2008 Huntsville Workshop abstract

Magnetic Reconfiguration in CMEs/Ejective Flares

Ron Moore, Alphonse Sterling, Steve Suess

We present (1) the standard concept for the large transient change in field configuration in the solar magnetic explosions that produce an ejective flare and become a coronal mass ejection (CME) and (2) an observational test of this picture of CME production. In linear span, the largest change in field configuration in these events is wrought by the CME in the outer corona and solar wind. In the outer corona, the CME is essentially a magnetic bubble that transiently pushes aside the previously radial surrounding field. The source magnetic field that explodes to become the CME is initially a closed arcade enveloping sheared and twisted sigmoid field that snakes along the polarity dividing line and forms the core of the arcade. The sigmoid field has a large store of pent-up free magnetic energy. This eventually causes the sigmoid to become unstable and to begin to erupt as a flux rope. The erupting flux rope becomes the core of the CME plasmoid. The flux rope and enveloping CME plasmoid are created and built up (given more magnetic flux) and unleashed to escape by reconnection of the legs of the erupting sigmoid and arcade. Simultaneously, this tether-cutting reconnection produces beneath the escaping plasmoid a growing coronal X-ray flare arcade rooted in two separating ribbons of chromospheric flare emission. As the unleashed CME plasmoid propels itself into the outer corona, it takes with it the top of the arcade envelope field that arches over it. The continuing reconnection finally recloses the "opened" stretched legs of the envelope, thus restoring the pre-eruption closed-arcade field configuration. This reconnection scenario for producing the CME plasmoid implies that the magnetic flux spanned by the full-grown flare arcade nearly equals the magnetic flux in the CME plasmoid in the outer corona. We have found that a wide range of exploding source regions produce CMEs that pass this test for production by tether-cutting reconnection (Moore, Sterling, & Suess 2007, Apj, 668, 1221).

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Typical CME

Observed by LASCO/C2 Coronagraph on SOHO

2002 May 20
Typical CME Source Explosion

Filament-traced sheared core field and enveloping arcade erupt, expand, and escape to form the CME

CME/Ejective Flare of 2002 Jan 4
Big Idea:

A CME is a Self-Propelled Magnetic Bubble
Main Points

- The standard scenario for CME production is basically the right physical picture.
- A CME is a magnetically inflated (low-beta) “plasmoid with legs.”
- Tether-cutting reconnection is only one way to trigger a CME explosion.
- Tether-cutting reconnection does most of the building and unleashing of the CME plasmoid.
- The CME propels itself by pushing on the surrounding coronal magnetic field.
Outline

I. Introduction

II. Standard Scenario for CME Production

III. Observational Test

IV. Conclusion
Birth and Release of the CME Plasmoid

- Before Onset
- Eruption Onset
- Confined Eruption, Ending
- Ejective Eruption, Midlife
Escape Path Determined by Surrounding Field
Resulting CME in Outer Corona
Lateral Pressure in Outer Corona

\[ B^* = 1.4 \text{ Gauss} \]

\[ \frac{B_{oc}^2}{8\pi} \]

\[ 3n_e kT \]

\[ T = 10^6 \text{ K} \]
Testable Prediction of the Standard Scenario for CME Production:

$$B_{\text{Flare}} \approx 1.4\left(\frac{\theta_{\text{CME}}}{\theta_{\text{Flare}}}\right)^2 \text{ Gauss}$$
Our 3 Test CMEs at Final Width in Outer Corona

- 2002 May 20
- 1999 Feb 9
- 2003 Nov 4

C2 Difference Image
C3 Difference Image
C3 Direct Image
Measured Angular Widths of each CME

![Graph showing measured angular widths of CMEs at different radial distances from the Sun.]

- **2003 November 4**
- **1999 February 9**
- **2002 May 20**

Where:
- $\theta_{\text{CME}}$ is the angular width of a CME.
- $R/R_{\text{Sun}}$ is the radial distance from the Sun.
Source of the CME of 2002 May 20
Source of the CME of 1999 Feb 9
Source of the CME of 2003 Nov 4

Oct 28 X17 Flare Arcade

EIT 195 Å Corona

Giant δ Sunspot Centered Under Flare Arcade

MDI Photosphere

Nov 4 X20 Flare Arcade

EIT 195 Å Corona
# Test Results

<table>
<thead>
<tr>
<th>CME (date)</th>
<th>Source Region</th>
<th>$\theta_{\text{CME}}$ (deg)</th>
<th>$\theta_{\text{Flare}}$ (deg)</th>
<th>Predicted $B_{\text{Flare}}$ (Gauss)</th>
<th>Predicted $B_{\text{Flare}}$ Fits Source Region?</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002 May 20</td>
<td>Centered on small $\delta$ spot</td>
<td>41</td>
<td>2.2</td>
<td>$\approx 490$</td>
<td>Yes</td>
</tr>
<tr>
<td>1999 Feb 9</td>
<td>Quiet region filament arcade</td>
<td>64</td>
<td>27</td>
<td>$\approx 8$</td>
<td>Yes</td>
</tr>
<tr>
<td>2003 Nov 4</td>
<td>Centered on giant $\delta$ spot</td>
<td>128</td>
<td>8.7</td>
<td>$\approx 300$</td>
<td>Yes</td>
</tr>
</tbody>
</table>

* Predicted $B_{\text{Flare}} \approx 1.4(\theta_{\text{CME}}/\theta_{\text{Flare}})^2$ Gauss
CONCLUSION:

A CME is a Self-Propelled Magnetic Bubble

- Low-beta plasmoid
- Built and unleashed by tether-cutting reconnection
- Propelled by own magnetic field pushing on surrounding field