# Distribution and Development of Electric Current in Active Regions

Y. Liu(1), T. Török(2), J. Leake(3), X. Sun(1)

(1) Stanford University

(2) PSI

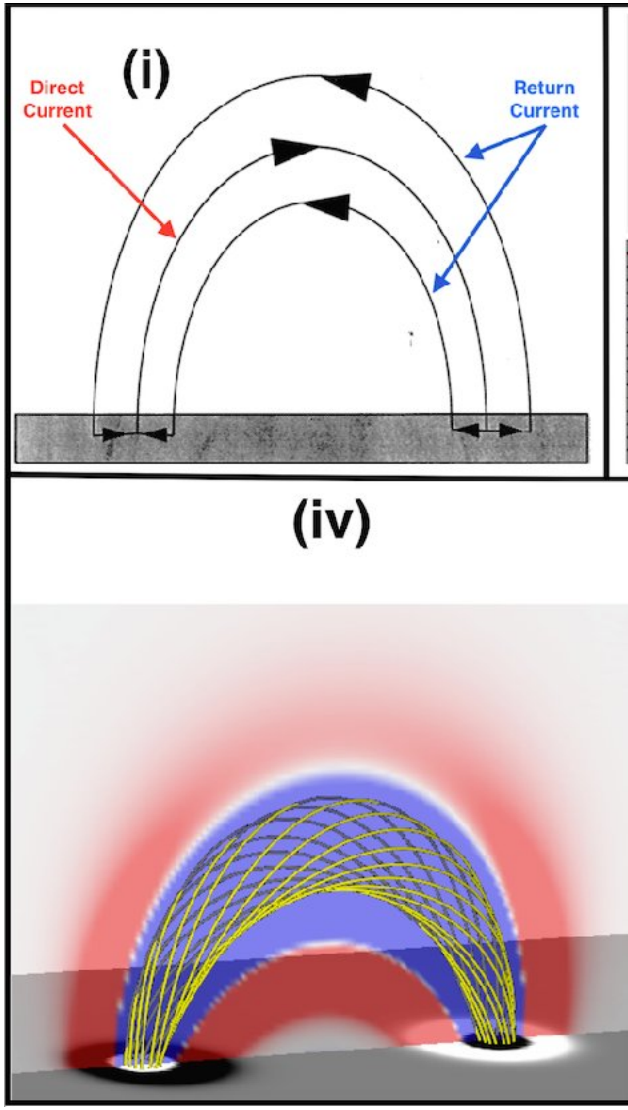
(3) NRL

# Introduction

Theoretically, direct electric current in an isolated magnetic tube should be balanced by return current, as illustrated in Panel (i).

Simulation (Török et al. 2014) shows  thst, in a simple flux tube, the direct current is balanced perfectly by the return current (see Panel iv).

So what does observation tell us? How does current distribute and evolve?



**Tests with simple sunspots (ARs 11084 and 11092) have shown direct current is well balanced with return current (Gosain et al. 2014).**

