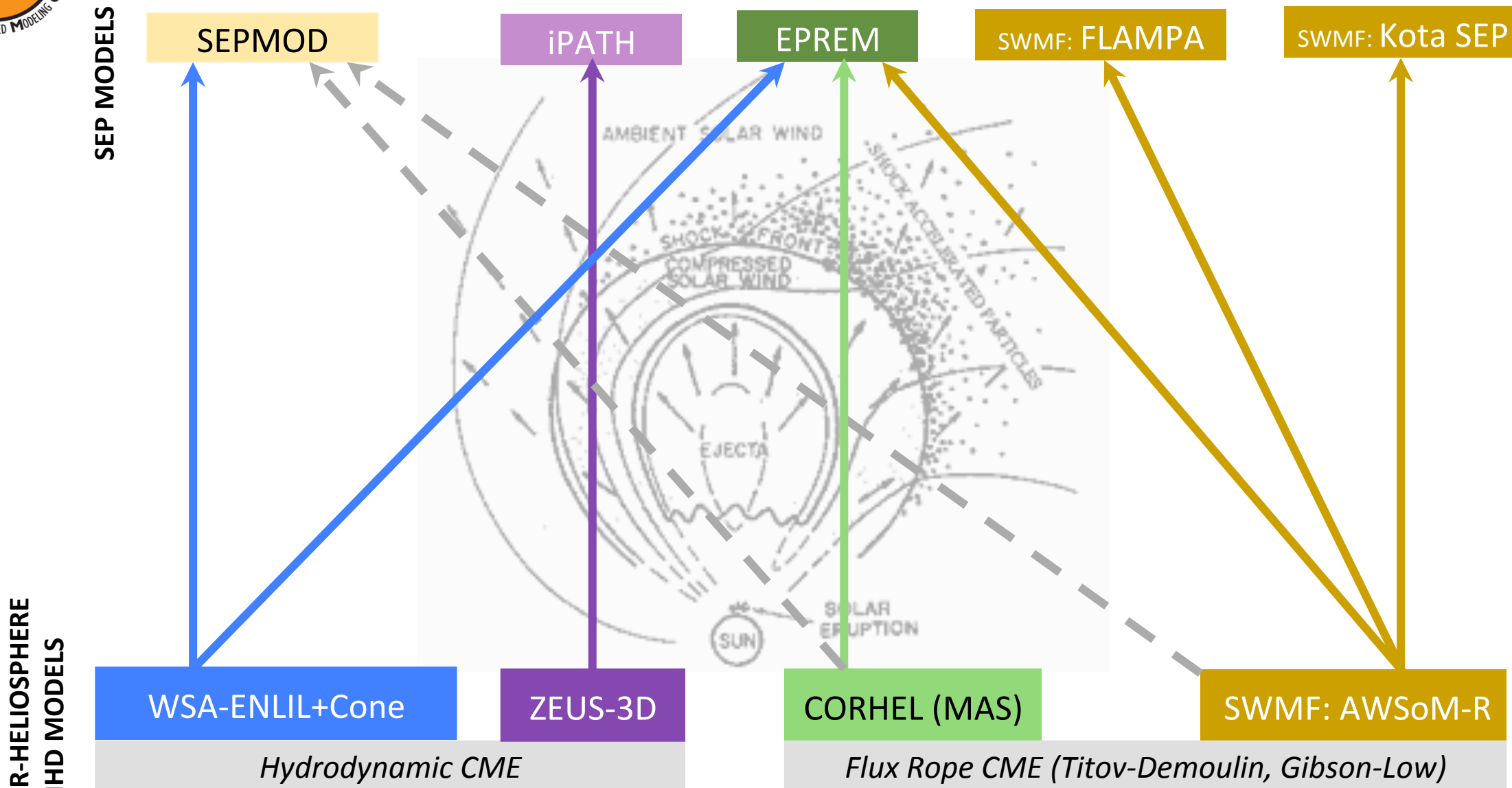# Coupled Heliosphere and SEP models

CCMC is making steps towards offering a system to run SEP models driven by a variety of heliospheric models.

SEP MODELS

SEPMOD iPATH EPREM SWMF: FLAMPA SWMF: Kota SEP

AMBIENT SOLAR WIND

SHOCK ACCELERATED PARTICLES

SHOCK FRONT

COMPRESSED SOLAR WIND

EJECTA

SUN

SOLAR ERUPTION

SOLAR-HELIOSPHERE MHD MODELS

WSA-ENLIL+Cone ZEUS-3D CORHEL (MAS) SWMF: AWSoM-R

Hydrodynamic CME *Flux Rope CME (Titov-Demoulin, Gibson-Low)*

Modelers: N. Arge, D. Odstrcil, J. Luhmann, J. Linker, N.Schwadron, M. Gorby, I.Sokolov

SEPMOD

M. Leila Mays (NASA GSFC)

for

J. Luhmann (UCB/SSL)

SEPMOD was developed under CISM in the mid-2000s to provide a WSA-ENLIL-cone simulation-based SEP model

What it is:

- A *generalized** test particle code that uses the time-dependent fields and shock information from MHD heliospheric CME/ICME simulations for **FORWARD MODELING** *SEP event time profiles*

   (* can actually use any MHD model results)

- Approach:

   Transport : A field-line tracer adapted for time-integrating guiding-center particle trajectories of ~1-100 MeV protons.

   Source: Uses an MHD shock parameter-based source description that is the same for all events. An ESP enhancement with a softer spectrum is assumed to travel with the shock.

