

EPSC2018
MTI7 abstracts

Scientific rationale for *in situ* exploration of the ice giants

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Abstract

The ice giants Uranus and Neptune are the least understood class of planets in our solar system but the most frequently observed type of exoplanets. Presumed to have a small rocky core, a deep interior comprising ~70% heavy elements surrounded by a more dilute outer envelope of H₂ and He, Uranus and Neptune are fundamentally different from the better-explored gas giants Jupiter and Saturn. Because of the lack of dedicated exploration missions, our knowledge of the composition and atmospheric processes of these distant worlds is primarily derived from remote sensing from Earth-based observatories and space telescopes. As a result, Uranus's and Neptune's physical and atmospheric properties remain poorly constrained and their roles in the evolution of the Solar System not well understood. Exploration of an ice giant system is therefore a high-priority science objective as these systems (including the magnetosphere, satellites, rings, atmosphere, and interior) challenge our understanding of planetary formation and evolution. Here we describe the main scientific goals to be addressed by a future *in situ* exploration of an ice giant. An atmospheric entry probe targeting the 10-bar level, about 5 scale heights beneath the tropopause, would yield insight into two broad themes: i) the formation history of the ice giants and, in a broader extent, that of the Solar System, and ii) the processes at play in planetary atmospheres.

Solar System formation

To understand the formation of giant planets and the origin of our Solar System, statistical data obtained

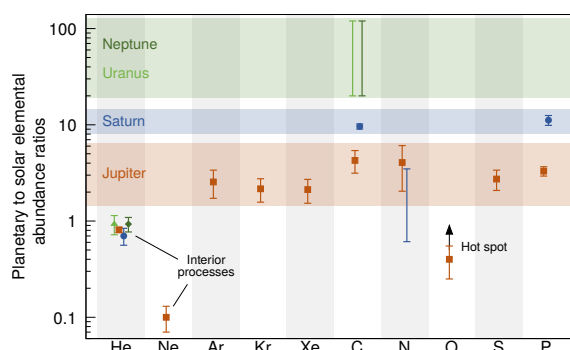


Figure 1: Enrichment factors (with respect to the solar value) of noble gases and heavy elements in the giant planets. See Mousis et al. (2018) and Atreya et al. (2018) for references.

from the observation of exoplanetary systems must be supplemented by direct measurements of the composition of the planets in our Solar System (see Fig. 1). A giant planet's bulk composition depends on the timing and location of planet formation, subsequent migration and the delivery mechanisms for the heavier elements. By measuring the chemical inventory in at least one of the ice giants, and contrasting these with measurements made (i) at Jupiter by the NASA *Galileo* probe and the Juno mission, (ii) primitive materials found in small bodies, and (iii) the composition of our parent star and the local interstellar medium, much can be revealed about the conditions at work during the formation of our planetary system (see Fig. 2).

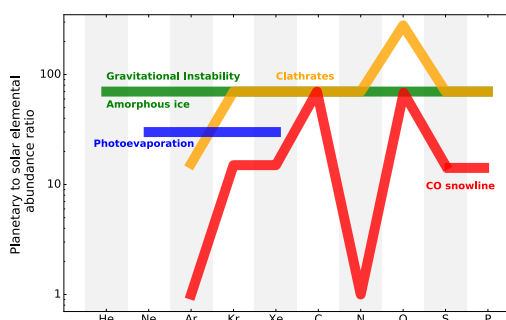


Figure 2: Qualitative differences between the enrichments in volatiles predicted in Uranus and Neptune predicted by the different formation scenarios (calibrations based on the carbon determination). The resulting enrichments for the different volatiles are shown in green (disk instability model and amorphous ice), orange (clathrates), blue (photoevaporation) and red (CO snowline). See Mousis et al. (2018) for a comparison between the existing formation scenarios.

Planetary Atmospheric Processes

Uranus and Neptune provide a tantalising opportunity to sample atmospheric processes in environments not found elsewhere in our Solar System – namely the complex, cloud-dominated weather layers of cold ice-rich giants. Remote sensing has revealed stark differences between these two worlds – sluggish Uranus, with its fine banding, extreme axial tilt and negligible internal heat source; and vigorous Neptune, with its episodic cloud outbursts and polar vortices. But remote sensing is challenging without in situ “ground-truth”. A probe would (i) provide access to chemical species that have not been previously detected due to the low atmospheric temperatures; (ii) reveal the vertical temperature, chemical and aerosol structure down to at least 10 bar; (iii) determine the vertical changes to ice giant winds as a function of depth; and (iv) reveal how energy is transported upwards through an ice giant atmosphere. A probe to Uranus, Neptune, or both worlds would provide a vital counterpoint to our understanding of atmospheric processes on the H_2 -dominated gas giants, Jupiter and Saturn.

Conclusions

Results obtained from an ice-giant probe are necessary to improve our understanding of the processes by which the ice giants formed, including the composition and properties of the local solar nebula at the time and location of ice giant formation. By extending the legacy of the Galileo probe mission and possibly a future Saturn entry probe mission, Uranus and Neptune probe(s) would further discriminate between and refine theories addressing the formation, and chemical, dynamical, and thermal evolution of the giant planets, the entire solar system including Earth and the other terrestrial planets, and the formation of other planetary systems.

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In situ measurements of the xenon isotopes at Uranus and Neptune: a powerful tool to decipher the origin of ice giant building blocks

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Abstract

The isotopes of xenon in the coma of comet 67P/Churyumov-Gerasimenko (67P/C-G) have recently been analysed by the ROSINA instrument aboard the Rosetta spacecraft (Marty et al. 2017). The xenon isotopic composition measured in 67P/C-G displays important deficit in heavy xenon isotopes compared to the solar wind, and suggests that this element might result from a nucleosynthetic mix that is different from that which produced solar xenon (Marty et al. 2017). The xenon isotopic composition has also been measured by the Galileo probe in the atmosphere of Jupiter, with isotopic ratios indistinguishable from terrestrial and solar ratios (Niemann et al. 1998). This difference between the xenon isotopic compositions of Jupiter and 67P/C-G suggests that the outer solar system bodies might have formed from different reservoirs of materials.

Meanwhile, the deuterium-to-hydrogen ratio sampled in 67P/C-G, which is higher than most of the values measured in other comets, suggests that this body formed at very high heliocentric distances (Altwegg et al. 2015), thus in regions potentially corresponding to those where the building blocks of Uranus and Neptune formed. A key measurement to investigate this hypothesis would be then to measure *in situ* the xenon isotopic ratios in the atmospheres of the ice giants Uranus and Neptune. A deficit in heavy xenon isotopes similar to that measured in 67P/C-G would confirm that, at least, two reservoirs of materials contributed to the formation of the outer solar system bodies. This would also suggest that the two giants would have grown from materials formed in a region located further away in the PSN than those from which Jupiter, and eventually Saturn, formed.

Such measurements could be achieved during the

descent of an atmospheric probe released by an orbiter in the atmospheres of Uranus or Neptune in the context of a joint NASA/ESA mission (Atkinson et al. 2018; Mousis et al. 2018).

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The Jovian Dynamics and Composition Analyzer on JUICE

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Abstract

The Jovian Dynamics and Composition Analyzer (JDC), a new instrument design currently developed and built by the Swedish Institute of Space Physics, as part of the Particle Environment Package (PEP), will explore the Jovian system on board of the JUICE spacecraft. The sensor's science objective is to study the Jovian moons and Jupiter's magnetosphere. In the development process the functionality and performance were simulated. These results will be compared to the behavior of the manufactured sensor in the second half of 2018.

1. Introduction

The Jovian Dynamics and Composition Analyzer (JDC), a new instrument design, built at the Swedish Institute of Space Physics, is included as one of six sensors into the Particle Environment Package (PEP)[1]. PEP is one of the scientific payloads on the Jupiter ICy moons Explorer (JUICE) which is part of ESAs cosmic vision 2015 - 2025 program. JUICE will be launched in 2022 with its mission goal to explore the Jovian system with a focus on the moons Europa, Callisto and Ganymede. JDC will measure the 3D distribution functions of positive and negative ions, including electrons, in an energy range from 1 eV to 40 keV.

2. JDCs scientific Objectives

The scientific objectives of JDC can be split into two parts, (1) studying the structure, creation and maintenance of the Jovian magnetodisc and (2) studying properties of the four Galilean moons, like (2a) the interaction of the Jovian magnetosphere with the moons; (2b) the study of the exospheric composition for Ganymede, Callisto and Europa; (2c) the precipitating plasma populations on the surfaces of Ganymede

and Callisto; (2d) and 3D continuous plasma moment measurements to investigate the interior of Ganymede.

3. Instrument

The JUICE payloads will be exposed to a high flux of penetrating electrons in the harsh Jovian radiation environment. While electronics are most affected by the Total Ionization Dose (TID), degradation of the detectors depends on the peak instantaneous flux. Appropriate shielding is reducing the amount of penetrating electrons, to ensure the required performance over the complete mission of electronics and detectors. The electrons absorbed by the shielding produce Bremsstrahlung, which affects the detectors. Therefore, the shielding is optimized to reduce the impact of the Bremsstrahlung on the measurements.

The sensor with its different subsystems is shown in Figure 1.

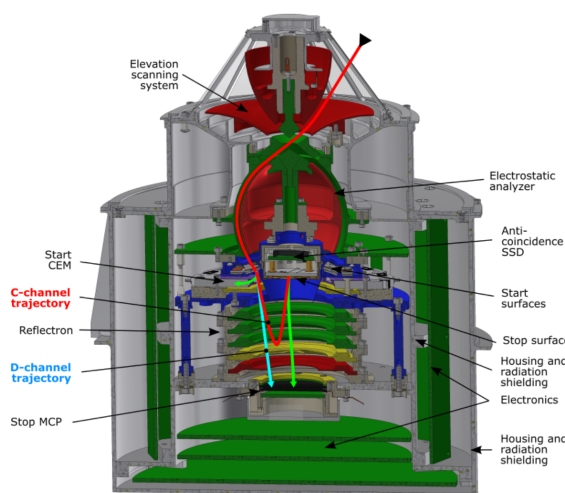


Figure 1: cross section of JDC with typical particle trajectories indicated

Following a typical trajectory, particles will enter JDC through the elevation scanning system on top of the

sensor. This subsystem consists of two electrodes between which an electric field is applied. By adjusting this electric field 12 elevation steps are covered. The field-of-view is further divided into 16 azimuthal sectors. With this a hemispherical field-of-view is obtained.

