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

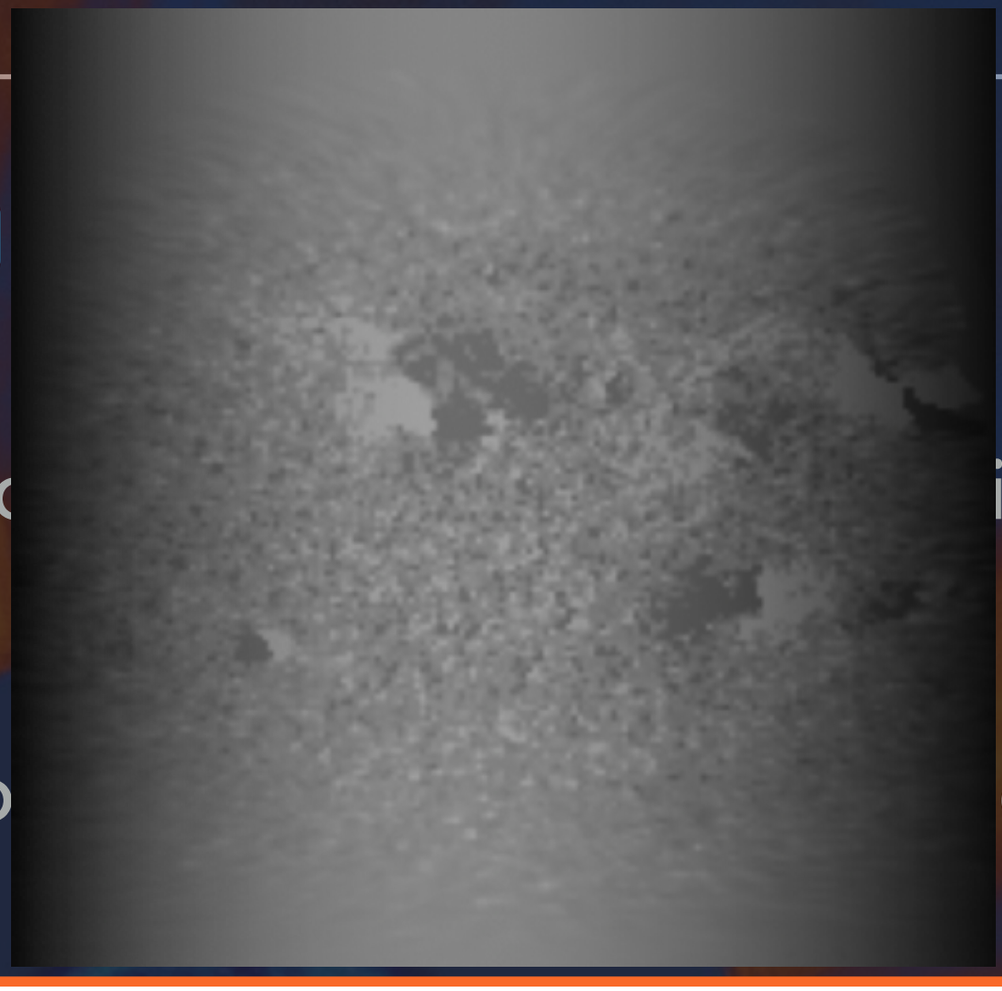
Operationally, these capabilities are enabled at SWPC through reliance on the Wang-Sheeley-Arge (WSA) coronal and solar wind model, fed by GONG photospheric observations, and coupled to the Enlil Heliospheric MHD model.

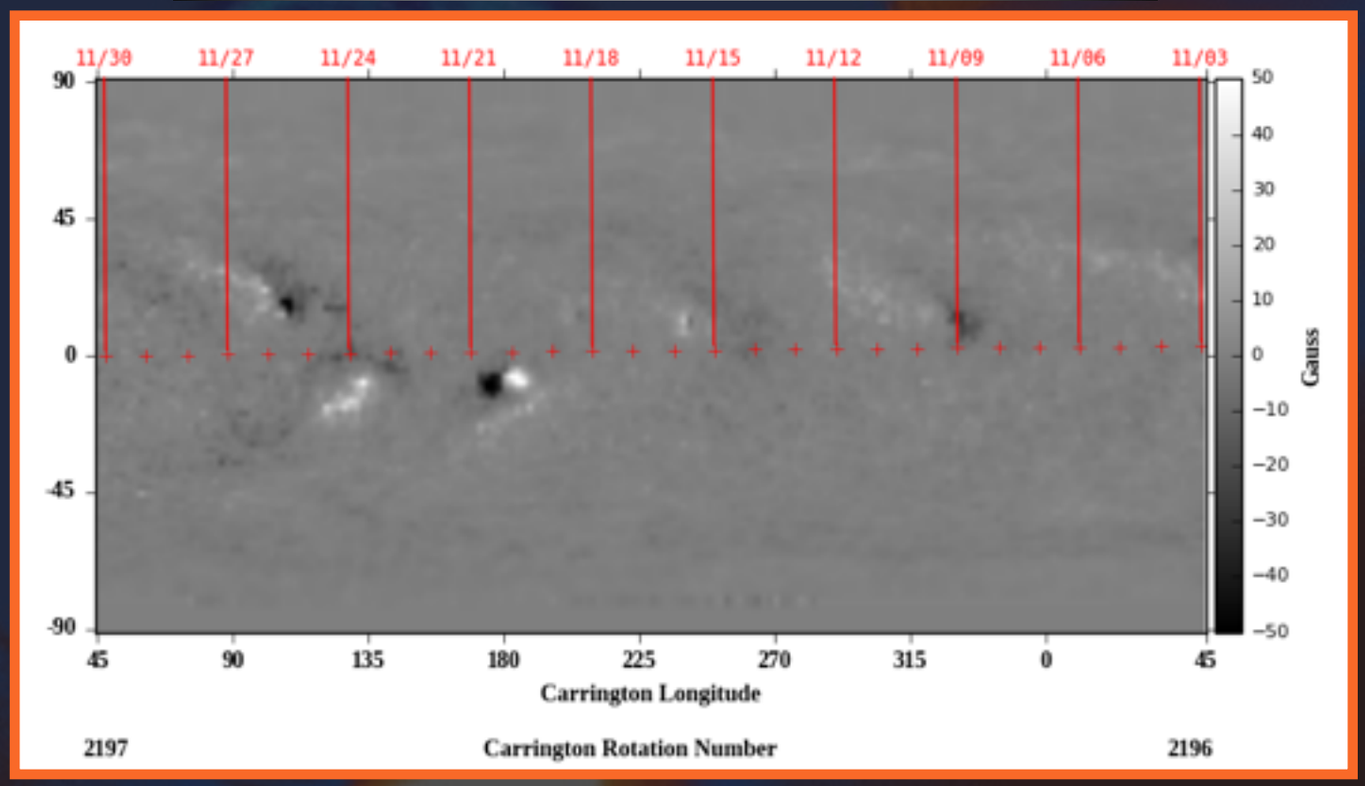
NSO GLOBAL OSCILLATION NETWO

Producing Science Quality Photo ince 2006 from 6 sites worldwide

Operational Daily-updated syno d full synoptic maps)

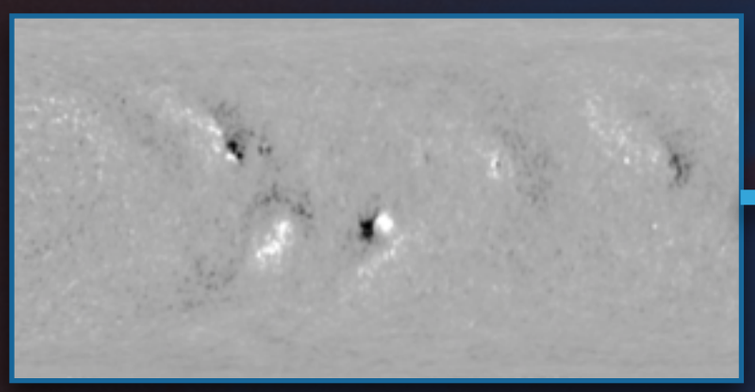
- *Comprised of many magnetograms centered on CM*
- *Longitudinal weighting function ~cos^2 θ*
- *Polar field filler*

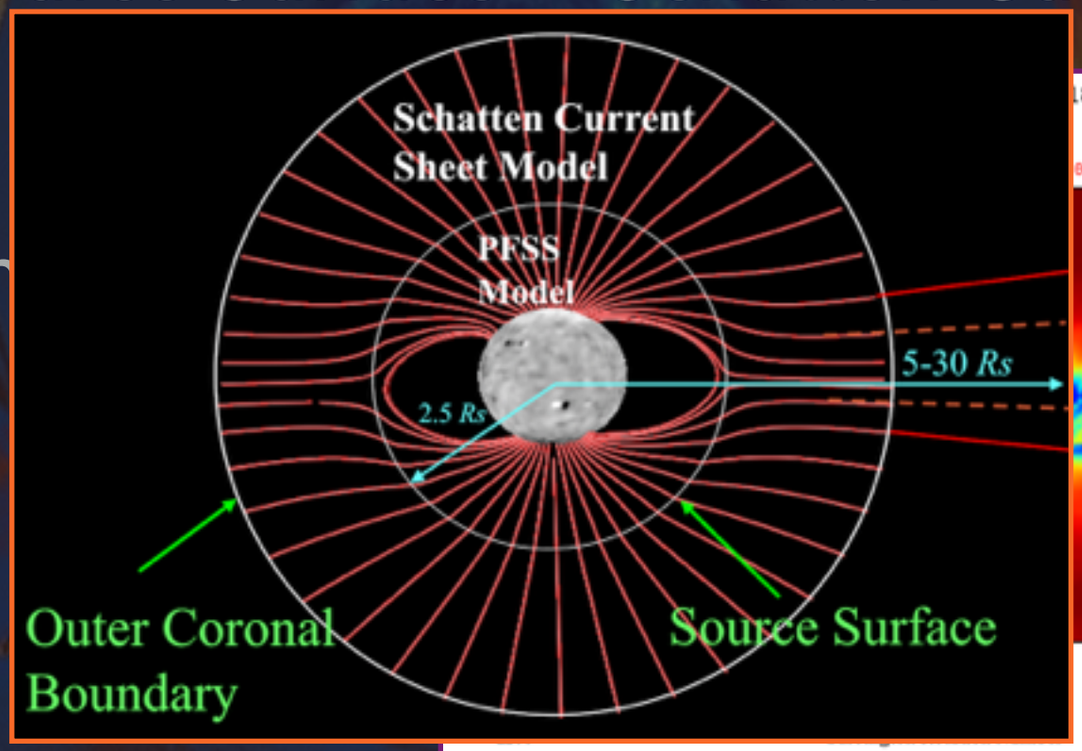


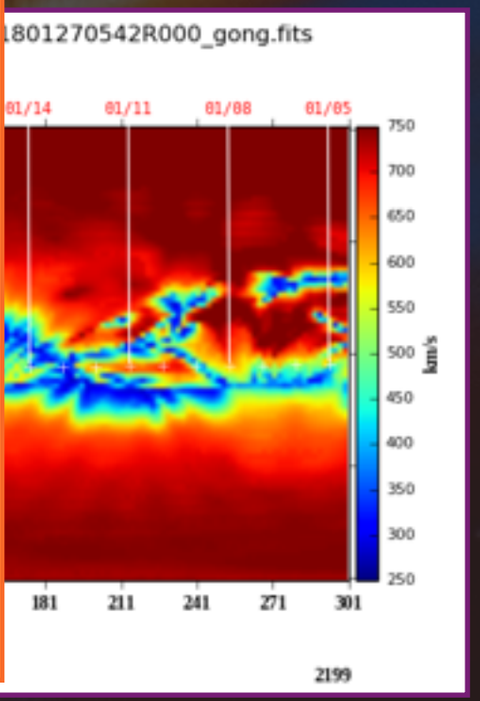


WANG-SHEELEY-ARGE (WSA)

- 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

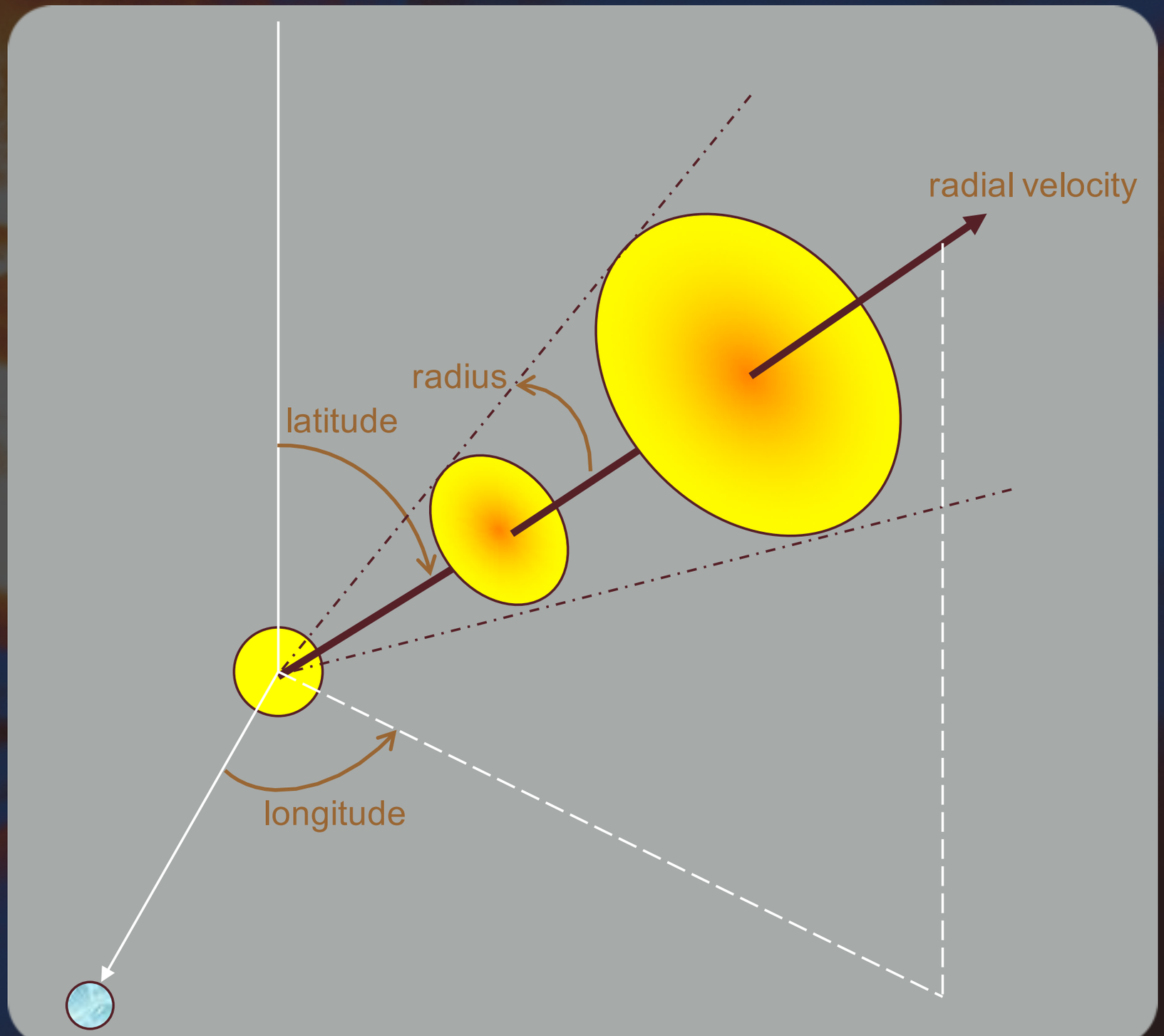






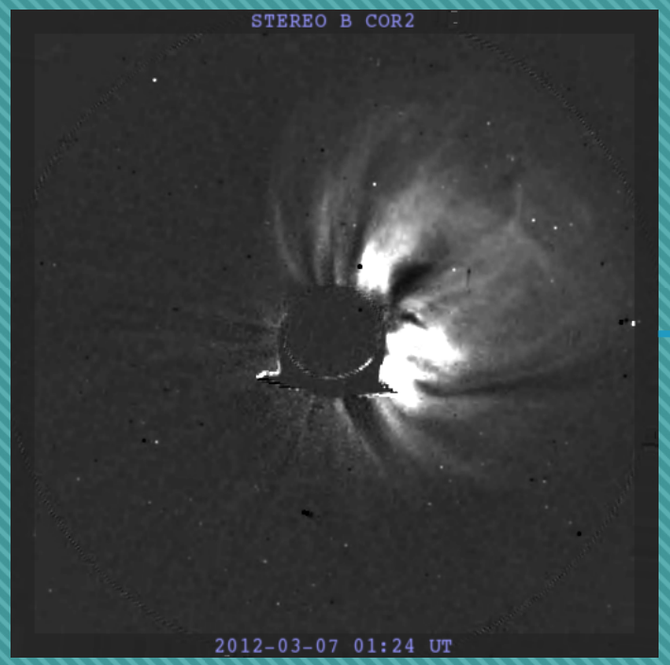
CONE MODEL

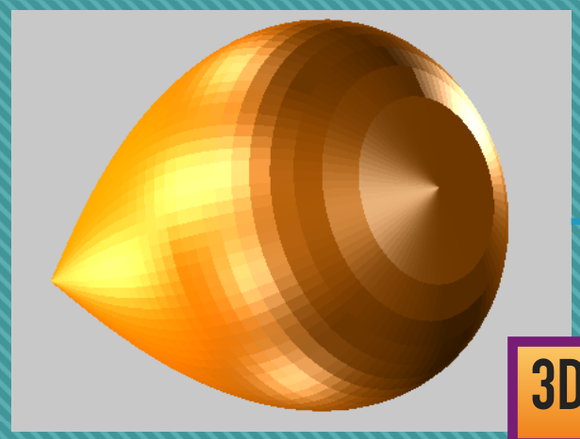
- Latitude:
- Longitude:
- CME Half-Width:
- CME Speed:



