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ADVANCED POINTING IMAGING CAMERA (APIC) CONCEPT. R.S. Park[1] and J.E. Riedel, [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (e-mail Ryan.S.Park@jpl.nasa.gov)

Introduction: Advanced Pointing Imaging Camera (APIC) is a high-resolution imaging system which simultaneously takes images of targets and star fields with two-axis control capability, allowing rapid target imaging and image motion compensation (IMC) with extremely precise pointing knowledge. Such imaging data can accurately measure the geophysical property and high-resolution topography of target objects. Figure 1 shows the CAD drawing of APIC and Table 1 shows its characteristics.

Main Objectives: The main science application of APIC is to serve as a geodesy/geophysical instrument which can provide the data to constrain the interior structure of planetary objects. Specific science objectives include: Determination of geometric tidal flexing of natural satellites and Determination of rotational libration, nutation, and precession of natural satellites and asteroids.

Science and Engineering Enabled by APIC:

- APIC's 2-DOF actuation would allow significantly more effective and efficient science/mission operations by providing rapid and flexible imaging capability (e.g., significant reduction in mission duration and much less constraints on spacecraft operational geometry).

- APIC's IMC ability, using the internal gimbal and attitude knowledge dramatically reduces the implementation and operational cost of IMC for any mission, and increases the achievable resolution of fast flyby missions.

- APIC's high-resolution narrow-angle-camera (NAC) and a wide-angle-camera (WAC) would provide important unique science return via the ability to simultaneously take the images of target body and star field, allowing high-resolution surface imaging with extremely precise pointing knowledge. Such imaging data with precise pointing information can accurately measure the tidal deformation and/or libration/precession of the target body, and thereby reveal target body's interior structure

- Furthermore, APIC can provide data for stereo (or stereophotoclinometric) reconstruction of target topography, including shape, size and volume, with control networks that would provide very accurate determination of the target-relative position of the spacecraft.

- APIC's combined functionalities would offer a powerful optical navigation capability, that would significantly enhance spacecraft orbit reconstruction and prediction accuracy, and thus, reducing operational cost. Furthermore, APIC can serve as an ideal platform for autonomous navigation and internal star-finding/tracking can provide backup attitude information for the host spacecraft

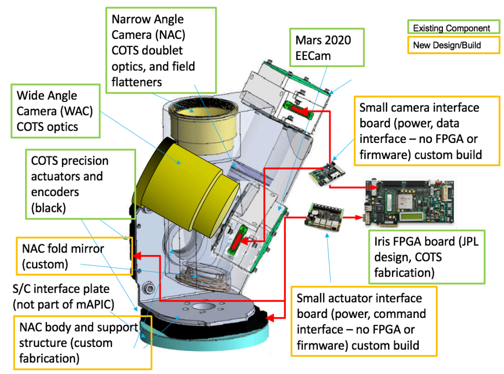

Figure 1: APIC current design showing principal components and heritage

Parameter	Values
Dimension	~2U
Mass	4 kg
Rad Shielding	0.5 kg
Power	12 W
Image Res	19 µrad
Pointing Knowledge	2 arcsec
Az Range	inf
El Range	±90°
Az max rate	30°/s
El max rate	30°/s

Table 1: APIC characteristics

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SPRITE (Saturn PRobe Interior and aTmosphere Explorer): A Saturn Entry Probe Mission Concept

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Abstract

To improve models of Solar System origin, formation, and evolution, and to provide an improved context for exoplanet systems, measurements of the composition, structure, and processes within giant planet atmospheres are needed. In particular, measurements that cannot be made in any other way than direct sampling are particularly important, including the abundances of noble gases and noble gas isotopes. Other measurements of high value for in situ measurement include isotope ratios of hydrogen, carbon, oxygen, and nitrogen, as well as the atmospheric dynamics, thermal profile and processes, and cloud structure are necessary. To improve understanding of Saturn's interior structure and composition, and (by proxy) those of extrasolar giant planets, the Saturn PRobe Interior and aTmosphere Explorer (SPRITE) entry probe mission concept would address these science priorities as well as provide ground truth for remote sensing.

The SPRITE Mission concept comprises a solar powered Carrier Relay Spacecraft (CRSC) and an entry probe descending through ten bars in about 90 minutes. The primary scientific instrument payload of SPRITE would comprise two spectrometers – a a Tunable Laser Spectrometer and a Quadrupole Mass Spectrometer, and an Atmosphere Structure Instrument that includes a simple nephelometer and a Doppler Wind Experiment for characterizing Saturn's tropospheric thermal, cloud, and dynamical structure. The Atmospheric Structure Instrument also includes accelerometers to measure entry accelerations from which the probe entry trajectory and descent location would be reconstructed and from which the thermal structure of the upper atmosphere would be determined. The Carrier Relay Spacecraft carries a Multi-Channel Imager to provide local and global context imaging for the probe measurements and for pre-entry imaging of the probe entry location.

SPRITE would reach Saturn in ten years following an Earth-Venus-Earth-Earth gravity assist trajectory. The SPRITE probe would enter Saturn at an atmosphere-relative velocity of ~27 km/s resulting in a peak deceleration up to 45 g's and a peak heat flux near 3000 W/cm^2. The aeroshell would be released above the tropopause, initiating the descent science sequence and allowing up to 2 hours for the probe to reach 10 bars. The descent probe design is fully-redundant to ensure low risk data return, with a dual-channel telecommunication system powered by primary batteries. After the probe science data is collected by the Carrier Relay Spacecraft, the probe data and carrier imaging data would be downlinked to Earth multiple times through the Deep Space Network.

In the context of giant planet science provided by the Galileo, Juno, and Cassini missions to Jupiter and Saturn, a small, relatively shallow Saturn probe to make measurements not possible from remote sensing including the abundances and isotopic ratios of noble gases, as well as the vertical profile of other key atmospheric constituents, the atmospheric structure and processes including the profiles of pressure, temperature, dynamic, and the location and properties of the clouds would serve to test competing theories of solar system and giant planet origin, and chemical and dynamical evolution.

Acknowledgements

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Mars Energetic Particles Analyzer onboard the Orbiter of China's First Mars Exploration

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Abstract

China's Mars probe including an orbiter and a lander/rover will be launched in 2020. A Mars Energetic Particles Analyzer (MEPA) instrument has been selected as one of the payloads on the orbiter. The main scientific objective of the MEPA is to study the characteristics of energy particles in Mars space environment and Earth-Mars transfer orbits. The MEPA is an energetic particle spectrometer consisting of a solid-state detector stack and CsI scintillator with active coincidence logic to identify energetic particles using the method of dE/dx vs E. A prototype version of MEPA was designed and some experiments have been conducted to test the validity of the design.

1. Introduction

China's first Mars exploration mission will be performed around 2020. One scientific objective of the orbiter is to detect and analyze the Mars ionosphere and the interplanetary environment[1]. MEPA is designed based on this scientific objective. In addition to the detection of the interplanetary space and the Mars space radiation environment, MEPA is designed to provide environmental parameters for many other scientific objectives and technological objectives.

1.1 Scientific Objectives

The scientific objectives of the MEPA are as follows:

(1)Study the characteristics and changes of energy spectrum, elemental composition and flux of energetic particles, including electrons, protons, α-particle and heavy ions(Z≤26), in Mars space environment and Earth-Mars transfer orbit.

(2)Plot the spatial distribution maps of radiation of different energy particles by combining the time information of the acquired particles.

(3)Study the relationship between near-Mars space energy particle radiation and the atmosphere, the effect and interaction of solar energetic particle events on Mars' atmospheric escape, and the process of active particle acceleration and transport, by cooperating with Mars Ions and Neutral Particle Analyzer and Mars Magnetometer.

1.2 Technical Requirements

The specifications for the MEPA are listed in Table 1.

Table 1: Specifications for the MEPA

Instrument Parameter	Characteristics
Energy Range	Electrons：0.1～12MeV; Protons：2～100MeV; α-Particles、Heavy Ions：25～300MeV.
Energy Resolution (ΔE/E)	15%
Flux Range	$0\sim10^5 cm^{-2}s^{-1}$
Elementary Composition	H～Fe (1≤Z≤26)
Heavy Ion Mass Resolution (Δm/m)	≤25% (Z≤9, energy range 25~300MeV); ≤25% (10≤Z≤26, energy range 100~300MeV); ≤60% (10≤Z≤26, energy range 25~100MeV).
Field of View (FOV)	60°
Time Resolution	4s (Electrons, Protons, α-Particles); 60s (Heavy Ions).

2. The MEPA Instrument

MEPA is an energetic particle analyzer designed to characterize the energy particles in near-Mars space environment and Earth-Mars transfer orbit, including both charged particles (1≤Z≤26) and electrons. The MEPA instrument (Figure 1) consists of a solid-state detector telescope with two different thickness silicon detectors (SDs, referred to as the SD1 and SD2) for the detection of electrons and charged particles, and two scintillators for the detection charged particles. The scintillators include a CsI crystal to stop the charged particles and an anti-coincidence shield to veto charged particles entering the MEPA from the side or bottom. MEPA uses a coincidence logic system which base on the dE/dx method to identify charged particles.

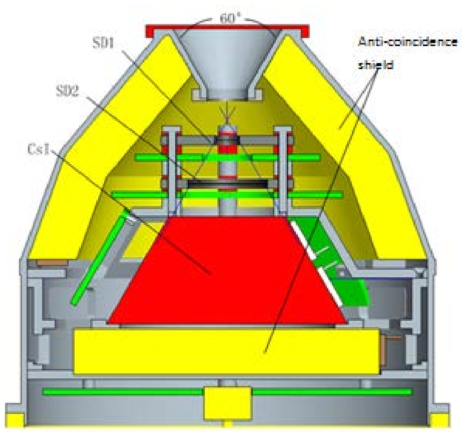

Figure 1: View of the MEPA instrument.

3. Test and Results

The sensor head of the MEPA prototype consists of a 30µm silicon detector, a 300µm silicon detector and a 32.5mm CsI detector. During the development of the prototype, a beam generated by a heavy ion accelerator was used to test the sensor head of the prototype. The beam test experiment used a ^{40}Ar beam flow of 300MeV/u to bombard a 3mm thick CH target. To detect the reaction product, the prototype was placed approximately 1m away from the target, and the angle between the beam and the prototype is around 30 degrees. The energy loss on SD2 and the energy loss on CsI are plotted in a two-dimensional spectrum (Figure 2).

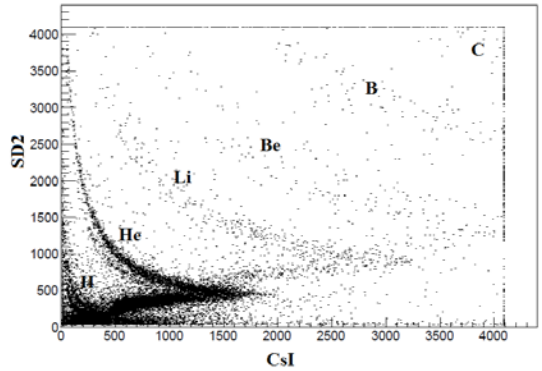

Figure 2: The particle identification spectrum of the prototype beam test.

According to the simulation parameters obtained from the prototype beam test results, the ΔE-E two-dimensional spectrum (Figure 3) of all detected particles of the MEPA was calculated using the Geant4 simulation program.

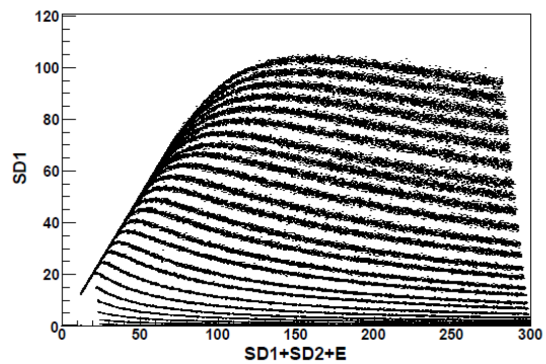

Figure 3: Simulation analysis of all detected particles using Geant4 simulation program (vertical incidence).

4. Summary and Conclusions

The MEPA is an important space environment exploration payload on the orbiter of China's first Mars exploration. The energy particle characteristics of near-Mars space and Earth-Mars transfer orbits can be obtained by using MEPA, which provides support for subsequent Mars scientific exploration.

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The Hera Saturn Entry Probe Mission Concept

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Abstract

1. Introduction

A fundamental goal of solar system exploration is to understand the origin of the solar system, the initial stages, conditions, and processes by which the solar system formed, how the formation process was initiated, and the nature of the interstellar seed material from which the solar system was born. Key to understanding solar system formation and subsequent dynamical and chemical evolution is the origin and evolution of the giant planets and their atmospheres. Additionally, the atmospheres of the giant planets serve as laboratories to better understand the atmospheric chemistries, dynamics, processes, and climates on all planets in the solar system including Earth, offer a context and provide a ground truth for exoplanets and exoplanetary systems, and have long been thought to play a critical role in the development of potentially habitable planetary systems.

Remote sensing observations are limited when used to study the bulk atmospheric composition of the giant planets of our solar system. A remarkable example of the value of *in situ* probe measurements is illustrated by the exploration of Jupiter, where key measurements such as noble gases abundances and the precise measurement of the helium mixing ratio have only been made available through in situ measurements by the Galileo probe. Representing the only method providing ground-truth to connect the remote sensing inferences with physical reality, *in situ* measurements have only been accomplished twice in the history of outer solar system exploration, via the Galileo probe for Jupiter and the Huygens probe for Titan. *In situ* measurements provide access to atmospheric regions that are beyond the reach of remote sensing, enabling the dynamical, chemical and aerosol-forming processes at work from the thermosphere to the troposphere below the cloud decks to be studied. The Hera Saturn entry probe mission was proposed to the European Space Agency in response to the Medium Class mission announcement of opportunity and is currently under consideration as an ESA M-class flight mission. The proposed Hera mission comprises an atmospheric entry probe built by the European Space Agency with contributions from NASA, to be released into the atmosphere of Saturn by a companion solar-powered Saturn Carrier-Relay spacecraft (CRSC) possibly provided by NASA. The CRSC would deliver the probe to the Saturn entry interface point and subsequently act as a relay station to receive the probe science telemetry for recording and later transmission to Earth. Hera would descend under a sequence of parachutes to depths of at least 10 bars in approximately 75 minutes. By probing deep into the cloud-forming region of the troposphere to locations where certain cosmogenically abundant species are expected to be well mixed and far below regions accessible to remote sensing, Hera would measure the atmospheric composition, most notably noble gases and key isotopes not accessible by remote sensing, as well as the thermal and dynamical structure of Saturn's atmosphere at the probe descent location.

The battery-powered Hera probe would be designed from ESA elements with contributions from NASA, with the Carrier Relay Spacecraft possibly supplied by NASA. The only major subsystem to be provided either by direct procurement by ESA or by contribution from NASA is the probe entry aeroshell and thermal protection system.

Following the example set by the highly successful example of the Cassini-Huygens mission, the Hera probe science team would comprise an international science team and would carry European and American instruments, with scientists and engineers from both agencies and many affiliates participating in all aspects of mission development and implementation. The basic Hera probe science payload would include a Mass Spectrometer to measure the bulk composition of Saturn's atmosphere, an Atmospheric Structure Instrument to measure the thermal structure and stability of Saturn's atmosphere, and a Doppler Wind Experiment to measure the dynamics of Saturn's atmosphere. Other possible instruments in the Hera scientific payload include a Net Flux Radiometer to measure the energy balance of the Saturn atmosphere and a Nephelometer to measure cloud location and structure.

In the context of giant planet science provided by the Galileo, Juno, and Cassini missions to Jupiter and Saturn, the Hera Saturn probe would provide critical measurements of composition, structure, and processes that are not accessible by remote sensing. The results of Hera would help discriminate between competing theories of solar system and giant planet origin, chemical, and dynamical evolution.

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A Joint NASA/ESA Mission Concept for In Situ Probe Explorations of the Ice Giants

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Abstract

1. Introduction

The top-listed goal in the NASA 2018 Strategic Plan is to "Expand Human Knowledge through New Scientific Discoveries", with a key Strategic Objective to *Understand the Sun, Earth, Solar System, and Universe*. The outer solar system comprises many unexplored bodies within which exists evidence of solar system origin, formation, and processes central to the evolution of the solar system. The ice giants Uranus and Neptune are a largely unexplored class of planet that has received only the briefest of glimpses by the Voyager 2 spacecraft. The value of further studying the ice giants as essential to understanding the solar system is reflected in the Planetary Sciences Decadal Survey Vision and Voyages 2013-2022 recommendation of a Uranus orbiter and probe as the highest priority new start Outer Planet flagship mission [1]. Following up on that, a joint NASA-ESA study of potential ice giant missions was recently completed [2]. Preliminary planning for the ESA Cosmic Visions 2050 prioritizes an M-class mission contribution to a possible future NASA flagship ice giant mission, utilizing a unique planetary alignment in 2028-2032 [3].

The ice giant planets fill the gap in size between the larger gas giants and the smaller terrestrial planets including Earth. Aside from the initial reconnaissance by Voyager 2, to date much of our knowledge of ice giant cloud-top composition and atmospheric processes arises from distant observations from space-based telescopes and observatories on Earth. However, whether from Earth or from a local spacecraft, remote observations cannot directly provide unambiguous measurements of the abundances of noble gases and key isotopes, as well as the altitude profiles of atmospheric thermal and energy structure, stability and dynamics, composition, and cloud properties. [4]

Due to the physical limitations of remote sensing and the lack of *in situ* measurements, many of the most important physical and atmospheric properties of the ice giants are poorly constrained and the ultimate role of the ice giants in the evolution of the Solar System is currently impossible to ascertain. Only *in situ* exploration by a single or multiple descent probes can reveal the secrets of the deep, well-mixed atmosphere that contains clues from the epoch and location of ice giant formation. Of particular importance are the chemically inert noble gases. With no detectable radio signature and therefore requiring direct sampling, the noble gases reflect the processes of ice giant origin, formation, and evolution, including the delivery of heavy elements, and evidence of possible giant planet migration.

A mission concept for a flagship mission to one of the ice giants includes a NASA-provided spacecraft that would carry and deliver a European probe to the ice giant atmospheric entry interface point, and would subsequently act as a relay receiving station for the atmospheric probe science telemetry. The primary goal of the European ice giant atmospheric probe would be to measure the well-mixed abundances of the noble gases He, Ne, Ar, Kr, Xe and their isotopes, the altitude profile of the heavier elements C, N, S, and P, key isotope ratios $^{15}N/^{14}N$, $^{13}C/^{12}C$, $^{17}O/^{16}O$ and $^{18}O/^{16}O$, and D/H, and disequilibrium species CO and PH_3 which act as tracers of internal processes. The atmospheric probe would sample well into the cloud-forming regions of the troposphere where many cosmogenically important and abundant species are expected to be well mixed, far below regions directly accessible to cloud top remote sensing.

Throughout the atmospheric descent, the probe would measure pressure and temperature to provide valuable context for the composition measurements, the vertical thermal and energy structure and static stability, the location, density, and composition of the upper cloud layers, as well as direct tracking of the planet's atmospheric dynamics including zonal winds, waves, convection and turbulence.

It is important to recognize that a single probe can make the most critical measurements of noble gases and isotopic ratios, as atmospheric weather and circulation do not significantly alter those abundances in the troposphere. Multiple probes are most valuable for studying horizontally varying conditions due to weather, seasonal, and circulation-driven processes.

The ice giant planets represent the last unexplored class of planets in the solar system and along with super-Earth sized planets (up to 2x Earth diameter), Uranus-Neptune sized planets are the most frequently observed exoplanets. Extended studies of one or both ice giants would include interiors, moons, rings, magnetospheres, origins, and atmospheres. In particular, detailed studies of atmospheric structure, processes, and composition, noble gas abundances require *in situ* measurements from an entry probe to further constrain models of solar system formation, chemical, thermal, and dynamical evolution, the formation and evolution of atmospheres, atmospheric processes, and to provide further ground-truth for many exoplanetary systems.

Additionally, the ice giant planets offer laboratories for studying the dynamics, chemistry, and processes in other planetary atmospheres including that of Earth. By extending the legacy of the Galileo Jupiter probe mission and possibly a future Saturn entry probe mission, an ice giant probe or probes would further discriminate between and help refine theories addressing the formation, and chemical, dynamical, and thermal evolution of all the giant planets, the solar system including Earth and the other terrestrial planets, and lend significant insight into the formation and structure of exoplanetary systems.

Acknowledgements

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Multiband, infrared imager for study of high temperature volcanism on Io

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Abstract

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

1. Introduction

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

2. Current state of the technology

In the ideal application scenario, infrared imagers and spectrometers would provide high-resolution images containing spectral and temporal information with high signal-to-noise ratio and infinite dynamic range. The currently existing technologies are capable of providing only two out of three types of information (Fig. 1). For example, the currently deployed imaging spectrometers only acquire one-dimensional spatial imaging and utilize scanning to obtain a two dimensional image. This results in a time delay between obtaining data at different wavelengths for different points in the image, which is highly undesirable when a target event (e.g. a volcanic eruption) is changing on a time scale faster than the data acquisition time. Also, these instruments can be saturated if the signal is higher than anticipated. With volcanic eruptions for example, the strength of the thermal emission is impossible to predict.

3. Simultaneous multiband, infrared imager

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

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

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

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

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

4. Figures

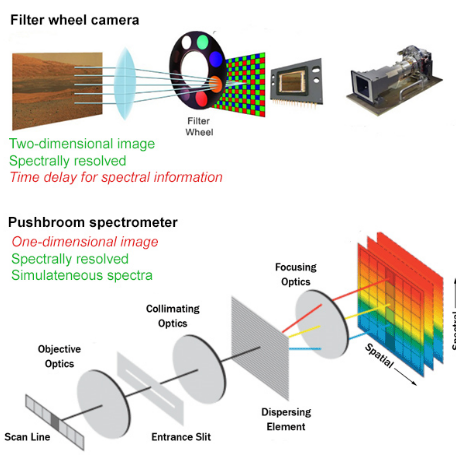

Figure 1: Two most commonly used approaches to acquire spectrally resolved images. (Top) The filter wheel camera that can obtain two dimensional images but has a time delay between images acquired in different spectral windows. (Bottom) Pushbroom spectrometer that only acquires a one-dimensional spatial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

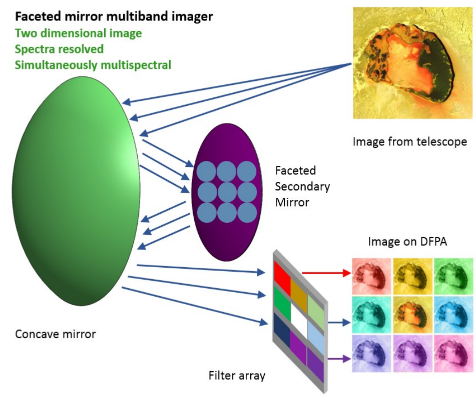

Figure 2: Illustration of a faceted mirror multiband imager. The faceted secondary mirror creates multiple images at the focal plane. Each image except for central one is filtered by a bandpass filters in a filter array mounted above the digital focal plane array.

5. Summary and Conclusions

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

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MetNet Mission for Mars – Current Status and Future Prospects

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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. Introduction

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 (see Figure 1):

<u>Atmospheric instruments:</u>

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

<u>Optical devices:</u>

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

<u>Composition and Structure Devices:</u>

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

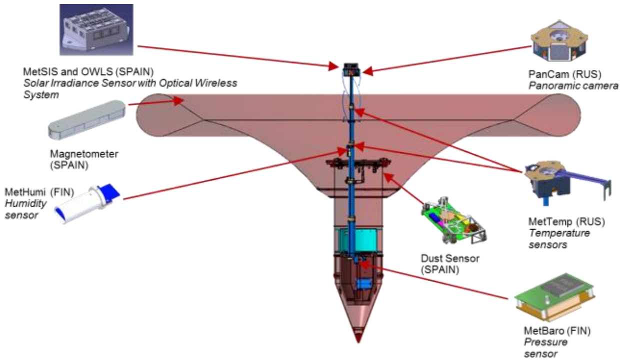

Figure 1: MetNet Lander strawman payload scheme.

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

Full Qualification Model (QM) of the MetNet landing unit with the Precursor Mission payload is currently under functional tests (Figure 2). In the near future the QM unit will be exposed to environmental tests with qualification levels including vibrations, thermal balance, thermal cycling and mechanical impact shock. One complete flight unit of the entry, descent and landing systems (EDLS) has been manufactured and tested with acceptance levels (See also Figure 3). Another flight-like EDLS has been exposed to most of the qualification tests, and hence it may be used for flight after refurbishments. Accordingly two flight-capable EDLS systems exist.

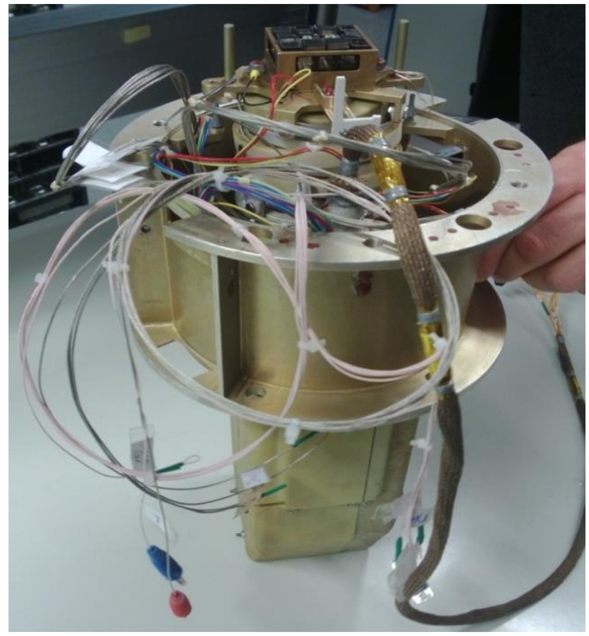

Figure 2: Payload bay EQM in tests in FMI.

