

IPM 2018

International Workshop on Planetary Missions

Berlin, September 12-14, 2018

Workshop Program

Tuesday, Sep 11, 2018

18:00– 20:00 p.m.

TU Main Building, Gallery 2nd floor Atrium (Lichthof)

Icebreaker Party

Wednesday, Sep 12, 2018

08:00 – end

TU Main Building, Room H 2035

Registration

08:30 – 08:50 a.m.

TU Main Building, Room H 2053

Welcome and Information

Novel instruments for sample return and lander missions

TU Main Building, Room H 2053

Chairs: Oberst; Lakew

08:50 – 10:15 a.m.

D. SCHURR (keynote)

NASA's new lunar program, Planetary SmallSats, and instrument technology investments

M. GRANDE (keynote)

The Planetary Exploration Horizon: Visions for 2050-2061

D. BLAKE et al.

MapX: A Full-Field X-ray Fluorescence Imager for Landed Planetary Science

B. AVENSON, D. N. DELLA GIUSTINA, S. H. BAILEY, VERONICA BRAY and the SIIOS team

The Seismometer to Investigate Ice and Ocean Structure

S.-W. CHIOU and N. YU

Atomic sensors for planetary gravity and seismic measurements

Coffee Break

10:35 – 12:20 a.m.

J. E. BLEACHER, K. GENDREAU, Z. ARZOUMANIAN, K.E. YOUNG and A. MCADAM

Basic Science Instruments as Dual Function Human Exploration Tools: An XRD/XRF Strategy

B. A. COHEN and Y. CHO

Continued development of the Potassium-Argon Laser Experiment (KArLE) for in situ geochronology

W. SMITH

Low Risk Technique for Sample Acquisition from Remote and Hazardous Sites on a Comet

K. ZACNY, S. INDYK et al.

Application of pneumatics to drilling, excavation, sample acquisition and transfer on planetary missions

K. RAMMELKAMP et al.

LIBS and Raman Spectroscopy for Planetary in-situ Exploration

S. KAMEDA et al. (invited)

Martian Moons eXploration (MMX): its science and instruments

L. BLEACHER, B. LAKEW, T. BROWN, R. RIVERA and J. BRACKEN

NASA Goddard's Planetary Science Winter School: Training Early Career Planetary Scientists in Flight Instrument Design

Lunch Break

Instruments on past, ongoing and upcoming missions- lessons learned

TU Main Building, Room H 2053

Chairs: Coustenis; Getty

13:50 – 15:25 p.m.

P. MAHAFFY (keynote)

Six years of geochemical measurements in an ancient martian lakebed with the Curiosity rover in Gale crater

J. F. BELL III and the MARS 2020 PAYLOAD INVESTIGATOR teams (invited)

NASA's Mars 2020 Rover Instrument Investigations: Enabling Exploration and Sample Return from Ancient Mars

L. W. BEEGLE et al.

SHERLOC on Mars 2020

A. SHAKUN et al.

Fourier-spectrometer FAST for ExoMars 2020 surface platform

S.-E. HAMRAN et al.

Field Testing the RIMFAX GPR on the Mars 2020 Rover Mission

R. STABBINS, A. GRIFFITHS, M. GUNN, A. COATES and the PANCAM SCIENCE team

Spectral Imaging System Simulation: Preparations for the ExoMars 2020 Rover PanCam Wide Angle Cameras

Coffee Break

15:50 – 16:55 p.m.

E. H. MAIZE (invited)

Cassini Lessons Learned

E. P. TURTLE, R. S. MILLER et al. (invited)

Instruments for Dragonfly, a Rotorcraft Lander Concept for In Situ Exploration of Titan's Organic Chemistry and Habitability

D. P. GLAVIN et al.

The CAESAR New Frontiers Mission: Comet Surface Sample Acquisition and Preservation

S. KAMEDA et al.

Cameras (TENGOO and OROCHI) for Martian Moons Exploration (MMX)

Thursday, Sep 13, 2018

Instruments for Orbiters, Flybys and descent probes Missions

TU Main Building, Room H 2053

Chairs: Turtle; Lakew

08:30 – 10:05 a.m.

H. RAUER and the PLATO team (keynote)

Plato Instrumentation and Mission Status

J. B. ABSHIRE et al.

MARLI: MARs Lidar for global wind and aerosol profiles from orbit

L. K. TAMPPARI, N. J. LIVESEY et al.

A Sub-millimeter sounder for vertically measuring Mars winds, water vapor, and temperature

F. LUEDICKE et al.

A proposed next-generation Laser for Polar Altimetry on Mars (LaPALMa)

A. BÖRNER, P. IRMISCH, I. ERNST and D. BAUMBACH

Cameras for navigation and 3D modelling on planetary exploration missions

G. BRYDON and G. H. JONES

Rotational push-broom Imaging from a Planetary Penetrator

Coffee Break

10:30 – 12:00 a.m.

G. CHIN et al.

Picture this SELFI: A Maturation Project for a Submillimeter Enceladus Life Fundamentals Instrument (SELFI)

L. E. HEFFERN et al.

Pulsed Neutron Experiments with SINGR (Single-scintillator Neutron & Gamma-Ray spectrometer)

J. SIMCIC, C. LEE and D. NIKOLIC

Piezoelectric valve for atmospheric descent sampling

C. L. SMITH et al.

MAPLE: Mars Atmospheric Panoramic camera and Laser Experiment

A. SOIBEL, A. G. DAVIES, D. TING, W. JOHNSON, M. BLACKWELL and P. HAYNE

Non-saturating, simultaneous multiband, infrared imager

R. C. GHAIL and the ENVISION team (invited)

VenSAR on EnVision

Lunch Break

Bepi Colombo mission special session: Science objectives and instruments status

TU Main Building, Room H 2053

Chairs: Michaelis; Oberst

13:30 – 15:10 p.m.

M. DI BENEDETTO, L. IESS and S. CIARCIA (keynote)

MORE – Mercury Orbiter Radio science Experiment

J. BENKHOFF, E. MONTAGNON and J. ZENDER (keynote)

Unveiling Mercury's Mysteries with BepiColombo

G. CREMONESE and the SIMBIO-SYS team (invited)

The SIMBIO-SYS Imaging System on Board the BepiColombo Mission

N. THOMAS and H. HUSSMANN (invited)

The BepiColombo Laser Altimeter (BELA)

J. HELBERT, H. HIESINGER, A. MATURILLI, M. D'AMORE, I. WALTER and G. PETER (invited)

MERTIS – MErcury Radiometer and Thermal infrared Imaging Spectrometer

J.-Y. CHAUFRAY, E. QUÉMERAIS and PHEBUS team (invited)

PHEBUS – Probing of Hermean Exosphere by UV Spectroscopy

Coffee Break

15:30 – 17:25 p.m.

J. HUOVELIN and M. GRANDE (keynote)

Solar Intensity X-ray and particle Spectrometer (SIXS)

A. MARTINDALE (keynote)

The Mercury Imaging X-ray Spectrometer

M. WIESER and S. BARABASH (invited)

The Miniature Ion Precipitation Analyzer (MIPA)

S. ORSINI, E. DE ANGELIS et al. (keynote)

The SERENA experiment: four particle sensors for Mercury environment dynamics understanding (ELENA, STROFIO, PICAM, MIPA)

I. MITROFANOV (invited)

BepiColombo - MGNS - Mercury Gamma-Ray and Neutron Spectrometer

D. HEYNER (invited)

Bepi Colombo – MPO-MAG

N. ANDRÉ et al. (invited)

The Mercury Electron Analyzers onboard the Bepi Colombo Mercury Magnetospheric Orbiter

Friday, Sep 14, 2018

Instrumentation for life detection in Ocean Worlds

TU Main Building, Room H 2053

Chairs: Sotin; Feldman

08:30 – 10:35 a.m.

S. A. GETTY (keynote)

Signatures of Life in Ocean Worlds and Implications for In Situ Instrumentation

R. AREVALO JR. et al.

Advanced capabilities of a laser-enabled Orbitrap mass spectrometer adapted for spaceflight

J. S. CREAMER, M. F. MORA and P. A. WILLIS

Stability of Reagents used for Chiral Amino Acid Analysis during Spaceflight Missions in High-Radiation Environments

A. GRUBISIC et al.

European Molecular Indicators of Life Investigation (EMILI) for Habitability and Biosignature Analysis on Ocean Worlds

C. A. LINDENSMITH et al.

Holographic Microscopy for Extant Life Detection

M. S. FERREIRA SANTOS, T. G. CORDEIRO, A. NOELL, C. D. GARCIA and M. F. MORA

Simultaneous Detection of Inorganic Cations and Amino Acids in High Salinity Samples: Implications for In-Situ Exploration of Ocean Worlds

C. SZOPA et al.

MEMS based gas chromatograph for molecular characterization of planetary environments

S. YU, T. RECK, J. PEARSON, M. MALASKA, R. HODYSS and B. PATE

Millimeter-wave Chirality Spectrometer (ChiralSpec)

Coffee Break

Science Instruments for Deep-Space SmallSats and CubeSats

TU Main Building, Room H 2053

Chairs: Oberst; Sotin

11:00 – 12:15 p.m.

A. NÄSILÄ, T. KOHOUT, K. VIHARKANTO, A. RISSANEN, R. TROPS and H. SAARI

Miniaturized hyperspectral imager for small interplanetary spacecraft – ASPECT

P. DEVOTO, C. BELMANT and N. ANDRÉ

Development of a low energy threshold particle detector and application to CubeSats

C. HARDGROVE et al.

Neutron Spectrometer for the Lunar Polar Hydrogen Mapper Mission

T. HEWAGAMA et al.

Primitive Object Volatile Explorer (PROVE) – Mission to an Oort Cloud Comet

N. P. PASCHALIDIS et al.

The mini INMS instrument on NASA GSFC's Dellingr Mission and initial results

Lunch Break

JUICE mission special session: Science objectives and instruments status

TU Main Building, Room H 2053

Chairs: Oberst; Michaelis

13:45 – 16:35 p.m.

C. ERD, O. WITASSE, G. SARRI, P. GARÉ, D. RADOLA and X. MOISSON (keynote)

JUICE Instrumentation and Mission Status

Y. LANGEVIN, G. PICCIONI, G. FILACCHIONE, F. POULET, C. DUMESNIL and the MAJIS team (invited)

MAJIS, the VIS-IR imaging spectrometer of JUICE

H. HUSSMANN, K. LINGENAUER for the GALA team (invited)

The Ganymede Laser Altimeter (GALA) for the Jupiter Icy Moons Explorer (JUICE)

H. MICHAELIS et al. (invited)

Design, development and performances of the JANUS camera onboard JUICE

G. FILACCHIONE, G. PICCIONI, Y. LANGEVIN, F. POULET, C. DUMESNIL and the MAJIS team (invited)

The JUICE/MAJIS optical head design

M. K. DOUGHERTY, A. MASTERS and the J-MAG team (invited)

J-MAG for JUICE: Science objectives and instrument status

S. BARABASH, P. BRANDT, P. WURZ and the PEP team (invited)

Particle Environment Package (PEP): science objectives, instrument overview, and status

P. WITTMANN, S. KARLSSON, M. WIESER, M. KERENYI, H. ANDERSSON and S. BARABASH (invited)

The Jovian Dynamics and Composition Analyzer – Performance and design challenges

R. GLADSTONE et al. (invited)

The UVS Instrument on ESA's JUICE Mission

P. HARTOGH and the SWI team (invited)

The Submillimeter Wave Instrument on JUICE

H. KORTH et al. (invited)

The Europa Clipper Instrument Suite

Thursday, Sep 13, 2018

Poster Session

TU Main Building, Gallery 2nd Floor Atrium (Lichthof)

17:45 – 19:45

J. A. MEZILIS and Z. DEKSIT (poster)

Coordinated Multimedia Efforts on Mars 2020

M. E. CASTILLO et al. (poster)

Field Studies of the Linear Ion Trap Mass Spectrometer (LITMS) Instrument for Future Life-Detection Planetary Missions

I. KANIK, M. MENLYADIEV, V. ABRAHAMSSON, B. HENDERSON, and FANG ZHONG (poster)

Extraction of Organics using Supercritical Carbon Dioxide for in Situ Planetary Exploration

S. R. N. MCINTYRE (poster)

Multi-Parameter Approach to Habitability (M-PaH)

F. H. W. VAN AMEROM et al. (keynote)

LITMS planetary mass spectrometer overview

A. DE LA CRUZ et al. (poster)

Experimental Rotor Induced Collision Cell (RICC) for studying hypervelocity impact fragmentation of neutral molecules sampled by a flyby/orbiter closed-source neutral mass spectrometer (CN-MS)

E. SITTLER et al.

Tandem Ion Mass Spectrometer for Planetary Missions

J. F. BELL III and the MARS 2020 PAYLOAD INVESTIGATOR teams (poster)

MAZE: A Testbed Unit for the Mars 2020 Mastcam-Z Stereoscopic Multispectral Investigation

R. BHARTIA et al. (poster)

Biosignature detection on icy worlds through Deep UV resonance Raman and Fluorescence Spectroscopy: SHERLOC-E

S. DIBB, J. F. BELL III, L. T. ELKINS-TANTON, D. A. WILLIAMS, R. P. BINZEL and the PSYCHE MISSION team (poster)

Optimized Narrowband Visible to Near-Infrared Filters for the Psyche Multispectral Imager

D. A. KAPLAN et al. (poster)

Development and Performance Verification of a Robust MSMS Routine for the Mars Organic Molecule Analyzer (MOMA) Mass Spectrometer

A. PONTONI et al. (poster)

The Jovian Neutrals Analyzer for observation of Energetic Neutral Atoms onboard JUICE/PEP

N. ANDRÉ et al. (poster)

Secondary electron generation from conversion surfaces

E. L. GUSTAFSON et al. (poster)

A Printed Circuit Board Analyzer for Characterizing the Charge and Mass of Martian Dust

C. E. HUNTLY et al. (poster)

Proposed Hyperspectral Imager for Planetary Surface Missions

J. MCCAULEY, A. L. BUTTERWORTH and R. A. MATHIES (poster)

Developing a 3D Printed Fluidic Manifold for Support of a Chemical Analysis System for Space Flight Applications

S. ROMAINE et al. (poster)

Developing Miniature Wolter-I X-ray Optics for Planetary Science

B. TURNER, E. SEVY and D. AUSTIN (poster)

A Microchannel Thermalization Inlet to Eliminate Impact-Induced Molecular Fragmentation in Closed-Source Mass Spectrometers

M. SANDFORD et al. (poster)

Proving the Capability of Remote Raman Spectroscopy In-strumentation for Planetary Missions Through the Detection of Various Molecules with Astro-biological Significance at 120 meters

C. J. COCHRANE et al. (poster)

Gas and Ice Spectrometer Radar (GAISR) for Investigation of Planetary Plumes and Cometary Jets

C. J. COCHRANE, H. KRAUS, N. MURPHY, C. RAYMOND, P. NEUDECK and D. SPRY (poster)

Miniaturized Solid-State Magnetometer using Electrical Readout of Quantum Centers in Silicon Carbide

B. BERGMANN, T. BRANDT et al. (poster)

MW Class Nuclear Spacecraft: Real Time Natural and Artificial Radiation Detection on INPPS Flagship

MW Class Nuclear Spacecraft: Real Time Natural and Artificial Radiation Detection on INPPS Flagship

B. Bergmann¹, S. Pospisil¹, T. Brandt¹, A.S. Koroteev², A. V. Semenko², A. Solodukhin², F. Jansen³

¹CTU Prague, ² KeRC Moscow, ³DLR Bremen

Medipix/Timepix radiation detectors have challenging, qualified applications both on Earth and in space. One most important application that will be presented here: it is the INPPS flagship (International Nuclear Power and Propulsion System) - a nuclear electric spacecraft under design by the European-Russian DEMOCRITOS consortium. INPPS will face a particularly challenging radiation environment. The INPPS cluster of electric thrusters avoids a relatively longer orbit in Earth's Van Allen belts (around 2022). However, the Van Allen belt propagation prepares INPPS flagship already for the interplanetary journey – in the sequence first into Near Earth Space Environment (NESE) with potential extension to NEO, later to EUROPA and finally to MARS. During these INPPS journeys, it occurs a considerable strengthening and changes in radiation environment due to increasing galactic cosmic ray flux, abundant solar energetic particle storms plus JUPITER's additional stronger radiation source effecting INPPS at EUROPA. Because of INPPS flight to EUROPA it becomes maximal qualified with respect to natural and artificial radiation, the flagship is best tested and prepared for human MARS transportation in the 2030th. Due to the NESE/NEO-EUROPA-MARS mission scenario, INPPS power supply by the nuclear reactor subsystem is also completely tested with respect to all flagship subsystems and approved for human transportation within the payload basket to MARS.

First results of an investigation are shown in how to best implement Medipix/Timepix on the INPPS. Geant4 will be used, a toolkit for the simulation of the passage of particles through matter. It can be used for simulating both - the active material in Medipix/Timepix chips, as well as the INPPS flagship. That means Geant4 will be used to determine "hot spots" of radiation and increase sensor density on the INPPS subsystems.

The real time measurement and data transfer by Medipix/Timepix is supposed to increase operational security of this unique spacecraft.

Geant4 is also used to better understand the behavior inside the active semiconductor sensor material of the chip. The effect investigated here in particular is that charges generated in events spread out before reaching the readout chip layer. This is due to diffusion and repulsion. Extensions of the Geant4 code are written to account for this. The aim is to improve the comparability between simulations and experiments done for this chip.

MORE – Mercury Orbiter Radio science Experiment

M. Di Benedetto (1), L. Iess (1) and S. Ciarcia (2)

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1. Introduction

In October 2018, the joint ESA/JAXA mission BepiColombo will start its six-year cruise to Mercury. It consists of two separate orbiters: the Mercury Planetary Orbiter (MPO), under ESA responsibility, and the Mercury Magnetospheric Orbiter (MMO), provided by JAXA. In the cruise phase they will be combined in a single composite spacecraft, guided by means of an electric propulsion module. The two elements host a suite of 16 different instruments to carry out a variety of scientific investigations [1].

The MPO carries the key element of the Mercury Orbiter Radio-science Experiment (MORE): a Ka band transponder (KaT), enabling a two-way coherent Ka band radio link and supporting precision range and range rate measurements. The KaT will be complemented by the standard Deep Space Transponder (DST) to establish a multi-frequency radio link in X/X (7.2/8.4 GHz), X/Ka (7.2/32.5 GHz) and Ka/Ka band (34/32.5 GHz). This configuration will provide range rate measurements as accurate as 3 $\mu\text{m/s}$ (at 1000 s integration time), independently of the solar elongation angle. A 24 Mcps pseudo-noise code in the two-way Ka link will also enable two-way range measurements with 20 cm accuracy after a few seconds integration time. Such measurement accuracies are possible thanks to the plasma noise cancellation scheme successfully used in the Cassini mission [2, 3]. The dynamical noise induced by the non-gravitational accelerations (mainly the solar radiation pressure) will be largely accounted for by means of the onboard Italian Spring Accelerometer (ISA).

2. MORE: scientific goals

The MORE investigation addresses scientific goals in geodesy, geophysics, fundamental physics and space navigation. The BepiColombo spacecraft will basically act as a test mass in near free fall in the

gravity field of Mercury and the other solar system bodies. The scientific parameters of interest will be estimated as part of the orbit determination process. The quantities that will be measured by MORE are:

Gravity field of Mercury (Geodesy):

- Spherical harmonic coefficients of the gravity field at least to degree and order 25 with an accuracy up to 10^{-9} (depending on the degree and order)
- Love number k_2 with an accuracy of about 10^{-3} .

Rotation Experiment (Geophysics):

- Obliquity of the planet to about 1 arcsec
- Amplitude of physical libration in longitude with an accuracy < 1 arcsec
- Cm/C (ratio between mantle and planet MoI) to 0.05 (or better)
- C/MR² (condensation coefficient) to 0.003 (or better)

Fundamental Physics (relativistic gravity):

- γ to 2.5×10^{-6} (controlling the deflection of light and time delay of ranging signals)
- β to 2.5×10^{-6} (controlling the relativistic advance of Mercury's perihelion)
- η to 2×10^{-5} (controlling the gravitational self-energy contribution to the gravitational mass)
- $d(\ln G)/dt$ to $3 \times 10^{-13} \text{ years}^{-1}$
- J_2 of the Sun to 2×10^{-9}

Additional goals in the field of geodesy (topography of the planet) will be achieved in conjunction with other instruments, mainly the onboard laser altimeter (BELA).

In meeting its goals, MORE will be supported by another instrument, the Italian Spring Accelerometer (ISA), measuring the strong non-gravitational

accelerations perturbing the spacecraft orbit. With sensitivities of about 10^{-9} - 10^{-8} m/s² in the frequency band 10^{-4} - 10^{-1} Hz, ISA measurements will be combined with range and range-rate measurements provided by the KaT to mimic a drag-free system in software.

3. MORE instrument: KaT

The MORE's KaT is a very compact (216mm x 188mm x 140mm) and light equipment (its mass is less than 3.5 kg). The unit is based on a combination of advanced signal processing algorithms and novel digital technological implementation. The KaT core is based on a digital architecture, providing the following advantages with respect to a fully analogue solution (as the one adopted for the Cassini mission):

- Optimization of carrier acquisition and tracking performance
- Inclusion of PN ranging processing capabilities (demodulation and remodulation)
- Data rate flexibility with easy matched filtering implementation
- Design flexibility with receiver tuning based on programmable constants
- All-digital modulation capabilities based on Direct Digital frequency Synthesis



Figure 1: MORE's KaT Flight Model

Performance tests carried out in environmental conditions have shown the KaT has an internal stability of $\sim 4 \times 10^{-16}$ at 1000 s integration time. The KaT also implements a PN ranging modulation scheme up to 24.3 Mcps (also a lower chip rate at approximately 3.1 Mcps is supported). The unit supports an internal group delay calibration mode with an accuracy better than ± 0.4 ns pk-pk (aging not included) and a stability of ± 0.2 ns pk-pk.

The ESA/JUICE mission to Jupiter will also host a KaT to perform gravity experiments and unveil the interior structure of Europa, Ganymede and Callisto. The JUICE's KaT will be a recurrent unit from MORE's KaT, adapted for the harsh Jovian environment.

Acknowledgements

This work has been supported in part by the Italian Space Agency.

References

- [1] Schulz, R. and Benkhoff, J.: Advances in Space Research, 38, 572, 2006
- [2] Bertotti, B. et al.: A test of General Relativity using radio links with the Cassini spacecraft, Nature, 425, 2003
- [3] Tortora, P. et al: Precise Cassini Navigation During Solar Conjunctions Through Multifrequency Plasma Calibrations, Journal of Guidance, Control, and Dynamics, 27, 2, 2004

The SERENA experiment: four particle sensors for Mercury environment dynamics understanding (ELENA, STROFIO, PICAM, MIPA)

Stefano Orsini (1), Anna Milillo (1) Stefano Livi (2), Herbert Lichtenegger (3), Stas Barabash (4), Elisabetta De Angelis (1), Esa Kallio (5), Peter Wurz (6), Angelo Olivieri (7), Christina Plainaki (7), and the SERENA Team

- (1) INAF/IAPS, Rome, Italy;
- (2) SouthWest Research Institute (SwRI), USA;
- (3) Institut für Weltraumforschung (IWF), Austria;
- (4) Swedish Institute of Space Physics (IRF), Sweden;
- (5) Bern University (UniBe), Switzerland;
- (6) Finnish Meteorological Institute (FMI), Finland;
- (7) Italian Space Agency (ASI), Italy

Abstract

SERENA (Search for Exospheric Refilling and Emitted Natural Abundances) is a package of four instruments devoted to Hermean environment investigation on-board the Mercury Planetary Orbiter of the BepiColombo mission.

Mercury's environment is a complex and tightly-coupled system where the magnetosphere, exosphere, and surface experience temporal and spatial variations linked to each other. The interaction between energetic plasma particles, solar radiation and micrometeorites with the Hermean surface gives rise to both thermal and energetic neutral particle populations in the near-planet space; such populations will be recorded by the SERENA neutral particle analysers: a mass spectrometer and an Energetic Neutral Atom imager (STROFIO and ELENA). The photo-ionised or charged component of the surface release processes as well as the precipitating and circulating plasma in the Hermean magnetosphere will be recorded by the SERENA ion spectrometers: two ion sensors (PICAM and MIPA).

SERENA is a key experiment for the investigation of the Mercury environment having both neutral and ionised particles detection systems. Nevertheless it is the only particle experiment on board the MPO, able to provide a unique link with the MMO plasma instrumentation.

J-MAG for JUICE: Science objectives and instrument status

Michele K. Dougherty, Adam Masters and the J-MAG team

Department of Physics, The Blackett Laboratory, Imperial College London, SW7 2AZ, UK (m.dougherty@imperial.ac.uk)

Abstract

The magnetometer instrument is one of the core instruments on the ESA/JUICE spacecraft and is critical in order to resolve prime science objectives of the JUICE mission. The instrument is a dual fluxgate plus scalar sensor package on a spacecraft provided 10.6m boom.

1. Instrument

The combination of two fluxgate instruments plus a scalar sensor is driven by the science performance requirements necessary to meet the JUICE science objectives on a non-spinning spacecraft, as well as enabling calibration of the instrument suite once inside the Jovian system. The two heritage fluxgate sensors are being built by Imperial College London, UK and the Technical University of Braunschweig, Germany and the scalar sensor is a coupled dark state magnetometer from the Space Research Institute in Graz, Austria.

2. Overarching science themes

The importance of a magnetometer instrument on JUICE can be described under two separate themes:

1. The magnetic field drives the plasma processes occurring within the Jupiter system. Understanding such observations allows for a better understanding of dynamical plasma processes, of the generation of aurora and of the various current systems which arise within this rapidly rotating magnetosphere; the interactions of the magnetosphere of Ganymede within the Jovian magnetosphere within which it is embedded; to name but a few.

2. However the cutting edge magnetometer science which is unique to JUICE lies in being able to gain an understanding of the interior structure of the icy moons of Jupiter, specifically those of Ganymede,

Callisto and Europa. Of particular interest are knowledge of the depth at which the liquid oceans reside beneath their icy surfaces, the strength of any internal magnetic fields such as at Ganymede and the strength of any induced magnetic fields arising within these oceans.

3. Science objectives

The primary science objectives of JUICE which will be constrained by the magnetic field observations and which drive the performance requirements of the J-MAG instrument include:

- At Ganymede:
 - Characterization of the extent of the ocean and its relation to the deeper interior
 - Characterization of the ice shell
 - Characterization of the local environment and its interactions with the Jovian magnetosphere
 - Description of the deep interior and magnetic field generation
- At Europa, further constrain the depth of the liquid ocean and its conductivity
- At Callisto, characterize the outer shells, including the ocean
- Compare differentiated (Ganymede and Europa) and undifferentiated bodies (Callisto)
- Explore the Jovian magnetosphere
 - Characterize the magnetosphere as a fast rotator
 - Characterize the magnetosphere as a giant accelerator
 - Understand the moons as sources and sinks of magnetospheric plasma.

THE SIMBIO-SYS IMAGING SYSTEM ON BOARD THE BEPICOLOMBO MISSION. G.Cremonese¹ and the SIMBIO-SYS team, ¹Osservatorio Astronomico di Padova-INAf, vicolo Osservatorio 5, 35122 Padova, Italy, gabriele.cremonese@inaf.it

Introduction: The BepiColombo ESA-JAXA mission has as main scientific objective the exploration of Mercury and the fundamental physics, improving the accuracy of some General Relativity constants. The mission is composed by two modules: the Mercury Planetary Module (MPO) realized in Europe and having 11 instruments to analyze the surface, the internal structure and the environment nearby the planet, and the Mercury Magnetospheric Module (MMO) realized in Japan having 5 instruments to explore the environment around the planet.

On board the MPO there is the Spectrometers and Imagers for MPO BepiColombo Integrated Observatory SYStem (SIMBIO-SYS), that is a suite of three optical heads.

The SIMBIO-SYS team is lead by one PI and 5 CoPIs, the lead funding agency is the Italian Space Agency (ASI) and the main partner is the French Space Agency (CNES). The team is composed by 63 CoIs and 16 Associates, of 11 different countries (Italy, France, Belgium, Finland, Germany, Poland, Spain, Switzerland, Taiwan, UK, USA).

SIMBIO-SYS configuration: The instrument is composed by three separate channels managed by one common Main Electronics (ME), integrating all channel telecommand and handling functions, data handling and compression, and management with the S/C electronics. There is the High Resolution Imaging Channel (HRIC) working in the visible spectral range with one panchromatic and three broad band filters, the Stereo Imaging Channel (STC) working in the visible spectral range with two panchromatic and four broad band filters, and the Visual and Infrared Hyper-spectral Imager (VIHI) working in the spectral range of 0.4-2.2 μm . All the data will be compressed on board by using a compression software based on the wavelets.

SIMBIO-SYS scientific objectives: The instrument will provide in the first 6 months of the nominal mission the global mapping in stereo mode with a pixel scale between 50-120 m/pixel with the two panchromatic filters (STC) and spectral global mapping with a pixel scale of 500 m/pixel and the spectral sampling of 6.25 nm (VIHI). HRIC is a target oriented camera and will provide high resolution images, with a pixel scale

of 5-12 m/pixel, of 20% of the Mercury surface in one year.

In the second half of the nominal mission STC will provide color images of selected regions and VIHI high spatial resolution spectral maps, up to 100 m/pixel, of selected regions.

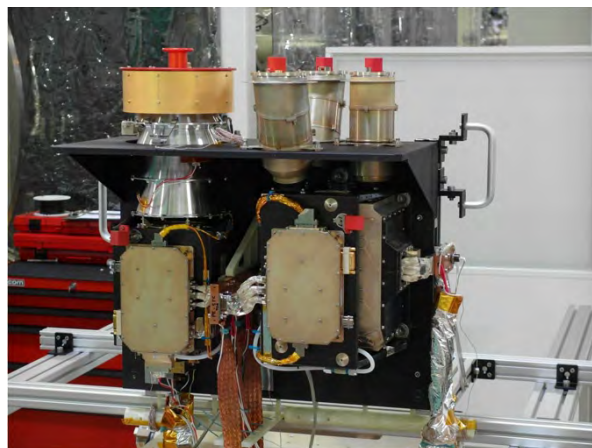


Figure 1. April 2015, SIMBIO-SYS before the delivery to ESA. From left to right HRIC, STC (two baffles are visible), VIHI.

Miniaturized Solid-State Magnetometer using Electrical Readout of Quantum Centers in Silicon Carbide

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Abstract

We report on the initial stages of development of a new solid-state silicon carbide magnetometer (SiCMag) intended for planetary field mapping. SiCMag measures magnetic field induced changes in spin dependent recombination (SDR) current within a SiC pn junction [1,2]. This change in SDR current arises from the interaction of external magnetic fields with the quantum centers (i.e., atomic scale defects) intrinsic to (or implanted in) the SiC semiconductor [3]. Once the sensitivity of the sensors are optimized, SiCMag will not only have the ability to investigate the internal dynamics, composition, and formation of planetary bodies by mapping its internally generated magnetic field, but will also be able to measure induced magnetic fields generated from conductive subsurface oceans, crustal fields originating from magnetized rock, and the interplanetary magnetic field carried by the solar wind. SiCMag has the added bonus that it is significantly smaller in volume and weight, requires significantly less power, and is significantly less complex than heritage designs which opens the door for missions involving constellation or swarms of cubesats.

1. Introduction

The material properties of silicon carbide, namely radiation and temperature hardness, are very attractive for space applications. Spaceflight magnetometry nowadays consists of the state-of-the-art heritage fluxgate and optically pumped atomic gas magnetometer technologies. These well-tried systems have excellent sensitivities on the order of $\sim 100\text{pT/Hz}^{1/2}$ or less, but are intrinsically complex and require non-miniaturizable parts and electronics. Here, we discuss a silicon carbide magnetometer, promising to be a lightweight and inexpensive alternative to these technologies, especially considering the trend to low-cost, high-volume

cubesat spaceflight missions. The working principle is as follows: When two energy levels of a spin system cross, at very near zero ambient magnetic field, spin state transitions between these levels become possible. This changes the physical properties of the system, specifically the recombination rates in the crossing region (spin dependent recombination). These effects can be observed for the silicon vacancy spin system in silicon carbide, both optically [4], [5] and electrically [1]. The latter approach can be leveraged to build an all-electrical solid-state magnetometer: The SDR current of an electrical device (e.g. a diode) changes close to zero field, thus, by actively nulling the ambient magnetic field, one can reconstruct the true field from the nulling field. We leverage a 3D printed 3-axis Helmholtz coil system to achieve this task, which is illustrated in fig. 1. Additionally, higher order electron resonance transitions in the vacancy quantum center can be utilized to obtain an absolute calibration of the sensor.

2. This Work

In this work, we show a proof-of-concept miniaturized magnetometer using silicon carbide diodes fabricated by NASA Glenn Research Center, based on the aforementioned principle, reaching a sensitivity on the order of $\sim 100\text{nT}/\sqrt{\text{Hz}}$.

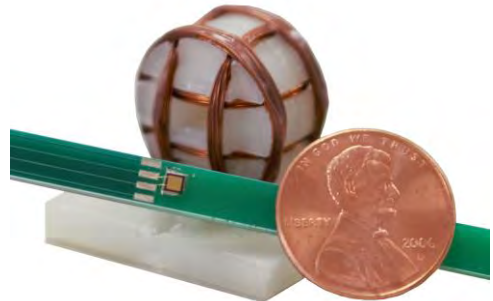


Figure 1: Prototype of the coil system and SiC sensor.

This metric, although not currently competitive with state-of-the-art technology, is actually quite impressive as the diodes leveraged were not designed in any way for magnetic field sensing. We will discuss the potential increase in sensitivity obtainable that results from fabricating our custom diodes (see fig. 2 for our baseline structure) and defect-engineering practices. By trading geometry, size, doping concentration and species, we're confident that we can reach and eventually outperform the aforementioned heritage technologies. We demonstrated previously, that nitrogen implantation provided higher sensitivity magnetic field sensing [2]. We will also illustrate the differences in defect spectra and magnetic field sensing capabilities of our newly fabricated devices, each with uniquely implanted layers of carbon, silicon, boron, aluminum, gallium, nitrogen, phosphorus, and arsenic or various combinations thereof, including a discussion of the implants' influence on device performance. Finally, we will discuss space-specific issues and opportunities that need to be addressed or when constructing such technologies for the various harsh conditions encountered in space and planetary systems.

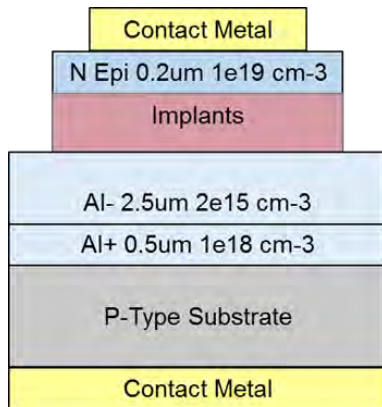


Figure 2: Baseline 4H SiC diode structure.

3. Future Opportunities

There are numerous relevant mission opportunities applicable for SiCMag, ranging from the large flagship missions to the smaller New Frontiers and Discovery missions. Because of the extremely small scale of the technology, it has significant potential for

use on small spacecraft such as nanosats and picosats, where fluxgate and optically pumped sensors are too large for implementation. These small satellites can be used in swarms, thereby allowing for synchronous mapping of a planet's geomagnetic field without the need to make multiple orbits as required for large spacecraft. Additionally, if used on larger spacecraft, SiCMag's size and simplicity allows for multiple sensors to be placed around the spacecraft which would provide redundancy and inter-sensor calibration, allow for cancelation of stray fields from the satellite payload, make differential measurements for gradiometric science needs, and also allow for simultaneous measurements of magnetic fields at different frequencies. The collection of this information would make it significantly easier to distinguish between magnetic fields generated by internal dynamos, crustal magnetic fields due to ferromagnetic material, induced magnetic fields from conductive sub-surface oceans, and the interplanetary magnetic field carried by the solar wind.

Acknowledgements

Parts of this study were carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (NASA). Devices used in this studied were fabricated by NASA Glenn Research Center. HK also acknowledges support by an appointment to the NASA Postdoctoral Program at the Jet Propulsion Laboratory, administered by Universities Space Research Association under contract with NASA.

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Gas and Ice Spectrometer Radar (GAISR) for Investigation of Planetary Plumes and Cometary Jets

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Abstract

The Rosetta mission at 67P/Churyumov-Gerasimenko enabled the first detailed and long-term survey of cometary activity, which occurs primarily through water outgassing and emission of dust. Its highly-capable instrument suite improved our understanding of the outgassing and the dust emission and size distribution separately, however the coupling between the two remains poorly understood. GAISR consists of a dual-channel submillimeter-wave spectrometer inspired from MIRO/Rosetta, coupled to a small-particle Doppler radar for simultaneous observations of outgassing and emission of the large dust particles (comprising most of the mass emitted) in cometary jets and plumes of outer solar system satellites.

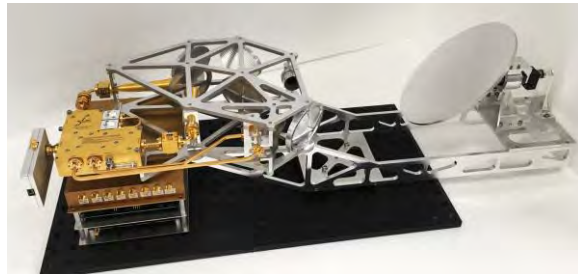


Fig 1: Integrated GAISR instrument final assembly

GAISR's medium-range W-band (95 GHz) radar will operate in a frequency-modulated continuous-wave (FMCW) mode with 1 Watt of transmit power to achieve high sensitivity detection of the range and velocity distribution of 0.1-10 mm sized ice and dust particles released by jets and plumes. The radar's primary aperture also functions as an antenna for two passive heterodyne spectrometer channels at 270 and 560 GHz for detecting the abundance, temperature, and velocity of water vapor and its isotopes (including HDO), as well other major cometary volatiles such as CO, NH₃, CH₃OH. GAISR has

been designed with a priority placed on low mass and power needs, to facilitate its infusion in future planetary missions. This is accomplished by leveraging recent innovations in W-band signal generation using low power silicon integrated circuits, state-of-the art III-V semiconductor devices for signal amplification and detection, and compact quasi-optical duplexing. A new signal processing algorithm for FMCW Doppler radar detection out to the maximum range ambiguity limit has also been developed. GAISR's performance testing has begun, and this poster will summarize its proven capabilities and plans for validation in relevant environments.

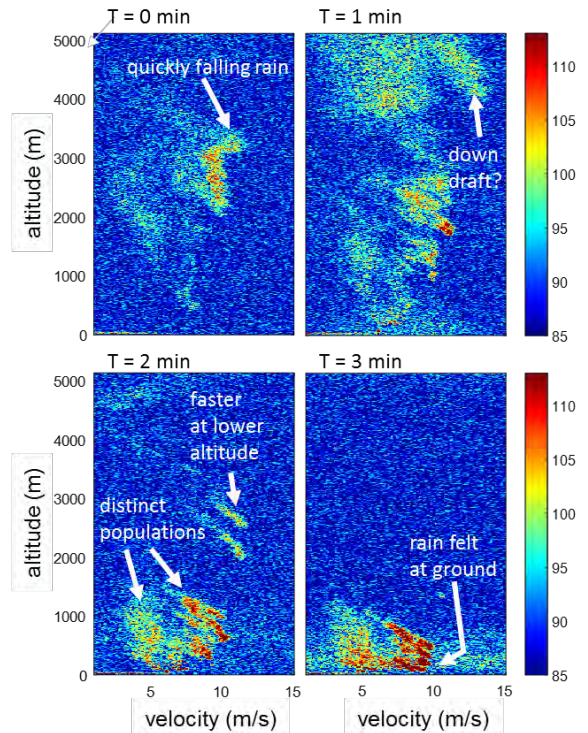


Fig. 2: GAISR's 95 GHz Doppler radar detection of rain out to 5 km.

JUICE Instrumentation and Mission Status

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The “JUperiter ICy moons Explorer” (JUICE), is the first large mission in the ESA Cosmic Vision 2015-2025 programme. The mission is planned on being launched on 20 May 2022 by an Ariane 5 ECA and will perform a 7 ½ year cruise toward Jupiter based on an Earth-Venus-Earth-Mars-Earth gravitational assist sequence. The Jupiter orbit insertion will occur in October 2029, and will be followed by a tour of the Jupiter system with repetitive flybys of Calisto, Ganymede and Europa until an insertion into a Ganymede orbit in September 2032. This paper gives a brief summary of the mission and describes the current status of the spacecraft and payload development. Key challenges of the instrumentation development will be described.

The Mercury Imaging X-ray Spectrometer

Adrian Martindale, *Space Research Centre, Department of Physics and Astronomy, University of Leicester, UK.*

BepiColombo, the ESA/JAXA mission due for launch in October 2018, will carry two spacecraft whose payloads are designed for comprehensive exploration of the planet Mercury and its environment. The Mercury Imaging X-ray Spectrometer (MIXS) is designed to measure X-ray emissions from the surface of the planet. On the day side, surface materials decay back to their ground state after excitation by solar coronal X-rays, revealing the planet's elemental composition by remote sensing the characteristic X-ray fluorescence photons that are released in this process. Additionally, interactions of charged particles with the surface produce characteristic X-ray emission and observations of unlit regions will reveal the structure and dynamics of magnetospheric currents impacting with Mercury.

I will describe the scientific goals and novel design of MIXS in the context of our existing knowledge - as derived from observations undertaken by NASA's MESSENGER spacecraft.

Proving the Capability of Remote Raman Spectroscopy Instrumentation for Planetary Missions Through the Detection of Various Molecules with Astro-biological Significance at 120 meters.

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1. Introduction

The search for life within our Solar System is a key goal for NASA. The NASA Decadal Survey outlines indicators of past or present life, such as Carbon (C), Nitrogen (N), Oxygen (O), Sulfur (S), Phosphorous (P), Hydrogen (H), proteins and organics. A widely used technique in laboratories for analyzing compounds of these elements is Raman Spectroscopy. It is used to identify molecules by characterizing the interaction of monochromatic photons and the vibrational modes of the molecules. Raman emission from vibrational interactions are very narrow; the lack of overlap simplifies detection and quantification of important molecules. [1] While not *all* molecules have Raman active vibrational modes, we are able to detect most molecules with astro-biological significance such as water, amino acids, organics, sulfur, sulfates, nitrogen (N_2), nitrates, oxygen (O_2), oxides, and hydrous minerals. [2-4].

While Raman spectroscopy is commonly thought of as a laboratory technique, we have developed the capability to detect Raman spectra at ranges of over 100 meters with a compact system compatible for planetary landers or rovers. We present the detection of liquid water, water ice, CO_2 ice, hydrous minerals, organics and amino acids using a compact portable remote Raman spectroscopy system at a range of approximately 120 meters in daylight conditions. Being able to detect materials with high astro-biological significance at remote distances is directly applicable to Mars missions as well as those in the future, including the asteroid belt and towards the outer solar system moons such as Europa.

1.1 System Set-up

The compact portable remote Raman system used in this experiment is shown in Figure 1. It consists of a frequency-doubled mini Nd:YAG pulsed (532 nm, 10

ns pulse width, 20 mJ/pulse, 20Hz) laser source, a 3 inch diameter telescope, a compact spectrograph with dimensions 10 cm (length) x 8.2 cm (width) x 5.2 cm (height) and a mini-ICCD detector [5]. The spectra in this experiment were collected in daylight conditions from approximately 122 m using the intensified CCD in gated mode with 70 ns gate width. A short gate width helps in minimizing the background signal from daylight and mineral phosphorescence.

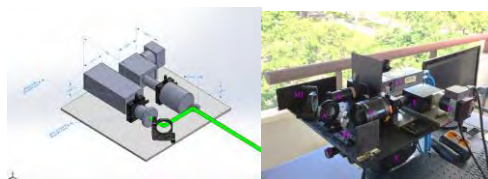


Figure 1: A compact remote Raman system developed at the University of Hawaii. Left: CAD rendering of system. Right: Photo of system at UH during experiment.

2. Results

The compact remote Raman spectroscopy system covers the entire Raman spectral range ($\sim 100\text{ cm}^{-1}$ to 4500 cm^{-1}) with 12 cm^{-1} spectral resolution. Figure 2 shows remote Raman spectra of water, water ice, and CO_2 ice with an integration time of 30 seconds, from a distance of 122 meters. Three measurements of the same sample are overlaid to show repeatability of the system. Since the frequency of a vibrational mode is inversely proportional to square root of the reduced mass of the atoms involved in the molecular vibration, molecules containing hydrogen show Raman peaks in the high frequency region ($2400\text{--}4500\text{ cm}^{-1}$). Thus, water, organics, and biological material are easily identified with Raman spectroscopy. Water gives a very strong Raman signal in the $3100\text{--}3600\text{ cm}^{-1}$ spectral region, and we can distinguish water in various forms using Raman spectroscopy. Liquid water, which may occur as inclusions in rocks formed in hydrothermal systems, show strong, broad Raman bands at 3278 and

3450 cm^{-1} that are the symmetric (ν_1) and antisymmetric stretching (ν_3) vibrational modes of the water molecule, respectively. Ice can be distinguished from liquid water by the presence of a sharper band at 3150 cm^{-1} . The Raman spectra of carbon dioxide ice has a characteristic doublet at 1284 cm^{-1} and 1392 cm^{-1} , as shown in Figure 2. Our remote Raman spectra also show the presence of atmospheric gases, oxygen at 1556 cm^{-1} and nitrogen at 2331 cm^{-1} from the interaction of the laser and the atmosphere as the laser travels to and from the targets. [2,6]

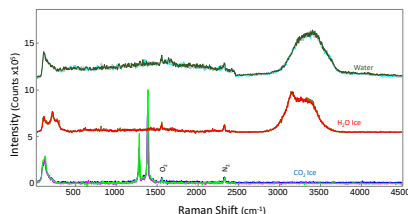


Figure 2: Remote Raman detection of water, ice and dry ice from 122 m with 30s integration time.

Remote Raman spectra of gypsum ($\text{CaSO}_4 \cdot 7\text{H}_2\text{O}$) and epsomite ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$), are shown in Figure 3; each was acquired with 30 seconds integration time, from 122 meters. Three spectra for each sample are overlaid to show repeatability. Various functional groups such as nitrates, sulfates, phosphates and carbonates can be easily identified in their Raman spectra through the location of vibrational modes of the functional group. The sulfate ion gives a strong Raman band near 1000 cm^{-1} . The symmetric stretching vibrations (ν_1) in the sulfate ions, SO_4 , is observed at 1008 cm^{-1} in Gypsum and at 984 cm^{-1} in Epsom. The position of the sulfate band can also determine the hydration state of the chemical [7]. The chemically bonded water molecules in Gypsum are observed at 3405 cm^{-1} and 3493 cm^{-1} .

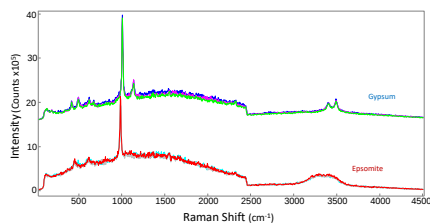


Figure 3: Remote Raman detection of gypsum and epsomite from 122 m with 30s integration time

Figure 4 shows remote Raman spectrum of an amino acid Beta-Alanine (98% purity) [8] from a distance of 122 m with 30 seconds integration time. The biological nature of the amino acid is confirmed by the presence of biofluorescence background and presence of Raman

bands in the CH stretching region (2800-3100 cm^{-1}). We have previously reported remote Raman spectra of various amino acids and DNA bases using this system from 10 meters distance [9].

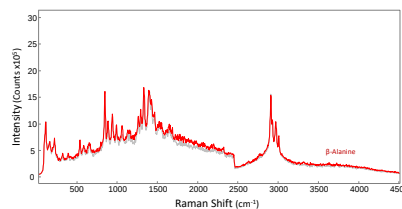


Figure 4: Remote Raman detection of beta alanine from 122 m with 30s integration time

3. Summary

Using a compact portable remote Raman spectroscopy system, we were able to successfully demonstrate the detection of elements and minerals of high astro-biological significance from a distance of 122 meters during daylight conditions. This work is relevant to planetary science as longer range Raman detection can heighten the capabilities of a rover or lander to analyze targets in a planetary setting. Targets which are difficult to reach by wheels or drills such as cliffs, deep trenches, and lakes, are more readily available for analysis concerning the presence of water and organics using a system capable of long distance Raman detection.

Acknowledgments

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The Submillimeter Wave Instrument on JUICE

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Abstract

The Submillimeter Wave Instrument (SWI) is part of the payload of ESA's L1 mission JUICE (JUpiter ICy moons Explorer). It sounds the middle atmosphere of Jupiter and the exospheres and surfaces of the Galilean satellites with a 290 mm telescope, movable in azimuth and elevation using two heterodyne spectrometers covering the frequency ranges of 530 to 625 GHz and 1080 to 1275 GHz. The heterodyne receivers with tunable solid-state local oscillators and subharmonically pumped mixers are passively cooled. The performance of the receivers has been steadily improved during the last 2-3 years. Presently the receiver temperatures are about 1100 and 2000 K DSB (600 and 1200 GHz respectively). The intermediate frequency output of 3.5 to 8.5 GHz is analyzed by two real-time spectrometer backends consisting of broadband autocorrelators, high resolution multi-channel Chirp Transform Spectrometers and continuum channels. In order to fulfill the very stringent mass limitations of the JUICE payload, the structure of the Telescope and Receiver Unit (TRU) is made of AlBeMet 162. The instrument is now in the phase between PDR and CDR and the design has mostly been completed. This presentation will address the science objectives, the technology challenges and recent break-throughs, the instrument hardware development status and future plans until the launch of the JUICE mission. Finally potential applications of SWI-like instruments for other explorations of the solar system will be addressed.

Solar Intensity X-ray and particle Spectrometer (SIXS)

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SIXS is one of the scientific instruments on board the BepiColombo Mercury Planetary Orbiter (MPO). SIXS monitors the solar X-rays and energetic particles. It consists of two independent sub-systems packaged into a single sensor unit:

- **SIXS-X:** Three High-Purity Silicon PIN X-ray detectors measure direct solar X-rays in the energy range of 1-20 keV. Their combined field of view covers about $\frac{1}{4}$ of the whole sky.
- **SIXS-P:** A closely packed arrangement of five Si PIN detectors and a CsI(Tl) scintillator working in coincidence measures electrons in the energy range of 0.1-3 MeV and protons in the energy range of 1-30 MeV with rough angular resolution over a field of view that covers about $\frac{1}{2}$ of the whole sky.

SIXS will monitor solar X-rays, energetic electrons, and protons in a wide field of view. The main scientific objective of these measurements is to provide data necessary for the analysis of simultaneous X-ray measurements of Mercury's surface by the MIXS (Mercury Imaging X-ray Spectrometer) instrument. The measurements by SIXS are also used for investigations of the solar corona and the magnetosphere of Mercury.

LIBS and Raman Spectroscopy for Planetary in-situ Exploration

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Abstract

Laser-induced breakdown spectroscopy (LIBS) and Raman spectroscopy have a high potential for in-situ geochemical and mineralogical analyses for planetary exploration, in particular when combined. These techniques provide complementary information about elemental composition (LIBS) and molecular structure (Raman). The techniques are highly synergetic and can be integrated into one instrument, sharing hardware components such as the laser, spectrometer, and focus mechanisms. The DLR is currently developing a compact and light-weight instrument for application in in-situ robotic exploration of planets, moons, or asteroids where one or both techniques will be applied.

1. Introduction

In general there are strong constraints on the mass, size, and power consumption for rover and lander payload instruments. In the context of the search for habitable environments and extraterrestrial life (a major goal of both NASA and ESA), mission payload instruments for in-situ planetary research must have the ability to do geochemical and mineralogical analyses and, ideally, also be able to detect organics. A combined LIBS and Raman instrument is both capable of realizing these scientific goals as well as meeting the requirements for a compact and lightweight analytical tool. Both techniques are active and use the radiation of a laser to provoke different physical phenomena, leading to specific spectra from a sample of interest and giving complementary information. But also each technique on its own provides interesting insights of extraterrestrial surfaces and an instrument with mass ~1 kg would be a very useful scientific payload for a small pioneering spacecraft.

1.1 LIBS

LIBS is an atomic emission spectroscopy method which permits rapid multi-elemental analysis and relies on ablating material from the sample by focusing a pulsed laser onto its surface. This produces an expanding plasma of atoms, ions, and electrons. The plasma emission is collected and analyzed spectroscopically. With the ChemCam instrument on NASA's Mars Science Laboratory (MSL) mission the LIBS technique was for the first time applied to study the surface of an extraterrestrial body [1-3]. It was shown that LIBS is suitable even with a low-energy laser in ultra-high vacuum environments [4].

1.2 Raman spectroscopy

Raman spectroscopy is a nondestructive method. It is sensitive to the vibrational and rotational states of molecules, and thus can be used for the determination of the mineralogy of geological samples as well as identifying organic and biogenic samples. A small fraction of monochromatic light is inelastically scattered by the substance under investigation, thereby shifting the energy of these exciting photons. The shift relative to the excitation energy is characteristic for the material and provides a unique fingerprint by which the sample material can be identified and its molecular structure determined. Mineralogical, inorganic, organic, or biological compounds can be deduced from Raman spectra by comparing the fingerprint like spectra with a database.

Raman spectrometers are under development for future planetary missions: the RLS instrument for the ESA-Roskosmos ExoMars mission (2020) and a UV Raman spectrometer (SHERLOC) [5] as well as Raman combined with LIBS in the SuperCam instrument [6] both for NASA's Mars 2020 rover. A miniaturized Raman instrument was proposed for instance in [7].

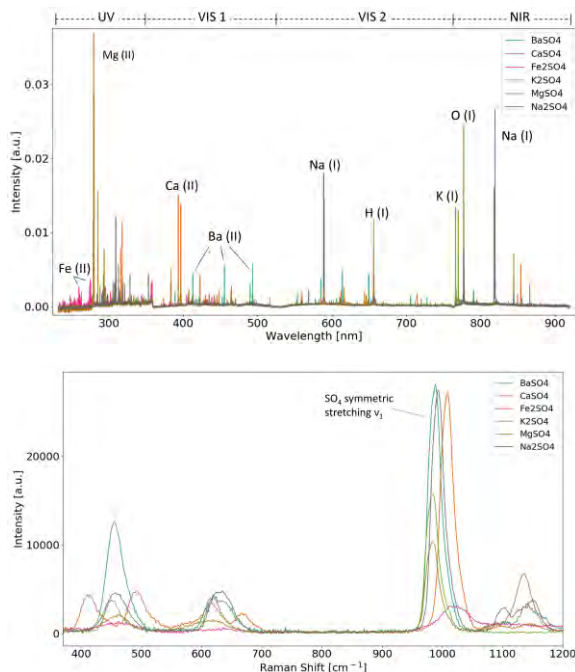


Figure 1, top: LIBS spectra of different sulfates measured with a miniaturized set-up with four spectrometers. Bottom: Raman spectra of sulfates obtained with a miniaturized set-up.

2. Combination of LIBS and Raman spectroscopy

Advantages of combined LIBS and Raman spectroscopy include the capability for high sensitivity mineralogical characterization, high spatial resolution, simultaneous multi-element detection of elements (major, minor, and trace), fast analysis with no sample preparation, and the removal of dust layers. Rock penetration by laser ablation gives information about subsurface material, while with Raman spectroscopy organic compounds can be identified – indicators for possible current or distinct life in subsurface areas. Both techniques have a short acquisition time (seconds/minutes). Furthermore, microscopic as well as remote measurements up to several meters are possible. Remote LIBS-Raman instruments for Mars in particular have been proposed in a number of studies [e.g., 8-10]. The first combined LIBS-Raman instrument SuperCam for remote analysis is currently being developed for NASA's Mars 2020 mission [6].

While the stand-off remote configuration in distances of up to 7 m needs a telescopic system and a powerful laser, a close-up setup with a much more lightweight and compact instrument can also be applied. Such a miniaturized system can be as light as ~3 kg in total, including the laser, the spectrometer and the electronics. As a compact and lightweight instrument it can be mounted on a rover or robotic arm together with complementary instrumentation like a camera. One promising configuration would be a separation of the instrument into a module housed inside the lander or rover (including the optical spectrometer, pump laser and electronics) and one or several optical heads connected with optical fibres. The latter could be part of a robotic arm or get attached, for instance, to the locomotion system of a small rover or crawler.

3. Miniaturization Approach

We report here on the current state of development of a miniaturized LIBS/Raman instrument at DLR. A set-up comprising prototype components is used to test and evaluate different configurations of the instrument for different mission scenarios and their objective. Special focus is on the detection of volatiles and the applicability in vacuum such as encountered on atmosphereless bodies which poses a particular challenge to LIBS.

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Cameras for navigation and 3D modelling on planetary exploration missions

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Abstract

Mobile exploration systems on planetary missions require technologies for navigation and 3D modelling. Both are mandatory prerequisites for any interaction in an unknown environment. Since GNSS will not be available, technical alternatives have to be developed. In this paper, a sensor system will be introduced which contains a stereo camera and an inertial measurement unit. Data of both sensors are fused to achieve a precise 6DoF ego-pose in real-time. Image data can be processed to depth maps optionally. Trajectories and 3D models are essential for path planning of the robots, for identification of scientific regions of interest and for spatial referencing of the scientific payload data. The paper gives an overview about the technology, the approaches for navigation and 3D modelling, an end-to-end software simulator and a planet like test campaign.

1. Integrated Positioning System

DLR has developed an Integrated Positioning System (IPS) during the last 10 years. It copies the human perception system by applying a stereo camera and an inertial measurement unit (IMU). Additional sensors providing position or orientation data or their derivatives can be considered. No external reference data (e.g. GPS) are needed, but they will be used if they are available.

1.1 Navigation

By detecting features in images (e.g. natural landmarks such as edges and corners) and tracking them over time, an ego-trajectory can be estimated. These data will be fused with rotational and translational measurements of an IMU which delivers angle velocities and accelerations. After integrating these signals once and twice, respectively, the position and orientation ('pose' refers to both quantities) can be obtained building a 6DoF

trajectory. IMU offsets and noise lead to drifts and random walk, which can disturb the 6DoF information very fast (within seconds) if not compensated. By the combination of camera data and IMU data, the influence of the drifts can be minimized. Applying such a technology requires detailed knowledge about the system and its components. Sensor data need an unambiguous assignment w.r.t. time, a precise calibration (e.g. interior orientation of the camera) and information about the spatial co-registration between different sensors [1]. IPS can deliver a real-time 3D position with an accuracy of $2\text{m}/\sqrt{\text{hr}}$, e.g. 1m after 15min.

