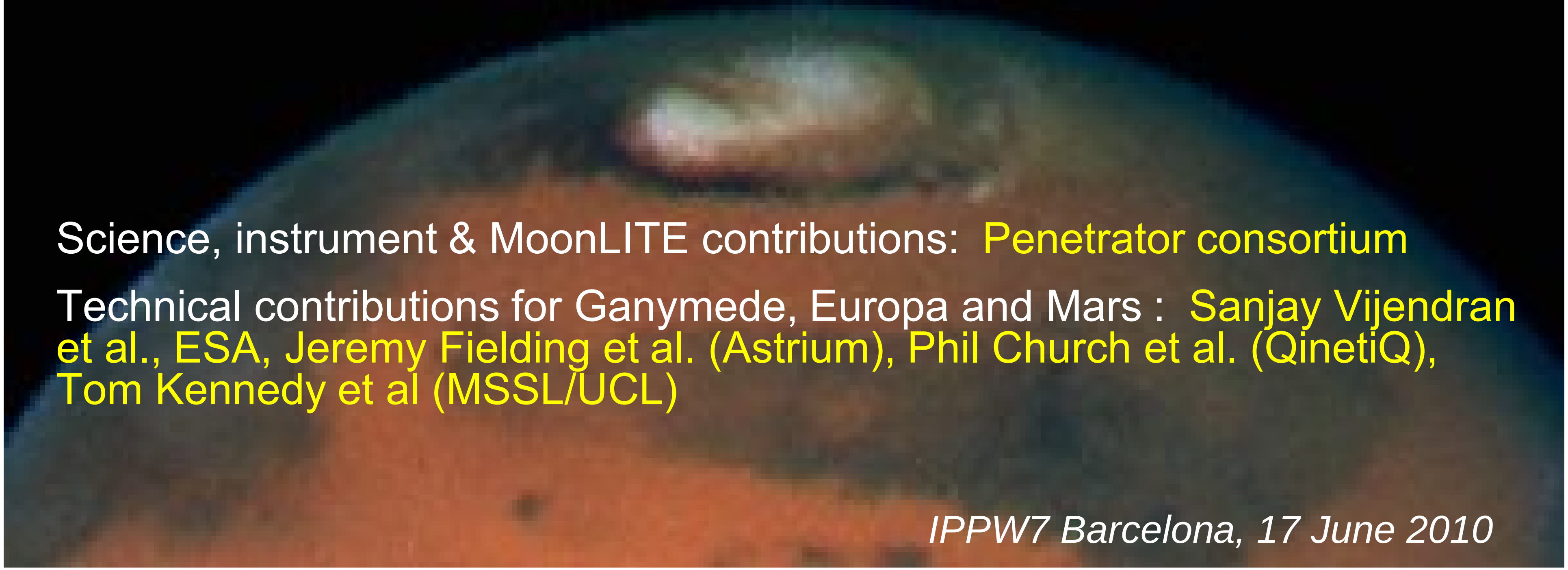
Potential Applications of Micro-Penetrators within the Solar System

Presented by Rob Gowen, MSSL/UCL

on behalf the Penetrator Consortium

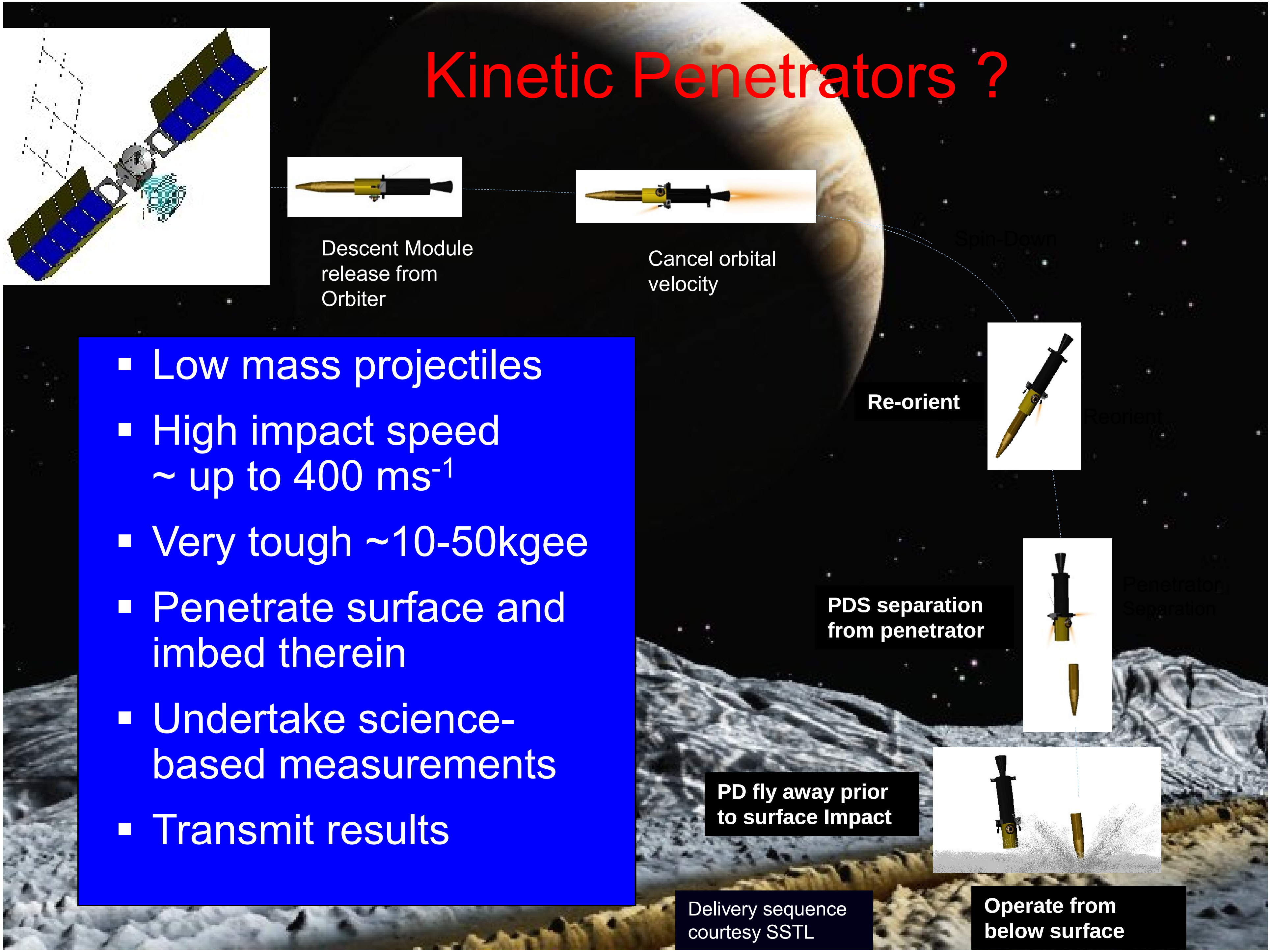


Science, instrument & MoonLITE contributions: Penetrator consortium

Technical contributions for Ganymede, Europa and Mars : Sanjay Vijendran et al., ESA, Jeremy Fielding et al. (Astrium), Phil Church et al. (QinetiQ), Tom Kennedy et al (MSSL/UCL)

IPPW7 Barcelona, 17 June 2010

Introduction


Kinetic Penetrators ?
Descent Module release from Orbiter
Cancel orbital velocity
Re-orient
PDS separation from penetrator
PD fly away prior to surface Impact
Operate from below surface
Delivery sequence courtesy SSTL
▪ Low mass projectiles
▪ High impact speed ~ up to 400 ms-1
▪ Very tough ~10-50kgee
▪ Penetrate surface and imbed therein
▪ Undertake science-based measurements
▪ Transmit results

Why penetrators ?

Advantages:

- Simpler architecture
- Low mass
  - Low cost
  - Explore multiple sites
  - Natural redundancy
- Direct contact with sub-regolith (drill, sampling)
- Protected from environment (wind, radiation)

Limitations:

- Require a suitable impact surface
- Low mass limits payload options
- Impact survival limits payload options
- Limited lifetime
- Limited telemetry capacity

Penetrator Science Capabilities

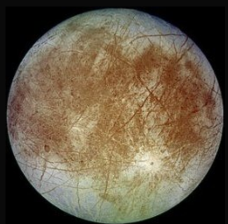
A wide variety of candidate Instruments …

Geophysics (interior)	Geophysics (surface/chemistry)	Environment
Astrobiology habitat	*Astrobiology biosignatures*	*Astrobiology relevant*
Seismometer *Engineering tiltmeter*	*Mass spectrometer*	*Light level monitor*
Magnetometer	*Thermo gravimeter*	*Radiation monitor*
Radio beacon	*X-ray spectrometer*	Thermal sensor
Gravimeter	*Raman, IR, or UV-Vis-NIR spectrometer*	Atmospheric package (pressure, gas, humidity)
Geophysical tiltmeter	*Microscopic imager*	
Heat flow probe	*Astrobiology Habitability Package*	
Microphone	*Descent camera*	
	Accelerometer	
	Dielectric/permittivity	

Opportunities — Status

MoonLITE (UK) → Postponed indefinitely following adverse UK funding situation. Pursuing other options

JGO (ESA) → Mass budget insufficient to include penetrators in JGO reference payload



