Spectral Studies of Solar Flares with SoLEXS Onboard Aditya-L1

Archana P[1*] Gazi Ameen Ahmed[1]
[1] Department of Physics, Tezpur University
Email: archanapalliyoth@gmail.com

1.Abstract

Solar flares release magnetic energy, causing plasma heating and changes in coronal properties. We study the thermal and compositional evolution of solar flares using soft X-ray observations from SoLEXS onboard Aditya-L1. Type-I PI spectra were generated at 30-second intervals and fitted in XSPEC over 2.8–12 keV using an isothermal plasma model with 4% systematic error. Temperature rises during the impulsive phase and decreases during decay, while the volume emission measure increases due to chromospheric evaporation. Ca and Fe abundances show a decline towards photospheric values followed by recovery, whereas Ar remains relatively stable. These results provide insights into chromospheric evaporation and FIP fractionation across flares of different GOES classes.

2. Introduction

The Sun is a G2-type main-sequence star powered by nuclear fusion, with a core temperature of approximately 16 million K [1,2]. Its atmosphere comprises the photosphere, chromosphere, transition region, and corona, where temperatures exceed 1 MK [2,4]. Solar active regions exhibit strong magnetic fields and bright coronal loops. X-ray emission provides important diagnostics of coronal plasma properties, including temperature, density, and emission measure [5].

Solar Flares

Solar flares are sudden, intense releases of magnetic energy in the Sun's corona, primarily driven by magnetic reconnection. The total energy released varies depending on the intensity of the flare. Flares emit radiation across the electromagnetic spectrum, particularly in X-rays and gamma rays. Based on their peak soft X-ray flux measured by the GOES satellites, they are classified into five categories: A, B, C, M, and X [5].

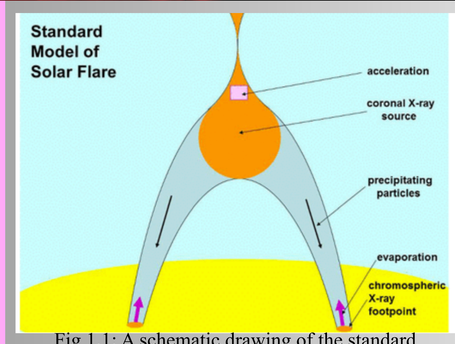

Fig 1.1: A schematic drawing of the standard flare scenario

Standard flare scenario

Magnetic reconnection accelerates electrons towards the chromosphere, producing hard X-rays through non-thermal bremsstrahlung. The deposited energy heats the plasma, driving upward expansion (chromospheric evaporation) that fills coronal loops with hot plasma, emitting soft X-rays through thermal bremsstrahlung [6].

2. Objectives

- To determine the evolution of coronal plasma temperature and volume emission measure during solar flares.
- To investigate the temporal variations of elemental abundances during solar flares, particularly Fe, Ca and Ar.

3.Instrumentation: Aditya-L1 and SoLEXS

Aditya-L1

Aditya-L1, launched by ISRO on 2 September 2023, is India's first space-based solar observatory, successfully entering a halo orbit around the Sun–Earth L1 point on 6 January 2024 [7].

SoLEXS

SoLEXS (Solar Low Energy X-ray Spectrometer) onboard Aditya-L1 observes solar X-rays in the 2–22 keV range using two Silicon Drift Detectors (SDDs), covering both small and large flares [7]. It studies solar flares, coronal heating, elemental abundances, and flare dynamics, providing 1s cadence spectra with onboard calibration [8].

4. Data and Methodology

SoLEXS Data and SoLEXS_Tools

SoLEXS data are available at three processing levels (L0, L1, and L2). Level-1 FITS data from the PRADAN portal include calibrated spectra, GTI files, and 1-second light curves. The SoLEXS_Tools Python package provides calibration files (ARF and RMF) and utilities to extract Type-I spectra over selected time intervals and bins for spectral analysis using XSPEC and Sherpa [9].

Spectral Fitting and chisoth

X-ray spectral fitting compares observed detector counts with model predictions using the instrument response. The XSPEC chisoth model uses CHIANTI-based isothermal spectra, with temperature (log T), elemental abundances (Ax), and volume emission measure (EM) as input parameters to characterize coronal plasma [4].

