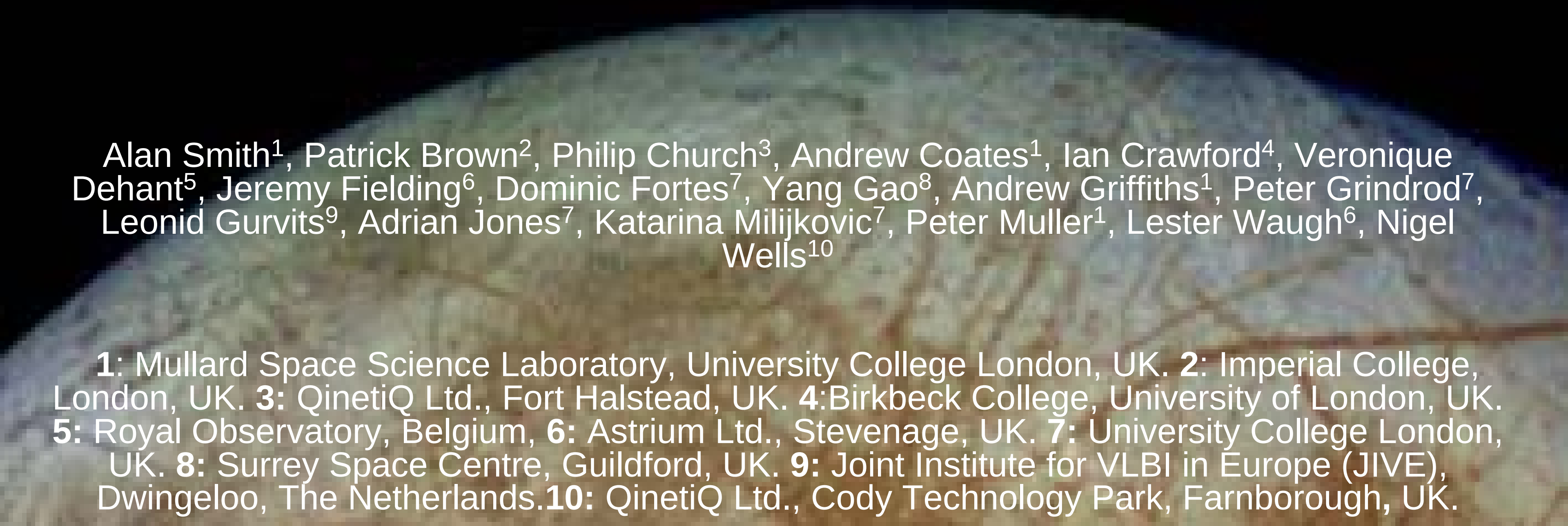
An Update on Penetrators for Ganymede and Europa

Presented by Rob Gowen, MSSL/UCL

on behalf the penetrator Consortium



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Science Objectives/Synergy

❑ Provide Science not possible from orbit

•Direct material sampling & identification -> astrobiology, chemistry
•Determine deep internal body structures, quake magnitudes and frequencies
•Surface mechanical, electrical & environment properties

❑ Provide Synergies with Orbiter measurements

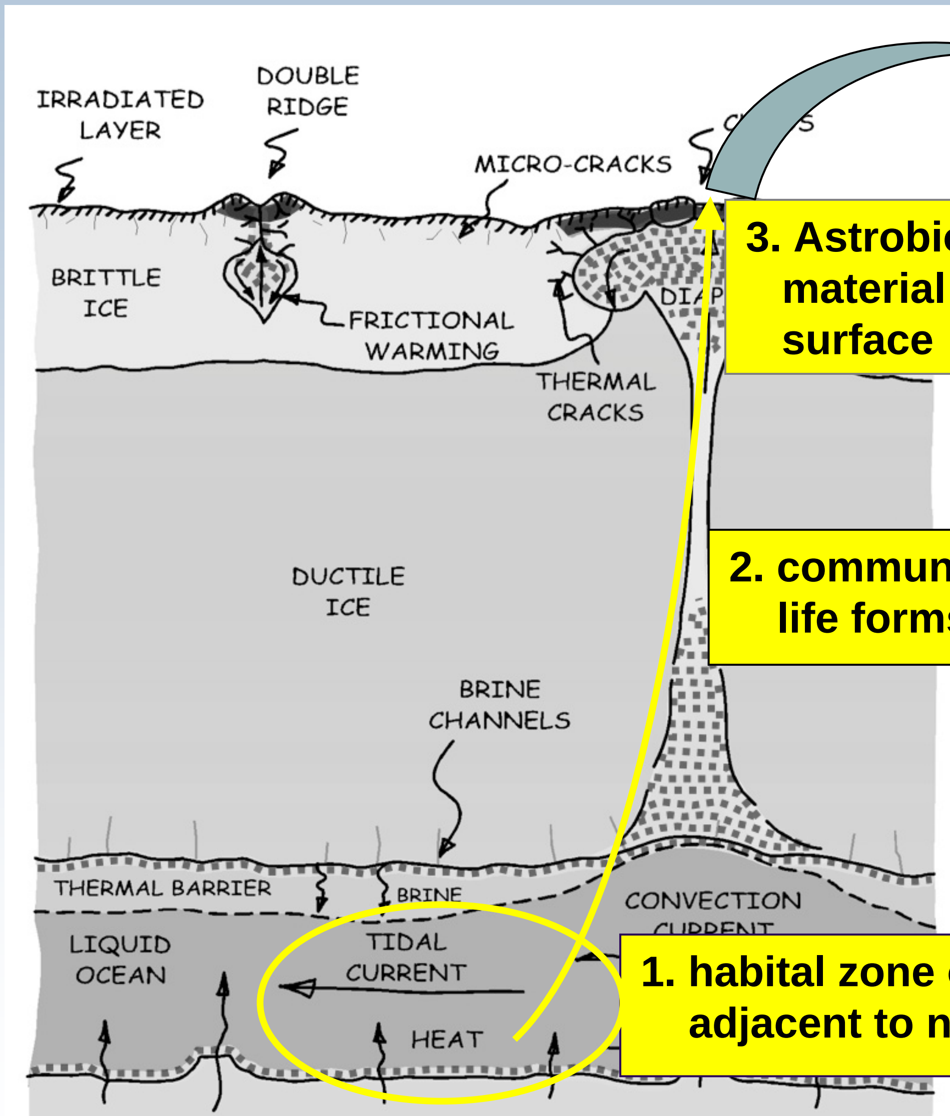
•Identify/confirm actual surface chemicals indicated by orbital observations
•Orbital instruments can extend observations at specific surface locations globally to whole body.
•Help interpret ground penetrating radar data.

