JAIN DEEMED-TO-BE UNIVERSITY
SCHOOL OF SCIENCES

Department of Physics and Electronics

Masters Thesis Presentation

Investigating temperature variations of solar corona during Coronal Mass Ejections

By

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Introduction

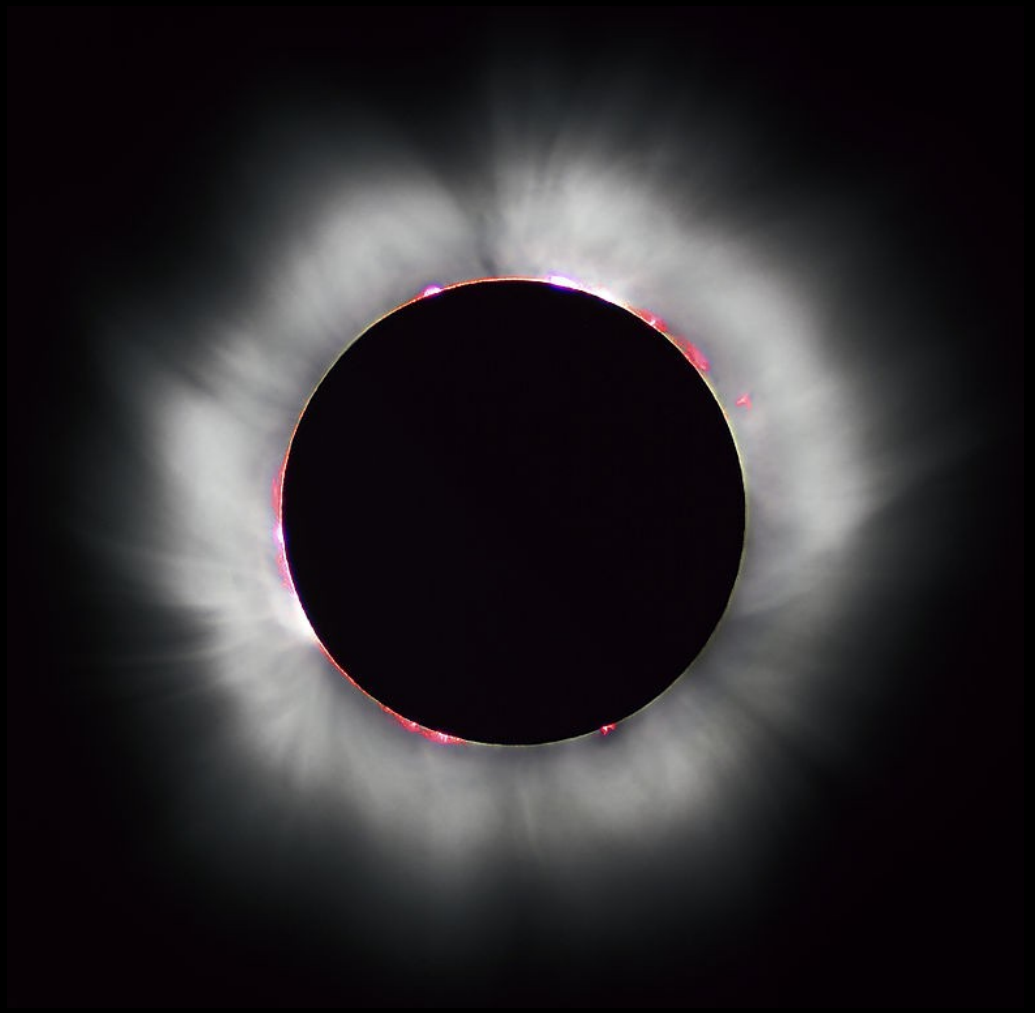
- Solar Corona
- Filaments/Prominences
- Flares
- Coronal Mass Ejections (CMEs)
- Stellar CMEs
- Coronal Dimming
- Emission Measure & Differential Emission Measure

Objectives

1. Understand the temperature variation of solar corona during Coronal Mass Ejections (CME)
2. Which temperature plasma shows the most coronal dimming ?
3. Differential Emission Measure (DEM) analysis of point source converted Sun.

Solar Corona

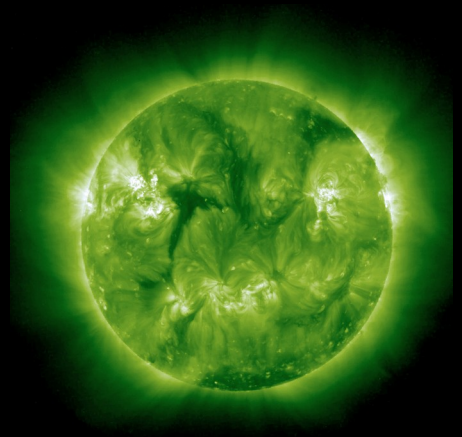
- Outermost part of atmosphere of Sun
- Several million degree Kelvin
- Contains forbidden Iron lines (Fe XIV)
- Very low density compared to the lower layers



Solar corona seen during total solar eclipse
(Image credit: NASA)

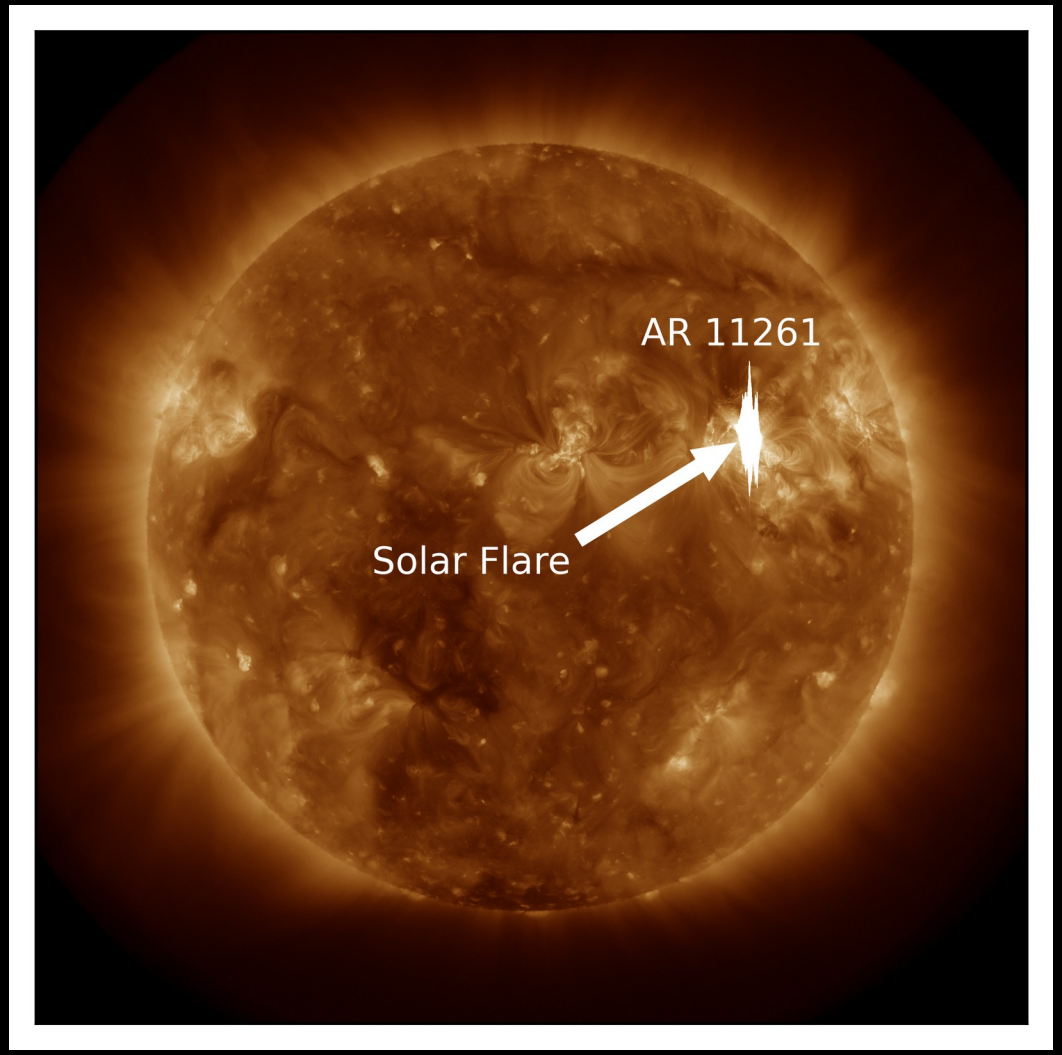
Solar flares

- Explosive phenomenons due to magnetic reconnection
- Accompanied by filament/prominence eruptions and CMEs



Filament

Prominence (Image credit: NASA/SDO)



Flaring event of 2011 August 4th

Coronal Mass Ejections

- Plasma Ejections into Heliosphere
- Often associated with flares
- Very high association of phenomena of coronal dimming
- Made up of charged particles
- High magnetic field enclosure
- Affects the space weather, satellite communications etc.

