TDm Designer

An Interface for Modeling Stable and Unstable Flux Ropes in Realistic Solar Magnetic Fields

Cooper Downs

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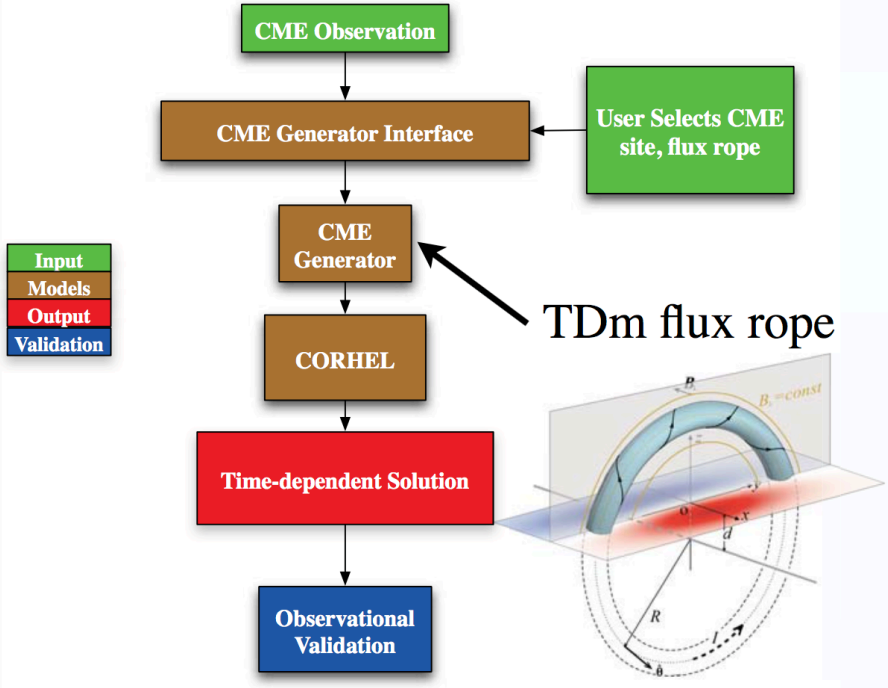
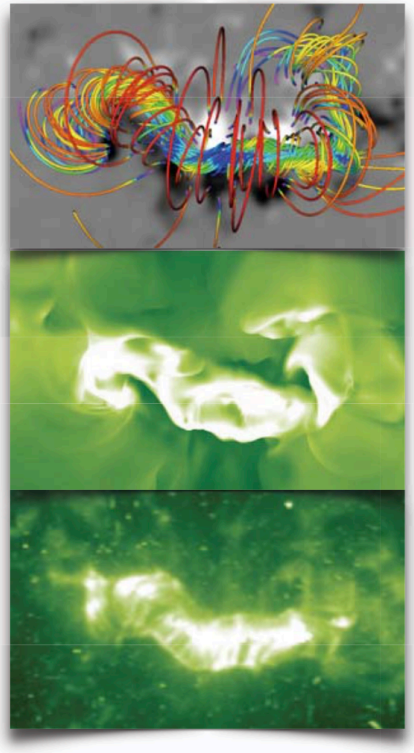
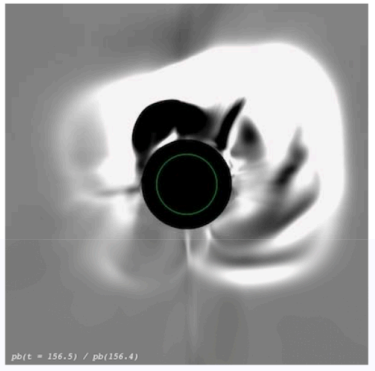
2018 CCMC Workshop
April 24, 2018

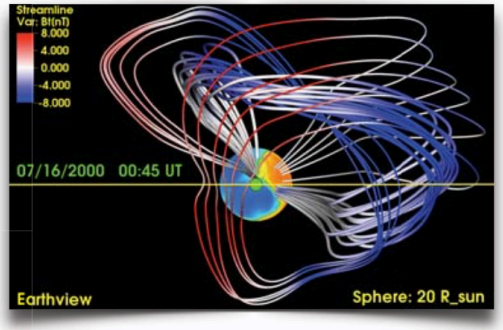
Overview of CORHEL-CG

- The over-arching goal of our project is to develop CORHEL-CG, a user-friendly tool for simulating CMEs in realistic coronal/solar wind solutions.
  - Build around existing coronal and solar wind models (MAS/CORHEL).
  - Use modern methods for simulating CMEs (thermo-MHD + TDm Flux-rope model).
  - Interface for constructing accurate CME simulations (TDm Designer). **[THIS TALK]**
  - Designed with operational and scientific contexts in mind. Deliver to AFRL and CCMC.





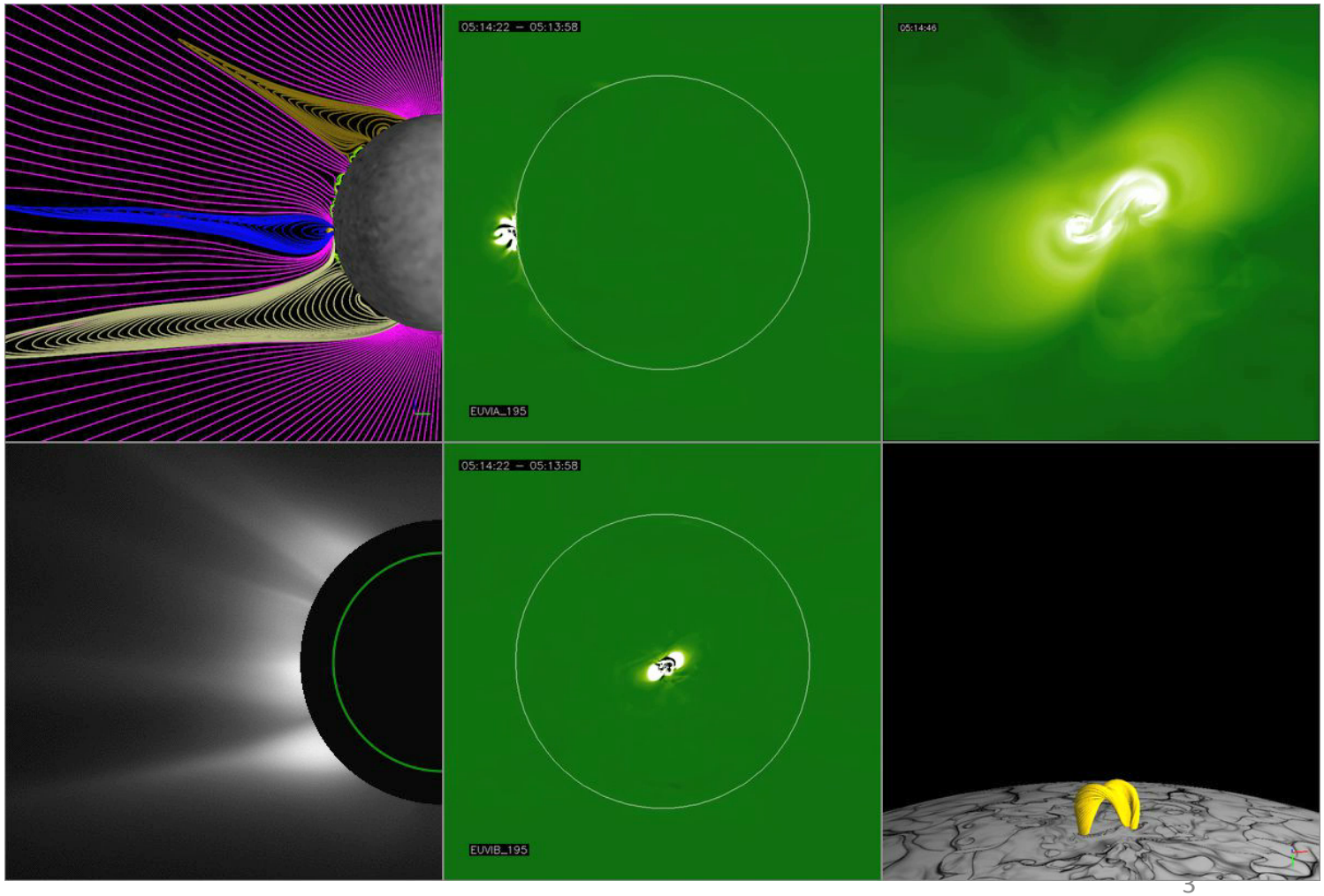




Supported by AFOSR BRI program

TDm Designer Philosophy: Facilitate Use

- Realistic coronal CME simulations, particularly case-studies of observed events, are primarily performed by experts and can be very manpower intensive.



CME Evolution EUV waves Coronal Dimming

TDm Designer Philosophy: Facilitate Use

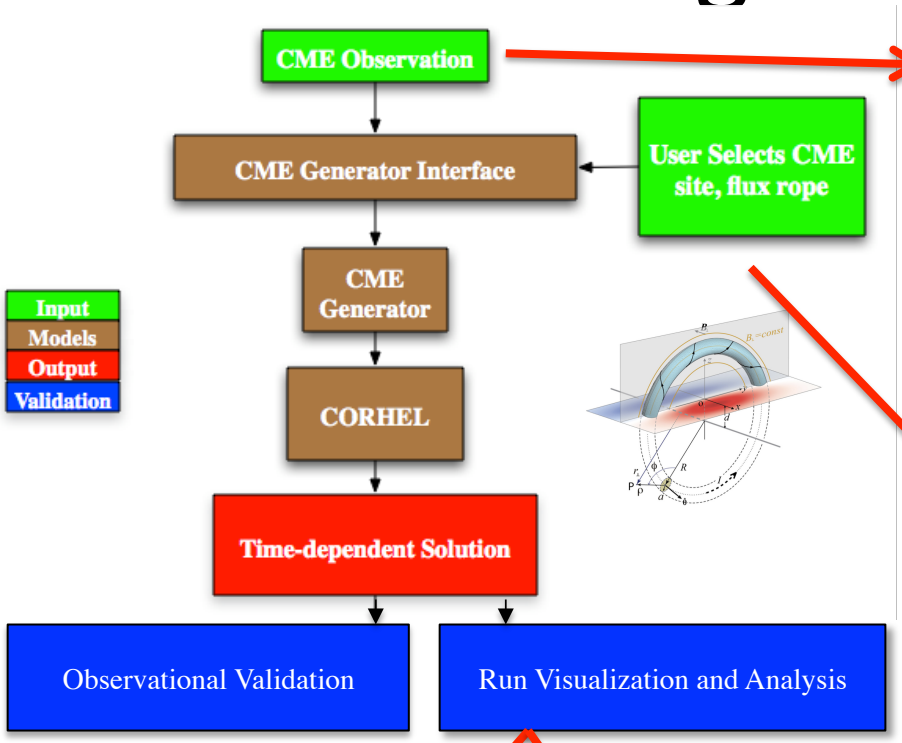
- Realistic coronal CME simulations, particularly case-studies of observed events, are primarily performed by experts and can be very time consuming.

