Synergistic Science & Instrument Poster Abstracts

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PLASMA ION AND EXOSPHERIC GAS COMPOSITION OBJECTIVES FOR EJSM

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Abstract

Synergistic measurements of plasma ion and neutral gas composition by the multiple spacecraft of the Europa Jupiter System Mission offer the unprecedented opportunity to completely survey the elemental and isotopic abundances of magnetospheric and moon surface materials in the Jovian system. Origin and evolution of this system may be determined in part from the abundances of ion and neutral species from the various sources, predominately Io for major heavy ions (O, S) but potentially also traceable to other sources when measured at the extremely low abundance limits now accessible with advanced plasma and neutral instrumentation (Sittler et al., this workshop). The otherwise unseen processes driving Io volcanism are recorded in the full abundance distributions of elements and isotopes freely accessible to plasma measurements in the middle magnetosphere throughout the realm of the Galilean moons. This abundance record is also implanted via the iogenic plasma onto the surfaces of these moons, so that measurements of surface and exospheric abundances at trace levels provide indirect measures of Io's volcanic history. The relative paucity of the minor ions Na and C in the iogenic plasma suggests significant inputs to measured abundances from other sources, respectively from Europa and the solar wind, but perhaps also for C from sputtering off of Ganymede and Callisto, both known to have surface or exospheric CO_2. Constant (e.g., C) or increasing abundances of some species between the orbits of Europa and Ganymede would indicate sources from Ganymede, Callisto, Jupiter's polar atmosphere, or the solar wind. These external magnetospheric inputs to moon surface composition must be fully mapped with direct measurements and plasma interaction modeling to extract information on the intrinsic composition sources and chemical processes of these moons. The material states and thermal evolution of the moon interiors, including the putative subsurface ocean layers of the icy Galilean moons, may be recorded in the spatial distributions and abundances of emergent materials to the surfaces, but these records may be obscured in places. e.g. on the trailing hemispheres, by the exogenic components. The interior thermal evolution is controlled in part by decay of radioisotopes that may contribute to surface and magnetospheric abundances, while also impacting radiolytic molecular chemistry of the accessible ice crust. The chemical impact of surface irradiation is particularly evident on Europa with its global oxygen atmosphere and the concentration of sulfuric irradiation products on the trailing hemisphere maximally irradiated by magnetospheric plasma ions and energetic electrons. Chemical evidence for Europa's ocean layer is not yet definitive due to concentration of sulfates, potentially from oceanic salts, on the heavily irradiated trailing hemisphere, but this uncertainty could be removed by global trace abundance mapping of potential oceanic species at the surface, and within the overlying exosphere, by the Jupiter Europa Orbiter component of EJSM. Although the deeper oceanic layer of Ganymede is presumably less accessible for emergence of major or trace species to the sensible surface, this largest moon of the solar system does offer the advantage for chemical origin investigations of relatively lower magnetospheric irradiation at its jovicentric orbit and maximal magnetic shielding in the equatorial zone. Paucity of exospheric oxygen in this protected zone is known from ultraviolet airglow measurements and would enable higher sensitivity to trace gases from surface materials. Exospheric H_2O is expected from thermal sublimation of ices near Ganymede's subsolar point but elsewhere could indicate ongoing activity of Enceladus-like cryovolcanism and fresh samples of associated trace abundances from the interior. Finally, the equatorial surface of Ganymede may be littered with relatively pristine crustal materials from the other moons via ejection by cometary impacts. Any organic materials of oceanic origin at Europa would be better preserved in bulk ejecta ices deposited in this accessible surface region at Ganymede.

Planetary Radio Interferometry and Doppler Experiment (PRIDE) for the Europa Jupiter System Mission

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The Planetary Radio Interferometry and Doppler Experiment (PRIDE) is a multi-disciplinary enhancement of the science return of the Europa Jupiter System Mission (EJSM). The essence of PRIDE is the estimation of the state-vector of a spacecraft using Very Long Baseline Interferometry (VLBI) tracking and multi-station Doppler measurements by a network of Earth-based radio telescopes. The technique proved to be very efficient in the VLBI experiment with the Titan Huygens probe [1]. Several scientific topics will be addressed by the PRIDE EJSM measurements. These include creation of an ultra-precise celestial mechanics model of the Jovian system, studies of the internal structure and composition of Ganymede and Europa, as well as the shape and parameters of the gravitational field of Callisto. In a broader perspective, PRIDE will provide data on the electrical properties of icy satellite surfaces and their plasma environments. It will also contribute to the studies of fundamental physics effects, such as the anomalous accelerations of deep space probes [2].

The experiment offers a high degree of synergy with the EJSM on-board instrumentation and does not include components requiring mission-critical technology developments. The Earth-based segment of PRIDE includes a network of radio telescopes and a specialised data processing centre. These components of PRIDE constitute a backbone of the European and global VLBI networks. Their current state is consistent with the PRIDE requirements. The work in progress at JIVE and the European VLBI Network (EVN) will extend the broad-band capability the EVN and data processing facility. This will further advance PRIDE by enabling high-accuracy VLBI observations with weaker celestial background reference radio sources.

In addition to the science topics, PRIDE EJSM will provide support to mission operations, in particular, mission navigation and trajectory determination, as well as diagnostics of the on-board systems. A separate and potentially beneficial application of PRIDE EJSM is its ability to provide limited Direct-to-Earth delivery of data from EJSM spacecraft [3].

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ADVANCED RADIO SCIENCE INSTRUMENTATION FOR PLANETARY INTERIOR, ATMOSPHERIC, AND SURFACE STUDIES

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Abstract

Investigations of planetary gravitational fields for interior structure modeling, radio occultations for atmospheric profiling, as well signal scattering for surface properties have been conducted via Radio Science techniques on many planetary bodies. Advances in flight instrumentation technology have led to reduction in mass and power for spacecraft payload components and improvement in investigation accuracy from end-to-end flight and ground calibration techniques. This paper describes two new classes of Radio Science instruments, one for gravitation and one for propagation, that can provide improved measurement accuracy at lower mass and power along with processing methods developed to improve science data quality, including the simultaneous utilization of multiple links. The gravitation instrument is centered on a transponder operating at Ka-band frequency (32-34 GHz) for precision Doppler (to ~3 micron/s two-way, over 1000 s integration times, after all calibrations) and improved ranging data; parallel architectural concepts in the US and Europe will be discussed. The propagation and scattering instrument utilizes spacecraft-to-spacecraft links between the NASA and ESA assets as well as uplink signals from the ground. It is based on a new digital open-loop receiver that already has flight heritage and demonstrated with two Mars orbiter and has since been optimized in the digital design for science observations. This paper will also discuss the potential achievable scientific investigations with the proposed instrument configurations.

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Synergistic radio and plasma wave science for EJSM

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Abstract

The radio and plasma wave diagnostics provide a unique access to critical parameters of space plasma, in particular in planetary and satellite environments. Concerning giant planets, this has been demonstrated by major results obtained by the radio investigation on the Galileo and Cassini spacecraft, but also during the Ulysses, Voyager, and Pioneer flybys of Jupiter. Several other missions, past or in flight, demonstrate the uniqueness and relevance of radio and plasma wave diagnostics to basic problems of astrophysics.

The EJSM mission consists of two platforms operating in the Jupiter environment: the NASA-led Jupiter Europa Orbiter (JEO), and the ESA-led Jupiter Ganymede Orbiter (JGO). JEO and JGO will execute a choreographed exploration of the Jupiter System before settling into orbit around Europa and Ganymede, respectively. The EJSM mission architecture hence offers unique opportunities for synergistic and complementary observations that significantly enhance the overall science return of the mission.

In this paper, we will first review new and unique science aspects of the Jupiter system that may benefit from different capabilities of radio and plasma wave investigations onboard JGO and/or JEO: spectral and polarization information, mapping of radio sources, measurements of in situ plasma waves, currents, thermal noise, dust and nano-particle detection and characterization.

We will then illustrate unique synergistic and complementary science opportunities offered by radio and plasma wave investigations onboard JGO and/or JEO, both in terms of Satellite science and in terms of Magnetospheric Science.

SYNERGISTIC RADIO AND PLASMA WAVE MEASUREMENTS AT JUPITER

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Overview

Voyager, Ulysses, Galileo, and Cassini have all shown the value of radio and plasma wave measurements in studies of the Jupiter system. The aspects of the system which have been addressed by wave instruments extend well beyond strictly planetary radio astronomy and the study of plasma waves, which are worthy aspects of Jupiter system in their own right. However, aside from a few hours when Cassini skirted the outermost limit of the duskside magnetosphere, no comprehensive plasma wave measurements (with 3-axis magnetic and at least 2 axis electric fields) have been made in the Jovian system. Such measurements are necessary to understand the source and propagation of whistler-mode hiss and chorus (and other modes) which strongly interact with the magnetospheric plasma and likely lead to both particle acceleration and loss. The inclusion of well-conceived radio and plasma wave instrumentation in Europa and Jupiter System Mission payloads can greatly enrich the scientific return and provide synergy between the various components of the next mission to the Jovian system addressing a number of disciplines.

Thermal Plasmas

The accurate determination of thermal plasma densities has been a challenge for every charged particle instrument which has flown to Jupiter. In fact, most of these have managed to make reasonable measurements, due in large part to the availability of plasma wave measurements which provide accurate electron densities without the complicating factors of spacecraft charging, high radiation backgrounds, and limited fields of view. Each of the above-mentioned missions have included wave investigations that utilized resonances or cutoffs [1] at the electron plasma frequency or upper hybrid frequency, quasi-thermal noise spectroscopy [2], or Bernstein-mode spectroscopy to accurately determine the electron density, and in some cases, electron temperatures and bulk flow speeds.

Jovian Magnetospheric Dynamics

The Galileo mission, including the additional measurements provided by Cassini on its way to Saturn, demonstrated the important contribution of the entire gamut of Jovian radio emissions to monitoring the state of the magnetosphere. Jovian energetic events, which apparently play a major role in the loss of Iogenic mass down the magnetotail, are reflected in decametric and hectometric radiation from Jupiter's aruroral field lines, in narrowband radio emissions from the outer edge of the Io torus, and even continuum radiation trapped in the magnetosphere, particularly in the tail region [3]. The radio observations show the system-wide involvement of the magnetosphere in these events.

Additional Studies

The detection of whistlers was used (in conjunction with nightside time exposures) to identify the existence of atmospheric lightning at Jupiter, the first detection of extraterrestrial lightning. Also, a wave instrument is sensitive to the impact of micron sized dust particles which provides information on the flux and size distribution of dust in the Jovian system.

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COMPLEMENTARY AND SYNERGISTIC SCIENCE FROM THE JEO AND JGO SPACECRAFT

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Introduction

The presence of two spacecraft in the Jupiter system at the same time opens up many opportunities for rich complementary (measurements at either similar or different times with each contributing to the greater picture as a whole) and synergistic (measurements made near-simultaneously with the sum being greater than the parts) science. The details of this science will depend on the precise mission profiles and instrument complement of the respective spacecraft. A number of high priority complementary and synergistic investigations are discussed here.

Magnetospheric Studies

A major challenge in understanding the structure and dynamics of the Jovian magnetosphere is a general lack of simultaneous field and plasma measurements from multiple vantage points. With observations from a single spacecraft, it is not possible to distinguish between temporal and spatial gradients in the magnetosphere. The presence of two spacecraft will facilitate assessment of changes in the structure, shape and size of the magnetosphere that occur in response to the variable buffeting by the solar wind.

Jupiter Atmosphere

With differing instrument packages, the JEO and JGO spacecraft will obtain data that will increase knowledge of Jupiter's atmosphere. JEO will obtain medium-to-high resolution visible-wavelength imaging of the planet, which will allow definition of the zonal jets and eddies that appear to be pumping these jets at cloud level. JGO, in contrast, will emphasize the acquisition of thermal observations and possibly, with microwave sounding, could provide the first direct measure of the stratospheric jet pattern. This direct characterization of the stratospheric temperature and wind pattern with JGO will complement the cloud-level tropospheric information obtained from JEO.

Satellite Atmospheres

Observations of satellite atmospheres are enabled through the simultaneous operation of remote sensing instruments on both JEO and JGO. Specific experiments such as dual-spacecraft radio occultations will provide insight into satellite ionospheres, infer atmospheric conditions and allow assessment of plasma interactions at a wide range of local times.

