STAT SPE THREAT ASSESSMENT TOOL
Recent Updates

Predictive Science Inc.
University of New Hampshire

SPD54
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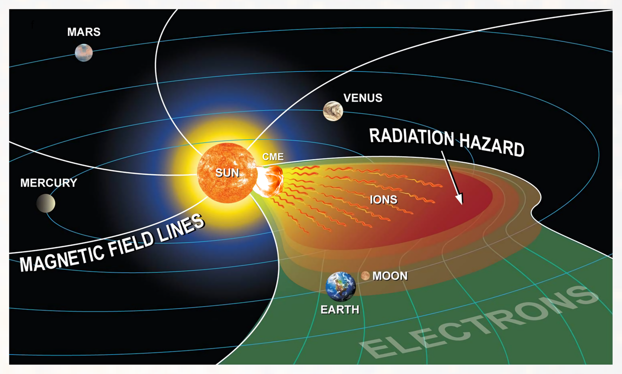
INTRODUCTION



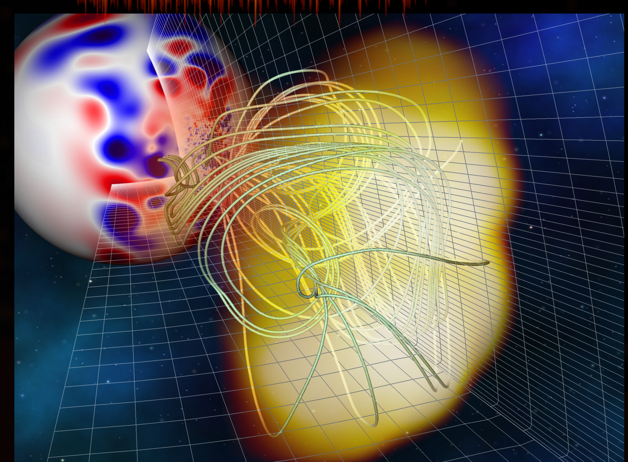
The Solar Particle Event (SPE) Threat Assessment Tool (STAT) is a software suite that combines a state-of-the-art thermodynamic magnetohydrodynamic model (MAS) with a global energetic particle simulation (EPREM).

STAT can be used to simulate the acceleration and transport of Solar Energetic Particles (SEPs) produced in specific events driven by large solar eruptions. STAT provides detailed diagnostics that allow analysis of the global properties of an event, as well comparisons of simulated SEP fluxes with multi-spacecraft in-situ data.

Here we describe recent feature updates and improvements to the STAT model. These include algorithm improvements in the EPREM model, the ability to simulate an SPE using multi-resolution CME simulation output generated by the on-demand CORHEL-AMCG framework hosted at NASA's Community Coordinated Modeling Center, and improvements to the post-processing of STAT output that allow more accurate comparisons to SEP in situ data.

THE STAT MODEL

MAS — MAGNETOHYDRODYNAMIC ALGORITHM OUTSIDE A SPHERE



Non-uniform spherical Eularian grid

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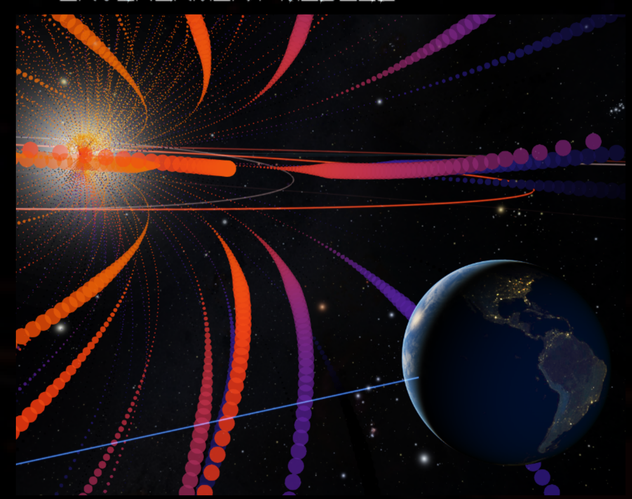
EPREM — ENERGETIC PARTICLE RADIATION ENVIRONMENT MODULE



