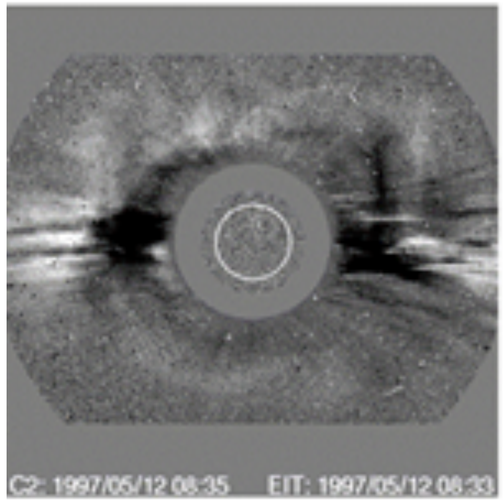
Integrated Real-Time Modeling System for Heliospheric Forecasting

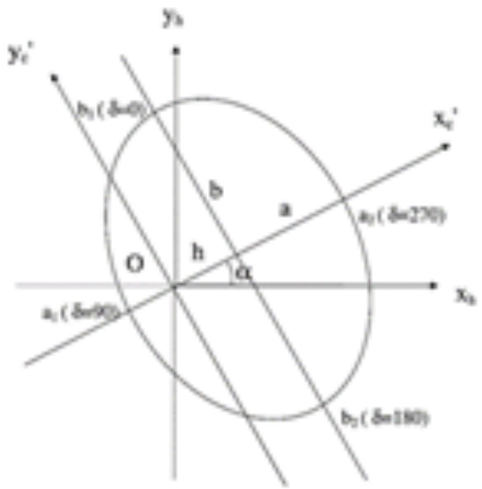
Dusan Odstrcil (PI) — George Mason University & NASA/GSFC
Lan Jian (Co-I) — University of Maryland College Park & NASA/GSFC
Janet G. Luhmann (Co-I) — University of California at Berkeley
and the CCMC Modelers Support Team

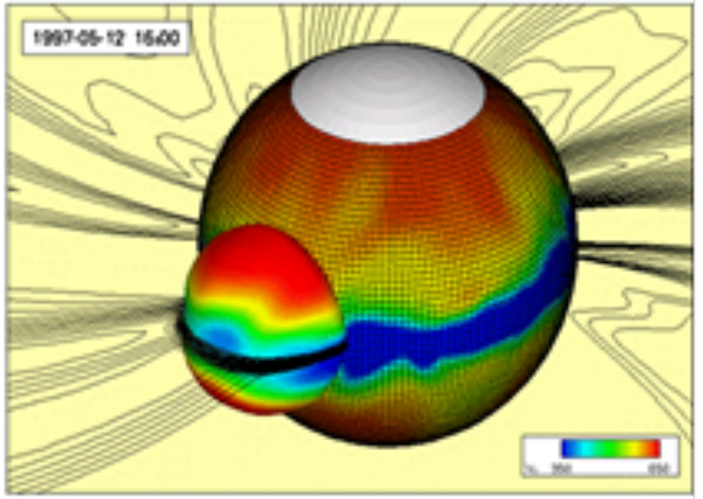
- Introduction
- Improvements in Background Solar Wind Modeling
- Improvements in Launching Transient Disturbances
- Application of Synthetic White-Light Imaging
- Prediction of the Long-Duration Solar Energetic Particles (SEPs) Events
- Using IPS Data to Drive Heliospheric Predictions
- Summary

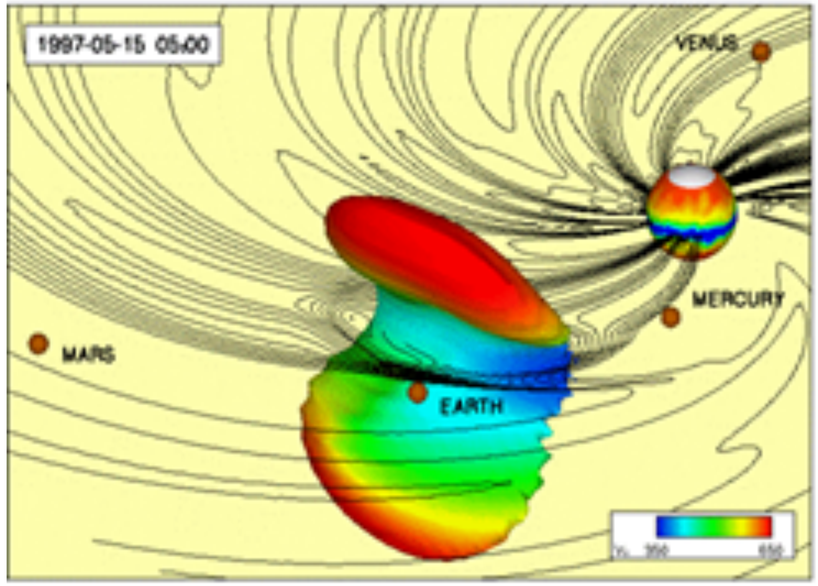
Acknowledgments: This work has been supported by NASA+NSF/LWS-SC Program and also by AFOSR and NOAA/SWPC

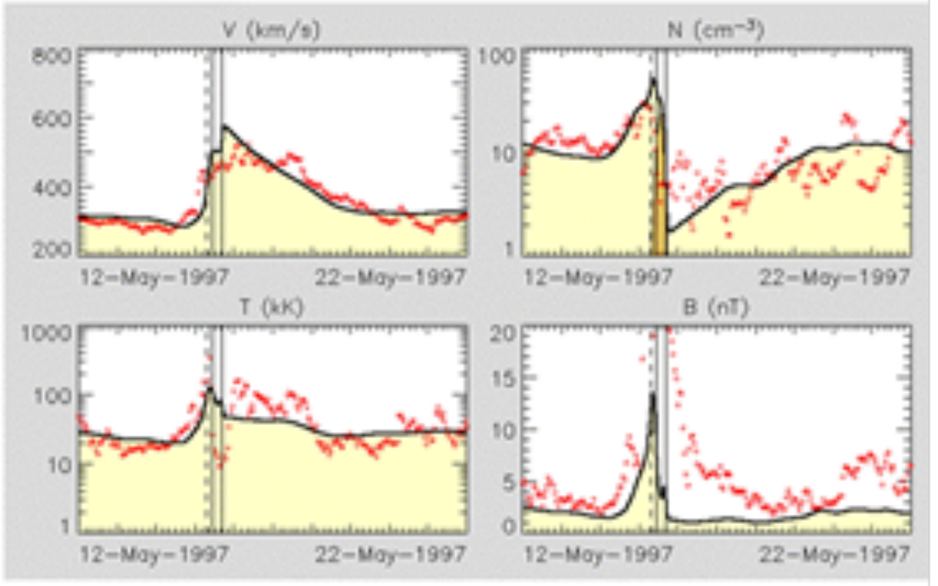
WSA-ENLIL-Cone — Operational Predictions of Heliospheric Disturbances











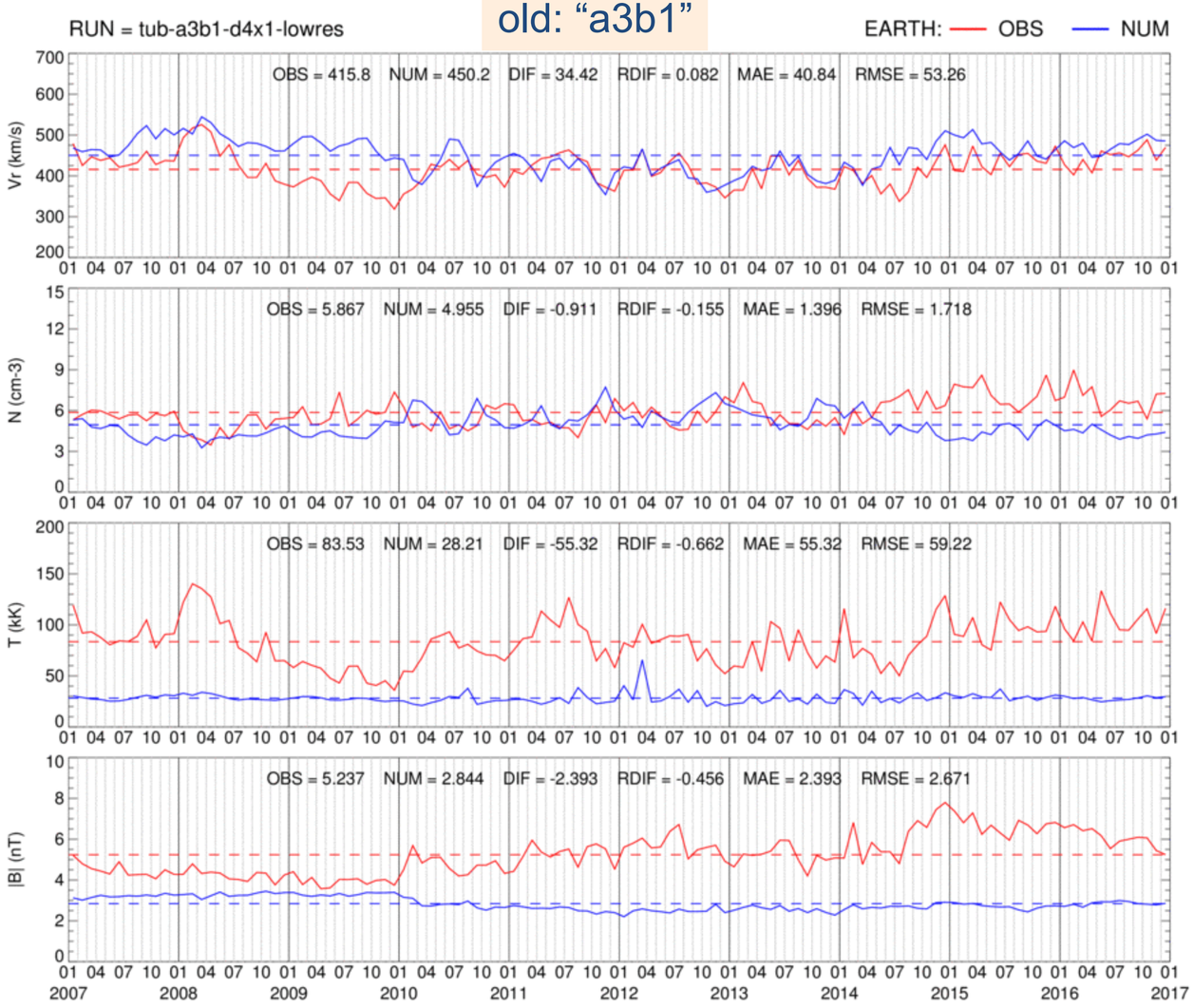
- Observationally driven, near-real time, “hybrid” modeling system for heliospheric space weather
- Routine simulation of co-rotating streams and CMEs, event-by-event, much faster than real-time
- Used at NASA/CCMC, NOAA/SWPC, UK Met Office, and Korean Space Weather Center

