Toward Connecting the Sun-to-Earth Picture: What we can do Today

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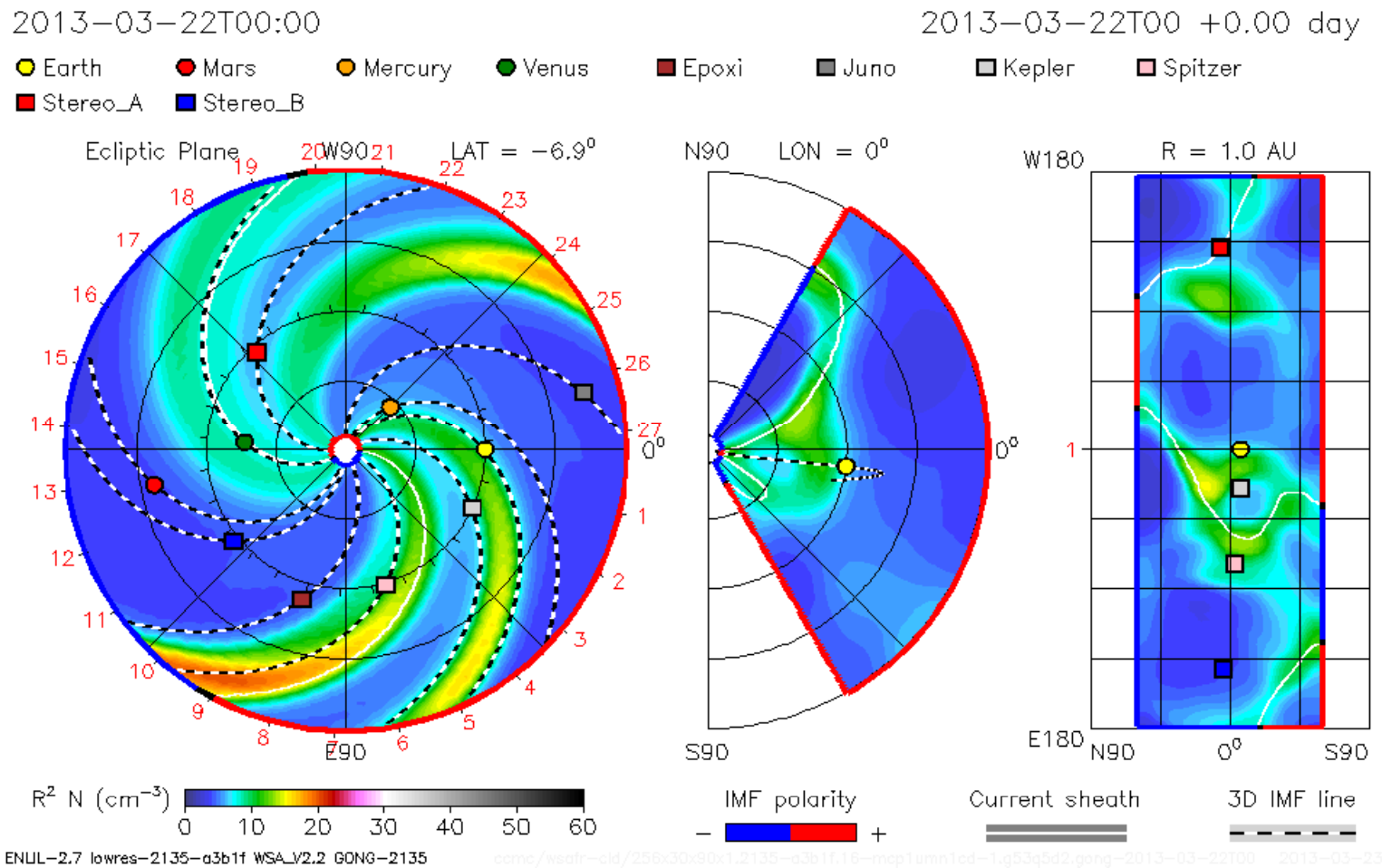
C.N. Arge, C.O. Lee, L.K. Jian,
Yan Li, H.Bain

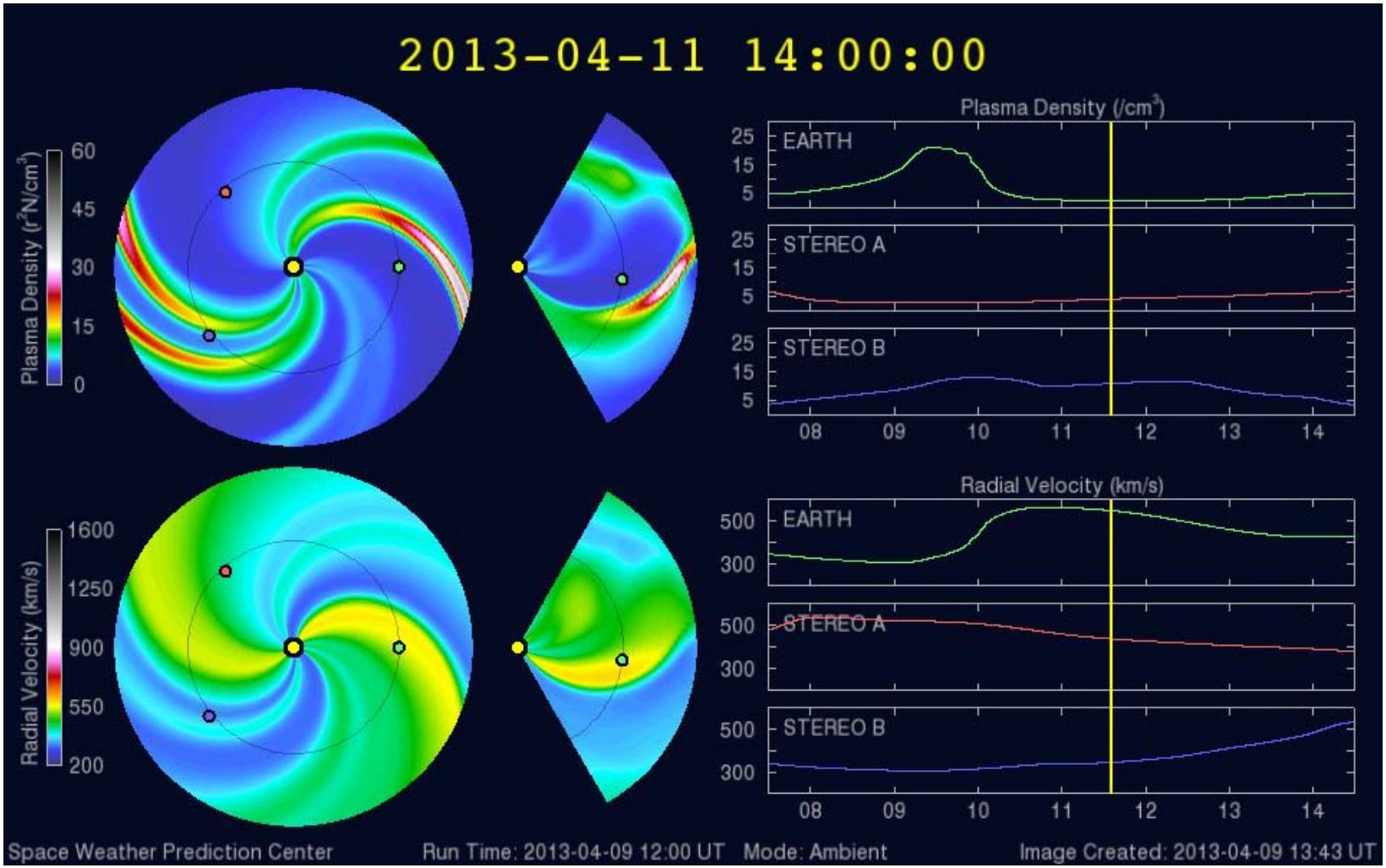
LWS Meeting, Portland, November 2014

Heliospheric model runs based on near real-time SDO, SOHO and STEREO images are now regularly made at the GSFC Space Weather Research Center using WSA-ENLIL.

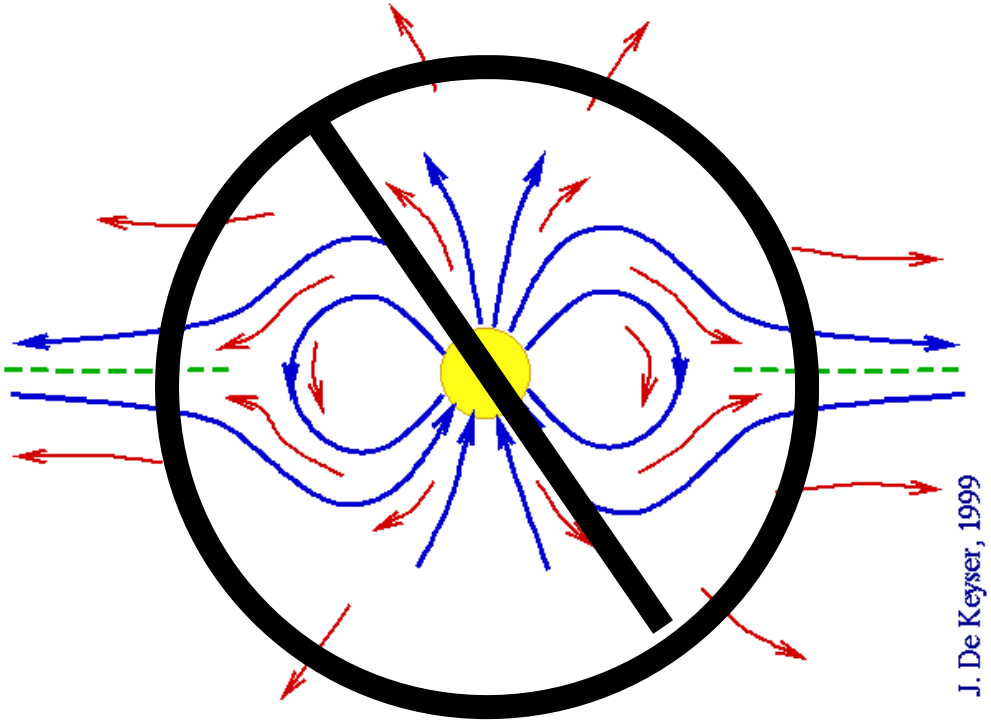


swrc.gsfc.nasa.gov- using the WSA/ENLIL model (D. Odstrcil, N. Arge)

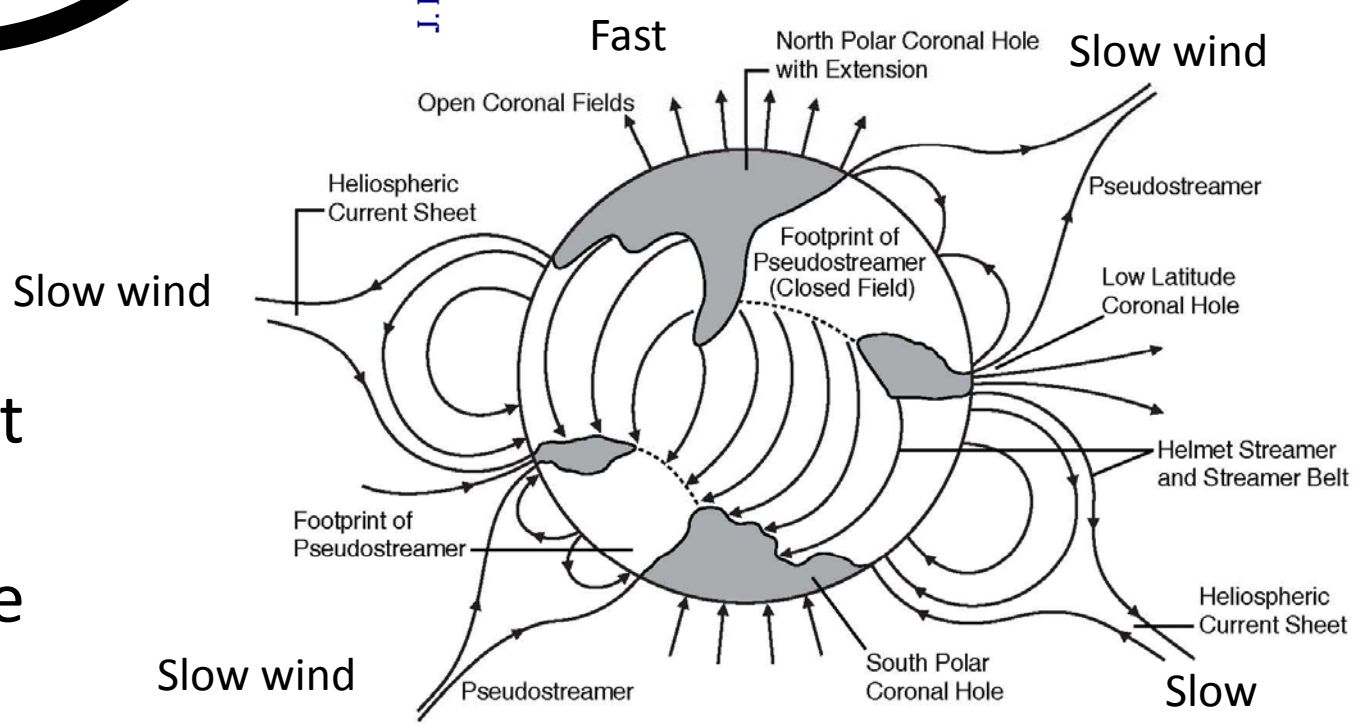
WSA-ENLIL Model is also run at NOAA SWPC to forecast Solar wind at 1 AU at Earth and the STEREO locations up to a month ahead (a solar rotation is ~27 days)



