Thermal and Compositional Signatures of Confined and Eruptive Flares with SoLEXS/Aditya-L1

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Abstract

Solar flares are broadly classified as confined (no CME) or eruptive (with CME). This study performs a comparative X-ray analysis to quantify the distinct physical characteristics that govern a flare's eruptive potential. We analyze high-cadence soft X-ray spectra of 43 flares observed by the Solar Low Energy X-ray Spectrometer (SoLEXS) onboard Aditya-L1. By fitting the spectra, we derive the temporal evolution of key plasma parameters, including temperature (T), emission measure (EM), and elemental abundances. Our results reveal a clear dichotomy: confined flares are systematically hotter than their eruptive counterparts, while eruptive flares exhibit a significantly higher emission measure, indicating a larger volume of heated plasma. These findings provide direct observational evidence of the different thermodynamic conditions that distinguish confined flares from large-scale eruptive events.

Introduction

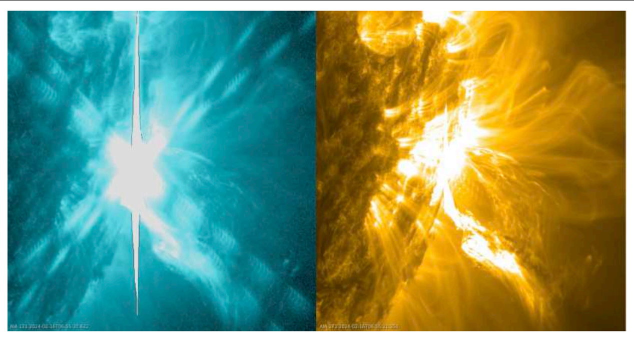
- A solar flare is a **sudden, intense burst of radiation** coming from the release of magnetic energy in the Sun's atmosphere.
- These events usually occur **near active regions** around sunspots, where the magnetic field lines are **twisted and realign** themselves to release vast amounts of energy.

Flare Class	Associated X-ray Flux (W/m²)
A	< 10^{-7}
B	10^{-7} - 10^{-6}
C	10^{-6} - 10^{-5}
M	10^{-5} - 10^{-4}
X	> 10^{-4}

Classification

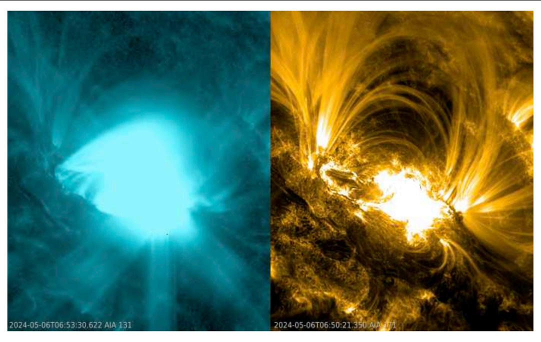
Confined

Magnetic structure remains intact and no significant plasma is ejected into interplanetary space **(No CME)**



Eruptive

Where large amounts of plasma and magnetic flux are expelled from the Sun **(CME Associated)**



SoLEXS & Data Products

- The Solar Low Energy X-ray Spectrometer (SoLEXS) is a soft X-ray spectrometer aboard Aditya-L1, designed to measure the solar soft X-ray flux to study flares.
- Sun as a Star Spectrometer

- **Data Products -**

1. **Good Time Intervals (.gti) Files:** Time periods of valid data collection by the detector
2. **Light Curve (.lc) Files:** 1-second-cadence count rates (2–22 keV) .
3. **Pulse Invariant (.pi) Files:** Calibrated energy spectra recorded every second .

Parameter	Specification
Energy Range	2 – 22 keV (2.8 – 22 keV for spectral fitting)[1]
Energy Resolution	~ 170 eV @ 5.9 keV
Time Cadence	Spectral Channel: 1 second Temporal Channel: 1 second
Detector	
Type	Silicon Drift Detector (SDD)
Number	2 (named SDD1 & SDD2)
Active Area	30 mm^2
Thickness	450 ± 20 μm
Entrance Window	8 μm thick Be
Aperture Area	SDD1: 7.106 mm^2 SDD2: 0.106 mm^2
Field of View	SDD1: ± 1.8° SDD2: ± 1.3°
Calibration Source	Fe-55 with Ti foil
Digital Pulse Processing parameters	
Pulse peaking time (triangular pulse)	Spectral Channel: 2 μs Temporal Channel: 0.35 μs
Number of channels in the spectrum	340
Channel Width	1 - 168 channel: ~ 47.6 eV 169 - 340 channel: ~ 95.2 eV