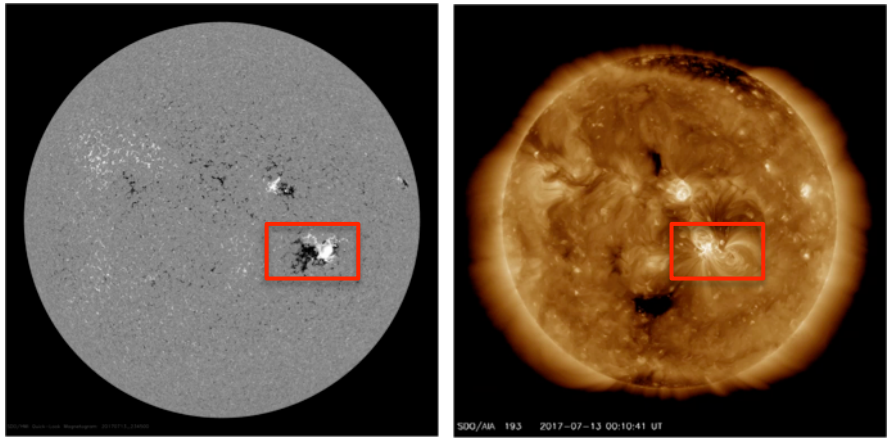
- **Expertise:** To do a "realistic" sun-to-earth CME simulation need familiarity with:
  - Observations that feed the models (magnetograms, EUV and/or white light images).
  - Energized magnetic field models (flux-ropes or boundary driving).
  - Sun-to-earth plasma environment, coronal heating / solar wind models.
  - In situ plasma/particle measurements.

- **Time**: Time and effort required to build runs can be a major hurdle.
  - Complex modeling framework implies time to install and familiarize self with tools.
  - Human hours required to set up and analyze science quality runs can far exceed the model run time.

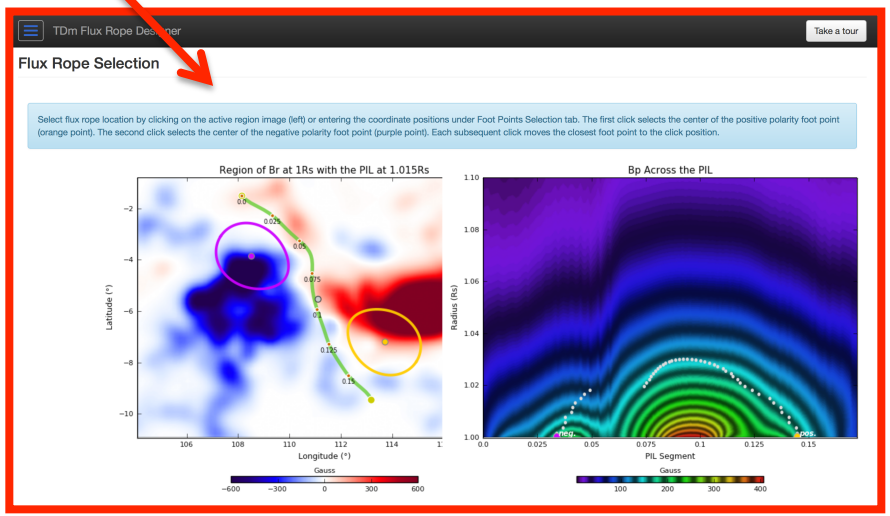
- Facilitating model use can lead to better **operations and science**!
  - **Model Experts:** Having better ways to rapidly protype and test ideas can save me a lot of time!
  - **Scientist Community:** If we want the broader community to use our model, we can't expect them to become familiar with all aspects.
  - **Operations:** A model interface useable by non-modeling experts is needed for operations.
  - **Everyone:** Canned, automatic visualizations are a great way to sift through runs. Get around big-data problems and analysis complexity/time overhead (but they must be useful and informative!).

TDm Designer in CORHEL-CG

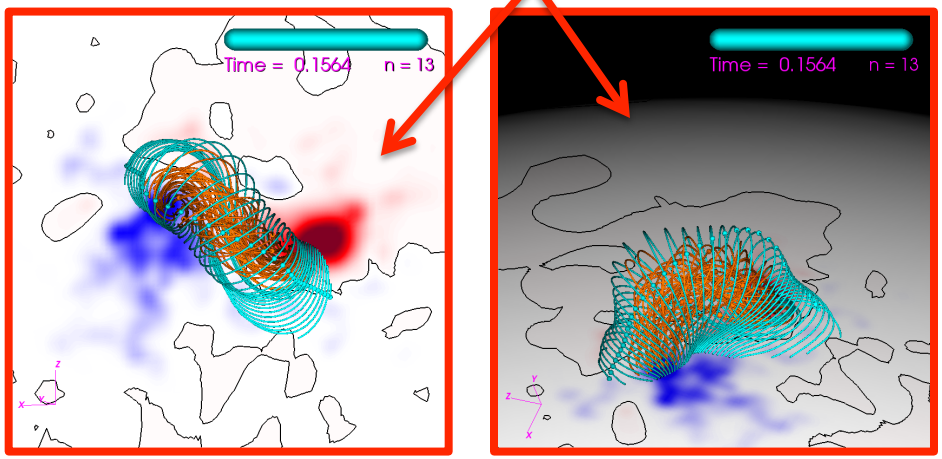




AR and/or CME Observation



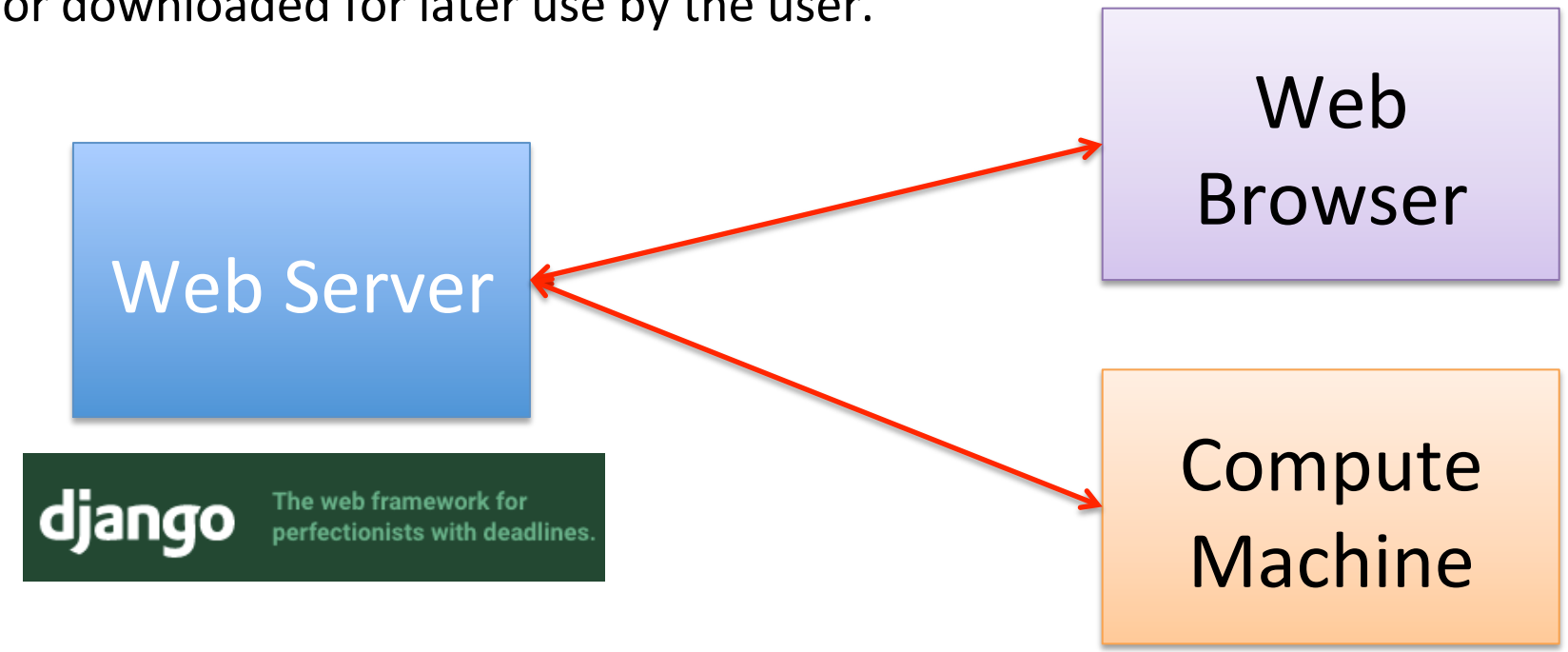
User Interface to Setup Simulations.