www.swpc.noaa.gov/wsa-enlil

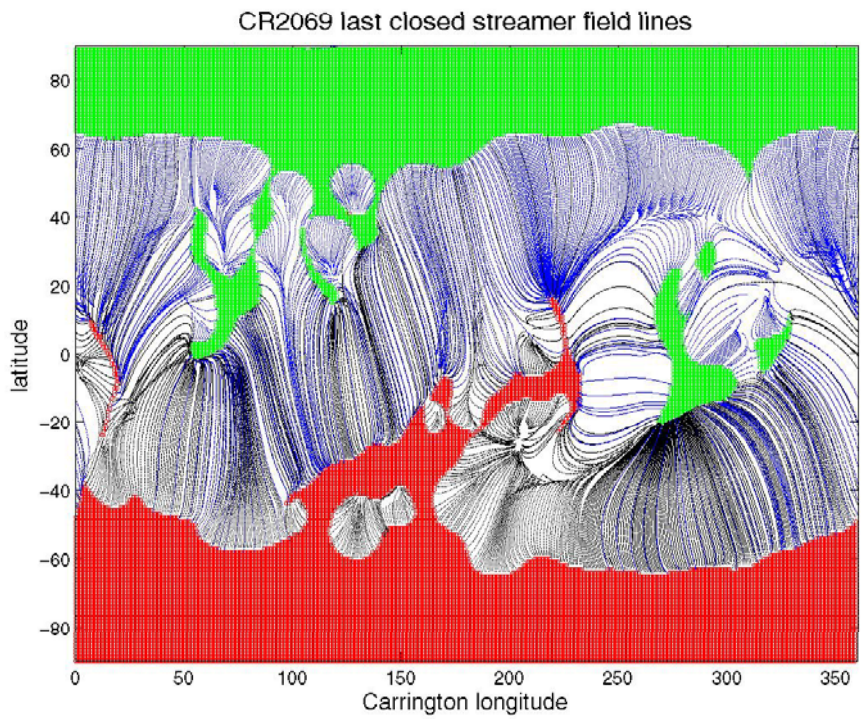


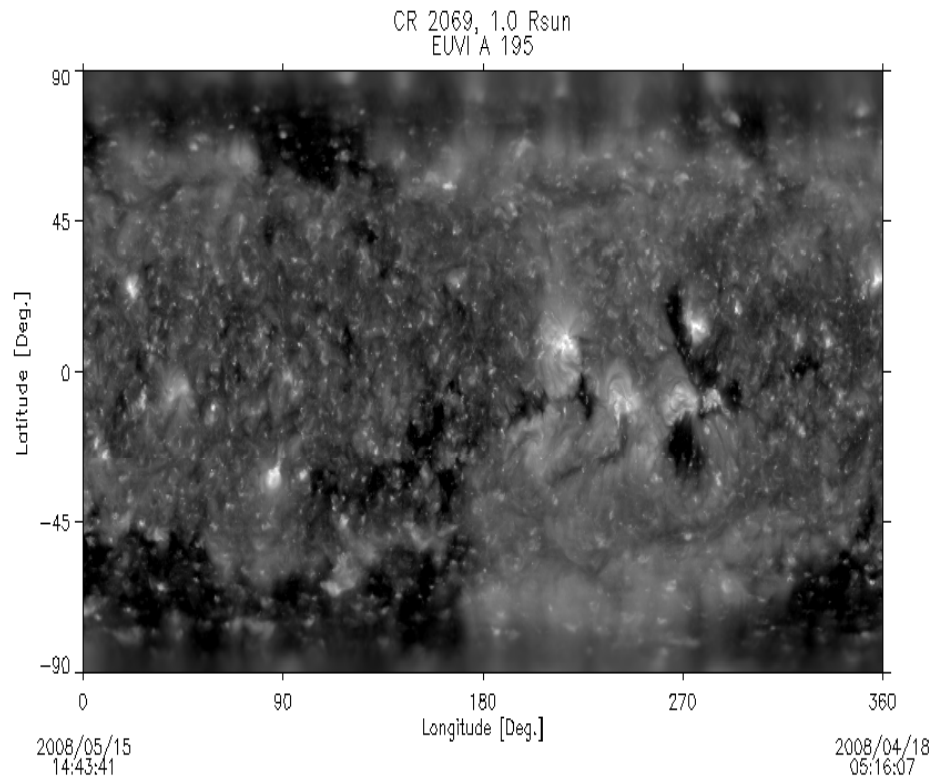
A user no longer has to assume the solar wind is described by a dipolar corona source with polar coronal hole outflows.



This is important …especially in the current cycle

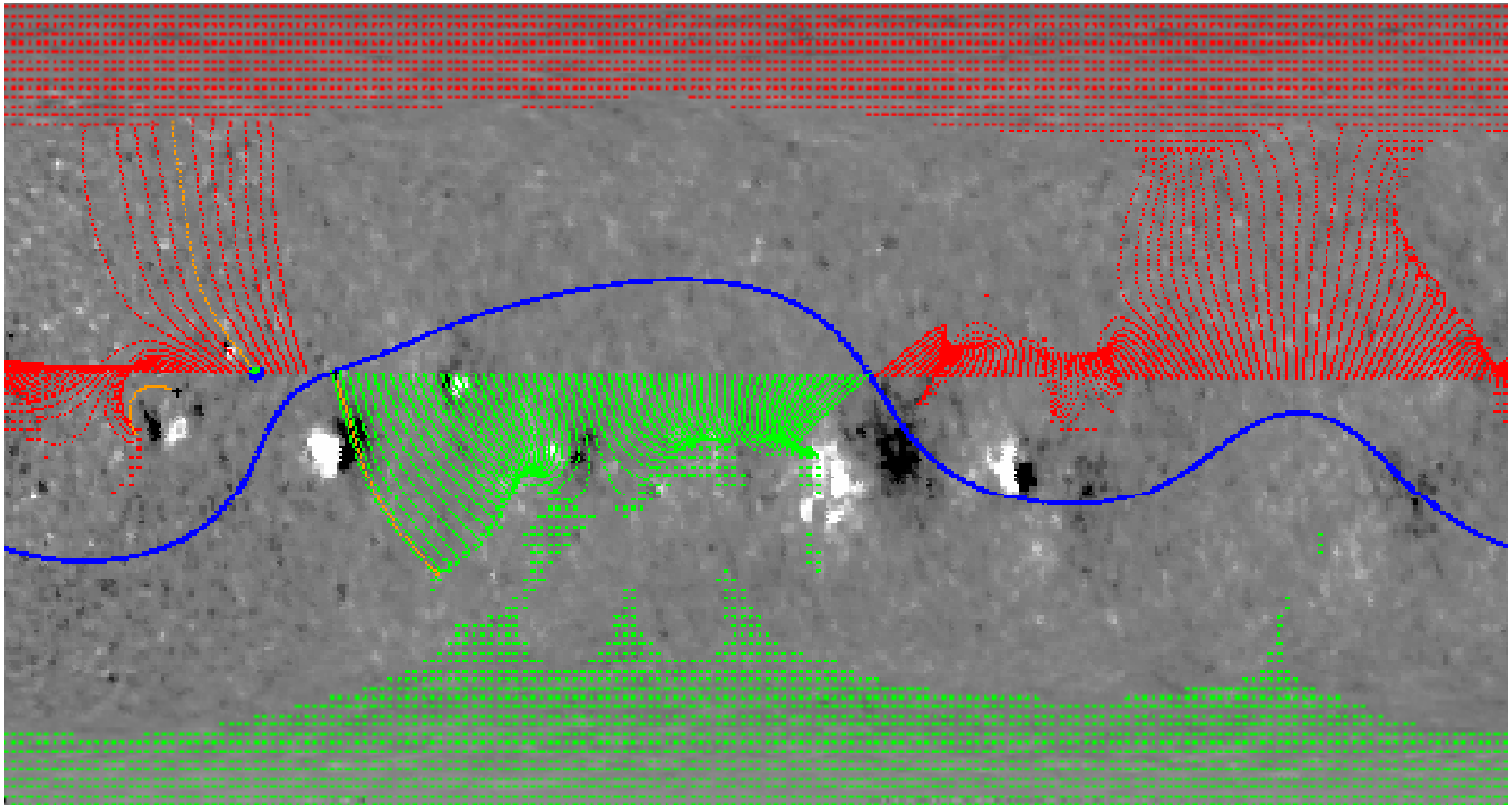
Potential Field Source Surface models of the coronal field provide an easy way to approximate real coronal field structure using photospheric field 'synoptic' maps.





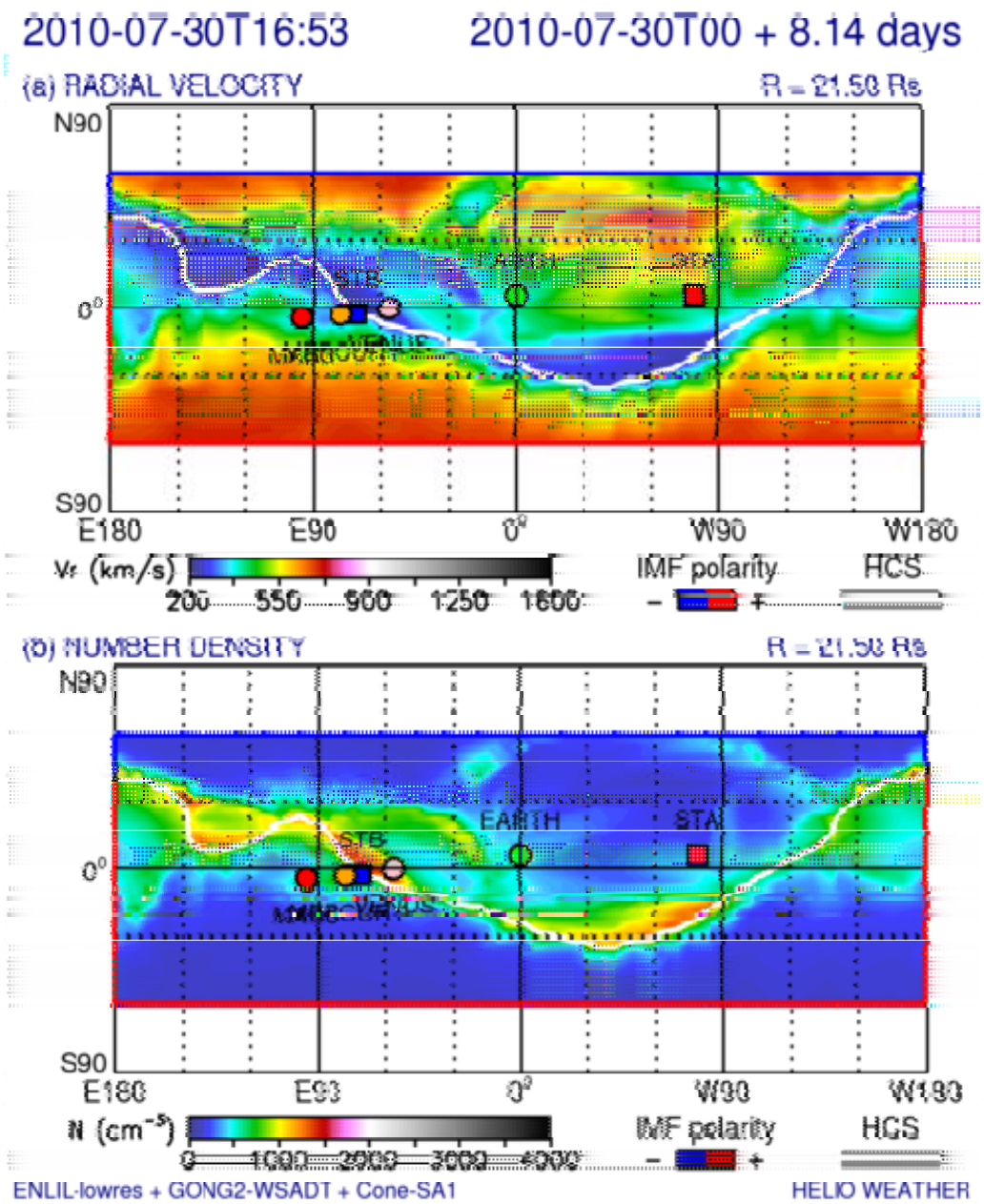
Here, compare CR2069 GONG-based PFSS model with the SECCHI EUVI map showing the dark coronal holes. GONG magnetic maps are typically used in WSA-ENLIL.

The ecliptic solar wind is inferred to often come from small mid-low latitude coronal holes and extensions



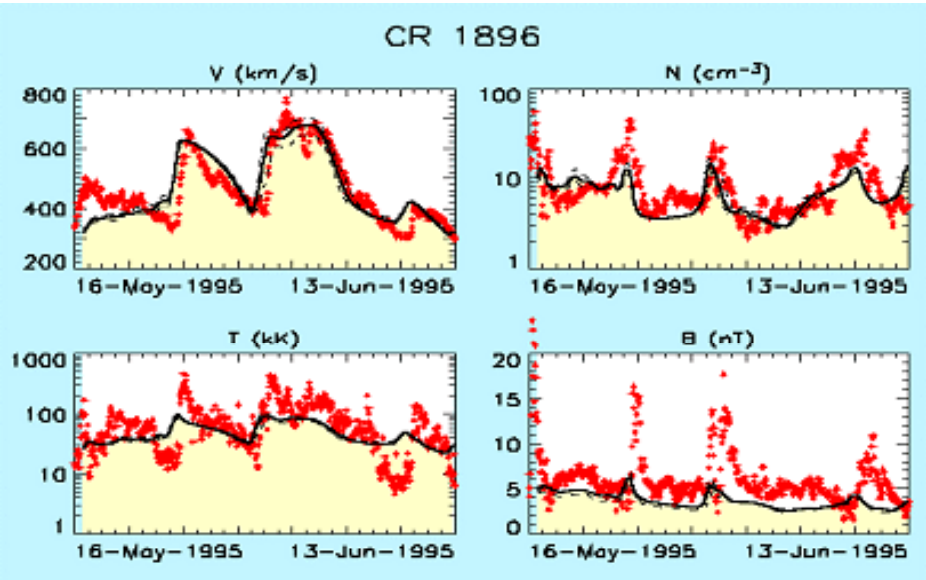
(GONG website magnetograms and PFSS model movie for early 2007 to mid-2013 (loops))

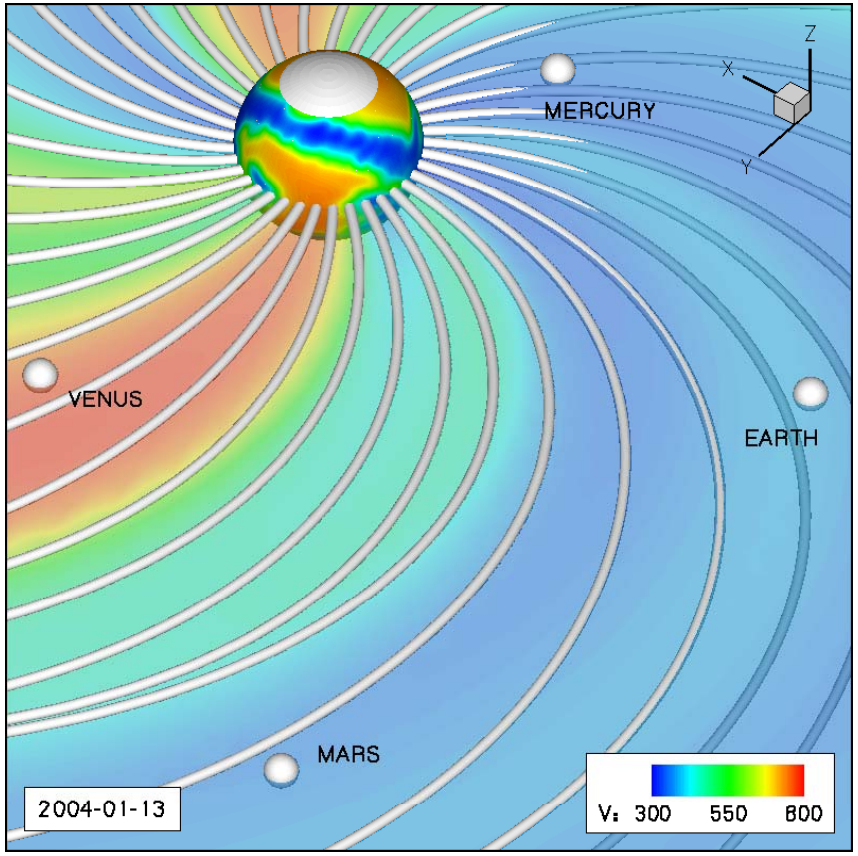
The PFSS Model Source Surface fields and WSA empirical velocity formula are used to make the inner boundary maps for ENLIL solar wind and IMF at a radius of ~20 Rsun.



