

DEM modelling of the penetration process of the HP³ Mole

J. Poganski (1,2), G. Kargl (1), H. Schweiger (2) and N. Kömle (1)

(1) Space Research Institute, Graz, Austria, (2) Graz University of Technology, Austria (joshua.poganski@oeaw.ac.at)

Abstract

The NASA InSight Mission will be launched in March 2016 and will reach the surface of Mars roughly nine months later in the Elysium Region. One of the instruments on board is the HP³ Mole to measure the planetary heat flow. For this purpose it needs to penetrate five meters deep into the surface of Mars and thus offers also the possibility to analyse the soil properties. For the reconstruction of the soil behaviour and also to predict the mole performance and maximum reachable depth in advance, numerical simulations are used. The simulation of the soil during the hammering process of the HP³ Mole requires a substantial numerical effort due to the local high dynamics and large soil deformations that occur. After comparing the capability of various simulation methods (FEM, MPM and DEM) a discrete element method (DEM) was chosen.

1. Introduction

The mechanical characterization of Martian soil is not yet accurate and complete and has to be further investigated to understand the processes and history of the planet and also to get better information for planning space missions in future. Until now the mechanical properties of the soil are tried to be captured indirectly by analysing the stability of natural slopes which can be measured by images of the surface of Mars and by measuring the imprint of the wheels of the Mars Exploration Rovers. Due to slope stability analyses it was obtained that the soil behaves like cohesionless dry silts and sands [1]. The studies of the imprint by the wheels of the Mars Exploration Rovers provide an estimated stiffness of the shallow surface on the Mars [2]. However, it needs to be kept in mind that these results are not very precise. Therefore, the penetration response of the HP³ Mole will be a great opportunity to get a better mechanical characterization of the Martian soil. The mechanical soil behaviour as response due to the mole penetration is very complex and cannot

be calculated in a closed form solution. Numerical simulations are needed to reconstruct the material properties from the penetration process. Also a first prediction of the maximum reachable depth of the Mole shall be done by simulations.

2. Numerical Simulation

The discrete element method is used to simulate the dynamic penetration process of the HP³ Mole. In the DEM the granular material is represented by a finite amount of discrete spherical particles that interact amongst themselves. The advantages of the DEM in comparison to a FEM-based simulation software is that the material is not implemented as a continuum and therefore it is not required to provide a suitable soil mechanical constitutive model. The mechanical soil effects, like hardening and dilation, are captured automatically by the structure of the particles and the rearrangement of particles. The particle approach allows local high dynamics and distortions inside the soil.

2.1 Calibration of Materials

In order to be representative, the numerical properties of the particles in the simulation need to be calibrated against real soil behaviour. The calibration of materials in DEM is quite different to continuum based methods. In the DEM it is necessary to define the micro-scale parameters of a single grain. This can be done by comparing the soil response of macro-scale laboratory experiments with numerical models. The calibration of the material is done with four different laboratory experiments:

- Angle of repose experiments
- Oedometer test
- Triaxial compression test
- Particles on an inclined plane

Here, the first three experiments are used to determine the interparticle soil behaviour and the last experiment is used to determine the frictional parameters between soil particles and the penetrator.

2.2 Dynamic Cone Penetration

The dynamic cone penetration generates locally a high acceleration of particles, which will result in a pressure wave propagation through the soil. This in turn leads to undesirable wave reflections at the boundaries of the specimen. With a large specimen size these reflections could be avoided, but this will result in a large amount of particles and thus a high computational effort. A promising solution is the usage of absorbent boundaries. This has already been done for some test cases, and needs to be verified for the dynamic penetration case. The force profile, representing the stroke of the mole internal hammer mechanism forcing the penetrator, is approximated as half of a sine curve with a certain time interval and magnitude. This profile has been taken from calculations of an one dimensional pile drive model [3]. For the first assumptions on the reachable depth, a small chamber with absorbent sides and bottom boundaries and a top plate with a defined mass, to approximate the overburden pressure, has been used. The resulting acceleration force on each particle due to the hammer stroke during penetration can be seen in Figure 1.

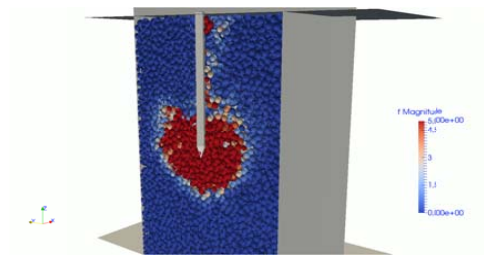


Figure 1: Simulation of a dynamic cone penetration in DEM

6. Summary and Conclusions

The progress data from the penetration of the HP³ Mole in the Martian soil provide an unique opportunity to derive an accurate mechanical characterization of the Martian soil at the landing site. The simulation of the initial penetration process will provide a first prediction of the maximum reachable depth and gives a better understanding of

the mechanical soil behaviour on Mars by back-calculations afterwards. The DEM allows insights into the particle scale interactions and is able to simulate high dynamics within the soil.

Acknowledgements

The authors wish to acknowledge the funding of this work by the FFG grant 844356.

References

- [1] Perko, H., Nelson, J., and Green, J. (2006). "Mars Soil Mechanical Properties and Suitability of Mars Soil Simulants." *J. Aerosp. Eng.*, 19(3), 169–176.
- [2] Zöhrer, A. (2006). "Laboratory Experiments and Numerical Modelling of Cone Penetration Tests into various Martian Soil Analogue Materials", Ph.D., Graz University of Technology, Austria.
- [3] Kömle, N. I., Poganski, J., Kargl, G. and Grygorczuk, J. (2015). "Pile driving models for the evaluation of soil penetration resistance measurements from planetary subsurface probes", *Planetary and Space Science*, Volumes 109-110, May 2015, Pages 135-148.

Aging and analytical performances evolution of a gas chromatographic system at Mars

J.Y. Bonnet (1), C. Szopa (1), M. Millan (1), D. Coscia (1), M. Cabane (1), I. Belmahdi (2), A. Buch (2), T. Dequaire (3), P. Coll (3), S. Teinturier (4) and P. Mahaffy (4)

(1) LATMOS, Univ. Pierre et Marie Curie, Univ. Versailles Saint-Quentin & CNRS, 75005 Paris, France, (2) LGPM, Ecole Centrale de Paris, 92295 Châtenay-Malabry, (3) LISA, Univ. Paris-Est Créteil, Univ. Denis Diderot & CNRS 94010 Créteil, France, (4) NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA

Abstract

Health data from the gas chromatography (GC) module onboard the SAM instrument [1] will be presented to assess the analytical performances evolution of a GC device in Martian environment through 3 years.

1. Introduction

Gas chromatography (GC) is a very powerful tool to investigate the chemical diversity in Martian soils and rocks. The NASA Curiosity rover gets on board an analytical chemistry laboratory, the Sample Analysis at Mars (SAM) instruments suite. SAM is composed of three different instruments: a tunable laser spectrometer (TLS), a mass spectrometer (QMS) and a gas chromatography apparatus (SAM-GC). In this work we will focus on the aging and the analytical performances of one of the GC column onboard SAM compared with its nominal state that should not have been modified by the cruise in space [2].

2. Gas chromatography module and health data

The complete GC system that will be presented here is the column 5 of the GC module (GC5). This column was extensively used at Mars during the first 2.5 years of the mission. This system is composed of an injection trap (IT), a chromatography column (GC5) and a TCD detector. It can also be coupled with QMS to have retention times and masses of the molecules. Health data from these three GC sub-systems will be presented.

The column health will be followed using two different housekeeping data sets. The first one is the retention time difference between two compounds observe in all experiments: benzene and toluene. The variation of this parameter can help us assess the separation performance of the column and its

evolution. The second parameter is the bleeding signal. This signal corresponds to the detection of molecules coming from the degradation of the stationary phase of the column.

The TCD health will be followed using the benzene signal. The signal detected with the TCD can be compared with the QMS signal. A correlated evolution can be interpreted as a perfectly healthy TCD, while a decorrelated one can be a sign of degradation.

The IT health is more difficult to follow, as there is only one temperature measurement for this sub-system. An important decorrelation between measured and real trap temperature is present and can interfere with health statement. To be able to assess the health state of the trap, mainly the state of the chemical trapping (Tenax), a laboratory study was conducted, on a spare laboratory model, to correlate the measured temperature with the true IT temperature.

3. Results

3.1 Column health state

The column health state is an important parameter to have in mind while interpreting the retention times to identify molecules. The capability of a column to maintain a constant retention time is important or at least it is important to know how the retention time of a compound evolves. On Figure 1, the relative evolution of benzene and toluene retention time is plotted as a function of the experiment number at Mars. What we observe is a decreasing time between benzene and toluene detection with the TCD (confirmed with QMS). This time decreases of 20 seconds while the column was used 21 times to make blank and sample measurements.

