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A multichannel diode laser spectrometer for *in situ* study of atmosphere near the Martian surface for the ExoMars-2020 mission Landing Platform

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Abstract

An application of tunable diode laser absorption spectroscopy (TDLAS) in combination with integrated cavity output spectroscopy (ICOS) has been suggested for Martian atmosphere study as an experiment, named Martian multichannel diode laser spectrometer (M-DLS), by a team of researchers from IKI RAS, MIPT, GPI RAS. M-DLS has been proposed for scientific payload of the ExoMars-2020 mission Landing Platform [1, 2], and further modified into a very compact and lightweight instrument for continuous *in situ* study of chemical and isotopic composition variations of atmosphere near the Martian surface at short-term and seasonal time scales.

1. Introduction

In the M-DLS experiment, Martian atmosphere study will be based on regular measurements of molecular absorption spectrum in an optical cell, filled with ambient gas sample, taken at the stationery Landing Platform location. TDLAS flexibility and radical optical path enhancement of ICOS will be combined in the M-DLS instrument for fine measurement of weak absorption values at low pressure of the Martian atmosphere. H_2O and CO_2 molecular content and isotopic ratio variations will be retrieved from absorption data continuously during one Martian year.

2. Measurement method

The optical cell with the gas sample will be sounded by highly monochromatic radiation of two tunable distributed feedback diode lasers, emitting at IR range near 2.7 microns. Measurements will be carried out sequentially in series of 1 cm^{-1} wide intervals at 2.65 microns for H_2O and at 2.79 microns for CO_2 with spectral resolution of 3 MHz (~ 0.0001 cm^{-1}), providing for fine recording of molecular absorption line contours of H_2O and CO_2 main molecules and isotopologues HDO, $HO^{18}O$, $^{13}CO_2$, $CO^{17}O$, $CO^{18}O$. Examples of simple modelling for Martian atmosphere absorption are shown right below.

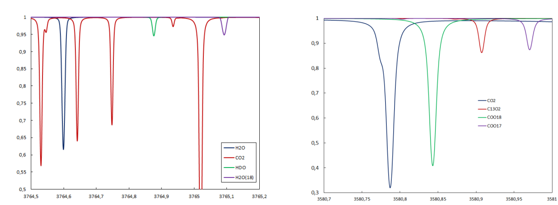

Figure 1. Absorption spectra for CO_2 and H_2O mixture, modelling atmosphere near the Martian surface: H_2O isotopologue lines for ~ 1 km effective optical path (left), CO_2 isotopologue lines for 2.5 m effective optical path (right).

Table 1: Sensitivity estimations for 95% CO_2 and 200 ppm H_2O gas sample in the ICOS cell.

Isotopologue	Wavelength, cm^{-1}	Precision
CO_2	3580.786	~ 0.2%
$^{13}CO_2$	3580.843	~ 0.2%
$CO^{18}O$	3580.907	~ 0.2%
$CO^{17}O$	3580.970	~ 0.2%
H_2O	3764.599	< 0.2%
$H_2{}^{18}O$	3765.091	< 2%
HDO	3764.876	< 2%

Modelling of the absorption spectra has shown noticeable temperature dependence of the line amplitudes, which demands for a fraction of a degree precision for the gas sample temperature control in the optical cell, corresponding to adequate molecular concentration retrieval and isotopic ratio measurement accuracy of: D/H < 2%, $^{18}O/O < 2\%$ (H_2O), $^{18}O/^{17}O/O < 0.3\%$ (CO_2), $^{13}C/C \sim 0.3\%$.

General ICOS cell design views for the M-DLS experiment are shown in Figure 2. High reflection R = 99.9% of the cell mirrors at 2.65 microns results in ~ 220 m effective optical path in a compact cell for H_2O isotopologue weak absorption lines. A few meters long effective optical path at 2.79 microns is considered for CO_2 isotopologue strong absorption lines.

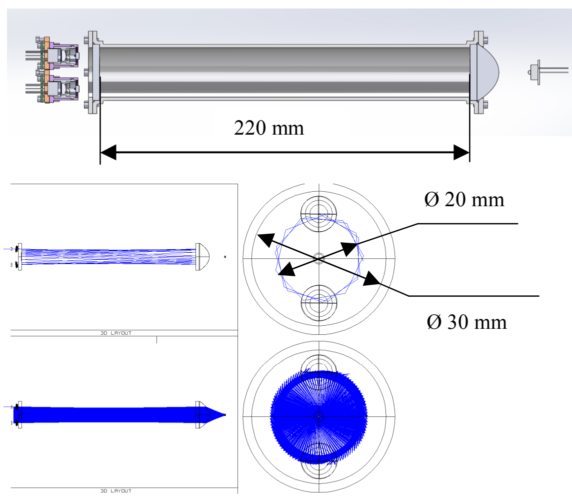

Figure 2. A cross-section model of the optical cell with partially shown input laser and output photodetector interfaces (up). Calculated beams and optical field pattern at the ICOS cell mirrors (down).

Special system of gas sampling for the M-DLS instrument will be shared with Martian Gas Analytic Suite (MGAS), which is another instrument, proposed for the same Landing Platform. Gas sampling inlet will be lifted up by a telescopic tube to a point, 15 cm higher than the Landing Platform top. The sampling system will efficiently refresh ambient Martian atmosphere gas sample in the ICOS cell analytical volume and will optionally enhance measurement accuracy by increasing ~ 5 times up concentration of sampled gas in the ICOS cell.

Following the M-DLS experiment idea, we are carrying out industrial design of a compact and lightweight M-DLS instrument for the ExoMars-2020 mission Landing Platform scientific payload, see Figure 3. M-DLS is aimed to continue *in situ* study of atmosphere near the Martian surface after the TLS/SAM/MSL instrument of the NASA Curiosity rover [3].

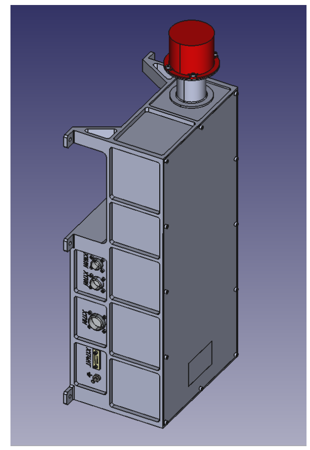

Figure 3: 3D-model of the M-DLS instrument external view.

3. Summary and Conclusions

The idea of M-DLS experiment, combining TDLAS and ICOS methods, has been proposed for continuous study of atmosphere near the Martian surface during the ExoMars-2020 mission. M-DLS instrument aims for measuring of H_2O and CO_2 molecule content and of D/H, $^{18}O/^{17}O/^{16}O$, $^{13}C/^{12}C$ isotopic ratio variations with ~ 1% accuracy *in situ* at the stationery Landing Platform location.

Acknowledgements

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Microphone characterisation for the Mars 2020 rover

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Abstract

We have used the Aarhus planetary simulator facility to test the Mars 2020 rover microphones in a fully representative environment. Wind characterisation experiments were performed in addition to the first ever tests of a LIBS acoustic measurement in a Martian environment at long range.

1. Introduction

The SuperCam instrument suite onboard the Mars 2020 rover will include the Mars Microphone (provided by ISAE-SUPAERO in France) to support the Laser Induced Breakdown Spectroscopy (LIBS) investigation of soils and rocks on Mars [1,2]. The primary purpose of the LIBS instrument is to investigate at remote distances the elemental composition of Martian rocks, thanks to a pulsed laser and the spectroscopic analysis of the plasma that is created when the laser beam is focused to achieve >1 GW/cm2 irradiance. The LIBS plasma bubble expands in a few hundreds of ns, and therefore generates a pressure shock wave. The overall intensity of the resulting acoustic wave is proportional to the laser irradiance and to the mass of ablated materials [3,4] thus revealing some unique physical properties of the targets probed with LIBS such as the target hardness and other mechanical properties that are otherwise unknown at remote distances [5].

In order to satisfy the SuperCam requirements, the Mars Microphone must be able to record audio signals from 100 Hz to 10 kHz on the surface of Mars, with a sensitivity sufficient to monitor a LIBS impact at distances up to 4 m. In addition to supporting the LIBS investigation, the Mars Microphone will also contribute to basic atmospheric science studies such as studying the Martian wind properties, convective vortices and dust devils [e.g., 6]. To meet these requirement, a condenser microphone has been selected and the amplification gains and dynamics of the instrument have been carefully chosen. Therefore, realistic testing in Mars conditions is essential given the strong acoustic attenuation at high frequencies due to the low surface pressure and the difference of acoustic impedance with respect to Earth [7].

2. Aarhus Wind Tunnel Tests

The tests were performed using the Aarhus Wind Tunnel Simulator II (AWTSII) [8] in Denmark over the course of three days in January 2017. AWTSII is a climatic chamber housing a recirculating wind tunnel. The cylindrical chamber has a 2.1 m inner diameter, and is 10 m in length. The tests were performed at 6 mbar of CO_2, achieved by evacuating the chamber and then repressurizing with CO_2. The facility is fitted with a suite of environment sensors (temperature, pressure, humidity, …) in addition to an in-situ webcam.

The first set of tests focussed on the wind speed characterisation to evaluate a possible aeroacoustic saturation of the microphone. Wind speeds of 2-10 m/s were generated. There were five microphones inside the chamber: two Mars Microphone Engineering Models (EMs) without front end electronics (FEE), two Mars Microphone EMs with FEE, and a ½ inch reference microphone. One of the Mars Microphones was attached to the Structural and Thermal Model (STM) of the SuperCam thermal enclosure. See Fig. 1.

The second set of tests focused on performing the first ever tests of a LIBS acoustic measurement in a Martian environment at long range. A portable LIBS was used outside the chamber and was fired through a 8 mm thick chamber window onto a small aluminium target. Table 1 gives the characteristics of both the portable LIBS and the SuperCam LIBS. For these tests the 5 microphones were all orientated towards the LIBS target with two different source-microphone distances: 1.2 m and 4 m.

Table 1. Comparison of the characteristics of the portable LIBS used in these experiments and the SuperCam LIBS

	PORTABLE LIBS	**SUPERCAM LIBS**
Laser wavelength	1064 nm	1064 nm
Pulse duration	5 ns	4 ns
Laser energy	40 mJ	24 mJ
Spot diameter at target	400-500 µm	300-600 µm
Incident angle of laser onto target (from normal)	~80°	0° (calibration targets); 45° (typical rock targets)

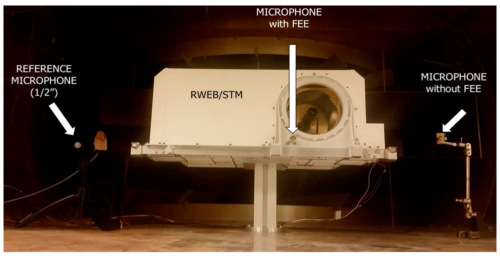

Figure 1. Test configuration for the wind characterization tests. At one end of the tunnel there was a Mars Microphone EM with FEE attached to the SuperCam thermal enclosure STM (RWEB/STM in figure), a Mars Microphone EM without FEE, and a reference microphone. At the other end of the tunnel there was a Mars Microphone EM with FEE and a Mars Microphone EM without FEE (not shown here).

