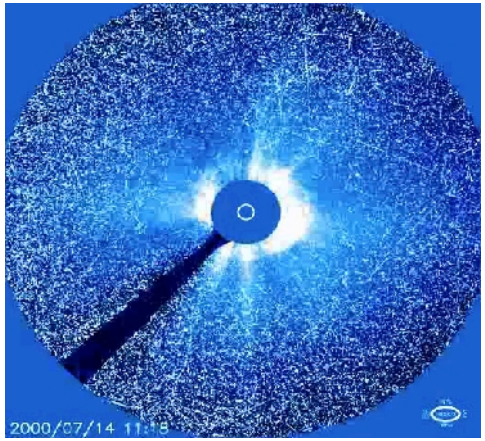
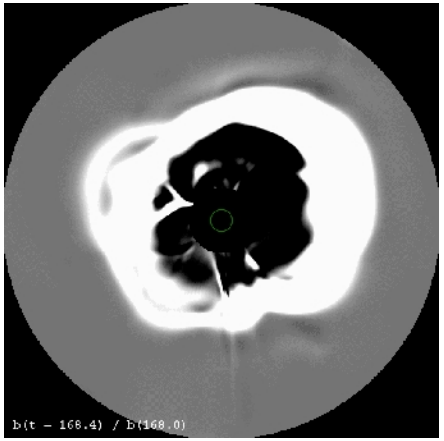
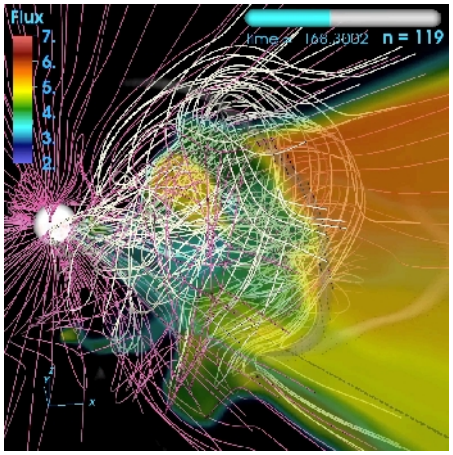
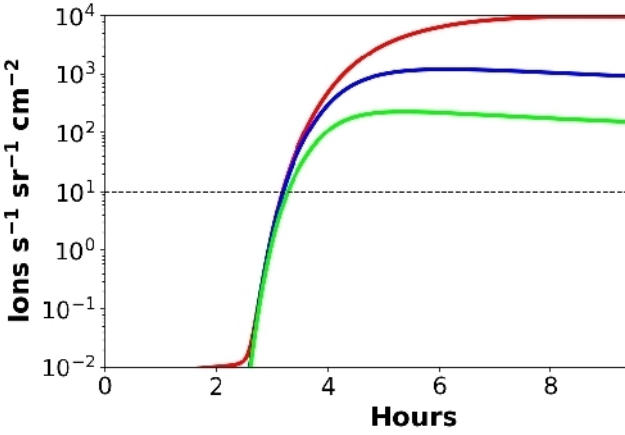
SPE Threat Assessment Tool (STAT): Coupled Coronal Mass Ejection - Solar Particle Event Simulations









A NASA STTR Project

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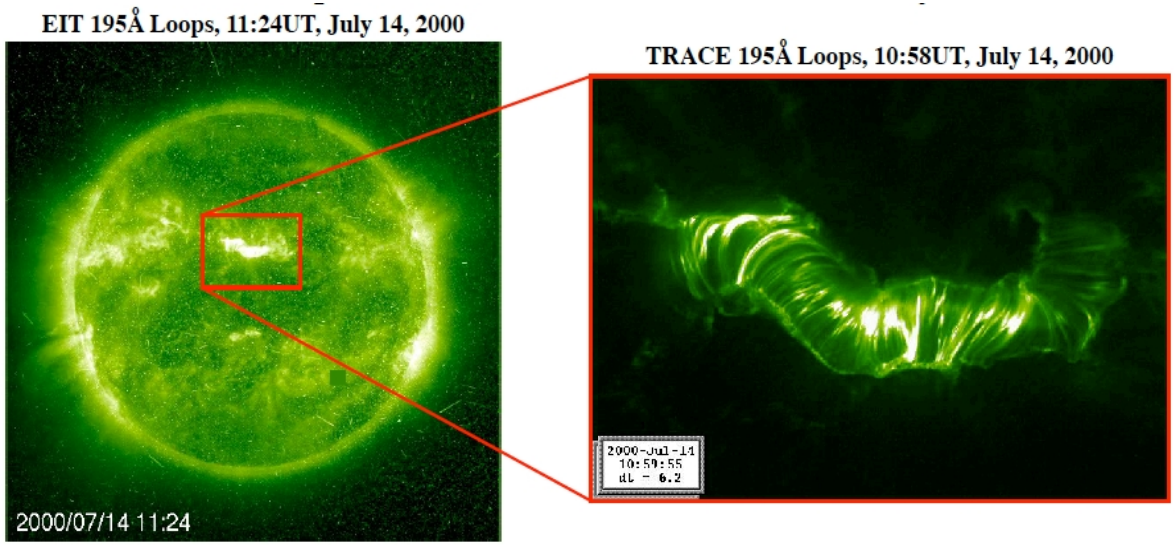
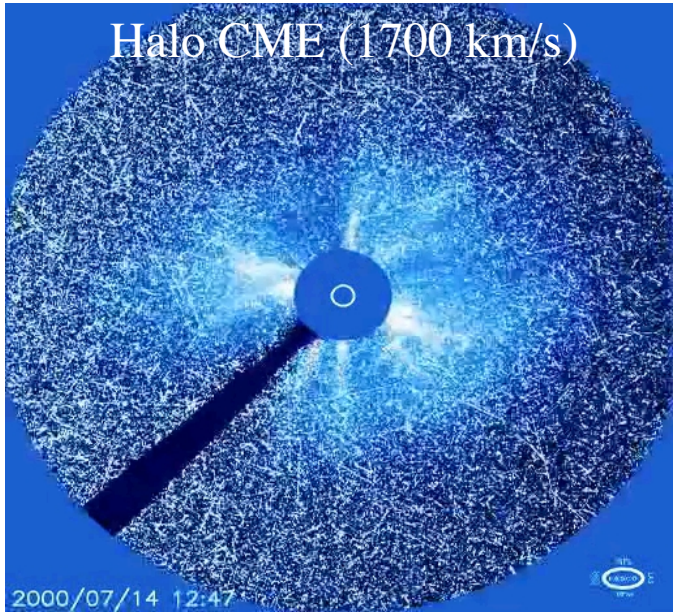
Introduction