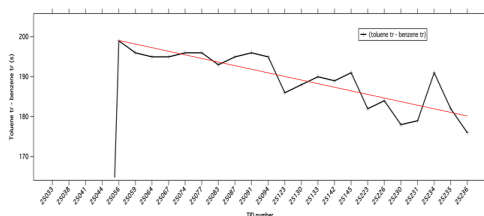


Figure 1: Evolution of the retention time difference between benzene and toluene during Martian experiments.

The bleeding signal is a key parameter that helps us to assess the health of the stationary phase. This can also help us to interpret the retention times evolution previously described. A few masses can be used to follow the evolution of the bleeding signal through time. The main mass is $m/z=207$. This mass corresponds to hexamethylcyclotrisiloxane and is the major product of polydimethylsiloxane thermal degradation [3].

3.2 TCD health state

TCD is a detector that is coupled with 5 of the 6 columns onboard SAM. They allow us to have a QMS independent measurement of retention times. These very interesting data also help us to follow column health state. TCD are relatively fragile devices and Figure 2 represents the evolution of the TCD benzene signal compared with the total mass area from QMS at benzene retention time. As seen on this diagram the TCD signal is dropping while the QMS signal is in a “steady mode”. This can indicate a lower TCD sensitivity and is a fingerprint of a degrading TCD.

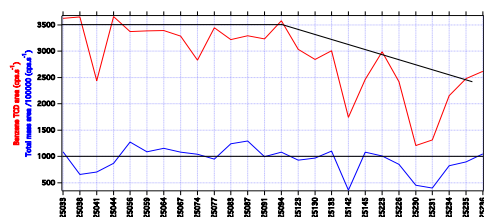


Figure 2: Evolution of the Benzene TCD signal and total mass area through time.

3.3 IT health state

ITs are key devices that allow us to have a time resolved injection into the column. They are composed of an adsorbant (TENAX) that retains organic molecules until it is flashed. This adsorbant is thermally degraded and rapidly became a hard pellet instead of the initial powder. The precise monitoring of the IT temperature is thus of great interest to better constrain the IT health and adsorption capabilities. On SAM the temperature measurement is decoupled from the trap and a huge gradient is observed between real trap temperatures and measured ones. For instance the trap activation sequence allows us to heat it up to 270°C while the measurement is about 49°C. A laboratory experiment on a spare IT was conducted to correlate the measured and the real temperature of the trap and allows us to better follow the health state of this key device.

4. Conclusion

Although GC is a powerful tool to explore the chemical diversity of planetary environments, a complete GC apparatus is relatively fragile. IT, column and TCD detector are all subject to their own degradation and key housekeeping data can help us assess the evolution of their health state. This information is mandatory, not only characterize the instrument status and predict its life times but also to interpret science data. Great caution should then be taken while designing new GC instruments.

References

- [1] Paul R. Mahaffy, Christopher R. Webster, Michel Cabane, Pamela G. Conrad, Patrice Coll, et al.. The Sample Analysis at Mars Investigation and Instrument Suite. *Space Science Reviews*, 2012.
- [2] Cyril Szopa, R. Sternberg, David Coscia, F. Goesmann, R. Gomes, et al.. Gas chromatography for in situ analysis of a cometary nucleus V. Study of capillary columns' robustness submitted to long-term reduced environmental pressure conditions. *Journal of Chromatography A*, 2014.
- [3] Camino, S.M Lomakin, M Lageard, Thermal polydimethylsiloxane degradation. Part 2. The degradation mechanisms, Polymer, 2002.

MOMA Gas Chromatograph-Mass Spectrometer onboard the 2018 ExoMars Mission: results and performance

A. Buch¹, V. T. Pinnick², C. Szopa³, N. Grand⁴, O. Humeau³, F. H. W. van Amerom⁵, R. M. Danell⁶, R. Arevalo¹, C. Freissinet², W. B. Brinckerhoff², Z. Gonnissen², P. R. Mahaffy², P. Coll⁴, F. Raulin⁴, F. Goesmann⁷, and the MOMA Team¹⁻⁷, (1) LPGM, Ecole Centrale Paris, Châtenay-Malabry, France, (2) NASA Goddard Space Flight Center, USA, (3) LATMOS, Univ. Pierre et Marie Curie, Univ. Versailles Saint-Quentin & CNRS, Paris, France (4) LISA, Univ. Paris Est Créteil & Paris Diderot, CNRS, Créteil, France (5) MiniMass Consulting, USA, (6) Danell Consulting, USA, (7) Max Planck Institut für Sonnensystemforschung, Germany

Introduction: The Mars Organic Molecule Analyzer (MOMA) is a dual ion source linear ion trap mass spectrometer that was designed for the 2018 joint ESA-Roscosmos mission to Mars. The main scientific aim of the mission is to search for signs of extant or extinct life in the near subsurface of Mars by acquiring samples from as deep as 2 m below the surface. MOMA will be a key analytical tool in providing chemical (molecular and chiral) information from the solid samples, with particular focus on the characterization of organic content. The MOMA instrument, itself, is a joint venture for NASA and ESA to develop a mass spectrometer capable of analyzing samples from pyrolysis/chemical derivatization gas chromatography (GC) as well as ambient pressure laser desorption ionization (LDI). The combination of the two analytical techniques allows for the chemical characterization of a broad range of compounds, including volatile and non-volatile species. Generally, MOMA can provide information on elemental and molecular makeup, polarity, chirality and isotopic patterns of analyte species. Here we report on the current performance of the MOMA prototype instruments, specifically the demonstration of the gas chromatography-mass spectrometry (GC-MS) mode of operation.

The MOMA GC-MS Instrument Suite: The MOMA GC-MS instrument consists of three main components, lead by three international hardware development teams. The martian regolith samples will be deposited into an oven (Figure 1a) and sealed using a tapping station developed by colleagues at the PI institution (Max Planck Institut für Sonnensystemforschung, Germany). The gas chromatograph design, being matured by teams at LATMOS, ECP and LISA in France, consists of an internal He reservoir, 2 hydrocarbon injection traps, 4 chromatography columns, each equipped with a thermal conductivity nanodetector (nanoTCD). The MOMA mass spectrometer, made at NASA-GSFC, consists of a linear ion trap with 2 redundant filaments for electron impact ionization and 2 redundant channel electron multiplier detectors. The

ion trap is modeled after the 4X larger trapping volume Thermo LXQ [1].

Until recently, most of the GC-MS performance testing occurred using the brassboard GC (Figure 1b) and the prototype mass spectrometer. However, some initial testing using the advanced prototype GC (Figure 1c) with the same prototype mass spectrometer has demonstrated basic functionality of the GC-MS interface with higher flight fidelity.

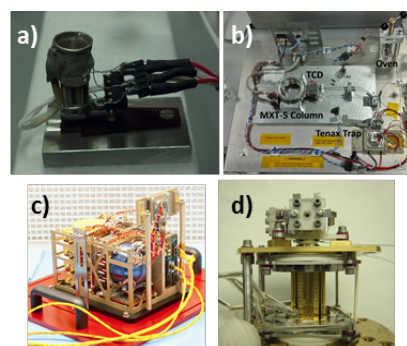


Fig. 1. (a) MOMA prototype oven. (b) Single column MOMA brassboard gas chromatograph. (c) Full-up MOMA advanced prototype model gas chromatograph. (d) MOMA mass spectrometer with EI source.

Performance Testing: Brassboards of the individual MOMA instrument components (sample oven, GC and MS) were developed and their performances tested independently. Interface tests are therefore critical to provide insight into the end-to-end GC-MS performance of the MOMA instrument. Both brassboard and prototype GCs were connected to the prototype MS in flight-like configurations (Figure 2). Volatiles can be directed into the MS for calibration and sensitivity measurements either by a directly plumbed line or through volatilization of liquid or solid phase analogs from the sample oven. Solid samples were doped with various organic compounds and extracted by pyrolysis. Analytes were then separated with an MXT-5 chromatographic column (30m, 0.25mm, 0.25

μm , Restek) and analyzed by a thermal conductivity detector followed by the linear ion trap MS.

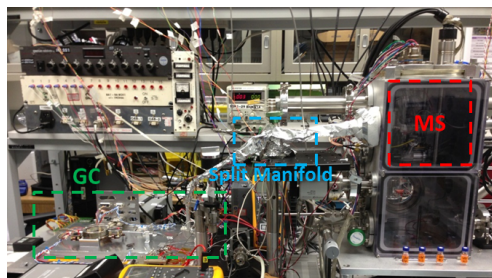


Fig. 2. Laboratory configuration for GC-MS interface testing with single column GC, split manifold with exhaust at mars pressure (bottom chamber of MS vacuum housing) and mass spectrometer (top chamber of MS vacuum housing).

Initial testing of the end-to-end GC-MS MOMA instrument involved the injection of a 1000 ppm gas phase mixture of butane, pentane, hexane and benzene in bulk helium. An overlay of the MS and TCD signals showed (figure 3) a similar response in terms of separation efficiency and peak shape, confirming that the interface between the GC and LIT introduces minimal dispersion. Key operational parameters such as column temperature and separation efficiency were determined.