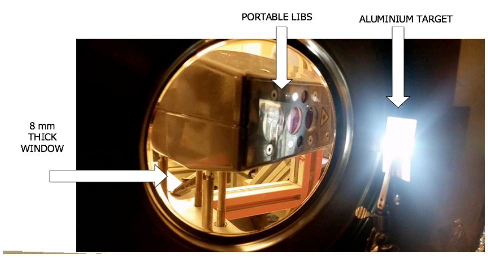

Figure 2. The LIBS experiment configuration.

3. Results and Conclusions

We have used the Aarhus Mars chamber to test the Mars Microphone in a fully representative environment before flight. The tests performed were successful, with no saturation of the instrument under Martian wind and a recording of the LIBS signal at 4 meters with a signal-to-noise ratio consistent with the requirements. The wind characterization tests demonstrated that the microphone signal RMS varies with the square of the wind velocity, indicating that the Mars Microphone may be used for wind speed determination. However, further experiments are required to understand the influence of the incident wind direction. The large size of the chamber also ensured that we could perform the acoustic measurements at the required distance of 4 m from the LIBS target (Fig 3). Now that the feasibility of the measurement has been demonstrated, further testing will be performed to provide a detailed characterization of the LIBS acoustic emission from various rock samples in the Martian environment.

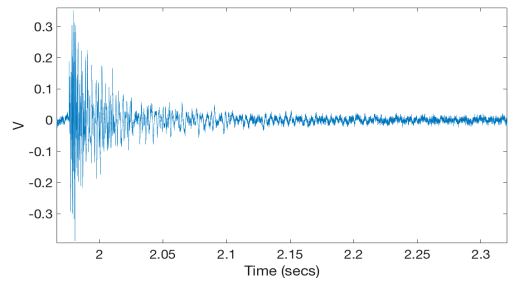

Figure 3. LIBS acoustic signal recorded by the EM of the Mars Microphone in 6 mbar, CO_2 at 4 m from the source.

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Miniaturized Raman/LIBS instrument for in situ exploration of planetary bodies without atmospheres

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1. Introduction

In our solar system, there is a multitude of planetary bodies without substantial atmospheres, including asteroids, comets, moons, and minor planets. Due to the lack of atmospheres, these bodies are not affected by atmospheric alteration processes. Asteroids and comets especially are considered to be the least evolved objects in the solar system, possibly still containing pre-solar grains from the proto-solar nebula [1]. Therefore, the study of planetary objects without atmospheres can yield important information about the formation of the solar system. This makes them interesting targets for robotic exploration with instruments that are able to determine the chemical and mineralogical composition of both their surface and subsurface.

Here we present first results of the design and characterization of a miniaturized instrument for the application on planetary bodies with low or non-existent atmospheric pressure. The instrument will combine Raman spectroscopy and laser-induced breakdown spectroscopy (LIBS) and is optimized to be very lightweight and small, with working distances of up to 1 m.

2. Raman spectroscopy

Raman spectroscopy is a powerful technique for the analysis of sample compositions and structure. It is based on the Raman effect. This Raman scattering produces a spectrum that is characteristic of the scattering molecule and can be considered as a “fingerprint” of the investigated material. For Raman spectroscopy, a CW laser with a tightly controlled output wavelength is advantageous for the exact determination of the observed Raman shift.

3. LIBS

LIBS is an atomic spectroscopy method which permits rapid multi-elemental analysis. It relies on the ablation of material from the sample by focusing a pulsed laser onto its surface. This produces a plasma plume of atoms, ions, and electrons. A spectrum of the plasma will contain atomic and ionic emission lines from which the elemental composition of the sample can be determined. With the ChemCam instrument on board the NASA Mars Science Laboratory (MSL), LIBS was applied to study the surface of an extraterrestrial body for the first time [2, 3]. While the Martian atmosphere is well-suited for LIBS, lower pressures lead to a faster expansion of the plasma. This makes the detection of LIBS spectra at very low atmospheric pressures challenging. However, it has been shown that LIBS measurements can be performed with relatively low-energy lasers in ultra-high vacuum environments [4].

4. Combined Raman/LIBS

Raman spectroscopy and LIBS are highly complementary techniques. The complementary information of LIBS and Raman spectra on the composition of a sample increases the accuracy of rock/soil determination. Furthermore, material ablation by LIBS can be used to penetrate the surface to reach the subsurface material (up to mm in soft materials), while Raman spectroscopy can be used to search for potential organic compounds in these subsurface areas. Neither technique requires sample preparation and both have short acquisition times (seconds to minutes). The measured spectra can be interpreted directly. Combining both techniques in a single device also has the benefit that the spectrometer and large parts of the optical components can be shared, which helps to keep the instrument lightweight and compact.

5. Miniaturized design

Several configurations of a Raman/LIBS instrument are conceivable and have been proposed for planetary exploration already [5–8]. SuperCam will be the first instrument to combine Raman and LIBS for planetary exploration as part of the Mars2020 mission. In order to cover distances of up to 12 m, it uses a telescopic system as well as a powerful laser, which increase size and weight of the device. With a close-up setup that only covers distances of up to 1 m around the probe, a telescope is not required and less powerful lasers can be used, so that the instrument can be miniaturized. This is especially advantageous for pioneering missions with a smaller scope. We estimate that our Raman/LIBS instrument can be as light as ~3 kg in total, including lasers, spectrometer and electronics.

For our miniaturized design, one option is the combination of a custom miniaturized echelle spectrometer for both Raman and LIBS spectra with two separate lasers. The echelle spectrometer offers high spectral resolution over a large spectral range, while separate lasers for Raman and LIBS are beneficial with regards to resolution and signal strength. Separate lasers also provide more flexibility, as Raman and LIBS spectra can be measured independently from one another, and the Raman laser can be used as a focusing laser. However, a single (pulsed) laser for both Raman and LIBS is also promising due to the possibility of gating out the fluorescence in Raman spectra. Currently, a continuous wave (CW) Nd:YAG laser at 532 nm is used for Raman, and a pulsed Nd:YLF laser at 1053 nm is used for LIBS. The advantages and disadvantages of different configurations will be investigated.

6. Summary and Conclusions

Raman spectroscopy and LIBS are complementary measurement techniques that are well-suited for the robotic exploration of planetary bodies without atmospheres. The presented instrument combines these techniques, enabling the identification of both the elemental composition and the molecular structure of a sample at distances of up to ~1 m and without prior sample preparation. We strive for a miniaturized and lightweight design. First spectra and a characterization of a combination of a miniaturized laser and a miniaturized echelle spectrometer are presented.

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Scientific rationale and concepts for in situ probe exploration of Uranus and Neptune

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Abstract

Uranus and Neptune, referred to as ice giants, are fundamentally different from the better-known gas giants (Jupiter and Saturn). Exploration of an ice giant system is a high-priority science objective, as these systems (including the magnetosphere, satellites, rings, atmosphere, and interior) challenge our understanding of planetary formation and evolution. The importance of the ice giants is reflected in NASA's 2011 Decadal Survey, comments from ESA's SSC in response to L2/L3 mission proposals and results of the 2017 NASA/ESA Ice Giants study. A crucial part of exploration of the ice giants is in situ sampling of the atmosphere via an atmospheric probe. A probe would bring insights in two broad themes: the formation history of our Solar System and the processes at play in planetary atmospheres. Here we summarize the science driver for in situ measurements at these two planets and discuss possible mission concepts that would be consistent with the constraints of ESA M-class missions.

Solar System formation

To understand the formation of giant planets and the origin of our Solar System, statistical data obtained from the observation of exoplanetary systems must be supplemented by direct measurements of the composition of the planets in our Solar System. 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.

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.

Mission concepts

Different mission architectures are envisaged, all based on an entry probe that would descend through the stratosphere and troposphere under parachute down to a minimum of 10 bars. Future studies will focus on the trade-offs between science return and the added design complexity and cost of a probe that could operate at pressures greater than 10 bars. Three possible mission configurations can be envisaged (with different risk/cost trades):

- Configuration 1: Single Probe + Flyby Carrier/Relay. The probe would detach from the carrier several weeks to months prior to probe entry. The carrier trajectory would be designed to enable probe data relay during over-flight as well as performing approach and flyby science;
- Configuration 2: Two Probes + Flyby Carrier/Relay. Same as in Configuration 1 but in the case of a two-planet mission (Saturn/Uranus or Uranus/Neptune) that uses the same spacecraft and probe designs;
- Configuration 3: Single Probe + Orbiter (similar to the Galileo Orbiter/Probe). Following the probe descent mission and relay, the carrier spacecraft would transition to an orbit around Uranus or Neptune, and continue to perform orbital science.

In the three configurations, the carrier/orbiter would be equipped with a combination of Radioisotope Thermoelectric Generators (RTGs), secondary batteries and possibly a set of primary batteries for phases that require a high power demand, for example during the probe entry phase. Note that NASA and ESA agreed that a flyby with probe (Configuration 1) does not meet the science requirement for the next mission to the ice giants (NASA Ice Giants Science Definition Team Report, 2017).

Payload

To meet the mission science goals and measurement requirements, a model payload would include a Mass Spectrometer, an Atmospheric Structure Instrument (also dedicated to the measurement of the atmospheric electricity), a Doppler Wind Experiment, a Nephelometer, and a Net-Flux Radiometer. For budgetary and technological reasons, ESA does not have currently the capacity to prepare a standalone mission. However, in the context of NASA-ESA cooperation, ESA could provide an entry probe to a US ice giant flagship mission. Additional contributions could be also supplied by EU states independently from ESA. Such a probe, whose design would be very close to that of a Saturn entry probe, would fit well into the envelope of an ESA M-class mission.

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The *Hera* Saturn Entry Probe Mission: a Proposal in Response to the ESA M5 Call

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Abstract

The *Hera* Saturn entry probe mission is proposed as an ESA M-class mission to be piggybacked on a NASA spacecraft sent to or past the Saturn system. *Hera* consists of an atmospheric probe built by ESA and released into the atmosphere of Saturn by its NASA companion Saturn Carrier-Relay spacecraft. *Hera* will perform in situ measurements of the chemical and isotopic composition as well as the structure and dynamics of Saturn's atmosphere using a single probe, with the goal of improving our understanding of the origin, formation, and evolution of Saturn, the giant planets and their satellite systems, with extrapolation to extrasolar planets. *Hera* will probe well into and possibly beneath the cloud-forming region of the troposphere, below the region accessible to remote sensing, to locations where certain cosmogenically abundant species are expected to be well mixed.

