Real-Time Modeling of CMEs Using the WSA-ENLIL+Cone Model

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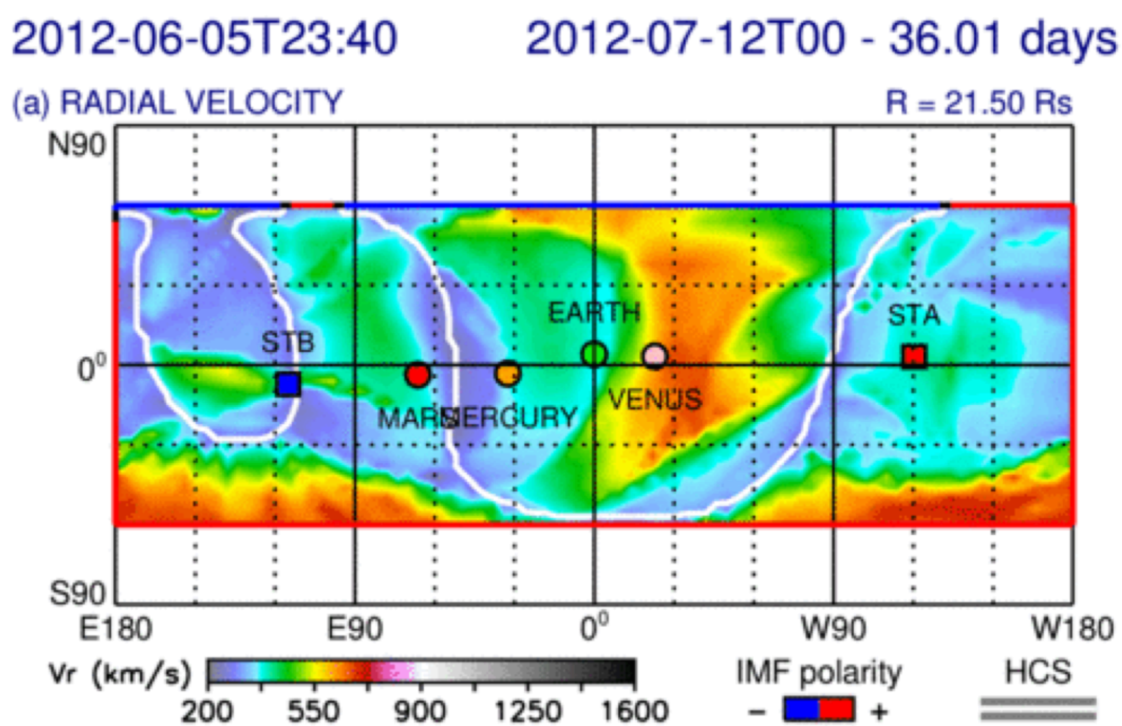
Modeling CMEs with WSA-ENLIL+Cone

- WSA-ENLIL is a global 3D MHD model which provides a time-dependent description of the background solar wind plasma and magnetic field into which a spherical or ellipsoid shaped CME can be inserted.
- A CME-like hydrodynamic structure is launched into the solar wind and magnetic field computed from the WSA coronal model at 21.5 R_s.

- WSA coronal maps generated from synoptic magnetograms provide the magnetic field and solar wind speed at the boundary between coronal PFSS and heliospheric models
- Other coronal models can also be coupled with ENLIL (e.g. MAS, heliospheric tomography).



Model References: Arge and Pizzo, 2000; Arge et al., 2004.
Odstrcil et al. 1996; Odstrcil and Pizzo, 1990a,b; Odstrcil, 2003.

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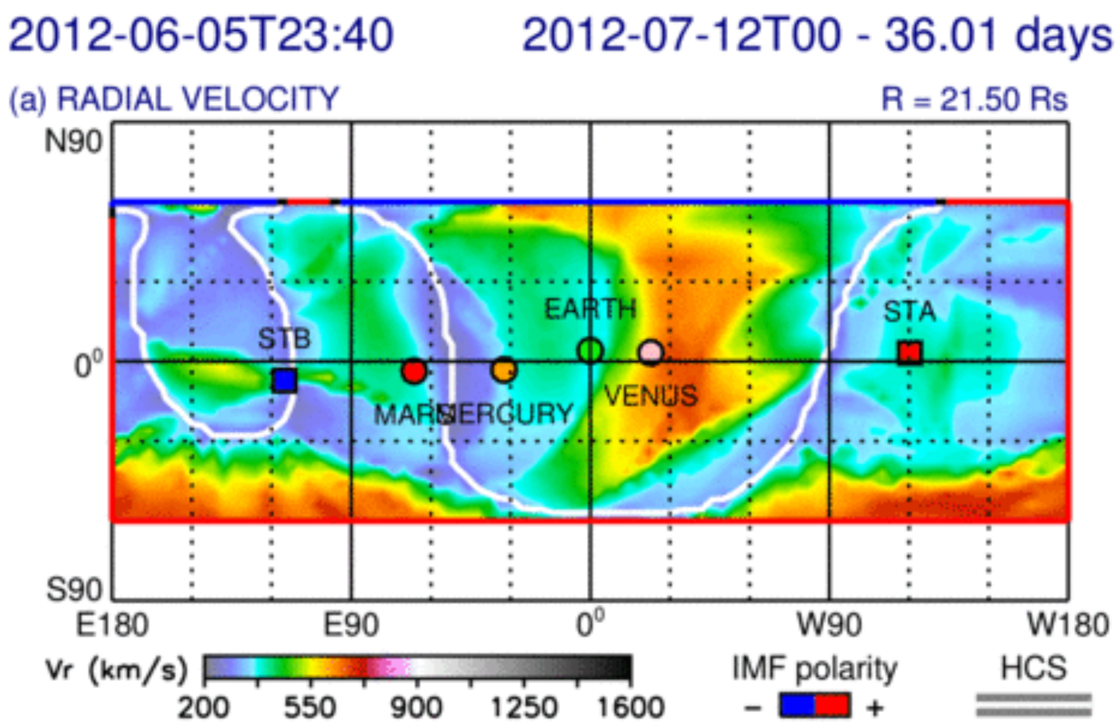

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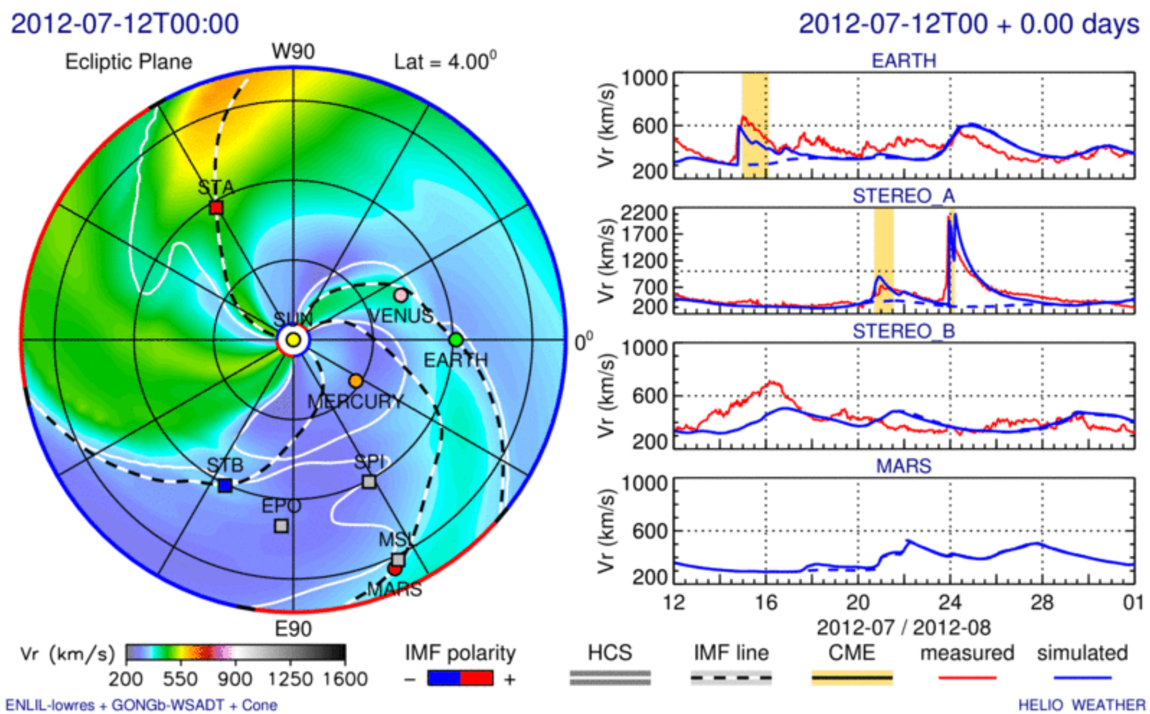

