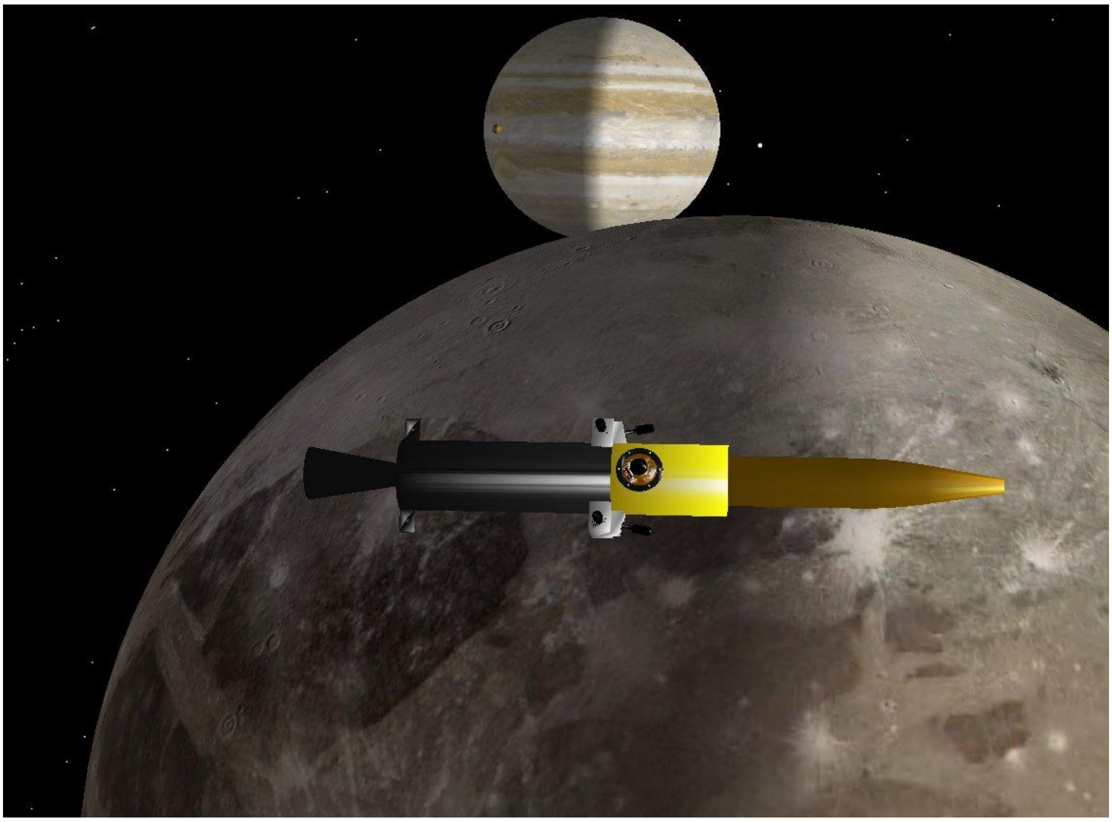
Declaration of Interest in science instrumentation in response to the Announcement of Opportunity for Europa Jupiter System Mission (EJSM/Laplace) Cosmic Vision Candidate

Surface Element Penetrators



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Executive Summary

On behalf of the UK Penetrator Consortium and European proposers we are very pleased to submit this declaration of interest in the proposed EJSM mission for kinetic penetrators for both Ganymede and Europa.

Whilst in-situ surface elements are not formally indentified in the EJSM model payload (either JGO or JEO) we believe the inclusion of such elements can significantly enhance the scientific return of this mission and provide a massive boost to both public support and the scientific community.

A payload of 2 penetrators is advocated for each of Ganymede and Europa, to provide redundancy, and improve scientific return, including enhanced seismometer performance and diversity of sampling regions.

The purpose of this DOI is to enable a coordinated study with the agencies to perform the necessary initial steps to assess and demonstrate feasibility of this hard lander concept in the EJSM context; determine the resources required to a level acceptable to generate confidence for inclusion in a following industrial study; and develop a roadmap to inform further necessary developments. This study will follow the initial UK penetrator studies and successful full scale impact trial.

We propose studies and technical developments which are complementary to the existing UK/NASA proposed MoonLITE mission penetrator Phase-A assessment and technical developments; an associated ESA penetrator technology development program; and additional European nationally funded studies.

Contents

1. Introduction

We provide here a brief introduction to penetrators; their scientific relevance; the system hardware and operational architecture; and current development status, in the context of EJSM.

Basic concept
For Ganymede and Europa we propose two hard landers (penetrators) for each body which impact at around 100-300m/s to bury them a short depth below the surface (around 20-100cm). These probes will contain impact hardened scientific instruments which perform key scientific measurements, whose data are transmitted to the orbiting spacecraft.

Two penetrators are advocated for each of Ganymede and Europa, to provide redundancy, and improve scientific return, including enhanced seismometer performance and diversity of sampling regions.

Scientific Motivation
A variety of scientific instruments are proposed which can address the following principal areas of scientific importance, either not possible from orbit, or which enhance or improve orbital measurements and interpretation :-

1. Enabling direct astrobiological investigation.
2. Enabling direct geophysical investigation (near-surface, and deep internal structures, crustal and internal seismic activity)
3. Enabling direct subsurface chemical inventory.
4. Enable comparison of surface element data for Europa and Ganymede as satellite bodies to strengthen interpretation of gained scientific knowledge.
5. Provide synergy with orbiting instrument data, not only for Ganymede and Europa but also to support interpretation of orbital data for other Jovian icy bodies.
6. Enabling direct surface characterisation of landing sites for future soft landers.

System Architecture
The baseline system architecture consists of, for each penetrator:-

- A spacecraft support system comprising descent module attachment and ejection system, and interfaces with the spacecraft.
- A descent module responsible for delivering the penetrator to the surface.
- The penetrator itself which contains most of the scientific instruments. An exception is a descent camera which is envisaged to be part of the descent module and does not need to survive impact.

Heritage
Though there has yet been no successful planetary penetrator mission, three systems have been developed and tested on the ground – DS-2, Mars'96 and Lunar-A. Of these only DS-2 was deployed, and failed for reasons unknown along with its carrier soft lander. The Mars'96 spacecraft failed to leave Earth orbit, and Lunar-A was cancelled after an extended development period, but after a full ground test of the penetrator was demonstrated.

In May 2008 the UK penetrator consortium demonstrated a first successful full scale impact trial after a period of only 9 months technology development. The consortium is formed of experienced space instrument and system providers allied with the defence sector which has extensive experience in survival of high speed impacting projectiles.

2. Definition of the science payload item proposed for study

The baseline penetrator system for study consists of the following basic elements, for each penetrator :-

- A **spacecraft support system** which provides an attachment and ejection system for the descent module from the spacecraft, together with power and data interfaces with the spacecraft when attached. These interfaces will be required for engineering support of the penetrators during cruise phase and just before release. Of particular interest will be to monitor the health of internal penetrator systems including processing system, batteries charge status, and internal temperatures particularly with regard to an internal RHU. It is also envisaged that just prior to delivery this should allow systems within the penetrator descent module to be initiated ready for the descent and post landed operations.
- A **descent module** consisting of the penetrator and its delivery system (PDS), plus a descent camera. The module enables communication with the orbiting spacecraft during descent to at least provide descent status information. It is envisaged that the descent system will arrange to separate the PDS from the penetrator to avoid the PDS contaminating the penetrator landing site. The descent module will also include appropriate harnessing and interfaces with the above elements. The descent module, in effect, will comprise a small spacecraft, albeit for a short duration. On separation from the orbiter, the PDS attitude control and de-orbit motor system will act to control the descent to impact at a controlled impact speed, incidence and attack angles to the planetary body's surface.
- The **penetrator** itself which consists of (a) platform elements comprising shell structure, thermal, power, communications, data handling, and (b) scientific instruments.

Conceptual images of a descent module and penetrator are shown in Figs. 2.1, 2.2 and 2.3, and product breakdowns of the hardware system are provided in Figs. 2.4 and 2.5.

