# SEP Modeling and Forecasts Based on the ENLIL Global Heliospheric Model

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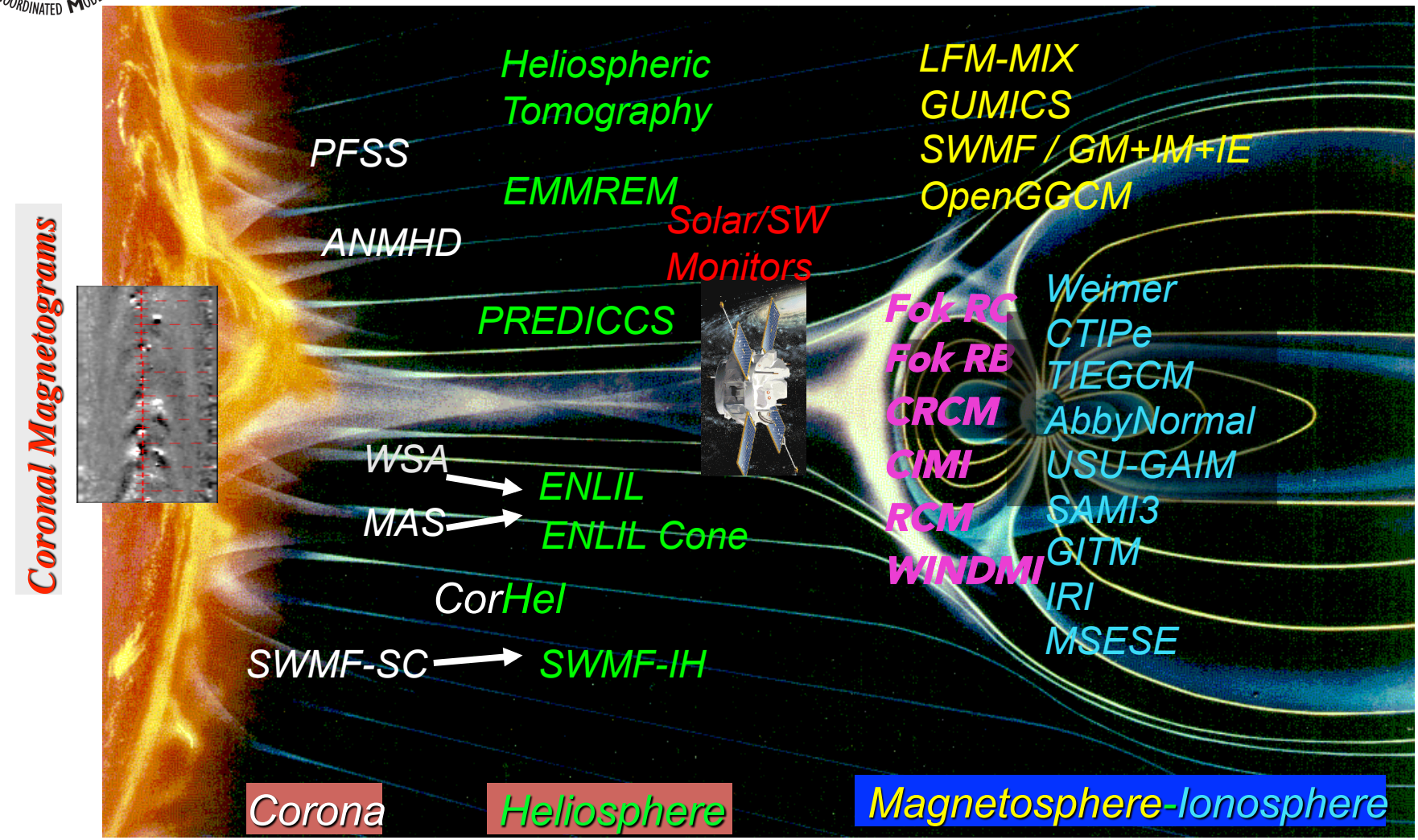
European Space Weather Week, Wednesday 19 November 2014

*Session 8: Solar Energetic Particle Events: from forecast to radiation impact*

# Expanding Collection of Models at the CCMC




**Making SEP models and model combinations available for CCMC research and operational users is one of CCMC's top priorities.**

# SEP modeling at the CCMC

- Heliospheric model outputs are a necessary ingredient for SEP simulations.
- The CCMC is making steps towards offering a system to run SEP models driven by a variety of heliospheric models available at CCMC such as CORHEL, ENLIL, and SWMF.
- Models can be combined as a chain, or coupled in parallel together
- CCMC is facilitating some first steps:
  - Combining/Coupling of ENLIL with EPREM with model developers D. Odstrcil, N. Schwadron and M. Gorby
  - Combining WSA-ENLIL+Cone and SEPMOD with model developers D. Odstrcil and J. Luhmann (this presentation).

# 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 cone 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).
- For more on the latest ENLIL developments see talk by D. Odstrcil tomorrow in session 13 (transitioning space weather research to operations) "*Toward Integrated Real-Time Modeling System for Heliospheric Space Weather".*

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

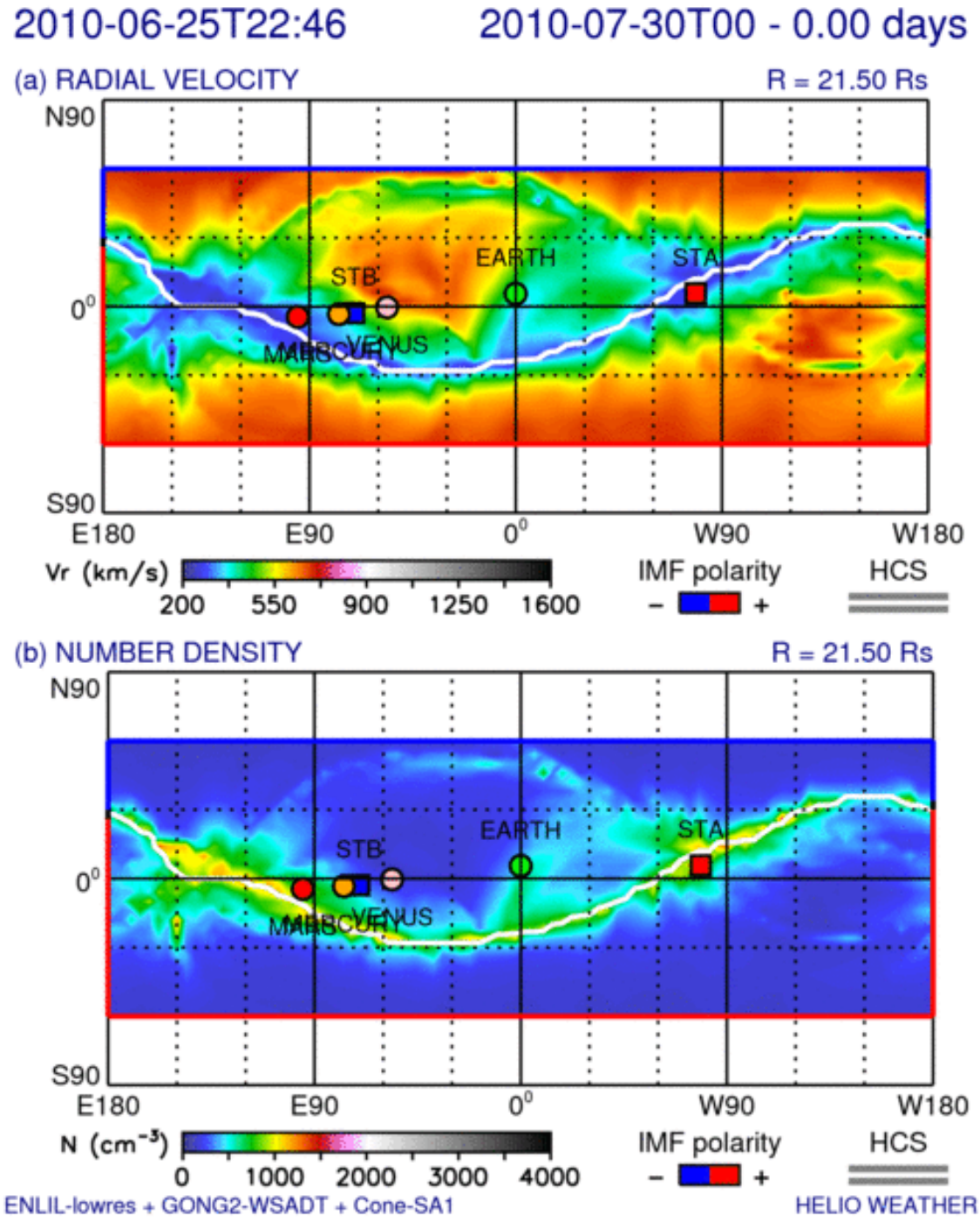
# Considerations for SEP modeling with WSA-ENLIL+Cone

- Understanding gradual SEP events requires a realistic picture of the global background solar wind.
- During active periods there can be multiple CMEs driving shocks which can merge and produce SEPs over a wide range in longitude.
- To characterize observed SEP profiles it is essential to include all of the relevant CMEs and allow enough time for the events to propagate and interact.
- Using a larger outer boundary of 5.5 AU is also needed when the spacecraft:
  - may be magnetically connected to the shock from behind
  - observes particles from magnetic mirroring or from a reflecting boundary from behind.
- Accurate descriptions of the heliosphere, and hence modeled SEPs, are achieved by ENLIL only when the background solar wind is well-reproduced and CME parameters are accurate.