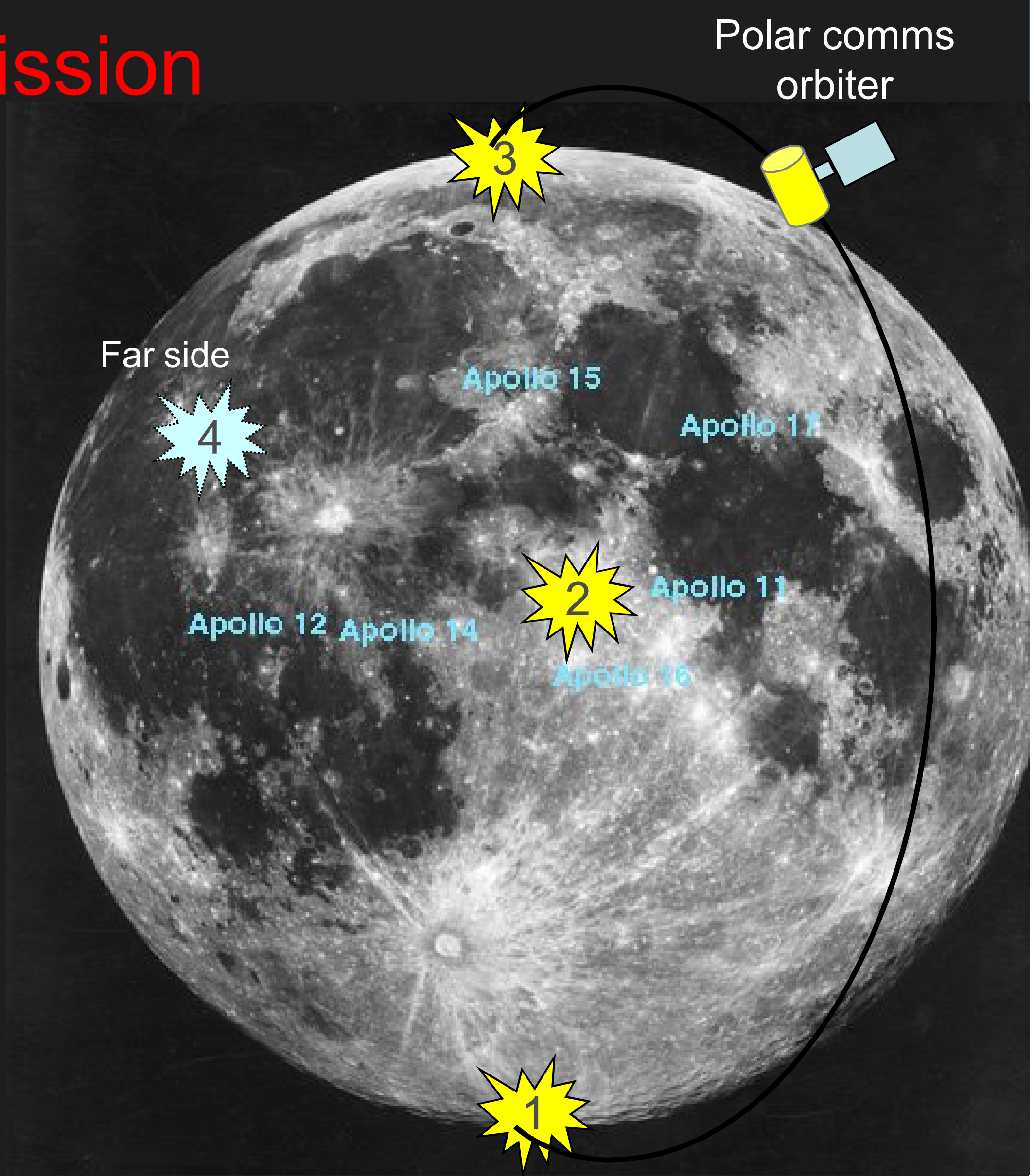
JEO (NASA) → Penetrators currently being studied for inclusion on JEO

Mars ? → Mars options being studied in current ESA contract

Moon

MoonLITE Mission

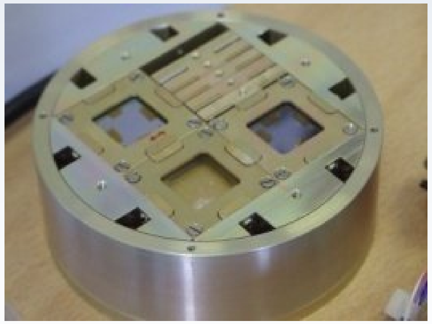
- **Delivery and Comms Spacecraft (Orbiter)**
- **Payload:**
  4 penetrator descent probes
- **Landing sites:**
  Globally spaced
  - far side
  - polar region(s)
  - one near an Apollo landing site for calibration
- **Duration:**
  >1 year for seismic network.



Pendine Impact Trial – May 2008

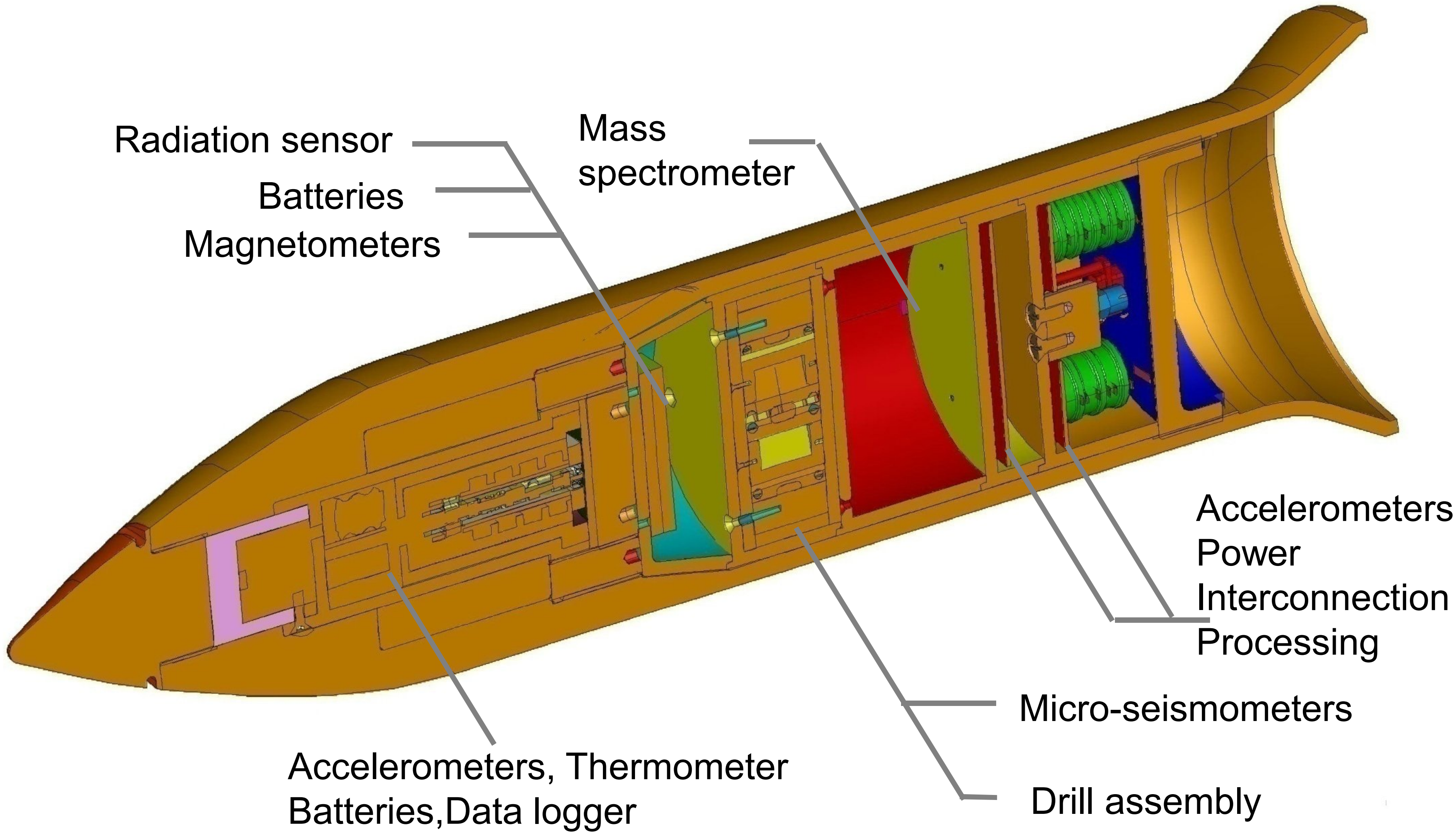
- Designed and built 3 full scale penetrators (~0.5m long, ~13kg mass)
- Aluminium body
- Segmented aluminium inner compartments

- Fired into large sand target (~2m*2m*7m) (lunar regolith simulant)
- One firing per day for 3 days.
- All at 300m/s