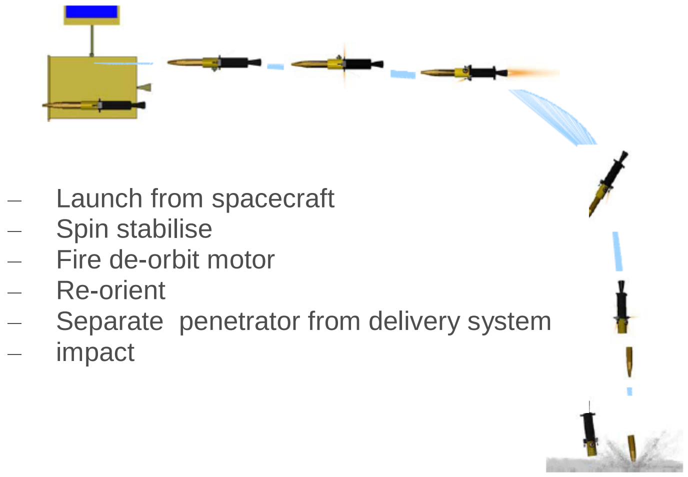

Figure 2.1: Preliminary Concept Of Penetrator Descent Module (DM) descent (courtesy SSTL)

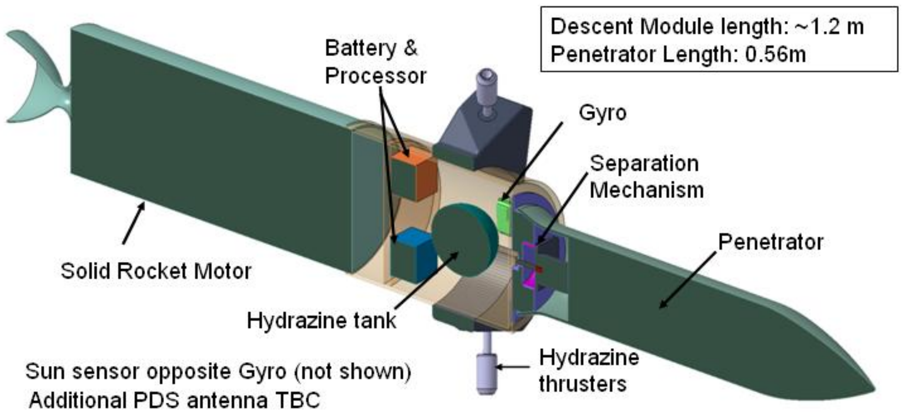

Figure 2.2: Descent Module Preliminary Design

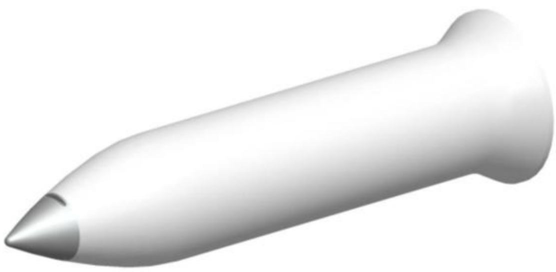

Figure 2.3: Preliminary Penetrator Design (~13Kg, ~0.5m long)

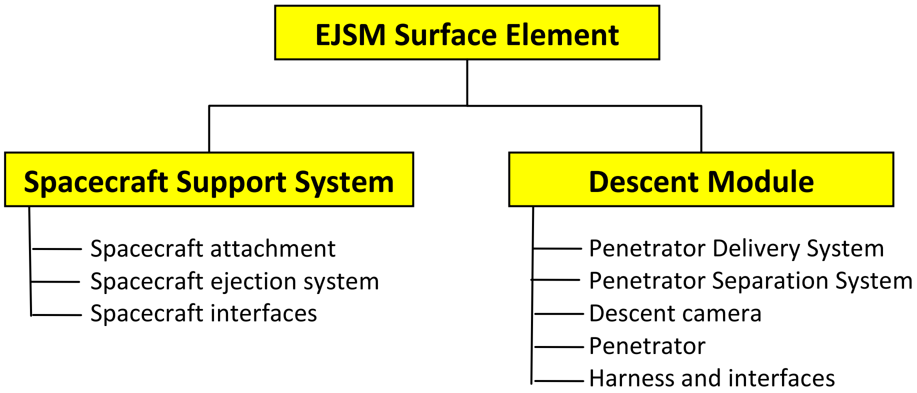

Figure 2.4: Top Level Penetrator System Breakdown

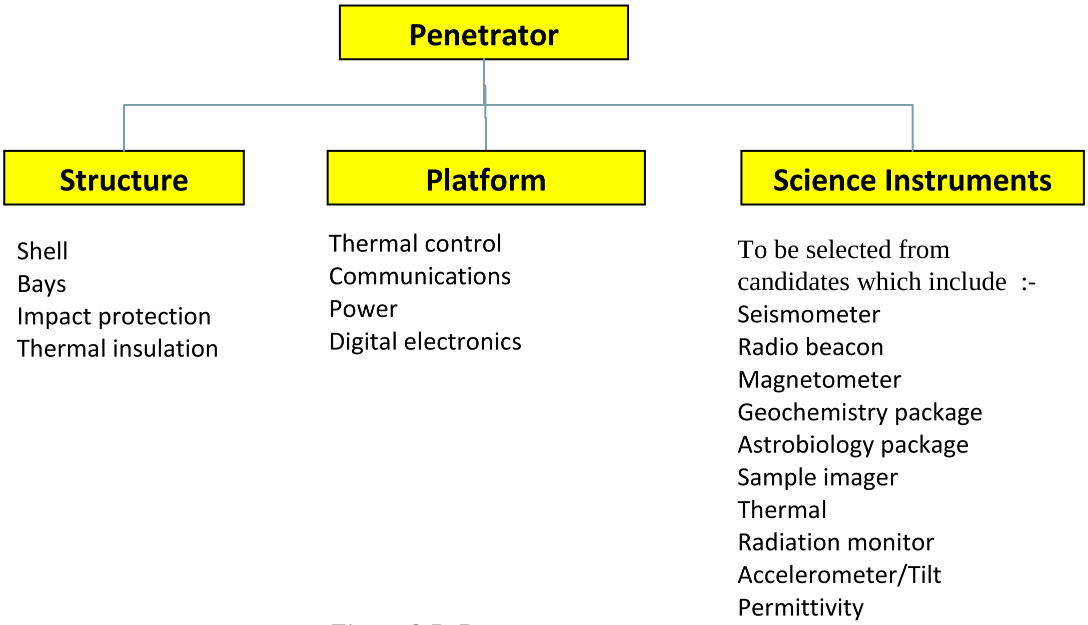

Figure 2.5: Penetrator

The penetrator is the only component which has to survive impact, and further definition of its components follows :-

- **Penetrator Structure:** This comprises the outer shell and inner bays, impact protection mechanisms, and thermal insulation. The shell is required to survive impact with its internal contents undeformed. The inner bays are designed to enable quick and easy AIT (Assembly, Integration and Test), and also to isolate any damage to a single bay. Impact protection can be provided by various mechanisms which including void fills. Thermal insulation is envisaged to limit heat losses in the cold landed phase, thereby increasing the lifetime, and improve the ability to make external thermal measurements.
- **Penetrator Platform:** This comprises all the non-scientific instrument sub-systems within the penetrator, comprising of thermal control, communications, power, and digital electronics. The thermal control may include an RHU (Radio-isotope Heating Unit) (designed to save battery power by providing heat to keep the internal subsystems within operating temperature) and a heat switch designed to prevent overheating by the RHUs during pre-launch and cruise phase. It is envisaged that the impact would be used to mechanically disable the cooling path. The communications would consist of at least a transmitter and possibly a transceiver, with transmission via patch antennae located in the rear body of the penetrator. Power would be provided by primary batteries via a PCU (Power Conditioning Unit) routed through an internal backbone harness within the penetrator. Digital electronics would be responsible for

instrument control; collection of data from the subsystems; data processing including data compression; and transmission via the communications subsystem.

