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Mars MetNet Mission - Martian Atmospheric Observational Post Network

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Abstract

A new kind of planetary exploration mission for Mars is under development in collaboration between the Finnish Meteorological Institute (FMI), Lavochkin Association (LA), Space Research Institute (IKI) and Institutio Nacional de Tecnica Aerospacial (INTA). The Mars MetNet mission is based on a new semi-hard landing vehicle called MetNet Lander (MNL).

The scientific payload of the Mars MetNet Precursor [1] mission is divided into three categories: Atmospheric instruments, Optical devices and Composition and structure devices. Each of the payload instruments will provide significant insights in to the Martian atmospheric behavior. The key technologies of the MetNet Lander have been qualified and the electrical qualification model (EQM) of the payload bay has been built and successfully tested.

1. MetNet Lander

The MetNet landing vehicles are using an inflatable entry and descent system instead of rigid heat shields and parachutes as earlier semi-hard landing devices have used. This way the ratio of the payload mass to the overall mass is optimized. The landing impact will burrow the payload container into the Martian soil providing a more favorable thermal environment for the electronics and a suitable orientation of the telescopic boom with external sensors and the radio link antenna. It is planned to deploy several tens of MNLs on the Martian surface operating at least partly at the same time to allow meteorological network science.

2. Strawman Scientific Payload

The strawman payload of the two MNL precursor models includes the following instruments:

Atmospheric instruments:

- MetBaro Pressure device
- MetHumi Humidity device
- MetTemp Temperature sensors

Optical devices:

- PanCam Panoramic
- MetSIS Solar irradiance sensor with OWLS optical wireless system for data transfer
- DS Dust sensor

Composition and Structure Devices:

- Tri-axial magnetometer MOURA
- Tri-axial System Accelerometer

The descent processes dynamic properties are monitored by a special 3-axis accelerometer combined with a 3-axis gyrometer. The data will be sent via auxiliary beacon antenna throughout the descent phase starting shortly after separation from the spacecraft. MetNet Mission payload instruments are specially designed to operate under very low power conditions. MNL flexible solar panels provides a total of approximately 0.7-0.8 W of electric power during the daylight time. As the provided power output is insufficient to operate all instruments simultaneously they are activated sequentially according to a specially designed cyclogram table which adapts itself to the different environmental constraints.

3. Mission Status

The eventual goal is to create a network of atmospheric observational posts around the Martian surface. Even if the MetNet mission is focused on the atmospheric science, the mission payload will also include additional kinds of geophysical instrumentation. The next step is the MetNet Precursor

Mission that will demonstrate the technical robustness and scientific capabilities of the MetNet type of landing vehicle. Definition of the Precursor Mission and discussions on launch opportunities are currently under way.

4. MetNet Payload Precursors

The first MetNet Science Payload Precursors have already been successfully completed, e,g, the REMS/MSL and DREAMS/Exomars-2016. The next MetNet Payload Precursors will be METEO/Exomars-2020 and MEDA/Mars-2020. The baseline program development funding exists for the next seven years. Flight unit manufacture of the payload bay takes about 18 months, and it will be commenced after the Precursor Mission has been defined.

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On aluminum tapes treated for missions at Jupiter

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Abstract

Electrodynamic tethers are effective at Jupiter because of its high magnetic field, the length-averaged tether current lying well below its high *short-circuit* bound for dimensions of interest. Efficiency of Jovian capture of an incoming spacecraft, gauged by the M_{SC}/m_t mass ratio, is then higher for low perijove radius and a thin, long tape [1]. If too long, however, it could result in some attracted electrons hitting it at values of energy with *range (penetration depth)* larger than thickness h. Mission-design depends on keeping electron *range* below tape thickness for all conditions at capture, to ensure current collection; since the electron range decreases with energy, it suffices to set h equal to the *range* for maximum energy of attracted electrons throughout the entire capture operation, which occurs at the anodic end, when the S/C is at the *drag-arc* perijove and the spinning tether is parallel to the *motional* field $\mathbf{E}_m$ driving its current. This is achieved by setting the perijove just hundreds of kilometers above Jupiter, while using short, moderately thin tapes ($L \sim 3$ km, $h \sim 0.02$ mm, say), resulting in a mass ratio about 3 and a S/C of several hundred kg, tape-width being determined by the scaling with M_{SC} [2].

This is down by one order of magnitude from typical mass in studies of Giant Planets, allowing for a *fast/light mission*, with direct S/C launch into a 2.7 years Hohmann transfer to Jupiter, for multiple flybys of moon *Europa*. After a few perijove passes, Lorentz-drag would take the S/C to an orbit with *apojove* about the moon Ganymede — and perijove very near Jupiter —, for a 1:1 resonance orbit with Europa, tether current being kept off through flybys, and radiation dose per orbit reaching 0.1 Mrad under 200 *mils* (about 5 mm) of *Al* shielding [2]. A remaining issue, however, is the strong heating of the tape aluminium, which, in principle, would have very low thermal emissivity, if highly conductive as required from a tether.

With aluminium tethers having thermal emissivity as low as 0.03 at a temperature of 300 K, over the entire spectrum, they present inadequate heat dissipation in the thermal infrared region. A nanostructured coating with high thermal-emissivity and high conductivity, as compared to Al and Al_2O_3 respectively, is being developed in the present work for tethers exposed to the hard conditions at *Jovian* operation. A coating of aluminum oxide is anodically grown on the aluminum tether and treated to make it electrically conductive, in particular to suppress discharges of static electricity, while compatible with emissivity about 0.7. The design objective of this research is to anodically grow an alumina *antidot array* on Al tethers. This anodic aluminum oxide has an intrinsic double-layered structure: a porous external oxide layer and a barrier layer at the bottom of the pores. A

chemical pore-widening technique is used to thin or even remove the barrier layer so as to reduce the transverse electrical resistivity.

The chosen design involves an antidote array coating structure that has a nanoporous size adequate to incorporate conductive material inside. Our approach relies on structures with different pore-size arrays to allow direct metals deposition by electrochemical methods. The electrical conductivity of the coating is tailored to a value between 10^6 and 10^7 S/m. This surface finishing process is made of four main steps: 1) The surface roughness of the aluminum tethers will be increased by etching processes until R_a (average roughness) = 1.6 μm. 2) A nanometric porous aluminum oxide array will be grown on flat and rough Al with a thickness in the order of 100 nm to 10 μm and a pore size in the range 100 - 400 nm. 3) A chemical pore-widening technique will be used to thin the barrier layer at the bottom of the porous aluminum oxide. 4) The nanopores in the aluminum oxide array are filled with T_i or N_i-based materials by chemical methods: electroless and electroplating [3].

Filling the nanopores with electrically conductive material also increases the coating conductivity. This proposed nanoscale patterned metal/dielectric coating also offers the possibility of tuning the local distribution of dielectric surface in a controlled way. That compares favourably with continuous high-resistivity thin oxide films. For space applications, such coating would also provide the required electrical contact with the outer-space plasma. Remarkably, the anodization and electro-deposition processes are compatible with commercial anodizing production lines.

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Conception of China's Small-Body Exploration

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Abstract

Deep-space exploration is expanding to the small-bodies from the major planets, for the small-body explorations greatly enhance our understanding of the solar system formation process. This presentation firstly provides the overview of the Chang'e-2 Toutatis asteroid flyby mission, in which the backgrounds, operations, mainly scientific and technical achievements of the mission are summarized. Secondly, the presentation gives a brief introduction on the science objectives, mission operations and science payloads of Chinese future small-body exploration. The technical approaches of the key mission phases including approaching, landing, sampling and reentry are discussed.

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The Jet Dust Pump. An Ad Hoc Solution for Pumping Systems on Mars by Using the Martian Dust

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Abstract: The basis of an ad hoc pumping technology for Mars exploration called a *Jet Dust Pump* is outlined. In space exploration, in situ resource utilization (ISRU) is defined as "the collection, processing, storing and use of materials encountered in the course of human or robotic space exploration that replace materials that would otherwise be brought from Earth".[1]. However ISRU philosophy not just should be applied on materials but also in suitable technology considering the special Martian environment.

One of the most important aspects to be considered on Mars exploration and settlement is its ubiquitous dust mantle. Here, it will be discussed the possibility to harness the martian dust to develop an ad hoc martian pumping technology. Years ago, in 2004 it was found that almost all dust particles in the Martian atmosphere are magnetic according to the data obtained by NASA-Mars Exploration Rover Spirit. If so, dust particles will respond to an imposed magnetic field, and this feature could be used for accelerating the dust under a magnetic field to produce a dust jet. This dust jet could be used to induce aerodynamic entrainment in devices and then generating suction. This kind of ad hoc technology for Mars could provide an interesting alternative to traditional rod vacuum pumps used on Earth which not just will have a reduced performance on Mars owing to its lower atmospheric pressure but because the dust and sand inflow would be a common problem. Indeed, with a mechanically driven pump, the moving parts will be always at risk of rapid abrasion failure because the dust where plungers, barrels, rods and tubing will be common failure points. Dust could also often plug the system causing the pump to fail.

With a *Jet Dust Pump*, such problems would no longer exist. There are no moving parts. The driving force is the external magnetic field generated by a conical magnetic coil and being the dust the working media generating the aerodynamic entrainment and therefore dust plugging will not occur.

Jet Dust Pumps could be used on rovers to clean up the soil for analysis of the subsoil or cleaning the soil for mining for water.

Acknowledgements

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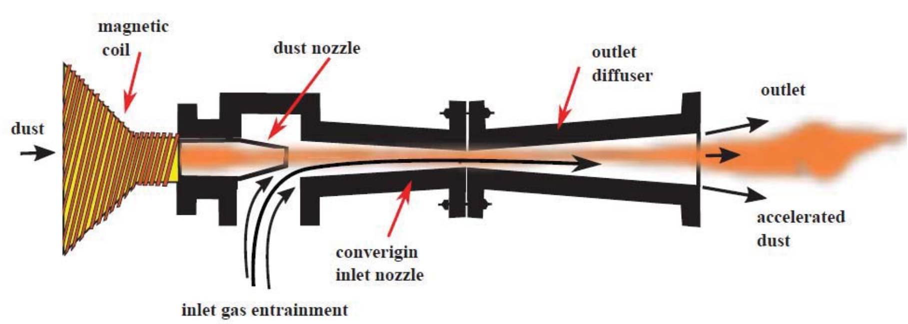

The Jet Dust Pump

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OCEANUS: A New Frontiers mission concept to study Titan's potential habitability

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Abstract

Oceanus is a proposed Titan orbiter that would characterize Titan's habitability globally. It would decipher organic photochemistry in the atmosphere, observe the transport pathways of organics on the surface, locate near-surface liquid water and evaluate its longevity, and discern processes that may transport organics into the ocean. It would carry a multistage mass spectrometer, an IR camera that sees through Titan's atmosphere, and a radar altimeter. It would spend two years in Saturn's orbit with 20 Titan flybys followed by two years in a circular polar orbit around Titan.

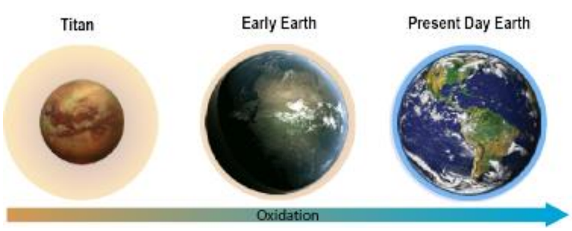

Figure 1: Oceanus would determine the details and mechanisms of the organic chemical pathways on Titan and would teach us about the fundamental chemical processes that can occur on potentially life-bearing "pale orange dots."

1. Introduction

The Decadal Survey describes Titan as the most accessible location in the solar system for studying planetary organic chemistry, including prebiotic and potentially exotic biochemistries [1]. It's an Ocean World with a methane-rich reducing atmosphere, similar to early Earth's [e.g.,2,3]. On Earth, synthesis of complex organics from methane may have created an orange hazy layer. Before Earth was a 'pale blue dot' (Fig. 1), it may have been a 'pale orange dot' like Titan [4]. On Earth, methane-producing organisms evolved early, and the atmosphere remained reducing for about a billion years after the origin of life. If other worlds follow Earth's path, 'pale orange dots' may be widespread in the universe. By studying Titan, Oceanus would provide insight into the chemistry, geology, and geophysics of exoplanets with reducing atmospheres [5].

2. Proposed Science goals and objectives

Oceanus would follow the organics from their synthesis in the upper atmosphere to their hydrolysis in subsurface water reservoirs. With its four science goals, Oceanus would address the two objectives stated in the New Frontiers AO for Titan: (i) Understand the organic and methanogenic cycle on Titan, especially as it relates to prebiotic chemistry, and (ii) Investigate the subsurface ocean and/or liquid reservoirs, particularly their evolution and possible interaction with the surface. Science Goal 1 reveals the workings of organic chemistry in the upper atmosphere and whether biologically relevant elements (oxygen) and repeating subunits (e.g., HCN) are incorporated into large organic molecules. Science Goal 2 investigates how organics are transported across the surface, where they have accumulated, and where processed organic materials have been eroded. Science Goal 3 examines impact craters and candidate cryovolcanic features to determine whether organics have been in contact with near-surface liquid water, or where water deposits, such as ice dikes and sills, were emplaced in organic sediments in the subsurface. Science Goal

4 determines if pathways exist for the transport of surface organics to the subsurface ocean. It studies Titan's tectonic history; detects crustal thickness, thermal properties, and mass distribution; and answers whether Titan's ocean is in contact with the rocky core.

These science goals lead to eleven science objectives which can be addressed by a payload of three instruments and the gravity investigation.

3. Instruments

The proposed payload is composed of three instruments. The first instrument is a multistage quadrupole ion-trap mass spectrometer with mass range of 2-1000 Da (10x higher range than Cassini, and 100x higher sensitivity). It would inventory organic molecules in Titan's atmosphere at multiple altitudes down to 750 km. Oceanus would provide a unique data set of organic molecules built in an environment common to a number of planets in the solar system and beyond.

The second instrument is a camera tailored for Titan. The Cassini mission has demonstrated that Titan's surface can be observed in seven infrared atmospheric windows [6]. The Oceanus camera can see through the atmosphere in three colors (1.3, 2.0, and 5 μm). Oceanus has the capability to image half of Titan's surface at <70 m resolution (Fig.2), including at least eight fluvial networks, four basins, three craters, three cryovolcanic regions, and five tectonic features.

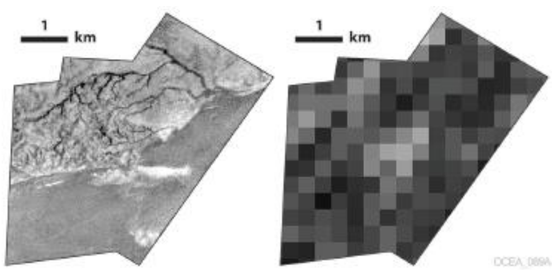

Figure 2: **(Left)** Oceanus would image up to 50% of Titan at ≤70-m resolution, similar to the DISR mosaic acquired over <0.002% of the surface during the Huygens descent (~100-m resolution). (**Right**) Cassini SAR image of the same area at ~1-km resolution. Cassini SAR mapped less than 50% of Titan.

The third instrument is an X-Band radar altimeter with 1-m vertical resolution. Combined with gravity science, it would measure tidal deformation, crustal thickness and viscosity, lateral density variations, and other interior properties to learn whether the ocean is in direct contact with the silicate core. Oceanus would provide a global coverage with 1-m vertical resolution and spatial posting of <100 km at the equator

Oceanus would be launched in 2024, with a 10-year cruise. The spacecraft would spend two years orbiting Saturn with 18 science flybys of Titan as close as 750 km followed by another two years in a 1500-km circular, 5-hr polar orbit. In its first day orbiting Titan, Oceanus would spend more time close to Titan than Cassini has with 127 targeted flybys in 13 years.

4. Summary and Conclusions

Oceanus would answer fundamental questions about organic synthesis in planetary atmospheres. In situ observation of Titan's complex photochemistry is key to understanding the evolution of other worlds with atmospheric methane photolysis, including ice giants, Pluto, early Earth, early Mars, and exoplanets. Oceanus would investigate the transport of organic material on Titan's surface, characterizing the myriad processes that affect surface evolution on sedimentary worlds. Revealing Titan's interior structure and the properties of its crust and internal ocean would reframe our understanding of the construction and habitability of ocean worlds.

Acknowledgements

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A nuclear spectrometer aboard microsatellites for near-earth asteroids exploration

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Abstract

Small and frequent missions to Near Earth Asteroids (NEAs) using 50kg-class microsatellites are a promising approach for both planetary science and space resources. Low cost, short time delivery, and innovation in technology are tangible advantages of the microsatellite missions. It is essential for the progress of planetary science to obtain elemental compositions of planetary bodies as well as their size, mass, density and geometrical shape. Nuclear spectroscopy supported on neutron and gamma-ray spectrometers (NGS) is a powerful and useful tool for directly obtaining the elemental composition of planetary bodies. Spectroscopic analysis of neutron and gamma-ray fluxes emitted from NEAs surfaces is found to provide useful information in characterizing their elemental composition. We have conducted numerical studies of both neutron and gamma-ray fluxes emitted from NEAs surfaces complemented by basic NGS experiments. The investigation of NGS aboard microsatellite towards the future exploration of NEAs is presented and discussed.

1. Introduction

Asteroids are rocky celestial bodies in the 1 m - 10 km size range, thought to be the building blocks of planets and/or their satellites. Some of the main-belt materials are primordial material that has never differentiated before. Other asteroids are pieces of planetary bodies that were broken apart by a collision during the formation stage of planets. These asteroids are thought to be linked with meteorites. Therefore, the exploration of these tiny asteroids is closely associated with the study on how the solar system formed and evolved.

Part of the numerous asteroids that approach or cross the Earth's orbit are called Near-Earth Asteroids (NEAs). They are not only an important scientific study target but also relevant for space exploration and development because they represent a huge storage of natural resources free of Earth's gravity. NEAs can supply materials for a wide range of operations both in space and on Earth, as they are thought to contain large amounts of water, carbon, structural metals such as iron and aluminum, industrial material such as rare-earth metals, and precious metals.

To approach basic questions on the origin and evolution of planetary bodies such as Mercury, Mars, the Moon, comets, and asteroids, observation data on their chemical composition are essential and indispensable. Nuclear spectroscopy is a powerful method to achieve it and has been widely applied to orbital and landing exploration of extraterrestrial planetary bodies: the Moon, Mars, Mercury and asteroids [1-7].

Gamma ray and neutron radiations are produced steadily by galactic cosmic ray (GCR) interaction with the surface and atmospheric materials of planetary bodies in the solar system, and by the nuclear decay of natural radioisotopes within the solid body. Those produced gamma rays and neutrons leak from the planetary surface bringing along important information about the abundance of major and trace elements. Global mapping of elemental composition by an orbiting spacecraft is thus accessible. The main benefit of joint neutron and gamma ray spectroscopy is the ability to reliably identify elements important to planetary geochemistry and to accurately determine their abundance [5,8].

Hence and with the growing interest on NEAs elemental composition characterization for both planetary science and space exploration, [9,10] it was natural to us taking up the task of studying the expected performance of the nuclear and gamma ray spectrometer (NGS) aboard a deep space microsatellite .

2. Deep space microsatellite

Space activities using microsatellites (microsats) are promising for planetary science development and space resources exploration. With the recent progress in miniaturization and increased capabilities on advanced electronic, materials and information technology, microsats show unprecedented potential on performing successful missions. Despite some limitations in lifetime expectancy and resolution accuracy, microsats are very low in cost and short in delivery time what turns out in huge innovation potential in space systems utilization and also on performance assessment of new technologies.

The use of a 50–100 kg class microsat as miniature deep space probe would make it highly attractive for NEAs rendezvous missions paving the way for the next steps on deep-space exploration [11-14]. Such microsats have light weight engines (e.g. a Xe-ion engine) and can approach small bodies moving near the orbit of Earth. Moreover, they offer a very quick turnaround and an inexpensive means of exploring well-focused, small-scale science objectives.

As an education program in a graduate course, a doctoral student can initiate his researching, proposing and building an instrument, for the retrieval of orbital data for analysis and presentation on a thesis, all within a normal period of postgraduate study. Driven by their own vision and efforts and not limited by high threshold budgets, university teams will be able to launch their own satellite into space reaching a new horizon in space research.

At Waseda University, cub-sats (Waseda sat-1,-2, 1nee -3) developed by students have been launched into space. Deep space microsat carrying a nuclear spectrometer will naturally be the next step. We have started microsat designing and partly fabricate and test their elements including the NGS. In this work, we describe in particular the NGS fitting 50 kg-class microsats for future deep space NEAs exploration.

3. Simulation methods

Our numerical calculations were carried out with the simulation tool PHITS (Particle and Heavy Ion Transport code System [15] and some nuclear models and data libraries [16-20] In this section, we briefly describe details of simulation methods.

3.1. GCR Projectiles

The GCR particles of hydrogen and helium in the energy range of 10 MeV/n-100 GeV/n were assumed as the prevailing projectiles. Energy spectra of the GCR particles are given by the following equations (1) and (2) [21, 22]. The fitting parameters and the normalized constant are determined by BESS and PAMELA observation data in 1997, solar minimum phase (φ = 491 [MV]) [23, 24]. These values are shown in Table. 1.

$$J(E,\phi) = C \times \frac{E\left(E + 2m_p c^2\right)\left(E + \chi + \phi e \times \frac{Z}{A}\right)^{-\gamma}}{\left(E + \phi e \times \frac{Z}{A}\right)\left(E + 2m_p c^2 + \phi e \times \frac{Z}{A}\right)} \quad (1)$$

$$\chi = a \exp(-bE) \quad (2)$$

Table1. Parameters used in Eq.(1)

	C	A	b	γ
H	1.24×10^{6}	780	2.50×10^{-4}	2.65
He	2.26×10^{5}	660	1.40×10^{-4}	2.77

3.2 NEA type targets

In our simulations, four types of elemental compositions are assumed as sample compositions. One is that of Earth's core composition with some light elements [25]. The others are three types of meteorites compositions; C-type, S-type, and Martian meteorites [26-28]. These compositions are shown in Table. 2. They are assumed as the parent bodies of M-type, C-type, and S-type asteroids.