   Results include: Time series of SEP fluxes at user-specified energies for any observer(s) in the ENLIL domain , pitch angle distribution (anisotropy) information, option to add flare SEPs.
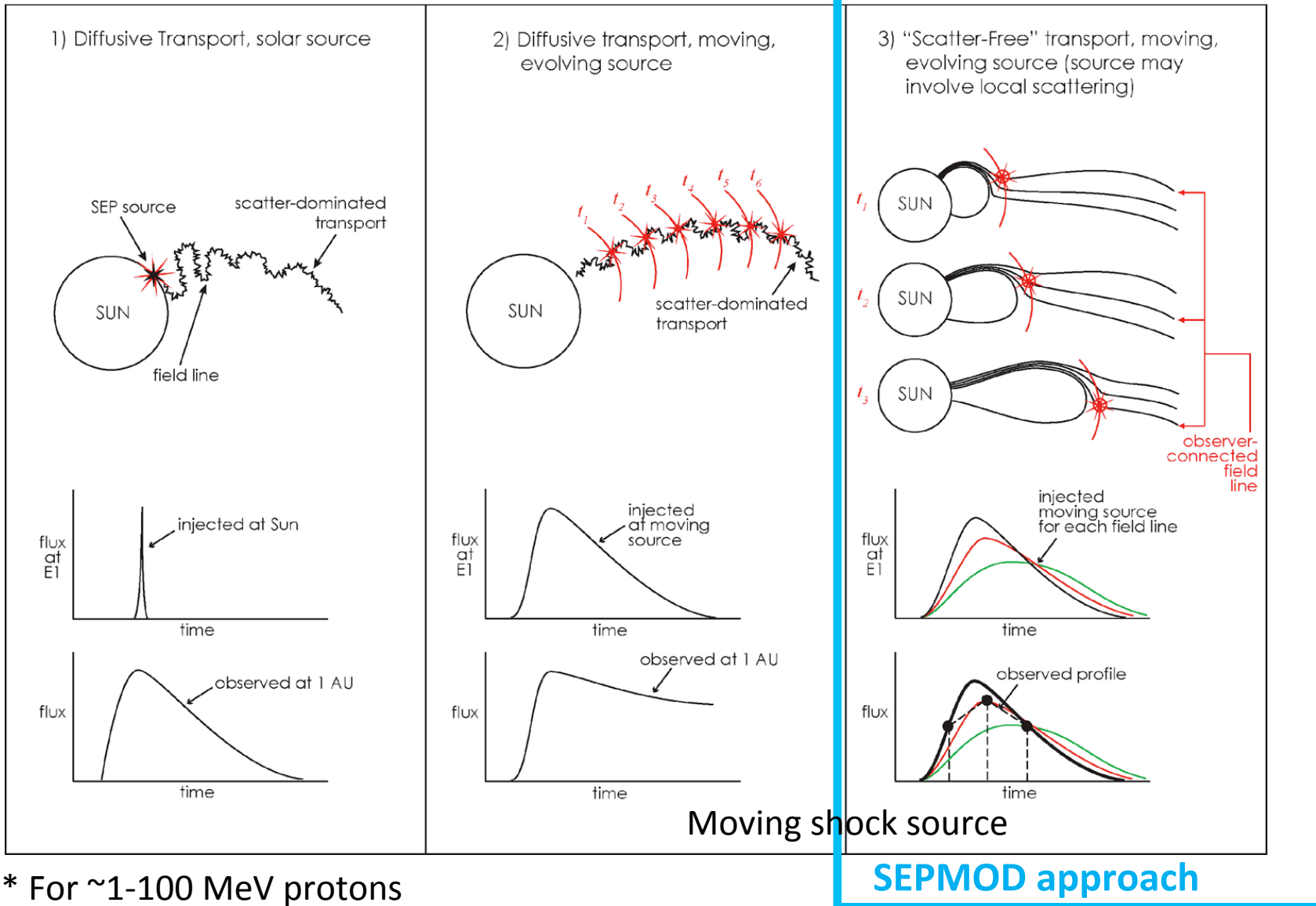
Underlying SEPMOD Assumption:
Interplanetary shocks are *the* sources of the major SEP events