- **Penetrator scientific instruments**:
  The scientific instrument complement for these penetrators is flexible according to need, TRL and resources, though it is envisaged that a modest ~2kg payload selected from the candidate lit below in Table 2.1 could address in full the science objectives listed above.

Candidate Instruments	Purpose	Supplier	Heritage
Micoseismometer*	Determine existence of subsurface oceans, interior body structure; and seismic activity levels.	Imperial College London	Under development for ExoMars.
Radio beacon	Crustal tidal and seismic movements.	JIVE Holland	Huygens (DWE), ExoMars (LaRa) (and PRIDE DOI)
Magnetometer*	Presence of internal oceans, Ganymede internal field.	Imperial College London	New technology which survived hi-gee test.
Biogeochemistry package (GC/MS/MS & isotope ratio-MS)*	Miniature instrumentation package for analysis of volatiles and biologically important species through advanced sample extraction, processing, separation and mass spectrometric analysis	Open University, SSC & Magna Parva, UK	Ptolemy GC/MS (ROSETTA lander); Gas Analysis Package (Beagle 2); expertise in analysis of organic compounds in meteorite and terrestrial samples. Sample acquisition similar to DS-2
Sample imager	Mineralogy & astrobiology	MSSL	Beagle-2 SCS, ExoMars PANCAM & MSSL WALI development
Geochemistry*	Elemental geochemistry	Univ of Leicester UK.	Beagle-2 XRS, γ-ray backscatter densitometer
Astrobiology package	Detection of astrobiological material	(INTA)	e.g. simple pH, redox to be studied.
Micro-thermogravimeter	Detect volatile and refractory molecules of astrobiological interest	IFSI-INAF, & IMM-CNR, Italy	Under development for Marco Polo.
Accelerometer*	Regolith mechanical properties, and important for future landers.	QinetiQ	DS-2, and mature defense system technology.
Tiltmeter	Constrain surface tidal displacement, and aid interpretation of seismometer & thermal measurements	QinetiQ/OU	TRL 6-8 (Lunar-A, Huygens, Mars’96)
Thermal sensors*	Temperature of regolith and heat flow	OU/QinetiQ	Lunar-A
Permittivity instrument	Physical state of local material, abundance of non-ice components.	IWF, Austria	Similar instrument under development for ExoMars
Radiation monitor*	Measure subsurface dose rate, relevant to astrobiological material decay and surface age.	QinetiQ	Survived hi-gee impact test.
Descent Camera	Geological context of impact site, and PR	MSSL	Developing similar for ExoMars.

* Components of these instruments survived impact test at ~17kgee maximum impact force.

Table 2.1: Science Instrument Candidates

Although this describes a baseline system architecture which could achieve a comprehensive scientific investigation with modest mass, it should be noted that there is considerable trade-flexibility with architecture and instruments. This can range from a simple spherical radio beacon penetrator which would provide a very low mass and risk solution with limited science, to an enhanced system providing full scientific capability.

3. Rationale for proposing the study

We believe that recent advances in both the EJSM mission architecture and successful impact demonstration of penetrator technology provide a significant rationale for proposing this study. Also, since penetrators were not formally identified in the EJSM model payload, we include the scientific and technical case.

3.1. General Rationale

We propose including penetrators in the mission study at this stage because :-

1. The emergent EJSM mission architecture of two spacecraft offers the possibility of additional payload mass. It is believed that such mass is possible with the JEO though its magnitude depends on the ultimate launch date, and the Ganymede orbiter no longer requires such a heavy radiation shielding.

   We believe that the greatest benefit for such mass would be from inclusion of surface element science, and that penetrators offer an efficient and flexible usage of such mass. Penetrator systems can be very low mass and their flexibility can range from the number of penetrators to their payload and architecture. This flexibility can range from simple radio beacon to full geochemical and astrobiological science payload.

   We also believe that this enhancement to the existing mission architecture has strong support across a broad swathe of the scientific community, and can offer extremely high public interest.
2. The recent rapid advances in the UK MoonLITE program, which included the recent (May 2008) successful full scale impact trial of penetrators at 300m/s has significantly the impact survivability of such probes; can reduce development costs for EJSM, and provide a relevant space technical demonstration in an appropriate timeframe.
3. Inclusion of penetrators into the mission study at this time allows consideration of accommodation within the mission which would otherwise be costly at a later stage.
4. Extensive commonality between Ganymede and Europa penetrators offer additional cost saving.
5. Penetrators can provide landing site information relevant to future soft lander missions to Ganymede and Europa
6. Penetrators are applicable to other solar system body missions, and their delivery systems may also be applicable to ‘micro’ satellites and swarm missions.

3.2. Science case for Europa and Ganymede penetrators

3.2.1 Introduction

The overall theme of the Europa-Jupiter System Mission (EJSM) is concerned with the emergence of habitable worlds around gas giant planets, offering unique opportunities for detailed comparative studies of Europa and Ganymede.

The proposed penetrator package would address several of the Jupiter-Ganymede Orbiter (JGO) and Jupiter-Europa Orbiter (JEO) sub-goals, providing key results on each moon individually and also providing a comparison between corresponding processes at both moons. In particular, penetrators would play a key role in addressing:

- ➢ Determination of whether the Jupiter system harbours habitable worlds;
- ➢ Characterization of processes within the Jupiter system;
- ➢ Provision of new insights into the origin of the Jupiter system.

Europa is believed to have a salt water ocean beneath a relatively thin and geo-dynamically active icy crust. Europa is unique among the large icy satellites because its ocean is in direct contact with its rocky mantle beneath, where the conditions could be similar to those on Earth's biologically rich sea floor. The discovery of hydrothermal fields on Earth's sea floor suggests that such areas are excellent habitats, powered by energy and nutrients that result from reactions between the sea water and silicates. Consequently, Europa is a prime candidate in the search of habitable zones and life in the Solar System. However, the details of the processes that shape Europa's ice shell, and fundamental question of its thickness, are poorly known.

Ganymede is believed to have a liquid ocean sandwiched between a thick ice shell above and high-density ice polymorphs below, more typical of volatile-rich icy satellites. It also possesses a magnetic field, making it (with Mercury and Earth) one of only three known solid objects in the solar system to possess such a field. However the existing evidence from Galileo is not conclusive for an internal ocean, and the confirmation or exclusion of an ocean is a high priority goal for EJSM. Tidal deformation, which would be more enhanced with an ocean, is one key measurement required to resolve this. The bright and dark terrains on Ganymede are also important to understand, as is the existence and analysis of non-ice components on the surface.

The EJSM mission will provide the first detailed study of these moons from orbit, offering key opportunities for remote sensing measurements of the surface and the interior structure. We propose to complement these studies with in-situ penetrators which will provide measurements which significantly extend those available from orbit and also give ground truth for the orbiter measurements. Such measurements range from a simple bleeping transmitter (for tidal deformation measurements), magnetic field, seismometry, accelerometry, temperature and radiation, to measurements of chemical/astrobiological analysis, permittivity and sample imaging at different scales.

Penetrator Package Science Objectives

The proposed penetrator package will provide key geophysical and geochemical parameters to help our understanding of the formation and evolution of Europa and Ganymede. To achieve this, investigations are required on the following aspects of each satellite:

1. Determine the internal structure of Europa and Ganymede and their dynamics.
2. Determine the existence and characteristics of sub-surface oceans
3. Search for bio-signatures in near-surface material.
4. Characterize the physical and chemical environment of the near-surface region
5. Provide ground truth for remote sensing observations

We now discuss each of these in turn, and then discuss the measurement requirements.

