Role of small-scale impulsive events in heating the X-ray bright points of the quiet Sun

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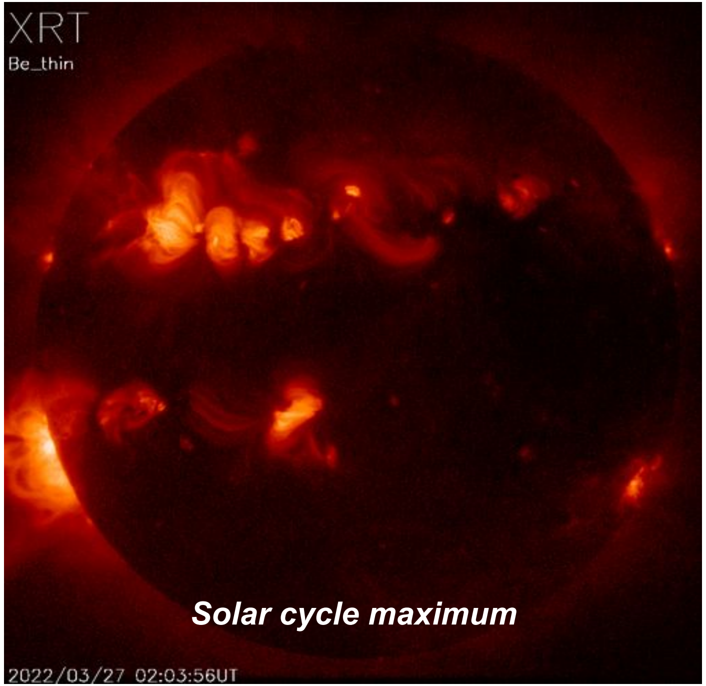
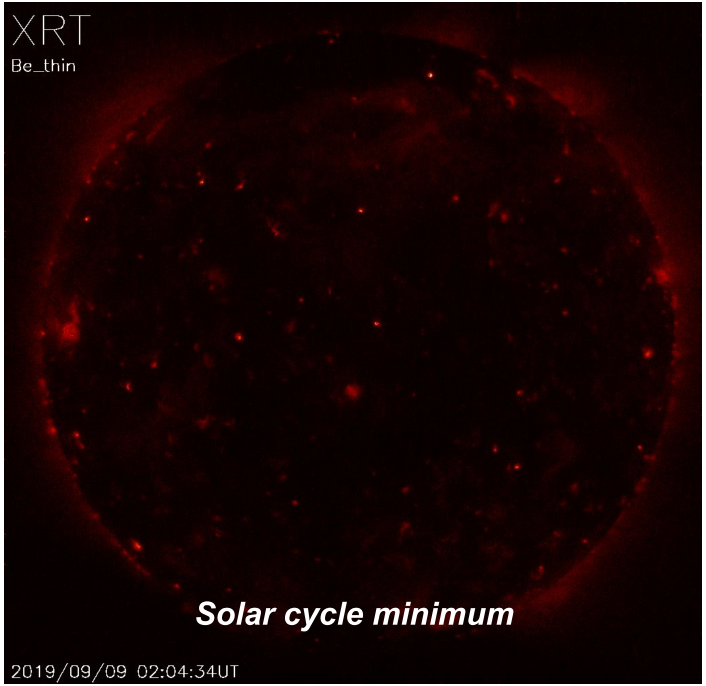
What are the XBPs?





- XBPs are located all over the solar disk. (see Vaiana et al., 1973; Krieger et al., 1971; Golub et al., 1974)
- In the solar maxima, their contribution is hidden behind the huge AR emission.
- During the quiet phase XBPs are the primary on-disk X-ray contributors.

Chandrayaan-2 Solar X-ray Monitor (XSM)

- ➢ XSM is a soft X-ray spectrometer, which is observing the Sun as a star from the lunar orbit and functional from mid of the year 2019, covering the minimum of solar cycle 24.
- ➢ It provides disk-integrated Solar spectrum at every second in the energy range of 1-15 keV (upto M5 class of solar activity) or 2-15 keV (> M5 solar activity).
- ➢ Very good energy resolution of 175 eV @ 5.9 keV for a broad band soft X-ray energies.