❑Provide Synergies with observations of other bodies

•Can compare Ganymede & Europa surface measurements (astrobiology, chemical species...)
•Improve interpretation & confidence of orbital measurements of other Jupiter moons.

New Science + Ground truth

Astrobiology material search…



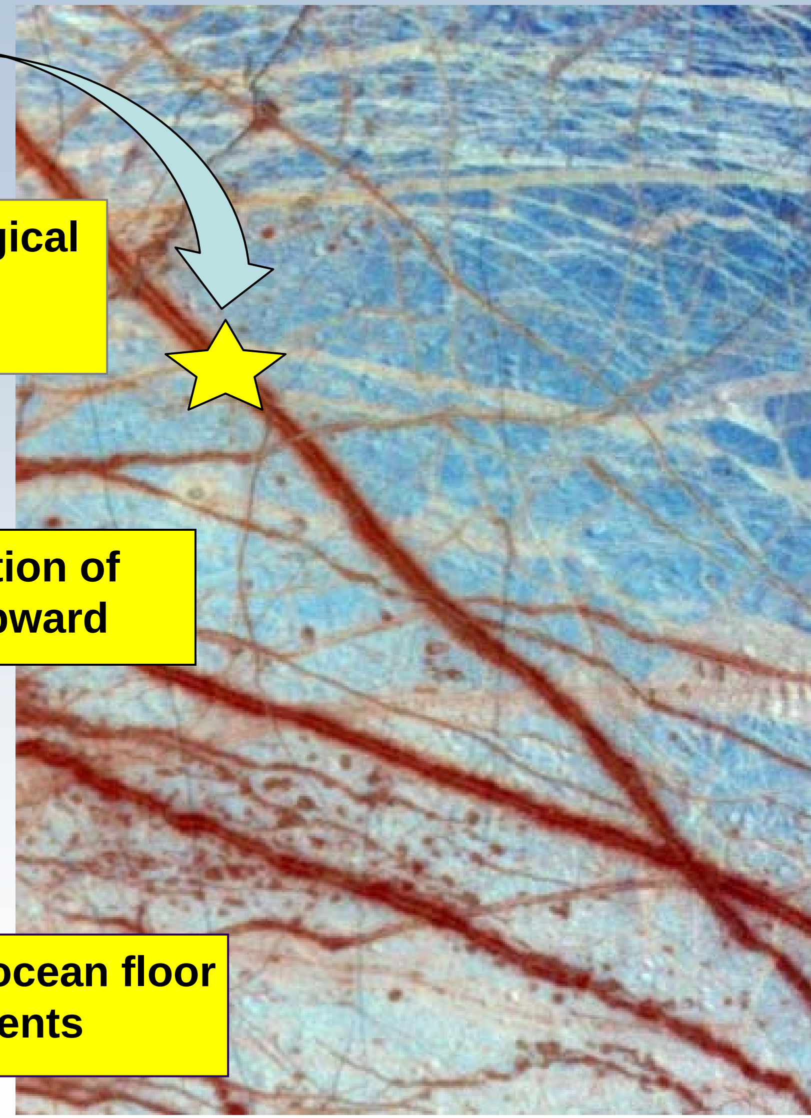
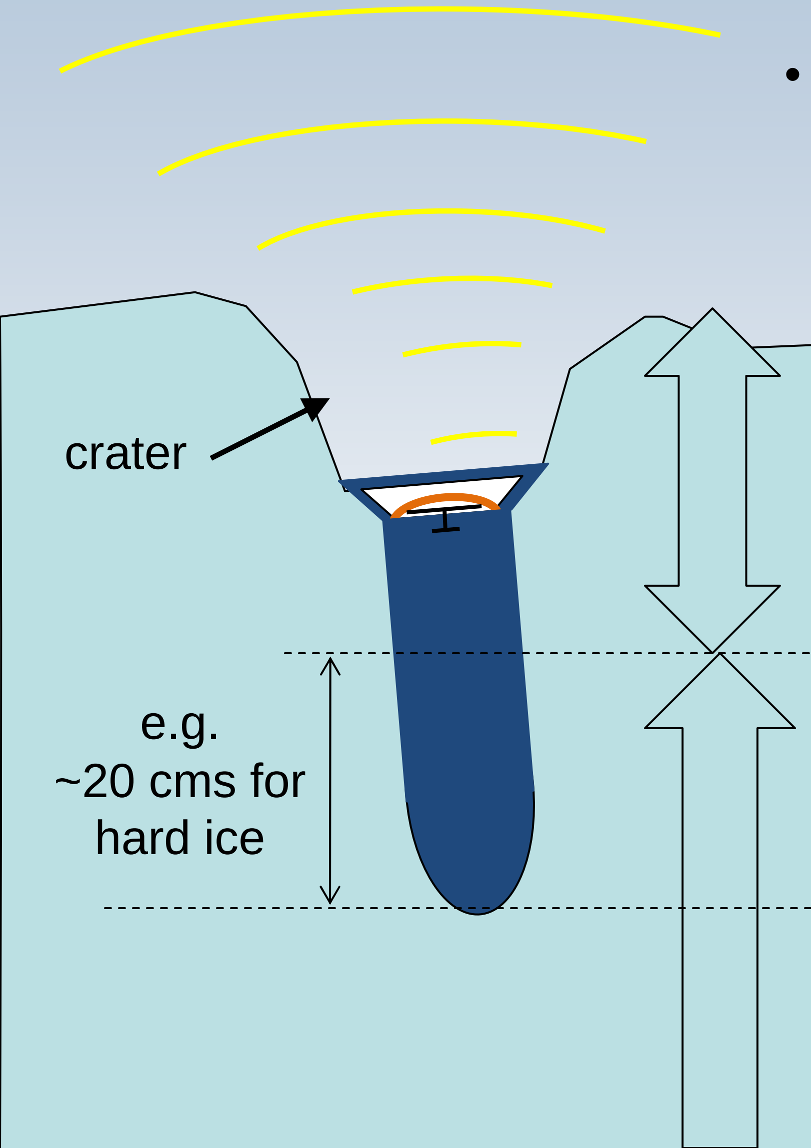