3.2.2 Discussion of scientific objectives

1. Determine internal structure of Europa and Ganymede and its dynamics.

The seismic activity of Europa and Ganymede shall be investigated by an ultra broad band Micro-Seismometer (μ-SEIS) experiment. It will determine the level of seismic activity on the surface by observing body-waves of mainly tidally-induced deep quakes which may be located close to the ice-ocean interface. Thermally-induced shallow quakes caused by daily variations of surface temperature are likely to occur. It is anticipated that the physical extent of individual sources will be smaller than on Earth, and that the seismic attenuation is likely to be lower. The seismometer will also allow the characterization of the outer ice shell's structure and thus will also provide clues regarding the nature of the internal ocean. The signal to noise ratio is critical. A minimum lifetime of ~2 Europan days (7.1 Earth days) and ~2 Ganymede days (14.3 Earth days) is required. The surface heat flow on Europa deduced from geological structures is estimated to be 70-200 mW m-2, more than an order of magnitude higher than that inferred from radioactive dissipation in the deep interior (Ruiz et al, 2007). The former value suggests a much lower thickness of Europa's ice shell than deduced from Europa's morphology. The onset of convection in the ice shell is model dependent but it could start below 45 mWm−2 (Schenk, 2002), so most of the surface heat flow would be caused by tidal heating (Ruiz et al., 2007). Therefore, surface heat flow provides a critical constraint on all models of Europa's interior. Its measurement will enable us to better understand the thickness of Europa's ice shell and its deep interior.

2. Existence and characteristics of sub-surface oceans.

For this topic, penetrator measurements are complementary to those of the orbiter radio science, magnetometer and laser altimetry investigations. Both Europa and Ganymede are subject to tidal forces as they revolve about Jupiter on their 3.55 and 7.15-day orbits. Because of the moons' orbital eccentricities the surfaces (and interiors) are deformed periodically. The satellites' response to the external forcing strongly depends on whether or not subsurface oceans are present in the moons' interiors. Radial surface peak-to-peak displacements are of the order of 30m on Europa in case of an ocean and less than a metre for a completely solid ice-shell. The equivalent values for Ganymede are ~7m if there is an ocean and ~10cm if there is no ocean present. Furthermore, the amplitudes of the forced librations (periodic variations in the rotation period) strongly depend on the presence of subsurface oceans.

A radio beacon emplaced on the satellite's surface transmitting its time-dependent (due to periodic radial surface deformation and longitudinal variations because of forced librations) location relative to the Earth or to an orbiter would constrain the tidally varying shape (determination of dynamical Love number h2) and the amplitude of forced libration. Furthermore, a radar beacon could precisely determine the satellite's obliquity and pole position.

A single penetrator with such a beacon on the surface is sufficient to provide a two-way link from/to Earth ground station as well as the JGO orbiter. Since the instrument is coupled to the surface, exposed to seismic and tectonic movements and, possibly, non-synchronous rotation of the outer ice shell, a drift connected to the corresponding tidal cycle is expected. Thus, a minimum lifetime for the instrument is required to be ~1 Europan day (3.55 Earth days) and ~1 Ganymede day (7.15 Earth days). Variations of the gravitational potential at the surface (determination of the dynamical Love-number k2) due to the tidal displacement of mass in the interior could be measured by gravimetry.

Complementary to gravity and topography variations, the measurement of the induced magnetic fields as a response to the rotating Jovian magnetosphere would indicate the presence of an ocean. Magnetometers emplaced on the surface can yield important contributions in addition to the magnetometer data from orbit. Europa and Ganymede are both embedded in Jupiter’s magnetosphere and are subjected to an inducing field which has two principal frequencies due to Jupiter’s rotation and a satellite’s revolution. The combination of magnetic field measurements in orbit and on the surface would define both the inducing and the induced field, and thus provide clues on the magnetic environment of each satellite. Also, the electrical conductivity and depth of the ocean could be inferred independently. Furthermore, the location and thickness of the internal ocean can be determined by detailed analysis of the electromagnetic induction signal. A magnetometer would also help characterize Ganymede's intrinsic magnetic field. In addition, magnetic measurements may address 'Europan oceanography' by monitoring time-variable magnetic field signatures induced by the directed flow of salty subsurface ocean water (ocean currents). With a recording signal as weak as a few nT, the signal to noise ratio is a critical issue. Thus the ideal lifetime of the experiment would extend for at least several Europan or Ganymede days.

3. Search for bio-signatures in surface material.

Constraining the habitability of the Jovian satellites is one of the prime goals of EJSM. Habitability is defined on the basis of what we know about terrestrial life. Thus, there are three conditions that a planetary object should fulfil to be considered as habitable: a) liquid water, b) chemical building blocks, and c) energy sources to maintain metabolism of microorganisms. Europa is especially interesting since all three of these characteristics may be achieved. However, Ganymede and Callisto should also be considered because they have internal oceans, although they are deeper and sandwiched between ice layers. Exploration of the potential habitability of Ganymede, for instance, in contrast to Europa may help to identify the astrobiologically important factors on these different objects.

Astrobiological exploration of Jovian satellites should not be restricted to the remote observation of the surface for three main reasons: 1) The habitable environments are in the subsurface, where liquid water may be present. 2) The surface has an intense radiation environment where many materials, including organic molecules, may not survive unaltered for a long time. If the aqueous reservoirs are linked with the surface, by fractures for instance, materials indicative of the habitability may ascend from the interior. But exposed materials will be affected and may lose the signatures from the potential habitable environment. So, remote measurements will be from secondary materials, modified on the surface from the original conditions at the interior aqueous reservoirs. 3) The concentration of biosignatures at the surface may not be sufficient for remote detection. Therefore, it is mandatory to be able to observe the subsurface in-situ as deeply as possible in areas suspected to be connected to the liquid water. A penetrator would provide this information because of its capability to penetrate to a depth of around a metre below the gardened regolith. Traversal through the altered layer would allow us to sample pristine materials of Europa or Ganymede and to test the conditions of habitability in more detail.

Important measurements for astrobiology would be related to a) physical-chemical environmental constraints of the original aqueous solution, such as conditions of pH and redox, temperature, conductivity, or composition, and b) biosignatures, such as organic compounds related to life or isotopic ratios. In situ characterization of the local mineralogical assemblages and direct physical-chemical measurements may provide information about the environment. Raman spectroscopy and GCMS are useful instrumentation for mineral and organics determination. In addition, a micro-camera is also required for the recognition of mineralogical and, if present, life-related structures and patterns. The search for life could be enhanced by UV illumination for fluorescence studies.

The question of habitability of Europa

Prominent in the priorities of the question of habitability is the interpretation of the sulphur-bearing patches on the Europan icy surface. The source of these patches is testable by EJSM, in which the instrumentation on board includes penetrators with miniaturized mass spectrometry in the component selection of the payload.

Based on combined spectral reflectance data from the Galileo mission's Solid State Imaging (SSI) experiment, the Near Infrared Mass Spectrometer (NIMS) and the Ultraviolet Spectrometer (UVS), it has been argued that the non-water ice materials are endogenous in three diverse, but significant terrains (Fanale *et al.*, 1999). Effusive cryovolcanism is clearly one possible endogenous source of the non-water-ice constituents of the surface materials (Fagents, 2003). The most striking feature of the non-water surficial elements is their distribution in patches. Indeed, implantation would be expected to produce a more uniform surface distribution if the source were ions from the Jovian plasma. It may be argued that if the plasma from the magnetosphere were responsible for the sulphur distribution, some geologic process has to be invoked to allow for a non-uniform distribution. Such possibilities have been discussed (Carlson et al. 1999). Alternatively, the sulphurous material on the surface may be endogenous. In other words, the cryovolcanism on Europa would not be from its core, but rather from the bottom of the global ocean. It might be more like the "black smokers" that are found on the Earth seafloor. The compounds produced at the bottom of the ocean would make their way up to the surface. Penetrators are particularly suitable for testing the chemical evolution that has taken place on Europa. The issue of biogenicity (Singer, 2003, Chela-Flores and Kumar, 2008) is amongst the several hypotheses that penetrators can decide upon.

