Sun-as-a-star Differential Emission Measure analysis of Coronal Dimming associated with CMEs

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Abstract ID: 83

Abstract: Coronal dimmings on the Sun are temporary reductions in coronal plasma emissions, often linked to coronal mass ejections (CMEs) associated with solar flares or filament eruptions. These dimmings typically last from a few hours to several days, characterized by an initial rapid intensity decrease followed by gradual recovery. In this study, we perform a differential emission measure (DEM) analysis using a Sun-as-a-star approach to investigate the relationship between dimming depth and emission measures across various temperature bands. Using data from the Atmospheric Imaging Assembly (AIA) aboard the Solar Dynamics Observatory (SDO), we analyze 17 CME-associated events, including 14 flaring events and 3 filament eruptions. Our findings reveal that while the temperature band exhibiting maximum dimming varies between events, significant dimming is primarily observed within the logT = 5.85–6.45 K temperature range. In contrast, emissions in higher temperature bands show minimal or no dimming. Additionally, the DEM-weighted coronal temperature indicates a noticeable difference between pre-event conditions and the peak dimming phase. Intriguingly, signs of coronal heating are observed during the early stages of dimming, particularly when using the Sun-as-a-star approach. This highlights the complex thermal dynamics of the corona during CME evolution. Furthermore, we calculate the mass and velocity of CMEs using empirical formulae and compare these estimates with values reported in the CME CDAW catalog. The analysis uncovers significant discrepancies, particularly in CME mass estimates, which exhibit the largest deviations. These findings suggest that the empirical formulae, originally developed for close-up CME observations, require modifications for application to the Sun-as-a-star approach. These results offer valuable insights into the coronal response to CMEs, the associated plasma heating, and the limitations of current modeling methods.

Objective

1. To analyze the relationship between temperature and coronal dimming in CME events using a Sun-as-a-star approach.
2. To find the most prominent temperature dimming band
3. Investigate the limitations of applying empirical CME models developed for spatially resolved solar observations to unresolved stellar observations.
4. Calculate the average temperature using weighted DEM Tavg

Data

Source: SDO/AIA data (2011–2014).
Events: 14 flares and 3 filament eruptions showing coronal dimming.
Processing:

- Data calibration using the ***aiapy*** package.
- Reduced resolution from 4096x4096 to 512x512 pixels for DEM analysis.

Sun-as-a-star Approach

- Full-disk solar images averaged into a single pixel to simulate stellar observations.
- DEM calculated for both full-disk and point-source views.

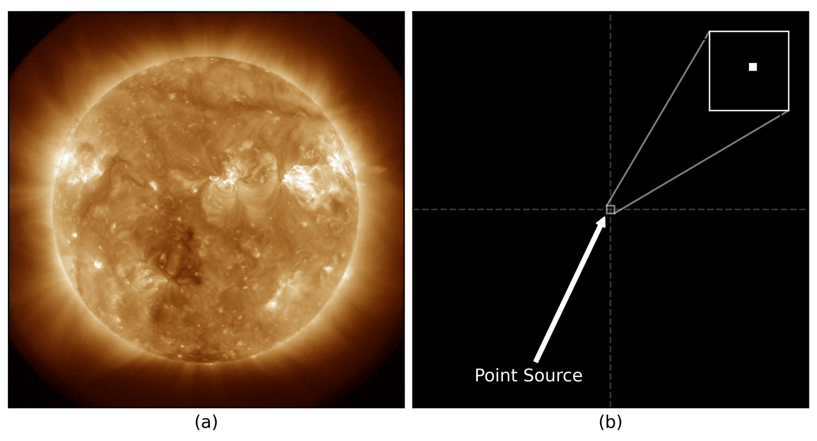

Fig 3: a) 193 Å Image of sun b) point source obtained by averaging all the pixels

$$v_{\rm CME} \approx 2.36 \times 10^6 \left[\frac{\rm km}{\%}\right] \times s_{\rm dim} \left[\frac{\%}{s}\right]$$

$$m_{\rm CME} \approx 2.59 \times 10^{15} \left[\frac{g}{\%}\right] \times \sqrt{d_{\rm dim}}\ [\%]$$

Eqn 1: Mass and Velocity of CME Empirical Formula (Mason et al.)

