

NOAA SWPC 🤝 NASA CCMC

SPACE WEATHER MODELING ASSESSMENT

WSA-ENLIL

+ Adapt

Eric Adamson

CU CIRES / NOAA SWPC

OUTLINE

1. HELIOSPHERIC MODELING IN SPACE WEATHER FORECASTING

2. CURRENT OPERATIONAL CAPABILITIES

1. Components of SWPC Heliospheric model:

1. WSA
2. Enlil
3. Cone Model

2. Operational Configuration

3. Products

3. NEED FOR IMPROVEMENT

4. UPGRADE EFFORTS

5. TIME-DEPENDENCE & ADAPT - QUANTIFYING IMPACT

HELIOSPHERIC MODELING IN SPACE WEATHER FORECASTING

1. Critical insight into heliospheric transients - Coronal Mass Ejections (CMEs), High Speed Streams (HSSs), Co-rotating Interactions Regions (CIRs)
2. Informs forecasts of potential Earth impacts and hazardous modifications of Geospace environment

Operationally, these capabilities are enabled at SWPC through reliance on the Wang-Sheeley-Arge (WSA) coronal and solar wind model, fed by GONG photospheric observations, and coupled to the Enlil Heliospheric MHD model.

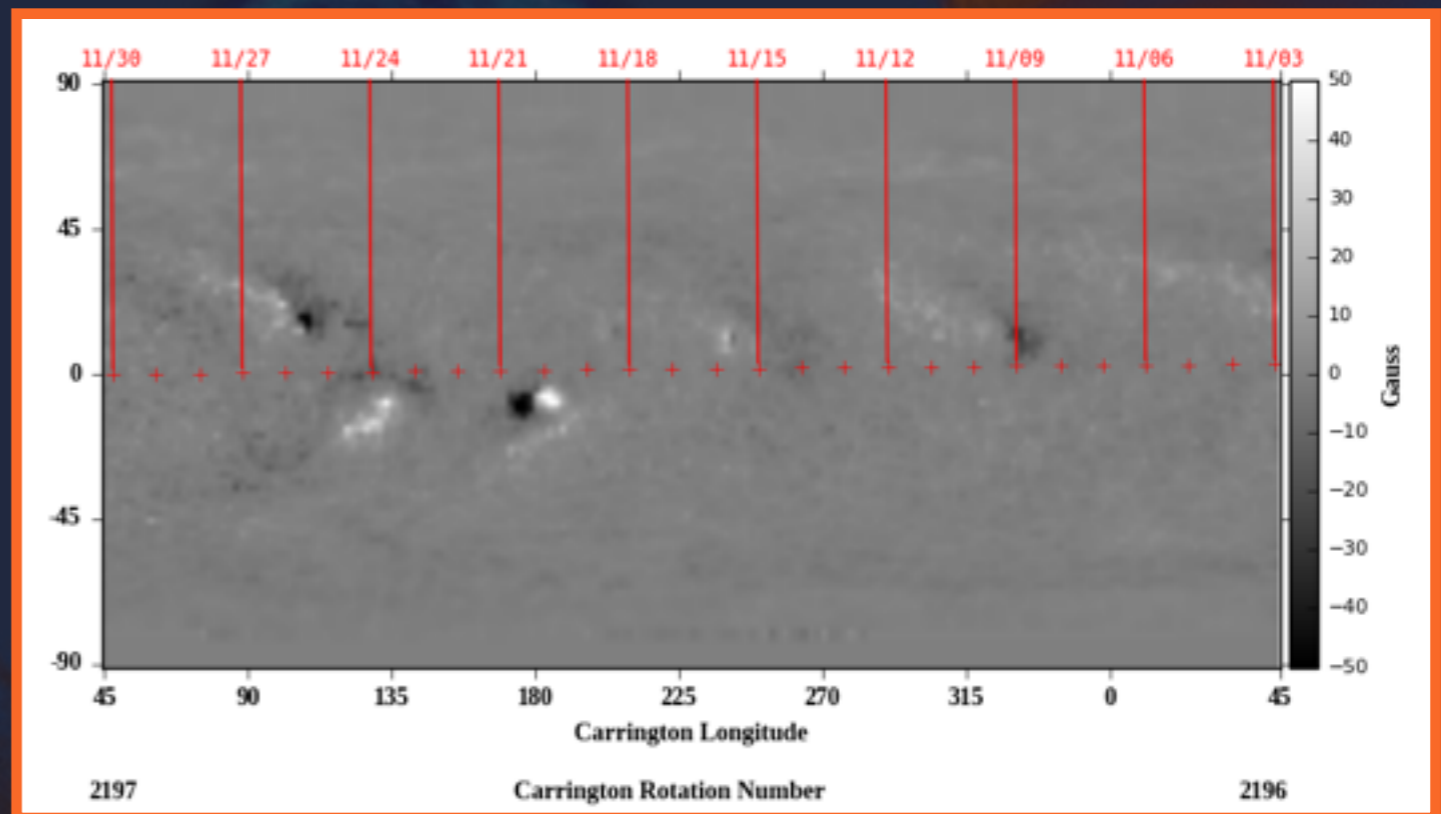
CURRENT OPERATIONAL CAPABILITIES

NSO GLOBAL OSCILLATION NETWORK

Producing Science Quality Photos since 2006 from 6 sites worldwide

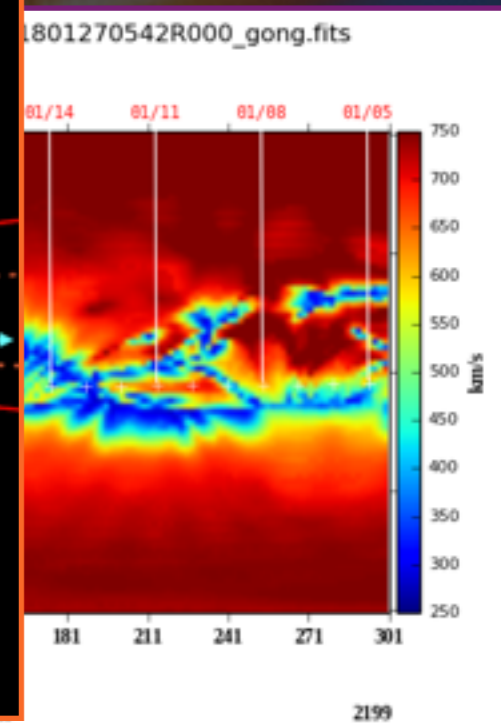
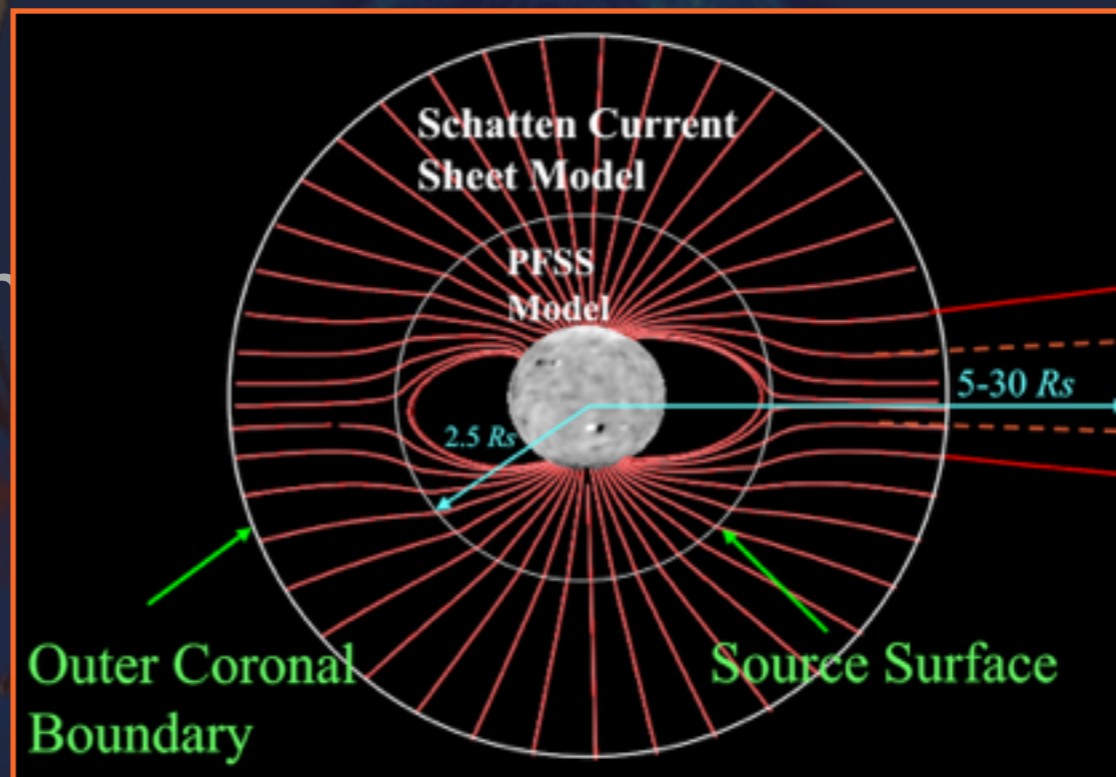
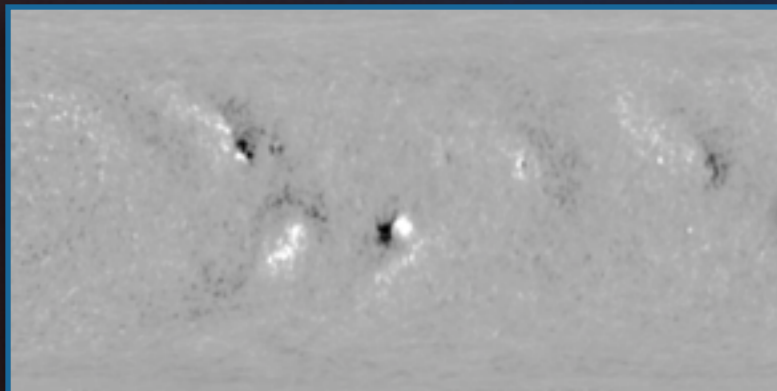
Operational Daily-updated synoptic full synoptic maps)

- Comprised of many magnetograms centered on CM
- Longitudinal weighting function $\sim \cos^2 \theta$
- Polar field filler



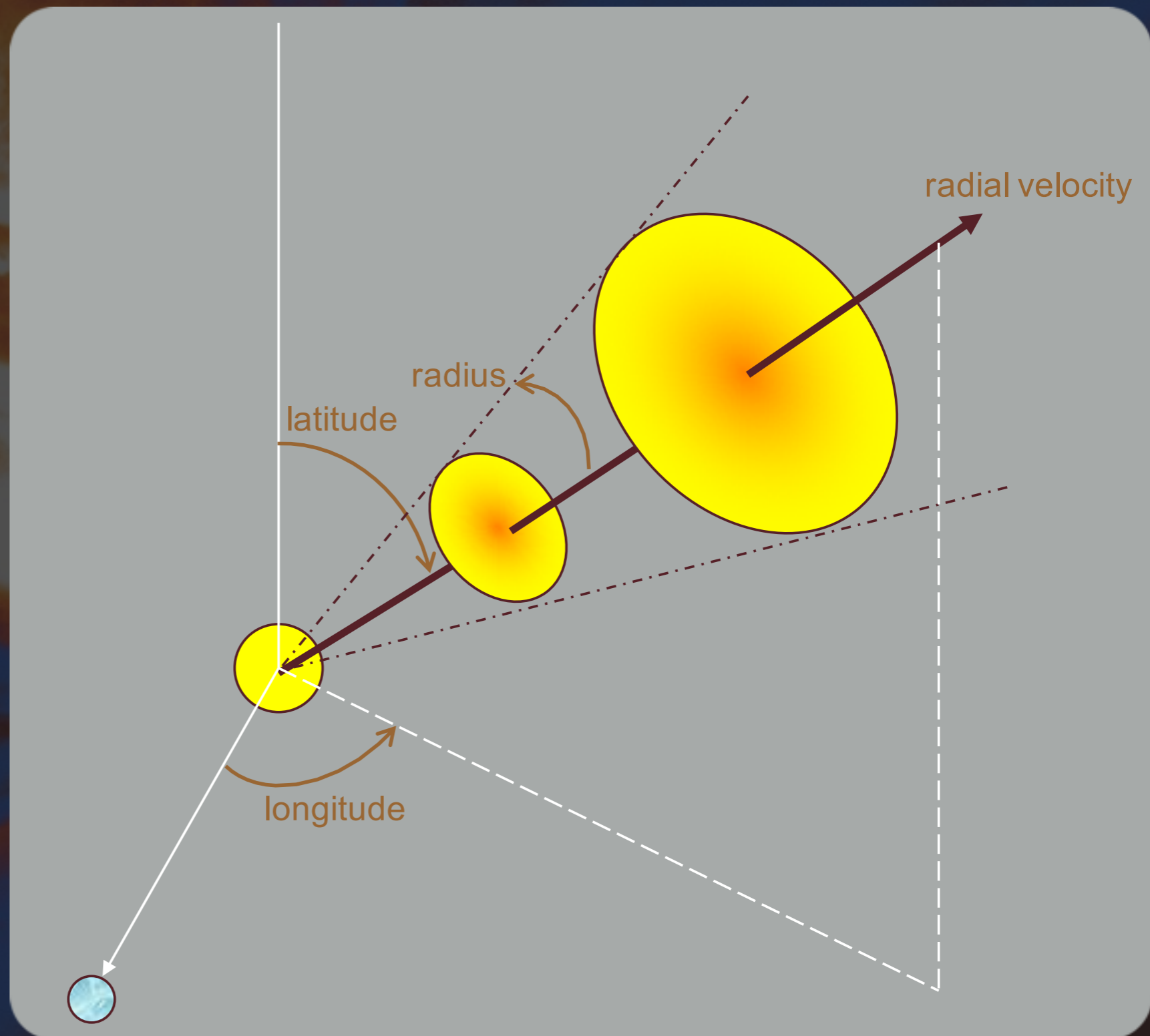
WANG-SHEELEY-ARGE (WSA)

