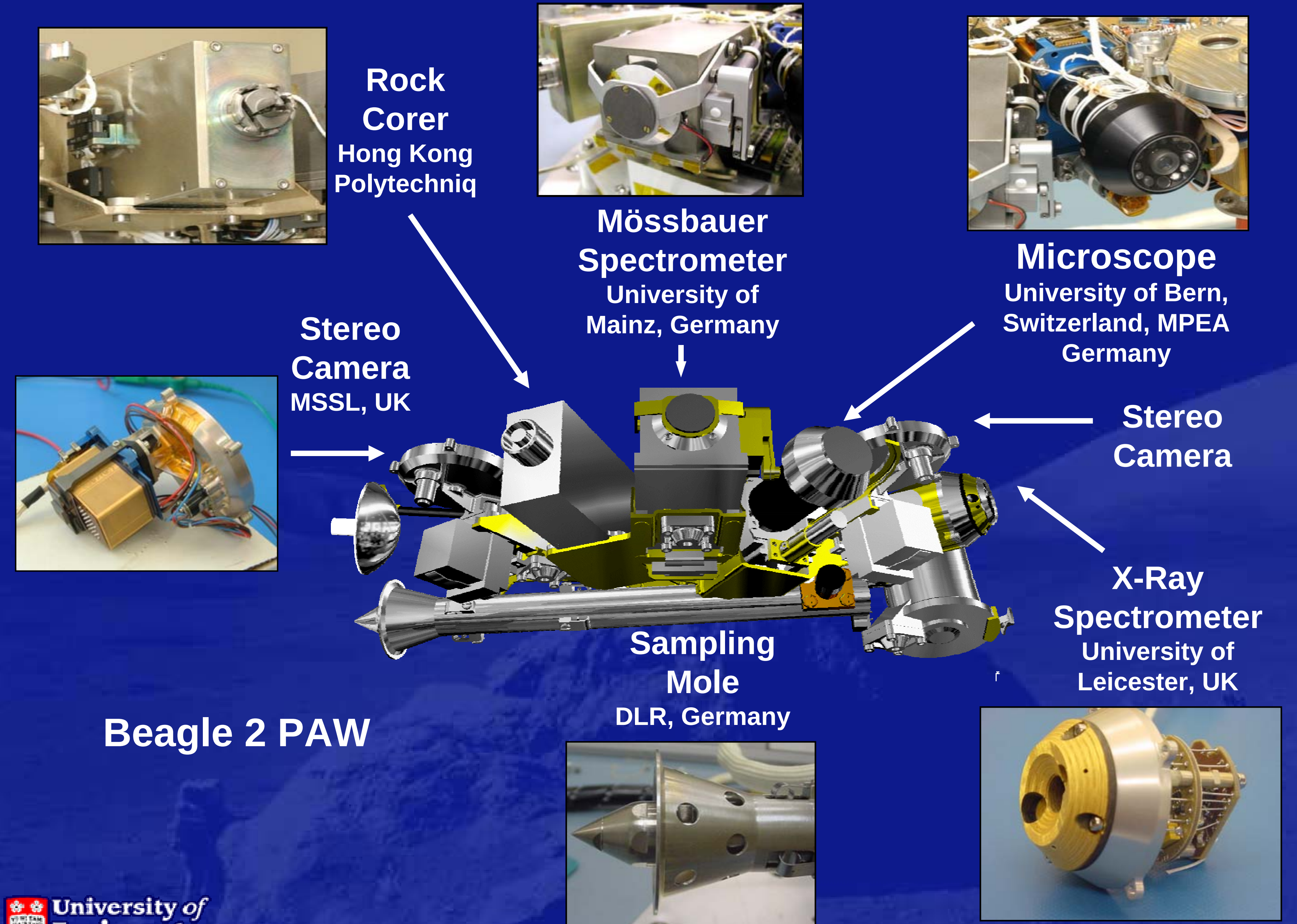
INSTRUMENTATION FOR LUNAR SCIENCE:

Instruments for Lunar Geochemistry, Radiation Environment and Search for Ice
&
A Candidate Payload for the Chinese Chang'e II Lunar Rover?