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 in the MetNet Precursor Mission is the demonstration of 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. The baseline program development funding exists for the next five years. Flight unit manufacture of the payload bay takes about 18 months, and it will be commenced after the Precursor Mission has been defined

Figure 3: Screen shots from the video showing the MetNet Lander drop and inflation tests.

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Supporting M5 Science Missions to Small Bodies – An OHB Perspective

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Abstract

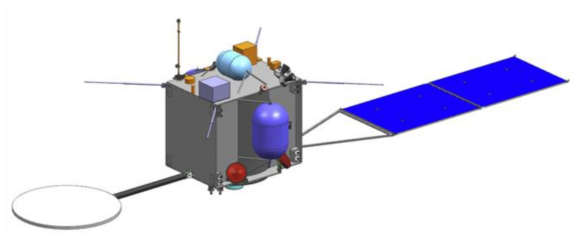
DePhine, Castalia, CASTAway and MarcoPolo-M5 were all proposed as possible mission concepts to ESA's next (M)edium class mission call. Thirty-seven proposals were submitted to ESA in October 2016, and evaluated against their scientific justification, payload selection, spacecraft design and programmatics. Ultimately, three mission candidates were selected by ESA in May 2018. OHB System provided industrial support by demonstrating how four of these different mission scenarios could be implemented. For each, a baseline scenario, with additional mass and cost saving opportunities were explored, assisted by concurrent engineering techniques. Each mission was proposed to be ESA-led, but within the context of international collaboration.

1. Introduction

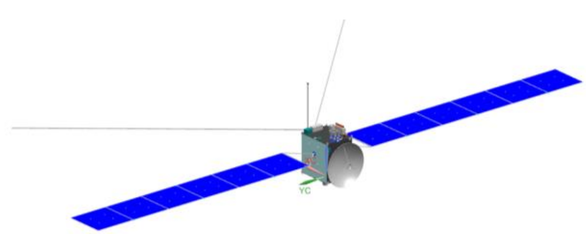
M5 is the fifth medium-class mission in the ESA Cosmic Vision Plan. It follows on from Solar Orbiter (M1), Euclid (M2), PLATO (M3) and ARIEL (M4). Thirty-seven proposal were received from a community wide science call, and evaluated against a competitive and peer-review process. OHB System supported four of these mission concepts – DePhine, Castalia, CASTAway & MarcoPolo-M5 – which demonstrates OHB's increasing role in space-science as a Large System Integrator. OHB was also awarded the prime contract of PLATO (exoplanet telescope, phase B2/C/D). This presentation reports on the key space-science competences at OHB; combining concurrent engineering techniques with industrial knowledge. The overarching science justification are fused with a feasible mission architecture and subsystem design. The mission call necessitated a launch in 2029/30+, with a preference for a European launcher (VegaC or Ariane 6 class) and qualified equipment, and a high technology readiness spacecraft (TRL 5/6 at mission adoption). All missions were proposed to be ESA-led, with options for international collaboration. There was no mission or in-orbit duration requirement (except the associated cost impact). There was also no constraint on the spacecraft and payload mass (dependent only on the limit of the launcher).

2. Mission & Spacecraft Concepts

The mission and spacecraft-system design of the four M5 concepts were developed using the Concurrent Engineering Design Facility (CEFO) at OHB. An international teams of scientists, mission analysis, (sub)system engineers and costs experts were combined simultaneously in a series of guided design-loops. The level of analysis is comparable to an internal phase 0, enabling the key drivers and main trade-off to be assessed. The results, as shown in Figure 1, demonstrates compliance to the M5 boundary conditions, and the feasibility of the mission architecture & spacecraft (sub)system design.



DePhine



Castalia

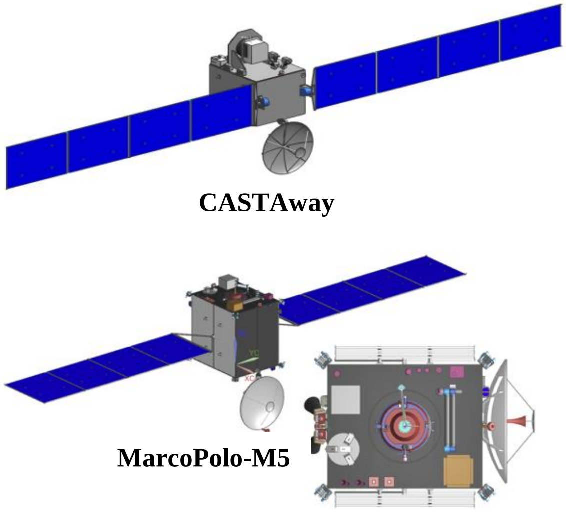


Figure 1: Spacecraft Designs

DePhine was proposed to explore the origins and evolution of the Martian satellite system of Deimos and Phobos [1][2]. The spacecraft will be injected directly into Mars transfer orbit, where it will first enter a quasi-satellite orbit with Deimos. Compressive mapping is performed and the spacecraft performs a number of low velocity flyby events. The spacecraft then transfers into a 2:1 resonance with Phobos. Multiple flyby and remote sensing observations (similar to those for Deimos) will be performed for comparative analysis. **Castalia** was proposed as a mission to rendezvous with a Main Belt Comet (MBC), 133P/Elst-Pizarro [3][4]. MBCs challenge the traditional definition of asteroids and comets, the early evolution of the main asteroid belt, and the origins of water on Earth. Castalia would rendezvous with 133P/Elst-Pizarro using electric propulsion. The spacecraft arrives before perihelion, where it hovers down towards the MBC's surface during periods of activity, performing in-situ measurements of the gas and dust. **CASTAway** combines a long-range (point-source) telescopic survey of the main asteroid belt, with a number of pre-planned asteroid flyby events [5][6]. The spacecraft will loop thorough the main asteroid belt, providing a comprehensive survey of the main asteroid belt at multiple size scales. **MarcoPolo-M5** seeks to rendezvous with a primitive D-type asteroid [7]. It will characterise the surface and interior in detail and then return material from the surface back to Earth.

3. Summary

Analysis demonstrated the initial feasibility of the DePhine, Castalia, CASTAway and MarcoPolo-M5 missions for the M5 call opportunity. Although ultimately not selected by ESA, they can be conceived with the boundary conditions of an ESA Medium class mission opportunity (or comparable to a US Discovery Class mission). The flexibility of using concurrent engineering technique enabled additional mass and cost saving measures to be examined. This addressed the uncertainty in the launcher performance. Similarly, the mission profiles can be easily supplemented to provide a greater, more compelling scientific return (e.g. transfer & orbit selection, number of flybys, small deployable lander). The speculative performance (or saving) relative was examined relative to the performance of the launcher.

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Analysis and Design for Parachute Deceleration and Landing Process on Mars

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Abstract

In deep space exploration, Mars exploration has always been the focus of national attention. As early as the 1960s, the United States and the Soviet union began the Mars exploration, and today, the Mars exploration is still in full swing. Since the Soviet union's first attempt to land on Mars in 1962, the world's space powers have carried out 18 landing mission, only seven successful missions. Although the success rate is less than 39 percent, future space powers will still include the Mars exploration in development planing, and China is working on a Mars exploration project.

Currently, all missions are using parachute to slow down the lander. A parachute landing on Mars is a key in the process of detection. But there is a big difference Mars parachute landing process has the characteristics of supersonic speed and low dynamic pressure. Moreover, the understanding of the atmosphere environment of Mars is not clear enough, and the understanding deviation of atmospheric parameters is large, which poses great challenges to the work of the parachute deceleration system. In addition, several key process directly affects the success or failure of the entire Mars exploration and landing mission.

Based on the above situation, this paper will focus on China's mission to Mars landing, identify the key process of the whole working process on the parachute system, and worth to pay close attention to each process of the specific issues. Through dynamic simulation method, it gives the key technical ways and research analysis of concrete problems, improving the working reliability of the Mars deceleration and landing mission.

In this paper, we first introduce the parachute deceleration system scheme and the four stages of the deceleration and landing process of China Mars exploration. On this basis, for the parachute opening condition, the parachute ejection straight load and working performance, parachute and capsule system stability, parachute stable drop speed, capsule attitude after dropping heat bottoms, landing site scope, effect on deviation, the paper research technology approaches and analysis. This paper has certain reference significance to the Mars exploration deceleration and landing task.

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Loss of potassium during the Moons history

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Abstract

To understand the origin of the Earth-Moon system and further evolution of the lunar composition one has to understand the unique chemical and isotopic signatures of the Moon compared to other planetary bodies. The Moon is significantly depleted in volatile elements such as potassium (K) and sodium (Na) compared to the bulk silicate Earth. We study the K loss of the K during the short expected magma ocean phase after the Moon forming event, and model the loss induced by surface sputtering due to the plasma (solar wind and coronal mass ejections) of the young Sun during the past 4.5 billion years. We discuss our results in relation with Moon-forming hypotheses and point out which future observations at the Moon are needed to quantify the escape rates from the Earth-Moon system and their variability due to different solar activity. This knowledge is important to understand the long-term evolution of the atmosphere and is essential to the understanding of the history of the Moon and Earth as well as their interaction processes with the early Sun. Finally, particle observations near or at the Moon will allow us to examine the exact composition of the escaping minor elements in the Earth magnetotail

1. Scientific Relevance

Potassium (K) and its isotopes are crucial elements for testing the giant impact theory and related processes during the Moon-forming event. This is because K is a moderately volatile element and the lunar environment is significantly depleted in K and other volatile elements such as Na relative to the bulk silicate Earth composition and the compositions of carbonaceous chondrites. The ratio between K and the heavier element uranium K/U is an important indicator of such depletion because U is a refractory element so that this ratio is expected to be largely preserved during the Moon-forming event.

On the Moon, the K/U ratio is about five times lower than that of the Earth and about twenty-five times lower than that of the CI chondrites. So far, the mechanism that caused this depletion is not well understood [1]. Some researchers think that volatile-element-depleted bodies such as the Moon should have been enriched in heavy potassium isotopes during the loss of volatiles. Because such enrichment was never found, hypotheses like high-angular-momentum giant impact scenarios, etc. are proposed [2]. However, outgassed elements like K during the magma ocean [1] phase may result in very efficient loss rates that do not separate between small mass differences [3]. We therefore study the depletion of K, its isotopes and other elements during the magma ocean phase after the Moon-forming events and investigate if these losses fractionate K isotopes or not. After the magma ocean solidified, the Moon was continuously bombarded by solar wind plasma and radiation, and by enhanced terrestrial outflow during its transitions through the magnetotail [4]. In the beginning, the CME occurrence rates and solar wind parameters (e.g., density, velocity) were much higher compared to that of today's Sun. We also estimate the loss of K during the past 4.5 billion years from the lunar surface by applying a surface sputtering model [5,6] during the Moon's orbit around the Earth. We also discuss the possible shielding effect of the Earth's magnetosphere. Finally, we discuss the relevance to measure the particle outflow from the Moon into space by a lunar orbiter or platform with dedicated instruments: plasma, magnetic field measurements, energetic neutral imager, and neutral particle detectors outside the spacecraft to continuously monitor the plasma and particle environment [see also 7].

2. Summary and Conclusions

We estimate the atmospheric loss and thus depletion of volatile elements with a focus on the radioactive heat-generating element K during and after the magma ocean phase of the Moon. This is important for reproducing the K/U ratio during the Moon's history. Understanding the K/U fraction will help to constrain the solar activity evolution of the young Sun and the thermal history of the Moon during the first 100 Myrs after its formation.

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Research on the asteroid landing and adhesion mechanism

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Abstract

In recent years, both at home and abroad in the study of biomimetic climbing robot adsorption technology has carried out a lot of work, biomimetic climbing robot has a good ability to adapt to complex terrain, based on the imitation of the beetle adhesion technology for reference, this paper proposes a asteroid claw thorn adhesion system, can be used for an asteroid landing task. Based on the attachment system, the working principle of claw attachment is described, the scheme design of the system is introduced, and the summary and prospect are given. This paper provides a reference for the exploration and research of deep space exploration adhesion technology.

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A Proposed Mission to Very Low Mars Orbit – Supported by an Electric Propulsion System

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Abstract

We investigate possible missions in Low Mars Orbit (LMO) (< 200 km), where the thin but significant Martian atmosphere causes a strong drag force and typically limits the lifetime of orbiting satellites. To prolong satellite operation, we investigate possibilities to compensate atmospheric drag with an electric propulsion system. As a reference we used a spacecraft system similar to the DAWN mission with electric thrusters of 90 mN. The results showed that a compensation of the drag force with these thrusters could be possible for a long-lasting mission at altitudes above 150 km. The mission opens opportunities for novel remote sensing approaches of Mars.

1. Introduction

Due to the atmospheric drag, spacecraft in circular orbits about the planet (e.g., MRO or the ExoMars Trace Gas Orbiter), typically travel in heights above 250-400 km. In our study we focus on the idea of placing an orbiter at closer distances (approx. 150 km) to the surface.

Remote sensing can benefit from such an orbital mission in terms of better data resolution, while sounding instruments may profit from high signal strength. We anticipate high-resolution imaging (not requiring excessive telescope equipment), as well as radar sounding and Laser altimetry (not requiring excessive power). Magnetic field mapping will enjoy high signal strength and high spatial resolution of data.

The thin atmosphere of Mars and the resulting drag reduces the altitude of a spacecraft. In order to avoid a de-orbiting of the spacecraft we plan to use an electric propulsion system which compensates the drag force continuously. In this study we investigate at which altitude a propulsion system would be capable to compensate this drag.

2. Method

First, we consider a simple density scale height model, which yields Mars' atmospheric density for given spacecraft height h. in our numerical simulation of the type:

$$\rho(h) = \rho_0 * e^{-h/H} \qquad (1)$$

with ρ_0 being the reference density at the reference surface and H is the atmospheric scale height of 11.1 km.

We used two different reference densities to best fit the data from the MCD. The first is the high density state with $\rho_0 = 0.001\ \mathrm{kg/m^3}$ and a low density with $\rho_0 = 0.0001\ \mathrm{kg/m^3}$.

We also considered the existing models of the Martian atmosphere, which is known to vary with latitude, with time of day and season. The Mars Climate Database (MCD v 5.3) [1][2] was used as a baseline.

To determine the drag force, which acts on the S/C, the following equation was used:

$$F(h) = {}^{1}\!/_{2}\, \rho(h)\, v(h)^2\, C_D\, A \qquad (2)$$

where A= 40.8 m² is spacecraft cross section (2.8 m² S/C + 38 m² solar panel), v(h) is spacecraft circular velocity at a given altitude and C_D = 2.0 is the drag coefficient. Typical spacecraft speeds in LMO are in the range of 3.45-3.55 km/s.

We adopt a spacecraft model to determine the resulting drag force. Mass and cross section of the

DAWN mission are used a reference to calculate the resulting drag force on the spacecraft.

DAWN is equipped with an electric propulsion system, with engines have a specific impulse of 3100s and a thrust of 90mN [4]. We determined at which distance the electrical propulsion system would be capable to compensate the atmospheric drag.

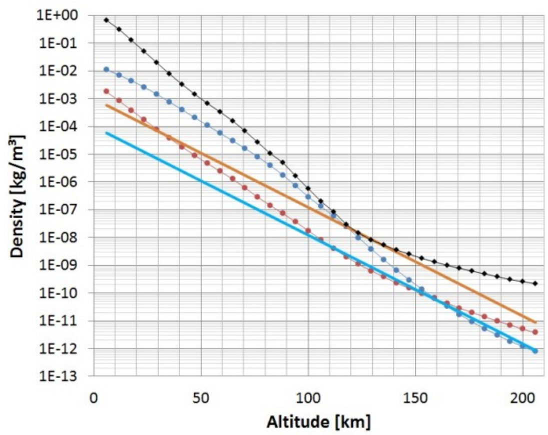

Figure 1: Martian atmospheric density over height, used in the study. Blue dots: MCD values for Lat 0N, Long 0E; red dots: MCD values for Lat 90N, Long 0E; solid orange: high density ($\boldsymbol{\rho_0 = 0.001\ kg/m^3}$); solid blue: low density ($\boldsymbol{\rho_0 = 0.0001\ kg/m^3}$); black dots: Earth atmosphere, for reference [3]

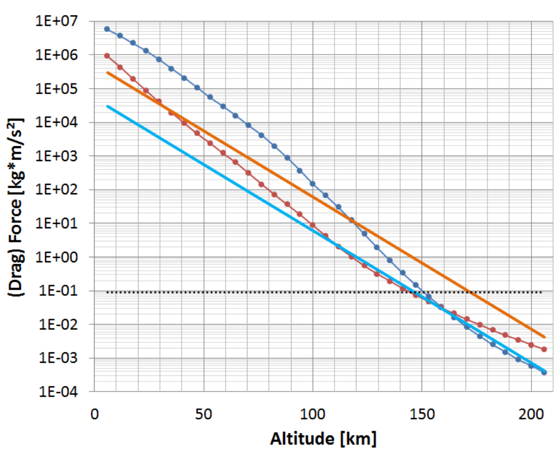

Figure 2: The figure shows the Martian atmospheric drag force over height used in the study, adopting the drag equation and parameters as described in the text. The black dots show the output of the 90 mN DAWNs ion thrusters (other color codes as in Fig. 1)

3. Results, Summary and Conclusions

The results show that the atmospheric drag is in the range of approximately 100 mN at a height of 150 km above the Mars surface. Using numerical integration, we find that the lifetime of a typical free-flying spacecraft would be in the range of 1 day up to two weeks. However, a spacecraft system similar to DAWN would generally be capable to compensate the atmospheric drag in a circular orbit by continuously using its ion thrusters. If we consider an eccentric orbit, a spacecraft may achieve temporarily lower altitudes. (Note that Mars Express, e.g., travels in a highly eccentric orbit of 258 x 11560 km).

Any such spacecraft mission must deal with the complex structure of the Martian atmosphere, varying regionally and over time. Also, the solar power requirements for the electric propulsion (and limited Sun viewing when in low Mars orbit) must be carefully studied.

With the given orbital mission, we anticipate new opportunities for spacecraft instrumentation and science. The mission would also allow for mapping of the density structure of the Martian atmosphere and its variations in space and time.

At approximately 150 - 170 km the density above the North Pole and above the equator are of the same order of magnitude. Consequently it could be possible to place a spacecraft in a polar orbit.

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Venturing to Near-Earth Asteroid systems using Nuclear Electric Propulsion

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Abstract

In an effort to explore mission opportunities made possible by Nuclear Electric Propulsion (NEP) systems we studied a transfer of a NEP spacecraft from a low-earth orbit (LEO) to the near-earth binary 1866 Sisyphus. Using a simple analytical approximation we find the required launch window and thrust to meet the asteroid at the point of ecliptic intersection. Numerical methods are used to find a physically possible transfer model, also taking into account various gravitational perturbations. Assuming a departure from Earth (i.e., entry to hyperbolic path) in August 2023, we find a transit time to the target of 510 days.

1. Introduction

The International Nuclear Power and Propulsion System (INPPS) spacecraft will be launched for a testing of Nuclear Electric Propulsion in Earth orbit. After commissioning the spacecraft it is foreseen to venture into near-Earth space, where Near-Earth asteroids pose attractive targets of opportunity. Here, we study a mission to the binary NEO 1866 Sisyphus. The challenge is that the point of Sisyphus ecliptic intersection must be met by the spacecraft at some exact time due to Sisyphus rather high inclination of 41.2°

1.1 Objectives

The goal of the mission is to reach the binary NEO 1866 Sisyphus for a flyby starting from a circular low-Earth orbit with 7,800 km radius. The encounter is possible when Sisyphus crosses the ecliptic plane at 1.104 AU distance from the Sun (Figure 1). This maneuver should be done using only electric propulsion.

2. Method

To reduce complexity of the problem, electric propulsion is simulated to accelerate the spacecraft continuously in the direction of flight. As a reference we used spacecraft parameters similar to the BepiColombo mission which is equipped with electric thrusters (T6, Kaufman-type) providing 290 mN of thrust; the spacecraft has a total mass of 2,900 kg [3]. Until more accurate parameters of the INPPS spacecraft are known we neglect the decrease of mass due to fuel consumption.

2.1 Analytic approximation

An analytical approximation for the two body problem with continuous thrust (a_θ) in angular direction can be obtained under the assumption of a circular orbit. The change of the orbital radius r with time t is then given by the approximation:

$$r(t) = r_0 \;/\; (1 - a_\Theta t / v_0)^2 \qquad (1)$$

with r_0 and v_0 being the initial radius and velocity respectively. As the orbit will increase in eccentricity with time and since leaving Earth requires an hyperbolic orbit, the assumption does not hold for longer time periods. Validation of the results with numerical methods is necessary. Nevertheless analysis provides the means to determine the required time and thrust to reach a given helio- of geocentric radius.

2.2 Numerical solution

For high-accuracy determination of the spacecraft trajectory, we apply numerical methods. The initial position and velocity together with all perturbing and propelling forces pose a second-order ordinary differential equation (ODE) for the spacecraft motion. It is solved by numeric integration. The differential equation must be sufficiently smooth for efficient error estimation and error minimization. Therefore it is beneficial for the accuracy to simulate the propulsion as continuously and not impulsive. To simulate the perturbing gravitational forces of Sun, Moon, Mars and Jupiter we included ephemeris data into the numeric simulation. The positional data of the planetary bodies are taken from standard ephemerides (DE 421 [1]).

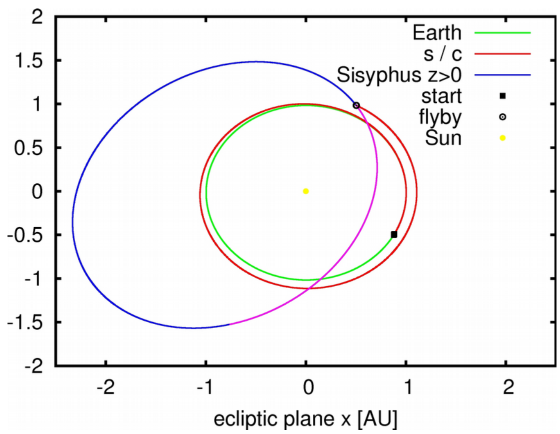

Figure 1: Transfer trajectory of the spacecraft (s/c) in the ecliptic plane. Starting outside Earth's sphere of influence on 24-AUG-2023 00:00 UTC, the encounter is on 06-JAN-2025 06:00 UTC. Sisyphus ecliptic ascending node indicated by color change violet to blue.

3. Results

Phase I of the maneuver is to reach a hyperbolic orbit relative to Earth. The initial orbit has a radius of 7,800 km and is assumed to be within the ecliptic. Assuming the full acceleration of 0.1 mm/s² of the electric thrusters (see 2.1) it takes 766 day of "orbit climbing" to increase the eccentricity to 1 and leave Earth. Despite the increasing eccentricity the analytic approximation holds up well and is accurate (Figure 2; top), except when the s/c passes the orbital height of the moon. Collision with the moon can be avoided by appropriate timing. In our simulations the inclination increased to 1° when passing the moon. With stronger thrusters the time required for Phase I is proportionally shorter. Starting in a geostationary transfer orbit will reduce the transit time about 600.

Phase II is the transfer to Sisyphus. Because the spacecraft mean motion changes with the radius according to Kepler's law we need a_θ to be an adjustable parameter to meet the longitude of the target intersection point at the correct time. Given the constellation of Earth and asteroid the acceleration through propulsion a_θ was decreased to 0.042 mm/s². The approximation (1) suggested a time of transfer of 396 days as first iteration. Starting with the eccentricity of Earth's orbit the actual solar distance differed significantly from (1) (Figure 2, bottom). Iterating numeric simulations gave a successful transfer arc (Figure 1,2). The time of travel is 510 days and 6 hours, accumulating a total delta-v of 2.18 km/s. We pass Sisyphus with a relative velocity of 24.43 km/s. The flyby distance can be chosen freely.

4. Summary and Conclusions

Even with the low acceleration provided by electrical propulsion it is possible, given sufficient time, to leave the low-Earth orbits and reach an asteroid such as Sisyphus. If the reduced acceleration of phase II is implemented by using the thrusters periodically the total operating time is approximately 980 days. We expect to find other favorable asteroid encounter opportunities, which require shorter transit times.

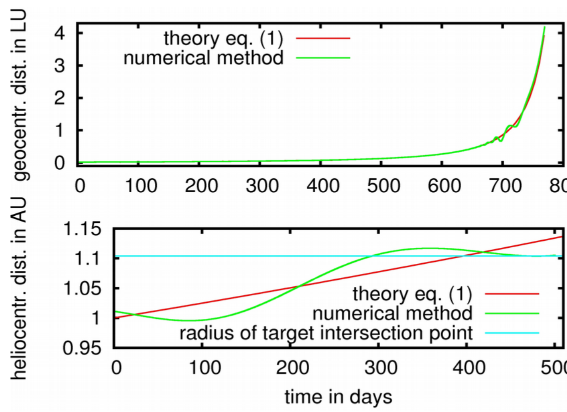

Figure 2: Change in radius during "orbital climb". Phase I (top) from LEO to hyperbolic escape. Distance shown in Lunar units LU. Phase II (bottom) from Earth orbit to Sisyphus encounter. Solution using numerical integration (green) is compared with analytical approximation (red).

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Proposed mission to Mars and his Trojan Asteroid Family – An Update Report

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Abstract

In the context of ESA's call for medium class missions, we have been investigating missions to Mars. As part of proposal development, we studied the option to visit a Mars Trojan on the way to the planet. We set up a three-impulse model to determine physically possible flyby scenarios and optimum trajectories in terms of mission time and costs. We propose several mission scenarios in the time frame 2020-2050 involving trajectories which require transit times of up to 5 years and an additional delta-v of 0.1-1km/s compared to a typical Mars-only mission.

