



# Evolution of CMEs in the Heliosphere: Status Report

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February 3 – 5, 2009



# 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.



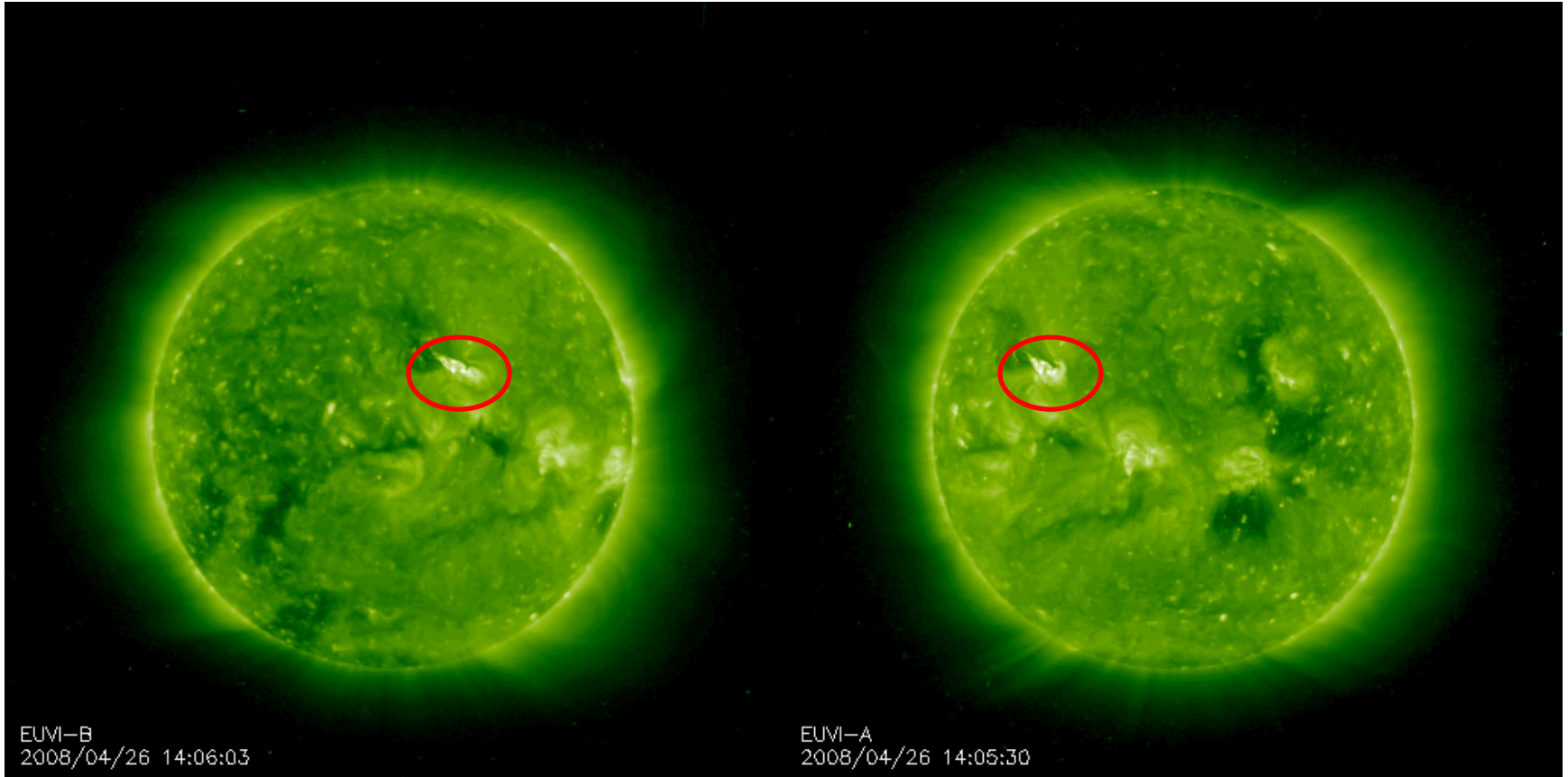
# Progress to Date

- 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