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ENLIL - Schematic Description

ENLIL – *Sumerian God of Winds and Storms*

Dusan Odstrcil, GMU & GSFC

Input: WSA (coronal maps of Br and Vr updated 4 times a day). For toroidal components at the inner boundary- Parker spiral.

ENLIL’s inner radial boundary is located beyond the sonic point: the solar wind flow is supersonic in ENLIL.

Computes a time evolution of the global solar wind for the inner heliosphere, driven by corotating background structure and transient disturbances (CMEs) at it’s inner radial boundary at 21.5 Rs.

Solves ideal fully ionized plasma MHD equations in 3D with two additional continuity equations: for density of transient and polarity of the radial component of B.

ENLIL Schematic Description

ENLIL model does not take into account the realistic complex magnetic field structure of the CME magnetic cloud and the CME as a plasma cloud has a uniform velocity.

It is assumed that the CME density is 4 times larger than the ambient fast solar wind density, the temperature is the same.

Thus, the CME has about four times larger pressure than the ambient fast wind. Launching of an over pressured plasma cloud at 21.5 **Rs,** roughly represents CME eruption scenario

Output:

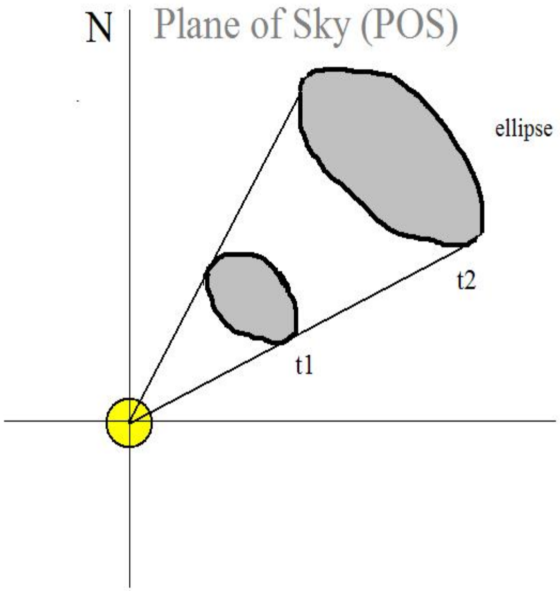
3D distribution of the SW parameters at spacecraft and planets and topology of IMF.

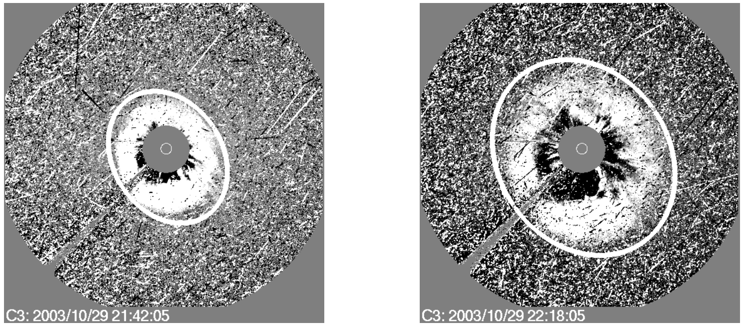
Cone Model for CMEs

CME measuring technique that assumes:

- CME propagates with nearly constant angular width in a radial direction
- CME bulk velocity is radial and the expansion is isotropic

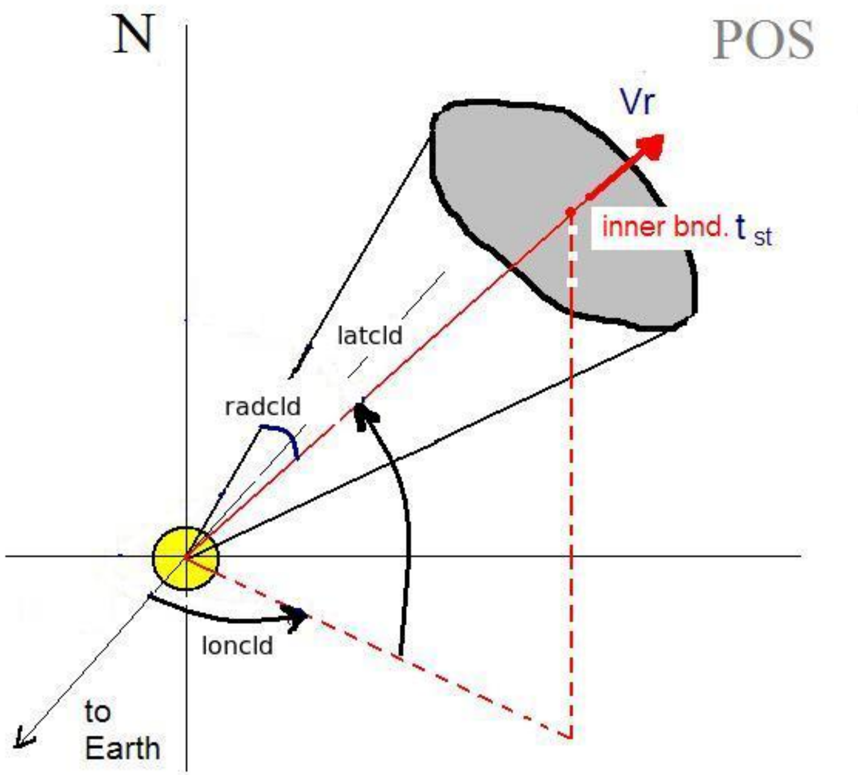
Zhao et al, 2002, Cone Model:





The projection of the cone on the coronagraph image is an ellipse

Cone model parameters



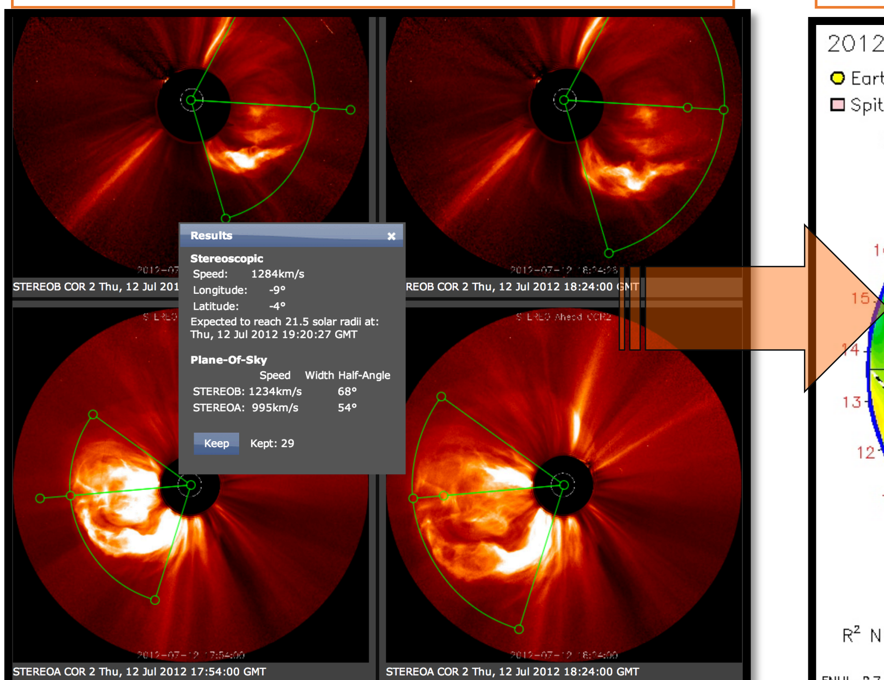
Input to ENLIL cone model run

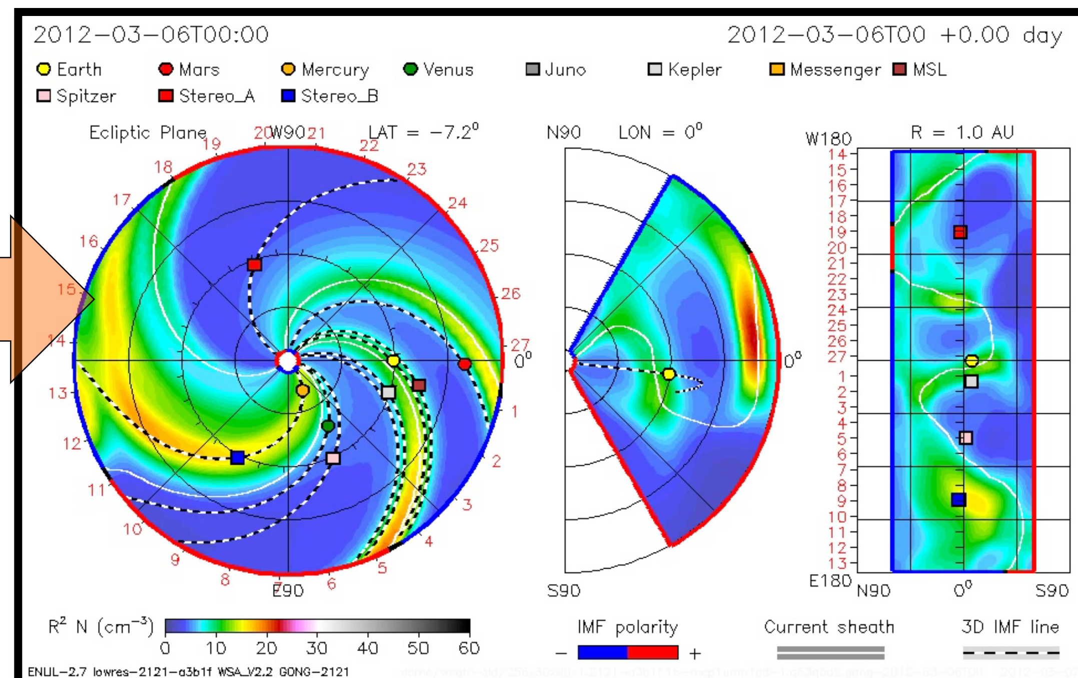
- time the CME reaches the inner boundary of 21.5 Solar Radii
- Latitude (in HEEQ coordinates)
- Longitude (in HEEQ coordinates)
- Half-width (deg)
- Radial velocity (km/s)

WSA-ENLIL Cone Model

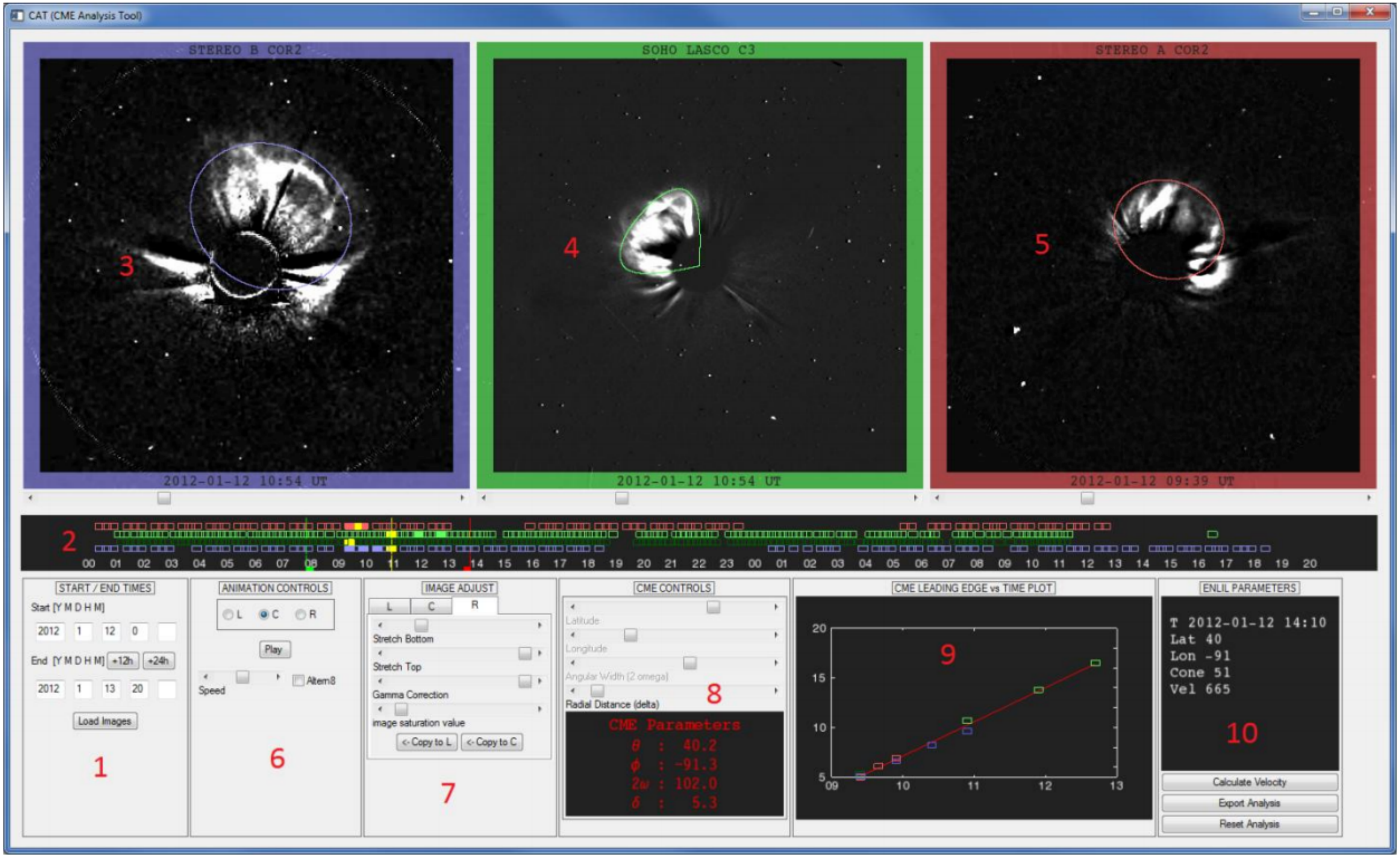
Parameters Defined with CCMC CME Triangulation Tool: StereoCAT

