
National Aeronautics and Space Administration
NASA
Make your own Solar Storms!
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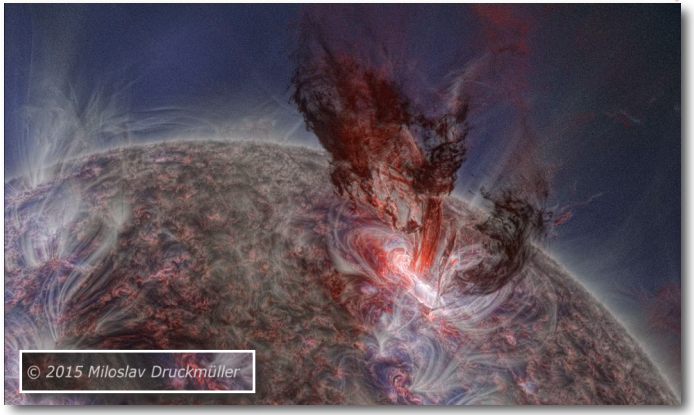
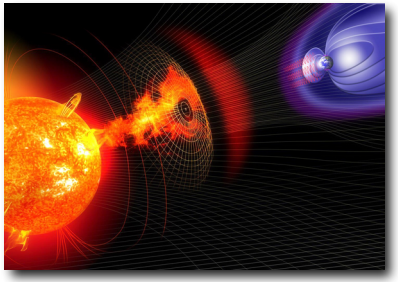
What are Solar Storms?

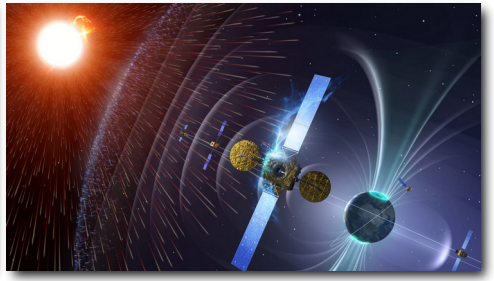
- Large explosive events on the Sun such as solar flares and coronal mass ejections (CME)
- CMEs can eject billions of tons of magnetized million-degree plasma out into space
- CME impacts at Earth can cause interference and damage to electronic infrastructure including GPS satellites and the power grid

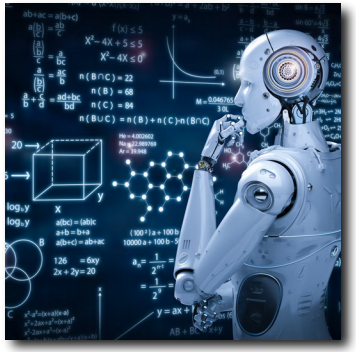


Modeling Solar Storms

- Solar storms are fascinating phenomena
- Due to the risk they pose, their study is also practical
- We want to predict their eruptions and/or trajectories, which can be approached in different ways:
- Empirical/ML/AI models (practical but simplified)
- Full physics models can using the Magnetohydrodynamic (MHD) description, requiring computationally expensive numerical solutions
- One such MHD model is the MAS model developed at Predictive Science Inc.