The penetrators: testing biogenicity on the icy surface of Europa

The argument in favour of such instrumentation and component selection is as follows: Active photosynthetic microbial communities are found on Antarctica, both in and on ice, in fresh water, in saline lakes and streams and within rocks. In the dry valley lakes of Antarctica close to the McMurdo Base, microbial mats are known to selectively remove a huge quantity of sulphur, especially in the recently discovered Blood Falls in the Taylor Valley (Mikucki *et al.,* 2009). However, these are unlikely to provide a good analogue for Europa because of temperature, radiation etc. A better analogue may be found elsewhere in Antarctica, namely Lake Vostok which possesses a perennially thick (3 to 4 km) ice-cover that precludes photosynthesis, thus making this subglacial environment a good model system for determining how a potential Europan biota might emerge, evolve and distribute itself. Jupiter's moon Europa may harbour a subsurface water ocean, which lies beneath an ice layer that might be too thick to allow photosynthesis, just as in Lake Vostok. However, disequilibrium chemistry driven by charged particles from Jupiter's magnetosphere could produce sufficient organic and oxidant molecules for an Europan biosphere (Chyba, 2000). In addition, deep sea hydrothermal vents provide interesting analogue structures.

Microbial mats could still be thriving in spite of the extreme conditions of radiation on Europa. Penetrator-borne instrumentation could settle this important issue. Moreover, the planned MoonLITE lunar mission will provide an important test for this technology (Smith *et al.*,2008). This mission would address key issues related to the origin and evolution of our own satellite as well as the astrobiologically important possibilities associated with polar ice. With such a precedent we can consider the MoonLITE mission an excellent preliminary stage for the most scientifically relevant question of our time, namely the habitability of our own solar system with a concrete example of a second Genesis that has so far eluded the major resources that have been invested in the exploration of Mars and the Saturn system. Penetrators indeed allow the probing of airless solar system bodies without the related costs exceeding the budgets of the main space agencies.

4. Characterise the physical and chemical environment of the near-surface region

The characterisation of near-surface material and of the environment for different terrains (including chemistry, structure, mineralogy, permittivity, and temperature) is important for astrobiology, geophysics, the interpretation of ground penetrating radar data, and for future mission landers.

Galileo NIMS spectra of the surface of Europa and Ganymede exhibit absorption bands attributable to H_2O bending and stretching overtones. Over large parts of their surfaces, the shapes of these bands are what would be expected from clean water ice; it is worth observing that these would be identical if the surface were instead composed of a clathrate hydrate[1]. However, in other areas the near-IR water bands exhibit considerable distortion indicative of either water or hydronium ions (H_3O^+) bound into non-ice solids. Although there is disagreement concerning the interpretation, comparison with a range of laboratory spectra suggests that the non-ice component may be hydrated Mg-sulphate (either epsomite, $MgSO_4{\cdot}7H_2O$, or meridianiite, $MgSO_4{\cdot}11H_2O$), Na-sulphate (mirabilite, $Na_2SO_4{\cdot}10H_2O$), Na-carbonate (natron, $Na_2CO_3{\cdot}10H_2O$), sulphuric acid ($H_2SO_4{\cdot}6½H_2O$ or $H_2SO_4{\cdot}8H_2O$), or hydrogen peroxide ($H_2O_2{\cdot}2H_2O$). It has been speculated that these non-ice materials have been emplaced as aqueous solutions, erupted from a liquid reservoir beneath the surface, possibly from a subsurface ocean. In this case, the composition of the non-ice material is a signature of the ocean chemistry, and places constraints on the interactions between aqueous fluids and the rocky interior, either during the differentiation of Ganymede, or at the present-day sea-floor on Europa. Given that the non-ice spectra on Europa are correlated with red-brown markings on the surface, which are in turn correlated with areas of purported rifting and diapirism, then this hypothesis appears well supported.

It is certain that the radiation environment has acted to modify the surface composition of Europa, perhaps by implanting sodium and sulphur ions, originating on Io, into the surface ices to form sodium sulphate hydrates and sulphuric acid hydrates. Radiation is almost certainly a driver for the production of highly oxidising species, such as O_3 and H_2O_2. Moreover, if CO_2 is present in the ice matrix then irradiation will also drive the formation of organic species, such as formaldehyde (CH_2O). It has been speculated that these species could be mixed back down into Europa’s ocean, providing a source of nutrients for an active biosphere. Radiation will also destroy organic material present on the surfaces of the icy Galilean satellites, whether it is endogenic or exogenic (supplied by cometary or chondritic impactors) to a depth of 1-10 cm (the expected depth of regolith gardening on a 10^7 yr timescale), resulting in a predicted steady-state abundance of roughly 1 part per 1000 on Europa. Given that a large portion of Ganymede’s surface is protected from charged particles by its intrinsic magnetic field, we would expect the equilibrium abundance of organic matter to be higher.

Key objectives of the proposed penetrators with respect to near-surface materials are to: (*i*) determine the physical state of the solid H_2O component that likely comprises the bulk of Europa’s and Ganymede’s crusts; is it water-ice or a clathrate hydrate? This may be achievable by measuring low-wavenumber lattice vibrations with a Raman spectrometer; (*ii*) identify the composition of the non-ice component and determine its vertical distribution, i.e., determine if it is a ‘skin’ deposit or mixed deeper into the regolith; (*iii*) identify the presence of any organic material and determine its vertical distribution.

5. Provide ground truth for remote sensing observations

The analysis of data on the Ganymede and Europa surface from an orbital platform is subject to assumptions regarding the nature of the surface. Clearly, measurements of surface properties, e.g., density, regolith structure, composition of non-ice components, temperature and temperature variations are required. These would yield ground-truth for the orbiter instruments (spectrometers, radar) that will determine the properties of the icy shell and the presence and location of shallow liquid water.

3.2.3 Measurement requirements

Bleeping transmitter – for tidal deformation measurements. Rotation period of Europa is 3.55d, Ganymede 7.15d. Would need to operate for at least 1 and, ideally, for 2 orbital periods.

Accelerometry – provide information on structure and composition of sub-surface material.

Seismometry – sound waves produced by tidal stresses can be measured by seismometers to determine the existence of any sub-surface ocean and its physical characteristics such as depth and extent. A seismometer will provide unambiguously the position of the ocean interface. To our knowledge, this is the only direct measurement of the position of the ocean that can be envisaged and which will provide information regardless of the internal structure. Determine interior dynamics of mantle and ice crust and relation to the extreme tidal forces. Seismometers at two or more different sites will extend capabilities for 3D mapping of internal structures.

Thermal – Simple temperature measurements could provide information on environment including temporal. Use of simple heaters would allow thermal conductivity determination of surface material. Distributed measurements could provide heat flow information on interior thermodynamics whether tidal or radiogenic origin, and the feasibility of these in the icy environments will be addressed during the study.

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[1] *This is not a trivial distinction since clathrate hydrates have a significantly lower thermal conductivity, and are much stronger, than water ice under the same conditions; therefore there are consequences for the resulting thermal evolution of these satellites.*

Chemistry/astrobiology - to provide information on surface and sub-surface material chemistry and refractory/volatile material including potentially astrobiological material brought up from the sub-surface ocean. Astrobiological material determination may be explored through detection of unusual balance of several organic species via mass spectrometry and isotopic ratio determination (e.g. Sulphur which is expected to be quite different for a biological origin). If sufficient precision can be achieved, isotopic ratios in detected ice may be used to infer its origin.
Permittivity - Constrains the physical state of the material surrounding the penetrator and abundance of non-ice components, and useful to interpreting data from orbital ground penetrating radar.
Ground imaging/microscope/astrobiology – determine mineralogy of surface material (e.g. grains), and possible astrobiological material via imaging and fluorescence.
Radiation sensor – determines sub-surface dose rate, and is relevant to potential astrobiological structure decay states to be detected commensurate with surface age, and the density of the near surface material layers.
Magnetometer - In order to define both the inducing magnetic field at Europa or Ganymede and the resulting induction signal simultaneous magnetometer measurements from an orbiter and penetrators are desirable.
Driving requirements for the magnetometer include the need to have measurements made over periods of months in order to resolve multiple frequencies

- For example to resolve the effects of a single frequency (that of the rotation period ~ 10 hrs) one would need 10hr x 20 rotation periods so ~ 10 days
- In order to study frequencies linked to Europa's/Ganymede's orbital period of 3.55/7.15 days – one would require say 10-20 orbital periods and so: 2-4 months.

Descent Imaging – Determine surface morphology of landing site, and identify its precise location to place observations in global context. Also excellent for inspiring public interest in mission and outreach.