Diagram adapted from K.Hand et. al. Moscow'09, who adapted it from Figueredo et al. 2003

Astrobiology Material on Europan Subsurface

- **Total penetration depth not very large**. (**from ~20cm to 2m below gardened regolith)**
- **High radiation environment (age of exposure).**
  - **degree of chemical bonding damage ?**
  - **mechanical damage due to impact/gardening**



Regolith *(few mm to1.5m)*

- *heavy mechanical and radiation material degradation.*

Solid layer *(ice/other material)*

- *no significant mechanical degradation*
- *less radiation with depth.*

completely/partially degraded chemical bonds

sample point ?

unmodified chemical bonds

Candidate Scientific instruments

- 19 candidate instruments
- grouped according to scientific area
- instruments marked in yellow contribute to both astrobiology & geophysics
- So can make selection which includes both geophysics and astrobiology

Geophysics **Ocean/interior** **Astrobiology habitat**	**Geophysics** **Surface/chemistry** **Astrobiology biomarkers**	**Environment** **Astrobiology relevant**
Seismometer Engineering tiltmeter	Mass spectrometer	Light level monitor
Magnetometer	Gravimeter	Radiation monitor
Radio beacon	X-ray spectrometer	Thermal sensor
Geophysical tiltmeter	Microscopic imager	
Heat flow probe	Astrobiology (pH,redox)	
Microphone	Descent camera	
	Accelerometer	
	Dielectric/permittivity	

Potential Science Return

Geophysics Ocean/interior **Astrobiology habitat**	**Geophysics Surface/chemistry** **Astrobiology biomarkers**	**Environment** **Astrobiology relevant**
Habitability. Subsurface ocean characterisation - depth	chemical distribution: astrobiological cf. geological origin. *(even if chemical bonds completely degraded due to heavy radiation)*	Radiation level (->depth) combine with age to expected level of biochemical degradation
- Ocean currents - salinity	Determine specific biochemical presence (if little radiation degradation)	Temperature Diurnal variation (indication of depth)
Quake frequency and magnitude distribution and tidal coordination	Lifeform shape *(even if heavy radiation degradation)* UV flouresence *(if little radiation degradation)*	
Other subsurface features	(pH,redox) *(if little radiation degradation)*	
	Isotope ratios (*even if heavy radiation degradation)*	
	Material layering and strength	

Implementation

Ganymede↔Europa Comparison

❑ Differences

Ganymede	Europa
•Geophysics 1'st Science priority •Astrobiology 2'nd Science priority	•Astrobiology 1'st Science priority •Geophysics 2'nd Science priority
•High radiation environment •Cat II planetary protection	•Extreme radiation environment •Cat IV planetary protection
•200km delivery/comms orbit •Higher delivery Δv ~2km/s •Prefer no RHUs	•100km delivery/comms orbit •Lower delivery Δv ~1.4km/s •RHU's OK

❑ Commonalities

- similar impact materials and temperatures
- common penetrator shell, internal architecture, and impact survival
- common penetrator subsystems (comms, processing, power) (rad. differences ?)
- some common scientific instruments (the more the better -> synergy).
- common polar orbiter (comms) (orbital period: ~2.5 hrs Ganymede,~2.1 hrs Europa)

Penetrator Development Activities

2 main activities :-

- Penetrator System Study
  - ESA funded study (special provision for UK)
  - Primarily for icy moons of Jupiter, with strong **Ganymede** focus.
  - Completes July 2010
  - Currently less than 3 months into 9 month study (preliminary results)
  - Study requirement for 2 week Ganymede observational lifetime, and to assess battery only solution.

- Instrument TDA (Technical Development Activities)
  - ESA coordinated
  - Nationally funded
  - Target TRL 5-6 by end 2012

Penetrator System Study

Objectives
- feasible, low risk, science capability
- resource estimates (mass, power, volume, telemetry)
- include resource margins, high TRL

Inputs/Guidelines
- total system mass <100 kg
- prioritized instruments with geophysics highest priority

System study activities and status
- Preliminary assessment of requirements & system design complete.
- Baseline scenario agreed and studies continue..

Impact site selection & characterisation
Penetrator delivery system & spacecraft attachment
Penetrator body and subsystems
Environment (thermal, radiation & planetary protection)

Model Payloads ?