Differential Emission Measure (DEM) Analysis

Concept: Quantifies the plasma distribution as a function of temperature.
Technique:

- DEM inversion using the ***Re-iterative Maximum Likelihood*** (RML) method (Massa et al.).
- Focus on logT = 5.85–6.45
- Calculate the weighted DEM Tavg.

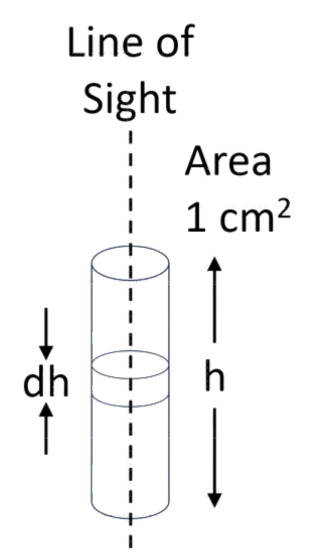

Fig 4: Definition of Emission Measure

$$EM = \int_h n_e^2 \, dh$$

$$DEM(T) = n_e^2(T) \, \frac{dh}{dT}$$

$$y_i = \int_0^\infty K_i(T) DEM(T) \, dT$$

$$\langle T \rangle = \frac{\int_T \mathrm{DEM}(T) T \, \mathrm{d}T}{\int_T \mathrm{DEM}(T) \, \mathrm{d}T}$$