ENLIL then uses MHD solutions to produce a structured solar wind with interacting high and low speed streams

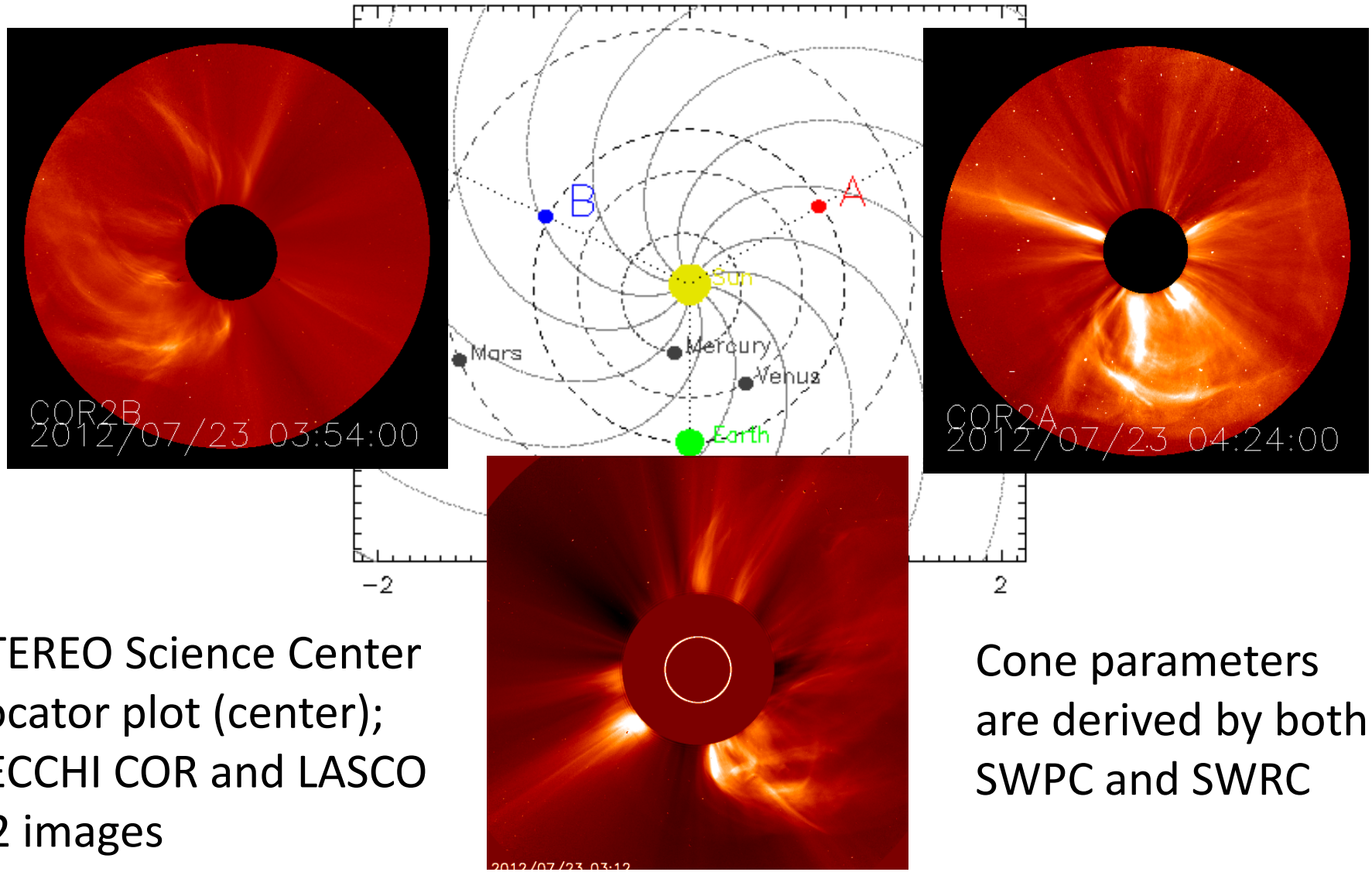
WIND spacecraft data compared to WSA-ENLIL results: Solar wind velocity (V), density (N), ion Temp. (T) and magnetic field strength (B)





(D. Odstrcil images, WIND spacecraft data)

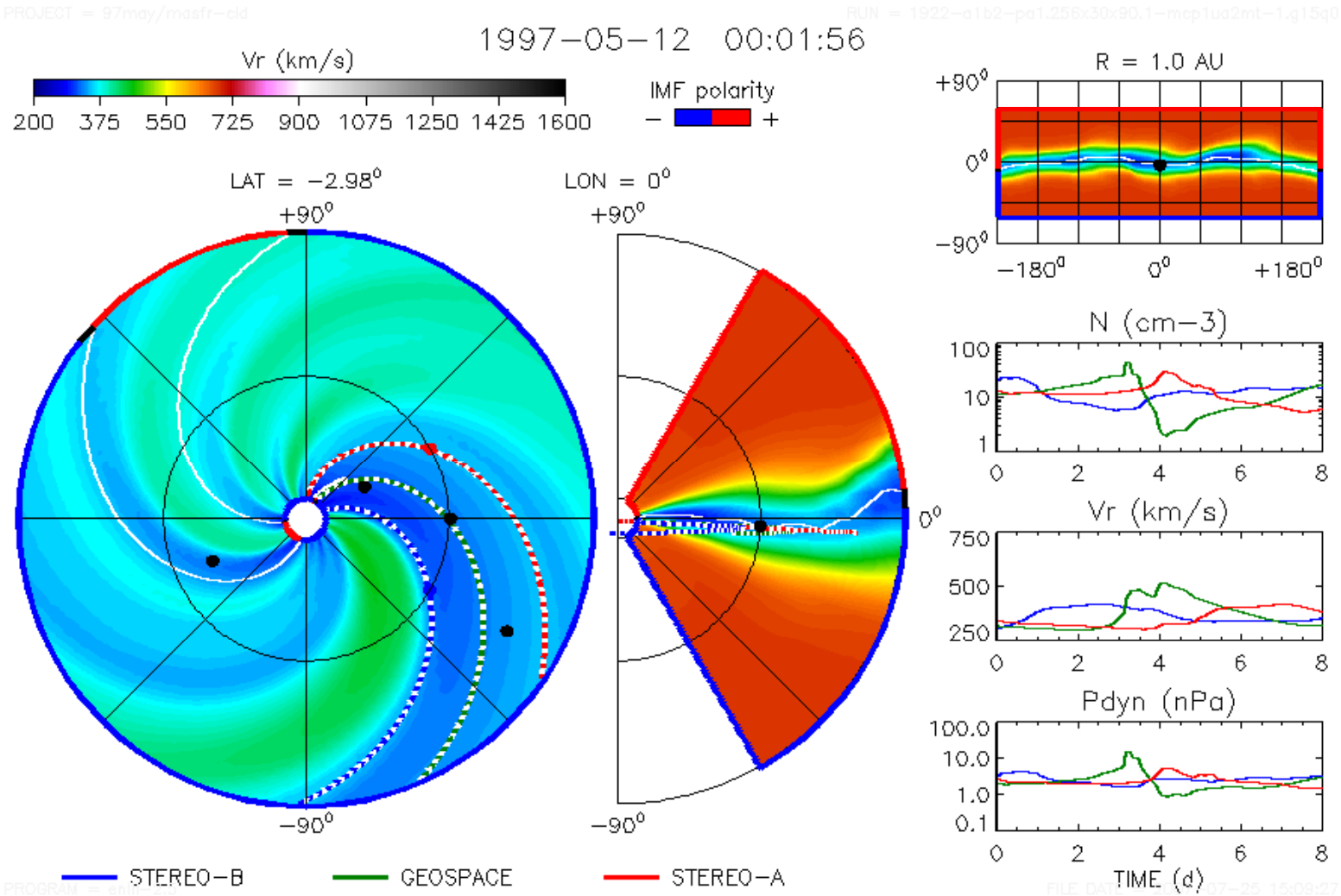
To simulate CME disturbances, ENLIL typically introduces a high-pressure solar wind gust within a cone-shaped volume determined by fitting coronagraph images: the 'cone model'



STEREO Science Center Locator plot (center); SECCHI COR and LASCO C2 images

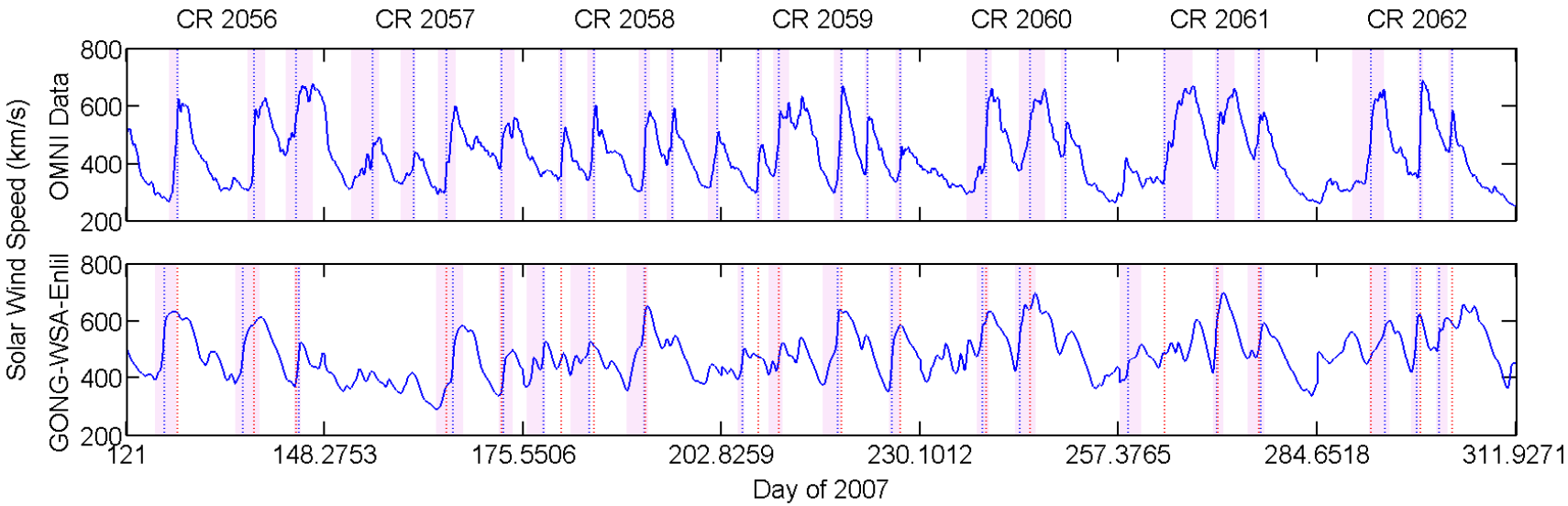
Cone parameters are derived by both SWPC and SWRC

The WSA-ENLIL model with cone model-initiated CME(s) is also available for users at the CCMC



(example from D. Odstrcil)

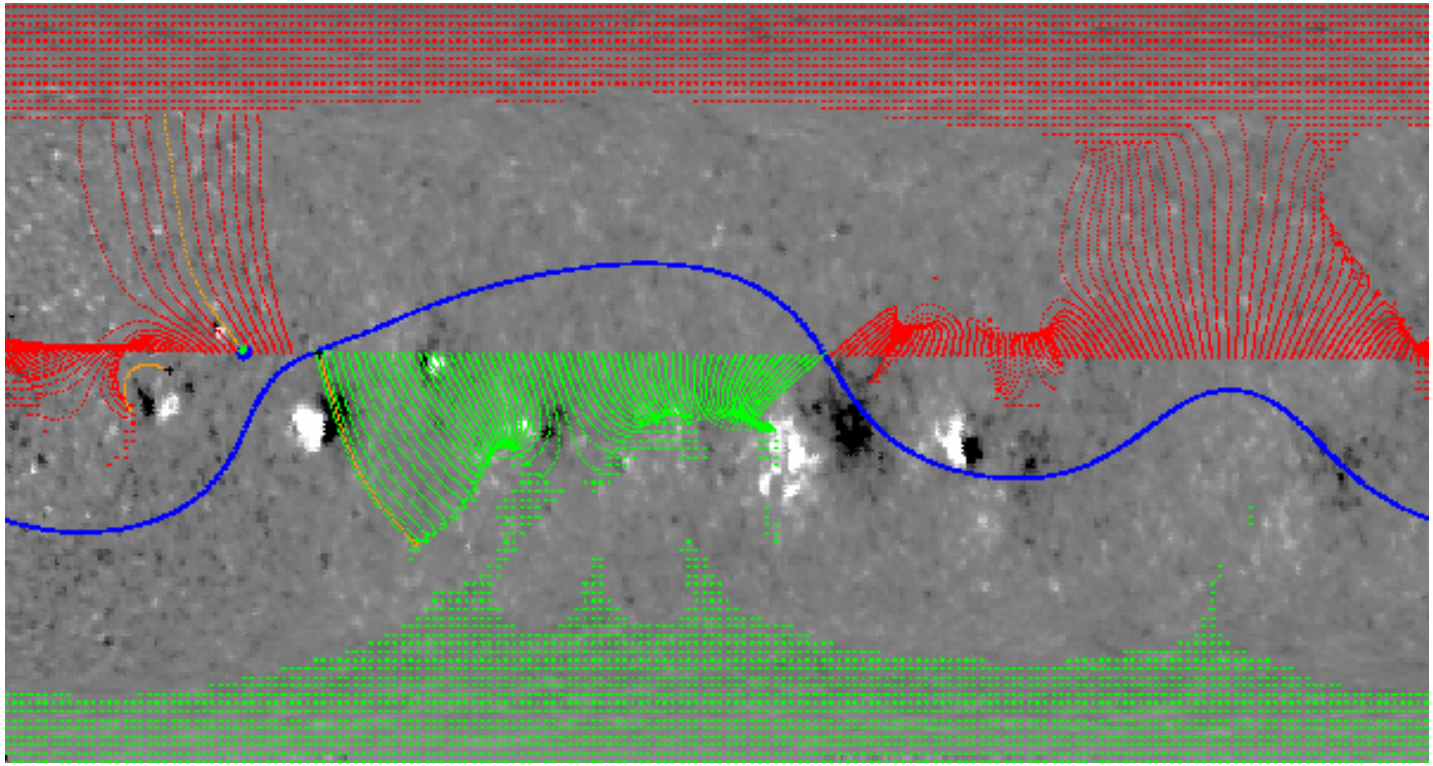
How well does ENLIL do under regular use circumstances?
Test of GONG-based WSA-ENLIL Solar Wind Velocity (L. Jian)