Ganymede penetrator

- payload –> desire geophysics oriented
- All geophysics instruments selected + radiation monitor and thermometer
- Ad-hoc use of baselined UHF penetrator comms system as radio beacon for tidal displacement measurements not possible *

*(*because of sensitivity limitations with low UHF frequency. Alternative radio science experiment is being considered to address science that would have been performed by radio beacon. Will need to address key issues of sensitivity, power, comms visibility, oscillator stability, mass/power etc)*

Europa penetrator *(not part of system study)*

- payload -> desire astrobiology oriented
- Require chemical analysis of local material
- Requires penetrator design to be 2-part (if no RHUs)
    i. nose section: short lifetime instruments -> astrobiology
    ii. rear section : long lifetime instruments -> e.g. seismometer.
- Probably a chute for surface material ingress through small aperture in penetrator (to be analysed)

Ganymede Model Payload

- 8 Ganymede selected instruments marked with *
- Instruments include all astrobiology & geophysics science fields
- No surface material chemistry/astrobiology instruments (simplifies architecture and eliminates additional lifetime problems)

Geophysics Ocean/interior Astrobiology habitat	Geophysics Surface/chemistry Astrobiology biomarkers	Environment Astrobiology relevant
* Seismometer * Engineering tiltmeter	Mass spectrometer	Light level monitor
* Magnetometer	Gravimeter	* Radiation monitor
Radio beacon	X-ray spectrometer	* Thermal sensor
* Geophysical tiltmeter	Microscopic imager	
Heat flow probe	Astrobiology (pH,redox)	
Microphone	* Descent camera	
	* Accelerometer	
	Dielectric/permittivity	

Ganymede Model Payload Resources

Science Payload

1. Accelerometer
2. Magnetometer
3. Seismometer
4. Microphone
5. Geophysical tiltmeter
6. Engineering tiltmeter
7. Thermal sensor
8. Radiation monitor

Penetrator Payload Resources	Value	Value including 20% maturity margin
mass	1.08 kg	1.3 kg
energy	53.5 Whr	64.2 Whr
volume	462 cm^3	554 cm^3
telemetry	7.6 Mbits	9.1 Mbits

PDS Payload

1. Descent camera

PDS Payload Resources	Value	Value including 20% maturity margin
mass	0.16 kg	0.19 kg
energy	0.05 Whr	0.06 Whr
volume	27 cm^3	32.4 cm^3
telemetry	2.0 Mbits	2.4 Mbits

Resources are sized for lifetime requirement of 2 Ganymede orbits

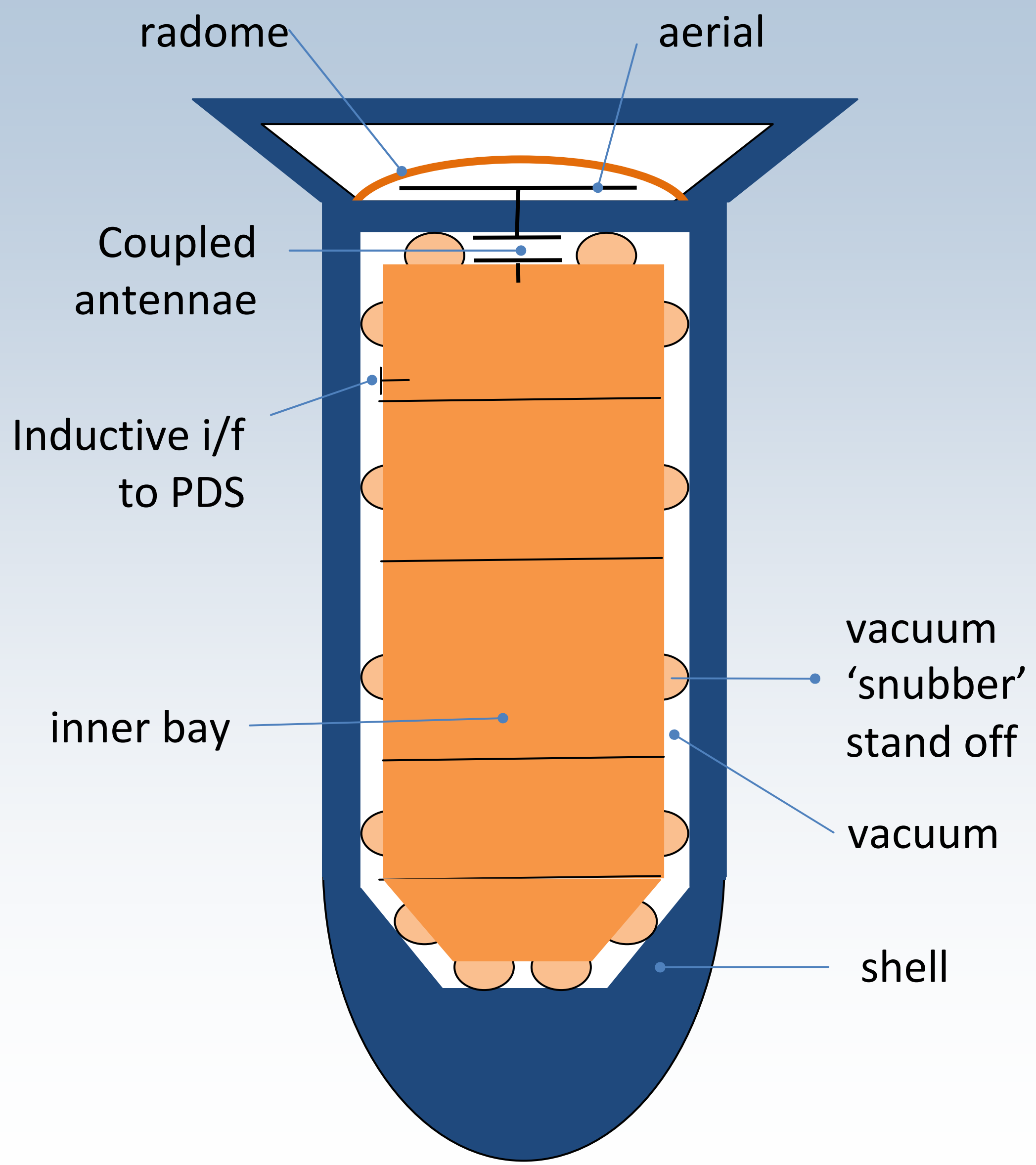
Penetrator Thermal Design

- External environment very cold (~80K) with moderate conductivity (significant water ice component)
- Requires (vacuum flask) design to reduce heat losses to achieve operational lifetime of 2 weeks just using battery power (no RHUs)