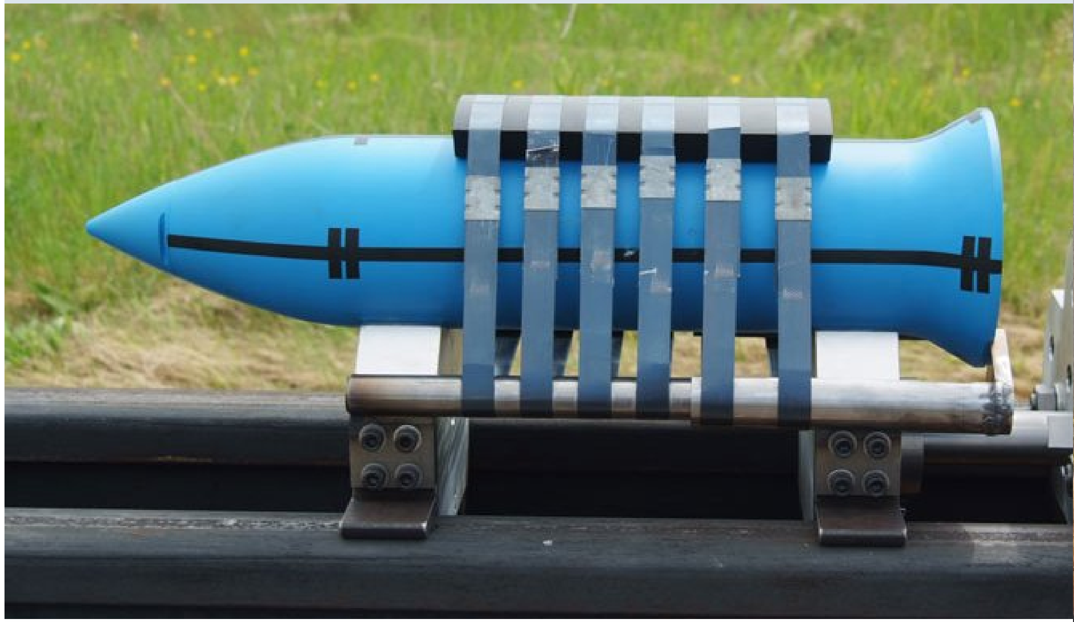
Inners Stack

Impact trial – internal architecture



Impact Trial - Configuration

- Rocket sled
- Penetrator

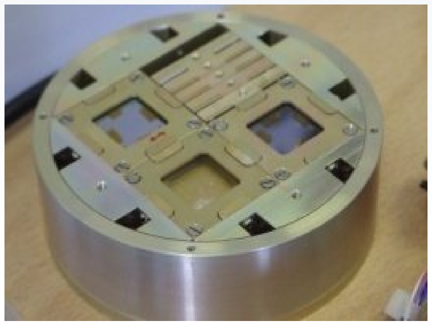


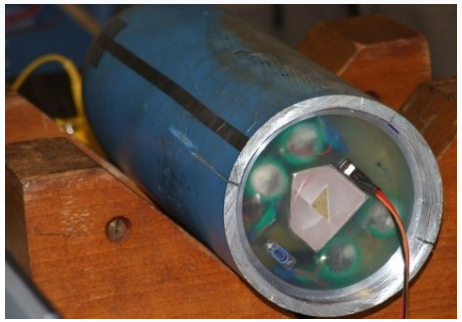
MSSL / UK Penetrator Consortium:
High Velocity Impact Trial
Qinetiq Pendine Test Track

Real-Time Impact Video

Pendine Trials Outcome

- All 3 impacts ~310m/s (nearly supersonic), ~8° nose up (worst case)
- Penetration depth ~3.9m
- Gee forces: ~ 5kgee along axis
  ~16kgee spikes
- Significant ablation to nose and underside
- No distortion to inner payload bays
- All 3 penetrators survived ✓





Where did this get us ?

For Lunar case :

- ✓ Demonstrate survivability of penetrator body, accelerometers, power, interconnect system, and instrument elements.
- ✓ Determined internal acceleration environment at different positions within penetrator.
- ✓ Extended predictive modelling to new penetrator materials, and impact materials.
- ✓ Assessed alternative packing methods.
- ✓ Demonstrated elements would fit into a penetrator of this size

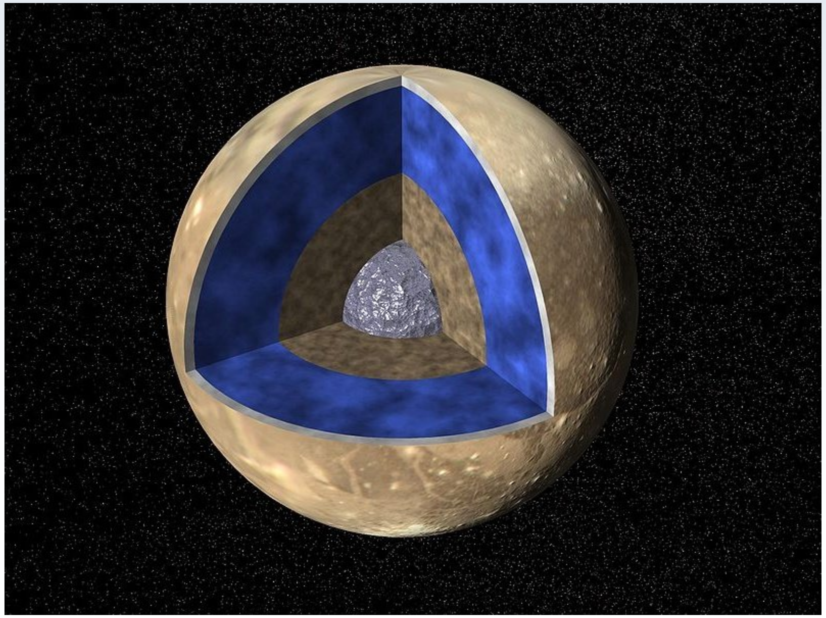
Ganymede

Ganymede

- Ganymede was prime focus of ESA 'Jovian Moons' penetrator study. (special provision for UK)
- Started ~Nov 2009, and ends next month (July 2010)
- Astrium Prime (Delivery System), MSSL (Penetrator), QinetiQ (impact survival, comms), UCL (impact sites and materials)
- Objectives:
  - define delivery system and penetrator for potential inclusion in EJSM ESA JGO spacecraft.
  - determine mass and feasibility
- Study requirements:
  - operational lifetime 2 planetary body orbits
  - assess battery only solution
  - total system mass <= 100kg
  - high TRL, feasible

Ganymede – General Characteristics

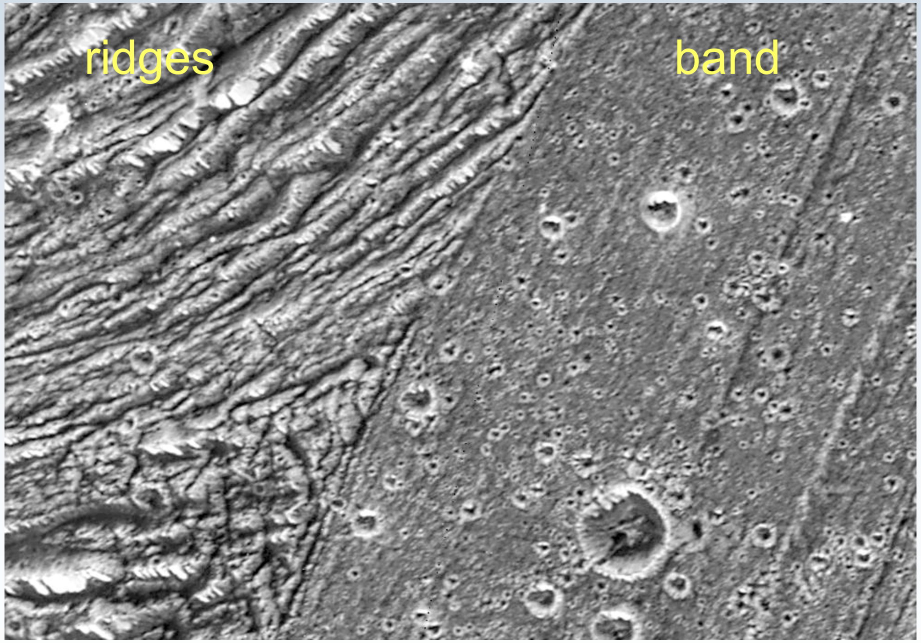
- Icy body (~70-150K)
- Habitable subsurface ocean ?
  Thick crust several 100's km.
  not suitable for ground penetrating radar – much more suited to in-situ, seismometer, magnetometer detection and characterisation



Ganymede – Impact Characteristics

- Surface Materials
  - Bright: believe water ice
  - Dark: spectrally consistent with hydrated silicates **(need in-situ measurements to confirm chemistry)**
- Varied Terrains
  - ridges, cracks, bands
  - many craters
- Impact surface conditions
  - Old heavily cratered surface (Byrs) with potentially substantial regolith.
  - Slopes in region 0-20° Uruk Sulcus and 0-30° for Galileo Regio at large scales*.

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



25km

**Giese et.al.[1998], Oberst et.al.[1999]*

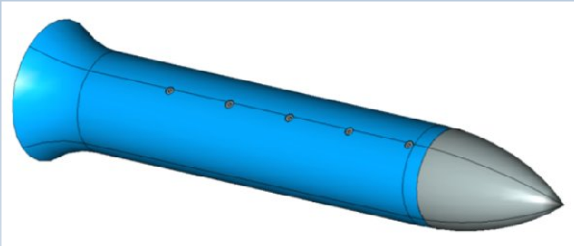
Ganymede Penetrator Payload

Model payload of 6 instruments selected for study.

