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Thursday 17:45-18:00

Solar-terrestrial Simulations in the STEREO Era

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Due to the scarcity of heliospheric observations, over the past decade global 3-D numerical simulations have become increasingly important in studying the propagation of coronal mass ejections (CMEs) from the Sun to the Earth. Since the launch of STEREO in November 2006, continuous white-light observations of solar transients on their way to the Earth in near-real time have become possible.

In this talk, we will discuss the significance of 3-D simulations in the interpretation of observations taken by the Heliospheric Imagers. We will focus on a series of two ejections in January, 24-25, 2007, which have been simulated with the Space Weather Modeling Framework (SWMF). We will present detailed comparisons between real and simulated time-elongation plots and discuss the appearance of CME-CME interaction in real and synthetic observations.

Solar-terrestrial Simulations in the STEREO Era

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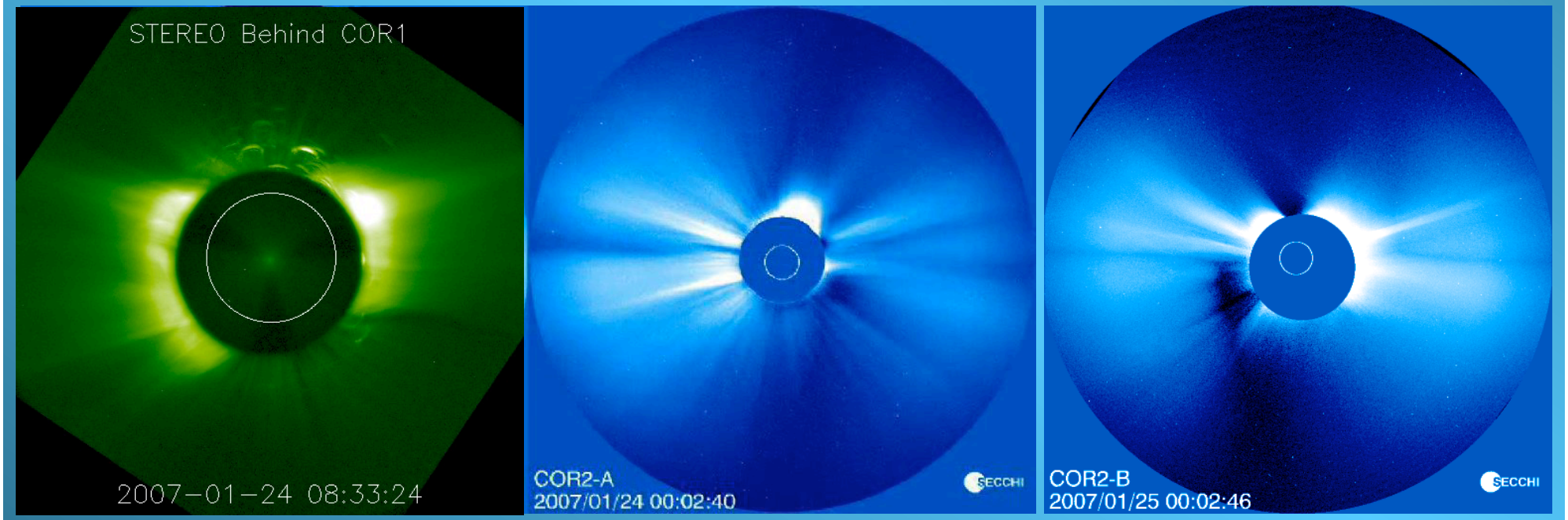
Institute for Astronomy
Angelos Vourlidas
Naval Research Laboratory

