



TEAM 53

End Term Submission Report



HIGH-RESOLUTION ELEMENTAL MAPPING OF LUNAR SURFACE

Abstract

This solution proposes a systematic high-resolution elemental mapping of the lunar surface using X-ray fluorescence (XRF) data from Chandrayaan-2's CLASS instrument. XRF line signatures, calibrated with XSM solar data and response files (ARF, RMF), are analyzed using Gaussian fitting, chi-square filtering, and flux integration. The pipeline integrates spectral data with spatial metadata, extracting K α lines of lunar elements. Ratios like Mg/Si, Al/Si, and Ca/Si were calculated, mapped onto a lunar base map, and visualized using QGIS and Python. Overlapping observations enabled sub-pixel resolution mapping and optimized elemental ratios, ensuring reliable large-scale coverage. This workflow refines prior methodologies, providing a robust pipeline for detailed lunar compositional analysis, suitable for advancing geological and exploration studies. The study highlights the potential for accurate resource identification and supports future lunar mission planning with enhanced data visualization tools.

Understanding Problem statement

X-ray fluorescence (XRF) lines are detected by the CLASS instrument installed in Chandrayaan 2 during solar flares. The XRF line energy identifies the element while intensity depends on solar flare strength, solar zenith angle, and composition. The problem statement aims to find elemental abundances of different elements by applying some algorithm on the given CLASS data, taking into account the given calibration data like XSM data. After finding elemental abundances, the ratios like Mg/Si, Al/Si should be plotted on a lunar base map which can be referred for certain scientific observations.

End Evaluation report deliverables

- A catalogue of XRF line detections and the elements along with source codes.
- Map the coverage of the XRF lines onto a lunar base map.
- Compositional groups based on ratios.
- Map the ratios onto a lunar base map.

- Best ratios to use and visualization of data on a lunar map.
- Subpixel resolution maps.

Understanding Dataset

CLASS dataset contains an 8-second observed spectrum observed by SCDs (Spectral Calibration Data). Each CLASS file contains:

- **FITS Data(Flexible Image Transport System):** Contains the observed spectrum interpreted through the **Fv viewer** source codes.
- **XML File(eXtensible Markup Language):** Contains metadata such as latitude and longitude information for each FITS file.

XSM Data (X-ray Solar Monitor): Contains calibrated/raw data about solar flares on per day intervals.

- **FITS Data:** Raw datafile.
- **LC:** light curve, number of incident photons incident on detector wrt time.
- **GTI:** good time intervals.
- **PHA:** spectrum files.
- **HK:** house keeping parameters of machinery.
- **SA:** Sun angles.

SPICE: Contains information about geometric parameters such as solar zenith angle, and emission angle.

RMF (Response Matrix File): A 2048 x 2048 re-distribution matrix with a Non-Gaussian spectral re-distribution function SRF in the CALDB directory.

ARF (Auxiliary Response Function): A 2 x 2048 ancillary response file (ARF) that gives the effective area as a function of energy.

XRF line intensity

Description:

The solution provides an efficient pipeline for processing FITS spectra, identifying elemental signatures, and linking them to geographic regions. Using **Gaussian fitting** and **chi-square** analysis, it calculates elemental fluxes and intensity ratios relative to silicon, while excluding specified energy ranges for accuracy and noise considerations. Geographic coordinates are extracted from FITS file header, and all results are stored in a structured CSV for cumulative analysis. Ideal for applications in astrophysics and remote sensing, this workflow ensures precise spectral analysis, robust data handling, and seamless integration of elemental and spatial insights.

Software Tools and Scripts:

- **Automation Script:** An Ubuntu/linux script designed to automate the entire data processing pipeline, enabling efficient handling of large datasets.
- **Compile Fits Script:** This script designed for processing FITS files using Gaussian fitting and chi-square analysis. It filters, categorizes, and merges FITS files based on chi-square results and supports external tools for contiguous file merging.
- **Background Adder:** a script that processes FITS files by filtering them based on solar angle, identifying background files, and merging contiguous files using an external tool. It provides an efficient way to handle and combine background data for further analysis.
- **Find Line Intensity ratios:** This outlines a detailed workflow for analyzing FITS spectra, including data extraction, peak detection, flux calculation, and intensity ratio computation relative to silicon. It also describes linking elemental data to geographic coordinates and storing results in a structured CSV file.

Methodology:

This project involved the systematic processing and analysis of CLASS data obtained from the ISRO Pradan website. The dataset comprises FITS files, which can be categorized into **day-time** and **night-time** data based on their associated **solar angles**. These files were divided into two distinct groups for specialized purposes: files with solar angles greater than 90° were designated as background files, while those with solar angles less than 90° were earmarked for spectral analysis. To streamline this initial step, a custom code was developed to automate the segregation of files based on solar angle

criteria, ensuring accuracy and efficiency in the data preprocessing stage. The spectral analysis commenced with the application of three Gaussian fits to the FITS files, a method chosen to model the observed spectral features accurately in the range 1-2 keV. The quality of the Gaussian fits was evaluated using the chi-squared metric, a standard measure for assessing the goodness of fit. A chi-square value within the range of 0.8 to 2.0 was considered acceptable, signifying a reliable fit to the spectral data. However, when the chi-square value fell outside this range, the analysis was refined by incrementally adding additional FITS files, prioritized based on their temporal sequence. This iterative approach, implemented through the GDL compiler using the ch2_class_analysis_sw_v1.0.pro script, allowed for improved modeling of the spectral data while maintaining computational efficiency.

Background subtraction, a critical step in spectral analysis, was addressed using a dedicated code processed background files ($solarangle > 90$) to create a comprehensive background dataset. The resulting background data was subsequently input into the line_intensities.py code, which performed the following subtasks:

1. Calibration of the L1 CLASS file by applying corrections for background while taking into account the response files (**arf**, **rmf**).
2. Extraction of the $K\alpha$ lines of pertinent elements from a text file.
3. Identification of **spectral peaks**.
4. For each identified peak, it is checked whether a $K\alpha$ line is present within a threshold (0.5 keV), if it exists, then the peak is assigned to that element.
5. Flux calculations were done by integrating within a defined bin size (0.1 keV) centered around the peak. This meticulous approach ensured that the calculated fluxes represented the true intensities of the spectral lines, free from background interference.
6. Ratios were calculated using the flux values.
7. Geographic data, the longitude, and latitude, were extracted from the input FITS file header.
8. The latitude, longitude and the ratios were written into a CSV file.

Silicon was chosen as the reference element for this analysis. The flux of silicon served as a baseline for calculating line intensity ratios. The final output of this methodology includes a set of line intensity ratios for the analyzed spectral data, providing insights into the spectral characteristics of the dataset. These ratios serve as parameters for further interpretation, and map cartography.

