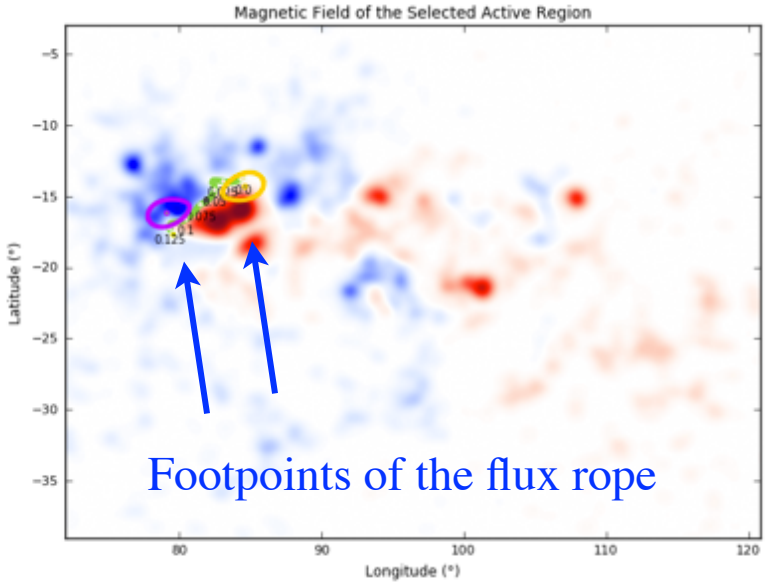
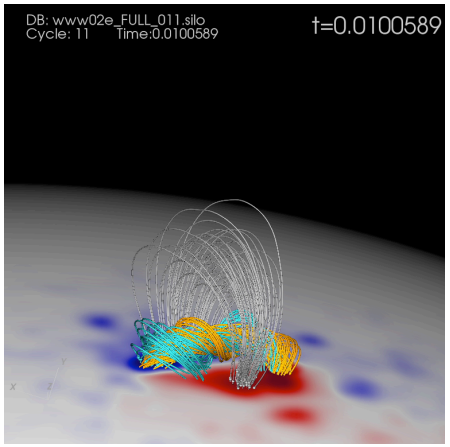
CORHEL at the CCMC

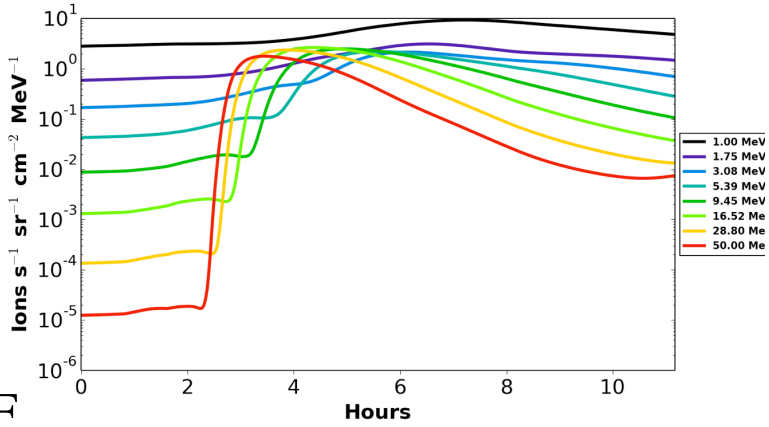


Jon Linker, Cooper Downs, Tibor Torok, Viacheslav Titov, Zoran Mikic, Pete Riley, Roberto Lionello, Ron Caplan, & Janvier Wijaya

Predictive Science, Inc. (PSI), San Diego, CA, USA



http://www.predsci.com



Supported by AFOSR, NASA, &NSF

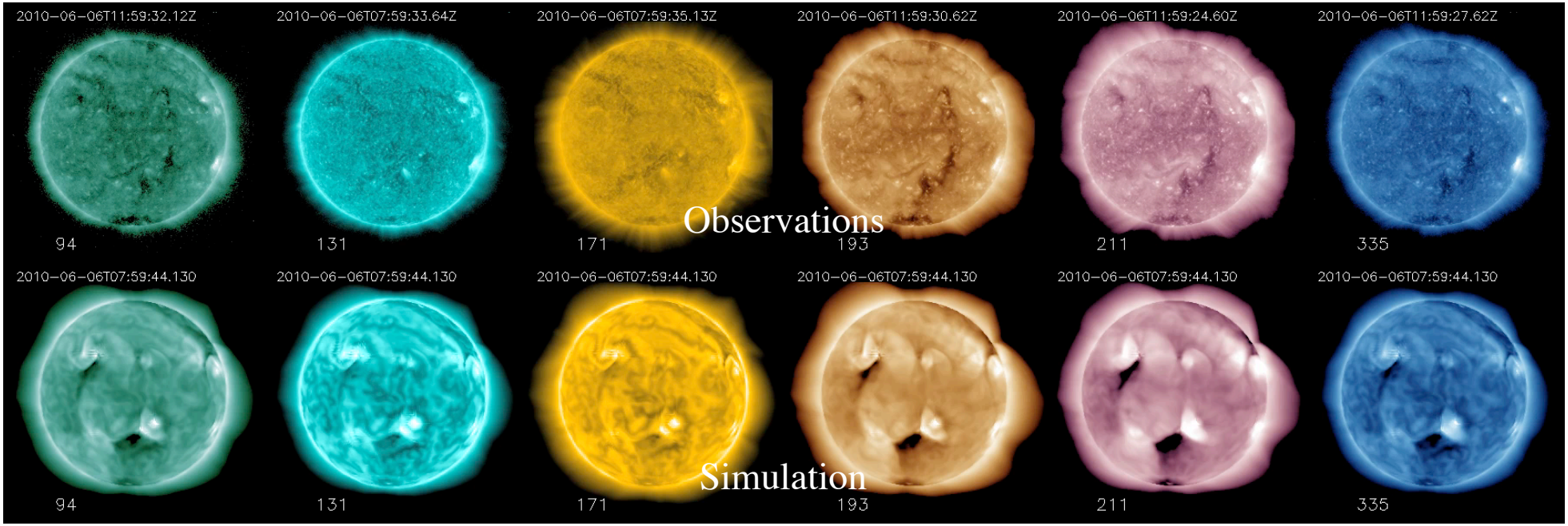
Predictive Science, Inc.

