

## Toward Improved Understanding of Magnetic Fields Participating in Solar Flares

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#### How Do Photospheric Magnetic Fields Participating in the Flare Differ From Non-Flaring Magnetic Fields?

Flare ribbons, shown below, are the chromospheric footpoints of reconnected field lines

Plotting areas swept by ribbons on top of photospheric magnetic fields, we can identify flare-reconnecting B



#### Methods / Data

Main idea: analyze properties of **B** within ribbon, ARs and PILs.

Data: vector **B** and ribbon images from SDO.

We use these data to find magnetic flux, shear, current density, net current.









# PIL vs. Ribbon Morphology

We find that PIL regions and ribbons have different morphology

Below is an event where PILs <u>overlap</u> with ribbons

Here is another event where PILs <u>do not overlap</u> with ribbons

120110215\_0144\_11158\_X2.2

2020140107\_1804\_11944\_X1.2



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# Magnetic Fluxes

<u>On the right</u>: AR, ribbon and PIL magnetic fluxes vs. flare peak Xray flux

We find:

- I. Larger flares have larger PIL and rec. fluxes.
- 2. Confined flares
  (▲) have larger
  PIL fluxes



Flare peak X-ray flux,  $I_{X, peak}$  [ $W/m^2$ ]

## **Reconnection Flux Fraction**

<u>On the right</u>: reconnection flux fraction vs. flare peak X-ray flux:

We find:

- Moderate correlation between the flare peak X-ray flux and the fraction of AR magnetic flux participating in the flare
- Confined events (▲)
   have lower R<sub>Φ</sub>



# Mean Magnetic Shear

<u>On the right</u>: mean magnetic shear within AR, ribbon and PIL vs. flare peak X-ray flux:

We find:

- Mean shear increases from AR to ribbon and PIL areas.
- Weak correlation between shear and flare size.
- Confined flares (▲) have lower PIL shear.



### Net current proportional to shear at PIL

12

8



We find that vertical currents are

- Neutralized over AR as a whole,
- Non-neutralized over individual polarities,
- On the left: We find that net current within ribbon is proportional to the mean shear at PIL confirming earlier case studies & simulations



Eruptive vs. Confined Events



We find that for a given X-ray flux **confined** events have:

larger PIL fluxes,

lower PIL shear &

lower net current than eruptive events.

#### We find that for **eruptive** events:

CME speed has the strongest correlation with the reconnection flux fraction (rs=0.6) vs. flare peak X-ray flux (rs=0.3) or the net current (rs=0.4).

#### Which physical quantities correlate with others most?

- Let us look at correlation matrix with Spearman Correlation Coefficients.
- Quantities that correlate most with the <u>peak X-ray flux</u>:
  - Reconnection flux (0.9)
  - Total current within ribbons (0.8)
- Quantities that correlate most with the <u>CME speed</u>:
  - Reconnection flux fraction (0.6)
- Quantities that correlate most with the <u>net current</u>:
  - PIL shear (0.7)