European Solar Physics meeting,
September 11, 2008

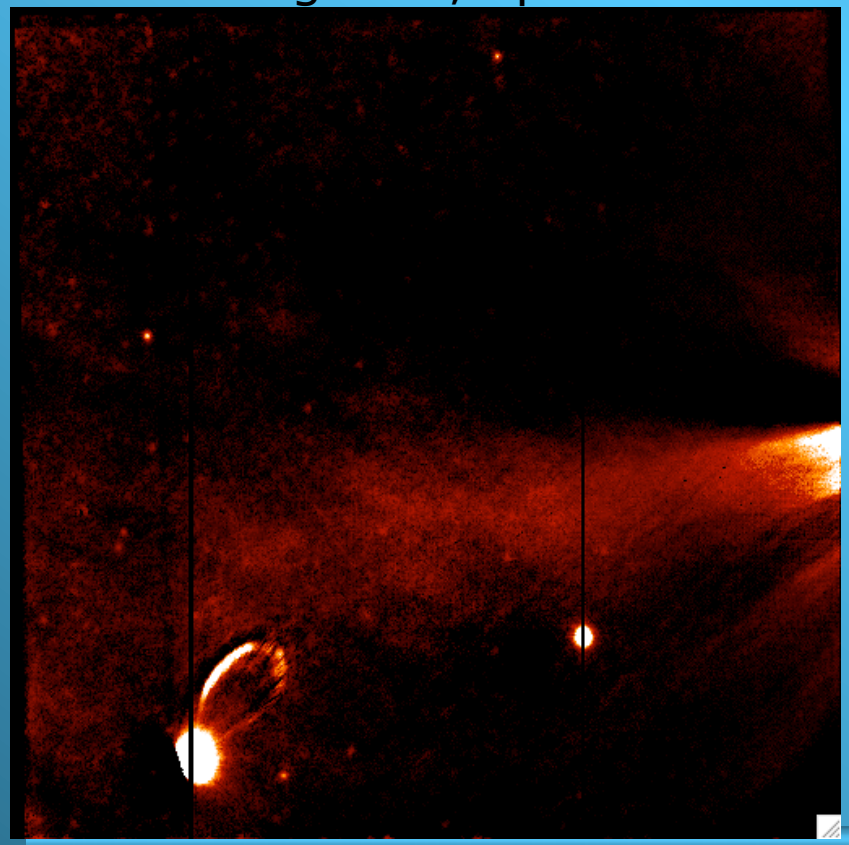
The January 24-26, 2007 CMEs

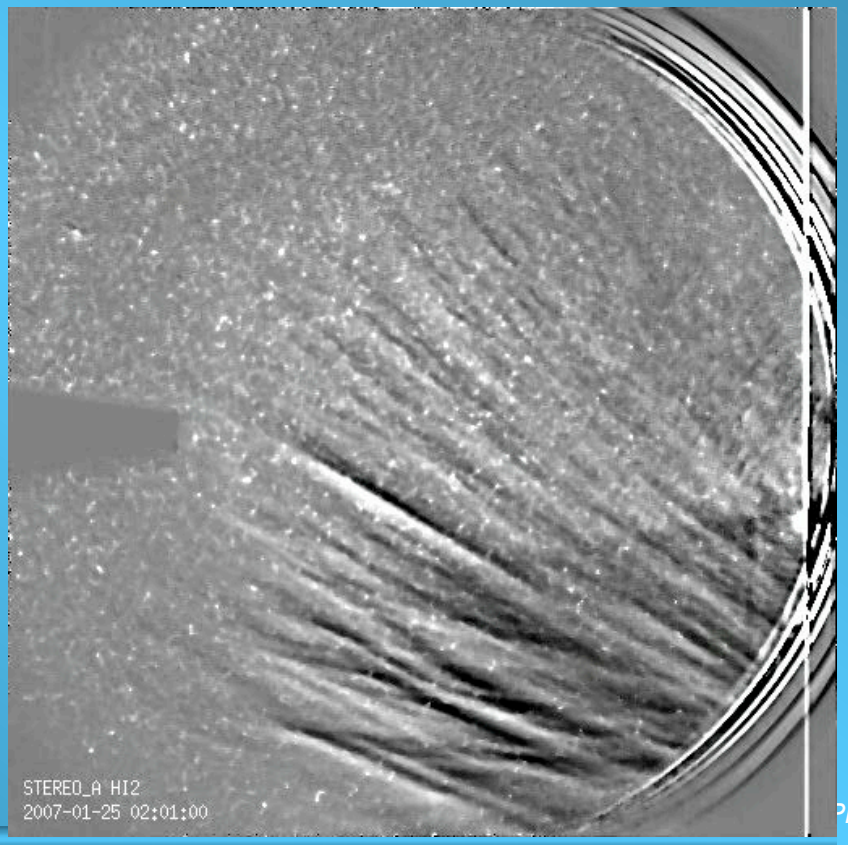
- First major CMEs observed by the SECCHI suite…
  … but with a 20 hour gap while the CMEs were in HI1's FOV.
- *1st CME*: 01/24 @14:03 ~700 km/s - *2nd CME*: 01/25 @06:43 ~1200 km/s
- Data gap: 01/25 06 UT to 01/26 00 UT



SECCHI Heliospheric Imagers Observations

- Reported in Harrison et al. 2008
- First CME observed in HI1-A between 4.4 and 12.1° elongation
- Bright fronts observed in HI2-A on January 26 up to 32.5° for the brightest, up to 42° for one front ahead and dimmer.