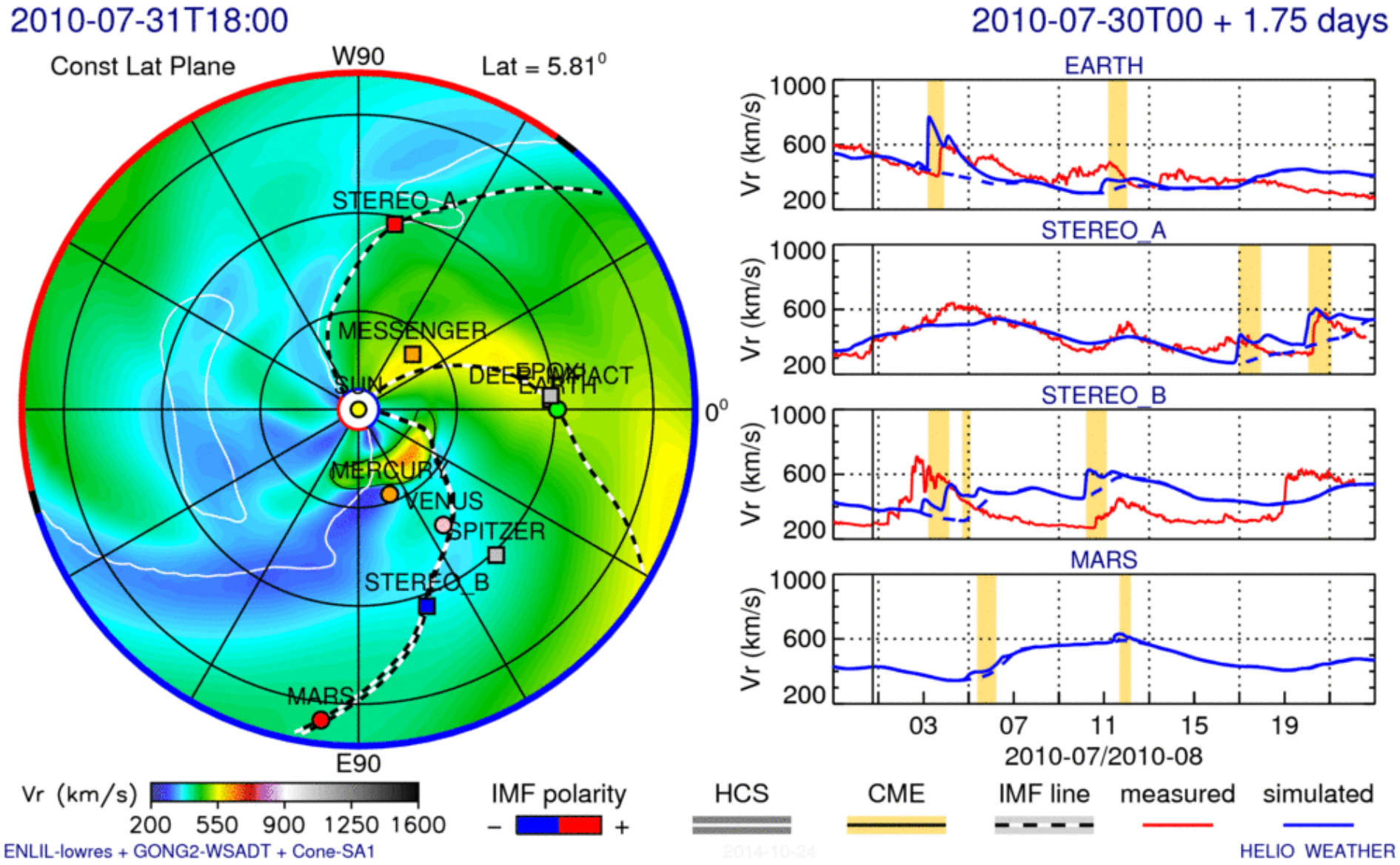
# August 2010 period

ENLIL inner boundary map at 21.5 $R_s$

Animation shows 6 CMEs launched into the solar wind and magnetic field computed from the WSA coronal model.

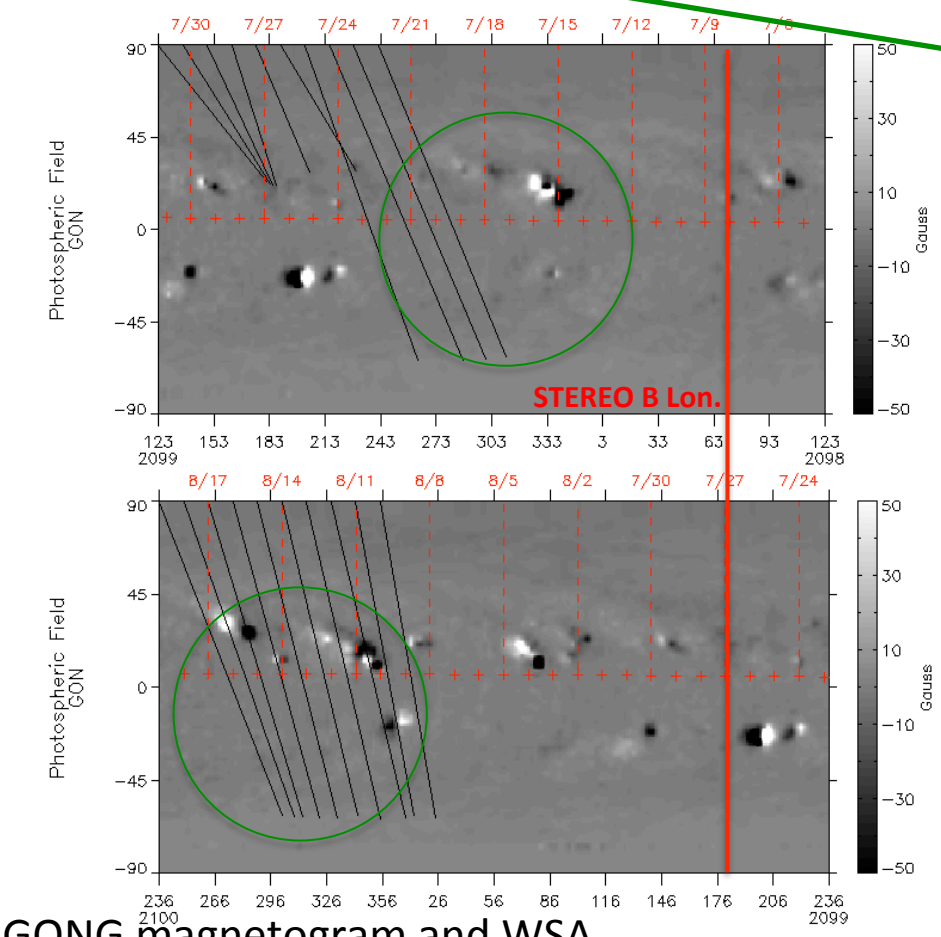


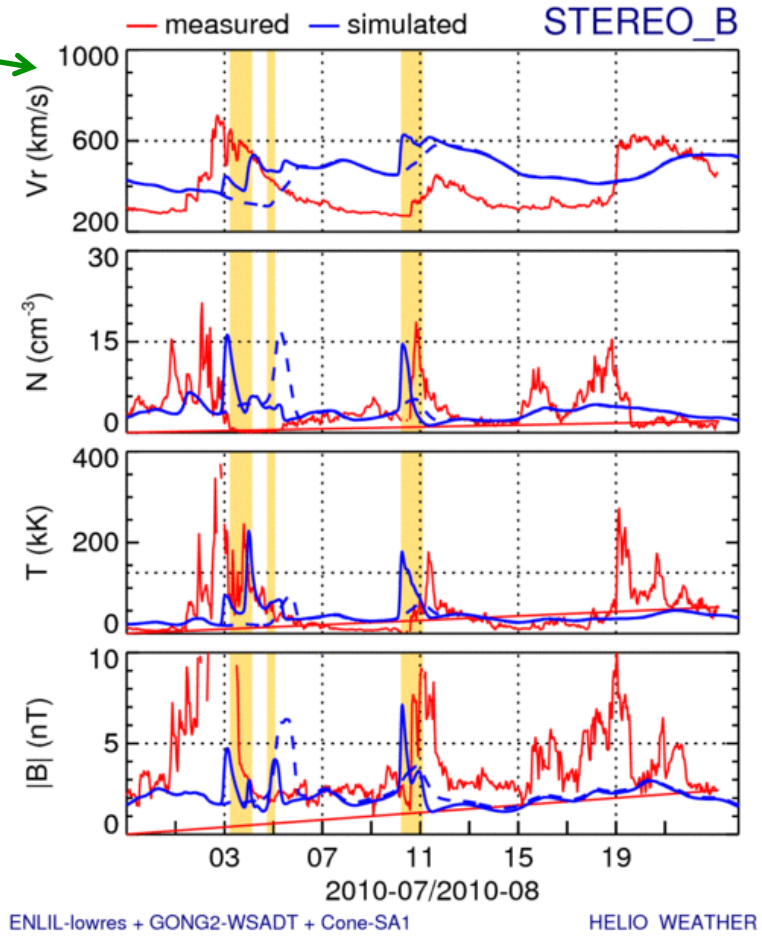
# August 2010 period - 6 CMEs




WSA-ENLIL+Cone velocity contour plot

- These simulations are driven by synoptic magnetograms updated daily.
- Accurate descriptions of the heliosphere, and hence modeled SEPs, are achieved by ENLIL only when the background solar wind is well-reproduced.
- If the synoptic magnetogram or PFSS model is not accurate, WSA-ENLIL will have difficulties reproducing the solar wind. This is particularly apparently for the farside.

