NEW LUNAR ELEMENTAL MAPS FROM CHANDRAYAAN-2. S. Narendranath[1], Netra S. Pillai[1], K. Vadodariya[1], Srikar P. Tadepalli[1], A. Sarwade[1], V. Sharan[1],Radhakrishna V[1], A. Tyagi[1], M. Bhatt[2],1.Space Astronomy Group, U R Rao Satellite Centre, Indian Space Research Organisation, Bengaluru, India. Email: kcshyama@ursc.gov.in, 2. Physical Research Laboratory, Ahmedabad, India.

Introduction: The surface composition of the Moon has been remotely mapped since the early days of lunar exploration that built a framework for models of its formation and subsequent evolution. Returned samples from Apollo, Luna and more recently the Chang'e-5 mission have provided deeper insights into the composition and stratigraphy. Though the spatial scales and uncertainties in the techniques are vastly different for these two extremes in compositional studies, ground truth validation (using returned soil samples) of the remote sensing techniques in UV-Vis-NIR, X-ray and gamma ray wavelengths have been an important component in global compositional data sets. X-ray fluorescence spectroscopy is a relatively well-established technique where models based on known physics and material properties can be used to fit the spectral data without using reference standards. We use XRF spectra (Figure 1) from the Chandrayaan-2 Large Area Soft X-ray spectrometer (CLASS) to derive lunar elemental maps. These maps have been derived from XRF line intensities during solar flares. These are the largest coverage maps of the Moon in XRF and provide a new independent data set for lunar geochemistry.

Chandrayaan-2 [1] is the second Indian Lunar mission currently in-orbit at an altitude of 100 ± 20 km around the Moon in a polar circular orbit. CLASS onboard Chandrayaan-2 is an enhanced version of the Chandrayaan-1 X-ray Spectrometer (C1XS) [2] that was in operation during Dec 2008 to July 2009. The Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS) [3] is in the lunar orbit since Sep 2019 and continues to provide high quality lunar X-ray spectral data. We present the elemental maps of Na, Mg, Al, Si, Ca and Fe from three years of data at a spatial resolution of 150 km (along track) x 12.5 km (across track) as a first effort.

Methods: CLASS operates continuously on the sunlit side of the orbit with additional night side observations every orbit to measure the background. There are sixteen X-ray detectors called Swept Charge Devices (SCDs) which counts every X-ray photon incident that is registered as an event. The time tagged events from individual detectors are read out and binned on ground to spectra of a chosen time interval. Since the instantaneous field of view of the mechanical collimators on CLASS define a ground foot print of 12.5 km x 12.5 km, the lowest time bin is 8s (time taken to sweep 12.5 km with ground trace velocity of 1.55 km/s).

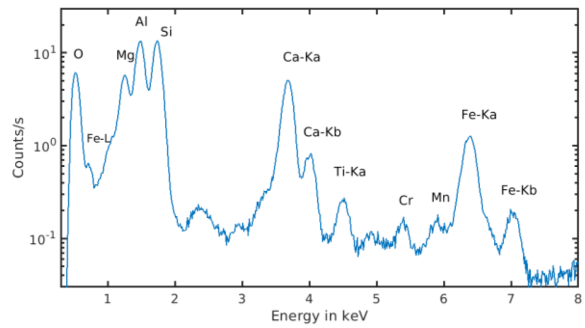

Figure 1: An XRF spectrum measured by Chandrayaan-2 Large Area Soft X-ray Spectrometer showing detection of all major elements on the lunar surface. Minor elements Cr and Mn are also detected during strong flares

The spectra across the sixteen X-ray detectors are added in energy space, applying the temperature dependent calibration constants. The Level 1 (L1) CLASS data is thus a single added spectra of all the detectors at 8s cadence. The co-ordinates of observation and geometry such as the zenith angle and emission angle is determined from the spice kernels and provided in the header of the CLASS L1 spectral files in FITS format.

To derive elemental abundances, we use spectra binned at 96s-time intervals to ensure good statistics. We use solar spectra from X-ray Solar Monitor (XSM) [4] for the same time intervals to calculate the scattered continuum component in lunar X-ray spectra. There are several intervals where Sun is not in the field of view of XSM. In such cases, we use GOES broad band flux to estimate the solar coronal temperature from which a solar spectrum is calculated. In both cases, we use CHIANTI based solar spectral models.

The background subtracted lunar X-ray spectrum is fitted with a model that consists of two components: (a) XRF model (b) Scattered solar spectrum. The XRF model is based on an algorithm named 'x2abund' which uses the fundamental parameter method to generate a model XRF spectrum. This is coded in python and called as a local model using pyxspec (python interface to X-ray spectral Analysis Package XSPEC) and is available at https://pradan.gov.in/ch2. The scattered solar spectrum is called in xspec as a table model. The elemental abundances are derived by forward modeling in XSPEC with the instrument response contained in a Re-distribution matrix file (RMF) and Ancillary Response File (ARF).

The X-ray fluorescence model requires a compositional matrix to begin with the iteration. We use LP-GRS abundance values for Oxygen and Ti abundances (except for a few spectra where it is available from CLASS). The Fe abundance is derived from the Fe-L line that is detected at 0.7 keV.

Results: Maps of Na, Mg, Al, Si, Ca, Fe is derived from XRF spectra measured during the period from September 2019 to August 2022 (Figure 2). The pixels are 150 km along track and 12.5 km across track. Strong flares allow generation of maps at 12.5 km x 12.5 km and an example is shown in Figure 3.

