AUTHOR: F. Rocard, Solar System program scientist
CNES, 2 place Maurice Quentin, 75039 Paris, France.

Solar System


Fig. 1

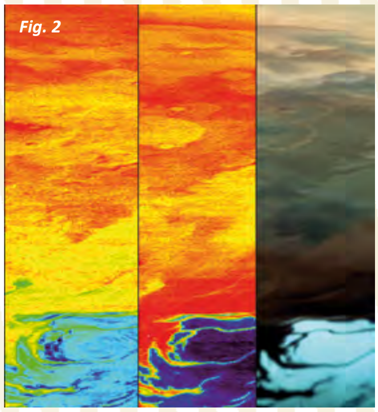
Fig. 2

ROSETTA, deciphering the Rosetta stone of our origins

The ROSETTA spacecraft of ESA, launched on March 2, 2004, is en route toward his target, the comet 67P/Churyumov-Gerasimenko. After nearly 31 months of hibernation, the probe woke up on January 20 with success. The coming months will be very busy during the approach of the comet and for its planned arrival early August at the comet and the landing of PHILAE in November (Fig. 1).

CNES coordinated all French contributions to the payload and the lander PHILAE: eleven instrumental and two technical contributions to the lander. CNES is in charge of the SONC (Science Operation and Navigation Centre) of PHILAE as part of the ground segment and in cooperation with DLR. During the last years, CNES has worked in tight coordination with the LCC (Lander Control Center) in DLR-Cologne to finalize the FSS (First Science Sequence) and the LTS (Long Term Science). The FSS is the first automatic sequence that will run just after landing during several days. This sequence will be powered by the primary battery, provided by CNES, until the end of the available energy. The FSS is expected to start later when the energy on the solar panels will be sufficient to charge the secondary battery. This long-term sequence will be uploaded periodically in order to activate one instrument after the other due to energy limitation.

After the FSS, Rosetta will escort the comet to study the emergence of its activity up to the perihelion from August 2015 onward.

A case for a warmer and wetter Mars

For more than ten years, the European probe MARS EXPRESS has been observing the red planet. It represents a great success for Europe, being its first mission dedicated to this planet. Consequently, the mission has been extended until the end of 2014 and probably onward.

New analysis of data sent back by the OMEGA spectrometer together with the data of CRISM on NASA MRO mission suggests that the planet was warm and wet in the Noachian eon around four billion years ago. A team from IAS (Institut d'Astrophysique Spatiale), LGL (Laboratoire de Géologie de Lyon) and LPGN (Laboratoire de Planétologie et de Géodynamique de Nantes) conducted a global analysis of widespread hydrous sediments, mainly sulphates and clays. But the question is how these sediments were formed and what the consequences for early Mars conditions are. It has been proposed that the clays may be formed subterraneous or have a non-aqueous origin. Weathering under a dry and cold climate results in a thin (< 1 m) upper layer of Fe/Mg-rich clays, whereas warmer and wetter climates generate thicker vertical sequences where Fe/Mg-rich clays are overlain by a layer of Al-rich smectites. The widespread distribution of weathering sequences and the consistency in their estimated ages are best explained if Mars experienced a period between the middle Noachian (> 3.85 Ga) and the end of the Noachian (~3.7 Ga) during which climatic conditions allowed sustained liquid water flow on its surface.

CASSINI, a distant cousin of the African salt lakes discovered on Titan

With the exception of Earth, Titan, Saturn's largest moon, is the only planetary body known to maintain liquids on its surface in a stable manner. On Titan, a complete hydrocarbon cycle, similar to the water cycle on Earth, is based on carbon, hydrogen and nitrogen atoms, and involves the atmosphere, the surface and the sub-surface. Titan's hydrocarbon lakes, discovered by the CASSINI mission, are an integral part of this process.

A new study analyzing the data from the CASSINI probe indicates that the lake known by the name Ontario Lacus on Titan behaves in a similar way to those known as "salt lakes" on Earth.

Ontario Lacus is the largest lake on Titan's southern hemisphere. It is a large topographical depression, 230 km long and 75 km wide, and only a few meters deep. It is located in a large sedimentary basin, very flat and several hundred kilometers wide, surrounded by small mountains of only a few hundred meters high at the most.

Recently, a group from the LPGN found proof of the existence of channels enduring through the period 2007 to 2010, dug into the lake bed in its southern half. This has led them to suppose that Ontario Lacus, until now assumed to be completely full of liquid hydrocarbons (principally methane and ethane) might in reality be a topographic depression with a very flat bottom, which dries up and is refilled thanks to subterranean liquids, thereby forming liquid zones surrounded by wet materials (probably sand or mud).