What is CORHEL?

- CORHEL - “Corona-Heliosphere”
- A coupled set of models and tools for quantitatively modeling the ambient solar corona and solar wind
- The principal observational input to CORHEL are maps of the radial magnetic field at the photosphere, derived from solar magnetograms
- CORHEL provides coronal solutions using 3 approximations:
  - WSA model (numerical potential solver)
  - Polytropic MHD (MAS Code)
  - Thermodynamic MHD (MAS code)
- CORHEL provides two different heliospheric codes: Enlil & MAS
- CORHEL outputs plasma and magnetic field quantities in 3D space
- It also outputs observable quantities for validation
- CORHEL has been delivered to AFRL, CCMC, and CISM

Thermodynamic MHD Models

June 6 - July 3, 2010: Simulated and Observed Emission Lines



94Å 131Å 171Å 193Å 211Å 335Å

- To accurately simulate plasma density, a more sophisticated energy treatment is required (coronal heating, radiative cooling, thermal conduction)

What's Next for CORHEL?

- CORHEL presently provides time-integrated solutions that describe the quasi-steady solar corona and inner heliosphere.
- We are engaged in two projects that will provide community models that describe Coronal Mass Ejections (CMEs) and Solar Energetic Particles (SEPs)
- CORHEL-CG (CORHEL with CME Generation)
  - Primarily supported by AFOSR BRI on CMEs
- STAT - Solar particle event (SPE) Threat Assessment Tool
  - NASA STTR program
  - Joint effort between Predictive Science Inc (PSI) and University of New Hampshire (UNH)
  - Couples PSI CME simulations (MAS/CORHEL) with UNH simulations of SEP acceleration and transport (EMMREM)
- I will briefly describe these today

CORHEL-CG

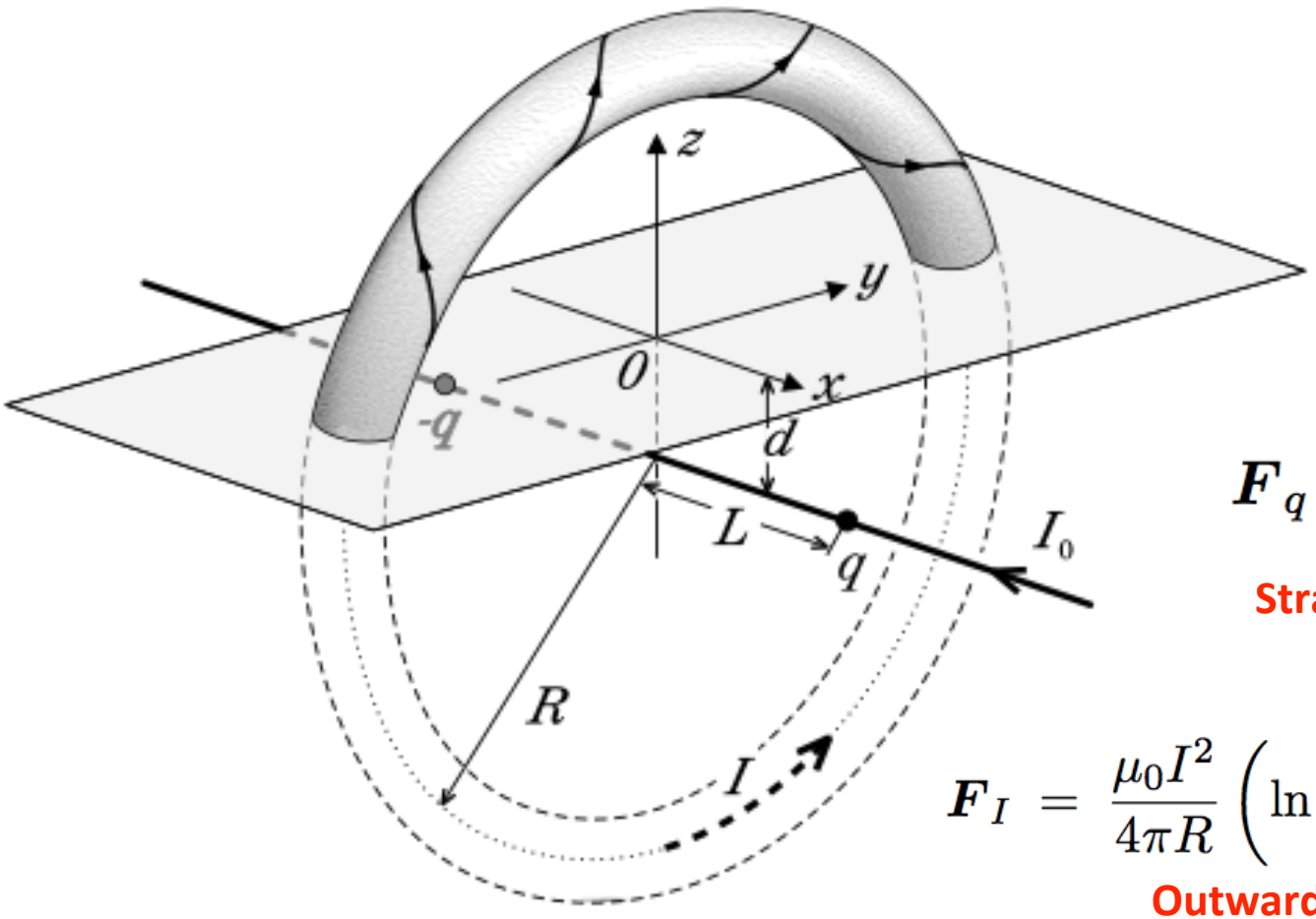
- Our goal is to develop a community tool for simulating CMEs in realistic coronal/solar wind solutions
- At the present time, coronal CME simulations are primarily performed by experts and are typically very manpower intensive
- CORHEL-CG utilizes modified Titov-Demoulin (TDm) flux ropes - Titov et al. 2014
  - Allows user to develop stable equilibrium with embedded flux rope(s)
  - Destabilize configuration to initiate CME
- PSI is developing the interface
  - An intuitive interface requires deep knowledge of the model
  - We developed the CORHEL interface presently implemented at the CCMC
- We used this approach to model the Bastille Day (7/14/2000) flare/ CME