LASCO C3 image of a CME
(Image credit: SOHO/LASCO (ESA & NASA))

Stellar CMEs

- Like solar CMEs
- Highly energetic
- Difficult to observe
- No spatial resolution
- Indirect methods to detect stellar CMEs
  - Coronal Dimming
  - Blueshifted chromospheric lines
  - Type-II and Type-IV radio bursts etc.

Literature Survey

- EM distributions from SDO/AIA data alone can overestimate the amount of high temperature (logT > 6.4) plasma in the solar corona by a factor of 3-15 (Athiray and Winebarger, 2024)
- About 73 % association of CME events with eruptive filaments has been observed (Sinha et al., 2019)
- Information about the underlying CMEs like mass and velocity of the CMEs ejected by knowing the depth and slope of the dimming curve (Mason et al., 2016)
- The association of dimming with a CMEs and assocation of CME with dimming has been observed to be very high (Veronig et al. 2021)
- Kinetic energy of stellar CME to the stellar flaring energy not being anywhere close to being a scaled version of the solar case (Namekata et al., 2022).
- Redshifted components of stellar filament eruptions in Sun-as-a-star analysis in Hα spectra may develop into CMEs (Otsu et al.,2022)

Methodology

1)Downloading level 1 Images of Sun

2) DEM is obtained for the full disk image of Sun.

3) Convertion of full disk to point source: full disk data is converted to a point source (pointification).

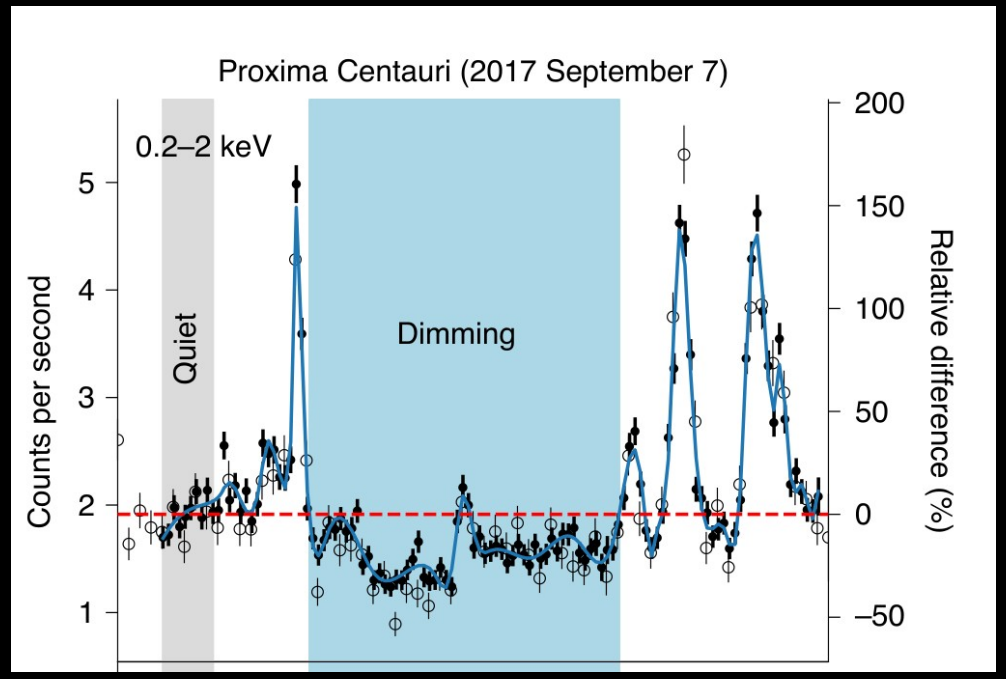
4) Calculating DEM for the point source

5) Compare the DEM curves of full disk and point source.

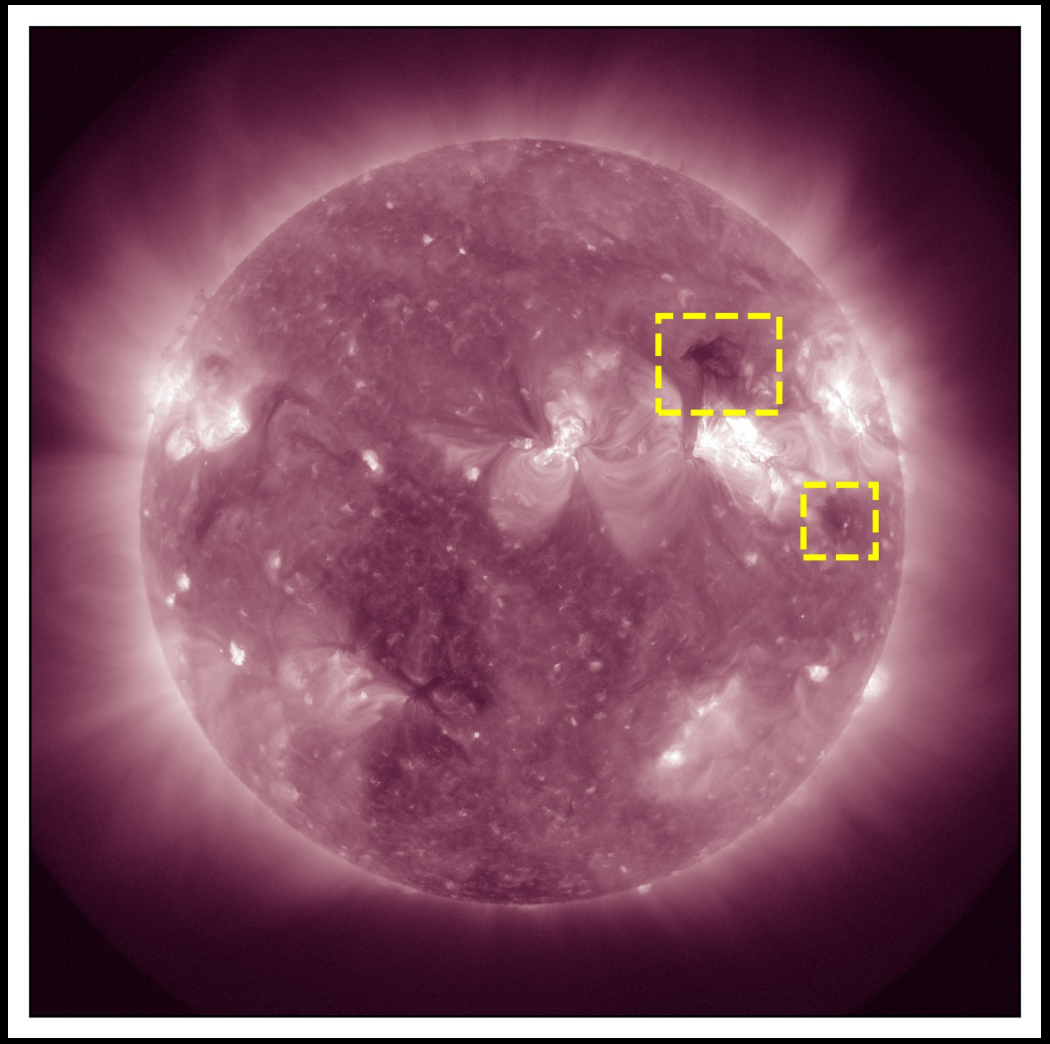
6) If CME is associated with dimming, find the maximum dimming temperature region.

7) Study the DEM profile which gives information about the coronal temperature variation

Coronal Dimming



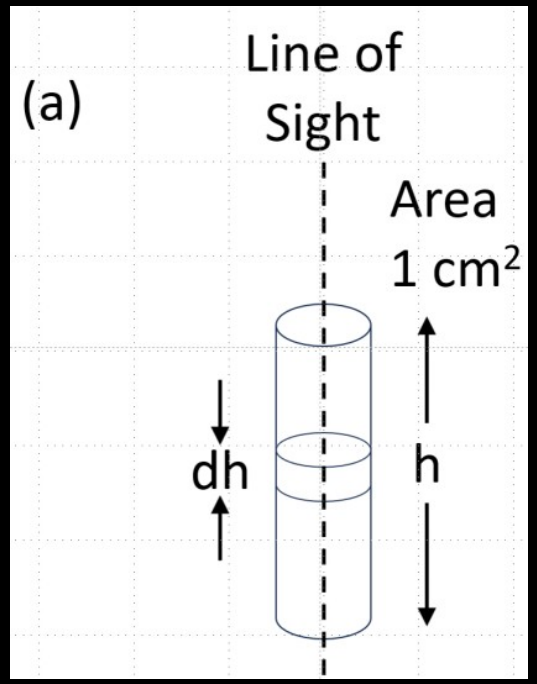
Dimming seen on a star. Image Credit: (Veronig et al.)



211 Å channel of AIA. Yellow boxes shows the dimming

Differential Emission Measure (DEM)

- DEM – emission measure with respect to temperature. Function of temperature.



