance Saturn seems to exude an aura of serenity and peace. In spite of this appearance, Saturn is an active and dynamic world. Its atmosphere is a fast-moving and turbulent place with wind speeds in excess of 1,100 miles per hour (1,800 km per hour) in places. The lack of a solid surface to create drag means that there are fewer features to slow down the wind than on a planet like Earth. *© NASA/JPL-Caltech/Space Science Institute*

This study gives us a better understanding of how Titan's liquids interact and move around the surface and in the moon's interior [4].

Could there be a methane source in Enceladus' ocean?

A study carried out by LAM researchers has shown that the methane observed by the CASSINI mission in geysers of Enceladus, one of Saturn's main satellites, may come from a contemporary source in its hidden ocean.
It showed that under conditions of the Enceladus' internal ocean, clathrates – a particular form of water ice containing gases trapped inside cages – could form and deplete the ocean of volatile species.

Simulation results show that methane is efficiently trapped in clathrates, and that it becomes nearly ten times less abundant in the ocean than the value measured in geysers. CASSINI can observe as much methane if it is added into the ocean by an unknown source even more quickly than its sequestration allows it in the clathrates. The implications are particularly interesting, considering that methane can be produced by hydrothermal reactions or by biogenic sources. CASSINI has detected silicate nanoparticles in the geysers, which suggests that there could be hydrothermal activity in Enceladus' ocean. In addition, the bottom of Enceladus' glacial ocean might also harbor hot spots, with temperatures as high as 100 °C [5].

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