Why is Starting from Equilibrium Important?

- Non-equilibrium solutions can have any energy and expand at any speed.
- Solar active regions can store only a finite amount of energy - this bounds the size of the eruption.
  - Bounds on energy storage are well described by Aly-Sturrock theorem
- Solar eruptions often show rotation of the erupting flux rope:
  - Strongly out-of-equilibrium flux ropes don't display this property
  - This has can have important consequence for geo-effectiveness
- We want the equilibrium flux rope(s) to disturb the background as little as possible:
  - CME at 1 AU is a combination of initial eruption and overlying fields
- We first study in zero-beta, prior to inserting in full thermodynamic MHD

TD Flux Rope

Titov & Démoulin 1999



$$\boldsymbol{F}_q = -\frac{2qLI\boldsymbol{n}}{(R^2+L^2)^{3/2}},$$

Strapping force from charges

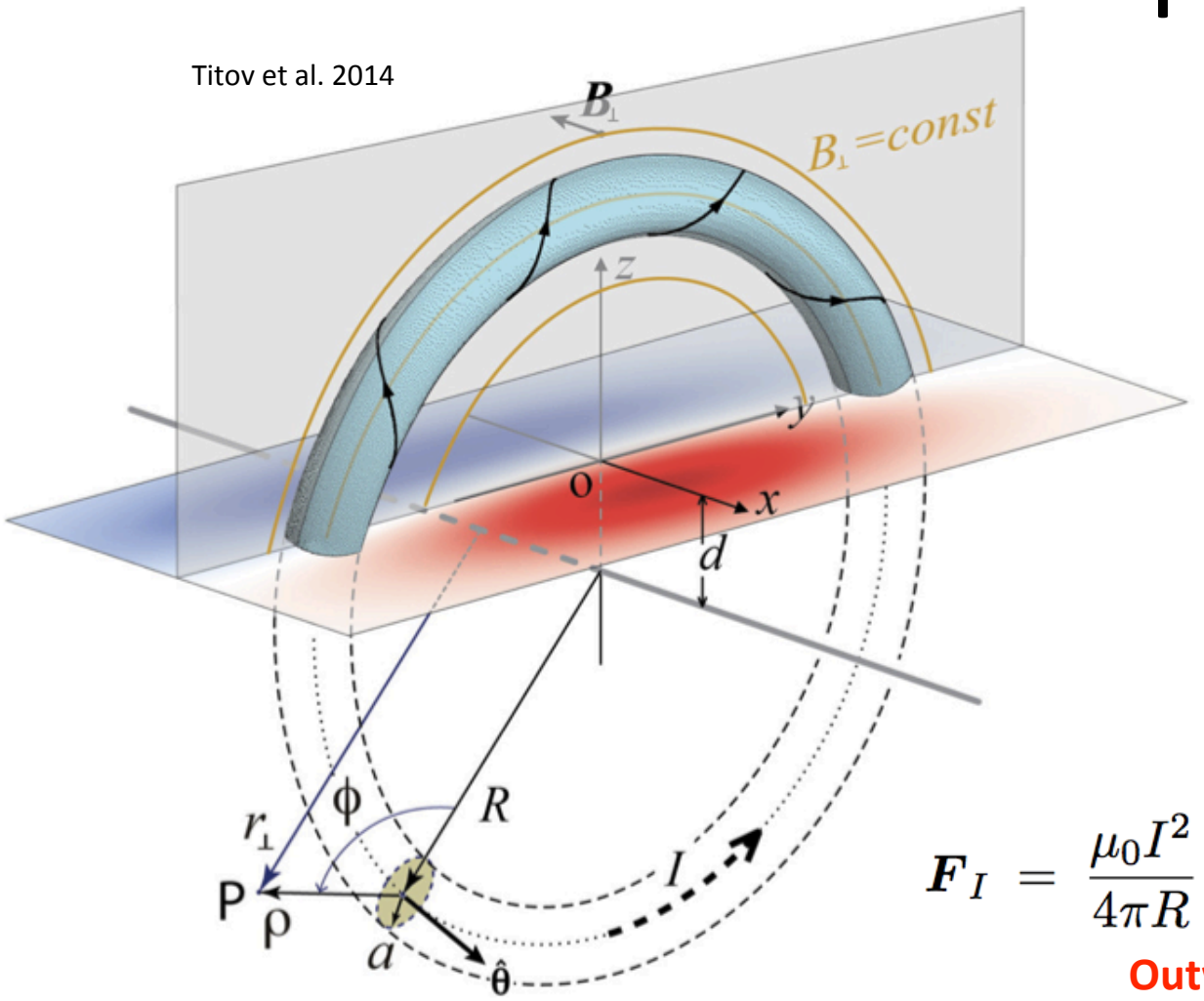
$$\boldsymbol{F}_I = \frac{\mu_0 I^2}{4\pi R}\left(\ln\frac{R}{a} + \ln 8 - 3/2 + l_i/2\right)\boldsymbol{n}$$