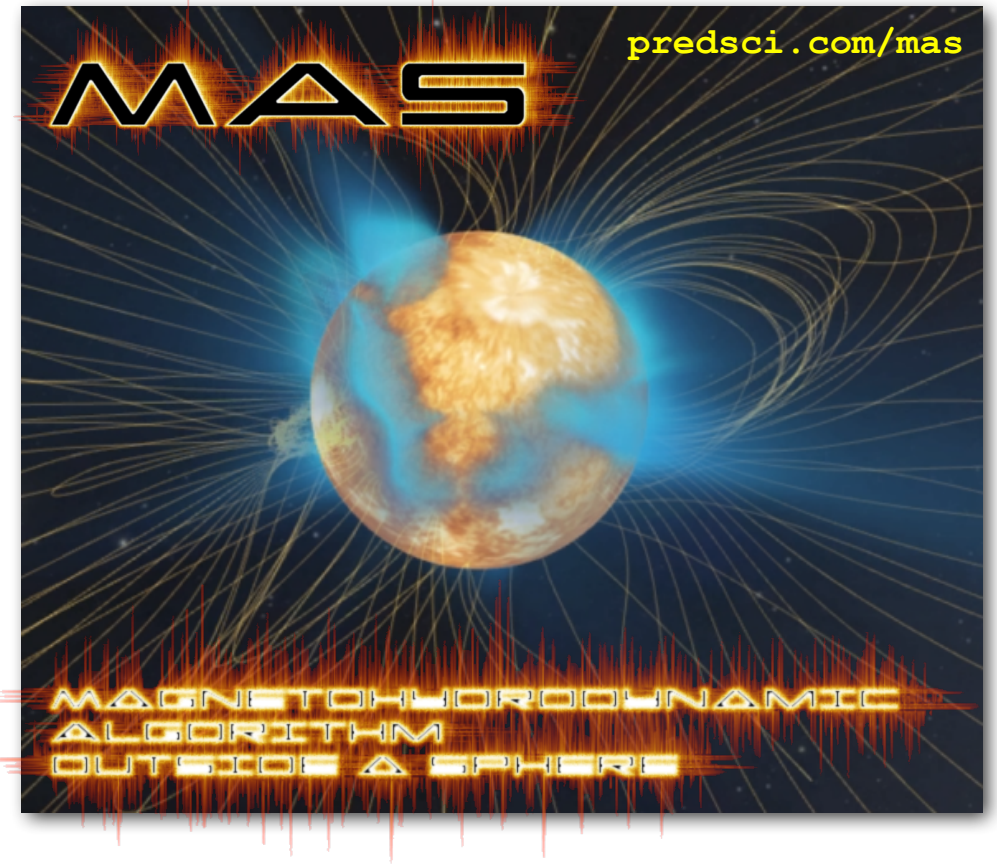






Predictive Science Inc.

The MAS MHD Model



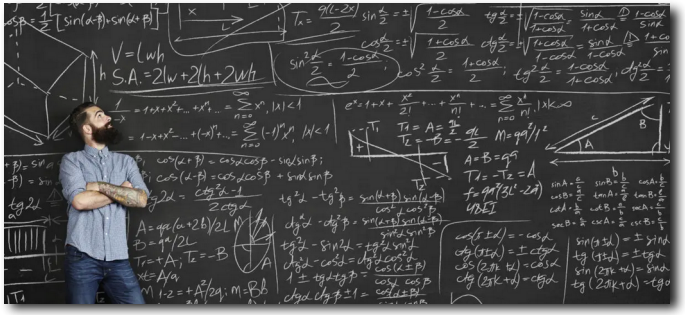
- Established MHD code with over 15 years of development
- Used extensively in solar physics research
- Written in Fortran (~70,000 lines of code)
- Parallelized with MPI+OpenACC for CPUs and GPUs

MPI

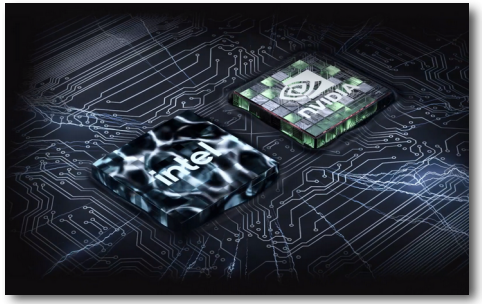
OpenACC

Making MAS CME Simulations Accessible

- Designing and analyzing a CME simulation is very complex and specialized
- For space weather and other applications, need to make accessible to non-experts
- Towards this end, we have developed the CORona-HELiosphere Automatic Multiple CME Generator (**CORHEL-AMCG**) software suite which contains:
  - Modeling suite (including MAS) that can run on CPUs and GPUs
  - Web interface for designing and analyzing simulations

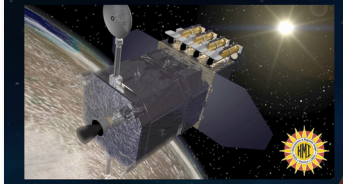


CORHEL-AMCG

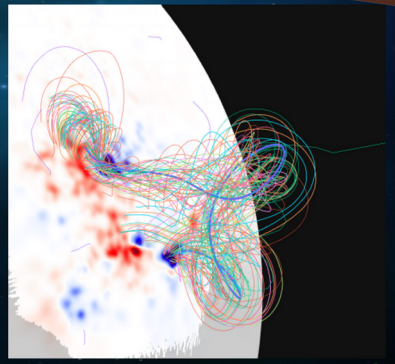


Corhel-Amcg's Recipe for Making Solar Storms

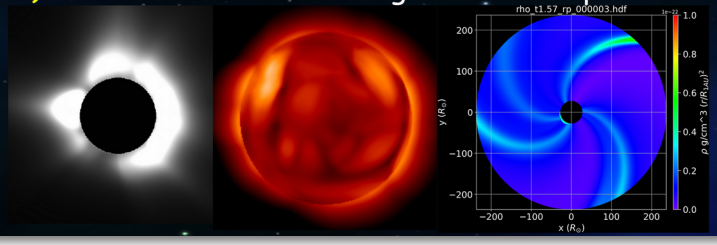
1) Get the Sun's surface magnetic field from satellite observations:



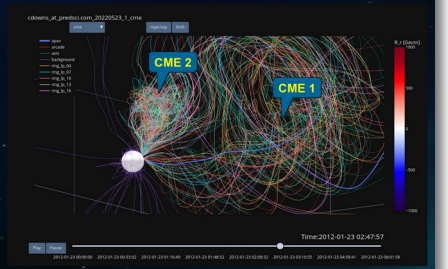
2) Design twisted magnetic rope(s) to erupt:

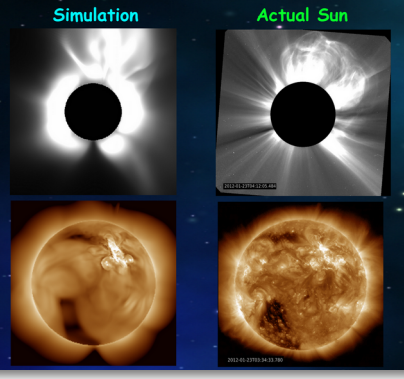


3) Simulate the Sun's background atmosphere:

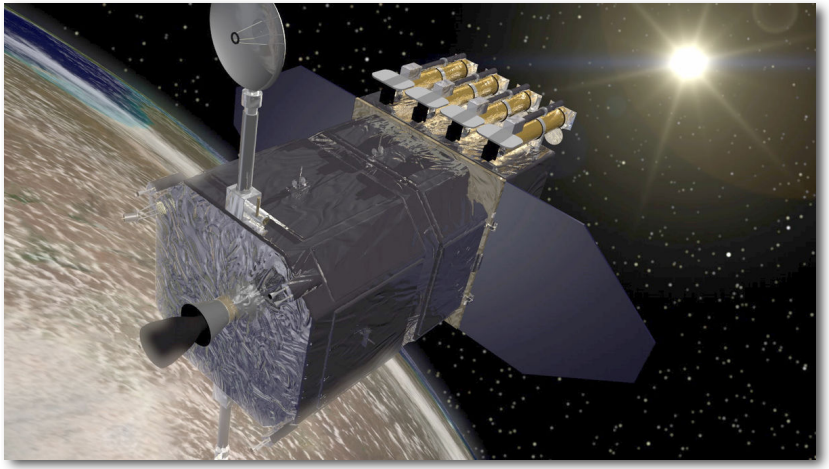


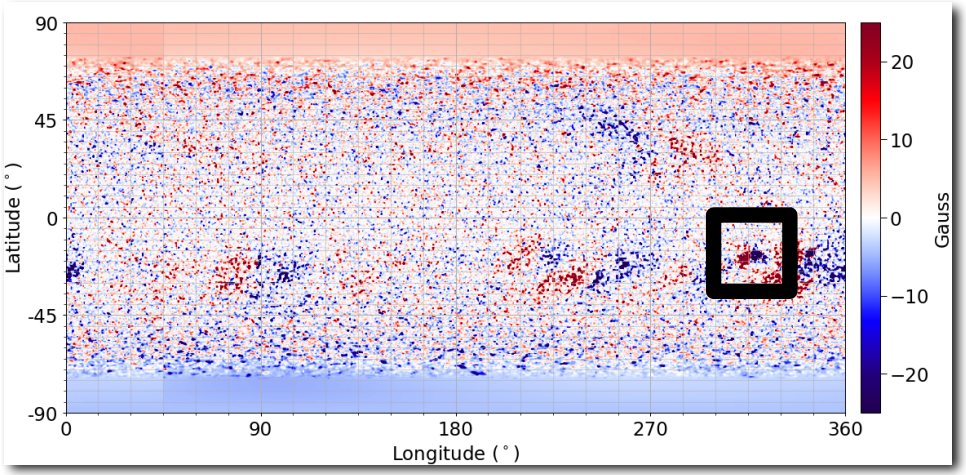
4) Insert the rope(s) and run a simulation to make them erupt and travel to Earth!





