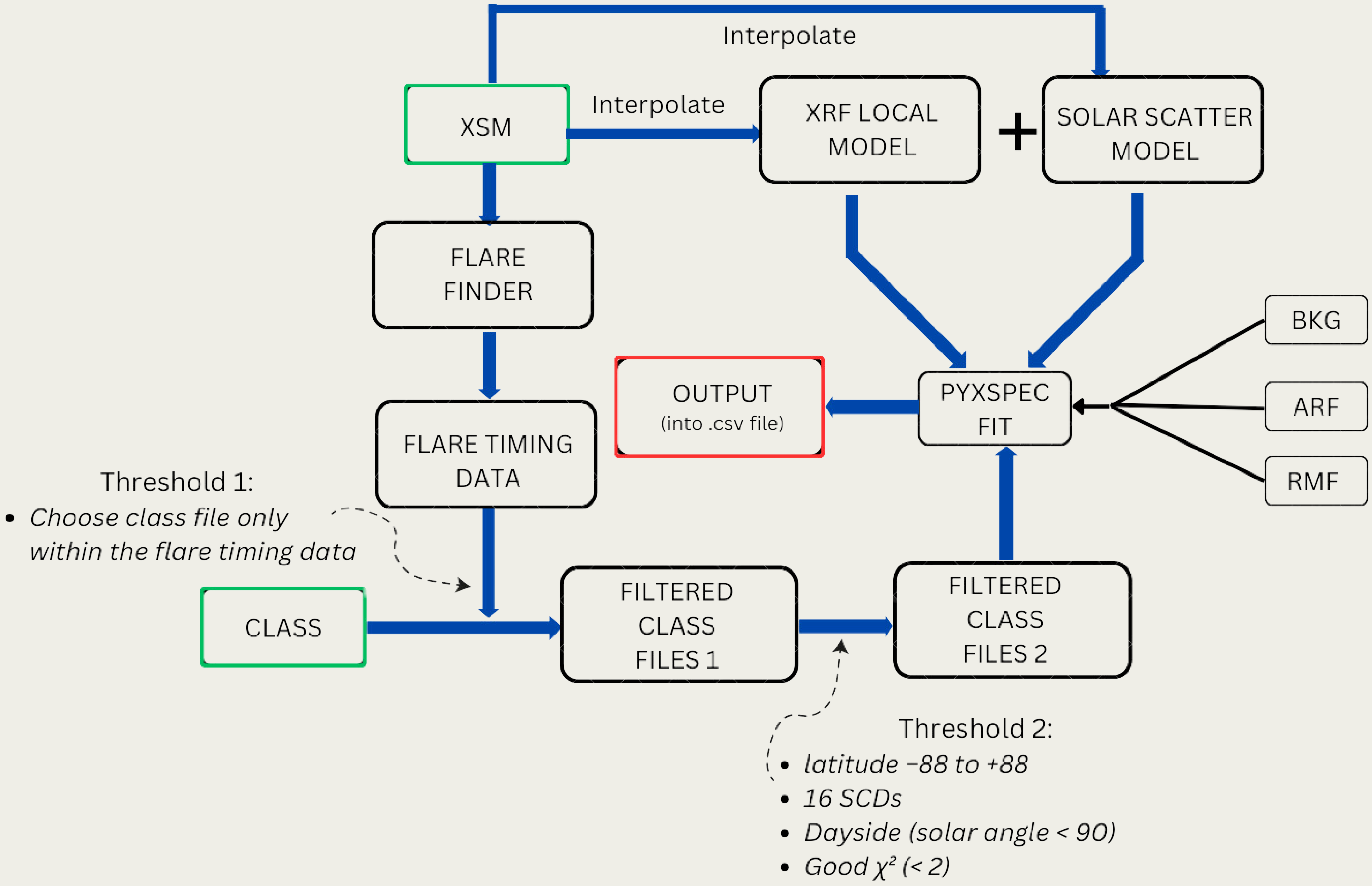
Team 18

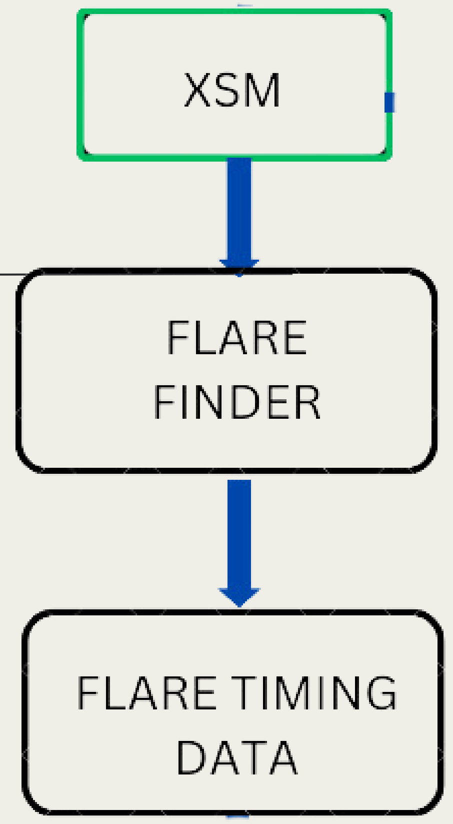
ISRO HIGH PREP PRESENTATION

INTER IIT TECH MEET 13.0

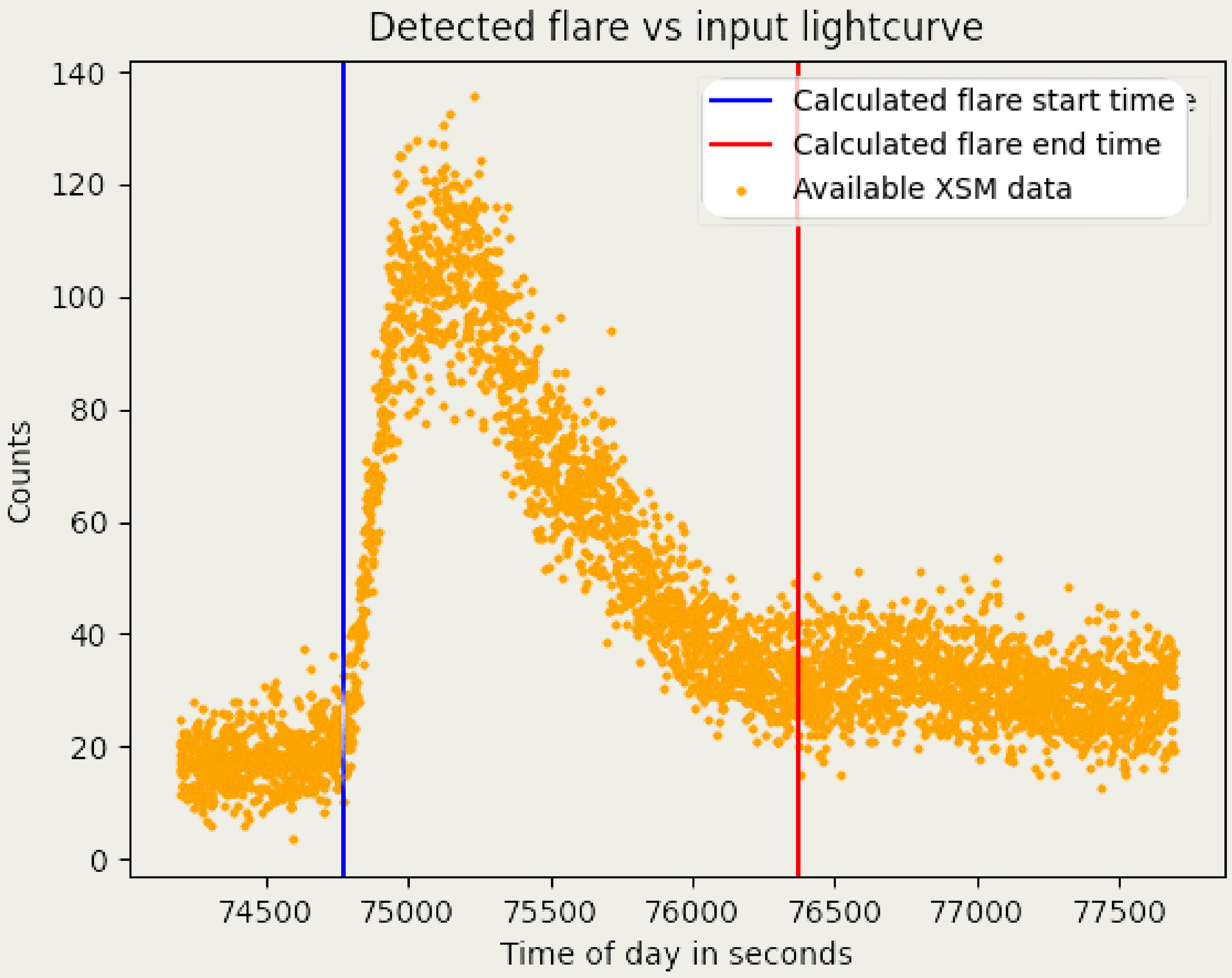
APPROACH PIPELINE



SOLAR FLARE DETECTION - XSM

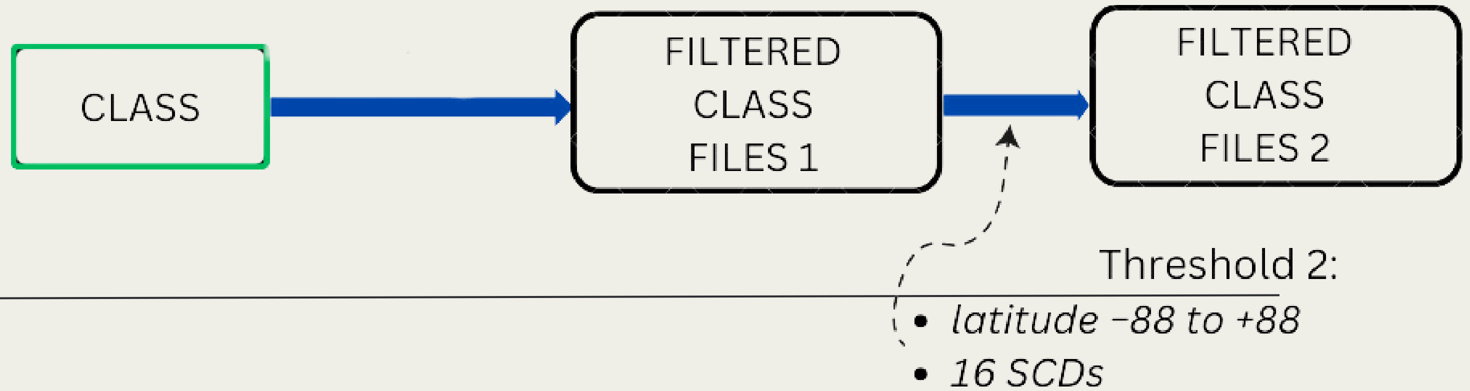


- Fit **exponentially-modified-Gaussians** to the .lc files.
- Removed interpolation-induced flare artefacts.
- **33,650** flares were detected.
- These translated to **3,16,925** CLASS files.



