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Tether-mission design for multiple flybys of moon Europa

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Abstract

A tether mission to carry out multiple flybys of Jovian moon Europa is here presented. There is general agreement on elliptic-orbit flybys of *Europa* resulting in cost to attain given scientific goals lower than if actually orbiting the moon, tethers being naturally fit to fly-by rather than orbit moons[1]. The present mission is similar in this respect to the *Clipper* mission considered by NASA, the basic difference lying in location of periapsis, due to different emphasis on mission-challenge metrics. Clipper minimizes damaging radiation-dose by avoiding the Jupiter neighborhood and its very harsh environment; periapsis would be at Europa, apoapsis as far as moon Callisto. As in all past outer-planet missions, Clipper faces, however, critical power and propulsion needs.

On the other hand, tethers can provide both propulsion and power, but must reach near the planet to find high plasma density and magnetic field values, leading to high induced tether current, and Lorentz drag and power. The bottom line is a strong radiation dose under the very intense Radiation Belts of Jupiter. Mission design focuses on limiting dose. Perijove would be near Jupiter, at about 1.2-1.3 Jovian radius, apojove about moon *Ganymede*, corresponding to 1:1 resonance with Europa, so as to keep dose down: setting apojove at Europa, for convenient parallel flybys, would require two perijove passes per flyby (the *Ganymede* apojove, resulting in high eccentricity, about 0.86, is also less requiring on tether operations).

Mission is designed to attain reductions in eccentricity per perijove pass as high as $\Delta e \approx - 0.04$. Due the low gravity-gradient, tether spinning is necessary to keep it straight, plasma contactors placed at both ends taking active turns at being cathodic. Efficiency of capture of the incoming S/C by the tether is gauged by the ratio of S/C mass to tether mass; efficiency is higher for higher tape-tether length and lower thickness and perijove. Low tether bowing due to the Lorentz force requires opposite conditions. Low heating requires not too low perijove and not too long length. In addition, too long a tape will result in attracted electrons hitting the anodic end with somewhat relativistic energy, and penetration depth larger than thickness[4]. Tape width is not involved in the above design criteria, just scaling with S/C mass.

A no-tilt, no-offset dipole model of the magnetic field and the plasma density in the equatorial plane as given by the classical Divine-Garrett model, are used in calculations; Δe proves near-independent of the e-value before each perijove pass[1-3]. Capture from the direct (no-gravity assists) hyperbolic, Hohmann–like, transfer orbit, corresponds to an incoming velocity of about 6.4 km/s, and eccentricity $e_h \approx 1.02$, requiring a net Δe decrement around 0.16 to reach Ganymede.

Dose per orbit for eccentricity above 0.5, say, proves also nearly independent of perijove at 1.2-1.5 Jovian radius, the number of perijove passes thus being a metric for total dose. The dose per orbit is about 0.1 Mrad for 200 *mils* of Aluminum shielding (or 13.5 kg for 1 m^2 surface). Dose is also near independent of longitude, proving accurate the simple dipole model in the inner magnetosphere. The GIRE radiation model was used throughout calculations[2-3].

A typical sequence of eccentricity decrements Δe = - 0.04, would allow reaching e = 0.86 in about 4 perijove passes, though the last decrement previous to a first resonant orbit must be reached in two convenient steps, by switching current off appropriately over part of the drag arc, to allow for a first flyby of Europa; switching off the current afterward over the entire resonance orbit would allow for repeated flybys.

Over 20 flybys would then make a total of 25 perijove passes, leading to 25 × 0.1 Mrad, or 2.5 Mrad cumulative dose under 200 mils shielding (to be compared with 2.9 Mrad for 100 mils shielding of the *Jupiter Europa Orbiter* in the originally planned *EJSM* mission. As with *Clipper*, individual payload electronics could have their own shielding and use existing components currently qualified. Also, some nesting radiation protection could be used. The suggested flyby tour is quite rapid. The apojove lowering steps to reach Ganymede would add to over three months, whereas the 20 flybys, each taking the Europa period of 3.5 days, amount to 70 days. The total duration of the mission would add to about 6 months.

In addition to Europa flyby measurements, perijove passes could allow high resolution determination of gravity and magnetic fields, and bulk abundance of water. Also, the orbiting tether itself could be an active instrument. During each flyby, with hollow cathodes off, the tether will be electrically floating; ions will be attracted over most of the tether, resulting in a continuous beam of energetic secondary-emission electrons, energy and flux increasing with distance from tether top. This will allow for artificial auroral effects to probe the Jovian ionosphere.

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CRYOLITOZONE OF MARS – AS THE CLIMATIC INDICATOR OF THE MARTIAN RELICT OCEAN (ACTIVE-PASSIVE MICROWAVE REMOTE SENSING OF MARTIAN SALT PERMAFROST AND SUBSURFACE SALT PORE WATER)

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The existance of a large Martian cryolitozone consisting of different cryogenic formations both on the surface- polar caps ice and in subsurface layer (and probably overcooled salt solutions in lower horizons) is conditioned mostly by the planet's geological history and atmosphere evolution. The very structure of the cryolitozone with its strongly pronounced zone character owing to drying up of 0 to 200 m thick surface layer in the equatorial latitudes ranging from + 30 to - 30° was formed in the course of long-periodic climatic variations and at present is distincly heterogeneous both depthward and in latitudinal and longtudinal dimensions.

The dryed up region of Martian frozen rocks is estimated to have been developing during more than 3.5 bln years, so the upper layer boundary of permafrost can serve as a sort of indicator reflecting the course of Martian climatic evolution.

Since the emount of surface moisture and its distribition character are conditioned by the cryolitozone scale structure its investigation is considered to be an important aspect of the forthcoming Martian projects.

In order to create Martian climate and atmosphere circulation models the whole complex information on surface provided by optical and infrared ranges observations, regional albedo surface measurements, ground layer thermal flow investigations, etc. must be carefully studed.

The investigation of permafrost formation global distribution and their appearance in $h \leq 1$ m thick subsurface layer may be provided successfully by using active-passive microwave remote sensing techniques [1].

Along with optical and infrared observations the method of orbital panoramic microwave radiometry in centi- and decimeter ranges would contribute to the mapping of the cryolitozone global surface distribution.

This proposal discusses methodical and experimental possibilities of this global observation of Martian cryolitozone as the additional way for investigation subsurface of Mars.

The main idea of this approach is – the salt component of subsurface is the global geoelectrical marker of the Martian relict ocean in the past.

Mars' observations by means of ground and onboard instruments are known to have been conducted in recent years. These observations provided information on Mars' surface mean temperature values and their seasonal variations. Radar measurements allowed to estimate dielectric constant and soil upper layer density values.

Mars' surface radiation measurements by a 3,4 cm radiometer aboard Mars-3 and 5 automatic interplanetary stations (1971-1973) proved to be more informative. Radio brightness temperature variations were registered along the flight route. As a result surface temperature latitudinal distribution estimates in a spatial resolution element, were obtained as well as more precise values of dielectric constant and soil density of centimeter fractions this surface layer.

No more experiments using microwave radiometers were conducted since.

The only way to obtain information about Mars surface mezoscale structure is to use a high spatial resolution panoramic equipment on-board. Mars' surface radio images would allow to identify regions differing in ice percentage content in cryogenic surface structures or in mineralized solutions of negative temperature and to estimate relative quantity of cryogenic formations - permafrost fractions as well as to measure the soil looseness or porosity degree.

In addition it would be possible to restore various regions' average vertical temperature, humidity and porosity profiles of less than 1 m thick surface layer. These dependencies combined with the results of depth inductive sounding (0.5 km) and magnitotelluric (1- 5 km) sensing would provide new and more detailed information on Martian crust structure and character and its cryolitozone, necessary to create a more reliable paleoclimatic model of the planet.

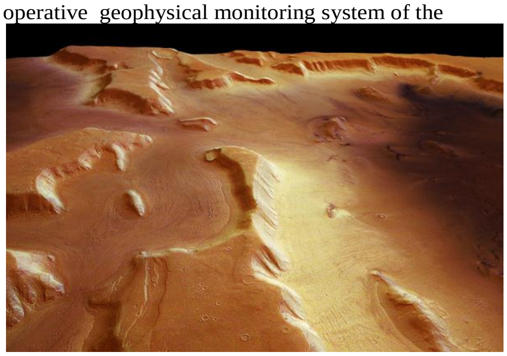
Experiment equipment and methods

Space experiment is conducted to obtain maps of temperature and humidity global distribution of Martian cryolitozone upper layer by means of radiothermal images of the surface. Analysis of the available data produces estimates of the soil integral content, degree of salt solutions mineralization and porosity.

Regions of permafrost and ice formations are identified as well. One could possibly estimate average profiles of temperature, humidity and porosity of a 0,5-1 m thick surface layer. For that purpose one should apply observations by a two channel scanning radiometer of centimetre and decimetre ranges.

Fluctuational sensitivity of each channel is ~ 0,1° K, time constant of integration is 1 s. The two channels share an antenna, an inflatable or self-opening one with a mechanically scanning beam; aperture is about 3-4 m in size; directivity diagram - 3°. Spatial

resolution element (pixel) is about 20 km, observation belt is of 200 - 400 km depending on the orbit parameters. Restoration accuracy of the radiobrighness temperature absolute values is of order of 2-3$_0$K. Microwave block dimensions are up to 500x500x300 mm; weight is ~ 10 kg.
An optimal frequency range for Martian radiometric measurements is 8-18 or 21 cm. Suggested radiometer presents a synthetic aperture microwave radiometer-imager. An optimal frequency range for Martian radiometric measurements is 8 -18 or 21 cm. It employs an interferometric technique to synthesize high resolutions from small antennas. This radiometer can be build, for example as analog of Electronically Steerable Thinned Array Radiometer (ESTAR). ESTAR operates at 1.4 GHz and has been deployed on the C-130 and P-3 aircrafts. It was used by NASA to measure soil moisture and to assess the potential to measure ocean surface salinity.
Antenna fastening and joint to microwave block are hard. Registering system is a digit tape-recorder. Information stream is up to 1 kb/s. Power consumption is up to 50W/27V. Radiometer observations are conducted along the route of the Martian orbital station in accordance with the experiment general program. Observation angle is θ ~ 0-30$_0$; polarization is vertical. Frequency of the radiometer calibration is not less that once in 24 hours. Radiometer scale calibration and measurement of antenna-feeder unit transition coefficient can be carried out against standard sources as well as the relict radiation (~ 3$_0$K) with the antenna proper orientation.
Generally it is desirable to match the radiometer system observation zone with that of optical and TV systems and infrared radiometer as well. Martian surface radio images should be geographically identified. Data processing and temperature and humidity maps drawing is performed by processor system back on Ground.
On the base space- technology platform - the small satellite CHIBIS, also will planning to create prototype of Martian instrumentation for the operative geophysical monitoring system of the