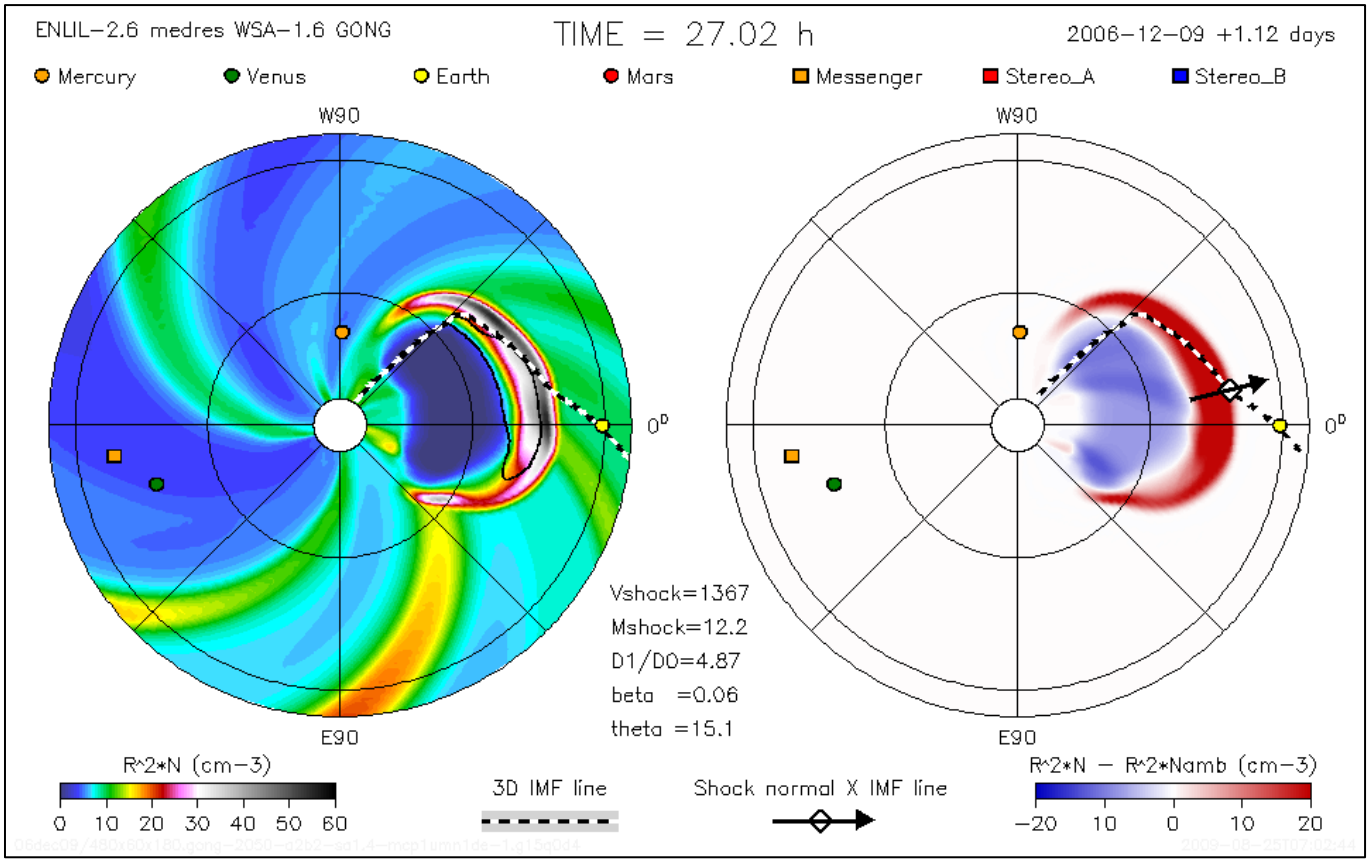



GONG magnetogram and WSA

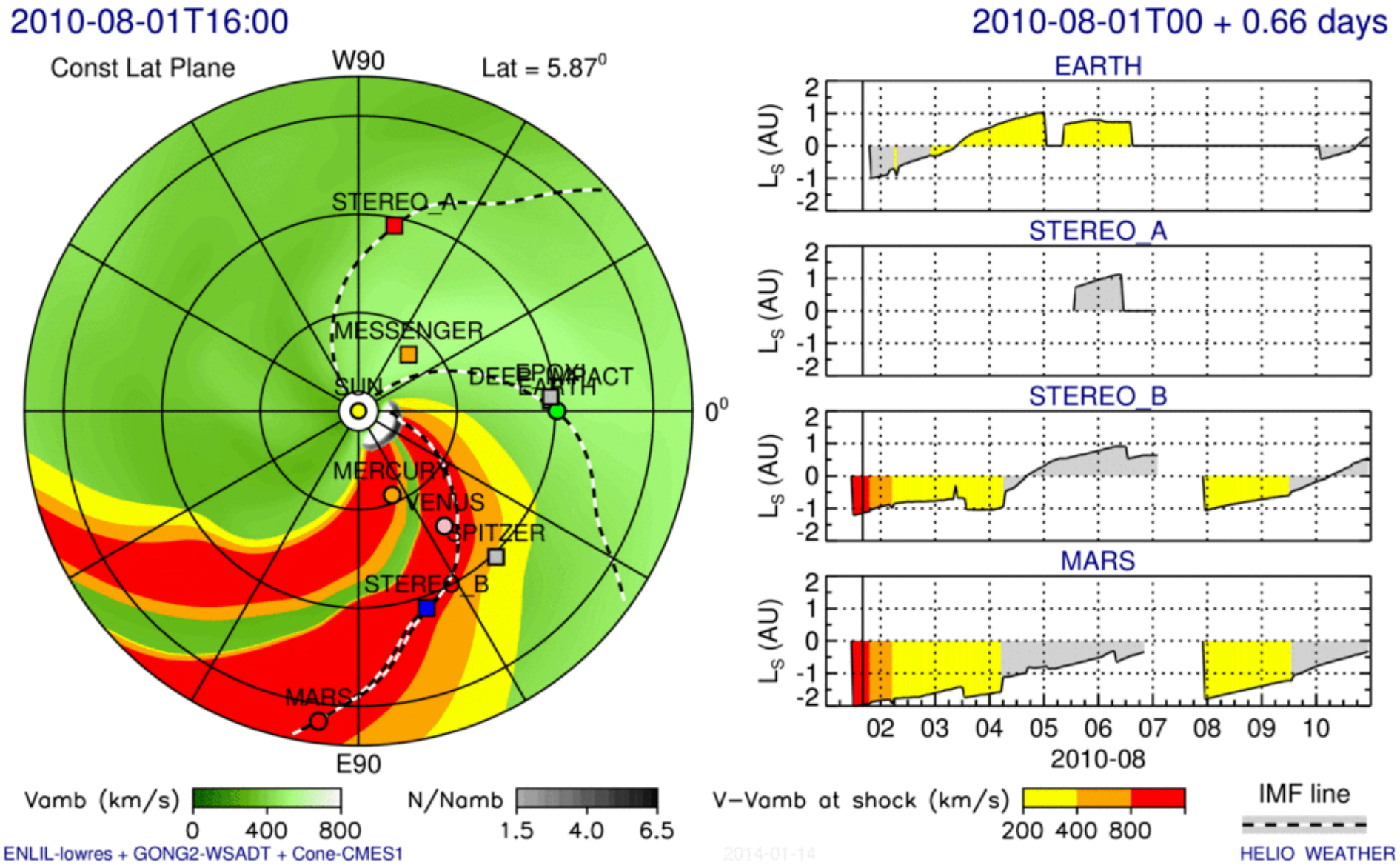
# Deriving Shock Parameters

- ENLIL-derived shock parameters are useful for interpreting the timing and magnitude of SEP observations, and as input for SEP models.
- D. Odstrcil developed a procedure for automatically detecting CME-driven shocks:
  - Two numerical simulations used, one for the background only, and the other for background + transient.
  - Subtraction the two results to clearly identify shock leading edge along observed-connected IMF line.

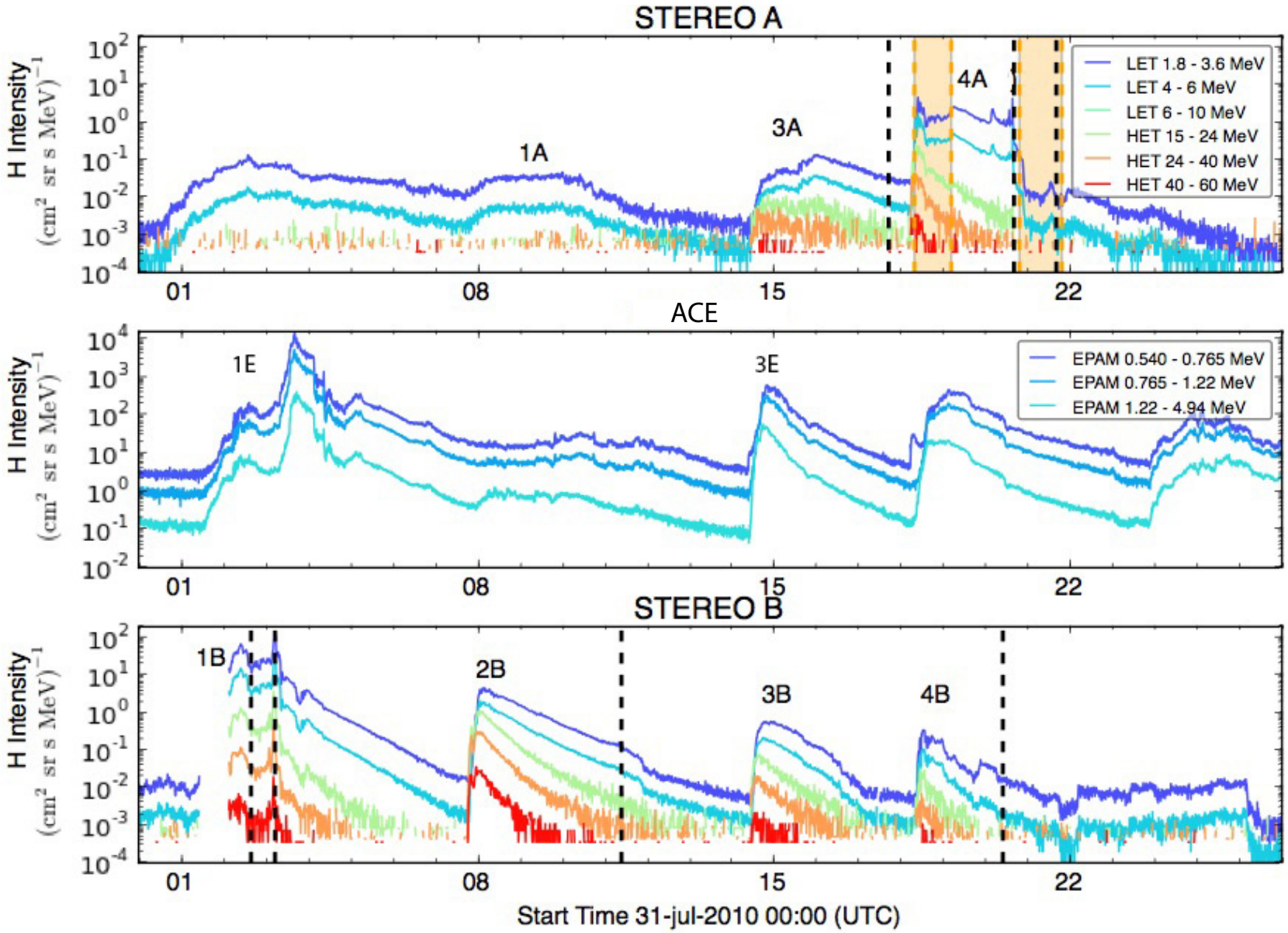



*When modeling multiple CMEs, the current technique requires multiple simulations (number of CMEs +1). Now developing a procedure to detect multiple shocks along observer-connected field lines using only two simulations.*

