The Width of a CME and the Source of the Driving Magnetic Explosion
R. L. Moore, A. C. Sterling, and S. T. Suess

We show that the strength of the magnetic field in the area covered by the flare arcade following a CME-producing ejective solar eruption can be estimated from the final angular width of the CME in the outer corona and the final angular width of the flare arcade. We assume (1) the flux-rope plasmoid ejected from the flare site becomes the interior of the CME plasmoid, (2) in the outer corona the CME is roughly a “spherical plasmoid with legs” shaped like a light bulb, and (3) beyond some height in or below the outer corona the CME plasmoid is in lateral pressure balance with the surrounding magnetic field. The strength of the nearly radial magnetic field in the outer corona is estimated from the radial component of the interplanetary magnetic field measured by Ulysses. We apply this model to three well-observed CMEs that exploded from flare regions of extremely different size and magnetic setting. In each event, the estimated source-region field strength is appropriate for the magnetic setting of the flare. This agreement indicates via the model that CMEs (1) are propelled by the magnetic field of the CME plasmoid pushing against the surrounding magnetic field, and (2) can explode from flare regions that are laterally far offset from the radial path of the CME in the outer corona.
Main Points

- The "standard model" for CME production is basically the true physical picture for all major CMEs.

- A CME is a magnetically inflated (low-beta) "plasmoid with legs."
  - Built and unleashed by tether-cutting reconnection.
  - Propelled by its own magnetic field pushing on the surrounding field.

- The tether-cutting reconnection also produces a flare arcade at the source of the driving magnetic explosion.

- The source region can be anywhere in the lateral span of the CME, from about centered to far off to one side.
Outline

• Standard Scenario for CME Production

• New Observational Test
Birth and Release of the CME Plasmoid

Before Onset

Eruption Onset

Confined Eruption, Ending

Ejective Eruption, Midlife
Resulting CME in Outer Corona
Governing Role of Surrounding Field

(a)  

(b)  

(c)
Testable Prediction of the Standard Scenario
Magnetic Bubble CME Model:

\[ B_{\text{Flare}} \approx 1.4 \left( \frac{\theta_{\text{CME}}}{\theta_{\text{Flare}}} \right)^2 \text{ Gauss} \]
Measured Angular Widths of 3 CMEs

\[ \theta_{\text{CME}} \text{ (deg)} \]

\[ R/R_{\text{Sun}} \]

2003 November 4

1999 February 9

2002 May 20
LASCO Image of each CME at Final Width

2002 May 20  1999 Feb 9  2003 Nov 4

C2 Difference Image  C3 Difference Image  C3 Normal Image
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

Giant δ Sunspot Centered Under Flare Arcade

Nov 4 X20 Flare Arcade

EIT 195 Å Corona

MDI Photosphere

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>Required $\mathbf{B}_{\text{Flare}}$ (Gauss)</th>
<th>Required $\mathbf{B}_{\text{Flare}}$ Fits Source Region?</th>
<th>Source Region Magnetic Energy (ergs)</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>
<td>$\sim 10^{32}$</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>
<td>$\sim 10^{32}$</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>
<td>$\sim 10^{33}$</td>
</tr>
</tbody>
</table>

* Required $\mathbf{B}_{\text{Flare}} \approx 1.4(\theta_{\text{CME}}/\theta_{\text{Flare}})^2$ Gauss

** Source Region Magnetic Energy $\equiv (\mathbf{B}^2_{\text{Flare}}/8\pi)(\theta_{\text{Flare}} R_{\text{Sun}})^3$
CONCLUSION:

A CME is a

Magnetic Bubble

- Low-beta plasmoid
- Built and unleashed by tether-cutting reconnection
- Propelled by own magnetic field pushing on surroundings
Lateral Pressure in Outer Corona

B* = 1.4 Gauss

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

\[ 3n_e kT \]

T = 10^6 K

Log Pressure (dyne/cm²)

\[ R/R_{Sun} \]