These glaciers have been hiding in plain sight whole time, under a blanketing of dust. There's so much ice, in fact , that if the glaciers were spread uniformly over the entire surface of the world, Mars would be covered in one meter of ice. Mars' dusty cover is doing more than hiding the glaciers from evaporation in the thin, radiation-prone atmosphere of Mars/
(*Credit: ESA/DLR/FU Berlin,Copengahen University*)

natural ecosystem for remote sensing in the range of 18-21 cm and 8-13 mkm.
This is allowed to realize preliminary testing and calibration of the prototype of the Martian instrument in the Earth's condition.
One of the areas of future studies on the surface of Mars are providing the measurements in situ in the local geophysical martian polygon by different geophysical instruments, including: radar measurements in the range of 0.5 – 50 Mhz, low-frequency sounding by MARSES - TDEM instruments, MTS (magneto –telluric sounding) with depth of sounding until 1 km, in the frame work of the rover survey of the different areas of Martian surface .
Additional information about MARSES-Active experiment on
www.iki.rssi.ru/MARSES/english/info.htm

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[2] ACTIVE-PASSIVE MICROWAVE REMOTE SENSING OF MARTIAN PERMAFROST AND SUBSURFACE WATER.
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The Asteroid Impact Mission (AIM)

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Abstract

The Asteroid Impact Mission (AIM) is ESA's contribution to an international cooperation targeting the demonstration of deflection of a hazardous near-earth asteroid as well as the first in-depth investigation of a binary asteroid. After launch in 2020, AIM will rendezvous the binary near-Earth asteroid (65803) Didymos in 2022 and observe the system before, during, and after the impact of NASA's Double Asteroid Redirection Test (DART) spacecraft. The AIM mission will test new technologies like optical telecommunications by laser and Cubesats with nano-payloads and will perform scientific measurements at the asteroid system.

1. Introduction

Binary asteroids and their formation mechanisms are of particular interest for understanding the evolution of the small bodies in the solar system (e.g. [1]). Also, hazards to Earth from impact of near-Earth asteroids and their mitigation have drawn considerable interest over the last decades [2].

Those subjects are both addressed by ESA´s Asteroid Impact mission, which is part of the Asteroid Impact & Deflection Assessment (AIDA) collaboration between NASA and ESA. NASA's contribution to this cooperation, the DART mission will impact a projectile into the minor component of the binary near-Earth asteroid (65803) Didymos in 2022. The basic idea is to demonstrate the effect of the impact on the orbital period of the secondary around the primary. ESA's AIM will monitor the Didymos system for several months around the DART impact time. In what follows, we describe the ESA AIM component of the AIDA mission.

2. The Target

The near-Earth asteroid Didymos was detected in 1996 and its binary nature was derived from light-curve measurements in 2003. From data taken over several years, the diameters of the primary and the secondary are estimated to be 800 m and 170 m, respectively, and the separation between the centres of the two bodies is approximately 1.1 km [3]. Those parameters make the Didymos system the most suitable target for an impact deflection demonstration mission.

3. Mission Profile

AIM will be launched in October or November 2020 with a Soyuz rocket from Kourou, French Guyana. It is foreseen to arrive at Didymos in April 2022. The mission takes advantage of a close approach of Didymos to Earth. The next opportunity would arise in 2040 only.

AIM will stay near Didymos for approximately 6 months. Most of the time it will be placed on station-keeping trajectories on the illuminated side of the system, at distances of approximately 35 km and 10 km. AIM is expected to move away from Didymos for some time around the DART impact.

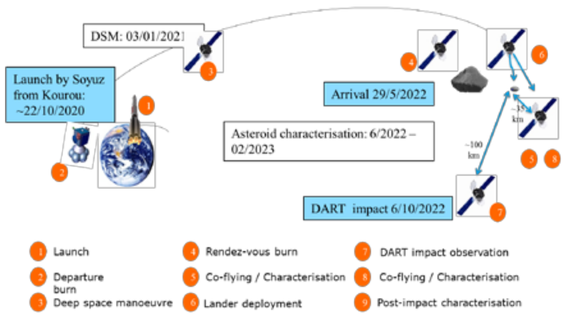

Figure 1: Overview of the AIM mission

4. Payload

The payload elements foreseen for AIM are listed below. In addition, the spacecraft will carry a camera to be used for navigation, characterisation of global parameters and the geomorphology of the asteroids, measurement of the orbital parameters of the system, and observation of the impact cloud created by DART.

Payload Instruments:

- A small, Hayabusa-2 MASCOT-type lander that will provide ground truth for the physical properties of the surface of Didymoon.
- A thermal infrared imager to determine the thermal and physical properties of the surface of the asteroids.
- A High Frequency Radar (HFR) to measure the subsurface structure of both the primary and the secondary component. It may also be used to investigate the impact cloud from DART. A Low Frequency Radar to measure the internal structure of the target body. The radar will send radio waves between the AIM spacecraft and the MASCOT-type lander, through the asteroid.
- An Optical laser terminal is onboard to enhance science in two ways: firstly, it will be used as a range finder to accurately position the spacecraft and determine the surface topography and 3D shape of the asteroids. Furthermore the laser altimeter can perform ranging for mass determination and provide measurements of the impact cloud. Secondly, the laser terminal will be used as a demonstration of optical telecommunications with interplanetary space.
- AIM will carry 2-6 Cubesats that will transport nano-sensors to the Didymos system. Studies for possible Cubesat payloads are ongoing. It is foreseen to use the Cubesats, together with the MASCOT-type lander, to test inter-spacecraft communication in interplanetary space.

5. Conclusions

AIM is a small and innovative mission that is expected to accomplish several goals for the first time:

- The first rendezvous with a binary asteroid and its characterization, including its surface, subsurface and internal structures as well as its thermal properties
- The first demonstration of optical telecommunications in interplanetary space, between spacecraft and Earth and possibly also between different satellites
- In the framework of AIDA, the first demonstration of asteroid deflection and documented impact experiment at asteroid scales

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WEGENER: Solid Body Dynamics Investigation of Venus. Results from Summer School Alpbach 2014.

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Abstract

The work presented in this paper was performed by the Orange Team during Summer School Alpbach 2014, which mainly concerns about geophysics of terrestrial planets. A mission is designed to investigate the past and current tectonic and volcanic activity on Venus. During the mission, a simultaneous observations from topographic, magnetic and gravitational measurements will be performed and the combination of the information has the potential to provide an improved understanding of the formation and evolution of the planet.

1. Introduction

The presence of tectonic features and related surface movements has yet to be identified on Venus' surface and is still an unsolved question. Understanding which bodies in the solar system have plate tectonics tells us more about the evolution of young terrestrial planets, more about Earth during its earlier years, and potentially constrain formation and evolution scenarios for exoplanets.

The Solid Body Dynamics Investigation of Venus, also known as Wegener, is a mission proposed to search for evidence of tectonic and volcanic activity, and to provide insight into geomorphological processes modifying Venus' crust. Therefore, Wegener shall enhance the knowledge in the field of tectonics, volcanics and surface activity on the planet.

2. Science objectives

The aim of the Wegener mission is summarized in the list of its scientific objectives:

- SO1. Search for evidence of tectonic activity.
  - SO1.1. Search for evidence of resurfacing.
  - SO1.2. Search for crust movement.
- SO2. Search for evidence of volcanic activity.
  - SO2.1. Search for evidence of eruptions.
  - SO2.2. Search for inflation in volcanic edifices.
- SO3. Understand geomorphological processes modifying the surface.
  - SO3.1. Identify geomorphological processes modifying the surface by searching for landslides and dunes.

These objectives will be achieved by allowing the spacecraft to be in an orbit of 91.5° inclination ~400 km above the planet's surface and using sophisticated instruments, described in the payload section.

This low-cost mission is designed to be launched on a Soyuz rocket to drive the spacecraft to its end-destination, where it will be operating for five years and increase our knowledge of young and active planets.

3. Payload

To satisfy the science objectives of the mission, the Wegener spacecraft will carry the following instruments: an altimeter, a magnetometer and a gradiometer. An altimeter with SAR mode and SARIn mode, i.e. two 1.7 m in diameter antennas will operate at a frequency of 6 GHz. A Double Star like magnetometer instrument (fluxgate) and a dark state magnetometer (absolute) will be used in combination to detect magnetic fields and potentially trace their origin. And lastly, a Cold Atom Gradiometer will be used onboard to enhance the position determination for orbital tracking and to improve existing gravity field models for Venus, which is imperative for detecting subtle changes in surface features.

4. Spacecraft design

The preliminary design of the spacecraft is shown on figure 1.

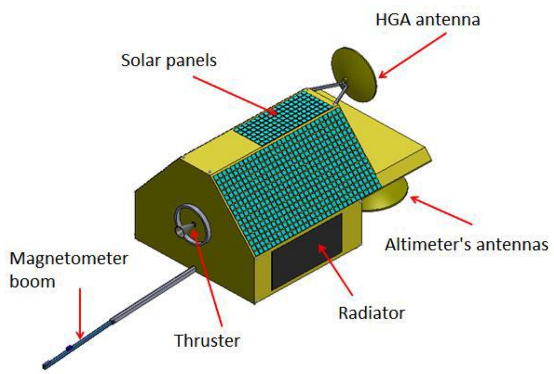

Figure 1: Preliminary Wegener spacecraft design.

The spacecraft consists of the main bus on top of which the solar panels are mounted. On the front side of the spacecraft the HGA antenna of about 1.2 m in diameter is mounted and the bench holds two altimeter antennas each 1.7 m in diameter. On the rear side of the spacecraft the thrusters and the magnetometer boom are located. The flanks are reserved for the radiators. The interior of the spacecraft houses all of the electronics, power supply, batteries and fuel tanks.

The power budget for the spacecraft is estimated at around 1300 W, where ~400 W is dedicated to the payload. The spacecraft's total mass is estimated at about 570 kg as a dry mass and with propellant around 940 kg.

5. Mission overview

The Wegener spacecraft is going to operate on a polar orbit around Venus at about 400 km altitude.

The timeline including the satellite design, launching, transfer and science operation is presented in figure 2.

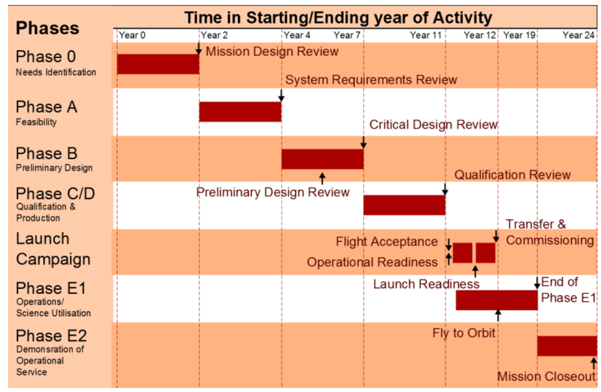

Figure 2: Wegener mission phases.