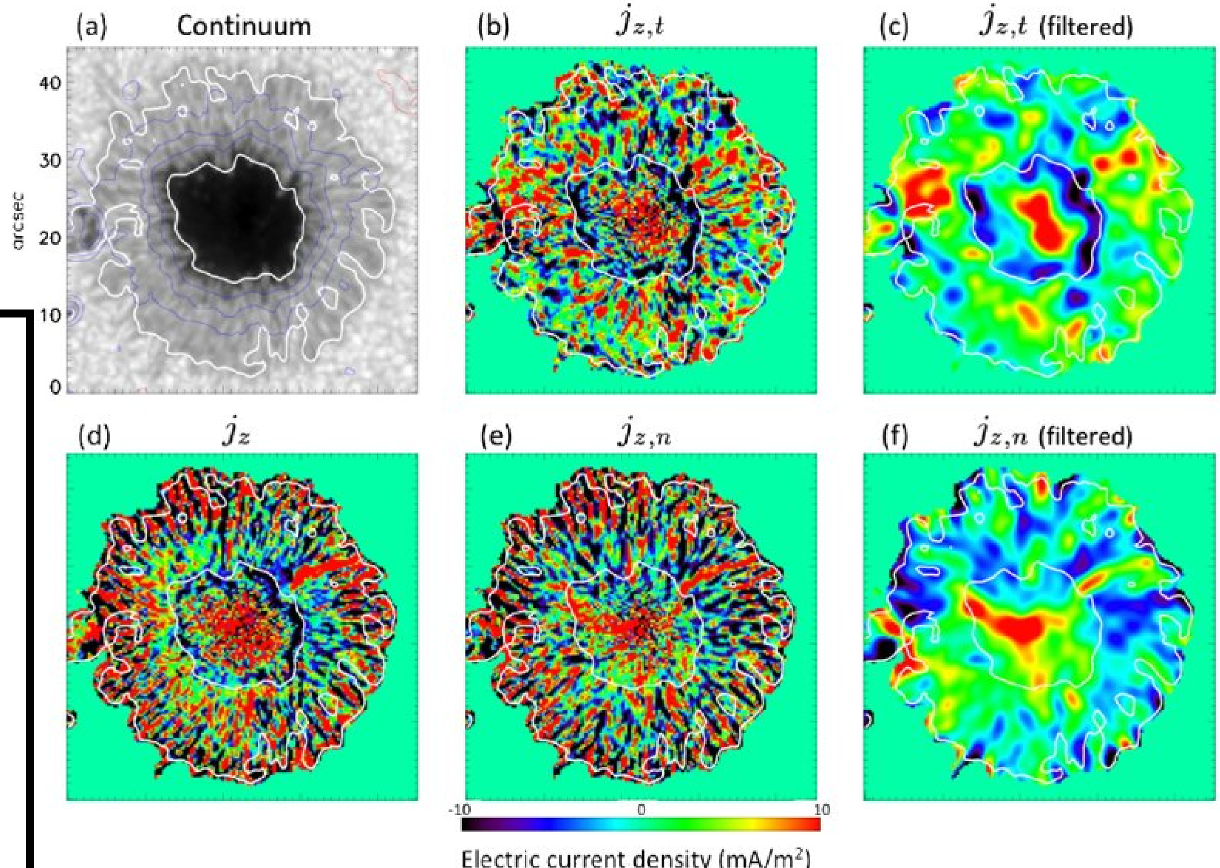



**Figure 6.** Same as Figure 5, but for NOAA 11092.
(A color version of this figure is available in the online journal.)

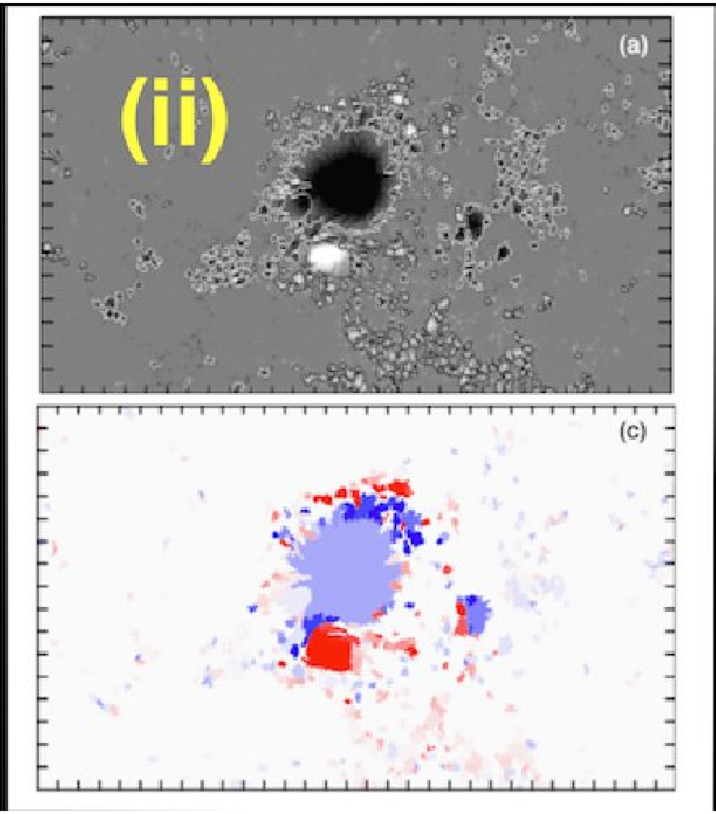
**Table 2**
The Current Imbalance (CI)