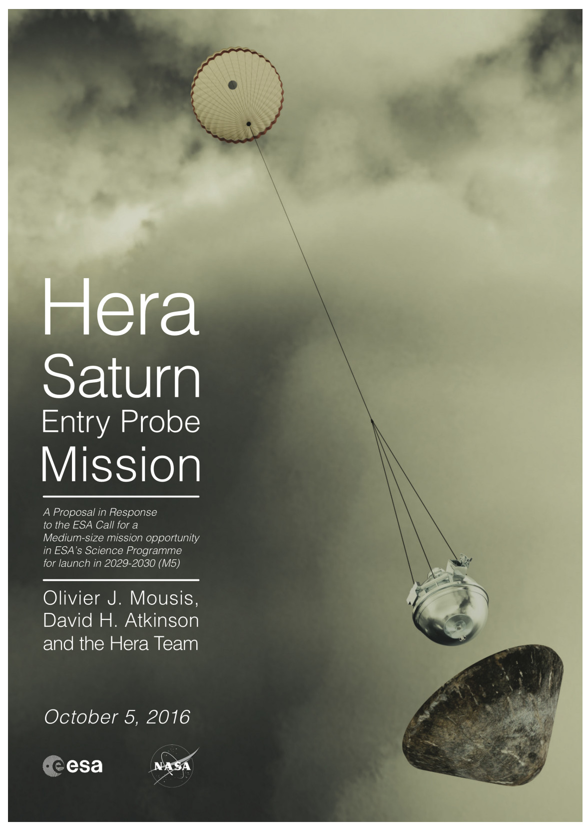

Figure 1: Cover of the Hera Saturn probe proposal submitted to ESA (illustration by Dr. Tibor Balint).

The *Hera* probe will be designed from ESA elements with possible contributions from NASA, and the Saturn/Carrier-Relay Spacecraft will be supplied by NASA through its selection via the New Frontier 2016 call or in the form of a flagship mission selected by the NASA "Roadmaps to Ocean Worlds" (ROW) program. The *Hera* probe will be powered by batteries, and we therefore anticipate only one major subsystems to be possibly supplied by the United States, either by direct procurement by ESA or by contribution from NASA: the thermal protection system of the probe.

Following the highly successful example of the *Cassini-Huygens* mission, *Hera* will carry European and American instruments, with scientists and engineers from both agencies and many affiliates participating in all aspects of mission development and implementation. We refer the reader to [1] for a full description of the science payload aboard the Hera probe. A Saturn probe is one of the six identified desired themes by the Planetary Science Decadal Survey committee on the NASA New Frontier's list, providing additional indication that a Saturn probe is of extremely high interest and a very high priority for the international community.

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Retrieval of martian dust and cloud properties from ground-based radiance sensors observations

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Abstract

On Mars, dust and clouds are primary elements for studying the interactions of solar radiation with the atmosphere and surface and their influence on the radiation balance. Depending on dust opacity and parameters such as size distribution, airborne dust can provide positive or negative radiative feedbacks into dynamical processes. This role played by dust in the circulation of the martian atmosphere points out the need of retrieving the concentration and physical properties of dust at different time periods and locations.

In order to address those measurements a number of ground-based sensors were selected for Exomars missions: the solar irradiance sensor (SIS) [1,2] selected for Exomars 2016 and 2020, and the optical depth sensor (ODS) [3,4] selected for Exomars 2020. These instruments measure the solar flux at two wavelengths (UVA and NIR) and have a specific field of view (FOV) (see **Figure 1**) that allows them to measure the scatter flux and the direct flux at different time intervals during the course of the day. In this work, we will discuss different retrieval procedures developed for ground-based sensors. We first perform several sensitivity tests of the sensors signals to parameters such as the dust opacity and size distribution to establish which dust parameters can be retrieved by the different sensors. Subsequently, in order to adopt for each sensor the retrieval procedures capable to obtain as much information as possible on the optical properties of martian aerosol, we will evaluate different configurations of the procedures as well. A similar study will be presented for the detection and characterization of martian clouds.

1. Description of the model

The retrieval procedure for dust is based on the use of radiative transfer simulations reproducing the signals that should be observed by the instruments as a function of key dust parameters: size distribution (r_{eff}, ν_{eff}), refractive index ($m=n+ik$) and opacity (τ). These different parameters can be whether retrieved or fixed in the model. The selection of the free parameters during the retrieval depends on the instrument properties (e.g. FOV or sampling frequency) and it is based on several sensitivity analyses. The phase function and single scattering albedo are computed using T-Matrix method [5] through the refractive index and the size distribution.

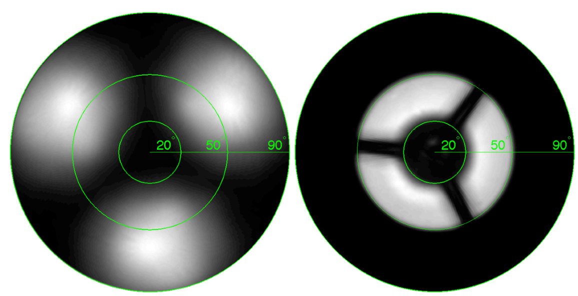

Figure 1: *Measured FOV of SIS'16 (left) and ODS (right). White and black areas correspond to 100 and 0 % of transmission, respectively. The SIS FOV is employed using a total of three sensors oriented at different zenith angles while the ODS one using only one sensor and optical components.*

For the cloud detection, the index colour (CI) is used, defined as the ratio between the scattered light at NIR and UVA wavelength ranges. If a cloud is present during twilight, then a minimum must be observed in the time variation of CI [2,3,4]. The retrieval procedure is similar to the one for the dust but with the addition of two more free parameters: the cloud opacity and altitude. In order to test the reliability of the retrieval procedure, we simulated the signals of the sensors for specific values of τ, m, r_{eff} and ν_{eff}, and then we added a random noise of amplitude 5% (O_{Mars}). Subsequently, those signals were analyzed by the retrieval procedure using different initial conditions. Some examples for the three UVA sensors of SIS'16 instrument are illustrated in **Figure 2** and **Table 1**.

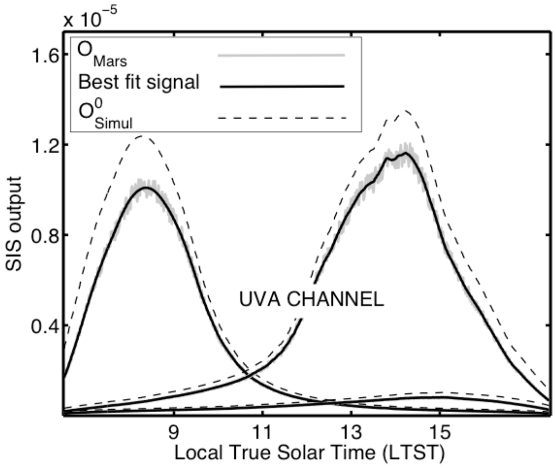

Figure 2: *Comparison between OMars signals computed for τ^{UVA}=0.7, m^{UVA}=1.5+i0.02 and r_{eff}=1.4 µm (grey solid lines), and those simulated using the retrieved (black solid line) and a priori (black dashed line) values of the free parameters illustrated in first line of* ***Table 1****.*

Table 1: *Retrieved values of τ^{UVA}, k^{UVA} and r_{eff} when applying the procedure to O_{Mars} signals computed for τ^{UVA} =0.7, m^{UVA} =1.5+i0.02 and r_{eff}=1.4 µm, and using different a priori values in the retrieval procedure.*

Initial values			Retrieved values		
τ^{UVA}	k^{UVA}	r_{eff}	τ^{UVA}	k^{UVA}	r_{eff}
0.50	0.0129	1.30	0.699	0.01995	1.403
0.30	0.0129	1.28	0.700	0.01998	1.406
0.40	0.0143	1.68	0.698	0.01995	1.403
0.20	0.0143	1.48	0.697	0.01996	1.399
0.25	0.0193	1.78	0.700	0.01997	1.401

2. Terrestrial validation

In addition to the sensitive analysis performed to the sensors, the ODS and SIS'16 participated in different terrestrial campaigns in Africa in 2004 and 2014, respectively [4, 1]. We will discuss the results of these campaigns for which the two sensors were compared against photometer observations. For example, **Figure 3** shows a comparison between ODS and a AERONET photometer that was localized at the same place during the campaign in Africa in 2004.

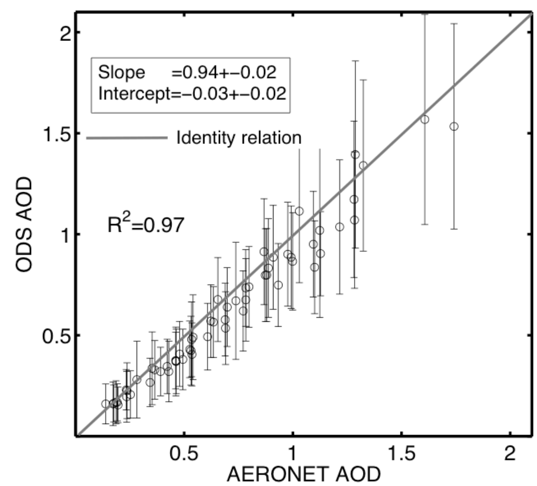

Figure 3: *Correlation between ODS UVA channel and AERONET aerosol opacity at 370 nm.*

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Pressure and Relative Humidity Measurement Devices for Mars 2020 Rover

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Abstract

One of the scientific payloads onboard the NASA Mars 2020 rover mission is Mars Environmental Dynamic Analyzer (MEDA): a set of environmental sensors for Mars surface weather measurements. Finnish Meteorological Institute (FMI) provides a pressure measurement device (MEDA PS) and a relative humidity measurement device (MEDA HS) for MEDA.

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. 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.

2 MEDA PS

MEDA PS is pressure measurement device based on silicon micro-machined capacitive Barocap® pressure sensors developed by Vaisala Inc. The measurements are controlled by Vaisala proprietary ASIC. The technology of the Barocap® is well known and it has been used before in 6 missions, including MSL (REMS-P) and Exomars 2016 Schiaparelli lander (DREAMS-P). MEDA PS design is very similar to REMS-P, inheriting some parts also from DREAMS-P.

MEDA PS is located inside the the temperature controlled Instrument Control Unit (ICU) and connected to the atmosphere through a dedicated pipe. The pipe exits the rover body through a small opening in Rover Avionics Mounting Panel with a dust filter. The electronics are protected by box-like Faraday cages. Dimensions of the instrument are 62 mm x 50 mm x 17 mm (height without the pipe) and the total mass is only approximately 40 g. Power consumption of MEDA PS during pressure measurements is 15 mW.

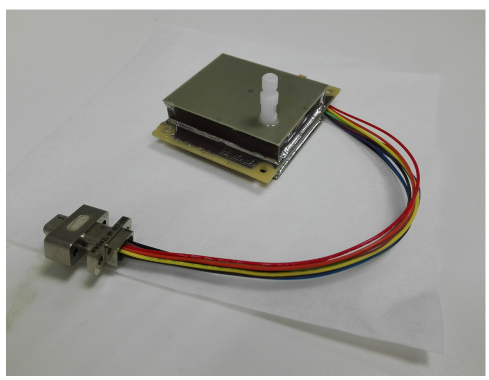

Figure 1: Flight model of MEDA PS.

2.1. MEDA PS Performance

- Measurement range: 1-1200 Pa (optimized for Mars range 400-1200 Pa).
- Accuracy: ±20 Pa from 1-400 Pa and ±10 Pa from 400-1200 Pa.

