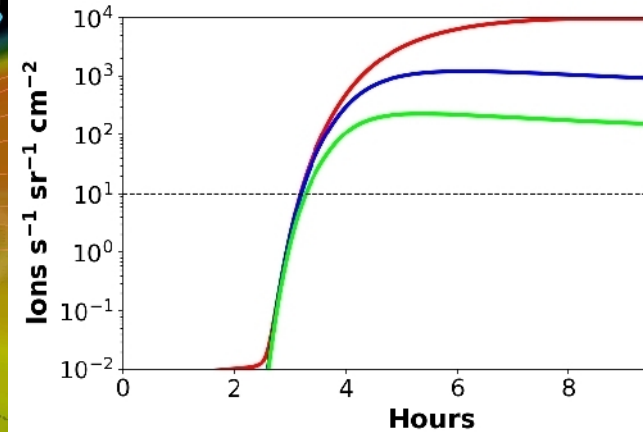
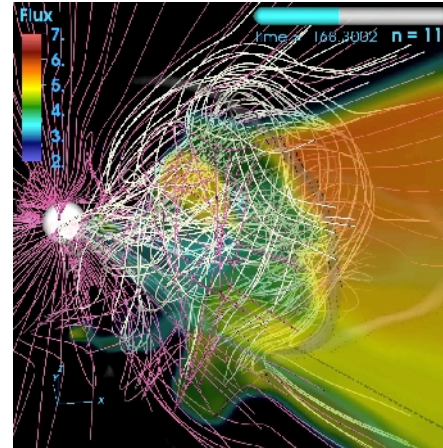
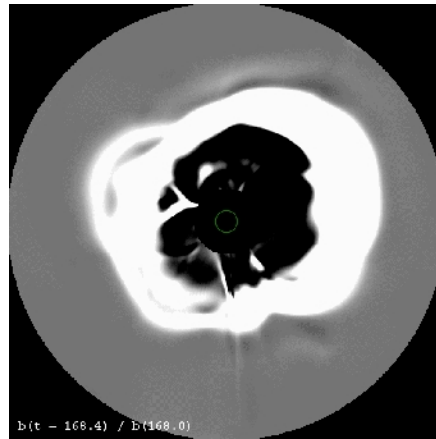
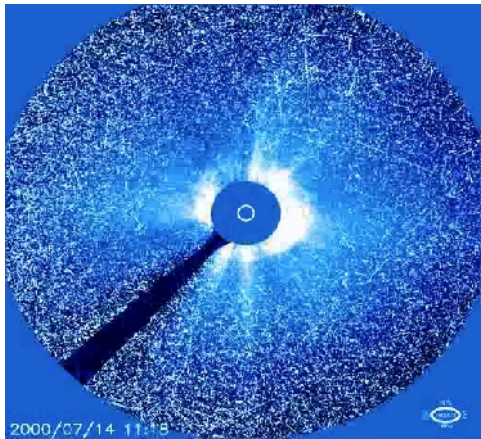


SPE Threat Assessment Tool (STAT):

Coupled Coronal Mass Ejection - Solar Particle Event Simulations



A NASA STTR Project

Predictive Science Inc:

Jon Linker, Ronald Caplan, Cooper Downs, Roberto Lionello, Tibor Torok, Janvier Wijaya

University of New Hampshire:

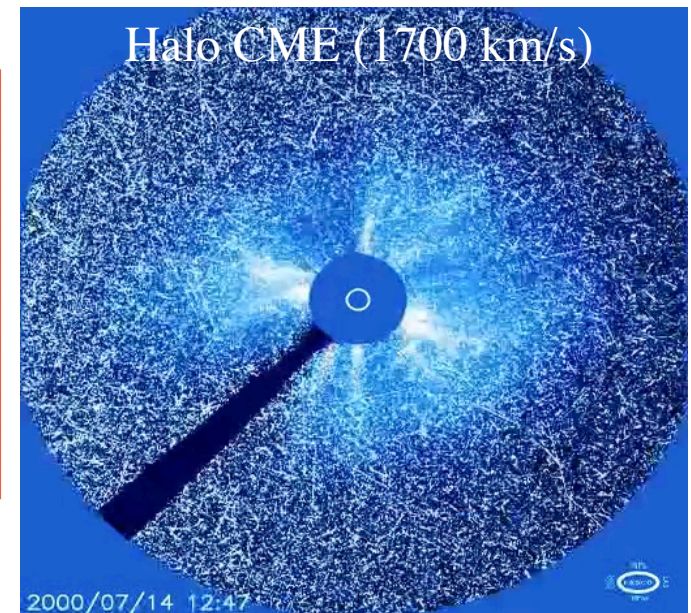
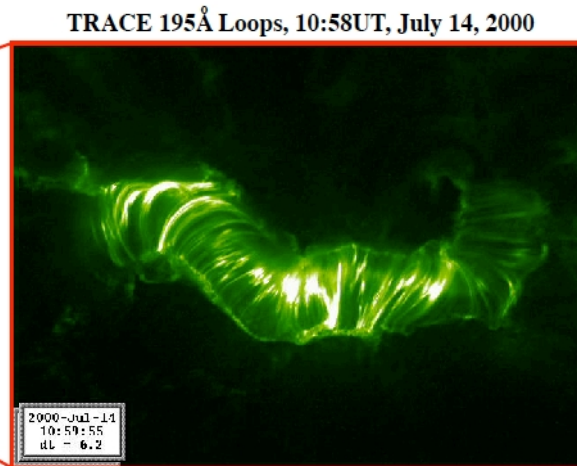
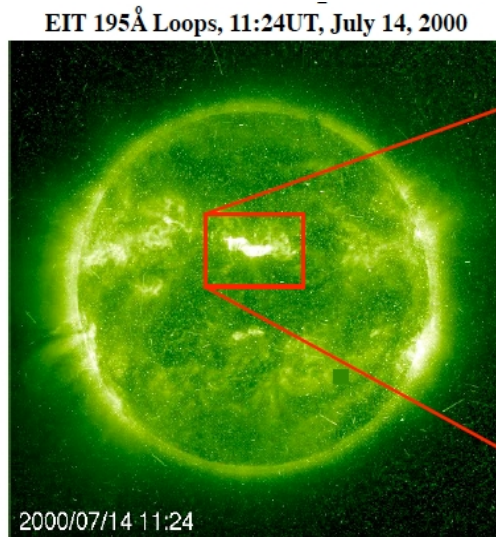
Nathan Schwadron, Matthew Gorby

Introduction

- Solar Particle Events (SPEs) represent a significant hazard to humans and technological infrastructure in space and aviation.
- A physics-based description of solar energetic particles (SEPs) is difficult:
 - Their generation spans very different plasma regimes and large regions of the heliosphere
 - Details of physical mechanisms for both CMEs and SEPs are under debate
- Through NSF and NASA sponsored collaborations, PSI and UNH have developed coupled MHD and focused transport simulations of the acceleration and transport of SEPs
- Through the NASA STTR program, we are developing STAT (SPE Threat Assessment Tool), to deliver runs on demand for simulations of SEP events at the CCMC.
- STAT combines CORHEL (Corona-Heliosphere) and EMMREM (Earth-Moon-Mars Radiation Environment Module)

Introduction (continued)

- The most difficult aspect of the SEP problem are the particles created early in the eruption that can reach Earth in minutes to hours. July 14, 2000 (Bastille Day Event):



- Modeling SEP acceleration low in the corona requires detailed physical models:
 - Thermodynamic MHD simulations of the corona
 - Coronal Mass Ejections (CMEs)
 - Kinetic Acceleration and Transport coupled to MHD

Acronyms

1. BRYTRN: Baryon Transport Module (component of EMMREM)
2. CORHEL: Corona-Heliosphere
3. EMMREM: Earth-Moon-Mars Radiation Environment Module
4. EPREM: Energetic Particle Radiation Environment Module (component of EMMREM)
5. MAS: Magnetohydrodynamic Algorithm outside a Sphere (component of CORHEL)
6. OMGTMA: Oh My God Too Many Acronyms
7. SEP: Solar Energetic Particles
8. SPE: Solar Particle Event
9. TDm: Modified Titov-Demoulin (flux rope model, component of CORHEL)

The Big Picture: STAT

Cooper's Talk

My Talk

CME observations
(or High Threat Active Regions)

Magnetic
Maps

TDM Designer/Explorer

Background Corona/
Heliosphere
(MAS)

EUV, White Light,
Solar Wind

Observational
Validation

CME Simulation
(MAS)

Data Base of CME
Simulations

CORHEL

EPREM Designer - Parameters for
Focused Transport Simulation

SEP Simulation
(EPREM)