Wegener is a M-class (Medium size) mission and its overall budget is estimated at around 750 M€ for a 5 year long mission. The total cost excluding the payload is estimated at around 570 M€.

6. Summary and Conclusions

The Wegener mission will provide a unique opportunity to study the surface activity of Venus and its solid body dynamics. The ideal combination of topographic, magnetic, and gravity measurements will lead to a significant improvement of understanding plate tectonics, volcanism, and crustal structure of an Earth-like planet. The improved knowledge of the solid body dynamics of Venus will also enhance the general understanding of planetary geophysics and evolution of terrestrial planets.

Acknowledgements

The work was performed in frame of the ESA Summer School Alpbach 2014, with the subject: "The geophysics of the terrestrial planets". Team Orange would like to specially thank our tutors Günter Kargl and Roger Haagmans for their support and the other Alpbach tutors and experts for sharing their knowledge and experience.

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Science Opportunity Analysis for the Jupiter Icy Moons Explorer (JUICE) mission

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Abstract

JUICE is the first large mission chosen in the framework of ESA's Cosmic Vision 2015-2025 program. JUICE will survey the Jovian system with a special focus on the three Galilean Moons. The mission has recently been adopted and big efforts are being made to analyze the future mission scenarios by the Science Ground Segment (SGS). The Science Operations Centre (SOC) at the European Space and Astronomy Centre (ESAC) is providing active support to the Science Working Team (SWT) to build the preliminary science observations timeline and therefore evaluate the feasibility of the mission with respect to the science goals. This contribution will outline some of the science opportunity activities carried out by the SOC, in close collaboration with the Navigation and Ancillary Information Facility (NAIF), with a summary of the main tools and the support provided to JUICE development on the study of its critical operational scenarios and the early developments of its Science Ground Segment demonstrating the added value for planetary missions.

1. Science Opportunity Analysis

One of the main tasks of the Science Operations Center in the support to the Science Working Team is the science opportunity analysis, meant to identify and analyze all the science opportunity windows to build the observations timeline and therefore evaluate the feasibility of the science goals of the mission.

1.1 Opportunity Analysis Input Data

Observation Geometrical Conditions: JUICE science working groups provide the geometrical conditions necessary to cover the main scientific objectives via the definition of detailed observation geometry. (e.g. occultation events, surface landmark coordinates with particular illumination angles, etc).

Operational Constraints and Events: operational information based on the mission events, either in the form of geometrical conditions (e.g. ground station visibilities), technical constraints (e.g. spacecraft illumination limits) or in the form of pre-computed events (e.g. orbit control maneuvers, etc)

Spacecraft Geometry Information: knowledge of the spacecraft ephemeris, reference frames, planetary constants, instrument models, etc, usually available in the form of SPICE kernels or other file formats coming from Mission Analysis.

1.2 Opportunity Analysis Core Elements

Event Finder: responsible for finding the list of time windows for any defined geometrical or operational parameter (distances, angles, visibilities, etc), based on any mathematical condition (equal, less, greater, minimum, etc) and flexible enough to cover multiple observers, target bodies and reference frames.

Context Finder: used to compute, for any given list of opportunity windows (basically a list of times), the contextual information on other geometrical and operational parameters (e.g. altitude, illumination angle, ground station visibility,...) that may be of interest for the scientific and operational analysis.

Event Handler: this module is used to load the list of opportunity windows and contextual information and combine them following basic logical rules (e.g. illuminated AND north pole OR south pole) and filter them based on any of the contextual parameters (e.g. occultation in the northern hemisphere). This is the core module for the analysis of the scientific or operational quality of the opportunity windows through visualization of the contextual parameters and advanced display capabilities (latitude and longitude coverage maps, illumination plots, etc).

1.3 Opportunity Analysis Output Data

Science Opportunity Database: all science opportunity windows, including the contextual parameters and all the results of the combination/filtering process are stored in an internal Science Opportunity Database (in the form of ascii event time tables or more advanced SQL data bases)

Observation Opportunity Windows: The final output of the Opportunity Analysis are the list of observation opportunity windows (event times) which serve as input for the science operations scheduling and planning processes.

2. SOC Support Tools

A number of software planning tools are being used by the Science Operations Centres at ESAC in development and operations of planetary missions. The following tools are currently being used to cover some of the functionalities required for Science Opportunity Analysis.

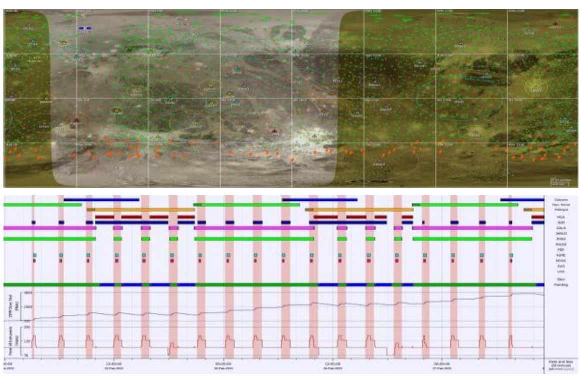

Figure 1. MAPPS coverage map and timeline simulation of Ganymede phase at 500km altitude.

2.1 MAPPS/EPS

The Mission Analysis and Payload Planning Support (MAPPS) and the Experiment Planning System (EPS) [1] tools have been used by most of ESA's planetary missions to generate and validate science observation timelines for the simulation of payload and spacecraft operations. MAPPS and EPS have the capability to compute and display all the necessary geometrical information such as the distances, illumination angles and projected field-of-view of an imaging instrument on the surface of the given body.

2.2 SPICE based tools: WebGeoCalc, Cosmographia, SOLab eFinder

The Navigation and Ancillary Information Facility (NAIF) at JPL provides valuable SPICE support to the JUICE mission and several tools are available to compute and visualize science opportunities. In particular the WebGeoCalc [2] and Cosmographia [3] systems are provided by NAIF to compute time windows and create animations of the observation geometry available via traditional SPICE data files, such as planet orbits, spacecraft trajectory, spacecraft orientation, instrument field-of-view "cones" and instrument footprints. Other software tools developed by ESA are being used to support the science opportunity analysis for all missions, like the eFinder within the SOLab project [4].

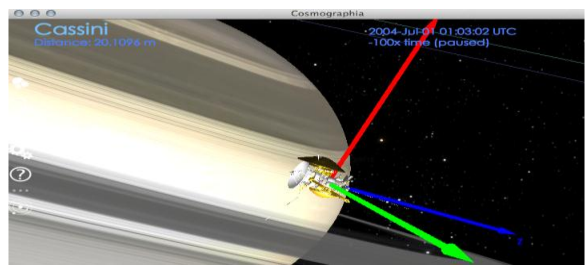

Figure 2. SPICE Cosmographia example visualization of Cassini geometry over Saturn rings.

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Hesperos: A Post-Alpbach Mission Result

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Abstract

Despite similarities between Venus and Earth relatively little is known about its internal structure and processes. For this reason a geophysical mission to Venus is proposed. Its aim is to investigate the existence of tectonic activity, Venus internal structure and composition. The mission consists of an orbiter and balloon that will investigate Venus for a total of five years.

1. Introduction

Despite Earth and Venus having very similar radii, mass and consequently density and gravitational acceleration, the two planets have evolved very differently. The surface pressure is 92 bar and the temperature about 464°C, which makes it a very hostile environment for human and machines alike. For this reason Venus has not received as much attention as Mars, which seems to be more benign to life. However, for a better insight into planetary formation a better understanding of why Venus has evolved so differently from Earth is essential. This is becoming more relevant with the increasing number of exoplanets being discovered.

During the Alpbach Summer School 2014 the geophysics of the terrestrial planet was the central topic. The above considerations were for a large part the reason that all groups decided to design a mission to Venus to investigate various aspects. During the post-Alpbach week in Graz two of those mission were combined and worked out in greater detail.

This paper presents the results of the post-Alpbach week. It starts with an explanation of the scientific goals of the mission. This is followed by a discussion of the required observables to fulfill the scientific goals including requirements on range, resolution, accuracy etc. Then the satellite design is discussed which will carry the payload. Subsequently, an overview is given of the mission timeline. In the last section a short summary is given and conclusions are drawn.

2. Science objectives

Surface dating of Venus has revealed that its surface is relatively young with values varying between 500 and 1000 Ma. Several theories have been developed to explain this feature. The most prominent ones are:

- the stagnant lid theory [1] and [2]
  Here, heat accumulation in the mantle results in periodic catastrophic resurfacing of large parts of the planet. Periods in between these events show hardly any activity. According this theory tectonic plates do not exist.
- tectonic plates but disimilar from Earth [3] and [4]
  Here it is assumed that tectonic plates exists but are different from Earth's. Large scale tectonic and volcanic activity should be expected.
- mantle plumes [5]
  In this theory mantle plumes cause resurfacing on a smaller scale than the stagnent lid theory.

To explain the relative young surface of Venus and to be able to determine which theory is most accurately describing Venus not only requires careful monitoring of Venus' surface, but also a deeper understanding of Venus' interior. For this reason the proposed mission is centred around two scientific questions:

1. Is Venus tectonically active and, if yes, on what time scale?
2. Is Venus' internal structure and composition similar to Earth?

To answer the first question the mission will investigate the existence of plate movement and its characteristics as well as the extent of volcanic activity. For the second question the core size and phase need to be further constrained. It will also be investigated how mantle processes drive surface activity.

Although the above objective suggest that all secrets of Venus' interior will be revealed it is not foreseen that the proposed mission will give definite answers to all these questions. However, the mission is designed in such a way that existing models of the interior of Venus can be further constrained.

3. Observables

Investigating whether Venus is tectonically active requires first of all tracking of topographical changes. However, a change in topography is not conclusive evidence of tectonic activity. It has to be related to the structure of the mantle as well. This is best studied by accurately mapping the gravity field of Venus. For further characterisation of the internal structure and processes also atmospheric species and their ratios will be determined as well as the heat signature and surface emissivity.

4. Satellite design

4.1 Orbiter

The orbiter will carry the SAR, gradiometer and IR and UV cameras. Body mounted solar panels reduce pertubations that could interfere with gradiometer measurements.

4.2 Balloon

The balloon is a so-called phase change balloon which will carry a sounding device, nephelometer, mass spectrometer and magnetometer. Its altitude will oscillate between 40 and 60 km and gradually drift to one of the poles.