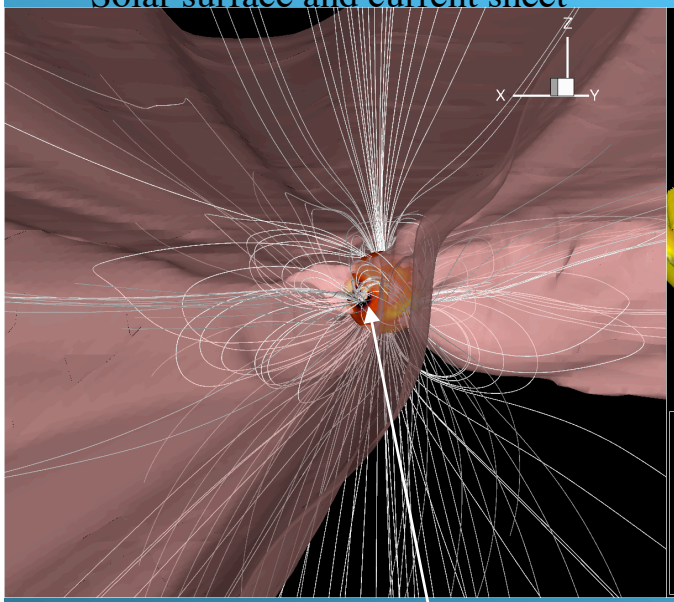
courtesy of H. Morgan

courtesy of A. Vourlidas

Simulation set-up

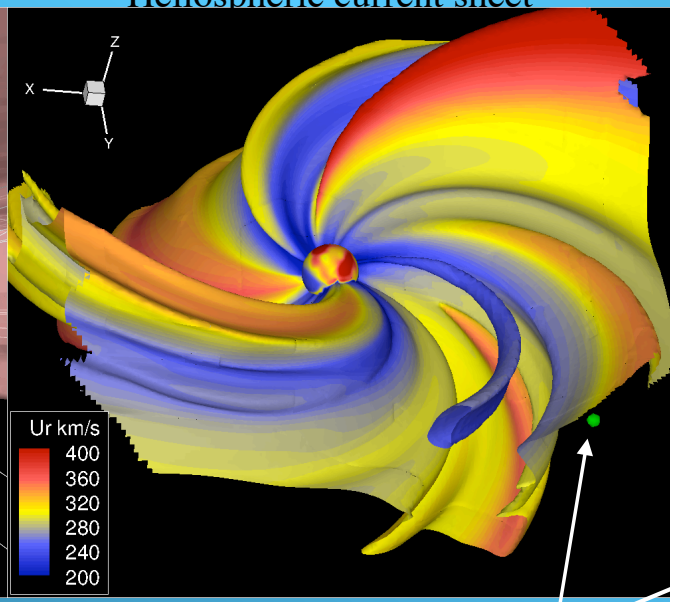
- Space Weather Modeling Framework (Univ. Michigan)
- Solar wind model of Cohen et al. (2007), out-of-equilibrium flux ropes chosen to match initial observed speed.
- From $1R_{Sun}$ to 1 AU: 40,000 4^3 blocks + 15,000 8^3 blocks (> 10M cells)

Solar surface and current sheet



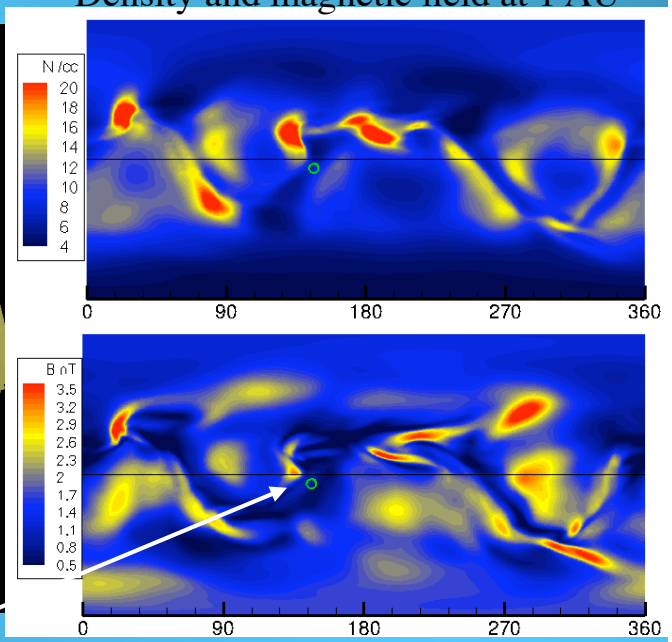
AR 940

Heliospheric current sheet



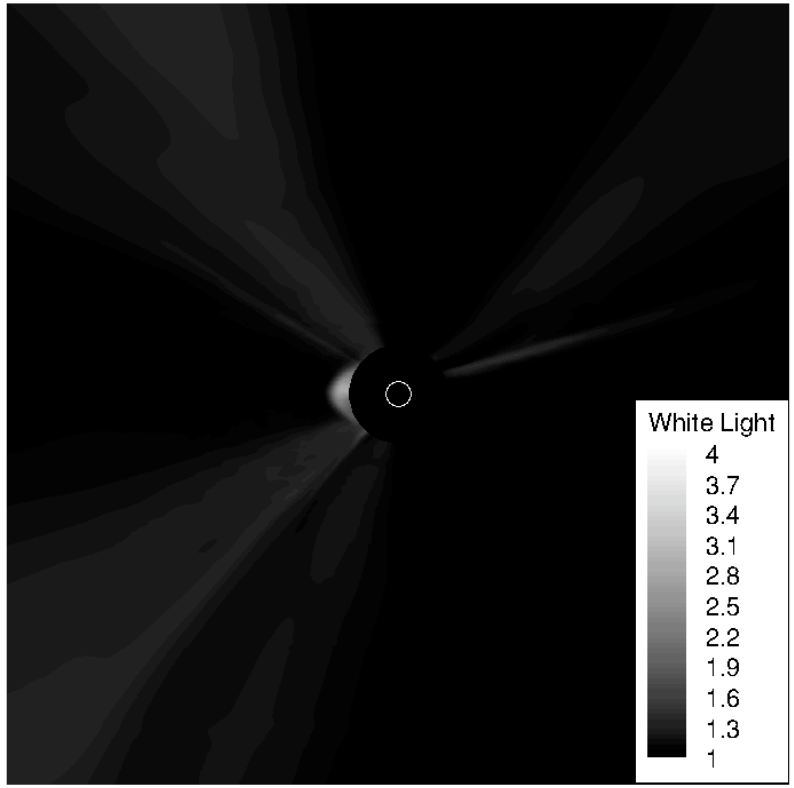
Earth (2007, January 24)