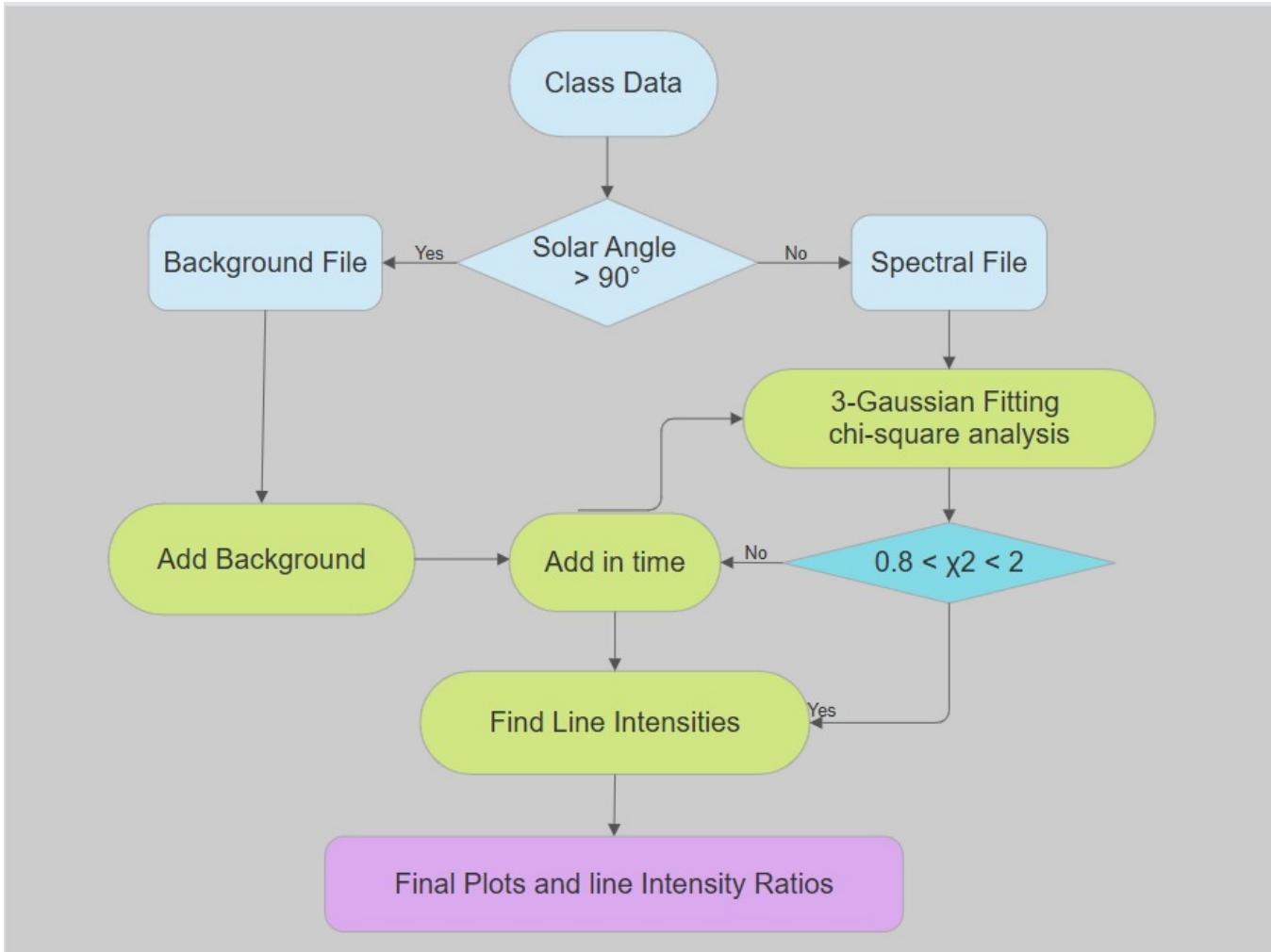


Figure 1: Flowchart of the steps for processing lunar spectral data using XRF analysis.