Subsequently particles pass through the electrostatic analyzer, which has a compact wedge shaped form[2]. In the electrostatic analyzer the particles are separated according to their energy per charge. The polarity of the voltages in the electrostatic analyzer can be switched, to measure positive and negative particles, including electrons.

Table 1: Expected performance of JDC

Parameter	Performance
Particle species	(i+),(i-),(e)
Energy range	1 eV - 40 keV
Energy resolution	12%
Mass range	1 amu - 70 amu
Mass resolution	2 - 3 (D-channel) ≥ 20 (C-channel)
Field of view	90° x 180° (< 25 keV) < 90° x 180° (> 25 keV)
Angular resolution	5.5° x 19.5°
Time resolution	2D per 0.8 s 3D per 11 s
G - Factor	Total: $8 \times 10^{-3} \frac{\text{cm}^2 \text{sreV}}{\text{eV}}$ Pixel: $5.6 \times 10^{-4} \frac{\text{cm}^2 \text{sreV}}{\text{eV}}$

The exit of the electrostatic analyzer leads the particle to one of 16 azimuthal start surfaces. The particle produces secondary electrons upon scattering on the start surface, changing its charge state to either positive, negative or neutral - with the neutral particles being dominant. The before mentioned secondary electrons are guided into start Channel Electron Multipliers (CEMs), to create the start signal for the time-of-flight measurement. Depending on the new charge state of the particle, different trajectories are possible: The neutral particles propagate on straight lines, without any further interaction inside the reflectron until they hit the stop Multi Channel Plate (MCP). Positive ions are reflected in the linear electric field of the reflectron and will hit the stop surface guarded by an anti-coincidence Solid State Detector (SSD). During this interaction additional secondary electrons are produced which are focused into the center part of the stop MCP. Negative ions are accelerated inside the linear

electric field and their trajectory is slightly bent compared to the trajectory of the neutrals. The stop MCP anode is divided into three separate regions: The center region for the electrons, the outer region, where negative ions and neutrals are detected and a ring in between where particles from both particle populations can be detected. With this setup it is possible to get a high sensitivity for neutrals and negative ions in the D(ynamics)-channel and a high mass resolution for positive ions in the C(omposition)-channel. The performance values are shown in Table 1.

The detectors are placed in the center of JDC, surrounded by an onion shaped radiation shielding: The innermost shell is built out of aluminum, followed by the electronic boards and the outermost layer out of tungsten alloy.

The mechanical assembly of the technological model is currently ongoing and first light of JDC is in the second half of 2018. A first glimpse on the mechanical parts of the entrance system of JDC can be seen in Figure 2. After first light the sensors performance will be compared with the predicted properties, shown in Table 1.

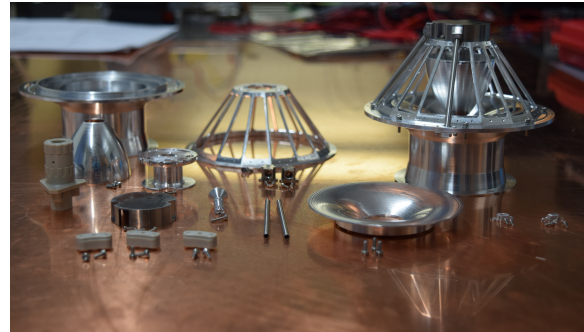


Figure 2: JDC TM deflector mechanical parts assembly

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The CheMin X-ray Diffractometer: Results from Mars and Prospects for Next Generation XRD Instruments

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Abstract

The CheMin X-ray Diffractometer (XRD) on the Mars Science Laboratory rover *Curiosity* provided the first definitive and quantitative mineralogy of the Mars surface. In its 5+ year deployment, data from CheMin revolutionized our understanding of surface processes and environments on early Mars.

CheMin follow-on instruments are being designed with improved diffraction and fluorescence capabilities and relaxed sample preparation requirements for landed missions to Mars, Earth's moon and other solar system objects.

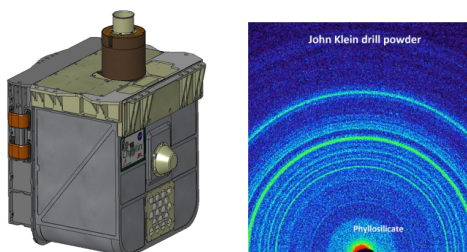


Figure 1: The MSL CheMin instrument (left) and 2D XRD data (right). Resolution is $\sim 0.3^\circ 2\theta$.

1. The CheMin Instrument

X-ray Diffraction is the reference analytical method for mineral identification and quantification in terrestrial laboratories. Data from CheMin, the first X-ray diffractometer flown in space (see Fig. 1) established the quantitative mineralogy of the Mars soil [1], characterized the first habitable environment on another planet [2], placed an upper limit on the concentration of CO_2 in the Hesperian atmosphere of Mars using the mineralogical composition of ancient lake sediments [3], and provide the first *in situ* evidence of the dessication and oxidation of early Mars [4]. All CheMin XRD patterns and mineral

abundances derived using Rietveld refinement, as well as open access journal articles are available and downloadable from the Open Data Repository [5].

Powder XRD typically requires samples comprised of small grains ($<10 \mu\text{m}$) packed in random orientations. In CheMin, piezo-vibrated sample cells cause the convective flow of loose powder, improving particle statistics and relaxing the requirement for fine-grained samples. This plus the use of a single photon counting X-ray CCD detector allow the collection of Debye-Scherrer XRD patterns in a small format instrument having no moving parts.

Analysis of scooped soils, or rock powders produced by a percussion drill is possible without any sample preparation other than sieving. Nevertheless, CheMin still relies on a complex sample collection and delivery system, limiting its deployment potential on smaller missions.

2. Relaxed Sample Preparation and Miniaturized XRD Geometries

Deployment of XRDs on smaller missions will require simplified sample preparation and decreased instrument size and complexity. It is also desirable to improve 2θ resolution to enhance the ability to resolve complex mineralogies, such as for example samples that contain mixtures of three pyroxenes.

2.1 ExtraTerrestrial Regolith Analyzer (XTRA)

XTRA has been proposed to analyze fines of as-received regolith from the Earth's moon without sample preparation [6]. Fine-grained regolith coats the surfaces of most airless bodies in the solar system, and because this fraction is comminuted from the rocky regolith it can often be used as a proxy for the surface as a whole. XTRA differs from CheMin in that it collects diffraction data in reflection geometry. Reflection geometry reduces sample preparation

requirements because the sample can be infinitely thick relative to the X-ray beam, allowing bulk samples to be measured. Figure 2 shows a 3-D model and prototype of the XTRA instrument. Fine-grained regolith is dumped into a bulk holder having a Kapton™ window. The X-ray beam strikes the sample through the window at an acute angle (red line in Figure 2 (right)) and diffracted beams are detected by a CCD detector.

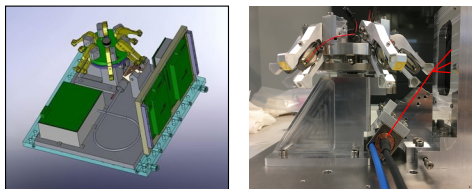


Figure 2: The XTRA reflection geometry XRD. 3-D model (left) and prototype (right) showing X-ray beam path and diffracted beams entering the detector (red lines).

2.2 Hybrid XRD

Hybrid-XRD (HXRD) is a concept under development to analyze rocks or soils without sample preparation [7]. If the material is fine-grained, a powder XRD pattern is obtained, similar to CheMin or XTRA. With coarse-grained crystals, the white bremsstrahlung radiation of the tube is diffracted into single crystal Laue patterns. Unlike typical Laue applications, HXRD analyzes the energy of each Laue spot, enabling the measurement of single crystal Bragg diffractions. Dedicated crystallographic software has been developed for identification of minerals responsible for the Laue patterns.

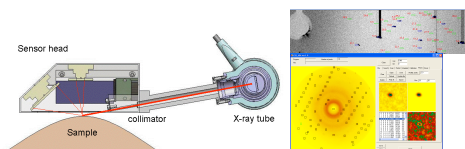


Figure 3: Arm-deployed HXRD concept (left), example data from olivine (upper right) and data reduction software (lower right).

2.3 Guinier XRD

An XRD based on Guinier geometry is under development to provide a compact high-resolution instrument. This design uses a para-focusing geometry with a curved 2D detector to cover the angular range of interest. A substantial gain in resolution has been demonstrated with a basic proof-of-concept instrument.

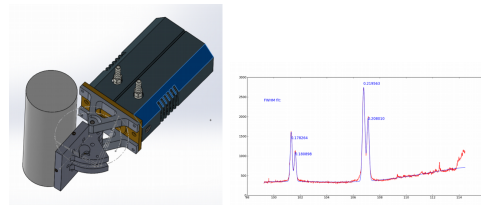


Figure 4: Guinier XRD. 3-D model with commercial camera (left) and example data (right) showing an observed resolution of $0.18^\circ 2\theta$ ($0.13^\circ 2\theta$ achievable).

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Status of MEDA PS and MEDA HS Pressure and Relative Humidity Devices for Mars 2020 Rover

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Abstract

Finnish Meteorological Institute (FMI) provides a pressure measurement device (MEDA PS) and a relative humidity measurement device (MEDA HS) for MEDA. MEDA is one of the scientific payloads on-board the NASA Mars 2020 rover mission: Mars Environmental Dynamic Analyzer, a set of environmental sensors for Mars surface weather measurements. This paper presents the current status of the devices. Calibration results will be presented in EPSC conference.