Thermodynamic, resistive MHD:

$$\frac{\partial \mathbf{A}}{\partial t} = \mathbf{v}\times\mathbf{B} - \frac{c^2}{4\pi}\eta\nabla\times\nabla\times\mathbf{A}$$

$$\frac{\partial \rho}{\partial t} = -\nabla\cdot(\rho\mathbf{v})$$

$$\frac{\partial T}{\partial t} = -\nabla\cdot(T\mathbf{v}) - (\gamma-2)(T\nabla\cdot\mathbf{v}) + \frac{(\gamma-1)}{2k}\frac{m_p}{\rho}\left[-\nabla\cdot(\mathbf{q}_1+\mathbf{q}_2) - \frac{\rho^2}{m_p^2}Q + H\right]$$

$$\rho\frac{\partial \mathbf{v}}{\partial t} = -\rho\mathbf{v}\cdot\nabla\mathbf{v} + \frac{1}{c}\mathbf{J}\times\mathbf{B} - \nabla(p+p_w) + \rho\mathbf{g} + \mathbf{F}_c + \nabla\cdot(\nu\rho\nabla\mathbf{v}) + \nabla\cdot\left(S\rho\nabla\frac{\partial\mathbf{v}}{\partial t}\right)$$

See www.predsci.com/mas for more details

Nodes advected in domain: $\frac{\partial x}{\partial t} = \vec{V}$

Focused transport in Lagrangian frame:

$$\frac{df_s}{dt} = -v\mu\hat{b}\cdot\nabla f_s + \frac{\partial}{\partial\mu}\left(\frac{D_{\mu\mu}}{2}\frac{\partial f_s}{\partial\mu}\right) - \frac{(1-\mu^2)}{2}\left[-v\hat{b}\cdot\nabla\ln B - \frac{2}{v}\hat{b}\cdot\frac{d\vec{V}}{dt} + \mu\frac{d\ln(n^2/B^3)}{dt}\right]\frac{\partial f_s}{\partial\mu} - \left[-\frac{\mu}{v}\hat{b}\cdot\frac{d\vec{V}}{dt} + \mu^2\frac{d\ln(n/B)}{dt} + \frac{(1-\mu^2)}{2}\frac{d\ln B}{dt}\right]\frac{\partial f_s}{\partial\ln p}$$

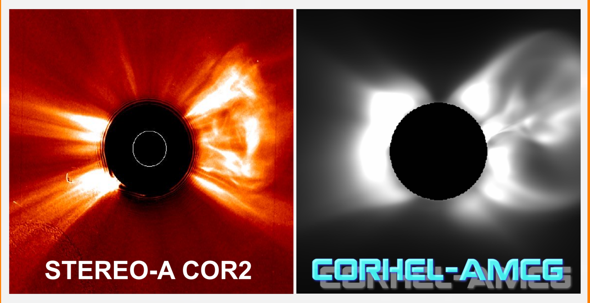
Seed Population:

$$f_{s;0} = \frac{1}{2E}\left[J_0\left(\frac{E}{E_1}\right)^{-\gamma}e^{-E/E_0}\right]\left(\frac{r}{r_1}\right)^{-\beta}$$