Geophysics

There are several geophysical investigations that are enhanced by the presence of multiple spacecraft. Specifically, the potential to address interior properties and dynamics of the satellites is a high priority. These investigations will be particularly valuable for Ganymede and Callisto, for which there will be multiple flybys from both JEO and JGO. The determination of gravity fields by Doppler tracking is enhanced as multiple spacecraft allow globally distributed closest approach positions over each satellite and provide a range of flyby geometries.

Synergistic Science Traceability Matrix

No abstract required.

Submillimeter Wave Instrument for EJSM

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Abstract

The Submillimeter Wave Instrument (SWI) is part of the model payload on the Jupiter Ganymede Orbiter (JGO). JGO is ESA's contribution to the Europa Jupiter System Mission (EJSM). SWI's primary scientific objective is to investigate the middle atmosphere of Jupiter. SWI will contribute to the understanding of the circulation regime in the atmosphere as a function of latitude and altitude, how the various atmospheric regions are dynamically coupled, and how the energy originating in Jupiter's interior vertically propagates to the upper layers to be radiated in space. In this sense SWI complements the Juno mission. Secondary objectives of SWI are related to the study of Galilean satellites. Io's volcanic atmosphere will be studied through lines of SO_2, SO, NaCl, and perhaps other species. Water vapor will be observed in Europa's atmosphere. Thermophysical properties of the Galilean satellite surfaces will be measured by radiometric observation of the surface.

In the baseline configuration SWI will operate in two submillimeter wave bands around 600 GHz and 1200 GHz. Both receivers will be tunable within a bandwidth of approximately 20 % around the centre frequency. The antenna has a diameter of 30 cm and will be movable in at least one dimension. Two wideband high resolution spectrometers are foreseen. The observations geometry includes limb and nadir sounding. We have proposed to ESA to carry out a study, called "Submillimeter Wave Instrument for EJSM" that will meet the requirements of the instrument proposed in the JGO payload definition document. This study intends to find the optimal concept in terms of functional performance and requirements on JGO spacecraft resources, but will also investigate how the science and instrument design can be optimized for the Jupiter Europa Orbiter (JEO).

ORbiter Terahertz Infrared Sensor - ORTIS

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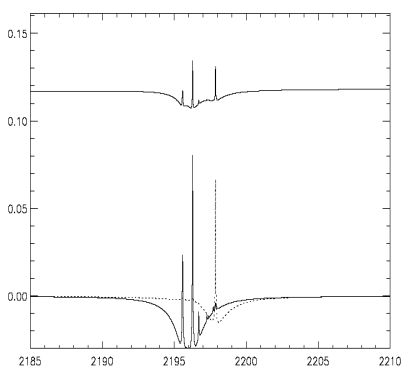
Abstract
The sub-millimetre wave spectra of the outer planets are rich in absorption line features that can be measured with extremely high spectral resolution (~10^6) with sub-millimetre wave heterodyne technology to determine temperature, winds and composition in the stratosphere. To measure stratospheric temperature requires the observation of the absorption of a well-mixed gas such as methane and while there is a methane absorption feature near 1.2 THz that is measurable with current solid-state receiver technology, this feature is relatively weak. Methane absorption lines become stronger at increasing frequency and the feature at 2.2 THz is particularly attractive as there is a strong water line lying ~2GHz from the line centre that could be measured simultaneously with the methane absorption line. This can be seen in the accompanying figure, which shows a close-up of methane absorption feature in Jupiter spectrum near 2.2 THz (top plot). The vertical scale is radiance (W m^{-2} sr^{-1} $(GHz)^{-1}$). The plots at the bottom show the sensitivity to changes in abundance of methane (solid line) and water vapour (dotted line). The close proximity between the CH_4 and H_2O lines is clear.



The technology for sub-millimetre wave spectroscopy at this frequency has advanced very considerably in recent years and we believe that observation of this feature will be technically feasible from a highly efficient and integrated payload. The advantages of this observation scenario over lower frequency measurements are numerous and include: 1) the methane absorption line is stronger, allowing sounding to higher altitudes; 2) the field-of-view is smaller for the same antenna size allowing the instrument to observe smaller features and also making limb-sounding easier; 3) it is easier to determine the Doppler shifting of lines due to winds at these higher frequencies; and 4) the instrument payload is more compact.

A sub-millimetre wave device would provide valuable information Jupiter's stratosphere, but the radiance away from the line centres is governed by the temperature in the upper troposphere and also by the abundance of ammonia, which is very variable. We propose to combine the sub-millimetre wavelength device with an infrared spectrometer or radiometer, bore-sighted with the sub-millimetre wave spectrometer covering the wavelength range 200 – 1400 cm^{-1}. The infrared spectrometer would be able to measure the upper tropospheric temperature profile in the H_2-H_2, H_2-He collision induced continuum (200 – 650 cm^{-1}), which is not affected by ammonia. Such an addition would very simply extend the vertical coverage of temperature of the combined instrument from the tropopause right down to the cloud tops and would also return the para-H_2 fraction, which is an indicator of vertical motion. This addition would also mean that the sub-millimetre wave continuum measurements could then be used to determine the variable abundance of ammonia and allow the combined device to probe temperature, dynamics and abundances in the upper troposphere as well as in the stratosphere. At higher frequencies, the emission features of several hydrocarbons in Jupiter's atmosphere can be sounded and ORTIS' combination of terahertz and infrared spectrometers would also allow the instrument to address the satellite surface science goals of EJSM and measure the surface properties of the Ganymede and other Galilean satellites.

ULTRAVIOLET SPECTRAL MAPPING INSTRUMENT

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Abstract
The Ultraviolet Spectral Mapping Instrument (USMI) is a multi-spectral imaging instrument for the spectral range 200-400 nm. Its primary scientific aim is the first global mapping of Ganymede and a large part of Callisto in several UV bands with a spatial resolution of 200 m at 200 km altitude. It shall perform observations in parallel to the medium-resolution visual/NIR (350-1000 nm) multi-spectral imaging camera that is one of ESA's Jupiter Ganymede Orbiter (JGO) model payload instruments. UV and visual spectrometry are complementary tools to characterise the mineralogy of non-ice components of Jupiter's moons and to interpret geologic and morphologic surface observations. An instrument study proposal for USMI was submitted to ESA in response to the Call for Declarations of Interest in Science Instrumentation for EJSM. The proposal is based on a Phase-A-Study for USMI that was performed in 2008 in the context of the planned German Lunar Exploration Orbiter. In our poster we present the science case for high-spatial resolution UV spectral mapping and a description of the instrument.

ULTRAVIOLET SPECTROGRAPH CONCEPTS FOR THE JUPITER SYSTEM ORBITER MISSIONS

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Abstract
SwRI's Alice line of ultraviolet spectrographs (UVS) is founded on a lightweight, low power, and highly capable and versatile instrument design. With generally small changes in detector photocathode, detector pixel size, slit size and shape, optical coatings, pinhole aperture implementations, and other minor tweaks we've found a wide variety of applications for the Alice design, to date, at comets (Rosetta/Alice), Pluto (New Horizons/Alice), Luna (LRO/LAMP), and Jupiter (Juno/UVS). The SwRI UVS heritage includes very broad experience and strong performance to date on the Rosetta (Phase E; successful Mars and Earth flybys), New Horizons (Phase E; successful Jupiter flyby), LRO (Phase D; launch planned 17 June 2009), and Juno (Phase C) missions. Alice's high capability, low resource requirements, and our experience with Juno-based radiation environment and NH-based outer solar system environment requirements make this UVS a good choice for both the Jupiter Europa Orbiter and Jupiter Ganymede Orbiter missions. We present several observations obtained with these instruments and other example UV observations of the Jovian system to discuss the objectives for UV instruments on the Jupiter system orbiter missions.

Response to Request for Information
"Design of IR Detector Integrated with SiGe RHBD ROIC for the Europa Environment"

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EXECUTIVE SUMMARY

The Boeing Company, working with B&W Tek, Inc., and Georgia Institute of Technology is developing a new type of near-infrared detector and integrated readout circuit for a near-infrared imaging spectrometer suitable for the Europa Jupiter System Mission (EJSM). This RFI response describes the features of this new detector and memory readout circuit technology and its suitability and benefits for EJSM. Our design objectives include:

a. Development of an indium gallium arsenide (InGaAs) photon-multiplying integrated circuit (PMIC) detector pixel array, with micron-sized pixels, with gain greater than 1000, over the near infrared (NIR) spectral range, and with and a signal-to-noise ratio (SNR) ~100 times higher than available InGaAs avalanche photo-diode (APD) detectors.

b. Development of a front-end stage memory readout integrated circuit (ROIC), comprising a silicon germanium (SiGe) radiation-hard-by-design (RHBD) trans-impedance amplifier, column/row selector, and threshold comparator, for operation in cryogenic environments without "warm boxes" and with minimal shielding.

c. Development of interconnect packaging, electronic interface, and integrated operation of the PMIC detector array together with the front-end ROIC.

d. Experimental evaluation of the performance of the integrated PMIC plus front-end ROIC, tested in vacuum in helium cryostat and radiation beam.

e. Analytical design of enhancements required to operate in the Europa environment, including design at the circuit level and at the subsystem level, supported by modeling of local shields, and of technology computer-aided design (TCAD) simulation of the electron charge-cloud.

Developing a detector and ROIC to operate in the intense radiation of Europa orbit is extremely challenging. Our development approach combines three advanced technologies, each separately having a technology readiness level (TRL) of ~4 in the Europa environment. Our team has unique and directly relevant experience in these three technologies, as discussed below.

Higher Detector Sensitivity. The PMIC nanotechnology is a unique construction of photodetectors, using novel built-in nano-passivation and amplification layers to achieve very high sensitivity, low noise, and high signal-to noise ratio (SNR). The amplification layer delivers high signal gain (>1000X at zero avalanche noise and minimal 1/f flicker noise), achieving >1000X SNR. The passivation layer maintains the high SNR even in small pixel geometries, thus enabling large-scale integration of many pixels into a high-resolution detector array. Recent laboratory tests at Boeing have demonstrated PMIC pixels with electrical gain of >1000, with SNR approximately 100 times higher than available avalanche photo-diode (APD) detectors. Both the amplification and the small pixel size enabled by nano-passivation are evolved from the most radiation-hard cryogenic-compatible semiconductor technologies. Hence, the PMIC is radiation-hard and cryogenic-operable by design.

The work leverages the IR detector design experience of B&W Tek from its US Army Phase II Small Business Innovation Research (SBIR) for development of an IR detector for a Laser Induced Breakdown Spectrometer (LIBS), Topic A06-065.

Operation at Cryogenic Temperatures. For the ROIC, SiGe bipolar complementary metal oxide semiconductors (BiCMOS) offer unparalleled performance at cryogenic temperatures, wide temperature capability, and tolerance to space radiation. RHBD can further enhance the radiation tolerance of the SiGe ROIC circuits.

In a SiGe ROIC, degenerate doping above the Mott transition prevents electron freeze-out at cryogenic temperature. Indeed, SiGe devices have been demonstrated to operate at 10 Kelvin. We leverage the NASA Radiation-Hardened Electronics for Space Environments (RHESE) program's development of SiGe electronics project and apply those design principles in this project.

RHBD at the Device Level. We also leverage the RHBD experience at Boeing. These radiation-hard design techniques involve employing unique geometries of the device and isolation trenches in the device to contain charge-bursts created by radiation. Clearly, Europa represents "worst case" conditions of harsh radiation. Resiliency to the Europa environment can only be achieved by a combination of mitigating factors: (1) utilize the intrinsic radiation-hard properties of the SiGe heterojunction bipolar transistors (HBT) for the ROIC, (2) reduce radiation effects at the device level using RHBD techniques, (3) apply local (spot) shielding, (4) use geometry of packaging that minimizes direct "straight-line" impact into the sensitive areas of the PMIC and ROIC, (5) build-in redundancy features in the detector and the ROIC design, and (6) ensure recognition of the time-signature characteristic to a charge-cloud formed by an impacting particle and eliminate it by data processing software.

This work leverages the capabilities and facilities of the Boeing Solid-State Electronics Development (SSED) organization in Seattle, Washington, which has for many years been developing RHBD characterization, design, and library development work, including activities for DARPA, DTRA, SPAWAR, and radiation-hardened process foundries.