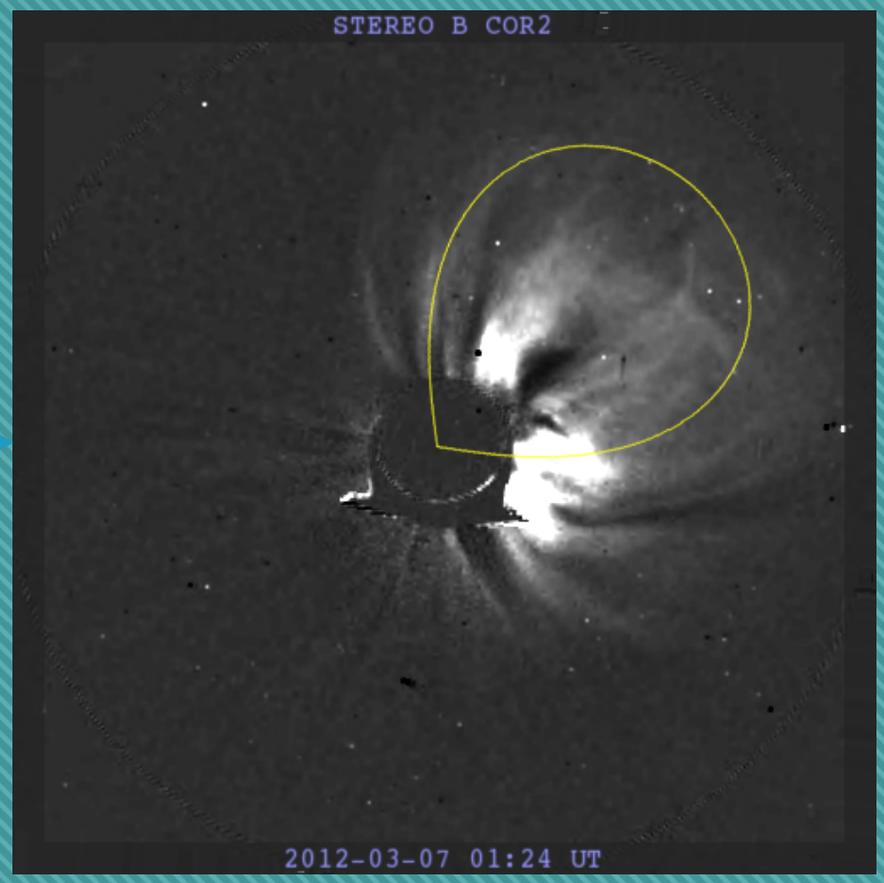
CONE MODEL

Characterize CME for insertion into Enlil using CAT





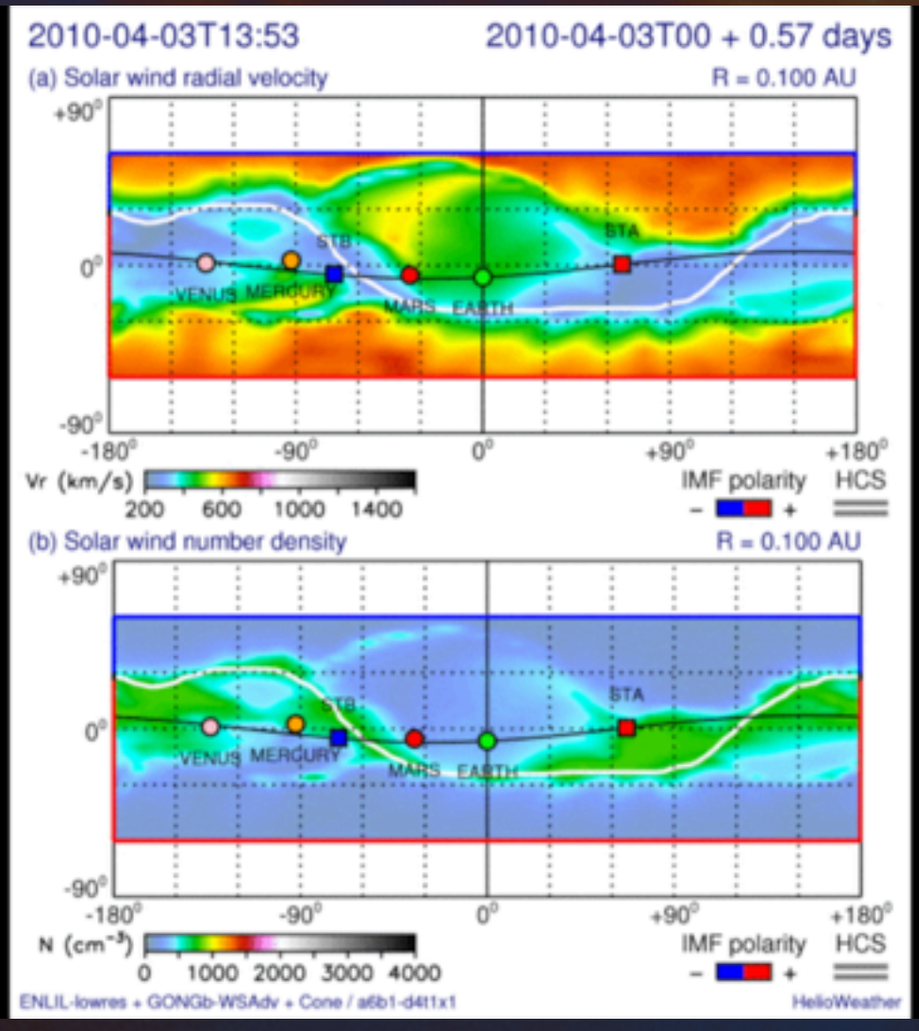
3D LEMNISCATE

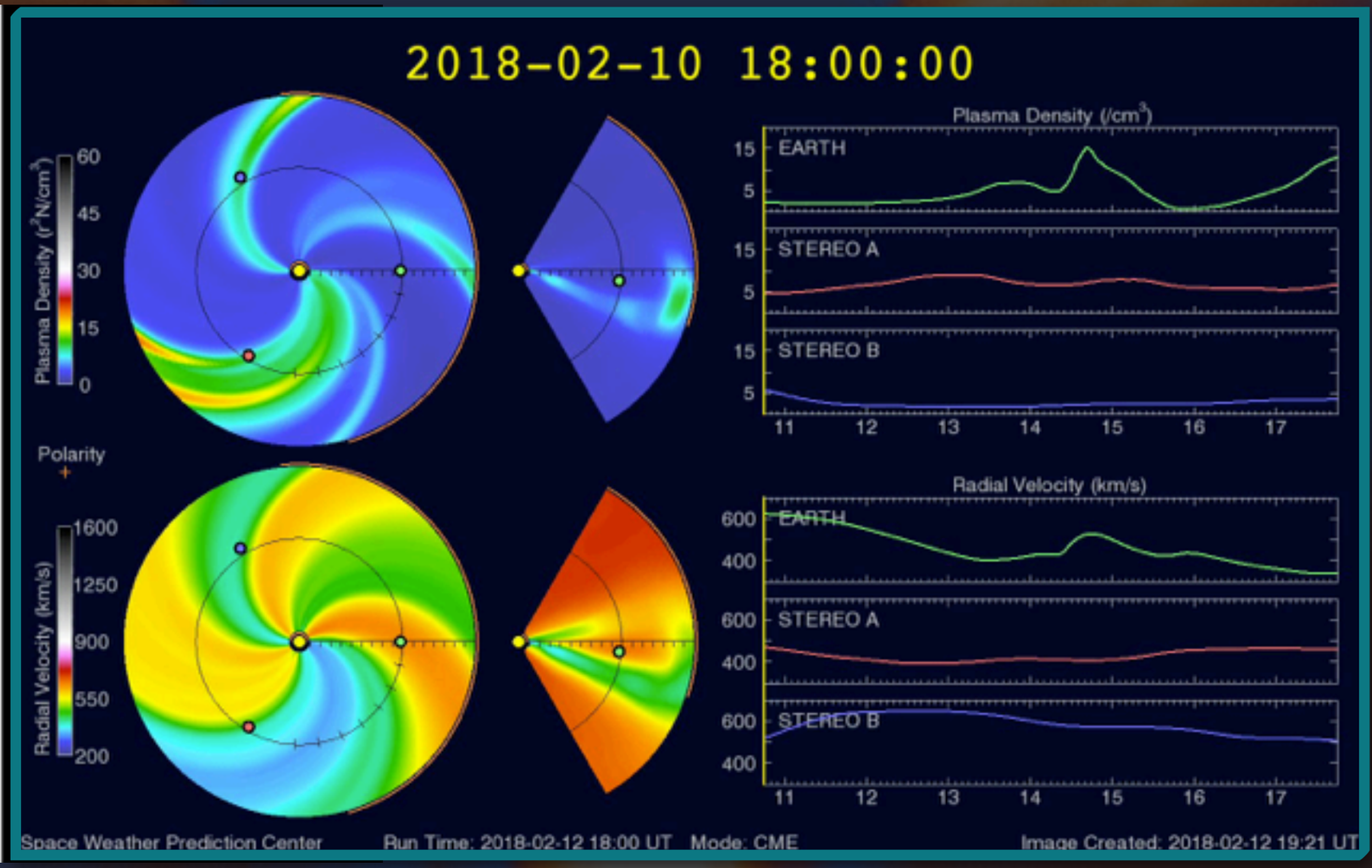


CME INJECTION INTO ENLIL

- 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 (WCOSS)
- 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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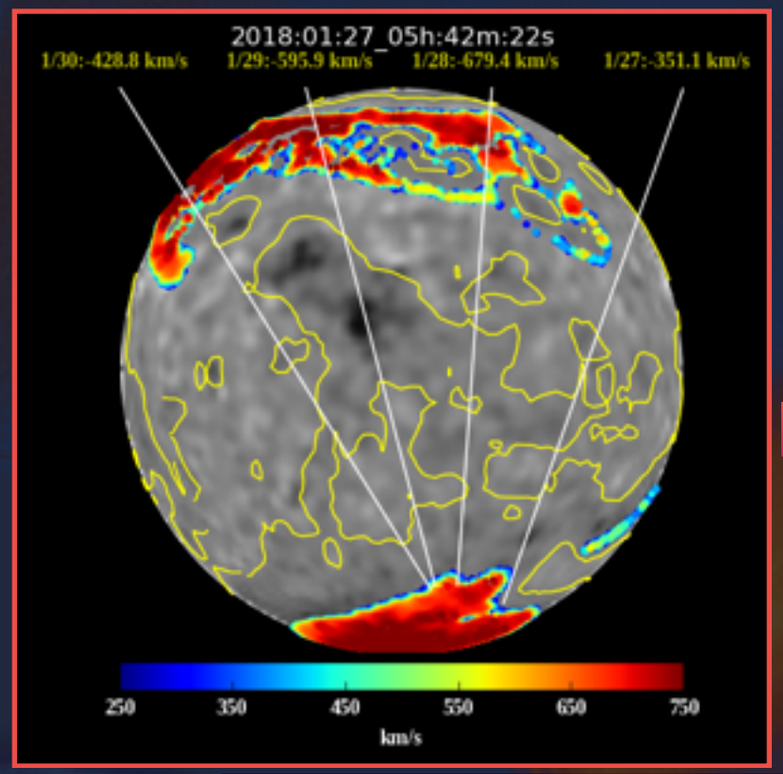
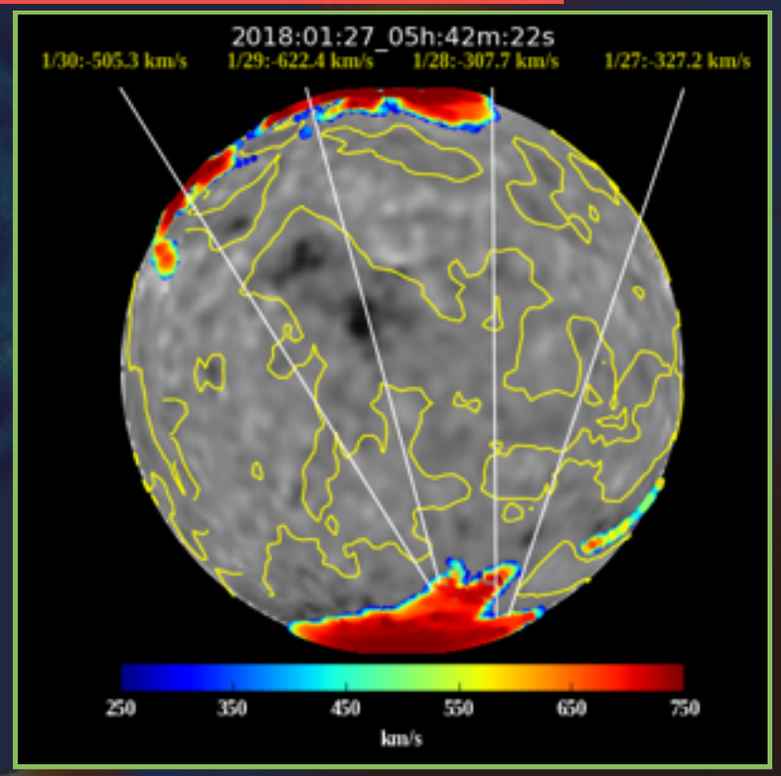
WSA-ENLIL ENHANCEMENT

- 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!