Model Free Parameters — Background Solar Wind

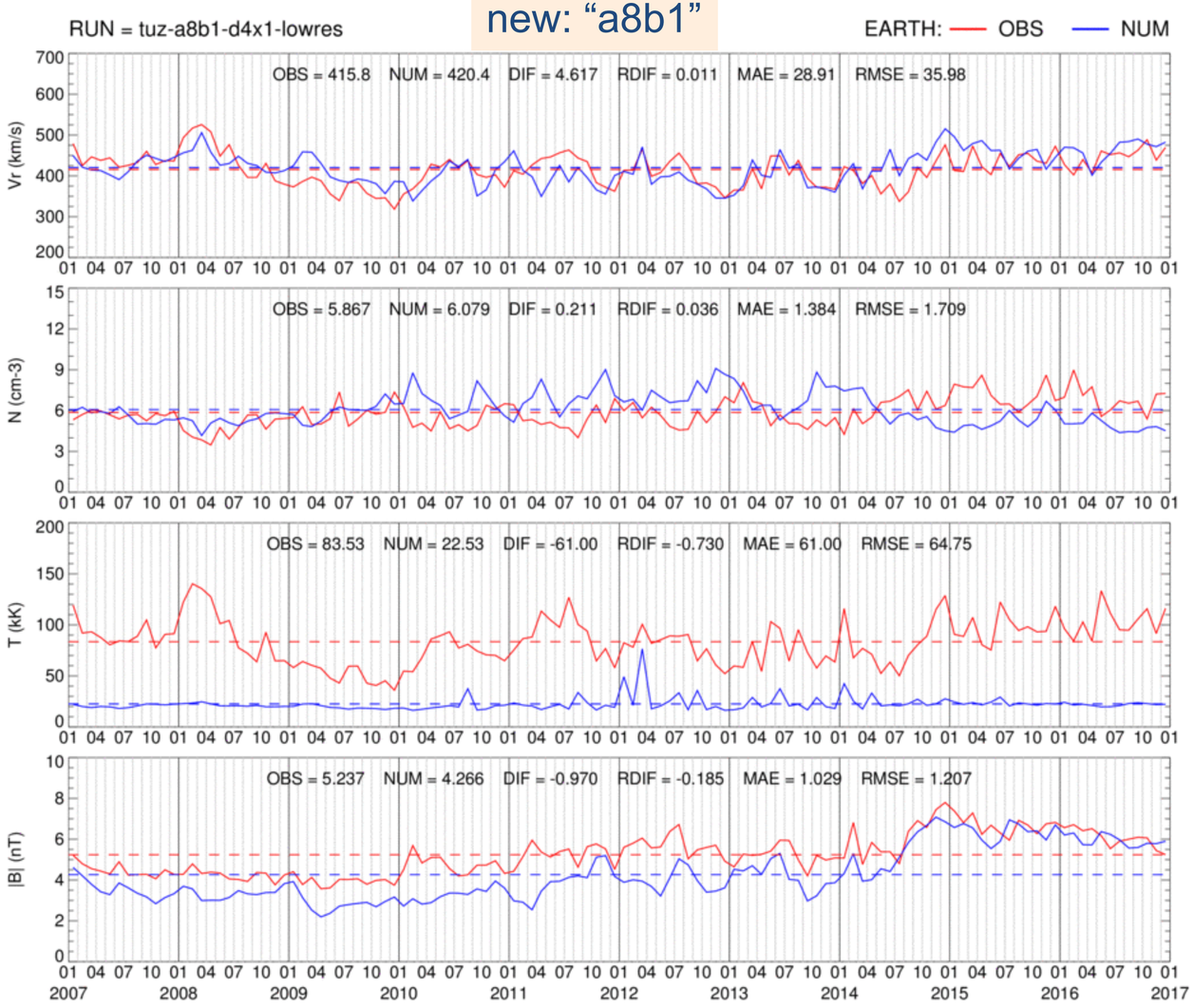
Parameter	a3b1	a6b1	a8b1	Description
bfast	300	350	500	dial magnetic field of fast streaRam (nT)
bslow	0	0	0	Radial magnetic field of slow stream (nT)
bmean	0	0	400	Radial magnetic field of mean stream (nT)
bscl	4	4	5	Magnetic field scaling factor
dfast	200	125	300	Number density of fast stream (cm-3)
dslow	2000	4000	5000	Number density of slow stream (cm-3)
dmean	0	0	500	Number density of mean stream (cm-3)
tfast	0.8	1.5	1.2	Mean temperature of fast stream (MK)
tslow	0.1	0.1	0.1	Mean temperature of slow stream (MK)
tmean	0	0	0.3	Mean temperature of mean stream (MK)
vfast	675	700	700	Radial flow velocity of fast stream (km/s)
vslow	225	200	200	Radial flow velocity of slow stereo (km/s)
vrfast	25	25	20	Reduction of the maximum flow velocity (km/s)
vrslow	25	75	50	Reduction of the minimum flow velocity (km/s)
shift	8	9	8	Azimuthal shift at the inner boundary (deg)
nshift	1	1	1	Azimuthal shift at the inner boundary (0-3)
alpha	0.05	0.05	0.05	Fraction of alpha particles (rel. to protons)
dvexp	2	2	2	Exponent in N*V^dvexp-const condition
nptot	0	0	0	0 (1) if P_the (P_tot) balance at boundary
nbrad	3	1	1	Magnetic field correction

Model Free Parameters — Background Solar Wind — Calibration

old: “a3b1”



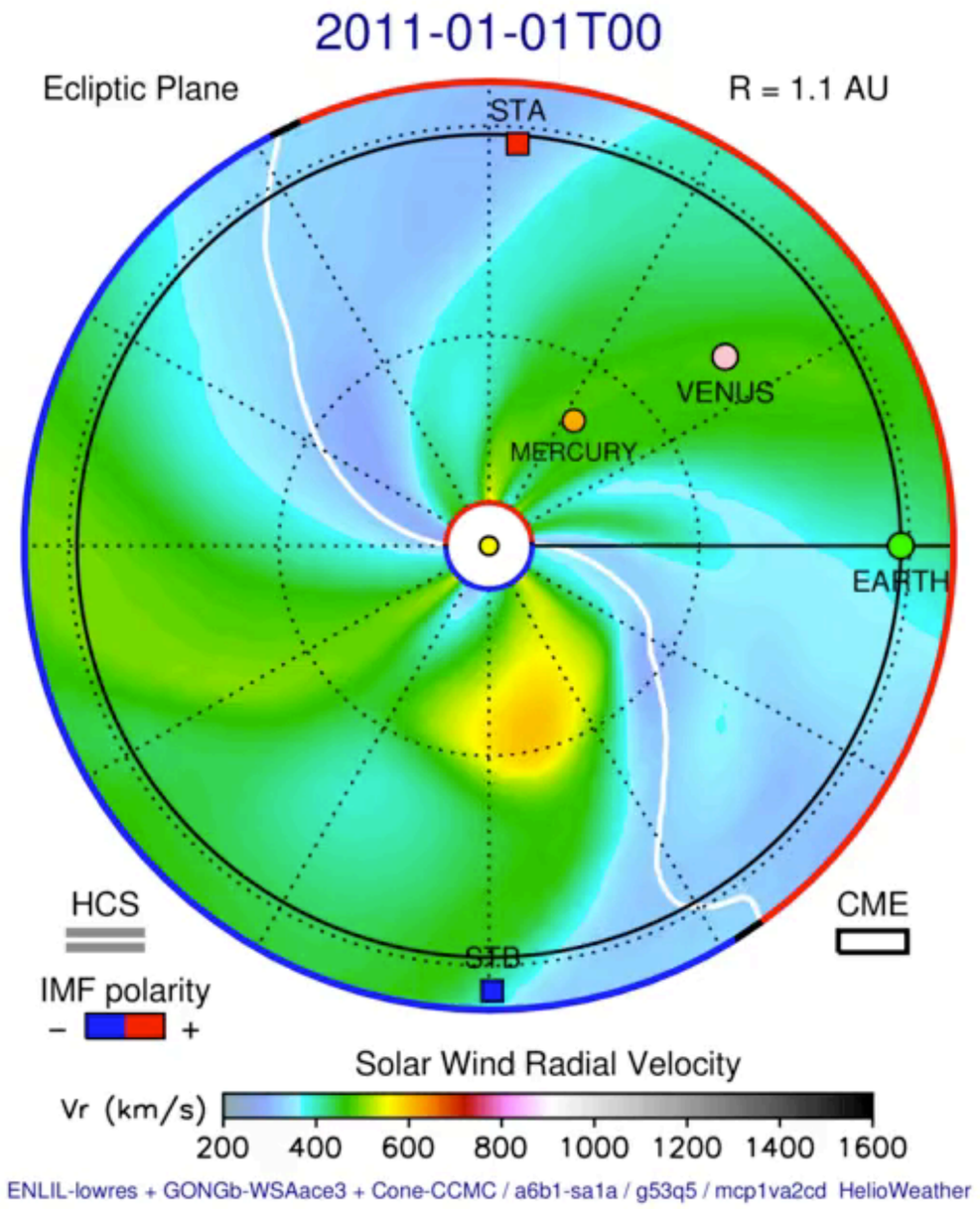
new: “a8b1”



- Delivered: beginning of the solar cycle with limited calibration
- Motivation: ensure robustness & reasonable accuracy during the upcoming solar cycle maximum