Column emission measure

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

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

Where n_e is the electron number density

DEM Inversion

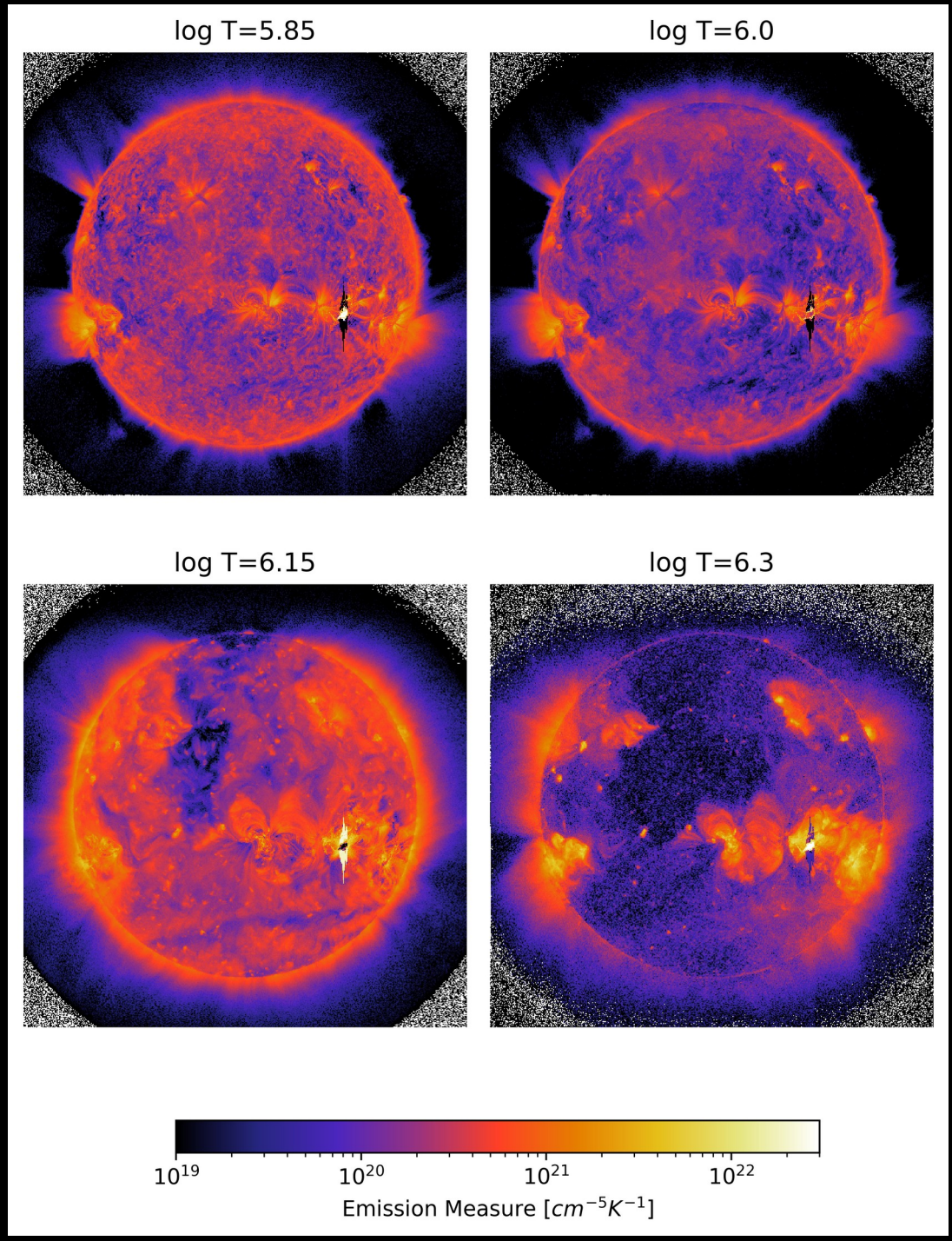
- Obtain the information about the plasma from the line intensities observed

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

K_i is the temperature response of each channel

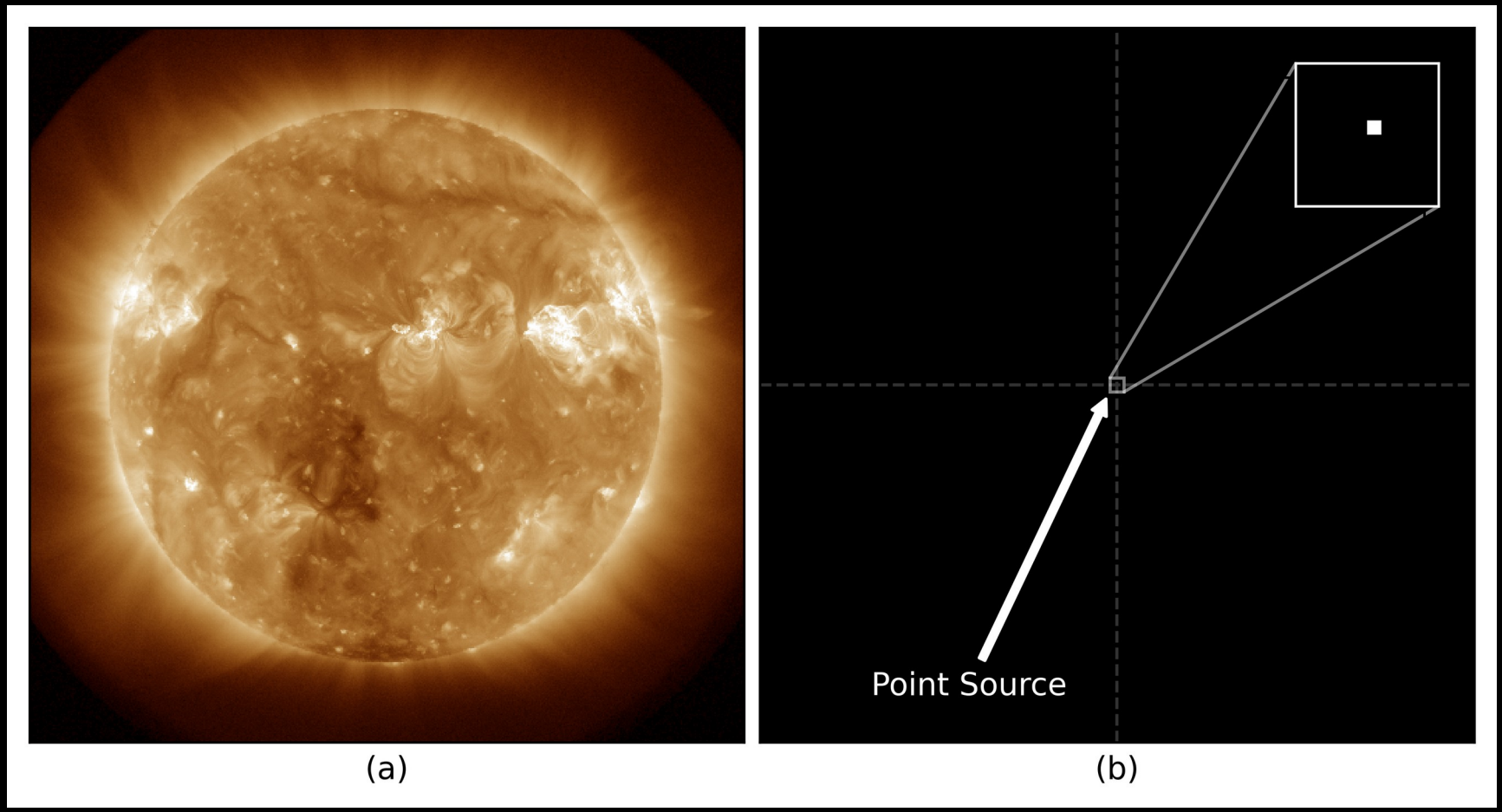
- We can only approximate the underlying EM profile.
- We use Reiterative Maximum Likelihood (RML) method (Massa et al., 2023)

DEM of Sun during the flaring event of August 4th 2011



Temperature variation of the Solar Corona during Coronal Mass Ejections

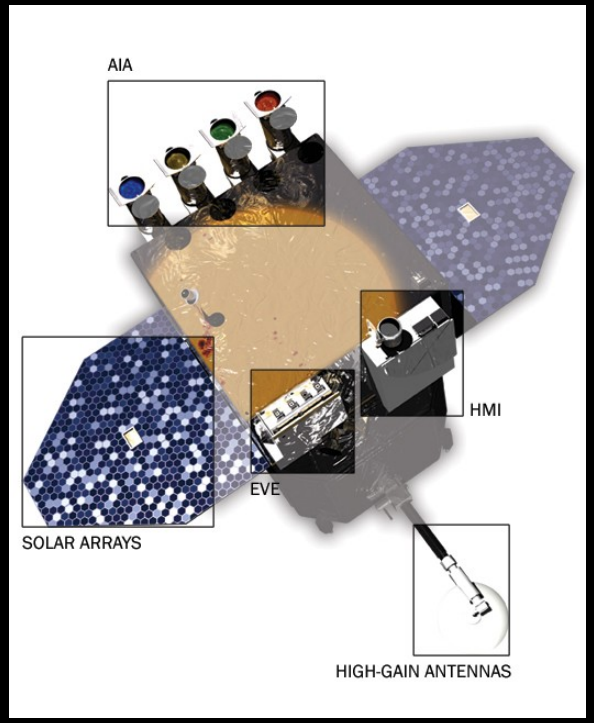
“Pointification” of sun full disk image



a) shows the full disk image of Sun. (b) Image after pointification

Data

- NASA’s Solar Dynamics Observatory - Atmospheric Imaging Assembly (SDO/AIA)
- Three CME event data
  - Flare associated CME (August 4th 2011)
  - Long filament eruption associated with a CME (August 31st 2012)
  - Ground Level Enhancement CME (21st October 2021)