These characteristics make Ontario Lacus very similar to the ephemeral lakes known as "salt lakes" on Earth, among them the Etosha pan in a semiarid region of Namibia (Southern Africa) (Fig. 4).

CURIOSITY, results from ChemCam & SAM

Curiosity has successfully landed on August 6, 2012 in the Gale crater. France has contributed to ChemCam (IRAP) and SAM (LATMOS) instruments.

The FIMOC (French Instruments Mars Operation Centre), the MSL operation centre at CNES Toulouse, is operating in coordination with JPL both instruments, ChemCam with LANL and SAM with GSFC.

In November 2013, ChemCam fired its 100 000th shot on Martian rocks and soils. Up to a distance of seven meters, the instrument measures the elementary composition of rocks and soils by LIBS (Laser Induced Breakdown Spectroscopy), detecting the emission rays of the light in UV, visible and infrared induced by laser. ChemCam is very simple to use, producing one spectrum for each shot; it is the most used instrument on Curiosity. Among the huge amount of data, ChemCam has determined that Martian dust is enriched in hydrogen coming from water. Thus the dust is made of 2% water in weight. ChemCam has also detected the presence of calcium sulphate – known on Earth as gypsum – in the form of light-toned veins. Their spectra are most useful to determine what rock will be analysed more thoroughly by the analytical laboratory (SAM and Chemin).

The French team of LATMOS has delivered the chromatography columns of SAM suite. SAM has measured with a very high accuracy the atmospheric composition and determined the isotopic ratio of argon confirming that Mars has lost a huge amount of its atmosphere. Very precise analysis of the atmosphere has not confirmed the presence of methane at a level around 1 ppbv. SAM will regularly continue to make such analysis to detect possible evolution of the atmospheric composition.

JUICE, an ambitious mission to Jupiter and its moons

JUICE (JUpiter ICy moon Explorer) has been selected as the L1 mission of *Cosmic Vision* to study Ganymede, Callisto and Jupiter, for a launch in June 2022 and an arrival at Jupiter in 2030.
The SPC (Science Programme Committee) of ESA has announced the selection of the payload at the February 2013 meeting. This payload includes the following French contributions:

- MAJIS (Moons and Jupiter Imaging Spectrometer) is a visible & infrared imaging spectrometer. IAS will take the PIship of the instrument after the confirmation of the mission in late 2014;

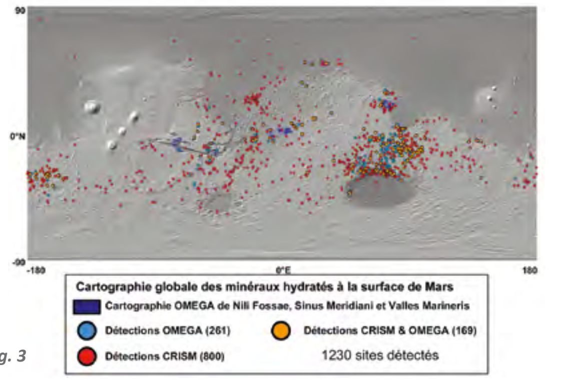

Fig. 3

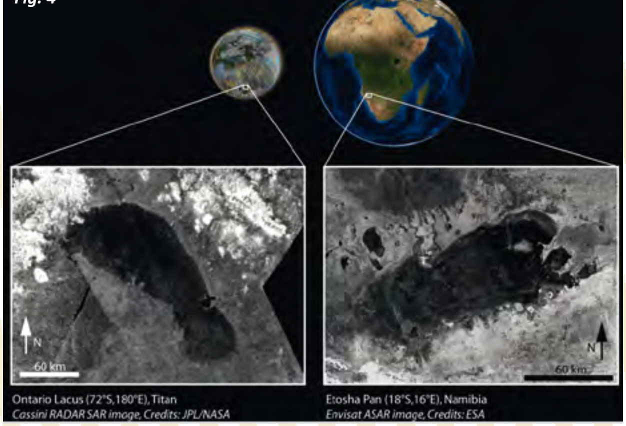

Fig. 4

- PEP (Particle Environment Package): participation of IRAP on particles sensors;
- RPWI (Radio & Plasma Wave Instrument): participation of LPC2E (provision of the Mutual Impedance Measurements), LPP (provision of the Search Coil Magnetometer) and LESIA (scientific coordination);
- SWI (Submillimeter Wave Instrument): participation of LERMA (synthetizer & tripler frequency) and LESIA (Co-Investigators);
- UVS (Ultraviolet Spectrometer): participation of LATMOS (grating);
- Scientific investigators on 3GM, GALA, JANUS, MAG, RIME and SUDA.