5. Mission timeline

An overview of the mission timeline is given in Figure 5-1. The nominal mission duration is five years. After a Hohmann transfer period of 117 days the balloon phase will commence, which will take 25 days. During the phase the orbiter acts as a relay station to transfer science data gathered by the balloon to Earth. After the balloon phase has finished an aerobreaking maneuver will be performed to bring the orbiter in its final orbit where it will do all the measurement for the remainder of the mission.

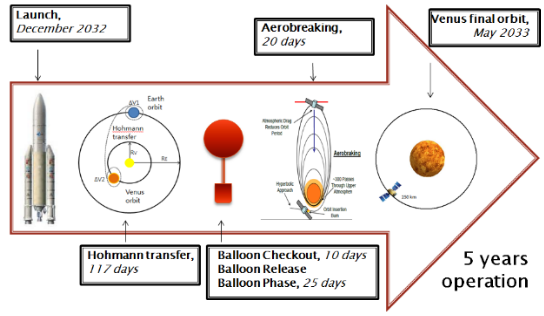

Figure 5-1: Mission timeline

6. Summary and Conclusions

The proposed mission will make a significant contribution to the understanding of planetary formation in general and how Venus has evolved in particular.

Acknowledgements

The authors would like to express their gratitude to ESA and FFG for organising the Alpbach Summer School as well as the post-Alpbach week. We would also like to thank our supervisors Günter Kargl and Olivier Baur from the Space Research Institute of the Austrian Academy of Sciences, Richard Ghail from Imperial College London and Manuela Unterberger from the Technical University of Graz for their valuable advice and enthusiasm.

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The Hera Entry Probe Mission to Saturn, an ESA M-class mission proposal

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Abstract

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.

A proposal for a Saturn entry probe mission named Hera was recently submitted to the European Space Agency Medium Class mission announcement of opportunity. Hera comprises a single entry probe carried by a flyby spacecraft that will also act as a relay station to receive the probe science telemetry for recording and later transmission to Earth. A solar powered mission, Hera will take approximately 8 years to reach Saturn and will descend under a sequence of parachutes to depths of at least 10 bars in approximately 75 minutes. The Hera probe will carry a Mass Spectrometer to measure the composition of Saturn's atmosphere, an Atmospheric Structure Instrument to measure atmospheric pressures and temperatures, 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 locations and densities.

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

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The EvolVe mission concept - unveiling the evolution of Venus

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Abstract

Venus and Earth are similar in size, bulk composition and distance from the Sun; both are located within the habitable zone. Nevertheless, their surface conditions reveal that they are two very different worlds; Venus, unlike Earth, cannot support life on its surface. The aim of this mission is to determine how and why Venus evolved so differently by exploring its past and present geologic activity. The concept was designed by young scientists and engineers during Alpbach Summer School 2014.

1. Science objectives, requirements

To understand the reasons of this difference, we address the following scientific questions:

1. What is the tectonic history of Venus?
2. What is the current volcanic activity of Venus?
3. Was the initial bulk chemical composition of Venus and Earth different?

Plate tectonics is ever-present and determines the face of our planet, creating new crust at mid-ocean ridges and destroying it at converging margins. Tectonism on Venus shows differences that are not fully understood, such as features suggesting obduction zones. On a global scale, the surface presents a half billion year record of volcanic activity, but notably, based on impact crater distribution, it appears uniform in age. This has led to theories of catastrophic global resurfacing [1], and change to a stagnant lid state [2], while others suggest a stable tectonic regime [3].

One way to retrieve information on tectonic structures and crustal thickness is by investigating the gravitational field generated by the upper mantle and the lithosphere, including correction with the topography. Venus topography shows rift-like features of 1000s of km length and 10-100 km width along great circles, with similarities to Earth's mid-ocean ridges. Currently the gravity field is known with a spatial resolution of 700 km [4], insufficient to analyse such effects. Our simulations show that using a GOCE-type gravity gradiometer at an orbital height of 250 km, a spatial resolution of 85 km can be reached. Additionally, terrain models are to be improved, and for selected areas (10% of the surface), high resolution (40 m spatial, 4 m vertical) stereo topography shall be obtained (using InSAR, scanning targeted areas twice).

Lithospheric thickness can also be estimated by aerial EM sounding, which shall be achieved by a balloon at 50-60 km altitude, using naturally occurring EM resonances and perturbations. These can penetrate the crust to 50-100 km depth on a dry Venus.

The degassing rate of Venus has implication to its overall tectonic and thermal evolution. Previously measured $^{40}Ar/^{36}Ar$ ratio can be indicative of this, but an independent isotope ratio such as $^{3}He/^{4}He$ is to be measured to better constrain models, calling for a balloon mounted gas chromatograph mass spectrometer.

Volcanic activity on Venus is suggested by surface geochemistry from Venera landers, landforms resembling volcanoes and variations in atmospheric SO_2 abundance. Recently, heat pulses from the surface detected by Venus Express have been interpreted as a sign of magma release.

We plan to monitor long-term SO_2 abundance variations using a UV spectrometer. Secondly, we intend to identify hotspots with an IR spectrometer. Based on those measurements, we will select target areas of probable activity to detect changes in morphology and elevation with an InSAR (spatial and vertical resolution <100 m and <1 cm, respectively). This requires repeated passes over at least one Venerean day, which is met by the designed circular polar orbit.

Initial bulk chemical composition can determine the evolution of a planet. Measuring the currently poorly known size of the core of Venus could constrain its composition. We plan to do so by estimating low-degree gravity field coefficients by Doppler tracking [4]. Additionally, an EM sounding method based on magnetic field observations from the balloon will be used to determine core size, in a manner used before for the Moon [5]. Finally, to compare the source of water on Venus and Earth during their formation, isotopic ratios of noble gases (as a proxy to other volatiles [6]) will be measured, such as ^{22}Ne/^{20}Ne and ^{21}Ne/^{20}Ne.

Table 1: Orbiter and balloon (below) payloads.

Instrument, objective#	Ranges
Gradiometer[1]	BW: 5MHz-0.1Hz
	Noise: 3mEHz$^{-1/2}$;
Radar altimeter[1,2]	sample freq.: 50Hz
	alt. accuracy: 1 m;
SAR/InSAR[1,2]	S-Band, SW=40-70 km
	sp. res.: $\sim$10 m;
IR/UV	λ: 0.7-5μ, 110-310μ
spectrometer[2]	sp. res.: 50km;
Mass Spectrometer[2,3]	2-150, res. 0.1 AMU;
MT sounding[1,3]	freq.: 100Hz;
Flux gate	
magnetometer[1,3]	sample freq.: 20Hz;

2. Mission Overview

The mission consists the following phases:

Phase 0: Hohmann transfer to Venus (5 months)
Phase 0a: orbit injection, aerobraking (2-6 months)
Phase 1: balloon operation (19 Earth days)
Phase 2a: geodesy (1 Venus day)
Phase 2b: stereo topography (2 Venus days)
Phase 3: delta topography (1 Venus day)
The total mission duration is 3.2 Earth years.

3. System Overview

The mission consists of an orbiter and a balloon. The balloon, travelling passively with the winds, will circle the planet 2-3 times during its short lifetime. The main drivers of the orbiter system and mission design were the conflicting requirements of the gradiometric measurement (needing a drag-free environment) and the InSAR (drawing high power and producing high data rates). During phase 2a steerable elements are fixed to reduce drag and vibrations and remaining drag is compensated by an electric microthruster taken from LISA. During phases 2b and 3, solar arrays are pointed to increase output and downlink to Earth is made via a 2 m steerable X-band parabolic main antenna. A further challenge is thermal control, which is maintained by insulation and a radiator on 1 permanently cold face.

Risk assessment shows that even though we used the most pessimistic atmospheric model, its uncertainties remain the largest risk factor to achieving the primary science objective. This can be mitigated by large margins on the propulsion system and by further investigation of atmospheric models (e.g. incorporation of VexADE and other new results).

Acknowledgements

We thank our tutors Alejandro Cardesín Moinelo and Oliver Baur, Richard Ghail for his insights and patience, all lecturers and all the staff that made the Alpbach Summer School Possible.

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Analysis of the dynamics of movement of the landing vehicle with an inflatable braking device on the final trajectory under the influence of wind load

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Abstract

This research work is devoted to analysis of angular motion of the landing vehicle (LV) with an inflatable braking device (IBD), taking into account the influence of the wind load on the final stage of the movement. Using methods to perform a calculation of parameters of angular motion of the landing vehicle with an inflatable braking device based on the availability of small asymmetries, which are capable of complex dynamic phenomena, analyzes motion of the landing vehicle at the final stage of motion in the atmosphere.

1. Introduction

Landing stage of the landing vehicle on surface of the planet is responsible for the successful conduct of the flight. To perform this it is proposed to use a special inflatable braking device, allowing to carry out a "soft" landing of landing vehicle on the planet's surface without the use of a parachute system.

During the movement in the atmosphere of the planet of landing vehicle with an inflatable braking device subjected to significant aerodynamic loads, which can lead to changes in non-rigid shell shape inflatable braking device and the emergence of the current asymmetries.

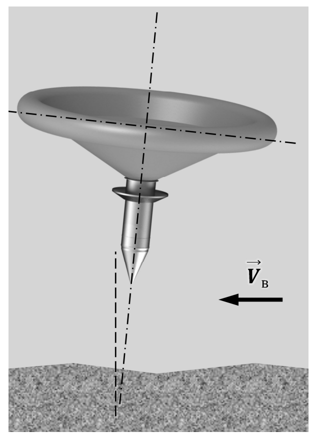

Figure 1. Exterior view of the landing vehicle deployed with an inflatable braking device

In author's work [1, 2], in more detail the methods for calculating the parameters of the angular motion of space landing vehicle with an inflatable braking device. In the scientific work [3] that a description of the project RITD - Re-entry: inflatable technology development in Russian collaboration

2. Modeling

As shown above in the final trajectory the landing vehicle moves almost vertically to the surface of the planet. Wherein the spatial angle of attack is of the order of two degrees.

Consider the additional effect of the horizontal wind on the dynamics of angular motion of the landing vehicle. For example, take a longitudinal horizontal wind with a speed of six meters per second, the effect on the last five hundred meters before landing on the planet's surface.

At Figure 2 shows the pattern of the angular movement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the absence of additional asymmetries. From Figure 2 shows that the center of the vibrational motion of the landing vehicle relative velocity vector is shifted by about 5.5 degrees. This corresponds to the average angular displacement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the presence of wind. Thus the character of the dynamics of angular motion of the landing vehicle does not change. Only shifts the center of the vibrational motion of the landing vehicle.

