Penetrators for Planetary Exploration and Science

Professor Alan Smith

University College London's
Mullard Space Science Laboratory

as@mssl.ucl.ac.uk

Landers and Impactors

NASA Viking, 600kg, 1975, $1b

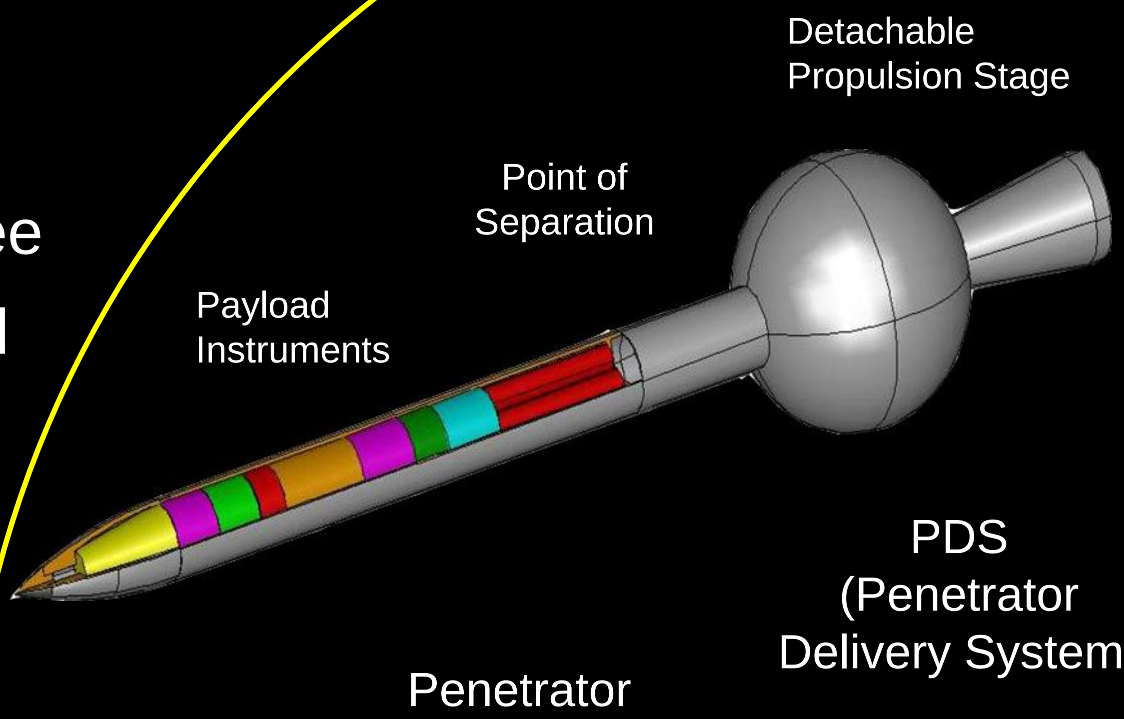
NASA Spirit, 174kg, 2004, $820m

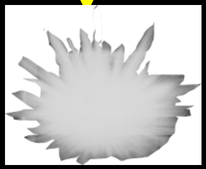
NASA LCROSS, 2009, $79m

NASA Deep Impact, 370kg, 2005

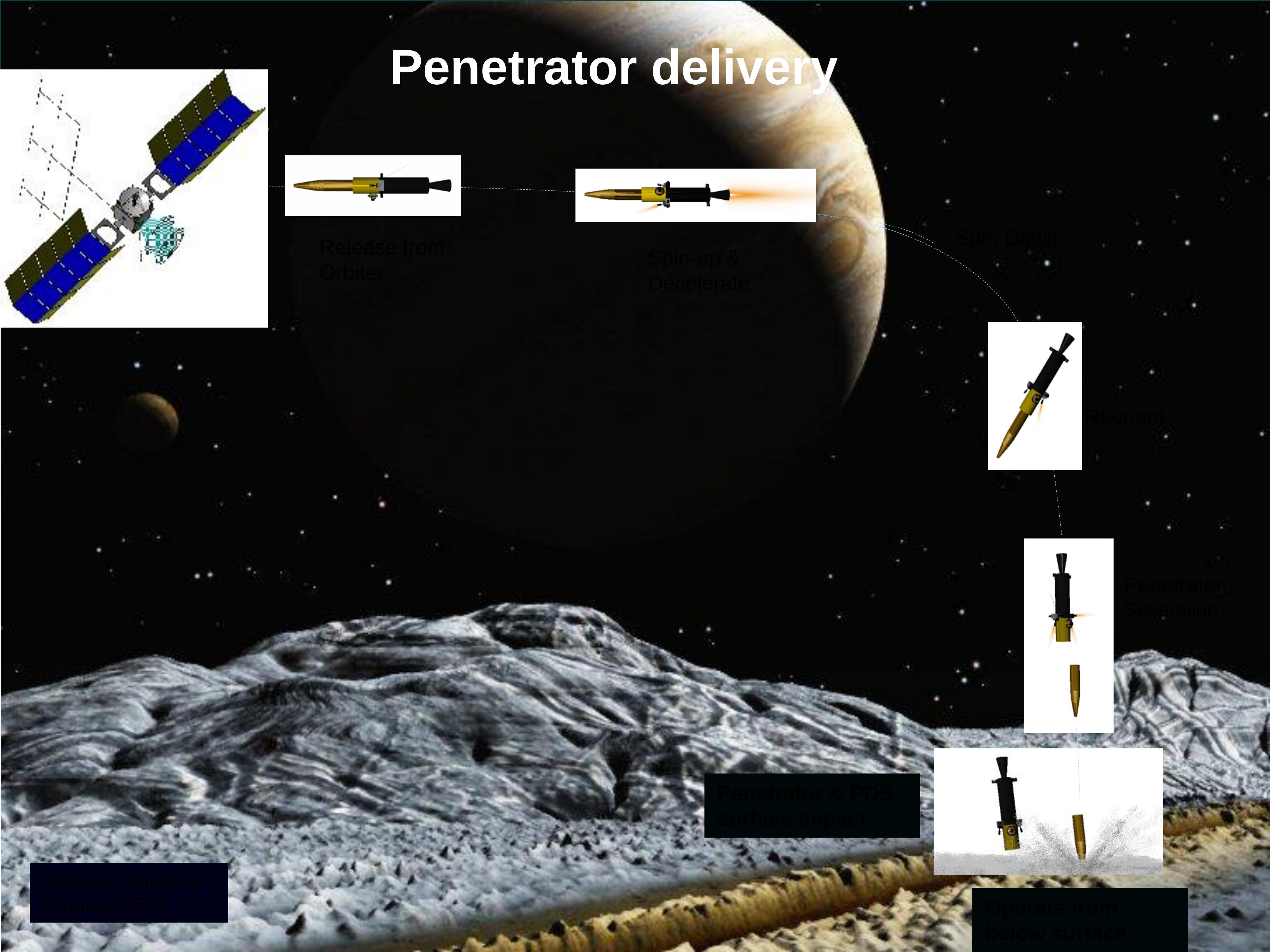
Penetrators

- Low mass projectiles (<15kg)
- High impact speed
  ~ up to 400 ms^{-1}
- Very tough ~10-50kgee
- Penetrate surface and imbed therein
- Undertake science-bases measurements
- Transmit results





Penetrator delivery



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)

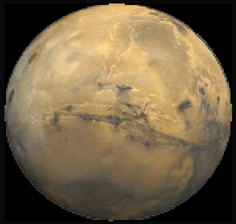
Limitations:

- Low mass limits payload options
- Impact survival limits payload option
- Limited lifetime
- Limited telemetry capacity

Complementary to Soft Landers for *in situ* studies

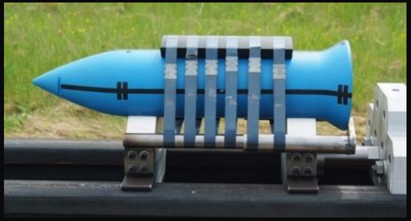
Heritage

Military Heritage in instrumented impact projectiles
Numerous laboratories looking at high velocity impacts with gas guns



1996: Mars96 (Russia/Lavochkin), 2 off, 60-80 ms^{-1} impact, each 65kg incl braking system. Lost when Mars96 failed to leave Earth orbit.
1999: Deep Space-2 (NASA/JPL), 2 off, 140-210ms^{-1} impact, each 3.6kg with entry shell. Failed, cause unknown.