Outward force of the Rope

- Analytic model of circular flux rope as current carrying ring + axial field
- Hoop force of the flux rope is known
- This force is balanced by a strapping field

TDm Flux Rope

Titov et al. 2014



Instead you can use the arcade of the AR you want to study

$$\boldsymbol{F}_q = -\frac{2qLI\boldsymbol{n}}{(R^2+L^2)^{3/2}},$$

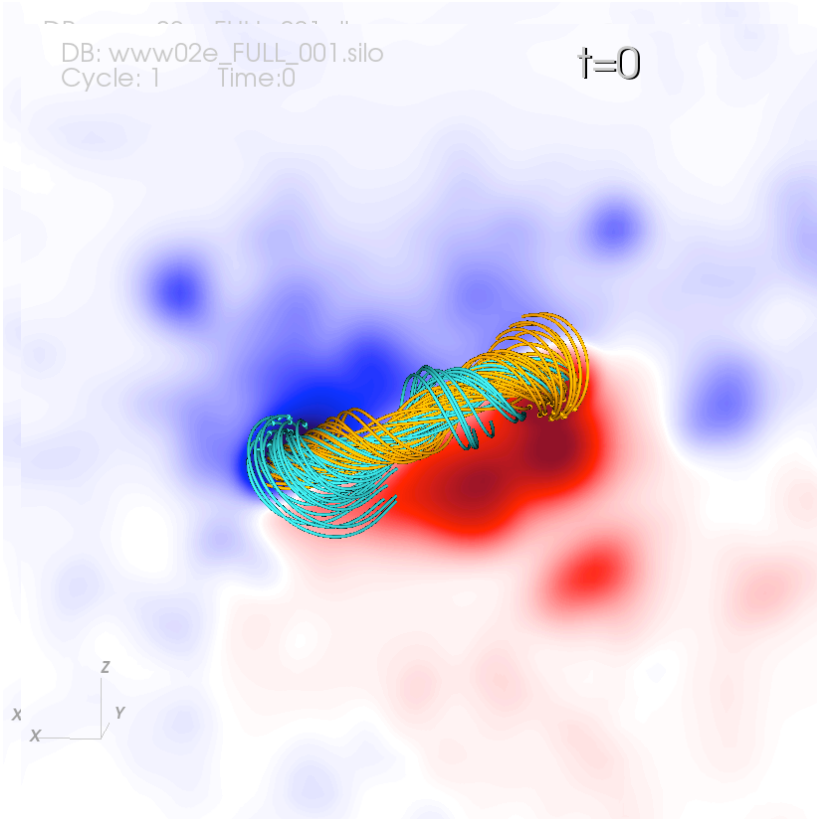
Strapping force from charges

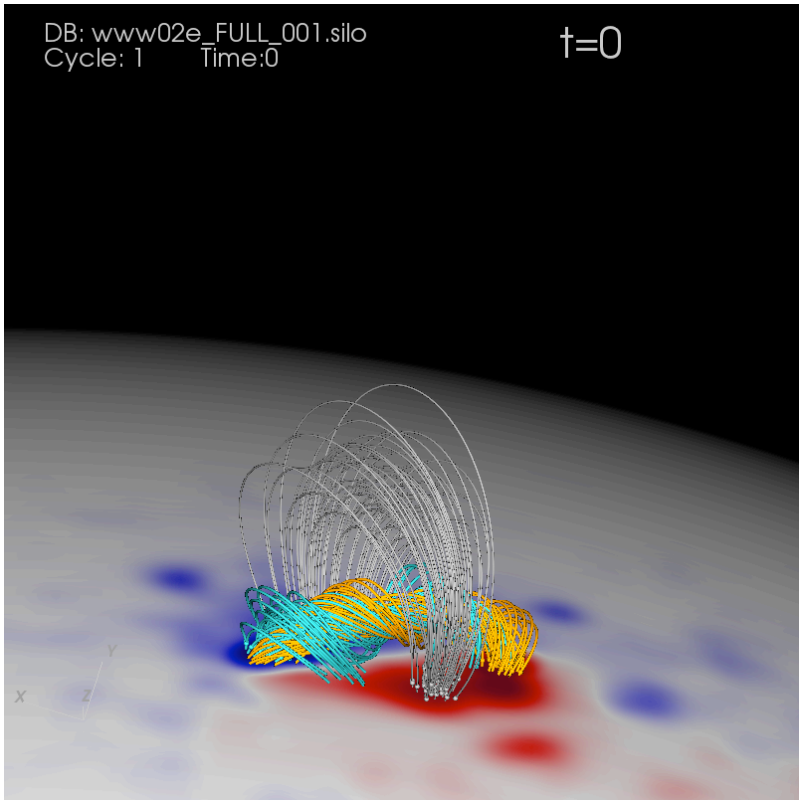
$$\boldsymbol{F}_I = \frac{\mu_0 I^2}{4\pi R}\left(\ln\frac{R}{a} + \ln 8 - 3/2 + l_i/2\right)\boldsymbol{n}$$

