The iPATH model

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on behalf of
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iPATH:
improved **P**article **A**cceleration and **T**ransport in the Inner **H**eliosphere

Structure of iPATH

Three blocks:

Background solar wind and shock tracing

2D/3D MHD Zeus code for the background SW, can be replaced by other MHD code in the future

Particle acceleration at and propagate with the shock

instantaneous solution of the Parker transport equation at the shock front

Particle transport after escaping from the shock

Monte-Carlo simulation following single particle motion with pitch angle diffusion & adiabatic cooling

Model descriptions: Zank+ (2000), Rice+ (2003), Li+ (2003, 2005, 2012)., Hu+ (2017)

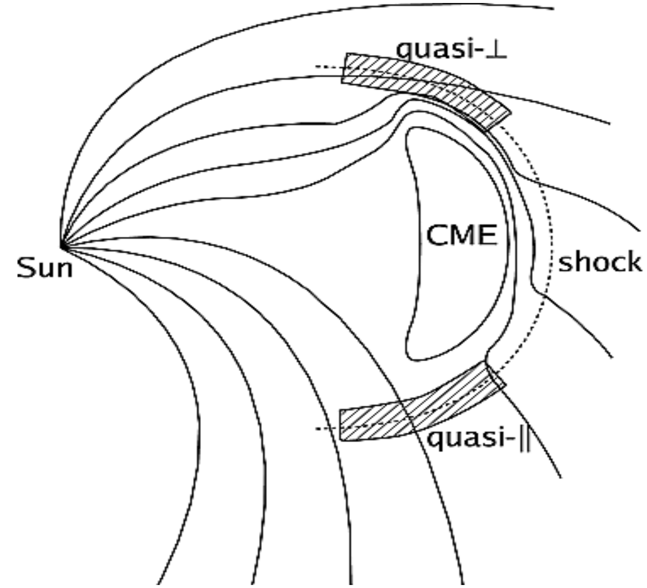
Model applications: Li+ (2004), Li +Zank (2005), Verkhoglyadova et al. (2009, 2010, 2012), Ao et al. (2016), Hu+ (2018)

iPATH Flowchart

Input from remote sensing measurements (e.g MAG4)

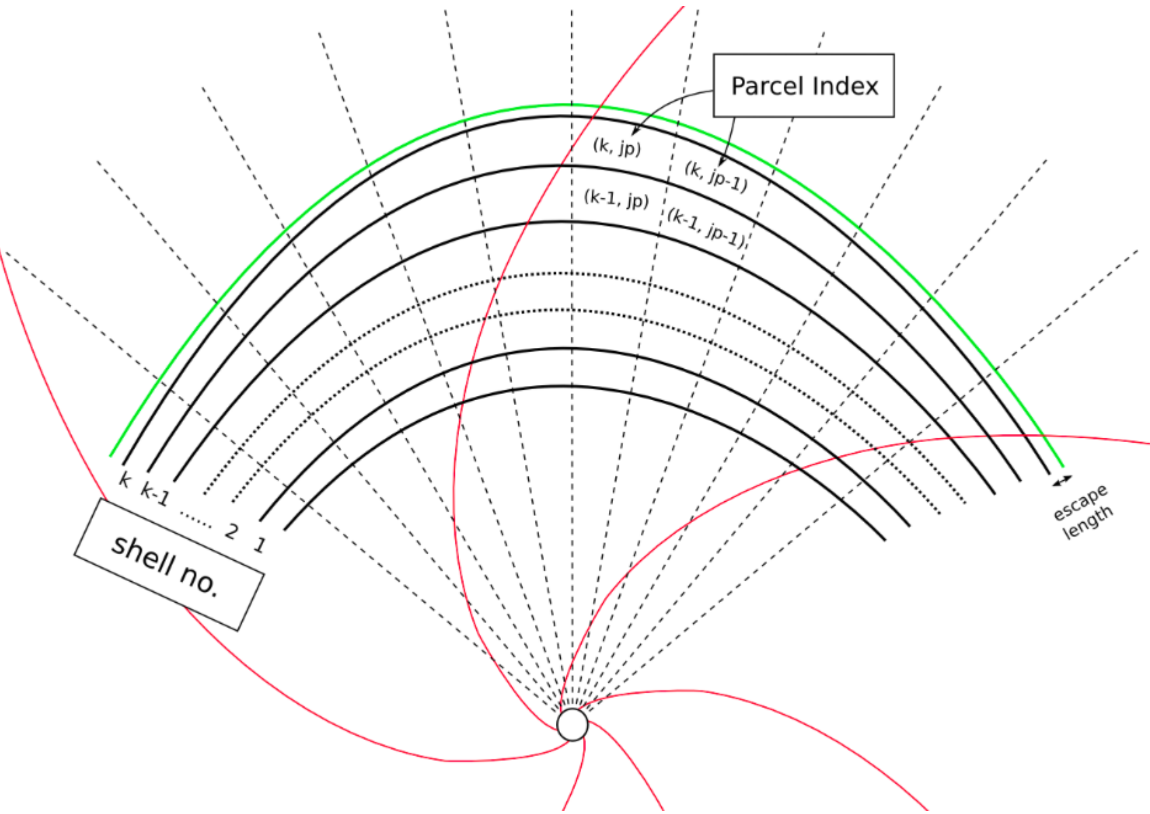
Modeling effort:
acceleration + transport