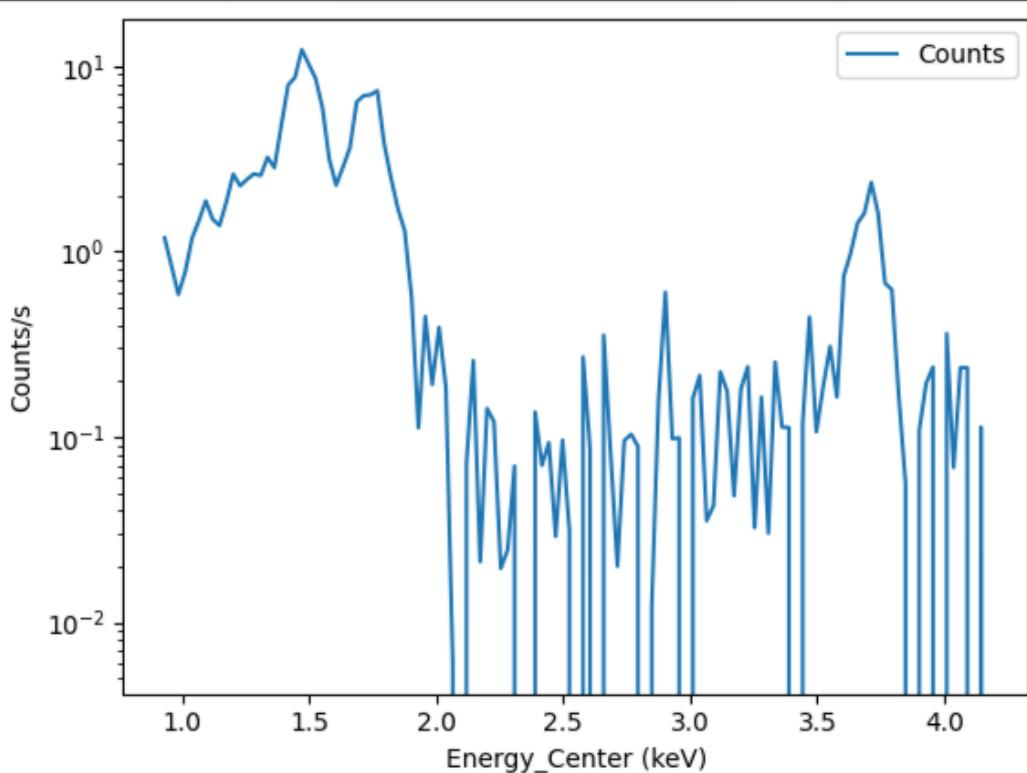


Figure 2: Lunar spectral data after calibration

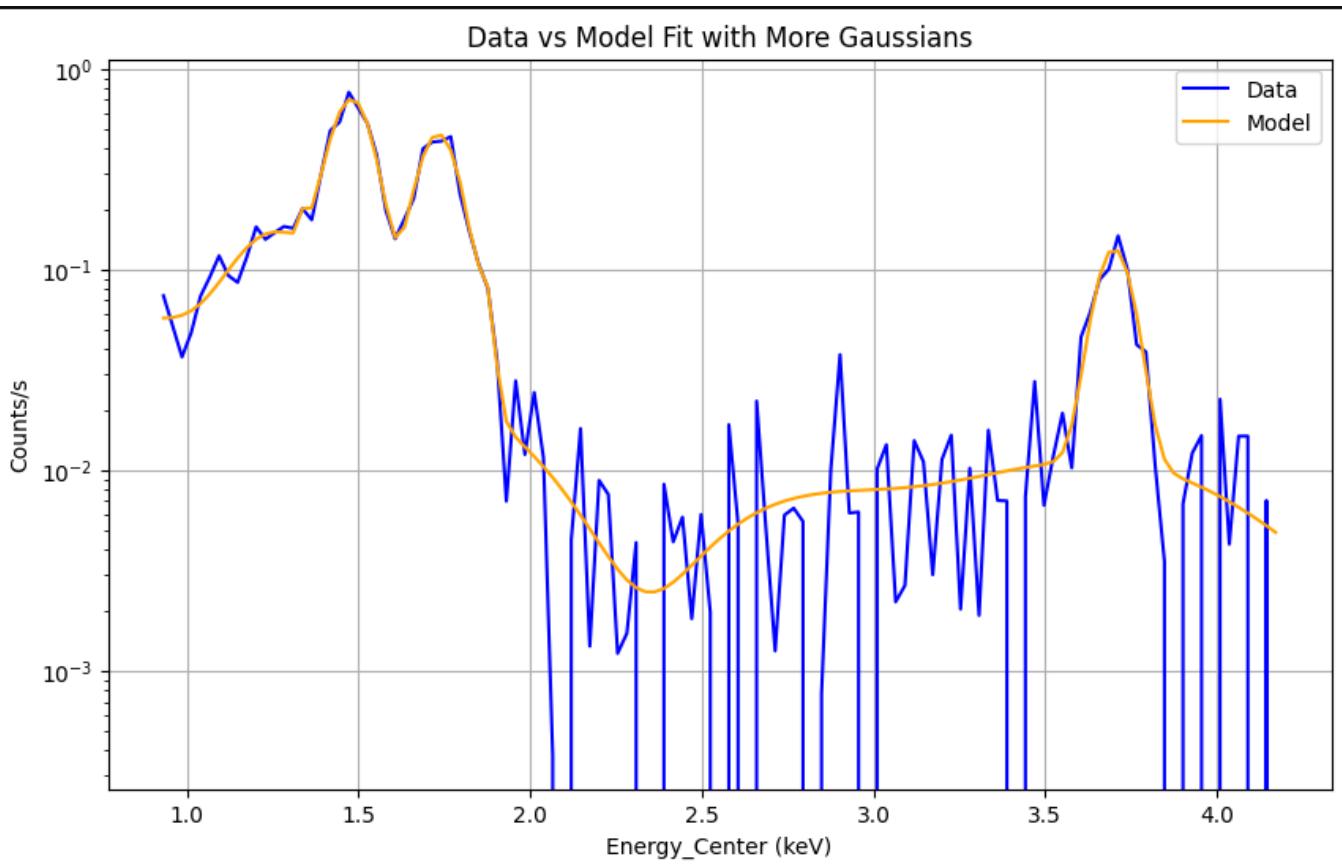


Figure 3: Gaussian Fitting

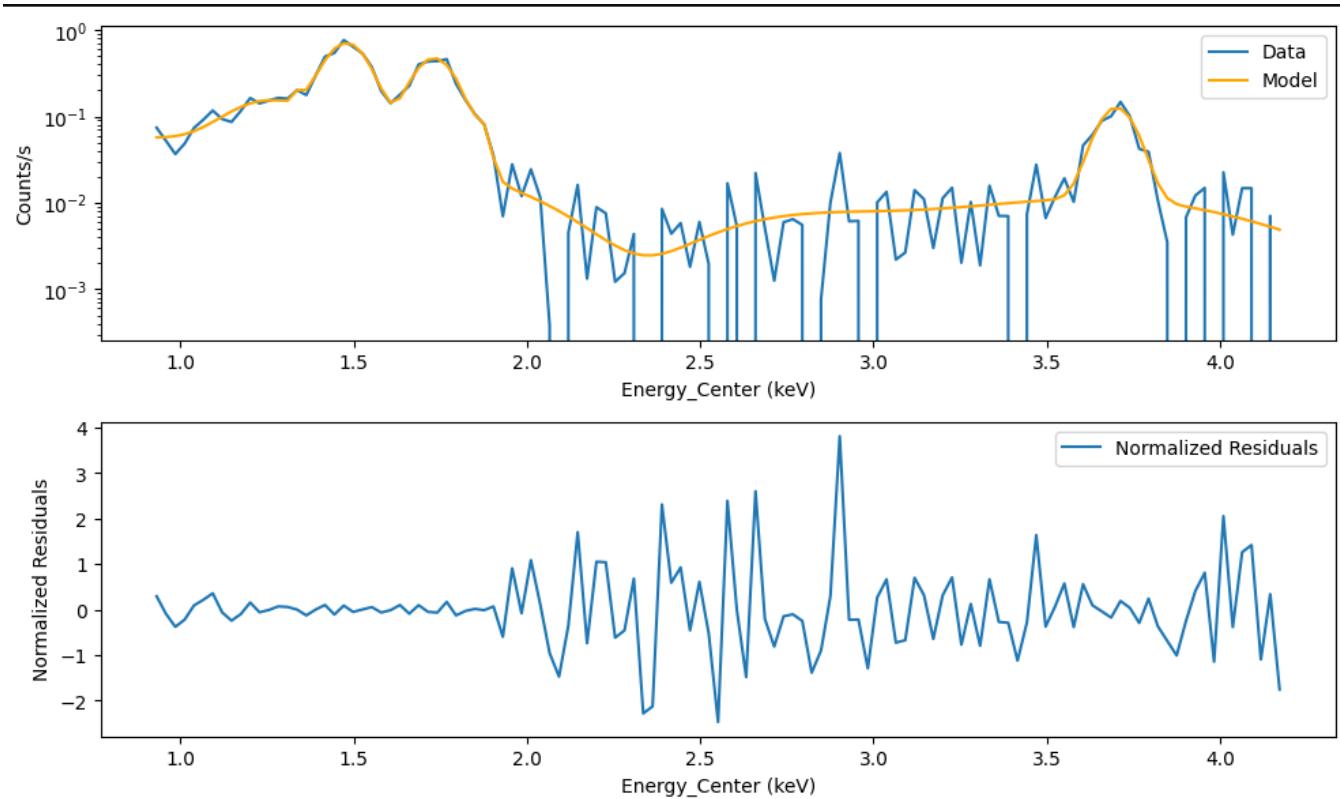


Figure 4: Final XRF Line Fitting

Coverage of CLASS data on lunar map

Description

Mapping the coverage of X-ray fluorescence (XRF) lines onto a lunar base map involves superimposing elemental data gathered from XRF analysis over a detailed lunar map. This helps visualize the distribution of elements and minerals across the Moon's surface, providing valuable insights for geological studies, resource identification, and planning of lunar exploration missions.

Methodology

The task is to show the coverage of XRF lines detected on a lunar base map. Our first and foremost task was to extract the integrated FITS files from the given 12.5km * 12.5km 8 seconds FITS files in the CLASS data, to get better statistics and reliable results. We selected files in **continuum** order of **start time** and **end time**, such that the start time of the second FITS file is equal to the end time of the first and so on. the data available on pradaan website spans over a very large span of time, we decided to use only 1 month of data (Oct 2019), although even 1 month of data covered the whole surface of the moon at least once(with some partial overlap). We extracted the coordinates of the four corners of each file and saved them into a CSV file, using Python libraries like astropy (for handling scientific data) and pandas (for storing it into a CSV file), it contained around **20,000** data points each having latitude and longitude of the four corners. Having the CSV file containing the coordinates of the polygons, we plotted those polygons onto a lunar base using Python libraries like **matplotlib** (for plotting), and **astropy**(for handling coordinates with numerical accuracy and stability. The lunar base image was taken as an open source standard from Unified Geologic Map of the Moon GIS v2 and LROC QuickMap. Additionally, an Open source software named **QGIS** has been explored and utilized.

Therefore lunar map coverage can be achieve by 2 ways, either through Computer Vision or through industrial approved cartographhr softwares like GQIS.

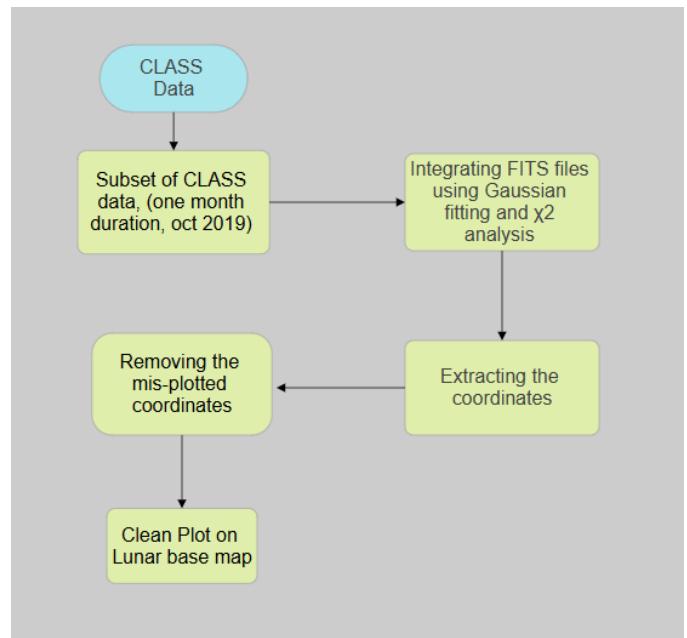


Figure 5: Flow chart representing steps taken to find the lunar coverage by the given CLASS Data



Figure 6: Lunar Coverage of CLASS Data for 1 month timeline

Lunar surface composition

The lunar surface is almost entirely composed of only **7 elements** Oxygen, Silicon, Aluminium, Calcium, Iron, Magnesium, and Titanium. Apart from these, there are a few scarce elements such as Manganese, Sodium, Potassium, and Phosphorus. These elements compose less than **2** percent of the lunar surface. The lunar surface consists of various minerals in the form of different rocks. These minerals are present in various ratios giving these rocks unique characteristics. This very basic fact was used in mapping the lunar surface for the presence of these rocks.