- 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):



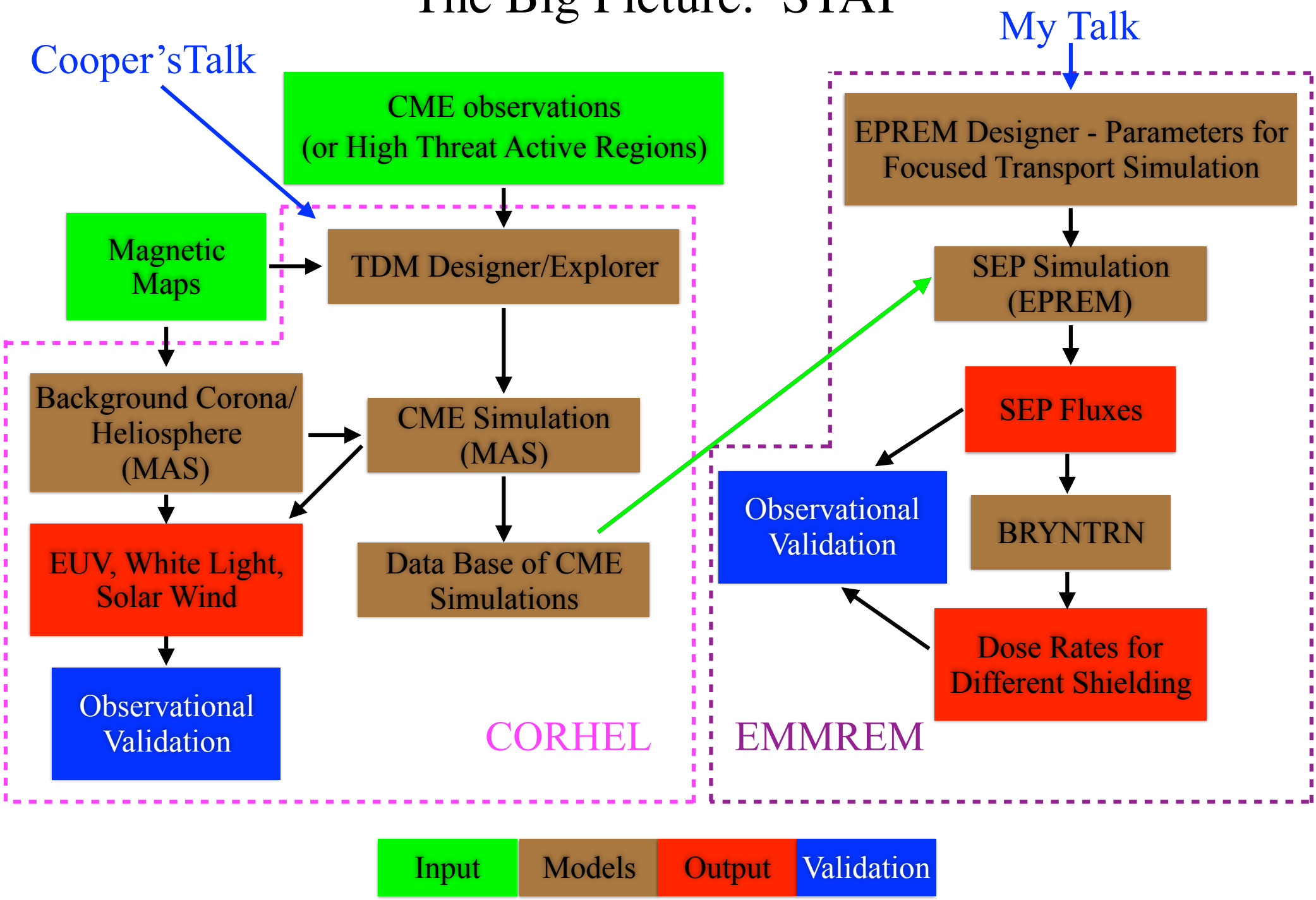


- Modeling SEP acceleration low in the corona requires detailed physical models:
  - Thermodynamic MHD simulations of the corona
  - Coronal Mass Ejections (CMEs)
  - Kinetic Acceleration and Transport coupled to MHD

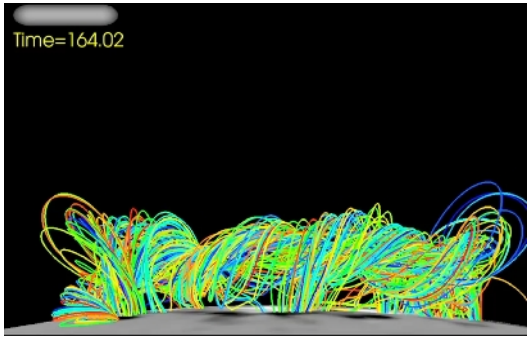
Acronyms

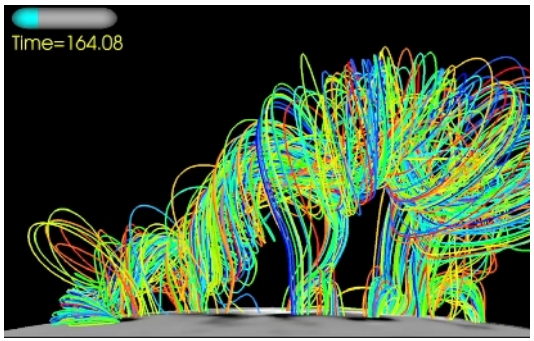
1. BRYTRN: Baryon Transport Module (component of EMMREM)
2. CORHEL: Corona-Heliosphere
3. EMMREM: Earth-Moon-Mars Radiation Environment Module
4. EPREM: Energetic Particle Radiation Environment Module (component of EMMREM)
5. MAS: Magnetohydrodynamic Algorithm outside a Sphere (component of CORHEL)
6. 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)