Lunar – A (Japan/JAXA), 2 off, 285 ms^{-1} impact, each 45kg including de-orbit and attitude control. Programme terminated before launch after extensive development and trials
Lunar Glob (Russia/Lavochkin), status unclear but may include Lunar-A penetrators



2008: UK Penetrator Pendine Trials, 3 off, 300 ms^{-1} impact into compacted sand, each 13kg, demonstrated survivability of a range of key technologies in preparation for MoonLITE

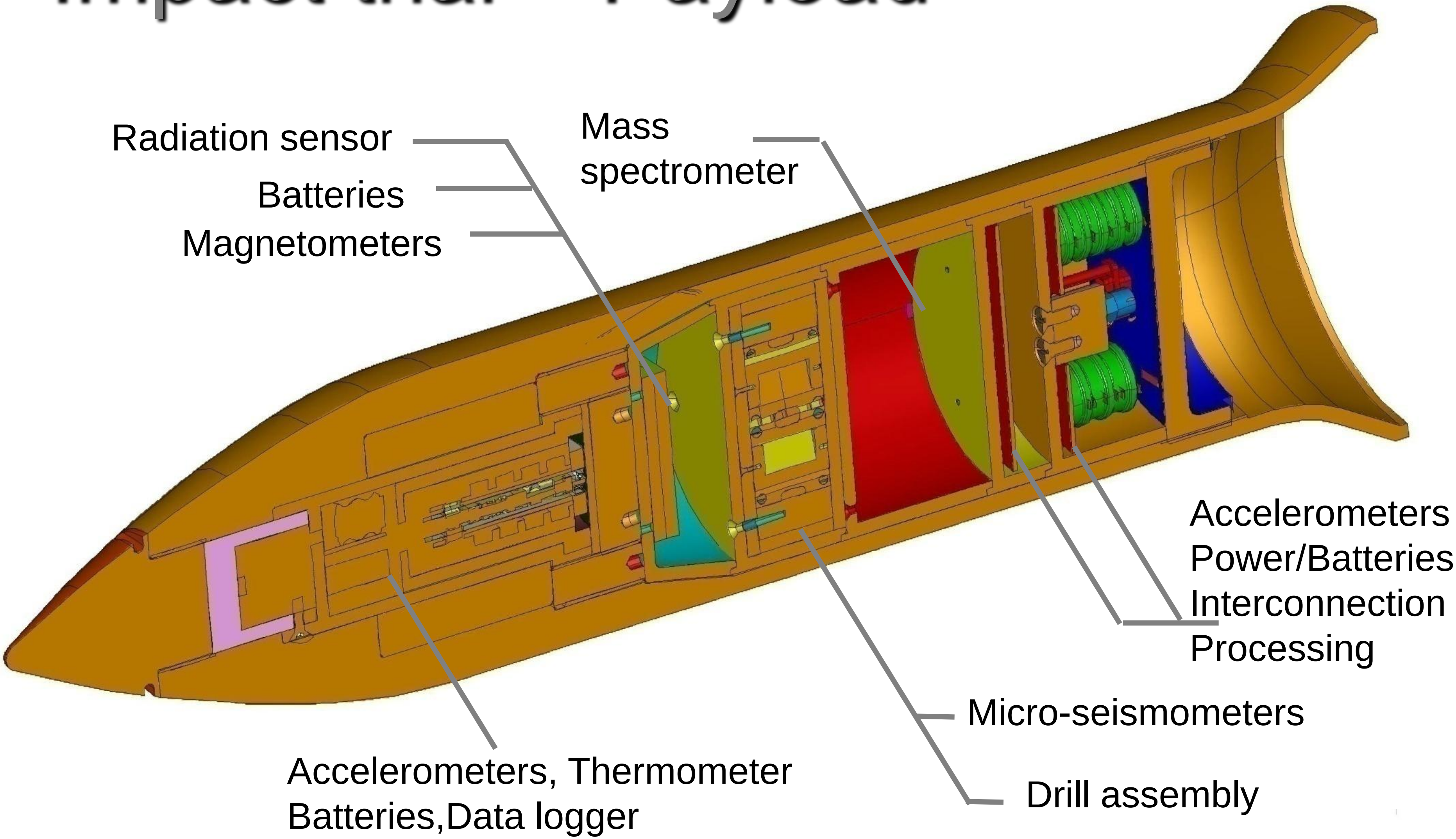
Pendine Impact Trials

- Full Scale ‘component level’ trials
- Conducted at Pendine, South Wales
- May 2008
- 3 x 300m/s into dry sand
- ~8^o nose up attitude

UK Penetrator Consortium:

Mullard Space Science Laboratory,
Astrium Ltd; Birkbeck College; Cavendish Laboratory, University of Cambridge; CEPSAR, Open University; Imperial College; QinetiQ Ltd.; Surrey Satellite Technology Ltd.; Surrey Space Centre; Department of Earth Sciences, UCL; University of Lancaster; University of Leicester