- Resolution: $\leq$ 0.5 Pa.
- Operational temperature range: -45°C to +55°C.
- Response time: $\leq$ 1 s.

3 MEDA HS

MEDA HS is a miniature relative humidity device based on polymeric capacitive Humicap® humidity sensors developed by Vaisala Inc. As in MEDA PS, the measurements are controlled by Vaisala proprietary ASIC. The same technology has previously been used in MSL (REMS-H).

The humidity device is mounted on the Remote Sensing Mast providing ventilation with the ambient atmosphere through a filter protecting the device from airborne dust. Humicap® sensors are located on the PCB inside a protecting cylindrical Faraday shield. Dimensions of the instrument are 55 mm x 25 mm x 95 mm and the total mass is approximately 45 g. Power consumption during nominal measurements is less than 20 mW.

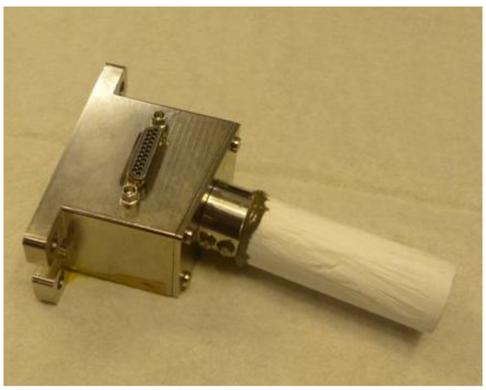

Figure 2: Engineering model of MEDA HS.

3.1 MEDA HS Performance

- Measurement range: 0-100% RH in -83°C to -3°C
- Accuracy: $\pm$10% RH in temperatures greater than -70°C, and $\pm$20% RH in -83°C to -70°C.
- Resolution: $\leq$1% in -83°C to -3°C.
- Operational temperature range: -128°C to +50°C (scientific measurements meaningful down to -83°C only).
- Response time: $\leq$30 min for temperatures above -70°C.

4. Measurements on Mars

MEDA HS enables investigations of atmospheric humidity variations of both diurnal and seasonal scale to better understand the Martian hydrological cycle. MEDA PS will measure the dynamics of the Martian pressure environment and is also able to detect pressure changes with a variation speed of at least 1 Pa/s.

MEDA is powered on and checked out already during the cruise towards Mars. The Flight System will calibrate MEDA HS and PS at zero pressure at least once during the cruise phase. Pressure and relative humidity measurements on Mars are recorded by ICU at least once per hour. MEDA PS and MEDA HS and the whole MEDA sensor package is expected to operate for at least 1 Martian year.

5. Summary and Conclusions

MEDA's goal is to help understand the Martian surface conditions by sampling the near surface environment. The MSL REMS heritage permits easier comparisons to measurements taken from the meteorological station on MSL in Gale Crater. After 2020 NASA's Mars rover landing and ExoMars 2020 landing it is possible to get pressure and relative humidity measurements from at least two locations on Mars simultaneously. Surface measurements from multiple locations will significantly help to validate global atmospheric models and understand the relations between the surface environment and large scale dynamics.

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NEWTON - NEW portable multi-sensor scienTific instrument for non-invasive ON-site characterization of rock from planetary surface and sub-surfaces

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Abstract

In space instrumentation, there is currently no instrument dedicated to susceptibly or complete magnetization measurements of rocks. Magnetic field instrument suites are generally vector (or scalar) magnetometers, which locally measure the magnetic field. When mounted on board rovers, the electromagnetic perturbations associated with motors and other elements make it difficult to reap the benefits from the inclusion of such instruments. However, magnetic characterization is essential to understand key aspects of the present and past history of planetary objects. The work presented here overcomes the limitations currently existing in space instrumentation by developing a new portable and compact multi-sensor instrument for ground breaking high-resolution magnetic characterization of planetary surfaces and sub-surfaces. This new technology introduces for the first time magnetic susceptometry (real and imaginary parts) as a complement to existing compact vector magnetometers for planetary exploration. The objective is to obtain unique information on the magnetic structure recorded during the formation of the studied rocks, and thus to derive information regarding the ancient global magnetising field. This novel instrument is being developed under a H2020 RIA project entitled NEWTON. This project started in November 2016 and has a duration of 36 months.

1. Introduction

Apart from the Earth, the Moon, Mars, Ganymede and possibly Mercury possess an intrinsic magnetic field. On the Moon and Mars, this magnetic field is purely the remanent signature of a past global magnetic field whose spatial and temporal characteristics remain largely inaccessible. This is because remote measurements (on board spacecraft) do not allow to unambiguously determine the magnetization [1]. To fully characterize these magnetic bodies and sources, planetary surface prospection with rovers carrying compact and light multi-sensor instruments are necessary. These can obtain detailed information on the magnetic signatures and rock susceptibilities, allowing for instance the required identification of key landing sites for a more complex sample-return mission. The combination of magnetic and susceptibility measurements can be used to investigate the disputed origin of Martian moons Phobos and Deimos: whether they were captured asteroids, remnants from Mars formation, impact ejecta from the planet reaccreted in its orbit or a combination of all [2], [3]. Landed instruments which combine vector magnetometers and susceptometers can shed new light on key questions like the intense magnetic anomalies of Mars, or the disputed origin of the small scale lunar magnetic anomalies

This work provides a first and unique technology capable of performing a complete characterization of the rocks based on a magnetic instrument. This instrument will include a recurrent vector magnetometer, a highly innovative susceptometer with a power supply system and a very sophisticated frequency generation and shift detection. The goal is to achieve a TRL6 at the end of the current project, to make the multi-sensor instrument suitable for boarding on a planetary exploration rover in the short term.

2. Instrument Requirements

The proposed instrument will measure the magnetic susceptibility, environment magnetic field and other paleomagnetic parameters on the Earth, Mars, Moon and other bodies. In order to define the instrument requirements needed to perform such measurements, an exhaustive analysis of available literature has been done to compile the magnetic parameters of the rocks most representative of the Earth, Mars and the Moon. Other parameters such as mass susceptibility and saturation remanence of their principal rocks have also been considered. All this data analysis is reported in [4]. As an example, the mass susceptibility of rocks from the Moon is shown in Figure 1.

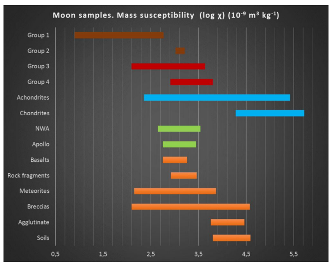

Figure 1: Mass susceptibility of rocks from the Moon. The units for the mass susceptibility are in 10-9 S.I. The graph represents the log of the magnetic susceptibility, i.e.: log(χ(m3/kg)).

3. Proposed Solution

The instrument suite will combine complex susceptometry to existing compact vector magnetometers for planetary exploration in order to provide complete non-invasive in-situ magnetic characterization. Figure 2 shows the block diagram of the proposed multi-sensor instrument.

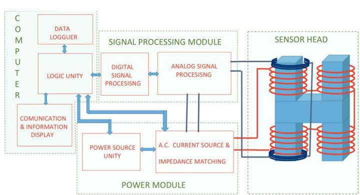

Figure 2: Block diagram of the multi-sensor instrument.

The multi-sensor instrument includes a recurrent vector magnetometer, a novel susceptometer and highly innovative power supply system. The sensor head includes the magnetometer and the susceptometer. The susceptometer is a ferrite with H shape. This shape allows the susceptometer to perform a differential measurement, which increases the sensitivity to measure the imaginary part of susceptibility, which is expected to be very low in most of the rocks.

To achieve the goal to measure the complex susceptibility of rocks with sufficient sensitivity, the instrument is designed with a zero method based on a temporal measurement. This implies the introduction of an original and innovative system to both generate and retrieve the signals at different frequencies resolving at least one part in a million to cover the wide range of susceptibility of natural rocks. An important challenge also concerns an efficient generation of the power that is needed to apply high magnetic fields able to penetrate the rocks during rover missions. At this point the proposed solution addresses this by using magnetic amplifiers to generate the power needed for these systems for application in space. Such technology is well known but the large dimensions of such devices have so far prevented their application to space and planetary exploration. The latest generation of magnetic amplifiers has however greatly matured and progressed towards miniaturization.

4. Summary and Conclusions

This work aims to solve the limitations currently existing in space instrumentation by means of providing a new portable and compact multi-sensor instrument for use in space, science and planetary exploration to solve some of the open questions on the crustal and more generally planetary evolution within the Solar System.

Acknowledgements

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Investigation of plasma parameter determination of LIBS plasmas in martian conditions

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1. Introduction

Laser Induced Breakdown Spectroscopy (LIBS) is a powerful tool for the elemental analysis of rocks and soils, in particular in-situ for planetary explorations [1]. The ChemCam instrument is part of NASA's Mars Science Laboratory mission and is analyzing Martian targets with LIBS since 2012 [2]. Also the follow-up instrument SuperCam on Mars2020 will use LIBS in combination with other spectroscopic methods[3]. Despite its many advantages, LIBS suffers from variations of the plasma emission due to varying experimental conditions, small-scale inhomogenities and physical and chemical matrix effects. This is important in particular for LIBS applications in the field of planetary exploration, as the encountered geological samples show variations on different scales and the measurement parameters are not fixed like in a laboratory. The differences in the LIBS data reduce the precision and accuracy of computed quantities by univariate and multivariate approaches. Since the LIBS plasma is characterized by parameters such as temperature and electron density, which can be calculated from the LIBS spectra, these parameters can be used for normalization and correction of the differences in the total emission or for particular emission lines.

Panne et al. [4] have shown that normalization with both parameters reduces the fluctuations of line ratios in terrestrial laboratory LIBS data. Also Feng et al. [5] observed a smaller signal variation in a pulse-to-pulse analysis by normalizing to temperature and the ratio between densities of neutral and single ionized species.

In this work we investigate the experimental conditions, mainly the timing of the measurement, for an optimized derivation of the plasma parameters from LIBS data taken under martian atmospheric conditions. With the results we will further evaluate their suitability for normalization.

2. Plasma parameters

The LIBS plasma is a complex state and simply measuring the plasmas temperature and electron density is not possible. However, they can be derived from the spectral data. The theory for the plasma temperature determination is based on a Boltzmann distributed level occupation of the electrons. For that a thermal equilibrium or at least a local thermal equilibrium (LTE) is a necessary assumption, which can be favored by short measuring times. Detailed explanations of the theory and calculations can be found in [6] and [7].

In general the plasma temperature and electron density determined from measurements without any spatial resolution and finite measurement times should be understood as temporal and spatial averages and not as real values for the whole plasma.

3. Experimental

Data was taken with the DLR LIBS set-up with a simulation chamber, an Echelle spectrometer (Aryelle Butterfly, LTB Berlin) with a time-gated intensified CCD and a pulsed Nd:YAG Laser (1064 nm, 8 ns, 10 Hz). The laser energy was reduced to 15 mJ and measurements were performed under simulated martian conditions(pressure 7 mbar, appropriate gas mixture).

