ENLIL: Recent Enhancements

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⇓

George Mason University & NASA/GSFC

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<u>Collaboration on code couplings with:</u>

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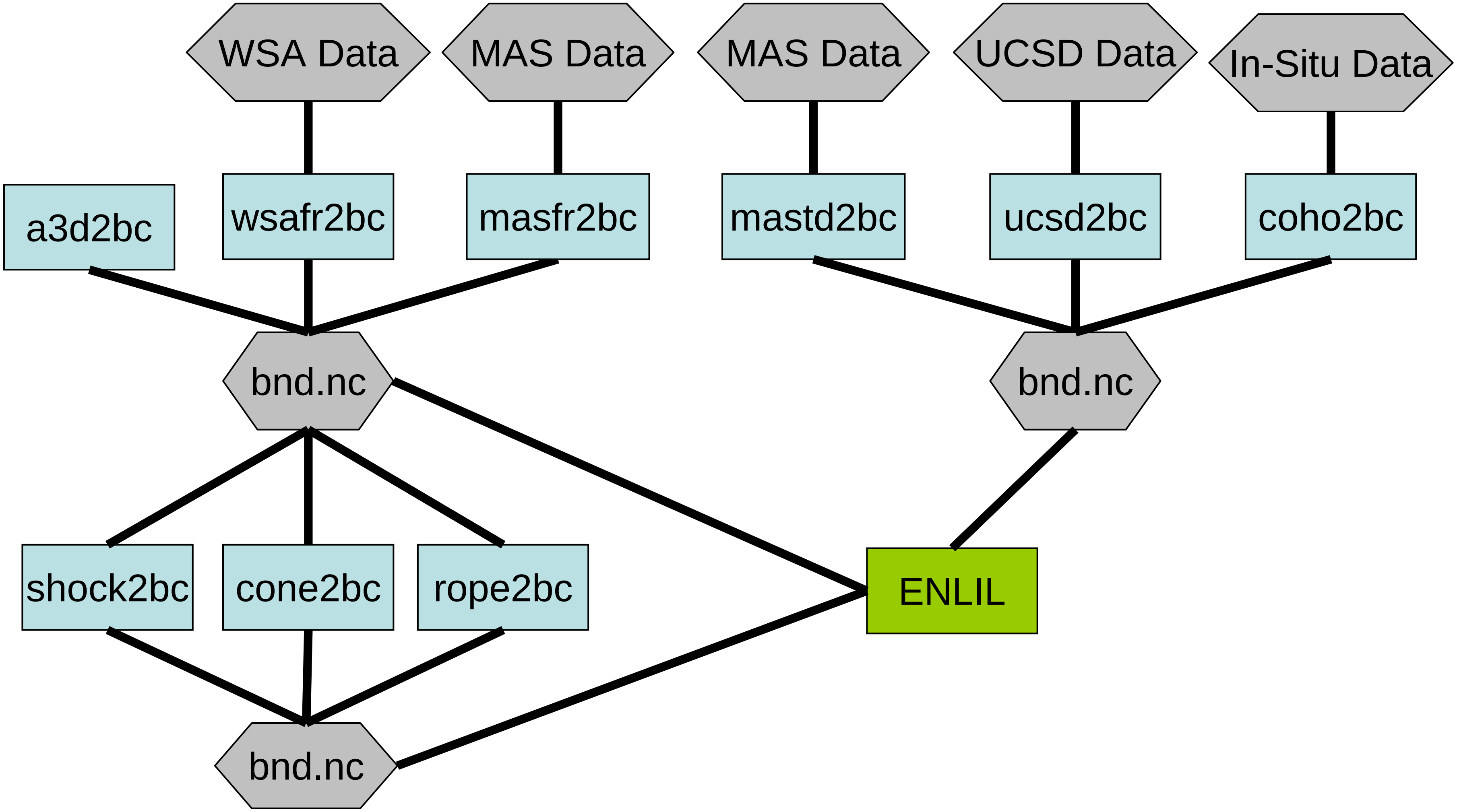
OUTLINE

- Driving Heliospheric Computations
- Space Weather Forecasting
- Launching of Hydrodynamic ICMEs
- Tracing of IMF and Interplanetary Shocks
- Heliospheric Mission Support

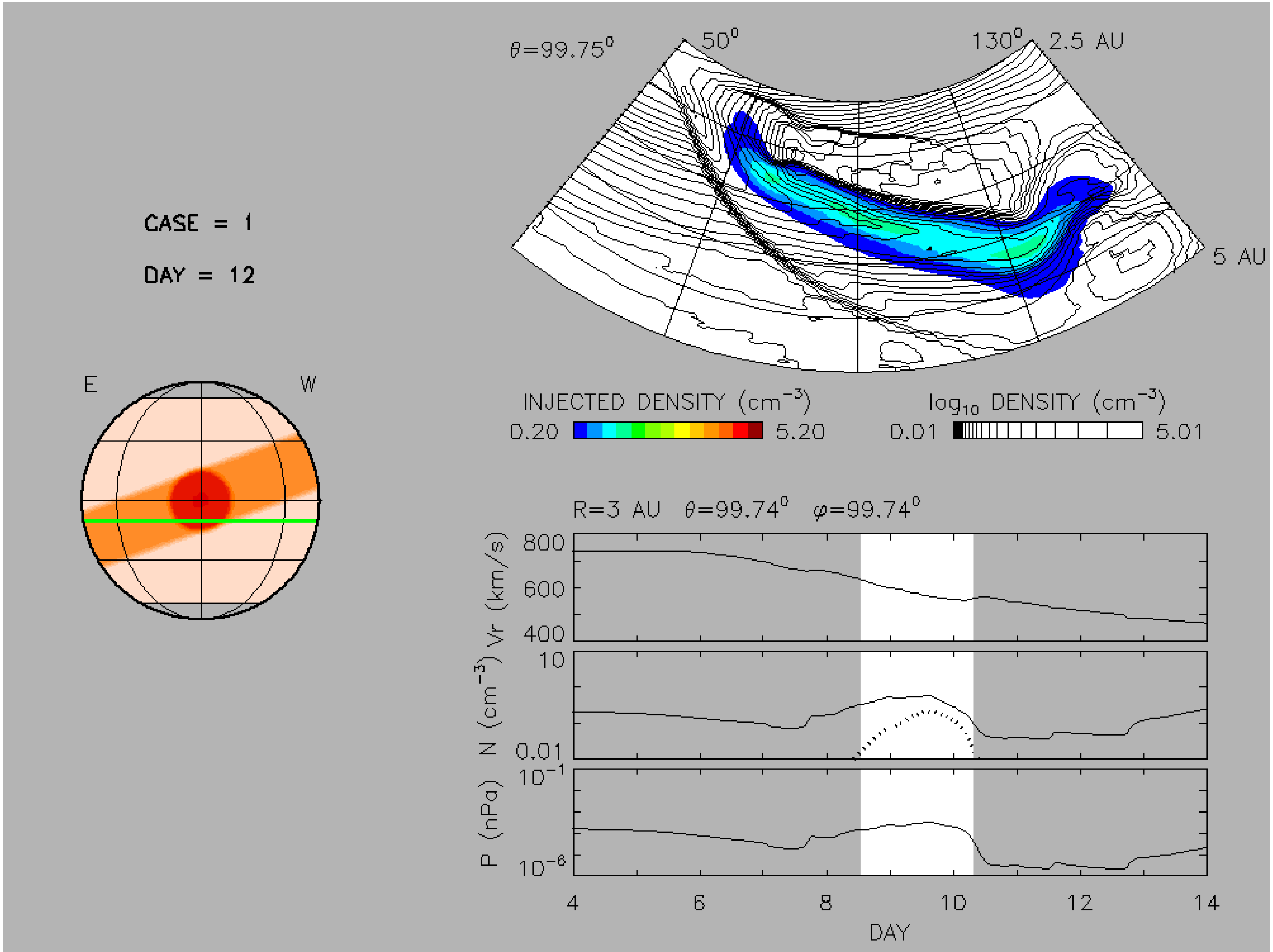
Driving Heliospheric Computations

Driving Heliospheric Computations

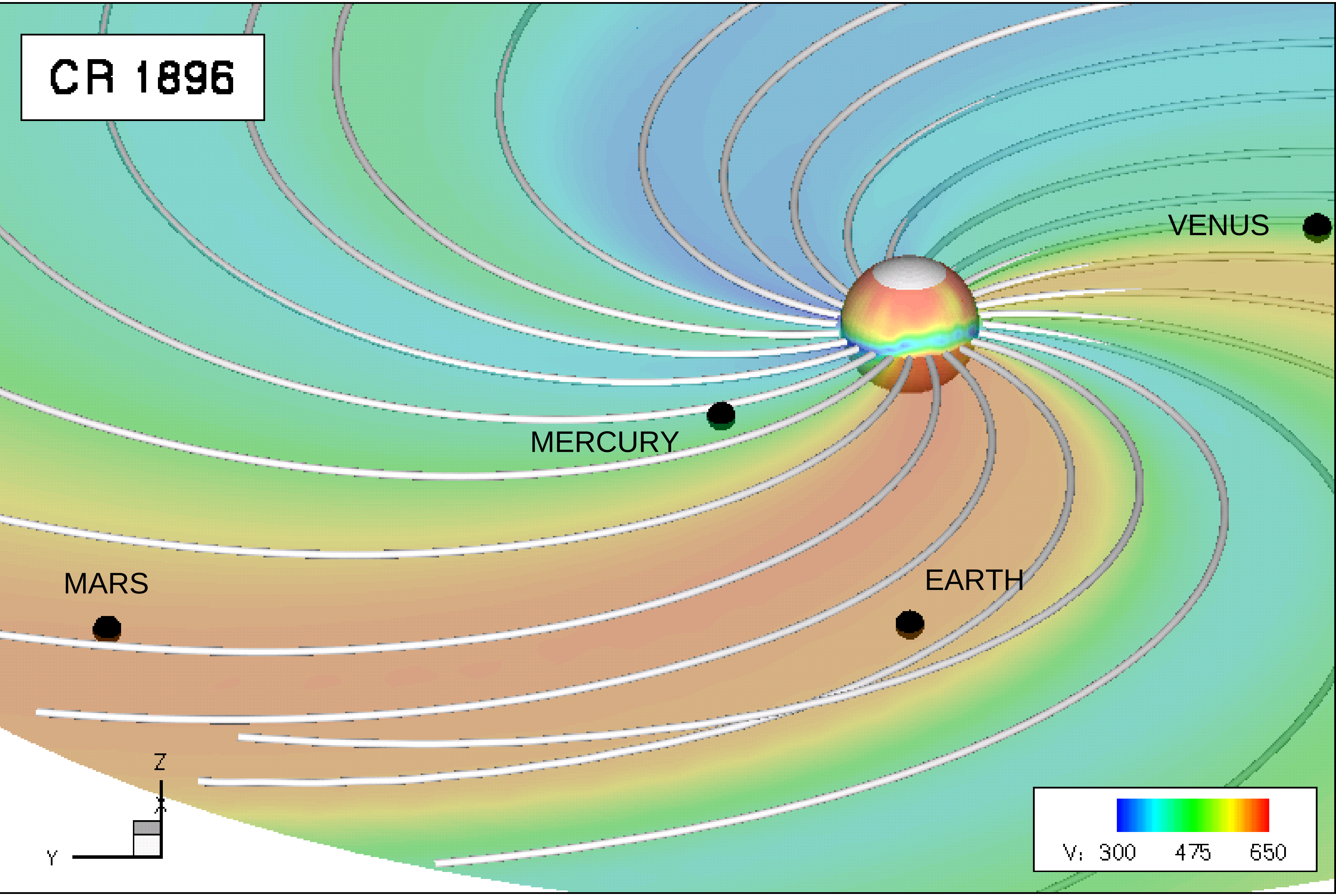


- Analytic, empirical, and numerical models and observational data can be used to drive ENLIL (green) by sharing data sets (grey) and using couplers (blue).

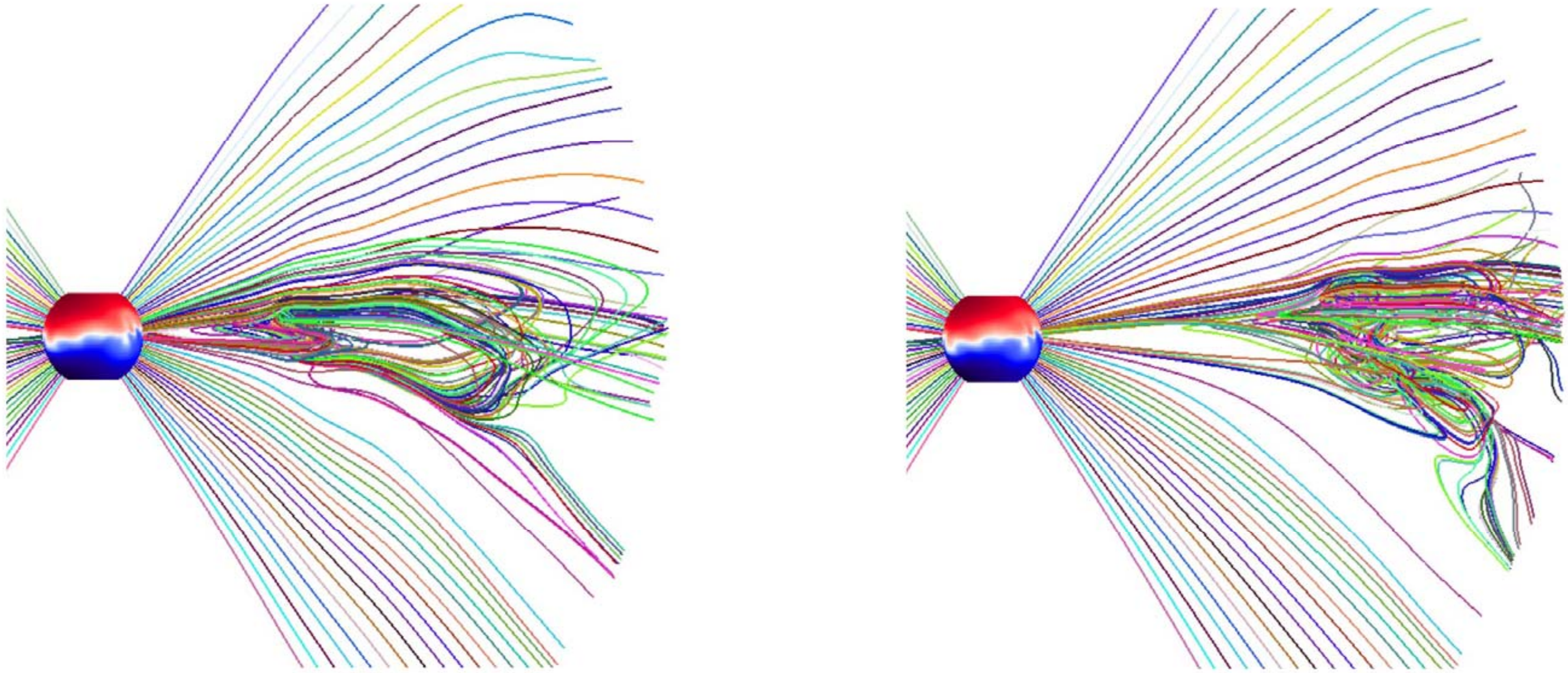
Driving by Analytic Models



Driving by WSA Model

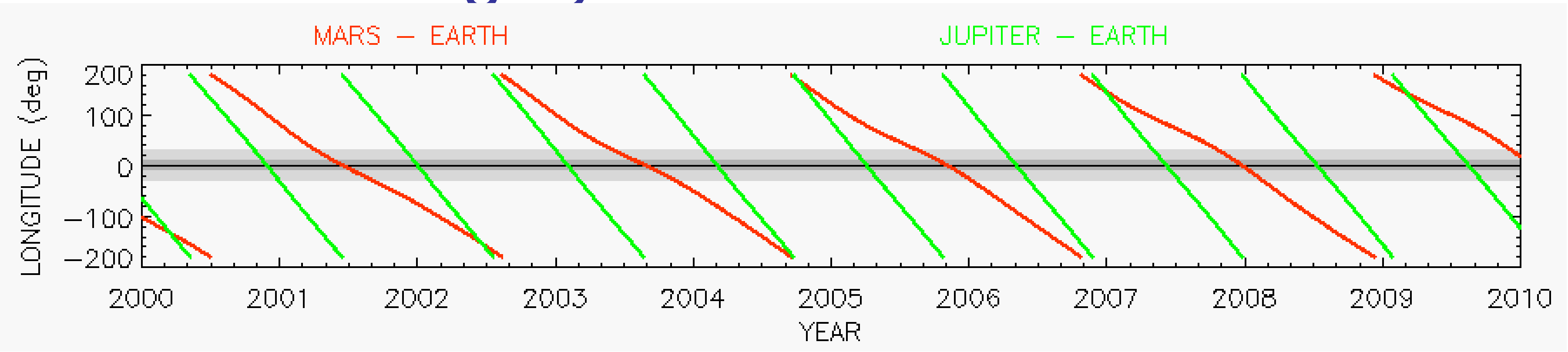


Driving by MAS Model

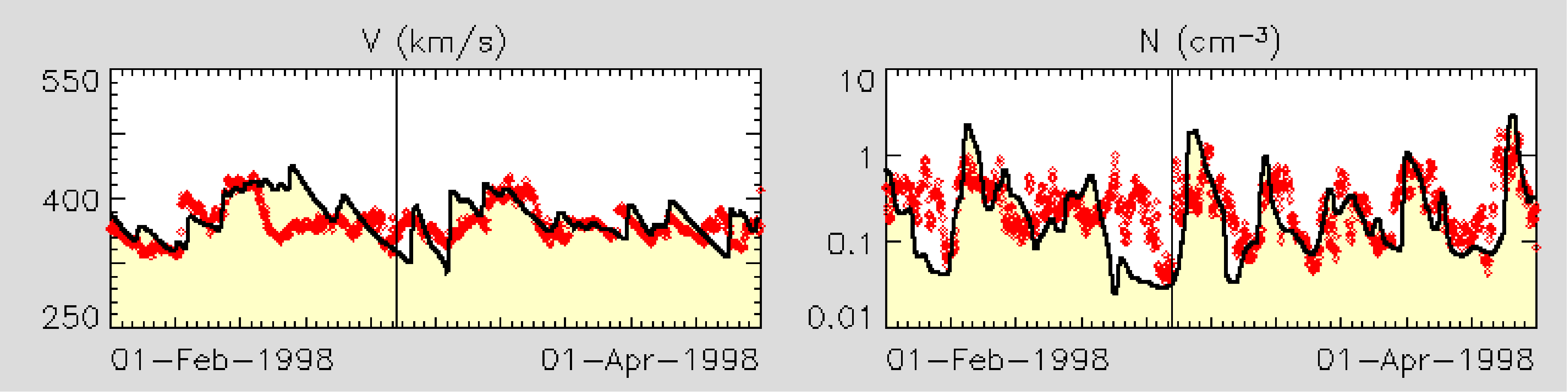


Self-consistent end-to-end numerical simulation of space weather event (in progress)

Driving by In-Situ Observations

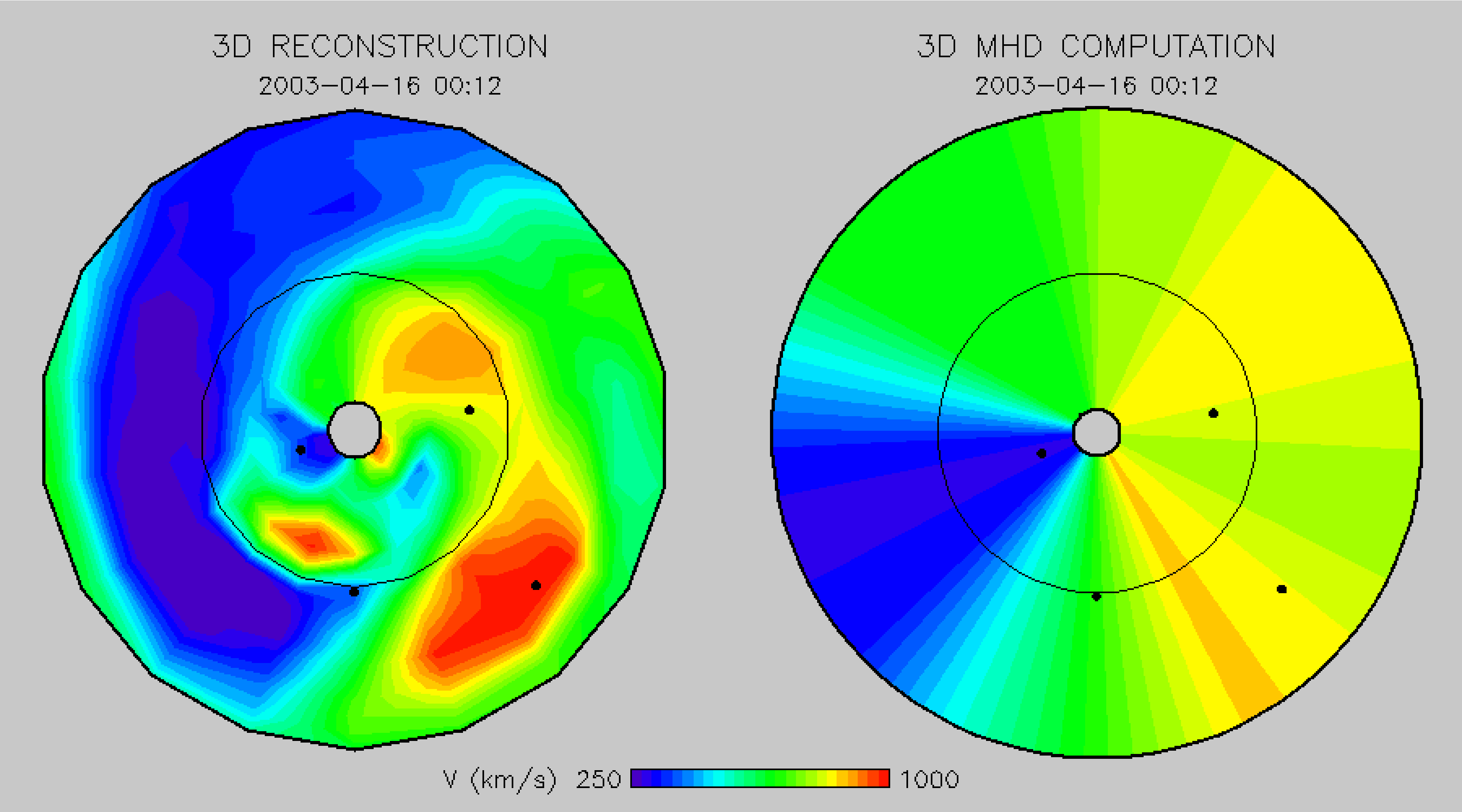


- Heliospheric computations can be driven by accurate in-situ observations of solar wind parameters
- This approach can be strictly applied only during times of radial alignment, and potentially important 3-D interactions are not accounted for