3.3 Target geometry setting

The numerical simulations were divided into two steps to shorten calculation time. The GCR particles were injected into a homogeneous target of 20 × 20 × 20 m^3 to obtain energy spectra of gamma-ray emission on a target area of 10 × 10 m^2. The emission spectra was used in the NGS. The methods of numerical simulations are described in detail in the proceeding of ISTS 2017 by Naito et al. [25] and Ishii et al. [26].

Table 2. Elemental targets composition (wt%)

	Core	C-type	S-type	Martian
H	0.60	2.02	0.33	-----
C	-----	3.46	1.03	-----
O	2.05	46.5	38.9	41.4
Mg	-----	9.55	14.1	9.24
Si	2.05	10.7	17.6	21.7
K	-----	-----	0.08	0.08
Ca	-----	0.93	1.21	5.35
Ti	-----	-----	0.08	0.46
Fe	89.6	18.6	20.7	15.0
Ni	5.40	-----	1.12	-----
Others	0.30	8.80	3.20	6.60

3.4 Neutron and Gamma-ray Spectrometer

The NGS consists on a neutron and a gamma-ray spectrometer. Two kinds of gamma-ray spectrometers are assumed: one employs a high purity Ge detector (HPGe) cooled by a small mechanical cooler, and the other is a scintillation detector of 3” thick x 3” ϕ $CeBr_3$. These detectors are surrounded by a thin (5 mm) plastic scintillator as a veto counter to reject GCR events. The HPGe size is 200 cm^3 while $CeBr_3$ has a 350 cm^3 volume. The densities of these detectors are 5.32 g/cm^3 and 5.2 g/cm^3, respectively. And their energy resolutions in fwhm are assumed to be 3.0 keV at 1.332 MeV for HPGe and 26.5 keV at 662 keV for $CeBr_3$.

On the other hand, the neutron detector measures neutron fluxes in three different energy ranges; thermal (< 1 eV), epithermal (1 eV-500 keV), and fast neutron (< 500 keV). The neutron spectrometer consists on 4 mm thick ^{6}Li-enriched lithium glass scintillator (LiG) , Boron loaded plastic scintillator (BLP; 4”ϕ x 3”) surrounded with thin Gd foil for thermal neutron shielding and a plastic scintillator (PLS) to reject GCR charged particles.

4. Results and Discussion

4.1. Samples gamma-ray spectra

The emitted gamma-rays energy spectra from NEAs targets with the elemental composition of Table. 2 are shown in Fig. 1. The differences in the elemental compositions are visible and those are the distributions used to test the gamma-ray spectrometers.

Energy spectra from C-type composition obtained by HPGe detector and $CeBr_3$ scintillator are compared in Fig. 2. Many sharp gamma-ray peaks can be seen in the energy spectrum of HPGe. The differences in energy resolution and the detection efficiency of these detectors clearly appear in the energy spectra. Although the gamma-ray lines emitted from various elements are observed by both HPGe and CeBr3, some gamma-ray lines with close energies at 1.779 MeV and 1.809 MeV24) emitted from silicon and magnesium gamma-ray lines through inelastic scattering reaction are difficult to separate the gamma-ray energy spectra by $CeBr_3$

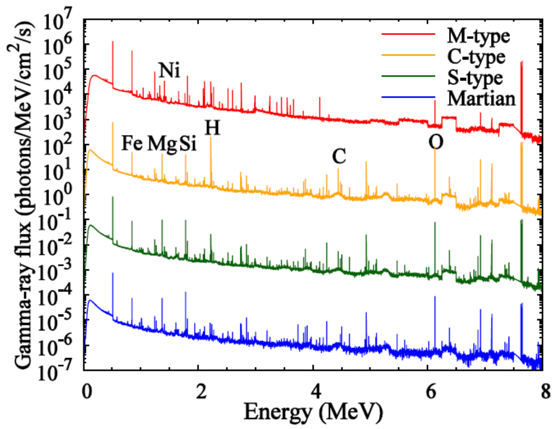

Figure 1. Gamma-ray energy spectra emitted from four different target samples.

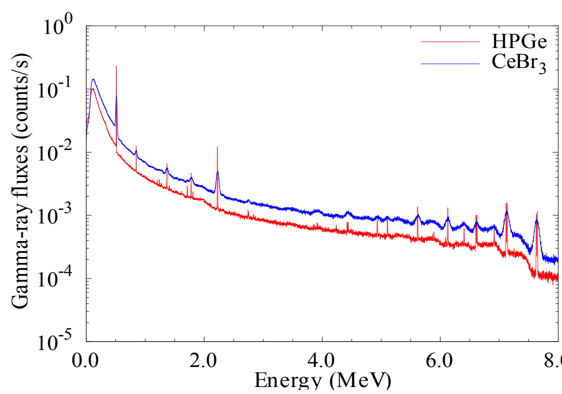

Fig. 2 Gamma-ray energy spectra of C-type composition obtained with HPGe and $CeBr_3$ gamma-ray spectrometers.

4.2 Neutron emission

The target neutron fluxes are shown in Fig. 3. The lowest flux of epithermal neutron is produced by the C-type asteroid as it has the highest hydrogen concentration. There is also a difference in the thermal neutron flux between the S- and M-types. The abundance of Fe and H concentrations greatly affect the energy spectra, especially in the thermal and epithermal energies. Therefore, the measurement of their neutron fluxes provides useful information in determining the NEAs elemental composition.

The estimated neutron counting rates are shown in Fig. 4. The epithermal neutron counting rates detected by the BLP drastically change with the hydrogen concentrations in these meteorites. The counting rates of epithermal neutron detected by the BLP drastically change by concentrations of these meteorites. Therefore, the NS can determine hydrogen concentrations of NEAs surface and will give a constraint on the elemental composition to NEAs by the measurements of neutron fluxes to be obtained by LiG and BLP. As can be seen from Fig.3 and Fig.4, the combination of lithium glass scintillator (LiG) and boron loaded plastic scintillator (BLP) is a good method to measure a wide range of neutron energy and to identify the meteorites and hydrogen-concentration in the meteorites.

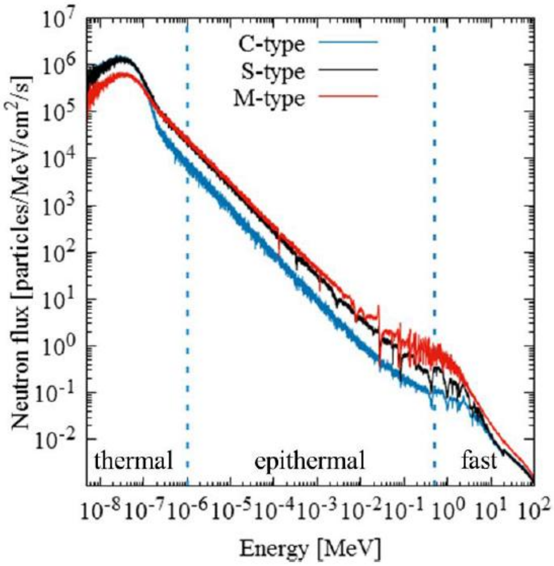

Fig. 3. Energy spectra of neutrons emitted from NEAs with different elemental compositions shown in Table.1.

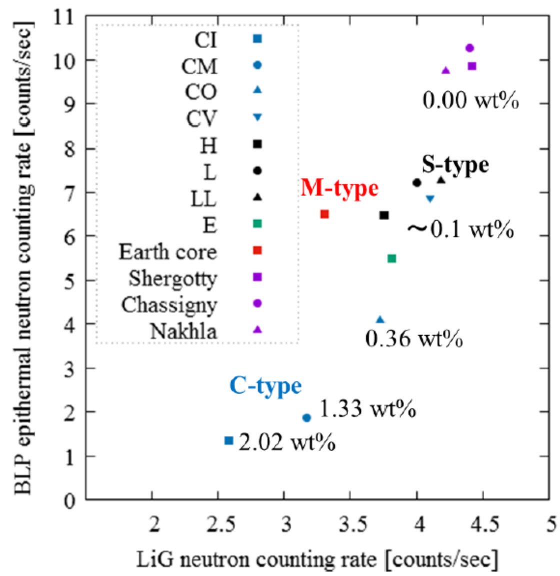

Fig. 4. The correlation of neutron counting rates between LiG and BLP scintillators for different meteorites elemental compositions. The parameter of mass fraction (wt%) in the figure represents the hydrogen concentration in the meteorite composition.

5. Summary and Conclusions

The NGS for NEA exploration based on miniaturized spacecraft, measures the surface abundances of major elements, trace elements, and volatile elements as hydrogen over the whole surface of the NEA bodies. Major objectives for the exploration are to study the NEAs geological features and elemental survey for future space utilization. Gamma-ray and neutron fluxes emitted from different NEA targets types with elemental compositions were numerically calculated for future microsatellite missions. Numerical calculation also tells us that HPGe is better than CeBr3 as gamma-ray spectrometer. However, both the HPGe and CeBr3 are arguably favourable, depending on the mission constraints.

As a general concluding remark we can state that the NGS is proven to be a powerful tool for space science and elemental/geological survey towards the fast approaching miniaturized deep space missions age. In the near future, the NGS carried on a 50 kg-class microsatellite is expected to play an important role in NEAs exploration.

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Spectrometer ISEM for ExoMars-2020 space mission

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Abstract

Robust design, small dimensions and mass, the absence of moving parts in acousto-optic tunable filters (AOTFs) make them popular for space applications [1-3]. Here we introduce a pencil-beam near-infrared AOTF-based spectrometer ISEM for context assessment of the surface mineralogy in the vicinity of a planetary probe or a rover analyzing the reflected solar radiation in the near infrared range [4]. The ISEM (Infrared Spectrometer for ExoMars) instrument is to be deployed on the mast of ExoMars Rover planned for launch in 2020.

ISEM spectrometer

The instrument covers the spectral range of 1.15–3.3 μm with the spectral resolution of ~25 cm-1 and is intended to study mineralogical and petrographic composition of the uppermost layer of the regolith. The instrument targets waterbearing minerals, phyllosilicates, sulfates, carbonates in the vicinity of the Mars rover. Besides, it will help in real-time assessment of surface composition in selected areas, in support of identifying and selection of the most promising drilling sites. A study of variations of the atmospheric dust properties and of the atmospheric gaseous composition is also of interest.

The instrument consists of two parts: Optical Box (Fig. 1) and Electronic Box. The optical scheme includes entry optics, the AOTF, focusing optics, and a Peltier-cooled InAs detector. A wide-angle acousto-optic tunable filter manufactured on the base of TeO_2 crystal is used. Incident optical radiation has ordinary polarization and the diffracted optical beam has the extraordinary polarization. The angle between the passed and diffracted optical beams is 6° at the output of the AO crystal. A pair of polarizers with crossed polarizing planes is used to filter out the non-desired zero diffraction order.

Up to now, two qualification models have been manufactured. The test campaign is planned.

Fig.1. Optical Box of ISEM.

Acknowledgements.

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The New Frontiers Venus In Situ Atmospheric and Geochemical Explorer (VISAGE) Mission Proposal

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Abstract

The exploration of the inner solar system is driven by the overarching concept of comparative planetology - that understanding the structure, history, processes, and evolution of each inner solar system planet directly addresses the understanding of the other planets. The 2013-2022 Planetary Science Decadal Survey [1] identified the Venus In Situ Explorer as the highest priority New Frontiers mission concept for future inner solar system studies. VISAGE, the Venus In Situ Atmospheric and Geochemical Explorer mission concept proposes to address three fundamental goals: 1) to understand why Venus is so different from Earth: VISAGE would measure noble gases to test models of the origin and evolution of Venus, and measures sulfur compounds and trace gas profiles to constrain atmospheric cycles, surface-atmosphere interactions, and climate models, 2) to understand whether Venus was ever like Earth: VISAGE would measure surface and subsurface composition, determine surface rock type, mineralogy, and texture to understand geochemical processes, weathering, and aeolian processes, and 3) to understand what Venus can teach about exoplanets.

The VISAGE Venus lander mission would perform atmospheric and surface science investigations with a flyby spacecraft that delivers a Lander and serves as telecom relay. The proposed VISAGE Lander science payload comprises five instruments: an Atmospheric Structure Investigation including Doppler Wind measurements, a Neutral Mass Spectrometer, an Imaging System, an X-ray Fluorescence experiment, and a Visible Near-Infrared Spectrometer. In the extreme surface environment of Venus, VISAGE is proposed to be a relatively short (several hours) autonomous landed mission that requires no ground control. Once on the surface, VISAGE measures the mineralogy and elemental composition at two depths, with samples brought inside the Lander for analysis. Science investigations include measuring the inventory of noble gases and light stable isotopes, the abundance of trace and reactive gases from surface to clouds, and to provide descent imaging of the surface below 15 km. During descent, the thermal, compositional, and dynamical structure of the atmosphere along the Lander trajectory is measured. Once on the surface, the elemental and mineralogical composition of surface rocks are measured, and panoramic images of the landing site are made.

Measurements of noble gases in the atmosphere help discriminate between models of Venus's origin, and the composition of the surface can elucidate the history of Venus. On the surface the mass spectrometer is used to get extremely precise measurements of atmospheric composition, including noble gases and isotopes, taking advantage of the multi-hour duration afforded there. Additionally, the trace gas analysis on the surface and in the lower atmosphere on descent helps determine the nature of surface-atmosphere interactions.

VISAGE would launch in December, 2024 with a targeted flyby of Venus in May, 2025 and Venus arrival in December, 2025. The VISAGE Lander descends under parachute and drag plate for one hour before landing at 8.8 m/s. Once on the surface, VISAGE conducts surface atmosphere measurements, surface and sub-surface

composition measurements, and take panoramic images of the surface region for up to 3.6 hours. The total surface science data return is expected to be ~1.4 GBits.

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CASTAWAY: A MISSION TO MAP THE EVOLUTION OF OUR SOLAR SYSTEM

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Abstract

CASTAway is a mission concept to explore our Solar System's Main Asteroid Belt (MAB). Variations in composition across the asteroid and comet populations can provide a tracer for the dynamical evolution of the Solar System. This presentation will describe the CASTAway mission concept and how it can provide a comprehensive survey of the objects in the MAB.

1. Science Questions and Objectives

CASTAway combines a long-range (point source) telescopic survey of thousands of objects, targeted close encounters with 10 – 20 asteroids [1] and serendipitous searches into a single mission concept. With a carefully targeted trajectory that loops through the MAB, CASTAway will provide a comprehensive survey of the main belt at multiple size scales. Specific science questions and objectives that CASTAway seeks to address include:

a) How do asteroid surface compositions relate to meteorite mineralogy?
b) How do measured surface compositions of asteroids vary?
c) How do surface composition, morphology and regolith cover vary between asteroids?
d) Is our understanding of surface ages correct?
e) How do visible wavelengths photometric "mega-surveys" (e.g. Gaia, Large Synoptic Survey Telescope etc.) correlate with composition?

2. Spacecraft and Instruments

CASTAway concept uses a high Technology Readiness Level (TRL) spacecraft design (Figure 1) and instrument suite (Figure 2) for the mission's flyby and point source survey capabilities. The science payload consists of three linked instruments: a) The Main Telescope for CASTAway (MTC) that comprises a 50 cm (baseline) diameter telescope feeding a Visible Context Imager (VCI) for narrow angle (~10-20 m at 1000 km) imaging and a moderate resolution (R = 30-100) spectrometer with spectral coverage from 0.6-5 µm. b) Thermal Infrared imager for temperature, albedo and composition mapping of the target asteroids during flybys. c) Asteroid Detection cameras, based on micro advanced stellar com-pass (µASC) star tracking cameras. A minimum of four science star trackers will be used to detect new objects in the 1-10 m size range. In addition there are opportunities for determination of asteroid mass etc. using radio science techniques.

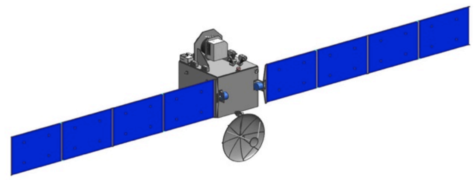

Figure 1. CASTAway spacecraft design concept (OHB Systems AG). The deployed wingspan is 16 m tip-to-tip. From [2]

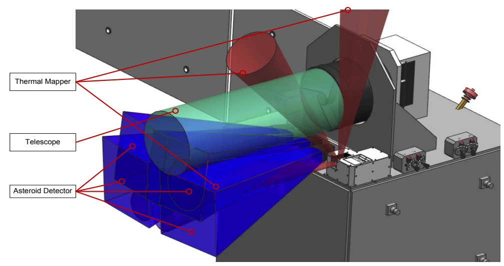

Figure 2. Payload accommodation and instrument fields of view. From [2].

The spacecraft (Figure 1, [2]), its subsystems and associated mission architecture were developed using the concurrent engineering facilities at OHB System

AG in Bremen, Germany. A simple space-based telescope and space segment is pro-posed. The baseline spacecraft design is compatible with a Soyuz-like performance. Optional mass-saving measures are also available. An improvement of only 23 % w.r.t the Soyuz (as expected for the Ariane 6.2 in the mid 2020s) enables the deeper exploration of the main belt with an improved delta-v and flexibility of the launch window. A larger number of scientifically compelling flyby targets would also be enabled.

3. Trajectory Options

Optimized trajectories, based on a database of 100,000 asteroids, already demonstrate the feasibility to perform 10 or more asteroid flybys within 7 years and European medium-lift launcher capabilities (i.e. Soyuz/Ariane 62). Trajectories (e.g. Figure 3, [1]) will not only encounter objects of varying spectral class and double the number of main belt objects visited by spacecraft, but also spend nearly 2000 days surveying the interior of the belt and allowing > 10,000 asteroids to be spectroscopically surveyed and discovering small (1-10 m) size objects.

4. Summary and Conclusions

The CASTAway mission concept will map compositional diversity of the asteroid belt to constrain our models of the evolution of our Solar System and provide essential context to current and future generations of small bodies sample return missions. It can achieve this with a spacecraft and payload that has high levels of technology readiness and fits within the programmatic and cost caps for e.g. an European Space Agency "M" or medium class mission.

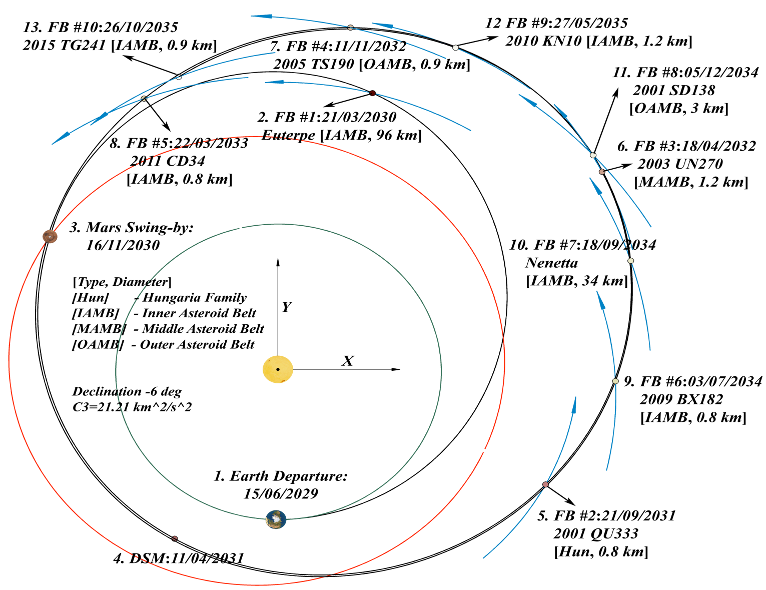

Figure 3. Baseline trajectory for CASTAway with Mars swingby, multiple options and opportunities in the 2029-31 time frame of e.g. ESA's M5 mission call (from [1]).

Acknowledgements

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Joint IKI/ROSCOSMOS - NASA Science Definition Team and concept mission to Venus based on Venera-D

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Abstract

NASA and IKI/Roscosmos established in 2015 a Joint Science Definition Team (JSDT), a key task of which was to codify the synergy between the goals of Venera-D [1] with those of NASA [2,3]. In addition, the JSDT studied potential NASA provided mission augmentations (experiments /elements) that could to fill identified science gaps. The first report to NASA - IKI/Roscosmos was provided in January 2017. The baseline Venera-D concept includes two elements, and orbiter and a lander, with potential contributions consisting of an aerial platform/balloon, small long-lived surface stations or a sub-satellite.

1. Introduction

The Venera-D mission concept is devoted to the detailed study of the atmosphere, surface, and plasma environment of Venus [1]. Envisioned as launching in the post-2025 timeframe and consisting of an orbiter and lander with advanced, modern instrumentation, this mission would build upon the Venera, VEGA, Pioneer Venus, and Magellan missions carried out in the 1970's and 1990's [4,5,6] along with the more recent Venus Express [7].

2. Lure of Venus

Our knowledge of Venus' basic atmospheric properties (composition, thermal structure, clouds, winds, etc.), and how different this planet is from Earth has come through the success of the Soviet, US, ESA and now, JAXA missions to Venus as well the Earth-based observations of last decades. Venus was formed in the inner solar system out of the same proto-planetary material as Earth, and is considered Earth's twin. Although these siblings have nearly the same size, mass, and density, unlike Earth, which has a comfortable condition for the life, Venus' climate presents a "hellish" condition, fueled by a massive (90 atm) CO_2 atmosphere which is responsible for an enormous greenhouse effect and a near-surface temperature of 470°C, sulfuric acid clouds, lack of water. Its young surface is sculpted by volcanism and is deformed by folding and faulting resulting in belts of mountains and rifts. The lack of an intrinsic magnetic field suggests the planet's interior structure may also be different than that of the Earth. Why did Venus take an evolutionary path so different from that of the Earth, why and when did the evolutionary paths of these twin planets diverge? Were there ever favorable conditions for starting life on Venus?

3. The goals of Venera-D mission components

Specific areas of scientific investigation would focus on the dynamics of the atmosphere with emphasis on atmospheric superrotation, the origin and evolution of the atmosphere, and the geological processes that have formed and modified the surface with emphasis on the mineralogical and elemental composition of surface materials, the chemical processes related to the interaction of the surface and atmosphere, solar wind interaction and atmospheric losses.