Valluvan et al., Solar flare catalog from 3 years of Chandrayaan-2 XSM observations

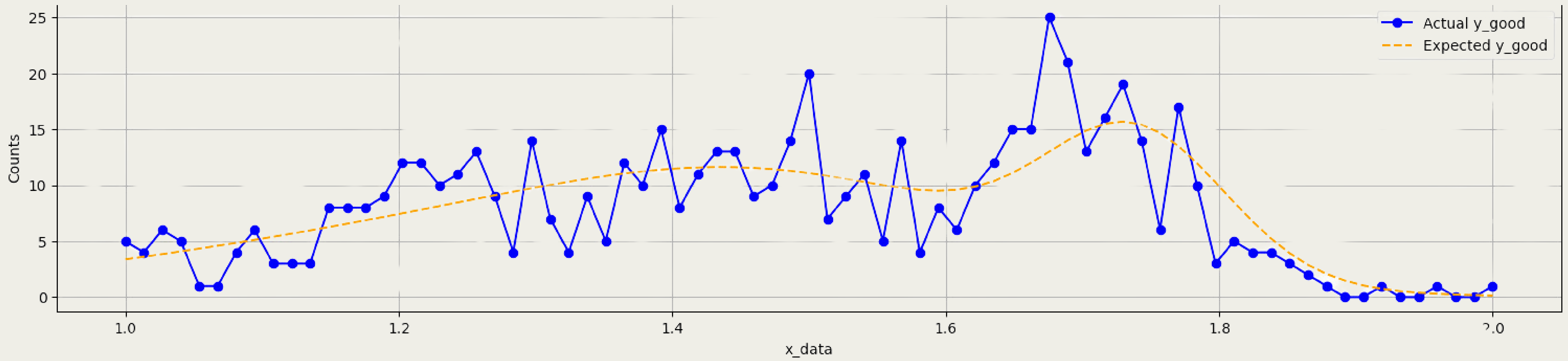
FILTERING GOOD CLASS FILES



Threshold 2:

- *latitude −88 to +88*
- *16 SCDs*
- *Dayside (solar angle < 90)*
- *Good χ^2 (< 2)*

- After first round of filtering based on flares, we apply some **more checks**
- Consecutive CLASS files are combined **until *Reduced Chi-square* value drops below 2**

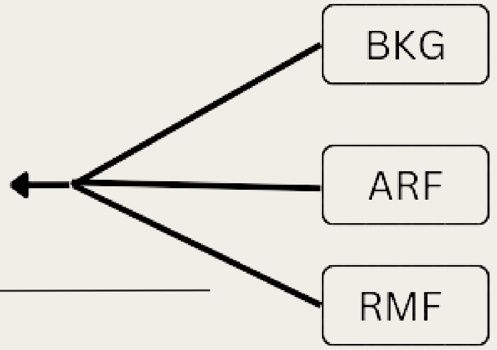


FILTERING GOOD CLASS FILES FOR SPECTRAL FITTING

- Files that are present at (80-90°) solar angles do not record many counts and can produce erroneous bad fits

- XSM and CLASS spectra were fed. Using filtering mechanism as shown, the spectra were fit using XSPEC local models with background, RMF and ARF files.

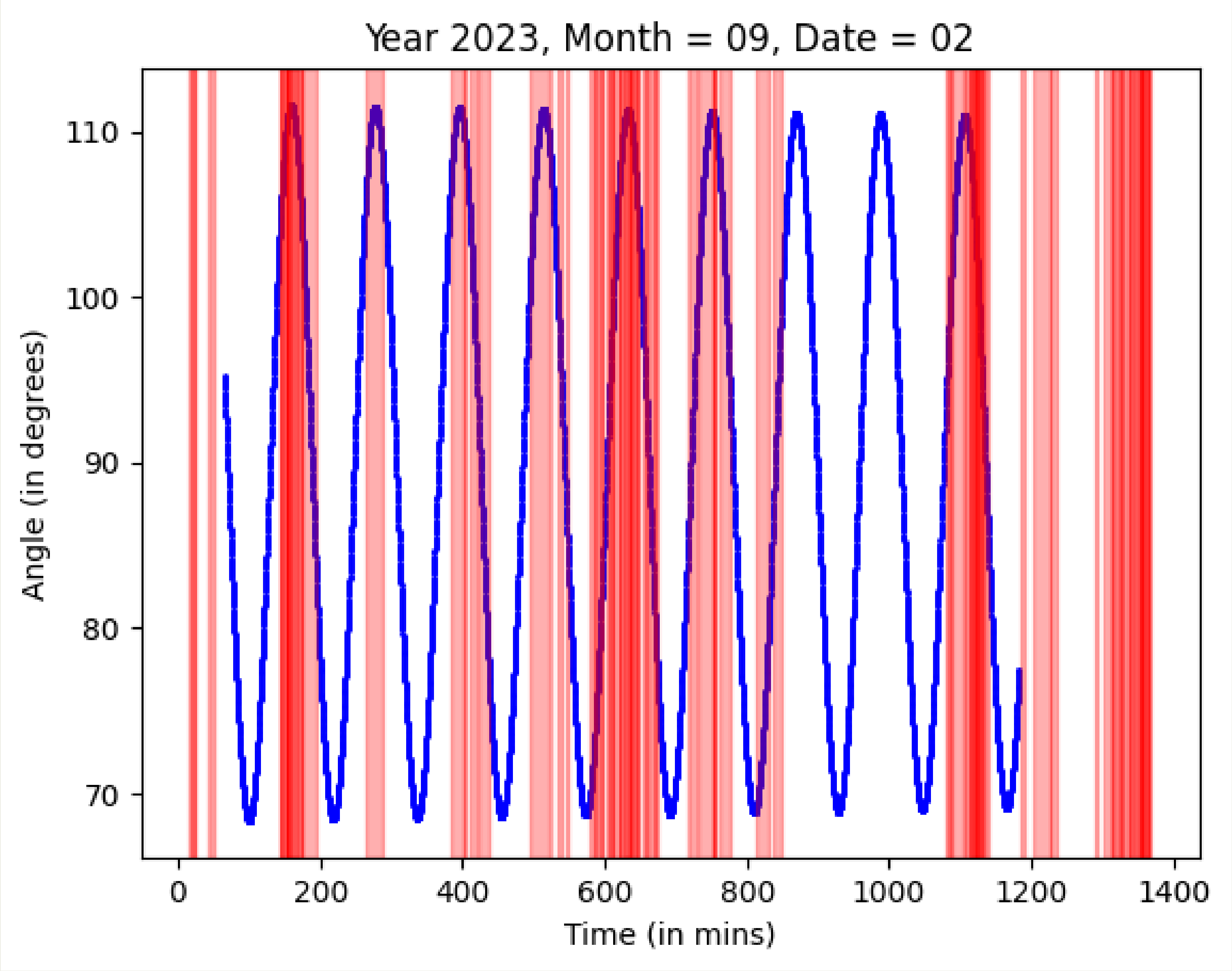
Description	Number of files
Inside a Good flare	3,16,925
16 SCDs and latitude -88^0 to $+88^0$	2,12,039
Dayside (solar angle < 90^0)	1,99,348
Good χ^2(< 2)	1,50,854



BACKGROUND FITS FILE GENERATION

- PIXE Effect on CLASS Spectrum adds to the recorded spectrum.
- Background file generation:
  - Collect CLASS files during CH2's **dark time** (solar angle > 90°), absence of **Solar flares,** near the **Max solar angle** of the day (within 6°).
  - These files are average to create a nominal background for the day, which is subtracted during XSPEC fitting.
  - If Max solar angle is (<110°), we use background file from the PRADAN website.

Terminator effect: A large Aluminium peak is seen in **Solar Angle 90^0-110^0**.

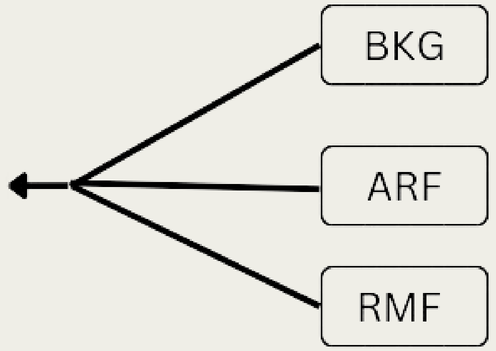


Max solar angle for this day is around 110^0

Blue curve - CH2 Orbit
Red lines - Flare Intervals

Lunar X-ray fluorescence observations by the Chandrayaan-1 X-ray Spectrometer (C1XS) S. Narendranath, P.S. Athiray et al

ARF AND RMF FILES



- Response Matrix Files (RMFs).
  - information about energy redistribution.
  - probability of being measured at each possible pulse height for each incident energy

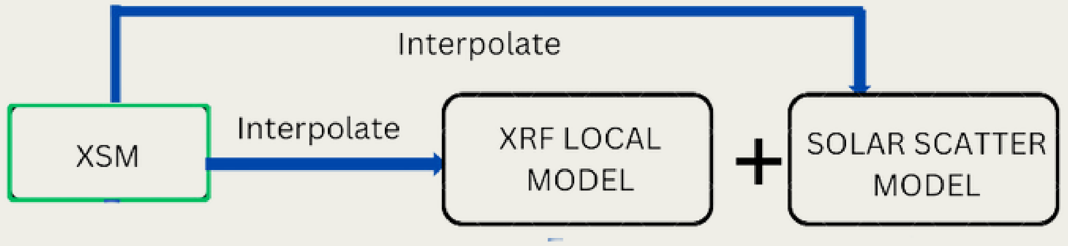
- An Auxiliary Response File (ARF) gives area versus energy and is used to modify the response matrix for a spectrum.

- The ARF provided did not comply with the latest OGIP spectral file standards.

- We rebuilt ARF from scratch with **`xsmgenspec`** from the **`XSMDAS`** module.

- The files were also verified by **`HEASoft`**'s **`fitsverify`** program. **`x2abundance`** also successfully loads these files without any warnings or errors.

FRAMEWORK FOR MODELLING CLASS SPECTRUM



XRF Model

- Models XRF spectrum for a given I_0 using FP method [1]
- "Matrix" effect between different elements
- Ignored Secondary XRF lines [3]

$$I_P^{ij} = \int W_i \omega_i R_j^i K_i \frac{\mu_{ij}(E) I_0(E)}{\mu_{ij}(E) \csc\phi + \mu_{ij}(E) \csc\psi} dE$$

Solar Scatter Model

- Model the solar scatter spectrum using a fast scattering integral
- Accounts for Coherent scattering off the Lunar surface [2]
- Ignored Compton scattering [2]

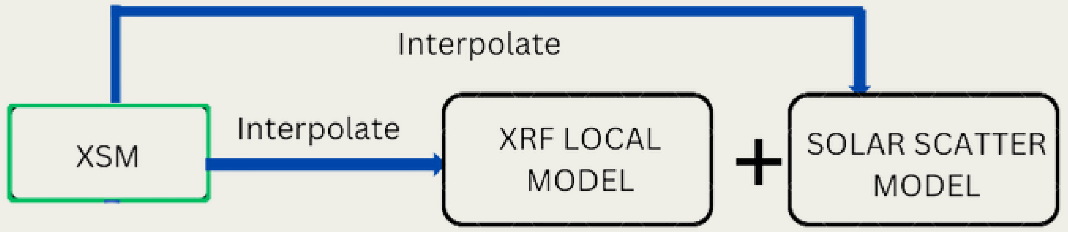
$$I_R(E') = \int I_0(E) \frac{\sigma_R(E)}{\mu(E) \csc\phi + \mu(E') \csc\psi} dE$$

$$I(E') = \int_{E=0}^{\infty} \frac{w_i\ \xi_i\ J(E)}{\mu(E) + \mu(E') \dfrac{\cos\theta}{\cos\phi}}\, d\Omega\, dE,$$