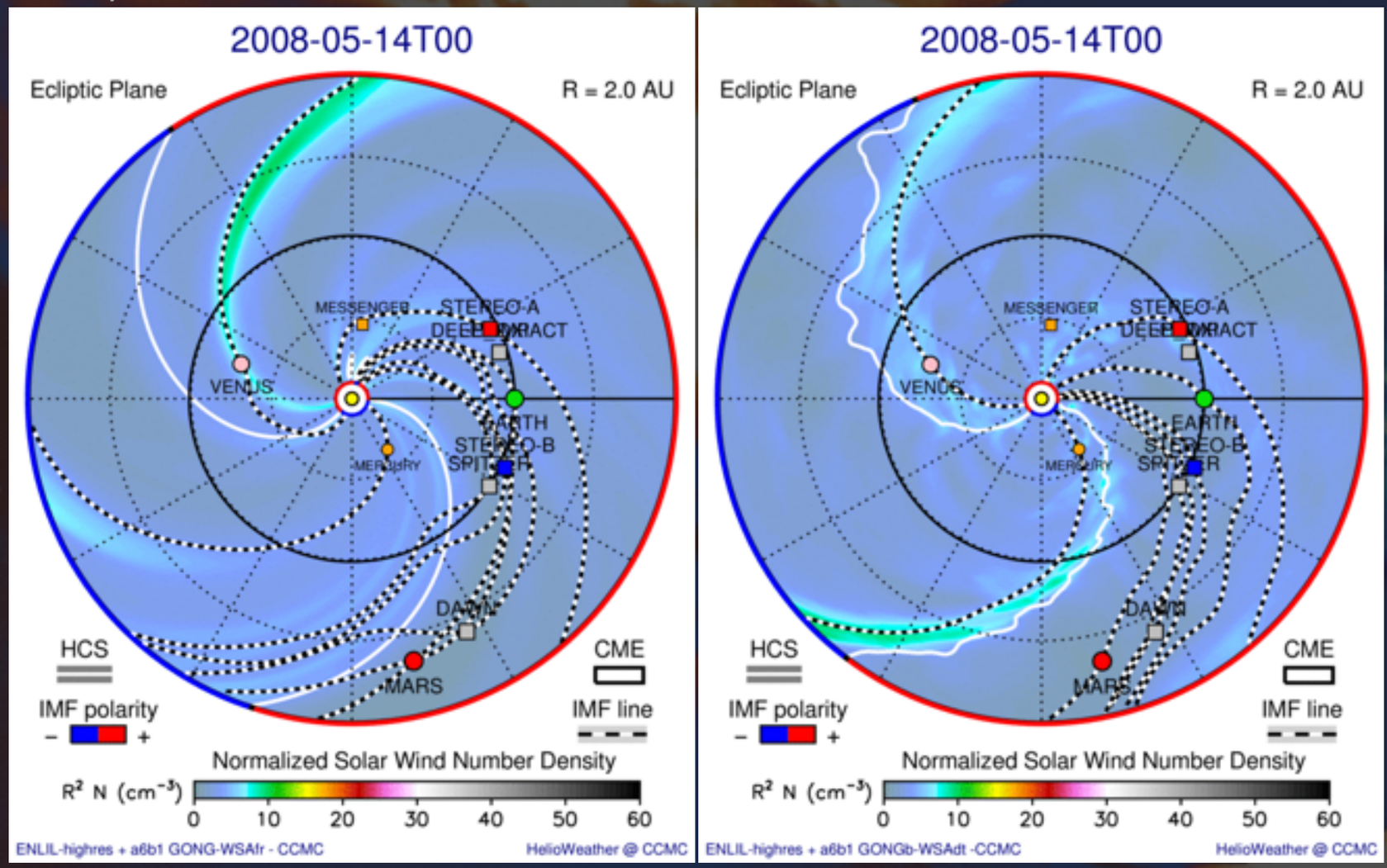
TIME-DEPENDENT DRIVING

Static synoptic map

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

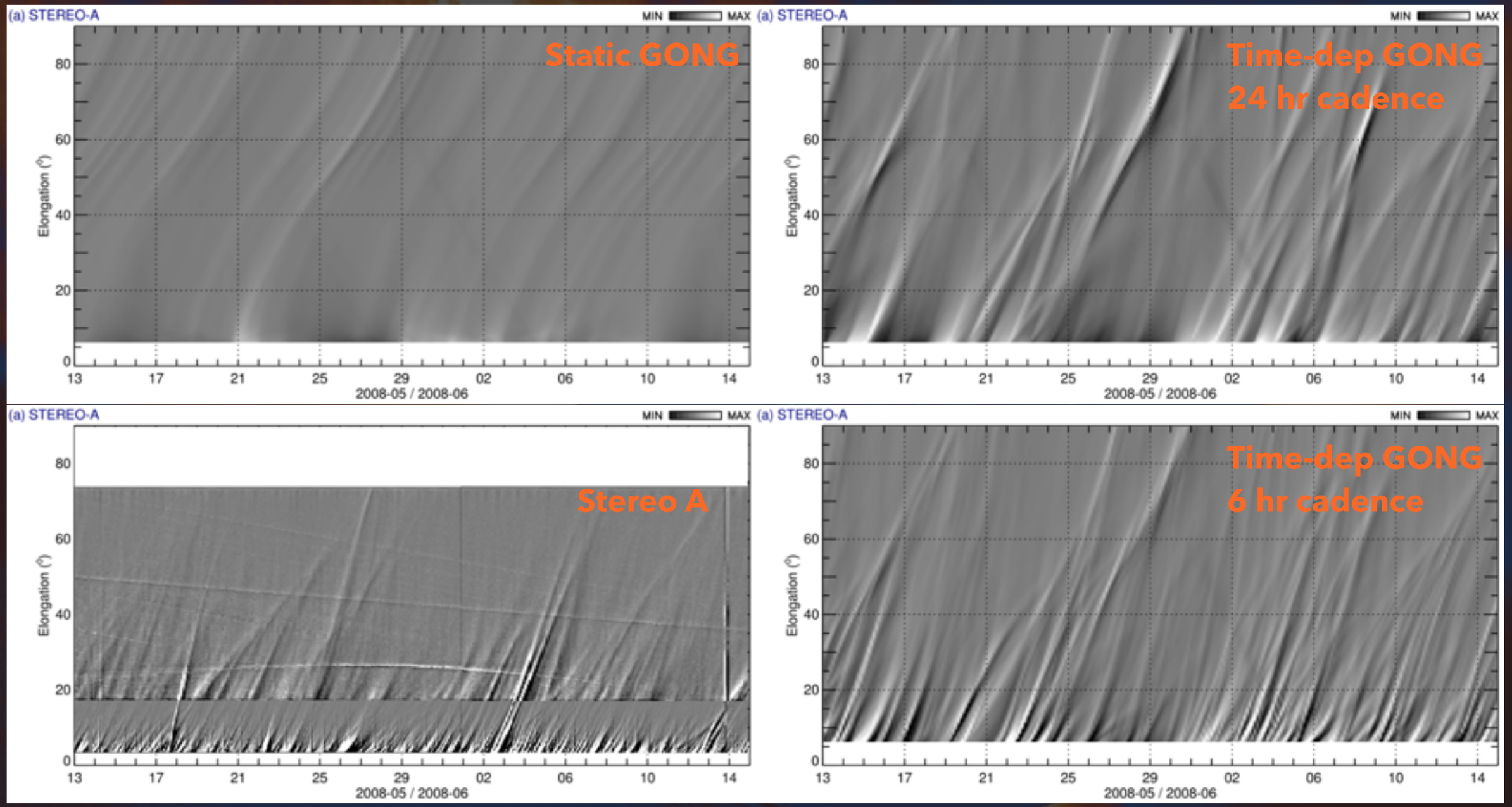
Sequence of maps

Includes photospheric dynamics



- "smooth" heliospheric solution
- Impacts CME propagation

TIME-DEPENDENT DRIVING . . . CADENCE?

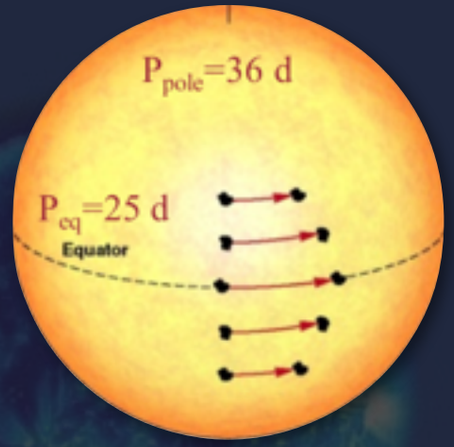


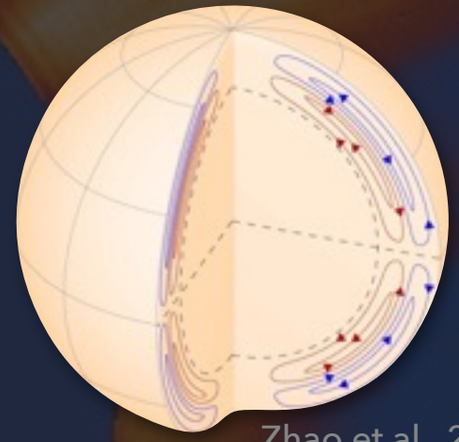
M. Leila Mays, NASA CCMC

ADAPT: FLUX TRANSPORT / DATA ASSIMILATION

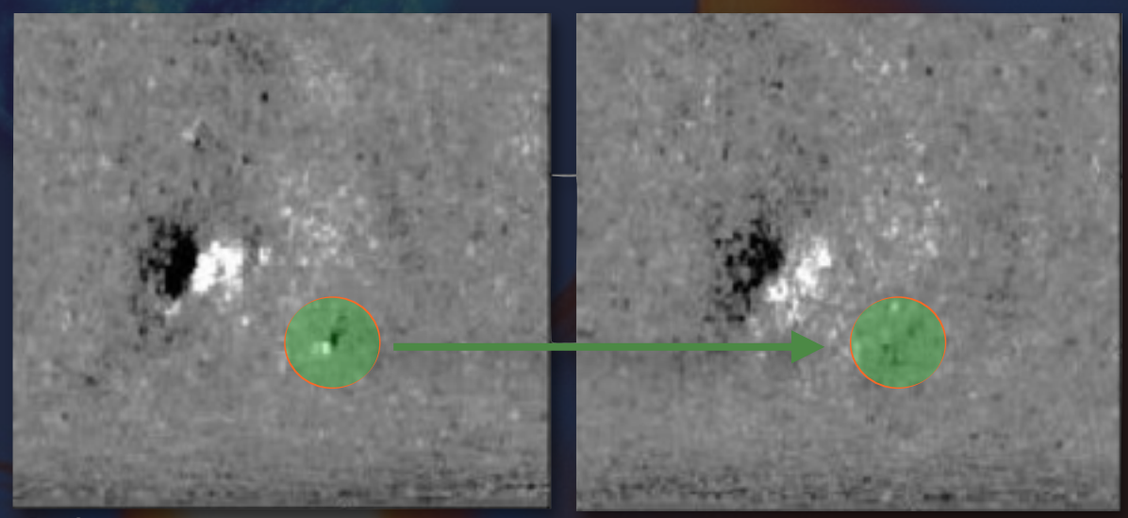
The Air Force Data Assimilative Photospheric Flux Transport Model (ADAPT) - Ensemble model of photospheric transport processes + data assimilation:

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



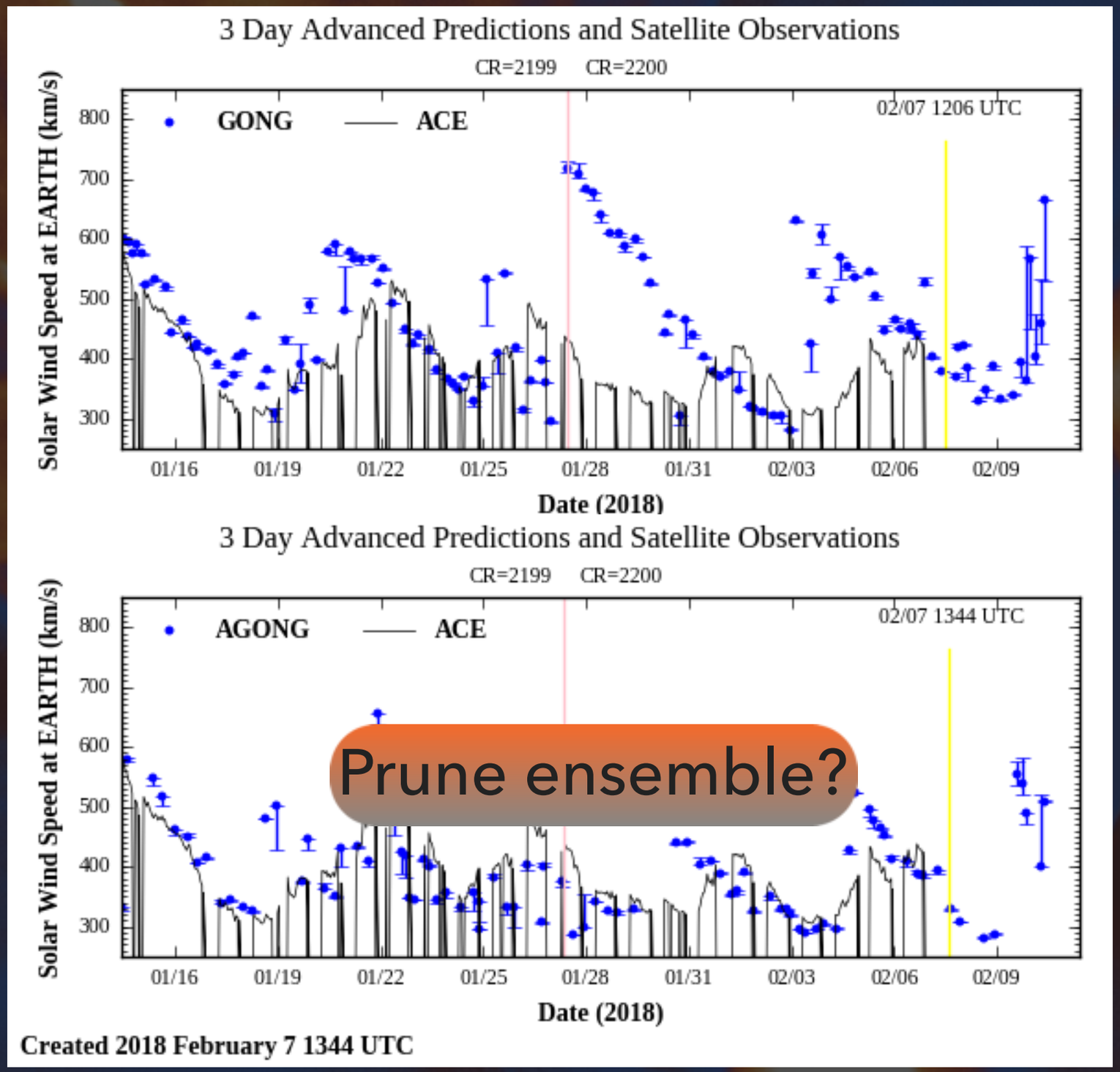


Zhao et al., 2013



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

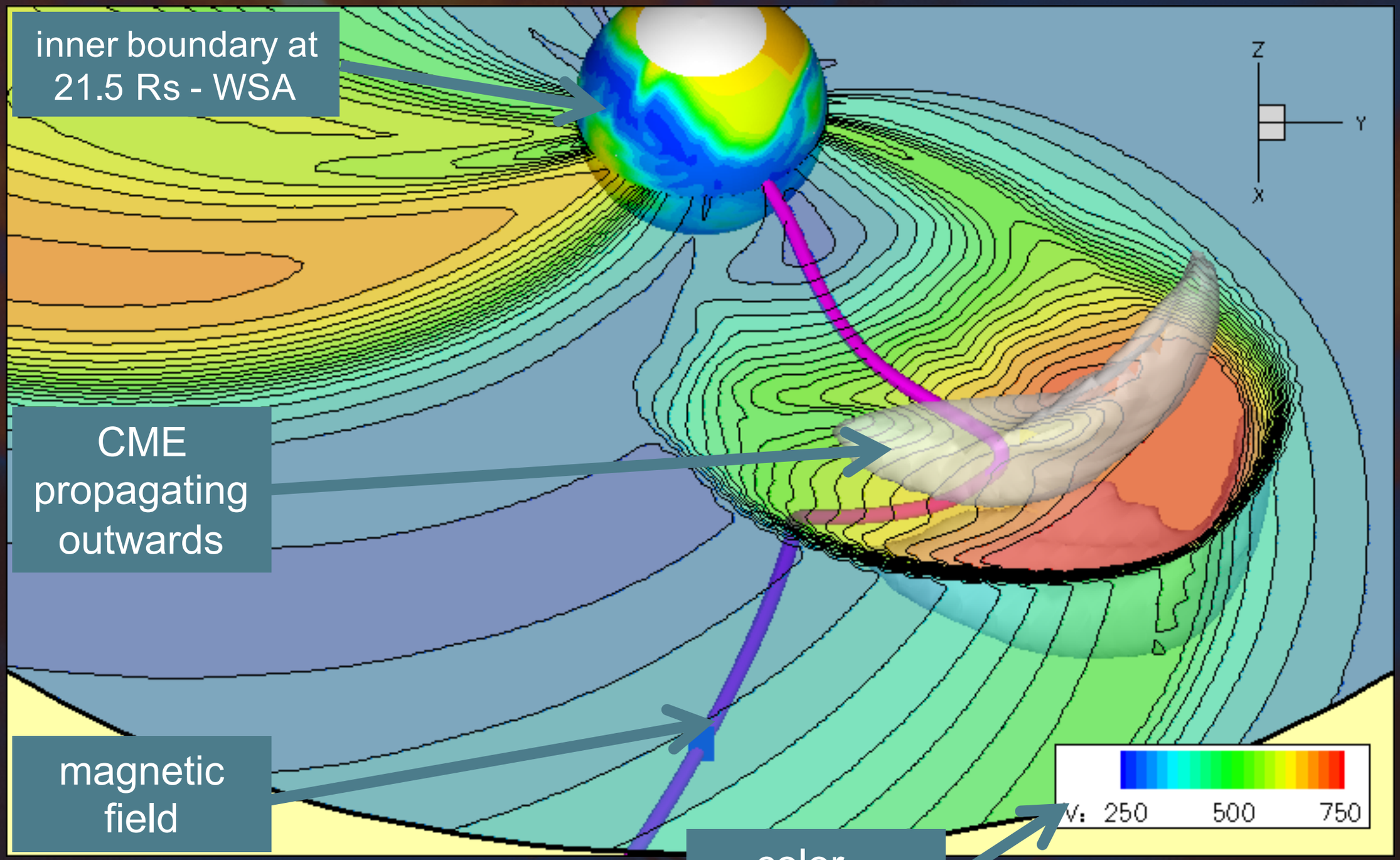
NASA CCMC: M. Leila Mays, Peter Macneice, Neel Savani, Aleksandre Taktakishvili