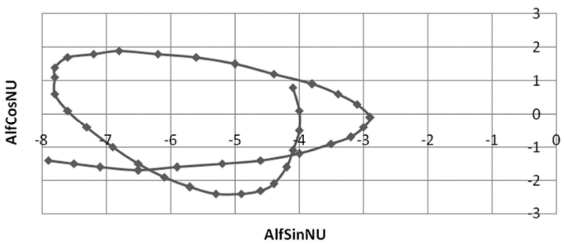

Figure 2. Angular movement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the absence of additional asymmetries.

Consider the dynamics of angular motion of the landing vehicle under the same conditions, but with additional asymmetry. Figure 2 shows a picture of the angular movement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the presence of additional asymmetry of the external form (mz = 0.004). This asymmetry may be due to the additional stiffness not inflatable braking device.

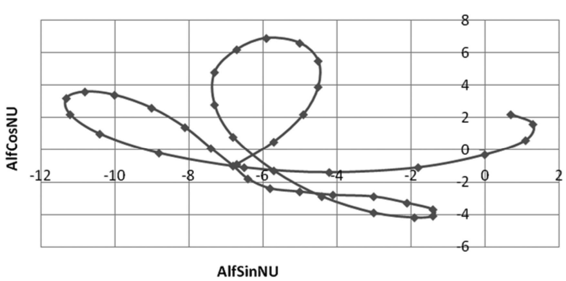

Figure 3. Angular movement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the presence of additional asymmetry of the external form.

We next consider the dynamics of angular motion of the landing vehicle under the same conditions, but with smaller magnitude of the asymmetry caused by the deformation of the outer shape (mz = 0.002).

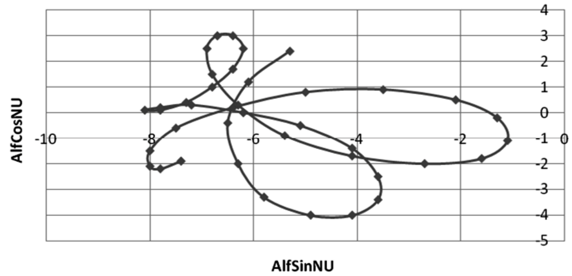

Figure 4. Angular movement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the presence of asymmetry in the external form (mz = 0.002).

Figure 4 shows a picture of the angular movement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the presence of additional asymmetry of the external form (mz = 0.002).

3. Summary and Conclusions

Comparing the pattern of angular motion of the landing vehicle presented in Figure 2 and Figure 3 see that the presence of asymmetry caused by the deformation of the outer shape, changes the nature of the angular motion. Increases the value of the spatial angle of attack. Instead, nearly circular motion to the longitudinal axis relative to of the landing vehicle velocity vector appears loop-like movement of the longitudinal axis. Almost three times increase lateral deviations of the longitudinal axis from the velocity vector. The center of the oscillation is roughly the same as that in the absence of additional asymmetry.

Comparing the pattern of angular motion of the landing vehicle shown on Figure 4 and Figure 3 we see that a decrease in the asymmetry due to the deformation of the external form, the nature of the angular movement of little change. Reduces the magnitude of the spatial angle of attack. Reduces the deviation of the longitudinal axis of the velocity vector. But in general, the angular movement of the longitudinal axis of the of the landing vehicle relative to the velocity vector in the presence of additional asymmetry persists.

Acknowledgements

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Castalia – A Mission to a Main Belt Comet

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Abstract

Main Belt Comets (MBCs), or Active Asteroids, constitute a newly identified class of solar system objects. They have stable, asteroid-like orbits and some exhibit a recurrent comet-like appearance. It is believed that they survived the age of the solar system in a dormant state and that their current ice sublimation driven activity only began recently. Buried water ice is the only volatile expected to survive under an insulating surface. Excavation by an impact can expose the ice and trigger the start of MBC activity. We present the case for a mission to one of these objects. The specific science goals of the Castalia mission are: 1. Characterize a new Solar System family, the MBCs, by in-situ investigation 2. Understand the physics of activity on MBCs 3. Directly sample water in the asteroid belt and test if MBCs are a viable source for Earth's water 4. Use the observed structure of an MBC as a tracer of planetary system formation and evolution. These goals can be achieved by a spacecraft designed to rendezvous with and orbit an MBC for a time interval of some months, arriving before the active period for mapping and then sampling the gas and dust released during the active phase. Given the low level of activity of MBCs, and the expectation that their activity comes from only a localized patch on the surface, the orbiting spacecraft will have to be able to maintain a very close orbit over extended periods - the Castalia plan envisages an orbiter capable of 'hovering' autonomously at distances of only a few km from the surface of the MBC. The strawman payload comprises a Visible and near-infrared spectral imager, Thermal infrared imager, Radio science, Subsurface radar, Dust impact detector, Dust composition analyser, Neutral/ion mass spectrometer, Magnetometer, and Plasma package. In addition to this, a surface science package is being considered. At the moment, MBC 133P/Elst-Pizarro is the best-known target for such a mission. A design study for the Castalia mission has been carried out in partnership between the science team, DLR and OHB Systems. This study looked at possible missions to 133P with launch dates around 2025, and found that this, and backup MBC targets, are reachable by an ESA M-class mission.

More details are available at http://bit.ly/mbcmission

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The Ganymede Laser Altimeter (GALA) for ESA's JUICE Mission

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Abstract

The Ganymede Laser Altimeter (GALA) is one of the instruments selected for ESA's JUICE mission (Jupiter Icy Moons Explorer) [1]. The scientific goals of the GALA instrument cover a wide range of questions of geology, geophysics and geodesy. Here we will present an overview on the scientific goals and performance as well as an update on the instrument status.

1. Introduction

A fundamental goal of any exploratory space mission is to characterize and measure the figure, topography, and rotation of the target bodies. This is essential for understanding both the interior state and global aspects of satellite evolution as well as regional and local processes that have shaped the body's surface. A state of the art tool for this task is a laser altimeter because it can provide absolute topographic height and position with respect to a Ganymede (or Europa/Callisto) centered co-ordinate system.

2. Scientific Goals

With respect to Ganymede, the GALA instrument aims at

• the global subsurface ocean and further characterization of the water-ice/liquid shell by monitoring the dynamic response of the ice shell to tidal forces
• global, regional and local topography to understand the processes that have shaped Ganymede's surface
• measurements of forced physical libration and spin-axis obliquity that would provide additional information on the existence and extent of a subsurface ocean
• provide accurate data for determining Ganymede's shape (a, b and c-axis) low- and high-degree topographic measurements
• detailed topographic profiles crossing the linear features of grooved terrains.
• as well as at information about slope, roughness and albedo (at 1064nm) data from Ganymede's surface

During flybys of Europa and Callisto GALA will provide topographic profiles during closest approach for geological interpretation as well as providing constraints for shape measurements of these two satellites.

GALA will form an integral part of a larger geodesy and geophysics package, incorporating radio science, stereo imaging and sub-surface radar. The synergy will tackle the problems of planetary figure, rotation, gravity field determination, interior structure, surface morphology and geology, and tidal deformations. By interpreting the tidal measurement, the presence of an ocean can be confirmed and the ice shell thickness can be constrained by a few tens of km [2].

The latter is crucial for the detection of subsurface oceans on Ganymede (and on Europa and Callisto).

Precise time-of-flight measurements could improve the high-precision determination of the spacecraft position during the inter-planetary cruise and in the later orbital phases around Jupiter and Ganymede. The technical feasibility of laser links between Earth and the JUICE spacecraft is therefore also studied for GALA.

2. The Instrument

The principle of laser altimetry is straightforward. The time of flight between the emission of a photon and the receipt of the reflected photon is measured. This time of flight is then converted to a distance using the well-known speed of light. In a laser altimeter, a laser emits a short laser pulse, which is reflected from the surface of the body, received by a telescope and then analyzed by an electronic.

The instrument is designed to work at in circular orbit at 500 km altitude (GCO-500). Measurements with high accuracy during flybys at Europa and Callisto as well as in lower orbits around Ganymede are possible as well.

As pumping scheme, side-pumping is proposed here due to reduced technical complexity and heritage from the BELA transmitter laser. Redundancy can be realized easily with this scheme on diode stack level. Table 1 gives an overview on the transmitter sub-system Basic instrument parameters.

The GALA instrument is developed in collaboration of institutes from Germany, Japan, Switzerland and Spain.

Parameter	Value/description	Unit
Laser rod crystal	Nd:YAG	N/A
Wavelength	1064	nm
Pulse energy	17	mJ
Pulse repetition rate	30	Hz
Q-Switch	RTP pockels cell	N/A
Collimator aperture	ca. 45 x 60	mm
Divergence (full cone)	100	µrad
Receiver Telescope diameter	25	cm
Detector	Silicon APD, 100 MHz bandwidth	
Detector electronics	digital rangefinder, 200 MHz sampling rate,	

6. Summary and Conclusions

The diversity of targets and the different phases of the trajectory including flybys and the Ganymede orbital phase during the course of the JUICE mission require flexibility of the instrument to achieve the various scientific objectives. The instrument is capable of achieving the scientific goals related to geology, geophysics and geodesy will be covered.

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Mars MetNet Mission Status

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Abstract

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

The scientific payload of the Mars MetNet Precursor [1] mission is divided into three categories: Atmospheric instruments, Optical devices and Composition and structure devices. Each of the payload instruments will provide significant insights in to the Martian atmospheric behavior.

The key technologies of the MetNet Lander have been qualified and the electrical qualification model (EQM) of the payload bay has been built and successfully tested.

1. MetNet Lander

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

2. Scientific Payload

The payload of the two MNL precursor models includes the following instruments (Figure 1):

Atmospheric instruments:

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

Optical devices:

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

Composition and Structure Devices:

- Tri-axial magnetometer MOURA (INTA)
- Triaxis System Accelerometer and Gyroscope (FMI)

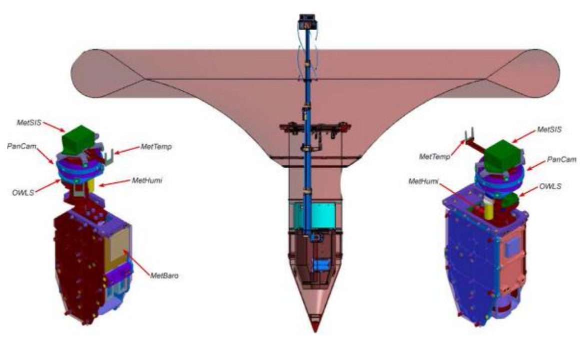

Figure 1: MetNet Lander payload. Figure: LA/FMI.

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 in 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 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. 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.