Step 1: Get Observed Data

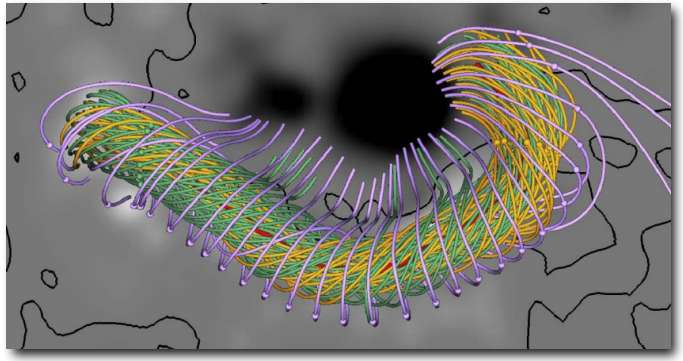


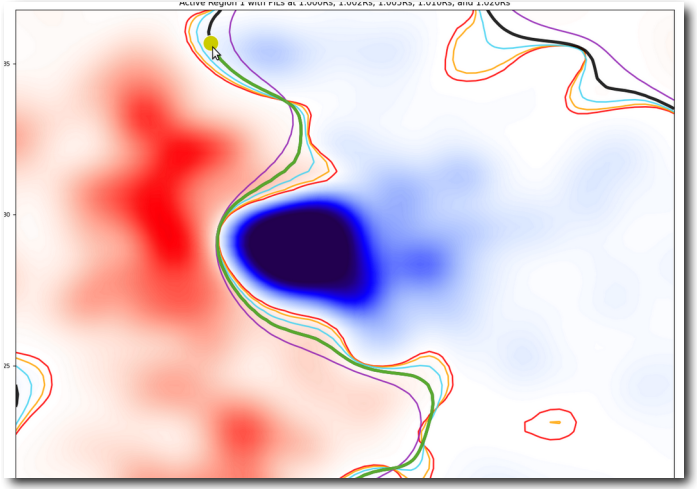


- Get Solar surface radial magnetic field observation and process
- Select “active regions” where the CMEs will be inserted/launched

Step 2a: Design your CME(s)

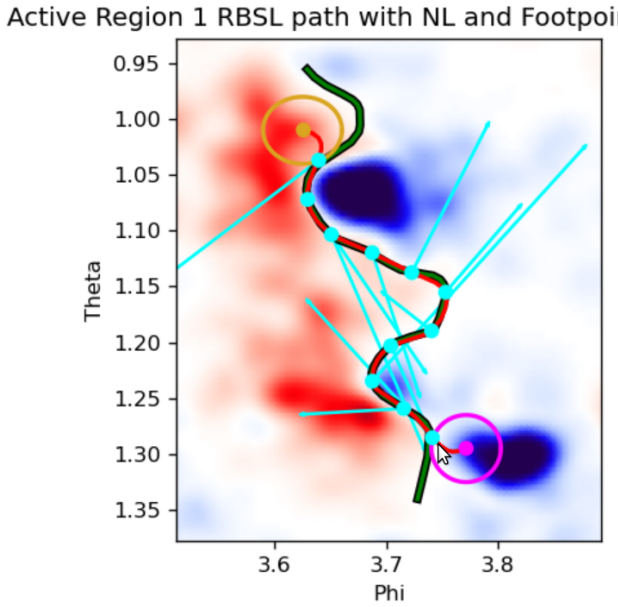
- We model CMEs as an eruption of a magnetic flux rope (twisted, current carrying fields, magnetically confined by the surrounding region).
- A simplified coronal magnetic field (called a potential field source surface) is computed to use as a background
- Select a polarity inversion line (across which the radial magnetic field changes sign) along which the flux rope will lie

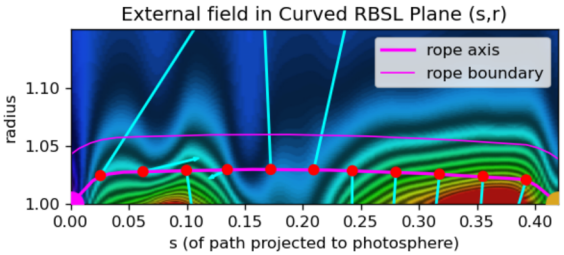




Step 2b: Design your CME(s)

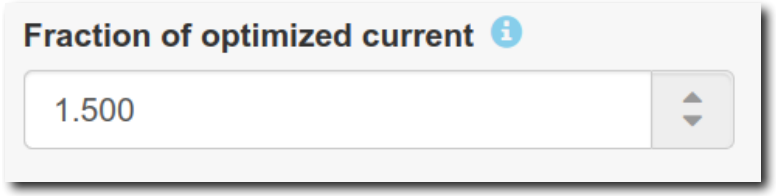
- Foot point selection & flux rope properties
- Interactive visual guide to help the user
- Flux rope can be set to be stable (non-eruptive), or unstable (eruptive CME)