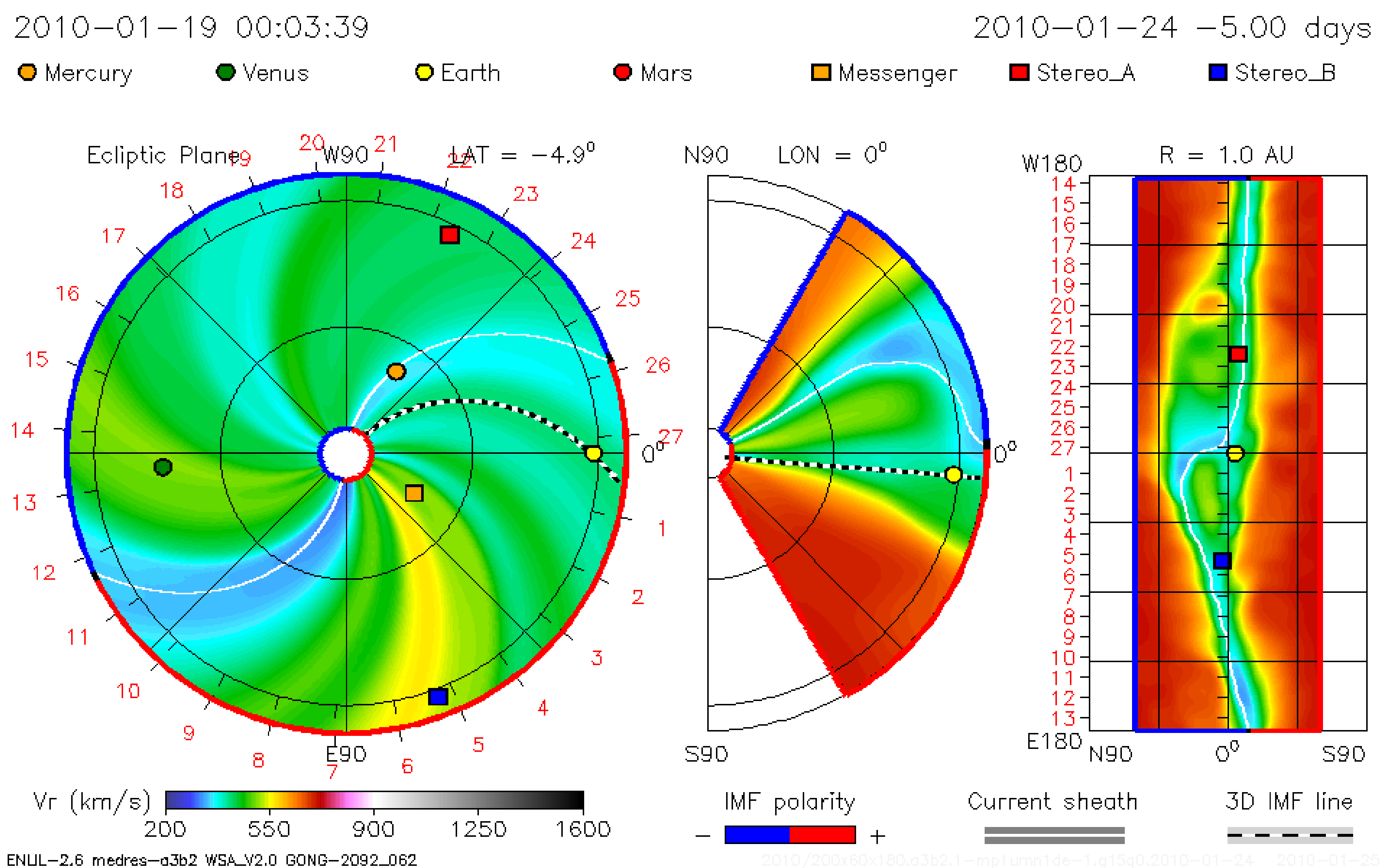
Prediction of the solar wind flow velocity (left) and proton number density (right) at Ulysses. Red dots show observations by Ulysses and a solid line shows results from 1-D MHD simulations driven by values observed at Earth.

Driving by UCSD/IPS Model

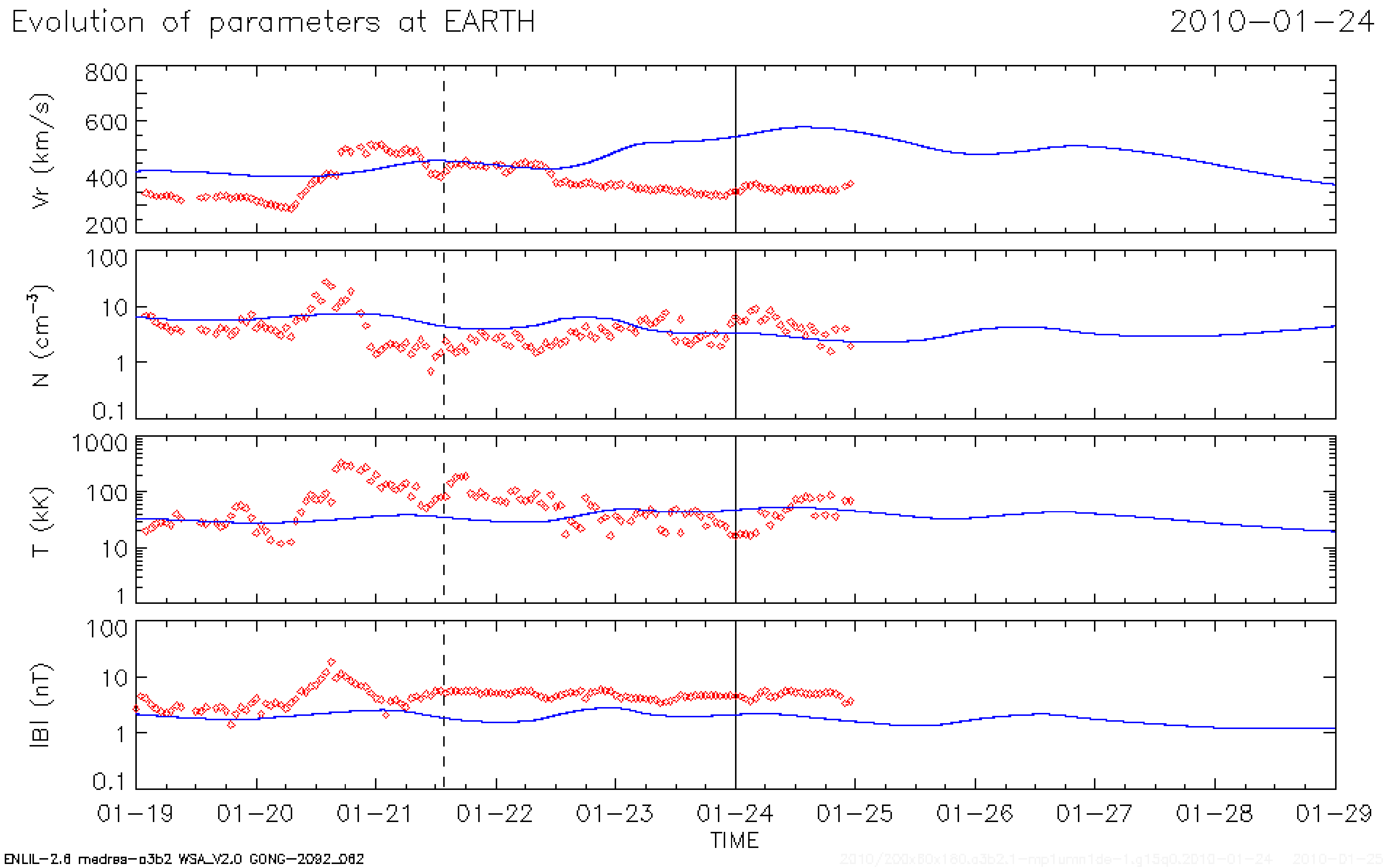


Space Weather Forecasting

Prediction of Solar Wind Streams

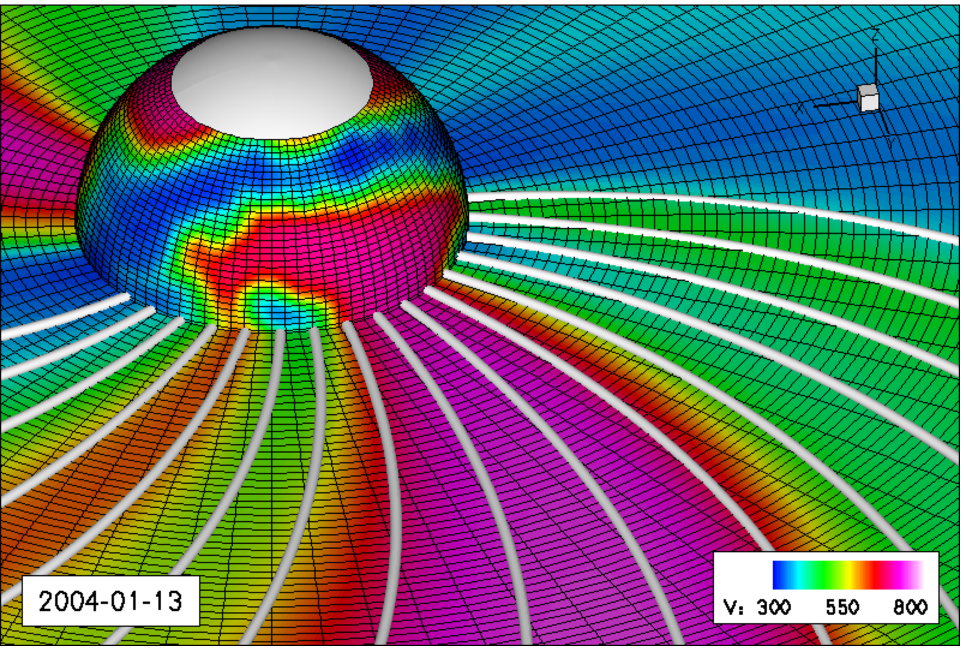


Prediction of Solar Wind Streams

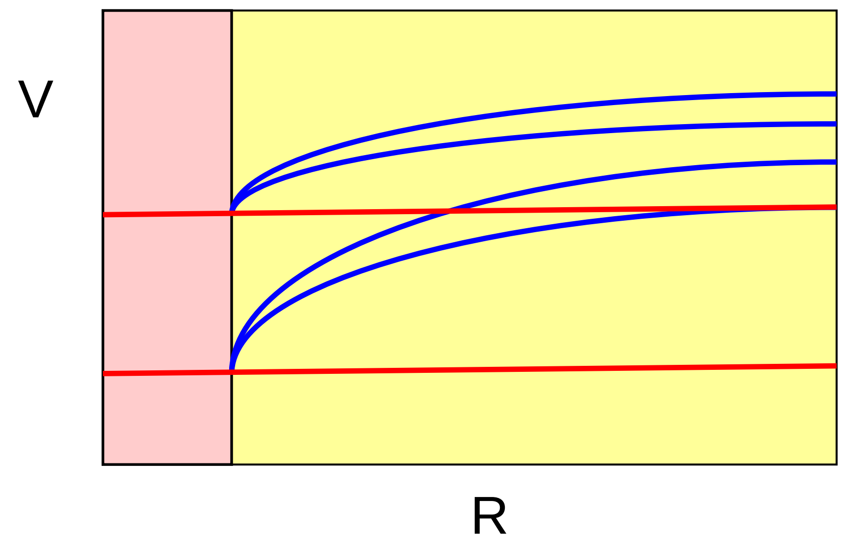


Calibration of Ambient Solar Wind

Solar wind velocity and IMF lines at the inner boundary (21.5 or 30 Rs)



Radial profiles of the solar wind flow velocity for WSA and ENLIL



- WSA model provides: Vr and Br
- ENLIL further needs: N, T, and Bphi

ENLIL needs to modify MAS or WSA solar wind flow speeds at the models interface boundary.

Ambient Solar Wind Parameters

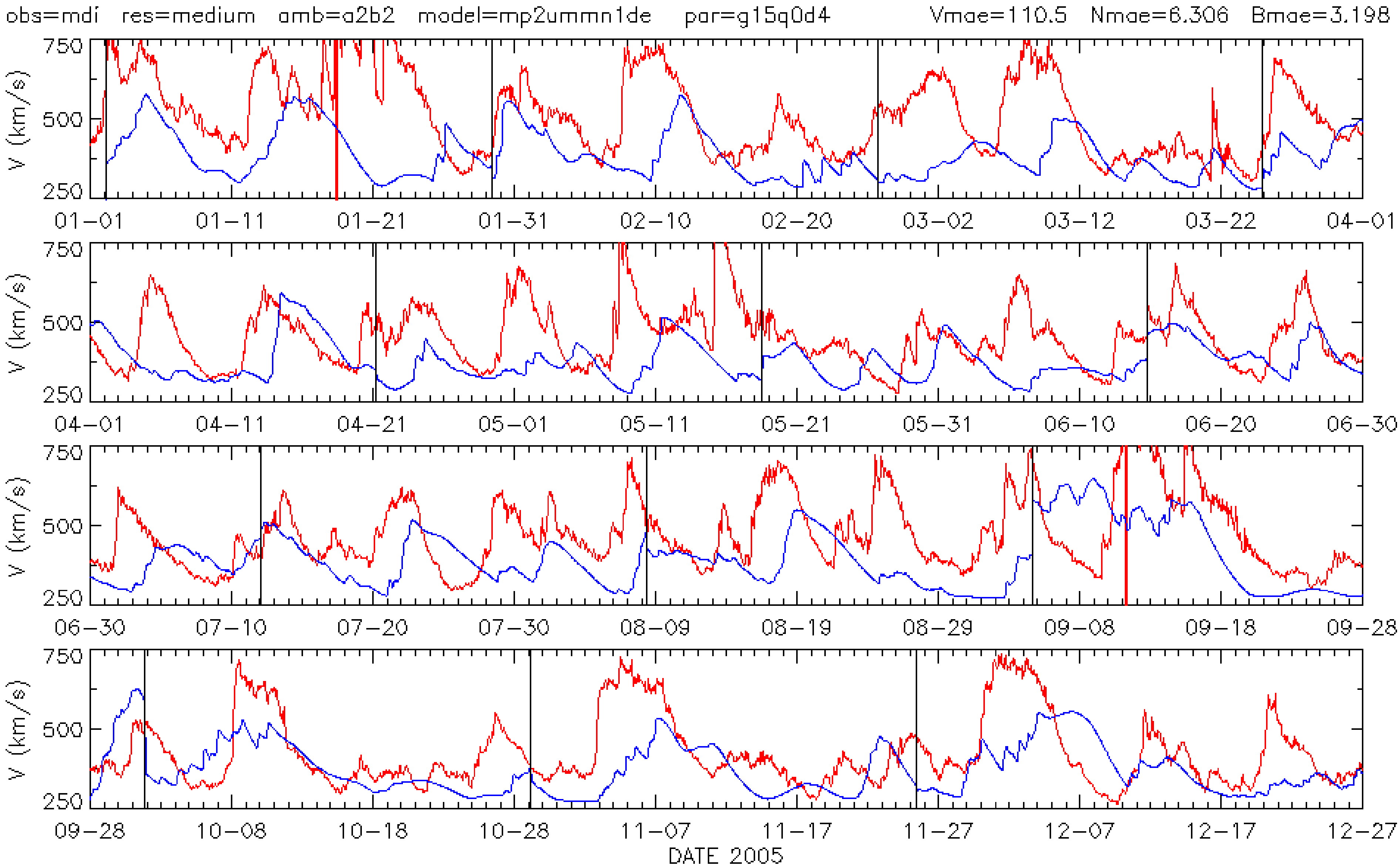
Basic Mode – Association with the Coronal Model and Resolution

Name	Title	Default	Range
cr	Carrington Rotation number	1922	1890 – present
resolution	Numerical grid resolution	low	low | medium

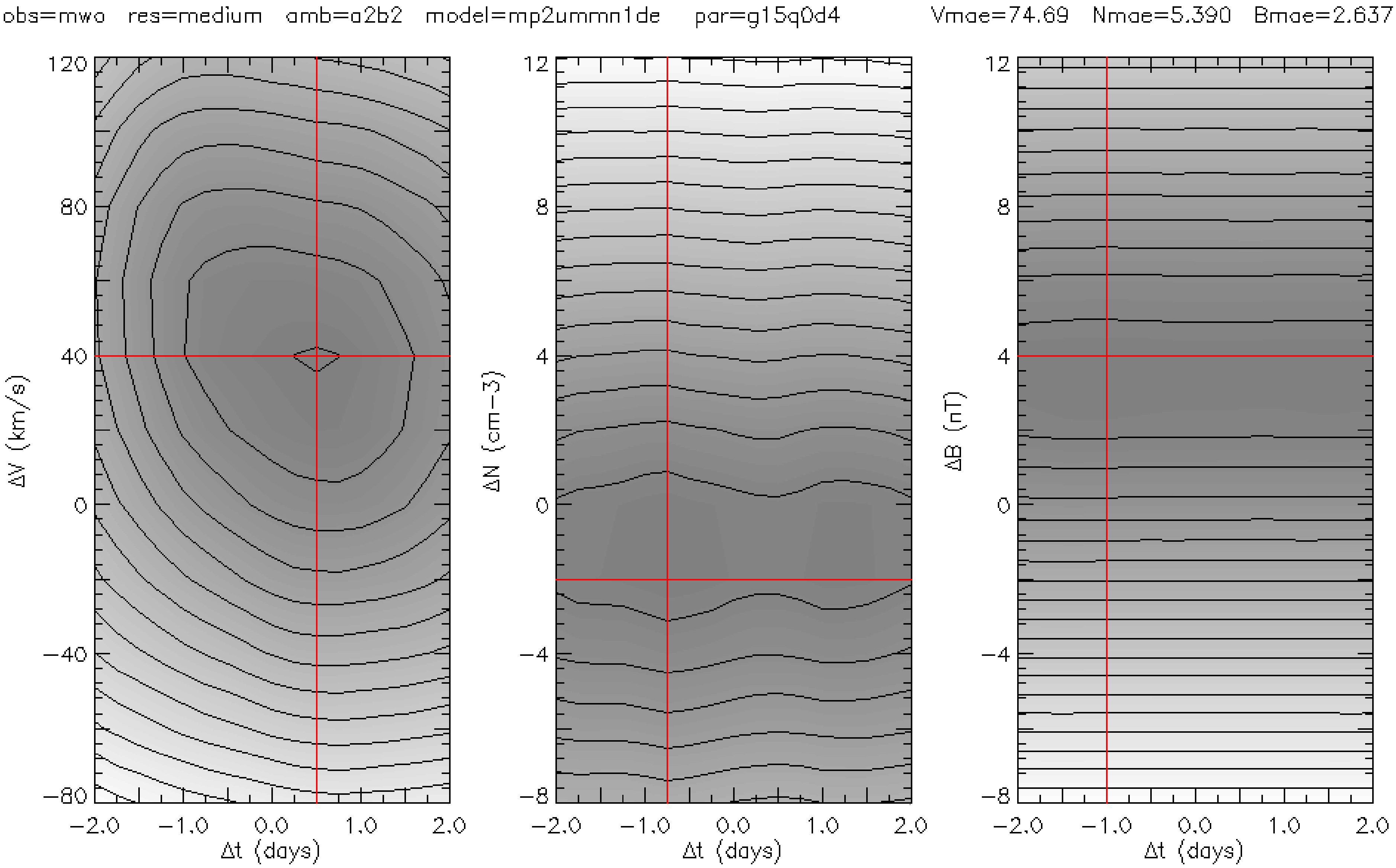
Advanced Mode – Free Parameters at the Inner Boundary

Name	Title	Default	Range
vfast	Radial flow velocity of fast stream (km/s)	650.	600. – 700.
dfast	Number density of fast stream (cm^{-3})	150.	100. – 200.
tfast	Temperature of fast stream (MK)	0.6	0.5 – 0.8
bfast	Radial magnetic field of fast stream (nT)	150.	100. – 200.
gamma	Ratio of specific heats	1.5	1.05 – 2.
xalpha	Fraction of alpha particles (rel. to protons)	0.	0. – 0.1
dvexp	Exponent in $N V^{dvexp}$ = const	2.	1. – 2.
nptot	=1 (=2) if P_{the} (P_{tot}) = const	1	1 | 2