1. Introduction

Mars Environmental Dynamic Analyzer (MEDA) is a set of environmental sensors on board NASA's Mars 2020 rover provided by Spain's Centro de Astrobiología. MEDA's principal goals are to provide continuous measurements that characterize the diurnal to seasonal cycles of local environmental dust properties and near-surface environment. MEDA sensor package is designed to record dust optical properties and multiple atmospheric parameters: wind speed and direction, pressure, relative humidity, air temperature, ground temperature, and radiation in discrete bands of the UV, visible, and IR ranges of the spectrum.

Finnish Meteorological Institute (FMI) provides a pressure measurement device (MEDA PS) and relative humidity measurement device (MEDA HS) for MEDA. Both devices are designed, built and calibrated by FMI.

MEDA PS is a pressure measurement device based on silicon micro-machined capacitive Barocap® pressure sensors developed by Vaisala Inc. The technology of the Barocap® is well known and it has been used before in 6 missions, including Mars Science Laboratory mission (REMS-P) and Exomars 2016 Schiaparelli lander (DREAMS-P).

MEDA HS is a miniature relative humidity device based on polymeric capacitive Humicap® humidity

sensors developed by Vaisala Inc. The same technology has previously been used in MSL (REMS-H) and Exomars 2016 Schiaparelli lander (DREAMS-H).

Main scientific goal of both devices is to measure the meteorological phenomena (pressure and humidity) of the Martian atmosphere and complement the previous Mars mission atmospheric measurements for better understanding of the Martian atmospheric conditions.

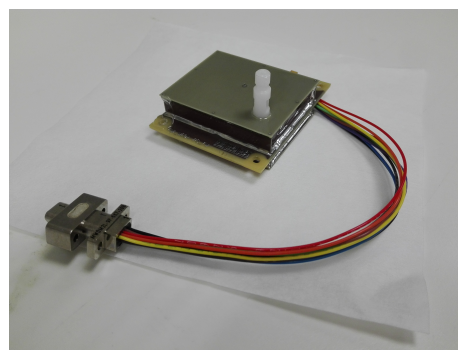


Figure 1: MEDA PS Flight model

2. Status of the devices

MEDA PS flight model (FM) and flight spare (FS) have been delivered to CRISA for higher level integration. Calibration tests in FMI are completed and initial calibration results are under work. The results will be presented in the EPSC conference.

MEDA HS flight model (FS) and flight spare (FS) will be delivered to CRISA in summer 2018. Calibration tests in FMI are completed and results will be presented in the EPSC conference.



Figure 2: MEDA HS Flight model

3. Calibration

Both MEDA PS and MEDA HS have been calibrated by FMI in FMI facilities.

For MEDA the calibration of relative humidity requires in minimum two humidity points - dry (0%RH) and (near)saturation (95-100%RH) - over the expected operational temperature and pressure range of the device. Custom-made, small, relatively low-cost calibration chamber has been developed in FMI for this purpose. Both dry points and saturation points were measured in Martian range pressure CO₂, in temperatures down to -70 °C.

MEDA PS has been calibrated in different constant temperature and pressure points in vacuum and in Martian pressure, in changing temperature and in rapidly changing pressure. Calibrations were performed inside a small vacuum chamber placed inside a temperature test station. Pressure was controlled with a commercial pressure controller and calibrations are calculated against Mars-range pressure references traceable to national standards.

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LIBS and Raman Data Fusion for in-situ Planetary Exploration

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1. Introduction

The combination of Raman spectroscopy and laser-induced breakdown spectroscopy (LIBS) is promising for in-situ planetary exploration. The first LIBS instrument in space, ChemCam, that is part of NASA's Mars Science Laboratory mission is analyzing Martian targets since 2012 [1]. The follow-up instrument, SuperCam, of NASA's Mars2020 mission joins LIBS with Raman spectroscopy [2]. Apart from these missions there exist several proposals for combined Raman/LIBS instruments in the context of in-situ extra-terrestrial research, e.g. [3]–[6].

We study LIBS-Raman data fusion strategies for optimized identification and quantification of minerals and salts that might be important for the SuperCam instrument as well as for other future missions. Data from both techniques is acquired with instrumentation that is built from miniaturized and prototype components.

2. Raman Spectroscopy and LIBS

LIBS uses high power laser pulses that are focused onto the surface of the target to create a luminous plasma. This plasma emits characteristic radiation corresponding to the elemental composition of the target. The Raman effect is non-destructive and based on inelastic scattering processes. These are initiated by laser radiation and the scattered light contains information about molecules and crystal structures in the target, due to vibrational and lattice excitations, respectively.

The two techniques have several advantages for planetary exploration as they are fast and need only optical access to the samples. Furthermore, hardware components such as the laser, focusing optics and the spectrometer can be shared allowing for a miniaturized instrument design. LIBS is capable of easily detecting alkalis, alkaline earth elements and metals that appear as cations but is challenged with anionic spe-

cies, such as the halogens sulfur and chlorine. Raman spectroscopy on the other hand gives fingerprint spectra of minerals that contain strong features belonging to modes of anionic groups. But depending on symmetries there exist also minerals and salts without Raman active modes as for example halite (NaCl). Thus, LIBS and Raman data can complement each other and more information can be gained with a joint instrument of both techniques.

To obtain the maximum scientific output with regard to strong constraints on mass and energy in space applications the study of data fusion strategies is of great interest and gives input to the instrument design [6]. It has been shown in terrestrial applications that LIBS-Raman data fusion can improve the classification of explosives [7] or inks [8] and first attempts of data fusion for planetary exploration have been reported [9]. All of these examples use multivariate methods, which have already proven to be reliable tools for LIBS [10] and Raman [11] alone. We implement and compare different ways of combining the data from both techniques. Besides that, we investigate which wavelength regions from LIBS and Raman data, respectively, are most crucial for successful identification and quantification and which regions are redundant and could be left out or reduced in resolution. This can allow for a more miniaturized design.

3. Experimental

Raman and LIBS measurements were performed with different set-ups. For Raman measurements a frequency doubled Nd:YAG laser (532 nm, continuous wave, 50 mW output, Oxxius) is focused onto the sample and the light is spectrally analyzed with an Ocean Optics spectrometer. The LIBS laser is based on a Nd:YLF crystal (1053 nm, 4-5 ns pulse length, 3 mJ output). The plasma radiation is collected, split and guided to four different spectrometers (Avantes): UV (233-400 nm); VIS1 (360-515 nm),

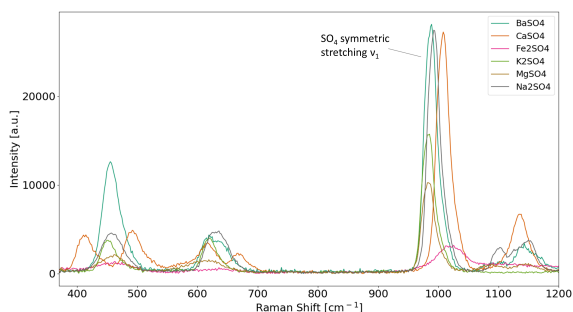


Figure 1: Raman spectra of the sulfates measured with a miniaturized set-up. The ν_1 mode is strong indicator for the presence of SO_4^{2-} ions.

VIS2 (530-760 nm), NIR (740-900 nm). For LIBS measurements each sample is measured in a small chamber under Martian atmospheric conditions, which means a pressure of 7 mbar and a CO_2 dominated gas. More details about the set-up can be found in [6].

4. Results

One set of samples that we studied with this set-up contains sulfate salts, in particular $\text{MgSO}_4 \times 7\text{H}_2\text{O}$, $\text{CaSO}_4 \times 2\text{H}_2\text{O}$, Na_2SO_4 , Ba_2SO_4 , K_2SO_4 and $\text{Fe}_2\text{SO}_4 \times n\text{H}_2\text{O}$. Sulfates and other hydrated salts as chlorides and perchlorates play an important role in the geological analysis of the Martian surface as they are linked to areas where liquid water has evaporated in the past [12]. The sulfate anion SO_4^{2-} has several Raman active modes with the strongest one ν_1 in the range 950 to 1100cm^{-1} . We observed this peak in every Raman measurement, see Figure 1. The LIBS spectra do not indicate the presence of sulfur but show strong emissions of the cations, see Figure 2.

5. Summary and Outlook

The preliminary study of pure sulfates using miniaturized Raman and LIBS set-ups confirms the advantage of combining LIBS and Raman spectroscopy: The data is complementary and the substances can be better identified with both data. The sulfates can be identified by means of the Raman ν_1 mode and cation emissions in the LIBS data. For further investigations we will produce binary mixtures of the sulfates and additional chlorides, perchlorides and Martian regolith simulant JSC-1A. We will apply multivariate data analysis approaches and compare the results of single Raman and LIBS with the fused data.

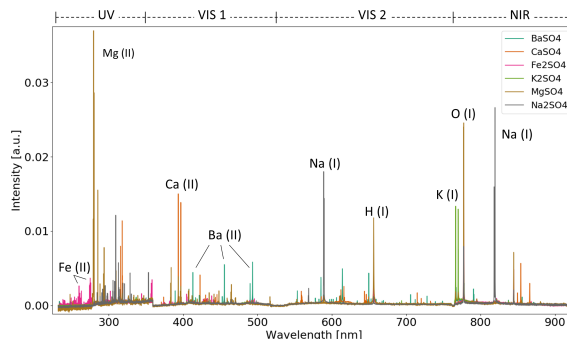


Figure 2: LIBS spectra of the sulfates measured with a miniaturized set-up. Besides the strong indicated cation emissions LIBS is also sensitive for hydrogen and oxygen detection.

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Time-resolved spectral imaging of LIBS plasma at low pressures for the exploration of Solar System bodies

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Abstract

Laser-induced breakdown spectroscopy (LIBS) is an increasingly important technique for the robotic exploration of Solar System bodies. We investigate the spatial distribution of species inside the plasma plume of a LIBS measurement for different atmospheric compositions and pressures. The results can help with the interpretation of Martian LIBS data (ChemCam, SuperCam) and from other planetary exploration missions using LIBS.