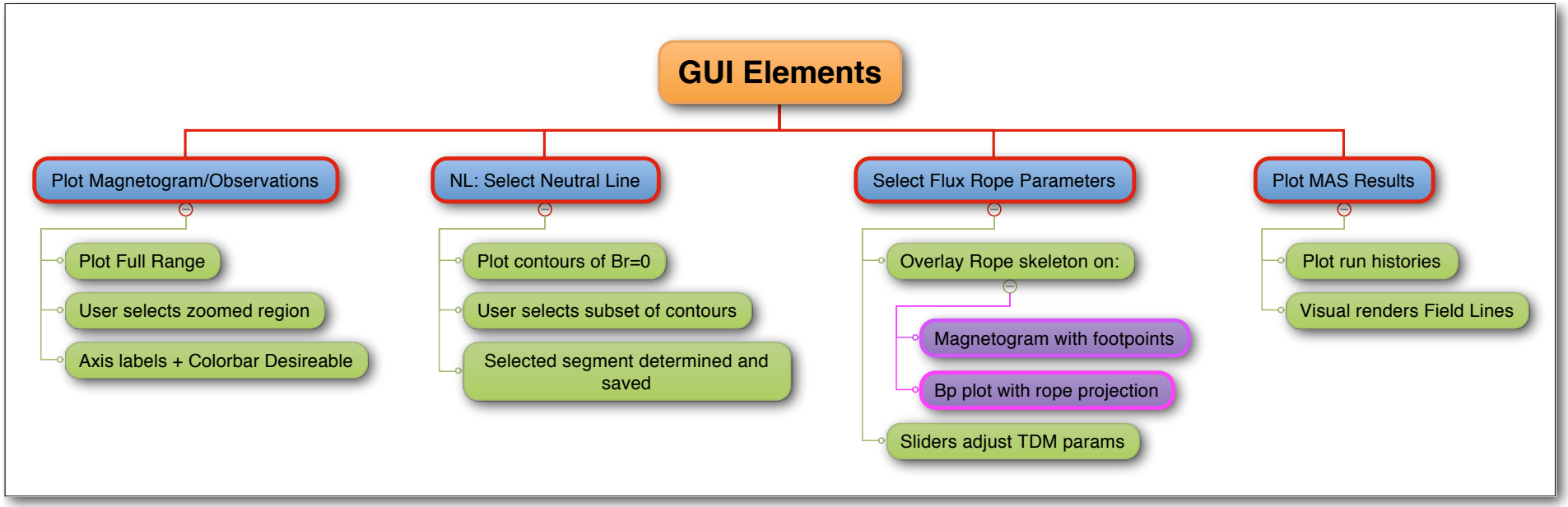
Automatic Visualizations

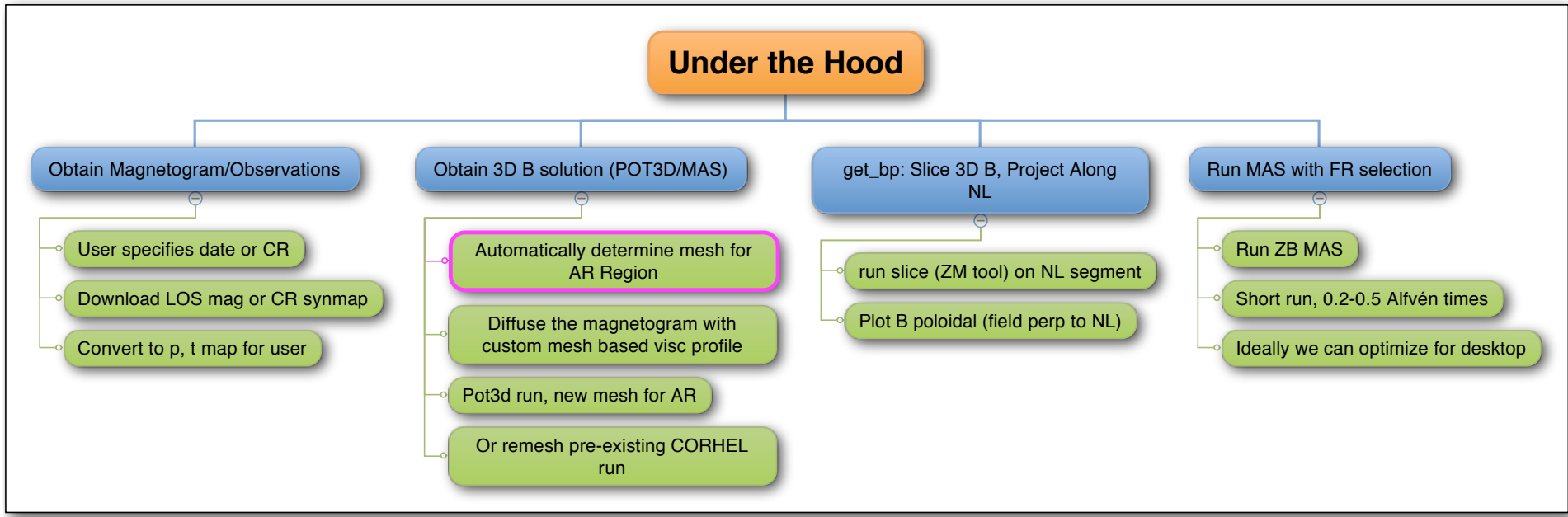
Software Design

- The TDm interface is built as a standalone web app using django/python.
- The web server uses a combination of CORHEL/MAS tools and python scripts to process the interface tasks and build a CORHEL/MAS run.
- The user only needs a web browser, no local software installation necessary.
- The simulations can be automatically run on a remote compute machine or downloaded for later use by the user.



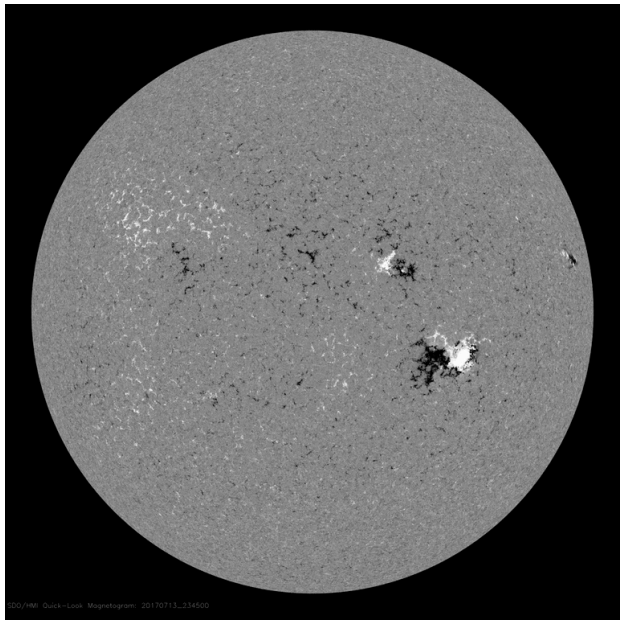
Interface Flowchart



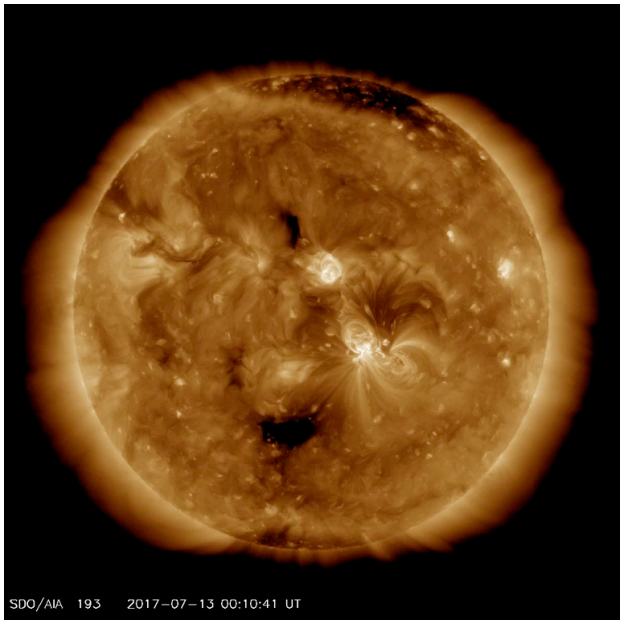


An Example: 7/14/2017

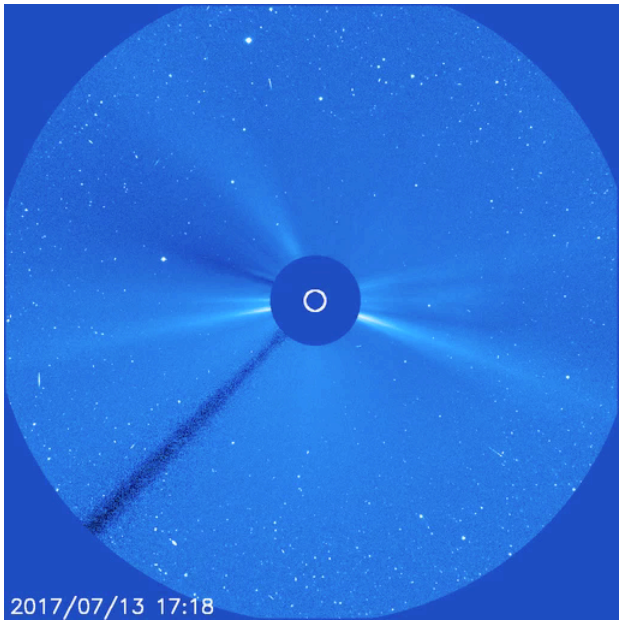
- A month before the 2017 total solar eclipse, as a large sunspot transited the disk, an M2 flare and CME occurred.
  - Was reasonably sized for this phase of the cycle.
  - 7/14/2017 ~01:00 UT – a new "Bastille Day" Event.
  - AR2665, near the west limb at the time of the eruption.
  - CME hit Earth ~2 days later, producing G2 storm.



