DEM INVERSION FAILURES DURING SOLAR FLARES

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BACKGROUND

Plasma emits different amounts of light in different wavelengths depending on its temperature and composition.

Solar flares are extremely energetic phenomena in the solar atmosphere, caused by magnetic field lines reconnecting (Fig. 1). This reconnection heats the surrounding plasma (ionized gas) to millions of kelvin, causing it to emit light in a broad spectrum, including in the extreme ultra-violet (EUV).

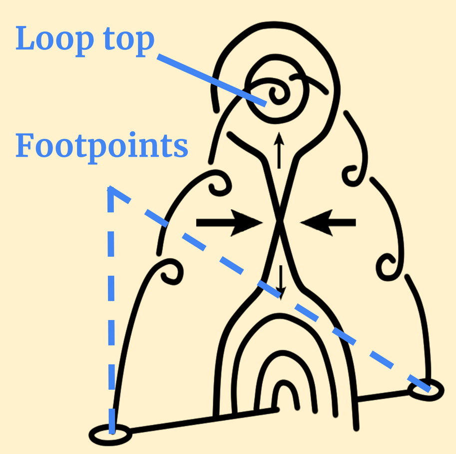

Figure 1. Diagram of magnetic field lines for a typical solar flare. Reconnection of field lines occurs at the pinch point.

By taking images of the Sun in several wavelengths and analyzing the intensity of light at each pixel, we can find the temperatures present in the emitting plasma.

For a pixel of an image taken in a wavelength λ, its brightness y_λ is given by:

$$y_\lambda = \int_0^\infty K_\lambda(T)\ DEM(T)\ dT$$

y_λ	amount of light observed in wavelength λ (data from image)
K_λ	encodes camera information and how plasma emits light at different temps, calculated from plasma properties and telescope parameters
$DEM(T)$	gives information regarding plasma temperature profile integrated along line-of-sight

The Differential Emission Measure (DEM) is calculated by inverting this equation. This is an ill-posed problem, but solutions can often be found.

The Differential Emission Measure (DEM) characterizes plasma temperature distributions. We calculate it via DEM inversion.

METHOD

Flare	Class	Time	AR #	AIA Channels
1	X6.9	20110809 07:48	11263	94 Å, 131 Å, 171 Å, 193 Å, 211 Å, 335 Å
2	X1.6	20140910 17:20	12158	

We analyzed two X-class flares using data from the Atmospheric Imaging Array (AIA) [3, 4]. We calculated standard equilibrium response functions via CHIANTI [2], and then used these to calculate DEMs via the sparse inversion method [1] for each pixel and timestep.

We found where AIA data was unreliable (oversaturated), but it did not overlap entirely with the DEM failures. We also noted a distinction between the DEM method failing to converge and the DEM having no solution at all.

We found that DEMs failed at the tops of flare loops because no solution could exist.

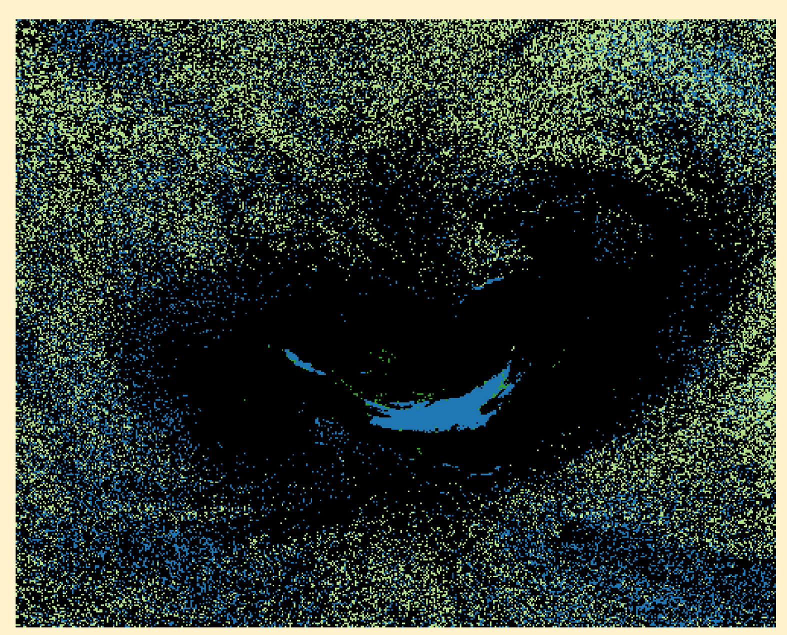

Figure 2. The implementation of the sparse DEM inversion method [1] that we used provided reasons for the failures we found.

Blue regions represent where the problem has no solution.

Green regions represent unbounded solutions.