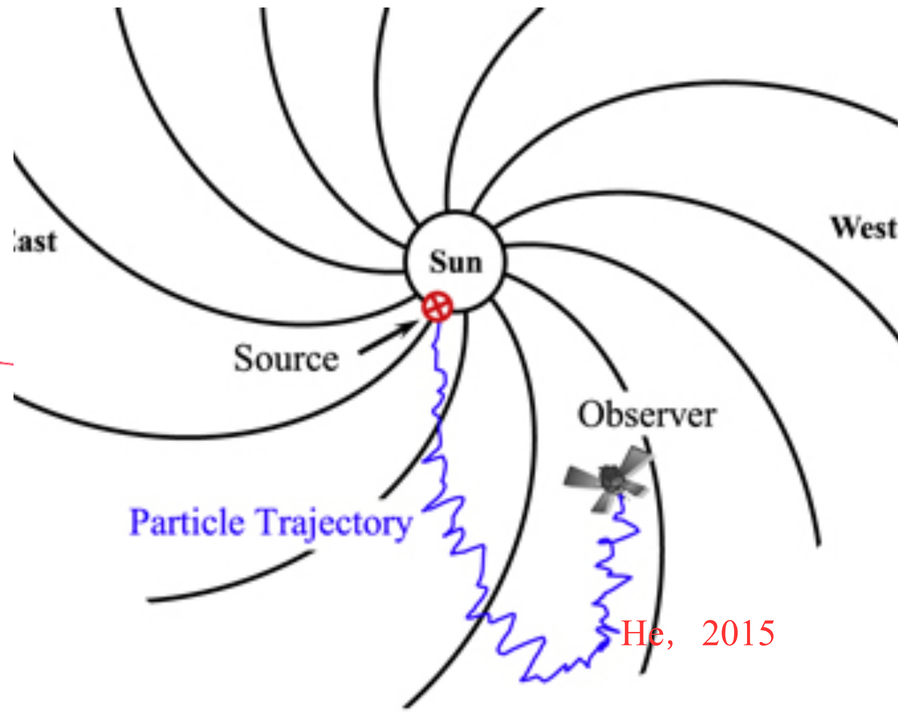
Output: time intensity profile and particle spectra at L1 and other locations of interest



KEY issues:
shock propagation
seed population
shock geometry
transport
turbulence