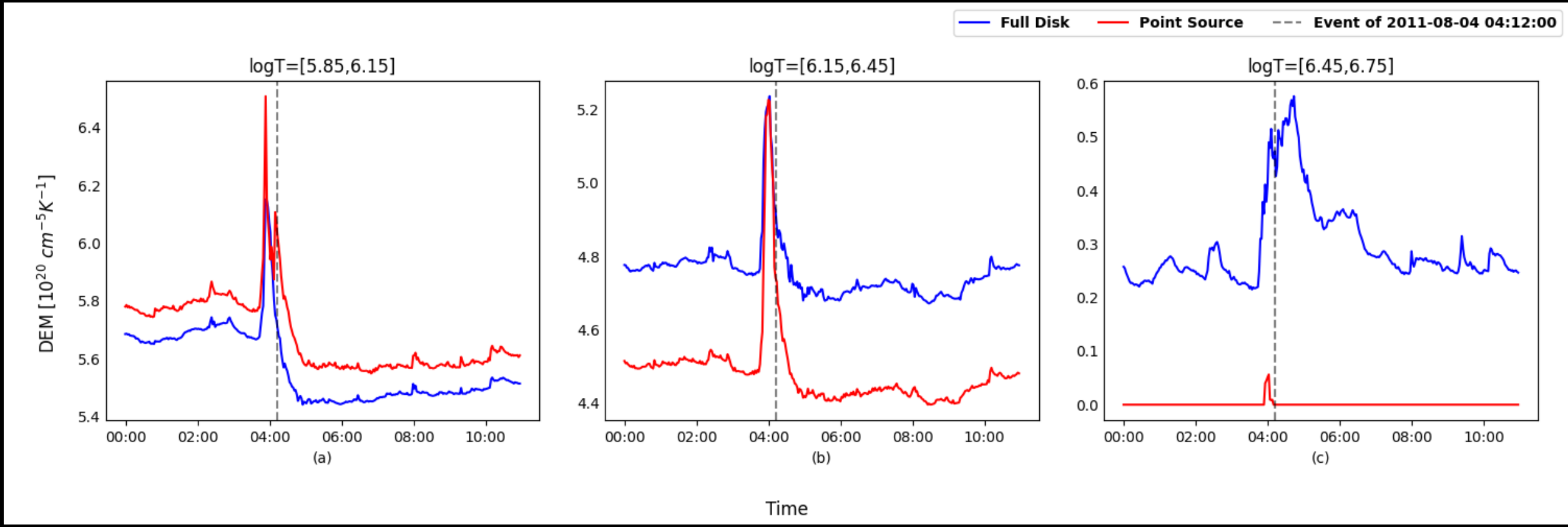


NASA’s SDO Space Observatory (Image Credit: NASA/SDO)

Four telescopes of SDO/AIA (Image Credit: NASA/SDO)

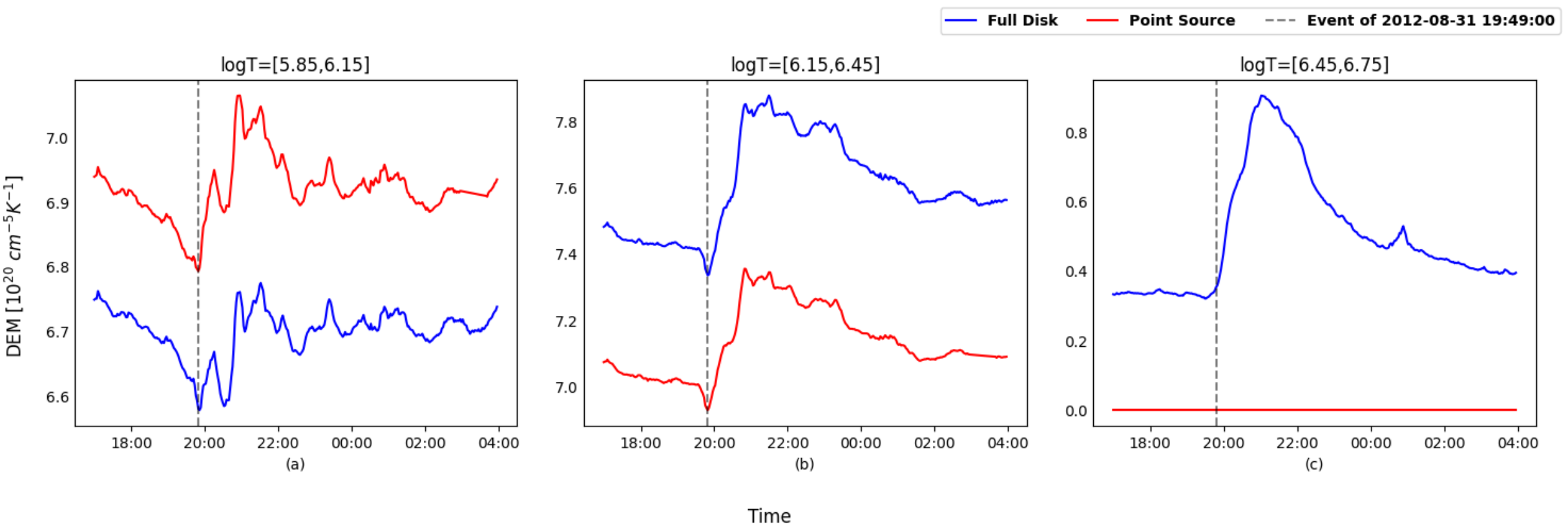
Results

Coronal Dimming



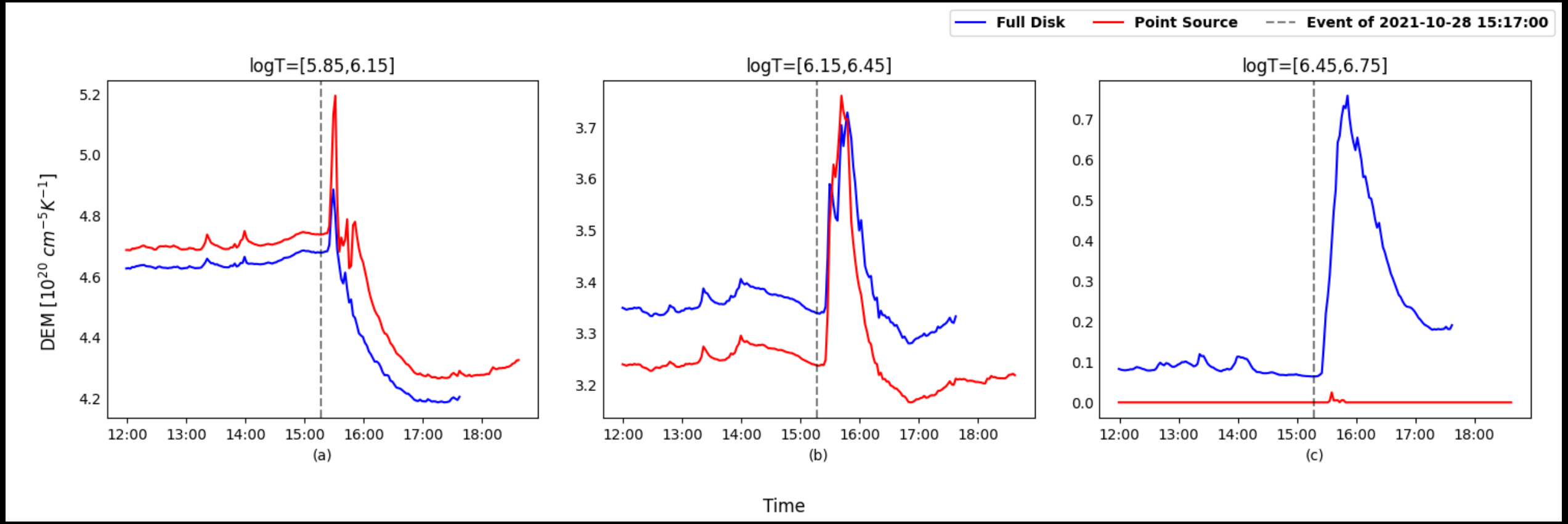
DEM Timeseries of August 4th 2011 CME event