- Micro-seismometer (seismic activity levels, internal body structure including subsurface ocean characterisation)
- Magnetometer (internal ocean and currents, intrinsic and induced fields)
- Microphone (acoustic frequencies to listen ice cracking rates and strengths)
- Thermal Sensor (engineering use, subsurface temperature & temporal variations)
- Accelerometer (engineering use, surface hardness and layering)
- Descent camera (PDS mounted, geological context)

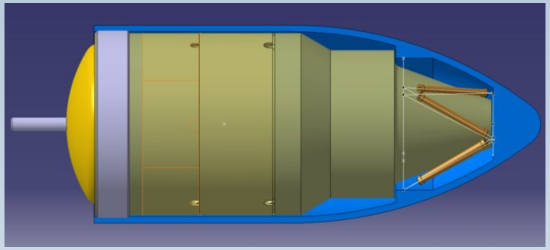
(avoided instruments which require external access due to perceived low TRL of this technology)

Ganymede Penetrator Design



Lunar Penetrator design

Length : ~55cm
Diameter: ~16cm



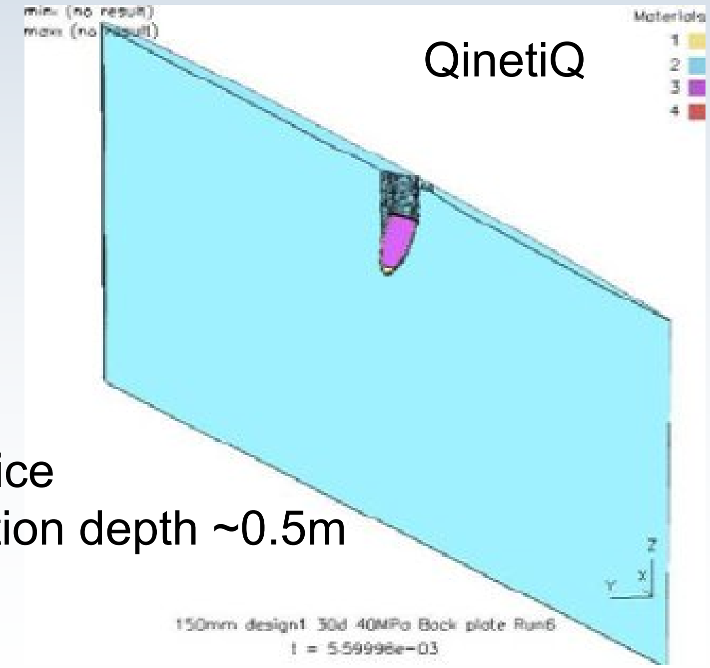
Ganymede Penetrator design

Length : ~34cm
Diameter: ~15cm

- Harder ice impact material (→ steel shell)
- Fatter body for shallower penetration (→ less signal attenuation, improved aerial area)
- Shallower penetration (→ less need for tail)
- Rear release stud (→ for connection to PDS)

Impact Modelling (QinetiQ)

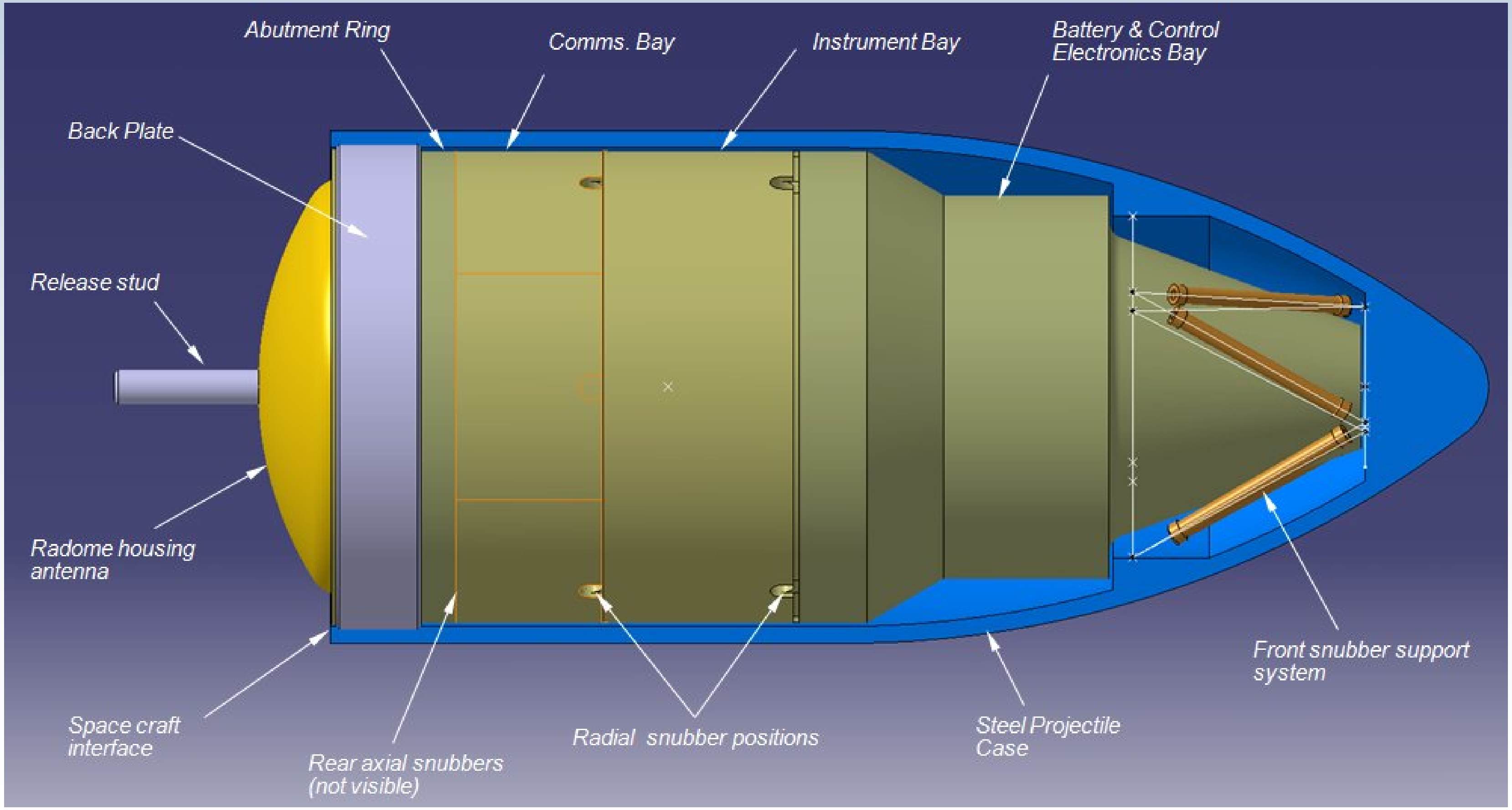
- Baseline impact material for simulation selected as polycrystalline ice at -10°C with 10 Mpa compressive strength.
  (adaption for cryogenic ice to be performed)
- Simulations up to 40 Mpa show that steel shell can survive 300m/s impact.
- Penetration depth range ~0.5 to 1m depending on impact material strength.



40 Mpa ice
Penetration depth ~0.5m

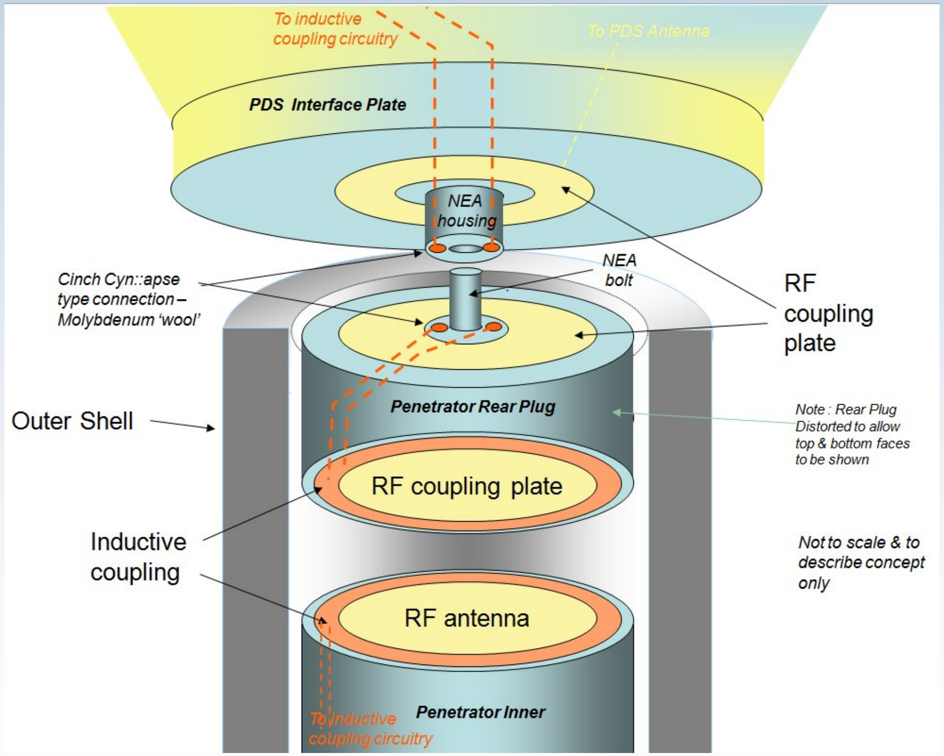
Detailed Design (MSSL/UCL)