XSM Observed spectrum at different Solar activity in 1-15 keV

Peak of an M2 flare

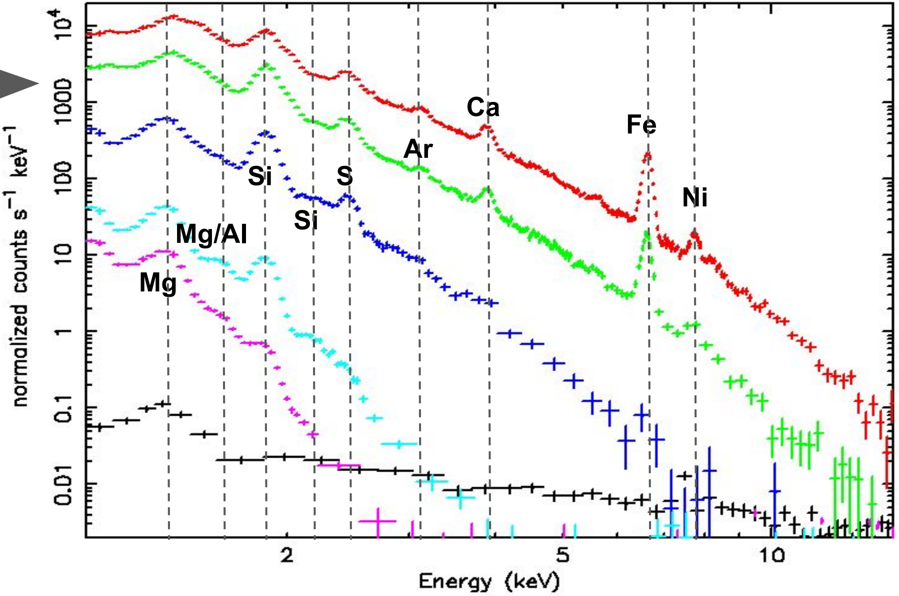
Peak of an C3 flare

Peak of an B4 flare

Active Region

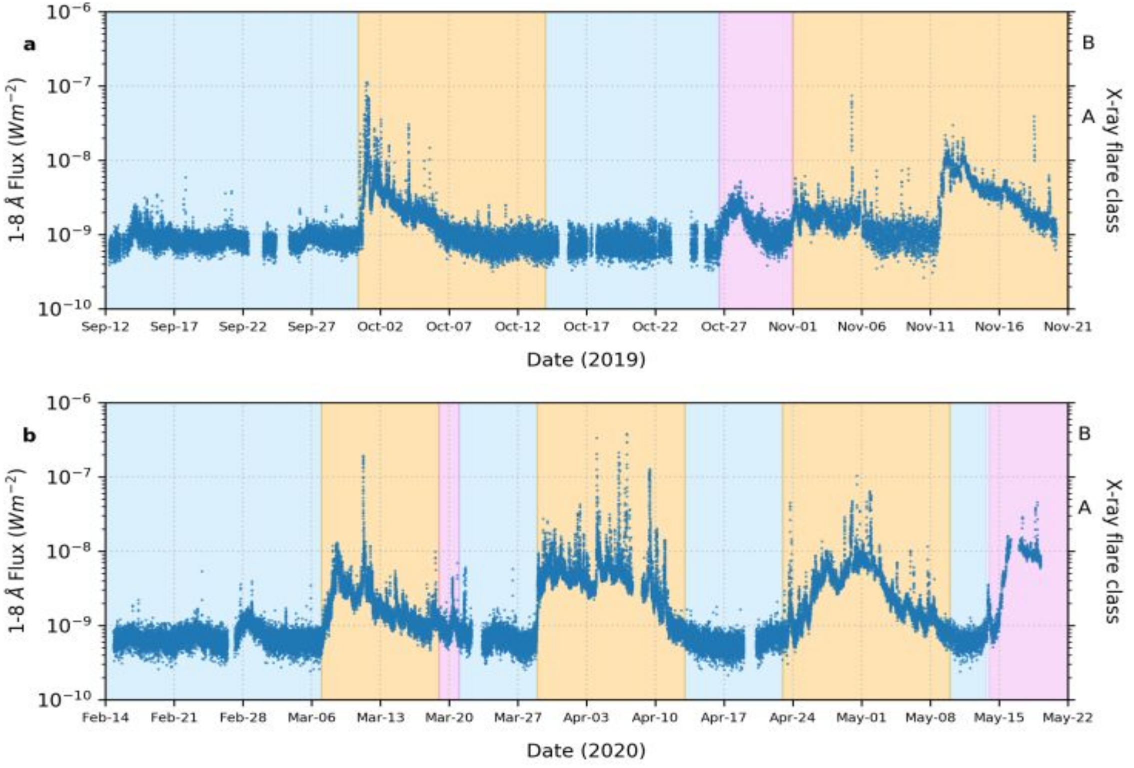
Quiet Sun

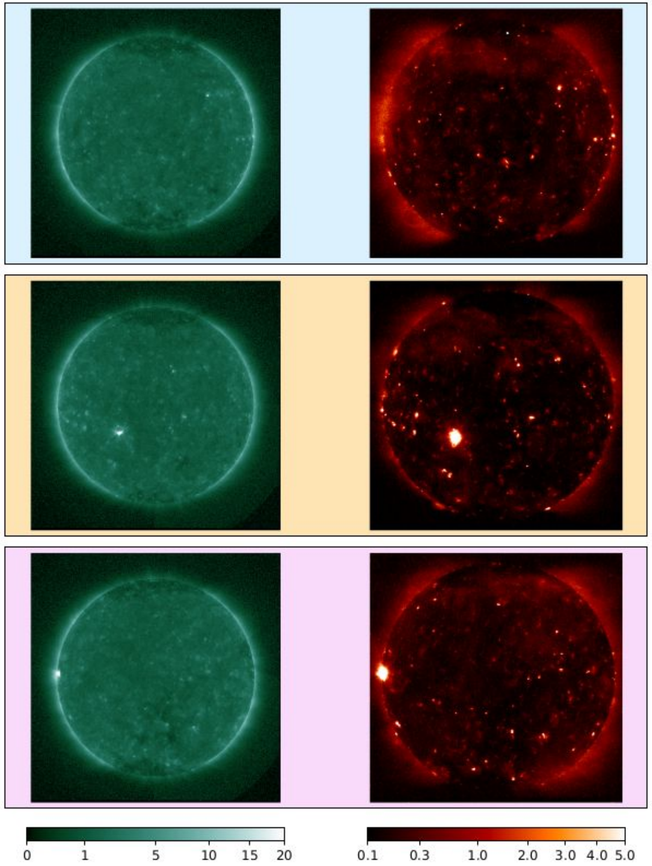
Non-Solar background



XSM website: https://www.prl.res.in/ch2xsm/

XSM Observations during the minimum of solar cycle 24





- By modeling the XSM spectra during the QS period, we have estimated the temperature, emission measure as well as the abundances of Mg, Al, and Si for the XBPs, ARs, and Flares..

Ref : Vadawale et al. (2021a,b)
Mondal et al. (2021)
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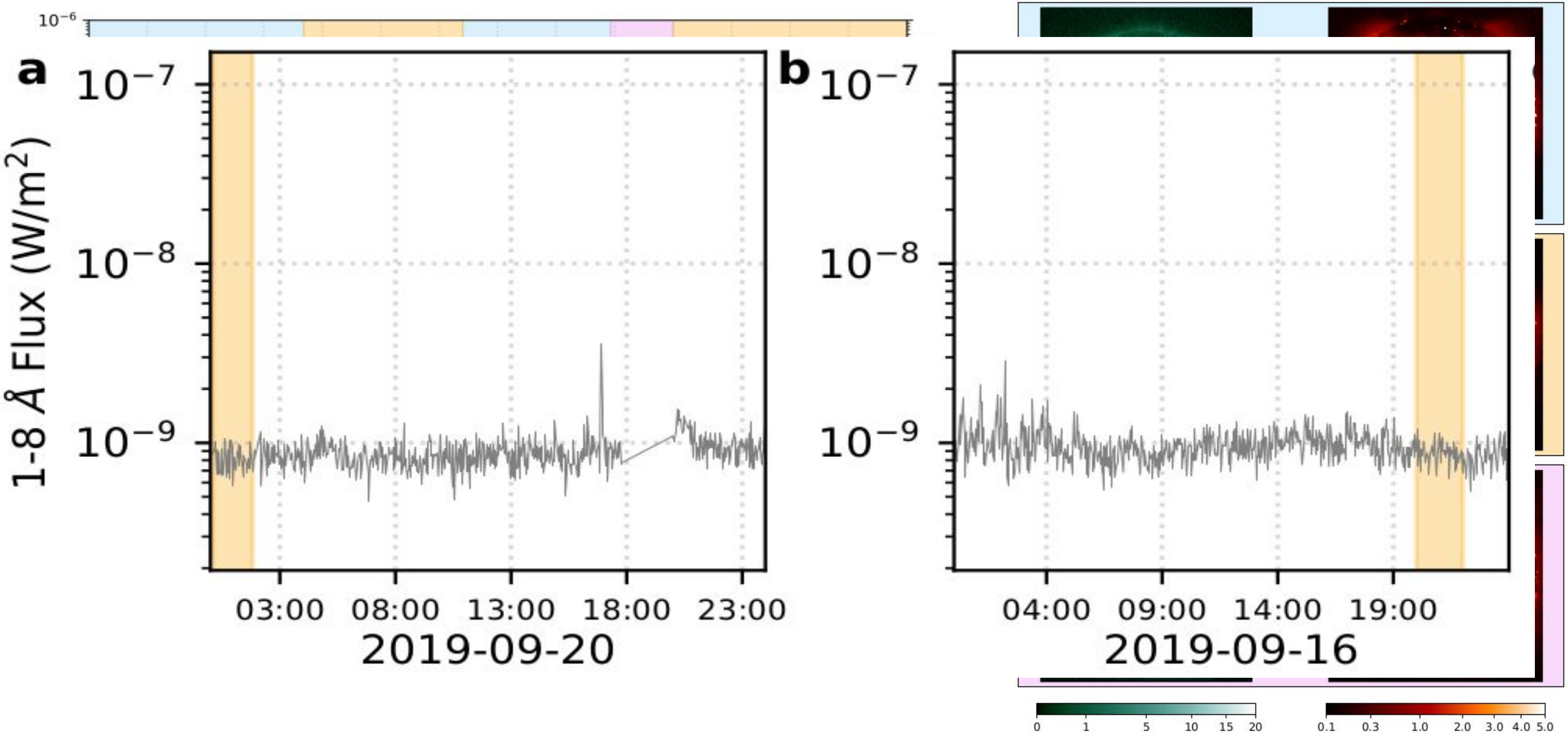