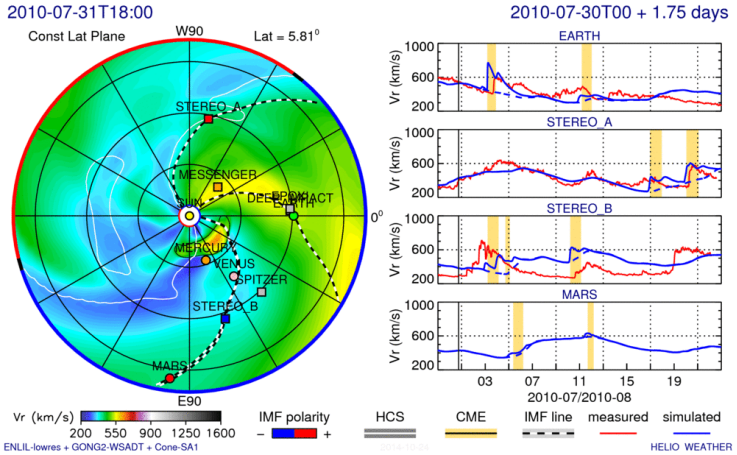
# August 2010 period – "likelihood/all clear" map
## shows possible SEP affected areas



# August 2010 period - Multiple SEP events observed

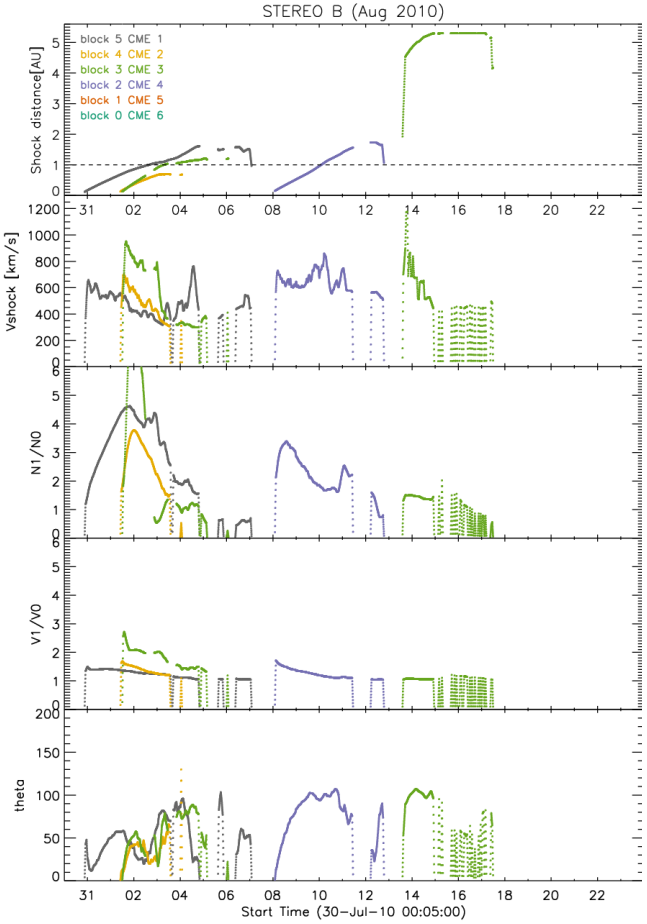


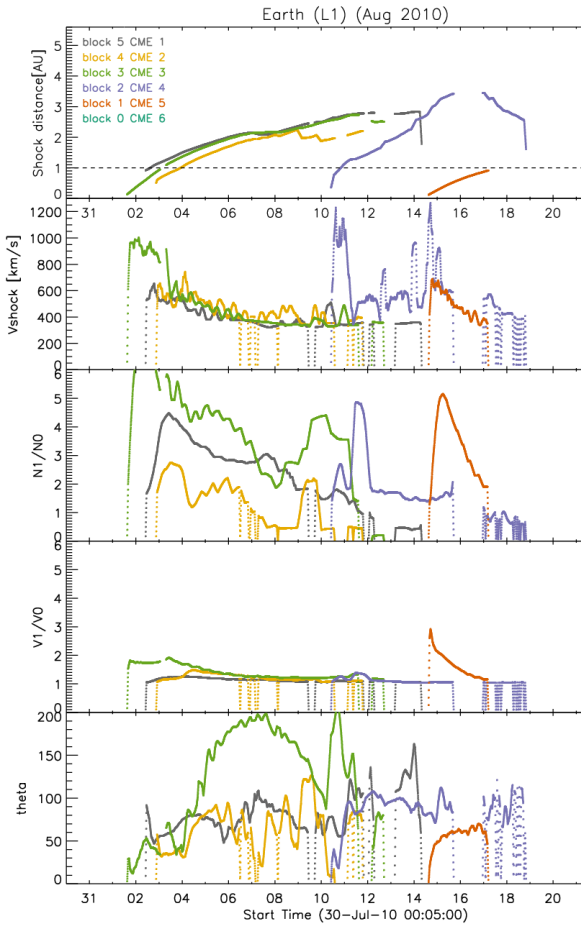

(from H. Bain)