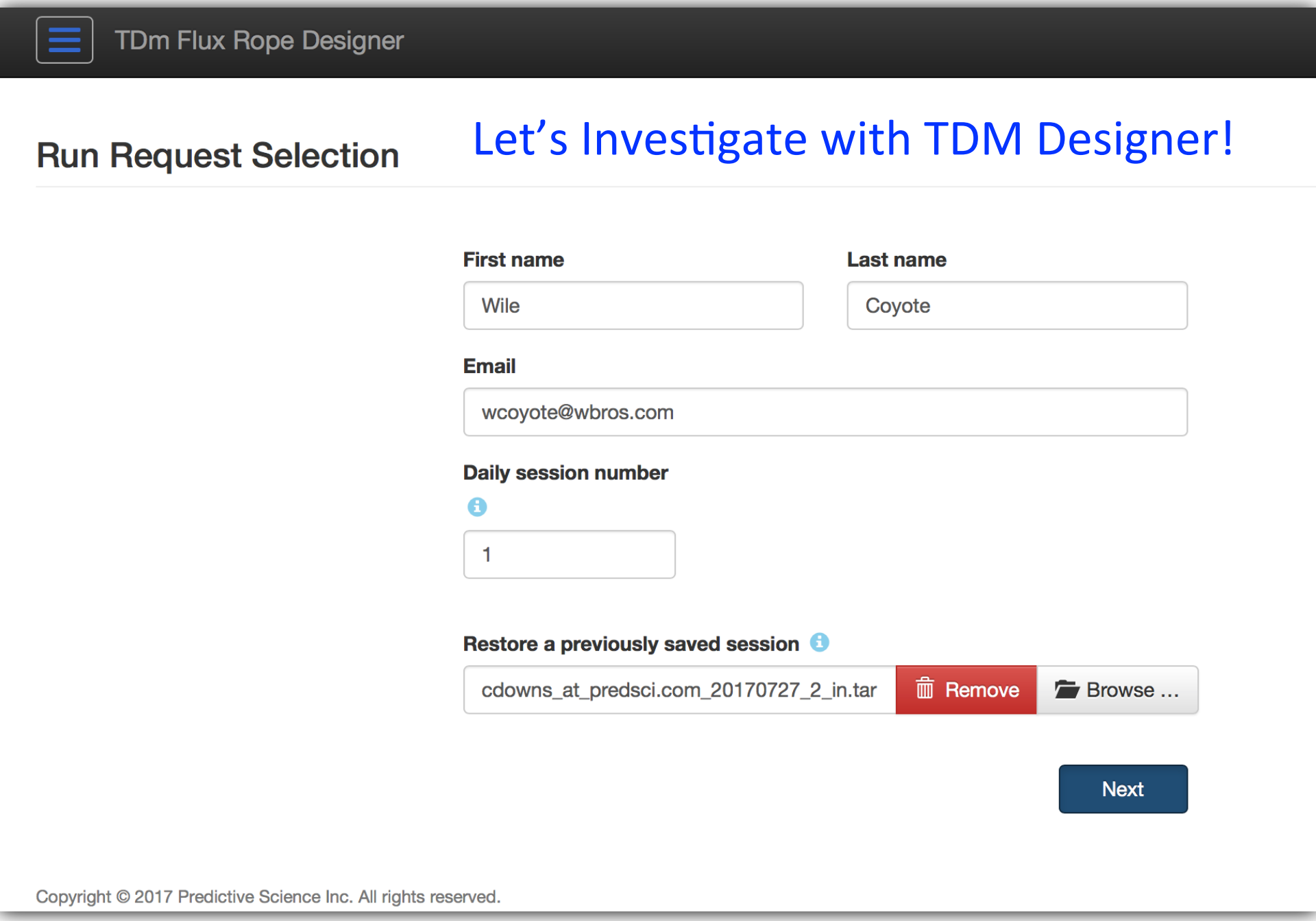
SDO HMI Magnetogram

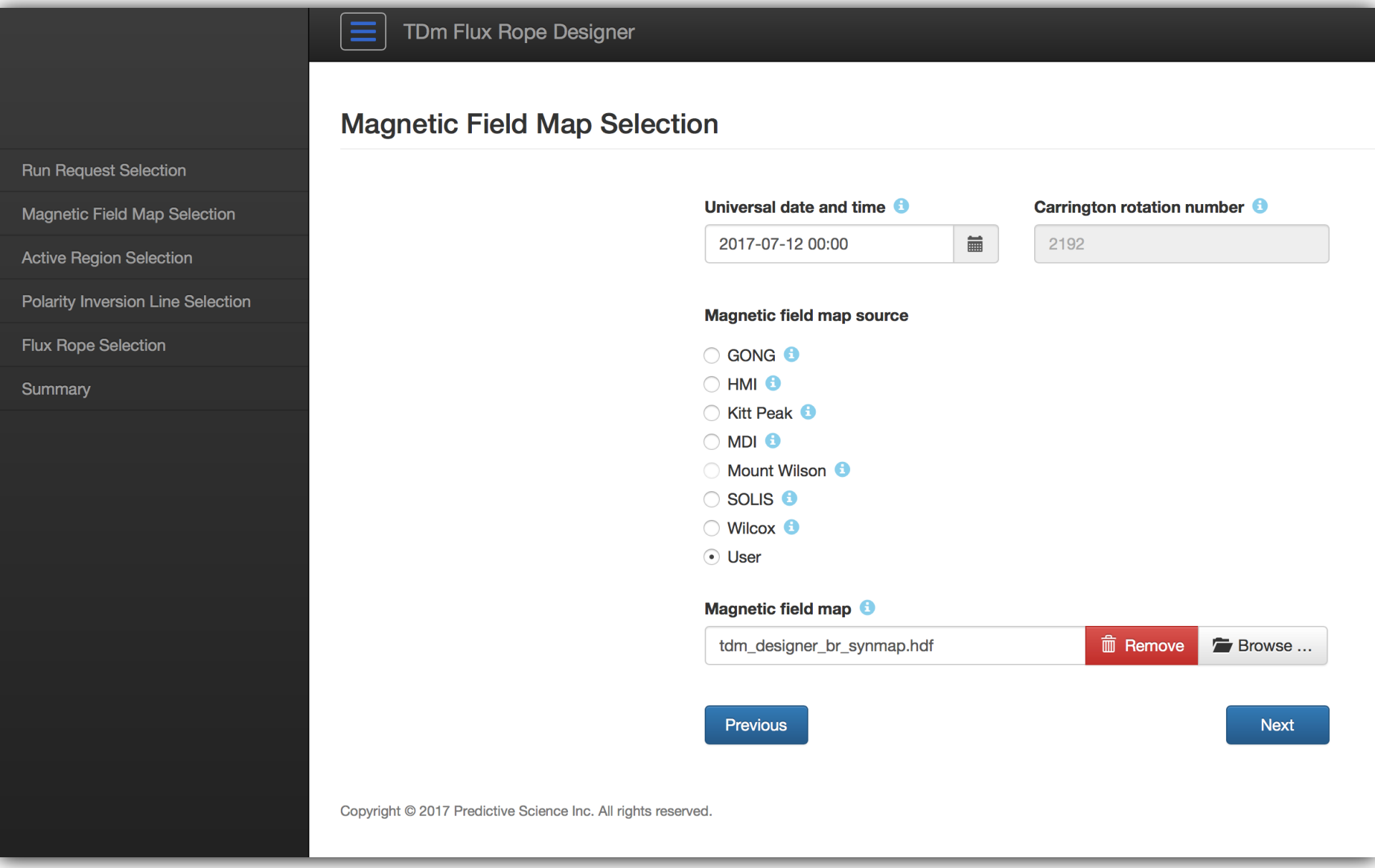


SDO AIA 193



SOHO LASCO C3




TDm Flux Rope Designer
Run Request Selection
Magnetic Field Map Selection
Active Region Selection
Polarity Inversion Line Selection
Flux Rope Selection
Summary
Magnetic Field Map Selection
Universal date and time
2017-07-12 00:00
Carrington rotation number
2192
Magnetic field map source
GONG
HMI
Kitt Peak
MDI
Mount Wilson
SOLIS
Wilcox
User
Magnetic field map
tdm_designer_br_synmap.hdf
Remove
Browse ...
Previous
Next
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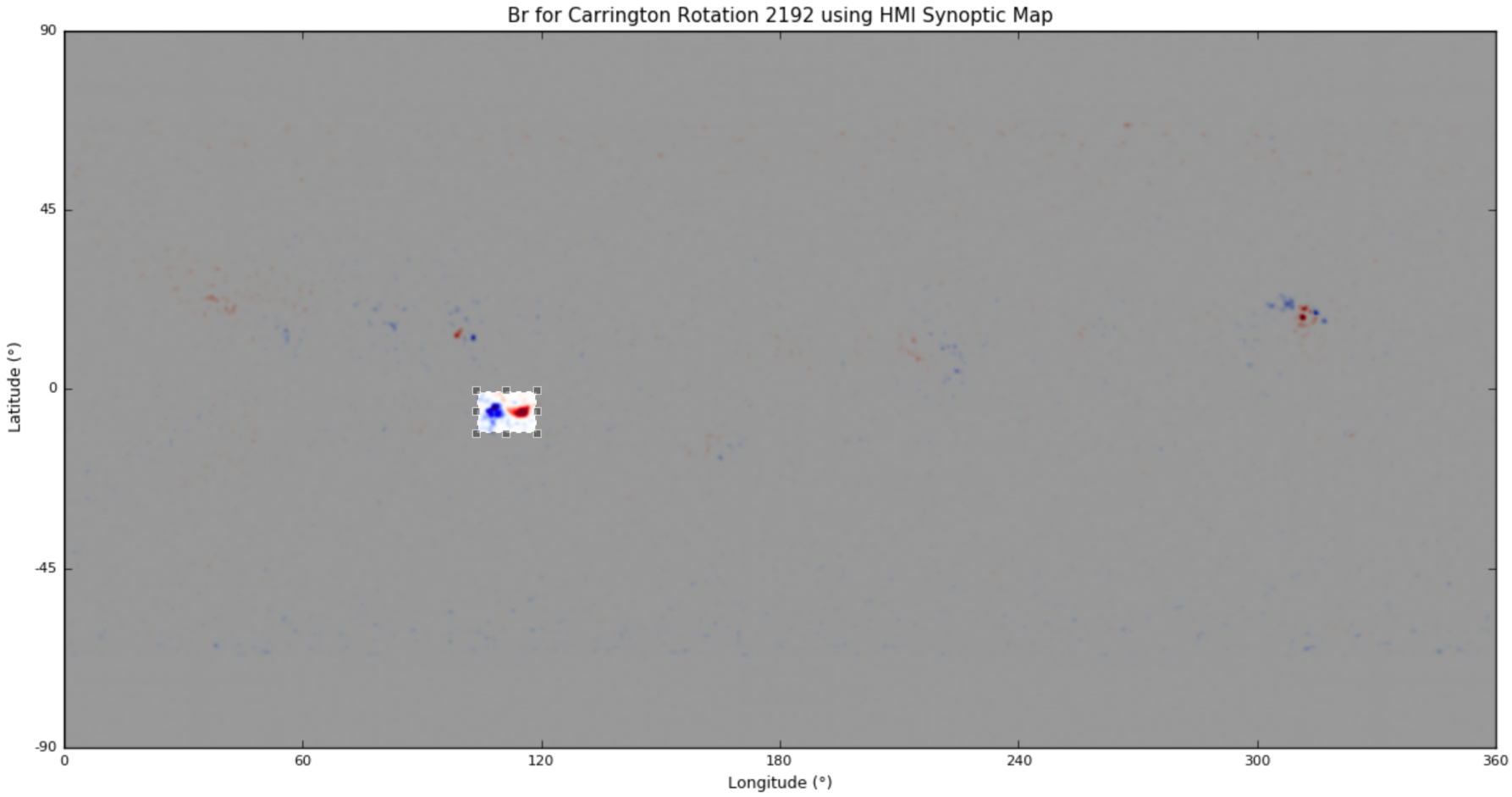
TDm Flux Rope Designer

Take a tour

Select an active region of interest by clicking and dragging the cursor on the magnetic field image or entering the position of the top-left and bottom-right corners of the rectangle under AR Selection tab.



TDm Flux Rope Designer

Take a tour

Active Region Selection

Active region selection

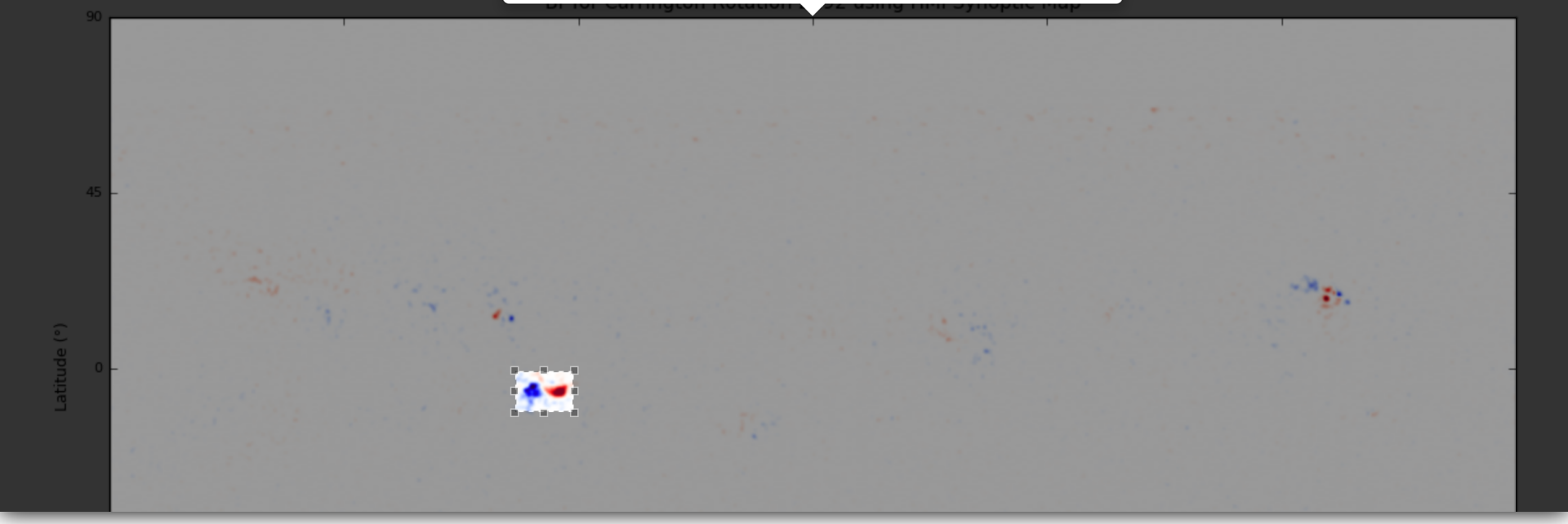
Select an active region of interest by clicking and dragging the cursor on the magnetic field map. In general, a smaller area of selection requires less computing power and/or time.

