Magnetic Chirality and Coronal Reconnection

Richard C. Canfield & Alexei A. Pevtsov

Department of Physics, Montana State University, Bozeman MT 59717-0350 USA

Alexander N. McClymont

Institute for Astronomy, University of Hawaii, 2680 Woodlawn Drive, Honolulu HI 96822 USA

Abstract. We have used Mees Solar Observatory vector magnetograms and Yohkoh Soft X-Ray Telescope images to study the role of magnetic chirality in the trans-equatorial reconnection of active regions. We conclude that active regions reconnect preferentially with others of the same chirality. We explain this result with a simple model of the closure of their current systems.

1. Introduction

Helicity is a topological parameter of magnetic fields and plasma flows, and is manifested by twist, linkage, and knottedness. Measures of helicity include the magnetic helicity density H_m:

$$H_m = \mathbf{A} \cdot \mathbf{B}, \tag{1}$$

the current helicity density H_c:

$$H_c = \mathbf{B} \cdot \nabla \times \mathbf{B}, \tag{2}$$

and the force–free field parameter α:

$$\nabla \times \mathbf{B} = \alpha \mathbf{B}. \tag{3}$$

For a linear force–free field,

$$H_m = \alpha^{-1} \mathbf{B}^2, \tag{4}$$

$$H_c = \alpha \mathbf{B}^2, \tag{5}$$

where

$\mathbf{B}$ is the magnetic induction,
$\mathbf{A}$ is the magnetic vector potential,
$\mathbf{B} = \nabla \times \mathbf{A}$.

Chirality measures the handedness of twist; like sign, it has only two values. Positive sign of α, H_m, and H_c means positive chirality, or right-handed twist.

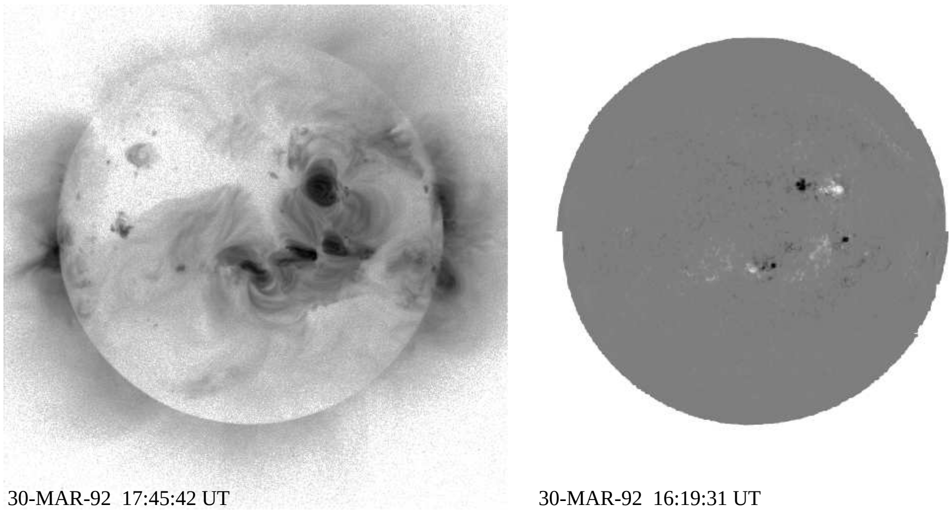

Figure 1. SXT image (negative) and Kitt Peak magnetogram (white indicates negative magnetic field) showing a well-connected trans-equatorial pair of regions of the same (negative) chirality, AR 7116 ($\sim$S05W15) and AR 7117 ($\sim$N06W15).