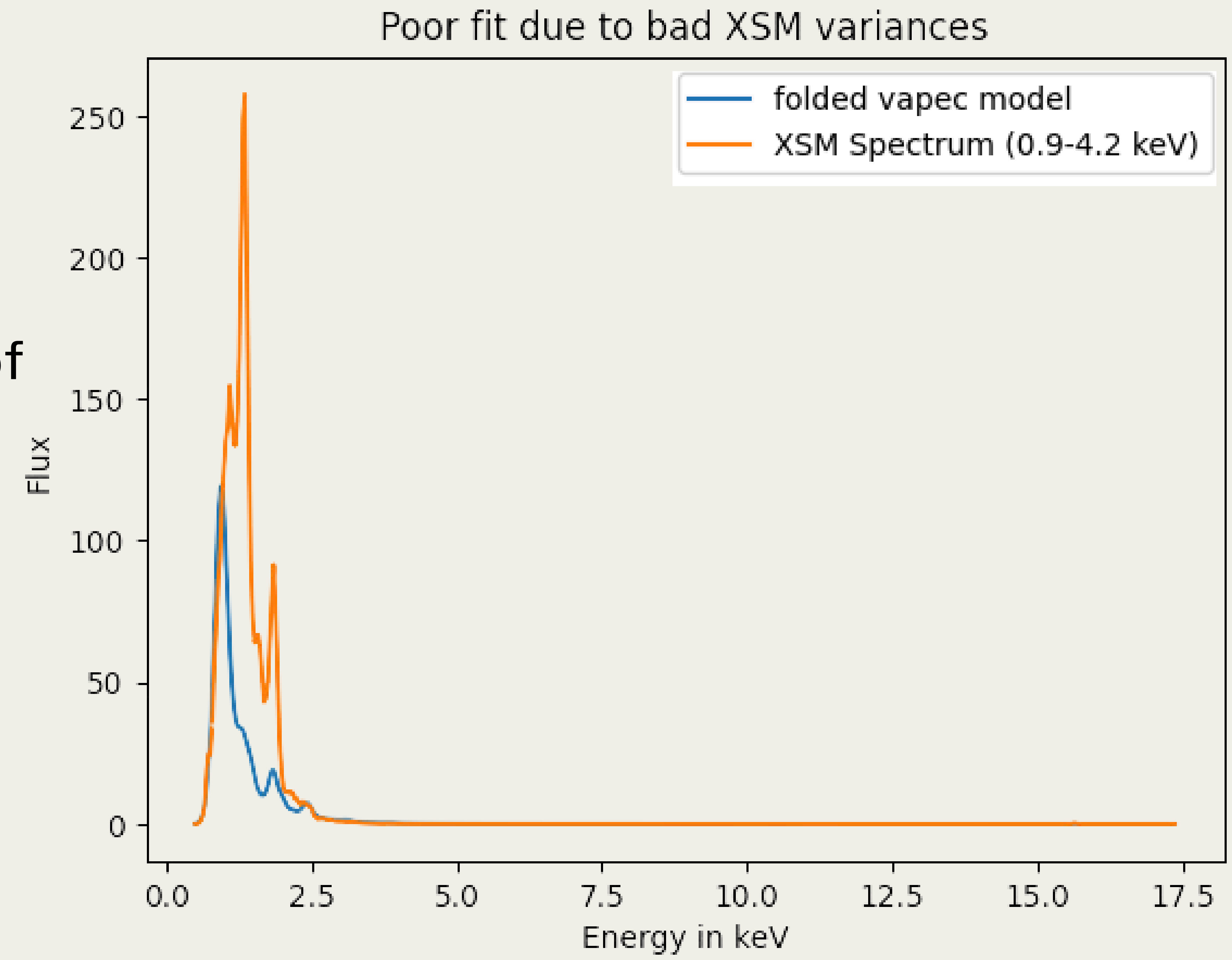
$\boxed{\text{Generalized Scattering Integral}}$

[1]. Toshio Shiraiwa and Nobukatsu Fujino, 1966 Jpn. J. Appl. Phys. 5 886
[2]. Ogawa et al, 2008
[3]. Fernandez et al., 1992

FITTING THE SOLAR MODEL

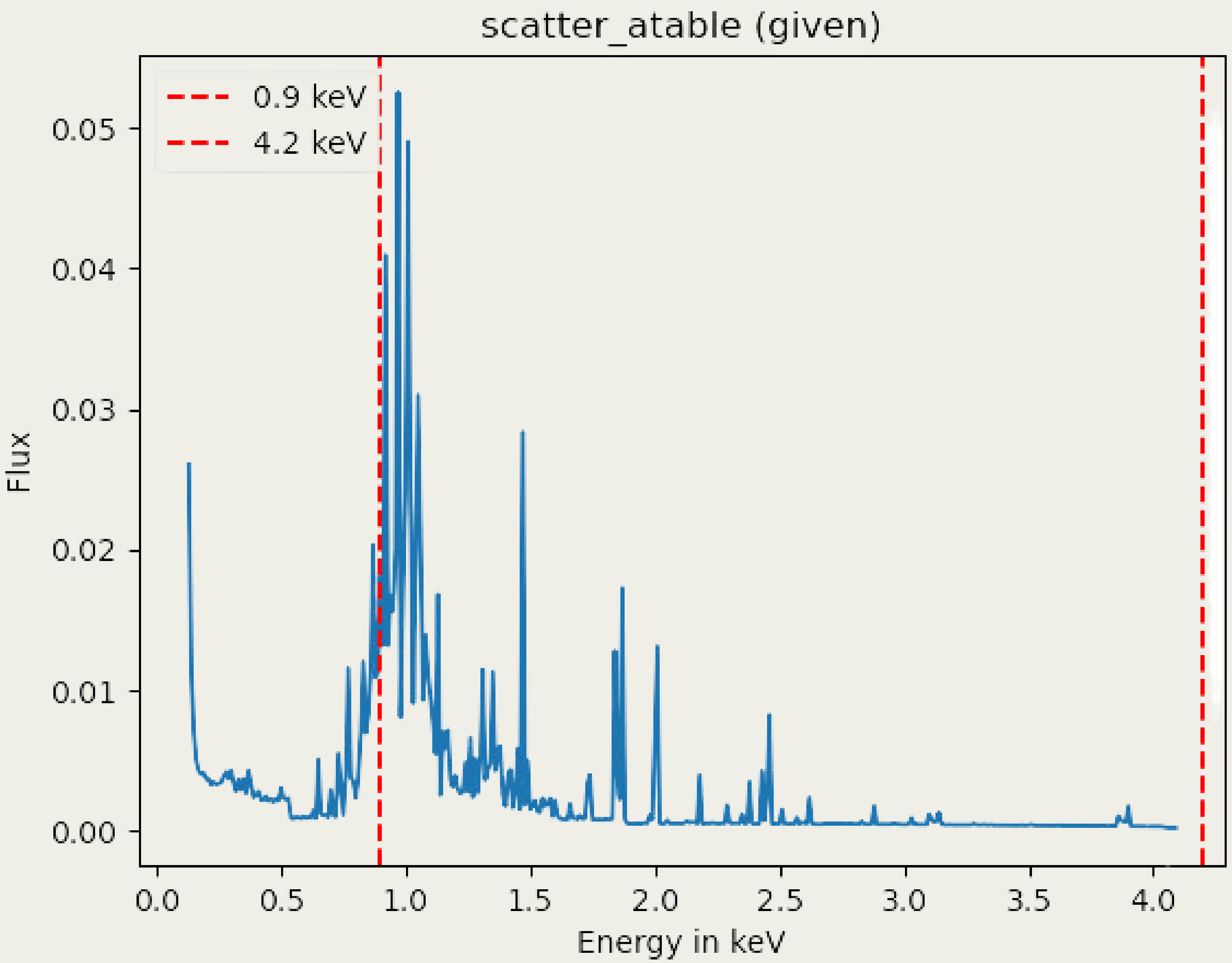


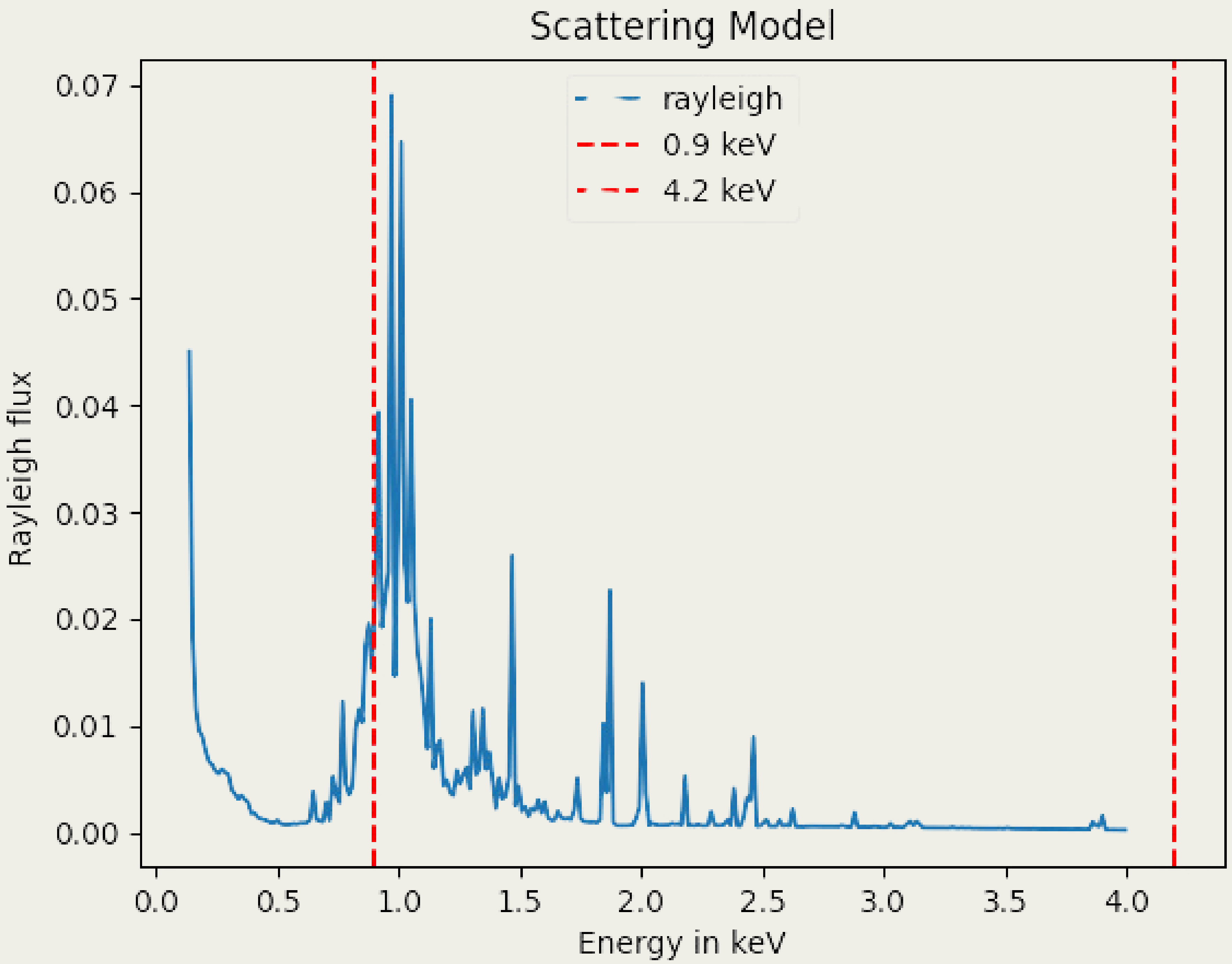
- As suggested in the XSM Data Analysis Guide, the XSM spectrum was fit to a **two-temperature plasma model**.
- However, an error was incurred due to zero values of "STAT_ERR" and "SYS_ERR" columns in extension of .pha solar spectrum file, leading to bad chi-sq values.
- To work around this, we used **interpolation** of XSM spectrum within its energy range.



