Improving the CME Forecasting by Heliospheric Imagery and Ensemble Modeling

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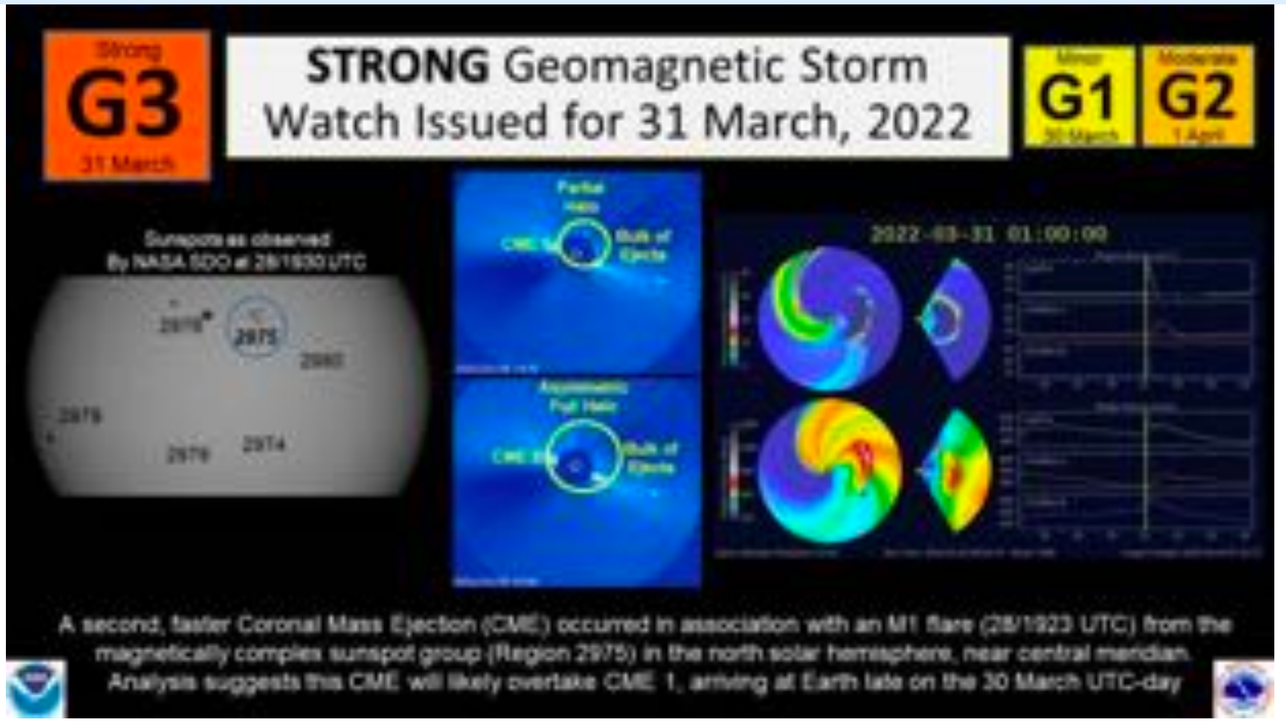
OUTLINE

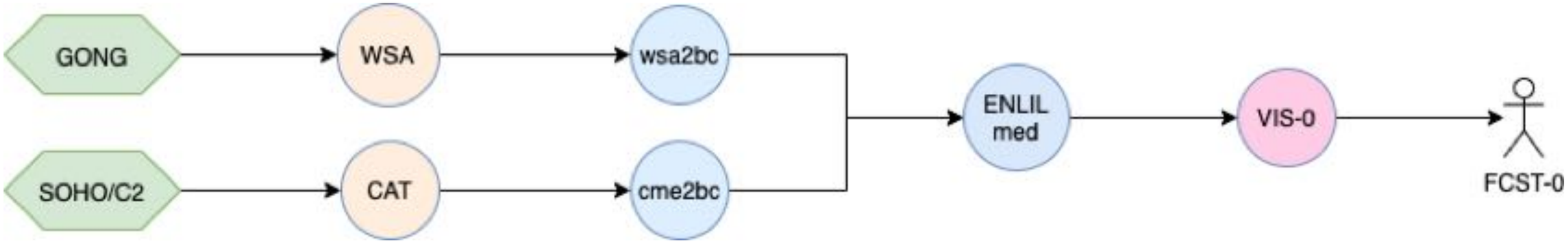
- Currently used heliospheric model for operational forecasting
- Can heliospheric imagery see differences in synthetic white-light images in simple hypothetic ensemble run?
- Can synthetic white-light images be compared with STEREO-HI observations?

PUNCH 4 Science Meeting, Boulder, Colorado, July 6-7, 2023

Currently Used Forecasting Scheme at NOAA & NASA — Single ENLIL Run

- 3-D magnetohydrodynamic (MHD) numerical heliospheric code
- Observationally driven, near-real time, “hybrid” modeling system
- Routine simulation of background solar wind (BSW) & coronal mass ejections (CMEs), event-by-event, much faster than real-time
- Input data: WSA coronal model (used GONG magnetograms) and Cone model (uses SOHO and STEREO coronagraph CME observations)
- Run-on-request service at NASA/CCMC Operational predictions since 2010





ENLIL is implemented and used at: NOAA/SWPC, NASA /CCMC, UK/MetOffice, Korean Space Weather Center, and Australian Bureau of Meteorology

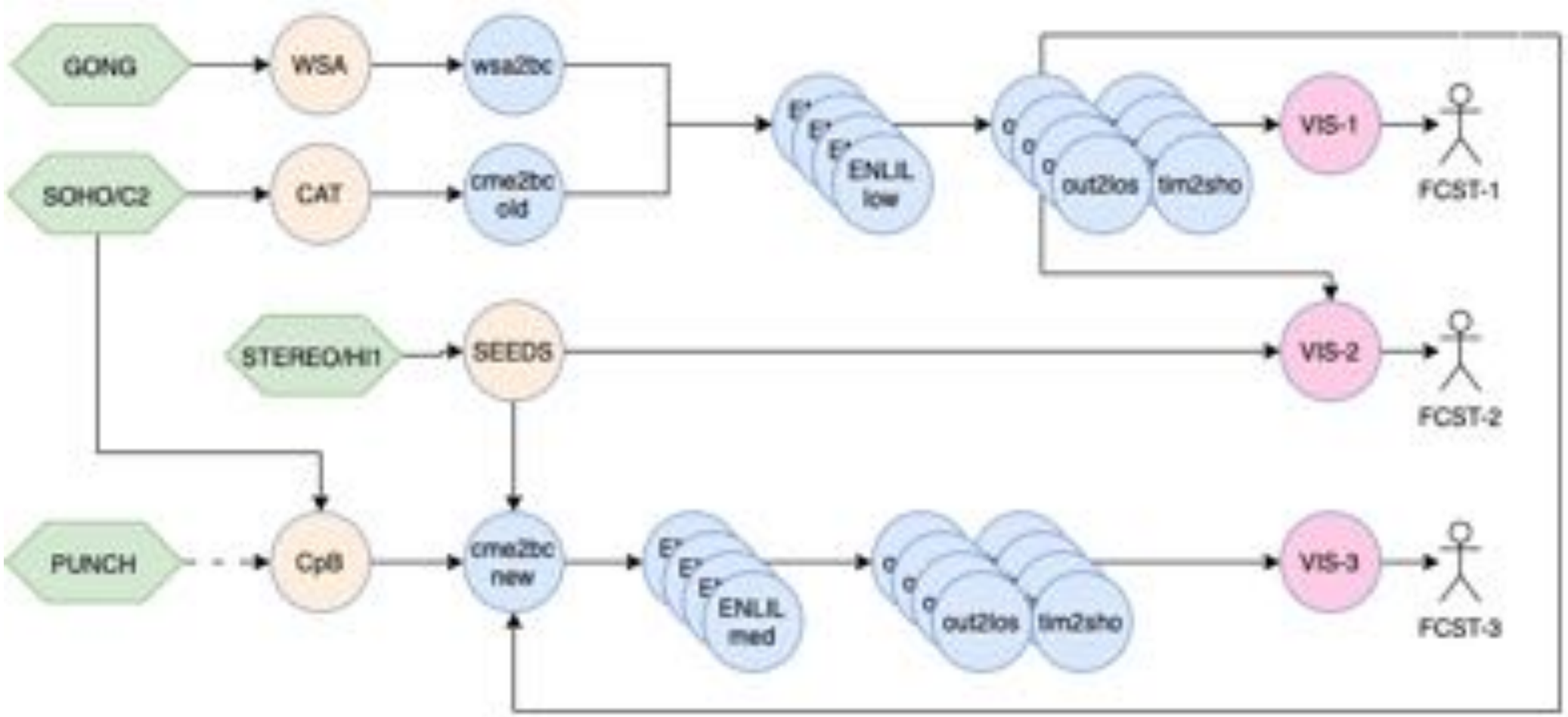
Predictions of the Arrival Time at Earth — NCEI Archive & CCMC Scoreboard