Orbiter Goals consist of the following: study of the dynamics and nature of superrotation, radiative balance and greenhouse effect; investigation of the thermal structure of the atmosphere, winds, thermal tides and solar locked structures; measurement of the composition of the atmosphere; study of the clouds, their structure, composition, and chemistry;

evaluation of the nature of the 'unknown' UV-absorber; and investigation of the upper atmosphere, ionosphere, electrical activity, magnetosphere, and the escape rate.

Lander Goals focus on the detailed chemical analysis of the surface material; study of the elemental and mineralogical composition of the surface, including radiogenic elements; characterize of the geology of local landforms at different scales; study of the interaction between the surface and the atmosphere; investigation of the structure and chemical composition of the atmosphere down to the surface, including abundances and isotopic ratios of the trace and noble gases; and direct chemical analysis of the cloud aerosols.

To fill the "science gaps," where important VEXAG science may not be addressed by the baseline Venera-D concept, the JSDT generated a list of possible contributed options: from specific instruments such as a Raman Spectrometer and an Alpha-Particle X-Ray Spectrometer (APXS) to possible flight elements such as a maneuverable aerial platform, small long-lived surface stations, a balloon, and a small sub-satellite.

In situ measurements, both in the atmosphere and on the surface have not been carried out for more than 30 years. The Venera-D mission is proposed to correct this gap. Long-duration measurements in the atmosphere (from several weeks to several months) would aid in understanding the processes that drive the atmosphere. A well instrumented mobile platform or balloon that could maneuver to different altitudes in the clouds could help understand the 'puzzles' of the UV-absorber, its nature, composition, vertical and horizontal distribution as well as providing a platform to measure key trace and noble gases and their isotopes, meteorology and cloud properties, composition, etc., depending on scientific payload. Another high priority augmentations that are considered are small long-lived surface station (possibly 1-5 stations with an operation life time from 60 days to up to one year) and subsatellite.

4. JSDT recommendations

The JSDT identified priorities for the science goals and objectives for the comprehensive scientific exploration of Venus. Based on these priorities, a baseline Venera-D mission would consist of a single highly capable orbiter and a single highly capable lander. In addition to the baseline mission, the JSDT identified potential "contributed" augmentations that would enhance the science return.

In formulating a strategy for the development of Venera-D, the JSDT identified areas where investments would need to be made to bring the mission concept to fruition.

5. Future work

The next phase of development of the Venera-D concept would focus on a more detailed examination of the science measurements and potential instrumentation along with the specifications of the spacecraft requirements.

In its ongoing work, the JSDT will incorporate into its deliberations information from a set of science community modeling workshops (in May at GRC, Cleveland, USA and in October at IKI, Moscow) to identify additional key measurements (and corresponding instruments) that could be achieved by the planned Venera-D mission. In addition these workshops will identify needed high-value data that could be obtained by Venera-D that would advance future modeling work, specifically the development of new GCMs.

Acknowledgements

The members of the JSDT acknowledge NASA and Roscosmos for support of our current activities and future work through 2018.

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RLS Spectrometer Unit Qualified for ExoMars 2020 & Future Planetary Missions

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Abstract

ExoMars 2020 mission is an ESA-Roscosmos collaboration and will deliver a European rover and a Russian surface platform to the surface of Mars. The ExoMars rover will search for signs of life. It will collect samples with a drill that is designed to extract samples from various depths. Once collected, it is delivered to the rover's analytical laboratory, which will perform mineralogical and chemistry determination investigations. Establishing if life ever existed on Mars is one of the outstanding scientific questions of our time.

To address these exobiological and geochemical issues, **Raman Spectroscopy technique** has been selected through to **Raman Laser Spectrometer Instrument (RLS)** that forms part of an Analytical laboratory instruments in the body of the vehicle. The Rover subsurface sampling device will drill down tomaximum 2 m. The sample will be crushed into a fine powder. By means of a dosing station the powder will then be presented to RLS and other instruments.

It is a well recognized **non-destructive** analytical tool. The shift in energy appears as a spectral distribution and therefore provides an **unique fingerprint by which the substances can be identified and structurally analyzed**.

1. Raman Laser Spectrometer Instrument

One of the key rover´s laboratory instruments is the Raman Laser Spectrometer (RLS) which capabilities and objectives are in the line of ExoMars ones. RLS is able to characterize mineral phases produced by water-related processes, to characterise water/geochemical environment as a function of depth in the shallow subsurface, to identify the mineral products and indicators of biologic activities and to identify organic compound and search for life.

The RLS working flow is depicted in Figure1; the powdered sample will be illuminated by means of the iOH optics, with the laser light coming (through the excitation fiber) from the pump diode housed at the ICEU. The Raman signal obtained will be properly filtered and delivered by the iOH (through the reception fiber) to the SPU. At the SPU the Raman signal will be sent through the transmission diffraction grating to the CCD. Image obtained will be sent to the ICEU FEE (Front End Electronics), and processed by the processor electronics, previous to be sent to the Rover.

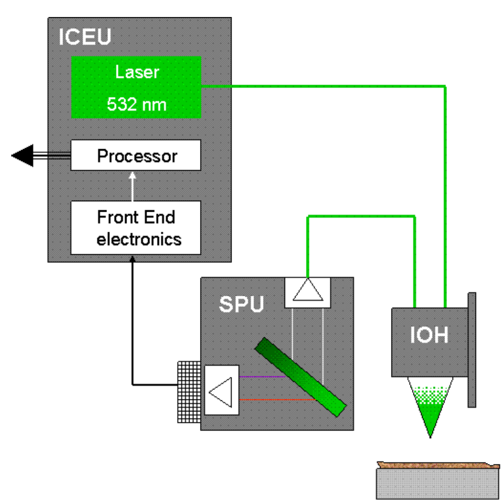

Figure 1: RLS functional Flow

2. Spectrometer Unit

One of the most critical Units of the RLS instrument is the Spectrometer Unit (SPU) that performs spectroscopy technique and operates in a **very demanding environment** (radiation, temperature, dust, etc.) with very restrictive design constraints (mass, power, schedule). It is a very small optical instrument capable to cope with 0.12 – 0.15 nm/pixel of spectral resolution and withstand with the Martian environment (operative temperature conditions: from -40ºC to 0ºC (6ºC for CCD thermal I/F while dissipating 2W)). The solution selected is based on a single transmisive holographic grating especially designed to actuate as the dispersion element.

The main driver of the design of the SPU is not only to reach the scientific requirements as spectral resolution and linear dispersion, but to reach them in 935 grams (including margins), in a very reduced envelope and maintaining performances in the operative termal range. It should be remarked that this transmission spectrometer has demonstrate to be as **flexible** as needed due to several changes in the mission along last years.

2.1. SPU Optical Design

As explained before, the design of a spectrometer unit that withstand with the Martian environment is a very demanding optical effort. The very small optical instrument required can be based on a single transmisive holographic grating especially designed to actuate as the dispersion element that separates the spectral lines in one row on the detector. Efficiency up to 70% at the whole spectral range (533-676nm).The selection of glasses is also of vital importance to assure the behaviour of the instrument in the operative thermal range.

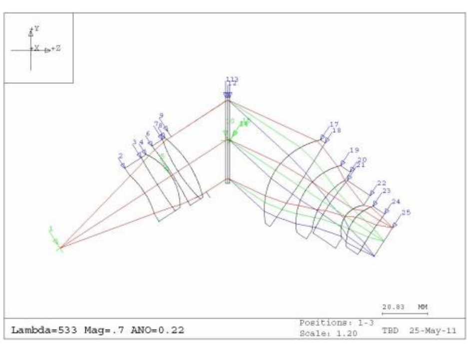

Figure 2: SPU Optical Design.

2.2. SPU Structural Design

SPU is composed by the external Ti6Al4V structure (receptacle, collimator, main body, cover, collector and focal plane assembly) and internal optical lenses fixed by Ti6Al4V retaining rings and spacers, grating assembly and the detector assembly.

The selected material for SPU structural components is titanium due to its CTE, which is similar to the selected optical materials CTE. Titanium has a relative low thermal conductivity, however the temperature of the different SPU optical components is uniform due to the absence of dissipative components and the temperatura stability assured through SPU stands conductive I/F, by the Rover ALD thermal control.

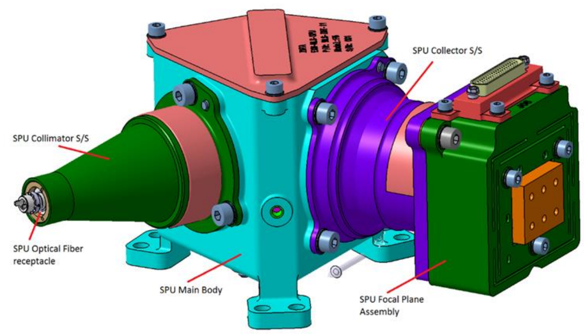

Figure 3: SPU FM Design.

2.3. SPU Thermomechanical Design

The SPU is sensitive both to operating thermal range and to the thermal stability along the Raman operation. The Thermal Control maintains the required thermal environment for proper operations of SPU taking into account the different Mars environment conditions. Two sensitive items are hosted within this unit:

- The optical elements sensitive to alignment mismatching due to temperature variations and gradients (both of them)
- CCD that requires a specific cold condition to provide the required performance.

Thermal analyses have been performed to guarantee that the different components are within their allowable and the required temperatures to assure performances, and also to verify that the required I/F heat fluxes and electrical heat power (to keep critical components at their operating range of temperatures) do not exceed the specified values for SPU operating conditions.

Thermal Design Concept assure the good performance of some critical component by means of a thermal active control; on one hand, a TEC (Thermo Electrical Cooler) implemented in the FPA (Focal Plane Assembly), is used to maintain the CCD temperature below the maximum operating temperature, and on the other hand, three heaters and several temperature sensors are used to keep SPU optics above the specified temperature limits.

3. Spectrometer current status

As part of RLS SPU Development and validation plan, the Engineering Qualification Model of the SPU has been designed, manufactured, tested and delivered to the Instrument for RLS EQM test and further delivery to ESA.

The SPU EQM is based on the optical concept design of the SPU FM (Figure 2), and is the most complete model relative to the tests. A summary of its design characteristics, objectives, functionalities and build standard are given in the Table 1 and here below.

The SPU EQM is representative of the FM in terms of:

- Optics and Electronics flight standard.
- Electrical design flight representative (pinout and grounding).
- Optical design flight representative.
- Thermal design flight representative (thermal control, although heater standard is not FM one).
- Mechanical design flight representative for structural behavior, mounting, mass, shape and alignment.
- External and internal IFs
- Compliant with PP and C&CC requirements.

SPU Model	Objectives	Functionalities	Design	Build standard
EQM	Verification of TH and mechanical models.	SPU FM functionalities.	Same SPU FM desing (Electrical, Optical, thermal and mechanical).	- Mechanical Parts, Materials and processes flight-like. - Components: Commercial not qualified but with extended temperature range. Same technology and supplier than FM with the exception of the heater.
	Verification of SPU performances		SPU FM external and internal IFs.	- Optical Fiber receptacle EQM (flight-like).
	Verification of SPU functionality and electrical performance.		Including bonding stud.	- Grating EQM (flight-like).
	Verification of SPU external and internal IFs.		PP protocol including S/S.	- Detector Assembly EQM (flight-like build).
	Radiometric model validation.		FM Grounding representative.	
	Validation of Electrical test facilities/ EGSE and related procedures.		DA: Fully functional flight-like detector assembly	

Table 1: SPU EQM characteristics

4. Summary and Conclusions

SPU is a very demanding and challenge Unit which has been successfully qualified for ExoMars2020 and that could be on board on future planetary missions. Next milestone is the Critical Design Review (CDR) expected for July 2017 and then the FM.

Acknowledgements

Authors would like to emphasize that the development of the Raman Laser Spectrometer Instrument and of the Spectrometer Unit is being feasible thanks to the Deep collaboration within all parts (national institutes, agencies and private companies) involved, from all different countries.

Finally, from UVa-CAB & INTA, we would like to thank to Spanish MINECO for the financial support to the Spanish contribution to this program.

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Small Next-generation Atmospheric Probe (SNAP) Concept

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Abstract

A concept is presented for a small, atmospheric entry probe designed to be added as a secondary payload to future giant planet missions. The main science objectives of the Small Next-generation Atmospheric Probe (SNAP) are to determine the distribution of clouds and cloud-forming chemical species, thermal stratification, and wind speed as a function of depth. As a case study, we present the advantages, cost and risk of adding SNAP to a future Uranus Orbiter and Probe flagship mission. In combination with the mission's primary entry probe, SNAP would perform atmospheric in-situ measurements at a second location, and thus enable and enhance the scientific objectives recommended by the 2013-2012 Planetary Science Decadal Survey and the 2014 NASA Science Plan to determine atmospheric spatial variabilities.

The primary goal of the SNAP concept development is to achieve the science objectives with a 30-kg entry probe ~0.5m in diameter (less than half the size of the Galileo probe) that could reach a pressure of 5-bars and return data to the Carrier spacecraft prior to downlink to Earth. The probe baseline instrument payload comprises an Atmospheric Structure Instrument (ASI) to measure entry and descent accelerations and the altitude profile of temperature and pressure, a carbon nanotube-based NanoChem atmospheric composition sensor, and UltraStable Oscillators (USO) on both the probe and the Carrier spacecraft to conduct a Doppler Wind Experiment (DWE). Although the current SNAP concept is developed as a possible element for a future Uranus Orbiter and Probe flagship mission, the probe conceptual design and mission architecture will maintain flexibility so as to be easily adapted to other giant planets.

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Missions to Mars and his Trojan Asteroid Family – A Feasibility Study

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Abstract

In the context of ESA's call for medium class missions (M5), we investigated missions to Mars. As part of proposal development, we studied the possibility to visit at least one Martian Trojan either through a flyby on the way to Mars or by going from Mars to a Trojan at the end of the mission. We find that both options are possible but require considerable mission resources. While the first option requires less fuel, it is very limited in terms of available time windows and margins. In contrast, the second option offers a more flexible mission schedule, but requires more propellant and time.

1.Introduction

DePhine – the Deimos and Phobos Interior Explorer – has been proposed as an M-class mission in the context of ESA's Cosmic Vision program [1], with a projected launch in 2030. The mission will explore the origin and the evolution of the Martian natural satellites. In addition, we analyzed rendezvous scenarios with Martian Trojans, which could possibly be achieved in combination with missions to Mars.

In our study we focused on two different scenarios:

- Option 1: Flyby of one Trojan as part of a transfer to Mars
- Option 2: Going from high Mars orbit (i.e. an orbit near Deimos) to one or more Trojans at the end of the mission.

2.Mars Trojans

The Martian Trojans are small, with diameters between hundreds of meters to a few kilometers. While the origins of these objects are uncertain, they were likely deposited at their present locations during the early Solar system [5] and some of them may represent rubble originating from large impacts on Mars [4]. Eight of currently nine known Trojans are located near the Lagrangian point L5 (trailing by approx. 60° behind Mars). Seven of these, including the asteroid Eureka, have recently been identified as members of a family (the "Eureka family") of olivine-rich asteroids [2], which probably formed in a break-up or fission event [3]. A mission to the Trojans would shed further light on the properties of the population, their relation to Mars and other asteroids and is therefore of high scientific interest.

Eureka family members have significant inclinations, >10° relative to the ecliptic and, specifically, to the orbital plane of Mars. For a mission to the Trojans launched from the Earth or Mars, this implies either high flyby velocities for a spacecraft approaching or high delta-v demands for a rendezvous mission.

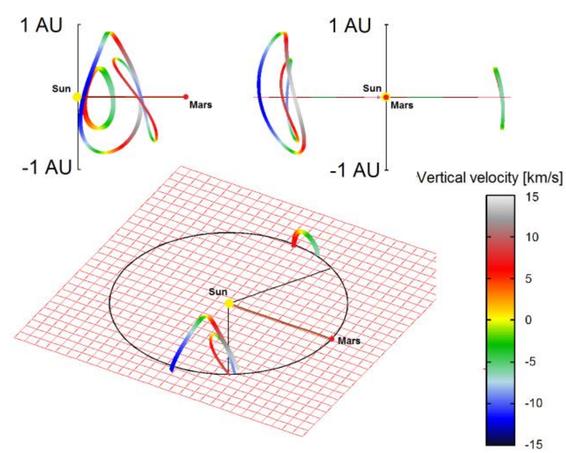

Figure 1: Orbits and color-coded vertical velocities of 3 Martian Trojans (5261 Eureka and 101429 near L5 and 121514 near L4) in a Sun-Mars co-rotating reference frame; top-left: xz-plane, top-right: yz-plane, bottom: 3D view

3.Transfer Scenarios

In our study we consider flyby missions only following two different scenarios. One is a flyby during the transfer from Earth to Mars. We studied scenarios in the time frame 2028 – 2032 including transfers that involve more than one revolution about the sun. As the Mars trajectory is relatively fixed in space and time, the Trojan candidate has to be “at the right place at the right time” to minimize costly spacecraft course adjustments. We report on several flyby opportunities, which require only moderate course corrections.

As a second option, we studied a transfer starting from Mars, moving along Mars’ solar orbital path initially in high equatorial Mars orbit (e.g. near Deimos). Here, the spacecraft may stay at Mars to await a favorable nodal crossing for a selected Trojan and leave the Martian gravity field just in time for a flyby. We study flyby opportunities and produce associated time tables. Such a transfer requires a velocity increment of approximately 1-1.2 km/s while transfer times are approximately 600 days.

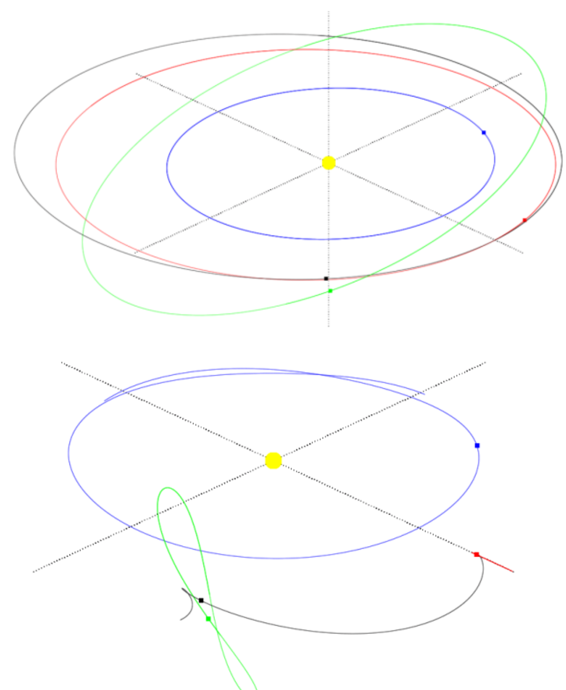

Figure 1: Example of a transfer orbit from High Mars Orbit to 5261 Eureka; shortly before arrival at Eureka (blue: Earth, red: Mars, green: 5261 Eureka, black: spacecraft; top: inertial reference frame, bottom: Sun-Mars: co-rotating reference frame)

4.Summary and Conclusions

We evaluate the possibility to combine a mission to Mars with a flyby of Martian Trojans in the Eureka family. We show that both options (flyby during transfer to Mars and launching from a High Mars Orbit to a Trojan) are technically feasible.

We show that a flyby during the transfer to Mars is possible. This option has a very narrow time window and requires a transfer orbit with ~1.5 revolutions about the sun leading to transfer durations of approximately 2.5 years. The transfer to a Trojan from an orbit close to Deimos allows departing within a wider margin in mission schedule, but requires more propellant mass, along mission duration and increased total operation costs.

Consequently, both options would increase mission resources, complexity and overall cost. Nevertheless, while a standalone mission to a Mars Trojan is currently probably far from practical, a combined mission to Mars and one of its Trojans may have a valuable scientific case, conceivable in the future.

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THE CASTALIA MISSION TO A MAIN BELT COMET

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Abstract

Castalia is a proposed ESA M-class mission to rendezvous with a Main Belt Comet (MBC), in order to investigate this new population and test whether or not the asteroid belt could be the source of Earth's water. We describe the scientific motivation for the mission, the spacecraft and payload needed to achieve our goals, and the various options and trades that should be considered in a phase A study.

1. Introduction – the MBCs

MBCs constitute a recently identified class of solar system objects [1]. They have stable, asteroid-like orbits and some exhibit a recurrent comet-like appearance (Fig. 1). It is believed that they survived the age of the solar system in a dormant state and that their current ice sublimation driven activity only began recently. Buried water ice could survive under an insulating surface: Excavation by an impact can expose the ice and trigger the start of MBC activity.

2. The Castalia mission

We present the case for a mission to a MBC, which was submitted to the European Space Agency's M5 call for a medium-class mission. The specific science goals of the Castalia mission are:

1. Characterize a new Solar System family, the MBCs, by in-situ investigation

2. Understand the physics of activity on MBCs

3. Directly sample water in the asteroid belt

4. Test if MBCs are a viable source for Earth's water

5. Use the observed structure of an MBC as a tracer of planetary system formation and evolution.

These can be achieved by a spacecraft designed to rendezvous with and orbit an MBC for a time interval of some months, arriving before the active period for mapping and then sampling the gas and dust released during the active phase.

3. Spacecraft and Instruments

Given the low level of activity of MBCs, and the expectation that their activity comes from only a localized patch on the surface, the orbiting spacecraft will have to be able to maintain a very close orbit over extended periods - the Castalia plan envisages an orbiter capable of 'hovering' autonomously at distances of only a few km from the surface of the MBC. The strawman payload comprises four packages, each containing two instruments:

- MBC surface reconnaissance package: vis/NIR cameras, thermal cameras
- MBC body interior package: radars and radio science
- MBC material and composition package: mass spectrometers for gas and dust, dust counter
- MBC plasma environment package: plasma instruments & magnetometer

The instruments are based on heritage from Rosetta, including the ROSINA, COSIMA and GIADA instruments (the latter two combined into a single dust instrument for Castalia). Various optional elements, including a simple surface science package, are being considered. At the moment, MBC 133P/Elst-Pizarro is the best-known target for such a mission. A design study for the Castalia mission has been carried out in partnership with OHB System AG. This study looked at possible missions to 133P, and found that this, and backup MBC targets, are reachable by an ESA M-class mission (figs. 2 & 3). More details are available at http://bit.ly/mbcmission

Acknowledgements

We thank OHB System AG (Bremen, Germany) for support in the mission and spacecraft design.