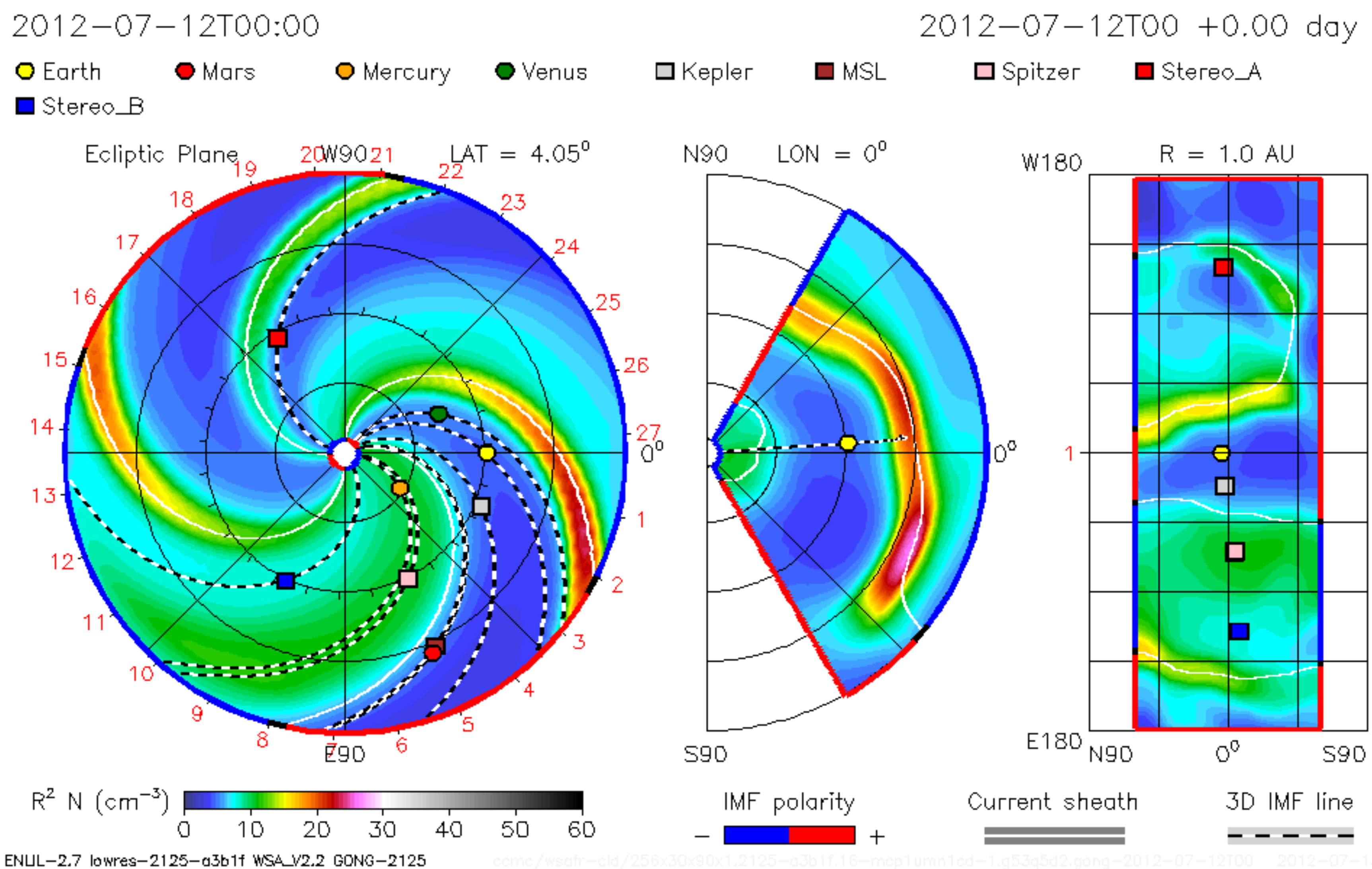
CME Parameters: Input To WSA-ENLIL Cone Model

