Characterizing Steady and Bursty Coronal Heating of a Solar Active Region

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Abstract

One of the biggest problems in solar physics today is our inability to explain why the solar corona is so hot. In this project, we aimed to quantify transient and background coronal heating for a given active region in order to better understand coronal heating. We used SDO/AIA data of the active region NOAA 12712 observed on May 29, 2018 over a period of 24 hours with a 3-minute cadence. We calculated FeXVIII emission (hot component of AIA 94 Å channel) by removing warm components using AIA 171 and 193 Å channels. From the maximum, minimum, and mean brightness values of each pixel over the full 24 hour period, we made maximum, minimum, and mean brightness maps. We repeated this process in moving time windows of 16 hours, 8 hours, 5 hours, 3 hours, 1 hour, and 30 minutes. We used the total luminosity from each of these maps over time to make time-luminosity lightcurves that show the evolution of maximum, minimum, and mean luminosity over time for each running window. Finally, we took the ratios of the maximum luminosity and the minimum luminosity to the mean luminosity, and plotted these ratios over time. The average maximum to mean ratio was 8.40±0.00, 6.36±0.46, 5.29±0.34, 4.73±0.24, 4.19±0.19, 3.21±0.17, and 2.64±0.15 and the average minimum to mean ratio was 0.053±0.00, 0.08±0.00, 0.12±0.01, 0.14±0.02, 0.17±0.02, 0.26±0.02, and 0.33±0.03 for 24h, 16h, 8h, 5h, 3h, 1h, and 30m windows, respectively. As expected, the ratio of minimum luminosity to mean luminosity increased as the time window decreased, and the ratio of maximum luminosity to mean luminosity decreased as the time window decreased. As such, the ratio of background to mean luminosity is a new and effective technique to quantify the background intensity of the active region. The 24h window value of 5% for this ratio means that at most 5% of the luminosity of the AR at a given time comes from steady heating. This upper limit on the steady-luminosity fraction of the AR's mean luminosity increases to 33% for the 30-minute running window.

Background

- Coronal heating is currently a big issue in solar physics.
- Two primary forms of transient heating:
  - Nano flare heating from entangled magnetic field lines (Parker 1983, 1988)
  - Wave heating from convection (e.g., van Ballegooijen et al. 2011)

Goals

- Uncover background and transient coronal heating within an active region
- Quantify ratio of background to transient heating

Data

- 24 hours of SDO/AIA data with 3 minute cadence from active region NOAA 12712 on May 29, 2018.
- "hot 94 Å" data
  - FeXVIII emission at 6-8 MK.
  - Calculated by removing warm components using AIA 171 and 193 Å channels (Tiwari et al. 2021).
  - Chose this wavelength because emphasized hottest loops.

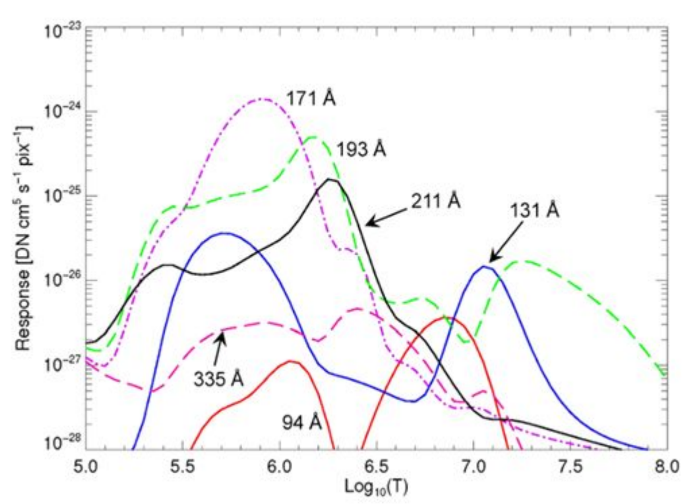

Figure 1: Plot of temperature response functions of various AIA channels. This project focused on intensities within the second 94 Å peak (from Lemen et al, 2012).