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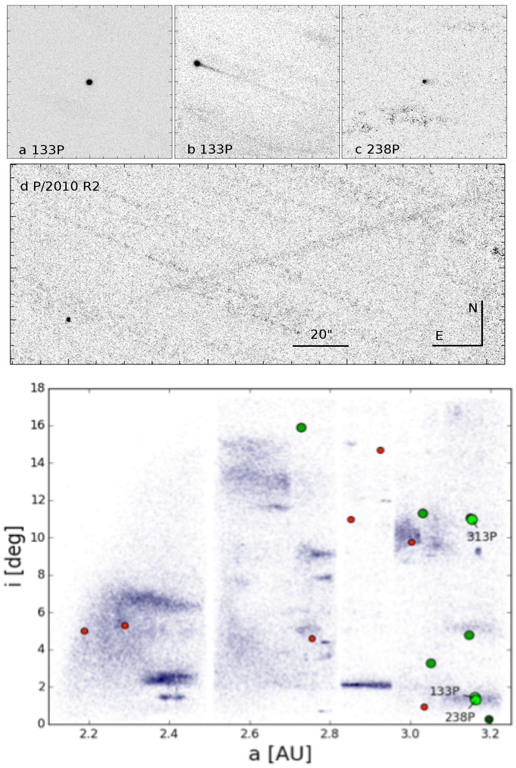

Figure 1. *Top:* Images of MBCs with active and inactive appearance, showing their comet-like morphology. *Bottom:* Orbital distribution of MBCs (green), including those with repeated activity at more than one orbit (bright green), and other active asteroids (red), within the main asteroid belt (points).

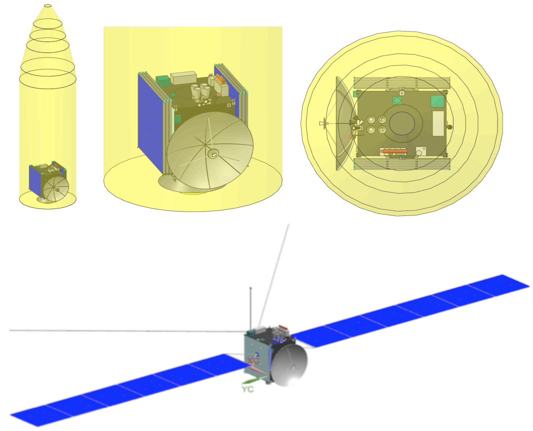

Figure 2. The proposed Castalia spacecraft, in its stowed configuration within the Ariane 6.2 fairing (top row) and in deployed configuration.

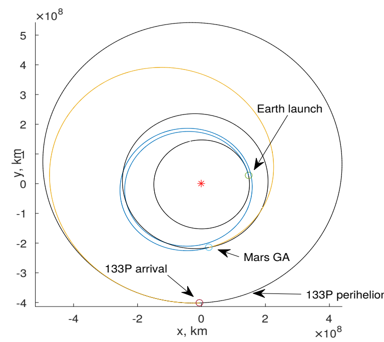

Figure 3. Trajectory to reach 133P for ESA M5 launch window, departing Earth in late 2028 to arrive before the 2035 perihelion.

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VICI: Venus In situ Composition Investigations

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Abstract

The overarching goal of the proposed New Frontiers Venus In situ Composition Investigations (VICI) mission is to answer long-standing questions about the origins and evolution of our sister planet and provide new insights needed to understand terrestrial planet formation, evolution, and habitability [1-3]. To address this goal, VICI sends two identical landers to unexplored tessera regions that may hold the key to understanding Venus' geologic history prior to volcanic resurfacing. The two landers gather comprehensive atmospheric composition and structure information during two descents, while also quantifying the similarities and differences in surface chemistry, mineralogy, and morphology at multiple independent, representative tessera landing sites.

1. Introduction

Venus remains one of the least understood planets in our solar system, and many significant questions regarding its atmosphere, surface, and interior remain unanswered. Lack of understanding of this major silicate planet not only limits our understanding of evolutionary pathways Earth could experience, but also suggests we are ill-equipped to understand the evolution of other star systems with similar-sized planets.

1.1 Mission Concept

VICI is a proposed NASA New Frontiers mission addressing the Venus In Situ Explorer (VISE) objectives [3] that would launch in December 2024. The spacecraft delivers the landers on two separate Venus fly-bys. The landers are delivered to representative tessera sites in January 2027 and April 2028, respectively. VICI would be the first mission to land on the Venus surface since 1985, and the first U.S. mission to enter the Venus atmosphere in 49 years. VICI is designed to study the chemical and isotopic composition of Venus' atmosphere at a level of detail that has not been possible on earlier missions. In addition, VICI images the tessera surface during descent enabling detailed topography to be generated using the latest Shape from Motion (SfM) techniques [4]. Finally, VICI makes multiple elemental chemistry measurements, including depth profiles through the weathering rind and subsurface, and the first ever direct mineralogy measurements on the Venus surface. The four major VICI science objectives are:

- <u>Atmospheric origin and evolution:</u> Understand the origin of the Venus atmosphere, how it has evolved, including how recently Venus lost its oceans, and how and why it is different from the atmospheres of Earth and Mars, through *in situ* measurements of key noble gases, nitrogen, and hydrogen.
- <u>Atmospheric composition and structure:</u> Reveal unknown chemical processes and structure in Venus' deepest atmosphere through two comprehensive, *in situ* vertical profiles.
- <u>Surface properties and geologic evolution:</u> For the first time ever, explore the tessera from the surface, specifically to test hypotheses of ancient content-building cycles and erosion using multi-

point mineralogy, elemental chemistry, imaging and topography.

- Surface-atmosphere interactions: Characterize Venus' surface weathering environment and provide insight into the sulphur cycle at the surface-atmosphere interface by integrating rich atmospheric composition and structure datasets with imaging, surface mineralogy, and elemental rock composition.

1.2 Payload

VICI's payloads build on the success of the Mars Science Laboratory (MSL) by carrying the same instrumentation that has delivered high-impact science results on Mars [5-11]. For example VICI employs the same neutral mass spectrometer (built by NASA's Goddard Space Flight Center, GSFC) and tunable laser spectrometer (built by the Jet Propulsion Laboratory, JPL) that are the heart of MSL's Sample Analysis at Mars (SAM). Borrowing from MSL's ChemCam and the Mars 2020 SuperCam that is in development, VICI uses the same Raman and Laser-Induced Breakdown Spectroscopy (LIBS) built by Los Alamos National Laboratory (LANL) (with contributions from Institut de Recherche en Astrophysique et Planétologie, IRAP) to provide surface mineralogy and elemental composition, avoiding complex sample ingest and enabling multiple measurements at each landing site. A gamma-ray spectrometer (built by Johns Hopkins University Applied Physics Laboratory) complements the LIBS with bulk measurements of naturally radioactive elements to a depth of ~10 cm. A descent imager also plays an important role.

1.3 Payload

VICI leverages NASA GSFC internal investments in Venus pressure vessel designs as well as substantial analysis and drop testing [12] to demonstrate the resiliency of the Lander design to safely land on rugged tessera terrain. VICI also leverages NASA investment in the Heatshield for Extreme Entry Environment Technology (HEEET).

2. Summary and Conclusions

By definitively measuring atmospheric and surface composition at two sites, VICI goes beyond the Venus exploration goals of NASA's Planetary Decadal Survey, revealing how and why Earth's sister is not her twin.

Acknowledgements

The authors would like to thank all mission partners for investment in the VICI mission concept and for major contributions in the preparation of the Step 1 New Frontiers proposal.

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Dragonfly: In Situ Exploration of Titan's Prebiotic Organic Chemistry and Habitability

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Abstract

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 to document the habitability of an extraterrestrial environment [*e.g.*, 1-6]. Moreover, Titan's dense atmosphere and low gravity provide the means to access different geologic settings over 10s – 100s of kilometers apart, via exploration by an aerial vehicle. *Dragonfly* is a rotorcraft lander mission proposed to New Frontiers to use Titan's unique natural laboratory to understand how far chemistry can progress in environments that provide key ingredients for life.

1. Introduction

Exploration of Titan is a high science priority due to the level of organic synthesis that it supports. Moreover, the opportunities for organics to interact with liquid water at the surface and via exchange with the interior ocean further possible progression of chemical processes, providing an unparalleled opportunity to investigate prebiotic chemistry, as well as to search for signatures of potential water-based or even hydrocarbon-based life. Beyond this rich chemistry, Titan's Earth-like geology, with a methane cycle instead of a water cycle, allows study of familiar processes under different conditions. The diversity of Titan's surface materials and environments drives the scientific need to be able to sample a variety of locations, thus mobility is key for *in situ* measurements.

2. Exploring Titan by Air

It has long been recognized that Titan's rich organic environment provides a unique opportunity to explore prebiotic chemistry (for example, the Campaign Strategy Working Group (CSWG) on Prebiotic Chemistry in the Outer Solar System [5, 6]), and development of Titan mobile aerial exploration was identified as a desirable next step after *Cassini-Huygens*. Several airborne strategies have been considered for Titan, including exploration by helicopter [6], helium or hydrogen airship [7, 8], Montgolfière hot-air balloon [9-12], and airplane [7, 13], but access to surface materials for analysis presents a challenge. While multiple *in situ* landers could also address Titan's surface chemical diversity, multiple copies of instrumentation and sample acquisition equipment would be necessary to achieve the same breadth of science as a mobile vehicle.

A more efficient approach is to convey a single instrument suite to multiple locations using a lander with aerial mobility. Heavier-than-air mobility at Titan is highly efficient [6, 14]. At the surface, Titan's atmosphere is 4 times denser than Earth's, reducing the wing/rotor area required to generate a given amount of lift, making all forms of aviation easier (lighter- and heavier-than-air). The low gravity ($1.35\ m/s^2$) reduces the required magnitude of lift – a strong factor in favor of a heavier-than-air vehicle.

Recent developments in autonomous aircraft make such an exploration strategy a realistic prospect. Modern control electronics make a multi-rotor vehicle [15] mechanically simpler than a helicopter (*cf.* proliferation of terrestrial quadcopter drones). Multi-rotor vehicles offer improved flight control authority and surface sampling capability, redundancy, and failure tolerance; moreover, the system is straightforward to test on Earth and to package in an entry vehicle.

Although for a given vehicle mass and rotor diameter, the shaft power required to hover on Titan is 38 times less than on Earth [6, 15], this is still too high for continuous flight if powered by an MMRTG. However, flight ranges of a few 10s of km are possible using power from a battery, which can be recharged via an MMRTG in less than one Titan day, between flights, science activities, and direct-to-Earth communication. Adopting rotors as a substitute for the retrorockets used to effect soft touchdown on Mars landers means the ability to take off and land elsewhere follows with little incremental cost but with tremendous science enhancement. Furthermore, a relocatable lander is robust to power source underperformance or to science energy demands – the system merely takes longer to recharge between flights. *In situ* operations strategies similar to those proven by Mars rovers [16,17] can proceed at a more relaxed pace with 16-day Titan-sols.

Dragonfly is a rotorcraft-enabled lander designed to take advantage of Titan's environment to be able to sample materials in different geologic settings. Dune sands likely represent a 'grab bag' site of materials sourced from all over Titan [10], much as the rocks at the *Mars Pathfinder* landing site collected samples from a wide area [18]. Environments that offer the most likely prospects for chemical evolution similar to that on Earth occur on Titan's land. Areas of particular interest are impact-melt sheets [19] and potential cryovolcanic flows where transient liquid water may have interacted with the abundant photochemical products that litter the surface [2].

3. Titan *In Situ* Science

The compositions of the solid materials on Titan's surface are still essentially unknown. Measuring the compositions of materials in different environments will reveal how far prebiotic chemistry has progressed. Surface material can be sampled with a drill and ingested using a pneumatic transfer system [20] into a mass spectrometer [21] to identify the chemical components available and processes at work to produce biologically relevant compounds. Bulk elemental surface composition of each site can be determined by a neutron-activated gamma-ray spectrometer [22]. Meteorology measurements [23-25] can characterize Titan's atmosphere and diurnal and spatial variations therein. Geologic features can be characterized via remote-sensing observations, which also provide context for samples. Seismic sensing can probe subsurface structure and activity.

In addition to surface investigations, *Dragonfly* can perform measurements during flight, including atmospheric profiles and aerial observations of surface geology, which also provide sampling context and scouting for landing sites.

Dragonfly is a truly revolutionary concept, providing the capability to explore diverse locations to characterize the habitability of Titan's environment, investigate how far prebiotic chemistry has progressed, and search for chemical signatures indicative of water- and/or hydrocarbon-based life.

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The New Frontiers Saturn PRobe Interior and aTmosphere Explorer (SPRITE) Mission Proposal

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Abstract

The 2013-2022 Planetary Decadal Survey Vision and Voyages [1] identified Saturn as a target of high priority for a New Frontiers probe mission concept. To better constrain models of Solar System formation, giant planet formation and evolution, and to provide an improved context for understanding exoplanetary systems, fundamental measurements of Saturn including noble gas abundances, isotope ratios of hydrogen, carbon, oxygen, and nitrogen, and measurements of the interior structure including thermal structure, dynamics, and clouds are needed. Of particular importance is helium, needed to understand the formation history and thermal evolution of Saturn, and water since it is thought that the heavy elements were delivered to Saturn by water-bearing planetesimals.

The Saturn PRobe Interior and aTmosphere Explorer (SPRITE) Mission concept would consist of a Carrier Relay Spacecraft (CRSC) and an entry probe that descends to at least ten bars. The primary payload of the SPRITE probe is proposed to comprise two spectrometers – a Quadrupole Mass Spectrometer and a Tunable Laser Spectrometer, and an Atmosphere Structure Instrument including a simple nephelometer and a Doppler Wind Experiment for measuring and characterizing the thermal, cloud, and dynamical structure of Saturn's troposphere. The Atmospheric Structure Instrument also includes accelerometers to measure entry accelerations from which the probe entry and descent trajectory can be reconstructed and the thermal structure of the upper atmosphere characterized. The solar powered CRSC carries a Multi-Channel Imager for pre-entry imaging of the probe entry location, and to provide global context imaging for the probe measurements.

SPRITE is proposed to launch in late November 2024 launch and follows an Earth-Venus-Earth-Earth gravity assist trajectory to reach Saturn in November, 2034. The SPRITE probe enters Saturn's atmosphere at a relative velocity of ~27 km/s, experiencing a peak heat flux near 3000 W/cm^2 and a peak deceleration up to 45 g's. The aeroshell is released above the tropopause and the descent science sequence is initiated, permitting up to 2 hours for the probe to pass through 10 bars. To ensure low risk data return, the descent probe is a fully-redundant dual-channel design powered by primary batteries. Once the probe science data is collected by the flyby Carrier Relay Spacecraft, the probe data and Carrier imaging data downlinked to Earth multiple times through the Deep Space Network.

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Predecisional information for planning and discussion only

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The Radio & Plasma Wave Investigation (RPWI) for JUICE – From Jupiter's Magnetosphere, through the Ice Shell, and into the Ocean of Ganymede

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Abstract

The Radio & Plasma Wave Investigation (RPWI) for the ESA JUICE mission provides an elaborate suite of electromagnetic fields and plasma instruments. Several different types of sensors will sample the plasma and the electric field, signals from radio and plasma waves, and act as a dust detector by counting transient emissions caused by micrometeorites hitting the spacecraft. RPWI focuses on cold plasma studies and will investigate how the transfer of momentum and energy occur in the different space environments, including the electrodynamic coupling with the icy Galilean moons. In Jupiter's magnetosphere, remote sensing and direction finding of the Jovian decametric radio emissions will be carried out. RPWI is also devoted to the ices and the deep interiors of the icy moons. Investigations of the ice shells will be performed by means of a novel passive ground penetrating radar technique, which utilizes Jupiter's strong decametric radio emissions as the transmitted signal. In Ganymede orbit, continuous measurements of the electric field, simultaneous with the JUICE Magnetometer (JMAG) measurements, will determine the electric coupling between any ocean, the ionosphere, and the magnetosphere, to provide constraints on the physical characteristics of the ocean of Ganymede, if it exists.

1. Introduction

The RPWI suite of instruments was selected by ESA as one of ten science payloads onboard the JUICE mission. The selection was based on our primary science goals [1] , which are focused on magnetospheric and ionospheric physics, as well as the heritage and experience of the RPWI Consortium members from previous ESA and NASA missions. The primary science goals include investigations of plasma electrodynamics in the Jovian system, identification of Alfvén and whistler waves by means of a searchcoil magnetometer, as well as studies of filamentary currents, flux ropes, and electrostatic structures involved in energy and momentum transfer between different particle populations in interaction between the Jovian magnetosphere and the ionospheres of the moons. Using Langmuir probe and mutual impedance measurements to measure the cold plasma characteristics, the proposed methods are also capable of inferring the ion drift speed. A radio antenna will be used to measure high frequency radio emissions in the Jupiter system. Their polarization and source locations in the auroral regions of Jupiter and Ganymede, as well as their variability with time and response to external forcing, will be determined. The Langmuir probes and the radio antenna will furthermore monitor electrically charged dust to identify dust-plasma interactions. Studies on open versus closed magnetic field lines at Ganymede, and observations of the electric field, which accelerate the particles, will give insight into surface sputtering processes. RPWI will as well have the capability to directly measure, *in situ*, the partially ionized gas exhaust of water-rich plumes above any active surface regions on the icy moons. The RPWI science performance is given in Table 1.

1.1. The Deep Interior: Ice and Oceans

After the selection, the RPWI Consortium has come to realize that we can do more than investigating magnetospheric and ionospheric processes, and address the JUICE mission's science goals related to the deep interiors. The RPWI suite of instruments is capable of targeting the ice shells and the oceans of the moons without modifications of the hardware. By operating the radio antenna as a passive ground penetrating radar, using the extremely powerful Jovian radio emissions as transmitter, it will be possible to characterize the electric properties of the ice shell of Ganymede, see Fig. 1, and, possibly penetrate the ice and measure its

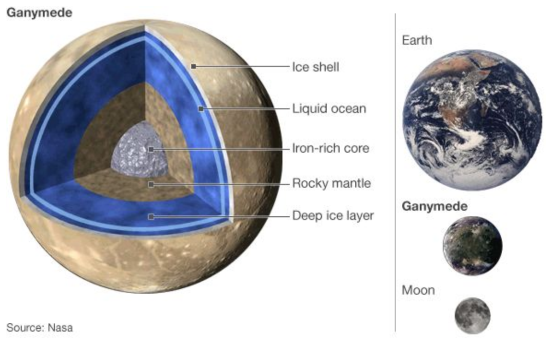

Figure 1: Deep interior of Ganymede (left) and size comparisons with Earth and Moon (right). ©NASA

thickness. RPWI will take snapshots of selected locations and data will be analyzed on ground. If successful, RPWI will ask for more observation time. Detecting the ocean of Ganymede is a primary science goal of JMAG but a detection could also be made by electric field measurements. RPWI will be in operation continuously in Ganymede orbit and work in parallel with JMAG. The salinity of the ocean and possibly the presence of ocean currents should be possible to estimate, or at least constrain. In addition, a double detection of the ocean by JMAG and RPWI, would make the discovery indisputable.

2. Inter-instrument Collaboration

The three JUICE *in situ* instruments, RPWI, JMAG, and PEP (Particle Environment Package) have been in collaboration from day one. We share similar science goals and will share our data in the future. A thorough investigation of the space plasma environment in the Jovian system is impossible without this collaboration. Our three payloads will also share data onboard. RPWI will receive magnetic field data from JMAG to align our electric field measurements with the magnetic field. PEP will receive the spacecraft potential from RPWI, needed for the charged particle instruments' calibration. RPWI will also receive ion data from PEP, to perform wave-particle interaction analysis on board. The low telemetry rate (1.4 Gbits/day) prevents such correlations to be performed on ground.

3. Summary and Conclusions

RPWI's main objective is to study space physics processes in the Jovian system, with emphasis on Ganymede. By using innovative techniques, RPWI will investigate its ice shell and help detect its subsurface ocean. Thereby, RPWI will contribute to many science objectives not foreseen when the instrument was selected for flight on JUICE. Close collaboration with the other two *in situ* payloads (JMAG and PEP), on ground and in space, will further enhance the value of our combined data sets.

Table 1: RPWI Science Performance.

Quantity	**Range**	**Sensitivity**
Electric field vector, $\delta\mathbf{E}(f)$	DC–1.6MHz	<0.1mV/m, $2\mu\mathrm{V/m}/\sqrt{\mathrm{Hz}}$
Electric field vector, $\delta\mathbf{E}(f)$	80kHz–45MHz	$10\mathrm{nV/m}/\sqrt{\mathrm{Hz}}$ (@10MHz)
Magnetic field vector, $\delta\mathbf{B}(f)$	0.1Hz–20kHz	$20\mathrm{fT}/\sqrt{\mathrm{Hz}}$ (>@500Hz)
Electron density	10^{-4}–10^{5} cm^{-3}	<10%
Density fluct., δn	DC–10kHz	<10%
$\delta\mathbf{E}$ or δn interferometry	<1000 km/s	<10%
Ion density	1–10^{5} cm^{-3}	<20%
Electron temp.	0.01–100eV, <1Hz	<20%
Ion drift speed	0.1–200km/s	<20%
Ion temp.	0.02–20eV	<mVdi^2/2e
S/C potential	$\pm$100V,<1Hz	<10%
Integrated EUV flux	<1Hz	Res. 0.05 Gphotons/cm^2/s
Passive radar dynamic range	85dB	
Ice depth	<20km	<1km
Iceconductivity	2.5–10μS/m	

Acknowledgements

We wish to acknowledge the JMAG and PEP teams, the SWI PI, Dr Paul Hartogh, for his proposal to implement the passive radar, the JUICE Project Office, ESA PRODEX, and Airbus DS. Special thanks to Mr Sven Landström and Dr Ronan LeLetty.