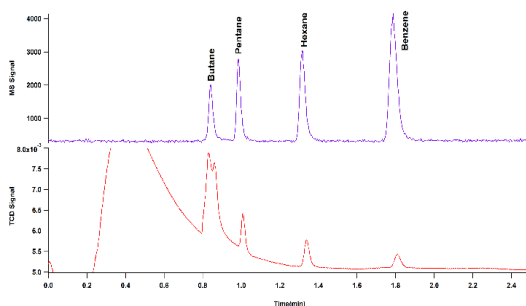


Figure 3: Separation of $10\mu\text{L}$ gas mixture of butane, pentane, hexane and benzene in He (1000 ppm)

The end-to-end sensitivity of the GC-MS interface depends heavily on the ionization efficiency of the analyte, the quality of the thermal control along the sample path, and the split manifold design. The MOMA requirement for sensitivity for organics in GC-MS mode is 1 pmol injected into the sample oven. Sensitivity was determined for the GC-TCD and MS response to a dilution series containing phenylethanol, 1-butanol, methyl-acetate, hexane, benzene, toluene,

dodecane, fluoronaphthalene, heptanol, pentanol, dimethylformamide (DMF) diluted in methanol and deposited onto silica beads in the MOMA oven (figure 4). During the first iteration of testing, transfer lines were not completely heated (i.e. cold spots were present), thus the potential for condensation after TCD but before MS detection is high. However, the MS was found to be 5-10 times more sensitive than the GC-TCD for hexane and benzene respectively with an ultimate sensitivity of $\sim 1\text{-}10$ pmol.

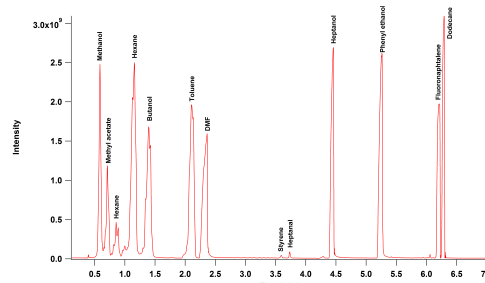


Figure 4: GC-MS analysis of the liquid mixture containing $5\mu\text{L}$ of phenylethanol, 1-butanol, methyl-acetate, hexane, benzene, toluene, dodecane, fluoronaphthalene, heptanol, pentanol, dimethylformamide (DMF) diluted in $100\mu\text{L}$ of pure methanol.

Additional experiments investigating solid soil samples pyrolyzed in the brassboard oven are currently underway in order to investigate system performance with higher fidelity samples similar to what would be expected on Mars. Results from this testing, demonstrating MOMA's ability to extract and detect trace organics via *in situ* derivatization are currently being planned.

References: [1] Schwartz J. C. et al. (2002) *J Am. Soc. Mass Spectrom.* 13, 659–669.

Acknowledgement: The development of MOMA-GC is supported by the French Space Agency, CNES, gratefully acknowledged. The support by DLR (FKZ 50QX1001) is gratefully acknowledged. The development of MOMA-MS is supported by the Mars Exploration Program (HQ Program Executive: Lisa May).

Microfluidic low-cost devices for Mars-sample handling by ultrasounds

I. González, J. Gómez Saavedra and V. Acosta

Institute of Physical Technologies, Group of Ultrasonic Resonators, Consejo Superior de Investigaciones Científicas CSIC, Spain (icier.gonzalez@csic.es/ Fax: +34-914117641)

Abstract

Application of ultrasounds on microfluidic devices present certain advantages to perform handling and sorting of small samples in suspensions and aerosols. They drive each single particle toward certain positions of acoustic equilibrium where remain stable and can be delivered separated from their host sample. This work presents low cost chips to perform particle sorting, fixation or clustering.

1. Introduction

A capillary attached to a piezoelectric actuator is able to perform a free-label particle handling by the action of the ultrasounds at frequencies close to 1MHz. The principle of operation is based on the establishment of a standing wave generating a radiation force to push the particles toward a location of equilibrium inside a cavity (channel) at a frequency $f=1153\text{kHz}$, at which the capillary cavity behaves as a half-wavelength 2D resonator. This force is described by equation (1) (Gor'kov [1]), assuming the particle with volume V_p , density (ρ_p) and compressibility (β_p), much smaller than the wavelength of the incident wave, λ , applied with a pressure amplitude P_0 on a liquid with density ρ_l and compressibility β_l :

$$FR = -\frac{\pi P_0^2 V_p \beta_l}{2\lambda} \phi(\beta, \rho) \sin\left(\frac{4\pi x}{\lambda}\right) \quad (1)$$

where $\phi(\beta, \rho) = \frac{5\rho_p - 2\rho_0}{2\rho_p + 2\rho_0} - \frac{\beta_p}{\beta_0}$ is known as the acoustic contrast factor. It defines the particle collection at the pressure nodes (for $\phi > 0$) or the antinodes of acoustic pressure (for $\phi < 0$). The radiation force is directly proportional to the particle volume (cubic power of spherical particle radii). Therefore, slight variations in the particle size give

rise to strongly different values of the radiation force. This effect is used to carry out differentiated particle collection and enrichment, with applications of particle sorting or separation.

2. Ultrasonic devices for the particle handling

A glass capillary with inner square cross section ($700\mu\text{m} \times 700\mu\text{m}$) is attached to a pz26 piezoelectric square plate ($30\text{mm} \times 30\text{mm}$) (Figure 1).

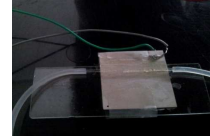


Figure 1. Acoustic device including a glass capillary attached on a piezoelectric pz26 ceramic.

Dilute aqueous suspensions of polystyrene particles (diameters of $6\mu\text{m}$ and $20\mu\text{m}$) were used in the experiments. Driven by the radiation force the particles collect at the pressure node locations, established along the central axis of the capillary at $f=1153\text{kHz}$ (Fig 2.a), and at other positions varying slightly the acoustic frequency (Fig 2.b). They remain fixed at these positions during the acoustic application.

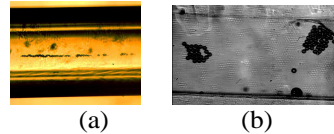


Figure 2: particle collection at $P=0$ established along the central axis at $f=1153\text{kHz}$ (a) and close to the sidewalls at $f=1020\text{kHz}$ (b)

Polymeric chips implemented by ultrasonic actuators have been developed by the authors to perform particle separation [2]. They are low cost devices able to achieve very high efficiencies of actuation with inorganic samples. Figure 3 shows one of these chips, which includes an upper layer of SU-8 including a channel along which the samples flow over a PMMA substrate with a thickness approximately three times higher.

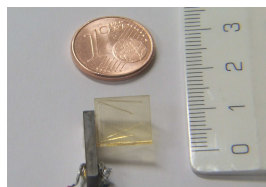


Figure 3: a polymeric chip with a piezoelectric ceramic attached to its lateral edge

The device is a lab-on-a-chip that comprises a technological advantage since it uses a polymer as its constitutive material instead of other more rigid material used in conventional devices for ultrasonic micromanipulation [3]. The chip behaves as a multilayer system resonating at frequencies close to 1MHz. A strategic combination of the widths of the layers (taking into account their relationship with the acoustic wavelength) allows the establishment of a node of pressure inside the channel at a desired location. Separation, sorting or other applications define such a position and the number of outlets for the differently sized particle delivery.

These devices have been also used to perform tumor cell extraction processes from peripheral blood samples as an early diagnosis method [3], based in a mass transfer between two media flowing in parallel along the channel of treatment. The Radiation Force exerted on epithelial cells (whose diameter is approximately 20 microns) is larger than that on experience by the leukocytes (8-12um),

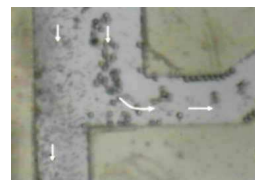


Figure 3: The 20um-sized particles leave the chip separated from 6um- particles, through different outlets

6. Summary and Conclusions

Application of these devices to perform particle handling in Mars or other planetary missions is evidenced, either for particle sorting or, on the contrary, to fix some samples at certain positions.

Acknowledgements

The study was performed in the framework of two Spanish National Research Projects, BIO2008-06843-C04 and BIO2011-30535-C04-01,02,03, "Development of a high throughput for isolation of tumor cells circulating in peripheral blood".