1.2 Environment modelling

IPS's stereo data can be used to retrieve a 3-dimensional model of the environment. The choice of the matching algorithm, which is the most demanding software part w.r.t processing time, will depend on the mission and the resources being available. A broad spectrum of algorithms has been implemented (sum of absolute differences, normalized cross correlation [2], semi-global matching [3]). The coordinates of the matched pixels and the knowledge about camera calibration can be used to estimate the 3D position of each matched object point resulting in a (dense) point cloud.

1.3 Simulation

The evaluation of an IPS like system (software and hardware) is demanding, since generating ground truth data is very difficult. DLR decided to develop an end-to-end simulator to estimate the performance of IPS, to evaluate data processing steps and to optimize system parameters. The simulator generates image data and IMU data in a virtual world based on a defined trajectory and based on known auxiliary data (e.g. calibration). These data will be processed with IPS's standard processing chain. The resulting 6DoF information will be compared with the ideal trajectory. By doing this, single sources of errors can

be detected and sensitivity analyses can be performed (e.g. how does the system behave if the cameras will have low SNR).

1.4 Validation and test

IPS was developed for several terrestrial and space applications in commercial and research projects. For mining applications IPS was further developed to an industrial product in cooperation with partners, for this application the development cycle from an idea (technology readiness level TRL1) to a product (TRL 9) was completed [4]. In order to test IPS in an environment being more relevant for planetary science, in 2018 a geological measurement campaign at island Vulcano [5] was joined. The images and results shown below are taken at this campaign.



Figure 1: IPS experiments on island Vulcano

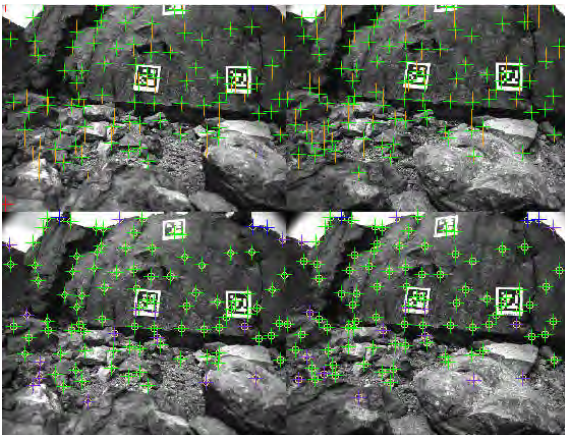


Figure 2: IPS stereo images with detected/ tracked features

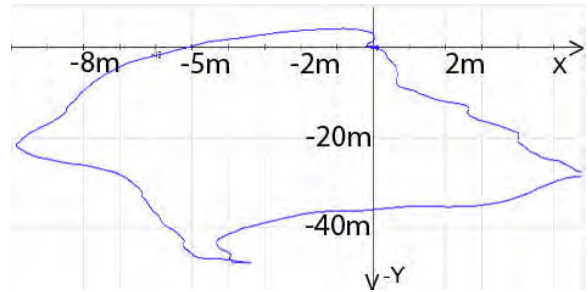


Figure 3: Trajectory derived from IPS data

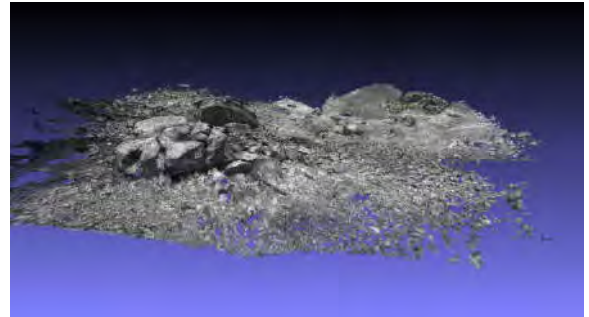


Figure 4: 3D model derived from stereo data

2. Summary and Conclusions

DLR developed a positioning system which determines its ego motion on camera data and IMU data. DLR is able to offer this technology for space applications, e.g. exploration or on-orbit servicing. Team's experience, the transfer to an industrial product and the availability of a simulator enables DLR to apply for a space mission.

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Design, development and performances of the JANUS camera onboard JUICE

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JANUS (Jovis, Amorum ac Natorum Undique Scrutator) is the visible camera selected for the ESA JUICE mission to the Jupiter system. Resources constraints, S/C characteristics, mission design, environment and the great variability of observing conditions for several targets put stringent constraints on instrument design. In addition to the usual requirements for a planetary mission, the problem of mass, power limitation, high radiation doses and electrons and proton fluxes are particularly stringent due to the long-lasting cruise phase and operations at large distance from the Sun and in a high radiation environment.

The JANUS design shall cope with a wide range of targets, from Jupiter rings and lightning, exosphere, atmosphere, to solid satellite surfaces, all to be observed in several colours and narrow-band filters. The instrument design is based on a single optical channel, which was fine-tuned to cover all scientific objectives based on low to high-resolution imaging. A catadioptric telescope with excellent optical quality is coupled with a radiation-hard CMOS image detector array, avoiding any scanning mechanism.

In this contribution the JANUS design, development status and expected performances are discussed.

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A proposed next-generation Laser for Polar Altimetry on Mars (LaPAIMa)

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Abstract

We are carrying out an instrument study for a next-generation laser altimeter on a spacecraft orbiting Mars. The science focus is on the geodetic control and morphology of polar ice caps of the planet. We discuss the scientific goals and the technical requirements of the instrument as well as possible spacecraft orbits and mission scenarios.

1. Introduction

The main technical goal of a laser altimeter is to measure and track the distance between an orbiting spacecraft and the surface with high precision (cm-level), which may ultimately lead to a planetary topographical model, orbital coverage permitting. The measurement principle is straightforward: The laser sends a short pulse of photons to the surface, which will be scattered back and detected by the receiver (typically, a photo diode). The high-precision electronics measure the timing of the outgoing and incoming pulse and thus the pulse's time of flight. The distance between the instrument and the surface can be calculated for every shot, given the speed of light. Besides the range, the altimeter may give information about the albedo (at the specific wavelength of the laser), the surface roughness and slopes, as well as about time-varying characteristics such as surface deformation due to tides or albedo variations due to snow cover.

Laser altimeters have become a standard scientific instrument aboard planetary missions. Examples are the Mercury Laser Altimeter (MLA) aboard MESSENGER (2011-2015) [1] and the laser altimeters in Lunar orbits (e.g. LOLA [2]). The only laser altimeter operating at Mars was the Mars Orbiter Laser Altimeter (MOLA) aboard the Mars Global Surveyor (MGS) spacecraft [3]. The instrument operated in active remote sensing mode from 1999 until 2001 and changed to passive albedo

mapping mode thereafter. Due to saturation of its receiver in high albedo regions, MOLA could not map albedo and roughness at the polar ice caps; hence, Mars' polar areas remain to be explored.

2. Science Case

We study a laser altimeter mainly focusing on the polar areas of Mars. The science goals are:

- Map regional and local morphology of north and south polar areas, including the complex structures of layered deposits.
- Measure volumes of seasonal deposits and sublimation of snow in polar areas to improve models of the global CO₂ cycle.
- Carry out multi-temporal mapping of polar scarps to study dynamics of ice sheets: identify rock falls and avalanche events.
- Measure cloud heights, opacity of the Martian atmosphere and the vertical distribution of dust, in particular, during dust storms.
- Map intricate rotation function of the planet, in particular variations in length-of-day for interpretations in terms of moment of inertia and comparisons with observed seasonal mass-redistributions.
- Improve global coordinate knowledge, in particular, to improve control in high-sloped terrains.

3. Technical Description

The laser altimeter will follow ideas realized on the ICESat-2 laser altimeter ATLAS (Advanced Topographical Laser Altimeter System). As in the case of ATLAS, we aim at high (kHz) shot rate and multiple parallel altimeter tracks from one orbit pass, using a beam splitter [4]. Shot statistics will be used to measure surface albedo and roughness.

The main components of the instrument will be the laser and its electronics (transmitter), the detector, (APD, avalanche photo diode) or a photomultiplier and its optics and mechanisms (receiver). The data processing unit and the power module will be shared with the spacecraft. The laser shall operate at a wavelength of 532 nm, and a shot frequency of 10 kHz. The typical pulse width is < 1.5 ns and energy is around 1 mJ per shot (Table 1).

We are expecting newly developed noise cancellation technique onboard to improve signal detection and range acquisition [5] The main ground data processing tasks include the formation of super-resolution gridded topographic models, benefitting from multiple overlap of laser spots, laser cross-track analysis (or self-registration [6]) to solve for spacecraft orbit corrections and Mars rotation model parameters. Finally, we aim at change detection methods to identify time-varying features.

4. Orbit

We will analyse orbit options and the impact on the spot size and distance of the shots across and along track and the resulting overall coverage and science performance. As a baseline, we assume a circular polar orbit an altitude of 400 km. However, also missions in low-Mars orbit (supported by electric propulsion [7]) and elliptical orbits will be investigated.

We aim at a laser spot size of < 40 m on the ground. Adopting the ground speed of 3.5 km/s and a 10 kHz shot rate, we may achieve a shot spacing of 35 cm on the ground. (For reference: the nominal MOLA spot size was approx. 160 m and shot spacing was 200 m).

Table 1: Main technical parameters

Parameter	Value
Wavelength	532 nm
Shot frequency	10 kHz
Pulse width	< 1.5 ns
Energy per shot	1 mJ

5. Summary and Conclusions

We have initiated a study for the laser altimeter LaPAIMa (Laser for Polar Altimetry on Mars) aboard a Mars orbiter to improve geodetic control and study the morphology of the icy polar caps of the planet.

The experiment will follow-up on the accomplishments of the previous laser altimeter MOLA and may greatly improve our understanding of the intricate dynamics of polar areas on Mars.

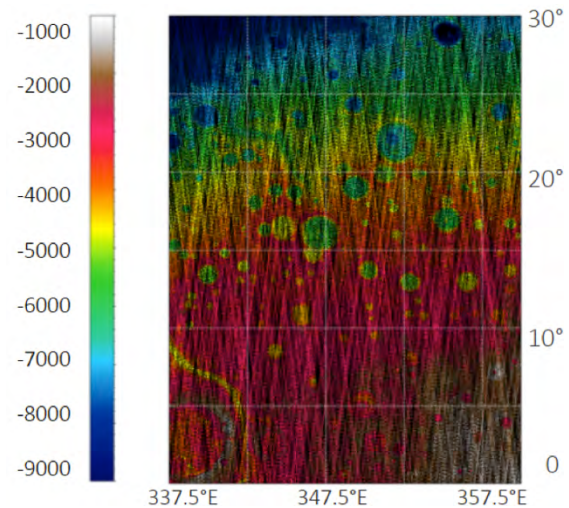


Figure 1: Example of MOLA altimetric profiles near the Mars equator. Heights in meters refer to the Mars reference sphere (radius: 3379 km).

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Abstract:

The dual satellite mission BepiColombo targeted for planet Mercury is scheduled to be launched in October 2018. It will carry dual fluxgate magnetometers to the innermost planet in order to map the planetary magnetic field as well as its interaction with the intense and dynamic solar wind there. Mercury possesses a very weak and very axisymmetric magnetic field. Both features are still to be explained by dynamo theory with more in-situ global magnetic field data from the BepiColombo mission. In addition, as Mercury is not able to maintain a stable atmosphere it also lacks a significant ionosphere. Therefore the tiny and dynamic magnetosphere couples directly to the planetary surface (if not even further downwards). In consequence, magnetospheric currents as well as heavy ions may directly interact with the planet. Also, varying magnetic fields drive induction currents in the interior. The full implications of these direct couplings are to be investigated. An introduction to the working principle of the magnetometer, to the data analysis challenges as well as to the scientific goals will be presented.

UNVEILING MERCURY'S MYSTERIES WITH BEPICOLOMBO

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Abstract

BepiColombo is a joint project between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). The Mission consists of two orbiters, the Mercury Planetary Orbiter (MPO) and the Mercury Magnetospheric Orbiter (MIO). The mission scenario foresees a launch of both spacecraft with an ARIANE V in late October 2018 and an arrival at Mercury in 2025. From their dedicated orbits the two spacecraft will be studying the planet and its environment.

1. Introduction

NASA's MESSENGER [2] mission has fundamentally changed our view of the innermost planet. Mercury is in many ways a very different planet from what we were expecting. Now BepiColombo [1] has to follow up on answering the fundamental questions that MESSENGER raised and go beyond.

1.1 Science goals:

The scientific payload of both spacecraft will provide the detailed information necessary to understand Mercury and its magnetospheric environment and to find clues to the origin and evolution of a planet close to its parent star. The internal composition of Mercury has become one of the most important question during the last decades. Mercury is the smallest planet in our solar system and for that reason scientist assumed that the planet must have cooled down faster than the bigger planets after its formation some 4.5 billion years ago. This assumption could not stand after the NASA mission Mariner 10 found in 1974 that Mercury seems to have an Earth like magnetic dipole field although much weaker. NASA MESSENGER mission confirmed the magnet field measurements of Mariner 10 but postulated that the centre of this field is shifted to the north by about 400 km.

MESSENGER found further that a lot of volcanism took place in Mercury's history and more than expected volatile elements on the surface. The source of all these phenomena lies in the interior and is still not fully understood.

BepiColombo has a comprehensive suite of instrument onboard to study and understand the interior of Mercury, its composition, geophysics, atmosphere, magnetosphere and evolution history. In addition, the MPO orbiter has a very sophisticated radio science suite with a dual band up and downlink Radio link and an accelerometer compensating external (solar radiation pressure) and internal noise (movements of e.g. solar panel and high gain antenna) to measure the internal structure. These measurements will be complemented by several instruments onboard the second orbiter MIO like a magnetometer, particle and plasma wave sensor measurements, a sodium imager and a dust monitor.

The BepiColombo mission will provide a rare opportunity to collect multi-point measurements in a planetary environment. This will be particularly important at Mercury because of short temporal and spatial scales in the Mercury's environment. The foreseen orbits of the MPO and MIO will allow close encounters of the two spacecrafts throughout the mission. Such intervals are very important for the inter-calibration of similar instruments on the two spacecraft.

1.2 BepiColombo's way to Mercury

BepiColombo will be launched on an Ariane 5 from Europe's Spaceport in Kourou, French Guiana. It will use the gravity of Earth, Venus and Mercury, in combination with the thrust provided by the Mercury Transfer Module (MTM) to reach Mercury. The MTM is powered by a solar electric propulsion system. Upon arrival after a cruise phase of a bit more than seven years, the MTM will be jettisoned and chemical propulsion of the MPO will be used to inject both spacecraft into their dedicated polar orbits. The Japanese MIO will be released first, after

which an additional thrust phase will insert the European MPO into its final orbit. The choice of the orbit is mainly a compromise between the ambitious science objectives and thermal load onto the spacecraft.

The baselined lifetime of the MPO and MIO in Mercury orbit is 1 Earth year (about 4 Mercury years, or 2 Mercury solar days). A mission extension by another Earth year is optional. Orbit maintenance is not required over the planned operational MPO and MIO lifetime.

The BepiColombo mission will complement and follow up the work of NASA's MESSENGER mission by providing a highly accurate and comprehensive set of observations of Mercury.

The mission has been named in honour of Giuseppe (Bepi) Colombo (1920–1984), who was a brilliant Italian mathematician, who made many contributions to planetary research, celestial mechanics, including the development of new space flight concepts.

1.3 Spacecraft operation challenges

The choice of the orbit is mainly a compromise between science objectives and thermal load onto the spacecraft. Science objectives prefer a global, high-resolution coverage, implying a polar orbit at low altitude. However, the closer the spacecraft will be over the Mercury surface, the larger the received thermal flux from the planet infra-red and albedo, which will come on top of the Sun's flux of about 10 Solar constants. A full high-resolution mapping coverage of the planet is one of the main scientific objectives. For that reason a polar orbit at 400km times 1500km with a 2.3 hour period was selected with its apoherm on the equator on the sun side when Mercury is in its perihelion. This is a subsolar point where the thermal load on the spacecraft is at its maximum. Half a Mercury year later, at aphelion, the subsolar point occurs when the spacecraft is at its minimum distance to the planet. A highly eccentric orbit at 590x11640 km was selected for the MMO, co-planar with the MPO orbit, in order to allow mapping of the magnetic field and study the magnetosphere, covering the bow-shock, the magneto-tail and the magnetopause.

The frequency of contacts between the Ground Operations and the spacecraft (passes) will vary between once per week in cruise to daily during

routine science operations at Mercury. The duration of a ground station pass is constrained by the Earth rotation to typically 7 to 12 hours. Given the long periods in which the spacecraft remains out of contact from ground, and considering the long signal propagation delays (up to 13 minutes one-way), operations during all mission phases will be carried out with an 'off-line' approach, with limited possibility of quasi-real-time intervention from ground only in selected critical phases and in major contingency cases.

2. Summary and Conclusions

BepiColombo is a joint project between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA) and consist of two orbiter. Together, the scientific payload of both spacecraft will provide the detailed information necessary to understand Mercury and its magnetospheric environment and to find clues to the origin and evolution of a planet close to its parent star.

In this talk we provide an overview about the BepiColombo mission its technical challenges, its science instruments, its operation and the current status a few weeks before launch in late October 2018.

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Application of pneumatics to drilling, excavation, sample acquisition and transfer on planetary missions

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Abstract

Pneumatic systems are used extensively on Earth to move drill cuttings out of the hole during a drilling process as well as to transfer powders. Pneumatic systems have been well characterized and both fundamental equations as well as empirical data can be used to size tanks, valves, and hose diameters.

The main benefit of pneumatics is that they are extremely well suited for handling unstructured material such as powder or rock cuttings. In the most basic design, sample to be transported is placed on one side of a tube and some time later it appears on the other side of a tube with the help of a carrier gas. Even sticky material can be moved with increased gas pressures and flow rates.

For almost twenty years, Honeybee Robotics has been developing pneumatic-based systems for planetary surface missions requiring samples for the in-situ instruments, sample return, or for deployment of instruments at some depth [1-3]. Reduced gravity flights (lunar g) in vacuum conditions (5 torr) revealed that with 1 gram of gas at 60 kPa pressure, up to 6000 g of gas can be lofted at high speeds [3]. This high mass ratio efficiency is mainly attributed to vacuum, with secondary effect being lower gravity.

Although specific applications require some technology development to increase the so-called Technology Readiness Level (TRL), the heart of the pneumatics (valves, tanks, pressure regulators etc.) is at much higher TRL, since it is used in liquid propulsion (Helium pressurant) and cold gas propulsion systems. Pneumatic systems could either use dedicated gas canisters or the system could tap into residual Helium pressurant used in a lander's propulsion system.

Here we present several applications of pneumatic based systems in drilling and sample handling.

1. Pneumatic Drilling

The pneumatic drilling mechanism is normally mounted on the lander's leg (**Figure 1**). It spools out a carbon fiber boom, in a manner similar to a steel tape measure. The boom (as small as 2 cm in diameter), once spooled out, has a lenticular cross-section and a cone at its leading end. The cone

advances by discharging gas jets at its tip and blowing away regolith clumps, while the actuator of the boom pushes the cone down.

This compact, rapid-penetration drill can be used to deploy a heat flow probe, seismic sensor, to anchor a Corner Cube Reflector and to acquire samples from great depths [4, 5]. Even rocklets as large as 8 mm (or larger) in diameter can be easily excavated.

The drill can be designed for shallow (1 m) and deep (5 m or greater) penetration with minimal impact to the system mass. Since the actual drilling stem is a collapsible tube that is initially spooled on a reel, to penetrate deeper, only the tube length has to increase. The pneumatic drill applied to a Heat Flow Probe (Figure 2) has been tested in compacted (1.9 g/cc) NU-LHT-2M lunar soil simulant in a vacuum chamber. It achieved penetration rate of 1 m/min and demonstrated that the system can re-start at any depth.

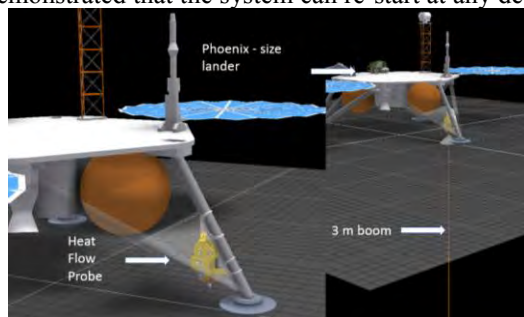


Figure 1. Pneumatic drill used to deploy heat flow probe. [4, 5]



Figure 2. Heat flow probe penetrated compacted NU-LHT-2M simulant at 1 m/min. [4, 5]

2. PlanetVac

PlanetVac [6] is a pneumatic sampling system connected to a foot of a lander, capable of capturing regolith sample upon landing (Figure 3). Terrestrial vacuum cleaners create vacuum suction at the back end, while PlanetVac creates high pressure at the front end. The end result, significant pressure differential, is the same in both cases. As such, PlanetVac captures and delivers a sample to a required location in seconds. System redundancy is achieved via numbers – each footpad has a PlanetVac system. Hence, if one footpad is above the ground, the remaining two or three (depending on lander configuration) will be touching the ground. This technology addresses the critical capability needed by in-situ missions and sample return missions.

PlanetVac has been tested in vacuum chamber onboard a prototype lander as well as on actual rocket (Figure 4). During the former tests 20 grams of sample was captured using 2 milligrams of compressed gas. During the latter tests at 1 ATM pressure, over 300 grams of sample was captured each time.

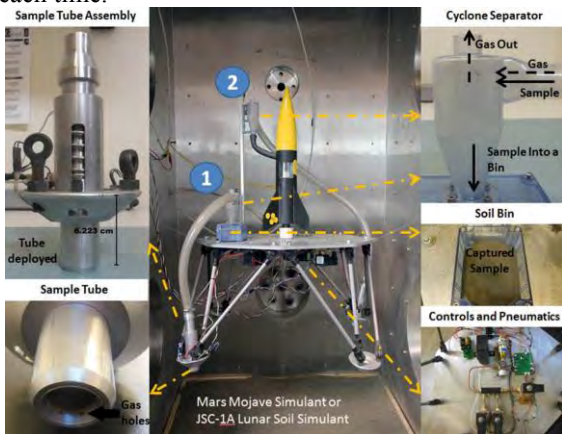


Figure 3. PlanetVac testing in vacuum chamber.

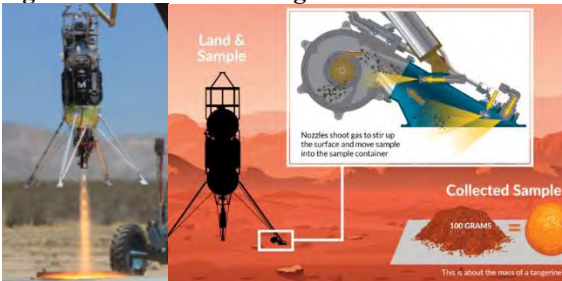


Figure 4. PlanetVac tests on Masten's rocket.

3. Pneumatic transfer from a drill

In most cases sample transfer relies on gravity. This is not a problem if sample is non-cohesive or if

sample is kept cold to prevent volatiles from subliming away. However, if sample needs to be kept cold or is cohesive, the use of pneumatics would be desirable. By exerting strong pneumatic control and avoiding reliance on gravity, sensitivity to cohesion is minimized. Additionally, fast pneumatic transfer prevents thermal alteration or sublimation of a sample. The pneumatic transfer is especially convenient if sample acquisition drill is placed further away from instruments, since it's easy to route tubes around other hardware.

We developed and tested numerous pneumatic-based sample delivery drills [7]. These included systems for Venus [8] and Titan [9] (with significant atmosphere) and for Mars [7], the Moon [4], and comets [10]. In most applications samples are delivered to instruments or sample cups, eliminating sample handling hardware altogether.

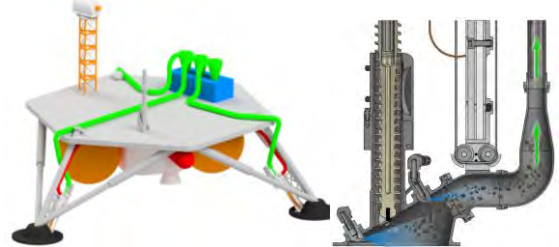


Figure 5. Example of pneumatic transfer system from a drill deployed along a leg.

Acknowledgements

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Millimeter-wave Chirality Spectrometer (ChiralSpec)

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Abstract

In this presentation we report the status of the development of a chirality spectrometer (ChiralSpec). ChiralSpec has a TRL of 2 and is a millimeter-wave 3-axis resonator spectrometer operated in two modes: (1) survey mode, with the instrument acting as a traditional millimeter-wave spectrometer to characterize chemical composition and quantify abundance of planetary samples; (2) chirality detection mode. The survey mode gives sum abundance of enantiomeric pair while the chirality detection mode gives their difference abundance. Combining sum and difference abundances give absolute abundance for individual enantiomer. ChiralSpec is applicable to in-situ missions to Enceladus, Europa, Titan, Mars, and any bodies where amino acids/organic compounds are in gas phase or can be brought into gas phase.

1. Introduction

Life detection through chemical analysis requires nearly unambiguous detection of specific chemical biosignatures. The US 2013 Planetary Decadal Survey [1] recommends “*a detailed characterization of organics to search for signatures of biological origin, such as molecules with a preferred chirality or unusual patterns of molecular weights*” as a key future investigation of life detection (page 240). While mass spectrometry has often been proposed for measuring the abundance patterns of molecular weights, it lacks the chirality detection capability required for chiral analyses of chiral molecules such as amino acids, and cannot uniquely identify specific structure-based isomers such as fatty acids.

ChiralSpec incorporates an innovative microwave three-wave mixing technology for chirality detection and the cavity resonance technology for sensitivity enhancement. It is designed to use millimeter wavelengths (75-205 GHz) where there is a path for instrument miniaturization.

Currently, ChiralSpec’s TRL is 2. The basic principles for ChiralSpec’s three-wave mixing technology have been formulated in literature [2]. In the 2–18 GHz frequency region, chirality detection experiments with full-scale data sets have been successfully performed [3–5]. Therefore, this technology is at TRL 3 in the 2–18 GHz region. However, in the 75–205 GHz region of ChiralSpec, the technology is at TRL 2 because the technology concept and application in planetary and astrobiology science instruments is formulated, with theoretical estimations of the performance; the technology feasibility of chiral detection has not been proven in the 75–205 GHz. The TRL of ChiralSpec’s three-wave mixing technology is expected to fully reach 3 in April 2019 through successful Laboratory chirality detection of propylene oxide.

The cavity resonance technique is routinely employed in cm-wave and longer wavelength regions with sensitivity enhancement factors of four orders of magnitude. But this technique has not been experimentally demonstrated in the full 75-205 GHz region. Therefore, ChiralSpec’s cavity resonance technology is at TRL 2. We will advance the TRL to 3 with a success criterion that signals of propylene oxide are ~1000 times enhanced.

ChiralSpec is a noninvasive technique and has two advantages in addition to chirality detection: (a) It has an extraordinary capability of distinguishing isomers; (b) it can analyze the mixture of gases without separating them first. ChiralSpec is a simple instrument and does not require derivatization, in contrast to the two existing chirality detection technologies, the gas chromatography mass spectrometer (GC-MS) and the capillary electrophoresis based laser induced fluorescence (CE-LIF). GC-MS was implemented in Rosetta/COSAC and Curiosity/SAM. CE-LIF is under development with focus on amino and carboxylic acids. Its measurements involve liquid extraction of samples, fluorescent tagging, introduction of two chiral recognition agents.

2. Figures

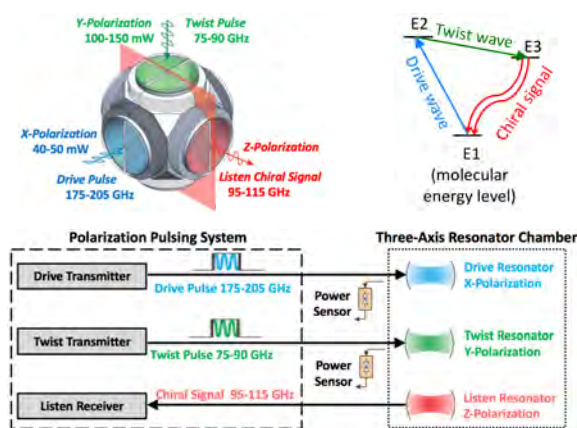


Figure 1: Under chirality detection mode, ChiralSpec generates a time-domain chiral signal via exciting targeted species with two excitation pulses. Chiral signal is detected at a third frequency with both intensity and phase. The phases of enantiomeric pair are different by 180 degrees. It is this phase difference allowing enantiomer differentiation. Due to the 180° phase difference, the chiral signal is a net signal from the enantiomer, i.e., it gives difference abundance of enantiomeric pair.

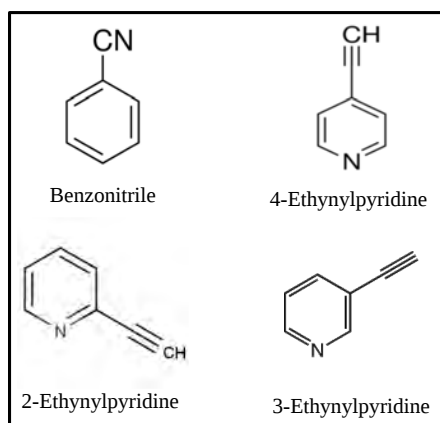


Figure 2: ChiralSpec compliments mass spectrometer for distinguishing isomers of the same molecular weight: shown above are example isomers distinguishable by ChiralSpec: C_7H_5N (103 Da) is interesting to Titan with questions such as where is N inserted to? What is arrangement of atoms? Additional isomeric molecules distinguishable by ChiralSpec include chiral nitriles/amines/alcohols, PAHs, small organics (cyclopropane vs. propene; methylcarbamic acids vs. glycine).

3. Summary and Conclusions

ChiralSpec is a simple in-situ instrument that can detect chirality and perform chemical analysis. In addition to its chirality detection capability, ChiralSpec has extraordinary capability of distinguishing isomers that pose challenges to mass spectrometers.

ChiralSpec addresses planetary science objectives related to the history of organics, the existence of habitats beyond Earth, and search for life, by looking for biosignature patterns: chirality of amino acids; double-bond position in fatty acids; amino acids distribution, etc.

Acknowledgements

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The Jovian Dynamics and Composition Analyzer – Performance and design challenges

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Abstract

The Jovian Dynamics and Composition analyzer (JDC) on board of the European Space Agencies (ESA) JUICE spacecraft, as part of the Particle Environment Package (PEP), will explore the Jovian system with its harsh radiation environment. To survive in such an environment and fulfill its scientific mission a new instrument design was needed. Main challenges were shielding against penetrating radiation to reduce the Total Ionisation Dose (TID) on the electronics and the peak instantaneous flux, which is decreasing the Signal-to-Noise-Ratio (SNR) and degrading the detectors faster.

1. Introduction

As one of the instrument packages on board of ESAs JUper ICy moons Explorer (JUICE) the Particle Environment Package (PEP)[1] was chosen. The Jovian Dynamics and Composition analyzer (JDC) is one of six sensors in PEP. JDC is developed and built by the Swedish Institute for Space Physics (IRF). The sensor can measure mass resolved positive and negative ions as well as electrons in an energy range between 1eV/q-40keV/q in a hemispheric field of view.

2. Scientific objectives

The two scientific goals of JDC are to study the Jovian magnetodisc and the properties of the four Galilean moons. The study of the Jovian magnetodisc includes its creation, structure and maintenance. The second objective includes the interaction of the Jovian magnetosphere with the Galilean moons; the study of the exospheric composition of Ganymede, Callisto and Europa; the study of the precipitating plasma populations on the surfaces of Ganymede and Callisto; and the study of Ganymede's interior with help of the 3D continuous plasma moment measurement.

Table 1: JDC performance

Parameter	Performance
Particle species	(i+),(i-),(e)
Energy range	1 eV/q – 40 keV/q
Energy resolution	12%
Mass range	1 amu -70 amu
Mass resolution	2-3 (D-channel) ≥ 20 (C-channel)
Field of view	90° x 180° (< 25keV/q) <90° x 180° (> 25keV/q)
Angular resolution	5.5° x 19.5°
Time resolution	2D per 0.8s 3D per 11s
G – Factor	Total: 8.0E-3 cm ² sreV/eV Pixel: 5.6E-4 cm ² sreV/eV

3. Instrument Design

Figure 1 shows a cross section of JDC. A particle enters the instrument through the elevation scanning system. The elevation scanning system divides the hemispheric Field of View (FoV) in 12 elevation slices by adjusting the electric field between its electrodes. For particles with energies of less than 25keV/q complete hemispheric coverage is obtained. The FoV is additionally divided in 16 azimuthal sectors obtained from the 16 start surfaces, resulting in an angular resolution of 5.5°x19.5°. For particles between 25keV/q and 40keV/q, the angular coverage is reduced. Particles are then filtered in a compact wedge-shaped electrostatic analyzer[2] according to their energy per charge. Particles then hit one of the 16 start surfaces, which are mounted at the entrance of a linear electric field reflectron. At the start surface incoming particles will collide and may change their charge state while producing a secondary electron that is detected by one of 16 start Channel Electron Multipliers (CEM). The detected signal is used to start

a time-of-flight measurement. In the reflectron, the particle will follow different paths depending on their charge state. Neutral and negative particles will directly travel to the stop Micro Channel Plate (MCP) and a time-of-flight stop signal is picked up on the ring-shaped dynamics (D)-anode. Positive ions will be reflected to the stop surface where a secondary electron is created. An anti-coincidence Solid State Detector (SSD) guards the stop surface against penetrating particles. The stop electron is subsequently detected by the stop MCP with a signal collected from the centrally placed composition (C)-anode.

sensitive electronics boards, a housing layer of aluminum and with the sensitive detectors in the center of the instrument. Despite the optimized shielding, all detectors will still be affected by penetrating radiation resulting in continuous detections of unwanted events, accelerating the aging of the detector. Nevertheless, the time-of-flight coincidence system combined with the anti-coincidence guard of the stop-surface guarantees a sufficient SNR during all mission phases. To guarantee detector performance throughout the mission, the detectors are subject to a lifetime test to verify that the expected amount of events can be detected without significant degradation.

In the lifetime test, an ultraviolet light source is used to produce photoelectrons that are then guided into the entrance of the detector eventually hitting the detector. The resulting pulse collected from the anode is counted and its size measured. The count rates obtained are then converted to total extracted charge. For a detector to qualify the total extracted charge must be higher including a margin than the simulated total extracted charge obtained for different mission scenarios.

5. Status

The assembly of JDC technological model is currently ongoing and expected to be finished with first light end of 2018.

Acknowledgements

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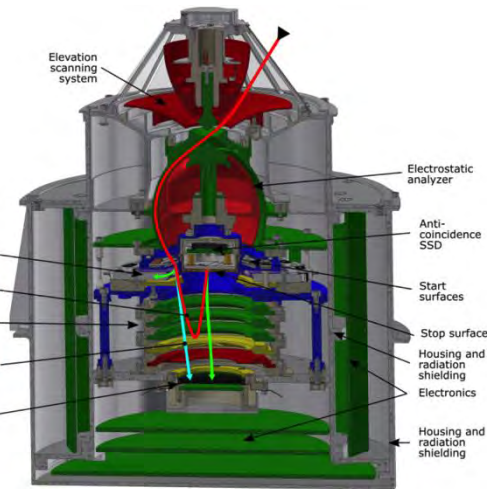


Figure 1: Cross-sectional view of JDC with typical particle trajectories indicated

4. Design Challenges

Any spacecraft entering the Jupiter system is bombarded by beta radiation (electrons). The flux of this is in the range of 10^{10} electrons $\cdot$ s $^{-1}$ $\cdot$ m $^{-2}$ [3]. These electrons can penetrate instrument walls and directly hit the detectors. They also interact with instrument structures and create secondary radiation, mostly in form of gamma photons. Extensive radiation transport simulations have been performed with the radiation transport tool GRAS[4] to reduce both electron and gamma photon created noise. The electronics also need to be protected against TID and Single Event Effects (SEE), but primary design driver has been the reduction of radiation-induced noise on the detectors. This has resulted in a design with a mixture of High-Z and Low-Z materials and where the electronics is used as further protection for the detectors: The outer hull is made out of a tungsten alloy followed by the less

The Miniature Ion Precipitation Analyzer (MIPA)

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Abstract

The Miniature Ion Precipitation Analyzer (MIPA)[1] is one of four sensors of the SERENA[2] instrument package (Search for Exosphere Refilling and Emitted Neutral Abundances) on the Bepi Colombo Mercury Planetary Orbiter (BC-MPO). MIPA will measure the solar wind and solar wind ions precipitating onto and possibly reflecting from the Hermean surface. MIPA is designed to directly "look" at the Sun while in orbit around Mercury. The intense solar radiation at Mercury posed the main design challenge for this instrument.

1. Introduction

The Miniature Ion Precipitation Analyzer (MIPA) is a lightweight ion mass analyzer based on the Solar Wind Monitor (SWIM)[1] instrument flown on the Indian Chandrayaan-1 mission to the Moon. MIPA is a single pixel instrument that obtains near hemispheric coverage using an electrostatic deflection system. Energy analysis is done in a 127° long segment of a cylindrical electrostatic analyzer. A subsequent surface interaction based time-of-flight section allows for particle velocity measurement and, combined with the known setting of the electrostatic analyzer, for mass determination. Two ceramic channel electron multipliers are used to detect secondary electrons from both the start and the stop surfaces of the time-of-flight section. Front-end electronics with a time-to-digital converter, event buffer memory, digital control logic, and a high voltage system complete the sensor. The System Control Unit (SCU) of SERENA interfaces MIPA via a 2Mbps data link and provides data processing, telemetry formatting and also power. The main design changes relative to its ancestor SWIM, included a reduced geometric factor to accommodate for the higher solar win flux at Mercury and a changed entrance system to be able to withstand direct exposure to the sunlight at Mercury. Table 1 summarizes the MIPA performance values.

Table 1: MIPA performance.

Parameter	Value
Size (mm x mm x mm):	232 x 105 x 93
Mass (g)	582
Power (W)	1.8
Energy range (eV/q)	10 - 15000
Resolved mass groups (amu/q)	1, 2, 4, 8, 16, 32
Energy resolution ($\Delta E/E$)	6.7%
Field of View:	2π
Number of angular pixels	24 (48)
Number of energy steps	96 (48)
Integration time per step (ms)	7.81
Full energy-direction scan (s)	20
Geometric factor ($\text{cm}^2 \text{sr eV/eV}$)	1×10^{-5}

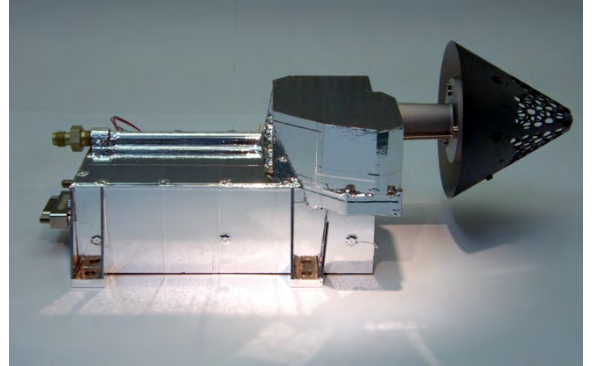


Figure 1: MIPA flight model. The conical part on the right is the entrance system.

2. Looking at the Sun

The large solar constant of up to 14kW/m² at perihelion drives the thermal design of MIPA and especially of its entrance system to avoid excessive heat flux into the instrument, and, through the instruments mounting, to the spacecraft. A conical shape with holes to allow ions to enter was chosen for the entrance system (Figure 1). The conical shape combined with an Acktar Black based coating with an α/ϵ ratio <1 optimizes radiative cooling. The conical section with the electrostatic deflection

system is connected to the remaining sensor by a titanium tube providing thermal isolation and geometric factor reduction. It also allows the remaining sensor to be located below the high temperature multi layer insulation (HT-MLI). While the MIPA sensor and electronics can be kept below 80°C, temperatures in the entrance system reach up to 450°C.

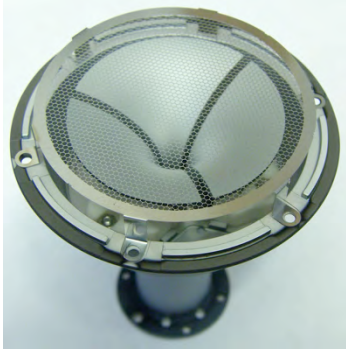


Figure 2: MIPA deflection system with top conical section removed (from [1]).

The deflection system inside of the cone houses three high voltage electrodes on potentials up to 4kV to achieve near hemispheric coverage (Figure 2). To guarantee performance, both solar illumination testing (Figure 3) and high temperature testing with high voltages under vacuum conditions was performed. Large temperature swings, e.g. when entering Mercury's shadow required a carefully temperature compensated mechanical design.



Figure 3: Solar balance testing of the MIPA entrance system. Illumination is from the right side. The white surface represents the HT-MLI.

3. Ion optical consequences

The conical shape of the entrance system with holes for particles to enter results in an unusual angular response of MIPA: Each viewing direction setting has in its angular response the hole pattern of the entrance cone superimposed. However, even modest plasma ion temperatures will almost completely blur out this pattern. The whole pattern in the cone is also advantageously used: "Missing" holes correspond to directions that are obstructed by spacecraft structures. This actively prevents detection of signals originating from solar wind reflecting off these structures.

4. Summary and Conclusions

The MIPA sensor is specially optimized for the conditions in the Hermean environment. Unusual design solutions like the conical entrance system enable it to cope with the thermal environment and to "look" directly at the Sun while keeping its performance. MIPA is currently waiting for launch on Bepi Colombo later this year.

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LITMS planetary mass spectrometer overview

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Abstract

The Mars Organic Molecule Analyzer (MOMA) [1] is a key instrument on the Pasteur Payload of the ExoMars rover, which will operate in the harsh Martian environment. MOMA is a lightweight (~12 kg), low power (75 W in average), dual-source, mass spectrometer-based instrument, utilizing a miniaturized linear ion trap (LIT). This instrument enables two modes of operation: i) pyrolysis/gas chromatography mass spectrometry (pyr/GC-MS); and, ii) laser desorption/ionization mass spectrometry (LDI-MS) at ambient Mars pressures. Advances in technology since MOMA have been incorporated in LITMS to enhance the LIT instrument performance. A discussion will be presented below.

1. Introduction

A highly compact linear ion trap mass spectrometer (LITMS) [2] has been built and is characterized under NASA's MatISSE program as an incrementally advanced follow up on the MOMA linear ion trap. LITMS (see Figure 1), is capable of examining organic and inorganic sample composition by integrating both Mars-ambient laser desorption and precision subsampling with pyrolysis/gas chromatography of drill cores at fine (≤ 1 mm) spatial scales and is designed to perform the in situ characterization of organics and elements in individual rock core layers and features (see Figure 2). This level of integrated analysis is critical to achieve advanced astrobiology objectives at Mars. Capabilities are dual frequency RF supply (0.7 and 1.5 MHz) for extended mass range (20-2000 Da), fast ion gating (<50 μ s) for extended dynamic range and switchable polarity on all key ion trap components to analyze negative ions. It uses a 266 nm pulsed YAG laser (250 μ J/pulse) capable of 100 Hz bursts that facilitates rapid laser energy adjustments.

2. Method of characterization

Characterization of the mass spectrometer was performed to verify its initial build quality and to optimize its functionality. Settings were verified leveraging the earlier MOMA mass spectrometer development in which functional scans were developed to establish a baseline performance on Mars. These functionals are expected to run fully automatic to check electronics components and find optimum settings for the ion source, ion trap, laser and detection system of the mass spectrometer.

3. Waveform capabilities

LITMS has been tested with additional ion manipulation waveforms as compared to MOMA. The waveforms are utilized with the dual frequency main RF to manipulate ions and can be used for isolation, selection, excitation, fragmentation (MS/MS) and ion neutral reactions inside the ion trap. Waveforms such as SWIFT waveforms, frequency sweeps, chirps have been tested and allow scan modes such as, AC frequency scans (continues or segmented), SWIFT Waveform ion isolation and linear frequency sweeps in addition to auxiliary excitation for increased mass resolution and sensitivity.

4. Negative ion mode

Negative ion mode measurements are possible with the LITMS instrument to aid in chemical identification. Figure 3 shows the trap assembly including the detection system. The detection system has an added buffer electrode to allow the dynode to operate at either voltage polarity while maintaining the channeltron at a negative voltage polarity. Careful rounding and polishing of the machined parts allows for dense packaging of high voltage components.

5. Figures

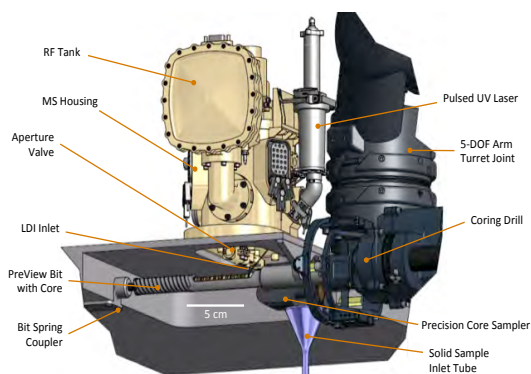


Figure 1: Overview of the LITMS mass spectrometer.

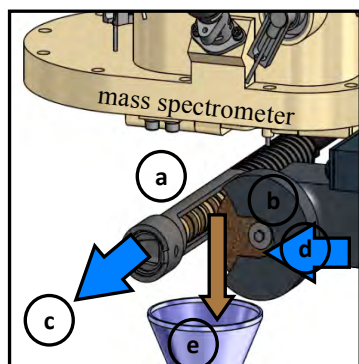


Figure 2: a) Core holder and core. b) Spin Grinding Wheel at high speed. c) Extend Grind Linear Stage and monitor preload with Load Cell. d) Cuttings deposited into SSIT and vibrated into pyrolysis oven for GCMS. e) Guidance funnel.

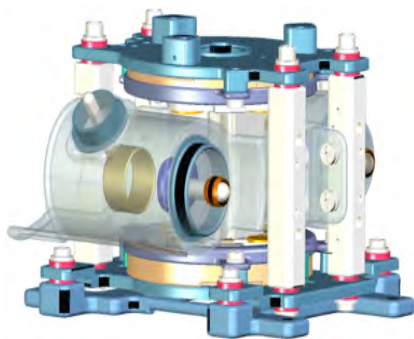


Figure 3: Detector assembly for LITMS. Size of trap assembly and detection system is about 4x4 cm.

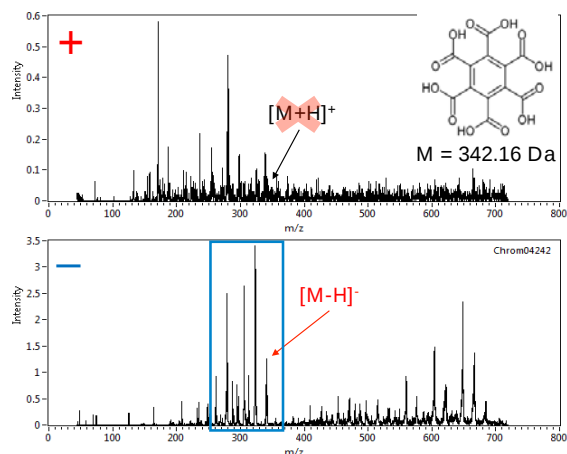


Figure 4: Positive and negative ion mode measurement of mellitic acid recorded with LITMS.

6. Summary and Conclusions

Performance measurements confirmed agreement with desired requirements. MOMA breadboard electronics and flight-like software integration with LITMS has been completed and negative ion mode electronics have been incorporated and tested for functionality. The extended mass range capability is confirmed at 2000 amu but can be extended further by adjusting operational parameters up to 3000 amu. A field campaign with the complete instrument is planned for the Atacama dessert in Chile to examine autonomous operation aboard a rover.

Acknowledgements

Funding has been provided by the Maturation of Instruments for Solar System Exploration (MatISSE) Program (Program Executive: Janice Buckner, NASA/HQ).

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A Microchannel Thermalization Inlet to Eliminate Impact-Induced Molecular Fragmentation in Closed-Source Mass Spectrometers

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1. Introduction

The closed-source Ion and Neutral Mass Spectrometer (INMS) onboard the Cassini-Huygens spacecraft was used to characterize molecules in tenuous atmospheres [1]. A typical closed source consists of a spherical antechamber with a circular opening in the direction of spacecraft motion. Neutral molecules enter this antechamber with a high relative velocity due to the difference between the spacecraft velocity and the ambient atmosphere. Neutrals are then thermalized through multiple collisions with the chamber walls prior to ionization and mass analysis (Figure 1). These collisions with the chamber walls cause a transfer of the initial translational energy of the neutrals into vibrational energy. In many cases, this vibrational excitation can have enough energy to cause a chemical change in the neutrals, such as isomerization or fragmentation [2]. However, even understanding the impact fragmentation pathways may not predict all atmospheric components because only stable, volatile fragments can be observed, and different organic compounds can give very similar fragmentation products. Fragmentation caused by the ionization process, typically electron ionization, acts in addition to impact fragmentation and together make it very challenging to know the native chemical composition of planetary exospheres [3]. We are developing a hardware solution to the problem of impact-induced molecular fragmentation in closed ion sources: a microchannel thermalization inlet to replace the conventional, spherical antechamber.

1.1. Thermalization Inlet Design

The new thermalization inlet is a plate consisting of multiple microchannels. Incoming neutral molecules undergo an initial, high-kinetic-energy impact within a microchannel and then further collide along the walls of the channel (Figure 1). The number of collisions is the same as in the conventional antechamber. However, the narrow channels allow thermalizing collisions to occur on a timescale of tens to hundreds of nanoseconds rather than tens to

hundreds of microseconds, energetically relaxing the neutrals faster than in a conventional antechamber and faster than the dissociative lifetimes of many of the vibrationally excited neutrals. In our design, the channels must be long enough for thermalization to take place, and the channel width will govern how quickly thermalization will happen. As such, the channel length must be around 0.5 mm and the channel width should be between 10-50 μm . The angle of impact on the channel walls does not matter, as channel materials will be rough on the size scale of the molecules sampled. Although the inlet is similar in structure to the familiar microchannel plate ion detector, the inlet is preferably made from a robust material.

2. Performance Analysis

Calculations were performed to determine both the dissociative lifetimes and thermalization timescales of representative molecules to demonstrate the new inlet design. The speed of thermalization depends on the number of collisions needed for thermalization and the speed with which these collisions take place, which is determined by geometrical factors. In addition, the ram pressure enhancement factors, which show the overall improvement in sensitivity within the closed-source portion of the instrument were also calculated for the new microchannel thermalization inlet (Figure 2). It shows an even greater improvement in sensitivity with the new inlet than was achievable in the conventional antechamber.

Our calculations show a large reduction in the time needed to thermalize neutral molecules with the new microchannel thermalization inlet (Figure 3). In addition, the fraction of molecules that survive at higher encounter velocities is significantly greater in the new inlet than in the conventional, spherical antechamber (Figure 4). For molecules of a much wider range of molecular weights, the thermalization times of the neutrals entering the new inlet are well below their corresponding dissociative lifetimes. This means that many more molecules will be able to

reach the ionization region of orbiter and flyby mass spectrometers intact due to reduced fragmentation. As such, molecules with a larger range of molecular weights can be found in ambient atmospheres on future orbiter and flyby space missions using the new microchannel thermalization inlet.

3. Figures

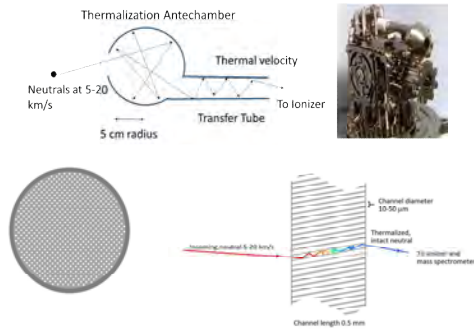


Figure 1: Comparison between the conventional antechamber (top pictures) and the new microchannel thermalization inlet (bottom pictures).

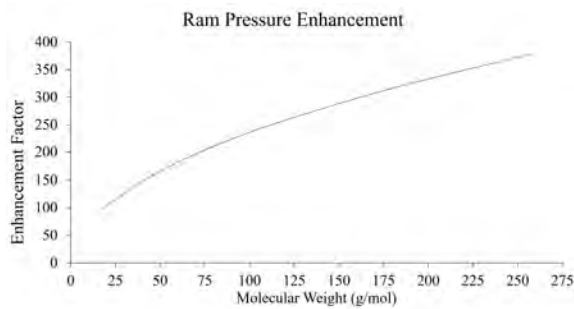


Figure 2: The ram pressure enhancement factor to sensitivity in the new microchannel thermalization inlet at different molecular weights, increasing as molecular weight increases.

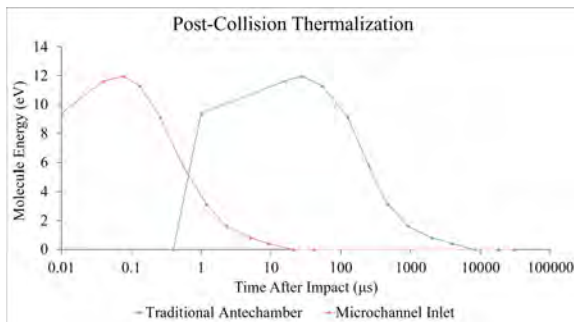


Figure 3: Comparison between the calculated thermalization times in the conventional antechamber (blue) and the microchannel thermalization inlet (orange) showing significantly reduced thermalization times with the new design.

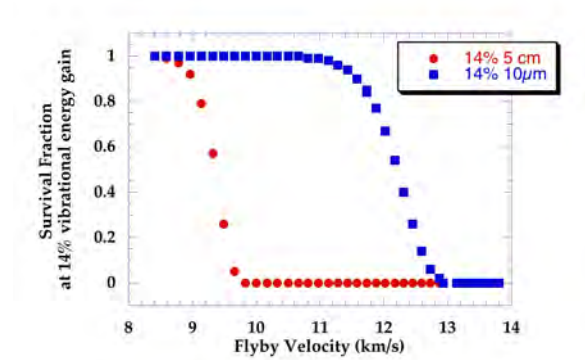


Figure 4: The fraction of neutral molecules that survive at varying encounter velocities, showing that more molecules survive at higher encounter velocities in the microchannel thermalization inlet.

4. Future Work

The new microchannel thermalization inlet is being designed and built according to the dimensions determined from preliminary calculations. Laboratory experiments are planned to verify performance and the results will be compared to those obtained from the calculations. These will demonstrate applicability for this new microchannel thermalization inlet on future orbiter and flyby space missions.

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The BepiColombo Laser Altimeter (BELA)

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Abstract

BELA, the Laser Altimeter on ESA's BepiColombo mission will be launched to Mercury in October 2018. The instrument is equipped with a Nd:YAG-Laser, operating typically at 10 Hz. The instrument is designed to acquire range measurements up to a distance of 1,050 km enabling global coverage of the planet. A unique full digitization of the returned pulse is implemented supporting albedo and surface roughness measurements on the scale of the laser footprint. The main goal of BELA is to obtain the low-degree shape and global, regional and local topography of the planet. In addition Mercury's rotation, including long-period librations will be measured and corresponding reference frames will be updated. Assuming a two-year mission (one year extension) in orbit, we aim at measurements of Mercury tides. Results from BELA will impose strong constraints on interior structure models and will improve our understanding of formation and evolution of the planet. Here we give an overview on the instrument and its expected performance at Mercury.

1. Introduction

Size, shape, and rotation constitute basic geodetic data for any planet. This is particularly true for Mercury, where the precise knowledge on the global shape and the rotational state reveals important information on the inner workings of this planet. Owing to its proximity to the Sun, its elliptical orbit and its moments of inertia, the planet is captured in a 3:2 spin-orbit coupling, a rotational resonance unique in the Solar System. On its eccentric orbit, Mercury is subjected to periodic tidal deformation.

Laser altimeter experiments are particularly suited to determine geodetic parameters of the planets from orbit and produce precise maps of topography and surface morphologies. Here we discuss the BepiColombo Laser Altimeter (BELA) [1], which will be launched to Mercury in 2018 to provide

unique information about the innermost planet of the Solar System.

2. The BepiColombo Mission

BepiColombo is a joint mission to Mercury under responsibility of the European Space Agency (ESA) and the Japan Aerospace Exploration Agency (JAXA), scheduled for launch in October 2018 and for arrival in late 2025. A nominal mission of 1 year is foreseen, with a possible 1-year extension. ESA is responsible for the overall mission design, the integration, and the launch. BepiColombo consists of two spacecraft, the Mercury Planetary Orbiter (MPO) provided by ESA and the Mercury Magnetospheric Orbiter (MMO) provided by JAXA. The two spacecraft are inserted in different orbits optimized for their respective measurements [2].

3. Instrument and Performance

BELA is designed to acquire range measurements up to a distance of 1050 km from Mercury's surface, implying that global altimetry measurements will be possible, allowing coverage of the southern Hemisphere for the first time.