No	Error (h)	WSA Vers	GONG	Mode	ENLIL Vers	Res	Ambient Params	CME Launch	Lat (deg)	Lon (deg)	Rmaj (deg)	Vcld (km/s)	Ejecta Params	CME Method	Submitted by
P1	-32.28	2.2	mrbqs	Single	2.6	med	a8b1	28T16:42	-10	1	45	1477	d4t1x1	Cone (SWPC)	Duty Forecaster (SWPC)
P2	-28.22	2.2	—	—	—	—	—	—	—	—	—	—	d4t1x1	Cone (BoM)	Duty Forecaster (ASFC)
P3	-19.22	2.2	—	—	—	—	—	—	—	—	—	—	—	Cone (SWPC)	Robert Loper (M2M Office)
P4	-17.22	4.5	mrzqs	single	2.7	low	a3b2	28T16:00	-20	1	52	1200	sa1	Cone (MOSWOC)	Duty Forecaster (MOSWOC)
P5	-16.32	2.2	—	—	2.7	low	a3b1f	28T17:52	-17	0	49	1109	d4t1x1	Cone M2M)	Robert Lopez (M2M Office)
P6	-15.97	—	—	—	—	—	—	28T17:53	-17	0	49	1109	—	Cone (M2M)	Anna Chulaki (M2M Office)

- 4 forecasting centers predicted too early CME arrival
- Simulated CME propagated in “false” fast near-equatorial stream that caused faster CME propagation

Proposed Forecasting System with Ensemble Runs & Inclusion of HI Data

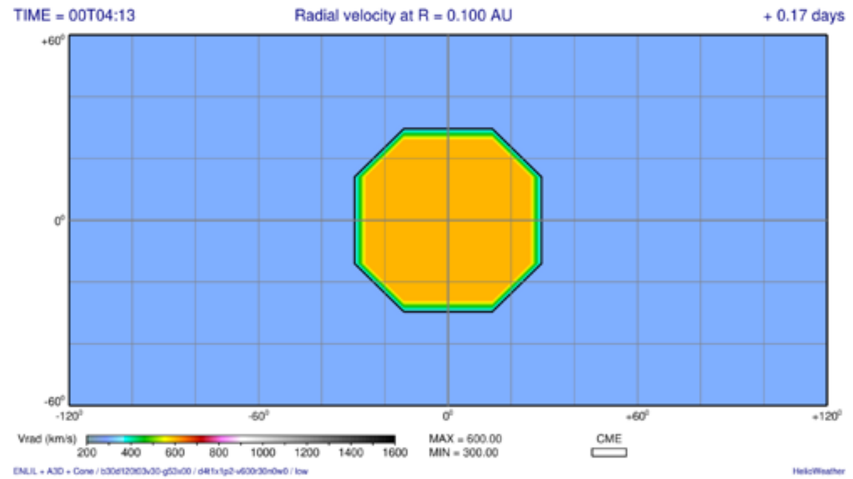
NASA R2O2R Project: D. Odstrcil, C. de Koning, J. Zhang,
In collaborations with: E. Adamson, L. Barnard, J. Davies, C. DeForest, S. Gonzi, L. Mays, M. Owens, and V. Pizzo



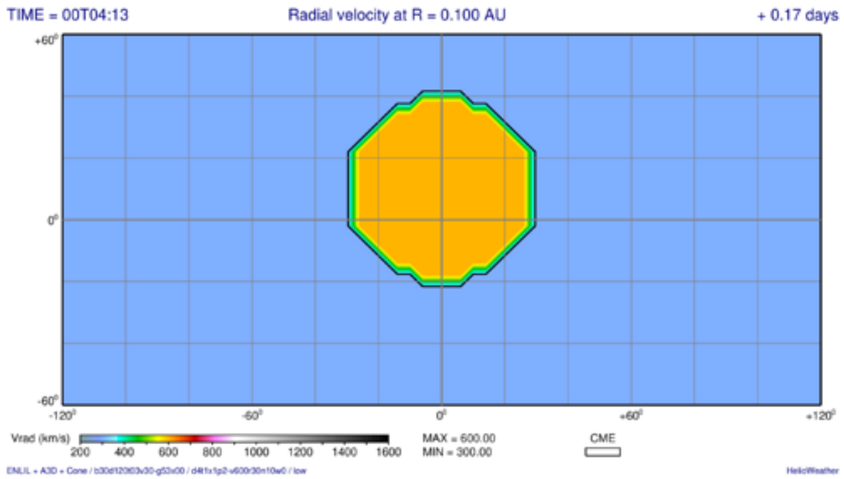
- FCST-1 like current FCST-0 but with ensemble runs for range of uncertainty
- FCST-2 if HI observations to suggest the relevant run and/or to prune bad ensemble members
- FCST-3 revised model initiation & ensemble runs