- Battery only solution can provide 2 week lifetime with vacuum flask concept



Communications (QinetiQ)

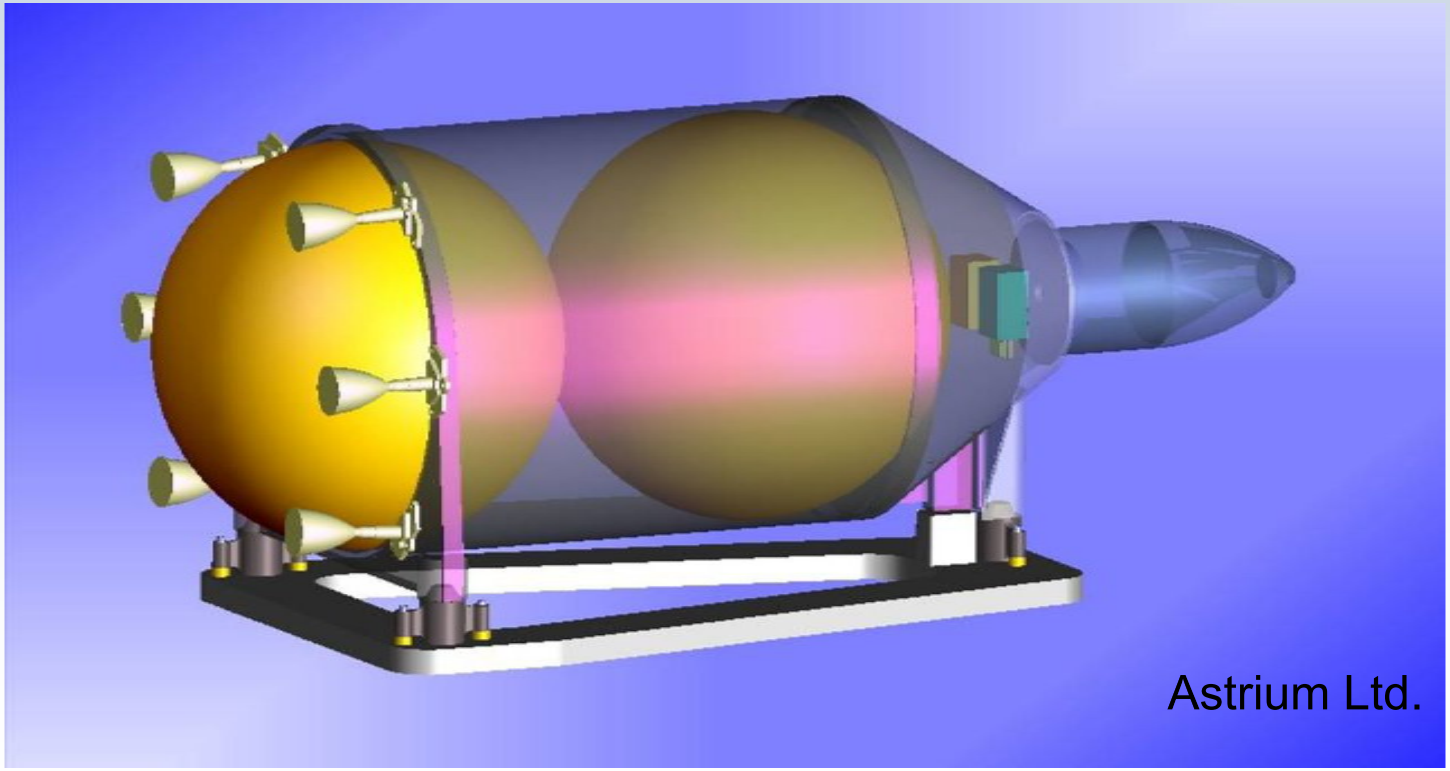
- Rear mounted non-conductive coupling
- UHF based, high TRL
- Conservative signal attenuation assessed
- High latitude site (e.g. ~75°) for best data volume return



QinetiQ

Delivery System (Astrium)

- Bipropellant delivery system solution
- Achieve impact velocity, orientation (incident and attack angles)
- Orbiter visible throughout descent
- Fly away before impact



Ganymede Penetrator Resources

- **Mass for JGO:** (including maturity and system margins)
  - Penetrator ~15.4kg
  - PDS Mass ~70kg
  - Total PDM mass therefore ~85kg

- **Penetrator:** (2 weeks operational lifetime)
  - Power: ~428 Whrs (with maturity margin)
  - Telemetry: ~9-193 Mbits (from budget 8 - 256 kbps)
    (& near polar latitude emplacement)

Where did this get us ?

For Ganymede:

1. Penetrator Delivery System designed and scoped.
2. Penetrator body designed, which can survive impact into ice (modelling).
3. Operational lifetime of 2 weeks conceptually achievable with battery only power using vacuum flask concept.
4. Technology identified which is accessible with relatively high TRL/low risk (shell, comms, data processing, power).
5. Can accommodate full subsystems and instruments in a penetrator of this size.
6. Radiation environment within penetrator assessed to be very low.
7. Determined mass, power, telemetry resources.