References

- [1] L. Gor'kov, On the forces acting on a small particle in an acoustic field in an ideal fluid, Sov. Phys. Acoust., 6(9), 1962, 773-775
- [2] I. González, L. J.Fernández, T. Gómez, J. Berganzo, J. L. Soto, A. Carrato. A polymeric chip for micromanipulation and particle sorting by ultrasounds based on a multilayer configuration. Sensor and Actuators B: Chemical., 144 (2010) 310–317 .
- [3] I. González, L.J. Fernández, N. López, J. Berganzo, A. Martin, T. Gómez, M. Bouali, J.L. Soto, and A. Carrato, Ultrasonic extraction of circulating tumor cells fom peripheral blood- a noninvasive method to keep the cells viable for later biomolecular analysis, Proc. 6th Int Conf Microtech. in Med. and Biol. MMB 2011, pp:60-61, Volume: ISSN: 1947-5160
- [4] Evander M., Nilsson A., Nilsson J. and Laurell T., Acoustophoresis in wet etched glass chips, Analytical Chemistry, 80 (13), 2008, 5178-5185

Extraterrestrial material analysis: influence of the acid hydrolysis on the mtbstfa derivatization

I. Belmahdi(1), A. Buch(1), A. Brault(1), C. Szopa(2), C. Freissinet(3,4), V. Pinnick(3), J. El Bekri(1), P. Coll(5) and M. Cabane(2). belmahdii@ecp.fr. (1) LGPM, Ecole Centrale de Paris, 92295 Châtenay-Malabry (2) LATMOS, Univ. Pierre et Marie Curie, Univ. Versailles Saint-Quentin & CNRS, 75005 Paris, France (3) NASA Goddard Space Flight Center, Greenbelt, MD 20771, USA (4) NASA Postdoctoral Program Administered by Oak Ridge Associated Universities, Oak Ridge, Tennessee 37831, USA (5) LISA, Univ. Paris-Est Créteil, Univ. Denis Diderot & CNRS 94010 Créteil, France

1. Introduction

1.1 Interest of Mars exploration

Sources of organics on Mars: Sources of endogenous organic matter (OM) could have existed; these sources include (a) abiotic production *via* hydrothermal, igneous or atmospheric synthesis and (b) biotic synthesis. Currently, proven sources of exogenous organic compounds delivered to Mars are known: carbon-rich meteorites, micrometeorites, comets and interstellar dust particles.

MOMA experiment, onboard the ExoMars mission, will search for “signs of life” molecules (large, non-volatile organic or biological molecules that suggest existing or prior biosynthetic activity) on the Martian surface and near subsurface. MOMA will also be able to distinguish between the endogenous and exogenous sources of Martian organics. MOMA’s main instrument is a gas chromatograph coupled with a mass spectrometer (GC-MS), which provides the unique capability to characterize a broad range of compounds, including both volatile and non-volatile species. Nevertheless, an additional derivatization step is necessary for non-volatile species.

Organic compounds targeted. To target molecules which can be still present on Mars, we have to determine the resistance of some particular molecules against environment stress. We also have to take in account the organic matters detected in Martian meteorites related and the molecules related with earth life. Among the molecules, we identify (1) the carboxylic acid which is found to be resistant to radiation and (2) organic molecules such as amino acids (AAs), nucleic bases and lipids. These molecules have the advantage of being detected in the Martian meteorite ALH 84001, to be predominant in terrestrial organisms (i.e. these molecules represent respectively 50 %, 25% and 10% of *Escherichia coli* bacteria (*I*) and finally to expose two chiral forms (homochirality is a strong indicator of biological trace).

However, most of these molecules are not volatile, and thus are not directly analysable by GC-MS. This analytical technique requires the compounds to be gaseous or volatilisable.

1.2 Extending the range of application of GC-MS

To extend the capabilities of GC-MS, it is possible to manipulate two parameters: the mass of the molecule and its polarity. The issue with high molecular mass molecules is that their temperature of volatilization is lower than their temperature of fragmentation. Polar molecules show sites where intermolecular interaction can be formed which makes them difficult to volatilize. To modify physicochemical properties, Erwin Kaal (7), three techniques can be employed: (A) Pyrolysis involves exposition of compounds at temperatures leading to thermal fragmentation, therefore the masses of molecules is reduced. (B) Derivatization replace labile hydrogens (e.g. present in a group -OH, -COOH, =NH, -NH₂) by apolar groups (Fig. 1, derivatization of glycine by MTBSTFA) thereby reducing the polarity of the molecule. MTBSTFA (N-(tert-butyldimethylsilyl)-N-methyltrifluoroacetamide) is a derivatization reagent present in MSL and ExoMars missions. (C) Thermochemolysis is a technique that combines pyrolysis and derivatization: it reduces the mass and polarity of the compounds. Indeed, the molecules are thermally fragmented before their acidic hydrogen is substituted by a apolar group from the thermochemolysis agent (TMAH). High temperature acid hydrolysis is applied to fragment the macromolecules (e.g. the proteins break into amino acids) and solubilizes mineral matrices which can contain OM.

Aim of this study: (1) Define the influence of the pH on the MTBSTFA derivation reaction (2) Determine if the quantity of protons delivered during hydrolysis has an influence on the derivatization of amino acids (3) Identify the cause of the variation of detection of amino acids according to proton concentration (pH)

2. Experiments and methods

To determine the influence of pH on the derivatization, silylation with MTBSTFA of amino acids is carried out at several pH values. The solution of amino acids is a standard solution of Sigma Aldrich and it is composed of

17 amino acids including L-alanine, L-arginine, L-aspartic acid, L-cystine, L-glutamic acid, glycine, L-histidine, L-isoleucine, L-leucine, L-lysine, L-methionine, L-phenylalanine, L-proline, L-serine, L-threonine, L-tyrosine and L-valine. The concentration of amino acids is 2.5 $\mu\text{mol/mL}$ in a 0.1 M HCl solution except for L-cystine which is 1.25 $\mu\text{mol/L}$. Firstly, 10 μL of amino acids are dried out under a stream of argon. Subsequently, 0.4 mL of a basic solution (NaOH) or acidic (HCl) is added to set the pH at a given value. We studied two types of sample: samples with pH between 1 to 13 and sample with excess of HCl (6 and 12 M of HCl). It is then dried again under argon. The derivatization step is carried out on the solid residue via a solution of MTBSTFA/DMF (2:1). We added 30 μL of this solution to the sample and heated to 75 $^{\circ}\text{C}$ for 15 min. To allow the quantification of amino acids, 4 μL of an internal standard (methyl laurate (8.4.10–3 M) in DMF) was added. The derivatized amino acids solutions are analysed by a commercial GC-MS equipped with an RTX-5 column (30m x 0.25 x 0.25 μm).

3. Results and Discussion:

During the analysis, we detected 15 of the 17 amino acids: alanine and arginine are not found in our study conditions. In order to compare quantitatively the different analytes, we normalize the areas of amino acids obtained by the area of the internal standard. The results are shown in Fig. 2, and represent the ratio of the peak areas of few amino acids (Gly, Val, Leu, Pro and Met) at several proton concentrations.

In a basic environment, for pH 12 and 13, no amino acid is highlighted: the quantity of derivatized amino acid is lower than the detection limit.

In the pH range from 3 to 11, the results show a chemical stability of amino acid concentrations as a function of pH.

Under conditions of hydrolysis (12 M HCl and 6 M HCl), the concentration of proton does not influence the behavior of the amino acids except for serine and threonine. The results suggest that for these two compounds, the amounts detected are lower than the concentration of the reference sample and the concentration in the stable area (pH = 3–11).

Finally, the quantity of valine, leucine and isoleucine at pH 1 and 2 is higher than the other concentration measured for other pH.

4. Figures



Figure 1: example of MTBSTFA derivatization of glycine

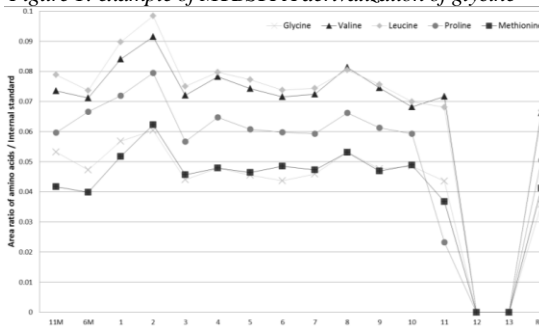


Figure 2: Influence of the pH on the MTBSTFA derivatization yield.

5. Conclusion

The effect of pH on the amount of amino acids may come from two phenomena:

- The amino acid is not in the same form according to the pH of the solution: they can be subject to deprotonation of the carboxyl and amine group. In fact, below a pH of 11, all of the amino acids have under-gone deprotonation and this explains the absence of amino acid in strongly basic solutions.
- The second hypothesis suggests that the acid or base used interacted with the derivatization agent.

