Evolution of Non-neutralized Electric Currents in Eruptive Solar Active Regions

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Introduction and Background

Magnetic Flux Ropes (MFRs) are an important element in Coronal Mass Ejections (CMEs; Patsouraskos et. al, 2020). Despite knowing the structure involved, we are unsure of when it develops and what role it plays in the production of CMEs. One theory states that the MFR structure is established prior to eruption and evolves to a point where it destabilizes, and a CME occurs (Green et. al, 2018)
This theory has previously been explored by measuring the current distribution, non-neutralization, and evolution of prominent CMEs (Liu et. al, 2017).

In this study, we are looking for sustained non-neutralized electric current prior to the production of CMEs. In three Active Regions (ARs), NOAA 11261, 11283, and 11305, we measure the radial component of the current distribution and its evolution, and identify CMEs produced in these ARs during their disk passage. Specifically, we locate the feet of CME flux ropes on disk, study their geometric and magnetic properties in terms of the vertical current, to help understand the conditions that lead to the eruption.

Temporal Evolution of Current and CME Association in ARs

3 chosen ARs were observed for a week of their on disk duration. Multiple CMEs were identified in each through use of the LASCO and CACTus CME databases, and matching eruptions caught in AIA and STEREO A & B with Coronagraph C2 in JHelioViewer (JHV).

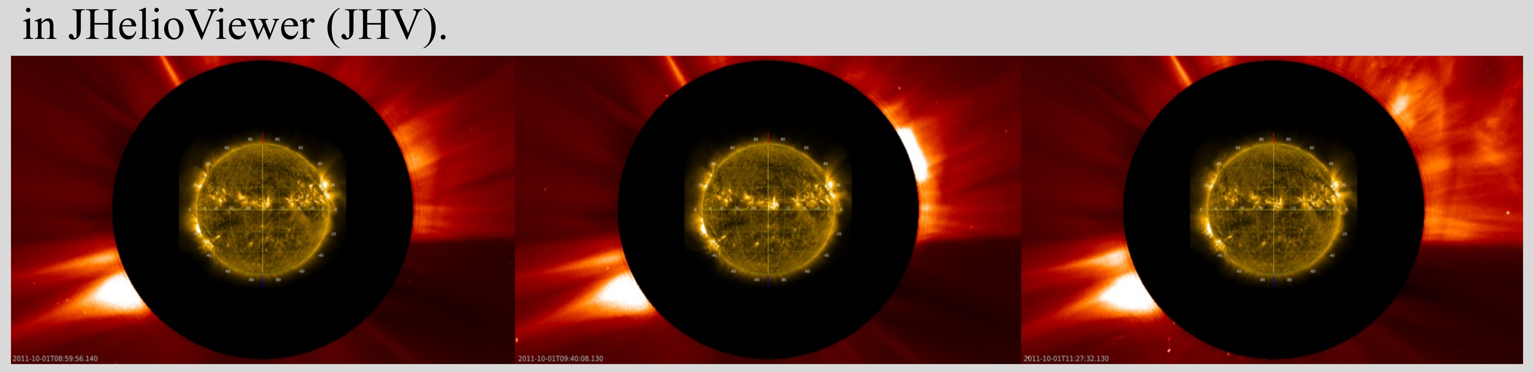


Fig.1 (Above) Three frames from Oct. 1, 2011 displaying NOAA 11305, while on disk center, through JHV. This displays correlation of an eruption between AIA 171Å (center) and in the lower left of C2 coronagraph (right)