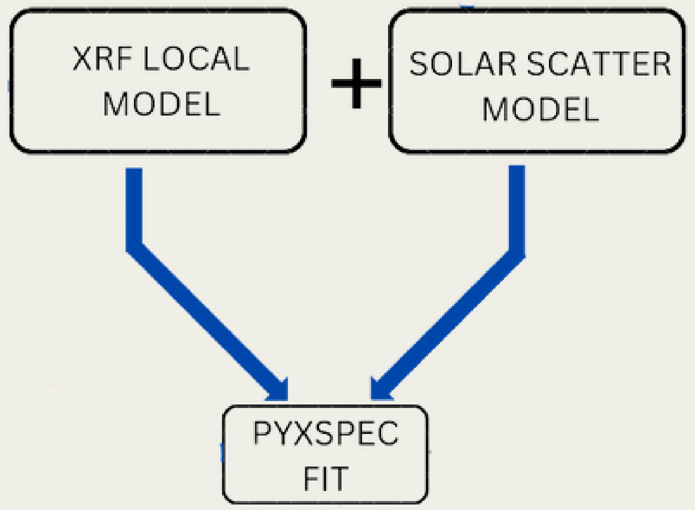
VERIFICATION OF SCATTER MODEL

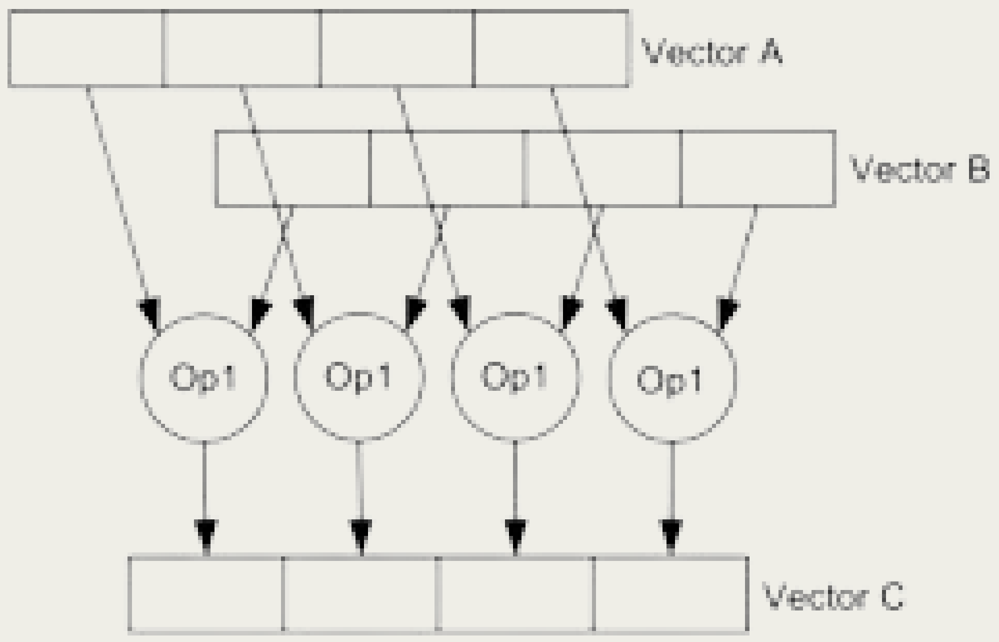
We compare the output plots of our Rayleigh model to the **original code and dataset** (Athiray et.al, available on the PRADAN portal)

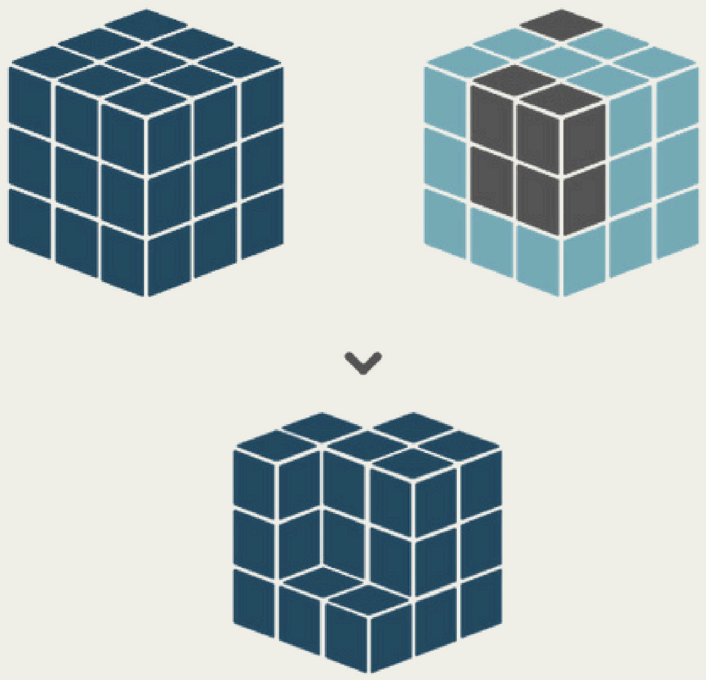


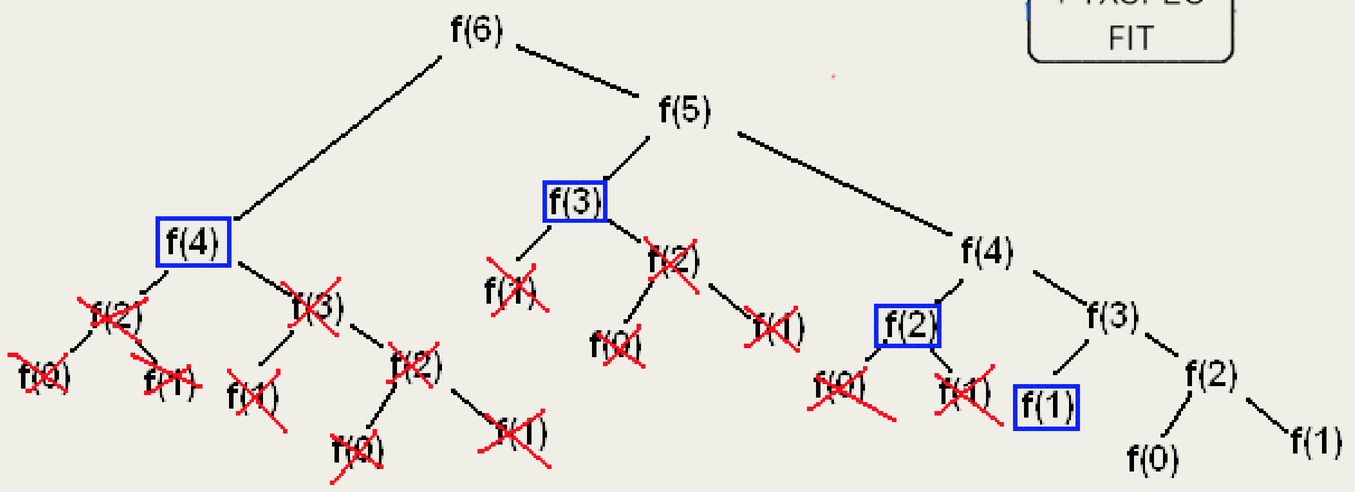


PYXSPEC FITTING - BETTER, FASTER









Vectorization

Use numpy

Simple loops can be replaced by numpy vectorised operations. Can be generalised to tensor operations.

Masking

Replace Conditionals

Conditions replaced by boolean masks to simplify loops, allowing more vectorization

Memoization

Track last input

Functions are called many times consecutive with the same inputs. The computation can be skipped.

One-time Computing

Preprocess Constants

Global constants like elemental lines can be computed only once instead of every time

OVERALL SPEEDUP

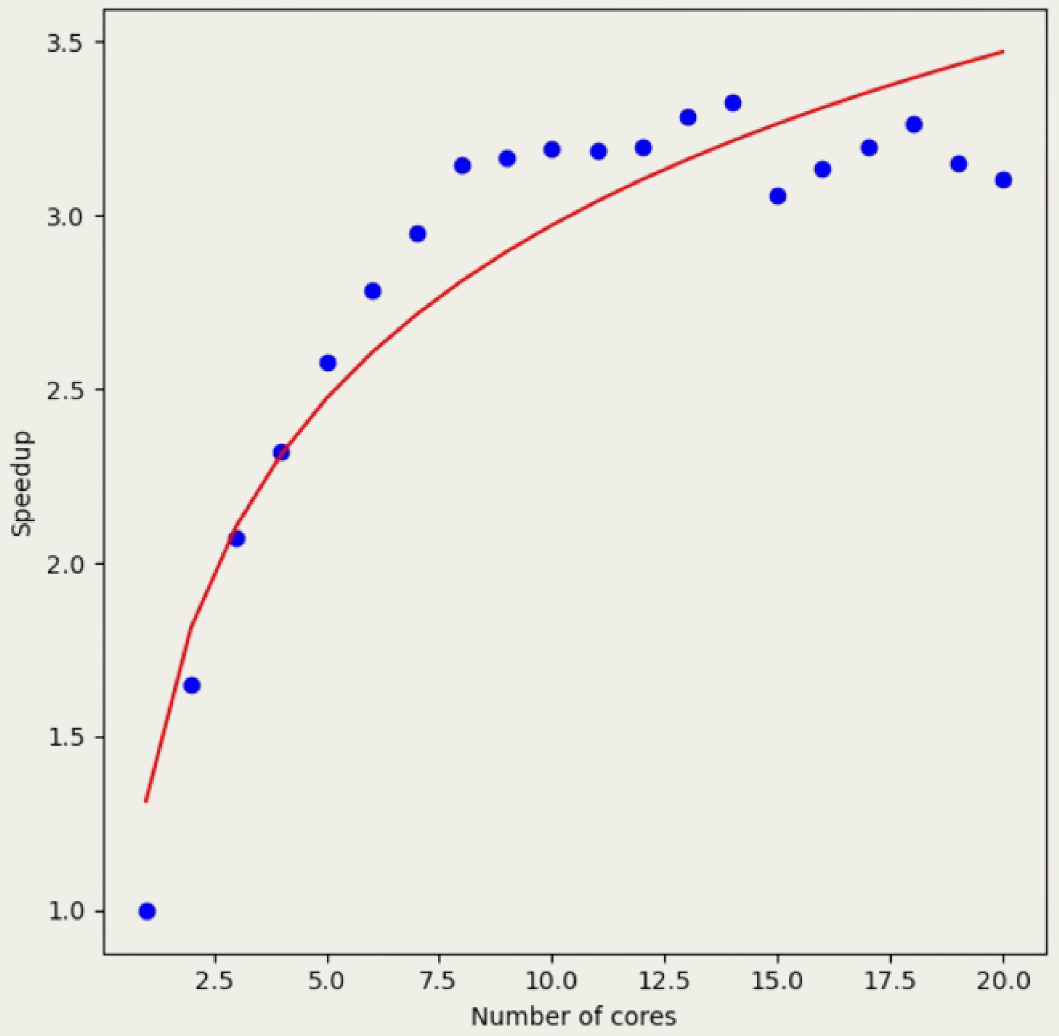
We compare the speed of our data analysis pipeline to the provided code and dataset (Athiray et al., available on the PRADAN portal)

- Speed of the original program :
  - secondary : ~ 15 min / CLASS file
  - primary : ~ 80 s / CLASS file

- Final speed :
  - secondary: < 45s **/ class file**
  - primary : **<2s / class file**

- **>40x** increase in speed (primary)