These investigations are currently in Phase A, supported by CNES up to the end on 2014. Phase B is expected to start next year.

[Fig. 1]
Artist view of the PHILAE lander on Comet Churyumov-Gerasimenko.
© CNES/ill./DUCROS David, 2014

[Fig. 2]
OMEGA image of the southern polar cap of Mars, January 18, 2004
© ESA/OMEGA

[Fig. 3]
Global and systematics investigation of hydrated minerals on Mars: 1 230 sites (Red observed by CRISM, Blue observed by OMEGA).
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[Fig. 4]
Ontario Lacus (230 x 75 km, Titan) and the Etosha pan (120 x 65 km, Namibia), two ephemeral lakes separated by 1.4 billion kilometers.
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Laboratory contribution

AUTHORS: M. Cabane(1), P. Coll(2), C. Szopa(3), A. Buch(4), D. Coscia(3), S. Teinturier(2)
(1) LATMOS, UMR 8190, 4 place Jussieu, 75005 Paris, France.
(2) LISA, UMR 7583, 5 rue Thomas-Mann, 75013 Paris, France.
(3) LATMOS, UMR 8190, 11 boulevard d'Alembert, 78280 Guyancourt, France.
(4) LGPM, Grande voie des vignes, 92295 Chatenay-Malabry, France.

Solar System

Exploration of Mars by Curiosity: some characteristics of soil and rocks as observed by SAM in Gale crater

Exploration de Mars : résultats de l'instrument SAM

➔ **Abstract:** The Sample Analysis at Mars (SAM) instrument suite onboard the rover Curiosity provides analytical techniques for exploring Martian materials, including volatile composition and search for organic compounds. Here we focus on the analysis of soil and rocks during the first 20 months on Mars, using mass spectrometry and gas chromatography.

➔ **Résumé :** La suite instrumentale SAM (Sample Analysis at Mars), à bord du rover Curiosity permet l'analyse des matériaux martiens, entre autres la recherche de volatils et de composés organiques. Nous examinons ici les résultats d'analyse de sols et de roches par spectrométrie de masse et chromatographie en phase gazeuse pendant les 20 premiers mois sur Mars.

During its journey towards Mount Sharp, Curiosity examined three sites, to obtain a better knowledge of Martian mineralogy, geochemistry and habitability. Capabilities of Curiosity were used to search for places of interest, collect (drill rocks or scoop soil), prepare samples and deliver them to SAM, which was developed at GSFC/NASA – P-I: P. Mahaffy [1]. Most of SAM subsystems are used: samples (~50 mg) are heated or pyrolyzed, up to about 1 000 °C, and the gases that they deliver (from H_2O to complex organic molecules) represent the sample's signature. Two analytical paths are possible. The first one is an Evolved Gas Analysis (EGA): the mass spectrometer is tuned on a mass that is representative of a given species, and its intensity is recorded along with the sample temperature (Fig. 1). Such spectra typically reflect a combination of processes including desorption of trapped volatiles, mineral thermal decomposition, and chemical reaction during heating. The second way consists, for a given temperature interval during an EGA, in trapping all gases into a physico-chemical trap. Later, the whole content of the trap is released for a GC-MS analysis. This leads to a separation of the various species, and helps to understand intricate MS spectra (Fig. 2). SAM-GC was developed by University of Paris/CNES. Besides, in parallel with what is done on Mars, experiments and simulations are performed on Earth, using spare models of GC-MS, GC, MS, or laboratory experiments, to provide a better understanding of SAM results [2].

Two different kinds of sites were examined. The first one is a sand-shadow dune, Rocknest (RN): Curiosity scooped the soil and ingested fine aeolian material into SAM [3], and into Chemin for X-Ray diffraction. The second sampling occurred at Yellowknife Bay, where mudstone rocks were drilled, at John-Klein (JK) and Cumberland (CB), and powders were delivered to SAM [4] and Chemin. These sands and stones were also examined by other instruments: at contact by APXS, from distance by ChemCam. We will focus here on SAM results for EGA and GC-MS analyses, and especially on what is understood from the observation of H_2O, O_2 and CO_2, and organics (other molecules were observed, e.g., SO_2, H_2S, HCl).

Water vapor is observed during EGAs. For sands (RN), a broad H_2O peak is observed around 150 to 300 °C. However, two peaks appear when heating rock powder at JK and CB, the first one from 150 to 300 °C as in RN and the second one between 500 and 800 °C (Fig. 1). The first peak, that is observed in both cases, sand and rock, at somewhat low temperatures, is mainly explained by the release of adsorbed water, of structural H_2O – e.g., bassanite $CaSO_4\,(H_2O)_{0,5}$ – and H_2O produced by dehydroxylation – e.g., akaganeite FeO(OH,Cl). These hypotheses are confirmed by Chemin results on RN samples; this corresponds to an amount of water that lies between 1.5 and 3 wt%. The second peak appears only for specimen collected by drilling rocks. It is fully consistent with the dehydroxylation of phyllosilicates, and the signature of clays that appeared in Chemin spectra. The main constituent could be smectite and, from SAM and Chemin, the total amount of clays in JK and CB could be 18 ± 11 wt%.