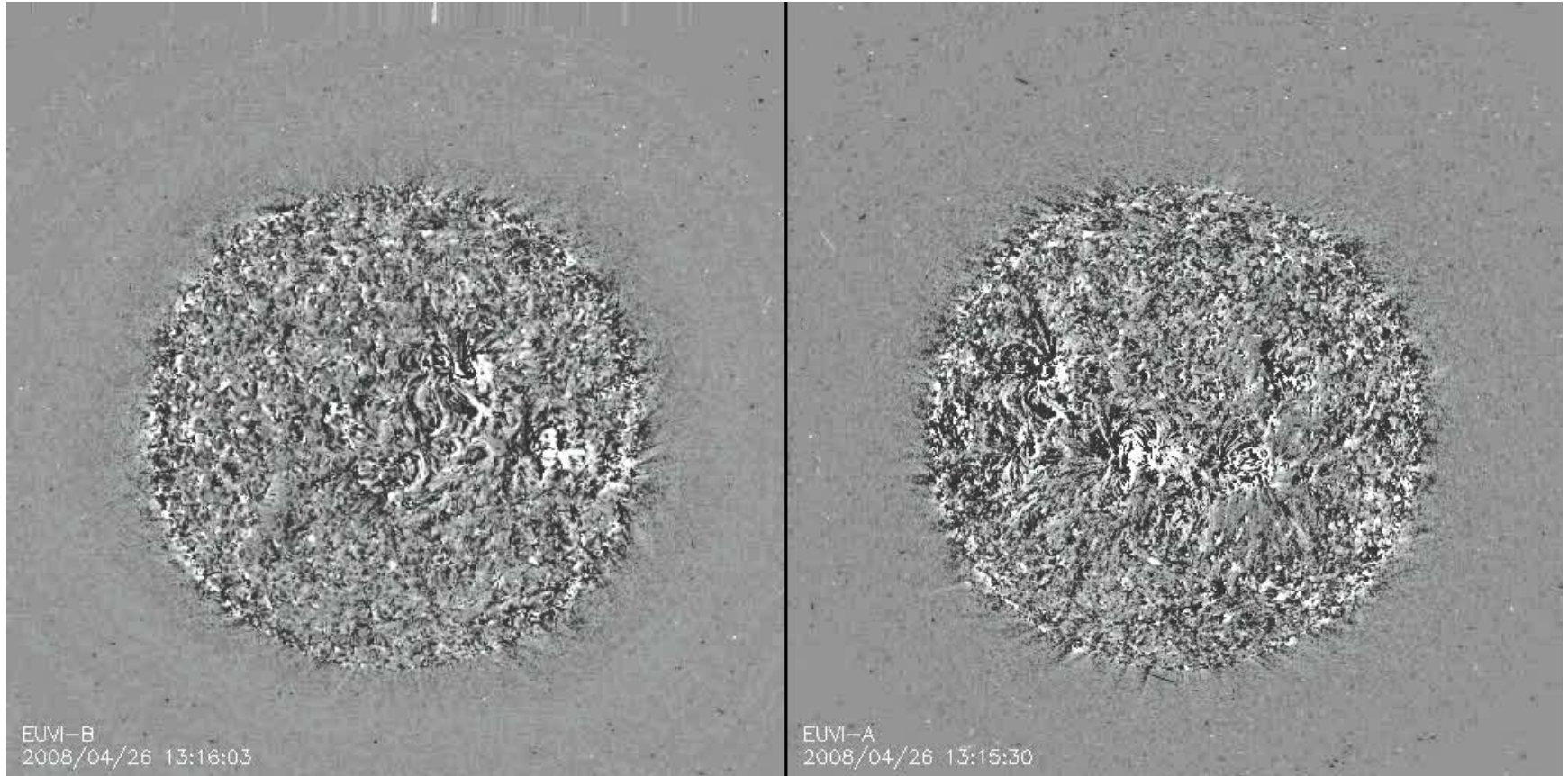


EUVI-B  
2008/04/26 14:06:03

EUVI-A  
2008/04/26 14:05:30



# April 26, 2008 CME





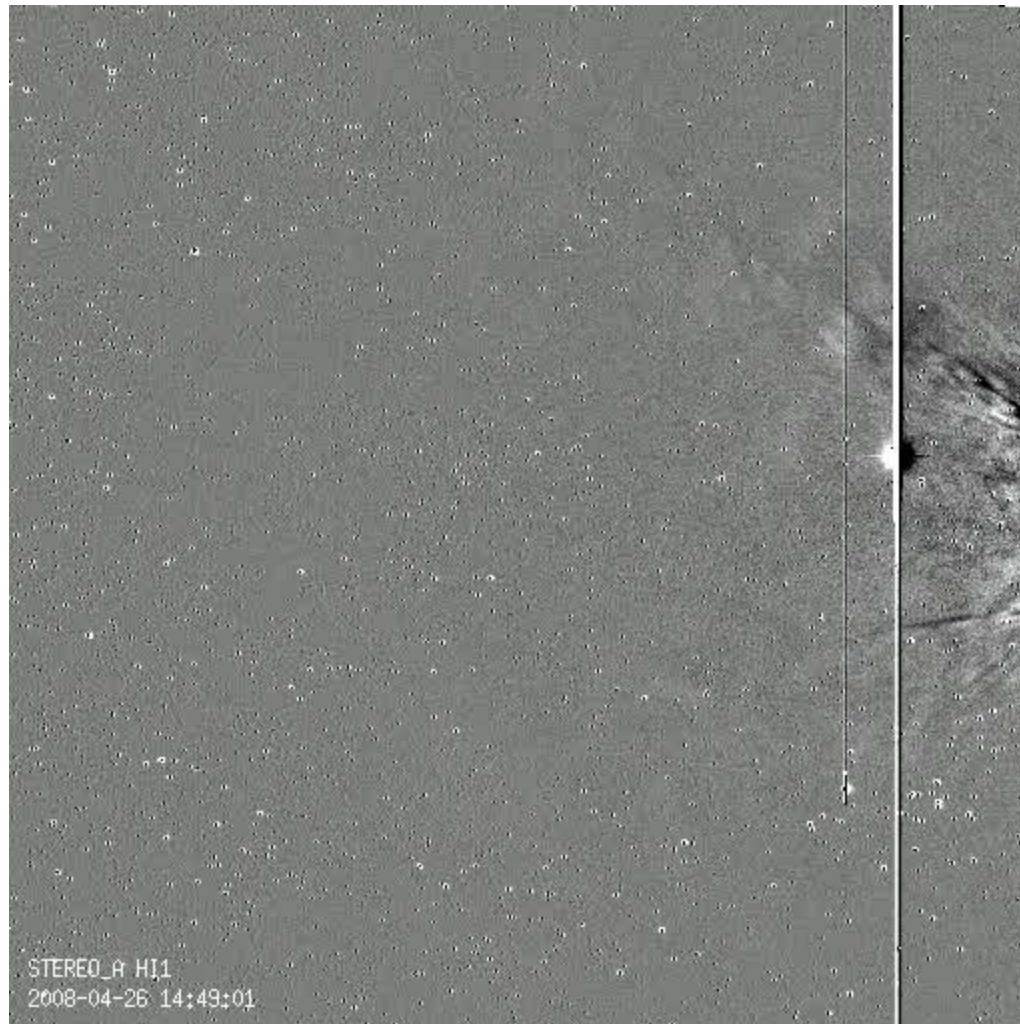
# April 26, 2008 CME





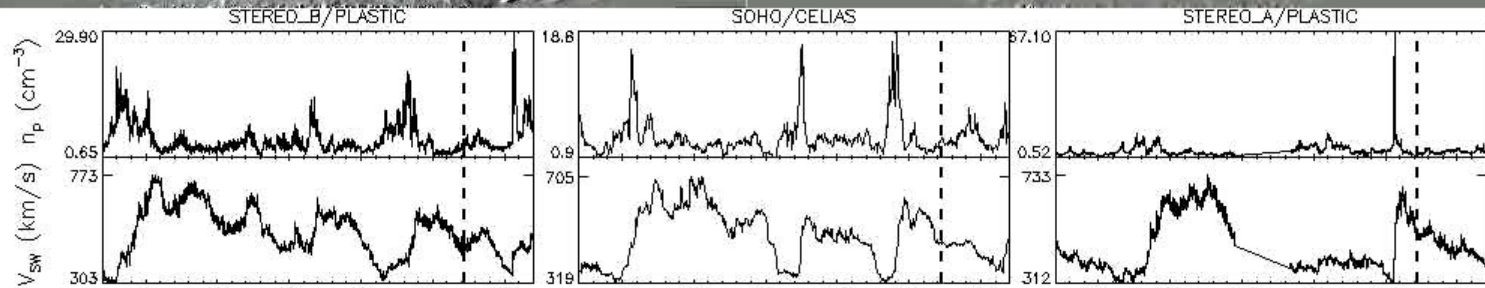
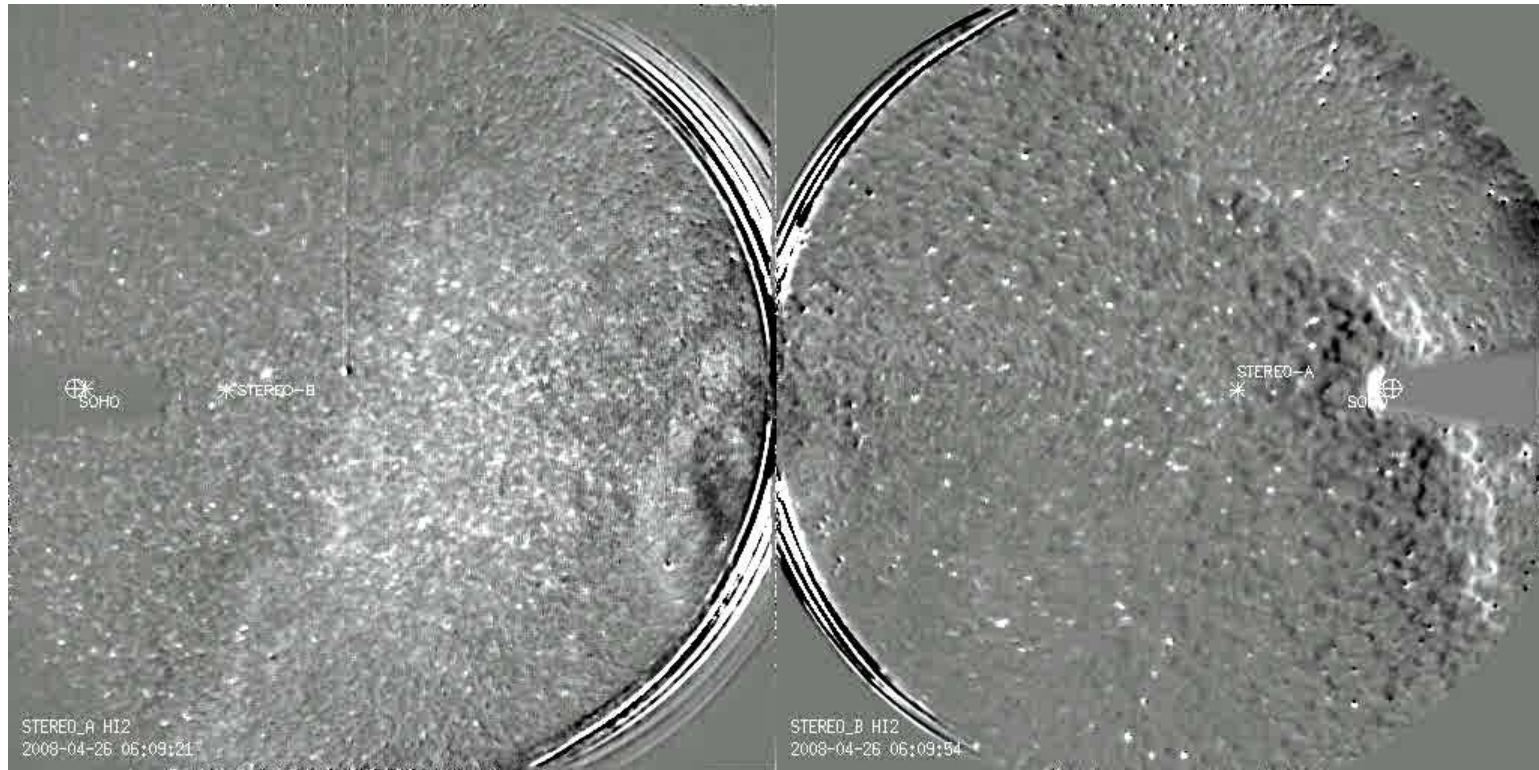