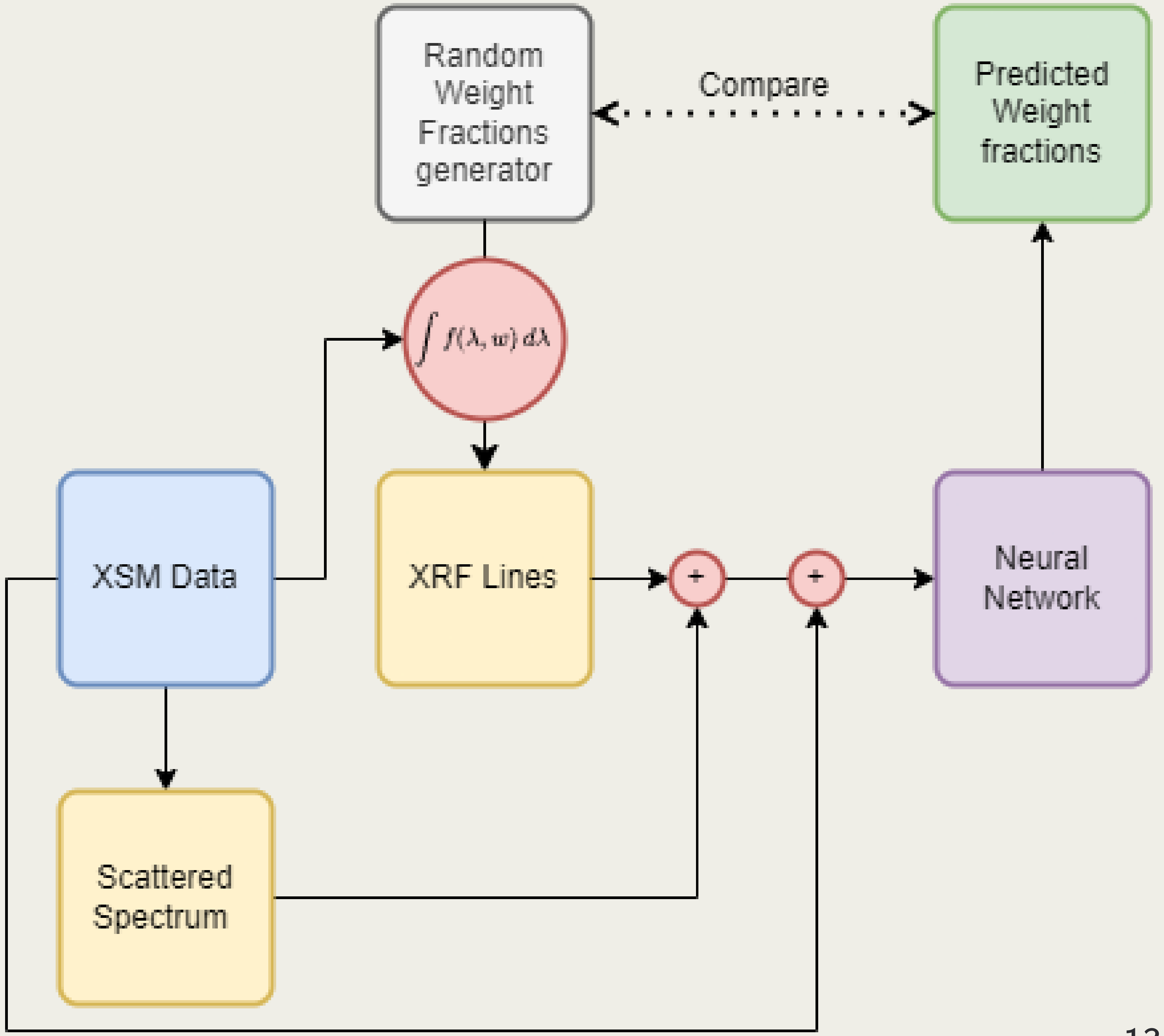
- Additionally, developed scripts to process the spectrum files in multicore cluster architectures.



Parameter	Athiray et al. Primary	Our code Primary	Athiray et al. Primary + Secondary	Our code Primary + Secondary
Fe	7.19114	7.19114	7.26368	7.26368
Ti	1.00000E-06	1.00000E-06	1.00000E-06	1.00000E-06
Ca	20.0000	20.0000	20.0000	20.0000
Si	9.90302	9.90302	9.90538	9.90538
Al	15.2227	15.2227	15.1573	15.1573
Mg	2.48872	2.48872	2.47914	2.47914
Na	0.194459	0.194459	0.194473	0.194473
O	45.0000	45.0000	45.0000	45.0000
Time taken	1m 15s	1.7s	16m 50s	42s

NEURAL NETWORK FOR INVERSION

- Data driven approach to derive weight fractions from CLASS and XSM data.
- Function from weights to spectrum is known. Our aim is to invert this function.
- Generate synthetic CLASS and XSM data with random weights.
- Train Neural Network on synthetic data.
  - RMSE error ~1e-4



Yang, C., Zhang, X., Bruzzone, L. et al., 2023

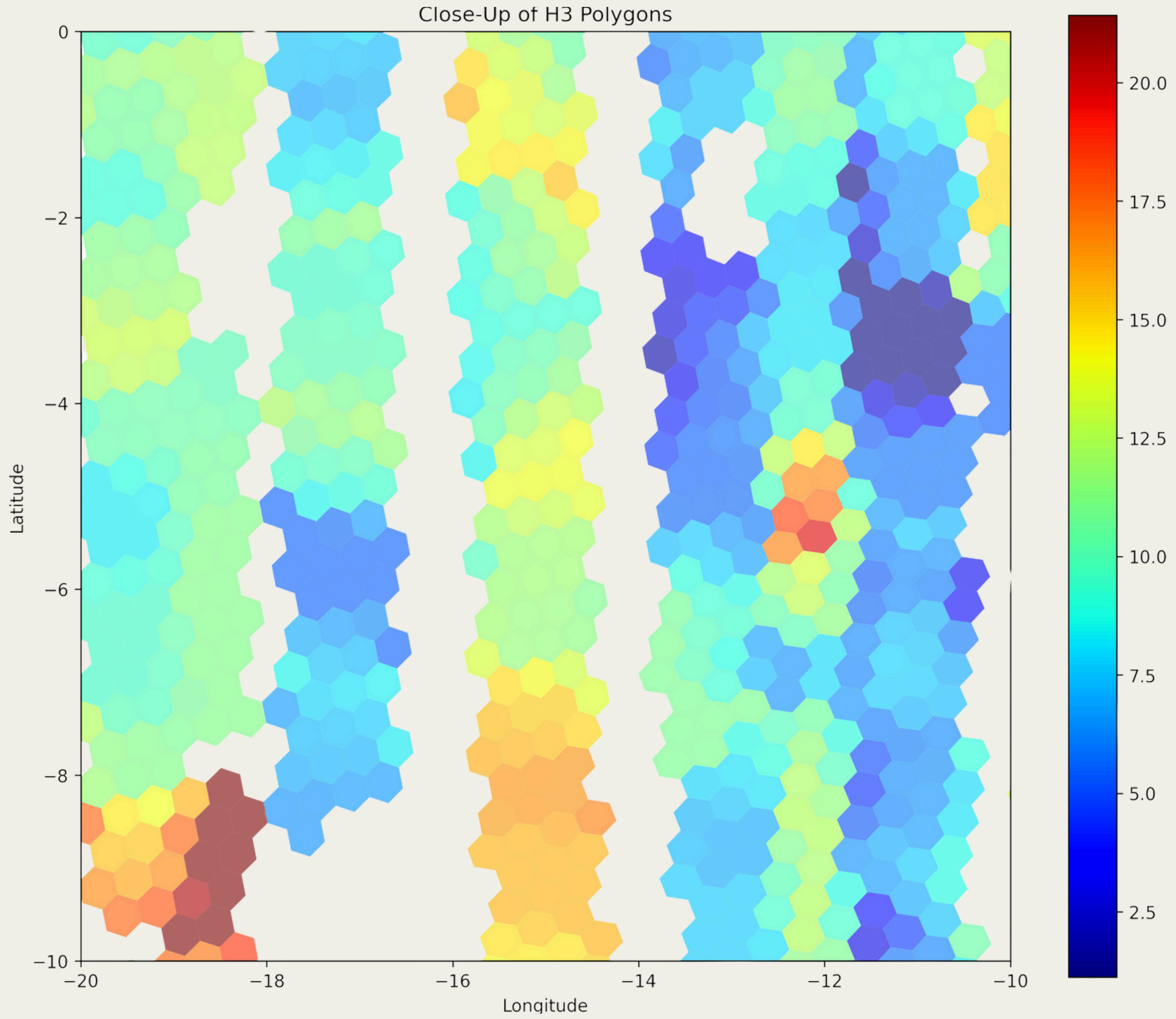
DATA PLOTTING

- **Pixelate** the lunar surface into hexagons and pentagons (using h3 library)[1]

- This accounts for overlaps and provides **sub-pixel resolution**

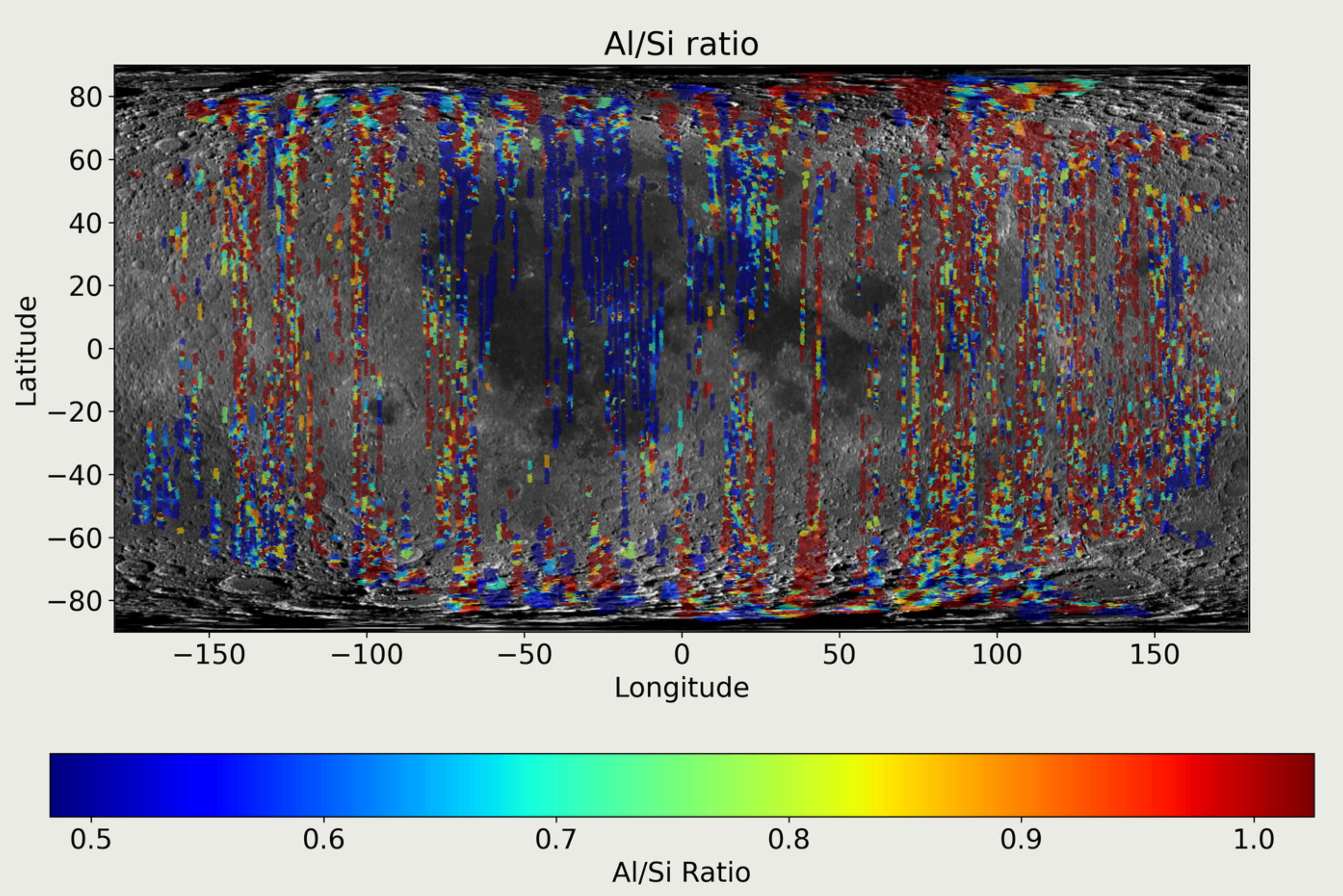
- The area of each of these polygons is **131 square km** on lunar surface