NOAA SWPC: Eric Adamson, Vic Pizzo, Doug Biesecker

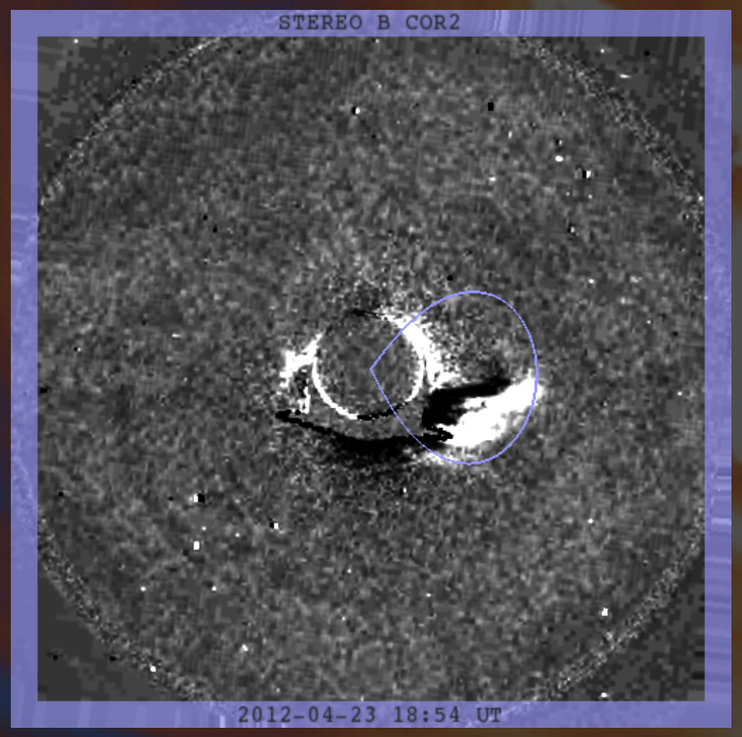
- Results compiled in community accessible database
- Year-1 report to appear within the CME Arrival Time Working Team paper
- Culminates in final report advising path forward toward improved space weather forecasting

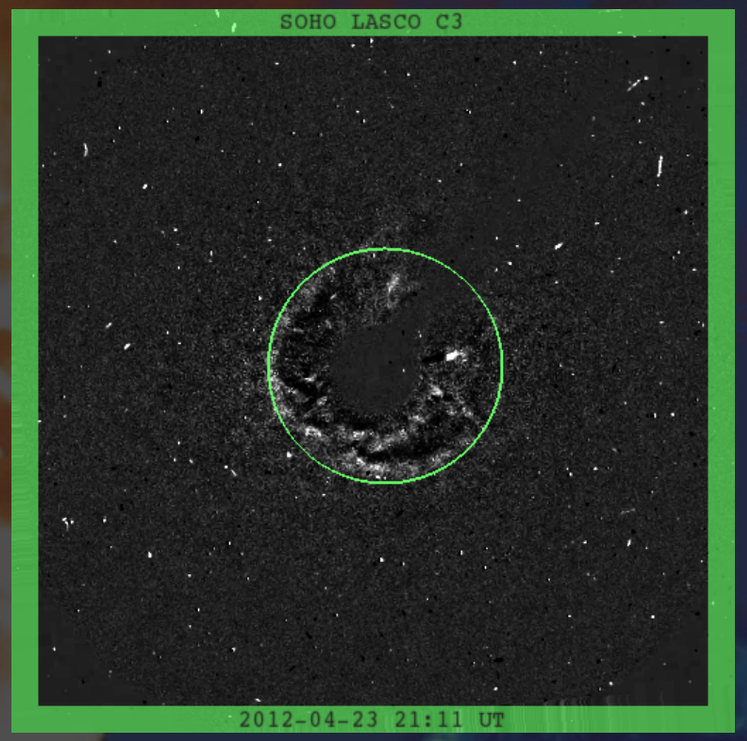
The End

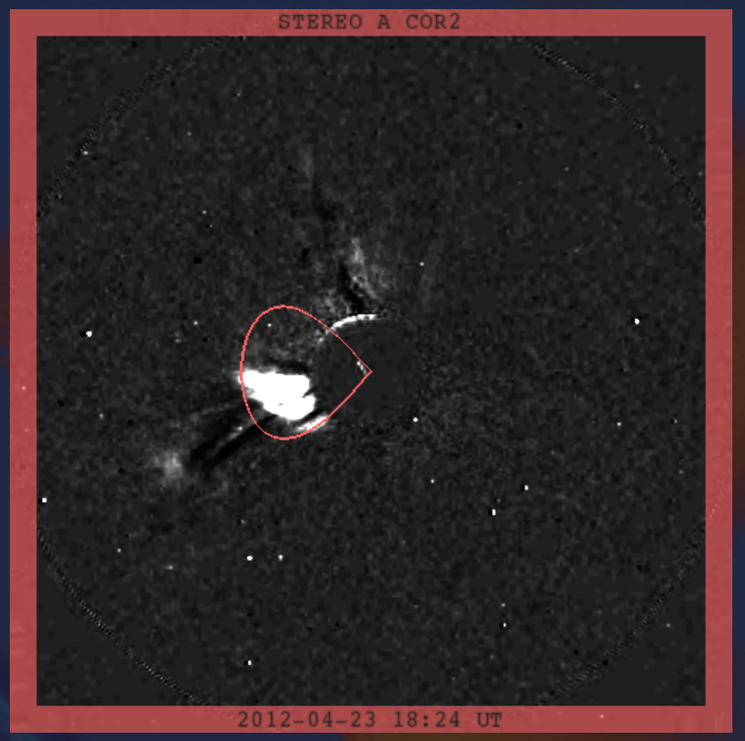
ENLIL – 3D MHD HELIOSPHERIC MODEL



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







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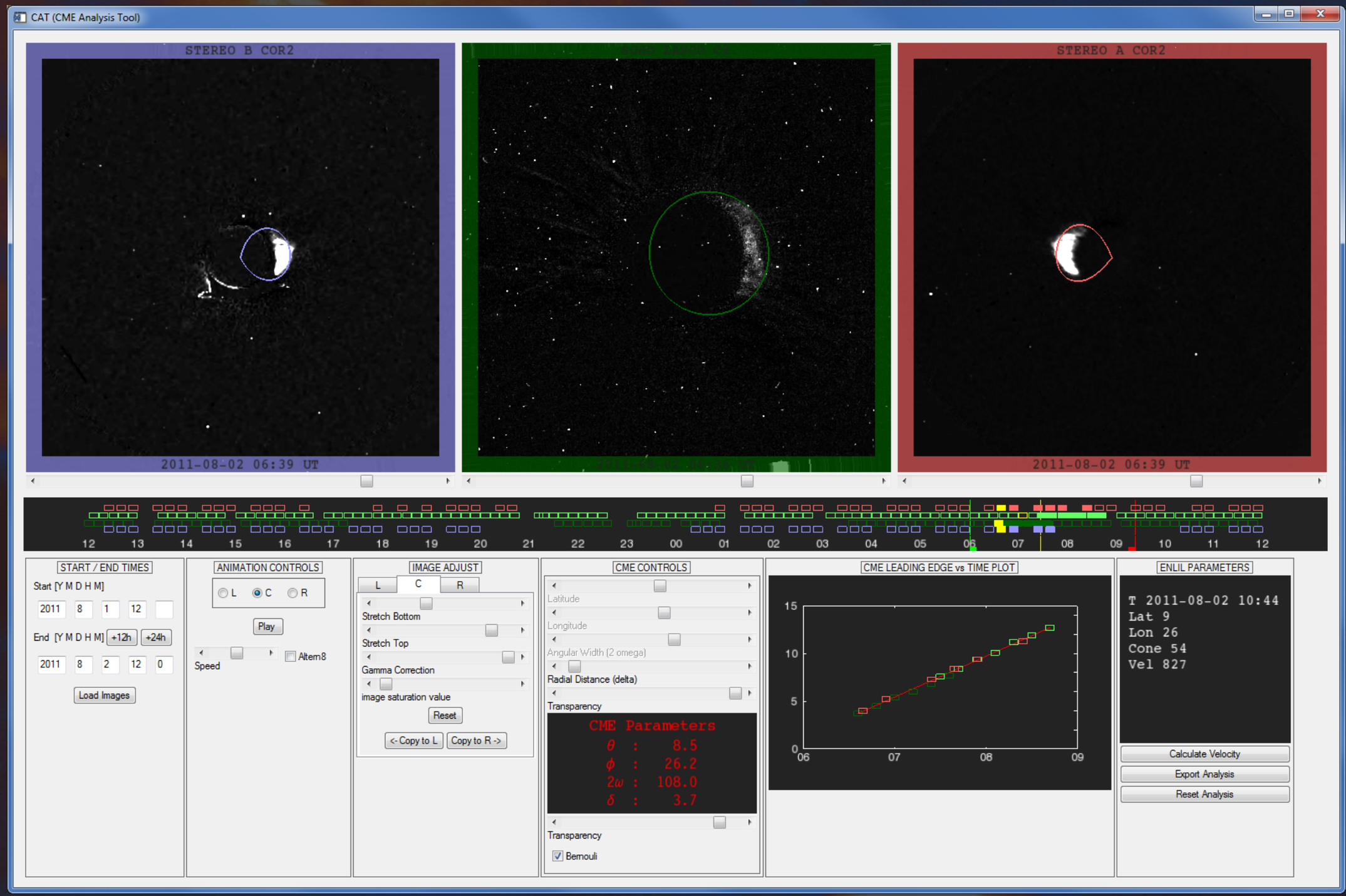

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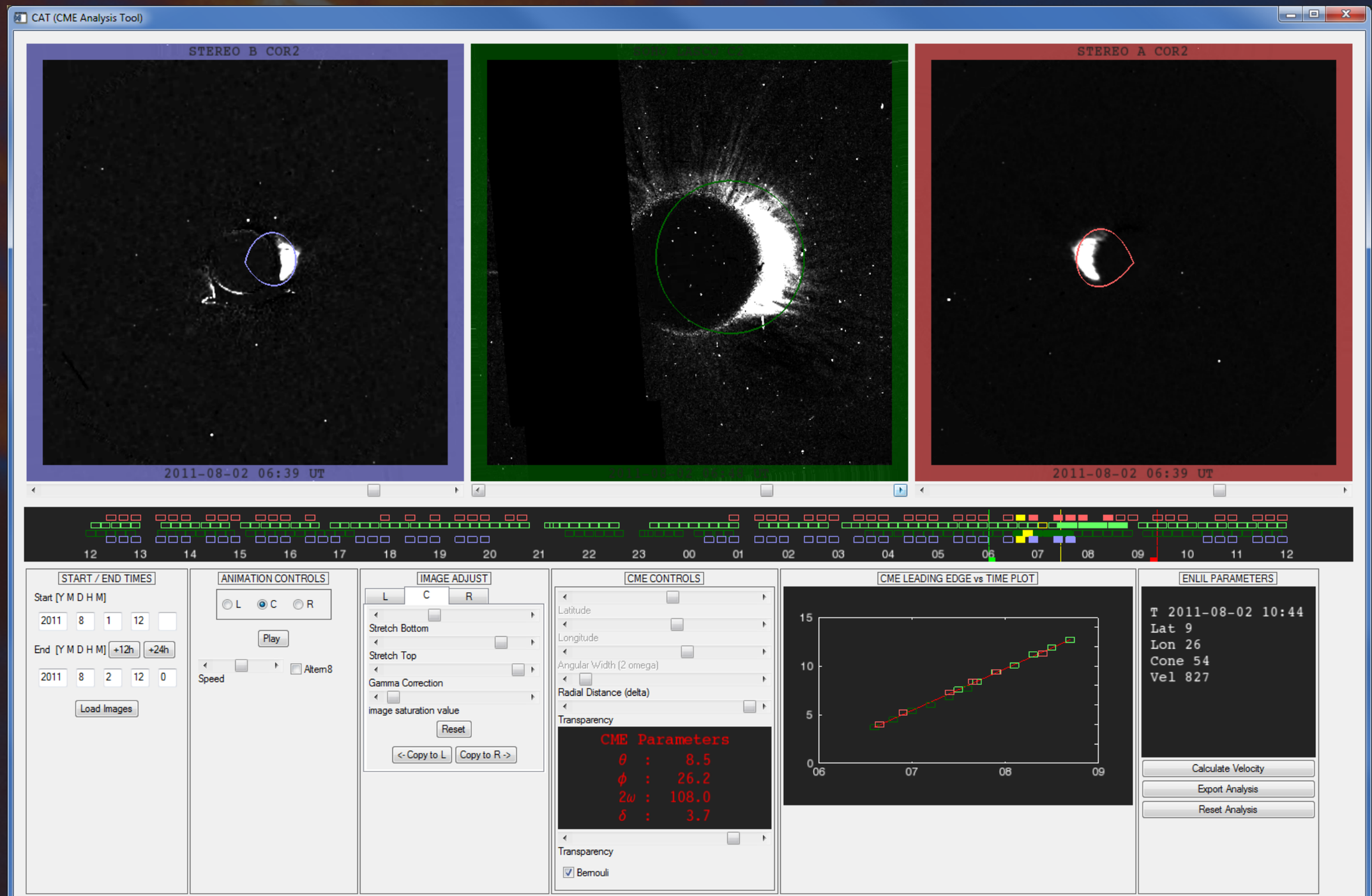

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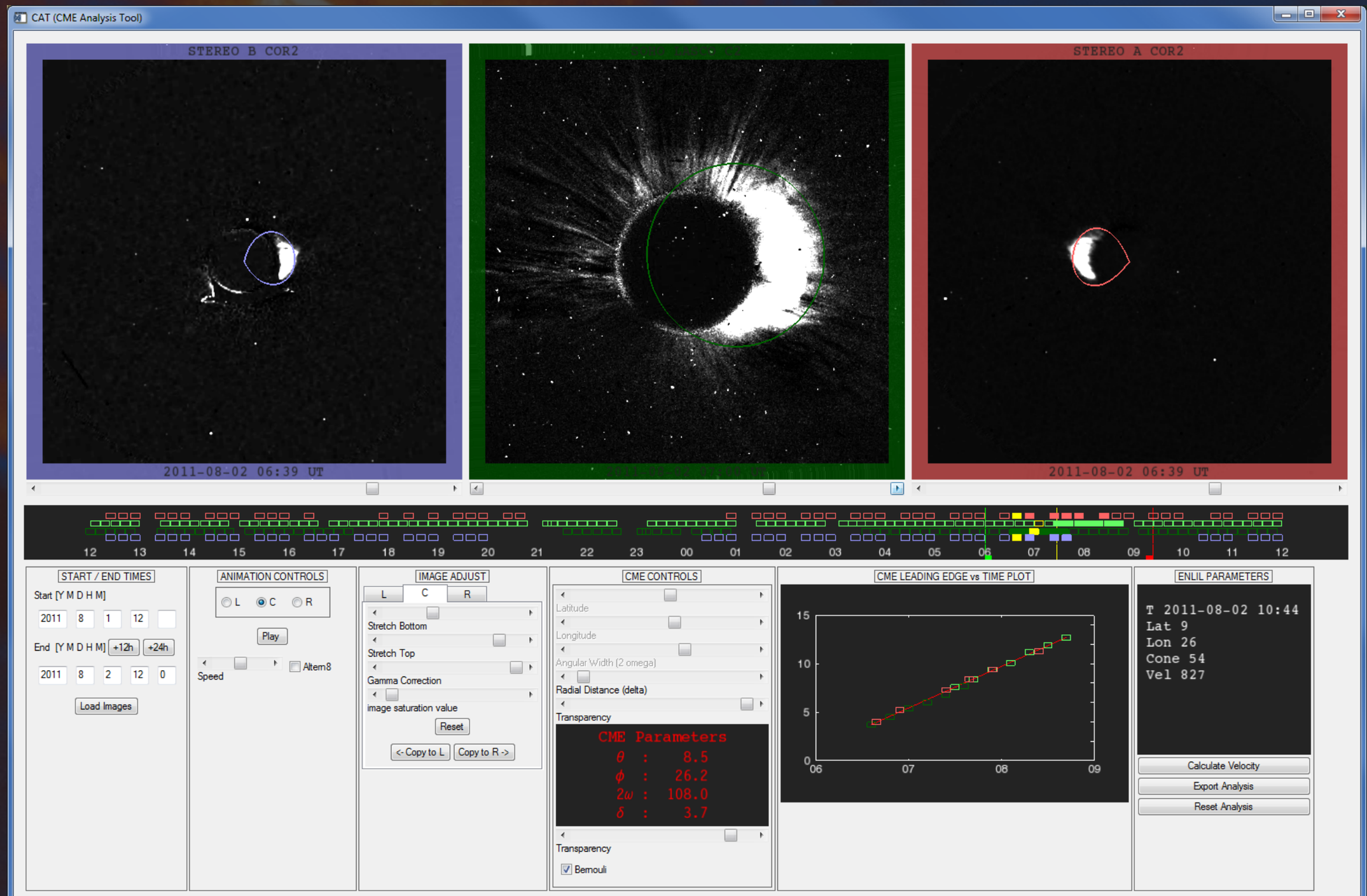