Insulation	Heat loss	Lifetime
Solid layer	~ 50 Watts	few hours
Granular	~ 10 Watts	day
Vacuum	< 1 Watt	2 weeks

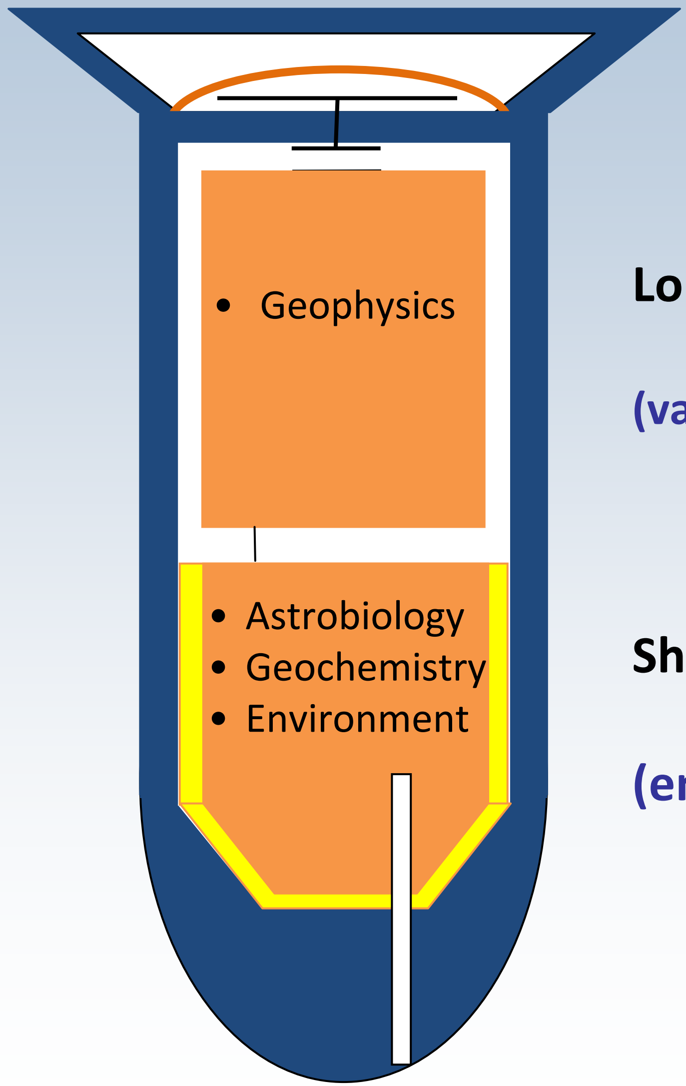
- Design solution identified, including non-conductive links for comms and PDS interfaces
- More difficult to implement instruments which require external access

Ganymede Penetrator Schematic



- **Vacuum flask concept to minimise thermal losses**
- **No conductive external links (comms or PDS link)**

Europa Penetrator Concept



Not part of system study (applied concept of system study to Europa)

Long lifetime bays

(vacuum isolated)

Short lifetime bays

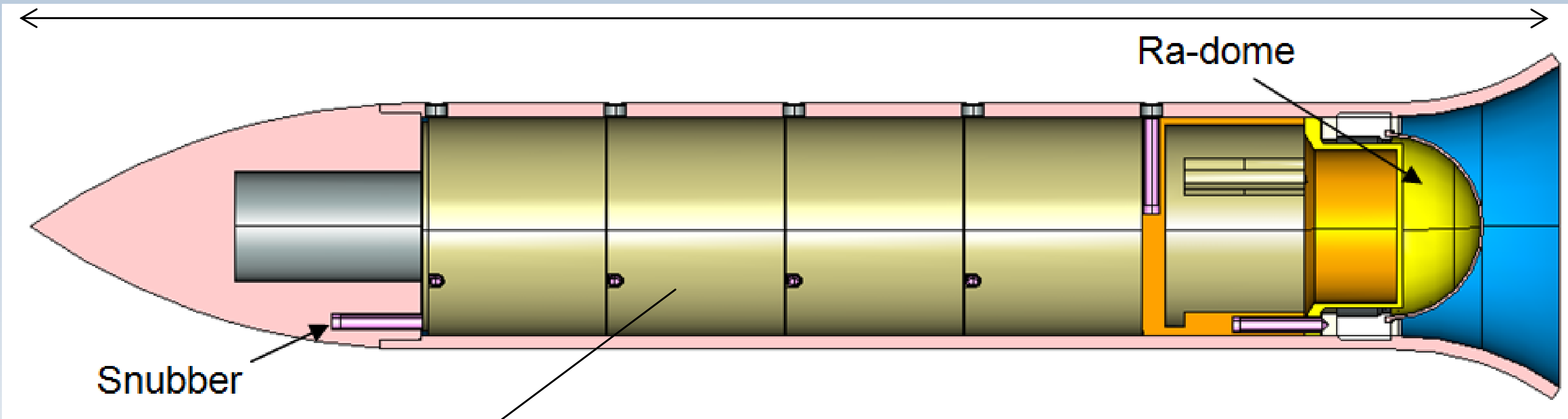
(enable contact with environment)

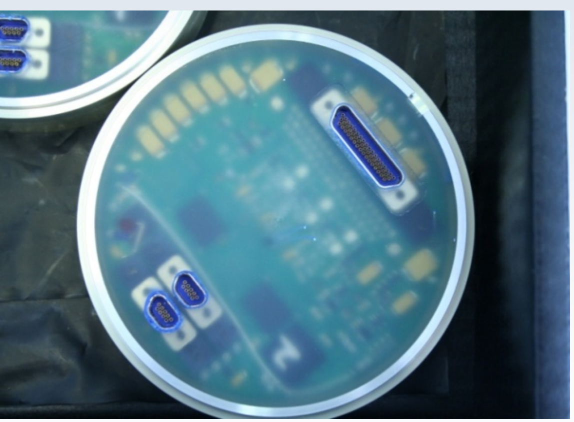
Penetrator

- Communications (QinetiQ)
  - UHF baseline
  - Patch aerial protected by radome at rear of penetrator
  - No conductive path to aerial
  - Will perform surface materials attenuation assessment
- Penetrator (MSSL/UCL)
  - Preliminary mechanical design performed (which accommodates subsystems and model payload)
  - Preliminary electronic system design performed (including harnessing, dpu, pcu)
- Impact survival (QinetiQ)
  - To perform strength of materials assessment (titanium alloy, steel)
  - Design for shallow penetration to minimise communications signal attenuation.