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Heavy Metal – Exploring a magnetized metallic asteroid

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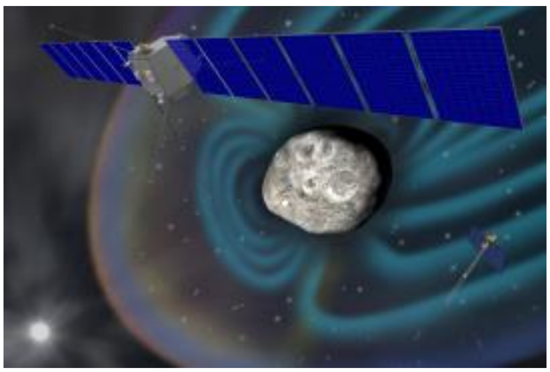
Abstract

This is an ESA/M5 proposal for a spacecraft mission to orbit and explore *(16) Psyche* – the largest M-class metallic asteroid in the main belt. Recent estimates of the shape, ~279×232×189 km and mass, ~2.7×10^{19} kg of *(16) Psyche* make it one of the largest and densest of asteroids, ~4.5 g cm^{-3}, and together with the high surface radar reflectivity and the spectral data measured from Earth it is consistent with a bulk composition rich in iron-nickel. *(16) Psyche* orbits the Sun with semi-major axis 2.9 AU, 3º inclination, and is as yet unexplored in-situ.



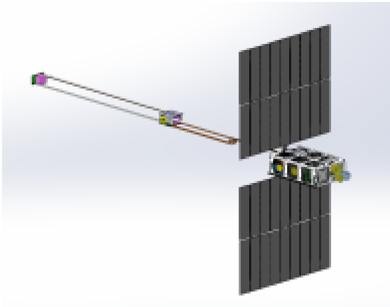
1. Science Objectives

The ESA/M5 mission *Heavy Metal* will investigate if *(16) Psyche* is the exposed metallic core of a planetesimal, formed early enough to melt and differentiate. High-resolution mapping of the surface in optical, IR, UV and radar wavebands, along with the determination of the shape and gravity field will be used to address *the formation and subsequent evolution of (16) Psyche, determining the origin of metallic asteroids*. It is conceivable that a cataclysmic collision with a second body led to the ejection of all or part of the differentiated core of the parent body. Measurements at *(16) Psyche* therefore provide a possibility *to directly examine an iron-rich planetary core, similar to that expected at the center of all the major planets including Earth*. Meanwhile, comparison with the terrestrial meteorite record will address *whether metallic asteroids are the parents of magnetized iron meteorites*. A short-lived dynamo producing a magnetic field early in the life of *(16) Psyche* could have led to a remnant field (of tens of micro Tesla) being preserved in the body today.

Like the large-scale magnetospheres of the Earth, Mercury, etc. and the induced magnetospheres of Venus and Mars, *(16) Psyche* is embedded in the variable flow of the solar wind. Whereas these planetary magnetospheres and induced magnetospheres are the result of intense dynamo fields and dense conductive ionospheres presenting obstacles to the solar wind, *(16) Psyche* may show an entirely new 'class' of interaction as a consequence of its lack of a significant atmosphere, the extremely high bulk electrical conductivity of the asteroid, and the possible presence of intense magnetic fields retained in iron-rich material. The small characteristic scale of *(16) Psyche* (~200 km) firmly places any solar wind interaction in the "sub-MHD" scale, in which kinetic plasma effects must be considered. *Heavy Metal* will *investigate if (16) Psyche has an extended magnetosphere* by mapping the local plasma density, composition, energy state and dynamics around the body, along with the magnetic field. By accurately mapping any internally retained magnetic field of *(16) Psyche*, we will address *the origin of any magnetization* (the possible remains of an early magnetic dynamo).

1.1 Need for a 6U CubeSat companion

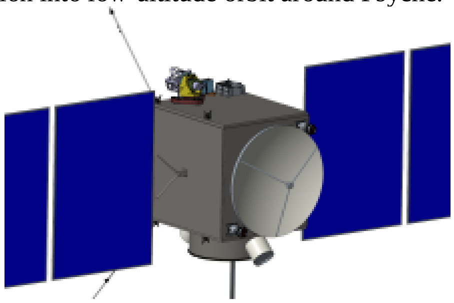
The possibility of remnant magnetization of the asteroid occurring only in localized regions, or otherwise being 'disordered' necessitates magnetic measurements close to the surface. A close approach (<100 km to the surface) with the main spacecraft is difficult due to the potentially complex gravity field and rapid rotation period of 4.2 hours of the irregular shaped asteroid. We propose instead to use a 6U CubeSat companion spacecraft to be inserted into a lower-altitude orbit for a short duration (1 month) before it makes a controlled crash toward the surface. This will facilitate near surface measurements of the magnetic field, the composition of any volatile products and produce truly high-resolution pictures of the surface, complementing the extensive measurements by the main spacecraft further away. Additionally, simultaneous measurement of the magnetic field at both the CubeSat and the main S/C will allow a detailed study of the induction of electrical currents in the asteroid surface by the solar wind.



2. The Spacecraft Mission

The *Heavy Metal* spacecraft will be launched from Earth with an Ariane 6.2 rocket in the time window 2029 – 2031, and by using electric propulsion, along with a possible gravity assist manoeuvre by Mars, arrive at *(16) Psyche* some 4 – 4.5 years later. The S/C is then planned to orbit the body for a period of 1 year, doing science operations, where after it may be sent to the surface for a controlled crash. During the nominal science operations, the main platform will orbit as close as 300-500 km from the centre of *(16) Psyche*.

Spacecraft: 3-axis stabilised, 45 m^2 solar array, launch mass 1430 kg. Carry a 6U CubeSat for insertion into low-altitude orbit around Psyche.



3. Science Instruments

Main S/C Instrument	PI / Institute
Optical Imager (NAC)	N. Thomas U. Bern, CH
Wide Angle Camera (WAC)	J. Trigo-Rodriguez CSIC-IEEC, Barcelona, ES
Infrared Imager / Spectrometer (IR)	M. C. De Sanctis INAF-IAPS, Roma, IT
UV Spectrograph (UVS)	K. Retherford SwRI, San Antonio, US
(Sub-)Surface radar	A. Herique IPAG, Genoble, FR
Magnetometer (MAG)	A. Masters Imperial College, London, UK
Plasma Spectrometer Package	Y. Futaana IRF, Kiruna, SE
Electric field & Cold Plasma	D. J. Andrews IRF, Uppsala, SE
Radio Science Experiment	P. Tortora U. Bologna, IT
CubeSat Instrument	**PI / Institute**
Narrow Angle Camera (NAC)	J. Trigo-Rodriguez CSIC-IEEC, Barcelona, ES
Volatile Composition Analyser (VCA)	Y. Futaana IRF, Kiruna, SE
Magnetometer (MAG)	N. Ivchenko KTH, Stockholm, SE

4. Summary and Conclusions

Heavy Metal is a mission of exploration to one of the major unexplored solar system bodies, and a potential window into conditions and processes in the early solar system, the formation of the terrestrial planets and their metal rich cores. Simultaneously, it will lead to new insights in space plasma physics and the interaction of magnetised bodies with the solar wind. The mission clearly falls within the scope of the ESA Cosmic Visions programme by addressing the major questions, *"What are the conditions for planet formation and the emergence of life?"* and *"How does the Solar System Work?"*.

Acknowledgements

The *Heavy Metal* team acknowledges the support from the Swedish National Space Board (SNSB) for financing the industrial study support from OHB-Sweden in preparation of this proposal. The contact persons of the *Heavy Metal* spacecraft and mission study at OHB-Sweden are Peter Rathsman and Stefan Lundin. Support has also been given from ÅAC Microtec in Uppsala regarding the CubeSat mission and design. The contact person there is Emil Vinterhav.

Website for the *Heavy Metal* project: http://www.irfu.se/Heavy_Metal

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The ExoMars Rover Science Archive: Status and Plans

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Abstract

The ExoMars program is a co-operation between ESA and Roscosmos comprising two missions: the first, launched on 14 March 2016, included the Trace Gas Orbiter and Schiaparelli lander; the second, due for launch in 2020, will be a Rover and Surface Platform (RSP).

The ExoMars Rover and Surface Platform deliveries will be among the first data in the PSA to be formatted according to the new PDS4 Standards, and will be the first rover data to be hosted within the archive at all.

The archiving and management of the science data to be returned from ExoMars will require a significant development effort for the new Planetary Science Archive (PSA). This presentation will outline the current plans for archiving of the ExoMars Rover and Surface Platform science data.

1. The ExoMars Rover Archive Challenge

PDS4 data are already available within the PSA, so this in itself does not present the biggest challenge for the archive. However, when this is combined with the fact that it will be delivered from a moving platform on another planet, a whole host of new challenges arise.

For example, there are significant differences in the way in which a scientist will want to query, retrieve, and use data from a suite of rover instruments as opposed to remote sensing instrumentation from an orbiter. This is well demonstrated by NASA's *Analysts Notebook*, which has developed a strong user community interaction for the exploitation of science data from their rovers. It is likely that similar approach will be needed for the future PSA, and discussions are underway with our NASA counterparts to understand how we may be able to work towards this.

Such an interface is a long way detached form the type of experience currently offered to users of the PSA data, and will require not only major updates to the front-end of the archive, but also new ways to manage and access meta-data that is specific to a rover operations. A significant amount of operational information is required by an end user to understand what the rover was doing at the time of an observation, and how it was working in connection with other instrumentation. This type of information will need to be carefully formatted and stored in an easily accessible form for the end-user.

Data and information will need to flow between the Rover and the Surface Platform as well, so ESA and Roscosmos are coordinating very closely to ensure that information is shared and interfaces are established at a very early stage to permit this.

2. Data Production and the Archiving Process

In addition to the archiving interface itself, there are differences with the overall archiving process being followed for ExoMars compared to previous ESA planetary missions.

For the Rover mission, the data pipelines are being developed by European industry, in close collaboration with ESA PSA experts and with the instrument teams. The first level of data processing will be carried out for all Rover instruments at ALTEC in Turin where the pipelines are developed, and from where the Rover operations will also be run. The pipelines themselves are being constructed based on software that has been developed by ESA personnel for use on the ExoMars 2016 mission.

This setup introduces additional challenges in terms of ensuring that the science products that are output from the ALTEC pipelines are compliant with the internal needs of the external ESA archive, as well as those of the end users and instrument teams.

To mitigate this, ESA are coordinating very closely with our colleagues in ALTEC to follow the pipeline development and assess the outputs wherever possible. Additionally, a ‘Data Handling and Archiving Working Group’ (DHAWG) has been established. Lead by ESA, this working group includes data producers from ALTEC, and members from every instrument team as well as our colleagues from Roscosmos and the Surface Platform. This forum will be used throughout the development of the mission to coordinate the data archiving activities, and will continue through the complete mission lifetime to track the archiving progress and ensure that the process from data reception through to ingestion and release in the archive is as smooth as possible.

3. Summary

This presentation will focus on the challenges involved in archiving the data from the ExoMars Rover and Surface Platform, and will outline the plans and current status of the system being developed to respond to the needs of the missions.

Acknowledgements

The authors would like to acjnowledge the efforts of ALTEC, Roscosmos and the ES Project in thir support of the ExoMars Rover archiving development.

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The Jovian Electron and Ion Spectrometer (JEI) for the JUICE mission

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Abstract

The magnetosphere of Jupiter is apart from the Sun the strongest source of charged particles in the Solar system. The interaction of these particles with the exospheres of the Jovian moons forms one of the most complex plasma laboratories encountered by human space flight. For this reason the plasma analyzer package forms a crucial experiment of the Jupiter Icy Moon Explorer (JUICE) [1,]. As part of the Plasma Environment Package (PEP, [2]) we here describe a combined electron and ion spectrometer which is able to measure the electron and ion distribution functions in the energy range 1 to 50000 eV with high sensitivity and time resolution. This instrument is called the Jovian Electron and Ion Analyzer, JEI.

Sensor Design

The main design drivers for the Jovian Electron and Ion Analyzer, JEI, are: (1) Usage of robust and proven components to allow stable measurements after 8 years of interplanetary cruise and 2 years in the harsh Jovian environment. (2) Usage of front end electronics with very high radiation hardness (better than 200krad) - more sensitive electronics are located in the PEP common rack. (3) Usage of a sensor technique with very high signal to noise ratio to allow simple front end electronics. (4) Minimize the sensitive area to allow measurements during times of high radiation background (5) Achieving a spatial resolution of at least 22.5 deg in azimuth and polar angle to allow measurement of electron and ion loss cones and spatial extend of ion beams. (6) Achieving an energy resolution of better than 10% to allow detection of local acceleration processes and mass discrimination in cold ion beams. (7) Minimize sensor entrance opening and move all radiation sensitive parts to the bottom of the sensor. (8) To achieve a total geometric factor of better than 10^{-4} cm^{2}sr(eV/eV) to have a high signal to noise ratio .

Sensor Technique

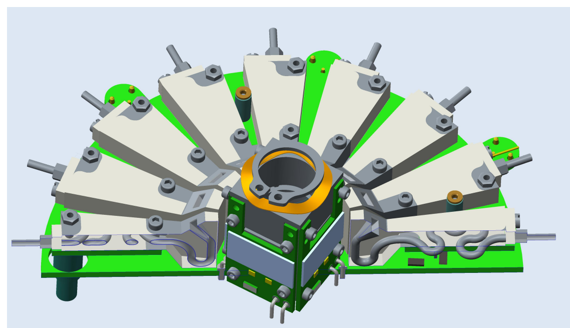

Figure 1: Cut through the JEI detector plane consisting of 16 CEMs .

The considerations listed above did lead to the conclusion that the electron and ion detection should be via Channel Electron Multipliers (CEMs) and not via Micro Channel Plates (MCP). General performance of CEMs and MCPs on previous space mission is discussed in [3]. Both CEMs and MCPs have been shown to survive 11 years of operation in the Earth radiation belts on the Polar Hydra experiment. But we think that CEMs have following advantages for use on the JUICE mission: (1) CEMs have a much higher signal to noise ratio than MCPs. This means that the lower signal produced by penetrating radiation can be easier suppressed by an amplifier threshold for CEMs as it was done for the Galileo PLS sensor [4,]. (2) CEM entrance area can be made significantly smaller than for MCPs reducing the sensitive area for background radiation. (3) CEM electronics are simpler than MCP electronics and have thus lower radiation protection requirements. (4) CEMs use one amplifier per pixel which means that count rates of 1MHz per pixel can be measured without saturation. Usual MCP setups use fewer amplifiers such that maximum count rate per pixel is much lower. (5) CEM design can be adapted in close cooperation with the manufacturer.

In the study phase for the JUICE mission we developed with Sjuts Optics, Göttingen, a specific sensor design which allows to arrange 16 CEMs in a circular array (2) with 22.5 degree azimuthal resolution and a total opening area of only 16x0.08cm^2=1.28cm^2. The area of the CEM which is sensitive to penetrating radiation is defined by the CEM entrance cone. It is about 10 times larger than the entrance cross-section. For this reason we will position an anti-coincidence solid state detector (SSD) above the CEM plane.

Sensor Ion Optics Design

The ion optics design of the JEI sensor is driven by points 4 to 8 listed above. To keep the geometry simple and allow measurement of both ions and electrons we decided to choose a pure electrostatic analyzer with a spherical energy analyzer (ELSA) and electrostatic entrance deflectors. The diameter of the analyzer is limited by the diameter of the circular CEM array and by the available sensor mass of about 800g without radiation shielding components. Energy resolu-

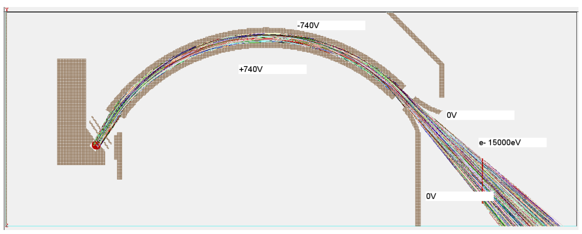

Figure 2: JEI SIMION simulation of ion optics for specific voltage/energy setting.

tion and range are determined by the analyzer constant k=R/ΔR where ΔR is the gap distance between the analyzer spheres and R is the midpoint radius of the analyzer gap. To avoid discharges in non-pure vacuum voltage difference between charged parts of the sensor should be smaller than 2.0kV/mm. For this reason we have chosen a gap distance of ΔR=2mm. This results in an analyzer constant of k=19.75 with an energy resolution of ΔE/E=8.3% and a maximum analyzer voltage of 4.0kV to measure particles up to energies of 40keV/q. In clean vacuum conditions the voltage can be increased to 6kV, allowing a maximum energy of 60keV/q.

Mechanical Design

The mechanical design of the JEI sensor is driven by the mass and volume constraints and by the fact that

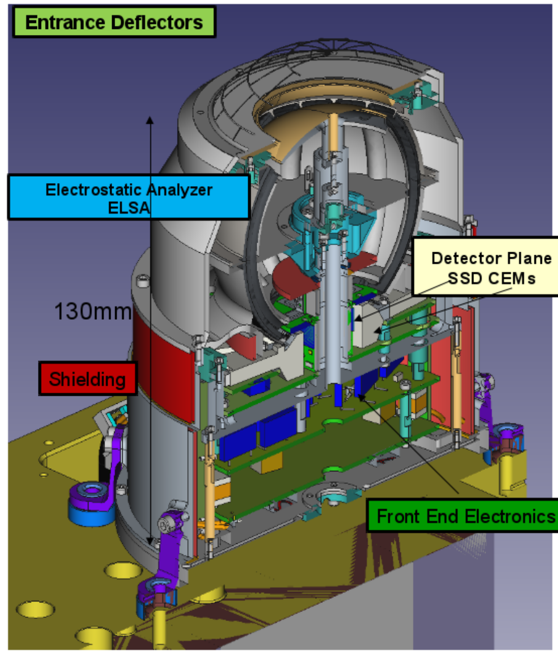

Figure 3: JEI sensor mechanical construction.

part of the electronics must be located close to the detectors to avoid noise from long signal cables. Thus the design follows the cylindical symmetry given by the ion optics. Electronic boards are also circular and added at the bottom of the sensor. All other electronic boards (high voltage supply, channeltron preamplifier, control board) are located in a common rack of the PEP instrument located below the spacecraft panel (not shown here). Radiation shielding elements made from tungsten-copper alloy (red parts in Fig.3) are optimized to reduce the count rates by secondary emission in the detector area.

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PRIDE: Ground-based VLBI observations for the JUICE mission

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Abstract

Precise determination of the lateral position of spacecraft on the celestial sphere is the main deliverable of the Planetary Radio Interferometry and Doppler Experiment (PRIDE). Using the radio astronomical technique of phase referencing (near-field) VLBI, PRIDE provides ultra-precise estimates of the spacecraft state vectors. As a selected experiment of the ESA's flagship mission Jupiter Icy Moons Explorer (JUICE), PRIDE will provide JUICE's lateral position in the International Celestial Reference Frame. These measurements, in synergy with the onboard radio science and optical astrometry instruments, will help to improve the current values of the ephemerides of the Galilean moons.

PRIDE and JUICE

PRIDE near-field VLBI observations of spacecraft can be used for a variety of scientific applications, including improvement of ephemerides, ultra-precise celestial mechanics of planetary systems, gravimetry, spacecraft orbit determination, and fundamental physics. These scientific applications are based on two observable quantities: the radial range rate (Doppler shift of the service communication system carrier signal) and the lateral (transverse) celestial position of the spacecraft with respect to the International Celestial Reference Frame (ICRF). The measurements of the spacecraft differential lateral position relative to ICRF are performed by VLBI observations of spacecraft and background extragalactic radio sources with accuracy of tens of μas (1-σ RMS) over integration time of $60 - 1000\,\mathrm{s}$[3]. The geometry of a typical PRIDE measurement is shown in Figure 1. This technique is complementary to radio science experiments and addresses those areas of spacecraft mission science objectives that require accurate estimation of spacecraft state vector.

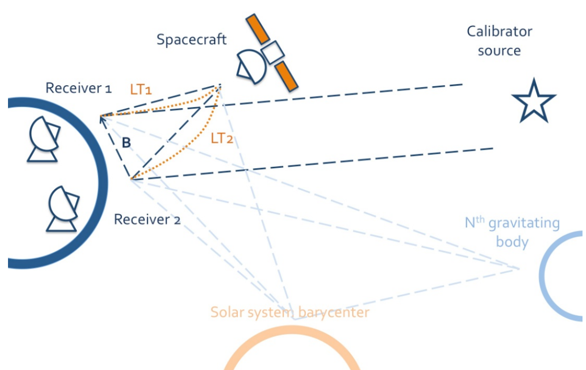

Figure 1: Geometry of a PRIDE experiment.

In the course of its orbits around the Galilean moons, the JUICE mission will perform detailed studies of the dynamics of the Jupiter system. The synergy of the onboard instrumentation and Earth-based observations will allow us to measure with unprecedented accuracy the dynamics of the Galilean moons. This will provide crucial input to the determination of the ephemerides and physical properties of the Jupiter system.

In this contribution, we introduce a covariance analysis of the relative quantitative influence of the JUICE-PRIDE observables to the determination of the ephemerides of the Jovian system and the associated physical parameters [2]. Furthermore, we present the experiments our team carried out to develop and improve VLBI and Doppler measurements of spacecraft and to study their scientific applications. The amount of data collected during PRIDE tests have also had a number of scientific outcomes: ESA's Venus Express (VEX) and Mars Express (MEX) has been extensively targeted by PRIDE for studying the solar wind by observing the effects of intervening ionized plasmas on the spacecraft signal [5]. Radio occultation experiments of both Venus Express and Mars Express have performed to derive vertical density, pressure and temperature profiles of planetary atmospheres [1]. In the case of MEX, a number of observations were carried out during the Phobos flyby on December 2013 [4].

PRIDE is a versatile experiment with zero impact on the science payload mass, and it offers a high degree of synergy with the typical on-board instrumentation. Near field VLBI can complement the scientific suite of any future missions with transmitting orbiters and/or landers.