Outward force of the Rope

- Complete expression for rope vector potentials given in Titov et. al 2014.
- Two types of volumetric current profiles considered (hollow core, parabolic)
- This model is implemented in the MAS code and can be inserted into any configuration

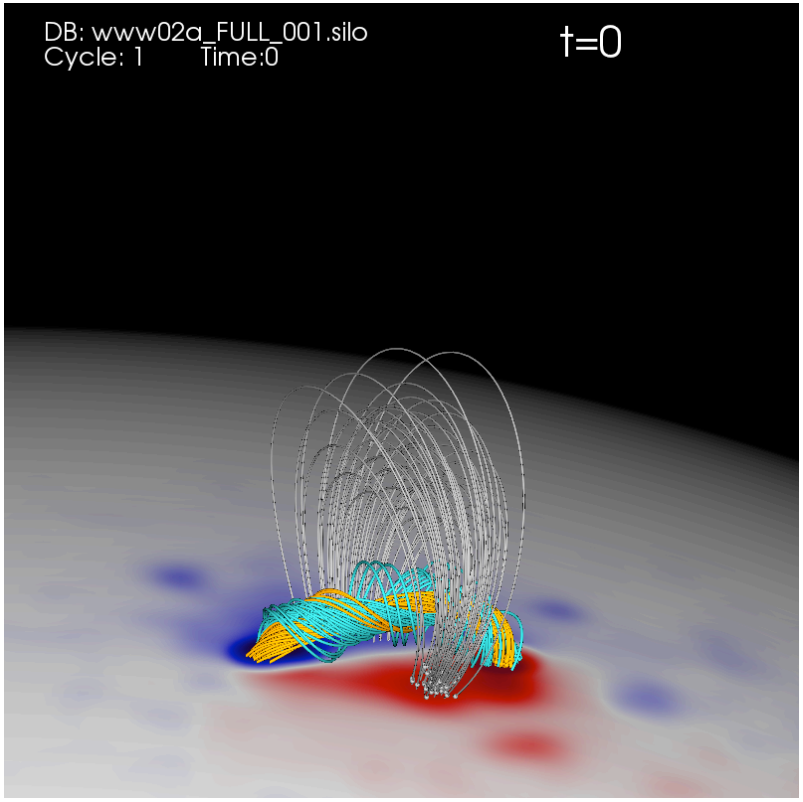
Test Stability with Trial Runs in Zero-Beta





- Zero-beta runs can be performed in minutes on a few hundred processors
- Example of a stable flux rope