# April 26, 2008 CME



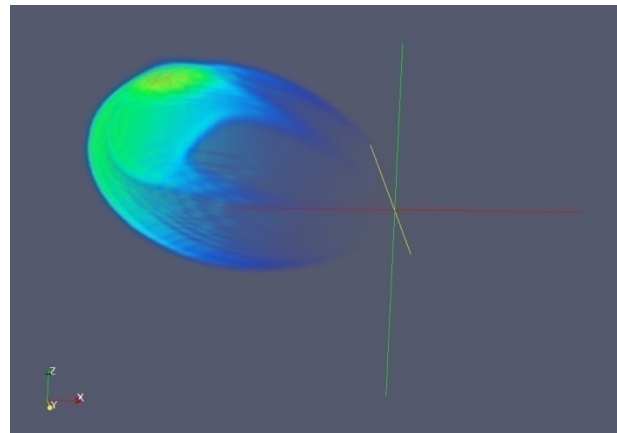
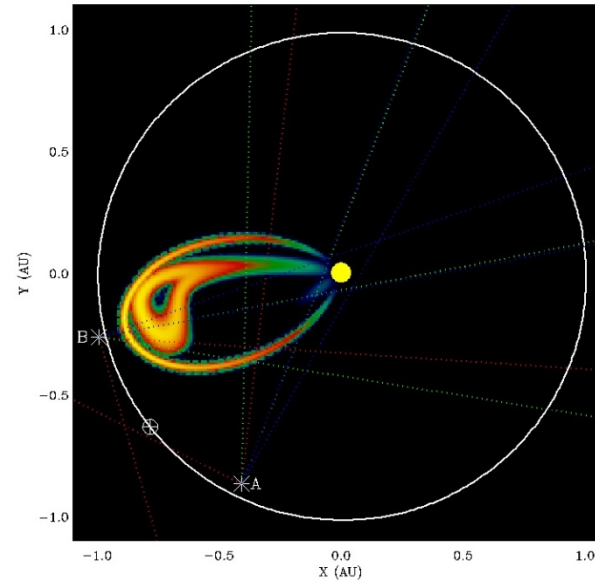
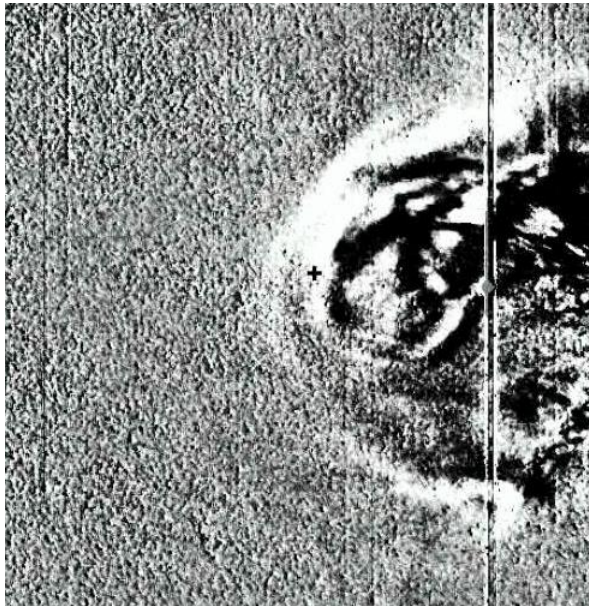


# April 26, 2008 CME





# Intuitive' 3D Model of April 26 CME



Results courtesy of Brian Wood



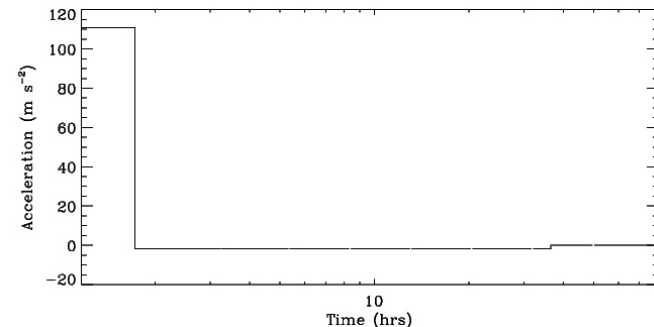
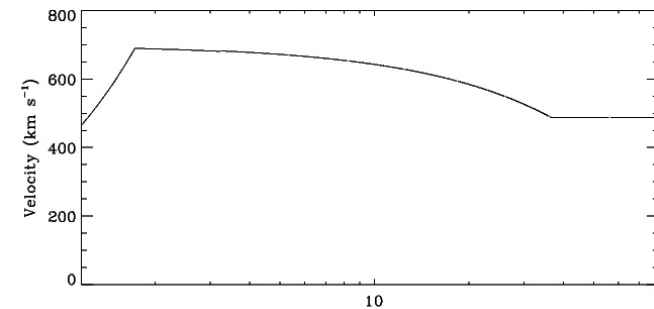
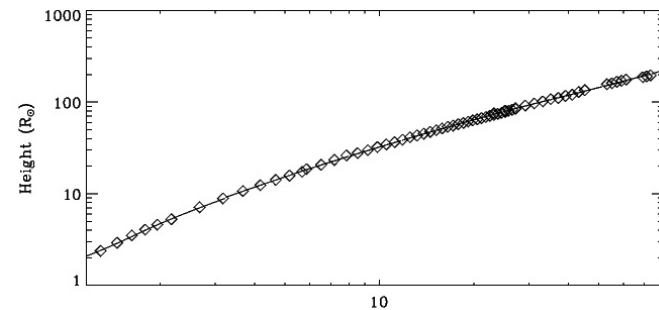