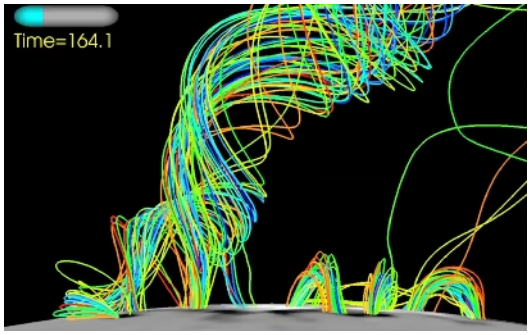
The Big Picture: STAT

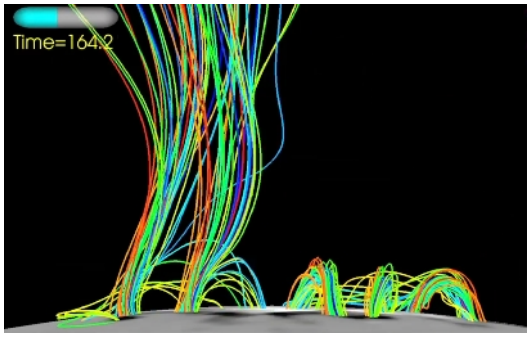


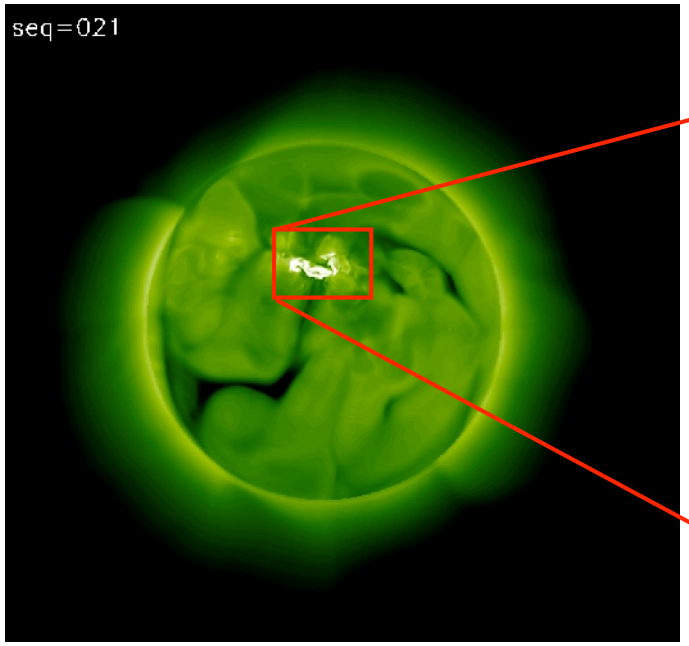
Simulated Bastille Day Eruption

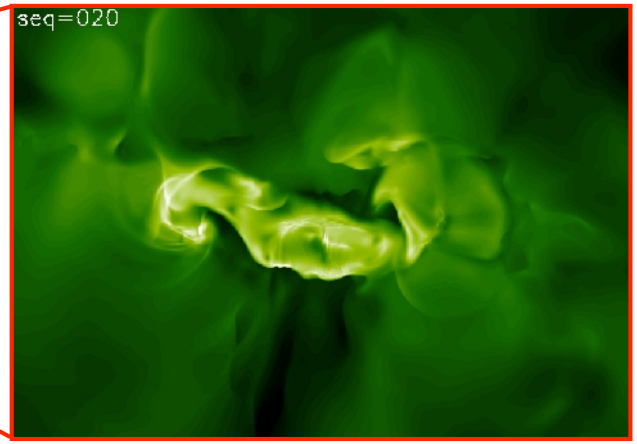