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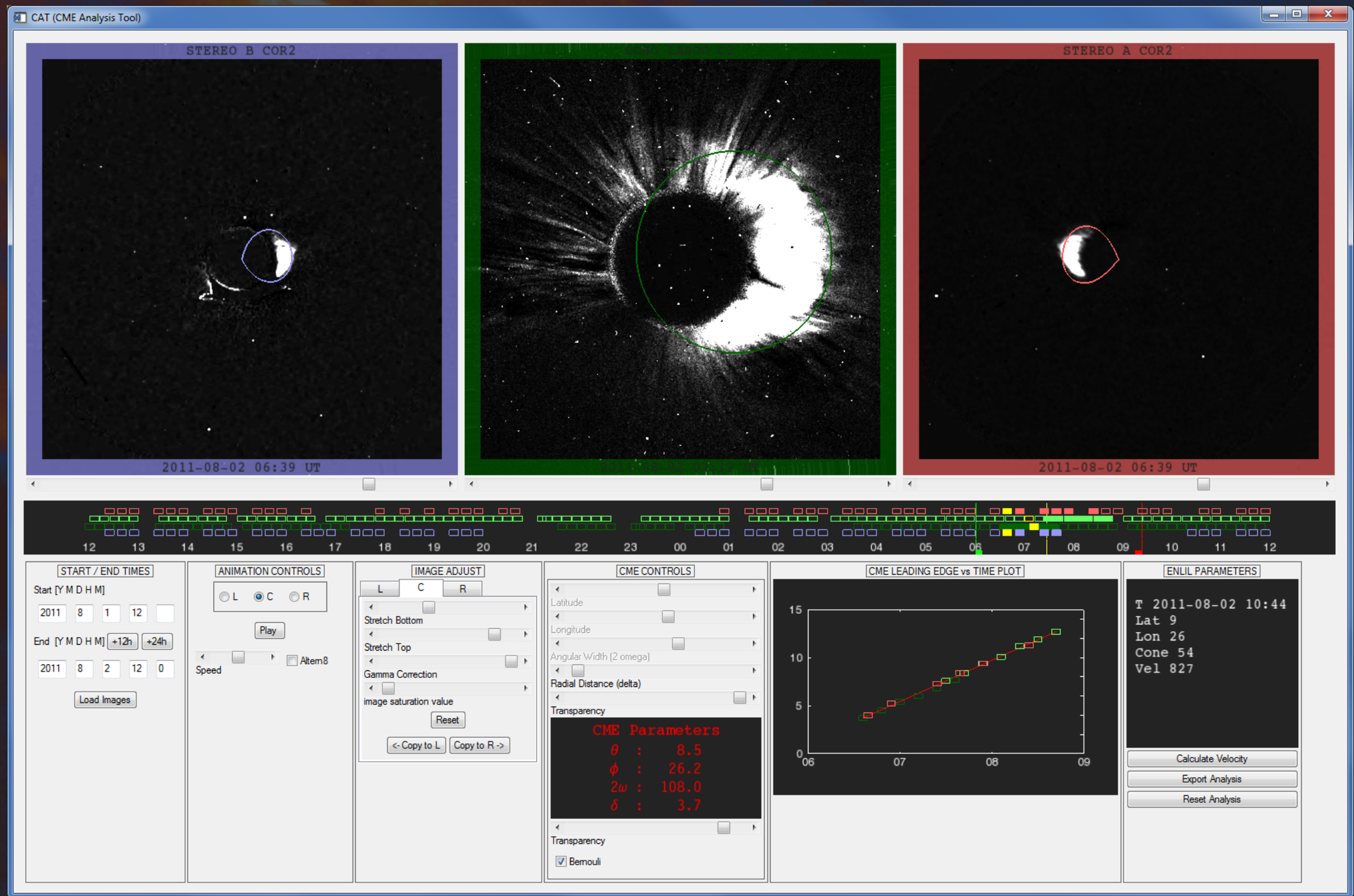

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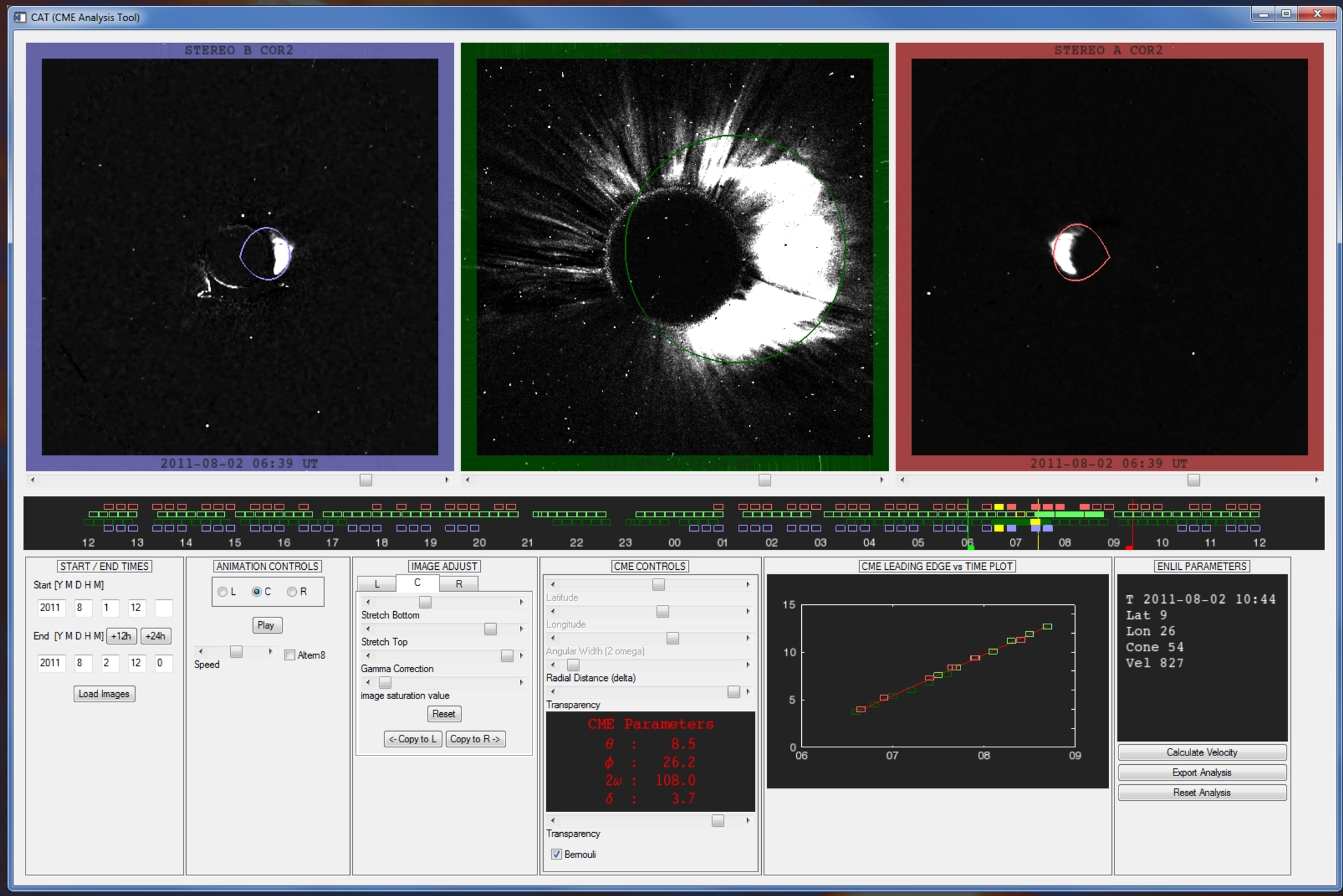

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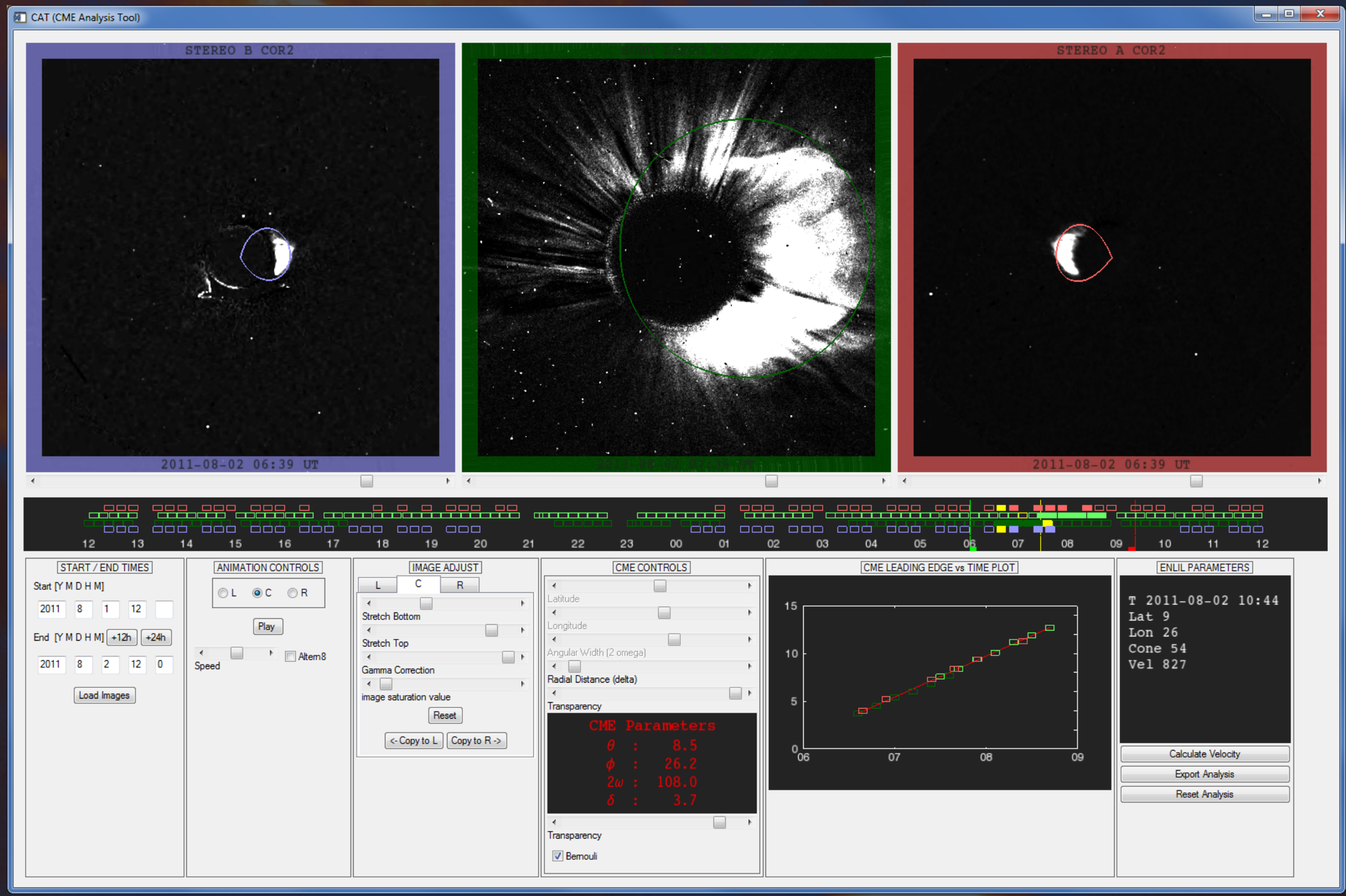

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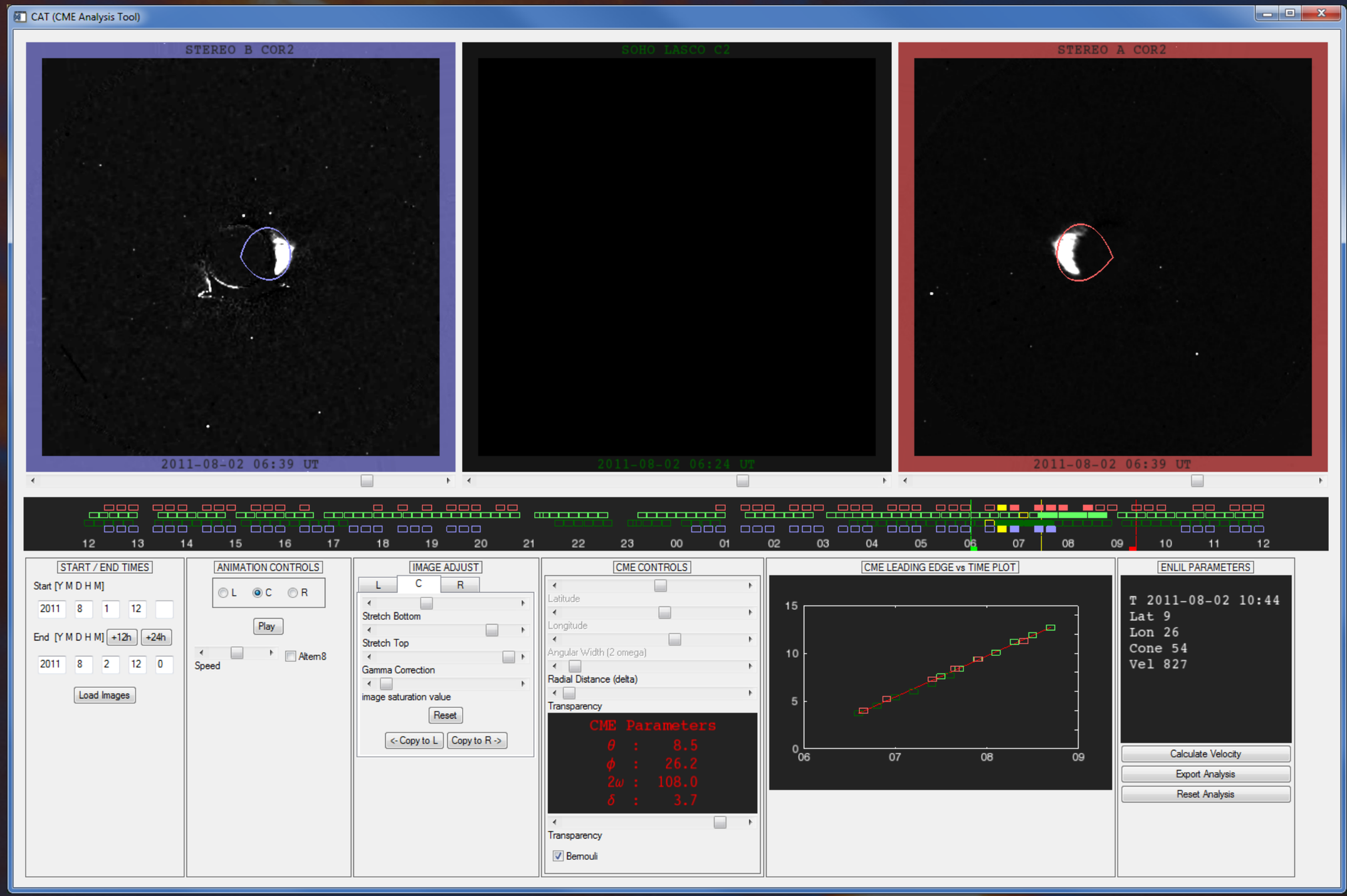