Methods

1. Find the minimum brightness of each pixel over the 24h period to create total min brightness map.
2. Repeat this process but with maximum and mean brightness to create total max brightness and total mean brightness maps.
3. Repeat this process with cadence to create movie of mean/max/min brightness over 6 different moving time windows (16h, 8h, 5h, 3h, 1h, 30m).
4. Overlay HMI contours to the above images of the AR.
5. Estimate noise by averaging background of the mean 24h map.
6. Find total luminosity of each 24h map using noise filtered signals (mean/max/min).
7. Repeat this process for each window to visualize total luminosity over time.
8. Take ratio of maximum and minimum total luminosity to mean luminosity to quantify background and transient heating.

Results

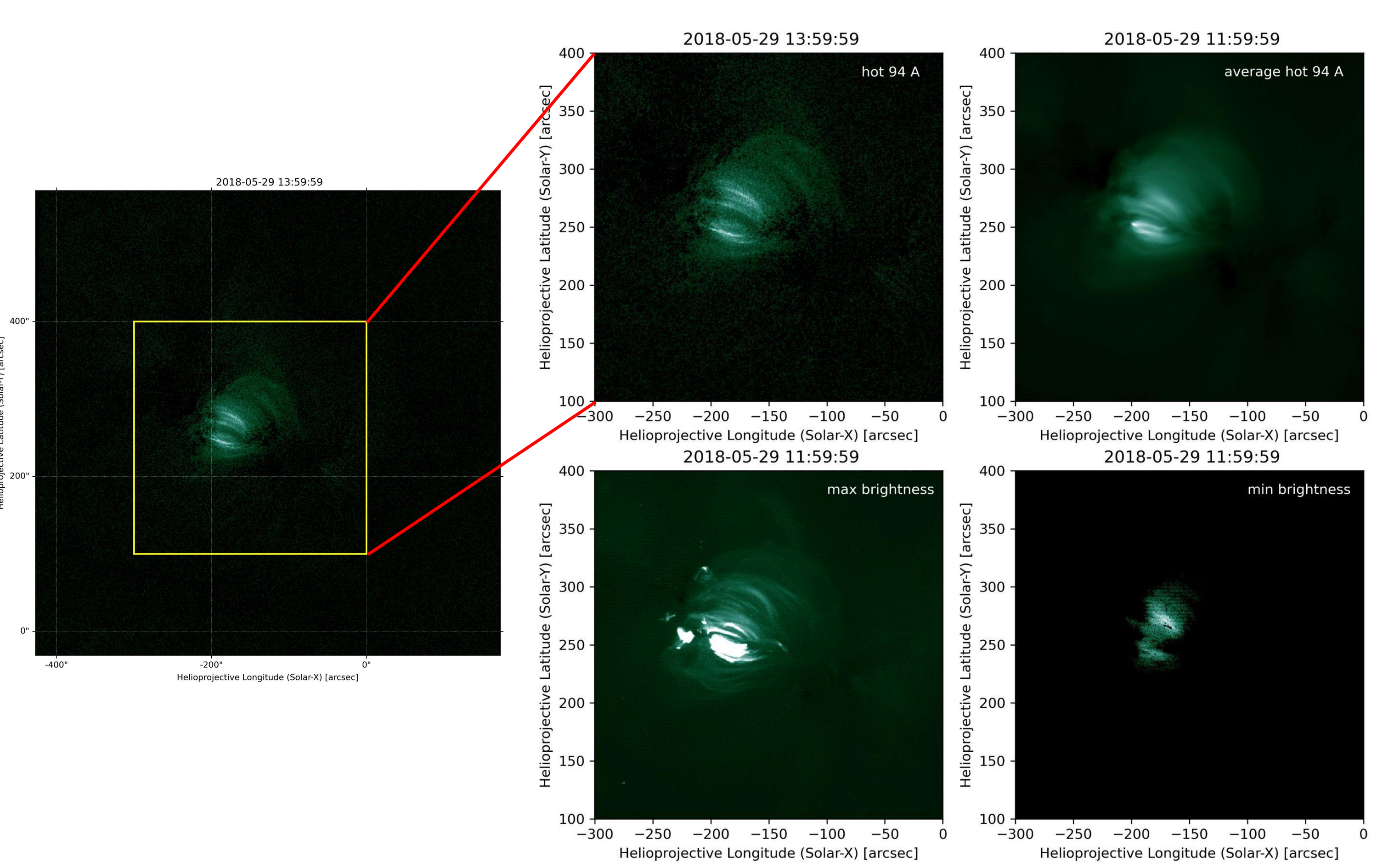

Figure 2: 4-panel image showing the first image of the data set (hot 94 Å), the mean pixel values over 24h (mean brightness map), the max pixel values over 24h (maximum brightness map), and the min pixel values over 24h (minimum brightness map), clockwise starting from the top left. Similar maps were made for the 16h, 8h, 5h, 3h, and 30m running windows.