Filament Eruption



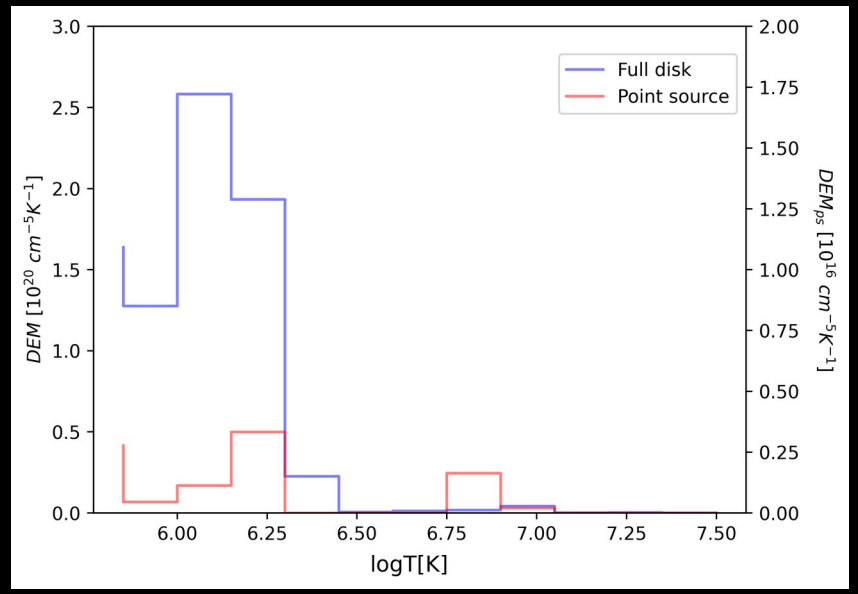
DEM Timeseries of August 31th 2012 CME event