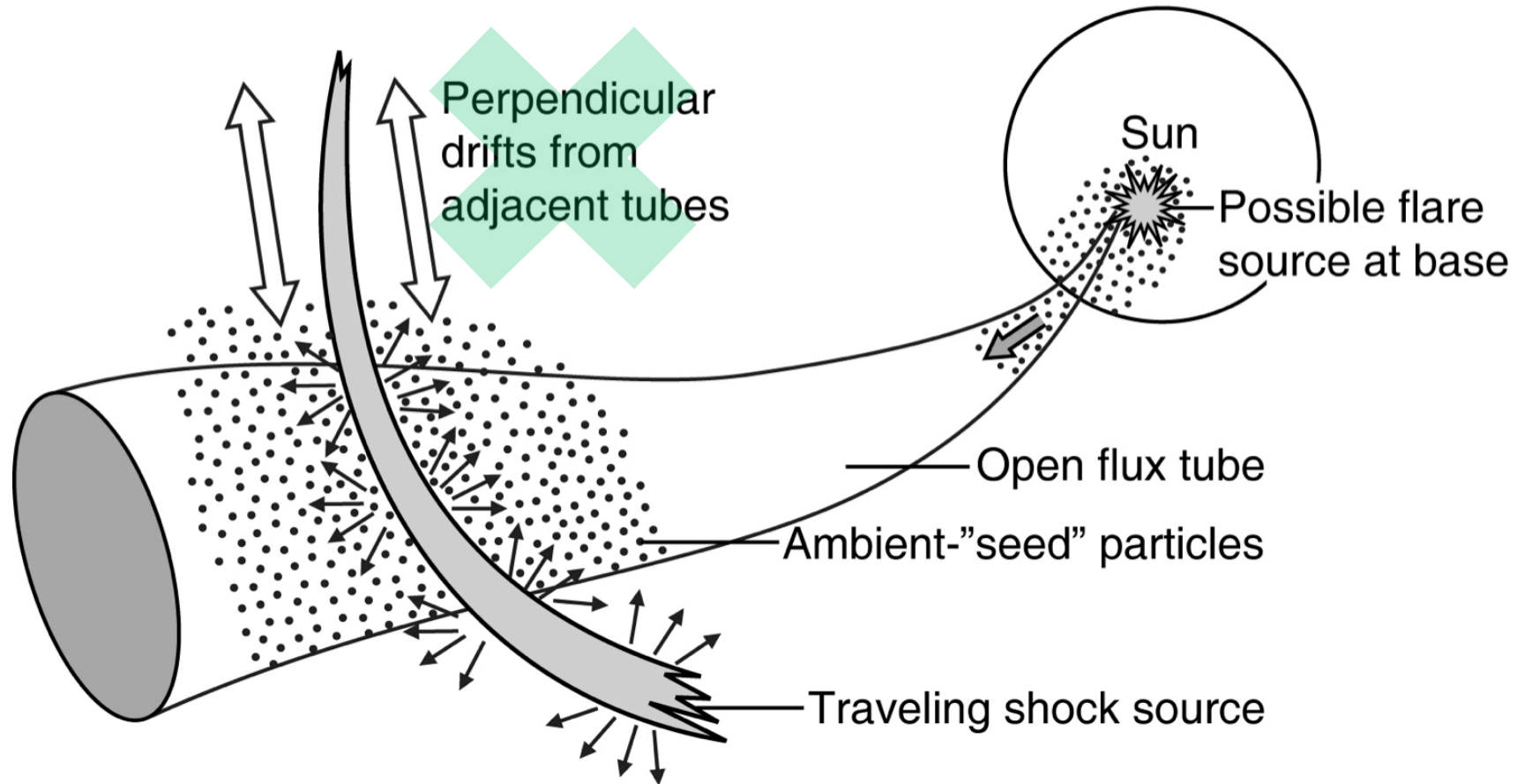
Tests idea that **Observer connection to a shock** is a necessary condition for a SEP event (in absence of significant perpendicular transport/diffusion)
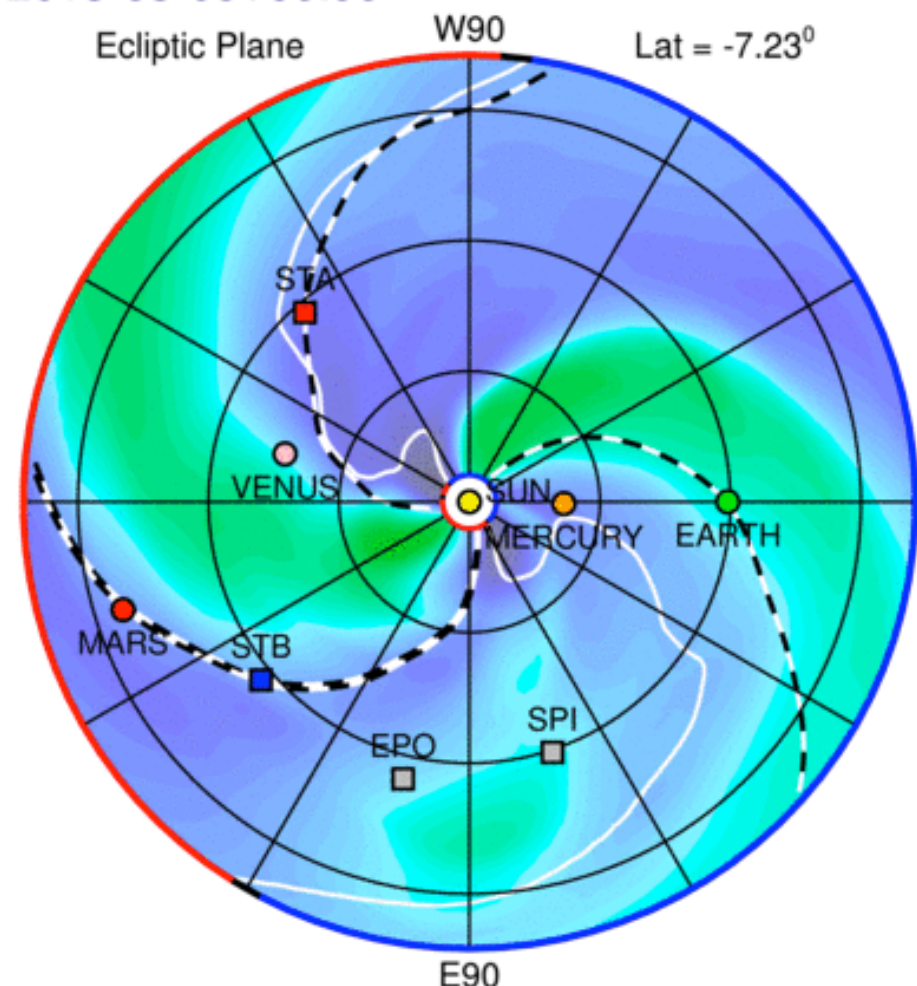
SEP Transport Viewpoints *