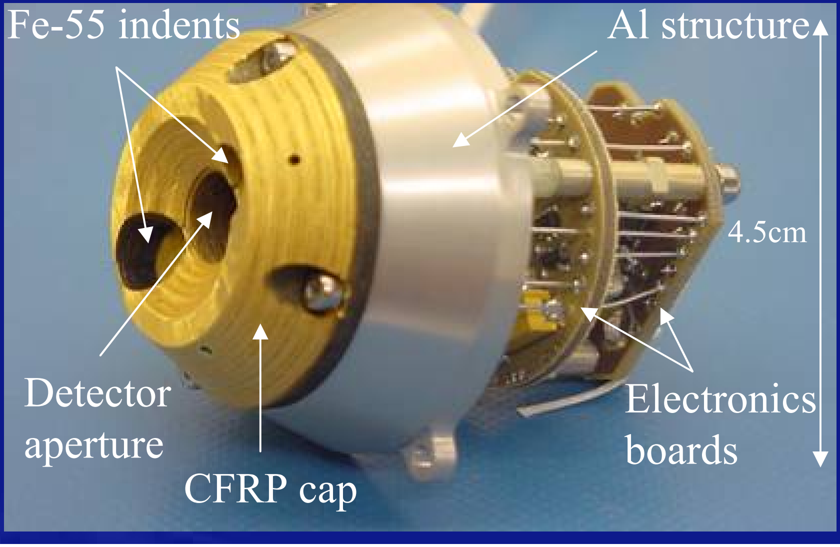
Dr. Mark Sims

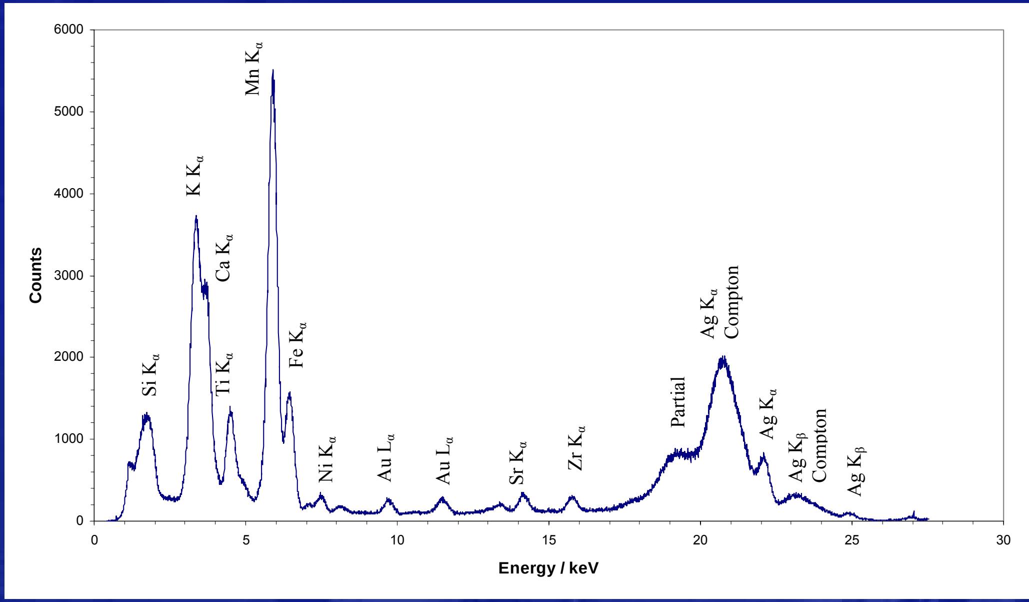
Space Research Centre
Department of Physics & Astronomy
University of Leicester
University Road
Leicester LE1 7RH
UK.

email dlt3@star.le.ac.uk


Rock
Corer
Hong Kong
Polytechniq
Mössbauer
Spectrometer
University of
Mainz, Germany
Microscope
University of Bern,
Switzerland, MPEA
Germany
Stereo
Camera
MSSL, UK
Stereo
Camera
X-Ray
Spectrometer
University of
Leicester, UK
Sampling
Mole
DLR, Germany
Beagle 2 PAW

X-ray Fluorescence spectroscopy





Beagle 2 XRS spectrum of a granite sample with main constituent peaks identified.

Based on Beagle2 X-ray Spectrometer

Science aims:

Major and trace element geochemistry

Potential lunar applications:

Sample selection for return to base / Earth.

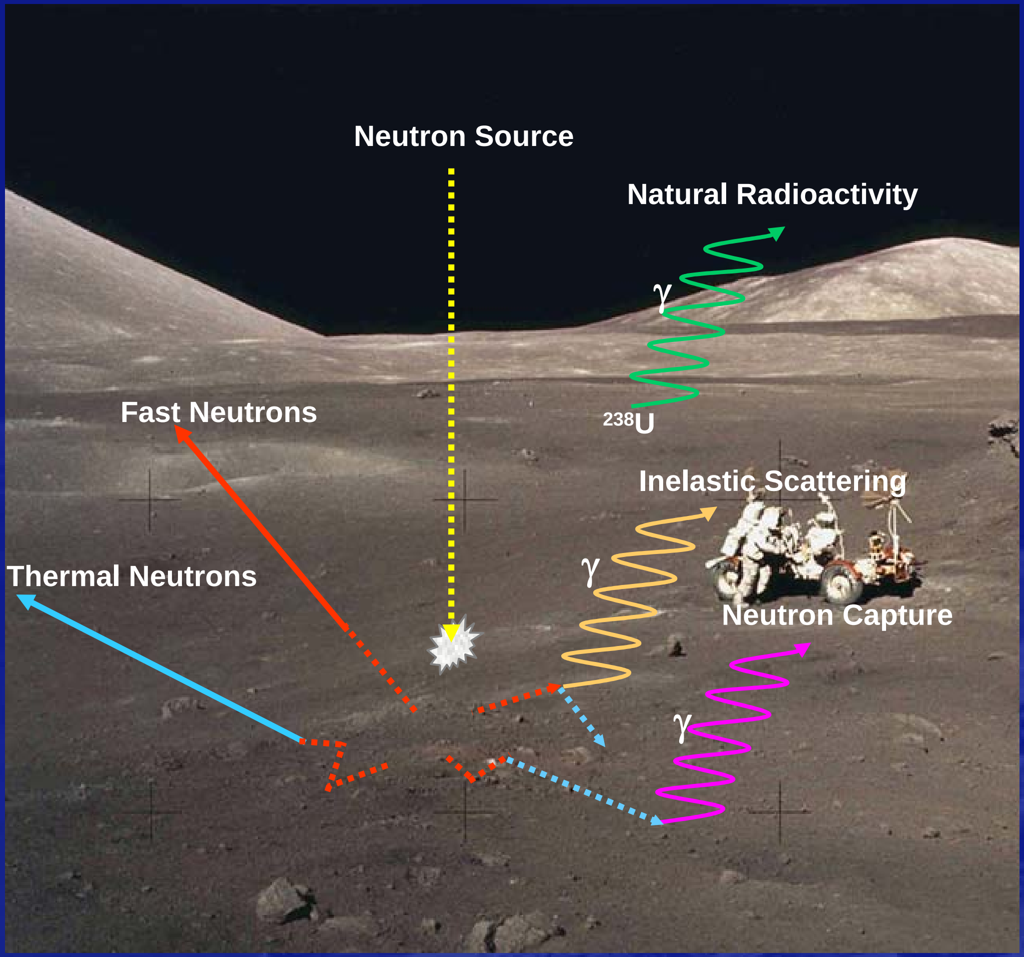
Rapid geochemical analysis for classification in-the-field

Ground truth measurements to complement e.g. orbiting IXRFS data

Resource location (e.g. from signatures of Fe/Si-Al/Si & Mg/Si-Al/Si, it is possible to identify deposits of ilmenite).