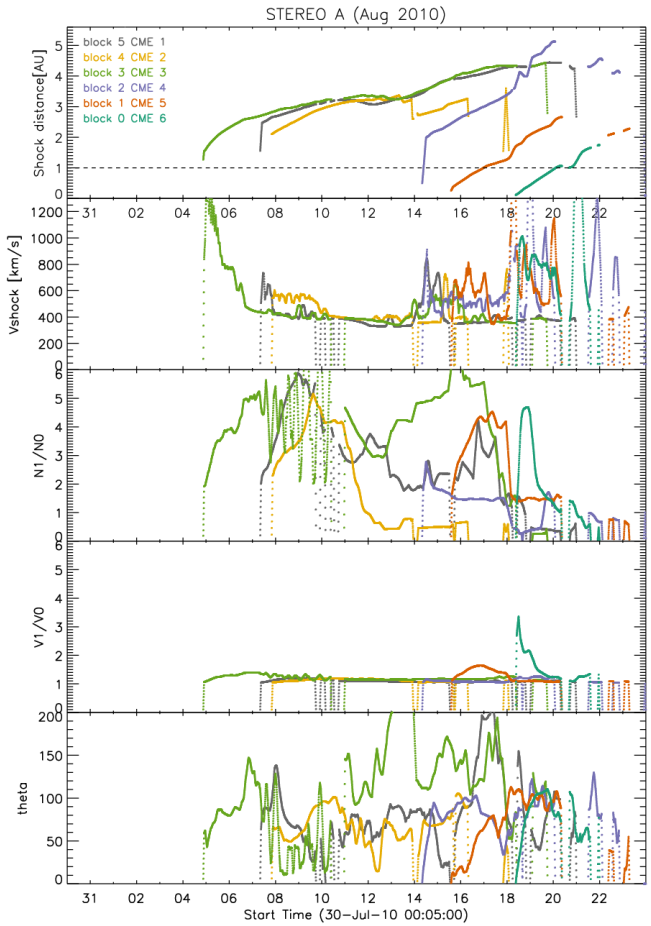


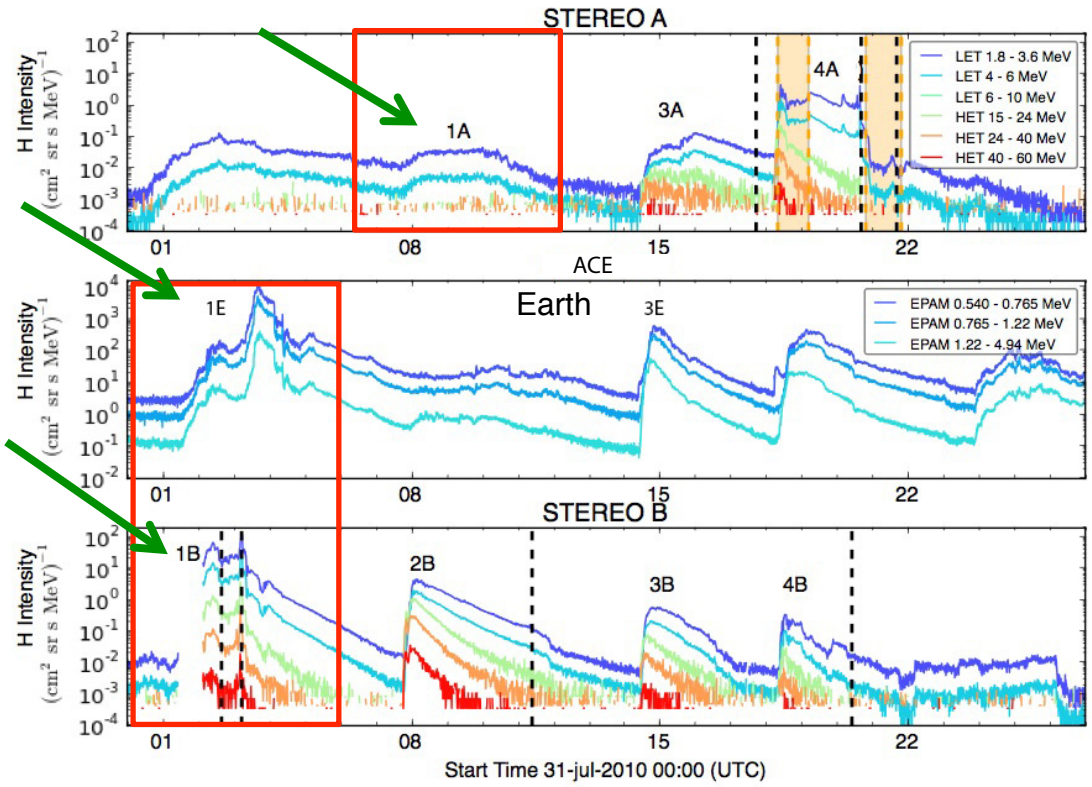

# August 2010 period

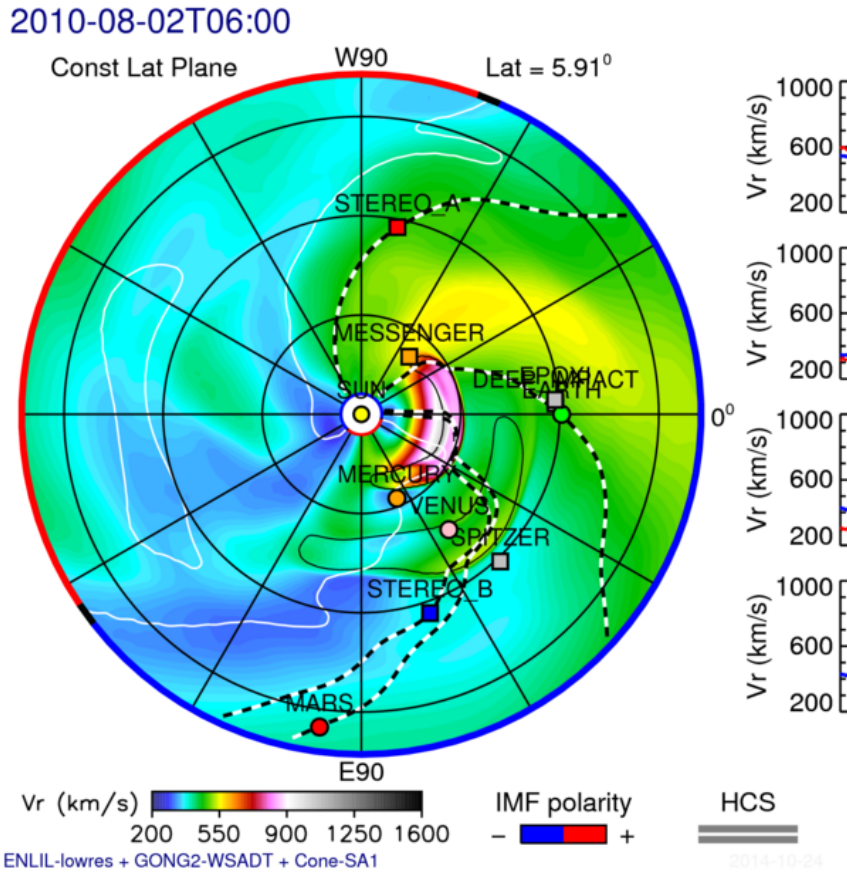
ENLIL derived shock parameters along observer-connected field lines provide first level of SEP forecast, and context for observations.



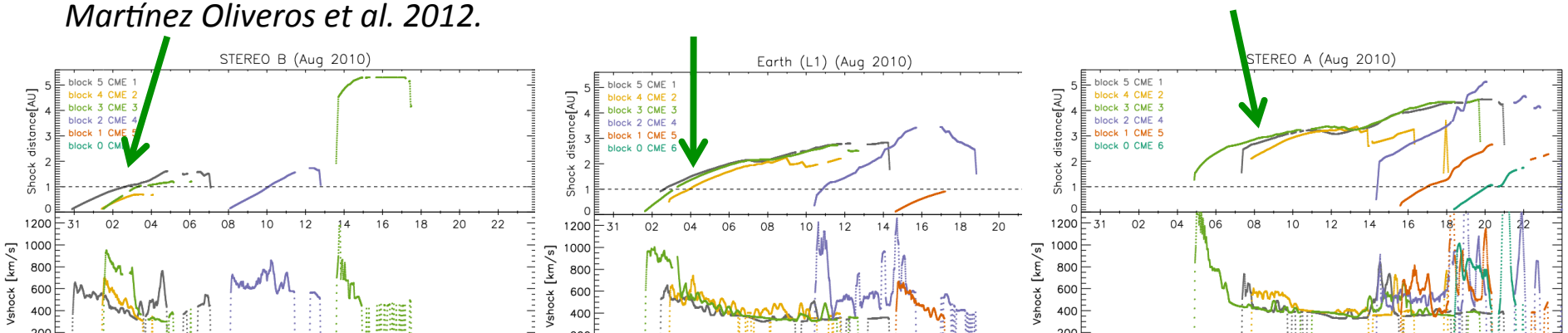



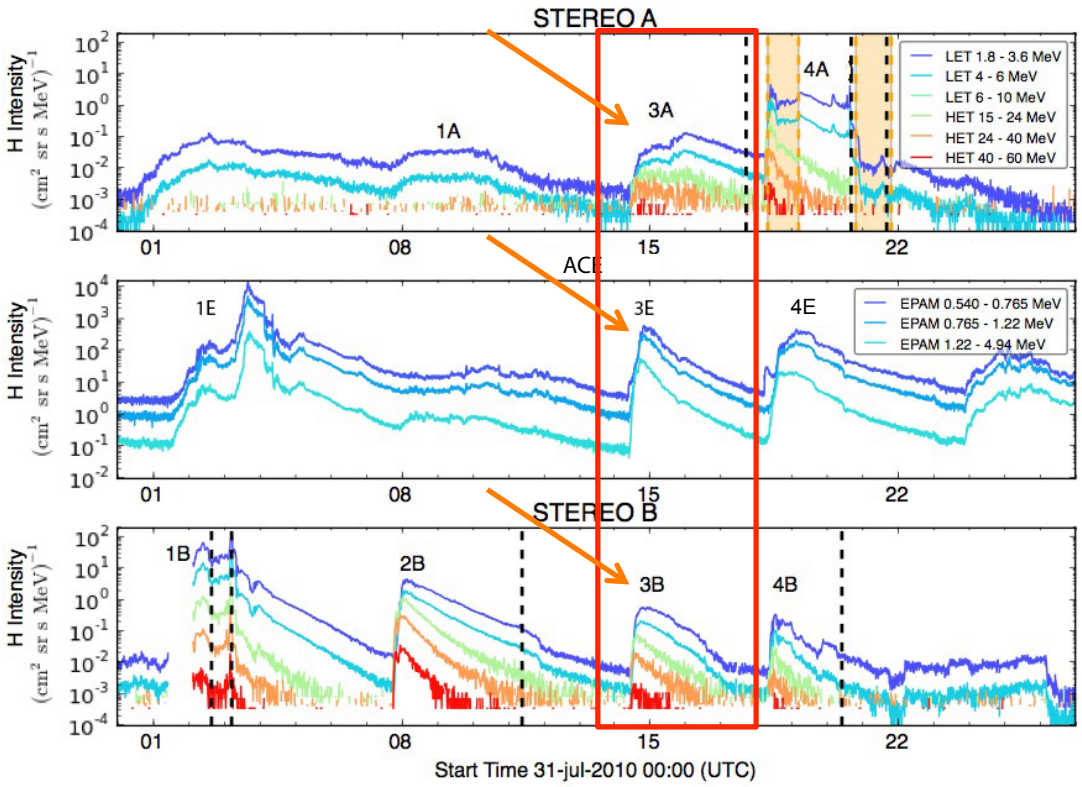


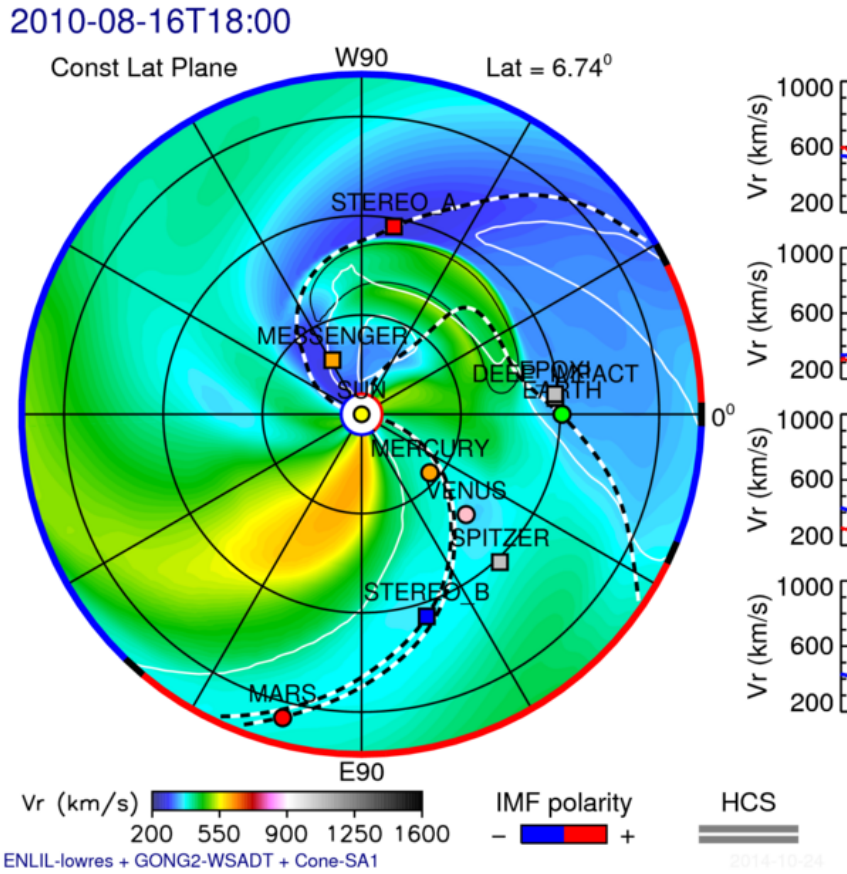




CME on 7/30 and CMEs on 8/1 contribute to SEPs observed at Earth and STEREO B, and also at STEREO A from behind.