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Magnetic field fluctuations measurement onboard ESA/JUICE mission by search-coil magnetometer: SCM instrument as a part of RPWI consortium

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Abstract

The JUpiter ICy moons Explorer (JUICE) mission is the first large-class (L1) mission in ESA Cosmic Vision. JUICE is planned for launch in 2022 with arrival at Jupiter in 2029 and will spend at least three years making detailed observations of Jupiter's magnetosphere and of three of its largest moons (Ganymede, Callisto and Europa). The Radio and Plasma Wave Investigation (RPWI) consortium will carry the most advanced set of electric and magnetic fields sensors ever flown in Jupiter's magnetosphere, which will allow to characterize the plasma wave environment and the radio emission of Jupiter and its icy moons in great detail. The Search Coil Magnetometer (SCM) will provide high-quality measurements of the magnetic field fluctuations' vector $\delta\mathbf{B}$ for RPWI. Here we present the technical features of the SCM instrument and we discuss its scientific objectives. We show the improvements of the SCM instrument onboard JUICE with respect to search-coil instruments onboard earlier planetary missions such as Galileo and Cassini, and we discuss the impact of such improvements on Jupiter's in situ plasma observations.

1. Introduction

1.1 SCM technical features

SCM will provide for the first time high-quality three-dimensional measurements of magnetic field fluctuations' vector in Jupiter's magnetosphere. The frequency range is 0.1 Hz – 20 kHz, which is sufficient to cover a broad range of fluctuations of scientific interest. High sensitivity (4 fT / √Hz at 4 kHz) will be assured by combining an optimized (20 cm long) magnetic transducer with a low-noise (4 nV /√Hz) pre-amplifiers based on ASIC technology. The impact of low-frequency perturbations by the spacecraft will be strongly reduced by accommodating SCM more than 8m away from the spacecraft on JUICE magnetometer boom.

1.2 SCM science objectives

The combination of high sensitivity and high cleanliness of SCM measurements will allow unpreceded studies of waves and turbulence down to kinetic scales in the Jovian system. SCM measurements, in combination with electric field measurements, will allow to quantitatively determine the properties of different kinds of waves at boundaries such as Jupiter's bow shock, magnetopause and magnetotail current sheet as well as at the magnetopause and tail current sheet of Ganymede's small magnetosphere. As an example, whistler waves will be accurately identified through the measurement of all the three components of the magnetic fluctuations' vector $\delta\mathbf{B}$ and measurements of key quantities such as Poynting's vector will be obtained combining $\delta\mathbf{B}$ measurements with electric field fluctuations $\delta\mathbf{E}$ measurements. Whistler waves are crucial to understand the dynamics of electrons at shocks and during magnetic reconnection in current sheets. SCM measurements will also allow to perform novel studies of turbulence in Jovian system, such that associated to fast flows in Jupiter's and Ganymede's magnetotail current sheet as well as turbulence in the solar wind upstream of Jupiter's bow shock. The combination of SCM measurements with those from the fluxgate magnetometer JMAG will allow studying turbulence from large scales down to kinetic scales, where the strongest particle energization occurs. Another important example are measurements of Alfvén waves and turbulence in Ganymede's auroral region, such as dispersive Alfvén waves which are important for particle acceleration therein. We illustrate JUICE SCM's science case by showing a few examples of Galileo and Cassini search-coil measurements and we discuss how improvements on JUICE will allow improving our understanding of waves and turbulence in the planetary environments.

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Electron Density Measurement on JUICE Mission by Mutual Impedance Technique: MIME Instrument as a Part of RPWI Consortium

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Abstract

Mutual Impedance MEasurements (MIME) instrument is a part of the Radio Wave Plasma Investigation ((RPWI) consortium which has been selected by European Space Agency (ESA) on the nest planetary mission JJUpiter ICy moons Exploer (JUICE) for a launch in 2022. The goals are to explore Jupiter and its potentially habitable icy moons and to study its plasma environment.

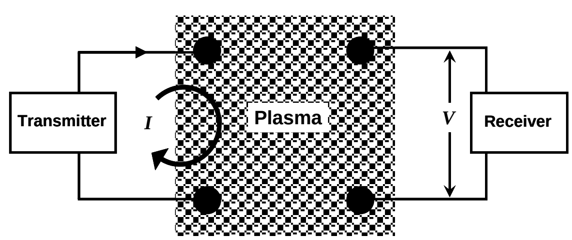
Impedance probes, which are well known in geophysical prospection, in particular for ground permittivity investigations, have been successfully transposed to space plasmas diagnostic. Transmitting and receiving electrodes are used for measuring on open circuit the dynamic impedance of the system at several fixed frequencies over a range that includes characteristic frequencies of the ambient plasma. The measurements are then interpreted using a suitable theory and the values of plasma parameters, such as the electron density and possibly the temperature of the plasma can be deduced. To show how powerful this technique is, results obtained in the Earth's plasmasphere by the mutual impedance probe onboard ROSETTA are presented as example. MIME instrument proposal is then described and its ability to make valuable measurements in the Jupiter space environment and in particular around Europe, Callisto and Ganymede is investigated..

1. MIME instrument features

MIME instrument is dedicated to measure the electron density in the plasma environment of Jupiter and, in particular, around its three Galilean moons : Europe, Callisto and Ganymede. Density measurement is done by mutual impedance technique. Plasma density is derived from the plasma frequency which is determined by a measurement of the frequency response in regard to AC electrostatic field excitation. The low power level below the thermal energy minimizes the plasma disturbance. Moreover, this way using frequency domain allows us to obtain an absolute value of the electron density. And, the density range is mainly set by the geometrical dimension between two electric antennae. Typically, the antennae distance must be between 2 up to 40 Debye lengths.

1.1 Principle of measurement

MIME takes advantage of existing electric antennae of the RPWI consortium in using a particular functioning mode. The principle is to evaluate the mutual impedance between two electric antennae that is strongly depending, especially at resonances, of the surrounding plasma permittivity. This method gives us an evaluation of the plasma permittivity as a function of the frequency.



Schema showing how the mutual impedance

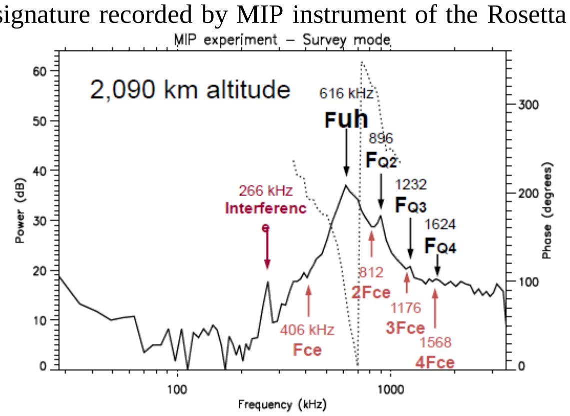
$Z = V/I$ of a quadripole probe is determined.

RPWI consortium owns two antennae sets that allow MIME to sweep two frequencies bandwidths. One is dedicated to Low Frequency (LP/LP mode) investigation [3 kHz- 1.6 MHz], and use four Langmuir probes (LPW) as couple of transmitting/receiving antennae in monopole or dipole configuration. Another set provides High Frequency (LP/RWI mode) recording [80kHz - 3 MHz] range. MIME configuration uses LPW monople/dipole as transmitting antenna and the three RWI dipoles as receiving antennae.

The technique consists to use two-antennae systems, one as a transmitting and the second as a receiver. The antennae system can be double probes (LP/LP probes) or wire antennae (RWI). If only one probe is used, the AC current is injected in it and the voltage is measured between the probe and the spacecraft body. The transmitting electrodes are excited from a sinusoidal signal generator, while the receiving electrodes are connected to a voltmeter whose input impedance is very high compared to the self-impedance of the plasma between the receiving electrodes. Providing that the internal impedance of the current source is very large compared to the self-impedance of the transmitting electrodes, the current may be considered as known and constant.

2. Example of frequency response

Similar instruments have been already included in the previous space satellites payload and have worked with successfully results in space plasma like earth magnetosphere or comet environment (Rosetta). Below figure shows an example of spectrum signature recorded by MIP instrument of the Rosetta



mission during an earth crossing. We can notice strong peaks corresponding to plasma resonances which are interpreted on ground to extract the electron density.

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DePhine – The Deimos and Phobos Interior Explorer – A Proposal to ESA's Cosmic Vision Program

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1. Introduction

DePhine – Deimos and Phobos Interior Explorer – is a mission proposed in the context of ESA's Cosmic Vision program, for launch in 2030. The mission will explore the origin and the evolution of the two Martian satellites, by focusing on their interior structures and diversities. Are Phobos and Deimos true siblings, originating from the same source and sharing the same formation scenario? Are the satellites rubble piles or solid bodies? Do they possess hidden deposits of water ice in their interiors? After the transfer to Mars, DePhine will first enter into a quasi-satellite orbit of Deimos to carry out comprehensive surface mapping and very close flybys. The spacecraft will then enter into a resonance orbit with Phobos to perform multiple close flybys and similar remote sensing experiments as for Phobos.

2. Science Case

In spite of a long observational history, the origins of Phobos and Deimos are unknown. They may have co-accreted with the parent planet [1], or formed from Martian basin ejecta [2-5]. Alternatively, they may represent captured primitive asteroids or comets [6]. Clues on the origins of the satellites may come from comparative studies of whether Phobos and Deimos are true siblings, originate from the same source and share the same formation scenario and history. Other clues may come from investigations of the interior structures of the satellites, e.g., to resolve whether the satellites are rubble piles or solid bodies, or whether they possess hidden deposits of water ice in their interiors. The answer to the origin of Deimos and Phobos is a key to understanding the evolution of the Martian system and the workings of the solar system.

3. Measurement Goals

The mission will first focus on Deimos, to obtain the satellite's physical parameters and characteristics comparable to data already available for Phobos. In particular, we wish to determine the properties of the Deimos soil to enable comparisons with Phobos samples, assumed to be available from the Phobos sample return missions, at the launch time of DePhine [7]. In addition, the mission will address the interior structures of both satellites. We will determine shape and gravity field parameters of high degree and order to enable joint inversions, and will study the subsurfaces of Phobos and Deimos using a powerful radar. We wish to understand the spatial distribution and layering of the regolith on both satellites and map the structure of impact craters and, in particular, the Phobos grooves.

4. Science Instrumentation

The interior of the moons will be studied through several experiments. First decimetre deep layer structures and elements can be detected with the *Gamma Ray Neutron Spectrometer* (GRNS). A powerful radar instrument (SSR) will sound several tens of meters deep to detect layering or block boundaries. The bulk mass distribution will be detected through the *Gravity Radio Science Investigation of the Martian Moons* (GRIMM) experiment used to determine higher degree and order gravity field coefficients. The *Wide Angle Survey Camera* (WASC) will enable surface characterization and morphology studies, while the *Deimos Magnetometer* (DeMag) will provide information on the magnetization state of Deimos and Phobos providing indications for origin scenarios. The *eXtra Small Analyzer of Neutrals-2* (XSAN-2) and the Dust in the Martian EnviRonment (DIMER) experiments will study the environment in the vicinity of the moons.

5. Mission

The DePhine spacecraft will be inserted into Mars transfer and will initially enter a Deimos quasi-satellite orbit to carry out a comprehensive global mapping. The goal is to obtain physical parameters and remote sensing data comparable to data expected to be available for Phobos at the time of the DePhine mission to enable comparative studies. As a highlight of the mission, close flybys will be performed at low velocities, which will increase data integration times, enhance the signal strength and data resolution. 10 – 20 flyby sequences, including polar passes, will result in a dense global grid of observation tracks. The spacecraft will then change from the circular to an eccentric Mars orbit in resonance and with a pericenter close to Phobos. Benfitting from the resonance, the spacecraft will carry out multiple close flybys at low relative speeds and perform similar remote sensing as for Deimos to calibrate collected Deimos data against Phobos. A steerable antenna will allow simultaneous radio tracking and remote sensing observations by onboard instruments during flybys (which is technically not possible for Mars Express). If Ariane 6-2 and higher lift performance are available for launch (the baseline mission assumes a launch on a Soyuz Fregat), we expect to have more spacecraft resources. In particular, we may carry a small lander to be deployed on Deimos to complement the science goals of the mission.

6. Team

The mission and system design for DePhine was developed by a consortium of OHB System AG, DLR and scientists from international institutes and organisations, including: UCL, MSSL, UK; IPAG Grenoble, France; TU Dresden, Germany; INTA, Spain; IKI Moscow, Russia; IRF, Sweden; Universität zu Köln, Germany; ROB, Belgium; Johns Hopkins University, APL, USA; IMCCE, Paris, France.

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The Jovian Neutral Atoms Analyser onboard JUICE/PEP: Performance and Calibration Measurement Results

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Abstract

The Jovian Neutral Atoms Analyser (JNA) is one of the sensors of the Particle Environment Package (PEP) onboard the JUICE spacecraft. One of the main JNA science objectives is the investigation of the plasma dynamics in the Ganymede magnetosphere using energetic neutral atom imaging. We will show the results from laboratory testing of the JNA prototype with particular focus on the angular resolution, the mass resolution and the detection efficiency.

1. Introduction

Instruments for energetic neutral atom (ENA) imaging were flown on numerous space missions to different planetary bodies. The measurements of these ENA imaging instruments have greatly helped to answer questions on the different interaction processes of the solar wind with the planetary surfaces, the resulting space weathering processes and interaction of ions and neutrals with the space plasma [1].

The JUICE mission will be launched in 2022 and reach Jupiter and the Jovian system 8 years later. The JNA onboard the JUICE spacecraft will measure energetic neutral atoms in an energy range from 10eV to 3keV with an angular resolution 11°x7° resolving hydrogen and heavy atoms throughout the mission [2].
Special importance is attached to the mission phase of the JUICE spacecraft orbiting Ganymede. The Jovian moon possesses an intrinsic magnetic field. As a result, certain terrains on the surface of the Jovian moon are protected against space weathering processes while others are not. As the interaction of plasma ions with the icy surface of Ganymede result via different processes in ENAs, mapping the ENAs is a direct means of mapping the plasma interaction processes with the surface. JNA onboard the JUICE mission will provide the scientific data to quantify ENA fluxes from Ganymede and to create ENA maps of the surface, hence offer valuable clues to the plasma environment of Ganymede and the space weathering effects in the Jovian system [2].

2. Technical

The JNA instrument is built at IRF Kiruna with heritage from the CENA sensor, which was one instrument of the SARA (Sub-keV Atom Reflecting Analyser) experiment onboard Chandrayaan-1 [1], and the ENA sensor, one of the instruments of the MPPE (Mercury Plasma Particle Environment), which will be launched onboard BepiColombo [4]. Shape and dimension of the JNA will be similar to the ENA instrument, which is shown in Fig. 1.

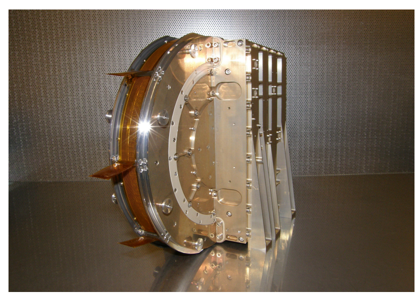

Figure 1: The flight model of the ENA instrument for BepiColombo, image credit: IRF

In comparison to the instruments mentioned above, the JNA instrument is designed for being operated in the harsh radiation environment of Jupiter. Thus, the design includes radiation shielding and minimization of penetrating background radiation by a reduced time of flight (TOF) and the use of channel electron multipliers instead of micro channel plates. Additionally, it is considered to apply a diamond coating to the surface, which triggers the start of the

TOF measurement. Synthetic diamond has yielded promising results regarding its ionisation efficiency and angular scattering properties [3]. In addition, the chemical inertness of diamond would be advantageous regarding radiation hardness.

3. Experimental

We operated a prototype of the JNA instrument as well as the test model in the calibration facility at IRF Kiruna. We carried out numerous measurements with different particle species, different energies and different angles of incidence to analyse the detection efficiency, to proof the required mass and energy resolution as well as the angular resolution. As an example, Fig. 2 shows the TOF spectrum of 1.3 keV H, measured with the JNA prototype.

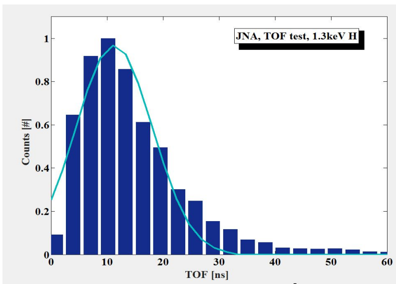

Figure 2: TOF spectrum of 1.3 keV hydrogen, measured with the JNA prototype

Furthermore, we tested the instrument with the start surface being coated with synthetic diamond. We will report on the analysis and results of the test measurements and show the JNA performance meeting all mission requirements.

4. Summary and Conclusions

Numerous models and former space missions have shown that the detection of neutral atoms in the vicinity of a planetary body is a measurement, which yields the data for answering key scientific questions. ENA measurements onboard space missions, e.g. Chandrayaan-1, offer valuable clues about the interaction of the space plasma with the planetary body and the different processes that are alterating the planetary surface.

The PEP/JNA instrument will measure the fluxes of neutral atoms at Jupiter and the Jovian icy moons on the JUICE mission. JNA measurements at Ganymede will help to understand the complex interactions of the Jovian plasma environment with the icy surface of the moon. We present the JNA instrument, the different performance evaluations that were carried out and the results from the test campaign. We will show that the JNA is a high performance instrument to significantly contribute to our understanding of the Jovian system.

Acknowledgements

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Geodetic Framework for Martian Satellite Exploration II: Astrometry; Phobos Geodetic Control and Maps

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Introduction

Phobos, the larger of the two Martian moons is currently of great interest to the science community. While there were several Phobos mission proposals in the scope of NASA's discovery program [1-3], ESA and Roscosmos are currently studying the feasibility of a sample return mission [4], the Japanese space Agency plans to launch a sample return mission by 2024 [5], and ESA's M5 call received a mission proposal to explore the Martian moons [6]. Following the successful launch in 2003, ESA's Mars Express Mission (MEX) moves in an orbit, which has close encounters of Phobos on a regular basis, favorable for Phobos observations [7]. Here we report on current activities of Phobos research in the various fields of interest based on image data of the High Resolution Stereo Camera on-board the MEX spacecraft.

1. Astrometric observations

We carry out astrometric observations of Deimos and Phobos to support orbit determination for the two satellites. In the recent past mutual event observations – showing Phobos or Deimos together with yet another body in the stellar sky – were reduced to determine the angular separation between two visible objects, respectively. The spacecraft pointing is not relevant for this kind of observations which eliminates one of the largest error sources of past astrometric observations [8-11]. Observations include Phobos and Deimos, or the relative position of Phobos or Deimos with respect to Jupiter and Saturn,. Observations and data reductions are ongoing. Phobos' and Deimos' secular orbital motion may constrain interior models, in particular the mass distributions within the two satellites [12, 13].

Figure 1: Example of a Phobos-Jupiter mutual event observation by the Super Resolution Channel of the HRSC (Image Credit: ESA/DLR/FU Berlin).

2. Rotation parameters

Deimos and Phobos are tidally locked. In the past, observations of the rotation parameters such as the forced libration amplitude were based on an empirical approach to find a best fit to control point network solutions. We have now implemented a least-squares adjustment algorithm that can directly solve for rotation parameters by computing the bundle block in the inertial reference frame. The forced libration amplitude can be solved for directly when computing coordinates of control points of a global network. The approach also allows us to test the orientation of the pole axis and the precession motion [14].

3. Cartographic products

In 2016 all HRSC Phobos map products have been released to the public through PSA and PDS. This information was now brought together with other GIS mapping products in a catalogue and as a web-map. Both, catalog and maps, are used to support

Mars Express Phobos observation planning, to further exploit the existing data and to support future missions to Phobos in the preparation and planning phase.

Acknowledgements

We wish to thank the HRSC Experiment Team at DLR, Institute of Planetary Research, Berlin, and at Freie Universität Berlin, the HRSC Science Team, as well as the Mars Express Project teams at ESTEC, ESOC, and ESAC for their successful planning, acquisition, and release of image data to the community.

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ORISON, A Stratospheric Project

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Abstract

This paper reports the concept and preliminary outcomes of the ORISON study, addressing an observatory-type, regularly flying high stratospheric research infrastructure. Implemented with a focus on comparably low costs and flexible operations, balloon-based systems such as the one presented have the potential to complement ground and space based observations and, in addition, to provide a test platform for future space-based instrumentation. The stratospheric observation conditions make such systems particularly suitable for planetary observations. They not only provide access to spectral regimes inaccessible from the ground and photometric stabilities not obtainable from the ground, but also observational opportunities at additional times of the daily cycle and throughout the year. In this paper, we present the overall ORISON concept, exemplary applications for planetary science, and propose first-light instrumentation for a balloon-based observatory to serve these applications.

1. Introduction

The objective of ORISON (http://www.orison.eu) is to investigate an infrastructure providing a flexible platform, tailored for astronomical use and designed to carry light-weight medium-sized telescopes and other exchangeable instruments. The focus thereby lays on a reusable platform performing regular flights from accessible locations and an operations concept that provides researchers with a similar access to observations as practiced on ground-based observatories. As such, the ORISON concept aims at complementing the current landscape of scientific ballooning activities by providing a service-centered infrastructure tailored towards broad astronomical use**.** Beyond the technical feasibility, ORISON also includes a study on different procurement options for the designed infrastructure, including instruments of innovative procurement.

2. Technical Concept

The goal of ORISON is not to provide a fixed observation system, but to provide a modular flight platform that can accommodate exchangeable instruments. In order to exemplify its application, however, both the flight platform as well as potential instruments with a wide applicability are presented.

2.1 Flight Platform

The ORISON flight platform will be designed to accommodate two classes of instruments: (1) telescope instruments, to be installed at the telescope, and (2) platform add-on instruments, to be installed on the platform, not using the telescope. For all these instruments, the platform will provide the conditions and services necessary for operation, including power, data and command handling, and thermal environment. For the telescope, the platform aims to provide coarse pointing with an accuracy on the order of 10 arcsec rms. Maybe most importantly, the flight system will be designed to be readily reusable which prominently requires undamaged return and landing of the instruments and the platform itself.

An assessment of scientific needs and the technical challenges of the balloon system showed that a platform capable of carrying a 0.5 m aperture diameter telescope for the UV to the NIR would constitute a good compromise between performance and size/mass.

2.2 Telescope and Instrumentation

The baseline telescope chosen for the ORISON feasibility study is a Ritchey-Chretien design with achievable system focal ratios between f/4 and f/16, allowing both wide field observations and high angular resolution. To enable high-resolution imaging, the optical system will include a tip/tilt mirror system aiming to provide image stabilization at the order of 0.1 arcsec rms.