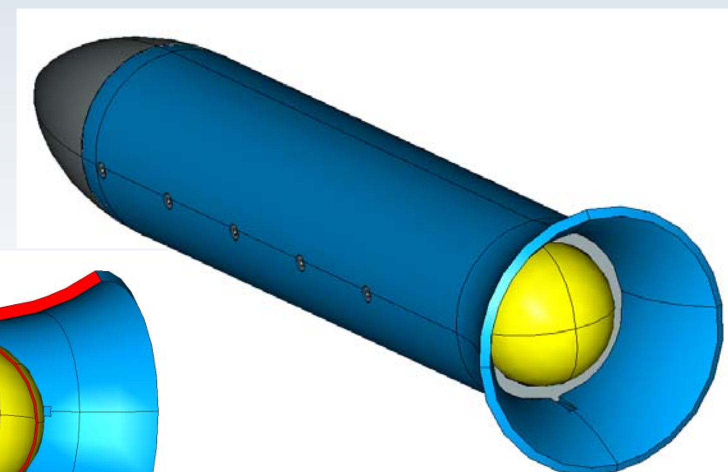
Preliminary Penetrator design

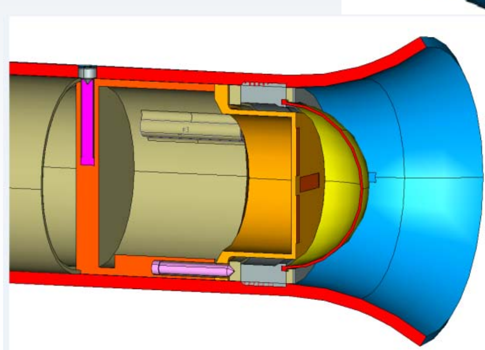
Length ~ 0.5m; Radius ~0.04m;





Example instrument Payload bay





Penetrator Delivery

- Penetrator Delivery (Astrium)

  – Optimal delivery is from circular orbit around Ganymede (for mass, communications, science).

  – Bipropellant delivery system solution design.

  – Orbiter can be visible for comms during descent (enables HK to confirm correct delivery milestones)

Impact site selection criteria

body orbit direction

Polar impact sites

- colder
- much more frequent comms slots (every ~2 hrs)
- no line of sight to Earth
- worst for tidal displacements

Jupiter

Leading hemisphere [1]

- less energetic electron radiation
- more regolith gardening (young features < 10^5 yrs)

Hemisphere facing Jupiter

- less thermal variation

Ganymede or Europa

Equatorial impact sites

- warmer
- fewer comms slots (~every 3.5 days Ganymede, 1.7days Europa)
- direct line of sight to Earth periodically
- best for tidal displacements

[1] *Patterson,Paranicas, Prockter, 2009*

Preliminary Mass Estimates

UCL

Ganymede Penetrator System

~1.3 kg	Payload (including 20% margin)
~10.6 kg	Penetrator (including 20% margin)
~ 63 kg	Delivery System*
within100 kg [ESA study limit]	Study total mass allocation only sufficient to deliver a single penetrator to Ganymede ** (does not include any additional JGO fuel)

* *expect Europa delivery system mass to be significantly less due to much lower ΔV.*

** *Is for a batteries only solution to provide 2 weeks operational lifetime*.

Summary / Way forward

❑ Summary

- Identified design concept for a batteries only solution for a 2 week operational lifetime.
- Selected a modest 1.3kg payload within an 11kg penetrator, plus a 63kg delivery system for Ganymede.
- Can only deliver a single penetrator within 100kg [ESA study limit] (excluding any additional JGO propellant)
- Concept realised for a Europa penetrator (not part of system study)

❑ Way Forward

- Continue current study, and improve definitions and allow reductions of 20% mass margins where appropriate.
- For significantly reduced mass will need to look at alternative solutions and their TRL (payload, lifetime requirement, RHU, subsystem elements, delivery system)
- Need to produce similar level of analysis for Europa penetrator.

- End -

Europa Candidate Impact Sites

Candidate sites of potential upwelled biogenic material

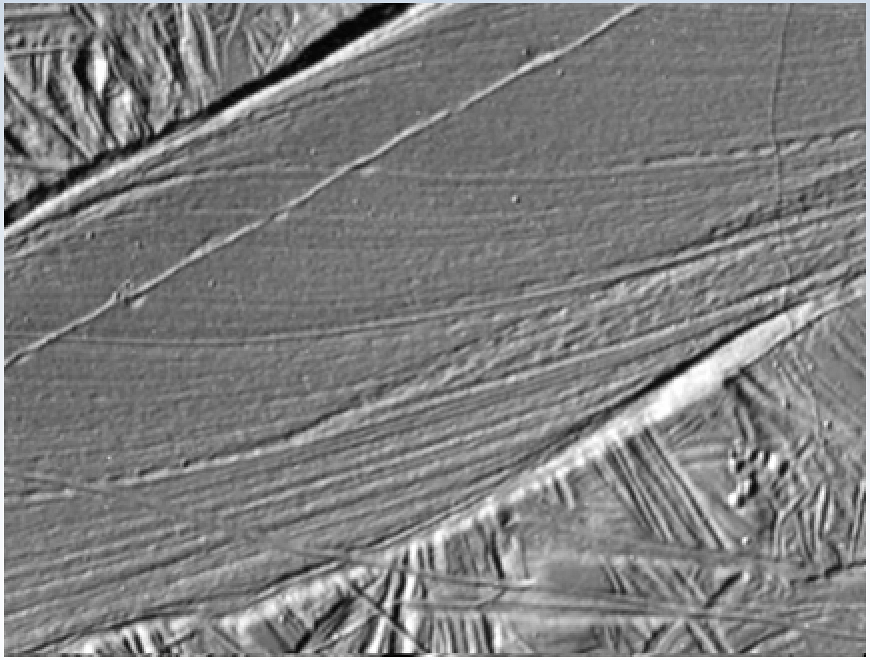
a) gray dilational bands *[Schenk, 2009]*