SEP Fluxes

BRYNTRN

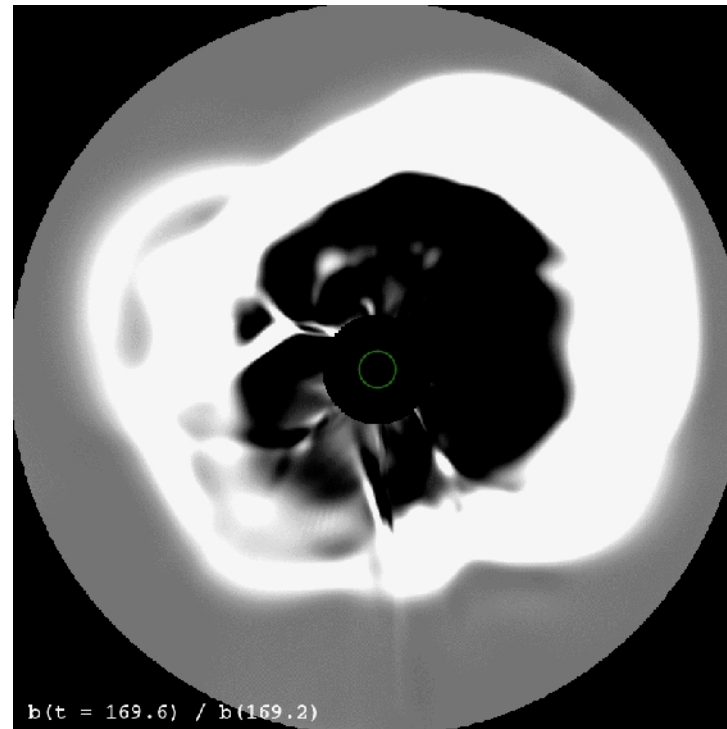
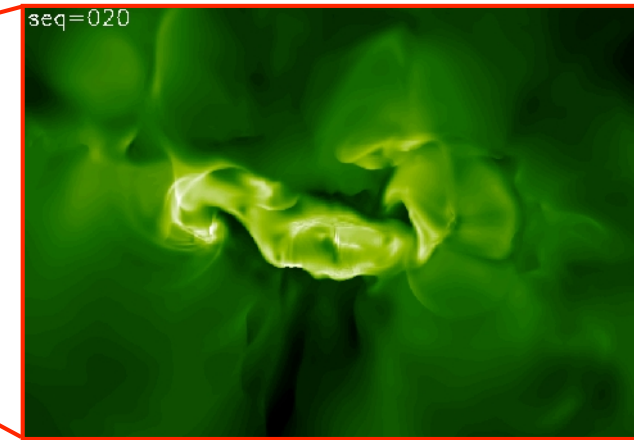
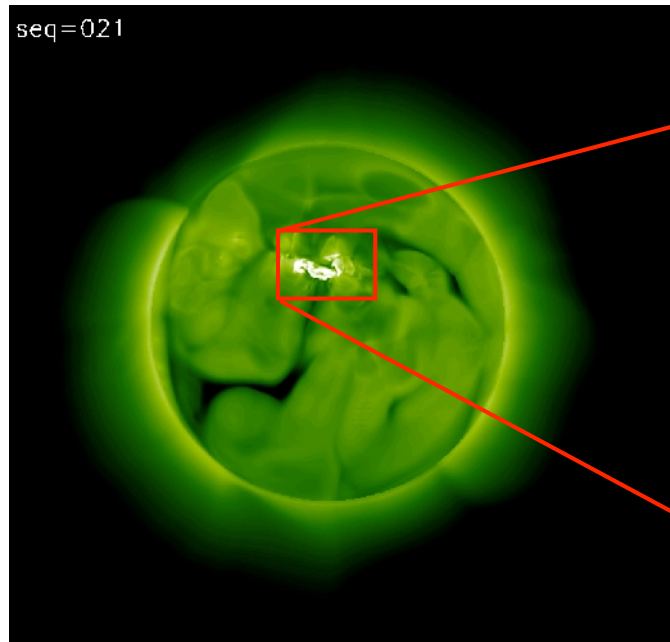
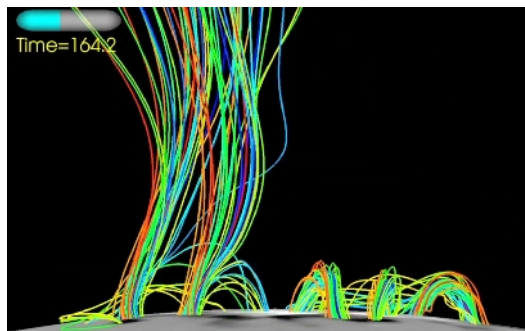
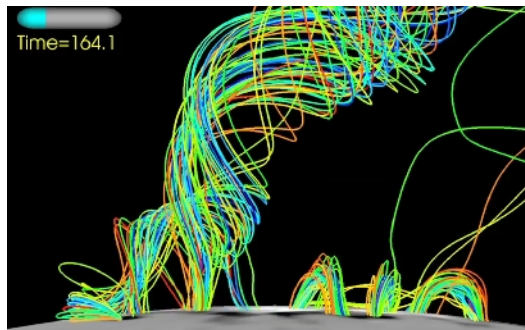
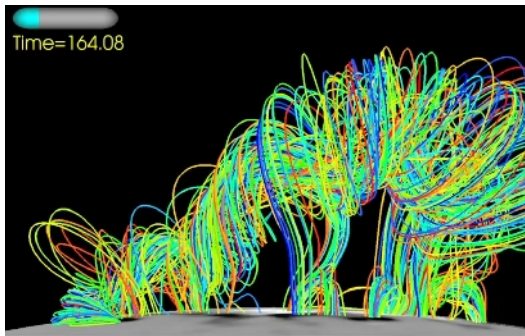
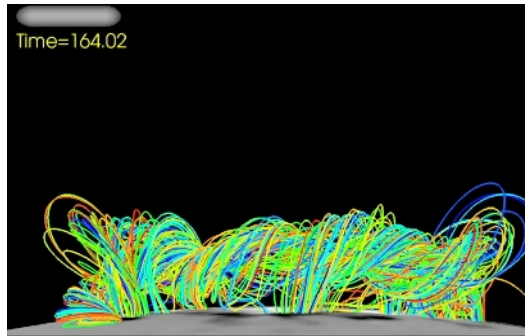
Dose Rates for
Different Shielding