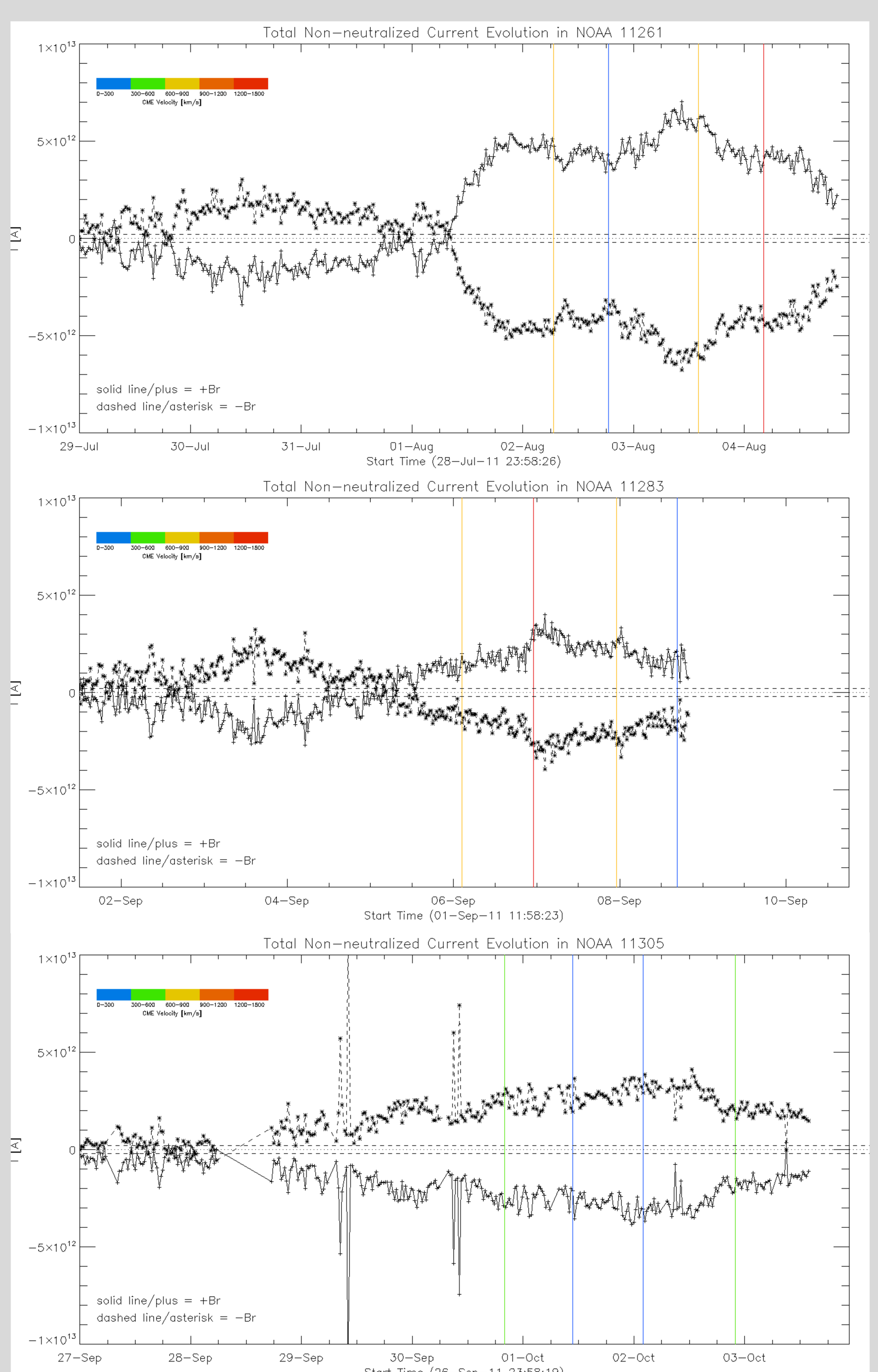


Fig.2 (Left) On Disk, non-neutralized radial current evolution of NOAA 11261 (top), 11283 (middle), 11305 (bottom) with markers indicating CMEs and speeds.

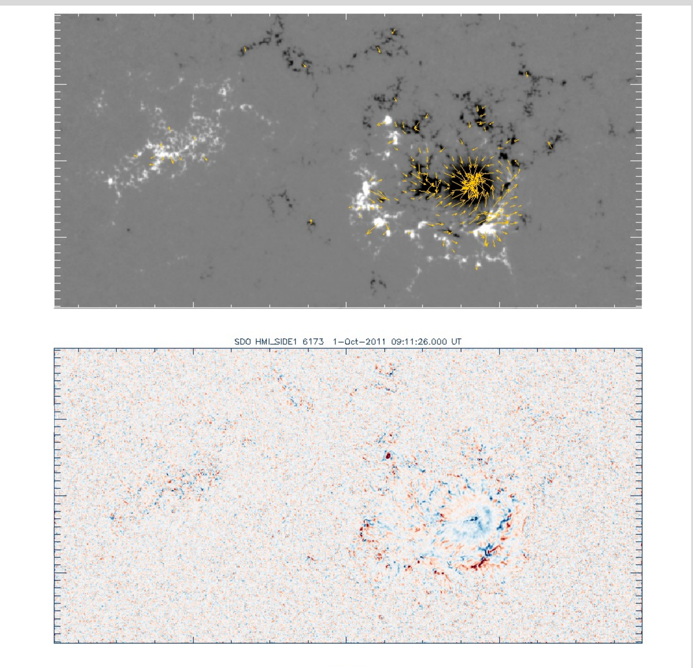


Fig.3 (Above) Example of transverse magnetic field and radial electric current distribution