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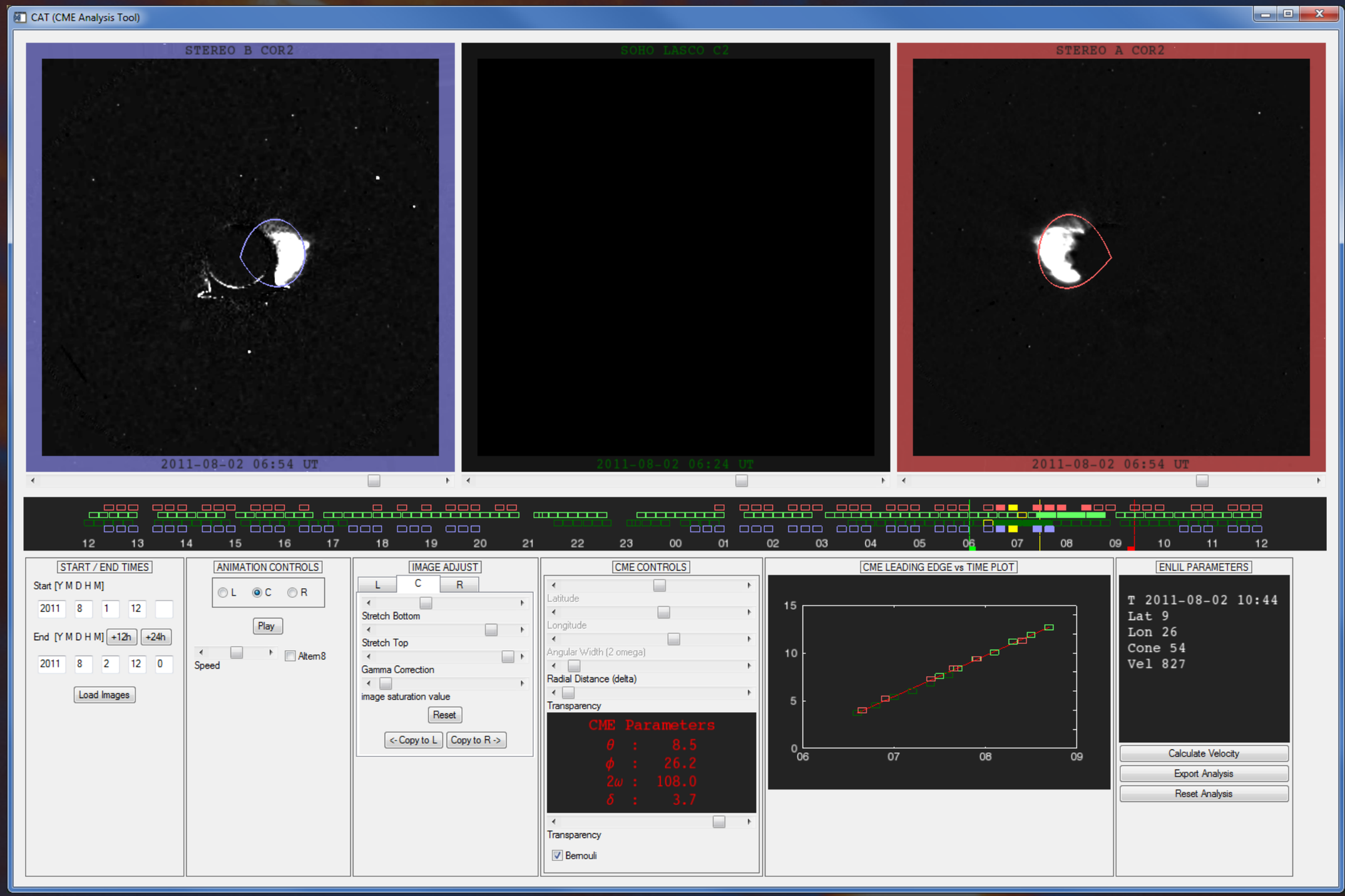

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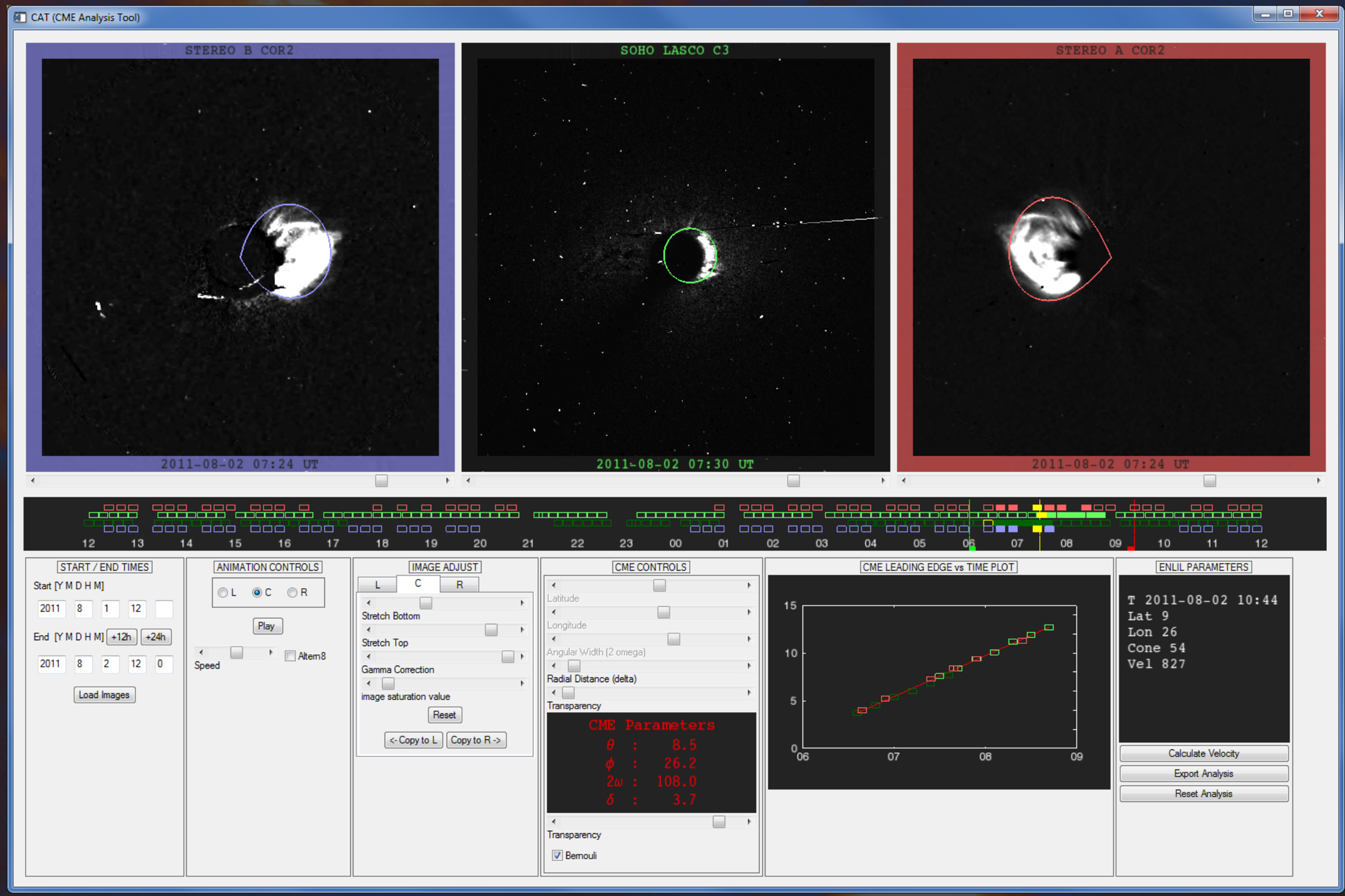

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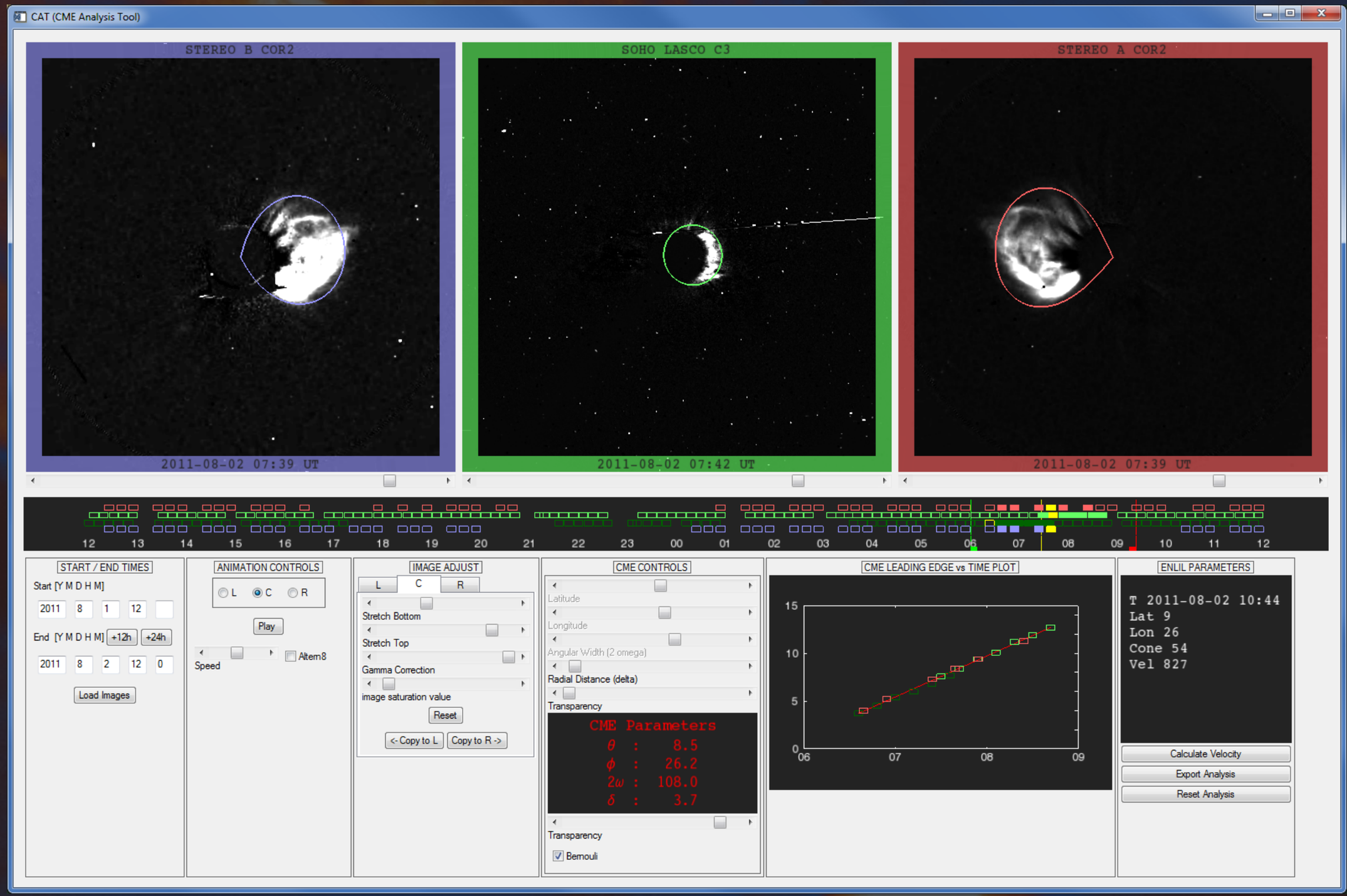

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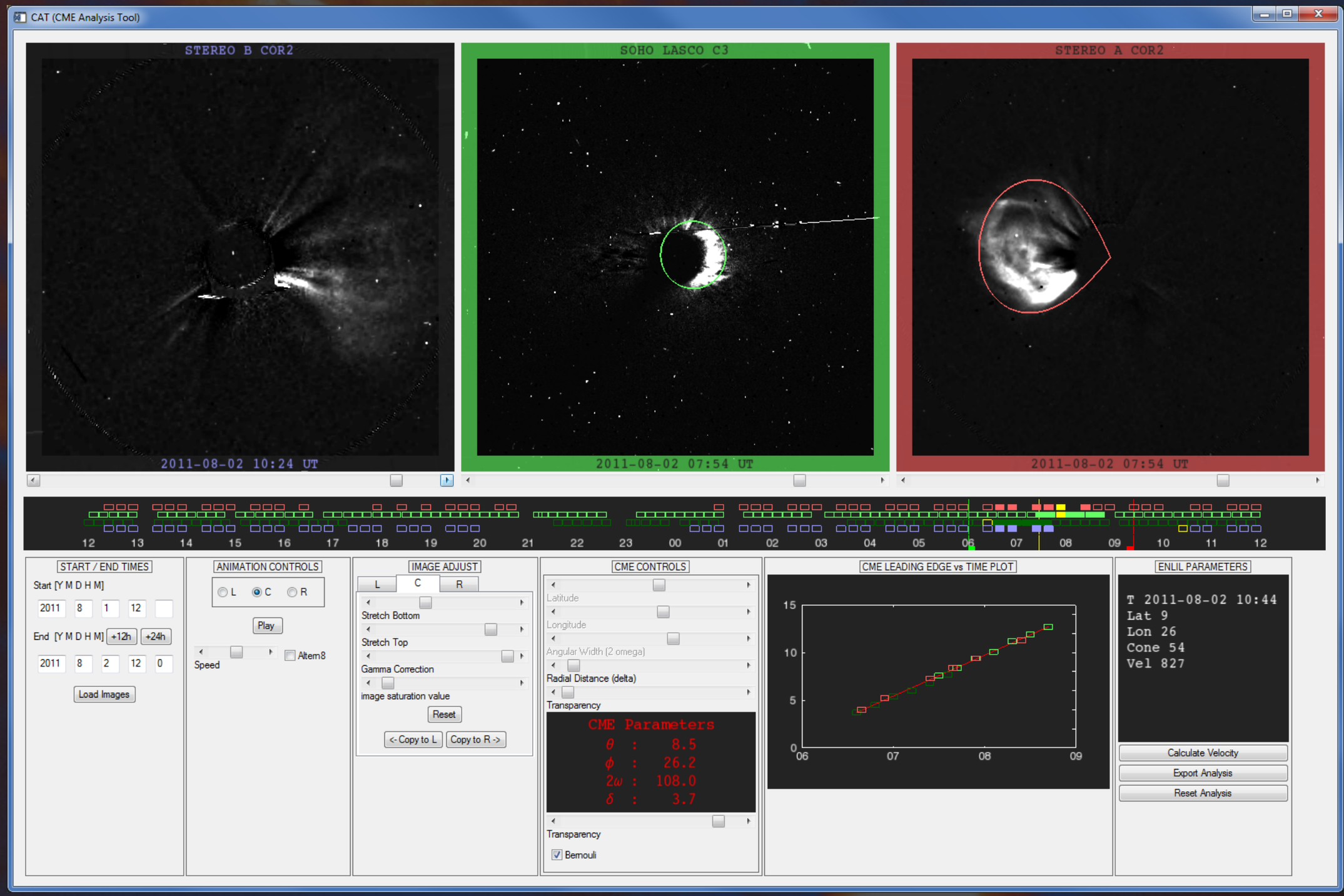