Simple CME Ensemble — Boundary Values at 0.1 AU

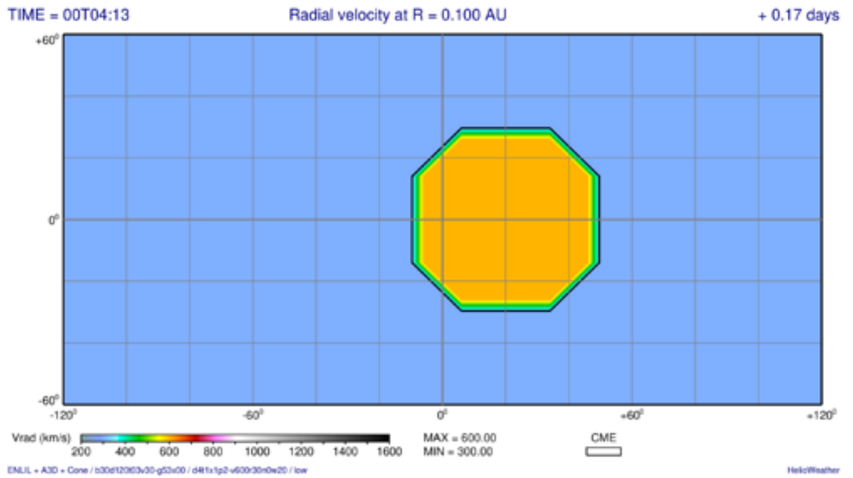
CASE 1: N00W00, Rmaj=30, Vcme=600



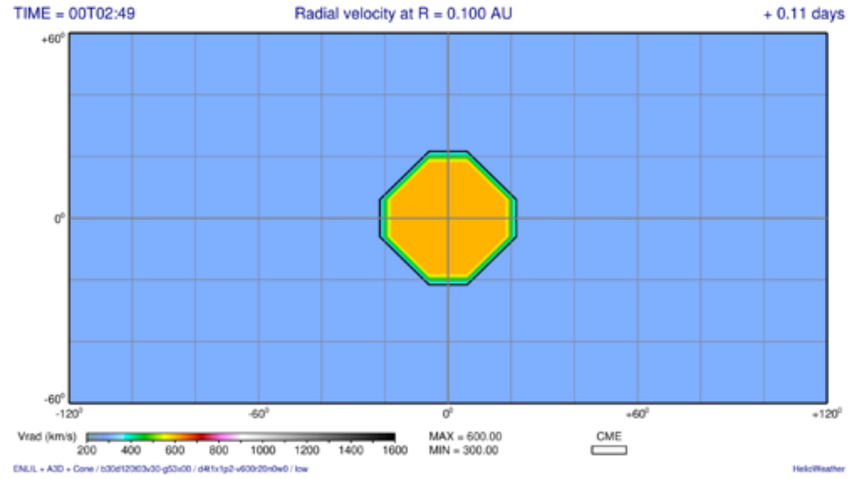
CASE 2: N10W00, Rmaj=30, Vcme=600



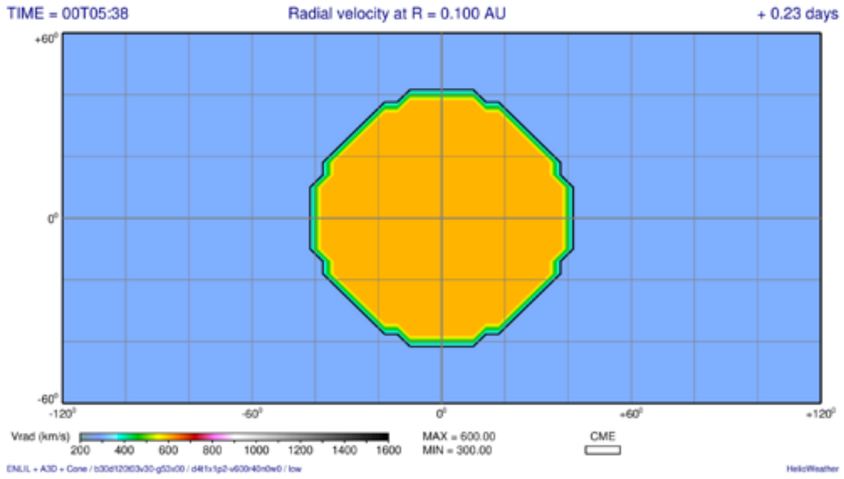
CASE 3: N00W20, Rmaj=30, Vcme=600



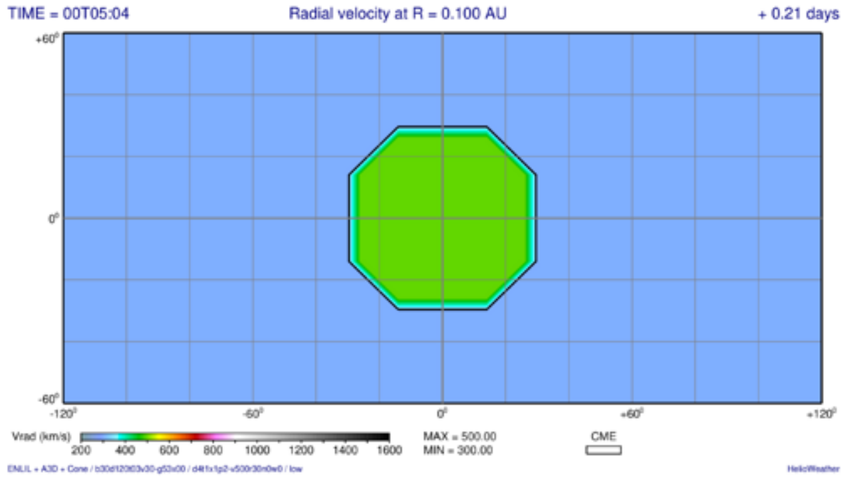
CASE 4: N00W00, Rmaj=20, Vcme=600



CASE 5: N00W00, Rmaj=40, Vcme=600



CASE 6: N00W00, Rmaj=30, Vcme=500



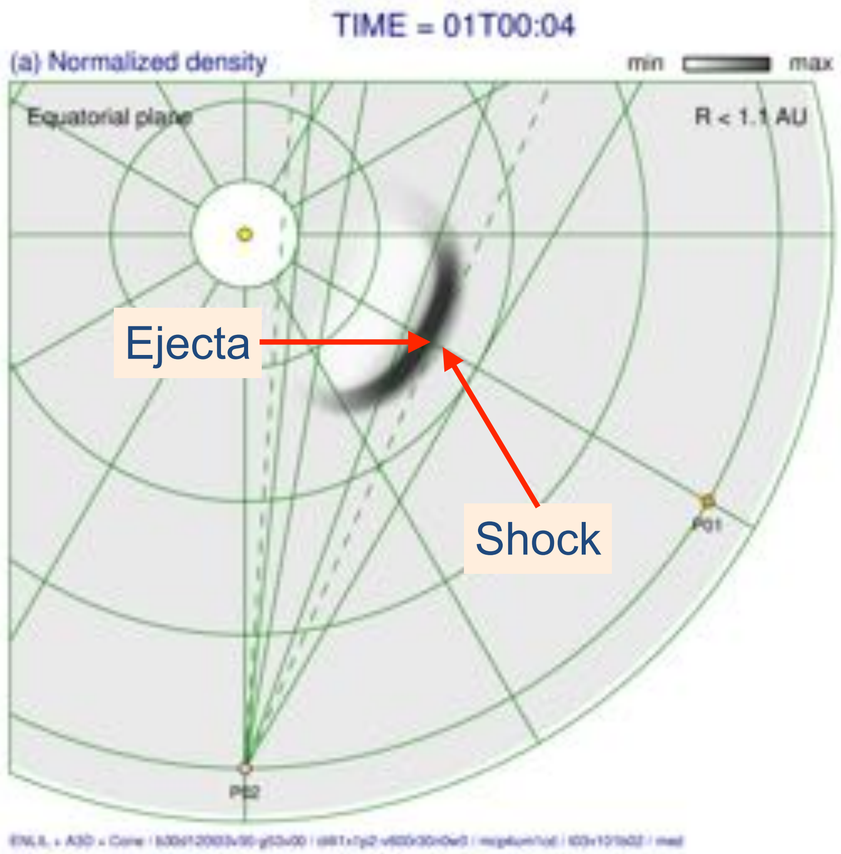
- SW radial velocity is shown when a hydrodynamic ejecta passes the computational boundary at 0.1 AU
- Reference Case 1 and variations of the cone model parameters (Cases 2-6) are used for computations

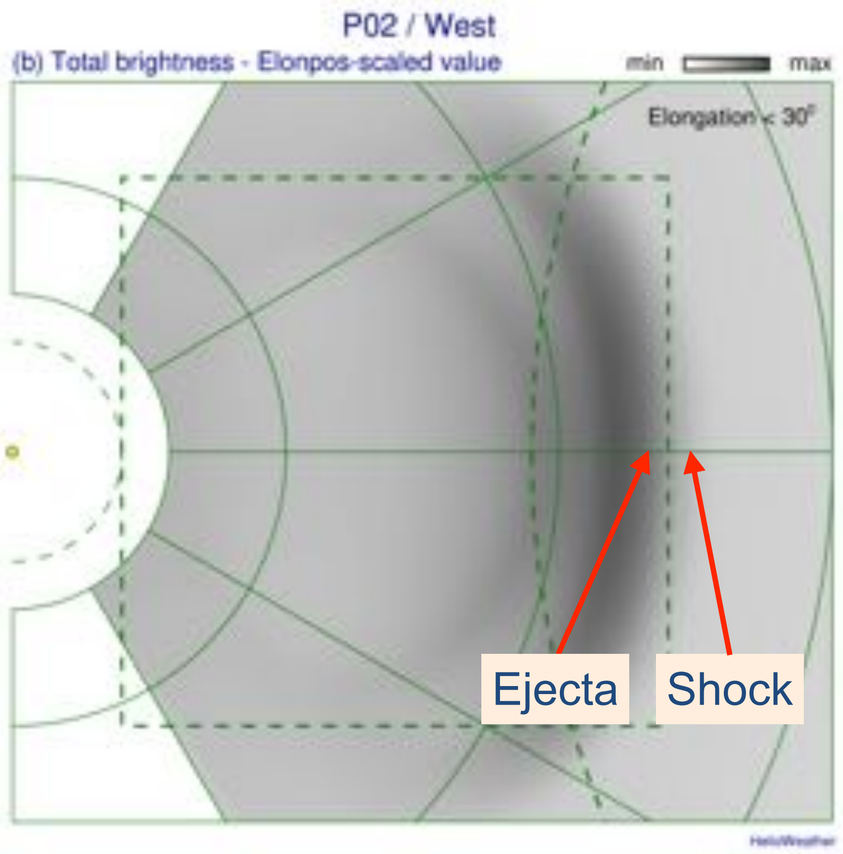
Simple CME — SW Density & Synthetic WL Image