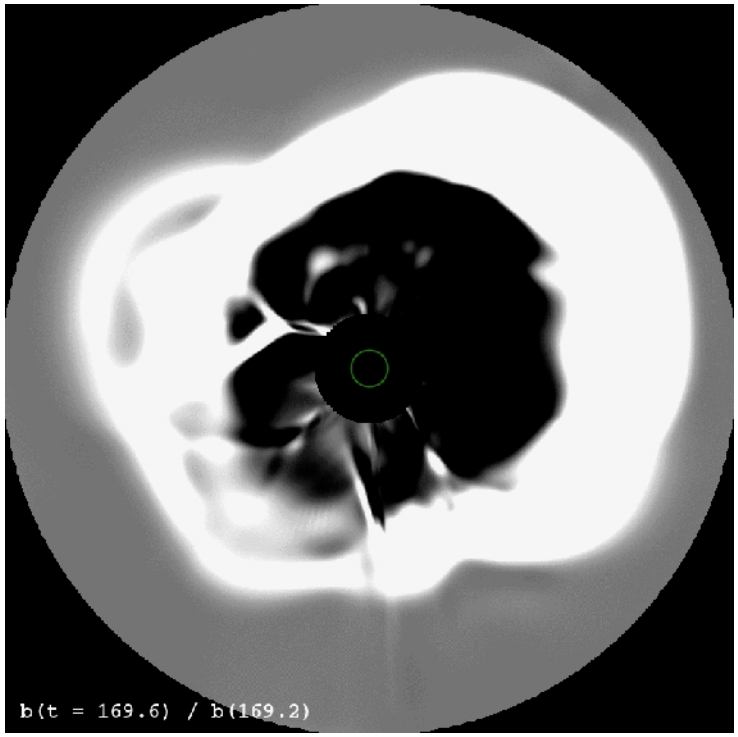






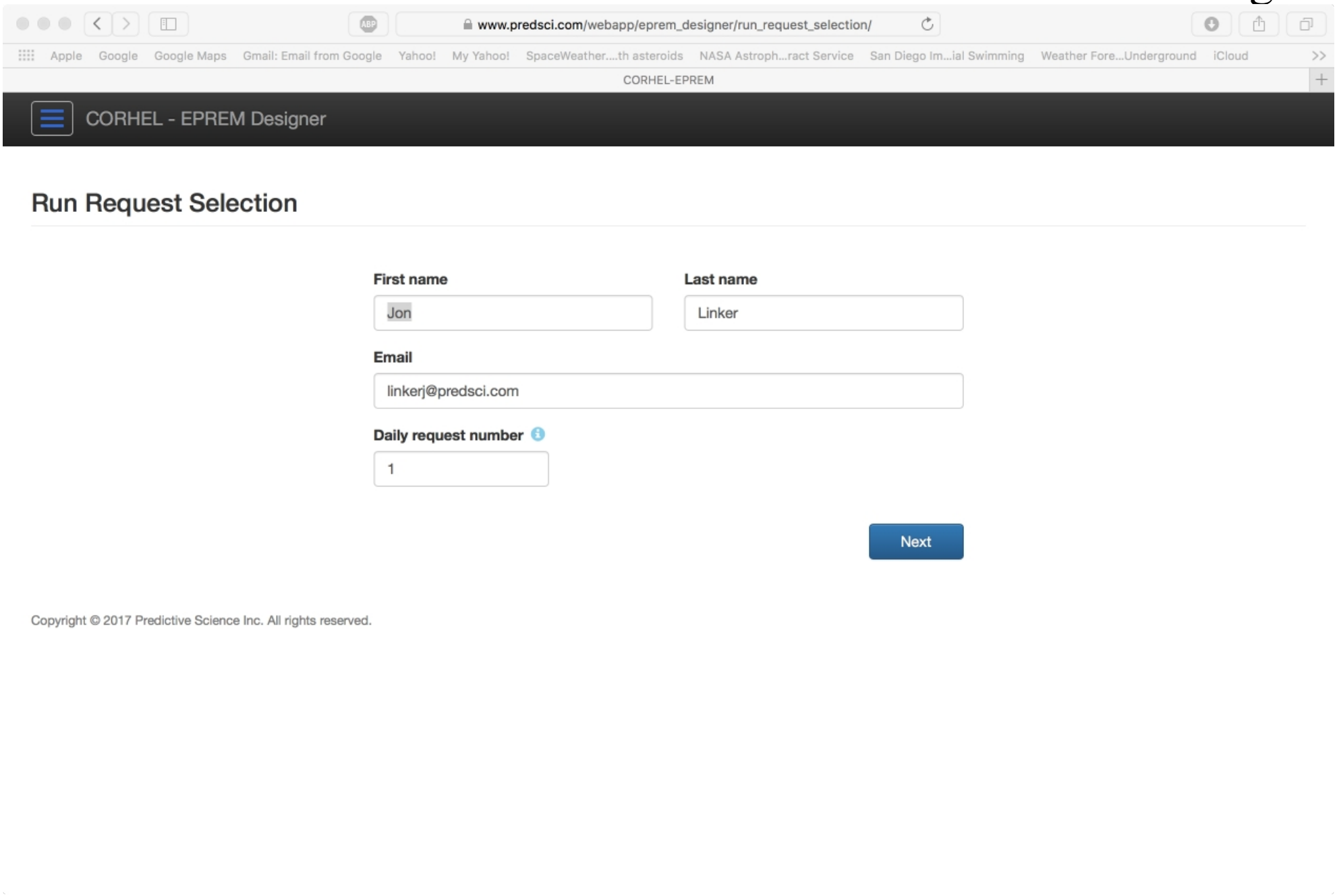






- Flare loops form west to east as was observed
- CME propagation speed ≳ 1500 km/s
- See Linker et al. (2016) and Torok et al. (2018) for details