« Prev | Next »

End tour

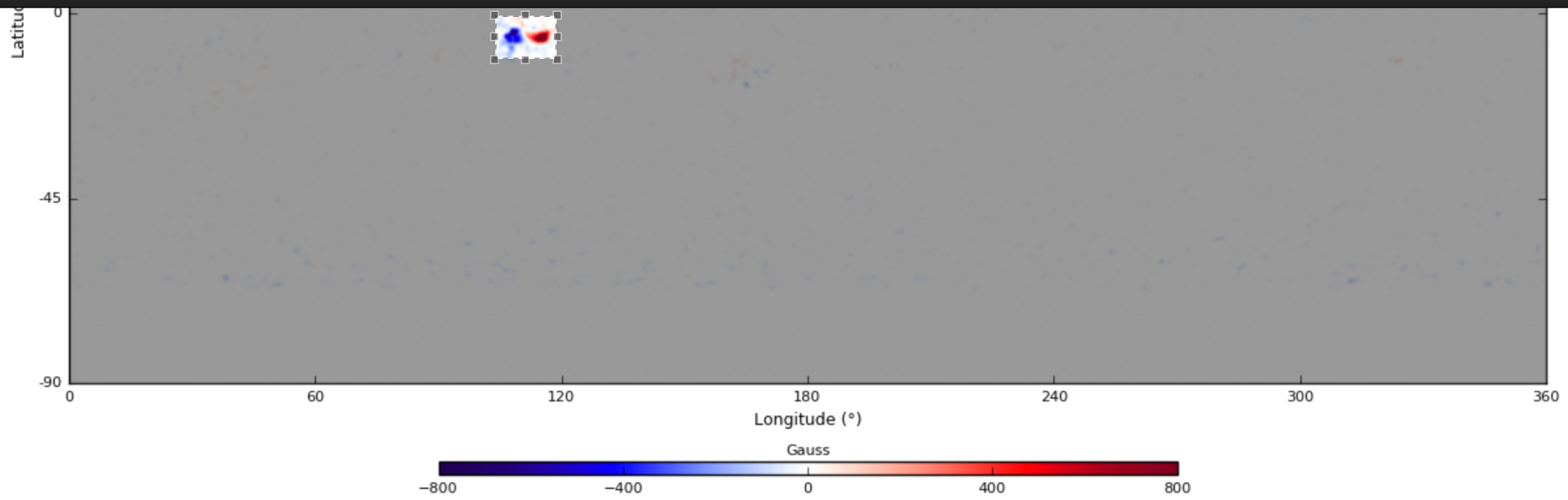
Select an active region of interest by clicking and dragging

nd bottom-right corners of the rectangle under AR Selection tab.



TDm Flux Rope Designer

Take a tour



Magnetic Flux Info

Negative flux (10^{22} Mx)	Positive flux (10^{22} Mx)	Fractional flux imbalance
-1.32	1.42	7.411e-2

B_r Image Scaling | **AR Selection** | **Mesh Resolution**

Minimum scale

-800.00 Gauss

Maximum scale

800.00 Gauss

Color palette

Blue Red

☑ Symmetric min/max scale values

Previous

Reset

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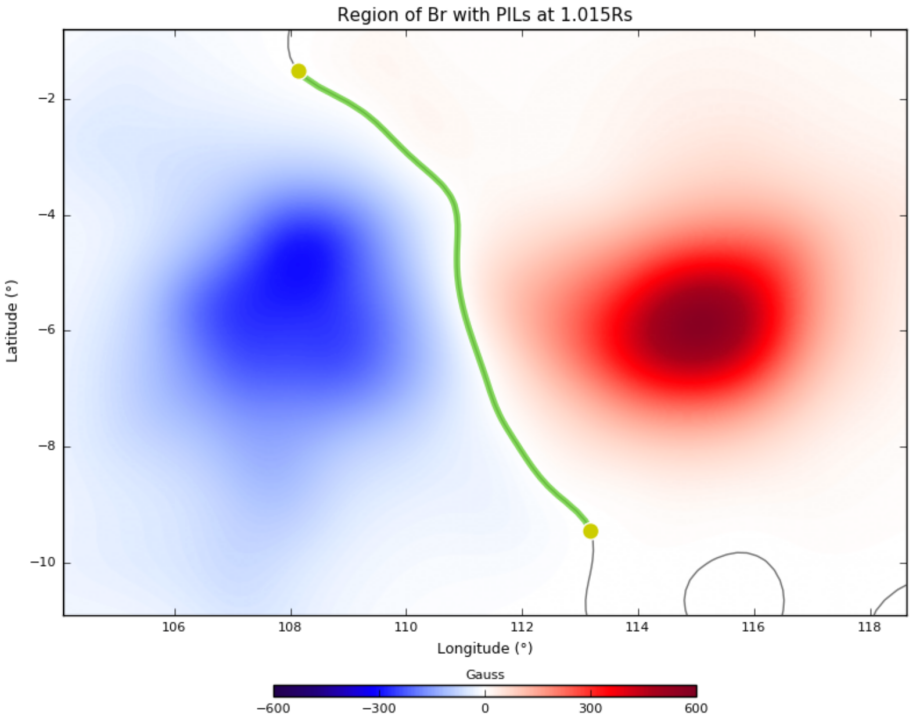
TDm Flux Rope Designer

Take a tour

Polarity Inversion Line Selection

Select a polarity inversion line (PIL) segment by clicking on or near a PIL on the active region image twice, one for each desired end point. The first click selects a point on a PIL closest to the click position. The second click selects another point on that PIL closest to the click position. Each subsequent click moves the closest end point to the click position in the same way as the second click.



AR Image Scaling | PILs Radial Height | PIL Selection Info

Radial height

1.015 Rs

View PILs at photosphere

Previous

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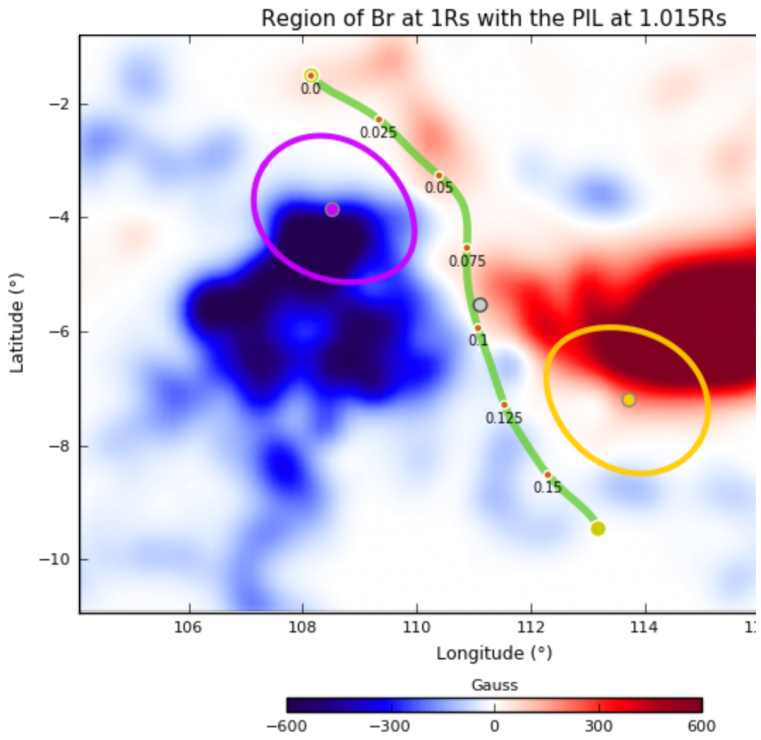
Next

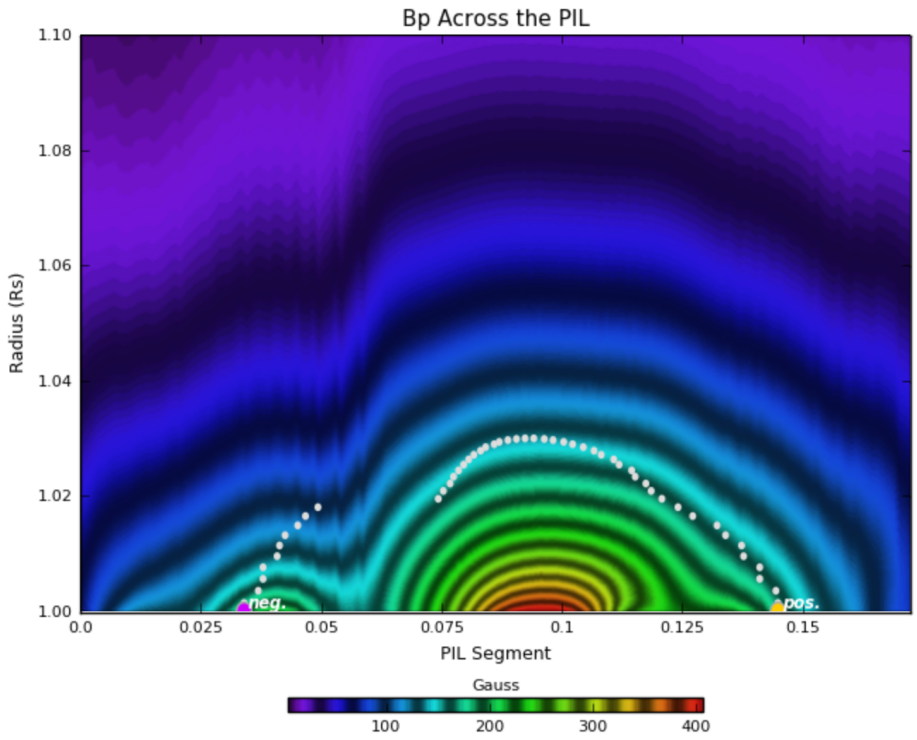
TDm Flux Rope Designer

Take a tour

Flux Rope Selection

Select flux rope location by clicking on the active region image (left) or entering the coordinate positions under Foot Points Selection tab. The first click selects the center of the positive polarity foot point (orange point). The second click selects the center of the negative polarity foot point (purple point). Each subsequent click moves the closest foot point to the click position.



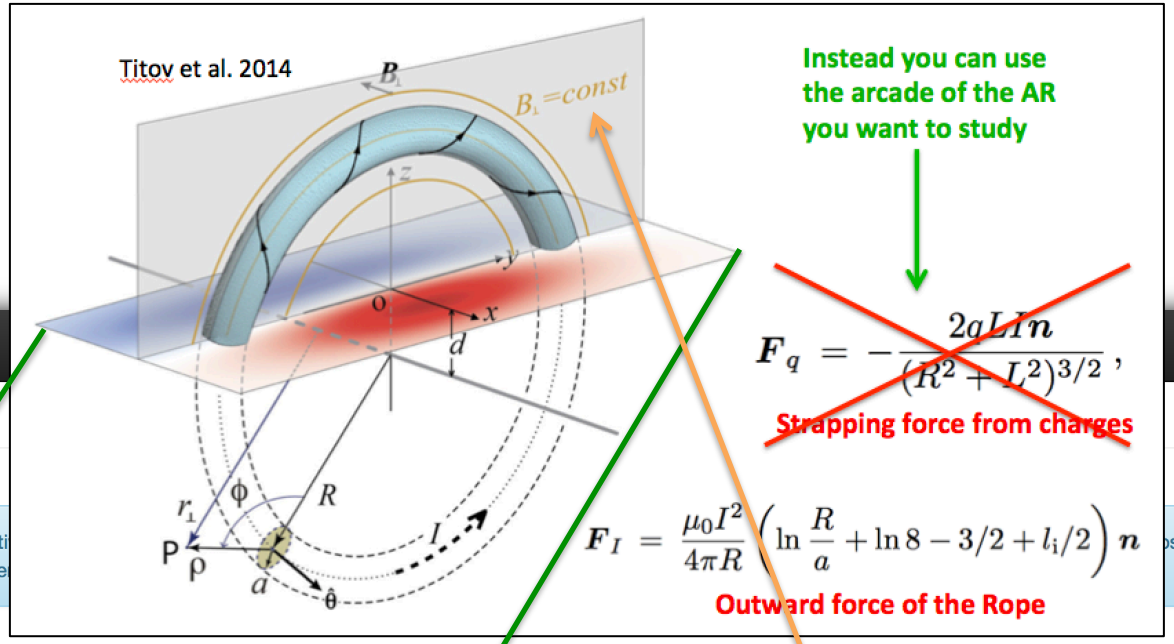


TDm Flux Rope Designer

Take a tour

Flux Rope Selection

Select flux rope location by clicking on the acti … positive polarity foot point (orange point). The second click selects the ce…