Event Selection & Dataset

- **Flare identification**
  - Selected events from the **GOES Flare Catalog**
  - Time period: **1 July 2024 – 31 July 2025**
- **Verification**
  - Cross-checked with **SoLEXS X-ray light curves**
- **CME association**
  - Identified using the **SOHO/LASCO CME catalog**

Flare Class	Eruptive	Confined	Total
C-class	4	4	8
M-class	17	7	24
X-class	10	1	11
Total	**30**	**13**	**43**

Methodology

Data Processing → **Spectra Extraction** → **Free Paramters** → **Spectral Fitting**

Data Processing: Used **SoLEXS_Tools** to create light curves and define flare phases (rise, peak, decay)

Spectra Extraction: Spectral File were generated for each Flare using **solexs-genmultispec.**

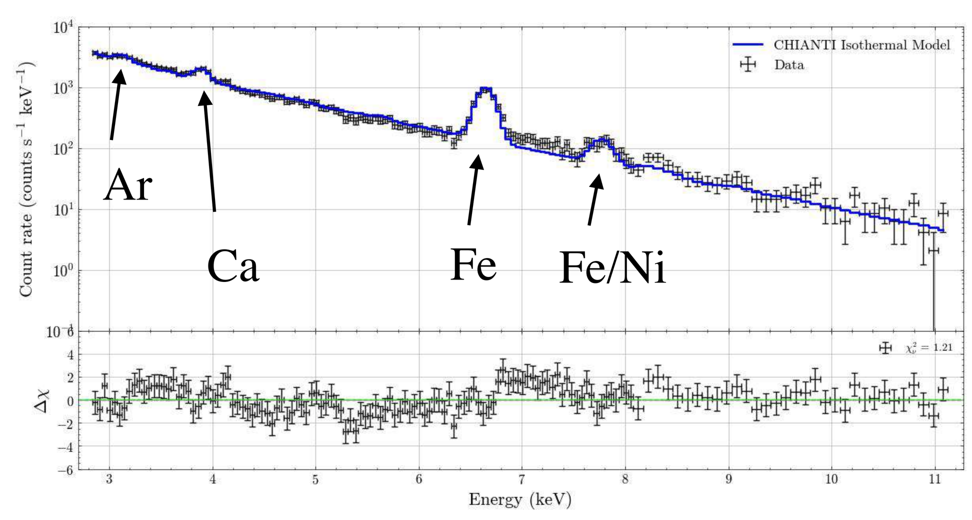
Time bin intervals were optimized ensure a high signal-to-noise ratio and goodness of fit.

Free Paramters: Spectra were fitted within **PyXSPEC** using Chianti Isothermal Model **(chisoth)**.

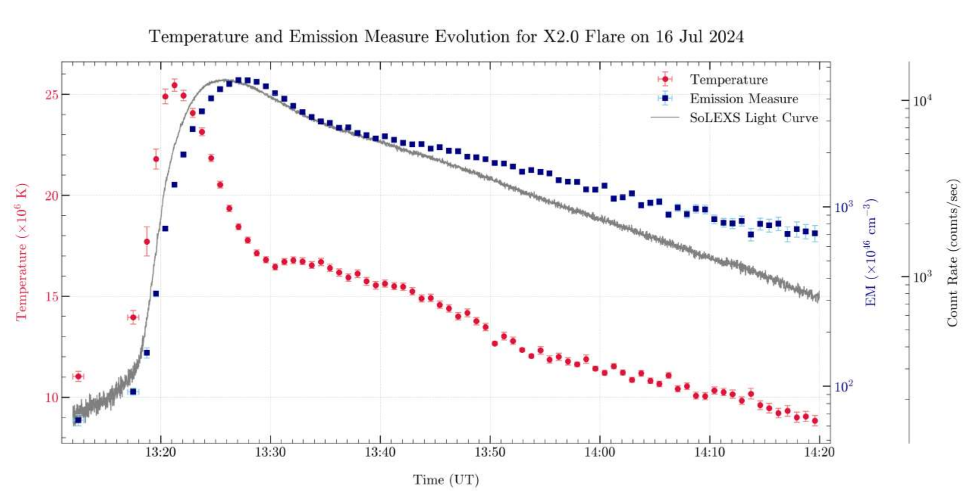
The analysis was restricted to the **2.8–15 keV** energy range to maximize spectral feature.