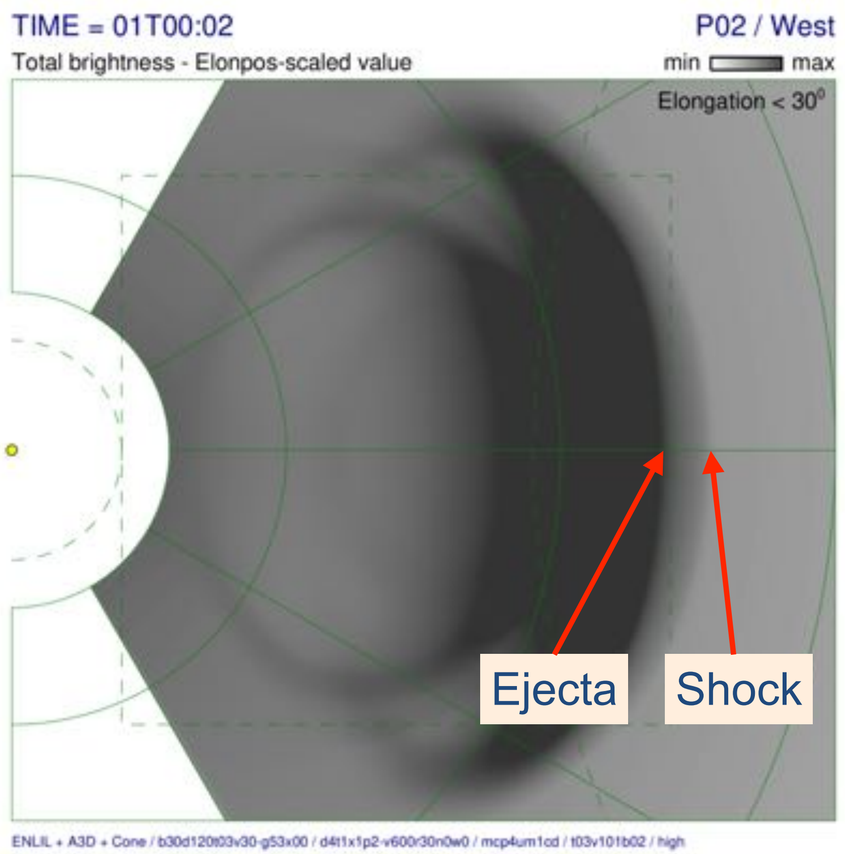
SW density for Case 1
- med-res run, 2^0 angularly

WL image — basic resolution
- (med-res run, 2^0 angularly)
- 0.5^0 image grid

WL image — increased resolution
- (high-res run, 1^0 angularly)
- 0.15^0 image grid, values < 0.5 max



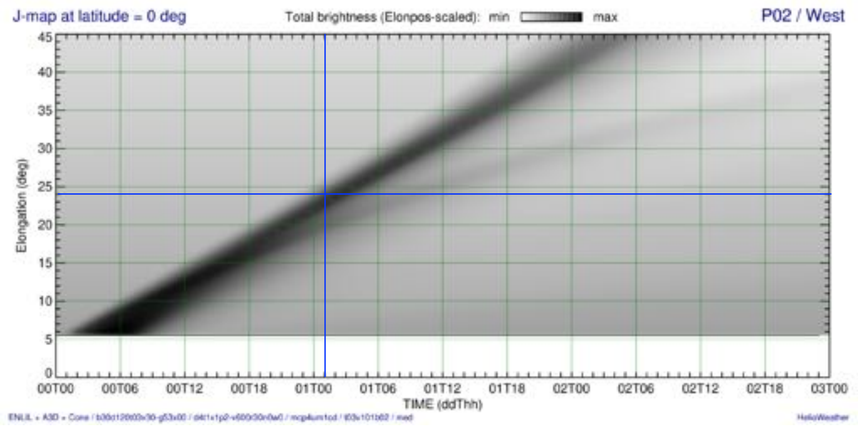




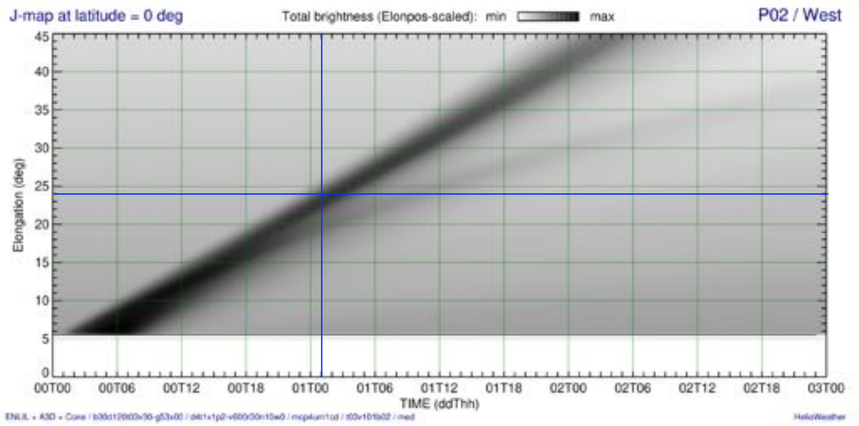
- CME propagates to P01 and WL is calculated for P02
- Heliospheric computations can show the CME ejecta and surrounded sheath (SW compressed by a CME-driven shock)
- Synthetic imaging can differentiate between those structures but this is more challenging