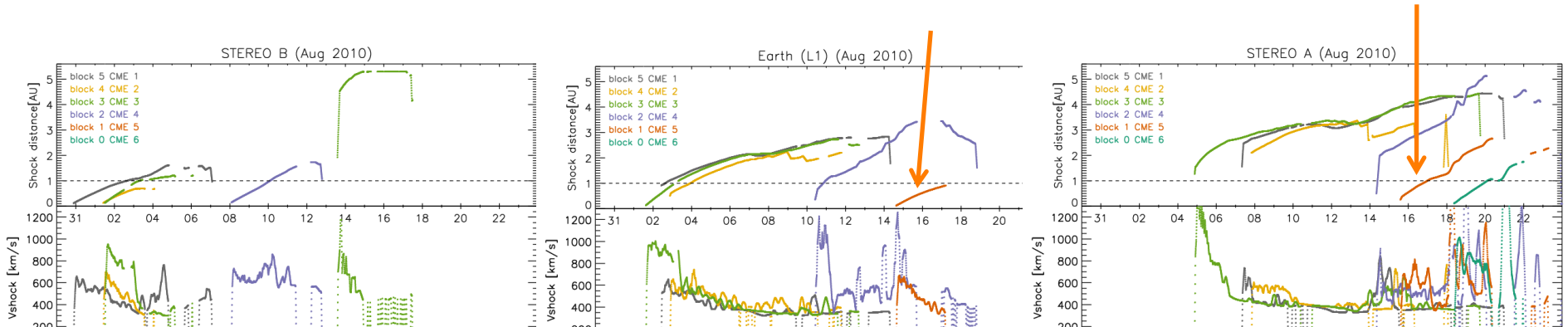
*Interaction of these CMEs are described in Möstl et al., 2012; Liu et al. 2012; Temmer et al. 2012; Martínez Oliveros et al. 2012.*





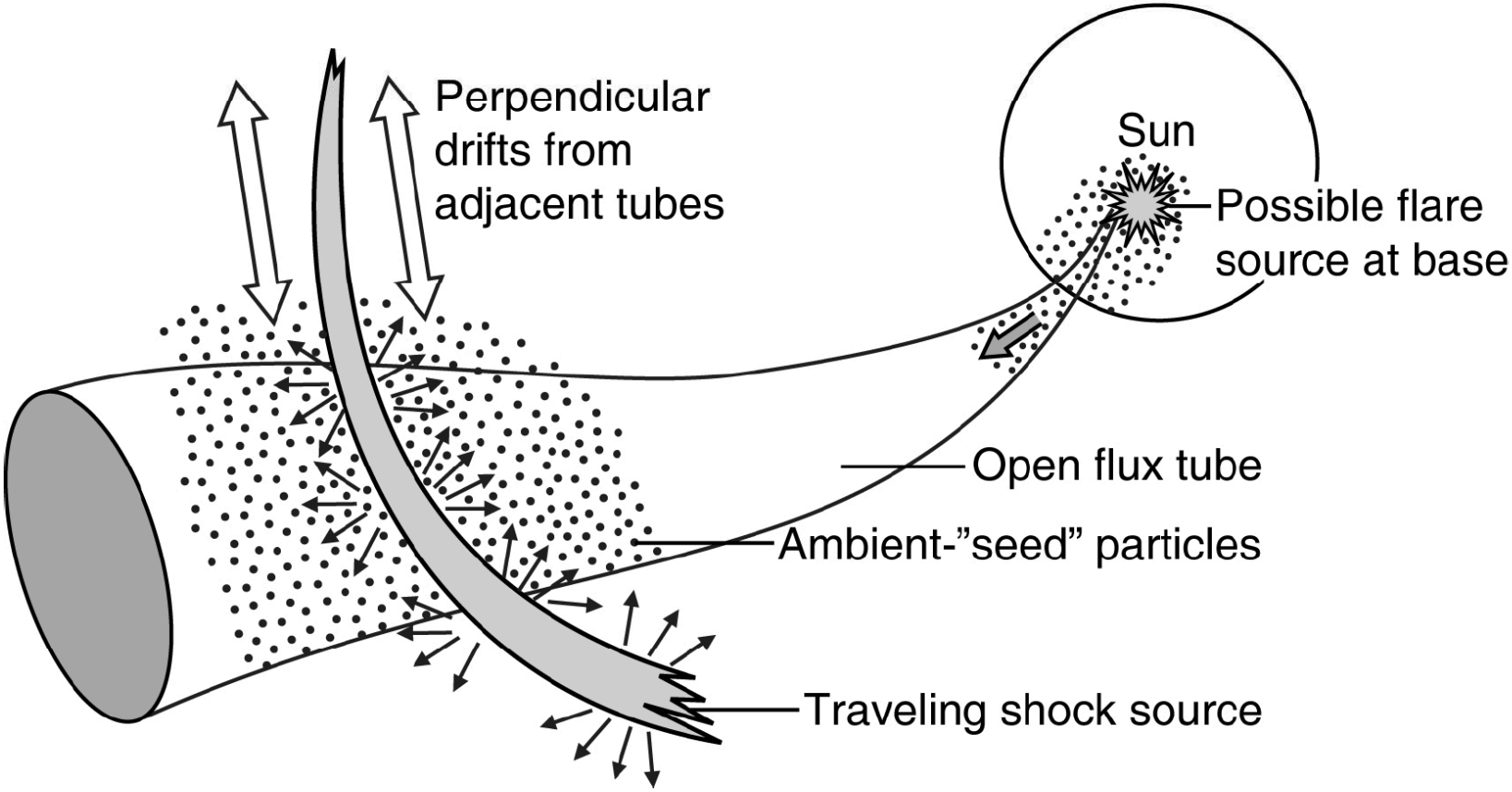




CME on 8/14 contributes to SEPs observed at Earth, STEREO A, and STEREO B.



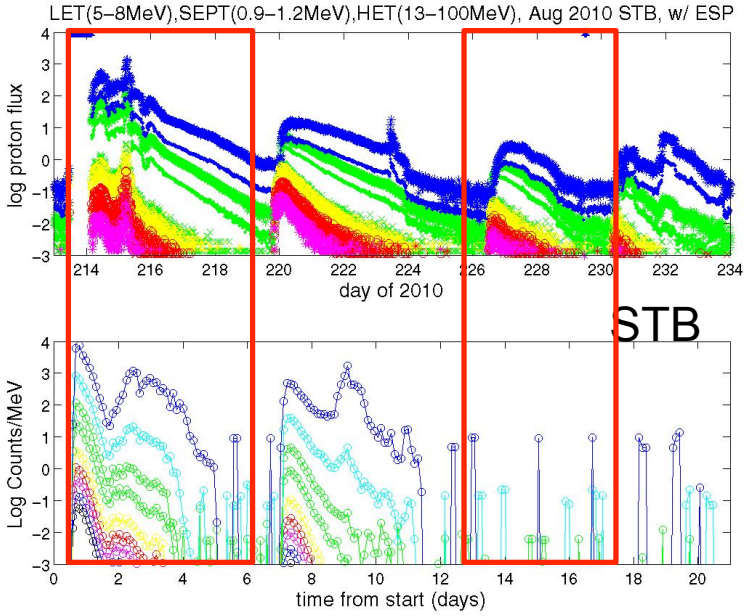
# SEPMOD

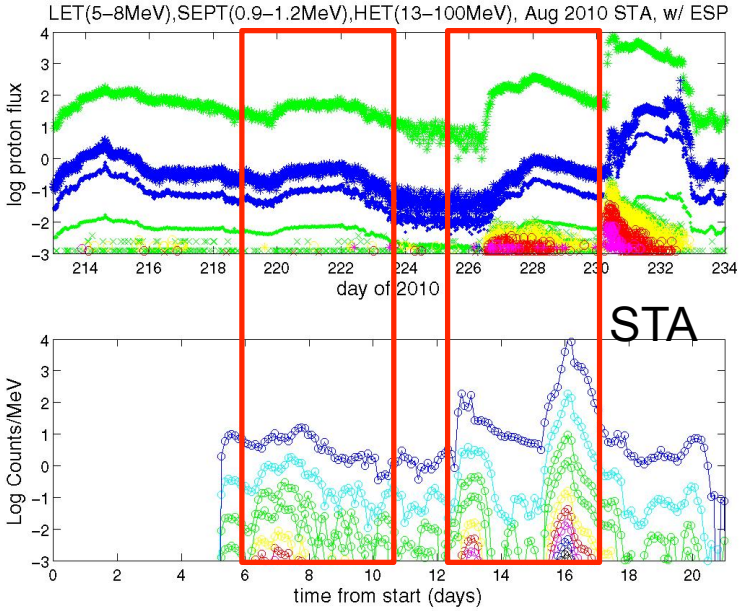
SEPMOD injects SEPs onto the observer's field line at intensities dependent on the connected shock source strength

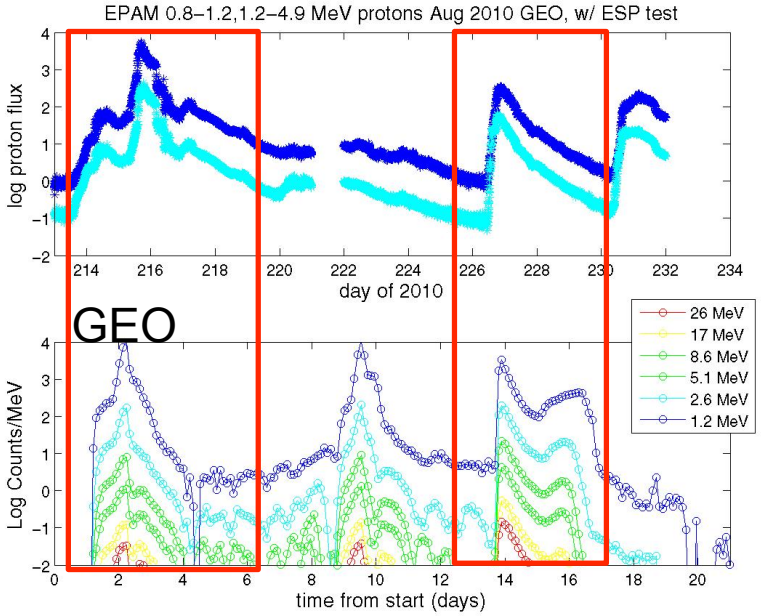



Assumes that field-aligned propagation determines what is detected.
The observer can be located anywhere within the ENLIL model domain.