The ICCD allows for time gated measurements but limits the quality of single shot LIBS spectra. The plasma of at least 5 shots have to be accumulated to obtain a spectrum of sufficient intensity. A similar problem occurs for measurements with short (< 300 ns) integration times. As short integration times are required to hold LTE conditions, several measurements were done to determine the best combination of number of accumulated LIBS spectra and the integration time.

A silicon wafer was used as a simple and homogeneous target. The delay time was 150 ns and we measured with two integration times, 50 and 100 ns, respectively, where the number of accumulated spectra was varied.

4. Evaluation

First, the signal-to-noise ratios (SNR) of the Si(I) 288 nm emission line was determined, see Table 1. For further comparison we took previously measured data with longer integration times (500 and 1000 ns). The SNR becomes better with more accumulated LIBS spectra. Note here that we did three measurements and for the data with longer integration times ten.

Plasma temperatures were calculated applying the Boltzmann plot method with Si(III) lines. Figure 1 shows the temperatures for different integration times and number of accumulated shots. For the shorter integration times the variation is larger. Also the temperature itself is in most cases higher for a shorter integration time.

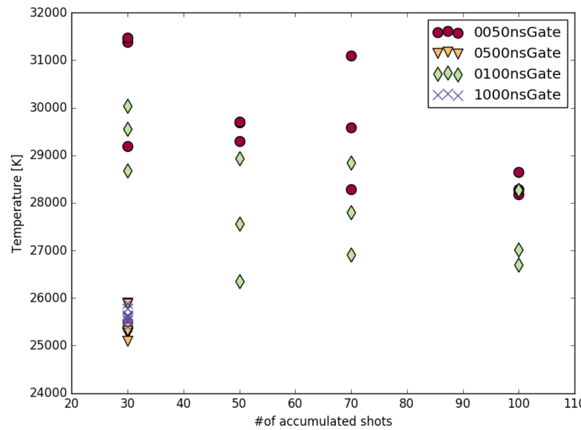

Figure 1: Plasma temperatures calculated from the measurements with the shorter gate (integration) times (50 and 100 ns) and the previous measured data with longer gate (integration) times.

Table 1: Signal-to-Noise ratios of Si(I) at 288 nm.

gate time [ns]	# of acc. shots	SNR
500	30	20
1000	30	41
50	30	5
50	50	16
50	70	23
50	100	23
100	30	12
100	50	12
100	70	16
100	100	52

5. Conclusion and outlook

Although the temperature determination is more stable for longer integration times, we will further investigate the shorter gate times and study their effect on the LTE conditions. Also the electron density will be analyzed. Since this study has the final objective to evaluate the plasma parameters for normalization, we have to bring the best conditions and measuring parameters for their determination in line with the largest gain of information about the analyzed target. Even though short integration times are favored to fulfill LTE conditions, they do not allow for high SNR and the detection of molecular bands for example. The results of this study are interesting for upcoming missions to Mars that will have the possibility for time-resolved LIBS measurements such as SuperCam on Mars2020. With SuperCam, the third wavelength range can be used for time gated measurements.

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METEO-P/H: Measuring ambient pressure and relative humidity on the ExoMars 2020 landing site

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Abstract

Finnish Meteorological Institute (FMI) has designed and is in the process of building and testing a pressure and humidity measurement device for the ExoMars 2020 lander. The ExoMars 2020 mission consists of the Russian Roscosmos Surface Platform (SP) and the European Space Agency (ESA) Rover. The Surface Platform will perform the Entry, Descent and Landing for the lander combo and start stationary science operations after landing, while the Rover will drive off the SP to explore the landing site surroundings and soil.[1] The FMI measurement device is installed on the Surface Platform to give continuous measurements from a stationary location. The METEO-P pressure device and METEO-H humidity device are part of the METEO meteorological science package, which also includes a thermometer and an anemometer from IKI, Russia, as well as the RDM Radiation and dust sensors, and the AMR magnetic field sensors from INTA, Spain.

1. Introduction

Finnish Meteorological Institute has an extensive history in providing pressure and humidity measurement devices for Mars landers. FMI's pressure device development started for the Russian led Mars 96 mission, which failed during launch. After Mars 96 FMI has provided a pressure measurement device for most of the successful and unsuccessful Mars surface missions: Mars Polar Lander, Beagle-2, Mars Phoenix, Curiosity and ExoMars 2016 Schiaparelli. FMI's humidity devices were also flown on Curiosity and Schiaparelli. Curiosity's pressure and humidity measurement device continues to provide science observations to this day.

2. METEO-P pressure device

The METEO-P pressure device is based on capacitive Barocap® pressure sensors by Vaisala Inc., Finland. Vaisala originally developed the micromachined silicon sensors for weather balloons. The Barocap® sensors for Mars landers are further optimized for the Martian surface 4-12 hPa pressure range.

METEO-P consists of two pressure transducers each containing 8 measurement channels. Each transducer contains 2-3 Barocap® pressure sensors, 2 capacitive Thermocap® temperature sensors and 3-4 constant reference channels.

During pressure measurement, frequency signals are read from the capacitive transducer sensor and constant channels. The actual calibrated pressure readings are obtained through data analysis on ground.

The pressure device is installed inside the ExoMars SP warm compartment and has access to the outside ambient pressure through a dedicated tube. METEO-P connects to the METEO Central Electronics Unit and METEO-H through connectors mounted on the METEO-P circuit board. The METEO CEU acts as the higher level controlling computer for all METEO devices.

METEO-P specifications:

- Approximate mass 100 g
- Accuracy: ± 20 Pa from 1-400 Pa and ± 10 Pa from 400-1200 Pa
- Resolution: ≤ 0.5 Pa
- Operational temperature range: -45°C to +55°C
- Response time: ≤ 1 s

3. METEO-H humidity device

The METEO-H humidity device is built around the capacitive Vaisala Humicap®sensor technology. A similar measurement circuit is used as with the Barocaps®.

METEO-H has a single humidity transducer with 2 Humicap®sensors, 2 capacitive Thermocap® temperature sensors and 4 constant reference channels. Humidity readings are obtained through on ground data analysis from the transducer capacitive channel frequencies.

As the Humicaps® are substantially sensitive to temperature change, there is a resistive PT1000 temperature sensor integrated on each of the sensors for calibration purposes. The PT1000s are measured by the measurement controller. Also, a heating resistor is integrated on each of the Humicap® chips for regenerating the sensor from chemical contaminants or frost.

The METEO-H device is attached, along with other meteorological devices, on the deployable mast outside the ExoMars Surface Platform. There is a connector mounted on the METEO-H mechanics that is used to interface the METEO-H through cabling to the measurement controller integrated on the METEO-P board.

METEO-H specifications:

- Approximate mass 45 g
- Measurement range: 0-100% RH in temperatures from -83°C to -3°C
- Accuracy: $\pm$10%RH in temperatures greater than -70°C, and $\pm$20%RH in -83°C to -70°C
- Resolution: $\leq$ 1% over a Mars temperature range of -83°C to -3°C
- Operational temperature range: -128°C to +50°C (calibration down to -80°C only)
- Response time:$\leq$ 30 min for temperatures above -70°C

4. Measurement controller

The METEO-P/H measurement controller is integrated on the METEO-P printed circuit board. The controller is based on a commercial automotive microcontroller unit (MCU), the Freescale MC9S12XEP100, that was custom qualified[2] for use on Mars lander missions. The measurement controller derives most of its design from the DREAMS-P/H pressure and humidity measurement controller that flew on the ExoMars 2016 Schiaparelli lander, which was destroyed during a failed landing. Earlier FMI Mars devices were controlled by space grade Field Programmable Gate Array (FPGA) chips. The approach of using a commercial MCU enabled more autonomy for the controller and leaner development process.

The METEO-P/H controller communicates with the METEO Central Electonics Unit (CEU) through a RS-422 serial interface to receive telecommands and transmit scientific and status telemetry. The controller distributes power to the two pressure transducers on METEO-P and the single humidity transducer on METEO-H using switches on the METEO-P board. Also, METEO-H humidity sensors are regenerated by power delivered through a switch driven with Pulse Width Modulation (PWM) signal.

A PT1000 measurement circuit for measuring the METEO-H humidity sensor temperature is implemented using operational amplifiers and the MCU internal ADC module.

5. Summary and Conclusions

METEO-P/H continues the in-situ studies of Martian atmospheric pressure and humidity. Continuous data sets of these parameters are of great importance in Martian atmospheric science. The measurement device utilizes well-established technology from past missions, while improving the design based on lessons learned.

In parallel with the ExoMars 2020 METEO-P/H project, FMI is building another pressure and humidity measurement device for the NASA Mars 2020 rover. Both of these missions are scheduled to launch towards Mars during the 2020 launch window. If both missions are successful, this opens up interesting science possibilities as two FMI pressure and humidity device sets would for the first time measure simultaneously on the surface of Mars in a meteorological mini-network. Even a third observation point would be added if the NASA Curiosity rover is still operational at the time of ESA's ExoMars 2020 and NASA's Mars 2020 landings.

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Miniature laser mass spectrometer and optical microscopy: current capabilities for the quantitative analysis of micro-sized solid materials

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Abstract

High resolution in situ chemical analyses on planetary surfaces are highly desirable. They can yield important information on surface heterogeneity, basic grain mineralogy and chemical composition of surface and subsurface. This data allows to understand the physical and chemical processes which led to the formation, alteration and evolution of planetary material In particular, a small size living species or micro-sized fossilised materials are currently discussed to be potentially important for searches of live on the other planets.

The current progress in the development of the instrumentation for the context analysis of planetary surfaces is described. By combining a miniature laser time-of-flight mass analyser with a microscope-camera system, one can conduct detailed optical and mass spectrometric analyses of the solid material down to micrometre-sized samples. Improvements of the instrument performance made by installation of a pulser, high-resolution microscope and modification of laser ion source are discussed. It is shown that with the current instrument capabilities quantitative elemental and isotope analyses even of small micrometer-sized grains or fossilized materials are possible. The performance capabilities are demonstrated by measurements conducted on standard and natural samples of rocks and meteorites.

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Overview of ChemCam Activities and Discoveries during 5 years at Gale Crater, Mars

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Abstract

The first extraterrestrially employed LIBS (laser-induced breakdown spectroscopy) instrument is ChemCam [1,2] on NASA's Mars rover Curiosity, which has been successfully analyzing materials on the martian surface since the rover's landing in August 2012. Since then, the rover drove more than 16 km from the Bradbury landing site southwest, traversing the dark colored Bagnold Dunes, and is now ascending the foothills of Mt. Sharp (formally Aeolis Mons). Here, we are presenting the major findings of ChemCam along the traverse with a focus on the geochemical stratigraphy of the recently explored lower Mt. Sharp.

1. Introduction

ChemCam is composed of two instruments: a LIBS instrument for assessing the chemistry of targets in distances of up to 7 m and a Remote Micro-Imager (RMI) [3] that provides high resolution context images. The LIBS measurements require relatively little time and energy, enabling that ChemCam data is taken almost on a daily basis on Mars. Variations in composition can be uniquely tracked at the submillimeter scale and ChemCam collects ample of data on the geochemical stratigraphy while Curiosity is climbing up Mt. Sharp.