GEORAD

Neutron Activation, Gamma Ray Spectroscopy & Environmental Monitoring



Gamma-ray spectrometer, neutron source, neutron backscatter & solar particle detector.

Geochemistry: establish elemental composition of surface & subsurface rocks & soils using Neutron Activation Analysis & Gamma Ray Spectroscopy. Obtain density information from γ-ray flux.

Water / ice: measure distribution of water (Mars) & ice (Mars/moon) using the 2.2 MeV γ–ray associated with n-capture by H. Map H & water/ice content beneath the surface using change in thermal:fast neutron flux.

Human factors: study the risks associated with the radiation environment on the surface of the Moon.

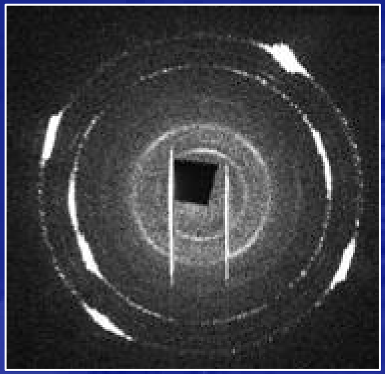
X-ray Diffraction

The mineralogy of surface material reflects the geological history of a body. X-ray powder diffraction, combined with elemental measurements from X-ray fluorescence, provides a powerful analytical tool for mineral identification and quantification.

The Space Research Centre is part of an international team that has put forward a proposal for an autonomous X-ray diffraction and fluorescence instrument as part of the ESA Aurora ExoMars Pasteur payload.

The detector system is being provided by the Space Research Centre and a prototype (using an X-ray sensitive CCD) is now operational. Diffraction images from powdered aragonite and a lysozyme protein crystal are shown below. Implementation of photon counting and data post-processing algorithms are under development.

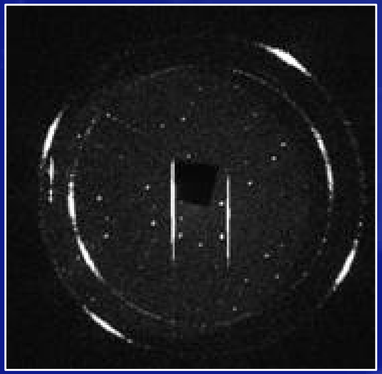
X-ray diffraction/X-ray fluorescence detector



Diffraction measurement from prototype XRF/XRD detector system. The bright columns are defects in the detector and the two outer diffraction rings are from the aluminium window.