1. Introduction

LIBS is a type of atomic emission spectroscopy that is very well-suited for the robotic exploration of planetary bodies [1]. The technique has been successfully employed on Mars with the ChemCam instrument on board of NASA's Mars Science Laboratory [2]. SuperCam, the successor of the ChemCam instrument on NASA's Mars2020 mission, will use LIBS again in combination with Raman and fluorescence spectroscopy [3]. India's Chandrayaan-2 mission will also feature a lunar rover with an on-board LIBS instrument [4]. Additionally, concepts for LIBS instruments that could be used on other planetary bodies in the Solar System have been proposed [e.g. 5, 6].

The spectra obtained with LIBS are highly dependent on atmospheric conditions, especially the ambient pressure [7]. The technique relies on the creation of a plasma plume from material that has been ablated from the sample surface by a laser pulse. A spectrum of the light emitted by the plasma contains information about the elemental composition of the sample. At high atmospheric pressure, the plasma plume is confined to a small volume above the sample surface. Due to this confinement, it has a relatively long lifetime, but it is also optically dense

and shields the sample surface from further ablation [8]. At low atmospheric pressure, the plasma expands and cools quickly, but its low optical density allows for more material ablation. The tradeoff between both effects yields maximum signal intensities at around 10 mbar, close to Martian atmospheric pressure [1, 9].

In this study, we investigate the effect of atmospheric pressure in more detail. We measure the spatial distributions of the species inside the plasma and the spatial variation of the plasma temperature at pressures between 1 μ bar and 1 bar. The results will support the understanding of plasma formation, which in turn can help with the interpretation of LIBS data from Mars and other planetary exploration missions.

2. Experimental setup

A custom-made time-resolved plasma imaging setup with a low-pressure simulation chamber is used for the measurements. The simulation chamber can be filled with Mars-analog atmosphere, air, or other gases. It can be evacuated to a pressure as low as 1 μ bar. For a measurement, a pulsed high-energy laser ($\lambda = 1064$ nm, 8 ns pulse FWHM, up to 30 mJ/pulse) is focused onto the sample surface through a window above the sample, generating a plasma plume. A slice of the plasma plume that is perpendicular to its propagation axis is then projected onto the slit of an imaging monochromator with a time-gated ICCD through a sideward window of the simulation chamber. By adjusting the height of the objective lens, slices of the plume at different heights can be measured. Various metals as well as salts and simulants that are relevant to planetary exploration are analyzed. Samples are pressed into pellets of 1 g and 1.4 cm in diameter.

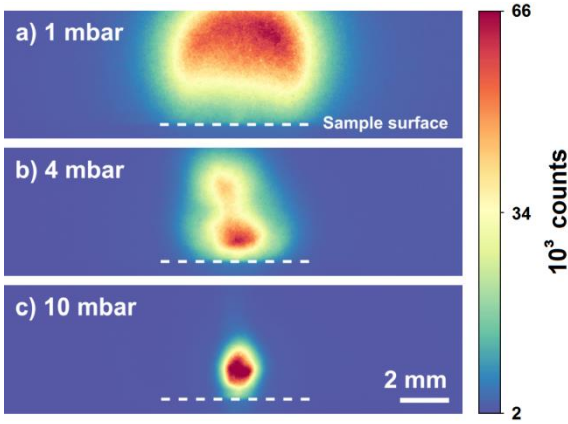


Figure 1: Plasma plume of a steel sample at different pressures (350 ns delay, 100 ns integration time).

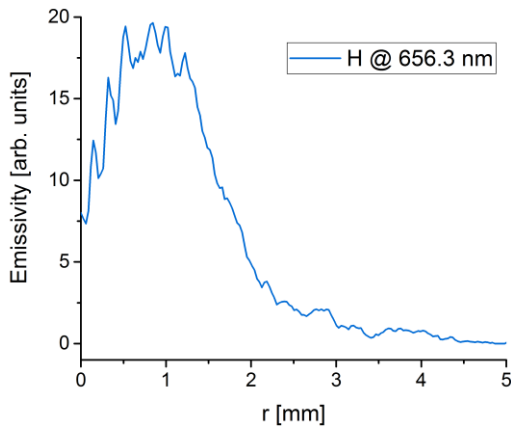


Figure 2: Radial emissivity of hydrogen at 656.3 nm, with the axis of the plasma at $r = 0$ mm. (NaCl sample measured at 1 mbar, 1 mm above the sample surface, with no delay and 100 ns integration time.)

3. Results

Figure 1 shows monochromatic images (color-coded by intensity) of the plasma plume of a steel sample in air at 1 mbar, 4 mbar, and 10 mbar. The delay time between plasma initiation and measurement was 350 ns. The integration time was 100 ns. The plasma plume is notably smaller at higher pressures, and a slight asymmetry can be observed at 4 mbar. Figure 2 shows an example of the emissivity of hydrogen after performing an Abel inversion on the data. The highest emissivity is not at the center, so that electron densities calculated from the hydrogen line will not describe the inner plasma correctly. This result is in contrast to previous studies at 1 bar [10].

4. Summary and Conclusions

The atmospheric composition and pressure cannot be ignored in the analysis of LIBS data. The spatial and temporal distributions of emitting species inside the plasma plume change with ambient pressure, which can have significant impact on the calculation of plasma parameters and calibration curves. The influence of atmospheric conditions is especially important for LIBS used in planetary exploration, as many planetary bodies of interest have low-pressure atmospheres.

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A miniaturized Raman/LIBS instrument for in-situ investigation of celestial bodies in pioneering missions

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1. Introduction

Different approaches for combined Raman/LIBS (laser-induced breakdown spectroscopy) instruments have been proposed. With SuperCam as part of the Mars2020 mission one will soon be used on another planet for the first time [1,2]. Launching and landing such a large mobile laboratory as the Mars2020 rover with a mass of around 1000 kg is, however, an exception in planetary exploration and most landers and rovers are much smaller.

We propose a miniaturized Raman/LIBS instrument in the order of < 3 kg [3] that could be mounted on a small spacecraft for spectroscopic analysis. The design aims for a lightweight and low power solution with a working distance of up to one meter to keep the advantage of being an in-situ remote science instrument. In the final version the device shall feature an auto-focus mechanism and a close-up context imager.

We report on the current state of development, present data acquired with a prototype model and discuss the capabilities and limits of a miniaturized combined Raman/LIBS instrument. To ensure conclusive results we utilize an atmospheric simulation chamber simulating different planetary atmospheres and vacuum conditions, which strongly influence the LIBS signal [4].

2. Raman spectroscopy

Raman spectroscopy is based on an inelastic scattering process observable in many fluids and solids. The resulting spectra allow for identification of functional molecular groups but also reveal structural differences between minerals of identical chemical composition. For Raman spectroscopy a laser with precisely controlled emission wavelength is desired, as the Raman signal is a relative spectral shift of the incident light. Continuous wave (cw) and pulsed operating mode are both possible. While

pulsed lasers in combination with time gated detection enable reliable suppression of fluorescence cw-systems are more robust, easier to handle and less power consumptive. Example spectra of sulphates recorded with the prototype setup are shown in Fig. 1.

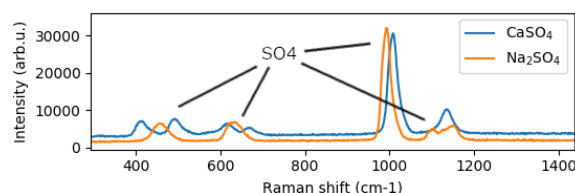


Figure 1: Example Raman spectra of CaSO_4 and Na_2SO_4 . Both show typical sulphate Raman modes.

3. LIBS

In LIBS a high energy laser pulse is tightly focused onto the sample in order to ablate a small amount of the sample material. The excess energy heats the ablated material and creates a plasma emitting atomic and ionic spectral lines of the elements from the sample and a superimposed continuum from bremsstrahlung and recombination [5]. Excitation above the plasma threshold of $\sim 10 \text{ GW/cm}^2$ is often achieved with nanosecond pulses of a few milliwatts pulse energy provided by q-switched lasers. Fig. 2 shows LIBS spectra of the same sulphates acquired with the prototype components.

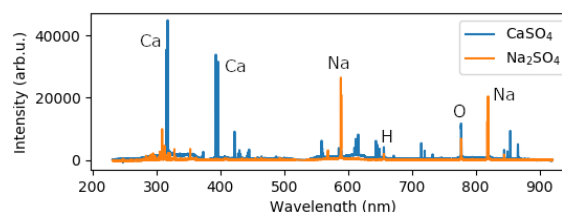


Figure 2: Example LIBS spectra of CaSO_4 and Na_2SO_4 . Both show the respective cation lines.

4. Combining Raman and LIBS

Raman spectroscopy and LIBS are complementary techniques that work well together in a complete analysis of geological samples [6]. For the example spectra in Fig. 1 the choice of cation introduces a slight shift of the sulphate Raman modes, which can be used for analysis. However, due to other influences on the Raman modes and experimental limitations the unambiguity might not be given. The complementary LIBS spectra in Fig. 2 clearly show atomic and ionic emission lines of either Ca or Na allowing a classification. On the other hand, sulphur is hardly evident in the LIBS spectrum but can be identified via the SO_4 modes in the Raman spectrum.

The experimental setups used for both methods only differ in the laser specifications and the observed spectral range, leaving great potential for miniaturization. With the use of shared components and the intended integration of a high resolution camera the scientific return can be maximized without noticeably increasing the instruments mass. Simple sample preparation tasks such as dust removal can be achieved with the plasma shock wave of a LIBS laser shot exposing a clean rock surface to the Raman system. Due to laser ablation in the LIBS process subsurface layers in depth of up to one millimetre, depending on the material hardness, can be investigated as well.