This Boeing team has the capability and experience to design, fabricate, and test a flight-ready near-IR detector for an imaging IR spectrometer for the Europa Jupiter System Mission.

Response to Request for Information
"Design of Dual Langmuir Probe for the Europa Environment"

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EXECUTIVE SUMMARY

The Boeing Company is pleased to submit this request for information (RFI) response to address the capability of Boeing and our team members to provide design, fabrication and test of radiation-hardened cryogenic electronics for science instruments, suitable to be deployed on the Europa Jupiter Systems Mission (EJSM). In this response, we describe our capability to provide the radiation-hardened and cryogenic-capable front-end electronics for a "Versatile Langmuir Probe" (VLP) for measuring plasma density and electron temperature. Boeing is teamed with Utah State University and Georgia Institute of Technology in the development of the Versatile Langmuir Probe.

A Langmuir Probe (LP), in theory, is one of the simplest types of instrumentation for measuring plasma density and electron temperature. The Langmuir Probe has proven to be a valuable instrument for capturing scientific data on charged particles in tenuous atmospheres, as demonstrated by the successful (though limited) readings collected by the Cassini mission in the exosphere of Titan. Understanding particles and fields at Europa, including surface and atmospheric interactions, is critical to developing a comprehensive picture of the moon's surface chemistry and habitability.

Our Versatile Langmuir Probe design leverages the LP instrument developed by Utah State University (USU) that is currently being flown on the International Space Station (ISS) as part of the Floating Potential Measurement Unit (FPMU) (see Figure 1). Our new VLP instrument design entails two or more sensors, with each sensor mounted on a different rigid boom. The two sensors can operate independently as two single LPs or they can operate together as a single instrument in the double-LP mode. The double LP mode can provide science return that has not been achieved by Langmuir Probes in previous outer planet missions.

The VLP instrument has two collecting surfaces mounted at the end of two long booms. To save weight, the flight boom design will be lightweight, likely in the form of a long wire boom. This long boom enables low-level electric field measurements and can be operated in single and double Langmuir probe modes. In the single LP mode, instrument voltage sweep patterns and sampling frequencies are configured to target plasma density and electron temperature measurements. In the double LP mode, the instrument is configured to target plasma wave velocity and dc and low-frequency electric fields measurements.

The essential components of the front-end electronics for this Versatile LP are high-impedance low-noise operation amplifiers (HILNOA), an analog-to-digital converter (ADC), and a gallium nitride (GaN) high-voltage sweep circuit. To improve the signal-to-noise ratio and eliminate potential interference issues, it is desirable to mount the front-end electronics near the LP probe tips, exposing the electronics to the extreme environments of the Jovian system. The front-end electronics may be located inside a housing "puck" mounted near the sensor at the end of a relatively long boom. For Europa, the critical design drivers are the intense radiation environment of Europa and exposure to cold temperatures on the boom.

In existing Langmuir Probe instruments (e.g., on the International Space Station), the HILNOA and ADC are fabricated using bipolar complementary metal oxide semiconductor (BiCMOS) technology. These parts are susceptible to radiation and have total ionization dose (TID) capability in the range of tens of krad to hundreds of krad. These parts will not function in the Europa radiation environment without heavy shielding, which increases the size and mass of the front-end electronics and thus does not facilitate mounting the electronics at the end of long thin wire booms. Additionally, for operation on the boom, these traditional parts need an external heater or radioactive heater source (RHU), both of which are a significant drain on the very limited spacecraft resources. Devices fabricated using silicon-germanium (SiGe) technology are capable of operating in cryogenic temperatures, with a TID capability in excess of 5 Mrad, and tolerance to single event upsets (SEU).

Our SiGe design capability leverages the NASA Exploration Technology Development Program (ETDP) project, entitled "Silicon-Germanium Integrated Electronics for Extreme Environments." This project has demonstrated that commercially available SiGe BiCMOS technology can be successfully used to support the various extreme environment electronics needs for the planned NASA lunar and planetary missions, to technology readiness level (TRL) 6/7. This SiGe technology project, managed by NASA MSFC and led by Professor John Cressler from Georgia Tech, includes participants from academia, industry (including Boeing), and NASA.

The SiGe radiation-tolerant technology enables the front-end electronics of the VLP to operate in Europa orbit with minimal spot-shielding and without the use of survival heaters. We are planning to fabricate the HILNOA and ADC front-end LP electronics using SiGe technology, and to demonstrate that the SiGe front-end electronics can provide the necessary resolutions in plasma parameters and electric fields measurements. Our team has the capability and design experience to develop and qualify a space-flight VLP instrument for the Europa Jupiter System Mission (EJSM).

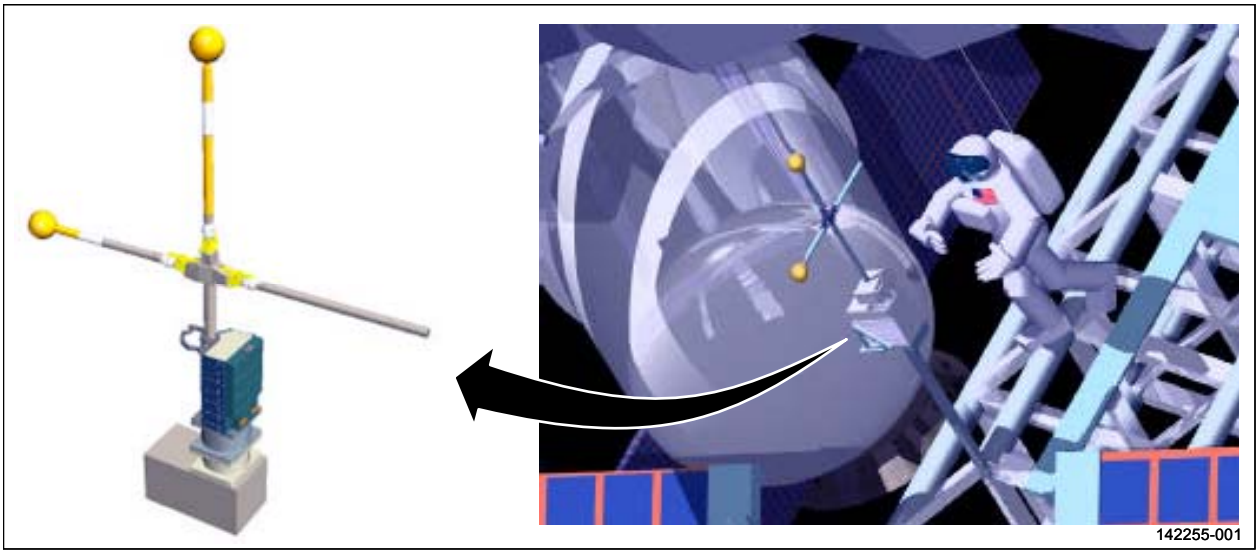

Figure 1. The Boeing Team Versatile Langmuir Probe (VLP) Design Leverages the Utah State University Floating Potential Measurement Unit Currently Flying on the ISS

The Visible and InfraRed Hyperspectral Imaging Spectrometer (VIRHIS): a study for EJSM

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Abstract

The VIS-IR imaging spectrometer for the EJSM mission, named VIRHIS (*Visible and InfraRed Hyperspectral Imaging Spectrometer*) on the Jupiter Ganymede Orbiter, is perfectly suitable to obtain a comprehensive picture of the Jupiter system by combining information of the surfaces of the Galilean satellites, the Jupiter's atmosphere, and the possibly other targets. The level of details and the extended mapping capabilities of this instrument will unveil crucial aspects of the Jovian system, including the investigation of the nature, location and abundance of chemical compounds (especially organic and non-ice constituents) on the surfaces of the Galilean satellites, the characterization of longitudinal variations like leading/trailing asymmetries and the possible association with geologic features, the characterization of the satellites' exospheres, the monitoring of peculiar aspects (Io and Europa torii, Io's volcanic activity), the study of Jupiter's atmosphere at different levels (including aurorae and magnetic footprints) and the spectral characterization of the whole Jupiter system (including the ring system, the small inner moons, and other targets of opportunity like irregular satellites).

The VIRHIS instrument baseline for JGO (Jupiter Ganymede Orbiter) is an advanced imaging spectrometer that in one compact instrument combines two spectral channels operating in the 0.4-2.2 µm and 2.0-5.2 µm ranges. It can operate both in pushbroom and in scanning mode, according to the different operational phases and scenario of the mission. The instrument can collect simultaneously 480 spectra taken across the spectrometer's slit, corresponding to a 3.44° × 125 µrad FOV and allowing image reconstruction during time. To meet the scientific requirements a spectral sampling of 2.8-5.0 nm/band is assumed, respectively, for the 0.4-2.2 and 2.0-5.2 µm ranges. Two HgCdTe sensors arrays are foreseen as focal planes for the VIS-NIR and IR spectral channels. The instrument will be designed to survive in the harsh radiation environment as well as to be compliant with the decontamination procedures imposed by the planetary protection rules. A delta study will be executed in order to make the VIRHIS concept applicable to the JEO (Jupiter Europa Orbiter) mission requirements.

The consortium proposing the VIRHIS study has a relevant heritage in VIS-NIR imaging spectrometers guaranteed over decades on full payloads or subsystems and technical aspects including optical design, scan mirror, focal plane arrays, signal digitalization, data compression, thermo-mechanical design, internal calibration units and Jovian radiation shielding (Cassini/VIMS, Rosetta/VIRTIS, Venus-Express/VIRTIS, Dawn/VIR-MS, Mars-Express/OMEGA, BepiColombo/SIMBIO-SYS, Juno/JIRAM).

In this paper we present the study proposal that will define with a sufficient detail the characteristics, interfaces, resources and expected performances of the instrument.

Infrared Imaging Spectrometers for the JEO Thermal Instrument and the JGO Thermal IR Mapper

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Preliminary calibration and science results are presented for a pushbroom thermal infrared spectrometer based on an ultra compact concentric design. The results show how the instrument can provide very promising noise equivalent delta temperature measurements (approaching 150mK per channel) and alignment results with minimal spatial-spectral crosstalk. Atmospheric and mineralogical science results based on solar illuminated earth science data are presented. Reflected down welling radiance is acquired while observing a gold standard in direct sunlight. Earth atmospheric water bands are easily resolved as shown in figure 1 (L.). This field testing was performed which acquired plots of apparent emissivity for various known standard minerals (such as quartz) as shown in figure 1 (R.). A comparison is made using data from the ASTER spectral library. The small form factor of the design (optics mass < 0.5kg) allows minimal cooling to achieve the required background levels while the high throughput (F/1.6) maximizes the system efficiency. Quantum well infrared photo detectors developed at JPL are utilized at the focal plane for spatial and spectral detection due to their excellent response uniformity and high yield. HyTES will be the state of the art thermal pushbroom sensor having a spatial swath of 512 spatial cross track samples at approximately 35-60m resolution at varying altitudes and spectral resolution of 256 channels between 7.5µm-12µm. This type of sensor is ideally suited for the pushbroom thermal imager planned to be aboard JGO.

The results are in support of the Hyperspectral thermal emission spectrometer (HyTES) which is an airborne sensor being developed under NASA's Instrument Incubator Program (IIP). It'll support the thermal Hyperspectral Infrared Instrument (HyspIRI) mission. The HyspIRI mission will be a space based earth scanning platform having multiple thermal channels. It multi-channel design characteristics will be well suited for the thermal mapper aboard JEO.

