X-RAY SPECTROSCOPY OF THE LUNAR SURFACE USING THE D-CIXS INSTRUMENT ON ESA'S SMART-1 MISSION TO THE MOON.
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Introduction: The D-CIXS Compact X-ray spectrometer on ESA's SMART-1 mission will provide the first global coverage of the lunar surface in X-rays, providing absolute measurements of elemental abundances. The instrument will be able to detect elemental Fe, Mg, Al and Si under normal solar conditions and several other elements during solar flare events. These data will allow for advances in several areas of lunar science, outlined in this abstract. In combination with information to be obtained by the other instruments on SMART-1 and the data already provided by the Clementine and Lunar Prospector missions, this information will allow for a more detailed look at some of the fundamental questions that remain regarding the origin and evolution of the Moon.

D-CIXS (Figure 1) demonstrates a radically novel approach to building a type of instrument within a resource envelope far smaller than previously thought possible. It will use new technology which does not require cold running, reducing the associated overheads to the spacecraft. This makes D-CIXS suitable for many potential and future science targets, including ESA's fifth cornerstone mission, BepiColombo, which will study Mercury.

The Instrument: D-CIXS works from a different concept to traditional X-ray telescopes, and is designed as a modern version of "X-ray detecting paper". In order to obtain adequate statistics for what can be very weak sources, it is necessary to have a large effective area, while maintaining a low mass. To achieve this, D-CIXS has been designed as a thin, low profile detector. The instrument is a new technological evolution, centering around a purpose-designed matrix of the newly developed Swept Charge Device (SCD) X-ray sensors mounted behind low profile gold/copper collimators and aluminium thin film filters. The system has the virtue of providing superior X-ray detection, spectroscopic and spatial measurement capabilities, while also operating at near room temperature.

D-CIXS has an effective area of 14 cm^2 at around 1 keV and consists of 24 swept-charge devices arranged in a configuration of three facets, the middle with an 8 degree FOV and the outer two with a FOV of 12 degrees. 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.

Figure 1: The D-CIXS instrument, fully assembled. Note the three facets each with 8 swept charge devices. The door protects the instrument from proton damage. The total mass of D-CIXS is ~4.5kg

D-CIXS Science: The energy range of interest is 0.5 to 10 keV, which covers many of the important lines such as Mg, Si and Al as well as Fe. D-CIXS will have an energy resolution of ~200eV FWHM, sufficient to resolve all of the major lines of interest. The spatial resolution of D-CIXS will vary according to the orbit of the SMART-1 spacecraft. Therefore, although the instrument is intrinsically capable of resolutions better than 40km, the average spatial resolution will be approximately 100km, with higher resolution measurements being taken in the southern hemisphere. Figure 2 gives a graphical representation of the anticipated spatial resolution (footprint) for an orbit of 4000km × 300km. The lines are given for both 8° and 12° fields of view, and the actual mapping pixel which will be the survey resolution we finally work with, although individual observations during flares can of course approach the geometrical resolution, and will yield much useful information. In order to record the incident solar X-ray flux at the Moon, which is needed to derive absolute elemental surface abundances, D-CIXS also carries an X-ray solar monitor (XSM).

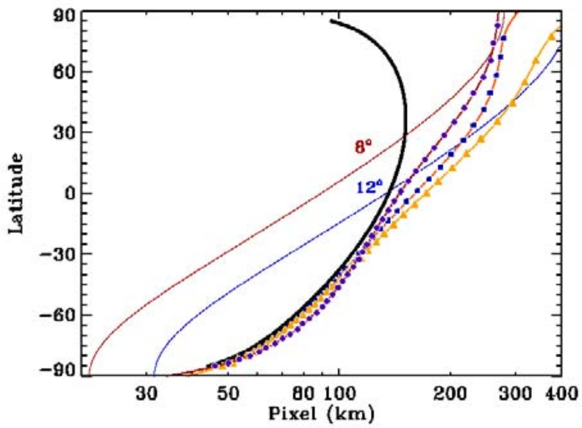

Figure 2: The anticipated footprint of the D-CIXS instrument for a 4000km x 300km orbit. The blue square-orange line represents the resolution to be obtained with the instrument, while the solid black line is the theoretical maximum based on a given photon flux, while the 8^0 and 12^0 lines show the best geometrical resolution available in a high illumination condition. It can be seen that for much of the southern hemisphere D-CIXS is close to that maximum.

Several key science areas can be addressed using D-CIXS data with full details to be found in [1]. Briefly, there is evidence that the Moon is enriched in Al, one of the prime elements that D-CIXS will measure. Seismic data suggest a bulk abundance of about 5% [2], and D-CIXS will allow a quantitative assessment of the extent of lunar refractory enrichment to be made. This is a potential constraint for models of the global melting event that produced the Al-rich crust. Detailed X-ray mapping of several elements across the whole of the Moon will allow for a refined estimate of the composition of the surface on a global scale which can then be combined with models that have been produced based on sample analyses alone.

The global mapping of *Mg#* is of great importance in furthering models of the thermal evolution of the Moon. For instance, a magma ocean model will produce Mg-suite rocks that exhibit specific relations to other rock types, perhaps displaying an association with ferroan anorthosites or KREEP (Potassium, Rare-Earth Elements, Phosphorus) materials. More comprehensive characterisation of these will aid estimates of bulk crustal composition and improve theories for the evolution of the lunar crust.

An important question about the early evolution of the lunar crust is whether pre-mare volcanic activity (i.e. KREEP basaltic volcanism) occurred in the lunar highlands and, if so, to what extent. KREEP basalts may be identified through the mapping of Mg and Fe across the highlands as they have a high *Mg#* value. Further, the potential to map the distribution of K and P during solar flare events will aid the identification of possible KREEP materials and will complement the measurements made by Lunar Prospector.

Another major goal of the D-CIXS investigation is the study of the lunar basins. These provide an ideal candidate for observations using D-CIXS, as the instrument's footprint will provide good coverage across features of this scale. These measurements can be used to help refine estimates of the bulk composition of the lunar crust, and will result in a complementary improvement in the evolutionary models to which this is applied. Of particular interest is the South Pole-Aitken (SPA) basin. This is the largest impact feature yet identified in the Solar System and may have exposed materials from the lunar mantle [3]. D-CIXS will help us to further characterise the SPA terrane, identified by [4] from Clementine and Lunar Prospector data as having an anomalously strong mafic signature and high Th abundance. In combination with the other two remote sensing instruments on SMART-1 (the infrared spectrometer SIR, and micro-imaging camera AMIE) D-CIXS will be able to provide global mineralogical and elemental coverage of the Moon. Combining these measurements with data from previous missions will give us a more complete picture of the Moon than ever before.

Full details of the instrument and science can be found in [5] and [1].

Acknowledgements: SKD was funded as a Royal Society Eliz Challenor Dorothy Hodgkin Research Fellow for the duration of this work.

References: [1] Dunkin et al. (2003) *Planet. Space Sci.*, in press. [2] Hood L. L. and Jones J. H. (1986) *Lunar Plan. Sci.*, 17, 354. [3] Lucey P.G., Taylor G.J., and Hawke B.R. (1998) *JGR*, 103, 3701-3708. [4] Jolliff B. L. et al. (2000) *JGR*, 105, 4197-4216. [5] Grande M. et al. (2003) *Planet. Space Sci.*, in press