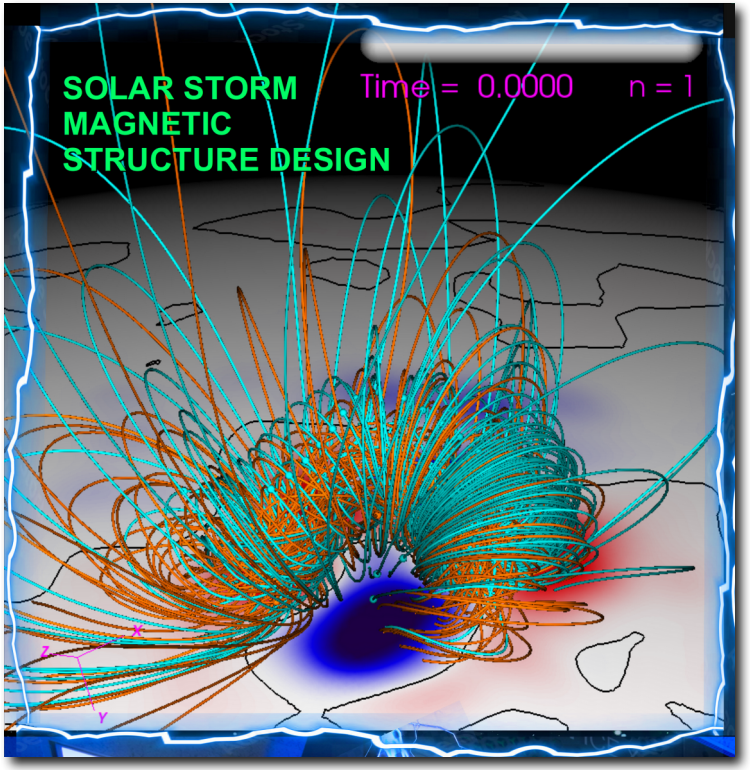
RBSL Optimization Info

	Value
Average Poloidal Field (Bp rope)	107.59483
Standard deviation	42.43746
stdev(Bp_tot) / mean(Bp_rope)	0.39442
mean(|JxB|) / mean(|J.B|)	0.09858



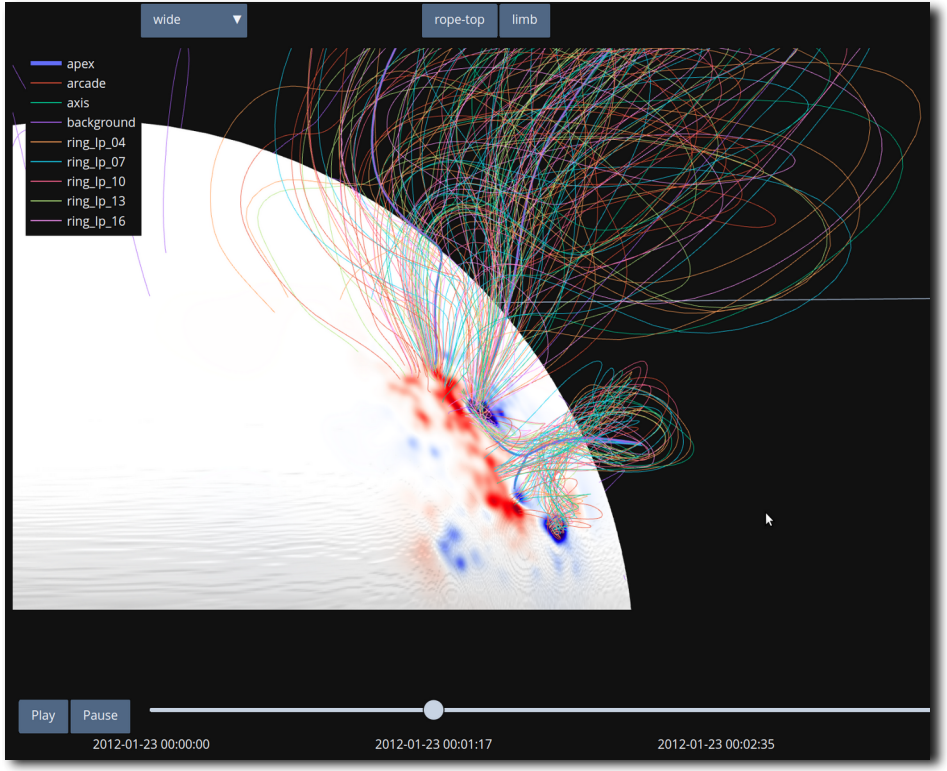
Step 2c: Design your CME(s)