5. Miniaturization approach

The miniaturized design features a passively q-switched Nd:YLF prototype laser operating at 1053 nm in pulsed mode for LIBS, which was originally developed for ExoMars. It has TRL ~5 and the optically pumped laser head weighs only 36 g [7]. A frequency doubled continuous Nd:YAG laser emitting at 532 nm (1 MHz linewidth, < 3 pm wavelength stability) is used for Raman excitation. Both excitation and detection are co-aligned on one optical axis and share the focusing optics. The collected light is split into four spectral ranges from 240 to 850 nm and delivered to and analysed by four separate miniaturized grating spectrometers. Input from sophisticated data analysis methods and data fusion of LIBS and Raman [8] may reduce the requirements to spectral range and resolution, thus potentially enabling further miniaturization. To focus at various distances a Cassegrain telescope with 50 mm diameter of the primary mirror is considered.

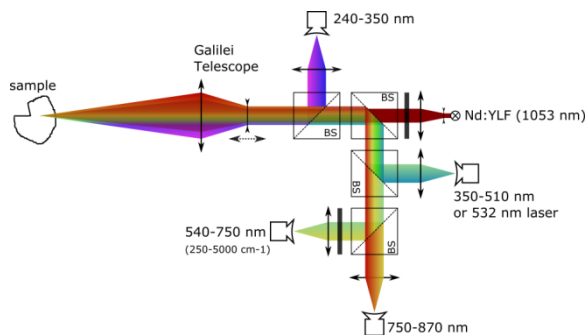


Figure 3: Schematic drawing of the instrument.

6. Summary and Outlook

Combining Raman spectroscopy and LIBS in a miniaturized instrument is a promising approach to equip future missions to explore new planetary bodies, moons and asteroids. With the presented prototype of such a combined instrument elemental components and molecular structures of samples can be identified without sample preparation in small distances around the vehicle. The performance of the system will be evaluated with respect to working distance, laser spot size and focus precision requirements for different potential sample materials. As a next step an auto-focus mechanism and a context imager will be developed and integrated.

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Correction of Galileos Energetic Particle Detector, Composition Measurement System

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Abstract

Over the course of its 8-year mission the Energetic Particle Detector, launched in 1989 on the Galileo satellite, took data on the Jovian Particle environment. In the high radiation environment, the EPDs Composition Measurement System (CMS) visibly decayed; higher mass particles, specifically oxygen and sulphur, reading at far lower energies and count rates later in the missions. By considering the non-steady accumulation of damage in the detector, as well as the operation of the priority channel data recording system in place on the EPD, a correction can be made. A model of dead layer build-up in semiconductor detectors is built, based on SRIM results, and then used to reverse the effects of the build-up. The result, assigns an estimation of dead-layer depth during the mission data recordings, and produces a corrected version of the high rate data and the count rate channels, for future use.

1. Introduction

This paper focuses on the data from the EPD; specifically, from the CMS telescope on the top of the instrument. Comparing data from the beginning of the mission to the final data retrieved [Figure 1] there is a clear discrepancy in the loci defining the elements. The uppermost is Sulphur (orange line) followed by Oxygen (yellow) beneath it, the green line in the box labelled TA1 is Helium and the final loci, Protons in blue.

The loci of these elements reveal that the detector is decaying in sensitivity. The amount of energy drop noted corresponds to the

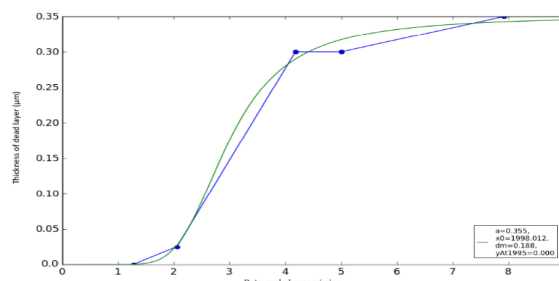


Figure 2: Dead Layer thickness evolution over time.

element in question; as a dead layer builds up on the front of the detector, the larger particles lose more energy passing through this layer than lighter elements. This thickening of the dead layer is caused by the radiation impacting onto the detector denaturing the sensitive volume.

2. High Rate Data Correction

The High rate data is only available in short sections of the mission, mainly during the flybys and periods of interest. The correction of this data is based on the nature of the detector, and the build up of the dead layer. The dead layer thickness is estimated throughout the mission using calibration masses with a simulated depth of dead layer. The comparison between this and the real values gives the evolution of the dead layer thickness [Figure 2].

Knowing the thickness of the dead layer allows a correction to be made using a selection of masses and the known energy lost

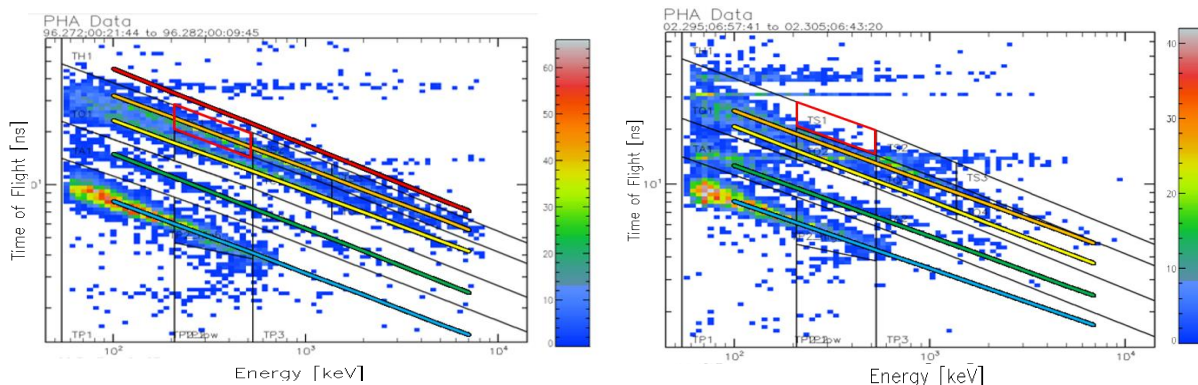


Figure 1: LEFT: EPD data beginning on the 29th Sep 1996 shortly after the arrival of Galileo in the Jovian system. RIGHT: EPD data beginning on the 22nd Oct 2002 nearing the end of the mission lifetime shortly before the demise of Galileo into Jupiter itself

for the dead layer present. The final correction is made by working backwards; starting with all the possible test masses, and calculating the energy loss of the particle passing through the established dead layer. This loss is applied to the possible starting energies and a final comparison to real readings is made. This highlights the closest value of the original particle.

3. Count Channels Data Correction

Correcting the count rate channels requires a different approach; the dead layer thickness is used only in assessing the progress of the correction. Instead, this correction method uses comparative count rates from relative locations in the Jovian system at different times. This is used to calculate a value of the decay in terms of number of counts hitting the detector. By systematically applying this value to the counts registered by the detector brings the values closer to the true values (Figure 3).

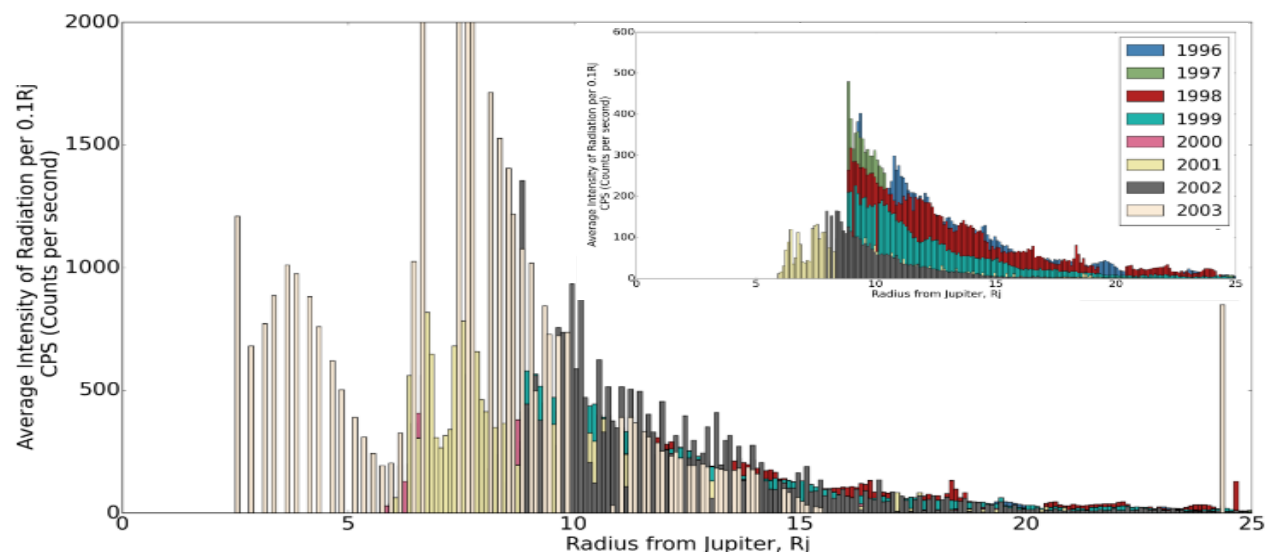


Figure 3: TOP RIGHT OVERLAY: Average count rate against radius for each year of the original TS1 Sulphur channel.
MAIN IMAGE: Matching plot of corrected data from TS1 sulphur channel.

This is an intensive iterative process that encompasses the changing values of counts over the mission and the effects of efficiency dropping over the mission. Each individual count rate channel is processed in this manner.

3. Summary and Conclusion

The correction results are dramatic; both in the high rate data and the individual count rates. The count rates are greatly increased over the whole mission, particularly during the final years. The High rate data, whilst not accounting for efficiency drops, still offers a differing view of the environment composition. All the corrected data matches considerably better with calibration data, both for overall count rates and estimated

dead layer thickness. It also fits well with ratioed data taken by Voyager across all elements [1].