Interface for CME-SEP Simulations: CORHEL-EPREM Designer



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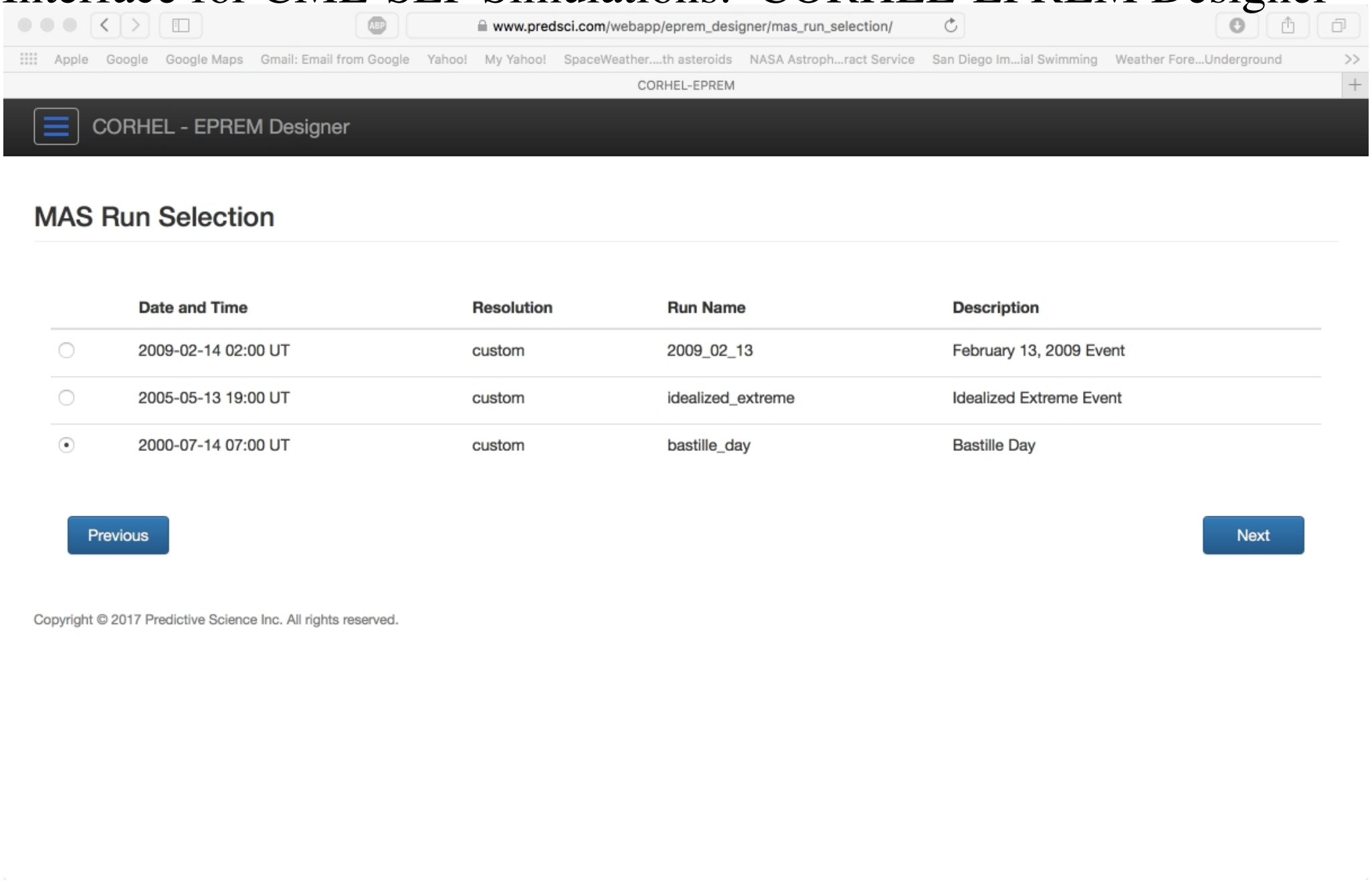

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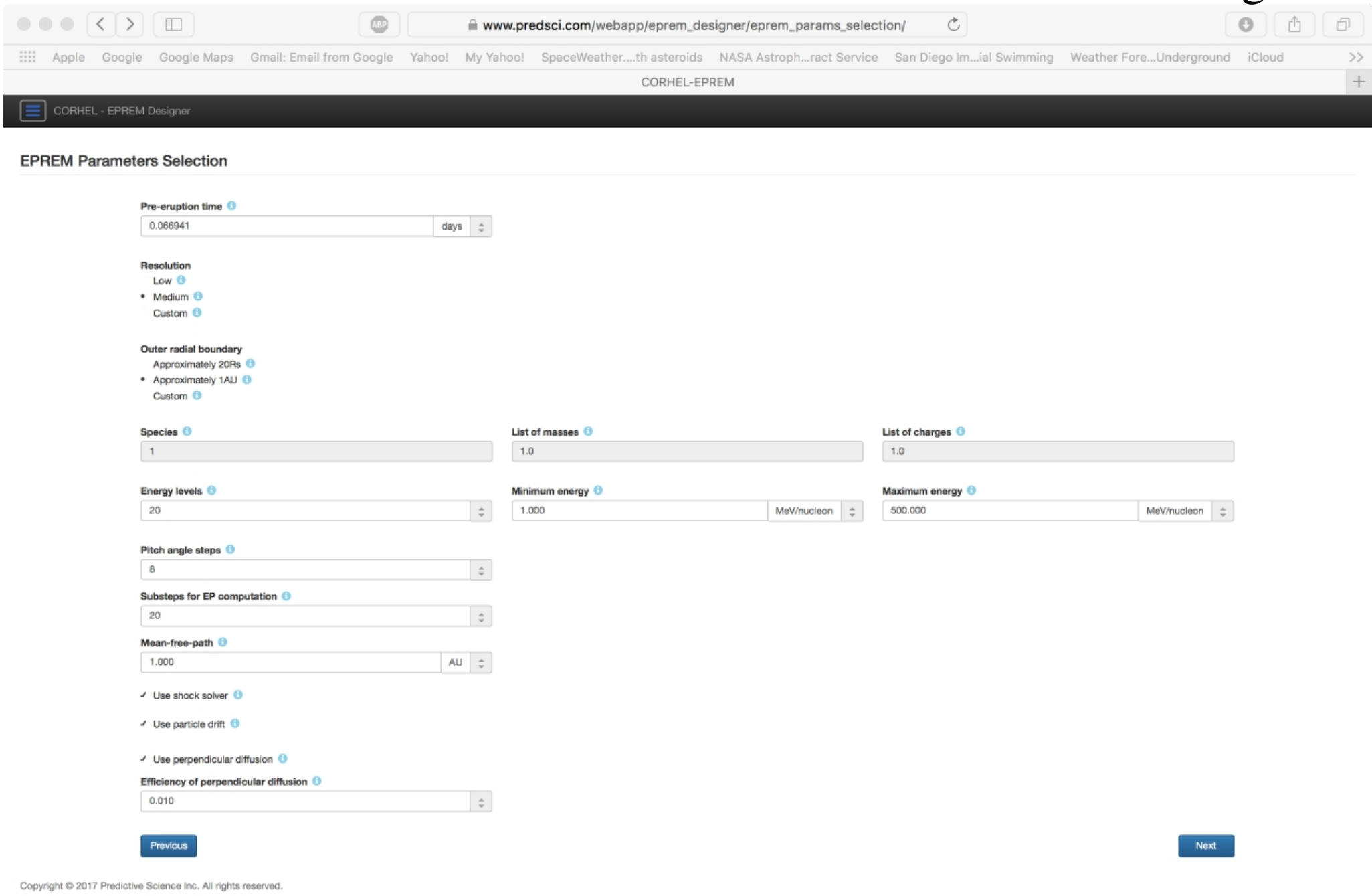