- Revised calibration with 2007-2016 (WSA) and 2010-2016 (CME-“cone”) data & larger robustness experience
- Using “mrzqs” instead of “mrbqs” GONG data

WSA-ENLIL-Cone — All CMEs in 2007-2016 — Heliospheric Disturbances



Simulation:

- Sequence of 1826 WSA daily-updated (DU) maps provides radial components of the solar wind velocity and interplanetary magnetic field
- All 1756 CMEs fitted by CCMC/SWRC provides geometric and kinematic parameters to lunch spherical hydrodynamic

Visualization:

- Solar wind velocity at ecliptic (color scaled) together with IMF lines, heliospheric current sheet, IMF polarity, and CME outlines

Validation Study — ICME Arrival Time in 2010-2016

	Observed	Captured	Rate of Hits (%)	Rate of Misses (%)	Simulated	Rate of Correct Alarms (%)	Rate of False Alarms (%)	Absoulte Offset of Arrival Time (hr)
ICME	170	60	35.3	64.7	114	52.6	47.4	11.5±1.4
MC	105	47	44.8	55.2	N/A	N/A	N/A	13.4±1.8
ICME with shock	99	46	46.5	53.5	N/A	N/A	N/A	9.2±1.2

- All CMEs listed in the DONKI “best fit” catalog in 2010-2016 launched into old “a3b1” (left) and new “a8b1” (right) background
- New background provides slight improvement in the prediction accuracy (*see Lan Jian’s talk for details*)
- NOTE: Operational CME fitting realized by various forecasters with various experience and various tools

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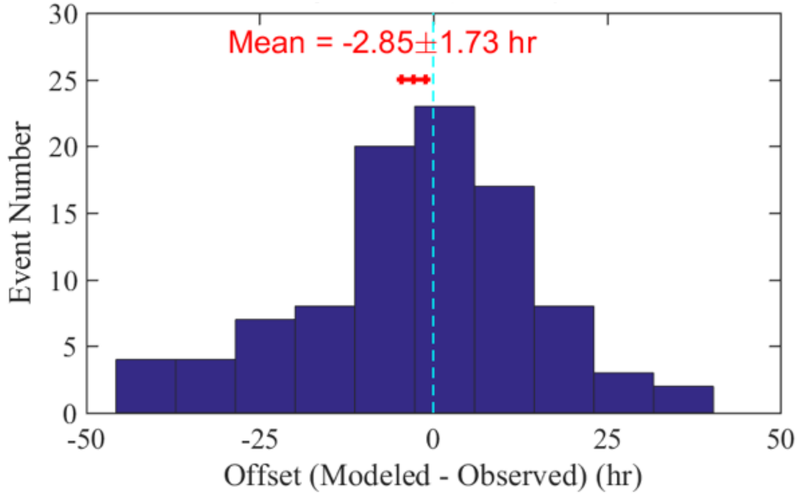

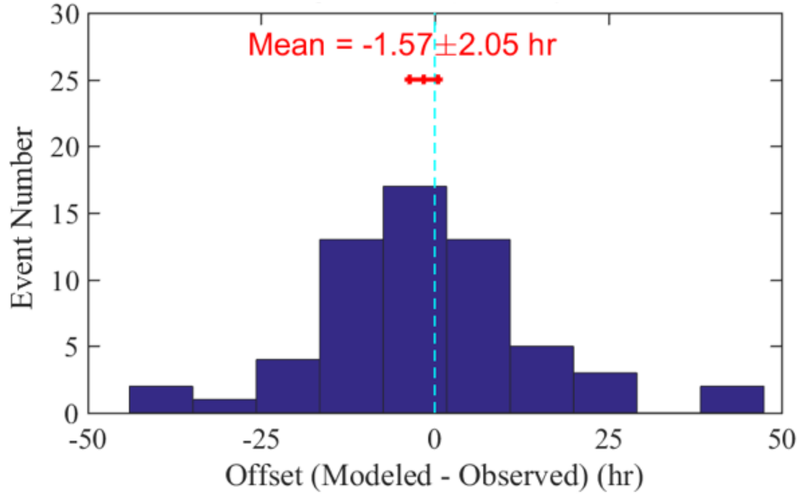

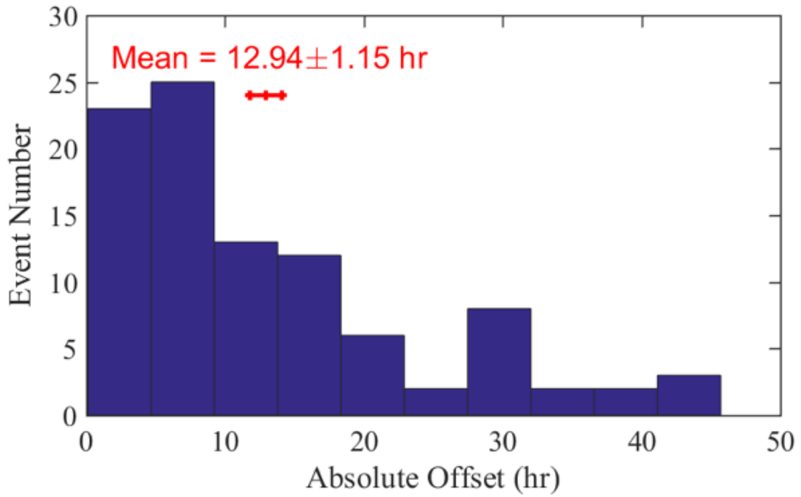

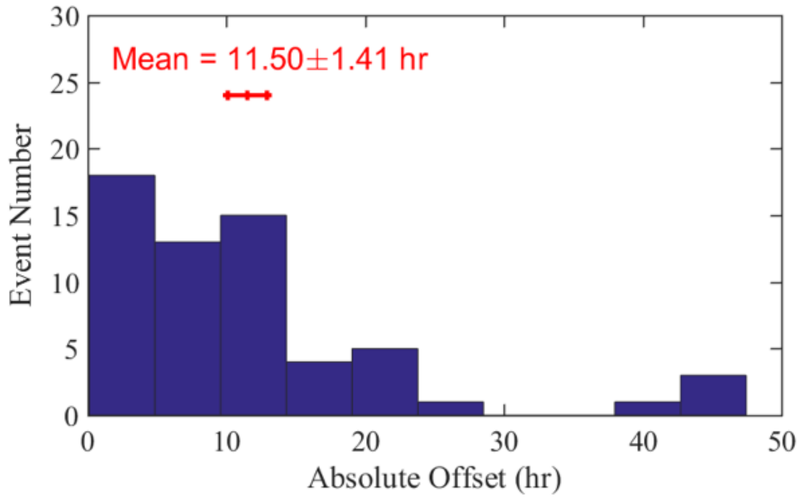

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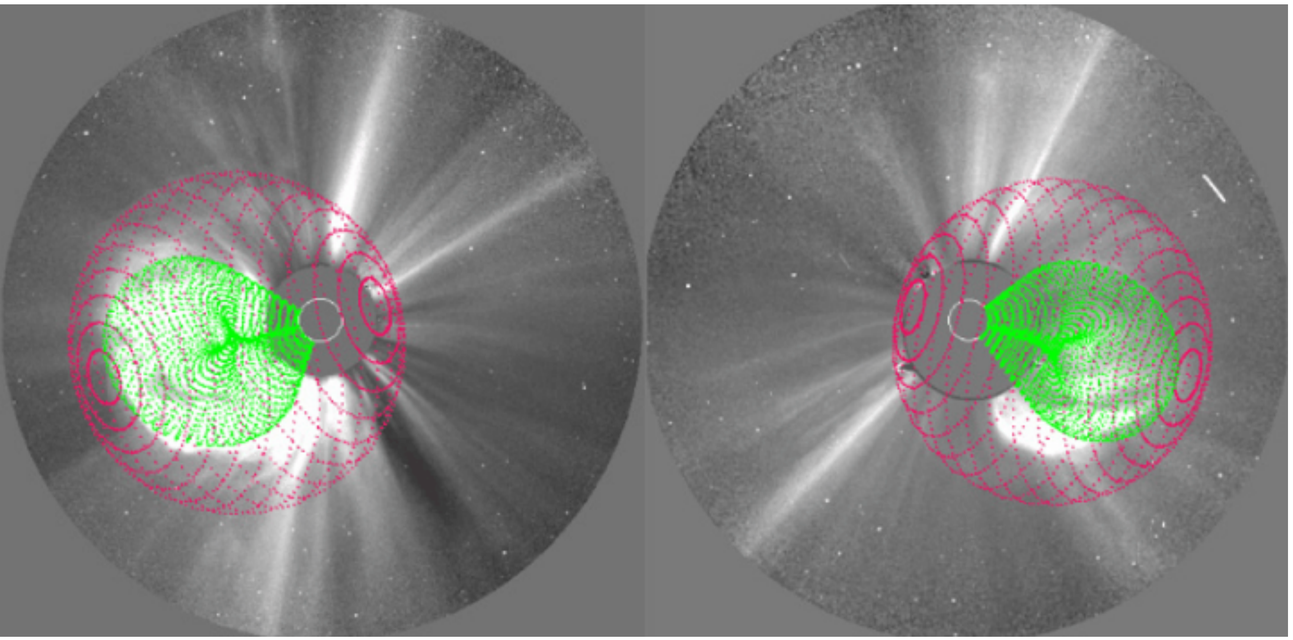
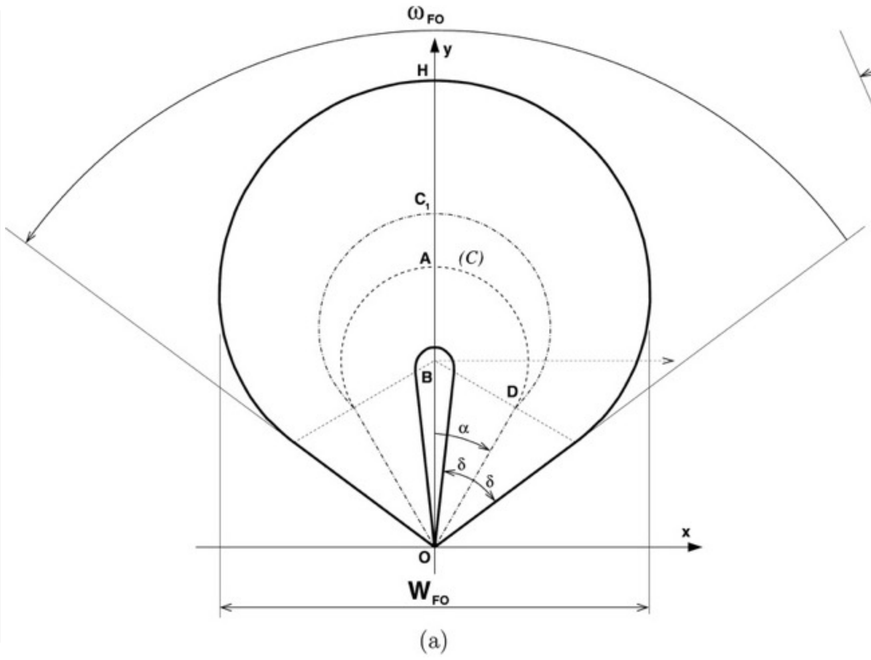
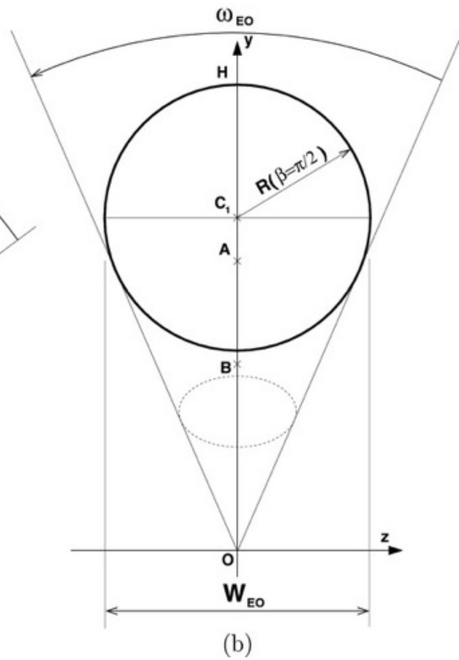
Launching Hydrodynamic Ejecta — Various Approaches & Tools