Shaded region: SIR Blue dashed line: stream interface (SI) determined by highest speed gradient Red dashed line: matching SI from observation

- There are 26 stream interaction regions (SIRs) between slow and fast solar wind observed during Carrington rotations (CRs) 2056 – 2062 (May – Oct 2007)
- **Rate of hits: 69%**, rate of misses: 31%, rate of false alarms: 14%
- *HOW TO IMPROVE ENLIL SOLAR WIND???*

The ecliptic solar wind is inferred to often come from small mid-low latitude coronal holes and extensions



(GONG website magnetograms and PFSS model movie for early 2007 to mid-2013)

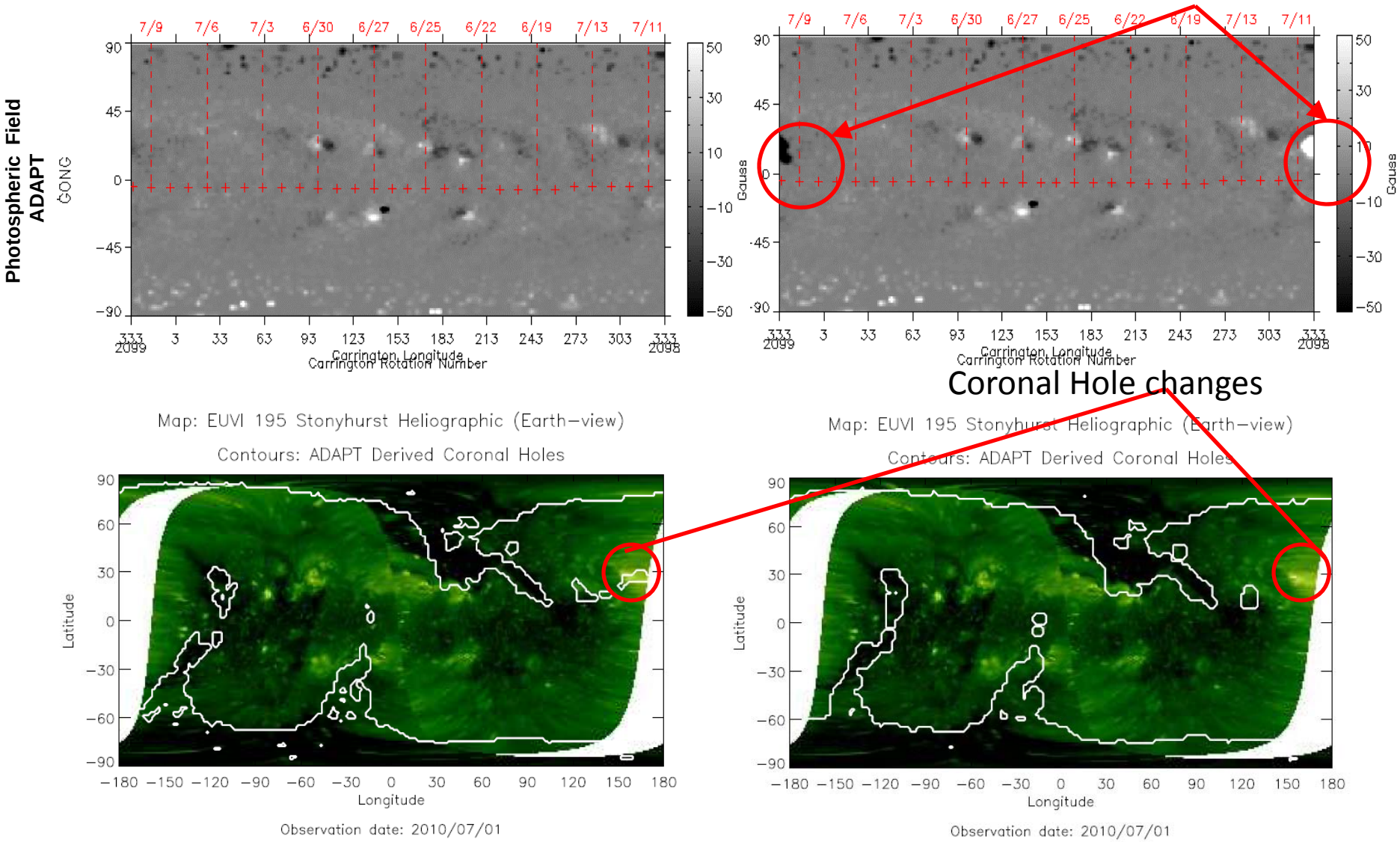
If the synoptic map is wrong, the model will not perform!
A major problem: No Farside Magnetgraph Observations

Photospheric Field 'Correction'- ADAPT@AFRL

(Far-Side Active Region Insertions based on helioseismology)

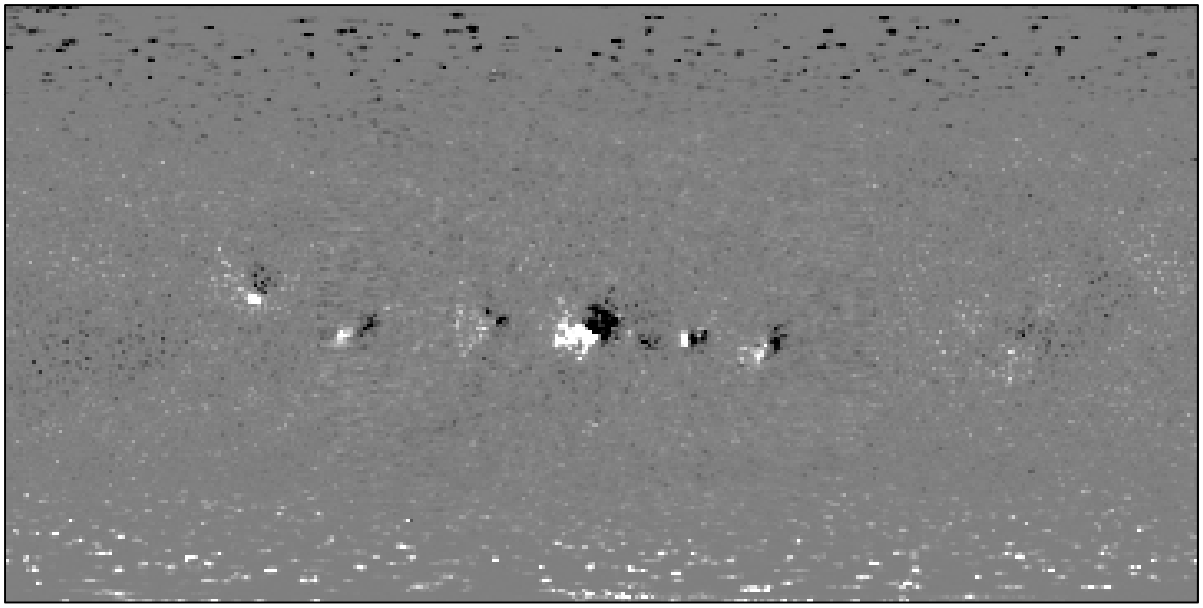
WITHOUT **Active Region Inserted**

WITH **Active Region Inserted**



Air Force Data Assimilative Photospheric Flux Transport (ADAPT) Model

1. Evolves the solar magnetic flux using well understood transport processes where measurements are not available.
2. Updates modeled flux with new observations using data assimilation methods
   - Rigorously takes into account model & observational uncertainties.



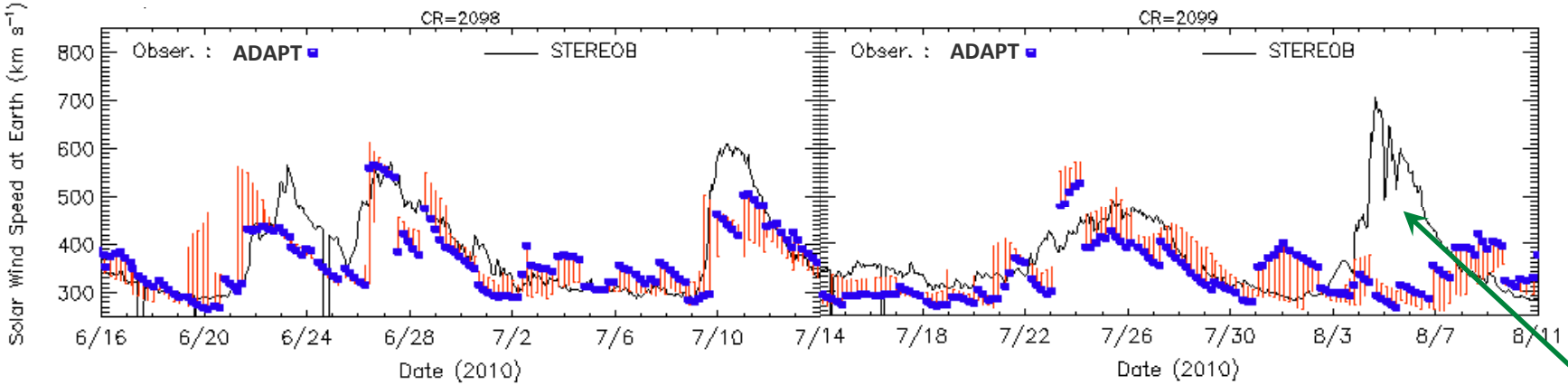
Sun's surface magnetic field (*movie length ~60 days*)

Provides more realistic estimates of the instantaneous global photospheric magnetic field distribution than those provided by traditional synoptic maps.

WSA-ENLIL Solar Wind Speed vs Observations at STEREO B (With & Without Far-Side Active Region Inserted)

Without Far-Side Active Region Inserted

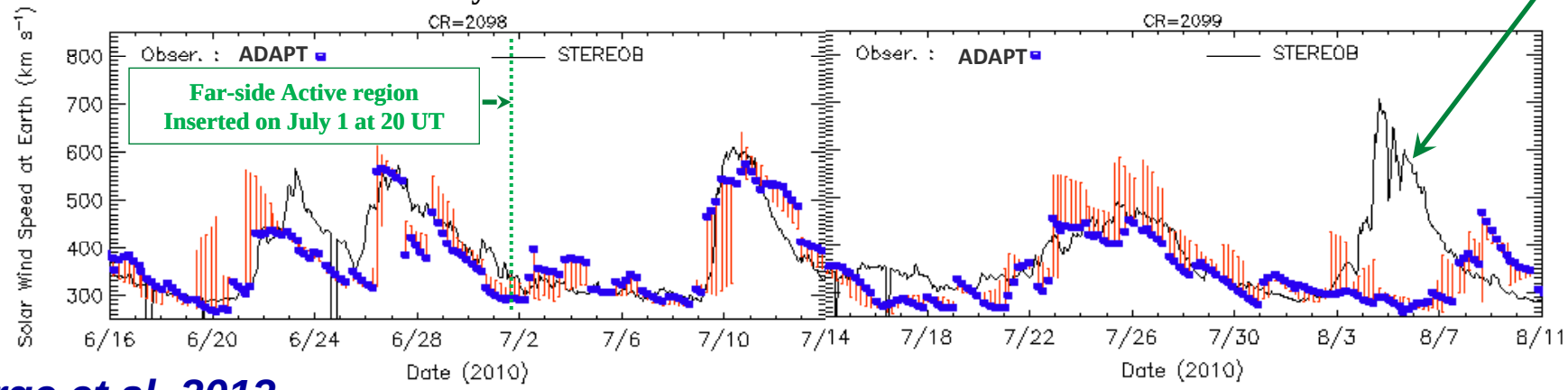
4 Day Advanced Predictions and STEREO B Observations