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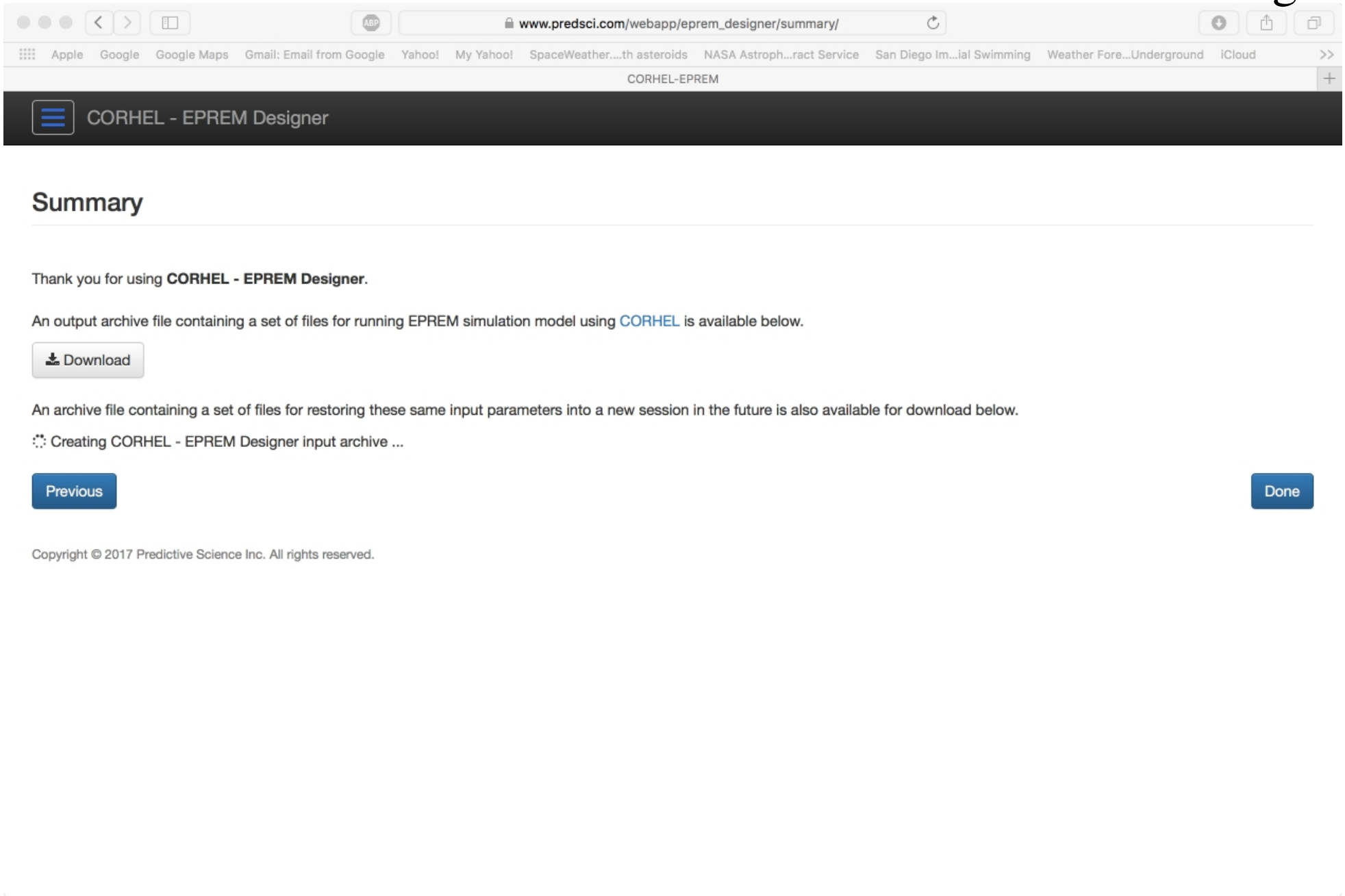