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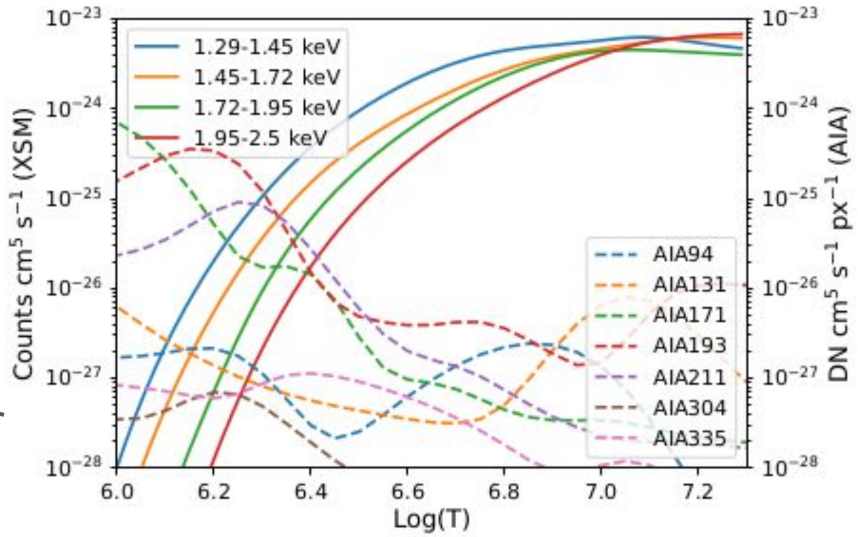
Motivation

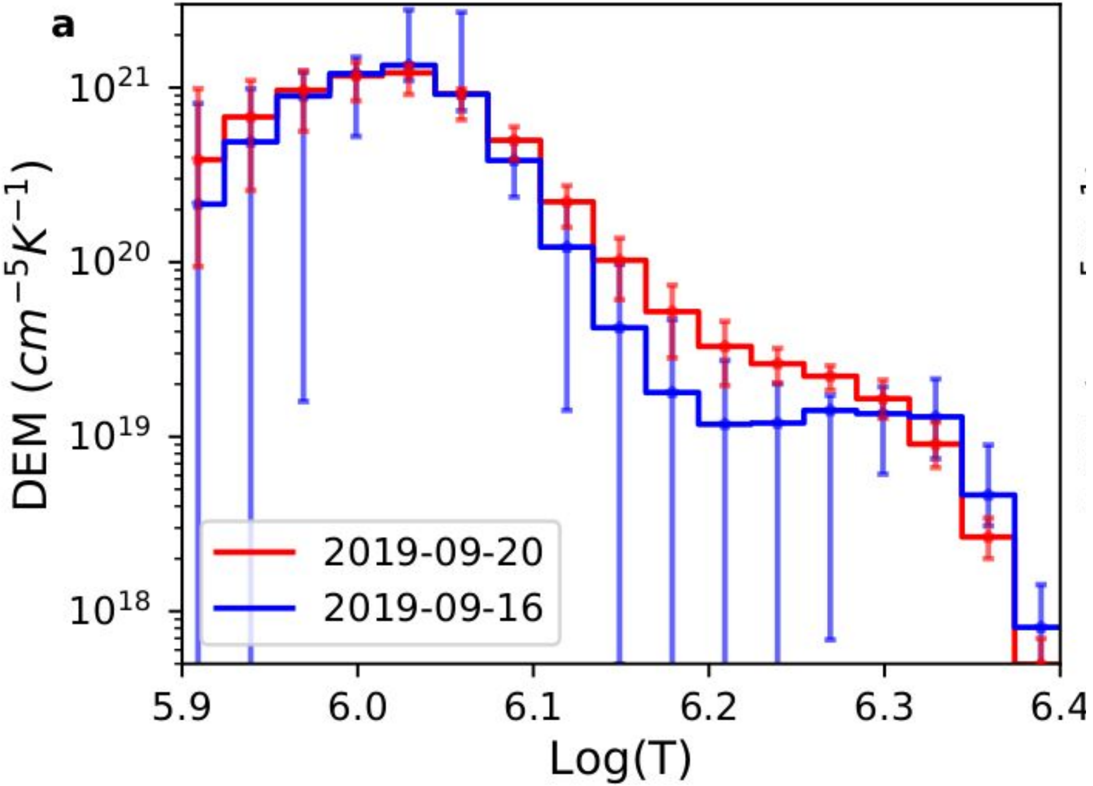
- What fraction of the total quiet Sun X-rays contributed by the XBPs and at what temperatures?

- What is/are the origins behind the heating of XBPs?
    - derive DEM for full Sun
    - DEM for X-ray emitting regions (XER)