Data Processing and Methodology

- Download Level-1 SoLEXS data and select the appropriate detector (SDD1 or SDD2) based on data-quality criteria.
- Generate the solar X-ray light curve using the Level-1 LC file to identify the flare and select the appropriate time interval.
- Extract Type-I PI spectra using solexs-genspec or solexs-genmultispec with a suitable time bin.
- Load the extracted spectra into XSPEC along with the corresponding instrument response files (RMF and ARF), and select the chisoth isothermal plasma model.
- Perform spectral fitting by optimizing plasma temperature, emission measure, and elemental abundances using the chi-square statistic. Assess the goodness of fit using reduced chi-square.
- Record the best-fit parameters for each spectrum and use Python to plot their temporal evolution, investigating variations in temperature, emission measure and elemental abundances (Ca, Fe and Ar).

5. Results and Discussion

Light Curve Analysis

Examine the light curves of the two selected flares to understand their temporal profiles and identify their phases.

The SoLEXS light curves exhibit distinct intensity peaks, indicating sudden enhancements in X-ray emission associated with solar flare activity.

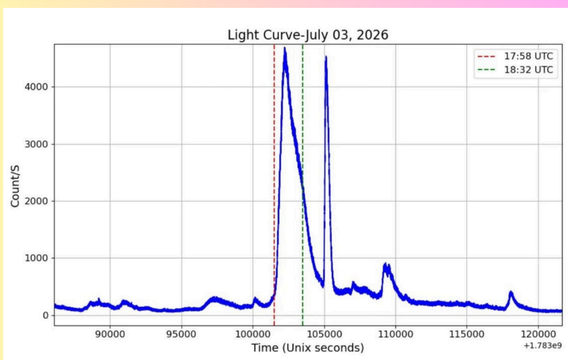

Fig 5.1: SoLEXS Light Curve on 3 July 2026 Showing the Selected Flare Interval

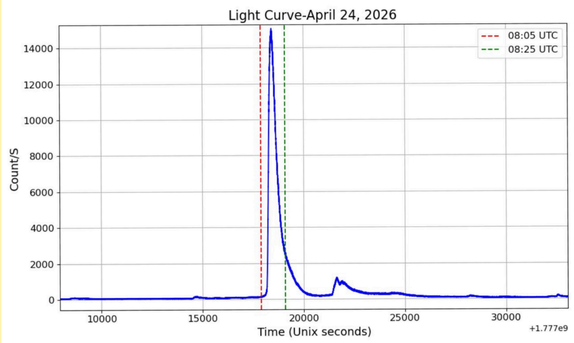

Fig. 5.4: SoLEXS Light Curve on 24 April 2026 Showing the Selected Flare Interval

Spectral Parameter Evolution

The evolution of plasma temperature, volume emission measure, and Ca, Fe, and Ar abundances was studied across two selected solar flares to investigate changes in plasma properties during flare activity.

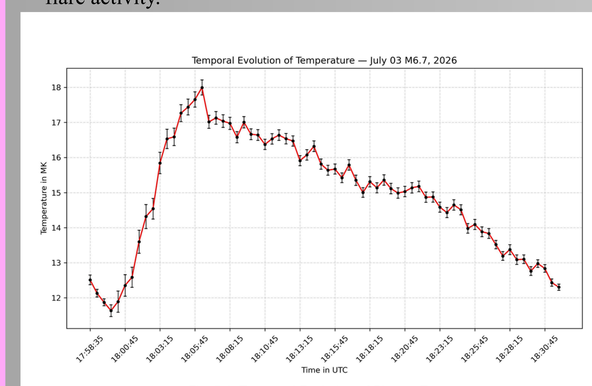

Fig. 5.1: Temporal Evolution of Plasma Temperature During the M6.7-Class Solar Flare on 3 July 2026.

