LUNAR CHEMISTRY FROM CHANDRAYAAN-1, C1XS RESULTS FROM SOUTHERN NEARSIDE HIGHLANDS OF THE MOON.

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Introduction: X-ray fluorescence experiments onboard the Apollo 15 and 16 missions estimated Mg/Si and Al/Si intensity ratios for ~10% of the equatorial near-side of the lunar surface [1]. The D-CIXS instrument on the SMART-1 mission detected x-ray florescence from ~1.5 keV (Al K_α) up to 6.4 keV (Fe K_α) [2, 3] during bright solar flares [2]. However there is still no consistent set of uniform, good spatial resolution, x-ray elemental data for the full Moon.

The Chandrayaan-1 X-ray Spectrometer (C1XS) [4, 5] developed by the Rutherford Appleton Laboratory in collaboration with ISRO, was to provide a global map of the abundance of the major rock forming elements [6]. Though C1XS could not complete all of its scientific objectives due to constraints from low solar activity and a reduced mission life, there are several observations that have yielded good XRF data. Here, we discuss the methods used to analyze C1XS data and present as an example, data from the southern near-side of the Moon (Fig. 1) obtained during a C3 solar flare on 5th July 2009.

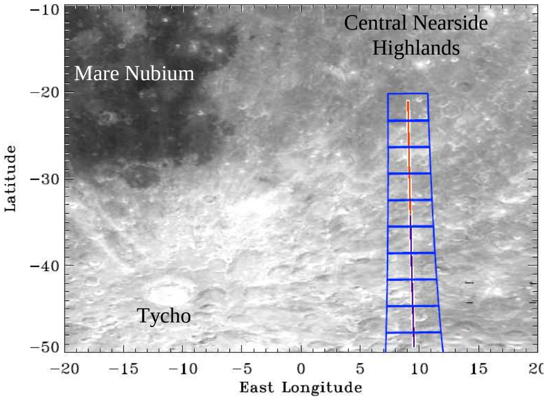

Figure 1. C1XS coverage for solar flare event on the 5th July 2009 projected onto a Clementine albedo map of the nearside south-central region of the Moon.

Observations and analysis: A C3 flare on 5th July 2009 which reached a maximum intensity at 07:13:59 UT, provided the highest spatial resolution XRF data for Mg, Al, Si and Ca. During this observation, Chandrayaan-1 was in a 200 km circular orbit resulting in a C1XS footprint of 50 x 50 km (FWHM) on the lunar surface (Fig. 1). The data were collected from a region spanning from 48° S to 55° S latitude and ~ 8° E longitude on the nearside whilst the spacecraft was overflying the lunar highlands (Fig. 1). This region of the Moon is part of the Outer-Feldspathic Highlands Terrane (FHT-O: [7]) and is to the south west of the Apollo 16 landing site (15.6° E, 9° S), and north east of the Tycho impact crater (11.2° W, 43.3° S).

The X-ray Solar Monitor instrument (XSM [8]) simultaneously measured the input solar X-ray spectra making this a good data set to derive lunar elemental abundance. C1XS data are available as time-tagged events while XSM generates 16 s spectra. We have extracted correlated 32 s spectra for both C1XS and XSM. From ground calibration, we have constructed a detailed response of C1XS, enabling us to maximally enhance the detector efficiency [9]. The detection efficiency of the 24 detectors has been determined within an absolute uncertainty of less than 5%. Along with this instrument response, we used the standard x-ray spectral analysis package XSPEC [10], to derive x-ray line flux.

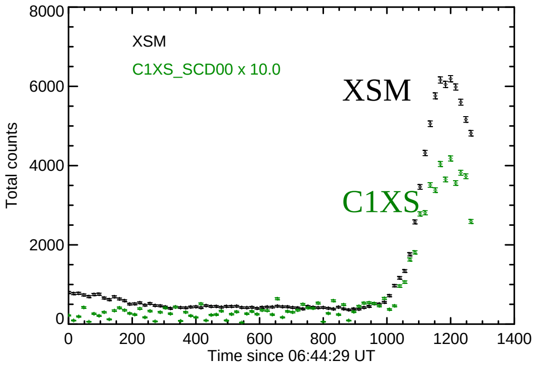

Figure 2. Evolution of x-ray intensity measured by C1XS (green), counts in a single C1XS detector scaled up) and XSM (black) during solar flare on the 5th July 2005.

Spatial variation of line ratios: C1XS observed XRF emission from 07:04:44 UT to 07:15:33 UT (Fig. 2). The x-ray line flux of the four elements (Mg, Al, Si and Ca) are determined at a spatial resolution of 50 km for ten ground pixels during this time. The remaining flare data was analyzed at a coarser resolution of 250 km because of the weaker signal. The background spectrum was taken from pre-flare data.