$$O_i = \int_T DEM(T)\, R_i(T)\, dT + \delta O_i$$

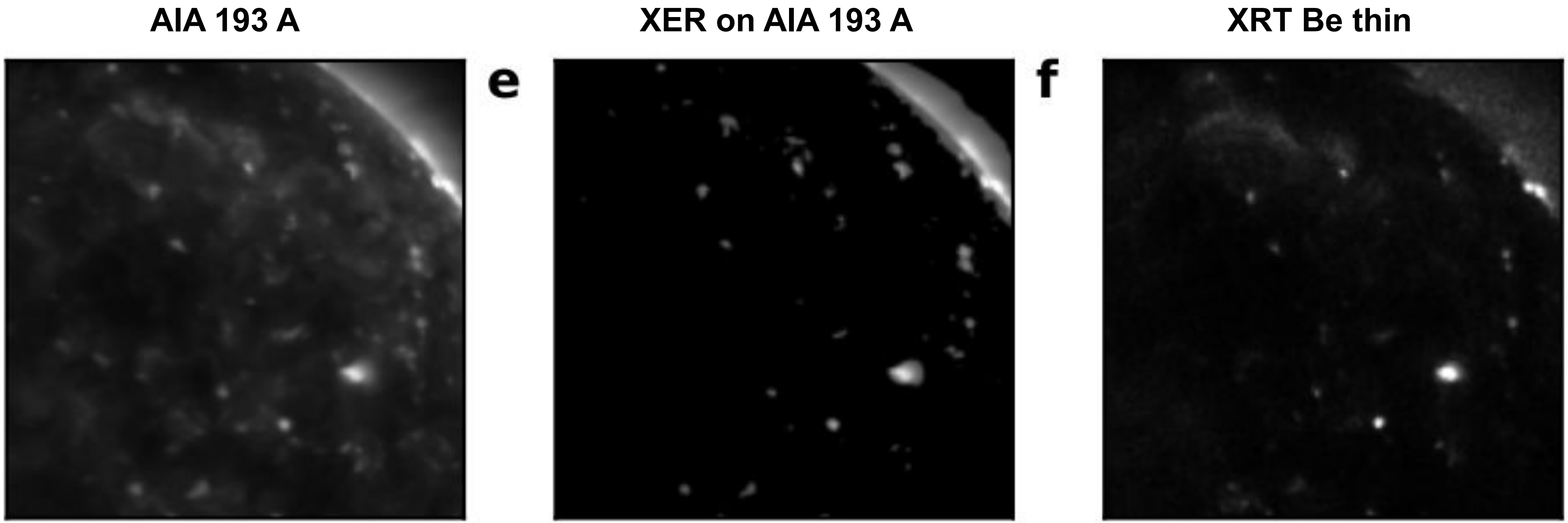


DEM of Full Sun



- DEM peak near 1 MK is similar to the earlier studies of QS DEM, e.g., Lanzafame et al. 2005; Brooks et al. 2009; Del Zanna 2019

Extracting the XER emission from AIA



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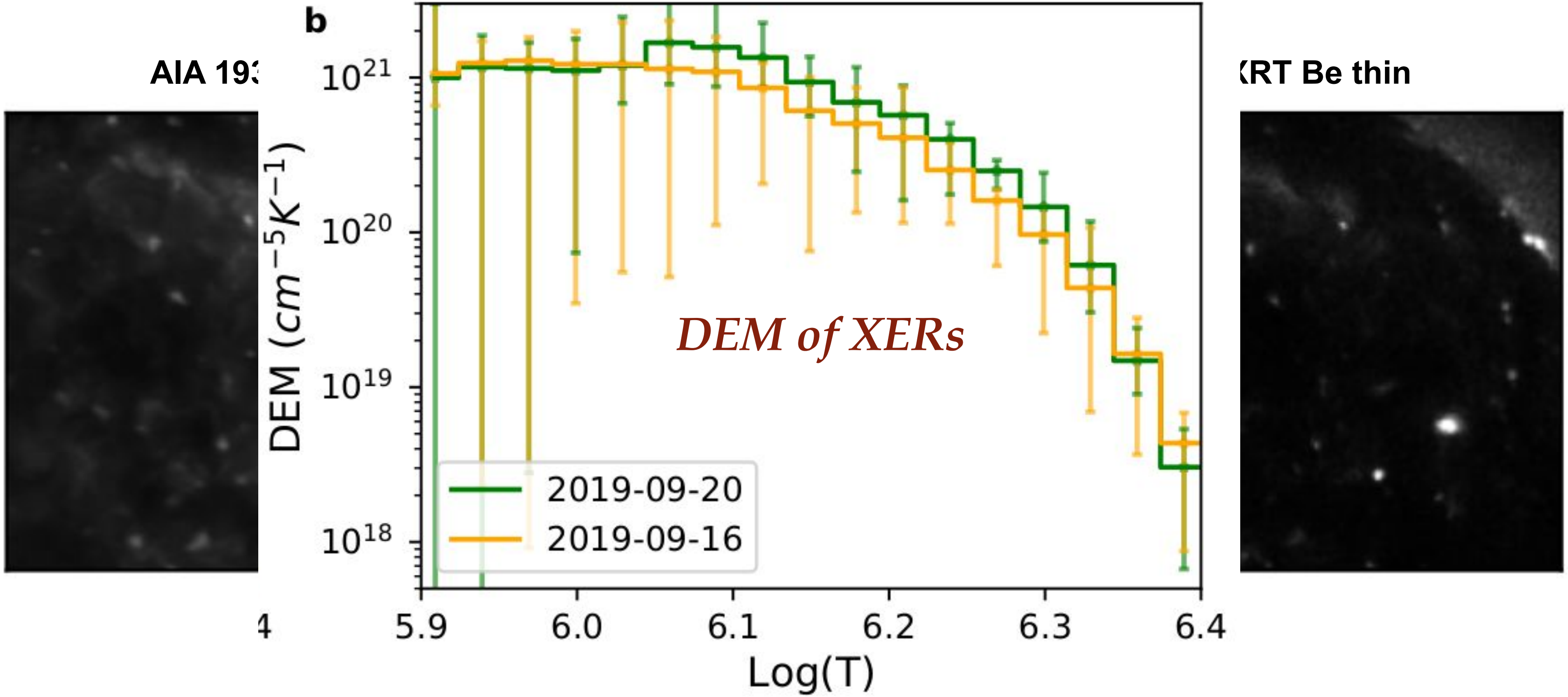
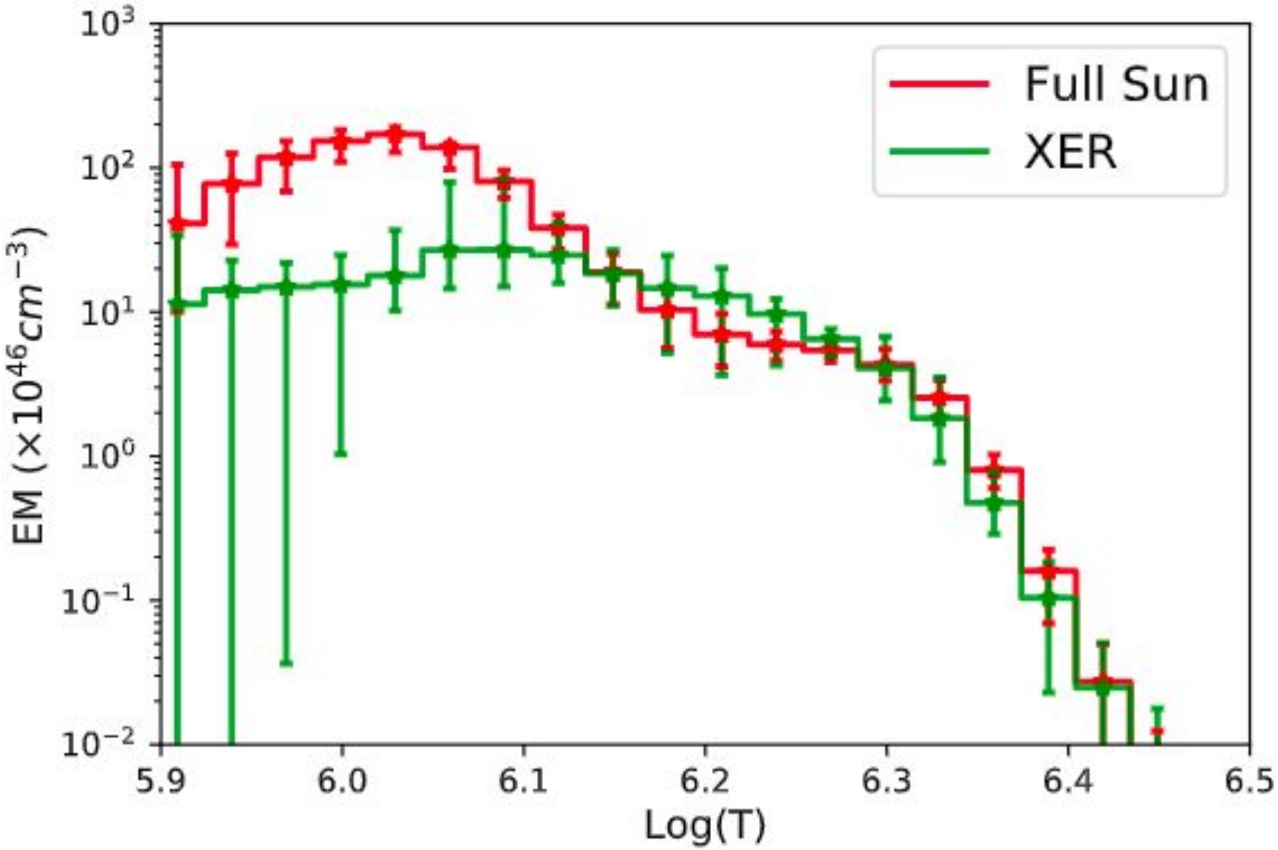
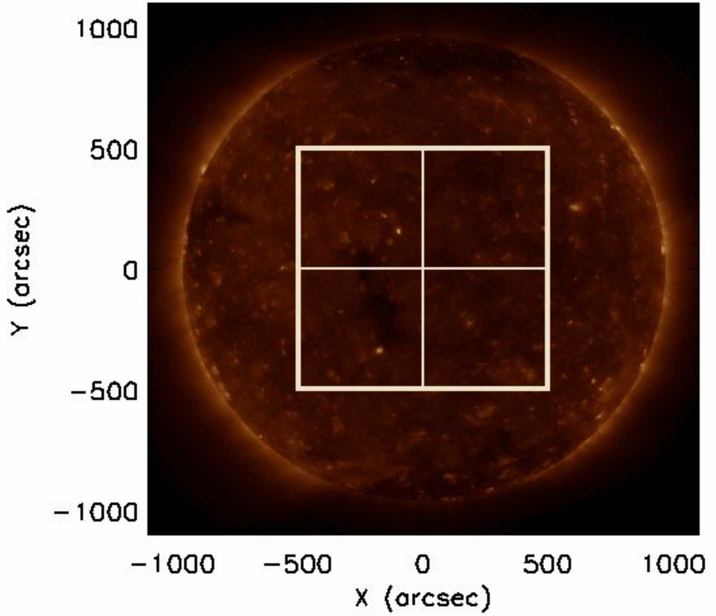