Solar Wind – 2005 – MDI

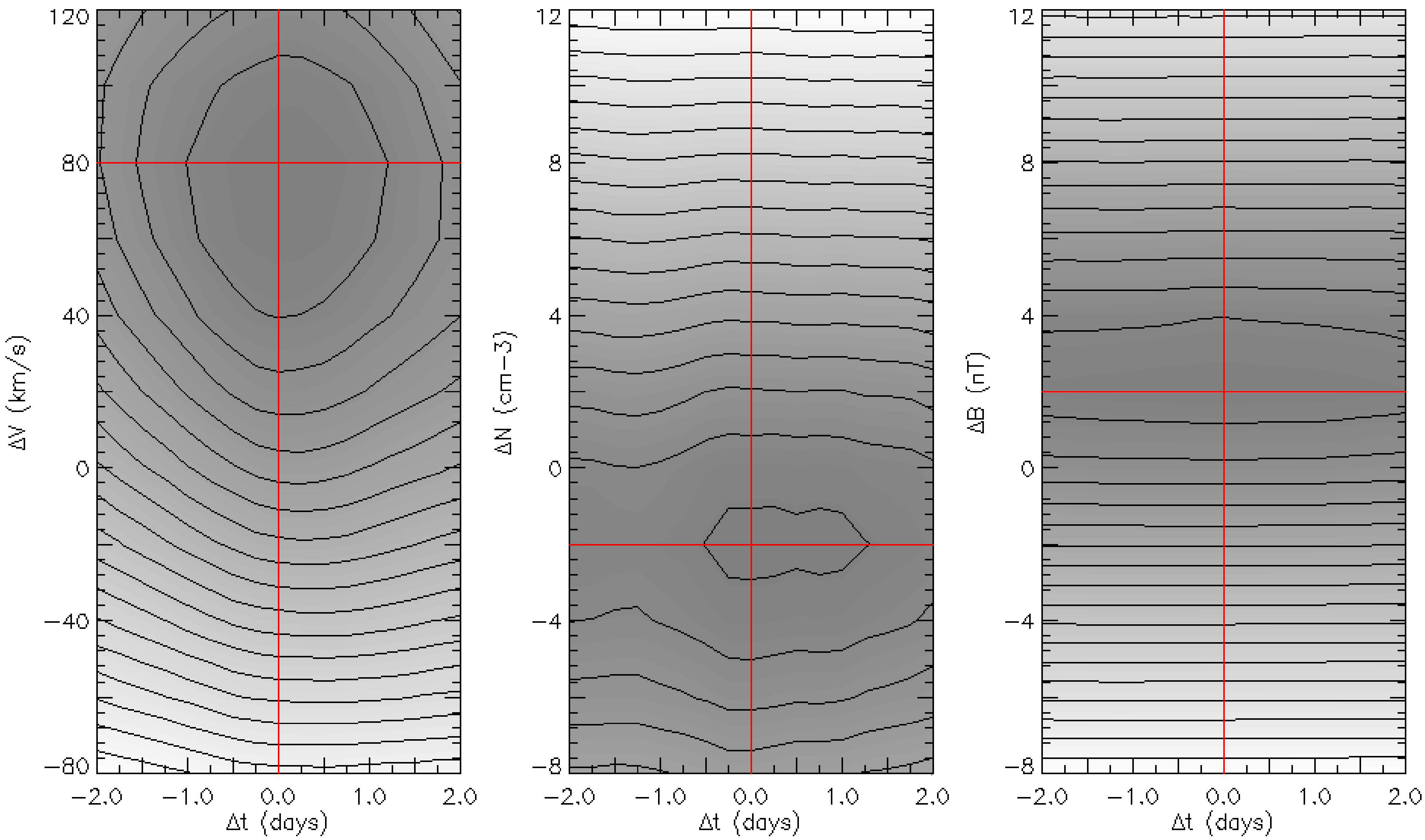


Solar Wind – 2005 – MWO

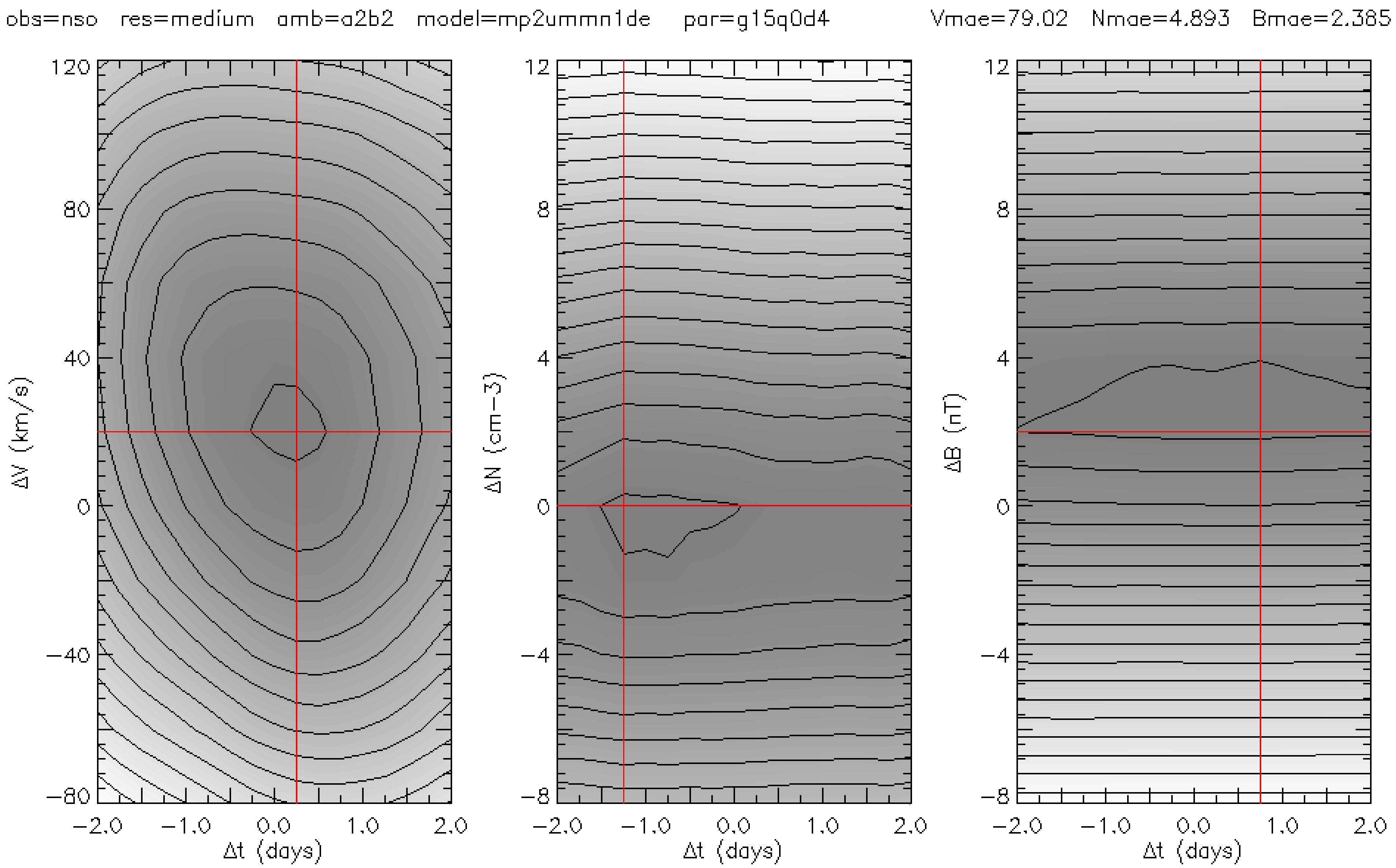


Solar Wind – 2005 – MDI

obs=mdi res=medium amb=a2b2 model=mp2ummn1de par=g15q0d4 Vmae=80.31 Nmae=5.638 Bmae=2.060

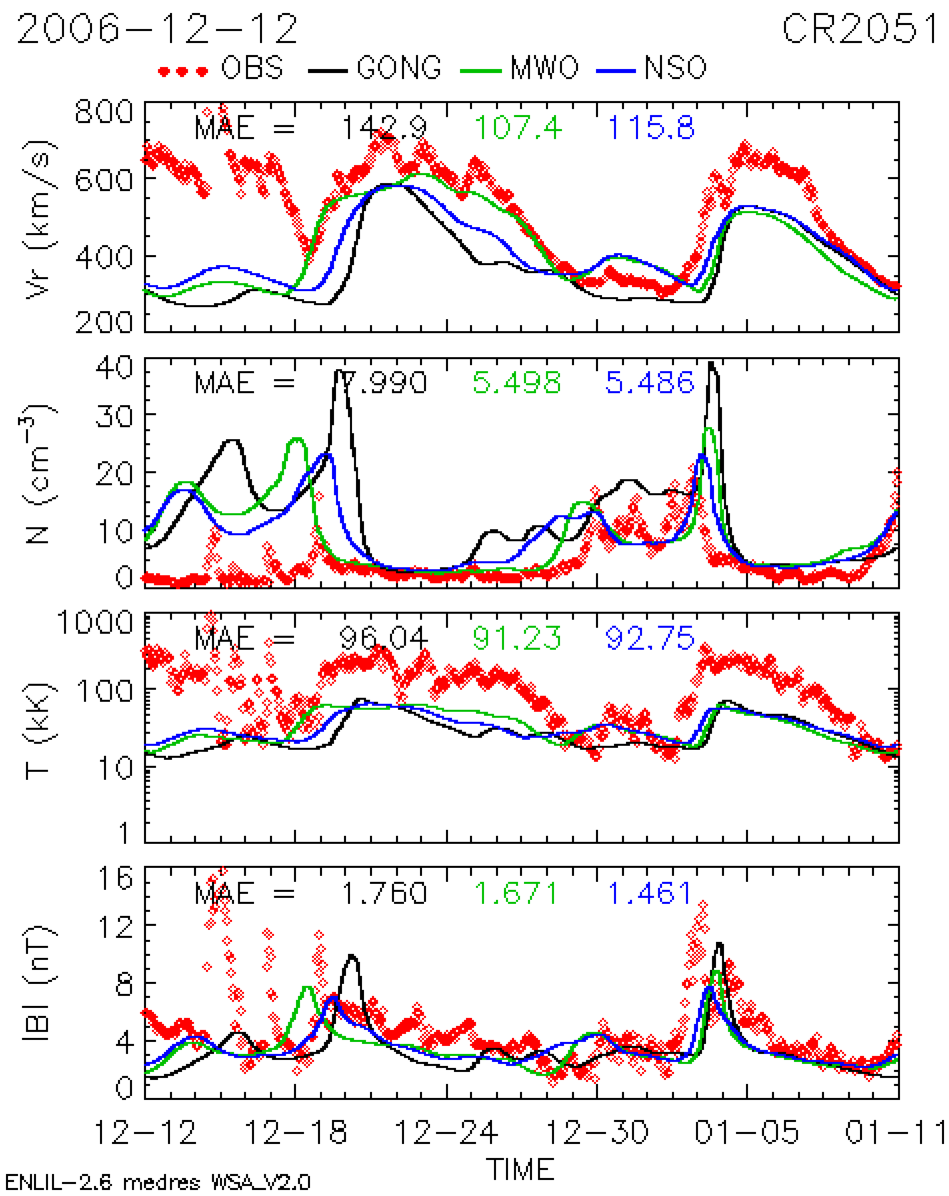


Solar Wind – 2005 – NSO

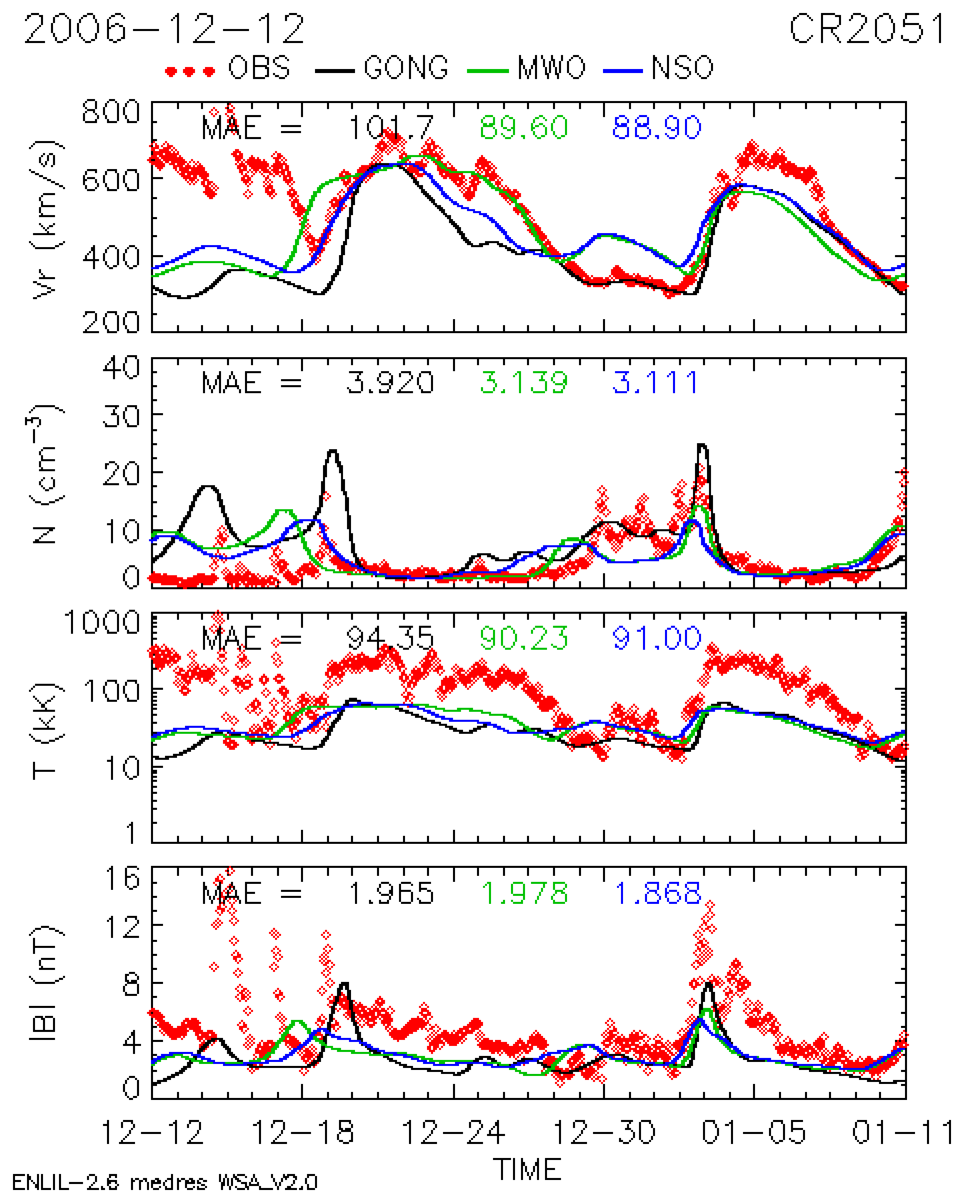


Solar Wind – 2007 – CR2051

a2b2

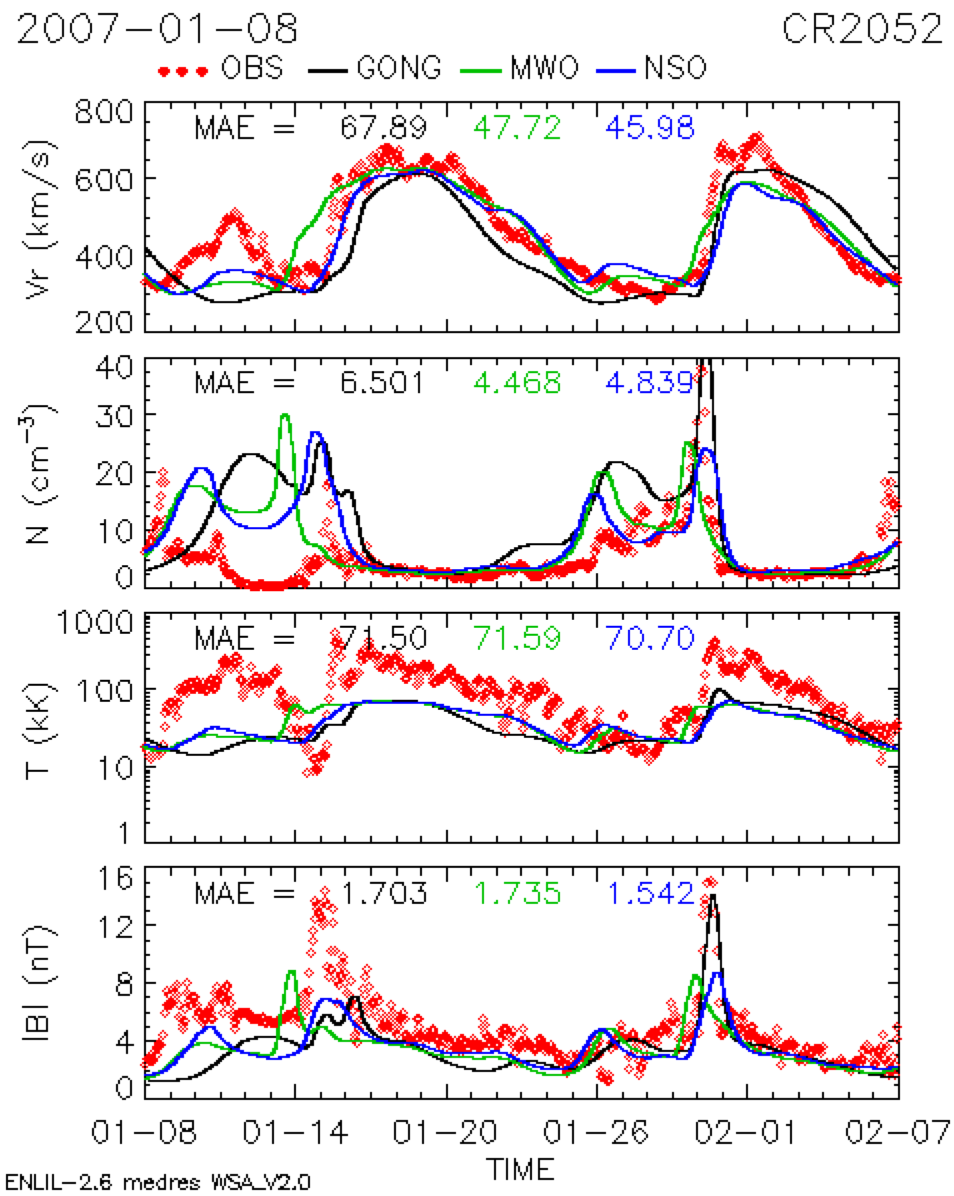


a3b2



Solar Wind – 2007 – CR2052

a2b2



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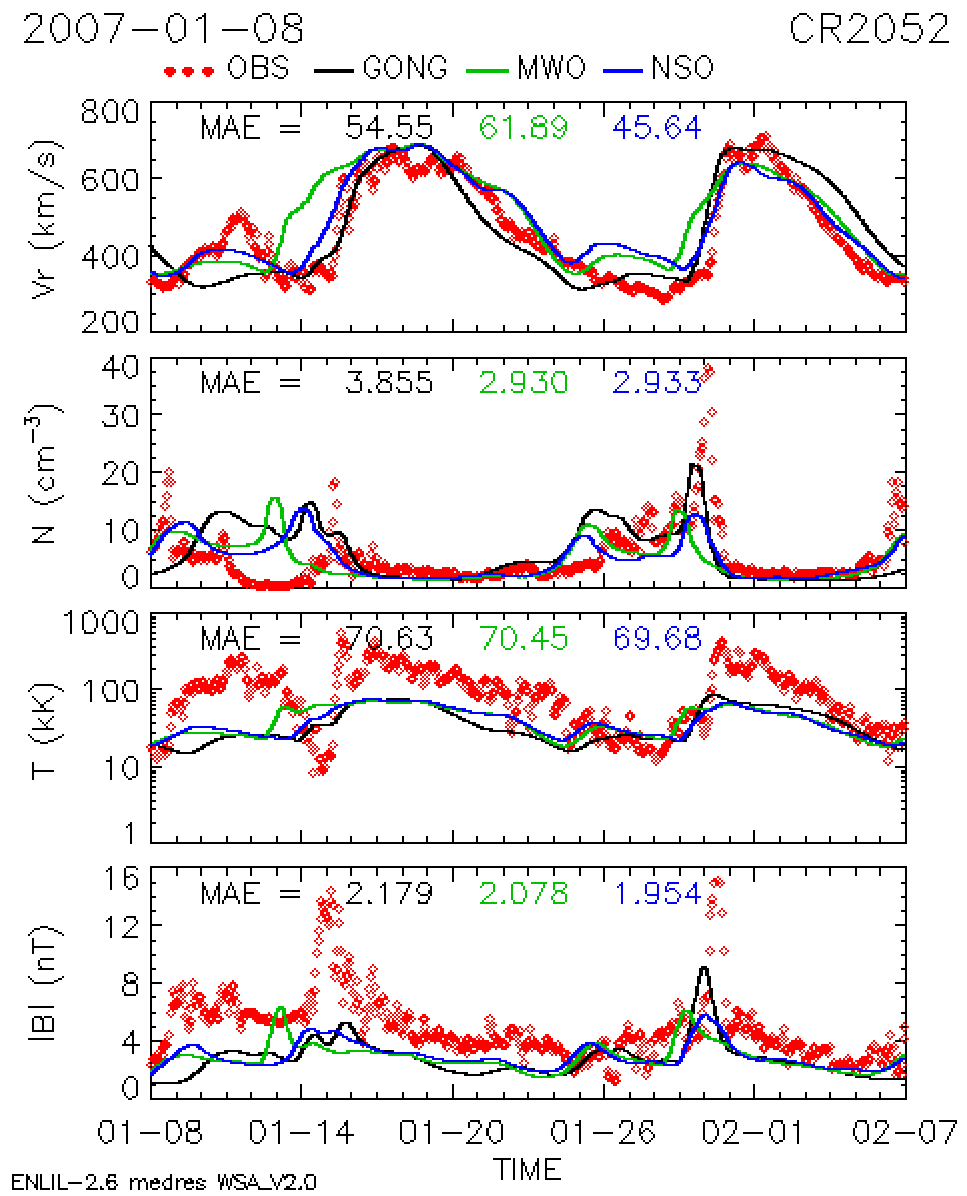
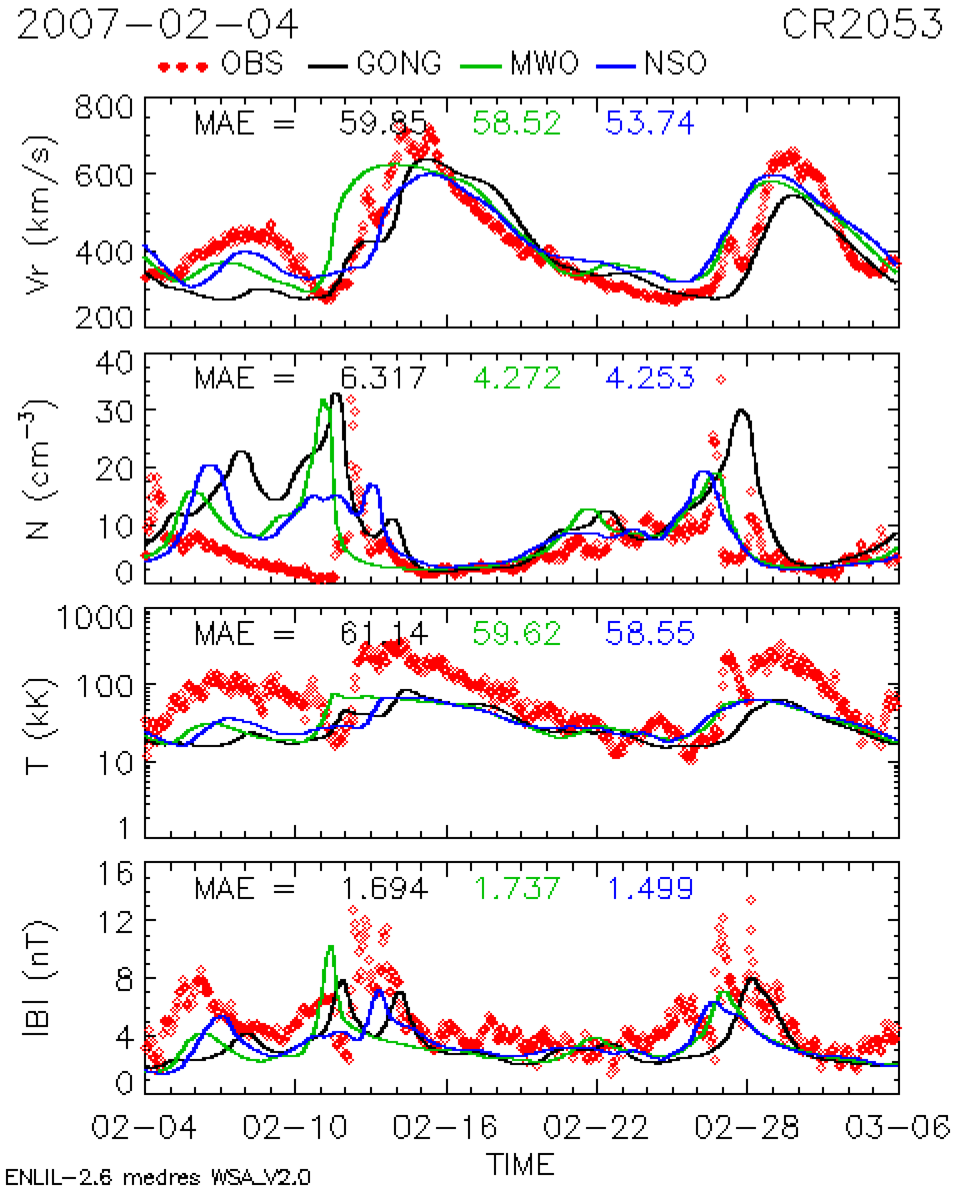