The most abundant element found in the rocks of the Moon is Oxygen. Most of the other elements are present as oxide. However these oxides are not present as standalone compounds instead they combine and form the constituent mineral of the rocks, as described above. For example, nearly all of the Silicon is present as Silicon dioxide as SiO_2 , all of this Silicon dioxide is present in plagioclase, pyroxene, and olivine.

Methodology

For mapping, the lunar surface was studied in detail and various mineral compositions were taken into account to derive one-to-one correlations. These correlations use the basic stoichiometry of various elements present in a mineral and then output a range of percentages to conclude the presence of a certain mineral. Some of the information used while arriving at these correlations is presented.

Atomic Weight Percent is the average weight of an element's isotopes, taking into account their relative abundance.

$$\text{Atomic Weight Percentage of } A = \frac{n_A \cdot A_w}{\sum_{i=1}^n n_i \cdot A_{w,i}} \times 100$$

Molar Percent is the percentage of moles of a component in a mixture compared to the total moles of components in the mixture.

$$\text{Molar Percentage of } A = \frac{n_A \cdot M_A}{\sum_{i=1}^n n_i \cdot M_i} \times 100$$

Converting Atomic Weight Percentage to Molar Percentage To convert atomic weight percentage of element A to molar percentage:

$$\text{Molar Percentage of } A = \frac{\frac{\text{Atomic Weight Percentage of } A}{A_w}}{\sum_{i=1}^n \frac{\text{Atomic Weight Percentage of } i}{A_{w,i}}} \times 100$$

- n_A : Number of atoms (or moles) of element A in the compound.

- A_w : Atomic weight of element A .
- M_A : Molar mass of element A .
- n_i : Number of atoms (or moles) of each element i .
- $A_{w,i}$: Atomic weight of each element i .
- M_i : Molar mass of each element i .

Name	Al	Fe	Mg	Ti	Ca	O	Si
Plagioclase	24.7	0	0	0	18.3	44.0	12.9
Clinopyroxene	0	17.8	7.7	0	26.6	30.7	17.9
Orthopyroxene	0	27.8	12.1	0	0	31.9	28.1
Olivine	0	32.4	14.1	0	0	32.4	21.0
Ilmenite	0	36.8	0	31.5	0	31.6	0

Table 1: Atomic Weight Percentage

Name	Al	Fe	Mg	Ti	Ca	O	Si
Plagioclase	20	0	0	0	10	60	10
Clinopyroxene	0	8.3	8.3	3.3	16.6	50	16.6
Orthopyroxene	0	12.5	12.5	0	0	50	25
Olivine	0	14.2	14.2	0	0	57.1	14.2
Ilmenite	0	20	0	20	0	60	0

Table 2: Molar Percentage

By carefully analyzing Table 4, the respective range of each element for different rock types is derived as follows:

- It is assumed that the second major mineral is at least 50% of the remaining composition after Plagioclase. source codes.
- Minimum & maximum range of elemental percentage is the respective min & max of

$$\sum (\text{Mineral Abundance} \times \text{Molar \% of element in mineral})$$

Process of Mapping Rocks on a given patch of area:

Due to limitations of the resolution, it is assumed each area, represented by a square of **12.5km by 12.5km**, has a 100% composition of only one rock and the contribution of other rocks is thus neglected.

- The percentage weight fractions, of every element present in that pitch are considered while concluding the geological features of the surface.
- All the weight fractions are converted to molar fraction and then based on the satisfied elemental range, the rock type is decided for that region.
- It is possible that, in a particular region the elemental percentage is such that it creates ambiguity in deciding between two or more rock types.
- In this case we use clustering algorithms. We decide the type of rock based on the nearest neighbor.

- Sources of Errors:** Various sources of errors are possible. The contradictions of statements described earlier are themselves a source of error. However, the assumptions taken while calculating the ratios and in the process of determining the geochemical composition of an area are major sources of error.

Key inferences:

- Presence of Plagioclase in higher concentration indicates a brighter area on the lunar surface. This can be used to check the model prediction for the highlands.
- A similar statement can be made for dark mares where there is a higher concentration of FeO and MgO.
- FeO and MgO composition remains nearly the same throughout the lunar surface; however, in areas of significant concentration of Ilmenite, FeO concentration increases.
- There is an anticorrelation observed on the lunar surface between iron and magnesium with aluminium.

Rock Name	Mineral Composition
Anorthosite	more than 90% Plagioclase
Noritic Anorthosite	60-90% plagioclase remainder mostly orthopyroxene
Gabbroic Anorthosite	60-90% plagioclase, remainder mostly clinopyroxene
Troctolitic Anorthosite	60-90% plagioclase, remainder mostly olivine
Norite	10-60% plagioclase, remainder mostly orthopyroxene
Gabbro	10-60% plagioclase, remainder mostly clinopyroxene
Gabbronorite	10-60% plagioclase, remainder includes orthopyroxene and clinopyroxene
Troctolite	10-60% plagioclase, remainder mostly olivine

Table 3: Lunar Rock Types

Rock Name	Al	Fe	Mg	Ca	Ti
Anorthosite	18.0 -	0 -	0 -	9.41 -	<0.5
	20.0	1.37	0.87	10.0	
Noritic Anorthosite	12.0 -	5.34 -	4.0 -	7.11 -	<1.33
	18.0	8.0	8.0	9.27	
Gabbroic Anorthosite	12.0 -	3.33 -	3.33 -	9.33 -	<1.33
	18.0	4.78	3.45	12.67	
Troctolitic Anorthosite	12.0 -	5.57 -	4.24 -	7.11 -	<1.33
	18.0	5.70	5.70	9.27	
Norite	2.0 -	11.25 -	9.02 -	1.0 -	<3.0
	12.0	12.02	11.25	3.50	
Gabbro	2.0 -	7.49 -	7.49 -	8.50 -	<3.0
	12.0	10.76	7.76	16.0	
Gabbronorite	2.0 -	8.75 -	8.75 -	6.0 -	<2
	12.0	11.11	10.0	12.67	
Troctolite	2.0 -	12.55 -	9.55 -	1.0 -	<3.0
	12.0	12.86	12.86	3.50	

Table 4: Elemental Percentage in Lunar Rocks

Mapping of Ratios on Lunar Base Map

Description:

Mapping the line intensity ratios of X-ray onto a lunar base map involves superimposing elemental data gathered from XRF analysis over a detailed lunar map. This helps visualize the distribution of elements and minerals across the Moon's surface, standard available GeoTIFF lunar maps (NASA Libraries) are utilized as an albedo base map. Mapping further, has been done using two approaches:

- Using QGIS software.
- Using Web based Python script.