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 satellites. In addition to the nominal mission plan, flyby scenarios with Martian Trojans on the way to Mars were analyzed. We present results from our initial search for physically possible trajectories within given constraints of time and costs.

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 evolution [5] and some of them may represent rubble piles, 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 Earth, this implies either high flyby velocities (> 5 km/s) for a spacecraft approaching or high delta-v demands for a rendezvous mission.

Table 1: Main osculating elements of the five largest Martian Trojans [6]

Asteroid	Semi-major axis [AU]	Eccentricity []	Inclination [deg]
5261 Eureka	1.5236	0.065	20.28
101429	1.5241	0.101	31.297
121514	1.5244	0.039	16.749
311999	1.5237	0.054	18.622
385250	1.5237	0.035	24.402

3.Transfer Scenarios

We consider flyby missions in the time frame 2020 – 2050 including transfers that involve more than one revolution about the sun. With the Earth and Mars ephemerides 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. Hence, we designed a transfer to Mars, during which the Trojan would intersect the course of the spacecraft [7]. We introduced a three-impulse model. The first impulse is used to depart from Earth, the second impulse is used for a course correction at the time of the Trojan flyby and the third for orbit insertion at Mars.

While flybys in theory are possible for any target, time and costs permitting, we cut-off and present models having delta-v < 1 km/s and transit time of < 5 years. We report on several scenarios, each including a flyby at one of two different Trojans. For our scenarios, overall additional delta-v demand is between 100 m/s and 1 km/s compared to a "regular" mission to Mars with a direct Hohmann-transfer.

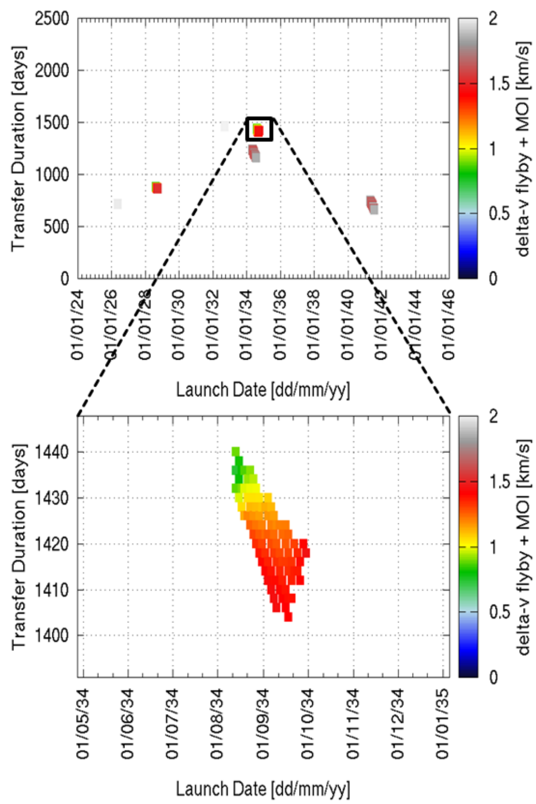

Figure 1: Example of possible Mars transfers with flybys at Martian Trojan 311999 (top). The color coding shows the overall delta-v demand for maneuver 2 and 3 (impulse after Trojan flyby and Mars orbit insertion)

4. Conclusion and Outlook

We evaluate the possibility to combine a mission to Mars with a flyby at Martian Trojans of the Eureka family. We show that it is possible to carry out flybys at Trojans with only a low demand for additional delta-v and propellant. On the other hand the low delta-v transfer requires a longer transfer time of up to 5 years. Such a scenario will increase project time line, complexity and overall costs of a mission to Mars.

While our crude model, involving 3-impulses at given time, suggests that a mission is possible in principle, the proposed trajectories can certainly be optimized. In our next steps we want to include a new model, which allows for more than 3 impulses, with the optimal time and magnitude of the impulses to be solved for. We expect to reduce the demand for delta-v.

We realize that a standalone mission to a Mars Trojan is currently probably far from practical in spite of an excellent science case. However, a combined mission to Mars and one of its Trojans may be conceivable, and science may be obtained at reasonable added costs.

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Emirates Mars Mission (EMM) 2020 Overview

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Abstract

The United Arab Emirates (UAE) has entered the space exploration race with the announcement of the Emirates Mars Mission (EMM), the first Emirati mission to another planet, in 2014. Through this mission, the UAE is to send an unmanned observatory, called Hope, to be launched in summer of 2020 and reach Mars by 2021 to coincide with the UAE's 50th anniversary. The mission will be unique, and has a strong potential to create novel and significant discoveries that contribute to the ongoing work of the global space science community. EMM has passed its development phase milestone reviews including Mission Concept Review (MCR), System Requirements Review and System Design Review (SRR/SDR), Preliminary Design Review (PDR), and Critical Design Review (CDR) phases. The mission is led by the Mohammed Bin Rashid Space Centre (MBRSC), in partnership with the Laboratory for Atmospheric and Space Physics (LASP) at University of Colorado, Boulder, Space Sciences Laboratory (SSL) at University of California, Berkeley, and School of Earth and Space Exploration at Arizona State University (ASU). The mission is designed to answer the following three science questions:

- How does the Martian lower atmosphere respond globally, diurnally, and seasonally to solar forcing?
- How do conditions throughout the Martian atmosphere affect rates of atmospheric escape?
- How does the Martian exosphere behave temporally and spatially?

Each question is aligned with three mission objectives and four investigations that study the Martian atmospheric circulation and connections through measurements taken using three instruments that image Mars in the visible, thermal infrared and ultraviolet wavelengths. Data will be collected at Mars for a period of an entire Martian year to provide scientists with valuable understanding of the changes to the Martian atmosphere today. This paper provides an overview of the mission and science objectives, instruments and spacecraft, as well as the ground and launch segments.

1. Introduction

The Emirates Mars Mission (EMM) is the United Arab Emirates (UAE) first mission to Mars and is the first Arab mission to another planet. The mission was announced by the UAE's Government in July 2014 with the objectives to complete Mars orbit insertion by the UAE's 50th anniversary in 2021, to contribute to the development of the Science and Technology Sector in the UAE, to develop the UAE's scientific capabilities, and to increase the UAE's contribution to the international scientific community. The mission also should have significant contribution to the ongoing work of the global space science community, and should be of a great value to ".

EMM will launch an unmanned observatory called "Hope" into an elliptical orbit around Mars in the summer of 2020 carrying three scientific instruments to study the Martian atmosphere in the visible, ultraviolet, and infrared bands.

The mission is led by Emiratis from Mohammed Bin Rashid Space Centre and will expand the nation's human capital through knowledge transfer programs set with international partners from the University of Colorado Laboratory for Atmospheric and Space Physics (LASP), University of California Berkeley Space Sciences Laboratory (SSL), and Arizona State University (ASU) School of Earth and Space Exploration.

2. Science Objectives and Investigations

Our understanding of Mars' atmosphere has been significantly limited by the fixed local time of recent measurements made by several spacecraft, leaving most of the Mars diurnal (i.e. day-to-night) cycle unexplored over much of the planet. Thus important information about how atmospheric processes drive diurnal variations is missing. This limited coverage has hindered our understanding of the transfer of energy from the lower-middle atmosphere to the upper atmosphere. These Martian atmospheric science issues can be distilled to three motivating science questions leading to three associated objectives summarized in Table 1.

Table 1: EMM Motivating Science Questions and Objectives

Motivating Questions	EMM Science Objectives
How does the Martian lower atmosphere respond globally, diurnally and seasonally to solar forcing?	A. Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability
How do conditions throughout the Martian atmosphere affect rates of atmospheric escape?	B. Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere.
How do key constituents in the Martian exosphere behave temporally and spatially?	C. Characterize the spatial structure and variability of key constituents in the Martian exosphere.

EMM will achieve these three objectives through four science investigations. All four investigations require atmospheric variability to be determined on sub-seasonal timescales. The correspondence between the mission objectives and investigations are shown in Table 2.

Table 2: EMM Science Objectives and Investigations

EMM Science Objectives	EMM Science Investigations
A. Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability	1. Determine the three-dimensional thermal state of the lower atmosphere and its diurnal variability on sub-seasonal timescales.
B. Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere.	2. Determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales.
	3. Determine the abundance and spatial variability of key neutral species in the thermosphere on sub-seasonal timescales.
C. Characterize the spatial structure and variability of key constituents in the Martian exosphere.	4. Determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescales.

3. Instruments Overview

EMM will collect information about the Mars atmospheric circulation and connections through a combination of three distinct instruments that image Mars in the visible, thermal infrared, and ultraviolet wavelengths. The instrument suite includes the Emirates eXploration Imager (EXI), the Emirates Mars InfraRed Spectrometer (EMIRS), and the Emirates Mars Ultraviolet Spectrometer (EMUS). A summary of the three instruments is in Table 3.

Table 3: EMM Payload

	EXI	EMIRS	EMUS
Payload Type	Ultraviolet & Visible imager	Fourier transform infrared spectrometer	Ultraviolet imaging spectrograph
Developer	LASP & MBRSC	ASU & MBRSC	LASP & MBRSC
Spectral Range	205-235nm 245-275nm 305-335nm 405-469nm 506-586nm 620-650nm	6 – 40 microns	100 – 170 nm

4. Spacecraft Overview

The spacecraft, named "Hope" and shown in Figure 1, provides the capabilities required to achieve and maintain the Mars orbit post-launch, supply the above-described payloads with needed structural support, power, thermal control, data handling, pointing, and fault management responses, send science, ancillary, and housekeeping data to the ground, and receive command data from mission operations centers. The spacecraft system includes the harnessing required to connect the payloads to the spacecraft for full space segment capability.

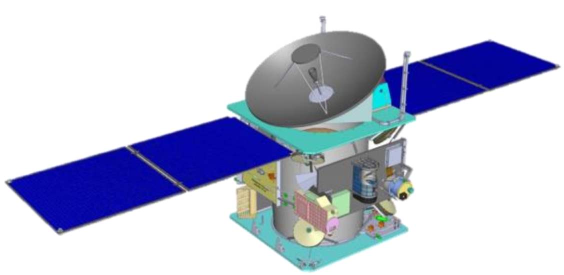

Figure 1: "Hope" Spacecraft Design

The observatory launch mass is 1500kg with a primary structure consisting of composite honeycomb panels and a propulsion subsystem capable of changing orbit trajectory, orbit braking to Mars target orbit plane and orbit maintenance.

While in space, Hope generates and stores power using two deployable solar arrays and batteries and communicates with Earth-based ground antennas using a 1.85m diameter high gain antenna and coupled low gain antennas. It utilizes the Applied Physics Laboratory (APL) Frontier Radio deep space transponder that performs uplink and downlink of data and supports deep space tracking for navigation purposes. For attitude determination, it will have a redundant pair of 3-axis inertial reference units and a redundant pair of star trackers. For attitude control, it has a set of four Reaction Wheel Assemblies (RWA), as well as eight Reaction Control System thrusters for momentum dumping.

5. Mission Timeline, Operation and Lifetime

EMM design, development and testing phase commenced in mid-2014 with the launch scheduled in mid-2020 for a total of 6 years. Figure 2 summarizes the timeline and major milestones of the mission.

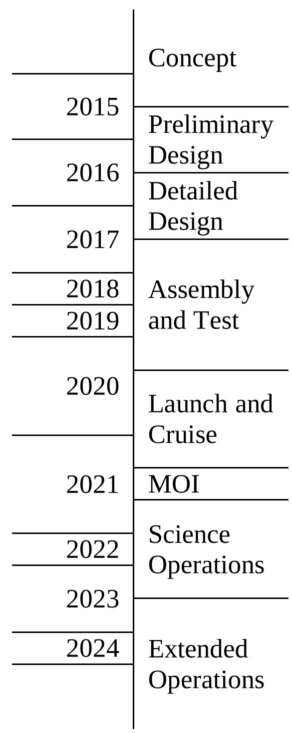

Figure 2: EMM Timeline

The Hope Probe is designed for a three Earth-year lifetime. Its operational life consists of the Cruise Phase, for around seven months, that follows launch and it will be limited to instrument checkout and calibration activities. Following Mars Orbit Insertion (MOI) that will last for a week, the Capture Orbit phase is characterized by a highly elliptical 35-hour orbit (500 km periapsis, 44,500 km apoapsis) from which all three instruments will be checked out and their science sequences tested, resulting in early observations of the Mars disk and upper-atmosphere. Following this, a Transition Orbit phase will be achieved by the gradual enlargement of the orbit over the course of approximately one month until it is optimized. The required science orbit for data collection is 20,000 km x 43,000 km. The Primary Science phase will begin and is expected to last 1 Martian year to meet the science requirements. The 20,000 km periapsis altitude during the Primary Science phase is sufficient to ensure global-scale, near-hemispheric views throughout the orbit and to allow daily coverage of all longitudes and local times. The orbital period will be approximately 55 hours which will enable a comprehensive characterization of Mars' lower atmosphere variability as a function of location, time of day, and season, as well as an understanding of how physical processes in the lower atmosphere affect the rates of escape from the exosphere.

6. Ground Segment Overview

The EMM project is responsible for developing complete ground segment capabilities in support of mission development and operations. The EMM ground segment is composed of the ground network and its ground stations, navigation system, operations centers, mission design, Science Data Center (SDC), and Instrument Team Facilities (ITFs).

The Mission Operations Center (MOC) and SDC are located at the MBRSC and the Mission Support Facility (MSF) is located at LASP. Telemetry is routed to both the MOC and MSF every contact, so that full flight data sets reside at each location. The MSF serves as a redundant operations capability. The ground network supports contacts as scheduled for each phase of the mission.

The navigation team provides determined ephemeris, predicted ephemeris, and burn solutions to maintain the orbit or trajectory. The ITF for each instrument is responsible for instrument builds and tests, as well as building a repository of engineering information supporting each instrument.

7. Conclusions

EMM will explore the dynamics in the atmosphere of Mars on a global scale while sampling contemporaneously both diurnal and seasonal timescales. Using three science instruments on an orbiting spacecraft, EMM will provide a set of measurements fundamental to an improved understanding of circulation and weather in the Martian lower and middle atmosphere. Combining such data with the monitoring of the upper layers of the atmosphere, EMM measurements will reveal the mechanisms behind the upward transport of energy and particles and the subsequent escape of atmospheric constituents from the atmosphere of Mars. The unique combination of instruments and temporal and spatial coverage of Mars' different atmospheric layers will open a new and much-needed window into the workings of the atmosphere of our planetary neighbor.

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Lunar Active Experiment (LAX) for Lunar Water Investigations

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Abstract

The lunar environment is characterized by complex interactions among several domains. Due to the lack of the atmosphere, the lunar surface, exosphere, space plasma, and dust are a closely coupled system. It is entirely different from that at Earth, while similar environments can be found elsewhere in the Solar System. The proposed experiment, LAX, Lunar Active Experiment, aims to investigate these couplings by actively disturbing the system and monitoring its responses through remote sensing in various wavelengths and particles. LAX is an equipment installed onto the Deep Space Gateway with two main modules: the Lunar Impacting Module (LIM), injecting a projectile with sizes of 0.1–10 kg depending on the experiment and the Remote Sensing Module (RSM), monitoring the response. LIM can be re-charged by the crew allowing various impact experiments.

1. Science background

The complex environment of the Moon is characterized by couplings of the surface, exosphere, dust, and the plasma [1]. In particular, several independent measurements claim the existence of water at the lunar surface and the cold traps, but its dynamics, including the source, transport, loss mechanisms are not fully characterized. We proposed the mission SELMA (Surface, Environment, and Lunar Magnetic Anomalies), which also planned to study such interactions, in response to the ESA's M5 mission call.

An area of particular scientific interest where the Deep Space Gateway can contribute is the study of the water (or hydroxyl) at the top-most layer of the lunar surface, and its coupling to the environment, including the exosphere, magnetic anomalies, and dust. Top-surface lunar water was first observed by infrared spectroscopy (e.g., [2]), and it exhibits a diurnal variation (e.g., [3, 4]). Recently, Wöhler et al. [5] reported a reduction of surface water signatures in the South Pole Aitken, where a local magnetic field can shield the proton flux precipitating onto the surface [6]. These measurements indicate that the solar wind proton precipitation is a strong candidate for surface water production. Transport (or loss) of such water is yet unknown, in particular the transport to cold traps at the lunar poles is not solved. The Lunar South Pole has several permanently shadowed regions where water molecules are thought to be stored in a form of ice. An impact experiment by L-CROSS mission [7] concluded that up to 6% of the surface materials in the Cabeus crater is water (likely ice). However, how much water exists is still controversial, mainly because different measurements led to different conclusions on the water content distributions. Most likely, states of the ice (e.g. embedded depth of the ice cube) are the reason for the contradicting observations.

2. Equipment and DSG

LAX is composed of two permanent units. Lunar Impacting Module (LIM) and Remote Sensing Module (RSM). LIM is a module to inject an impactor with a volume of up to 1 liter and a mass of 0.1–10 kg from the Deep Space Gateway. RSM will monitor the signatures of the lunar surface. RSM is equipped with four remote-sensing sensors and a dust monitor. RSM remote sensing sensors are an infrared spectrometer, with a wavelength coverage of 1.5–3.6 μm, a UV spectrometer, with a wavelength covering 115–315 nm, a visible camera and an energetic neutral atom (ENA) sensor. These wavelength ranges are optimized for water absorption bands, but by extending the IR wavelength to 3.6 μm we can mitigate the ambiguity of thermal background, which has been a problem of existing IR measurements (e.g. [2]). The UV wavelength range is also capable of exospheric gas composition measurements. The ENA spectrometer can detect the solar wind flux and the speed at the lunar surface, which we can directly correlate with the surface water signatures. RSM also includes dust monitor. Impact experiment (as well as natural meteoroids) can produce dust, which may potentially reach to DSG. The mass flux and the speed characterize the response of lunar regolith to the impact experiment (and bombardment of natural meteoroids). Dust monitoring also mitigates the potential hazard for the crew during DSG activities. Instrumentations are based on the proposed SELMA mission [1].

The unique idea of using the Deep Space Gateway and its crews is that the projectiles can be prepared right before the ejection. For example, we may even suggest to launch a water ice cube to emulate a comet nucleus. Such preparation and curation of projectiles and LIM recharging are only possible with manned missions.

Ideas for projectiles and the science

• Copper ball (or equivalent) with 10 cm diameter, impacting at cold traps to make a dust and water plume. See [1] for details.

• Copper ball (or cubesat) to impact a magnetic anomaly in order to monitor the volatile motion and its difference to other un-magnetized areas. See [1] for details

• Water ice cube impacting to the surface to make artificial "pond" of surface water to simulate a cometary nucleus impact

3. Expected impact

The active experiment conducted by LAX provides multiple opportunities of projectiles. Such repeatable controlled impacts provide a statistical view of the water contents inside the cold traps, as well as insights on the transport of the water molecules.

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The Surface Dust Analyzer (SUDA) on Europa Clipper

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Abstract

The Surface Mass Analyzer (SUDA) measures the composition of ballistic dust particles populating the thin exospheres that were detected around each of the Galilean moons. Since these grains are direct samples from the moons' icy surfaces, unique composition data will be obtained that will help to define and constrain the geological activities on and below the moons' surface. SUDA will make a vital contribution to NASA's Europa Clipper mission and provide key answers to its main scientific questions about the surface composition, habitability, the icy crust, and exchange processes with the deeper interior of the Jovian icy moon Europa.

SUDA is a time-of-flight, reflectron-type impact mass spectrometer, optimized for a high mass resolution which only weakly depends on the impact location. The small size, low mass and large sensitive area meet the challenging demands of mission to Europa. A full-size prototype SUDA instrument was built in order to demonstrate its performance through calibration experiments at the dust accelerator at NASA's IMPACT institute at Boulder, CO, with a variety of cosmo-chemically relevant dust analogues. The effective mass resolution of $m/\Delta m$ of 150-300 is achieved for mass range of interest m = 1-150.

In January 2018, SUDA has passed its Preliminary Design Review (PDR), a major cornerstone of the project. Flight prototypes of major instrument components including the high voltage and low voltage power supplies, the FPGA board, the ion detector, and the velocity detector have been designed and fabricated. The mechanical designed of the sensor head will be finished in a few month.

In this talk I will report about the status of the instrument development, the mission design, as well as about exiting new impact experiments into water ice.

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Hera – the European contribution to the first Asteroid deflection demonstration

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Abstract

Hera is ESA's contribution to the international Asteroid Impact Deflection Assessment (AIDA) cooperation, targeting the demonstration of deflection of a hazardous near-earth asteroid. Hera will also be the first in-depth investigation of a binary asteroid and make measurements that are relevant for the preparation of asteroid resource utilisation. Hera is foreseen to rendezvous with the binary near-Earth asteroid (65803) Didymos in 2026, four years after the impact of NASA's Double Asteroid Redirection Test (DART) spacecraft. Here we describe the contribution of Hera to the AIDA cooperation.

1. Introduction

Hera is a small mission of opportunity whose primary objective is to observe the outcome of a kinetic impactor test and thus, to provide extremely valuable information for possible future mitigation of the impact of a hazardous asteroid [1]. It is part of the Asteroid Impact & Deflection Assessment (AIDA) mission, in which the second component is the NASA Double Asteroid Redirection Test (DART) mission, which aims to send an artificial projectile to perform an asteroid deflection test [2]. The outcome will be observed by a cubesat provided by the Italian Space Agency (ASI) and carried to the target asteroid by DART, from ground-based observatories and from later observations by Hera during its rendezvous mission with the target asteroid. AIDA will thus be the first test ever to use a kinetic impactor to deflect an asteroid. The AIDA target is the binary Near-Earth Asteroid (NEA) (65803) Didymos (1996 GT), in particular the secondary component and target of the DART mission, called hereafter Didymoon. Here we discuss the Hera mission, an updated version of the Asteroid Impact Mission (AIM), originally proposed to be at Didymos during the DART impact. We show that most of the goals of AIM are still being fulfilled with the investigation of Didymos by the Hera mission.

2. Hera payload

The following instruments form the baseline payload of Hera:

- Asteroid Framing camera. This is a flight spare of the DAWN framing cameras [3] and will be used for science imaging and Guidance, Navigation, and Control. The image scale is ~1m/pixel from a distance of 10 km.

- A 6 U cubesat that will performed very close-proximity observations down to few cm-scale resolution of the crater and its surroundings. Payload options for the cubesat currently include two of the following: a spectral imager from 0.5 μm to 1.6 μm and as a point spectrometer from 1.6 μm to 2.5 μm, a spacecraft relative-radioscience package, a gravimeter, a high-frequency radar and a nephelometer.

- Planetary Altimeter (PALT). This is a lidar that will perform accurate distance measurements. The operating wavelength is 1.5 μm and the beamwidth 0.5 mrad.

- Hyperspectral imager (HYP), an imager with a linear variable filter attached to it, based on the CHIEM instrument developed for earth observations [4]

- Radio Science Experiment (RSE). Radio science makes use of existing hardware on the spacecraft to measure the gravity field of Didymos

It is expected that additional resources will be available onboard Hera. These will be allocated for additional payload should it be supported by ESA Member States. A workshop will be organized in late 2018 to provide an overview of available options. It will be followed by an announcement of opportunity to be expected in mid-2019.

3. Hera relevance for mitigation of an asteroid impact

Although the probability of an asteroid impact on Earth during the coming years is low, the potential consequences to our society could be very severe. Small bodies are continually colliding with Earth, however, the vast majority of these objects are very small (below 10 m in size) and pose no threat to human activity. Larger impacts (1 km or more) occur far less often but, when they do occur, they can lead to a major natural catastrophe. Fortunately more than 90% of the asteroid population with diameter of 1 km or larger is known and poses no risk. On the intermediate size (100-500 m range), damage can still be of regional scale (a country or a continent) and we only know a small fraction of these objects while their impact frequency becomes high enough (centuries to millenia, i.e., within the duration of a civilization) that we must study how to protect ourselves from the threat they pose. Indeed, the impact of an asteroid is the only natural disaster we may be able to accurately predict and prevent. For this we need to (1) improve our knowledge of the geophysical properties of bodies in this size range, (2) test our ability to deflect such a small asteroid, (3) complete the inventory of this population.

AIDA will allow us to address (1) and (2) for the first time. In terms of deflection techniques, we will never know whether we are ready if no test is performed. DART will hit the smallest component, whose size is the most relevant one for mitigation purposes. Groundbased observations will measure the change of the orbial period of Didymoon around Didymos imposed by the impact. However, only Hera can measure the mass of Didymoon, required to estimate the efficiency of the momentum transfer from DART to Didymoon. Furthermore, Hera will accurately measure the dynamical state of the Didymos system after the impact, directly measuring the excentricity imposed by the impact and any libration that may be have been introduced as a consequence of the impact. The investigation of the DART impact crater by Hera, together with the geophysical and surface properties of both asteroids, will allow us to validate/refine our numerical impact models that can then be used with higher confidence at such scales. All those measurements together will allow scaling of the results to other asteroids and therefore to predict the efficiency of the momentum transfer should the deflection of an asteroid be needed in the future.

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Design and development of an interferometric readout for planetary seismometers.

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1. Context

Seismometers are now likely to be placed on other planets and a seismic return on the Moon is currently considered. Indeed, the Apollo seismometers had a good sensitivity : 60 pm/$\sqrt{\text{Hz}}$ at 1 Hz but were however unable to detect all the seismic signals produced by the Moon, like the « lunar continuous meteoritic hum » estimated to be about 1/100 of the Apollo sensors resolution (Lognonné et al. 2009). The different core seismic phases, although detected through stacking (Weber et al. 2011, Garcia et al. 2011), have not also been individually recorded. A new generation of broadband planetary seismometers, 100 to 1000 times more sensitive than the Apollo ones is thus required. The idea consists in using the gravitational waves detectors' technology which is the reference in terms of interferometric measurements at low frequency and very low noise levels in order to improve the performances (linearity and noise level) of the seismometers' mass displacement sensors. The final objective is to reach a sensitivity of 40 fm/$\sqrt{\text{Hz}}$ at 1 Hz.