Spectral Fitting: **Temperature, Emission Measure**, and **Abundances** of **Ar, Ca, Fe, Ni** are left free during fitting

Results: Temporal Evolution



- The observed flare spectrum (black points) is well reproduced by a **CHIANTI isothermal model** (blue line).
- Prominent emission lines are detected from highly ionized elements:
  1. **Ar** (~3.1 keV)
  2. **Ca** (~3.9 keV)
  3. **Fe** (~6.7 keV)
  4. **Fe/Ni blend** (~8 keV)



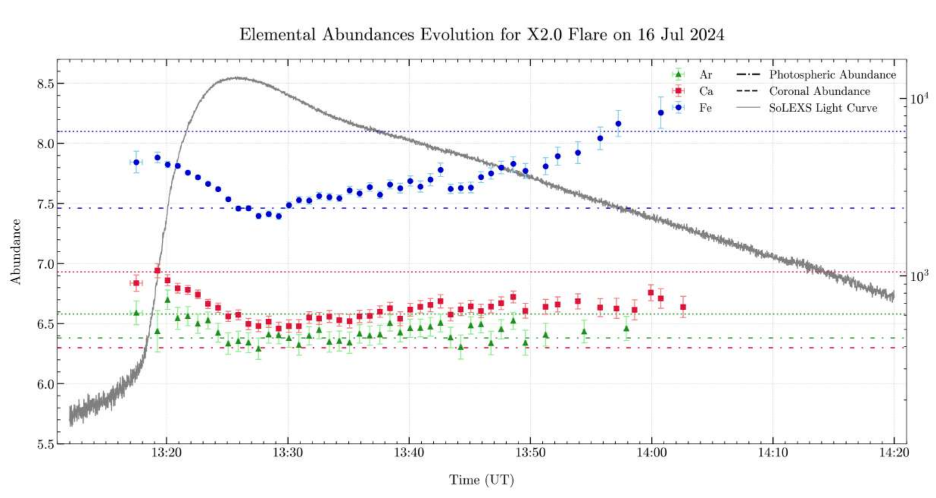
Temperature peaks

↓

X-ray light curve peaks

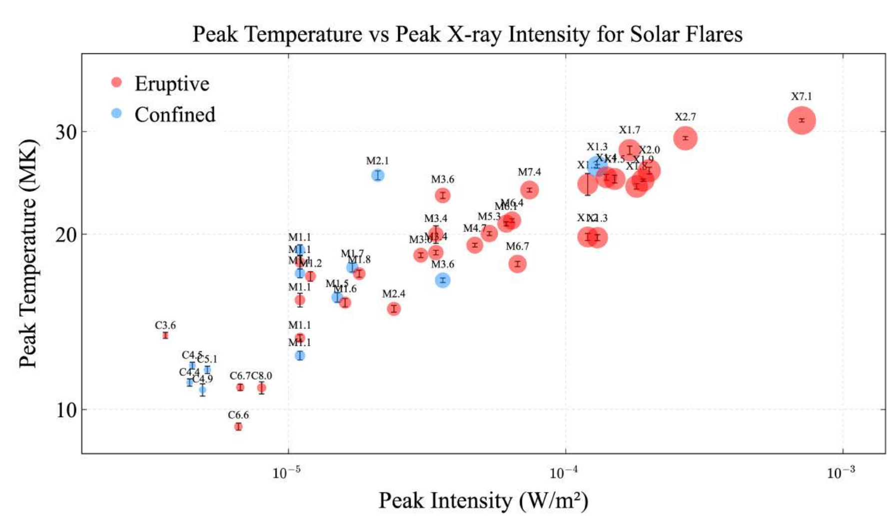
↓

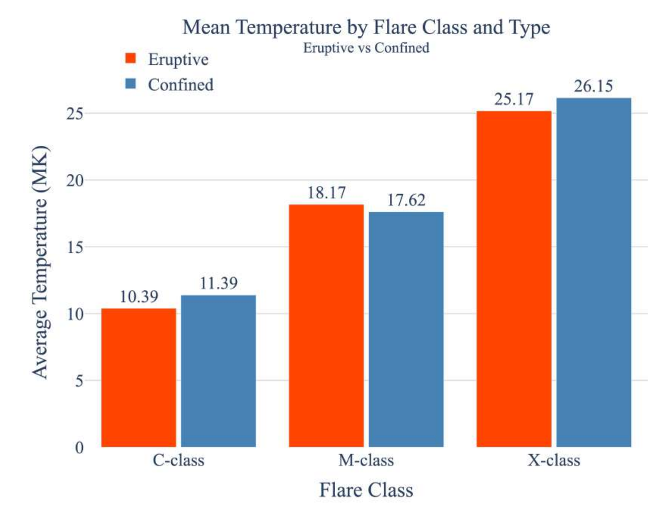
Emission Measure peaks



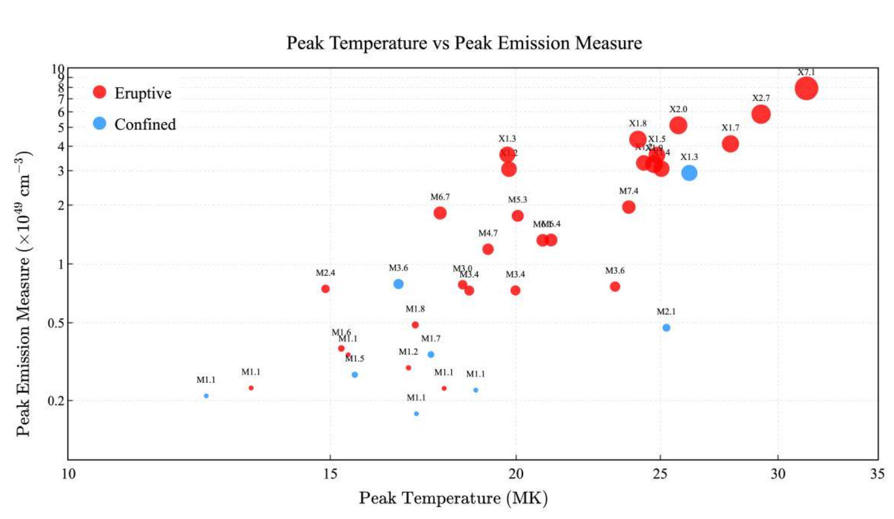
- **Depletion** of elemental abundances during **flare peak**.
- Abundances drop toward **photospheric values**, indicating **chromospheric material injection.**
- Recovery to **coronal levels** post-flare.
- **Ca** and **Fe** **(low-FIP):** Min Abundance is **higher** in confined flares → more coronal-like.