Uncertainties in Net Electric Current in ARs

To estimate uncertainties, a Monte Carlo analysis is conducted by adding random Gaussian noise to the transverse magnetic field components in each pixel.

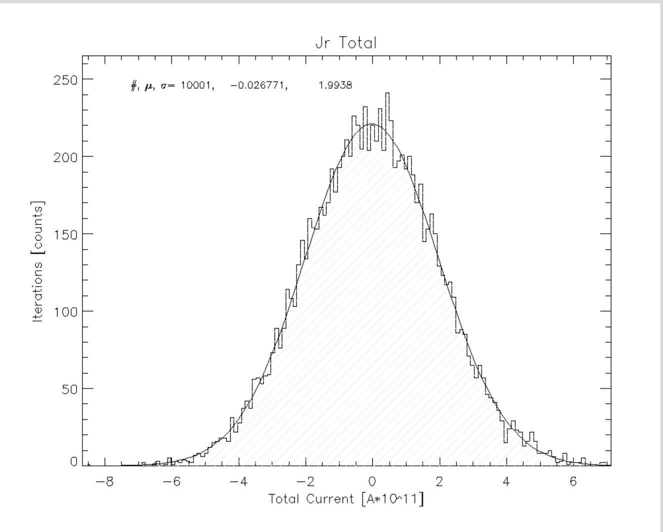


Fig.4a Net Current in AR

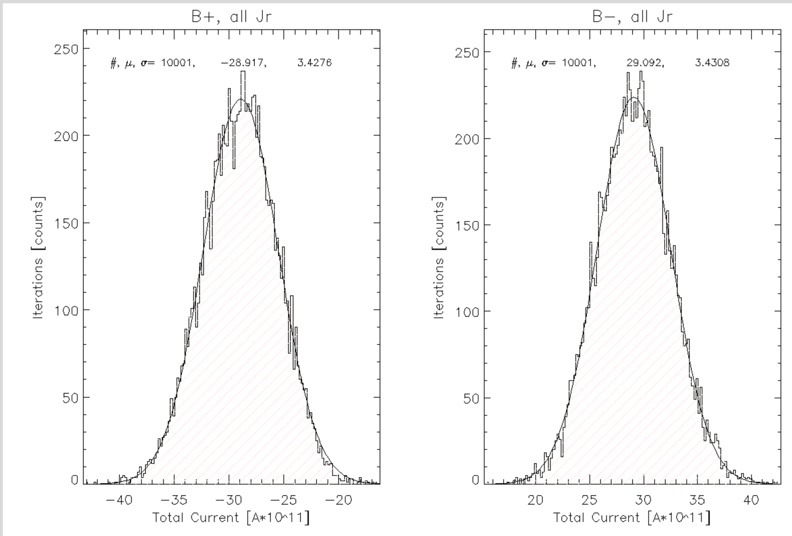


Fig.4b Net Current in positive (left) and negative (right) magnetic field

- Positive and negative currents are balanced in the whole AR, I_{total}= -0.027 ±1.994 × 10^{11} A
- There is significant non-neutralized current in individual magnetic polarities, I_{pos}=-28.917 × 10^{11}A and I_{neg}=29.092 × 10^{11}A
- Fig.2 displays non-neutralized current significantly above uncertainties (horizontal dashed lines)

MFR Footprint Identification

Locations of footprints are identified by coronal signatures including eruption, sigmoidal structure, and coronal dimming.