(from J. Luhmann)



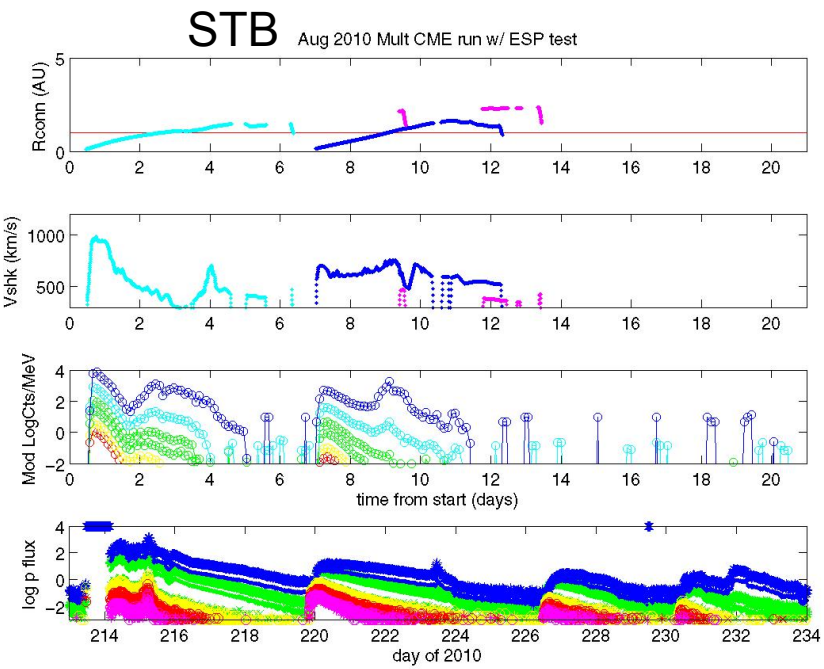



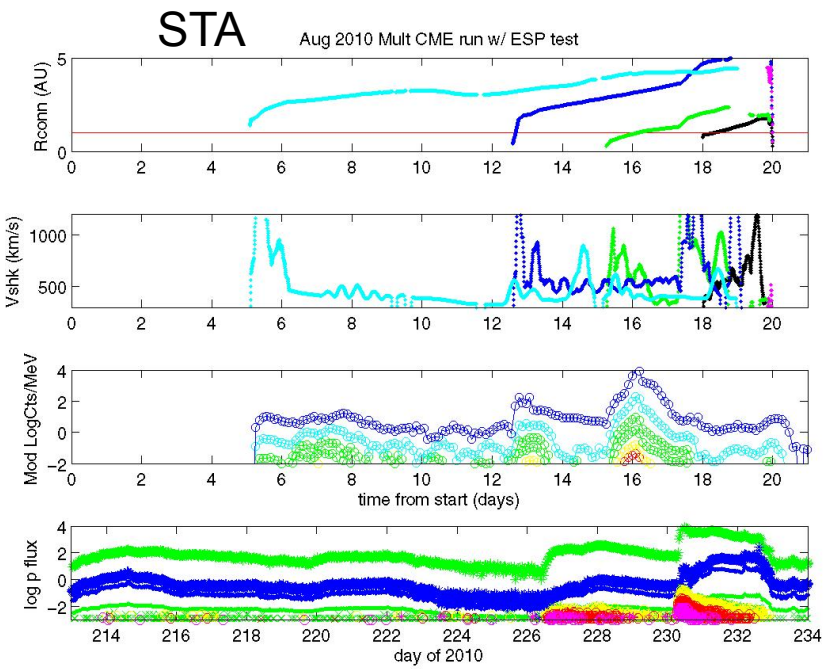




August 2010 case SEPMOD protons results based on ENLIL: includes model ESP

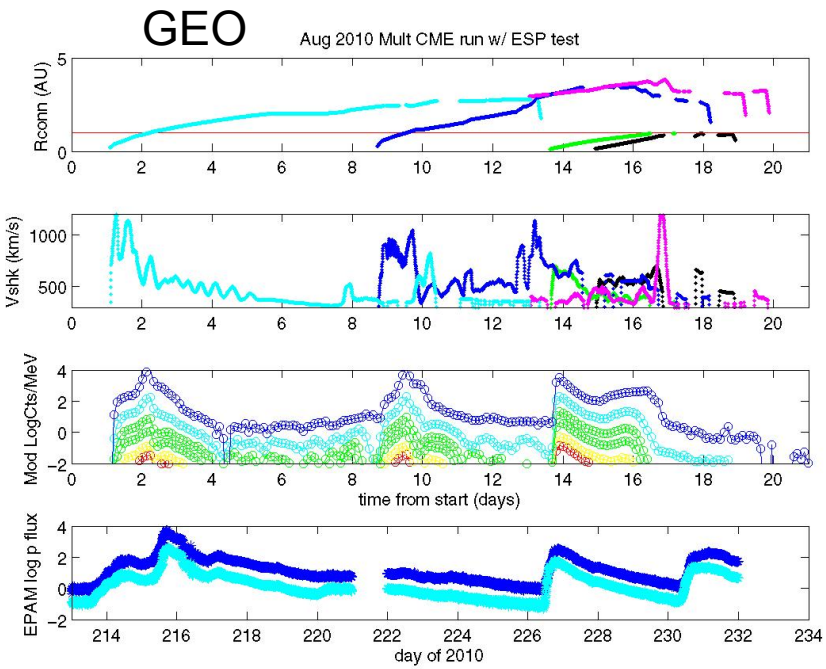
AUGUST 2010 case: STB , STA GEO

(from J. Luhmann)



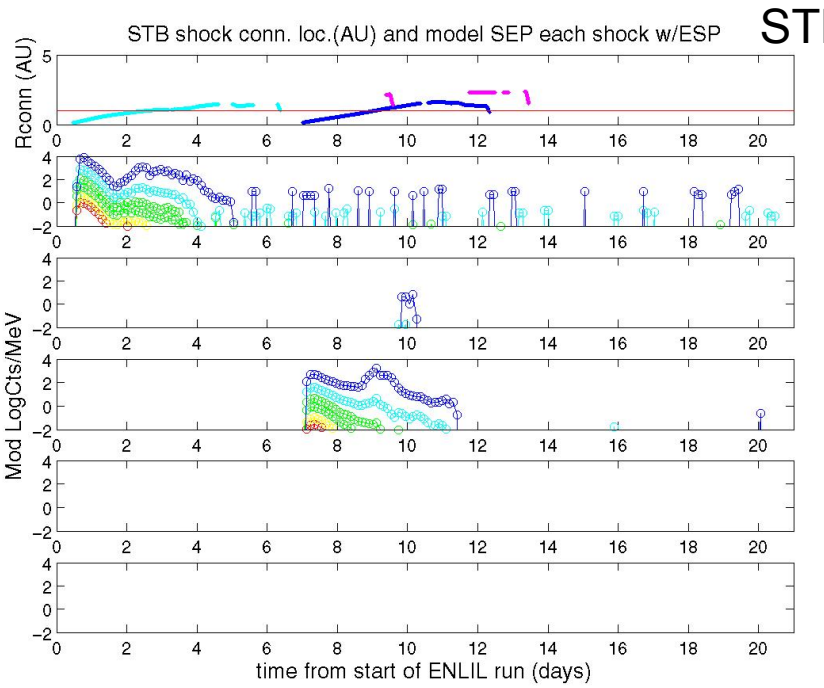




Combined display showing shock jumps

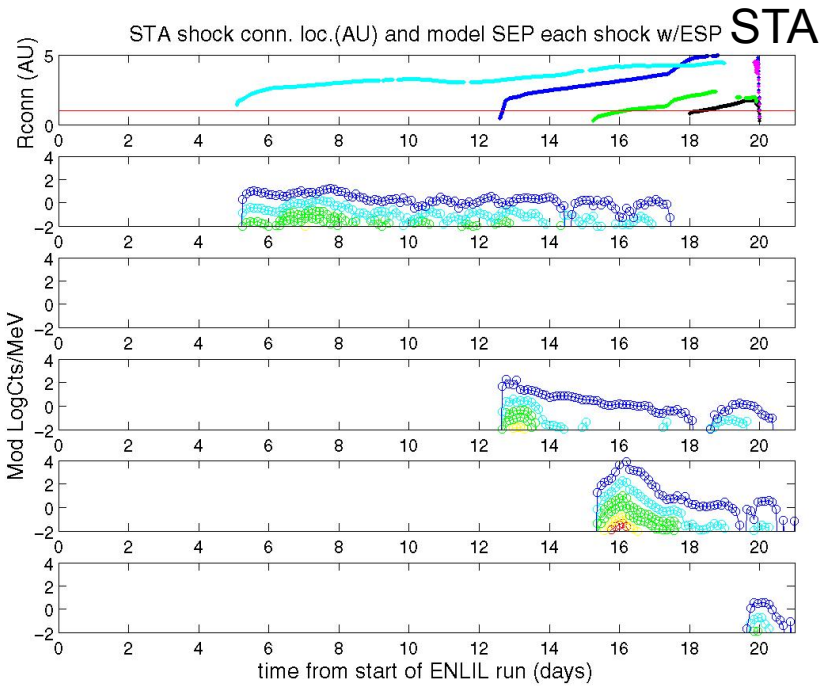



AUGUST 2010 case: STB , STA GEO

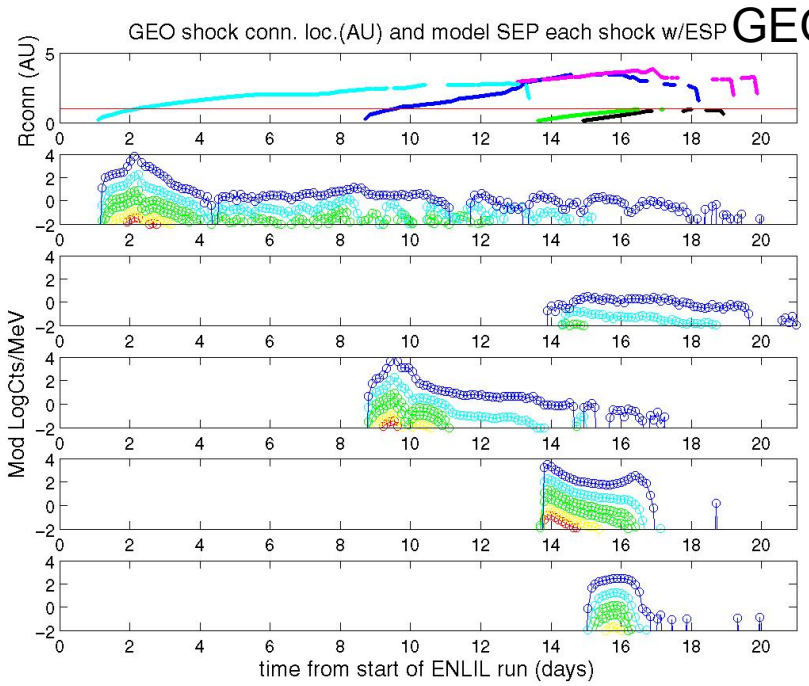
(from J. Luhmann)




STB




STA




GEO

Model results for individual shocks detected by ENLIL

AUGUST 2010 case: STB , STA GEO

(from J. Luhmann)

# Modeling August 2010

- Shock information from WSA-ENLIL+cone is very beneficial for forecasting and interpreting SEP profiles.
- Sudden onset events from the west limb are well-captured at Earth and STEREO A.
- SEPs due to shocks/CMEs connected from ahead/behind of the observer days later are captured as a long duration profiles.
- Some challenges: accurate CME parameters are important.
  - CMEs that measured to be too wide, or have a large error in longitude might contribute to profiles that are not observed (e.g. at Earth from 8/7 CME).
  - CMEs that are not measured wide enough, might not contribute to profiles which are observed (e.g. at STEREO B from 8/14 CME).

