An Exploration of Episodic Heating in a Solar Quiet Region Bright Coronal Loop

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Abstract

The main purpose of this project was to quantify a quiet-region bright coronal loop's bursty heating relative to its steady heating. We hoped that aspect of the heating of this loop would give clues to the longstanding fundamental solar-astrophysics problem of how the Sun's global corona is kept heated to mega-Kelvin temperatures. Our analysis of a quiet-region bright coronal loop is a follow-on to the similar analysis in the study of Tiwari et al. (2023, ApJ, 942, 2) of the variation of an active region's AIA hot-94 Å emission (from 4 - 8 MK plasma) over 24 hours. We use 171 and 211 Å 3-minute-cadance images of the loop from the Atmospheric Imaging Assembly (AIA) of the Solar Dynamics Observatory (SDO) over 41 hours. From them, we make maps of the maximum, minimum, and average brightness in each pixel for each 3-minute step of a time window of width ranging from 41 hours down to 30 minutes, and obtain the loop's luminosity in each 211 map and each 171 map. From that, we get the ratio of the loop's luminosity in the maximum-brightness map to that in the average-brightness map and the ratio of the loop's luminosity in the minimum-luminosity map to that in the average-brightness map for each time step of each running time window. We found our quiet-region bright loop's behavior in 171 emission (from 0.6 MK plasma) and in 211 emission (from 2 MK plasma) during the 41 hour interval was similar to but less bursty than the active region's behavior in hot-94 emission over the 24 hour interval. For the loop's 171 and 211 emission, at least a tenth of the loop's coronal heating is in 0.25 - 1 hour bursts and less than nine tenths is steady for an hour or more. For the active region's hot-94 emission, at least two thirds of the luminosity is in 0.25 - 1 hour bursts and less than a third is steady for an hour or more. In addition, for our quiet-region loop, we found that a peak in 211 luminosity usually leads a corresponding peak in 171 luminosity by 0.25 - 1 hour. This suggests that the loop's bursty coronal heating is in flare-like bursts that heat sub-strands of the loop initially to temperatures greater than 2 MK, and each newly heated hot sub-strand cools down first through 2 MK and then through 0.6 MK.

Goal

- To quantify diffuse heating and transient heating of an instance of explosive loop heating in quiet Sun

Background

- In Tiwari *et al. (2023),* the method of investigating solar coronal heating by creating minimum, maximum, and average maps was introduced.
- In this project, we use the same method.
- Previous work has suggested that coronal heating is mostly steady.
- Magnetograms show that our bright coronal loop is purely bipolar.

Method

1. A minimum brightness map is made by taking each pixel's minimum value from the entire 41 hours of 171 Å images stepped at 3 minutes
2. Similarly, maximum and average brightness maps are made by taking the corresponding values over the full 41 hour period in 171 Å
3. These steps are repeated for the 24h, 20h, 16h, 12h, 8h, 5h, 3h, 1h, and 0.5h time windows
4. The sum of all pixels in the loop's box in each minimum-/maximum-/average-brightness map is the box's luminosity in the map
5. Using the total luminosity, ratios of the min-to-avg brightness and max-to-avg brightness are found and are plotted over time
6. The same procedure is followed for the same time windows in 211 Å

Results

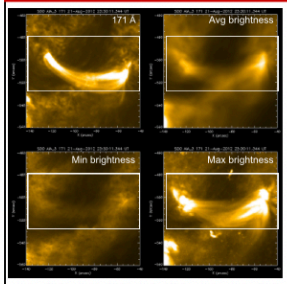

Figure 1: The 171 Å loop. Top left: Single image. Top right: 41-hr average-brightness map. Bottom left: 41-hr minimum-brightness map. Bottom right: 41-hr maximum brightness map. The white box outlines the area summed for the loop's luminosity.

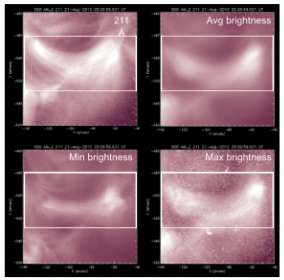

Figure 2: The 211 Å loop. Each panel is the same as in **Figure 1**, but from 211 Å images.