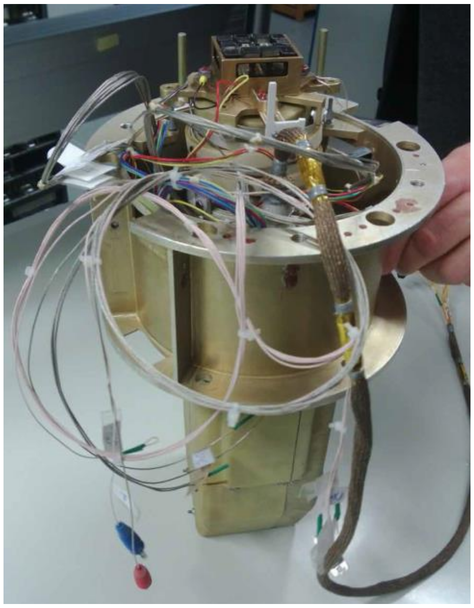

Figure 2: Landing unit QM model. Photo: FMI.

4. Summary and Conclusions

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

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THE OPTICAL DEPTH SENSOR (ODS) FOR MARS ATMOSPHERE

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Abstract

A small and sophisticated optical depth sensor (ODS) has been designed to work in both Martian and Earth environments. The principal goal of ODS is to carry out the opacity due to the Martian dust as well as to characterize the high altitude clouds at twilight, crucial parameters in understanding of Martian meteorology. The instrument was initially designed for the failed MARS96 Russian mission, and also was included in the payload of several other missions [1]. Until recently, it was selected (NASA/ESA AO) in the payload of the atmospheric package DREAMS onboard the MARS 2016 mission. But following a decision of the CNES, it is no more included in the payload.

In order to study the performance of ODS under a wide range of conditions as well as its capable to provide daily measurements of both dust optical thickness and high altitude clouds properties, the instrument has participated in different terrestrial campaigns. A good performance of ODS prototype (**Figure 1**) on cirrus clouds detection and in dust opacity estimation was previously archived in Africa during 2004-2005 and in Brasil from 2012 to nowadays. Moreover, a campaign in the arctic is expected before 2016 where fifteen ODSs will be part of an integrated observing system over the Arctic Ocean, allowing test the ODS performance in extreme conditions.

In this presentation we present main principle of the retrieval, the instrumental concept, the result of the tests performed and the principal objectives of ODS in Mars.

1. Motivations and objectives

On Mars, dust and clouds are primary elements for studying the interactions of solar radiation with the atmosphere and surface and their influence on the radiation balance. In the absence of massive condensed water and precipitation, dust lifted by storms are the unique condensation nuclei available at the Mars atmosphere. This fact highlights the importance of dust in the vertical structure of the Mars lower atmosphere.

Therefore a capability of modelling the dust and clouds is vital for understanding of meteorology and climate on Mars. The capacity of ODS is the monitoring of dust optical thickness and size distribution on a daily basis as well as the detection of the altitude and opacity of high altitude sub-visible cirrus at twilight.

For validation purpose, ODS prototypes were deployed in West Africa sahel region in Ouagadougou, Burkina Faso next to a AERONET station and now ODS is in Bauru in Brasil. Analyses of the signal returned by ODS are part of the preparation of the instrument for spatial missions.

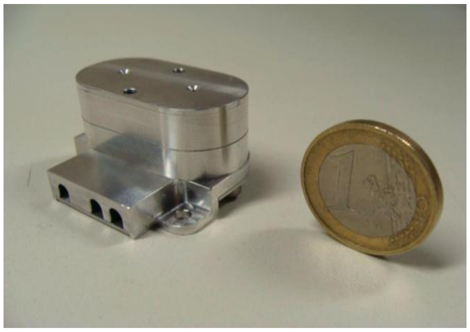

Figure 1: *Optical head of the ODS instrument. The total weight of the instrument for two channels is 63 g : 28 g for the optical head and 35 g for the electronics.*

2. Principle of the measurement

ODS is always oriented to zenith, with an annular field of view between ±25 and ±50 solar zenith angle, and two channels are selected by using different filters (375 nm and 780 nm). The scattered flux is observed from sunrise to sunset and the total flux, given by the direct + scattered flux, only when the sun passes in the ODS field of view. Dust opacity is retrieved by comparing the flux scattered by the atmosphere, and the sum of the scattered + direct solar flux. The ratio of these two fluxes depends on the aerosol load. The retrieval procedure is base on the use of look-up tables of intensities reproducing the signals that should be observed by ODS, as a function of the aerosol optical depth (AOD). Look-up tables of intensities are obtained by using radiative transfer simulations. **Figure 2** shows the evolution of simulated ODS blue signal during the course of a Martian day for different dust optical opacities. The bands delimited by the black dashed lines indicate the time intervals for which the sun is within the field of view of ODS. The shapes of theoretical signals are then compared to observations and the best fit is selected with a goodness test.

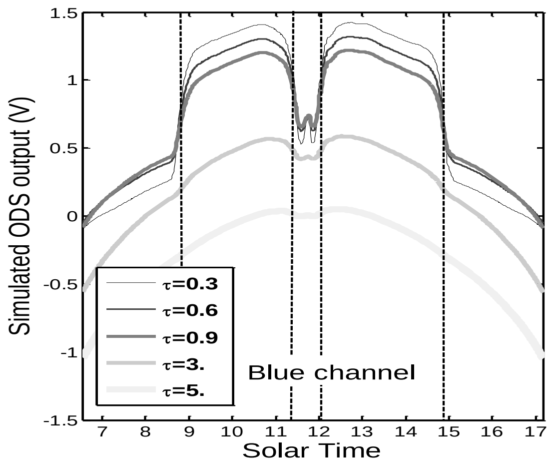

Figure 2: *ODS signal modelled, for different dust optical depth.*

A notable characteristic of ODS is that its retrievals are indeed independent of any absolute calibration. This fact is essential for ensure its performance in Mars. **Figure 3** shows ODS daily average AOD at 375 nm at Bauru. The results show the capability of ODS to identify the burning biomass season at Brazil.

For the cloud detection, the index colour (CI) is used, defined as the ratio between the scattered light at red and blue wavelengths. If a cloud is present during twilight, then a peak must be observed in the time variation of CI [2]. Clouds properties are retrieved by simulating the CI signal as a function of the cloud optical depth (COD) and the altitude of the cloud, by using a radiative transfer model, but in this case during twilight. Hence, look-up tables of intensities should be built by using a model in spherical geometry. Figure 4 shows a twilight simulation with MONTE CARLO model in spherical geometry where an ice cloud with different altitudes and COD values, is present.

In this work, we will present the procedures used to retrieve the AOD and the cloud properties. Such procedures were used to analyse the data taken during the terrestrial field campaign mentioned above. We then show our results concerning cloud properties and the dust optical depth. We will also show the type of observation that are possible to obtain in Martian environment, concerning the dust and cloud layers.

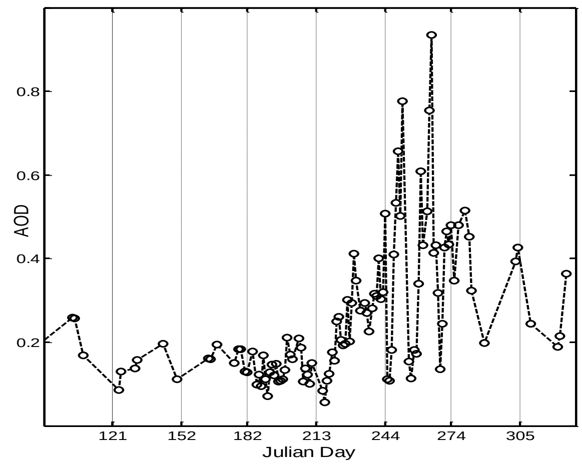

Figure 3: *ODS optical depth at 375 nm at Bauru during 2012*

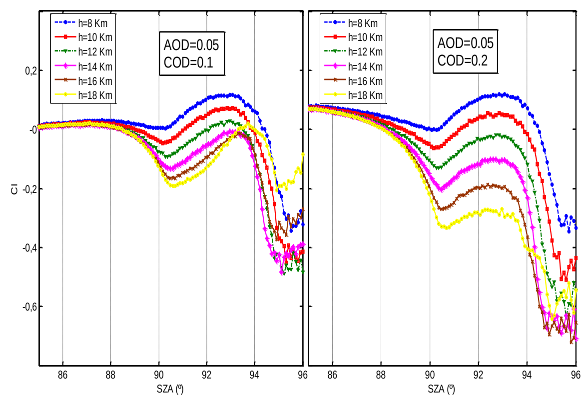

Figure 4: *Simulated ODS CI during twilight for different values of both, cloud height and cloud optical depth.*

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RITD - Adapting Mars Entry, Descent and Landing System for Earth

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Abstract

We have developed an atmospheric re-entry and descent system concept based on inflatable hypersonic decelerator techniques that were originally developed for Mars. The ultimate goal of this EU-funded RITD-project (Re-entry: Inflatable Technology Development) was to assess the benefits of this technology when deploying small payloads from low Earth orbits to the surface of the Earth with modest costs. The principal goal was to assess and develop a preliminary EDLS design for the entire relevant range of aerodynamic regimes expected to be encountered in Earth's atmosphere during entry, descent and landing. Low Earth Orbit (LEO) and even Lunar applications envisaged include the use of the EDLS approach in returning payloads of 4-8 kg down to the surface.

1. EDLS for Earth

The dynamical stability of the craft is analyzed, concentrating on the most critical part of the atmospheric re-entry, the transonic phase. In Martian atmosphere the MetNet vehicle stability during the transonic phase is understood. However, in the more dense Earth's atmosphere, the transonic phase is shorter and turbulence more violent. Therefore, the EDLS has to be sufficiently dynamically stable to overcome the forces tending to deflect the craft from its nominal trajectory and attitude.

The preliminary design of the inflatable EDLS for Earth has been commenced and the scaling of the re-entry system and the dynamical stability analyses has been performed. The RITD-project concentrates on mission and applications achievable with the current MetNet-type, called in RITD as a Mini-1, of lander and on requirements posed by other type Earth re-entry concepts.

2. Wind Tunnel Test to Confirm the Mathematical Analysis

The aim of the wind tunnel tests was the experimental determination of the Mini-1 DV (descent vehicle) damping factors in the Earth atmosphere and recalculation of the results for the case of the vehicle descent in the Mars atmosphere. The Mini-1 lander mock-up model (Figure 1) used in the tests was in scale of 1:15 of the real-size lander as the dimensions were (midsection) diameter of 74.2 mm and length of 42 mm. For wind tunnel testing purposes the frontal part of the Mini-1 DV mock-up model body was manufactured by using a PolyJet 3D printing technology based on the light curing of liquid resin. The tail part of the mock-up model body was manufactured of M1 grade copper. The structure of the dynamic mock-up model provided a CoG relative to the coordinates of the full-scale Mini-1 DV.