To maintain the goal of a comparably light-weight and low-cost system, the ORISON baseline system will be optimised for the wavelength range from 0.2 to 2 µm, complementing the GHAPS balloon telescope concept that focuses on infrared wavelengths up to 5 µm [1].

Two potential first-light instruments with industry-standard detectors are considered, covering a broad initial range of applications. The first one being a simple direct wide field imager with exchangeable filters, which by itself can be used to address a wide range of science cases. The second potential baseline instrument is a multichannel fast imager with spectroscopic capabilities, based on the HiperCam [2] or reduced Octocam [3] and GROND [4] designs, offering simultaneous, photometrically accurate imaging capabilities in the u/g, r, i/z, J, and H bands.

Attractive "second generation" instruments would be dedicated spectrographs for the near UV and near IR spectral ranges.

3. Planetary Science Applications

The stratospheric observation conditions will provide a beneficial environment for a large range of planetary science applications. To illustrate the applicability, we present a selection of planetary science cases that could be pursued with the baseline instrumentation described above in table 1.

Table 1: Planetary Science Cases for ORISON

Science Case	Stratospheric Advantage
Multichannel exoplanet follow-up/confirmation	Photometric stability, no scintillation noise
Extended asteroid topology including near UV	Accessibility to UV spectral regions
Study of the 1.4 and 1.9 µm OH/H_2O bands on asteroids	Absence of telluric bands limiting NIR spectroscopy from the ground
Study of Mercury's exosphere	Observations close to the Sun possible
Small body light curves and absolute photometry	Increased photometric stability

4. Summary and Conclusions

An observatory-type balloon telescope, designed for regular flights and flexible instrument deployment, will provide a beneficial tool for planetary scientists. It will particularly make stratospheric observations accessible for scientists and groups without the capacity or aspiration to design and organize their own ballooning missions. The ORISON study, once completed at the end of July 2017, will provide a technical concept and a potential funding approach for such an observatory. A follow-on project is planned to build upon these results towards an implementation.

Acknowledgements

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European SpaceCraft for the study of Atmospheric Particle Escape (ESCAPE): a planetary mission to Earth, proposed in response to the ESA M5-call

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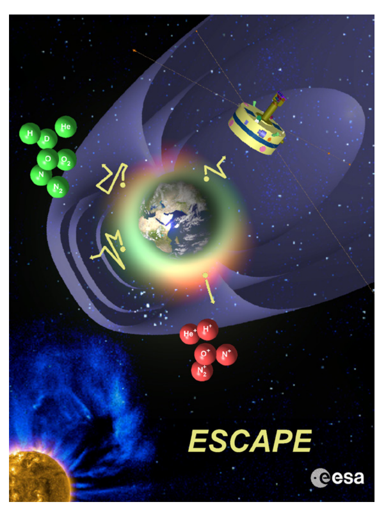
Abstract

ESCAPE is a mission proposed in response to the ESA-M5 call that will quantitatively estimate the amount of escaping particles of the major atmospheric components (nitrogen and oxygen), as neutral and ionised species, escaping from the Earth as a magnetised planet. The spatial distribution and temporal variability of the flux of these species and their isotopic composition will be for the first time systematically investigated in an extended altitude range, from the exobase/upper ionosphere (500 km altitude) up to the magnetosphere. The goal is to understand the importance of each escape mechanism (thermal or non-thermal), its dependence on solar and geomagnetic activity, in order to infer the history of the Earth's atmospheric composition over a long (geological scale) time period. Since the solar EUV and solar wind conditions during solar maximum at present are comparable to the solar minimum conditions 1–2 billion years ago, the escaping amount and the isotope and N/O ratios should be obtained as a function of external forcing (solar and geomagnetic conditions) to allow a scaling of the escape rates to the past. The result will be used as a reference to understand the atmospheric/ionospheric evolution of magnetised planets, which is essential for habitability. To achieve this goal, a slowly spinning spacecraft is proposed equipped with a suite of instruments developed and supplied by an international consortium. These instruments will detect escaping populations from the upper atmosphere and magnetosphere by a combination of in-situ measurements and of remote-sensing observations. The ESCAPE mission proposal successfully passed the first technical and programmatic screening by ESA and is now entering into the scientific assessment phase.



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JOINT EUROPA MISSION (JEM). A MULTISCALE STUDY OF EUROPA TO CHARACTERIZE ITS HABITABILITY AND SEARCH FOR EXTANT LIFE

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Abstract

Introduction: There is a consensus in the planetary community that Europa is the closest and probably the most promising target to search for extant life in our solar system. The Galileo discovery of a sub-surface ocean likely in direct contact with a silicate floor that could be a source of the key chemical species needed for the build-up of biomolecules, the many indications that the ice shell is active and may be partly permeable to transfer materials, including elementary forms of life, and the identification of candidate thermal and chemical energy sources necessary to drive a metabolic activity, have raised great hopes that Europa is likely habitable, and strongly support a scientific plan to go there and see if it is indeed inhabited.

We propose that ESA works with NASA, which presently leads the way towards in situ exploration of Europa, to design and fly jointly an ambitious and exciting planetary mission to reach this objective. In doing so, we aim at characterizing biosignatures in the environment of Europa (surface, subsurface and exosphere), while we also want to address a more general question: how does life develop in a specific habitable environment, and what are the evolutional properties of a habitable planet or satellite and of its host planetary/satellite system which make the development of life possible.

JEM proposal was submitted to the ESA M5 call last October 2016.

Scientific goals of JEM: Our search for life there will build on the advanced understanding of this system which the missions preceding JEM in its exploration will provide: improved understanding of its origin and formation (JUNO), of its evolutionary mechanisms (JUICE) and even a preliminary comparative understanding of its habitability: while JUICE will characterize a “type IV habitat” at Ganymede, NASA’s EMFM mission will provide a first characterization of a “type III habitat” at Europa, using a multiple fly-by strategy. Building on these invaluable assets, the overarching goals for JEM is:

“Understand Europa as a complex system responding to Jupiter system forcing, characterize the habitability of its potential biosphere, and search for life in its surface, sub-surface and exosphere.”

We suggest to address these goals by a combination of five Priority Scientific Objectives, each with focused measurement objectives providing detailed constraints on the science payloads and on the platforms used by the mission. Our observation strategy to address them will combine three types of scientific measurement sequences: measurements on a high-latitude, low-latitude Europan orbit providing a continuous and global mapping of planetary fields (magnetic and gravity) and of the neutral and charged environment during a period of three months; in-situ measurements to be performed at the surface, using a soft lander operating during 35 days, focusing on the search for bio-signatures at the surface and sub-surface by analytical techniques in the solid and liquid phases, and on the operation of a surface geophysical station whose measurements will ideally complement those of the orbiter; and measurements of the chemical composition of the very low exosphere in search for biomolecules originating from the surface or sub-surface, to be performed near the end of the mission during the final descent phase.

The implementation of these three observation sequences will rest entirely on the combination of two science platforms equipped with the most

advanced instrumentation: a soft lander to perform all scientific measurements at the surface and sub-surface at a selected landing site, and an orbiter to perform the orbital survey and descent sequences. In this concept, the orbiter will also provide for the lander the vital functions of carrier, with the objective of carrying the lander stack from the Earth to a Europan orbit on which it will release it before its descent, and of data relay during the 35 days of lander operations. Using its own instrument platform, it will in perform science operations during the relay phase on a carefully optimized halo orbit of the Europa-Jupiter system, before moving to its final Europan science orbit for three months.

Payload proposed for JEM: We derived from our science objectives a carefully selected science payload for the lander and for the orbiter.

Our proposed orbiter payload suite includes six well-proven instruments provided by European institutes in an international collaboration framework to characterize the planetary fields and the plasma, neutrals and dust environment, fitting within the allocated mass, and one additional instrument that will be considered depending on the mass margin to be identified after the assessment study. To efficiently address the radiation issue, we propose to decouple the sensor heads from the other parts of the electronics, and to group these parts in a dedicated vault, or a well-shielded location within the platform, that will facilitate radiation mitigation. Appropriate planetary protection measures corresponding to at least Planetary Protection Category IVb will be implemented to all subsystems, including the payload and the spacecraft element.

Our lander science platform is composed of a geophysical station and of two complementary astrobiology facilities dedicated to biosignature characterization experiments operating respectively in the solid and in the liquid phases. The design and development of the liquid phase laboratory, called AWL for “Astrobiology Wet Laboratory”, will be a specific European contribution to the surface science platform. The two astrobiology facilities will be fed by a common articulating arm operating at the platform level that will collect the samples at the surface or sub-surface and will deliver them to the analytical facilities. We are proposing two alternative options for the deployment of AWL: inside the main platform, where it would benefit from all its infrastructure and services, or outside of it as an independent sub-platform, to be deployed with the help of the articulated arm. Further discussions between NASA and ESA will be needed to identify the best option.

Mission configuration: To fly the JEM mission, while making it affordable to the two Agencies and making JEM an appealing joint exploration venture for the two of them, we propose an innovative distribution of roles; while NASA will provide an SLS launcher, the lander stack and will cover most of the mission operations, ESA will design and provide the carrier-orbiter-relay platform. This delivery is technically possible using a safe technical approach, taking advantage of a double heritage of European developments for space exploration: the JUICE spacecraft for the JEM orbiter avionics, and an adaptation of the ORION ESM bus to the specific needs of JEM for its structure. This approach to the provision of the carrier makes it possible to propose a total contribution of ESA to JEM that fits well within the limits of an M-class mission, as required. Thanks to this approach, a joint venture of NASA and ESA to fly the first mission that will go and search for extant life outside our own planet becomes both fully credible and extremely appealing.

This way, JEM can be the next major exciting joint venture of NASA and ESA to the outer solar system, inspired by and following the unique success of Cassini-Huygens. It will provide an outstanding opportunity to preserve and develop the unique spirit of collaboration and friendship which links the European and American planetary science communities, by proposing to these two communities to work together toward one of the most exciting scientific endeavours of the XXIst century: to search for life beyond our own planet.

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A Compact, Multi-view Net Flux Radiometer for future Uranus and Neptune Probes

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Abstract

A Net Flux Radiometer (NFR) is presented that can be included in an atmospheric structure instrument suite for future probe missions to the icy giants Uranus and Neptune. The baseline design has two spectral channels *i.e.*, a solar channel (0.4-to-3.5 µm) and a thermal channel (4-to-300 µm). The NFR is capable of viewing five distinct viewing angles during the descent. Non-imaging Winston cones with band-pass filters are used for each spectral channel and to define a 5° angular acceptance. Uncooled thermopile detectors are used in each spectral channel and are read out using a custom radiation hard application specific integrated circuit (ASIC). The baseline design can easily be changed to increase the number of detector channels from two to seven.

1. Introduction

Knowledge of the atmospheric thermal structure, and global energy balance of the ice giants Uranus and Neptune, Fig. 1, is required for quantitative investigations of the atmospheric dynamical regime and associated energy transport processes [1, 2]. The temperature at the top of the convective zone and the internal energy flux are fundamental parameters needed to constrain models of the interior and the evolutionary history of these planets. Information on temperature is also required to address problems in atmospheric chemistry and cloud physics. Ideally, it would be desirable to have in-situ measurements of the temperature and the down- and up-welling energy flux from the exosphere down into the deep planetary interior (~10 bar). The planetary energy balance, *i.e.*, the thermally emitted flux to the absorbed solar flux, is significantly smaller for Uranus than for the other three giant planets. Voyager 2 measurements [1] provided extensive phase angle coverage and a more nearly global determination of the thermal emission, establishing new limits on the internal energy flux, however an in-situ measurement would greatly constrain interior structure *via* thermal history models, and clarify the difference in heat flow as compared to Jupiter, Saturn and Neptune. Clouds and aerosols in the atmospheres of Uranus and Neptune are related to the atmospheric composition, chemistry, motion, and temperatures, but the physical processes that control the interactions among these are not known. For example, clouds on both Uranus and Neptune appear at certain latitudes, but the reasons are still unclear [3]. The NASA Planetary Decadal Survey noted that the "best approach to truly understand giant planet heat flow and radiation balance would be a systematic program to deliver orbiters with entry probes to all four giant planets in

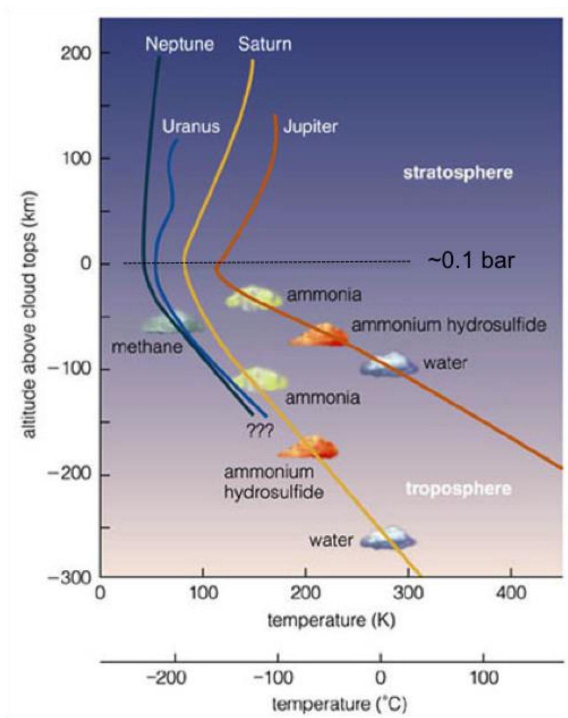

Figure 1: The atmospheric thermal structure and predicted cloud layers for the giant planets. A net flux radiometer would provide crucial ground-truth measurements to test these models.

the solar system. The probes would determine the composition, cloud structures, and winds as a function of depth and location on each planet." A probe would carry a complement of instruments to investigate giant/icy planet atmospheric dynamics along its descent trajectory, from (1) the vertical distribution of the pressure, temperature, clouds and wind speeds, and (2) deep wind speeds, differential rotation and convection, by combining probe, gravity and radiometric measurements. The thermal structure of *e.g.*, Uranus' atmosphere is expected to result in CH_4 and NH_3 clouds at p ~1 bar and ~3 bar, respectively. In the spectrum of Uranus, the S(0) and S(1) bands of H_2 tend to be opaque at p >300 mbar. Solar insolation dominates the heat flux at p <100 mbar. The net flux transition region depends on the opacity source. A NFR with spectral bandpass channels carefully tuned to sense these contributions will address the heat balance in the atmosphere.

2. Net Flux Radiometer

The NFR, Fig. 2, measures upward and downward radiation flux in a 5° field-of-view at five distinct look angles, i.e., ±80°, ±45°, and 0°, relative to zenith/nadir. The radiance is sampled at each angle approximately once every ~ 2s.

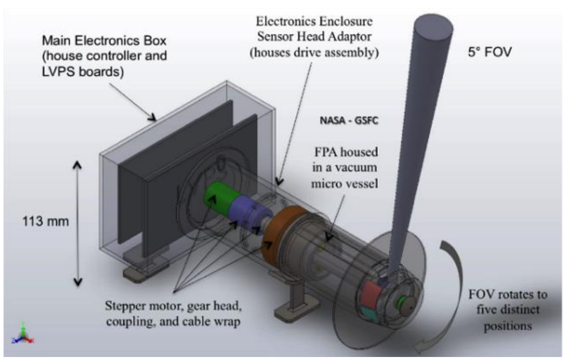

Figure 2: NFR instrument schematic showing a 5° field-of-view that can be rotated by a stepper motor into five distinct look angles.

The windowed vacuum micro-vessel, Fig. 3, houses the folding mirrors, non-imaging Winston cone concentrators, and thermopile focal plane assembly and is rotated to the look angle by a stepper motor. For a Uranus probe NFR, assuming a thermopile voltage responsivity of 295 V/W, an optical efficiency of 50%, a detector noise of 18 nV/√Hz and an ASIC input referred noise of 50 nV/√Hz, 1s integration with 12-bit digitization gives a system signal-to-noise ratio of 62 to 69 in the solar spectral channel (0.4-3.5 µm) and 27 to 9116 in the thermal spectral channel (4-300 µm) for atmospheric temperature and pressure ranges encountered in the descent, *i.e.*, ~70 to 300 K and 0.1 to 10 bar respectively.

Figure 3: Vacuum micro-vessel with sapphire and diamond windows. Each window has a 5° field-of-view.

3. Volume, Mass, Power, Data Rate

2-channel NFR
Mass: ~2.4 kg
Volume: ~113 mm x 144 mm x 279 mm
Basic Power: ~5 W
Average Data Rate: ~55 bps
Total Data Volume: ~297 kbits (90-minutes)

4. Summary and Conclusions

NASA GSFC has designed a NFR that will be suitable for integration into an atmospheric instrument suite on-board future Uranus and Neptune Probe Missions. If the exacting field-of-view can be opened up from 5° to 7° then the design of the NFR can easily be reconfigured to incorporate up to seven channels with an overall reduction of volume and hence mass.

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Software-type Wave-Particle Interaction Analyzer (SWPIA) by RPWI for JUICE

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Abstract

Software-type Wave-Particle Interaction Analyzer (SWPIA) will be realized as a software function of Low-Frequency receiver (LF) running on the DPU of RPWI (Radio and Plasma Waves Investigation) for the ESA JUICE mission. SWPIA conducts onboard computations of physical quantities indicating the energy exchange between plasma waves and energetic ions. Onboard inter-instruments communications are necessary to realize SWPIA, which will be implemented by efforts of RPWI, PEP (Particle Environment Package) and J-MAG (JUICE Magnetometer). By providing the direct evidence of ion energization processes by plasma waves around Jovian satellites, SWPIA contributes scientific output of JUICE as much as possible with keeping its impact on the telemetry data size to a minimum; we estimate that SWPIA outputs 0.2 kB at the smallest from 440 kB waveform and particle raw data.

1. Introduction

Fukuhara et al. (2009) proposed Wave-Particle Interaction Analyzer (WPIA) to measure the energy transfer process between energetic particles and plasma waves. Software-type WPIA (SWPIA) was firstly implemented in the ERG satellite of JAXA to measure interactions between relativistic electrons and whistler-mode chorus in the Earth's inner magnetosphere [Miyoshi et al., 2012; Katoh et al., 2013, 2014; Hikishima et al., 2014]. In the ESA JUICE mission, we apply SWPIA to ion-scale wave-particle interactions occurring in the Jovian magnetosphere. SWPIA will be realized as a software function of Low-Frequency receiver (LF) running on the DPU of RPWI (Radio and Plasma Waves Investigation). The prime target of SWPIA in JUICE is ion cyclotron waves (~1 Hz) and related wave-particle interactions occurring in the region close to Ganymede and other Jovian satellites. SWPIA uses wave electromagnetic field and ion velocity vectors provided by RPWI sensors and PEP (Particle Environment Package), respectively, with referring three-components of the background magnetic field detected by J-MAG (JUICE Magnetometer). For the particle data, SWPIA uses particle counts detected by JDC (Jovian plasma Dynamics and Composition) of PEP in the energy range from 1 eV/q to 25 keV/q.

2. Inter-instrument Collaboration to Realize SWPIA

SWPIA measures a relative phase angle between the velocity vector $\boldsymbol{v}_i$ of i-th particle and the wave electric field vector at the timing of particle's detection ($\boldsymbol{E}(t_i)$) and computes an inner product $W(t_i) = q_i\ \boldsymbol{E}(t_i) \cdot \boldsymbol{v}_i$, where $W(t_i)$ corresponds to the gain (positive) or the loss (negative) of the kinetic energy of the i-th particle. The net amount of the energy exchange between waves and particles can be obtained by accumulating W for detected particles in the region of interest. The accumulation of the measured W also contributes to the reduction of the amount of data to be transferred to the ground. By assuming 128 Hz sampled waveform of LF data and 32 kB particle data for every m/q of PEP/JDC data obtained during 8 sec, the size of raw data becomes 440 kB for each nominal data amount of SWPIA (80 sec observation in total). By integrating the measured W for the kinetic energy, pitch angle, and relative phase angle between waves and particles, the telemetry data size

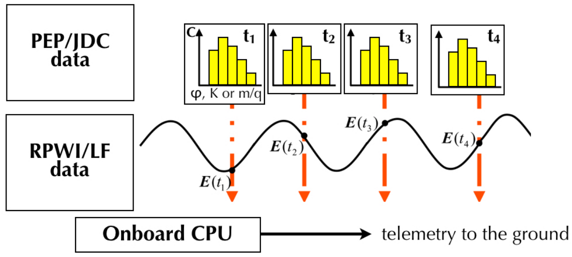

Figure 1: Schematic of the plasma wave and particle data used in SWPIA.

of SWPIA output can be estimated to be 0.2-27 kB for 1 m/q step.

Figure 1 illustrates the time sequence of the plasma wave and particle data to be used in SWPIA. The number of counts C as a function of azimuth (φ), or the kinetic energy (K), or mass-per-charge (m/q) etc. are stored with a time-tag showing the timing of the measurements. The time-tag will be used to identify the relative phase angle between the velocity vectors of detected particles and the wave electric field vectors. The synchronization of related instruments is essential to realize SWPIA in the time resolution better than the time scale of wave-particle interactions. For waves of frequency around 1 Hz, which corresponds to the typical cyclotron frequency of oxygen ions in the Ganymede's polar magnetosphere, the time resolution better than 100 msec should be required to measure the relative phase angle between wave and velocity vectors better than 40 degree. This time resolution can be realized in JUICE by inter-instrument collaboration.

3. Summary

SWPIA conducts onboard computations of physical quantities indicating the energy exchange between plasma waves and energetic ions. Onboard inter-instruments communications are necessary to realize SWPIA, which will be implemented by efforts of RPWI, PEP and J-MAG. The in-flight SWPIA computation significantly reduces the data volume to be downlinked to ground. By providing the direct evidence of ion energization processes by plasma waves around Jovian satellites, SWPIA contributes scientific output of JUICE as much as possible with keeping its impact on the telemetry data size to a minimum.

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Geodetic Framework for Martian Satellite Exploration I: Reference Rotation Models

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Abstract

We study most recent orbital data of Phobos and Deimos to derive reference rotational parameters of the two Martian satellites. With the two Mars companions captured in a spin-orbit resonance, their period of rotation is coupled to the orbital motion and the rotation axis follows the long-term precession and nutation of the orbit plane normal caused by perturbations by the Sun and planets. A comparison of our reference rotation parameters with actual measurements of the satellites' rotations may shed light on interior states and structure parameters.

