LUNAR ELEMENTAL COMPOSITION AND INVESTIGATIONS WITH D-CIXS X-RAY MAPPING SPECTROMETER ON SMART-1. M. Grande[1], S. Dunkin [1,9],C. Howe [1], R. Browning[1], B. Kellett[1], C. H. Perry[1], B. Swinyard[1], N. Waltham[1], B. Kent[1], J. Huovenin [2] , N. Thomas [3]U Mal[3], D. Hughes[4], H. Alleyne[4], S. Russell[5], M. Grady[5] , R. Lundin[6], S. Barabash [6] , D. Baker[7] , C. D. Murray[8], J. Guest [9], I Casanova [10], S Maurice [11]. B Foing [12]
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Introduction: The ESA SMART-1 mission to the Moon was successfully launched on 27 Sept 2003. A major payload element is ***D-CIXS***, a Compact X-ray Spectrometer which will provide high quality spectroscopic mapping of the Lunar surface. At the same time it will demonstrate a radically novel approach to building a type of instrument essential for the Mercury cornerstone mission. It will achieve ground breaking science within a resource envelope far smaller than previously thought possible for this type of instrument, using new technology which does not require cold running, with its associated overheads to the spacecraft. It consists of a high throughput spectrometer, which will perform spatially localised X-ray fluorescence spectroscopy, and a solar monitor to provide the calibration of the illumination necessary to produce global map of absolute Lunar elemental abundances.

The ***DCIXS*** instrument images fluorescence X-rays from the SMART-1 target object, as a means to carry out spatially resolved material analysis of the Lunar surface. With its large collecting area and angular acceptance, the technology is especially suitable for the Moon, where due to the orbital speed it is necessary to accumulate images quickly to avoid blurring due to the spacecraft motion over the surface, as well as to map the whole surface in a given time. ***DCIXS*** can derive 45 km spatial resolution images of the entire Lunar surface from a 300km orbiting spacecraft with a spectral resolution of 180 eV. This will enable it to provide a major improvement in our understanding of Lunar Geochemistry, and hence Lunar origins.

Instrument Concept: The essential concept of the instrument is that rather than a traditional X-ray telescope, we will produce a modern version of "X-ray detecting paper". In order to obtain adequate statistics for what can be very weak sources, it is essential to have a large effective area, while remaining light. The solution is to make a thin, low profile detector. The demonstrator D-CIXS has an effective area of 16 sq cm. The energy range of interest is 0.5 to 7 keV, and an energy resolution sensitivity of ~180eV FWHM. This is achieved in a mass of ~3.5 kg.

The instrument is a new technological evolution, centering around the use of advanced dual microstructure collimator and Swept Charge Device (SCD) X-ray detector technologies. SCD detectors, a novel architecture based on proven CCD technology, have the virtue of providing superior X-ray detection and spectroscopic measurement capabilities, while also operating at near room temperature. Thus we avoid the need for the large passive cooling radiator that was previously required to cool large X-ray focal plane CCDs. We have produced a new specification and layout, well suited to a space environment. All devices will be manufactured on high resistivity silicon, with supplementary 'narrow' channels made narrower to increase radiation tolerance, using the electrode structure developed by EEV for the Russian Spectrum-X JET-X mission.

The advanced low profile microstructure collimation and filter design builds on expertise developed in solid state and microwave technology to enable us to dramatically reduce the instrument mass.

Fig 1 The D-CIXS instrument

It is based on a new negative resist that mainly consists of an epoxy resin which can be exposed using ultra violet radiation. This resist has been designed for very thick layers and has very good mechanical properties and more importantly can be used to produce features that have very good sidewall angles approaching 90 degrees and high aspect ratios.

These technological innovations arose from the recognition of the need for more advanced and more compact instruments which are less demanding on spacecraft resources than previous designs. They are thus highly suitable for deployment on micro satellites. The technology is sufficiently versatile that the instrument can be configured for many proposed target objects, of which the Moon on SMART-1 is only one example.