1) Diffusive Transport, solar source

SEP source
scatter-dominated transport
SUN
field line

flux at E1 — injected at Sun
time

flux — observed at 1 AU
time

2) Diffusive transport, moving, evolving source

t_1 t_2 t_3 t_4 t_5 t_6
SUN
scatter-dominated transport

flux at E1 — injected at moving source
time

flux — observed at 1 AU
time

3) "Scatter-Free" transport, moving, evolving source (source may involve local scattering)

t_1 SUN
t_2 SUN
t_3 SUN
observer-connected field line

flux at E1 — injected moving source for each field line
time

flux — observed profile
time

Moving shock source

SEPMOD approach

* For ~1-100 MeV protons

- SEPMOD uses ENLIL shock and field line results to specify time-dependent source strength and transport paths

- SEPMOD estimates SEP fluxes at any location within the ENLIL simulation domain.

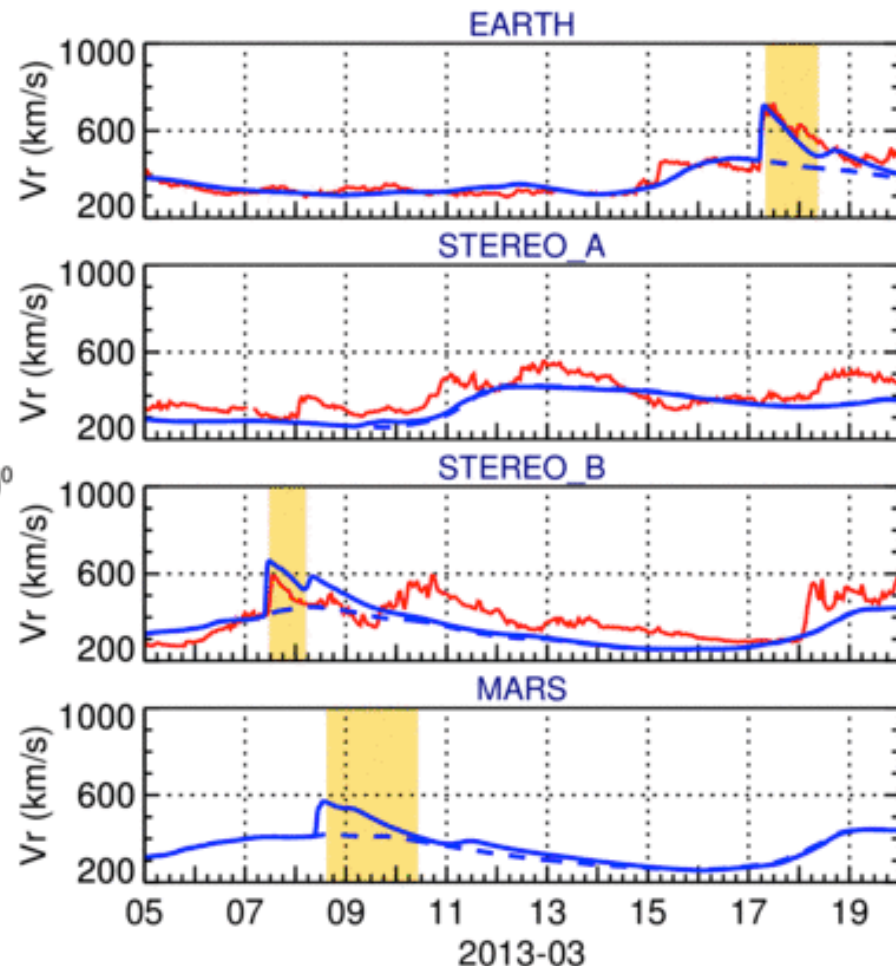*More details about SEPMOD: Luhmann et al. **Space Weather** (2017)*

Simple example (isolated CMEs) to illustrate SEPMOD results: March 2013

Observer 'layout' (from SSC)

EPAM 0.6–4.9 MeV protons and GOES 4.–15. MeV

shock connection radius (AU) for GEO

ACE+GOES

GEO Test of Mar 2013 multishock SEP model w/ESP

Mar 2013 case

LET(2–10MeV),HET(15–100MeV), Mar 2013 STA

LET(2–10MeV),HET(15–100MeV), Mar 2013 STB

shock connection radius (AU) for STA

shock connection radius (AU) for STB

STA

STB

STA Test of Mar 2013 multishock SEP model w/ESP

STB Test of Mar 2013 multishock SEP model w/ESP

Note each 'observer' experiences the ENLIL shocks differently

Sample SEPMOD run results for March 2013 STB:

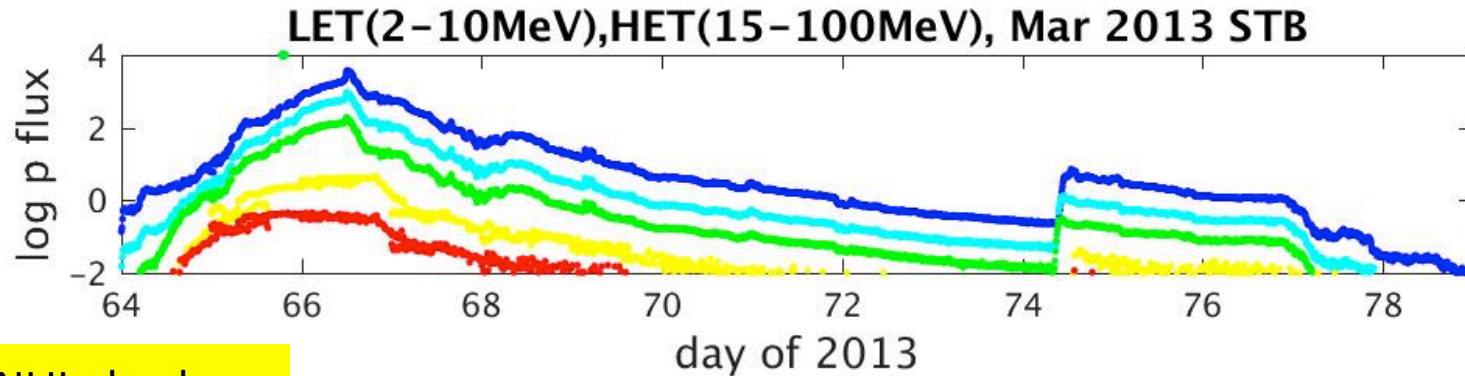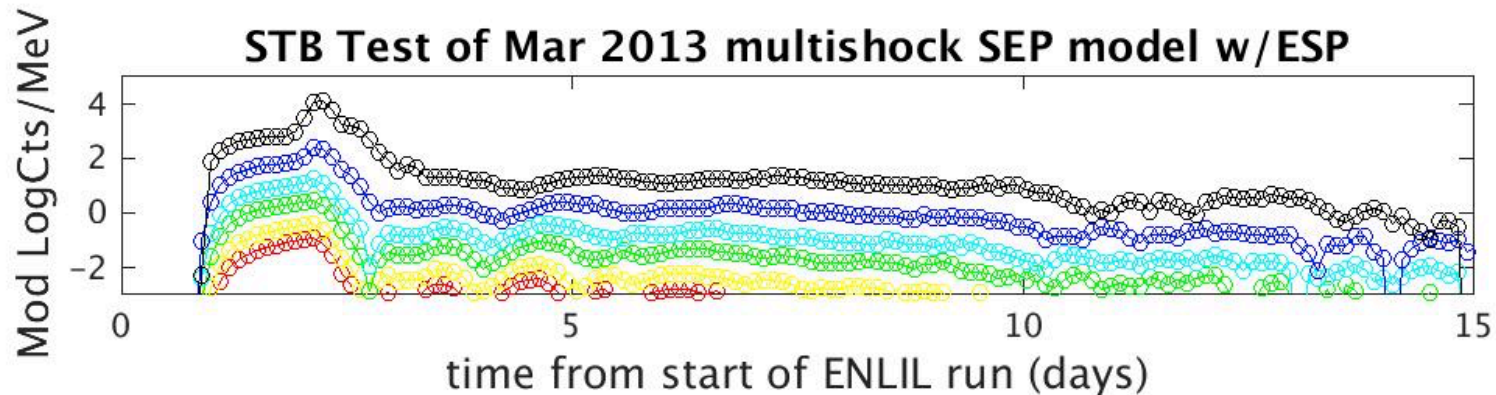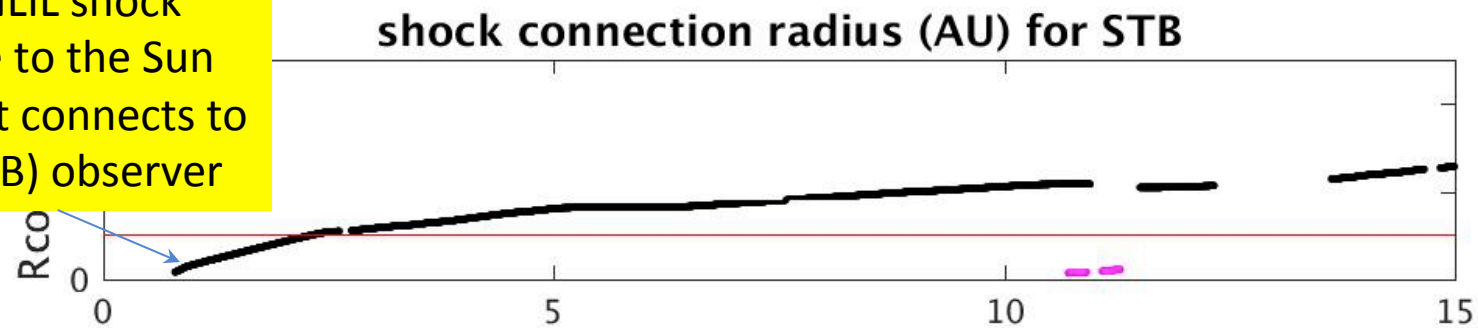*from top:* STEREO-B SEP data, ENLIL STB shock connections, modeled SEP event(s)

LET(2–10MeV),HET(15–100MeV), Mar 2013 STB

shock connection radius (AU) for STB

STB Test of Mar 2013 multishock SEP model w/ESP

Sample SEPMOD run results for March 2013 STB:

from top: STEREO-B SEP data, ENLIL STB shock connections, modeled SEP event(s)