- ▶ Semi-empirical coronal and solar wind model
 - ▶ Input: Ground-based photospheric magnetic field observations (GONG)
 - ▶ Potential Field Source Surface + Schatten Current Sheet -> Corona
 - ▶ Empirical relation



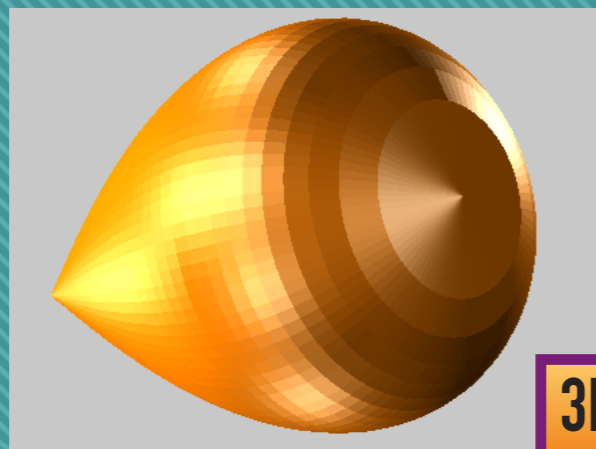
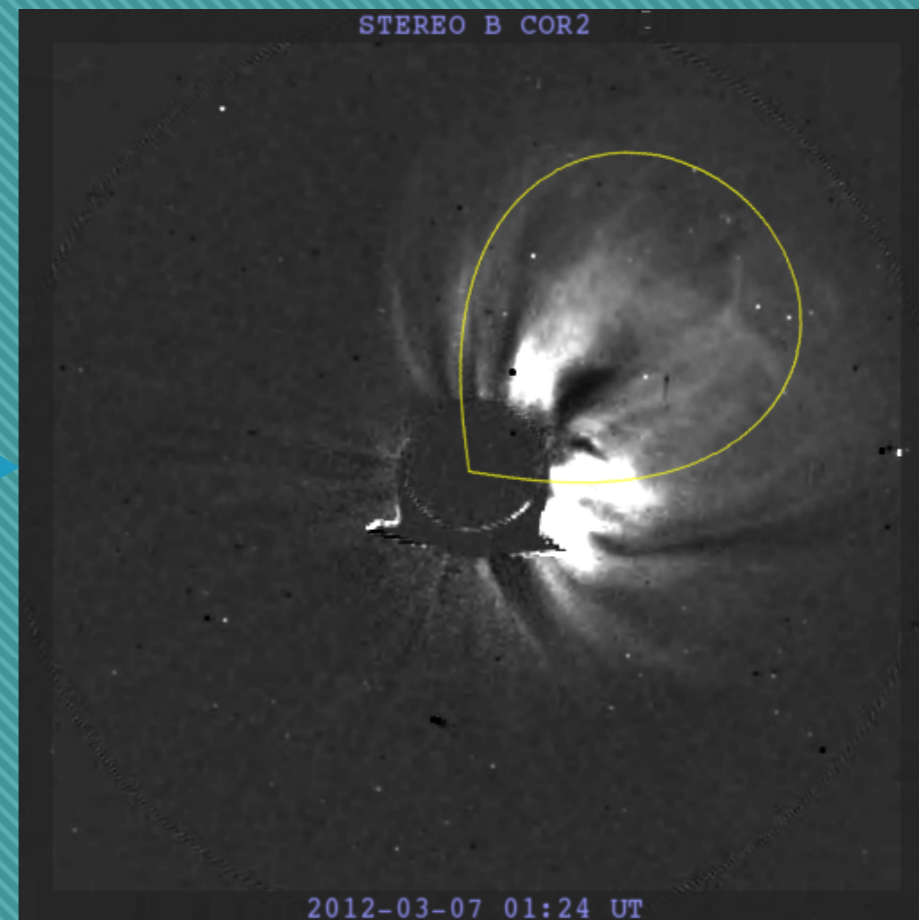
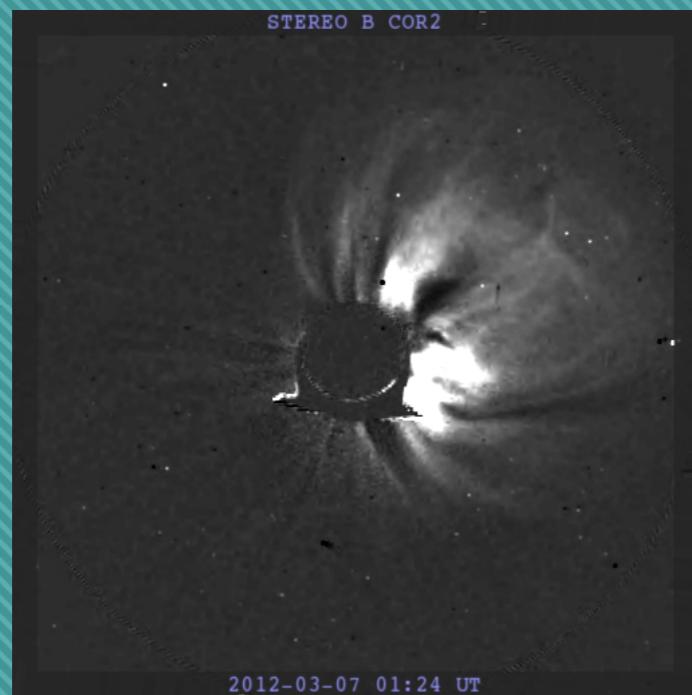
CONE MODEL

- Latitude:
- Longitude:
- CME Half-Width:
- CME Speed:



CONE MODEL

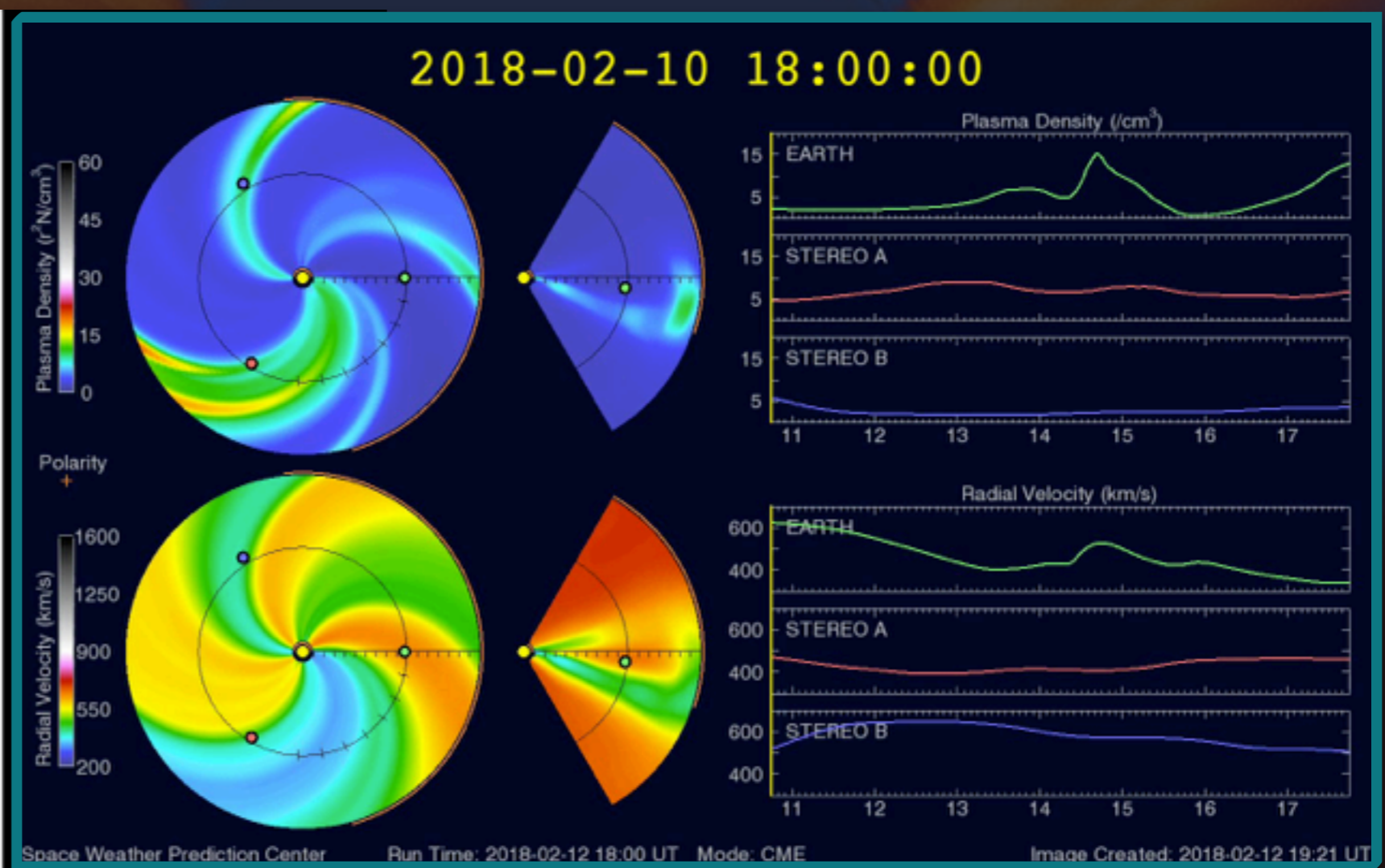
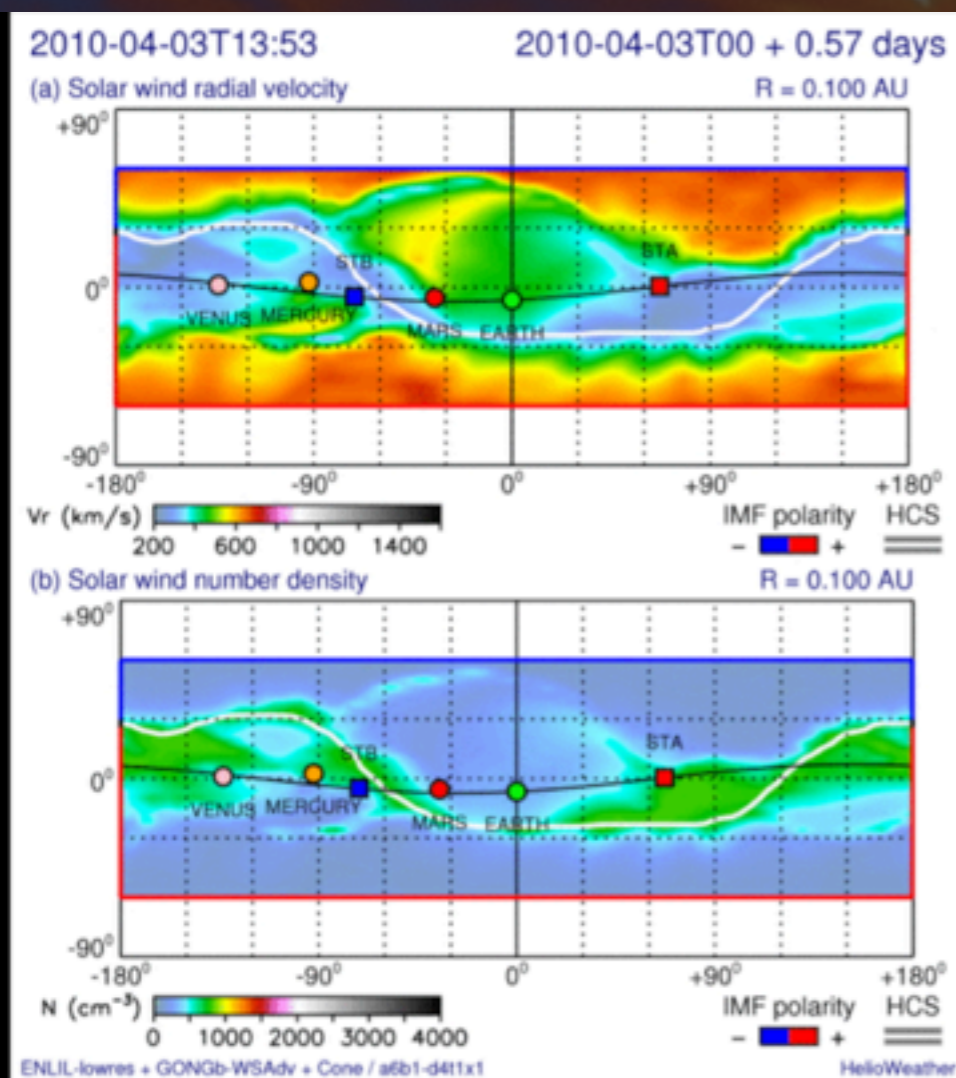
- ▶ Characterize CME for insertion into Enlil using CAT