Figure 3 shows the cumulative spectrum for 320 s with all the 24 C1XS SCD detectors co-added. Mg, Al, Si, Ca (both K_α and K_β), Ti and Fe lines can be identified in this spectrum. It is particularly notable that Ti is detected at significant levels within this region of the nearside highlands; regoliths from the nearby Apollo 16 landing site [11] indicate that these types of soils typically have ~0.5 wt. % TiO_2, suggesting either that C1XS is capable of measuring low concentrations of key elements, or that we have sampled a region of the highlands containing a Ti-rich lithology.

Line fluxes derived from this spectrum have to be converted to absolute elemental abundance for meaningful scientific interpretation. However, presented here in Figure 4 are the variations in the ratio of flux for each elemental line to the total line flux (i.e. sum of all line flux detected in the spectrum + O). Even though C1XS is unable to directly detect O, Lunar Prospector data are used to include a steady 45% flux fraction contribution from O in estimating the above ratios. Thus, to first order, these line ratios provide an estimate of the weight percentages. This approach also partially removes the effect of solar flux intensity variations. A more complete analysis leading to the estimation of the elemental weight percentages will be reported elsewhere. Preliminary interpretations are discussed below:

- On average, Al, Si and Mg flux ratios do not vary through the main flare event suggesting little geological heterogeneity in this area.
- Al and Si have high flux ratios compared with other elements. This is consistent with the region of interest being highly feldspathic in nature (i.e. high-Al composition).

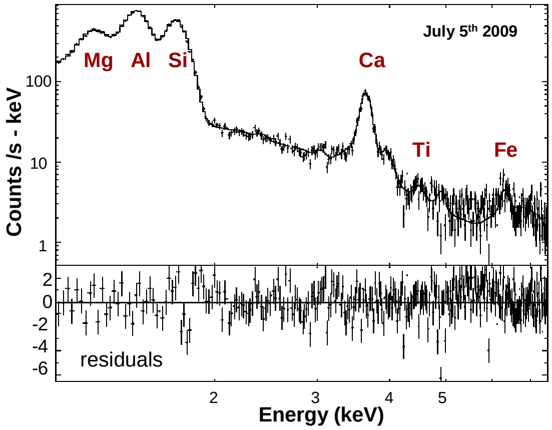

Figure 3. Spectral fit to the summed 320 second C1XS spectrum for the 5th July 2009 showing detection of Mg, Al, Si, Ca, Ti and Fe.

Conclusions and future work: We have presented the spectral analysis of XRF data from C1XS during a C3 flare. Under development are methodologies based on fundamental parameter algorithm [12, 13] to convert x-ray line flux to absolute elemental abundance. These are currently being verified with a number of laboratory experiments [14].

Though C1XS was operating during a period of minimal solar activity, the available data have proved its ability to provide unique elemental maps for select regions of the lunar surface.

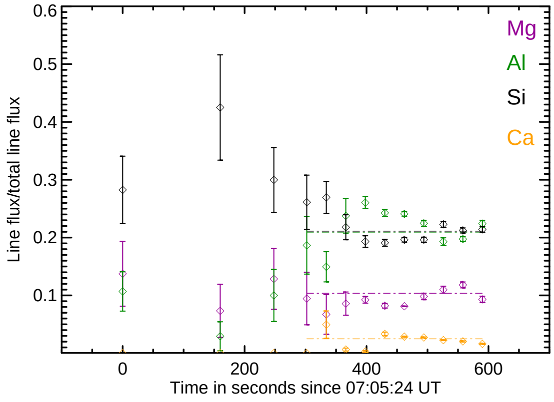

Figure 4. Variation in X-ray line flux ratios (flux in each element/total line flux) during the flare. The dotted horizontal lines show the average value obtained from the summed spectrum (Fig 3). The first three points are spectra for 250 km pixels while the rest are 50 km pixels.

References:

[1] Clarke .P.E (1979) *PhD thesis*. [2] Grande M. et al. (2007) *PSS*, 55, 494-502. [3] Swinyard B. et al (2009) *PSS*,.57,744-750. [4] Grande M. et al (2009) *PSS*, 57,717. [5] Howe C.J. et al (2009) *PSS*, 753. [6] Crawford.I et al (2009) *PSS*, 57,725. [7] Jolliff et al. (2000) *JGR*, 105,4197-4216. [8] Alha.L et al (2009) *NIM A*, 607, 544-553. [9] S.Narendranath et al in prep. [10] Arnaud, K. A (1996) *ASPConf series*, 10, 17. [11] Haskin and Warren(1991) *The Lunar Sourcebook* Chapter8. [12] Swinyard.B et al (2009) *Proc. XRF. Symp*, ESTEC. [13] Athiray et al in prep. [14] Weider et al in prep (2009), *Proc.XRF.Symp*, ESTEC

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