| Flux: AR      | 1.0         | 0.8  | 0.8  | 0.0  | 0.7    | 0.3   | 0.1      | 0.4      | 0.6      | 0.8         | 0.1    | 0.0   | -0.4     | 0.1                | -0.0   | -0.4   | 0.6    | 0.1    |
|---------------|-------------|------|------|------|--------|-------|----------|----------|----------|-------------|--------|-------|----------|--------------------|--------|--------|--------|--------|
| Flux: rbn     | 0.8         | 1.0  | 0.7  | 0.6  | 0.7    | 0.4   | 0.2      | 0.2      | 0.9      | 0.7         | 0.3    | -0.1  | -0.4     | 0.3                | -0.0   | -0.2   | 0.9    | 0.3    |
| Flux: PIL     | 0.8         | 0.7  | 1.0  | 0.2  | 0.8    | 0.6   | 0.4      | 0.4      | 0.7      | 1.0         | 0.3    | 0.2   | -0.3     | 0.4                | 0.2    | -0.1   | 0.6    | 0.0    |
| Flux Fraction | 0.0         | 0.6  | 0.2  | 1.0  | 0.3    | 0.2   | 0.3      | -0.3     | 0.6      | 0.1         | 0.2    | -0.2  | -0.2     | 0.4                | -0.0   | 0.1    | 0.5    | 0.6    |
| Shear: AR     | 0.7         | 0.7  | 0.8  | 0.3  | 1.0    | 0.7   | 0.3      | 0.3      | 0.6      | 0.8         | 0.2    | 0.1   | -0.4     | 0.3                | 0.1    | -0.2   | 0.6    | 0.2    |
| Shear: rbn    | 0.3         | 0.4  | 0.6  | 0.2  | 0.7    | 1.0   | 0.7      | 0.1      | 0.4      | 0.6         | 0.3    | 0.4   | -0.0     | 0.4                | 0.6    | 0.2    | 0.4    | 0.0    |
| Shear: PIL    | 0.1         | 0.2  | 0.4  | 0.3  | 0.3    | 0.7   | 1.0      | -0.2     | 0.2      | 0.4         | 0.1    | 0.3   | 0.0      | 0.7                | 0.7    | 0.5    | 0.2    | 0.2    |
| TotCur: AR    | 0.4         | 0.2  | 0.4  | -0.3 | 0.3    | 0.1   | -0.2     | 1.0      | 0.3      | 0.4         | -0.2   | -0.0  | 0.1      | -0.4               | -0.4   | -0.3   | 0.1    | -0.1   |
| TotCur: rbn   | 0.6         | 0.9  | 0.7  | 0.6  | 0.6    | 0.4   | 0.2      | 0.3      | 1.0      | 0.7         | 0.2    | -0.1  | -0.3     | 0.2                | -0.1   | -0.1   | 8.0    | 0.3    |
| TotCur: PIL   | 0.8         | 0.7  | 1.0  | 0.1  | 0.8    | 0.6   | 0.4      | 0.4      | 0.7      | 1.0         | 0.3    | 0.2   | -0.2     | 0.3                | 0.1    | -0.1   | 0.6    | -0.0   |
| MeanCur: AR   | 0.1         | 0.3  | 0.3  | 0.2  | 0.2    | 0.3   | 0.1      | -0.2     | 0.2      | 0.3         | 1.0    | 0.6   | -0.1     | 0.3                | 0.2    | -0.1   | 0.2    | 0.0    |
| MeanCur: rbn  | 0.0         | -0.1 | 0.2  | -0.2 | 0.1    | 0.4   | 0.3      | -0.0     | -0.1     | 0.2         | 0.6    | 1.0   | 0.1      | 0.2                | 0.4    | -0.1   | -0.0   | -0.3   |
| MeanCur: PIL  | -0.4        | -0.4 | -0.3 | -0.2 | -0.4   | -0.0  | 0.0      | 0.1      | -0.3     | -0.2        | -0.1   | 0.1   | 1.0      | -0.3               | 0.1    | 0.2    | -0.3   | -0.3   |
| DC/RC : AR    | 0.1         | 0.3  | 0.4  | 0.4  | 0.3    | 0.4   | 0.7      | -0.4     | 0.2      | 0.3         | 0.3    | 0.2   | -0.3     | 1.0                | 0.5    | 0.4    | 0.3    | 0.4    |
| DC/RC : rbn   | -0.0        | -0.0 | 0.2  | -0.0 | 0.1    | 0.6   | 0.7      | -0.4     | -0.1     | 0.1         | 0.2    | 0.4   | 0.1      | 0.5                | 1.0    | 0.4    | -0.0   | -0.2   |
| DC/RC : PIL   | -0.4        | -0.2 | -0.1 | 0.1  | -0.2   | 0.2   | 0.5      | -0.3     | -0.1     | -0.1        | -0.1   | -0.1  | 0.2      | 0.4                | 0.4    | 1.0    | -0.1   | 0.2    |
| X-ray flux    | 0.6         | 0.9  | 0.6  | 0.5  | 0.6    | 0.4   | 0.2      | 0.1      | 0.8      | 0.6         | 0.2    | -0.0  | -0.3     | 0.3                | -0.0   | -0.1   | 1.0    | 0.3    |
| CME speed     | 0.1         | 0.3  | 0.0  | 0.6  | 0.2    | 0.0   | 0.2      | -0.1     | 0.3      | -0.0        | 0.0    | -0.3  | -0.3     | 0.4                | -0.2   | 0.2    | 0.3    | 1.0    |
|               | A<br>R      | h    | ≓    | uo   | A<br>K | h     |          | AR<br>AR | hd       |             | A<br>R | h     |          | A<br>R             | uq.    |        | ХN     | eq     |
|               | X           | :×   | <br> | acti | ar: /  | ar: r | <u> </u> | nr:      | 1.:<br>T | ц<br>Ц      | :ur    | IL: L | <u>с</u> | $\frac{1}{\Omega}$ |        | ··· ;  | ay fl  | spe    |
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|               |             |      |      | Flux | S      | S     | S        | Ĕ        | Ē        | Ē           | lea    | lear  | lear     |                    | DC     |        | $\sim$ | S<br>S |
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|               | weak strong |      |      |      |        |       |          |          |          |             |        |       |          |                    |        |        |        |        |
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MaxDD. Convolation Math

### Conclusions

- Our analysis suggests that
  - flare peak X-ray fluxes and CME speeds are guided by the total amount of magnetic flux that participates in the reconnection process and the amount of the overlying field, rather than by the amount of PIL shear or AR net current.
  - **AR net current is proportional to the amount of shear at PIL** and is consistent with Ampere's law.
- As of know this study is the largest statistical analysis of flare vector magnetic fields within ribbon and PIL areas. Such approach is beneficial since it enables us to investigate general trends that may be overlooked in case studies of individual events.
- Thank you! Questions? Email me!