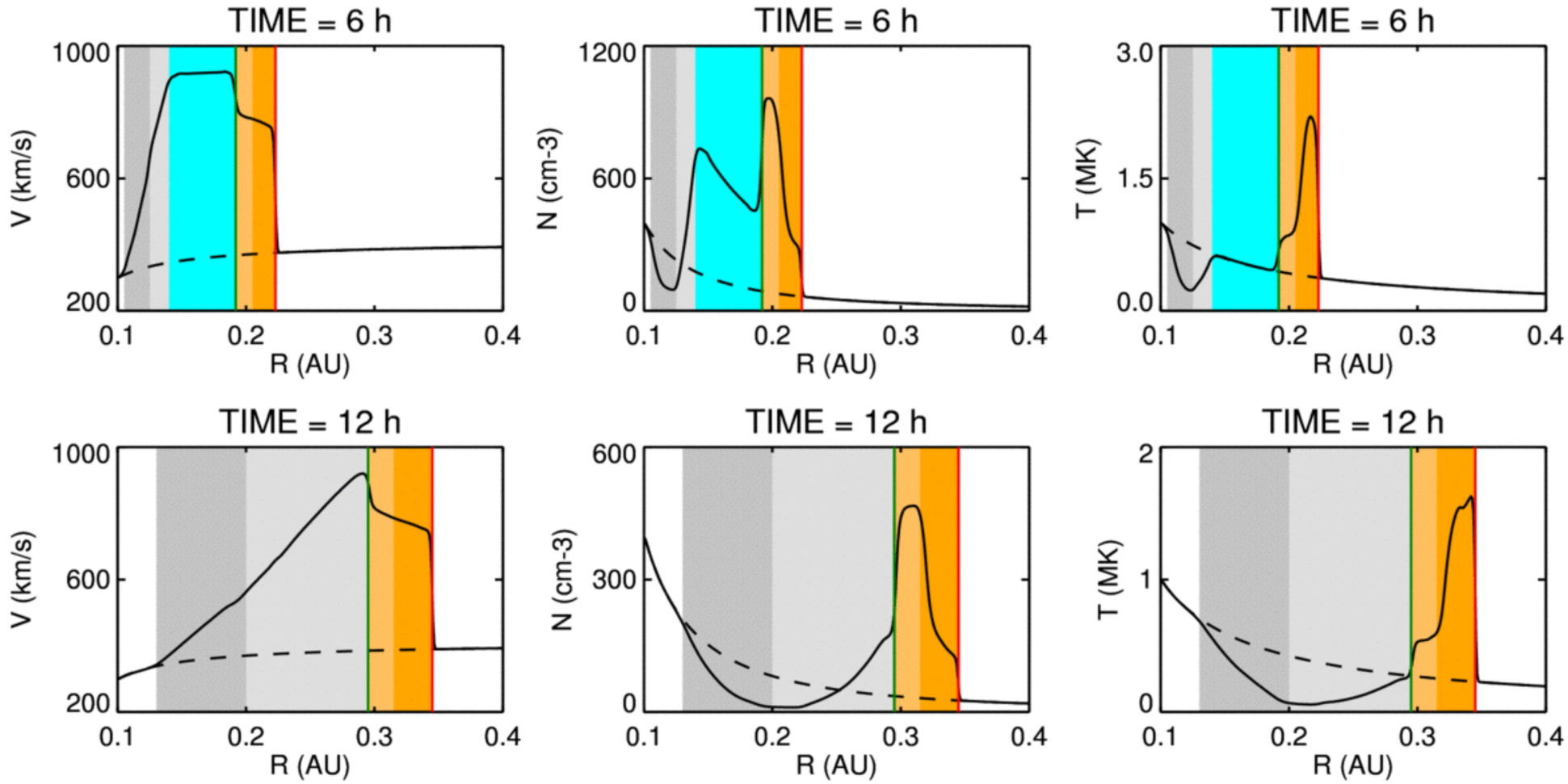




Driver vs compressive waves/shocks
(e.g., *Vourlidas, Zhao, etc.*)

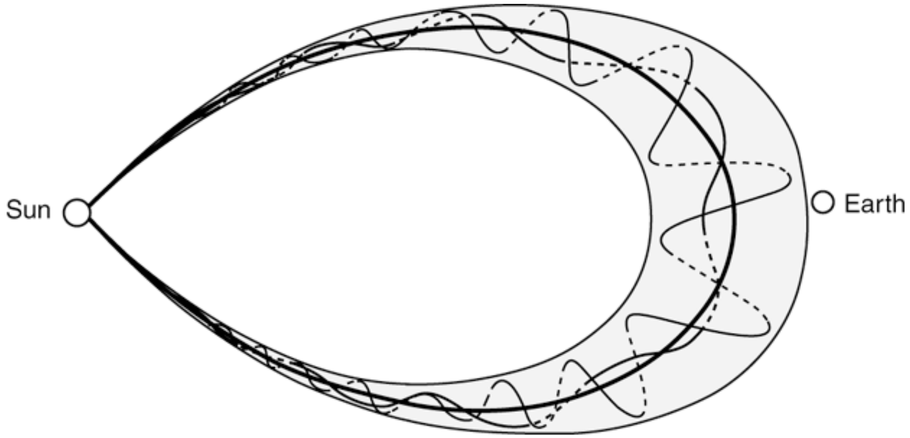
Fitting a 3-D structure of the CME (e.g., *Graduated Cylindrical Shell (GCS) model, Thernissien, 2011*)

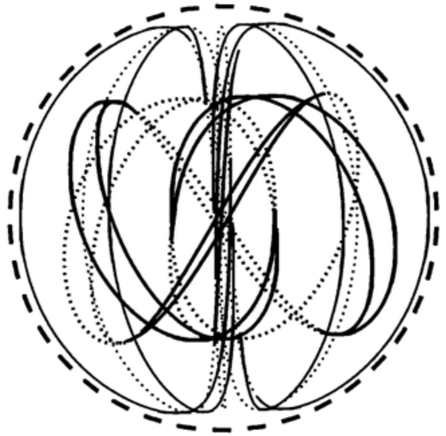
Launching Hydrodynamic Ejecta — Generation of Shocks and Rarefactions

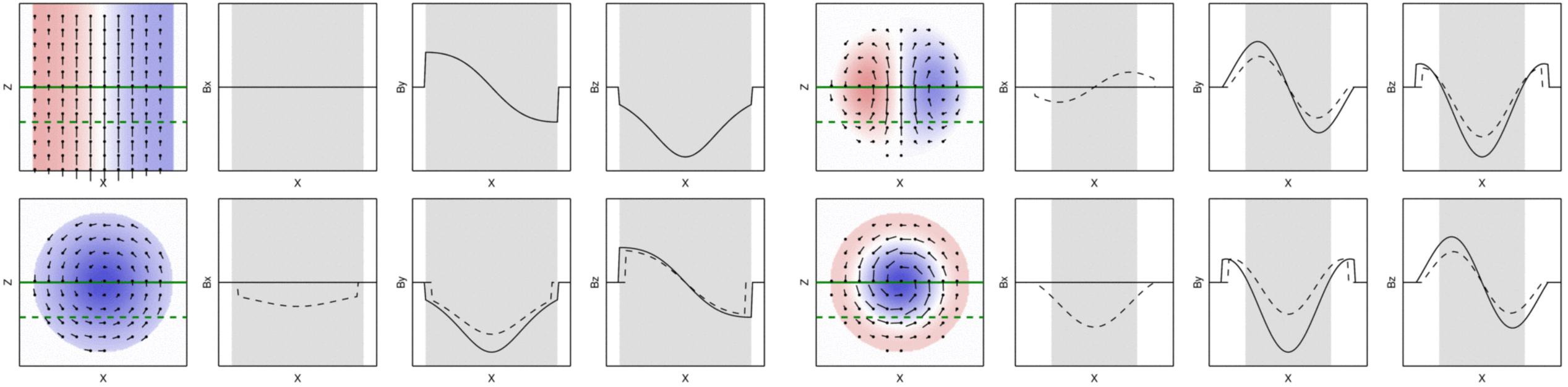


- The structures of the transient disturbance at 6 h (top) and 12 h (bottom) after the launch. The three panels (from left to right) on each row show the radial profiles of velocity, density, and temperature.
- Two shocks (forward and reverse) are generated at the leading edge of the ejecta
- Two rarefactions (forward and reverse) are generated at the trailing edge of the ejecta
- Driving momentum is reduced by a rarefaction that propagates into the ejecta