1. Introduction

The two Martian moons, Phobos and Deimos, orbit deep in the gravity field of their parent body. Tidal forces acting on the irregular shapes of the satellites have caused a rotational state which is resonant to their orbital motion. Due to the spherical asymmetry of the Martian gravity field as well as third-body perturbations by the Sun and the planets the orbits of the satellites deviate remarkably form perfect Keplerian orbits. For instance, the orbit plane normal as well as the argument of pericenter performs a precessional motion with main components of 2.26 and 54.5 years for Phobos and Deimos, respectively. The rotational states of the satellites follow adiabatically these long-period changes of the orbits and remain trapped in their spin-orbit resonance. Through a precise analysis of the orbital motion of the satellites and the condition of a synchronous rotation we can derive their resonant rotation states and use them for interpretation to actual measurements of their rotation [6].

2. Rotation of Phobos and Deimos

While the Martian satellites were discovered in 1877, it was the Mariner 9 spacecraft, which provided the first close-up observation of Phobos and Deimos. At that time, first rotational models based on the orbital motion were devised [1]. Based on Viking Orbiter data, a control network analysis was performed [2] providing the first observation of a forced libration of Phobos. These measurements were recently updated by Jacobson et al., [3], Willner et al., [4], Oberst et al., [5] and Burmeister et al., [6]. Likewise the model for the orbital motion of the Martian moons has been updated upon availability of new astrometric observations. In contrast the parameters for the resonant rotational state of the satellites remained the same throughout the decades leading to a disagreement between the rotation models for Phobos and Deimos and their actual state. Using most recent solutions for the orbits of the satellites we want to compute the resonant rotational states including the forcing terms for the physical librations in longitude.

3. Data and Method

The latest Martian moon ephemerides (mar097, [3]) covering a period of 200 years centered at the year 2000 were used for this analysis. With a sampling rate of 21.6 minutes we first compute the osculating orbital elements of the satellite in an inertial reference frame, i.e. International Celestial Reference Frame (ICRF). The resulting time series is then decomposed in a secular trend and a sum of periodic terms using an iterative algorithm. At first a Fourier transformation of the signal (time series of one osculating orbital element) is performed to identify the frequency of the highest amplitude in the power spectrum. Secondly a windowed Fourier transform at the identified frequency is used to constrain the frequency, phase, and amplitude of the signal component more precisely. The derived values were used as initial values within a least-squares fit of the secular and periodic parts. The obtained fit parameters are then used to extract the identified component from the original signal and the iteration cycle starts again with the residuals as input signal. More details on this approach can be found in [7].

As we want to derive resonant rotational parameters we can directly infer the orientation of the rotation axis (declination δ and right ascension α) from the inclination of the orbital plane and the longitude of the ascending node. The rotation angle W is derived from the sum of mean anomaly and argument of pericenter.

4. Results

The resonant rotation parameters for Phobos are

$$\alpha = 317.67071657° - 0.10844326°\,T$$
$$-1.78428399°\sin(M1) + 0.02212824°\sin(M2)$$
$$-0.01028251°\sin(M3) - 0.00475595°\sin(M4)$$
$$\delta = 52.88627266° - 0.06134706°\,T$$
$$-1.07516537°\cos(M1) + 0.00668626°\cos(M2)$$
$$-0.00648740°\cos(M3) + 0.00281576°\cos(M4)$$
$$W = 35.18774440° + 1128.84475928°\,d + 12.72192797°\,T^2$$
$$+1.42421769°\sin(M1) - 0.02273783°\sin(M2)$$
$$+0.00410711°\sin(M3) + 0.00631964°\sin(M4).$$

The forcing terms of the physical libration in longitude of Phobos are given by

$$W_{lib} = 1.73203319°\sin(M5) + 0.01635407°\sin(M6)$$
$$+0.00021426°\sin(M7)$$

and the arguments of the trigonometric functions are

$$M1 = 190.72646643° + 15917.10818695°\,T$$
$$M2 = 21.46892470° + 31834.27934054°\,T$$
$$M3 = 332.86082793° + 19139.89694742°\,T$$
$$M4 = 394.93256437° + 38280.79631835°\,T$$
$$M5 = 189.63271560° + 41215158.18420050°\,T$$
$$+ 12.71192322°\,T^2$$
$$M6 = 19.26538605° + 82430316.36864280°\,T$$
$$+ 25.42412173°\,T^2$$
$$M7 = 208.89882434° + 123645474.54466790°\,T$$
$$+ 38.13293168°\,T^2.$$

The resonant rotation parameters for Deimos are

$$\alpha = 316.65705808° - 0.10518014°\,T$$
$$+3.09217726°\sin(M8) + 0.22980637°\sin(M9)$$
$$+0.06418655°\sin(M10) + 0.02533537°\sin(M11)$$
$$+0.00778695°\sin(M12)$$
$$\delta = 53.50992033° - 0.05979094°\,T$$
$$+ 1.83936004°\cos(M8) + 0.14325320°\cos(M9)$$
$$+ 0.01911409°\cos(M10) - 0.01482590°\cos(M11)$$
$$+ 0.00192430°\cos(M12)$$
$$W = 79.39932954° + 285.16188899°\,d$$
$$-2.73954829°\sin(M8) - 0.39968606°\sin(M9)$$
$$-0.06563259°\sin(M10) - 0.02912940°\sin(M11)$$
$$+0.01699160°\sin(M12).$$

The forcing terms of the physical libration in longitude of Deimos are given by

$$W_{lib} = 0.03080596°\sin(M13)$$
$$+ 0.01248044°\sin(M14) - 0.00437509°\sin(M15)$$

and the arguments of the trigonometric functions are

$$M8 = 121.46893664° + 660.22803474°\,T$$
$$M9 = 231.05028581° + 660.99123540°\,T$$
$$M10 = 251.37314025° + 1320.50145245°\,T$$
$$M11 = 217.98635955° + 38279.96125550°\,T$$
$$M12 = 196.19729402° + 19139.83628608°\,T$$
$$M13 = 10.80071482° + 10414879.22849759°\,T$$
$$M14 = 345.99306351° + 4801583.39793913°\,T$$
$$M15 = 303.28024985° + 10415546.40050500°\,T,$$

with d and T denoting the ephemeris time measured in days and centuries, respectively.

The value for the prime meridian constant (zero order term in the expression for W) represents the orientation of an averaged rotation of the satellite at the J2000 epoch. Thus, the prime meridian of the satellite is defined dynamically, i.e. based on the orbital motion. This ensures that at apo- and pericenter the x-axis of the satellites body-fixed frame coincides with the direction to Mars' center of mass (within the accuracy of the rotation model of about 40 arc second).

In order to incorporate the physical libration in longitude into the rotational model of Phobos the expression for W has to be modified according to

$$W \rightarrow W + A1\sin(M5) + A2\sin(M6) + A3\sin(M7),$$

where $A1$, $A2$ and $A3$ are measurements of the forced libration amplitudes at the corresponding frequencies of the forcing terms in W_{lib}.

5. Discussion

The need for updated resonant rotational parameters for Phobos and Deimos was stated by Thomas C. Duxbury. He noticed a significant 1.4 degree deviation of Phobos' x-axis orientation with respect to Mars' center of mass, when rotational parameters currently adopted for Phobos are used [8]. This observation sparked discussion among the geodetic community. Robert A. Jacobson released a similar set of parameters for the rotation of the Martian moons that is equal to the presented model within about 40 arc seconds (about 5 m at Phobos surface) [9]. The current accuracy is considered sufficient for cartographic purposes but might need improvement for tasks like high precision landing on Phobos.

Acknowledgements

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A Raman Spectrometer for the ExoMars 2020 Rover

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1. Context

The Raman project is devoted to the development of a continuous wavelength Raman spectrometer and to support the ExoMars-2020 rover science.

ExoMars is a twofold mission with different launch opportunities: the first one (ExoMars-2016, launched March 2016) put into orbit the Trace Gas Orbiter (TGO) with a scientific payload to study Mars atmosphere and a communication system for the following mission. The second one (ExoMars-2020, to be launched July 2020) will land and deploy a rover which includes for the first time in the history of Mars exploration, a drill that is capable of obtaining samples from the surface down to 2 m depth. These samples will be crushed into fine powders and delivered to the analytical instruments suite inside the rover by means of a dosing station.

The ExoMars rover will carry a suite of instruments dedicated to exobiology and geochemistry research. Its main scientific objective is “searching for evidence of past and present life on Mars". A continuous wavelength Raman instrument (Raman Laser Spectrometer – RLS) has been selected as part of this analytical suite inside the body of the vehicle.

Raman spectroscopy is related with the inelastic scattering of coherent light. When a monochromatic beam impinges a material, a tiny part of the scattered radiation is emitted at different wavelengths of the incident light. This wavelength shift contains structural and chemical information of the irradiated material through their atomic and bounding vibrations. This makes Raman spectroscopy a powerful technique since no direct contact with samples is necessary. It is very fast, non-destructive, and very selective for molecular identification.

The RLS is being developed by a European consortium composed by Spanish, UK, French, and German partners. The science team also includes members from the US and other countries.

2. The RLS instrument

The RLS consists of three main units: 1/ the spectrometer is a transmission spectrograph using a holographic grating that disperses the Raman signal which is projected on a 2048 x 512 pixel CCD operating at cold temperature; 2/ the control and excitation unit includes the DC/DC power converters and the data processing capability. This unit includes the laser with two redundant excitation outputs. Its role is also to capture state-of-health parameters, to drive the autofocus, and to run the thermal management; 3/ the optical head focuses the laser on the sample mineral grains and collects light from the same spot. The range of focus is ±1 mm for both the excitation and the collection. The three units are connected by optical fibers and electrical harnesses. RLS carries its own calibration target.

3. First performance results

The RLS Engineering and Qualification Model (EQM) has been manufactured, integrated, and tested end of 2016, early 2017. The EQM has been qualified for the mission thermo-mechanical and EMI/EMC specifications, finally achieving flight qualification with the required scientific performances. It was finally delivered to ESA by July 2017.

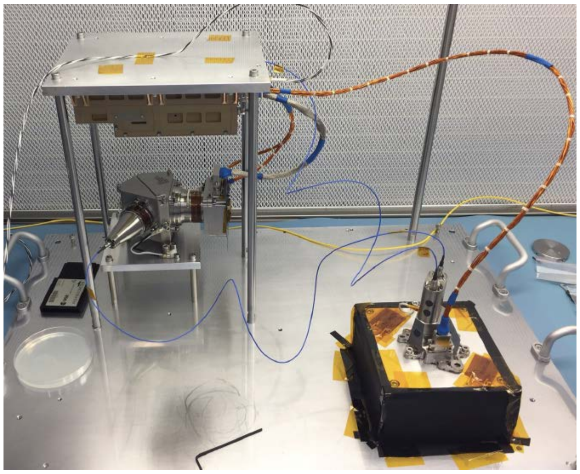

Figure 1: RLS EQM test setup. The 3 units are shown: top left, mounted upside-down, the excitation unit; below, the spectrometer; bottom right, the optical head

The EQM was used to characterize RLS baselined performances:

- Laser excitation: 532 nm (stable to ±20 pm)
- Irradiance on sample: 0.6 - 1.2 kW/cm^2
- Spectral range: 150 – 3800 cm^{-1}
- Spectral resolution: 6 – 8 cm^{-1}
- Spectral accuracy: < 1 cm^{-1}
- Spot size: 50 microns

The EQM was also used to produce Raman spectra under different operating conditions (temperature, integration time, electronic bias, etc.). 2D spectra are presented Figure 2 for the PET cal target.

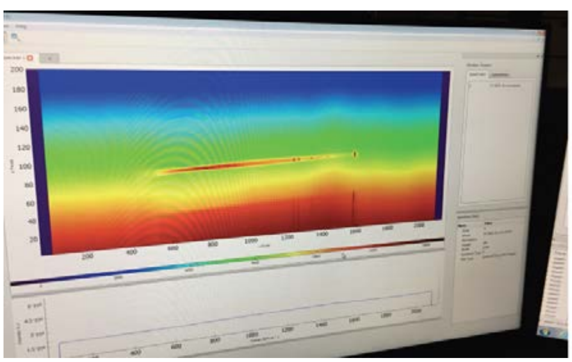

Figure 2: RLS EQM 2D spectra of the PET calibration target.

Standard processing was used to remove the darks, denoise the spectra, co-add several acquisitions, and to collapse the meaningful lines to obtain 1D spectra (Figure 3). The known molecular signature of this type of material is clearly observable.

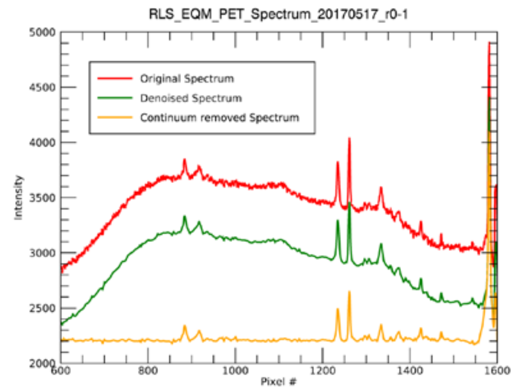

Figure 3: RLS EQM 1D spectrum of the PET calibration target. 1s Integration Time

4. Path forward

Next step is the RLS FM delivery to TAS-I (Q1 2018) for its final integration on the ExoMars-2020 Rover. As part of the final characterization, a library of reference spectra will be acquired under different operating conditions.

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How to improve a critical performance for an ExoMars 2020 Scientific Instrument (RLS). Raman Laser Spectrometer Signal to Noise Ratio (SNR) Optimization

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Abstract

The Raman Laser Spectrometer (RLS) is one of the Pasteur Payload instruments, within the ESA's Aurora Exploration Programme, ExoMars mission.

Raman spectroscopy is based on the analysis of spectral fingerprints due to the inelastic scattering of light when interacting with matter.

RLS is composed by Units: SPU (Spectrometer Unit), iOH (Internal Optical Head), and ICEU (Instrument Control and Excitation Unit) and the harnesses (EH and OH). The iOH focuses the excitation laser on the samples and collects the Raman emission from the sample via SPU (CCD) and the video data (analog) is received, digitalizing it and transmiting it to the processor module (ICEU).

To extract useful analytical information from Raman spectroscopy the spectral quality has to be increased. This quality is mainly limited by the signal to noise ratio (SNR). The SNR can be improved both increasing the intensity and decreasing the noise.

The RLS EQM Instrument has been characterized and configured for improving its high levels scientific performances, the SNR.

1. Introduction

One of the instruments of the ExoMars mission Pasteur Payload, within the ESA's Aurora Exploration Programme, is the Raman Laser Spectrometer (RLS). RLS will perform Raman spectroscopy for the first time in an out planetary mission. To do it, RLS have required different main elements:

- SPU, Spectrometer Unit, in charge of the spectral analysis. The CCD detects the data and transfers the spectrum to the ICEU.
- iOH, Internal Optical Head, responsible of focusing the excitation laser light in the sample (maximizing SNR).
- ICEU, Instrument Control and Excitation Unit, provides the excitation signal and the operational control of the instrument.

During the EQM integration and testing campaign, the instrument has been submitted to an continuous optimization process, operation, functionality; operation SW; and also obtaining representative data with real samples (SNR, accuracy…) which depending on a set of configurable parameters allows performances improvements:

- Excitation laser (power stability and wavelength)
- Autofocus to get the spectra in the optimum position.
- CCD control: gain, offset

- Operation: number of acquisitions (N) and integration time
- Thermal control (CCD and laser)

and also using analytical tools like the radiometric model.

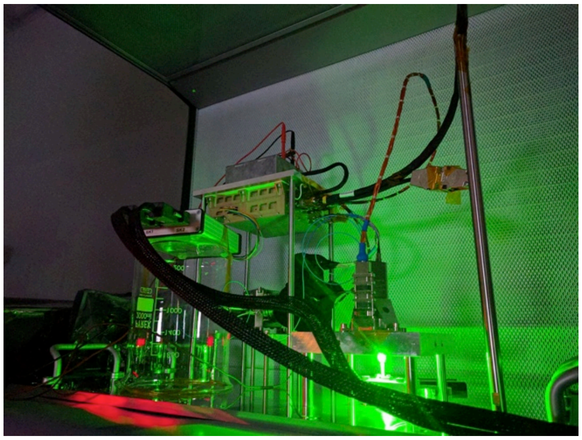

Figure 1: RLS EQM instrument test set-up

2. RLS instrument SNR dependability

The main sources of noise arise from the sample, the background, and the instrument (Laser, CCD, focuss, acquisition parameters, operation control). In this last case the sources are mainly perturbations from the optics, dark signal and readout noise. Also flicker noise arising from laser emission fluctuations can be considered as instrument noise.

In order to evaluate the SNR of a Raman instrument in a practical manner it is useful to perform end-to-end measurements on given standards samples. These measurements have to be compared with radiometric simulations using Raman efficiency values from literature and taking into account the different instrumental contributions to the SNR.

2.1 RLS Laser (ICEU)

The Raman Laser Module generates the optical monochromatic. The laser light is green (532.0 +/- 0.5 nm) and the output power is set by design to 36 mW.

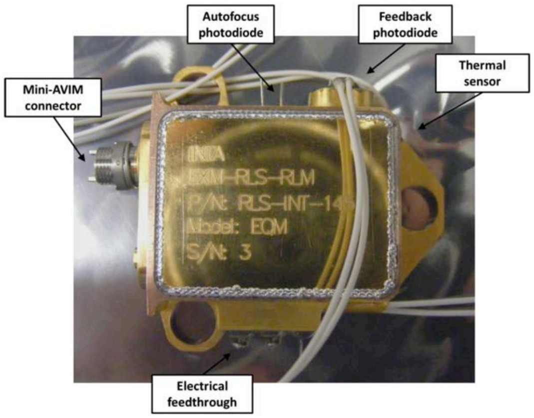

Figure 1: RLS laser EQM

The Raman Laser Module comprises a number of components whose functionality is guaranteed by the ICEU. Some of then are linked to the SNR performance:

- Photodiode feeds the ICEU laser driver with an electronic signal proportional to the laser beam output power.
- Autofocus photodiode receives the reflected beam from the sample. RLS On-board SW commands the AF system to guarantee that the iOH is optimally focused and SNR is maximized.
- Thermal control (TEM) to get the laser temperature in set point from any non operative conditions; once this temperature is reached on the laser can be switched on and thermally controlled for being able to provide the desired optimum laser performances in terms of power stability, peak width, peak stability and non secondary peaks.

2.2 RLS CCD (SPU)

The RLS CCD is a NIMO (non-inverted) controlled by the FEE (Front end electronics):

- Provides the required biasing and control signals to drive the CCD (within the SPU function). The commanding of the FEE function comes from the FPGA (processor module inside the ICEU) and the biasing is mainly fed from the internal supply lines generated at the power module

- Receives the video data coming from the CCD (analog), digitalizing it and transmitting it to the processor module

When acquiring Raman spectra, there are many instrument parameters, especially for the CCD device, that must be configured to optimize spectra (temperature, gain, offset) and SNR performance. Adjusting the CCD the sensitivity of the CCD (Gain), we can help boost the input throttle back video noise as appropriate. On the other hand with the video offset we can scale the real signal generated by the illuminating light.

The CCD is thermally controlled by a TEC that is capable of getting the CCD temperature cooled down from any hot operative conditions until a commanded temperature; to provide the desired optimum CCD performances in terms of noise reduction. As lower is the temperature the dark signal drops with a higher factor.

2.3 RLS spectra acquisition

Two operational-level parameters, Integration Time (ti) and Number of Accumulations (na), are the key parameters of Raman acquisition. Both helps the optimization of the signal/noise ratio (SNR).

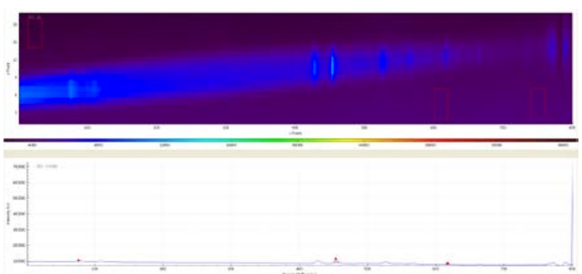

Figure 3: RLS EQM spectra acquisition over the CT

Performing accumulations in stable conditions. The laser excitation source needs to be stable and in similar thermal conditions than in previous acquisition.

Autonomous algorithm will be implemented in the RLS FM on board SW for helping the SNR improvements:

- Fluorescence removal
- Acquisition parameters estimation

3. SNR measurements

Signal to Noise ratio (SNR) values achieved by the instrument are considered end-to-end and needs to be estimated experimentally.

With the correct instrument configuration and the HW in operative conditions; the SNR for different samples material (Silicon, Cyclohexane, Calcite and Hematite) is achievable.

The acquisition time defined (one second) has been understood as total integration time (multiple acquisitions are allowed).

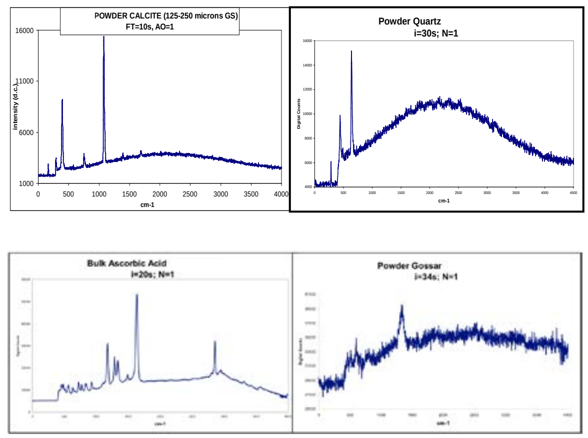

Figure 4: RLS EQM SNR analyisis over different materials

4. Summary and Conclusions

The RLS EQM instrument performances results and its functionalities have been demonstrated in accordance with the science expectations. The Instrument obtained SNR performances in the RLS EQM will be compared experimentally and via analysis, with the Instrument Radiometric Model tool.

The characterization process for SNR optimization is still on going. The operational parameters and RLS algorithms (fluorescence removal and acquisition parameters estimation) will be improved in future models (EQM-2) until FM Model delivery.

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