# Kinematic Model of April 26 CME

- Radial distances  $r$  derived from measurements of elongation angles  $\varepsilon$  using 'Fixed  $\phi$ ' assumption:

$$r = \frac{d \sin \varepsilon}{\sin(\varepsilon + \phi)}$$

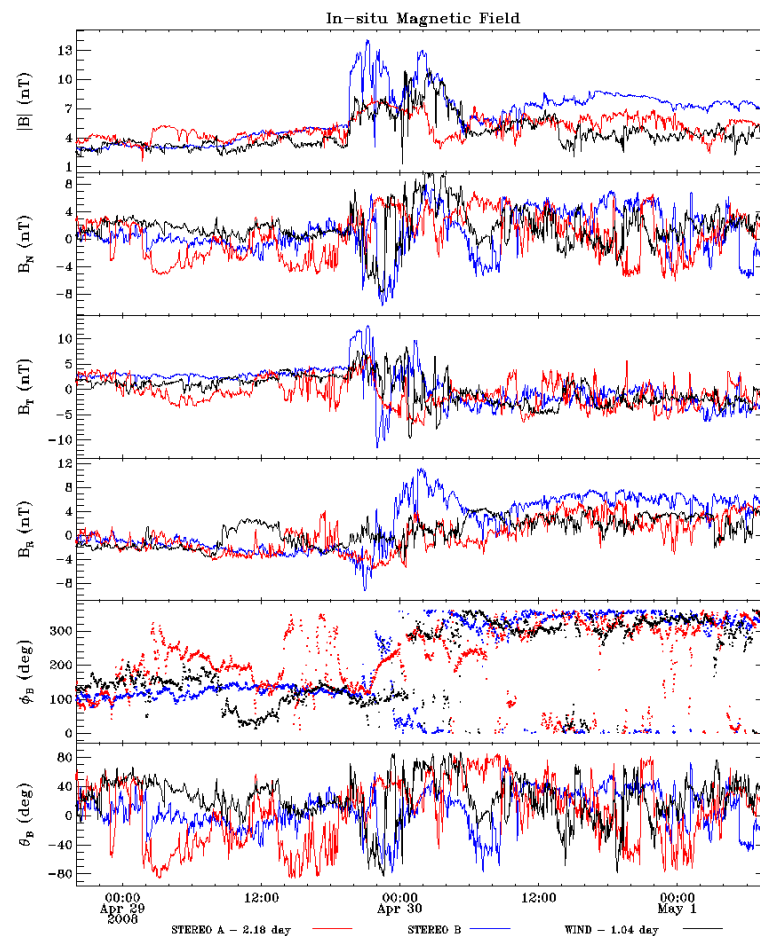
- Kinematic model fit to the CME assumes an initial acceleration phase, followed by a deceleration phase, and finally a constant velocity.
  - Fit shown for leading edge of flux rope (not front of CME).
- CME reaches STEREO-B around 14:00 UT on April 29.





# 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 ( $\sim 2$  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