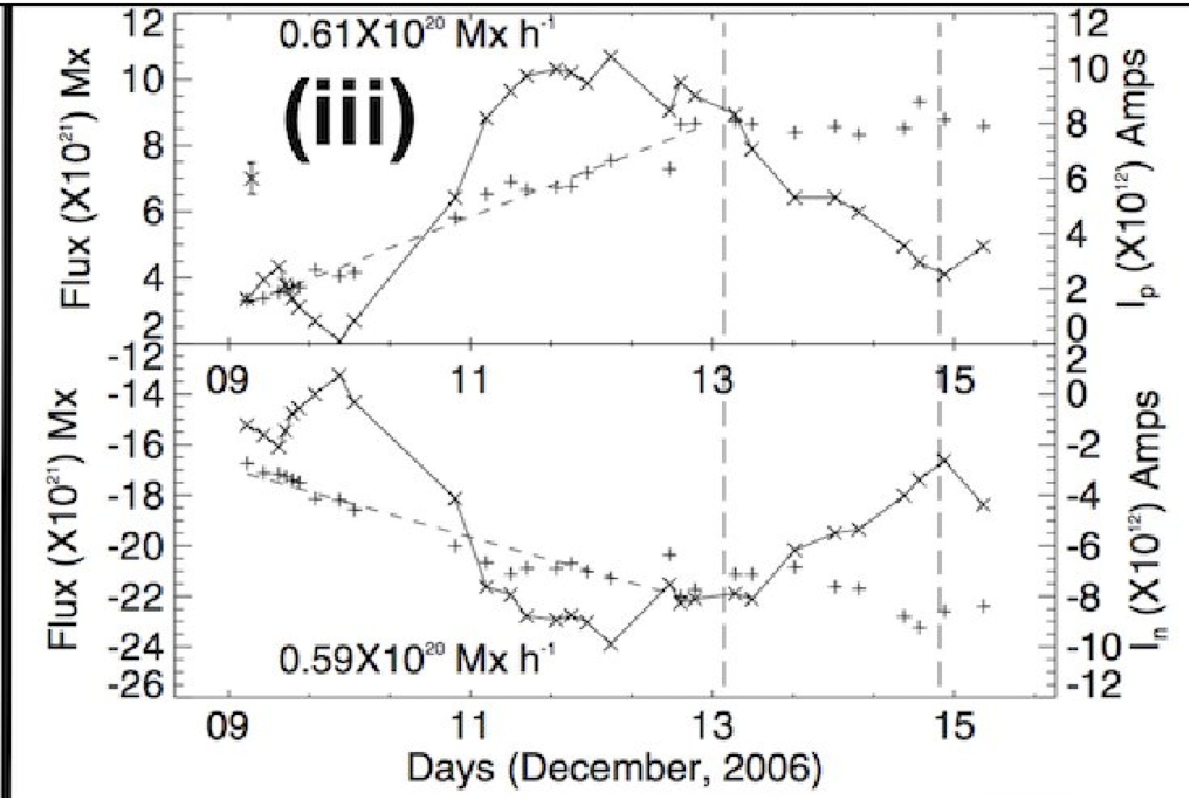
| Active Region No. | $J_z$ | $J_{z,t}$ | $J_{z,n}$ | $J^f_{z,t}$ | $J^f_{z,n}$ | $\Sigma\|J_z\|$ | $\Sigma\|J_{z,t}\|$ | $\Sigma\|J_{z,n}\|$ | $\Sigma\|J^f_{z,n}\|$ |
|---|---|---|---|---|---|---|---|---|---|
| NOAA 11084 | −11% | −34% | 9% | −69% | 38% | 5.3 | 3.1 | 4.9 | 1.2 |
| NOAA 11092 | 9% | 14% | −1% | 33% | −1.3% | 7.4 | 5.0 | 6.9 | 2.2 |

**Notes.** The current imbalance, CI(%)$=\Sigma_i j/\Sigma_i|j|$, is given in Columns 2–6. The summation is done over all the pixels above the noise threshold, as shown in Figures 5 and 6. The total unsigned current (in units of $10^{12}$ A) for the maps is given in Columns 7–10.