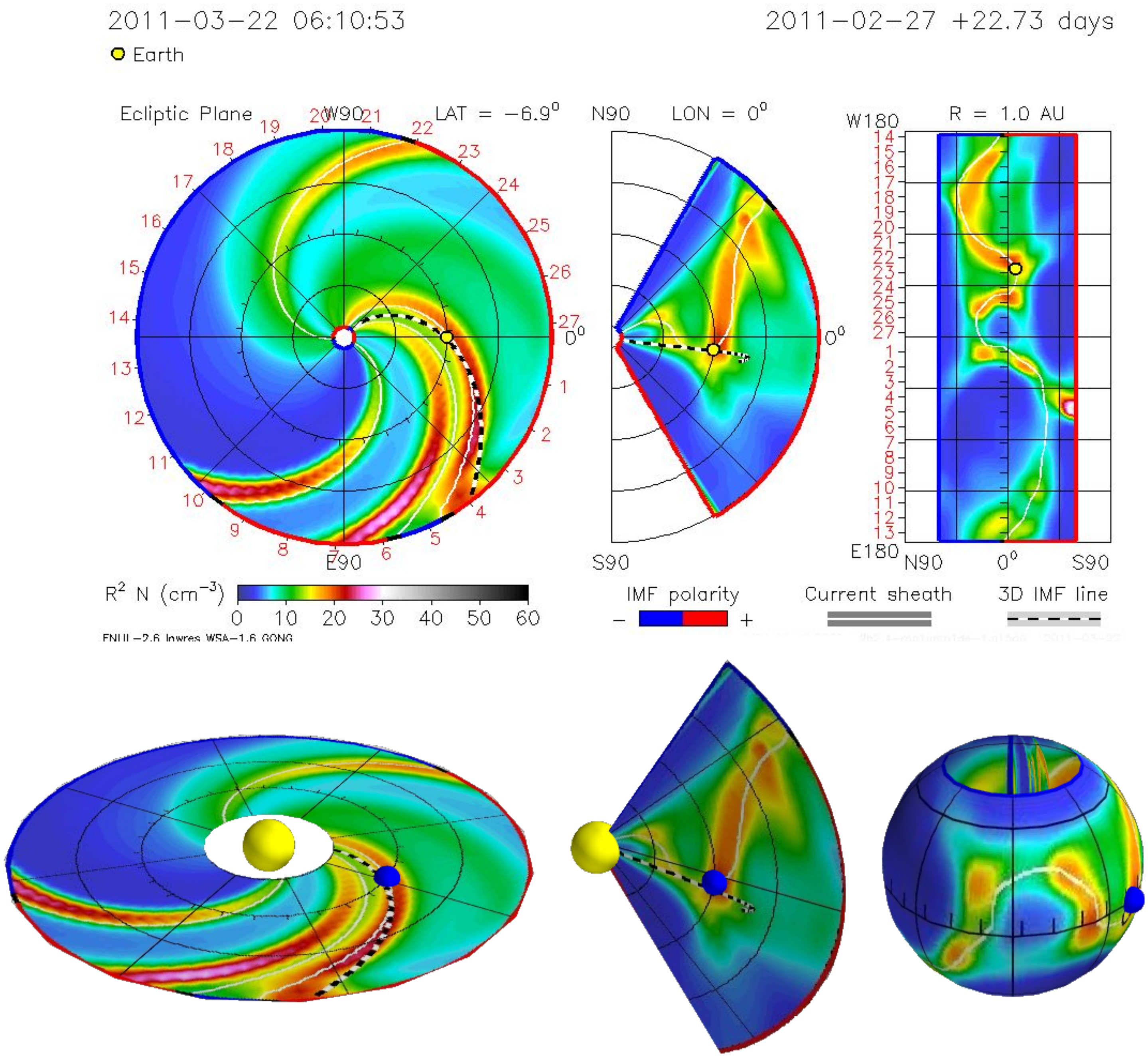


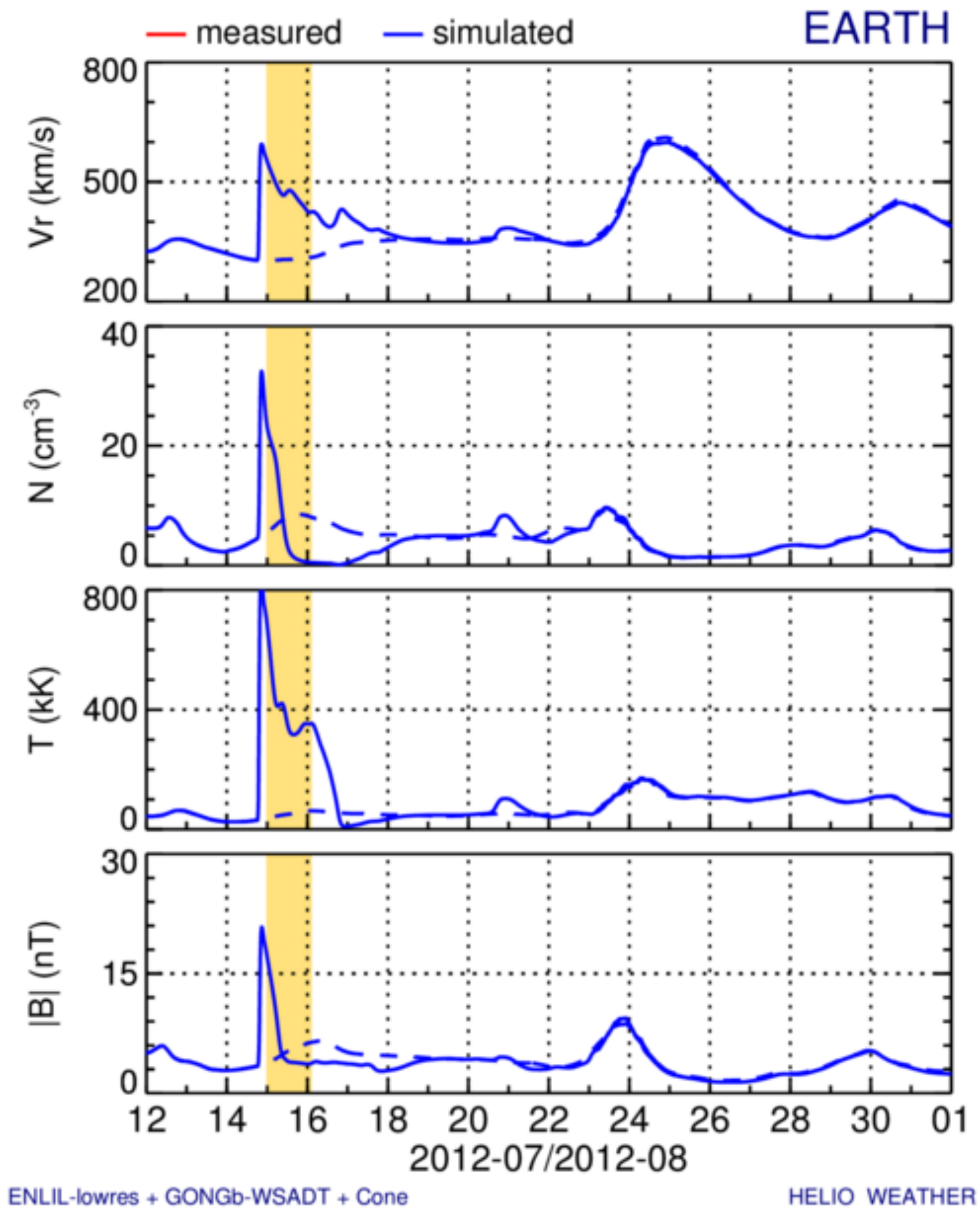


SWPC CME Analysis Tool (SWPC_CAT)

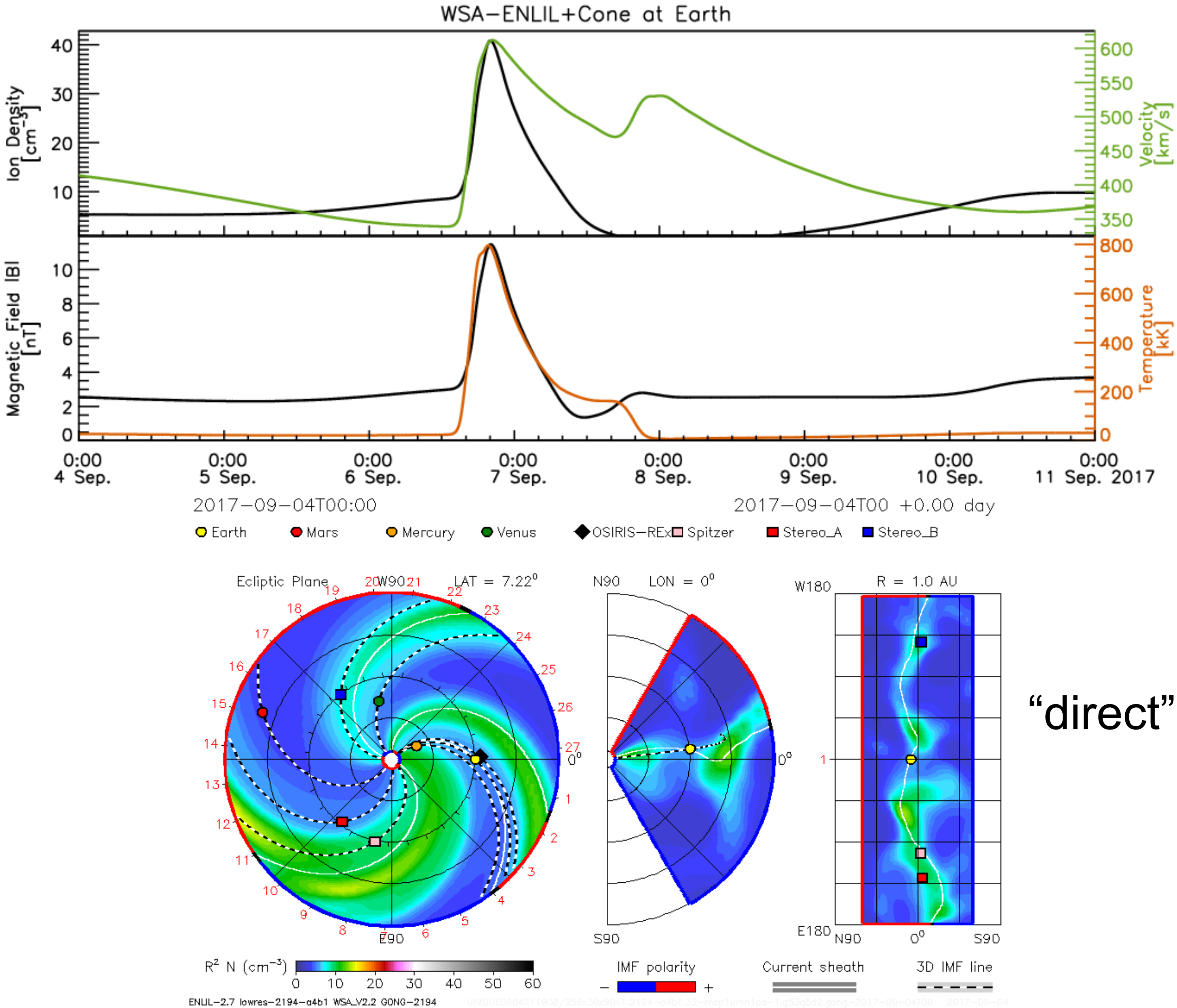



2012–07–12T00:00
2012–07–12T00 +0.00 day
Earth
Mars
Mercury
Venus
Kepler
MSL
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
W90
LAT = 4.05°
E90
N90
LON = 0°
S90
0°
W180
R = 1.0 AU
E180
N90
0°
S90
R² N (cm⁻³)
0 10 20 30 40 50 60
IMF polarity
– +
Current sheath
3D IMF line
ENLIL–2.7 lowres–2125–a3b1f WSA_V2.2 GONG–2125