The instrument is equipped with two redundant Nd:YAG-Laser, capable of generating 50 mJ laser pulses at 1064 nm wavelength. The laser can be operated from 1 to 10 Hz. The receiver is a Cassegrain-type telescope with an aperture of 20 cm and for detection of the reflected laser pulses an APD (Avalanche Photo Diode) is used. As is the case for other instruments on board the MPO, precautions against the intense solar radiation have to be taken. During orbital operation phases BELA needs an open nadir orientated aperture. Therefore, the instrument is designed to protect the laser and the telescope from high solar radiation and planetary infrared fluxes in order to keep the temperatures within the acceptable range. The Transmitter Baffle Unit is used to protect the inner side of the transmitter from direct sunlight, to reflect the incoming sunlight and to block direct IR flux from the planet. It is composed of a front ring

located on the outer side of the spacecraft, therefore exposed to the highest radiation. The front ring is well insulated from the baffle and prevents the front section of this component from being struck directly by solar radiation, keeping the temperature of the baffle sufficiently low. The baffle is a Stavroudis type and consists of nine vanes. To protect the baffle and the rest of the unit from radiation a gold coated titanium foil has been implemented. Contrary to the sunlight, the planetary IR radiation cannot be reflected by the baffle, as the aperture is always nadir orientated. Therefore a sapphire filter has been implemented which provides a narrow bandpass for the laser beam at 1064 nm, while blocking all other wavelengths mainly by reflection. Remaining straylight shall be absorbed by the Straylight and anti-contamination Protection Unit so that the heat flux to the Laser Head Box (LHB) is minimized. The "heart" of the transmitter side is the LHB. It contains a Nd:YAG laser emitting a wavelength of 1064 nm. The laser is pumped longitudinally having the advantage over conventional side-pumped lasers that the absorption path length can be longer making the laser less sensitive to temperature variations of the pump diodes. Two electronic boxes are located behind the laser: the Laser Electronics Unit houses the electronics for the laser. The Electronics Laser Unit (ELU) provides the instrument power supply, is the controller on instrument level including laser firing, and is the instrument-spacecraft power and data interface. Inside the ELU, the electronic boards are mounted inside metal frames, including the Power Converter Modules, the Data Processing Modules, and the Range Finder Module (RFM) which hosts the digital pulse fitting algorithm. BELA is a bistatic instrument, with the receiver side having a similar setup as the transmitter. The receiver telescope is mounted together with the transmitter on the Baseplate Unit (BPU). Behind the telescope is the focal plane assembly which hosts the APD. The signal is transmitted via the Analog Electronics Unit to the Range Finder Module, where the laser pulses are processed and transmitted as science data to the Data Processing Module.

The transmitted and returned pulses are sampled with a bin-size of 12.5 ns which would correspond to a range error of 1.875 m in this so-called 'coarse-detection' analysis. However, due to filter-matching algorithms within the range finder electronics, a sub-sampling accuracy smaller than 1.5 ns corresponding to a range resolution of about 20 cm can be achieved under optimum conditions. Depending on altitude and slope, the instrument error stays below 80 cm

even for steep slopes of 40° and measurements at a spacecraft altitude of 1,050 km [3]. However, due to additional error sources the range accuracy increases to several meters for typical measurements. The most important error contributions are (a) the pointing uncertainties of the instrument due to remaining small misalignment of the transmitter with respect to the spacecraft reference frame (corresponding to an estimated range error of ~ 9.5 m on Mercury's surface taking slope statistics on Mercury into account), (b) radial orbit errors (~ 1.8 m), (c) guidance errors due to the uncertainty in spacecraft position that translates into an additional angle with respect to the nadir axis (included in (a)), and (d) uncertainties in the known rotational state of Mercury (~ 2 m). Mainly due to uncertainties in the pointing, the along-track and cross-track errors at the surface are about 40 m at 400 km altitude and 120 m at 1200 km altitude. Concepts to calibrate the pointing of the transmitter with respect to the camera pointing, which will reduce the pointing errors significantly, are currently under study. Other error sources are related to electronics and clock drifts. Assuming uncorrelated errors, the overall range measurement error is less than 10 m assuming a certain roughness on different spatial scales (12.1 m at 200 m baseline and 6.4 m at 50m baseline) and an albedo of 0.19 [3].

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MEMS based gas chromatograph for molecular characterization of planetary environments

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Abstract

We present here the current state in the development of a gas chromatograph based on micro electro-mechanical system components. This development is specifically devoted to use this technology in future space probes for characterizing *in situ* the molecular composition of the explored environments, with the objective to limit the resources required for performing the analyses. We managed to develop a first prototype in the laboratory, demonstrating the technical feasibility of this ambitious project. We present here the results obtained on all the discrete components composing the gas chromatograph, and the first results of the integrated system.

1. Introduction

The characterization of the chemical composition of extraterrestrial environments is generally one among the primary objectives of planetary exploration probes. The nature and structure of molecules are important information to better understand the physical and chemical properties of solar system bodies, the way and conditions they were formed from the presolar nebula, and also how the prebiotic chemistry can have been initiated on Earth and possibly elsewhere in the solar system. With this aim, gas chromatography is used since the NASA Viking missions to Mars in the 1970's for the separation and analysis of volatile molecules. Often coupled to mass spectrometry which gives direct structural information about the molecules, gas chromatography has been demonstrated to be an efficient instrumentation to characterize the composition of various environments in the solar system as the Titan's atmosphere (Huygens probe) [1] or Mars regolith (Curiosity) [2]. Even if this instrumentation is very performant, it is a significant resource consumer in space probes, preventing from using it in small or low mass space probes payloads for instance.

With the aim to limit the amount of resources consumed, to meet the more and more constrained requirements for a use in space probes, but keeping a high analytical efficiency, our team develops a gas chromatograph based on the emerging micro-electromechanical system technology applied to microfluidic systems. We present here the results of the first step of this development that led to the building of the discreet individual components of the system and of a first functional prototype.

2. Individual MEMS components

The system is composed of three key individual components: an injector, a column and a detector. All are based on silicon microchip technologies.

The injector is a thermal desorption system allowing to trap the compounds to sample at low temperature and release them by fast heating the chip. The column (Figure 1) is a channel carved in the silicon. The walls are coated with a stationary phase allowing to separate all the compounds present in the mixture sample. Finally, we used two different physical MEMS detectors: a thermal conductivity detector (TCD), commonly used in space instruments, and a NEMS which is from a brand-new technology. The use of these two detectors simultaneously is of high interest as they are non-destructive towards the sample, and they are complementary in term of sensitivity, the TCD being sensitive to the low mass components, and the NEMS to the high mass components. This allows to reach limits of detection of the order of the nanomole for any volatile compound analysed. When performing an analysis, the components are flowed with helium to carry the sample and each GC component is independently thermally regulated. Figure 2 shows an example of separation achieved with a MEMS column tested with a laboratory GC set-up. All the components were characterized this way in order to test their intrinsic performances before coupling them together to build a whole GC. Each component showed very promising performances allowing to build and test a first prototype. After this first development, we estimate

to have reached a technical readiness level of about 4 and we started a second step in our development program to reach the next level.

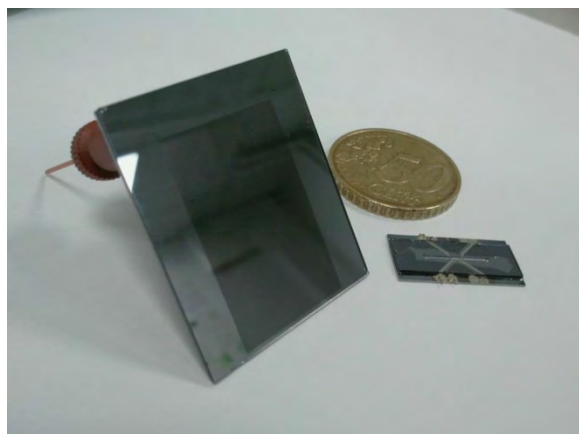


Figure 1: Column MEMS used in this study

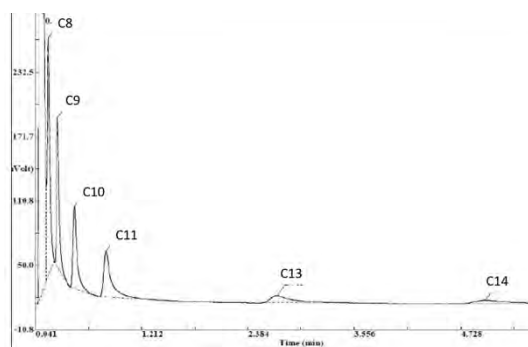


Figure 2: Chromatogram obtained with a column MEMS injecting a mixture of linear hydrocarbons. The labels give the number of carbon atoms in the chain

3. Summary and Conclusions

MEMS gas chromatography is a promising technique to be used in future space probes. Unlikely to the regular version of this instrumentation, MEMS GC could be used in small probes with very limited resources, to provide information about the molecular composition of the explored environments. The current development presented here shows a TRL 5 could be reached in a near future meaning this technology could be used in space probes developed in the next decade.

Acknowledgements

This development is funded by the French space agency (CNES) R&T program.

We thank ESIEE engineering school for supplying the columns chips and the TCDs, and the APIX company for supplying the NEMS detector and the injector chips. They are both technological partners of this project.

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Spectral Imaging System Simulation: Preparations for the ExoMars 2020 Rover PanCam Wide Angle Cameras

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Abstract

We present the status of a spectral imaging system simulation software package, developed for preparations for quantitative analysis of images from the PanCam instrument for the ExoMars 2020 Rover. The simulation has been expanded to be adaptable to a range of camera architectures, including emulator instruments and imaging systems of past and present Mars landers and rovers. We demonstrate the application of the simulation for problems involving optimisation of image capture and processing algorithms.

1. Introduction

PanCam [1] is a mast-mounted imaging system for the ExoMars 2020 rover [2], for panoramic VNIR imaging. The objectives of PanCam relate to geological context, operations planning, and atmospheric science, achieved by means of a stereo pair of wide angle cameras (WACs), enabling 3D scene reconstructions of local morphology, with a multispectral filter suite for composition studies of the surface and atmosphere. A third camera (HRC), provides high-resolution colour images of textural detail, from a vantage point between the WAC pair. Studies relating to the material composition of scenes rely upon the reconstruction of surface reflectance and atmospheric transmission functions. However, the mapping of reflectance/transmission functions to specific material abundances is an underconstrained problem for the multispectral data acquired by PanCam. To understand the capabilities and limitations of the system, the forward transfer function between spectral features of reflectance/transmission and raw (noisy) image data is required. We describe on-going development of a simulation of the transfer function of the PanCam Wide Angle Cameras (WACs) [3], and how this can be used as a tool for predicting the ability of PanCam

to capture spectral features of interest. We also demonstrate how the simulation can be used to validate and refine the algorithms and parameters involved in image acquisition and post-processing.

2. Simulating Image Capture

The transfer function of a camera system maps the spectral radiance of a scene to a digital image, according to a number of intrinsic properties of the architecture, and a small number of user-controlled and environmental parameters. Multiple subsystems are involved, including lens and filter elements, the detector substrate, and electronics. The transfer function is not constant across all pixels in the detector array, and this can be characterised by statistical distributions of intrinsic properties. Software simulation allows for these components to be modelled and these properties to be contained, such that the complete transfer function can be computed and applied to test input signals (synthetic scenes), in a time and cost efficient manner. This has been demonstrated in the literature for consumer digital cameras [e.g. 4], and in the context of remote sensing, for orbital spectral imaging systems [e.g. 5].

The input to the system is a pre-rendered, or measured, hyperspectral radiometric image cube, describing the light of a given scene passing through the aperture in radiometric units. The system is modelled in two parts. First, an optics function transforms the directional distribution of light entering the aperture into an image at the focal plane, subject to the selected filter. A detector function then transforms this irradiance image into the digital image output, subject to the exposure settings and detector temperature, and electronic components. The model is described in mathematical detail in [3]. Previously, the simulation was fixed to the PanCam architecture. Further expansions to the model now enable for arbitrary spatial and spectral resolution,

for application to a range of camera systems, and Bayer Pattern transmission functions, as applicable to the High-Resolution Camera, and also to Mastcam on MSL. This development allows for the testing of the implications of the system Point Spread Function on the demosaicing of Bayer pattern raw images.

3. Operations Optimisation

3.1 Exposure Time Predictions

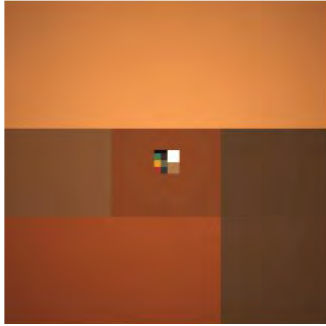


Figure 1: Simulation output from RGB channels for a synthetic test scene.

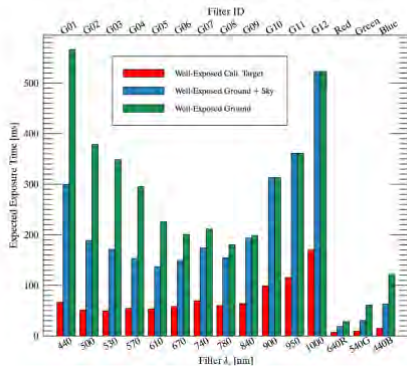


Figure 2: Predicted optimal exposure times for each filter, for the scene illustrated in figure 1.

There are many applications of the simulation. In this example, predictions are made for exposure times of all filters for an abstract synthetic Mars scene (figure 1). The scene consists of the sky spectral radiance (as measured by [6]) and several surface reflectance patches (as observed by MER Pancam [7]), and the reflectance of the PanCam Calibration Target (centre, described by [1]). The optimal exposure time is defined as the exposure that scales the brightest object of interest in the scene to 90% of the detector dynamic range. The plots in figure 2 show the

changes in exposure time, depending on whether the object of interest is the calibration target, sky, or ground only.

3.2 Algorithm Optimisation

Once in operation, SNR for WAC images can be maximised by 3 key tasks: auto-exposure, for optimisation of the dynamic range used in each image; noise-removal; and calibration, against the PanCam Calibration Target and pre-flight characterisation measurements. The simulation can be used to optimise such algorithms as follows. Ideal image products for a given task are defined and synthesized from an input test scene, as a hyperspectral radiance image cube. The parameter spaces of candidate algorithms are sampled, and the input test scenes processed according to the camera system simulation and implementation of the algorithm. Resultant images from the simulation are compared to the ideal examples via a cost-function. Cost-minimisation then guides the selection of optimal algorithms and parameter combinations. Further details of this method are described in [8].

4. Summary and Conclusions

Simulation of the transfer function of spectral imaging systems allows for a variety of studies to be undertaken in preparation for upcoming missions, and also to compare expected results against existing or emulator systems. We present continued development of a software simulation, and demonstrate its application, in preparation for the ExoMars 2020 Rover mission.

Acknowledgements

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Non-saturating, simultaneous multiband, infrared imager

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Abstract

We are developing a multiband imager that obtains simultaneous two-dimensional imaging at short-, mid- and long-infrared wavelengths. Moreover, this instrument will deliver non-saturating, wide dynamic range images of transient, rapidly-changing events. These capabilities enable a new range of previously unobtainable high science value planetary observations. In particular, this imager will enable study of high temperature volcanism on Io, Earth, and possibly Venus.

1. Introduction

Io's extraordinary volcanism presents unique observational challenges [1]. Thermal emission radiance from Io's volcanoes spans more than six orders of magnitude and volcano behavior is highly unpredictable. Based on past experiences with *Galileo* instruments, two criteria must be met to measure the eruption temperature of Io's dominant silicate lavas (likely between 1400 K and 1900 K). The first criterion is obtaining unsaturated, multi-wavelength data of the hottest (>1400 K) exposed areas present [2]. The second is obtaining these multi-wavelength data simultaneously and quickly, overcoming uncertainty introduced into temperature measurements caused by rapid cooling between observations.

2. Current state of the technology

In the ideal application scenario, infrared imagers and spectrometers would provide high-resolution images containing spectral and temporal information with high signal-to-noise ratio and infinite dynamic range. The currently existing technologies are capable of providing only two out of three types of information (Fig. 1). For example, the currently deployed imaging spectrometers only acquire one-dimensional spatial imaging and utilize scanning to obtain a two dimensional image. This results in a

time delay between obtaining data at different wavelengths for different points in the image, which is highly undesirable when a target event (e.g. a volcanic eruption) is changing on a time scale faster than the data acquisition time. Also, these instruments can be saturated if the signal is higher than anticipated. With volcanic eruptions for example, the strength of the thermal emission is impossible to predict.

3. Simultaneous multiband, infrared imager

We are currently developing a simultaneous multiband, infrared imager capable of observing a rapidly-changing transient events of unknown magnitude of thermal emission and areal extent without saturating the imager. This imager utilizes two new technologies: (1) a faceted mirror design of infrared imager (2) a digital focal plane array.

The faceted mirror design enables transient-event spectral imaging by simultaneously capturing a scene's spatial and spectral information in every frame. This design enables a multi-wavelength simultaneous data acquisition by incorporating a faceted, all reflective mirror system at near the stop plane of an Offner optical relay system [3]. Each facet imparts a phase term which diverts the beam to focus an image at a spatially shifted location on the focal plane. Once the light reaches the focal plane, each image is filtered using a "color" filter to obtain images in the selected spectral bands (Fig. 2).

The digital focal plane array enable non-saturating, very high dynamic range (>100 dB) infrared imaging at high operating temperature with excellent spatial uniformity and long term stability. This advance in the digital focal plane array performance are achieved by use of two recent technological breakthroughs: digital read-outs circuits (DROICs) with internal counter and high operating temperature barrier infrared detector.

The recently invented high operating temperature (HOT) barrier infrared detectors (BIRD) are based on III-V compound semiconductors [4]. These offer an innovative solution for the realization of high-performance, large-format focal plane arrays (FPAs). The long wavelength infrared HOT BIRD FPAs cover 1 - 10 μ m spectral band with high sensitivity and operate at $T = 70$ K with excellent pixel-to-pixel uniformity and pixel operability. Moreover, they do not suffer from 1/f noise, thus offering high temporal stability.

The novel DROICs used in this imager were developed by MIT Lincoln Laboratory [5]. These DROICs do not saturate due to the pixel-level analog-to-digital conversion and a digital counter integrated into each pixel. These digital counters do not saturate if their maximum count number is exceeded. Instead, they “roll over” and begin counting again from zero. The number of “roll overs” is stored so the true count number can be recovered using real-time processing. The result is a non-saturating detector with very high dynamic range.

4. Figures

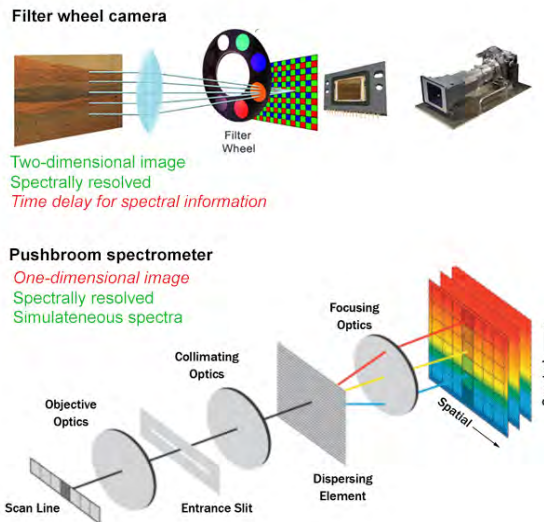


Figure 1: Two most commonly used approaches to acquire spectrally resolved images. (Top) The filter wheel camera that can obtain two dimensional images but has a time delay between images acquired in different spectral windows. (Bottom) Pushbroom spectrometer that only acquires a one-dimensional spatial image and utilizes scanning to obtain a two dimensional image.

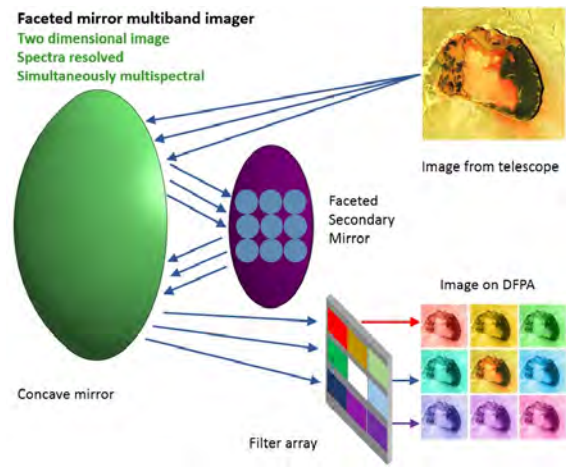


Figure 2: Illustration of a faceted mirror multiband imager. The faceted secondary mirror creates multiple images at the focal plane. Each image except for central one is filtered by a bandpass filters in a filter array mounted above the digital focal plane array.

5. Summary and Conclusions

We present our progress on development of non-saturating, simultaneous multiband, infrared imager that will enable investigation of Io’s extraordinary volcanism.

Acknowledgements

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Low Risk Technique for Sample Acquisition from Remote and Hazardous Sites on a Comet

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Abstract

This paper discusses the development efforts for a comet sample acquisition system capable of reaching remote and dangerous areas. The system is part of a mission proposal to return a subsurface regolith sample to earth. The mission proposal, CORSAIR, was coordinated by APL in Laurel, MD as a response to the NASA 2017 New Frontiers AO.

The technique consists of launching a projectile from a parent spacecraft with enough kinetic energy to penetrate the surface and collect a sample. The projectile returns to the spacecraft where the sample is transferred to an earth return vehicle. The method collects a sample regardless of surface hazards with minimum risk and complexity to the mission. By isolating the spacecraft from the comet, this technique allows site selection by scientific criterion and protects the spacecraft from hazards.

1. Introduction

The sampling system consists of 5 major subsystems: Launcher, Boom Retraction and Deployment System (aka BRAD), Sample Acquisition and Retrieval Projectile (aka SARP), Robotic Arm for sample transfer (aka RA) and Kinematic End Effector (KINEE) [3]

1.1 Launcher

The launcher is a propellant driven device developed by DLR in Munich, Germany[2]. The launcher uses a NASA Standard Initiator (NSI) to ignite a pyrogenic charge that propels the SARP towards its target. The launcher consists of an expansion chamber with a sliding piston that captures energy from the propellant expansion and transfers that energy to the SARP via additional structure. The design was validated through a test program at DLR shown in Figure 1. A simulator, designated ViPR, was built and tested at Goddard using compressed helium.

1.2 BRAD

The BRAD is an assembly that keeps the SARP connected to the spacecraft and provide means for returning and transferring the sample. The BRAD utilizes a deployable TRAC boom [1] that connects to the SARP on one end and to the spacecraft, via a drum, on the other. The TRAC boom pays out flexibly but becomes stiff when deployed providing for a controlled retraction that protects the spacecraft from contact damage. Once the SARP returns, BRAD preloads the assembly to mechanical ground such that that RA can grasp for extraction. Figure 3 shows the Goddard test unit.

1.3 SARP

The SARP consists of a cartridge and an outer sheath. The outer sheath adds additional inertia to increase penetration and provides a clear tunnel to ease extraction. The SARP uses two internal mechanisms to close a cartridge door and release the sheath. The SARP has an internal electronics package that supplies the energy and timing to activate these mechanisms. The mechanisms are tested to be reliable over a large range of temperatures and shock environments. Figure 4 illustrates the SARP and the unit used for testing.

1.4 Robotic Arm

The RA is a sophisticated robotic manipulator that uses force feedback to overcome issues of compliance and accuracy. Components of the RA have been qualified for space use by experiments on ISS. Testing demonstrated the RA could successfully interact with the various parts of the sampling system and the earth return vehicle. See figure 5.

1.5 KINEE

The KINEE is designed to provide a robust interface between the RA and the SARP. The design includes features that enable the RA to locate the SARP precisely before applying loads that might induce binding. Internal mechanisms inside KINEE allow

the RA to firmly grasp the SARP for manipulation and transfer. Once the RA actuates KINEE, forces and torques may be applied to the SARP cartridge as part of extraction and insertion processes. Figure 2 shows the actuator and mating plate.

2. Figures



Figure 1: Launcher test unit



Figure 2: KINEE Test Unit

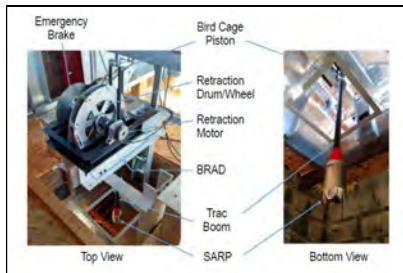


Figure 3: BRAD test unit

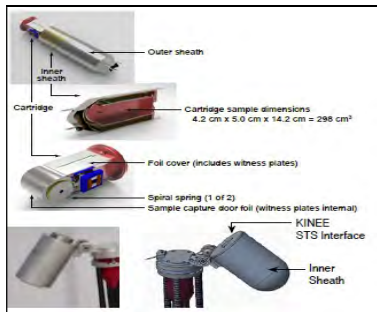


Figure 4: SARP Model and test unit

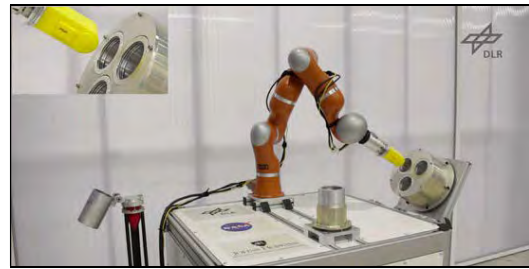


Figure 5: RA Demonstration at DLR

3. Summary and Conclusions

The CORSAIR sampling technique provides a low risk means to acquire a sub-surface comet sample from high hazard areas to return to earth. The work done to develop and test this system are described in this paper and provide insight to how various problems are solved and tested.

Acknowledgements

APL organized the proposal effort. GSFC provided IRAD funding to develop and test BRAD, SARP and KINEE. DLR provided development and testing of the Launcher and RA simulator working with all the parts of the system.

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MAPLE: Mars Atmospheric Panoramic camera and Laser Experiment

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Abstract

This abstract presents a study to increase the Science Readiness Level of a proposed instrument for use as a meteorological station on a future Mars lander. The Mars Atmospheric Panoramic camera and Laser Experiment (MAPLE) instrument is designed and will be optimized to constrain the shape and size distributions of near surface aerosols through measurements of backscatter properties via laser beam imaging, to monitor all-sky cloud activity, and to measure dust optical depths simultaneously in multiple directions from the surface of Mars.

1. Introduction

The Martian atmosphere, though substantially thinner, hosts many familiar atmospheric features, such as clouds, fog, snow, and dust phenomena [e.g. 2-6,9]. However, we are restricted by the limited availability of observational data; there is only one meteorological station currently in operation on the surface (Mars Science Laboratory Rover, [1]) and for the remainder of Mars we utilize indirect methods for determining the meteorological conditions (e.g. aeolian-originating surface features for wind speeds and directions, 7). By creating instruments that are sufficiently compact and efficient (power, data) that they could be included on most future landers without significantly impacting the mass and data-rate of the lander, the atmospheric science return of future missions could be significantly increased.

What follows in this abstract is a proposed study designed to increase the Science Readiness Level of an instrument concept combining a panoramic camera and vertically mounted lasers for use as a meteorological monitoring station on the surface of Mars.

2. The MAPLE Instrument

The use of cameras to monitor cloud activity and determine the optical depths of aerosols in a given direction from the surface of Mars has been proven to be effective on past Martian landers and rovers [e.g. 2-4, 9]. A panoramic imager can simultaneously carry out these observations in multiple directions and monitor full-sky cloud activity. A panoramic camera would also add relatively little power and data requirements and, if used in combination with low-powered lasers, would also be able to examine aerosol back-scattering close to the surface – the most active region of the Martian atmosphere. Using multiple monochromatic lasers at different wavelengths allows the scattering properties as a function of wavelength to be investigated, which in turn enables the shape and size distributions of the particles in the atmosphere close to the surface to be constrained. The thermal structure of the martian atmosphere is dominated by dust and dust processes, making knowledge of the abundance and scattering properties of such particles critical to understanding the martian environment.

The proposed Mars Atmospheric Panoramic camera and Laser Experiment (MAPLE) instrument is based around a prototype space-qualified, panoramic camera supplied through a partnership with Canadensys Aerospace Corporation (CAC) of Toronto, ON. The camera is small and lightweight and will be surrounded by three vertically mounted, monochromatic lasers (one red, one blue, and one green). The camera will be able to image the laser beams within tens to hundreds of meters of the surface and thus can determine particle abundances and vertical distributions close to the surface. This style of observation was demonstrated in flight with the Mars Phoenix Lander using its lidar in combination with the Stereo Surface Imager (SSI, field of view 13°). The on-board lidar was not able to

image the laser beam close to the surface, however the SSI could image the beam at 200m altitudes and below and the observations used to calculate near-surface ice particle abundances [6]. However, this was a highly complex observation requiring combined use of two instruments whose relative positions were not optimized for such an observation, thus, this could only be carried out four times over the course of the mission [6]. A dedicated panoramic camera for meteorological observations optimized for such an observation would significantly reduce the operational complexity of this activity.

Through the development outlined in the following section, the most effective laser wavelengths, optimal camera-laser separation, and the system's accuracy and reliability would be determined for the MAPLE instrument.

3. Proposed Stages of Development

There are three main stages of development for this instrument. The first, "construction, testing, and verification", will cover the initial construction of the instrument from the constituent camera and lasers. The optimal configuration of the camera relative to the lasers and ideal laser wavelengths will also be initially determined, subject to adjustments as required during and after field tests. The instrument will then be tested and calibrated in the laboratory and in the local Toronto area, using the York University Lidar system, a facility based upon the successful Phoenix Lidar, as a validator. Image contrast optimization algorithms, building on the work of [8] will also be investigated and implemented.

The second and third phases take the instrument out into different environments, nominally an aerosol-rich environment such as St. John's to further refine the instrument set-up and data collection methods, and an extreme environment in the Arctic. The latter will demonstrate the instrument's capabilities at temperatures comparable to that on Mars in a low atmospheric water vapour environment which has comparable sized aerosols to that found in the lower martian atmosphere.

4. Summary

This abstract presents a study to increase the Science Readiness Level of a proposed instrument for use as a meteorological station on a future Mars lander.

Based around a space-qualified panoramic camera (Canadensys Aerospace Corporation) in combination with multiple low-power lasers, the Mars Atmospheric Panoramic camera and Laser Experiment (MAPLE) instrument will be optimized to measure backscatter properties of near surface aerosol, monitor all-sky cloud activity, and measure atmospheric optical depths in multiple directions from the surface. The development process includes optimization of the instrument set-up and calibration and verification under a variety of atmospheric conditions, including extreme Arctic conditions.

Acknowledgements

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Piezoelectric valve for atmospheric descent sampling

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Abstract

Following the same manufacturing procedures that were used for the development of a micro-propulsion piezoelectric valve, manufactured at JPL 12 years ago [6-8], we have produced 2 batches of leak-tight piezoelectric micro-valves, operating at extremely high upstream pressures and suitable for flight mass spectrometry applications. The devices were fabricated mostly by the micro-machining of silicon wafers and do not include any fragile membranes in order to allow high-pressure operation. In its final version, the valves will be able to operate in a wide pressure range (5 mbar – 100 bar), allow for leaking rates below 2×10^{-6} mbar l/s when fully closed under maximum pressure, and be capable of a fine flow regulation (in 1×10^{-8} mbar l/s steps) of a gas mass-flow. In addition, the time response of the valves will be on the order of 1ms (1kHz pulsed operation), they will consume less than 10mW of power, when operating in static mode, and will be able to function in the temperature range of 0-125°C. The achievements of the first year effort of the two year project will be presented.

1. Introduction

Mass spectrometers (MSs) have been employed on missions to the Moon, Mars, Venus, Jupiter, Saturn, Titan, and various comets to study the composition of atmospheres and solar system bodies. An inherent challenge with spaceflight MSs is the introduction of the material to be sampled (gas, solid, or liquid) into the instrument interior, which operates at vacuum. Especially, if being employed in an Atmospheric Descent Probe (ADP), spaceflight MSs typically require a specially designed sample inlet system which ideally provides highly choked, nearly constant mass-flow intake, despite ambient pressure variations. In addition to being sufficiently low in conductance, an inlet leak for spaceflight MS must also be chemically inert, must not distort the gas composition being sampled by adsorbing or reacting with sampled gases differentially, and must have a

reasonably fast response time (on the order of seconds or less). Finally, it must be simple, robust and operable over a wide temperature range. Past methods of producing such inlet systems have included pulled glass[5], crimped metal tubes[1,2], porous frits, micro-machined leaks[9-12] and pulsed piezoelectric valves [3-4]. So far none of these methods have produced an inlet system that would satisfy all the conditions mentioned above and would be able to finely regulate sample mass-flow in a continuous fashion in wide pressure interval.

2. Principle of operation

The valve consists of a custom-designed piezoelectric stack actuator bonded onto the two silicon valve components: a) seat layer, b) boss layer (featuring a tether). Figure 1 shows the most important features of the micro-valve which include narrow edge seating rings and tensile-stressed silicon tether that contribute to the desired leak-tight operation. The custom-designed stack of piezoelectric actuators consists of peripheral active zones and an inactive central zone. The active zones are mechanically separated from the central, inactive zone. These zones are bonded to corresponding peripheral and central areas of the boss plate. Application of a voltage (~ 60 V) to the piezoelectric stack causes the active zones to vertically expand by 5 μm , lifting the boss center plate (bonded to the inactive zone), away from the seat plate. This actuation creates a channel between the two seating surfaces, permitting the passage of gas as shown in Figure 2. Since the piezoelectric actuator is essentially a stacked capacitor, it consumes extremely low power when it is not moving, thus allowing a near zero-power, open or closed operation for the micro-valve.

3. Testing setup

After the valves have been manufactured, they are first evaluated using a He leak detector. The inlet port of the valve connects straight to the He cylinder

pressure regulator and the outlet port to the detector. After the pressure range with acceptable leak rates is determined, the inlet of the valve is connected to the programmable Syringe Pump (SP) and outlet to the Quadrupole Ion Trap Mass Spectrometer (QITMS). SP is programmed to follow pressure profile of descent through Venus atmosphere and the maximum pressure is limited to previously established value. QITMS operates best at the pressures below 10^{-7} mbar (QITMS' base pressure when no flow equals 5×10^{-10} mbar), which requires a constant flow of $\sim 5 \times 10^{-6}$ mbarL/s. The whole pressure range is mapped in a step by step mode and corresponding piezo voltages which are necessary to produce a required inlet flow are determined. Finally, both SP and piezovalve are ran in a continuous synchronous mode. Figure 3 shows the experimental setup for valve evaluation.

4. Figures

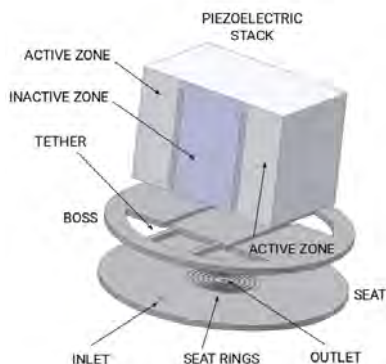


Figure 1: Schematic view of a piezoelectric valve.

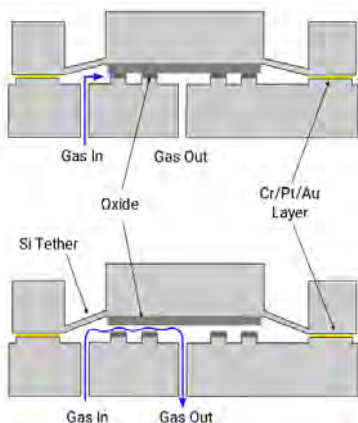


Figure 2: No voltage on the valve – closed (top), valve opened - boss is lifted from the seat (bottom).

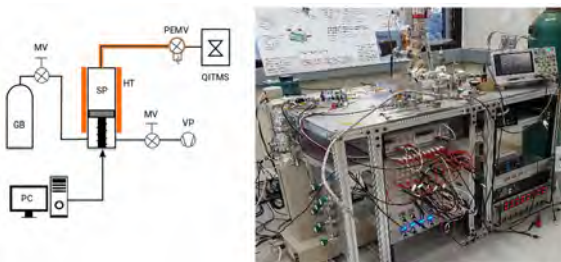


Figure 3: Schematic view and the photo of the test station which includes QITMS(top) and SP (far left).

5. Summary and Conclusions

We have manufactured a piezoelectric microvalve capable of operating in a wide pressure range with short responding times of ~ 1 ms, and less than 10mW of power consumption. The valve is ideal solution for inlet system of a wide variety of mass spectrometers which require very low and precise inflow of gas for their operation.

Acknowledgements

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Fourier-spectrometer FAST for ExoMars 2020 surface platform

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Abstract

FAST (Fourier for Atmosphere and Surface Temperature) is a Fourier-transform infrared spectrometer (FTIR) for ExoMars 2020 Surface Platform. Instrument based on 1-inch interferometer with two-coordinate scanning system and internal “black body” for calibration. The mass allocation is only 3.5 kg that imposes a very compact design.

The science objectives of FAST are: studies of composition of the Mars atmosphere; measurements of temperature profiles from surface to 20 km; determination of aerosol characteristics [1].

The main part of FAST, the interferometer can be operated in two regimes: a “high sensitive” mode to obtain one-side interferograms with a maximal optical path difference (MOPD) of 16 cm (or a spectral resolution of $\sim 0.05 \text{ cm}^{-1}$), and an “atmospheric” mode to obtain two-side interferograms with the MOPD of 0.5 cm (the spectral resolution of $\sim 2 \text{ cm}^{-1}$). The instrument’s spectral range is 1.7-17 μm (defined by Ge and ZnSe optics). A pyro-electric detector is used. The S/N ratio for a single measurement in the “high sensitive” mode will be ~ 1000 . For the “atmospheric” mode the S/N estimations are ~ 100 and ~ 50 (day and night respectively, for a single measurement).

The tracking of the Sun is necessary during “high sensitive” measurements of the trace gases. The precise 2-coordinate scanning system is based on a rope transmission [2]. The tracking accuracy achieved is 0.1 mrad.

Acknowledgements

ExoMars is the space mission of ESA and Roscosmos. The FAST experiment is led by Space Research Institute (IKI). Authors acknowledge Roscosmos for funding.

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Plato Instrumentation and Mission Status

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Abstract

PLATO (PLANetary Transits and Oscillations of stars) is ESA's M3 mission, scheduled for launch end 2026. It will detect and characterize extrasolar planets for their radius, mass, mean density and age via photometric lightcurves. The talk will provide an overview of the current status of the PLATO mission and instrument.

1. Introduction

PLATO (PLANetary Transits and Oscillation of stars) is ESA's M3 mission of the Cosmic Vision 2015-2025 program. Its goals include detecting exoplanets and providing their prime planet parameter, including small planets orbiting in the habitable zone of solar-like stars. Furthermore, PLATO will provide stellar parameters for thousands of stars obtained via asteroseismology.

2. Science objectives

The PLATO mission addresses the following main science objectives:

- Determine the prime properties (orbit, mass, radius, mean density) of planets in a wide range of systems, including terrestrial planets in the habitable zone (HZ) of solar-like stars.
- Analyse the correlation of planet properties and their frequencies with stellar parameters.
- Study how planets and planet systems evolve.
- Study the typical architectures of planetary systems.
- Study the internal structure of stars and how it evolves with age.
- Identify good targets for spectroscopic follow-up measurements to investigate planetary atmospheres.

Planetary radii will be derived via transit photometry. Ages of planetary systems can be derived from asteroseismology analysis as well as the prime stellar parameters. Planetary masses for bright stars are derived from ground-based spectroscopic observations via the radial velocity technique.

3. The instrument

The PLATO instrument consists of 26 cameras, 24 "normal" cameras and 2 "fast" cameras for fine-pointing, with CCD-based focal planes. The "normal" cameras are dedicated to monitor stars with $V > 8$. They are arranged in four groups of six cameras each. Figure 1 shows the arrangement of cameras on the field-of-view. The ensemble of cameras is mounted on an optical bench.

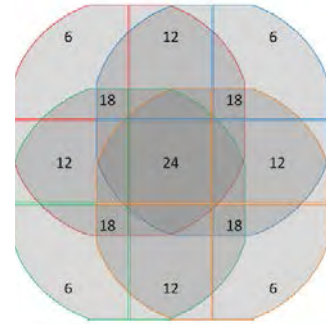


Figure 1: PLATO field of view indicating the number of cameras (ESA-SCI(2017)1).

The cameras are based on a fully dioptric design with 6 lenses. Each camera has a 1037 deg^2 field-of-view and a pupil diameter of 120 mm. They are each equipped with a focal plane array of 4 CCDs with 4510×4510 pixels of $18 \text{ }\mu\text{m}$ size. Normal cameras work in full frame mode with 25s cadence, and frame transfer mode is used for the fast cameras in 2.5 s cadence. Together with Data Processing Units, the central Instrument Control Unit, and respective electronic units, the mission consortium provided payload is formed.

4. Observing Strategy

PLATO is foreseen to be launched end 2026 from Kourou and injected onto a transfer trajectory to the second Lagrangian point of the Sun-Earth system, L2. After a commissioning, a nominal science operations phase of 4 years will be performed. In the design

baseline PLATO will observe two target fields for 2 years each. However, mission extensions are possible, since the satellite will be designed for an in-orbit lifetime of 6.5 years and accommodates consumables for 8 years.

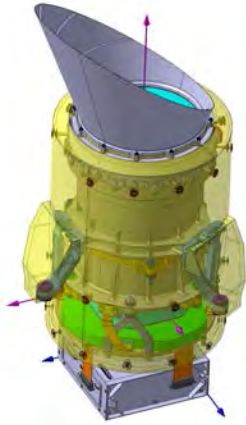


Figure 2: PLATO “normal” camera (ESA-SCI(2017)1).

During long observations, the spacecraft must maintain the same line-of-sight towards one field for up to several years. To ensure that the solar arrays are kept pointing towards the Sun, the spacecraft is rotated around the line-of-sight by 90° roughly every 3 months.

The 26 cameras provided by the Payload Consortium of scientific institutes and universities funded by ESA Member States will be mounted on an optical bench and satellite provided by ESA’s industry contractor (OHB System AG). ESA furthermore contributes to the payload by supplying the CCDs.

5. Summary

PLATO will provide raw (Level-0) and calibrated (Level-1) light- and centroid-curves for all observed core targets. In addition, a guest observer program based on an open call issued by ESA will be performed. For core targets high-level products (Level-2) with stellar characteristics and identification of planetary candidates will be derived. Final products will include follow-up data from ground-based observations as well as the final planet and stellar parameters.

Altogether, PLATO data will provide inputs not only to exoplanetary science but also a huge legacy for many aspects of stellar and galactic research.

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The Jovian Neutrals Analyzer for observation of Energetic Neutral Atoms onboard JUICE/PEP

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1. Introduction

The Jovian Neutrals Analyzer (JNA) is one of the six sensors which constitute the Particle Environment Package (PEP), a suite of particle instruments which will fly on the JUpiter ICy moon Explorer (JUICE).

JUICE is the first Large-class mission in ESA's Cosmic Vision program, planned for launch in 2022 and arrival at the Jovian system in 2029. JUICE will perform detailed observations of Jupiter and its Galilean moons to provide a better understanding of the Jovian system as a whole.

JNA will produce images of Energetic Neutral Atoms (ENAs) in the range of 10 eV to 3.3 keV.

2. Scientific objectives

The JUICE spacecraft will probe the Jovian system for a nominal mission of 2.5 years with a focus on Jupiter and its largest moon Ganymede complemented by a series of fly-bys of the smaller moons Europa and Callisto.

PEP will characterize the plasma environment by measuring ions, neutrals, and electrons, covering an energy range from <0.001 eV to >1 MeV.

JNA will focus on low energy Energetic Neutral Atoms (10eV to 3.3keV) created by different physical processes occurring at different locations.

ENAs can be created when solar wind ions or Jovian plasma impinge on the surface of icy moons and are backscattered as neutrals, or cause sputtering of surface constituents (mostly hydrogen and oxygen).

Another process which can produce ENAs in the Jovian system is charge-exchange in the corotating plasma associated to Io's and Europa's orbits. These tori are fuelled by, particles ejected by the intense volcanism on Io and ionized by solar wind UV, as well as ion pick up of exosphere constituents by the solar wind.

As the trajectory of neutrals is not affected by local electric or magnetic fields, imaging ENAs at Jupiter is equivalent to mapping the ions impinging on icy surfaces and flowing around Jupiter.

3. Instrument description

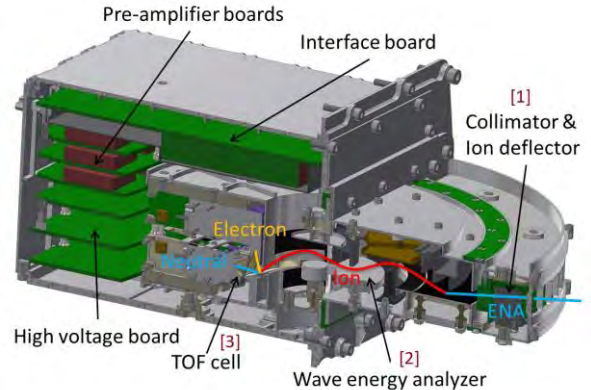


Figure 1. Longitudinal cut of 3D model of JNA. In red, numbers indicate the 3 different steps of ENA measurements.

Measuring neutrals with JNA involves three main steps, as shown of Fig. 1.

Firstly, ENAs enter the instrument through the collimator, which is a fan shaped set of blades to restrict the incoming direction of ENAs. This set of blades also acts as an ion deflector as they are biased to high voltage (3kV), thus preventing ions up to 9 kV from entering the instrument and possibly creating unwanted signal. ENAs which are admitted into the instrument hit an Al_2O_3 coated, highly polished Si surface which converts them to ions.

Secondly, these ions are guided through a wave energy analyser [2], where several electrodes are used to select the energy of the particles.

Thirdly, the energy-analysed ion is guided into the Time-of-Flight (TOF) cell where its speed is measured.

In the TOF cell, the ion hits a second polished surface (called the start surface) and releases a secondary electron which is detected by a Channel Electron Multiplier (CEM) and used as a START

signal. The reflected particle (neutral or ion) is then detected by a second CEM and used a STOP signal.

The time difference between the detection of these two particles constitutes a Time-Of-Flight which can be used to determine the mass of the particle in combination with energy analysis.

JNA is equipped with 11 pairs of CEMs arranged in a fan-like fashion which gives JNA a field-of-view of 150° with an angular resolution of 15° to 20° in azimuth.

4. Design features

The design of JNA is strongly inherited from CENA on Chandrayaan-1 and ENA on Bepi-Colombo [1, 2], but a few changes were necessary to accommodate the harsh radiation environment at Jupiter.

For example, the distance between the start surface and the STOP CEMs was reduced from 50 mm on JNA predecessors to 10-15 mm, to produce shorter Time-of-Flight, thus reducing the sensitivity to penetrating radiation. Indeed, as JNA uses a coincidental system to detect neutrals, background noise is caused by accidental coincidences. By shrinking the Time-of-Flight, JNA can use shorter TOF windows, reducing the probability of detecting accidental coincidences.

Additionally, the area of the START surface itself was reduced by a factor of four, reducing the possibility of detecting secondary electrons produced by penetrating radiation.

Finally, the MicroChannel Plates (MCPs) used on ENA and CENA were replaced by CEMs, which have the advantage of having a smaller detection area as well as a relatively bulky ceramic structure, which, while making the TOF cell very compact, also shield each other from penetrating radiation.

Table 1. JNA performance specifications

Energy range	10 eV – 3.3 keV
Energy resolution $\Delta E/E$	100%
Mass range	1 – 32 amu
Masses resolved	1, Heavy
Field-of-View	15° x 150 °
Angular resolution	7° x (15-20°) 11 pixels
Time resolution	15 seconds

As shown in Table 1, JNA's mass resolution is limited to resolving hydrogen and heavier ions. This results from a large energy resolution, which is needed for measuring low energy ENAs at Jupiter, where fluxes are expected to be of the order of a few counts per second. The wave energy analyser allows for such a broad energy band, while being very efficient to suppress UVs.

5. Current status

The JNA Technological Model (TM), first flight-like model to be built, has now passed successful functional and mechanical tests. The functional test was performed in a vacuum chamber in the calibration facility at the Swedish Institute of Space Physics in Kiruna Sweden. The model was exposed to an ion beam and allowed us to confirm the design of JNA by showing that the instrument behaves as expected. Later, the TM and subsequent models will be exposed to a neutral beam.

Flight Model assembly will start later this year, with calibration planned for early 2019, aiming at a delivery in June 2019.

Acknowledgements

JNA/PEP is supported by the Swedish National Space Agency (SNSA).

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The mini INMS instrument on NASA GSFC's Dellingr Mission and initial results.

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Abstract

A mini Ion and Neutral Mass spectrometer has been developed and flown on NASA GSFC's tech demo Dellingr mission deployed in a LEO orbit from in November 2017. The INMS is suitable for cold ionospheric plasma measurements in the mass range of 1-40 amu with mass resolution of $M/dM \sim 12$, fast spectra sampling < 1 sec, and high density dynamic range. The original scientific motivation was to study the response of earth's Ionosphere - Thermosphere - Mesosphere system to solar and magnetosphere drive, with multi point distributed measurements. However this mini - INMS can operate in planetary orbits to study analogous space weather phenomena. The instrument is based on a novel gated time of flight technique that allows for a high density dynamic range, parallel operation for neutral and ions and compact size. The INMS occupies a volume 10cm x 10cm x 13cm, weights ~560 grams and dissipates ~1.8W peak power. This presentation will show initial INMS measurements on the Dellingr mission. The INMS data show excellent mass separation of H, He, O species with very low noise and negligible spacecraft potential effects. Detailed science data analysis work is underway to calculate ion species densities, temperatures and drifts. The INMS is under continuous development for improved performance and characteristics. It was originally flight validated on the NSF Exocube 1 mission flown on January 2015; improved versions are onboard the NSF Exocube 2 mission scheduled for flight on December 2018 and on the NASA PetitSat missions scheduled for flight on 2020.

Miniaturized hyperspectral imager for small interplanetary spacecraft – ASPECT

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Abstract

ASPECT hyperspectral imager is a scalable instrument for small spacecraft to study composition of planetary surfaces.

1. Introduction

The ASPECT Hyperspectral Imager was originally developed as a payload for ASPECT CubeSat (Asteroid Spectral Imaging Mission) [1] within the ESA-NASA AIDA (Asteroid Impact & Deflection Assessment) project. It is a miniaturized, CubeSat-sized, hyperspectral imager with primary scientific task of high resolution compositional mapping of target surface. Thanks to its modular design, ASPECT hyperspectral imager range and resolution can be easily modified to match specific mission objectives.

2. Scientific and prospecting capabilities

The scientific and prospecting objectives of the instrument are supported by its VIS-NIR (visual – near-infrared) spectral range. The ASPECT Hyperspectral Imager allows for global compositional mapping and imaging of the target asteroid with sub-meter resolution.

The spectral range of 500-2500 nm covers the most common silicate mineral (olivine, pyroxene, and plagioclase) absorption bands related to Fe^{2+} ions in their structure. Additionally, hydrated minerals as serpentine can be detected using ~ 700 nm Fe^{3+} absorption features. Direct presence of -OH and H_2O can be detected at 1400 and 1900 nm respectively. Observations at various phase angle allows for

estimation of surface roughness. An extension of the spectral range into MIR (mid-infrared) region is being currently investigated. This spectral range allows for direct detection of hydrated materials and water/ice in 2700-3000 nm region as well as organic materials at 3200-3600 nm (Fig. 1).

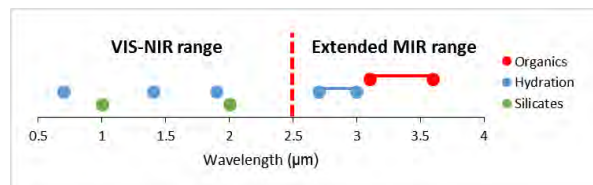


Figure 1: Spectral features detectable with ASPECT hyperspectral imager.

3. Design

The ASPECT Hyperspectral Imager is a miniaturized instrument with range extending from the visible (VIS) up to near-infrared (NIR) wavelengths. In contrast to more traditional spatial scanning imaging spectrometers, the Asteroid Spectral Imager takes 2D snapshots at a given wavelength. When multiple snapshots are combined, a spectral datacube is formed, where the wavelength bands are separated in the time domain. The spectral separation is done by a tunable Fabry-Perot Interferometer (FPI).

The ASPECT asteroid hyperspectral imager is split into three measurement channels, one in the visible (VIS), and two in the infrared (NIR1 and NIR2). The parameters of each channel as well as possible extensions are summarized in Table 1. Sub-meter imager resolution can be achieved at orbital distances of 3 km or lower. All three channels have dedicated FPIs optimized for the desired wavelength range and are independent on each other. The imaged

wavelengths are freely selectable within these ranges, and the targeted spectral resolution is 10-50 nm. Recently, a feasibility study of additional MIR channel with spectral range of 2500-4000 nm was launched. An extension in other direction towards UV (ultraviolet) is also currently under development for ESA ALTIUS and can be potentially integrated into the ASPECT Hyperspectral Imager.

4. Customization

The number of ASPECT imager channels, spectral range and resolution can be customized to meet specific mission objectives. Spectral resolution can be increased using FPI's higher orders of interference. However, this will result in more limited spectral range of the single channel and subsequently more channels are needed to cover equal wavelength range.

But as the instrument size is very small, adding a more channels is still feasible even within small spacecraft. For example, improving the spectral resolution from 20 to 10 nm in NIR1 channel, the range will decrease from 900-1400 nm to approx. 900-1100 nm. Cascading the FPI's will also result in better spectral resolution; however, the throughput will be slightly decreased. Thus, there is a possibility for customization of ASPECT hyperspectral imager configuration to satisfy different mission requirements.

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Table 1: ASPECT Hyperspectral Imager configuration with optional extensions.

Range	VIS	NIR1	NIR2	UV (optional)	VIS (optional)	MIR (optional)	VNIR mini
Size	0.5U	0.5U	0.25-0.5U	0.5-1U	0.5U	0.25U	1 cubic inch
FoV [deg]	10 × 10	5.3 × 5.3 10 × 10	5.3 × 5.3	TBD	2.5 × 2.5	TBD	10 × 10
Spectral range [nm]	500-900	900-1600	1600-2500	250 - 400	430-800	2500-4000	500-800 or 700-1000
Image size [px]	1024 × 1024	512 × 512	256 × 256	Single point	2048 × 2048	Single point	512 × 512
Spectral resolution [nm]	10-15 nm	20-40 nm	20-30 nm	< 2.5 nm	< 2.5 nm	30-50	20 nm
TRL	9	7	5	5	8	3	3-4
Flight heritage	Aalto 1 (in orbit, 2017)	Reaktor Hello World (FM delivered, launch 2018)	Under development , prototype in 2018	ESA ALTIUS (under development)	VISION (FM delivered, launch 2019)	Concept	Under development with ESA
Note			2 FPI cascade. With a single FPI the range is 1600 - 2100	4 FPI cascade. Can also be used with imaging detector		2 FPI cascade. With a single FPI the range is 2500 - 3500	Based on MEMS technology

Simultaneous Detection of Inorganic Cations and Amino Acids in High Salinity Samples: Implications for In-Situ Exploration of Ocean Worlds

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Abstract

Capillary electrophoresis (CE) is an attractive technique for in-situ planetary investigations with tremendous promise for missions to ocean worlds. CE allows the detection of a wide range of compounds and it doesn't require bulky pumps or packed separation columns. Instead, CE only needs a low power high voltage supply, an electrolyte solution, and a hollow glass capillary. Moreover, the combination of CE with capacitively coupled contactless conductivity detection (CE-C⁴D) [1] provides a "universal" approach capable of detecting any charged species.

Although CE allows for the detection of multiple analytes, in general, CE methods are targeted to a specific set of compounds. For example, current CE protocols are focused on the analysis of either trace organic or bulk inorganic species, but not both at the same time. This presents an opportunity to combine these protocols for a planetary habitability survey instrument that can simultaneously detect both organics and inorganics and reduce setbacks from unknown samples [2]. We are developing CE-C⁴D methods to simultaneously analyze inorganic and organic ions (i.e. calcium, sodium, perchlorate, amino acids, carboxylic acids etc.), as they are likely to be present at the same time on samples collected from the most relevant astrobiology targets like Mars, Enceladus, or Europa.[3]

1. Introduction

On Ocean Worlds, such as Enceladus or Europa, where liquid analyses would be especially powerful, the primary sample matrix is expected to be composed of dissolved salts and other inorganic ions. Soluble salts are of importance to biological activity, prebiotic organic synthesis, and the thermophysical properties of most liquid mixtures.[4] On the other side, amino acids are essential for all terrestrial life as the building blocks of proteins. The distribution of amino acids on a sample is one important indicator for determining the presence of life.[5]

CE-C⁴D does not require derivatization of the sample, providing an attractive and robust alternative to other more labor-intensive detection methods for detection of organics. CE-C⁴D can be used as a screening platform before performing more sensitive analyses that require also more complex sample preparation. It is also well-known that the presence of salts in combination with organics can hinder their detection by methods that require derivatization. Thus, an initial sample screening by CE-C⁴D can help determine the right pathway for sample preparation before analysis with other techniques in order to successfully detect organic biosignatures. CE-C⁴D has a small footprint so it can be readily integrated into other more complex analytical instrumentation.

1. Results

The purpose of this work was to identify a buffer system suitable for simultaneous separation of a set of inorganic cations and the detection of amino acids. A standard mixture with the most relevant analytes for planetary studies was selected. The inorganic salts include the main ions detected in the Mars regolith by the Phoenix Mars Lander (Na^+ , K^+ , Ca^{2+} , Mg^{2+}) plus ammonium (NH_4^+) and lithium (Li^+) due to their importance as indicators of biological and hydrothermal processes, respectively. The amino acids (Ala, AIB, Asp, GABA, Glu, Gly, His, Iva, Leu, Ser, Val, and β -Ala) were chosen based on their abundance in biotic and abiotic sources. [5] In this work, we analyzed the performance of multiple buffer systems for analysis of the selected standard mixture in samples of varying salinity. Regardless of the sample total salinity, 5.0 M acetic acid was determined as the optimum buffer system. The methods were evaluated by analyzing natural samples of low and high salinity from Hot Creek Gorge, Mono Lake, and Pacific Ocean (from Santa Monica, CA). Inorganic ions were detected and quantified in all the samples. Two amino acids, glycine and alanine, were detected in the sample from Mono Lake. The detection of these amino acids is consistent with the fact that they are the most abundant amino acids found in biological samples. These analyses demonstrate the applicability of the protocol developed here for fast detection of inorganic ions and simultaneous screening for the presence of amino acids.

2. Summary and Conclusions

Here we present a simple method for simultaneous analysis of inorganic cations and amino acids by CE- C^4D . A one-component buffer system was selected as optimum for the quantification of inorganic cations and detection of amino acids, regardless of the salinity of the sample. Due to the short analysis time (less than 15 minutes), this method could be used in

future missions to identify samples with potential biosignatures for further analysis with more sensitive instrumentation. The sensitivity of this method for amino acids is similar to GC-MS instruments previously developed towards flight. Moreover, CE- C^4D has a much greater tolerance for sample matrix effects (i.e. high salinity) on the analysis.