3.2.4 A lander as a complement to the agility of the penetrators

There is an attractive suggestion of the Russian Space Agency Roscosmos for a spacecraft launched by Soyuz rocket, separate from the main JEO and JGO platforms. This proposal includes a descent module to land on the icy surface of Europa. Such a lander, with a considerable payload as envisaged by Roscosmos would be extremely welcome, but would operate only at a single site. The more moderately budgeted penetrators have the non-trivial advantage of being able to be deployed at multiple sites to enhance scientific return, with direct and instant access to subsurface materials, better seismic coupling, and a less severe radiation environment.

To sum up, penetrators could, in principle, be able to take advantage of chosen areas that are in the process of being identified in the significant studies at Johns Hopkins University as part of NASA's Exobiology and Evolutionary Biology program. The JHU team are building up detailed maps of the surfaces of Europa and Ganymede. The project will identify zones of possible safe havens that might harbour material expelled from any subsurface ocean. As mentioned above this strategy will be put to the test several years before JEO on the Moon with the MoonLITE mission. This multiple landing strategy of the penetrator technology becomes more evident in providing ground truth for the remote sensing studies of the chemical elements on the icy surface using mass spectrometry, which is another major objective of the EJSM mission.

3.3. Technology Case

Heritage and Consortium

1. The UK penetrator consortium, consisting of experienced space technology providers, allied with the defense industry who are similarly experienced in impact survival of instrument projectiles, has recently demonstrated that it is an effective collaboration with the highly successful 300m/s impact test of full scale penetrators into a dry sand regolith target, as part of the proposed Lunar MoonLITE mission, which could also form a timely technology demonstrator for EJSM.
2. The consortium builds on previous developments, with a focused engineering approach which provides effective de-risking for impact survival by application of modeling, small scale testing and full scale testing underpinned by extensive experience in each area. Allied with the penetrator inner bay concept which simplifies AIT, this is also a cost effective approach.

3. The consortium also includes leading scientists experienced in planetary surface morphology, composition and impact cratering with appropriate modeling capability to study impact into regoliths.

4. The consortium has recently benefitted from a growing list of European contributors which greatly strengthens the underpinning science, and broadens the technology base from experienced space technology providers to enable selection of the most appropriate scientific instruments. The consequent spread from additional funding inputs helps to ease individual national financial burdens. We also welcome U.S. participation, as for MoonLITE.

Payload

1. Most candidate instruments have space heritage, or are relatively simple developments, by experienced space instrument providers.
2. Many key components of the candidate instruments have already successfully survived the first UK full scale impact test resulting in forces of around 17kgee. Whilst impact into the surface ices of Ganymede and Europa is expected to be significantly harder, the experience of our defence sector collaborator indicates that such survival is still well within their capabilities, and we plan to demonstrate this with impacts into appropriate ice simulants.
3. The scientific instrument complement for these penetrators is flexible according to need, TRL and resources, where a modest ~2kg payload selection from the list below could address in full the following science objectives :-

   - **Astrobiology:**
     (a) Micro-seismometers of similar sensitivity to the Lunar Apollo seismometer could detect the posited sub-surface oceans, potentially habited, and their boundaries (depth). This capability could extend to much greater depths than an orbiting ground penetrating radar which would be limited to a few tens of km deep.
     (b) Magnetometer could also help characterize the posited sub-surface oceans.
     (c) Microscope imaging of material upwelled from the ocean below can be examined for astrobiological life markers which includes UV RNA/DNA imaging capability.
     (d) Chemical analysis of organic inventory would allow detection of signatures associated with life (presence and balance of chemical species present, and S^{34} isotope measurements) [Penetrators would embed below the upper micrometeoroid surface gardening into the hard ice (initial estimates of gardened depth are around a few decimetres to a metre) to minimise radiation degraded astrobiological material.] GCMS analysis would enable the characterisation of the bulk and trace components of the surface and sub-surface material at the impact site. Pre-analysis sample processing techniques, such as pyrolysis, solvent extraction or thermo-chemolysis would further enhance the measurement capability of the instrument allowing full characterisation of the organic inventory and detection of any compounds of biological significance. Isotope ratio measurements may enable the detection of biogenic signatures (i.e. through measurement of delta 34S) and accurate measurement of D/H ratio would allow the distinction between the meteoric origin and local production of any organic material to be determined.

   - **Geophysics:**
     (a) Micro-seismometers could allow direct detection of signals associated with geological investigations mentioned above, and the strong tidal forces acting on these bodies are expected to provide significant signals in a few days.
     (b) Direct detection from Earth of penetrator (communication) radio beacon signals could be used to sensitively detect horizontal crustal movements.
     (c) Magnetometers could provide internal structure via characterization of the sub-surface ocean (on Europa) and in the case of Ganymede via its own internal field source.

   - **Synergy:**
     Almost all the measurements made will aid orbital measurements with more direct ('ground truth') observations. In particular :-
     (a) Co-ordinated multipoint magnetometer measurements across the sub-surface and orbital detectors would form a very strong theme, particularly as it is a key instrument for the outer moons not just for magnetospheric plasma physics/surface magnetism but also for internal structure via characterization of the sub-surface ocean (on Europa) and in the case of Ganymede via its own internal field source.
     (b) Synergies with the orbiting ground penetrating radar can help in both directions.

Measurements of sub-surface material dielectric properties may help to interpret orbiting ground penetrating radar measurements, and if the orbiting instrument detects a sub-surface ocean upper boundary this can help with interpretation of micro-seismometer signal analysis.

- **Future Landing Site Characterisation:** Accelerometers would allow characterisation of the surface hardness as a function of depth; descent camera the morphology of the landing site(s); and micro-seismometers would characterise seismic activity levels/frequency to aid future soft lander designs.

It is currently envisaged that each penetrator shall be as identical as possible to provide cost effective development and production. However, where requirements or constraints are different, such as radiation tolerance, regolith characteristics and planetary protection, it would still be planned to take advantage of common subsystems, instruments, and shell and accommodation designs to much as possible

It is our philosophy to enable a minimum mass penetrator system, though we recognise that science and other requirements can increase this. For a ~2kg payload we currently estimate a total penetrator mass in the range ~4 to 13kg. Added to this is required a spacecraft attachment system and a Penetrator Delivery System (PDS) to deliver the penetrator from orbit. The total mass for the combined system for a single penetrator is estimated to be around 3 times the penetrator mass, but will be affected by the velocity and altitude at release, gravitational field strength at both target bodies, and selected impact velocity. All these elements will be the subject of definition and trade studies.

4. Scope of the study

The main objective of this study are :-

1. To have more accurate determination of the resources required for the spacecraft attachment and descent module and the landing ellipse precision capabilities.
2. To have more precise determination of the dynamic impact properties of the icy regoliths, and selected the most appropriate penetrator architecture to achieve the science goals within the resource requirements.
3. To have selected a strawman payload compatible with resources available, acceptable TRL, which can reliably achieve the best science return.

The scope of this study will include the elements below, some of which will be performed as part of the parallel MoonLITE development program, and some specific to the EJSM mission.

1. **Delivery System**:
   The study will focus strongly on definition, performance and resource requirements for the underpinning delivery system, which are key for delivering the penetrator at required impact velocity and orientation for penetrator survival and successful operation. These studies will include:-
   – Restrictions on global landing sites arising from planned spacecraft orbits around the bodies.
   – Determination the landing error ellipse sizes which are key for target selection.
   – Descent communications for both engineering status report and potential descent imaging uplink during descent, which will be dependent on descent module to spacecraft visibility and look directions.
   – Separation of the penetrator from the delivery system to avoid contamination of the impact site.
   – Effects of radiation in transit and planetary protection on the delivery system.
   – Selection and definition of suitable rocket de-orbit motor, and assessment of fuel type and potential effects of environment (e.g. radiation) due to long storage time before use.
   – Selection and definition of associated suitable attitude control system.
   – Assessment of a common communication system which is located within the penetrator, or a separate system for the descent module.
   – Accommodation of a descent camera.
2. **Spacecraft Support**:
   Study of spacecraft accommodation for penetrator descent modules is considered a key element since this affects the spacecraft geometry, provision of mechanical, power and communication interfaces, as well as moment of inertia, thermal, emc and radiation environment, field of view effects on other instrument, and planetary protection of the whole spacecraft, and these can only

be performed effectively with the engagement of the agencies. The study aim would be to assess these aspects, and produce resource requirements for the support system and consequent impacts on the spacecraft. Where launch mass may vary according to launch date, optimising spacecraft architecture to minimise disruption to the mission of inclusion or exclusion of penetrators, would also be desirable. Also, assessment of the effects on the spacecraft to support post deployment communications during descent, and landed phase communications are also important.