**LET(2–10MeV),HET(15–100MeV), Mar 2013 STB**

log p flux

day of 2013

shock connection radius (AU) for STB

Rco
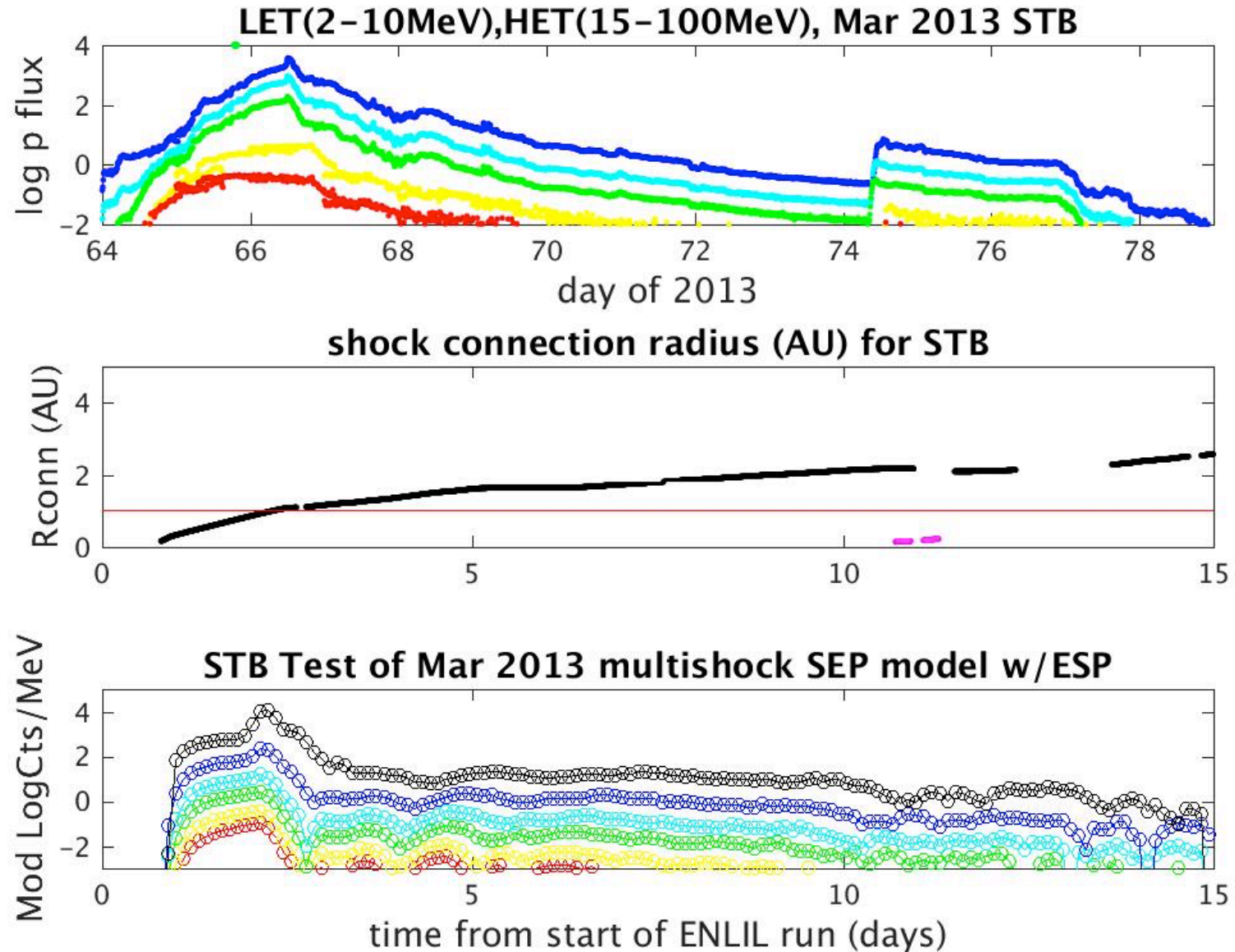
This ENLIL shock is close to the Sun when it connects to the (STB) observer

STB Test of Mar 2013 multishock SEP model w/ESP

Mod LogCts/MeV

time from start of ENLIL run (days)
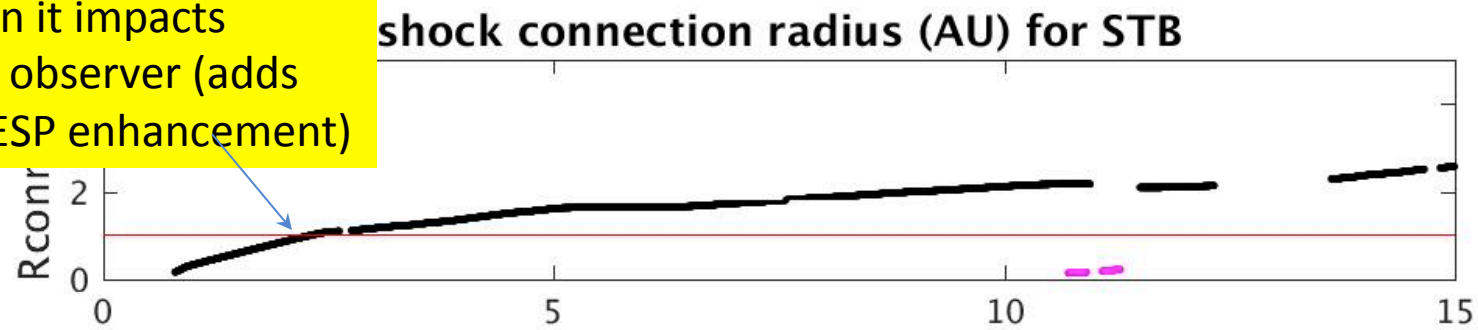
Sample SEPMOD run results for March 2013 STB:

from top: STEREO-B SEP data, ENLIL STB shock connections, modeled SEP event(s)