The method presented here achieves baseline separation of the major inorganic cations expected on ocean worlds. The rapid determination of the inorganic and organic composition of a sample with a single method is a key capability for future missions looking to understand the chemistry and potential for life on other worlds.

Acknowledgements

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ABSTRACT:

BeppiColombo - MGNS - Mercury Gamma-Ray and Neutron Spectrometer

I.G. Mitrofanov

The objectives of MGNS investigations will be presented in correspondence with the goals of the ESA's BeppiColombo mission.

There are nine known models of the elementary composition of Mercury. To test these models for particular regions of Mercury, MGNS will provide the data for the set of gamma-ray lines of the main soil constituting elements, which are necessary and sufficient to discriminate between the models. Also, there are three natural radioactive elements, K, Th and U, whose contents in the celestial bodies soil characterize the physical condition of their formation in the protoplanetary cloud. The data from GRS segment of MGNS will allow comparing Mercury with Earth, Moon and Mars.

Finally, the neutron data are known to be very sensitive for detection of hydrogen within heavy soil-forming elements. Mapping measurements of neutrons and 2.2 MeV line will allow us to study the content of hydrogen on the surface of Mercury, in particular at its north and south poles.

The instrument capabilities and expected results will be considered in the conclusion in comparison with the previous results from the gamma and neutron spectrometers of the NASA's Messenger mission.

The Juno Microwave Radiometer: Analysis of Instrument Calibration and Performance

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Abstract

The performance of the Juno MicroWave Radiometer (MWR) are presented here. The results include the instrument calibration during cruise period to Jupiter, as well as stability over several Jupiter orbits made since July 2016. Juno MWR calibration is assessed using stable data points obtained from the sky during its cruise period. These same points are then used to maintain calibration stability during Jupiter orbits. Results indicate that the MWR has an absolute calibration stability better than 2%. We present an assessment of several systematic calibration issues such as antenna pattern and pointing, synchrotron emission interference etc.

1. Introduction

The NASA New Frontiers mission Juno was launched on August 5th, 2011. After spending nearly 5 years in cruise, Juno underwent Jupiter orbit insertion on July 4th, 2016. As of June 30th, 2018 Juno has orbited Jupiter thirteen times, providing invaluable information on Jupiter's atmospheric dynamics and composition.

Juno's overall objective is to understand the solar system beginnings, by understanding the origin of Jupiter. Jupiter origins can be revealed by measuring the current atmospheric composition as well as the structure of the planets internal magnetic field.

The MWR instrument is one of the payloads of Juno. The MWR measurements aid in our study of bulk properties of the atmosphere [1]. The MWR instrument carries six channel microwave radiometer on-board that operate from 600 MHz to 22 GHz. These microwave frequencies aid in probing the Jovian atmosphere down to 100 bars. The MWR instrument rotates along-track, so as to observe the atmosphere at different incidence angles. Brightness temperature measurements from MWR along with limb-darkness measurements (ratio of brightness

temperature difference between nadir and off-nadir to nadir brightness temperatures) is used to constrain bulk properties retrievals from the Jovian atmosphere.

The MWR instrument was calibrated during pre-launch and cruise period. The cruise calibration used stable vicarious sources in the galactic sky as its calibration sources. This helped tune and de-trend any calibration anomalies observed. During Juno's long orbit around Jupiter, apojove data was used to confirm the antenna beam patterns. During perijove as MWR rotates, fore and aft measurements were used to confirm the lack of systematic errors in the calibration. The two years of data since Juno orbit insertion has consistently been tracked and the calibration has been consistent over Jupiter in terms of absolute values and inter-channel differences. The galactic sky calibration points are still used to ensure consistent calibration across perijoves.

The next section gives a few more details with respect to the MWR microwave radiometer and a summary of calibration results is presented in Section 3, before summarizing in Section 4.

2. MWR instrument

The MWR instrument has six channels at 600 MHz, 1.2 GHz, 2.5 GHz, 5.5 GHz, 10 GHz and 22 GHz. The two low frequency channels have a patch array antenna with a 20 degree beam-width and the other channels have a slotted waveguide or horn antenna with 12 degree beam width. The five higher channels are co-located, whereas the 600 MHz channel is rotated by 120 degrees from the other five in the spin plane direction.

All radiometers are equipped with internal calibration sources. The radiometers have three noise-diode sources that afford redundancy in the channels and provide receiver gain measurements. The radiometers also have an internal dicke-load to provide offset calibration. The noise-diode and dicke-loads calibrate

everything behind the reference load plane of the radiometers. Any front-end RF signal between the antenna and the reference plan is calibrated with via instrument thermistors and pre-launch calculated front-end coefficients.

3. MWR Calibration and Results

Juno MWR performed pre-launch calibration end-to-end test through the antenna with a large thermally uniform target to tune the RF front-end calibration parameters of the radiometer channels over temperature. These results indicated a preliminary absolute calibration stability of less than 2%.

Post-launch, the MWR instrument spin-plane ensured that the instrument consistently observes two galactic sky calibration points at the spin-pole (Fig 1). These points provided an invaluable second calibration point (cold) with respect to the pre-launch end-to-end calibration data. The spin-poles were used to maintain and monitor calibration stability of the MWR instrument as well as recalibrate the front-end losses, noise-diode values to better match the observed TAs (Fig. 2).

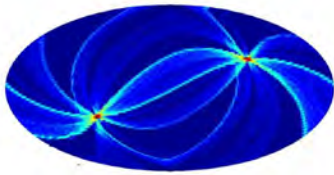


Figure 1: Spin-poles as observed during Juno Cruise.

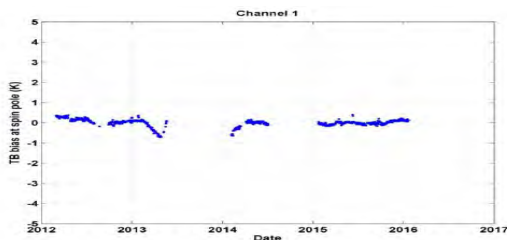


Figure 2: Brightness Temperature bias (K) tracked while observing the spin-pole

During apojove, the MWR team confirmed the pre-launch antenna pattern measurements by using Jupiter as a point source while the instrument rotated over a 10 hour period. The point source observed at

several antenna angles relative to boresight indicate no difference above the instrument noise-floor. Similarly during perijove, any systematic intrusion due to the synchrotron, or different orbital positions was analyzed by taking fore and aft differences for the same emission angle over the same location. Results indicated a mean of around 0 K for all channels with agreement to within 0.2% in terms of standard deviation. As expected, fore-aft differences became larger over larger emission angles.

Juno perijove results from PJ1 to PJ13 for all six channels have shown to be extremely consistent relative to each other in terms of absolute level. The MWR data is currently undergoing recalibration by using the non-perijove data and spin poles along with measured instrument temperature variables to further tune the calibration algorithm.

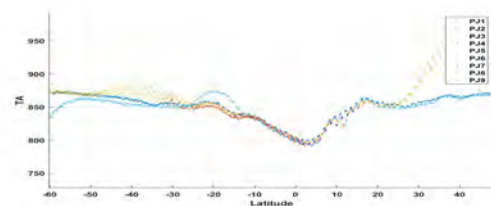


Figure 3: Channel 1 on MWR over several Perijoves. The TA is very consistent across perijoves

4. Summary and Conclusions

The Juno MWR shows excellent calibration performance. The instrument has an absolute calibration of less than 2% with no observed systematic errors or drifts.

Acknowledgements

The research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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Instruments for Dragonfly, a Rotorcraft Lander Concept for In Situ Exploration of Titan's Organic Chemistry and Habitability

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Abstract

1. Introduction

Titan's abundant complex carbon-rich chemistry, interior ocean, and past presence of liquid water on the surface make it an ideal destination to study prebiotic chemical processes and document the habitability of an extraterrestrial environment [e.g., 1-6]. In addition to the level of organic synthesis that Titan supports, opportunities for organics to have interacted with liquid water at the surface (e.g., sites of cryovolcanic activity or impact melt [4]) increase the potential for chemical processes to progress further, providing an unparalleled opportunity to investigate prebiotic chemistry, as well as to search for signatures of potential water-based or even hydrocarbon-based life.

The diversity of Titan's surface materials and environments [7] drives the scientific need to be able to sample a variety of locations, thus mobility is key for in situ measurements. Titan's dense atmosphere provides the means to access different geologic settings over 10s – 100s of kilometers apart, via exploration by a vehicle with aerial mobility. Dragonfly is a rotorcraft lander mission currently being studied in Phase A under NASA's New Frontiers Program that would take advantage of Titan's unique natural laboratory to understand how far chemistry can progress in environments that provide key ingredients for life.

2. Dragonfly Science Objectives

Compositions of the solid materials on Titan's surface are still essentially unknown. Compositional measurements [8] in different geologic settings [7,9] will reveal how far organic chemistry has progressed. Sites where transient liquid water [4] may have interacted with the abundant photo-chemical products that litter the surface [2] are of particular interest.



3. Dragonfly Science Measurements and Payload

At each landing site, bulk elemental surface composition can be determined by a neutron-activated gamma-ray spectrometer [8, 10]. Surface material can be sampled with a drill and ingested using a pneumatic transfer system [11] into a mass spectrometer [8, 12] to identify the chemical components available and processes at work to produce biologically relevant compounds. Meteorology and remote sensing measurements can characterize Titan's atmosphere and surface [13-15] – Titan's Earth-like system with a methane cycle instead of water cycle provides the opportunity to study familiar processes under different conditions. Seismic sensing can probe subsurface structure and activity [16].

The science payload includes the following instruments:

3.1 Dragonfly Gamma-Ray and Neutron Spectrometer (DraGNS)

This instrument enables the elemental composition of the ground immediately under the lander to be determined without requiring any sampling operations. Because Titan's thick and extended atmosphere shields the surface from cosmic rays that generate characteristic gamma-rays on Mars and airless bodies,

the instrument includes a pulsed neutron generator to induce the element-specific gamma-ray signatures. The abundances of carbon, nitrogen, hydrogen, and oxygen allow a rapid classification of the surface material (for example, ammonia-rich water ice, pure ice, and carbon-rich dune sands). This instrument also permits the detection of minor inorganic elements such as sodium or sulfur. This rapid geochemical reconnaissance will provide context and can inform the science team as to the types of sampling (if any) and detailed chemical analysis that should be performed on a site-by-site basis.

3.2 Dragonfly Mass Spectrometer (DraMS)

A central element of the payload is a highly capable mass spectrometer instrument with front-end sample processing able to handle high-molecular-weight materials and samples of prebiotic interest. The system has elements from the highly successful SAM (Sample Analysis at Mars) instrument on Curiosity, which has pyrolysis and gas chromatographic analysis capabilities, and also draws on developments for the ExoMars/MOMA (Mars Organic Material Analyzer).

3.3 Dragonfly Geophysics & Meteorology Package (DraGMet)

This instrument is a suite of simple sensors with low-power data handling electronics. Atmospheric pressure and temperature are sensed with COTS sensors. Wind speed and direction are determined with thermal anemometers (similar to those flown on several Mars missions) placed outboard of each rotor hub, so that at least one senses wind upstream of the lander body, minimizing flow perturbations due to obstruction and by the thermal plume from the Multi-Mission Radioisotope Thermoelectric Generator (MMRTG). Methane abundance (humidity) is sensed by differential near-IR absorption. Electrodes on the landing skids are used to sense electric fields (and in particular the AC field associated with the Schumann resonance, which probes the depth to Titan's interior liquid water ocean) as well as to measure the dielectric constant of the ground. The thermal properties of the ground are sensed with a heated temperature sensor to assess porosity and dampness. Finally, seismic instrumentation will assess regolith properties (e.g., via sensing drill noise), search for tectonic activity, and possibly infer Titan's interior structure.

3.4 Dragonfly Camera Suite (DragonCam)

A set of cameras, driven by a common electronics unit, provides for forward and downward imaging (landed and in flight), and a microscopic imager can examine surface material down to sand-grain scale. Panorama cameras can survey sites in detail after landing. In many respects, the imaging system is similar to those on Mars landers, although the optical design takes the weaker illumination at Titan (known from Huygens data) into account. LED illuminators permit color imaging at night, and a UV source permits the detection of certain organics (notably polycyclic aromatic hydrocarbons) via fluorescence.

4. Summary and Conclusions

The Dragonfly mission concept [17] is a dual-quadcopter designed to take advantage of Titan's environment to explore dozens of diverse sites, covering 10s – 100s of kilometers during its >2-yr mission, to characterize Titan's habitability, investigate prebiotic chemistry, and search for chemical signatures indicative of water-based and/or hydrocarbon-based life.

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Coordinated Multimedia Efforts on Mars 2020

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1. Introduction

Groundbreaking multimedia sensory development is being planned for the NASA Mars 2020 [M2020] rover mission. This will include multiple independently sourced data systems for both audio and video capture.

Through a coordinated effort between department heads and staff of these independent systems, it may be possible to strategically capture and later combine all this data into a singular multimedia presentation for a more robust analysis that could greatly enhance its scientific viability.

This abstract seeks to provide joint awareness and promote inter-departmental communication amongst the various science teams of M2020 engaged in this instrumentation development in order to anticipate, and address prior to launch, any variables that may give rise to an ease of collaboration in later combinatory multimedia development once the rover is in operation on the Martian surface.

2. Mars 2020 Multimedia Systems

A brief overview of multiple audio and video sources that are being planned for M2020 are listed below. Note that only true video sources are indicated. While a still-camera can in theory produce video from multiple sourced single images via time-lapse photography, the goal of this abstract is to provide capability for synchronized stereophonic audio and video playback.

a. Listed Independent Data Sources

There are four separate and independently operated multimedia data capture systems planned for M2020, as follows:

- (1) Entry Decent and Landing Camera System (EDL-C): This system comprises multiple video sources and a monophonic (mono) audio source, all of which are operated under the umbrella of the EDL-C system

and designed primarily for operation during the initial M2020 landing sequence.

- (2) SuperCam: This system includes a mono audio source, designed primarily for usage throughout the operation of M2020.
- (3) Mastcam-Z: This system builds upon the operational design parameters of the MSL Mast Camera, including HD video capture.
- (4) SHERLOC: This system upgrades the MSL MAHLI camera into WATSON, which will carry the same video capabilities thereof.

2.2 Pre-Existing Coordination Efforts

The only currently planned audio-video (A/V) coordination within M2020 exists within the EDL-C system, wherein multiple video camera and single-source mono audio data will be captured in a one-time event during the “sky-crane” landing sequence. Both video and audio recording for this sequence are operated and recorded directly under the blanket of the EDL systems management and computer systems, thus coordination of data capture and latter Earth-bound sequencing is already under full consideration.

3. Stereophonic Audio Capture

As stated above the M2020 rover will employ two single-sourced monophonic audio systems. Though the architecture of these independently designed systems will most likely be varied, it is nevertheless possible to combine these two mono data sources into a viable stereophonic audio playback.

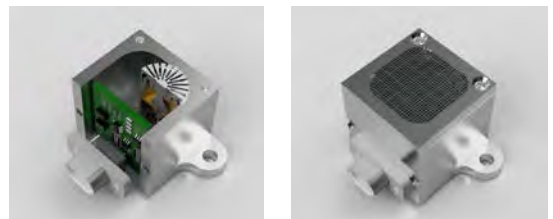


Figure 1: Early design for M2020 EDL-C Microphone [3]

Key to producing this stereo signal will be a coordinated planning effort for timed recording sequences, shared between the SuperCam and EDL-C systems. A reliable means of time-stamping data captured from both systems will be required for both signals to be time-aligned by an audio engineer back on Earth to produce true stereo playback without any phase variance or incoherence.

Disparity in engineering and design aspects of the microphones themselves do not inherently pose any detrimental obstacle in combining the audio signals. Likewise, sampling and bit rate capture in the data capture systems may be ideally coordinated but pose no inherent risk if varied. As long as no latency is present in either system, variance in recording levels and equalization concerns can be compensated for during the assembly process to recreate as closely as possible an accurate stereophonic audio sampling.

4. Synchronized A/V Capture

Video recording via the Mastcam-Z and WATSON instrumentation can likewise be coordinated with one or both microphones to produce mono/stereo visual playback. An investigation of the possibilities of numerous recording scenarios (including potential for both stationary and mobile recording events) ideally should be noted and explored for scientific relevance and ease of execution, as well as cost-benefit analysis.

5. Prior IPM relevance

The considerations herein represent an example of real-world development of the “Bridging the Gap” panel discussion at IPM 2016 held in Pasadena, CA., which “emphasized the importance of scientists, technologists, and engineers connecting at meetings...(these) groups must be willing to consider partnerships with private industry, learn new roles, and become fluent in disciplines outside of their formal training.” [4]

6. Summary and Conclusions

There is a breadth of knowledge and information to be gained by the independent audio and video measurements of these systems. Similar to our shared experience of day-to-day awareness and perception of human audio/visual sensory input, a coordination in the application and presentation of these systems may very well result in an exponential rise in the interpretation and useful application of this data.

The potential for a rise in examination and troubleshooting of various M2020 systems through a multimedia data presentation, including mobility and terrain mapping, helicopter observations, drilling and sampling cycles, weather measurements and so forth cannot be understated. Nor can the positive effects of increased multimedia presentation for the purposes of general public interest and outreach, in a manner that affects the imagination and inspiration among youth as well as public support for the funding base of future missions of exploration to Mars and beyond.

Acknowledgements

The author gratefully acknowledges the talented research team at Zandef Deksit Inc., of Caesar T. Garcia and Brad Avenson. Additional insight and assistance into NASA / M2020 systems and coordination thoughtfully provided by Joseph L. Carsten, Jim Bell, Edward Miller, Todd Fulks, Chris Boshuizen, Matthew T. Wallace and Roger Wiens.

Special acknowledgement to Robert A. Jones (SBIR) and David Graziosi (ILC Dover) for continual support of research into extraterrestrial audio design, as well as prior studies conducted by countless individuals on prior missions and development teams including NASA Phoenix Mars Descent Imager (MARDI) and Mars Polar Lander (MPL), and the Planetary Society.

Systems coordination for development of the EDL-C microphone in partnership with Zandef Deksit, Inc. has been under the direction of David C. Gruel / JPL.

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Multi-Parameter Approach to Habitability (M-PAtH)

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Abstract

We are standing on the cusp of a major discovery in planetary sciences. For the first time in human history, upcoming surveys and telescopes working together will be able to remotely detect potential biosignatures in exo-Earth atmospheres and discover signs of life beyond our Solar System. The conviction that biosignatures will be detected by remote sensing from space telescopes is moderated by current time limitations and observational opportunities. Unfortunately, none of the new space- and ground-telescopes will be solely dedicated to the characterization of exoplanet atmospheres. In order to make the most of the limited observational resources available, optimal target selection will be of the utmost importance. Selection of targets for this characterisation relies on ambiguously defined concepts of habitability, which are currently constrained by only the density of the planet and the distance from its host star [1][2]. With the expected increase in the number of detected exoplanets from TESS, we might end up with hundreds of planets that suit these criteria and are accordingly all equally likely to host life [3]. Therefore, it is imperative that we rethink our classification of what makes a planet habitable.

Recent research has shown that a planet's ability to maintain liquid water and potentially host life depends on the type of star, the planet's density, atmospheric composition and planet-star interactions [4][5]. Additionally, there are a variety of previously undefined factors such as magnetic field, albedo, impact events, and plate tectonics that could also affect habitability. By analysing, modelling and constraining how these factors interact on any given planetary body, we can generate a flexible framework for prioritisation that involves multiple observable characteristics and features that influence continuous planetary habitability. Based on the results, we will be able to provide a revised model of planetary habitability and suggest a suitable strategy for future astrobiological and biosignature observations of life in the universe. In conjunction with the rapidly

increasing information from exoplanet databases expected within the next 2 years, this research will help determine optimal targets for near-future ground- and space-based spectroscopic observations of planetary atmospheres and the potential detection of life in space.

Acknowledgements

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Developing a 3D Printed Fluidic Manifold for Support of a Microfluidic Chemical Analysis System for Space Flight

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Abstract

Enceladus Organic Analyzer (EOA) is an *in situ* detector of biosignatures which measures composition and chirality of amino acids at icy moons [1]. We present a novel fluidic manifold to provide support of the space-based chemical analysis system on the microfluidic chip. The manifold provides all fluidic and gaseous interfaces to the microfluidic chip and provides structure for the optical and electrical interfaces, as well as the functional components in support of operations. After evaluating various manufacturing methods, we determine the best approach is 3D printing by Direct Metal Laser Sintering (DMLS) in Titanium 6Al-4V.

1. Introduction

Supported by NASA MatISSE program, the Space Sciences Laboratory at the University of California at Berkeley (SSL) was presented with the challenge of supporting a chemical laboratory in space. The task is to develop the Enceladus Organic Analyzer (EOA) instrument to NASA TRL 6 with a clear and defined path to TRL7. The core Organic Analyzer of EOA essentially comprises a microfluidic “Lab on a Chip” device which labels organic functional groups with fluorescent dye, separates compounds by electrophoresis, and detects by laser induced fluorescence. Limits of detection for undiluted labeled samples are sub-ppb. EOA has a collector with macrofluidic sample processing for an Enceladus plume sample, intended for a fly-through mission. The same Organic Analyzer also fits in a configuration for a lander (Microfluidic Organic Analyzer for Biosignatures, MOAB).

We describe here the primary mechanical development work underway to mature the instrument, including determining how to provide services to the numerous valves, pumps, sources, reservoirs and reagent wells that make up the chemical test lab – all of which is arranged on a 100mm diameter chip.

2. ICD Definition

EOA Science and Engineering together defined the basic parameters of the chip. We made a reasonable estimate of 5 samples plus 1 blank for target analyses of amines/amino acids and carboxylic acids groups. This bounded the number of reagent wells and hence the number of valves to process the samples, the analysis geometry, and the required source materials. A total of 39 valves and 4 source lines are required for this generation of development. Addressing and usage are defined for each port. Additional access points and high voltage (HV) clearances were added as required for the various services at this early stage. The result was an Interface Control Document (ICD) in the form of a drawing. Changes which impact on other components are tightly controlled at this level.

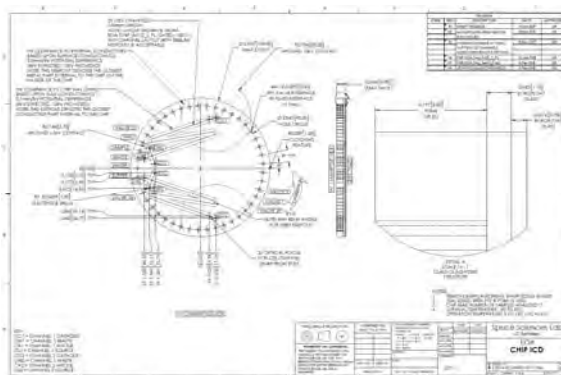


Figure 1: The Chip ICD, based on early decisions by full team, allows different institutions and disciplines to progress independent of one another.

2.1 Geometry Considerations

The basic circular architecture of the microfluidic chip and the desire for light and compact structures for space flight recommend a cylindrical interface for the associated valves and source lines. Access points at the top of the chip provide specific orientation for the interface between source lines and the chip inputs. We

explored various configurations to determine the most compact final arrangement as well as the most straightforward plumbing requirements. The solution was to incorporate valves into the manifold at the point of use. A stock 3-port latching valve was chosen from The Lee Company [2] that meets space-flight materials requirements, is compact and is similar to heritage valves used for prototype applications (TRL3–5). This design simplifies plumbing, lowers risk of mistakes, removes dead space in the plumbing and limits potential leaks.

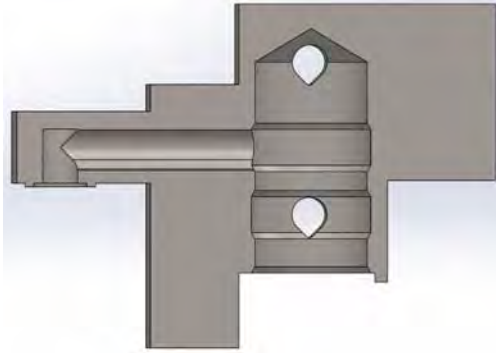


Figure 2: Manifold profile section showing the valve interface and access plumbing to interface with the defined chip.

3. Material Selection

The chip and manifold must withstand a proposed flight survival range of -50C to +50C, based upon typical mission definition documents for deep space cruise to the outer solar system. The thermal environment makes the interface between glass substrate and cylindrical interface challenging, because the glass must be protected from contraction of the metallic structure around it. Further, the optical nature of the detection system requires optical elements to be interfaced and registered throughout the flight environments without losing alignment or breaking due to stresses. To endure these potential extremes, either elaborate isolation measures were needed, or choice of a suitable material was required. Invar 36 provides a material that meets the CTE requirements for interfacing with glass and lenses and yet is relatively easy to machine. However, building the complex manifold routings would be challenging using standard machining processes.

3.1 A Solution: 3D Printing

The development of Direct Metal Laser Sintering (DMLS) as a 3D manufacturing technology provided another solution: complete printing in metal: 6Al-4V Titanium has suitable properties (see Table 1).

Table 1: Material properties of DMLS Titanium. [3]

Material	Yield Strength	Modulus of Elasticity	Density
Ti64	150ksi	16Msi	100%

The DMLS process allows complex vias to be routed within a single manufactured part. Leakage concerns are minimized because the part is constructed as a solid unit and has no interfaces. Complex interfaces for the plug-in style valves are incorporated directly into the part without the need for complex machining or specialized tools. Some modification of via geometry was necessary to increase the successful construction of the manifold (note teardrop profiles in Figure 2). Final machining is required to provide the smooth o-ring seats and flat interfaces required by the valves, source lines and chip. Threads will also be tapped after printing.

4. Summary and Conclusions

The design of a fluid manifold for a space-based chemical analysis instrument is developed from initial requirements through design considerations to final process selection of a Direct Metal Laser Sintering manufacturing method.

Acknowledgements

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MERTIS – MErcury Radiometer and Thermal infrared Imaging Spectrometer

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Abstract

The MErcury Radiometer and Thermal infrared Imaging Spectrometer (MERTIS) [1] is part of the payload of the Mercury Planetary Orbiter spacecraft of the ESA-JAXA BepiColombo mission that will be launched in October 2018. MERTIS combines an imaging spectrometer covering the wavelength range from 7-14 μm with a radiometer covering the wavelength range from 7 to 40 μm . The instrument will map the whole surface of Mercury with a spatial resolution of 500m for the spectrometer channel and 2km for the radiometer channel. The compositional map of Mercury provided by MERTIS will allow unique insights into the evolution of the least explored terrestrial planet. MERTIS will also address directly questions raised by the NASA MESSENGER mission. For example we will be able to provide spatially re-solved compositional information on the hollows and pyroclastic deposits and answer the question whether hollows are actually predominately sulfide deposits.

1. Introduction

The availability of uncooled microbolometer arrays allowed a new generation of thermal infrared instruments [2, 3]. Based on this technology we MERTIS in 2003 for the ESA-JAXA BepiColombo mission.

1.1 The MERTIS instrument

MERTIS combines IR grating spectrometer (TIS) with a radiometer (TIR), both operating in a push-broom mode. It represents a modular concept of the sensor head, electronic units and power/calibration systems within a mass budget of only 3.0 kg and power consumption of less than 12 W nominal.

MERTIS features more than 10 miniaturized, highly integrated subsystems, including mirror optics, two

IR detectors (bolometer and radiometer) with read-out electronics, two actuators (pointing unit and shutter), two on-board blackbody calibration targets at 300 and 700 K, two baffles (planet, space), heater, temperature sensors, and two cold redundant instrument controllers and power supplies (Fig. 1).

The optical design of MERTIS combines a three mirrors anastigmatic (TMA) with a modified Offner grating spectrometer [3]. A pointing device allows viewing the planet (planet-baffle), deep space (space-baffle), and two black bodies at 300 K and 700 K temperature, respectively. The combination of spectrometer and a radiometer channel using the same optics and calibration sources allows retrieving emissivity, surface temperature and thermal inertia independently [4,5].

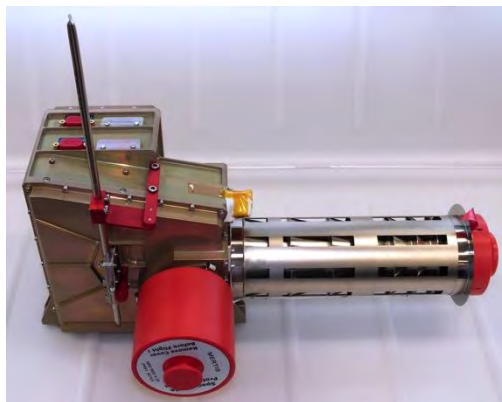


Figure 1: MERTIS flight model before delivery to ESA for integration on the spacecraft

1.2 MERTIS TIS

TIS operates between 7 and 14 μm with a 200nm spectral resolution and will record the day-side emissivity spectra from Mercury at a spatial resolution up to 280m. The instrument uses an uncooled microbolometer, developed under ESA contract at LETI and ULIS in France. This is the first

space-qualified microbolometer developed and built in European. It is based on the commercial detector with 160 x 120 pixels with a pixel size of 35 μm . A part of the development the detector was not only space qualified but also the sensitivity was significantly increased and the cut-on wavelength was reduced from 8 to 7 μm . The detectivity (NEP) of the detector is in the range of 10-15 pW.

1.3 MERTIS TIR

Sharing the same optical path a pushbroom radiometer (TIR) is implemented by an in-plane separation arrangement, effectively acting as the slit of the spectrometer. The TIR uses a thermopile line detector arrays of $7 \cdot 10^8 \text{ cm Hz}^{1/2} \text{ W}^{-1}$ detectivity. TIR is going to measure the surface temperature at day- and night side at a spatial resolution of 2km with two broadband channels. The 7-14 μm channels facilitates cross calibration with the spectrometer, while the 7-40 μm channel allows to accurately measure the night-side temperatures of Mercury with a noise equivalent temperatures difference (NETD) of 1K at 80K

2. Getting ready for the journey to Mercury

BepiColombo is a dual spacecraft mission to Mercury to be launched in October 2018 and carried out jointly between the European Space Agency (ESA) and the Japanese Aerospace Exploration Agency (JAXA). BepiColombo uses a solar electric propulsion system. The trajectory is a combination of low-thrust arcs and flybys at Earth (1), Venus (2), and Mercury (5) and will be used to reach Mercury with low relative velocity. Before arriving at Mercury BepiColombo will perform Venus flybys in 2019 and 2020. The launch will be performed by an Ariane 5 from the ESA launch facility in Kourou (French Guyana). The ESA Mercury Planetary Orbiter (MPO) and the JAXA Mercury Magnetospheric orbiter will be launched in a composite with a propulsion element - the Mercury Transfer Module (MTM) and a sunshade cone (MOSIF) to protect the MMO.

2.1 Operation planning

We are currently preparing for launch and the Near-Earth commissioning phase, as well as planning for Venus flybys, and the first year of Mercury

observations. For the Mercury observations, we are developing a Science Activity Plan (SAP), which will be verified with our Science Traceability Matrix. This requires a definition of hierarchic observation sequences and the implementation of our operations concept into ESA planning tools.

2.2 Ground Reference Model:

The MERTIS FS is setup at the Planetary Spectroscopy Laboratory at DLR in Berlin and serves as ground reference model for testing software procedures and instrument performance. For this purpose, we developed and built a nitrogen-purged chamber with two black bodies (high and low T) that allow us to simulate observations at Mercury. The set-up is fully functional and will support our launch and Near-Earth commissioning activities (Fig. 2).



Figure 2: MERTIS ground reference model

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The Cassini Mission – Lessons Learned

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Abstract

The Cassini Mission completed mission operations in September 2017 with a spectacular dive into Saturn's atmosphere after 13 years exploring the Saturn system. Dubbed a "discovery machine" by its scientists, Cassini returned an incredible number of discoveries and scientific revelations. Among the mission's many revelations were the unmasking of the surface of Saturn's giant moon Titan and revealing the astonishing nature of the tiny moon Enceladus, which appears to have all the ingredients for life. The mission was both a scientific and engineering triumph that will fuel scientific research for decades to come. In order to achieve the incredible scientific return from the mission, the flight system operators had to overcome a number of significant challenges. Among these were

- 1) 12 body fixed instruments, each with their own science teams (spread throughout Western Europe and the US) with vastly differing observing campaigns and scientific objectives;
- 2) Five distinct investigation topics (Saturn, Rings, Titan, Icy Moons, Fields & Particles) each with competing priorities;
- 3) A partner spacecraft (the ESA developed Huygens Titan Probe) with its own set of objectives and requirements;
- 4) Limited data storage capability;
- 5) Aging, balky, and in some cases, failed hardware;
- 6) Limited opportunities and time;
- 7) New discoveries that drove reprioritization and redesign.

Our talk will summarize some of Cassini's most profound discoveries and discuss how the flight system developers and operators overcame, and in some cases, utilized the constraints and challenges of the extremely capable and ambitious Cassini spacecraft. Many of their solutions and observations will have relevance for any multi-instrument planetary mission

Six years of geochemical measurements in an ancient martian lakebed with the Curiosity rover in Gale crater

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Abstract

The Sample Analysis at Mars (SAM) instrument suite of the Mars Science Laboratory (MSL) mission has enabled a wide range of geochemical investigations. These include: (1) a range of light isotope measurements of both gases in the present atmosphere and those released from solid samples that ground models of atmospheric loss and redox transitions in ancient aqueous environments, (2) K/Ar dating of rock formation ages, (3) cosmic radiation exposure determinations from release of noble gases, (4) clays, perchlorates, sulfates, and hydrated minerals fingerprinted by evolved gas analysis (EGA), (5) atmospheric composition (including methane) and its seasonal variation, and (6) organic compounds extracted from soils and rocks. These will be briefly summarized with selected examples of how SAM geochemical measurements are robustly complemented by data from the same samples from the x-ray diffractometer (CheMin) and the alpha-particle x-ray spectrometer (APXS).

1. Introduction

The ten instruments on the one-ton nuclear powered Curiosity martian rover have enabled groundbreaking exploration of the habitability of Mars in the ancient lakebed of Gale crater. Following its arrival in August of 2012 the Curiosity rover has been systematically exploring an environment that ~3.5 billion years ago was a long-lived lake that had formed in a crater produced by an impact event hundreds of millions of years earlier. Later in the Hesperian following burial of the lake deposits and lithification, exhumation and erosion the present structure was revealed showing a mineralogical diversity of layers in the central mound (Mt. Sharp) of Gale crater. The Curiosity rover traversed to the lower layers of Mt. Sharp, sampled the active Bagnold dune field, explored hundreds of meters of sedimentary stratigraphy of the Murray formation, and reached a unit identified from orbit as hematite-rich designated the Vera Rubin Ridge. The next phase of the mission will explore additional clay and

hydrated sulfate rich layers further up the lower layers of Mt. Sharp's central mound.

2. Isotopes of H, C, O, N, and Ar

Isotopic enrichment of the heavy isotopes of C and O in CO₂ [1], H in H₂O [1], N in N₂ [2], and Ar [3,4] all point toward substantial atmospheric loss over billions of years of martian history. Measurement of the D/H in the water that formed clays found early in the mission [5] provided evidence that substantial water likely amounting to 10's of meters (global equivalent depth) were lost from the atmosphere both before and after the time the Gale crater lake had formed. In situ SAM calibration runs provided a small correction [6] to earlier reports of Ar and N₂ mixing ratios and demonstrated consistency with both Viking and meteorite N isotopic measurements.

3. Chronology

In a first for in situ planetary chronology, the determination of the amount of ⁴⁰Ar thermally released into SAM from a drilled Yellowknife Bay Cumberland sample combined with the K elemental abundance measured by the APXS instrument in the same mudstone enabled a K/Ar rock formation age of 4.2 billion years to be established [7]. From the same sample evolved ³He, ²¹Ne, and ³⁶Ar gave independent estimates [7] of ~80 million years for the exposure of this sample to cosmic radiation as surface erosion slowly removed the overlying material. Several other chronology experiments have been conducted using combined SAM and APXS data with one of the most interesting revealing formation of jarosite [8] by acidic/aqueous processes hundreds of millions of years after the sedimentary layers of the Murray sequence had formed.

4. Evolved gas analysis

A summary of EGA data [9] from the first 11 sites (9 drill holes and 2 scooped samples of eolian sediments) interrogated by SAM illustrates the signatures of evolved H₂, H₂O, SO₂, H₂S, NO, CO₂, CO, O₂, and

HCl. Although the hot O₂ produced by decomposition of perchlorates or oxychlorine compounds converts much of the reduced carbon into CO₂ or CO these results demonstrate 10's to 100's of parts per million by weight of carbon in typical samples. Phyllosilicates, nitrates, sulfates, and carbonates are also revealed by evolved H₂O, NO, SO₂, and CO₂ while the evolution temperature further constrains the mineral type. These measurements are highly complementary to those of the CheMin mineralogy experiment that does not detect the substantial amorphous fraction found in every sample.

5. Atmospheric variability

The seasonal changes in the non-condensable (N₂, O₂, and Ar) mixing ratios caused by the annual CO₂ polar condensation has now been followed for more than 3 Mars years. Atmospheric methane has spiked up to several parts per billion on several occasions during the mission and seasonal variations in the sub-parts-per-billion background methane abundances have recently been reported [10].

6. Organics

The first in situ detection of organic compounds from the surface of Mars was of chlorobenzene and chlorinated alkanes [11] from the Cumberland mudstone. A later report [12] of sulfur compounds such as thiophene and other aromatic or alkyl compounds shows that in the higher temperature releases from some samples parts per million of carbon containing compounds can survive the combustion caused by the decomposition of perchlorates and oxychlorine compounds.

7. Summary and Conclusions

The SAM instrument working in concert with other investigations of the Curiosity rover has provide fundamental steps forward in understanding ancient environments on Mars. The MSL mission has paved the way for a more direct search for ancient or modern life on this planet.

Acknowledgements

MSL's SAM was funded by NASA's Mars Exploration Program and implemented by numerous dedicated and talented engineers, technicians, and scientists.

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A Sub-millimeter sounder for vertically measuring Mars winds, water vapor, and temperature

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Abstract

We are developing a submillimeter instrument that will be able to measure vertical profiles of wind, water vapor, and trace gases in the Martian atmosphere, along with simultaneous temperature profiles. We envision that the instrument would fly on an orbiter in a near-circular polar or inclined orbit. We describe the instrument and the performance analysis.

1. Introduction

The vertical water vapor and winds on Mars are not well known, yet are critical for understanding fundamental Martian processes and for ensuring safe landing of robotic and human spacecraft.

NASA's Next Orbiter Science Analysis Group [NEX-SAG; 1] recognized the need for these measurements and envisioned a sub-mm instrument aboard a possible Mars orbiter launched in 2022. One of the five compelling science objectives noted was to *"Measure winds and characterize transport and other dynamic processes to understand current climate, water, and dust cycles, with extrapolation to past climates"* and a Finding was *"Observation of wind velocity is the single most valuable new measurement that can be made to advance knowledge of atmospheric dynamic processes. Near-simultaneous observations of atmospheric wind velocities, temperatures, aerosols, and water vapor with global coverage are required to properly understand the complex interactions that define the current climate."*

The various Mars orbiting spacecraft that have been flown to date have characterized the Martian atmosphere fairly well in terms of temperature, pressure, dust and ice aerosols, and column water

vapor amount. The ExoMars Trace Gas Orbiter will measure profiles of the abundance of many key trace gases, and MAVEN is studying the upper atmosphere and its interaction with the space environment.

However, measurements of temperature, aerosol and water vapor are needed simultaneously with wind measurements, to fully understand the impact of thermal forcing on wind, and the consequences for transport.

1.1 Submillimeter Instrument Design Concept

A passive sub-mm limb sounding instrument is ideally suited to provide the needed wind, water vapor, and temperature profile measurements. The technique has high heritage in Earth-science, and dramatic advances in associated technology in the past decade (driven in part by the communications industry) enable significant reductions in needed power, mass and complexity. Such an instrument can make measurements both day and night, and in the presence of atmospheric dust loading. Our instrument design will be optimized to sample winds, temperature, and water vapor between 0–80 km, at ~5 km vertical resolution.

Our concept [2] for such an instrument builds on prior JPL-led instruments such as the Microwave Limb Sounder currently flying on EOS *Aura* [3], and the MIRO instrument aboard *Rosetta* [4]. The instrument would employ a single, steerable antenna (~23 cm diameter), and observe a diverse set of spectral lines, both weak and strong, from multiple species to cover the full range of altitude desired (Fig. 1).

1.2 Performance Analysis

Initial simulations have been undertaken to show performance of our notional sub-mm sounder (Fig. 3).

These simulations employed algorithms and software developed for Aura MLS (suitably adapted to the Martian atmosphere) to model performance of the instrument under conditions taken from the Mars Climate Database.

2. Figures

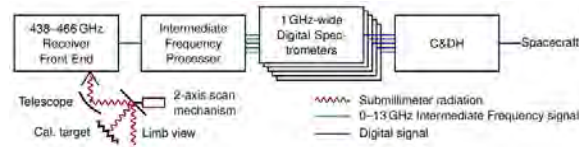


Figure 1: Block diagram of instrument

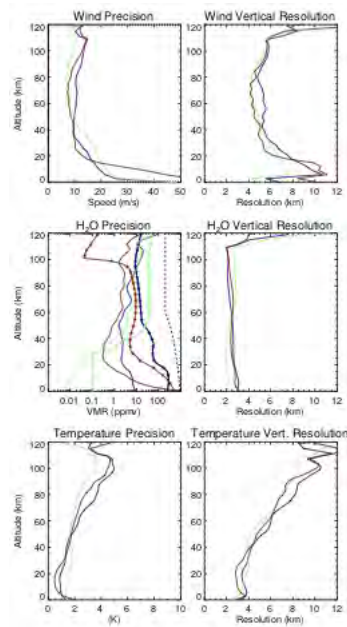


Figure 2: Precision and vertical resolution for a variety of frequencies for wind speed (top), water vapor (middle), and temperature (bottom).

3. Summary and Conclusions

There is a long outstanding desire to measure vertical winds and water vapor in the Martian atmosphere. Our studies show that our submillimetre instrument could provide these data sets with good precision and vertical resolution. Our instrument

requires moderate mass, power, and data return resources, appropriate for a Discovery-class mission, but could be scaled down (in resources, with some science capability loss) to fit on smaller spacecraft, if desired. The instrument is likely TRL-6 and could be ready for a flight in the early 2020's.

Acknowledgements

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Holographic Microscopy for Extant Life Detection

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Introduction

Optical microscopy is one of the key technologies needed for detection of extant life on other solar system bodies[1, 2]. Microscopic images can be used to identify the presence of cell-like objects and discriminate probable cells from other abiotic particles of similar scale through observations of morphology. Phase-sensitive imaging modes allow measurement of index of refraction and can be used to image transparent cells that might otherwise require the addition of stains[3, 4]. Time resolved image sequences can be used to determine particle density through observation of Brownian motion, enabling discrimination of liquid-filled vesicles from solid mineral grains; non-Brownian motion that is also inconsistent with background flow can also indicate biotic particles[5]. Because of the likely limited energy available for replication on the moons of Jupiter and Saturn, potential unicellular life would likely be present only at very low concentrations[6], requiring a search through substantial volumes of material at very high resolution.

We have been developing digital holographic microscopes (DHM) that addresses the need for high resolution search at low concentrations. Our DHM designs provide both the sub micrometer resolution necessary to detect the smallest forms of life and the high throughput needed to do so at very low concentrations. A significant feature of the holographic recording is that all objects in a large volume can be recorded simultaneously, without the need for focus or tracking to image individual objects. Figure 1 shows the results of tracking many objects in a single volume at multiple time points. At each time point, a single 2048x2048 hologram records the positions of all particles simultaneously. Images of each can be obtained afterward via digital image reconstruction at the desired plane.

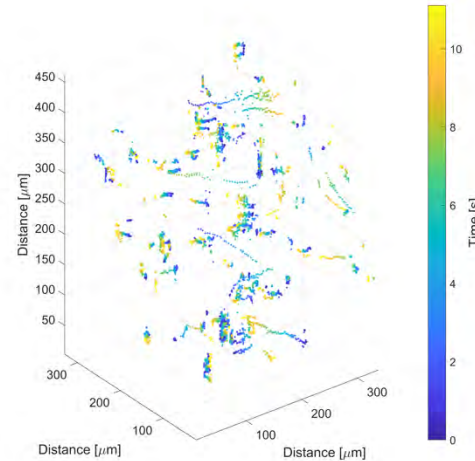


Figure 1: Sample data showing 10 s of tracking many particles simultaneously. The data each time point come from a single hologram at that time.

We have developed two promising DHM architectures for possible use in potential future life detection missions. Both architectures use off-axis reference beams, enabling both high resolution and image reconstruction at high particle concentrations[7], as well as quantitative phase imaging. A robust field instrument based on the compact common mode architecture has been used in desert and arctic environments[8, 9]. A more compact “lensless” design has been developed to a prototype but not yet fielded[10]. Both designs have similar performance (Figure 2), but different trade spaces that can make one or the other preferable for a specific application. We will discuss these characteristics and the trade space available.

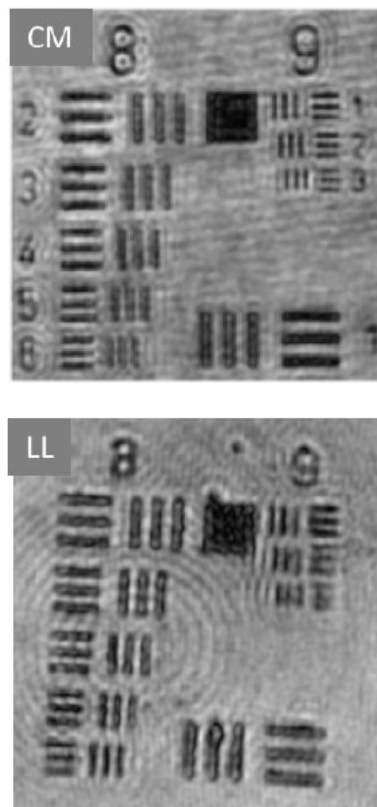


Figure 2: The common mode architecture (top) and lensless architecture (bottom) show similar resolution.

Acknowledgements

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MAJIS, the VIS-IR imaging spectrometer of JUICE

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Abstract

The MAJIS VIS/IR imaging spectrometer will provide a data gathering capability which is unprecedented in this spectral range for studying the Jupiter system. The main technical issues for developing this instrument stem from the harsh radiation environment around Jupiter. As a result, shielding constitutes a significant fraction of the total mass (60 kg), and specific on-board data processing strategies had to be developed and validated for handling the impact the deposition of charges by high energy particles on data quality.

1. The MAJIS instrument

MAJIS is an imaging spectrometer operating with two channels (VIS-NIR: 0.5 – 2.35 μm ; IR: 2.25 - 5.54 μm) in the visible and IR range. It will address most of the major science goals of the JUICE mission for studying Jupiter, its icy satellites and their environment [1]. Science observations strategies are being developed for regional and HR observations of icy satellites during flybys and during the 280 days long orbital phase around Ganymede at the end of the JUICE mission, for monitoring the atmosphere of Jupiter during nearly 4 years over a comprehensive range of local times and phase angles and for ring and exosphere investigations.

H1RG detectors from Teledyne (1024 x 1024 pixels, including 4 columns and lines of reference pixels along the edges) have been selected for both channels. An ASIC from Teledyne configures the detector, then it acquires frames and it converts the video signals in digital format. In the baseline mode, spatial and spectral binning x 2 will be implemented. The FOV (3.43°) will be covered by 400 binned pairs of rows, providing a resolution per pixel of 150 μrad , corresponding to 150 km/pixel for Jupiter as observed from 1 million km and 75 m/pixel when in circular orbit around Ganymede, at an altitude of 500 km. The nominal spectral sampling is 3.65 nm for the VIS-NIR channel and 6.49 nm for the IR channel). It will be possible to oversample up to 132 selected

spectral bands out of 508 by not binning them in the spectral direction.

The maximum data production capability of MAJIS is 16 Mbits/s. In order to best achieve its science goals within the tight downlink constraints of JUICE (2.5 Gbits/day on average), MAJIS implements flexible acquisition capabilities: spatial windowing and summing, spectral editing (transmitting only selected spectral windows) and binning. These functionalities are implemented in two processing units dedicated to each channel. After this step, the processing units implement a predictive compression algorithm derived from the CCSDS-123 standard. It will provide a baseline nominal throughput of 5 bits/data element, up to 5 Mbits/s, with the capability of adjusting the compression ratio for each spectral range depending on their signal level and level of science priority.

2. Coping with the harsh radiation environment around Jupiter

The JUICE spacecraft will operate for nearly 4 years around Jupiter, with a minimum distance of 640,000 km shortly before or after the two Europa flybys. The radiation belts of Jupiter constitute the harshest radiation environment in the solar system. This requires a combination of shielding and on-board processing so as to ensure nominal operations for the full nominal mission as well as to obtain scientifically meaningful data.

The approach selected for MAJIS has been to focus on the first goal (successful operation until EOM) by shielding the main electronics and the optical head so as to maintain the total dose received by each component below its demonstrated qualification limit. The main electronics module is located in a vault, but additional shielding is required so as not to exceed the maximum dose specifications of electronics components. The optical head is mounted on an external optical bench. The radiation issues linked with the optical head are presented in a companion abstract.

A second important issue linked with radiation is that of data quality. Data from imaging VIS-IR spectrometers flown around Saturn (Cassini/VIMS) and presently operating around Jupiter (JUNO/JIRAM) can be corrupted by “spikes”, i.e. large numbers of electrons deposited in a detector pixel by a high energy particle. The largest contribution is expected from electrons in the 0.5 – 5 MeV range. Any spike event exceeding the noise level by a significant factor precludes meaningful interpretation of the impacted pixel in terms of radiometry. Radiation modelling demonstrated that with the level of shielding which meets EOL radiation dose requirements, the occurrence rate of spikes taking into account shielding is still very high close to Jupiter, up to 13/s/data element (nominal binning 2x2) during the Europa flybys and 0.7/s/data element at Ganymede on the basis of the environment model provided by the JUICE project. As the minimum integration time of MAJIS is 0.5 s, an elaborate on-board de-spiking strategy is required.

The selected de-spiking approach consists in splitting the integration time into smaller intervals which is in any case required for observations of Jupiter and icy satellites with the VIS-NIR channel as the limited full well capability of the HIRG leads to saturation even with the shortest integration time (0.5 s). A series of sub-integrations is sorted before spatial and spectral binning, and a selected number of the lowest values are averaged. As spikes provide spurious increases of the number of collected electrons, this approach effectively selects the sub-integrations which are least likely to have been impacted by spikes. A critical underlying assumption is that the signal from the HIRG gets back to nominal for the sub-integration following a spike. It was recently validated by exposing a HIRG detector to electrons in the MeV energy range.

For the most demanding case (Europa flybys: 13 events/s/data element), splitting the 500 ms minimum integration time into 5 sub-integrations of 100 ms (which also avoids saturation even with the brightest expected targets) then selecting only the lowest value meets the MAJIS requirement of < 1% corrupted data elements after de-spiking. This procedure introduces a small negative bias which can be evaluated from the rate of residual spikes. Selecting only the lowest value instead of averaging 5 values reduces the SNR by a factor of 0.59 instead of $1/\sqrt{5} = 0.45$ due to the tighter bunching of lowest values in the left wing of a Gaussian distribution compared to random

samples. This reduction by 41% of the SNR is definitely an acceptable price to pay for reaching 99% of legitimate data elements during Europa HR observations instead of 0.15% without de-spiking. Milder de-spiking strategies (e.g. selecting the lowest of two sub-integrations, or the lowest 4 out of 6) are adequate for coping with the much lower spike rate around Ganymede or farther out from Jupiter while providing a higher SNR. Therefore, the parameters of the de-spiking strategy (sub-integration time, total number of sub-integrations, number of lowest values to be averaged after sorting) can be selected by TC.

This capability will be implemented by the two FPGA-based MAJIS proximity electronics dedicated to the VIS-NIR and IR channels, each with a processing capability of 5 Msamples/s.

3. Summary and Conclusions

MAJIS is a state of the art imaging spectrometer covering the VIS-NIR and SWIR range. Its data gathering capabilities and excellent SNR performances will make it possible to provide new insights on the composition of the surface and exosphere of icy satellites as well as on the composition of the atmosphere of Jupiter and its dynamics. Specific developments have been implemented so as to cope with the radiation environment of Jupiter, in particular a flexible de-spiking strategy aiming at obtaining > 99% of scientifically meaningful data for each observation. A comprehensive binning and editing strategy combined with an adjustable compression approach will make it possible to optimize the science return within the tight downlink constraints of the JUICE mission.

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The Europa Clipper Instrument Suite

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Abstract

By investigating the potential habitability of Jupiter's moon Europa, the Europa Clipper mission will aid understanding of habitability across the solar system. With passing of the Preliminary Design Review, the mission is on the path to enter full implementation. Here we focus on an updated view of the scientific payload moving toward the final design and fabrication phase. We review mission's science objectives and mission design to provide context for design considerations and operation of the instruments.

1. Mission Goal and Objectives

The overarching science goal of the Europa mission is to explore Europa to investigate its habitability. Following from this goal are three Mission Objectives: (1) characterize the ice shell and any subsurface water, including their heterogeneity, ocean properties, and the nature of surface-ice-ocean exchange; (2) understand the habitability of Europa's ocean through composition and chemistry; and (3) understand the formation of surface features, including sites of recent or current activity, and characterize high science interest localities. Folded into these three objectives is the desire to search for and characterize any current activity, notably plumes and thermal anomalies.

2. Exploring Europa Through Synergistic Investigations

To address the science questions of the Europa mission, NASA selected a scientific payload comprised of five remote-sensing instruments, which observe in the wavelength range from the ultraviolet through radio (radar), and four *in situ* instruments, which measure fields and particles. The capability of the science payload includes the following investigations: The *Europa Ultraviolet Spectrograph* (Europa-UVS) will measure the composition,

chemistry, structure, and variability of Europa's tenuous atmosphere. In addition, it will characterize the plasma environment and search for and characterize any active plumes to constrain surface composition and microphysics and relationships to endogenic and exogenic processes. The *Europa Imaging System (EIS)* will map Europa globally at 100 m resolution and image almost any point on the surface at better than 20 m resolution to provide constraints on the formation of surface features and insight into small-scale regolith processes, search for active plumes, and characterize the ice shell through modeling of the limb shape. The *Mapping Imaging Spectrometer for Europa (MISE)* will observe the distribution of surface compounds to identify and map the distributions of organics, salts, acid hydrates, water ice phases, altered silicates, radiolytic compounds, and warm thermal anomalies. The *Europa Thermal Imaging System (E-THEMIS)* will detect and characterize thermal anomalies that may indicate current or recent activity and provide information on thermal inertia to characterize regolith particle size, block abundance, and subsurface layering. The *Radar for Europa Assessment and Sounding: Ocean to Near-surface (REASON)* will map Europa's vertical crustal structure and search for shallow subsurface water and the deeper ice-ocean interface to provide insight into material exchange among the ocean, ice shell, surface, and atmosphere, and constrain the amplitude and phase of the tides. The *Interior Characterization of Europa using Magnetometry (ICEMAG)* investigation will measure magnetic fields generated by currents induced in Europa's subsurface ocean, ionized material ejected from any plumes, and electromagnetic coupling of the moon to Jupiter. The *Plasma Instrument for Magnetic Sounding (PIMS)* will measure ions and electrons in Europa's atmosphere to infer the contributions to the magnetic field from plasma currents and to understand the interaction and coupling of the plasma with the moon's surface and with Jupiter. The *MASS Spectrometer for Planetary Exploration (MASPEX)*

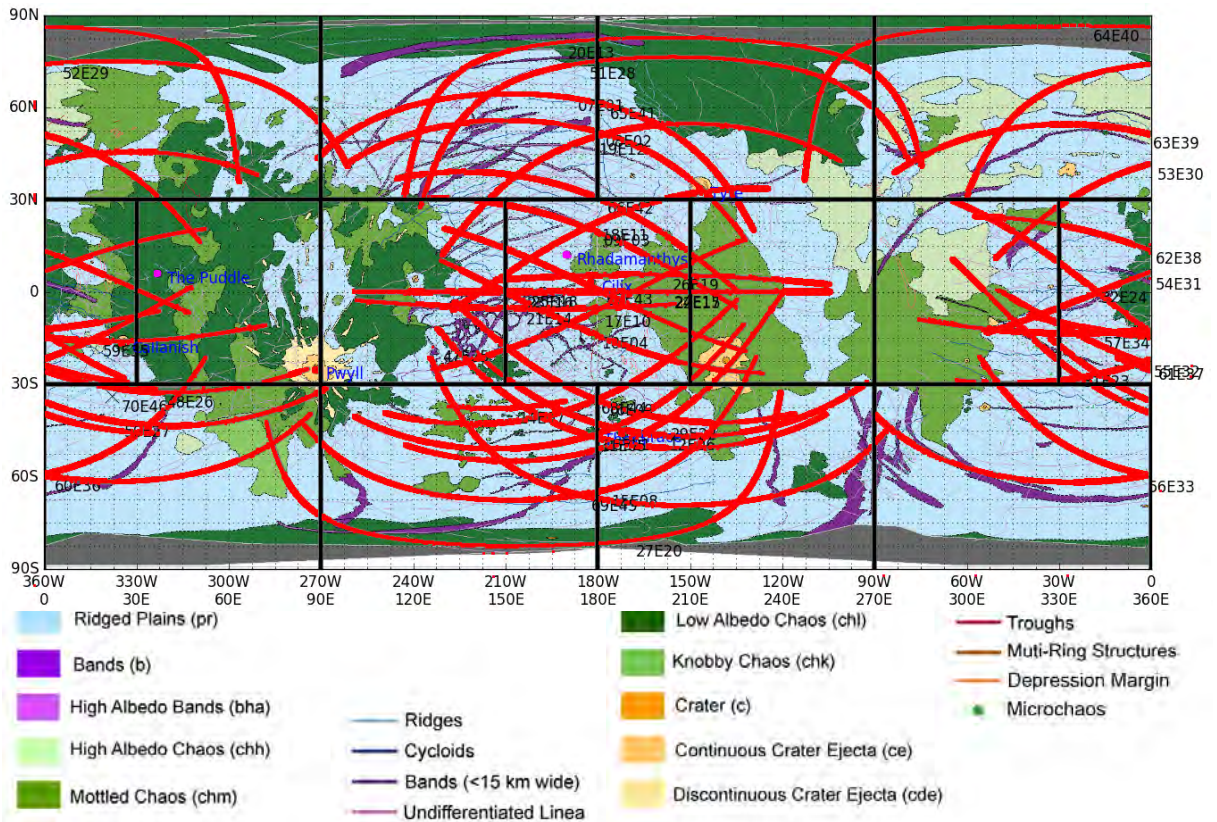


Figure 1: Planned Europa Clipper close approach ground tracks below 1000 km altitude (red) overlaid on the geologic map of Europa [1]. Blue areas are dominated by ridges. Purple areas are bands. Orange and yellow colors are associated with impact features. Chaos, pits, domes, and dark plains are most strongly concentrated in the green areas, but small examples are also found outside these regions.

will measure trace neutral species to determine the composition in Europa's sputter-produced exosphere and potential plumes. Finally, the *Surface Dust Analyzer (SUDA)* will map the chemical composition of particles ejected from Europa's surface and identify the makeup of potential plumes by directly sampling microscopic particles originating from the surface, entrained in the plumes, or delivered from elsewhere within or outside the Jovian system. In addition, the spacecraft's telecommunication system in combination with radar altimetry will enable geodesy, and the spacecraft's radiation monitoring system will provide information on Europa's energetic particle environment.