Oxygen and carbon dioxide are observed in EGA spectra for all samples (RN, JK, CB; see Fig. 1). The onset of the O_2 peak, from 150 °C, correlates with the release of chlorinated hydrocarbons [3] (see next paragraph about organics). This is understood as the presence of perchlorates, near equator; up to now, perchlorates had been identified at high latitude only, at Mars PHOENIX landing site. Release of O_2 from RN aeolian material is consistent with the decomposition of Ca-perchlorate. In the case of JK and CB, it could be Mg- and Fe-perchlorates. Perchlorate amounts are close to the

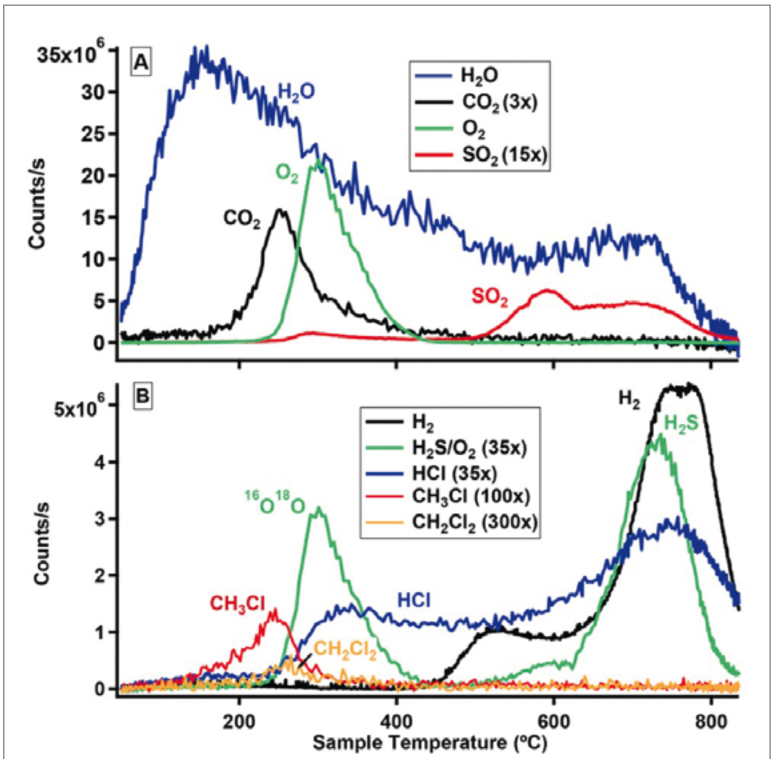

Fig. 1

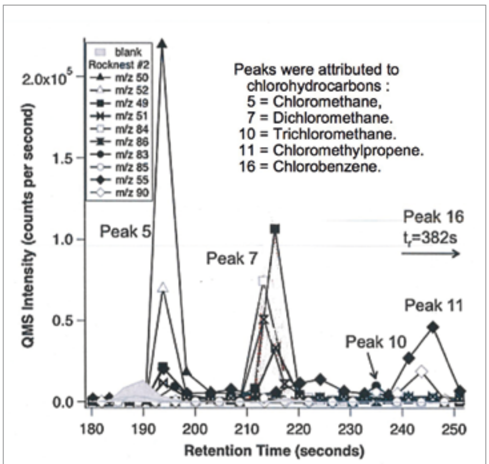

Fig. 2

[Fig. 1]
Evolved Gas Analysis for a mudstone drilled at Yellowknife Bay (CB-2 sample). For species that saturated the MS (CO_2 and H_2O) isotopologues were used (resp. m/z = 12 and 20).
© From [4]

[Fig. 2]
Chlorohydrocarbons: a raw chromatogram is shown for a soil sample from Rocknest (RN-2 sample). The MS is tuned on masses indicated in the box.
© Adapted from [5]

ones observed by PHOENIX (0.4 to 0.6 wt%). Concerning CO_2, adsorbed gas is released, as structural CO_2, from Fe/Mg carbonates for example. So, carbonates appear to be a source (< 1%, below Chemin detection), but some of the observed CO_2 comes likely from a combustion of organic matter in the presence of O_2. This matter might be indigenous, but MS and GC-MS led to the conclusion that MTBSTFA, an organic silylated organic reagent that was carried to Mars for future wet chemistry experiments, plays a non-negligible role, due to a possible leak [5]. Nevertheless, experiments in which the amount of sample was increased, and so the amount of measured CO_2, show that, at least in JK and CB, the dominant source for CO_2 came from the mudstone itself [4].