3D LEMNISCATE

CME INJECTION INTO ENLIL

- Injected through Enlil inner boundary (21.5 Rs) → Ensuing Heliospheric evolution modeled by Enlil



OPERATIONAL CONFIGURATION

- ▶ Execution on NOAA's Weather and Climate Operational Supercomputing System (WCROSS)
- ▶ First operational space weather model - implemented in 2011
- ▶ Execution takes ~ 1.25 hr on 36 cores @ medium res (512x60x180)
- ▶ Executes every 2 hours
 - ▶ **Ambient** run unless Cone file exists
 - ▶ **CME** - forecasters fit CME by characterizing the speed, width, and location of eruption using CME Analysis Tool (CAT)

ISSUES WITH CURRENT PARADIGM:

CME Characterization:

- * Forecaster training - improved CME fitting
- * More realistic ejecta: flux rope, spheromak, density

Improved Background:

- * Accuracy of model inputs: classic GONG maps -> zero-point corrected
- * Incorporation of photospheric dynamics: time dependent synoptic maps
- * Limb/farside data: Additional observations, flux transport modeling (ADAPT)

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CME Characterization:

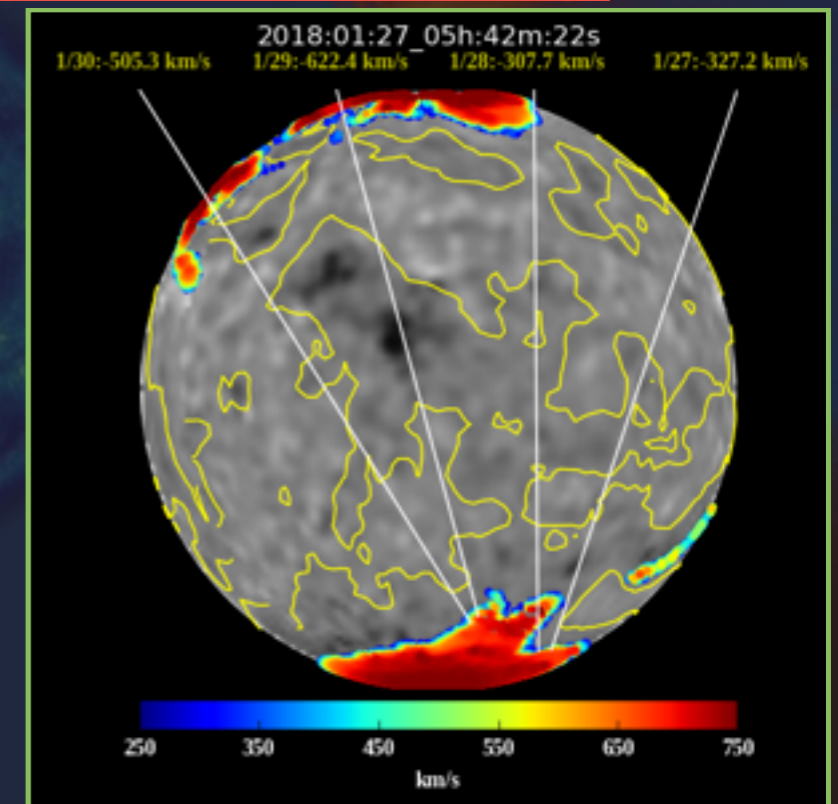
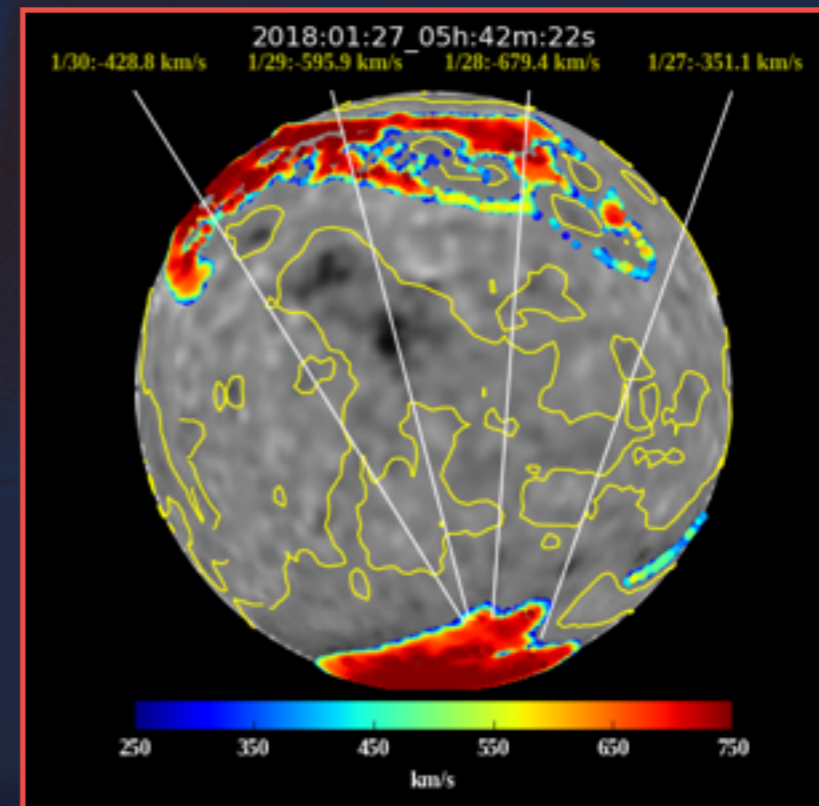
- * Forecaster training - improved CME fitting
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Improved Background:

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- * Incorporation of photospheric dynamics: time dependent synoptic maps
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WSA-ENLIL ENHANCEMENT

- ▶ Inputs: uncorrected GONG maps -> zero_point corrected
- ▶ WSA-2.2 -> WSA-4.4:
 - * Retuned empirical relationship
 - * Increased resolution
 - * Reduced kinking at PFSS/SCS interface
 - * Updated code-base: Perl, IDL -> Python
- ▶ Enlil-2.6 -> Enlil-2.9:
 - * Compatible with time-dep. inner boundary
 - * Option for less diffusive numerical scheme
 - * Density prescription w/in ejecta
- ▶ Both updated codes are compatible with ADAPT!



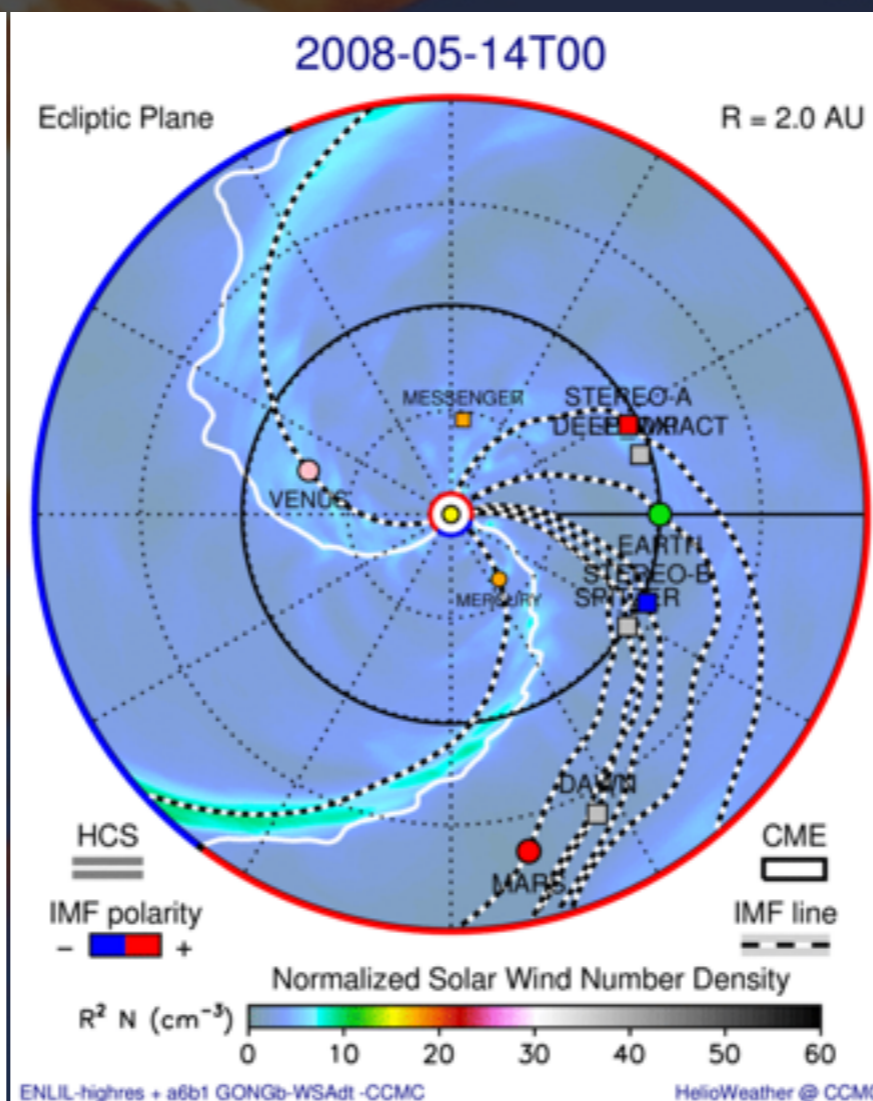
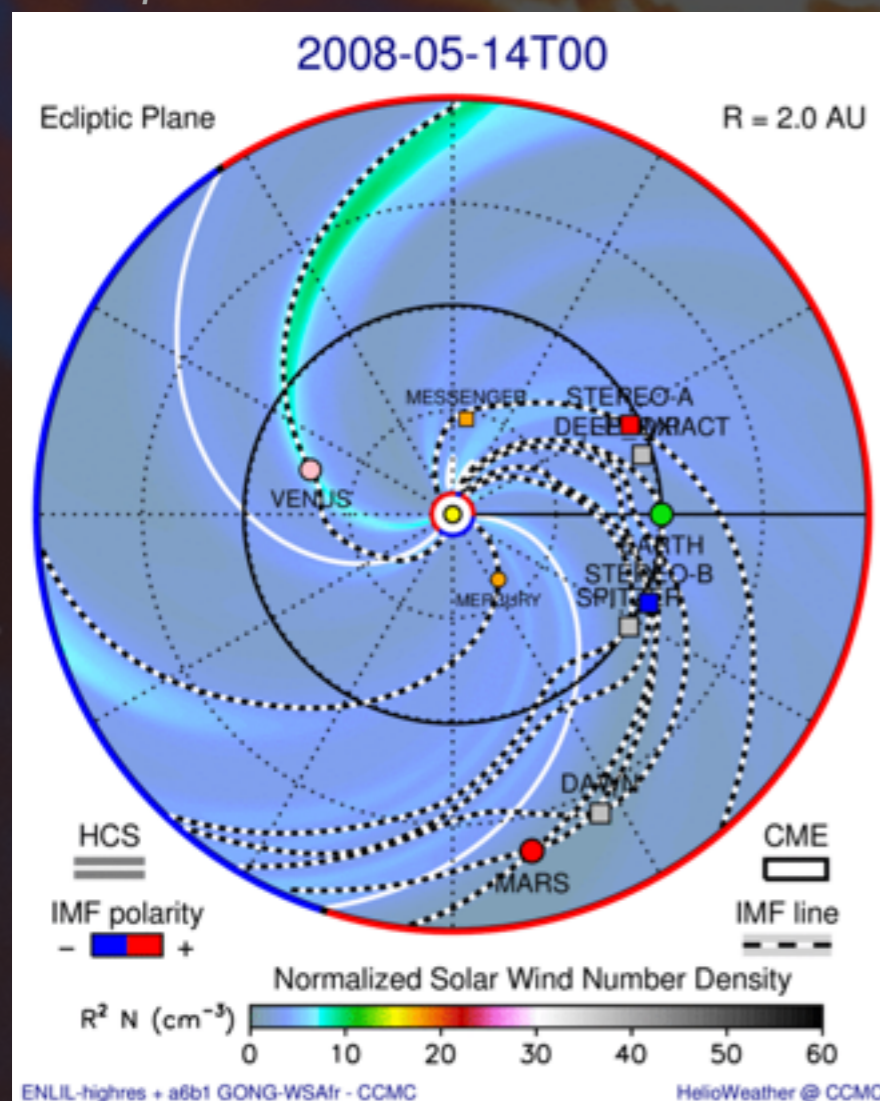
TIME-DEPENDENT DRIVING