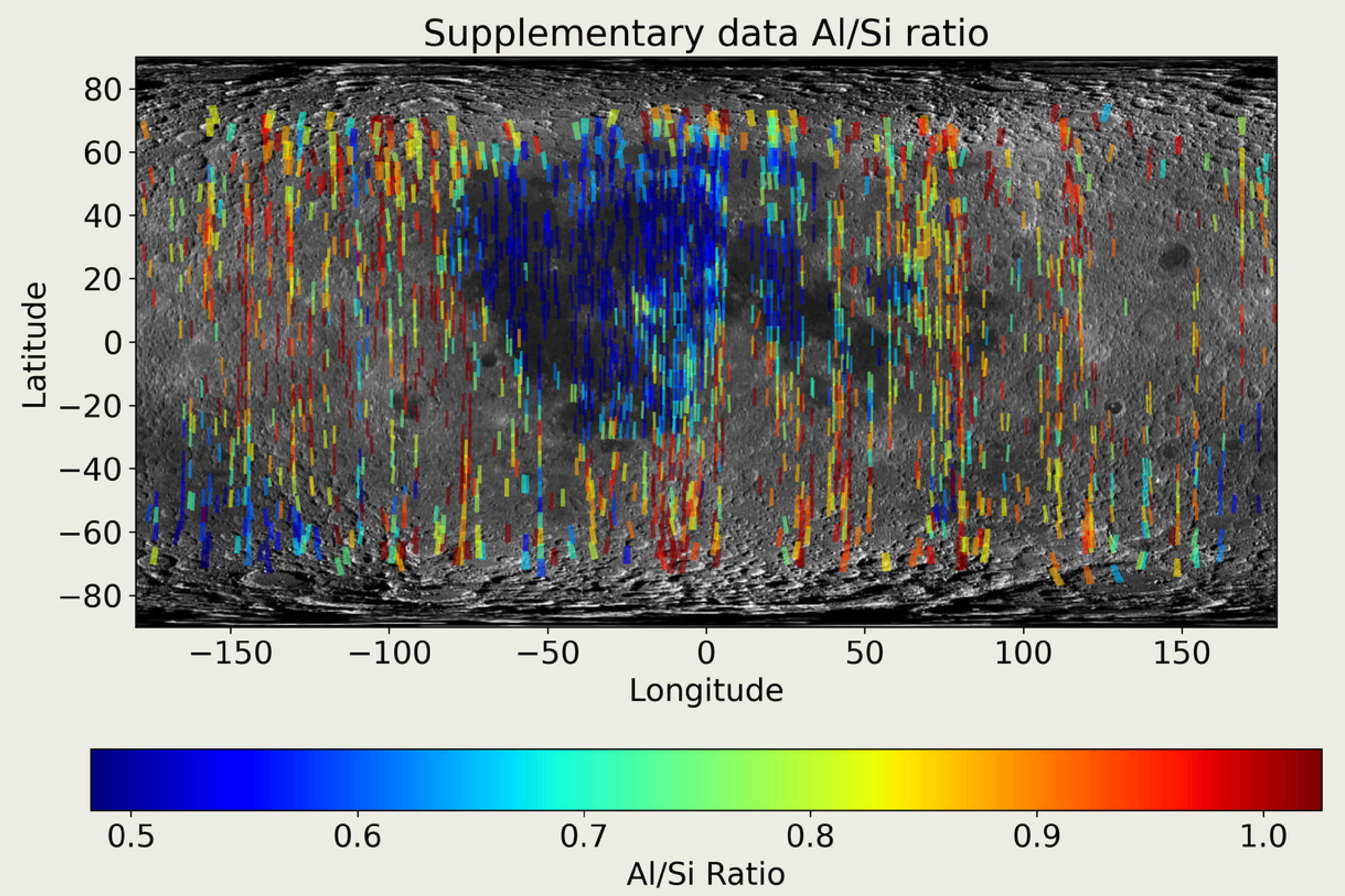
- We validate our data with the **supplementary data** [2]



[1]. Github - Uber/h3
[2]. Narendranath et al., 2024

DATA PLOTTING - 2D PLOTS



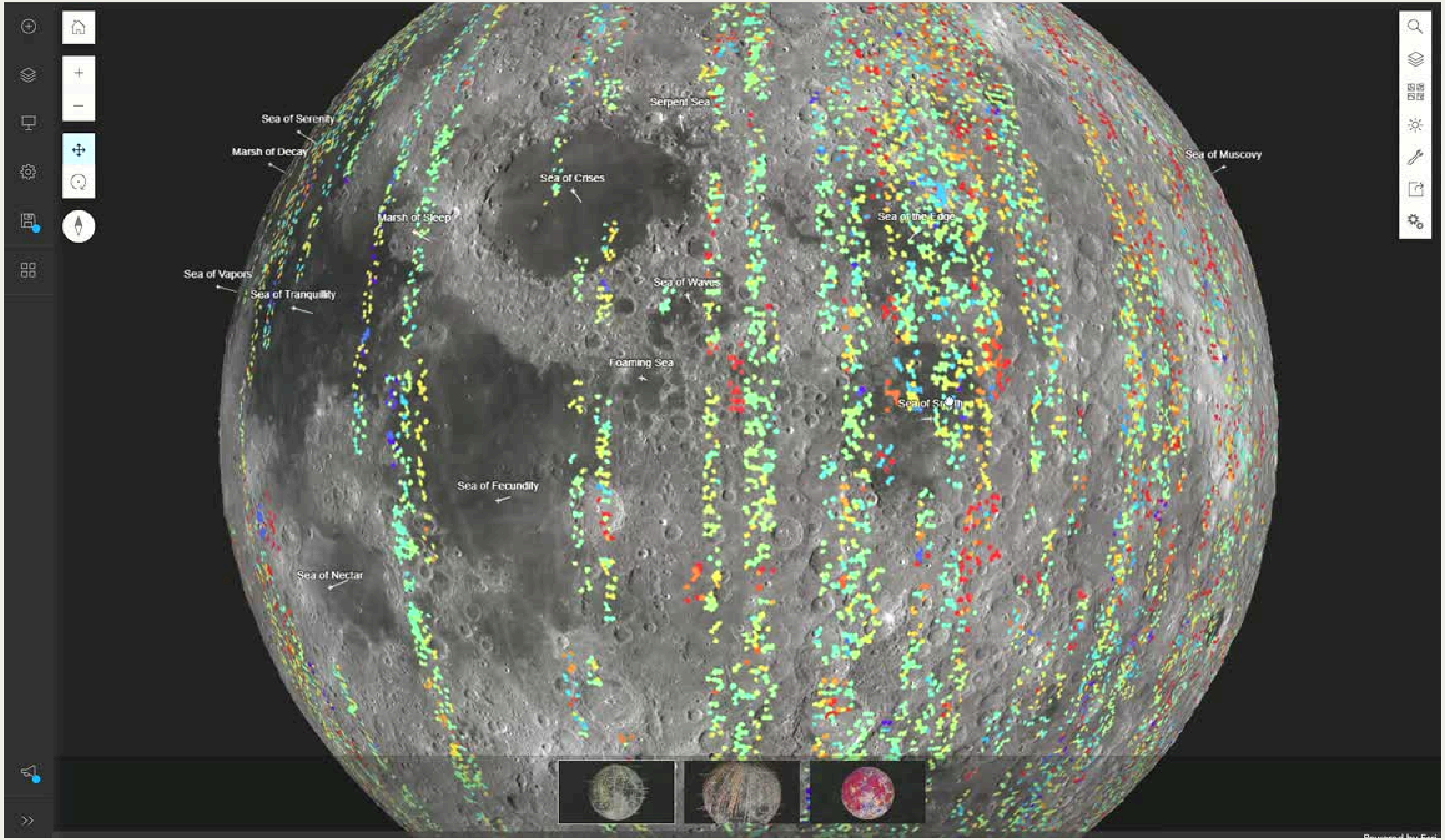


Al-Si ratio obtained from our pipeline

Supplementary data [1].

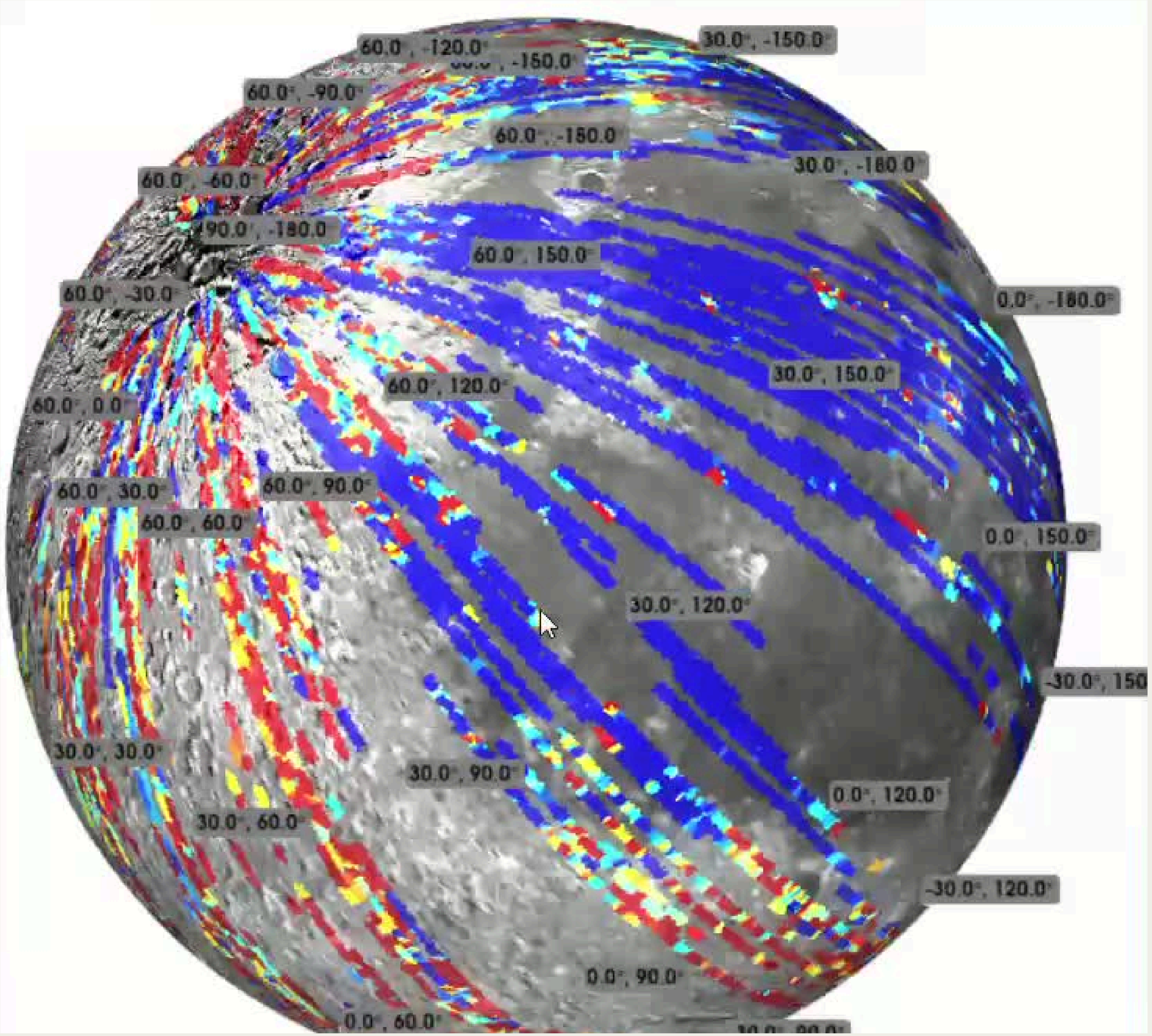
[1]. Narendranath et al., 2024

DATA PLOTTING - 3D PLOTS (GIS SOFTWARE)