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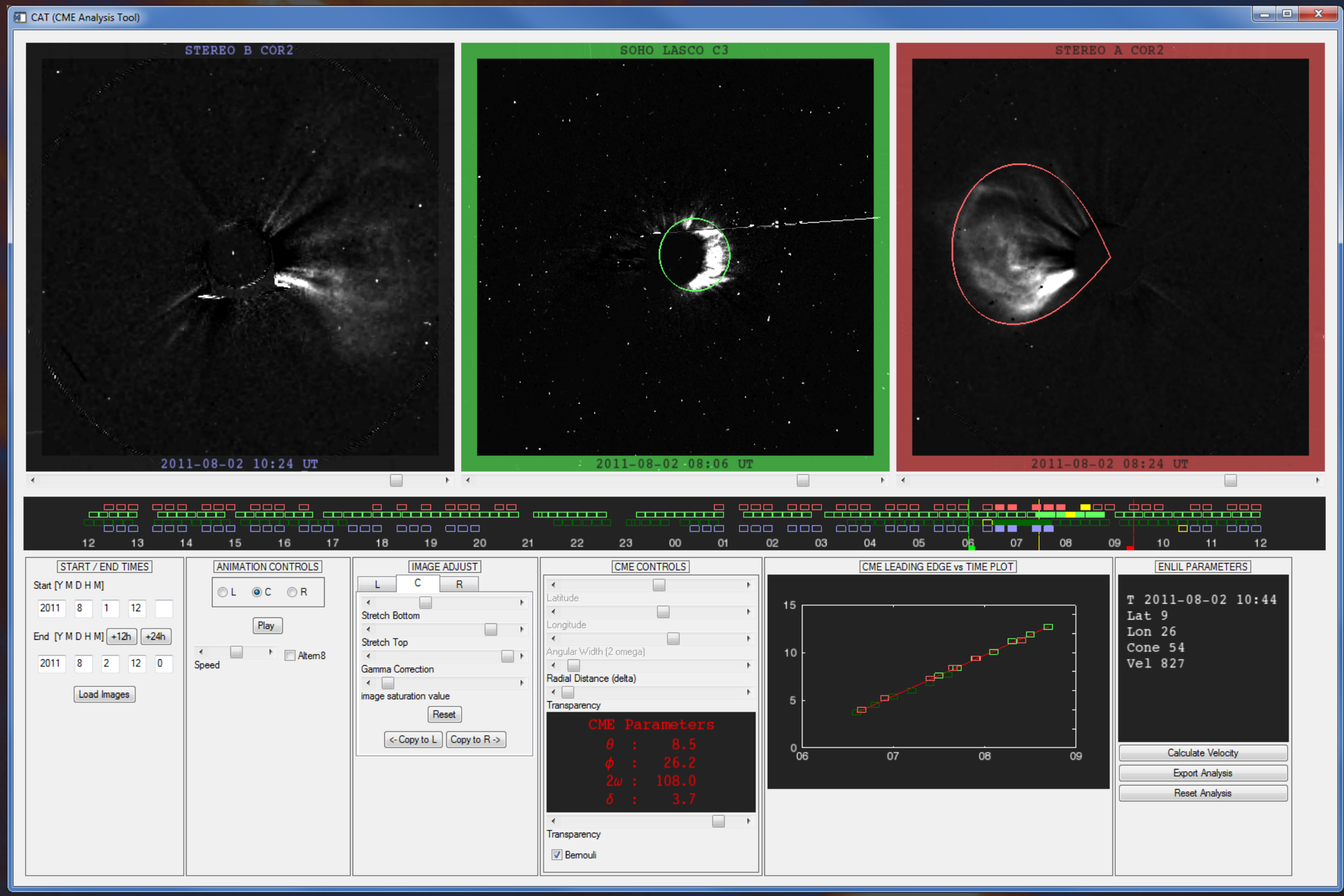

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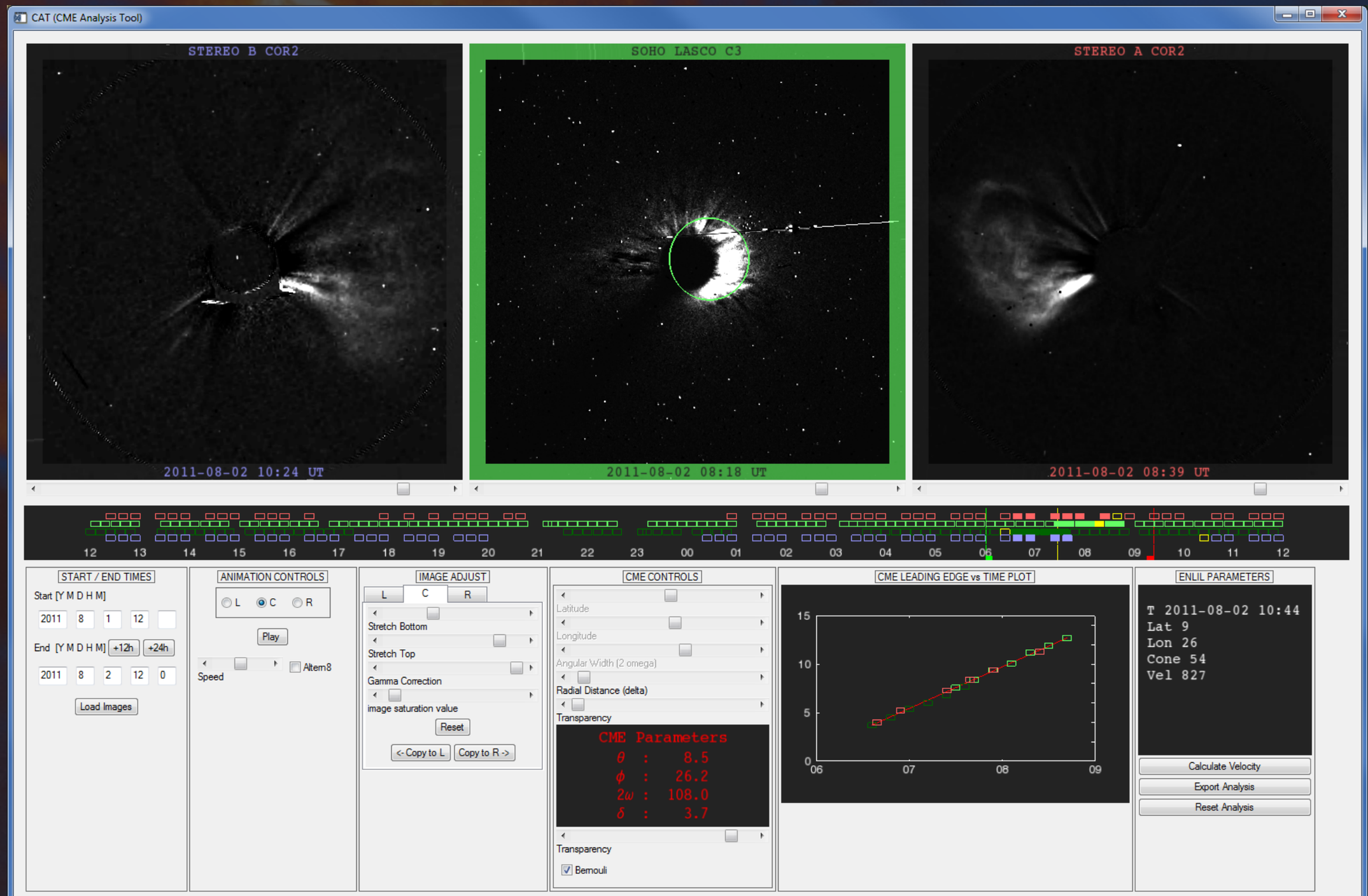

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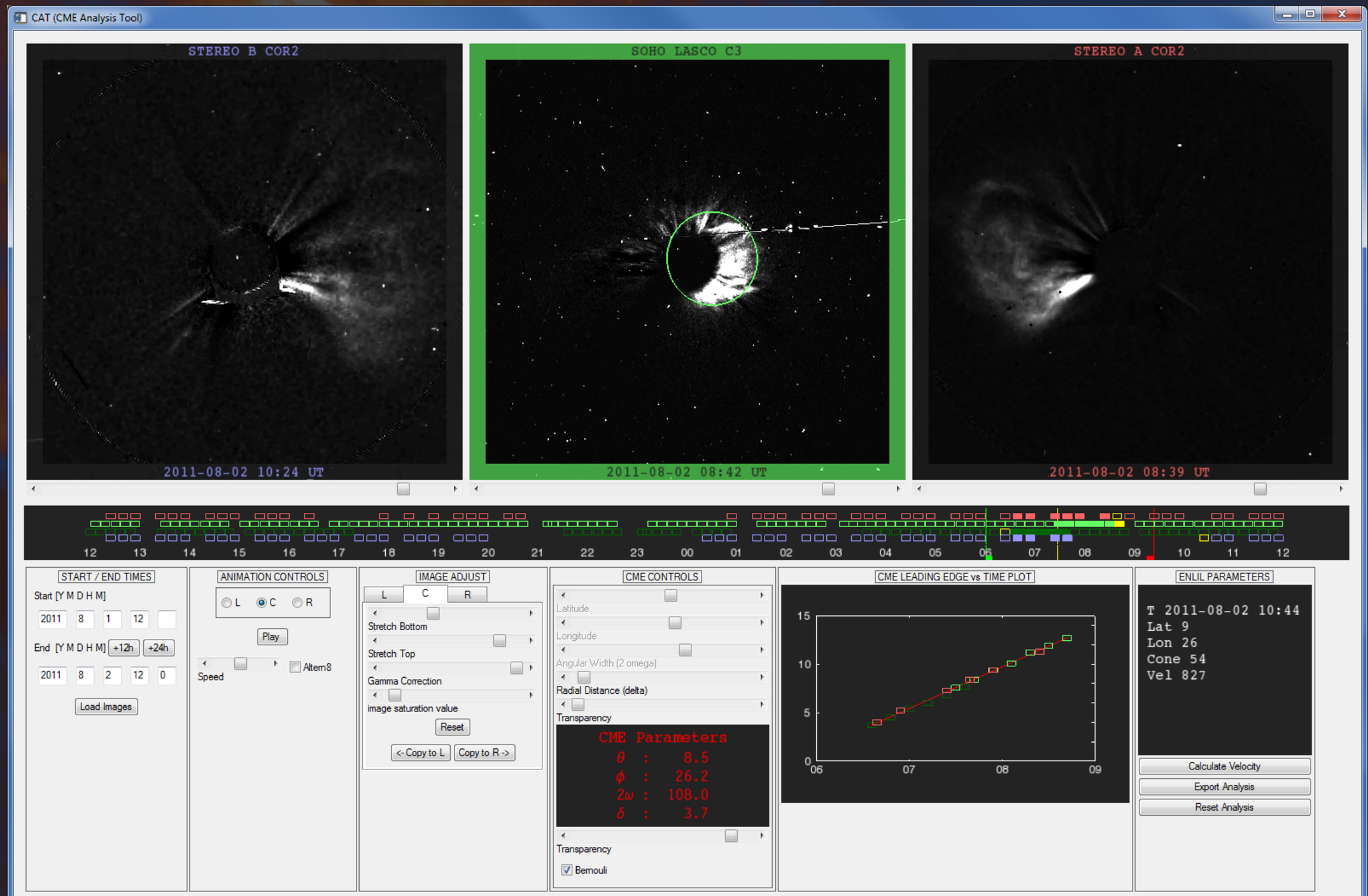

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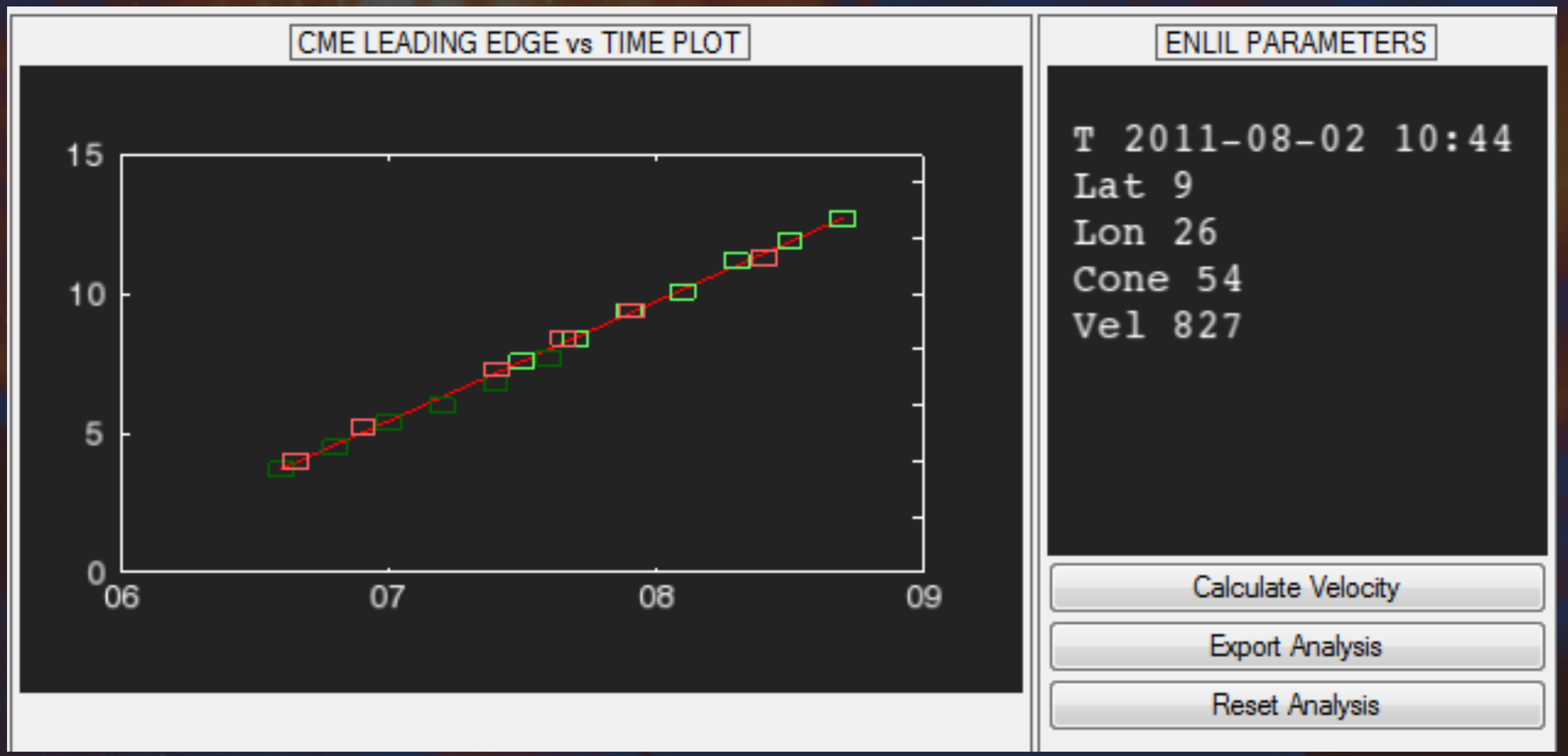
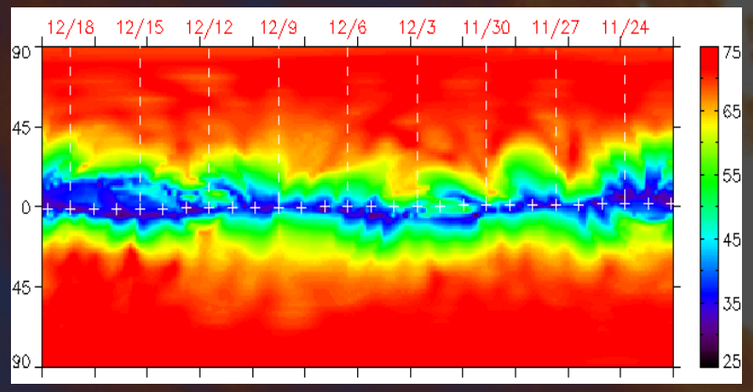
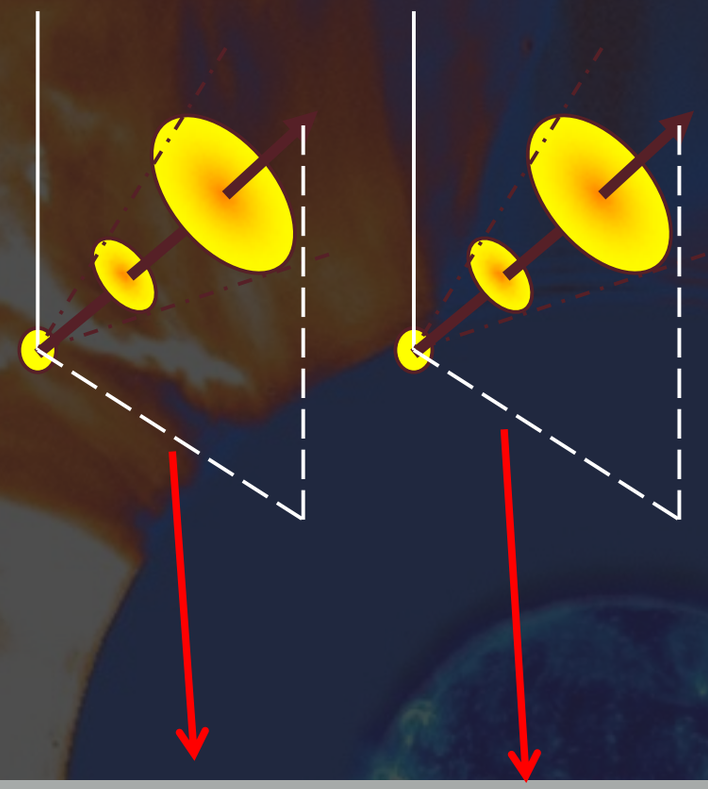
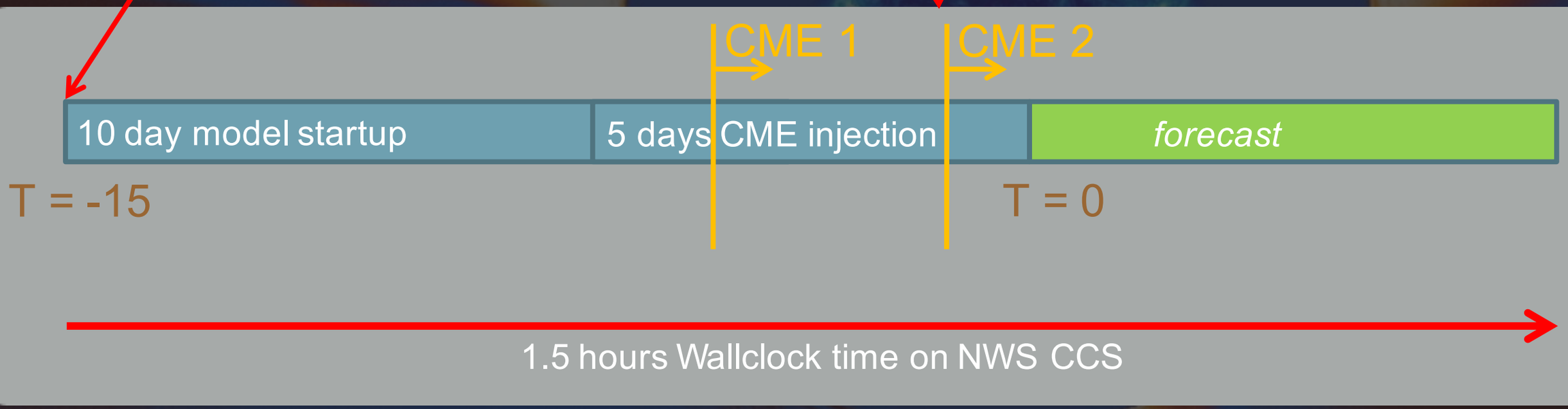


