A Physical, Chemical, Isotopic and Astrobiology Instrumentation Package

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Overview of PSSRI

PSSRI

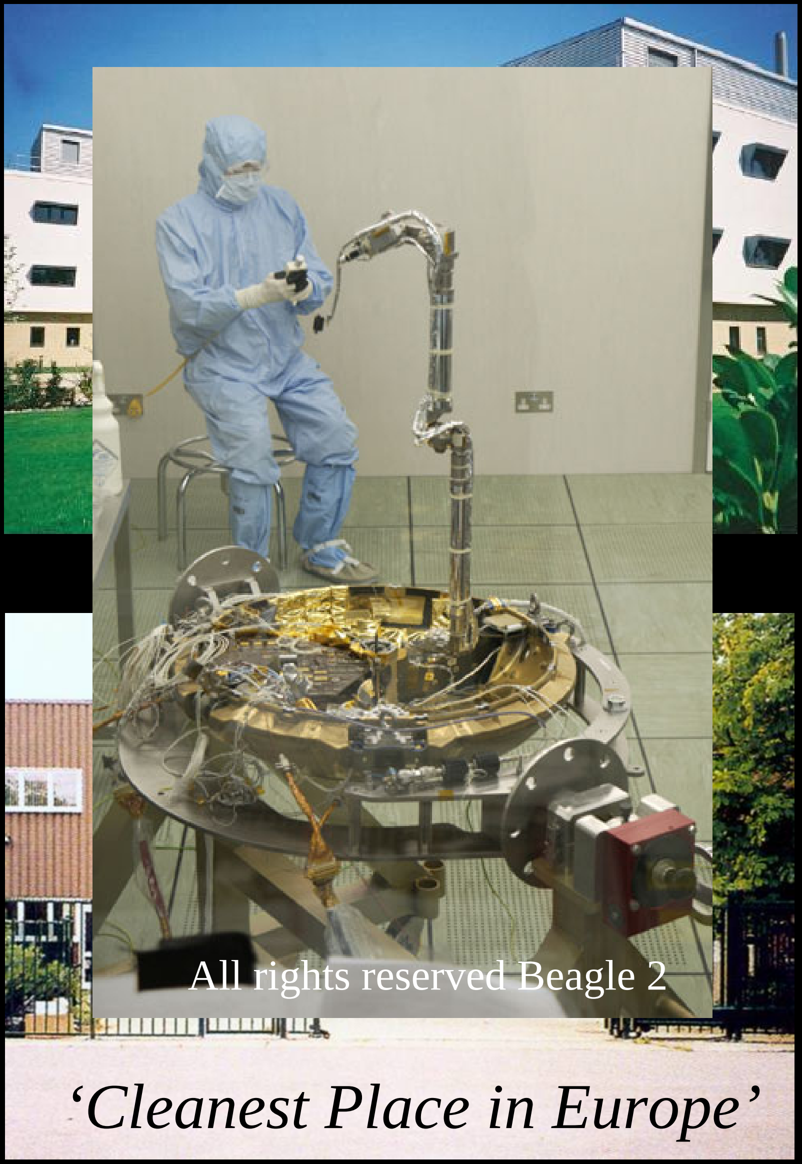
CEPSAR Centre for Earth, Planetary, Space & Astronomical Research

The Open University

The UK’s largest planetary science group, ~60 researchers & support staff

Part of the new Centre for Earth, Planetary, Space and Astronomical Research (CEPSAR) at the OU.

Multidisciplinary – astronomy, geophysics, geochemistry, microbiology, instrument development and more!