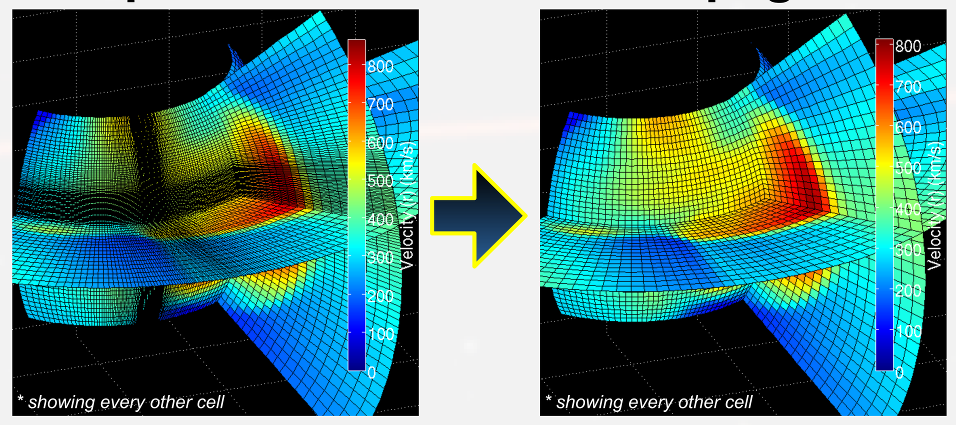
STAT RUNS FOR CORHEL-AMCG CME SIMULATIONS