Observational
Validation

EMMREM

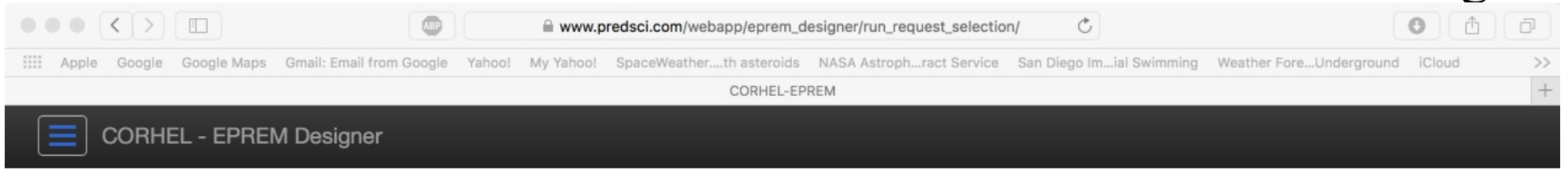


Simulated Bastille Day Eruption



- Flare loops form west to east as was observed
- CME propagation speed ≥ 1500 km/s
- See Linker et al. (2016) and Torok et al. (2018) for details

Interface for CME-SEP Simulations: CORHEL-EPREM Designer



Run Request Selection

First name

Last name

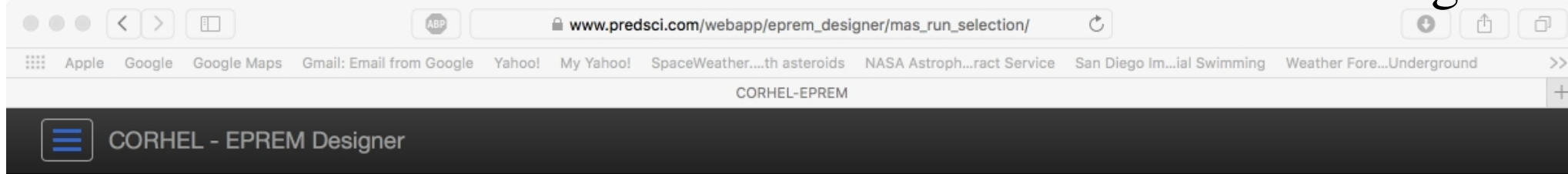
Email

Daily request number 

Next

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Interface for CME-SEP Simulations: CORHEL-EPREM Designer