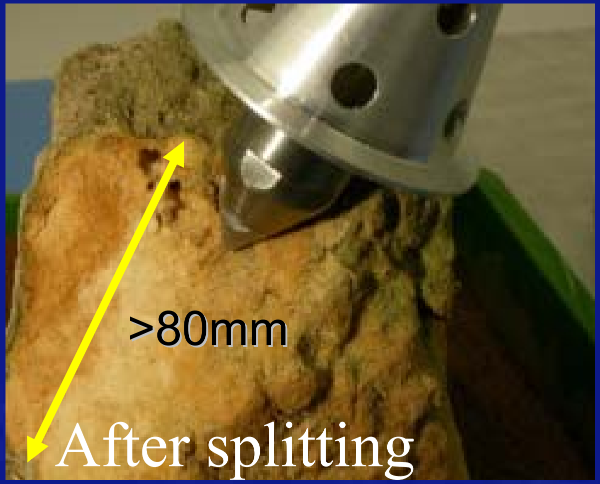
← Powdered aragonite

Lysozyme crystal →

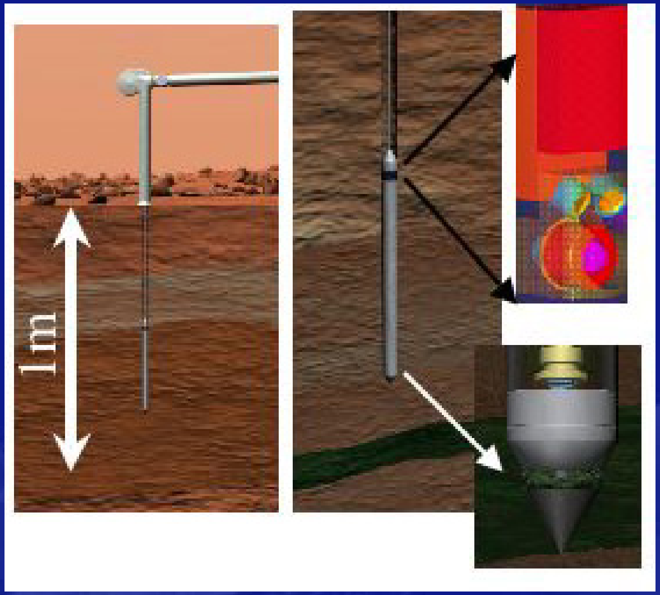


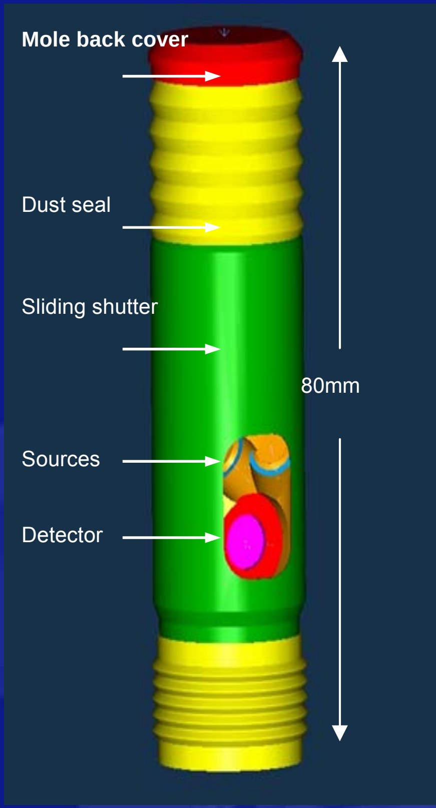
Subsurface techniques

Rock Splitting Tool



Mole for Soil Compositional Studies & Sampling





Imaging X-Ray Fluorescence Spectroscopy

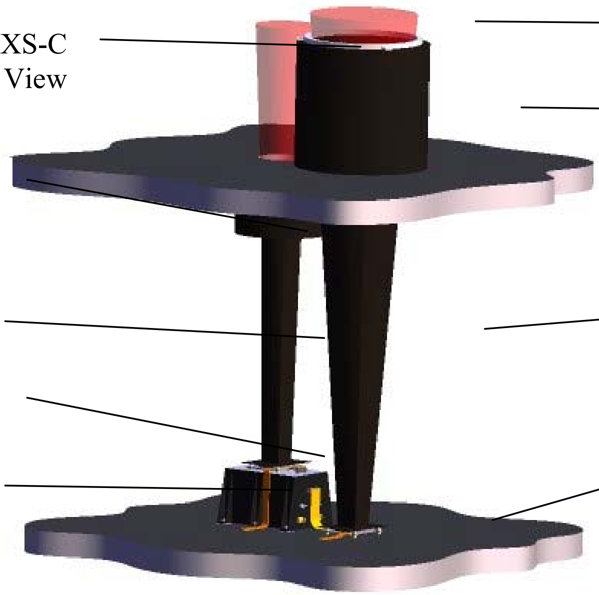


Figure 1: Schematic view of MIXS

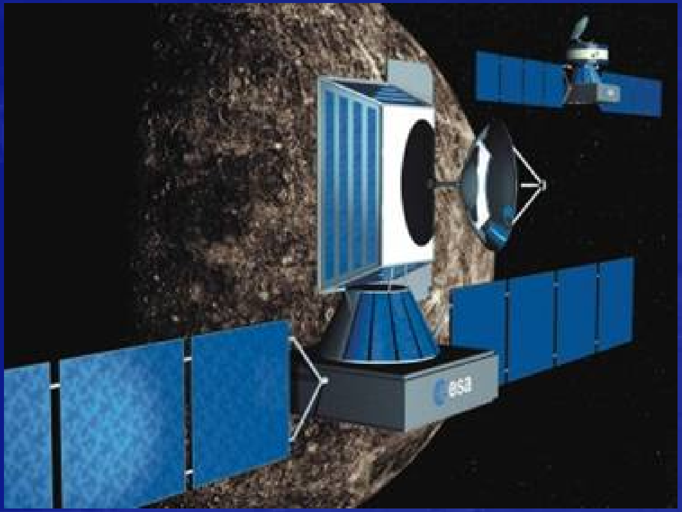
MIXS: Leicester / RAL collaboration for Bepi Colombo.

Production of global elemental abundance maps at low/medium to ~10-20% precision.

Production of high resolution local maps at ~km resolution.

Measurement of the influence of energetic particles on surface PIXE and auroral zone (Mercury) X-ray emission

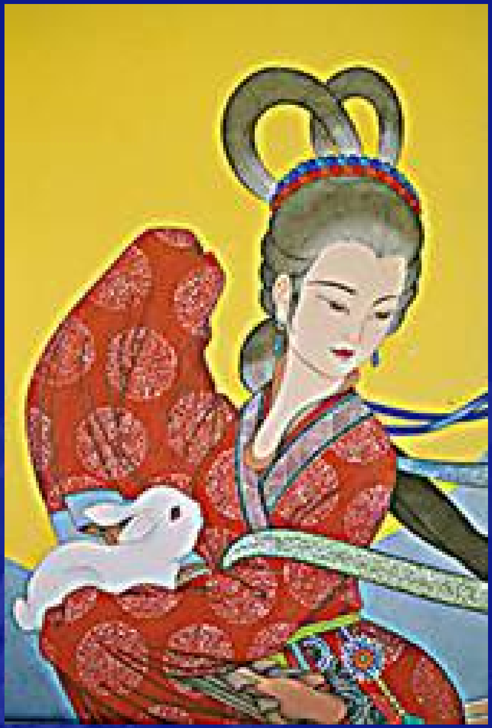
Complementary information from co-pointed gamma-ray and neutron detectors on MPO



Current Research and Development for Lunar Exploration in the Chinese programme

Collaborators: Dr J.-S. Wang, Prof. H.-F. Chen, Prof. Z.-Y. Pu, Prof. W.-X. Jiao
Peking University, Beijing, China

- Chinese Chang-E programme
  - Stage 1: Lunar Orbiter
    - Chang-E I 2007
  - Stage 2: Lunar rover
    - Chang-E II c. 2010
  - Stage 3: Sample return
    - Chang-E III c. 2020



Chang'e I

- Chang'e I Science Objectives
  - Acquire three-dimensional stereo images of lunar surface.
  - Analyse distribution and abundance of useful elements on the lunar surface
  - Survey the thickness of the lunar regolith to evaluate resource of He-3
  - Explore the particle environment of the Moon