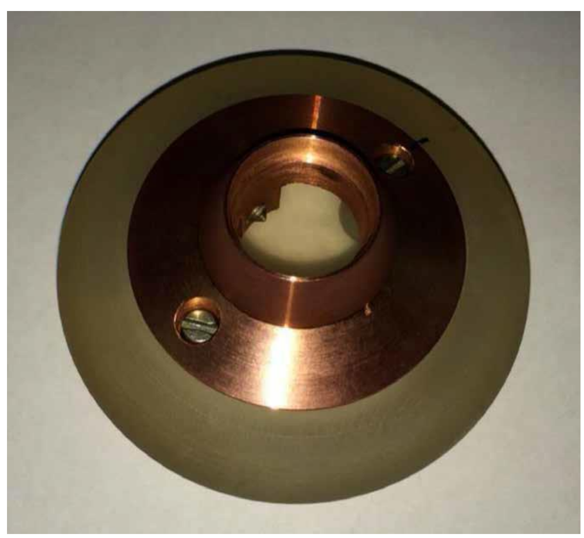

Figure 1: Wind tunnel test mock-up model. Image: LA.

2.1 Wind Tunnel Tests Program of the Mini-1 Mock-up

The Mini-1 DV damping characteristics within the wind tunnel were experimentally determined by the technique of free oscillations of dynamically similar mock-up model installed on the holder with one degree of freedom. The method of testing and damping factor Cmq determination was based on the characterization of the model oscillatory motion with regard to the free oscillation holder's hinge in gas flow within the wind tunnel. The Mini-1 DV mock-up model mounted on the free oscillation holder (Figure 2) was placed into gas flow of the wind tunnel at the known angle of attack. In case the factor of damping moment Cmq value is negative ($Cmq < 0$) the descending DV rotation will be decreased and the DV will be stable. If its value is positive ($Cmq > 0$) it will lead to increase of the amplitude of DV oscillations and causes instability.

The wind tunnel test program included the defining of the damping factor Cmq at seven values of Mach numbers 0.85; 0.95; 1.10; 1.20; 1.25; 1.30 and 1.55 at different angles of attack ($A_H = 0$ degree to 40 degree with the step of 5 degree).

Figure 2: Lander mock-up model inside the wind tunnel during the RITD test program. Image: LA.

2.1 Wind Tunnel Test Results

Using the transonic wind tunnel the factors of the longitudinal damping moment of scaled Mini-1 DV mock-up model were determined experimentally within the range of angles of attacks (A_H) 0 degree to 10 degree at Mach numbers of 0.85 to 1.53.

The wind tunnel tests showed that within the range of Mach numbers 1.1 to 1.53 and angles of attacks (A_H) 0 degree to 10 degree the excitation of self-oscillations and increase of oscillations' amplitude (A_0) up to the value 9 degree to 11.5 degree take place. With that the factor of antidamping varies within the limits of the aerodynamic factor of longitudinal damping moment 0.01 to 0.25.

Within the range of Mach numbers 0.85 to 0.95 and angles of attacks (A_H) 5 degree to 10 degree the damping of oscillations within the limits of the aerodynamic factor of longitudinal damping moment -0.07 to -0.12 was observed.

3. Summary and Conclusions

Our development and assessments show clearly that this kind of inflatable technology originally developed for the Martian atmosphere, is feasible for use by Earth entry and descent applications. The preliminary results are highly promising indicating that the current Mars probe design could be used as it is for the Earth. According to our analyses, the higher atmospheric pressure at an altitude of 12 km and less requires an additional pressurizing device for the in atable system increasing the entry mass by approximately 2 kg. These analyses involved the calculation of 120 different atmospheric entry and descent trajectories.

The analysis of the existing technologies and current trends have indicated that the kind of inflatable technology pursued by RITD has high potential to enhance the European space technology expertise. This kind of technology is clearly feasible for utilization by Earth entry and descent applications.

Acknowledgements

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Nitrogen Ion TRacing Observatory (NITRO): A planetary mission to the Earth

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Abstract

The NITRO mission that was proposed for the recent ESA M-class mission call (M4) in January 2015 studies the budget and dynamics of magnetospheric nitrogen ions (N^+ and N_2^+) by separating them from O^+ as well as the structure of the exosphere. This presentation summarizes the importance of such studies in the context of the planetary atmosphere formation and the measurement strategy of the proposed mission.

1. Introduction

Behavior and budget of nitrogen ions (N^+) in the magnetosphere have not been well investigated in the past due to the difficulty in separating N^+ from oxygen ions (O^+) in the in-situ measurements. However, the nitrogen budget could be more important than the oxygen budget in modeling the ancient atmosphere of the Earth, and even Venus and Mars. Also the terrestrial exosphere is very little known, particularly for nitrogen, although it is a key region for the atmospheric escape.

2. Scientific importance

The observation of non-thermal escape of nitrogen is a mandatory step in examining any theory on the atmospheric formation of Earth/Mars/Venus and other planets/moons. For nitrogen, the total amount of N^+ escape over 4 billion years can be comparable to, or higher than, the present day's nitrogen inventory of the Earth (and much higher than present day's nitrogen inventory of Mars), because of the following reasons:

The total amount of nitrogen on Earth (the majority is in the atmosphere, where it constitutes 78% of it) is about $4\text{-}5 \cdot 10^{18}$ kg. Consequently, if the non-thermal escape rate reaches 10^9 kg/year (10^{27} ions/s), one can no longer ignore the non-thermal nitrogen escape over the Earth's history compared to the present days nitrogen inventory.

To the present day's knowledge, heavy ion escape is of the order of 10^{25} ions/s in average[1] and this amount varies by more than three orders of magnitude from geomagnetically quiet periods (quiet Sun) to magnetic storm times (active Sun)[2]. Furthermore, the very limited observations of the cold N^+ outflow above the ionosphere indicate that the N/O ratio increases to nearly unity (or even more) during major geomagnetic storms[3].

The conditions for a high escape rate for heavy ions and particularly N^+ (high EUV flux and large geomagnetic activity) correspond to the ancient Earth conditions, because the early Sun is believed to have had high EUV flux (one order of magnitude higher than present), stronger magnetic field due to faster rotation, and faster solar wind velocity. Therefore, it is quite possible that the total amount of non-thermal escape of nitrogen could be comparable to or more than the present nitrogen inventory.

In such a case, one of two major models of nitrogen atmosphere formation (outgassing models of NH_3) becomes more likely than the other (N_2 delivery models by comets or asteroids)[4]. This also constrains planetary formation models in how the volatiles are included in the proto-Earth (this is not simple because of very low condensation temperature of N_2 and NH_3).

If the total nitrogen escape is less than the present inventory, the initial nitrogen inventory of the Earth would be much less than that of Venus. This would also constrain the planetary formation model because more volatiles should have been condensed at locations closer to the Sun. In both cases, the combination with the measured exospheric distributions (no direct measurements exist today above 1500 km altitude) would provide an improved estimate of the evolution of the terrestrial atmosphere.

The study of nitrogen ion dynamics and its budget has many other scientific merits on the topics of the interpretation of $^{14}N/^{15}N$ ratio of solar system bodies and atmospheres (non-thermal escape leads to a different isotope ratio than thermal escape that is gravity-mass-filtered), the magnetosphere-ionosphere coupling and basic space plasma physics (different initial velocity between M/q=14 and M/q=16 gives extra information on energization mechanisms in space).

3. Mission

The proposed baseline mission consists of two spacecraft for full science. However, a back-up option using a single spacecraft could still fulfill the most important science goals, but with lower spatial/temporal resolution. The two-spacecraft baseline consists of a spin-stabilized (22-26 s) spacecraft (800 km x 33000 km, 68.5° inclination) for in situ plasma measurements, and of a 3-axis stabilized remote sensing spacecraft (500 km x 2400 km, 88.35° inclination) for line-of-sight integrated optical measurements and for direct measurements for neutrals and ions in the exosphere and topside ionosphere. With these orbit parameters, the two spacecraft orbital planes would have the same longitudinal drift velocity.

The details of the proposal will be presented during the Congress.

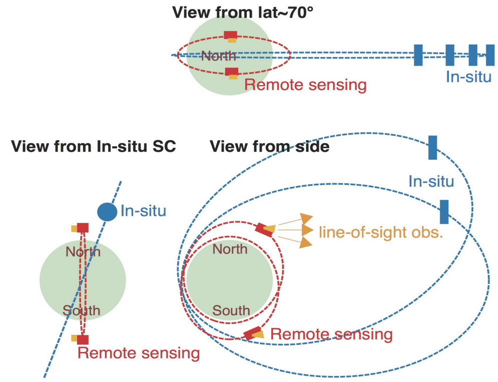

Figure 1: Proposed orbit for two spacecrafts. They have an identical longitudinal drift velocity.

Acknowledgements

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EXPLORATION OF MARTIAN SURFACE USING AN AUTONOMOUS OCTOCOPTER

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Abstract:-

To make an Octocopter that will land with the rover that will be deployed in 2018/20. This Octocopter will carry a set of instruments and will hover upto a certain height of 20-65m or more.

1) The main aim of the Octocopter is the analysis of the Martian atmosphere for the presence of methane or other gases and its composition.

2) It will also help the rover by delivering it samples of the Martian soil. Ex:- Suppose right now this Octocopter is present on mars it can help the curiosity rover by directly taking samples of soil in Mount sharp base and deliver it to the rover.

3) It can act as an orbiter that will send HD images back on Earth.

This Octocopter can also help in investigation of Mars moon's – Phobos and Deimos. It can also be used for studying and going deep down in the atmosphere of Titan and Enceladeus.

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CLIpSAT for Interplanetary Missions: Common Low-cost Interplanetary Spacecraft with Autonomy Technologies

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Abstract

Blue Sun Enterprises, Inc. is creating a common deep space bus capable of a wide variety of Mars, asteroid, and comet science missions, observational missions in and near GEO, and interplanetary delivery missions. The spacecraft are modular and highly autonomous, featuring a common core and optional expansion for variable-sized science or commercial payloads.

Initial spacecraft designs are targeted for Mars atmospheric science, a Phobos sample return mission, geosynchronous reconnaissance, and en-masse delivery of payloads using packetized propulsion modules. By combining design, build, and operations processes for these missions, the cost and effort for creating the bus is shared across a variety of initial missions, reducing overall costs.