Steps for Plotting the map:

1. **Preparing the CSV file:** The CSV file prepared during task 1 (i.e line intensity ratios) is taken into account. The CSV file contains different columns like set of latitude and longitude of 4 different corners forming a polygon, Mg/Si ratios, Al/Si ratios and Ca/Si ratios. The CSV file was prepared by automation scripts written in linux Operating System. Thus, a CSV file for 1 month of CLASS data is being made with usage of calibration data like background file, ARF data, RMF data, Solar angle, and exposure time.
2. **Downloading Lunar Map:** The Lunar Map was downloaded from the USGS's official website in .tiff(Tagged Image File Format) format ensuring minimum quality loss and High Definition.
3. **Final Mapping of Ratios Using QGIS:** For final mapping of ratios on lunar map a python script was executed in the python console of QGIS. The python script combines all the four points to make the polygon and calculates maximum-minimum ratios. The script symbolises the entire range of ratios to a color ramp as per the range of ratios calculated. At last appropriate partition was made based on the minimum ratio and maximum ratios. This creates a layer, overlaying the albedo map.
4. **CRS(Coordinate Reference System)** is a framework that defines how a planet's coordinates should be projected onto a 2D map. Choosing appropriate CRS was the important step for assuring the correctness of the plot on QGIS.EPSG:3832 - Lunar 2000 was chosen as the CRS for the project which is specifically designed to represent lunar coordinate system, taking into account the Moon's geometry, shape, and topography. The CRS of all the imposed layers were chosen wisely to be compatible

with the lunar map used. These steps are followed for plotting all the three ratios i.e. Al/Si, Mg/Si and Ca/Si.

5. **Final Mapping of Ratios Using Python Script:** libraries like rasterio, pyproj, pandas, plotly.graph_objects, PIL (Pillow), io.BytesIO,shapely.geometry are used. The Python script processes geospatial data to create an interactive map that overlays polygonal regions from a CSV file on a raster GeoTIFF background. The GeoTIFF represents spatial data in a custom lunar coordinate system, which is downsampled and normalized for efficient visualization. The CSV file contains quadrilateral coordinates in Earth-based WGS84, which are transformed to match the lunar projection. Simplified polygons are generated from the coordinates, with each polygon color-coded based on its ratio value, a numerical attribute from the CSV. The map has properties like showing ratios, centroid latitude and longitude on hovering alongwith adjusting resolution on zooming in and zooming out. The visualization is saved as an interactive HTML file
6. **Exportation of map:** In QGIS the map is exported using **qgis2web**, a popular QGIS plugin that facilitates the export of QGIS projects to interactive web maps using OpenLayers or Leaflet. The map is exported in the form of a html file. By python script map is saved as html file by writing the necessary code inside the script only.