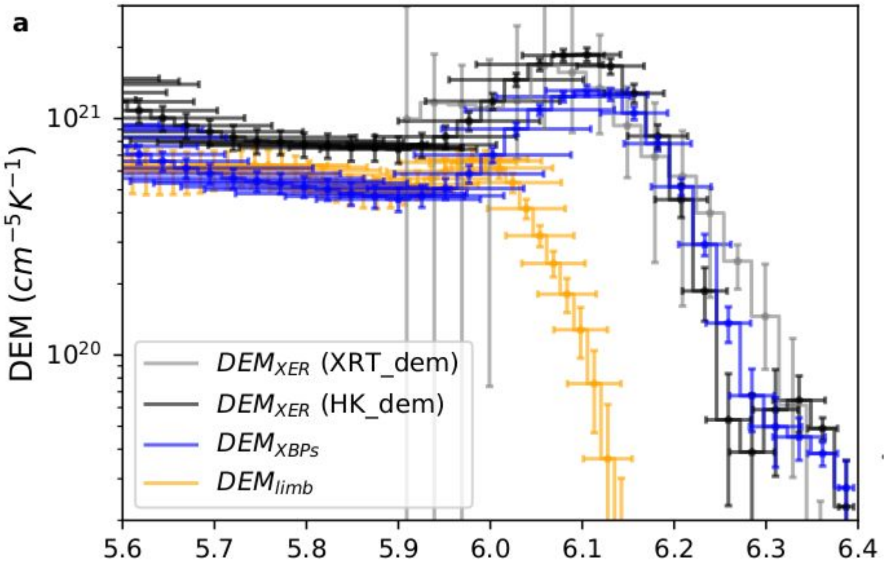
Full sun vs XERs



- XER —> XBPs + limb brightenings

DEM of XBPs



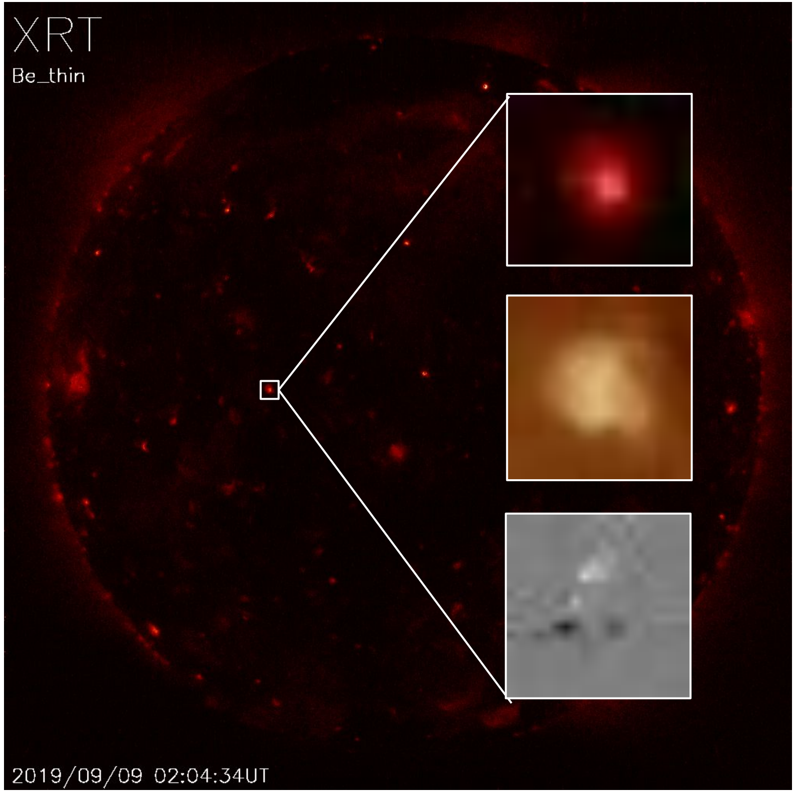


$$\mathcal{R} = \sum_i EMD(T_i)\,\Lambda(T_i)$$

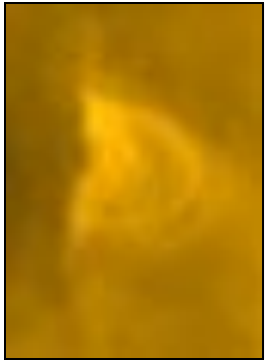
DEM used	$\mathcal{R}(5.6 \leq logT \leq 6.1)$ (erg cm^{-2} s^{-1})	$\mathcal{R}(6.1 \leq logT \leq 6.4)$ (erg cm^{-2} s^{-1})
$DEM_{FullSun}$	0.78×10^5	0.09×10^5
DEM_{XER}	1.69×10^5	1.01×10^5
DEM_{XBPs}	1.08×10^5	0.87×10^5