Eqn 2: DEM Formula

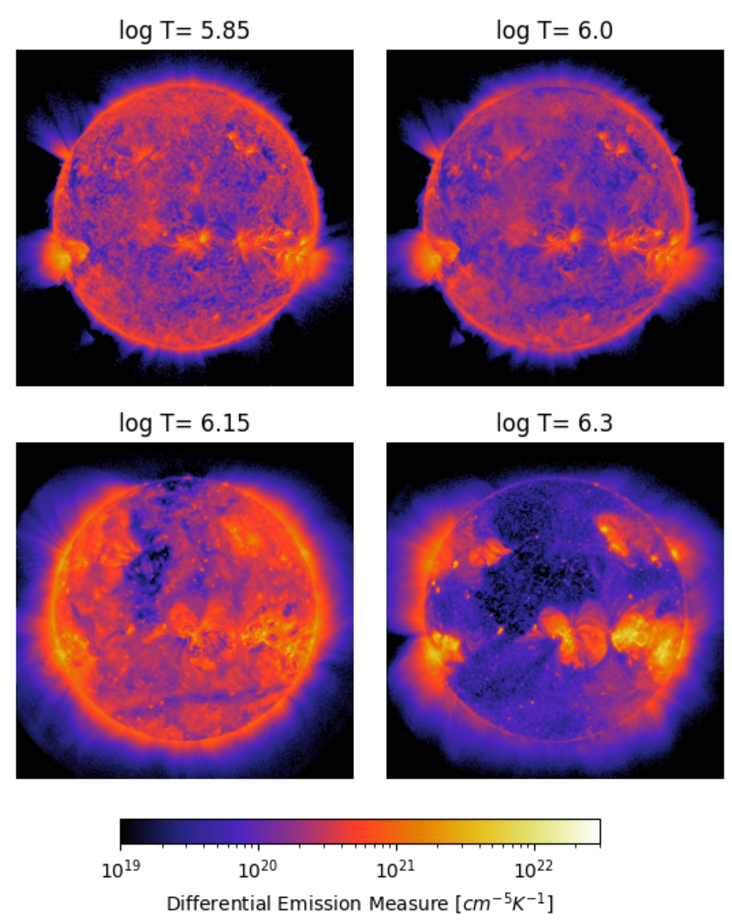

Fig 5: DEM Inversion Solution

Results

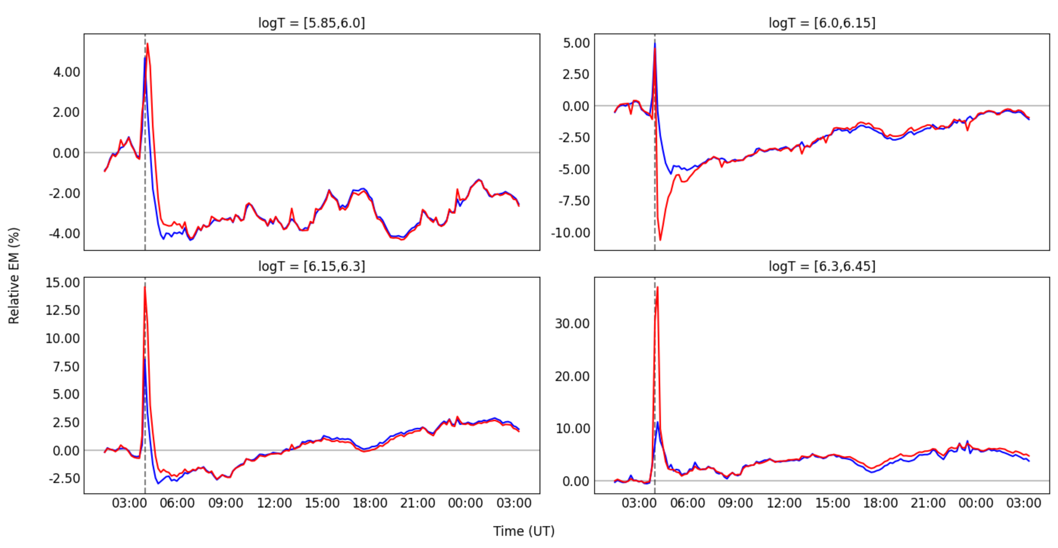

Fig 6: DEM timeseries for flaring event (04/08/2011 @ 03:57 UT)

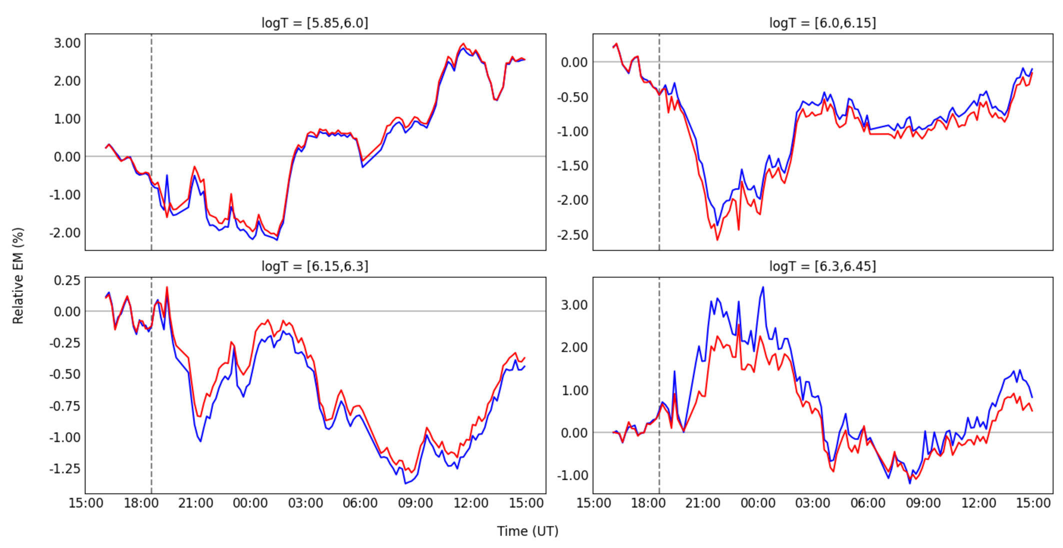

Fig 7: DEM timeseries for filament eruption event (24/09/2013 @ 18:36 UT)