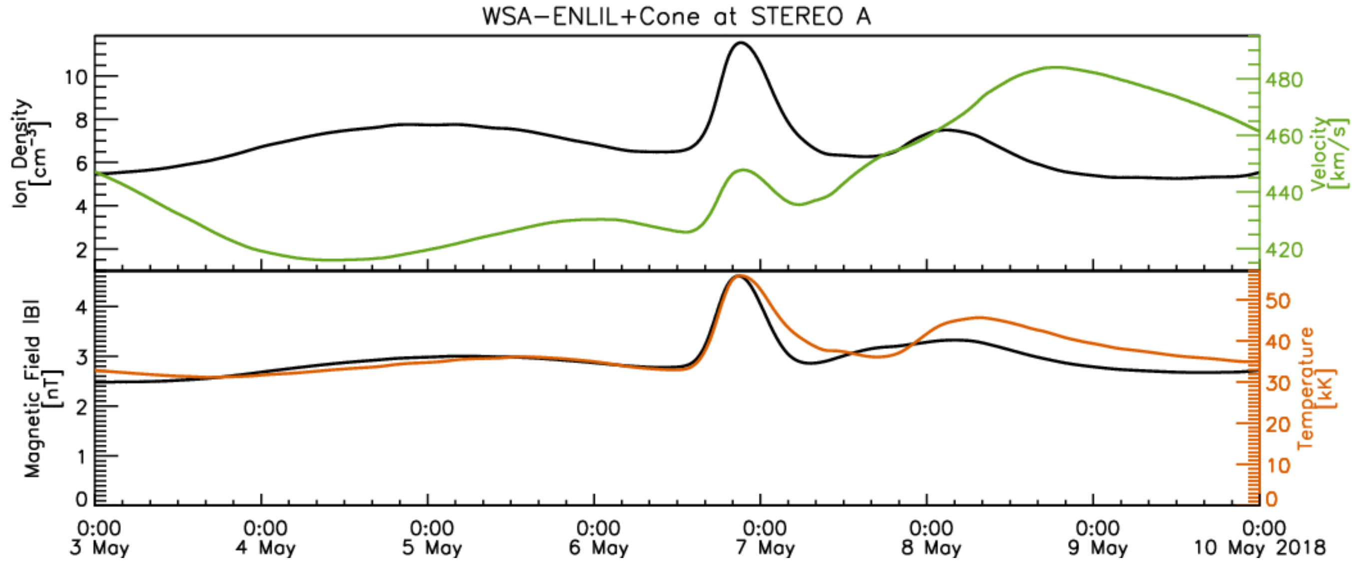

2011-03-22 06:10:53
2011-02-27 +22.73 days
Earth
Ecliptic Plane
W90
LAT = −6.9°
N90
LON = 0°
W180
R = 1.0 AU
E90
S90
E180
N90
0°
S90
R^2 N (cm^{-3})
0 10 20 30 40 50 60
IMF polarity
− +
Current sheath
3D IMF line

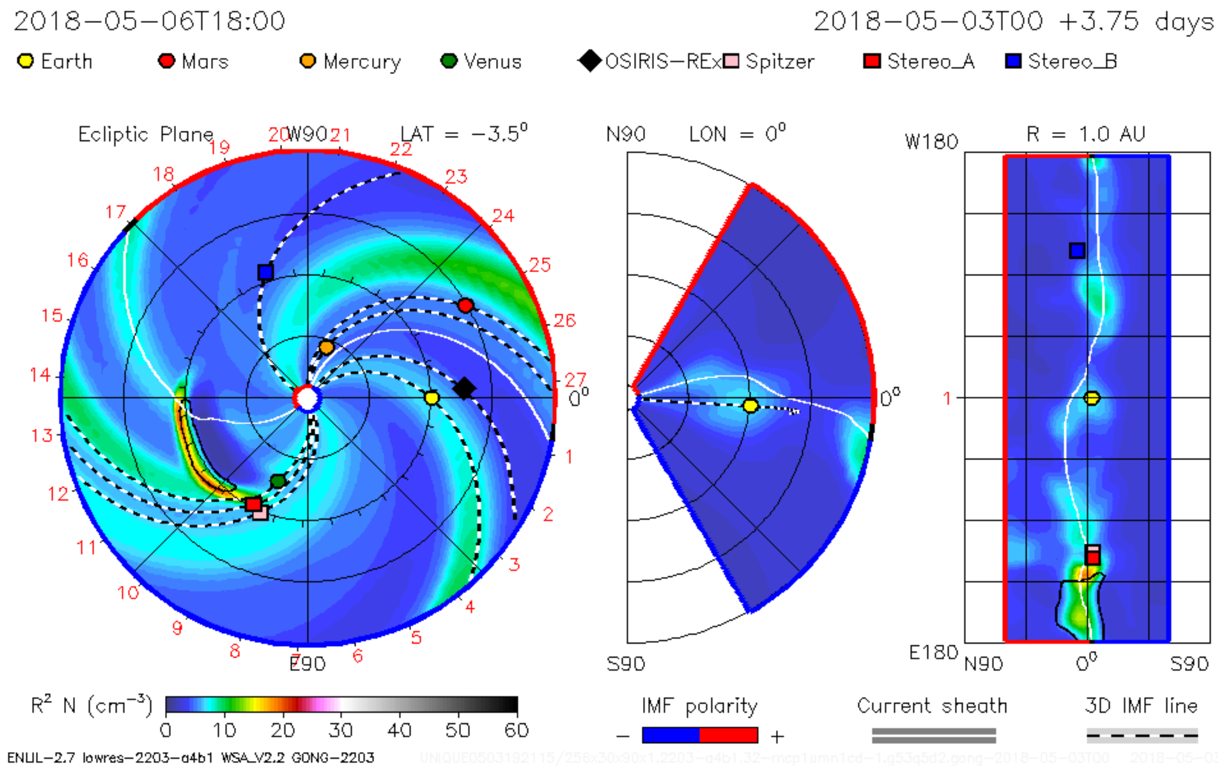

measured
simulated
EARTH
Vr (km/s)
800
500
200
N (cm^-3)
40
20
0
T (kK)
800
400
0
|B| (nT)
30
15
0
12
14
16
18
20
22
24
26
28
30
01
2012-07/2012-08
ENLIL-lowres + GONGb-WSADT + Cone
HELIO WEATHER