- small slopes (average 5±2°,15%>10°) ~20km wide.
- other regions analysed slopes<30°
- age ? (effect of radiation)

b) chaos, lenticulae regions

[Proctor et al., Moscow, Feb09].

- reasonably flat/smooth in some areas
- young.



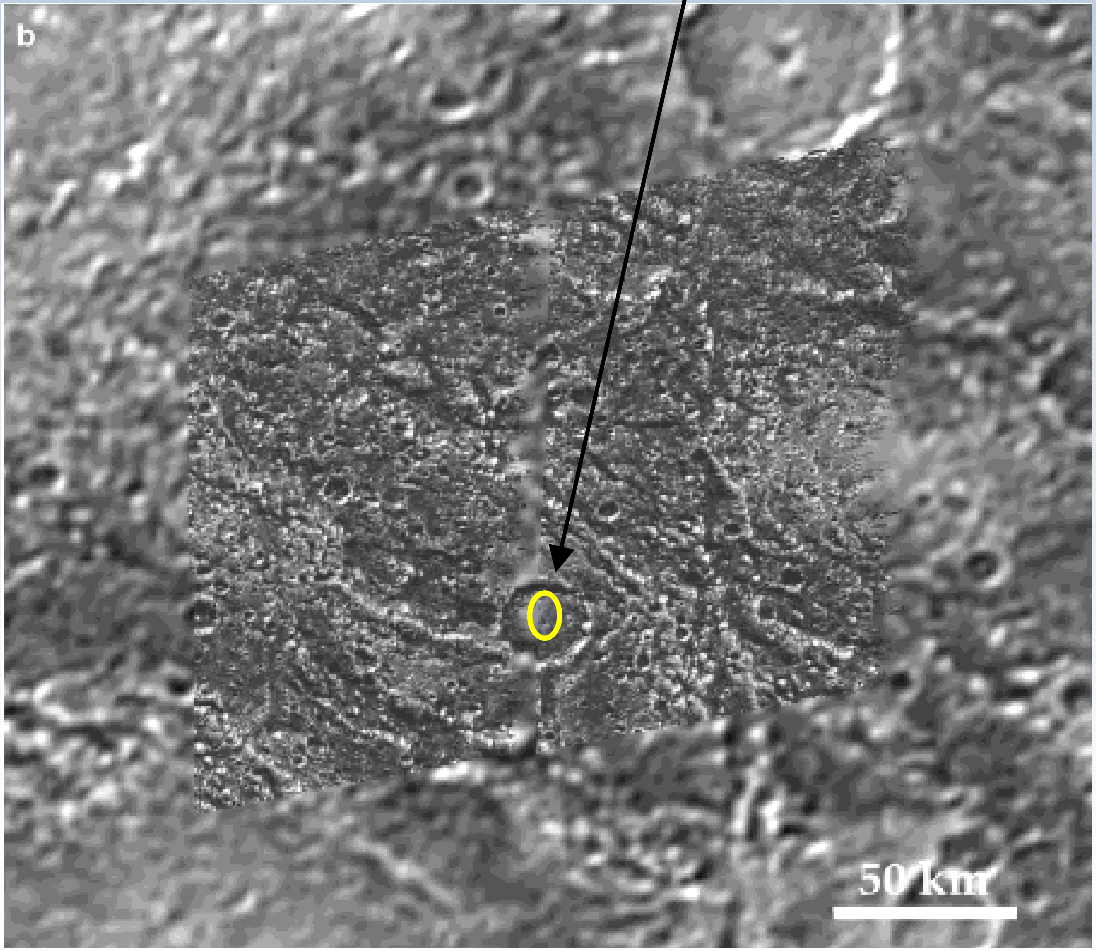
Galileo image

Ganymede example Impact Area -2

- Ea Crater floor
- Dark terrain likely dominated by non-ice components

Impact Site – B: 17.7°N

region	**Galileo Regio**
location	17.7°N, 148.7°W
size	10x20km
slopes	3 to 25°
hazards	~10-40%
temperature	90-130K diurnal cycle



High resolution Galileo mosaic 77m/pixel within Voyager image [IR3: Prockter et al, 1998]

Impact site characterisation parameters

Parameter	Comments
Target area	
• Impact ellipse	Impact on GNC
• Impact slopes	Ricochet avoidance
• Hazards	Avoid fissures, craters, etc, within impact site
Material Properties	
• Impact mineralogy	Harder impact, Ricochet avoidance, RF attenuation
• Impact hardness	Harder impact, Ricochet avoidance, RF attenuation (backfill)
• Thermal conductivity	Higher thermal losses
• Chemical composition	RF attenuation
• Dielectric properties	RF attenuation
Environment	
• Temperature	Thermal losses
• Radiation	Equipment survival

Ganymede Impact Area -1

- Plank line ridge PLT2 in lineated terrain
- Bright terrain likely dominated by water ice
- Suggested relatively old (degraded craters)

