Verification of the “Standard” Model of Flare-CME Connection

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Based on work from Patsourakos, Vourlidas & Kliem (2010)
The “Standard” Flare-CME Concept
(from Vourlidas’ Review at NAPA 2008 workshop)

Still at cartoon level (pick your favorite from solarmuri.ssl.berkeley.edu/~hhudson/cartoons)

Ribbons = CME expansion

Forbes 2000

Asai et al 2006

Lin & Forbes 2002
CME Internal Structure

• The tip of the post-CME current sheet is visible.
  – The current sheet should be visible in the low corona.
CME main acceleration coincides with flare energy release phase

CME Kinematic Evolution and Timing with Associated Flare

- **Phase 1**: Initiation
- **Phase 2**: Acceleration
- **Phase 3**: Propagation

<table>
<thead>
<tr>
<th>CME Event</th>
<th>Flare (Soft X-ray)</th>
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</thead>
<tbody>
<tr>
<td>Onset 1</td>
<td>Onset of Instability</td>
</tr>
<tr>
<td>Onset 2</td>
<td>Onset of Main Energy Release</td>
</tr>
<tr>
<td>Peak</td>
<td>Peak CME Velocity and End of Main Energy Release</td>
</tr>
<tr>
<td>Time</td>
<td>From Zhang &amp; Dere (2006)</td>
</tr>
</tbody>
</table>

(from J. Zhang's SHINE 2007 presentation)
Observing the Genesis of Impulsive CMEs

Patsourakos et al (2010)

25 March 2008 – 47 deg separation
huge bubble forms in 10 min
typical of impulsive CMEs;
12-31-07, 1-2-08, 2-13-09, …
Two Views Determine the ‘Real’ Bubble

Transformation of a set of loops into a bubble ‘real’ bubble induces deflections which could confuse analysis …

Patsourakos et al (2010)
3D Modeling of the Bubble

Use parameterized geometric 3D model of Thernisien et al. to simultaneously fit the bubble in A+B
CONCLUSIONS:

- Expansion speed ~1000 km/s
- Aspect ratio decreases with time
- Conversion of arcade → flux rope
- Part of the flux rope forms on-the-fly
Flare-CME Synchronization

Non-linear expansion of flux rope coincides with impulsive phase of flare!
Implications from a STEREO/EUV Wave

EUVI 171A, 12/7/07 Event from Patsourakos et al 09

- Loops start to rise
  - 10 min BEFORE wave

- Wave appears
  - No flare!
  - Connection between wave & rising loops?

- Flare ribbons appear
  - Rising loops disappear
  - Wave accelerates or forms?

Phase transition in 90 sec!!
The “Standard” Flare-CME Concept

Where is the direct physical connection between CME and Flare?

Ribbons = CME expansion

Forbes 2000

Lin & Forbes 2002
Conclusions

• CME starts as a set of rising loops at AR core (speed ~ 50 km/s)
• Extremely sharp transition (< 75 sec) from loops → erupting bubble
• Bubble = CME fluxrope
• Two phases in formation of fluxrope
  – Non-linear expansion along neutral line followed by
  – Self-similar expansion → CME
• Non-linear expansion coincides with flare impulsive phase
• Expansion speed of ~1000km/s drives the EUV wave.
  – When expansion ceases, EUV wave becomes blast wave (hence deceleration)?
• The above event sequence seems to be common to impulsive EUVI events!

• “Standard” model of solar eruptions consistent with observations!
Backup Slides
EUV Wave and Bubble are Different Entities
Flare-CME Connection: Ions don’t like Electrons?

- Ions & electrons seem to be accelerated at different sites
  - Different loop sizes? (Emslie et al 2004)

But if we look at the big picture…

Hurford et al (2006)

Putting it all together

A possible scenario (see Schrijver 2009):

1. Magnetic field rises as fluxrope from convection zone
2. Top of fluxrope bursts through the chromosphere; rests stays anchored in photosphere
3. The new coronal fluxrope interacts w/ background:
   1. Flare only if reconnection is quick
   2. Flare+CME if enough $E_{mag}$
   3. Eruption only if energy release is slow
Putting it all together

MHD models support such scenario

From Manchester et al 2004
Nugget 2: EUV Wave Structure/Evolution

- A-B separation = 42 deg
- Cadence = 2.5 min
- Mild wavelet enhancement

- First EUV wave with
  - High cadence (< 2.5 min)
  - Multi-temperature (4 wavelengths within minute)
  - Stereoscopic (EUVI-A, -B, EIT)