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[1] Cheung, M. C. M., Boerner, P., Schrijver, C. J., et al. 2015, The Astrophysical Journal, 807, 143, doi: 10.1088/0004-637x/807/2/143

[2] Dere, K. P., Zanna, G. D., Young, P. R., & Landi, E. (2023). CHIANTI—An Atomic Database for Emission Lines. XVII. Version 10.1: Revised Ionization and Recombination Rates and Other Updates. *The Astrophysical Journal Supplement Series*, 268(2), 52. doi: 10.3847/1538-4365/acec79

[3] Lemen, J.R., Title, A.M., Akin, D.J. *et al.* The *Atmospheric Imaging Assembly* (AIA) on the *Solar Dynamics Observatory* (SDO). *Sol Phys* **275**, 17–40 (2012). doi: 10.1007/s11207-011-9776-8

[4] Pesnell, W.D., Thompson, B.J. & Chamberlin, P.C. The *Solar Dynamics Observatory* (SDO). *Sol Phys* **275**, 3–15 (2012). doi: 10.1007/s11207-011-9841-3

RESULTS

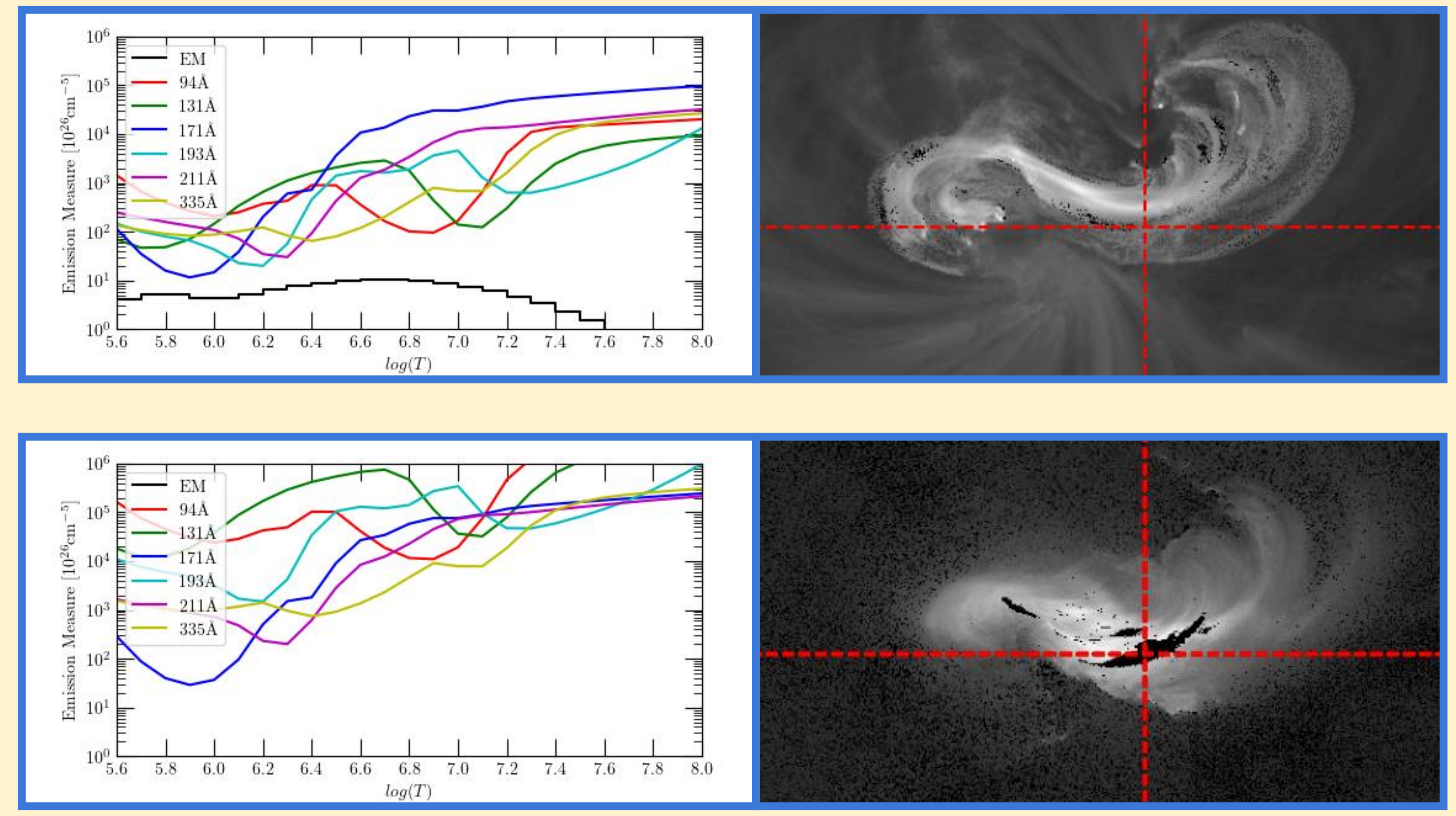

Figure 3. **Pre-flare (left), post-flare (right). Top:** The DEM summed over temperature for the 2014 flare. Pink indicates where data is oversaturated. A pixel is indicated by +. **Bottom:** For the pixel indicated, we compute EM loci curves, and show a derived DEM solution in black when it exists.

Pre-flare, we see noisy non-convergence.

After, failures are localized to the tops of the loops.

The EM loci curves (y_λ / $K_\lambda(T)$) represent the maximum isothermal emission that can match the data from a given channel. We consider the implications of Fig. 3.

- Pre-flare, a DEM solution can be derived to explain the observations.
- Post-flare, the jump in channels 94 Å and 131 Å is consistent with significant emission from high-temperature plasma, which would conflict with the constraints imposed by other channels and result in no solution.
- This may suggest that at the loop tops there is departure from equilibrium, contrary to the assumptions made in computing the shape of K_λ.

We see that the DEM inversion method fails at the tops of flare loops for our case studies. Our analysis suggests that this may be due to high-temperature plasma that is out-of-equilibrium at these locations.