GLE CME event

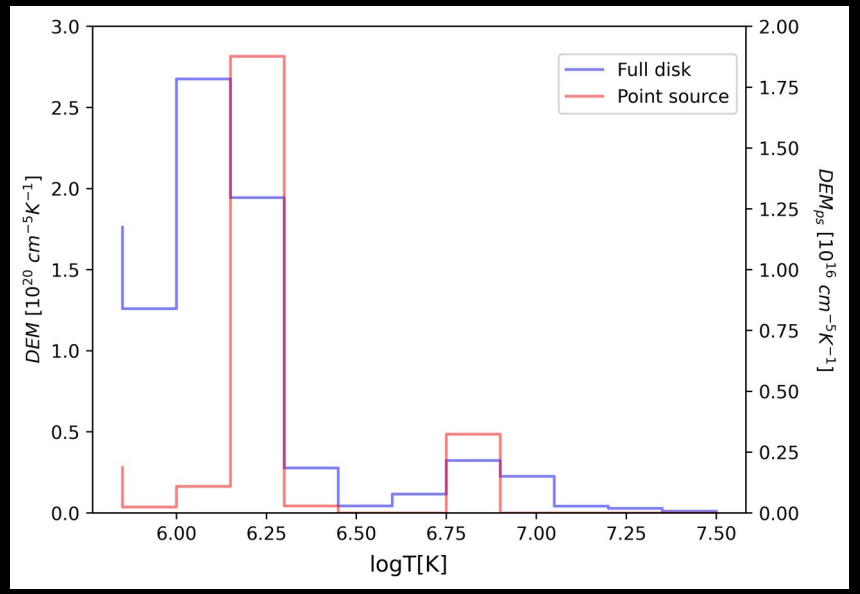


DEM Timeseries of August 31th 2012 CME event

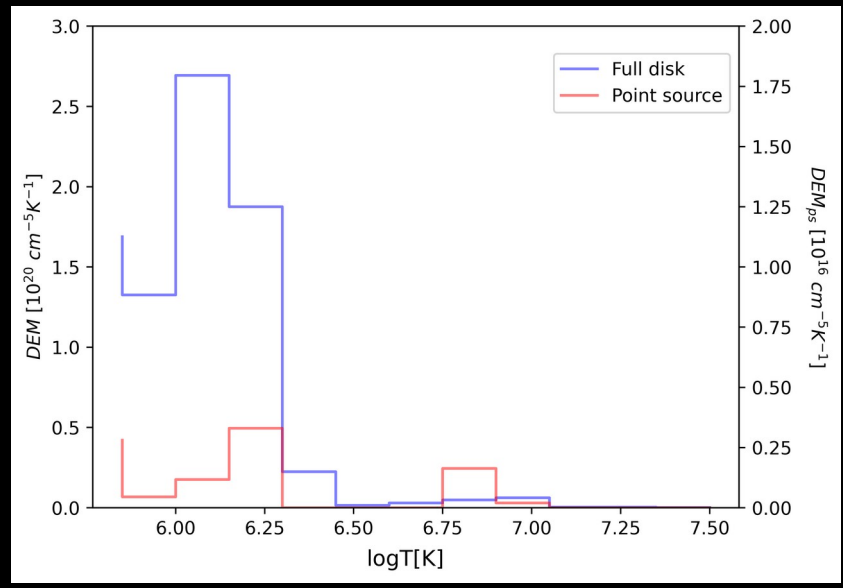
DEM profiles of 4th August 2011 Event



Before event

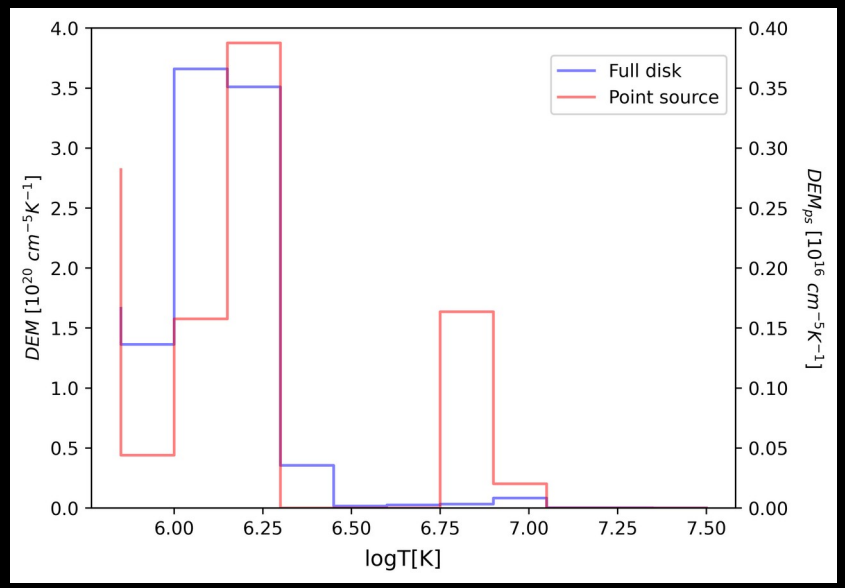


During event

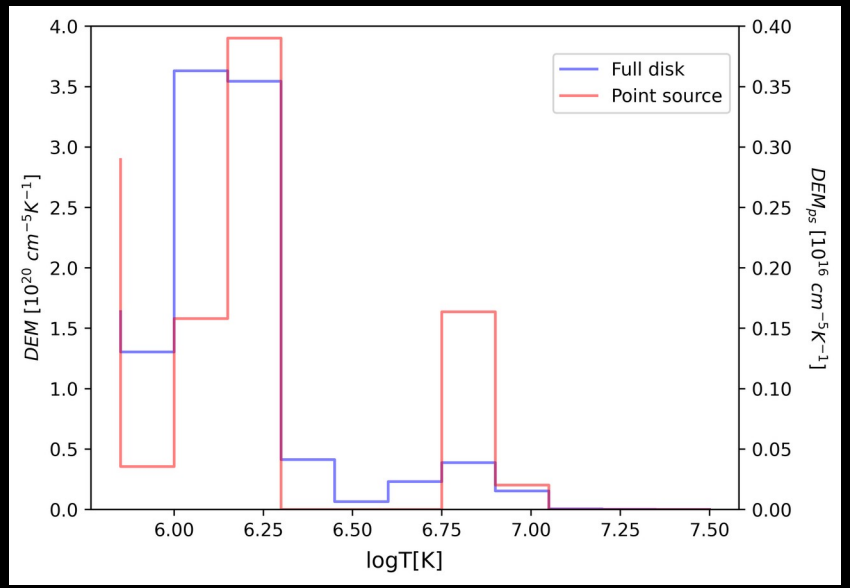


After event

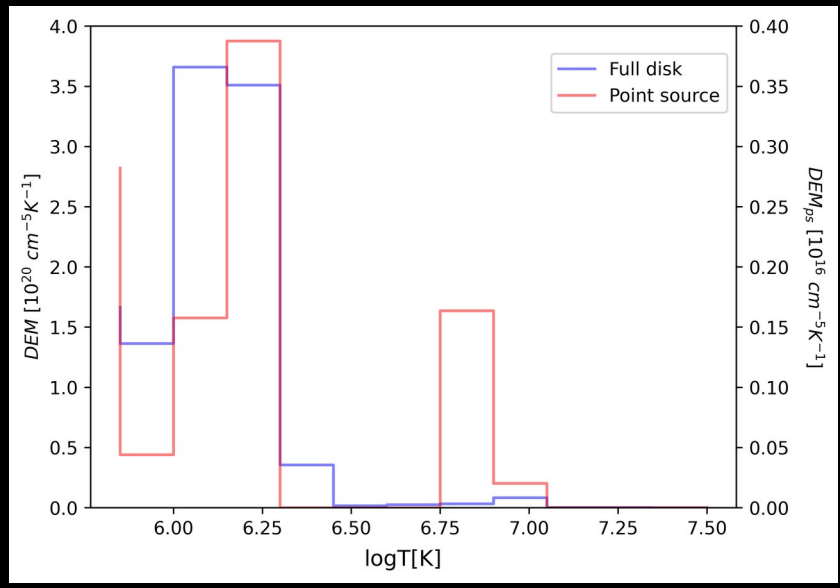
DEM profiles of 31st August 2012 Event



Before event

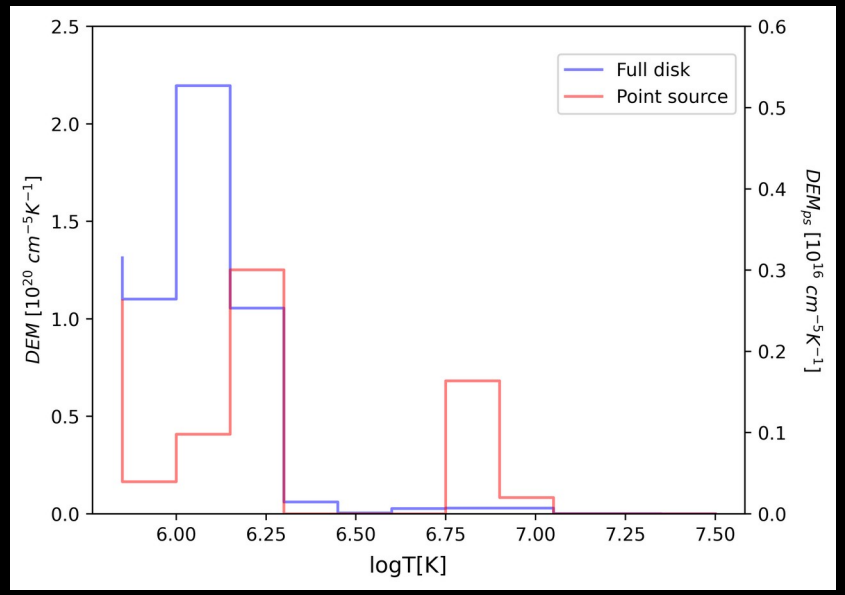


During event

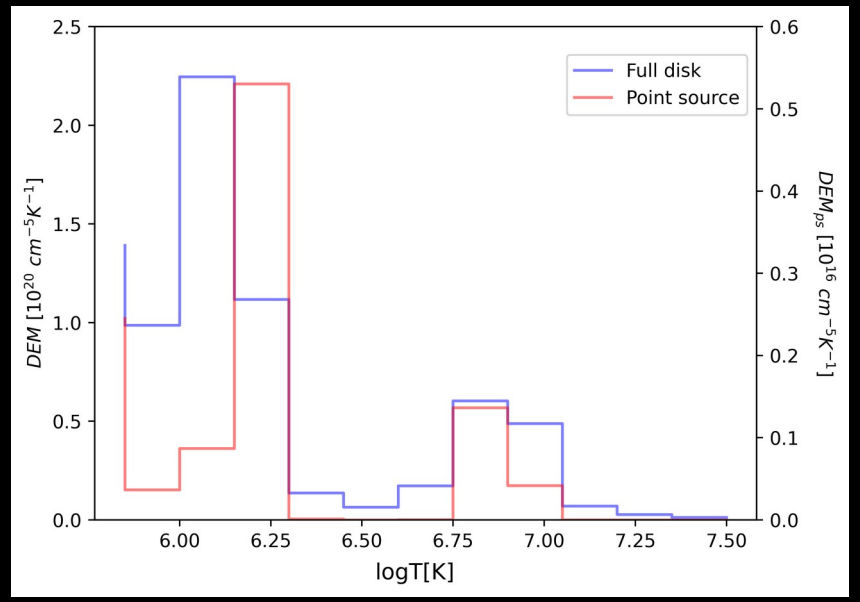


After event

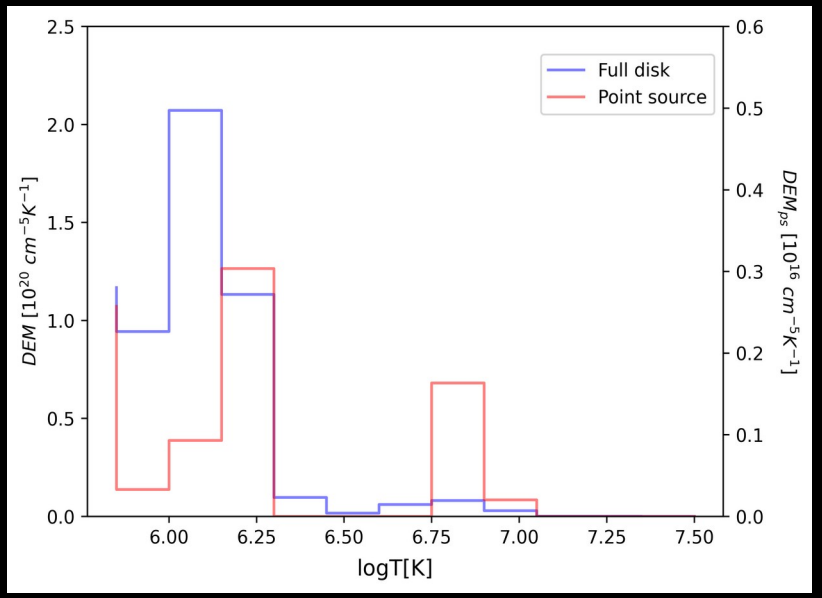
DEM profiles of 28th October 2021 Event



Before event



During event



After event

Conclusion

- Coronal dimming for 4th August 2011 event is most prominent in logT = [5.85, 6.15] range. Mass loss is more in this temperature
- Good correlation between point source and full disk DEM solutions (below logT = 6.45).
- Characteristic features of the CMEs on the full disk is still visible in the point source
- Variations in coronal plasma temperature has been observed in both point source and full disk image before, during and after the event

Moving forward

- Correcting the *pointification* process by not direct averaging.
- Look at events originating from various regions on the Sun
- Statistical analysis to check the correctness of the correlation

Acknowledgements

- *M. N. Sundar*, Jain University
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- *Dr. Dhanush Shenoy* for his constant support

Publications and Conferences

- Manuscript of this work is under preparation to be submitted to the journal (**The Astrophysical Journal**).
- The two-days Scientific Extravaganza '**MillCon–2023**' is an Internation Conclave on Millets, held at Jain (Deemed-to-be University), School of Sciences. Best paper and presentation award for the paper titled "**Could AI/ML help yield loss in Millets?**".
- Paper titled "**Crop Health Managemenet in Millets using Satellite Imagery and Neural Networks**" has been submitted to **VEGETOS**: An International Journal of Plant Research & Biotechnology, The paper is currently under review for publication.
- National Space Science Symposium - 2024 Conference , Goa University: Poster presentation for the paper titled "**Crop Health Management in Millets using Satellite Imagery and Neural Networks**"