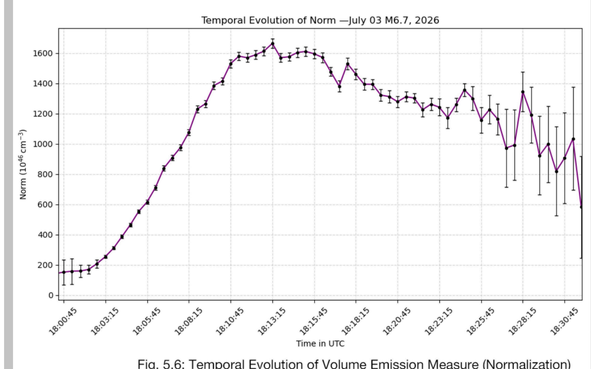

Fig. 5.6: Temporal Evolution of Volume Emission Measure (Normalization) During the M6.7-Class Solar Flare on 3 July 2026.

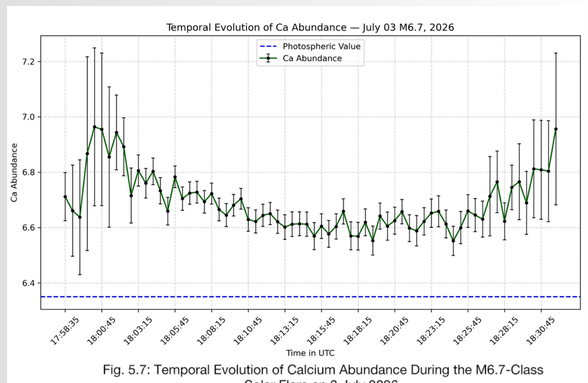

Fig. 5.7: Temporal Evolution of Calcium Abundance During the M6.7-Class Solar Flare on 3 July 2026.

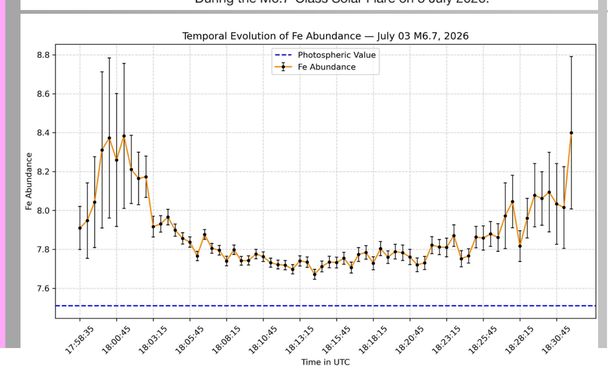

Fig. 5.8: Temporal Evolution of Iron Abundance During the M6.7-Class Solar Flare on 3 July 2026.

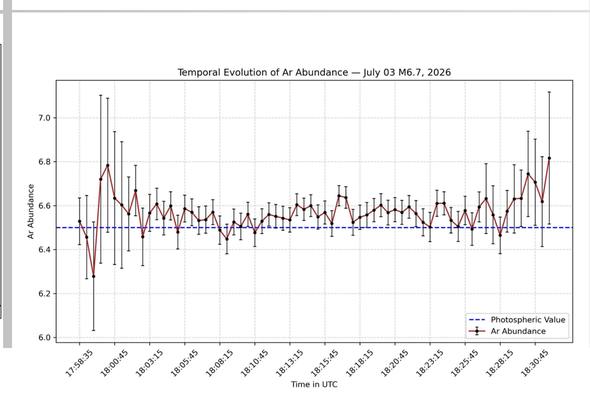

Fig. 5.9: Temporal Evolution of Argon Abundance During the M6.7-Class Solar Flare on 3 July 2026.

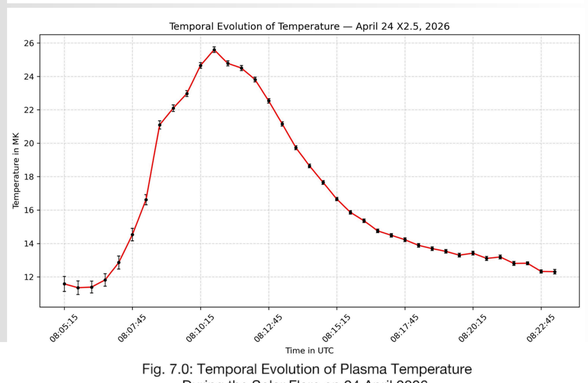

Fig. 7.0: Temporal Evolution of Plasma Temperature During the Solar Flare on 24 April 2026.