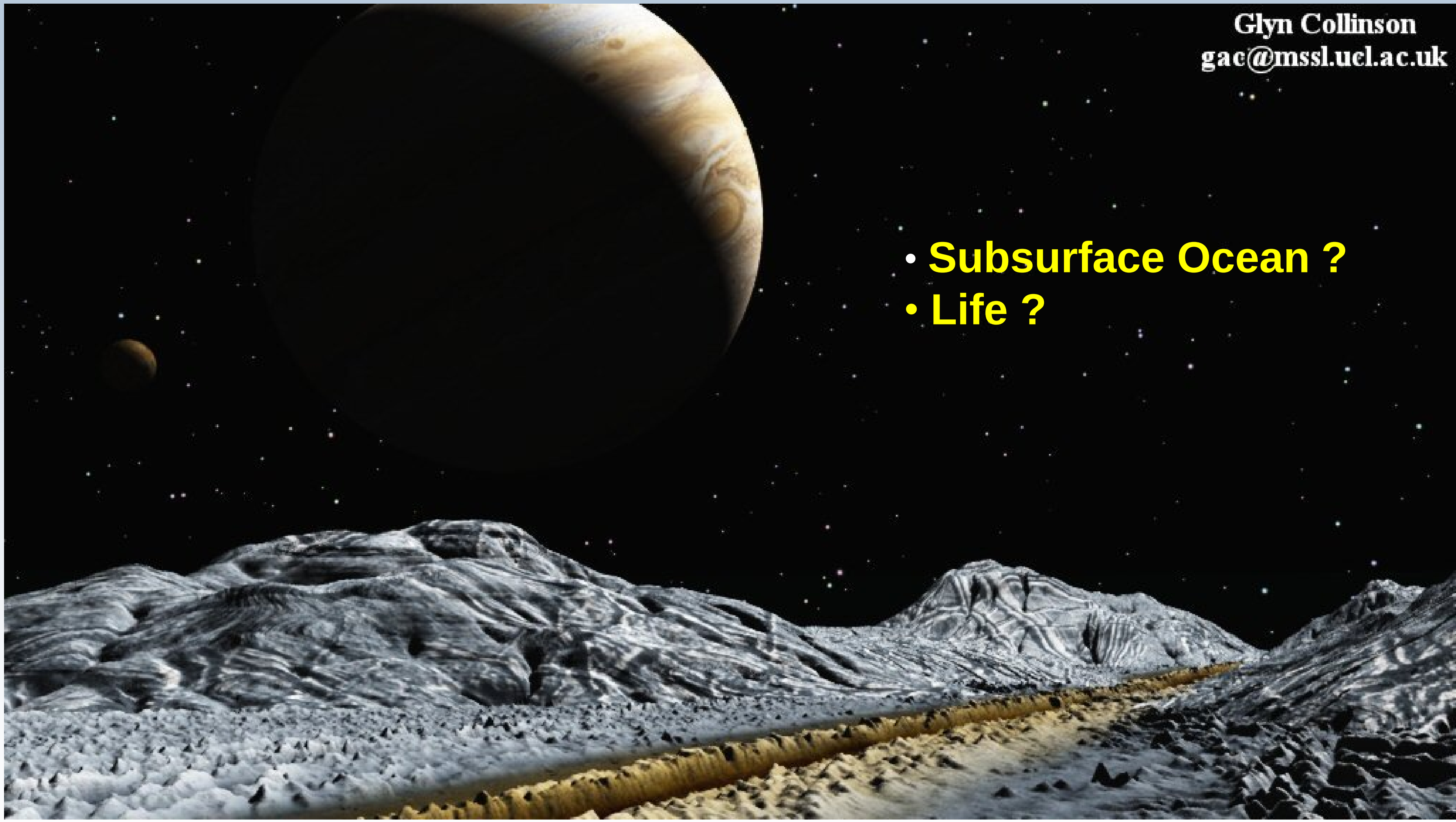
Europa

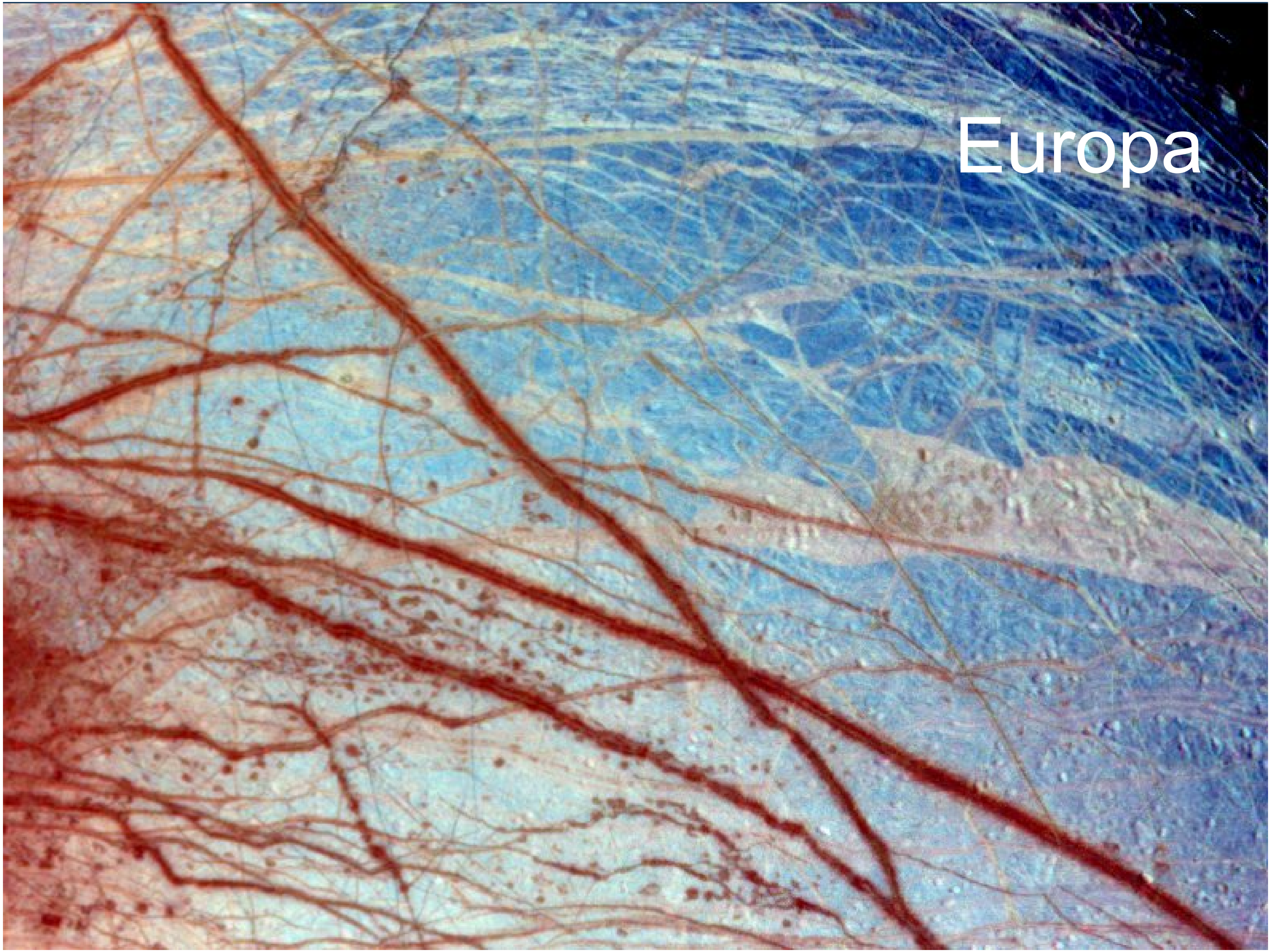
Differences between Ganymede & Europa

UCL

item	Ganymede	Europa
Science payload	P1 - geophysics	P1 - astrobiology
	P2 - astrobiology P2 - composition	P2 - geophysics P2 - composition
Operational lifetime	2 weeks	1 week
Delta-V	~2 km/s	~1.5 km/s
Radiation	high	extreme
Planetary protection	Cat II	Cat IV
Surface roughness	• Higher slopes/rougher • more regolithed (old)	• Lower slopes/smoother • less regolithed (younger)
Surface material	Medium to high ice content -> more thermal conductivity uncertainty -> more comms attenuation possible	Much higher ice content -> higher thermal conductivity -> lower uncertainty for comms attenuation

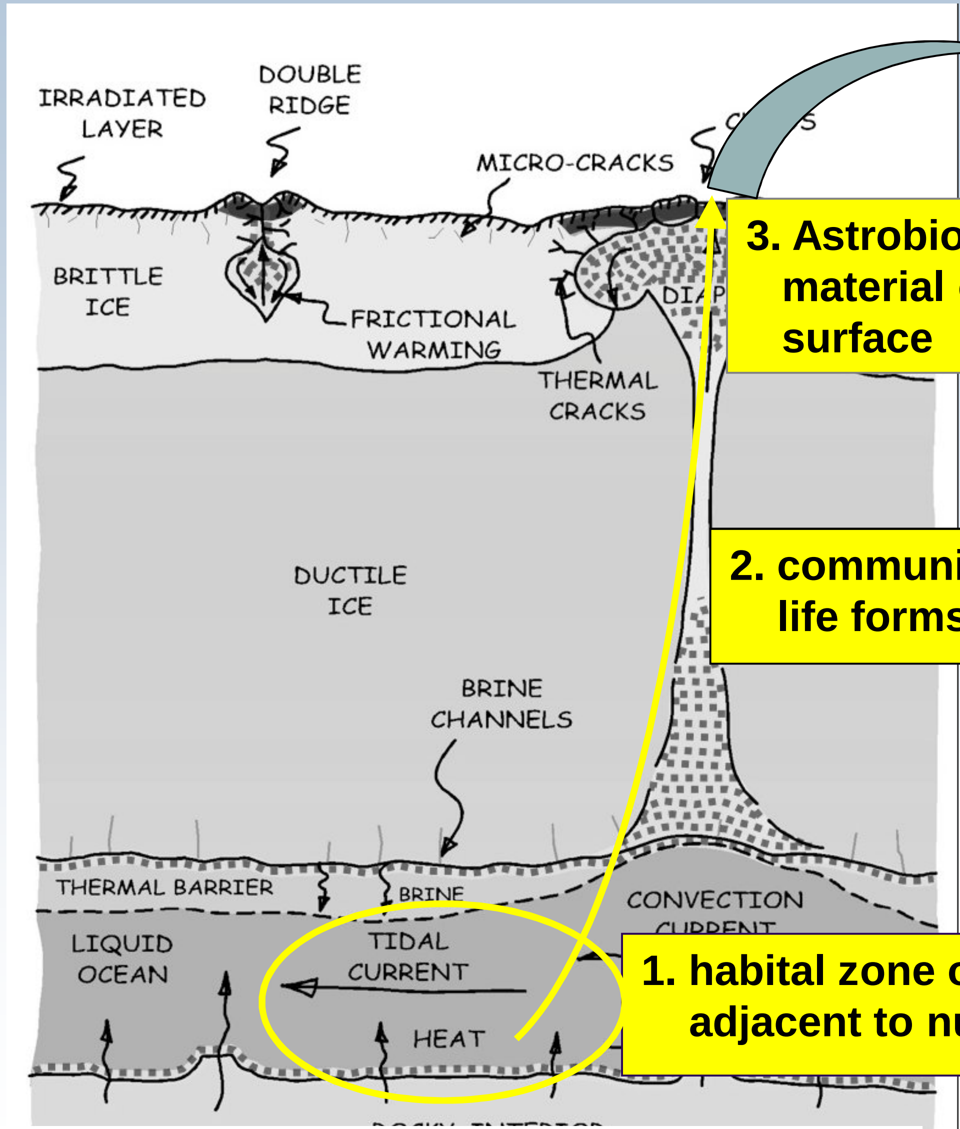
Europa - Science




Europa

Europa

Astrobiology material search…?