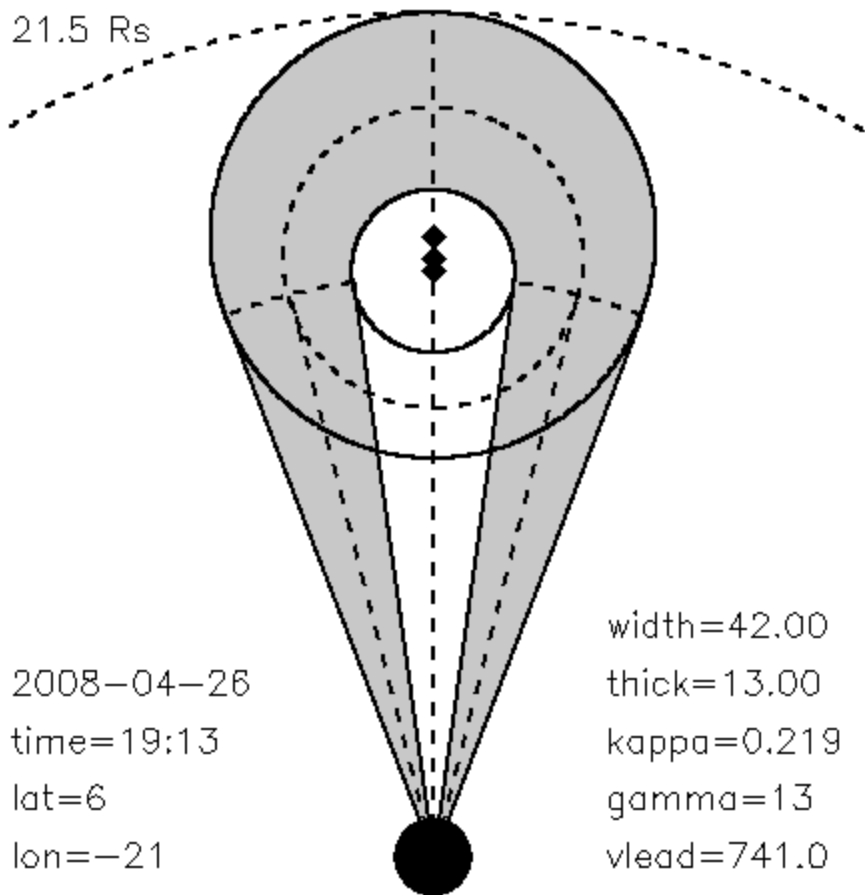


ENLIL-2.5 medres WSA-1.6 GONG

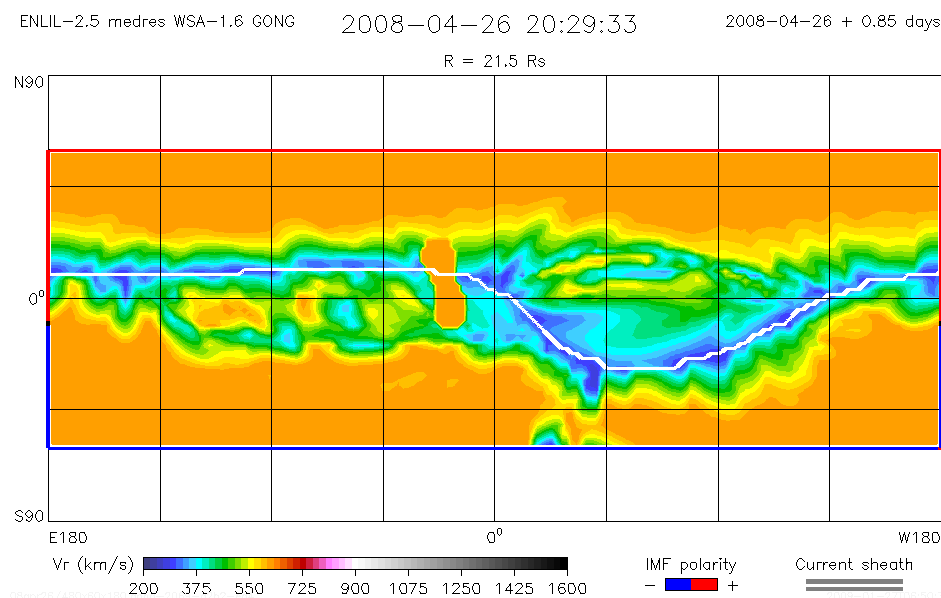
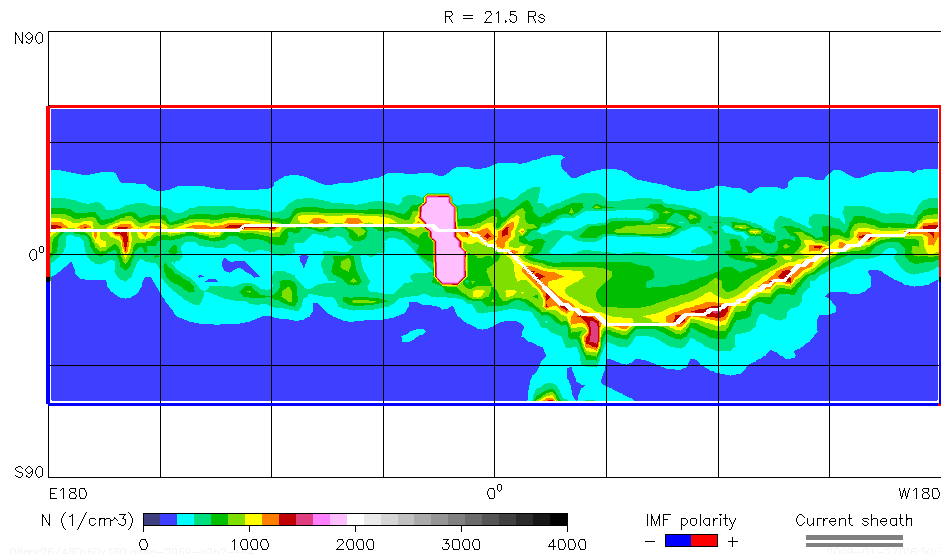
2008-04-26 20:29:33

2008-04-26 + 0.85 days

21.5 Rs



(Thernisien et al., 2009)



(WSA-1.6-GONG-CR2069)



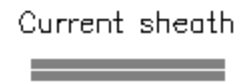
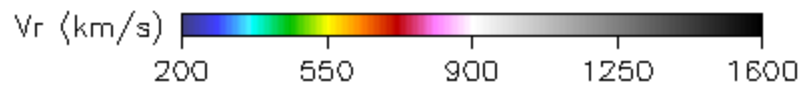
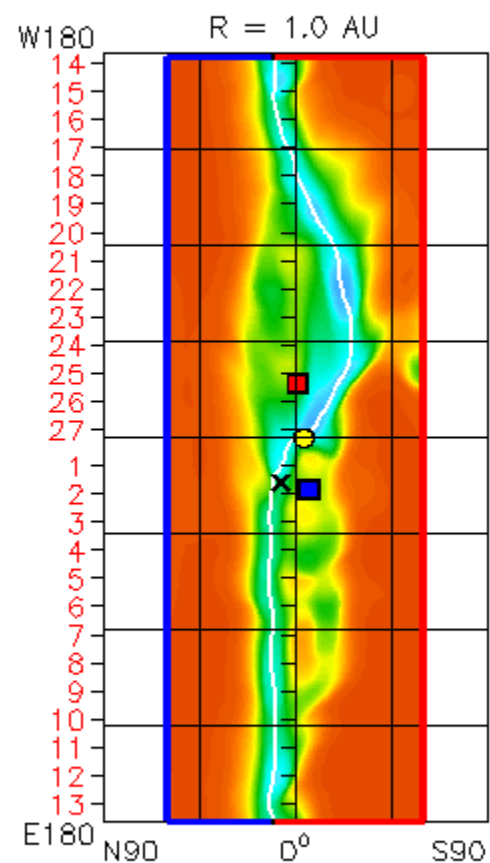
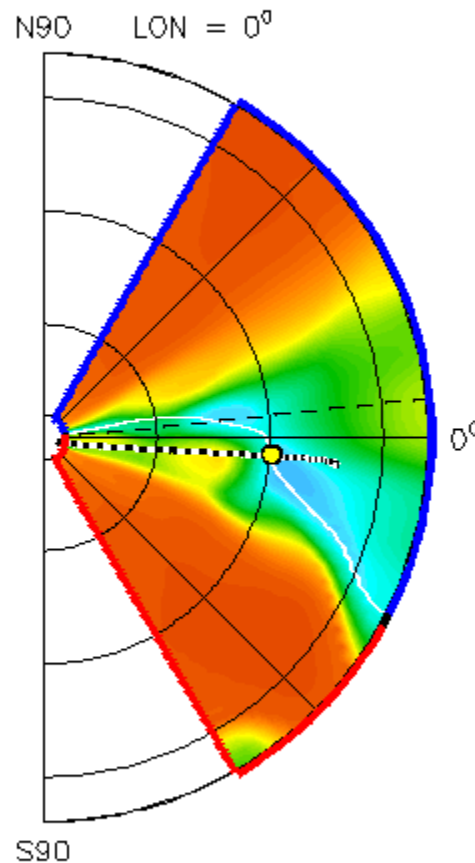
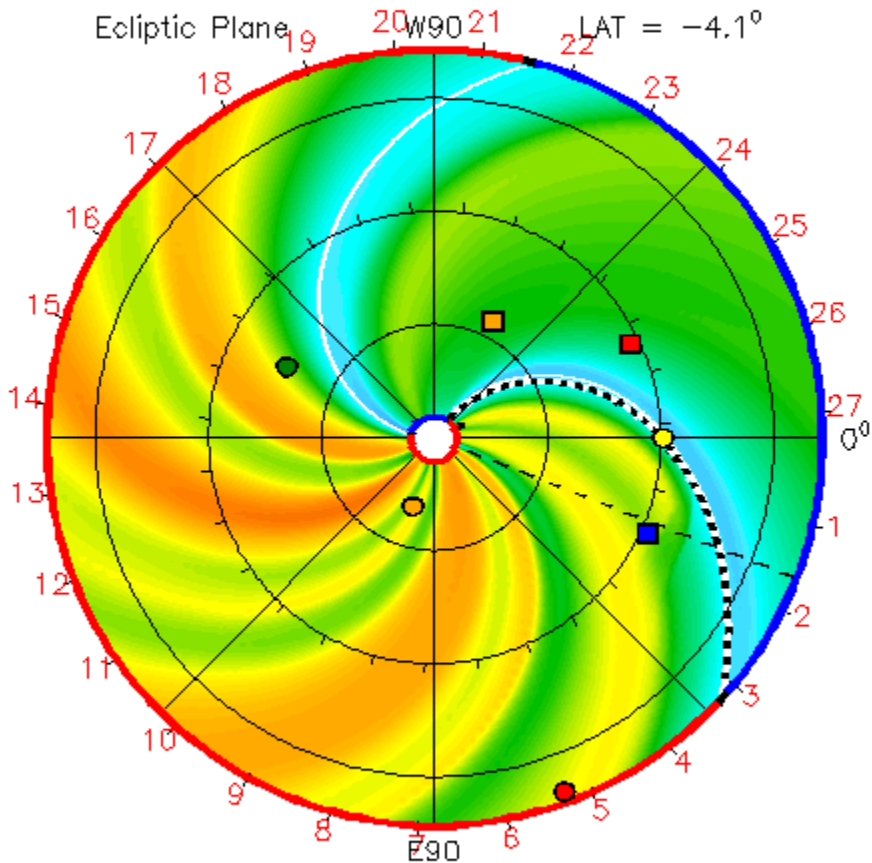
# 2008 April 26 CME with Rope Model