**Gosain et al. (2014)**

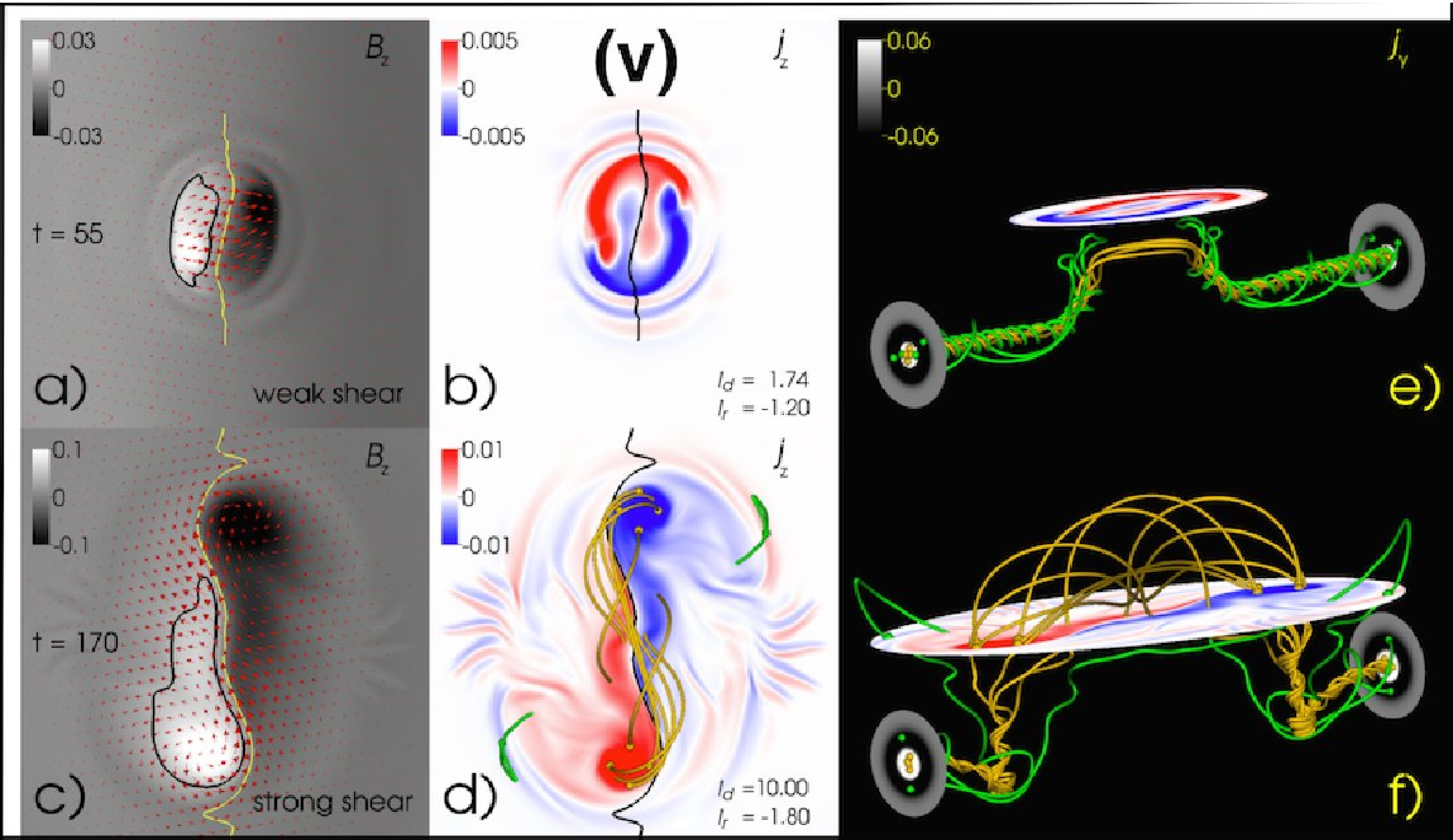
# Observation: AR 10930-eruptive AR




**Test with AR 10930 (complex and eruptive) showed significant imbalance between direct and return currents. Left: Bz (top) and Jz (bottom) from Georgoulis et al. (2012); right: temporal profiles of magnetic flux (cross) and net currents (solid lines) for positive and negative fields measured separately (Ravindra et al. 2011).**

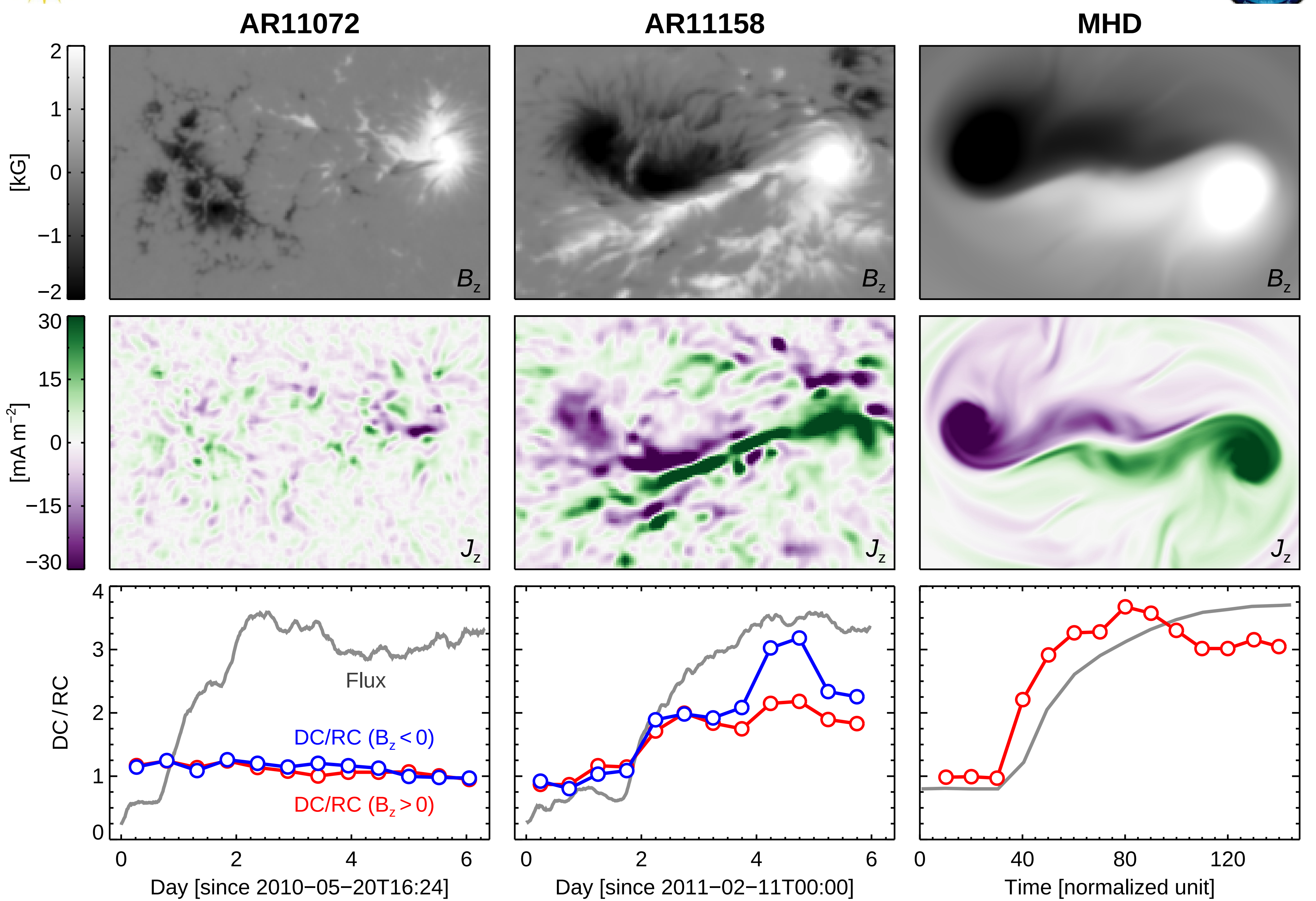
# Distribution and evolution of current: simulation