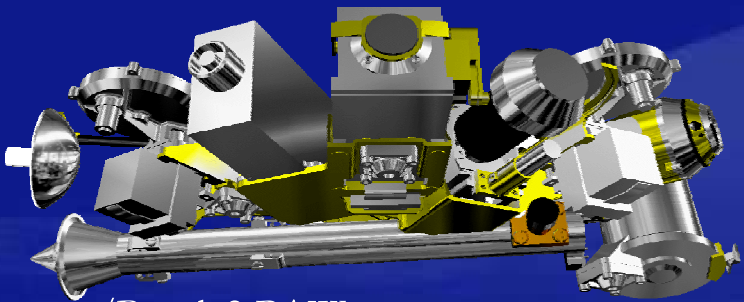
Chang'e II

- Development of a potential payload for the Chang-E II lunar rover
  - Peking University
  - Set of instruments on end of robotic arm and in body of rover
- General goals
  - Successfully deliver rover to surface of Moon;
  - Perform a full geological characterisation of the landing area;
  - Evaluate the lunar resources at the landing area;
- Mission Architecture
  - Managed by Chinese Academy of Space Technology (CAST)
  - Near side, non-polar landing for safety
  - Lander and Rover components (both instrumented)
  - Model Payload under consideration: X-ray spectrometer, panoramic camera, mass spectrometer, VIS/IR imaging spectrometer, microscope & tools / samplers
- Instruments
  - Chinese & European
  - Most can be based on instruments and technologies developed for Beagle 2

Chang'e II benefits

- Potential international collaboration between ESA and China
  - Foundation established with Double Star
  - Future Chinese planetary missions, manned spaceflight

- Early Component of Lunar Exploration programme
  - World-class science - such a sophisticated science package has never been sent to the Moon
    - Evaluation of lunar resources
    - Characterisation of landing site
    - Ground truth to orbiting missions



- Payload
  - Some instruments can draw on heritage of ESA Mars Express/Beagle2 PAW
  - minimum development work
  - maximise science return for investment
- Field-tests a set of innovative tools (designed initially for Mars) for lunar exploration

- Future
  - **Need ESA to co-ordinate and organise any contribution**
  - **Develop proposal with a view for submission as candidate payload for Chang-E II**

Summary

•UL Proven expertise in the design & construction of planetary instrumentation for flight programmes.

•Strong R&D programme covering a wide variety of technologies for in-situ and remote sensing of surface & sub-surface environments.

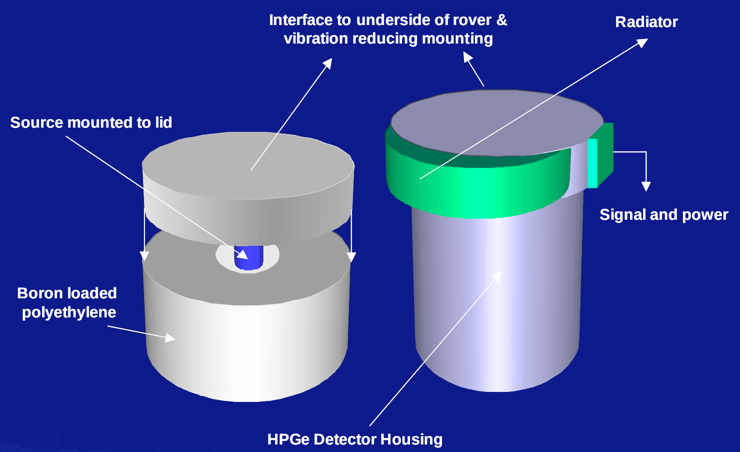
•Experienced systems engineering team, complemented by extensive in-house facilities for testing & calibration of instruments & sub-systems.

•Experience in the provision of mission Ground Segments & data centres (e.g. Beagle-2 LOCC, XMM-Newton Survey Science Centre, Swift UK Science data centre.

•Active collaboration with University of Peking to place a comprehensive instrument suite on the Lunar surface as part of the Chang'e II mission. This is an initiative started and lead by the University of Leicester which is being offered to ESA and Europe as an early potential lunar exploration opportunity.

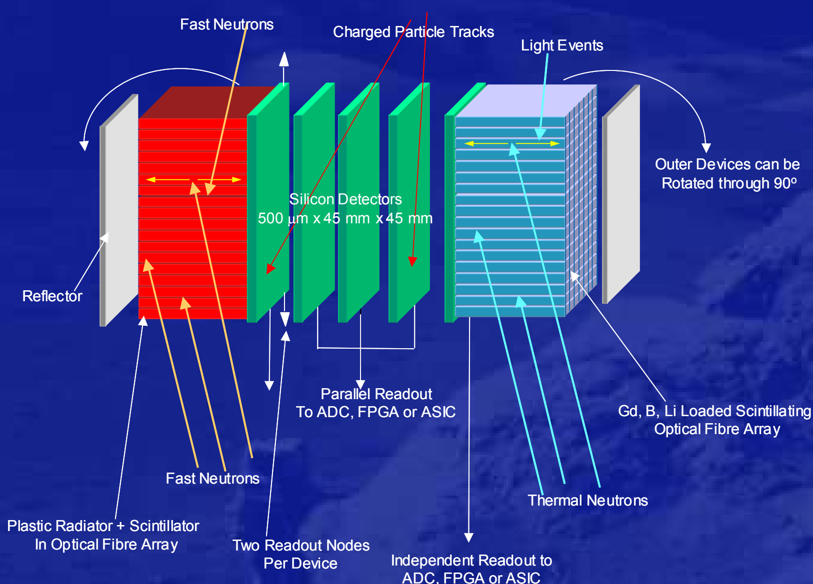
GEORAD

Neutron Activation, Gamma Ray Spectroscopy & Environmental Monitoring

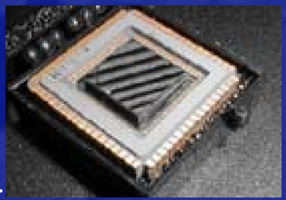


Gamma-ray spectrometer: measures signal from n-induced activation of elements on surface & subsurface; detection of naturally radioactive elements (^{40}K, ^{235}U, ^{238}U and ^{232}Th). Range: 100 keV – 10 MeV.

