Fifth Hinode Science Meeting: Exploring the Active Sun
ASP Conference Series, Vol. 456
L. Golub, I. De Moortel, and T. Shimizu, eds.

Asymmetric Magnetic Reconnection in Coronal Mass Ejection Current Sheets

N. A. Murphy,[1] M. P. Miralles,[1] C. L. Pope,[1,2] J. C. Raymond,[1] K. K. Reeves,[1] D. B. Seaton,[3] and D. F. Webb[4]

[1]*Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA*

[2]*Elmhurst College, Elmhurst, IL, USA*

[3]*SIDC-Royal Observatory of Belgium, Avenue Circulaire 3, 1180 Brussels, Belgium*

[4]*Institute for Scientific Research, Boston College, Newton, MA, USA*

Abstract.
We present resistive MHD simulations of magnetic reconnection in the context of coronal mass ejection current sheets. We hypothesize that several commonly observed features of solar flares such as sub-Alfvénic downflows, candle flame shaped post-flare loops, and current sheet drifting are the result of asymmetry in the inflow and/or outflow directions during the reconnection process.

1. Introduction

Models of coronal mass ejections (CMEs) generally predict the formation of an elongated current sheet (CS) in the wake behind the rising flux rope (e.g., Lin & Forbes 2000). CS features have been identified in many events (e.g., Webb et al. 2003; Ciaravella & Raymond 2008; Savage et al. 2010; Reeves & Golub 2011). Magnetic reconnection in a CME CS is asymmetric along the outflow direction (Murphy et al. 2010). Reconnection exhaust directed towards the Sun impacts a region of strong magnetic and plasma pressure while antisunward exhaust impacts the rising plasmoid. There is significant vertical stratification of the upstream magnetic field and density, and it is unclear which quantity drops more quickly with height. Reconnection events often have some asymmetry along the inflow direction when the upstream magnetic field strengths and densities differ (Cassak & Shay 2007). For our poster[1] we discuss the observational implications of two sets of resistive MHD simulations of asymmetric reconnection.

2. Numerical Simulations of Asymmetric Reconnection

The first set of simulations begin with two initial X-lines placed very near each other in a periodic Harris sheet (see Murphy 2010). The X-lines retreat from each other as the

[1]We did not present an electronic poster at this meeting. There were, however, electrons in it.

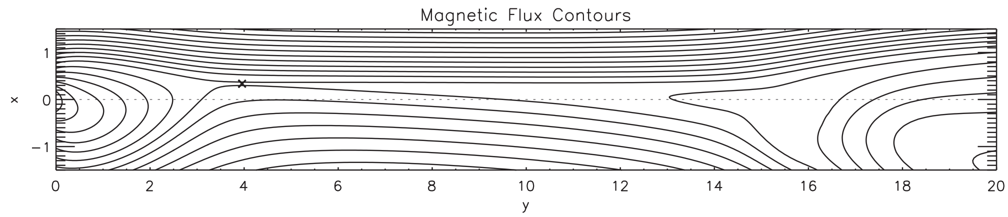

Figure 1. Numerical simulations of line-tied asymmetric reconnection performed with the NIMROD code (Sovinec et al. 2004). The upstream magnetic field strengths differ by a factor of two. The '×' marks the spot of the X-line.

reconnection process develops. Suprisingly, the relative positions of the X-line and the flow stagnation point switch so that late in time there is strong plasma flow across the X-line in the opposite direction of X-line retreat. This violates our intuition based on the ideal MHD frozen-in condition, but occurs because of significant diffusion of the normal component of the magnetic field. The outflow velocity towards the obstructing magnetic island between the two X-lines is about a third of the upstream Alfvén speed whereas the unobstructed outflow is approximately Alfvénic.

The second set of simulations are of line-tied asymmetric reconnection where an initial X-line is placed near a conducting wall in a modified Harris sheet equilibrium between different magnetic field strengths (see Figure 1). Total pressure balance is maintained by changing the plasma pressure. In a low-β plasma such as the corona it is not straightforward to sustain a large magnetic field imbalance by plasma pressure differences alone; however, modest asymmetries of $\sim$10–25% are probably common. As in previous simulations of asymmetric inflow reconnection, the X-line drifts towards the upstream region with the stronger magnetic field. The post-flare loops are distorted so that the loop-tops are not immediately above each other. There is net vorticity in the ejected plasmoid because the outflow jet impacts it at an angle.

3. Relation to Observations

While these 2D simulations use idealized initial and boundary conditions, there are many aspects which could explain observed features of reconnection in the corona.

3.1. Downflow speeds

While symmetric models of reconnection predict two Alfvénic outflow jets, downflowing loops during solar flares are frequently observed to propagate at speeds much lower than the Alfvén velocity (e.g., Warren et al. 2011). In our simulations, the reconnection exhaust towards the obstructed exist is a fraction of the Alfvén speed for two reasons. First, there is strong downstream plasma and magnetic pressure in that direction. Second, the X-line is located on the side of the current sheet nearest the obstruction so that the tension force directed away from the obstruction is much stronger than the tension force directed towards the obstruction (e.g., Murphy & Sovinec 2008). Indeed, Savage et al. (2010) identify the flow reversal in the 'Cartwheel CME' CS at a height of just $\sim 0.25 R_{\odot}$. The difference in sunward and antisunward outflow speeds suggests that more outflow energy is directed upward, which has consequences for the heating of CME plasma (Murphy et al. 2011).

3.2. Post-flare loop structure

The post-flare loop structure in the line-tied asymmetric reconnection simulations is distorted from the case with symmetric upstream magnetic field strengths. The loop-top positions do not appear immediately above each other but rather appear more like a candle flame (Figure 1). Flares often yield structures similar to this, including the 1992 Feb 21 event analyzed by Tsuneta (1996). Projection effects and 3D geometry complicate the comparison between simulation and observations.

3.3. Current sheet drifting

Several CME CS features have been observed to drift or tilt with time, including the Cartwheel CME CS. Savage et al. (2010) suggest that the apparent drifting is due to different parts of the current sheet actively reconnecting at different times. Another possibility is that the current sheet is slowly drifting into the region with the stronger magnetic field as in the simulations. The simulation drift velocity is of the same order as the drift velocity derived from observations. Improved models are needed to distinguish between these effects observationally.

4. Discussion

The simulations of asymmetric magnetic reconnection we present could explain several observed properties of solar eruptions. More realistic simulations will improve our understanding of asymmetric reconnection and allow more direct comparisons with Hinode/XRT and SDO/AIA observations. CME CSs are also expected to be unstable to the plasmoid instability (Loureiro et al. 2007; Huang & Bhattacharjee 2010).

Acknowledgments. The authors thank S. Guidoni, J. Lin, D. McKenzie, S. Savage, C. Shen, S. Takasao, H. Warren, and H. Winter for useful discussions. We acknowledge NASA grants NNX09AB17G and NNX11AB61G. C. L. P. acknowledges support from the NSF-REU solar physics program at the Center for Astrophysics (ATM-0851866).

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