2. Pound-Drever-Hall method

An optical readout is proposed, based on the Pound-Drever-Hall laser frequency stabilization method. This technique allows to lock a laser frequency on the resonance frequency of a Fabry-Perot cavity. This kind of cavity acts like a frequency filter with reflection holes (which correspond to resonances) regularly separated by one FSR (Free Spectral Range). The idea is to send many frequencies inside the cavity. To do that, a phase modulation of the signal is realized by using an EOM (Electro-Optical Modulator) which keeps the signal carrier and creates two sidebands at $+f_m$ and -f_m, with ω_m the modulation frequency. These different frequencies have different reflections inside the cavity and their combination is equal to zero only if the incident light frequency is exactly the cavity resonance frequency. In the perfect case, the cavity output contains the unaltered sidebands and the phase shifted carrier. This shift depends on the offset between these frequencies. The important parameter of the Pound-Drever-Hall method is ϵ, the error signal, which is the amplitude of the sinusoidal signal at the modulation frequency reflected outside the cavity. It can be extracted by using a demodulation and is equal to zero in the perfect case of a laser beam frequency equal to the cavity resonance (Black, 2001). Then, this quantity of interest is sent thanks to a feedback loop to the laser in order to lock its frequency.

3. Optical readout global design

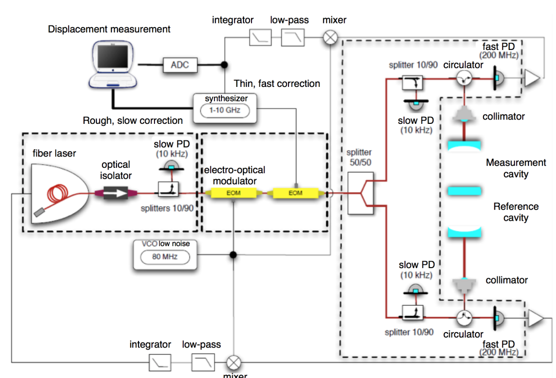

Figure 1: Global design of the optical readout proposed for the mass displacement sensor of a planetary seismometer. Red lines represent the optical fiber and black lines the electronic links.

The global design shown on Fig. 1 contains 2 back-to-back FP cavities with a central plan mirror which is supposed to be linked to the arm of a seismometer. The "reference" cavity allows to lock the laser frequency on its resonance by using the Pound-Drever-Hall method. The measurement of the reflected light outside the second cavity allows to determine the central mirror motion and thus the ground acceleration.

To do that, an additional EOM is placed to create like a second laser beam, at a different frequency, which is locked on the second cavity (Fig. 2). Its modulation frequency is tuned to match one new sideband with the second cavity resonance. In a perfect case, both cavities have exactly the same length, which means exactly the same FSR. The correction which has to be applied on the second EOM to keep the match between one new sideband and the cavity resonance allows to determine the difference between the both resonance frequencies (of both cavities) which is an information about their difference of length and thus about the ground acceleration.

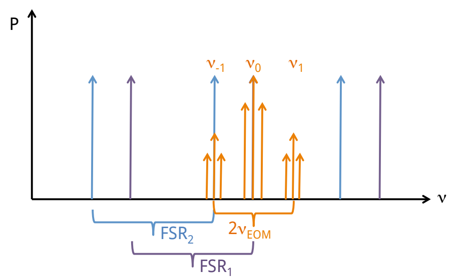

Figure 2: Result diagram of both feedback loops. First cavity resonance comb is in purple and the second one is in blue. The signal after passing through both EOM is represented in orange.

4. First results

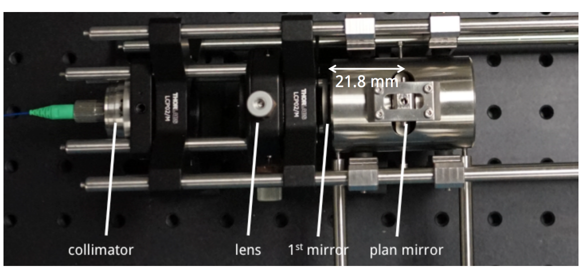

Figure 3: Implementation of the first cavity in a cleanroom. A 21.8 mm length induces a FSR of 6.876 GHz.

The first cavity is implemented in a cleanroom (Fig. 3) and its gain is measured. All the following noise source contributions are theoretically considered: shot noise, laser frequency stabilisation, cavity mechanical deformation, thermal common noise, temperature gradient, thermodynamic agitation noises (thermoelastic noise, thermorefractive noise, Brownian noise). Their worst estimated values and the measured cavity gain induce a total sensitivity of 12.8 fm/$\sqrt{}$Hz at 1 Hz in the worst case. This value is widely under the best expected sensitivity but calculated by only considering the optical and mechanical parts.

5. Summary and Conclusions

The Pound-Drever-Hall method is studied in order to build an optical readout to replace the current mass displacement sensors of the broadband planetary seismometers. A global design is proposed to reach a maximum sensitivity of at least 40 fm/$\sqrt{}$Hz at 1 Hz. The study of the first performances realized thanks to the implementation of the first loop are highly encouraging.

The next steps are to close the first loop in order to lock the laser frequency on the first cavity resonance and make the first measurements of noise. Then, the second loop has to be built to observe the second locking (second EOM) in order to set the central mirror in motion in the future and have the first experimental measurements of the optical readout performances. Some design improvements were also already identified for the optical cavity.

Acknowledgements

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PRIDE: Near-field VLBI observations for Planetary Probes

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Abstract

Planetary Radio Interferometry and Doppler Experiment (PRIDE) is a multi-purpose experimental technique aimed at enhancing the science return of planetary missions. It is based on, the near-field phase-referencing VLBI (Very Long Baseline Interferometry) and radial Doppler measurements. It has been developed initially by the Joint Institute for VLBI ERIC (JIVE) for tracking the ESA's Huygens Probe during its descent in the atmosphere of Titan in 2005 and from that point forward actualized for various planetary science missions. It was selected by ESA as one of the eleven experiments of the ESA's L-class JUpiter ICy moons Explorer mission (JUICE) mission, planned for launch in 2022.

1. Introduction

The essence of the PRIDE technique is in interleaving observations of the spacecraft radio signal and the signal of background natural celestial sources, generally quasars, enabling estimates of the lateral position of the spacecraft in the celestial reference frame [1] and Doppler-shift of the spacecraft's radio signal (radial range rate) [2, 3]. These estimates can be applied to a broad scope of research fields including atmosphere and precise celestial mechanics of planetary systems, geophysics and planetary dynamics and estimations of interplanetary plasma properties. PRIDE has been included as a part of the scientific suite on various ESA missions.

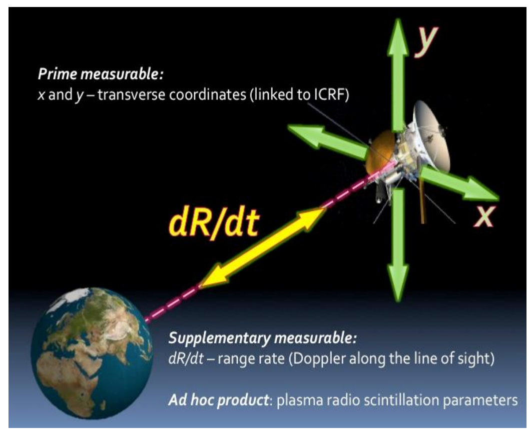

Figure 1: PRIDE Deliverables

1.1 Scientific Heritage

We introduce and present some of the experimental results accomplished recently in VLBI and Doppler measurements of the ESA's Venus EXpress (VEX) and Mars EXpress (MEX) missions [1, 2, 3]. PRIDE has been demonstrated in occultation experiments with Venus Express for determining the vertical density, pressure and temperature profiles of the Venus atmosphere [7] as well as ad hoc diagnostics of the interplanetary medium and detection of the Coronal Mass Ejection Event [6,8].

2. PRIDE-JUICE

PRIDE-JUICE will provide an enrichment of the JUICE science return achievable with minimum PRIDE-specific requirements to the onboard science payload [5]. It will address mission goals of JUICE that require exact determination of the lateral position of spacecraft on the celestial sphere, in particular for improvement of the Jovian system ephemerides [4].

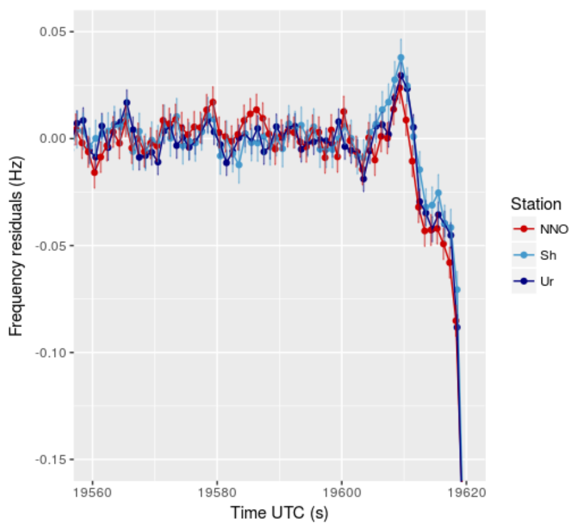

Figure 2: Frequency residuals of the spacecraft signal as it gets refracted by Venus' ionosphere and neutral atmosphere. This figure shows the comparison between the residuals found during ingress for Ur (Urumqi) and Sh (Shanghai) with respect of those of NNO, as provided by ESA's planetary science archive (PSA), for the 2012.04.27 session. The highest peak of positive frequency residuals corresponds to the main layer of the ionosphere. The immersion in the troposphere is marked by the change of sign in the frequency residuals at ~19610 s [7].

The PRIDE measurements can be used to investigate the Jovian atmosphere and physical properties by means of radio occultation observations [7,8]. The experiment will contribute to investigations of the interior structure of the moons can also be obtained from the joint investigation of topography and gravity field data. Also, although PRIDE could provide some support to gravity field determination using the Doppler data, the bulk of gravity science will be obtained from 3GM data.

A covariance analysis for a broad scope of the PRIDE measurable and Jovian system parameters have been performed in order to optimize the observation planning and the overall science impact of the JUICE mission [4].

PRIDE provides measurements of the spacecraft differential lateral position relative to the ICRF background extragalactic radio sources with the highest accuracy of 100-10 μas (1 sigma RMS) over integration time 60-1000 s. In addition to the JUICE mission objectives, PRIDE can also provide a backup support to mission operations in a form of rapid-response radio signal diagnostics.

We will also present some of the current & imminent PRIDE targets like LaRa (Lander Radio Science) on ExoMars mission. The PRIDE method described in this presentation exhibits its relevance and adaptability to any various space and planetary science missions.

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The Science Process for Selecting the Landing Site for the 2020 Mars Rover

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Abstract

Identifying the landing site for NASA's Mars 2020 rover began by: defining threshold mission science criteria related to seeking signs of ancient habitable conditions; searching for biosignatures of past microbial life; assembly of a returnable cache of samples for possible future Earth return; and collection of data for planning human missions to Mars. Mission engineering constraints helped identify candidate landing sites addressing mission science objectives. For the first time, however, these constraints did not have a major influence on candidate viability due to reductions in ellipse size and the ability to avoid hazards, Hence, sites were evaluated and down-selected based on science merit.

1. Introduction

The Mars 2020 rover will evaluate surface materials to achieve mission science objectives that include: exploration of an ancient astrobiologically relevant environment preserving information on the geological record, including past habitability and biosignature preservation potential; searching for potential biosignatures; and caching samples for possible future Earth return [1]. All landing site selection activities serve to maximize the probability of landing safely with access to high-priority science targets. Because the rover and entry, descent, and landing (EDL) system are evolved from the Mars Science Laboratory (MSL) rover [2], many engineering constraints are comparable. The higher atmospheric density expected on arrival at Mars in 2021 [3] and inclusion of Range Trigger and Terrain Relative Navigation (TRN) EDL capabilities on the 2020 rover [1, 3-5], however, enables a smaller landing ellipse at higher elevation and provides access to locales where surface relief precluded landing by MSL. All activities related to discussion of the candidate landing sites are available at: https://marsnext.jpl.nasa.gov.

2. Landing Site Workshops

Candidate sites with likely acceptable surface and atmospheric conditions were assessed at workshops in the years prior to launch (Fig. 1). During that period, iteration between engineering constraints and the evolving relative science potential of candidate sites led to identification of three final candidate sites.

2.1 The First Landing Site Workshop

Initial evaluation of ~30 sites (including landing sites and final candidate sites from prior missions) was made at the first landing site workshop in 2014 (Fig. 1). The focus was on identifying which sites were best suited to achieve mission science objectives within the constraints imposed by engineering and planetary protection requirements, and the necessity of ensuring a safe landing. Voting determined which sites: 1) had the highest overall science merit; 2) were most in need of additional imaging by orbital assets; and 3) included regions of interest likely accessible upon landing or located outside the landing ellipse. Proposed sites with a range of science regions of interest, encompassing a wide range of martian history, and relatable to important events in the Mars stratigraphic record were ranked highest. Nevertheless, all sites remained under consideration and were targeted for additional orbital data to better assess their science merit and ability to meet engineering or planetary protection constraints.

2.2 The Second Landing Site Workshop

The focus during the second landing site workshop in 2015 was to distill the list of candidate sites down to ~8 sites (Fig. 1). Five scientific criteria guided assessment and included: 1) confidence that the geologic setting and history of the landing site could be characterized and understood; 2) evidence that the site offers an ancient habitable environment; 3) rocks with high biosignature preservation potential are available and accessible for investigation of astrobiological potential; 4) the site offers an adequate abundance, diversity, and quality of samples suitable for addressing key astrobiological questions if returned to Earth; and 5) the landing site offers an adequate abundance, diversity, and quality of samples suitable for addressing key planetary evolution questions if returned to Earth. The rank ordering of the final eight sites became: Jezero crater (18.5ºN, 77.4 ºE), Columbia Hills (Gusev crater, 14.4 ºS, 175.6 ºE), Northeast (NE) Syrtis Major (17.8 ºN, 77.1ºE), Eberswalde crater (23.0ºS, 327.0ºE), Southwest (SW) Melas Basin (12.2ºS, 290.0ºE), Nili Fossae (21.0ºN, 74.5ºE), Mawrth Vallis (24.0ºN, 341.1ºE), and Holden crater (26.4ºS, 325.1ºE).

2.3 The Third Landing Site Workshop

With focus on science merit rather than engineering concerns as the driver for final landing site selection, discussion at the third workshop in 2017 provided community input into culling the candidate sites down to three (Fig. 1). The Jezero crater and NE Syrtis sites were consistently assessed higher for astrobiological relevance and potential of returned samples and were highly ranked relative to confidence of site interpretations and accessibility of targets in regions of interest. By contrast, the Holden crater and SW Melas basin sites were consistently assessed the lowest relative to astrobiological relevance and potential of returned samples and were ranked low relative to confidence of site interpretations and accessibility of targets in regions of interest. Columbia Hills, Eberswalde crater, Mawrth Vallis, and Nili Fossae sites received intermediate assessments

3. Three Final Candidate Sites

Following the third workshop, the Mars Landing Site Steering Committee, the Mars 2020 Project Science Group, representatives from the Returned Sample Science Board, and 2020 Project engineers down-selected the candidate sites. The NE Syrtis site was chosen because it includes lithologic diversity in an accessible and understood stratigraphic context that appears to span a broad interval of early Mars history. The Jezero crater site was selected because it offers a well-defined Noachian-aged delta environment including bottomset and lacustrine facies deemed to be fine-grained and most favorable for organic concentration and preservation. The Columbia Hills site includes a range of potentially attractive exploration targets including a silica-rich, putative hydro-thermal sinter deposit and the presence of a diverse suite of previously characterized volcanic rocks. The Columbia Hills site is relatively less favorable compared to the NE Syrtis and Jezero crater sites and its retention is contingent on further development and testing of its geologic setting and work to overcome potential engineering challenges involving sampling the putative sinter deposits. A fourth workshop in October 2018 will focus on assessing new results on site science potential, possible extended mission targets, and Project provided mission scenarios that includes discussion of potential exploration targets, observations, and sampling strategies relative to mission goals and important Mars science described in the 2013-2022 Planetary Science Decadal Survey.

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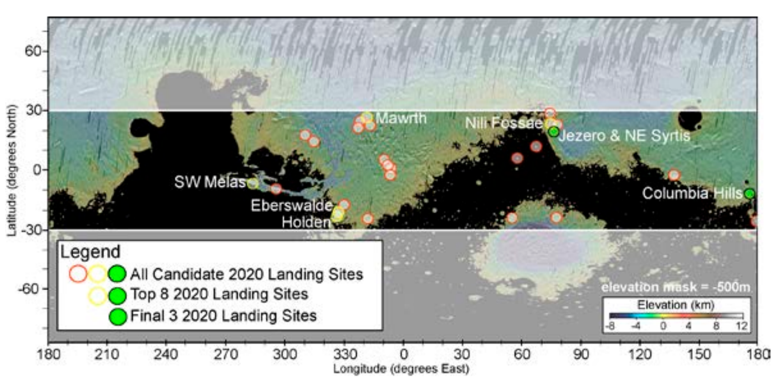

Figure 1. Map showing location of all 2020 candidate landing sites. Excluded elevations (above -500 m) are black and excluded latitudes (above 30^0 N and S) are shaded white. Actual ellipse size is smaller than dots. MOLA data over global THEMIS daytime IR data (irregular black areas indicate data gaps).

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AIRS: the Infrared Spectroscopic Instrument of ESA M4 ARIEL mission

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Abstract

ARIEL the Atmospheric Remote - sensing Infrared Exoplanet Large - survey has been selected in March 2018 as the Cosmic Vision M4 mission. This 1.4-tons satellite will be launched in mid-2028 by an Ariane 62 from Kourou toward a large amplitude orbit around L2 for a 4 years mission. It will perform transit spectroscopy of over a 1000 of exoplanets to complete a statistical survey, including gas giants, Neptunes, super-Earths and Earth-size planets around a wide range of host stars. It will complement the ESA and NASA continuing effort to understand the diversity of planetary system and the complexity of planet formation scenarios. AIRS will be the infrared spectroscopic instrument of the ARIEL mission providing spectroscopic data to answer the key scientific questions addressed by this mission: what are the exoplanets made of? How do planets and planetary system form? How do planets and their atmospheres evolve over time? Following trade-off analysis during the phase A of the study, a prism-based design was selected for the 2-channels spectrometer of the instrument. The instrument is based on two independent channels covering the CH0 [1.95-3.90] µm and the CH1 [3.90-7.80] µm wavelength range with dispersive elements producing spectrum of low resolutions R>100 in CH0 and R>30 in CH1 on two independent detectors. The spectrometer is designed to provide spectrum Nyquist-sampled in both spatial and spectral directions to limit the sensitivity of measurements to the jitter noise and intra pixels pattern during the long (10 hours) transit spectroscopy exposures. From the optical design, a full instrument overview will be presented covering the thermal mechanical design of the instrument functioning in a 60-K cold environment, up to the detection and acquisition chain of both channels based on 2 HgCdTe detectors functioning at 42-K. The instrument is composed of three main architectural blocks: the AIRS-OB optical bench including the two channels slits, and the optical elements within an aluminum structure; AIRS-FPA the focal plane assembly including the detectors with its mechanical housing and thermal control elements along with their interface to the active cryo-cooler, and the AIRS-DCU Detector Control Unit in charge of control of the detector system and on-board processing of the spectroscopic data.

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FOSSIL: Fragments from the Origins of the Solar System and our Interstellar Locale

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Abstract

Interplanetary and interstellar dust particles (IDP and ISD) continually bombard the Earth. They ablate in the atmosphere, and their trajectories change due to drag forces by the time ground based optical and/or radar observations could fully characterize them. These particles carry valuable information about their parent bodies that can now be fully harvested by in situ dust measurements, using newly developed instrumentation. Placing dust instruments onboard a near-Earth spacecraft will revolutionize our understanding of the composition of interstellar and interplanetary dust, contributing to our fundamental understanding of the evolution of our solar system, and will improve our dust hazard models for the safety of crewed and robotic missions to Mars and other destinations.

1. Interstellar Dust

The observations of the inward transport of interstellar dust [1] provide a unique opportunity to explore dusty plasma processes throughout the heliosphere. The flux, direction, and size distribution of interstellar dust can be used to test our models about the large-scale structure of the heliospheric magnetic field, and its temporal variability with solar cycle [2]. Interstellar dust particles are entrained in the flow of interstellar gas across our solar system and can be identified by their narrow speed distribution and directionality [1].

2. Interplanetary Dust (IDP)

The orbital elements of dust particles that are generated, for example, by active comets; by impacting dust onto the surfaces of airless bodies; or by collisions between asteroids, are initially similar to their parent bodies. Collections of such particles form meteoroid streams. Depending on the size of these grains, their initial orbital elements will change and randomize over timescales of centuries or longer, and they become part of the sporadic background of meteoroids. In general, long period comets (LPC) likely come from the Oort Cloud, and short period comets likely originate from the Kuiper Belt. Main belt asteroids have moderate inclinations, and nearly circular orbits. Hence, the orbital elements of the offspring dust particles from comets and asteroids can be used to identify their parents.

3. Instrumentation

FOSSIL is envisioned to carry multipole copies of the Dust Experiment (DEX) instrument. DEX is an in situ, high-resolution compositional dust analyzer developed specifically for the detection and analysis of interstellar dust (ISD) and interplanetary dust particles (IDP). It measures the dust speed and mass distributions, as well as its elemental and chemical composition [4]. It is based on the proven measurement method of Cassini's Cosmic Dust Analyzer (CDA) instrument [5]. Compared to CDA, however, it provides a larger effective target area to collect a statistically significant number of dust impacts and provides a drastically higher mass resolution due to its use of a unique ion-optics design. Individual dust particles entering the instrument pass through a set of grid electrodes and impact a 0.5 μm thick target layer of high-purity rhodium. A charge sensitive amplifier (CSA) attached to the target measures the impact-generated charge which is a function of the particle's mass and speed. A mass spectrum is obtained for each particle from the time-of-flight (TOF) analysis of the impact generated atomic and molecular ions. The target is biased at +3 kV to provide positive ion acceleration, and reflectron type ion optics is used to enable resolving powers in excess of $m/dm > 200$. The electrostatic field is shaped by a set of biased rings and one curved grid electrode to provide spatial and temporal focusing of the accelerated ions. The centrally located ion detector is a single plate, 40 mm diameter, small pore-size microchannel plate detector with a high dynamic range and sensitivity even for minor species. DEX records a wide mass range of 1 – 500 u to identify elemental and molecular ions and to reveal the chemical and mineralogical makeup of impacting particles. DEX may also be implemented with a negative ion detection mode that could deliver critical new information of the makeup of ISD/IDP particles.

Operationally, DEX is an event-driven instrument. A trigger for data acquisition is derived from the impact charge signals detected on the target, the ion grid, or the ion detector. The TOF spectra are recorded at a rate of 250 MS/s on two analog channels from an unevenly split anode behind the microchannel plate (MCP) detector achieving a high dynamic range. The impact charge and auxiliary signals are sampled at 12.5 MHz Each trigger event is time-stamped, post-processed, and checked for validity before data compression. The DEX low-mass mechanical design consists of a simple aluminium shell structure that provides support for the biased electrodes of the TOF analyser and the grids over its aperture. The centrally located ion detector, along with the front-end CSAs are integrated into the bottom of the instrument. The electronics box (not shown), housing the high- and low-voltage power supplies, the digital and processing boards, is mounted near the instrument. The interpretation of the measured impact spectra is supported by laboratory calibration measurements using analog dust sample materials and the DEX engineering prototype [6,7].

4. Summary and Conclusions

The DEX instrument is capable of measuring the mass, charge, composition, and velocity vector of impacting dust particles. By deriving the orbital elements of dust particles their source regions can be identified. This presentation will summarize the scientific rationales for the ***FOSSIL*** mission concept to carry the DEX instruments onboard a proposed Earth orbiting spacecraft on a highly elliptic trajectory to mitigate near-Earth environment interferences. ***FOSSIL*** will explore the diversity of the chemical makeup of a broad range of bodies in our solar system and beyond, offering a powerful approach to testing the genetic relationships between small body reservoirs.

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Observations of Transient Luminescent Phenomena on the Moon From a Deep Space Platform

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Abstract

We propose monitoring of the lunar surface for impact flashes and other transient events from the Deep Space Gateway. Such observations from space, which overcome the terrestrial day-and night cycles, cloudy skies, and atmospheric stray-light effects, may shed light on the relationships between lunar crater statistics, seismic detections of impacts and the terrestrial meteor rates – as well as on impact hazards.

1. Introduction

Several thousand tons of extraterrestrial material enter the Earth's atmosphere every year. Most of our knowledge on this "meteoroid flux" is based on the observations of the terrestrial "meteors". However, the Moon is an efficient meteoroid detector likewise, as is attested by the large inventory of craters and the substantial number of impacts recorded by the Apollo seismic station network [1]. From the temporal/spatial distribution of impact events, constraints can be obtained on the meteoroid approach trajectories, velocities, and shower memberships. Only as late as 1999, it was successfully demonstrated that meteoroids produce "flashes" upon impact. During the peak of the Leonid meteor shower, at least 6 impact flashes were recorded on a single night [2]. Today, observatories worldwide are engaged in the observation of impact flashes. A unique very large impact flash (m=2.9) was detected on September 11, 2013 [3], and a crater presumably related to the event was later identified in LRO images [4].

We propose monitoring of the lunar surface for impact flashes from the Deep Space Gateway. Detections from the Gateway may be complemented by the inspection of craters resulting from the events by high-resolution cameras (if available in lunar orbit). Precise impact locations and impact times are also useful for lunar seismic experiments (if available on the lunar surface), as the impacts represent useful energy sources for sounding of the lunar interior. The impact monitoring will also provide a direct assessment of the danger to human assets or humans on and near the Moon.