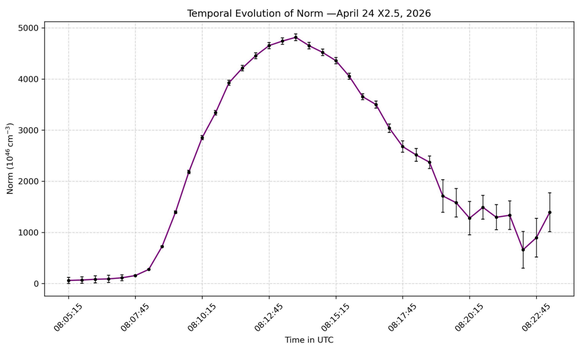

Fig. 7.1: Temporal Evolution of Plasma Emission Measure (Normalization) During the Solar Flare on 24 April 2026.

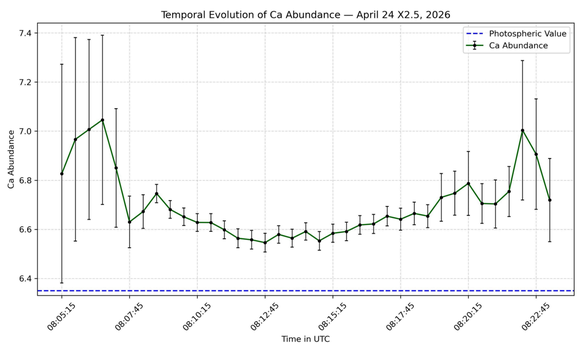

Fig. 7.2: Temporal Evolution of Calcium Abundance During the Solar Flare on 24 April 2026.

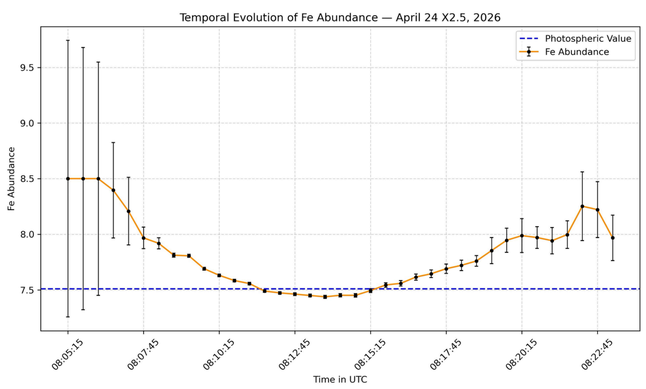

Fig. 7.3: Temporal Evolution of Iron Abundance During the Solar Flare on 24 April 2026.

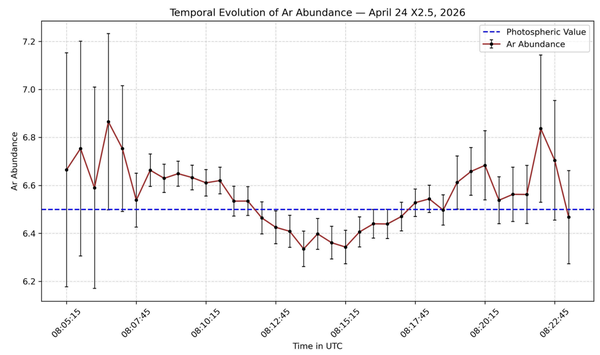

Fig. 7.4: Temporal Evolution of Argon Abundance During the Solar Flare on 24 April 2026.

The peak plasma temperatures for the two solar flares were approximately 18 MK (3 July 2026) and 26 MK (24 April 2026). The volume emission measure (VEM)/Norm peaks slightly after the temperature maximum, then decreases. Ca and Fe abundances decline towards their photospheric values near the flare peak.

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Discussion

The temperature evolution follows the standard flare scenario, with plasma heating by magnetic reconnection followed by conductive and radiative cooling. VEM increases due to chromospheric evaporation, peaks after the temperature maximum, and then declines. Ca and Fe abundances decrease towards photospheric values as evaporated plasma fills coronal loops, while the high-FIP element Ar remains relatively stable.

Conclusions

- Plasma temperature rises rapidly and cools gradually, while VEM peaks after the temperature maximum.
- Ca and Fe abundances decrease towards photospheric values, while Ar remains relatively constant.