References

- [1] Brock TD, Smith DW, Madigan MT. Biology of microorganisms. 1984. p. 14–93.
- [2] Lutzow M V., Kogel-Knabner I, Ekschmitt K, Matzner E, Guggenberger G, Marschner B, et al. Stabilization of organic matter in temperate soils: mechanisms and their relevance under different soil conditions - a review. Eur J Soil Sci. 2006; 426–45.
- [3] Becker L, Popp B, Rust T, Bada JL. The origin of organic matter in the Martian meteorite ALH84001. Adv Space Res. 1999; 477–88.
- [4] Bada JL, Glavin DP, McDonald GD, Becker L. A search for endogenous amino acids in martian meteorite ALH84001. Science. 1998; 62–5.
- [5] Steele a, McCubbin FM, Fries M, Kater L, Boctor NZ, Fogel ML, et al. A reduced organic carbon component in martian basalts. Science. 2012; 212–5.
- [6] Benner S a, Devine KG, Matveeva LN, Powell DH. The missing organic molecules on Mars. Proc Natl Acad Sci U S A. 2000; 2425–30.
- [7] Kaal E, Janssen H-G. Extending the molecular application range of gas chromatography. J Chromatogr A. 2008; 43–60.
- [8] Mabey W, Mill T. Critical Review of Hydrolysis of Organic Compounds in Water under Environmental Conditions. J Phys Chem. 1978; 383–415.

MicroMED: an optical particle counter for the direct in situ measurement of abundance and size distribution of dust suspended in the atmosphere of Mars

F. Esposito (1), F. Cozzolino (1), C. Molfese (1), F. Cortecchia (1), B. Saggin (2), and F. D'Amato (3)

(1) INAF-Astronomical Observatory Capodimonte (Naples, Italy), (2) Polytechnic University of Milan (Milan, Italy), (3) CNR-INO National Optical Institute (Florence, Italy)

Abstract

The MicroMED experiment has been developed for the characterization of airborne dust close to the surface of Mars and is suitable to be accommodated on Martian landers or rovers. It is an optical particle counter, analyzing light scattered from single dust particles to measure their size and abundance. An Elegant Breadboard of the instrument has been realized and successfully tested in a Martian simulated environment. Test results demonstrate the expected functionality and performances of the experiment.

1. Introduction

Monitoring of airborne dust is very important in planetary climatology. Indeed, dust absorbs and scatter solar and thermal radiation, severely affecting atmospheric thermal structure, balance and dynamics (in terms of circulations). Wind-driven blowing of sand and dust is also responsible for shaping planetary surfaces through the formation of sand dunes and ripples, the erosion of rocks, and the creation and transport of soil particles.

Dust is permanently present in the atmosphere of Mars and its amount varies with seasons. During regional or global dust storms, more than 80% of the incoming sunlight is absorbed by dust causing an intense atmospheric heating. Airborne dust is therefore a crucial climate component on Mars which impacts atmospheric circulations at all scales. Main dust parameters influencing the atmosphere heating are size distribution, abundance, albedo, single scattering phase function, imaginary part of the index of refraction. Moreover, major improvements of Mars climate models require, in addition to the standard meteorological parameters, quantitative

information about dust lifting, transport and removal mechanisms. In this context, two major quantities need to be measured for the dust source to be understood: surface flux and granulometry. While many observations have constrained the size distribution of the dust haze seen from the orbit, it is still not known what the primary airborne dust (e.g. the recently lifted dust) is made of, size-wise.

MicroMED has been designed to fill this gap. It will measure the abundance and size distribution of dust, not in the atmospheric column, but close to the surface, where dust is lifted, so to be able to monitor dust injection into the atmosphere. This has never been performed in Mars and other planets exploration.

2. MicroMED experiment

MicroMED is a miniaturization of the instrument MEDUSA, developed for the Humboldt payload of the ExoMars mission.

It is able to measure the size of single dust grains entering into the instrument from 0.2 to 10 μm radius, giving as products the dust size distribution and abundance. It is an Optical Particle Counter, analyzing light scattered from single dust particles. A pump is used to sample the Martian atmosphere, generating a flux of gas and dust across the instrument trough the inlet. When the dust grains reach the Optical Sensor (OS), they cross a collimated IR laser beam emitted by a laser diode. The light scattered by the grains is detected by a photodiode, which is amplified by the Proximity Electronics (PE).

3. Performances

MicroMED acquires the intensity of the light scattered by single dust grains entering into

the instrument. This is related to grain size via scattering models. The run duration has been tuned in order to acquire about 400-2000 particles depending on dust concentration. This will allow to obtain enough statistics to sample the dust size distribution. The system has been designed in order to work up to particle concentrations of several hundreds cm^{-3} before coincidence effects become significant. The estimated fraction of coincidences goes from 0.01% (constant haze) to $< 4\%$ (dust devil).



Figure 1: MicroMED Breadboard.

The minimum detectable current from the photodiode is $< 5 \text{ nA}$. Using Mie scattering theory evaluation, this implies an expected minimum detectable grain radius of $< 0.2 \mu\text{m}$ (see theoretical curve in Figure 2). The maximum detectable size is related to fluid dynamics constraints inside the instrument and is around $20\text{-}30 \mu\text{m}$, in the range of expected suspended grain size (radius $\sim 10 \mu\text{m}$). Dust abundance will be computed starting from size measurements and sampled volume (fixed by pump flux and run duration). The mentioned performances have been verified with the MicroMED breadboard.

Monodisperse particles with calibrated size have been injected in the Martian simulation chamber where the MicroMED instrument was placed. Results are shown in Figure 2. MicroMED output current, generated by the photodiode as a response of the detection of light scattered by the grains, perfectly corresponds to the values predicted using Mie's theory.

Performed tests clearly show that the instrument satisfies technical and scientific requirements and perfectly reproduces the results obtained during the simulations that drove its design.

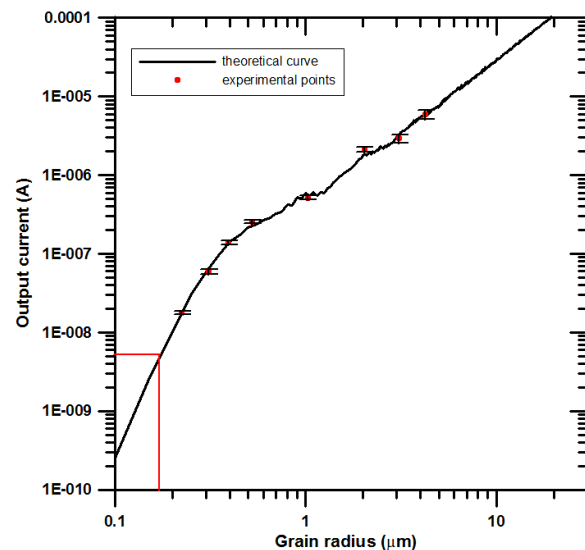


Figure 2: MicroMED performances.

MicroMED has a mass $< 500 \text{ g}$ and a power consumption of $< 3 \text{ W}$.

The DREAMS experiment on-board the Schiaparelli lander of ExoMars mission

F. Esposito¹, S. Debei², C. Bettanini², C. Molfese¹, I. Arruego Rodríguez³, G. Colombatti², A-M. Harri⁴, F. Montmessin⁵, C. Wilson⁶, A. Aboudan², S. Abbaki⁵, V. Apestigue³, G. Bellucci⁷, J-J. Berthelier⁵, J. R. Brucato⁸, S. B. Calcutt⁶, F. Cortecchia¹, F. Cucciarrè², G. Di Achille¹, F. Ferri², F. Forget⁹, E. Friso², M. Genzer⁴, P. Gilbert⁵, H. Haukka⁴, J. J. Jiménez³, S. Jiménez¹⁰, J-L. Josset¹¹, O. Karatekin¹², G. Landis¹³, R. Lorenz¹⁴, M. Mannetta¹, J. Martinez³, L. Marty¹, V. Mennella¹, D. Möhlmann¹⁵, D. Moirin⁵, R. Molinaro¹, E. Palomba⁷, M. Patel¹⁶, J-P. Pommereau⁵, C.I. Popa¹, S. Raffin¹⁷, P. Rannou¹⁸, N.O. Renno¹⁹, P. Schipani¹, W. Schmidt⁴, E. Segato², S. Silvestro¹, F. Simoes²⁰, E. Simoncini⁸, A. Spiga⁹, F. Valero²¹, L. Vázquez²¹, F. Vivat⁵, O. Witasse²², R. Mugnuolo²³, S. Pirrotta²³, E. Marchetti²³

¹INAF - Osservatorio Astronomico di Capodimonte, Napoli, Italy, ²CISAS - Università degli Studi di Padova, Padova, Italy, ³INTA, Spain, ⁴Finnish Meteorological Institute (FMI), Helsinki, Finland, ⁵LATMOS - CNRS/UVSQ/IPSL, France, ⁶Oxford University, Oxford, United Kingdom, ⁷INAF - Istituto di Fisica dello Spazio Interplanetario (IFSI), ⁸INAF-Osservatorio Astrofisico di Arcetri, ⁹CNRS, LMD, France, ¹⁰Universidad Politécnica de Madrid, Spain, ¹¹Space Exploration Institute, Switzerland, ¹²Royal Observatory of Belgium, Belgium, ¹³NASA, GRC, USA, ¹⁴JHU Applied Physics Lab (JHU-APL), USA, ¹⁵DLR PF Leitungsbereich, Berlin, Germany, ¹⁶Open University, UK, ¹⁷SwRL, Switzerland, ¹⁸GSMA, France, ¹⁹University of Michigan, USA, ²⁰NASA, GSFC, USA, ²¹Universidad Complutense de Madrid (UCM), Spain, ²²ESA-ESTEC, Noordwijk, The Netherlands, ²³Italian Space Agency, Italy

Abstract

The DREAMS package is a suite of sensors for the characterization of the Martian basic state meteorology and of the atmospheric electric properties at the landing site of the Entry, descent and landing Demonstration Module (EDM) of the ExoMars mission. The EDM will land on Meridiani Planum in October 2016, during the statistical dust storm season. This will allow DREAMS to investigate the status of the atmosphere of Mars during this particular season and also to understand the role of dust as a potential source of electrical phenomena on Mars. DREAMS will be the first instrument to perform a measurement of electric field on Mars.