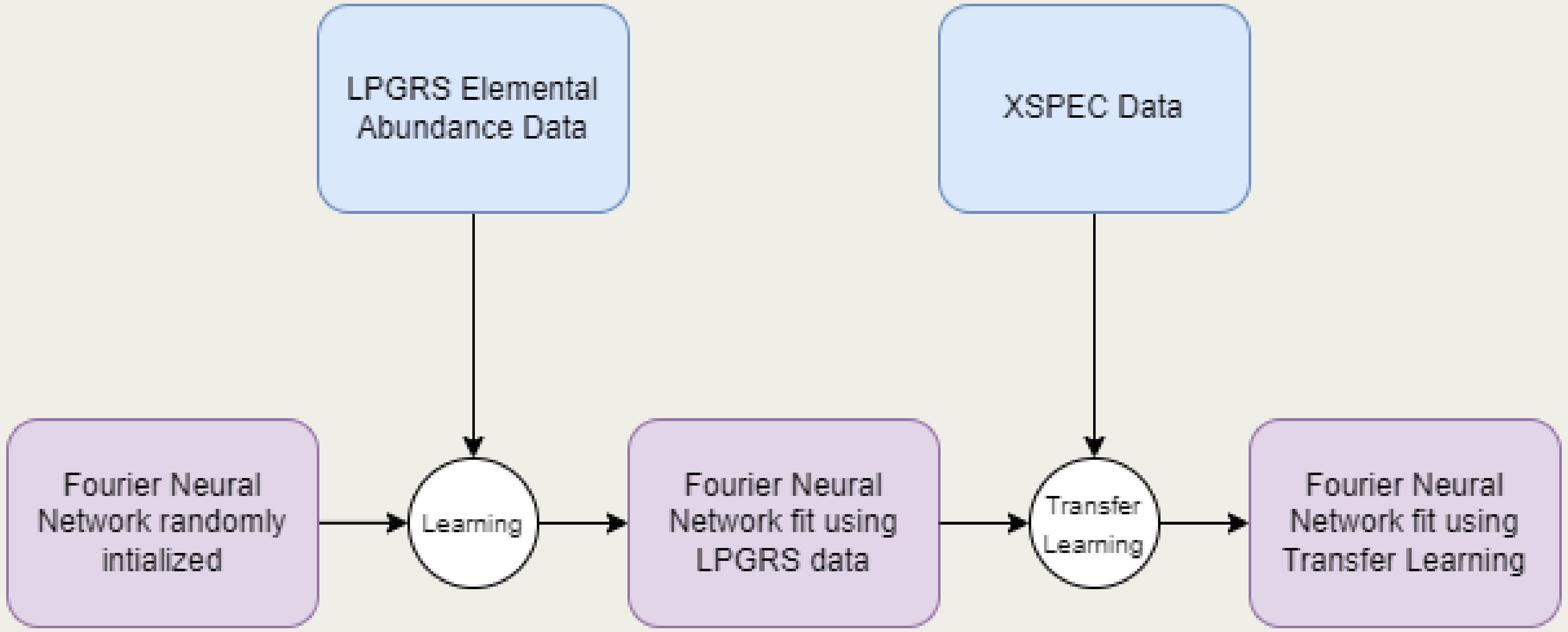
DATA PLOTTING - 3D PLOTS

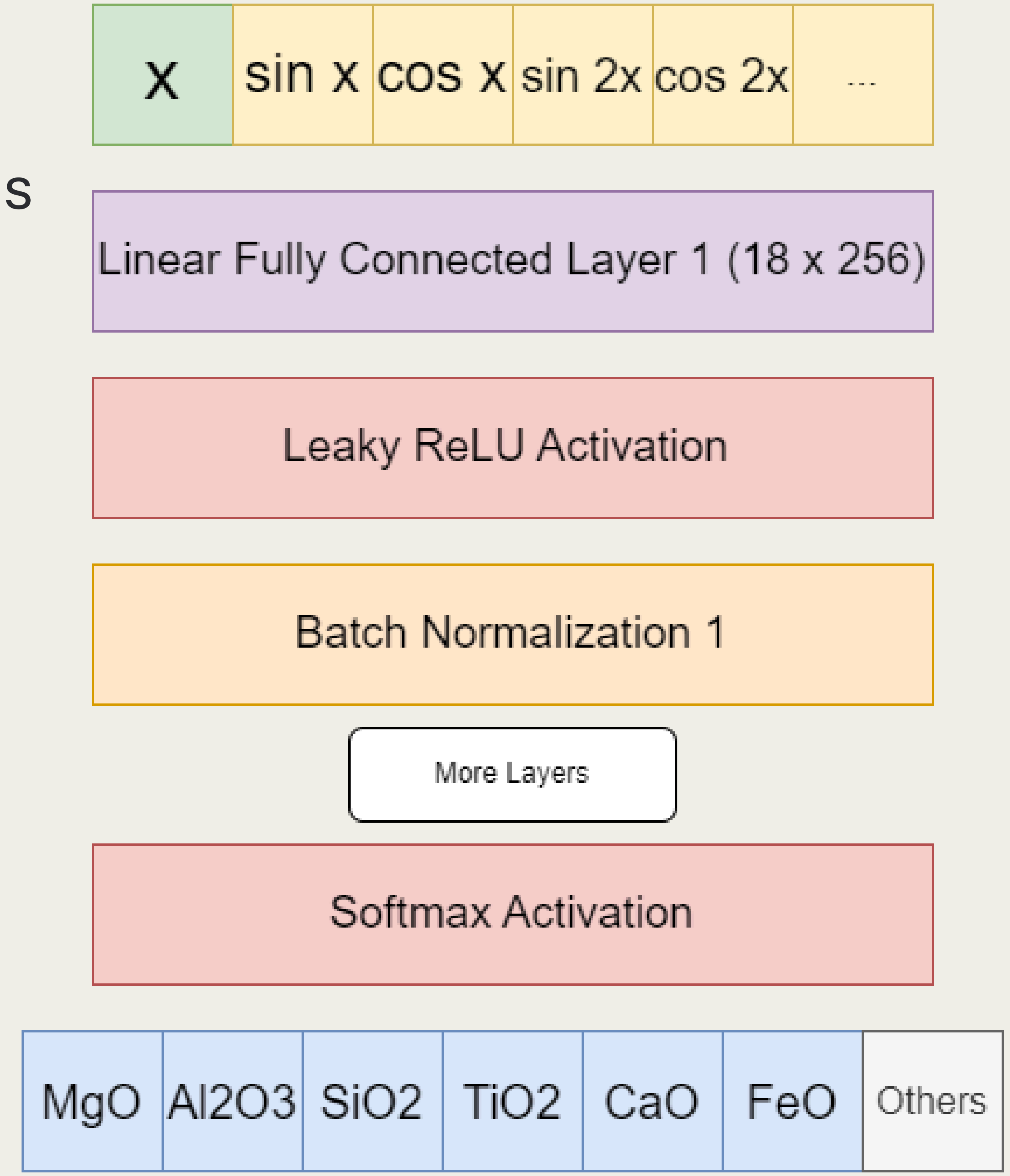
A 3D plot created using python libraries



ACHIEVING SUBPIXEL RESOLUTION (ALTERNATE)

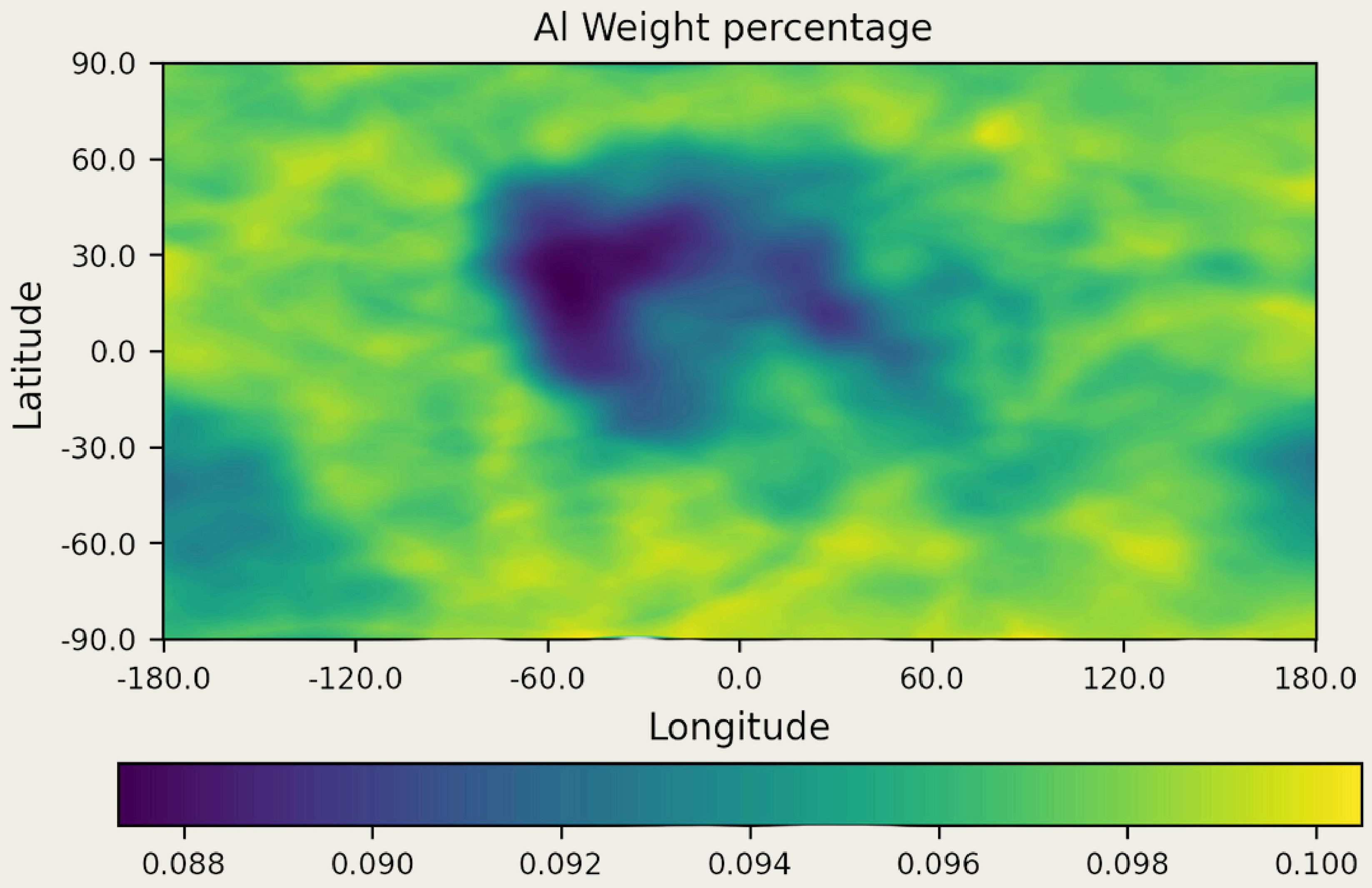
- Fourier Neural Network-based Positional Encoder
  - Trained with **LP-GRS** data using latitude and longitude as inputs, weights as outputs.[1]
- Transfer Learning Framework
  - Adapted the model for Chandrayaan's XRF-based data.
- Subpixel Resolution Algorithm
  - Demonstrates potential for enhancing XRF data resolution.