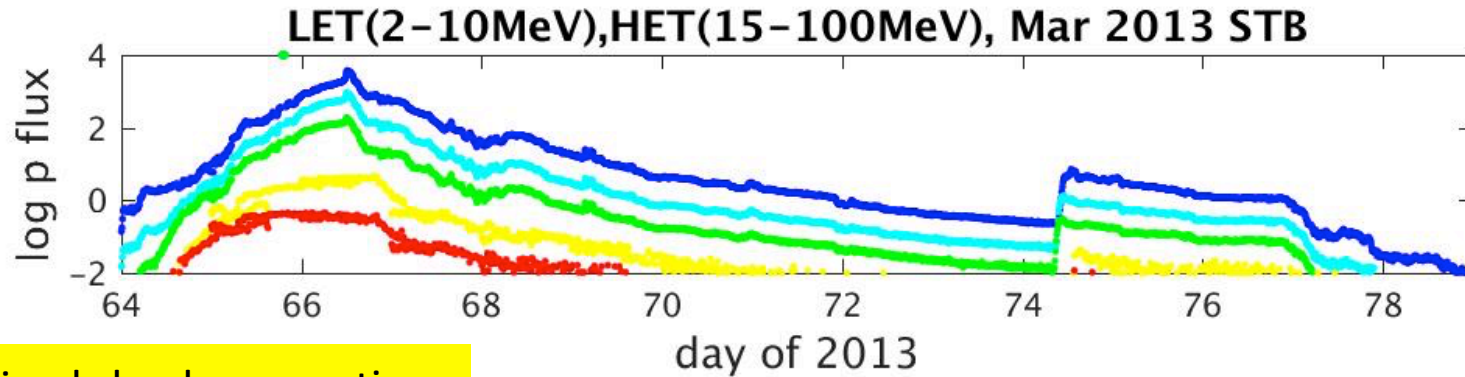LET(2−10MeV),HET(15−100MeV), Mar 2013 STB
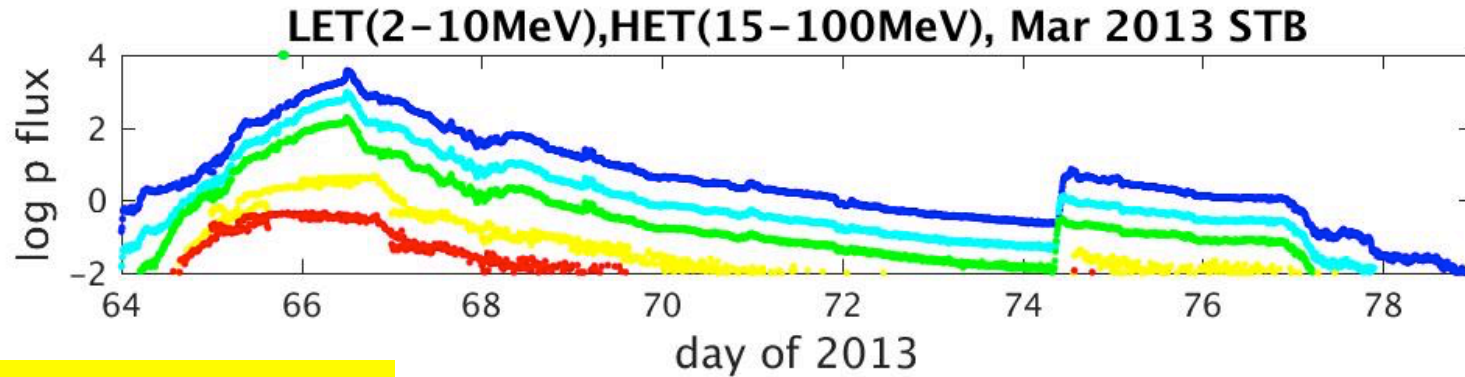
Then it impacts this observer (adds an ESP enhancement)
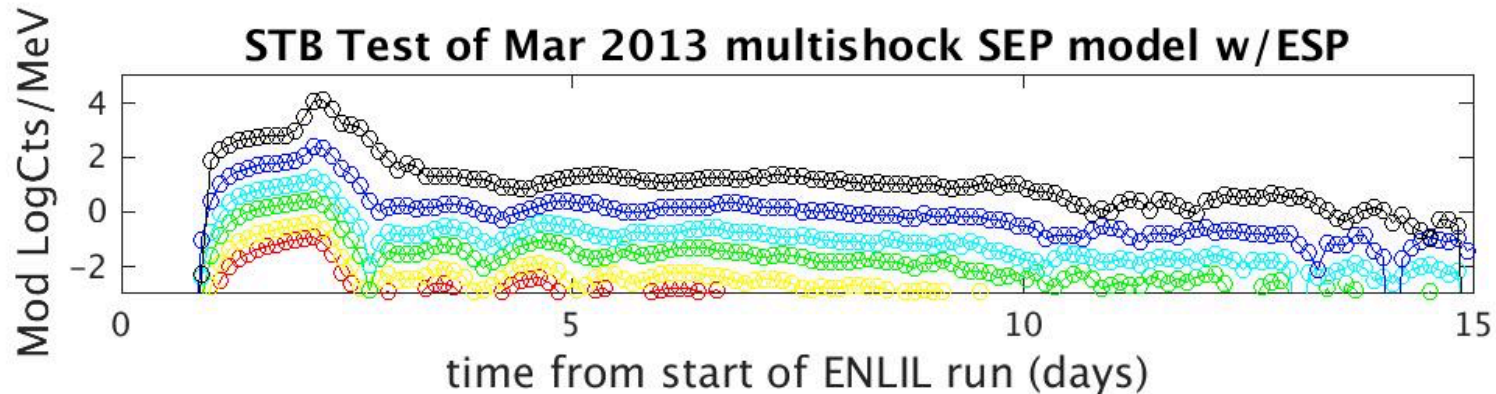
shock connection radius (AU) for STB