Heritage of sample analysis

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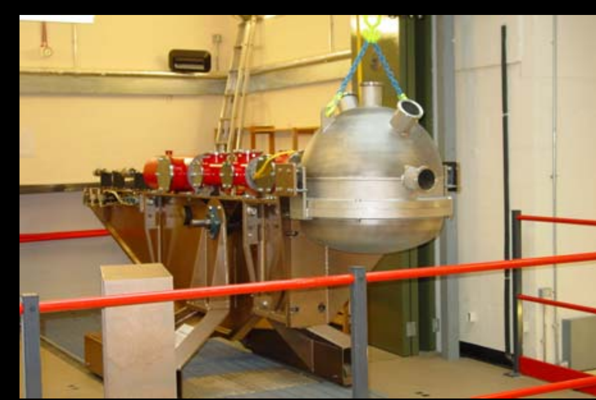
PSSRI has a long heritage of sample analyses, including:

- Meteorites
- Lunar samples
- Planetary analogue
- Genesis

… and shortly Stardust!

When this is not practical, we want to take these instruments to the sample…

$\Rightarrow$ lander instrumentation



Overview of Instruments

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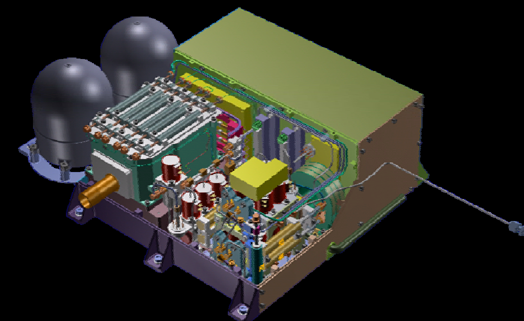
DELVE

Search for polar volatiles at depth

SOLVE

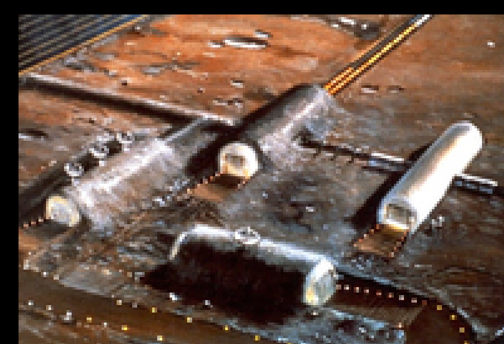


Isotopic study of volatile sources

Magnetic Susceptibility

In situ analysis of space weathering

Lunar Astrobiology Suite



Study of minimum mass for suite

The MODULUS Concept

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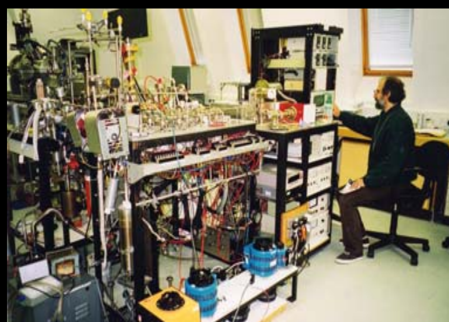
The challenge:
shrink a room
full of equipment…



…to shoe box size!

All isotopic results from MODULUS instruments (lab, comet, Mars, Moon…) are **inter-comparable** due to on-board reference materials