DREAMS FM has been completely developed and tested and it has been delivered to ESA for integration on the Schiaparelli lander of the ExoMars 2016 mission.

Launch is foreseen for January 2016.

federal Space Agency (Roscosmos). It is a two-steps mission. It includes an orbiter, the *Trace Gas Orbiter*, and an EDM (Schiaparelli), that will be launched on January 2016, and a descent module and surface platform, plus a rover, to be launched in 2018.

DREAMS will be accommodated on the EDM. It includes six sensors: MarsTem (thermometer), DREAMS-P (pressure sensor), DREAMS-H (humidity sensor), MetWind (2-D wind sensor), MicroARES (electric field sensor), SIS (Solar Irradiance Sensor), a CEU (Central Electronic Unit) and a battery (Figure 1).

The development of the instrument is at its final stage, with the Flight Model delivered to ESA in spring 2015 and ready for the integration on the EDM.

The system has been fully characterized and calibrated.

1. DREAMS

The ExoMars mission is carried out by European Space Agency (ESA) in cooperation with the Russian

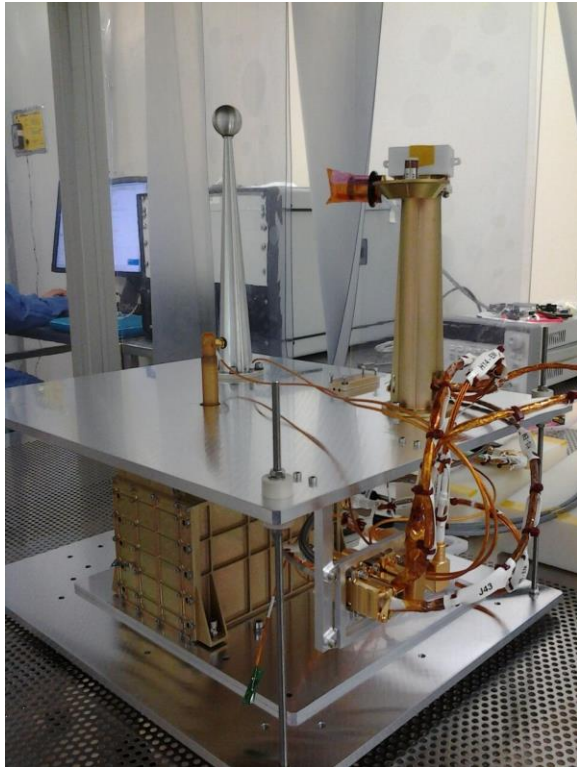


Figure 1: DREAMS Flight Model

Field experiments have been also performed in the Sahara desert (Figure 2) in 2013 and 2014 during the dust storm season to test sensor response to harsh environment.

Sahara tests have also allowed the study of the rising and evolution of dust storms and their effects on the electric properties of the atmosphere. This study will prepare the analysis of the data that will be acquired on Mars by the instrument DREAMS.



Figure 2: Field test campaign in the Sahara desert.

Acknowledgements

The activities related to the DREAMS project have been supported by the Italian Space Agency, CNES, ESA, INTA (Spain), Oxford University, FMI (Finland).

Toward the next TRL of KArLE (in situ geochronology for planetary experiment)

D. Devismes (1), B. A. Cohen(1) and H. Haight (1)

(1) NASA Marshall Space Flight Center, Huntsville AL 35812 (damien.p.devismes@nasa.gov)

Abstract

The instrument 'Potassium (K) Argon Laser Experiment' (KArLE) is developed and designed for *in situ* absolute dating of rocks on planetary surfaces. It is based on the K-Ar dating method and uses the Laser Induced Breakdown Spectroscopy – Laser Ablation – Quadrupole Mass Spectrometry (LIBS-LA-QMS) technique. We use a dedicated interface to combine two instruments similar to SAM of Mars Science Laboratory (for the QMS) and ChemCam (for the LA and LIBS). The prototype has demonstrated that KArLE is a suitable and promising instrument for *in situ* absolute dating.

1. Introduction

In planetary exploration, *in situ* absolute geochronology is an important measurement. Thus far, on Mars, the age of the surface has largely been determined by crater density counting, which gives relative ages. These ages can have significant uncertainty as they depend on many poorly-constrained parameters. More than that, the curves must be corrected with absolute ages to relate geologic time-scales on Mars to the rest of the solar system. Thus far, only the lost lander Beagle 2 was designed to conduct absolute geochronology measurements, though some recent attempts using MSL Curiosity show that this investigation is feasible [1] and should be strongly encouraged for future flight.

2. Experimental

Developed at the MSFC through the NASA Planetary Instrument Definition and Development Program (PIDDP), KArLE is one of several projects working on *in situ* geochronology [2, 3, 4]. The protocol is based on several instruments already used in planetary exploration. A laser ablates a rock under high vacuum and creates a plasma, whose spectrum

yields elemental abundances, including K (Laser Induced Breakdown Spectroscopy, LIBS). The ablated material frees gases, including radiogenic ^{40}Ar which is measured by a mass spectrometer (MS). The potassium and ^{40}Ar are related by the ablated mass. Because the very small mass displacement cannot be easily measured, the mass is calculated using the ablated volume and the density of the material. The determination of the chemistry, and therefore the mineralogy, is provided by the LIBS spectra and their treatment (univariate calibration, Partial Least Square, etc.) enabling the density to be determined. The volume of the pit is measured using optical imagery, for example, stereo imaging.

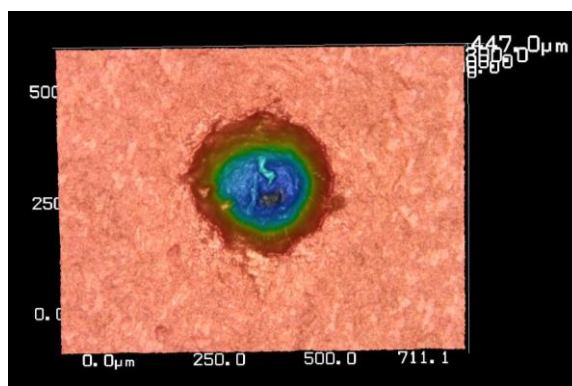


Figure 1: Ablated pit after 1000 pulses. 3D model made with Keyence microscope VK-X100.

3. Recent studies and future upgrades

Fair recently, this method has been demonstrated by several prototypes in independent laboratories [2, 3, 4 and 5]. As a very new technique, these teams explore the effects induced by the ultra-long ablation under high vacuum on the results and on the protocol [6], the performances of the K measurement by LIBS [7] and the ability to estimate the ablated volume with

the LIBS spectra [8]. These works and the future studies should bring some breakthroughs to enhance the performances of the K-Ar ages.

All this new 'know-how' will help to determine opportunists upgrades for the next Technology Readiness Level (TRL) design. We will enhance the protocol by using the closest parameters as possible compared to ChemCam and SAM on MSL (e.g. laser power, laser pulse frequency...).

Summary

We present here the new technological developments of KArLE and several results depending on the future advancement. We will talk about the performances of the last upgrades and discuss about the new abilities of the prototype.

Acknowledgements

This research was supported by an appointment to the NASA Postdoctoral Program at the Marshall S.F.C., administered by Oak Ridge Associated Universities through a contract with NASA.