Instrument Performance: ***D-CIXS*** X-ray spectrometer has been commissioned after launch and is working well. Fig 2 shows instrument response to penetrating particles measured during in-flight commissioning. The design is such that all lines of sight to the detectors have a gold coating on the last surface, to ensure that penetrating radiation and scatter should only produce line emission at the characteristic energies for gold. These are the two lines seen in the spectrum. It indicates that the energy range corresponds to the ground calibration. The fitted energy resolution is 185 eV. The instrument has now been turned off until the ion driven spacecraft emerges from the Earth's radiation belts, at which point full in flight calibration and cruise science will begin.

The design of the instrument is intended to fulfil the specific tasks:

- It can measure the absolute abundances of the major rock-forming elements Si, Al, Fe, Mg, Ca, and others. Al/Mg and Al/Si ratio maps are particularly useful for discriminating between different surface materials.
- It has a large effective apperture, of at least 16 cm^2 needed to obtain statistically meaningful results from an extremely weak signal.
- High spatial resolution measurement of abundances at the lunar surface of the order of 50 km for the low energy lines to upwards of 100 km for the highest energy lines.
- High spectral resolution of the order of 185 eV to be able to distinguish the relatively close lines of Al, Si and Mg at the low energy end of the spectrum.
- It simultaneously monitors the solar X-ray flux in order to obtain absolute surface abundance measurements.

Lunar X-ray Science: Remote X-ray spectrometric analysis offers particular power when applied to the Moon due to the ability to tie global coverage to the localised 'ground-truth' sample measurements obtained by lander and return missions. The prime objective of the X-ray spectrometer is to map the elemental composition of the lunar surface by the X-ray fluorescence radiated by the upper regolith. We will obtain absolute rather than relative elemental abundances as the instrument also incorporates a solar X-ray monitor to calibrate the flux returned from the lunar surface. Thus, the ***DCIXS*** instrument will provide the first high-resolution global map of surface geochemistry and the relative abundances of the major lunar rock types, with 45 km spatial resolution at perilune (300km). The X-ray coverage of the moon by Apollo 15 and 16 was limited to measurements within 25° of the equator and thus the data covers less than 15% of the lunar surface.

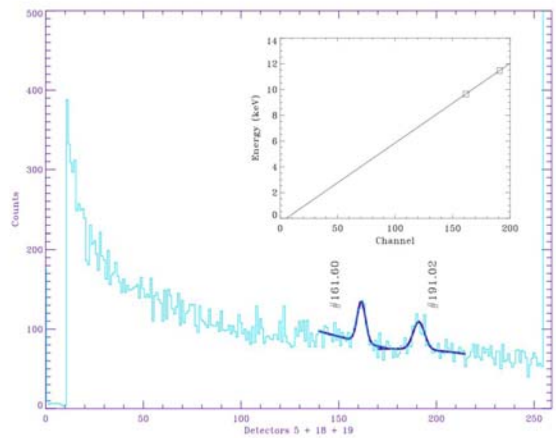

Fig2 shows the instrument response to penetrating particles measured during in-flight commissioning (see text for details) .

Clementine provided multispectral coverage of the Moon, enabling the identification and mapping of major mineral phases. However this data does not provide a breakdown of elemental composition, which is crucial for a full petrological analysis of the lunar rocks. Prospector has provided good maps of some heavier elements, and some lighter elements with a limited spatial resolution. Together with the visual and infrared mapping spectrometer ***D-CIXS*** will provide the first high-resolution global map of surface geochemistry and the abundances of the major lunar rock types.

Probably the most important question that D-CIXS will be able to address is the Mg number Mg/(Mg + Fe) of the Moon. Knowing this, will allow tighter constraints to be placed on models of the lunar origin ratios will constrain models of Lunar evolution. Of fundamental importance is to understand the reasons for the differences between crust and maria. We can also probe the geochemistry of the central regions of the South Polar Aitkin basin which is 12 km deep, may contain exposed mantle material, and exhibited unusual spectral signatures within the Clementine data. The ***D-CIXS*** X-ray spectrometer will also be able to probe the geochemistry of the central regions of large impact basins.

The information returned by ***D-CIXS*** will be of direct relevance to lunar resource evaluation, as a precursor to future exploitation of the Moon as a base for space exploration.