Rosetta - Ptolemy

Beagle 2 – Gas Analysis Package

Methods

Of

Determining and

Understanding

Light elements from

Unequivocal

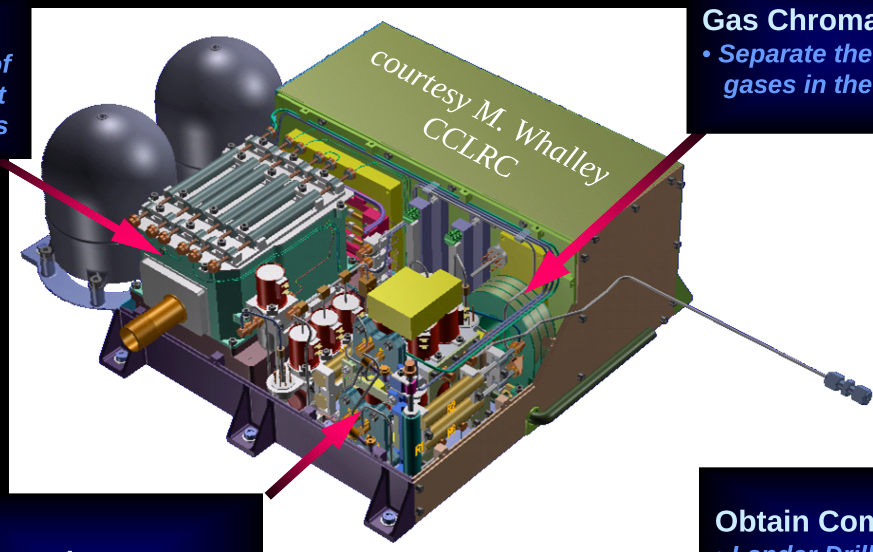
Stable isotope

compositions

Ptolemy on Rosetta

Mass Spectrometry
- *Measure the masses of the molecules present*
- *Measure Isotope ratios*

Gas Chromatography
- *Separate the different gases in the sample*



Preparation
- *Chemical processing*

Obtain Comet Sample
- *Lander Drill*
- *Oven*

Ptolemy
An instrument on the Rosetta Lander
Searching out the origins of life

An evolved gas analyser, utilising novel chemical sample preparation techniques, gas chromatography and an ion trap mass spectrometer

Aims to determine the chemical identity and isotopic composition of samples drilled from nucleus => source of water and its evolution.

Size 33 x 25 x 11 cm; Mass 4.5 kg

Science team (OU) + Engineering team (CCLRC Rutherford Appleton Laboratory)

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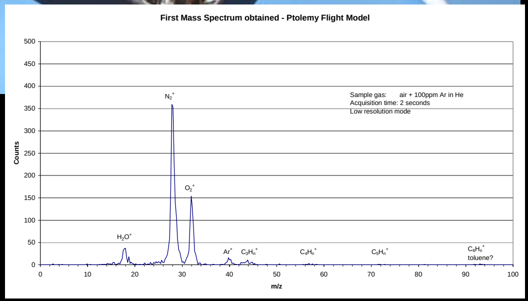
SOLVE

European Lunar Lander Workshop

Source Of Lunar Volatiles Experiment

understanding the source (cometary, volcanic, solar wind…) of lunar volatiles (H_2O, CO_2 ?, SO_2 ?, etc.) through measurement of their precise stable isotopic composition

- A new MODULUS instrument concept, evolved from Ptolemy
- Accepts solid samples from drill, mole, etc.
- Seals sample in oven
- Heats sample to release volatiles
- Chemical processing of volatiles
- Chemical and isotopic analysis by GC-MS (m/z 10-200)
- 4.5 kg, 15 W peak, 33 x 25 x 11 cm, 12 analyses each 1Mbyte
- Status: based on currently active Ptolemy FM