Density and magnetic field at 1 AU



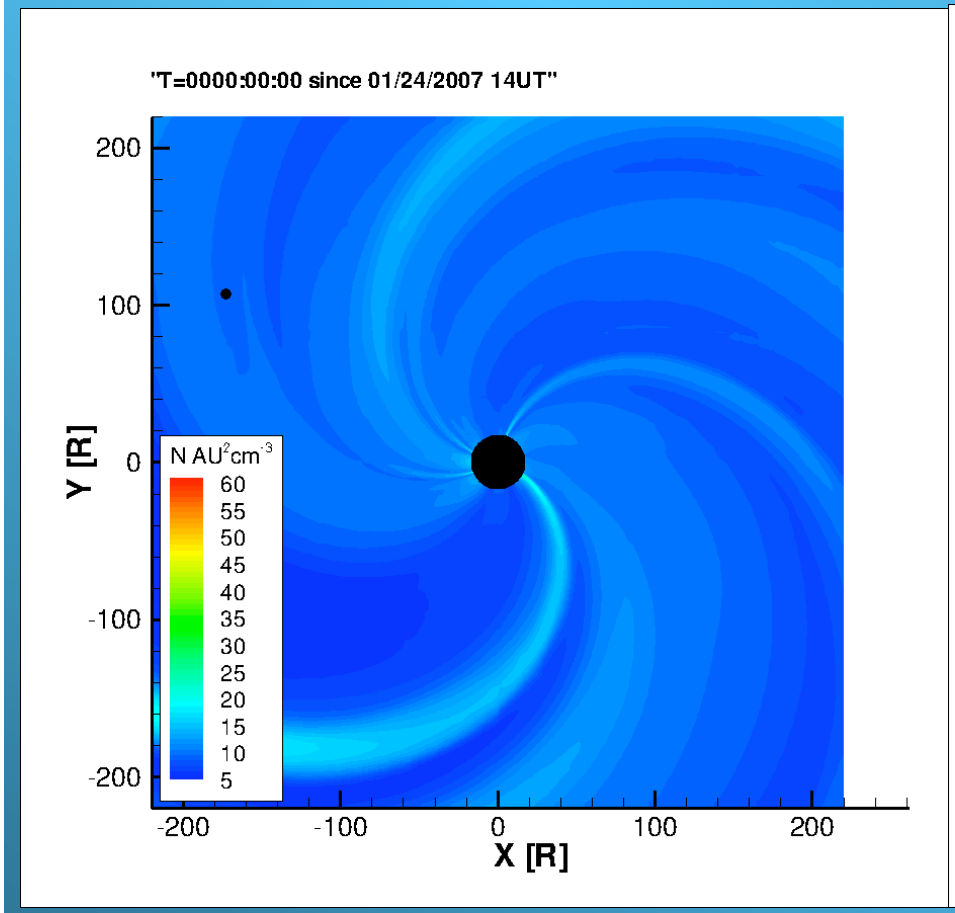
Line-of-sight images

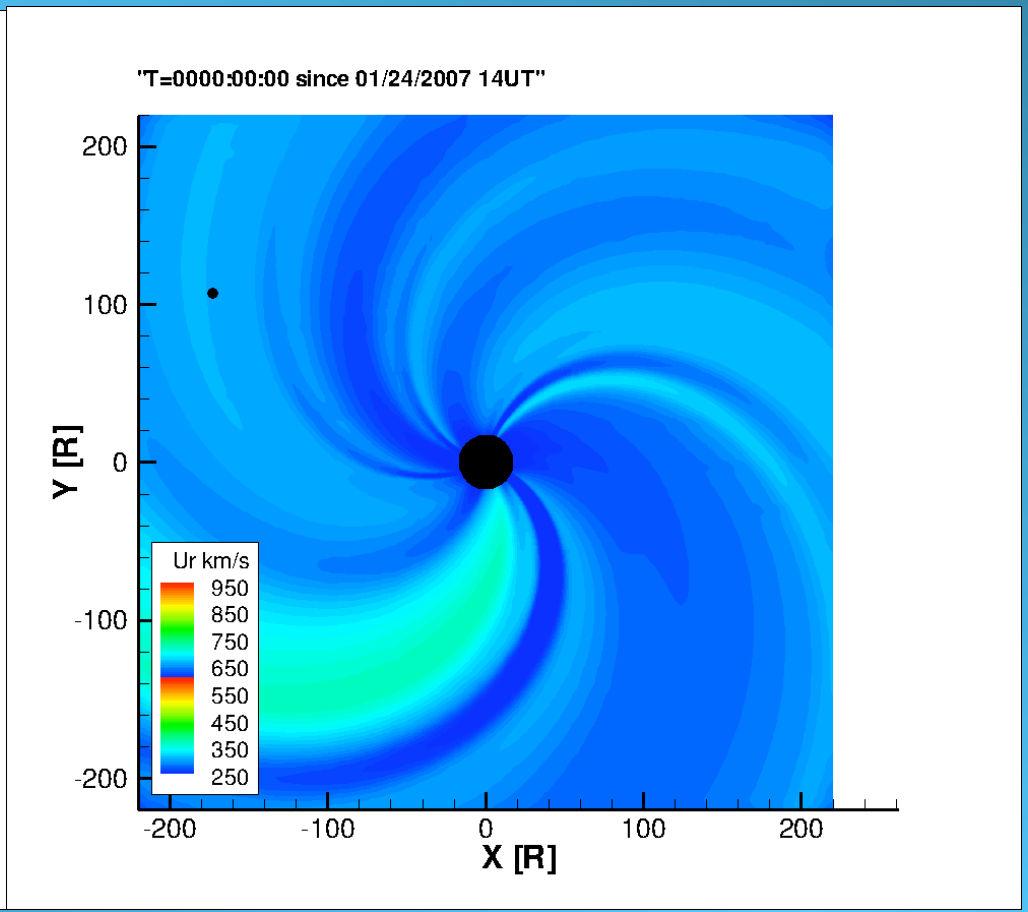
- Simulated background is calculated by deriving the minimum image from 27 steady-state LOS images.