Impact Site - A: Equatorial

region	**Uruk Sulcus**
location	0.8°N, 160°W
size	5x5 km up to 20km
slopes	3 to 20°
Hazards	~30%
temperature	100-150K diurnal cycle

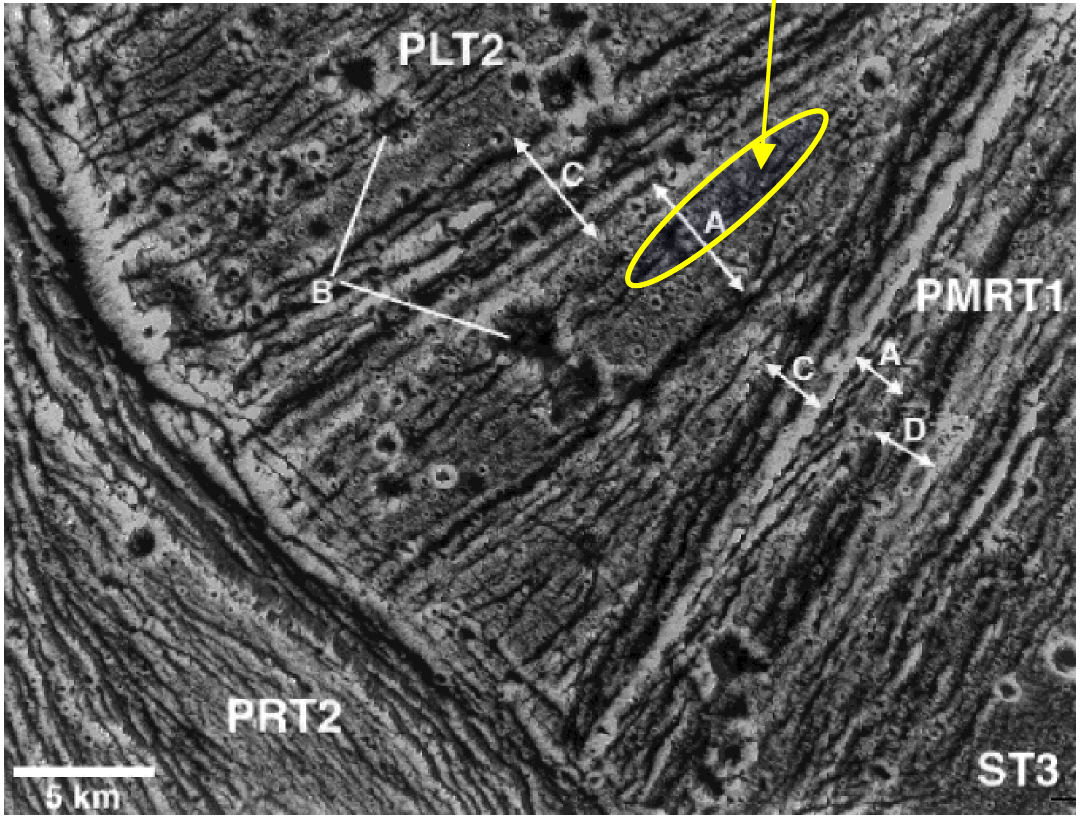
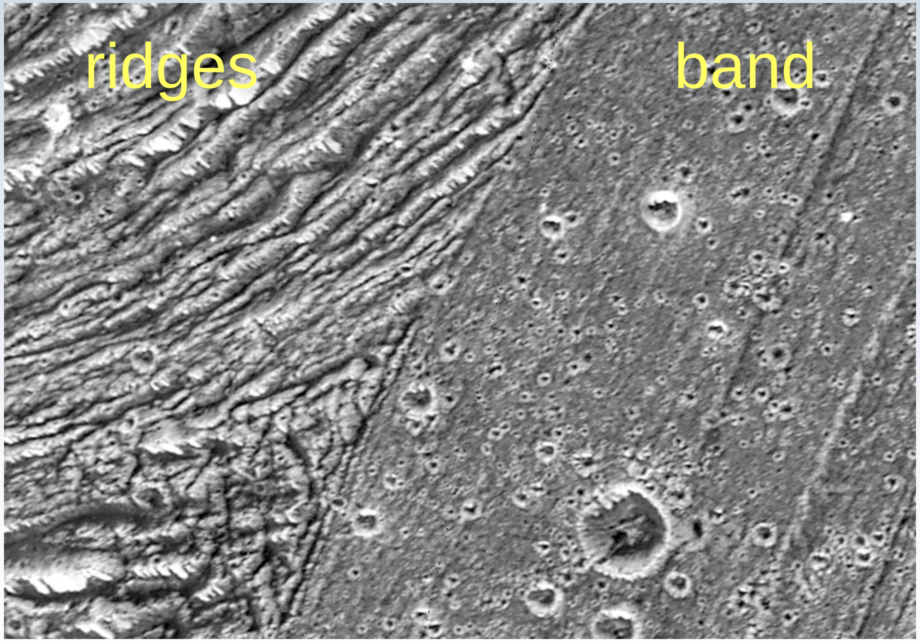


FIG. 5. Detail of lineated grooved terrain in Uruk Sulcus (units PLT2 and PMRT1). Examples of (A) plank-like ridges. Examples of the ubiquitous small-scale dark lineations (B) are highlighted where they transect preexisting craters. These dark lineations define small-scale blocks between them. Prominent troughs (C and D) are marked across their widths and typically contain multiple subparallel small-scale blocks; trough D shows a ramp-like termination style toward the southwest. Note the abundance of craters, some of which are degraded, suggesting a relatively old age for the NE–SW trending PLT2 and PMRT1 units. In contrast, the NW–SE trending parallel ridged terrain unit (PRT2) shows few large craters. Boundary relationships suggest that the parallel ridged terrain formed at the expense of the lineated grooved terrain units.

[IR4: Pappalardo et al, 1998]

Portion of Galileo Regio
(old dark terrain)
Note smoother area on right



25km