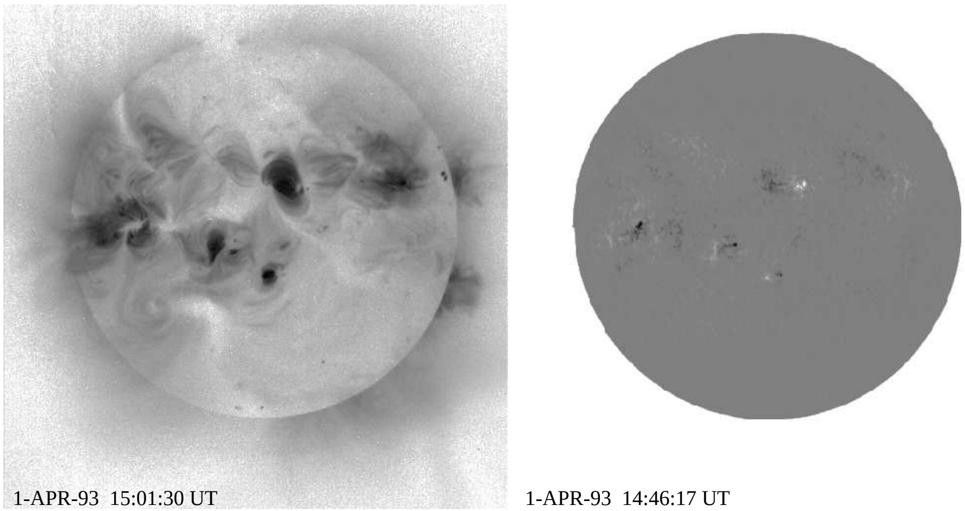

Figure 2. Kitt Peak magnetogram and SXT image showing three regions that are close in longitude, but are not well connected across the equator. NOAA AR 7461 ($\sim$N04W04) has negative chirality, but NOAA AR 7463 ($\sim$S07E09) and NOAA AR 7466 ($\sim$S14W01) have positive chirality.

Laboratory studies (e.g. Yamada *et al.* 1995) offer one method for exploring the influence of chirality in magnetic reconnection; solar coronal observations offer another, under different physical circumstances.

Following Pevtsov, Canfield, & Metcalf (1995), we determine the magnetic chirality of active regions in the photosphere by establishing the value of the linear force-free field parameter α that best represents (in a least-squares sense) the observed horizontal magnetic fields in vector magnetograms made with the Haleakala Stokes Polarimeter (Mickey, 1985). The determination of α, and the consequent inference of the chirality of the region based on the sign of α, is based directly on the vector magnetograms. We do not have to assume that the photosphere is force-free. Since only the vertical component of current enters the corona and determines the coronal helicity, the value of α determined from the ratio of the vertical components of current and magnetic field (which is what we can measure) is the relevant parameter, even if the current and magnetic field vectors are not parallel in the photosphere.

We focus our attention on pairs of active regions that are on opposite sides of the solar equator, since these are more clearly independent before emergence than two regions in the same hemisphere. We find ample numbers of pairs with both the same and opposite chirality because that hemispheric chirality rule is so weak (Pevtsov, Canfield & Metcalf 1995).

We determine the coronal connections between regions using movies of images from the Soft X-Ray Telescope (Tsuneta *et al.* 1991) on board the Yohkoh spacecraft. The SXT dataset gives numerous examples of solar active regions connected in the corona across the solar equator. Studying the coronal and magnetic evolution of a pair of such interacting active regions, Tsuneta (1996) concluded that magnetic reconnection was responsible for developing new magnetic flux tubes connecting them.

2. Observations

Figure 1 shows an example of a pair of regions whose leading and following parts are well connected across the solar equator. Tsuneta (1996) studied this pair of regions as it crossed the disk. He showed that at the East limb very few trans-equatorial connections were visible, while at the time of West limb passage the regions were very well connected. Through studies of coronal morphology and temperature structure, he argued that these interconnections were developing through reconnection in the corona, not flux emergence from below.

Tsuneta's (1996) observations imply that the separation between active regions should be a parameter of the reconnection process. However, we find that closeness of active regions is not a sufficient condition for reconnection. Both close non-interacting (Figure 2) and well-separated interacting active regions may be found in the Yohkoh dataset. In the latter case, the regions do not all have the same chirality, whereas they do in Tsuneta's example. This suggests that magnetic helicity is also a key parameter in solar magnetic reconnection.

For this paper we searched the 1991 – 1995 SXT database for pairs of regions that were close in longitude, but on opposite sides of the equator. We found 27 such pairs for which we had vector magnetograms, and could thus determine magnetic chirality. These pairs are described in Table 1, in which the 27 pairs