Static synoptic map

No dynamic evolution of solar surface during model run - steady state heliosphere

Sequence of maps

Includes photospheric dynamics

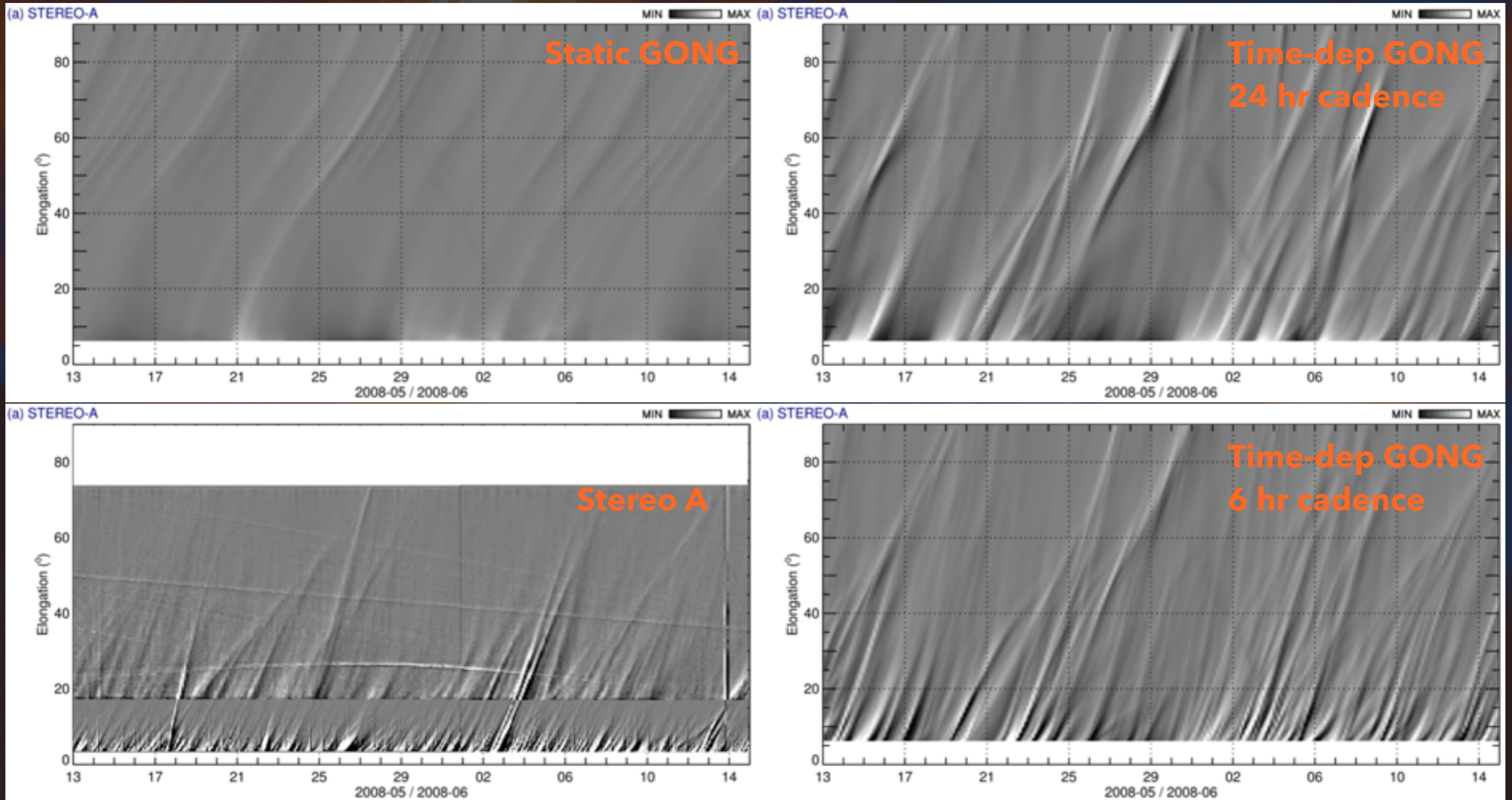


✦ "smooth" heliospheric solution

✦ Impacts CME propagation

NEED FOR IMPROVEMENTS

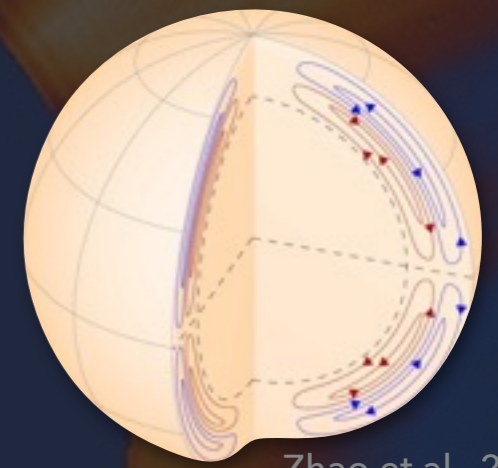
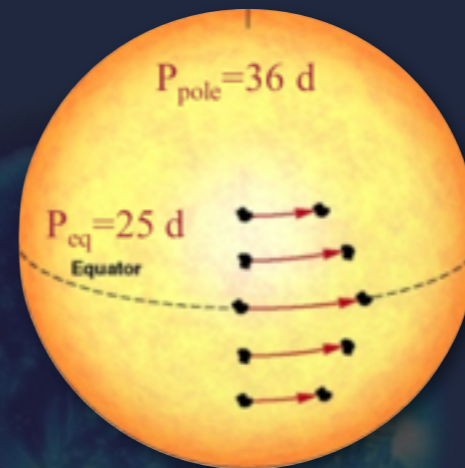
TIME-DEPENDENT DRIVING ... CADENCE?



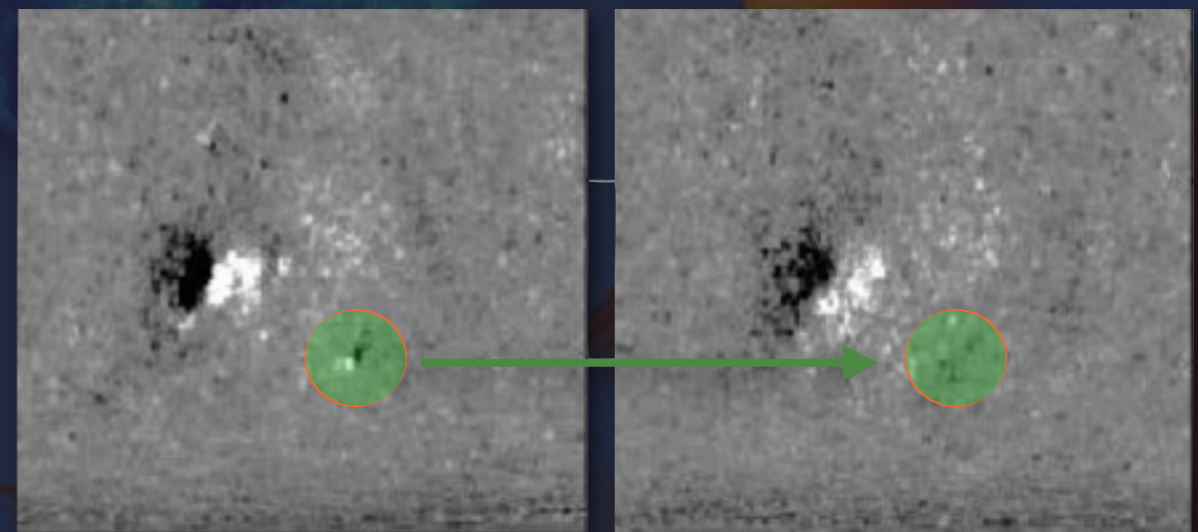
ADAPT: FLUX TRANSPORT / DATA ASSIMILATION

The Air Force Data Assimilative Photospheric Flux Transport Model (ADAPT) - Ensemble model of photospheric transport processes + data assimilation:

- ▶ Differential Rotation
- ▶ Meridional Flow
- ▶ Supergranular Diffusion
- ▶ Random Flux Emergence