ICME

With Far-Side Active Region Inserted

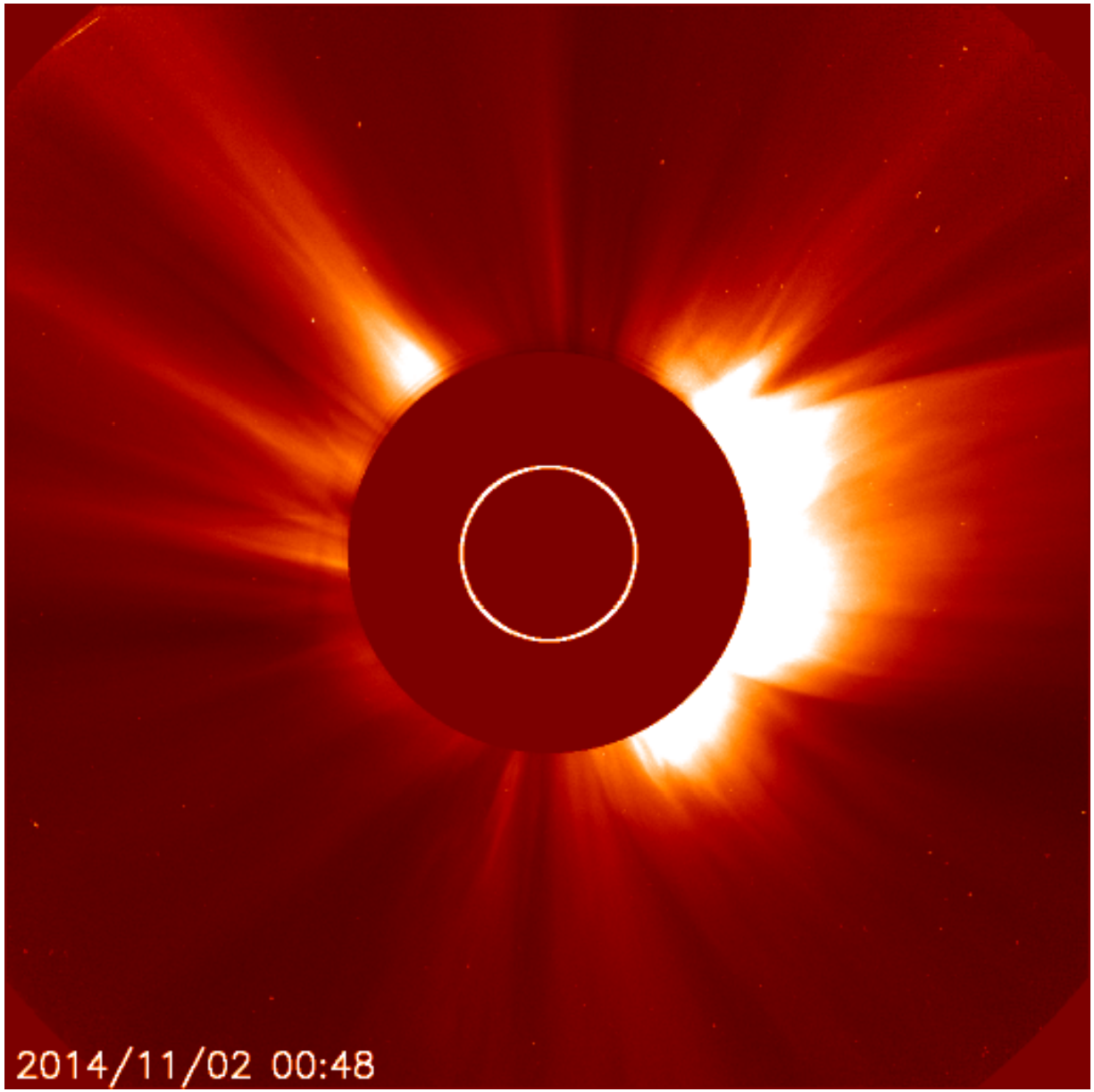
4 Day Advanced Predictions and STEREO B Observations



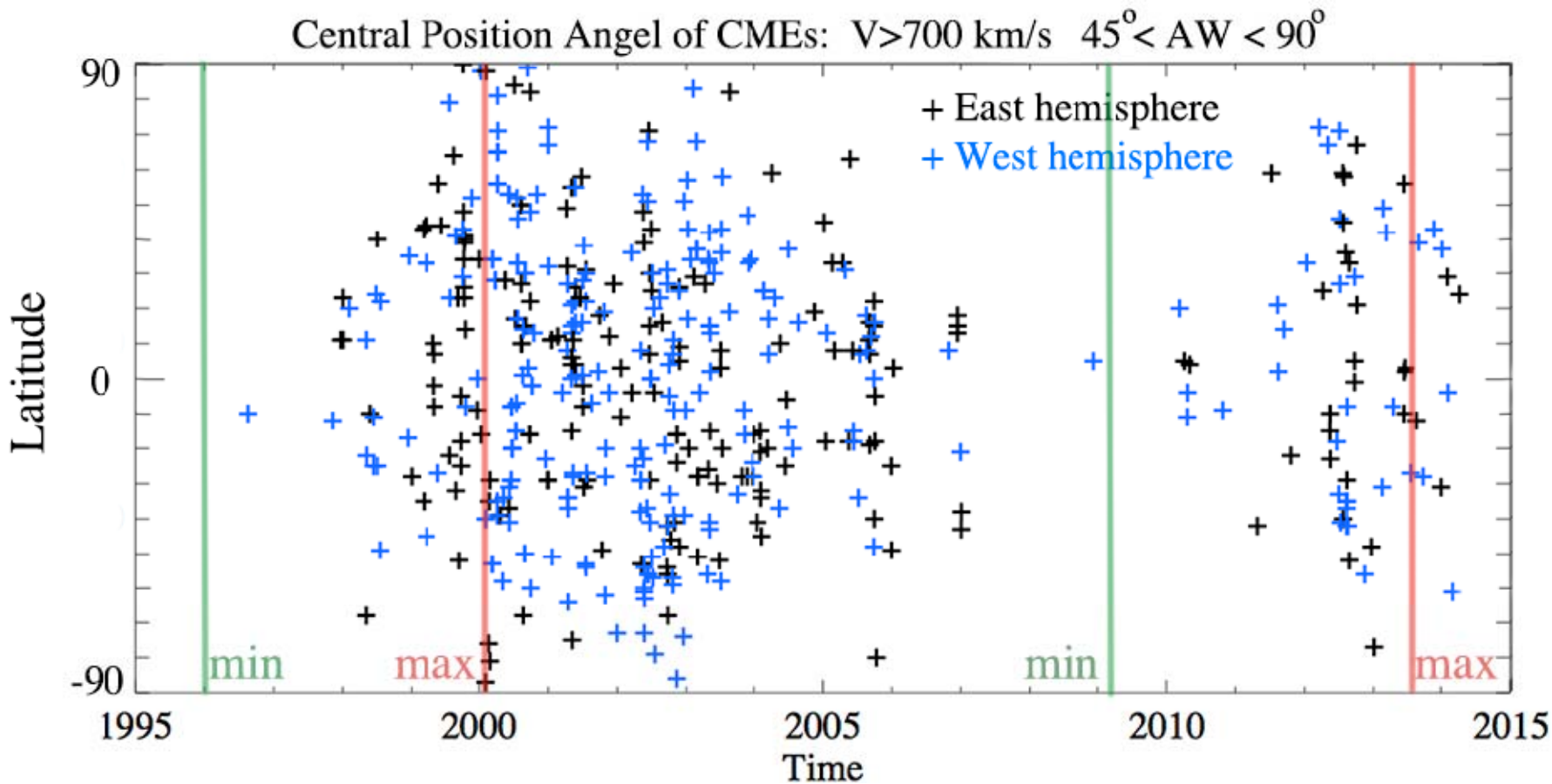
Arge et al. 2013

The corona is often disturbed by transients including CMEs

LASCO
C2 movie



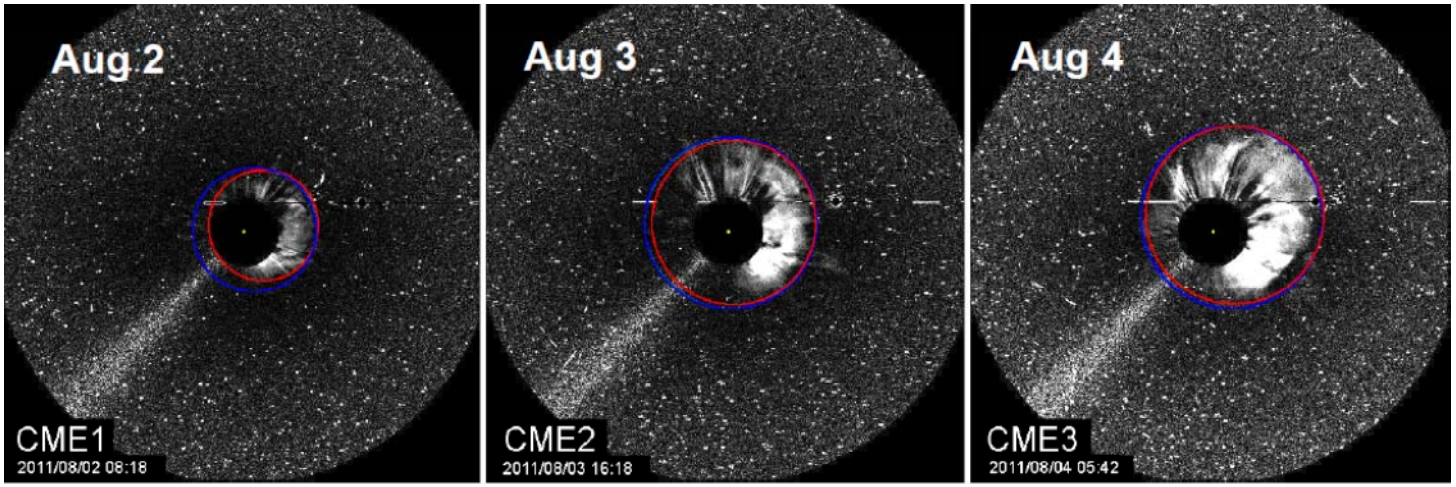
CME Clustering in space and time is common



(Y. Li, Based on the CDAW LASCO CME Catalog)

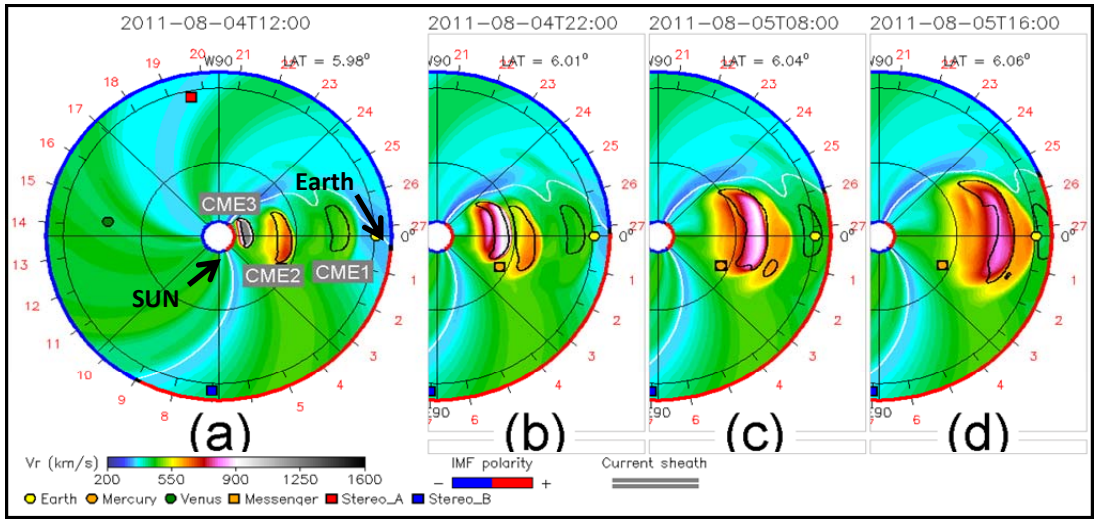
ENLIL now allows for multiple CMEs that may be closely spaced in time and location (e.g. C. Lee et al., 2014)

SOHO LASCO/C3 white light difference images of 3 successive Earth directed CMEs



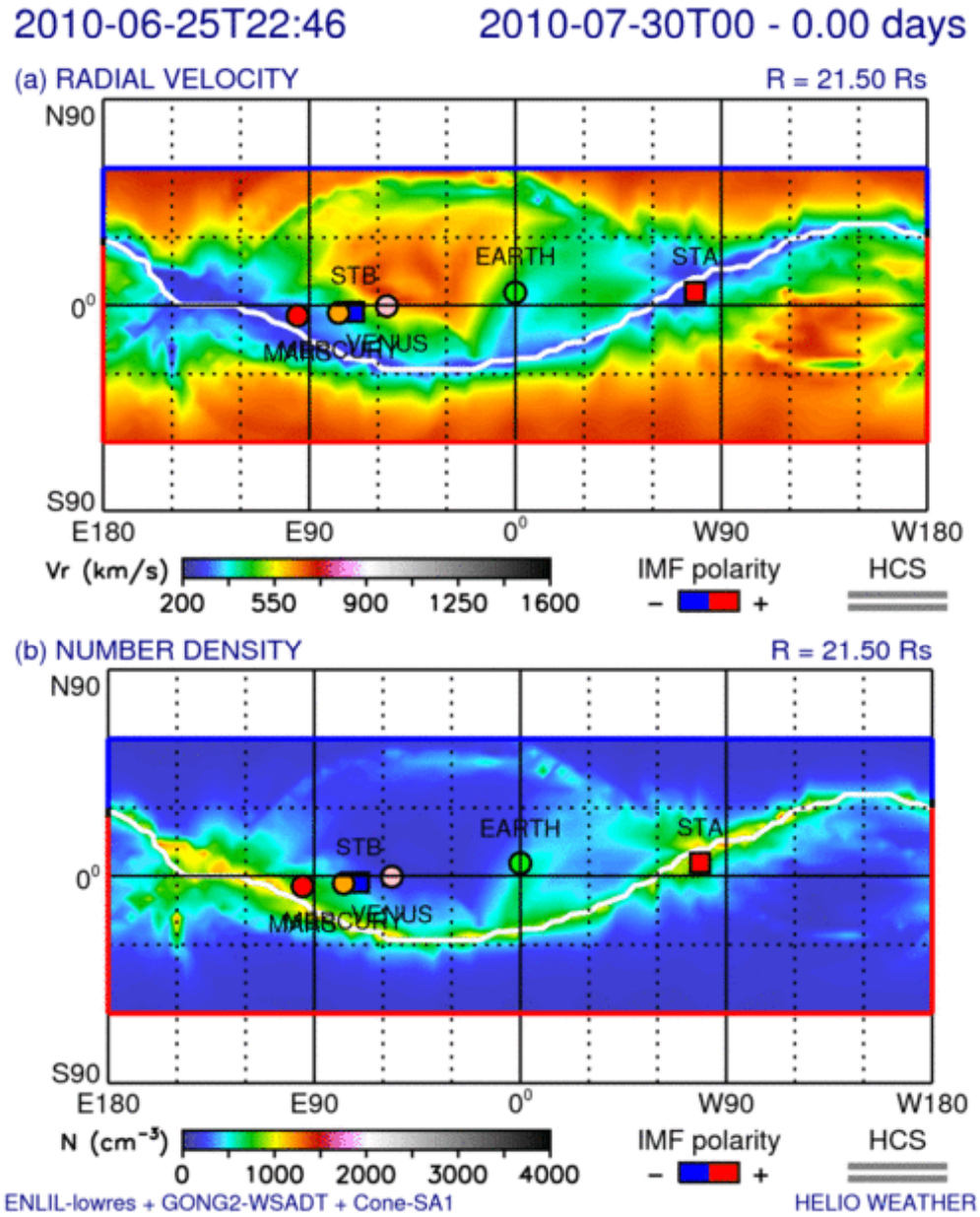
WSA+Enlil solar wind simulation of 3 interacting Earth directed CMEs

WSA-ENLIL
Solar wind speed
(ecliptic plane)