Concerning organics, silylated hydrocarbons and chlorohydrocarbons (chloromethane CH_3Cl etc. at nmol level, Fig. 2) appear when heating solid samples at temperatures up to 350 °C [5]. Laboratory experiments show that this is fully understandable by reactions between MTBSTFA (see above) and minerals that compose the sample. Traces of chloro- and dichloro-methane were identified by VIKING, at pmol level, which could be attributed to the presence of perchlorates and indigenous or terrestrial organics. Up to now, there are no conclusive EGA or GC-MS observations of organic molecules indigenous to the Yellowknife mudstones, but the possibility is not ruled out [4].

What is observed at Yellowknife Bay leads to important conclusions: this place, where one observes clays representative of past aqueous environment, at neutral pH and low salinity, where key nutrients and redox possibilities are available, may represent a habitable fluvio-lacustrine environment [6]. Curiosity carries on with analyses, making its way towards Mount Sharp and its strata.

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AUTHORS: S. Maurice(1), R. C. Wiens(2), O. Gasnault(1), S. M. Clegg(2), O. Forni(1), E. Lorigny(3), B. L. Barraclough(2) and the ChemCam team

(1) IRAP, UMR 5277, 9 avenue du Colonel Roche, 31028 Toulouse Cedex 4, France.
(2) Los Alamos National Laboratory, P.O. Box 1663 Los Alamos, NM 87545, New Mexico, USA.
(3) Centre National d'Etudes Spatiales, 18 avenue Edouard Belin, 31401 Toulouse Cedex 9, France.

Solar System

Elemental composition at Gale Crater, Mars, from ChemCam instrument onboard the Curiosity rover

Composition élémentaire du cratère Gale, Mars, à partir de l'instrument ChemCam à bord du rover Curiosity

➔ Abstract: The Mars Science Laboratory (MSL) prime mission has been a tremendous success, as Curiosity revealed the past habitability of Mars at Gale crater. ChemCam is one instrument of the Curiosity science payload. Since it was activated, it has fired its laser more than 130 000 times, acquiring each time the signature of the elemental composition of Mars rocks and soils. We describe a few of ChemCam's results, with regards to the soil physics and chemistry, the composition of igneous rocks, the detection of minor elements, and finally the composition of sedimentary rocks.

➔ Résumé : La mission nominale du projet Mars Science Laboratory (MSL) est un franc succès : le rover Curiosity a mis en évidence l'habitabilité passée de Mars dans le cratère Gale. ChemCam fait partie de la charge utile de cette mission. Depuis sa mise en route, il a activé son laser plus de 130 000 fois, acquérant chaque fois la signature de la composition élémentaire des roches et des sols de Mars. Nous décrivons quelques un des résultats de ChemCam, à savoir la physique et la chimie des sols, la composition des roches ignées, la détection d'éléments mineurs, et finalement la composition de cibles sédimentaires.

The Mars Science Laboratory (MSL) prime mission has been a tremendous success. It landed on August 6, 2012 in a 150 km diameter crater, named Gale, which is situated at the northern edge of the southern highlands. Within its first year[1] of operation, its rover Curiosity traversed over stream-rounded pebbles to the "Yellowknife" site where mud had accumulated in an ancient lake. The mudstones were drilled and comprehensively analyzed. This yields evidence for long-lived fresh water, the major elemental building blocks of life, and a source of chemical energy capable of sustaining microbial life [1].

ChemCam[2] is one of ten instruments onboard Curiosity. Its aim is to perform compositional measurements at remote sensing distances. ChemCam uses a technique called Laser-Induced Breakdown Spectroscopy (LIBS) in which a pulsed laser is focused to a 350-550 µm spot to ablate material from targets up to 7 m from the rover and it observes the atomic emission spectra. These yield semi-quantitative elemental compositions after calibration and comparison to a spectral library. Typical spectra are collected from 30-50 laser pulses for each observation (Fig. 1). The first several shots remove surface dust, while spectra from the remaining shots are averaged to obtain the rock or soil compositions. ChemCam includes a remote micro-imager (RMI) to provide 50 micro-radian resolution gray-scale context images. Pairs of NavCam and Mastcam images provide broader contexts and true color for the ChemCam observations.

