X-RAY FLUORESCENCE OBSERVATIONS OF THE MOON – HIGHLIGHTS FROM THE FIRST YEAR OF OBSERVATIONS FROM D-CIXS ON SMART-1. B. J. Kellett[1], M. Grande[1], and the D-CIXS Science Team, [1]Space Science & Technology Dept., Rutherford Appleton Laboratory, Chilton, Didcon, Oxon., OX11 0QX, U.K., (B.J.Kellett@rl.ac.uk).

Introduction: The SMART-1 mission arrived at the Moon in mid November, 2004 and strated its orbital lowering strategy immediately. The final science orbit was achieved in mid-March, 2005 when the main science phase of the mission started. However, there was also around three weeks of observations in mid-January, 2005 with an intermediate orbit. The SMART-1 payload includes the D-CIXS instrument, a compact X-ray fluorescence spectrometer. D-CIXS utilizes novel technologies to enable new capabilities for measuring the fluorescent yield of a planetary surface illuminated by solar X-rays. At the Moon, our initial observations were over Mare Crisium and the highland area to the north and east. These observations show a first unambiguous remote sensing of calcium in the lunar regolith. The data returned are broadly consistent with current understanding of mare and highland composition and the ground truth abundances provided by the samples returned by Luna 20 and 24 match the D-CIXS results. Later observations cover a broad range of longitudes across the nearside southern highlands including the Apollo 12 landing site and we have one swath of data down the farside of the Moon included entry into the South-Pole Aitken basin.

.

D-CIXS Instrument: D-CIXS demonstrates a new approach to building planetary X-ray spectrometers. It is the first time that electronic solid-state detectors have been used for this purpose. It combines an X-ray fluorescence spectroscometer with spatial resolution with an X-ray solar monitor to provide calibration which is necessary for producing absolute lunar elemental abundances. A more complete description of the instrument is given in [1].

The instrument uses Swept Charge Device detectors (SCDs) and advanced low profile microstructure collimators to define the field-of-view. SCD detectors are a novel architecture based on proven CCD technology. They have the virtue of providing superior X-ray detection and spectroscopic measurement capabilities, while also operating at temperatures that can be achieved without the need for active cooling. The devices are manufactured on high resistivity silicon, with supplementary 'narrow' channels to increase radiation tolerance. D-CIXS has 24 such detectors, providing an effective area of 14 cm^2 at 1-2 keV. These are grouped in three facets of 8 detectors. The central nadir pointing facet (Facet 2) has a field of view of 8 degrees, while the two outer facets (1 and 3) have fields of 12 degrees and are offset from nadir by +/-10 degrees. Facets 1 and 2 have thin filters of aluminium while facet 3 has a thick magnesium filter so is essentially only sensitive to magnesium fluorescence in the low energy region. The energy range of interest is 0.7 to 7 keV with an energy resolution sufficient to separate elemental lines. This is all achieved in a mass of only ~4.5 kg.

Mare Crisium: A long duration M-class solar flare began at 06:00 UTC, on the 15th Jan., 2005 The flare lasts for more than 1 hour but only ~30 minutes corresponds to D-CIXS observations. At this time SMART-1 was orbiting over the Moon's near-side eastern limb from about the equator, travelling northwards (Fig. 1). As SMART-1 flies north, its altitude increased from around 2100 km at 06:00 to ~3100 km at 06:35. Fortunately, the instrument FOVs included areas of both mare basalt and highland lithologies, which have different and recognisable elemental signatures. Facet was oriented throughout the observation to highland areas to the north-east of Crisium while Facet 3 (Mg-filter) had a groundtrack that crossed Mare Crisium.

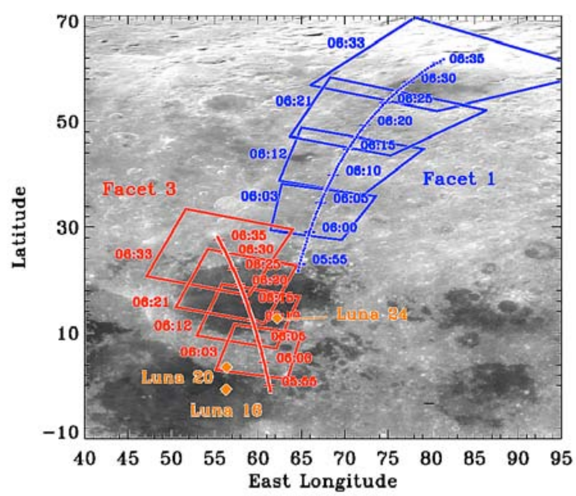

Figure 1: Sample footprints from two of the different look directions (facets) of D-CIXS for the Jan. 15th, 2005 flare. Facet 3 passes right across the centre of Mare Crisium while facet 1 mostly samples the highlands to the north.