Neutron source: reduces acquisition times compared to solar-induced case alone. ^{252}Cf, Am-Be, Pu-Be or 14 MeV neutron tube.



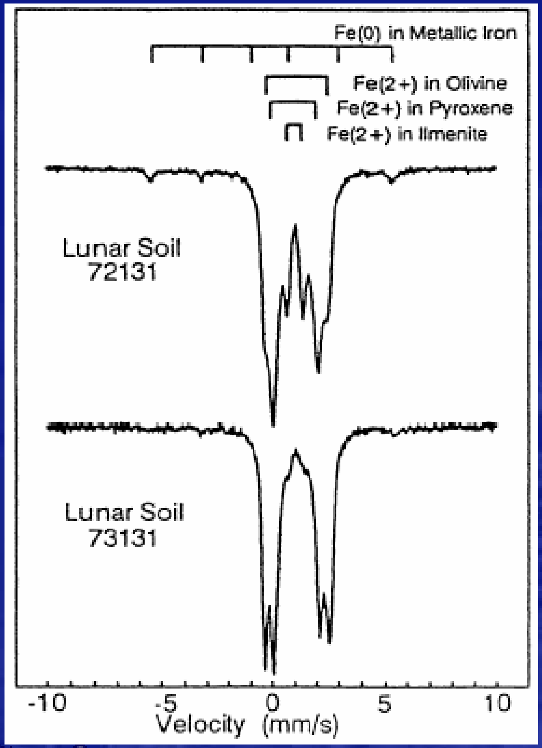
Neutron backscatter & solar particle detector: 20-100 MeV. Separate thermal & fast n-sensitive detectors => variations in subsurface H-content indicated by change in fast/thermal n ratio. Distinguishes between direct detection of charged particles & signal from thermal & fast neutrons. On-board differentiation between signal characteristics. Directional properties of CRB, with 5 MeV energy resolution.



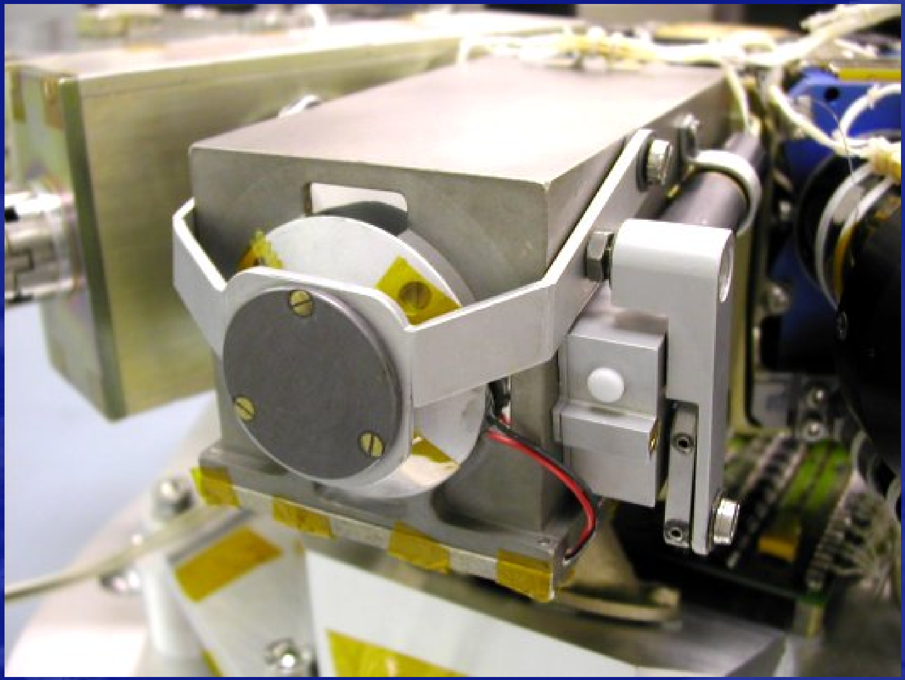
Solid state pixellated Si detectors under development at UofL.

PAW: Mössbauer Spectrometer (Mainz/UL)

- **FM Specifications**
- Radioactive sources
  - ⇒ 1 x ^{57}Co (HL = 271.79 days) @ **9.99 GBq** *
  - ⇒ 1 x ^{57}Co (HL = 271.79 days) @ **0.37 GBq** *
- Primary emission energies:
  - ⇒ 6.4 keV (X-rays)
  - ⇒ 14.41 keV (gamma rays and X-rays)
  - ⇒ 122 keV (X-rays)