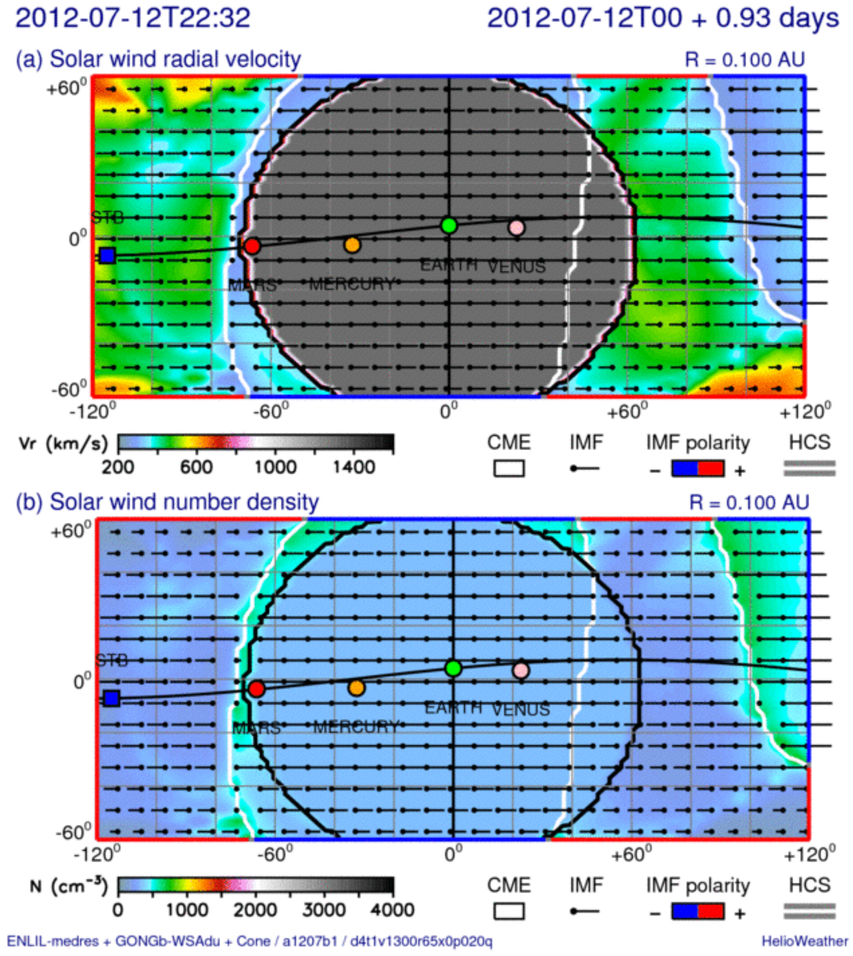
Launching Magnetic Structures — Flux-Rope vs Spheromak

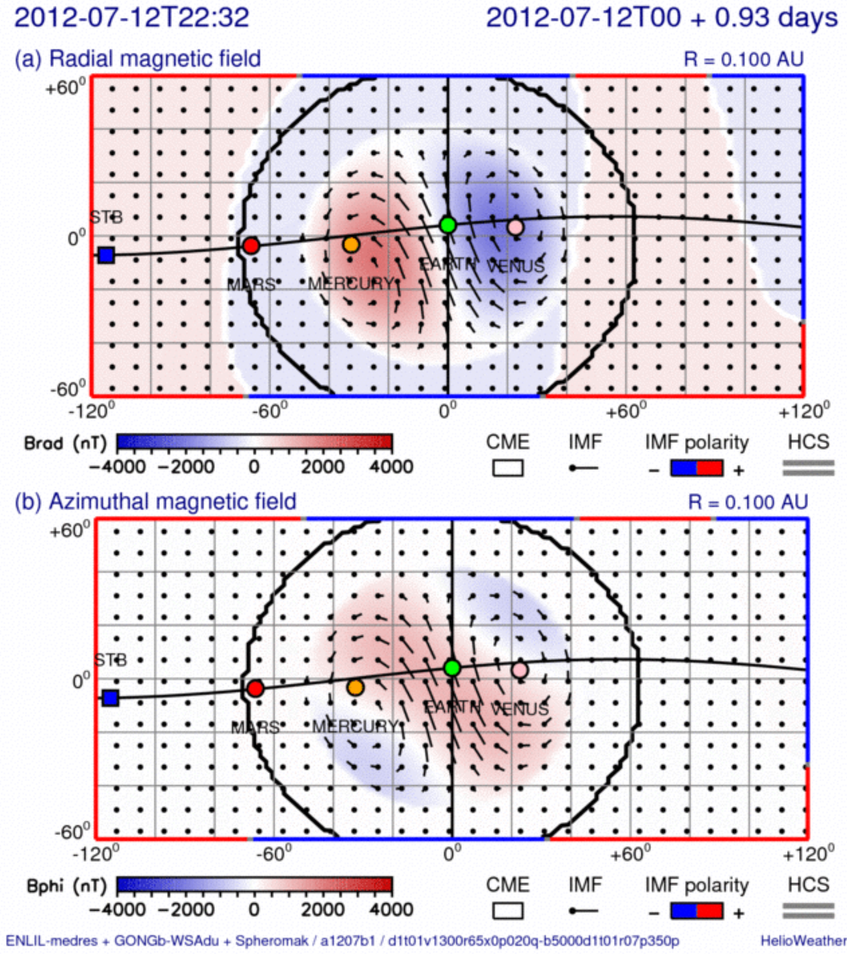






Launching a Spheromak — Boundary Conditions





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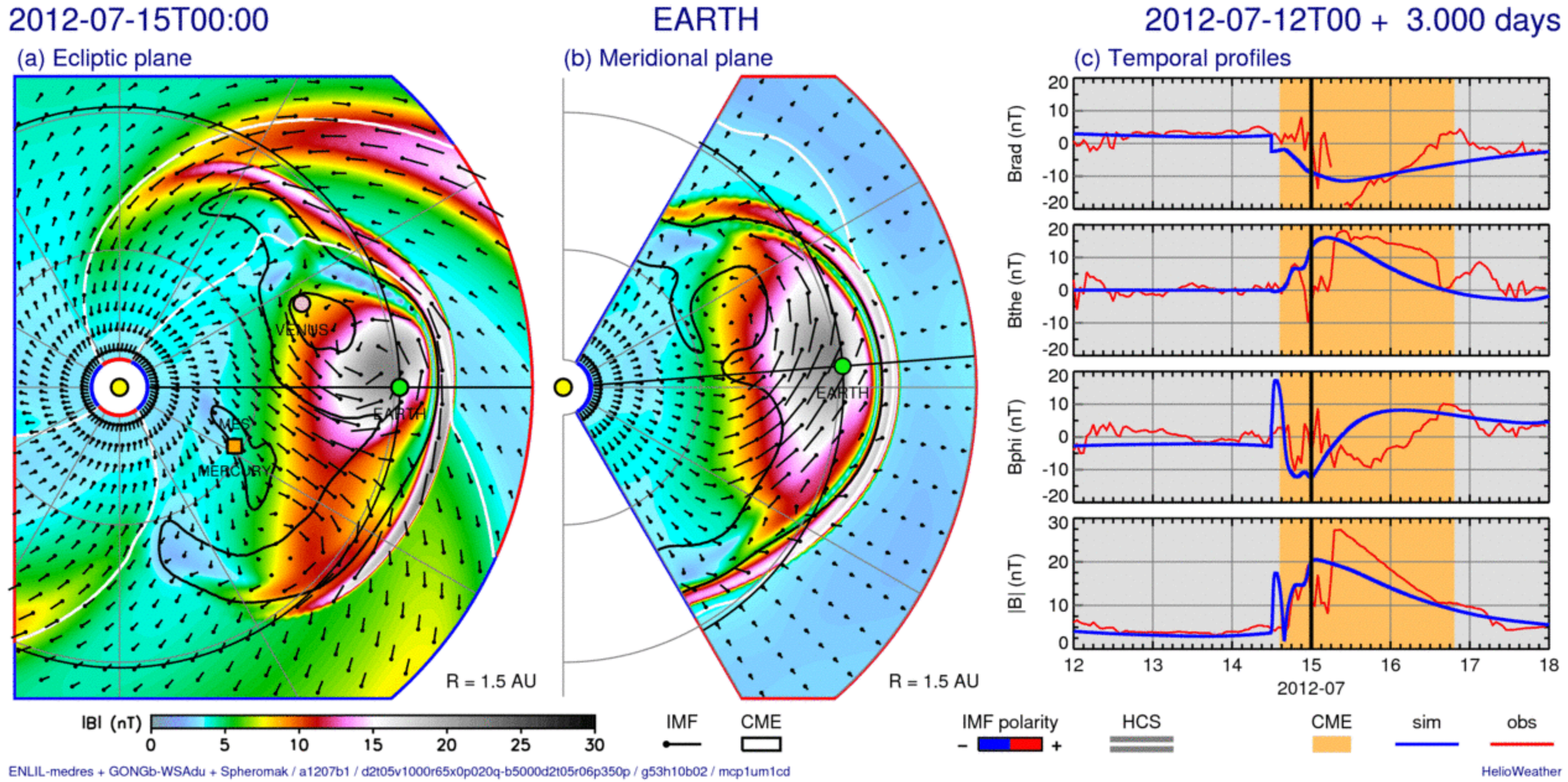
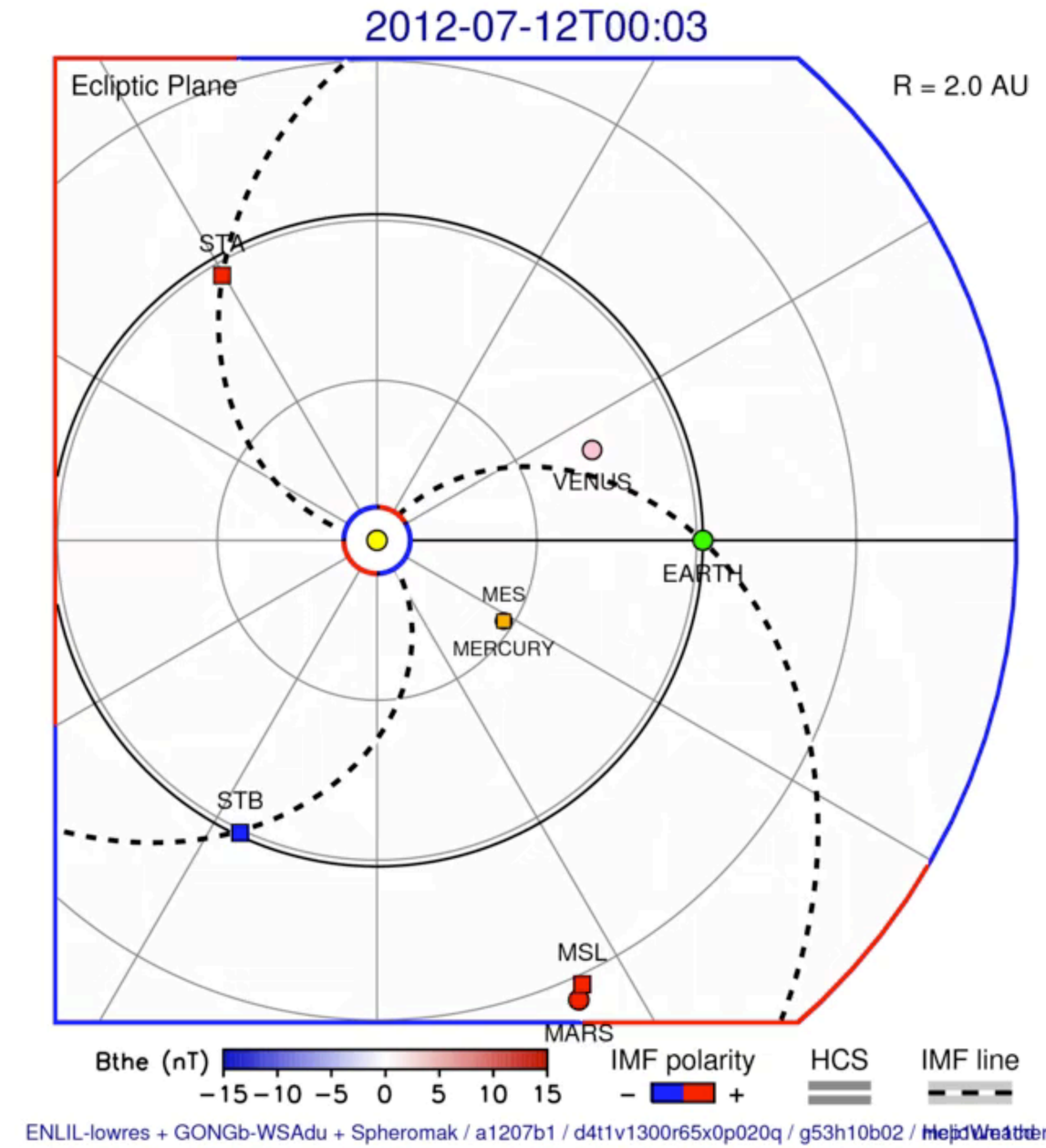
- Operational CME fitting realized by various persons with various experience and various tools