Test Stability with Trial Runs in Zero-Beta

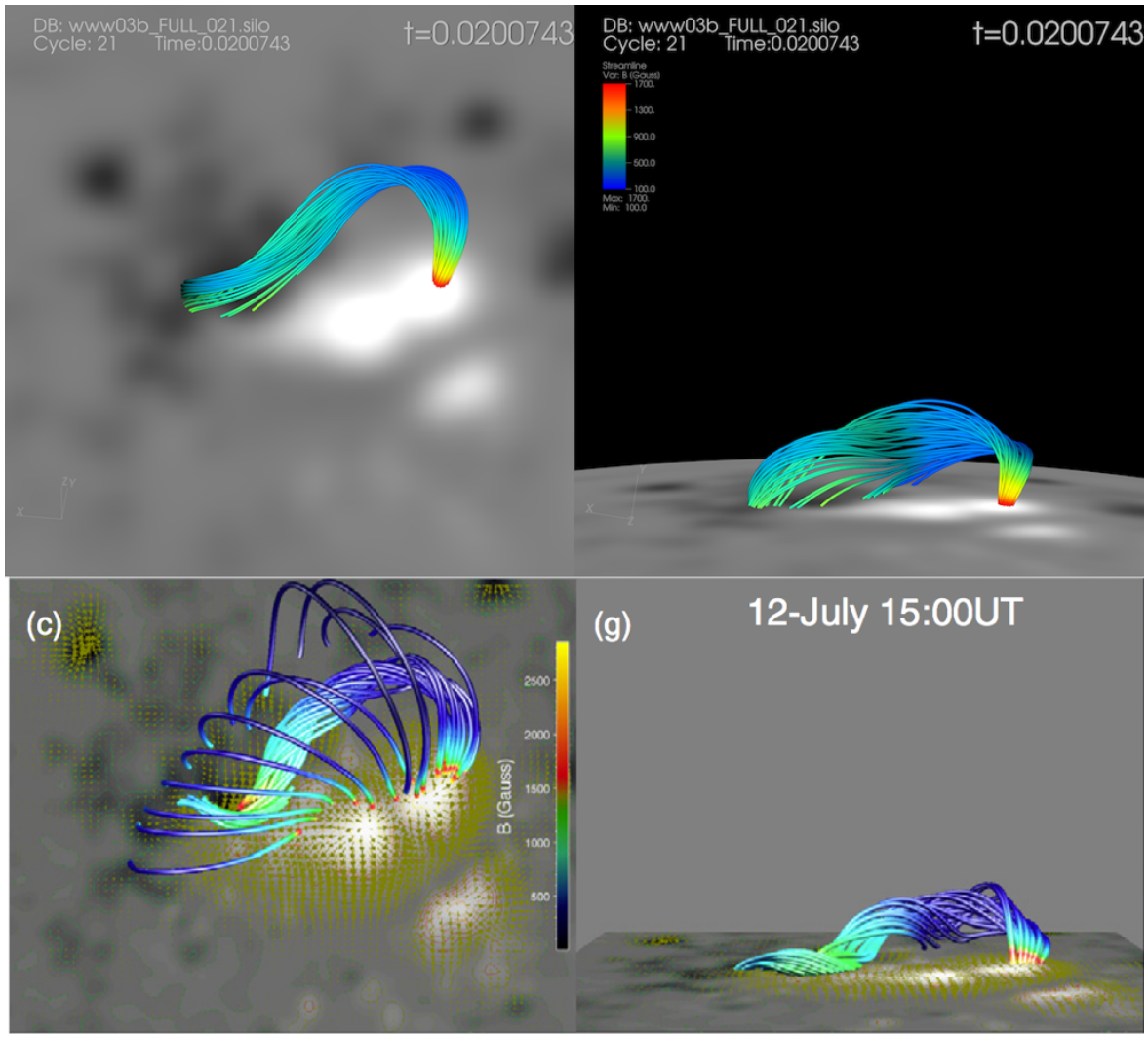


- Eruption - choosing B_p above stability limit
- Also via flux cancellation

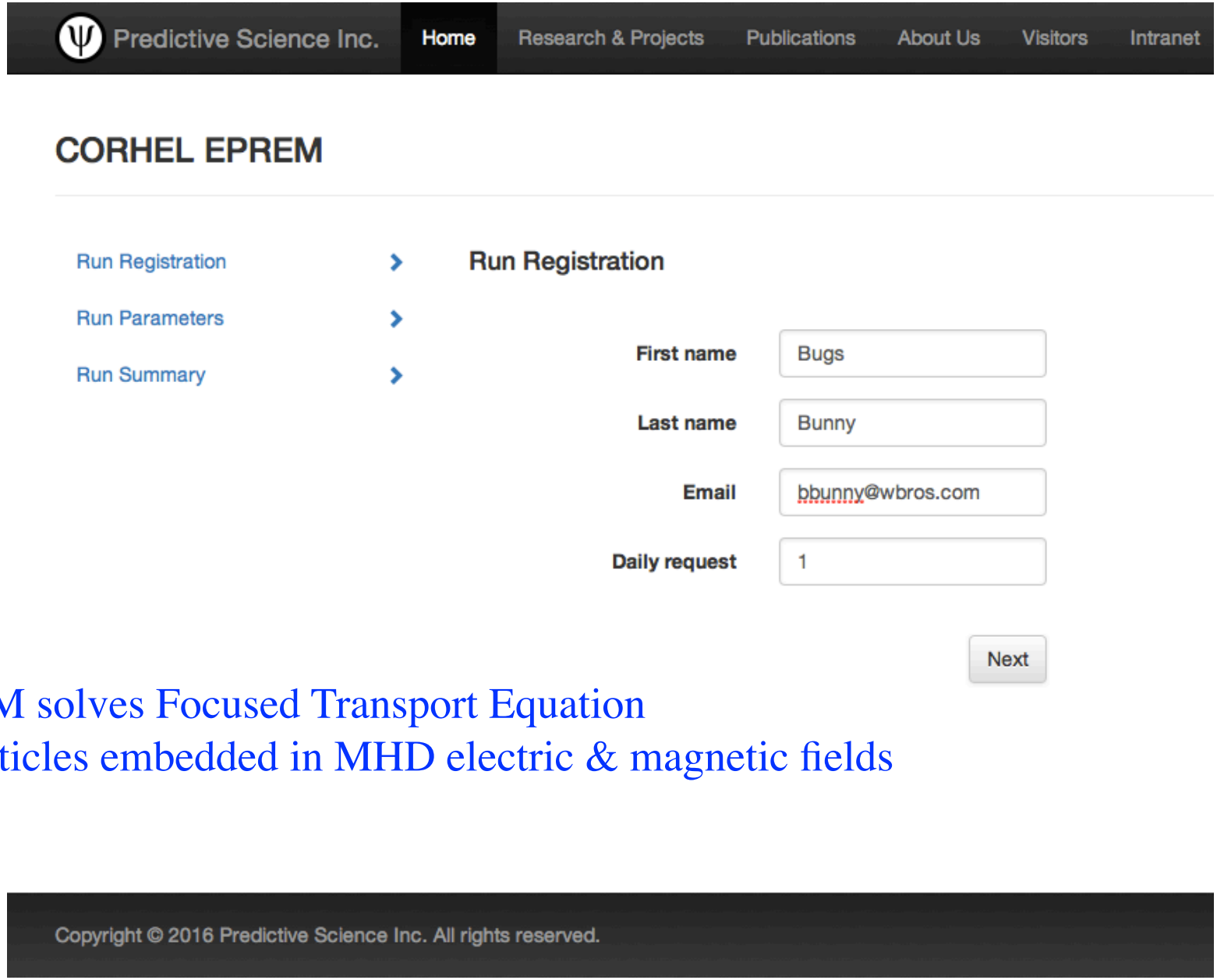
Comparison of TDm Flux Rope with NLFF Model