MAS Run Selection

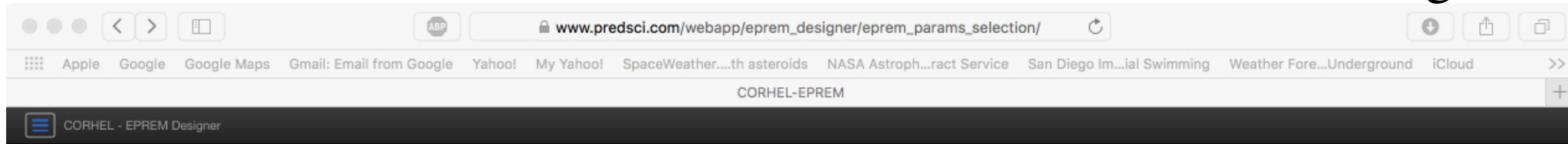
	Date and Time	Resolution	Run Name	Description
<input type="radio"/>	2009-02-14 02:00 UT	custom	2009_02_13	February 13, 2009 Event
<input type="radio"/>	2005-05-13 19:00 UT	custom	idealized_extreme	Idealized Extreme Event
<input checked="" type="radio"/>	2000-07-14 07:00 UT	custom	bastille_day	Bastille Day

Previous

Next

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Interface for CME-SEP Simulations: CORHEL-EPREM Designer



EPREM Parameters Selection

Pre-eruption time [?](#)

0.066941 days

Resolution [?](#)

- Low [?](#)
- Medium [?](#)
- Custom [?](#)

Outer radial boundary [?](#)

- Approximately 20Rs [?](#)
- Approximately 1AU [?](#)
- Custom [?](#)

Species [?](#)

1

List of masses [?](#)

1.0

List of charges [?](#)

1.0

Energy levels [?](#)

20

Minimum energy [?](#)

1.000 MeV/nucleon

Maximum energy [?](#)

500.000 MeV/nucleon

Pitch angle steps [?](#)

8

Substeps for EP computation [?](#)

20

Mean-free-path [?](#)

1.000 AU

Use shock solver [?](#)

Use particle drift [?](#)

Use perpendicular diffusion [?](#)

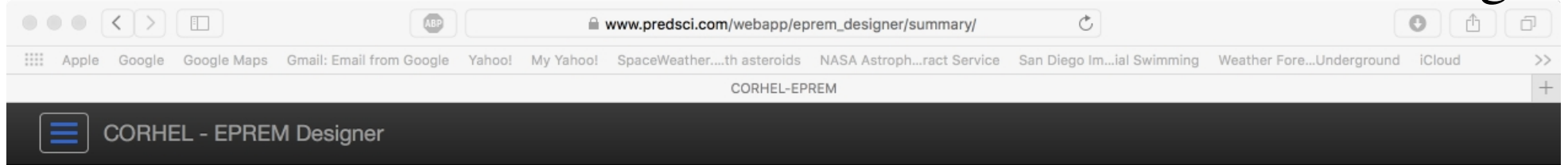
Efficiency of perpendicular diffusion [?](#)

0.010

Previous

Next

Interface for CME-SEP Simulations: CORHEL-EPREM Designer



Summary

Thank you for using **CORHEL - EPREM Designer**.

An output archive file containing a set of files for running EPREM simulation model using [CORHEL](#) is available below.

[Download](#)

An archive file containing a set of files for restoring these same input parameters into a new session in the future is also available for download below.

⚙️ Creating CORHEL - EPREM Designer input archive ...

[Previous](#)

[Done](#)