2008-04-30 08:01:52

2008-04-26 +4.33 days

● Mercury   
 ● Venus   
 ● Earth   
 ● Mars   
 ■ Messenger   
 ■ Stereo\_A   
 ■ Stereo\_B





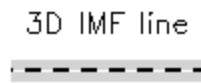
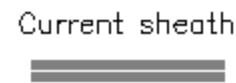
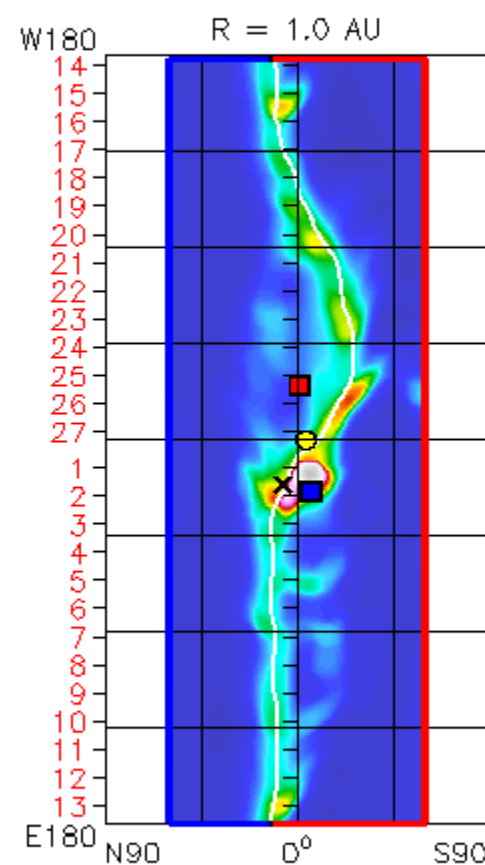
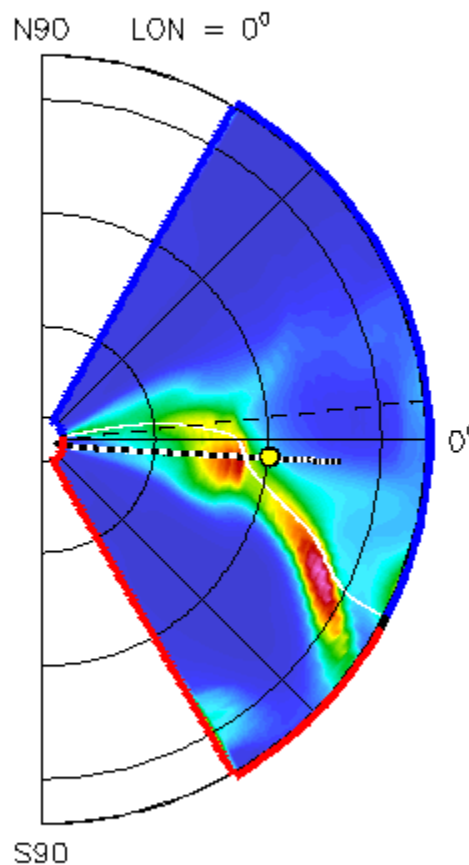
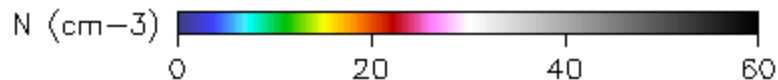
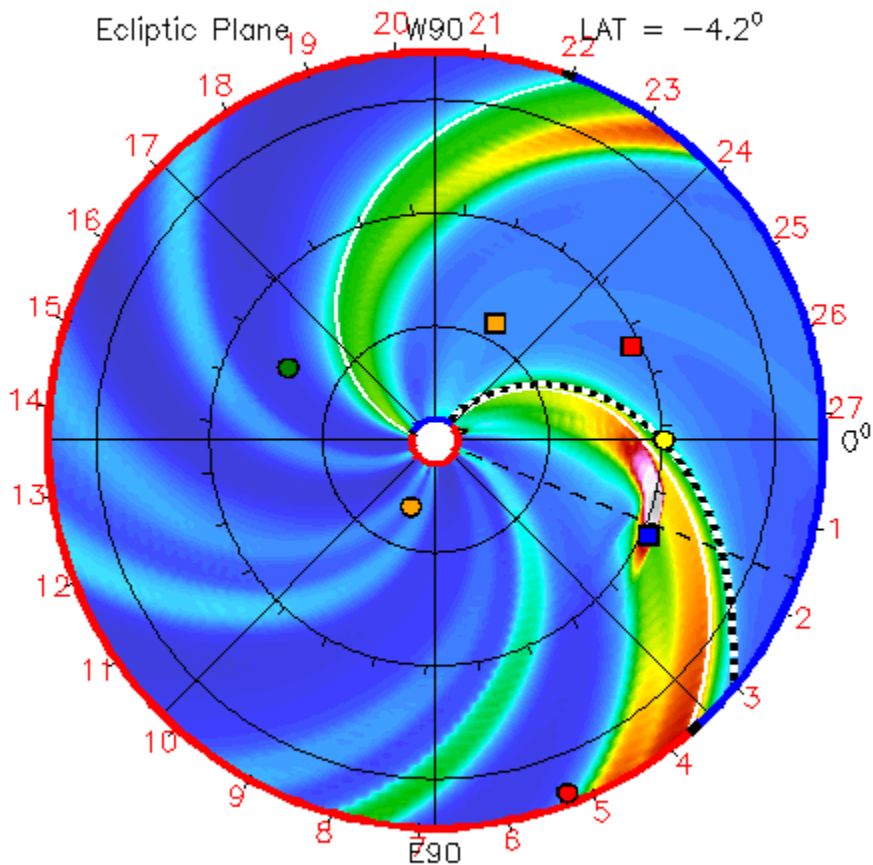
# 2008 April 26 CME with Rope Model