Solar Wind – 2007 – CR2053

a2b2



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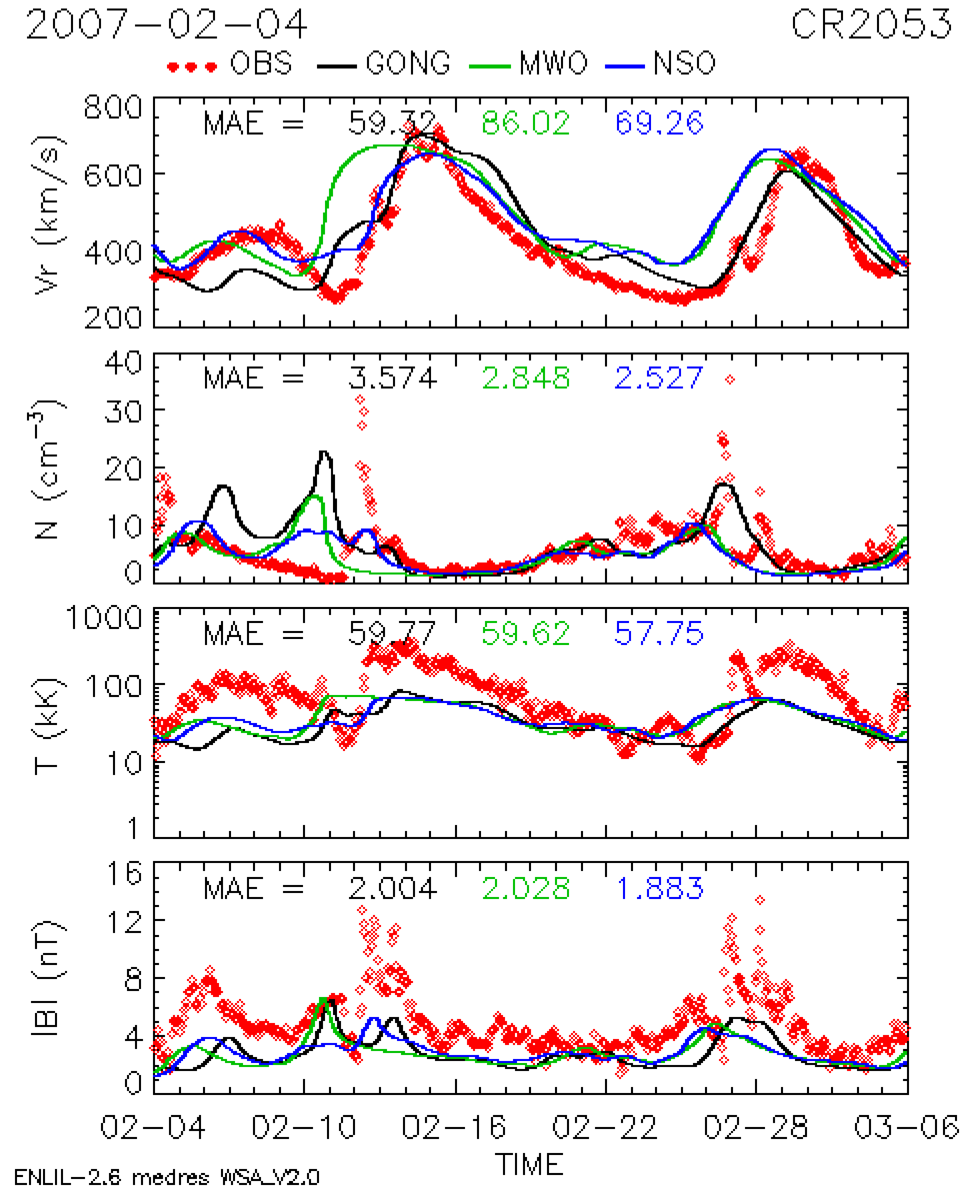
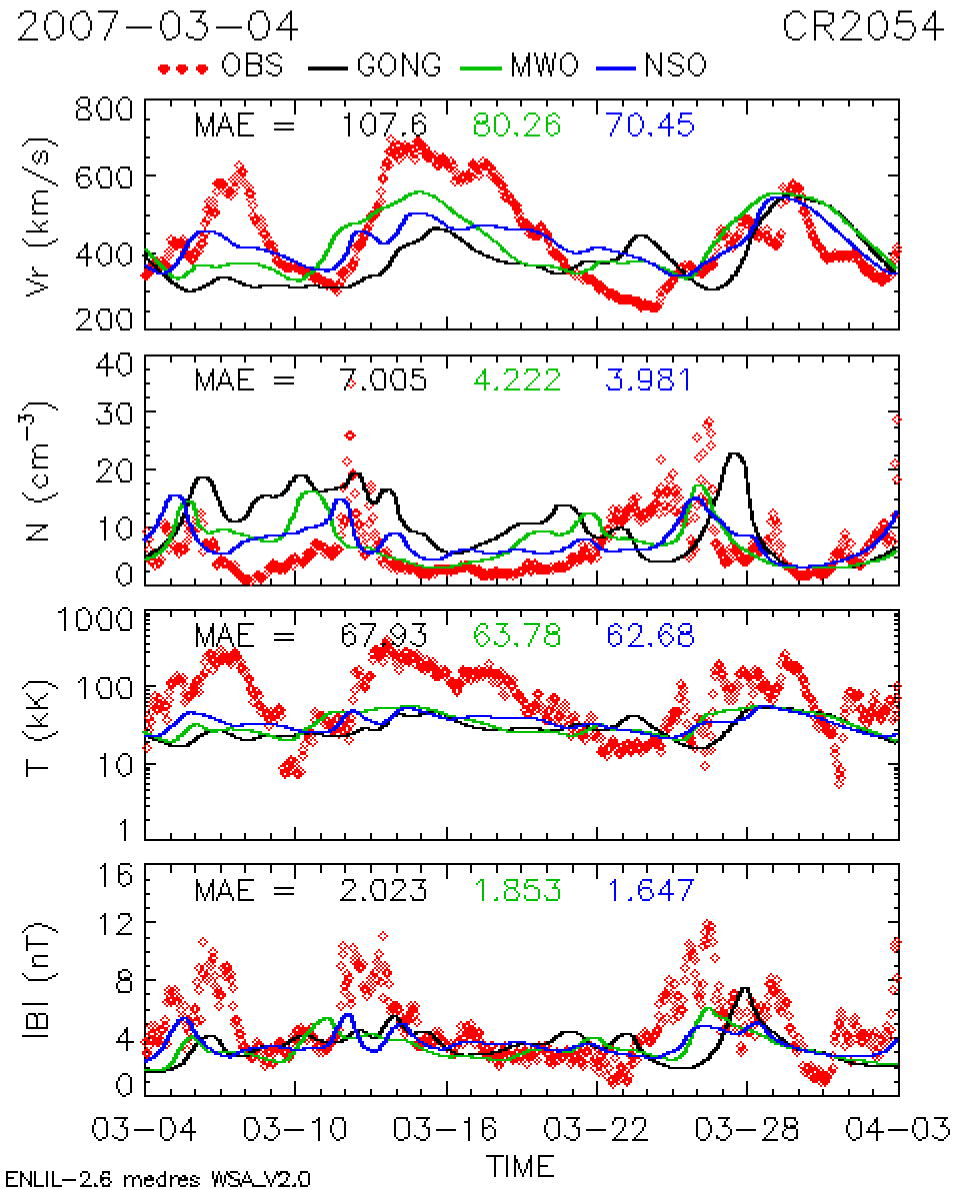


Solar Wind – 2007 – CR2054

a2b2



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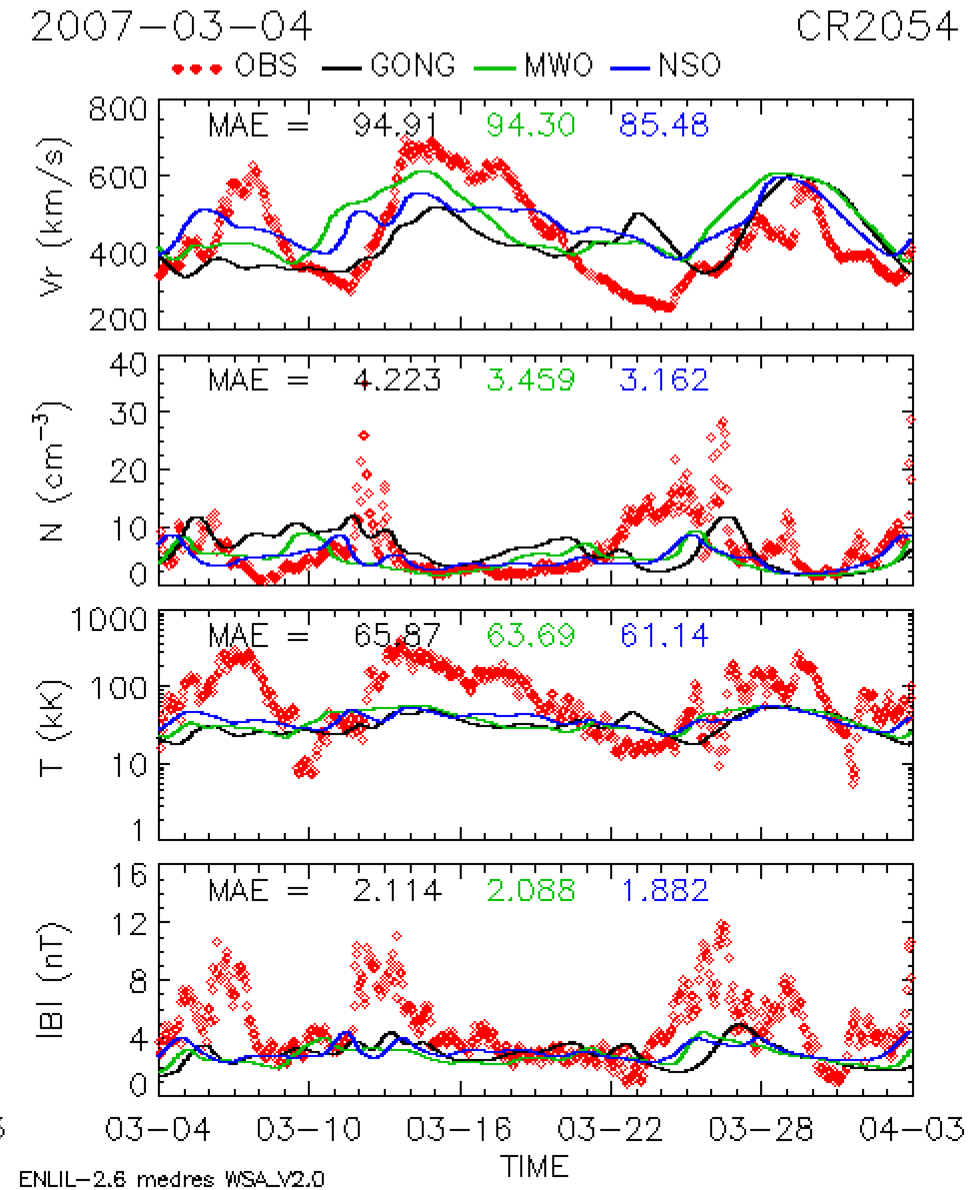
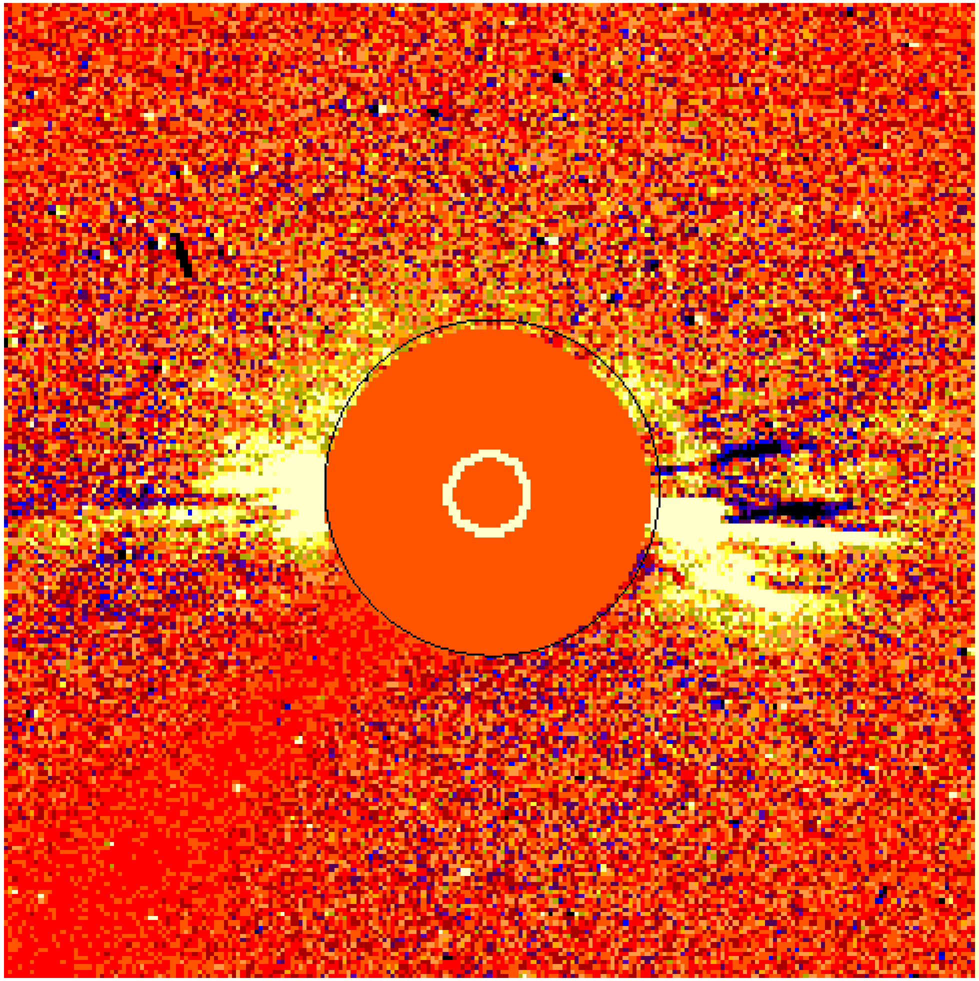


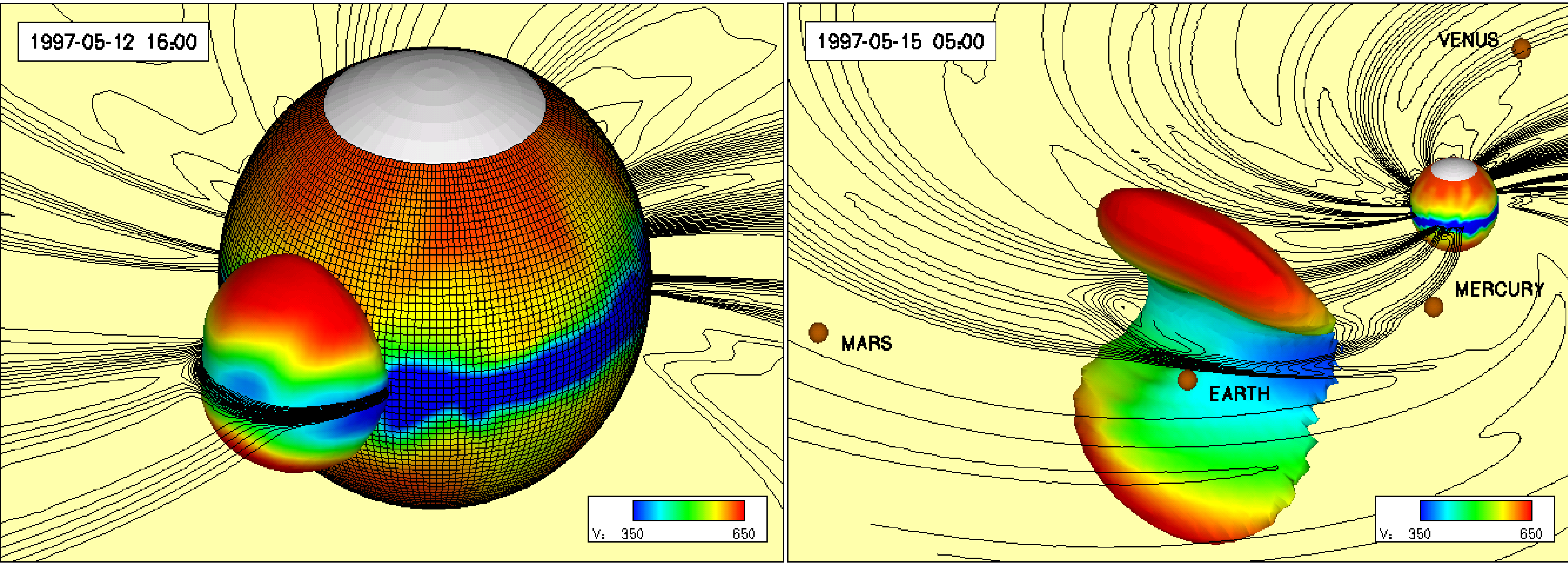
Launching of Hydrodynamic ICMEs

May 12, 1997 Halo CME



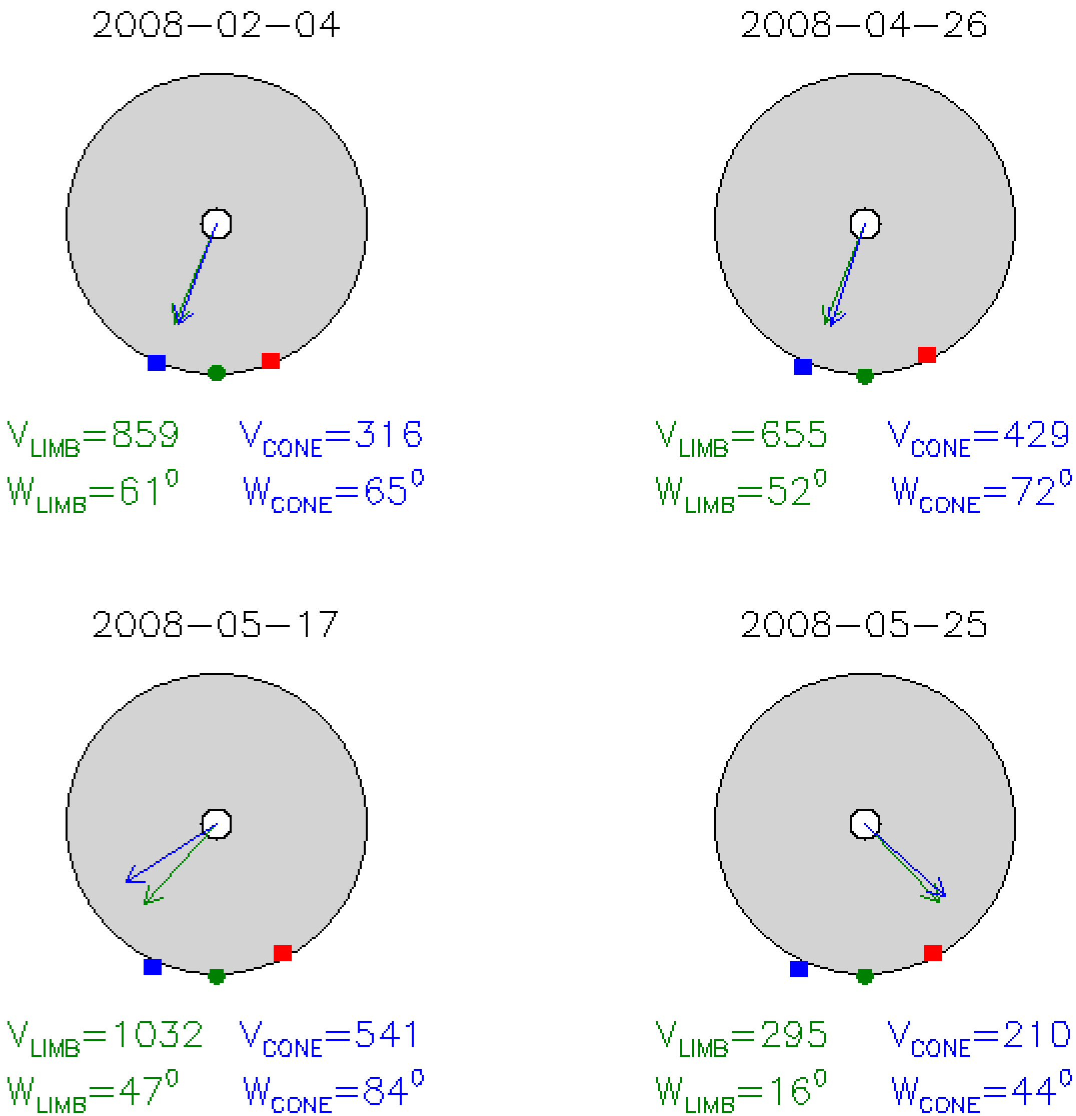
Running difference images fitted by the cone model [*Zhao et al.*, 2002]

Transient Disturbances

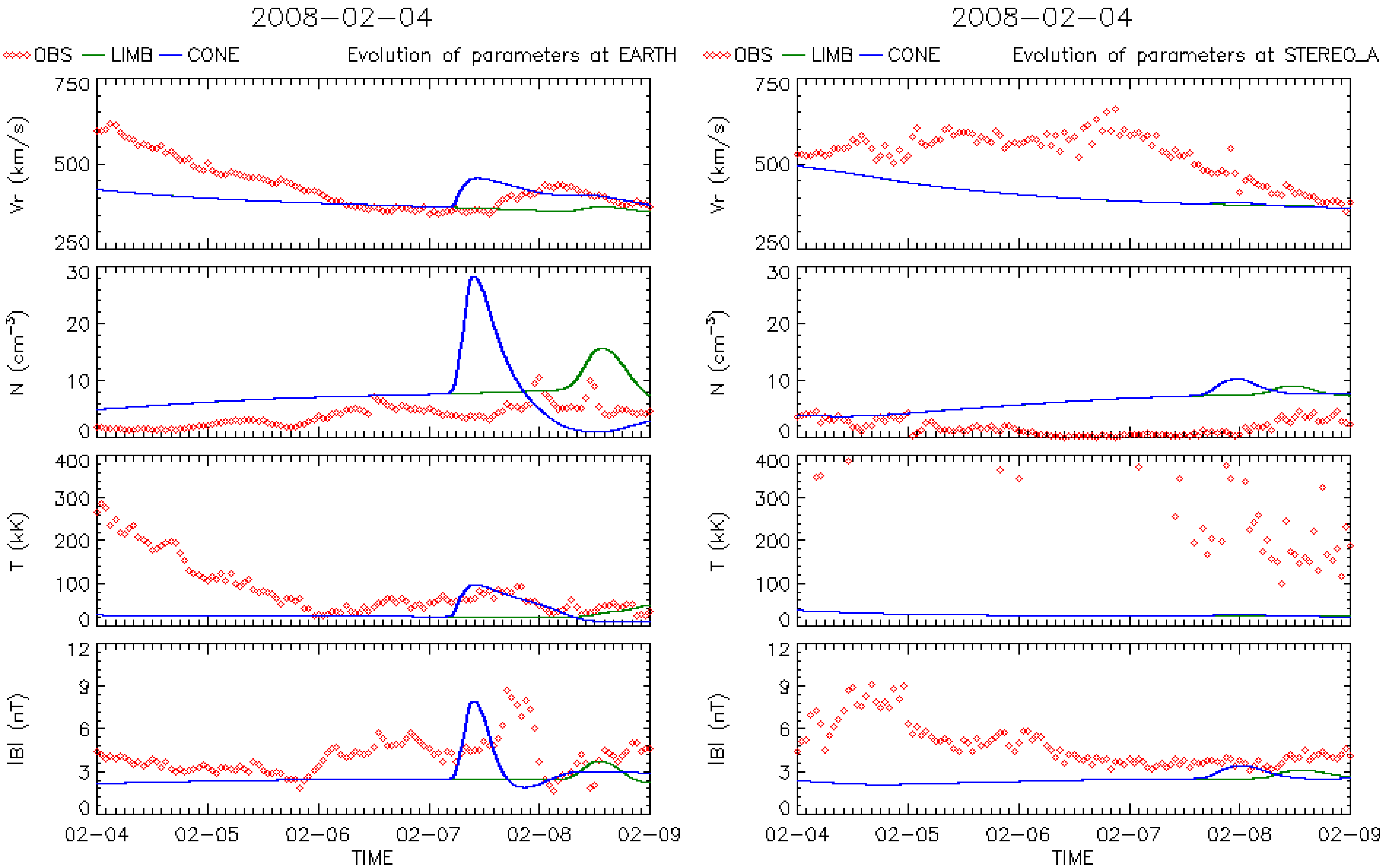


Modeling of the origin of CMEs is still in the research phases and it is not expected that real events can be routinely simulated in near future. Therefore, we have developed an intermediate modeling system which uses the WSA coronal maps, fitted coronagraph observations, specifies 3D ejecta, and drives 3D numerical code ENLIL.