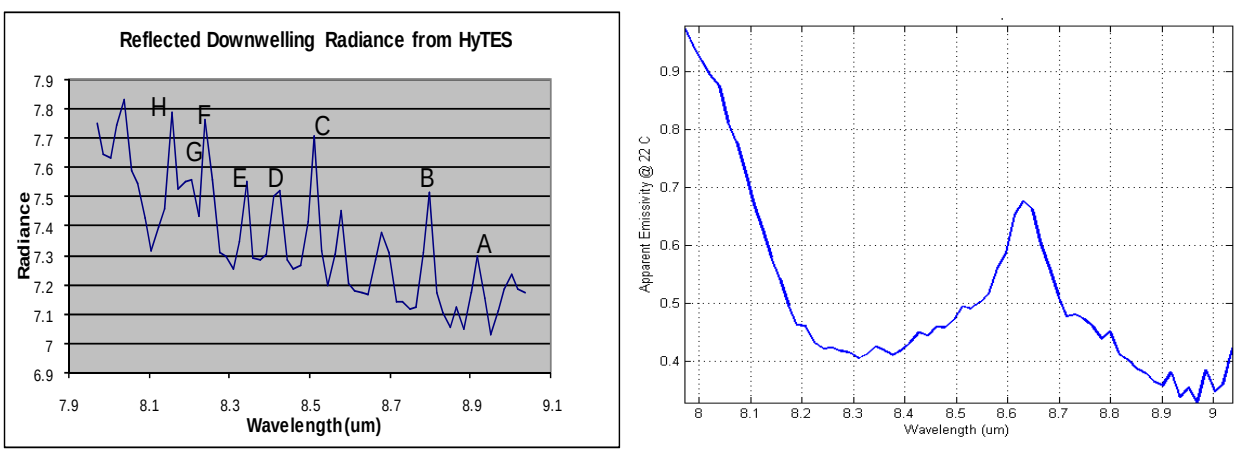

Figure 1. Spectral calibration of gold standard with superimposed atmospheric bands as measured in direct sunlight (L.) Apparent emissivity of quartz as measured by HyTES in direct sunlight (R.).

A Far-UV Imager for the Jupiter Ganymede Orbiter

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The rapidly rotating magnetosphere of Jupiter forms an extensive laboratory in which to study fundamental astrophysical processes which involve planetary magnetism and the plasma state, which comprises the overwhelming majority of matter in the Universe. By taking a global view of the gas giant coupled solar wind-magnetosphere-ionosphere system we will improve, for example, our understanding of extrasolar space environments which will never be studied in situ. A system-level approach to studying the magnetospheres of solar system bodies is the first step to a true understanding of these complex systems. The principal interaction between a planet and its plasma environment is mediated by the magnetic field, through the formation of large-scale current systems. Investigations of the planetary magnetic field and plasma configuration from a spacecraft in-situ can thus provide significant information about both local dynamics and the instantaneous physical state of the global system. The far ultraviolet (FUV) auroral emissions from planetary upper atmospheres are largely produced by precipitation of magnetospheric charged particles that are heated in the magnetosphere and/or accelerated in large and small scale field-aligned current systems. Importantly therefore, the observed auroral zone presents a 2D view onto which 3D magnetospheric dynamics are continuously magnetically mapped, and as such the aurora provides a measure of the state of activity of the entire system. It follows that high spatially and temporally resolved imaging will yield remote-sensing information on the real-time dynamics that are magnetically connected to a wide volume of the magnetosphere and tail, and which cannot be constantly monitored in situ via orbiting spacecraft. In a similar way, high spatial resolution observations of the Galilean satellites over a variety of FUV wavebands will provide important information about these moons, their exospheres and surfaces, and their interaction with the ambient planetary magnetosphere in which they are embedded. In addition, global coverage of the time-dependent variations of Ganymede's auroral emissions will be possible as well as simultaneous observations of moon-based aurora and their magnetically mapped counterparts in Jupiter’s ionosphere.

The Jupiter Ultraviolet Dynamic Explorer (JUDE) aims to resolve spatial scales as small as 100 km at a distance of 12 Jupiter radii. Two alternative design approaches for the instrument are currently under consideration, based on novel micropore optics (MPO), and conventional reflective UV optics. The heritage for the MPO version of the instrument comes from the BepiColombo Mercury Imaging Spectrometer (MIXS) and from a wide field UV imager currently under development for the KuaFu space weather mission, while the reflective UV optic approach has its roots in several instruments already flown in Earth orbit, onboard the Cassini mission, and currently under development for JUNO. The instrument incorporates a photon-counting UV (900-1700 Å) microchannel plate detector with novel readout system providing high spatial resolution and high count rate capability in a radiation tolerant device.

Fourier Transform Spectroscopy on the EJSM

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Abstract
Passive spectroscopic remote sensing of planetary atmospheres and surfaces in the thermal infrared is a powerful tool for obtaining information about surface and atmospheric temperatures, composition, and dynamics (via the thermal wind equation). Due to its broad spectral coverage, the Fourier transform spectrometer (FTS) is particularly suited to the exploration and discovery of molecular species. NASA's Goddard Space Flight Center (GSFC) developed the CIRS (Composite Infrared Spectrometer) FTS for the NASA/ESA Cassini mission to the Saturnian system. CIRS observes Saturn, Titan, icy moons such as Enceladus, and the rings in thermal self-emission over the spectral range of 7 to 1000 μm. CIRS has given us important new insights into stratospheric composition and jets on Jupiter and Saturn, the cryo-geyser and thermal stripes on Enceladus, and the winter polar vortex on Titan.

CIRS has a mass of 43 kg, contrasted with the earlier GSFC FTS IRIS (14 kg). For EJSM, which has 5 kg designated for a thermal imager on the strawman payload (both JEO and JGO), we must return to an IRIS-like architecture:

- non-cryogenic detectors (CIRS thermo-electric detectors)
- long wavelength limit of 300 μm
- single FTS architecture
- conventional amplitude-division beam-splitter (CVD diamond).

We call this circa 5 kg instrument IRIS-lite.

IRIS-lite has a primary scientific goal, Europa, and a secondary scientific goal, Jupiter.
Primary goal: characterize the temperature and heat flow on the Europa surface, producing surface temperature maps as CIRS does for Enceladus. Coarse spectral resolution is sufficient.
Secondary goal 1: characterize abundances of minor species (water, ammonia, etc.) in the Jupiter atmosphere to understand planetary evolution;
Secondary goal 2: investigate the east-west jet streams and evaluate the likelihood of various models for their formation mechanism, aided by remote sensing over extended time periods and with spectroscopic resolution sufficient to characterize temperature and composition; relate small-scale convection patterns to large-scale storm dynamics.

A LASER ALTIMETER STUDY FOR THE EUROPA-JUPITER SYSTEM MISSION (EJSM)

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Abstract

The proposed instrument is a laser altimeter with time-of-flight measurement and pulse-waveform analysis capability. The former measures the range from the spacecraft to the satellite's surface; the latter allows for the determination of surface characteristics.

The vertical measurement accuracy of the instrument is less than 1m which will allow for determination of the dynamical tidal deformation of Europa or Ganymede as they revolve about Jupiter. Global, regional and local topography will be measured at very high precision. At Europa, ranging will be possible at altitudes of about < 400 km and at Ganymede and Callisto at a distance of about < 300 km (the smaller value compared to Europa is due to the lower albedo of Ganymede and Callisto). These specifications are optimized for the orbits about Europa (JEO) and Ganymede (JGO), respectively, while still allowing for measurements at close flybys of the satellites. The proposed active q-switched Nd:YAG laser will have adjustable pulse repetition rates and output energies in order to work power-efficiently, but with high quality data generation even in different operation scenarios. The instrument will be designed with cold-redundant subsystems where applicable (data processing, rangefinder, power converter, laser electronic, laser optics) because of reliability reasons.

We will also focus on the assessment of alternative technical approaches that would reduce the mass, size and power requirements of the instrument. In particular a single photon counting device will be studied. Here, especially the robustness against false detections due to the harsh radiation environment in the Jupiter system will be crucial.

As another way to reduce resources, sharing of devices with other instruments will be subject of upcoming studies. This will include e.g., possible sharing of the receiver telescope with the camera, and sharing of the receiver electronics with a range detector for Laser pulses from Earth if such a detector should be included on-board the Europa (JEO) and/or Ganymede (JGO) orbiter, respectively.

The Laser Altimeter is one of the key instruments to achieve the science goals defined by the EJSM Joint Science Definition Team (JSDT) and is part of the Jupiter Europa Orbiter (JEO) planning payload defined by the JSDT [ref.1].

In the poster presentation we will give an overview on the technical concept of the instrument. Additionally, we will summarize the studies to be carried out within the next months that will include adaptation of the instrument components to the Jovian radiation environment as well as taking into account the requirements for planetary protection.

References

[1] JEO Report (Public Release): available at http://opfm.jpl.nasa.gov

EJSM-JGO THERMAL MAPPER

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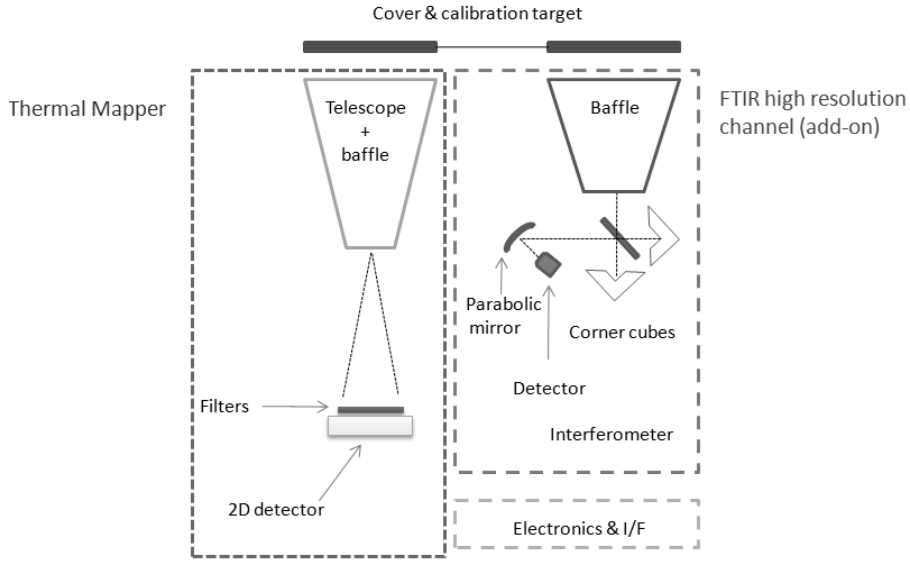
Abstract
The study team intends to propose an instrument for the Jupiter-Ganimede orbiter mission, called Thermal Mapper, able to study the atmosphere of Jupiter, the thermo-physical properties of Ganimede and Callisto, providing also clues on their mineralogy, and to monitor the heat flux variations of Io and Europa. The study is based on heritance from previous developed space instruments having similar or complementary technical characteristics (Mars Express/PFS, Exomars/MIMA, TIMM). The study team will investigate also the possibility to include, as add-on, a high resolution Fourier spectrometer in the 7-30 micron wavelength range which will improve the Thermal Mapper scientific return.
The study of the Jovian atmosphere is the main goal of the TM instrument. Four narrowband filters have been selected at specific wavenumbers to retrieve the vertical temperature profile of Jupiter's atmosphere between 400 and 3 hPa (mbar), from the upper troposphere up to the middle stratosphere. The spatial resolution on Jovian atmosphere will be around 500 km/px. The high resolution spectral channel we also propose, acquires complete spectra between 7 and 30 µm with a 5 cm^{-1} spectral resolution and at a field of view of 1°. It will allow to retrieve complete vertical temperature profiles and several molecular abundances at different latitudes. High spatial resolution thermal inertia maps (up to 100 m/px) of Ganimede and Callisto will be obtained by monitoring daytime and nighttime temperatures. This will allow the identification of young surfaces and the study of regolith property variations with latitude and longitude, as well as the identification of possibly nighttime thermal anomalies that can support the hypothesis of the presence of endogenic geological activity. In the figure below, the simplified instrument concept is shown



DESIGN CONSTRAINTS AFFECTING SURFACE ELEMENT MAGNETOMETERS FOR FUTURE JUPITER MISSIONS

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Abstract

The JEO and JGO missions pose considerable engineering challenges for payload developers. This is particularly true in the case of the proposed descent elements (penetrators and landers). In addition to contending with extremely low mass and power constraints as well as the expected intense radiation fluence, landers and penetrators must be equipped with instrumentation capable of successful operation at low temperature ranges (75K - 130K).

For the DC vector magnetic field measurement these present particular difficulties given that the traditional space magnetometer sensor of choice, namely a fluxgate is mass limited according to its noise performance (typical mass of the order 200g) and generally operates at working temperatures much higher than 70K employing a heater element where necessary. It is therefore worthwhile to ask at the mission concept stage if there are other technologies for DC field measurement that can mitigate either the low mass constraints or permit heater free operation while delivering science grade capability on the timescales of future Jupiter and Saturn missions.

We describe a novel design based on a magneto-resistive sensing element that may deliver heating free, very low mass magnetic sensors compatible with the descent science requirements on the required timescales.