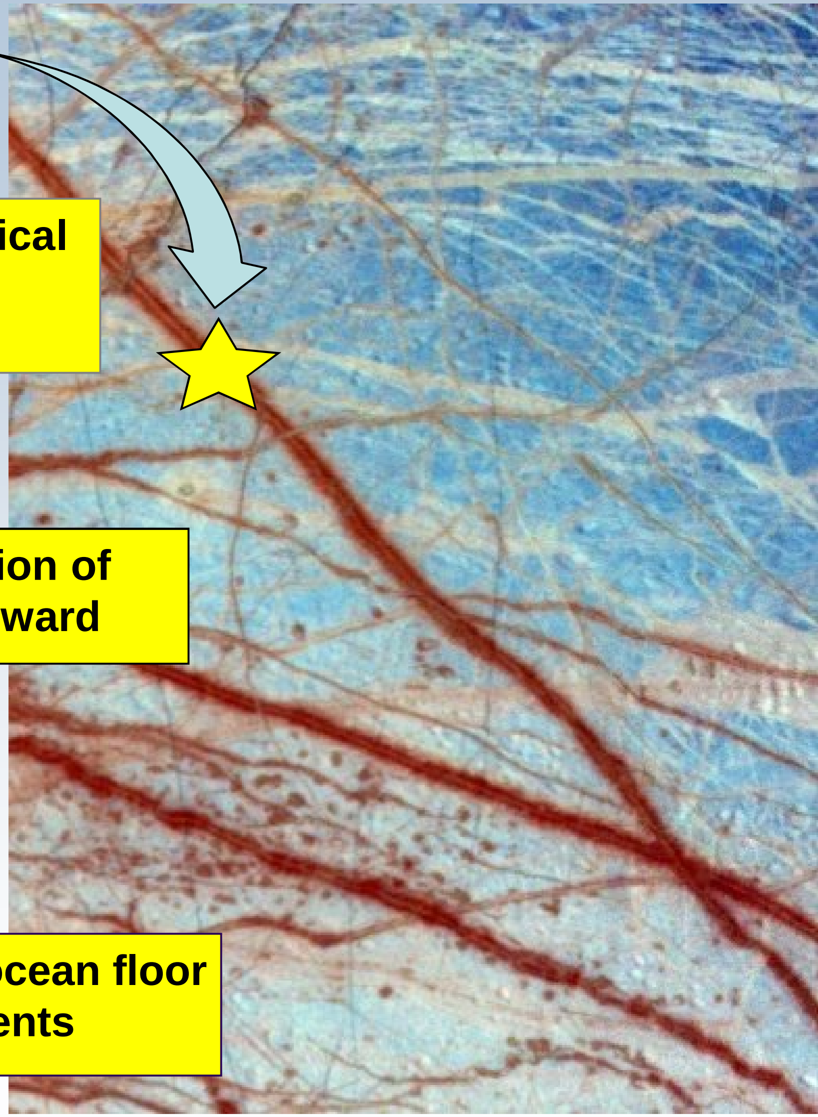
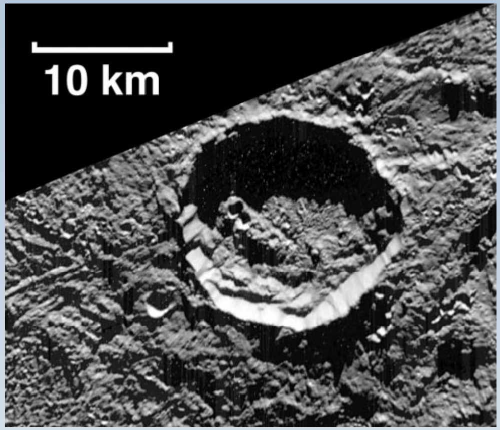


Diagram adapted from K.Hand et. al. Moscow'09, who adapted it from Figueredo et al. 2003

Europa Candidate Impact Sites

a) Bright icy polar craters

- morphologies generally well known
- low slopes at large scale
- need to avoid central areas of some type of craters, and boulder hazards.
- scientifically more oriented to geophysics & habitability; not for young upwelled material.



Crater Rhiannon, 80.9°S

Candidate sites of potential upwelled biogenic material

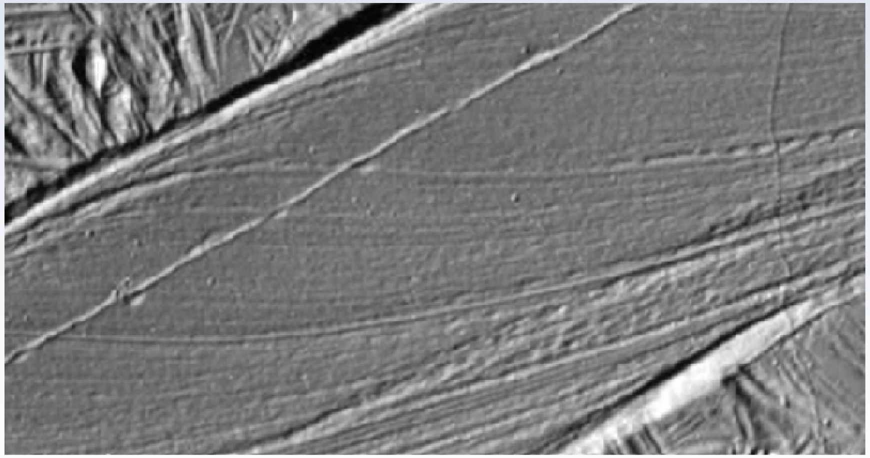
b) Gray dilational bands *[Schenk, 2009]*

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

c) Chaos, lenticulae regions

[Procktor et al., Moscow, Feb09].

- reasonably flat/smooth in some areas
- young.



Galileo image

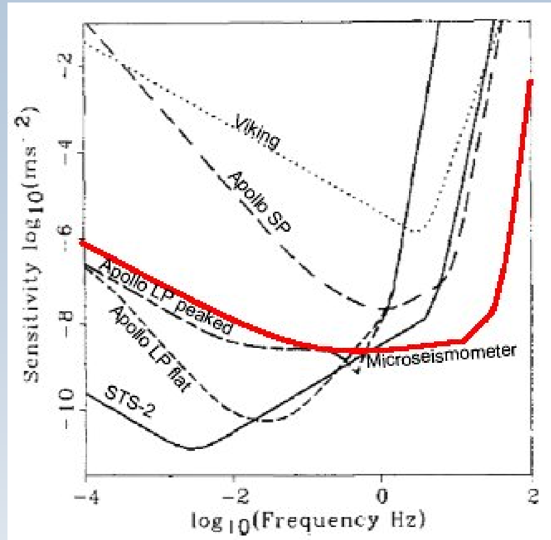
Full study required including impact hazards assessment

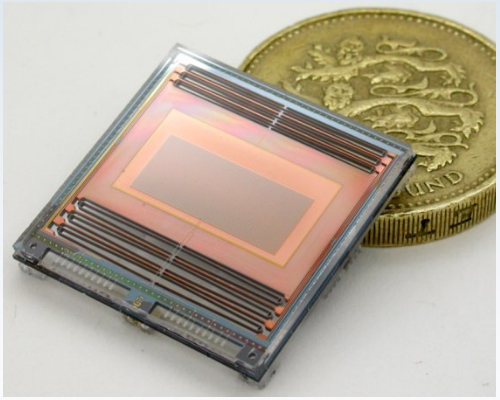
Europa Penetrators

UCL

- **Determine minimum mass system**
  - single instrument payload (micro-seismometers)
  - reduced period of operation (1 week vs 2 weeks) → less power → ~1/2 battery system mass.
  - less substantial PDS mounting interface

	Ganymede	Europa	Comments
Length	34 cm	31 cm	shorter
Mass	15.4 kg	14.3 kg	including maturity and system margins