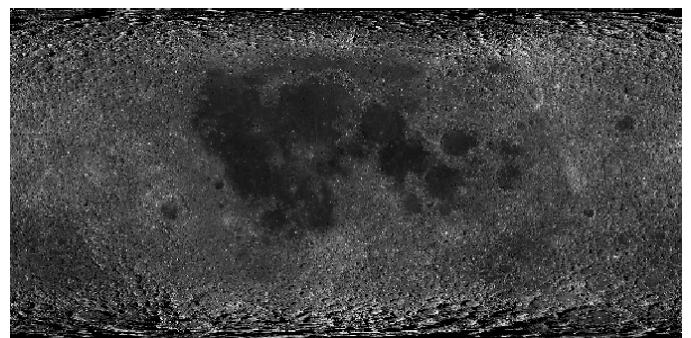


Figure 7: Lunar Base Map

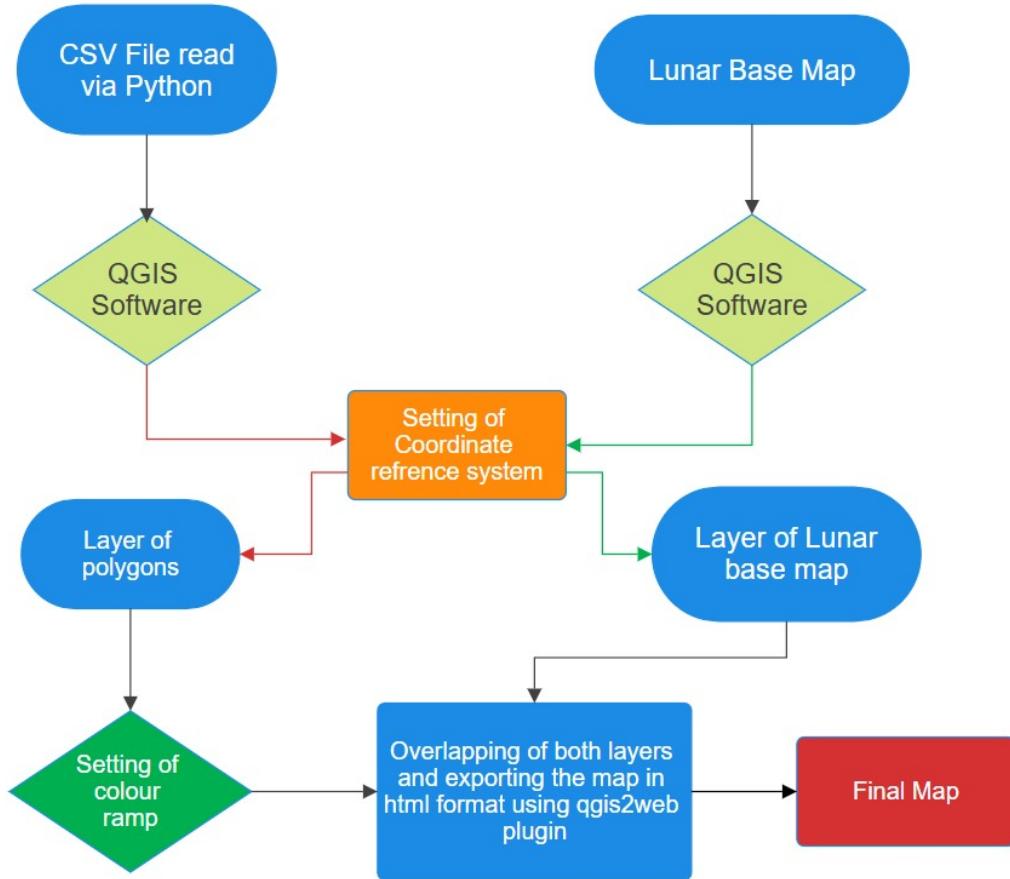


Figure 8: Flowchart of the steps for mapping of ratios on Lunar base map

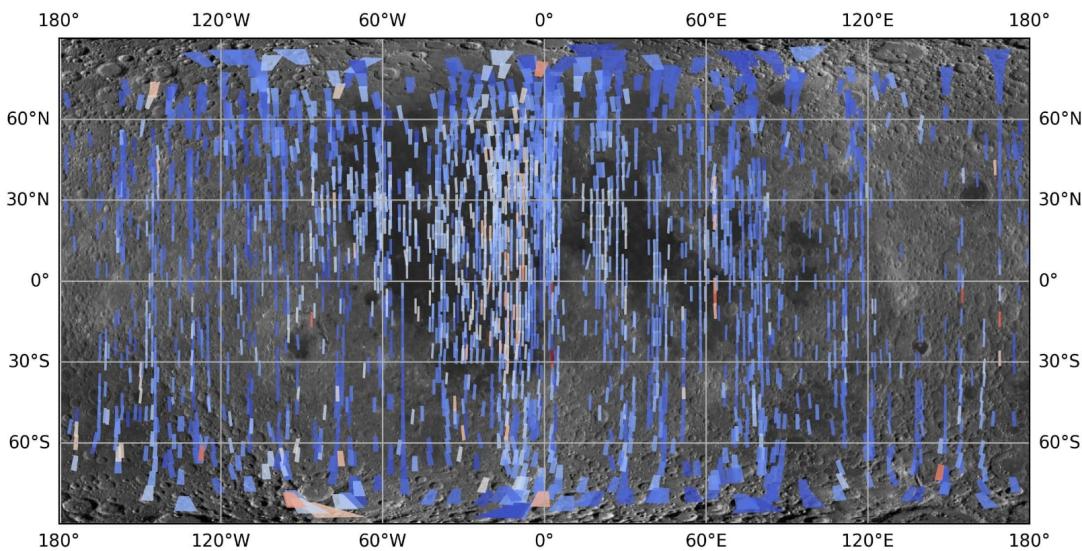


Figure 9: Mapping of Line Ratios

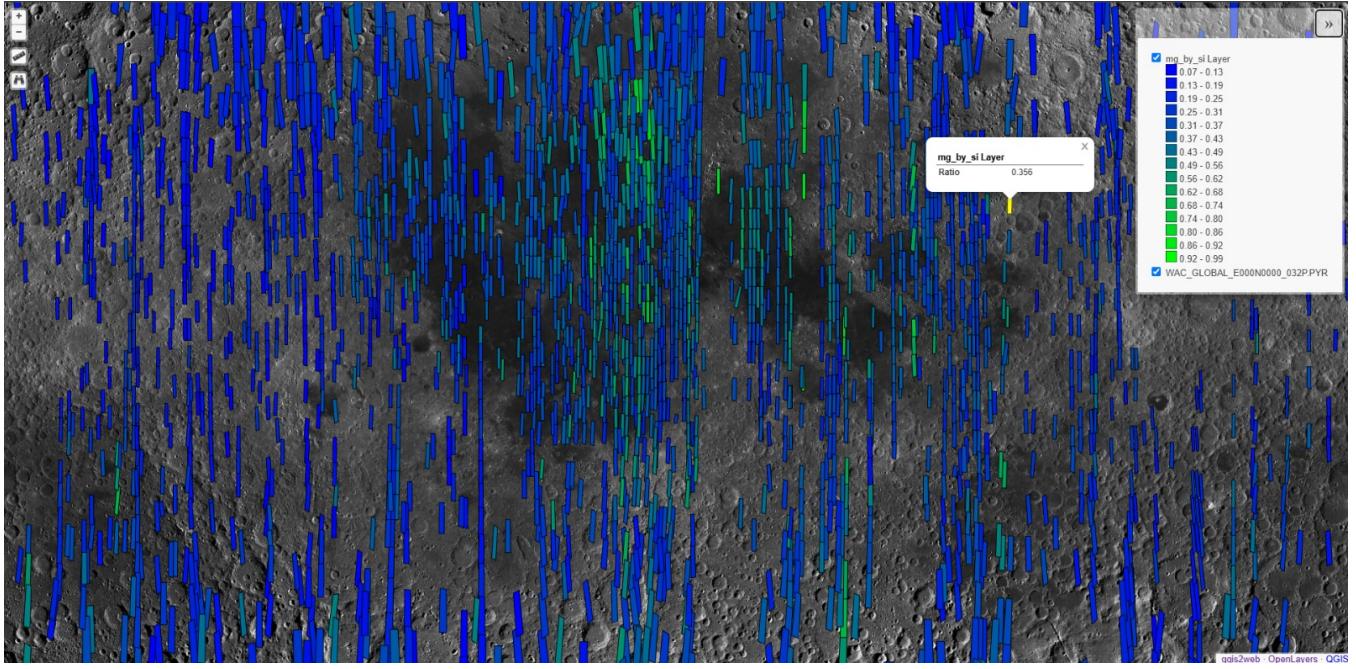


Figure 10: Interactive Mapping of Ratios on Lunar Base Map (QGIS)

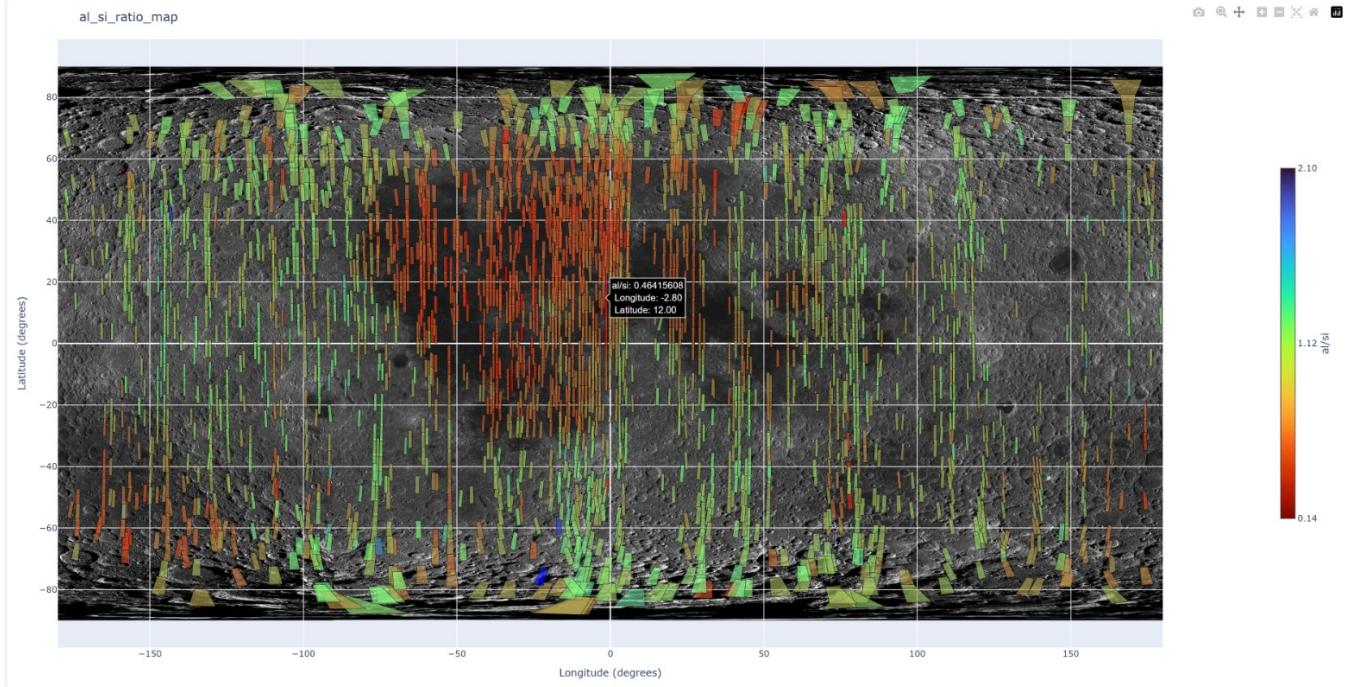


Figure 11: Interactive Mapping of Ratios on Lunar Base Map

Best ratios and Subpixel resolution maps

Description:

The Solution is to derive best elemental ratios (e.g., Mg/Si, Al/Si, Fe/Si) for lunar surface composition and visualize this data on a high-resolution lunar map. This involves processing spatial data at both pixel and sub-pixel levels to achieve a fine-grained understanding of compositional heterogeneity.

1. Calculating Best Ratios:
2. Sub-Pixel Resolution Mapping:
3. Visualization:

1 Best Ratios:

The Chandrayaan 2 orbiter sweeps the lunar surface multiple times during the course of operation. This very fact can be used to get the best line intensity ratios for a particular coordinates

Assuming the orbiter remained active for 5 years and that had 5X365 days=1825 days of operations

Based on sample calculation the module takes 22.5 days to cover once the complete surface area of the moon and hence the orbiter will visit any given coordinate 80 times approximately.