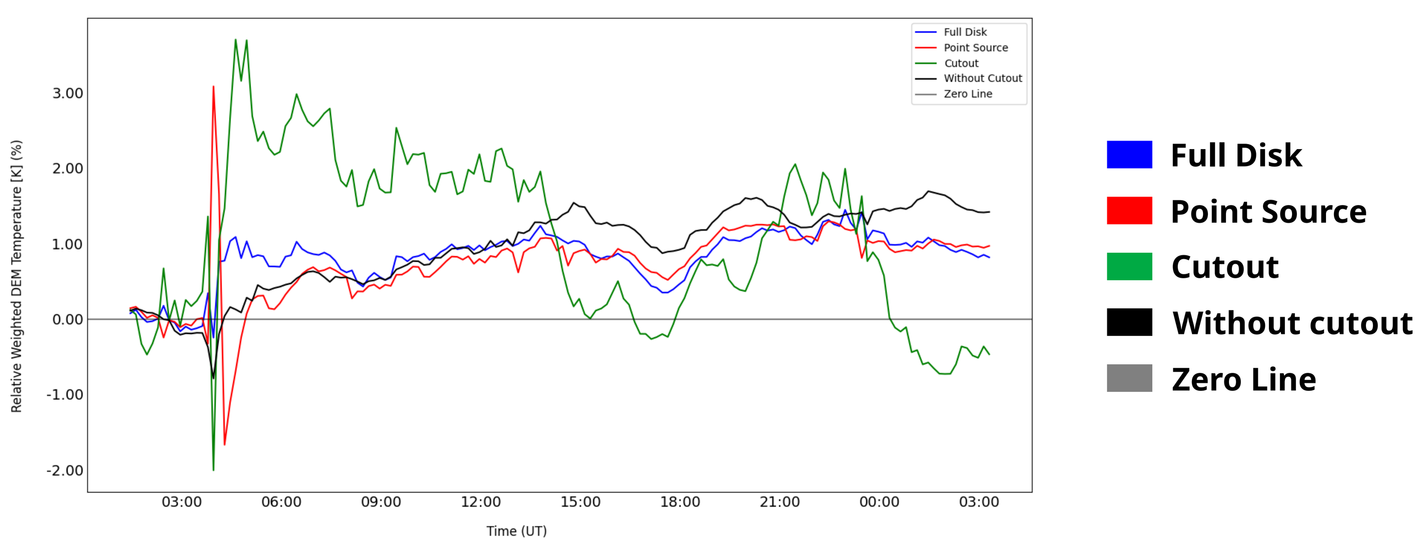

Fig 12: Tavg of full disk, point source, cutout region and without cutout region

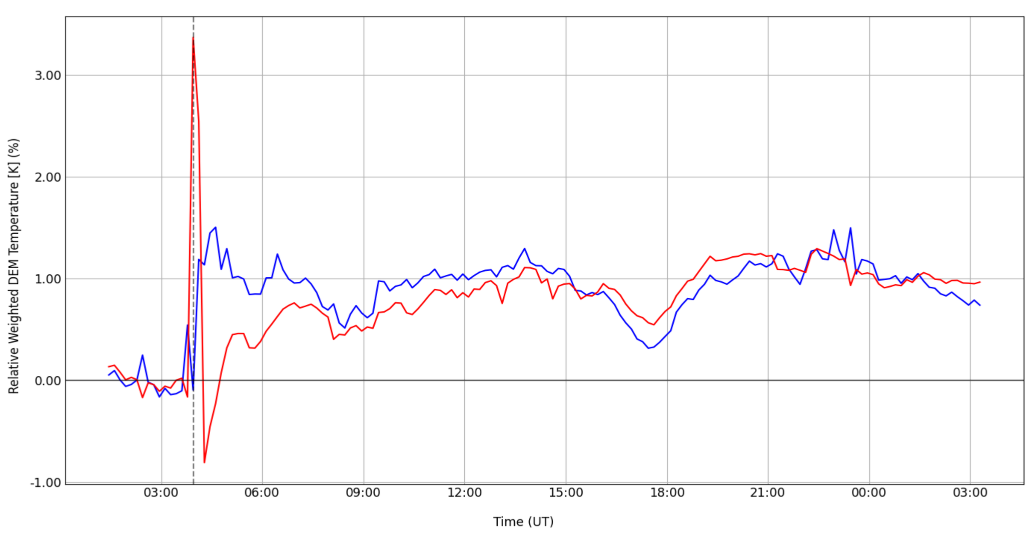