References

- [1] Farley, K. A., Malespin C., Mahaffy P. et al.: In Situ Radiometric and Exposure Age Dating of the Martian Surface. *Science*, 343(6169), 1247166, 2013.
- [2] Cohen, B. A., Miller, J. S., Li, Z.-H., Swindle, T. D. and French, R. A.: The Potassium-Argon Laser Experiment (KArLE): In Situ Geochronology for Planetary Robotic Missions. *Geostandards and Geoanalytical Research*, 38: 421–439, 2014
- [3] Cho et al. (2011) PERC Planetary Geology Field Symposium, Abstract #30.
- [4] Devismes, D., Gillot, P.-Y., Lefèvre, J.-C. and Boukari, C.: A K-Ar development based on UV laser for in situ geochronology on the surface of mars. Firsts results and isochrones. *European Planetary Science Conference*, 8, #2013-71, 2013
- [5] Solé J.: In situ determination of K–Ar ages from minerals and rocks using simultaneous laser-induced plasma spectroscopy and noble gas mass spectrometry. *Chemical Geology*, 388, 9-22 (2014)
- [6] Devismes, D., Cohen, B. A. and Gillot, P.-Y.: Developing a relationship between LIBS ablation and pit volume for in situ dating of geologic samples LPSC 2015, Abstract #1406.
- [7] Cho, Y., Sugita, S. et al.: High-precision potassium measurements using laser-induced breakdown spectroscopy under high vacuum conditions for in situ K–Ar dating of planetary surfaces. *Spectrochimica Acta Part B: Atomic Spectroscopy*, 106, 28-35, 2015.
- [8] Devismes, D., Cohen, B. A. et al.: Relationship between LIBS ablation and pit volume for geologic samples: Applications for in situ absolute geochronology. *SciX*, Abstract #216

Space qualification of an automotive microcontroller for the DREAMS-P/H pressure and humidity instrument on board the ExoMars 2016 Schiaparelli lander

T. Nikkanen (1,2), W. Schmidt (1), A.-M. Harri (1), M. Genzer (1), M. Hieta (1,2), H. Haukka (1) and O. Kemppinen (1,2)
(1) Radar and Space Technology research group, Finnish Meteorological Institute, Helsinki, Finland, (2) Aalto University, Finland (timo.nikkanen@fmi.fi)

Abstract

1. Introduction

Finnish Meteorological Institute (FMI) has developed a novel kind of pressure and humidity instrument for the Schiaparelli Mars lander, which is a part of the ExoMars 2016 mission of the European Space Agency (ESA) [1]. The DREAMS-P pressure instrument and DREAMS-H humidity instrument are part of the DREAMS science package on board the lander. DREAMS-P (seen in Fig. 1 and DREAMS-H were evolved from earlier planetary pressure and humidity instrument designs by FMI with a completely redesigned control and data unit. Instead of using the conventional approach of utilizing a space grade processor component, a commercial off the shelf microcontroller was selected for handling the pressure and humidity measurements. The new controller is based on the Freescale MC9S12XEP100 16-bit automotive microcontroller. Coordinated by FMI, a batch of these microcontroller units (MCUs) went through a custom qualification process in order to accept the component for spaceflight on board a Mars lander.

2. Space qualification test process

Thermal, mechanical and material outgassing tests were performed for the component qualification. The thermal tests of the MCUs were conducted at FMI premises, while the component evaluation constructional analysis was performed at HI-REL Laboratories, USA and the material tests at Instituto Nacional de Técnica Aeroespacial (INTA), Spain. Mechanical qualification vibration and shock tests were performed at instrument level in VTT Expert Services, Finland.

Thermal cycling and cold soak tests for the microcontroller took place at the FMI space laboratory in Helsinki, Finland. All of the samples were cycled between -65 °C and +70 °C in an environmental cham-

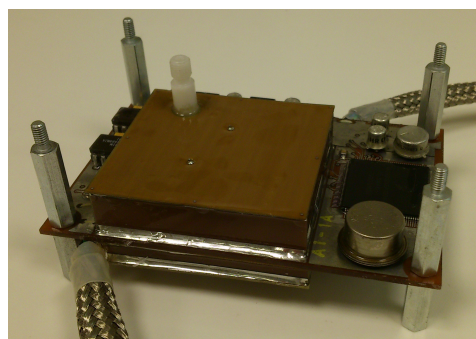


Figure 1: DREAMS-P pressure instrument Flight Model with the integrated instrument controller.

ber. One batch of samples were cycled 50 times, while another was cycled 100 times. The microcontrollers were also subjected to extended cold periods in -86 °C.

For component evaluation constructional analysis, HI-REL inspected 60 samples of the MC9S12XEP100 MCUs with X-ray and Scanning Acoustic Microscopy (SAM) techniques. Three of the samples were further examined via a Destructive Physical Analysis (DPA) against a set of military standards, including MIL-STD-1580B.

Actual mechanical qualification tests were performed at instrument level with the MCU integrated to the DREAMS-P circuit board. The qualification and flight models of DREAMS-P were vibrated and shock tested at VTT Expert Services in Espoo, Finland. These tests mimicked the type of actual loads encountered during the ExoMars 2016 mission.

Samples of the MCU plastic chip carrier material were tested at INTA to determine the outgassing properties of the material.

3. Space qualification test results

At FMI, the thermal cycling and cold soak tests were followed by a functional test of the MCUs. Each one of the samples was successfully tested to function in the socket of a software development evaluation board.

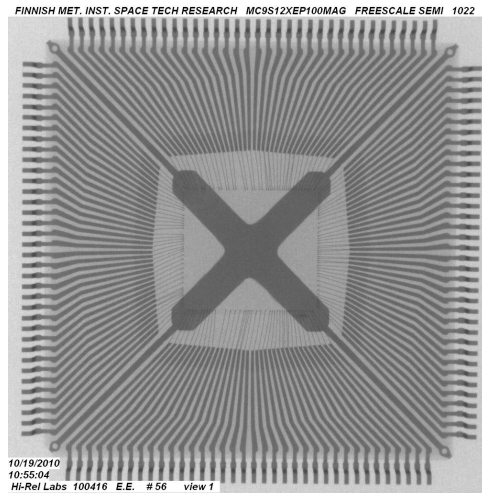


Figure 2: Example of a MC9S12XEP100 X-ray image.

The HI-REL X-ray (example seen in Fig. 2) or SAM inspections revealed no unacceptable mechanical defects in the components. However, some non-critical delamination and voids were detected on few samples with SAM. [2] Likewise, the DPA was passed without unacceptable defects [3].

Mechanical shock and vibration tests were successfully carried out at VTT Expert Services. The DREAMS-P qualification model was shown to function normally after being subjected to qualification test levels and the DREAMS-P flight model after being subjected to flight acceptance test levels.

The outgassing tests by INTA measured the Recovered Mass Loss (RML) of the material as 0.073 % and the Collected Volatile Condensable Materials (CVCM) ratio as 0.000 % [4]. These values are clearly under the ESA outgassing limits of < 1 % for RML and < 0.1 % for CVCM [5].

4. Conclusions

A capable microcontroller with low resource requirements was successfully qualified for spaceflight use.

Following the component and instrument level qualification, the MCU is currently being subjected to additional environmental tests on a higher integration level as part of the DREAMS instrument package and the Schiaparelli spacecraft. Finally, as part of the ExoMars 2016 mission, the MC9S12XEP100 microcontroller will be subjected to the rigors of launch, transplanetary cruise, entry, descent and landing as well as the actual Mars surface operations.

The choice to use a commercial component for a planetary lander instrument controller in DREAMS-P/H represents the growing trend in spacecraft engineering of using capable commercial electronic components instead of components designed for space use. Compared to traditional designs, this trend offers more flexible development of efficient autonomous instrument control and data units, while maintaining a high level of reliability, when proper qualification and design guidelines are followed.

References

- [1] F. Esposito, et al.: DREAMS for the ExoMars 2016 mission: a suite of sensors for the characterization of Martian environment. European Planetary Science Congress 2013. EPSC Abstracts, Vol. 8, EPSC2013-815.
- [2] HI-REL Laboratories. Report Number: US- 100416x. Washington, USA. Technical report, December 2010. DREAMS-P/H team internal document.
- [3] HI-REL Laboratories. Destructive Physical Analysis 100416. Washington, USA. Technical report, December 2010. DREAMS-P/H team internal document.
- [4] Instituto Nacional de Técnica Aeroespacial. ESE-RPT-4316-055-INTA-13. Outgassing Test: DMAV-1314, Spain. October 2013. DREAMS-P/H team internal document.
- [5] ECSS-Q-ST-70-02C. European Cooperation for Space Standardization. Noordwijk, the Netherlands, second edition, 2008.

Scientific calibration and analysis of calibration data for the CaSSIS instrument of the ExoMars Trace Gas Orbiter

V.A. Roloff, L. Gambicorti, A. Pommerol, N. Thomas.

Physikalisches Institut, University of Bern, Switzerland (victoria.roloff@space.unibe.ch / Fax: +41(0)31 631 44 05)

Abstract

The Colour and Stereo Surface Imaging System (CaSSIS) is a camera, the development of which is led by the University of Bern (CH), with hardware contributions from the University of Padova (I) and the Space Research Center of Warsaw (PI). It will take high resolution stereo images in 4 colours of the Martian surface, from on board the ExoMars Trace Gas Orbiter. Our calibration facility stands ready to perform the required measurements. We are currently testing the procedures on a dummy system and we will report on calibration results of the CaSSIS instrument.