T = 15:00:00 since January 24, 2007 00 UT

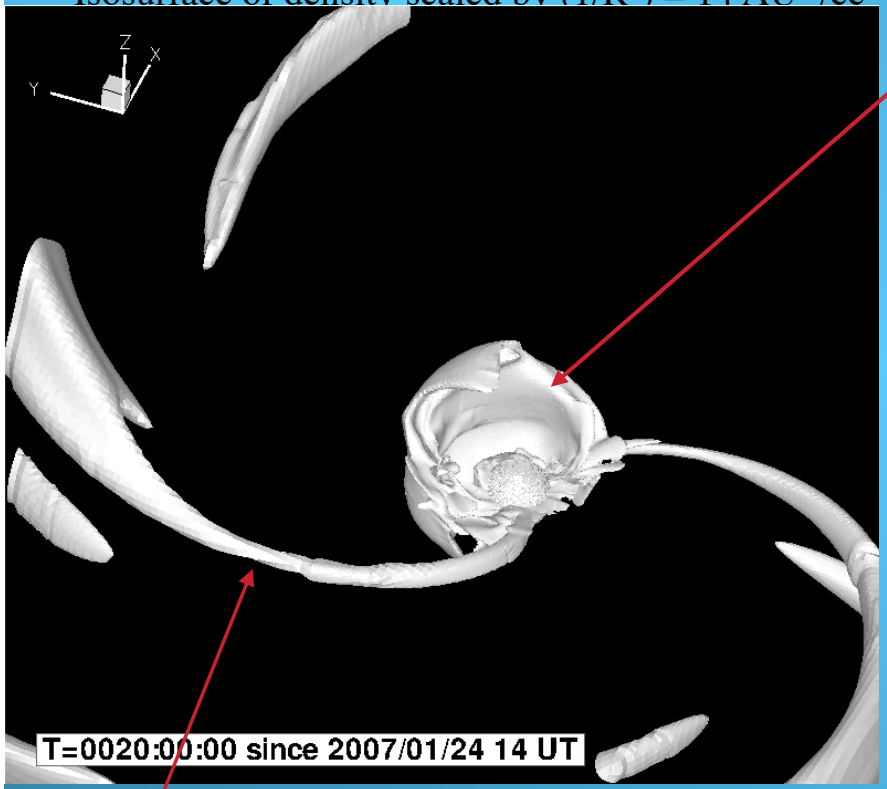
Heliospheric Evolution





3-D evolution and interactions

Isosurface of density scaled by $(1/R^2) = 14$ AU^2 /cc



1st CME

Dense stream

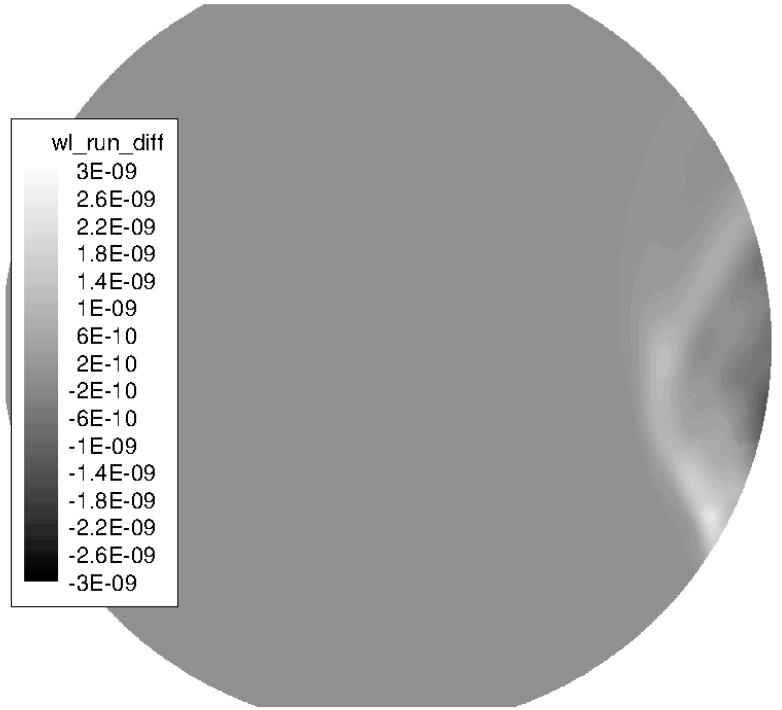
- Near solar minimum: there are a number of steady structures (CIR-like).
- Interaction involves not only the 2 CMEs but also these dense stream structures.
- The main phase of the interaction between the 2 CMEs occur between 19 UT on the 25th and 3 UT on the 26t^{h} during SECCHI down-time.
- This timing highly depends on the angle with respect to the center of the CMEs.
- As seen in previous studies, after the merging of shocks, there are still two extrema of density. **Without a time series, it is hard to associated a bright front with one CME.**

Heliospheric Imagers: what is being observed?