Limb vs. Halo CME Speeds



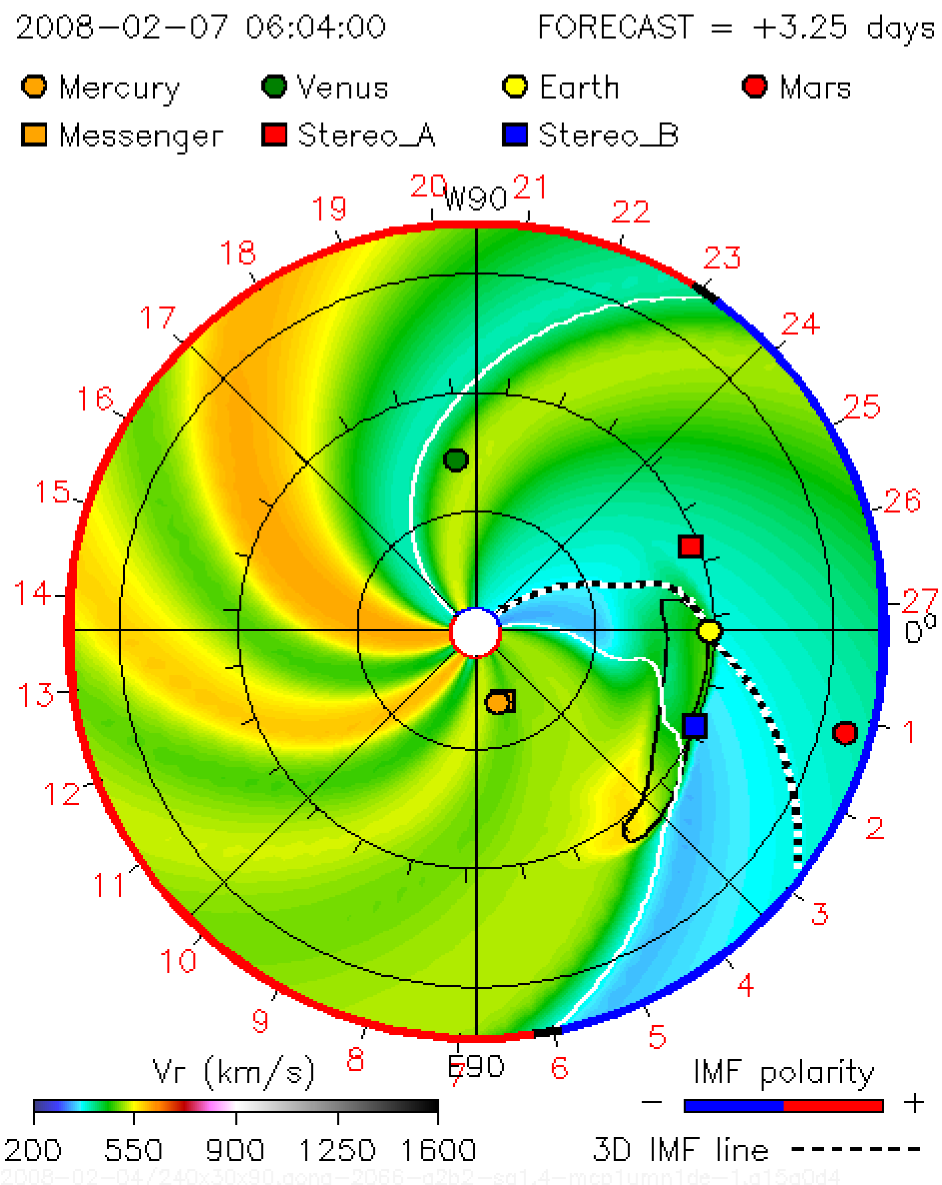
Limb vs. Halo CME Speeds: 2008-02-04

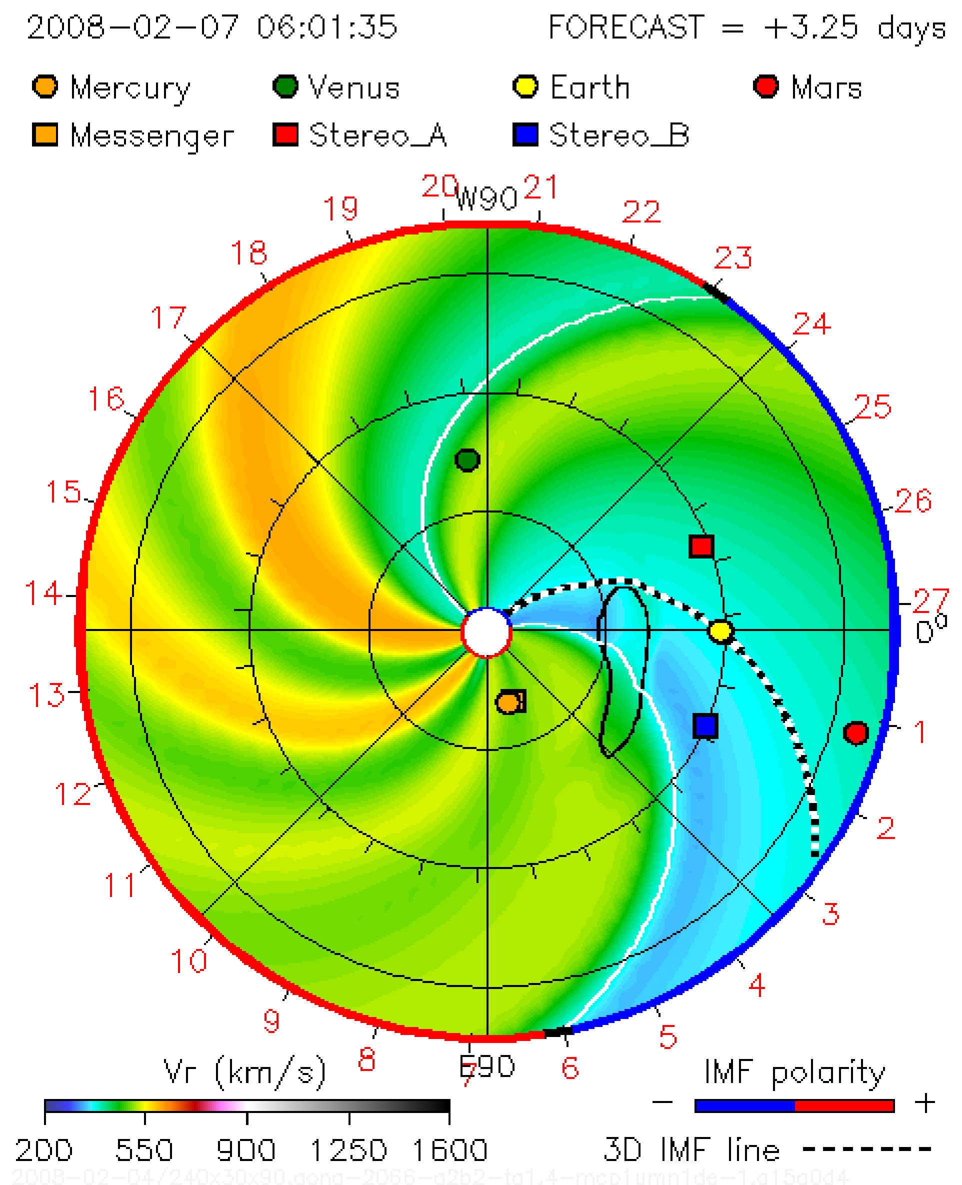


Limb vs. Halo CME Speeds: 2008-02-04

STEREO Model

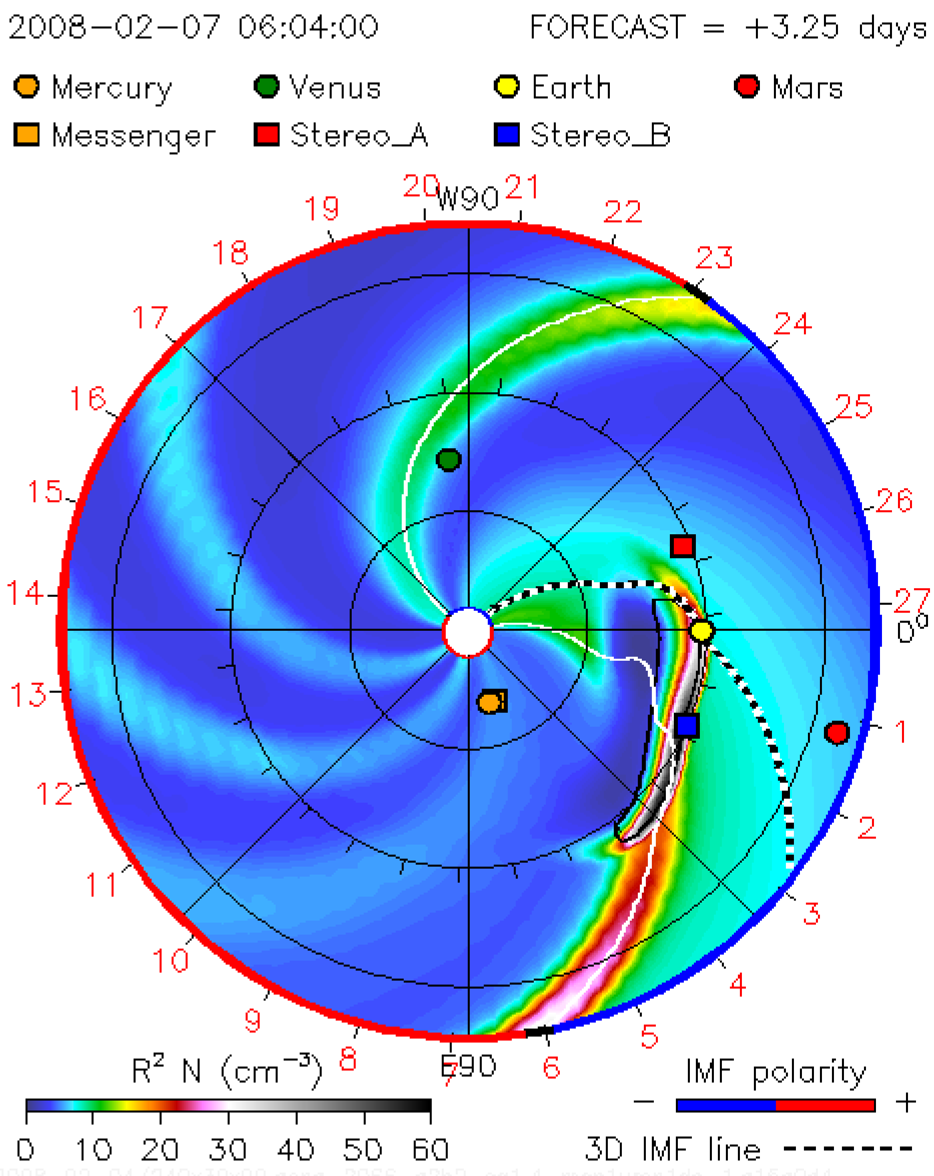
Cone Model



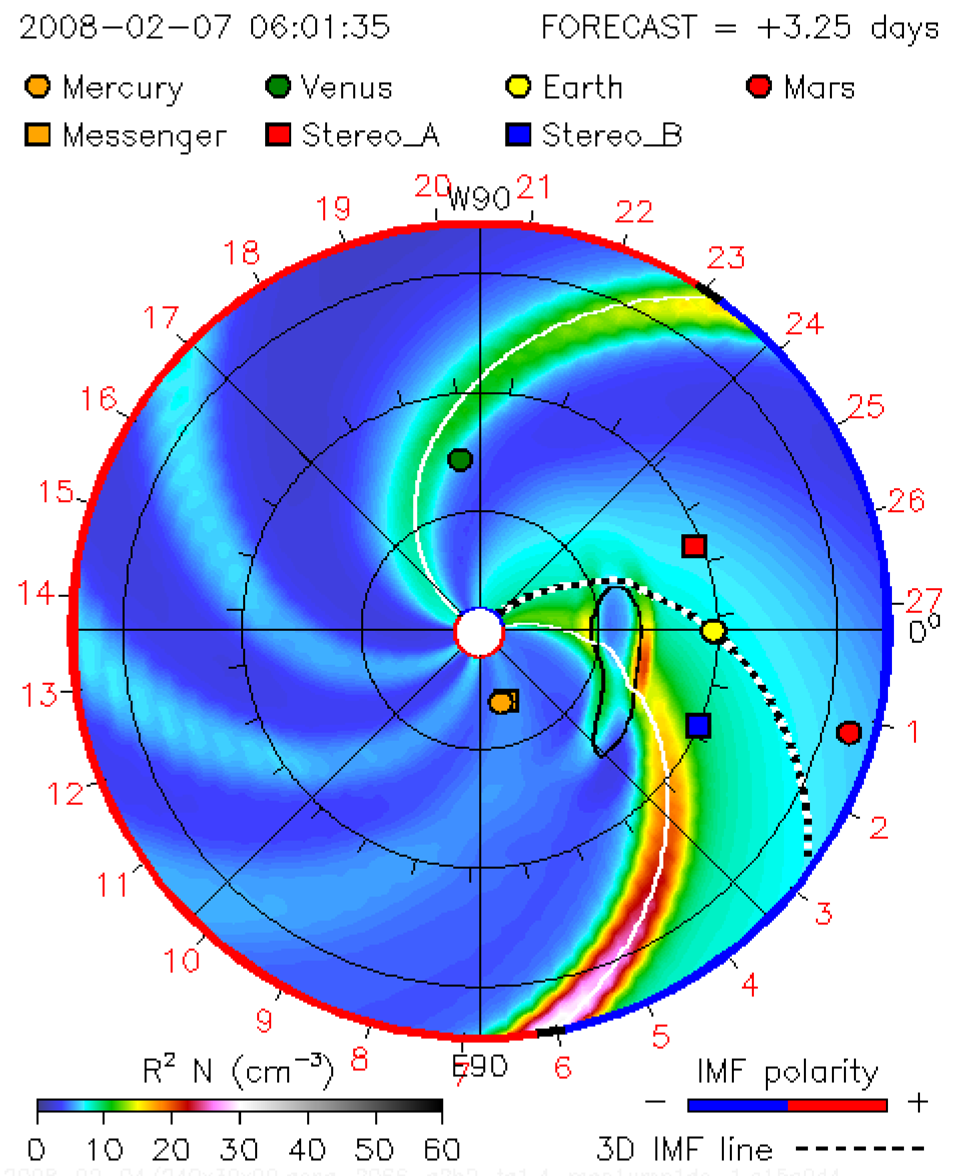


Limb vs. Halo CME Speeds: 2008-02-04

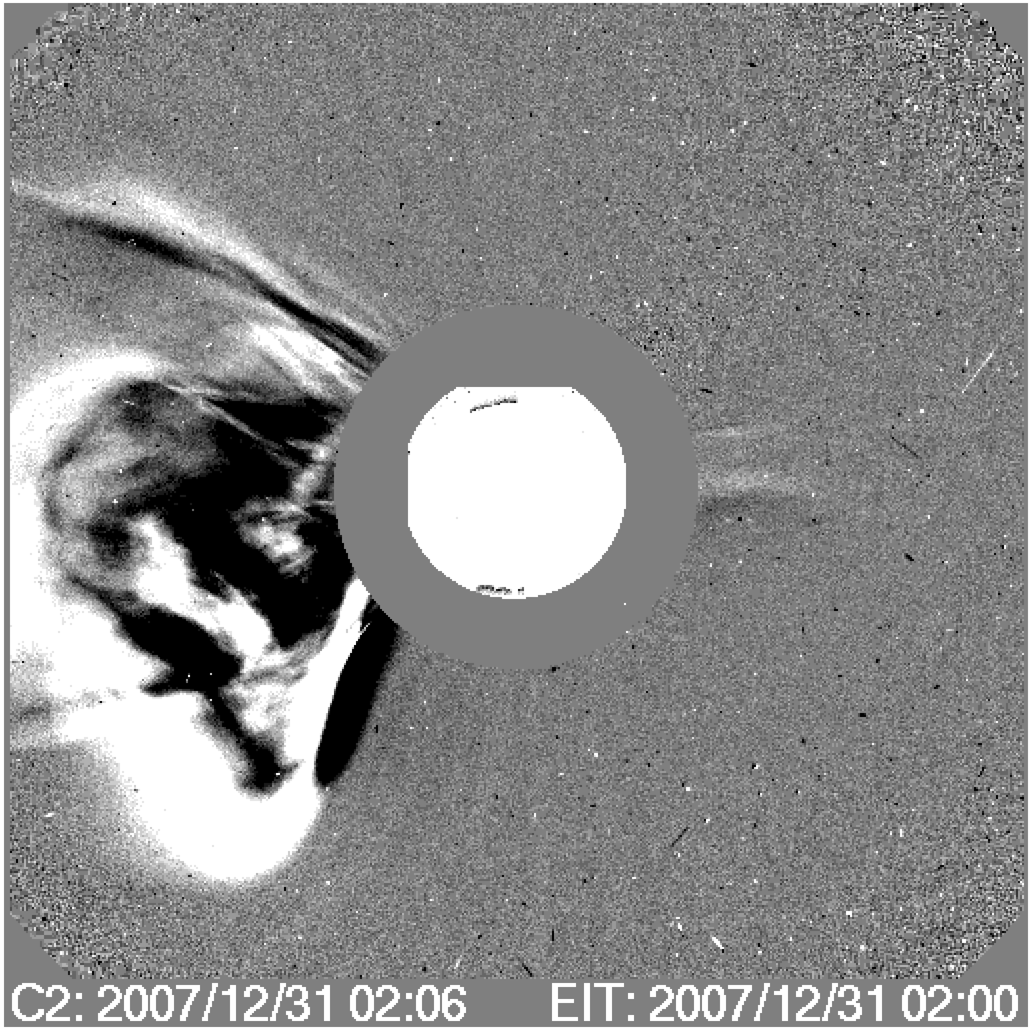
STEREO Model



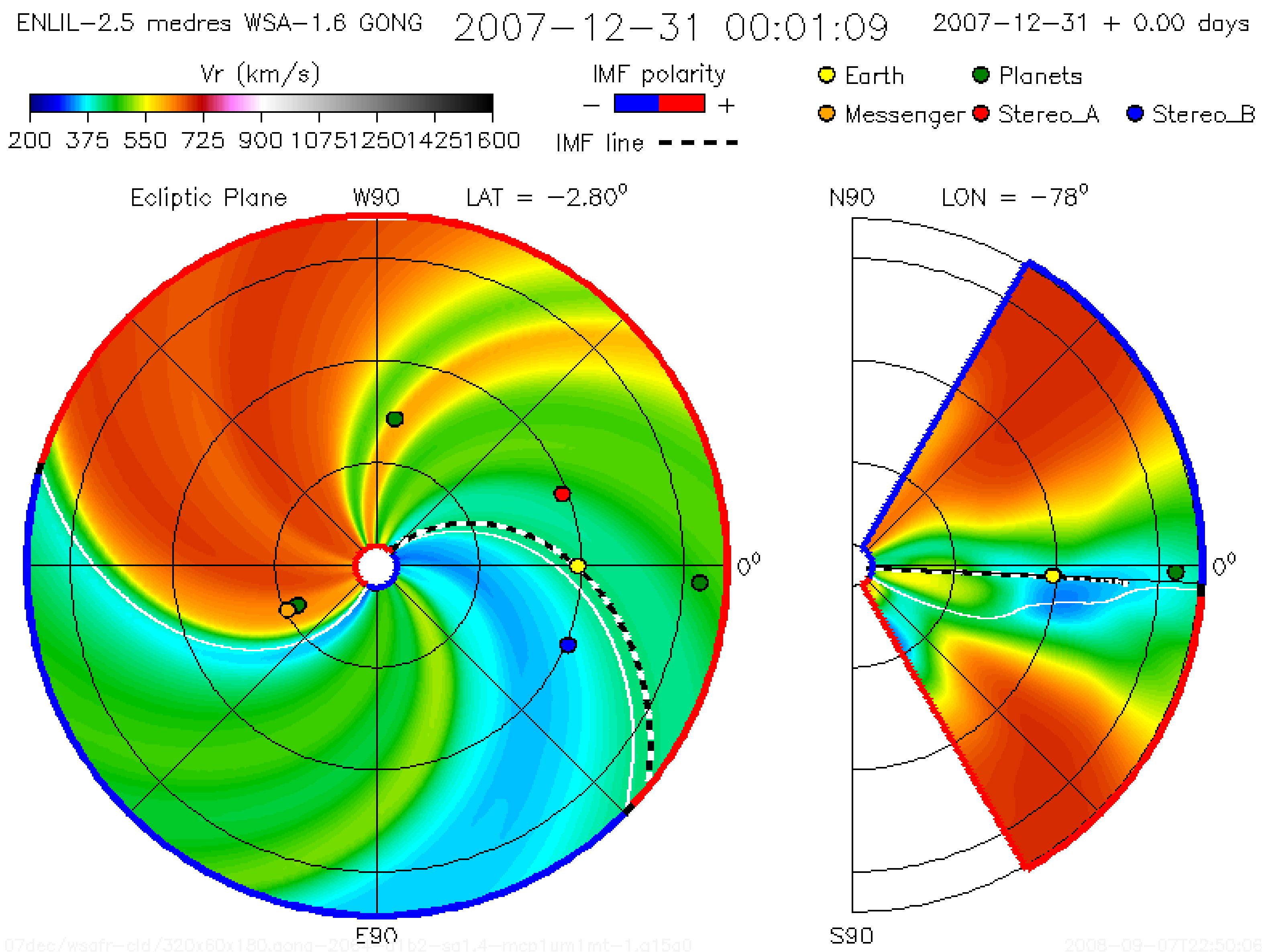
Cone Model



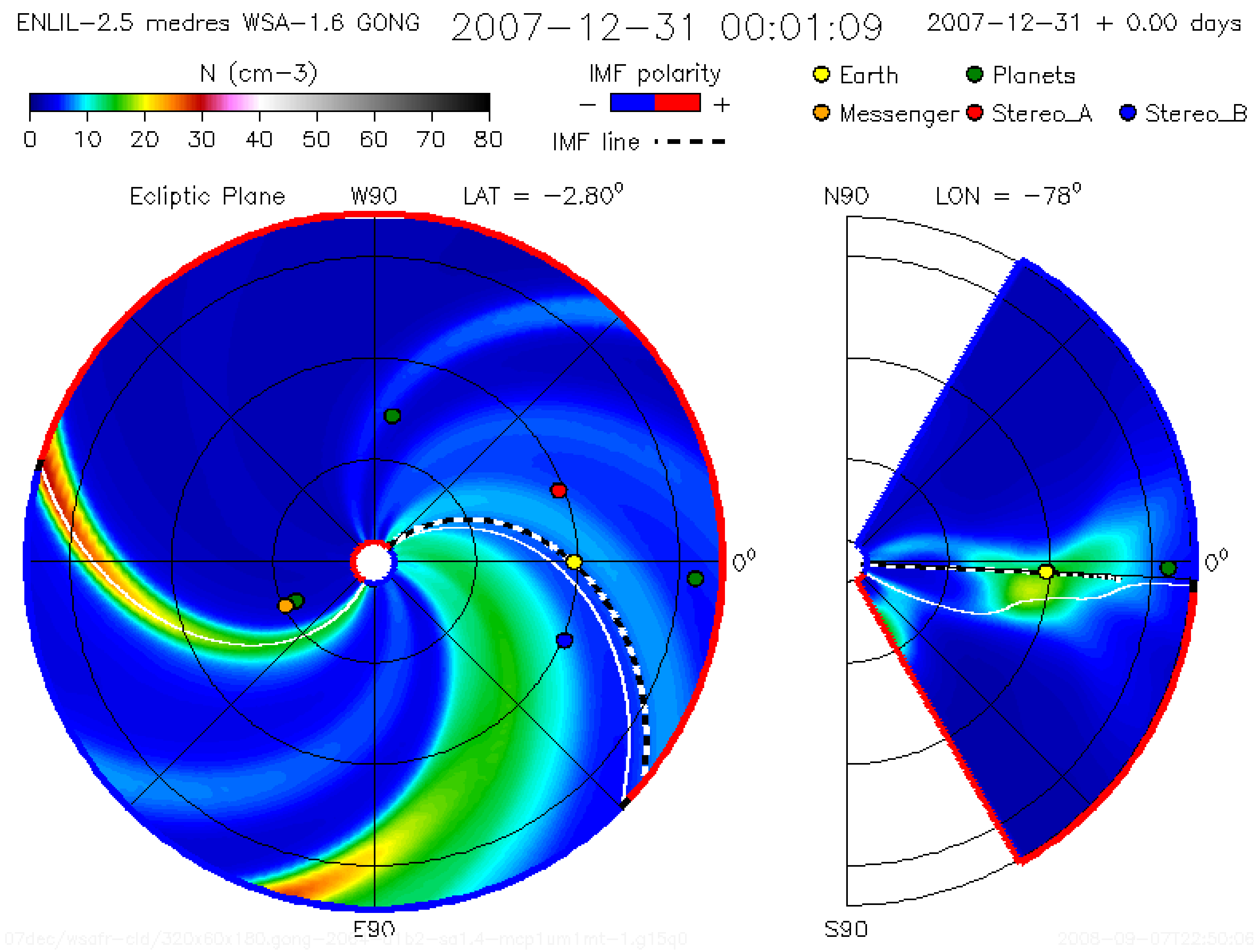
2007 December 31 ICME Event



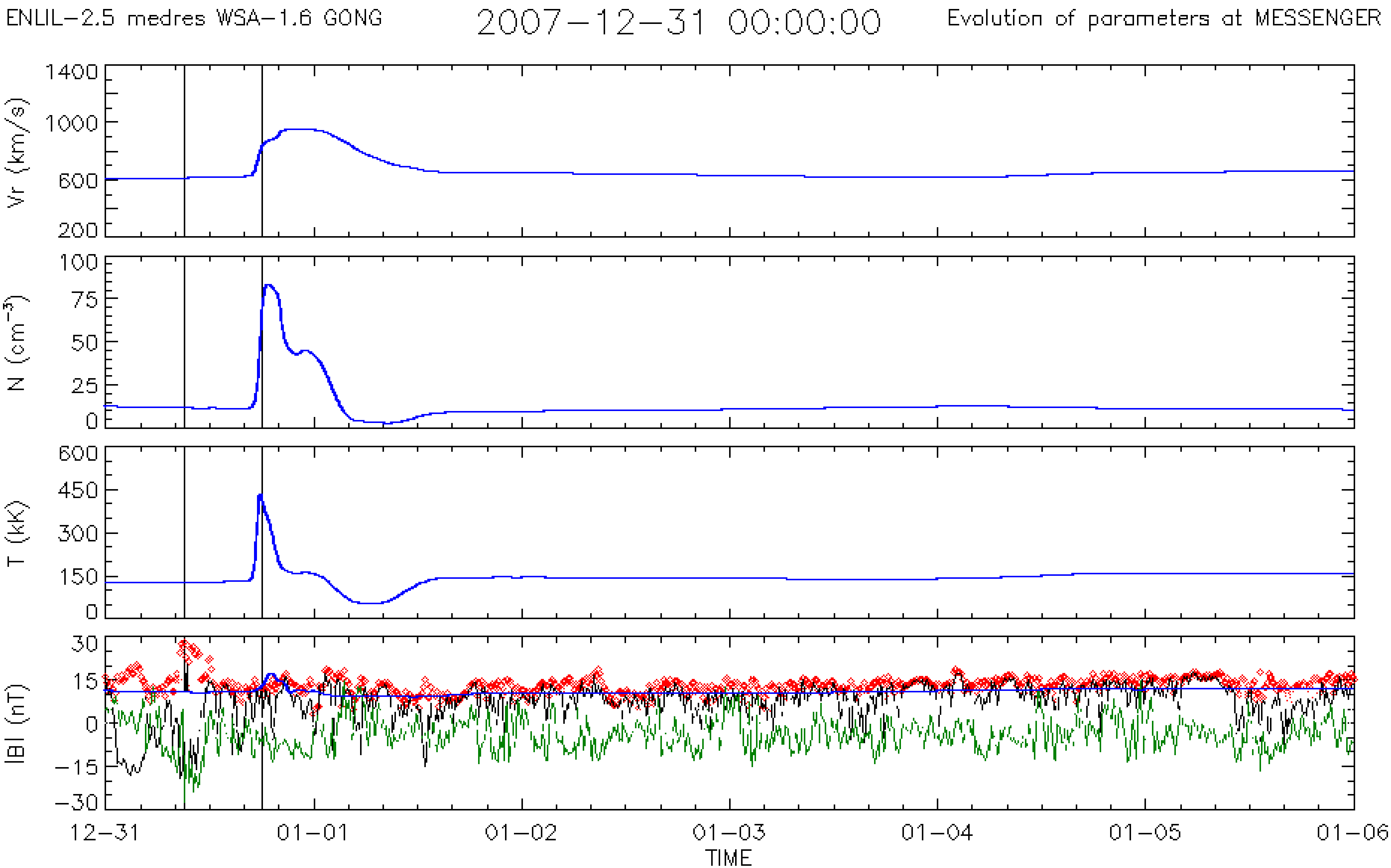