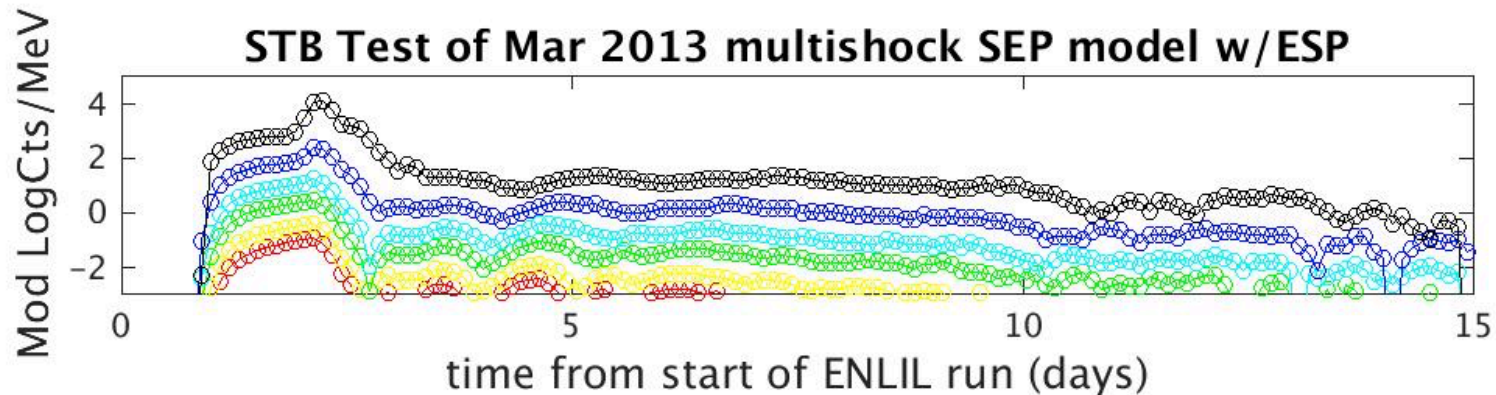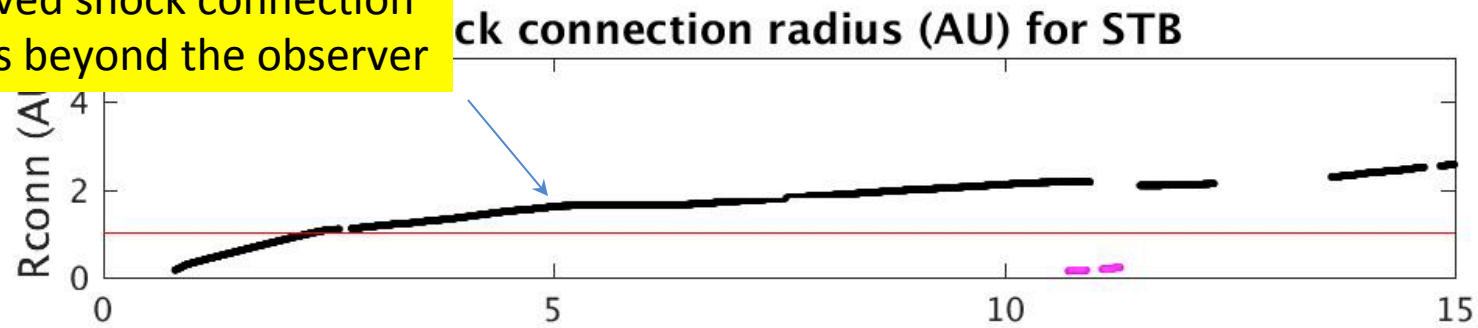STB Test of Mar 2013 multishock SEP model w/ESP

Sample SEPMOD run results for March 2013 STB:

from top: STEREO-B SEP data, ENLIL STB shock connections, modeled SEP event(s)

Long-lived shock connection persists beyond the observer

Summary

- SEPMOD has been **delivered and installed at CCMC** and is currently being tested. It will be made available to the community very soon.
- SEPMOD is an approach to SEP event analysis (and forecasting) that can **"ride along" with WSA-ENLIL-cone model runs.**
- It requires **minimal extra computational resources** and can provide a first-order estimate of SEP proton flux time profiles

Future Plans
- More testing/adjusting of SEPMOD is underway and can be undertaken by others
- Like PFSS model it is relatively straightforward in concept, and easy to run and modify
- Other physics and phenomena can be introduced: e.g. a flare source addition exists but is not generally added, and/or phenomenological diffusion processes
- Physically, SEPMOD helps test the limits of the shock source connectivity picture of observed SEP events