HI1-A

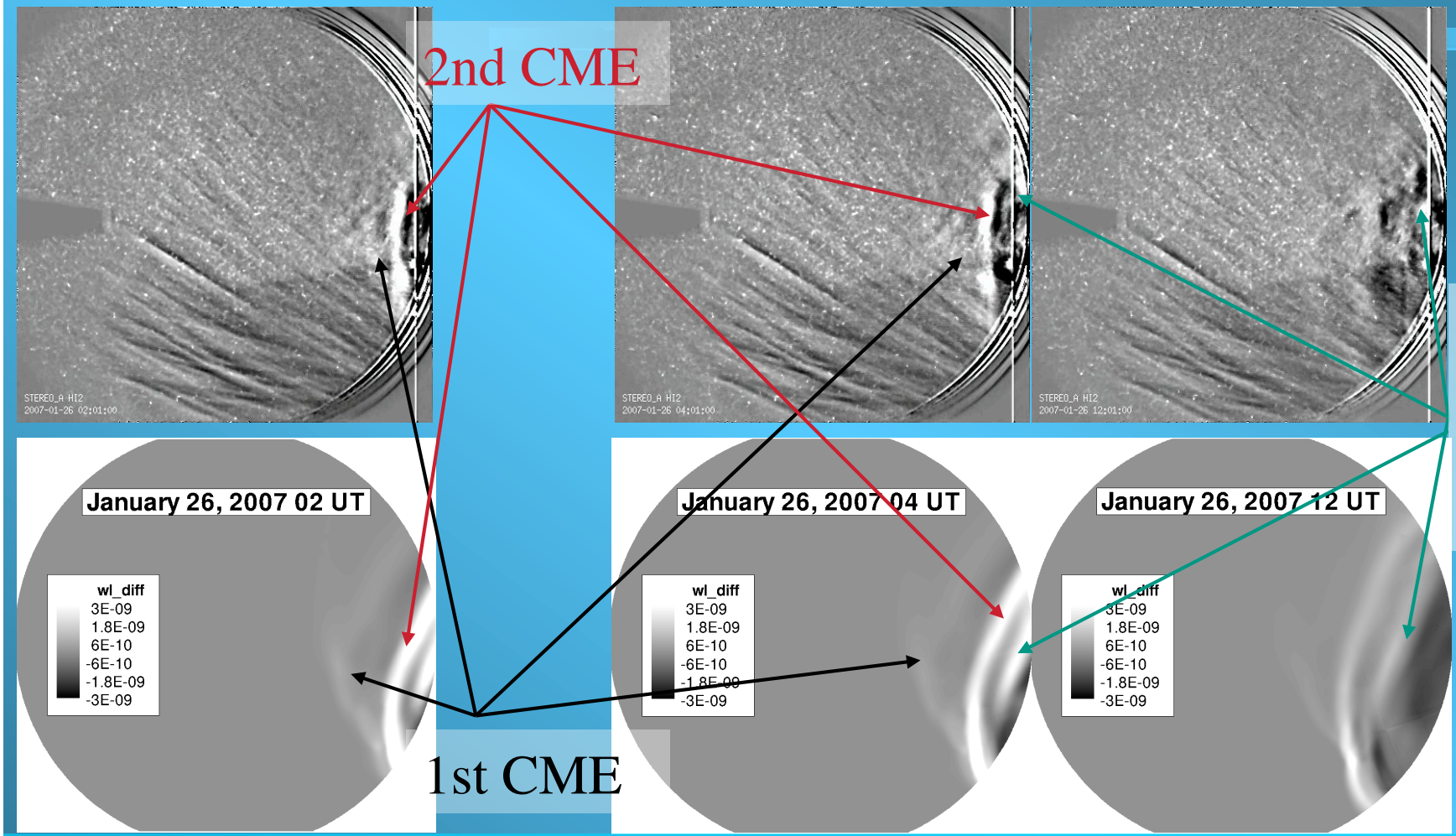
T = -7:00:00 since January 25, 2007 00 UT

HI2-A



T = -5:00:00 since January 26, 2007 00 UT

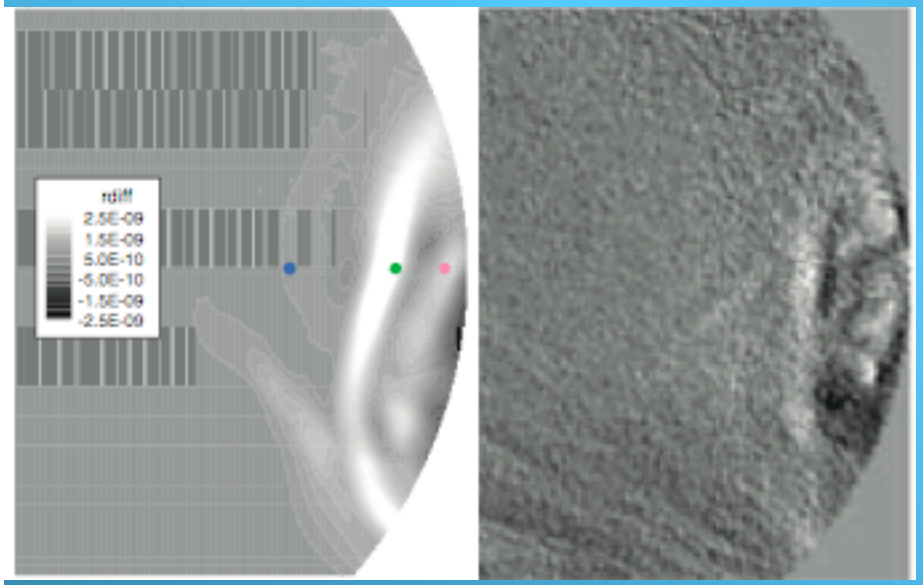
Heliospheric Imagers: what is being observed (2)?



2nd CME is brighter because the leading front propagates inside the sheath of the 1st CME.