Fig 8: Tavg filament eruption event (24/09/2013 @ 18:36 UT)

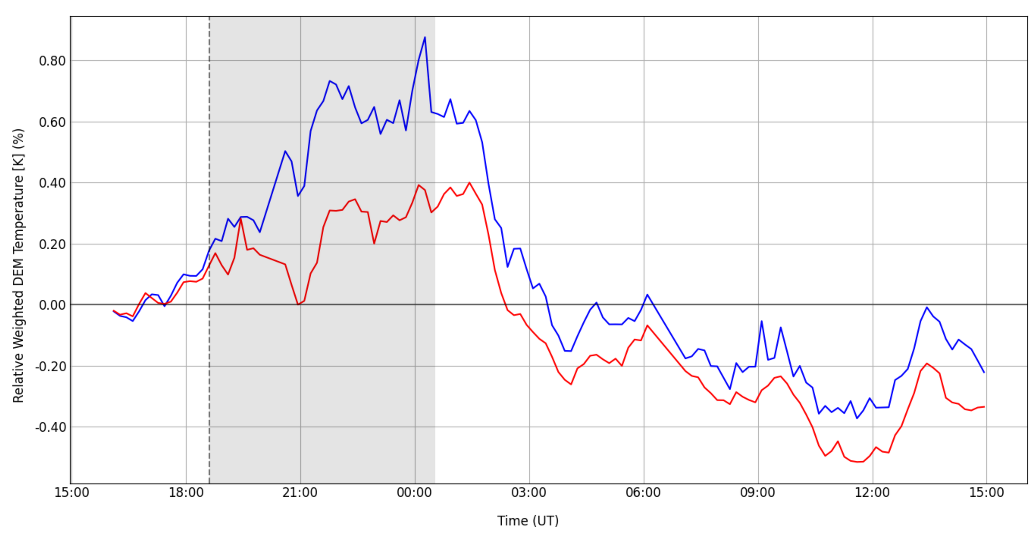

Fig 9: Tavg filament eruption event (24/09/2013 @ 18:36 UT)