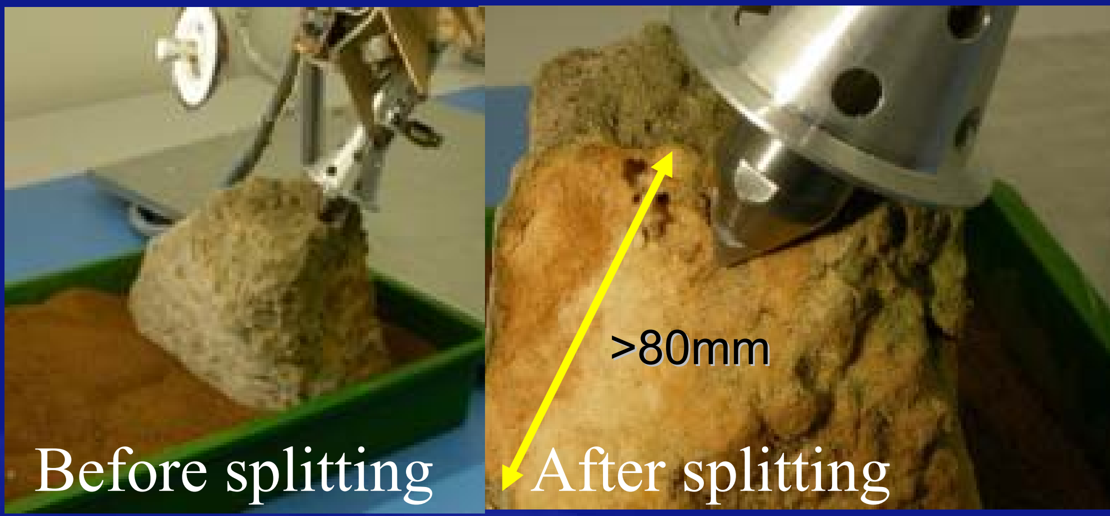


- **Science Goals**
- Identification of Fe bearing phases
- Oxidation state of Fe bearing minerals
- Soil oxidation and magnetic phases
- Detection of nanophase and amorphous hydrothermal Fe minerals
- Relict environmental conditions (Fe carbonates etc)



Subsurface techniques I: SPLIT

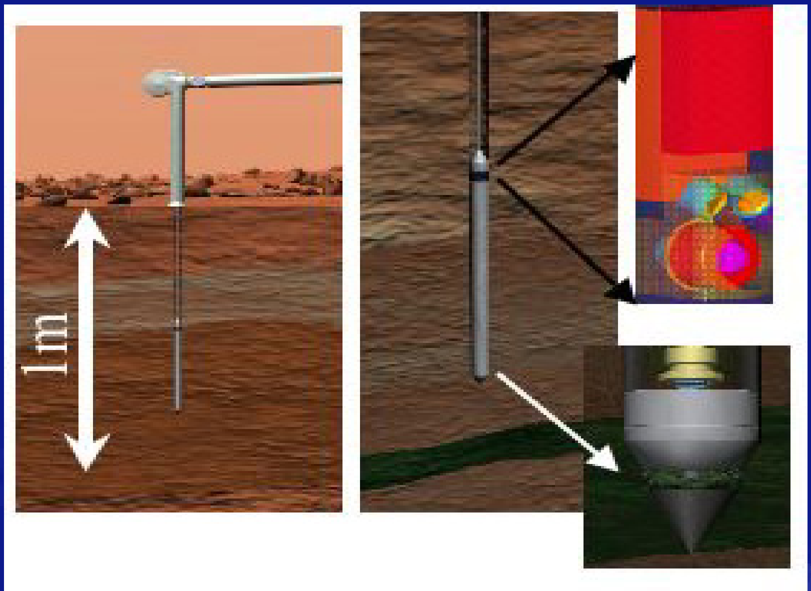
Small **PL**anetary **I**mpulse **T**ool

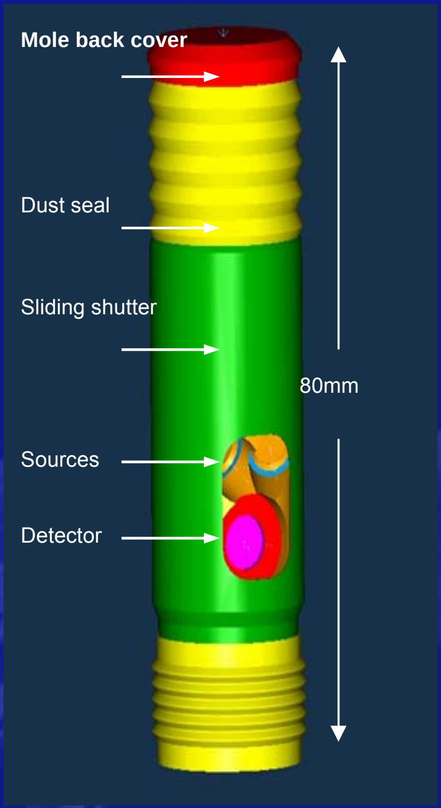


- Rock Splitting Tool
  - Advantages
    - Preserves grain & crystal structures & chemical distribution in sample
    - No contact between tool tip & pristine interior material
    - Easier access to information on strata, surface rinds, etc.
    - Additional data from on-board accelerometers provides information on hardness & other geo-technical properties.