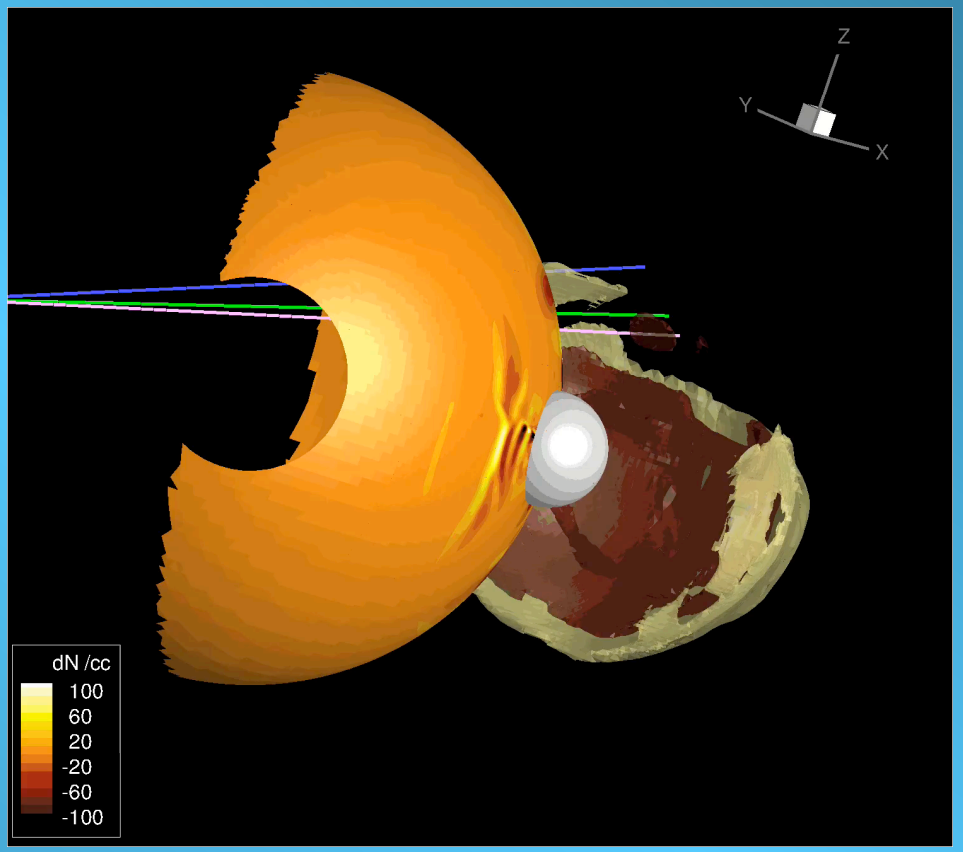
Dense stream can be identified as such in these images, because its propagation speed is different.

Heliospheric Imagers: what is being observed (3)?



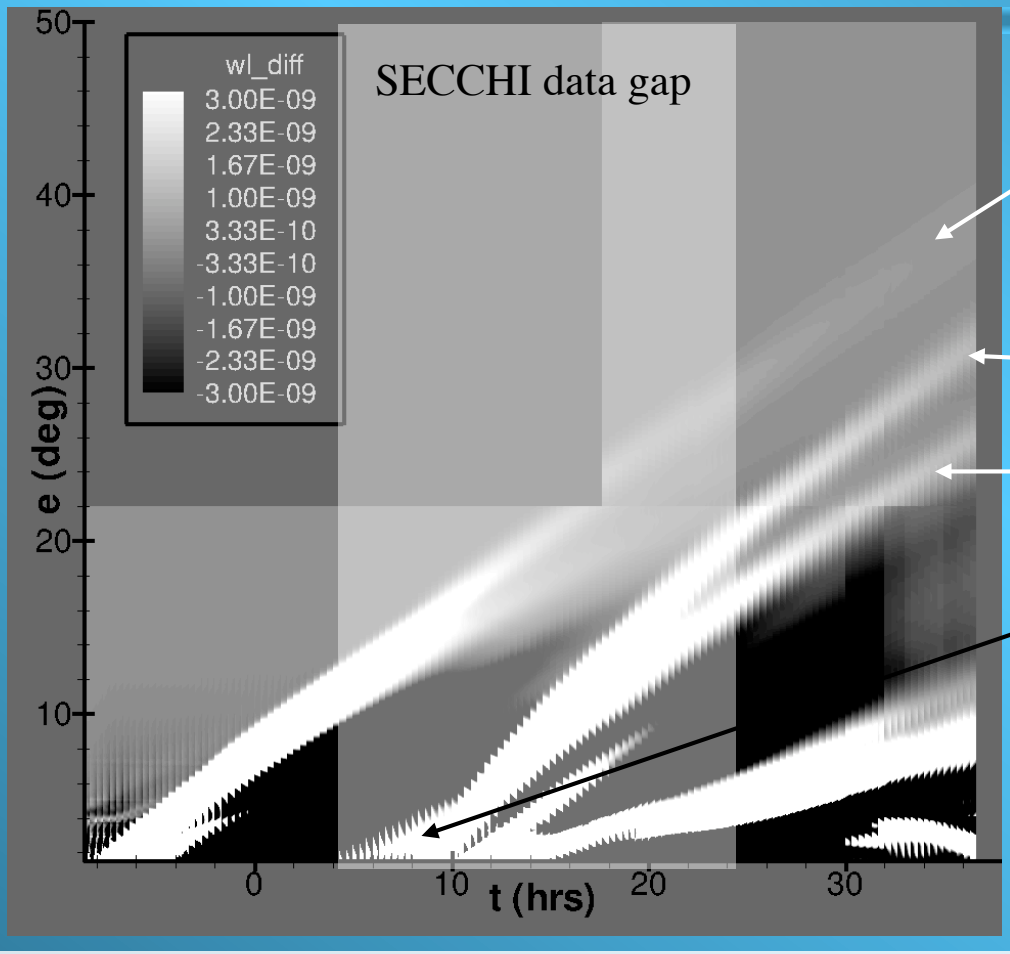
Simulated and observed HI-2A image on January 26, 2007 @ 06 UT.