- After all flux ropes are designed, the interface generates a compressed file containing everything needed to run a “zero-beta” simulation
- Zero-beta MAS simulations use a reduced physics model that is much faster to compute, allowing you to see the initial dynamics of the CME (does it erupt?, what’s its direction?, etc.)
- File is moved to a compute server and launched with a single command



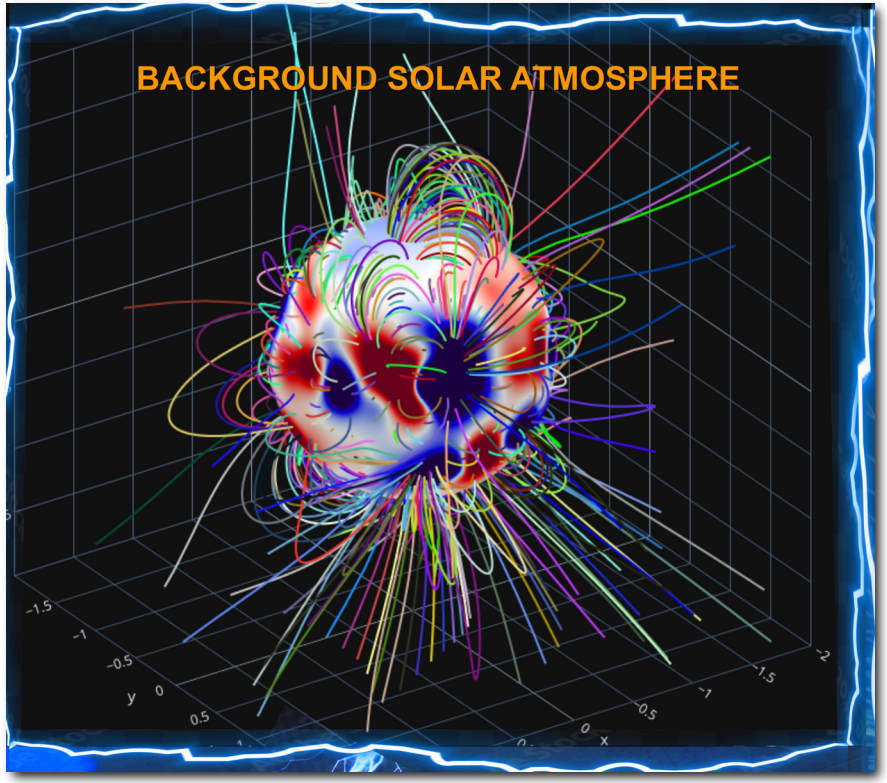
Step 2: Design your CME(s)

- When run is completed, a stand-alone web page report is generated which shows a time-dependent movie of the flux ropes and diagnostics
- Based on the results, you can load your save state into the interface, tweak parameters of the rope(s), and then re-run the zero-beta simulation
- After rinsing and repeating, the flux ropes are ready to go!