- **Ar (high-FIP):** Similar between eruptive and confined.

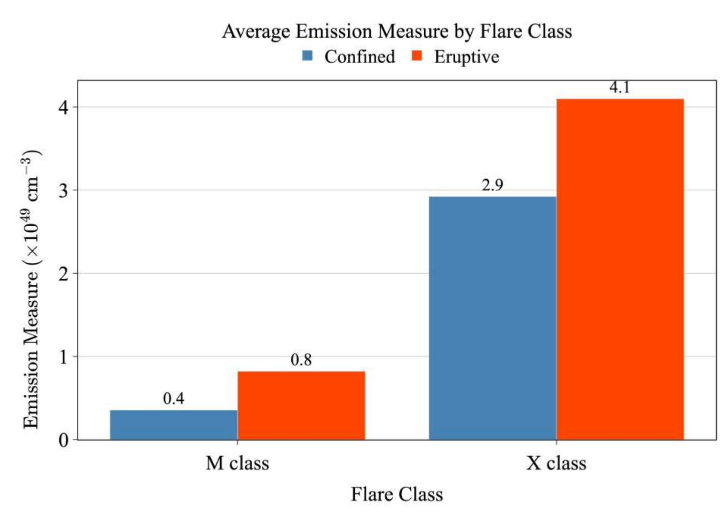
Results: Comparative Analysis





- **C-Class & X-Class: Confined flares** show **higher peak temperatures** than **Eruptive**.
- **M-class flares: Mixed behavior**—some **confined flares** are hotter, others not.





- Peak Emission Measure **increases** with Peak Intensity (Flare Class).
- **Eruptive Flares** have significantly **higher Emission Measure** than **Confined Flares.**

Summary

- Significant Time lag between Peak Temperature, Peak X-ray Flux, and Peak Emission Measure.
- Peak Temperature and Peak Emission Measure increase with Peak Intensity.
- Confined Flares exhibit higher peak temperatures than Eruptive Flares
- Eruptive Flares have a higher EM than Confined Flares
- Confined Flares show a stronger FIP effect.

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For further details:

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