Simple CME Ensemble — Synthetic WL J-Maps

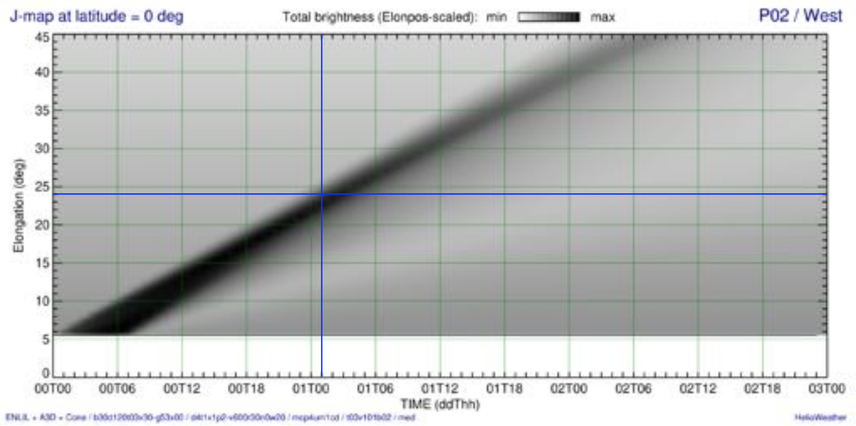
CASE 1: N00W00, Rmaj=30, Vcme=600



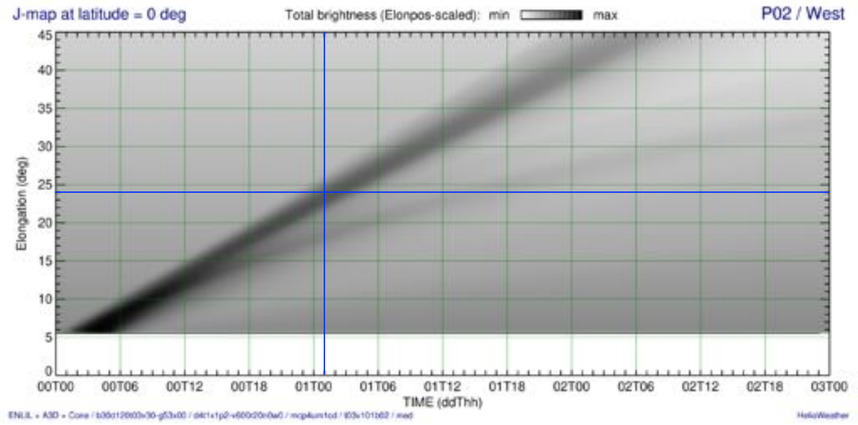
CASE 2: N10W00, Rmaj=30, Vcme=600



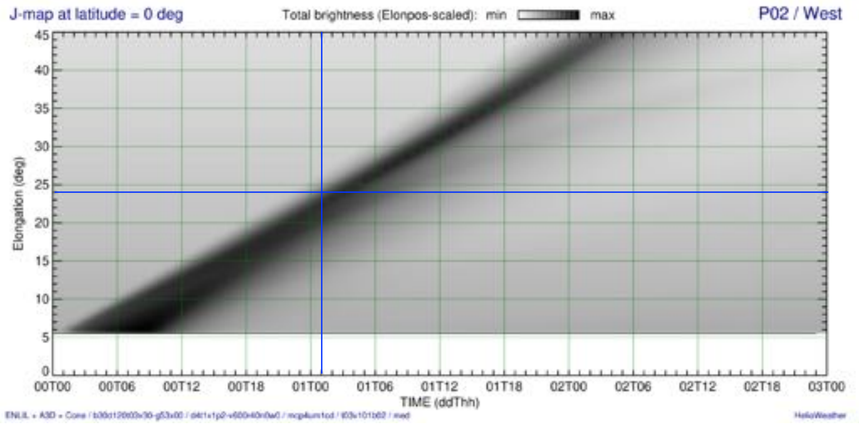
CASE 3: N00W20, Rmaj=30, Vcme=600



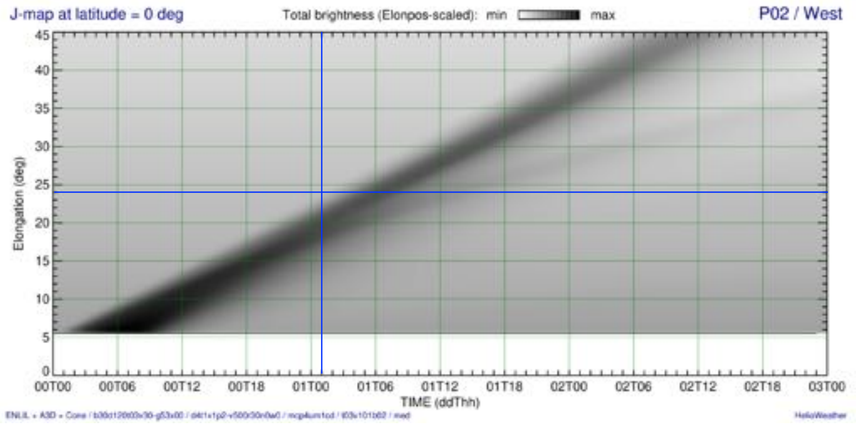
CASE 4: N00W00, Rmaj=20, Vcme=600



CASE 5: N00W00, Rmaj=40, Vcme=600



CASE 6: N00W00, Rmaj=30, Vcme=500

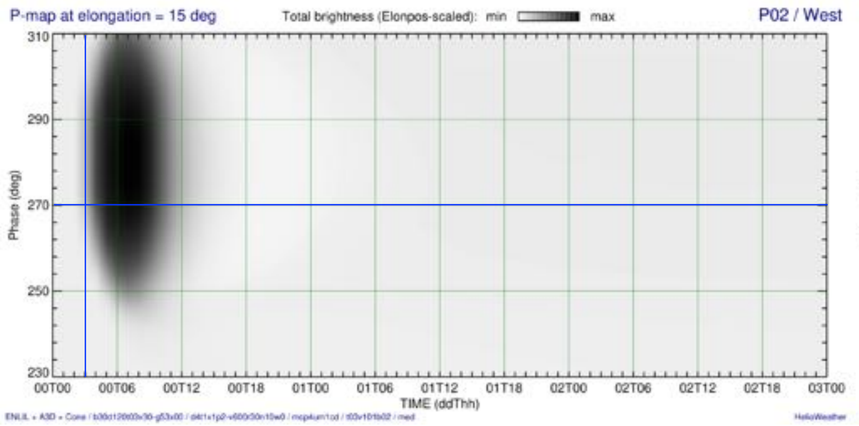


- Blue crossing lines are at elongation = 24 deg (outer range of HI-1A) and time = 01T01
- This corresponds to the leading edge of the WL disturbance for the Case 1 and its position is the same on all panels
- Only Case 6 visibly differs from the reference Case 1

Simple CME Ensemble — Synthetic WL P-Maps (at elongation=15^0)

CASE 1: N00W00, Rmaj=30, Vcme=600

CASE 2: N10W00, Rmaj=30, Vcme=600



CASE 3: N00W20, Rmaj=30, Vcme=600

CASE 4: N00W00, Rmaj=20, Vcme=600

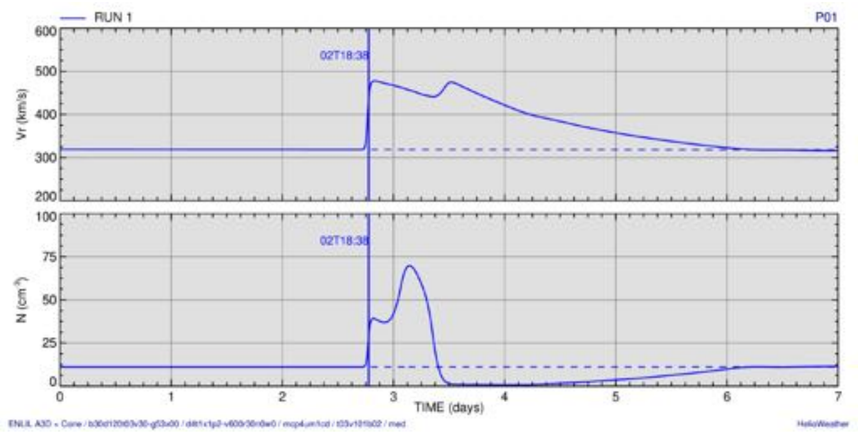
CASE 5: N00W00, Rmaj=40, Vcme=600

CASE 6: N00W00, Rmaj=30, Vcme=500

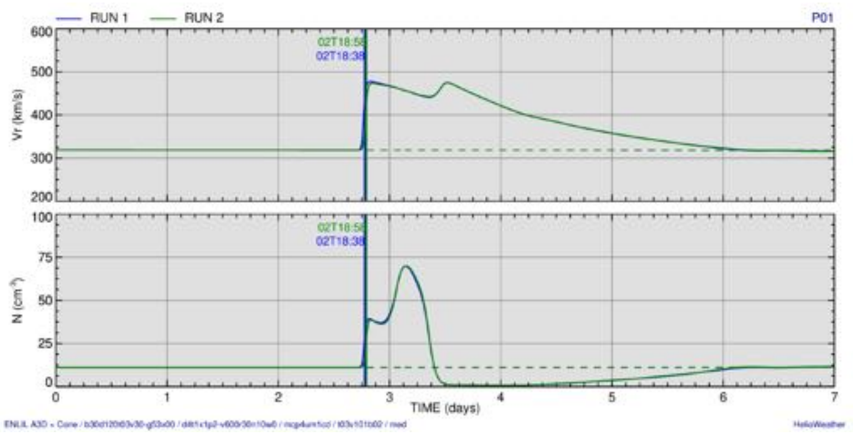
- Blue crossing lines are at phase = 270 deg, equatorial plane) and time = 00T03
- This corresponds to the leading edge of the WL disturbance for the Case 1 and its position is the same on all panels
- In addition to later arrival in Case 6, an effect of the latitudinal position and ejecta width can be seen too