Impact trial – Payload

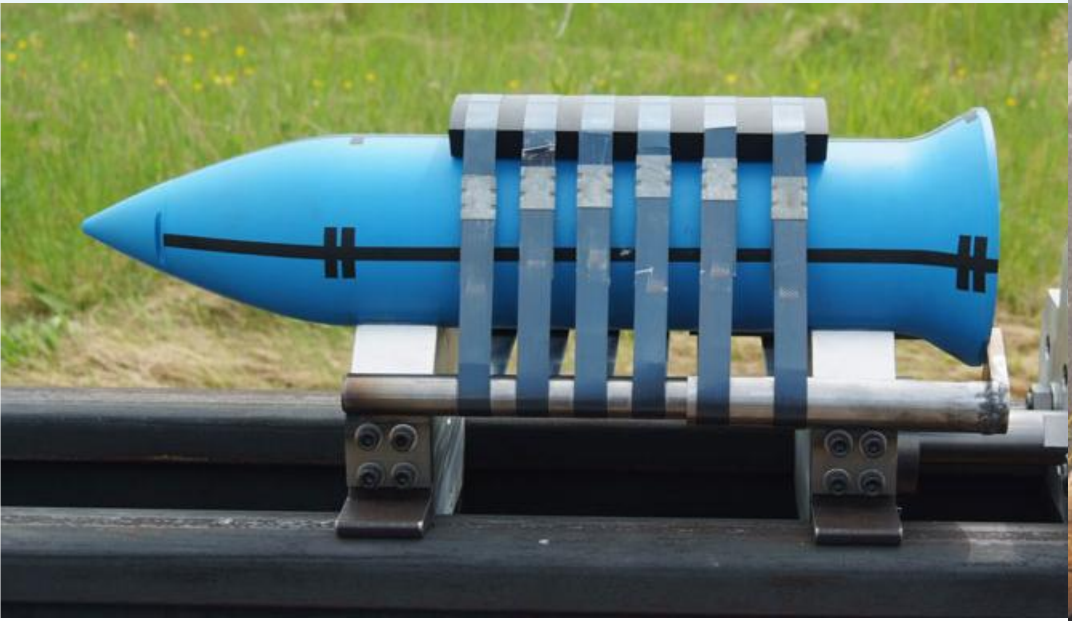


Trial Hardware

Bays Stack

Impact Trial - Configuration

- Rocket sled
- Penetrator



Target

Dry sand

2m x 2m x 6m


QinetiQ Pendine


UCL
Birkbeck
Leicester
QinetiQ
SURREY

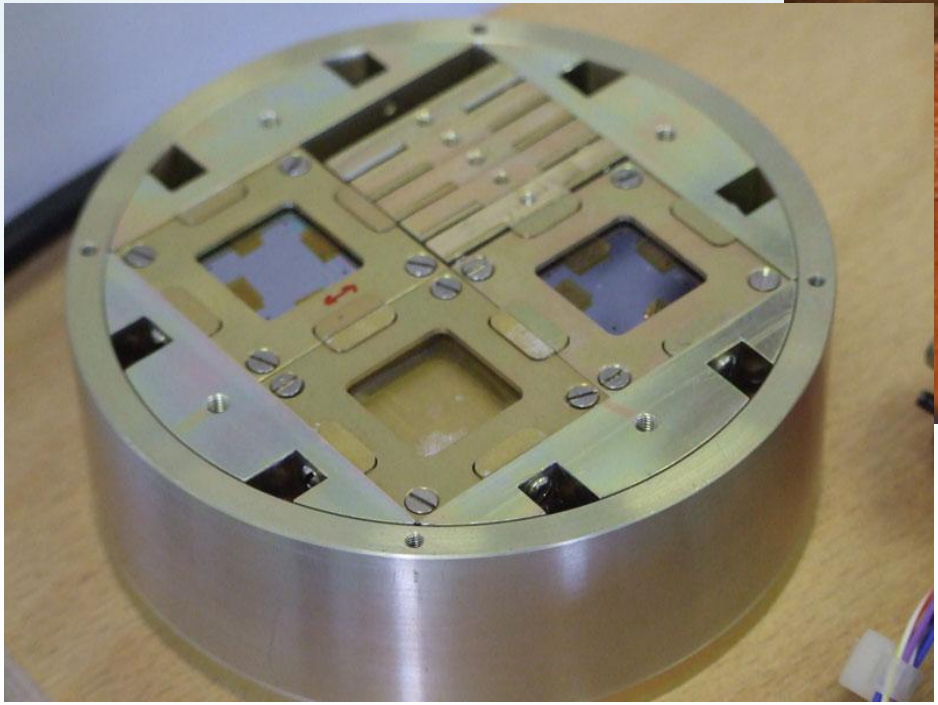
1st Trial

Firing parameters:
- Impact velocity: 310 m/s
  (c.f. 300m/s nominal)
- Nose-up ~10degs
  (c.f. 0 degs nominal)