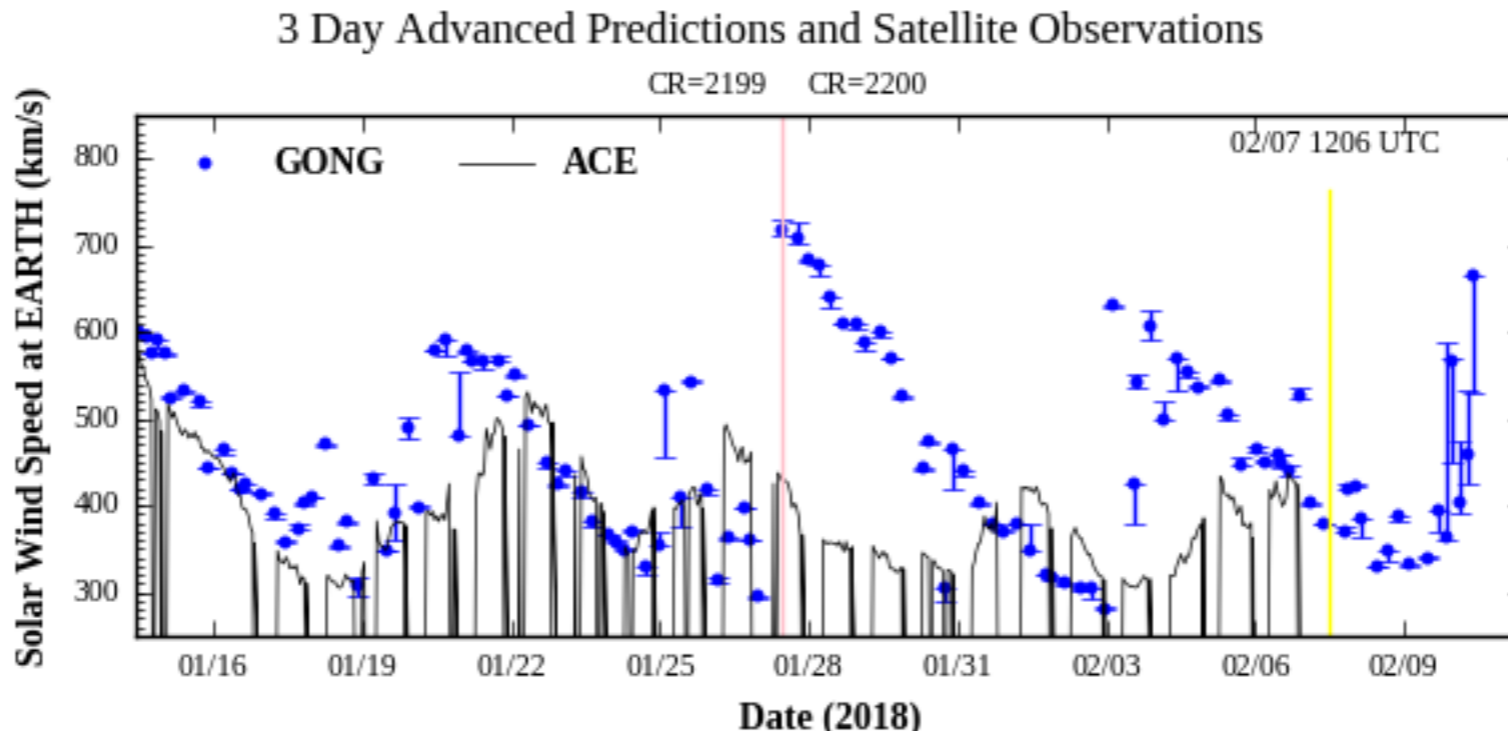


Zhao et al., 2013

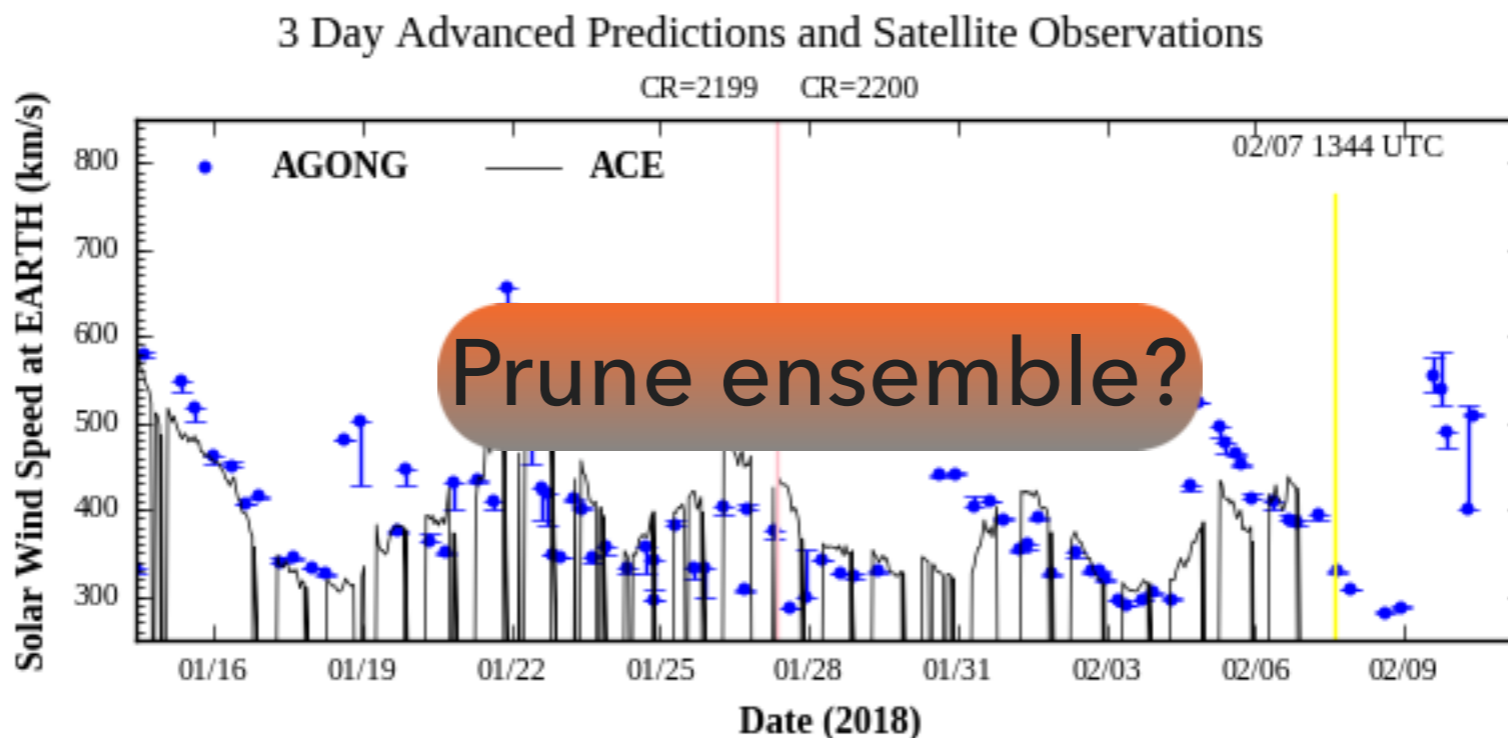


Carl Henney, AFRL

ADAPT REALIZATIONS DRIVING WSA PREDICTIONS:



GONGb



ADAPT

COLLABORATION WITH NASA CCMC

Effort to quantify impact of time-dep. GONG inputs and ADAPT modeling

- ▶ Define historic event list comprised of official SWPC model runs
- ▶ Verify replication of SWPC configuration at CCMC
- ▶ Compare arrival time metrics for the following sets of boundary conditions:

Static	Time-Dep.
GONG driven (Baseline)	GONG driven
ADAPT driven	ADAPT driven

COLLABORATION WITH NASA CCMC

Team

NASA CCMC: M. Leila Mays, Peter Macneice, Neel Savani,
Aleksandre Taktakishvili

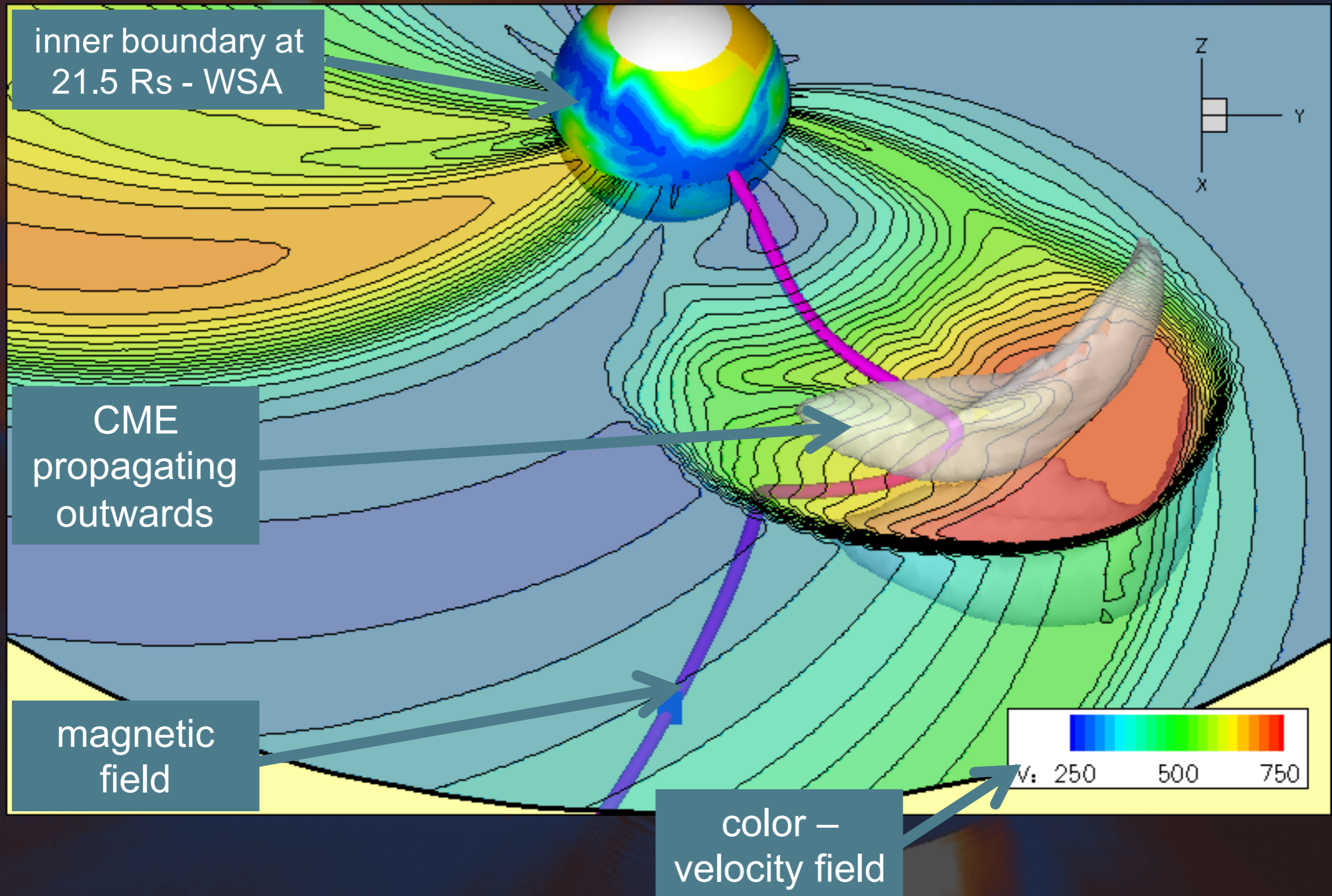
NOAA SWPC: Eric Adamson, Vic Pizzo, Doug Biesecker

- * Results compiled in community accessible database
- * Year-1 report to appear within the CME Arrival Time Working Team paper
- * Culminates in final report advising path forward toward improved space weather forecasting

The background features a large, glowing sun with prominent rays in shades of orange and yellow, set against a dark blue sky. In the lower center, there is a circular inset showing a view of the Earth from space, with blue oceans and white clouds. The text "THE END" is centered over the sun and the Earth inset.

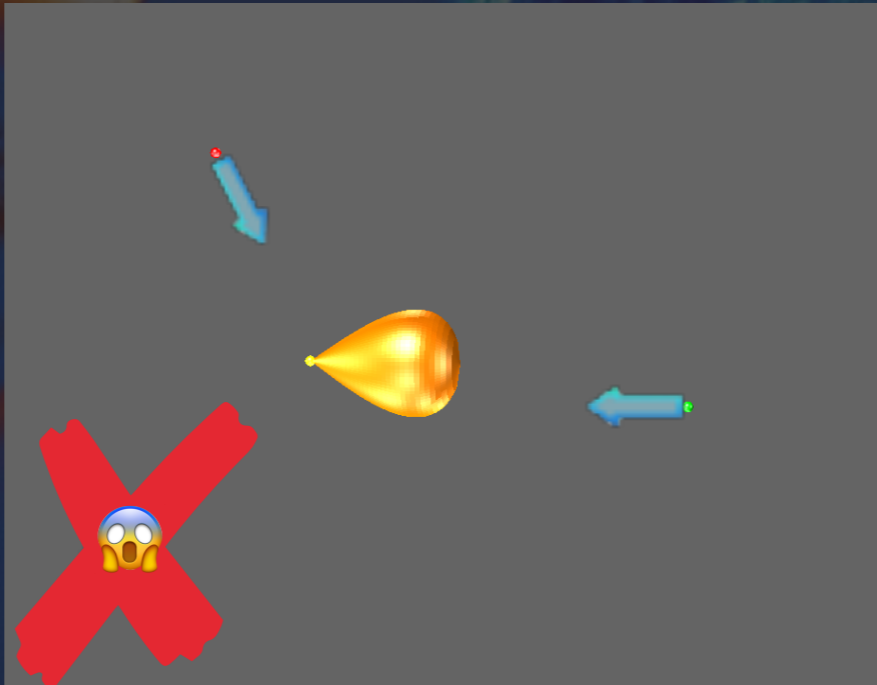
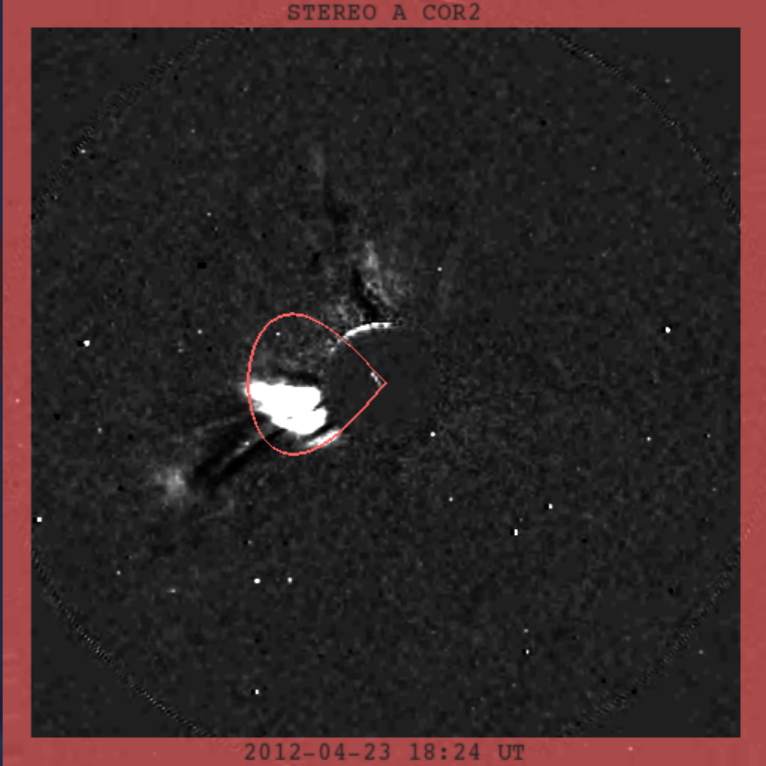
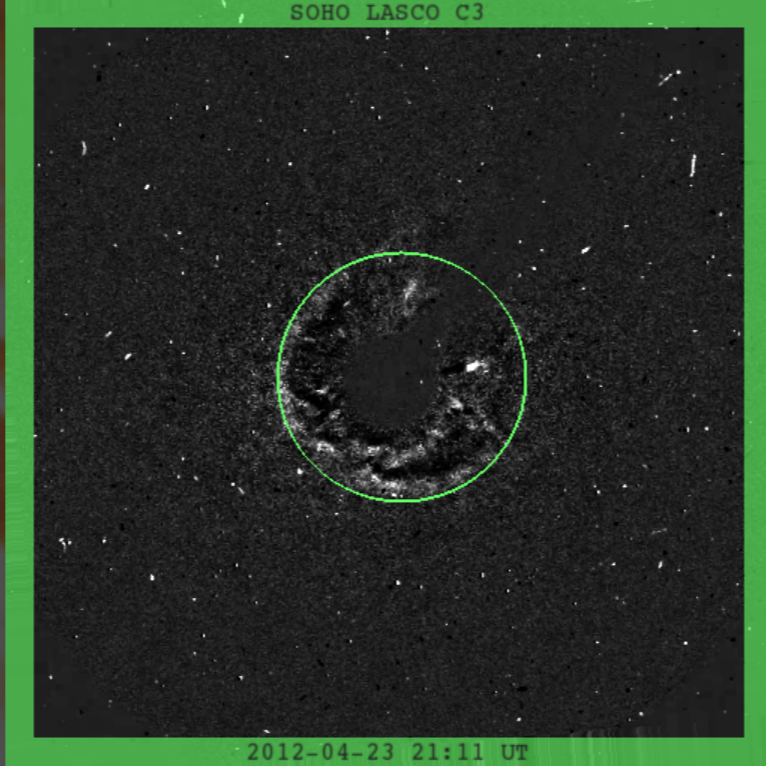
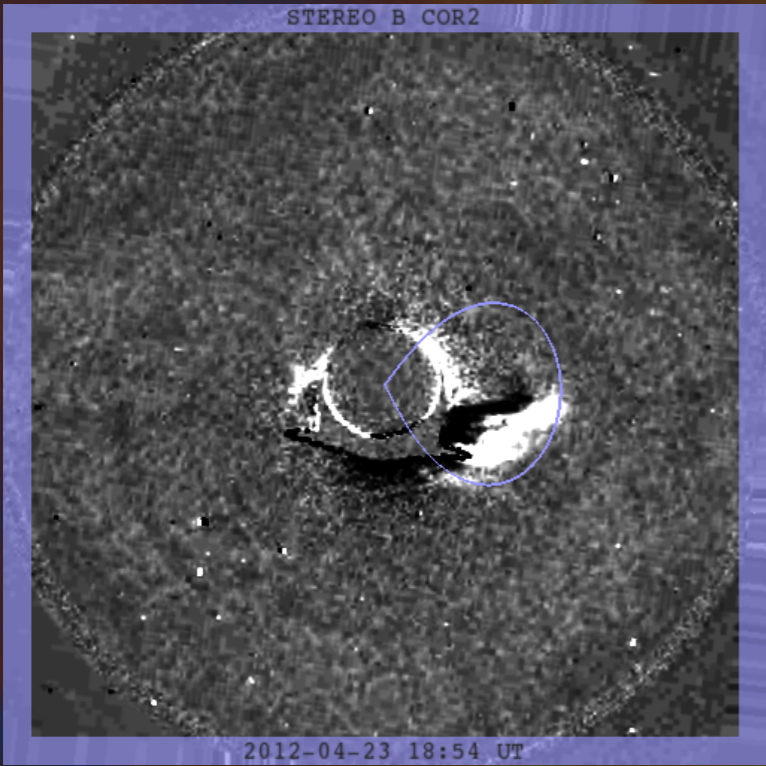
THE END