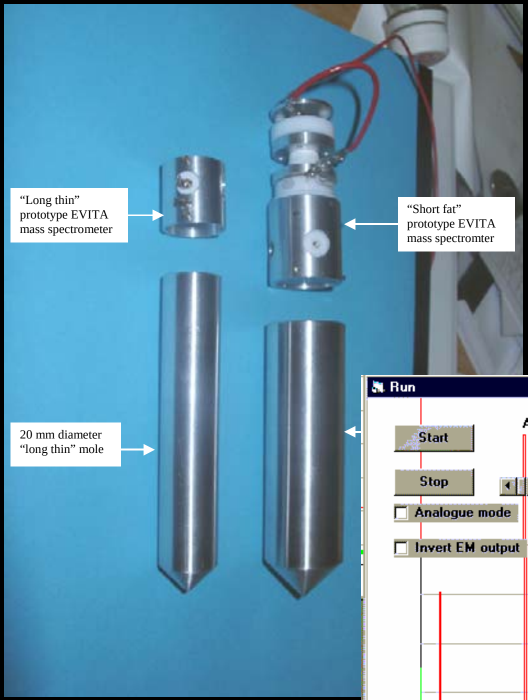


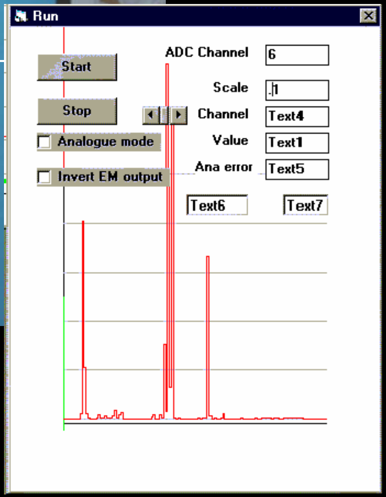
DELVE

DEpth of Lunar Volatiles Experiment

understanding the depth distribution and physical/chemical composition of lunar volatiles (H_2O, CO_2, SO_2 etc.) through in-situ analysis on board an instrumented mole

- An evolution of PSSRI's EVITA concept
- Passive collection of fines as mole descends
- Fines heated (hotplate/laser) in steps to release volatiles
- Chemical identification and quantification by ion trap mass spectrometer (m/z 10-200)
- Only limited isotopic information ($^{18}O/^{16}O$?) compared to SOLVE
- <400 g, <10 W, dia. 28mm x 65mm, 12 analyses each 1 Mbyte
- Status: prototypes working in lab, development ongoing on electronics





courtesy S. Sheridan, OU

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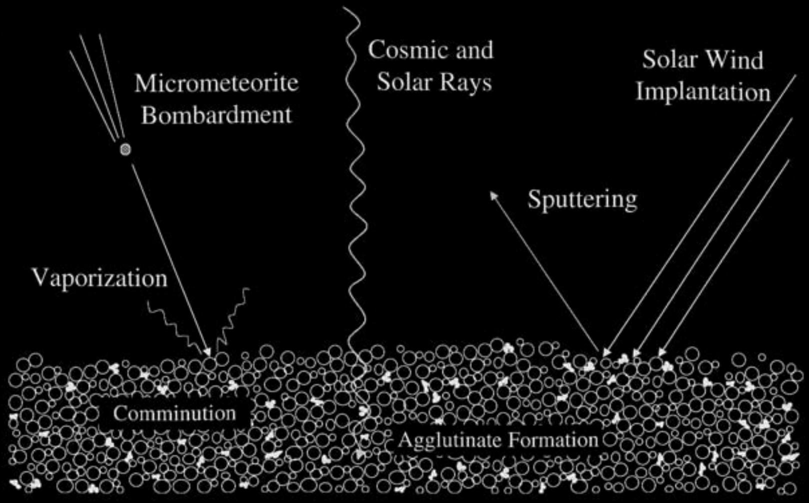
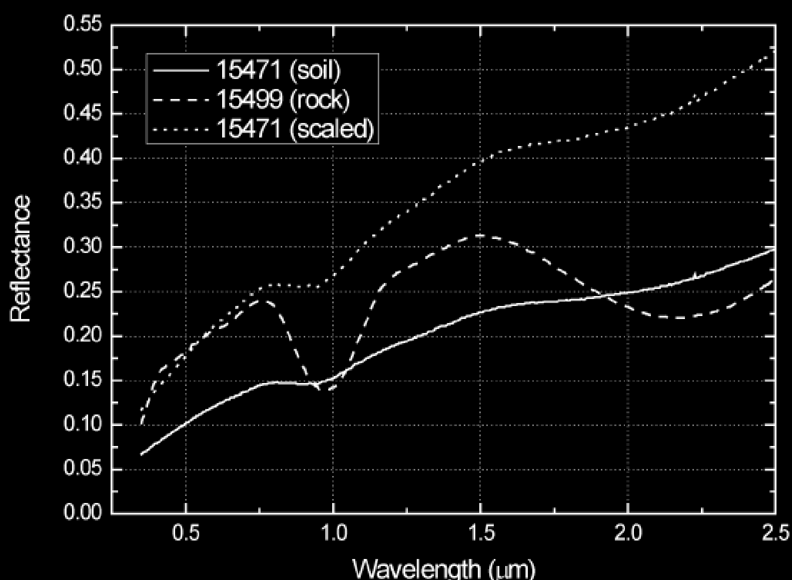
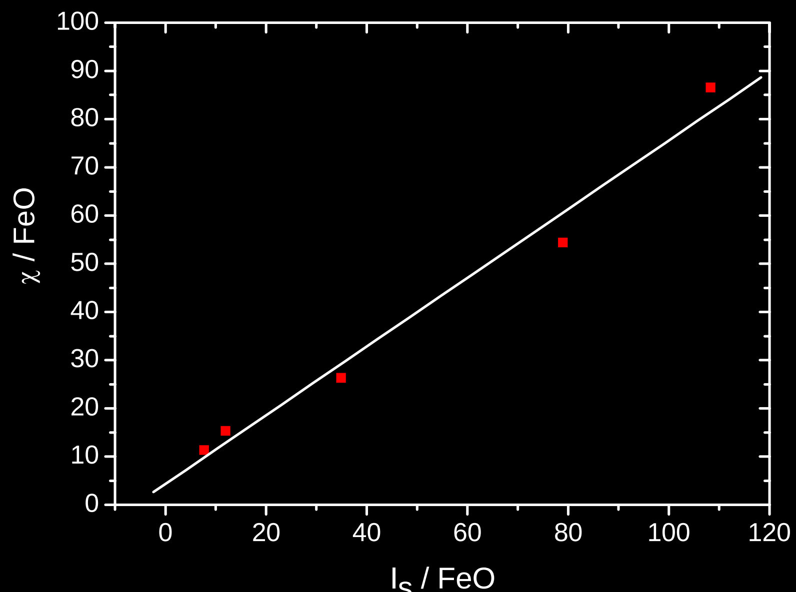
Space Weathering