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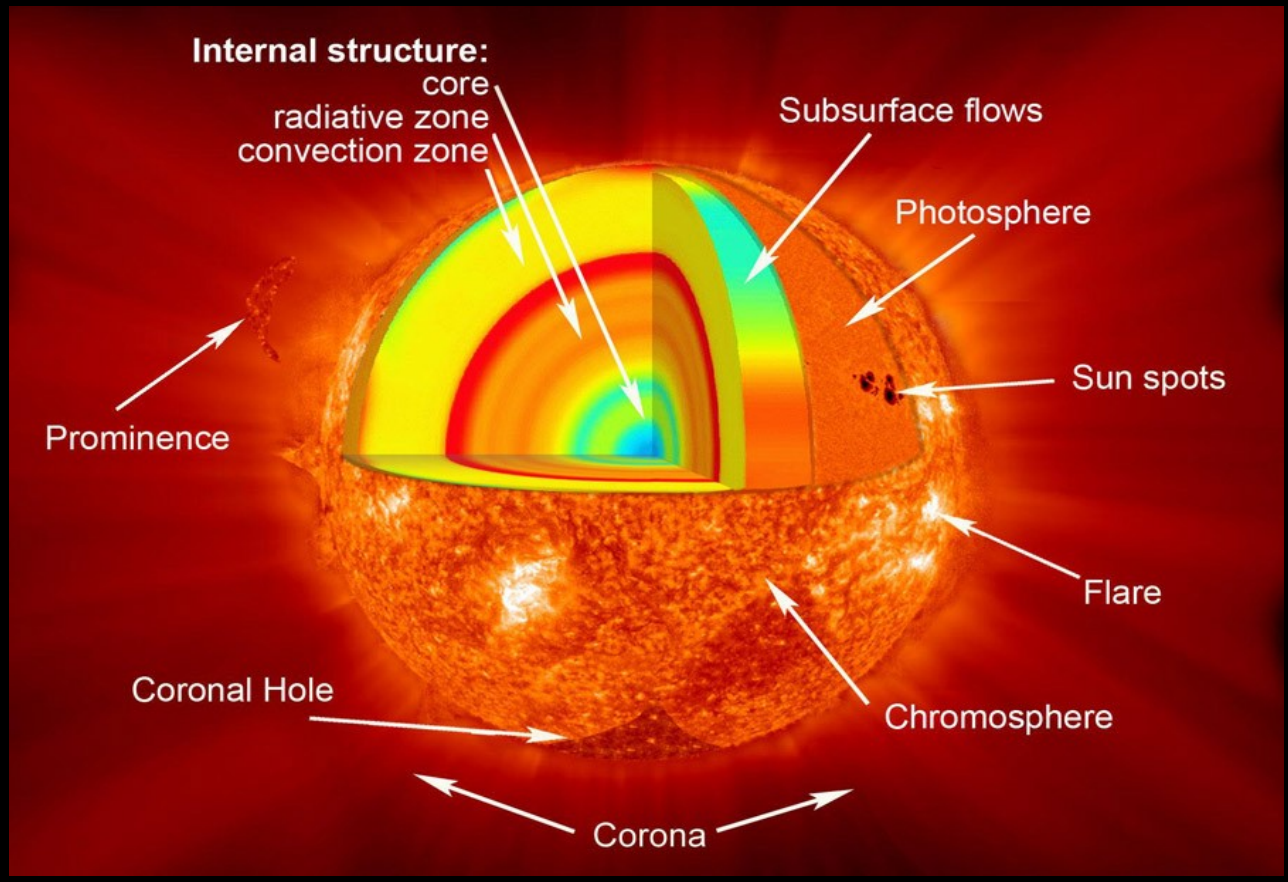
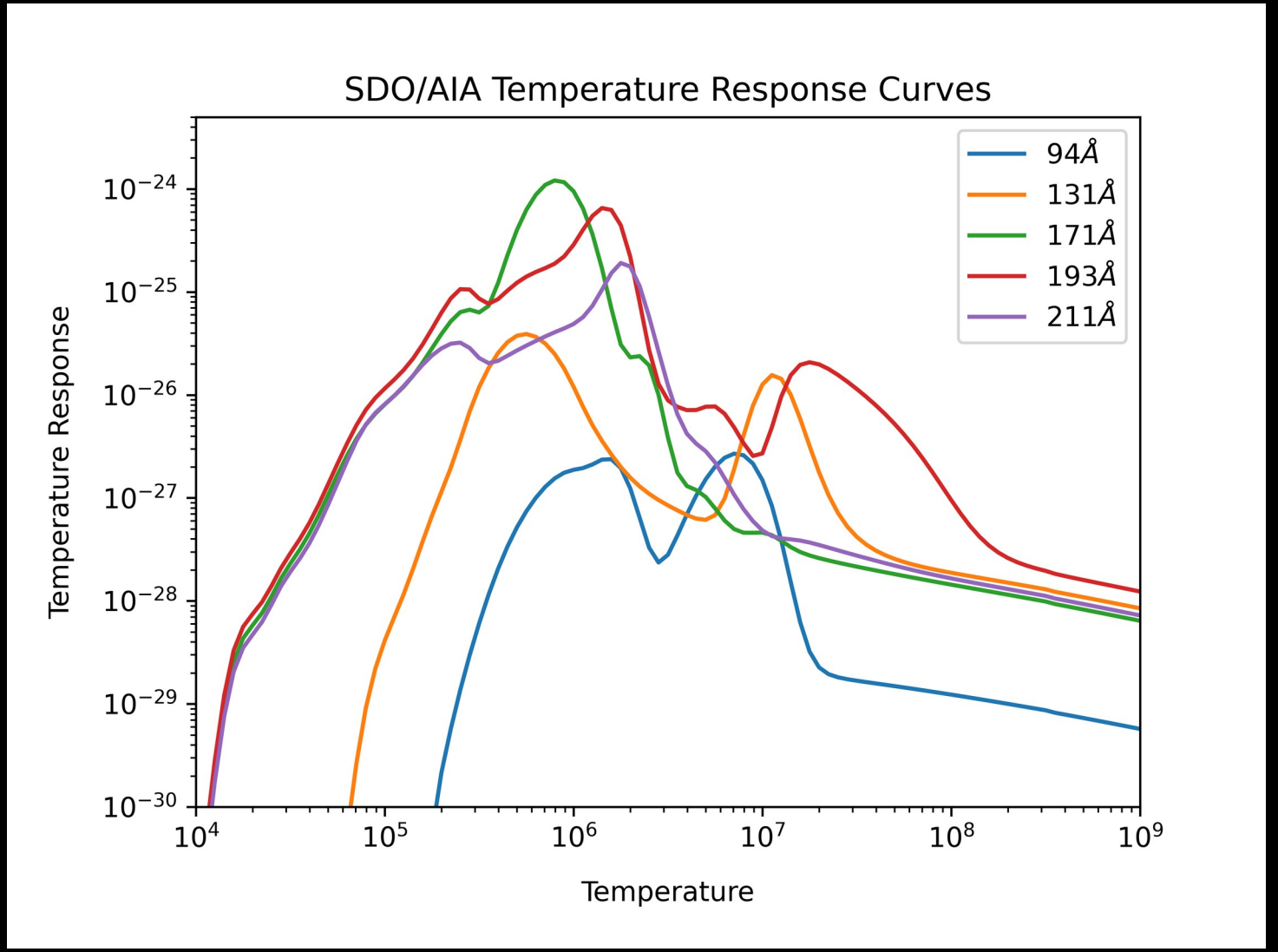
Thank you

Solar structure

- Interior region
  - Core
  - Radiative zone
  - Convective zone
- Visible surface
  - Photosphere
- Atmosphere
  - Chromosphere + Corona



Structure of Sun (Image credit: NASA)


SDO/AIA Temperature Response Curves
Temperature Response
Temperature
94Å
131Å
171Å
193Å
211Å
10^{-24}
10^{-25}
10^{-26}
10^{-27}
10^{-28}
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Magnetic Reconnection