Optimization of EPREM

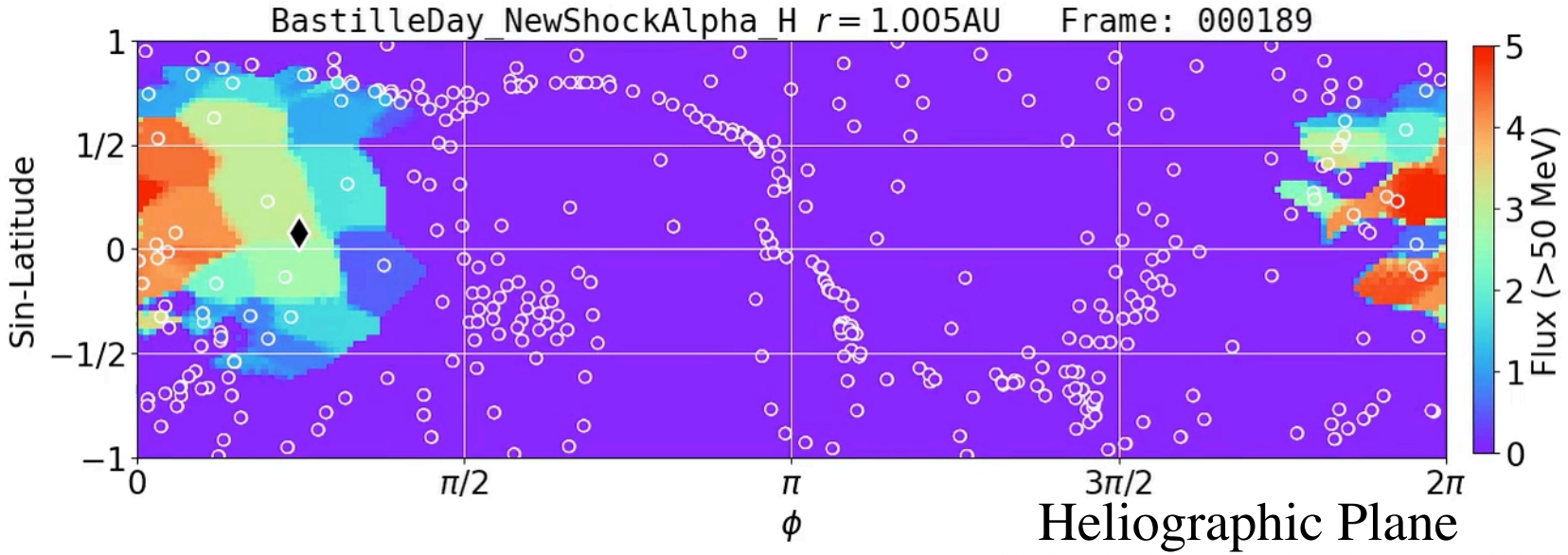
- Status prior to STAT:
  - EPREM (Lagrangian grid) allocates streams.
  - Streams/number of cores tied together - must be specified at compile time
  - EPREM simulations at modest resolution required days on 100s of cores
- STAT optimization:
  - More efficient initialization
  - Re-organize memory, 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

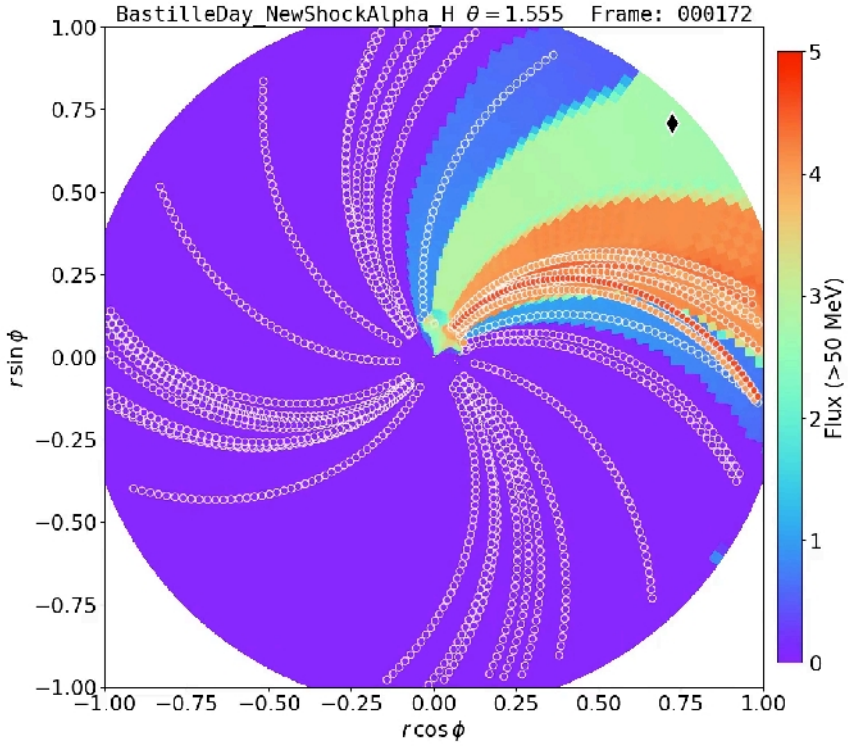
- EPREM uses a Lagrangian method that follows the solar wind flow - grid populates the heliosphere sparsely
- Typical visualizations are of particles fluxes at a single point – making it difficult to understand context
- Using interpolation, we develop particle fluxes as a 3D quantity
  - Nontrivial!
- 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