2. Science Goals

We foresee the following science goals:

- Determine the rate of crater formation on the Moon on the different hemispheres
- Determine the temporal/spatial distribution of the impactor flux
- Study characteristics of impact events to improve our understanding of impact dynamics
- Determine impact locations for follow-up crater inspections by cameras
- Locate impact events for use as seismic energy sources in seismic experiments
- Identify specific event characteristics, which might allow us to distinguish between asteroidal or cometary impactors
- Search and characterize other lunar transient luminous events, e.g., outgassing
- Estimate the threat from a meteoroid impact and associated ejecta to a future lunar habitat

We foresee capturing effectively > 2000 hours of observations of the night hemisphere in one experiment run, during which we would expect to detect several hundreds of flash events.

3. Camera Systems

We have previously carried out camera studies (two parallel studies with industry partners Jena Optronics, Germany, and Officine Galileo, now Leonardo, Italy, contract through ESA) dedicated to imaging faint transient noctilucent phenomena, such as aurorae, electric discharges, meteors or impact flashes, on dark planetary hemispheres [5]. The German-led SPOSH (Smart Panoramic Optical Sensor Head) is equipped with a back-illuminated 1024 x 1024 CCD chip and a custom-made optical system of high light-gathering power and wide field of view, 120º x 120º. The Italian solution is based on a so-called EM-CCD (electron-multiplied CCD), which features 512 x 512 pixels and a 70º field of view. Images can be obtained over extended periods at high rate (up to 3 images per second) to enable monitoring for transient events. To reduce data volumes, only those images (or portions) are returned that contain events. Tests demonstrate that the cameras have excellent radiometric performance at low light levels over their large field of view. We estimate that a SPOSH-like camera would see about one impact per 2 hrs from 40000 km distance to the Moon.

Upgraded camera systems (e.g., equipped with CMOS sensors) may produce detailed impact flash lightcurves and/or flash spectra. We propose to use multiple camera systems operating jointly, each of them optimized for high temporal-, high spatial- or high spectral resolution. At least dual systems are also required eliminate false detections by cosmic-ray hits. Owing to the varying distance from the Moon of the platform, we may consider the deployment of complimentary wide-angle and narrow-angle optical systems. We propose the impact detection system to be complemented by a dust detector to allow for a full characterization of the near-Lunar meteoroid environment over a wide range of meteoroid sizes.

4. Operation

The sensor systems of moderate mass (< 20 kg) and size is to be mounted on the outer surface of the Gateway. A mechanism is required to ensure camera pointing to the Lunar surface (i.e., the dark portion). For special observing runs, we require Earth pointing or star observations. Once the system is set-up, the operation is autonomous and does not require any actions by the crew. The operation of the system in space will be supported by ground-based observations worldwide

5. Proposing Team

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Exploring the Ice Giant Systems

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Abstract

The Ice Giant planets, Uranus and Neptune, along with their satellites, rings, and magnetospheres, are priority targets for future exploration. Given the scientific importance of these systems, a NASA-led mission study has recently been completed [1] and an ESA-led study is expected in the near future. In addition, there have been recent mission proposals, white papers, and community discussions regarding these planets. This presentation will summarize the current status and expectations for ice giant exploration.

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Mapping Trojan Asteroids in the thermal infrared with TROTIS

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Abstract

TROTIS (TROjan asteroid Thermal Infrared multi-Spectral imager) is a high spatial-resolution thermal imaging system optimized for asteroid targets with heritage from the Miniaturized Asteroid thermal infrared Imager and Radiometer (MAIR) for the AIDA mission as well as the Bepi-Colombo mission's MErcury Radiometer and Thermal Infrared Spectrometer (MERTIS). Minor modifications of the three-mirror antistigma (TMA) optics and the updating of the discontinued ULIS microbolometer provide over five times better spatial resolution than the MERTIS instrument as well as an extension to shorter wavelength – potentially as far down as 2 µm.

1. Introduction

Mapping the surface of Trojan Asteroids in the thermal infrared will allow a set of complementary information important to understand the origin and evolutions of Trojan asteroids (see presentations by [1-2] at this meeting). Broadband thermal infrared imaging provides temperature maps from which thermophysical parameters can be derived. Narrow-band spectral imaging in this highly diagnostic spectral range allows deriving compositional information. Nightside radiometry will provide detailed information on the thermal inertia of the surface material. The combination of visual imaging and thermal imaging allows mapping day- and nightside and providing accurate shape models of the asteroids.

Thermal information provided by TROTIS will be crucial for selecting landing and sampling sites. The thermal infrared mapping will allow to link remote IR based studies on size, albedo, thermal inertia, grain size distribution, etc to the in-situ findings. This is especially important when trying to transfer the in-situ findings to other objects not visited by any spacecraft. Finally the thermal information also allows deriving limited sub-surface properties: for example young/old surface structures have different thermal properties (conductivity, compactness), providing information, which will complement the optical images.

A potential extension of the spectral coverage into the near infrared would significantly increase the science return.

2. TROTIS design concept

TROTIS builds more than a decade of development work at DLR for imaging spectrometer using uncooled microbolometers [3-10].

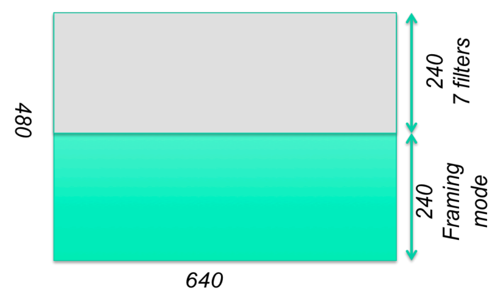

Figure 1: Microbolometer with filter strips and clear area allows simultaneous framing and multi-spectral imaging observations

TROTIS has two channels: a multispectral imager (microbolometer) and a radiometer that provides greater precision than the imager for background temperatures (80–150 K) over broad regions. The optical design is simplified from MERTIS, replacing the spectrometer with simple stripe filters (Figure 1). The microbolometer allows mineral absorptions and spatially resolved daytime temperatures to be characterized by collecting resolved images of the illuminated side of each asteroid over the wavelength range of 5–20 μm using a clear and several narrow filters positioned between 5–20 μm to characterize mineral absorptions and spatially resolved daytime temperatures. With the ongoing development on microbolometers the spectral coverage might be extended us far down as 2 μm.

The radiometer, which has lower spatial resolution but is more sensitive at low temperatures, provides the temperatures on the dark side of each asteroid that help constrain each asteroid's shape. Resolved temperature measurements enable thermal inertia estimates of the surface to be derived, while filtered emissivity data enable distinguishing bulk mineralogy.

TROTIS has a monoblock configuration (Figure 1), with the optical module mounted on top of electronic modules. It has a fully reflective, gold-coated F/2.5 TMA optical path with 135-mm focal length (TBC based on mission design). A flip-mirror selects the channel and serves as a calibration target for the imager. The flip-mirror follows the standard design used in a wide range of flight instruments. It is actuated by a flight-qualified, Faulhaber-type, 1016 DC motor and returns to microbolometer view when unpowered as a failsafe.

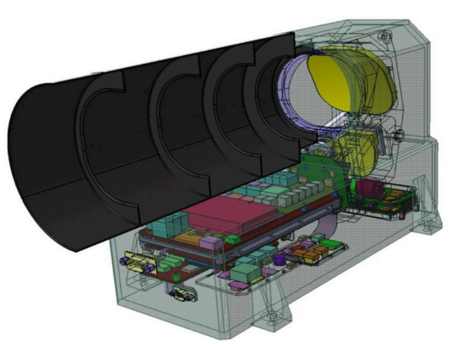

Figure 2: CAD model of current TROTIS design

TROTIS has a mass of 4kg and an average power consumption of 10W. The monoblock configuration allow for easy accommodation on any spacecraft bus.

The TROTIS sensor and electronics aluminum housing, with spot shielding as necessary, is sufficient to reduce TID to <100 krad (RDM 2). All components are immune to single event latchup and are rad-hard to >100 krad or spot shielded. Transient noise from energetic particles has an insignificant impact (smaller than read noise) on radiometer and microbolometer detectors.

3. Conclusion

TROTIS will provide unique science observations that will foster our understanding of Trojan asteroids. It will provide compositional information, thermal physical properties as well as accurate shapes. In addition TROTIS can aid optical navigation as it will be able to detect targets from any phase angle. The thermal information will also be very important to see, find and avoid very small satellites around the target body.

Based on the strong heritage the TROTIS design is currently assessed as TRL 6. No new development is necessary and all changes are standard engineering practice.

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Europe's future exploration of Main Belt Comets

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Abstract

We discuss options for the future exploration of Main Belt Comets (MBCs) using European spacecraft. MBCs are objects with asteroid-like orbits in the main belt, but comet-like appearances. They are an important 'missing link' in our understanding of the small bodies of our Solar System, and a high priority population to explore with spacecraft, but so far no mission to visit a MBC has been selected. We briefly review previous proposals to ESA, before considering future options to either visit a MBC or study them via space-based remote observation.

1. Main Belt Comets

MBCs were only recently identified as a population in their own right [1], following the discovery of additional objects like the puzzling 133P/Elst-Pizarro, which was first seen active in 1996 and caused some debate over whether it was a comet or collisional debris. It has not yet been possible to obtain direct confirmation that MBC activity is comet-like, i.e. driven by sublimating ice, via detection of a gas coma [2]. The question has been convincingly settled for 133P and four other MBCs, as they have returned to activity after each perihelion passage since discovery, meaning that sublimation of ice is the only reasonable explanation [3]. Direct study of the volatile component of MBCs, and remaining questions about their nucleus structure, composition, and history, will require spacecraft exploration, or more sensitive telescopic observations.

2 Previous proposals

2.1 Caroline

Proposed at the ESA M3 call, Caroline [4] was a sample return MBC mission, making use of aerogel capture of dust released from the MBC in a similar way to the Stardust comet mission [5]. Although this would not be sensitive to volatiles at the MBC, returning a sample of dust from the main belt to apply the full range of techniques possible in Earth-based laboratories would be very valuable, and would allow comparison with results from NEO sample return missions (Hyabusa, OSIRIS-Rex).

2.2 Castalia

Castalia was proposed to the ESA M4 and M5 calls [6]. It would 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. Given the low level of activity of MBCs, the Castalia plan envisages an orbiter capable of 'hovering' autonomously at distances of only a few km from the surface of the MBC, allowing in situ sampling of gas and dust in sufficient quantities to measure composition and isotopic ratios. The payload comprises vis/NIR cameras, thermal cameras, radars and radio science, mass spectrometers for gas and dust, a dust counter, plasma instruments and a 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, could also be considered. At the moment, MBC 133P is the best-known target for such a mission. A design study for the Castalia mission, carried out in partnership with OHB System AG found that a mission to 133P, or backup MBC targets, is achievable by an ESA M-class mission.

2.3 CASTAway

CASTAway is a mission concept, proposed for M5, to explore the diversity of the main asteroid belt [7], by combining a long-range (point source) telescopic survey of thousands of objects, targeted close encounters with 10 - 20 asteroids, and serendipitous searches for very small asteroids. The science payload consists of three linked instruments: a 50 cm diameter telescope feeding a CCD camera for narrow angle imaging and a moderate resolution spectrometer with spectral coverage from 0.6-5 μm; a thermal infrared imager for temperature, albedo and composition mapping during flybys; asteroid detection cameras, based on star trackers, to detect new objects in the 1-10 m size range. Ideally, CASTAway would include one MBC in its flyby target list, although the relatively small population of known MBCs make this a challenge when selecting a trajectory optimised for the largest number of targets. Even without a flyby, CASTAway would be valuable for MBCs in performing remote observations, including searches for outgassing, and in giving a better comparison between MBC and asteroid properties.

3 Future missions

3.1 ESA future missions study

In 2016 ESA released a call for 'new ideas' for future missions. From this, and following a discussion with representatives of the European planetary science community at ESA headquarters in 2017, an ESA concurrent design facility study looked at various concepts. These included the possibility of using multiple small satellites instead of (or in combination with) one larger one to explore asteroids or comets. This was partially inspired by the 'CubeSats' that have become increasingly common in Earth orbit in recent years, although operation in deep space presents its own challenges. The case of a mission to a MBC was considered, with similar science goals to Castalia, but instruments spread between a series of small satellites.

3.2 Involvement in non-ESA missions

Proteus is a MBC rendezvous mission with similar goals to Castalia, which was proposed to the last NASA Discovery round [8], and will likely be proposed again, potentially with European payload involvement. Conceptually similar to the ESA-China proposal for Marco-Polo at the ESA M4 call, a proposal from the China Academy of Space Technology would see a mission visit a NEO, return a sample to Earth, and then send the main spacecraft on to a MBC [9]. If selected it would arrive at the MBC (expected to be 133P) in the late 2020s. Discussions with international partners are ongoing, but European institutes could provide extra instruments, releasable CubeSat-sized probes, or even a penetrator to sample the subsurface and measure its composition [10].

4 Remote observations

Although the most detailed information on MBCs will only be obtained by visiting them, telescopic observations can look at composition, and have the advantage of being able to study the whole population. The big challenge is detecting outgassing water. Attempts were made using the ESA Herschel space telescope, which was sensitive to water emission at 557 GHz. Upper limits for 176P and 358P found $Q(H_2O) < 4$ and 8×10^{25} molecules s^{-1}, respectively [11, 12].

JWST will have excellent sensitivity to faint emissions that could enable direct detection of water outgassing [13]. To perform a broader survey than will be possible with JWST, a small telescope could be launched to perform a dedicated water search. Collecting various comet observations to assess the sensitivity of current technology suggests that the most sensitive searches, for a given telescope size, could be performed in the far UV, where the hydrogen Ly-α line is a strong emitter [2]. Such a telescope would have to be placed in an orbit away from Earth's geocorona, e.g. in heliocentric or lunar orbit, but could be a useful mission for MBC science on a budget smaller than M-class, e.g. for the anticipated F-class ESA call.

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Exploring geospace via solar wind charge exchange X-rays

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Abstract

We propose to investigate the impact of the variable solar wind on the Earth's magnetosphere by taking the global approach afforded by remote sensing, to be precise by imaging the solar wind charge exchange X-ray emission from the dayside magnetosheath and the magnetospheric cusps. We propose an ultra-light-weight X-ray telescope with a 10º x 10º FOV capable of encompassing a large part of the primary region of scientific interest centred on the nose of the magnetopause and covering both magnetospheric cusps together. This will lead to having long term, semi-continuous monitoring of the response and evolution of geospace conditions under the buffeting of the solar wind and will expand very significantly the coverage available at any one time to the X-ray imager currently being developed for SMILE.

1. Introduction

As our world becomes ever more dependent on complex technology, both in space and on the ground, it becomes more exposed to the vagaries of space weather, i.e. the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of technological systems and endanger human life and health. Fundamental research into the Earth's plasma and magnetic field environment, and its response to solar activity, directly leads to the validation of models, and to strategies for predicting and mitigating the effects of space weather. This is the area of research that our idea is focused on.

2. In situ measurements vs remote sensing

Plasma and magnetic field environments can be studied in two ways – by in situ measurement, which provides precise information about plasma behaviour, instabilities and dynamics on a local scale, or by remote sensing, which offers the global view necessary to understand the overall behaviour and evolution of the plasma. The vast majority of our knowledge of the Earth's magnetospheric boundaries response to solar activity comes from very localised in situ measurements which inform us on the microscale. However, piecing the individual parts together to make a coherent overall picture, capable of explaining and predicting the dynamics of the magnetosphere at the system level, proves to be extremely difficult.

3. Solar wind charge exchange and SMILE

A novel and global way to explore solar-terrestrial relationships by soft X-ray imaging is offered by the SMILE (Solar wind Magnetosphere Ionosphere Link Explorer) mission (Figure 1), currently being developed jointly by the European Space Agency and the Chinese Academy of Sciences and due for launch in the 2021-2022 timeframe [1]. Remote sensing of the magnetosheath and the cusps with X-ray imaging is now possible thanks to the relatively recent discovery of solar wind charge exchange (SWCX) X-ray emission, first observed at comets, and subsequently found to occur in the vicinity of the Earth's magnetosphere [2]. SWCX occurs when highly charged ions of the solar wind interact with exospheric neutrals, acquire an electron, are left in an excited state and then decay emitting soft X-ray lines of wavelengths characteristic of the de-exciting ion.

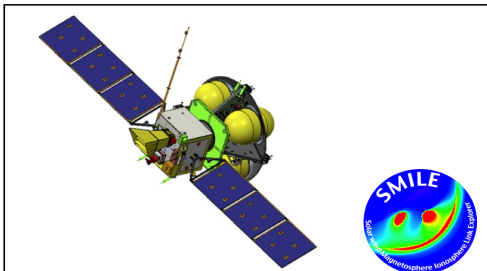

Figure 2: SMILE spacecraft (ESA/CAS) and logo

4. The DSG opportunity

SMILE's soft X-ray imaging of the Earth's magnetopause and magnetospheric cusps will establish this novel technique as a powerful diagnostic tool of the conditions of geospace under the vagaries of the solar wind; SMILE will break new ground, but as a small class mission will have limited spatial, temporal and sensitivity reach over the whole of geospace.

The Deep Space Gateway (DSG) allows observing from a distance of 50 – 70 R_E (Earth-Moon L1 or L2) from Earth depending on orbit, hence offers the opportunity of expanding very substantially the coverage of geospace available at any one time to an X-ray imager compared to SMILE: for example a 10º x 10º FOV provides a good compromise for encompassing continuously a large part of the primary region of scientific interest (7 – 10 R_E centred on the nose of the magnetopause depending on L1 or L2) whilst excluding the bright Earth, and covering both magnetospheric cusps together (which SMILE cannot do most of the time from its Earth polar orbit).

5. Instrumentation

For the DSG X-ray imager we are considering adopting as a baseline the Japanese concept instrument GEO-X which has been proposed for magnetosheath imaging from the Earth-Moon L1 point. It is therefore well-matched to adoption for the DSG. GEO-X employs novel ultra-light-weight X-ray telescope units (see Figure 2) with large aperture (Φ100 mm ~ 5º), short focal length (250 mm) and good spatial resolution (<10 arcmin). The Wolter-type optic is a low cost in-house fabrication constructed from metal coated Si wafers [3]. To realise the combined 10º x 10º FOV required for the DSG X-ray imager four GEO-X telescope units are required. Radiation hard DepFET devices operating at -70º C, ideal for deep space missions, are under consideration for the detector. The X-ray imager would be accommodated externally, operate autonomously and require no intervention by the crew of the DSG. Preliminary estimates of the resources required include a total hardware mass of 60 kg, 60 W power, and a volume of 20 cm x 20 cm x 30 cm for each one of the 4 telescope units.

It is worth noting that for a small increase in required resources (~4 kg, 5W) the addition of an in situ package (comprising a light ion analyser and a magnetometer) would add very significant benefit to the research by self-sufficiently providing measurements of the solar wind conditions, so as to set the X-ray observations into context.

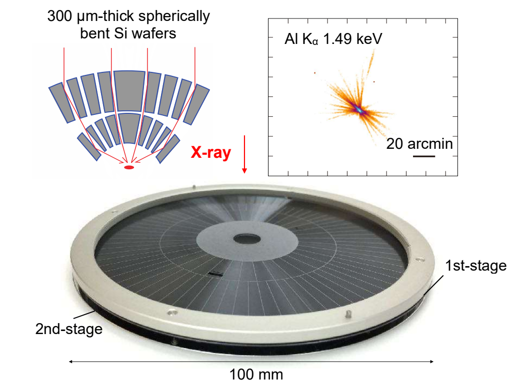

Figure 2: Ultra-light-weight X-ray telescope

6. Summary and Conclusions

Observations with the DSG X-ray imager which we propose will extend those of SMILE to the level of having long term, semi-continuous monitoring of the response and evolution of geospace conditions under the buffeting of the solar wind. This will provide direct scientific input to the studies of space weather and to the validation of global models of solar wind-magnetosphere interactions, leading to the mitigation of the possibly disastrous effects of space weather on Earth's technological infrastructure and human life and health.

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Observing Solar System Bodies with Twinkle

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Abstract

Twinkle is a 45cm space telescope conceived to characterise extrasolar planets and Solar System objects over a broad wavelength range. The system design and mission implementation are based on existing, well studied concepts pioneered by Surrey Satellite Technology Ltd for low-Earth orbit Earth Observation satellites, supported by a novel international access model to allow facility access to researchers worldwide.

Twinkle's ability to study Solar System objects has been explored by determining when objects are observable as well as the data quality and resolution obtainable. The targets considered in this work include planets, moons, dwarf planets and asteroids

1. Introduction

Twinkle is designed for operation in a low Earth, sun-synchronous orbit. The instrumentation consists of three spectrometers which cover the spectral range 0.4 - 4.5μm with a resolving power of R$\sim$250 (λ < 2.42μm) and R$\sim$60 (λ > 2.42μm). As a space-based general observatory, Twinkle has the capability to provide significant new data on Solar System objects, especially in regions of the spectrum dominated by telluric absorption.

2. Results

A model has been created to calculate the exposure time required to achieve a desired SNR and resolution for Solar Systems bodies based either on their physical characteristics (radius, temperature, albedo) or visible magnitude [1]. Figure 1 highlights Twinkle's capabilities with 100s of integration time.

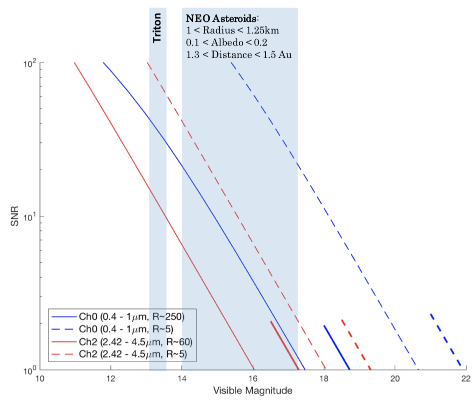

Figure 1: From the Twinkle Solar System model [1]: For an object of a given visible magnitude, the SNR achievable with an exposure time of 100s at different resolutions in channel 0 and channel 2. The capabilities of Twinkle to observe an object varies over the channels and the capability of channel 1 lies between channel 0 and channel 2. The short lines at the bottom of the diagram indicate the SNR possible with 1000s of observation time. The approximate visible magnitude of Titan and small NEO asteroids are also shown for reference.

3. Summary and Conclusions

It was found that many celestial bodies would have long periods during which they could be observed with observation windows occurring on a periodic basis. Having determined that a target was observable, the SNR for photometric and spectroscopic data was calculated for a given exposure time. For a number of targets, including the outer planets, their large moons and bright asteroids, the model created predicts short exposure times will achieve high quality (SNR > 100), high resolution (R $\sim$ 250, λ < 2.42μm; R$\sim$60, λ > 2.42μm) spectroscopic data.

For other targets this is found to not be achievable in one observation and thus multiple observations will be required if resolution or data quality cannot be reduced. Very small or distant objects (e.g. the outer dwarf planets, Haumea and Eris) are deemed too faint for Twinkle to obtain photometric or spectroscopic data of reasonable quality (SNR > 10) without requiring large amounts of observation time.

In conclusion, the Solar System is found to be permeated with targets which could be readily observed by Twinkle at visible and near infrared wavelengths.

Acknowledgements

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Rotational Push-broom Imaging from a Planetary Penetrator

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Abstract

Penetrators offer the potential to deliver scientific payloads to the surface and subsurface of solar system bodies at relatively low cost. An imaging regime during the delivery of the penetrator would provide valuable outreach, science and engineering data to complement data from any in situ penetrator experiments at bodies such as Earth's moon, Mars, and Europa. Visible images assist in the determination of landing site location, as well as the nature of the surface in that region. Multispectral and polarimetric imaging enhance the science potential by providing additional valuable compositional and structural information. Changes in imaging geometry throughout a penetrator's descent provide scale and three-dimensional information on the local terrain.

A concept will be presented for a rotational push-broom camera with multispectral and polarimetry capabilities for use on a penetrator. Scanning motion is to be provided by the penetrator's spin stabilisation, and wide angle optics imaging from nadir to horizon would permit a 360-degree field of regard with full surface coverage. An area array detector (CCD or CMOS) with a combination of multispectral and polarising filters oriented perpendicular to the scene's scan motion would allow the simultaneous capture of multiple images.

Imaging conditions change significantly throughout a penetrator's descent. Expected resolutions would obviously increase as the camera descends, whilst the imaging footprint would decrease, producing a sequence of nested multi-scale images. Optimum imaging heights and exposure times are a trade-off of desired surface coverage, resolution and signal requirements.

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Scientific payload of the Emirates Mars Mission: Emirates mars ultraviolet spectrometer (EMUS) overview

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Abstract

The Emirates Mars Ultraviolet Spectrometer (EMUS) instrument is one of three science instruments on board the “Hope Probe” of the Emirates Mars Mission (EMM). EMM is a United Arab Emirates’ (UAE) mission to Mars, launching in 2020, to explore the global dynamics of the Martian atmosphere, while sampling on both diurnal and seasonal timescales. The EMUS instrument is a far-ultraviolet imaging spectrograph that measures emissions in the spectral range 100-170 nm. Using a combination of its one-dimensional imaging and spacecraft motion, it will build up two-dimensional far-ultraviolet images of the Martian disk and near-space environment at several important wavelengths: the Lyman beta atomic hydrogen emission (102.6 nm), the Lyman alpha atomic hydrogen emission (121.6 nm), two atomic oxygen emissions (130.4 nm and 135.6 nm), and the carbon monoxide fourth positive group band emission (140 nm-170 nm). Radiances at these wavelengths will be used to derive the column abundance of atomic oxygen, and carbon monoxide in the Martian thermosphere, and the density of atomic oxygen and atomic hydrogen in the Martian exosphere both with spatial and sub-seasonal variability. The EMUS instrument consists of a single telescope mirror feeding a Rowland circle imaging spectrograph with selectable spectral resolution (1.3 nm, 1.8 nm, or 5 nm), and a photon-counting and locating detector (provided by the Space Sciences Laboratory at the University of California, Berkeley). The EMUS spatial resolution of less than 300 km on the disk is sufficient to characterize spatial variability in the Martian thermosphere (100-200 km altitude) and exosphere (>200 km altitude). The instrument is jointly developed by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder and Mohammed Bin Rashid Space Centre (MBRSC) in Dubai, UAE.