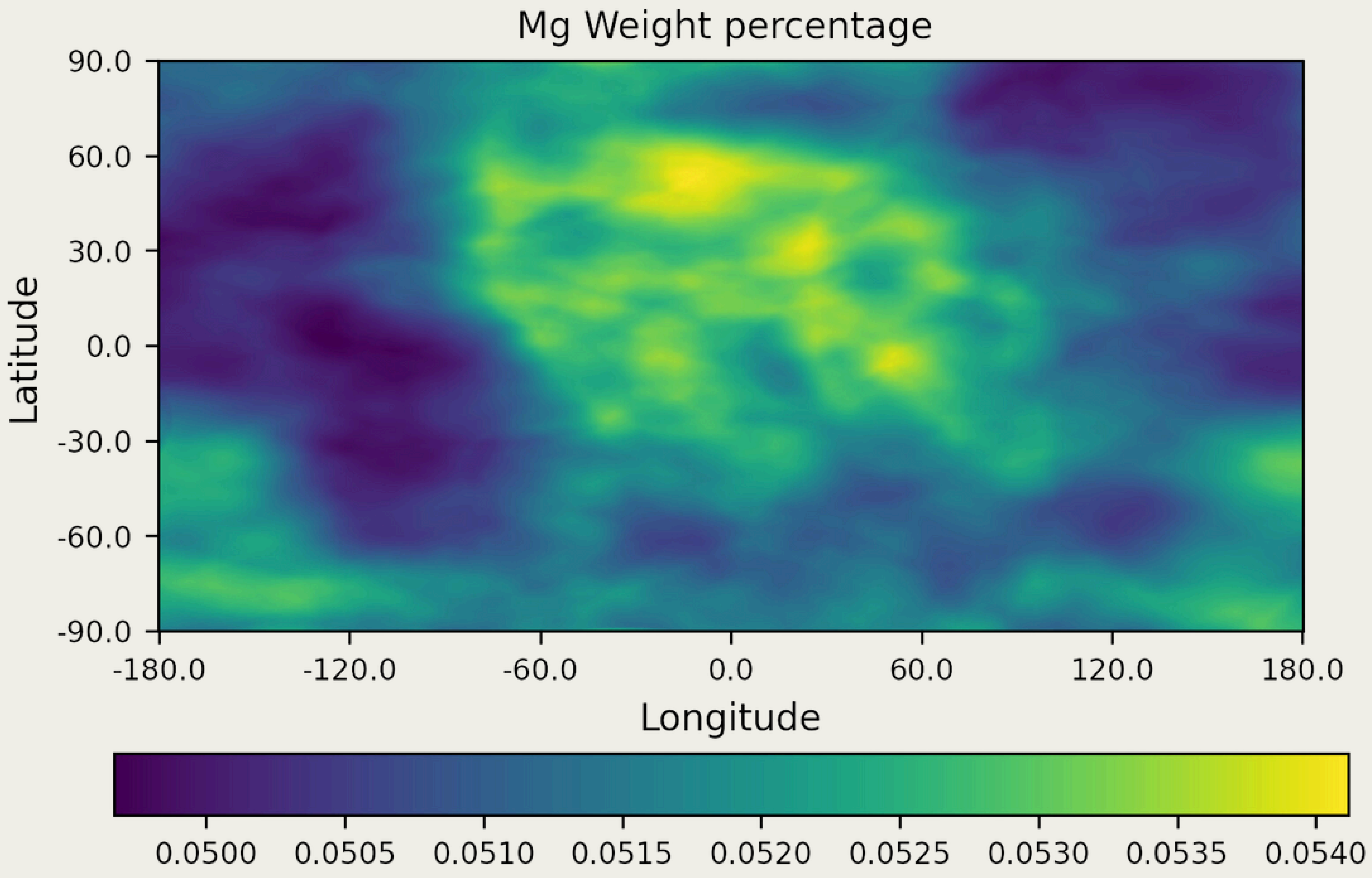




[1]. Tancik et.al., 2020

ACHIEVING SUBPIXEL RESOLUTION (ALTERNATE)





COMPOSITIONAL GROUPS

- Converting elemental abundances to **mineral abundances** using Matrix inversion

- We have 7 elemental weights and 7 different minerals, ensuring a **unique solution**.
  - Even in case of different numbers, a pseudo inverse can be computed

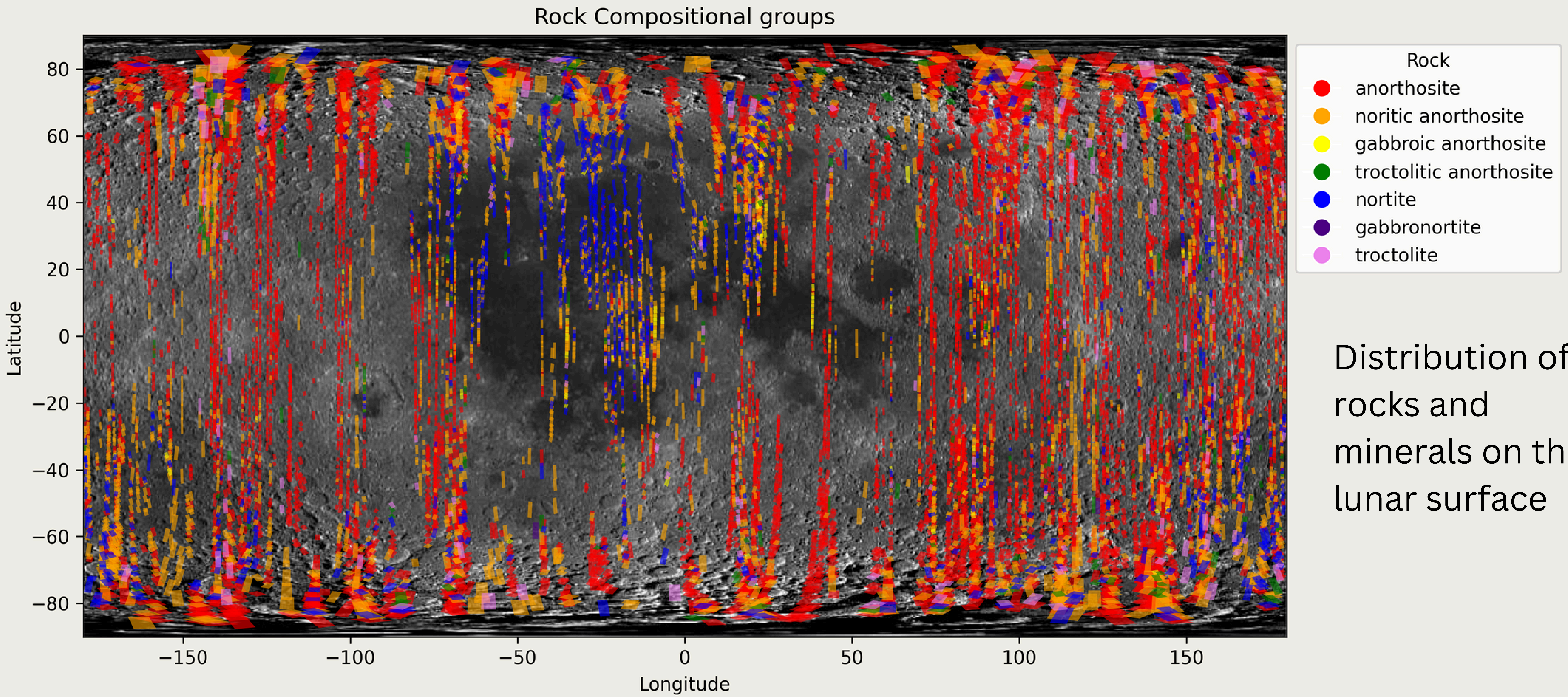
- **Compositional groups** (mixture of minerals) at each location can be identified .

$$P = [A' \quad B' \quad C' \quad D' \quad E' \quad F' \quad G']$$
$$Q = [\mathrm{O}' \quad \mathrm{Si}' \quad \mathrm{Al}' \quad \mathrm{Mg}' \quad \mathrm{Fe}' \quad \mathrm{Ti}' \quad \mathrm{Ca}']$$

$$R = \begin{bmatrix} \frac{\mathrm{O}}{\mathrm{A}} & \frac{\mathrm{Si}}{\mathrm{A}} & \frac{\mathrm{Al}}{\mathrm{A}} & \frac{\mathrm{Mg}}{\mathrm{A}} & \frac{\mathrm{Fe}}{\mathrm{A}} & \frac{\mathrm{Ti}}{\mathrm{A}} & \frac{\mathrm{Ca}}{\mathrm{A}} \\ \frac{\mathrm{O}}{\mathrm{B}} & \frac{\mathrm{Si}}{\mathrm{B}} & \frac{\mathrm{Al}}{\mathrm{B}} & \frac{\mathrm{Mg}}{\mathrm{B}} & \frac{\mathrm{Fe}}{\mathrm{B}} & \frac{\mathrm{Ti}}{\mathrm{B}} & \frac{\mathrm{Ca}}{\mathrm{B}} \\ \frac{\mathrm{O}}{\mathrm{C}} & \frac{\mathrm{Si}}{\mathrm{C}} & \frac{\mathrm{Al}}{\mathrm{C}} & \frac{\mathrm{Mg}}{\mathrm{C}} & \frac{\mathrm{Fe}}{\mathrm{C}} & \frac{\mathrm{Ti}}{\mathrm{C}} & \frac{\mathrm{Ca}}{\mathrm{C}} \\ \frac{\mathrm{O}}{\mathrm{D}} & \frac{\mathrm{Si}}{\mathrm{D}} & \frac{\mathrm{Al}}{\mathrm{D}} & \frac{\mathrm{Mg}}{\mathrm{D}} & \frac{\mathrm{Fe}}{\mathrm{D}} & \frac{\mathrm{Ti}}{\mathrm{D}} & \frac{\mathrm{Ca}}{\mathrm{D}} \\ \frac{\mathrm{O}}{\mathrm{E}} & \frac{\mathrm{Si}}{\mathrm{E}} & \frac{\mathrm{Al}}{\mathrm{E}} & \frac{\mathrm{Mg}}{\mathrm{E}} & \frac{\mathrm{Fe}}{\mathrm{E}} & \frac{\mathrm{Ti}}{\mathrm{E}} & \frac{\mathrm{Ca}}{\mathrm{E}} \\ \frac{\mathrm{O}}{\mathrm{F}} & \frac{\mathrm{Si}}{\mathrm{F}} & \frac{\mathrm{Al}}{\mathrm{F}} & \frac{\mathrm{Mg}}{\mathrm{F}} & \frac{\mathrm{Fe}}{\mathrm{F}} & \frac{\mathrm{Ti}}{\mathrm{F}} & \frac{\mathrm{Ca}}{\mathrm{F}} \\ \frac{\mathrm{O}}{\mathrm{G}} & \frac{\mathrm{Si}}{\mathrm{G}} & \frac{\mathrm{Al}}{\mathrm{G}} & \frac{\mathrm{Mg}}{\mathrm{G}} & \frac{\mathrm{Fe}}{\mathrm{G}} & \frac{\mathrm{Ti}}{\mathrm{G}} & \frac{\mathrm{Ca}}{\mathrm{G}} \end{bmatrix}$$

$$P \times R = Q \implies P = Q \times R^{-1}$$

COMPOSITIONAL GROUPS



Distribution of rocks and minerals on the lunar surface

FUTURE PROSPECTS AND UTILITY TO ISRO

- We have developed a robust back-end **data processing pipeline** that can analyze Chandrayaan-2 data rapidly, **saving** both **computing** time and energy

- We also have provided an effective open source framework for generating **3D, interactive, subpixel resolution plots** using Python.

- For practical utility, we are working toward integrating our analysis pipeline with a user-friendly **front-end** framework that can analyze CLASS and XSM data and update the interactive plots.

CONCLUSION

- Implemented a robust, multicore architecture pipeline to compute the model flux given input spectra in ultrafast times based on *x2abundance*.
- Developed an alternative approach based on Rayleigh Scattering and validated the results.
- Proposed a transfer learning-based neural-network architecture to achieve subpixel resolution.
- Created 3D interactive maps for elemental ratios on lunar surface . Scan QR code to visit the website!

Thank you!

Problem loading Scene Viewer

Your browser isn't using hardware acceleration for rendering which is required for displaying interactive 3D scenes.

Learn more