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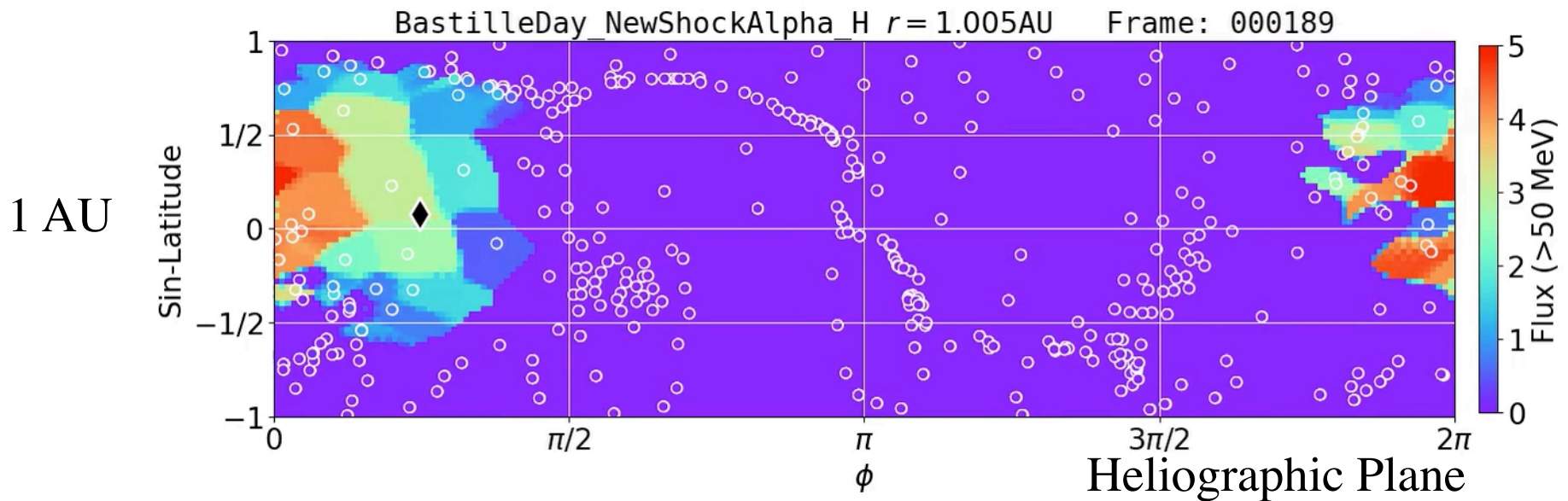
Optimization of EPREM

- Status prior to STAT:
 - EPREM (Lagrangian grid) allocates streams.
 - Streams/number of cores tied together - must be specified at compile time
 - EPREM simulations at modest resolution required days on 100s of cores
- STAT optimization:
 - More efficient initialization
 - Re-organize memory, dynamic allocation
 - Specifications occur at run time
 - Eliminate calculations where nodes “bunch up”
 - Code ~50 times faster
 - Faster code/better initialization: Earlier runs can now be performed in ~1 hour on 24 cores

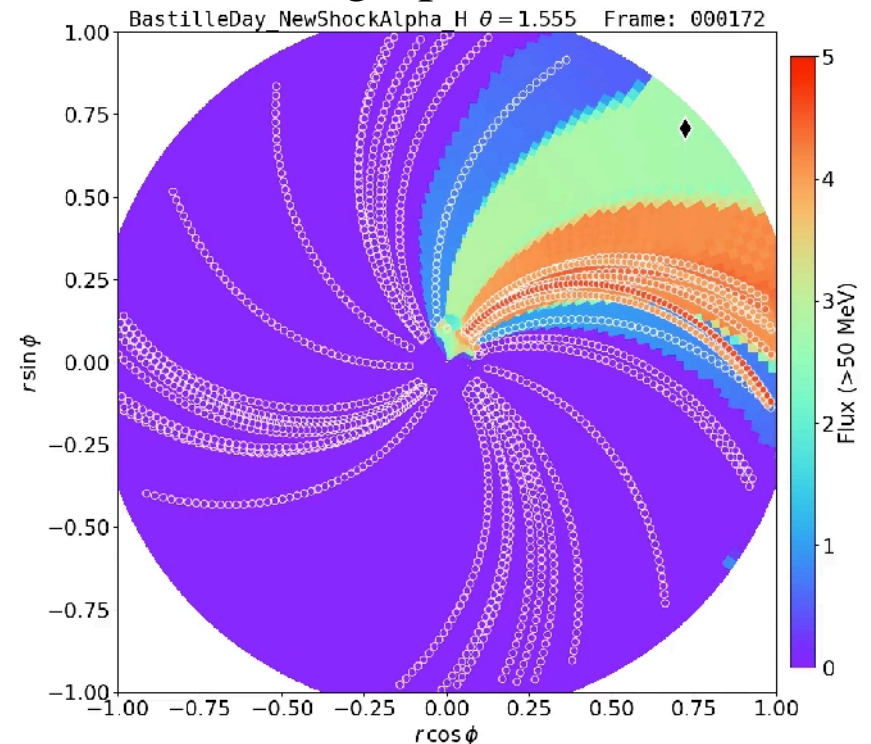
Diagnostics and Visualization

- EPREM uses a Lagrangian method that follows the solar wind flow - grid populates the heliosphere sparsely
- Typical visualizations are of particles fluxes at a single point – making it difficult to understand context
- Using interpolation, we develop particle fluxes as a 3D quantity
 - Nontrivial!
- This allows rapid assessment of simulated event
- Can visualize fluxes with MHD variables to reveal sources of acceleration
- We use tracer particles in the MHD calculation to automatically visualize the erupting flux rope