The Open University CEPSAR *Centre for Earth, Planetary, Space & Astronomical Research* PSSRI



- Spectral alteration from impacts and solar wind sputtering
- VNIR mineralogy confounded
- Degree of weathering from FMR
- Correlates well with magnetic susceptibility





Magnetic Susceptibility

European Lunar Lander Workshop

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In situ measurement of space weathering in support of remote mineralogy

Mark S. Bentley (m.s.bentley@open.ac.uk), Andrew J. Ball, Ian P. Wright, John C. Zarnecki, PSSRI, The Open University, U.K.

CEPSAR Centre for Earth, Planetary, Space & Astronomical Research

1. What is space weathering?

The Moon is a unique body for which we have remotely sensed data, *in situ* measurements and returned samples for terrestrial analysis. When the first lunar samples were studied it was apparent that rock and regolith specimens with similar mineralogy had significantly different optical and magnetic properties.

An example of this is shown in *Figure 1* in which the VNIR reflectance spectra of rock and regolith samples are plotted. The regolith spectrum is considerably darker, exhibiting a reddened continuum and subdued absorption features. These changes confound attempts to perform quantitative mineralogy remotely.

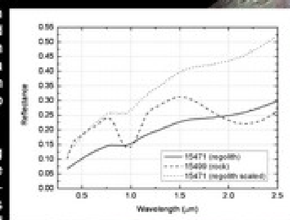

Figure 1

In recent years, research on space weathering has converged to show that these effects are caused by the reduction of ferrous iron to sub-microscopic metallic iron (SMFe). This process is driven by both micrometeorite impact and solar wind sputtering, resulting in ubiquitous deposits on almost all grains (*Figure 2*).

Figure 2

2. Optical effects of space weathering

Hapke (2001) has shown that reflectance spectra can be numerically "weathered" given the mass and size distribution of SMFe. In *Figure 3* the spectrum of a San Carlos olivine sample is plotted. This sample was then irradiated using a pulsed laser to simulate micrometeorite bombardment (Bentley, 2004). The effects of space weathering are apparent in the weathered spectrum. Hapke's technique was then used to weather the original spectrum until a best fit to the weathered spectrum was achieved at 0.00067 wt% Fe.