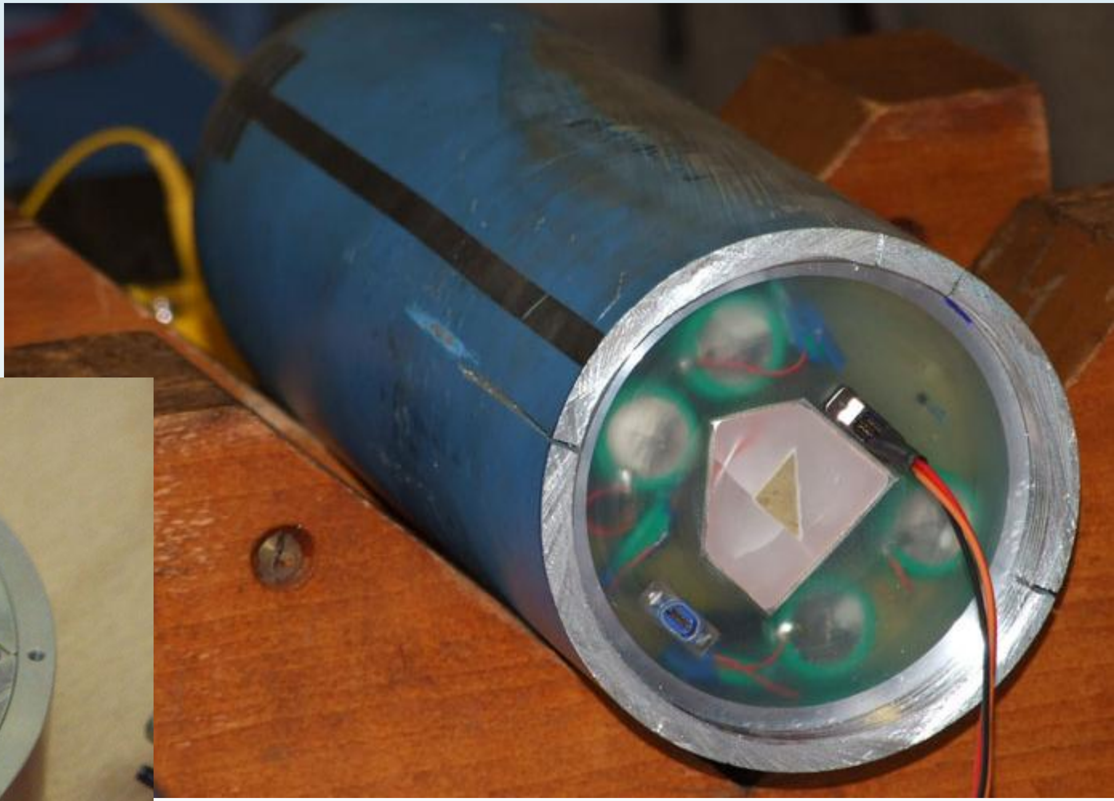
=> worst case

- Penetrator found in top of target
- Glanced off a steel girder which radically changed its orientation.
- Penetration: ~3.9m
- Much ablation to nose and belly
- Rear flare quite distorted.
- Penetrator in one piece ✓