3. **Icy Regolith**:
   Determination of impact forces and implications of surface characteristics to successful penetration and subsequent successful scientific operations is a high priority item.
   A key study is required of potential landing sites with regard to surface characteristics including likely regolith thickness, overall surface hardness and slopes/roughness, which can have implications for potential impact ricochet and subsequent consequences to configuration of scientific instruments or complement. Here, two penetrator configurations will be assessed – pointed and spherical. These will be assessed according to risks, and performance, including effects of micrometeoroid gardening, radiation processing, thermal annealing, and sublimation on the nature of the impact surface to penetration, and anti-ricochet techniques. Also of particular interest will be determination of survivable impact velocities; estimation of penetration depth which is important for astrobiology investigations; and crater morphology for sample acquisition, and communications through the regolith. Finally, assessment of attenuation of communication signal though regolith.
4. **Penetrator Platform**:
   Penetrator shell, communications system, power system, thermal system, and data processing system, will be studied as resources permit. Of particular importance is assessment of RHUs, which are key to enabling extended lifetime, and their associated heat switch. Radiation resistance and planetary protection implications will also be particularly important for JEO.
5. **Penetrator Scientific Instruments**:
   Candidate scientific instruments shall be identified and assessed for inclusion as strawman payload, and the studies will assess for tradeoff: scientific merit; technical resources; risk and cost. Risk assessment will include both instrument malfunction, and failure to achieve the desired science goals even with a perfectly functioning instrument.
6. **Science**:
   To continue investigation into desired science objectives; measurement precision requirements; existing scientific knowledge and possible consequent effects on the proposed instrument and platform technologies (e.g. hardness and roughness of surface for impact including regolith depth with age of surface; transmission properties of surface material for communications; and frequency and magnitude of likely seismic signals from e.g. tidal or interior forces.
7. **Technology roadmap**: To identify areas of risk and to produce a technology roadmap to achieve the necessary TRL.

TRL, environment, planetary protection, resources, and funding will be addressed for each hardware system.

5. Study logic

The following major activities and milestones are envisaged :-

1. **Preparation:** Prior to July'09, identify initial participants, clarify funding; and assignments for study areas. Prepare for Kick-Off Meeting.
2. **Agency Kick-Off Meeting:** To inform consortium of current mission definition and agency expectations for studies.
3. **Consortium Kick-Off Meeting**: To discuss and clarify goals, agree internal schedule and workplan.
4. **Intermediate Review**: Allow formal review of intermediate results, and any necessary mid-point redirections.
5. **Final Review**: Internal meeting assess results and plan preparation of a final report
6. **Produce Final Report & present to agency as required:**

Progress will be monitored via regular reporting via electronic and teleconference meetings as appropriate, not less frequent than bi-monthly. Agency participation at all major milestones is invited, and at required progress meetings.

The studies will be separated into separate areas as follows, coordinated though study management and system engineering :-

1. Study management (MSSL)
2. System Engineering (MSSL)
3. Science (MSSL lead)
4. Impact studies (UCL/Birkbeck lead)
5. Spacecraft attachment and penetrator delivery systems (*)
6. Penetrator platform elements (*)
7. Scientific instruments (see section 7).
8. Planetary protection (Open University) and radiation (Leicester University) (these groups will be responsible for collecting and coordinating these activities throughout the other areas)

* to be selected, depending on funding source. It is envisaged that ESA will determine some of these.

6. Preliminary plan for addressing radiation and planetary protection

6.1. Radiation Protection

The study team recognizes the harsh radiation environments facing JEO and JGO, in particular the potentially extremely challenging conditions to be faced at Europa, especially for an target active post-landing phase lasting weeks. The implications of the radiation environments for the design, components, and shielding of the penetrator delivery and experiment systems will be assessed in detail, and onboard software checks for corrupted experiment data caused by radiation effects investigated. It is recognized that the scientific payload at Europa may have to be curtailed to ensure enhanced protection for experiments. Landing site preferences based on radiation dose expectations at leading and trailing hemispheres of Europa will also be determined, using existing radiation models for the targets and through consultation with relevant research groups.

6.2. Planetary Protection

3.2.1 Categories and Requirements for Surface Element Penetrators for JEO & JGO

Planetary Protection (PP) concerns the minimisation of cross-transfer of biota between different planets, either from Earth (forward contamination) or in the case of sample return missions, back to Earth (backward contamination). PP policy is determined by COSPAR, under which each mission type is assigned a specific PP category, which then determines the approach required for compliance. (Non-compliant missions may not be granted permission to launch).

JEO is, according to the NASA study team [NASA Jupiter Europa Mission Study 2008: Final Report], classified as Category III under COSPAR regulations. The associated requirements are:

- requirements concerning avoiding harmful contamination of any other Jovian satellites during the Jovian Tour mission phase
- the probability of inadvertent contamination of a Europan ocean shall be less than $1x10^{-4}$

JEO penetrators, meanwhile, would be classified as category IV, which in principle would require a more stringent approach to PP. However, the delta over category III is in practice somewhat reduced because JEO would in fact need to meet certain aspects of category IV requirements (such as Probability of Contamination requirements) due to its targeting Europa.

COSPAR PP policy currently does not specifically identify Ganymede and Callisto, but notes that most small bodies are classified as category I or II. JGO would, according to the ESA study team [ESA Jupiter Ganymede Orbiter ESA-SRE (2008)2] be classified as category II, with relatively modest PP requirements relating mainly to documentation. However, the mission design, which includes Europa fly-bys, means that the mission may be classified as category III under current COSPAR policy.

JGO penetrators would be classified as either category II or potentially category IV, depending upon possible eventual reclassification of Ganymede as a target body.

Given the current uncertainties in classification and associated requirements, a conservative approach is proposed. The case of JEO is considered first, as it represents the most stringent requirements, then similarities and differences are considered for the case of JGO penetrators.

3.2.2 Implementation approach for JEO Penetrators

The overall approach proposed for the penetrators is:

- Pre-launch sterilisation to control the bioburden for items not sterilised in flight
- In flight sterilisation via radiation prior to Europa orbit insertion

Our approach is based upon that adopted for the JEO itself [NASA Jupiter Europa Mission Study 2008: Final Report, section 4.7]. It is assumed that the requirement for avoiding harmful contamination of any other Jovian satellites during the Jovian Tour mission phase will be met at system composite level (i.e. Penetrator will be part of JEO composite at this stage) and hence this requirement is not considered further herein. Hence the main requirement is that the probability of inadvertent contamination of a Europan ocean shall be less than $1\text{x}10^{-4}$. This can be met through ensuring that the penetrator has zero survivor organisms at the earliest credible encounter point for Europa, which is Europa Orbit Insertion (EOI). Thus the requirement simplifies to a probability of contamination at EOI, P_{cEOI}, :

$$P_{cEOI} = N \times P_{cs} \times P_{rad} \leq 1$$

Where N is microbial bioburden at launch; P_{cs} is probability of cruise survival and P_{rad} is probability of Jovian tour survival. Suitably conservative values will be used for N, P_{cs} and P_{rad}, in line with JEO approaches, based upon appropriate microbiological and radiation assessments.

PP planning will be implemented from the earliest mission phases, and will necessarily be considered in conjunction with radiation tolerance and spacecraft accommodation issues. All flight subsystems/element will be required to demonstrate compliance with the overall flight requirement of $P_{cEOI} = \leq 1$ by demonstrating compatibility with Dry Heat Microbial Reduction (DHMR - typical protocols involving time vs. temperature profiles ranging from 125°C for 5 hours to 110°C for 50 hours) and/or with environmental radiation sterilisation.