ENLIL - 3D MHD HELIOSPHERIC MODEL



CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT) "3-VIEW" "2-VIEW"



CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three stereoscopic images are shown: STEREO B COR2 (left, blue border), a central image with a green circle, and STEREO A COR2 (right, red border). All images are dated 2011-08-02 06:39 UT. Below the images is a timeline from 12 to 12, with colored blocks representing data points. The bottom section contains several control panels:

- START / END TIMES:** Start [Y M D H M] 2011 8 1 12, End [Y M D H M] 2011 8 2 12 0. Includes a "Load Images" button.
- ANIMATION CONTROLS:** Radio buttons for L, C, R; a "Play" button; a "Speed" slider; and an "Alt+8" checkbox.
- IMAGE ADJUST:** Sliders for Stretch Bottom, Stretch Top, Gamma Correction, and image saturation value. Includes a "Reset" button and "Copy to L" / "Copy to R" buttons.
- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. Includes a "Bemouli" checkbox.
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time from 06 to 09.
- ENLIL PARAMETERS:** T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Includes "Calculate Velocity", "Export Analysis", and "Reset Analysis" buttons.

CME Parameters

θ	: 8.5
ϕ	: 26.2
2ω	: 108.0
δ	: 3.7

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- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time from 06:00 to 09:00. The y-axis ranges from 0 to 15. Data points are connected by a red line.
- ENLIL PARAMETERS:** Displays parameters for T 2011-08-02 10:44: Lat 9, Lon 26, Cone 54, Vel 827. Includes buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis".

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- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. A "Bemouli" checkbox is checked. A "CME Parameters" box displays:
 θ : 8.5
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Below the images is a timeline showing data points from 12:00 to 12:00. The interface includes several control panels:

- START / END TIMES:** Start [Y M D H M] 2011 8 1 12, End [Y M D H M] 2011 8 2 12 0. Buttons for +12h and +24h, and a Load Images button.
- ANIMATION CONTROLS:** Radio buttons for L, C, R, a Play button, a Speed slider, and an Alt8 checkbox.
- IMAGE ADJUST:** Sliders for Stretch Bottom, Stretch Top, Gamma Correction, and image saturation value. A Reset button and Copy to L/R buttons.
- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. A checkbox for Bernoulli.
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- IMAGE ADJUST:** Sliders for 'Stretch Bottom', 'Stretch Top', and 'Gamma Correction'; a 'Reset' button; and 'Copy to L' / 'Copy to R' buttons.
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 2ω : 108.0
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- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time from 06:00 to 09:00. The y-axis ranges from 0 to 15. Data points are connected by a red line.
- ENLIL PARAMETERS:** A text box showing:
T 2011-08-02 10:44
Lat 9
Lon 26
Cone 54
Vel 827
Buttons for 'Calculate Velocity', 'Export Analysis', and 'Reset Analysis'.

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

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- CME CONTROLS:** Sliders for "Latitude", "Longitude", "Angular Width (2 omega)", and "Radial Distance (delta)"; a "Transparency" slider; a "Bemouli" checkbox; and a "CME Parameters" box showing:
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- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time from 06 to 09. The y-axis ranges from 0 to 15. Data points are connected by a red line.
- ENLIL PARAMETERS:** A box showing:
 - T 2011-08-02 10:44
 - Lat 9
 - Lon 26
 - Cone 54
 - Vel 827Buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis" are located below.

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three image panels are visible: STEREO B COR2 (left, blue border), SOHO LASCO C2 (middle, green border), and STEREO A COR2 (right, red border). Each panel shows a coronal mass ejection (CME) event. Below the images is a timeline from 12:00 to 12:00, with a vertical line indicating the current time. The interface is divided into several control panels:

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- IMAGE ADJUST:** Radio buttons for L, C, R; sliders for "Stretch Bottom", "Stretch Top", and "Gamma Correction"; a "Reset" button; and buttons for "<- Copy to L" and "Copy to R ->".
- CME CONTROLS:** Sliders for "Latitude", "Longitude", "Angular Width (2 omega)", and "Radial Distance (delta)"; a "Transparency" slider; a "Bemouli" checkbox; and a "CME Parameters" box showing:
 - θ : 8.5
 - ϕ : 26.2
 - 2ω : 108.0
 - δ : 3.7
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time, with data points and a fitted curve.
- ENLIL PARAMETERS:** A box showing calculated parameters: T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Includes buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis".

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three coronagraph images are shown side-by-side:

- STEREO B COR2** (left): Shows a coronagraph image with a blue circle highlighting a CME. Time: 2011-08-02 07:24 UT.
- SOHO LASCO C3** (middle): Shows a coronagraph image with a green circle highlighting a CME. Time: 2011-08-02 07:30 UT.
- STEREO A COR2** (right): Shows a coronagraph image with a red circle highlighting a CME. Time: 2011-08-02 07:24 UT.

Below the images is a timeline from 12 to 12, with colored bars indicating data availability. The bottom section contains several control panels:

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- ANIMATION CONTROLS:** Radio buttons for L, C, R; a "Play" button; a "Speed" slider; and an "Alt+8" checkbox.
- IMAGE ADJUST:** Sliders for Stretch Bottom, Stretch Top, Gamma Correction, and image saturation value. Includes a "Reset" button and "Copy to L" / "Copy to R" buttons.
- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. Includes a "Bemouli" checkbox.
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time. The x-axis is time (06 to 09) and the y-axis is position (0 to 15). Red squares represent data points connected by a line.
- ENLIL PARAMETERS:** Displays parameters for the selected CME: T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Includes buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis".

CME Parameters:

θ	: 8.5
ϕ	: 26.2
2ω	: 108.0
δ	: 3.7

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three panels show CME observations: STEREO B COR2 (left, blue border), SOHO LASCO C3 (middle, green border), and STEREO A COR2 (right, red border). Each panel shows a CME event with a colored outline (blue, green, and red respectively) and a timestamp at the bottom: 2011-08-02 07:39 UT for STEREO B and A, and 2011-08-02 07:42 UT for SOHO LASCO C3. Below the panels is a timeline with colored markers. The bottom section contains several control panels:

- START / END TIMES:** Start [Y M D H M] (2011 8 1 12) and End [Y M D H M] (+12h +24h) (2011 8 2 12 0). Includes a "Load Images" button.
- ANIMATION CONTROLS:** Radio buttons for L, C, R; a "Play" button; a "Speed" slider; and an "Alt+8" checkbox.
- IMAGE ADJUST:** Sliders for Stretch Bottom, Stretch Top, Gamma Correction, and image saturation value. Includes a "Reset" button and "<- Copy to L" / "Copy to R ->" buttons.
- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. Includes a "Bemouli" checkbox.
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time from 06 to 09.
- ENLIL PARAMETERS:** A panel displaying calculated parameters: T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Includes buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis".

CME Parameters

θ	: 8.5
ϕ	: 26.2
2ω	: 108.0
δ	: 3.7

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three coronagraph images are shown: STEREO B COR2 (left, 2011-08-02 10:24 UT), SOHO LASCO C3 (middle, 2011-08-02 07:54 UT), and STEREO A COR2 (right, 2011-08-02 07:54 UT). Below the images is a timeline showing data availability from 12:00 to 12:00. The control panel includes:

- START / END TIMES:** Start [Y M D H M] (2011 8 1 12) and End [Y M D H M] (+12h +24h) (2011 8 2 12 0). A "Load Images" button is present.
- ANIMATION CONTROLS:** Radio buttons for L, C, R; a "Play" button; a "Speed" slider; and an "Alt+8" checkbox.
- IMAGE ADJUST:** Sliders for Stretch Bottom, Stretch Top, Gamma Correction, and image saturation value. A "Reset" button and "Copy to L/R" buttons are also present.
- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. A "Bemouli" checkbox is checked.
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time from 06 to 09.
- ENLIL PARAMETERS:** A box displaying parameters: T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis" are provided.

CME Parameters

θ	:	8.5
ϕ	:	26.2
2ω	:	108.0
δ	:	3.7

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three coronagraph images are shown side-by-side:

- STEREO B COR2:** Shows a coronagraph image with a timestamp of 2011-08-02 10:24 UT.
- SOHO LASCO C3:** Shows a coronagraph image with a green circle highlighting a CME feature and a timestamp of 2011-08-02 08:06 UT.
- STEREO A COR2:** Shows a coronagraph image with a red circle highlighting a CME feature and a timestamp of 2011-08-02 08:24 UT.

Below the images is a timeline showing data points from 12:00 to 12:00. The interface includes several control panels:

- START / END TIMES:** Allows setting start and end times in Y M D H M format. Start: 2011 8 1 12. End: 2011 8 2 12 0. Includes a "Load Images" button.
- ANIMATION CONTROLS:** Includes radio buttons for L, C, and R views, a "Play" button, a "Speed" slider, and an "Alt+8" checkbox.
- IMAGE ADJUST:** Includes sliders for "Stretch Bottom", "Stretch Top", and "Gamma Correction", and a "Reset" button.
- CME CONTROLS:** Includes sliders for "Latitude", "Longitude", "Angular Width (2 omega)", and "Radial Distance (delta)", and a "Transparency" slider. A "Bemouli" checkbox is also present.
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time, with data points and a fitted curve.
- ENLIL PARAMETERS:** Displays calculated parameters: T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Includes buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis".