Simple CME Ensemble — Evolution & Shock Arrival at 1 AU

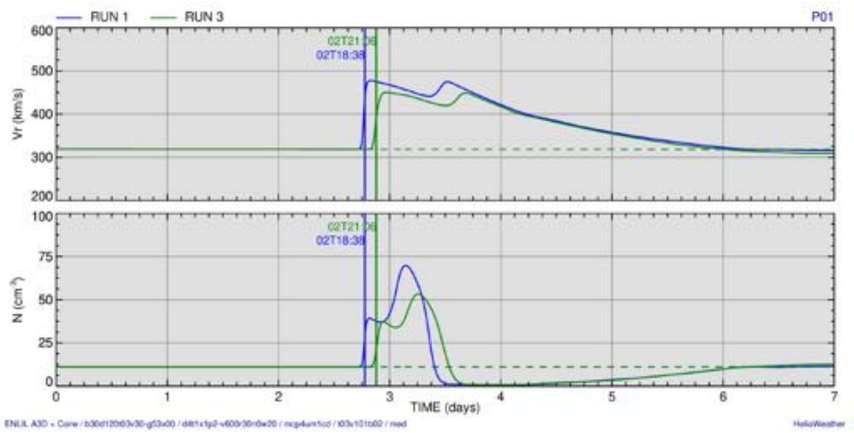
CASE 1: N00W00, Rmaj=30, Vcme=600



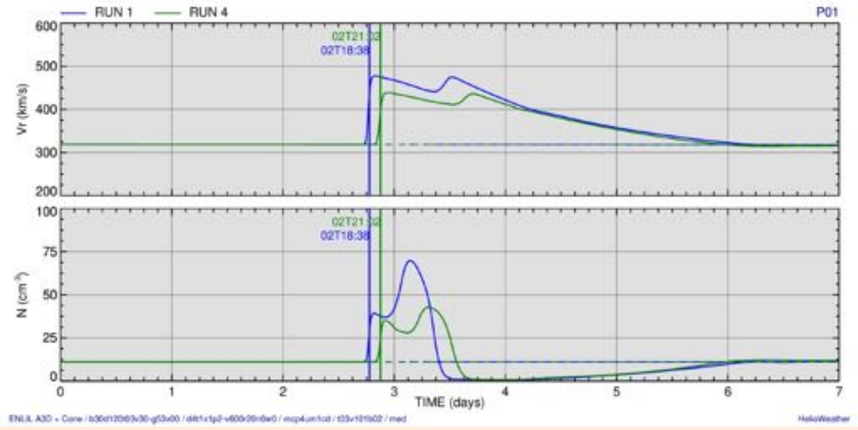
CASE 2: N10W00, Rmaj=30, Vcme=600



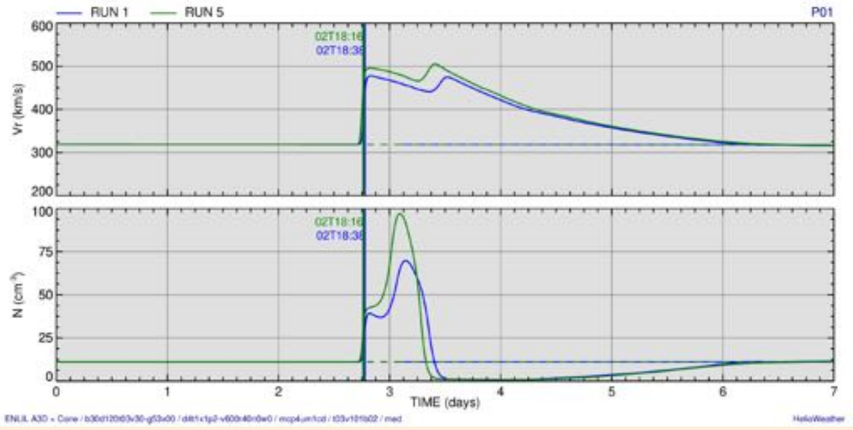
CASE 3: N00W20, Rmaj=30, Vcme=600



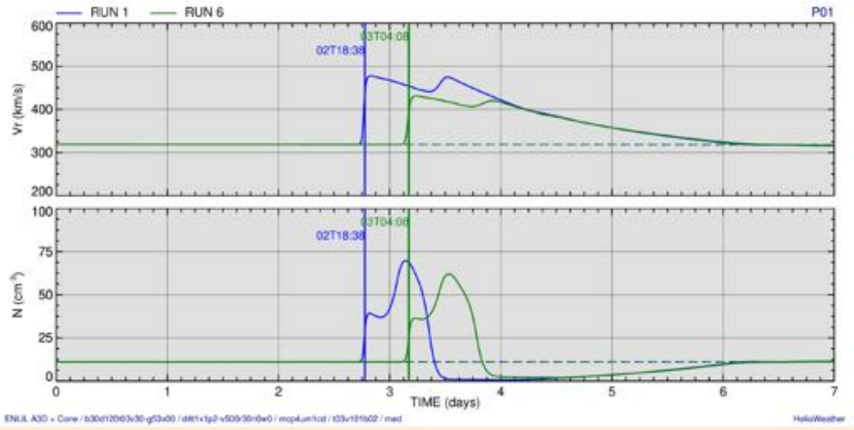
CASE 4: N00W00, Rmaj=20, Vcme=600



CASE 5: N00W00, Rmaj=40, Vcme=600

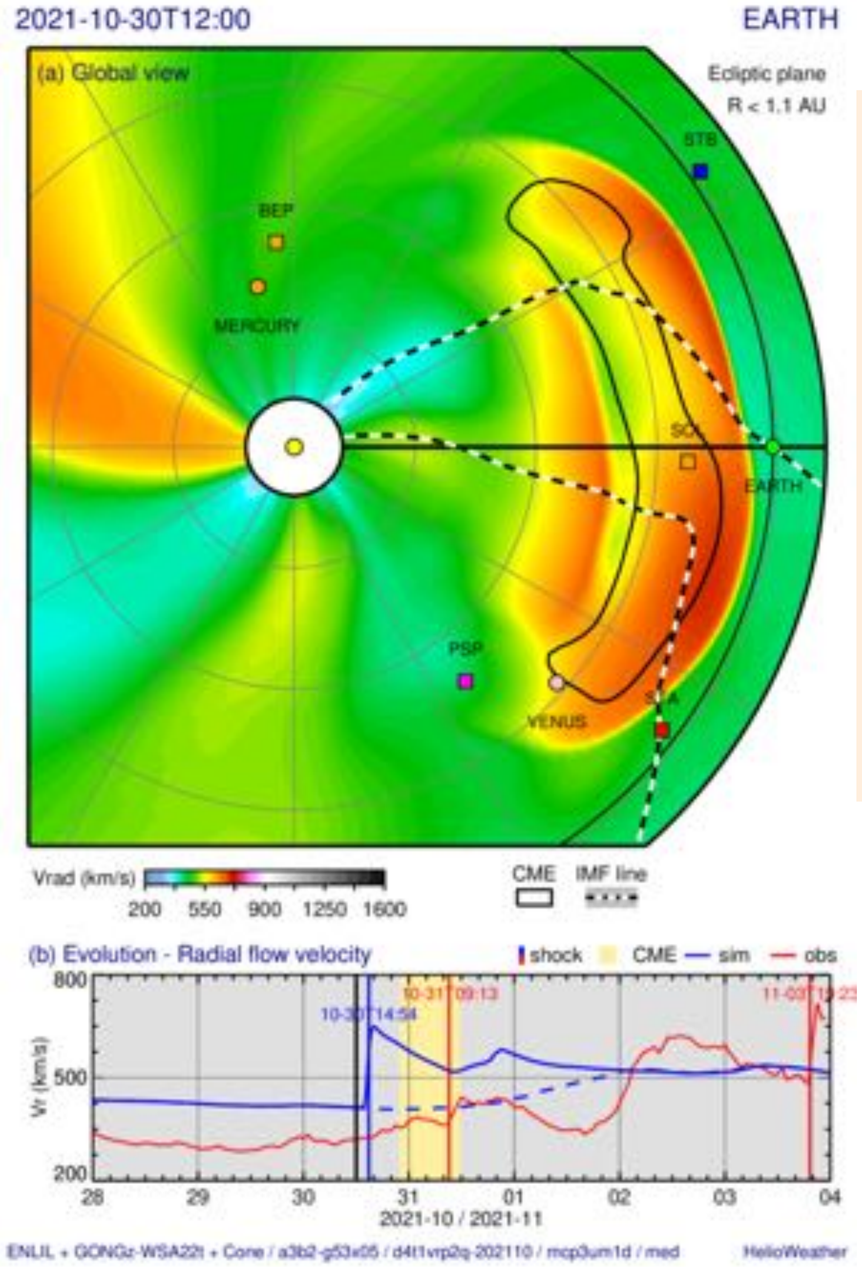


CASE 6: N00W00, Rmaj=30, Vcme=500



- CME 6 arrives later by ~9.5 hours — Difference from Case 1 can be clearly seen in WL imagery
- CME 3 arrives later by ~2.5 hours — Difference from Case 1 can be hardly seen in WL imagery
- CME 4 arrives later by ~2.5 hours — Difference from Case 1 can be barely seen in WL imagery
- CMEs 2 and 5 arrive at about the same time as Case 1 — Observer is within the shock-driving ejecta

CME 2021-10-28 — Predicted SW Velocity (2 Cases)