But the coordinate boxes (consisting of 4 latitude and 4 longitudes) may not coincide with the previous visit, in that case we shall assign the same coordinates to boxes which have more than 50

These ratios can be thought of as samples from the population and hence the mean value of these data points can be assumed to be the true value of the ratio of line intensity for elements present in the coordinate box since the number of points are high enough for a good degree of resemblance with the true value

Even in the case of maneuvers or unavailability of data or any other causes, machine learning models like KNN etc can be trained based on the images and data given and hence a best value can be obtained for a point from these model

Calculations

1. Radius of Moon:

$$\text{Radius of Moon} = 1737.4 \text{ km}$$

2. Surface Area of Moon:

$$\text{Surface Area of Moon} = 4\pi \times (1737.4)^2 \text{ km}^2$$

$$\text{Surface Area} = 37,932,328.1 \text{ km}^2$$

3. Areal Velocity of Orbiter:

$$\text{Areal Velocity} = \frac{12.5 \times 12.5}{8} \text{ km}^2/\text{s}$$

$$\text{Areal Velocity} = 19.53125 \text{ km}^2/\text{s}$$

4. Time to Sweep the Surface Area of the Moon:

$$\text{Time} = \frac{4\pi \times (1737.4)^2 \times 8}{12.5 \times 12.5}$$

$$\text{Time} = \frac{37,932,328.1 \times 8}{19.53125} \text{ seconds}$$

$$\text{Time} = 1,942,135.19 \text{ seconds}$$

5. Converting Seconds to Days:

$$\text{Time in Days} = \frac{1,942,135.19}{86,400}$$

$$\text{Time in Days} = 22.478 \text{ days} \approx 22.5 \text{ days}$$

6. Total Duration Orbiter Stayed (5 Years):

$$\text{Duration} = 5 \times 365 = 1825 \text{ days}$$

7. Number of Times the Surface Was Covered:

$$\text{Number of Cycles} = \frac{1825}{22.5} \approx 81.111$$

8. Conclusion:

Nearly 80 points for a given coordinate.

Methodology

1. Data Preparation

Input Data:

- Satellite-derived CSV files containing:
 - Elemental line intensity ratios (Mg/Si, Al/Si, Fe/Si).
 - Rectangular region coordinates (corner points defining bounds).
- Lunar surface grid generated programmatically.

Grid Creation:

- Defined a regular grid of latitude and longitude points with a resolution of 0.1 degrees.
- Latitude range: -90 to 90 degrees.
- Longitude range: -180 to 180 degrees.
- Stored grid points in a DataFrame (`moon_map_df`) with columns initialized for:
 - Elemental ratios (Mg/Si, Al/Si, Fe/Si).
 - A `count` column to track overlaps.

2. Calculating Best Ratios

Overlapping Region Handling:

- Processed each rectangle's data:
 - Identified grid points within its bounds using logical conditions.
 - Updated the corresponding elemental ratio columns by adding the rectangle's values.
 - Incremented the *count* for covered points to track data contributions.

Averaging Elemental Ratios:

- For each grid point, computed averages:

$$\text{Mg/Si}_{\text{avg}} = \frac{\text{Total Mg/Si}}{\text{Count}},$$

$$\text{Al/Si}_{\text{avg}} = \frac{\text{Total Al/Si}}{\text{Count}},$$

$$\text{Fe/Si}_{\text{avg}} = \frac{\text{Total Fe/Si}}{\text{Count}}.$$

- Ensured proper handling of points with Count = 0 to avoid division by zero.

3. Sub-Pixel Resolution Mapping

Grid Refinement:

- Created sub-pixel regions (e.g., 12 km × 12 km) to improve spatial resolution.
- Averaged ratios for all points within these sub-pixel regions to derive finer-resolution data.

Overlap-Based Adjustment:

- Used overlapping satellite tracks to further refine sub-pixel resolution.

Dynamic Outputs:

- Generated heatmaps to visualize compositional heterogeneity of Mg/Si, Al/Si and Ca/si.

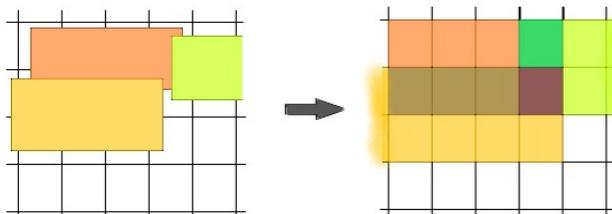


Figure 12: Illustration of overlapping regions and best ratio calculation.

Method 2

As per the data available on the class website, it is quite evident that the satellite has crossed the same region of moon multiple times. This indicates an important aspect about overlapping subregions. As per the large dataset, when plotted, we can carefully say that a large part of the moon will be under the overlapping subregions.

The idea here is that suppose multiple regions overlap, we can break them into disjoint sets such that the disjoint set created from overlapping regions will have the KNN values/mean values of the parent overlapping region.

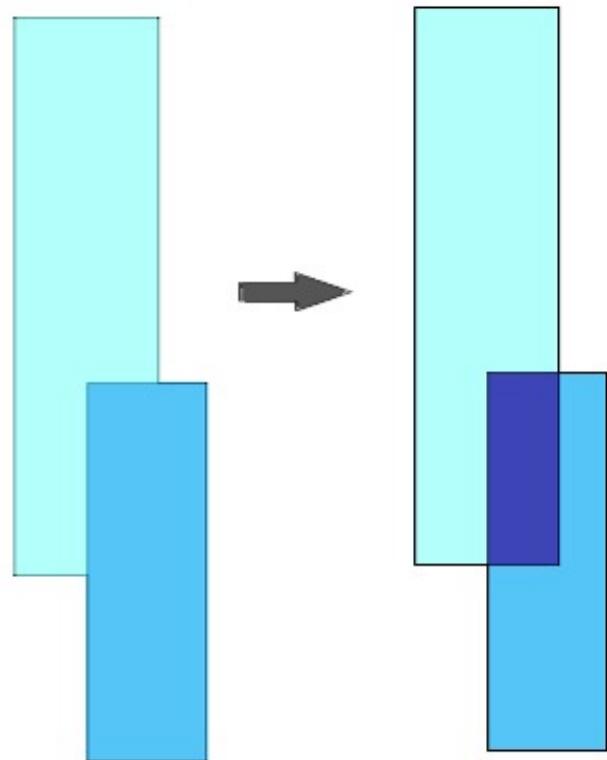


Figure 13: Grid-based compositional estimation: (Left) Previous ratios, (Right) Best ratios.

Consider an example depicted in the diagram below containing 2 boxes partially overlapping each other. We may use the concept of disjoint set to create 3 sets (depicted by different shades). The darkest shade will contain KNN/mean values of the 2 boxes and thus arrive at a lower resolution with precision.