Many original ChemCam results have been obtained. A few are summarized hereafter:

• *Soil physics and chemistry*. With the very first laser shot on Mars ChemCam discovered that the soil and even the wind-blown dust are hydrated. The SAM instrument quantified the amounts while ChemCam has shown the ubiquity of water in the soils with a large number of measurements and has helped constrain the mineral component in the soil containing the water. ChemCam showed that all soils so far consist of multiple components including contributions from the local rock types. We can correlate these components with characteristic grain sizes [2].

• *Igneous Mars*. In the very first week ChemCam yielded the first high-silicon rock compositions. These compositions have been found not only in float rocks, but in the pebbles comprising conglomerates and in coarse soil grains. The implication is that the igneous volcanism of Mars is much more varied and includes much more evolved magmas than previously thought [3].

• *Minor elements with major implications.* Fluorine could not be previously analyzed on Mars. ChemCam made multiple observations of fluorine. Its presence implies lower magma melting temperatures, and it is sometimes present as an element within alteration minerals. Another minor element, manganese, only occurs as a major mineral constituent under a highly oxidizing environment which currently does not exist on Mars. The discovery by ChemCam of a number of Mn-rich minerals has strong potential implications for the paleo-atmosphere of Mars [4]. LIBS is highly sensitive to alkali elements at ppm levels. Lithium is a strong indicator of alteration; Rb, Sr, and Ba each tend to be sequestered in different minerals: Rb in K-feldspars, Sr in plagioclase, etc. The global Rb/K ratio has important implications for crustal evolution [5].

• *Sedimentary Mars*. The micro-beam LIBS technique allows us to probe small areas, looking for interstitial material. For example, evidence for Fe-rich hydrated cements was observed in the conglomerate Link [6]. ChemCam was the first to observe the composition of the calcium sulfate veins in the Yellowknife Bay units [7] (Fig. 2). ChemCam provided additional

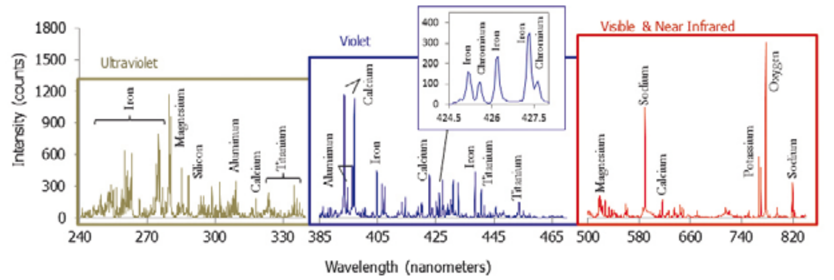

Fig. 1

Fig. 3

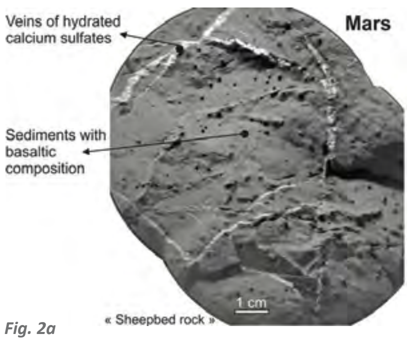

Fig. 2a

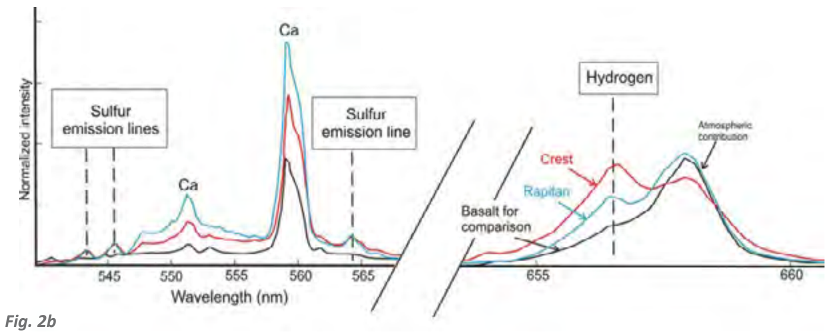

Fig. 2b

fine-scale geochemical constraints within the Yellowknife Bay formation: correlated Mg and Li variations were observed along diagenetic features such as raised ridges. ChemCam analyses of isopachous cements within early diagenetic raised ridges indicate the presence of a Mg-Fe-Cl-rich phase (or assemblage) [8]. ChemCam used > 30 000 shots and > 100 of RMIs to characterize the Yellowknife Bay sediments far more comprehensively than with any other instrument. Using large aggregates of observations provides high confidence in the relative differences in these units [9-10].

From this vantage point at the end of the prime mission ChemCam has performed more than 130 000 laser shots for ~4 000 individual LIBS observations and ~2 000 context images. ChemCam is healthy and continues to operate nominally.