1. Introduction

In 2014, the United Arab Emirates (UAE) announced the first outer-planetary Arab mission, Emirates Mars Mission, as a catalyst for science and technology sector development within the region. The mission focuses on developing national capabilities in both science and engineering, and on contributing with novel science to the human knowledge and civilizations. The Emirates Mars Mission’s (EMM) Hope Probe will launch in 2020 to explore the dynamics in the atmosphere of Mars globally while sampling on both diurnal and seasonal timescales. EMM’s primary science goals are aligned with the Mars Exploration Program Advisory Group’s (MEPAG) 2015 Goal II: “Understand the processes and history of climate on Mars” [1]. Moreover, EMM’s objectives and investigations will address the following MEPAG’s objectives of II.A): “Characterize the state of the present climate of Mars’ atmosphere and surrounding plasma environment, and the underlying processes, under the current orbital configuration” as well as II.C): “Characterize Mars’ ancient climate and underlying processes” [1]. EMM is the first mission to have full diurnal coverage on sub-seasonal timescales with a global coverage which enable under-standing of the transfer of energy from the lower-middle atmosphere to the upper atmosphere. On-board the Hope Probe are three scientific instruments which will provide a set of measurements fundamental to an improved understanding of the Martian climate. Two of the EMM’s instruments, which are the Emirates eXploration Imager (EXI) [2] and Emirates Mars Infrared Spectrometer (EMIRS) [3] will focus on the lower atmosphere observing dust, ice clouds, water vapor and ozone. On the other hand, the third instrument Emirates Mars Ultraviolet Spectrometer (EMUS) will focus on both the thermosphere of the planet and its exosphere. This poster will cover a description and overview of the latter instrument, EMUS, and the investigations it fulfills.

2. EMUS Science Targets

2.1 Thermosphere Investigation:

This EMM investigation will determine the abundance and spatial variability of key neutral species in the thermosphere on sub-seasonal timescales. To address this investigation, EMUS will provide a measure of the dynamics and energetics of the thermosphere, through which all escaping particles must travel, as it forms the lower boundary of the exosphere. This will be achieved by determining the column abundance and spatial variability of the key neutral species in the thermosphere: oxy-gen (O), carbon (C), and carbon monoxide (CO).

2.2 Exosphere Investigation:

EMUS will also address the EMM investigation that focuses on determining the three-dimensional structure and variability of the key species in the exosphere and their variability on sub-seasonal timescales. For this investigation EMUS will observe the neutral exospheric species hydrogen (H) and oxygen (O). Measurements of both hydrogen and oxygen in the upper atmosphere are essential for determining the loss of water from the upper atmosphere.

3. Instrument Overview

The EMUS instrument is a far ultraviolet imaging spectrograph that is jointly developed by the Laboratory for Atmospheric and Space Physics (LASP) at the University of Colorado Boulder and Mohammed Bin Rashid Space Centre (MBRSC). It consists of a single telescope mirror feeding a Rowland circle imaging spectrograph with a photon-counting and locating detector (provided by the Space Sciences Laboratory at the University of California, Berkeley). The EMUS spatial resolution of 0.36° is sufficient to characterize spatial variability in the Mar-tian thermosphere (100-200 km altitude) and exosphere (>200 km altitude). EMUS measures ultraviolet emissions in the spectral range 100-170 nm with a selectable spectral resolution of 1.3 nm, 1.8 nm, or 5 nm. In order to observe and discriminate between the hydrogen and oxygen coronas, EMUS will make one-dimensional spectral measurements. To measure the hydrogen corona, the instrument will be sensitive to Lyman alpha at 121.6 nm and Lyman beta at 102.6 nm. To measure the oxygen corona, it will be sensitive to 130.4 nm and to the dimmer 135.6 nm emission. EMUS will measure thermospheric carbon at 156.1 nm and 165.7 nm as well as CO emissions be-tween 140 nm and 170 nm. Table 1 summarizes EMUS design parameters.

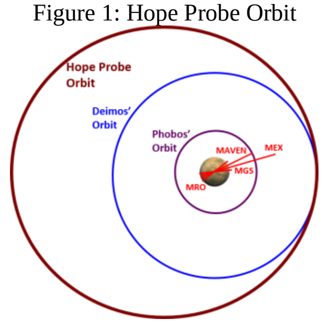
Table 1: EMUS Instrument Parameters

Field of view	(0.18°, 0.25°, 0.7°) × 11.0°
Wavelength range	100 – 170 nm
Spectral resolution	1.3, 1.8, 5 nm
Spatial resolution with narrow slit	0.14° × 0.20°
Detector photocathode	CsI

4. Concept of Operations

EMM target science orbit, as shown in Figure 1, is of 20,000km x 43,000 with 25° inclination, resulting in 55 hour orbital period. This unique high altitude orbit, which no space-craft had ever flown into, enables comprehensive observations of the exosphere, and full sampling of latitude, longitude, and local time. The Science Phase is planned for 2 Earth years (just over 1 Mars year long) to cover all the seasonal variations in the atmosphere.

Figure 1: Hope Probe Orbit



The EMUS instrument takes its observations utilizing 4 different observing strategies (U-OS) using spacecraft motion to build up two-dimensional far ultraviolet images of the Martian disk and near-space environment. U-OS1 addresses all thermospheric measurements up to 1.06 Mars Radii (RM). U-OS2 provides measurements of the hydrogen and oxygen corona up to 1.6 RM, while U-OS3 measures the extended H corona up to at least 6 RM using emission at Lyman alpha. U-OS4 addresses as well the oxygen and hydrogen corona as it will aid in observing the escaping oxygen (130.4 nm) and it will target Lyman beta at all altitudes. Summary of the observation strategies for EMUS is found in Table 2.

Table 2: Summary of EMUS Observations

Observation	Description	Slit	Frequency
U-OS1	Raster scanned images of the disk of Mars covering 0-1.06 RM	1.3 nm	2 times per orbit in one orbit per week
U-OS2	Raster scanned images of the disk of Mars covering 0-1.6 RM	1.8 nm	6 times in one orbit per week
U-OS3	Asterisk pattern scan where the spacecraft will slew out to 100 degrees in 4 swaths. It will cover 0 - at least 6 RM	5 nm	4 times in one orbit every other week
U-OS4	Provide long exposure times for the mid and outer corona when the instrument is not imagining and during charging	1.8 nm	Observe lines of sight in each 500km bin in one orbit per month

5. Data Completeness

There will be two types of EMUS image sets: standard and high cadence for both thermospheric and coronal measurements. To ensure adequate global coverage of the dayside thermosphere including the terminator, and continuous coverage of the equatorial (Mars-Centered Solar Orbital coordinate frame) thermosphere, the standard image set must encompass at least 6 of the 8 30°-wide intervals in MSO longitude spanning -120° to 120° (4 AM to 8 PM in MSO local time), and the high cadence image set must encompass at least 12 of the 16 15°-wide intervals. Both sets should be taken within 1/3 of a week. As for seasonal coverage, observations over 1 full Martian year shall be covered where 20 of the 24 15° intervals of solar longitude (LS) sampled for standard cadence, and at least 7 of the 8 45° intervals of LS sampled for high cadence sets.
For coronal measurements, the standard image set consists of images taken within 1/3 of a week, from at least 5 of the 8 45° intervals of MSO longitude spanning -180 to 180°, with no more than one 45° interval missed out of either the midnight centered 90°-wide quadrant of 135° to -135° (to characterize the nightside Hydrogen exosphere) or the three dayside-and-terminator quadrants spanning -135° to 135° (to characterize the dayside Hydrogen and Oxygen exosphere). The Hydrogen and Oxygen exospheres are not expected to be influenced by the lower atmosphere on timescales of less than one week. Therefore, at least 1 standard image set shall be collected per week. To allow the characterization of short-term, sub-week variability in all Mars seasons, high cadence data sets, consisting of 3 consecutive standard image sets in the same week, must be collected in at least seven of the eight 45° intervals of LS comprising a Martian year, to ensure that such variability does not manifest itself differently at different seasons or heliocentric distances.

6. Summary

Data returned from the EMUS instrument will enhance our understanding of the thermosphere and exosphere of Mars and their variability on sub-seasonal timescales as the instrument is designed to measure relative changes in the thermosphere and the structure – radial extent and scale height – of both the hydrogen and oxygen in the exosphere. Additionally, EMUS will measure changes in the structure of the corona with season, and lower atmosphere forcing (e.g. dust storms). Combined with data from other instruments on-board the Hope Probe, EMM will improve our understanding of the coupling between the upper and lower atmosphere and the climate of Mars.

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SCIENTIFIC PAYLOAD OF THE EMIRATES MARS MISSION: EMIRATES MARS INFRARED SPECTROMETER (EMIRS)

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Introduction:

The Emirates Mars Mission (EMM, Figure 1) will launch in 2020 to explore the dynamics in the atmosphere of Mars on a global scale. EMM has three scientific instruments selected to provide an improved understanding of circulation and weather in the Martian lower and middle atmosphere as well as the thermosphere and exosphere. Two of the EMM's instruments, the Emirates eXploration Imager (EXI) and Emirates Mars Infrared Spectrometer (EMIRS), will focus on the lower atmosphere observing dust, ice clouds, water vapor, ozone, and the thermal structure. In addition, the third instrument, Emirates Mars Ultraviolet Spectrometer (EMUS), will focus on both the thermosphere and exosphere of the planet. EMM will explore several aspects of Martian atmospheric science that are divided to three motivating science questions leading to the three associated objectives shown in Table 1.

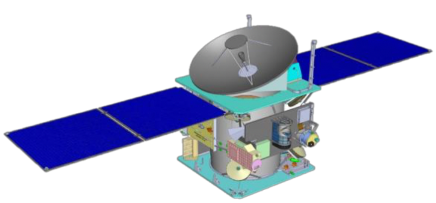

Figure1: Emirates Mars Mission.

Motivating Questions	I. How does the Martian lower atmosphere respond globally, diurnally and seasonally to solar forcing?	II. How do conditions throughout the Martian atmosphere affect rates of atmospheric escape?	III. How do key constitunets in the Martian exosphere behave temporally and spatially?
EMM Objective	A. Charactarize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability. (EMM Inves. 1&2)	B. Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere. (EMM Inves. 1-4)	C. Characterize the spatial structure and variability of key constituents in the Martian exosphere (EMM Ines. 4)

Table 1: Science Questions and EMM Objectives

EMM will achieve these objectives through four investigations shown in Table 2.

EMM Investigation	1. Determine the three-dimensional Thermal State of the lower atmosphere and its diurnal variability on sub-seasonal timescales	2. Determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales	3. Determine the abundance and spatial variability of key neutral species in the thermosphere on sub-seasonal timescales.	4. Determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescale.
Instruments	EMIRS	EMIRS, EXI	EMUS	EMUS

Table 2: EMM Investigations.

Objective A is achieved through the completion of Investigations 1 and 2, which are to determine the structure and variability of atmospheric temperatures (Investigation 1) and the geographic and diurnal distribution of key constituents (Investigation 2), respectively. Objective B is achieved through completion of Investigations 1 and 2, in addition to Investigations 3 and 4, which are to determine structure and variability in the Martian thermosphere and exosphere, respectively. Objective C is achieved solely through Investigation 4, which is to determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescales.

Instrument Overview:

The EMIRS instrument (Figure 2) is an interferometric thermal infrared spectrometer that is developed by Arizona State University (ASU) in collaboration with the Mohammed Bin Rashid Space Centre (MBRSC). It builds on a long heritage of thermal infrared spectrometers designed, built, and managed, by ASU's Mars Space Flight Facility, including the Thermal

Emission Spectrometer (TES), Miniature Thermal Emission Spectrometer (Mini-TES), and the OSIRIS-REx Thermal Emission Spectrometer (OTES).

Comparing EMIRS to its heritage line, it has the smallest instantaneous field of view (6 mrad, enabling small footprints from large distances), higher default spectral resolution (5 cm^{-1}) and a wider spectral range (6-40+ µm), with expected performance well beyond 50 µm. Further, this heritage enabled a relatively small (50x30x30cm), modest mass (~17kg) and relatively low power requirements (21W) without sacrificing measurement performance and reliability.

Figure 2: EMIRS Instrument System.

The EMIRS instrument will give a better understanding of how the Martian atmosphere will respond globally, diurnally, and seasonally to solar forcing as well as how conditions in the lower and middle atmosphere affect the rates of atmospheric escape. EMIRS will look at the geographical distribution of dust, water vapor and water ice, as well as the three-dimensional thermal structure of the Martian atmosphere and its diurnal variability on sub-seasonal timescales. The EMIRS instrument has a rotating mirror that will allow the instrument to do scans of Mars.

EMIRS measures light in the 6-40+ µm range with 5 cm^{-1} spectral sampling, enabled by a Chemical Vapor-Deposited (CVD) diamond beam splitter and state of the art electronics. This instrument utilizes a 3×3 array detector and a scan mirror to make high-precision infrared radiance measurements over most of a Martian hemisphere. The EMIRS instrument is optimized to capture the integrated, lower-middle atmosphere dynamics over a Martian hemisphere, using a scan mirror to make ~60 global images per week (~20 images per orbit) at a resolution of ~100-300 km/pixel. The scan-mirror enables a full-aperture calibration, allowing for highly accurate radiometric calibration (<1.5% projected performance) to robustly measure infrared radiance.

Concept of Operation:

The EMIRS Instrument has only one observation strategy, which is shown in Figure 3. This observation strategy is performed 20 times per orbit in the nominal science orbit. The spacecraft will do an EMIRS observation with the EMIRS boresight controlled to within 1 degree. The spacecraft will begin a single axis slew across the disk, maintaining a constant slew rate according to either the smear limit requirement or the time it takes EMIRS to complete the acquisition of the full disk of Mars, which is ultimately a function of altitude.

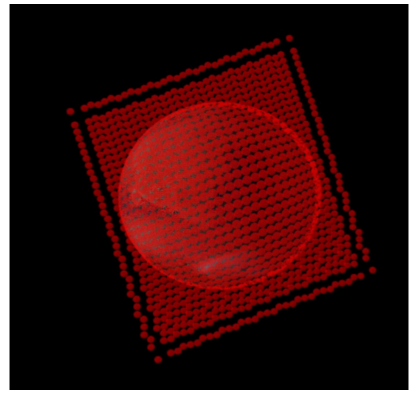

Figure 3: EMIRS Synoptic Observation strategy.

As the spacecraft slews, the EMIRS instrument will move its pointing mirror to scan across the planet with a single directional scan and retrace. This procedure enables EMIRS to collect data over the entire Martian disk with minimal gaps. In order to support a variety of slew rates, EMIRS will also be able to pause its acquisition sequence at the end of each row to allow for a range of spacecraft slew rates. A summary of the observation strategy for EMIRS is found in Table 3.

Observing Strategies	
S/C Slew Across Disk:	10.4º – 18.7º based on altitude
Instrument Scan:	15.6º – 23.9º based on altitude
Effective Scan Rate:	1.3º FOV takes 4 sec acquisition
Slew Rate:	≤ 0.71º/min at periapsis (20,000km) ≤ 1.09˚/min at Apoapsis (44,000km) variable by orbit height
Observation Duration:	~32 min at periapsis; ~15 min at Apoapsis

Table 3: Summary of EMIRS Observations.

Data Completeness:

EMIRS will measure the global distribution of key atmospheric parameters over the Martian diurnal cycle and year, including dust, water ice (clouds), water vapor and temperature profiles. In doing this, it will also provide the linkages from the lower to the upper atmosphere in conjunction with EMUS and EXI observations. A summary of the level 3 science product and level 2 measurement required is found in Table 4.

EMIRS will study the three-dimensional thermal state and diurnal variability of the lower atmosphere (0-50km) on sub-seasonal timescales and measures the CO_2 absorption band, from which temperature profiles can be retrieved via radiative transfer modeling. The atmospheric temperature profile accuracy will be ± 2.0K for 0-25 km altitude, ± 4.0K from 25-40 km altitude. The vertical resolution of the retrieved profile will be 10 km over all altitudes from 0-50 km. Dust will be retrieved using the broad and distinctive "V" shaped absorption centered at about 10.75 cm^{-1}. Water ice clouds will be retrieved using the broad and distinctive bowl-shaped absorption centered at about 825 cm^{-1}. Water vapor gas has a distinctive set of narrow absorptions between about 200 and 400 cm^{-1} that will be used for the retrieval. The EMM orbit and observation plan enables nearly complete global and diurnal coverage of all retrieved quantities over a time span of ~ 10 day.

Level 3 Science Product	Level 2 Measurement Required	Purpose
Dust optical depth at 9 μm	Relative radiance of dust absorption bands.	To characterize dust.
Ice optical depth at 12 μm	Relative radiance of ice absorption bands.	To characterize ice clouds.
Water vapor column abundance	Relative radiance of water vapor absorption bands.	To track the Martian water cycle.
Temperature profiles w.r.t altitude for 0 to 50 km	Absolute radiance of CO_2 absorption band	Track the thermal state of the Martian atmosphere.
Surface Temperature	Radiance at 1300 cm^{-1}.	Boundary condition for the lower atmosphere.

Table 4: Summary of Level 3 Science Product and Level 2 Measurement Required.

Summary:

The data provided from EMIRS will enhance the understanding of the lower atmosphere of Mars and its variability on sub-seasonal time scales. EMIRS will measure three-dimensional global thermal structure to provide temperature changes throughout the Martian surface and atmosphere. In addition, the abundances of dust, water ice and water vapor in the Martian atmosphere will be measured. The data from EMIRS combined with EXI and EMUS, will give us a better understanding of the connection between the lower and upper atmosphere.

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Scientific payload of the Emirates Mars Mission: Emirates Exploration Imager (EXI)

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Abstract

The Emirates eXploration Imager (EXI) instrument is one of three scientific instruments abroad the Emirate Mars Mission (EMM) spacecraft, “Hope”. The planned launch window opens in the summer of 2020, with the goal of this United Arab Emirates (UAE) mission to explore the dynamics of the Martian atmosphere through global spatial sampling which includes both diurnal and seasonal timescales. A particular focus of the mission is the improvement of our understanding of the global circulation in the lower atmosphere and the connections to the upward transport of energy of the escaping atmospheric particles from the upper atmosphere. This will be accomplished using three unique and complementary scientific instruments. The subject of this presentation, EXI, is a multi-band, camera capable of taking 12 megapixel images, which translates to a spatial resolution of better than 8 km with a well calibrated radiometric performance. EXI uses a selector wheel mechanism consisting of 6 discrete bandpass filters to sample the optical spectral region: 3 UV bands and 3 visible (RGB) bands. Atmospheric characterization will involve the retrieval of the ice optical depth using the 300-340 nm band, the dust optical depth in the 205-235nm range, and the column abundance of ozone with a band covering 245-275 nm. Radiometric fidelity is optimized while simplifying the optical design by separating the UV and VIS optical paths. The instrument is being developed jointly by the Laboratory for Atmospheric and Space Physics (LASP), University of California, Boulder, USA, and Mohammed Bin Rashid Space Centre (MBRSC), Dubai, UAE.

1. Introduction

Mars has long been the interest of many scientists around the globe. Several missions to Mars have helped in unlocking key information to the understanding of the processes and cycles of Mars atmosphere. However, a large part of the recently acquired observations of Mars have been obtained from spacecraft in sun-synchronous orbits (i.e., providing a limited range of local times), leaving much of the Mars diurnal cycle unexplored. Because of the limited coverage, it has been difficult to delineate potential diurnal aspects of such basic things as dust and water ice optical depths, as well as to validate the various algorithms used in the “physics packages” of Martian dynamical models.

The Emirates Mars Mission (EMM), a mission set to be launched in 2020 by the United Arab Emirates, will be able to provide a dataset that can fill this observational gap by sampling contemporaneously both diurnal and seasonal timescales on a global scale. Using three unique and complementary scientific instruments [1][2], EMM will further improve our understanding of the global circulation in the lower atmosphere and the connections to the upward transport of energy of the escaping atmospheric particles from the upper atmosphere. Aligned with MEPAG Goal II: “Understand the processes and history of cli-mate on Mars” [3], EMM will be satisfying four scientific investigations as illustrated in the traceability table below for EMM objectives and investigations. Investigations 1 and 2 will be focusing on the lower atmosphere to determine the three dimensional structure and variability of atmospheric temperature and to determine the geographic and diurnal distribution of key constituents in the lower atmosphere respectively. While investigation 3 and 4 focuses on determining the structure and variability in the Martian thermosphere and exosphere respectively. Table 1 summarizes the flow down from the motivating science questions, to the EMM mission objectives and investigations. In this poster, we will focus on EMM investigation 2 and one of the scientific payloads that satisfies it, the Emirates eXploration Imager (EXI).

Motivating Questions	I. How does the Martian lower atmosphere respond globally, diurnally and seasonally to solar forcing?	II. How do conditions throughout the Martian atmosphere affect rates of atmospheric escape?	III. How do key constituents in the Martian exosphere behave temporally and spatially?
EMM Objective	A. Characterize the state of the Martian lower atmosphere on global scales and its geographic, diurnal and seasonal variability. (EMM Invest. 1&2)	B. Correlate rates of thermal and photochemical atmospheric escape with conditions in the collisional Martian atmosphere. (EMM Investigation 1-4)	C. Characterize the spatial structure and variability of key constituents in the Martian exosphere. (EMM Investigation 4)

EMM Investigation	1. Determine the three-dimensional thermal state of the lower atmosphere and its diurnal variability on sub-seasonal timescales.	2. Determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales.	3. Determine the abundance and spatial variability of key neutral species in the thermosphere on sub-seasonal timescales.	4. Determine the three-dimensional structure and variability of key species in the exosphere and their variability on sub-seasonal timescales.
Instruments	EMIRS	EMIRS, EXI	EMUS	EMUS

2. EXI Science Targets

Table 1: EMM Science Flow

Investigation 2 is to "determine the geographic and diurnal distribution of key constituents in the lower atmosphere on sub-seasonal timescales". This investigation will help in better understanding the processes that are driving the global circulation in the current Martian climate by sampling key constituents (dust, water ice clouds and ozone) in the lower atmosphere on sufficient spatial and temporal scales. EXI will be able to capture the ice optical depth, dust optical depth and the column abundance of ozone.

2.1 Dust

Dust is one of the most abundant constituent and a major driver of the Martian atmospheric energy balance. Ob-serving dust will allow us to have a better understanding of the behavior and evolution of the atmosphere. To better characterize the geographic, diurnal and seasonal distribution of dust, EXI will capture an image in the 205 – 235nm and 620 – 680nm spectral bands, where the optical depth at 220nm can be retrieved. The ultraviolet band will provide the primary aspect of the optical depth retrieval, using the contrast of the dark dust against the bright background of Rayleigh scattering. Adding the 635nm band range provides context, as well the ability to constrain the dust column during higher opacity events, i.e., a dust storm. It is our goal to combine these products with the EMM Emirates Mars InfraRed Spectrometer (EMIRS) measurements of dust optical depth at 9µm to directly constraint additional dust properties such as the mean particle size.

2.2 Water Ice Clouds

Water ice clouds also play an important role in the Martian climate. In terms of their geographic, diurnal and seasonal distribution, water ice clouds are known to have an impact on the total energy balance, the transport of water and the photochemistry of the Martian atmosphere. In order to acquire the column optical depth of the ice cloud, EXI will be observing Mars in the wavelength band from 300 – 340nm. Exploiting the contrast of the bright clouds with the dark surface, we will derive the water ice optical depth in a manner similar to that of the Mars Reconnaissance Orbiter (MRO) MARs Color Imager (MARCI). As with dust, we will combine these optical depths with those for water ice from the EMIRS at the 12um-based retrieval to constrain microphysical properties such the mean particle size.

2.3 Ozone

Ozone, and its spatial and temporal distribution, is important in understanding the photochemical processes of the atmosphere. EXI will determine ozone geographic and diurnal distribution on sub seasonal timescales by imaging in the 245 – 275 nm band. The conversion of the observed radiance to an ozone column abundance will be based on the approach used by MARCI (i.e,.Clancy et al., 2016).

Table 2: EXI physical parameters

Physical parameter	Observable Quantity	Observable Quantity Requirement
Ice column-integrated optical depth	radiance at 300-340nm	Radiometric accuracy ≤ 5% (± 0.03 optical depth)
Dust column-integrated optical depth	radiance at 205-235nm	Radiometric accuracy ≤ 5% (± 0.1 optical depth)
Ozone Column integrated abundance	radiance at 245-275nm	Radiometric accuracy ≤ 5% (± 0.5µm-atm)

To better characterize the mesoscale behavior of these three constituents over both diurnal and seasonal timescales, a spa-tial resolution of 8km or less will be required. As for obtaining the radiance of ice, dust and ozone absorption bands, an accu-racy of ± 5% is required. Table 2 summarizes the requirements for the physical parameters.