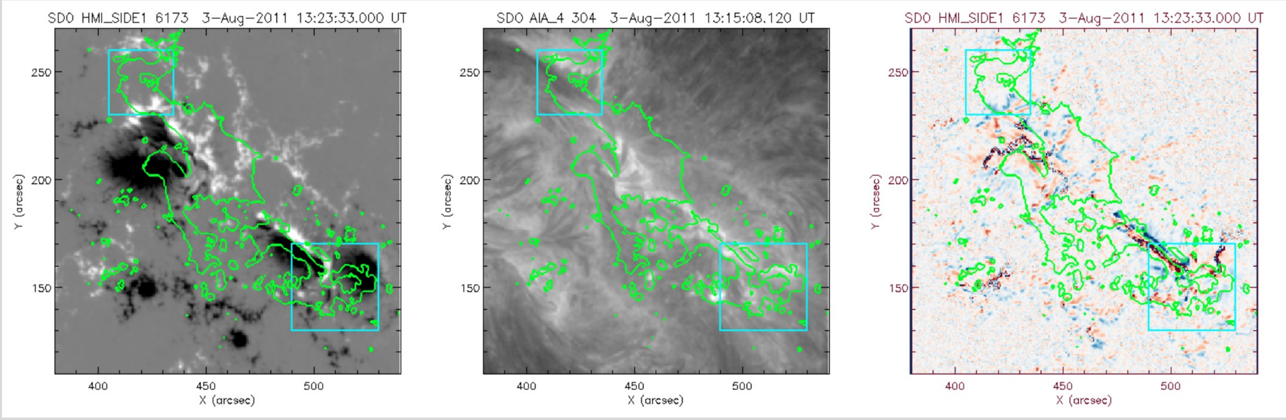
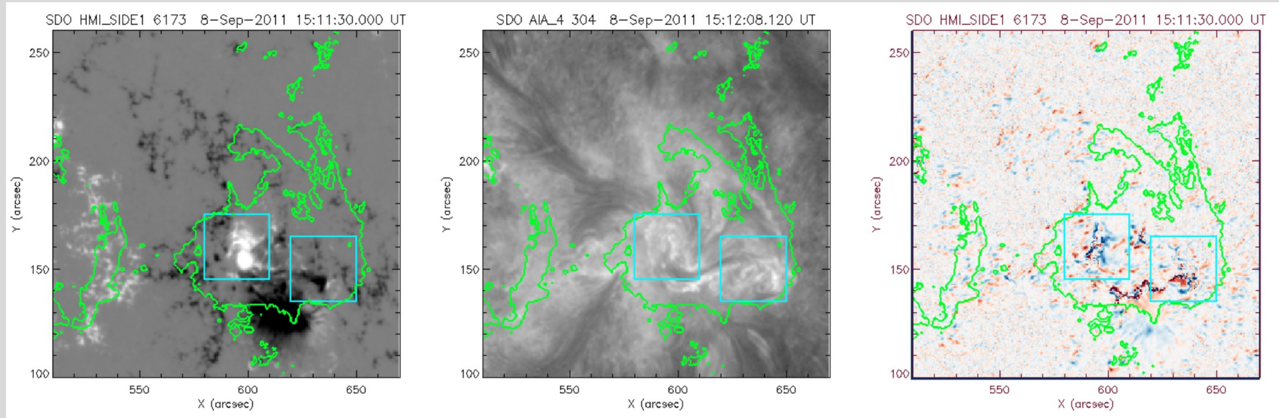


Fig.5a (Above) NOAA 11261, Aug. 3, 2011, Erupts at 13:20, Associated Flare: M6.0 Three frames displaying the radial magnetic component (left), the AIA 304Å image (center), and radial electric current density (right). Green outline is a mask of the foot-points of reconnecting field lines, and blue boxes are likely locations of MFR footprints.

Fig.5b (Below) NOAA 11283, Sept. 6, 2011, Erupts at 22:20, Associated Flare: X2.1



Observation, Analysis, and MHD Modeling of Oct. 1, 2011 Event in AR 11305

Evolution of localized current is studied within 12hr of CME. Current is measured in two footprints and along the Polarity Inversion Line (PIL). These measurements are compared with zero beta MHD model.