1st Trial



Micro seismometer bay



Connecting to MSSL accelerometer and data processing bay

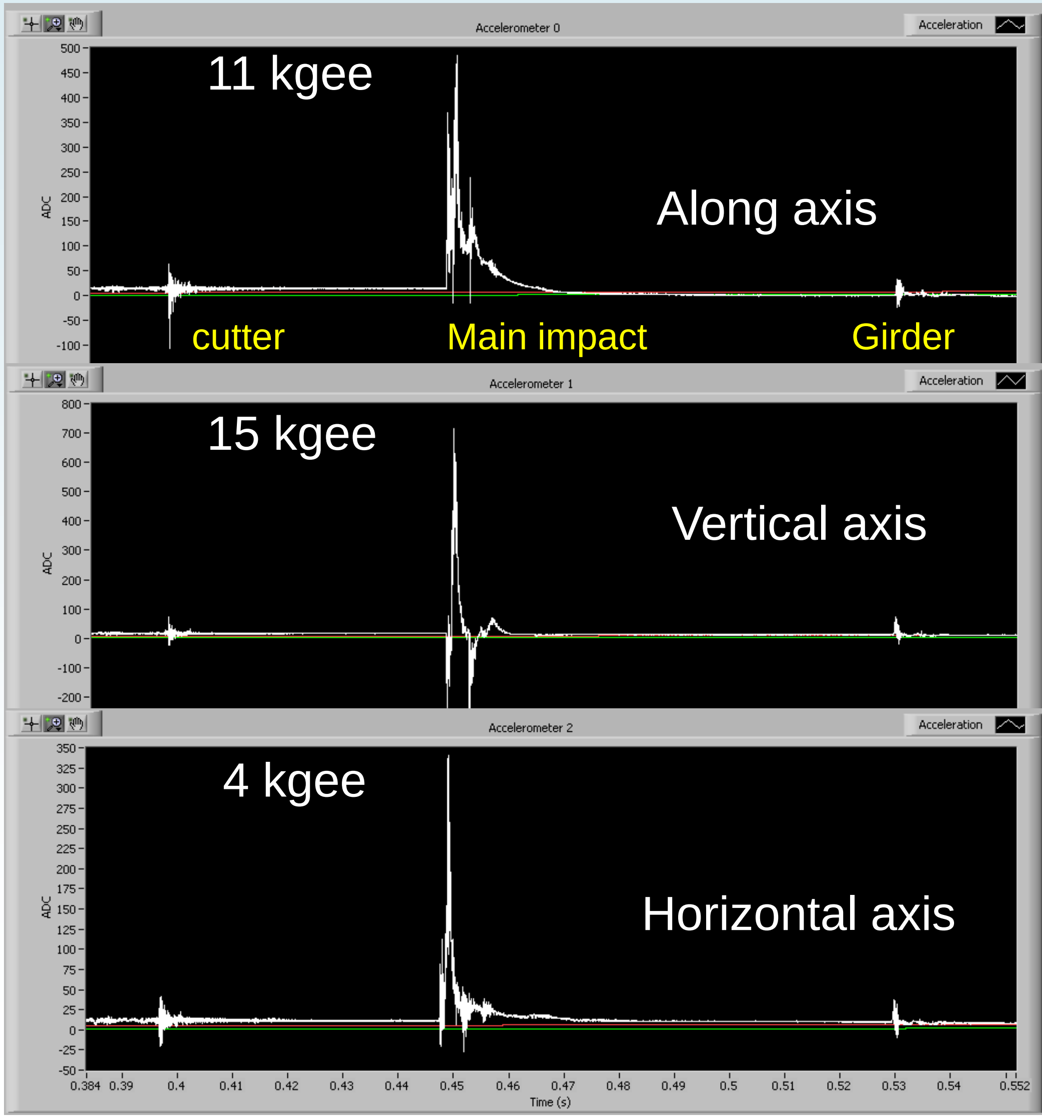
1st Trial – accelerometer data

Peak gee forces in rear of penetrator

Firing	Along axis	Vertical	Horizontal
1’st	10 kgee	15kgee	4kgee
3’rd	11kgee	17kgee	7kgee

Along axis:

- Cutter: 3kgee
- Main: 10kgee
- Girder: 1kgee



Survival Table

Item	Firing 1	Firing 2	Firing 3
Penetrator	✓	✓	✓
Q-accel sys	✓	✓	✓
Rad sensor	✓	n/a	n/a
Batteries	✓	n/a	n/a
Drill assembly	✓ (minor damage)	n/a	n/a
Magnetometer	✓	n/a	n/a
Micro seismometers	n/a	✓ (protected)	✓ (protected)
Mass spectrometer	n/a	✓ (minor damage)	✓
MSSL accel sys	✓	✓ (triggered prematurely)	✓

No critical failures – currently all minor to unprotected bays or preliminary mountings

Triple worst case: exceed 300m/s, >8deg attack angle

Impact Trial Objectives

- ✓ Demonstrate survivability of penetrator body, accelerometers and power system.
- ✓ Assess impact on penetrator subsystems and instruments.
- ✓ Determine internal acceleration environment at different positions within penetrator.
- ✓ Extend predictive modelling to new penetrator materials, and impact materials.
- ✓ Assess alternative packing methods.
- ✓ Assess interconnect philosophy.
- ✓ Attract media and space agency interest

Milestones to date

- Jan 06 - Penetrator Consortium created
- Dec 06 - RC study of Lunar Missions by SSTL
- Jun 07 - LunarEX CV proposal
- Feb 08 – UK Civil Space Strategy identifies robotic lunar exploration as a goal
- Feb 08 - BNSC-NASA Joint working group report on Lunar exploration and science
- May 08 - First Pendine impact trials
- Jul 08 - International Peer Review
- Nov 08 – MoonLITE Phase A announcement
- Dec 08 – MoonLITE Phase A ITTs issued
- Oct 09 – ESA funded Penetrator systems study kick-off
- Apr 10 – Phase A kick-off?