2007 December 31 ICME Event



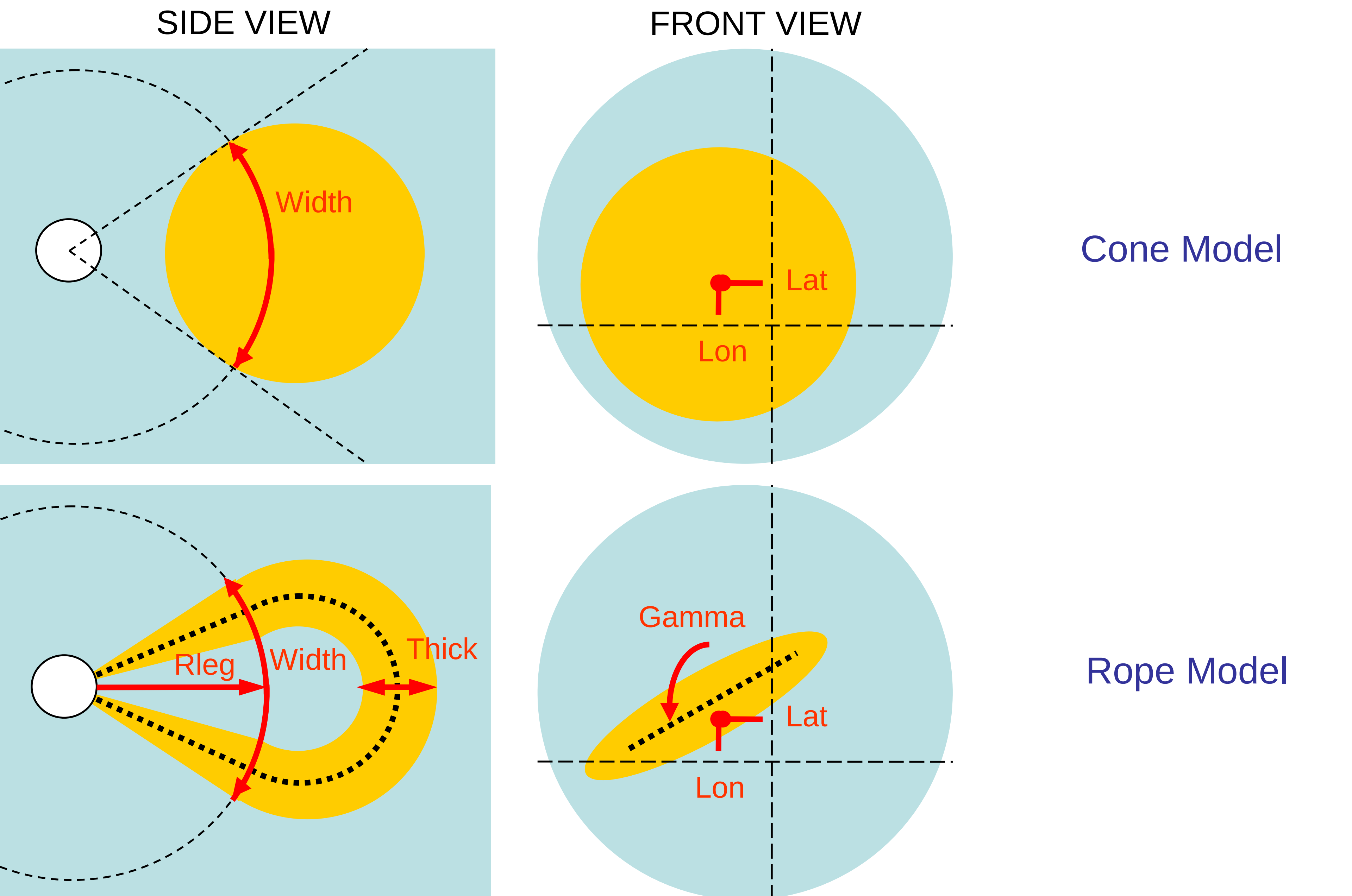
2007 December 31 ICME Event



2007 December 31 ICME Event



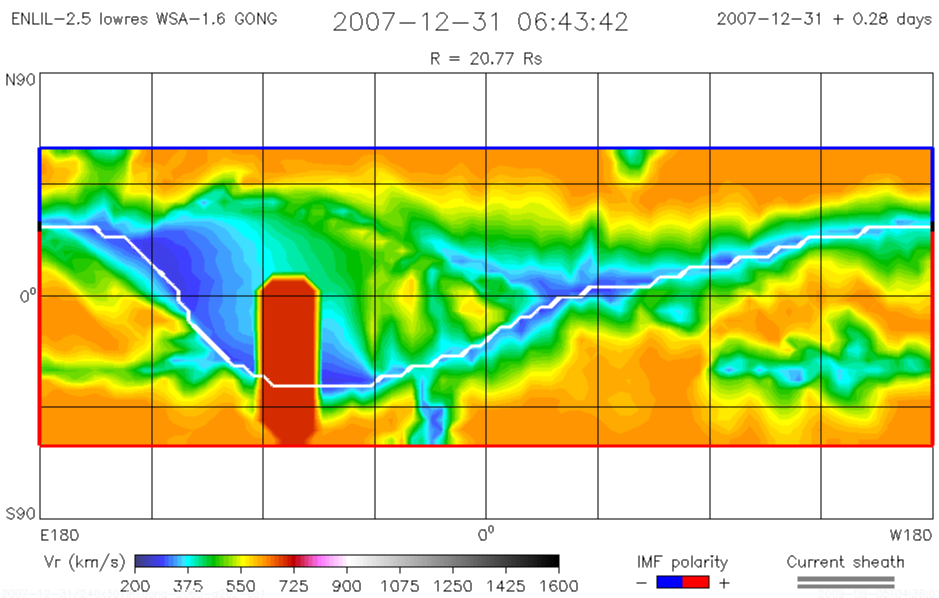
ICME – Hydrodynamic Models

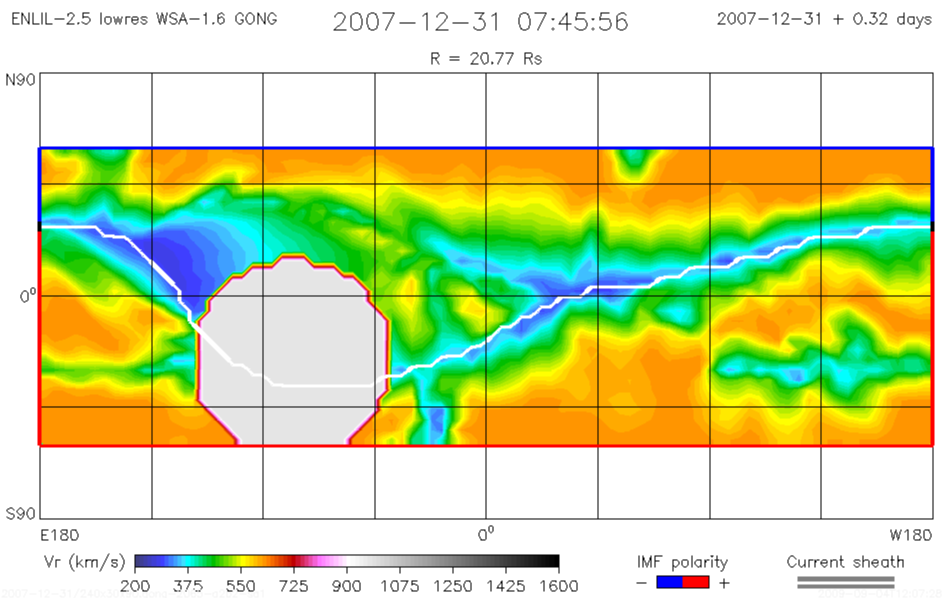


2007-12-31

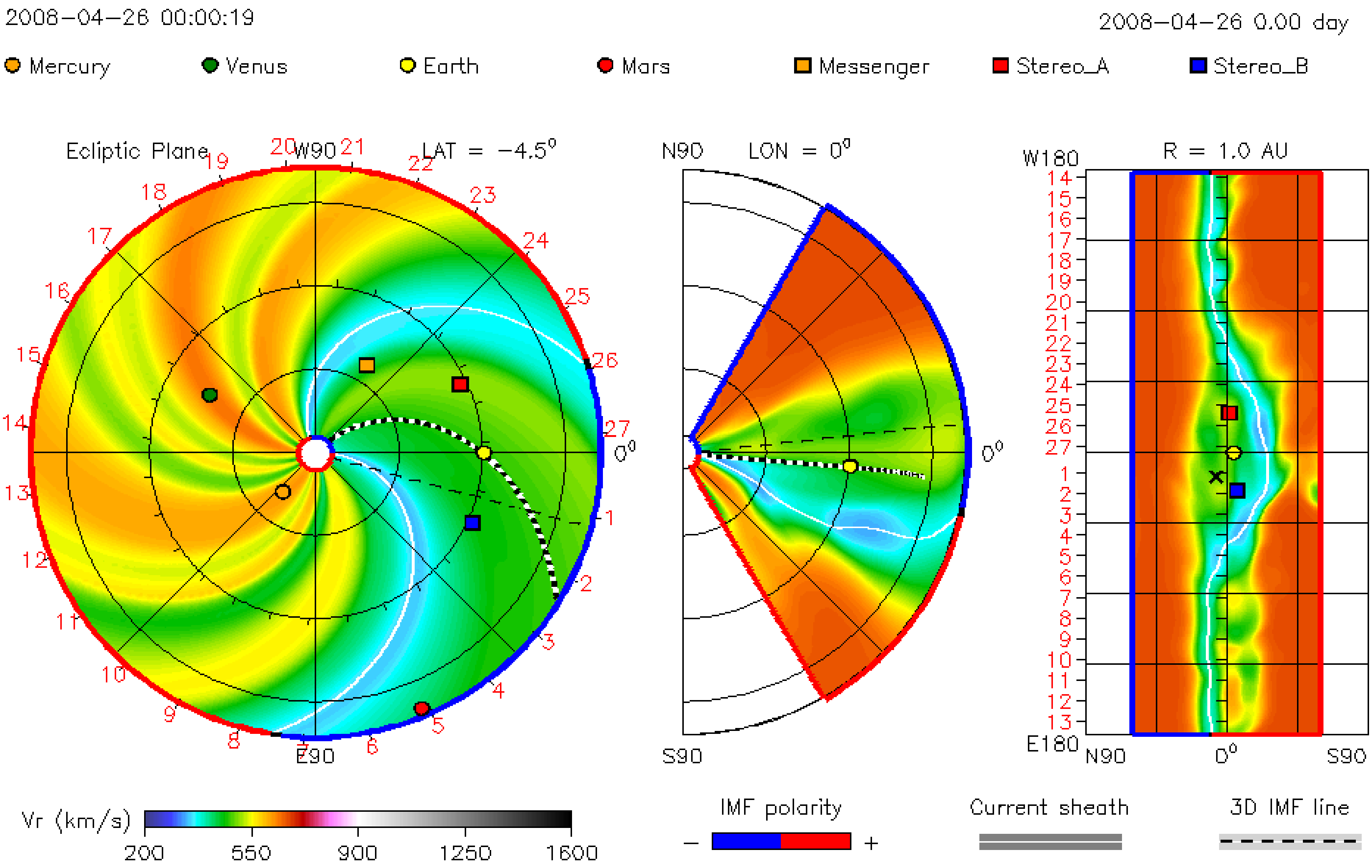
FLUX-ROPE MODEL	
Latitude (deg)	-25
Longitude (deg)	-80
Width (deg)	79
Time (hh:mm)	04:55
Velocity (km/s)	972
Thickness (deg)	24
Gamma (deg)	0

CONE MODEL	
Latitude (deg)	-25
Longitude (deg)	-80
Width (deg)	79
Time (hh:mm)	04:55
Velocity (km/s)	972