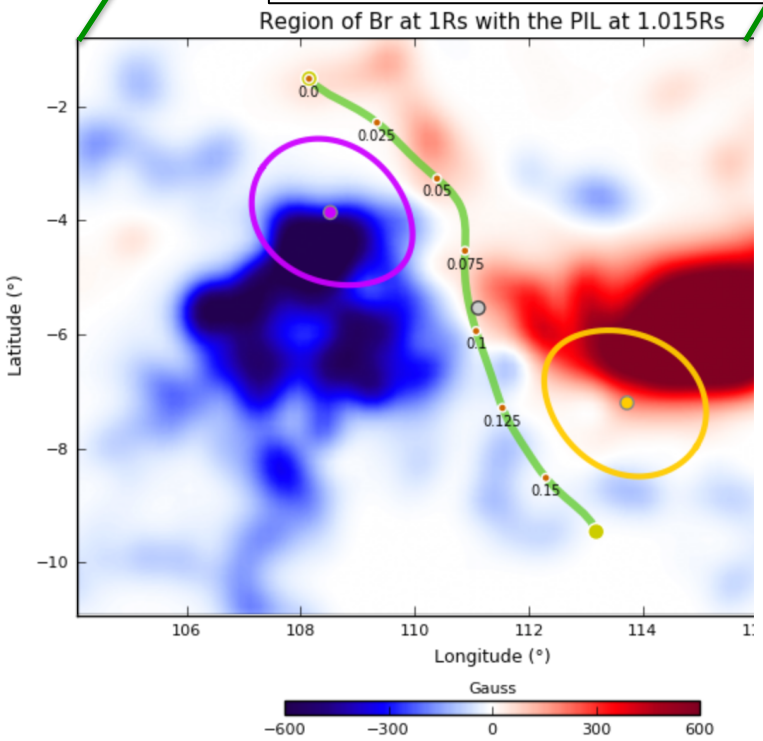
Instead you can use the arcade of the AR you want to study

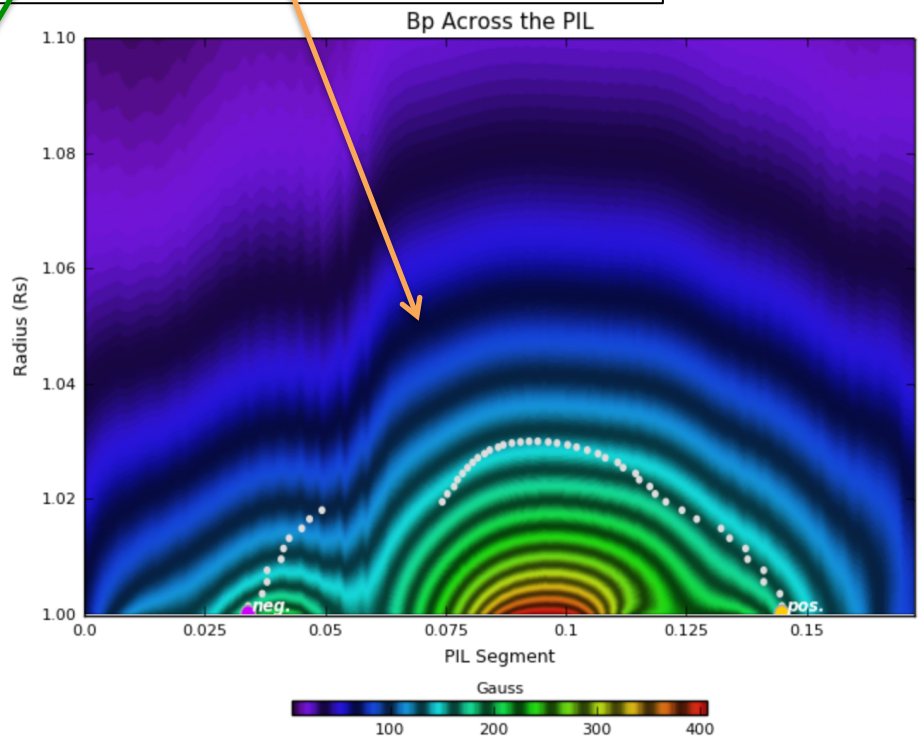
$$\boldsymbol{F}_q = -\frac{2qLI\boldsymbol{n}}{(R^2+L^2)^{3/2}},$$

Strapping force from charges

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

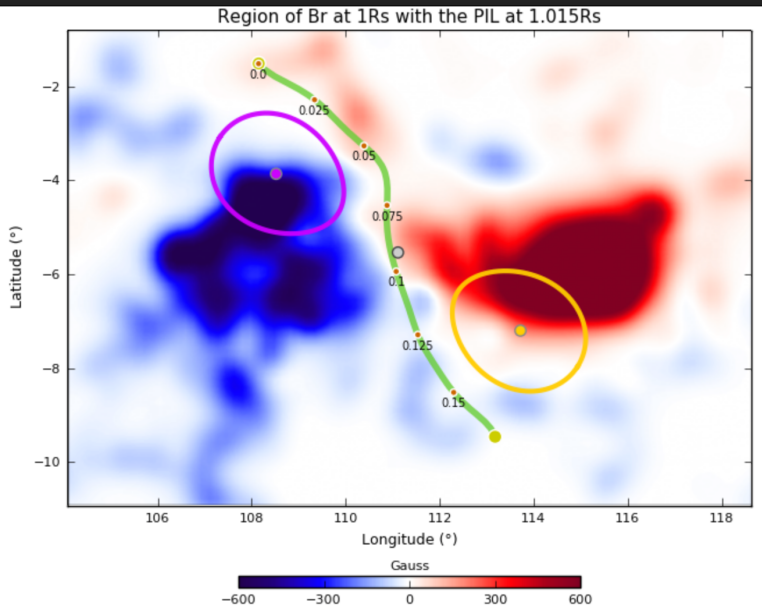
Outward force of the Rope

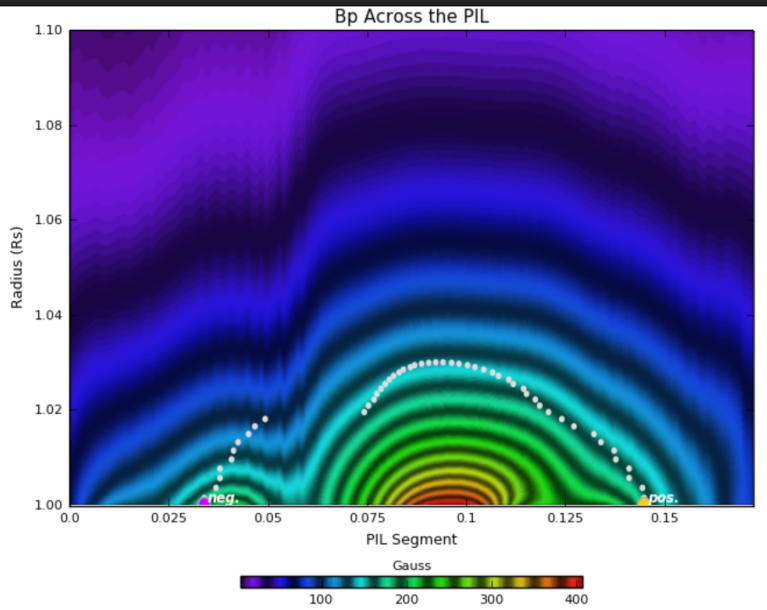




TDm Flux Rope Designer

Take a tour





Magnetic Flux Info

	Negative flux (10^{22} Mx)	Positive flux (10^{22} Mx)
Total flux of the selected active region	-1.298	1.413
Total flux of the TDm flux rope	-0.621	0.621
Magnetogram flux in the negative TDm foot point	-0.243	0.000
Magnetogram flux in the positive TDm foot point	-0.001	0.237
Axial flux of the TDm flux rope	-0.141	
Axial flux as fraction of magnetogram flux	-58.17%	59.57%

Strapping Field Info

	B_p (Gauss)
Average	147.29
Standard deviation	15.71
Value at apex height	138.65

AR Image Scaling | **B_p Image Scaling** | **Foot Points Selection** | **Flux Rope Properties**

Apex height 0.0300 Rs

Fractional width 0.7000

Foot point half distance 0.0537 Rs

Radius 0.0631 Rs

Fraction of average B_p 0.6000

Flux rope B_p 88.3737 Gauss

View subtracted magnetic field

Preserve magnetogram

Microsoft Word

Previous

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Summary

Thank you for using **TDm Flux Rope Designer**.

An output archive file containing a set of files for running TDm zero-beta simulation model using CORHEL is available below. You can also find information about the size of this simulation run compared to an average size simulation run and recommendation on selecting the number of processors to run this simulation model.

Download

Number of processors / node (•) 16 ( ) 20 ( ) 24 ( ) 28

Zero-beta Simulation Model Run Size Info

	Resolution	Processors decomposition	Number of processors	Estimated run time
Average run	150 x 200 x 250	4, 6, 8	192	20.00 minutes
Current run	137 x 184 x 234	4, 6, 8	192	16.39 minutes
Current run with optimal run time	137 x 184 x 234	5, 6, 8	240	13.11 minutes

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.

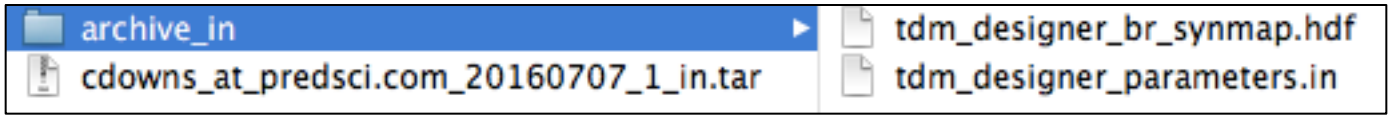
Download

Previous

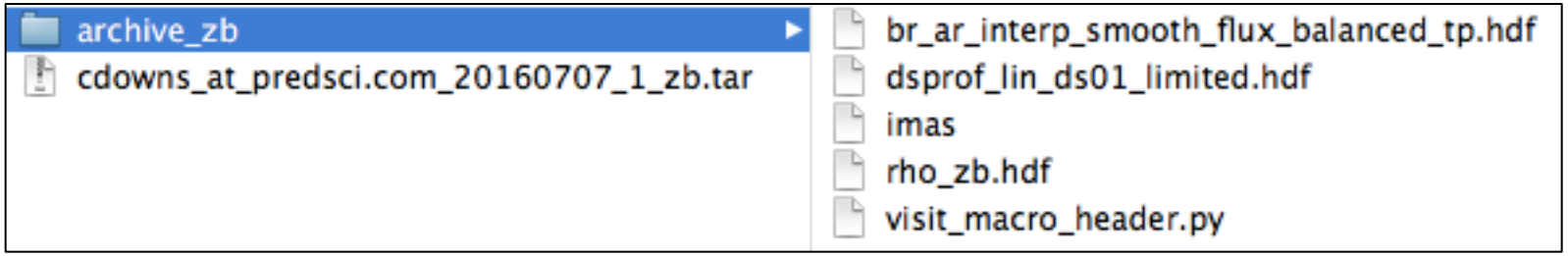
Done

Interface Outputs

- Interface Archive (*.in.tar)
  - Contains all parameters chosen in the interface session and the input magnetic map.
  - The archive can be loaded by the interface. Used to repeat/modify a previous session.