TDm Flux Rope

Cheng et al. 2012
NLFF model

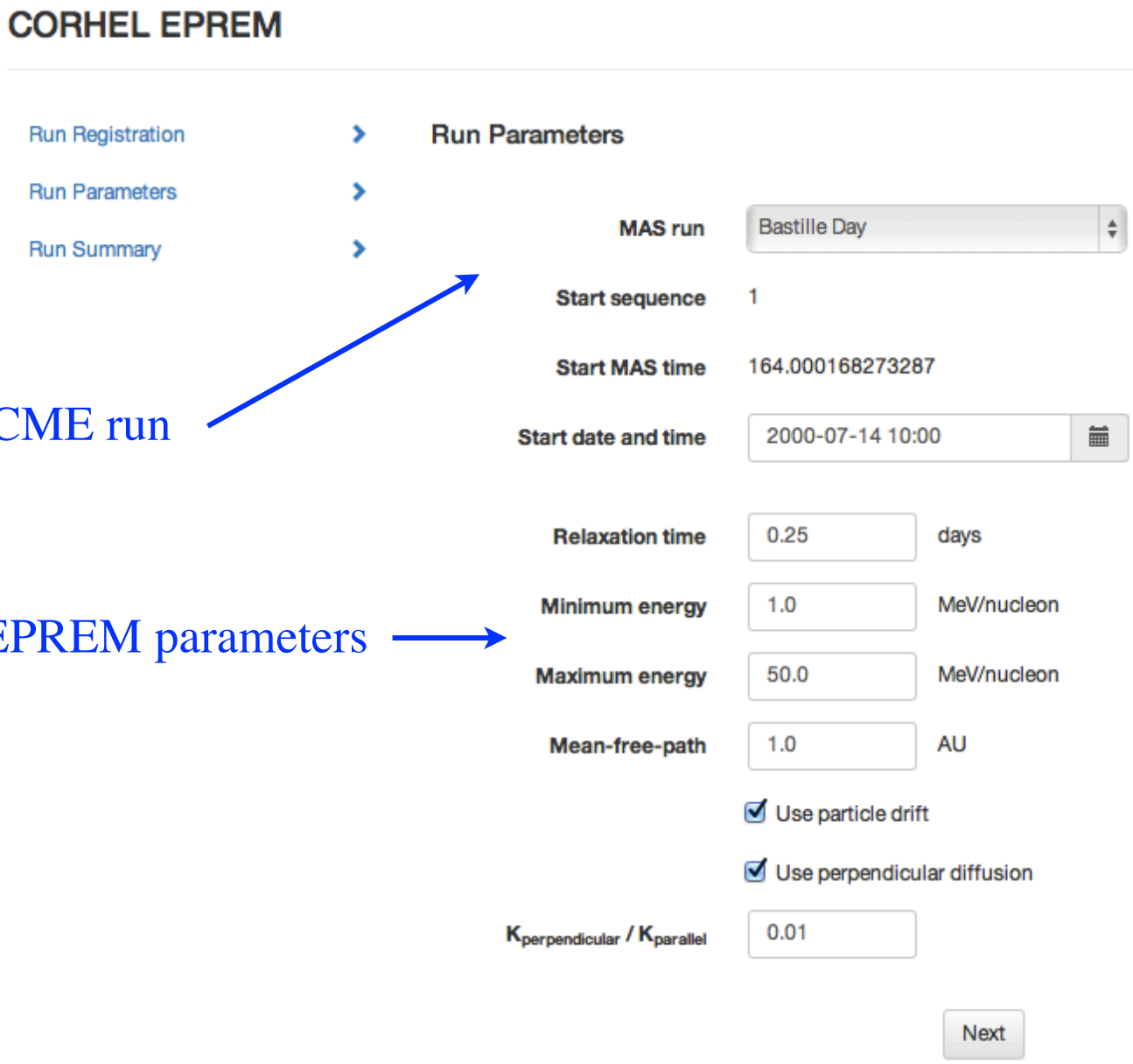


Coupled CME-SEP Simulations with CORHEL-EPREM



EPREM solves Focused Transport Equation
for particles embedded in MHD electric & magnetic fields

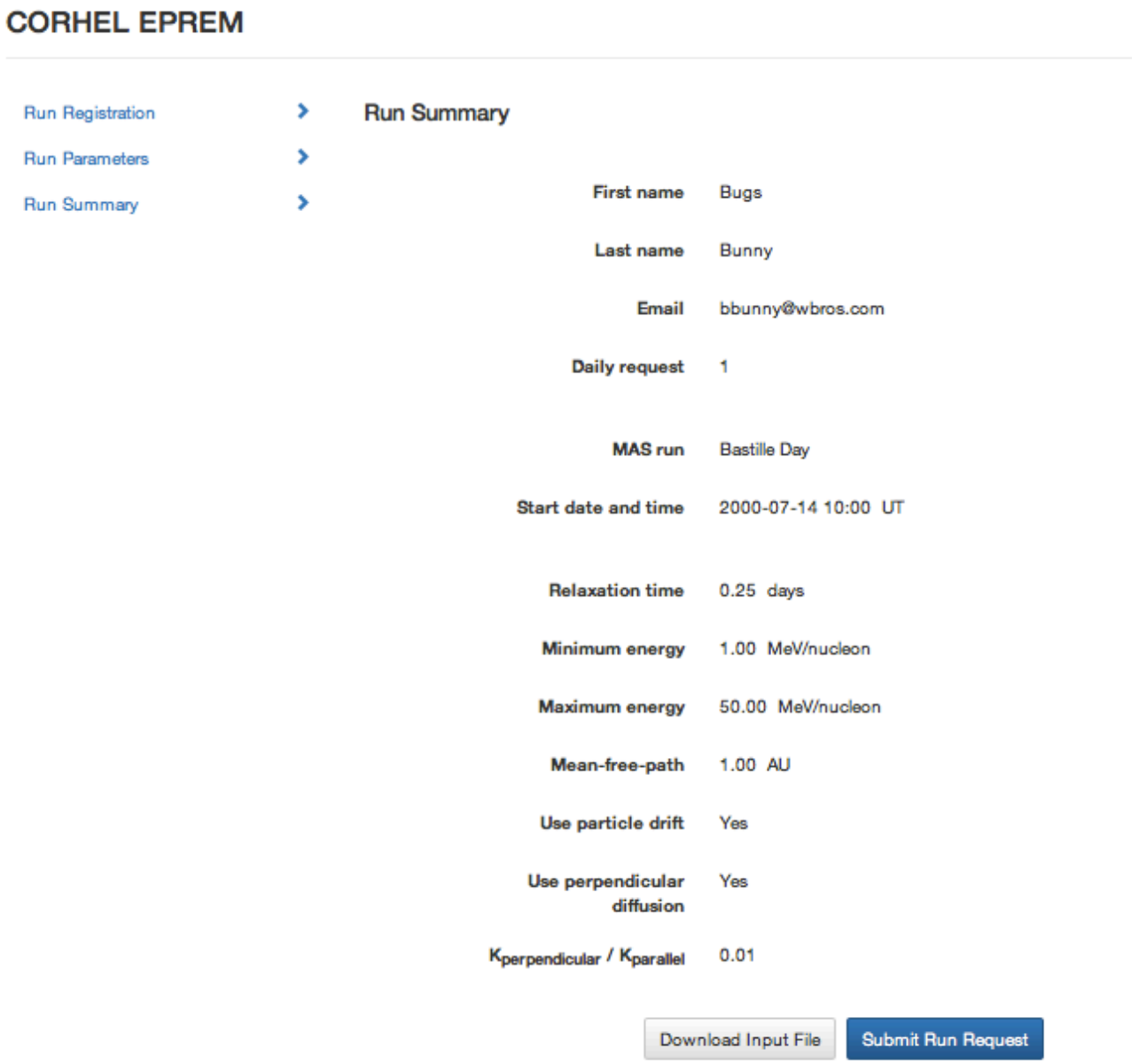
Coupled CME-SEP Simulations with CORHEL-EPREM