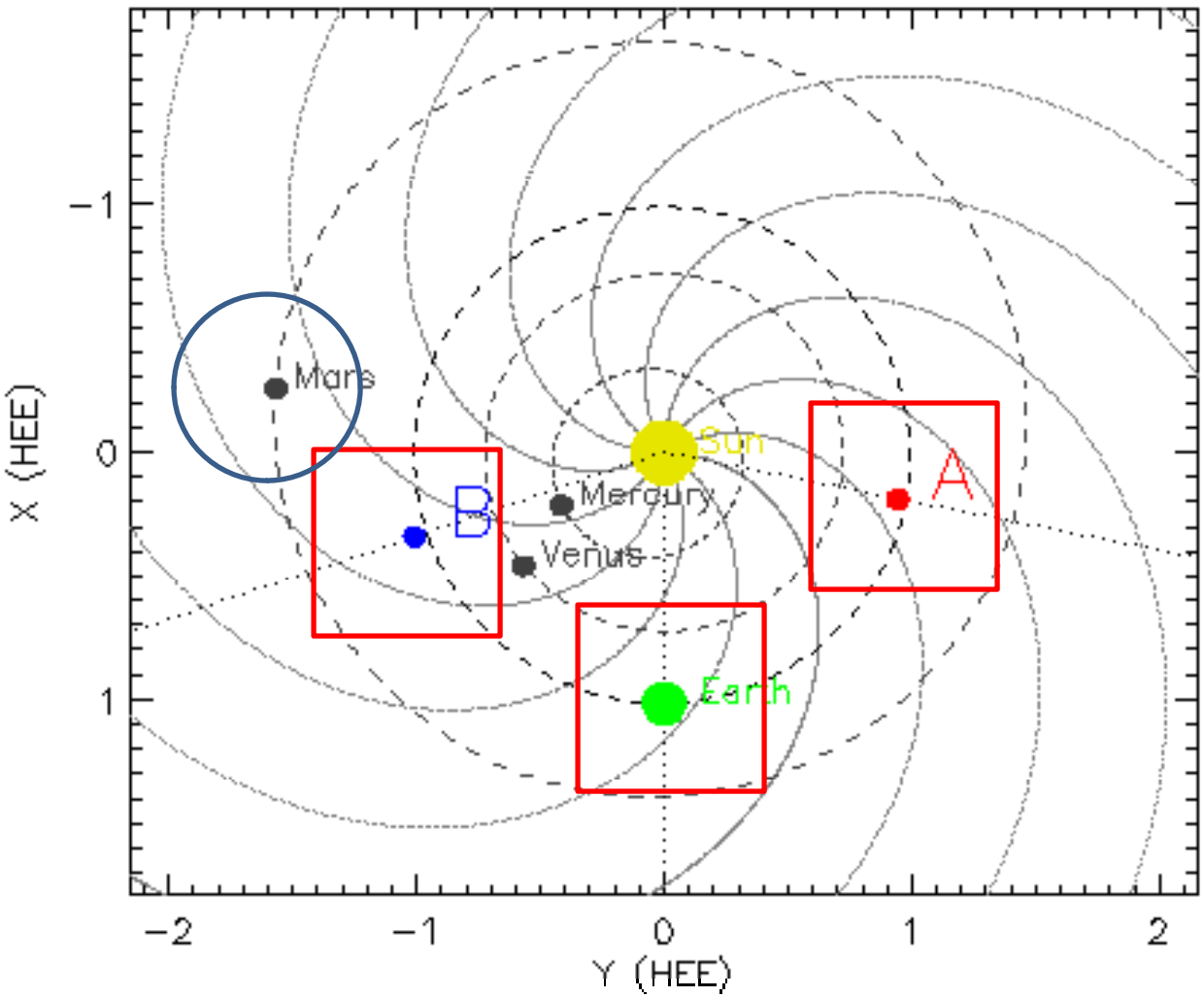


Time

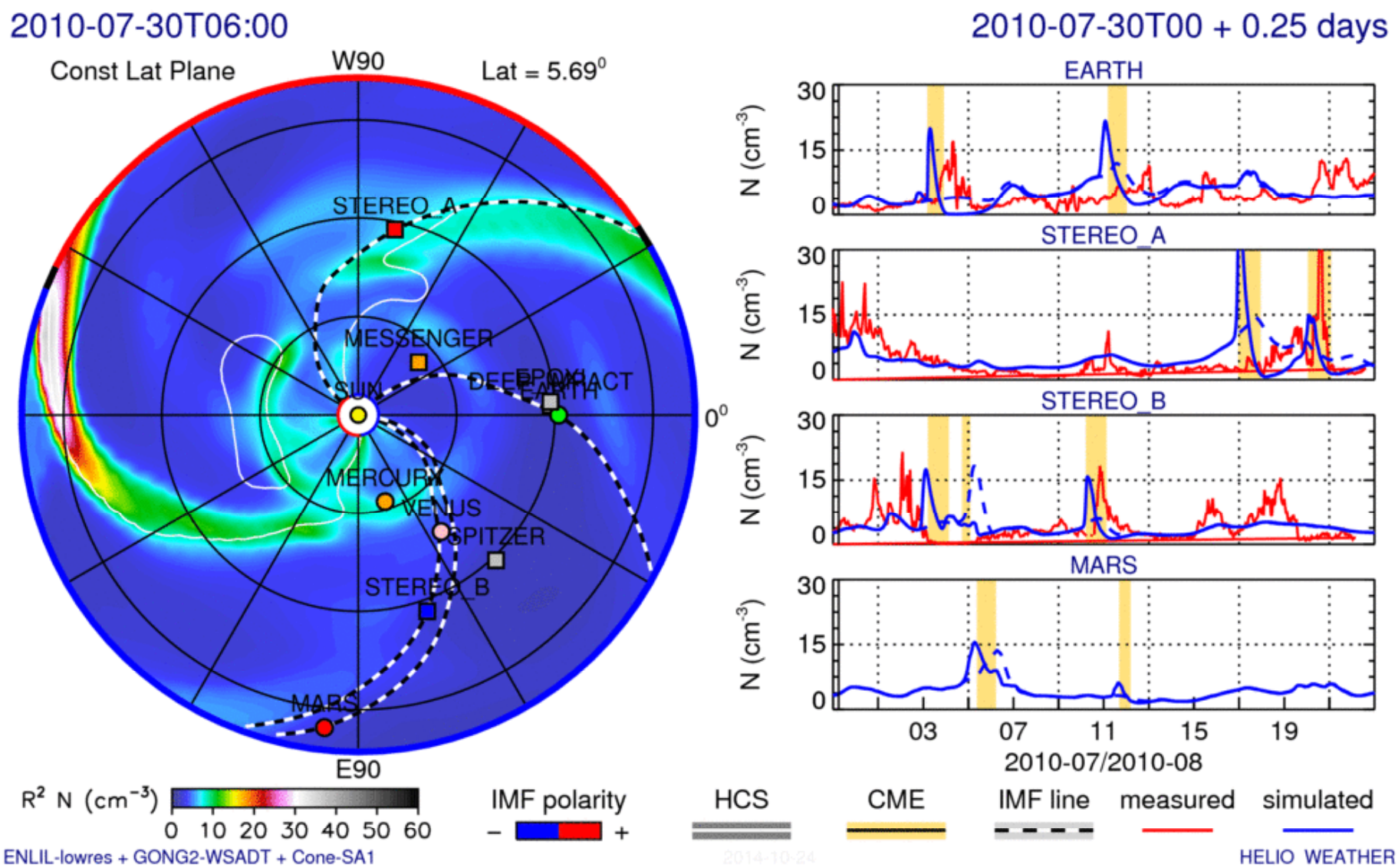
Example: the ENLIL inner boundary for August 2010 (L. Mays)



AUGUST 2010

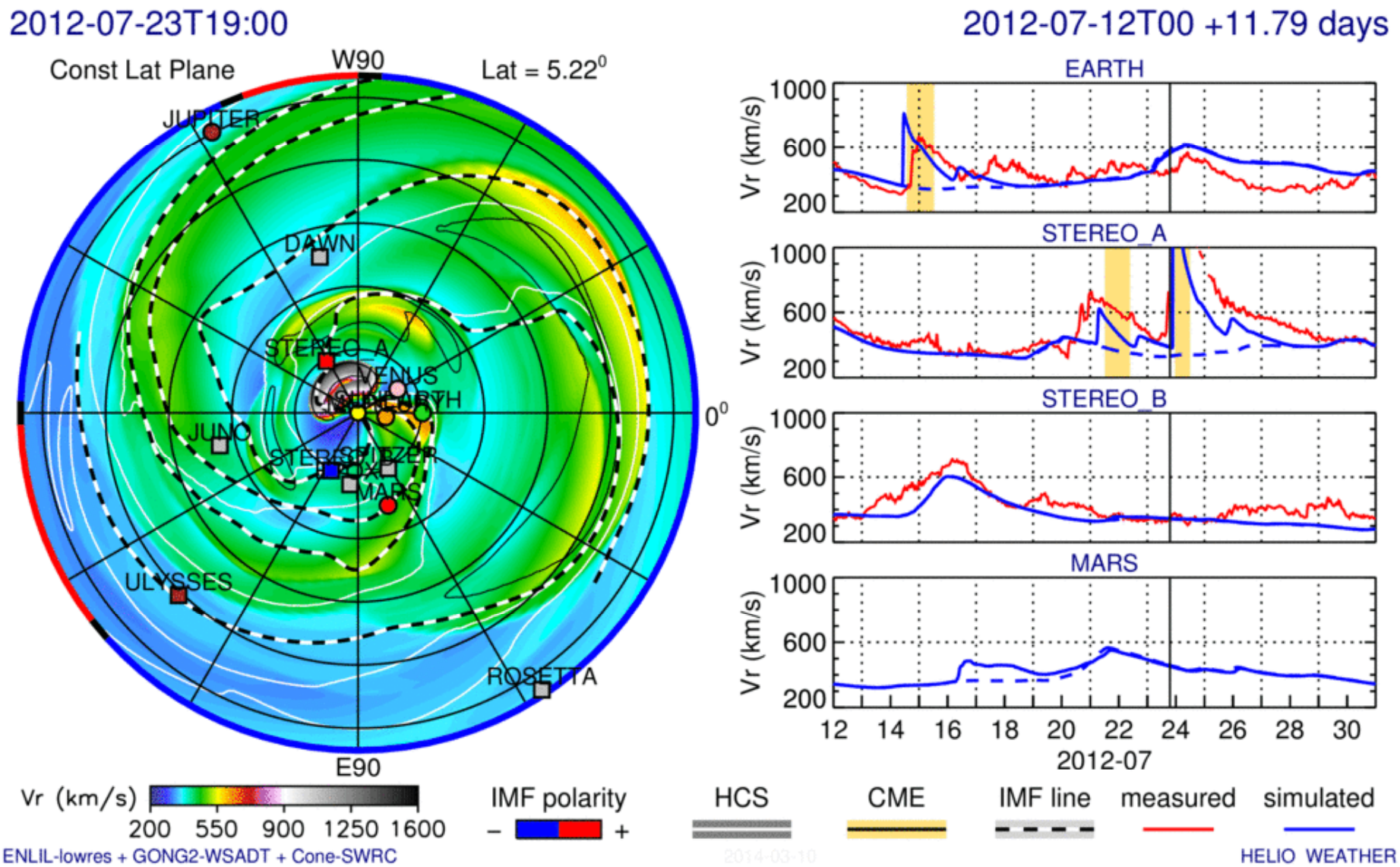


Locations of STEREO-A, STEREO-B and ACE (Earth) (SSC plot)