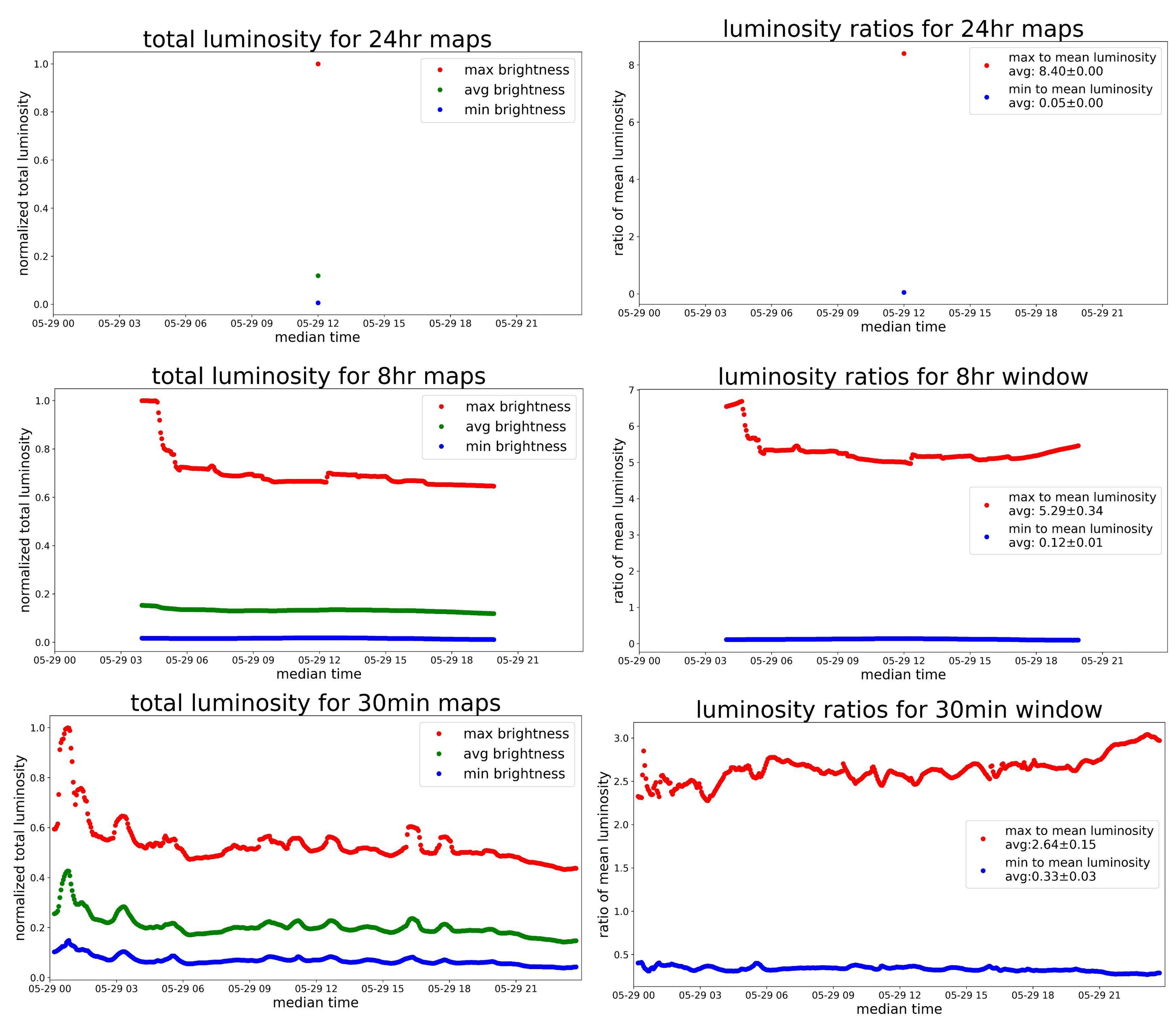

Figure 3: Lightcurves (left) and ratio plots (right) for 24h (top), 8h (middle), and 30m (bottom) time windows. These windows were found to have an average max to mean ratio of 8.40 ±0.00, 5.29±0.34, and 2.64±0.15 (from top to bottom). They were found to have an average min to mean ratio of 0.053 ±0.00, 0.12±0.01, 0.33±0.03 (from top to bottom).

Results (continued)

Time window	24 h	16 h	8 h	5 h	3 h	1 h	30 m
Avg max to mean ratio	8.40±0.00	6.36±0.46	5.29±0.34	4.73±0.24	4.19±0.19	3.21±0.17	2.64±0.15
Avg min to mean ratio	0.053±0.00	0.08±0.00	0.12±0.01	0.14±0.02	0.17±0.02	0.26±0.02	0.33±0.03

Table 1: Table showing results of ratio analysis for 24h and all running time windows.

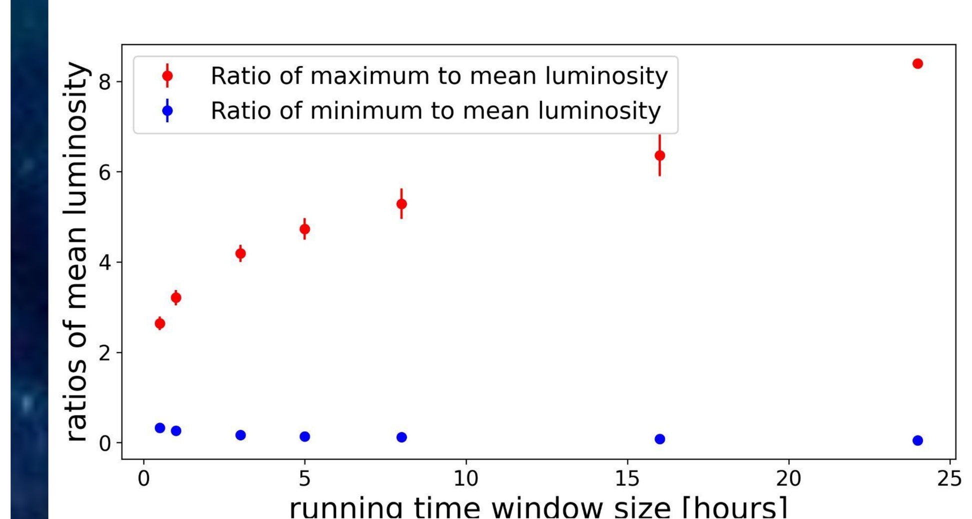

Figure 4: Results of average ratio analysis for all time windows. The average max to mean ratio is plotted in red, and the average min to mean ratio is plotted in blue. As expected, the ratio of background to mean luminosity increased as the time window decreased, and the ratio of transient to mean luminosity decreased as the time window decreased.

Discussion & Conclusions

- Creating minimum and maximum brightness maps is a new and effective technique that can help to quantify the background intensity and transient heating of active regions (in the way presented here for one active region).
- 24h window result suggests that at most 5% of the luminosity of the AR at a given time comes from the steady background heating. This upper limit increases to 33% for the 30m running window.
- By quantifying steady loops, we can see how the background evolves in time and how much background could contribute to overall heating.
- Future directions: Utilizing min/max brightness maps to explore potential sources of coronal heating.

References

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