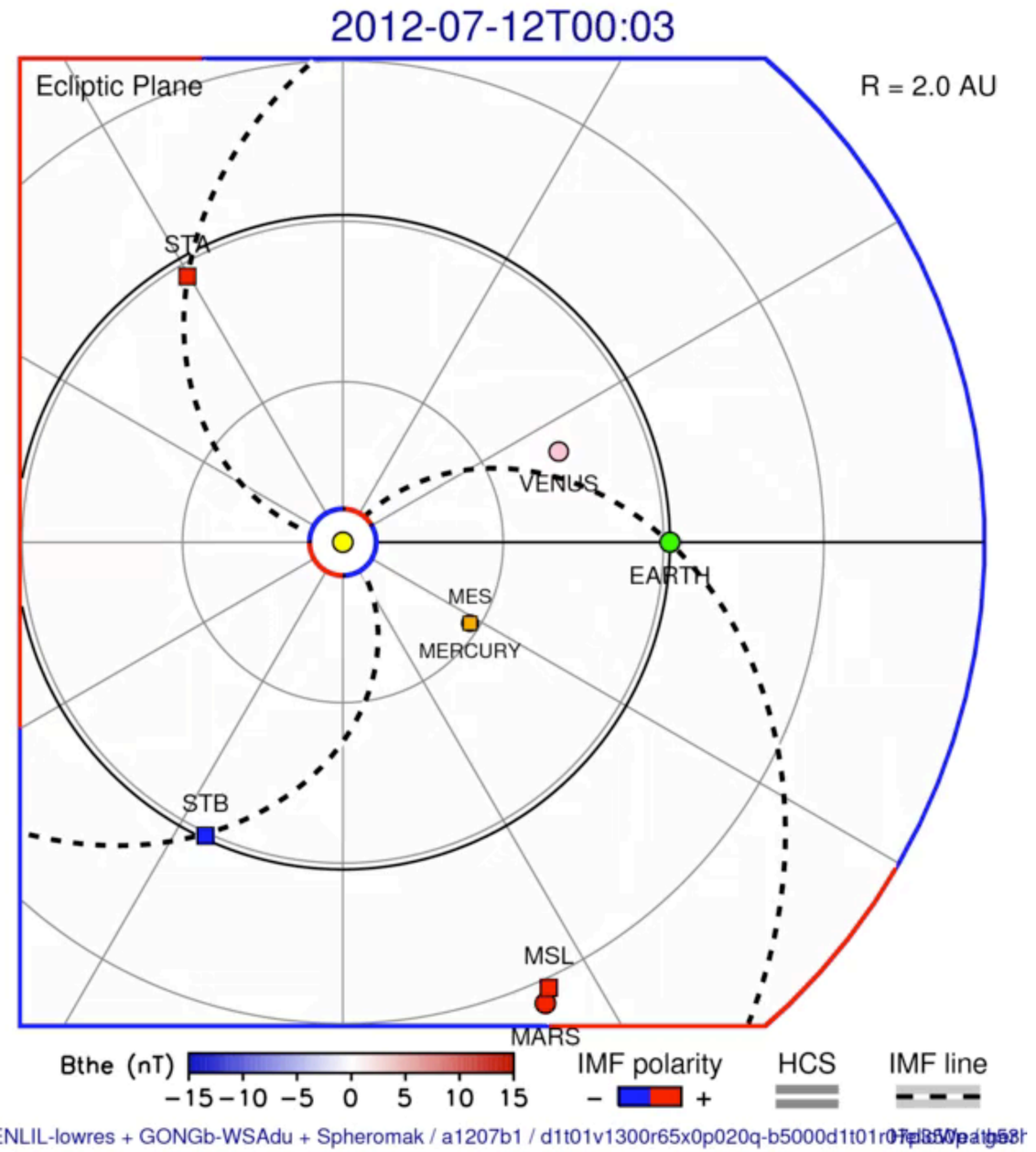
2012-07-12 CME Event — Spheromak Simulation



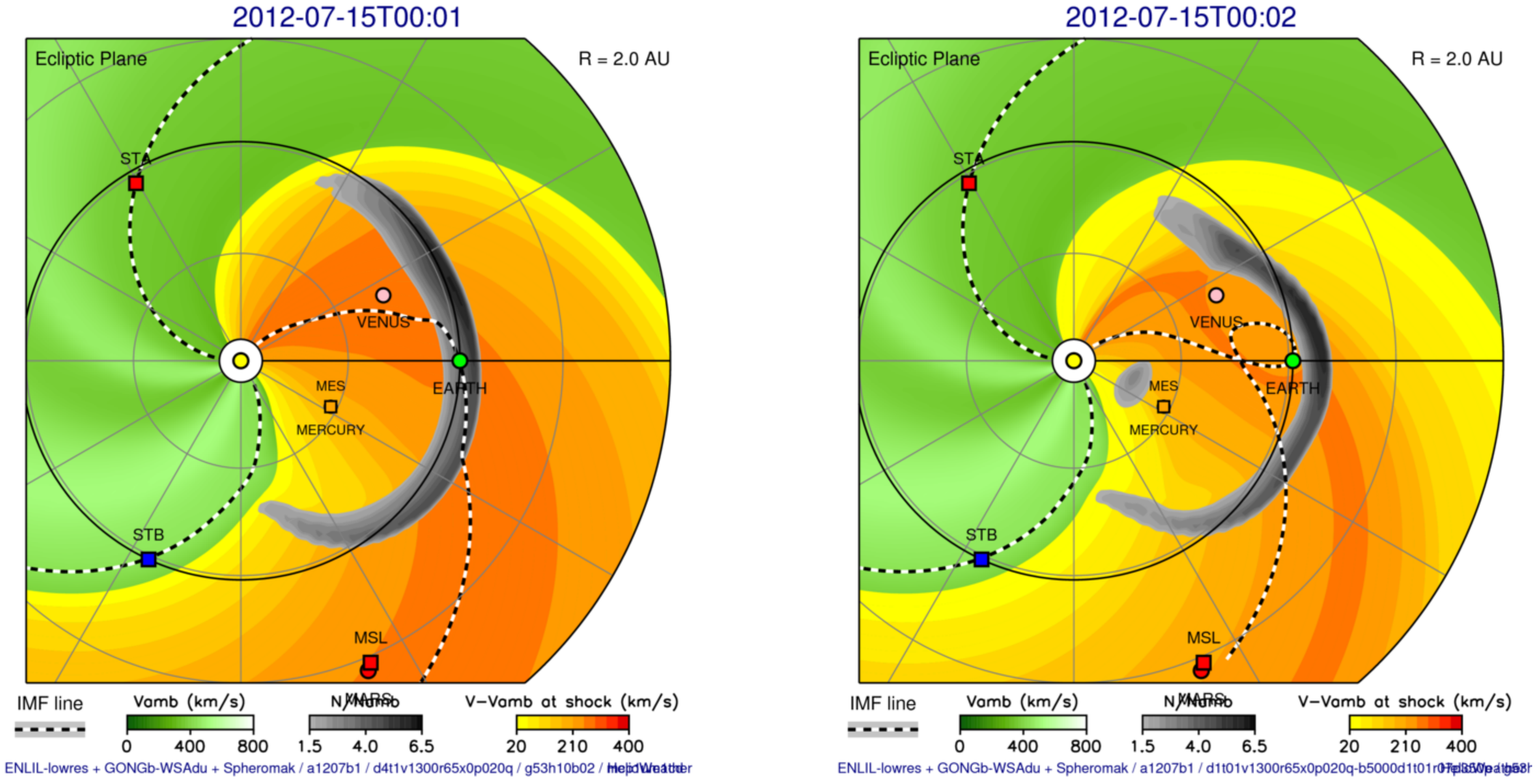
- Geometric and kinematic parameters (direction, width, and speed) from CME fitting (DONKI)
- Model-free parameters (density, temperature, magnetic field) adjusted to achieved similar arrival time at Earth as predicted by cone simulation.
- This is challenging and revision of the CME fitting & model initialization is needed