The current tour consists of 46 Europa flybys below 1000 km numbered E01 through E46, shown in Figure 1 superposed on the geologic map of Europa [1]. The altitudes of closest approach typically range from 25 km to 100 km. The tour is divided into two principal campaigns, visiting first

the anti-Jovian hemisphere followed by observations of the sub-Jovian hemisphere. As seen in Figure 1, flybys occur over a rich variety of terrains, including ridges, bands, impact features, chaos, domes, pits, and plains.

Working together, the Europa mission's robust investigation suite can be used to test hypotheses and enable discoveries relevant to the interior, composition, and geology of Europa, thereby addressing the potential habitability of this intriguing ocean world.

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Development and Performance Verification of a Robust MSMS Routine for the Mars Organic Molecule Analyzer (MOMA) Mass Spectrometer

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Abstract

In the present work, the development and performance of the MSMS routine that will be used on the flight mission for the MOMA MS is described and evaluated. The method takes a complex ion packet in the ion trap, removes ion signal from 90% of the mass range to allow for a survey mode and finally isolates the ion of interest to a 10 Da window for MSMS mode. The method was successfully tested over the operating conditions during a simulated Mars experiment in a thermal vacuum test. The method was found to operate over the temperature range from -40 to + 20 degrees Celsius. Additionally, the method can perform under a variable pressure range from 1-5 mTorr background Mars gas in the trap. Successful isolation and dissociation of ions from inorganic clusters and real world samples is demonstrated.

1. Introduction

The Mars Organic Molecule Analyzer (MOMA) [1] is a linear ion trap based mass spectrometer on the ExoMars rover mission, and will play a pivotal role in it's search for molecular "signs of life" in the near subsurface of Mars. MOMA will analyze crushed rock samples by laser desorption mass spectrometry (LDMS) at Mars ambient conditions (~6Torr, primarily CO₂) as well as by pyrolysis gas chromatography mass spectrometry (GCMS). An important mission objective is to perform unambiguous MSMS on identified species within the LDMS operational mode. A robust MSMS routine was developed for a 10 Da window over the range from m/z 100-1000. The development, characterization, calibration, and performance of this

MSMS routine on the flight MOMA instrument will be presented.

2. Methods

The Laser Desorption Ionization (LDI) MSMS routine and calibration methods were developed on the engineering test unit (ETU) MS instrument that was coupled with the MOMA ETU laser (Laser Zentrum, Germany). The MSMS routine consists of opening an aperture valve to allow ion transmission into the analyzer, sample ionization, closing of the valve, wait for pressure threshold to be met, removal of species greater than m/z 1000, coarse isolation of 100 Th window with inverse Mathieu q scan, fine isolation to 10 Th with Stored Waveform Inverse Fourier Transform (SWIFT) waveforms, post isolation clean-up RF ramps, and finally Collision-Induced Dissociation (CID). The routine was calibrated on the ETU and flight model instrument and tested on the CsI calibration target, TiO₂, Phosphorous, and other samples.

MSMS in the MOMA instrument presents several inherent challenges:

- (1) LDI of complex geologic samples results in mass spectra with ions at nearly every mass. We have found success in dealing with this complexity by breaking the ion isolation process into stages with each subsequent stage focusing on a narrower mass range.
- (2) The entire experiment occurs during the pressure decay while the instrument is being pumped down following valve opening and ion introduction. To avoid off resonance excitation resulting in dissociation, we have found that MSMS isolation steps need to occur at pressures below 5 mTorr.

Conversely to optimize MSMS efficiency dissociation needs to occur at pressures above 0.5 mTorr.

- (3) To ensure high voltage safety, the RF Voltage is limited to 700 V_{pp} in the pressure range where ion isolation occurs. Due to this limitation, different conditions are used of isolation of ions that are $\leq m/z$ 500 as compare to higher m/z ions.

The mass range for LDMS operation on MOMA is m/z 100-1000. The process of getting from this wide range, potentially containing ions at all nominal masses, to a 10 Da isolated mass window will be the subject of this presentation, including details of why the specific stage configurations were chosen. To optimize performance, the stages include both single frequency and multiple frequency (SWIFT) waveforms. Each stage of the experiment is calibrated as a function of the drive frequency, which can also shift with instrument temperature. The final result is a fully calibrated routine that can take a single input target mass and successfully isolate and fragment that species. The development processes, characterization and overall performance of the MSMS routine on the MOMA instrument will be presented.

An example of the isolation capabilities of the instrument is demonstrated in Figure 1. The top pane shows the overloaded mass spectrum of inorganic phosphorus. Notice that it is very difficult to resolve individual species. The isolation of the P₁₇ cluster at m/z 527 is shown in the middle pane. Only the target mass, 527, is used as input to the MSMS routine, no further calculations are required. The isolated spectrum appears to have a gain in sensitivity; however, this is actually due to poor ejection efficiency in the overloaded, non-isolated mass spectrum. The final pane is the dissociation of the isolated species.

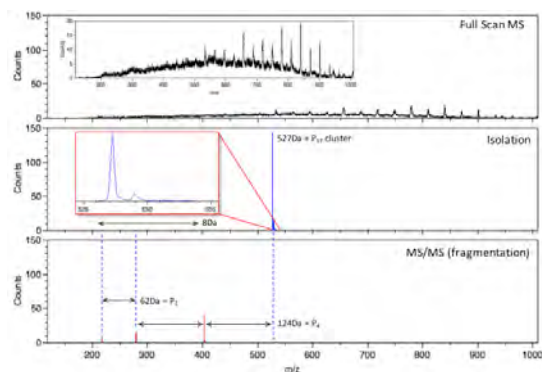


Figure 1: Top pane is mass spectrum of inorganic phosphorus, middle pane is the isolated mass spectrum of P₁₇ cluster, and bottom is the dissociation of the P₁₇ cluster.

3. Summary and Conclusions

The ability for MOMA to perform MSMS is an important capability because it allows the possibility of detailed chemical identification of an, unknown species during a search for chemical compounds that could possible be related to signs of life on Mars. The number and mass range of ions that are generated from LDI of real world samples often result in complex and dense mass spectra. The isolation and MSMS routine demonstrated in this presentation, however, is capable of cleanly isolating targeted species despite this spectral complexity.

This routine was successfully developed on one instrument and transferred to the flight instrument with only adjustments to the calibration. The minimum required calibration data sets have also been investigated and will be presented. This calibration routine leads to flight software being able to simply select intense species and then isolate and fragment those species without human intervention. Such simplified automation could be key for investigations deeper into the solar system where “scientist-in-the-loop” operations are not always possible due to mission timelines and communications constraints.

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Extraction of Organics using Supercritical Carbon Dioxide for in Situ Planetary Exploration

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Abstract

The detection of organic molecules that are indicative of past or present biological activity within the Solar System bodies and beyond is a key research area in astrobiology. Mars is of particular interest in this regard because of evidence of a (perhaps transient) warm and wet climate in its past. To date, space missions to Mars have primarily used pyrolysis technique to extract organic compounds from the Martian regolith but it has not enabled a clear detection of unaltered native Martian organics. The elevated temperatures required for pyrolysis extraction can cause native Martian organics to react with perchlorate salts in the regolith, possibly resulting in the chlorohydrocarbons that have been detected by mass spectrometry, a commonly used in-situ technique for space applications. Supercritical carbon dioxide (SCCO₂) extraction technique is a powerful alternative to pyrolysis that may be capable of extracting and delivering unaltered native organic species to an analyzer. In this study, we report the SCCO₂ extraction of astrobiologically important organics compounds such as amino acids. This work paves the path for more comprehensive extraction studies of astrobiologically relevant samples with thorough analyses of resulting extracts.

1. Introduction

Looking beyond Earth, recent efforts to explore the chemical evolution and origin of life have focused primarily on Mars, Europa, and Enceladus, which may have biochemistry similar to that of life on Earth [1]. While Mars today is a cold and dry planet, conditions in the past are thought to have been more benign [2] and included habitable environments compatible with terrestrial life [3].

The search for biogenic elements and organic compounds will be an important task for the various missions to Mars and icy moons that

are anticipated over the next few decades by major space agencies such as NASA and the European Space Agency. In recent years, exploration strategies have been developed to pursue astrobiological objectives for these targets such as determining the abundance and distribution of the biogenic elements and organic compounds, detecting evidence of ancient biota and determining whether indigenous organisms currently exist anywhere on the planet. State-of-the art analytical detection techniques with very high sensitivity will play a major role in these endeavors.

In this investigation, we examined the extraction efficiencies and subsequent detection of several representatives of twenty amino acids which commonly occur in nature using the Supercritical Carbon Dioxide (SCCO₂) technique. We chose Amino Acids (AAs) since a common chemistry at the origin of life also implies that some emergent properties of some biomolecules such as AAs in Earth life could be common on other planets. As argued by Davila and McKay [1] life on Mars, must have incorporated at least some of the canonical prebiotic amino acids and nucleobases into its biochemistry. Arguably, the presence of these compounds in a sample cannot, by itself, be used as a biomarker. However, some individual and collective properties of these compounds could be used as a diagnostic for life [4, 5]. These samples were used to model substrates to examine the effect of experimental parameters on the extraction efficiency of amino acids. Optimized extraction conditions were then used to extract native organics from JCS Mars-1. For detection, Capillary electrophoresis with laser induced fluorescence (CE/LIF) was used for the majority of experiments, and detection limits

were later confirmed with liquid chromatography/mass spectrometry (LC/MS) down to the ppb level. Despite the preliminary nature of this work, this investigation would pave new routes for more comprehensive extraction studies of polar organic biomarkers using SCCO₂ with small amounts of pure water (~5%) as co-solvent.

2. Approach

Extractions were conducted with a commercial supercritical fluid extractor system, SFT-100 (Supercritical Fluid Technologies, Inc, Newark, Delaware) comprised of an oven and a manual restrictor valve that controlled the flow of SCCO₂ out of the extraction cell. Flows of SCCO₂ and co-solvent into the extraction cell were controlled by two Teledyne ISCO Model 500 HP syringe pumps, with the syringe volumes held at a constant temperature of 20°C by a water chiller. These two flows were mixed at a tee union at the same pressure but different constant flow rates before the extraction cell. Both the oven and the restrictor were held 75°C except for experiments when temperature effect on extraction was studied (50°C). Custom extraction cells were made using 1/4" OD and 0.194" ID stainless steel tubing with an internal volume of 1.32 mL. Stainless steel frits (2 µm) were installed on both ends of the cell to prevent the escape of matrix material. Downstream of the restrictor valve, the system vent line was comprised of an 11.5 cm length of stainless steel tubing of 1/16" OD and 0.046" ID, which was inserted into test tube with 1-2 ml of water for extract collection.

Most of the extracts were analyzed using Beckman Coulter P/ACE MDQ capillary electrophoresis system equipped with 488 nm laser-induced fluorescence (LIF) detector. Invisible for LIF in the native state, amino acids in extracts were reacted with Alexa Fluor® 488 dye (tagging) which resulted in the formation of fluorescing product. For this, 0.5 µL of 10 mM solution of dye in DMSO were mixed with 90 µL of extract and 10 µL of 100 mM borate buffer (pH~10). This mixture was thoroughly vortexed and incubated in the dark overnight

(~16 hrs). Before the analysis of each sample of the tagged amino acids, the capillary was rinsed using pressure with the separation buffer for 2 minutes, and then the sample was injected (0.5 psi) for 5 seconds. Separations were conducted at 30 kV for 12 minutes using 10 mM borate buffer. After each separation, the capillary was rinsed again using pressure with pure water for two minutes. Capillary conditioning using 1M NaOH was conducted with a 5-20 minute rinse as needed.

Amino acid solution and extracts were derivatized for Liquid Chromatography/Mass Spectrometry (LC/MS) analysis following the method of Hess et al., 2002. For this, 10 µl of 6% freshly prepared aqueous solution of triethylamine were added to 10 µl of sample followed by addition of 10 µl of a 1% FDAA solution in acetone and reacted for 1 h at 50°C. The products were then diluted with 10 µl of 0.2% aqueous solution of formic acid and 20 µl aliquots were analyzed by LC/MS. Derivatized samples were analyzed on an HP1100 LC-MSD (Agilent, Palo Alto, CA) with an electrospray voltage of 4000V. The gas temperature for nebulization was set at 350°C. Mass spectra were scanned from 300 to 450 m/z in positive-ion mode. The diode array detector was monitored at 340 nm. A ZorbaxSB C¹⁸ 150x2.1-mm column was set 50°C to separate the analytes. Mobile phase A was a solution of 5% aqueous acetic acid and B was LC/MS grade acetonitrile. The flow rate was set at 250 µL/min. The gradient was as follows: 20 min at 25%B, 25 min at 100%B and 38 min at 100%B. The effluent was directed through the DAD detector into the mass spectrometer, after a 4-min delay to avoid salt contamination.

3. Results

Optimized experimental conditions (T=75°C, 5% H₂O) were used to extract native organics from JSC Mars-1A Martian regolith simulant samples. Three sets of extractions were carried out: with pure SCCO₂, with SCCO₂/water, and with pure water. Fig. 1 shows our results from LC/MS analyses. In this figure total ion chromatograms (TICs) of three extracts are

presented. These were generated by plotting the sum of all ions signals in the range of m/z 300 to 450 as a function of retention. This m/z range covers both ions from substances untagged with FDAA and ions of organic molecules with amino groups which can be derivatized with FDAA (such as all 20 amino acids). As can be seen from Figure 1, extracting JSC Mars-1A with different solvents leads to differences in the chromatograms. These differences become more apparent when several extracted ion chromatograms (XICs) are generated from respective TICs. Comparison of extractions with pure SCCO_2 , SCCO_2 /water, and pure water (Figure 1) suggests that SCCO_2 in the mixture

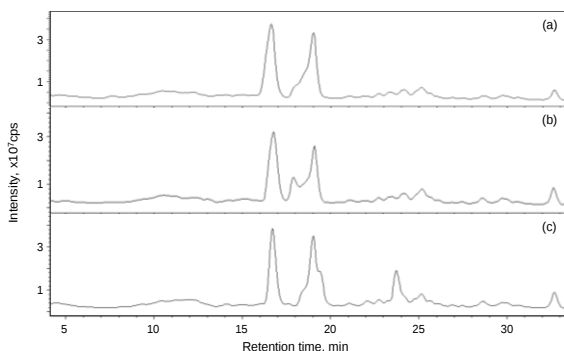


Figure 1. Total ion chromatograms (TICs) from LC/MS analysis of three extracts of JSC Mars-1A Martian regolith simulant: (a) pure SCCO_2 extract, (b) SCCO_2 /5% H_2O extract and (c) pure H_2O extract (P = 2800 psi, T = 75°C H_2O concentration 0, 5% or 100%, respectively).

with water as a co-solvent is capable of extracting both compounds extractable with pure SCCO_2 and those extractable with pure water.

4. Discussions and Conclusions

In this work, supercritical carbon dioxide with addition of small amount (5%) of water as co-solvent was used to examine the extraction efficiencies of representative essential amino acids from JSC Mars-1A Martian regolith simulant. With optimized experimental conditions, extraction efficiencies from JSC

Mars-1A were found to be ~40% for glycine, alanine and serine and ~10% for lysine. Extraction of native organics from JSC Mars-1A suggests that this solvent system can extract both organics extractable with pure SCCO_2 and those extractable with pure water. Additionally, organics not extracted by either pure SCCO_2 or pure water were extracted using SCCO_2 with 5% water. Further research into the applicability of this technique will eventually require automation and miniaturization [6] of instrumentation, as well as a systematic study of extractability of a wider variety of biomarkers and further optimization of extraction times, pressures and co-solvent composition. Despite the preliminary nature of this work, however, it paves the path for more comprehensive extraction studies of polar organic biomarkers using SCCO_2 for in situ measurements in space.

Acknowledgements

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Martian Moons eXploration (MMX) : its science and instruments

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Abstract

Martian Moons eXploration (MMX) is a round trip mission to the Martian moons, under phase-A study in ISAS/JAXA to be launched in 2024. This paper presents conceptual study results of this mission focusing on science and science instruments.

1. Science Goals and Requirements

MMX places two science goals; 1) To reveal the origin of the Mars' moons under debate between capture origin and giant impact origin, and then to make a progress in our understanding of planetary system formation and of primordial material transport around the border between the inner-and the outer parts of the early solar system. 2) To observe processes that have impacts on the evolution of the Mars system from the new vantage point and to advance our understanding of the Martian surface environmental transition.

The mission requirements deduced from those goals are summarized as follows: 1) Retrieval of Martian moon regolith samples and determination of the moons' origin from their laboratory analyses, 2) Close-up observations of independent proxies of the moons' origin, 3) Sample analyses and close-up observations to reveal the formation of moons' building materials and long-term evolution of the moons, 4) Ibid to constrain the Mars system evolution and its elementary processes.

2. Mission Profile

Five years round trip starting from launch in 2024 will be made by use of chemical propulsion system. The outward interplanetary cruise takes about 1 year by the Hohmann like transfer to arrive at Mars. MMX chooses 3 years' stay in view of acquisition of

sufficient science data and better conditions for the landing operation. The homeward interplanetary cruise takes about 1 year and the spacecraft will return to the Earth in 2029. To achieve sufficient acceleration, the spacecraft will be configured to be composed of propulsion, exploration, and return modules, some parts of which will be releasable during the mission sequence.

After the Mars orbit insertion, the spacecraft is injected into an orbit near the Phobos' one and approaches to Phobos by reducing the phase difference with Phobos. MMX is subsequently injected into a quasi-satellite orbit around Phobos to start its close-up observation. MMX will take successively lower quasi-satellite orbits (QSO) with minimum altitude from the Phobos surface 20 km or below. From these orbits, global imaging of Mars atmosphere is also conducted.

Phobos has weak but considerable gravity. MMX adopts a ballistic descent to reach right above a landing site just before a final vertical descent. After the short period of hovering, the final descent is conducted by free-fall without a thruster jet to avoid sample contamination and whirling up of regolith particles.

3. Science Payload

To explore the Martian moons, TENGOO (telescope camera) and OROCHI (wide angle multi-band cameras), MacrOmega (near IR spectrum imager), MEGANE (gamma-ray and neutron spectrometer), LIDAR (light detection and ranging), CMDM (circum-Martian dust monitor) and MSA (mass spectrum analyzer) are specified as nominal science instruments for proximity observations. Some optional instruments are under discussion (rover, deployable cameras, and etc.). MacrOmega and MEGANE will be provided from CNES/IAS and NASA/APL, respectively.

These instruments will complementarily reveal the global properties of Phobos and Deimos and search for proxies of the moons' origin, building materials and long-term evolution independently of sample analyses. For instance, high spatial resolution imaging (sub-m scale from QSO) by TENGOO will be used to search for young geologic structures on which fresh bedrock materials are exposed. Visible to near IR multispectral imaging for such structures by OROCHI and MacrOmega with several m scale spatial resolution from QSO will constrain the mineralogical composition of bedrocks with a particular focus on whether hydrous minerals exist or not, a proxy indicative of Phobos origin. Those instruments are also used for the landing site selection, sampling site characterization, geologic studies, and observation of Mars atmosphere.

MEGANE will also constrain averaged abundances of hydrogen and other elements such as Si, Fe, and O in surface layers across several tenths cm depth with a spatial resolution of hemisphere-scale or better, which enables to cross-check the bedrock composition(s) estimated by sample analyses and spectral imaging. The elemental abundance ratios such as Si/Fe are another useful proxy of satellite origin. MSA will attempt to detect ion particles originated from H₂O possibly outgassing from the moon's interior as well as the sputtered ions including metallic elements from the satellite surface. If a significant flux of H₂O-derived ion components is detected as expected for an ice-bearing Phobos, its cold origin, or capture origin is favored.

LIDAR measures the global topography of Phobos, which contributes to studies of geologic features such as grooves and craters and estimation of mass distribution inside Phobos in combination with gravity field analyses using orbital tracking and positioning data. CMDM monitors the dust particle flux around the moons, which provides basic data to understand the space weathering and gardening processes on the moon's surface and possible dust ring formation. This helps to understand the nature of returned sample grains and the long-term evolution of the surface of the Martian moons in combination with the improved surface geology, crater chronology and surface material distribution revealed by the other instruments.

4. Sampling and Sample Science

MMX will carry out samplings from multiple sites on Phobos which may have compositional diversity as inferred from the existence of two end members of representative reflectance spectra. The sampling site will be determined under the consideration of the safety for the landing operation and the availability of bedrock-derived materials by using the data from close-up global observations from QSO. In the case without the capability to hibernate in night time on a landing site, the time duration of a surface stay is limited within 2.5 hours by taking an hour margin to the full daytime duration. The time duration possibly allocated for the sampling operation is 1.5 hours. Taking also into account the communication delay, ~10 min is allowed for the decision of a sampling point based on the high-resolution surface image transferred to the Earth from the landing site.

Regolith samples more than 10 g enough for detailed and statistical analyses of Phobos-indigenous materials will be collected with characterization of sampling sites such as local regolith structure and surrounding geologic features by taking imaging data with mm-scale special resolution before and after each sampling. To collect such an amount of samples from specified points, MMX will use a sampler system with a manipulator that will transfer sampling corers onto targeting points and then into the return capsule. A gas-burst type sampler is also studied as a supplementary system.

After the return to Earth, isotopic, elemental and mineralogical compositions of sample particles will be examined with chronological analysis. If Phobos-indigenous materials are carbonaceous chondritic as favored from the reflectance spectra, capture origin is concluded. In this case, those data also tell us the birthplace and migration of Phobos precursor until the capture event had happened. If indigenous materials mostly show igneous rock textures with composition as a mixture of the Martian mantle and an exotic body, giant impact origin is concluded. In this case, samples may also tell us information about the source region of the moon-forming impactor, the age and processes of the giant impact event, and the physico-chemical state of primordial Martian mantle. Survey and analyses (if available) of younger materials ejected from Mars would provide us information on the evolutionary history of Mars.

Cameras (TENGOO and OROCHI) for Martian Moons Exploration (MMX)

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Abstract

JAXA's Martian Moons Exploration (MMX) mission is to reveal the origin of Phobos and Deimos. Both of the moons are to be observed by remote sensing and sample return from Phobos will be done. The nominal instruments have been selected and two of them are Telescopic Nadir imager for Geomorphology (TENGOO) and Optical Radiometer composed of Chromatic Imagers (OROCHI). The scientific objective of TENGOO is to obtain the geomorphological features of Phobos and Deimos. Spatial resolution of TENGOO is 13 cm at the altitude of 11 km in the quasi satellite orbit, which is 16 times higher than that of the telescopic camera onboard *Hayabusa2*. The scientific objective of OROCHI is to obtain material distribution by spectral mapping. OROCHI is composed of seven wide-angle bandpass imagers without a filter wheel and one panchromatic imager dedicated for landing phase. Using these two instruments, we plan to select landing sites and get information supportive for analysis of return samples.

1. Introduction

JAXA's Martian Moons Exploration (MMX) is planned to be a sample return mission from Phobos, one of the satellites of Mars. The nominal instruments have been selected and two of them are Telescopic Nadir imager for Geomorphology (TENGOO), Optical Radiometer composed of chromatic imagers (OROCHI), near infrared spectral imager (MacrOmega), gamma-ray and neutron spectrometer (MEGANE), ion mass spectrometer (MSA), dust monitor (CMDM), and LIDAR.

One of the scientific objectives of MMX is to determine the origin of the two martian moons. Phobos and Deimos seem to be asteroids captured by

Mars' gravity according to the result of spectroscopic observation of the surface reflectance. Conversely, they also seem to have been formed by a large impact of a body with Mars and subsequent accretion [1]. Elemental analysis is necessary to clarify the origin of the moons.

The MMX mission will acquire more than 10 g of regolith on the surface of the moon. A coring unit will be installed with a core diameter of 10–20 mm. Assuming that the sample is representative of Phobos, we will be able to clarify the origin of the moons. To test this assumption, we should determine suitable landing sites and identify the uniformity or nonuniformity of the distribution of surface material. Though we can obtain the globally averaged elemental composition using the GNS, the distribution of the elemental composition cannot be obtained by the selected instruments with a resolution of ~10 mm. Additionally, we should select the landing site where the flatness is <~30 cm in the range of 5 m in diameter. In this paper, we show the conceptual design of TENGOO and OROCHI and the requirement will be satisfied by these two instruments.

2. Instruments

TENGOO is composed of a Ritchey-Chretien telescope and CCD image sensor. In the conceptual design, the instantaneous field of view (iFoV) is 6 micro-radian/pix and Modulation Transfer Function (MTF) of optics is 0.3 at Nyquist frequency. Thus, the spatial resolution is 13 cm (2 pixels) at the altitude of 11 km in the quasi satellite orbit, in which we should select the landing site. The iFoV is 16 times higher than that of Optical Navigation Camera (ONC) onboard the *Hayabusa2* spacecraft (100 micro-radian/pix) [2]. Signal to Noise ratio is > 30 with an exposure time of 10 ms. Figure 1 shows the

conceptual optical design. The diameter of the main mirror is 120 mm and the focal length is 950 mm. Note that this conceptual design would be modified after the selection of prime contractor of this instrument.

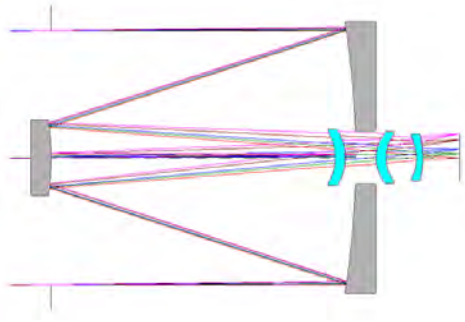


Figure 1: Optical design of TENG00.

OROCHI is composed of 7 wide-angle bandpass imagers and 1 panchromatic imager. We decided not to use a filter wheel which is used in *Hayabusa2* and OSIRIS-REx missions. Because of the high ground speed (~ 10 m/s) in descending and ascending phases, if it takes several seconds to change the filter, the field of view (FoV) of images with the 7 bandpass filters would not overlap. In OROCHI, we could take 7-color images simultaneously and get fully overlapped images.

The wavelengths are 390 nm, 480 nm, 550 nm, 650 nm, 700 nm, 800 nm, and 950 nm. The FoV is > 1 radian and the iFoV is 0.4 milli-radian and the MTF of optics is 0.3 at Nyquist frequency.

Additionally, we have one panchromatic imager dedicated for imaging at landing phase. The object distance, the distance between the instrument and Phobos surface, is estimated to be 0.5 to 1 m. The spatial resolution would be ~ 3 mm using the 7-color imagers dedicated for remote sensing, however, the typical particle size is estimated to be ~ 1 mm at the surface of Phobos and the spatial resolution of 1 mm is required to clarify the surface condition. The design of the panchromatic imager is quite similar to the others except that it has no filter and the sensor position is a little bit shifted to focus a close object.

3. Summary and Conclusions

We performed conceptual design of the TENG00 and OROCHI instruments. The spatial resolution of

TENG00 is 13 cm at the altitude of 11 km, which satisfies the requirement for selecting landing site. OROCHI is composed of 7 band imagers for remote sensing and 1 chromatic imager for landing phase which enables to simultaneously obtain multiband images and the spatial resolution of 1mm at the surface.

Acknowledgements

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The Ganymede Laser Altimeter (GALA) for the Jupiter Icy Moons Explorer (JUICE)

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Abstract

The Ganymede Laser Altimeter (GALA) is one of the payloads of ESA's Jupiter Icy Moons Explorer (JUICE) mission. Scientific goals of GALA focus on the Galilean moons, in particular on Ganymede. Here we give an overview on the instrument and the scientific performance of GALA.

1. Introduction

In 2013 ESA selected the Jupiter Icy Moons Explorer (JUICE) as the first L-class mission within the Cosmic Vision Program. This mission will explore Jupiter, its magnetosphere and satellites first in orbit around Jupiter before going finally into polar orbit around Ganymede the largest of the Galilean moons [1]. Ganymede is unique in having an intrinsic magnetic dipole field and the satellite has undergone phases of intense geological activity during its evolution. This is most evident in the so-called bright terrain characterized by extension and tectonism covering roughly two thirds of the surface. The Ganymede Laser Altimeter (GALA) is one of ten payloads onboard the spacecraft and is developed under responsibility of the DLR Institute of Planetary Research in collaboration with industry and institutes from Germany, Japan, Switzerland and Spain. Its major objectives are to measure the surface topography and the tidal deformation of the satellite.

1.1 The JUICE Mission

JUICE will be the first orbiter around a moon (other than Earth's moon) in solar system exploration. Its launch is planned for 2022 followed by an interplanetary cruise of about 8 years. Jupiter orbit insertion will take place by the end of 2029. The spacecraft will perform a 3-years Jupiter-orbiting tour including two flybys of Europa and multiple flybys at Ganymede and Callisto. Finally, JUICE will enter into a near-polar orbit around Ganymede. After Ganymede orbit insertion the initial highly elliptical

orbit will naturally evolve into a 5000-km circular orbit followed again by a highly elliptical (500 x 10,000 km) phase due to perturbations by Jupiter. During one of the pericenter passages an orbit maneuver will bring the spacecraft into a 500-km circular orbit in which it will be staying for at least 132 days until end of nominal mission. The latter phase will be the main period for GALA taking data. In addition data will be taken at Europa, Ganymede, and Callisto at closest approaches of flybys in the Jupiter orbiting phase.

2. Scientific Goals

GALA has two main objectives: (1) by range measurements it shall obtain Ganymede's topography on global, regional and local scales. This will reveal how surface features have formed and how they are connected with the shallow interior ice shell. Global shape measurements will tell us whether the satellite is in hydrostatic state with respect to rotational and tidal forces. (2) Obtaining range measurements distributed in time along the orbital cycle, tidal variations of surface elevations will be measured. The tidal amplitudes are indicative for the presence of a subsurface ocean and would (together with complementary measurements) constrain the ice-shell thickness.

In addition, GALA will provide surface roughness maps on global, regional and local scales that will be set into context with the geological surface record. With GALA the orientation of the polar axis can be determined and rotational models, including possible longitudinal librations, will be improved. This will be an important part of updating and improving the reference frames of the Galilean moons, in particular Ganymede.

3. Instrument and Performance

GALA is a single-beam altimeter: a laser pulse (at 1064 nm wavelength) is emitted by using an actively

Q-switched Nd:YAG laser firing at 30 Hz in nominal operation. A small fraction of the pulse is guided through fiber optics onto the detector characterizing the outgoing pulse and time of emission. After about 3 msec (assuming 500 km altitude) the Lambertian reflection of the pulse from the surface of Ganymede is received by a 26-cm aperture telescope and transferred to the detector, an Avalanche Photo Diode (APD). The signal is digitized at a sampling rate of 200 MHz and transferred to the range finder module, which determines (a) the time of flight between the emission and receiving of the pulse (b) the pulse shape, in particular the pulse-width, and (c) the energy of the received pulse. From the time of flight of the wave-package and the spacecraft position and attitude, the distance for each shot can be converted into height above a reference surface in post-processing of the data. The pulse-width is a measure of the surface roughness and slope at the scale of the laser footprint (50 m diameter at 500 km altitude orbit). A rough estimate of the albedo is obtained by comparing the energy of the emitted pulse with the one of the received pulse. GALA consists of three units which incorporate several sub-assemblies in order to provide the measurement data: (1) The Transceiver Unit (TRU) houses the laser optics and the corresponding electronics. The laser emits the pulse through the collimating transmitter telescope. The return pulse is received by the receiver telescope and focused on the detector (Si-APD) by the backend optics. The Analogue Electronics Module pre-amplifies and digitizes the detector output before it is directed to the Range Finder Module inside the Electronic Unit. The TRU includes a baffle that protects the receiver telescope against stray-light from Jupiter, from surface reflections from the target, and from reflection of light by other parts of the spacecraft and from the Sun. The baffle furthermore prevents laser stray-light from direct incidence to the receiver telescope and from hitting other parts of the spacecraft. (2) The Electronic Unit (ELU) houses the digital rangefinder module, which analyzes detector signal and computes range, pulse shape and albedo, similar to the concept developed for the BepiColombo Laser Altimeter (BELA) [2]. The Digital Processing Module is the main computer of the instrument and controls all instrument functions. It is also the interface to the spacecraft for commanding and telemetry. The Power Converter Module provides power in different voltages for all instrument assemblies. (3) The Laser Electronic Unit (LEU) consists of the laser control electronics including capacitors, high voltage supply, power

driver for the laser pump diodes. The laser pulse repetition rate covers the range of 1 Hz up to 30 Hz, optionally up to 50 Hz (with reduced pulse energy) for targeted observations and close flybys. The minimum required averaged laser pulse energy is 17 mJ until end of life. The laser pulse width is between 3 and 8 ns at FWHM (full width half maximum) and < 18 ns at 10% of the peak intensity. The temporal pulse shape is approximately Gaussian.

According to simulations of the signal-to-noise ratio, GALA can be operated from ranges smaller than 1300 km to Ganymede's surface. The primary observation phase at Ganymede is the final orbit phase with an altitude of 500 km for which the instrument and its performance are optimized [3]. In order to accomplish the goal of measuring the tidal deformation, range accuracies on the order of a few meters and about 1 m at best conditions are required. The inherent resolution of the instrument is on the order of a few tens of cm. However, orbit and pointing errors as well as interpolation errors between the cross-over points drive the error budget to a few meters.

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Proposed Hyperspectral Imager for Planetary Surface Missions

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Abstract

This paper introduces a novel hyperspectral camera, SPEC-I, based around a linear variable filter (LVF). The camera has been built, tested and the image processing pipeline created in Aberystwyth University. Presented here are initial results, calibration methods and performance of the camera in the field of planetary sciences.

1. Introduction

Spectral imaging is the combination of the fields of spectroscopy and imaging. Hyperspectral imagers build up sufficient spectral bands to form a contiguous spectrum. The data is stored in a three-dimensional image cube, where each pixel contains a complete spectrum. The dimensions in an image cube represent the traditional x and y dimensions in the two-dimensional spatial frame, with the third dimension, λ , representing the spectral information. [Li et al.] Hyperspectral imaging was developed initially for remote sensing purposes; this is still its primary use today [Goetz]. Hyperspectral imagers are used in fields including agriculture and health care, this paper will focus on planetary exploration applications.

SPEC-I

The SPEC-I concept is a novel hyperspectral imager being developed in Aberystwyth. Comprised of two LVFs for spectral discrimination, each covering an octave of spectral range. These are fitted in a linear actuator enabling a wide range of detection wavelengths in a small imaging system; SPEC-I covers 400 – 1000nm at a spectral resolution of ~10nm. The spectral range of SPEC-I coupled with fast acquisition times means that it is ideal for a range of applications, including planetary sciences.

The hyperspectral image from SPEC-I can be built up in two ways, by windowing-framing or windowing-pushbroom. The windowing-framing method is

achieved by scanning the LVF across the optical path meaning the camera and subject remain stationary. For the windowing-pushbroom method the LVF is fixed over a wavelength range and the hyperspectral data is built up by either moving the camera system or the subject.

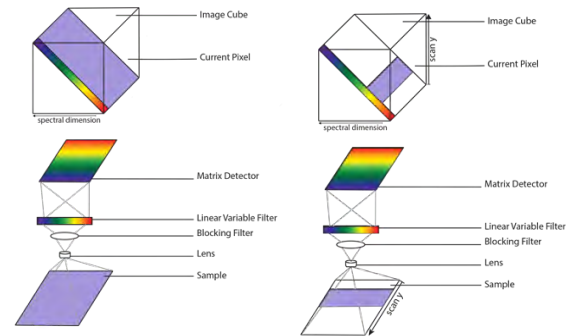


Figure 1: Windowing-Framing and Windowing-Pushbroom Methods – modified from [Li et al.]

SPEC-I has been designed to be applied in a cross-disciplinary manner. The application presented in this paper is the ability of SPEC-I to analyse geological materials, in particular fluorescent minerals that can be indicative of life on other planets. [Storrie-Lombardi et al.]

2. Initial Calibration

Calibration of the system is important to ensure that the data yields meaningful results. The data from SPEC-I is being calibrated and run through an imaging processing pipeline developed in Aberystwyth University. Presented in Figure 2 is the first step of this process. There may be discrepancies present between the manufacturer stated wavelength positions compared to measured values and these must be found and accounted for prior to data acquisition.

Wavelength calibration of SPEC-I was achieved using the Aberystwyth Tuneable Light Source (ATLS) and a calibrated spectrometer. Images were captured of an integrating sphere illuminated with

monochromatic light over the range 400 – 1050 nm at 10nm intervals.

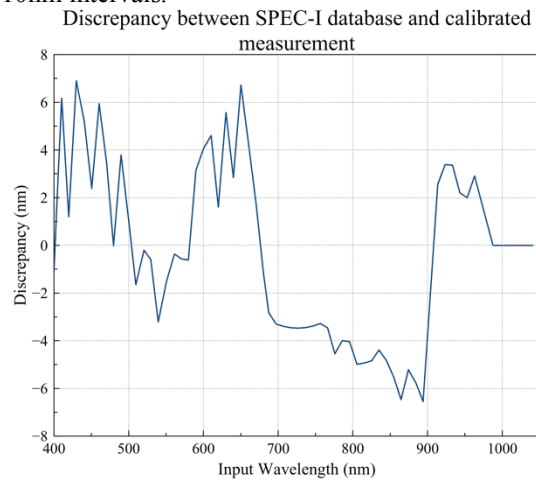


Figure 2: Differences between SPEC-I database and measured values

Figure 3 shows small discrepancies of $\sim \pm 6\text{nm}$ in the measured wavelength compared to the expected wavelengths. This can easily be corrected before image capture by interpolating data from the graph into the processing pipeline.

3. Preliminary Results

To assess the performance of the camera in lab conditions have been selected and analysed. First of which was a Macbeth Colour Checker. Figure 3 shows the reflectance measurements taken by SPEC-I compared to the manufacturer's reflectance data. SPEC-I compares favorably with the manufacturer data, the gradients taken between 600-630nm are within ± 0.1 of each other.

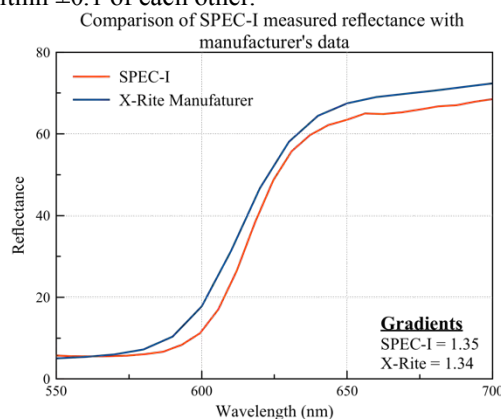


Figure 3: Reflectance Standard Comparison

Curated samples have been used to test the capabilities of SPEC-I as part of a planetary exploration payload.

Figure 4 are the results obtained from imaging a sample of Hackmanite under 365nm UV LED excitation. The data has been compared to that taken with a spectrometer and shows reproducible results.

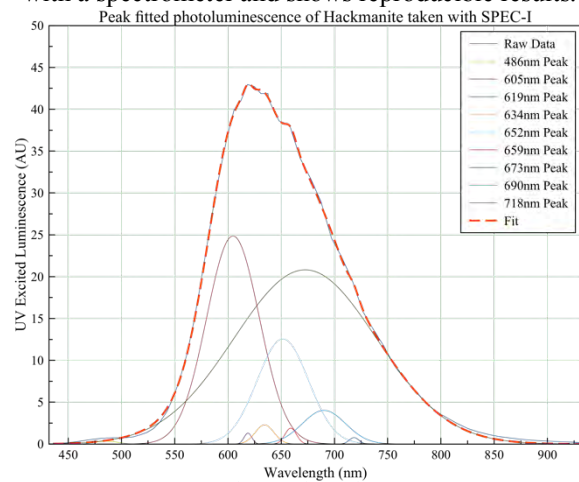


Figure 4: Peak Fitted Hackmanite Spectrum

4. Summary and Conclusions

Initial testing of SPEC-I has shown that it is capable of reproducing manufacturer data, taking data of enough spectral resolution to pick out features and compares well to low level spectrometer data. SPEC-I performs within its spectral resolution of 10nm, which is soon to be improved with the replacement of the visible LVF with a new 5nm resolved one.

Acknowledgements

The author would like to thank her PhD supervisors, D.P. Langstaff and M. Gunn for supervision on this project. Thanks, are also extended to the wider research team for their support and expertise. The SPEC-I camera has been developed with funding from UKSA grants ST/L00500X/1 and ST/N002903/1.

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Primitive Object Volatile Explorer (PrOVE) – Mission to an Oort Cloud Comet

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Abstract

Primitive Object Volatile Explorer (*PrOVE*) is a SmallSat mission concept to study the surface morphology and volatile inventory of an Oort cloud comet (OCC) near the first perihelion passage phase when volatile activity is near peak (Fig. 1). Comets carry a wealth of information about the state of the early Solar System (SS). Far from the Sun, as distant as half-way to Alpha Centauri, OCCs preserve an inventory of volatiles and dust that date to the distant past. We have developed instrumentation, a SmallSat spacecraft, and operational requirements to meet the demands of a high-energy, high-inclination flyby operations required of a mission to an OCC with limited time from discovery to perihelion passage.

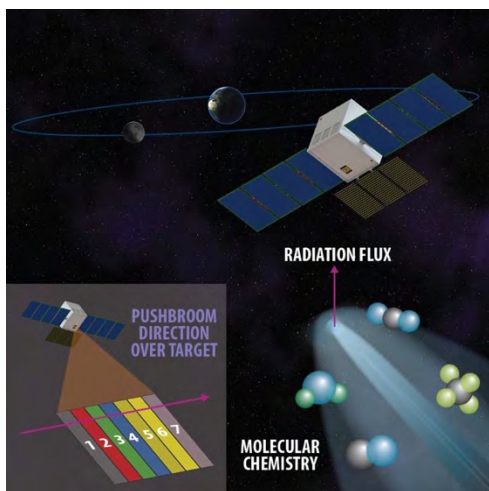


Figure 1: PrOVE will measure cometary infrared fluorescence and thermal emission using a focal plan integrated discrete filter assembly and spacecraft flyby pushbroom operations.

1. Introduction

Primitive bodies are key to understanding SS formation. The structure and composition of cometary nuclei provide a guide to the condensation and evolution of matter within the early SS ([1], and references therein). The relative abundance of volatile ices in the nucleus reflects its thermal and radiation history during its formation and subsequent evolution [2].

The current paradigm for dynamical processes in the early SS is the Nice Model [3],[4], which hypothesizes that comets that formed beyond ~ 17 AU from the protoSun, in the outer accretion disk, and were scattered into the Oort cloud and Kuiper Belt reservoirs [5]. Comets that formed in the region of the giant planets (5–14 AU) were ejected as the planets grew and also entered the Oort cloud and the higher-eccentricity Kuiper disk [6]. The dynamical mixing of the early SS is consistent with the significant chemical diversity found within the modest number of periodic comets that have been studied closely [1],[7]. The chemical composition and dynamical classification of observed comets are not correlated, which is consistent with the blurring of the formation regions for Oort cloud and Kuiper Belt comets. Even if a large fraction of primitive objects in the Oort cloud were captured from the reservoirs of other stars in the Sun's birth cluster, they would present similar compositional diversity [8].

The Oort cloud is a vast shell of volatile-rich bodies orbiting the Sun at heliocentric distances from ~ 1000 to $\sim 200,000$ AU at the gravitational boundary of our SS. The Oort cloud is the primary source of long-period and dynamically *new* comets, while the Kuiper Belt is the primary source of short period

“ecliptic” comets. The unique value of investigating an OCC lies in its unaltered character. The cryogenic conditions and low density of the Oort cloud severely restricts thermal and impact alteration processes that could change the nucleus after its formation, except from exposure to cosmic rays over the life of the SS. The abundances of volatiles such as CO₂, CO, H₂O, and organics are prime metrics for the physical conditions and radial mixing in the protosolar nebula.

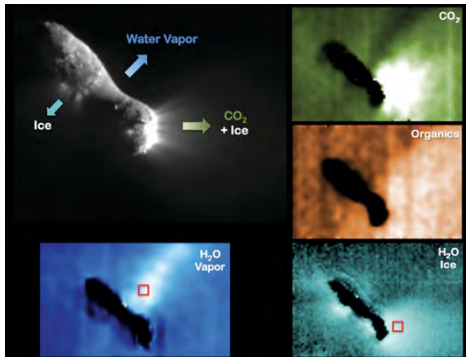


Figure 2: 103P/Hartley 2, which showed CO₂ sublimation driving comet activity (from [2]).

2. Instrumentation

A Malin Space Science Systems ECAM-50 imaging camera with <10 m spatial resolution will serve as the visible camera, VisCAM, to investigate surface layering, impact history, large- and small-scale morphology, and albedo distribution. The infrared comet camera, ComCAM, is based on a Institut National d’Optique non-cryogenic, broad spectral response microbolometer array with a focal plane integrated discrete filter assembly, and radiation tolerant electronics from GSFC. The ComCAM filters bracket the molecular fluorescence spectral bands (2.7 μ m, H₂O; 3.3 μ m, organics; 4.3 μ m, CO₂; and 4.7 μ m, CO; e.g., Fig. 2), and mid-infrared channels to study thermal radiation. ComCAM is compact and designed to fit into a 1.5U volume.

3. Waypoints

A parking orbit in space eliminates uncertainties due to launch delays and enables missions to new comets. A *waypoint* solution is also applicable for spacecraft missions to study other transient celestial events such as short period comets near perihelion and hazardous asteroids. PrOVE can be launched aboard a NASA, DoD, or NOAA LEO, MEO, or GTO EELV

rideshare mission and use the launch vehicle’s excess capacity to reach escape, or near escape, velocities. Waypoints can also be used to store multiple spacecraft for mass deployment as a constellation to a single target or individually to explore different targets. PrOVE will remain in the waypoint orbit pending opportunistic discovery of a new comet, and begin the cruise phase to a flyby encounter.

4. Conclusions

A mission to an OCC with VisCAM and ComCAM will provide compelling science with significant impact on our understanding of the early SS.

Acknowledgements

We gratefully acknowledge the support of the Planetary Science Deep Space SmallSat Studies (PSDS3) program, NASA Goddard Space Flight Center, and NASA Wallops Flight Facility.

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Pulsed Neutron Experiments with SINGR (Single-scintillator Neutron & Gamma-Ray spectrometer)

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Abstract

Here we present results from a new active nuclear instrument (selected in 2015 NASA PICASSO program) that combines a dual neutron and gamma-ray sensitive scintillator with a pulsed neutron generator (PNG) to rapidly characterize the hydrogen (H) content, depth distribution of H, and bulk geochemistry of planetary surfaces [3]. The Single-scintillator Neutron and Gamma Ray spectrometer (SINGR) can also be used passively, without a PNG, and is designed for accommodation on future interplanetary rovers or landers.

1. Introduction & Background

Active neutron measurements can be used to rapidly (~tens of minutes) characterize the H content and its depth within the top meter of planetary surfaces using a PNG [1-3, 5-9]. Active neutron measurements have been made on Mars for the first time with the Dynamic Albedo of Neutrons (DAN) instrument on the *Curiosity* rover and have revealed H enrichments throughout the traverse, as well as hydrated silica phases within fractures, and helped place constraints on hydrated amorphous phases [2, 7]. Like DAN, SINGR's neutron measurements characterize the H content and abundance of neutron absorbing elements within the top meter of a planetary surface. SINGR enhances the current state of the art by providing bulk elemental analysis through use of a dual neutron and gamma ray detector system. Combining active neutron techniques with gamma-ray spectroscopy, which is sensitive to the abundance of naturally occurring elements (K, Th, U), rock-forming elements (Si, Fe, Mg), and/or icy materials, is the goal of several instrument development programs [1, 3, 5, 8, 9]. Time resolved active gamma-ray analysis, enabled by the use of a PNG, can also be used to better distinguish elemental abundances based on

radiogenic decay [1, 9]. SINGR can be accommodated on a lander, rover, or drone which can collect data from the surface or at low-altitude ~1-2 meters. SINGR has undergone preliminary experimental characterization with a PNG at the NASA Goddard Space Flight Center (GSFC) Geophysical and Astronomical Observatory (GGAO) outdoor gamma ray and neutron instrumentation testing facility.

2. Instrument & Experiment

SINGR uses a relatively new scintillator material, an elpasolite called $\text{Cs}_2\text{YLiCl}_6\text{:Ce}$ (CLYC) that has a gamma-ray energy resolution of approximately 4% full-width-at-half-maximum at 662 keV; the ${}^6\text{Li}(n,\alpha)t$ reaction in CLYC allows for the detection of neutrons [4]. SINGR uses a technique called pulse shape discrimination (PSD) to detect neutrons and gamma-rays based on differences in the shape of the scintillator light-pulse. SINGR uses a three-inch diameter by three-inch long cylindrical CLYC crystal coupled to a Hamamatsu photomultiplier tube (PMT). The digital electronic system (sample rate ~ 250 megasamples per second) is a field-programmable gate array (FPGA) developed by RMD. The PNG used in testing was a commercial Thermo MF Physics Model MP320 DT neutron generator capable of producing up to 10^8 neutrons per second with a frequency range from 250 to 1000 Hz. SINGR testing was conducted using the Colombia River basalt monument at GSFC GGAO in late August of 2017 with follow-up tests performed in March 2018 [1, 9]. Plates of polyethylene, cadmium, and lead were used in a variety of configurations; by altering the amount of polyethylene in different layers within the basalt monument, we are able to simulate varying the H content with depth. Cd and Pb plates were placed in front of the detector to shield from low-energy (thermal) neutrons and x-rays.

3. Experimental Results

Data were collected using SINGR and a PNG at the basalt monument arranged with 2-inch thick polyethylene plates layered under 20 cm of basalt. After the initial 14 MeV neutron pulse, neutrons and gamma-rays are emitted from the target surface. Fig. 1 shows resulting neutron die-away curves from two of our experiments, one with Cd plates in front of the detector (green) and one without (blue). There is a drop in the thermal neutron count rate when Cd plates are used to shield the detector, this is due to Cd's high probability to absorb thermal neutrons, thus making the detector sensitive to only epithermal neutrons. The calculated difference between the thermal+epithermal and the epithermal neutrons results in the thermal neutron data (red) that is used to infer the H content and H depth distribution.

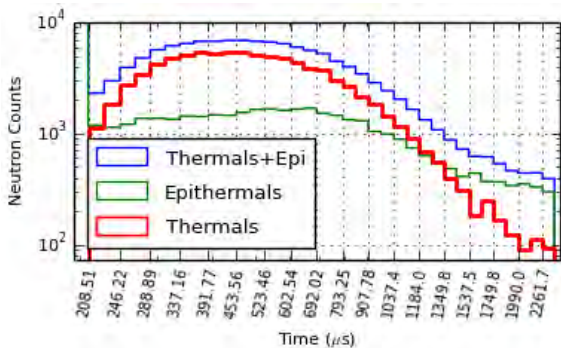


Figure 1: Neutron die-away curves (200 – 2500 μ s, after initial 14 MeV neutron pulse) of the basalt monument showing thermal+epithermal (blue), epithermal (green), and thermal (red) neutrons.

Gamma-ray spectra were acquired with SINGR both during and after the PNG pulse; the gamma-ray events were extracted from the data based on PSD. Immediately after the pulse (200 – 2500 μ s), pile-up events are significantly reduced and gamma-rays resulting from neutron capture and delayed neutron activation can be identified (Fig. 2). Previous high-purity germanium GRS data of the basalt monument from Bodnarik [1] were used to identify and calibrate SINGR during these tests; several elemental (stable isotope) lines, including Fe (692 keV, 4.1% energy resolution), O (~ 6 MeV triplet), and Si (1.79 MeV) are identified. The experimental set-up also includes an aluminum scaffolding which is associated with the doppler-broadened gamma-ray peak (2000 – 2500 keV energy region) present in our data.

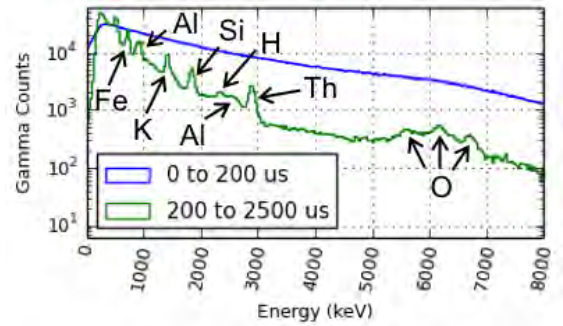


Figure 2: Gamma-ray spectra of the basalt monument acquired between-PNG pulses (green line: 200 – 2500 μ s) and during the PNG pulses (blue line).

4. MCNP Simulations

The Monte Carlo N-Particle (MCNP6) transport code has been used to simulate the detector response and the basic experimental test parameters at GSFC. We will be able to compare the H content and elemental abundances we derive from MCNP6 with the known (ground-truth based on mass spectroscopy and x-ray fluorescence sample testing) values from making neutron and gamma-ray measurements of those quantities at the test site using SINGR. Simulations of the instrument response and test setup will be used to determine sensitivities and optimize detector configurations for future experiments.

5. Summary & Conclusions

We have successfully demonstrated that SINGR can be used to construct neutron die-away curves and collect gamma-ray spectra between PNG pulses. Further experiments will be completed in spring and summer of 2019 in order to fully characterize the SINGR detector response and test elemental sensitivities for other relevant planetary mission environments.

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Neutron Spectrometer for the Lunar Polar Hydrogen Mapper Mission

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Abstract

The Lunar Polar Hydrogen Mapper (LunaH-Map) spacecraft will launch as a secondary payload on NASA's Space Launch System (SLS) Exploration Mission 1 (EM-1). LunaH-Map will use a low thrust ion propulsion system to maneuver into an elliptical orbit about the Moon with a low altitude perilune over the south pole. LunaH-Map will use a Miniature Neutron Spectrometer (Mini-NS) to constrain total H abundance within permanently shadowed regions (PSRs) of the lunar south pole.

1. Mission

LunaH-Map is a 6U CubeSat selected for flight under NASA's Small, Innovative Missions for Planetary Exploration (SIMPLEX) program. The LunaH-Map spacecraft is equipped with a low thrust ion propulsion system, gimbaled solar arrays, three reaction wheels, a star tracker, an X-Band radio, a command and data handling system, a power control system, and a neutron spectrometer array [1, 2]. After deployment, LunaH-Map will maneuver to perform a lunar flyby targeting L2 and will eventually be captured by the Moon within two months [3]. Upon lunar capture the spacecraft will spiral down to an elliptical low-altitude science orbit with perilune at the lunar south pole. During the science phase, the Mini-NS will measure epithermal neutron counts about the perilune of each orbit enabling mapping of H enrichments within PSRs at spatial scales < 15 square-km.

2. Instrument

Detector: The Mini-NS uses CLYC ($\text{Cs}_2\text{LiYCl}_6\text{:Ce}$) scintillation detectors [4, 5]; CLYC is an elpasolite sensitive to both neutrons and gamma rays with the characteristic pulse shape of the ^6Li neutron capture reaction used to distinguish neutrons [5]. CLYC was selected because it can be manufactured in large

boules, providing crystals of sufficient size to cover an entire face of the LunaH-map spacecraft. Other materials (i.e. ^3He) were considered, but the intrinsic efficiency of CLYC is greater for epithermal neutrons and CLYC can more readily maximize the surface area (and therefore, count rate) for LunaH-Map's relatively short-duration science mission phase.

System: The Mini-NS detector array consists of eight $4.0 \times 6.3 \times 2$ cm CLYC crystals, with a total detection area of 200 cm^2 . A photomultiplier tube (PMT) is mounted to each crystal, with each CLYC crystal and PMT pair comprising one of the eight detector modules. Four modules on either side of the detector are readout together, and each four-module unit can operate independently. A thin Gd sheet is used to absorb thermal neutrons and covers the nadir, sides, and a portion of the back of the instrument, which provides sensitivity to only neutron energies greater than ~ 0.4 eV. Mini-NS includes two redundant 32GB microSD cards which will store event-by-event data and instrument telemetry. The overall Mini-NS dimensions are $25 \times 10 \times 8$ cm, the mass is ~ 3.4 kg, and the maximum power consumption is 9.6 W.

Sensitivity: A dry lunar count rate, $C(0)$, was derived using MCNP6. The model uses a GCR spectrum with $\phi=550$, a lunar FAN surface composition, a model of the Mini-NS and a complete LunaH-Map spacecraft (to account for particle interactions within the spacecraft). The epithermal neutron count rate, $C(w)$, where w represents the water equivalent hydrogen (WEH) wt%, was modeled for several cases where the WEH varied from dry ($w=0.02$ wt%) to wet ($w=2.0$ wt%). The ratio $C(w)/C(0)$ follows the functional form derived by Lawrence et al. (2006), eq. 1. WEH of 0.5 wt% produces a reduction in epithermal count rate of $\sim 20\%$. The Mini-NS CLYC array was designed to achieve twice the epithermal count rates of the Lunar Prospector-Neutron Spectrometer (LP-NS). To size

the detector modules, models with varying thicknesses of CLYC were used to determine the size that achieved the desired epithermal C(0) count rate of ~40 counts per second [6].

