Evolution of CMEs in the Heliosphere: Status Report

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Research Objectives

• How does the structure of CMEs evolve as they propagate through the inner heliosphere?

• How are CMEs accelerated and/or decelerated as they propagate from the Sun to 1 AU and beyond?

• How do the features of ICMEs observed in-situ reflect their solar origins and the appearance of CMEs in remotely sensed imaging data?
Approach

- Combination of data analysis (SECCHI, IMPACT, PLASTIC, ACE, Wind) and numerical modeling (MAS, ENLIL) for selected events.
- Focus on small number of events with well-observed flux rope structure (ideally well-observed in both remotely sensed and in-situ data).
- Modeling in two steps:
  - Drive ENLIL heliospheric model using cone model (or similar) fits to SECCHI coronagraph observations;
  - Detailed self-consistent modeling using coupled coronal and heliospheric (MAS + ENLIL) codes for a subset of events.
- Compare remotely sensed and in-situ data for events with suitable spacecraft configurations (e.g. imaging observations from Ahead of a CME that is observed in-situ from Behind).
- Generate synthetic images and in-situ parameters from model results for comparison with data.
Progress to Date

• Analyzed remote sensing and in-situ data for two CME events (April 26 and May 17, 2008).
• ENLIL model has been run for both events, using both cone model and ‘croissant’ model parameterization of CMEs as inputs to ENLIL.
• Comparison of data and model results is just getting started.
The Corona on April 26, 2008
April 26, 2008 CME
April 26, 2008 CME
April 26, 2008 CME
Intuitive’ 3D Model of April 26 CME

Results courtesy of Brian Wood
Kinematic Model of April 26 CME

- Radial distances $r$ derived from measurements of elongation angles $\varepsilon$ using ‘Fixed $\phi$’ assumption:
  $$r = \frac{d \sin \varepsilon}{\sin(\varepsilon + \phi)}$$

- Kinematic model fit to the CME assumes an initial acceleration phase, followed by a deceleration phase, and finally a constant velocity.
  - Fit shown for leading edge of flux rope (not front of CME).

- CME reaches STEREO-B around 14:00 UT on April 29.
Magnetic Field Observations

- Magnetic field for April 29 to May 1, 2008 is shown at STEREO-A (red), STEREO-B (blue) and WIND (black).
  - STEREO-A and WIND data have been shifted in time to overlay with STEREO-B.

- Magnetic field enhancement with a rapid rotation (~2 hours) is observed in STEREO-B at around the time the CME is expected to arrive at the spacecraft (enhancement is also seen later at WIND and STEREO-A).

- However, most plausible interpretation is that the enhancement is caused by a high speed stream pushing into a slow wind structure with the HCS meshed between them.
  - Could also be an irregular ejecta?
2008 April 26 CME with Rope Model

21.5 Rs

2008–04–26
time=19:13
lat=6
lon=-21

width=42.00
thick=13.00
kappa=0.219
gamma=13
vlead=741.0

(Thernisien et al., 2009)

(WSA-1.6-GONG-CR2069)
2008 April 26 CME with Rope Model

Ecliptic Plane

LAT = −4.1°

N90  LON = 0°

W180  R = 1.0 AU

Vr (km/s)

IMF polarity

Current sheath

3D IMF line
2008 April 26 CME with Rope Model

2008–04–29 20:00:14

Ecliptic Plane

LAT = −4.2°

N (cm−3)

0 20 40 60

IMF polarity

−  →  +

Current sheath

3D IMF line

2008–04–26 +3.83 days

Mercury  Venus  Earth  Mars  Messenger  Stereo_A  Stereo_B

W180  R = 1.0 AU

S90  N90
2008 April 26 CME with Rope Model

ENLIL-2.5, meres WSA-1.6 GONG

2008-04-29 04:03:05

Solar Wind Density:

\[ R^2 \times N \ (\text{cm}^{-3}) \]

1 \hspace{1cm} 10 \hspace{1cm} 100

-90° \hspace{1cm} 90°

North

White-Light Images:

Stereo_A/HI2 \hspace{1cm} Stereo_B/HI2

Total Brightness

MIN \hspace{1cm} MAX

North

Sun
2008 April 26 CME with Rope Model
2008 April 26 CME with Rope Model
Coupled Modeling Plans

• To fully model and analyze a specific event takes many months of detailed study.
• So far, there hasn’t been a ‘perfect’ STEREO CME, given the constraints of:
  – Separation of the spacecraft;
  – Central disk eruption (as viewed from Earth, i.e. magnetograph observations);
  – Coverage from a wide array of observatories;
  – Simple, isolated eruption.
• From a modeling perspective, the May 2007 event is most ideal.
• From an observational perspective, the April and May 2008 events are better (but no clear ICME observed in situ).
• Perhaps May 2009 will be kind to us!
Status Summary

- Relatively few good events in first year.
- Two candidate events have been identified.
  - April 26 CME propagates directly towards STEREO-B.
  - Density and magnetic field enhancements observed at STEREO-B (and Earth) on April 29, but in-situ observations are more consistent with interaction between high and slow speed streams than with an ICME.
  - Timing of in-situ density and magnetic field enhancements is consistent with SECCHI observations and simple geometric and kinematic models of CME propagation.
  - Part of May 17 CME propagates towards STEREO-B, but no clear ICME signatures are seen.
    - ICME may be embedded in a CIR in one or both cases?
- Other events will be considered (e.g. June 2, 2008; January 22, 2009), but ideal event has not yet been observed.
- Modeling of candidate events is in early stages.