CME Parameters:

- θ : 8.5
- ϕ : 26.2
- 2ω : 108.0
- δ : 3.7

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three coronagraph images are shown: STEREO B COR2 (left), SOHO LASCO C3 (center, highlighted with a green border), and STEREO A COR2 (right). Below the images is a timeline showing data points from 12:00 to 12:00. The interface is divided into several control panels:

- START / END TIMES:** Start [Y M D H M] (2011 8 1 12) and End [Y M D H M] (+12h +24h) (2011 8 2 12 0). Includes a "Load Images" button.
- ANIMATION CONTROLS:** Radio buttons for L, C, R; a "Play" button; a "Speed" slider; and an "Alt+8" checkbox.
- IMAGE ADJUST:** Sliders for Stretch Bottom, Stretch Top, Gamma Correction, and image saturation value. Includes a "Reset" button and "Copy to L" / "Copy to R" buttons.
- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. Includes a "Bemouli" checkbox.
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time, with data points and a red trend line.
- ENLIL PARAMETERS:** A panel displaying calculated parameters: T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Includes buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis".

CME Parameters:

θ	: 8.5
ϕ	: 26.2
2ω	: 108.0
δ	: 3.7

CURRENT OPERATIONAL CAPABILITIES

CME ANALYSIS TOOL (CAT)

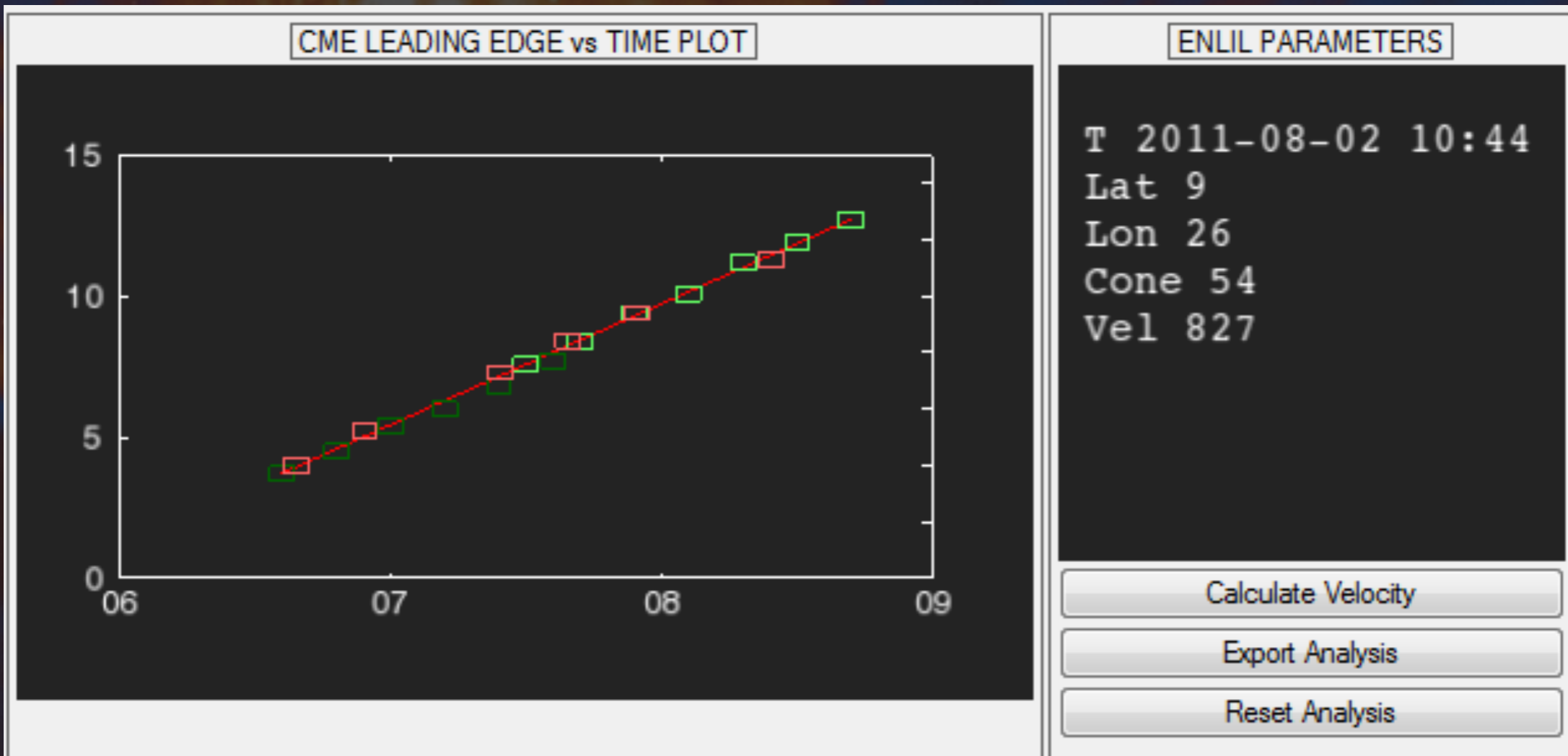
The screenshot displays the CAT (CME Analysis Tool) interface. At the top, three coronagraph images are shown: STEREO B COR2 (left), SOHO LASCO C3 (center, highlighted with a green border), and STEREO A COR2 (right). Below the images is a timeline showing data points from 12:00 to 12:00. The interface is divided into several control panels:

- START / END TIMES:** Start [Y M D H M] 2011 8 1 12, End [Y M D H M] 2011 8 2 12 0. Includes a "Load Images" button.
- ANIMATION CONTROLS:** Radio buttons for L, C, R; a "Play" button; a "Speed" slider; and an "Alt+8" checkbox.
- IMAGE ADJUST:** Sliders for Stretch Bottom, Stretch Top, Gamma Correction, and image saturation value. Includes a "Reset" button and "Copy to L" / "Copy to R" buttons.
- CME CONTROLS:** Sliders for Latitude, Longitude, Angular Width (2 omega), Radial Distance (delta), and Transparency. Includes a "Bemouli" checkbox.
- CME LEADING EDGE vs TIME PLOT:** A graph showing the leading edge position over time, with data points and a red trend line.
- ENLIL PARAMETERS:** A panel displaying calculated parameters: T 2011-08-02 10:44, Lat 9, Lon 26, Cone 54, Vel 827. Includes buttons for "Calculate Velocity", "Export Analysis", and "Reset Analysis".

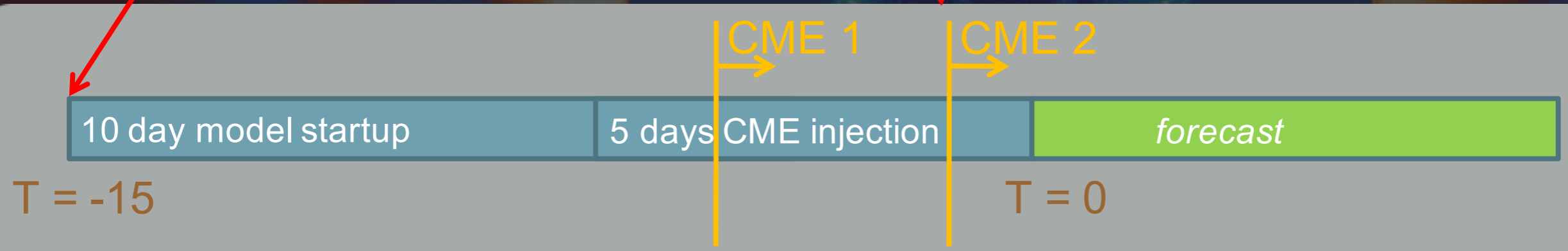
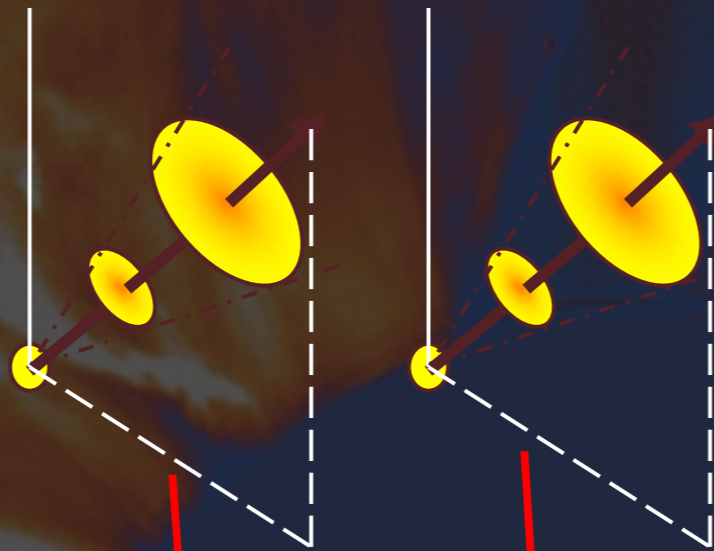
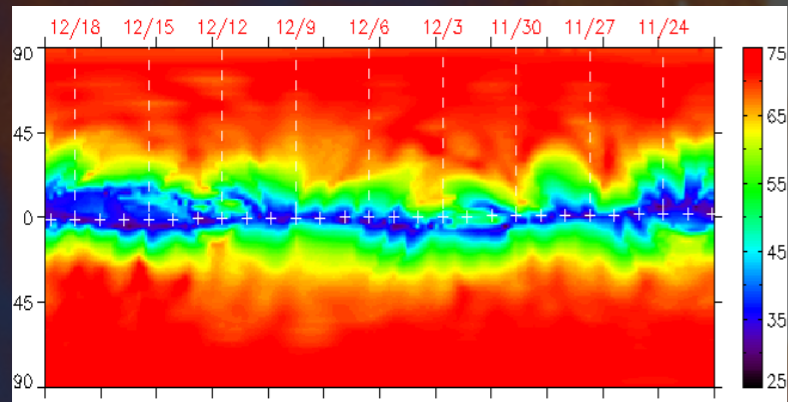
CME Parameters:

θ	: 8.5
ϕ	: 26.2
2ω	: 108.0
δ	: 3.7

CME ANALYSIS TOOL (CAT)