This technique can also be used in reverse to remove the effects of weathering if the amount of iron is known. *In situ* measurements of the SMFe content can therefore be used to remove weathering trends from the data.

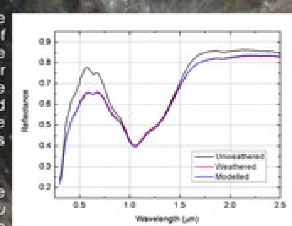

Figure 3

3. Magnetic effects of space weathering

Metallic iron is the dominant ferromagnetic phase in lunar mineralogy. Magnetic techniques are hence very sensitive to SMFe. Being fine-grained, SMFe is superparamagnetic (SPM), with a magnetic susceptibility (χ) orders of magnitude higher than single domain (SD) materials. Measuring χ at different temperatures and frequencies shifts this SD/SPM boundary and allows magnetic sizing, as shown in *Figure 4* (data taken from Stephenson (1971)).

Increasing the measurement frequency causes grains that were previously SPM to become SD, reducing the overall magnetic susceptibility of the sample. This frequency dependence is a very sensitive indicator of SPM material and hence SMFe in the lunar case.

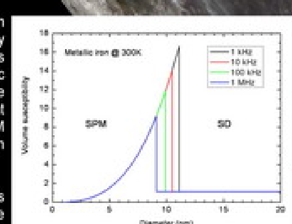

Figure 4

4. Space weathering in the solar system

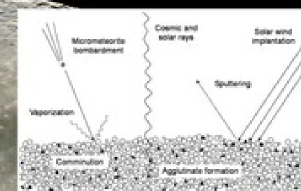

Figure 6

Our understanding of space weathering comes almost exclusively from th, but similar processes are expected on other airless bodies. Weathering has already been observed on asteroids, for example *Figure 5* shows a false colour image of Ida demonstrating the weathering trends.

Figure 6 summarises the key regolith maturation processes. The dominant weathering agents (micrometeorite impacts and ion sputtering) will have different strengths throughout the solar system, but with similar effects as on the Moon. Further modelling and laboratory studies are needed, particularly to prepare for the arrival of MESSENGER and BepiColombo at Mercury in the absence of any *in situ* measurements there.

Figure 5

5. Laboratory Measurements

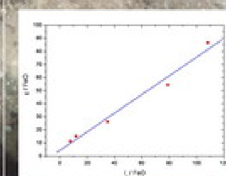

Figure 7

Electron spin resonance spectroscopy of lunar soils detects metallic iron spheres with diameters of between 4 and 33 nm. The intensity of this resonance, normalised to the wt% FeO provides the best maturity metric (Morris, 1976).

Magnetic susceptibility depends on the mineralogy of the sample, but is dominated by the amount and size of SMFe present. Plotting χ/FeO against I_s/FeO (*Figure 7*) shows a good correlation, hence this should also be a useful maturity and weathering index (Oder, 1992).

6. Instrument Proposal

Figure 8

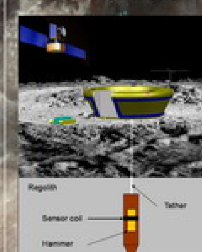

Figure 9

Magnetic susceptibility is well-suited to miniaturisation for spaceflight (*Figure 8* shows a commercial hand-held sensor). It has been shown to act as an index of maturity (weathering degree) and can be used to estimate the size distribution of SMFe, vital data for removing the effects of space weathering from remote reflectance spectra.

The basis of such a sensor is a coil, placed close to or in the regolith. The coil is energised with an alternating current to produce a low field (~0.1 mT). Its inductance then changes with the magnetic susceptibility of the regolith it couples to. Multi-coil techniques increase the depth of penetration; in this case one coil is energised and the others are receivers. This sensor can be deployed on a lander foot, rover, or mole, as shown in *Figure 9*, in which the coil is coaxial with the mole.