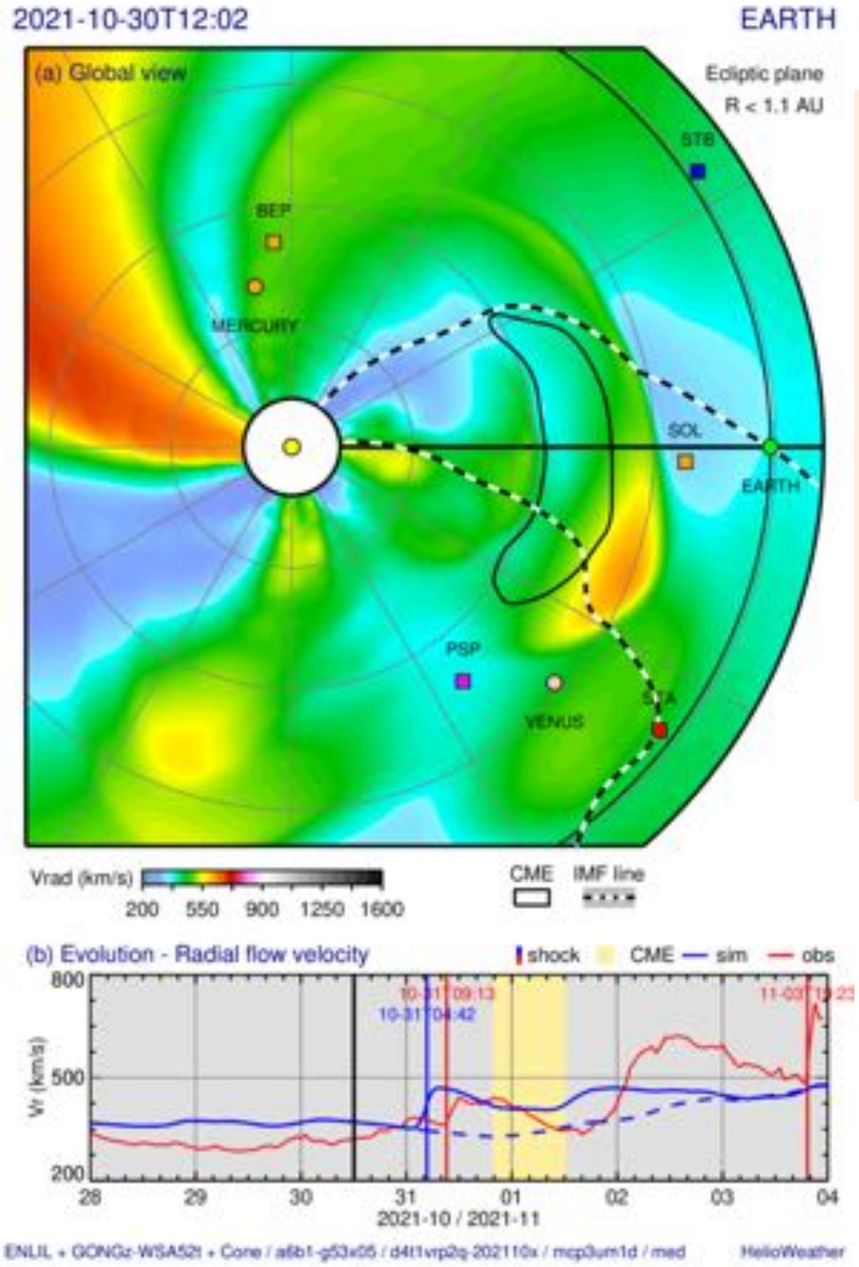


CASE 1:

Background SW
- GONG-b
- WSA-2.2
- “a3b2”

Fitted CME
- Vcld 1109 km/s
- Rmaj 49 deg

Arrival at Earth
- Earlier by **18 h**



CASE 2:

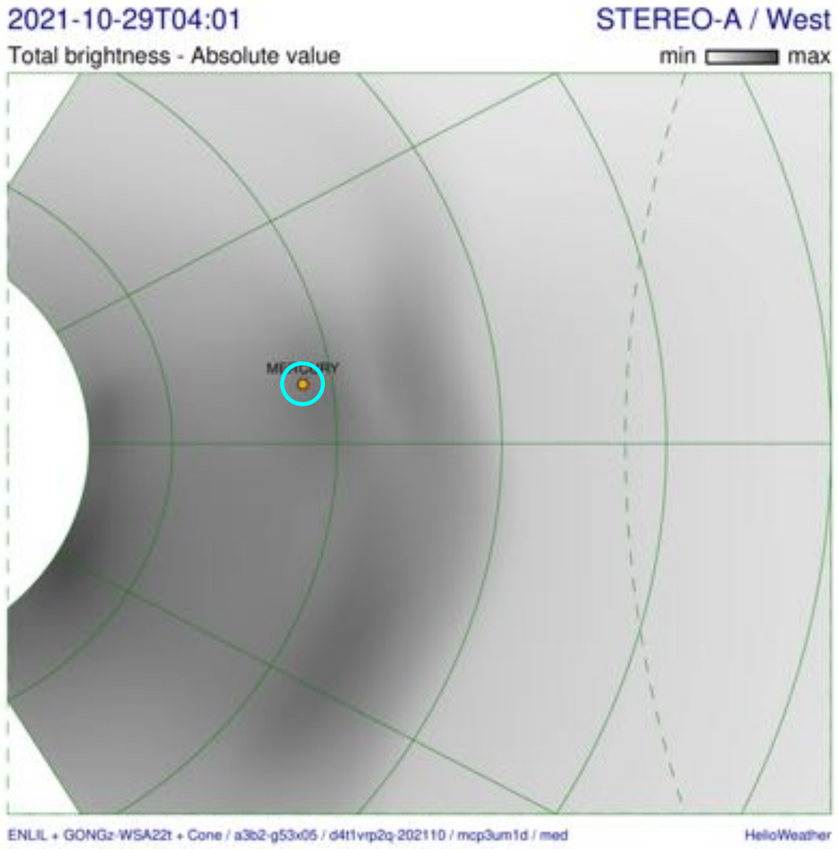
Background SW
- GONG-z
- WSA-5.2
- “a6b1”