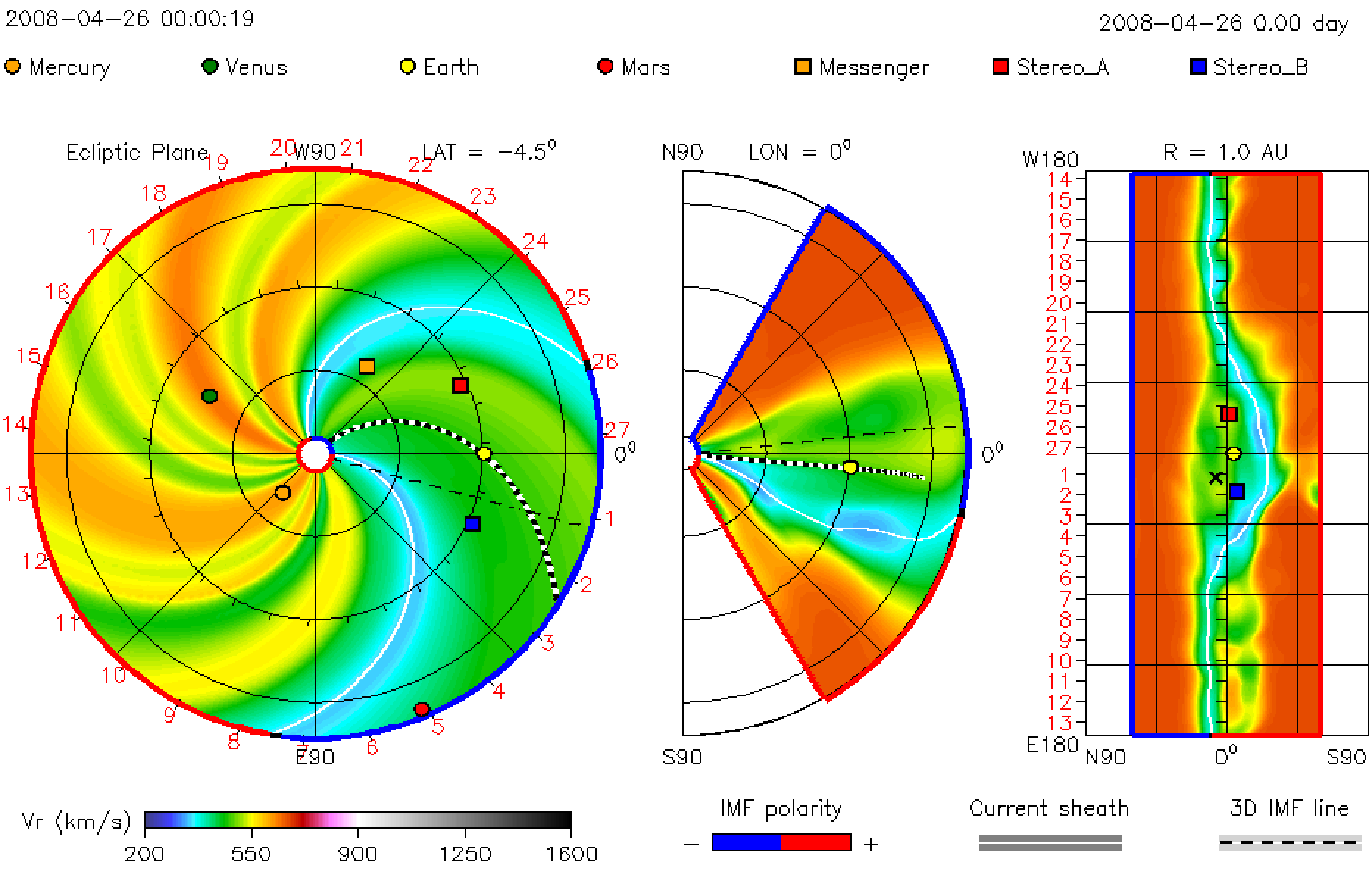




2008 April 26 CME with Cone Model



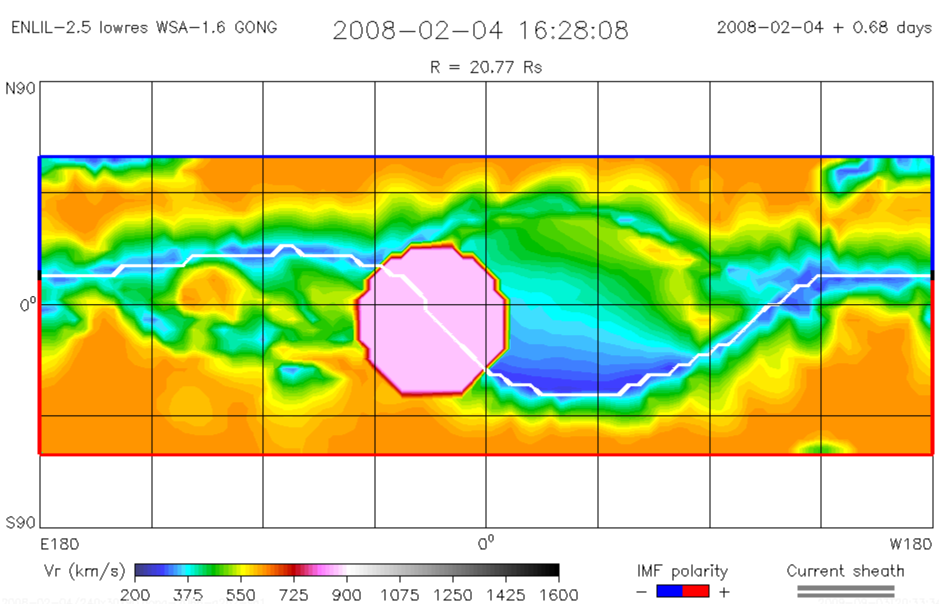
2008 April 26 CME with Rope Model

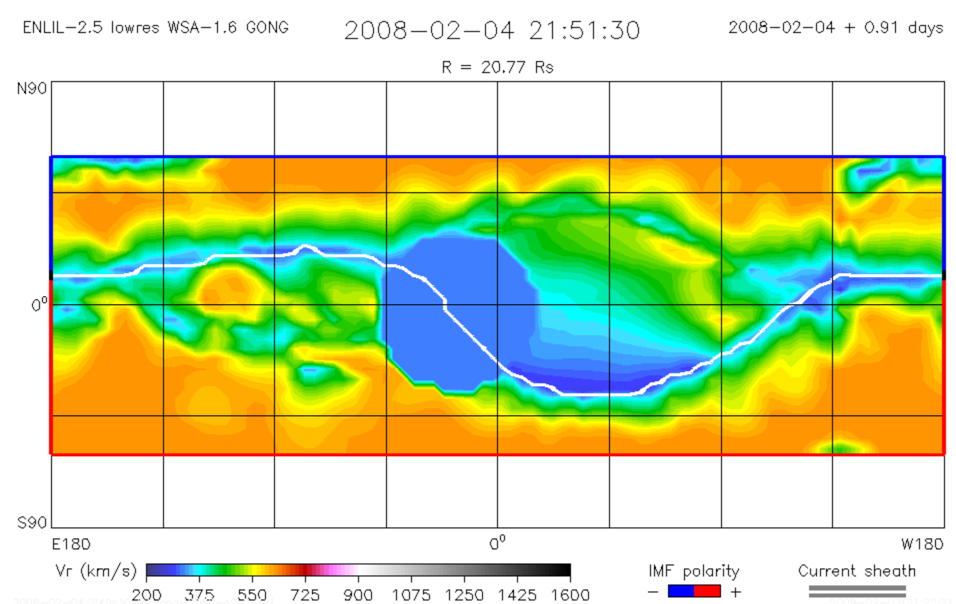


Limb vs. Halo CME Speeds: 2008-02-04

STEREO MODEL	
Latitude (deg)	-6.9
Longitude (deg)	-23.0
Width (deg)	60.5
R 12:52:20 (Rs)	16.4
R 13:22:20 (Rs)	18.6
Velocity (km/s)	859.0

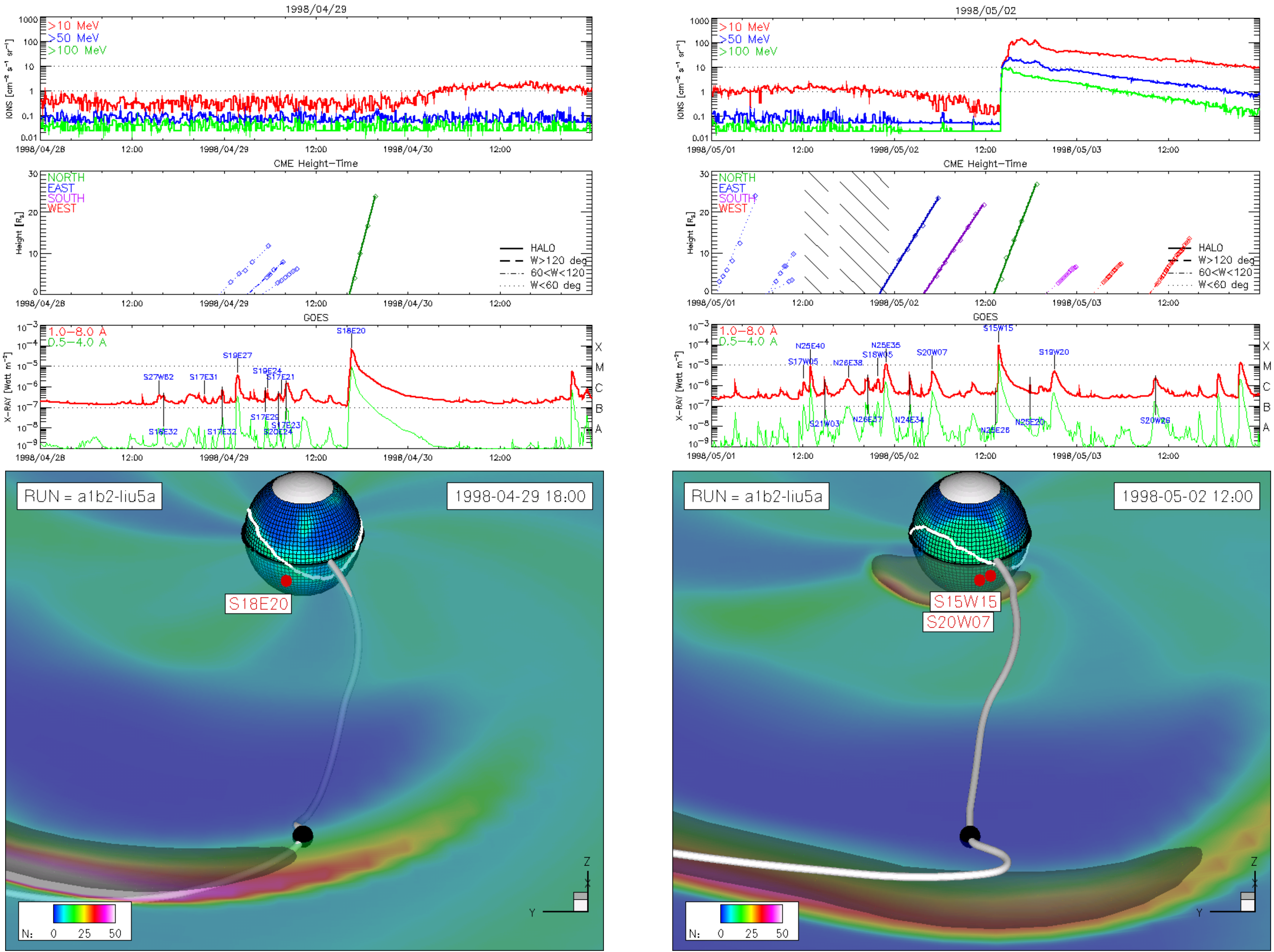
CONE MODEL	
Latitude (deg)	-2.7
Longitude (deg)	-20.8
Width (deg)	65.0
R 12:52:20 (Rs)	17.1
R 13:22:20 (Rs)	19.4
Velocity (km/s)	316.1





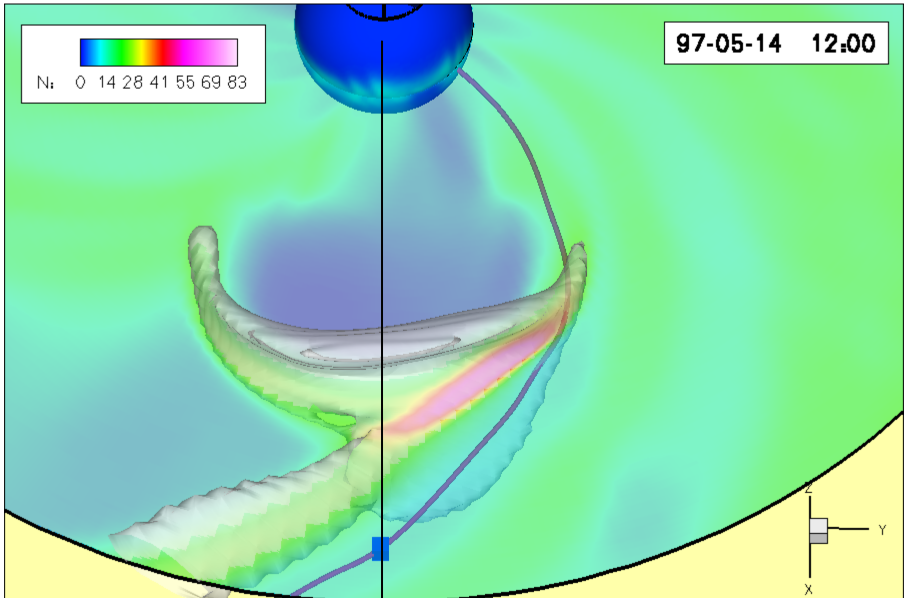
Tracing of IMF and Interplanetary Shocks

Connectivity of Magnetic Field Line

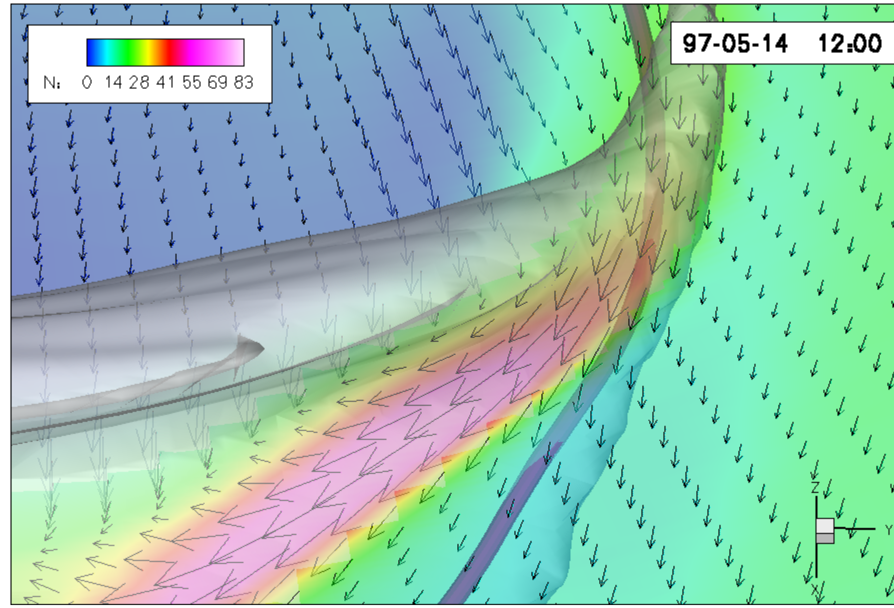


Shock Detection Challenge

Global view



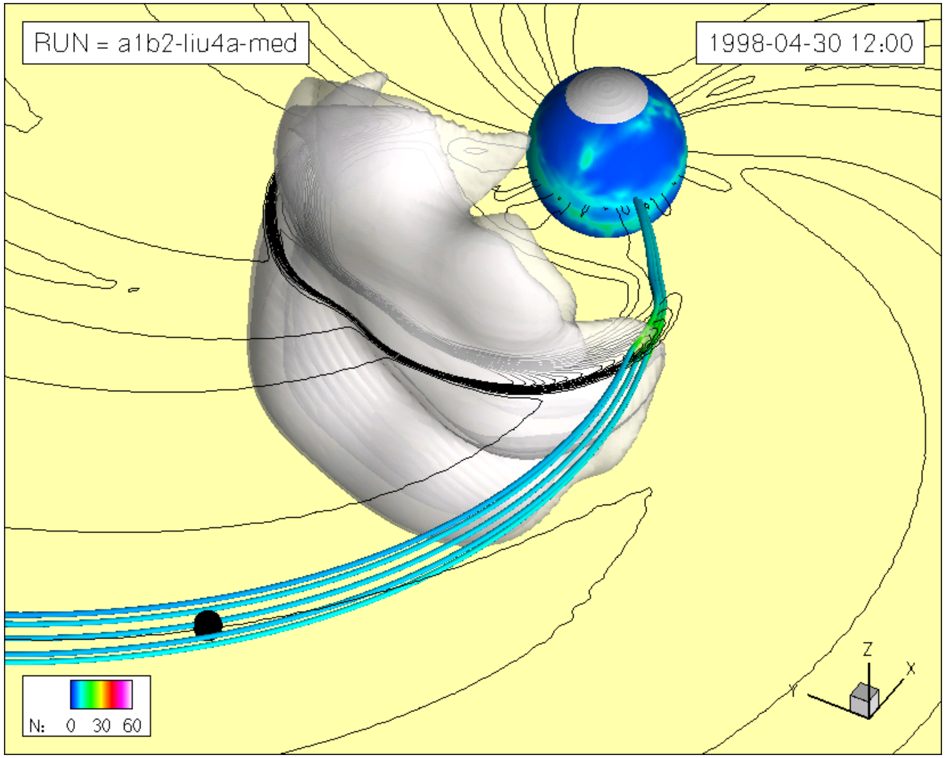
Detailed view



- IMF line connects geospace with an interplanetary shock under very large inclination angle because of: (1) spiralling IMF line and (2) bow-shaped shock front
- Thus determination of shock parameters from MHD values stored along the IMF line is very difficult because many numerical grid points are used across the shock structure and pre- and post-shock values are at differing solar wind

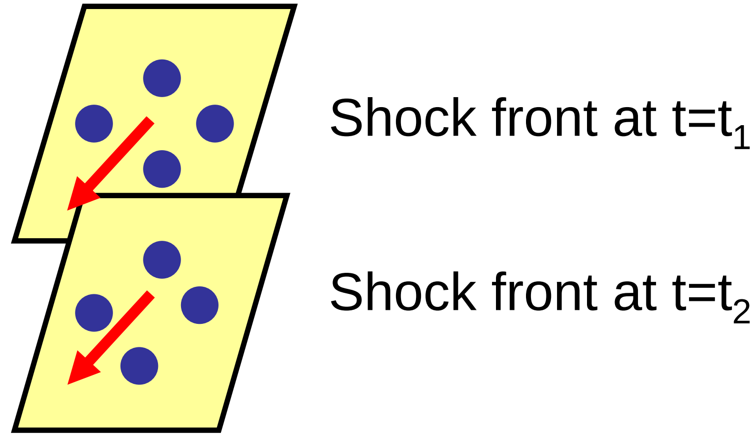
Shock Detection Challenge

Tracing Nearby IMF Lines



Four additional four IMF lines are traced from geospace, offset +/- 2^0 in latitude and longitude from the Earth location

Using 3-D Data

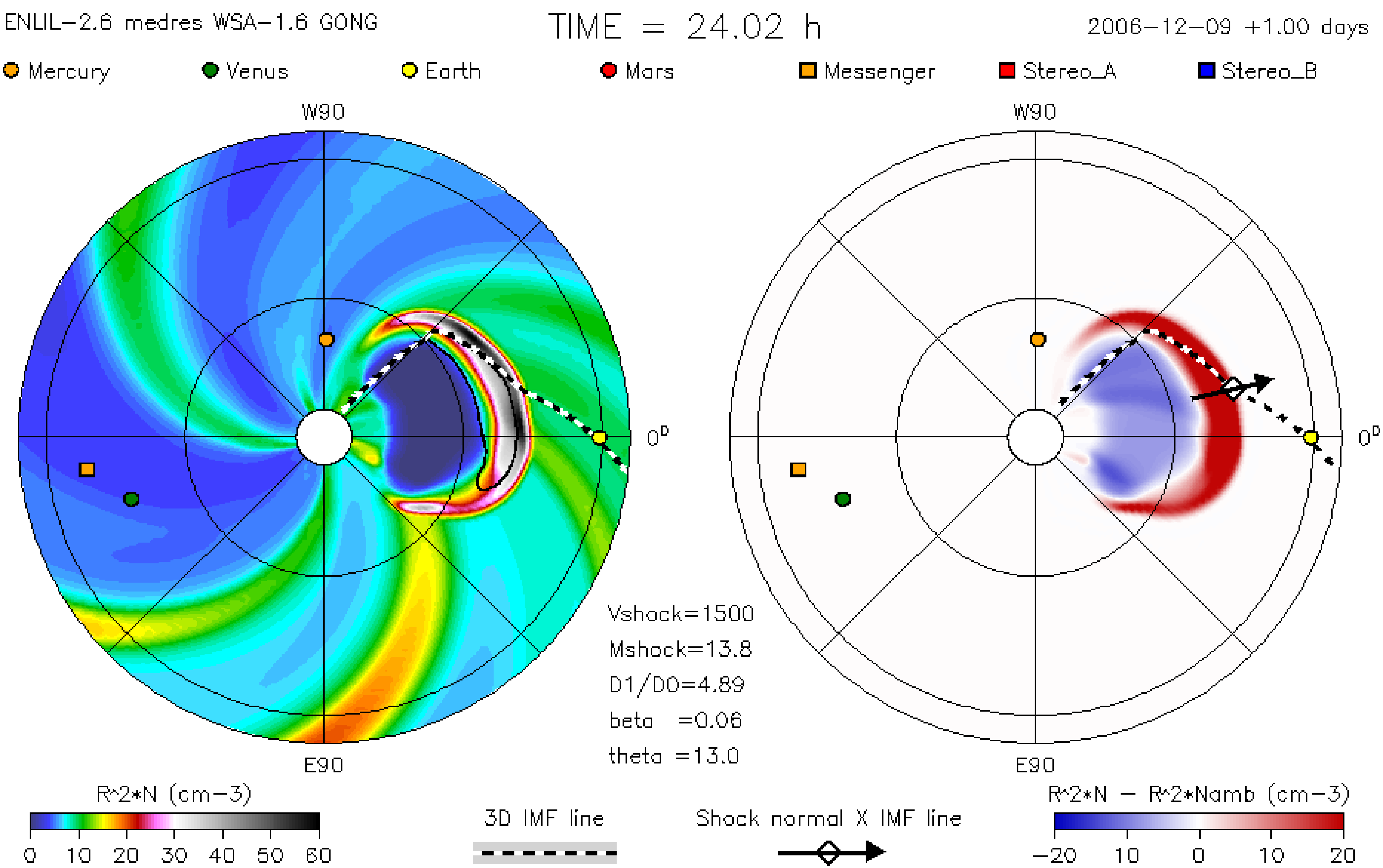


Geometrically fitted parameters:

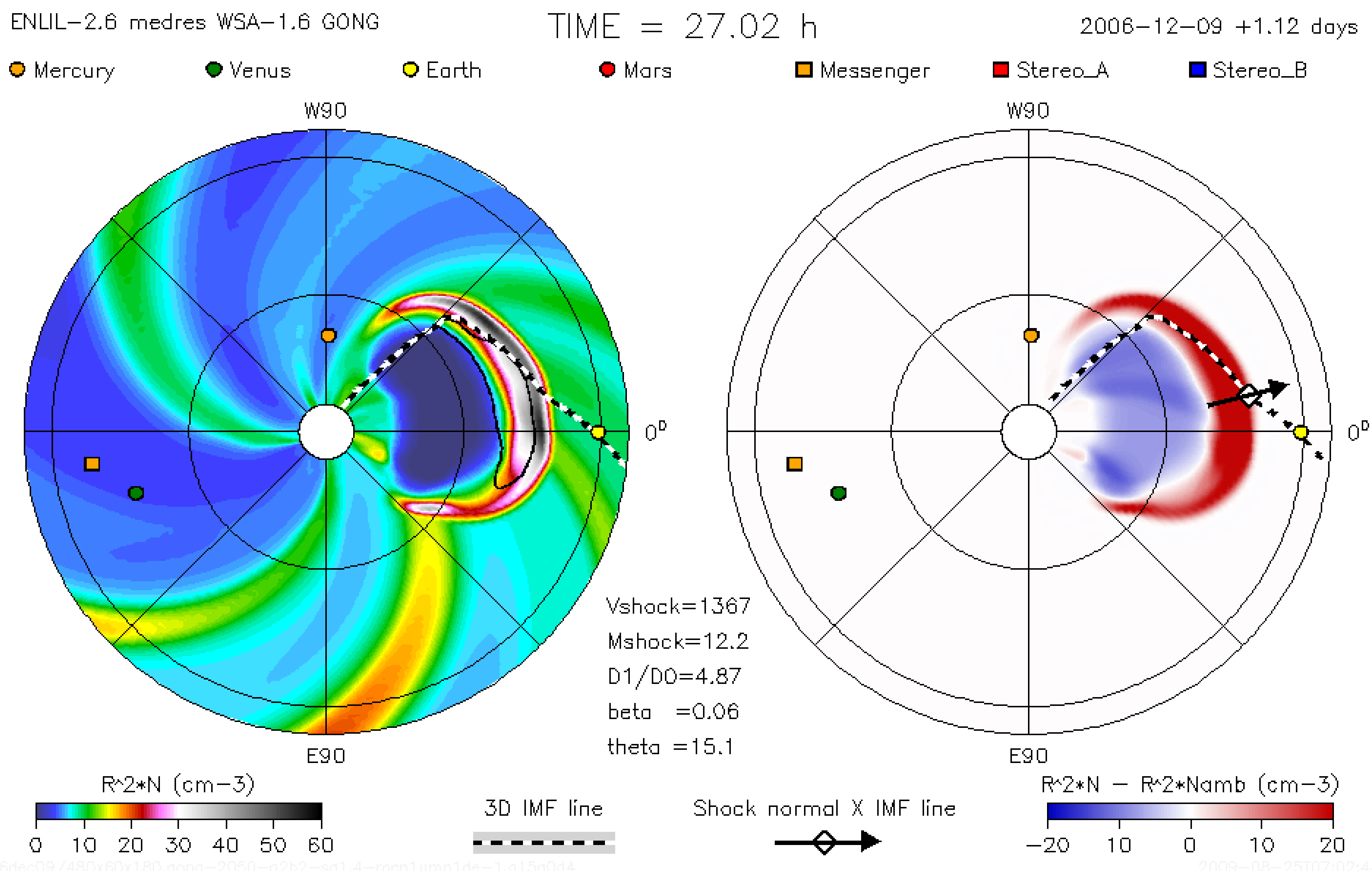
- shock inclination
- shock speed

Together with the pre-shock solar wind parameters, these enable application of the Rankine-Hugoniot formulae to determine shock jump conditions (*Steve Ledvina, in progress*)