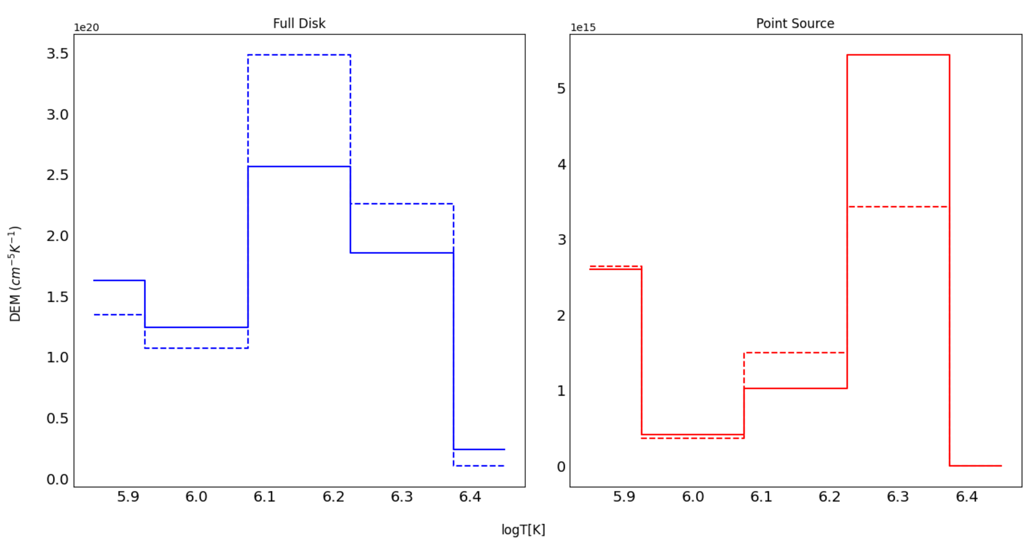

Fig 10: DEM Profile of flare event

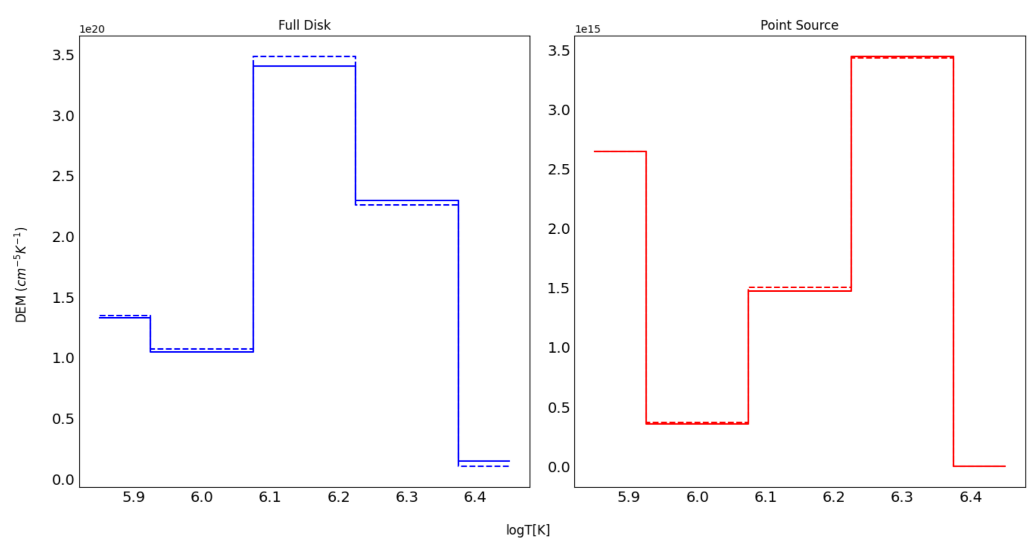

Fig 11: DEM profile of filament eruption event

Summary

This study explores coronal dimming associated with CMEs using a Sun-as-a-star approach. DEM analysis of 14 flares and 3 filament eruptions reveals significant dimming in the logT = 5.85–6.15 K range (1–2 MK). Notably, an initial coronal heating phase during the dimming process is observed in the Sun-as-a-star approach. This heating is in contrast to the temperature increase reported in the previous studies. Full-disk and point-source comparisons further emphasize the loss of localized plasma details in stellar-like observations, underscoring the need for improved models to estimate CME properties.

Conclusion

- Significant dimming occurs in temperature bands *logT = 5.85–6.15 K*, corresponding to plasma temperatures of 1–2 MK.
- Initial coronal heating is observed during the early dimming phase, highlighting complex thermal dynamics.
- Existing empirical formulae for CME mass and velocity exhibit significant discrepancies in Sun-as-a-star observations.
- Spatial averaging in Sun-as-a-star methods leads to loss of localized plasma information, diluting detailed DEM profiles.