OPERATIONAL CONFIGURATION: MODEL EXECUTION

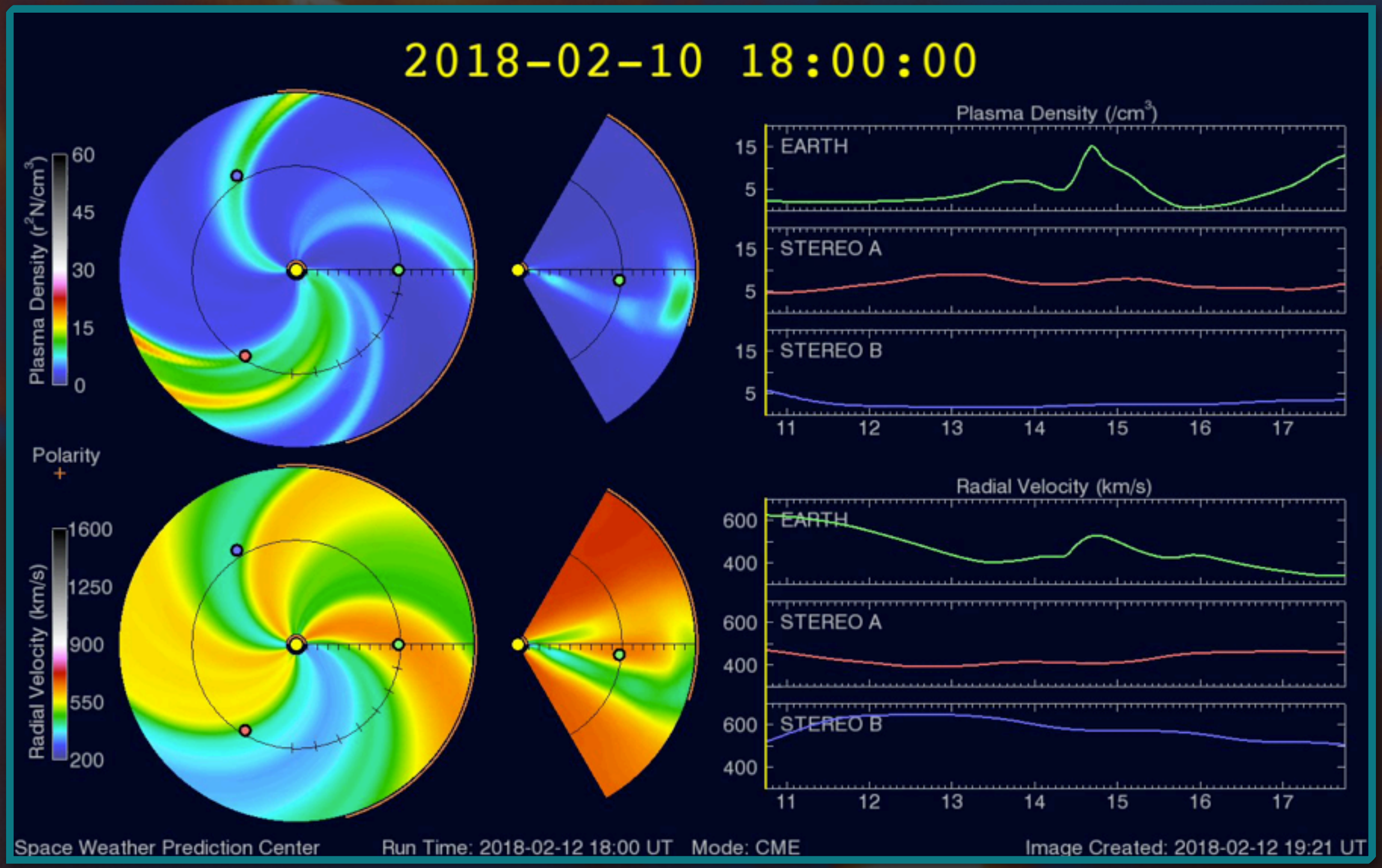






Source: George Millward, NOAA SWPC

PRODUCTS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Plasma Density (/cm3)
EARTH
STEREO A
STEREO B
Plasma Density (r2N/cm3)
60
45
30
15
0
Polarity
+
Radial Velocity (km/s)
1600
1250
900
550
200
Radial Velocity (km/s)
600
400
11
12
13
14
15
16
17
Space Weather Prediction Center
Run Time: 2018-02-12 18:00 UT
Mode: CME
Image Created: 2018-02-12 19:21 UT

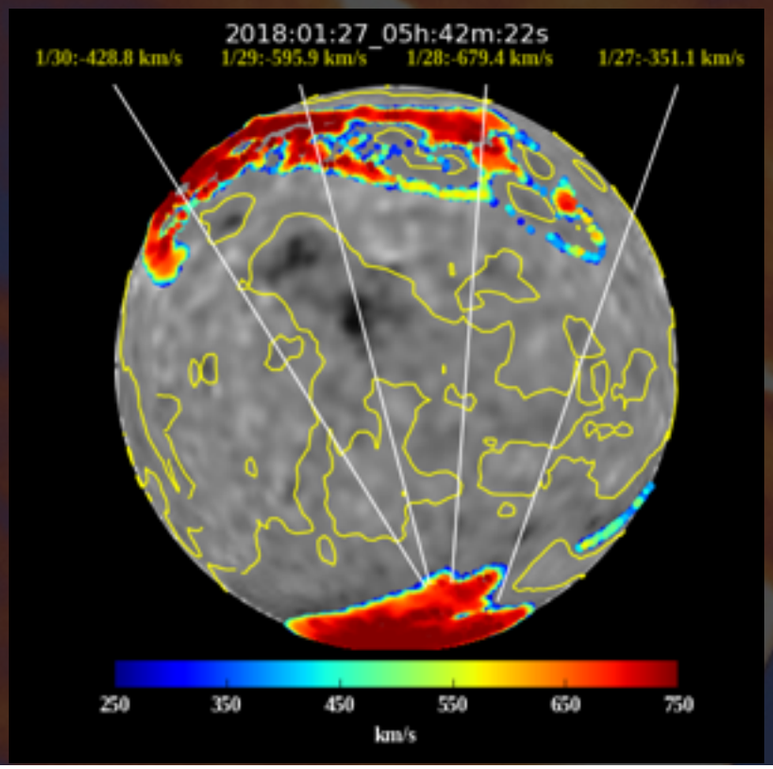
PHOTOSPHERIC INPUTS / CME CHARACTERIZATION

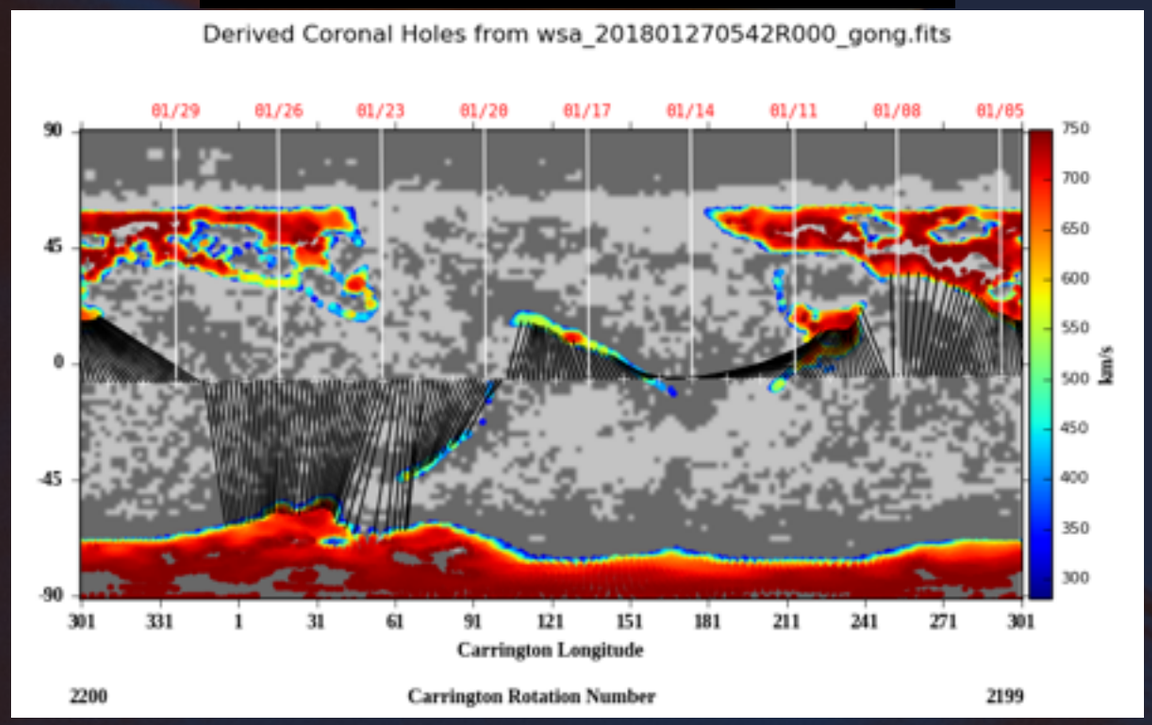
- Static synoptic map:
  - ➡ no dynamic evolution of solar surface during model run
  - ➡ stale far side observations
- Ejecta contains no magnetic structure:
  - ➡ magnetic pressure replaced by enhanced density/temperature
  - ➡ uniform density enhancement
- Inaccuracies in modeling:
  - ➡ CME characterization
  - ➡ 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

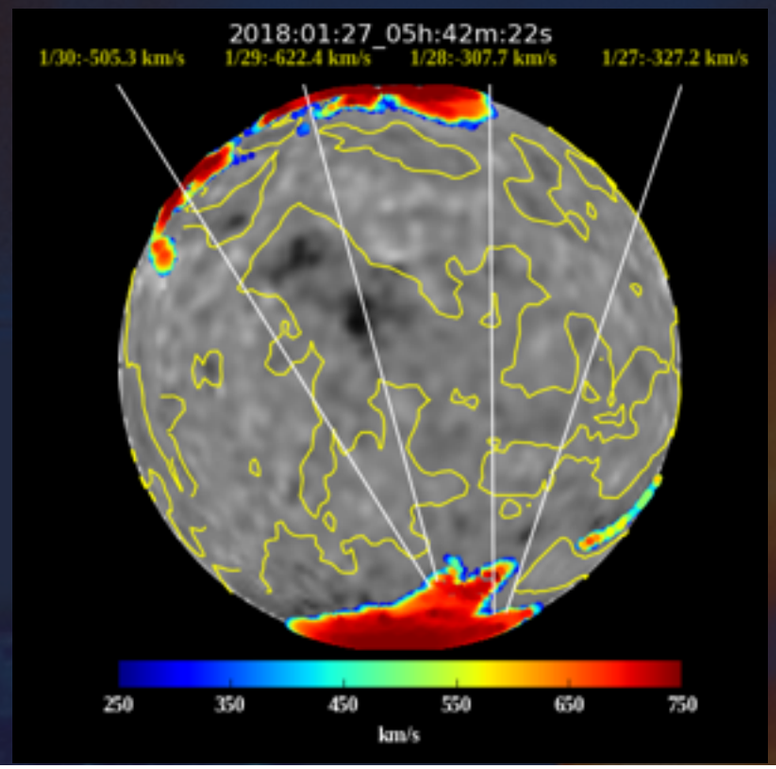
The End

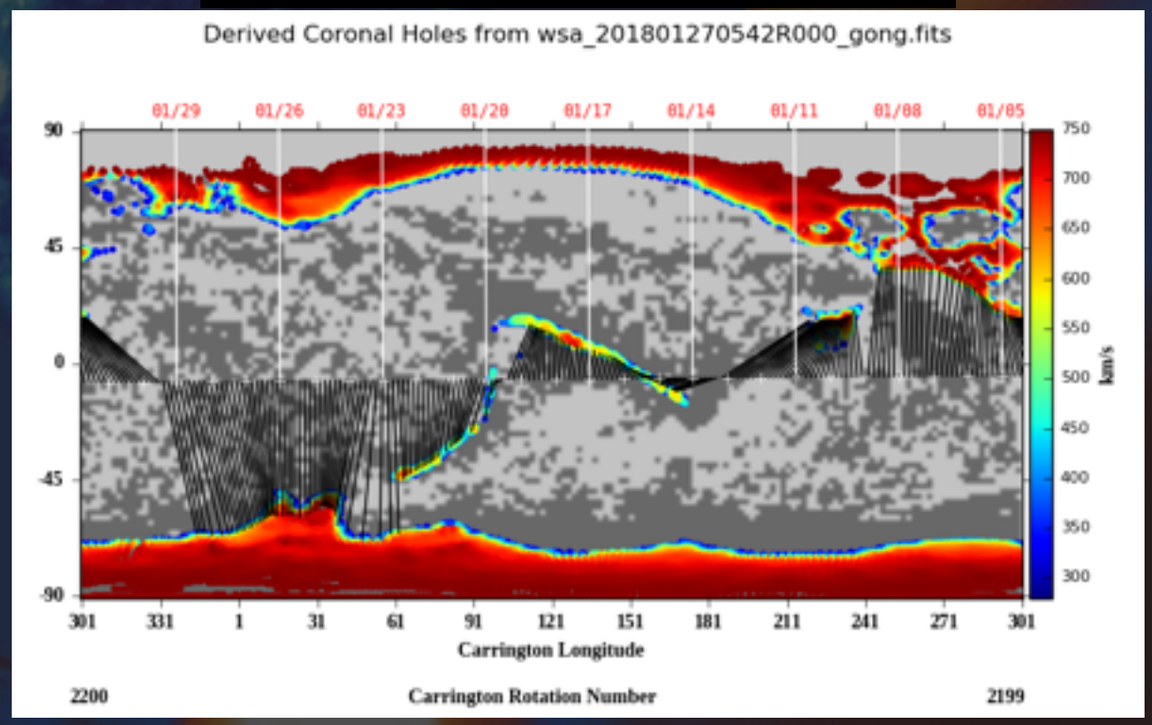
UNCORRECTED (GONGB)





CORRECTED (GONGZ)





WSA-ENLIL ENHANCEMENT: MOVE TO ZERO-POINT CORRECTED