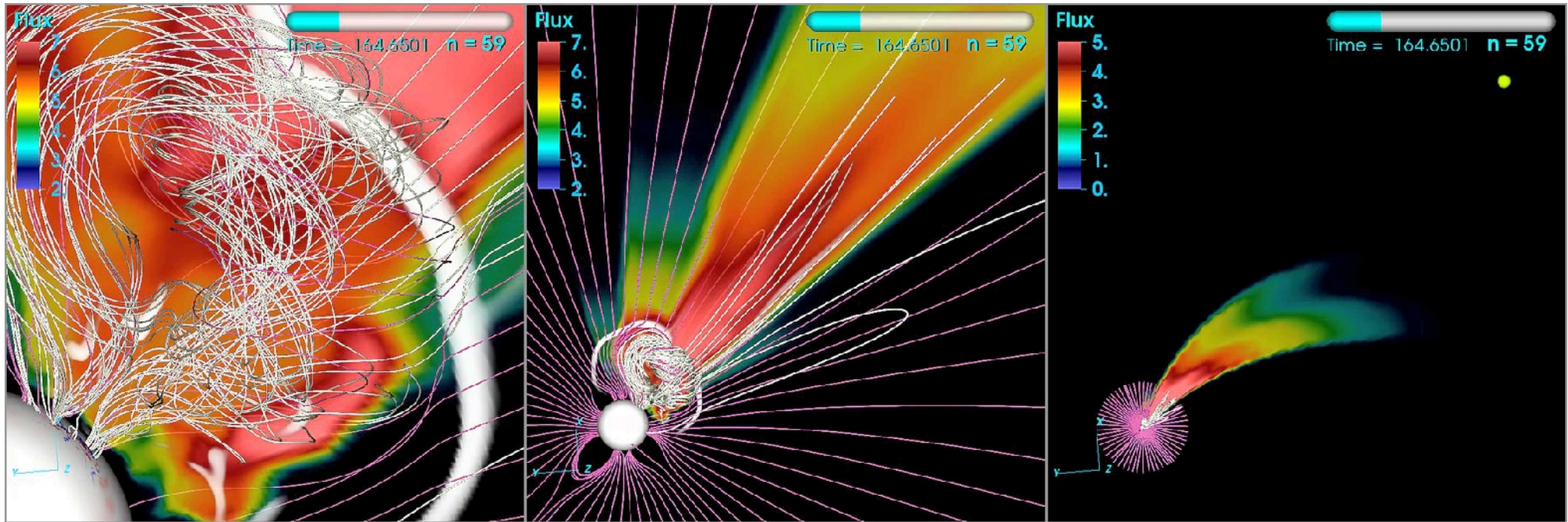
2D Visualization of Fluxes: Bastille Day Simulation > 50 MeV GOES Energy Channel



- Visualizations reveal extent of SPE
- Location of EPREM nodes: ○
- Allows assessment of sampling