Three colored dots correspond to the same -color rays in the movie.



Thomson sphere and isosurfaces of density increase and decrease (+ or - 80 /cc).

CME tracking (time-elongation plots)



First CME

Second CME

Compressed dense stream

Pre-existing dense stream

J-map are a good way to track and identify structures

CMEs are 3-D. **Information along 1 PA is not enough.**

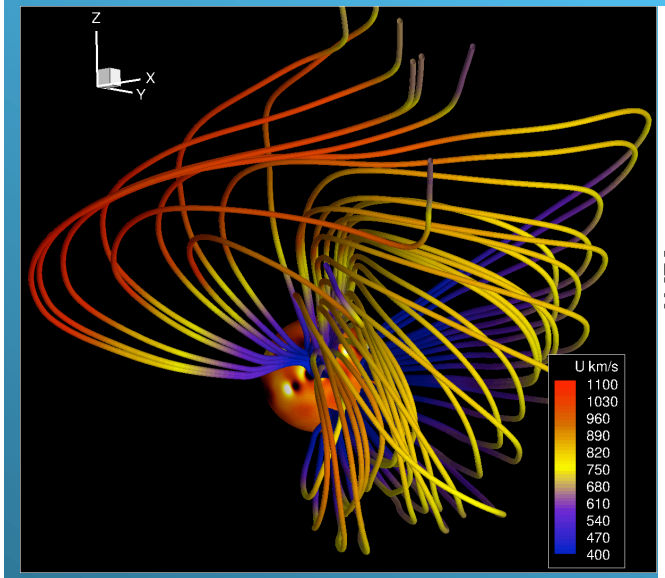
Ex: Here no direct interaction

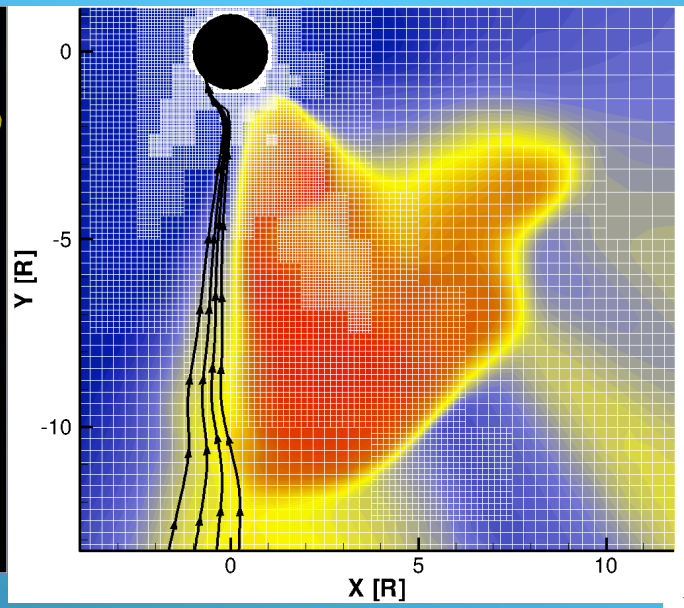
Time (from 01/25)-elongation plot for the central angle of HIs (~ PA 68). Difference of consecutive (2 hrs) images but with a 20-min cadence

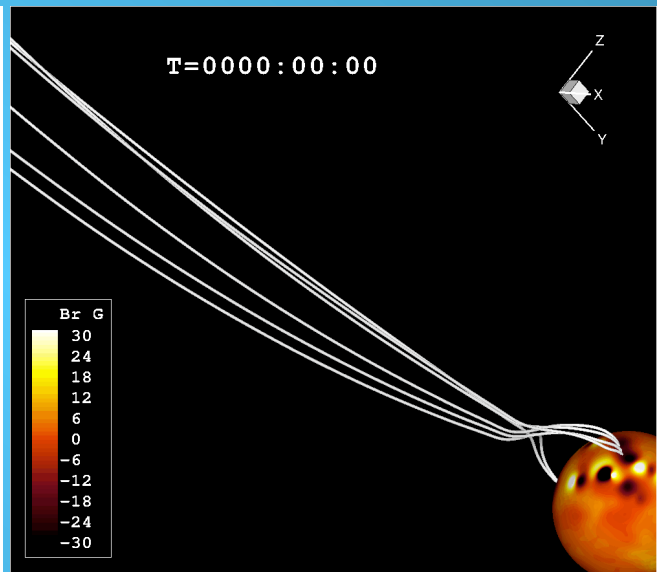
Combining global MHD simulations with realistic CME initiation mechanism

- I. Roussev talked about realistic CME initiation (ApJL 2007)
- Poster by C. Jacobs about CME footprints location & CME configuration.

  One more day to see her poster (p3.3-24).
- Application to the August 24, 2002 CME (W81) to study:
  - White-light aspect/flare (~90°)
  - Solar Energetic Particle and magnetic connection to Earth (~45°)
  - Shock formation and propagation to 1 AU (~0°)







Reconnection during the the eruption connects erupting AR to Earth, even though the AR is @ W81.

Institute for Astronomy

University of Hawai`i

- Ability to reproduce and **explain** observations by STEREO by 3-D MHD simulations.
- Things are often more complicated than they first look:
  - Heliosphere is rarely near steady-state, not at all uniform.
  - CMEs interact with each other and with dense streams and CIRs.
- Ability to use 3-D simulations to investigate **at the same time** different space weather effects, such as SEPs and shock propagation.

Dense stream analysis in Lugaz et al. ApJ (684) L111, Sept. 10, 2008
Solar Physics manuscript in preparation

Thank you!
Time for the banquet!

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