- At lower temperature the radiation loss from the diffuse corona is significant whereas at higher temperature it is negligible.
- At lower temperature XBPs emission is more than 63%, while at higher temperature it is more than 85%

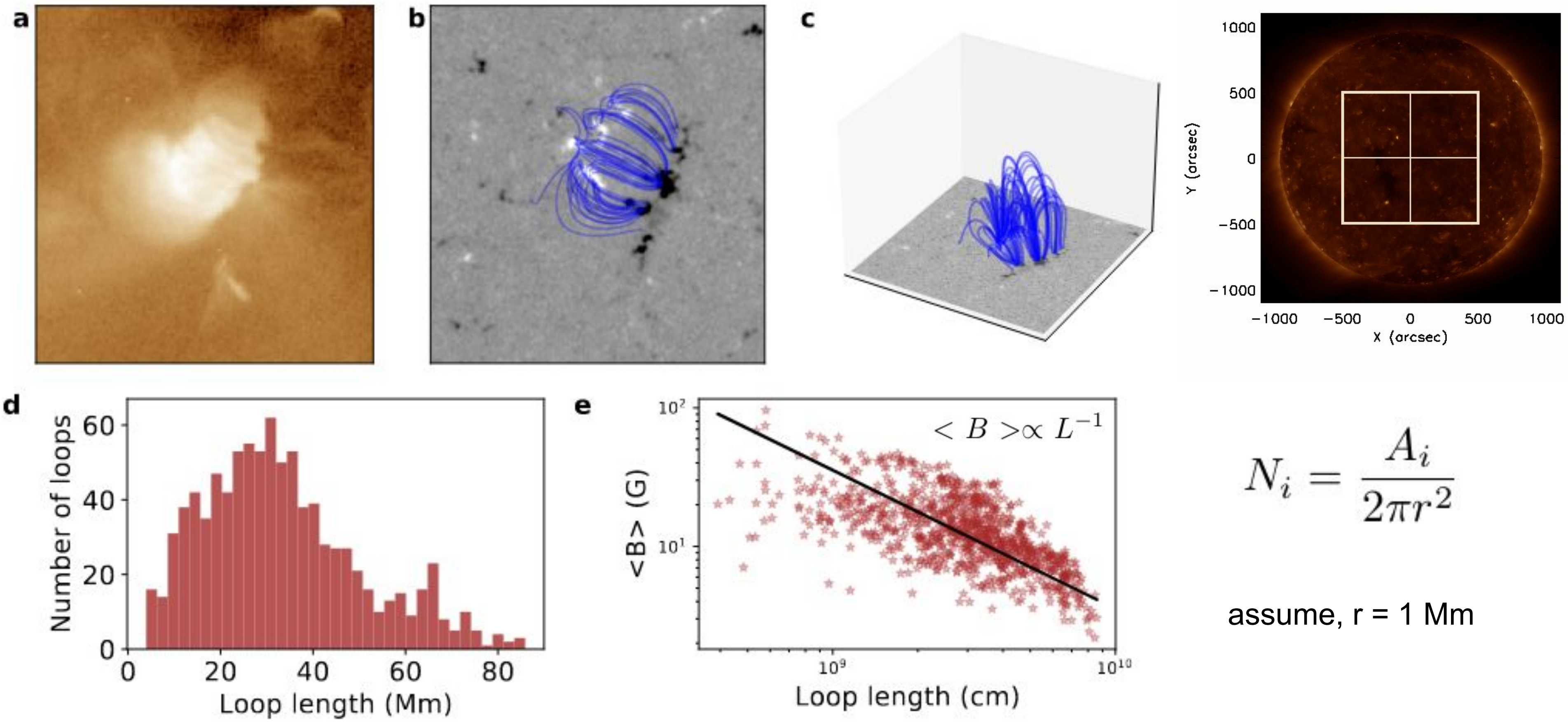
Can nanoflares be responsible to heat the XBPs?



- Modeled the XBP's assuming nanoflare heating scenario.
- Estimate the simulated DEM, which is compared with the observed DEM.
- We modeled the XBP loops using EBTEL model (Klimchuk et al. 2008; Cargill et al. 2012; Barnes et al. 2016).



Magnetic skeleton of XBPs



$$N_i = \frac{A_i}{2\pi r^2}$$

assume, r = 1 Mm

Heating function

- Here we consider that nanoflares occur with the release of stored magnetic energy (Parker, 1988)
- Magnetic stored energy density :

$$E = \frac{(tan(\theta) < B >)^2}{8\pi}(erg\ cm^{-3})$$

- $\tan(\theta) = c$ –> 0.2 − 0.3, to satisfy observed coronal heating requirement (Parker 1988; Klimchuk 2015).
- Consider triangular heating profiles having a duration (τ) of 100 s.
- The peak heating rate during an event is randomly chosen between minimum (H_0^{min}) and maximum (H_0^{max}) values that are loop dependent.

$$H_{0_{ij}}^{max} = \frac{1}{\tau}\frac{(c < B >_{ij})^2}{8\pi}(erg\ cm^{-3}\ s^{-1})$$