- Files for a zero-β MAS/CORHEL Run (*.zb.tar)
  - Contains all files necessary for a CORHEL-CG zero-beta run.
  - Run parameters (ifile).
  - 2D B_r map + 3D density/viscosity files.
  - ViSiT macro file tailored for the run.



Post-Processing the Result

- Use an automated script to generate diagnostics directly from the raw run results on the compute machine (no need to transfer data).
- History plots are generated with R scripts.
- Movies are generated using ViSiT:
  - The run-specific python macro is called by ViSiT in batch mode from command line.
  - With a general macro developed, it is easy to add/modify visualizations for new/ different applications.
- Everything combined into single folder with .html file.
  - Everything viewable in a web browser! Locally or remotely.
- Browsing results from several runs is as easy as switching browser tabs.

Run Visualization Page

TDm Zero-Beta Simulation Run

Cooper

file:///Users/cdowns/Dropbox/Writeups/CCMC_2018_Talk/InterfaceVisualizations/AR12665_Pre...

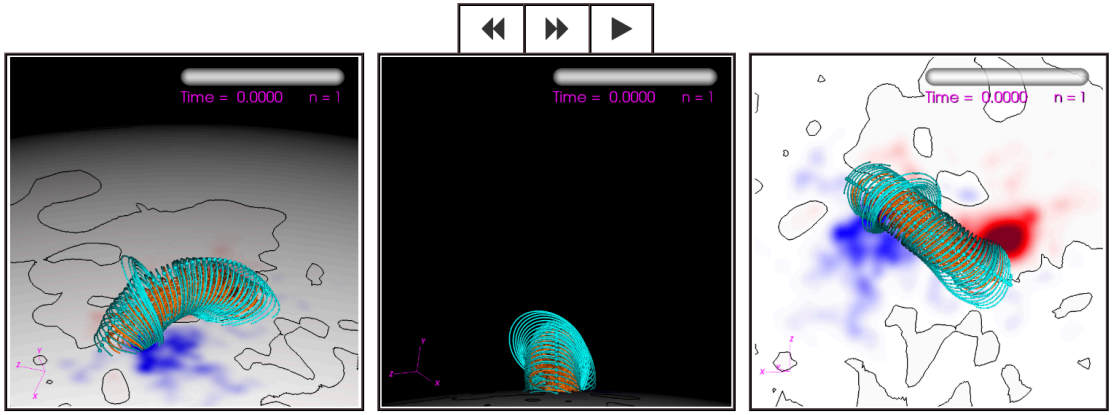
TDm Zero-Beta Simulation Run Report

Run ID: cdowns_at_predsci.com_20170727_1_zb

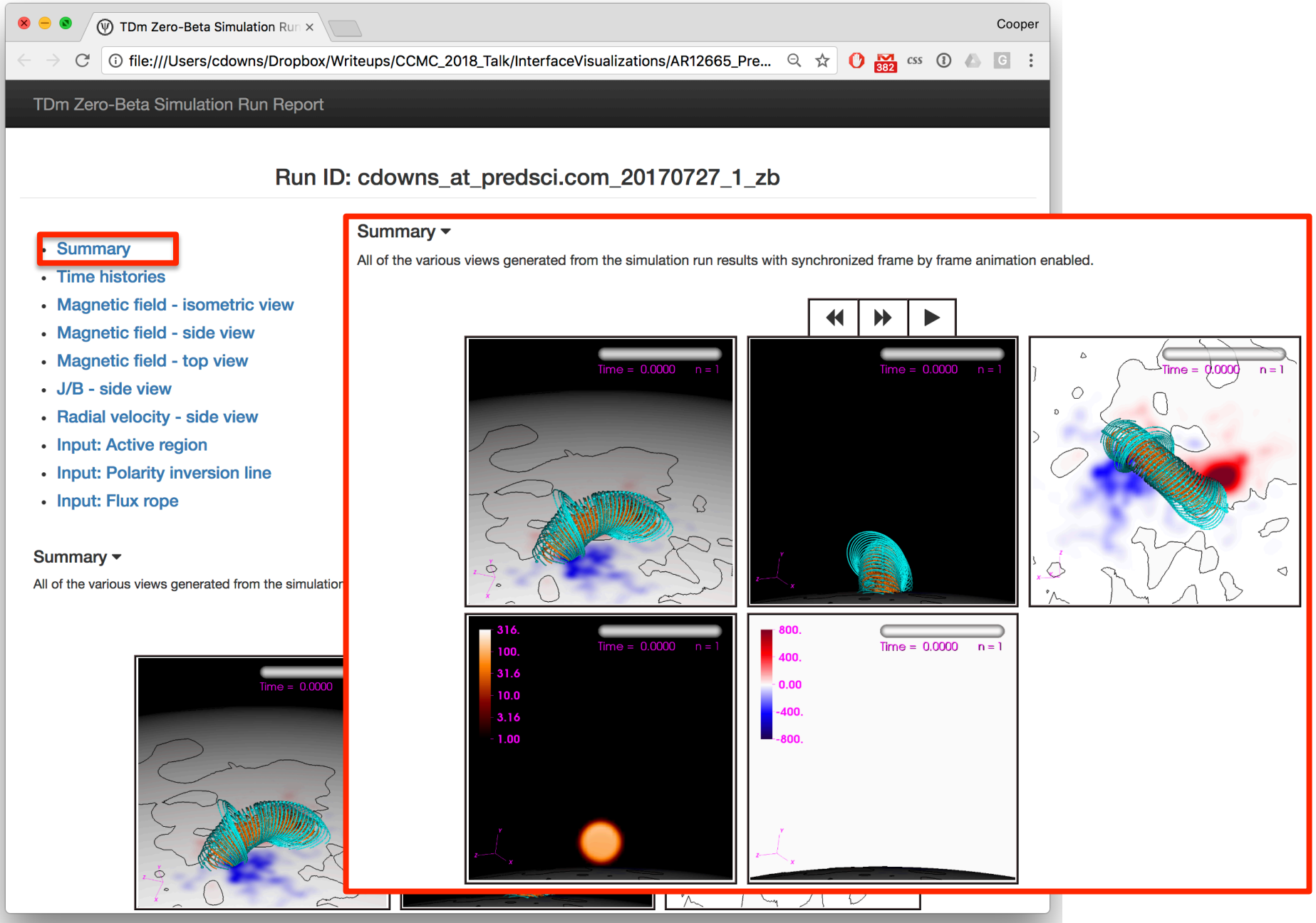
Summary

back to top

All of the various views generated from the simulation run results with synchronized frame by frame animation enabled.



Run Visualization Page



Run Visualization Page

TDm Zero-Beta Simulation Run

Cooper

file:///Users/cdowns/Dropbox/Writeups/CCMC_2018_Talk/InterfaceVisualizations/AR12665_Pre

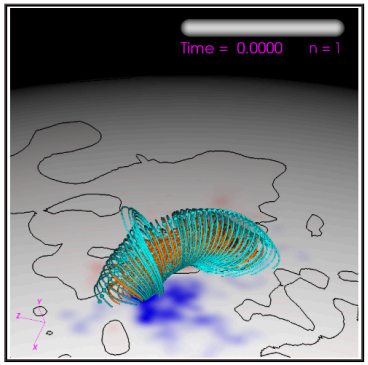
TDm Zero-Beta Simulation Run Report

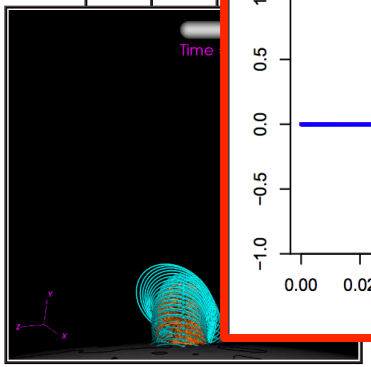
Run ID: cdowns_at_predsc

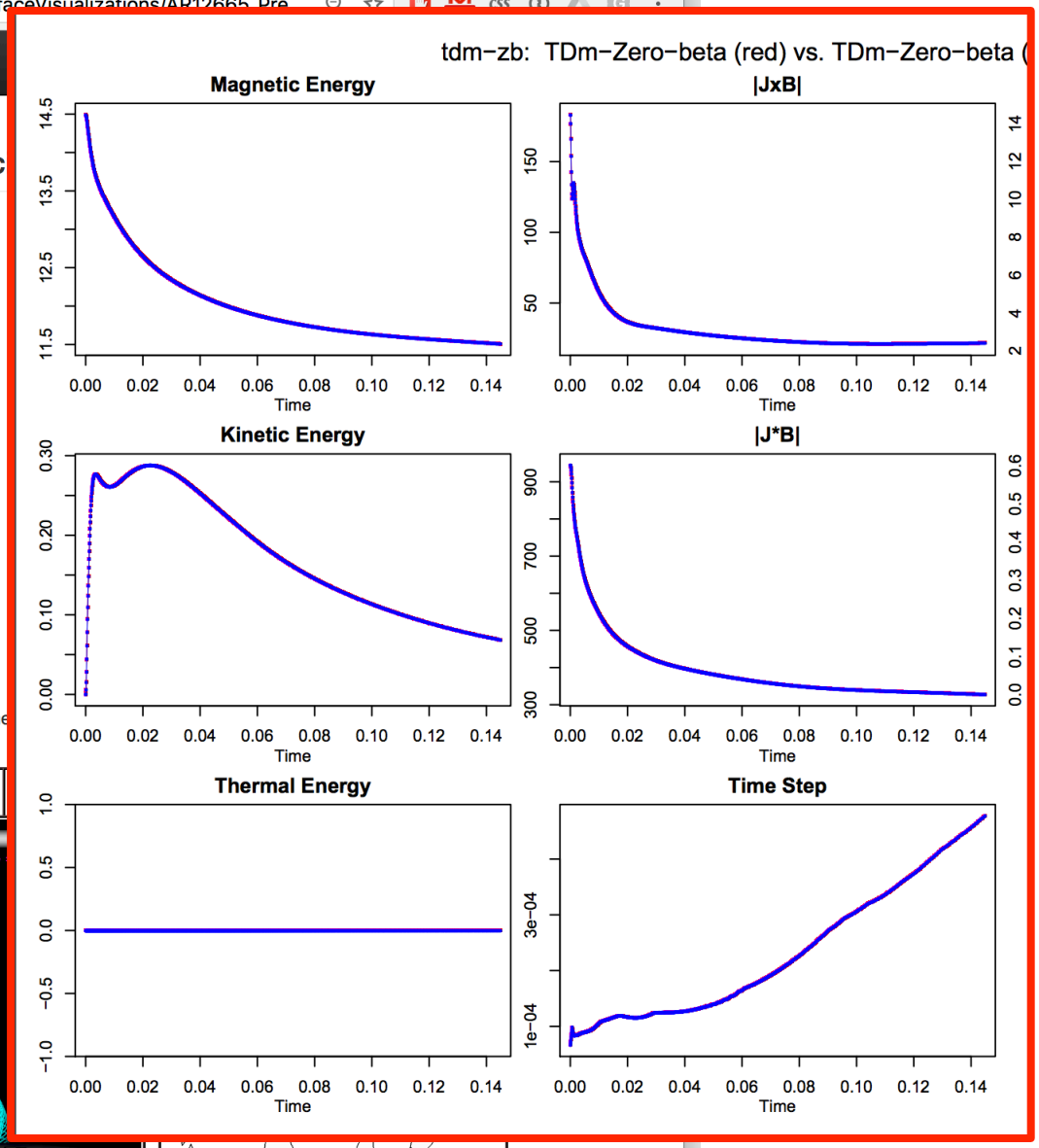
- Summary
- Time histories
- Magnetic field - isometric view
- Magnetic field - side view
- Magnetic field - top view
- J/B - side view
- Radial velocity - side view
- Input: Active region
- Input: Polarity inversion line
- Input: Flux rope