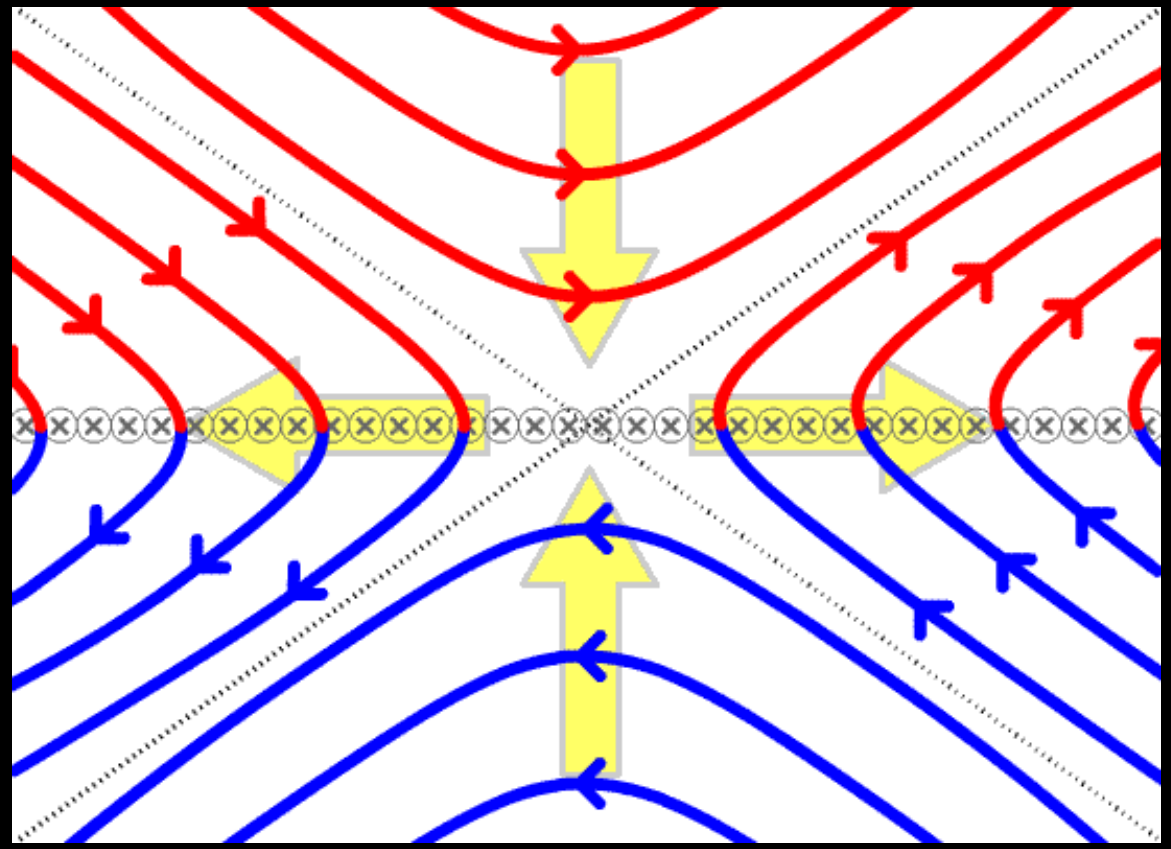
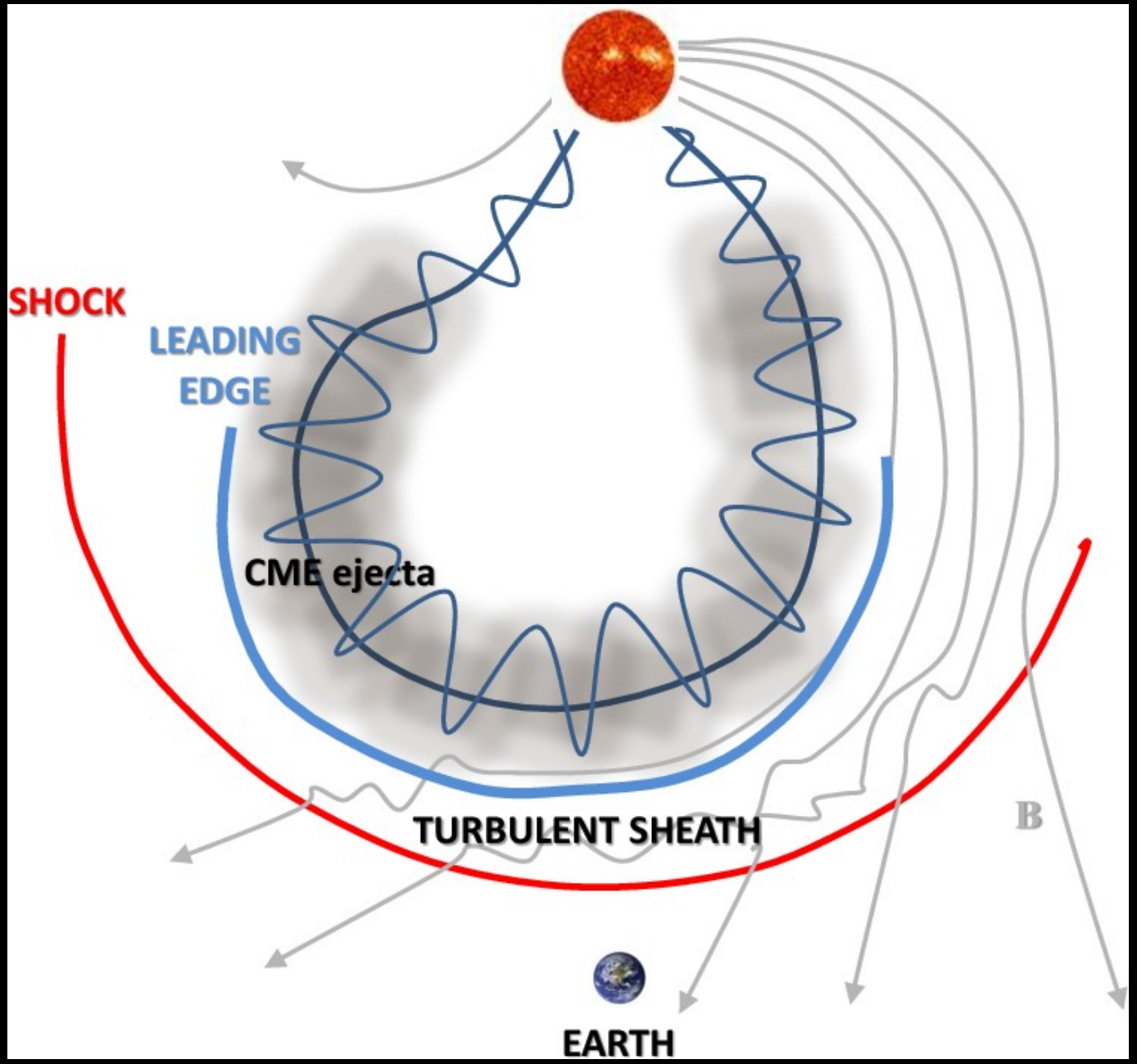
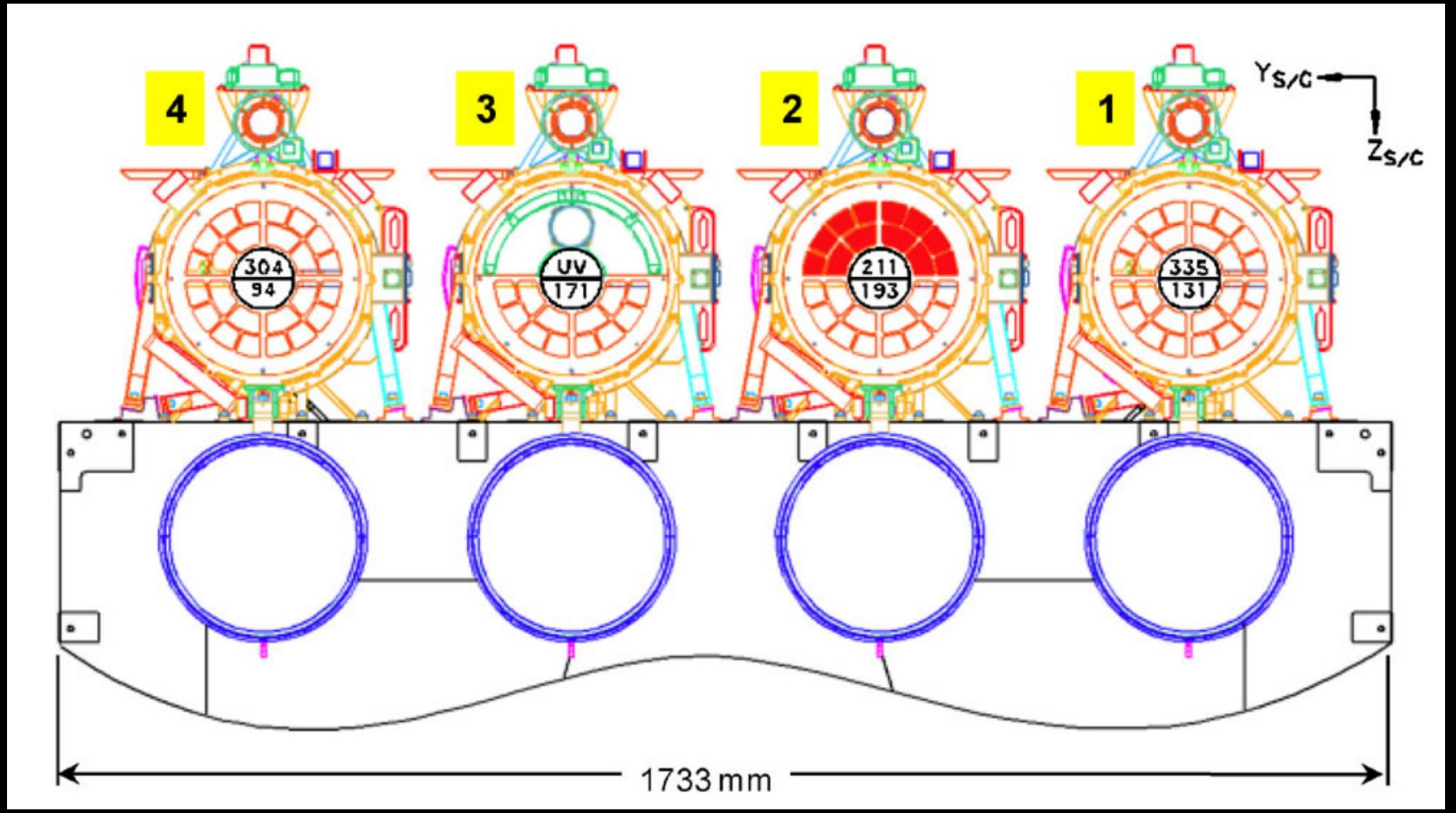


Image credit: Wikipedia


SHOCK
LEADING
EDGE
CME ejecta
TURBULENT SHEATH
B
EARTH



AIA telescope layout. Telescope 2 has aperture blade to select between it’s two wavelength channels. Rest of the channels rely on the filters in filter wheels to select the desired channels.

Event	**Pearson Correlation Coeffecient**		
	logT=[5.85, 6.15]	logT=[6.15, 6.45]	logT=[6.45, 6.75]
4th August 2011	0.9449	0.9767	0.2190
31st August 2012	0.7027	0.9885	0.2079
28th October 2021	0.9555	0.9577	0.2578