INITIAL RESULTS FROM THE C1XS X-RAY SPECTROMETER ON CHANDRAYAAN-1.

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Introduction: The Chandrayaan-1 lunar mission, which was successfully launched by the Indian Space Research Organisation (ISRO) on 22 October 2008, carried as part of its payload the C1XS Chandrayaan-1 X-ray Spectrometer [1]. It exploits heritage from the D-CIXS instrument [2] on ESA's SMART-1 mission. Whereas SMART-1 was a technology mission, Chandrayaan-1 is science oriented,, with a far more favourable orbit for science measurements. C1XS is designed to measure absolute and relative abundances of major rock-forming elements (principally Mg, Al, Si, Ca, Ti and Fe).

The C1XS hardware was designed and built by an international team led from the Rutherford Appleton Laboratory (RAL), STFC. There is also a major contribution from ISRO Satellite Centre, Bangalore, India; CESR, Toulouse, France provides 3-D Plus video processor integrated circuits, and there is an important contribution to the detector characterisation from Brunel University. In order to record the incident solar X-ray flux at the Moon, C1XS carries an X-ray Solar Monitor (XSM) provided by the University of Helsinki Observatory, Finland [3]. C1XS is primarily funded by ESA, with partial support to RAL from ISRO.

Instrument: The baseline instrument design consists of 24 nadir pointing Swept Charge Device (SCD) detectors [4]. A traditional box collimator defines the field of view of each SCD, resulting in a triangular angular sensitivity with 50% of the X-ray signal deriving from within +/-7° of the collimator axis, corresponding to 25 km FWHM spatial resolution on the lunar surface from Chandrayaan-1's circular 100 km orbit. A deployable door protects the instrument during launch and cruise, and also provides a ^{55}Fe calibration X-ray source for each of the detectors, allowing in flight calibration to be performed. The source strength is sufficient throughout the two year mission for gain calibration to be obtained within 10 minutes.

Detectors: The Swept Charge Device (SCD) detectors [5] provide high detection efficiency in the 0.8 to 7 keV range, which contains the X-ray fluorescence lines of interest. The principal requirement is a spectral resolution sufficient to clearly resolve the three common light rock forming elements (Mg, Al, Si).

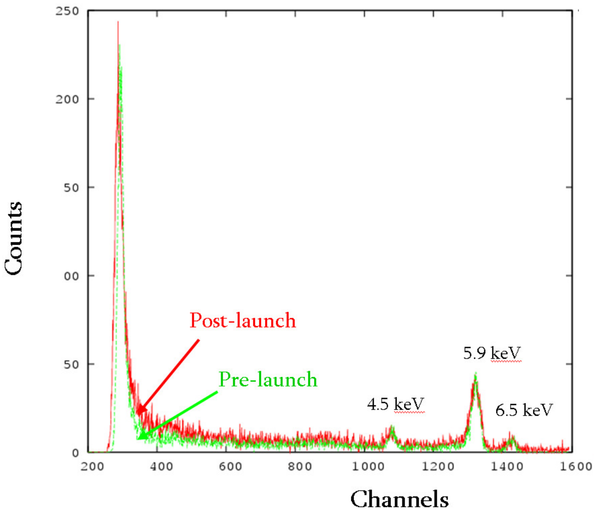

Figure 1: Comparison of in-flight and laboratory performance for C1XS, using the onboard Fe^{55} sources. Red line indicates performance in lunar orbit. Note the similarity between the two spectra.

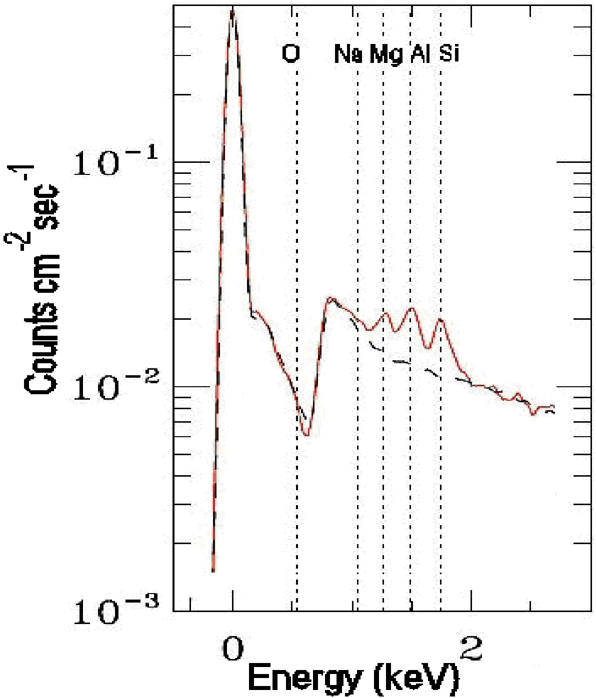

Figure 2: Lunar spectrum obtained on 12th Dec 2008, in low illumination conditions (A-class solar flare). Note the excellent resolution achieved in the magnesium, aluminium and silicon lines..Dotted line is average background signal.

