

GLOBAL OXYGEN DISTRIBUTION ON THE LUNAR SURFACE: FIRST RESULTS USING CHANDRAYAAN-2. A. Devaraj¹, S. Narendranath², S. S. Kartha¹, N. S. Pillai² and S. P. Tadepalli², ¹Department of Physics and Electronics, CHRIST (Deemed to be University), Bangalore, India, (email: ashish.devaraj@christuniversity.in), ²Space Astronomy Group, U R Rao Satellite Centre, ISRO, Bengaluru, India.

Introduction: Oxygen is the most abundant element in the lunar regolith, accounting for 40–45% by mass [1]. The X-Ray Fluorescence (XRF) signatures of oxygen from the lunar regolith can be detected using Chandrayaan-2 Large Area Soft x-ray Spectrometer (CLASS) onboard Chandrayaan-2 [2].

CLASS consists of 16 Swept Charge Devices (SCD) observing the soft X-ray energy regime spanning from ~ 0.4 to 20 keV. The spectral resolution of each SCD is better than 180 eV at 5.9 keV if operation temperature is below -20°C [3]. Similar to other XRF experiments sent to the Moon, CLASS also exploits solar X-rays as a source to excite elements on the lunar regolith, and it detects the resultant XRF emission from the elements. During strong solar flares, CLASS can detect the major and trace rock-forming elements O, Mg, Al, Si, Ca, Ti, Cr, Mn and Fe in its XRF spectrum with a ground footprint of $12.5\text{ km} \times 12.5\text{ km}$ from an orbit of 100 km [3].

In this work, we use the data from CLASS to prepare an Oxygen distribution map of the Lunar surface.

Data and Analysis: Oxygen XRF line peaking at an energy of 0.525 keV is easily excited by the soft X-rays from the Sun, even in the absence of any strong solar flares. Hence Oxygen can be observed throughout CLASS observations. Figure 1 shows CLASS spectra in the energy range of 0.4 to 2.0 keV during solar flaring and quiet times. The Oxygen $K\text{-}\alpha$ line is observed during both epochs. We analysed 34 months of CLASS data from September 2019 to June 2022 including both solar flaring and quiet times. The entire data were binned to an integration time of 300 seconds to generate 2,24,755 spectra. The $K\text{-}\alpha$ line parameters of O, Mg, Al, and Si detected in each spectrum was retrieved by fitting a Gaussian model. The line intensity measured by this method will have three components; (i) abundance of the element, (ii) solar scatter and flaring, and (iii) observation geometry. Therefore, if we remove (ii) and (iii) from the measured line intensity of Oxygen, we can arrive at a quantity which can act as a proxy for Oxygen abundance.

Solar scatter and flaring: The solar activity period can broadly be categorised as a quiet and flaring period. Detection of elements other than Oxygen in the CLASS XRF spectrum is only possible during the flaring period. The Solar quiet period causes less XRF emission

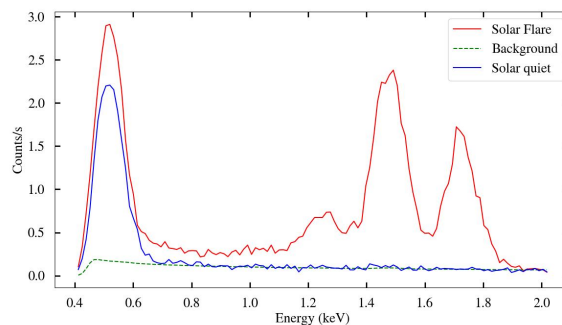


Figure 1: XRF spectra from CLASS during solar flaring (red) and quiet (blue) times. The night time background is shown in green dashed line. The XRF lines peaking at 0.525, 1.254, 1.487 and 1.740 keV in the spectra during solar flaring are O, Mg, Al and Si, respectively.

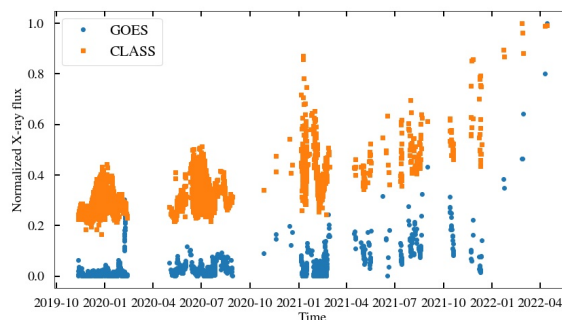


Figure 2: The light curve of integrated line flux from CLASS is given in Orange. The variation of solar flux from GOES-r during the observation period is shown in Blue. Both the quantities are normalized by its respective maximum value.

from the Lunar surface, but the solar flux reaching the Lunar surface is enough to excite Oxygen atoms. Mg, Al and Si were detected from the data based on a 3σ criteria, and these observation periods were identified as the period of solar flaring. Therefore, these observations were removed to negate the effect of solar flaring.