DIGITAL, TUNED, FLUXGATE MAGNETOMETERS FOR THE JGO MISSION

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Abstract

The magnetic field is a fundamental physical parameter, vital for the study of processes in interplanetary space. It is a key measurement in the study of the Jovian satellites and their interaction with Jupiter's giant magnetosphere. A magnetometer can provide information on induced and internal magnetic signatures at planetary bodies thereby constraining models of their internal structure. It can also resolve the planetary rotation rate, characterise local plasma transport etc. Its accurate measurement is crucial in future-missions to the outer planets.

Being rugged, low in mass and power and offering high precision, the fluxgate sensor has emerged as an excellent magnetic field sensor for measuring fields from DC to a few tens of hertz on space missions. Here we describe a digital field extraction fluxgate magnetometer sensor system for the Jupiter Ganymede Orbiter. We propose some incremental technology developments that will optimise the sensor and its associated electronics (which has considerable space heritage) for the harsh radiation environment and tight resource constraints of the mission. Digital detection can have considerable size, weight and power advantages (key requirements for outer planet missions) over analogue equivalent fluxgate magnetometer designs[1]. The digital design also lends itself to implementation on either an FPGA or ASIC based platform, which leads to flexibility in choice of radiation hard components and in terms of connectivity to distributed spacecraft systems. We will look at options to reduce the mass of the sensor, whilst still maintaining high performance, and options for reducing the operating temperature – which has the benefit of reducing the required sensor heating power budget.

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HIGH FREQUENCY MAGNETIC FIELD MEASUREMENTS IN THE EJSM PROJECT

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Abstract

Plasma and electromagnetic waves are known to contain very rich and important informations about physical processes occurring in planetary magnetospheres.

- For instance, the interaction of the satellite Io with the magnetic field and the magnetospheric plasma environment of Jupiter results in Io modulated S-bursts. The problem of interaction of the Jovian magnetosphere with the moons has already been studied for many years using ground-based as well as satellite observations, but close approach and direct in-situ information about plasma environment combined with local radio observations can shed new light on it. To achieve this goal, the determination of the directivity of arrival of radio-waves in a wide frequency range (up to about 40 MHz) will be necessary.
- The study of the magnetodisc rotation naturally includes the question of how the structure of the magnetodisc influences the structuring of the plasma environment and the closure of the current system in the magnetosphere. The electric field configuration that is formed determines the particle dynamics and acceleration that in turn results in different processes of wave generation and emission of radio waves.
- Studies of radiation belt dynamics and different kinds of wave activity cannot be performed without wave studies. The different characteristics of particle acceleration in the Jovian radiation belts are observed with different spectral characteristics in the Jovian metric and decametric radio bursts, and the particle precipitations in auroral regions of the magnetosphere result in the generation of specific types of radio emissions.

All these questions make the measurement of radio-waves emissions one of the most important scientific objectives of the EJSM/Laplace mission and can provide valuable data for answering all four major questions of the mission.

We propose a new scientific instrument, composed of three components closed loop antennas, and designed to measure the vector magnetic field fluctuations in the frequency range from several kHz up to 40 MHz. The sensitivity of such an instrument is better than the level of the background galactic noise. This sensor allows determining in real time the direction of propagation of electromagnetic plane waves, if used as a three orthogonal components instrument or if completing two electric field components measurements by two magnetic field components measurements. The instrument can be used to obtain the spectra of magnetic field fluctuations in a wide frequency band, or to capture waveforms as short time domain time series.

Despite the fact that the magnetic field sensors are less sensitive than the electric field antennas, they are sufficient to achieve all the scientific objectives mentioned above and the instrument is incomparably more compact. The weight and consumption of a one component instrument that will be launched onboard the CHARM rocket in December 2009 are 300 g and 0.8 W. A detailed description of the technical characteristics of the instrument can be found in Cavoit (2006) [1].

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EJSM ElectroMagnetic Sensor Study

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Abstract

This proposed study is submitted in response to the call for declarations of interest in science instrumentation for the Europa Jupiter System Mission issued by ESA. It is directly related to the Radio and Plasma Wave Investigation (RPWI) on JGO.

The radio and plasma wave diagnostics provide a unique access to critical parameters of space plasma, in particular in planetary and satellite environments. Concerning giant planets, this has been demonstrated by major results obtained by the radio investigation on the Galileo and Cassini spacecraft, but also during the Ulysses and Voyager flybys of Jupiter. Several other missions, past or in flight, demonstrate the uniqueness and relevance of the radio and plasma wave diagnostics to basic problems of astrophysics.

A critical issue for both the science and the spacecraft systems is related to the sensors: probes, antenna, loops, booms can stick out several meters from the spacecraft body. This issue has a specific incidence on a 3-axis stabilized spacecraft as JGO. The EMC (ElectroMagnetic Cleanliness) is also an issue that has to be considered very early in the spacecraft development in order to minimize the impact on sub-systems and instrument developments. There is a lot of experience on both issues (sensors and EMC) for several programs that have flown or are still flying very successfully. This early phase of the mission development is exactly the right time to study and assess these from the scientific and technical point of view.

These two, related issues (EM Sensors and EMC) are the objective of the present proposed study. In order to benefit from the state-of-the-art in radio instrumentation for space plasmas, this study has been opened to most groups in this field in Europe, the USA, and Japan. Hence, this study can be relevant to other spacecraft of the EJSM, e.g. the JEO.

JUPITER MAGNETOSPHERE AND MOONS PLASMA (JuMMP) INVESTIGATION FOR EJSM

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Abstract
We will describe the Jupiter Magnetosphere and Moons Plasma investigation, JuMMP, a proposed plasma instrument suite for the EJSM JGO spacecraft. Development of JuMMP for JGO will be coordinated with that of an instrument package to be proposed in a somewhat modified format for the JEO spacecraft. The instrument targets a 4 pi field of view for the electron and negative ion (JENI) and ion mass spectrometer (JIMS) sensors. An energetic neutral atom sensor (LENA) and an Advanced Mass and Ionic Charge Composition Experiment (AMICCE) will also be described. The JENI and JIMS sensors each have strong individual outer planets heritage from Cassini CAPS (ELS and IMS) and use detailed design knowledge from the Juno (Jupiter polar orbiting mission) plasma electron and ion instrument (JADE). The LENA sensor has strong design heritage from similar instruments on BepiColombo. Plasma measurements in an adverse high penetrating radiation environment represent a significant challenge. However, our Juno experience enables us to define the required approach regarding the radiation environment with confidence, and minimum resource impact. We will describe the scientific drivers and some design issues for the proposed investigation.

Miniaturised plasma analysis techniques for the JuMMP investigation

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Abstract
The Jupiter Magnetosphere and Moons Plasma (JuMMP) investigation team has strong heritage with plasma instrumentation for outer planetary environments, e.g., Cassini CAPS, JUNO JADE as well as significant relevant experience with many previous magnetospheric missions. We are currently pursuing miniaturisation and instrument tradeoff studies for the JuMMP sensor suite. These include using micromachining techniques such as MEMS and novel alternative geometries. Besides potential mass and power savings, miniaturised instrumentation is a particular advantage for the harsh radiation environment of the EJSM environment enabling improved radiation mitigation strategies and enhanced data quality. Here we highlight relevant activities at MSSL (JGO PI) and SwRI (JEO PI) and discuss some of the potential advantages for the EJSM mission. A proof-of-concept device based on these techniques has been fabricated at MSSL. Preliminary results from the device will be presented and compared with results from electron optic simulations.

An Ion Neutral Mass Spectrometer for the Europa Orbiter

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The primary science objective for mass spectrometry at Europa is to determine the surface composition through the sampling of material sputtered by energetic heavy ions from the surface to the tenuous atmosphere. The Jupiter Europa Orbiter (JEO) orbits around Europa varying between 100 and 200 km in altitude above the surface. Thus the primary measurement consideration is sensitivity to both ions and neutrals. The desired sensitivity goal is to determine all species with a surface concentration of greater than 1 part per million at an orbital standoff distance of 100 km.

The importance of determining both the composition and origin of the volatile content and the refractory materials rising up from an interior ocean through cracks in the surface ice suggest that mass resolution and mass range are the next most important measurement considerations. The Flagship review board cited being able to distinguish CO from N_2 as a science objective of primary importance and also indicated that isotopic analysis of the water vapor was a high priority. This requires a mass resolution of over 2500.

In order to address these challenging measurement requirements we have chosen a multi-bounce time-of-flight mass spectrometer (MBTOF) with both a closed and open ion source. The poster will describe the prototype development and testing of this instrument in the laboratory in the context of The Great Escape Mars Scout mission proposal and the modifications that are needed to fly this instrument to Europa. Of particular interest are the modifications to meet the radiation requirements of the Europa mission while at the same time maintaining the resource envelope found in the JEO Flagship proposal. Various ways of measuring the isotopes of water are also discussed. Finally, we address the unique features required to make ion measurements in this tenuous ion pickup environment.

PLASMA AND ION NEUTRAL COMPOSITION MEASUREMENTS FOR EUROPA AND GANYMEDE

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Abstract
A 3D Ion Mass Spectrometer (IMS) has two main goals for the EJSM/Laplace Mission, 1) measure the plasma interaction between Europa and Jupiter's magnetosphere and 2) infer the 4π surface composition at the isotopic level [1]. The first supports the magnetometer (MAG) measurements whose primary goal is detection of Europa's sub-surface ocean, while the latter gives information about transfer of material between the Galilean moons and between surfaces and subsurface oceans. The measurement of the interaction also allows one to trace the *in situ* ion measurements of pickup ions back to either Europa's or Ganymede's surface depending upon which body the spacecraft is in orbit. The IMS instrument, being developed under the Astrobiology Instrument Development Program, would maximally achieve plasma measurement requirements for the EJSM mission while moving forward our knowledge of Jupiter system composition and source processes to far higher levels than previously envisaged.

The composition of the surfaces of Europa and Ganymede can be inferred in 4π from the measurement of ejected neutrals and pick-up ions using the minimum, category 1 level, *in situ* payload composed of the IMS and MAG. These measurements should be made from a polar orbiting spacecraft about Europa or Ganymede at height ~ 100 km. The ejecta produced by sputtering of the surfaces of Europa and Ganymede has been shown to be representative of the surface composition [2,3]. In addition to the minimum payload one requires at the category 2 level 1) 3D Ion Neutral Mass Spectrometer (INMS), 2) 3D plasma electron spectrometer (ELS), and 3) hot plasma energetic particle instrument.

The measurement approach is to alternate between times measuring pickup ions and times measuring plasma and magnetic field parameters along the spacecraft trajectory. By measuring the pickup ion energy, arrival direction and mass-per-charge, one can trace back in time its origin if the 3-D electric field and magnetic field are known. *In situ* observations of plasma flow velocities and vector magnetic fields can be used to determine the local convective electric field (**E = -VXB**) along the spacecraft trajectory. Then by combining this information with models of the magnetospheric interaction with Europa [3], one can generate 3D maps of the electric and magnetic field and compute the trajectories of the pickup ions back to their surface or exospheric source points. The INMS observations and neutral exosphere models are needed to estimate production rates of pickup ions. The hot plasma measurements are needed to correct for sputtering rates which can be time dependent and electron plasma observations for electron impact ionization rates. Instrument characteristics, field-of-view requirements, modes of operation and effects of radiation on instrument functionality will be discussed.

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A MASS SPECTROMETER FOR PLANETARY AND MAGNETOSPHERIC STUDIES IN THE EUROPA/JUPITER ENVIRONMENTS USING TIME OF FLIGHT WITH AND WITHOUT CARBON FOILS

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Abstract
A good and accurate mass resolution is crucial to perform detailed and reliable measurements of the multi-species plasma observed in the Jovian environment and in the vicinity of the Galilean moons. Despite the successful Pioneer, Voyager and Galileo missions, these difficult measurements have still yet to be refined. We present a prototype reflectron mass spectrometer that has been designed, tested and validated at CESR and its performances. This spectrometer allows reaching a mass resolution of 30 on the reflectron channel. However, the relatively low efficiency does not allow performing fast measurements such as those needed to detail the microphysical processes occurring in the Jovian magnetosphere and in the vicinity of Europa that will be addressed for the first time by the Jupiter Europa Orbiter (JEO).