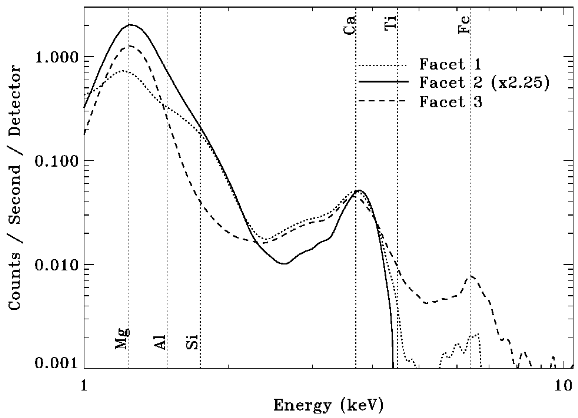

Figure 2: Average spectra for the Jan. 15th flare. Calcium was clearly detected by all 3 facets, but iron was much stronger in the Mare spectrum (facet 3). Notice also that facet 2 is essentially the average of facet 1 and 3 – since its ground track passed over both mare and highland terraines.

The spectra shown in figure 2 indicate low-energy lines (Mg: 1.25 keV, Al; 1.49 keV and Si: 1.74 keV) are observed in detectors from Facet 1 and 2 (Al-filter). Detectors in Facet 3 are covered by a Magnesium filter which was designed to attenuate the signal from Al and Si X-rays, and so in the Facet 3 spectrum Mg is the only significant low-energy peak detected. Data taken from Facet 3 spectrum also shows a clear Fe peak at around 6.4 keV which is interpreted to be related to fluorescence from Mare Crisium. All three facets clearly show the detection of a Ca emission peak at 3.69 keV. Although inferences about the distribution of Ca in the lunar crust have been made indirectly from neutron and gamma ray measurements [2-4], this observation represents the first ever unambiguous remote sensing of Ca on the Moon.

Southern Highlands: November 2005 saw seven C and M flares from the Sun, all of them while D-CIXS was passing over the southern highlands of the Moon (on the nearside). Two of the these flares were M1 category – including one that occurred while we were passing over the Apollo 12 landing site. The centre of the facet 1 and 3 footprints are shown in figure 3 at 1 minute resolutiuon for the 7 flares (the long dashes indicate every 5 minutes). The squares show the representative size of the D-CIXS footprint for the two M1 (bigger) flares. Figure 3 also shows that we have facet 3 data for several rayed craters, including (left-to-right) Tycho, Stevinus and Furnerius and also Mare Fecunditis, Tranquillitatis (edge – close to Apollo 11), Nubium and Mare Cognitum with facet 1 (near Apollo 12). This data will permit detailed studies and comparisons to be between highlands, maria, crater rays, etc.

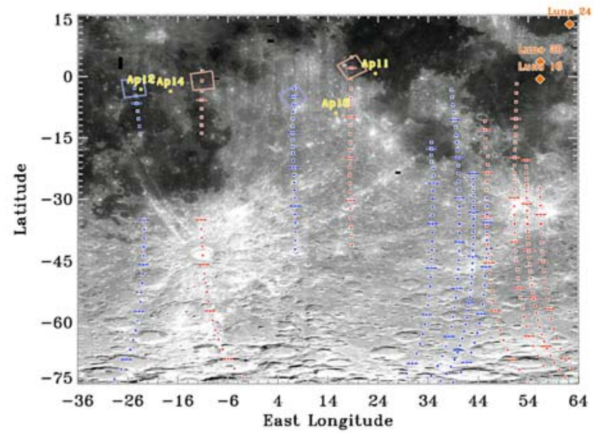

Figure 3: Nov., 2006 C and M flares (M flares indicated by footprint boxes) showing facet 1 and 3 (blue/red) positions every 1 minute (bars indicate 5 minutes).

South-Pole Aitken Basin: The only large flare to occur while D-CIXS was observing the lunar farside during our first year of operations was on July 27th, 2005 (M3 flare – i.e. ~x3 bigger than the M1 flares in November, 2005). SMART-1 was scanning/rotating north to south approximately following longitude 140W and crossed the boundary into the SPA at around 05:21 UT. Almost immediately, the signal in the 6.4 keV iron line was seen to increase. In total, the increase was more than a factor 6 (even though the flare is declining with time and the figure quoted is uncorrected for such effects). This data when properly modeled will permit the magnesium-to-iron ratio to mapped across a large swath of the farside including part of the SPA. The data already indicate that the iron abundance of the highlands north of SPA is very low and probably lower even than the highlands north-east of Crisium, although detailed modeling will be required to confirm this conclusion.

[1] Grande, M., et al. (+47 authors), 2003. *Planet. & Sp. Sci.*, **51** (6), 427.

[2] Elphic, R. C., D. J. Lawrence, W. C. Feldman, B. L. Barraclough, S. Maurice, A. B. Binder, P. G. Lucey, *JGR*, 105, #E8, 20333 – 20346, 2000.

[3] Prettyman, T. H., W. C. Feldman, D. J. Lawrence, G. W. McKinney, A. B. Binder, R. C. Elphic, O. M. Gasnault, S. Maurice, and K. R. Moore, 2002 *LPSC33,* Abstract 2012.

[4] Prettyman, T. H., J. J. Hagerty, R. C. Elphic, W.C. Feldman, D.J. Lawrence, G.W. McKinney, D.T. Vaniman, JGR, submitted, 2005.