Figure 2 shows the light curve of normalised oxygen line flux from CLASS during the non-flaring time and simultaneous normalised solar flux measurements from GOES-16 Extreme Ultraviolet and X-ray Irradiance Sensors (EXIS) [4]. It is seen that the flux mea-

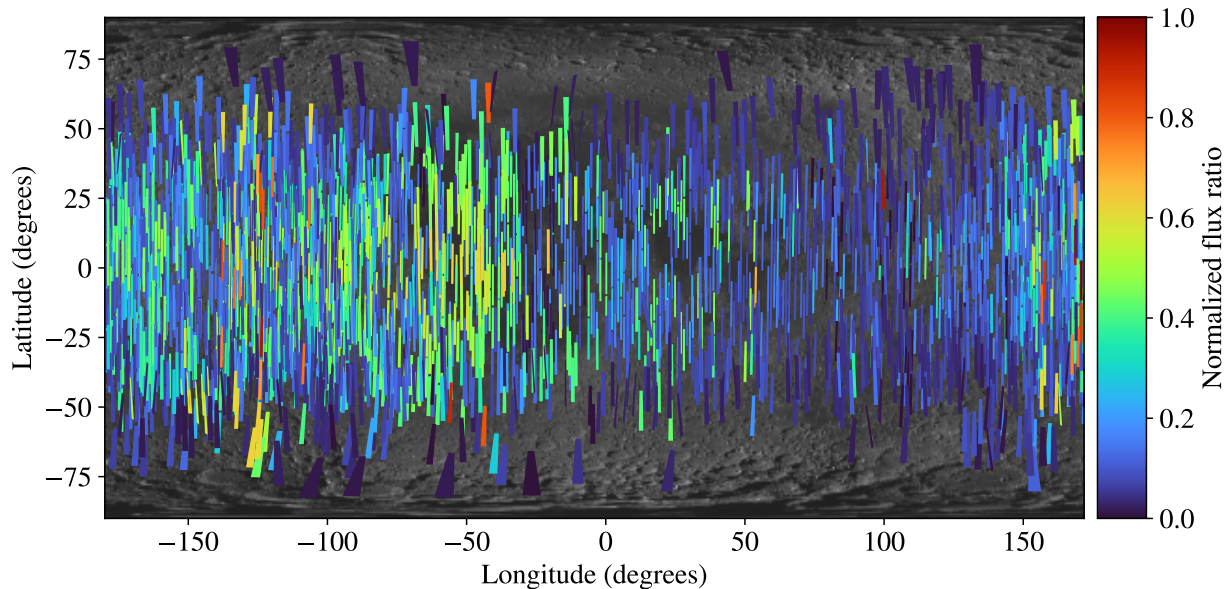


Figure 3: Oxygen line flux ratio corrected for solar activity and geometrical effects is plotted on the LRO-WAC albedo map (NASA PDS).

measurements are directly correlated. This correlation implies that the effect of solar activity is increasing during the period of CLASS observations. This effect persists even after removing the flaring events. A quantity called flux ratio was introduced to nullify this effect. It is defined as the ratio of CLASS XRF flux and GOES solar flux. This quantity was further corrected for the effects of observation geometry.

Observation geometry: CLASS orbits the Moon in a polar circular orbit of radius ~ 100 km. All the observations are performed in a Nadir viewing configuration. This particular geometry fixes the emission angle always to be zero and the incidence angle equal to the solar zenith angle (phase angle). [5] gives the formulation for the XRF geometrical factor as a function of solar zenith angle. This formulation was used and the oxygen line flux ratio was corrected for geometrical effects by dividing the flux ratio by the modified geometrical factor for the configuration of observation. Since this formulation is an approximate representation of geometrical variation, the first-order map presented in Figure 3 is only partially corrected for geometry. Hence the residuals of these corrections will be reflected in this map.

Results: Figure 3 shows the oxygen distribution map derived from CLASS data within $\pm 80^\circ$ lunar latitudes. The normalised flux ratio depicted in Figure 3 can be a proxy for Oxygen abundance on the lunar surface. This Oxygen distribution map shows higher val-

ues in the Procellarum KREEP Terrane. Specific pixels with high values have to be investigated to understand the possible correlation with mineralogy. This map is a preliminary result of our analysis of CLASS data. Further refinement of the distribution is in progress.

The oxygen distribution map presented here can contribute towards the growing interest in the possible exploitation of Lunar resources for future human missions to the Moon. Furthermore, it can help understand several interesting anomalies of the oxygen distribution on the Lunar surface due to differences in mineralogy at various terrains.

References: [1] McKay D. S. et al. (1991) *Lunar sourcebook*, 567:285–356. [2] Radhakrishna V. et al. (2020) *Current Science*, 118(2):219. [3] Pillai N. S. et al. (2021) *Icarus*, 363:114436. [4] Epavier F. et al. (2017) *EGU General Assembly Conference Abstracts* 9954. [5] Jenkins R., *Quantitative X-ray spectrometry*, CRC Press (1995).