A development programme to produce a breadboard model of this instrument could be undertaken at modest cost. Amongst the key issues to be addressed are the thermal and mechanical stability of the coils, and how such a relative measurement would be calibrated. In the case of a mole careful choice of the hammering mechanism alloy could prove ideal.

7. Acknowledgements

Mark wishes to acknowledge PPARC for funding this research.
Figure 2 is taken from Pieters et al (2000).
The spectrum in Figure 1 was acquired by J.B. Adams and in Figure 3 by C.M. Pieters and T. Hiroi using the NASA RELAB facility at Brown University.
Figure 8 is courtesy of Sarah Noble.
Figure 8 is taken from http://www.zhinstruments.cz/sm-30.html
Figure 5 and the background image are © NASA.

7. References

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Lunar Astrobiology Lab

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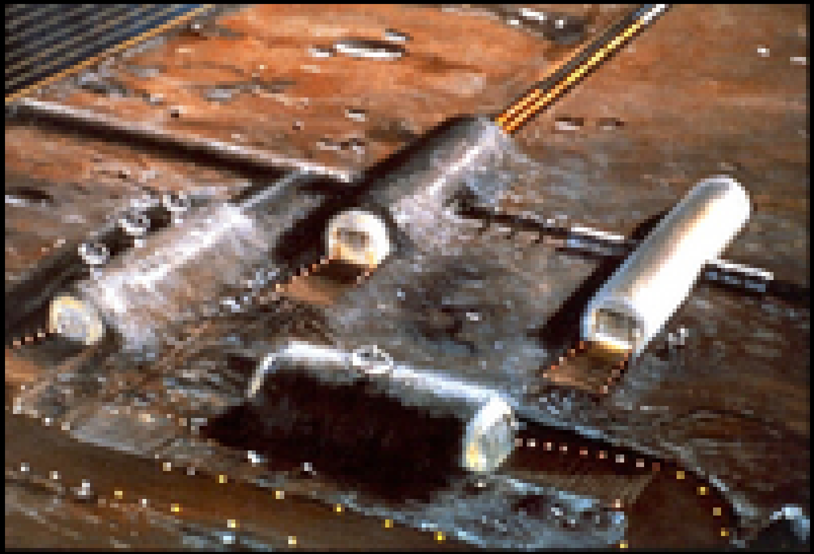
PSSRI is involved in a three month definition study on the International Lunar Astrobiology Laboratory (ILAL), working with ESA and Alcatel.

The study will define:

1) The minimal mass laboratory required for biological studies on the moon, including life support and crew health monitoring,

2) The required minimum laboratory to be taken to other planetary surfaces, particularly Mars, for astrobiological studies,

3) The expertise needed in lunar astrobiology for a productive scientific presence on the moon.



DLR Institute for Planetary Research

The Heat flow and Physical Properties Package (HP^3): an integrated sensor suite for planetary subsurface studies

Original slides: Riccardo Nadalini

Modified and presented: Mark Bentley

riccardo.nadalini@dlr.de

Lunar Lander Workshop

ESTEC, 16th December 2005

HP^3: the components

HP3 objective is the measurement of the **INTERNAL** heat flow of the planet. It does this with **Three Sensors:**

TEM, **T**hermal **E**xcitation and **M**easurement suite

- Temperature (ΔT)
- Soil thermal properties (κ,c)

DEN, **DEN**sitometer

- Density (ρ)