2. Major Findings of ChemCam

Within the first 1700 days of the mission over 450.000 ChemCam LIBS spectra of soils and rocks were recorded in Gale crater, analyzing more than 1800 targets and taking more than 7400 RMI images [4,5,6]. Additionally, many ChemCam passive spectra (i.e. without lasing) have been recorded and analyzed [7,8]. The numerous analyses revealed the compositional diversity of the igneous rocks, the sedimentary rocks, and the diagenetic features.

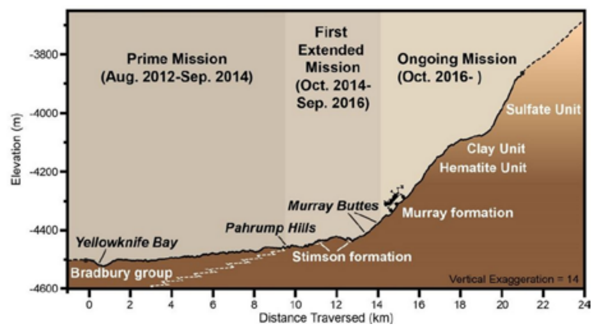

Figure 1: Driving distance, elevation, geological units and time intervals of Curiosity, as of late 2016 (Image Credit: NASA/JPL-Caltech).

2.1 Bradbury Rise

The Bradbury landing site, a plain located at a distal portion of the alluvial fan from Peace Vallis, exposed several float rocks [9,10] presenting igneous compositions ranging from mafic up to a trachytic endmember [11]. These observations provided an important clue concerning the diversity of early Mars magmatism that was not previously recognized. More igneous float rocks have been observed all along the traverse, being more felsic closer to the landing site, and more mafic near the cratered unit, after the Kimberley formation [12].

2.2 Sheepbed and Shaler

The Sheepbed area at Yellowknife Bay is essentially composed of mudstones that show a very homogeneous composition, close to the average Martian crust, providing evidence of aqueous episodes with little alteration in this area. ChemCam showed that the bedrock host experienced other diagenetic events with Mg- and Fe-rich clays in erosion-resistant raised ridges on one hand, and calcium sulfate veins on the other hand. The nearby Shaler fluvial sandstone outcrop [13], the first outcrop of potential deltaic foreset beds, shows K enrichment.

2.3 Conglomerates

Conglomerates have been analyzed in detail all along the traverse as they represent a link between the source rocks and the finer-grained sediments such as the sandstones and mudstones. They have shown an average composition that is enriched in alkalis, Al, and Si compared to the average Martian crust, with a clear enrichment in K_2O in the vicinity of the Kimberley formation [14]. Enrichment in K_2O at Kimberley in conglomerates and in sandstone outcrops reveals the presence of an alkali-rich source rock [15,16].

2.4 Pahrump Hills and Marias Pass

Further along the traverse, the Pahrump outcrop corresponds to the first observed material at Mt. Sharp's base and is part of the Murray Formation, mainly constituted of mudstones. Its facies suggest a stronger alteration, with presence of F-bearing materials such as apatite, fluorite, and phyllosilicates [17]. The Stimson unit, which is unconformably overlying the Murray formation, is composed of eolian cross-bedded sandstones possibly evolved from ancient dunes. Both Murray and Stimson formations are highly enriched in SiO2 (>80 wt. %) locally at Marias Pass and Bridger Basin [18,19,20]. The Murray enrichment may be from a pulse of volcanic ash, as it contains tridymite, with subsequent mobilization to fractures in the Stimson.

2.5 Soils

ChemCam analyzed >200 soil locations along the traverse ("Aeolis Palus soils"). The analyses indicate that fine-grained soils have a mafic composition. Analysis of coarser grains gave the possibility to study the link between local rocks and soils. ChemCam also adds new information on the ubiquitous hydration of these soils [21,22]. Soils investigated close to the active dark-colored Bagnold dunes and the Bagnold dunes themselves are overall similar in composition to the previously encountered Aeolis Palus soils but contain less altered phases with lower volatiles [23]. The Bagnold dunes are composed of grains that are mostly <250 µm. Coarser grains (150-250 µm) show an enrichment in the mafic elements Fe and Mn, suggesting a larger content in olivine compared to smaller grains of the Bagnold Dunes and Aeolis Palus soils.

2.6 Latest chemostratigraphy

Curiosity is now near the top of the Murray formation (200 m vertical thickness). The rover's cameras have observed indications of periodic desiccation in the sediments, including putative mud cracks [24,25]. In terms of chemistry, the upper Murray formation displays increasing chemical index of alteration (CIA) anticorrelated with Ca, suggesting increasing weathering, especially leaching of the latter [26]. Most recently ChemCam, APXS, and Mastcam have together observed locally high Fe abundances (to >35 wt.% FeO_T) associated with gray patches of bedrock yielding the multispectral signature of hematite, likely indicators of what is to come as the rover approaches Vera Rubin Ridge, where hematite signatures are observed from orbit.

Acknowledgements

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All Mars LIBS spectra and derived elemental compositions are available at
http://pds-geosciences.wustl.edu/missions/msl/chemcam.htm
and are described in > 40 peer-reviewed papers.

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In-situ chemical composition measurements with a laser ablation mass spectrometer for space research: Quantitative investigations of meteorites

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Abstract

We present a laser ablation/ionisation mass spectrometer (LMS). With this instrument we measured the quantitative chemical composition of Allende and Sayh al Uhaymir meteorites in-situ and with very high spatial resolution. From the main rock-forming elements, the mineralogy of the samples was inferred. Measurements of trace elements in SaU allowed dating analyses of the material and the calculation of the crystallisation temperature of the Zircon grains that were identified in the KREEP sample. The measurements on Allende made it possible to analyse the meteorite matrix in particular, beside the various chondrules embedded in the matrix. The LMS is suitable for being operated on a planetary lander or rover, where it would allow for high performance in-situ studies of rocks on the planetary surface.

1. Introduction

The knowledge of the chemical composition of moons, comets, asteroids or other planetary bodies is of particular importance for the investigation of the origin and evolution of the Solar System. High resolution in situ studies on planetary surfaces can yield important information on surface heterogeneity, basic grain mineralogy, chemical composition and age of surface and subsurface. In turn, these data are the basis for our understanding of the physical and chemical processes which led to the formation and alteration of planetary material [6].

2. Experiment

We present a highly miniaturised laser ablation/ionisation mass spectrometer (LMS) that was designed and built for space research at the University of Bern [3][4]. The instrument is suitable for its application on a planetary lander or rover.

With the LMS, we investigated samples of the Allende and the Sayh al Uhaymir (SaU) meteorite. Both meteorite samples were investigated with a spatial resolution of about 10µm in lateral direction. The high sensitivity and high dynamic range of the LMS allow for quantitative measurements of the abundances of the rock-forming and minor and trace elements with high accuracy [1],[3].

2.1 Allende meteorite

The chemical composition and mineralogy of a sample of Allende meteorite [2] was investigated with high spatial resolution. Fig. 2 shows an example from the various measurements carried out on the sample. The left panel shows the element map of K, derived from a measurement that covers a part of a CAI as well as the matrix material. A detail of the sampled area, marked by the red in the left panel, is shown in the right panel of Fig. 2. In this detailed picture, the sharp craters from the laser ablation measurements can be seen. The map in the left panel complements the optical image, showing that the Allende matrix material contains considerably more K than the CAI.

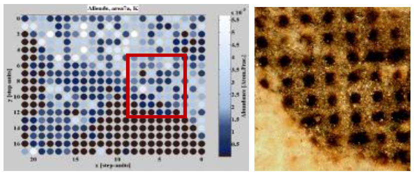

Fig.2: **Measurements on Allende meteorite** *Border of a CAI and the meteorite matrix and the according map of K.*

We measured the composition of various chondrules in Allende, offering valuable clues about the condensation sequence of the different components of the meteorite. We explicitly investigated the chemical composition and heterogeneity of the Allende matrix with an accuracy that cannot be reached by the mechanical analysis methods that were and are widely used in meteoritic research.

2.2 Sayh al Uhaymir

We investigated three samples of the SaU meteorite, which cover the KREEP-rich impact melt breccia as well as the regolith. Mineralogical analyses (see Fig. 3) allowed identifying several Zircon-grains in the sample. The high mass resolution of the LMS, coupled with a high-voltage pulser allowed for measurements of the rare earth elements. We demonstrate the capabilities for dating analyses with the LMS. By applying the U-Th-dating method, the age of the SaU169 sample could be determined.

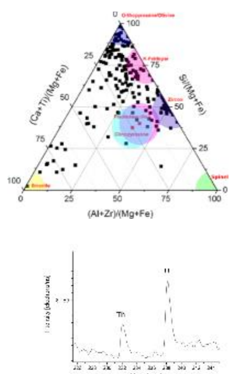

Fig. 3: **SaU 169**

Mineralogical analyses of the sample allowed for identification of several Zircon-grains and other pure mineral grains.
The detection of Th and U allowed for dating analyses.

3. Summary and Conclusions

Our analyses show that the LMS is a high performance instrument, designed for space research. The instrument data allow for in-situ measurements of main, minor and trace elements of rocks and soil. These data are fundamental for detailed analyses of the mineralogy and the age of the material and thus are key information for the reconstruction of the condensation sequence and the analysis of alteration processes. The LMS is a small and light weight instrument, designed for operation on a planetary lander or rover. With our studies of meteorites as an example, we show that the LMS would be a suitable instrument for high-quality quantitative chemical composition measurements on the surface of a celestial body like a planet, moon or asteroid.

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The MA_MISS experiment on board the ExoMars Rover

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Abstract

MA_MISS (MArs Multispectral Imager for Subsurface Studies) is the Visible and Near Infrared (VNIR) miniaturized spectrometer hosted by the drill system of the ExoMars 2020 rover. It will perform spectral reflectance investigations in the 0.4–2.2 µm range to characterize the mineralogy of the excavated borehole wall at different depths (≤2 m). The spectral sampling is 20 nm while the spatial resolution is 120 µm. Using the drill's movement the instrument slit can scan a ring and build up hyperspectral images of the borehole. MA_MISS findings will help to refine criteria for deciding from where to collect samples.

1. Introduction

Recent results from the MEX and MRO orbiters and from the MER and MSL rovers have clearly shown that water played a crucial role in the past history of Mars, providing favorable conditions for life. Due to the very tenuous Martian atmosphere, potential chemical bio-signatures at or in the vicinity of the Martian surface could have been degraded or destroyed by i) ultraviolet (UV) radiation ii) UV-induced photochemistry producing reactive oxidant species, and iii) ionizing radiation. Long-term effects of radiation decrease with depth. Organic molecules and potential biomarkers could be better preserved in the subsurface. Subsurface investigations are thus needed to search for possible indicators of past life. MA_MISS instrument [1] is a miniaturized imaging spectrometer designed to provide imaging and spectra in the VNIR wavelength region. By operating during pauses in drilling activity, it will produce hyperspectral images of the drill's borehole. MA_MISS is the only instrument in the rover's Pasteur payload able to analyze subsurface material in its natural condition (*in situ*), prior to extracting samples for further analysis.