OPERATIONAL CONFIGURATION: MODEL EXECUTION



10 day model startup

5 days CME injection

forecast

T = -15

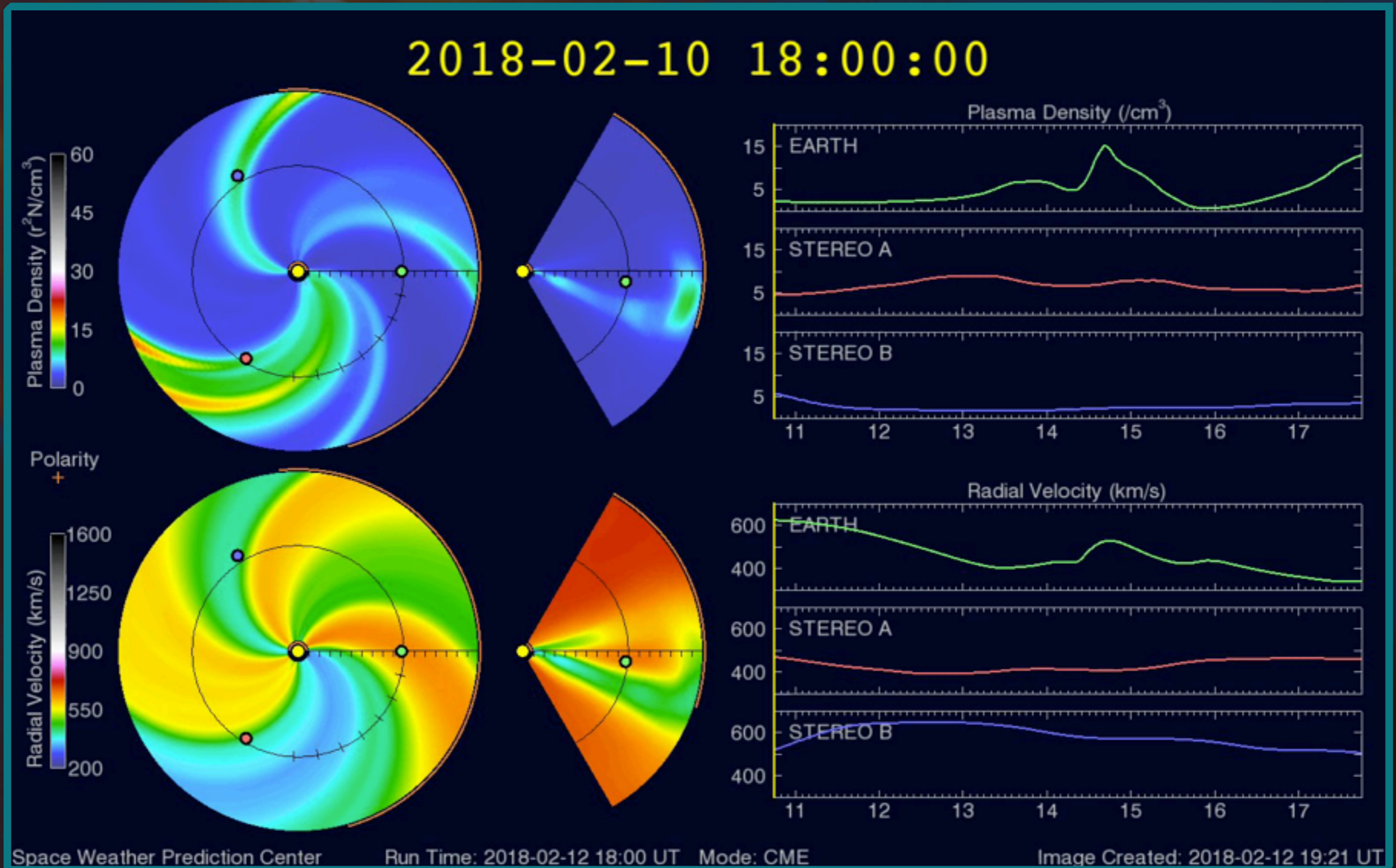
T = 0

CME 1 CME 2



1.5 hours Wallclock time on NWS CCS

PRODUCTS



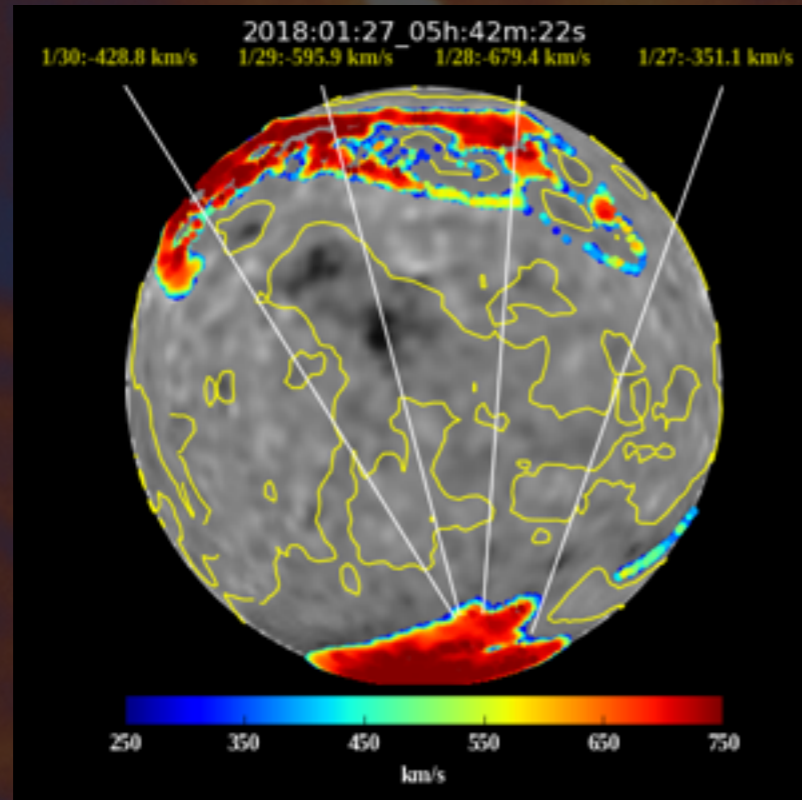
PHOTOSPHERIC INPUTS / CME CHARACTERIZATION

- ▶ Static synoptic map:
 - ➔ no dynamic evolution of solar surface during model run
 - ➔ stale far side observations
 - ▶ Ejecta contains no magnetic structure:
 - ➔ magnetic pressure replaced by enhanced density/temperature
 - ➔ uniform density enhancement
 - ▶ Inaccuracies in modeling:
 - ➔ CME characterization
 - ➔ ambient offset
- move toward time-dependent synoptic maps
 - employ flux transport model (ADAPT) + far-side helioseismic detections
 - investigate density distribution and spheromak insertion
 - pursuing potential for mid-course correction utilizing synthetic imagery

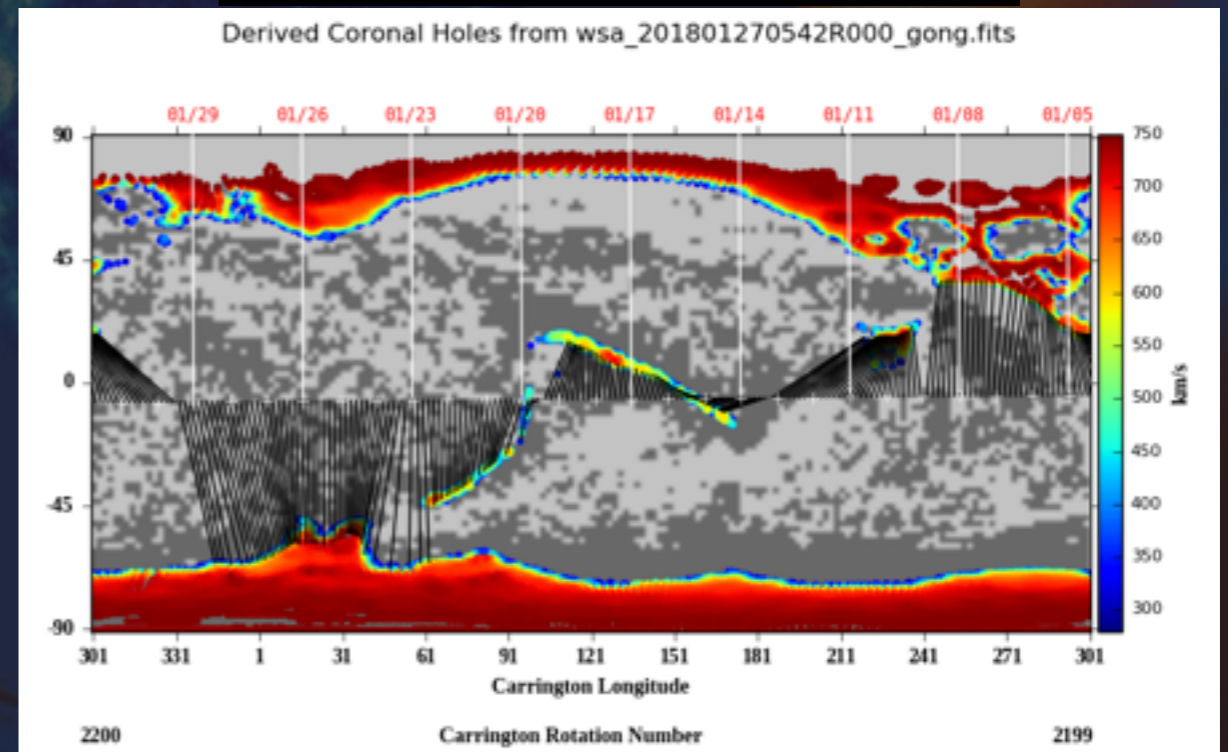
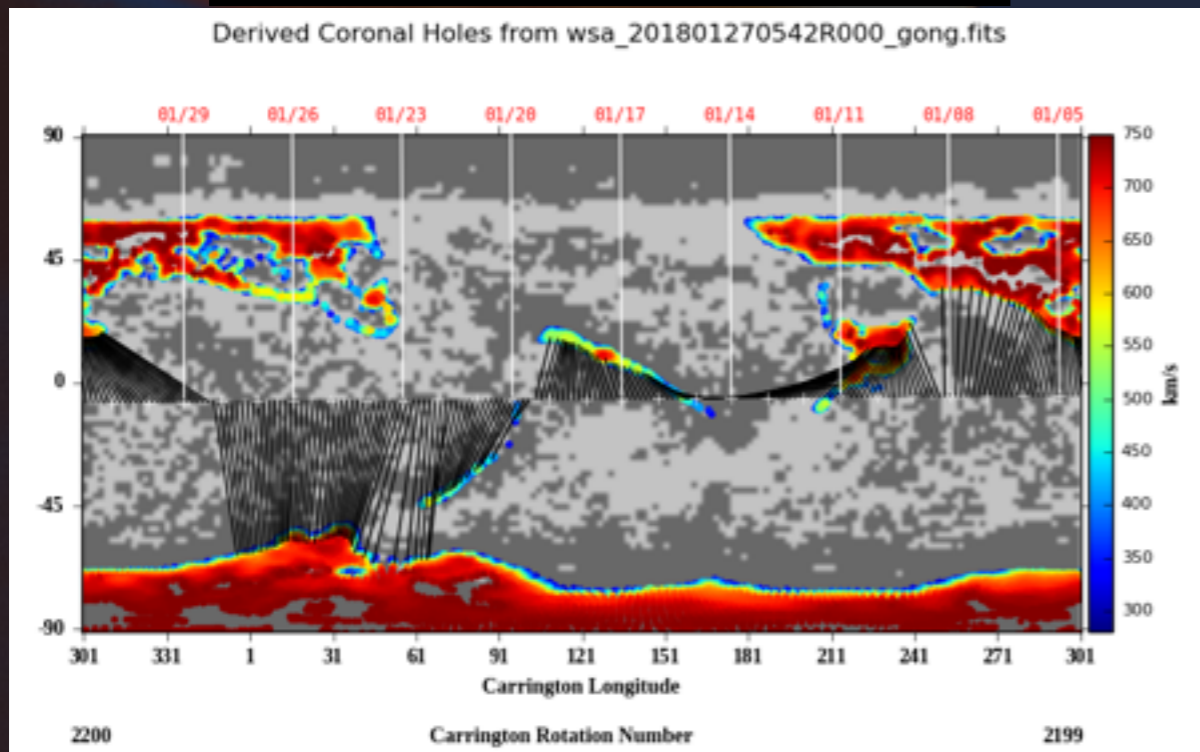
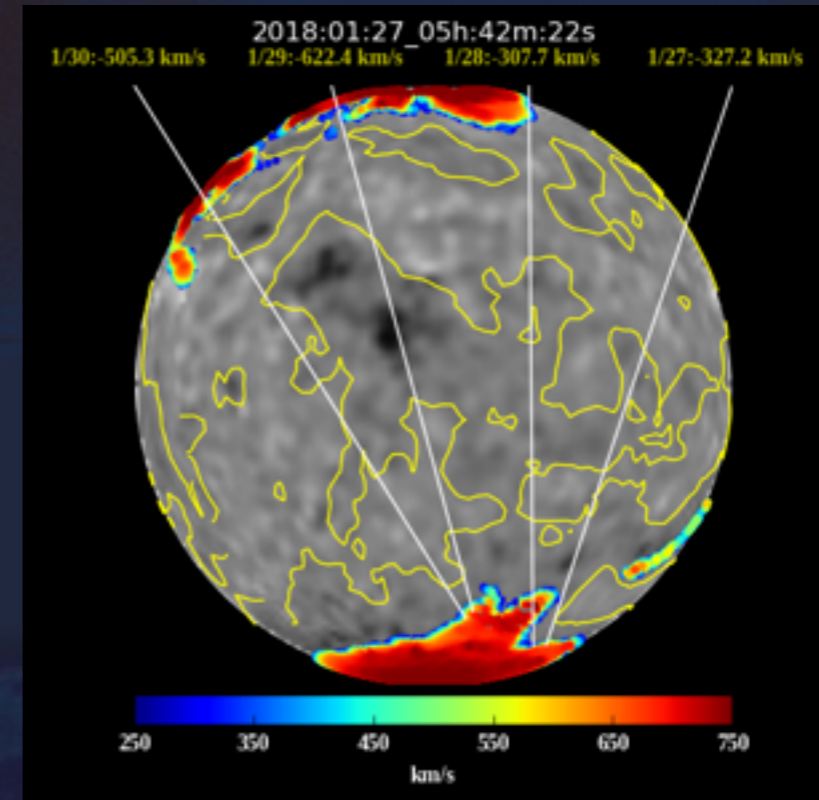
CONCLUSION

THE END

UNCORRECTED (GONGB)



CORRECTED (GONGZ)



WSA-ENLIL ENHANCEMENT: MOVE TO ZERO-POINT CORRECTED