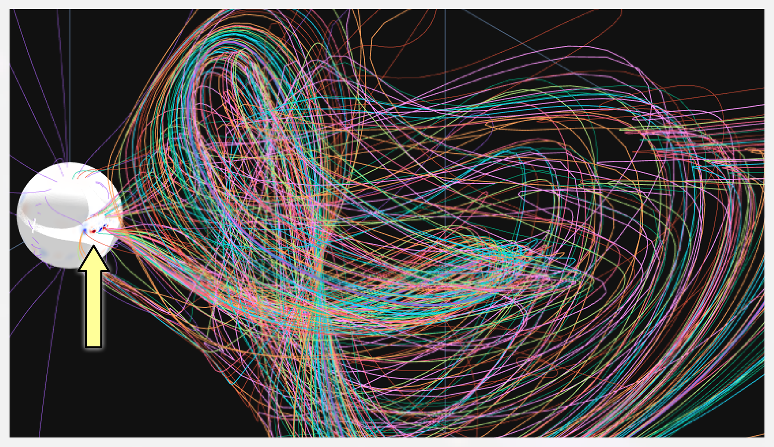
CORHEL-AMCG

CME 2022-03-28

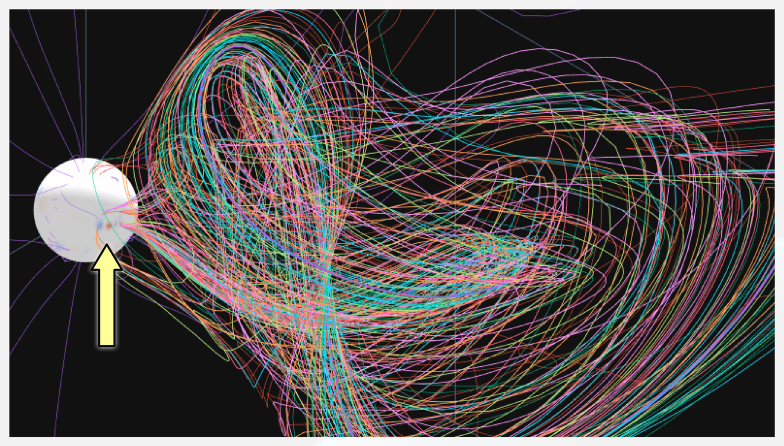


Eruption → Re-mesh → Propagation



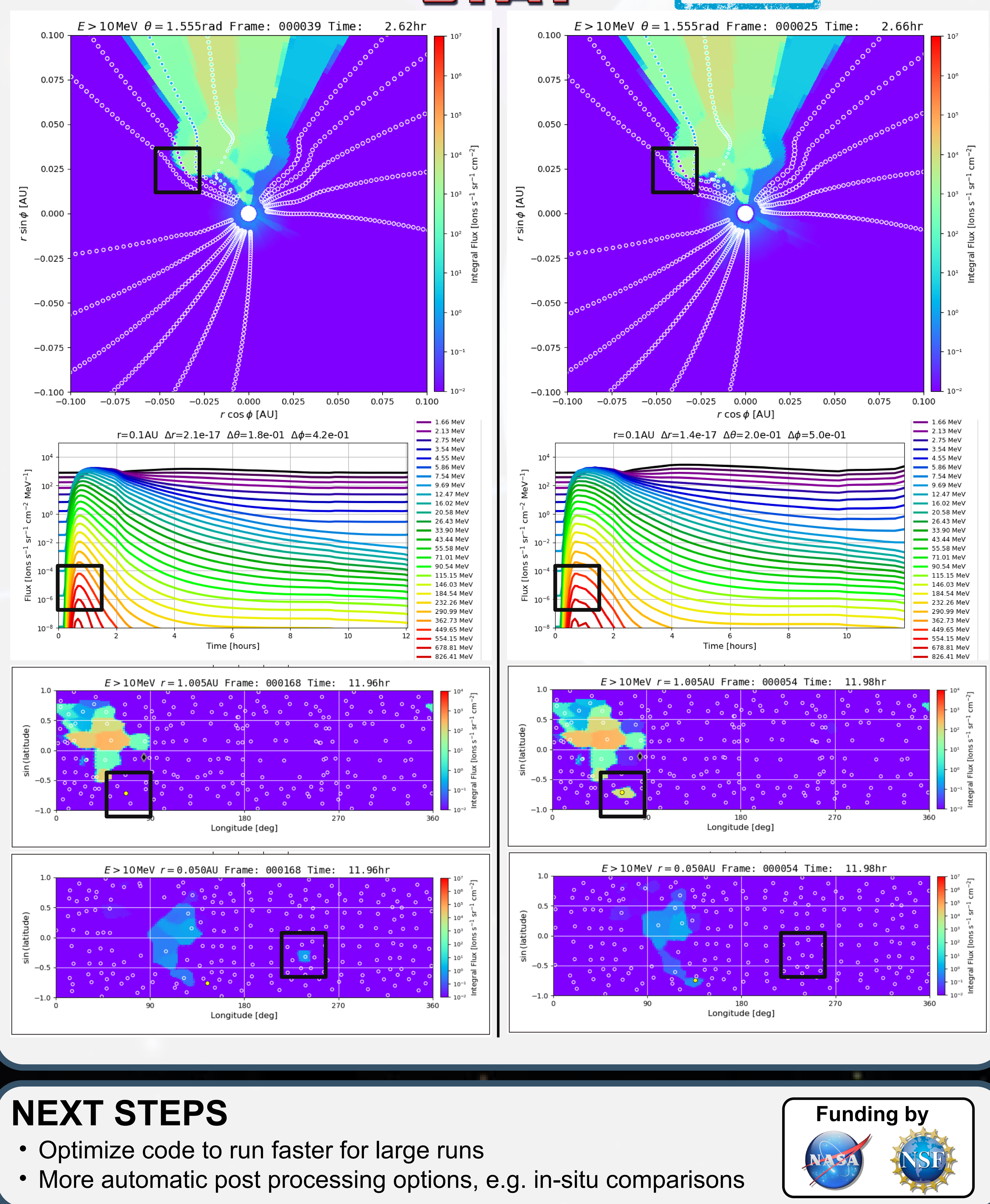


High-resolution only (no re-mesh)



Multi-resolution (with re-mesh)

STAT UPDATE



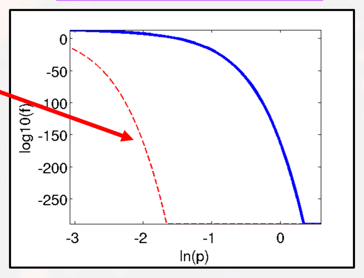
EPREM NUMERICAL SCHEME: ADIABATIC CHANGE INTEGRATION

Simple advection problem with initial seed population:

Uniform grid: $\Delta\ln p \quad p=\sqrt{E^2+2E} \quad u_0 = f_{s;0}$

$$\frac{\partial u}{\partial t} = v\frac{\partial u}{\partial \ln p} \quad \begin{pmatrix} v=-2 \\ t_{\mathrm{end}}=1 \end{pmatrix}$$