$$H_0^{min} = 0.01\ H_0^{max}$$

$$d_{ij}^l = \frac{\tau L}{F} \times H_{ij}^{l-1}$$

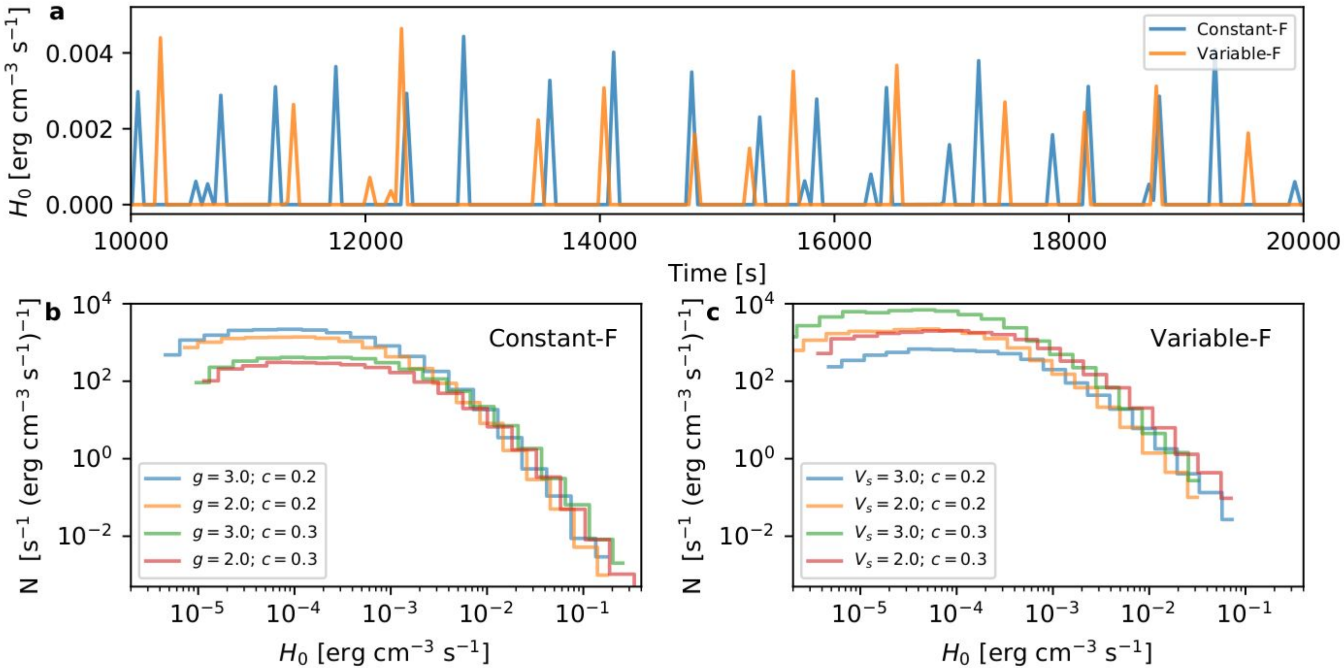
H_0 is randomly chosen between minimum (H_{0ij}^{min}) and maximum (H_{0ij}^{max}) for a loop.

- Model parameters → *c* and *F*

Heating function

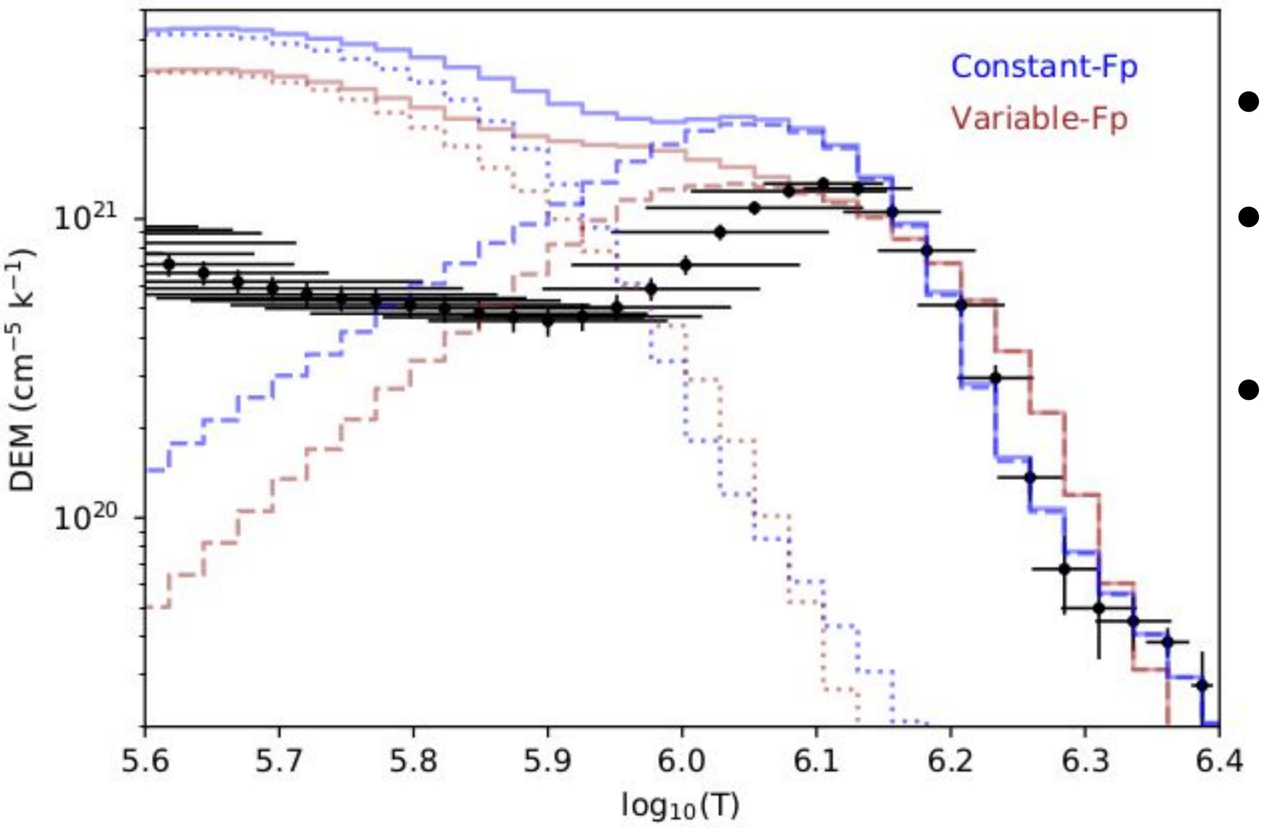
Coronal radiation loss

- Constant *F:* $$F = g \times \boxed{1.95 \times 10^5 \; (erg \; cm^{-2} \; s^{-1})}$$; *g* —> 2 to 3 (Klimchuk et al. 2008)
- Variable *F:* $$F_{ij} = -\frac{1}{4\pi} V_h \tan(\theta) \; B_{ij}^{base} < B >_{ij}$$; V_h —> 0.5 to 2 km/s