The most common miss-allocation of the particles was a sulphur particle measured by the Oxygen channel. The nature of the movement of the particles through the channels means that as the Sulphur channel increases by the correction, then the Oxygen must decrease with the correction. Overall the change is significant, meaning that sputtering on the surface is far more sulphur dominant than originally believed.

The correction of the EPD data is proving to be invaluable in re-evaluating the conditions on the surface of Europa. Re-calculating the surface sputtering and erosion, gives a far more accurate estimate on the age of the surface. Where others previously have only been able to estimate for global coverage, new techniques may be possible to give dates to specific features and bridge time spans between main formation events.

4. Acknowledgements

The authors would like to thank the EPD analysis team for access to their EPD data files and PHA plotting system software.

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Laboratory studies of tholins, analogues of Titan aerosols, with the LAB-CosmOrbitrap

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Abstract

Instruments on the Cassini-Huygens mission have allowed the collection of a big amount of data about Titan and revealed part of the complex organic chemistry in the dense atmosphere of this moon. Complementarily to the data received, analyses of laboratory analogues of Titan aerosols help the understanding of chemical mechanisms occurring on Titan. These analyses are also preparing the new generation of space mass spectrometer, such as the LAB-CosmOrbitrap, new high-resolution mass analyser based on the Orbitrap™ technology and coupled with laser ablation ionisation.

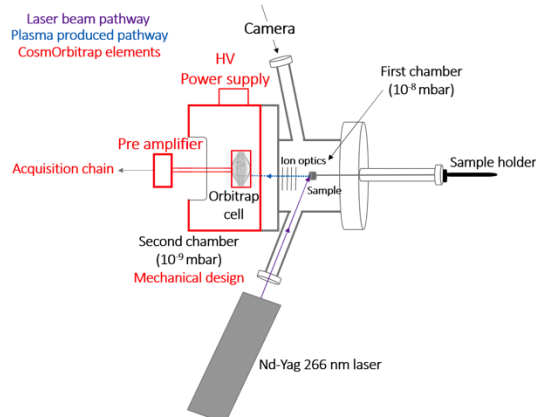


Figure 1: The LAB – CosmOrbitrap

1. Introduction

Among the discoveries about Titan allowed by the Cassini-Huygens mission, we can cite detections made by INMS (Ion and Neutral Mass Spectrometer) and CAPS (CASSINI Plasma Spectrometer). They have highlighted the presence of (i) positive ions and neutral up to 100 mass units [1] and (ii) very heavy positive and negative ions [1]. Instrumental limits, in terms of mass range and mass resolving power, don't allow to decipher the composition of the organic molecules detected nor the growth chemical pathways leading to the formation of aerosols.

1.1 The Laser-CosmOrbitrap: a new mass spectrometer dedicated to space exploration

Ultra-high-resolution mass spectrometer is needed to go further in the *in situ* chemical analysis of, for instance, Titan atmosphere. This work aims to show the potential of a new generation of simple mass spectrometer concept, the Laser Ablation - CosmOrbitrap (Figure 1) as future space exploration instrument of complex organic worlds. For that purpose Titan aerosol analogues have been studied.

Ionisation of the sample is provided by a Nd-Yag laser at 266 nm. Mass analysis is then performed by the CosmOrbitrap [2] high-resolution mass analyser, which is a space version of the Orbitrap technology [3], currently developed by a consortium of laboratories (LPC2E, LATMOS, LISA, IPAG and CSNSM) in close collaboration with ThermoFisher Scientific, with the support of CNES. This instrumental concept has demonstrated its potential for the identification of organic molecules [4].

1.2 Analogues of Titan aerosols

To go further in the chemical analysis of Titan aerosols started by the Cassini-Huygens mission, different experiments allow the synthesis of analogues of Titan aerosols called "tholins". One of them, the PAMPRE experiment [5] uses a radio frequency reactive plasma to produce solid particles in the volume, limiting wall effects and mimicking the coupled ion-neutral chemistry occurring in Titan ionosphere [1]. Particles studied are produced with gas mixture of 5% of CH₄ and 95% of N₂.

2. LAb-CosmOrbitrap analysis of tholins and comparison to other laboratory techniques

Fresh solid tholins particles have been gently pressed on the sample-holder indium surface. This simple deposition method allows adducts formation between the organic sample and the indium surface [4] that could help for the identification of compounds. To refresh the sample area destroyed under the laser ablation conditions, location of the laser beam on the sample-holder was set regularly. Energy of the laser shot has been explored. Under nano-pulsed single laser shot, patterns of organic molecules, polymeric structures and adducts with indium have been observed.

These results have been compared to previous studies made by LDI-FTICR (Figure 2, [6]) on the same tholins sample.

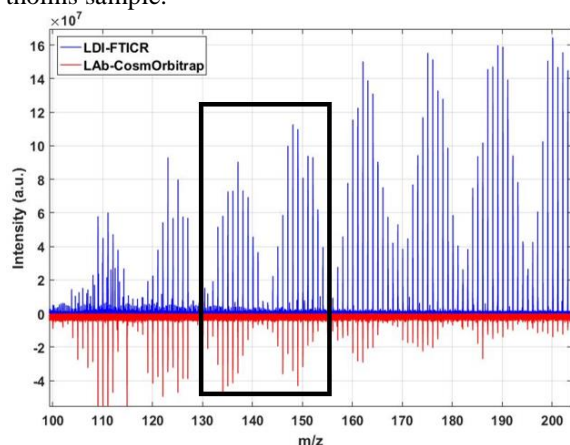


Figure 2: Comparison between LDI-FTICR mass spectrum (upper panel – in blue) and LAb-CosmOrbitrap mass spectrum (lower panel – in red) on the same tholins sample.

Different analytical representation such as the Mass Defect versus Mass diagram [7] and the Kendrick mass defect diagram ([8] and [9]) have been used for further data treatment. Interesting similarities such as the importance of HCN and CH₂ molecules as polymeric structures involved in the growth processes of tholins but also in the location and identification of chemical formula of tholins, have been highlighted.

These similarities demonstrate the possible ionisation and detection of tholins with the LAb-CosmOrbitrap, with mass accuracy better than 2 ppm and mass resolving power up to 350 000 (FWHM) in the m/z range 20 to 250. The relevance of our instrumental configuration as a future mass spectrometer for space exploration of ocean worlds is also evidenced.

3. Perspectives of this work

One of the main perspectives will be to switch the LAb-CosmOrbitrap in the negative ion mode due to the CAPS negative ions detection and as the use of both positive and negative ion modes is an important requirement, from an instrumental development point of view.

Acknowledgements

We gratefully acknowledge the financial support by the Centre National des Etudes Spatiales (CNES), the Région Centre-Val de Loire and the Labex Exploration Spatiale des Environnements Planétaires (ESEP). We also thank the CosmOrbitrap consortium and Dr Titaina Gibert for lending the Nd-Yag laser. N.C. thanks the European Research Council for funding via the ERC PrimChem (grant agreement No. 636829).

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Plenoptic cameras for in-situ micro imaging

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Abstract

This work discusses the benefits of plenoptic cameras for future hand lens imagers for in-situ planetology. Such cameras offer advantages over conventional cameras, especially at the small working distance that are common for in-situ micro imaging. For example, the extension of the depth of field without a focus mechanism while maintaining a more open aperture at the same time. Additionally, textured depth maps as well as views with small perspective changes are possible, all from a single recorded image. We present a brief introduction of the plenoptic camera technology and examples from laboratory experiments.

1. Introduction

A Hand Lens Imager (HLI) is a camera with a macro lens, on board a rover or a lander, that works as a remote version of a geologist's hand lens. Its primary purpose is to provide high resolution images of small geological features with a resolution of a few $\mu\text{m}/\text{pixel}$. This allows to categorize rocks or dust as well as to find hints on the geological history of a site. HLIs are also useful for tasks such as the planning and documentation of the operation of other instruments [1]. Examples of HLIs include the Mars Hand Lens Imager (MAHLI) on board the Mars rover Curiosity [1] or the Close Up Imager (CLUPI), which is currently developed for the ExoMars 2020 rover [2].

The minimum working distance for MAHLI and CLUPI is 21 mm and 100 mm, respectively, with a maximum ground resolution of $14 \mu\text{m}/\text{pixel}$ and $7 \mu\text{m}/\text{pixel}$, respectively. The short working distance results in a narrow Depth of Field (DOF) as small as approximately 1 mm [1, 2]. MAHLI and CLUPI are equipped with focus mechanisms in order to record a sequence of images, each focused to a different distance [1, 2]. This enables the creation of an Extended Depth Of Field (EDOF) image and a depth map by applying a z-stacking algorithm. However, it increases the complexity of the camera system.

1.1. Benefits of plenoptic cameras

In order to overcome these physical limitations, we propose the use of plenoptic cameras for future HLIs. They offer multiple advantages, which become most evident at small working distances. In addition, from a single plenoptic recording it is possible to derive more data products than from a focus image sequence of a conventional camera. First, the creation of 2-D images with a DOF multiple times larger than the one of a conventional camera while maintaining an open aperture at the same time [5]. Second, depth maps which directly can be textured with the EDOF image without a dedicated texture mapping process. Third, it is possible to compute novel views with a small perspective shift, as if the camera would have been moved slightly left or right. This might, for example, be used to detect glints from mineral enclosures or alike. Fourth, without a focus mechanism it is now possible to apply purely image based camera calibration to achieve precise metric depth values as shown in [6]. The calibration procedure can be repeated during the mission given a calibration target with a known geometry. As can be seen, a plenoptic camera can help to reduce the mechanical complexity by delegating some tasks to software. This becomes particularly beneficial in a demanding space environment such as the dusty surface of Mars or the Moon.