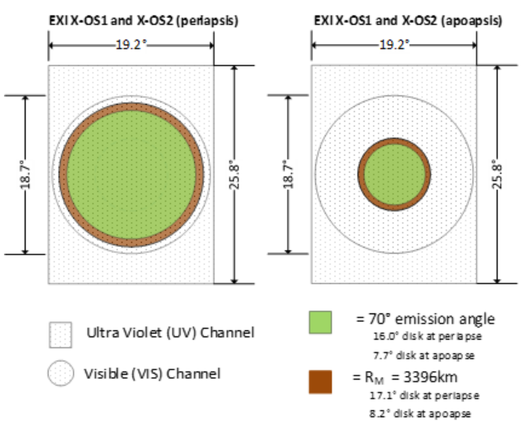
3. Implementation Overview

EXI is a multi-band, radiation tolerant camera capable of taking 12 megapixel images while maintaining the radiometric calibration needed for detailed scientific analysis. The instrument is being developed jointly by the Laboratory for Atmospheric and Space Physics (LASP) and Mohammed Bin Rashid Space Centre (MBRSC). It has a dual lens assembly separating the UV and VIS optical paths. EXI uses a selector wheel mechanism consisting of 6 discrete bandpass filters, 3 UV bands and the RGB bands. Table 3 and figure 1 summarizes EXI instrument specifications.

Table 3: EXI Instrument Specifications

Specification	UV	VIS
Focal Plane Format	12.6 MP 4:3 format 4096×3072 @ 5.5 µm	
Technology	CMOS	
Dynamic Range	12-bit, 13,500 e- full well	
Lens System	48 mm, f/3.6	51 mm, f/4.25
Field of View	19.0°	25.8° by 19.2°
Pixel Angular View	23 arcsec per pixel	22 arcsec per pixel
Plate Scale	0.85 mm/°	0.90 mm/ °
Distortion @ 9.35°	+6%	-2%
Ground coverage at apoapsis	Full disk	
Ground resolution at apoapsis	4.9 km per pixel	4.6 km per pixel
Ground coverage at periapsis	Full disk	
Ground resolution at periapsis	2.3 km per pixel	2.2 km per pixel

Figure 1 EXI Coverage at Periapsis and Apoapsis



4. Concept of Operation:

EXI will be capable of providing simultaneous observations to fulfill navigation, public relations (PR) and science products. Based on the current orbit parameters, EXI will be capable of observing nearly complete local time coverage of Mars throughout one full Martian year. The resulting dataset will cov-er key seasonal information for more than 80% of the geographic area of Mars. These will be accomplished using three EXI observation sets. Two of which are science observations and the third serves PR needs. The science observation sets (EXI OS 1 and 2) consists of the four bands needed to observe the dust and ice optical depth as well as the ozone column abundance in the 220nm, Red (635nm), 320nm and 260nm. The difference is that OS2 has lower resolution (<64km resolution) as it is done following EMIRS observation. While EMIRS is taking its observation, the planetary locations and local times within the field of view change and shift for EMIRS compared to EXI. Therefore, this second strategy is to ensure that any missing observation is being covered from the first EXI observation, which will then be overlapped with EMIRS observation data. While in third observation set (EXI OS 3), it consists of three bands in the Red (635nm), Green (564nm) and Blue (437nm) in order to produce beautiful image of Mars for PR purposes. Table 4 summarizes EXI observation strategies.

Table 4: EXI Observational Strategy

Observation Strategy	Observation Strategy Set
EXI OS 1 (science)	4 Contemporaneous images • 220 nm, 260 nm, 320 nm, 635 nm • Incident <80°; emergence < 70° • 2 x 2 pixel binning (≤ 0.19 mrad spatial resolution) 2 dark images (for each detector)
EXI OS 2 (science)	4 Contemporaneous images • 220 nm, 260 nm, 320 nm, 635 nm • Incident <80°; emergence < 70° • 16 x 16 pixel binning (≤ 0.49 mrad spatial resolution) 2 dark images (for each detector)
EXI OS 3 (PR)	3 Contemporaneous visible images • 437 nm, 546 nm, 635 nm • Full resolution (≤ 0.11 mrad spatial resolution)

5. Data Completeness and Utilization:

To understand the linkages between the aerosols and ozone and their impact, it is important to measure the diurnal variability of the Martian atmosphere happening across the seasons. EXI will be able to sample most local times on weekly timescales providing us with unique measurements in different areas of the Martian globe. In order to capture the variability of the aerosols and ozone across seasons, a 10-day sampling period is required. As for the geographic coverage, EXI will be able to sample nearly all longitudes and latitudes less than 72 hours providing rapid and continuous monitoring of any cloud and dust events during a Martian year. Table 5 summarizes the EXI coverage and sampling requirements.

Table 5: EXI Coverage Requirement

EXI Coverage Requirement	
Diurnal Requirement	In any given span of 10 days, the 4 three-hour intervals spanning 6am-6pm local time are sampled with at least 80% coverage of longitude in: ≥ 3 local time intervals for all latitude equatorward of ±30° ≥ 2 local time intervals for all latitude equatorward of ±50° In any given span of 10 days, at least one in the 4 three-hour intervals spanning 6am-6pm local time is sampled with at least 50% coverage of longitudes for all latitudes equatorward of ±80°
Geographic Requirement	≥ 80% of the geographic area of Mars sampled more frequently than every 72 hours. Latitudes ≤80° sampled more frequently than every 72 hours.
Seasonal Requirement	Observations over 1 full Martian year (Goal: 20 of the 24 15° intervals of L_s sampled)

References:

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[2] Fatma Lootah, Hessa Almatroushi, Greg Holsclaw, Justin Deighan, Michael Chaffin and the EMUS Team. Robert Lillis, Matthew Fillingim, Scott England, Suhail AlMheiri and Heather Reed (2).Mohammed Khoory, Ginger Drake, Andrew Jones and the EXI Team (2018). Scientific Payload of the Emirates Mars Mission: Emirates Exploraton Imager (EXI) Overview.

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Impedance measurements for RIME dipole aboard JUICE

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Abstract

The goal of the mission JUICE (JUpiter ICy moon Explorer) is the exploration of Jupiter and three of its Galilean moons. In the year 2030 the spacecraft (S/C) will arrive in the Jovian system and investigate the celestial bodies by RIME (Radar for Icy Moons Exploration) and other instruments aboard JUICE. In order to verify the simulation results, a simplified S/C-mock-up is built and measured.

1. Introduction

One of ESA's largest future missions is JUICE: JUpiter ICy moon Explorer. The launch is scheduled for 2022 and the arrival for the year 2030. The goal of this mission comprises the exploration of three out of the four Galilean moons, Europa, Callisto and Ganymede, as well as the atmosphere of Jupiter itself. Among several other experiments investigating the Jovian system, RIME will penetrate the celestial bodies with electromagnetic waves to analyse subsurface structures. This subsurface-radar operates at a centre frequency of 9 MHz with a bandwidth of 3 MHz. Due to the relatively low frequency range, RIME is capable to penetrate the surface up to a depth of about 9 km with a maximum vertical resolution of 50 m. The 16.6 m long RIME dipole antenna consists of two 8.3 m long rods, each fed by a 50 Ω coaxial cable. Both coaxial cables are connected to a matching network (MN) in order to achieve the required bandwidth. For the design of the MN, it is necessary to know the impedance within the bandwidth precisely. Due to the dimensions of the S/C, the tip-to-tip length of the solar panels is about 30 m, whereas a measurement with the original S/C model is not feasible. Therefore, the impedance values are determined with a 3D full-wave, frequency domain EM solver. For the verification of the simulation results a S/C-mock-up is built and measured.

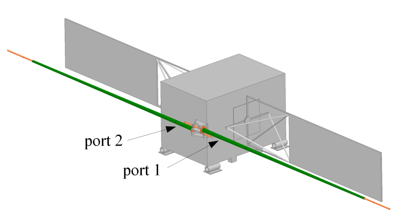
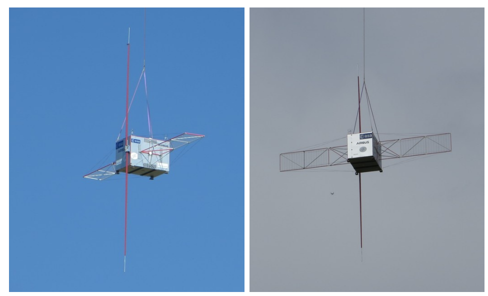


Figure 1: CAD model of the simplified S/C mock-up with horizontally orientated RIME dipole (orange) and GFRP flagpole for stabilization (green).

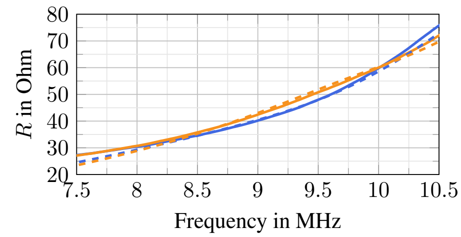


(a) Horizontal solar panel. (b) Vertical solar panel.

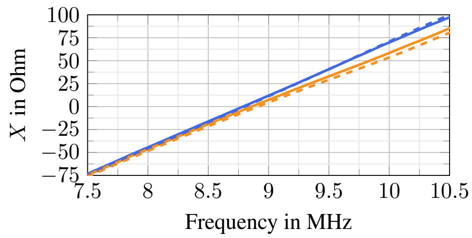
Figure 2: S/C mock-up fixed to helicopter with vertically oriented RIME dipole at an altitude of 320 m.

2. Measurements

Due to a centre frequency of 9 MHz, the mock-up cannot be measured in an anechoic chamber. Therefore, the determination of the impedance can only be done in free space. In this case, the mock-up is lifted by a helicopter to a height of 320 m, which corresponds to about ten times the wavelength at the centre frequency. This altitude is chosen in order to minimize the influence of the ground. Moreover, the use of a helicopter requires some simplifications on the S/C mock-up: Due to the wind load, the solar panels have to be shortened from $\approx 30\,\mathrm{m}$ to $\approx 14\,\mathrm{m}$, which complies with the maximum load of 1000 kg for the flight as well. Furthermore, a pivoted antenna is necessary for take-off and land-



(a) Resistance R



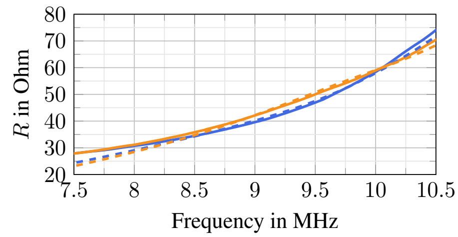
(b) Reactance X

Figure 3: Comparison of impedance between measurement and simulation for horizontal solar panel orientation. — port 1: measured, — port 2: measured, - - - port 1: simulated, - - - port 2: simulated

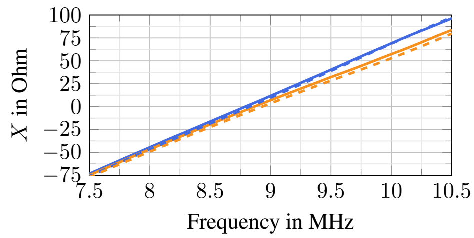
ing. A picture of the CAD model with the horizontally oriented antenna for take-off and landing is shown in Fig. 1.

All components of the S/C mock-up are made of aluminium and the solar panels can be rotated in steps of 45°. In addition to this, the solar panels are isolated with a resistor of 1 kΩ from the S/C body. The antenna consists of hollow aluminium cylinders with a diameter of 40 mm. Due to the gravitation, the dipole needs to be stabilized in order to avoid bending effects. This is realized by centring the antenna inside a flagpole using foam spacers. Glass fibre reinforced plastic (GFRP) with a relative permittivity of $\varepsilon_{\mathrm{r}} = 3.1$ is chosen for the flagpole in order to minimize the impact on the measurements.

The impedance measurements are conducted at an altitude of 320 m aboard the mock-up. As can be seen in Fig. 2, the mock-up is fixed with a 70 m long rope to the helicopter and two different solar panel positions are investigated. During the measurements, a coaxial cable with a length of 5 cm is connected to each feeding point of the antenna. These cables are de-embedded for the following comparison. The results are shown in Fig. 3 and Fig. 4. Both solar panel positions yield to



(a) Resistance R



(b) Reactance X

Figure 4: Comparison of impedance between measurement and simulation for vertical solar panel orientation — port 1: measured, — port 2: measured, - - - port 1: simulated, - - - port 2: simulated

similar impedance values. The maximum deviation for this analysis always occurs at port 2, which is located in the direction of the ground. For vertically oriented solar panels, the maximum deviation between measurement and simulation is 4.7 Ω in resistance and 4.5 Ω in reactance. However, horizontally oriented solar panels result in a difference of 3.7 Ω in resistance and 5.1 Ω in reactance.

3. Summary and Conclusions

For the verification of the simulated impedances of the RIME dipole a S/C mock-up is built and measured. Measurement and simulation results are in good agreement, which justifies the MN design on the basis of simulation results.

Acknowledgement

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Jovian Neutrals Analyzer for the Particle Environment Package onboard JUICE

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Abstract

Jovian Neutral Analyzer (JNA) is one of six sensors in the Particle Environment Package onboard the JUICE to Jovian system. The JNA provides the low-energy energetic neutral atom (ENA) images originating from the Jovian magnetospheric plasma interaction with the surface/magnetosphere of the Galilean icy moons, and Io torus images through ENA emissions generated from charge-exchange between the co-rotating plasma and the neutral torus. The JNA design is based on successful predecessors and optimized for a harsh radiation environment in Jupiter. We have built a flight-like test model and characterized the performance. In the paper, the design features of JNA together with predicted scientific performance are shown.

1. Introduction

Jovian Neutral Analyzer (JNA) is one of six sensors in the Particle Environment Package onboard the JUICE to Jovian system. The JNA provides low-energy ENA (L-ENA) images of the Jovian magnetospheric plasma interaction with the surfaces of Ganymede, Callisto, and Europa. The neutrals are produced via sputtering of ice by high-energy particles, and by backscattering of the original incident projectiles [2, 5]. ENA images in the low energy range map the plasma flux distribution at the surface and thus display precipitation regions on Ganymede, directly showing the open/close field lines boundary. The plasma precipitation maps from Callisto directly reveal the different modes of the plasma interaction. JNA also aims to detect L-ENAs from charge – exchange of the co-rotating hot plasma and neutral tori of Io and Europa in the inner magnetosphere. For Io torus imaging, the Io torus is not visible in high-energy ENAs due to low energetic ion fluxes in these regions. Futaana et al. [3] shows that the expected ENA fluxes in the 100–200 eV energy range is a factor of 10 higher than those from the Ganymede surface and thus readily detectable.

2. Instrument

3.1 Principle

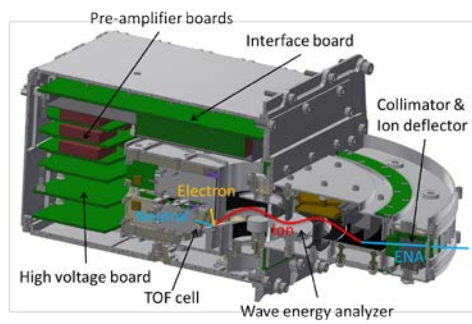

Figure 1: JNA model cut-off with particle trajectory.

The JNA detects L-ENAs by converting neutrals to ions on a charge conversion surface. Ionized neutrals, namely ions, are subsequently guided through “wave-type” electrostatic energy analyzer and subjected to time-of-flight (TOF) analysis as shown in Figure 1. Combination of energy and TOF analyses provides information on mass discrimination. Although the design is based on the Chandrayaan/CENA and BepiColombo/ENA analyzers [4], a TOF system is optimized to mitigate extremely harsh radiation environment in the Jovian system. JNA uses 11 Ceramic Channel Electron Multipliers (CCEMs) for start signal detection and 11 CCEMs for stop signal detection for the TOF measurement, which allow us to determine incident angle of ENAs. The performance of JNA is listed in the Table 1.

Table 1: JNA performance

Measured particles	ENAs (optionally ions)
Energy range	10 eV-3.3 keV (hydrogen)
Resolution, DE/E	~100%
Mass range	1 – 32 amu
Masses resolved	1, (Heavy)
Field-of-view	15°x150°

Angular resolution	7°x15°, 11 pixels
Time resolution	Nominal 15s
G-factor	Total: 0.21 cm^2sr eV/eV Efficiency: 10^{-4} – 10^{-3}

3.2 Surfaces

A surface material is a key element to characterize the instrument. Two types of surfaces are used: a charge conversion surface (CS) for ionization of ENAs and a start surface for generating secondary electrons for start signal of the TOF. A highly polished Si-waver coated with Al_2O_3 is a baseline for the CS, which shows high ionization yield and low angular scattering. For the start surface, a CVD diamond attached on Al substrate is used because of low secondary electron yield from gammas owing to a low-Z material, excellent secondary electron yield for ions and very low angular scattering [1].

3.3 Radiation mitigation

We optimized the design to adapt to the harsh radiation by (1) using a high-Z material for shielding of detectors and electronics, (2) use of CCEMs, which are less susceptible to radiations, (3) shortened TOF path length (5-15 mm) to minimize TOF window, (4) small TOF cell volume to minimize the detector size and shrink the exposed surface area to radiation, on which background electrons and gammas are generated.

3. Performance characterization

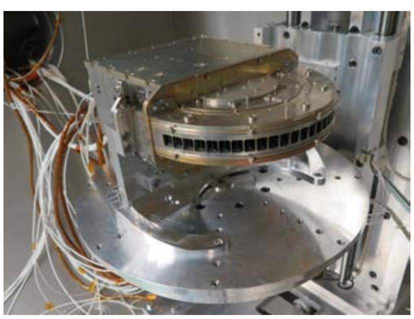

Figure 2: JNA TM testing in a vacuum tank

The performance of JNA is studied using a flight-like model. The instrument is exposed to a well-characterized particle beam and the response is investigated (Figure 2). According to the preliminary analysis, the fundamental performance, such as mass resolution and energy resolution, is verified, though full characterization requires additional analyses.

4. Performance analysis

To estimate the JNA scientific performance during observation of the Jovian moons, a signal-to-noise ratio (SNR) is calculated with help form a radiation analysis of the instrument and ENA modelling. Expected SNR for Ganymede precipitation mapping is 14 to 140 depending on the energy and species, and 30 to 240 for Callisto. For Io torus imaging, the SNR is largely dependent on the position of the spacecraft, but we expect the SNR is sufficiently high because of high foreground ENA fluxes for Io torus.

5. Summary

We have developed the Jovian Neutrals Analyzer onboard the JUICE primary to map ion precipitation on Ganymede/Callisto's surface and to image Io torus by observing L-ENAs. The basic performance is verified using a flight-like model. By combining the JNA performance, the detailed JNA radiation model and the ENA foreground model, the SNR is predicted to be sufficiently high to fulfil the scientific requirements for the instrument. A flight model is to be delivered to the spacecraft in 2019.

Acknowledgements

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The MASTER imaging spectrometer for the JAXA/Okeanos mission

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Abstract

We present an overview of MASTER (MApping Spectrometer for Trojans Exploration and Reconnaissance), an high resolution imaging spectrometer proposed for the JAXA/OKEANOS mission.

1. Introduction

The target of the JAXA Okeanos mission is a Trojan asteroid. These asteroids are located in the L4 and L5 Lagrangian points of the Sun-Jupiter system. Most of them are primitive bodies, belonging to the C- and mainly D-type taxonomic classes. The Okeanos science goals are directed at improving our understanding of the origin, evolution, composition and physical properties of the Trojans.

Their origin is still debated. One scenario suggests that the Jupiter Trojans formed in the same part of the Solar System as Jupiter and successively entered into its orbit [1]. In another scenario, the Jovian planets are assumed to have formed between 5-15 AU and were captured into their current orbits during the planetary migration triggered by the 1:2 Jupiter-Saturn resonance [2]. Whatever the origin, an in-depth exploration enables us to obtain information about planetary bodies in the snowline or the Kuiper Belt and their role in the delivery of building blocks of life to Earth.

There are several strategic knowledge gaps (SKGs) in understanding the primitive nature of the Trojans and their origin and evolution. The Trojan SKGs include: 1) What is their surface composition? 2) Do they include materials of astrobiological interest (e.g., CHONS? 3) Are they compositionally homogeneous both as a group and individual objects? 4) Do they experience cometary activity? 5) What is their link with comets and main belt asteroids?

2. Science objectives

The MASTER (MApping Spectrometer for Trojan Exploration and Reconnaissance) imaging spectrometer will perform science investigations aimed at addressing the SKGs. Specifically, the MASTER objective will be to detect, quantify and study the spatial distribution of spectral parameters related to surface materials (the following list is not exhaustive and can be expanded on the basis of future results from ground-based observation and the early phases of the SPS mission):

a) depth of absorption features in reflectance spectra associated with organics (3.1-3.3 μm), tholins (2.7 μm), hydrated materials (2.7 μm), ices (2.0-3.0 μm), and hydrous silicates (2.2-2.3 μm). The occurrence of some of these bands (2.3, 3.0, 3.2 and 3.4 μm) has been suggested, but never confirmed, by ground-based observations.
b) spectral infrared slope (e.g., between 2 and 3 μm).

In order to be sensitive to potentially low abundances of these materials, measurements should be able to identify a 1% band depth and this imposes a minimum required reflectance accuracy of 0.5%.

3. Specifications

MASTER acquires hyperspectral images, i.e. two-dimensional spatial images obtained simultaneously at different wavelengths, operating in pushbroom mode acquiring one line at a time through a slit of the spectrometer. The along-track spatial dimension is obtained by exploiting the spacecraft relative motion and velocity. Specification and performance of the MASTER instrument are summarized in Table 1.

Name	MASTER
Components	Optics, detectors, proximity electronics, radiator
Size	450Wx150Hx75D mm^3
Mass	5.5 kg
Power	0.5 W (detector) 5 W (proximity electronics)
Heat consumption	0.5 W (transmitted to IS)
Temp. range	120 K (detector), 160K (optics)
Amount of data	< 10 Gb
Telemetry rate	~300 kbit/s (average)
Detector	HgCdTe array
Wavelength range	1.8-3.6 μm
Resolution	20 nm
FOV	6°
IFOV	1mrad
SNR	>100
Quantum efficiency	>0.5
Spectral sampling	20 nm
Band depth accuracy	1%

Table 1. MASTER specifications.

Currently, a different MASTER configuration to expand the wavelength range up to 5 μm is under study.

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Penetrators as a deployment tool for Mass Spectrometer instrumentation

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Abstract

We discuss penetrator deployment systems and Mass Spectrometer (MS) based instrumentation that offer the potential for future characterization and understanding of the volatile content at the surface and near-surface of airless bodies in the Solar System. We review previous penetrator missions, systems and instrumentation, before considering future options to bodies such as the moon and small solar system bodies.

1. Introduction

Solar system exploration is currently in a phase where in-situ analysis is playing an increasingly important role. A number of mission opportunities are arising, and are under consideration that may provide the opportunity to gain access to surface and sub-surface material through deployment of either high-speed penetrator platforms [1], or low-speed sub-surface penetrating mole devices deployed by soft landers [2].

1.1 Penetrators

Penetrators (Figure 1) are small probes that offer the opportunity to gain access to surface and sub-surface material without the need for complicated drilling or excavation equipment. Multiple penetrators further offer geographically spaced investigations and mission redundancy. However, despite previous attempts penetrator technology has yet to be proven in flight. The Russian Mars 96 penetrator probes, launched in 1996 to investigate Mars was lost when the space-craft failed to leave Earth orbit. The NASA's Deep Space 2 (DS2) mission successfully reached Mars orbit however the probes never made contact with the orbiter. Despite these setbacks penetrators are seen as a viable concept with possibility to accommodate a wide range of target bodies.

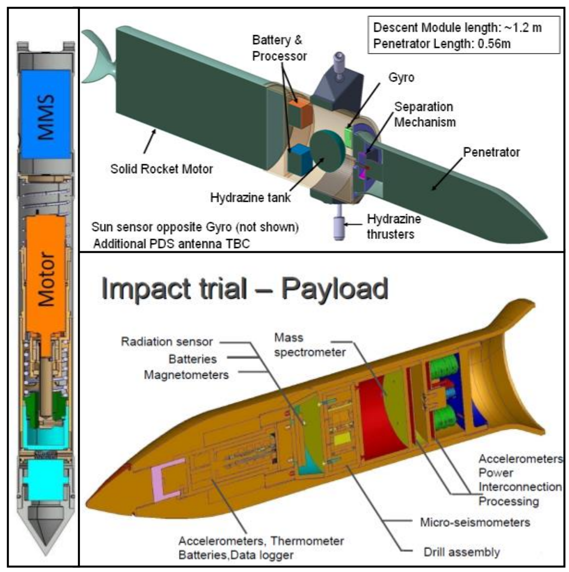

Figure 1: (left) low-speed Mole deployment (top-right) High speed penetrator system (bottom-left) Instrumented penetrator

1.2 Mass Spectrometry

Mass spectrometry is regarded as a "gold standard" analytical technique in terrestrial laboratories and is used for the determination of the elemental, isotopic and molecular composition of sample material. A high-speed deployable (Figure 2) and a low-speed deployable version of the Ptolemy MS [3,4], instrument on-board the Rosetta lander been developed. These instruments will allow in-situ volatile characterisation following penetrator deployment from either high-speed or low speed platforms.

Figure 2: (left) High-speed (right) low-speed deployable Mass Spectrometer instruments

2. Instrument testing

High-speed testing of the MS has been performed under a UK-led penetrator testing programme [5]. The objective of these tests was to demonstrate survivability of the penetrator shell and to assess the impact on instrument sub-systems. The impact tolerant MS was part of the payload. An Impact speed of 310 ms^{-1} was achieved with the use of a rocket propelled sled (Figure 2)

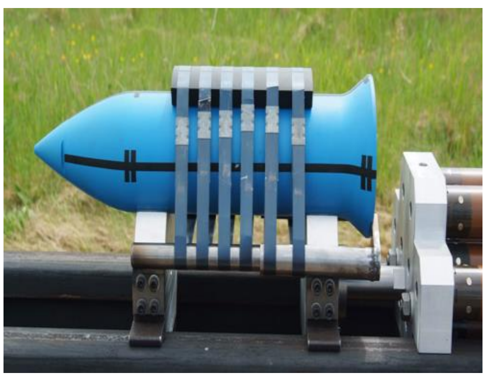

Figure 3: Instrumented penetrator prior to impact testing

3. Future missions opportunities

3.1 Lunar Penetrator mission

The L-DART mission concept [6], is currently under consideration and consists of one or more penetrators being released from lunar orbit into a targeted permanently shadowed region. The penetrator deployed MS would measure the rise and decay of volatiles released during and after the impact event. The results obtained by L-DART will provide ground truth for the numerous orbital measurements that provide indications concerning polar volatile deposits and their concentrations [7,8,9,10].