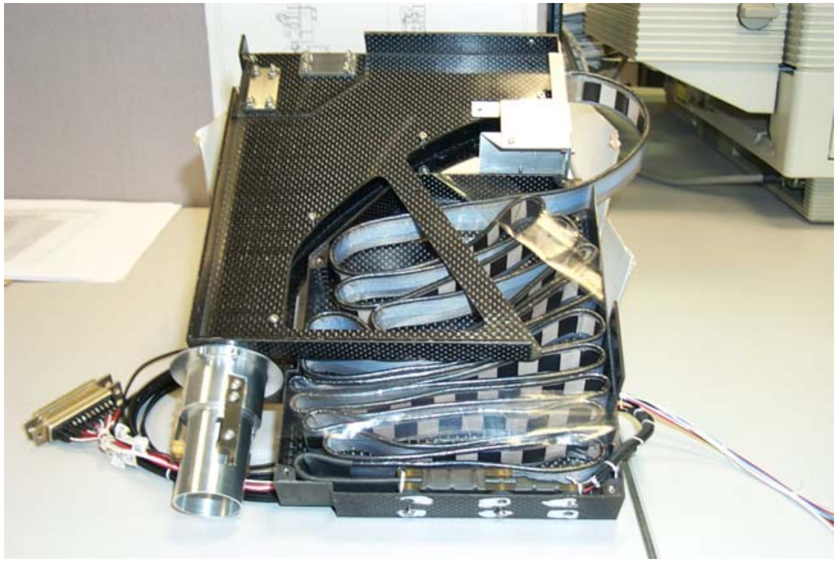
DACTIL, **D**epth, **AC**celerometry and **TIL**t suite

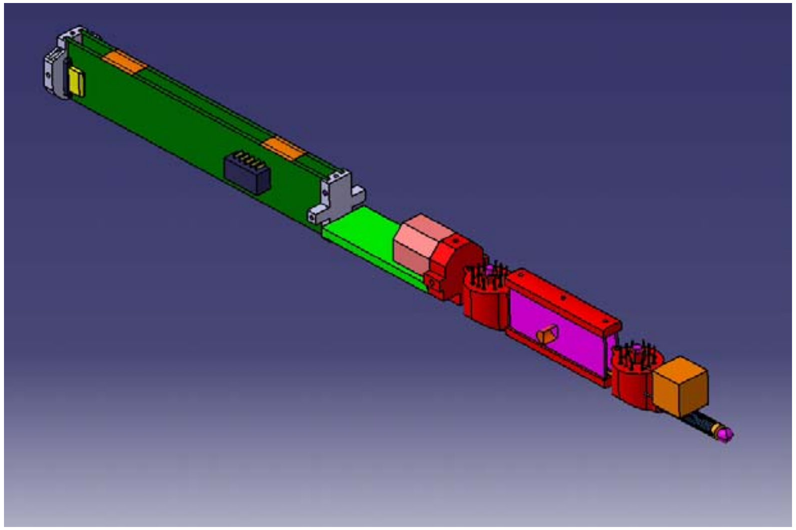
- Position, attitude (α), shape of borehole (by tracing)
- (Soil mechanical properties)

HP^3: status

Critical design review held in October 2005

Breadboard integration and test: Easter 2006





Current Team

DLR Institute of Planetary Research (Berlin)

- System, Electronics, Structure, TEM

DLR Institute of Space Simulation (Cologne)

- Mole, DACTIL

Open University

- DEN

Oxford University

- Tether

Galileo Avionica (Milano)

- Surface Systems, Tether Length Sensor

ESA-ESTEC

- Financing the present developments (payl. dev, TRP)

Any Questions?

PSSRI also involved in the HP^3/ DEN backscatter densitometer (being bread-boarded in PSSRI), and the spectroscopic follow-on X-Gamma (led by University of Leicester) and GEP (through the environmental sensor suite and UV spectrometer + possibly HP^3)

For further details on each of the instruments described, contact:

DELVE: Simon Sheridan (s.sheridan@open.ac.uk)

SOLVE: Simeon Barber (s.j.barber@open.ac.uk)

Space Weathering: Mark Bentley (m.s.bentley@open.ac.uk)

Lunar astrobiology: Charles Cockell (c.s.cockell@open.ac.uk)

DEN: Andrew Ball (a.j.ball@open.ac.uk)

HP^3: Riccardo Nadalini [DLR Berlin] (riccardo.nadalini@dlr.de)

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