1 AU

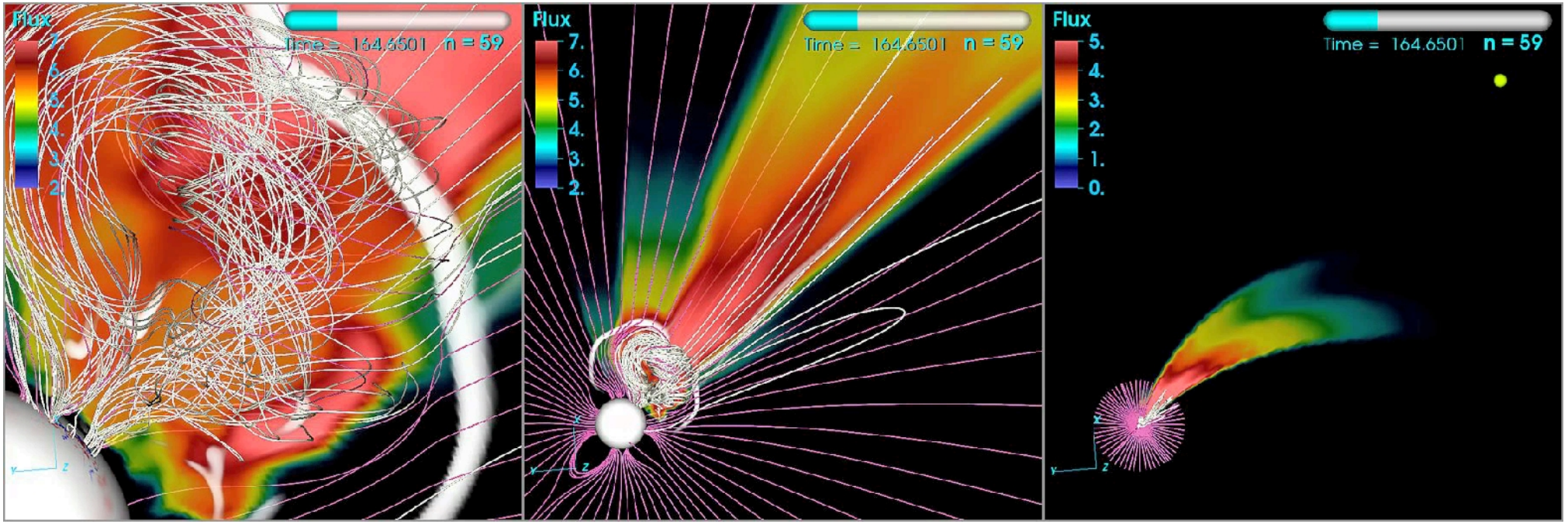


Heliographic Plane



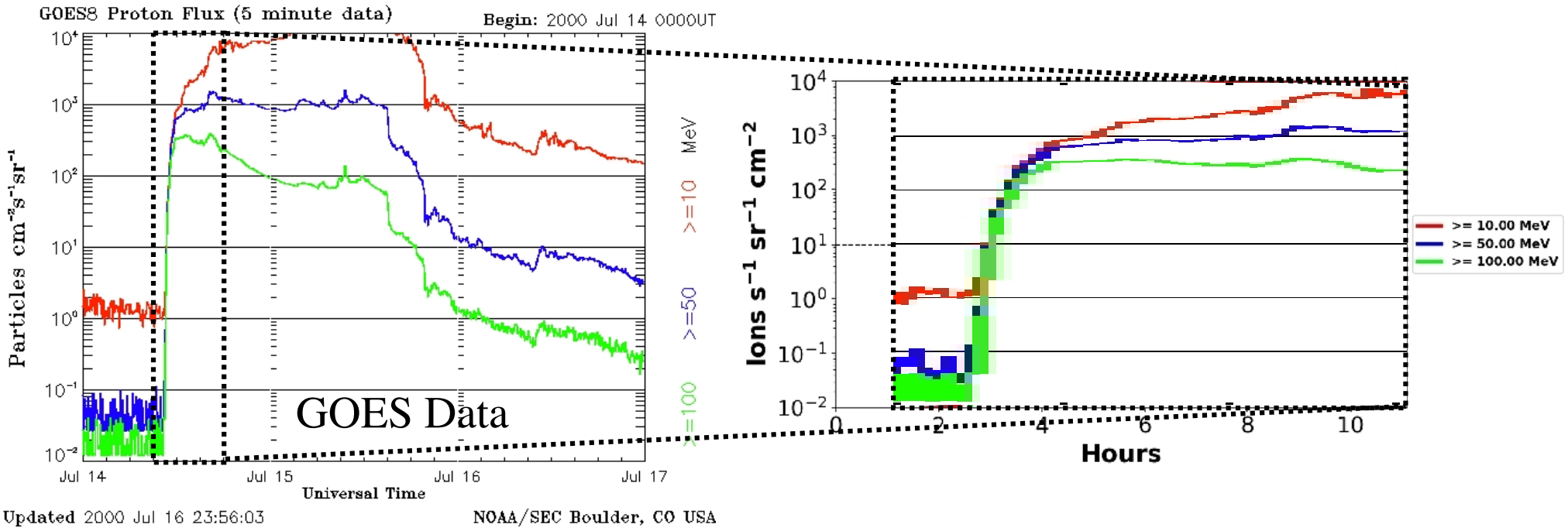
- Visualizations reveal extent of SPE
- Location of EPREM nodes: ○
- Allows assessment of sampling

3D Visualization of Fluxes and MHD Quantities

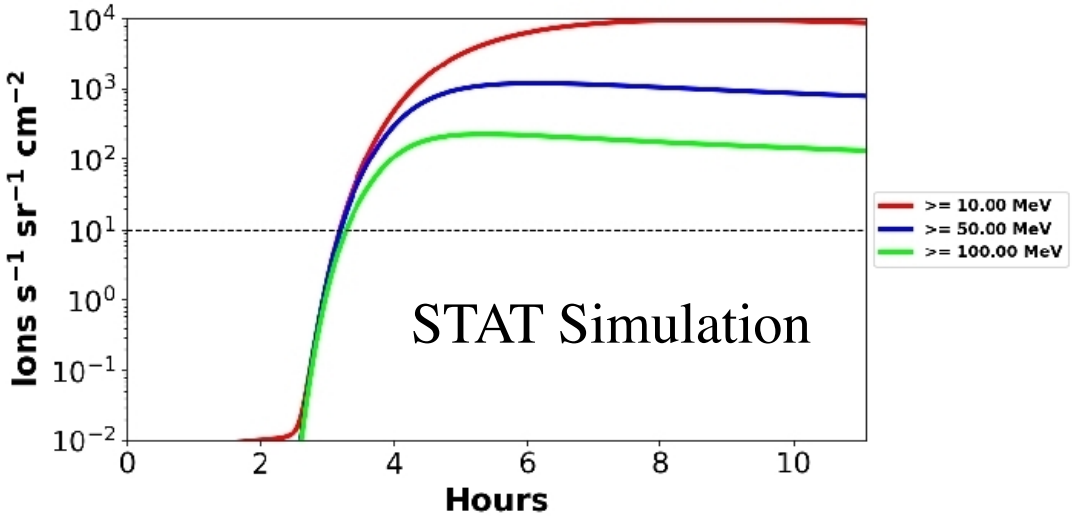


- Magnetic field lines: magenta - background, white - flux rope)
- -div(v) (compression): white contour
- > 50 MeV flux (GOES channel 2) contoured in color

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