DHMR and radiation compatibility will be considered when drawing up approved parts and materials lists. Battery technologies may require particular attention. Due consideration shall be given to the presence of any perennial heat source such as RHUs that could potentially form a warm liquid micro-environment in which terrestrial organisms might prosper (NB: JEO impacts Europa at EOL).

The AIT approach requires some consideration. Those elements that will not be subject to effective environmental sterilisation (e.g. because they are shielded) will require assembly in appropriate bioburden controlled conditions. Recontamination prevention e.g. by biobarriers may be required in such cases. The possibility of aseptic operations exists (e.g. for reworks or fitting of any non DHMR compatible subsystems) and requires further investigation

3.2.3 Implementation approach for JGO Penetrators

For the JGO penetrators, there exists a different scenario. This is due to the reduced radiation dose likely for JGO (37 krad behind 8 mm Aluminium up to Ganymede Orbit insertion; as opposed to order 10 Mrad for JEO). Further, the ancient surface of Ganymede is much less of a concern with regard to surface subduction and contamination of a liquid ocean in the same way as Europa.

The eventual classification of JGO under COSPAR rules is hence still TBD; currently it may be considered category II although this may be reclassified to category III if the mission includes Europa flybys (and, conceivably, category IV if Ganymede itself were reclassified as such a target body).

We will liaise with ESA PPO to ensure that up to date information regarding JGO penetrator classification is considered. A trade study may be required to consider the relative benefits of treating - at least in early mission study stages - the JGO penetrators as equal (in terms of PP treatment) to their JEO counterparts. This approach may bring concomitant benefits in terms of consistency of approach and robustness with respect to change in designated COSPAR category, at the cost of potentially implementing a more stringent PP approach than may ultimately be required. The cost increase could be mitigated by a timely definition of PP category and appropriate implementation approach.

7. Study team organisation

The Instrument Study Lead Institute will be MSSL/UCL (Mullard Space Science Laboratory of University College London).

The study teams will be organized around the interests in the major system aspects as follows (*industrial partners are marked with an asterisk) :-

System
- Lead, project management, system engineering - MSSL/UCL
- Planetary Protection - PSSI, Open University, UK.
- Radiation – Leicester University, UK.

Science
- MSSL
- Centro de Astrobiologia-INTA-CSIC, España
- DLR
- IFSI-INAF, IMM-CNR and ICTP Italy
- The Open University, Milton Keynes, UK.
- University of Lancaster
- Université Paris, France.
- UCL/Birkbeck

Impact Into Icy Regoliths
- UCL/Birkbeck College, London,
- Cavendish Laboratory
- Imperial College, London
- QinetiQ
- DLR

Impact Survival Modelling & Testing
- Cavendish Laboratory (small scale impact testing)
- *QinetiQ (impact modelling and large scale impact testing)

Spacecraft Attachment - *Astrium,*SSTL, *QinetiQ, DLR
Descent Module - *Astrium, *SSTL, *QinetiQ, DLR
Penetrator Platform
- impact survival, penetrator platform shell, communications, power - * QinetiQ
- thermal modelling - *Astrium
- communications, power - *SSTL
- data handling - MSSL/UCL

Penetrator scientific instruments
- accelerometers, radiation monitor -* QinetiQ
- biogeochemical package – PSSRI, Open University, UK.
- descent camera, sample imager - MSSL/UCL
- geophysical chemistry - University of Leicester, UK.
- heat flow and thermal properties – PSSRI, Open University, UK.
- magnetometers - Imperial College London
- microseismometers - Imperial College London
- micro-thermogravimeter science instrument - IFSI-INAF, IMM-CNR, Italy.
- permittivity – IAF, Austria.
- radio beacon – JIVE, Netherlands
- sample acquisition, heat switch, thermal probes - SSC, UK
- sample handling - Magna Parva, UK

A top level study organigram is shown in Fig. 7.1.

8. Expected study outputs: reports, models, etc

A variety of reports would be expected from this study including :-
1. Study Plan
2. Technical Notes (on specific areas)
3. Progress Reports
4. Final Report: Penetrators for EJSM mission to Ganymede and Europa
5. Ganymede and Europa Penetrator System Technology Development Roadmap
6. Cost estimate for a flight development system.

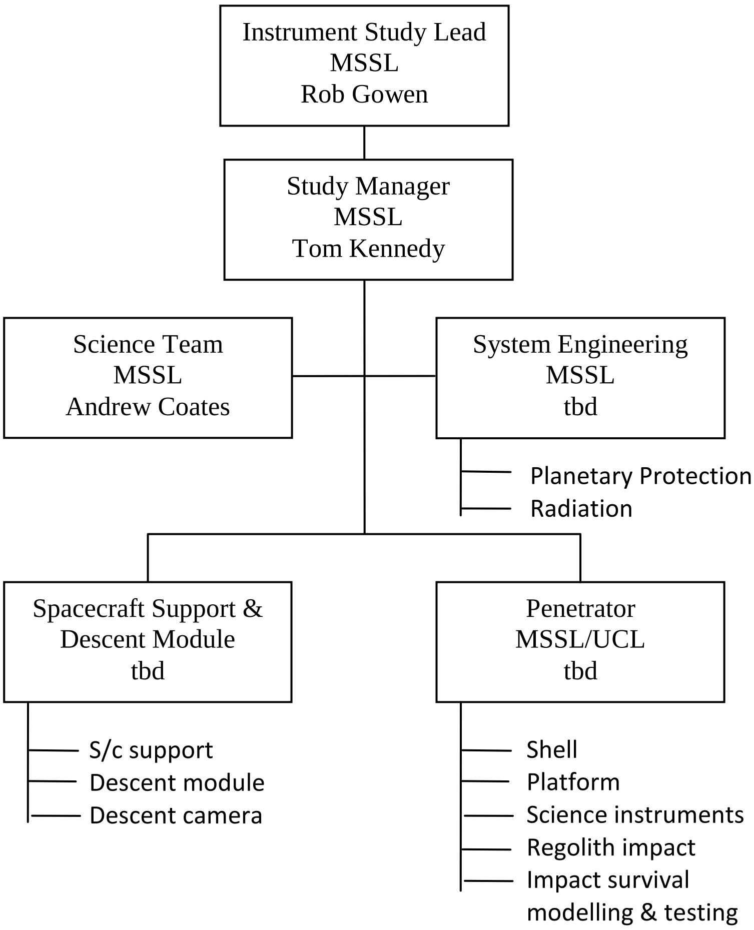

Figure 7.1: Study Organigram

9. Proposed funding scheme of the study through member states

Each member state in this study will be funded through its own national funding body.

The UK activities will be funded via an ongoing penetrator technology development program utilising both STFC, and associated ESA funding for penetrators proposed as a response to UK 'just-retour' shortfall.

DLR, Germany will use internal funds to support these studies.

10. Preliminary list of technology developments

Currently, technology developments are only identified for the penetrator system, and focused mostly on its impact survival and ability to operate successfully after impact. The study of the spacecraft attachment and descent module may raise issues requiring additional technology developments.

For each development item the following sequence of technical developments are planned:-

1. Element Design.
2. Impact Modelling, as required QinetiQ at Fort Halsted, England).
3. Small Scale Testing, as required (Cavendish Laboratory, Cambridge, England).

4. *Finally, though not planned for this study (depending on funds), we would undertake Full Scale Testing (at the Pendine Sands test site in Wales), preceded by vibration and thermal vacuum testing.

The following preliminary list of technology developments includes :-

1. Definition, characterisation and qualification of icy regolith simulant for use in impact testing, and the small and full scale test configurations.
2. Penetrator shell
3. Penetrator platform elements (communications, power, data handling, RHU and heat switch)
4. Penetrator scientific instruments.

Though many of the above elements have participated successfully in prior full scale impacts at Pendine, impact into icy regolith is expected to be more severe, though within the expected bounds of survivability.

** The parallel MoonLITE development program could provide a timely opportunity to perform such development tests, though the extent to which they can be realised will depend on available funding and its timing.*

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