To address this issue, our innovation consists in replacing the carbon foil by a thin MCP. The production of secondary electrons then results from the interaction of the incoming ions with the inner surface of the MCP channels. The scattering itself appears to be simpler than what occurs at the crossing of a carbon foil, with limited straggling in energy. Preliminary testing ([1]) suggests that the mass resolution is around 10 or better, especially when high ion masses are considered (oxygen ions and above). Based on this innovation, a new simple and light time of flight mass spectrometer is currently under development with interesting performances in terms of both mass resolution and fast measurements regarding the exploration of the Europa/Jupiter environments.

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NEXT GENERATION MASS SPECTROMETRY ON EJSM

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Abstract
The water-rich moons of outer solar system gas giants collectively represent a fascinating class of planetary environment, quite distinct from that of Earth yet with significant habitability potential. The Europa Jupiter System Mission (EJSM) will explore this environment in depth, directly addressing key measurement objectives for the habitability potential of Europa and Ganymede in particular, but also advancing our understanding of how common these conditions may be in extra-solar planetary systems.

A mass spectrometric investigation of the low-energy ion and neutral composition of the exosphere of Europa will provide critical support for a number of these objectives. Europa's exosphere samples its complex, radiation-processed surface and subsurface via particle sputtering and impacts. While dominated by O_2, H_2 and H_2O molecules, a host of minor neutrals and ions are expected which together may reveal the full extent of endogenic and exogenic chemical species and processes on Europa. At the nominal 100 km final orbital altitude of the Jupiter Europa Orbiter (JEO), many of the key minor species such as CO_2, SO_2, NH_3^+, CH_4^+, and Na are expected at concentrations of $n \sim 10^2 - 10^3$ cm^{-3} [1,2], likely within the capabilities of flight-proven techniques. Numerous other important species such as Mg, N_2, and any organic compounds, at lower abundances, may also be particularly significant for EJSM science.

An advanced ion and neutral mass spectrometer (INMS), derived from similar instruments developed by NASA Goddard over several decades, is expected to meet and exceed EJSM requirements with very low development risk. Highly successful NASA Goddard-developed mass spectrometers include the Galileo Probe Mass Spectrometer, the Cassini INMS, and the Huygens Gas Chromatograph Mass Spectrometer. Goddard is also the provider of the Sample Analysis at Mars (SAM) suite investigation on the Mars Science Laboratory, the Neutral Gas and Ion Mass Spectrometer (NGIMS) on the MAVEN Mars Scout mission, and the Neutral Mass Spectrometer (NMS) on the Lunar Atmosphere Dust Environment Explorer (LADEE) mission. Requirements of these upcoming missions have led to order-of-magnitude increases in overall sensitivity and field-of-view, compared with the Cassini INMS. These and other enhancements are expected on an EJSM instrument, achieving the limits of detection and quantitation required for Europa exospheric objectives as well as for Jupiter system, Io, and Ganymede science.

The baseline design of an advanced INMS incorporates a 2-550 Da quadrupole mass filter, with redundant electron ionization sources, and detector system with a dynamic range of 10^8 and very high abundance sensitivity across the mass range. A MAVEN/NGIMS or LADEE/NMS-like dual inlet system with expanded field of view and detection sensitivity enables efficient detection of both inert and reactive species along the spacecraft ram direction. Careful attention to radiation effects mitigation via hardening and shielding is expected to play a fundamental role in the design, development, and testing of this mass spectrometer for EJSM.

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NIMEIS : a Neutral and Ion Mass and Energy Imaging Spectrometer dedicated to the in situ characterization of the atmosphere/exosphere of the Galilean satellites

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Abstract

NIMEIS is an ion-neutral mass spectrometer dedicated to the characterization of the ionospheric and atmospheric/exospheric species of the Galilean satellites, Europa, Ganymede, and Callisto. Since there is a clear connection between the impacting plasma and photon flux, sputtered species, and the chemical composition of the surface we propose to measure at all satellites that will be approached by the EJSM/JEO spacecraft:
- the mass composition of the ion and neutral thermal exosphere/atmosphere components in a large range of mass and density,
- the mass and energy distributions of the main neutral and ion exospheric/atmospheric species for energy range from 0 to ~100 eV for the neutral and from 0 to 1 keV for the ion,
- to carry out chemical analysis of geysers, if any, and their temporal evolution.

NIMEIS will first of all measure the mass composition of the exosphere/atmosphere and ionosphere with a mass resolution of ~300 as well as the densities for all neutral species with density larger than 10 cm-3 and ion species with density larger than 10-2 cm-3. Such measurements will allow us to characterize the satellite atmosphere.
In order to connect the measured exospheric/atmospheric composition to properties of the surface and, possibly, sub-surface, we will also measure the energy spectra of the ions and neutrals in the exospheres/atmospheres of these satellites. Indeed, besides sounding the satellite atmosphere, one very exciting and central question is to quantify the surface loss rate in order to infer the origin of each atmospheric species. Such information will provide a major clue on the bulk composition of these satellites.
Therefore, the way Jupiter magnetosphere plasma interacts with the surface of the Galilean satellites, changes their surface composition and structure and produces their thin atmosphere will be investigated by both measuring the Galilean atmospheric composition **AND** the mass and energy distributions of the main atmospheric components.
Thanks to a new type of ion source based on carbon nano-tube component, NIMEIS will measure neutral densities larger than 10 cm-3 and ion gas densities larger than 10-2 cm-3.
NIMEIS will work:
- either simply as a mass analyzer for ion and neutral with a mass resolution of ~300 in order to identify the main atomic and molecular species but also salts and organic molecules and their fragments.
- or as a simultaneous mass and energy analyzer with a mass resolution of 60 and an energy range from 0 to an energy closed to 100 eV in the neutral mode and close to 1keV in the ionic mode with 5% resolution. In such modes, the measurement will be continuous allowing very short time resolution.

NIMEIS will not exceed:
- a total mass of 2.6 kg (with 20% margin),
- a power consumption of 5.8 W (with 30% margin).

A HIGH RESOLUTION CAMERA FOR THE JUPITER EUROPA ORBITER (HRC-E)

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The concept of a **High-Resolution-Camera** to be placed onboard the NASA-led Jupiter-Europa-Orbiter **(HRC-E)** yields a spatial resolution of 1 m/pixel at an altitude of 100 km and a swath width of at least 1000 pixels with the option of further improving the spatial resolution by a factor of 2 and to reach even a ground sampling distance of 0.5 m/pixel from the 100-km orbit around Europa. It has the capability to be operated as a framing as well as a pushbroom imaging device and includes multispectral imaging capabilities with more than 9 color filters.

The HRC capabilities allow performing high resolution imaging (including stereo-imaging) for a comprehensive achievement of the scientific goals of the JEO mission with special emphasis on the investigation of Europa's surface including the characterization of potential landing sites. Secondary objectives include the geologic activity of Io, investigation of the surfaces of Ganymede and Callisto, Jupiter's atmosphere and rings as well as inner and outer satellites. As a framing device the HRC-E will be perfectly suited to support the optical navigation and thus help to minimize fuel and overall mass requirements.

Due to the extremely challenging radiation environment in the Jovian system and the high degree of operational flexibility a CMOS detector has been selected as baseline for the HRC-E. The instrument will be designed with hi-rel. radiation tolerant components and cold-redundant subsystems where applicable (detector electronics, data processing, power converter). We will also focus on the assessment of alternative technical approaches that would improve performance, reduce the mass, volume and power-resources of the instrument. Here, especially the robustness of the detector and readout electronics due to the harsh radiation environment in the Jupiter system will be crucial.

The technical design considered for the proposed HRC-E benefits in particular from previous developments for the High Resolution Stereo Camera (HRSC) on-board the MarsExpress (MEX) mission, and of the presently on-going technical development of the High Resolution Imaging Channel (HRIC) of the SIMBIO-SYS (SIM) instrument for the BepiColombo (BC) mission. Other relevant heritage stems from the Dawn Framing Camera, the ROSETTA ROLIS Camera, the ROCKVISS camera system and the ExoMars PanCam/HRC.

In the presentation we will provide an overview on the technical concept of the instrument and the studies to be carried out within the next months.

A HIGH RESOLUTION CAMERA FOR THE JUPITER GANYMEDE ORBITER

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The Jovian system is a miniature solar system, with Jupiter as the largest planet of our solar system coupled with a unique solar-wind-magnetosphere-ionosphere system and its four large Galilean satellites, Io, Europa, Ganymede, and Callisto. They present diverse surfaces, from the volcanically most active surfaces of Io to one of the oldest surfaces of our solar system on Callisto. These satellites are differentiated bodies with thin atmospheres. Some of them might possess subsurface oceans and thus possibly establish a habitable environment. Ganymede is also the only known satellite with a permanent internal magnetic field due to dynamo-action in its core.

The **High-Resolution-Camera** (HRC) to be placed onboard the ESA-led Jupiter-Ganymede-Orbiter **(HRC-JGO)** will provide crucial information to a true understanding of this complex planetary system. The baseline performance requirements for HRC-JGO in orbit around Ganymede are: ground sampling distance of 1 m/pixel at 200 km altitude; swath width of at least 1000 pixels; monoscopic imaging for several 1000s of pixels along-track (pushbroom type); stereo observations at high spatial resolution of targeted features by multiple observations with camera tilt. Measurement tasks while orbiting within the Jovian system are rather different. Multispectral capabilities are needed for monitoring Io's activities at large distance as well as for characterizing the Jovian atmosphere and rings.

The resulting HRC-JGO baseline performance requirements are quite challenging: ground sampling distance of 5 km/pixel at 1 million km distance; image width of at least 1000 pixels; multispectral imaging capability with different colors; 2D-stable imaging (framing) also at large exposure times (co-registration of multiple images at far distance, long exposures for faint objects, astrometry measurements).

The proposed concept for **HRC-JGO** is based on heritage coming from past successful camera projects and on ongoing camera developments for various missions, such as the High Resolution Stereo Camera on-board MarsExpress, the High Resolution Imaging Channel of the SIMBIO-SYS instrument for the BepiColombo mission. Other relevant heritage stems from the Dawn Framing Camera, the ROSETTA ROLIS Camera, the ROCKVISS camera system and the ExoMars PanCam/HRC. Due to the extremely challenging radiation environment in the Jovian system and the high degree of operational flexibility a CMOS detector has been selected as baseline for the HRC-JGO.

Doppler Spectro Imager (DSI) for EJSM:
A study for an instrument looking inside Jupiter

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Abstract

The DSI instrument is designed to perform radial velocity maps monitoring in the visible spectral range. It enables a seismic study of the internal structure of Jupiter, through the measurement of the frequencies of the acoustic modes of the planet, with a spatial resolution of 100 to 200 in order to reach modes of spherical harmonic degree up to l=50, with a velocity noise level of 0.3 cm/s and a precision on the frequency measurements better than 0.5 µHz (primary goal). It also enables a long-term monitoring of wind fields at the Jupiter's troposphere level and at medium scales (100 - 200 km) with a precision of a few m/s with potential vorticity retrieval at several timescales (secondary goal).

The baseline concept for DSI is based on the principle a Fourier Tachometer (a compact Imaging interferometer of Mach-Zehnder design with a fixed optical path difference), inherited from the ground based SYMPA experiment, and a focal plane array (FPA) using a CMOS APS detector, operating at the wavelength of 590 nm. It will allow the monitoring of Jupiter continuously for several weeks during the approach phase and the very first orbits after Jupiter insertion, with a sampling rate of one image per minute, for the seismology program, and latter in the mission when the spacecraft is closer to Jupiter for atmospheric studies.

The study will be devoted to fit the resources requirements of the instrument into the constraints specified in the ESA's Payload Definition Document, to explore possible enhancements in the performances, to assess the radiation and planetary protection issues. The study will define the necessary technological activities to be carried out in order to reach a TRL higher than 5 for the instrument and his components at the end of phase B.

The proposing team has a proven experience in the field of instruments realization, scientific operations and scientific analysis of returned data. A relevant specific heritage in the field of spectrophotometers for helio and asteroseismology is guaranteed over years on several technical aspects including optical design, thermal and mechanical design (GOLF/SOHO, LOI/SOHO, SYMPA). All together, the institutions involved in the project have access to facilities that permit to reach the requested TRL.