Fitted CME - 20%
- Vcld 887 km/s
- Rmaj 39 deg

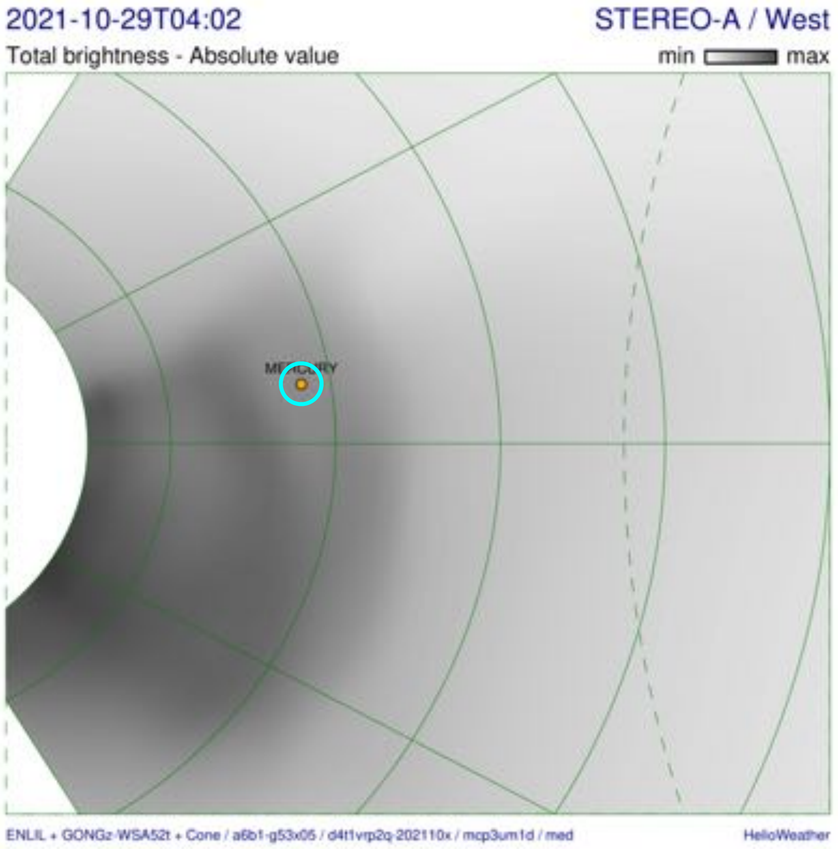
Arrival at Earth
- earlier by **4.5 h**

CME 2021-10-28 — Synthetic (2 Cases) and Observed WL Images

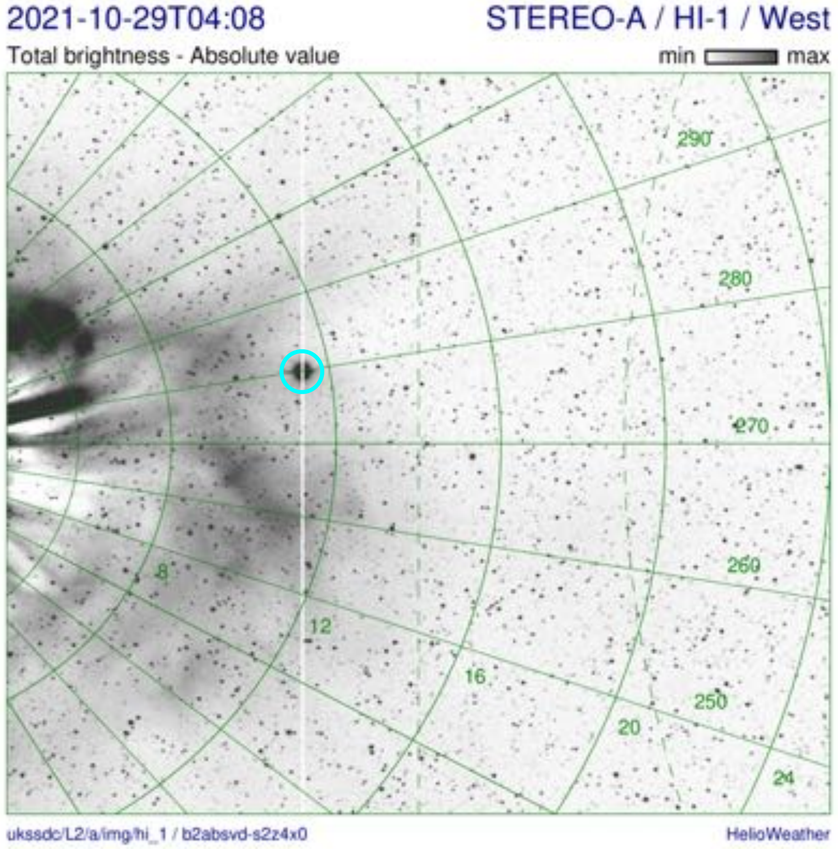
Case 1



Case 2



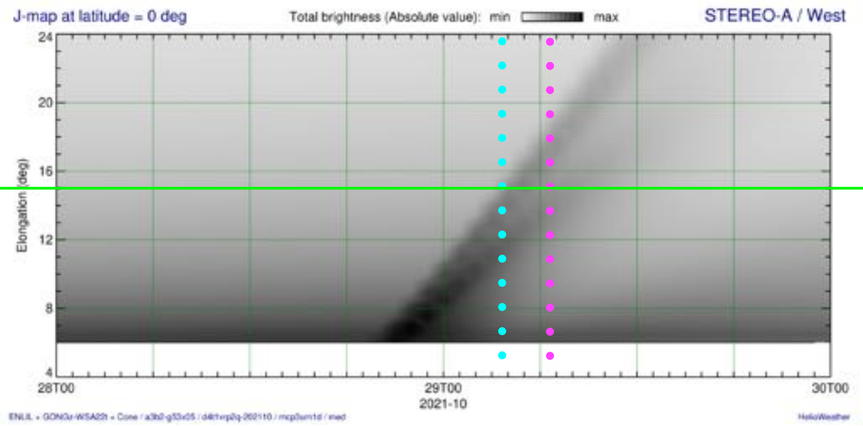
Observed



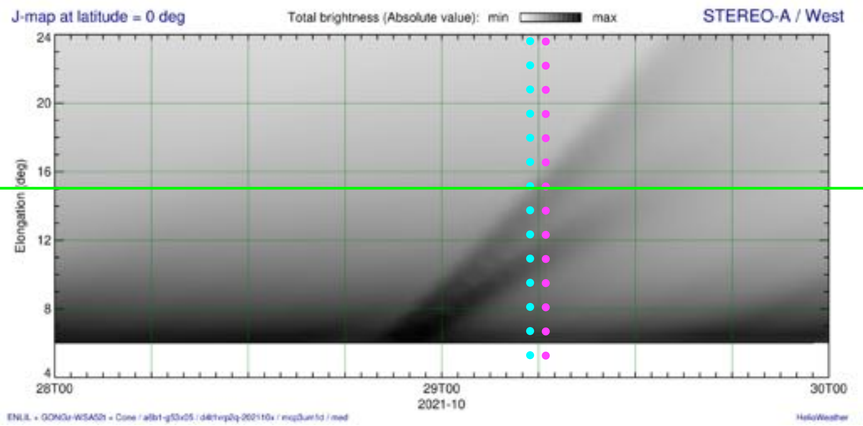
- Synthetic WL images show a leading edge of CME-driven disturbances that can be compared with the observed image
- Case 1 has much more advanced disturbance than (seen also relative to Mercury) and should not be used for predictions
- Observed CME has highly irregular structure and this complicates comparing with J-maps

CME 2021-10-28 — Synthetic (2 Cases) and Observed WL Jmaps & Pmaps

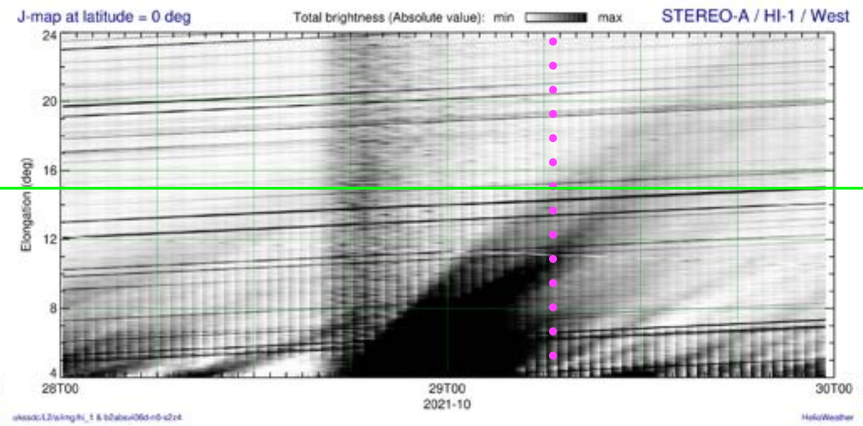
Case 1 — Jmap



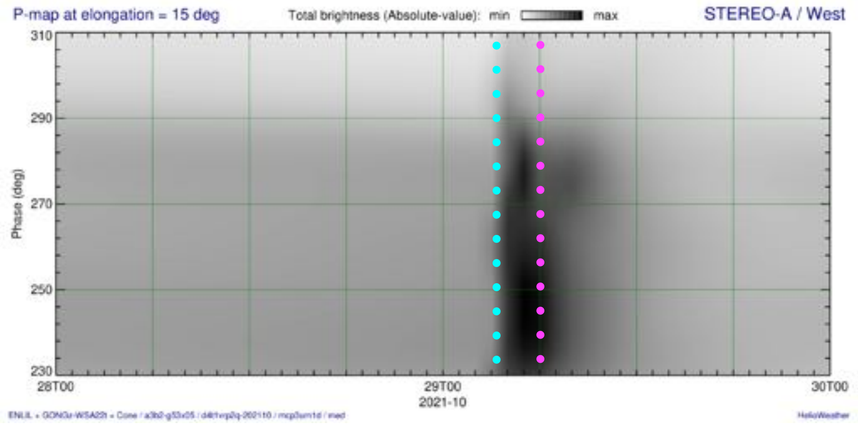
Case 2 — Jmap



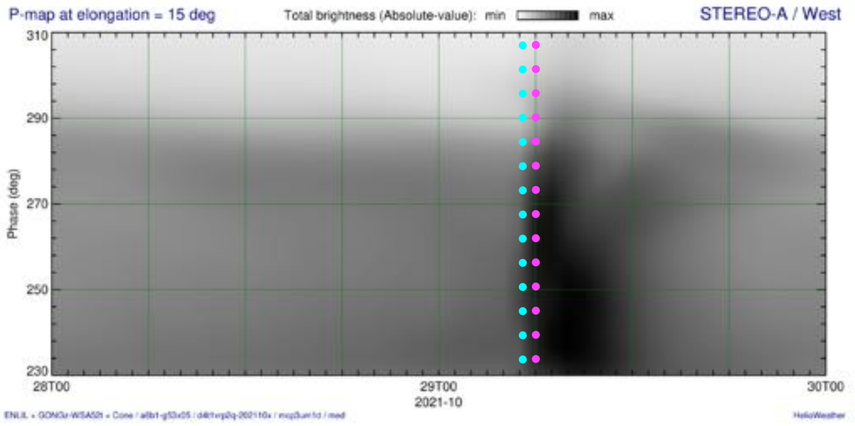
Observed — Jmap



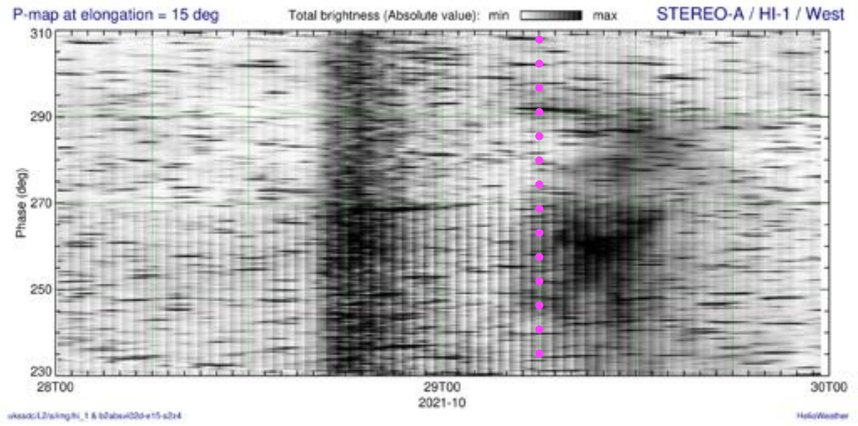
Case 1 — Pmap



Case 2 — Pmap



Observed — Pmap



- Dashed vertical magenta lines show the observed WL structure at elongation=15^0 (J-maps) and phase=270^0 (P-maps)
- Dashed vertical cyan lines show the synthetic WL structure at the same elongation and phase
- Case 1 (Case 2) are detected by 2-3 (0.5-1) hours earlier than observed