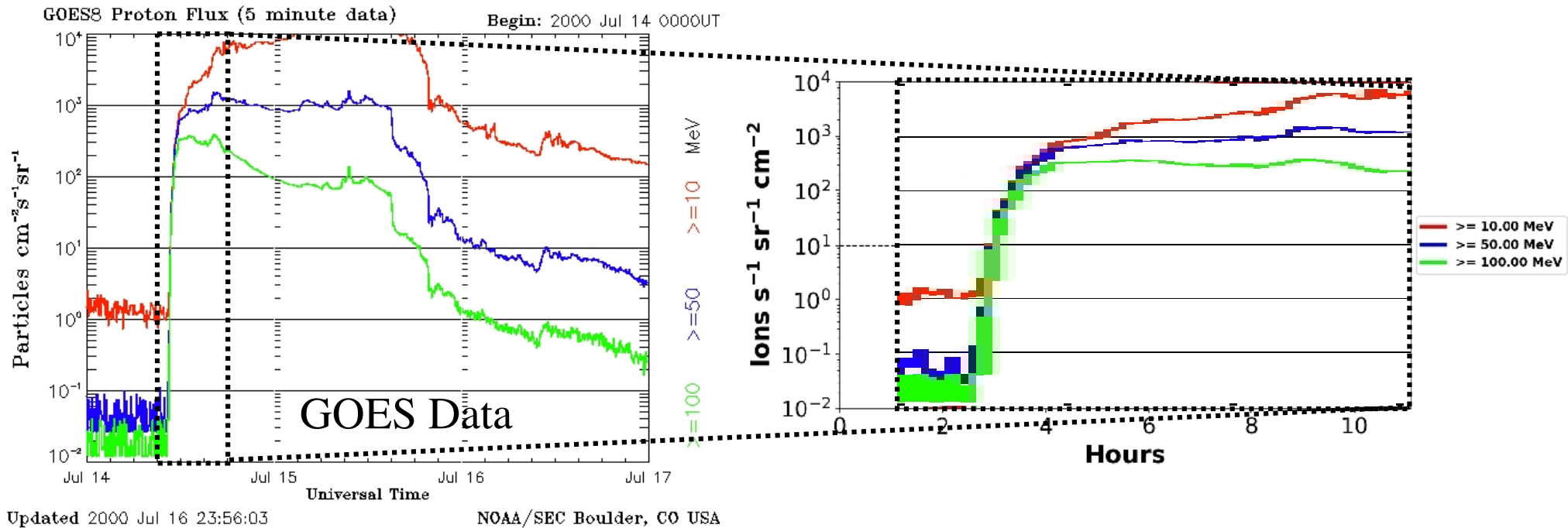


3D Visualization of Fluxes and MHD Quantities

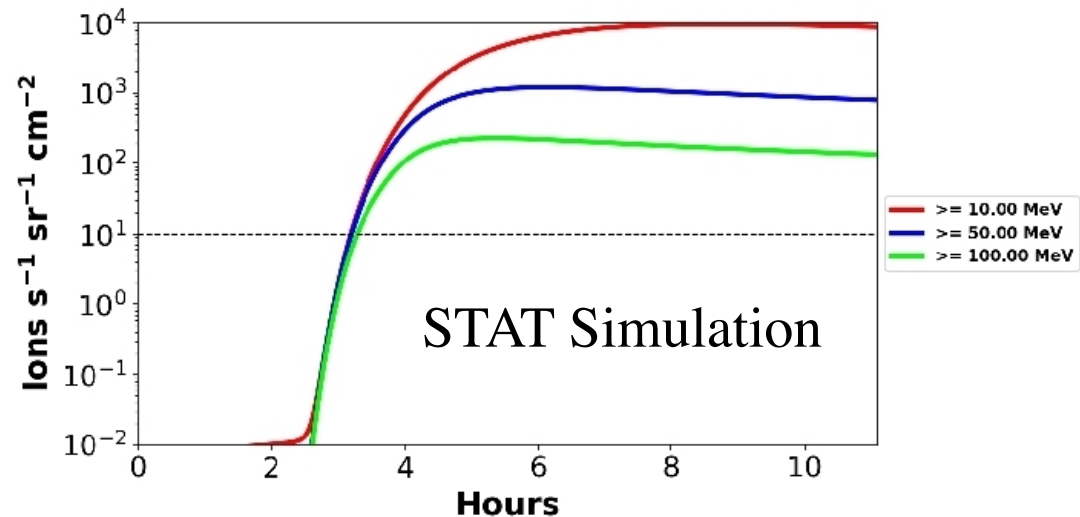


- Magnetic field lines: magenta - background, white - flux rope)
- $-\text{div}(\mathbf{v})$ (compression): white contour
- > 50 MeV flux (GOES channel 2) contoured in color

Very Preliminary Comparison with GOES



- Simulation of ~ 9 hours of event: ends when CME propagates out of coronal domain
- Longer simulation requires using our model of the CME propagation in the heliosphere



Summary

- Today I've described STAT (SPE Threat Assessment Tool), which is being developed by PSI and UNH.
- STAT provides 3D focused transport simulations of SEPs for CME event simulations.
- We have developed diagnostic techniques to allow exploration of the physical causes of acceleration/transport by melding of MHD and particle data.
- We have “trained” on the July 14, 2000 Bastille Day simulation and will be adding other events soon
- Delivery is expect in Fall 2018