SUB-SURFACE RADAR FOR THE JUPITER GANYMEDE ORBITER

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Abstract

This poster refers to the *Sub-Surface Radar (SSR)* instrument included in the core payload for the Jupiter Ganymede Orbiter (JGO) in the Europa Jupiter System/Laplace Mission (EJSM). The proposed instrument is a radar sounder system at low frequency (HF/VHF band) capable to penetrate the surfaces of Ganymede and Callisto and to perform a sub-surface analysis with a high vertical resolution. The design of SSR takes advantages from the experiences and heritage gained by the proposing team in the two successful precursor missions on Mars, i.e. MARS Express (with the MARSIS instrument [1]), and Mars Reconnaissance Orbiter (with SHARAD [2]). The instrument requirements are reported in Table 1.

Table 1 – Main instrument requirements

Orbiter altitude	200 Km (in the circular phase around Ganymede)
Transmitted central frequency	In the range 20-50 MHz
Transmitted bandwidth	10 MHz
Antenna dimension	< 10 m
Peak transmitted power	20 W
Geometrical resolution	Along track: < 1 km; across track: < 5 km
Vertical resolution	15 m (vacuum)
Penetration depth	< 5 km
Mass (without antenna)	10 kg

This active instrument is aimed at acquiring information on the Ganymede (and partially on the Callisto) shallow sub-surface with the following main scientific goals: i) characterization of the different stratigraphic and structural patterns; ii) understanding of the process of formation of surface features (and thus of evolution of the moons); iii) detection of subsurface structures not directly linked with surface; iv) analysis of the materials in the subsurface (through proper inference processes) and their metamorphism linked to the burial process; v) detection of possible shallow liquid resources; vi) understanding of the large scale geological processes active in the moons at the global scale and to reconstruct their geological evolution. The poster will address the main issues related to the design of the instrument in terms of interface and resource requirements, signal-to-noise ratio, signal-to-clutter ratio, noise environment (Jupiter radiation noise and Galactic noise), radiation problems and planetary protection issues.

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PLANETARY RADAR SOUNDING AT MARS AND THE GALILEAN SATELLITES

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Abstract
Radar sounding from orbiting spacecraft has been done successfully at Mars. MARSIS on Mars Express operates at low frequencies, providing maximum penetration depth, while SHARAD on the Mars Reconnaissance Orbiter operates at higher frequencies, providing higher vertical resolution at the expense of penetration depth. Icy terrains on Mars, highly amenable to radar sounding, may be good analogues for the icy crusts of the Galilean satellites of Jupiter (Europa and Ganymede) that can be probed with new radars on the Jupiter system orbiters.

Radar sounding of Mars
MARSIS (Mars Advanced Radar for Subsurface and Ionospheric Sounding) [1] and SHARAD (SHAllow RADar) [2] are synthetic aperture orbital sounding radars. MARSIS typically operates in two frequency bands between 1.3 and 5.5 MHz, with a 1 MHz bandwidth, giving a range resolution of approximately 150 m. Spatial resolution for the cross-track footprint is 10-30 km, and for the along-track footprint, 5-10 km. SHARAD operates at a central frequency of 20 MHz, with a 10 MHz bandwidth, giving a range resolution of 15 m. Lateral resolution is 3-6 km cross-track and 0.3-1.0 km along-track.

Both sounders detect reflecting horizons kilometers deep beneath the surface of the Martian polar layered deposits [3-5]. MARSIS data were used to detect and map the basal contact of the layered deposits, to a maximum depth of 3.7 km [4]. Analysis of the fine-scale internal stratigraphy of the NPLD, visible in the high-vertical-resolution SHARAD data, shows that deposition of the NPLD has been mostly uniform, but with shifts in depocenter with time [6]. The "basal unit" of the NPLD, thought to contain a higher fraction of sand and/or dust, is mostly opaque to SHARAD, but can be penetrated to its base by the lower frequency MARSIS signals. In most of the polar layered deposits, the very low attenuation of the radar signals indicates a low fraction of contaminants, typically <10% [3-5,7].

In non-polar regions, MARSIS and SHARAD have detected buried interfaces beneath ice masses 100s of m thick in lobate debris aprons [8,9]. Sounding of the enigmatic Medusae Fossae formation suggests low-density material that may contain ice [10,11].

Radar sounding of the Galilean Satellites
The experience at Mars is promising for detecting features in the subsurface of the icy crusts of Europa and Ganymede with radar sounding. As with Mars, higher frequency sounding may be preferable for studying detailed shallow stratigraphy and structure, while lower frequencies would provide maximum penetration to search for a deep ice-ocean interface. Challenges for these targets include: disruptive effects of surface topography, the unknown bulk composition and thermal structure of the icy crusts, and the technical implementation of the electronics and antenna systems in the Jovian environment.

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AN INSTRUMENT FOR MEASURING ICE THICKNESS ON EUROPA

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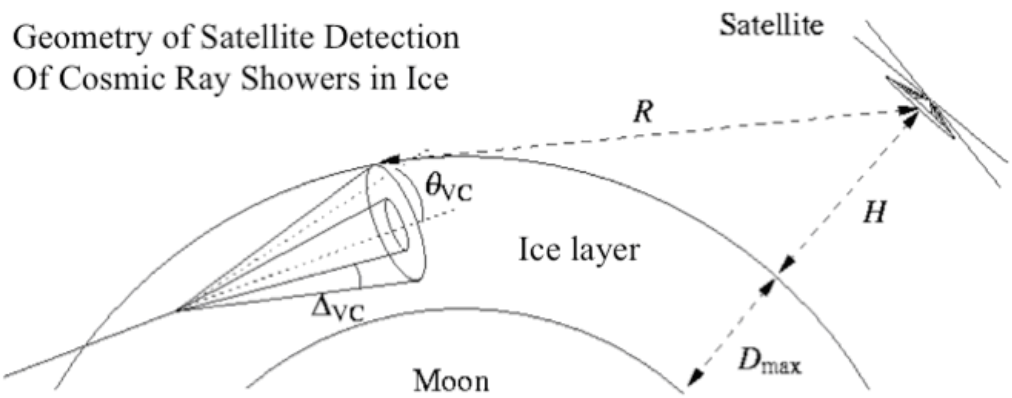
Abstract

An important goal of the Jupiter Europa Orbiter (JEO) is determination of the thickness of Europa's ice shell. The JEO mission report[1] illustrates a hypothetical example of how the current model payload instruments could constrain the thickness to be between 15-40 km thick. In this poster we briefly describe a concept for a passive instrument that uses naturally occurring cosmic ray generated GHz pulses generated in Europan ice as a probe to obtain a more accurate depth measurement. Furthermore, our investigations show that this instrument could be designed to use less power and have less mass than is estimated for the ice penetrating radar instrument on JEO.

Extremely High Energy (> 10^{18} eV) cosmic rays have been the subject of study in the astroparticle physics community for decades. In the last two decades the knowledge that EHE cosmic ray neutrinos will produce secondary showers that emit radio (~GHz) pulses that can be detected remotely has been used as the basis for a variety of Antarctic detector experiments. One such experiment, ANITA[2] (ANtarctic Impulsive Transient Antenna) has flown radio receivers on a long duration balloon above the Antarctic ice sheet. This detector concept is already being considered for use in missions to planetary moons[3]. The advantage in observing an ice-covered moon is that the volume of signal generating material (the ice shell) increases by orders of magnitude over the Antarctic ice sheet; so that we are able to derive the depth of Europan ice from the both the count rate and zenith angle distribution of the received signals. The poster will show the basic instrument detection concept, signal simulation results, noise background estimates, and a rough instrument component design.



An illustration of the concept behind the instrument described here. An energetic neutrino passes into the ice layer and eventually connects with an atomic nucleus, generating a shower of particles that produces a ~GHz pulse at the Cerenkov angle q_{nC} with width D_{nC}. This pulse passes through the surface of the ice at a range R from the satellite, which is a height H above the surface. By analyzing the distribution of pulses received at the satellite, we can deduce the depth of the ice (D_{max}). Figure adapted from ref [3].

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DUST DETECTOR OPTIONS FOR THE EUROPA-JUPITER SYSTEM MISSION

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Europa, as all other airless bodies in the solar system, is continually bombarded by interplanetary micrometeoroids. These impacts generate secondary ejecta particles and form a permanently present dust exosphere that was first recognized during the Galileo mission[1]. Close flybys of Europa will enable the mapping of the density and size distributions of the impact generated dust originating from this moon and will be used to learn about the physical properties of the icy surface. Measuring the chemical makeup of the ejecta grains will enable the direct sampling of the composition of the surface. Finding salts and minerals in these grains could be a tell-tale sign of a rocky core of Europa. Measuring the velocities of these grains could be used to trace their trajectories back to their origin, and hence to investigate any possible chemical variability in Europa's surface composition. There is a range of dust instruments with high flight heritage or high technical readiness levels (TRL) to operate on EJSM. The selection from the list below will depend on the science requirements, the actual orbit, and the available resources (mass, power, telemetry). This presentation is an overview of the capabilities of instruments developed at the University of Colorado. 1) ***PVDF dust detectors***. This instrument is measures the flux and the size distribution of particles. The detector is a thin, permanently polarized polyvinylidene fluoride plastic film that generates an electric signal when dust particles penetrate its surface. The generated charge is the measure of the particle's momentum. The advantage of these detectors is the combination of low power and potentially large collection area (> 0.1 m^2). PVDF detectors have a long flight heritage with most recent application on the New Horizons and the Aeronomy of Ice in the Mesosphere (AIM) missions [2]. The instrument is capable detecting particles from about a micron size and larger. 2) ***Impact ionization detectors*** offer a much higher sensitivity, capable of detecting submicron sized particles. An example of a flight instrument of this type is the Cosmic Dust Analyzer (CDA) onboard the Cassini spacecraft. This instrument measures the electrons and ions generated upon the hypervelocity impact of dust. CDA has a target area of 0.1 m^2. The Lunar Dust EXperiment (LDEX) is a smaller target area (0.01 m^2) version of impact detectors under development for the Lunar Atmosphere and Dust Environment Explorer (LADEE) mission. CDA also has a chemical analyzer subsystem that can provide a low resolution chemical analysis of the impacting dust particles. 3) ***High resolution chemical analyzer*** instruments have also been developed for detailed elemental and isotopic analysis of cosmic dust particles. The Large Area Mass Analyzer (LAMA) instrument has a ~ 0.1 m^2 target area and utilizes an electrostatic reflectron to achieve m/dm > 100 mass resolution [3]. 4) ***Dust trajectory sensors*** (DTS) concepts and laboratory prototypes have also been developed to measure the speed and direction of charged dust particles. The accurate measurements (1% accuracy for speed, 1° for direction) allow determining the origin of the dust by tracing its trajectory back in time.

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AN UPDATE ON MICRO-PENETRATORS FOR IN-SITU SUB-SURFACE INVESTIGATIONS OF EUROPA

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Abstract

In-situ elements are essential to significantly extend orbital observations to justify the large mission costs. They can provide ground truth, and new exploration capabilities, particularly for direct detection of astrobiologically significant material, and indirect habitability determination. They can also provide key seismic investigations of the deep interior of Europa, and chemical investigation of the subsurface material.

We propose a payload of 2 penetrators for Europa, to provide redundancy, and improved science return, including enhanced seismic performance and diversity of sampling regions. Each penetrator would be capable of achieving the above science goals with a modest payload of around 2kg. The total mass for such a penetrator system including the spacecraft attachment and descent module is estimated to be around 13kg, though a considerable degree of flexibility with payload and total mass is possible

The cold, icy and rough nature of much of the surface of Europa provides a challenge for securing a low risk impact, for which considerations of site selection and surface gardening effects will be presented. This will also include effects on penetrator impact forces, penetration depth, likelihood of ricochet, and communications. Penetrator shape options, including anti-ricochet techniques, and their consequent effects on science measurement feasibility will also be presented.

It is intended that these studies will be performed in concert with EJSM JGO and UK MoonLITE developments, as progressions from last year's highly successful $300ms^{-1}$ impact tests into dry sand targets but extended into icy impacts, and to include high radiation environment and planetary protection. Since last year we have also welcomed a number of European science and hardware contributors, and we also would welcome US involvement.