Determining CME Arrival Time

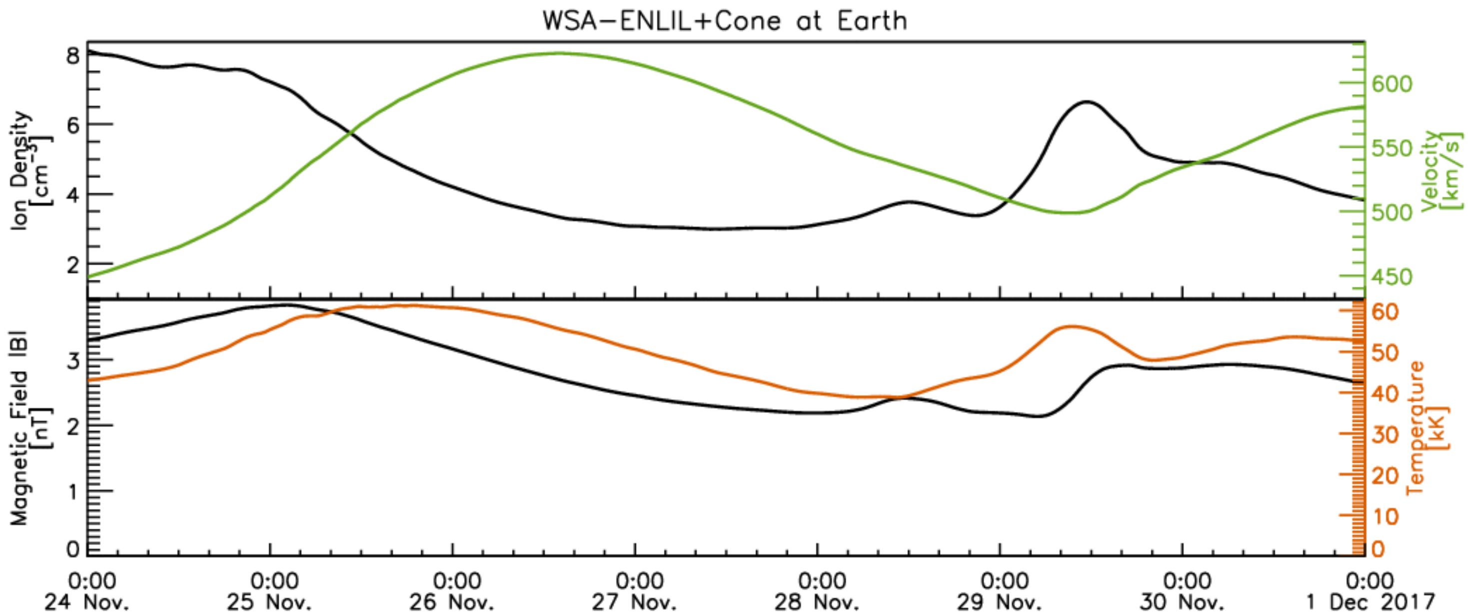


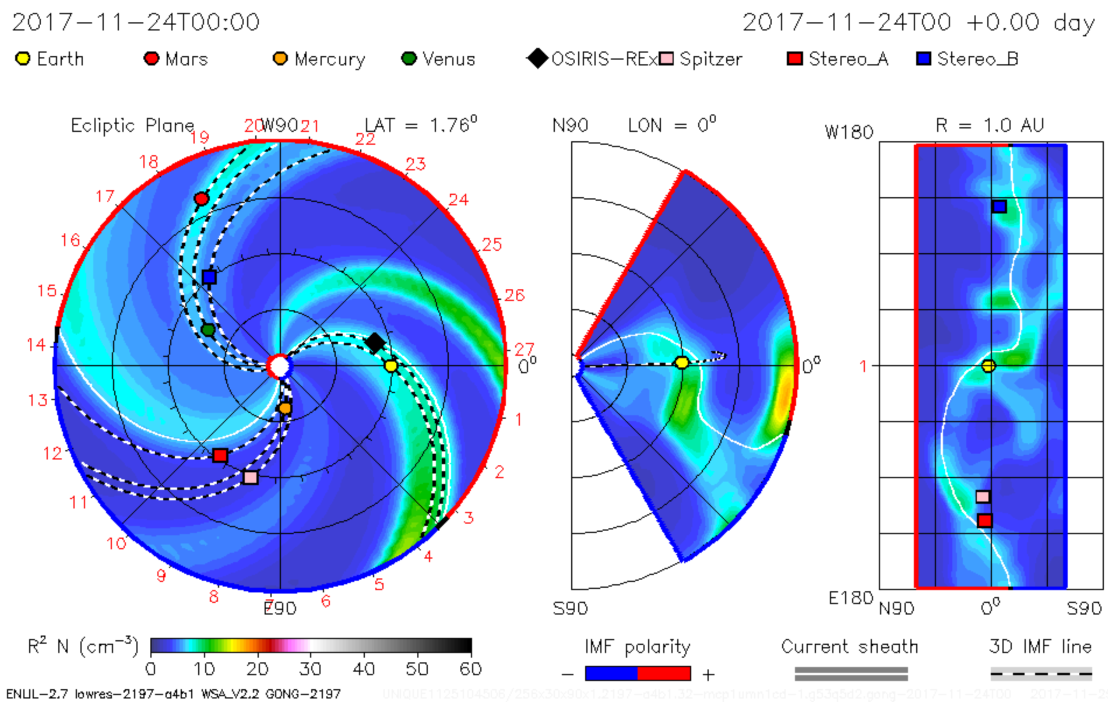
"direct" arrival





“flank” arrival


WSA−ENLIL+Cone at Earth
Ion Density [cm−3]
Velocity [km/s]
Magnetic Field |B| [nT]
Temperature [kK]
0:00 24 Nov.
0:00 25 Nov.
0:00 26 Nov.
0:00 27 Nov.
0:00 28 Nov.
0:00 29 Nov.
0:00 30 Nov.
0:00 1 Dec 2017

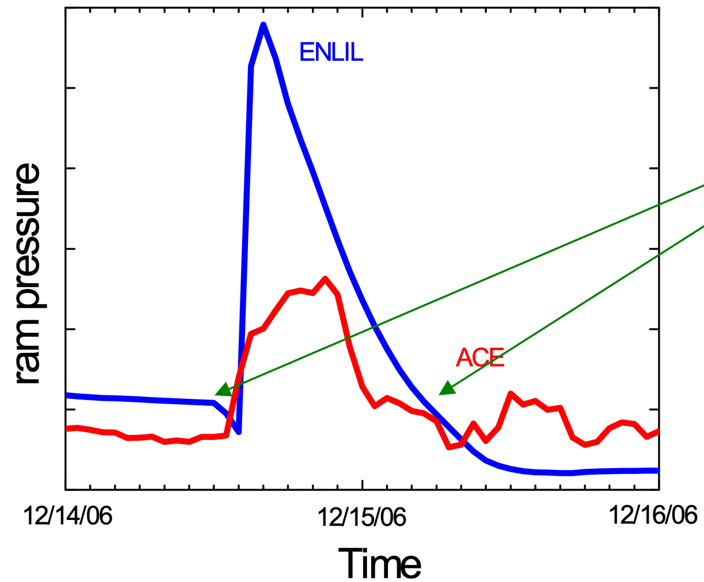

2017−11−24T00:00
2017−11−24T00 +0.00 day
Earth
Mars
Mercury
Venus
OSIRIS−REx
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
W90
LAT = 1.76°
N90
LON = 0°
S90
W180
R = 1.0 AU
E180
E90
R² N (cm−3)
IMF polarity
Current sheath
3D IMF line
ENLIL−2.7 lowres−2197−a4b1 WSA_V2.2 GONG−2197

glancing

CME Impact: Arrival time, duration of passage, magnetopause standoff distance

CME shock arrival – a sharp jump in the dynamic pressure

$$nm_pV^2$$



Duration of the disturbance – duration of the dynamic pressure hump

Magnetic field required to stop SW

$$\frac{B_{stop}^2}{2\mu_0} = Knm_pV^2$$

Magnetopause standoff distance

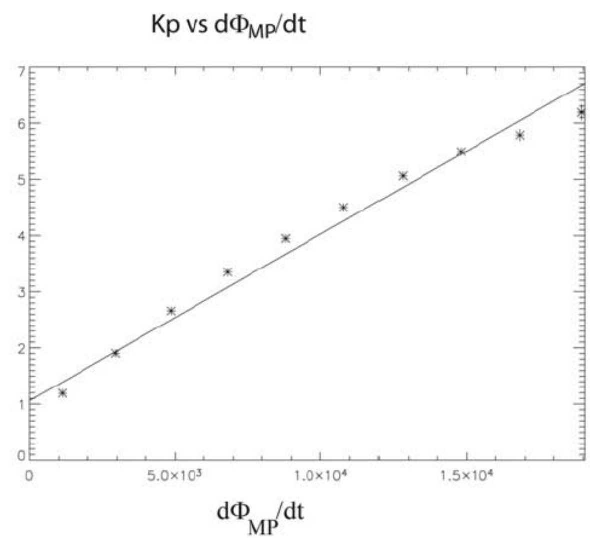
$$\frac{r_{mp}}{R_e} = \left(\frac{B_0}{B_{stop}}\right)^{1/3}$$