Calibration: The Mini-NS energy-angle response and neutron efficiency will be calibrated at the Neutron Free In-Air (NFIA) Facility at Los Alamos National Laboratory. The facility provides well characterized sources as referenced for the Lunar Prospector Neutron Spectrometer calibration effort [7]. Energy-angle response will be determined using the method outlined for the Dawn Mission's Gamma Ray and Neutron Detector [8]. The Mini-NS will be mounted on a rotating stage and a full set of rotational measurements will be made with an unshielded and shielded Cf-252 source to determine the energy-angle response of the detector array. The detector array temperature response will also be characterized.

3. Proto-Flight Unit Testing

The partially assembled flight unit (**Figure 1**) consists of four gain-matched detector modules connected to flight electronics. The unit has been functionally tested using an AmBe neutron and gamma-ray source. **Figure 2** shows data collected from the AmBe source, demonstrating separability of neutron from gamma-ray counts using pulse shape discrimination (PSD).

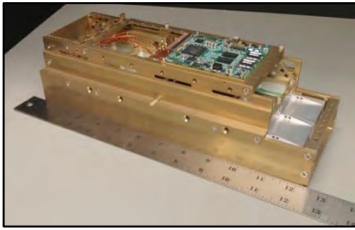


Figure 1: Photo of the MiniNS partially assembled with eight modules (no PMTs). One of the detector readout boards is placed in the support frame.

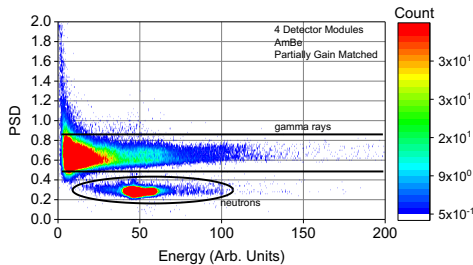


Figure 2: Energy spectrum and PSD ratio for four proto-flight non-gain-matched detector modules.

The Mini-NS FPGA derives PSD parameters from event waveforms and saves neutron counts every second. The Mini-NS threshold, gain and PSD settings can be adjusted in the instrument software. The flight software will also allow for readout of data from any of the 8 detector modules within the array, along with flexibility to disable any module during flight.

Figure 3 shows a reduced dataset filtered to one module. Event-by-event PSD parameters are saved for each data collection and include this channelized information. Data products can be staged for downlink by the spacecraft C&DH when bandwidth is available.

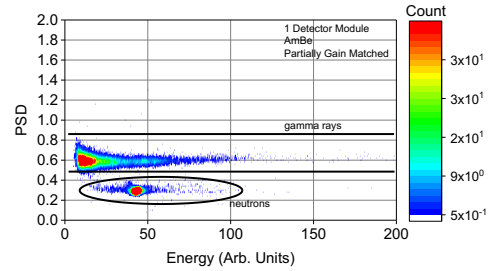


Figure 3: Energy spectrum and PSD ratio for one proto-flight module. Identifiers within each dataset can be used to analyze data from individual modules.

4. Summary

Construction and testing of the Mini-NS flight unit is underway and will be complete in Summer 2018. Calibration and thermal characterization at the LANL NFIA is currently planned for Fall 2018; instrument calibration is possible *after* spacecraft integration due to LunaH-Map's small spacecraft size. Spacecraft thermal vacuum and vibration testing, with the integrated Mini-NS, are scheduled for Spring 2019 at NASA Ames Research Center.

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Field Testing the RIMFAX GPR on the Mars 2020 Rover Mission

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Abstract

The Radar Imager for Mars' subsurface eXperiment (RIMFAX) ground penetrating radar (GPR) for the Mars 2020 Rover will image the shallow subsurface beneath the rover. The RIMFAX instrument will provide subsurface imaging capabilities at sufficient depth, resolution, and timing to be of operational value to the science objectives of the rover mission, while also providing valuable geological information. A GPR was flown on the Chinese Lunar rover Chang'E-3 successfully penetrated several meters into the lunar subsurface [1]. Additionally, the WISDOM GPR instrument is planned on the ExoMars mission to be launched in 2020 [2, 3]. A RIMFAX prototype has been field tested in different type of geological settings with good results.

1. Introduction

The RIMFAX radar uses a Gated Frequency Modulated Continuous Wave (FMCW) waveform operating from 150 MHz to 1200 MHz. The radar electronics are housed in a box mounted in the rover body in a temperature-controlled zone. The antenna is a slot bow tie antenna mounted outside on the back of the rover, see Figure 1. RIMFAX will collect soundings every 10 cm along all rover traverses. On each location three different modes of sounding will be collected: 1) Surface Mode where the radar records the reflection from the antenna and the surface; 2) Shallow Mode where the surface and the shallow subsurface are both imaged and 3) Deep Mode where the surface is gated out and only deeper reflections are imaged. The full radar bandwidth, 150 – 1200 MHz, is used in the Surface and Shallow Modes. A bandwidth from 150 – 600 MHz is used in the Deep Mode to reduce data volume.

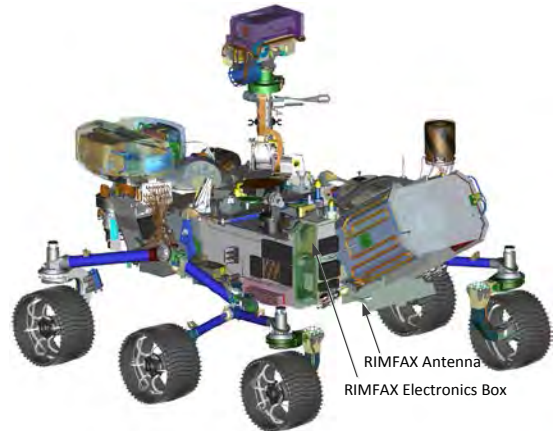


Figure 1. The RIMFAX Electronics box is mounted in the rear left tower and the antenna is externally mounted underneath the RTG¹ on the back of the rover. (Illustration courtesy of NASA/Caltech/JPL).

Time lapse soundings will be done while the rover is stationary to measure the effects of thermal changes in the subsurface over the diurnal cycle

2. Instrument development

Engineering Model (EM) and Engineering Qualification Model (EQM) versions of the electronics box and the antenna have been built. The EQM versions have been qualified per Mars 2020 requirements. Figure 2 shows the EQM electronics box and Figure 3 shows the EQM antenna during random vibration test. The mass of the electronics box is 1203 grams and the antenna is 2225 grams.

¹ Radioisotope Thermoelectric Generator

The Flight Model (FM) of RIMFAX is currently being built and delivered for integration on the Mars 2020 rover.



Figure 2. RIMFAX EQM of the electronics box.

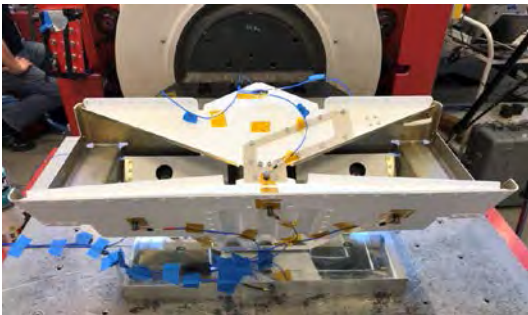


Figure 3. RIMFAX EQM antenna during testing.

3. Permafrost in Svalbard, Norway

An EM version of RIMFAX using flight like components and geometry was tested on Svalbard in April 2018. Figure 4 show a RIMFAX image of a part of limestones of Wordiekammen Formation. The reflecting structure is interpreted to be from bioherms in the limestone [4] and reflections can be seen down to more than 15 meter depth.

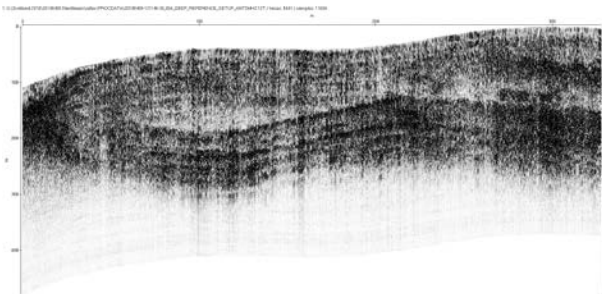


Figure 4. RIMFAX profile from permafrost in limestones (Wordiekammen Formation). The profile is 320 meter long and maximum depth scale is 30 meter.

4. Sand Dunes in Utah, USA

The RIMFAX EM version was also field tested in Utah, USA in different types of geology in April 2018. Figure 5 shows a RIMFAX image of a sand dune where the internal layers and cross bedding can be seen. The depth of the dune is about 9 meters.

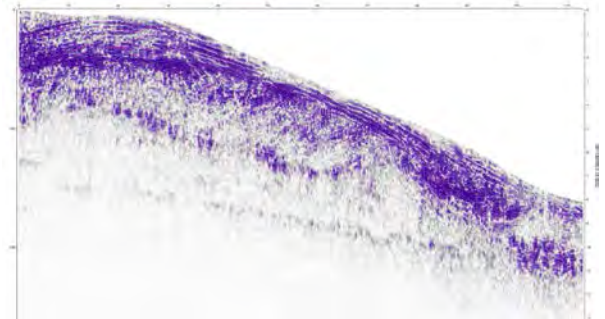


Figure 5. RIMFAX profile from Coral Pinks Sand Dunes. The profile is 110 meter long and maximum depth scale is 13 meter.

5. Summary and Conclusions

Several engineering models of the RIMFAX instrument have been developed. EM versions have been field tested in relevant geological settings with very good results. EQM versions have been used for qualification of the instrument.

The RIMFAX GPR will contribute to the Mars 2020 rover mission by studying the geology at the landing site, searching for evidence of paleo-environments and geologic histories, and helping to select the most valuable samples for caching and eventual return to Earth.

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A Printed Circuit Board Analyzer for Characterizing the Charge and Mass of Martian Dust

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Introduction

Major gaps exist in our understanding of the dust in the Martian atmosphere. The size of dust grains has been measured only indirectly and as an average, with significant disagreement in interpretation of the results. The electrical charge of Mars dust has never been measured and is difficult to model. Measurement of both size and charge is critical to our understanding of the Martian surface, atmosphere, and climate. Characterizing Mars dust is also important to estimating or mitigating risk to future missions, particularly crewed missions where dust may interfere with breathing, mechanical systems, solar power, and in situ resource utilization (ISRU) such as oxygen production.

We are developing an instrument based on charge-detection mass spectrometry (CDMS) that will accurately measure these important properties of individual dust grains. It will also measure the dust grain concentration and observe how all these properties vary with time of day, season, dust storms, and surface operational activities (e.g., roving, drilling). At the center of this instrument is a CDMS analyzer using multiple charge-sensing stages on the facing surfaces of two circuit boards. The instrument will be extremely low power, volume, and mass.

Mars Dust Analyzer

This instrument will be capable of determining both the size (mass) and the charge of individual dust grains in the Mars atmosphere. The instrument is based on charge detection mass spectrometry in which several image charge detectors determine both the charge and the mass-to-charge ratio of individual particles, thereby allowing calculation of the absolute mass of every particle of the ingested population. Charge-sensing electrodes are patterned onto two circuit boards, which are placed together with a small space in between (Figure 1). Using a pump or blower,

Mars atmosphere is drawn through an inlet and between the printed circuit boards (PCB). The PCB assembly will include several charge-sensing electrodes followed by an acceleration region, in turn followed by another set of charge-sensing electrodes. The resulting signal allows determination of both the charge (magnitude and polarity) and the mass-to-charge ratio of each dust grain. With an expected detection limit of roughly 30 elementary charges (positive or negative), and a size range covering approximately 0.2 to 10 μm diameter, the instrument covers the range of expected values for suspended dust.^{1,2}

Charge Measurements

As shown in Figure 1 the PCB detector has multiple electrodes. Alternating electrodes are either connected to a charge-sensitive preamplifier or to ground. Charge measurements are made as multiply-charged microparticles pass a sensing electrode and the image current is amplified. A differentiating amplifier converts the signal into two peaks, one positive and one negative, which correspond to the entrance and exit from the sensing electrode (Figure 2). The same particle is measured multiple times as it passes through multiple charge-sensing electrodes.

Amino-terminated polystyrene particles of the same varying size as expected for Mars dust are used to simulate the dust during development of this instrument. To simulate the electrical charge of Mars dust the polystyrene particles are charged and introduced to vacuum via electrospray at atmospheric pressure.

The output from the shaping amplifiers appears to be the derivative of the signal picked up by the charge-sensitive preamplifier. For this reason, we believe the charge is proportional to the area under each individual peak. Areas under all positive and negative peaks corresponding to the same particle are expected to be equal since the charge does not

change as the particle travels across the detector. Simulations and additional experimental testing is being done to confirm this hypothesis.

Mass Measurements

Addition of a central DC acceleration electrode to the PCB charge detector will enable the determination of particle mass from velocity and charge measurements. In order to monitor a wide range of particle sizes and charges, the acceleration region voltage will be stepped over the range 0.1 to 360 V. Unfortunately, this device is working very close to the minimum in the Paschen curve for Mars atmospheric pressure (4-7 Torr, or 500-900 Pa) and composition (95% CO₂, 3% N₂, 2% Ar), so voltages higher than 400 V would present a risk of discharge among electrodes and damage to the amplifier. However, 360 V is sufficient to produce measureable deceleration/acceleration of particles up to 11 μm in diameter with at least 10,000 charges.

Figures

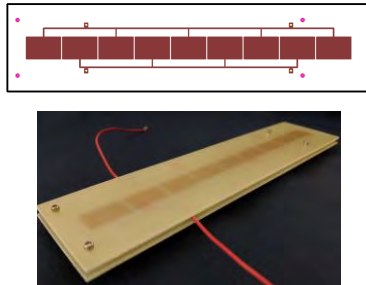


Figure 1: Schematic (top) of one PCB. Two mirrored PCBs face each other and spaced a few mm apart to form a sandwich-like array (bottom). Adding a central acceleration electrode will enable the determination of particle mass from velocity and charge measurements.

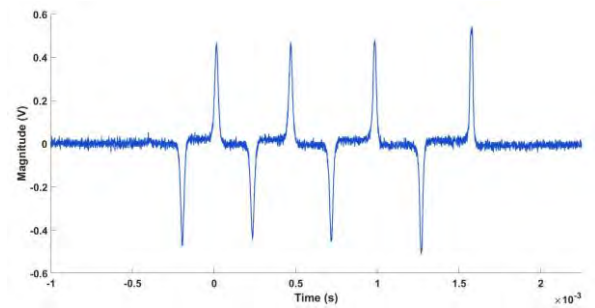


Figure 2: Data from a single, charged polystyrene particle (0.32 μm in diameter) crossing the PCB shown in Figure 1.

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European Molecular Indicators of Life Investigation (EMILI) for Habitability and Biosignature Analysis on Ocean Worlds

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Abstract

The European Molecular Indicators of Life Investigation (EMILI) is a mass spectrometry-based instrument adapted for operation in the harsh European surface environment, capable of addressing the ambitious scientific goals of a potential future mission to the European surface. In support of the search for signs of life on Europa, EMILI seeks to (i) detect and characterize a wide range of potential organic molecular biosignatures even if present at extremely low (nanomolar) concentrations, as well as (ii) characterize key aspects of the mineralogical context of the acquired samples to discern the provenance and degree of radiative or oxidative processing of any potential molecular biosignatures.

1. Introduction

EMILI builds on extensive mass spectrometry development experience recently developed at Goddard Space Flight Center (GSFC) and partners for Mars and other planetary missions. The EMILI design is based substantially on the Mars Organic Molecule Analyzer (MOMA) mass spectrometer (MS) recently delivered to the ExoMars Rover Mission [1, 2]. However EMILI is further developed to include analytical enhancements realized for the Linear Ion Trap Mass Spectrometer (LITMS) instrument derived from MOMA [3], and adapted for operation at Europa.

EMILI enables broad detection and structural characterization of organic and inorganic species point-by-point on a ~10 cm long ice-rich drill core or *any* presented solid sample. It combines a dual-source ion trap mass spectrometer (ITMS) coupled with a precision core sampler (PCS) and is

conceptually depicted in Figure 1. ITMS is capable of two *highly-complementary sampling and ionization approaches*:

- Direct pyrolysis (pyr) and pyrolysis/gas chromatography (pyr/GC) sampling with or without chemical derivatization (GCMS mode) provides temperature- and time-resolved neutral gas to the GC and the inlet of the MS, where molecules are charged *via* electron ionization (EI). Temperatures to 500 °C liberate targeted classes of organics and gas species from European surface samples that may be rich in water and salts..
- Ambient laser desorption/ionization (LDI) sampling (LDMS mode) liberates nonvolatile high molecular weight organics with a short (1 ns), intense ($\sim 10^2$ MW cm⁻²) ultraviolet ($\lambda = 266$ nm) pulsed laser. Numerous molecular ions are desorbed intact even in the presence of salts and oxidants expected on the European surface.

Both modes when combined with the precise and efficient EMILI ion trap are capable of exceedingly low limits of detection (nanomolar concentrations) for critically important organic species that may be present in European near surface materials.

2. EMILI Breadboard Development

The EMILI ITMS breadboard unit has been completed and integrated into an ultra-high vacuum (UHV) chamber (Figure 2) that replicates the hard vacuum environment at Europa and is equipped to exercise the ITMS across a range of operational conditions necessary to inform the requirements for a future higher-fidelity unit. The breadboard unit with

a reconfigured ion trap electrode assembly demonstrates higher mass resolution ($m/\Delta m > 1000$) than predecessor instruments, is capable of both positive and negative ion detection, and exhibits reduced background levels enabling lower limits of detection. The design inherits from earlier ITMS systems advanced MS capabilities such as (i) tandem mass spectrometry (MS/MS) for detailed molecular structure analysis and (ii) ion enrichment capabilities through SWIFT for improved detection sensitivity of targeted molecules.

The EMILI ITMS breadboard further features an LDI inlet redesigned for operation under high vacuum conditions to enable LDMS analysis of both positive and negative ions generated from a sample held at Europa ambient pressures.

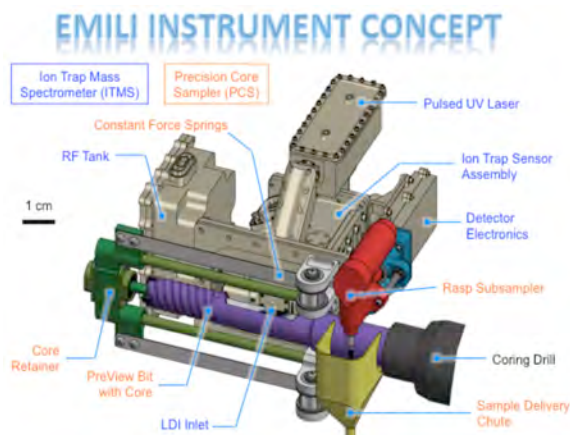


Figure 1: EMILI enables LDMS and pyr/der-GCMS analysis of cores acquired from the European surface by combining a highly capable **ion trap mass spectrometer (ITMS)** and a versatile **precision core sampler (PCS)**.

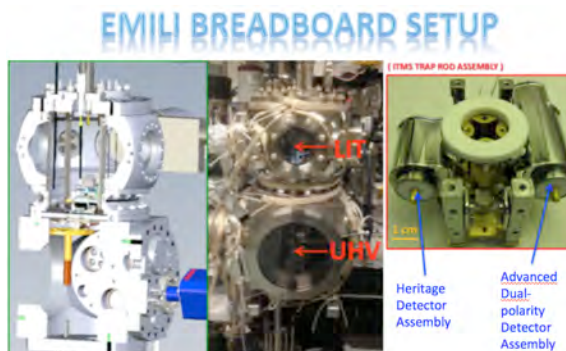


Figure 2: The EMILI breadboard setup incorporates an upgraded ITMS sensor assembly into a dual-zone UHV chamber to simulate Europa vacuum conditions.

3. Summary and Conclusions

An EMILI breadboard has been developed and its performance has been evaluated to establish key requirements for a future flight-like prototype. In parallel to the higher-TRL design we are carrying out end-to-end EMILI GCMS and LDMS performance characterizations with relevant analog samples to fully assess EMILI's powerful analytical capabilities to address the challenging scientific goals of a future Europa Lander mission implementation.

Acknowledgements

Funding has been provided by the Concepts for Ocean worlds Life Detection Technology (COLDTech) Program (Program Executive: Meagan Thompson, NASA/HQ).

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The CAESAR New Frontiers Mission: Comet Surface Sample Acquisition and Preservation

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1. Introduction

NASA recently selected the Comet Astrobiology Exploration Sample Return (CAESAR) mission for Phase A study in the New Frontiers Program. This mission will acquire and return to Earth for laboratory analysis at least 80 g of surface material from the nucleus of comet 67P/Churyumov-Gerasimenko (hereafter 67P). CAESAR will characterize the surface region sampled, preserve the sample in a pristine state, and return evolved volatiles by capturing them in a separate gas reservoir. The system protects both volatile and non-volatile components from contamination or alteration that would hamper their scientific analysis [1]. Laboratory analyses of comet samples provide unparalleled knowledge about the presolar history through the initial stages of planet formation to the origin of life.

2. Sample Acquisition and Sample Containment Systems

The Sample Acquisition System (SAS) developed by Honeybee Robotics has been explicitly designed to collect a sample of the smooth terrain on comet 67P, as observed by the Rosetta mission. The SAS is mounted on a robotic arm and contacts the comet surface during a brief touch-and-go maneuver. A pneumatic system attached to the robotic arm provides high-purity nitrogen gas to a series of pneumatic nozzles within the SAS sampling cone. During contact with the surface, the nitrogen gas jets act to funnel cometary particles and ices through flexible Kapton flaps into a centralized 1.5 L sample container. We demonstrated the performance of the SAS in both vacuum and zero gravity at the NASA Glenn Zero Gravity Research Facility, routinely

collecting over 300 g of autoclaved aerated concrete “Aircrete” which has a density similar to the bulk density of comet 67P [2].

Direct imaging of the sample container interior verifies sample acquisition, and a load cell on the end of the forearm measures the mass of the collected sample via artificial gravity. After sample verification is complete, the SAS sample cone jettisons (Fig. 1), exposing the cold sample container, which is then inserted into the Sample Containment System (SCS) mounted inside the Sample Return Capsule (SRC) and decoupled from the robotic arm. The SCS lid is closed and sealed with a knife-edge and copper ring that has been shown via test to substantially exceed leak rate requirements after sealing under a range of cold and dirty conditions. The SCS interfaces directly to the Gas Containment System (GCS), a gas reservoir for volatiles separation and isolation.



Figure 1: SAS (1), Jettison Sample Cone (2), Gold-Plated Sample Container (3), SCS Open (4), SCS Preloaded and Sealed (5).

3. Gas Containment System

Comet solids must be kept cold and dry to avoid aqueous-solid and gas-solid reactions. Even brief exposure to liquid water or brines would confound attempts to determine if aqueous activity ever

occurred on 67P. CAESAR preserves much of the science of a cryogenic sample return by retaining volatiles in a dedicated reservoir securely separated from the solid sample. After sealing, the SCS slowly warms the collected material from the cold temperatures of the collection to 67P surface temperatures experienced near perihelion. As gases evolve from the sample, they are passively cryo-pumped into a separate radiator-cooled GCS gas reservoir developed by the NASA Goddard Space Flight Center (Fig. 2). Once H₂O ice transfer from the SCS to the GCS is complete, the GCS is sealed to capture the volatiles it contains, and the SCS is vented to space to maintain the solid sample under vacuum. The SCS vent is closed before Earth entry to prevent atmospheric contamination of the sample. The system records sample temperature and pressure from sealing at the comet until opening on Earth. The interiors of the SCS, GCS, and associated plumbing are coated with an inert material to minimize surface reactivity and catalysis.

Brassboard H₂O ice transfer experiments conducted inside a thermal vacuum chamber have shown that >99.99% of sublimated H₂O can be captured inside a GCS cooled to less than -60°C while maintaining water pressure well below its triple point (4.58 Torr), preventing liquid formation. Other known comet species such as CH₃OH and H₂CO have similar volatilities to water and should also condense as ice in the GCS. More volatile species (e.g., noble gases, CO₂, CO, O₂, HCN, NH₃, CH₄) will not solidify in the SCS or GCS. The GCS gas reservoir is sized to maximize its volume (5 L) relative to the SCS headspace (~1 L), to trap the largest possible fraction (83%) of the non-condensable species. Preflight calibration of the SCS-to-GCS volume ratio enables recovery of the original portion of gas abundances.

The SCS temperature during gas transfer is controlled to enable H₂O ice sublimation from the sample and prevent aqueous alteration of the most reactive amorphous silicate minerals (based on measured amorphous Mg-silicate powder gas-solid hydration rates [3], a sample temperature of -30°C requires completion of H₂O transfer in ≤ 100 days. We are currently conducting a series of gas transfer experiments using a SCS-GCS breadboard at NASA Goddard to determine the optimal gas transfer conditions and to establish the conditions under which comet analog materials will not alter during exposure to water vapor. During the transfer experiments, the partial pressure of H₂O and CO₂ vapor is measured directly in a gas cell between the

SCS and GCS using two redundant thermopile detectors with 2.7 μm and 6.5 μm H₂O and 4.2 μm CO₂ spectral band absorption filters, each paired with IR sources. Laboratory breadboard experiments have shown that the gas sensor can measure water pressure down to ≤ 10 mTorr, the expected vapor pressure of water when gas transfer to the GCS is complete.

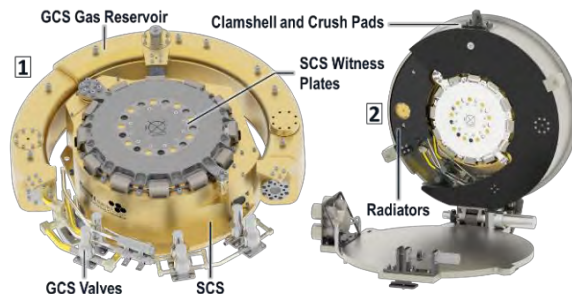


Figure 2: SCS and GCS (1), SCS and GCS mounted in a clamshell mechanism (2).

4. Sample Return Capsule

The Japanese Aerospace Exploration Agency (JAXA) provides the CAESAR SRC. Its design is based on the SRC flown on the Hayabusa and Hayabusa2 missions [4]. Before Earth re-entry, the GCS lid shuts, and the SRC closes by driving the backshell/payload into the front heatshield with a linear actuator. The spacecraft, built by Orbital ATK, releases the SRC using a spin-separation mechanism. The SRC uses a two-stage subsonic parachute system and drops its heat shield during parachute descent, greatly simplifying thermal control of the comet sample. The SRC lands at the Utah Test and Training (UTTR) range and the recovery team expeditiously places it into cold storage. The system maintains the SCS and GCS below 0°C throughout entry, descent, landing, and recovery. Phase change material sealed in aluminum housings mounted on the GCS ensures that no melting of H₂O ice will occur even if SRC recovery is delayed for several hours.

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The UVS Instrument on ESA's JUICE Mission

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Abstract

The ultraviolet imaging spectrograph on the JUICE mission (JUICE-UVS) is included in the ESA payload as part of NASA's U.S. contribution, and is being managed and built by SwRI in San Antonio, TX. With a bandpass of 55-210 nm, JUICE-UVS will observe: 1) airglow and auroral emissions, 2) far-ultraviolet surface reflectivities (both day and night sides), and 3) stellar and solar occultations of the Galilean satellites and Jupiter. These observations will support a large majority of the JUICE primary science objectives while providing useful context for in situ particles and fields measurements. In this presentation we provide the salient details of both our science goals and how JUICE-UVS operates.

1. Science Goals

The primary science goals of the JUICE-UVS investigation are to:

- 1) Explore the atmospheres, plasma interactions, and surfaces of the Galilean satellites;
- 2) Determine the dynamics, chemistry, and vertical structure of Jupiter's upper atmosphere, from equator to pole, as a template for giant planets everywhere; and
- 3) Investigate the Jupiter-Io connection by quantifying energy and mass flow in the Io atmosphere, neutral clouds, and torus.

These high level goals will be met by addressing key science questions in each area. For example, for the first goal of Galilean satellite science, some important questions of interest are:

- How are their tenuous atmospheres generated, how are they distributed, and what is their composition?
- How do the atmospheres respond to changes in Jovian plasma conditions?
- What are the non-ice surface components, and are they primarily exogenic or endogenic?

For the second goal of Jupiter science, a few key questions are:

- How do minor species vary with latitude in the upper and lower stratosphere?
- Is global thermospheric circulation dominated by auroral energy input?
- How do faint & diffuse auroral structures vary with changing magnetospheric conditions?

For the third goal of plasma transport in Jupiter's magnetosphere, some vital questions are:

- What controls the flow of mass and energy from Io's atmosphere into neutral clouds, the torus, and eventually the magnetotail? Volcanos? Sublimation? Can we image the postulated outward transport of cold plasma?
- How are the high-energy electrons re-energized? What do they contribute to the power emitted by the torus
- How are changing torus and inner magnetosphere conditions related to low-latitude Jovian auroras?

2. Instrument Description

JUICE-UVS is the fifth in a series of ultraviolet imaging spectrographs (including Rosetta-Alice, New Horizons Pluto-Alice, LRO-LAMP) and is largely based on the most recent of these, Juno-UVS [1]. It observes photons in the $55 < \lambda < 210$ nm range, at moderate spectral and spatial resolution along a 7.5° slit. A main entrance “airglow port” (AP) is used for most observations (e.g., airglow, aurora, surface mapping, and stellar occultations), while a separate “solar port” (SP) allows for solar occultations. Another aperture door, with a small hole through the center, is used as a “high-spatial-resolution port” (HP) for detailed observations of bright targets. Time-tagging (pixel list mode) and programmable spectral imaging (histogram mode) allow for observational flexibility and optimal data management. As on Juno-UVS, the effects of penetrating electron radiation on electronic parts and data quality are substantially mitigated through contiguous shielding, filtering of pulse height amplitudes, management of high voltage settings, and careful use of radiation-hard, flight-tested parts. Large reductions in technical and programmatic risk for UVS are enabled by lessons learned from Juno-UVS. UVS will obtain excellent airglow and auroral observations, stellar and solar occultations, and surface albedo maps to address the above goals, even in the worst-case radiation environment near Europa.

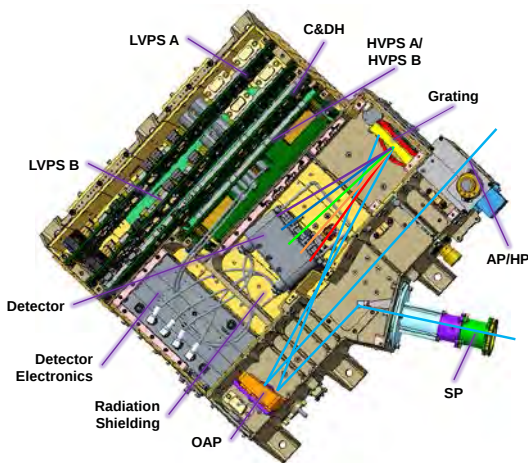


Figure 1: JUICE-UVS instrument drawing with the cover removed and with functional units identified.

The JUICE-UVS instrument consists of a single unit which houses a telescope/spectrograph assembly, detector electronics, and a general electronics assembly containing command and data handling, and redundant low-voltage and high-voltage power supplies. The telescope/spectrograph assembly contains a telescope which feeds a 0.15-m Rowland circle spectrograph. Light from any of the entrance ports reflects off the OAP and is focused onto the spectrograph entrance slit, which has a “lollipop” shape $7.3^\circ \times 0.1^\circ + 0.2^\circ \times 0.2^\circ$ long (the box on the end is used to observe the Sun during solar occultations). Light passing through the slit is dispersed by a toroidal grating which focuses extreme- and far-ultraviolet photons onto a curved microchannel plate cross delay line detector with a solar blind UV-sensitive CsI photocathode, which makes up the instrument’s focal plane. The detector electronics are located behind the detector. All other electronics are located in a section adjacent to the spectrograph section, including redundant low-voltage and high-voltage power supplies, command and data handling electronics, heater/actuator electronics, and event processing electronics. Tantalum surrounds the detector and electronics to shield them from high-energy electrons.

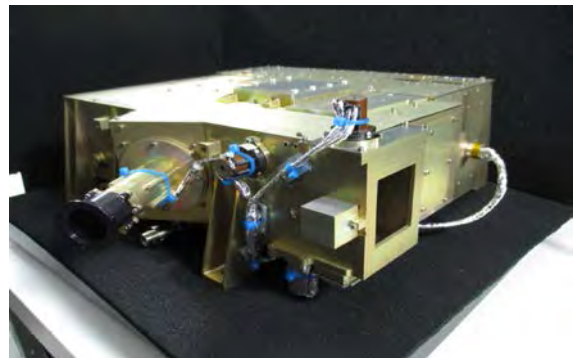


Figure 2: Photograph of the engineering model of the JUICE-UVS instrument.

Acknowledgements

We gratefully acknowledge the support of NASA.

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VenSAR on EnVision

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Abstract

EnVision is a proposed ESA M5 (medium class) mission to determine the nature and current state of geological activity on Venus, and its relationship with the atmosphere, to understand how Venus and Earth could have evolved so differently. Its prime instrument, VenSAR, is adapted from NovaSAR-S, the UK's Earth Observation radar. It will provide polarimetric imagery at 30 m resolution and snapshots at up to 1 m resolution, obtain topography at 15 m resolution vertically and up to 60 m spatially, and detect ground movements as small as 1 cm per year. The range and volume of data collected by a single instrument will be unprecedented for a planetary mission, requiring a smart, adaptive observation and data return strategy. These data will help to determine how geologically active Venus is today, whether it had oceans in its past, and why it evolved so differently to Earth.

1. Introduction

NASA's 1989—1994 Magellan mission provided a global image of the surface at ~150 m resolution, making our knowledge of Venus comparable with that of Mars after the Viking missions in the 1970s. Magellan revealed an enigma: a relatively young surface, rich in apparent geological activity, but with a crater distribution indistinguishable from random. The initial conclusion was that a global catastrophe half a billion years ago had resurfaced the planet: Venus was solved. After Viking, Mars was similarly thought to be understood, with everything known that needed to be known. Two decades later, Pathfinder launched the modern era of Mars exploration that has transformed our understanding of that planet.

ESA's 2006—2014 Venus Express, the most successful mission to Venus in the last two decades, revealed a far more dynamic and active planet than expected, uncovering tantalising evidence for present day volcanism that demands further investigation. Nevertheless, the enigma remains: how can a

geologically active surface be reconciled with the global stasis inferred from an apparently random impact crater distribution? The key science goals for EnVision are therefore to:

- Determine the level and nature of current geological activity;
- Unravel the sequence of geological events that generated its range of surface features;
- Assess whether Venus once had oceans or was hospitable for life; and
- Understand the organising geodynamic framework that controls the release of internal heat over the history of the planet.

Answers to these questions require investigations of target regions at different spatial resolutions and with different types of observations, including imagery, polarimetry and topography, using a nested approach that links high resolution snapshots to regional and global context data. The nested survey approach has been very successful on the Moon, Mars and Earth, where it has proven to be the most efficient way to maximise scientific insight from a minimum of data.

2. VenSAR

Radar is the only tool able to image the surface at high resolution and the technology has progressed enormously since Magellan. VenSAR can obtain repeat pass differential interferometry (DInSAR) and polarimetry (HH, VV and VH or HV), both at 30 m resolution (15 m/pixel), and 6-m high resolution and 1-m spotlight imaging; and calibrated radiometry. Uniquely, it can operate responsively, i.e. change its imaging mode and targeting in response to new discoveries, and it will return complete raw data with no loss of scientific value caused by lossy compression techniques. These VenSAR attributes are key to measuring how active Venus is today and how different it may have been in the past, questions that directly address the aim of understanding why Venus is so different to Earth.

VenSAR is a 5.47×0.60 m, 152 kg, phased array Synthetic Aperture Radar (SAR) antenna operating at 3.2 GHz, designed in Britain by Airbus Defence and Space, Portsmouth. Its core advantage is the use of modular high power density GaN microstrip patch phase centres. This technology, developed for NovaSAR-S, enables a low mass self-contained Front End that includes the RF electronics on the reverse side of the antenna panel. VenSAR uses 24 phase centres in a 6×4 arrangement of centre-fed sub-arrays each containing 24 patches. Each sub-array is individually controllable in polarisation for transmit (Tx) and receive (Rx) functions, and Rx gain, with a beam control unit to apply transmit and receive phase adjustments. These provide the antenna with considerable flexibility in the selection of the desired resolution and swath width within the 182 MHz available bandwidth, and incidence angles from 20° to more than 45° . Calibration paths have been included to enable characterisation of the phase centre distortions for replica generation, antenna beam pattern maintenance, and system diagnostics.

The back-end New Instrument Architecture (NIA) generic space radar central electronics is the first truly generic backend solution readily adaptable to a wide variety of space radar mission scenarios in a compact, lightweight and low power module that is ideal for VenSAR.

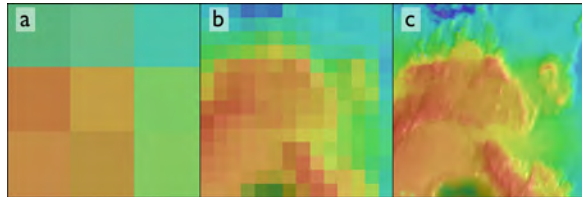
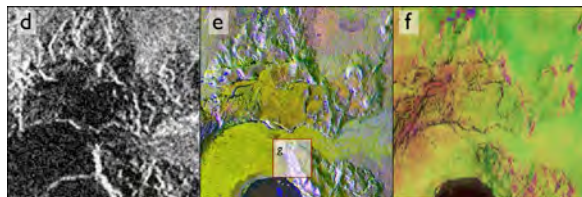
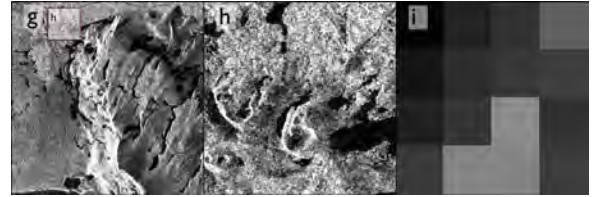


Figure 1: a: Magellan ~ 10 km resolution altimeter data. b: Magellan ~ 1 km resolution topographic data derived from stereo pairs. c: VenSAR 60 m resolution topographic data.



d: Magellan image at ~ 110 m resolution of Oskjuvatn volcanic caldera, lake, and flanks. e: VenSAR polarimetric (VV-VH-HH) 30 m resolution image,

revealing different lava flows and slope materials. f: VenSAR DInSAR 30 m resolution map of surface change; red areas are sinking, blue areas rising, and black areas have lost coherence.



g: HiRes 6 m resolution image of area shown by box in e. h: Spotlight 1 m resolution image of an individual vent in the area shown by box in g. i: The same area is represented by just 16 pixels in the Magellan image. Data simulated from Sentinel-1 and TerraSAR-X data across Oskjuvatn, Iceland.

3. Operations

Unlike Earth Observation satellites, EnVision is not in a fixed orientation since the spacecraft must be pointed in different orientations for the communications link and for other science experiments. The advantage of this is that VenSAR can be pointed optimally for each mode; beam steering is not required. All portions of the planet are accessible for high-resolution and polarimetric imaging during the nominal mission. InSAR stripmaps will include both contiguous equatorial strips and both poles, for geodesy, and targeted observations of regions of interest for geology.

The raw SAR data acquired in all active modes will be losslessly (FD-BAQ) compressed, stored and transmitted to Earth in 6-hour links every 24 hours. The imaging strategy depends on the Earth-Venus distance, with InSAR collected throughout the synodic period but StereoPolSAR and HiRes only when there is sufficient link capacity.

4. Conclusions

VenSAR is an extremely capable and versatile radar, optimised for operations at Venus, but building on decades of experience in Earth Observation. The breadth and quality of data it will collect will transform our understanding of our nearest neighbour.

Signatures of Life in Ocean Worlds and Implications for In Situ Instrumentation

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Abstract

In support of life detection in habitable regions of our solar system, there is currently an active and healthy interplay between the experimental, analog science, and theoretical disciplines [1]. These fundamental science activities promise to identify complementary suites of signatures of life beyond Earth. Complementary to these scientific endeavors is a review of the portfolio of scientific instrumentation that can provide a solid foundation for optimized in situ capabilities to search for life signatures on future missions. The resulting approach employing science-driven instrument developments will be most robust when capable of universal detection of life signatures, including those considered “agnostic” relative to life as we know it.

1. Introduction

Just in the past few years, the planetary science community have made a number of truly historic discoveries. It is now known that there is a measurable inventory of indigenous organics on Mars, through the investigations of the Mars Science Laboratory [2, 3]. There are liquid water oceans amongst the outer planets [4]. The dwarf planet Ceres harbors present-day geologic activity that may be producing mass transport of organics to the surface [5]. The robust analog and Earth life science community continues to demonstrate that life is found in the most extreme of environments on our planet. And we are on the cusp of really being able to probe the characteristics of exoplanets across a broad range of environments, with our solar system playing a critical comparative planetological role. The confluence of these discoveries means that we are poised to take the next step in the field of astrobiology: implementing in situ investigations to search for life in presently habitable environments in our solar system.

2. Analyzing for Life Signatures

It is critical to make sure that we are prepared to give upcoming life detection missions the best chance of a true result (avoiding a false positive or false negative), and this discussion is complementary to the number of efforts ongoing to optimize the suite of life signatures that can be targets of future in situ science payloads. Generically, we assume here that an example of a high quality life signature will reflect the biological preference for a subset of chemistries out of all possible chemistries in a given thermodynamic workspace. Biological preference on Earth, for example, results in the excess of one enantiomer in chiral biomolecules, such as L-amino acids and D-sugars [6, 7]. Biology as we know it also makes use of structural molecules whose physical structure and complexity is optimized to the prevailing environmental conditions, such as phospholipids that construct cell membranes occurring in a narrow distribution around a centroidal number of carbon atoms [8]. An emerging approach to life detection aims to assess chemical pathway complexity as an agnostic measure of biogenicity [9, 10].



Figure 1: The search for life beyond Earth will require optimization of all interactions with the sample and environment to meet rigorous scientific and environmental requirements.

A flexible instrument architecture that is adept at characterizing molecular inventory in a targeted environment would therefore be among the best candidates to serve the life detection goals of a future campaign. We present a framework and portfolio of analytical features that will meet the needs of the life detection community in a collaborative collaboration between the evolving field of life signature science and the state-of-the-art in mature and maturing flight instrument capabilities.

3. The Effect of Environment

The reality of making a life detection measurement in a planetary environment deserves particular attention. For example, the vastness of planetary habitability, compared to the scale of flight instrumentation, means that the targeted life signature may be present in exceedingly low abundance. The environment itself may prove challenging for instrument operation with performance goals that are otherwise readily met in more benign locations. Limitations to operational and mission design constraints exacerbates this challenge. Furthermore, the act of measurement has the potential to confound the intrinsic characteristics of a sample, such that sample handling and processing along the sample path must be done with great care.

A community could become quite pessimistic in the face of such challenges, but we will present a well founded approach to optimize, and adapt where necessary, proven flight instrumentation for the unique rigors of a life detection mission under particularly harsh environmental conditions and with particularly stringent requirements on planetary protection and instrument sensitivity.

Acknowledgements

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The JUICE/MAJIS optical head design

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Abstract

We report about the MAJIS (Moon and Jupiter Imaging Spectrometer) Optical Head (OH) design. The instrument is part of the scientific payload aboard ESA JUICE mission to the Jupiter system currently scheduled for a launch in 2022. The MAJIS instrument is an advanced imaging spectrometer encompassing visible and infrared wavelengths (0.5-5.54 μm) measured at high spatial and spectral sampling with internal pointing, scan and motion compensation capabilities. The instrument, currently in development phase C/D, is built by a France-Italy consortium.

1. Introduction

MAJIS spectrometer is part of the scientific payload selected for the ESA JUICE mission to Jovian system [1], aiming to the following scientific objectives: 1) investigation of the nature and location of chemical compounds on the surfaces of the Galilean satellites, in particular Ganymede for which a global coverage is planned; 2) characterization of the tenuous exospheres of the icy moons; 3) monitoring of Io and Europa tori and Io's volcanic activity; 4) study of Jupiter's atmosphere composition, dynamics and aurora emissions at different levels; 5) spectral characterization of the whole Jupiter system. The instrument is realized under a partnership between CNES (leading funding agency) and ASI. Science, operations and technical teams are mainly from IAS-Orsay, France (PI institution) and IAPS-Rome, Italy. Leonardo Company (Florence, Italy) is responsible for the MAJIS Optical Head design, manufacturing and testing, including auxiliary electronics board. The instrument design is driven by several constraints: 1) operative cryogenic temperatures ($T < 90\text{K}$ for IR detector); 2) very harsh radiation environment (up to 50 Mrad on the scan mirror); 3) limited mass allocation for the OH unit ($< 45\text{ kg}$); 4) motion compensation during fast Europa flybys and low Ganymede orbits; 5) high spatial and spectral sampling.

2. Optical design

MAJIS uses a TMA telescope (pupil diameter 75 mm, $F=240\text{ mm}$, $\text{FOV} = \pm 1.7^\circ$, $\text{IFOV} = 150\text{ }\mu\text{rad}$) followed by a slit and a Schmidt off-axis collimator. The optical beam is separated between the two spectral channels (VIS-NIR: 0.5-2.35 μm ; IR: 2.25-5.54 μm) by a dichroic filter. Two independent spectrometers are used to disperse the light on 400 pixels by 508 spectels MCT detectors with 36 μm equivalent pitch. Detectors and proximity electronics are procured by CNES. The OH layout, as shown in Fig. 1, is detailed in [2]. At the side of the telescope's entrance baffle is housed the internal calibration unit (ICU), containing a lamp, an IR emitter and a diffuser, which shall be periodically used to check the stability of the instrument response. The ICU signals are measured with an extra rotation of the scan mirror.

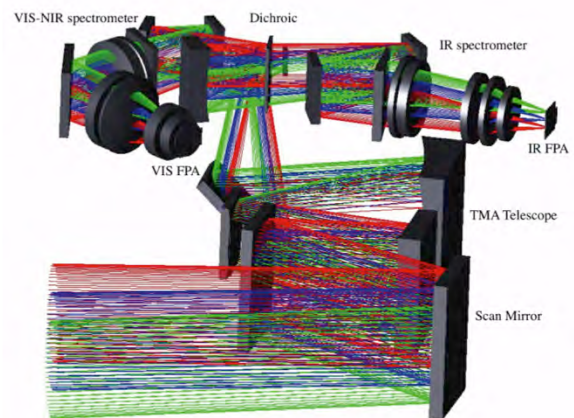


Figure 1: Rendering of the MAJIS Optical design.

3. Mechanical design

Optical elements are mounted on a bench stiffened by a ribs pattern plus a peripheral continuous rib to provide the maximum stiffness with minimal mass. Due to the complexity of the optical design, the bench is populated on both sides, with the telescope and scan mirror elements on the bottom side and collimator, spectrometers and detectors on the top

side. Three bipods in composite material are used to mount the OH on the S/C bench. Bipods are placed at an angle of about 120° from each other to equally distribute the mechanical loads. The direction of minimal flexural stiffness of each bipod is oriented towards a common point located in the proximity of the center of mass of the instrument resulting in an isostatic design. Thermal elongation of the optical bench is compensated by the bipod transversal flexibility minimizing the induced stress on the bench. The instrument employs two active mechanisms: 1) an electromechanical shutter placed at the entrance slit. This is used to close the slit's aperture for the time necessary to acquire the dark and internal background signals while is keep open during science observations. 2) a steerable scan flat mirror, placed at the telescope entrance, is operated to perform spatial scans, motion compensation and internal calibration modes. The scan axis is rotating on flexural pivots. The scan mechanism uses different CTE of the mirror material and support structure to lock it in a fixed position at ambient temperature and unlock it at operative temperature. With a similar design the scan mechanism is locked during the launch phase. Dedicated shielding is used in different places of the OH to reduce ionizing and non ionizing radiation on optical elements and detectors. The rendering of the OH unit is shown in Fig. 2.

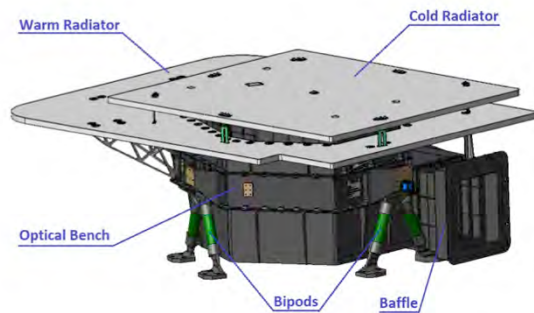


Figure 2: Rendering of MAJIS mechanical layout, including two stage radiators.

4. Thermal design

MAJIS OH is passively cooled to operative temperatures: $T < 140$ K for the optical elements and VIS-NIR detector, $T < 90$ K for the IR detector. To reach these temperatures are used: 1) thermally insulating composite bipods to decouple the OH from the S/C interface (at $T < 293$ K); 2) a warm radiator (Fig. 2) in thermal contact with the OH bench and

VIS-NIR detector; 3) a cold radiator coupled with the IR detector by means of a thermal strap. The cold radiator is mounted above the warm radiator by means of low conductance composite blades; 4) a double radiative barrier in SLI and MLI wraps the external walls of the OH; 5) dedicated survival and decontamination heaters.

5. Summary and Conclusions

The MAJIS team is working on the development of the entire instrument in order to pass the next project milestone (system CDR) currently scheduled by early 2019.

Acknowledgements

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Tandem Ion Mass Spectrometer for Planetary Missions

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Abstract

We are developing a Tandem Ion Mass Spectrometer (TIMS), whose design, fabrication, and prototype testing, will provide the requisite measurements at high mass resolution and abundance sensitivity for hot plasma ions at a moon's surface, or within ionospheric and magnetospheric environments of the giant planets and the local environments of their moons. TIMS would be a key component of "Ocean Worlds" science payloads that directly support extraterrestrial ocean detection and habitability objectives while also providing critical chemical context to the search for past and extant life, e.g. avoiding false positives if TIMS-measured elemental-molecular composition is inconsistent with biosignature detection. It would provide compositional measurements of the surface, ionospheric, and local magnetospheric environments of candidate ocean worlds including Enceladus, Europa and Titan, e.g. for a New Frontiers (NF) mission to Titan and Enceladus, and for a future orbiter to the latter. Just as the Apollo ALSEP experiments characterized the plasma environment of the Moon's surface, a lander could similarly achieve this for Europa with TIMS. TIMS would also benefit future missions to Io and Uranus. TIMS solves the problem in hot plasma ion mass spectrometers of resolving low-abundance species against the intense foreground of major species and the extreme background of radiation-induced noise in sensors and electronics.

1. Introduction

The Tandem Ion Mass Spectrometer (TIMS) is being developed with a multi-mission capability with modular design. It can work in the dense ionospheres of the giant planets, the plumes of Enceladus and Europa and planetary moons like Titan, while also having high sensitivity for the more tenuous plasma environments of planetary magnetospheres.

1.1 Subsection

The principle innovation of TIMS is the addition of a Circular Wien Filter (CWF) into the entrance system of a tophat Electrostatic Analyzer (ESA) which converts TIMS into an Ion Velocity Spectrometer (IVS) and allows it to preselect the incoming ion M/Q before entering the TIMS triple coincidence Tapered Linear Electric Field (TLEF) cylindrical Time-of-Flight (TOF) system to provide wide FOV, $\sim 2\pi$ steradians for 3-axis stabilized orbiting spacecraft or lander and 4π steradians for spinning spacecraft; full energy coverage at 1 V to 25 kV; ion mass resolution $M/\Delta M \sim 60$; and separation of ions with similar M/Q (i.e., O⁺/S⁺⁺, S⁺/O₂⁺). A Solid State Detector (SSD) is included for separating high charge state solar wind ions which might complicate the identification of low M/Q ions within a giant planet magnetosphere.

This preselection of the ion's M/Q by the CWF allows TIMS to tune out the more abundant major ions so the minor and trace ion species can be analyzed by the time-of-flight subsystem so provides a wide dynamic range in particle intensities which could be very useful for measuring the composition of Titan's ionosphere. Finally, as supported by simulations, the CWF provides a tandem capability which allows one to separate ions of similar M/Q. Basically, it selects the molecular ion's M/Q while the tapered LEF separates out the atomic components. The electric fields of the TLEF allows one to locate the SSD at ground potential which significantly reduces the risk of instrument failure. In addition to the TIMS development we have been measuring the response of microchannel plates (MCPs) to energetic electrons from 100 keV to 1.4 MeV using the NASA Goddard Van de Graaff accelerator and 8 MeV to 27 MeV electrons using the National Institute of Standards and Technology (NIST) linear accelerator. We've done this for

unshielded and shielded MCPs and have developed preliminary shielding designs. We are also developing techniques that can mitigate against the background noise from penetrating particles such as MeV electrons at Europa. The instrument has rad hard microelectronics which include the Front End Electronics (FEE), time to digital converter (TDC) and SSD pulse height analysis (PHD) electronics which makes TIMS a radiation tolerant instrument ideal for missions to Io and Europa.

2. Summary and Conclusions

We will present both laboratory measurements of our prototype of TIMS, the MCP response to energetic electrons and recent simulation results of TIMS using our 3D Electric and Magnetic Monte Carlo SIMION simulation code. TIMS is a multi-mission instrument that can be used in the dense ionosphere of planetary bodies such as Titan and the more tenuous plasmas within the giant planet magnetospheres. It will be radiation hardened to work within regions of high instantaneous radiation environments such as Io and tolerate high radiation doses such as a Europa class mission (i.e., shielding designs with triple-coincidence detection).

Acknowledgements

We acknowledge the support of the Chief Technologist at NASA Goddard Space Flight Center Internal Research and Development (IRAD) program.

Optimized Narrowband Visible to Near-Infrared Filters for the Psyche Multispectral Imager

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Abstract

The Psyche Multispectral Imager is a visible to near-infrared camera system that will be flown on the *Psyche* mission to the M-type asteroid (16) Psyche. The Imager is equipped with 8 filters that will be used for color imaging and multispectral observations. We present the results of a spectroscopic study of metallic and metal-silicate meteorites and laboratory minerals that have been used to optimize the Imager filters. Our study indicates that the merging of two previously-proposed filters and the addition of a new near-infrared filter will enhance mission science return.

1. Introduction

The Main Belt asteroid (16) Psyche is the largest of the M-type asteroids ($D > 200$ km) and the target of NASA’s *Psyche* Discovery mission [1]. Measurements of density, radar albedo, thermal inertia, and reflectance are consistent with (16) Psyche being largely composed of metal. The Psyche Multispectral Imager (henceforth the ‘Imager’) is a visible to short-wave near-infrared (~ 400 to ~ 1100 nm) CCD camera designed to characterize topography, geology, and composition of the surface of (16) Psyche [2]. The Imager consists of a pair of redundant, identical 148 mm focal length $f/1.8$ camera assemblies and accompanying digital electronics assemblies. Internal to the camera assemblies are filter wheels containing 8 filters specifically chosen to maximize the Imager’s ability to address *Psyche* mission science objectives (Table 1). These objectives include assessing the mixing of silicates and metal on the surface, as well as detecting the presence of sulfide minerals like oldhamite and troilite that are indicative of reducing conditions during (16) Psyche’s formation. The *Psyche* mission will be the first close-up encounter with a metallic asteroid, and thus the bandpasses of the Imager’s filters must be carefully chosen to best capture reflectance features in the spectrum of (16) Psyche that can address mission science objectives.

Table 1. Psyche Multispectral Imager Filters

	Band ^a	λ (nm)	Purpose
As-proposed filters	Clear	540 $\pm$ 140	Unfiltered for OpNav, topography, geology
	B	437 $\pm$ 25	Sulfide continuum, blue “true color”
	o	495 $\pm$ 12.5	Search for evidence of sulfides
	v	550 $\pm$ 12.5	Sulfide continuum, green “true color”
	^b _w	700 $\pm$ 25	Peak reflectance continuum, red “true color”
	0.75	750 $\pm$ 12.5	Search for low-Ca pyroxene
	p	948 $\pm$ 25	Search for high-Ca pyroxene, characterize weak Earth-based feature
	z	1041 $\pm$ 45	Search for evidence of olivine
Updated	$\sim$ w	725 $\pm$ 20	Peak reflectance continuum, red “true color”
	x	850 $\pm$ 25	Search for evidence of low-Ca pyroxene, other ~ 1.0 μ m features, capture Psyche Earth-based feature

^aEight Color Asteroid Survey designation [3]
^bAs-proposed filters highlighted in red have been replaced with new filters highlighted in blue.

2. Methods

We have selected a set of 26 meteorite samples from Arizona State University’s Center for Meteorite Studies collection that contain a broad range of materials relevant to potential Psyche surface compositions. These meteorites span a range of classes, including IAB and IVA irons, mesosiderites, pallasites, enstatite chondrites, a group of H and L ordinary chondrites, a lodranite, aubrites, and a diogenite. These classes were sampled to cover a broad range of bulk metal contents, from nearly entirely iron-nickel metal with minor sulfides seen in iron meteorites, to silicate-dominated assemblages with essentially no metal. When available, the samples were analyzed as powders, gravels, or roughened and polished surfaces. We used an Analytical Spectral Devices FieldSpec 4 (FS4) spectrophotometer to capture bidirectional

reflectance spectra from 350-2500 nm to cover the Imager’s spectral range. Our light source is a quartz-tungsten lamp and all spectra are calibrated to a Spectralon white reference standard, which has near-uniform reflectance in the FS4 measurement range. The phase angle was 30°. The wavelength range measured by the FS4 enables measurement of absorption features near 1000 nm that are attributable to iron in silicates like olivine and pyroxene. Furthermore, the Imager is intended to capture absorption features from some sulfide minerals, such as oldhamite at 495 nm and 948 nm, and a change in slope of the troilite reflectance spectrum at ~650 nm.