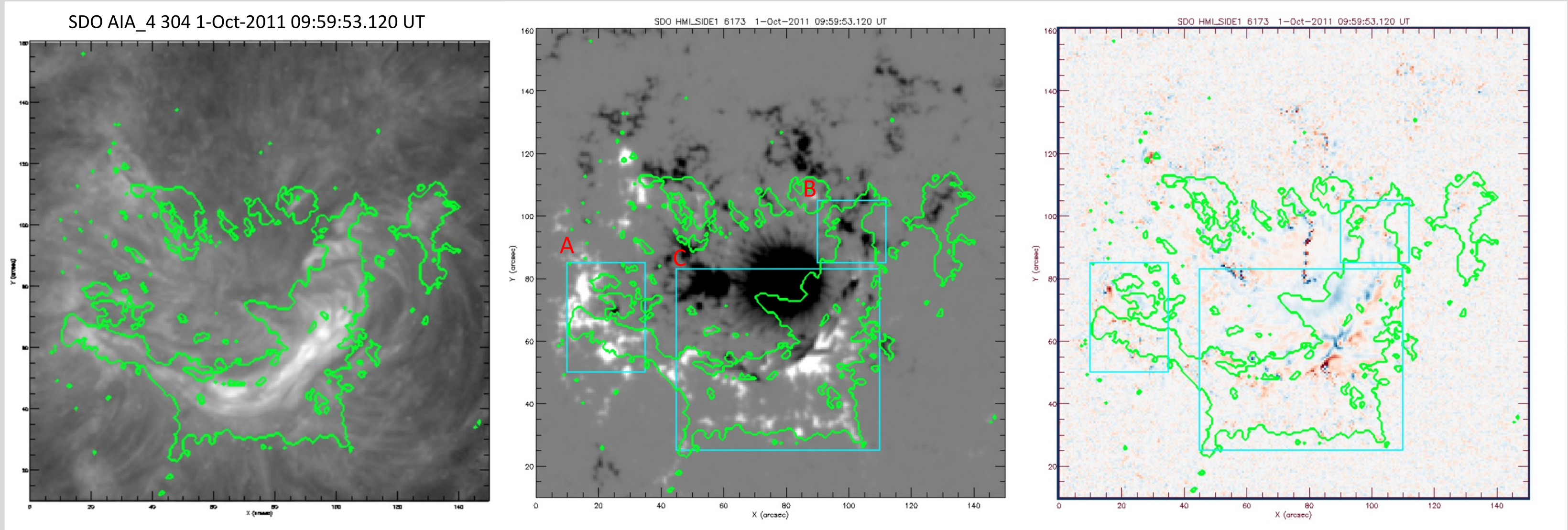
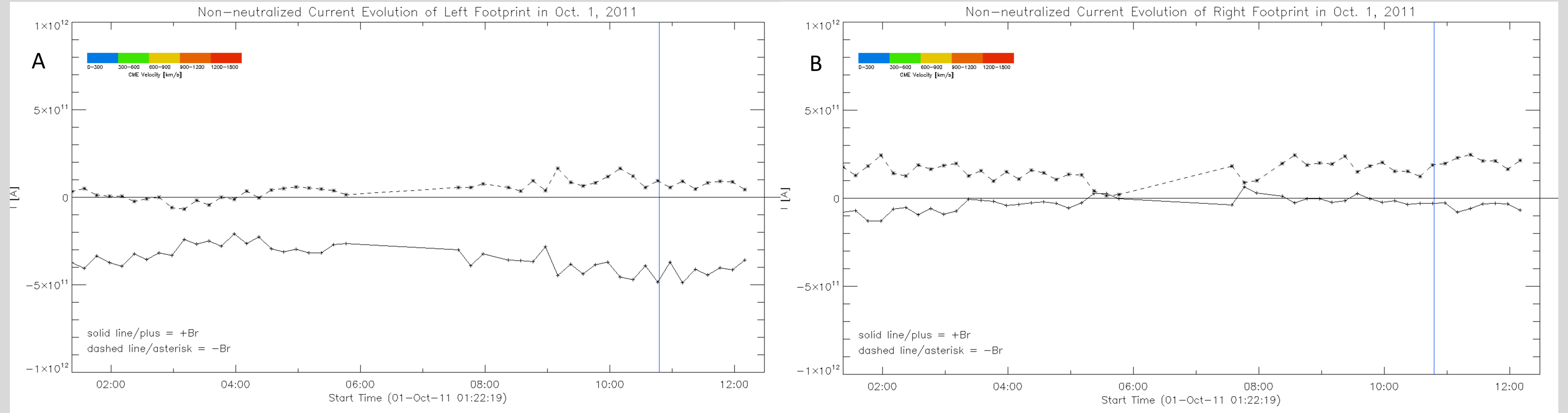