More details of iPATH

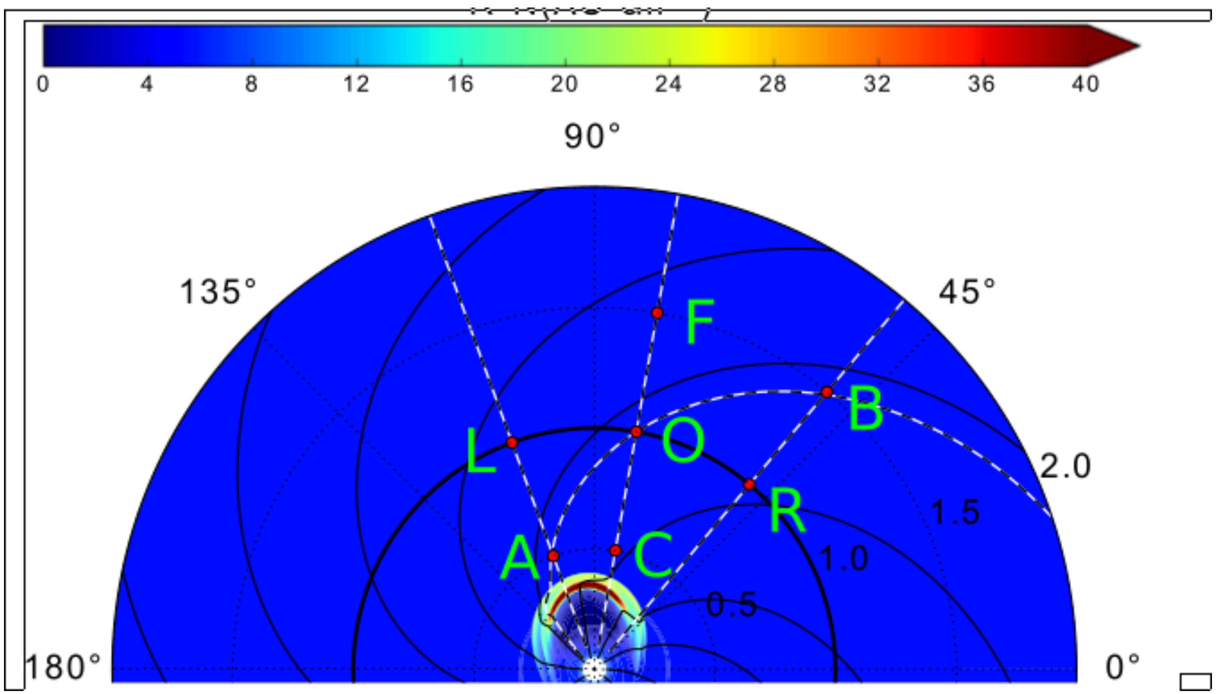




Acceleration: 2D onion shell module tracking SEPs downstream of the shock

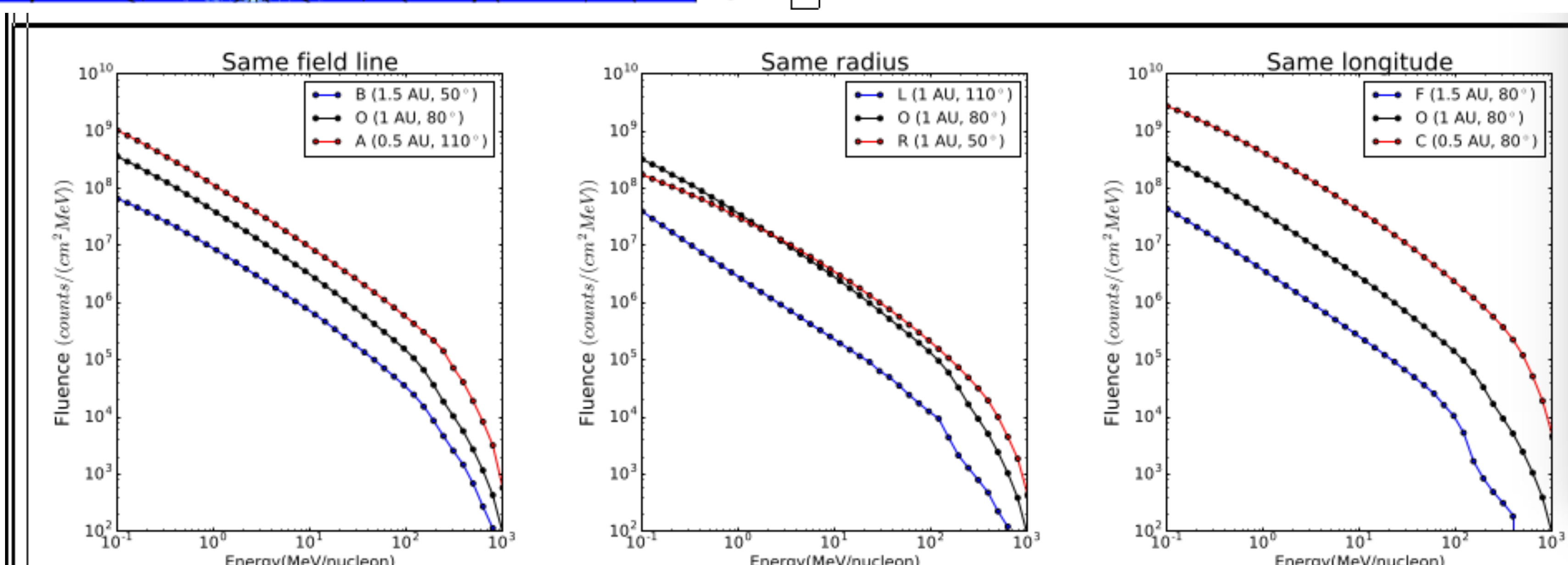
Transport module includes cross field diffusion