2008-04-29 20:00:14

2008-04-26 +3.83 days

Mercury Venus Earth Mars Messenger Stereo\_A Stereo\_B





# 2008 April 26 CME with Rope Model



ENLIL-2.5 medres WSA-1.6 GONG

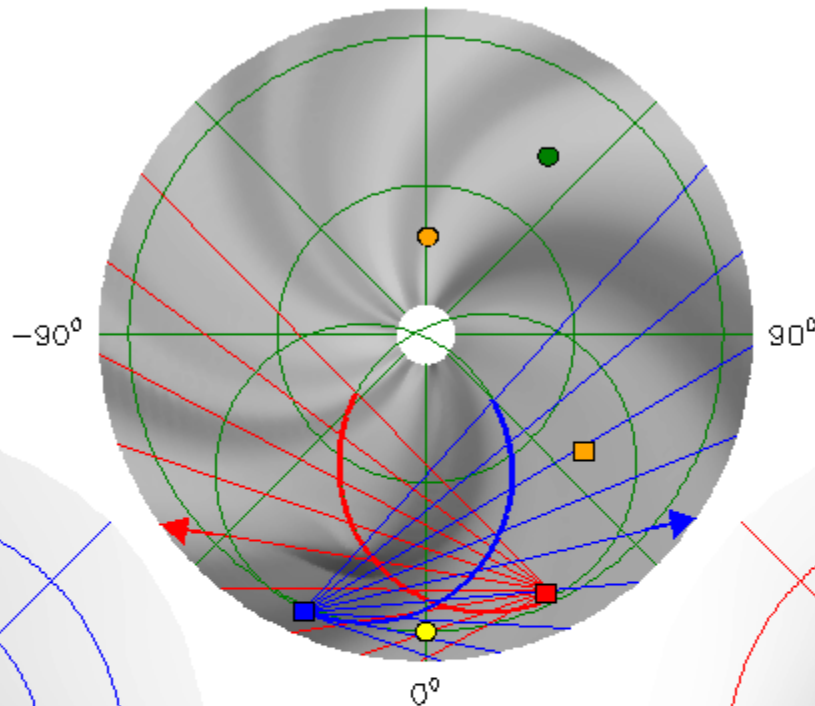
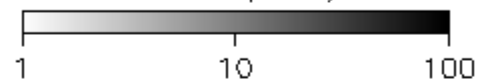
2008-04-29 04:03:05

2008-04-26 +3.16 days

- Mercury
- Venus
- Earth
- Messenger
- Stereo\_A
- Stereo\_B

Solar Wind Density:  
← Equatorial Plane

$$R^2 * N \text{ (cm}^{-3}\text{)}$$



North

North

Sun

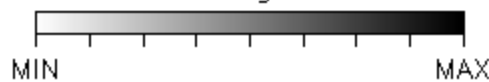
Sun

White-Light Images:

