Analyzing and Modeling Shear of Post-Reconnection Flare Loops



Abstract

Solar flares are events of increased radiation caused by heated plasmas confined in magnetic loops formed by magnetic reconnection. Astronomers have been attempting to observe and model flare loops for many decades. Previous investigations of solar flare loops have observed strong to weak shear as a phenomenon. Shear is the complementary angle between the projected flare loop and the polarity inversion line that divides the positive and negative magnetic fields on the surface of the Sun. However, 2D magnetic models of flare loops cannot account for shear. This necessitates a quantitative analysis of shear over time and a comparison of loop observations to 3D magnetic models. In this project, working with AIA's observations of the X1.0 flare on October 28th, 2021 in three different bandpasses, many thousands of flare loops were detected to calculate the shear over time. These observations confirm the trend of strong to weak shear in this flare as the flare progresses. Additionally, these observed loops were compared to a potential field and linear force free models which did not align with all the observed loops. This suggests that the magnetic field model must be further advanced to match the observed flare loops and explain the phenomenon of shear.

2021 October 28 Flare

- X 1.0 class
- Duration: 15:17 UT 15:48 UT
- Peak: 15:35 UT
- Observed by SDO
- Analysed loops using AIA observations in the 94 Å, 335 Å, and 171 Å wavelengths



Flare Structure

in 1600 AIA of flare loops that are rooted in positive and negative magnetic flux

- Polarity Inversion Line (PIL): the line that separates the positive and negative magnetic flux in the photosphere, generally between flare ribbons
- Shear: 90° minus the angle between the projected flare loops and the the PIL



HMI magnetic map (black and white represent ± magnetic flux), Flare ribbons (red) and a section of the PIL from the magnetic map (green)

- Previous observations have observed a trend of strong to weak shear as the flare progresses
- However, quantified measurements of this phenomenon are scarce
- There are multiple parts of the PIL and only one section was used to investigate shear

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Tracing Loops

- Used OCCULT program to detect projected flare loops that cross the PIL • Loops measured from 15:00 UT until 18:00 UT as they first appeared in the AIA maps
- Program allowed tracking of thousands of loops • AIA 171 (6.3•10⁵ K): 10141 flare loops
- AIA 335 (2.5•10⁶ K): 7163 flare loops
- AIA 94 (6.3•10⁶ K): 8877 flare loops
- Shear calculated and plotted over time



Sample plot of traced post-reconnection flare loops in the 171 Å bandpass plotted over a section of the AIA





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using HMI magnetogram as the boundary conditions.

$$\overrightarrow{F} = \overrightarrow{J} \times \overrightarrow{B} = 0$$

- Where:
- $\circ \alpha = 0$ is a potential field
- $\circ \alpha$ = *const*. Is a linear force free field
- $\circ \alpha \neq const.$ Is a non-linear force free field
- Modeled flare loops are traced from flare ribbons

Sample of late observed loops in 171 Å

This work accomplished many goals including:

- Tracing thousands of post-reconnection flare loops at different wavelengths
- Confirming the evolution of strong to weak shear in multiple wavelengths over time
- In all wavelengths, the shear started between 40° and 80° before dropping down to about 20°
- The transition of strong to weak shear occurs within approximately 30 minutes
- There is a time delay of this trend across different temperatures

Future Studies should look into:

- Using this data to advance the magnetic model of solar flares • Examining strong to weak shear evolution with other flares

Models

• Models developed using a Lorentz force free magnetic fields based on these equations

$$\nabla \cdot \overrightarrow{B} = 0$$

 $\nabla \times \overrightarrow{B} = \mu \overrightarrow{J} = \alpha \overrightarrow{B}$

 α = 0.02, linear force free field

Conclusions

• Showing that observed flare loops do not match the current linear force free model

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