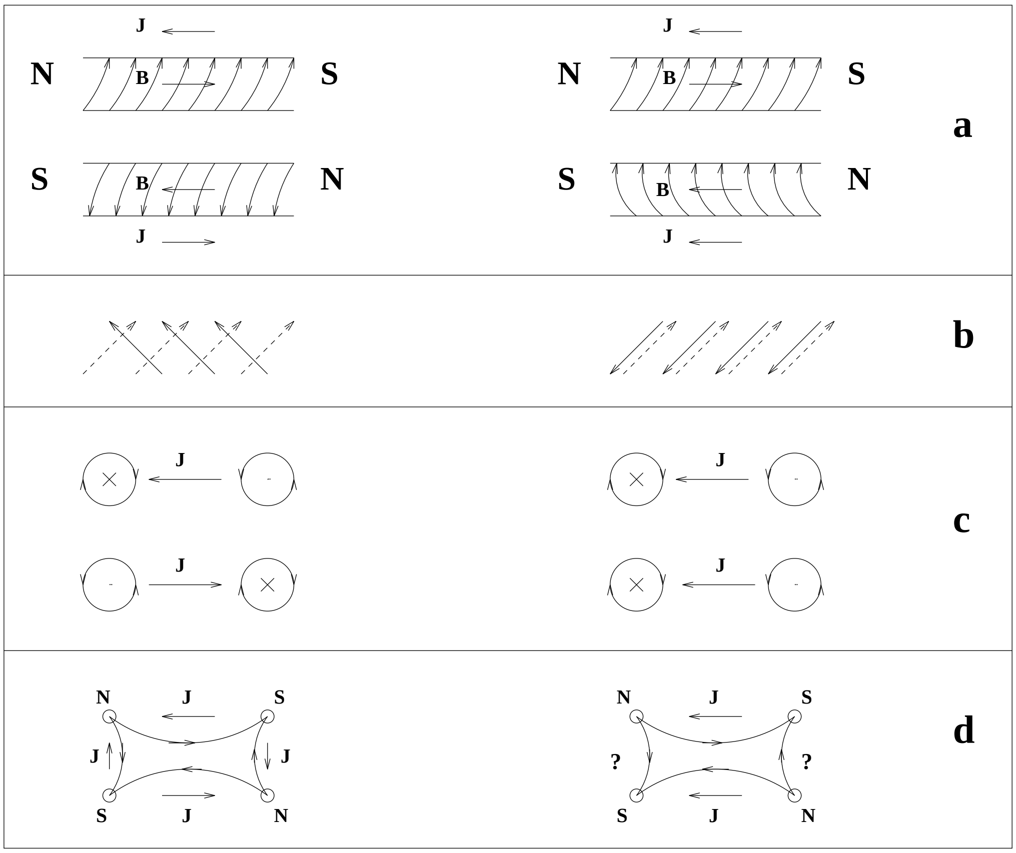

Figure 3. Two scenarios of reconnection between two twisted flux tubes having (left) same and (right) opposite chirality . (a) Schematic representation of a pair of twisted flux tubes in projection on the solar surface. Straight arrows show the longitudinal components of the field and current. (b) Projection of the magnetic field lines on the current sheet at the interface between the two reconnecting flux tubes in (a). Full arrows correspond to the front tube and dashed arrows to the back tube. (c) Schematic view from above of the photospheric footpoints of the flux tubes in (a), after they have been bent into semicircular arcs (modeling coronal loops). Circles with arrows show the direction of the azimuthal component of the field. Symbols at the center of the circle indicate the direction of the current. (d) Topology of the magnetic field lines and currents in the post-reconnection complex, viewed from above.

Table 1. Trans-equatorial Connections and Chirality

CLOSE PAIRS (27) ($\Delta\phi \leq 40°$, $\Delta\lambda \leq 20°$):

Connected?	Opposite chirality	Same Chirality
Yes	2	15
No	8	2

CLOSER PAIRS (25) ($\Delta\phi \leq 30°$, $\Delta\lambda \leq 20°$):

Connected?	Opposite chirality	Same Chirality
Yes	2	15
No	6	2

CLOSEST PAIRS (9) ($\Delta\phi \leq 20°$, $\Delta\lambda \leq 20°$)

Connected?	Opposite chirality	Same Chirality
Yes	0	6
No	3	0

are sorted into pairs close, closer, and closest in latitude ϕ, within $\Delta\lambda = 20°$ in longitude λ. It is clear from the table that there is a strong chirality rule; regions with the same chirality connect, those with opposite chirality do not.

3. Discussion

Figure 3 illustrates the basic point of our interpretation. Twisted magnetic fields will contain many sites which are more or less favorable to magnetic reconnection, two of which are shown in Figure 3 a,b. In a recent paper (Pevtsov *et al.* 1996) we showed that active regions have the same overall chirality in the photosphere and corona. Hence, our interpretation of Table 1 is that coronal active region magnetic fields of the same chirality are more likely to reconnect than those with opposite chirality. Interestingly, this result is consistent with recent laboratory plasma experiments (Yamada et al, 1995), which show reconnection that is three times faster for the same chirality than opposite.

What is the explanation for this relationship? Helical magnetic fields are associated with electric currents, and the closure of these current systems after reconnection furnishes an explanation for this tendency (Figure 3 c,d). The Pevtsov *et al.* (1996) result, cited above, implies that active region currents do not close in the corona; rather, they thread through the photosphere as they flow between the corona and the solar convection zone. If we assume that current flows along magnetic field lines, as it must do in the corona wherever it is force free, reconnection is favored in the same-chirality case (left).

Finally, generally speaking, reconnection does not change the total magnetic helicity of a system, but it may change the helicity density locally (*e.g.*, Ruzmaikin & Akhmetiev 1994). We examined several active regions that we observed on two successive solar rotations. All of them showed the same chirality before and after reconnection took place.

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