IMF Connectivity — Cone (left) vs Spheromak (right)



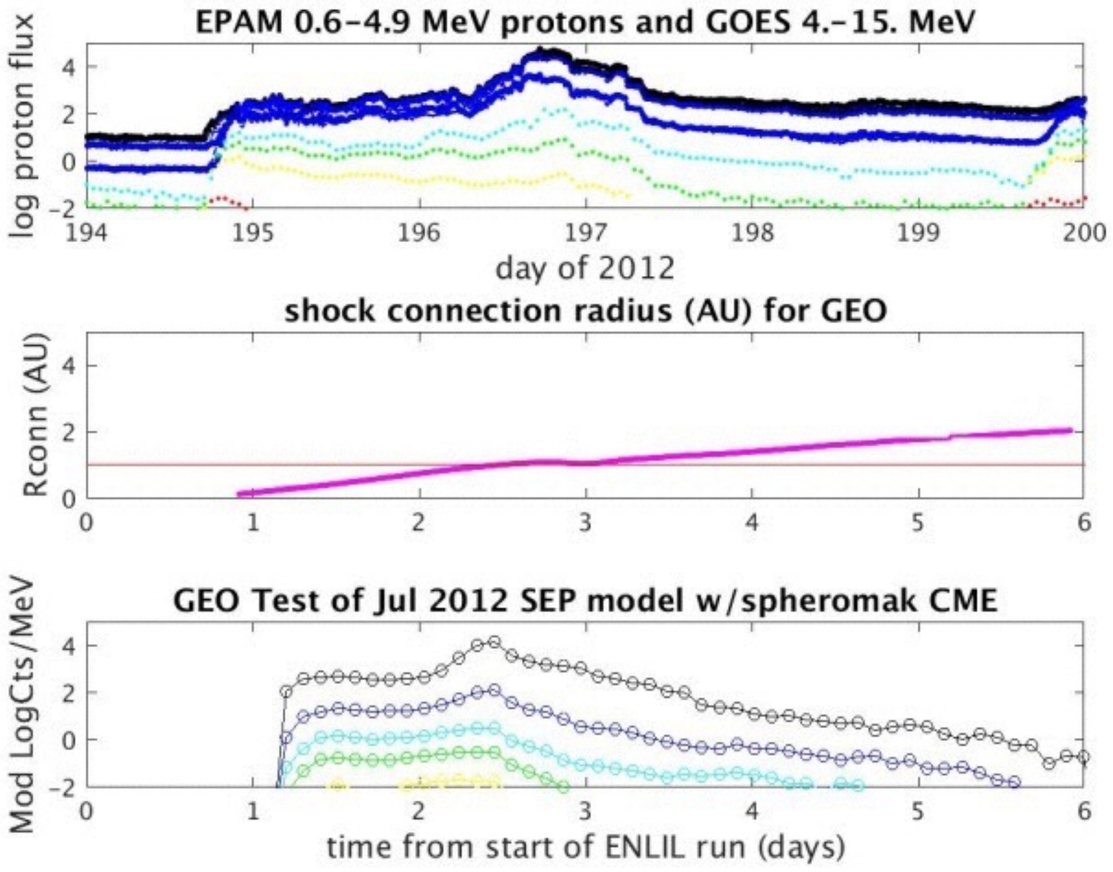


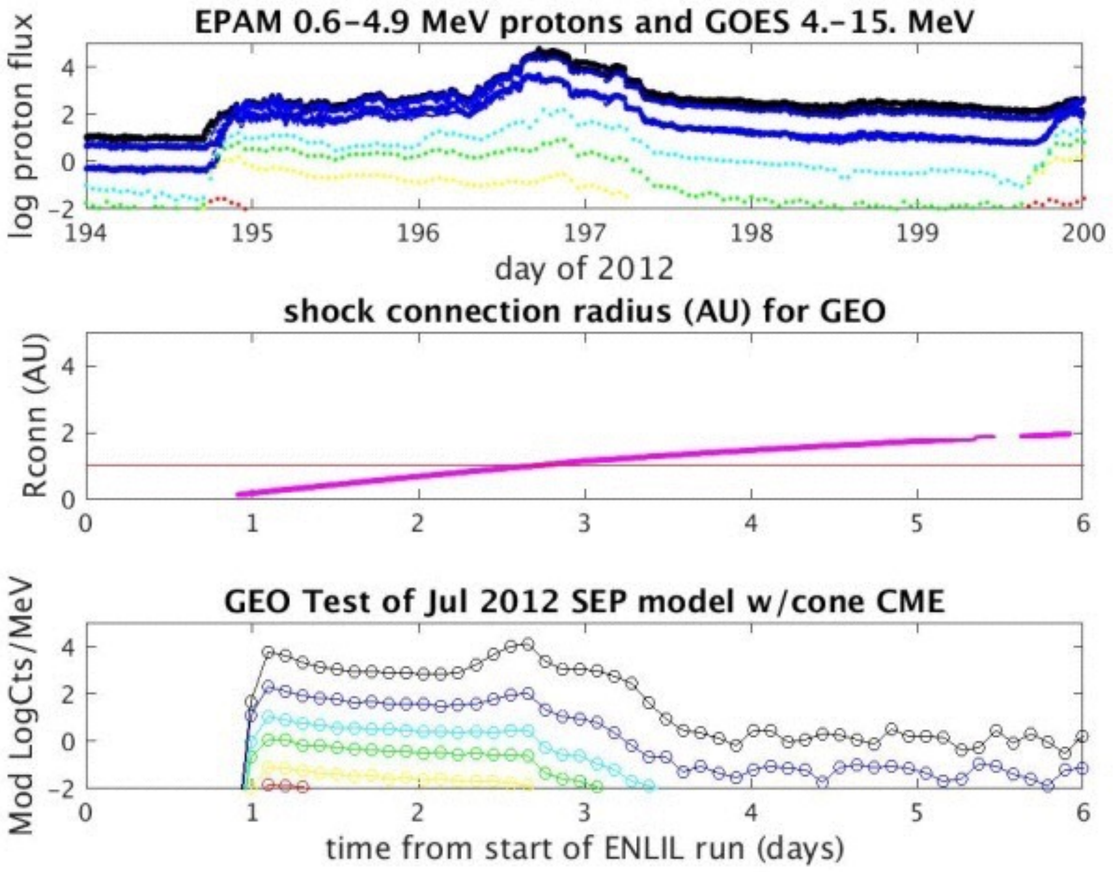
Shock Allert Prediction — Cone (left) vs Spheromak (right)



Shock-alert plot for the cone (left) and spheromak(right) simulations shows the solar wind velocity (green scale), density compression of the transient leading edge (dark-grey scale), and alert sectors colored by the shock strength (yellow-to-red), and the IMF lines passing through Earth and STEREO (dashed black lines).

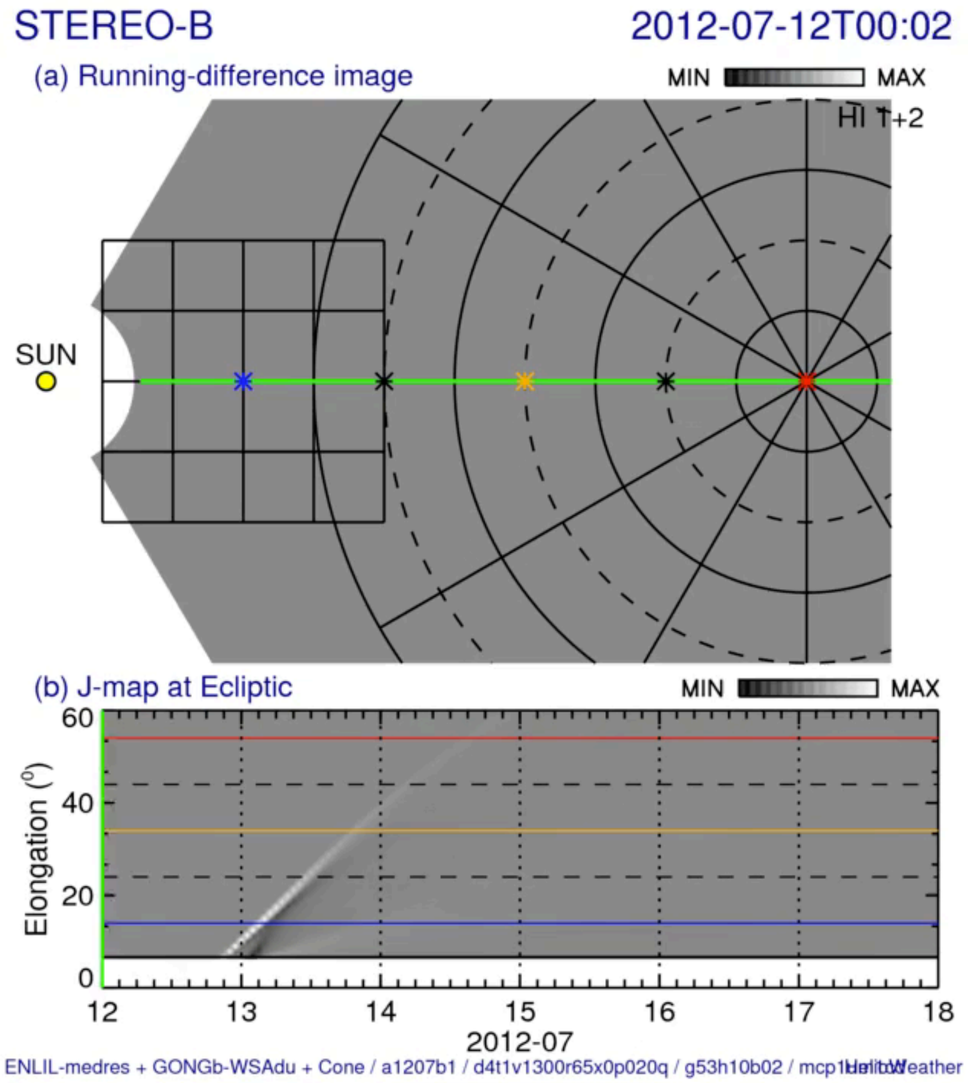
SEPMOD Predictions — Cone (left) vs Spheromak (right)