2. MA_MISS scientific objectives

MA_MISS will accomplish the following scientific objectives:

1) *determine the composition of subsurface materials*: MA_MISS spectral range and high spatial resolution will allow identifying differences in lithologies, and distinguishing between volcanic and sedimentary rocks. Analysis of absorption bands can be used to identify different mineralogical phases. Crystal field absorptions due to Fe^{2+}-Fe^{3+} (near 1 and 2 µm) and other transition elements in association with iron-bearing minerals can be used to identify many types of silicates, oxides, etc. [2]. The occurrence of OH^-/H_2O vibrational bands near 1.0, 1.4, and 1.9 µm (overtones and combinations) is indicative of the hydration state of materials [3]. Carbonates also display overtones and combinations of vibrational features that are in principle observable in the 1.75–2.20 µm range [3].

2) *map the distribution of subsurface water and volatiles*: Currently ice deposits in the Martian shallow subsurface have been inferred from remote-sensing detection of hydrogen based on neutron and gamma ray spectroscopy [4] and from permafrost evidences [5]. Detections of low latitude H_2O frost on pole facing slopes are also consistent with a subsurface ice layer at those latitudes [6]. Although no morphologic or spectroscopic evidence of H_2O or CO_2 ices have been observed at the ExoMars potential landing sites, ice inclusions cannot be ruled out. Both H_2O and CO_2 ices show diagnostic features in the Ma_MISS spectral range. Ice in the subsurface layers can be detected thanks to minima positions at 1.5 and 2 µm and band shapes analysis.

3) characterize important optical and physical properties of materials: The study of spectral parameters, such as continuum reflectance level and slope can help to determine important physical parameters like the different grain sizes in materials that can help us to assess the type and state of sediments in the subsurface.

4) *produce a model stratigraphic column to obtain clues about subsurface geological processes:* Mars surface is rich in sedimentary outcrops that exhibit

stratigraphic features at a range of spatial scales. On Earth, our understanding of the evolution of ancient climate and life development derives from the study of mineralogical, textural, and geochemical signatures preserved in the sedimentary rock record in stratigraphic sections. These insights could also have been preserved in Martian subsurface. Having access to the Martian subsurface will be fundamental to constrain the nature of processes at the ExoMars rover locations.

3. Instrument Description

The Ma_MISS instrument main requirement is miniaturization because it is embedded within drill. The spectrometer is placed in a box on the side wall of the drill box. The spectral range is 0.4–2.2 μm, with a spectral resolution of 20 nm and SNR~100. The light from a 5W lamp is collected and carried, through an optical fiber bundle, to the miniaturized Optical Head (OH), hosted within the drill tip. A Sapphire Window (SW) with high hardness and transparency on the drill tip protects the MA_MISS OH allowing to observe the borehole wall. Different depths can be reached by the use of 3 extension rods, 50 cm long, each containing optical fibers and a collimator. The first extension rod is connected to the non-rotating part of the Drill, hosted on the rover, through a Fiber Optical Rotating Joint (FORJ), that allows the continuity of the signal link between the rotating part of the drill and the spectrometer.

4. MA_MISS breadboard analysis

Spectroscopic campaigns have been performed to characterize the spectral performances of the laboratory model of the Ma_MISS instrument (breadboard, BB). Measurements have been carried out on both particulate samples and slab rocks [7]. Spectra of a slab rock are shown in fig.1. In box I spectra acquired on a lava sample with a FieldSpec Pro+QTH lamp (6 mm spatial resolution), in 4 areas (A,B,C,D), are shown. Spectra are very similar, at this scale the sample is homogeneous. In box II spectra acquired with Ma_MISS BB (120 μm) in different positions, in each area (A-D), are shown. At sub-mm scale the rock surface appears heterogeneous and a variety of mineralogical phases occur. Breadboard data analysis confirms that MA_MISS spectral range, resolution, and imaging capabilities are suitable to characterize the subsurface environment and the samples that will be delivered to rover's analytical laboratory.

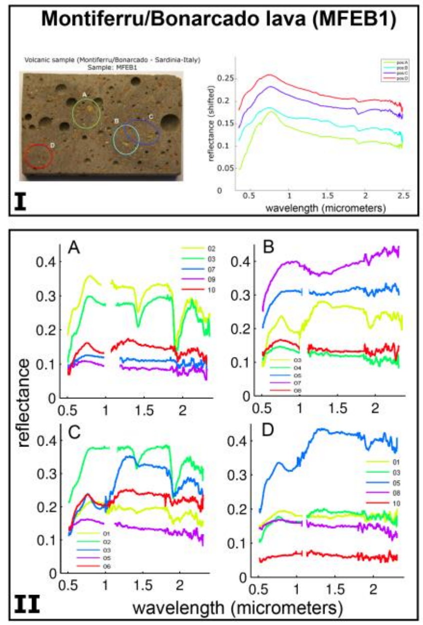

Figure 1: Box I: spectra acquired on a lava sample, with FieldSpec Pro + QTH lamp (6 mm spatial resolution), in 4 areas. Box II: spectra acquired with Ma_MISS BB (120 μm) in each area.

Acknowledgements

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Analysis Methods for the Polarimetric WISDOM Radar aboard the ExoMars Rover

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Abstract

In this paper, we describe the capabilities of the fully polarimetric antenna system of the WISDOM GPR aboard the ExoMars rover in terms of a polarimetric data analysis as well as the setting and procedure for left-right-detection and entropy-based classification of (buried) objects. By means of different experiments (laboratory, artificial environment, and field tests [3]) the principles are validated. The evaluation of radargrams allows the lateral discrimination of the position of scatterer with regard to the path of the rover. A rough classification of objects and single subsurface features is performed by applying the entropy-alpha decomposition (H-α).

1. Introduction

The main scientific objective of the ExoMars 2020 mission is to search for traces of past or present life on Mars. The experiment WISDOM is one of the panoramic instruments aboard the rover and allows the sounding of the shallow subsurface to about three meters of depth [1]. Thus, the search for places of high scientific interest where the drill aboard the ExoMars rover might take drilling samples from a depth down to two meters is supported by WISDOM. Depending on the ground permittivity, the expected vertical radar resolution is around 10 cm or less, if the full bandwidth from 0.5 GHz to 3 GHz is used.

During the mission, planned to last 218 sols, WISDOM will work in different scanning modes (e.g. long traverse scanning between science areas or zigzag-scanning at the area of interest). The method of left-right-evaluation for buried objects will be very helpful for long traverse scans since it provides additional information about the location of scatterers. The entropy-based polarimetric classification of localized buried scatterers and subsurface features in combination with processed data from other instruments (e.g. PanCam) will allow a short-term decision whether any additional places along the traverse are worth investigating.

2. Left-Right detection

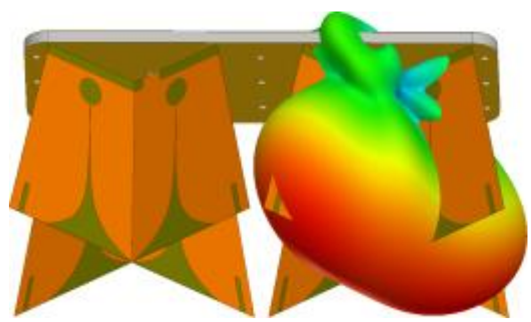

Figure 1: Simplified CAD model of the WISDOM antennas assembly with a radiation pattern at 2 GHz.

The antenna of the WISDOM radar consists of two crosswise arranged two-element Vivaldi arrays (see Fig. 1), which work over a wide bandwidth ratio of 6:1 and allow an ultralight weight construction. Due to this crosswise arrangement, one can record four orthogonal transfer-functions: two co-polar and two cross-polar. The radar itself is of the SFCW type [2]. To produce a radargram, the data recorded in the frequency domain has to be inverse Fourier transformed to the time domain. Moreover, some filters are applied to remove clutter and antenna coupling. The pattern of the WISDOM antenna assembly exhibits a small beam at the E-plane and a wide beam at the H-plane, as shown in Fig. 1 for 2 GHz. The antenna assembly is placed at the rear side of the ExoMars rover with a clearance of about 35 cm to the ground. Further, the antenna crosses are rotated by 45°. with respect to the direction of rover motion, as shown in Fig. 2. In addition to the detection of buried objects this particular arrangement allows the localization of objects left or to the right of the rover path. The procedure is described in the following. Let's assume an object is arranged e.g. on left of the rover path. Then this object is first illuminated by the beam of the transmitting antenna T1. Then the receiving antenna R3 will receive the main part of the reflected power (assuming that the object’s influence on the polarization of the incident wave can be neglected). By further moving the rover ahead, the illumination of the object by antenna T1 will decrease and the influence of antenna T2 will increase. In the end, one obtains a hyperbola in both co-polar radargrams (T1-R3 and T2-R4) caused by the scatterer. However, the location of the maximum magnitude is different. From the distance of the two maxima one can determine the gap between the object and the rover path.

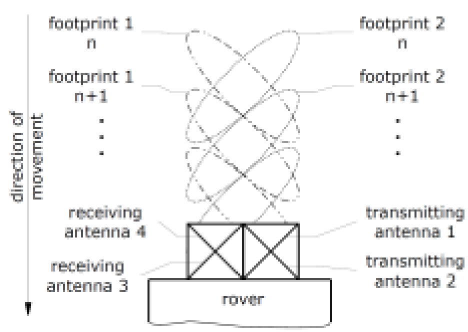

Figure 2: Scanning scheme of the WISDOM antenna system with respect to the rover path from top view.

3. Entropy-Based Classification of Subsurface Scatterers

One of the main tasks in the WISDOM data evaluation is the short-term reliable classification and correct localization of subsurface scatterers and layers. The fully polarimetric nature of the WISDOM measurements allows the use of the entropy-alpha decomposition (H-α). This method enables the classification of reconstructed images of the subsurface (obtained by inverse imaging algorithms) with regard to the main scattering mechanisms of geological features present in the image of the subsurface (see Fig. 3).

GPR measurements under laboratory conditions suggest the feasibility and value of the approach for the classification of geological features in the Martian subsurface in the context of WISDOM data processing and operations (see Fig. 4). It is a fast and reliable tool leveraging the whole amount of information provided by the fully polarimetric WISDOM radar.

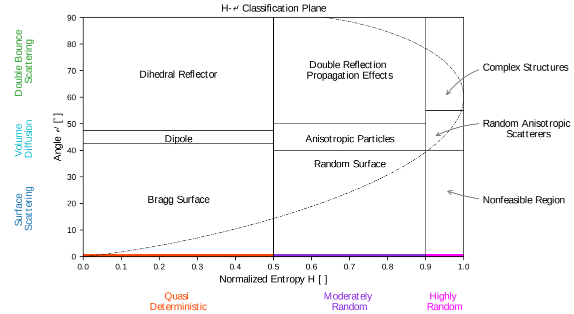

Figure 3: Entropy-alpha classification plane and scattering mechanisms.