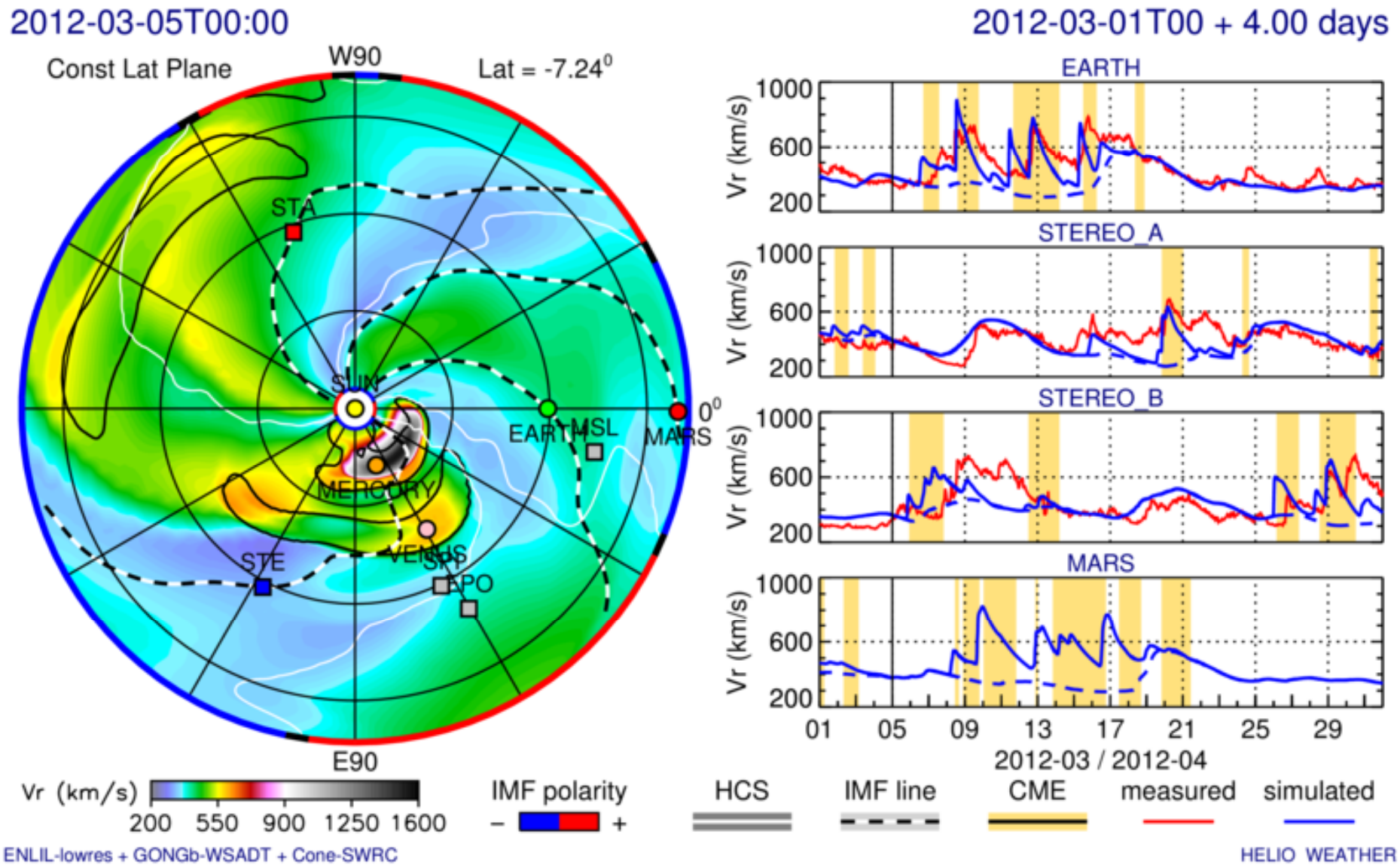


ENLIL results: D. Odstrcil, L. Mays

The July 2012 STEREO Extreme Event case

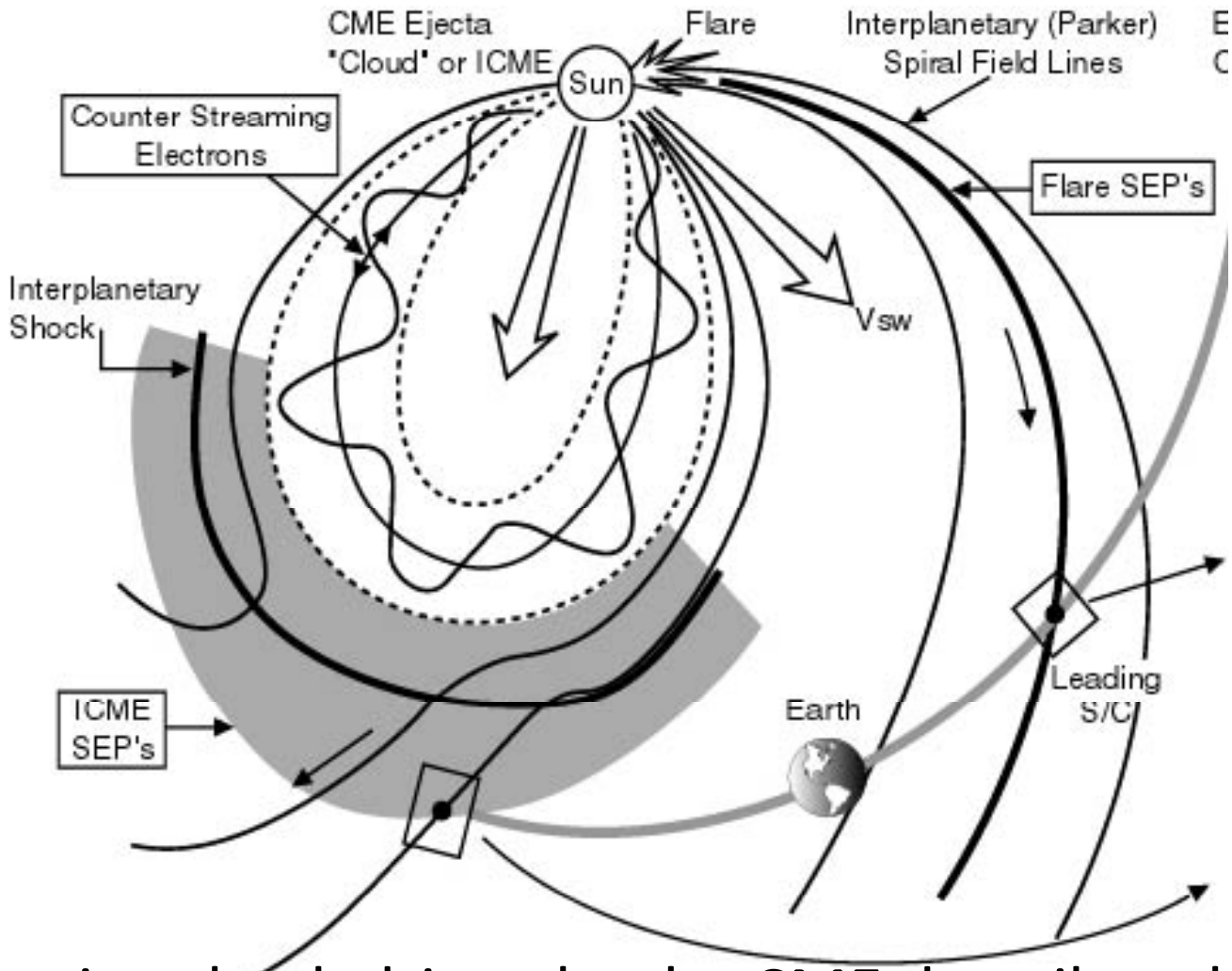


March 2012: 29 CME injections!!



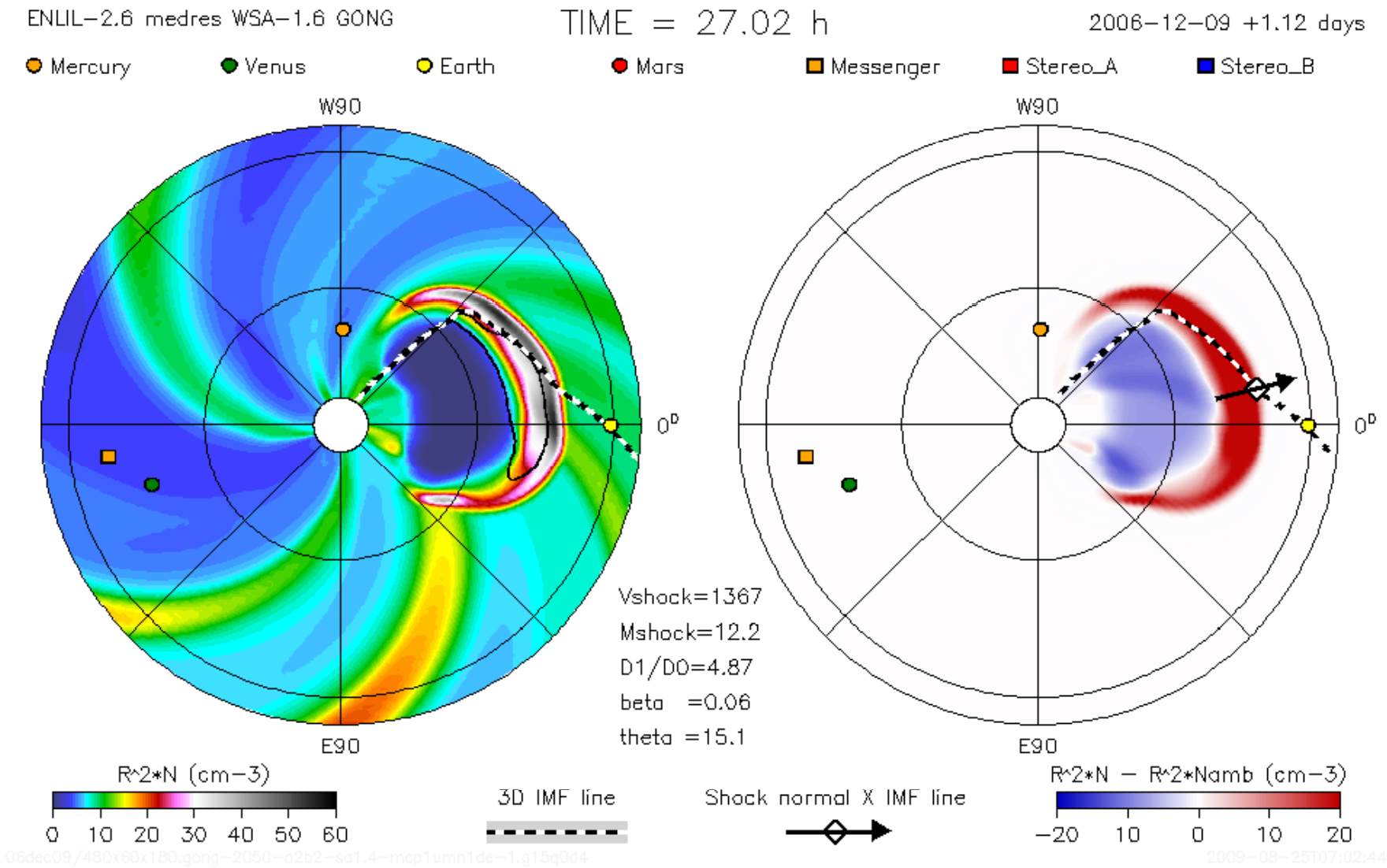
SWRC parameters (whole heliosphere considered)

Next step: Using ENLIL results to model large Solar Energetic Particle Events



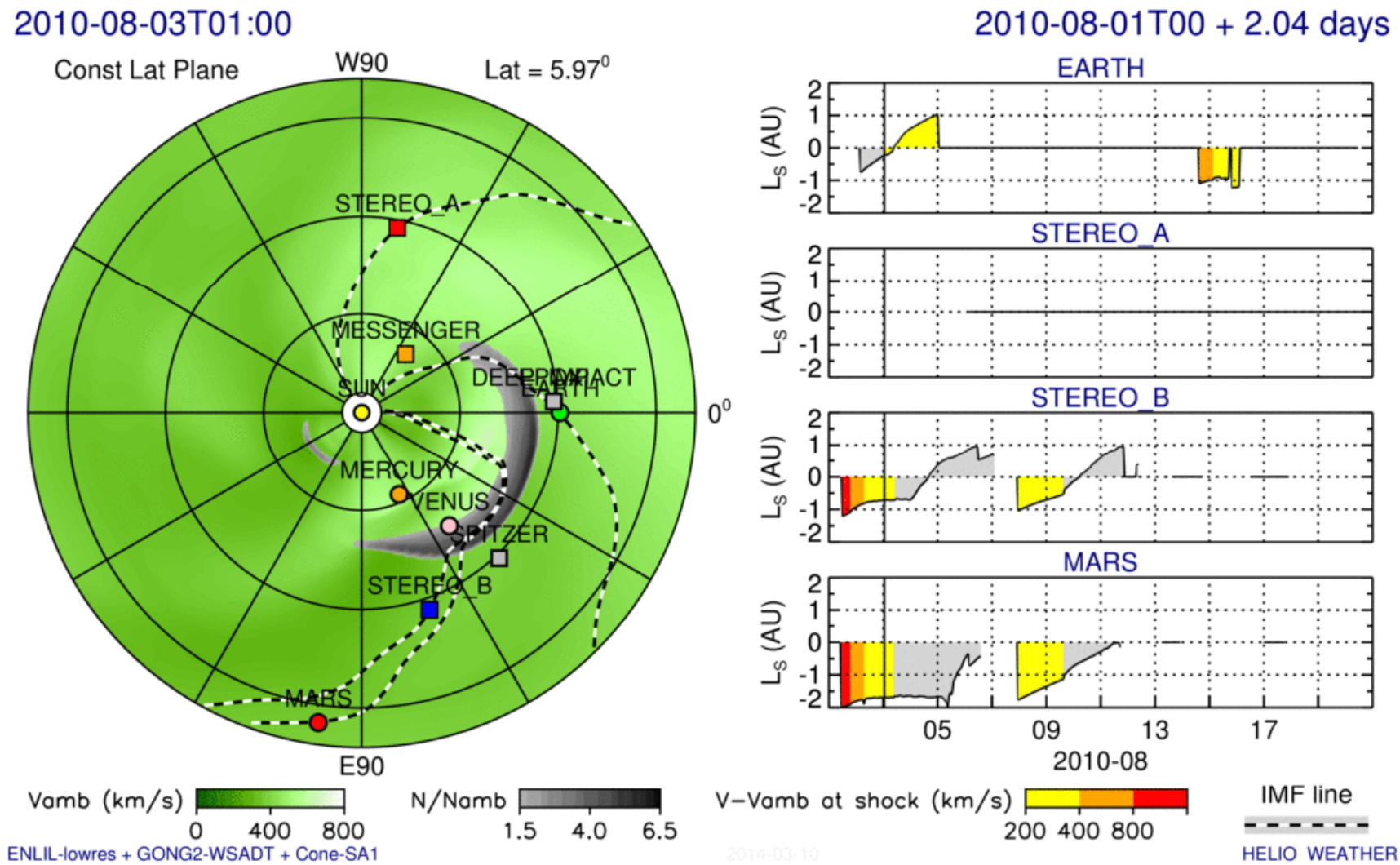
The moving shock driven by the CME describes the source

ENLIL now has a Shock Identification Scheme that provides both shock location and shock parameters

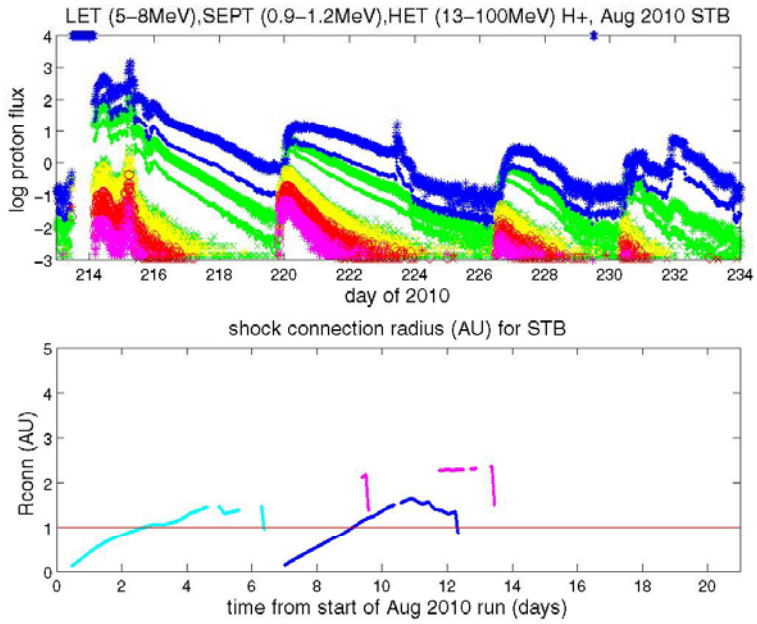


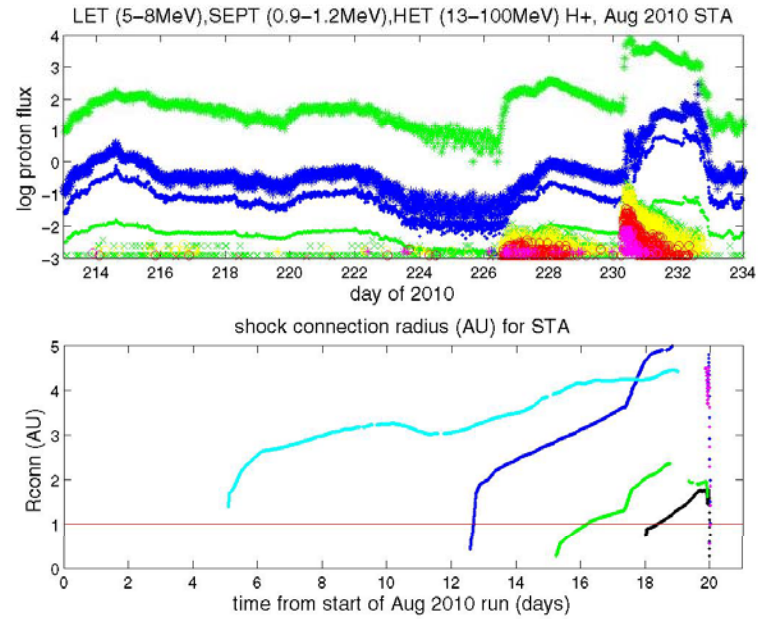
Observer-connected field lines are also available

Time series of the observer-connected shock locations within the ENLIL domain. Connected shock strength is indicated by color-fill.