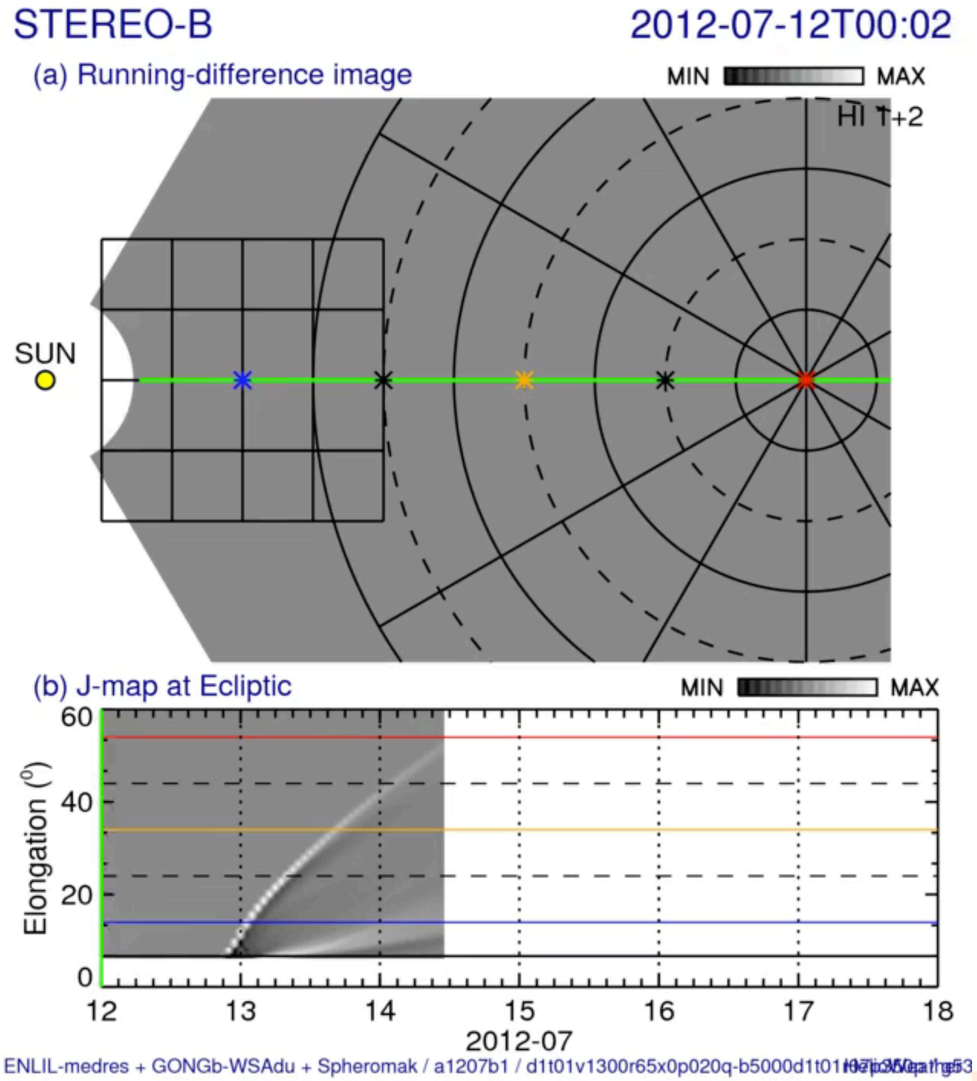




Earth-observer results of running SEPMOD on the test case of the ENLIL results with the cone (left) and without spheromak (right) launched into the heliospheric computational domain. The parameters of the spheromak were adjusted to make the shock arrival time similar, as seen in the second panels. SEP observations are shown in the top panels. Differences in the calculated SEP profiles (bottom panels) for the two ENLIL cases are subtle but significant.

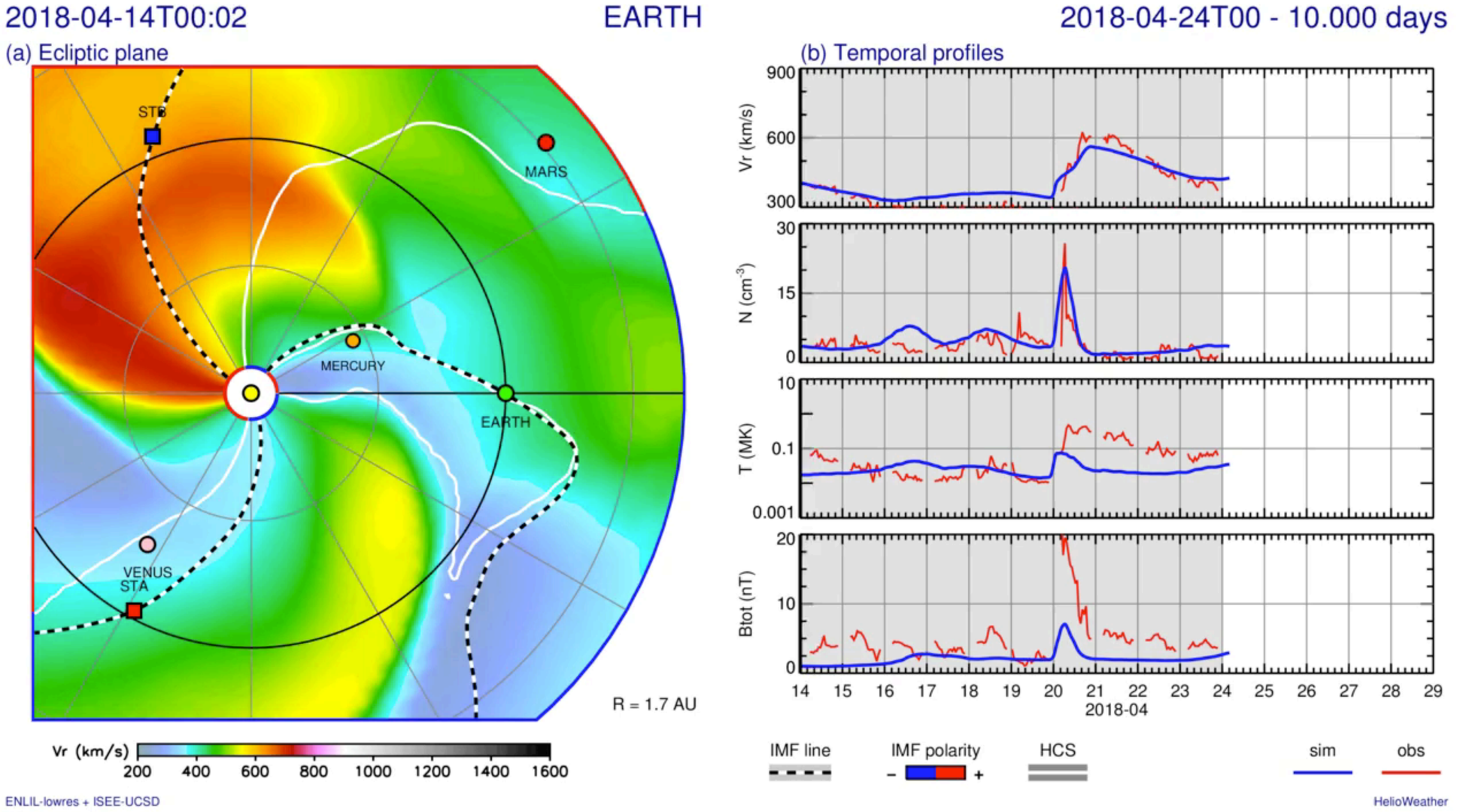
Application of Synthetic White-Light Imaging





- Remote observations by heliospheric imagers (STA & L4) can provide evaluation of various numerical predictions well before corotating and/or transient disturbances arrive at Earth
- Streams visibility can be enhanced by launching small-scale plasma “blobs”

Using IPS Data to Drive Heliospheric Predictions



- IPS observations from STELab + UCSD tomographic reconstruction — values at 0.1 AU
- Time-dependent boundary values drive ENLIL heliospheric computations
- Fully automatized alternative (backup) to coronagraph fitting — will improve with more radio arrays

Summary

- Updated WSA-ENLIL-Cone modeling system can now routinely predict:
  - ICME arrival times (ejecta and/or shock) in mid-heliosphere
  - ensemble modeling
  - evolving background solar wind
  - IMF topology and shock parameters for SEP models & alert plots
  - synthetic white-light images (for “mid-course” correction)
  - use UCSD-IPS data for alternative “backup” predictions

- We realized large-scale calibration & validation studies to evaluate new features, compare with previous versions, and with other models implemented at CCMC

- Updated WSA-ENLILCone modeling system facilitates:
  - direct comparison with remote and in-situ observations at planets and spacecraft
  - high-quality images and animations red for presentations/publications
  - scripting system to support research and prediction activities
  - supports heliospheric predictions & mission planning relevant to NASA missions

- We very appreciate collaboration with the CCMC staff that helped us to compensate the budget reduction, provided modeling support and feedback, and enhanced research and prediction applications