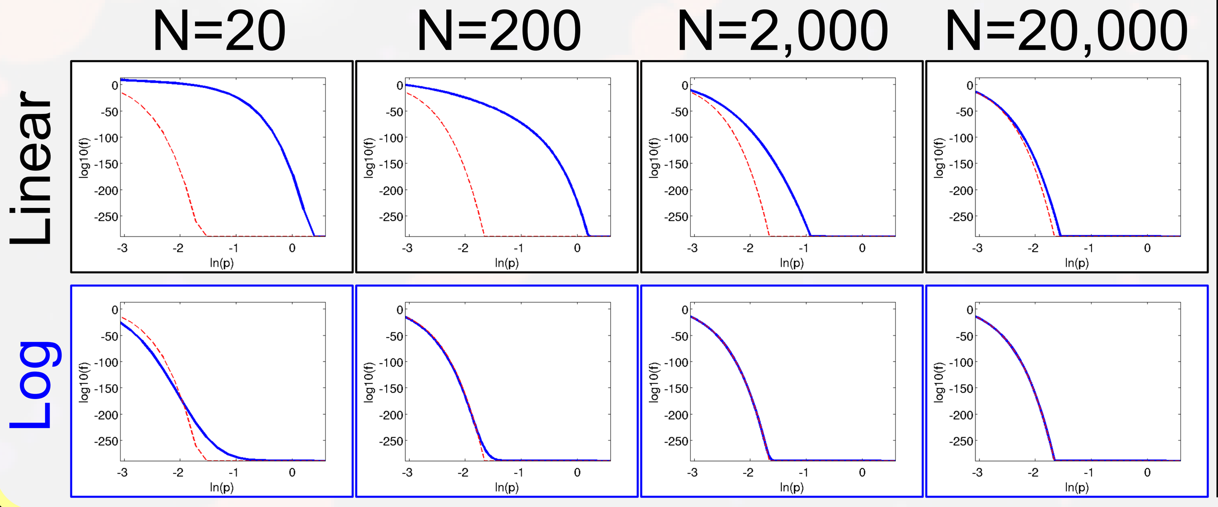
Exact solution



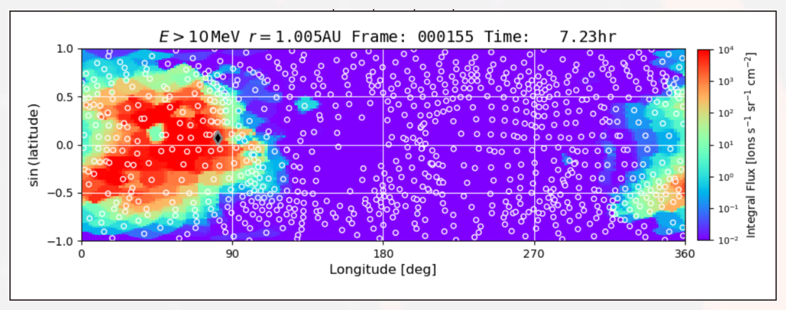
Linear vs. log integration
(1st order Euler + Upwind)

$$\frac{\partial \ln u}{\partial x} = \frac{1}{u}\frac{\partial u}{\partial x} \quad \Rightarrow \quad u^* = \ln(u), \quad \frac{\partial u^*}{\partial t} = v\frac{\partial u^*}{\partial \ln p}, \quad u=\exp[u^*]$$