[Fig. 1]
This graph shows a spectrum recorded by ChemCam on a rock target called "Ithaca" on October 30, 2013. The spectrum is typical of volcanic material, although Ithaca is a sedimentary rock with essentially unaltered chemistry. The identified elements include a standard major-element suite of Si, Mg, Al, Ca, Na, K, O and Ti. Cr and Mn, though not labelled, were also present.
© NASA/JPL-Caltech/LANL/CNES/IRAP/UNM

[Fig. 2a and 2b]
2a ChemCam analysis of "Sheepbed rock" on sol 126 of the mission. From RMI high resolution images, white veins can be identified.
© Caltech/LANL/CNES/IRAP/LPGNantes/CNRS/LGLyon/Planet-Terre.
2b For those veins, the LIBS spectrum identifies calcium sulfates through the unambiguous detection of S and Ca.
The 1 to 5-mm fractures are filled with calcium sulfate minerals that precipitated from fluids at low to moderate temperatures.
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[Fig. 3]
Curiosity sets its arm at John Klein location for a drill.
©NASA/JPL-Caltech/D. Bouic

[1] *End of primary mission was Jun. 24, 2014; 668 Martian days = 1 Martian year after landing.*

[2] *R. Wiens is ChemCam principal investigator and S. Maurice his deputy. Funding for ChemCam development was provided by NASA and CNES. ChemCam is operated every other week, alternatively from LANL and CNES.*

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AUTHOR: D. Bockelée-Morvan[1]

(1) LESIA, UMR 8109, Université Paris-Diderot, 5 place Jules Janssen, 92195 Meudon Cedex, France.

Laboratory contribution

Solar System

A water exosphere around dwarf planet Ceres discovered by the HERSCHEL space observatory

Une exosphère de vapeur d'eau autour de l'astéroïde Cérès révélée par l'observatoire spatial Herschel

➔ **Abstract:** Since the 70's, the question of the presence of water ice inside and on the surface of Ceres is strongly debated. Unequivocal evidence for ice would have strong implications on the distribution of water ice in the early Solar System, and on the formation place of the main belt primitive asteroids. Several times between 2011 and 2013, the HERSCHEL space observatory detected water vapor around Ceres originating from two localized sources linked to known mid-latitude regions.

➔ **Résumé :** Depuis les années 1970, la question de la présence de glace à la surface et dans le sous-sol de l'astéroïde Cérès est fortement débattue, avec ce que cela implique sur la distribution de la glace dans le Système Solaire primitif et sur le lieu de formation des astéroïdes de la ceinture principale. À plusieurs reprises entre 2011 et 2013, le télescope spatial Herschel a détecté de la vapeur d'eau autour de Cérès, provenant de deux sources bien localisées à la surface, mettant fin à la controverse.

While the "snowline" classically divides Solar System objects into dry bodies, ranging out to the main asteroid belt, and icy bodies beyond it, dynamical models of the young Solar System considering planetary migration suggest that such icy bodies may have migrated into the asteroid belt [1]. Recent observations indicate the presence of water ice on the surface of some asteroids [2], with sublimation a potential reason for the dust activity observed on others, the so-called main-belt comets [3].

With a diameter of 974 km, Ceres is the largest body of the asteroid main belt, representing about 25% of its total mass, and is also classified as a dwarf planet. Its composition remains uncertain. Some near-infrared signatures may be possibly due to water ice, but are more likely from hydrated minerals present on the surface [2-4]. The low density of Ceres argues for up to 25% of water ice inside Ceres, and interior models suggest the presence of an icy mantle and possibly liquid water below that mantle [5-6]. Since evidence from surface spectra has remained inconclusive, searches for water on Ceres concentrated on water vapor outgassing from the surface or subsurface. Indeed, an early search of OH, the main dissociation product of water vapor, with the International Ultraviolet Explorer resulted in a marginal detection in one out of two observations [7]. A later search for the same OH line did not confirm the earlier detection [8], possibly because it was performed when Ceres was further from the Sun.

As detailed by Küppers *et al.* (2013)[9], we observed Ceres with the Heterodyne Instrument for the Far Infrared (HIFI) on the HERSCHEL Space Observatory on four occasions between November 2011 and March 2013, partly through the MACH-11 (Measurements of Asteroids and Comets with Herschel-11 targets) guaranteed time program (PI L. O'Rourke). We searched for the first time for water vapour directly, by observing its fundamental 1_{10}-1_{01} rotational line at 556.936 GHz. The angular diameter of Ceres was < 1'', compared to the field of view of HIFI of approximately 40''. Therefore we derived information on the longitudinal distribution of the water sources from the variation of the signal over the rotation of Ceres (9 h). The non-detection at 2.94 AU in November 2011, and the first detection at 2.72 AU in October 2012, are consistent with the steep increase of water ice sublimation between 3 and 2.5 AU.