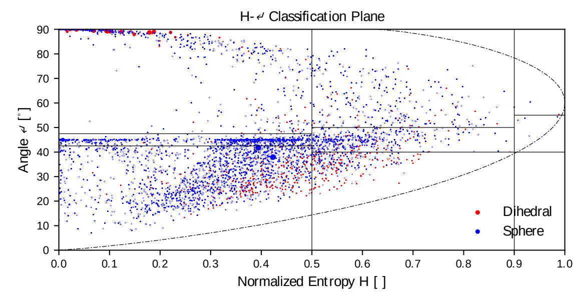

Figure 4: H-α results under realistic laboratory conditions for a buried sphere and dihedral.

Acknowledgements

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Soil mechanical simulation of the HP^3 penetrator using a discrete element software package.

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Abstract

The NASA InSight is a geophysics mission to investigate the interior of Mars and is due to launch in May 2018. Its major task is to deploy a seismometer and a heat flow probe on the surface of Mars. A mechanical arm will be used to place both main instruments within short distance from the lander main body. The seismometer will listen during the mission duration from one Martian year for internal seismic activity and impacts of larger meteorites. The HP^3 (Heat Flow and Physical Properties Probe) heat flow probe (henceforth called mole in short) will penetrate by an internal hammer mechanism into a depth of 3- 5 m into the top surface regolith to measure the planetary heat flow and the local thermal conductivity. This presentation will deal mostly with the simulation of the mechanical action of the penetration process which will be used to derive soil mechanical properties of the regolith beneath the InSight lander. Additionally we show that an extra manipulation of the regolith top layer with the instrument deployment arm (IDA) can be used to augment and constraint some soil mechanical parameters used for the penetration simulation.

1. Introduction

The HP^3 mole penetration process is dynamically in an interims area between the quasi static and continuous penetration with low speed but constant displacement and high speed impacts of projectiles e.g. anchor harpoons. Somewhere between these extreme cases is the fast but short distance displacement caused by the hammer mechanism of the mole. For quasi static penetration traditionally one dimensional models or specialized finite element software packages have been used whereas for large or even hypervelocity impacts even more specialized software solutions have been used. Unfortunately, neither of these software approaches is particularly useful to model the intermediate energy range of a hammer driven penetrator.

We investigated the usage of a Discrete Element Method (DEM) where the soil is simulated by an accumulation of single spherical particles and the physical interaction between them and the mole body during the hammering process.

For this purpose, a numerical model of the HP3 penetration progress has been implemented in the DEM software package LIGGGHTS to investigate the behavior of a dry granular materials representing Martian regolith during dynamic penetration. This model consists of the mole body penetrating into a calibrated spherical, granular material and a representation of the HP^3 hammering mechanism that generates the downward movement of the probe [1].

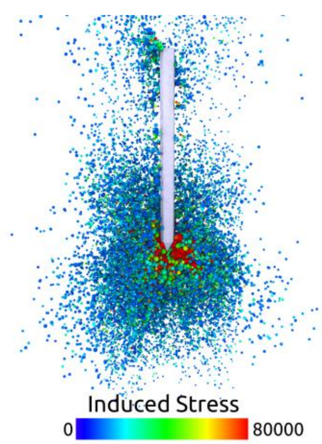

Figure 1: Color coded total stress imparted on particles during one hammer stroke. Particles below a stress threshold of 1 kPa have been blanked out do highlight the affected regions around the mole body.

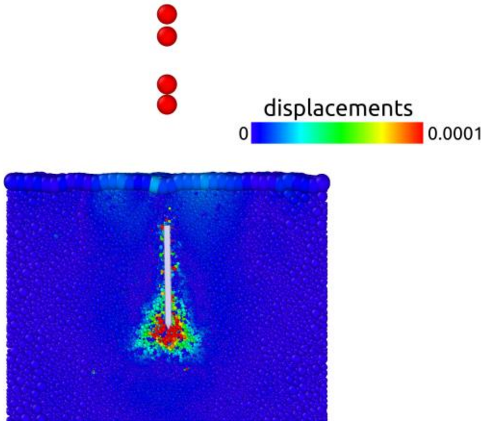

Figure 2: Displacement of particles around the mole tip as result of multiple hammer strokes. The layer of large particles on top simulate the overburden pressure encountered in different depths within the soil but providing more flexibility against horizontal stress and displacement than a rigid simulation boundary of more traditional approaches.

2. Summary and Conclusions

We report on the development of a discrete element model to simulate the hammering actions of the NASA InSight mission HP3 mole in the dry granular regolith of the Martian surface. The implementation in the LIGGGTHS software package showed that the hammer mechanism and the interaction of the mole body can be well matched for the dynamic processes inside the soil and the resulting penetration progress does match experiments performed with the real mole penetrator as it was tested during the development of the flight hardware.

A video of the simulation can be found at

https://youtu.be/y1GkoD0Vp0g

Acknowledgements

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Simulating the seismic pressure noise on Mars

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Abstract

The atmospheric pressure fluctuations on Mars will induce an elastic response in the ground that will create a ground tilt, detectable as a seismic signal on SEIS. We use Large Eddy Simulations of the wind and surface pressure at the InSight landing site, combined with ground deformation models to investigate the atmospheric pressure signals on SEIS. Full results have been reported in [1].

1. Introduction

The InSight mission, selected under the NASA Discovery program for launch in 2018, will perform the first comprehensive surface-based geophysical investigation of Mars. The objectives of the InSight mission are to advance our understanding of the formation and evolution of terrestrial planets and to determine the current level of tectonic activity and impact flux on Mars. SEIS (Seismic Experiment for Internal Structures) is the critical instrument for delineating the deep interior structure of Mars, including the thickness and structure of the crust, the composition and structure of the mantle, and the size of the core [2].

Meeting the performance requirements of the SEIS instrument is vital to successfully achieve the InSight mission objectives. However, there are many potential sources of noise on seismic instruments [3]. Also, the different environment on Mars compared to the Earth results in different noise conditions for the Martian seismometer. Meteorological activities induce noise on the seismometer through various mechanisms, such as the dynamic pressure due to the wind acting directly on the seismometer [4], and ground motion due to the interaction of the wind shield or the lander and the Martian winds [5]. The atmospheric pressure fluctuations on Mars induce an elastic response in the ground that creates ground tilt, vertical displacement, and surface pressure changes. Near, and at, the InSight seismic station, medium-scale atmospheric pressure variations (100s of m to kms) will generate ground deformations and, therefore, noise on the seismic records.

This pressure noise has been studied on Earth as a noise source at long-periods of 1-10 mHz, which is below the oceanic micro-seismic bands [6,7]. However, the situation is likely to be more severe on Mars due to the fact that the seismometer will be installed on top of the ground and on a soft regolith layer. Indeed, in addition to non-coherent seismic waves generated by the interaction of the planet's atmosphere with the ground and interior, the ground tilt due to atmospheric pressure fluctuations is expected to be one of the major contributors to the seismic noise recorded by the SEIS instrument [3]. The investigation of this atmospheric seismic signal is the primary goal of this paper.

2. Seismic pressure noise on Mars

3.1 Large Eddy Simulations

The investigation of the ground tilt caused by the local pressure field around the seismic station requires the thorough description of the regional pressure field. This is made possible by using turbulence-resolving Large-Eddy Simulations (LES) to describe the atmospheric environment of Mars at the InSight landing site and to model the excitation source, i.e., the surface-pressure field. [8] detail the LES model used in this study; in particular, the physical parametrizations, including radiative transfer, are adapted to the Martian conditions. The horizontal resolution of the model is 50 m, and the grid covers a region of 14.4 km by 14.4 km. This value is about three times the maximum expected height of the Planetary Boundary Layer (4.5 km, according to [9]), ensuring the development of convective cells [10]. The simulation starts at 8 am local time, and the vertical temperature profile is initialized according to the predictions of the Mars Climate Database [11]. With an output every 6 seconds, the simulation lasts until 9 pm local time, and thus covers the development and the collapse of the PBL convection as well as part of the calm nighttime period. Moreover, a West-to-East ``background'' horizontal wind of 10 m/s mimics the effects of regional-scale circulation and advects convective cells and vortices towards the East.

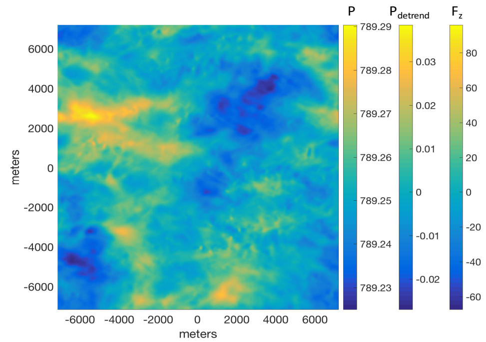

Figure 1. Large Eddy Simulations. The pressure (P, in Pa), detrended pressure ($P_{detrend}$, in Pa) and vertical force (F_z, in N) variations across the LES grid at one instant in time. North is aligned with the y-axis and East is aligned with the x-axis.

3.2. Ground deformation simulations

A point-load ground deformation approach, validated via comparison with in-situ seismic and pressure measurements of terrestrial dust devils [12], is used to calculate the displacement of the ground at the SEIS feet. The ground is modeled as an elastic half-space with properties of a Martian regolith [13]. For every section of the LES grid, the variation of the vertical force exerted on the ground at the center of the section of the grid can be given by the detrended value of the pressure of the grid section times the surface area of the grid section (Fig. 1). Then, the displacement of the ground at the seismometer feet will be a sum of the displacements caused by each section of the grid (each considered to be a point source in Green's function approximation). A detailed comparison of the Green's function approach has also been performed with two other independent methods: a spectral approach using the entire pressure field [14], and a single-station approach based on Sorrells' theory [15,16] using only the co-located seismic and pressure measurements. Results of the first of these two comparisons are shown in Fig. 2.

4. Results and Conclusions

The horizontal acceleration as a result of the ground tilt due to the LES turbulence-induced pressure fluctuations are found to be typically ~2 - 40 nm/s^2 in amplitude, whereas the direct horizontal acceleration is two orders of magnitude smaller and is thus negligible in comparison. The vertical accelerations are found to be ~0.1 - 6 nm/s^2 in amplitude (Fig. 2). These are expected to be worst-case estimates for the seismic pressure noise as we use a half-space approximation; the presence at some (shallow) depth of a harder layer would significantly reduce quasi-static displacement and tilt effects.

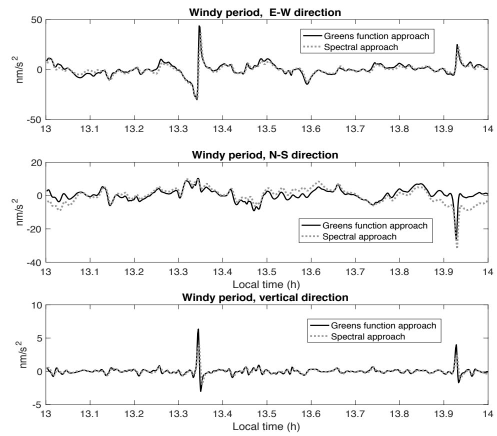

Figure 2. Comparison of the E-W, N-S and vertical accelerations calculated using Green's function method (black) and the spectral approach (grey dotted) for 1h during the most turbulent LES period.

Acknowledgements: We acknowledge funding from the French space agency (CNES).

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