Stereo\_A/HI2 →

← Stereo\_B/HI2

Total Brightness



MIN

MAX



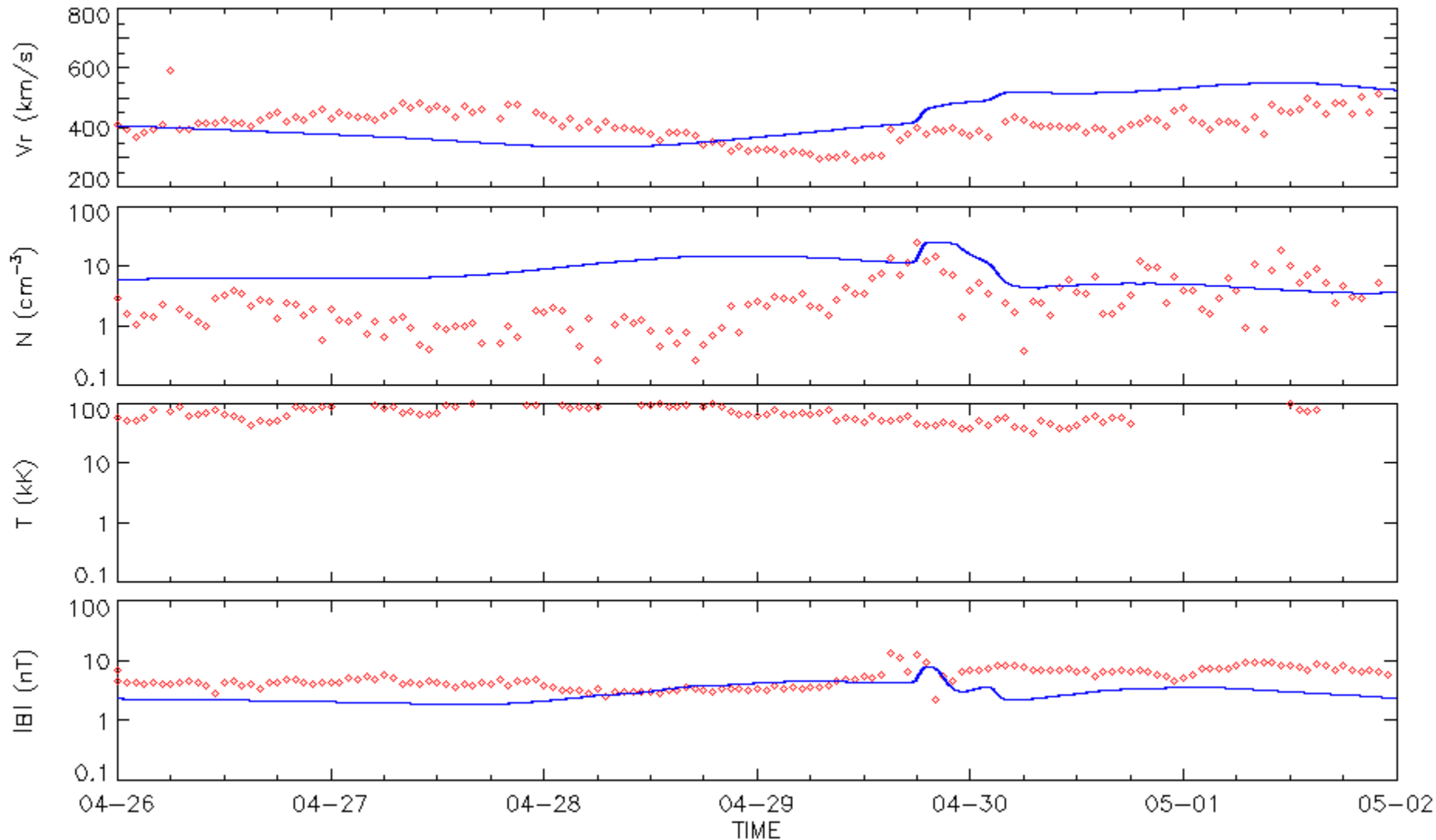
# 2008 April 26 CME with Rope Model



ENLIL-2.5 medres WSA-1.6 GONG

2008-04-26 00:00:00

Evolution of parameters at STEREO\_B





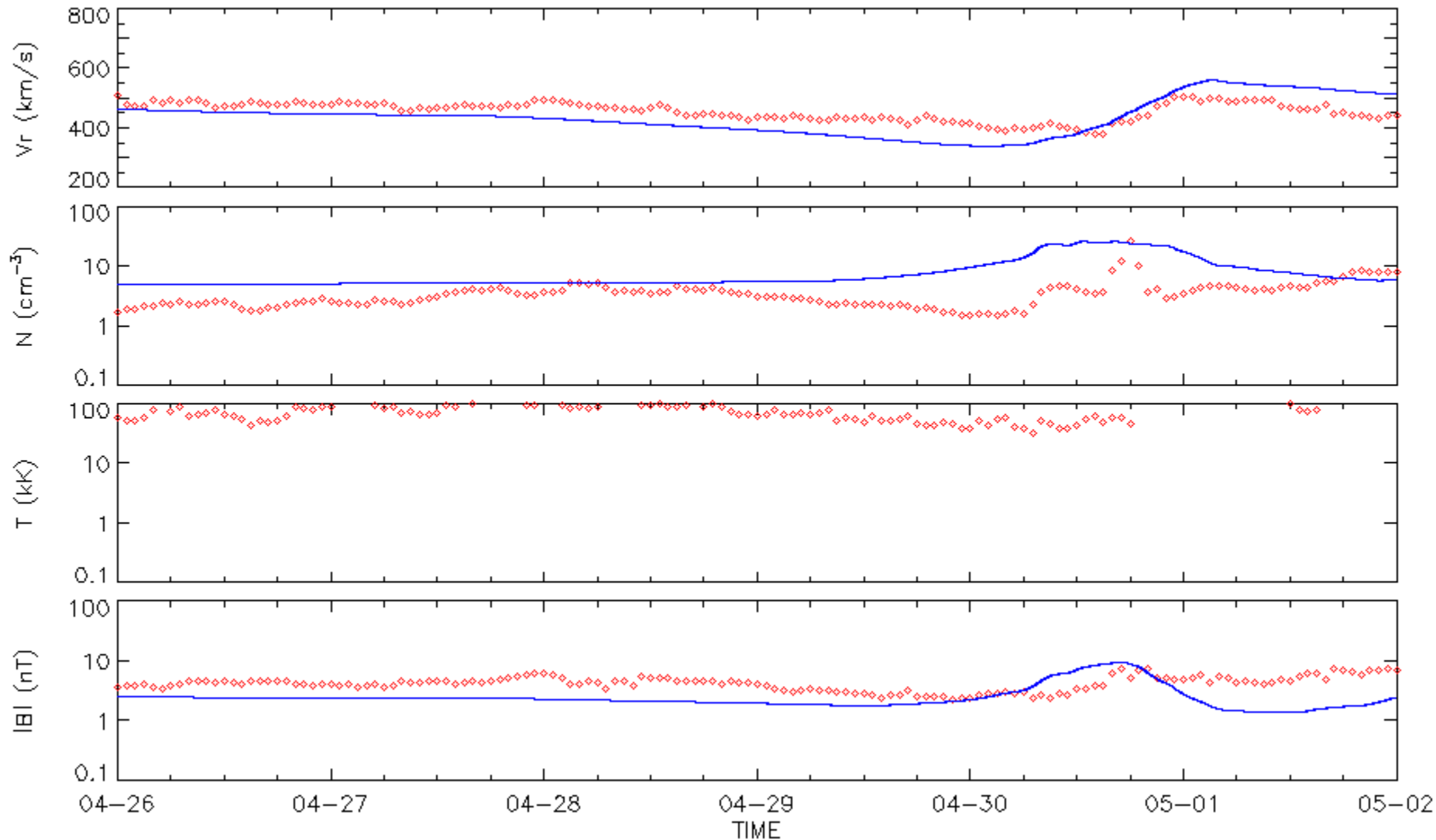
# 2008 April 26 CME with Rope Model



ENLIL-2.5 medres WSA-1.6 GONG

2008-04-26 00:00:00

Evolution of parameters at EARTH





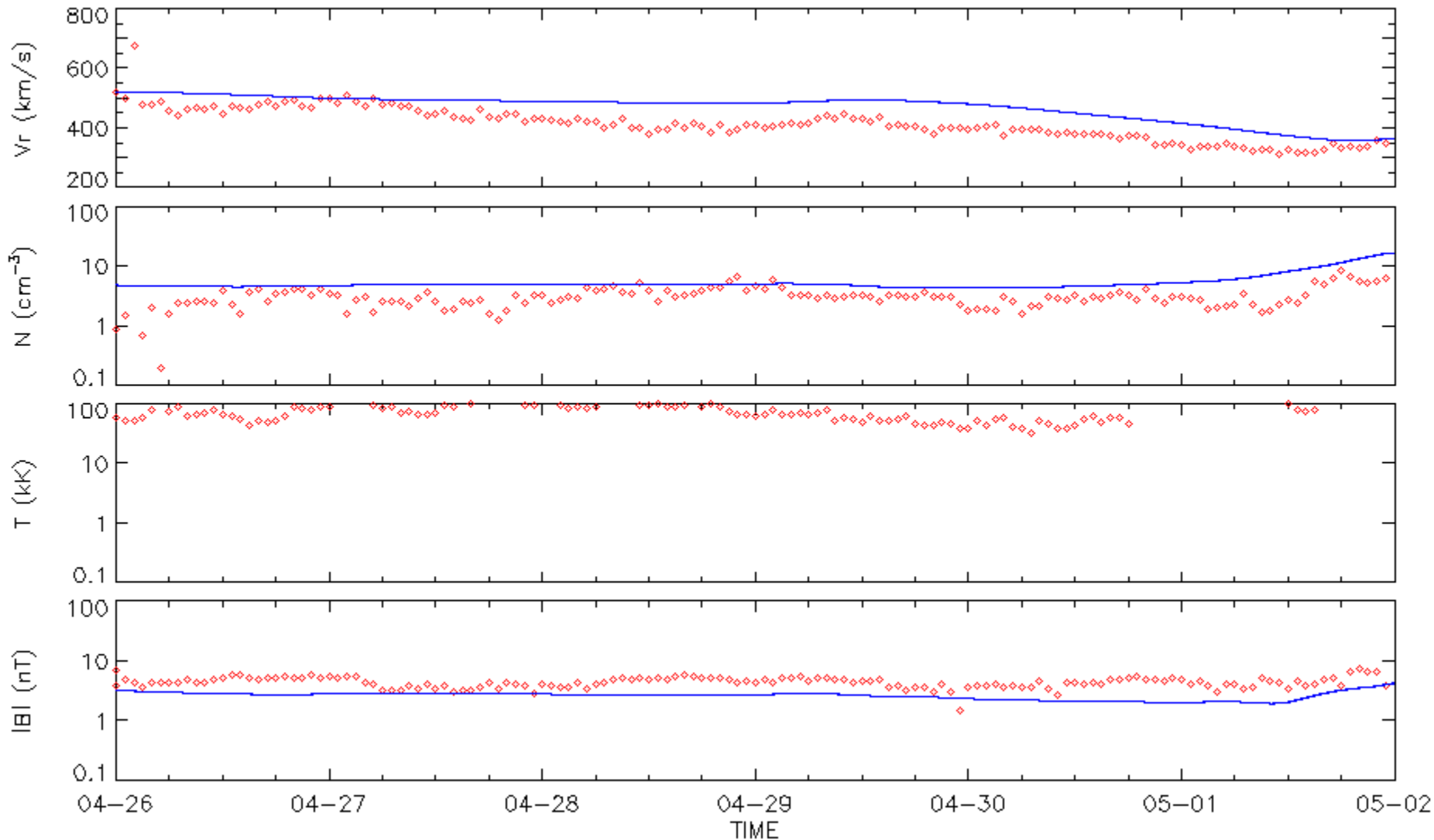
# 2008 April 26 CME with Rope Model



ENLIL-2.5 medres WSA-1.6 GONG

2008-04-26 00:00:00

Evolution of parameters at STEREO\_A





# 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.