Interplanetary Shock Tracing

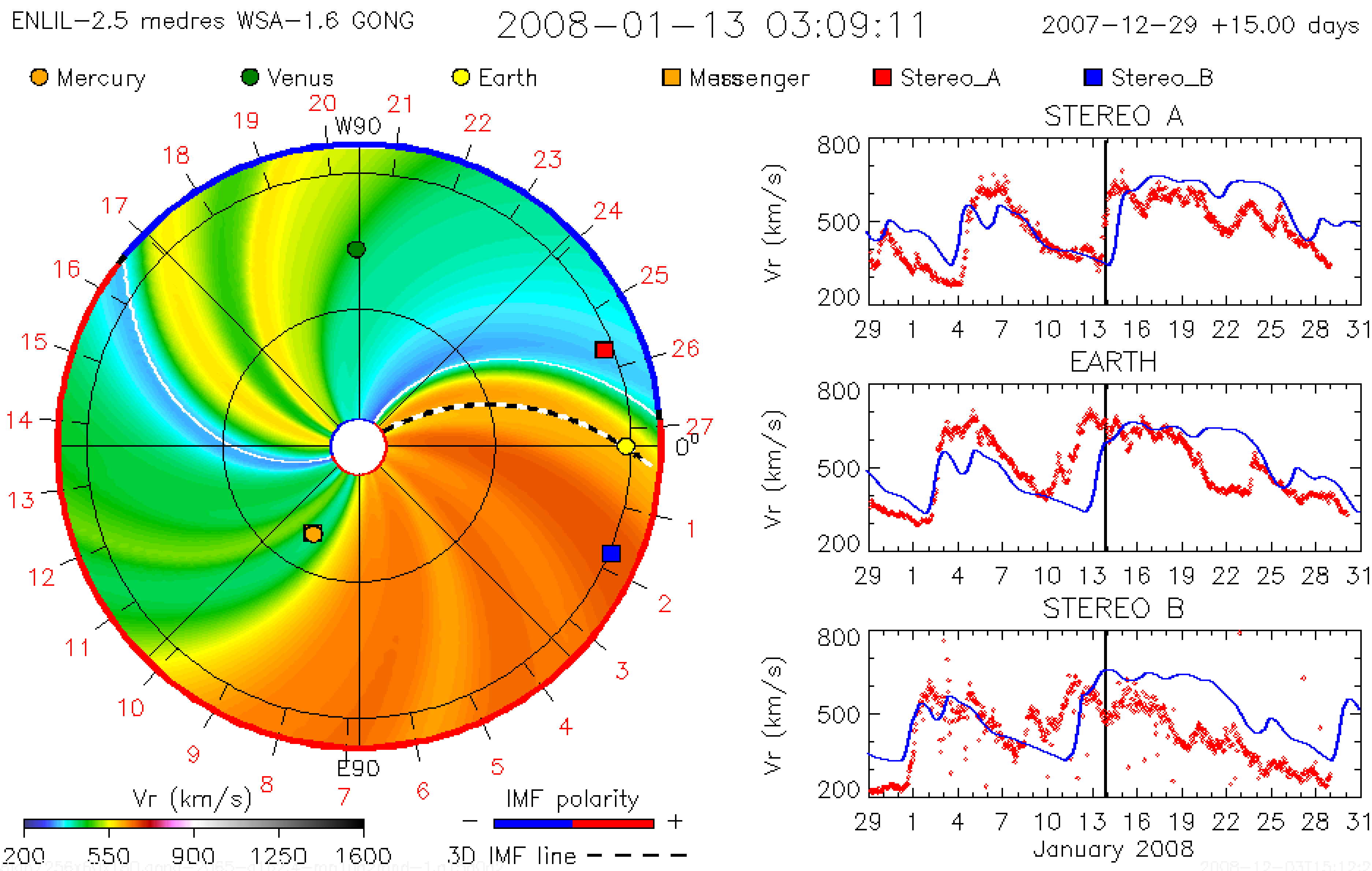


Interplanetary Shock Tracing

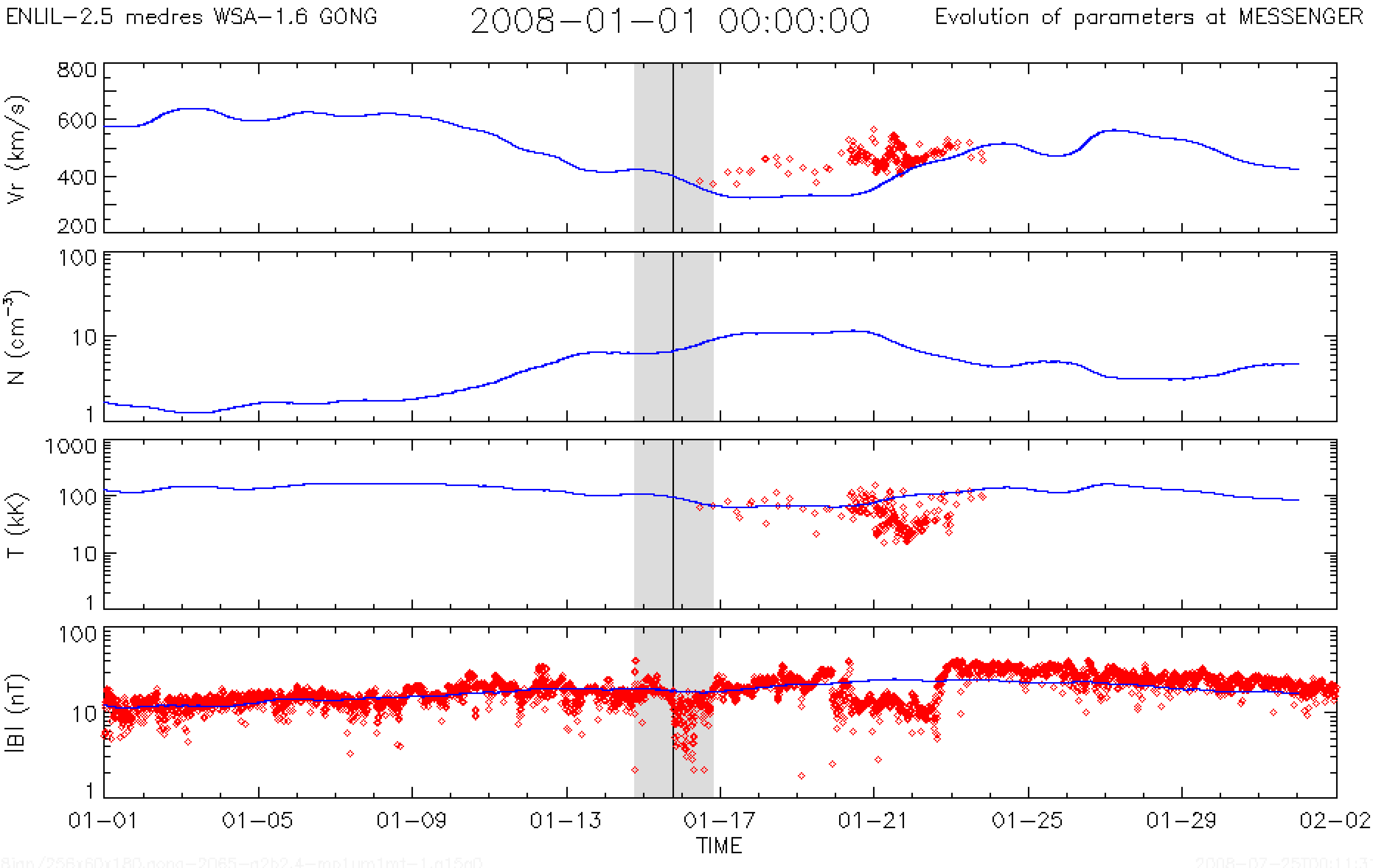


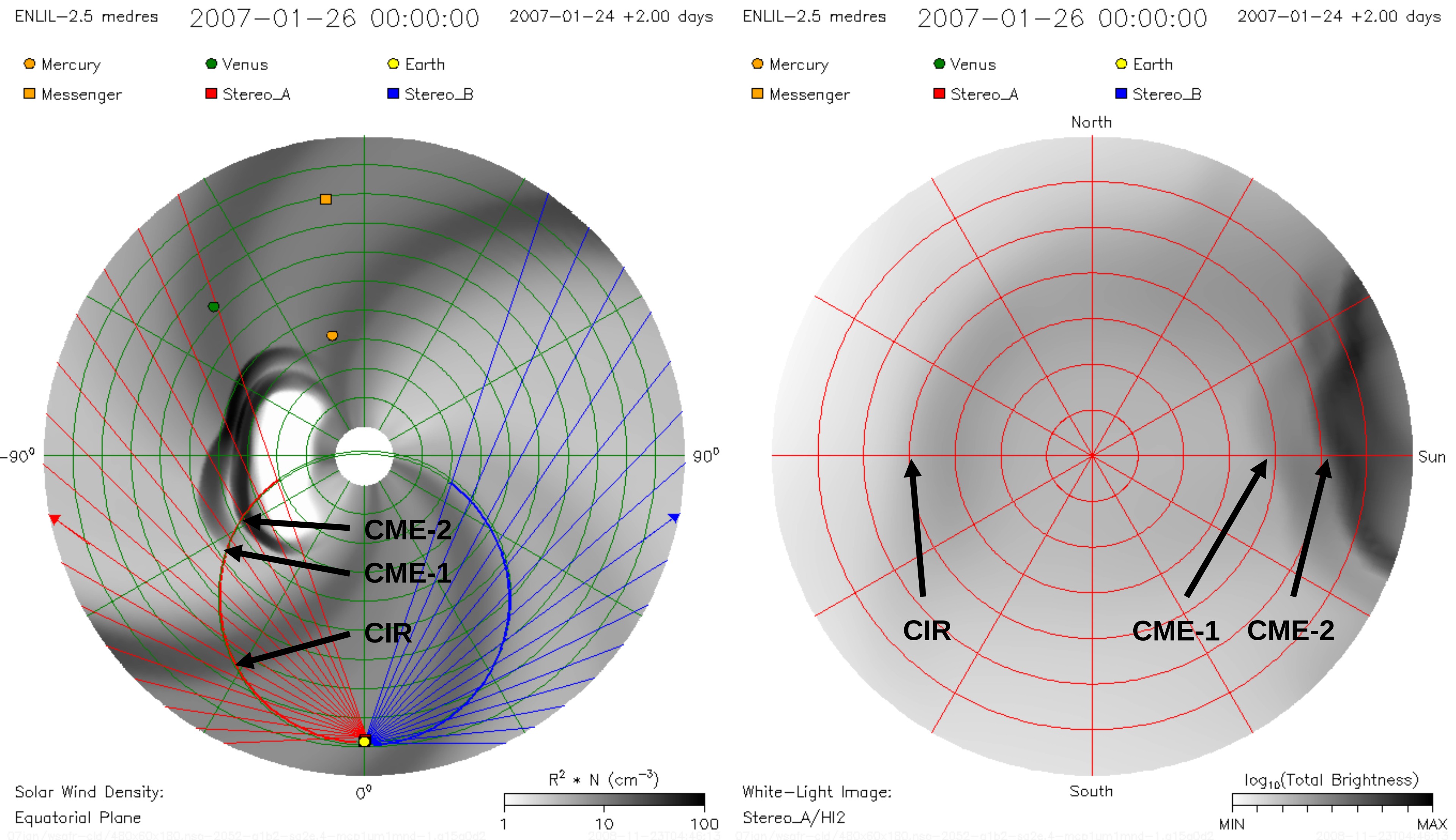
Heliospheric Mission Support

Messenger-Mercury Flyby – January 2008

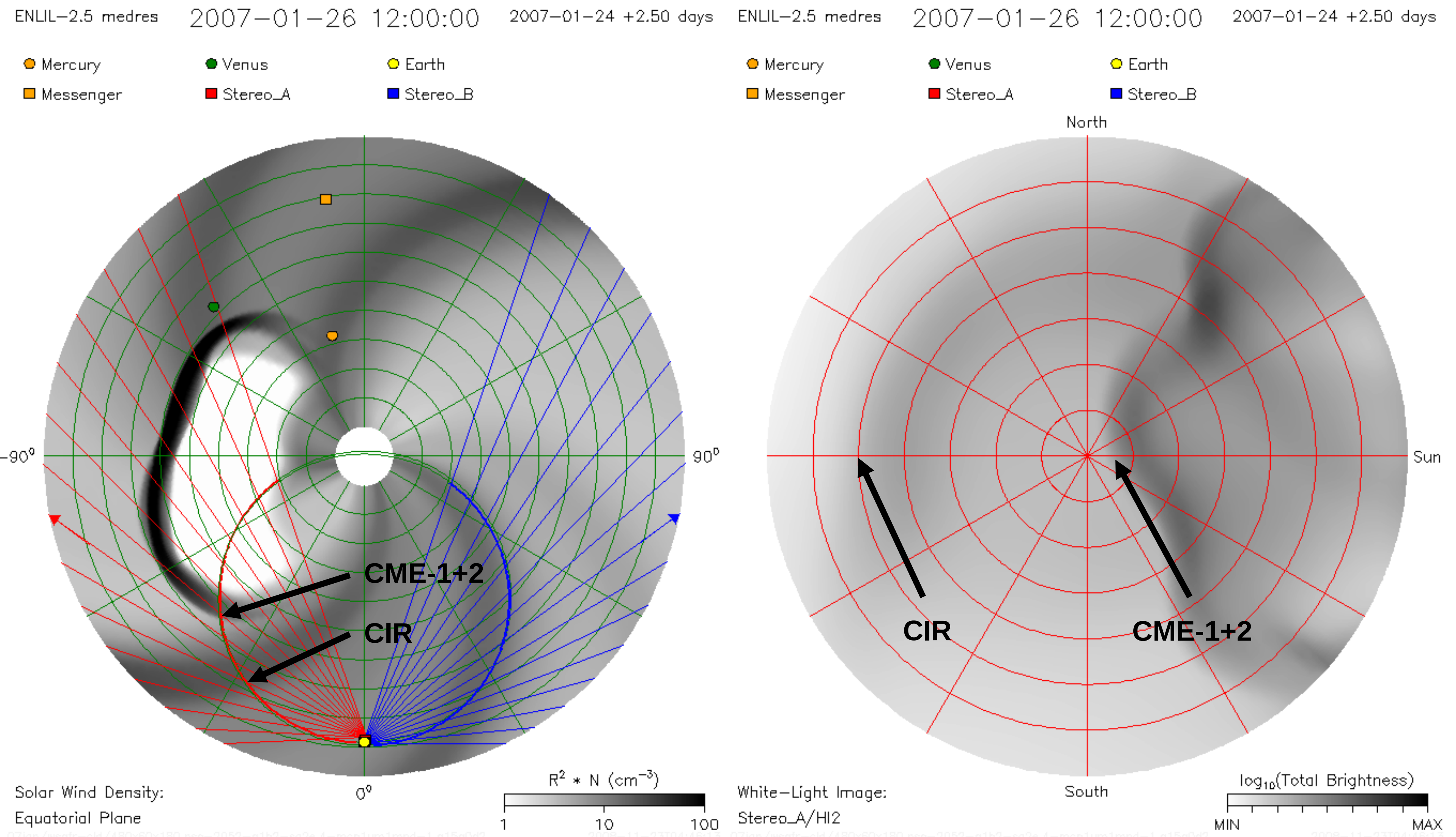


Messenger-Mercury Flyby – January 2008



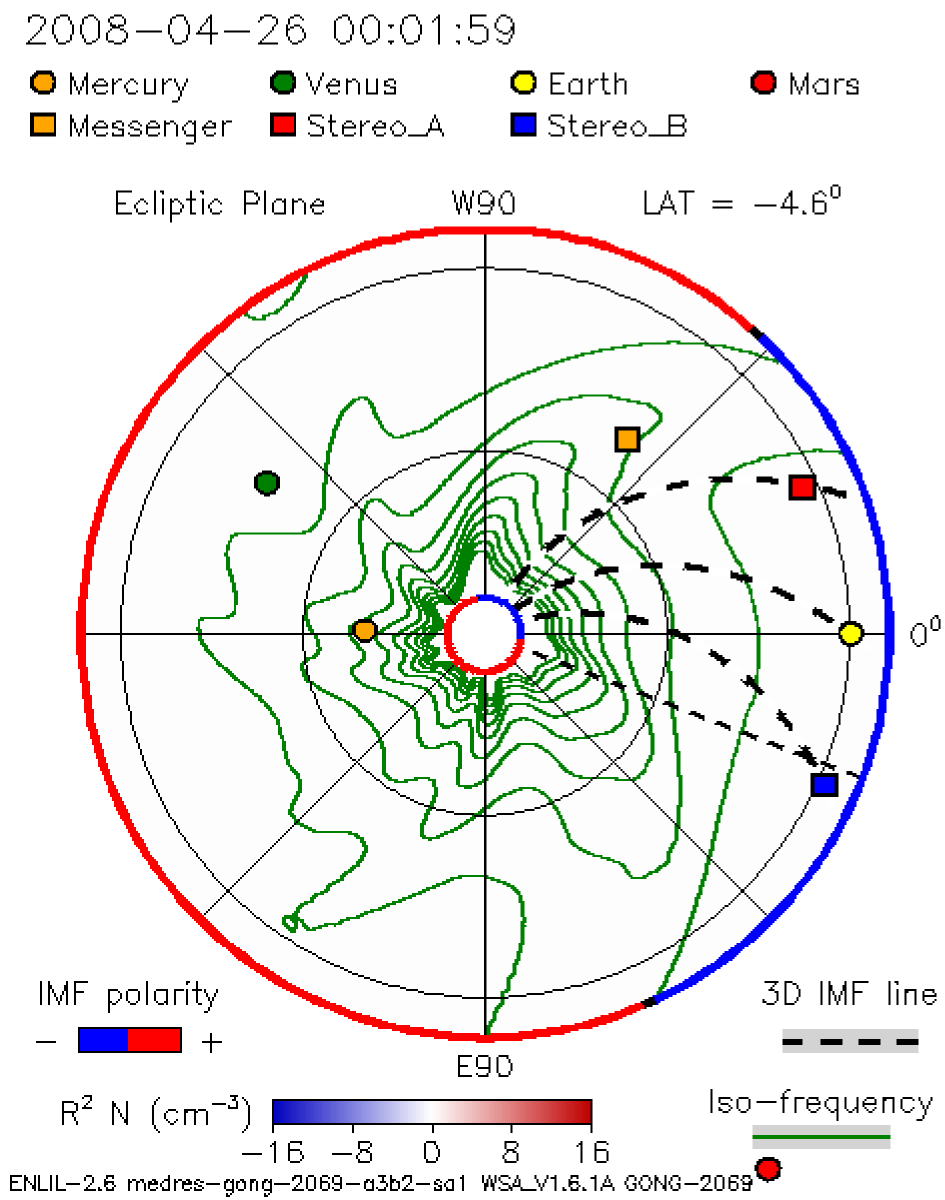


ENLIL-2.5 medres
2007-01-26 00:00:00
2007-01-24 +2.00 days
Mercury
Venus
Earth
Messenger
Stereo_A
Stereo_B
-90°
90°
0°
CME-2
CME-1
CIR
Solar Wind Density:
Equatorial Plane
R² * N (cm⁻³)
1
10
100
ENLIL-2.5 medres
2007-01-26 00:00:00
2007-01-24 +2.00 days
Mercury
Venus
Earth
Messenger
Stereo_A
Stereo_B
North
Sun
South
CIR
CME-1
CME-2
White-Light Image:
Stereo_A/HI2
log10(Total Brightness)
MIN
MAX



ENLIL-2.5 medres
2007-01-26 12:00:00
2007-01-24 +2.50 days
Mercury
Venus
Earth
Messenger
Stereo_A
Stereo_B
-90°
90°
0°
CME-1+2
CIR
Solar Wind Density:
Equatorial Plane
R² * N (cm⁻³)
1
10
100
ENLIL-2.5 medres
2007-01-26 12:00:00
2007-01-24 +2.50 days
Mercury
Venus
Earth
Messenger
Stereo_A
Stereo_B
North
Sun
South
CIR
CME-1+2
White-Light Image:
Stereo_A/HI2
log10(Total Brightness)
MIN
MAX

Interplanetary Shock Tracing – Type II Radio Bursts



- Interplanetary shocks can generate radio emission (type II radio bursts):

$F_p(\text{kHz}) = 9\,(N_e\,(\text{cm}^{-3}))^{1/2}$

- Inner heliosphere: dm & km wavelengths can be detected by spacecraft

Numerical simulations:

- Conditions for observed radio emissions
- On-fly adjustment of numerical predictions

(Coupling Issues)

STEREO Beacon Data – NASA CDF File Format

Old	cdf_varget,id_cdf,'Velocity_HGRTN',velocity,…
New	cdf_varget,id_cdf,'Velocity_RTN',velocity,…

Trajectories of Planets and Spacecraft – NASA HelioWeb Database

Old	YYYY DDD AU ELAT ELON HG_LAT HG_LON HGI_LON YEAR DAY RAD_AU HG_LAT HG_LON HGI_LON
New	YYYY DOY AU HG_LAT HG_LON HGI_LON YYYY DAY RAD_AU HGI_LAT HGI_LON