3. Results

After convolving each full-resolution spectrum to the as-proposed filter set, it was evident that the 700/750 nm filter pair (bands *w* and *0.75*) were not capturing significant differences in absorptions or spectral slopes. These filters have thus been replaced with a single filter at 725 nm, which enabled consideration of a new filter placed elsewhere in the Imager-relevant wavelength range. Two filters were considered for adoption: a near-UV filter at 380 nm and near-IR filter at 850 nm. The near-UV filter offered potential leverage discriminating FeS from iron meteorite powder, a possibility of characterizing space

weathering from UV slope, and higher detector quantum efficiency. The near-IR filter offered better silicate mineral discrimination, better capture of the near-IR absorption seen in CaS, and better capture of the possible minor absorption feature seen in reflectance data of (16) Psyche [e.g., 4]. For these reasons, the near-IR filter was selected as the best option for the available filter slot. Figure 1 shows the reflectance spectra from a variety of endmember compositions from the meteorite set convolved to the final filter bandpass selections, including iron meteorite powder, troilite, oldhamite, low- and high-Ca pyroxene, and olivine.

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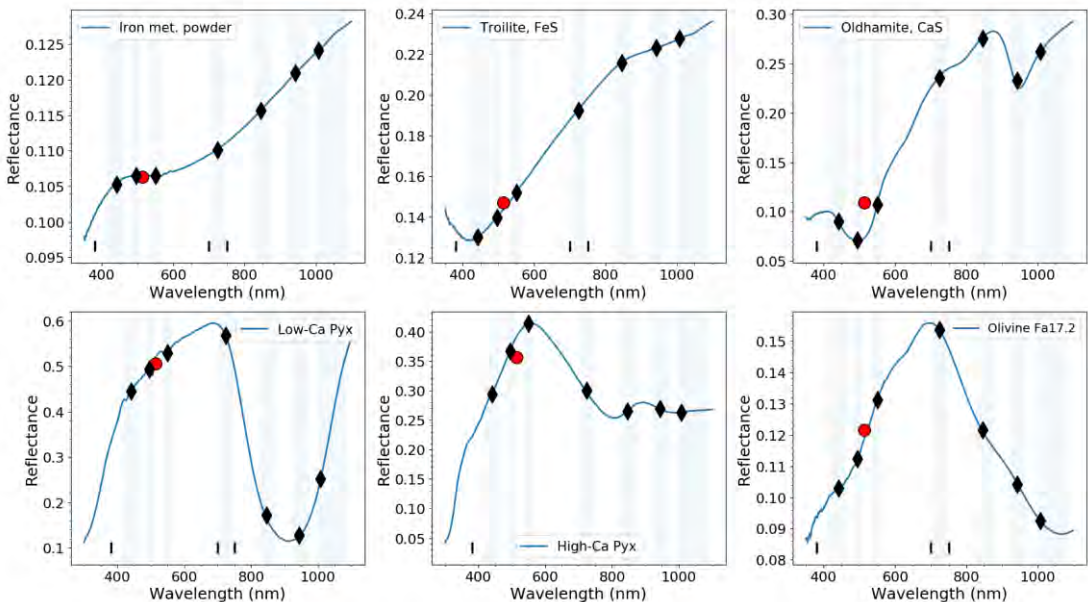


Figure 1: Reflectance spectra of materials relevant to the surface composition of (16) Psyche convolved to updated Imager bandpasses (Table 1). In all plots, the red circle is the convolved broadband clear filter and black diamonds are the convolved narrowband filters. Black ticks represent discarded filters. Samples graciously provided by L. Garvie, ASU Center for Meteorite Studies.

Development of a low energy threshold particle detector and application to CubeSats

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Abstract

We present an instrument concept with a low energy threshold in order to study plasma populations in the thermal energy range. The majority of the necessary building blocks are commercially available and some are even flight proven. The instrument mass is estimated to less than 1 kg and the power to less than 2W. This instrument is compatible with a 3U Cubesat.

1. Introduction

Particle measurements are fundamental for characterising and understanding plasma processes and related hazards, in heliophysics, planetology, and space weather research. Measurements are required for both electrons and ions, as well as neutrals, over a broad energy spectrum. They are critical to address key scientific questions related to planetary formation and the emergence of life, how the Solar System works, the origins of the Universe, and the fundamental physics at work in the Universe. These measurements are needed for a broad variety of space missions and science objectives. Particle instruments have thus been embarked on most missions launched in our Solar System.

At present, two main instrument types based on distinct technologies are used to cover the required large energy range from thermal ($\sim$ eV) to energetic (tens of MeV) particles. Energetic particle instruments covering the energy range from several tens of keV up to a few MeV use solid-state detectors (SSDs) to measure the residual energy (E) of the incoming particles [1]. Current SSDs detectors, which typically require bias voltages of a few tens to about a hundred volts, have historically had low energy thresholds of several tens of keV; a threshold typically too high for studying key plasma

populations in the thermal energy range. Recent advances in lowering the energy threshold for SSDs makes it possible now to construct an array of thin-contact solid state detector pixels with a lower energy threshold of only 1 keV for protons and 100 eV for electrons [2]. This detector should be operated at -30°C , in order to minimize the thermal noise. The charge created in the detector is amplified by a FET-based preamplifier, digitized by a fast Analog to Digital Converter (ADC) and processed by a Digital Pulse Processor (DPP).

2. Instrument concept

We present an instrument concept with a low energy threshold in order to study plasma populations in the thermal energy range. This detector is based on thin contact silicon detector, cooled by a thermoelectric cooler. The preamplifier is based on flight proven commercial components. The Digital Pulse Processor is implemented inside a System On Chip (SOC). The system is powered by a DC/DC converter protected by a delatcher. The architecture of the instrument is detailed in Figure 1.

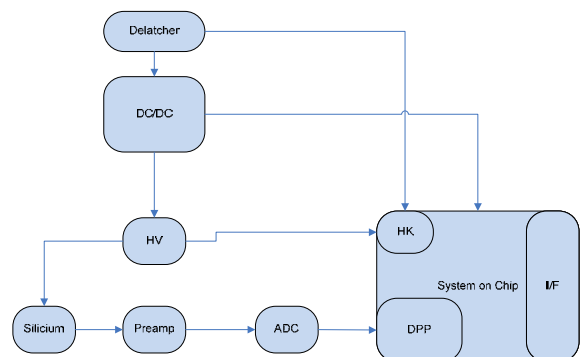


Figure 1 : Instrument Block Diagram

The majority of the necessary building blocks are commercially available and some are even flight proven. The instrument mass is estimated to less than 1 kg and the power to less than 2W. This instrument is compatible with a 3U Cubesat, with comfortable mass and power margins. The envisioned platform is based on commercial Cubesat components and boards, with four 3U deployable solar panels, magneto-torquers and reaction wheel AOCS, a SOC-based OnBoard Computer (OBC) a UHF/VHF transceiver and a S-band downlink transmitter. The system study has been performed and the mass and power breakdowns are presented. The cutout view of the resulting Cubesat is shown on Figure 2.

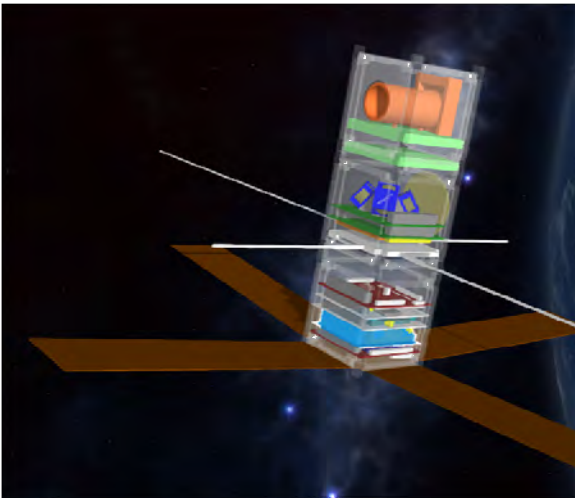


Figure 2: Cutout of the proposed Cubesat

This instrument is suitable for various applications, such as space weather, around earth or other planets, planetary plasma or heliophysics studies.

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Experimental Rotor Induced Collision Cell (RICC) for studying hypervelocity impact fragmentation of neutral molecules sampled by a flyby/orbiter closed-source neutral mass spectrometer (CN-MS).

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Abstract

High-velocity impacts of neutrals species unto a source surface involves sufficient energy to cause significant molecular changes, including fragmentation, leading to potentially incorrect interpretation of upper atmosphere's composition using Cassini's Ion Neutral Mass Spectrometer (IN-MS) and similar instruments. The experimental capability does not yet exist to study the products and thermodynamics of hypervelocity collisions of neutrals onto a surface. RICC, the Rotor Induced Collision Cell, was designed to study high velocity molecular impacts of neutrals. A carbon-fiber rotor (~2 km/s) combined with a seeded molecular beam (~2 km/s) create a high-velocity molecular impact of neutral species having the beam aiming towards the tip of the rotor's blade. Volatile products post-collision are trapped using a crybaffle, then extracted by thermal desorption and analyzed by gas chromatography - mass spectrometry (GC-MS) and by tandem mass spectrometry (MS-MS).

1. Introduction

When neutrals species impact at high velocities on solid surfaces of instrument inlets (e.g., prior to mass spectrometry detection in flybys/orbiters), significant energy is transferred into vibrational modes of the molecules, leading to unimolecular dissociation and other chemical changes. These transformations could lead to erroneous chemical identification [1]. Chemical changes that occur in such impacts may include dissociation, isomerization, racemization, and recombination. Methods have not yet been developed to study this relevant impact chemistry in the lab. An ultra-high velocity carbon-fiber rotor in combination with a seeded helium supersonic jet is being built to study high velocity impact reactions of neutrals.

Experiments consist in impacting molecules onto the surface of an ultra-fast rotor [2] with a tip speed of 2 km/s, where molecules are being introduced into the rotor using a seeded helium molecular beam traveling at approximately 2-3 km/s. The final energy of the impact is determined by the combined contribution of both the rotor and the molecular beam velocities. Impacting molecules are then thermalized by collisions with the walls of the vacuum chamber to subsequently be cryogenically trapped and analyzed. Finally, reaction pathways and thermodynamics can be determined for volatile compounds. Understanding the effects of impacts at high velocity of neutral molecules is of great importance in clarifying previous flight results, for instance, incorrect identification and abundancies, missing compounds, as well as developing new instrumentation for future orbiter missions that will minimize the effects caused by high velocity impacts.

2. Impact energy

Cassini's INMS was developed to study neutral species of planetary exospheres. Due to the high velocities at which the spacecraft encountered these neutral species, INMS developed a closed source antechamber where incoming neutrals were thermalized prior to analysis by bouncing within the metal surface of the chamber. The kinetic energy of the impact is dissipated into the surface and into vibrational and rotational modes of the impacting molecules. For instance, a molecule of molecular weight of 100 g/mol impacting at a relative velocity of 10 km/s represents 52 eV of kinetic energy, 8 eV of which is transferred to vibrational modes upon impact—enough to break chemical bonds—assuming 15% T-V conversion, a value which has been experimentally observed in ion-surface impacts [3]. Using simulations, a single impact may be sufficient

to break apart molecules at velocities as low as 5 km/s [1] see **Figure 3**. The larger the molecule, the more energy is available and the higher the likelihood for bonds to be broken [3].

3. Experimental set up of RICC

An ultra-high speed 1.5-2.0 km/s carbon fiber rotor (**Figure 1**) has been developed for this work. An RGA is located in the same chamber to detect any products or gases caused after the impact, although fragmentation in the RGA source reduces the sensitivity of this approach. After the impact any unreacted, volatile and semi-volatile products are trapped in a cryotrap. The cryotrap is then be heated to release the trapped gases, which are collected using a thermal desorption tube and transferred to the cryofocusing inlet of the GC-MS for analysis (see **Figure 2**).

A seeded helium molecular beam was build using a three-stage differential pumping setup. A piezoelectric x,y,z stage holds a heated nozzle which was attached to both the helium and the analyte gas line. Skimmers are used to separate the differential pumping chambers and admit the molecular beam into the rotor vacuum chamber.

4. Figures



Figure 1: Left, rotor design, with 25 cm titanium rotor installed. Right, carbon-fiber rotor.

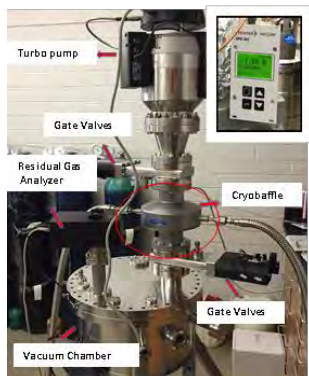
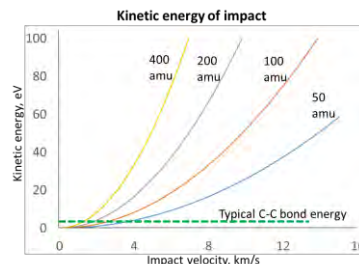


Figure 2: Rotor Induce Collision Cell set-up

During thermalization some fraction of the kinetic energy of the impact goes into vibrational modes of the molecule. This energy drives the dissociation and other chemical reactions. Even at velocities of 2-6 km/s chemical changes are expected.

Figure 3: Kinetic energy of impacts for volatile compounds mass range 50-400 amu over a range of encounter velocities.



5. Summary and Conclusions

This study will expand the understanding of chemical changes that result from hypervelocity impacts. In addition, this experimental set up could be used to test new improved mass spectrometer inlets.

Acknowledgements

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Stability of Reagents used for Chiral Amino Acid Analysis during Spaceflight Missions in High-Radiation Environments

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The search for extraterrestrial life in our solar system remains one of the highest-level goals for NASA. Towards this goal, the motto “follow the water” has lead us in the exploration of our solar system from Mars to ocean worlds orbiting gas giants. In particular, Europa, one of the Galilean moons of Jupiter, is an exciting target for astrobiological investigations and is the subject of two potential NASA missions in the near future [1, 2].

While life may exist within Europa’s ocean there is no telling what form it will take, or if it will use the same “alphabet” of biomolecules as life on Earth. To increase the chances of finding evidence for alien lifeforms on Europa or elsewhere we need life-detection strategies that can provide quantifiable evidence for life at the molecular level. One such strategy is to look for patterns of properties possessed by organic molecules within a given inventory [3]. For example, distributions within the type, relative abundance, and chirality of amino acids can be used as biosignatures to indicate the presence of life [4].

Capillary electrophoresis (CE) is an ideal candidate for in situ science missions, especially to areas where aqueous analysis is required. Recently, our lab developed a CE-LIF method for the simultaneous separation of the 13 astrobiologically relevant amino acids (including 5 chiral pairs) needed to detect three unique biosignatures [4]. The background electrolyte (BGE) for this method is composed of sodium tetraborate (STB), to maintain the pH at 9.2, as well as two chiral selectors (sodium taurocholate (STC) and γ -cyclodextrin (CD)), and acetonitrile (ACN) to adjust the viscosity and polarity. Finally, to achieve low limits of detection with LIF, the assay requires 5-carboxyfluorescein succinimidyl ester (CFSE) to label the amino acids prior to separation.

One perceived risk of including a CE-LIF assay on a mission of exploration is the degradation of the chemical reagents due to exposure to high levels of

radiation. While irradiation during spaceflight is a concern, the chemicals will also be exposed to the local radiation environment of the planetary target during the lifetime of the mission. This would be particularly extreme for landed missions to Europa and it will have a significant impact on the design of the electronics and instruments. In this paper, we investigate the effects of a Europa relevant TID of 300 krad on the reagents needed to perform the CE-LIF amino acid analysis.

Neither the fused silica capillary nor the fluorescent dye showed any significant change in separation or detection performance following irradiation. Following the irradiation of the background electrolyte, both the migration time and resolution of the amino acids were effected. However, when the dry reagents (STB, STC, and γ -CD) and the ACN solution were irradiated separately there was no change in the separation performance (Figure 1).

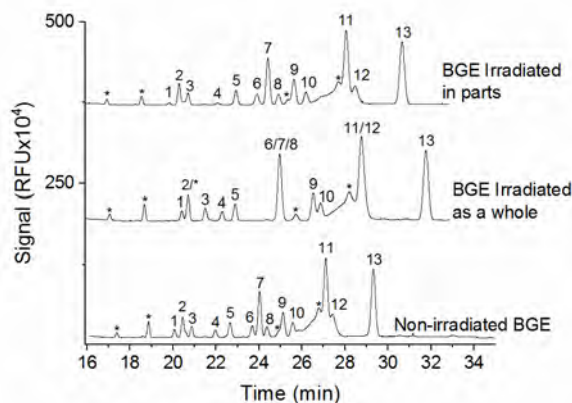


Figure 1: Three electropherograms that show the effect that irradiating the BGE has on the separation of 13 amino acids. Peaks: (1) D-His, (2) D-Leu, (3) D-Val, (4) L-His, (5) L-Leu, (6) D-Ser, (7) GABA, (8) L-Val, (9) D-Ala, (10) L-Ser, (11) β -Ala, (12) L-Ala, (13) Gly; *Dye side products.

These results put to rest the concerns regarding the chemical degradation of critical reagents needed for this sensitive and selective assay and has been submitted for publication in Electrophoresis [5]. While more work is needed to establish the long-term storage and thermal degradation that could be seen during instrument assembly, launch, and cruise phase of a mission, this is a significant step forward towards validating the CE-LIF technique for spaceflight.

Acknowledgements

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Continued development of the Potassium-Argon Laser Experiment (KArLE) for *in situ* geochronology

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Abstract

We are developing the Potassium-Argon Laser Experiment (KArLE) for *in situ* radiometric dating of planetary materials, as well as compositional measurements of major and minor elements, volatile compound analysis, and microimaging. The KArLE instrument simultaneously measures K and Ar using high-heritage hardware elements proven to operate in the planetary environment, interfaced through an innovative vacuum chamber and sample delivery system. We report new K-Ar isochron data for two ~380 Ma basaltic rocks, using a KArLE breadboard instrument. The basalts have K contents comparable to lunar KREEP basalts or igneous lithologies found by Mars rovers, whereas previous proof-of-concept studies focused primarily on more K-rich rocks. Our experimental results demonstrate that accurate and precise measurements are possible using the KArLE approach on basaltic rocks, which are ubiquitous on planetary surfaces and are useful in addressing a wide range of questions in planetary science.

1. Introduction

Geochronology is a fundamental tool to understand the history of planetary bodies. Radiogenic ages of rocks provide the absolute timing of geological events as well as the duration of geochemical or climatic conditions prevailing the planetary body. Dating rocks from multiple horizons by a rover travelling on the planet or multiple landers at different sites will enable us to place the history of individual planetary bodies into the context of the entire solar system evolution. The capability of *in situ* geochronology on board planetary landers or rovers is highly desired given the challenges and highly limited opportunities for sample return missions.

Geochronology experiments on the Curiosity rover have demonstrated the feasibility of *in situ* K-Ar dating on Mars and underlined the utility of acquiring absolute ages along with other geochemical data,

such as chemical and mineral composition of rocks [1-3]. However, the results also revealed challenges involved with this implementation, such as difficulty extracting ^{40}Ar from highly-retentive minerals using the onboard furnace, the incapability of directly measuring the mass of the sample, and the possibility of mineral sorting/separation during the sample delivery. To resolve these problems and expand the capability of *in situ* geochronology, several groups, including ours, have been developing K-Ar dating instruments based on a laser-ablation approach [4-6].

2. Approach

In the KArLE technique, laser pulses vaporize the sample surface, liberating K and Ar locally. The concentrations of K and ^{40}Ar in the laser spots are measured with laser-induced breakdown spectroscopy (LIBS) and mass spectrometry (MS), respectively (LIBS-MS approach). The LIBS-MS approach is attractive for flight implementation because its components (laser, optical spectrometers, mass spectrometer and microimaging) have flown on multiple missions, including aboard Curiosity as ChemCam, SAM, and MAHLI, respectively. This feature is advantageous because building on flight heritage reduces the cost, time, and risk of development.

Many planetary surfaces are covered with basaltic rocks, which are typically more K-poor and more homogeneous than the samples investigated in previous LIBS-MS studies. In this study, we assessed the capability of the LIBS-MS approach for basaltic rocks to further validate its performance as an *in situ* dating technique. This study used the breadboard geochronology instrument from [4] (with some upgrades) to measure two ~380 Ma basaltic rocks from Viluy traps, Siberia, with K_2O contents of 4200-6400 ppm. Both samples were cut into slabs and placed in the analysis chamber. The bulk density of the rocks was measured with an electronic scale to be $2.8 \pm 0.2 \text{ g/cm}^3$; in a mission setting, the density would be measured by combining elemental analysis and porosity assessment using LIBS and an imager.

3. Experimental Results

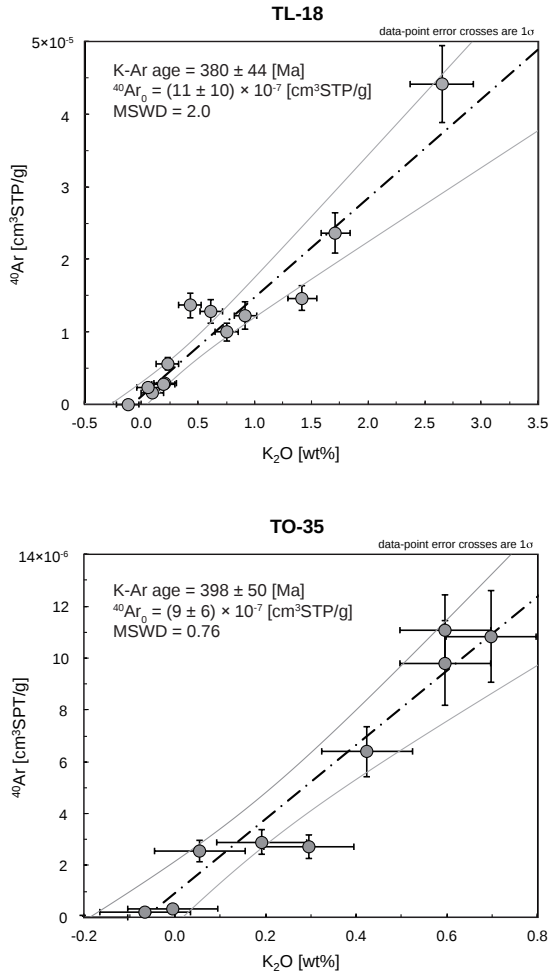


Figure 1: K–Ar isochrons for two basaltic samples. The dashed lines indicate the best-fit isochrons.

The LIBS-MS data form excellent isochrons with well-resolved trapped ^{40}Ar compositions for both samples (Fig. 1). The ages agree well with the K–Ar ages of the plagioclase grains measured with conventional techniques, and the observed scatter is small, suggesting a simple cooling history of the basalts, consistent with their ^{40}Ar – ^{39}Ar degassing spectra [7]. Our experimental results indicate that the current KArLE breadboard achieves a precision of 50 Ma ($\sim 12\%$, 1σ) for these rocks. The accuracy and precision of these results improves upon previously published results. The improvement is largely due to more extensive calibration and improved LIBS practices such as shutter synchronization.

4. Summary and Conclusions

The KArLE accuracy and precision suggest that *in situ* K–Ar geochronology with our LIBS-MS approach would be able to resolve a wide range of issues in planetary science related to the absolute ages of geologic units. Such measurements would provide key data to improve our understanding of the changing habitability of ancient Mars, anchoring the absolute timing of the transition between the Noachian and Hesperian. For *in situ* geochronology on the Moon, the measurement error would be sufficiently small to determine the age of key lunar basins where crater counting saturates, and constrain the impact flux at the 1000–3000 Ma range, where the crater chronology models may have an uncertainty up to ± 1000 Ma.

The capability for *in situ* geochronology would open up the ability for this crucial measurement to be accomplished at multiple locations aboard stationary landers or mobile rovers. KArLE is a low-risk, synergistic way to implement the first *in situ* geochronology experiment on the Moon.

Acknowledgements

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Atomic sensors for planetary gravity and seismic measurements

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Abstract

Much knowledge of planetary interiors and dynamics can only be learnt from gravity or seismic measurements. In this paper, we describe atomic inertial sensors, a new kind of inertial force sensors that can be deployed as onboard accelerometers for orbiter gravity measurements or as surface seismic and gravity tide measurement instruments. Atomic sensors use free-fall atomic particles as test masses and the quantum matter-wave interference for precise force measurements. Owing to the nature of atomic systems, the long-term stability and accuracy of the measurements are more attainable than those of the mechanical counterparts. The challenge in applying the atomic sensors for planetary missions is in reducing the mass and power of the instrument and maturing them from laboratory experiments. We will report on our recent efforts in reducing the system complexity and the resulting compact instrument demonstration for an atomic accelerometer for onboard spacecraft application.

1. Introduction

The atomic sensors are based on the techniques of laser cooling of atoms as test masses and atom-wave interferometer (AI) for displacement (or force) measurements [1]. Briefly, the atoms are first collected and laser-cooled to micro-Kelvin temperature. Then the atoms are released into the total free-fall state, in a very high vacuum, *decoupled* from any mechanical part of the spacecraft. These atoms only subject to the gravity force in the totally free-fall state. A specific laser (AI laser) is then used to interact with the atoms, essentially establishes a precise ruler between the atoms and the reference point to be measured, typically through a mirror (Fig. 1). The relative motion of the mirror with respect to the atoms is registered in the atomic state and can be easily read out. After each measurement, a new cloud of atoms is generated, at the same place of the instrument, essentially resetting the test masses. Because of the

inherent stability of atomic properties, the atomic sensors offer the precision and accuracy in long-period measurements and can be used for a number of planetary measurement scenarios.

Used on an orbiter spacecraft, it can serve as a drag-free reference accelerometer for non-gravity drag force measurements. Indeed, as both spacecraft and the atoms are under the same gravity, the relative motion of the spacecraft with respect to the atoms is then only caused by the non-gravity forces. Because of the atomic test mass reset, the spacecraft does not have to be drag-free controlled to allow drag-free self-calibrated measurements.

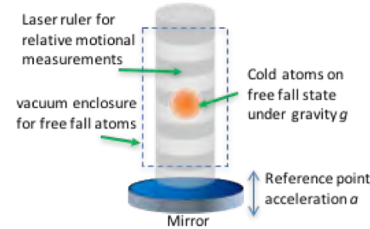


Figure 1. Illustration of the atomic accelerometer sensor measuring the relative motion of the free fall atoms and the reference mirror.

When used on a planetary surface, both gravity and surface motion contribute to measured signals (Fig.1). Under a constant gravity, the time varying signals and frequency spectrum will reflect the seismic motion of the ground. On the other hand, when the ground surface is motionless, the signal will be the measurement of the local gravity. Since typical time-varying seismic and gravity signals are mostly separate in frequency, data recovery and analysis for both science measurements are possible and the single instrument offers the capability of both seismic and gravity science measurements [2,3].

2. Instrument

While atomic sensors originated from laboratory demonstrations, the developments on miniaturizing

and mobilizing atomic sensors for field applications have progressed significantly in recent years (see references in [1]). The JPL compact atomic sensor design consists of three main subsystems, an atomic physics package (APP), a laser optics system (LOS), and integrated control electronics.

The physics package is the sensor head. It consists of a commercial compact ultra-high vacuum (UHV) enclosure for containing atoms as test mass, and optomechanics necessary to support AI operations. The apparatus requires six laser beams for the magneto-optical trap (MOT) and two counter-propagating beams for AI. Instead of having separate beam paths, we employ liquid crystal variable retarders to switch the polarization of light at different stages in the experimental sequence, thus enabling optics and optical access sharing for MOT and AI with the same laser beams [1,4]. It also supports optical pumping and other state preparation processes. In addition, the configuration will allow performing AI in any direction of choice, making it a 3-axis device in one simple arrangement. The physics package, including the vacuum system and beam delivering optics, is built on a 12" × 12" breadboard, shown in Fig. 2.

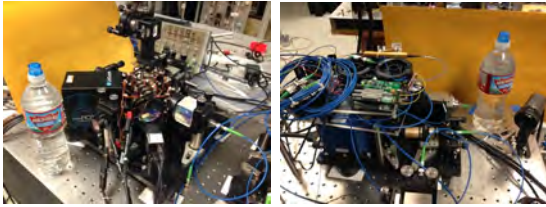


Figure 2. Pictures of the compact atomic accelerometer breadboards. The physics package is on the left and the laser optical system on the right. The water bottles are for size reference.

For the LOS, we designed a single laser system configuration that optimally utilizes the available power of the laser for atom trapping, cooling, and manipulation, supporting the entire instrument operation. This is achieved by dynamically changing the laser output frequency in GHz range while maintaining spectroscopic reference to an atomic transition via a sideband generated with phase modulation. Together with optical switches and polarization controls in the laser beam delivery optics, a given set of the laser light is delivered to the atomic cloud with the required frequencies and intensities. The LOS is integrated on a 6" × 12" breadboard.

In a typical experimental run, a cold cloud of Cs is collected in MOT for 300 ms followed by the optical

pumping and state selection steps. An AI interrogation up to 20 ms is performed. The vibration measurement results are shown in Fig. 3 [1]. The demonstrated sensitivity is $22 \mu\text{g}/\sqrt{\text{Hz}}$, mostly limited by the short free-fall time on the ground since the instrument is designed for microgravity operation. The performance is expected to improve as the square of the longer interrogation time while in space [1].

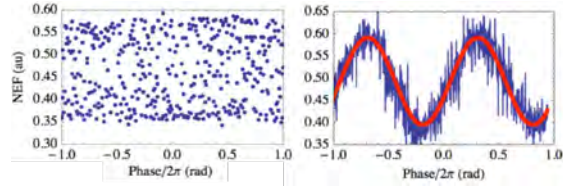


Figure 3. The fringes of the atom interferometer measurements. The right panel shows the high contrast fringes when the applied AI laser phase is varied while the sensor is on a vibration isolation platform, while the left is with the isolation platform removed, clearly showing the floor vibration.

3. Conclusion

We have demonstrated a simple design and compact implementation of the atom sensor. The results will pave the way for further maturation towards space-qualified atomic sensors and eventual infusion and applications of the atomic sensors in planetary science.

Acknowledgements

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Picture this SELFI: A Maturation Project for a Submillimeter Enceladus Life Fundamentals Instrument (SELFI)

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Abstract

The Submillimeter Enceladus Life Fundamentals Instrument (SELFI) is a passive remote sensing submillimeter spectrometer being developed under NASA's Maturation of Instruments for Solar System Exploration (MatISSE) program. SELFI will advance submillimeter receiver technology beyond that of the Microwave Instrument for Rosetta Orbiter (MIRO) and the Submillimeter Wave Instrument (SWI) for the JUPITER ICy moons Explorer (JUICE). SELFI's science goals at Enceladus are to 1) investigate the chemical and isotopic compositions and corresponding densities of the plumes, the plume thermal structures, and the transport mechanisms within the plumes, and 2) characterize the source regions from which the plumes emerge. To satisfy these science objectives, SELFI will have fine radiometric resolution, high spectral resolution (resolving power $R > 10^6$), multiple continuum channels with temperature sensitivity down to 10 K, and with high dynamical range, necessary to map Enceladus across its 30 K to 250 K temperature range.

SELFI will simultaneously observe fourteen molecular species in the Enceladus plumes that are important in the context of life and habitability of the subsurface ocean environment. These remote sensing measurements will:

- Assess the spatial and temporal variabilities in the plume chemical compositions;
- Provide insight into the subsurface ocean environment by monitoring H_2O , HDO , $\delta^{18}\text{O}$, and $\delta^{17}\text{O}$;
- Constrain the oxidation state of the surface ocean using H_2O_2 and O_3 , and;
- Utilize the SO_2 and H_2S spectral signatures to constrain the impact arising from both the sea-floor volcanoes and pre-biotic molecules.

Moreover, the detection of the remaining molecular species is vital to better understand the ocean habitability – this also enables us to explore the chemical alteration processes arising from primordial volatiles that have been observed in comets. Lastly,

the continuum observations correlate variations in plume activity with surface temperatures.

Under the MatISSE program, SELFI will advance – from TRL 4 to 6 – four key technologies of the RF-to-digital subsystem, which are:

- RF low noise amplifier design;
- Single-sideband (SSB) mixer and local oscillator (LO);
- IF assembly down-converter using monolithic microwave integrated circuit (MMIC) elements, and;
- Digital spectrometer electronics.

PHEBUS – Probing of Hermean Exosphere by UV Spectroscopy

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Abstract

Probing the Hermean Exosphere by UV Spectroscopy (PHEBUS) is a double EUV (55-155 nm) and FUV (145 – 320 nm) spectrometer aboard Mercury Planetary Orbiter (MPO) one of the two spacecrafts of the Bepi-Colombo mission [1]. The goal of this instrument is to study the composition; structure and dynamics of the exosphere of Mercury as well as measure the UV albedo of the surface to characterize water ice deposits in permanently shadowed regions. A one degree-of-freedom scanning system allows to probe selected regions and altitude ranges of interest. Different modes of observations will be used sequentially, and the instrument will be calibrated on stars regularly during the mission. In this presentation, we will present the instrument, its main scientific goals and performances measured on the ground. We will show first predictions based on these performances and recent results from the MESSENGER mission.

1. PHEBUS instrument

PHEBUS (Fig. 1) is a double UV spectrometer dedicated to observe the weak UV emissions from the tenuous atmosphere of Mercury .

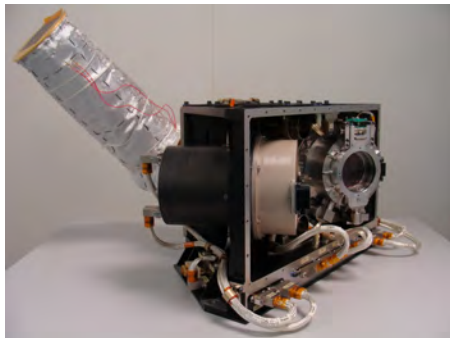


Fig.1 PHEBUS instrument

Its optical scheme is displayed in Fig.2 An entrance baffle allows to attenuate straylight (for example solar scattered light by the surface) outside its guard angle. A movable off-axis parabola mirror focuses the light on an entrance slit ($\sim 0.01^\circ \times 2^\circ$) retractable for star observations. The light beam is then shared by the two EUV and FUV gratings defining the two spectrometers with a spectral resolution for extended sources of 1 nm (EUV) and 1.5 nm (FUV). A double aperture deviation prism and two spherical mirrors take the light near 404 nm and 422 nm towards two NUV detectors dedicated to potassium and calcium lines respectively.

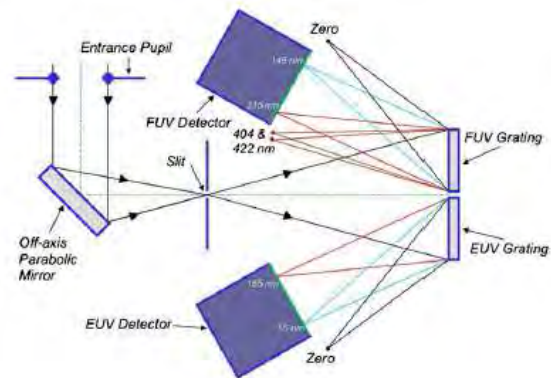


Fig. 2 PHEBUS optical layout from [1]

Performances will be regularly monitored during the cruise phase (star and interplanetary UV background observations, Venus flybys,...)

2. Scientific Goals

The main goals of PHEBUS are

1) Study the exosphere of Mercury :

Altitude profiles from each detector will be obtained regularly during the mission on both dayside and nightside to study the diurnal, latitudinal and seasonal variations of the exosphere of Mercury.

Several species are expected to be observed (He, H, Mg, Ca, Mn, Fe) and other could be detected (O, Si, K, Al, ...). These observations will provide information on the origin of these exospheric species (sputtering near the magnetic cups, thermal desorption or micrometeoroids impact, ...), their interaction with the surface, and the possible effect of radiation pressure to generate the extended tail in the anti-solar direction [2]. An example of a simulated spectrum in the FUV range, using recent ground measurements, is displayed in Fig. 3

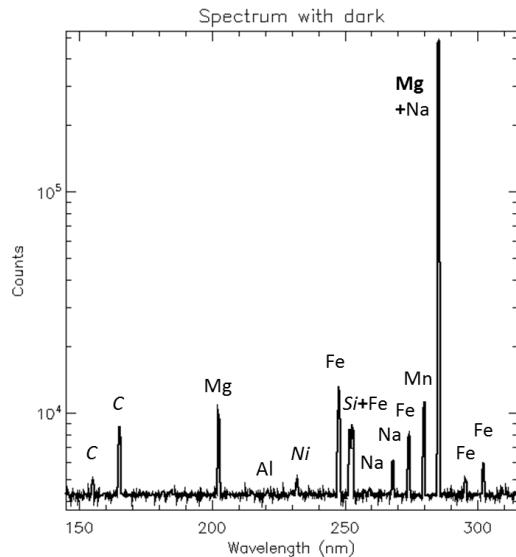


Fig. 3 Simulated FUV spectrum of the dayside exosphere of Mercury

2) Characterize and map of the permanently shadowed regions (PSRs)

A few regions near the poles of Mercury are never illuminated by the Sun (but only by interplanetary background and stellar fluxes). Water ices brought by comets could be stable in such region and should produce a signature in the UV albedo at 121.6 nm as observed on the Lunar PSRs [3].

3) Observe the interplanetary medium emissions (H, He).

The origin of the H and He populations in interplanetary space is the so-called “Interstellar Wind”, a flow of neutral particles due to the relative motion of the Sun through the diffuse partially ionized interstellar gas [4]. PHEBUS will observe the spatial variations of the H and He emissions

providing information about the heliospheric interface structure and solar wind mass flux latitudinal distribution.

4) Possible observations of comets in the vicinity of the Sun

Cometary hydrogen clouds are due to sublimation of water ice followed by the photodissociation of H₂O. Such cloud could be observed depending on the presence of comets near the sun during the Bepi-Colombo mission.

3. Summary and Conclusion

The PHEBUS instrument is well suited to provide new results on the exosphere of Mercury, the characterization of water ice content of PSRs and information on the heliosphere thanks to its two UV spectrometers from 55 to 320 nm. The combined use of UV spectroscopy and in-situ mass-energy spectrometry is a powerful means to understand the coupled system from the surface to the magnetosphere of Mercury.

Acknowledgements

Bepi-Colombo is an ESA/JAXA mission. PHEBUS has been developed in cooperation between LATMOS/France, IKI/Russia and DESP/Japan with support from their respective national space agencies.

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Field Studies of the Linear Ion Trap Mass Spectrometer (LITMS) Instrument for Future Life-Detection Planetary Missions

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Abstract

The Linear Ion Trap Mass Spectrometer (LITMS) instrument is scheduled to undergo field testing with Martian analogs in the Atacama Desert, Chile, in mid-late 2018/early 2019. LITMS will join other life-detection instruments deployed onboard the K-REX2 Rover as part of the Atacama Rover Astrobiology Drilling Studies (ARADS) project, headed by NASA's Ames Research Center.

1. Introduction

The LITMS instrument developed at NASA Goddard Space Flight Center is a highly compact ion trap based instrument developed through NASA's MatISSE program for instrument maturation. The LITMS design relies heavily on that of the Mars Organic Molecule Analyzer (MOMA) mass spectrometer (MS) instrument developed for the 2020 ExoMars Rover. LITMS can detect low concentration organic and inorganic molecules from solid samples utilizing both Mars-ambient laser desorption mass spectrometry (LDMS) employing a UV laser for laser desorption/ionization (LDI) and pyrolysis/gas chromatography mass spectrometry (GCMS) via electron impact (EI) ionization both interfacing to a single, miniaturized linear ion trap for mass analyses. LITMS features further enhancements compared to MOMA including a dual frequency RF power supply and a switchable polarity detection system allowing for an increased mass range and detection of both positive and negative ions, respectively [1].

To further supplement ongoing laboratory analyses, the LDMS capabilities of LITMS will be demonstrated in a preliminary field test campaign in the Atacama Desert of northern Chile, during the Chilean winter of 2018 before returning to the Atacama as part of the ARADS 2019 field campaign.

2. Atacama Field Site and ARADS Project Overview

The Atacama Desert is well known for its Mars-like terrain and extremely arid and high UV radiation surface environment. This results in low microbial counts in surface material and preservation of lipid biomarkers with increasing depth [2]. This makes it a highly suitable Mars analog for testing life-detection technologies designed to detect trace amounts of organics. The ARADS project aims to field test sample acquisition through drilling, sample manipulation and delivery to instruments, and sample analysis techniques for future planetary exploration [3]. In 2016, the ARADS project completed its first deployment in the Atacama, followed by field campaigns in 2017 and most recently 2018 in which fully remote operations were demonstrated through automated sample acquisition, delivery, and analyses via on board analytical instruments. For the ARADS 2019 field campaign, the field configured LITMS instrument will be added to the payload creating the full suite of life-detection instruments planned to be onboard the K-REX2 Rover.

3. LITMS Field Configuration

The current brassboard configuration of LITMS (Figure 1), powered by MOMA brassboard electronics, will be adapted to become a more compact, field-deployable configuration. This configuration will be field tested as a stand-alone instrument during a preliminary field campaign in the Atacama prior to its integration and deployment on the ARADS KREX-2 rover. Once on the rover, the even more compact and flight-like MOMA Engineering Test Unit (ETU) electronics will be utilized to power the instrument, allowing the entire LITMS system to be accommodated among the other life-detection instruments.

The field configuration for the LITMS instrument involves a fully packaged system that includes critical portions of the instrument such as the linear ion trap held at vacuum within the MS housing, the “Mars Box” in which solid samples of regolith can be analyzed at Mars ambient pressure and atmospheric composition, the dual RF supply, a 266 nm UV laser, and wide range pump (WRP) as part of the gas management system residing beside the instrument. This overall configuration sits within a finite footprint onboard the K-REX2 rover payload bay (Figure 2).

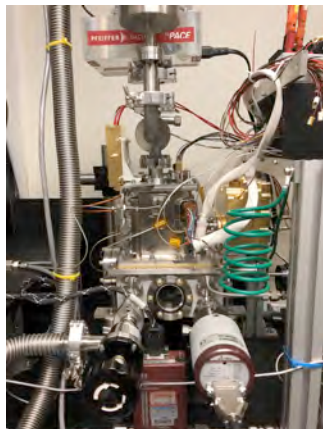


Figure 1: The LITMS instrument in its brassboard configuration at NASA Goddard Space Flight Center.

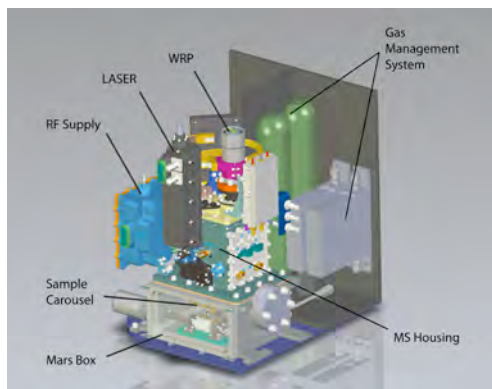


Figure 2: Conceptual drawing of the LITMS instrument in its field configuration confined to the allowed footprint on the ARADS K-REX2 Rover.

4. Summary and Conclusions

Performance of the LITMS instrument will be demonstrated in the Atacama Desert utilizing Mars analog samples collected on site in 2018 and 2019. The flight-like design of LITMS allows it to be configured in a highly compact form for field testing. LDMS analysis of organic and inorganic molecules from surface and subsurface samples will be carried out while onboard the K-REX2 rover during the ARADS 2019 field campaign.

Acknowledgements

Funding has been provided by the Maturation of Instruments for Solar System Exploration (MatISSE) Program (Program Executive: Janice Buckner, NASA/HQ), the Goddard Instrument Field Team (GIFT) Program, and the Planetary Science and Technology from Analog Research (PSTAR) Program.

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Rotational Push-broom Imaging from a Planetary Penetrator

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Abstract

Penetrators offer the potential to deliver scientific payloads to the surface and subsurface of solar system bodies at relatively low cost. An imaging regime during the delivery of the penetrator would provide valuable outreach, science and engineering data to complement data from any in situ penetrator experiments at bodies such as Earth's moon, Mars, and Europa. Visible images assist in the determination of landing site location, as well as the nature of the surface in that region. Multispectral and polarimetric imaging enhance the science potential by providing additional valuable compositional and structural information. Changes in imaging geometry throughout a penetrator's descent provide scale and three-dimensional information on the local terrain.

A concept will be presented for a rotational push-broom camera with multispectral and polarimetry capabilities for use on a penetrator. Scanning motion is to be provided by the penetrator's spin stabilisation, and wide angle optics imaging from nadir to horizon would permit a 360-degree field of regard with full surface coverage. An area array detector (CCD or CMOS) with a combination of multispectral and polarising filters oriented perpendicular to the scene's scan motion would allow the simultaneous capture of multiple images.

Imaging conditions change significantly throughout a penetrator's descent. Expected resolutions would obviously increase as the camera descends, whilst the imaging footprint would decrease, producing a sequence of nested multi-scale images. Optimum imaging heights and exposure times are a trade-off of desired surface coverage, resolution and signal requirements.

NASA Goddard's Planetary Science Winter School: Training Early Career Planetary Scientists in Flight Instrument Design

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Abstract

The NASA Goddard Planetary Science Winter School is an annual Goddard Space Flight Center-sponsored training program initiated by Brook Lakew in 2015 for Goddard-based postdoctoral fellows and early career planetary scientists. It is an experiential program in which participants learn the flight instrument lifecycle by designing a planetary instrument under actual consideration by Goddard for proposal and development. By working alongside the instrument Principal Investigator, science team, and discipline engineers in Goddard's Instrument Design Lab, participants experience first-hand the science and engineering trade-offs, cost constraints, and teamwork that are required for optimal instrument design. Since its inception in 2015, 30 scientists have participated. Participants report having a better understanding of the drivers behind spaceflight instrument design and greater interest in participating on an instrument team as a PI or team member in the future. Goddard is seeing a return on its investment as participants are increasingly writing successful proposals and returning to the Instrument Design Lab as customers.

1. Introduction

The NASA Goddard Planetary Science Winter School (PSWS) is an annual training program managed by Goddard's Solar System Exploration Division (SSED), for Goddard-based postdoctoral fellows and early career planetary scientists. Established in 2015 [1], the PSWS is an experiential training program [2] for scientists interested in participating on future planetary science instrument teams. Inspired by the NASA Planetary Science Summer Seminar [3], Goddard's PSWS is unique in that participants learn the flight instrument lifecycle by designing a planetary flight instrument under actual consideration by Goddard for proposal and

development. They work alongside the instrument Principal Investigator (PI) and engineers in Goddard's Instrument Design Lab (IDL; idc.nasa.gov) to develop a science traceability matrix and design the instrument during a week-long study, culminating in a conceptual design and science impact presentation to the PI and Goddard management that addresses how engineering trades will impact science return. By working alongside discipline engineers, participants experience first-hand the science and engineering trade-offs, cost constraints and teamwork that are required for optimal instrument design.

1.1 PSWS Goals

1) To develop a conceptual instrument design that: Meets the overall mission objective as described by the PI and science team; Includes all instrument subsystems as identified by the discipline engineers; Includes heritage hardware solutions that reduce risk and improve cost confidence; Can be parametrically costed for a credible, defensible proposal. 2) To create an awareness of the engineering drivers in spaceflight instrument design for participants by pairing them with discipline engineers. 3) To introduce participants to collaborative engineering.

2. Participant Roles

Approximately six months prior to the study week, prospective participants complete an application that includes a description of how their career goals will be advanced through their participation in the PSWS and a letter of recommendation from their advisor or supervisor. Upon selection, participants are presented with the instrument concept and associated discipline engineer roles, at which time they are asked to justify their discipline preferences. Some participants take on a second role during the study week to ensure active participation during all study phases. Participants are expected to be proactive players in

the collaborative engineering design process, but they are not expected to learn how to develop or manipulate the engineering models used in the IDL. Possible roles include: Concept of operations, Cryogenics, Data/Communications, Detectors, Electrical, Flight dynamics, Lasers, Mechanisms, Mechanical systems, Optics, Power, Principal Investigator, Structural, Systems, and Thermal

3. Implementation

Choosing the right instrument concept that will soon be competed for flight in response to a NASA announcement of opportunity (AO) is critical. Concepts that are already well-defined through previous work do not provide the right level of challenge for participants. Concepts are vetted for suitability by the PSWS leadership team. The PSWS leadership team works closely with the instrument PI to ensure value added for all stakeholders. After participants are assigned a discipline engineering role, they attend frequent “pre-work” meetings with the other participants, the instrument PI, and IDL leads to learn more about the target body and science questions, produce a science traceability matrix, lay out the draft concept of operations, identify hard engineering requirements to maintain throughout the study, and pull together existing resources such as mechanical models and science papers. Informal networking time with discipline engineers provides an opportunity for participants to learn more about the discipline prior to the study week. Participant feedback indicates that they spend approximately 30 hours, on average, preparing for the study. The study week is followed by an internal wrap-up, walkthrough of the Master Equipment List, and presentations on the parametric costing estimate and recommendations for further study.

4. Participant and Engineer Feedback

Survey results of participants indicate that PSWS goals are being met, with at least 75-100% of participants reporting that they have a better understanding of spaceflight instrument design after the study than before. Participants also consistently report being more interested in being on an instrument team after participation in PSWS than before. Consistent challenges include managing participant expectations regarding the time involved in the program and what to expect during the IDL

study week, which largely depends on the complexity of the instrument and participants’ background knowledge and prior experience. Challenges are addressed through frequent check-ins with the PSWS leadership team and by providing opportunities for current participants to network with past participants and their discipline engineer. In 2018, a feedback survey was issued for the first time to the discipline engineers involved in PSWS. While the IDL has consistently collected feedback regarding the implementation of its studies in order to inform its internal processes, our survey asked the engineers to address the PSWS specifically. The engineers reported an increase in their comfort level in working with planetary scientists after PSWS.

5. Summary and Conclusions

NASA Goddard’s PSWS is an effective opportunity for early career planetary scientists to experience collaborative engineering while designing an actual spaceflight instrument. They leave the program feeling more confident in their understanding of engineering drivers and more eager to participate on a future instrument team, as evidenced by successful proposals and participants returning to the IDL as customers. We hope to continue to offer this opportunity to GSFC’s postdoc and early career planetary scientists beyond 2018, pending funding.

Acknowledgements

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Basic Science Instruments as Dual Function Human Exploration Tools: An XRD/XRF Strategy

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Abstract

The Lunar Orbiting Platform-Gateway (LOP-G) could serve as a platform from which surface science is enabled on the Moon and Mars either directly by humans or via telepresence. From a scientific perspective, providing as much data as possible about the geologic context of a sample, from the outcrop scale to the local and regional scale of the surrounding terrain, is absolutely crucial in exploring an area. A well trained geologist inherently conducts such analyses in real time, factoring this information into sample selection and traverse execution. However, miniaturization of instrument components over the last several decades has enabled smaller and quicker portable versions of traditional laboratory instruments, which enables evaluation of science instruments as multi-purpose tools during human activities beyond Low Earth Orbit (LEO).

1. Introduction

Portable instruments can provide humans with enhanced awareness of surface units [1], whether the instrument is in the hand of a human or mounted on a teleoperated rover. Such approaches enable basic science research and could also be applied to laboratory settings inside of a LOP-G [2]. However, instruments intended for basic scientific research can also be designed to have applied science value throughout a human mission such that they are useful beyond scientific research. Here we present a model for instrument development as a multipurpose tool for use during human exploration. The LOP-G offers a laboratory for testing not only the science capabilities of instruments in a realistic environment but also utility as a tool for providing data of value to the safety and success of the mission as a whole.

2. Instrument Development

Portable, contact X-ray fluorescence (XRF) is a technique used to assess sample chemical

composition. Although typically applied to industrial and archeological applications, contact XRF has recently been a focus of geologic field activities [3]. Contact X-ray diffraction (XRD) is an area of technology development that requires no sample preparation (e.g., crushing and sieving). We have built a brass-board contact XRD/XRF device, CMIST (Chromatic Mineral Identification and Surface Texture), that provides chemical and unique crystalline “texture” analyses for unprepared samples, revealing surface crystal phases, morphologies, and orientations, including unambiguous identification of volatiles such as water ice.

The apparatus consists of two key components: a collimated broad-spectrum X-ray source and a low noise, photon-counting X-ray CCD. The CCD detects individual X-ray photons, reporting their (x,y) positions as well as their energies (and thus wavelengths) with ~2% resolution. When X-rays strike the sample, some are diffracted in accordance with Bragg’s law. Other X-rays are stopped by atoms in the sample, which then emit characteristic lines with known energies through fluorescence. The CMIST CCD captures diffracted and fluoresced X-rays, generating an “event list” of all individually detected photons. The measured photon properties are transformed so that diffraction and fluorescence signatures are distinct: for each event, a unique d-spacing value is derived given the photon energy and its position using Bragg’s law.

Our goal is to develop a tool that quickly differentiates relevant minerals to inform planetary sample collection during surface traverses, at reduced cost (in analysis time, volume, and power) and risk (through elimination of sample preparation steps) compared to existing systems. Depending on the sample’s crystalline structure, a CMIST measurement can be obtained in < 10 minutes, often within several tens of seconds. CMIST will consist of a low power (< 5 W), low mass (< 5 kg), compact (large coffee-cup size) XRD/XRF spectrometer and

optical imager for measuring element abundances, distinguishing mineral phases including ices, and determining the unaltered sizes and orientations of crystals over a few-mm², with no sample preparation. The lack of moving parts and sample preparation requirements, coupled with the instrument's small size, make this an ideal tool for use during future human exploration missions.

3. Applications

The application of CMIST to silicate sample analysis has been described [4]. We briefly discuss here other uses of CMIST as well as the requirements for system integration as a multipurpose tool.

3.1 Curation

If samples are to be collected and returned to Earth for analysis, CMIST can provide a base-line geochemical, mineralogical, and volatile measurement for comparison with subsequent laboratory analyses. This would enable an assessment of possible phase changes upon exposure of samples to a habitat or terrestrial environment. One manner in which CMIST could be used throughout a LOP-G mission is to routinely evaluate stored samples without removing them from their storage container. Sample storage interfaces can be designed to enable measurements at regular intervals during transit from the exploration target to Earth, thereby tracking the effects of any contamination of the sample.

3.2 Safety and Health

We envision capabilities related to crew health and safety during lengthy missions in deep space. Long-term exposure (e.g., through breathing) to dust and other contaminants poses potential health hazards for astronauts. CMIST enables in-situ analysis of air filters to assess the chemistry, mineralogy, and structure of particulates that are cleaned from a habitat's atmosphere; regular measurements would provide insights into the nature and concentrations of airborne contaminants, as well as any changes with time. Components integral to CMIST also easily adapt to medical use: extremely low-dose CT (computed tomography) imaging enables crew health monitoring or urgent-care diagnostic capability.

CMIST is also suited to evaluating the effects of exposure to the environment—irradiation or accumulated deposition of contaminants—on internal

or external surfaces critical to science or crew health; e.g., leak localization through surface deposition mapping is possible. XRF is used in aircraft Non-Destructive Testing (NDT). NDT approaches could be used on DSG to evaluate welding quality or material fatigue from space weather.

4. Test Plan

The DSG, as envisioned, involves reusable hardware in the form of a human-rated transit vehicle and could potentially include transfer vehicles to move science experiments to other locations (astrophysics observatories or lunar landing/return vehicles). Humans could potentially stay on the DSG for increasing periods of time throughout its development and utilization as a gateway to exploration of the Solar System. Beyond its primary application as a real-time sample triage instrument, CMIST can serve as an in situ mission assurance tool, providing assessments of environments and equipment vital for crew health and mission success.

Taking advantage of CMIST's potential applications as a multipurpose tool requires advance thought on system integration. Filtration systems can be designed to enable CMIST to analyze filters, potentially integrating for 1-2 days in order to map particulates accurately, as demonstrated in preliminary analyses of airborne filters. Similarly, sample curation hardware can be designed to enable NDT approaches to be applied by instruments such as CMIST. A common design effort for CMIST and a medical CT imager will enable mass-efficient implementation of both.

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MapX: A Full-Field X-ray Fluorescence Imager for Landed Planetary Science

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Abstract

Spatially resolved elemental images can reveal traces of physical, chemical and/or biological processes on the surface of a planet or planetesimal. The Mapping X-ray Spectrometer (MapX) is an *in-situ* instrument that produces 2.5 X 2.5 cm² elemental images with ~100 μ m lateral spatial resolution. MapX has no moving parts and a depth of field of ± 5 mm with minimal loss of resolution. The instrument can utilize either radioisotope or X-ray fluorescent sources. When equipped with Cm²⁴⁴ sources on an airless body, MapX can image all elements, $6 \leq Z \leq 39$. On planets with atmospheres, MapX can image all elements $10 \leq Z \leq 39$.

1. Introduction

Many planetary surface processes leave traces of their actions as features in the size range 10s to 100s of μ ms. The Mapping X-ray Fluorescence Spectrometer (MapX) will provide elemental imaging at $\leq 100 \mu$ m spatial resolution, yielding elemental chemistry at a scale where many relict physical, chemical, or biological features can be imaged and interpreted in rocky or icy regoliths.

1.1 The MapX Instrument

MapX can be positioned on soil or regolith with touch sensors, or held at a fixed working distance of ~25 mm from an object to be imaged. During an analysis, an X-ray source (tube or radioisotope) bombards the sample with X-rays or α -particles / γ -rays, resulting in sample X-ray Fluorescence (XRF). X-rays emitted in the direction of an X-ray sensitive CCD imager pass through a 1:1 focusing lens (X-ray μ -pore Optic (MPO)) which projects a spatially resolved image of the X-rays onto a CCD. The CCD is operated in single photon counting mode so that the energies and positions of individual X-ray

photons are recorded. In a single analysis, several thousand images are both stored and processed in real-time. The MapX concept is illustrated in Fig. 1.

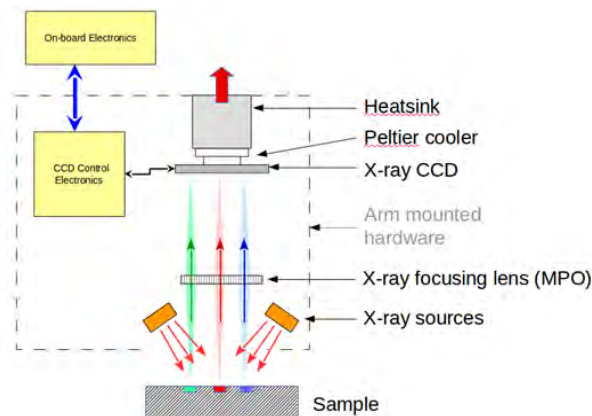


Figure 1: block diagram of the MapX instrument

Higher-level data products include single-element maps and quantitative XRF spectra from instrument-selected Regions of Interest (ROI). XRF spectra from ROI can be compared with known rock and mineral compositions to extrapolate the data to rock types and putative mineralogies.