2 Plenoptic Cameras

A plenoptic camera is similarly constructed as a conventional camera, with an additional Micro Lens Array (MLA), i.e. a matrix of lenslets each with a diameter of a couple of μm , which is mounted in a short distance B in front of the sensor plane as shown in Fig. 1. The main lens, with focal length f_M , projects an image of an 3-D object at an object distance of a_M into the camera to the main lens image distance b_M . Similar to the object, its image has also a depth extend scaled by the magnification of the main lens. In a conventional camera, the 3-D main lens image is projected

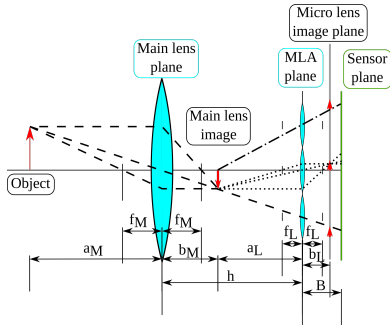


Figure 1: Concept of a focused plenoptic camera and its image formation process.

onto the sensor plane and the inherent 3-D information is lost.

In contrast, a plenoptic camera maintains the 3-D nature of the main lens image. Here, each lenslet of the MLA acts as a single camera with a focal length f_L that views the main lens image from a slightly different vantage point. The lenslets are focused on the main lens image at distance a_L and on the lenslet image distance b_L , which is not equal to the distance B . The fields of view of adjacent lenslets overlap and the parallax between them allows to triangulate the depth of an image point. By using lenslets with different focal length and grouping them accordingly, it is possible to achieve a significantly increased object space DOF only due to the camera concept [5]. Such a Multi-Focus Plenoptic Camera (MFPC) provides an image whose size is approximately a quarter of the sensor pixel amount. More details on the image formation process are provided in [3].

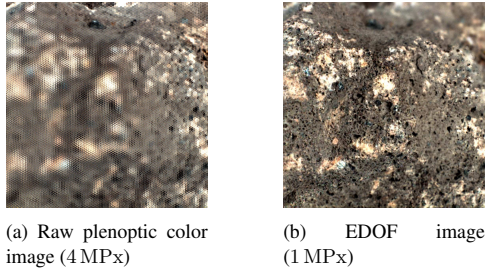


Figure 2: Image of a rock recorded from approximately 140 mm

Fig. 2a shows a raw plenoptic image of a rock surface recorded with a 4 MPx color plenoptic cam-

era (Raytrix R5-C). The micro images formed by the lenslets are visible. From the raw image it is possible to derive the different data products shown in Fig. 2b and Fig. 3. At the current state of the art, the plenoptic data processing is computationally demanding. However, as discussed in [4], algorithmic optimization and parallelization can result in higher efficiency, making it feasible for a planetary exploration mission.

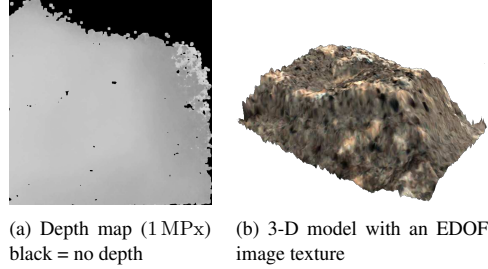


Figure 3: Derived data products

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Simple modelling of Plasma Parameters to Assist the Analysis of LIBS Spectra for Planetary Exploration

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1. Background

Laser-Induced Breakdown Spectroscopy (LIBS) is a method of atomic emission spectroscopy used for elemental analysis. A measurement is done by inducing a luminous plasma of sample material and capturing the emitted light through a spectrometer.

LIBS allows for multi elemental analysis of remote targets without any sample preparation and optical access only. This, and the possibility for a compact instrument design, e.g. [1], makes LIBS well-suited for planetary in-situ investigations. The Curiosity rover, which is exploring Mars since 2012, is carrying the first LIBS instrument for planetary exploration [2]. LIBS instruments have also been proposed for future missions to explore other bodies of the Solar System, e.g. [3].

In this study, we developed a method to assist the analysis of LIBS spectra acquired under different atmospheric conditions corresponding to different extraterrestrial mission scenarios. Plasma parameters, the plasma temperature and electron density, and concentrations estimates are obtained from LIBS data with labour-intensive steps automated and instead of manually identifying and choosing emission lines for the analysis, all lines in a spectrum are used and without the need for prior identification.

2. Method

In the case of negligible self absorption the total observed intensity from an electronic transition inside an atom is [4]:

$$I_{ul,e,s} = F \cdot A_{ul} \cdot c_e \cdot n_s \cdot n_u \quad (1)$$

F is an experimental parameter and is equal for all transitions in a spectrum, A_{ul} the Einstein coefficient for spontaneous emission, c_e the concentration of element e , n_s the population fraction of the ionic state s and n_u the population fraction of the upper electronic state. The value of F is linked to the units of measuring and to the fraction of the emitted light that is

captured. Its value might be unknown, but by considering relative concentrations it is divided out.

Assuming a local thermal equilibrium [4] and introducing the plasma temperature, T , and electron density, n_e , the ionic- and electronic state distributions are approximated by the Saha- and Boltzmann equations, respectively. By manually selecting and identifying intensities of different emission lines in a spectrum the elemental concentrations can be estimated by constructing Saha-Boltzmann plots using eq. (1) [4]. This is the general approach.

2.1. Our Approach

Our approach is to set up a system of linear equations between expected line intensities from eq. (1) and the extracted intensities from a spectrum. The inputs are tabulated reference lines from a database [5] and extracted intensities from a spectrum. The outputs are estimates of plasma temperature, electron density and elemental concentrations.

Eq. (1) is linear in the element concentrations. The intensity at a concentration equal to one will be referred to as the "transition amplitude" and is denoted with a hat:

$$\hat{I}_{ul,e,s} \equiv I_{ul,e,s}(c_e = 1) \quad (2)$$

Intensities at arbitrary concentrations can therefore be found by multiplication with the transition amplitude. Assuming that the temperature and electron density are known, transition amplitudes can be calculated from eq. (1). This allows us to set up linear equations between the expected line intensities, from the transition amplitudes, and the extracted intensities:

$$\begin{aligned} c_1 \cdot \hat{I}_{1,1} + c_2 \cdot \hat{I}_{2,1} + \dots + c_n \cdot \hat{I}_{n,1} &= P_1 \\ &\vdots \\ c_1 \cdot \hat{I}_{1,m} + c_2 \cdot \hat{I}_{2,m} + \dots + c_n \cdot \hat{I}_{n,m} &= P_m \end{aligned} \quad (3)$$

where $\hat{I}_{n,m}$ is the sum of transition amplitudes of element n with tabulated wavelengths inside peak m and P_m is the intensity of peak m , as extracted from the

spectrum. For each peak an equation appears which requires no line identification. All the reference lines from the database with wavelengths close to a specific peak are in the corresponding equation. The concentrations are solved semi-analytically by the method of linear least squares and the relevance of each transitions for the model is obtained from the derived concentrations.

In a fit routine are the transition amplitudes modelled using different sets of plasma parameters, temperatures and electron densities, and the residuals are minimized each time fitting the plasma parameters and concentrations so that they best match the extracted intensities.

3. Results

We have applied our approach to the spectra of a Martian regolith simulant recorded from 760 ns to 1260 ns after laser ignition in an experimentally simulated Martian atmospheric environment. Fig. 1 overviews the residuals for different sets of constant values of temperatures and electron densities. The best set of plasma parameters were found to be $n_e = 4.7e24 \text{ m}^{-3}$ and $T = 18276 \text{ K}$. The corresponding concentration estimates are visualized in Fig. 2. Here large deviations are seen and they will be discussed.

We are further discussing the insights obtained from our model with comparison to LIBS data taken in different environments and at different times after laser ignition. Also, we are discussing the limits of the model that so far uses only constant plasma parameters and the assumption of negligible self-absorption.

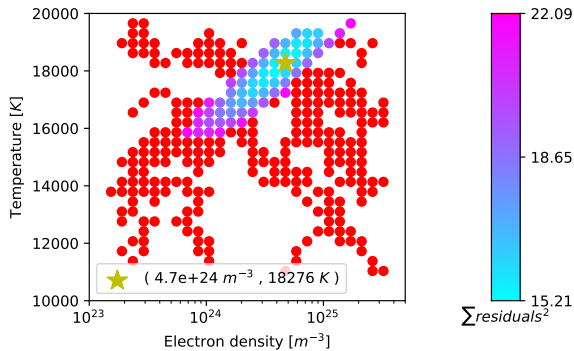


Fig. 1: Color plot showing the minimized residuals using transition amplitudes modelled from different sets of plasma parameters. Red dots corresponds to residuals above 22.09. The set of plasma parameters giving the minimum residuals is marked with the star.

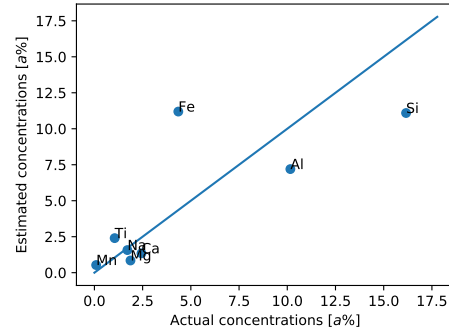


Fig. 2: Estimated concentrations from the best set of plasma parameters plotted against actual concentrations of the sample. The concentrations are normalized for better comparison since only relative concentrations are estimated.

4. Outlook

Inputs from time resolved plasma imaging [6] will allow us to include gradients of the plasma parameters in the modelling to better account for the transient and spatially varying nature of the plasma. We are furthermore working on corrections for self absorption that particular affect the intensities of the intense emission lines.

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Lithospace: an automated system for in situ petrographic thin section preparation on Mars

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Abstract

The aim of the LithoSpace project, supported by the CNES since 2014, is to work on the development of an automated system permitting preparation of petrographic thin sections on extraterrestrial bodies, in particular, on Mars.