Subsurface techniques II: MOCSS

Mole for Soil Compositional Studies & Sampling



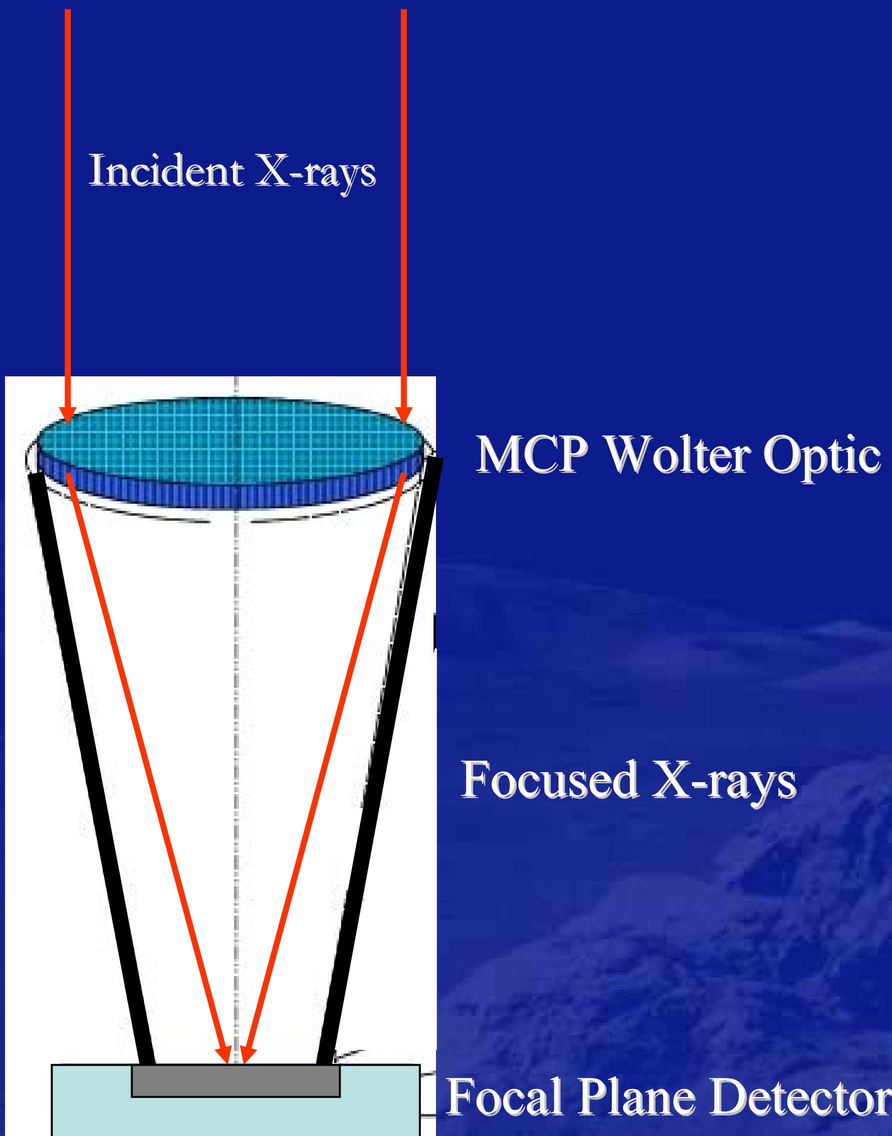


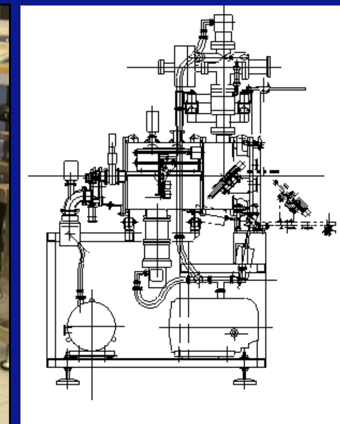
- Based on Beagle-2 *PLUTO* heritage
- Uses conventional borehole logging techniques (neutron & gamma ray sources, alpha particle sources).
- Carries X-ray spectrometer & thermal sensors
- XRS provides vertical profiles of soil chemical properties from undisturbed material surrounding drill hole.
- Retains sample-retrieval capability
- Compact (34 cm x 2.5 cm diameter, 1.5 kg with tether, reel & electronics).

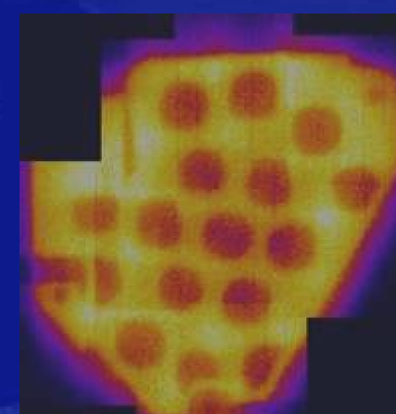
Key Science Returns

- Stratification of Ni can be used as a diagnostic for meteoritic impact rates
- Measurement of vertical stratification & distribution of lunar resources.
- Thermal conductivity, density, compositional information.

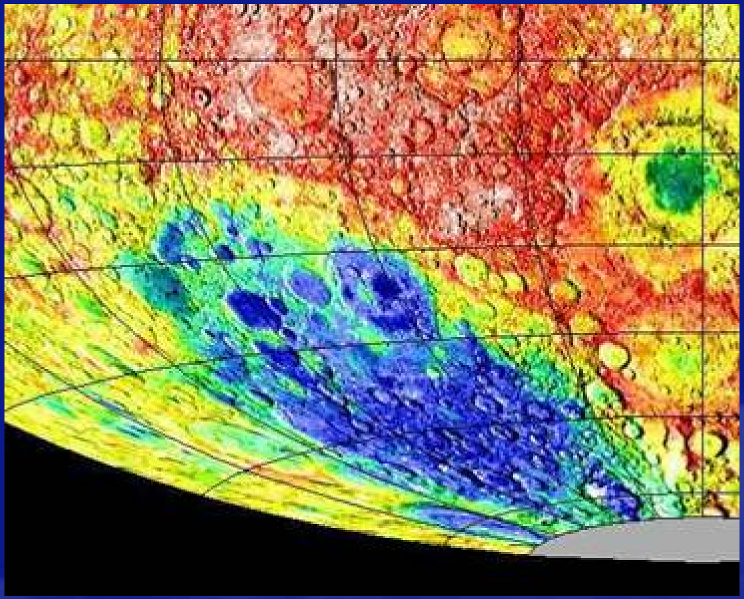
Imaging X-Ray Fluorescence Spectroscopy







Baseline Payload - Lunar Resources



- Geological Characterisation
  - Landing site, eg South Pole Aitken Region
    - Investigate material excated from lower crust / upper mantle
    - In-situ radiometric dating
- Evaluation of resources
  - Mass Spectrometer (China)
    - ^{3}He
  - Particle Monitor (China)
    - Origin of ^{3}He
  - X-ray Spectrometer (University of Leicester)
    - Identify ilmenite (oxygen)
  - Mole (Europe?)
    - Stratification of ^{3}He in sampling mode
  - Mössbauer spectrometer (Europe?)
    - Lunar mineralogy
    - Measure of residence time on upper 1mm of regolith (maturity)
    - Longer residence time means higher proportion of ^{3}He