Opportunities Status

MoonLITE (UK)
Lunar Glob (Russia)
→ UK/NASA agreed to full Phase A
Kick-off may happen in April ‘10

Mars Aurora (ESA) → Penetrators now being considered as an option in light of likely ExoMars rethink. Some UK Aurora money now funding key instrument developments

JGO (ESA) → Penetrator under consideration in ESA assessment study. ESA contract ITT for system level study

EJO (NASA) → UK preparing input to NASA AO

Application comparison

Aspect	Moon	Mars	Icy Moon
Descent	Airless	Air braking	Airless
Thermal Environment	~250K at equator ~70K at poles	~250K	~70K
Regolith	Compressed powder Icy sand at poles	Icy sand?	Icy powder, Ice or sandy Ice
Key science	Internal structure Volatiles Heat flow Geochemistry ...	Internal structure Volatiles Heat flow Geochemistry	Internal structure Volatiles Heat flow

Terminal Velocity

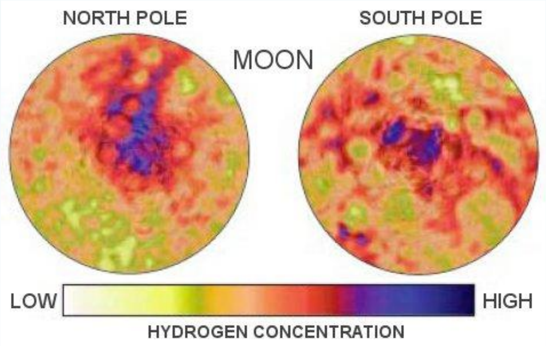
- Assuming:
  - 10kg, 12cm diam., Drag coefficient 0.2

- Venus 34 m/s
- Mars 1310 m/s
- Titan 48 m/s
- Earth 267 m/s

The Payload Delivery System must incorporate Atmospheric braking

Science

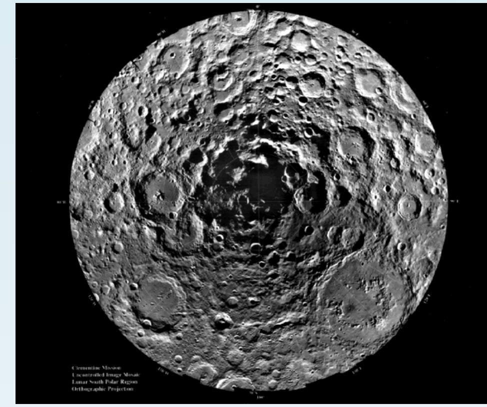
The Origin and Evolution of Planetary Bodies



Water and its profound implications for life and exploration

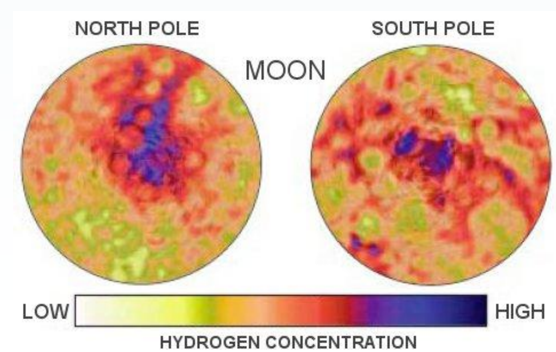
NASA Lunar Prospector

Icy volatiles



A suite of instruments will detect and characterise volatiles (including water) within shaded craters at both poles

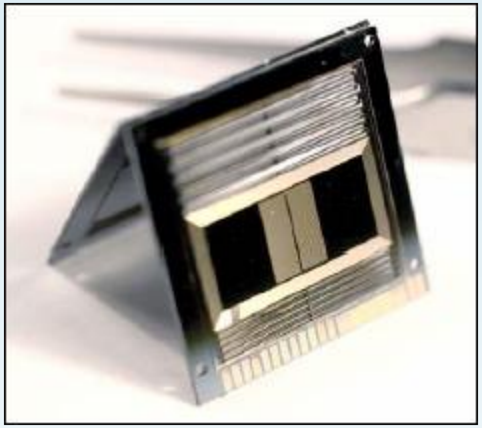
- Astrobiologically important
  - possibly remnant of the original seeding of planets by comets
  - may provide evidence of important cosmic-ray mediated organic synthesis
- Vital to the future manned exploration of the Moon