Chandrayaan-2 is providing the largest coverage in XRF leading to elemental abundance maps of the highest spatial resolution. Apart from the well-known Mare-Highland differences, we find specific areas of interest such as in the Oceanus Procellarum (Mg rich) and North Western high latitudes (Na rich) which will be further explored in detail.

Acknowledgments: For downloading CLASS data in PDS format [5] please refer to https://pradan.issdc.gov.in/ch2.

References: [1] M.Vanitha et al. (2020) *LPS L1*, Abstract#1994 . [2] Grande.et al. (2009) *PSS.57*, 717-724. [3] Radhakrishna. V. et al. (2020) *Current Science*, *118*, 219-225. [4] Mithun N. P. S. et al. (2002) *Sol. Phys*, *295*,*139*- 145. [5] Prapti et al *LPS LI1*, Abstract#1774.

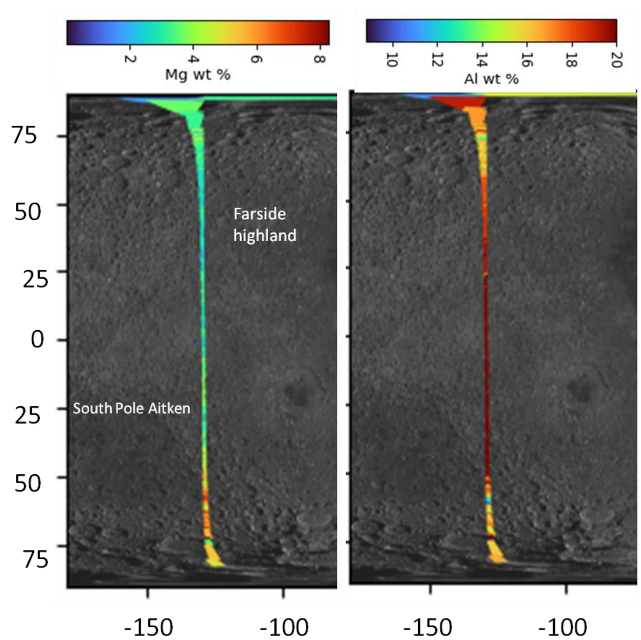

Figure 3: A sample high spatial resolution (12.5 km x 12.5 km) track showing Mg and Fe abundances from Chandrayaan-2 Large Area Soft X-ray Spectrometer

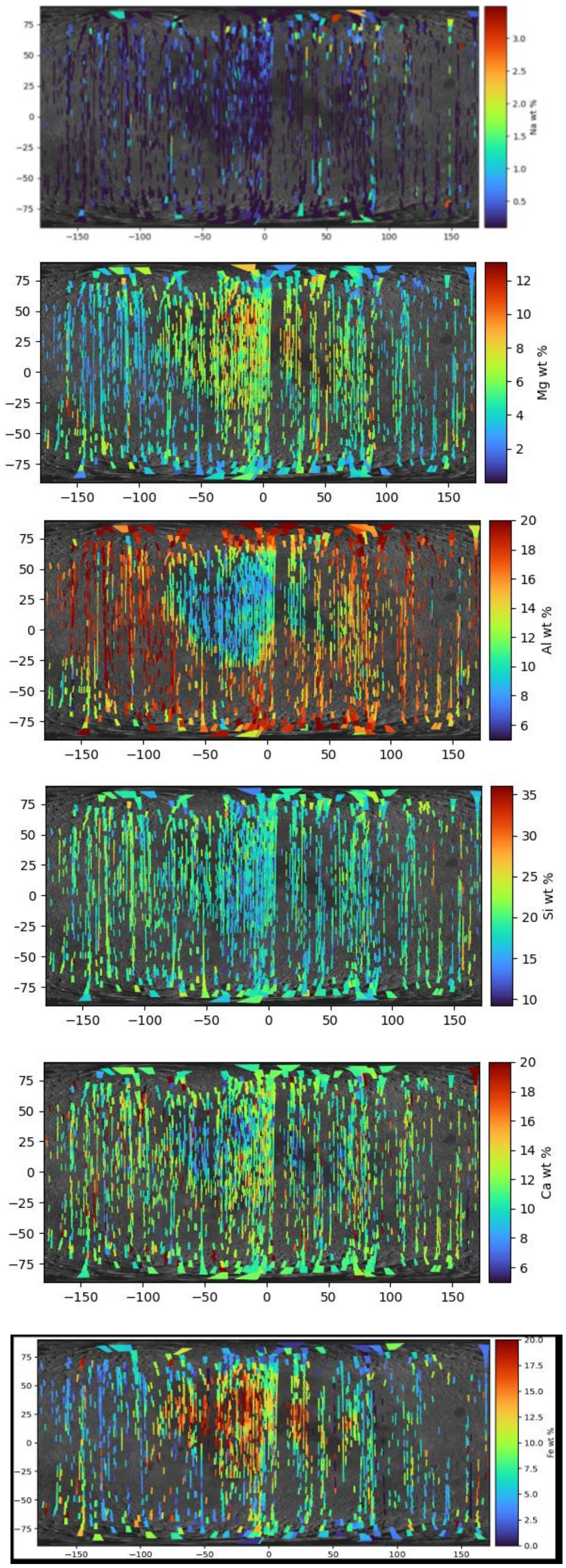

Figure 2: Lunar elemental maps derived from Chandrayaan-2 Large Area Soft X-ray Spectrometer