N=20 N=200 N=2,000 N=20,000



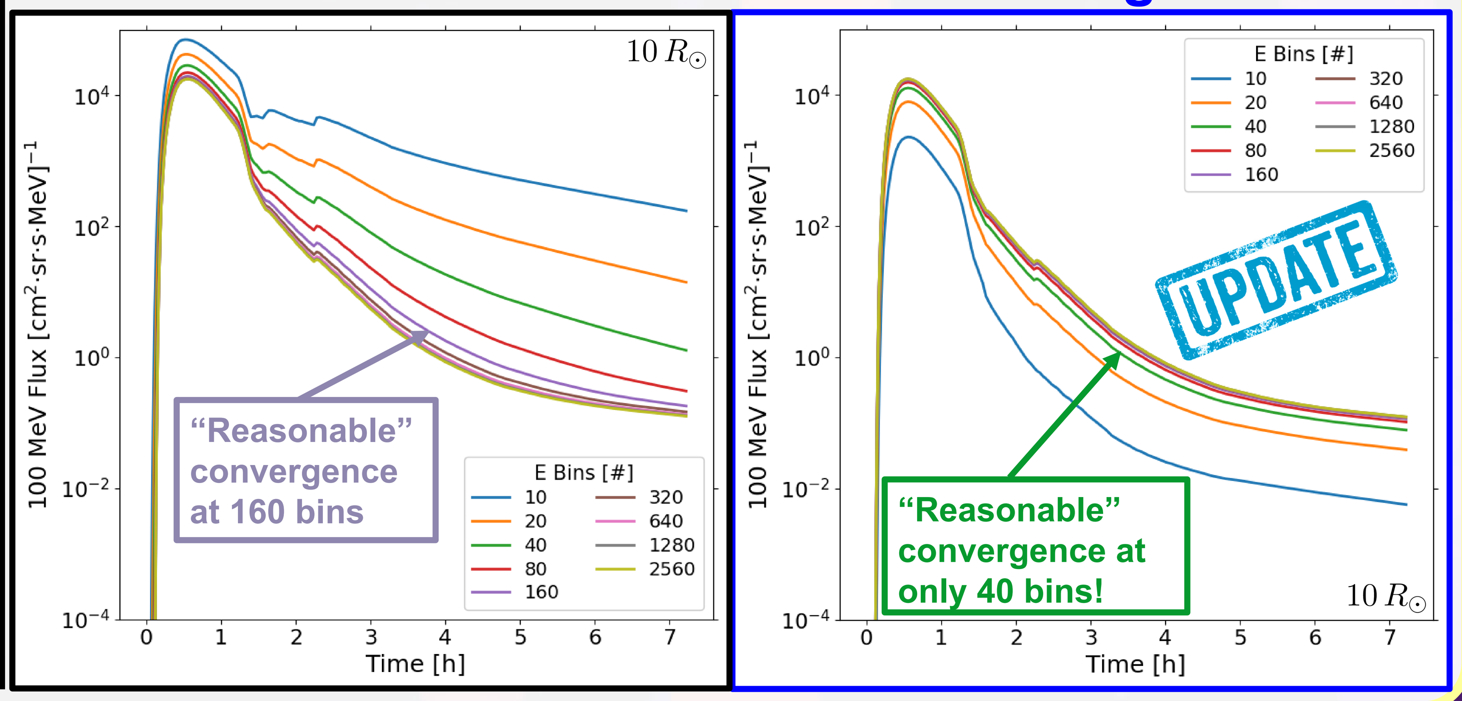
STAT CME 2012-07-12



Operator split adiabatic change within step, convert to and from log space:

- $f^*(E) = \ln f_s(E)$
- Integrate CFL-subcycled advance for 1 time step
- $f_s(E) = \exp[f^*(E)]$

Test convergence by running with increasing # of energy bins:



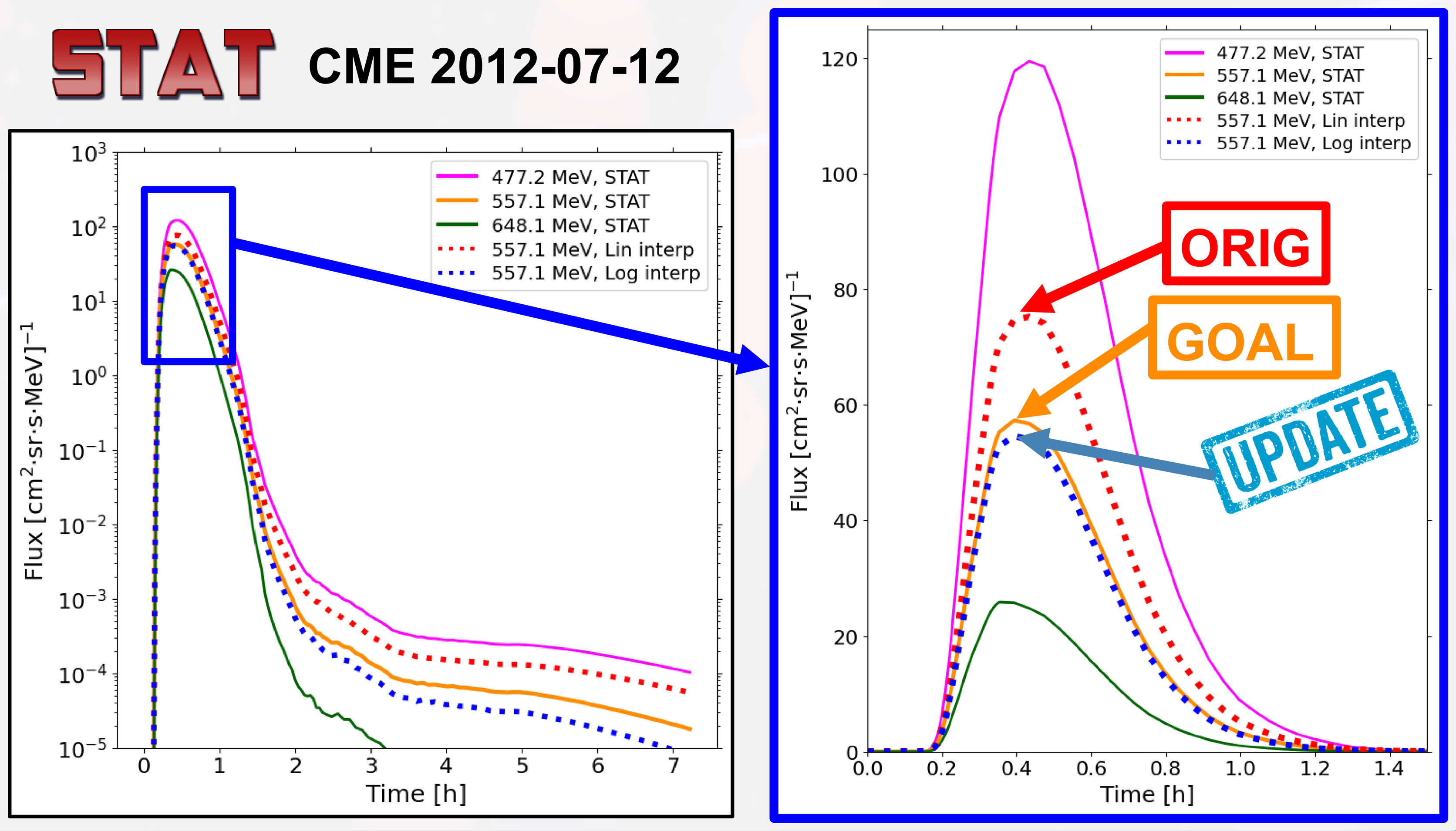
STAT POST PROCESSING: DIFFERENTIAL ENERGY INTERPOLATION

- We want to compare STAT results to various in situ instrument observations
- Each instrument reports data with a unique set of energy bins, requiring interpolation of the STAT energy bins to those of the observations
- Due to the typical form of the differential energy specrum, it is very important to interpolate in log space:

$$f^*(E_{\mathrm{STAT}}) = \ln f_{\mathrm{STAT}}(E_{\mathrm{STAT}})$$

$$f_{\mathrm{STAT}}(E_{\mathrm{obs}}) = \exp\left[I(f^*(E))\right]$$

STAT CME 2012-07-12



NEXT STEPS

- Optimize code to run faster for large runs
- More automatic post processing options, e.g. in-situ comparisons

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