AUTONOMOUS GEOPHYSICAL PACKAGE FOR IN-SITU PLANETARY SCIENCE APPLICATIONS: LANDERS AND PENETRATORS

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Nuclear analytical techniques commonly used in terrestrial geology are neutron activation analysis (NAA) and gamma-ray spectroscopy (GRS), which can determine elemental composition, elemental concentration and distribution of water in rocks and soils [1]. In addition we are exploring the feasibility of using these techniques for in-situ geochronology by using K-Ar, Ar-Ar and U-Pb methods [2, 3]. Gamma backscatter densitometry is a non-destructive *in-situ* method that exploits Compton scattering for measuring the bulk density of surrounding material. Bulk density can be used to constrain heat flow in planetary surfaces [4-6].

The instrument described in this study would incorporate its own radioisotope-based power source that could be exploited for NAA (through intrinsic neutron production), geochronology and heat generation for thermal management of lander subsystems and heat flow measurements. The University of Leicester is working together with the Centre for Space Nuclear Research and the Idaho National Laboratory in the US to develop alternative radioisotope power sources encased in new carrier materials produced by novel encapsulation methods such as spark plasma sintering [8, 9].

The ability to measure gamma rays produced by the local planetary radiation environment, solar and galactic particles will provide a measure of any hazards for future space exploration activities [10].

This study highlights the development of a geophysical package (based on solid-state or scintillator detectors) that will enable all of the analytical techniques and methods described above and that can be incorporated in a planetary lander or penetrator for in-situ measurements [7]. Experimental results, data from planetary radiation models and results from radioisotope source production activities are presented in order to highlight the technology readiness levels of the subsystems of the integrated geophysical instrument package described.

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OPTICAL RECEIVER FOR ONE – WAY RANGING TO THE ESJM / LAPLACE MISSION TO JUPITER

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Abstract

We are presenting the Instrument study proposal for EJSM/Laplace: the Optical receiver for one way optical ranging.

Powerful constraints on the interior of Ganymede can be obtained from combined analysis of topography and gravity data. While the topography will be derived by the onboard Laser altimeter, gravity field parameters will be obtained by a tracking of the spacecraft in its orbit. One-way laser ranging will greatly contribute to this measurement goal. Specifically, it will allow us to determine parameters of the gravity field to much higher order than it is possible by the standard radio tracking methods alone.

The proposed instrument is designed to provide one-way ranging results of unprecedented performance. Ranging measurements to laser receivers in space have been demonstrated over planetary distances [1]. Data products from this instrument will provide: an optical reference for distance measurements based on traditional ranging systems, being free from dispersive plasma effects normally encountered in standard RF-based ranging systems, complement radio science observations, by up-link signal time-of-arrival measurements vs. the on-board Ultra Stable Oscillator (USO). It will allow the use of standard TM/TC signals and down-link data transmissions for ranging and radio science purposes, while increasing significantly the observation time and the amount of data available for ranging and radio science. And last but not least it will enable time transfer capability ground to space.

This proposal is closely related to two instruments already contained in the baseline payload definition, the USO for Radio Science investigations and the Laser Altimeter, complemented with a small-sized, dedicated laser receiver module. This laser receiver detects the time-of arrival of pico-second laser pulses emitted at known epochs from earth with respect to the on-board time represented by the USO. The output is an instantaneous pseudo-range between the laser ground station and the S/C, using the group velocity of the pulsed laser signal. Moreover, it provides a time-interface between major components onboard, allowing for tight timely correlation between events encountered in these components.

This method has become feasible only recently, when all of the required components have been developed in current projects, in particular the optical receiver (SPAD) for the Chinese Compass-M1 navigation satellite system [2] and for the European Laser Time Transfer experiment. A significant feature of the photon counting detector is its radiation tolerance, it exceeds 100kRad without parameter change and a lifetime is more than 10 years.

The basic device concept along with key parameters of the device will be presented and discussed.

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JENRAGE (Jovian ENvironment Radio Astronomy and Ganymede Exploration): a Radio Astronomy Experiment for EJSM

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Abstract

The JENRAGE (Jovian ENvironment Radio Astronomy and Ganymede Exploration) experiment is a high frequency spectro-goniopolarimeter (ie a spectrometer with 3 channels providing auto- and cross-correlation of the different channel signals allowing to retrieve full polarization and incident wave vector). Such a spectrometer shall be connected to 3 antennas in case of a 3-axis stabilized spacecraft. The covered frequency range of observation should span from 2 kHz to 45 MHz, in order to include the full range of auroral radio emissions as well as the one linked to the satellite-magnetosphere interaction. The length of the antenna that have to be connected to such a receiver will be discussed within the ESJM-EM Sensor Study Team (see the corresponding poster for tradeoffs discussions). This instrument will be a miniaturized version of the spectro-goniopolarimeters of Cassini (RPWS/HFR) et STEREO (S/Waves). The goniopolarimetric capabilities makes this instrument very complementary with JUNO, as the radio instrument of that latter spacecraft is only measuring the total flux of the jovian radio emissions (close to and within the sources).

It would be however very interesting to have such an experiment on each of the ESJM spacecraft. This would ensure direct radio source localization (from multi-point wave vector measurements). This also would be used to remotely sound the plasma environment of the jovian satellites when such a satellite is in-between the spacecraft and Jupiter, occulting the radio planetary emissions.

An appealing byproduct of such a receiver is the Thermal Noise Spectroscopy, which allows performing passive radio measurements for electrons, similarly to our participation (with the SORBET radio HF spectrometer) to the PWI consortium onboard BepiColombo/MMO. Such radio HF experiment must include low-noise sensitive receiver and pre-amps, and must be designed for scanning frequency bands around the expected local plasma frequencies along the probes orbits. Provided adequate antennas are selected, this analysis technique could provide an accurate mapping of thermal and suprathermal electrons in the Jupiter magnetosphere, especially in the plasma torus around Europa (for studies of plasma source and sink, sputtering, recycling of the Io plasma torus, large scale strctures, etc...), as well as in the small genuine magnetosphere of Ganymede

SLOPE CHARACTERISTICS OF EUROPA AND THE GALILEAN SATELLITES

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Abstract
Limited Galileo-derived topographic mapping provides general slope characteristics for the Galilean satellites. RMS slopes for ridged plains, matrix, and crater deposits on Europa are typically between 10 and 15° at 20-50 m length scales, and slopes on Ganymede may be even steeper. Smooth dilational bands, have RMS slopes of ~5°, the shallowest slope statistics of any common terrain on Europa. Although regional topographic excursions rarely exceed 2 km on the 3 icy bodies, local slopes are consistently steep.

Topographic Mapping
Ongoing efforts to develop a robust program for the next phase of Europa and Jovian exploration include serious consideration of landed science packages, laser ranging (for ocean detection), and radar sounding of the subsurface. The success of landers depends in part on a firm understanding of the slope and roughness characteristics of these surfaces. Potential design and use of radar sounder instruments to probe the 3-dimensional characteristics of ice shells and discriminate between models of geologic features also depend on knowledge of the roughness and slope characteristics of the surface. In this report we survey and describe the available topographic data and slope characteristics for different geologic terrains, with emphasis on Europa.
In the absence of laser altimetry, elevation data for the Galilean satellites must be derived from digital stereo image analysis or from area photoclinometric (PC, or shape-from-shading in 2 dimensions) analysis of low-sun angle images to produce digital elevation models (DEM) of the surface. Shape-from-shading data at 500 m resolution and better are limited to ~15% of the surface, but are subject to long-wavelength uncertainties. Less than 30 resolvable stereo mosaics were acquired of small areas (typically less than 200 km across) covering <5% of Europa, and even less so on Ganymede and Callisto.

Data Analysis
Three measures of slope characteristics are presented (following Shepard et al. [1] and Beyer et al. [2]: histograms, cumulative histograms, and RMS slopes. Data windows 15 to 35 km across or so from each DEMs were selected to sample each major terrain type, avoiding inclusion of other geologic units. On Europa, ridge flanks slope roughly 10 to 25° in most cases. Ridged plains as a unit have RMS slopes ranging from ~5 to ~15° (between 10 and 100 m scales). These values probably reflect a small degree of both physical rounding and DEM subsampling (topographic averaging) of ridge crests and troughs. Although chaos samples were restricted to matrix material (excluding remnant blocks of ridged plains) RMS slopes values of matrix are similar to ridged plains. RMS slopes for crater ejecta and crater floor materials on Europa also fall in a similar range. Both grooved and dark terrains on Ganymede are even steeper on average. Collectively, these data all suggest that local slopes on Europa and Ganymede are inherently steep (Callisto analysis is ongoing), with few relatively flat areas.

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ATLAS OF THE GALILEAN SATELLITES

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Abstract
Knowledge of the geography and geology of the Galilean satellites is central to motivating and planning scientific observations. An Atlas of the 4 large moons of Jupiter is in press and will be published in late 2009. This large comprehensive volume will include global maps and all high-resolution images and will be an invaluable resource to anyone involved in investigating these diverse and dynamic bodies.

Importance of the Galilean Satellites
The Galilean satellites hold a unique place in the geography of the Solar System as well as in the history of science and human philosophy. This coming January, we celebrate the 400th anniversary of Galileo's discovery of his eponymous moons. The discovery of objects orbiting another world (coupled with the blemishes on the Moon, phases of Venus and other discoveries) delivered the death blow to the geo- or ethno-centric views of the Universe. In our own generation, the satellites, especially Europa, have lead the way to a new understanding that planetary systems may be rich in habitable environments. This revolution is still unfolding but as part of the celebration of these cosmic revelations, the Atlas of the Galilean satellites [1] has been completed and is now in final production for release later this year.

The Atlas
The Atlas of the Galilean Satellites represents a summation of the imaging component of the Galileo project, which orbited Jupiter between 199 and 2003. The Atlas includes an extended Introduction and a comprehensive map catalog of each of the Galilean satellites at 1 km. Each satellite is featured in a global 1 km mosaic and 15 roughly equi-dimensional labeled quadrangles (Fig. 1). The base maps are in 3-colors (the quadrangle maps for Ganymede and Callisto only are shown in gray-tone). One of the major advances of this Atlas is the inclusion of all Galileo high-resolution mosaics at better than 1 km resolution (Fig. 2). These mosaics have all been registered to the global 1-km base map for the first time (some mosaics were not acquired with context imaging and locations remain uncertain). The Atlas includes a Gazetteer, Data Tables, and Index Maps highlighting the locations of each high-resolution mosaic.

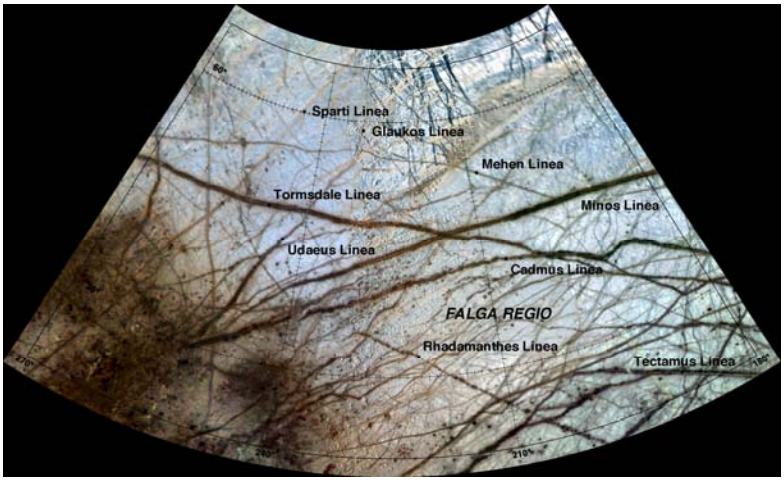

Figure 1.

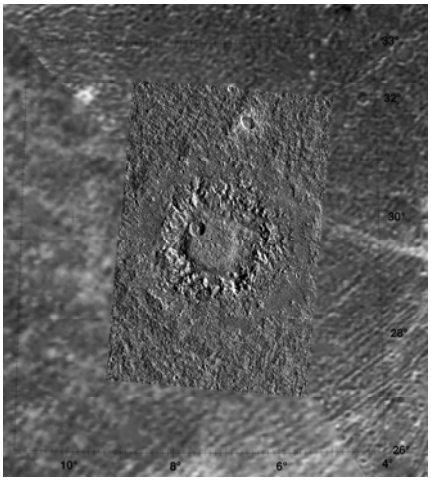

Figure 2.

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