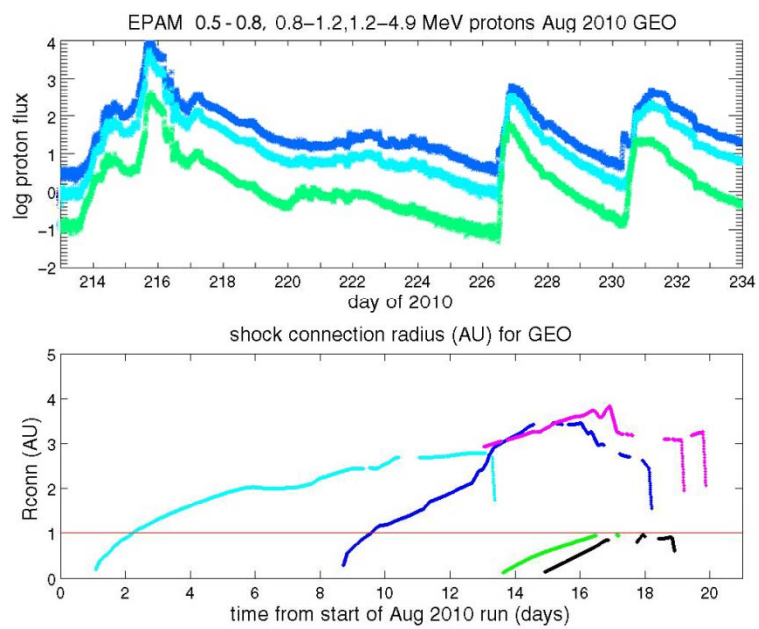


Several CMEs contribute to this ~20 day record.

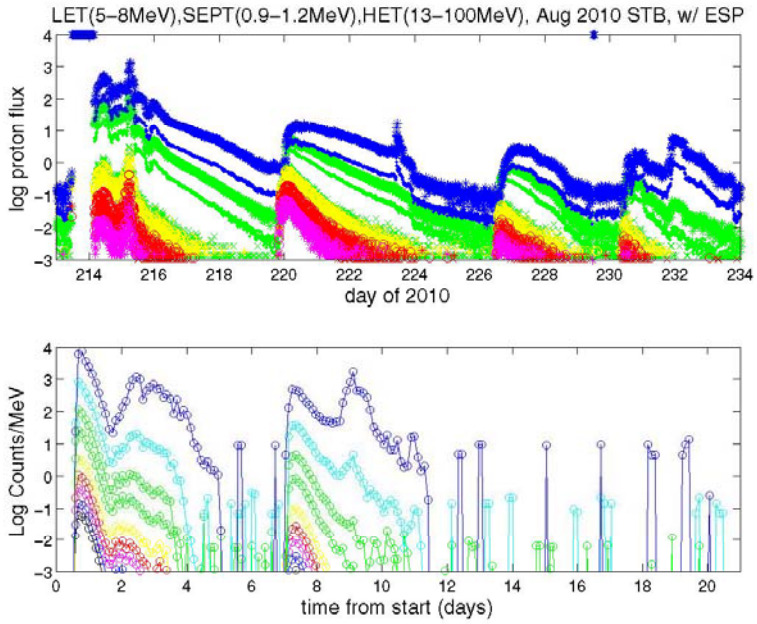


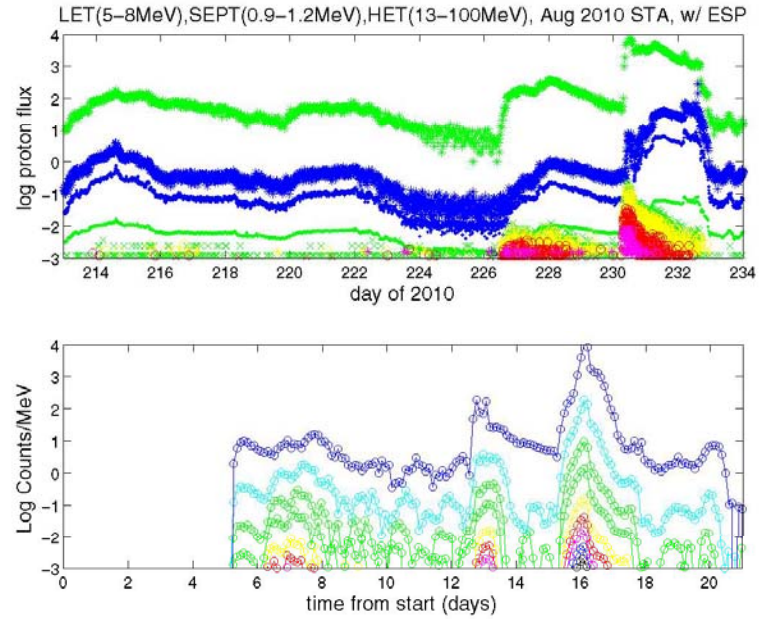


STEREO and ACE SEP data compared to times when ENLIL model suggests the observers are connected to various CME shocks (shown: heliocentric radius of the shock connection)

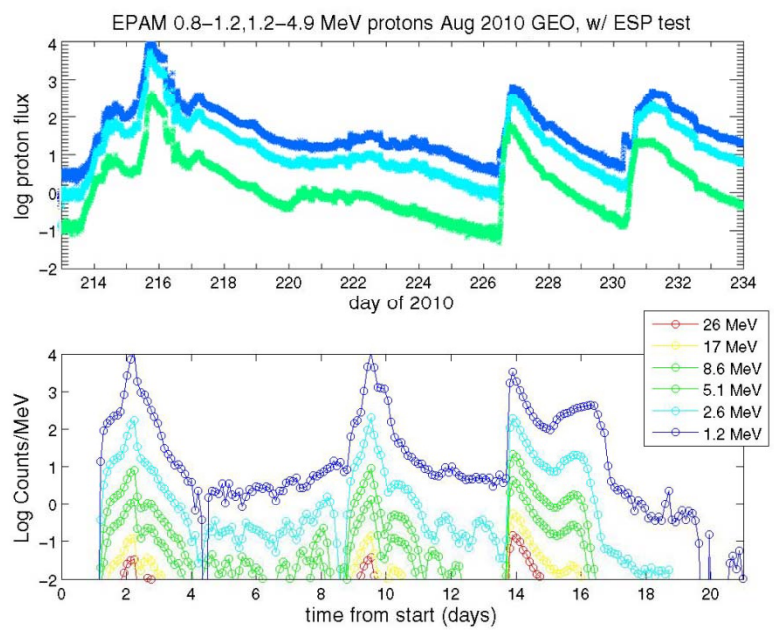


August 2010 SEP data at ACE (bottom) and STEREO A and B (top)- and ENLIL shock connection R





A basic SEP model that uses these ENLIL results as a post-process option.



August 2010 SEP data at ACE (bottom) and STEREO A and B (top)- and a SEP model

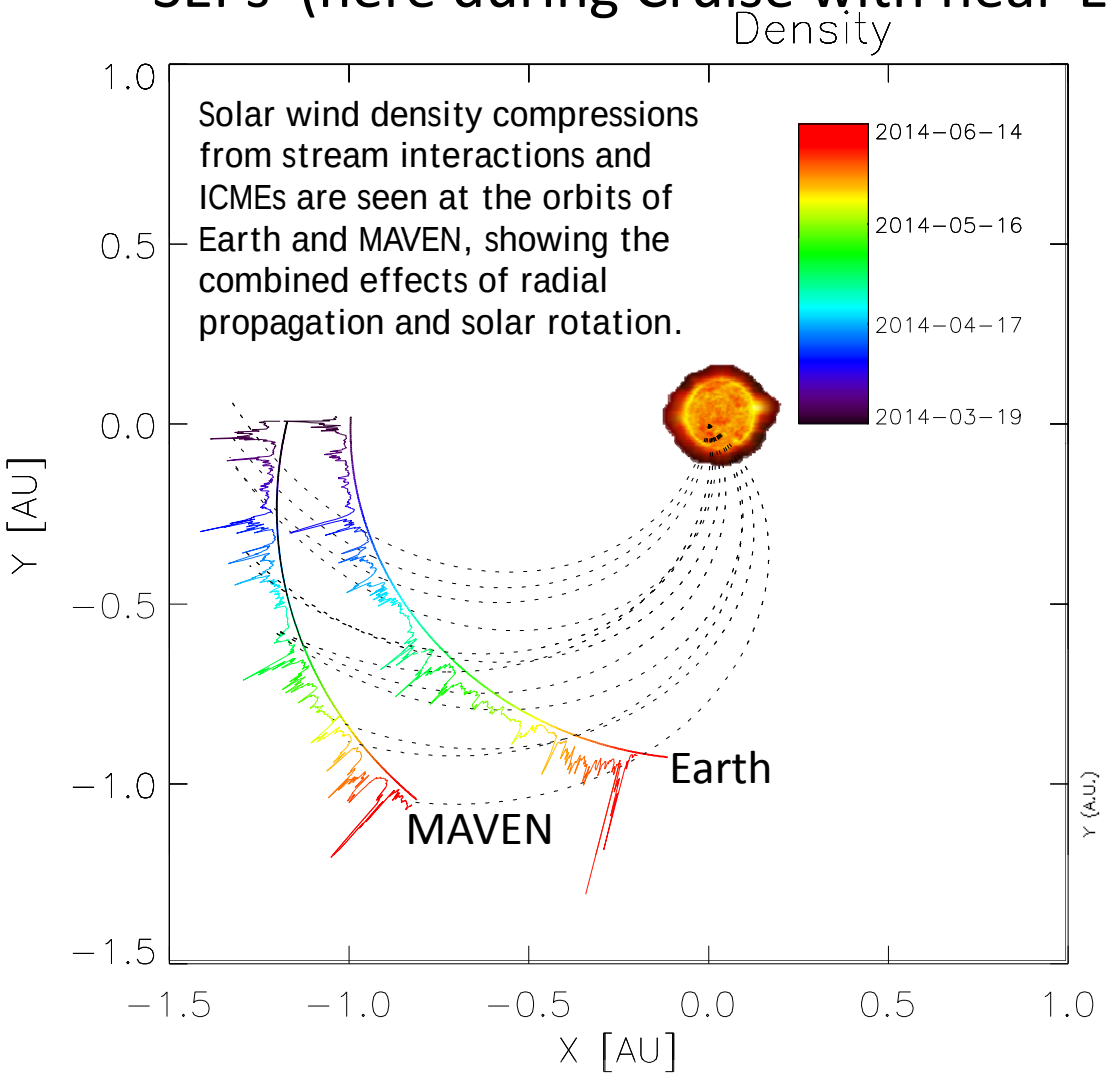
- WSA-ENLIL continues to be a useful simulation tool For both research and applications

- Many validations and improvements still remain to be done, but ENLIL already has impacts on other models and data interpretation studies.

- The interest in real event applications and global perspectives (including conditions at planets and in multiple heliospheric locations) continues to motivate this work.

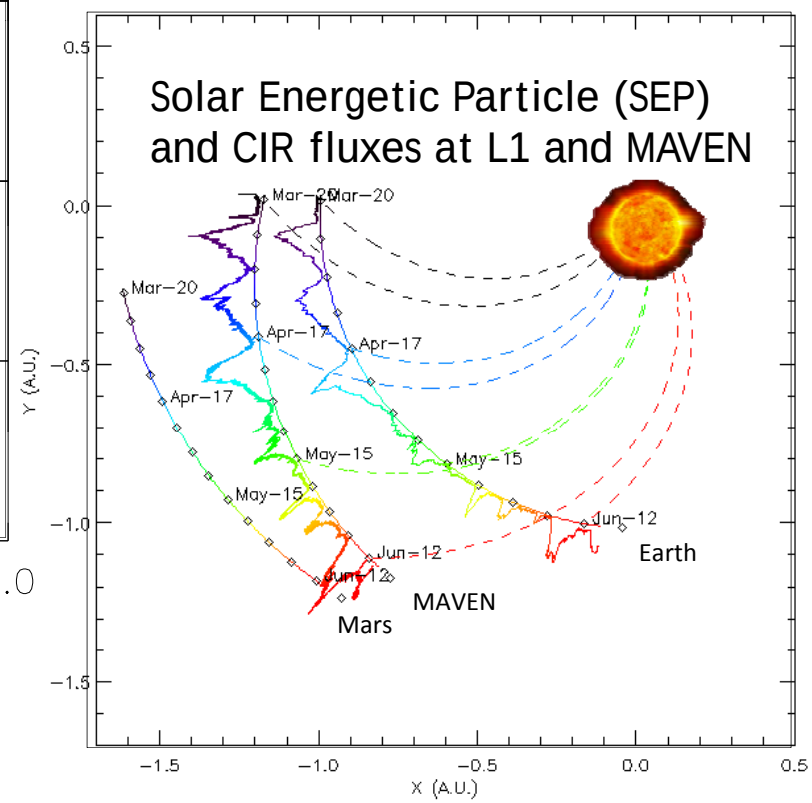
- Future releases should include the multiple CME and shock capabilities, as well as SEP-related options. Still in the process of development are more realistic descriptions of CME ejecta (e.g. flux ropes).

Coming soon: MAVEN measurements of Solar Wind, IMF and SEPs (here during Cruise with near-Earth data) , will add Mars



MAVEN provides a complementary view to NASA's L1 assets while preparing for its prime mission at Mars, where it is scheduled to arrive in September.

The MAVEN Particles and Fields Package is ready for Mars!



**The color code indicates time. The radial amplitudes of traces along the trajectories show solar wind density (above) and SEP flux (right). Dashed curves show approximate Parker spiral magnetic field lines.*

Solar wind data from MAVEN SWIA (J.S. Halekas) and OMNIWeb (N. Papitashvili), SEP fluxes from MAVEN SEP (D. Larson) and ACE EPAM (R. Gold)