1. Introduction

The ESA-lead ExoMars Trace Gas Orbiter (TGO), to be launched in 2016, will demonstrate key flight and in-situ enabling technologies by searching for signs of past and present life on Mars, and, investigate the geochemical environment and atmospheric trace gases and their sources [1]. The TGO will carry 4 scientific instruments: the atmospheric spectrometers NOMAD and ACS, the neutron detector FREND, and the camera CaSSIS (Colour and Stereo Surface Imaging System). The development of CaSSIS is led by the University of Bern (CH), with hardware contributions from the University of Padova (I) and the Space Research Center of Warsaw (PI).

2. CaSSIS

CaSSIS will characterise sites which have been identified as potential sources of trace gases, investigate dynamic surface processes, and thus certify potential future landing sites. The instrument comprises two major units: Camera Rotation Unit (CRU) and Electronics Unit (ELU). The CRU is composed of the telescope (including focal plane and associated electronics), the rotation system, cable management system and some structure to support all of the above and mount the

CRU to the spacecraft. The ELU contains the boards with the electronics required to operate the camera.

The CaSSIS telescope is a three-mirror astigmatic system (off-axis) and fold mirror, with power on all 4 reflecting surfaces. The detector is a Raytheon Osprey 2k CMOS hybrid comprising $2k \times 2k$ pixels with $10 \mu\text{m}$ pitch, which allows snapshot operation at a read-out rate of 5 MPixel/s with 14 bit resolution. CaSSIS will operate in the push-frame mode with this system, with a focal plane consisting of the detector mounted with 4 colour filters: PAN 550–800 nm; Red 790–910 nm; Blue-Green 435–565 nm; and IR 875–1025 nm.

It will observe a 9 km-wide swath width, with a surface resolution of $<5 \text{ m/pixel}$, capable of producing 1 full-resolution stereo image pair of the Martian surface per orbit. The imager has been designed to look 10° ahead of the spacecraft as the first image is taken. After the instrument rotates by 180° passing over a desired target, the imager is consequently pointing backwards by 10° for the second image. It is this process and mechanism that allows for the quasi-simultaneous stereo image acquisition.

3. Calibration Facility

A room at the University of Bern has been converted to a Class 100 (ISO 5) clean room (Figure 1). It includes a laminar flow system, calibration/integration room, and an optical bench. Our facility is complete and stands ready to perform the calibration of CaSSIS.

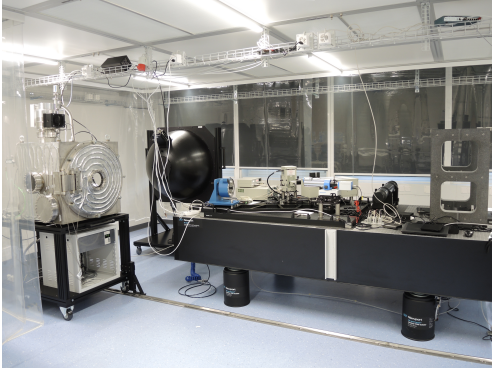


Figure 1: The class 100 (ISO 5) clean room, including laminar flow system and calibration/integration room. Left: the vacuum chamber, with the black integrating sphere distant centre-left. Right: dark grey optical bench on which stands the collimator, off-axis parabola, monochromator, and vertical stand.

4. Procedures

The calibration procedures of CaSSIS have been inspired by that of HiRISE and OSIRIS [2]. In order to correct for various types of noise and distortion, to characterise, and therefore optimise the performance of CaSSIS, we are to perform the following tests:

- *Flat-field, linearity, and absolute response.* For corrections caused by differences in pixel-to-pixel sensitivity and detector response.
- *Bias levels and dark current of the detector.* Needed to correct for the randomly-generated noise within the detector, and also its variance with temperature.
- *Point spread function (PSF).* To measure the response of the system when observing a point source, and how this response varies with temperature.
- *In-field straylight.* Light from scattered or diffuse reflections impairs ability to reach and maintain required signal-to-noise ratio. With measurements of the PSF, straylight may be corrected.
- *Relative spectral response.* Gives the combined system efficiency including filter transmission and detector sensitivity. Measured at ambient temperature, and under thermal load, it is important to determine the correct colour ratio in observations.

- *Focal length and angular scale.* Required to determine the scale of each image.
- *Geometric distortion.* Critical measurement for reconstructing the digital terrain models from the stereo images.
- *Performance of the rotation mechanism.* Ensuring the efficiency of its performance and to foresee potential problems.
- *Performance of the digital processing module in a flight data acquisition simulation.*

At the time of writing, we are testing the procedures listed on a dummy CaSSIS system. Figure 2, as an example, displays the results obtained testing the linearity of the system. The presentation will show some of the results.

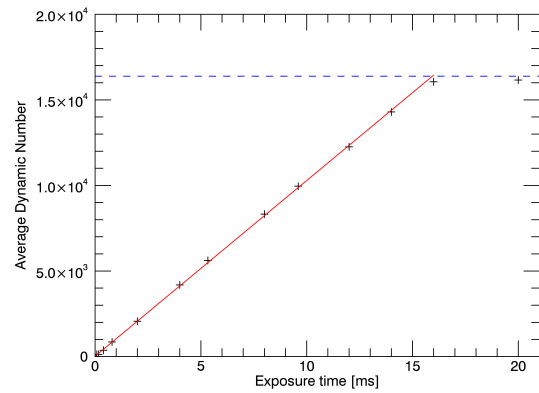


Figure 2: Linear response of the dummy CaSSIS system, from images of different exposure times.

Acknowledgements

The CaSSIS instrument is funded by the Swiss Space Office with contributions from ASI, NASA, and the SRC (Warsaw).

References

- [1] Cardesin Moinelo, A., et al.: Design of a Science Operations Centre for the ExoMars 2016 Trace Gas Orbiter Mission, European Planetary Science Congress, 7–12 September 2014, Cascais, Portugal.
- [2] Keller, H. U., et al.: OSIRIS – The Scientific Camera System Onboard Rosetta, Space Sci. Rev., Vol. 128, pp. 433–506, 2007.

The Micro Imaging and Dust Analysis System – New Possibilities for Space Sciences

R. Schmied (1), K. Torkar (1), H. Jeszenszky (1), J. Romstedt (2), T. Mannel (1), M.S. Bentley (1) and the MIDAS Team (1)
(1)Institut für Weltraumforschung, Graz, Austria, (2) European Space Research and Technology Centre, Future Missions Office (SREF), Noordwijk, Netherlands

Abstract

The Rosetta mission addresses a range of fundamental questions in Solar System and cometary science and the MIDAS instrument on-board the orbiter is one of the dust analysis systems. While GIADA analyses the dust flux and spatial distribution as a function of time and space and COSIMA investigates the elemental composition of cometary grains, MIDAS is a unique high resolution Atomic Force Microscope (AFM) combined with a dust collection and handling system designed to reveal the three-dimensional topographical structure of nano- and micrometer sized dust particles [1]. In this work we concentrate on the instrumental functionality and limitations coming from the construction and operation dealing with an AFM fabricated nearly 20 years ago and operating in a harsh environment.

1. Introduction

The technique of Atomic Force Microscopy was first published in 1986 by Binnig, Quate and Gerber [2] and was thus a very new technique at the time Rosetta was designed and MIDAS was proposed. The most important advantage compared to other surface characterization methods is the quantitative 3D information down to spatial nm resolution. Also the ease of sample preparation and its non-destructive character make AFM a perfect instrument for *in-situ* particle analysis. Due to the development of additional measurement modes, the available information goes beyond surface morphology and includes mechanical, electrostatic, chemical, electronic and magnetic properties. This additional information can often be acquired in a simultaneous manner. Beside morphological investigation, MIDAS is also designed to reveal the magnetic properties in the micro- and nanometre range.

2. The Micro Imaging and Dust Analysis System

MIDAS had to be designed to survive and operate with several environmental influences, such as launch vibrations, the intrinsic temperature variations in space and the vibrational loading during manoeuvres which cause problems for an AFM which is very sensitive to vibrations. The cantilever system in combination with the tip geometry is of particular importance, since it is responsible for the sensitivity of the microscope. On the one hand a robust cantilever will withstand all these influences, but as present-day developments show, a multitude of cantilever designs are available for specific purposes. Since MIDAS was developed 20 years ago and the fabrication technique was not that well developed some differences are shown compared to the well adapted designs. In the second part the possibility of imaging beyond the morphology will be discussed, including mechanical information and magnetic properties, which are of particular interest for Rosetta. A comparison the state-of-the-art AFM developments will be shown, which may indicate new possibilities for future flight instruments.

Acknowledgements

We gratefully acknowledge funding from the Austrian Academy of Sciences and the Austrian Research Promotion Agency (FFG).

References

- [1] W. Riedler, K. Torkar, H. Jeszenszky: MIDAS - The micro-imaging and dust analysis system for the Rosetta mission, *Space Science Reviews*, 128, 1-4, 869-904, 2007
- [2] G. Binnig, C.F. Quate and Ch. Gerber: Atomic Force Microscope, *Phys. Rev. Lett.* 56, 930, 1986