Fig.6 (Above) NOAA 11305, Oct. 01, 2011, Erupts at 9:36, Associated Flare: M2.1



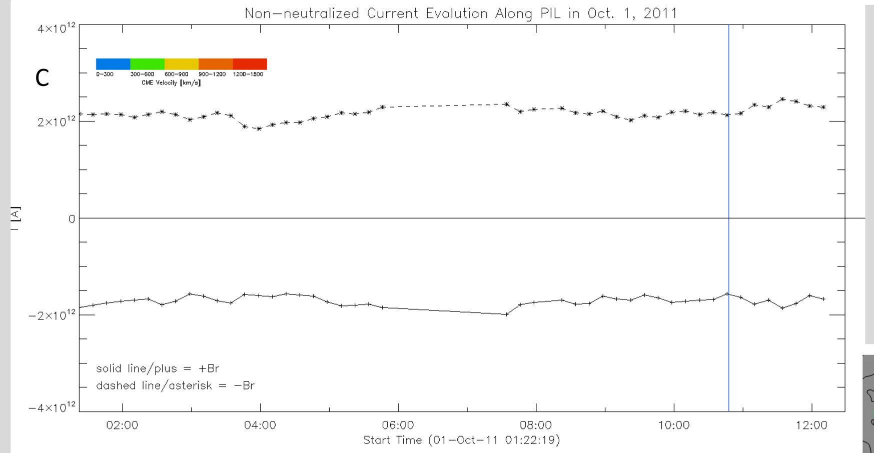


Fig.7 (Above) Non-neutralized current evolution in left (A) and right (B) footprints and along the PIL (C)

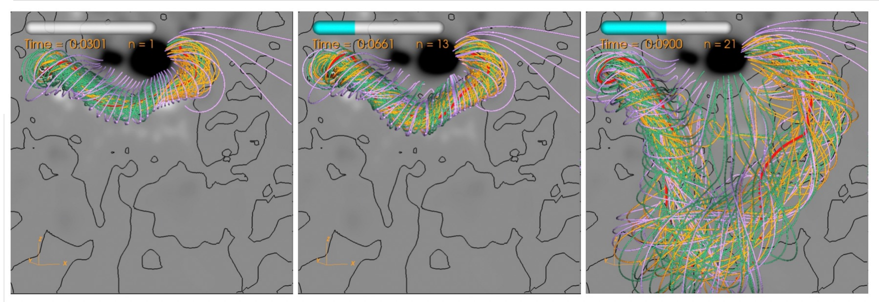


Fig.8 (Above) Three successive states of the erupting MFR modeled in zero-beta MHD simulations.

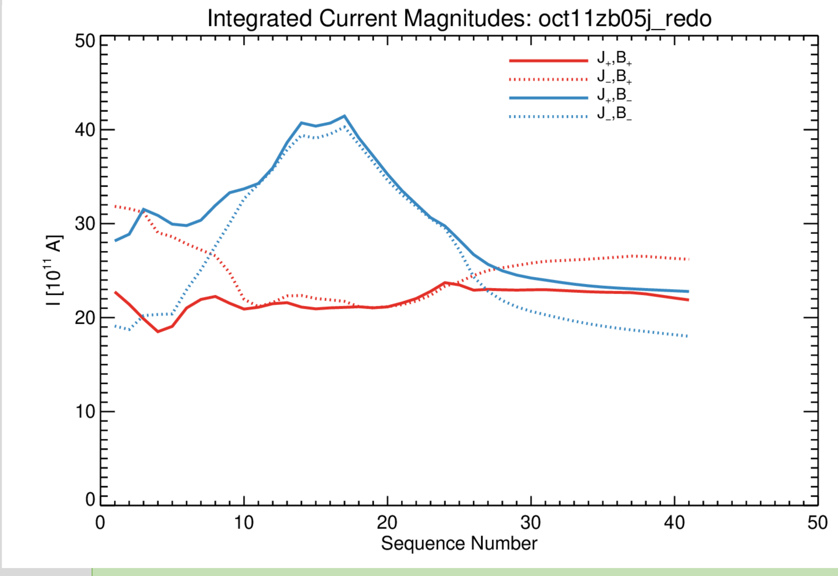


Fig.9 (Left) Evolution of non-neutralized current across eruption from model

Conclusion and Summary

- In three ARs studied, CMEs occur during significant non-neutralization of the net current.
- MFR footprints are currently being identified with coronal signatures
- The non-neutralization of current measured along the PIL in the Oct. 1, 2011 event agrees with the zero beta MHD model.

References:
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