L =30 Mm
< B >=10 G
c = 0.25
g = 2.0
V_h=1 km/s
B_{base} = 15 G

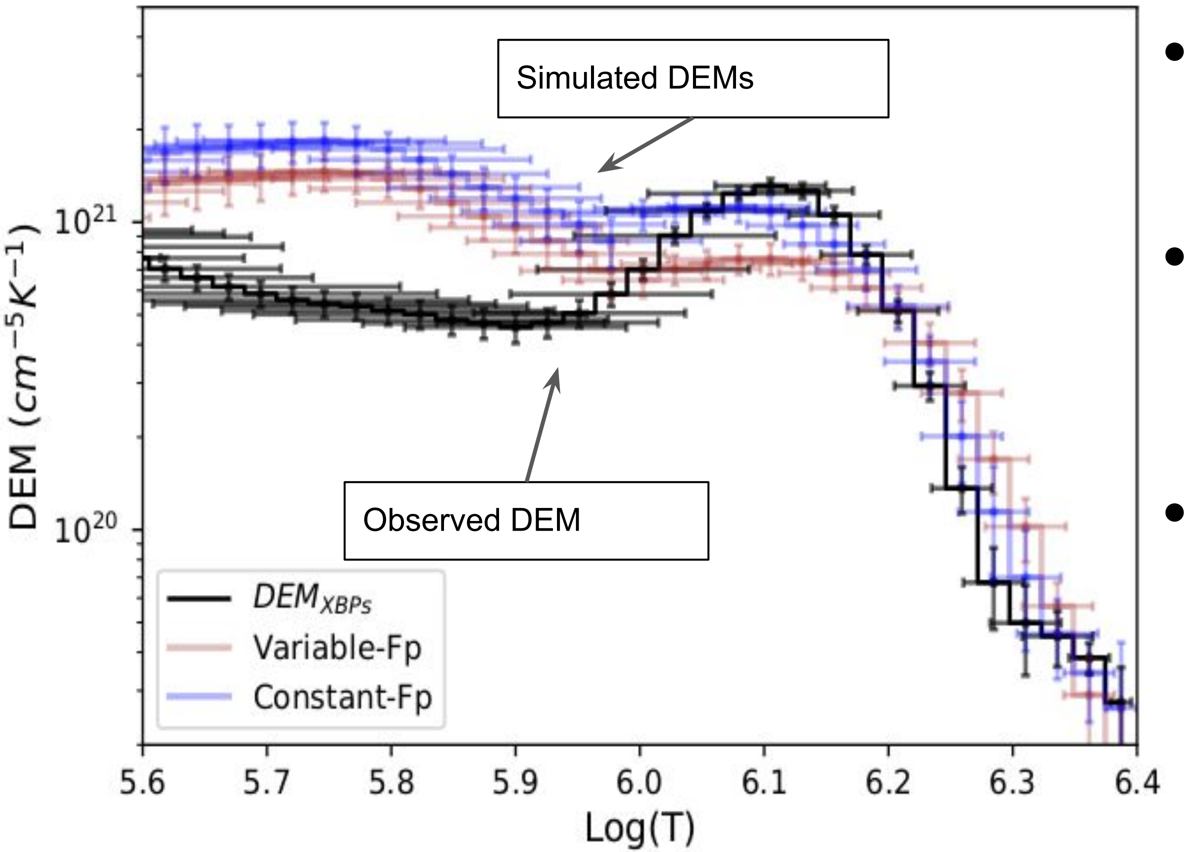
Simulated and Observed DEMs



- Matches well at logT>6.0
- What happened for logT < 6.0?
- Could be due to the poorly constrained DEM at lower temperatures by AIA??

- c = 0.21, g = 2.47, V = 1.5 km/s

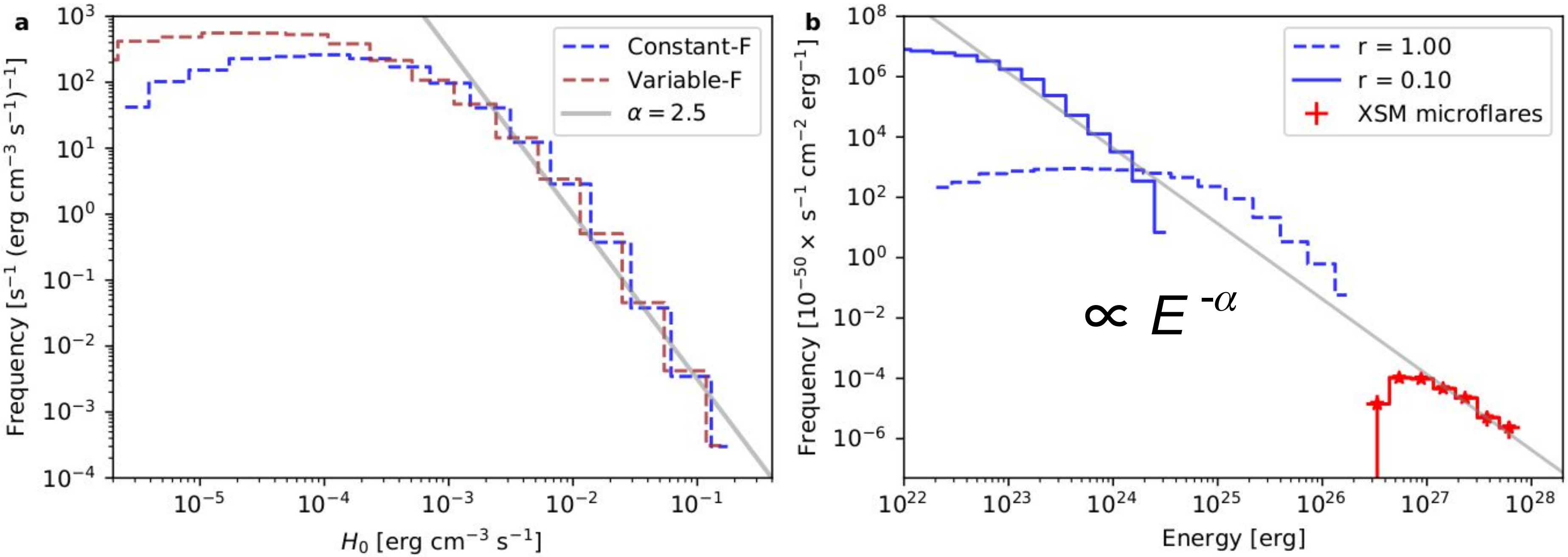
Simulated DEM convolved with instrument responses



- Still, model DEM predicts 2-3 times higher emission at lower T.
- Simulated TR predicts a larger emission than the observed one —> common (e.g., Warren et al. 2008) in loop simulations.
- Possibility – absorption TR emission by frequent chromospheric jets, such as spicules (De Pontieu et al. 2009)

➢ Agreement for the coronal portion of the loops are remarkable, suggesting nanoflare can mentioned the heating of XBPs.

Frequency distribution of the nanoflares



- A power-law slope of -2.5 indicates that combined energy of nanoflares is more compared to the energy of their bigger counterparts, namely, flares or microflares.

Summary

- Carried out a prolonged investigation of the quiet solar corona by separating out the contributions from its various emission components in the Sun-as-a-star mode observations.
- Most of the quiet or diffuse corona emit at low temperatures (log T < 6.1). In contrast, most emission above log T = 6.1 originate from XBPs.
- Agreement of the observed & simulated emissions for the coronal portion of the loops are remarkable, suggesting nanoflare can mentioned the heating of XBPs.
- The frequency distribution of nanoflares are found to follow a power-law with a slope close to -2.5, suggesting that combined energy of nanoflares is more compared to their bigger counterparts, namely, flares or microflares.
- The frequency distribution becomes flatter at very lower energies, indicating that very small loops with higher magnetic field strengths are not contributing here.

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Thank You for your attention!