# Distribution and evolution of current: simulation

**Simulation of flux tube emergence (Török, et al. 2014). Panels a (Bz), b (Jz), e (current lines: direct current = yellow, return current = green): low magnetic shear. Panels c, d, f: emergence continues and shear increases. This simulation shows that**

1. **Current is balanced and the shear is small (panel b); it becomes imbalanced and shear increases (panel d).**
2. **Shear increases along the polarity inversion line (PIL) and current concentrates near the PIL (Panels c & d).**
3. **Return current is trapped below the photosphere (panel f).**



AR11072
AR11158
MHD
[kG]
2
1
0
−1
−2
$B_z$
[mA m$^{-2}$]
30
15
0
−15
−30
$J_z$
DC / RC
Flux
DC/RC ($B_z$ < 0)
DC/RC ($B_z$ > 0)
Day [since 2010−05−20T16:24]
Day [since 2011−02−11T00:00]
Time [normalized unit]

# Distribution and evolution of current: observation

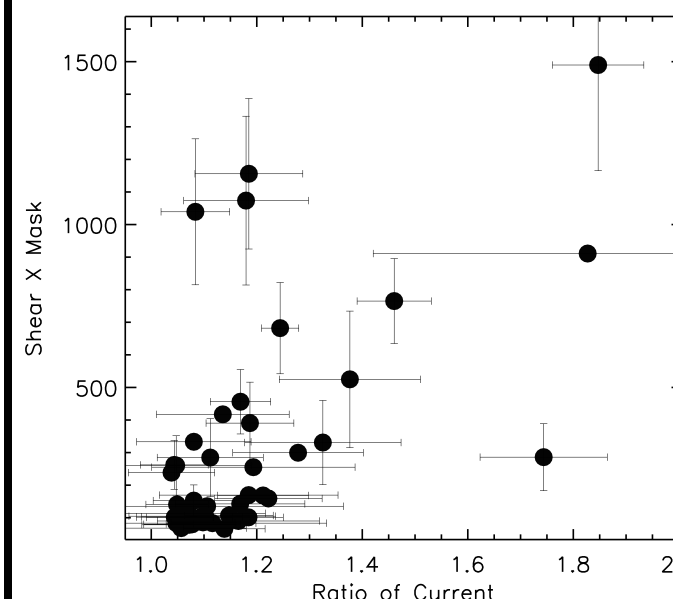
**Tests is done with two emerging active regions, a simple active region (AR 11072, left column) and a complex active region (AR 11158, middle column). They are also compared with MHD simulation (right column). From top to bottom are Bz, Jz, and temporal profiles of ratio of direct and return currents from positive field (red) and negative field (blue), together with magnetic flux (black). The results are as follows:**

1. **For the simple emerging AR 11072, very few shear is developed, and current is well balanced;**
2. **For the complex emerging AR 11158, shear is developed along the PIL and current concentrates near the PIL. Net current increases and becomes significant.**
3. **MHD simulation of emerging flux tube with high shear agrees with emergence of the complex active region AR 11158.**

# Distribution of current: observation

**The aforementioned studies suggest a possible relationship between current distribution (near PIL), shear development (along PIL), and current imbalance. Because high shear near PIL is closed related with flare occurrence (e.g., Schrijver 2007), it implies that level of current imbalance is a measure for eruptive activity in ARs.**

**Right: scatter plot of current imbalance (x-axis) versus a measure of magnetic shear near PIL (y-axis). Shear is a angle between observed and potential transverse fields; Mask is an area with high magnetic gradient near the PIL, following Schrijver (2007). The figure shows a tendency of imbalance current and shear along PIL.**