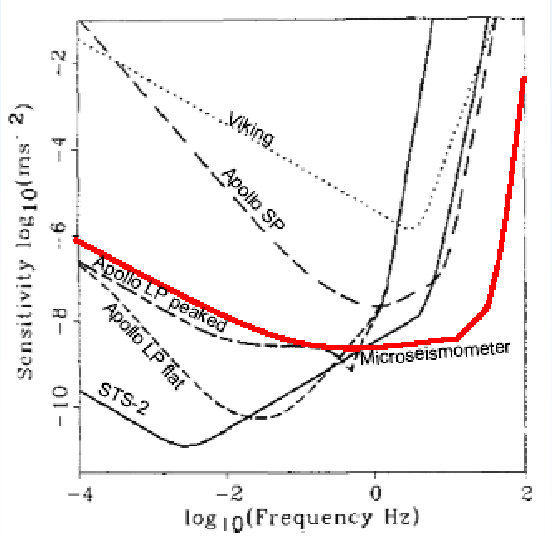


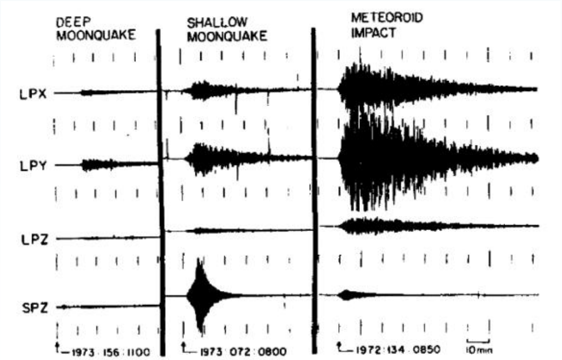
Seismology

A global network of seismometers will tell us:

- Size and physical state of the Core
- Structure of the Mantle
- Thickness of the far side crust (Moon)
- The origin of the quakes
- Depth of ocean (Europa, Ganymede)
- The seismic environment at potential manned landing sites (Moon and Mars)







Geochemistry

X-ray spectroscopy at multiple, diverse sites will address:

- Geophysical diversity
- Ground truth for remote sensing
- Radiation background

Leicester University

XRS on Beagle-2

Including:

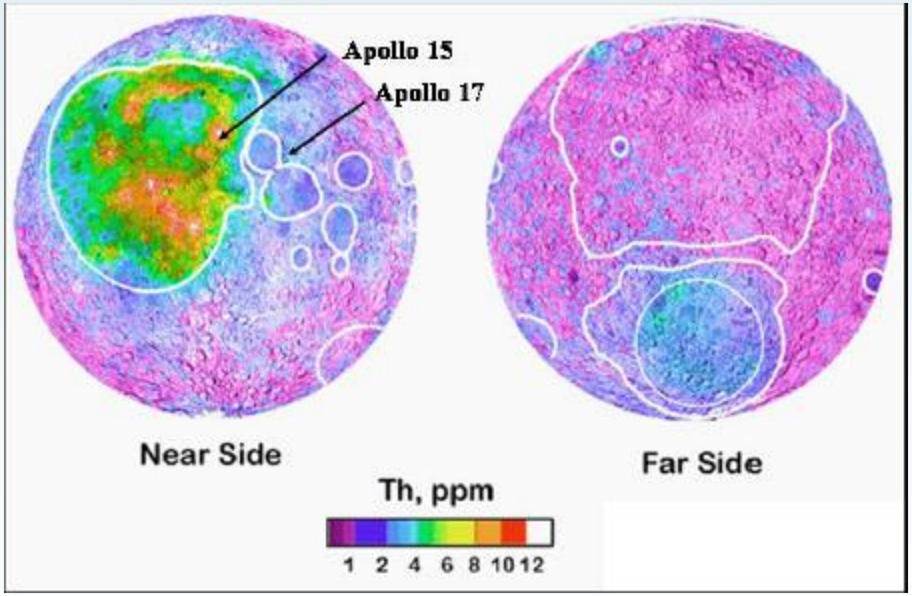
O, Mg, Al, Si, K, Ca, Ti, Fe, Rb, Sr, Zr

Heat Flow

Heat flow measurements will be made at diverse sites, telling us:

- Information about the composition and thermal evolution of planetary interiors

- Whether the Th concentration in the PKT is a surface or mantle phenomena (Moon)



NASA Lunar Prospector

Thank You