A CLIpSAT can be delivered to different orbits and still be able to reach interplanetary targets like Mars due to up to 14.5 km/sec of delta-V provided by its high-ISP Xenon ion thruster(s). A 6U version of the spacecraft form fits PPOD-standard deployment systems, with up to 9 km/s of delta-V. A larger 12-U (with the addition of an expansion module) enables higher overall delta-V, and has the ability to jettison the expansion module and return to the Earth-Moon system from Mars orbit with the main spacecraft. CLIpSAT utilizes radiation-hardened electronics and RF equipment, 140+ We of power at earth (60 We at Mars), a compact navigation camera that doubles as a science imager, and communications of 2000 bps from Mars to the DSN via X-band. This bus could form the cornerstone of a large number asteroid survey projects, comet intercept missions, and planetary observation missions.

The TugBot architecture uses groups of CLIpSATs attached to payloads lacking innate high-delta-V propulsion. The TugBots use coordinated trajectory following by each individual spacecraft to move the payload to the desired orbit - for example, a defense asset might be moved from GEO to lunar transfer orbit in order to protect and hide it, then returned to a useful GEO orbit as a replacement for a failed GEO asset.

Interplanetary payload delivery can be undertaken by arraying these spacecraft buses, then staging each one. This approach is implemented by using CLIpSATs as propulsion "packets", delivered independently to low earth orbit and directed to rendezvous individually with a structure. Once all packets have attached themselves, the ensemble burns to follow a trajectory, delivering the payload to the desired planetary or heliocentric orbit.

Autonomy technologies in CLIpSAT software include Virtual Machine Language 3 (VML 3) sequencing, JPL AutoNav software, optical navigation, ephemeris tracking, trajectory replanning, maneuver execution, advanced state-driven sequencing, expert systems, and fail-operational strategies. These technologies enable small teams to operate large numbers of spacecraft and lessen the need for the deep knowledge normally required.

The consortium building CLIpSAT includes Blue Sun Enterprises, the Jet Propulsion Laboratory, Millennium Space Systems, the Laboratory for Atmospheric and Space Physics, and the Southwest Research Institute.

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The ExoMars 2016 Landing Site

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Abstract

We present the analysis of the engineering constraints of the ExoMars 2016 landing site in order to assess the EDM landing safety The landing ellipse of ExoMars 2016 is located at Meridiani Planum. The EXM2016 ellipse is 100 km long and 15 km large, with a characterization of 110 km long and 25 km large; it covers a flat area to the west of the Opportunity landing site. The EDL operations require such landing area in line with its ballistic approach. A large number of data sets have been used for this analysis and the final outputs have been a set of maps and the final hazard assessment.

1. Data sets and analysis

The area of the landing site cover a flat area dominated by the Burns formation [1] and possible adjacent lava flows covered by aeolian deposits or a thin veneer of deflated material. The constraints that have been taken into account are the relief and slope at different scales. Relief and slopes at kilometer-scale base lengths can be evaluated using MOLA data down-sampled down to 1 km and 2 km per pixel of resolution using the Steepest Adjacent Neighbor algorithm. Relief and slopes at hectometer-scale base lengths can be evaluated using MOLA data and HRSC DEMs (with resolution down to 75-100 m/pixel, see example of Figure 1). However, the nominal resolution of MOLA data does not allow the direct investigation of the slope at hectometer scales ranging from 100 m to about 460 m. The characterization of the meter/tens of meter slope constraint can only be performed through high-resolution stereogrammetry at the meter length scale (e.g. with HiRISE, MOC, and CTX data). Photoclinometry has been performed on MOC images when stereo data were lacking and, basically, for comparison. In order to verify the slopes constraints at those scales not covered from the available data, it has been assumed that the landing site surface obeys self-affine behaviour. MOLA tracks, HRSC DEMs, HiRISE DEMs and MOC PC2D DEMs have been considered. TES and Themis data have been used to analyse several parameters including thermal inertia, albedo, and bolometric temperature. Impact craters are important morphological features that may create a signicative hazard. More than 190.000 impact craters have been manually mapped filed by morphology (pristine to degraded) and dimensions. The derivation of the rock abundance and spatial distribution can be performed in three ways: IRTM assessment and estimation, and extrapolation from models.

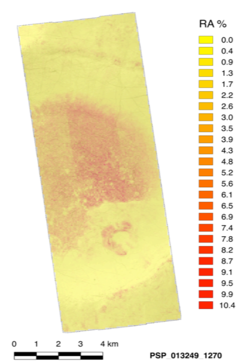

Figure 1: Rock abundance map binned at 64 m. The observed mean rock abundance is 1.7% but locally the area covered by rocks can approach 10% (HiRISE image PSP_013249_1270)

Visual inspection. IRTM has been widely used in the rock property assessment, but estimates are at a spatial resolution of 1 degree bins (60 km). Visual inspection of images is a key method and the automatic identification of rocks on HiRISE images can be extremely useful. To this aim, rock detection software has been developed by IRSPS

2. The landing site

The bedrock of the landing site is represented by the Burns formation, a sequence of similar to the terrestrial sedimentary deposits of desert. This unit consists of aeolian and sebkha-like deposits and it is supposed to underlay the area of the ExoMars landing. Its whitish color is observable all over the landing sites in the fresher crater rims and as small isolated patches. This unit is overlain by a thin (probably no more the a meter) of deflation deposits and megaripple fields. The Northern and Southern tips of the ellipse are dominated by ejecta from relatively large craters located outside the landing area. The area is remarkably flat and high slope values occur where a few large craters occur. Surface properties and geological reconstructions suggest that the area is predominantly composed of a thin layer of regolith made up of pebble size clasts and indurated intervening fines. Large clasts (B axes in excess of 10 cm) are scattered over the surface, mostly in correspondence of crater ejecta.

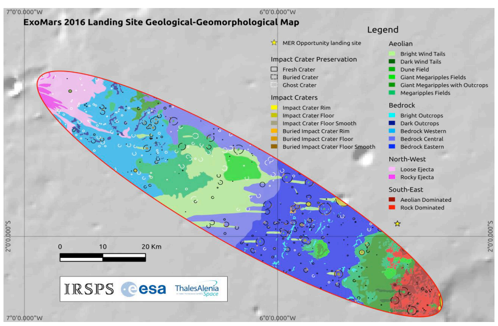

Figure 2: Morpho-geotechnical map of the landing site.

6. Summary and Conclusions

The landing site of ExoMars 2016 shows the typical features of the Meridiani Planum area as depicted by the Opportunity rover. The area has been deeply investigated in term of engineering constraints and geological features. This analysis has put in evidence and confirmed the suggestion that this area is one the safest zone on Mars for landing. Nevertheless, the geological variability and limited knowledge of the whole area at the requested resolution, still requires a probabilistic analysis for EDL operations.

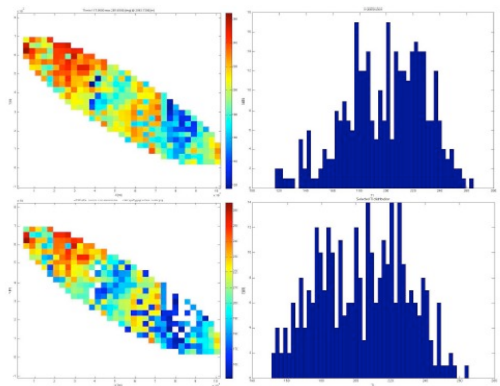

Figure 3: THEMIS-derived thermal inertia and histograms for the studied landing site.

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Near Space Observations: Planetary Science from a Balloon-Borne Telescope

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Abstract

On 25-SEP-2014, the BOPPS balloon mission (*Balloon Observation Platform for Planetary Science*) launched from Ft Sumner, NM. During its 17-hour flight, BOPPS observed three comets in wavelengths from 0.8 to 4.6 μm with its infrared camera and demonstrated 66 mas image stability with its visible-UV cameras. The BOPPS payload was intended to develop and demonstrate two key capabilities of balloon-borne telescopes: the ability to acquire IR wavelengths that are obscured from the ground or from SOFIA, and the ability to obtain diffraction-limited images at wavelengths shortward of 1 μm, where ground-based adaptive optics systems typically provide poor Strehl ratios.

Now that the successful BOPPS mission is behind us, there is the potential to re-use the BOPPS instrumentation for additional long-duration balloon missions to address other planetary science investigations: a planetary observatory in the stratosphere, with the possibility of performing observations that are proposed and competed by the planetary community. NASA's Columbia Scientific Balloon Facility just flew a record-setting 32-day circumglobal super-pressure balloon mission at southern mid-latitudes. Unlike previous long-duration flights from Antarctica (zero-pressure balloons flying in constant daylight), this recent flight launched from New Zealand and passed through day/night cycles, demonstrating the ability of balloons to carry science payloads weighing up to 3000 lb and provide hundreds of hours of dark time above 99.5 % of the atmosphere.

We will provide an overview of the BOPPS payload and a review of the BOPPS flight. We will highlight the recommended changes that would allow BOPPS to become a general purpose infrared and visible/UV observatory.

1. Figures

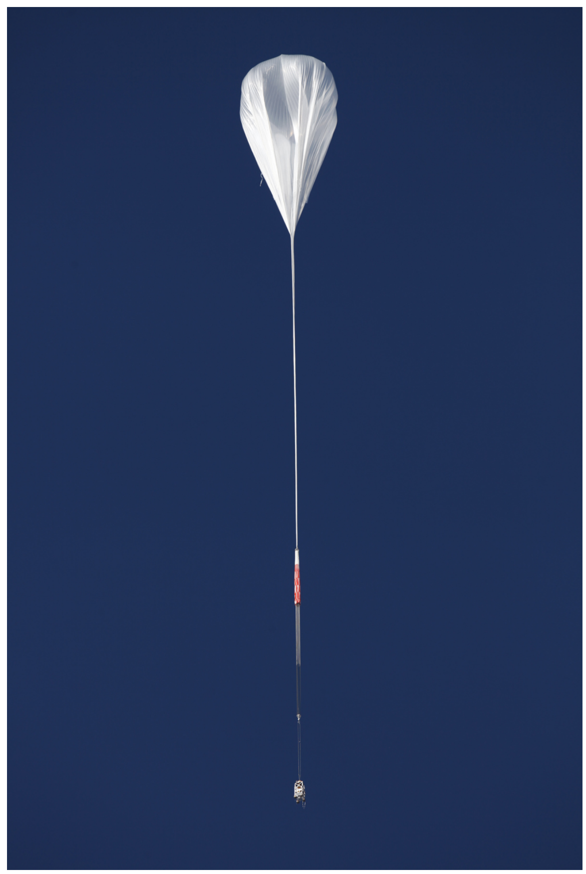

Figure 1: The BOPPS payload is shown here shortly after launch on 25-SEP-2015. The mission reached float altitude near 127,000 ft.