1.2 Proof of Concept Prototypes

Earlier prototypes [1-2] demonstrated proof-of-concept using COTS components. MapX-II (Fig. 2) utilizes an Andor iKon M camera with 1024x1024 back illuminated CCD. Two 30kV-4W Au X-ray tubes (Moxtek) illuminate the sample. An MPO X-ray focusing lens (PHOTONIS) is placed equidistant between the sample and the CCD. The lens derives from “lobster-eye” multichannel optics used for X-ray astronomy [3]. It is implemented here in a flat geometry for 1:1 focusing. This lens provides a much improved aperture when compared to pin-hole camera optics having similar spatial resolution, and

true focusing when compared to polycapillary collimating optics also used for X-ray mapping. The camera is driven at up to 3 frames per second, and the X-ray sources are shuttered during read cycles.

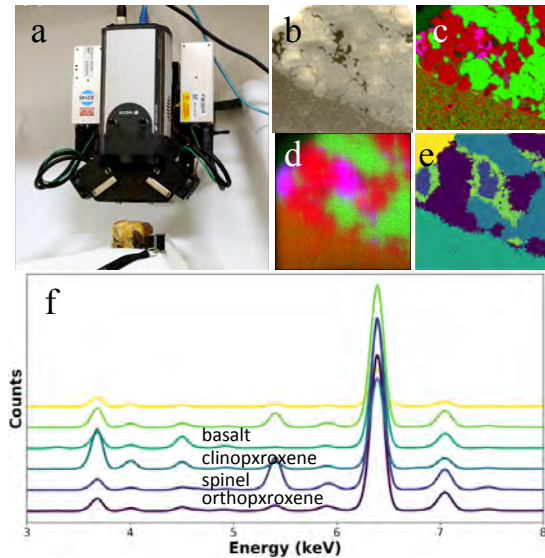


Fig. 2 a), MapX-II. b), optical image of a thin section of an ultramafic xenolith (field of view 1 cm). c), element map from commercial EDAX-Orbis instrument (50 μm resolution) Red = Fe, Green = Ca, Blue = Cr. d), element map from MapX-II ($\sim 200 \mu\text{m}$ resolution), same color scheme as in (c). e), ROI selected by elemental correlation cluster analysis. f), summed XRF spectra from individual ROI identified as mineral types.

2. Work in Progress

Improvements in MapX resolution are obtained through: 1), optimization of the sample-MPO-CCD geometry, and 2), characterization and correction the Point Spread Function (PSF) of the lens. Ray-tracing simulations and experimental measurements of the MPO at SSRL beam line 2-3 were used to refine the MapX geometry and characterize the PSF.

2.1 Refining the MapX Geometry

Fig. 3 shows the relationship between sample-to-MPO distance and image resolution for the MPO used in MapX-II. This measurement illustrates that $100 \mu\text{m}$ resolution is achieved with a distance of 25 mm, and that resolution degrades from $100 \mu\text{m}$ to $\sim 225 \mu\text{m}$ over sample-to-MPO working distances of $\pm 5 \text{ mm}$ from optimum.

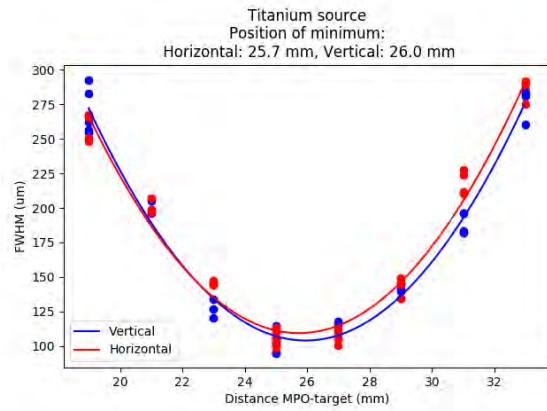


Fig. 3, Relationship between sample-MPO distance and lateral spatial resolution. Optimum resolution achieved is $100 \mu\text{m}$ at $\sim 25 \text{ mm}$ focus. Resolution decreases to $\sim 225 \mu\text{m}$ at a focus defect of $\pm 5 \text{ mm}$.

2.2 PSF Characterization

The PSF varies with photon energy and x,y position on the MPO. Experiments are being performed at SSRL to further characterize the PSF and ray-tracing models have been developed to evaluate the effects of defects on the PSF and to assist in the development of PSF deconvolution algorithms [4].

Acknowledgements

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Biosignature detection on icy worlds through Deep UV resonance Raman and Fluorescence Spectroscopy: SHERLOC-E

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1. Introduction

SHERLOC (Scanning Habitable Environments with Raman and Luminescence for Organics and Chemicals) is currently part of the Mars 2020 payload where it will identify organic molecules and mineralogy associated with aqueous processes. It combines imaging with UV resonance Raman and native deep UV fluorescence spectroscopy in order to identify potential biosignatures and understand the aqueous history of a site on Mars [1, 2]. A Deep UV laser (248.6 nm) is used to generate characteristic Raman and fluorescence photons from a target/area of interest. Spectral maps are generated through knowledge of laser position with respect to a contextual image. These spectral maps reveal more information than spectra alone by relating minerals and chemicals to textures in a way simple bulk analysis does not.

We have been developing a version of this instrument that is capable of measuring organic and minerals on the surface of an icy world.

The SHERLOC-E instrument that leverages the Mars 2020/SHERLOC flight instrument for spectral and mapping capabilities for detection and classification for organics and minerals. Using the same high TRL deep UV laser (248.6nm), SHERLOC-E maintains the <0.01wt% for organics and 0.1% mineral sensitivities in a 100 micron spot similar to the Mars implementation but advances the science return with a larger accessible scan area (1cm²), higher resolution visible and fluorescence imaging (10μm) and higher spectral resolution Raman analysis (0.15nm/25cm⁻¹). These advances enable characterization of the geochemistry of or within the ice, the salts, and the organics with spatial distribution/resolutions necessary to assess evidence

of biomarkers/life. This utilizes a non-earth centric concept that all life would cluster to form compartments or cells in order to concentrate organics to promote biological reactions. [3].

Key Advantages of combining DUV Raman and Fluorescence imaging are:

1. DUV Raman scattering occurs in a spectral region without a fluorescence background, allowing simplified acquisition of both fluorescence and Raman spectra.[4]

2. Excitation at DUV wavelengths enables resonance and pre-resonance signal enhancements (>100 to 10,000×) of organic/mineral vibrational bonds by coupling of the incident photon energy to the vibrational energy [5]

3. DUV Raman also capitalizes on the Rayleigh Law ($\propto 1/\lambda^4$) – 20× greater scattering efficiency than 532 nm, 100× greater than 785 nm. Combined with #2, this enables high-sensitivity measurements without requiring high-intensity excitation DUV sensitivities are 10 to 100x greater than visible Raman systems that use 150x more energy at the sample. Thus this technique avoids damaging or modifying organics or minerals by heating or chemical reactions with reactive species [4, 6].

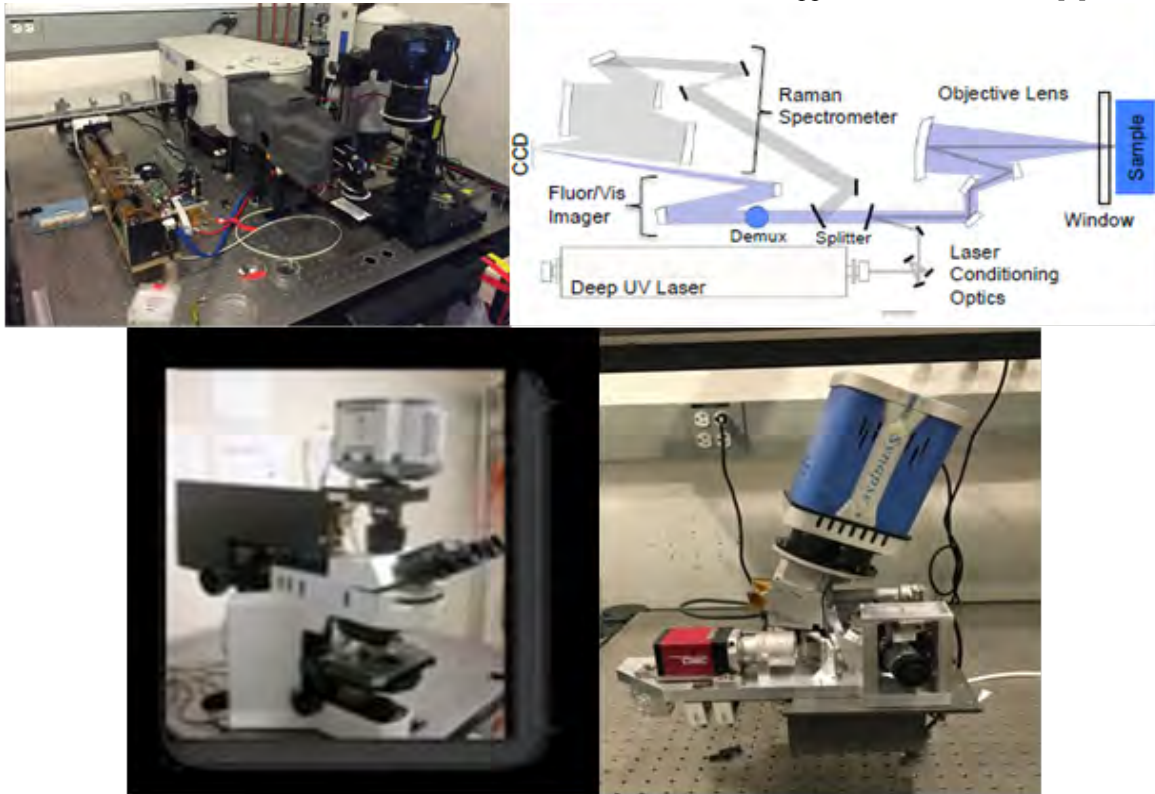
4. DUV Raman/fluorescence can observe over the macro and micro-spatial scales leading to better searching capabilities and the creation of better compositional maps than other techniques such as Raman alone and/or IR spectroscopy [8]

2. Summary and Conclusions

The different payload accommodations offered by being part of a landed platform on an icy body in some ways makes SHERLOC-E a simpler version of SEHRLOC. These aspects include limited surface life times (<< a Martian year), more stable thermal environments with respect to Mars, and reduced error

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the

Figure 1. SHERLOC-E optical layout and the existing instruments that demonstrate the Raman spectroscopy and fluorescence imaging capability that SHERLOC-E integrates. PT1 (upper left) is the lab standard used to generate sensitivity model and spectral resolution analysis, Deep UV microscope (lower left) is an all-reflective fluorescence banded imager demonstrating fluorescence imaging capability, and SHERLOC BB (Bottom Right) is the basis for SHERLOC-E’s overall architecture.

limited physical volume and data volume pose issues in development that we are currently working before a concept is high enough TRL to propose to an icy body lander.

Acknowledgement: This work was carried out at the Jet Propulsion Laboratory, The California Institute of Technology under a contract from NASA.

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NASA's Mars 2020 Rover Instrument Investigations: Enabling Exploration and Sample Return from Ancient Mars

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Abstract

This presentation describes the payload elements and individual payload investigation goals for the instruments on NASA's Mars 2020 rover, scheduled to launch in July 2020 and land in February 2021. We also discuss the current status of the instrument and rover development, as well as the ways that each investigation supports Mars 2020 mission goals as well as higher-level NASA and Mars Program goals.

1. Introduction

The Mars 2020 Rover will be NASA's next mobile mission to the surface of Mars, launching in July/August 2020 and landing in February 2021. The mission's main goals are to; (1) Determine whether life ever existed on Mars; (2) Characterize the Climate of Mars; (3) Characterize the Geology of Mars; and (4) Prepare for Human Exploration [1]. In addition, a major mission objective is to be the first step (identifying and caching samples) in the Mars robotic sample return campaign identified in the most recent Decadal Survey of Planetary Science [2].

A community process has narrowed the choice of landing sites down to three: Gusev crater (including regions studied by the NASA Spirit rover from 2004-2010), Jezero crater (which contains an ancient delta), and Northeast Syrtis Major (which contains geology and mineralogy consistent with a groundwater system). All of these sites are presumed to contain at least some regions dating back to ancient (Noachian) Mars, a time when conditions may have been most favorable to habitability and life.

2. Mars 2020 Rover Payload

To study the geology of the landing site and to select the ~20-40 samples to be cached for future return, the rover carries a payload (Figure 1) consisting of: (a) Mastcam-Z [3], cameras that acquire multispectral, stereo, and zoom images from the near-field to the

horizon; (b) SuperCam [4], active emission (LIBS) and passive reflectance spectroscopy of selected regions; (c) RIMFAX [5,10], a ground-penetrating radar that will provide cm-scale resolution of the subsurface; (d) PIXL [6], an arm-mounted instrument designed to measure and map elemental composition; (e) SHERLOC [7], another arm-mounted instrument designed to search for the presence of organics on small (few cm diameter) surface targets, which also includes a color microscopic imager; (f) MEDA [8], a weather and environmental monitoring station, and (g) 20 other cameras for science and engineering [9]. Additional technology demonstration experiments include an oxygen-generating instrument called MOXIE and a small helicopter designed to demonstrate free-flying scouting capabilities for future missions.

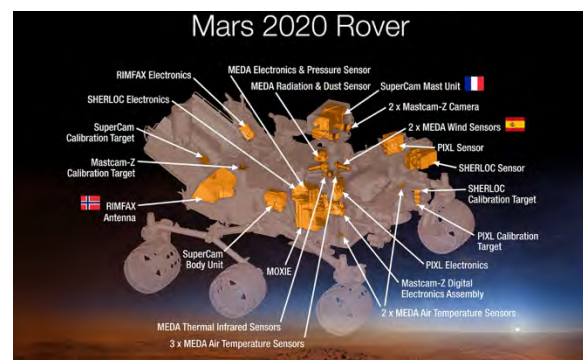


Figure 1: The Mars 2020 Rover Payload (NASA) [1].

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MAZE: A Testbed Unit for the Mars 2020 Mastcam-Z Stereoscopic Multispectral Investigation

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Abstract

One of seven scientific instruments on NASA's Mars 2020 rover payload, Mastcam-Z is a pair of multispectral, stereoscopic CCD imagers that will reside on the rover's Remote Sensing Mast. MAZE (Mastcam-Z ASU Zoom Emulator) is a Mastcam-Z testbed unit designed by its science team members. Utilizing a pair of commercial off-the-shelf cameras, a pan/tilt unit (PTU), microcomputer, IMU, and Li-ion batteries, MAZE is able to operate in both lab and field imaging campaigns (Fig. 1). A suite of software tools allows the team to command pan/tilt pointing, capture stereo images, generate Planetary Data System (PDS) compliant image products, and perform camera calibrations. The goal of the emulator is to understand what data, analysis tools, and processes the team needs to implement during actual operations on Mars.

1. Introduction

Early in the mission, scientists on the Mastcam-Z team identified the need for a testbed unit that would allow us to create and interact with image products prior to launch. Such products would allow the team to create and evaluate tools being developed for science and tactical rover operations. Through this interaction, the science team aims to have a better understanding of what is desired from the products returned by MAZE as well as which analysis tools provided by team members will most benefit the team and mission during science and tactical operations.

2. Hardware Design

MAZE uses two Canon EOS D60 digital cameras with manual zoom lenses capable of focal lengths comparable to that of Mastcam-Z [1]. 3D printed toed-in angle mounts are used to interface each camera to a metal bar, which mounts the cameras to the PTU (see Fig. 2). The camera placement and use of toe-in angle allow the cameras to mimic the approximate

orientation of the actual Mastcam-Z cameras when they are mounted on the rover. During operation the cameras, an IMU that collects GPS and movement telemetry, and the PTU, all establish a connection with a microcomputer via USB and an Ethernet network. The user then commands the system via laptop. A hard case, lithium ion battery packs and transport cart allow the system to become power independent and capable of performing field imaging campaigns for 8+ hours at a single time (see Figs. 1 and 2).

3. Planetary Data System Products

NASA's Planetary Data System manages the long-term archiving of pre-flight and in-flight data products from Mastcam-Z, including a specific file and label structure defined for all data products. To identify what meta-data will be important during mission operations the Mastcam-Z science team runs images taken by MAZE through its software library to create flight-like PDS3 and PDS4 image products. These test products allow us to confirm that the format and kinds of data currently developed work with team software tools and align with pre-defined PDS format definitions.

4. Camera Calibration

Investigation goals set out in [1] and other results derived from Mastcam-Z data require the camera system to be accurately geometrically calibrated to provide the science and operations teams with terrain meshes, digital terrain models (DTMs), and other dimensionally accurate products. Such products are created using a camera model to represent the transformation from the object domain (field site) to the image domain (camera sensor) [e.g., 2]. The camera model largely used by NASA for planetary exploration is the CAHVOR model. The CAHVOR model represents a set of vectors and parameters known about the specific camera to make this transformation from the object to image domain. Using specific targets and OpenCV software, MAZE can define a pinhole camera model (also called a

SHERLOC on Mars 2020

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1. Introduction

SHERLOC is an arm mounted instrument that is part of the Mars 2020 payload. It combines imaging with UV resonance Raman and native deep UV fluorescence spectroscopy in order to identify potential biosignatures and understand the aqueous history of a site on Mars [1]. It utilizes a Deep UV laser (248.6 nm) to generate characteristic Raman and fluorescence photons from a target/area of interest. The DUV laser is co-boresighted to a context imager and integrated into an autofocusing/scanning optical system that allows us to correlate spectral signatures to surface textures, morphology and visible features. These spectral maps reveal more information than spectra alone by relating minerals and chemicals to textures in a way simple bulk analysis does not.

The goals of the SHERLOC investigation are to:

- *Assess the habitability potential of a sample and its aqueous history.*
- *Assess the availability of key elements and energy source for life (C, H, N, O, P, S etc.)*
- *Determine if there are potential biosignatures preserved in Martian rocks and outcrops.*
- *Provide organic and mineral analysis for selective sample caching.*

To do this SHERLOC does the following:

- Detects and classifies organics and astrobiologically relevant minerals on the surface and near subsurface of Mars
- Bulk organic sensitivity of 10^{-5} to 10^{-6} w/w over an 7×7 mm spot.
- Fine scale organic sensitivity of 10^{-2} to 10^{-4} w/w spatially resolved at $<100\mu\text{m}$

- Astrobiologically Relevant Mineral (ARM) detection and classification to $<100\mu\text{m}$ resolution

The current CAD model of the SHERLOC instrument can be seen in figure 1. Major subsystems include an Aphere-Sphere Spectrometer system that utilizes a CHEMCAM heritage e2v CCD and a Wide Angle Imager that is MAHLI build to print.

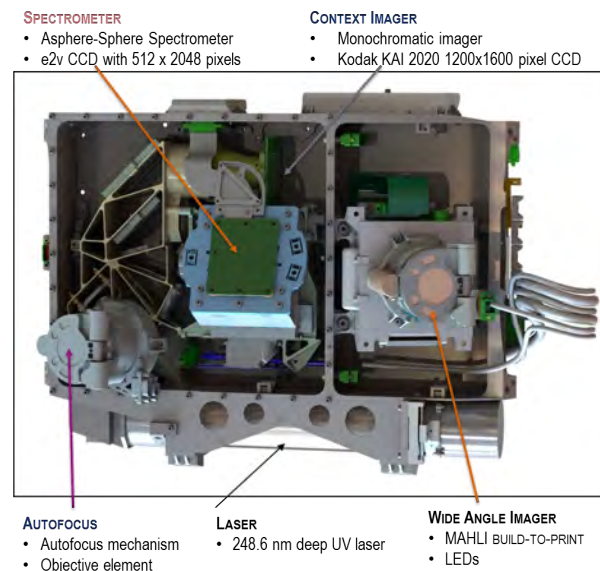


Figure 1. Current CAD model of the SHERLOC instrument.

2. Scientific Operations

SHERLOC performs both spectroscopy and co-boresighted microscopic imaging for scientific investigations. For wide field imaging and sample documentation, the Wide Angle Topographic Sensor for Operations and eNginEering (WATSON) imager provides images that document the sample at

distances of 2 to 25 cm. These images allow for co-located results from other payload images to the SHERLOC spectroscopy results.

For spectroscopy, operations are planned around a single arm placement, 48 mm above the target. Through the use of an internal scanning mirror, autofocusing lens, and a depth of focus of $\pm 500 \mu\text{m}$, the $100 \mu\text{m}$ laser spot can be systematically scanned over a $7 \times 7 \text{ mm}$ area with a fine-scale spatial resolution on natural or abraded surfaces, with the additional capability of investigating boreholes to a depth of at least 13 mm without further arm movement. The spectroscopic side of SHERLOC has a grey scale contextual imager. The grey scale contextual imager is easily matched to the colour images from the WATSON camera.

Initial observations will be performed on an abraded patch in survey mode (see Table 1). The laser will fire raster over a $7 \times 7 \text{ mm}$ area with $200 \mu\text{m}$ spacing to generate 1225 spectra arranged in a 35×35 point grid.

Table 1: Survey Mode

# of Spectra	1225
Area Scanned	49 mm^2
Duration of Ops	8.8 min
Avg Power (CBE)	$\sim 41 \text{ W}$
Data Volume	$\sim 50 \text{ Mbits (3:1)}$
Laser Pulses	9600
Aromatics ($<1\text{e-}6 \text{ w/w}$)	✓ Spatially resolved
Aliphatics ($1\text{e-}4 \text{ w/w}$)	✓ Bulk
Minerals (ARM)	$100 \mu\text{m}$ grains

A Raman/fluorescence spectrum is acquired within 1 sec at each point. These spectra can be averaged together to get bulk organic/mineral abundances over the entire scanned area.

In a typical operational scenario, survey mode would be used to identify an area of interest to be analyzed using detail mode (see Table 2). The internal SHERLOC computer will analyze the acquired spectra from survey mode for Raman and/or fluorescence signatures and determine a region of high interest to perform a detailed analysis. During detailed mode, a denser map is generated over a $1 \times 1 \text{ mm}$ areas. This consists of rastering the $100 \mu\text{m}$

laser beam at $100 \mu\text{m}$ steps to generate 100 Raman/fluorescence spectra in a 10×10 grid. Each spectrum is acquired in $<12 \text{ sec}$.

3. Summary and Conclusions

The two distinct operational modes in a nominal surface operation are designed to identify organics and ARM's on the 100 micron spatial scale and on a scale $>1 \text{ mm} \times 1 \text{ mm}$. Because of the built in FPGA, other modes of operations, including line scans, are possible depending on the evolution of operations on Mars 2020.

By bringing to bear multiple scientific instruments on a single sample, our ability to assess the habitability of ancient environments and search for potential biosignatures preserved within the geologic record will be greatly enhanced, making possible the selection of high-priority samples for caching.

Acknowledgement: This work was carried out at the Jet Propulsion Laboratory, The California Institute of Technology under a contract from NASA.

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Table 2: Detailed Mode

# of Spectra	100
Area Scanned	Up to 1 mm^2
Duration of Ops	23 min
Avg Power (CBE)	$\sim 54 \text{ W}$
Data Volume	$\sim 7 \text{ Mbits (3:1)}$
Laser Pulses	40,000
Aromatics ($<1\text{e-}6 \text{ w/w}$)	✓ Spatially resolved
Aliphatics ($1\text{e-}4 \text{ w/w}$)	✓ Spatially resolved
Minerals (ARM)	$<50 \mu\text{m}$ grains

Particle Environment Package (PEP): science objectives, instrument overview, and status

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Abstract

Particle Environment Package (PEP) is an instrument onboard ESA JUICE spacecraft (Jovian Icy moons Explorer) to launch 2022. PEP will investigate the Jovian and Ganymede magnetospheres, moon-magnetosphere interactions, and exospheres of the Galilean moons. PEP combines first-ever at Jupiter energetic neutral atom (ENA) global imaging with in-situ measurements, obtains 3D plasma flows in less than 10s probing structures of a few gyroradii, and performs first-ever high resolution gas mass spectroscopy at icy moons to identify surface and, if flying through a plume, subsurface constituents.

1. Science objectives

PEP will answer the following overarching science questions:

- (1) How does the corotating magnetosphere of Jupiter interact with the complex and diverse environment of Ganymede?
- (2) How does the rotating magnetosphere of Jupiter interact with the inert non-magnetized Callisto?
- (3) What are the mechanisms and global impacts of release of material into the Jovian magnetosphere from Europa and active Io?
- (4) What is composition and what are sources and sinks of exospheres and exo-ionospheres of Europa, Ganymede, and Callisto?
- (5) How do internal and external drivers cause such energetic, time variable and multi-scale phenomena in the rotating giant magnetosphere of Jupiter?
- (6) How is plasma accelerated, heated, and transported in the magnetodisk and how does it cause the Jovian and Ganymede aurorae?

2. PEP overview

The six (6) PEP sensors measure positive and negative ions, electrons, exospheric neutral gas,

thermal plasma and energetic neutral atoms present in all domains of the Jupiter system over nine decades of energy from < 0.001 eV to > 1 MeV with full angular coverage.

PEP provides instantaneous measurements of 3D flow of the ion plasma and composition to understand the magnetosphere and magnetosphere-moon interactions. It also measures instantaneously 3D electron plasma to investigate auroral processes at the moon and Jupiter. Measurements of the angular distributions of energetic electrons at sub-second resolution probe the acceleration mechanisms and magnetic field topology and boundaries.

PEP combines remote sensing using ENAs with in-situ measurements and performs global imaging of Europa/Io tori and magnetosphere combined with energetic ion measurements. Using low energy ENAs (10 – few 100s eV) originating from the particle – surface interaction PEP investigate space weathering of the icy moons by precipitation particles. PEP will first-ever directly sample the exospheres of Europa, Ganymede, and Callisto with extremely high mass resolution ($M/\Delta M > 1100$).

3. PEP sensors

The PEP includes (1) an ion mass analyzer, (2) an electron spectrometer, (3) a low energy ENA imager, (4) a high energy ENA and energetic ions imager, (5) an energetic electron sensor, and (6) a neutral gas and ions mass spectrometer. The six (6) sensors are grouped into two (2) groups: PEP-Hi for energetic particle measurements and PEP-Lo for low energy particle measurements. PEP-Lo includes also a common electronics unit. Each group has dedicated electrical interfaces (data and power) to the spacecraft. The PEP sensors and their performance are described in Table 1. The overall PEP configuration is shown in Fig. 1.

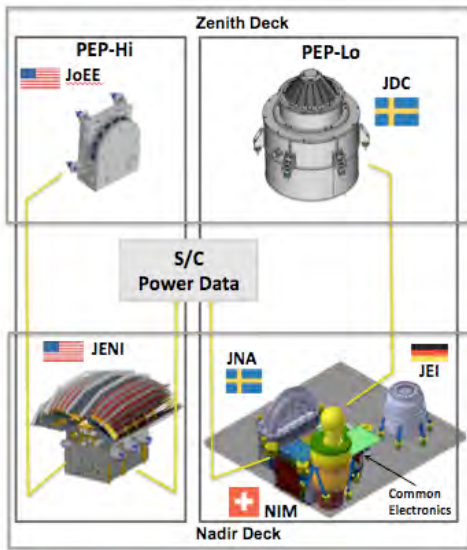


Figure 1: PEP configuration

Table 1: PEP sensors performance

PEP sensor	Key Performance
JDC - Jovian plasma Dynamics and Composition Concept: Electrostatic angular deflector followed by ultra-compact electrostatic analyzer and reflectron. Custom-made micro-machined silicon grid provides start electrons. Ceramic Channel Electron multipliers (CCEM) and MCP as detectors. SSD-based anti-coincidence system	3D distributions of positive and negative ions, charge-states, electron measurement capability 1 eV – 41 keV, $\Delta E/E=12\%$, $M/\Delta M=30$, Hemispheric FoV with $5.5^\circ \times 19.5^\circ$ ang. resolution
JEI - Jovian Electrons and Ions. Concept: Compact electrostatic angular deflector followed by a spherical electrostatic analyzer. CCEM with ultra-compact arrangement to reduce sensitive area.	3D distributions of electrons, ion measurement capabilities ~ 1 eV – 50 keV, $\Delta E/E=4.9\%$, Hemispheric FoV with $20^\circ \times 10^\circ$ resolution
JoEE - Jovian Energetic Electrons Concept: The circular magnetic field by permanent magnets radially separates	Energetic electrons 25 keV – 1 MeV, $\Delta E/E \leq 20\%$, FoV: $12^\circ \times 180^\circ$,

electrons of different energies. Electrons are detected by solid-state detectors (SSD) in a fan configuration.	$12^\circ \times 22^\circ$ resolution
NIM - Neutral gas and Ion Mass spectrometer. Concept: Compact design based on TOF and reflectron.	Thermal neutrals and ions (<5 eV) Mass range: 1-1000 amu, $M/\Delta M=1100$, Sensitivity: 2 cm^{-3} ($\sim 10^{-16}$ mbar)
JNA - Jovian Neutrals Analyzer Concept: ENAs converted to positive ions energy-analyzed by a wave-type electrostatic analyzer followed by a TOF cell. Start electrons are produced by a surface.	Low-energy ENA 10 eV – 3 keV (H) $7^\circ \times 13^\circ$ ang. resolution
JENI - Jovian Energetic Neutrals and Ions Concept: Combined energetic ion and ENA camera based on Cassini, and IMAGE. Foil-based TOF with triple coincidence and ultra-short (few ns) TOF window.	ENA and ions $\sim 0.5 - 300$ keV (ENA), 5 MeV (ions) $\Delta E/E=14\%$, FoV: $90^\circ \times 120^\circ$, 2° ang. resolution (>10 keV H)

4. PEP status

The instrument passed Critical Design Review (CDR). Flight model is being manufactured. The target delivery to JUICE is Q4 2019. Technological/Engineering models of JNA, JEI, JoEE were built and tested with particle beams. Subsystems / Prototypes of JENI, NIM and JDC were built and tested with particle beams (Fig. 2).

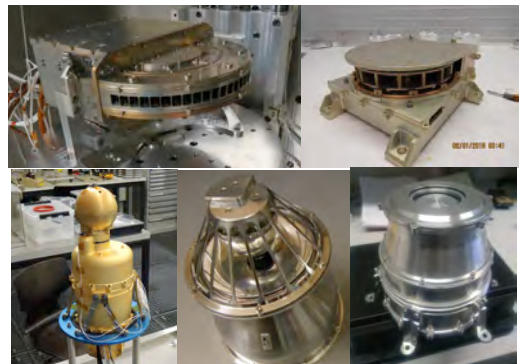


Figure 2: JNA and JoEE (upper photos); NIM, JDC, JEI (bottom photos)

The Seismometer to Investigate Ice and Ocean Structure

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Abstract

The Seismometer to Investigate Ice and Ocean Structure (SIIOS) is a program to advance the maturity of a commercial off the shelf (COTS) optical seismometer for spaceflight. The primary mission targets for SIIOS include landed spacecraft sent to the icy satellites of the outer solar system, including Europa. We present the capabilities of the SIIOS sensor and outline the work required to advance this device to TRL 6.

1. Introduction

Europa and Enceladus likely provide the three ingredients needed for life as we know it: liquid water, essential chemicals, and a source of energy. They are thought to have global subsurface oceans in contact with mineral-rich silicate interiors, making them two notable Ocean Worlds in the outer solar system. The possibility of life forming in their subsurface oceans relies in part on transfer of oxidants from the irradiated ice surface to the sheltered ocean below. Constraining the mechanisms and location of material exchange between the surface and subsurface is not possible without knowledge of the ice shell properties and the depth to water layers.

The Seismometer to Investigate Ice and Ocean Structure (SIIOS) will provide direct geophysical measurements that probe planetary ice shell and ocean layers by exploiting terrestrially demonstrated methods. In terrestrial settings, active and passive seismic studies have been used to measure the ice thicknesses and to determine the nature of sub-glacial materials. Seismic surveys can also inform the vertical temperature distribution within ice, an important property for tidally heated icy worlds. Thermal structure governs ice deformation in response to stress and indicates the amount of tidal heating.

Several studies have been published detailing the importance of a seismic experiment on a Europa

lander [e.g., Khurana et al., 2002; JPL D-71990, 2012; Pappalardo et al., 2013]. Beyond Europa, a rugged, cold-tolerant, and radiation hardened seismic sensor will bring this investigation to other landed missions: SIIOS enables the interior structure to be established for any seismically active planetary body. In particular, SIIOS will be designed and tested to operate in the harsh temperature and radiation environments of the moons of the outer solar system.

2. Performance of COTS Device

We present the commercial off the shelf capabilities of the SIIOS sensor, developed by Silicon Audio, Inc.

As a result of its capabilities, an early Silicon Audio (SiAu) 3-axis device was cited as an analogue of the seismic sensor envisioned on an eventual mission by the JPL 2012 Europa Lander Study. SiAu's optical seismometers have lower self-noise and a substantially higher clip level, where the sensor becomes overloaded, than other scientific grade seismic sensors. This allows a single SiAu sensor to capture large and low-noise signals simultaneously and across a wide bandwidth of frequencies (0.005 Hz to 400 Hz) free of spurious resonances. Prior planetary seismic experiments, including SEIS on InSight [Mimoun et al., 2012] and the Apollo seismic surveys [Goins et al., 1981], have required multiple sensors to record signals across the desired range of frequency bands. Due to its high clip level, the SiAu sensor enjoys the largest dynamic range in the industry at 183 dB (in a 1 Hz bandwidth @ 1 Hz). Another beneficial feature of SiAu's performance is its ultra-low distortion of $\leq 0.03\%$. This provides a large window of operation without compromising signal linearity. Finally, unlike most seismic instruments that only allow for a few degrees of tilt misalignment, the SiAu sensor is 360-degree tilt-insensitive in the low gravity field of Europa or Enceladus (e.g. "omni-tilt") and can be calibrated to work in any orientation. This is key, as the robotic deployment of a seismic experiment on irregular terrain may not guarantee a preferred orientation.

With a mechanical suspension mimicking that of a traditional geophone, the SiAu sensor has several features crucial to spaceflight accommodations including a small, light-weight form factor, low-power operation, ruggedized packaging and shock tolerant design. Unlike the traditional geophone, however, the sensor operates as a force-balanced accelerometer using a highly sensitive optical readout. A coil-wound bobbin is used, not as a velocity sensor, but to apply feedback forces to the proof mass in force-balanced operation. Force-balanced operation advantageously alters the open-loop response by 1) increasing passband and dynamic range, 2) removing the in-band resonant peak without adding additional noise and 3) improving linearity [Hall, 2008; Wielandt, 2002]. A miniaturized laser interferometer is used to sense the motion of the moving coil-wound bobbin. This technique is the basis for some of the world's most sensitive measurement devices such as the Laser Interferometer Gravitational Wave Observatory (LIGO) and can resolve displacements as small as $10^{-15} \text{mHz}^{-1/2}$. This frees the sensor from sensitivity limitations that restrict the noise performance of standard broadband seismometers.

The SiAu sensor has a lower noise floor than even the most sensitive broadband seismometers at frequencies above 10 Hz. Due to the SiAu sensor design, this low noise floor is accomplished without the need for a vacuum enclosure. In Figure 1 the self-noise for the Silicon Audio sensor is plotted along with theoretical noise floor of 10 Hz traditional geophone, as well as the Apollo seismometers and the performance of Insight's SEIS instrument. SiAu demonstrates improvement over all instruments at frequency bands >5 Hz. This is a key point because most seismic energy released during local events (especially at smaller magnitudes) occurs at high frequencies [Clinton & Heaton, 2002].

Attenuation of seismicity through a medium is quantified by the quality factor Q , for which attenuation goes as Q^{-1} . Colder ice has less attenuation ($Q \sim 100$), while warmer ice or ice closer to an ice-water interface presents greater attenuation ($Q \sim 10$) [Peters et al., 2012]. Using the large effective bandwidth and lower noise floor of the SiAu sensor this attenuation framework can be exploited: faint higher frequency signals may help locate events or ice thickness and lower frequency signals can be inverted for water depth.

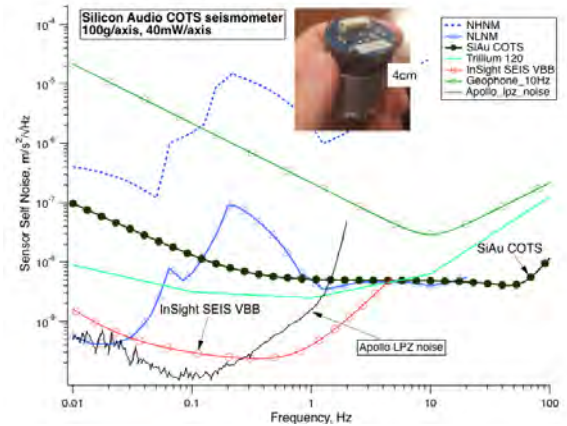


Figure 1: Sensor Self Noise of Silicon Audio sensor compared to other planetary seismic instruments.

3. TRL Maturation

The COTS SiAu has been deployed and successfully operated in analog environments in the terrestrial cryosphere. Qualification for spaceflight, however, requires electronics upgrades, specifically to the commercial-grade control/conditioning electronics mounted in the sensor. To advance the SiAu sensor to TRL6, we propose to separate the control electronics from the sensor head. After the electronics are partitioned for placement within a lander, two optoelectronics parts remain outside on the sensor: a laser diode and a PIN photodiode. Both components require qualification in a high-radiation cryogenic environment. To complete the environmental testing required to achieve TRL6, the engineering model will be tested for typical vibration and shock environments associated with launch.

Acknowledgements

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Advanced capabilities of a laser-enabled Orbitrap™ mass spectrometer adapted for spaceflight

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Abstract

Here, we describe a laser-enabled Orbitrap mass spectrometer that has been designed to explore a variety of cryogenic environments. The instrument configuration tested delivers measurements of major elements and organic molecules with ultrahigh mass resolution ($m/\Delta m \geq 120,000$, FWHM), highly accurate mass determinations within 3.2 ppm of absolute values, and the detection of amino acids in positive ion mode at ≤ 1 pmol/mm² concentrations.

1. Introduction

A spectrum of organic materials, ranging from simple (low mass) “prebiotic” hydrocarbons to complex (high mass) macromolecular networks, have been detected on asteroids [1], comets [2], Mars [3], Titan [4], and Enceladus [5]. Organic matter preserved on these and/or other planetary bodies may have been derived from one or more of the following mechanisms: the infall of C-rich small bodies; abiotic processes such as Fisher-Tropsch type reactions or Strecker synthesis; photochemical haze incorporation; or geological activity, such as water-rock interactions and thermogenesis. Consequently, understanding the origin of organics harbored in viable planetary environments, discriminating endogenous versus exogenous sourcing, and distinguishing biotic versus abiotic formational processes, requires advanced capabilities beyond traditional detection techniques.

To improve our understanding of potentially habitable cryogenic environments that may serve as sites of progressive organic polymerization and/or sanctuaries for biosignatures reflecting microbial activity (should life ultimately emerge), future missions need to enable comprehensive, *in situ* compositional analysis of surface, subsurface, and plume-derived materials from the various planetary

bodies described above. Critical investigations needed in the coming decades include:

- 1) the unambiguous identification of amino acids and other prebiotic organic compounds;
- 2) recognition and characterization of refractory macromolecular carbon networks;
- 3) accurate determinations of elemental and molecular abundance patterns;
- 4) precise isotopic measurements of C, N, S, and other elements essential to life; and,
- 5) quantitative mineralogy for geological context, including detection of potential biominerals.

2. Critical need: mass resolution

Planetary mass spectrometers, particularly legacy quadrupole analyzers, have enhanced our knowledge of the distribution and processing of organic materials discovered on Mars (via SAM/MSL and soon MOMA/ExoMars) and other bodies of astrobiological interest (e.g., Titan and Enceladus via Cassini-Huygens). However, heritage instruments struggle to untangle organic and inorganic isobaric interferences, chemical species characterized by the same nominal mass-to-charge ratio (or m/z), resulting in tenuous peak assignments. Thus, the unambiguous identification of molecular stoichiometry and the definitive characterization of population distributions, require more advanced technologies.

In the commercial realm, isobars are most commonly: i) separated physically via chromatographic methods; ii) identified by diagnostic fragmentation patterns via tandem mass spectrometry (MS/MS) techniques; or, iii) selectively excited and measured via resonance ionization. However, all of these approaches require auxiliary subsystems (e.g., gas/liquid chromatographs or myriad laser systems) that contribute to the instrument mass/volume, or multiple stages of analysis (e.g., ion isolation and fragmentation) that

demand additional power/energy resources. Mass analyzers that offer high mass resolving powers ($m/\Delta m \gg 10^3$), in contrast, enable the differentiation of isobars via exact mass determinations without excess hardware or experimental sequencing. The Orbitrap analyzer developed by Thermo Fisher Scientific [8] and adapted for spaceflight by a consortium of French laboratories [9] may hold the most promise for future astrobiology missions due to its unrivaled mass resolution (up to $m/\Delta m > 10^6$, [10]) and accurate mass determinations to ppm-levels [11].

3. Critical need: laser sampling

In situ laser desorption/ionization processing offers an ideal way to characterize precious sample specimens with high spatial resolution and specificity, and without requiring contact with the sample (thereby reducing the risk of contamination). Such techniques also support: (semi)quantitative detection of organic and inorganic molecules over a wide range in mass, volatility, and ionization energy; measurements of individual mineral phases and/or discrete geological strata; and, minimal analytical blanks, resulting in low limits of detection (LOD). Laser sampling also consumes orders-of-magnitude smaller quantities of sample (*i.e.*, ng) compared to pyrolysis techniques (*i.e.*, mg), including those executed by the Viking, Phoenix, and MSL missions.

4. Laser + Orbitrap demonstration

A pulsed UV (266 nm) laser system, interfaced to the CosmOrbitrap analyzer ruggedized for spaceflight, enables measurements of organic and inorganic content in analog samples representative of potential ocean world surface materials. All peaks measured in a sample of MgSO_4 (a potential component of Europa's subsurface ocean) doped with 0.35 wt.% of the α -amino acid valine were measured with a mass resolution of $m/\Delta m \geq 120,000$ (FWHM) and an accuracy within 3.2 ppm of absolute values (Fig. 1).

Further, in positive ion mode the instrument was also able to detect twelve α -amino acids down to pmol/mm^2 concentrations while maintaining mass resolution and accuracy performance metrics (Fig. 2).

The capability to measure negative ions, which should improve detection limits for organics bearing acidic side chains, is currently being tested in order to illustrate the complementarity of dual polarity ops.

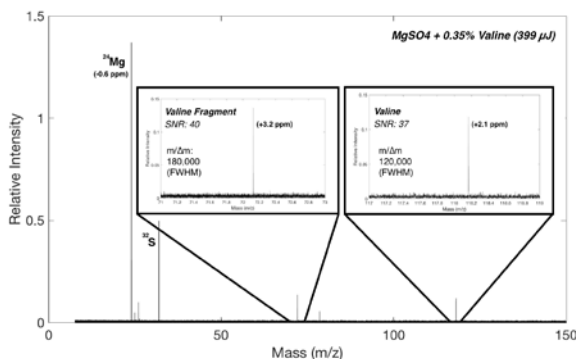


Fig. 1. Elemental peaks reflecting the MgSO_4 matrix (e.g., ^{24}Mg and ^{32}S), and organic peaks representing protonated valine and a primary fragment, are observed with a mass resolution of $m/\Delta m \geq 120,000$ (FWHM) and an accuracy within 3.2 ppm of truth.

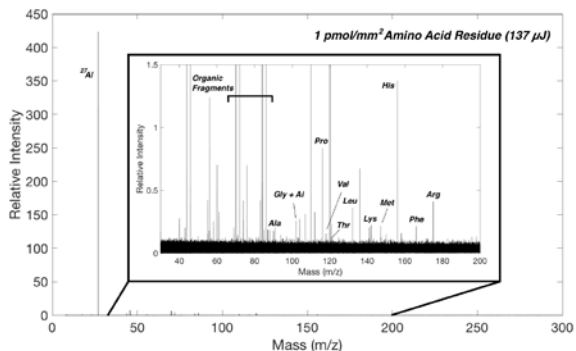


Fig. 2. In positive ion mode, twelve α -amino acids can be detected down to pmol/mm^2 concentrations while maintaining mass resolution/accuracy metrics.

A flight model point design developed by UMD, NASA, and the CosmOrbitrap Consortium was critically assessed by an independent review panel and confirmed to require only 7.7 kg (9.6 kg with 25% margin), 11,000 cm^3 (17,000 cm^3 preferred for harness routing), and 33 W average (46 W peak).

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Secondary electron generation from conversion surfaces

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Abstract

Traditionally the detection of energetic neutral atoms in space is based on the use of conversion surfaces and the measurement of the negative and positive ions resulting from the interaction of the incident neutral particle with the surface. The efficiency of the conversion neutrals/ions is usually very low (1-5 %) in particular at low-energy (< 1 keV). In order to increase the detection efficiency at low-energy and build more sensitive instruments for future planetary and heliospheric space missions one could also rely on the detection of the secondary electrons emitted during the neutral/surface interactions. We have tested in vacuum various conversion surfaces in order to characterize the properties of the secondary electrons emitted. In the present paper we will describe our experimental setup and present the results of our characterization. We will discuss the application of this detection technique for Energetic Neutral Atom imaging as well as ion mass spectrometry.

Acknowledgements

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The Mercury Electron Analyzers onboard the Bepi Colombo Mercury Magnetospheric Orbiter

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Abstract

Bepi Colombo is a joint mission between ESA and JAXA that is scheduled for launch in 2018 and arrival at Mercury in 2025. A comprehensive set of particle sensors will be flown onboard the two probes that form Bepi Colombo. Onboard the Mercury Magnetospheric Orbiter (MMO) the Mercury Electron Analyzers (MEA, [1]) sensors constitute within the Mercury Plasma Particle Experiment (MPPE, [2]) suite the experiment dedicated to fast electron measurements between 3 and 25,500 eV. They consist of two top-hat electrostatic analyzers for angle-energy analysis followed by microchannel plate multipliers and collecting anodes. A notable and new feature of MEA is that the transmission factor of each analyzer can be varied inflight electronically by a factor reaching up to 100, thus allowing to largely increasing the dynamical range of the experiment. This capability is of importance at Mercury where large changes of electron fluxes are expected from the solar wind to the various regions of the Mercury magnetosphere. Taking advantage of the spacecraft rotation with a 4 s period, MEA will provide for the first time fast three-dimensional distribution functions of magnetospheric electrons, from energies of the solar wind and exospheric populations (a few eVs) up to the plasma sheet energy range (some tens of keV). The use of two sensors viewing perpendicular planes allows reaching a 1=4 spin period time resolution, i.e., 1 s, to obtain a full 3D distribution.

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Acknowledgements

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MARLI: MARs Lidar for global wind and aerosol profiles from orbit

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Abstract

The Mars Exploration Analysis Group's Next Orbiter Science Analysis Group (NEX-SAG) identified atmospheric wind measurements as one of 5 top compelling science objectives for a future Mars orbiter [1]. To date, only isolated lander observations of Mars winds exist.

Winds are the key variable to understand atmospheric transport and answer fundamental questions about the three primary cycles of the martian climate: CO₂, H₂O, and dust. However, the direct lack of observations and imprecise and indirect inferences from temperature observations leave many basic questions about the atmospheric circulation unanswered. In addition to addressing high priority science questions, direct wind observations from orbit would help validate 3D general circulation models (GCMs) while also providing key input to atmospheric reanalyses.

The dust and CO₂ cycles on Mars are partially coupled and their influences on the atmospheric circulation modify the global wind field. Dust absorbs solar infrared radiation and its variable spatial distribution forces changes in the atmospheric temperature and wind fields. Thus it is important to simultaneously measure the height-resolved wind and dust profiles. MARLI provides a unique capability to observe these variables continuously, day and night, from orbit.

1. Measurement Approach

The MARLI lidar [2-3] is being designed to observe the atmosphere from a nominally circular polar orbit around Mars. The lidar measurement concept is shown in Figure 1. The simplest version of the instrument would be pointed ~30° off-nadir in a cross-track viewing direction. The lidar will continuously measure dust aerosol backscatter profiles, cross polarized backscatter profiles (for water ice aerosols), the component of the Doppler shift from wind profiles along the instrument's line-of-sight, and the range to the planet's surface. The MARLI approach uses a pulsed single-frequency

Nd:YAG laser and direct detection receiver and makes measurements at 1064 nm. Its measurement types are shown in Figure 2. The MARLI development is being supported by the NASA Picasso and Matisse Programs.

2. Lidar Description

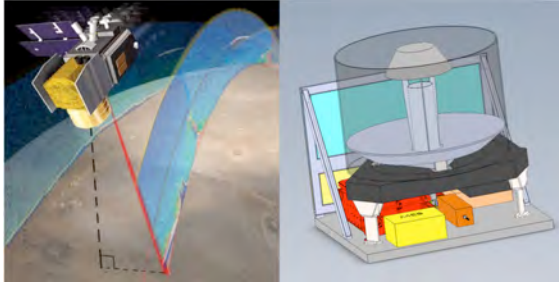
The laser backscatter from the Mars atmosphere is weak and is distributed in range and thus a highly sensitive lidar approach is necessary. The present MARLI approach measures the height resolved atmospheric characteristics along a single line-of-sight. The lidar uses an efficient pulsed Nd:YAG laser with flight heritage, a low-mass receiver telescope and photon-sensitive detectors.

The basic design of MARLI, shown in Figure 3, utilizes a pulsed single-frequency diode-pumped Nd:YAG laser. Its output pulses are wavelength stabilized near 1064 nm. The laser emits ~50 nsec wide pulses at a 1 kHz pulse rate. Nominally, the receiver uses a ~50 cm diameter telescope and splits the returned signal into 3 paths. One path is a cross-polarized channel to allow dust/ice discrimination. The other two paths are used to illuminate an etalon at different angles then are focused onto separate detectors. These receiver elements are configured as a double-edge Doppler (optical frequency-shift) discriminator. It is also feasible to measure vector-resolved wind profiles using a dual-telescope-receiver that shares the energy from a single laser.

Our approach leverages new lidar components developed for NASA, including a single frequency laser from Fibertek and photon-sensitive HgCdTe detectors from DRS Technologies. Our targeted instrument size is a ~70 cm cube, comparable to a medium-sized instrument such as the Mars Orbiter Laser Altimeter (MOLA). Nominal payload parameters are 40 kg, < 90W, and ~50 Kbits/sec. This approach leverages our work on measuring terrestrial winds and lidar technology supported by the NASA ESTO IIP program.

3. Performance and status

We have calculated the expected performance of MARLI using measurement models that we developed as part of this project. The performance estimates depend on the laser power, telescope diameter, vertical bin depth and averaging time. The instrument will report measurements at a rate of ≥ 10 Hz. The performance is summarized in Table 1 assuming 2 km vertical bins and 40 second averaging ($\sim 2^\circ$ latt.). We have demonstrated many aspects of the measurement with an instrument breadboard. Details of the approach, breadboard and the space version will be shown in the presentation.



References:

- [1] MEPAG: Chaired by B. Campbell and R. Zurek (2015), *Report from the Next Orbiter Science Analysis Group*, <http://mepag.nasa.gov/reports.cfm>
- [2] J.B. Abshire et al., MARLI, 2015 European Planetary Science Congress (EPSC), <http://meetingorganizer.copernicus.org/EPSC2015/EPSC2015-258.pdf>
- [3] S. D. Guzewich et al., MARLI, 2016 Lunar and Planetary Science Conference (LPSC), <http://www.hou.usra.edu/meetings/lpsc2016/pdf/1497.pdf>

Figure 1. (Left) The MARLI approach continuously measures the aerosol backscatter profiles, the cross polarized (ice) backscatter profiles, the Doppler (wind profiles), Nominally the lidar is pointed cross-track at ~ 30 deg off nadir, to measure the Doppler shift of the wind in the cross-track direction. (Right) Drawing of MARLI from an engineering study. In this concept the receiver telescope diameter is ~ 50 cm, the laser box is in red, and the radiator panel is in blue and yellow.

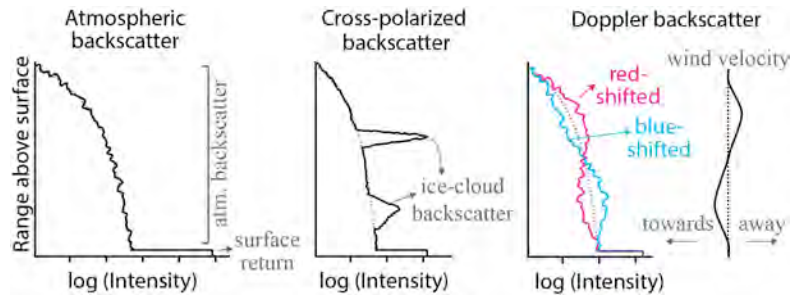


Figure 2. Illustrations of the MARLI measurement types. (Left) Range (height) resolved aerosol backscatter profiles. (Middle) Profiles of cross-polarized backscatter, caused by ice clouds. (Right) Height resolved Doppler backscatter profiles as seen by the two detectors after passing through the etalon used as the double-edge filter. (Far Right) The horizontal wind profile is computed from the detected signal ratio after the double-edge filter.

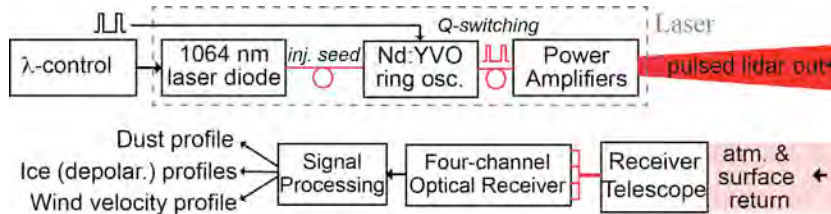


Figure 3. Simplified block diagram of MARLI lidar for single beam instrument configuration.

Table -1 Summary of MARLI performance versus altitude for the single beam configuration

Parameter	Surface	5 km	10 km	20 km	30 km
Backscatter SNR	360	320	260	140	80
Wind horiz. velocity (m/sec)	0.3	0.4	1	2	3

Developing Miniature Wolter-I X-ray Optic for Planetary Science

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Introduction: Comparative study of surface variation of the elemental abundance of diverse planetary bodies can provide clues to their formation and evolutionary history. X-ray fluorescence (XRF), intrinsic to atomic energy levels, carries a unique signature of the elemental composition of the emitting bodies. Unlike optical and infrared spectra that can be altered by space weathering, XRF can probe more than 10–20 μm deep below the surface (e.g., see [1,2]), and thus it is a powerful diagnostic tool to understand the true chemical and mineralogical composition of the planetary bodies.

The optical images of Comet 67P/Churyumov–Gerasimenko taken by the Rosetta mission such as the image shown (e.g. Figure 1, see also [3]) have revealed rich surface features and outgassing activities. If the Rosetta mission was equipped with a high resolution X-ray *Imaging* spectrometer, it could have directly identified elemental composition of diverse structures of the comet nuclei surface and coma in the image. For instance, an X-ray telescope with sub-arcminute angular resolution and a square degree field of view (FoV) can measure the surface elemental abundance of ~ 1000 different segments in the region marked by the orange square in Figure 1. Such an X-ray observation can greatly improve our understanding of the geological history of the comet nuclei and the physics behind the volatile activity.

Applications of X-ray imaging spectroscopy reach far beyond the study of elemental composition. Whether it is exospheric escape from Mars, pion reactions on Venus or sprite lighting on Saturn, sensitive X-ray imaging spectroscopy of planetary objects will greatly improve our understanding of the target bodies and the Solar System as a whole. Until now virtually all the X-ray spectrometers employed in planetary missions have been limited to simple collimator-type instruments without imaging capability. To make powerful, yet compact lightweight X-ray optics affordable for many future planetary missions where mass, volume and power for each instrument are limited, we have started a new program to develop miniature X-ray optics (MiXO) using metal-ceramic hybrid shells.

Technical Approach and Status: Nearly all modern X-ray astronomy missions utilize grazing-incidence optics with Wolter-I geometries which combines reflection from a parabolic and a hyperbolic surface in a barrel shape mirror. To increase the collecting area of these telescopes, several mirror shells of varying diameter can be nested one inside the other along the same optical axis. The majority of X-ray missions employ either Al foil, glass or nickel as the telescope substrate material.

Our new approach combines plasma thermal spray technology with electroformed Nickel replication process to largely replace thick high density NiCo shell (8.9 g/cm^3) with thin, light ceramic compound ($2.3\text{--}2.9 \text{ g/cm}^3$) [5, 6]. In our metal-ceramic hybrid technology, the ceramic ($\sim 200 \mu\text{m}$ thick) provides the necessary stiffness to hold the figure of the mandrel and supply the rigidity needed for handling, while the thin metal ($\sim 30 \mu\text{m}$ thick) provides micro-roughness required for X-ray reflection. In parallel, we are also investigating minimum thickness of NiCo layer required for self-supporting NiCo-only shells. Thin ($< 120 \mu\text{m}$) NiCo-only shells can be potentially used for inner small shells without need for the supporting ceramic layers.

Figure 3 (a) shows recently fabricated hybrid shells (62 mm diameter $\times$ 18 cm long, designed for small FoV: $< 0.1 \text{ deg}^2$) composed of $100 \mu\text{m}$ NiCo + $50 \mu\text{m}$ Bond layer + $200 \mu\text{m}$ Al_2O_3 . Metrology of the best hybrid shell predicts 1.2 arcmin resolution, which is similar to the 1.1 arcmin resolution measured for a $100 \mu\text{m}$ NiCo-only shell from the same mandrel. The resolution is limited by the polished figure of the mandrel used for shell fabrication. We recently fabricated two mandrels (shown in figure 2) using a new mandrel design to produce wide field ($\sim 1 \text{ deg}^2$) miniature X-ray shells suitable for planetary applications.

Telescope Design: Nearly all planetary targets for in-situ observations are diffuse sources, and thus a large FoV coverage with high resolution is essential in achieving sensitive X-ray observations. We employ mirror shells of the standard Wolter geometry but with varying lengths, and we defocus each shell slightly to improve off-axis resolution. Defocusing trades off the