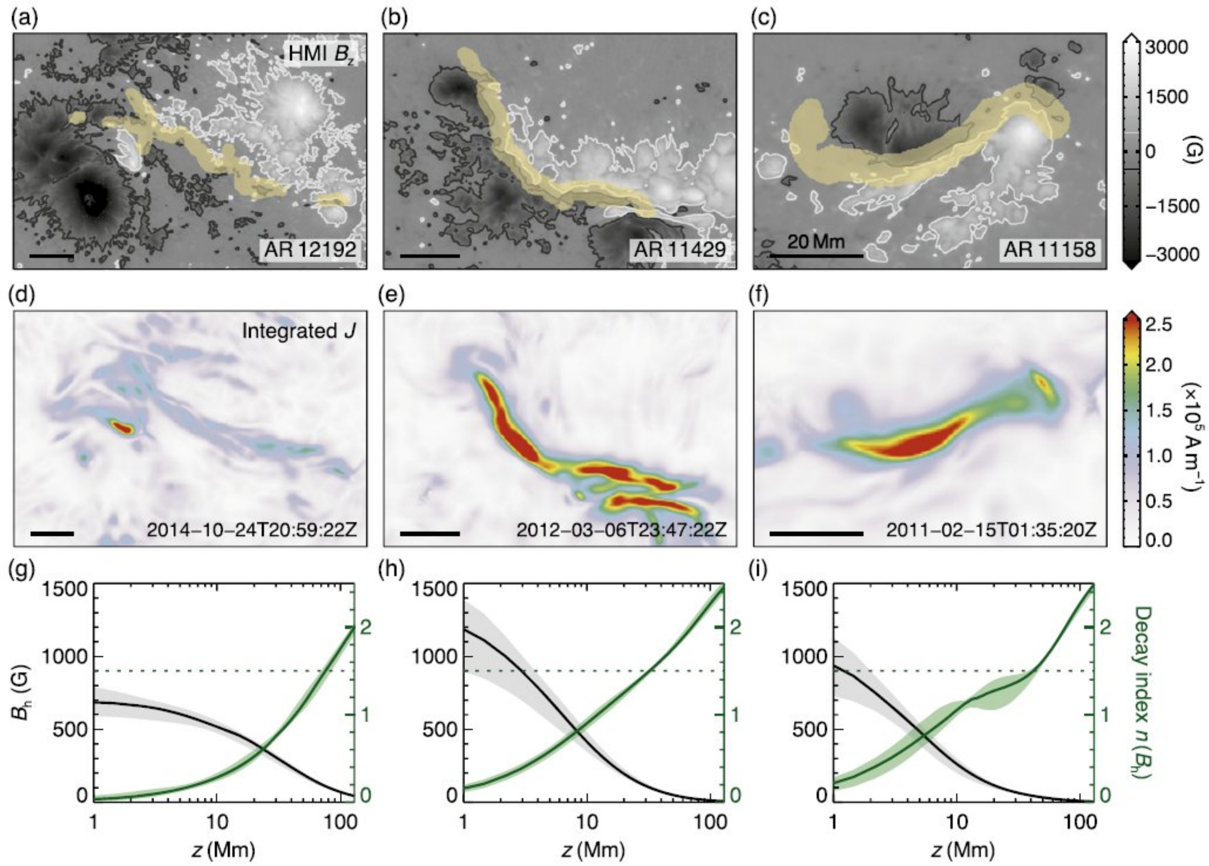


# Imbalance of current and eruptive events.

**Theoretically, it has been argued that presence of strong and concentrated return currents may impede and even inhibit the development of CMEs, because the concentrated return currents surrounding a magnetic flux rope shield the direct current in the rope and thus reduce the interaction of the rope with any other magnetic field (Forbes, 2010).**

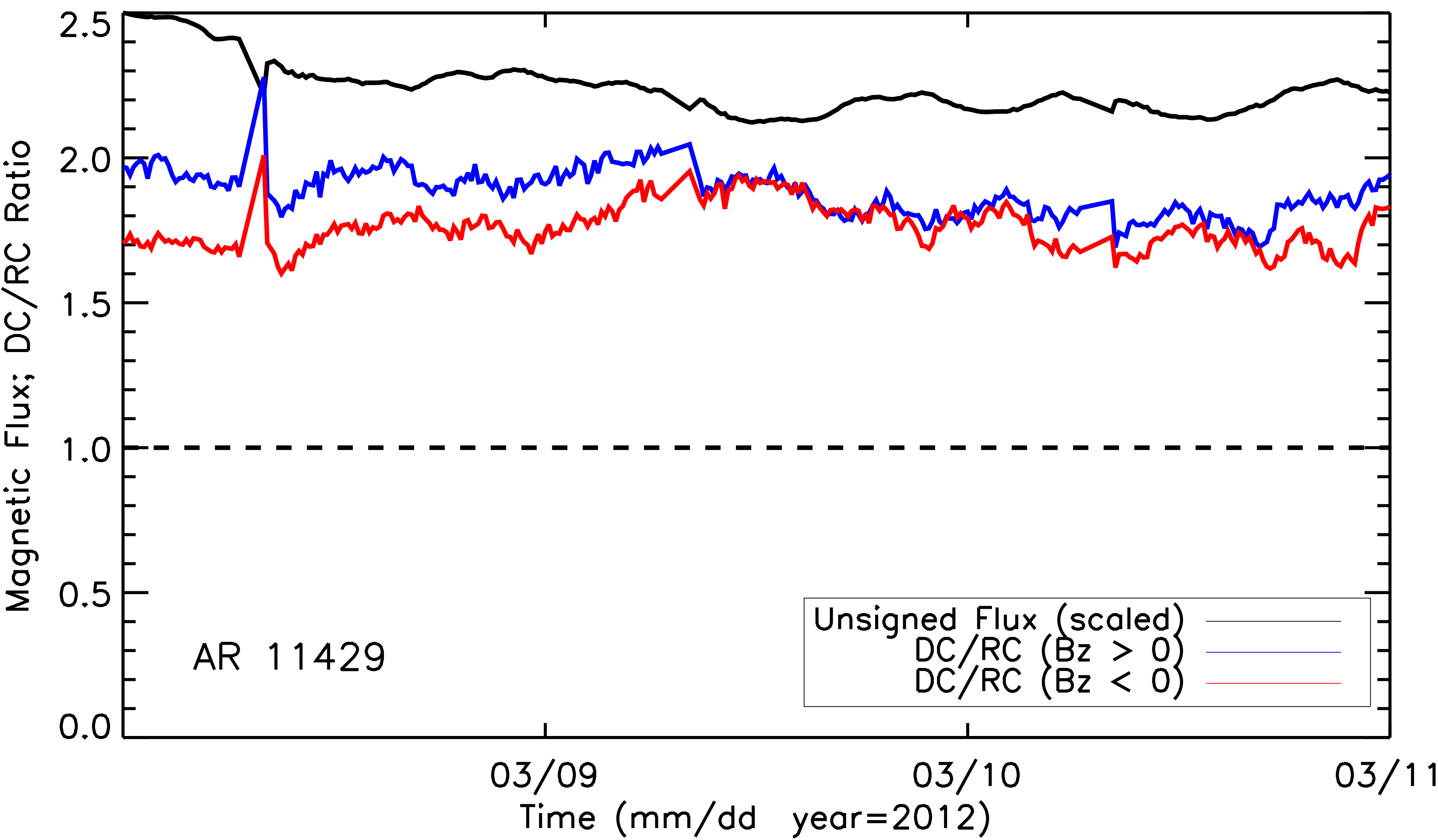
**We test this hypothesis with eruptive and non-eruptive events reported in Sun et al. (2015).**