Fig. 1 shows the time-averaged spectra taken on March 6, 2013, normalized to the continuum of Ceres. At the frequency of the water line, an absorption in the thermal continuum from Ceres is clearly visible, next to a weaker emission line. Water molecules outflowing towards the observer causes the absorption line to be blue-shifted. The emission line is from water molecules on the limb.

The strength of absorption is variable on short timescales (hours) (Fig. 2). We interpret the short-term variation in terms of localized sources on Ceres rotating into and out of the hemisphere visible by HERSCHEL [9]. Fig. 2 shows the correlation of the strength of the absorption line with the position of features on Ceres surface that are known from ground-based and HUBBLE Space Telescope observations [10][11]. The absorption line strength is strongly correlated with the visibility of surface areas identified as dark regions Piazzi and A (about 5% darker than the average surface). We identify those regions as the likely source of most of the evaporating water. The temporal variation of the absorption line over one Ceres rotation (9 h) is nicely explained with a model considering outgassing of 6 kg.s^{-1} of water from these two regions (Fig. 2) [9].

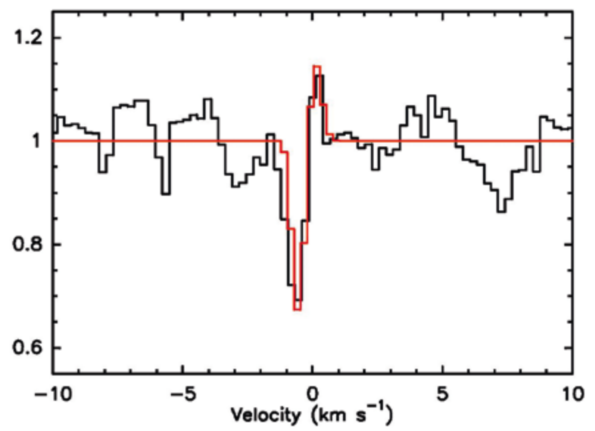

Fig. 1

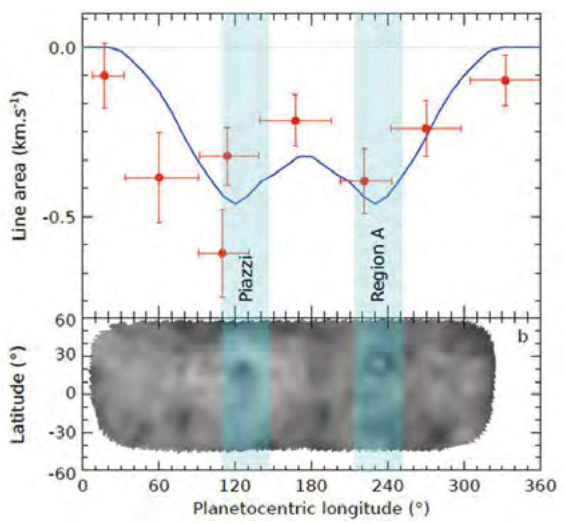

Fig. 2

Fig. 3

[Fig. 1]
Spectrum of the water 557 GHz line observed in Ceres on March 6, 2013 (black), and model fit (red). © Figure from [9]

[Fig. 2]
Variability of water absorption on March 6, 2013 as a function of the longitude of the sub-observer point. Top: Data are in red; the curve in blue is from a gas-dynamic model where water is released from regions Piazzi and A. Bottom : map of Ceres [10]. © Figure from [9]

[Fig. 3]
Artist view of water emission from Ceres.
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This vapor production requires only a small fraction of Ceres surface (0.6 km^2) to be covered by water ice.

The water activity of Ceres is not concentrated on polar regions where water ice is expected to be the most stable. Then, there are two possible mechanisms to explain the observed water production on Ceres. The first is cometary type sublimation of (near) surface ice. In this case the sublimating ice drags near-surface dust with it and in this way locally removes the surface layer and exposes fresh ice. Transport from the interior is not required. The second alternative is geysers or cryovolcanoes. An interior heat source is needed in this case. Some models suggest that a warm layer in the interior heated by long-lived radioisotopes may maintain cryovolcanism on Ceres at the present time [12].

This discovery supports the idea that Ceres possesses an icy mantle, and fits with the new vision of our Solar System, with a continuum in composition and ice content between asteroid and comet populations. The DAWN mission arriving to orbit Ceres in spring 2015 is expected to be a key-element in providing a long term follow up on the water outgassing behavior of Ceres.

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