1. Introduction

Optical microscopy in transmitted light is probably one of the most standard techniques in geology. It has been used for more than 150 years. Indeed, atlases of microscopic images of rocks and their characteristic mineralogy and textures are widely used in geological departments [1]. Observation in transmitted light permits identification of rocks having similar chemical and mineralogical compositions but different mineral organizations (basalt vs. gabbro for instance). Using polarized light, it permits identification of most of rock-forming minerals in thin section [2]. Observation in transmitted light is also essential for micropaleontology since it is the only way to observe individual microfossils, if they are large enough, and to document the mineralogical and textural context in which the biosignatures occur. Nevertheless, optical observation in transmission has never been carried out on Mars. Indeed, although optical microscopes can be readily designed for space exploration, thin section preparation is not easy to do *in situ*. In particular, it requires several human manipulations that are difficult to automate.

The aim of the LithoSpace project, supported by the CNES since 2014, is to work on the development of an automated system permitting preparation of petrographic thin sections on extraterrestrial bodies, in particular, on Mars. Several studies and tests were conducted and most of the problems solved. The final

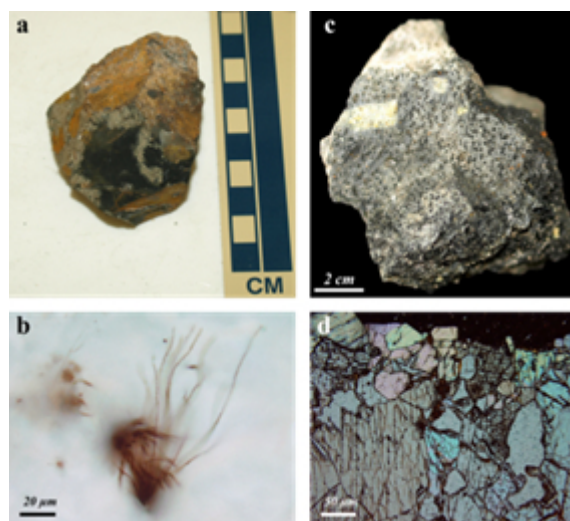


Figure 1: Pieces of rocks from (a) the Gunflint formation (-1,9 Ga) and (c) Svalbard, and (b,d) associated optical microscopy images in transmitted light. (d) Image in polarized-analyzed light.

protocol follows the process from obtaining a standardized drill core to observation of a thin section in a fully automated way.

2. Proof-of-concept

The objective of the project is now to make a “proof-of-concept” model. Thus, a first numerical model of the system has been designed by students in fifth year at the engineering school Polytech', University of Orléans. With the help of students in BTS (two-year technical degree) “industrialization of mechanical products”, from the Benjamin Franklin high school of Orléans, the objective is now to make this model real. Finally, this study is a good way to raise student aware-

ness of space exploration by involving them directly at the start of the project.

3. On the use of thin sections for *in situ* space exploration

In situ thin section preparation would be an important improvement for the geological and astrobiological exploration of the solar system, for Mars but also of other planetary bodies. The proposed instrument could incorporate new high resolution techniques, such as Raman mapping or micro-LIBS as well as optical microscopic observation in transmitted light

4. Summary and Conclusions

The LithoSpace project permit us to propose a concept for an automated system permitting preparation of petrographic thin sections on extraterrestrial bodies. This project appeared to be an excellent way to raise student awareness of space science and technology. A group of five students from the Lycée B. Franklin, helped by their teachers, have started the development of a physical demonstration model to be presented during the EPSC 2018 meeting.

Acknowledgements

We acknowledge the Polytech'Orléans students J. Li and T. Platel and the Benjamin Franklin high school students C. Navereau, Q. Truchot, R. Segret, S. De Olivera and A. Tessier-Neilel for their work. We acknowledge CNES for funding.

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Colorimetric analysis to help identification of drilled rock powders on Mars: the CaliPhoto method.

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Abstract

The aim of the CaliPhoto® project is to work on the development of an optical method permitting to identify rock powders from their colorimetric data obtained by the CLUPI instrument during the next ExoMars 2020 mission. This method also finds applications in many other studies.

1. Introduction

The objective of the ExoMars 2020 mission (ESA-Roscosmos) will be to search for past or extant traces of life on the red planet. The originality of the mission is its drill which will permit production of centimetric drill-cores from up to 2 meters in depth. During these drilling phases, the CLUPI camera will observe the pile of rock powder forming at the surface. The aim of the present study is to determine whether any geological information can be deduced from these observations. On Earth there is no need to observe rocks in powder form and thus, to date, no investigation has been done to link the colour of a powder with a particular type of rock. However, due to the particularity of the mission, colour information could become essential to improve the identification of the drilled rocks on Mars.

2. Analogue sample selection

The majority of rocks on the surface of Mars are volcanic [1, 2] thus, for this study, relevant samples were selected from the Massif Central, in France, in order to cover a large range of volcanic rock types, as designated in the compositional TAS diagram (Total Alkali Silica). The samples were then crushed to less than 60 μm and displayed next to each other showing a large variety of colour (Fig.1).

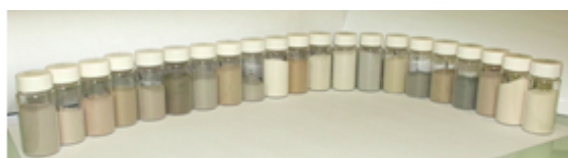


Figure 1: Powders of various volcanic rocks from the Massif Central, France.

3. Main issues

Although the preliminary observation shows differences in colour between the different samples, as shown in Figure 1, two main issues still remained to be tackled.

First, we observed that the main difference between the different powders was the brightness; the different powders being more or less all included in tones of greys exhibiting darkish tones. Unfortunately, it also appears that decreasing grain size induces an increase in brightness. The powders must thus be compared after sieving, i.e. for similar grain size distribution. Nevertheless, this step remains relevant since experiments have shown that drill powders (fines) are characterised by a more or less similar grain size ($<60 \mu\text{m}$).

Secondly, the most important issue was the fact that the colour of a powder is totally dependent on the ambient luminosity. In order to solve the last issue, a new method called CaliPhoto® was developed that consists of adding a reference target to the field of view of the camera, close to the powder. An image processing algorithm is then used to calibrate the images and permit comparison of the different powders. Well characterized rocks were then crushed, sieved and photographed using a commercial camera equipped with a detector similar to that used by the ExoMars Close Up Imager, CLUPI, i.e. a digital Foveon® sensor, in

order to create a database of the colours of rock powders.

4. The CaliPhoto® method

Several tests were carried out. For rocks included in the database created so far, the method permits identification with good accuracy. More interestingly, for those rocks not included in the database, it was still possible to make a good match based on rocks of similar composition in the database. Moreover, rocks having similar elemental composition but very different bulk colours, such as rhyolite (light) and obsidian (dark), have a similar powder colour, permitting thus a good identification. Finally, the CaliPhoto® method could be very useful on Mars to help identification of rocks during drilling without adding any new instrumentation

5. Summary and Conclusions

The CaliPhoto method permits to link laboratory measurements to optical images taken in the field. More largely, this method should be useful in many domains and found application in cosmetics for instance.

Acknowledgements

We acknowledge the Maison du parc national des volcans d’Auvergne for permission to sample. We thank CNRS, CNES and SATT Grand Centre for funding.

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Investigation of lunar dusty exosphere with future Russian lunar missions: Development of the Instrument & Simulation Control

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Abstract

One of the complicating factors of the future robotic and human lunar landing missions is the influence of the dust. Meteorites bombardment has accompanied by shock-explosive phenomena, disintegration and mix of the lunar soil in depth and on area simultaneously. As a consequence, the lunar soil has undergone melting, physical and chemical transformations.

Recently we have the some reemergence for interest of Moon investigation. The prospects in current century declare USA, China, India, and European Union. In Russia also prepare two missions: Luna-Glob and Luna-Resource. Not last part of investigation of Moon surface is reviewing the dust condition near the ground of landers. Studying the properties of lunar dust is important both for scientific purposes to investigation the lunar exosphere component and for the technical safety of lunar robotic and manned missions.

The absence of an atmosphere on the Moon's surface is leading to greater compaction and sintering. Properties of regolith and dust particles (density, temperature, composition, etc.) as well as near-surface lunar exosphere depend on solar activity, lunar local time and position of the Moon relative to the Earth's magneto tail. Upper layers of regolith are an insulator, which is charging as a result of solar UV radiation and the constant bombardment of charged particles, creates a charge distribution on the surface of the moon: positive on the illuminated side and negative on the night side. Charge distribution depends on the local lunar time, latitude and the electrical properties of the regolith (the presence of water in the regolith can influence the local distribution of charge).

On the day side of Moon near surface layer there exists possibility formation dusty plasma system. Altitude of levitation is depending from size of dust particle and Moon latitude. The distribution dust particle by size and altitude has estimated with taking into account photoelectrons, electrons and ions of solar wind, solar emission. Dust analyzer instrument

PmL for future Russian lender missions intends for investigation the dynamics of dusty plasma near lunar surface. PmL consists of three parts: Impact Sensor and two Electric Field Sensors.

Dust Experiment goals are:

1) Impact sensor to investigate the dynamics of dust particles near the lunar surface (speed, charge, mass, vectors of a fluxes) a) high speed micrometeorites b) secondary particles after micrometeorites soil bombardment c) levitating dust particles due to electrostatic fields. PmL instrument will measure dust particle impulses. Also Impact Sensor will measure the charges of dust particles. In case the charge and impulse of a dust particle are measured we can obtain velocity and mass of them.

2) Electric field Sensor will measure the value and dynamics of the electric fields near the lunar surface. Two Electric Field Sensors both are measured the concentration and temperature of charged particles (electrons, ions, dust particles). Electric Field Sensors contain of Langmuir probes. Using Langmuir probes near the surface through the lunar day and night, we can obtain the energy spectra photoelectrons in various periods of time.

PmL instrument is developing, working out and manufacturing in IKI.

These days the engineering model of PmL for LG-mission is finished. We obtained first practical results from the simulating chambers with dust particles injectors and plasma inside. All the important achievements are presented in this report as well as the roadmap for further development of PmL instruments in both of Russian lunar missions.

Acknowledgements

This work was supported by the Russian Scientific Foundation (the grant № 17-12-01458).