# Erupted or Non-erupted?

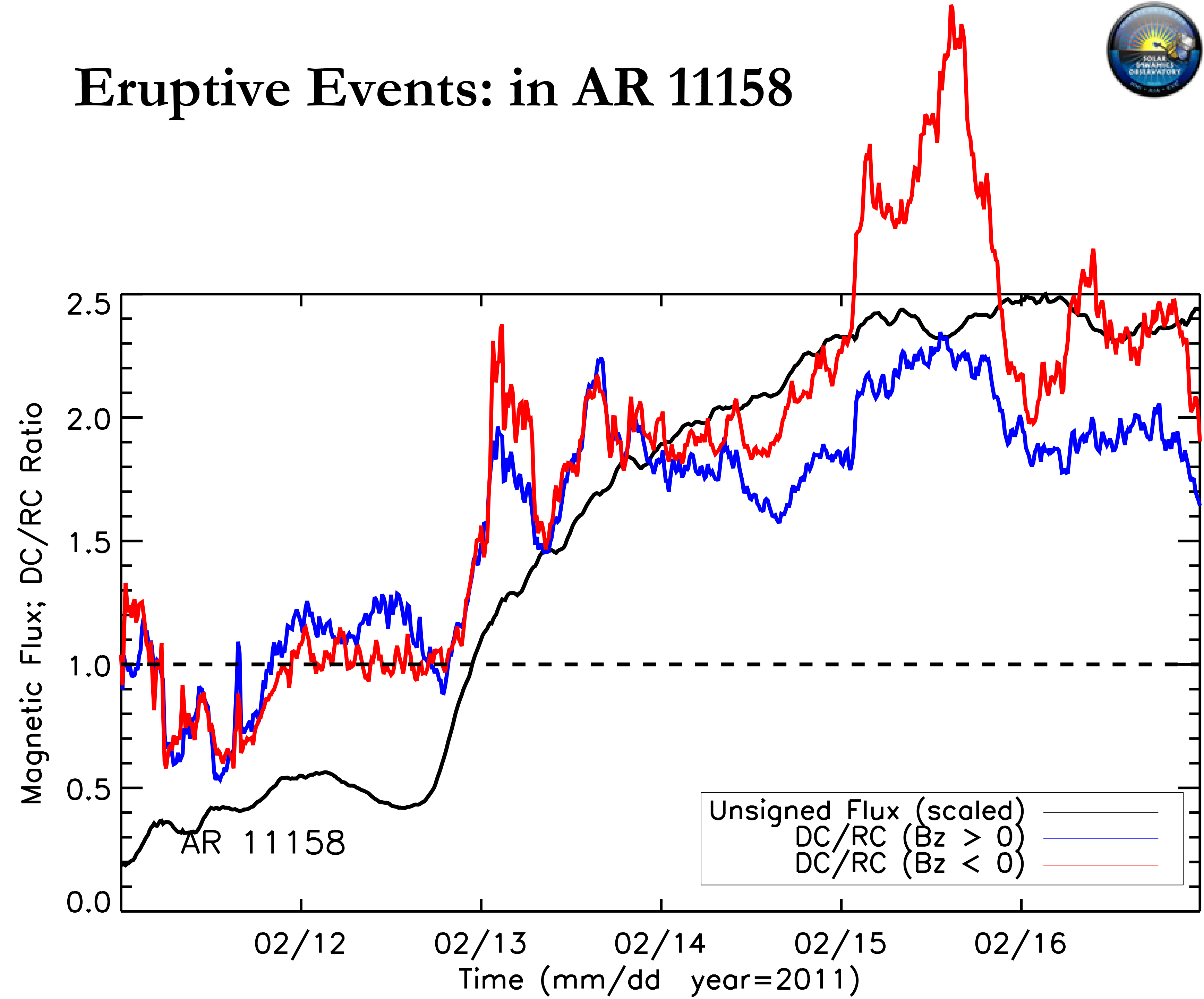



**Eruptive events in active regions AR 11429 (middle), AR 11158 (right), and non-eruptive events in active region AR 12192 (left). From Sun et al. (2015).**

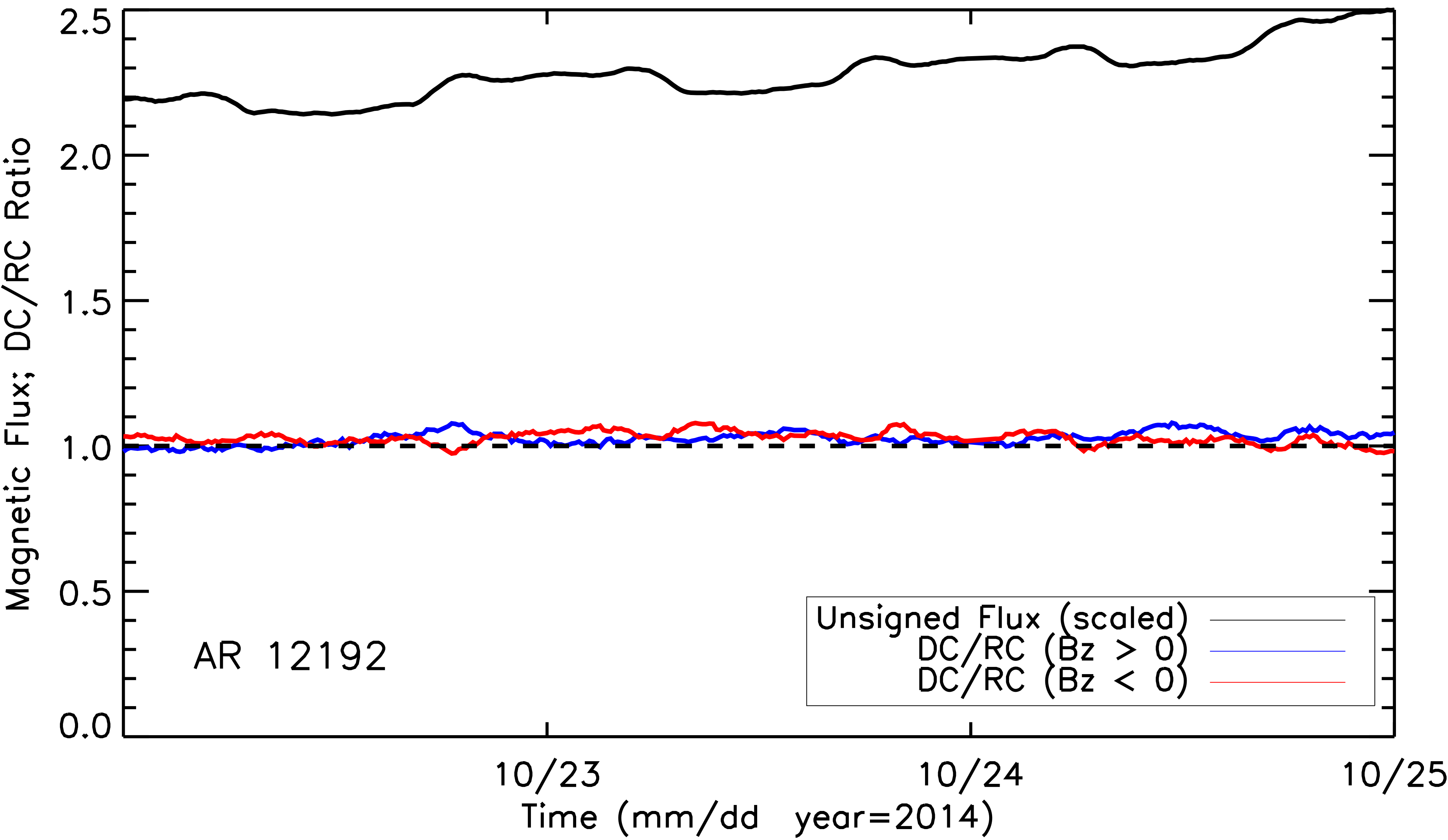
# Eruptive Events: in AR 11429



# Eruptive Events: in AR 11158



# Non-eruptive Events: in AR 12192



# Conclusions

- Our study implies there is relationship between current imbalance, magnetic shear, and eruptive activity, in line with previous results.
- This study places one piece of evidence to support the hypothesis that strong return current inhibits development of CMEs.