3.2 Deep space Penetrators

Conceptually similar to the ESA-China proposal for Marco-Polo at the ESA M4 call, a proposal from the China Academy of Space Technology would see a mission visit a NEO, return a sample to Earth, and then send the main spacecraft on to a Main Belt Comet (MBC) [11]. If selected it would arrive at the MBC, which is currently expected to 133P, in the late 2020s. Discussions with international partners are ongoing and a penetrator deployed MS is under investigation to allow access the subsurface and measure its volatile composition [3].

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Ultrasounds for Regolith and dust particles manipulation

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Abstract

1. Manipulation of dust particles or regolith with variable sizes is a challenge in microgravity or different gravity conditions than Earth. Rovers and sensors payloaded are subjected to the impact of micron-sized particles, which frequently remain adhered to their surfaces, generating or even inhibiting part of their functionality. Noninvasive techniques can be applied on these elements to prevent particle aggregation and sometimes blinding effects. Application of acoustic waves on these surfaces allow removal of the settled particles as a cleaning "mechanisms", preventing their loss in efficiency or, even, disabling.

2. Introduction

Acoustic chamber resonators generate a standing waves with pressure patterning including nodes. Inside the chamber resonating each particle, with a volume V_c much smaller than the acoustic wavelength λ, experiences a primary acoustic radiation generated by the acoustic standing wave with amplitude P_0 according to its specific properties [40] (Gor'kov 1962):

$$FR_c = \frac{\pi P_0^2 V_c \beta_l}{2\lambda}\varphi(\rho_c, \beta_c, \rho_l, \beta_l) \sin\left(\frac{4\pi x}{\lambda}\right) \quad (1)$$

where $\varphi(\rho_c, \beta_c, \rho_l, \beta_l) = \frac{5\rho_c - 2\rho_l}{2\rho_c + \rho_l} - \frac{\beta_c}{\beta_l}$ is the acoustic contrast factor. It defines the relationship between the densities and adiabatic compressibilities of both, cells (ρ_c, β_c,) and liquid (ρ_l and β_l) respectively. The distance from the cell to the node of pressure established inside the channel is defined by "x". The sign of φ indicates the motion of the particles, either toward the nodes (φ >0) or to the antinodes in the standing wave (φ < 0) respectively.

Figure 1 shows three equal beads approaching from three different distances toward a pressure node in a standing wave established inside a micfoluidic channel during the flow motion.

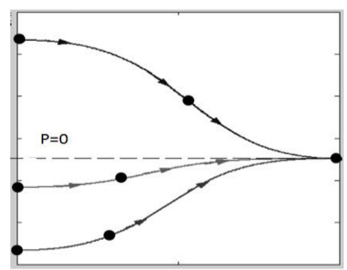

Figure 1. Numerical estimate (Matlab) of trajectories of three equal particles approaching a pressure node from different initial positions while circulating in a transverse direction.

The time required by the cells to reach a certain position "x" driven by the acoustic radiation force from any distance inside the resonating cavity can be numerically derived from Equation (1) as a function of all the parameters involved in this equation:

$$t = \frac{3\eta}{4\Phi(k R_c^2)E_{ac}} \ln\left[\frac{\tan[k \cdot x(t)]}{\tan[k \cdot x(0)]}\right] \quad (2)$$

It is possible to perform particle-size or density-based sorting of Lunar Regolith and dust in other planetary atmospheres using ultrasonic standing waves. Instead of particle-size sorting systems of Lunar & Mars Regolith using electrostatic or magnetic fields (Adachi et al in 2016 [1,2], we have developed different strategies for particle sorting based on the use of ultrasounds in microfluidic resonators and plate vibration systems respectively [YYY-ZZZ]. Our devices, tested on Ground, have demonstrated the ability of the ultrasounds to perform particle and cell separation and isolation.

These devices have also shown a high efficiency on the isolation of tumor cells as liquid biopsies.. Figure 2 shows the scheme of operation of our ultrasonic particle sorters.

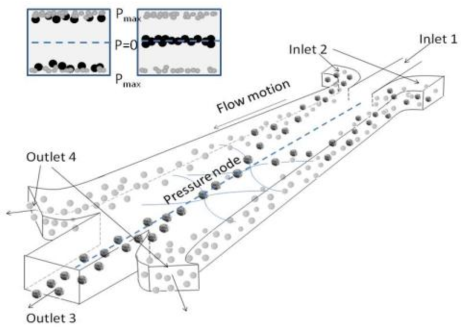

Figure 2: principle of operation of our ultrasonic particle separators.

The use of acoustic standing waves for particle manipulation can address this problem, as widely experimentally verified on Ground [3-5].

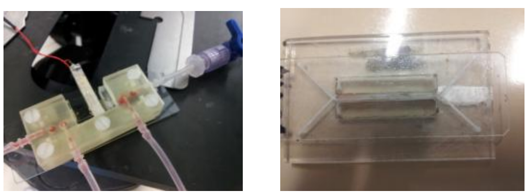

Figure 3: some of our chips for particle and cell manipulation

The efficiency of the acoustic waves to drive the particles depends also on the particle concentration as they influence the medium properties, efficiency also depends on the concentration of particles since they influence the properties of the medium, the more the greater their presence. A limit case is the grain matter, where other principles apply. Thus the importance of preventing settling down of large amounts of particles on surfaces exposed to the action of the particles impact. Therefore, the development of new methodologies to overcome these accumulation and clogging particle effects at different gravity conditions (including microgravity) is a challenge. The efficiency to remove the particles also depends on their concentration since they influence the properties of the medium: the greater their presence, the less fluid. In the limit case of regolith with a compacted grain matter and minimal interstitial spaces, another principle associated to the acoustics must be considered for the particle manipulation rather than the acoustic radiation force exerted through the fluid, and nonlinear or shock low frequency waves should be applied for the bulk grain motion by means of a shake of the grain matter.

Acknowledgements

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Research ideas in solar-system, lunar, and earth-sciences with Deep Space Gateway

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Abstract

On 5 and 6 December 2017, a Workshop: Research opportunities on the Deep Space Gateway (DSG), was held at the European Space Research and Technology Centre (ESTEC), to discuss the ideas for research opportunities on DSG. These ideas were submitted to European Space Agency (ESA) in response to the Call in August 2017. During this meeting, 23 ideas were presented in the research area of solar-system, lunar, and earth-sciences, followed by a panel discussion on the identified research topics, high impact areas, technical needs and general findings. In this paper, we introduce the outcome of the workshop in the research area of solar-system, lunar, and Earth sciences. A summary of the outcome from all the research area is given in the report ”Research Opportunities on the Deep Space Gateway: Findings from the Workshop and Call For Ideas” (ESA-HSO-K-RP-0284; 1.1)

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Cuve - Cubesat UV Experiment

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Abstract

Our Venus mission concept Cubesat UV Experiment (CUVE) is one of the proposals selected for funding by the NASA PSDS3 Program - Planetary Science Deep Space SmallSat Studies. CUVE concept is to insert a CubeSat spacecraft into a Venusian orbit and perform remote sensing (Fig. 1) of the UV spectral region using a high spectral resolution point spectrometer to resolve UV absorbers bands and also characterize the still unidentified main absorber present in the UV region. The UV spectrometer is complemented by an imaging UV camera with multiple bands in the UV absorber main band range for contextual imaging. CUVE would complement past, current and future Venus missions with conventional spacecraft, and address critical science questions cost effectively.

1. Introduction

The Venusian upper cloud deck, situated at an altitude range 60-70 km, is formed of small droplets comprising a mix of ~80% sulfuric acid (H_2SO_4) and water. These clouds are the reason for Venus' high albedo in the visible, where 70-80% of the incoming solar radiation is backscattered to space. For this reason, despite Venus being closer to the Sun than Earth, it absorbs a similar quantity of energy to that absorbed on our home planet. The maximum absorption of solar energy by Venus occurs in the UV where we observe spectral contrast features that originate from the non-uniform distribution of unknown absorbers within its clouds. This opacity source affects the energy balance in the Venusian atmosphere. The efficient absorbing power of the unknown UV absorbers in the clouds controls Venus' atmospheric engine. Determining the nature, concentration and distribution of these absorbers will increase the understanding of the overall radiative and thermal balance of the planet, in particular the atmospheric dynamics and the chemistry of the upper clouds. Sulfur dioxide SO_2 and the later discovered sulfur monoxide SO are strong UV absorbers present in Venus' spectrum between 200 and 340 nm; however, these species do not explain the strong absorption at longer wavelengths, around 365 nm which signifies a different substance (in gas or aerosol form) distributed non-uniformly in the cloud top and absorbing in the UV (for overview see [1]). Some candidate species have been proposed to explain the spectral contrast features in the UV: SO_2, $FeCl_3$, Cl_2, Sn, SCl_2, S_2O (e.g., [2], [3], [4], [5], [6]), elemental sulfur (S_8 o S_x in general) o polymeric sulfur ([7] and the recently hypothesized S_2O_2 (OSSO) ([8]). Spectroscopic measurements that reveal spatial and temporal variability will constrain contributions from these species. Previous missions and studies did not successfully detect the origin of the absorbers.

2. Concept

CUVE is a targeted mission, with a dedicated science payload and a compact spacecraft bus capable of interplanetary flight independently or as a ride-share with another mission to Venus or to a different target. CUVE Science Objectives are: 1) Nature of the "Unknown" UV-absorber; 2) Abundances and distributions of SO_2 and SO at and above Venus's cloud tops and their correlation with the UV absorber; 3) Atmospheric dynamics at the cloud tops, structure of upper clouds and wind measurements from cloud-tracking; CUVE has a high spectral resolution spectrometer capable of resolving SO and SO_2 lines. The payload measures a broad spectral range spanning all relevant UV absorbers, and also includes a UV imager.

3. Summary and Conclusions

CUVE will produce high spectral resolution UV spectra of Venus and broad spectral range imaging maps. These maps will characterize the nature of the components in its atmosphere that absorb in the UV. This mission will be an excellent platform to study Venus' cloud top atmospheric properties where the UV absorption drives the planet's energy balance.

4. Acknowledgments

This material is based upon work supported by the National Aeronautics and Space Administration under Grant/Contract/Agreement No. 16-PSDS316-0099 issued through the Planetary Science Deep Space SmallSat Studies Program.

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Design of the calibration bench for the characterization of MAJIS/JUICE VIS-NIR detectors

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Abstract

The MAJIS (Moons And Jupiter Imaging Spectrometer) instrument [1] is part of the science payload of the ESA L-Class mission JUICE (Jupiter ICy Moons Explorer) [2] to be launched in 2022 and arrival at Jupiter in 2030. The instrument and in particular its detectors need to be characterized in the laboratory before being calibrated at instrument level. Here we present the work that will be carried out at IASB-BIRA and ROB in order to fully characterize and calibrate the VIS-NIR detectors of MAJIS, both at spare mode as at flight mode, focused in the calibration bench design.

1. Introduction

MAJIS (Moons And Jupiter Imaging Spectrometer) is an instrument part of the science payload of the ESA L-Class mission JUICE (Jupiter ICy Moons Explorer) to be launched in 2022 and arrival at Jupiter in 2030 to perform detailed observations of the giant gaseous planet Jupiter and three of its largest moons Ganymede, Callisto and Europa, for at least three years. MAJIS will perform imaging spectroscopy through two channels: VIS-NIR (0.50-2.35 μm) and IR (2.25-5.54 μm), to characterize the Jovian atmosphere and magnetosphere, and to determine the global composition of surface materials of the icy moons. IASB-BIRA and ROB will contribute to MAJIS with the characterization of the VIS-NIR detectors, which includes the measurements of their power consumption, power dissipation, dark current, Read-Out Noise (RON), full-well capacity, conversion gain, persistence, linearity, defective pixels, quantum efficiency, fixed pattern noise and operability.

2. Set-up and Preliminary results

The opto-electronical calibration bench will guarantee the cleanliness of its components and the necessary stable thermal conditions to characterize the HgCdTe detectors (≤140K). It will provide a thermal control unit, N_2 flushing for the light path outside the vacuum chamber, the remote control of the spectrometer, temperature and vacuum monitoring, and a security system to avoid conditions which could damage the detector and other critical components (including both operation and storing), besides the data processing software to analyze the detector response. The facility will be developed at a dark clean room environment class 10000 at the IASB-BIRA laboratories.

Since some parameters require different illumination conditions, beam uniformity, exposure time, and/or data acquisition procedure for their measurement, three configurations have been established. The first one will be used to develop tests under dark conditions (shutter closed), the second one to assure light uniformity over the surface detector (integrating sphere), and the third one to provide as close as possible the light beam that the detector should receive from MAJIS (integrating sphere + focusing array). An additional configuration could be added to measure the Modulating Transfer Function (MTF) of the detectors. Figure 1 shows a preliminary schematic of the design. The optical components of the facility will include a stable light source covering the spectral range of MAJIS followed by a variable aperture and a filter wheel, then the light beam will be directed to a monochromator by an integrating sphere at the entrance. The monochromator will include its own wheel filter and a PBS detector to have a reference of the diffracted light beam at the output of the spectrometer. For the second configuration the spectra will be directed using an optical fiber to an integrating sphere (with another PBS detector as reference) and to the detector. For the third configuration the spectra from the integrating sphere will be focused by an optical array into the detector. The electronic shutter will be in front of the detector in every configuration.

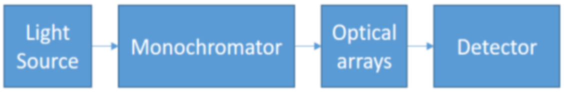

Figure 1: Preliminary schematic of the calibration bench. Optical arrays include the necessary elements to develop every measurement according to the configurations stablished: shutter closed, integrating sphere, and integrating sphere + focusing array, respectively. Some of these elements shall be inside of the vacuum chamber.

It is worth to mention that flux calculations shall be carried out in order to determine the irradiance and thermal emission of each component and their expected influence over the detector response (Signal-to-Noise Ratio). The results are considered to evaluate the preliminary design and make changes if necessary.

3. Conclusions

This document describes the objectives and the foreseen designs of the calibration bench which will be used to characterize the MAJIS/JUICE VIS-NIR detectors at the IASB-BIRA laboratories, and some of expected results. The facility should be validated at the beginning of 2019.

Acknowledgements

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DEMOCRITOS: Demonstrator Projects for MW class Nuclear Spacecraft.

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Abstract

DEMOCRITOS (Demonstrators for Conversion, Reactor, Radiator And Thrusters for Electric Propulsion Systems) was an international project founded by the European Commission to enable a realization of a mega-watt class electric propulsion spacecraft. Which concluded in early 2017. The project was a follow-on activity of the successful European-Russian cooperation in the frame of the MEGAHIT (Megawatt Highly Efficient Technologies for Space Power and Propulsion Systems for Long-duration Exploration Missions) project.

The DEMOCRITOS project aims at preparing demonstrators for a mega-watt class nuclear-electric spacecraft. The project involves the following partners: the Nuclear National Laboratory – NLL (U.K.), the German Aerospace Center – - DLR (Germany), the Keldysh Research Center – KeRK (Russia), Thales Alenia Space Italia – TAS (Italy), Airbus-Safran Launchers – ASL (France), the European Science Foundation – ESF, (France) and the Centre National d'Etudes Spatiales – CNES (France).

The Instituto de Estudos Avan¸cados – IEA (Brazil) has joined the project as an observer.

In this presentation we will review key aspects of the three demonstrator concepts underpinning DEMOCRITOS:

1) the development logic for a ground demonstrator, whose target is to test end-to-end nuclear-electric propulsion, with the nuclear core replaced by a conventional heater. Our target was to conceptualize ground tests for a 200 kWe conversion loop (closed Brayton cycle), linked to lower power heat-pipe radiator and electric thrusters.

2) Review of previous space reactor concepts and lessons learned applicable to the Democritos project

3) the assembly strategy for a MW class nuclear electric spacecraft. We will conclude with a discussion on future steps towards the realisation of a MW class nuclear electric spacecraft, within the context of international cooperation.Introduction

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Proposed Hyperspectral Imager for Planetary Surface Missions

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Abstract

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

1. Introduction

Spectral imaging is the combination of the fields of spectroscopy and imaging. Hyperspectral imagers build up sufficient spectral bands to form a contiguous spectrum. The data is stored in a three-dimensional image cube, where each pixel contains a complete spectrum. The dimensions in an image cube represent the traditional x and y dimensions in the two-dimensional spatial frame, with the third dimension, λ, representing the spectral information. [Li et al.]

Hyperspectral imaging was developed initially for remote sensing purposes; this is still it's primary use today [Goetz]. Hyperspectral imagers are used in fields including agriculture and health care, this paper will focus on space applications. On Mars, a rover-mounted camera offers a more compact, robust and practical solution than a conventional diffraction grating system. In that case, the camera must be optimized to offer a resolution on par with an actual spectrometer. The data sets are sent through an imaging processing pipeline on Earth to ensure calibrated data is analysed for the most accurate results.

SPEC-I

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

The hyperspectral image from SPEC-I can be built up in two ways, by windowing-framing or windowing-pushbroom. The windowing-framing method is achieved by scanning the LVF across the optical path meaning the camera and subject remain tationary. For the windowing-pushbroom method the LVF is fixed over a wavelength range and the hyperspectral data is built up by either moving the camera system or the subject.

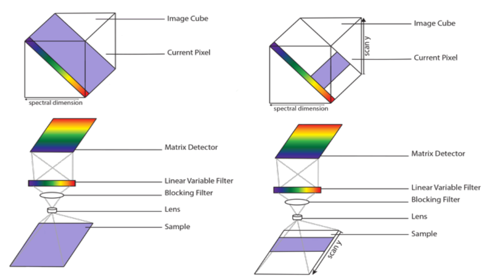

Figure 1: Windowing-Framing and Windowing-Pushbroom Methods – modified from [Li et al.]

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

2. Initial Calibration

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

The Aberystwyth Tuneable Light Source (ATLS), which provides a known wavelength of light into an integrating sphere was measured simultaneously by SPEC-I and a reference spectrometer was employed for comparison.

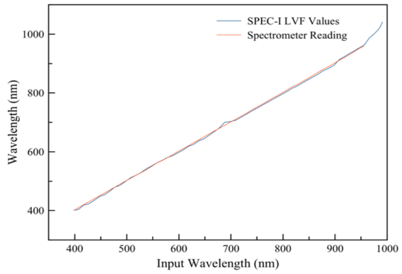

Figure 2: Graph to show offset of LVF wavelength

Figure 2 shows small discrepancies in the measured wavelength compared to the expected wavelengths. This can easily be corrected before image capture by extrapolating data from the graph into the processing pipeline.

3. Preliminary Results

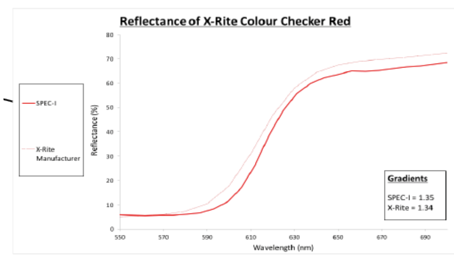

Figure 3: Reflectance Standard Comparison

Initial testing of SPEC-I on reflectance standards has yielded data which aligns with manufacturer reflectance spectra, shown in Figure 3. Curated samples have been used to test the capabilities of SPEC-I as part of a planetary exploration payload. Figure 3 are the results obtained from imaging a sample of Hackmanite under 365nm UV LED excitation.

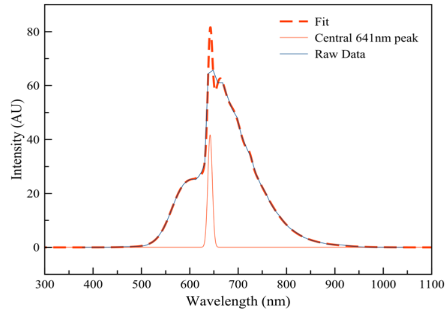

Figure 4: Peak Fitted Hackmanite Spectrum

4. Summary and Conclusions

Figure 3 shows that SPEC-I is capable of producing a spectrum that is clearly representative of the sample and has sufficient resolution to pick out spectral features for identification.

Acknowledgements

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Utilisation Opportunities on the Lunar Orbital Platform - Gateway

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The Lunar Orbital Platform - Gateway is being established as a strategic platform, from which human exploration of the Solar System can set forth. Its location in the lunar vicinity, and outside of the Earth's deep gravity well allow it to be used as a staging post for exploration missions to the lunar surface and eventually to other deep space destinations including Mars. It is also a platform in a location where the human and technological challenges of long duration human missions in deep space can be investigated and addressed. The platform is being prepared through international cooperation, led by the partner agencies of the International Space Station: ESA, NASA, JAXA, Roscosmos and CSA.

The technical definition of the Gateway is driven by the technical needs of preparing deep space human exploration. It could also support opportunistic scientific research. This research could relate to a wide range of scientific disciplines. Investigations related to these various research areas will carry with them specific technical implications.

A detailed description of the Gateway can be found at http://exploration.esa.int/moon/59374-overview/.

In this talk we present an overview of the Gateway, it's status in ESA and ESA's plans to enable scientific utilisation in coordination with its international partners.

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Towards a European Stratospheric Balloon Observatory – Planetary Science Applications

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Abstract

This paper presents the follow-up project to the ORISON study [1] and its approach to create a community-accessible, regularly flying stratospheric balloon-based observatory. Implemented with a focus on regular flights and broad access, balloon-based systems such as the ones presented have the potential to complement ground and space based observations. 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. Particularly long-duration circumpolar flights offer almost continuous observation possibilities over up to 30 to 40 days, with Ultra Long Duration mission on the horizon promising even longer flights of 100 days and more. In this paper, we present long-term plans to establish a European Stratospheric Balloon Observatory (ESBO), the prototype platform currently under development, and exemplary applications for planetary science.

1. Introduction

Over the last two years, the H2020-funded project ORISON studied the general feasibility of a balloon-based observatory. The work showed that the concept of versatile balloon-based telescopes operated as an observatory is feasible, but that some further technological development is required. The plans for ESBO and the currently ongoing ESBO *Design Study* (ESBO *DS*) pick up from these conclusions [2].

In particular, ESBO represents the goal of establishing a larger service provider that flies and operates balloon-based telescopes, providing instrument space and observation time on different flight platforms. Currently envisioned flight platforms include a prototype platform carrying a 0.5 m aperture telescope for the UV and visible range, an intermediate flight platform for telescopes in the 1.5 m aperture class, and, in the long term, a platform for far infrared observations in the 5 m aperture range.

2. Technical Concept

The goal of ESBO is to provide modular flight platforms that can accommodate exchangeable instruments. This observatory-type approach requires, besides a modular and scalable gondola that provides customized support for astronomical instruments, regular flights and ergo save recovery of the payload.

2.1 UV/visible prototype mission

The STUDIO (Stratospheric Ultraviolet Demonstrator of an Imaging Observatory) mission is being developed as the first prototype flight platform of ESBO, with a first flight currently foreseen for 2021. It will carry a fully-reflective ~0.5 m aperture telescope, along with an imaging and photon counting microchannel plate UV detector for the wavelength range from 180 to 330 nm as the main science instrument, developed and built by the Institut für Astronomie und Astrophysik Universität Tübingen [3]. In addition, it will carry a visible light imaging instrument that will mainly serve as the tracking sensor in a closed-loop fine image stabilisation system, but that may also be used as an auxiliary science instrument. With a telescope focal ratio of f/8, the UV instrument is baselined to achieve a circular field of view (FOV) of 35.2 arcmin diameter, at an angular resolution of 1 arcsec. The visible channel is baselined with a 11.4 x 11.4 $arcmin^2$ FOV and a pixel size of 0.7 arcsec. A centroid-tracking algorithm used on the visible channel will allow image motion tracking with a precision below the pixel scale and, in combination with a piezo-actuated tip/tilt mirror, an image stabilisation to below 0.5 arcsec.

Besides providing first scientific capabilities, the STUDIO platform will serve as a testbed and demonstrator for the image stabilisation system, the modular and scalable gondola, as well as for a controlled landing technique.

2.2 NIR / FIR future concept

The approach for ESBO is to extend the spectral coverage and telescope size range step by step. As a first step after the STUDIO mission(s), a platform for near infrared (NIR) telescopes in the 1 to 1.5 m aperture class is currently envisioned, in a timeframe of 2 to 3 years after the first STUDIO flight. This system could extend the wavelength coverage up to 3 or even 5 µm and could be optimized for photometric stability. Interesting instruments might be a multi-channel imager based on GROND [4] or the NIMBUS [5] proposal, or a low/medium spectral resolution (R ~ several hundred) spectrograph.

For the long-term (timeframe ~15 years), ESBO *DS* studies the feasibility of operating far infrared (FIR) telescopes with an effective diameter of 5 m and potentially elliptical shape under balloons, to offer a next-generation FIR platform, improving on the capabilities of SOFIA and Herschel in particular with regard to spatial resolution and confusion limit.

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, in table 1 we present a selection of planetary science cases that could be pursued particularly with the UV prototype or the NIR platforms described above.

Table 1: Planetary Science Cases for ESBO

Science Case	Stratospheric Advantage
Multichannel exoplanet transit observations for cloud and haze studies	Photometric stability, no scintillation noise, long continuous observations possible
Exoplanet transit spectroscopy for atmospheric studies	See multichannel transits, + accessibil-ity to UV & NIR
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

Acknowledgements

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