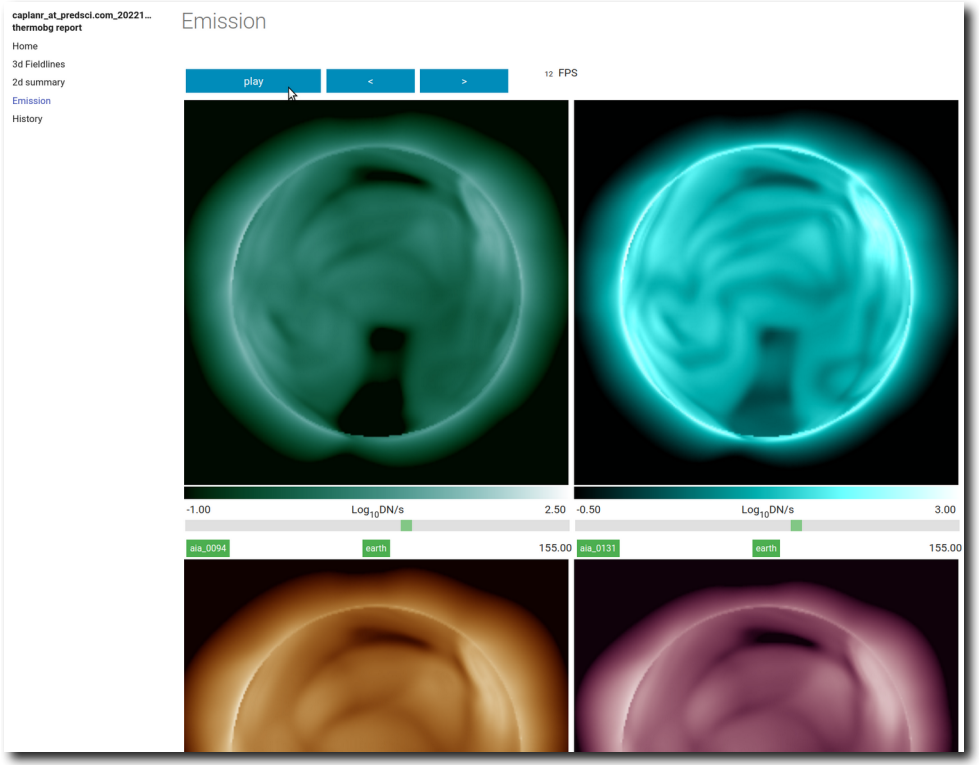
Step 3a: Background Solar Atmosphere

- In order to simulate the CME in a realistic manner, the quasi-steady-state background of the solar corona/heliosphere must be computed
- The web interface allows you to choose the model presets, and then generates a compressed file to use to run the background simulation
- The simulation is launched with a single command line



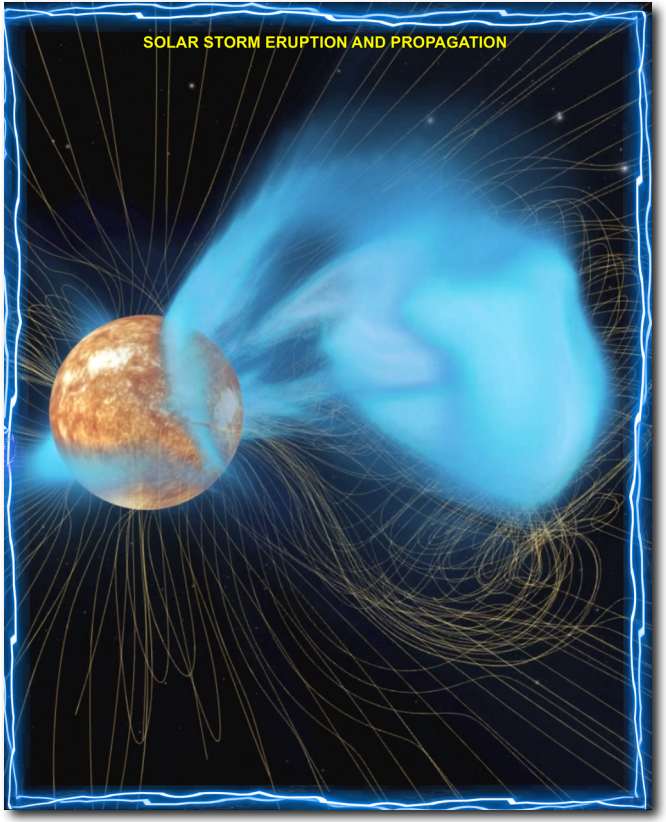
Step 3b: Background Solar Atmosphere

- When the run is complete, a stand-alone web page report is generated
- This shows forward-modeled emission images (for direct comparison to observations), magnetic field lines, derived quantities, and slices of the plasma
- If all looks OK, the you enter a command to package up the results and upload the file back to the web interface