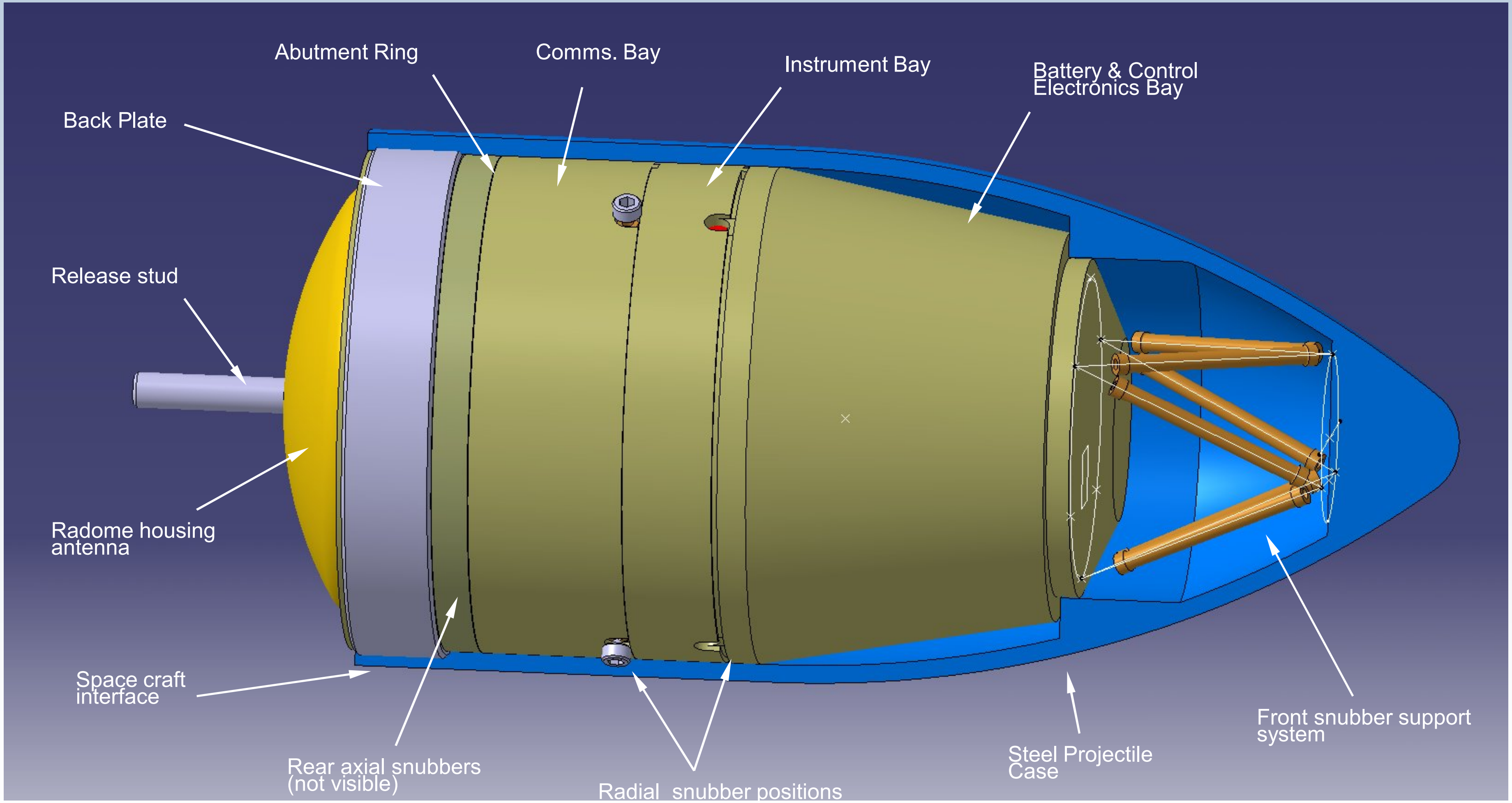


Micro-seismometer
Imperial College, London

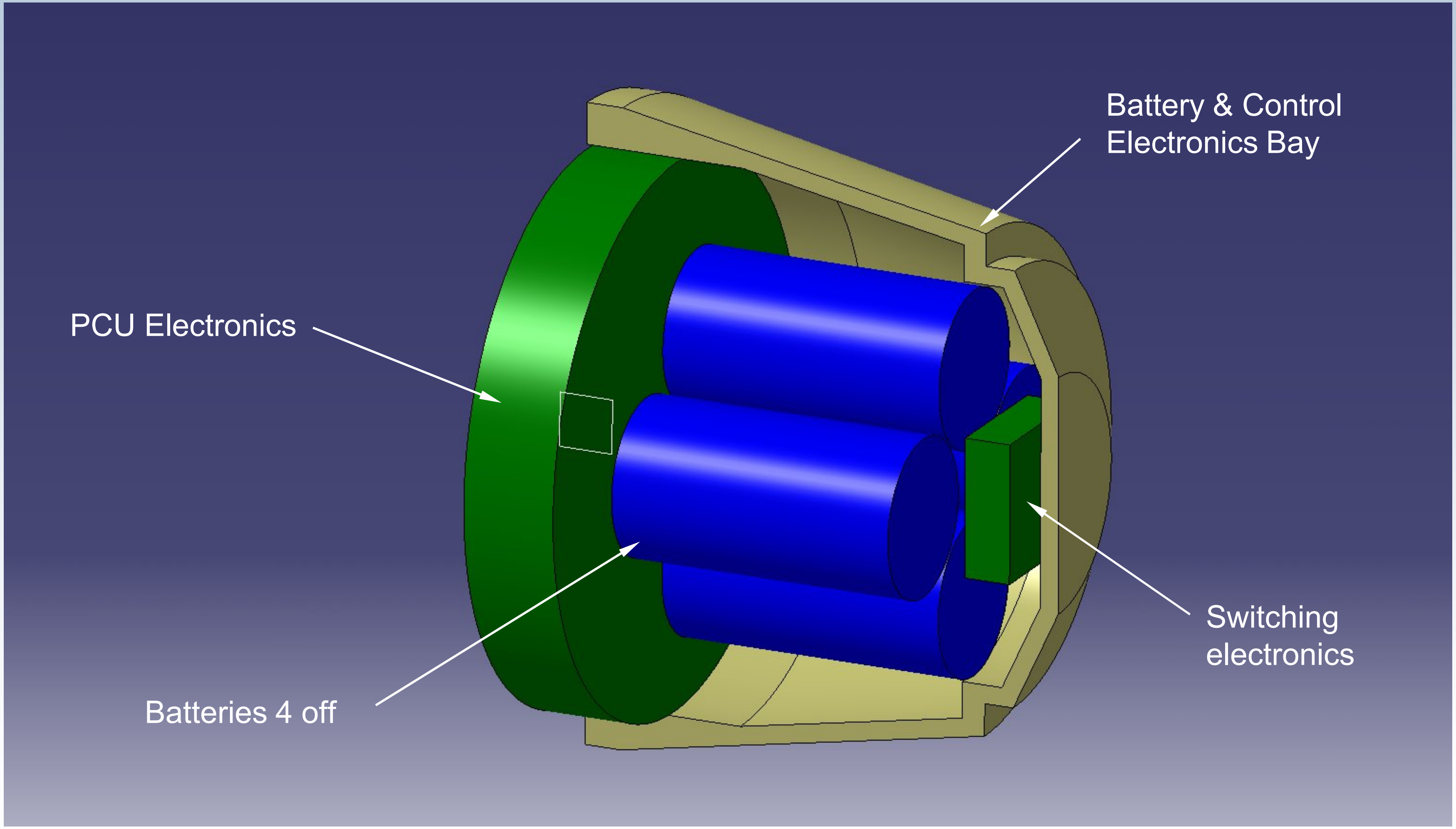
+ **Potential additional mass savings ...**
  - assessing titanium alloy shell (survivability)
  - improve packing (e.g. nose space – or accommodate accelerometers and thermometers)
  - further reduction in penetrator rear plate thickness
  - use of lower density packing material

Europa Penetrator

Single instrument (micro-seismometer) – for minimum system mass estimate



Europa - Power & Data Processing Bay



Model Payload for Europa ?

UCL

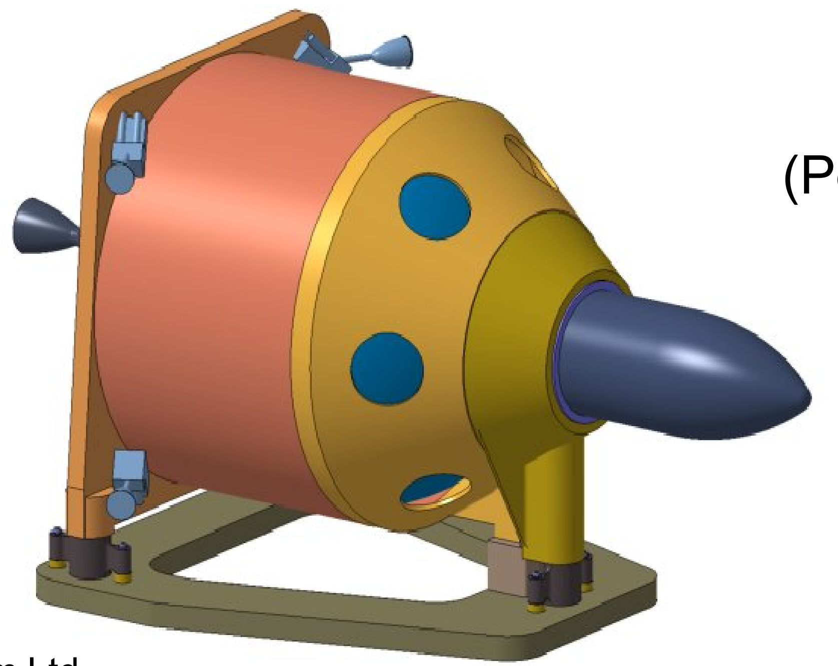
Instrument	Science	priority	mass
Seismometer	• geophysics • astrobiology	✓✓ ✓✓✓	~300g
Accelerometer	• composition	✓✓	~70g
Thermal sensors	• environment	✓	~50g
Magnetometer	• geophysics • astrobiology	✓✓ ✓✓	~250g
Descent camera	• geophysics	✓✓	160g
Microphone	• geophysics	✓	-
Material analysis package	• composition • mineralogy • astrobiology	✓✓ ✓✓ ✓✓✓	~300-600g
Radiation sensor	• environment	✓	~50g
Conductivity Permittivity	• composition • geophysics	✓	-

← floor payload modelled

total payload mass ~ 1.5 kg

Europa - Resources

- **Mass for JEO:** (including maturity and system margins)
  - Penetrator ~14.3kg
  - PDS Mass ~49.8kg *(Ganymede ~70kg)*
  - Total PDM mass therefore ~64.1kg



Astrium Ltd.

Europa PDM
(Penetrator Delivery Module)
and mounting plate

Where did this get us ?

For Europa:

1. Penetrator designed for floor payload (seismometer) (~1kg less than Ganymede). Other reduced mass options still being studied.
2. Delivery system designed (~20kg less than Ganymede).
3. Radiation environment within penetrator assessed to be moderate (advantage c.f. surface lander).
4. Risks and way forward identified...

Mars

Mars – ongoing preliminary analysis

- **Science Options**
  - Seismic network (low mass)
  - Deep 2-5m astrobiology probe
- **Impact Sites and Surface Materials**
  - Deep regolith, ice
  - low latitudes (<~40°) warmer → long lifetime ~year for seismic network (challenging)
- **Mission Scenarios**
  - Single body penetrator (+ following aerial and solar cells)
  - Fore-aft/surface body options
- **EDLS Technology**
  - Aeroshell
  - Parachutes

Conclusions

Way Forward ?

We have made good progress, but now to technically focus on ..

- **Impact survival** (into ice for shell, inners, subsystems and instruments → modelling, small scale testing, full scale testing)
- **Impact site selection and characterisation**
  - Impact material (cryogenic ice strength → small scale tests)
  - Impact cratering (modelling, small scale tests)
  - Full impact site hazards assessment (e.g. slopes, fissures)
  - Material RF properties (attenuation)
- **Battery performance at low temperatures** (lifetime)
- **Full study of radiation and planetary protection**
- **Develop TRL for access to external materials** (e.g. for chemistry, mineralogy and astrobiology investigations)
- **Develop TRL for science instruments**

End

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