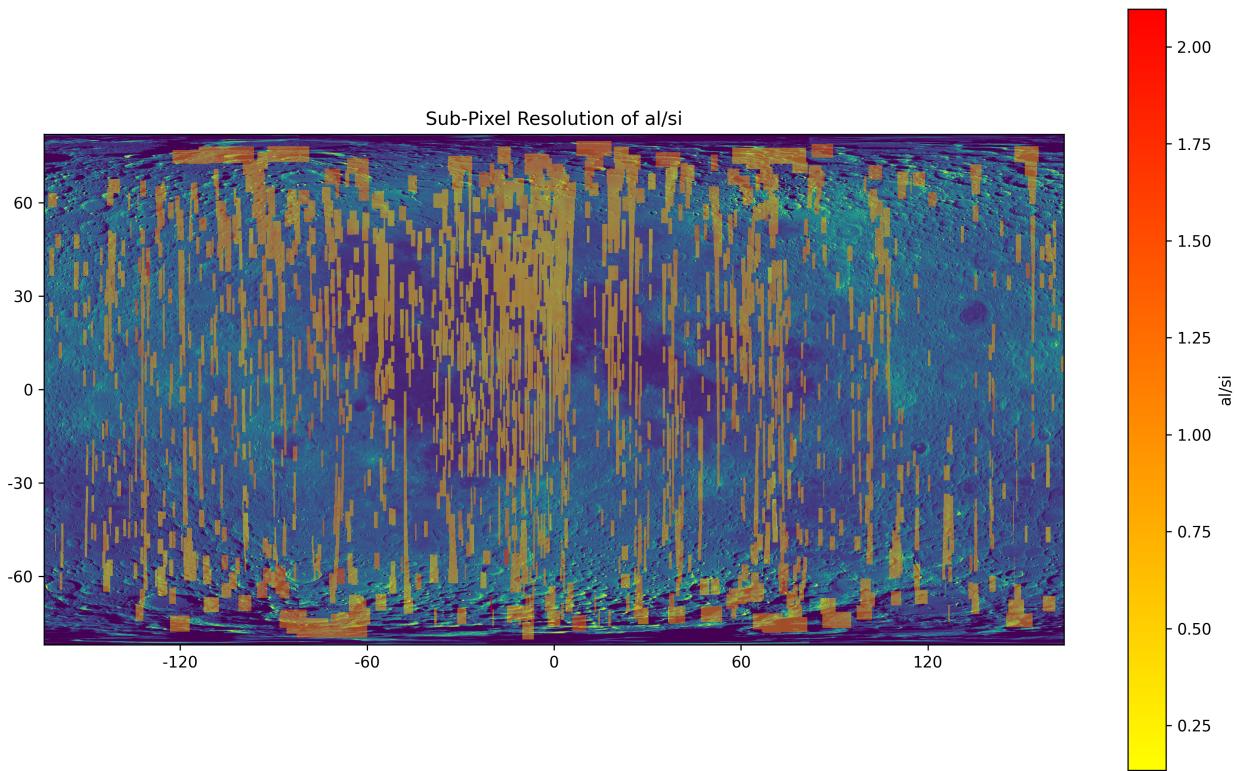


Figure 14: Results for al/si Subpixel resolution maps.

Problems faced

- The header data of ARF file was not compatible with the FITS file directly, they have to be manually changed by using PDS4 or FV fits file viewer. This posed compatibility issues.
- The EXTVERS of ARF has to be set 1, due to this ARF file cannot be directly loaded in the XSPEC.
- Different .TIFF maps are available over internet as an open source, however each with its own CRS (Coordinate Reference System). understanding the CRS and changing polygon coordinates according to it with valid conversion units posed new challenges.

Future prospects

- The sub pixel resolution part can be further improved by further reducing the window size from 0.1 degrees to 0.05 degrees, this requires class data computation for further months and high computation facility.
- Best data ratios interactive maps can now be plotted with respective CSV and KNN ML algorithms.

References

- [P.S. Athiray, S. Narendranath, P. Sreekumar, S.K. Dash, B.R.S. Babu] *Validation of methodology to derive elemental abundances from X-ray observations on Chandrayaan-1.*
<https://doi.org/10.1016/j.pss.2012.10.003>.
- [S. Narendranath, Netra S. Pillai, M. Bhatt, K. Vadodariya, Radhakrishna Vatedka, Srikanth P. Tadepalli, A. Sarwade, A. Tyagi, V. Sharan] *Lunar elemental abundances as derived from Chandrayaan-2.*
<https://doi.org/10.1016/j.icarus.2023.115898>.
- [Netra S. Pillai, S. Narendranath, K. Vadodariya, Srikanth P. Tadepalli, Radhakrishna V., Anurag Tyagi, Reena Yadav, Brajpal Singh, Vaishali Sharan, P.S. Athiray, P. Sreekumar, K. Sankarasubramanian, Megha Bhatt, Amit Basu Sarbadhikari, N.P.S. Mithun, Santosh Vadawale] *Chandrayaan-2 Large Area Soft X-ray Spectrometer (CLASS): Calibration, In-flight performance and first results*
<https://doi.org/10.1016/j.icarus.2021.114436>
- [N. P. S. Mithun, Santosh V. Vadawale, Aveek Sarkar, M. Shanmugam, Arpit R. Patel, Biswajit Mondal, Bhuvan Joshi, P. Janardhan, Hitesh Kumar L. Adalja, Shiv Kumar Goyal, Tinkal Ladiya, Neeraj Kumar Tiwari, Nishant Singh, Sushil Kumar, Manoj K. Tiwari, M. H. Modi & Anil Bhardwaj] *Solar X-ray Monitor On Board the Chandrayaan-2 Orbiter: In-flight Performance and Science Prospects.*
<https://doi.org/10.1007/s11207-020-01712-1>
- [M. Shanmugam, S. V. Vadawale, Arpit R. Patel, Hitesh Kumar Adalja, N. P. S. Mithun, Tinkal Ladiya, Shiv Kumar Goyal, Neeraj K. Tiwari, Nishant Singh, Sushil Kumar, Deepak Kumar Painkra, Y. B. Acharya, Anil Bhardwaj, A. K. Hait, A. Patinge, Abinandhan Kapoor, H. N. Suresh Kumar, Neeraj Satya, Gaurav Saxena, Kalpana Arvind] *Solar X-ray Monitor (XSM) On-board Chandrayaan-2 Orbiter.*
<https://doi.org/10.48550/arXiv.1910.09231>
- [N. P. S. Mithun, Santosh V. Vadawale, M. Shanmugam, Arpit R. Patel, Neeraj Kumar Tiwari, Hitesh Kumar L. Adalja, Shiv Kumar Goyal, Tinkal Ladiya, Nishant Singh, Sushil Kumar, Manoj K. Tiwari, M. H. Modi, Biswajit Mondal, Aveek Sarkar, Bhuvan Joshi, P. Janardhan & Anil Bhardwaj] *Ground calibration of Solar X-ray Monitor on board the Chandrayaan-2 orbiter*
<https://doi.org/10.1007/s10686-020-09686-5>
- [N.P.S. Mithun, S.V. Vadawale, A.R. Patel, M. Shanmugam, D. Chakrabarty, P. Konar, T.N. Sarvaiya, G.D. Padia, A. Sarkar, P. Kumar, P. Jangid, A. Sarda, M.S. Shah, A. Bhardwaj] *Data processing software for Chandrayaan-2 Solar X-ray Monitor*
<https://doi.org/10.1016/j.ascom.2021.100449>
- [Mithun N. P. S. & Santosh Vadawale; Physical Research Laboratory] *Chandrayaan-2 Solar X-ray Monitor (XSM) Data Analysis Guide*
- [Mithun N. P. S.; Physical Research Laboratory Ahmedabad] *Chandrayaan-2 Solar X-ray Monitor (XSM) Data Products and Archive Software Interface Specification*
- [Biswajit Mondal] *chspec: Local models in XSPEC for X-ray spectra from Astrophysical plasma with CHIANTI database*
- [Mithun N. P. S.] *xastprl/xsm-analysis: Solar X-ray Monitor*
- [Keith A Arnaud] *The File Format for XSPEC Table Models*
- [Keith Arnaud, Craig Gordon, Ben Dorman & Kristin Rutkowski] *An X-Ray Spectral Fitting Package Users' Guide for version 12.14.1*
- [Harrison H. Schmitt, Grant H. Heiken, David T. Vamanian & Bevan M. French] *Lunar sourcebook : a user's guide to the Moon*
- [Earth, Environmental, and Planetary Sciences, Washington University in St. Louis] *How do we know that it is a rock from the moon? — Some Meteorite Information*
- [Earth, Environmental, and Planetary Sciences, Washington University in St. Louis] *The chemical composition of lunar soil — Some Meteorite Information*
- [Mithun N. P. S.] *Demonstration of spectral analysis of CH-2 XSM data with pyxspec: Isothermal models*
- [Keith A Arnaud] *The File Format for XSPEC Table Models*
- [National Aeronautics and Space Administration: Goddard Space Flight Center] *NASA's HEASARC : Software*
- [Keith A Arnaud] *HEASP Guide*