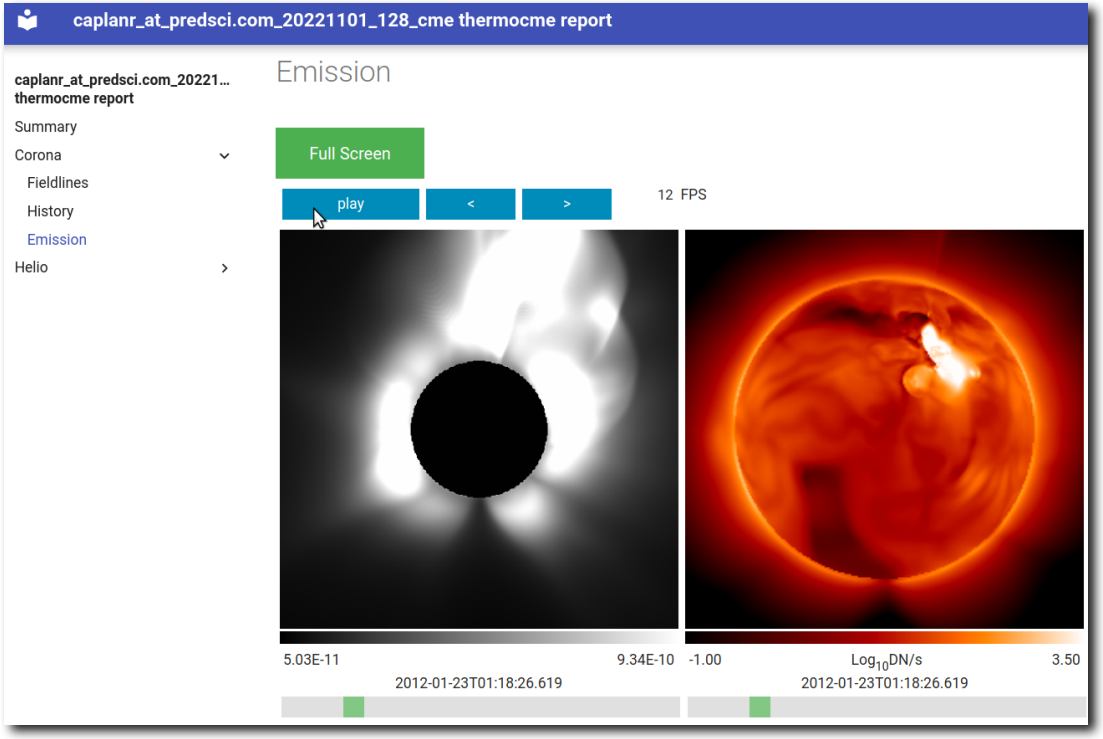
Step 4a: Run your CME(s) Simulation

- Once the background is uploaded, you review the interface steps once more to double check that all is well, and then it generates a compressed file used to launch the CME simulation.
- The simulation is launched with a single command



Step 4b: Run your CME(s) Simulation

- When the simulation is completed, it auto-generates a stand-alone web page report
- This report contains time-dependent movies of magnetic field lines, emission images, slice planes of plasma properties, etc.



High Performance Computing

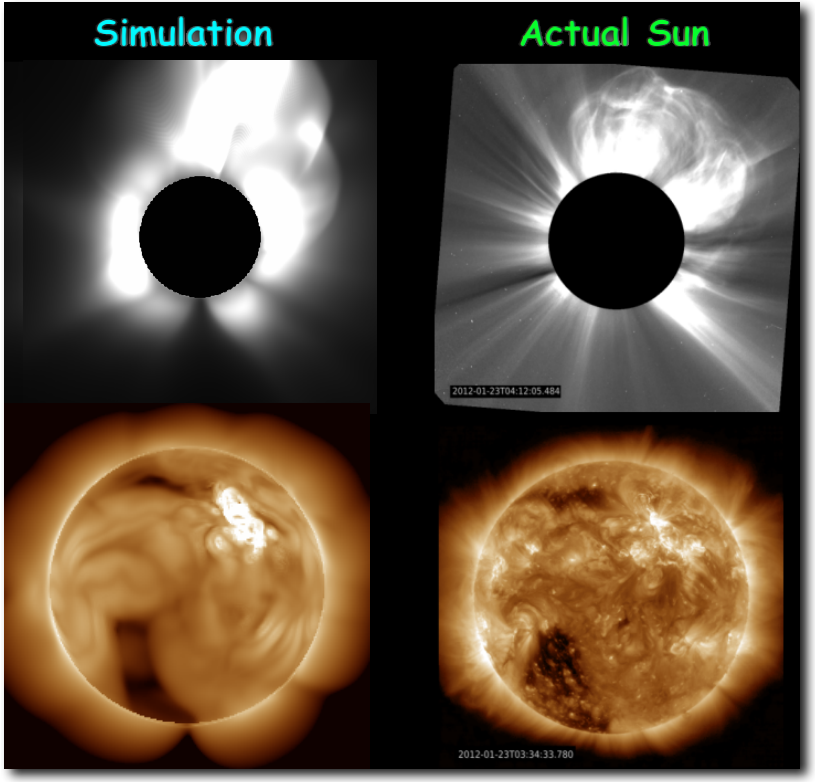
Simulations can run on a single GPU server, or across many nodes of a supercomputer depending on required turn-around time

NASA + aws

EC2 P3
8xV100

What can we do with our new storm?

- Study CME dynamics
- Compare with observations
- Use results as input to other models (e.g. solar energetic particles with STAT)



Where will I find CORHEL-AMCG?

- Already delivered to NASA's CCMC
- Once activated, it will allow users to run CMEs on-demand

CORHEL-AMCG

ccmc.gsfc.nasa.gov