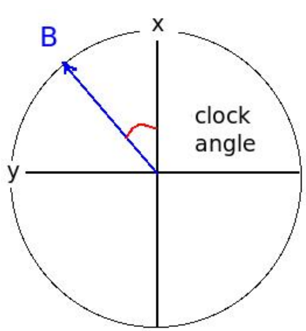
Kp Index Prediction– Newell Coupling Function

Kp is predicted using a relationship between the solar wind speed, magnetic field, and magnetic field clock angle. (Θ_C=90°, 135°, and 180°)

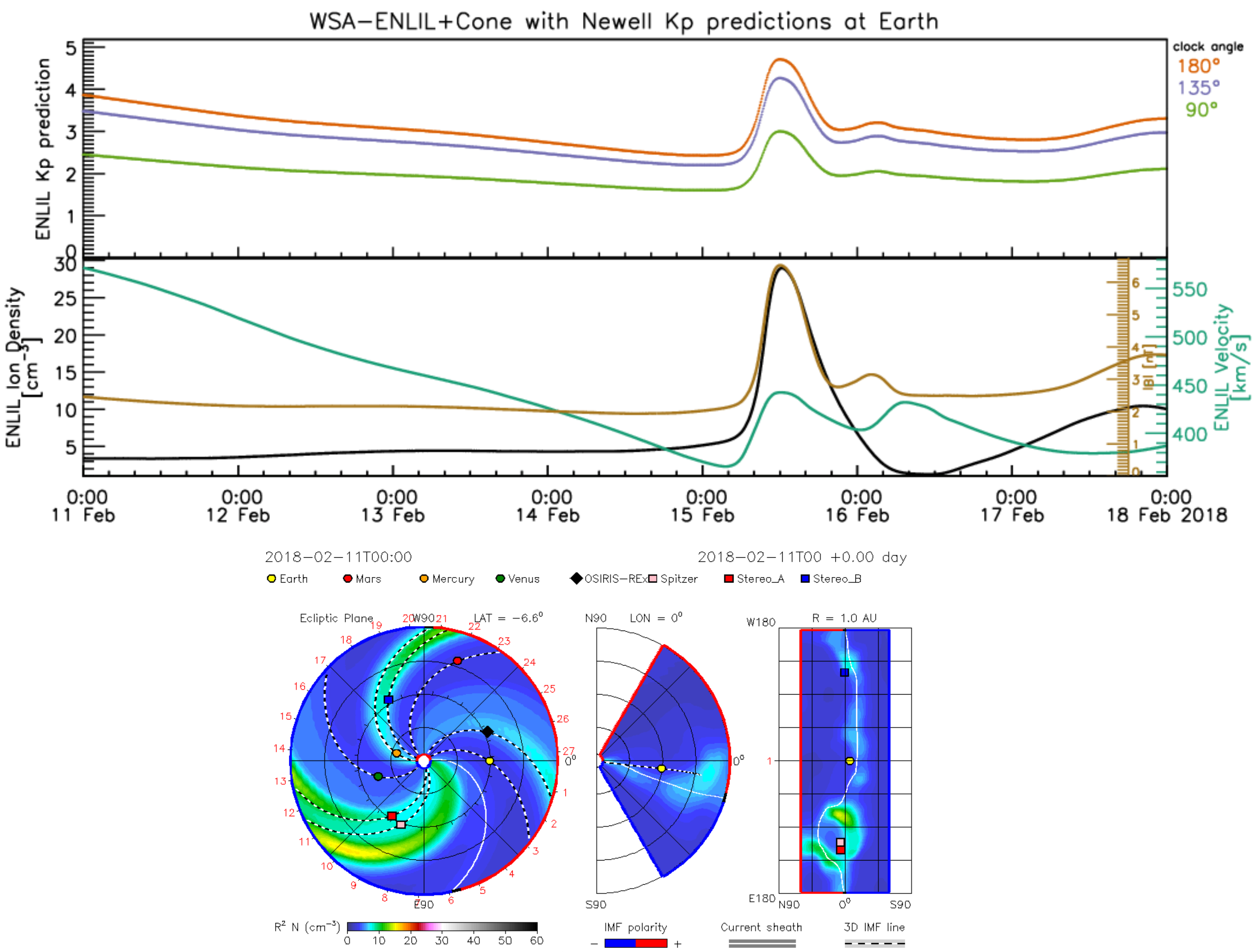
Magnetic flux opening rate at the magnetopause

$$d\Phi_{MP}/dt = v^{4/3} B_T^{2/3} \sin^{8/3}(\theta_c/2)$$





$$Kp = 9.5 - \exp\left(2.17676 - 0.000052001 \frac{d\Phi_{MP}}{dt}\right)$$


WSA–ENLIL+Cone with Newell Kp predictions at Earth
ENLIL Kp prediction
clock angle
180°
135°
90°
ENLIL Ion Density [cm⁻³]
|B| [nT]
ENLIL Velocity [km/s]
0:00 11 Feb
0:00 12 Feb
0:00 13 Feb
0:00 14 Feb
0:00 15 Feb
0:00 16 Feb
0:00 17 Feb
0:00 18 Feb 2018
2018–02–11T00:00
2018–02–11T00 +0.00 day
Earth
Mars
Mercury
Venus
OSIRIS–REx
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
W90
LAT = –6.6°
E90
N90
LON = 0°
S90
W180
R = 1.0 AU
E180
R² N (cm⁻³)
IMF polarity
Current sheath
3D IMF line
ENLIL–2.7 lowres–2200–a4b1 WSA_V2.2 GONG–2200

E-mail/text file with CME impact estimate at Earth

Arrival time(year/month/day, hr:min UT) =2012-07-31T15:02Z
(confidence level +-7 hours)

Duration of the disturbance (hr) = 10.3
(confidence level +-8 hours)

Minimum magnetopause standoff distance: Rmin(Re)=5.6
(under quiet conditions: Rmin(Re)=10;
R_geosynchr(Re)=6.6)

Kp index for three possible IMF clock angles
(angle 180 gives the maximum possible estimated Kp):
(Kp)_90=4
(Kp)_135=6
(Kp)_180=7

****

Here are the links to the movies of the modeled event

http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_afwa_anim.tim-pdyn.gif

Inner Planets
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-den-Stereo_B.gif
http://iswa.gsfc.nasa.gov/downloads/20120729_014700_anim.tim-vel-Stereo_B.gif

Timelines
http://iswa2.ccmc.gsfc.nasa.gov/downloads/20120729_014700_ENLIL_CONE_timeline.gif
http://iswa2.ccmc.gsfc.nasa.gov/downloads/20120729_014700_ENLIL_CONE_Kp_timeline.gif

Impact estimate at NASA mission locations

Mars
****

CME did not hit the Mars.
or
CME impact is very weak.

****

Stereo A
****

CME did not hit the StereoA.
or
CME impact is very weak.

****

Stereo B
****
CME did not hit the StereoB.
or
CME impact is very weak.

****

Spitzer
****

Arrival time(year/month/day, hr:min UT) =2015-05-11T20:49Z

Inner Planets
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel-Stereo_A.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-den-Stereo_B.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_anim.tim-vel-Stereo_B.gif

Inner Planet Timelines
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Mars_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_STA_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_STB_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Spitz_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Merc_timeline.gif
http://iswa.gsfc.nasa.gov/downloads/20150509_071500_2.0_ENLIL_CONE_Venus_timeline.gif