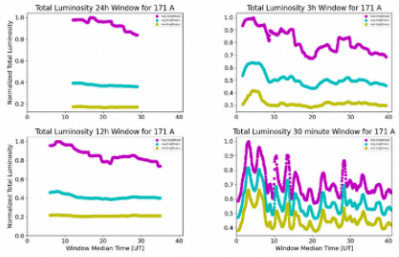

Figure 3: Time plots of the 171 Å loop's map luminosities for running time windows of width 24h (top left), 12h (lower left), 3h (top right), and 30 min (bottom right). In each panel, the loop's max-brightness map's luminosity is magenta, its average-brightness map's luminosity is cyan, and its minimum-brigthness map's luminosity is yellow.

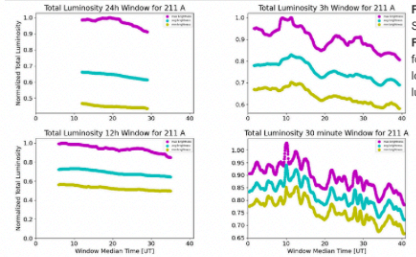

Figure 4: Same as **Figure 3,** but for the 211 Å loop's map luminosities.

- **Figures 3 & 4** show that the loop's dynamic behavior shows more in the loop's 171 Å and 211 Å map luminosities as the time window width decreases. The heating bursts are more obvious in the narrower time windows.

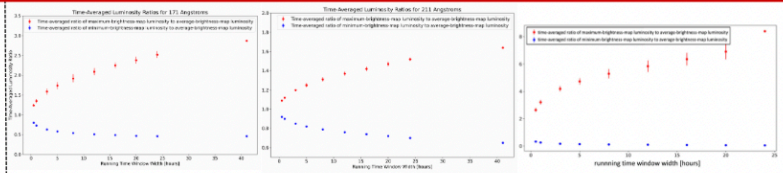

Figure 5: The first panel shows the max-to-avg ratios (red) and the min-to-avg ratios (blue) as the time window increases from 41 hours to 30 minutes in 171 Å in the quiet region bright coronal loop. In the second panel, we see the corresponding information for 211 Å. The third panel is from Tiwari *et al. (2023)* and shows the max-to-avg ratios and the min-to-avg ratios as the time window increases from 24 hours to 30 minutes in the active region that is investigated in that paper. The three plots demonstrate similar heating trends in the quiet and active regions of the Sun

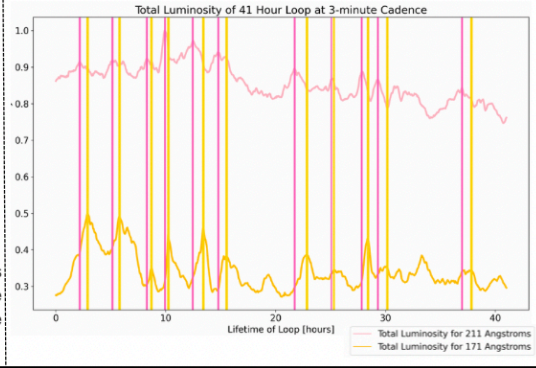

Figure 6: Time plots of the loop's 211 Å luminosity (pink) and 171 Å luminosity (yellow). Each prominent bursts lasts of order 1 hr. Each of the 11 marked 171 Å burst peaks lags a corresponding 211 Å burst peak. The lags range from about 0.25 hour to about 1 hour. The average lag is 40 min.

Main Findings and Next Steps

- The episodic (bursty) heating in the quiet-region coronal loop was similar to but less pronounced than that found from an active region's hotter emission by Tiwari *et al. (2023)*.
- The loop's bursty heating is flare-like in that the loop strands heating in each burst evidently brightens in 211 Å emission from 2 MK temperature plasma and then in 171 Å emission from 0.6 MK plasma via post-flare cooling of the strand's suddenly heated coronal plasma
- **Future work:** This project explored only one quiet-region bright coronal loop. We plan to analyze several more such loops the same way.

References

Tiwari *et al* 2023 *ApJ,* 942, 2
Lemen *et al* 2011 *Solar Physics*. 275. 17-40

Acknowledgments

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