# SEP modeling with WSA-ENLIL+Cone: Next Steps

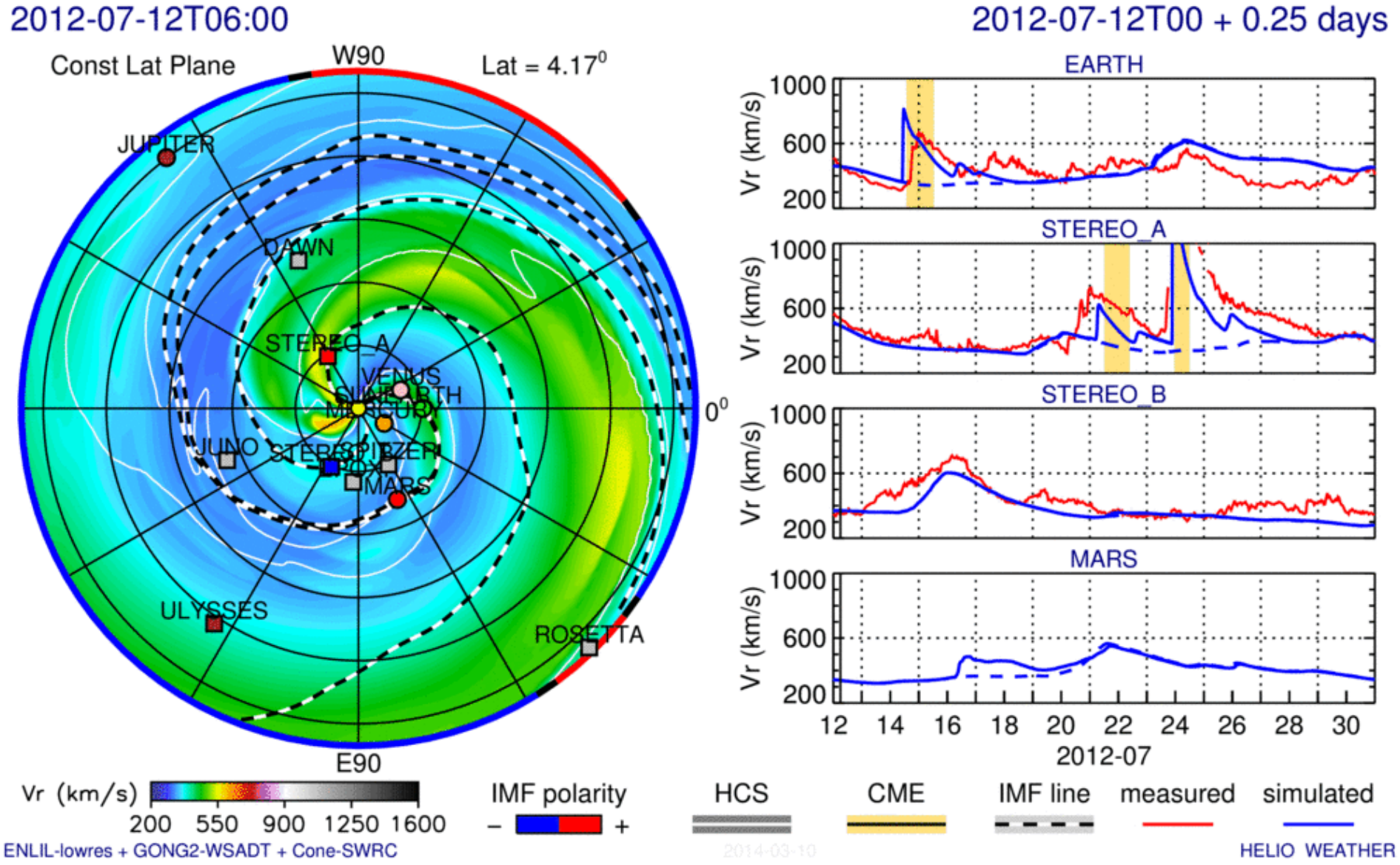
- Continue case studies of SEP observations and modeling using ENLIL modeling as context.
- Investigating which magnetograms to use to best reproduce the heliospheric conditions
- For multiple CME events, developing a procedure to detect multiple shocks along observer-connected field lines using only two simulations.
- Determining the effects of ENLIL inner and outer boundaries and resolution on producing useful output for SEPMOD
- Will begin to make routine ENLIL runs with similar fidelity and model shock information for testing with SEPMOD as a regular product option.
- J. Luhmann is working on adjustments to SEPMOD to better reproduce SEP observations.
- SEPMOD can also be used in combination with other heliospheric models.

# SEP modeling at the CCMC

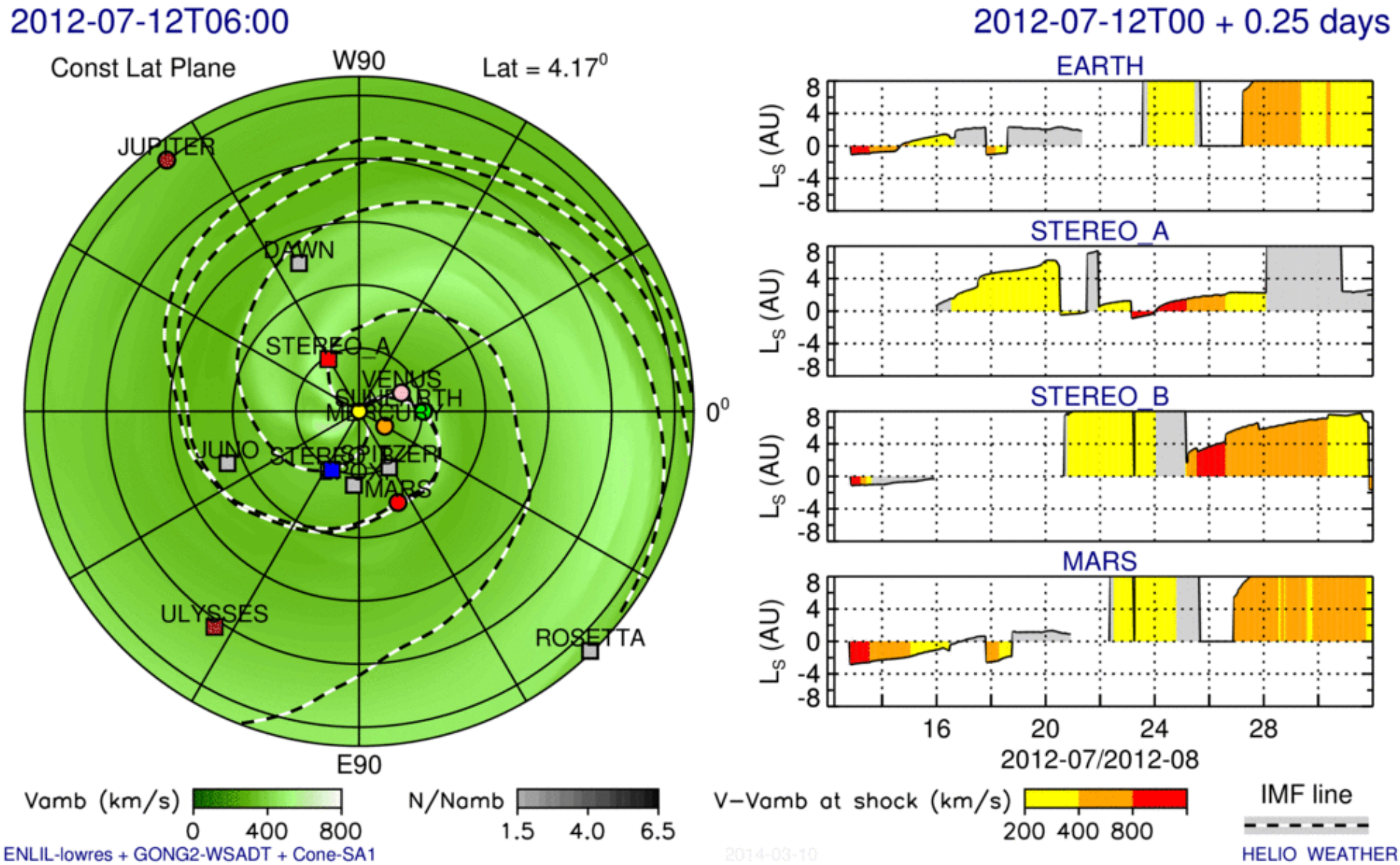
- CCMC will provide the new ENLIL shock and fieldline output to users with the installation of ENLIL v2.8 (coming soon), for the use of SEP models which require shock parameters along observer-connected field lines. Full 3D MHD output at a required time cadence will be available for other models (such as EPREM).
- CCMC is making steps towards offering a system to run SEP models driven by a variety of heliospheric models available at CCMC such as CORHEL, ENLIL, and SWMF.
- **We invite heliospheric and SEP model developers to participate in this testing and provide us with their computational requirements for coupling/ combination different models.**
- **We would like to hear about what aspects are necessary for making the system a useful tool for developers and users.**

Thank you!

Example: The period covering most of July 2012, which included a dominant wide, fast CME aimed at STEREO A



Example: The period covering most of July 2012, which included a dominant wide, fast CME aimed at STA




Parameters from CCMC/SWRC