Example of iPATH modeling



Simultaneous SEP fluxes at multiple locations: e.g., Earth and Mars.

Event-integrated spectra at 7 locations.



Hu +, 2018.

iPATH at CCMC

iPATH is being implemented at CCMC.

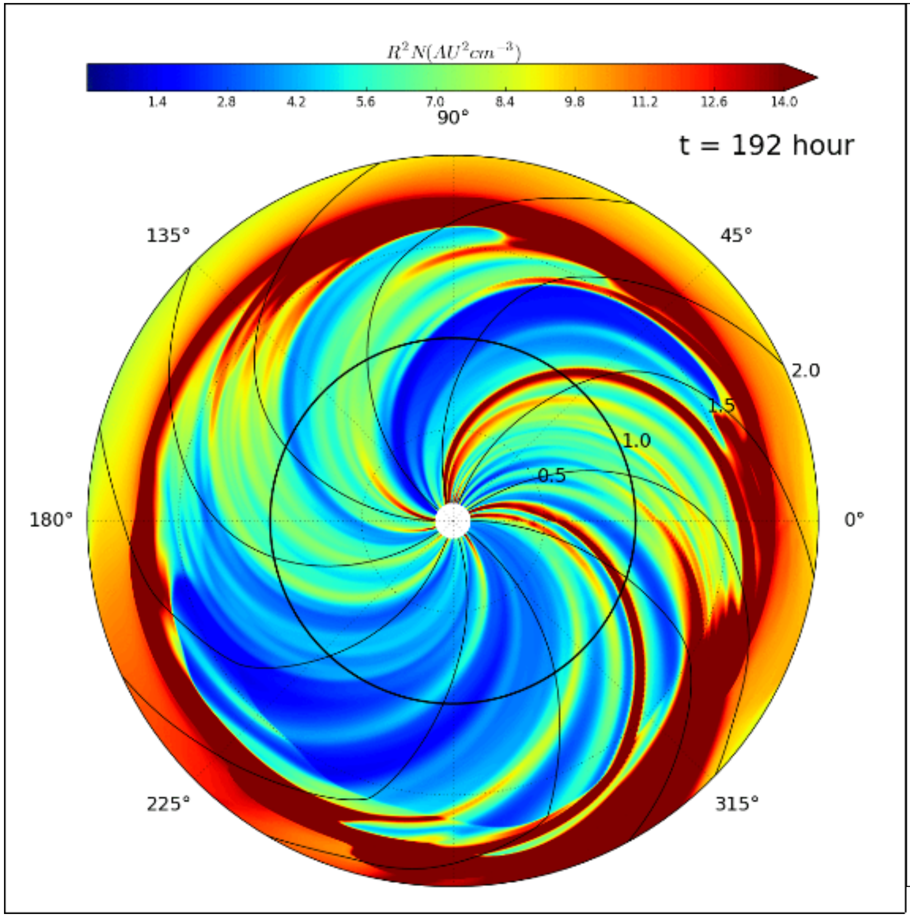
Two types of user interface/applications will be delivered:

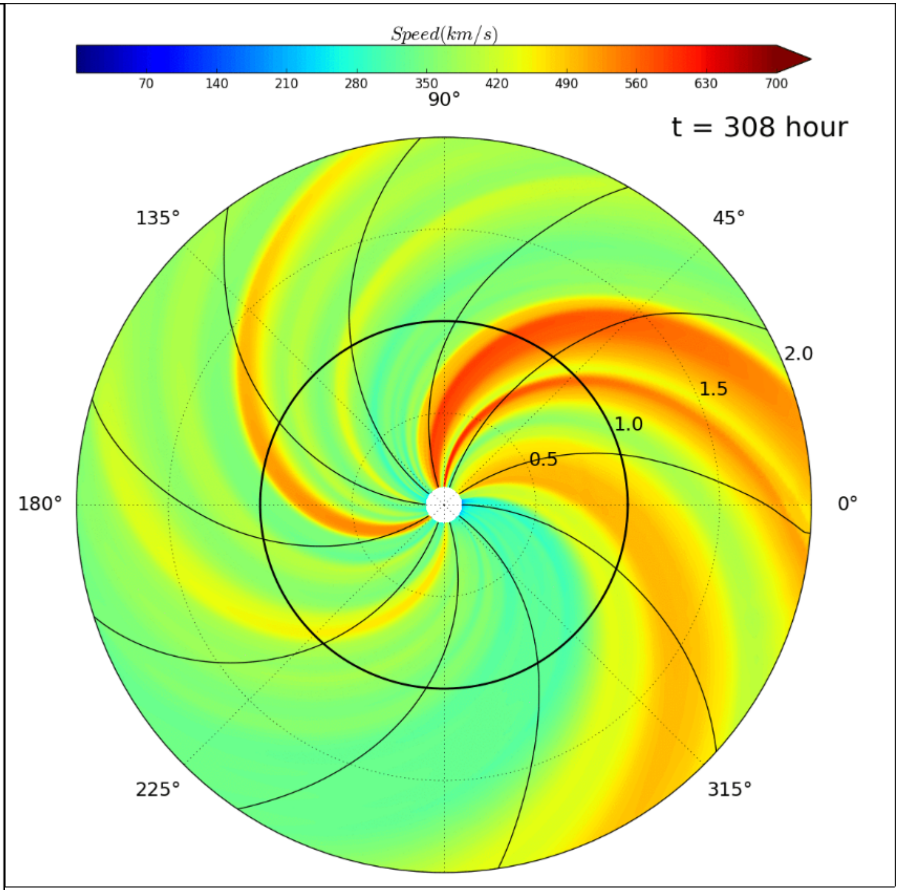
1) Real-time SEP forecasting: No user inputs are required, users can browse the forecast at anytime. Locations include Earth, Mars, and other places of interest.

2) Simulation of particular SEP event: users can vary the input parameters including: 1) background solar wind, 2) shock speed and strength (through disturbance period), 3) turbulence level in the solar wind, 4) cross field diffusion strength; 5) other parameters.

Backup Slides

drive iPATH by realistic solar wind inputs from ACE measurements, with CIR structures, etc.





Particle acceleration at the shock front

Parker's transport equation

$$\frac{\partial f}{\partial t} = -V_{w,i}\frac{\partial f}{\partial x_i} + \frac{\partial}{\partial x_i}\kappa_{ij}\frac{\partial f}{\partial x_j} + \frac{1}{3}\frac{\partial V_{w,i}}{\partial x_i}\frac{\partial f}{\partial \ln p} + Q$$

In conservation form:

$$\frac{\partial f}{\partial t} + \nabla \cdot S + \frac{1}{p^2}\frac{\partial}{\partial p}(p^2 J) = 0$$

$$\mathbf{S} = -\frac{p}{3}\mathbf{u}\frac{\partial f}{\partial p} - \kappa \nabla f$$

$$J = \frac{p}{3}\boldsymbol{u} \cdot \nabla f$$

Gleeson-Axford 1967

S: current in r space

J: current in p space

Effect of turbulence on particle

Acceleration time scale

the highest energy is decided by the acceleration time scale through kappa.

$$\Delta t = \frac{3s}{s-1} \frac{\kappa(p)}{u_{sh}^2} \frac{\Delta p}{p}$$

Axford (1981),
Drury (1983)

smaller κ lead to higher energy

What controls κ? Pre-existing turbulence and self-amplified waves.