X-ray Solar Monitor: The X-ray solar monitor (XSM) is based on the SMART-1 XSM [3] and consists of a separate silicon detector unit on the spacecraft. The non-imaging HPSi PIN sensor has a wide field-of-view (FOV) to enable Sun visibility during a significant fraction of the mission lifetime, which is essential for obtaining calibration spectra for the X-ray fluorescence measurements by the C1XS spectrometer. The energy range (1–20 keV), spectral resolution (about 200 eV at 6 keV), and sensitivity (about 7000 cps at flux level of 10−4 W m−2 in the range 1–8 keV) are tuned to provide optimal knowledge about the solar X-ray flux, matching well with the activating energy range for the fluorescence measured by C1XS.

In Flight Performance: The instrument has been commissioned, and is operating nominally. In flight calibration has been carried out using the onboard ^{55}Fe radiation sources, and the results are shown in Figure 1, as a comparison with the equivalent lab based calibration spectrum [6].

It is seen that the flight spectrum matches very closely the lab spectrum, indicating that the instrument is performing well, and has undergone very little degradation as a result of the two week cruise to the Moon, and the consequent radiation belt passages. Detailed analysis suggests a broadening of the FWHM by around 30 eV, far less than predicted.

The Sun continues to show X-ray emission characteristic of the Solar minimum. As has been commented [7] the onset of this solar maximum is significantly delayed. However, C1XS has been able to observe the Moon even in these very low illumination conditions.

Figure 2 shows the result of an integration during an A class flare on Dec. 12, 2008.. Characteristic energy lines at Mg, Al and Si are clearly seen and resolved from the average extreme quiet time data background. This performance shows that the instrument is easily meeting its design requirements, and in the higher illumination conditions expected during the rest of the mission will be capable of meeting its science goals.

Science Goals: C1XS science goals are discussed in detail in [8]. C1XS will determine the major element geochemistry (and especially Mg/Si and/or Mg/Fe elemental ratios) in the main lunar crustal terranes (i.e. Procellarum KREEP Terrane, South Pole-Aitken Basin, and the Feldspathic Highlands Terrane; [9]) and establish the geographical distribution of the magnesian suite of rocks. A key ambition is to determine the large-scale stratigraphy of lower crust (and possibly crust/mantle boundary region) by measuring the elemental abundances of the floor material of large basins not obscured by mare basalts (e.g. SPA and other farside basins), and the central rings and ejecta of large basins which expose material derived from depths of many tens of km. In addition, determination of the crustal aluminium abundance and distribution is important for the assessment of lunar refractory element enrichment, and C1XS-derived aluminium abundance maps will thus constrain models of lunar origins.

Last but not least, the ~25 km (FWHM) spatial resolution will enable C1XS to address a number of smaller-scale geological issues (e.g., the composition of discrete mare basalt lava flows and, pyroclastic deposits) which also refine our understanding of lunar geological evolution. .

Conclusions: The C1XS instrument is optimised to perform X-ray spectroscopy in the framework provided by the ISRO Chandrayaan-1 mission to the Moon. Initial results suggest that its performance as a science instrument will be outstanding.

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References: [1] Grande et al. The C1XS X-ray spectrometer on Chandrayaan-1. 2009. *Planet. Space. Sci. In press.* [2] Grande et al. The D-CIXS X-ray spectrometer on the SMART-1 mission to the Moon—First Results. 2007. *Planet. Space. Sci.* Vol. 55, 494 . [3] Huovelin et al. The SMART-1 X-ray solar monitor (XSM): calibrations for D-CIXS and independent coronal science. 2002. *Planet. Space. Sci.* Vol 50. Iss 14-15, pp 1345-1353. [4] Howe et al., Chandrayaan-1 X-ray Spectrometer (C1XS) – Instrument Design & Technical Details. *Planet. Space. Sci. In press.* 2009. [5] Gow J et al., Characterisation of swept-charge devices for the Chandrayaan-1 X-ray Spectrometer (C1XS) instrument. Art. no. 66860I, *OHW, UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy* [6] Kellett et al., Chandrayaan-1 X-ray Spectrometer (C1XS) – Instrument Calibration & Testing *Forthcoming. Planet. Space. Sci.* [7] Keating, 2008 *EOS*. [8] Crawford. et al. The Scientific Rationale for the C1XS X-Ray Spectrometer on India's Chandrayaan-1 Mission to the Moon. *Planet. Space. Sci. In press.* 2009. [9] Jolliff et al. 2000. *JGR*. Vol. 105 pp. 4197-4216.