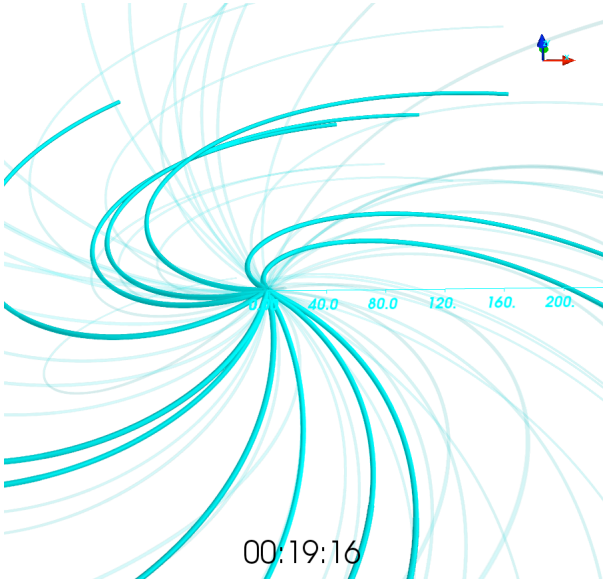
Select CME run

Select EPREM parameters

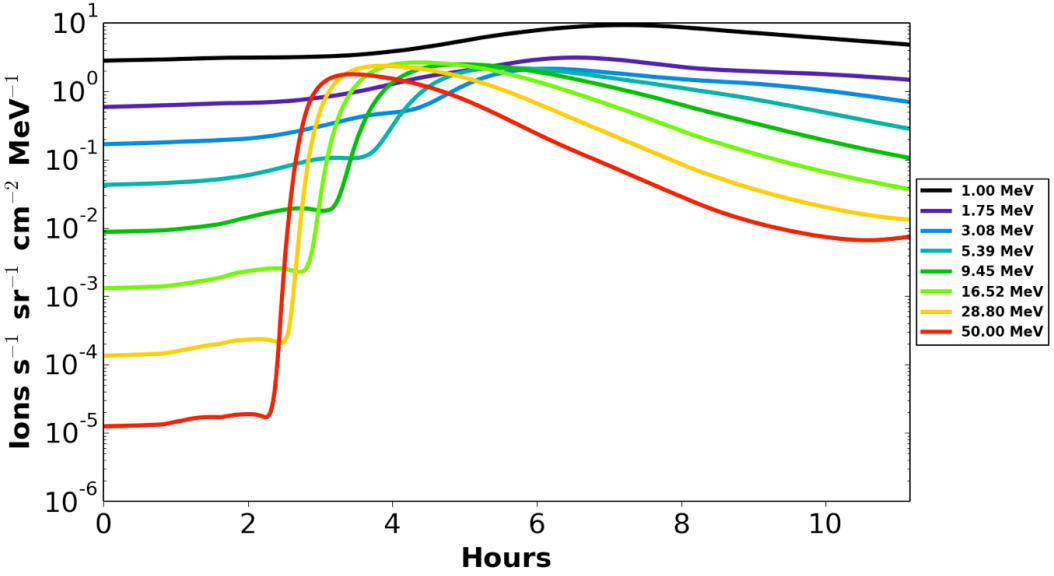
Coupled CME-SEP Simulations with CORHEL-EPREM



Coupled CME-SEP Simulations with CORHEL-EPREM



EPREM streams



Simulated SEP flux at 1 AU

- Example - (very preliminary) simulation of Bastille Day Event (July 14, 2000)

Summary

- Today I've described the extension of CORHEL into modeling of CMEs and consequent SEP production.
- CORHEL-CG will provide an approach to modeling CMEs starting from equilibrium configurations
  - Our AFOSR-supported project promises delivery to AFRL Kirtland
  - We welcome the opportunity to provide this capability to the CCMC
  - Presently investigating with zero-beta, eventually provide full thermodynamic MHD
- SPE Threat Assessment Tool (STAT)
  - Coupled CORHEL-EPREM Simulations
  - Presently focused on low-coronal response
  - Can also investigate energetic storm particles