Summary

All of the various views generated from the simulation run results with synchronized frame







Run Visualization Page

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TDm Zero-Beta Simulation Run Report

Run ID:

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- Input: Active region
- Input: Polarity inversion line
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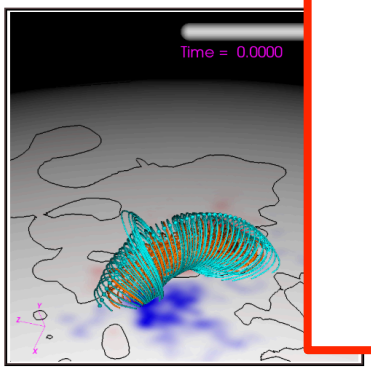
Summary

All of the various views generated from the simulation



Input: Flux rope

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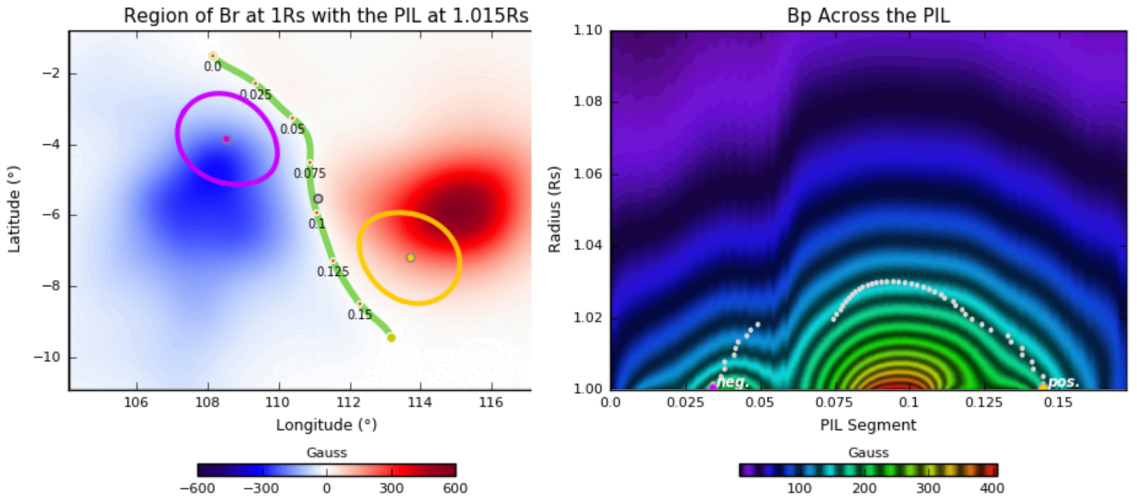
Left figure: Selected centers of the positive and negative polarity footpoints (orange and purple points) and the intersections of the flux rope with the active region at the photosphere (orange and purple contours) and the PIL segment. The composite figure shows the active region with the flux rope field subtracted from the magnetic field.

Right figure: Contours of the strapping field in the vertical plane tangent to the PIL segment.



Magnetic Flux Info

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Total flux of the selected active region	-1.298	1.413
Total flux of the TDm flux rope	-0.829	0.829
Magnetogram flux in the negative TDm foot point	-0.243	0.000
Magnetogram flux in the positive TDm foot point	-0.001	0.237
Axial flux of the TDm flux rope	-0.189	
Axial flux as fraction of magnetogram flux	-77.60%	79.47%

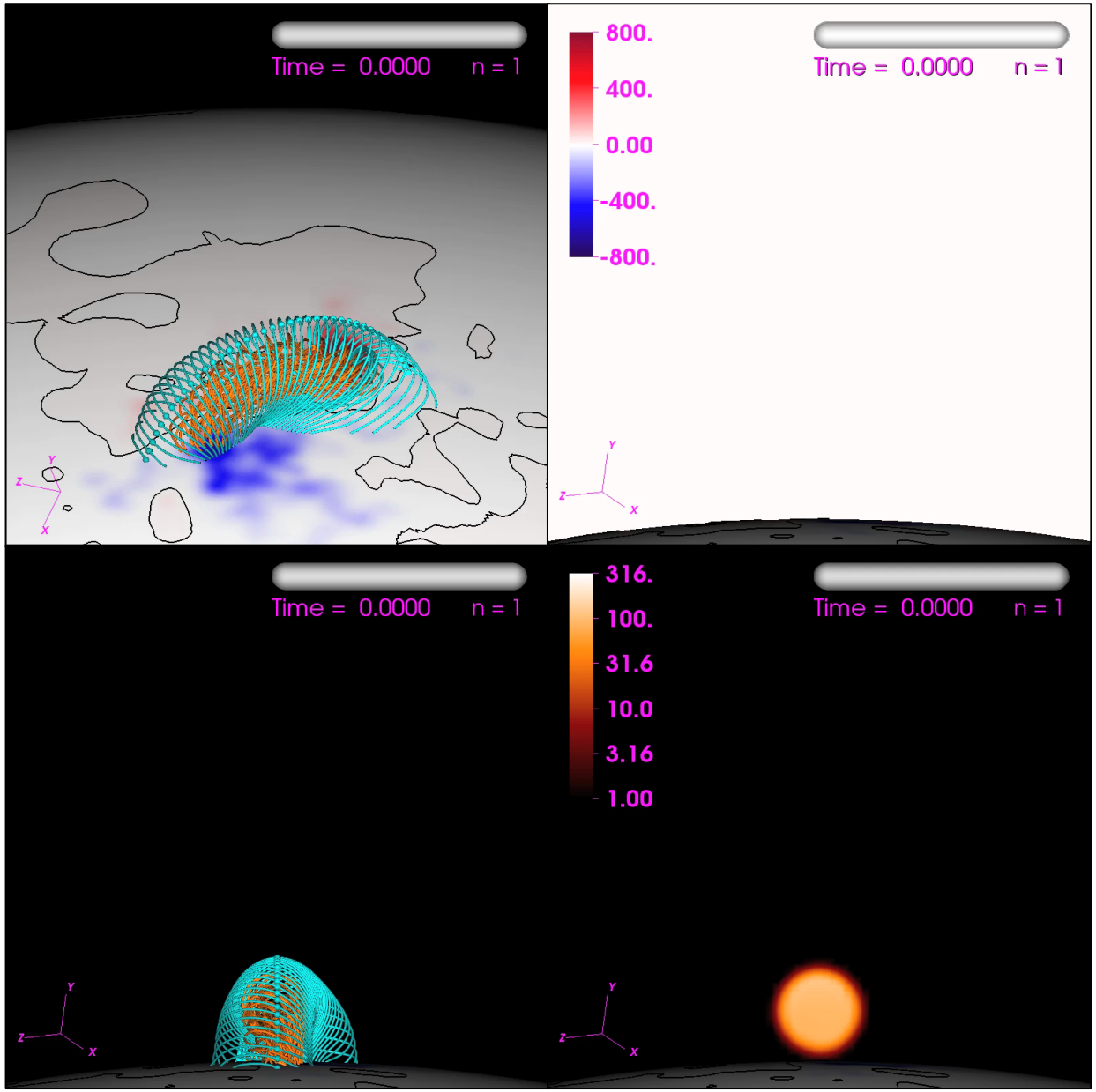
Strapping Field Info

	B_p (Gauss)
Average	147.38
Standard deviation	15.56
Value at apex height	138.64
B_p of the TDm flux rope	117.90
B_p as fraction of average B_p	80.00%

Flux Rope Info

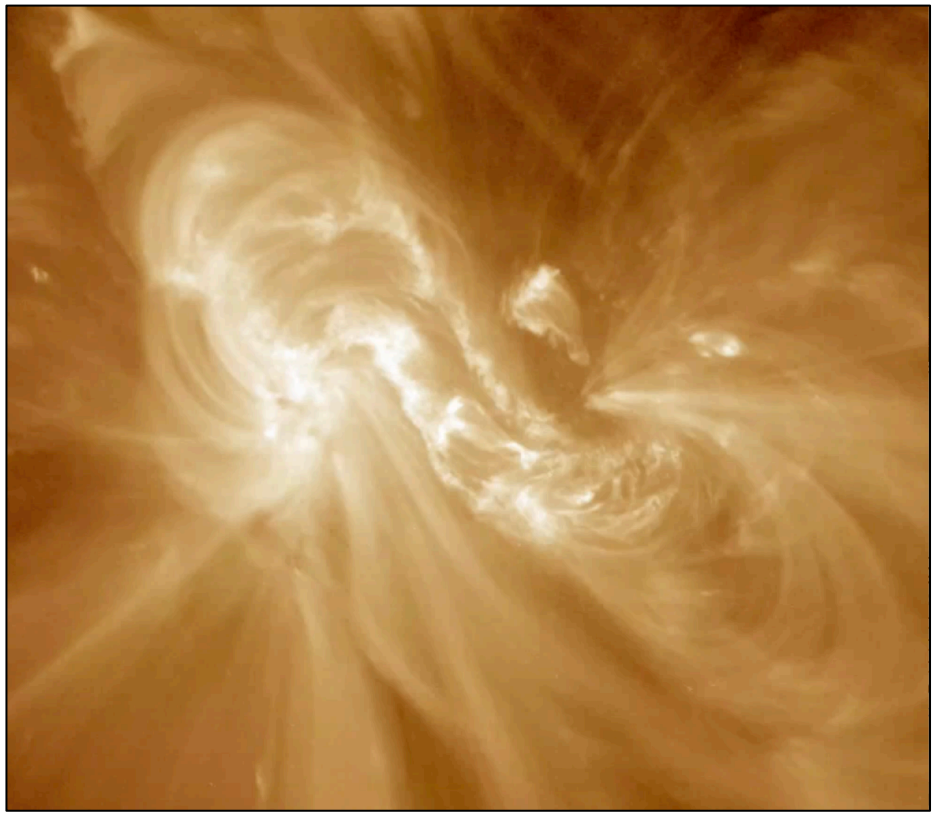
Apex height (Rs)	Fractional width	Foot point half distance (Rs)	Radius (Rs)
0.0300	0.7000	0.0537	0.0631

Run Visualization: Stable Case (Bp frac 0.6)

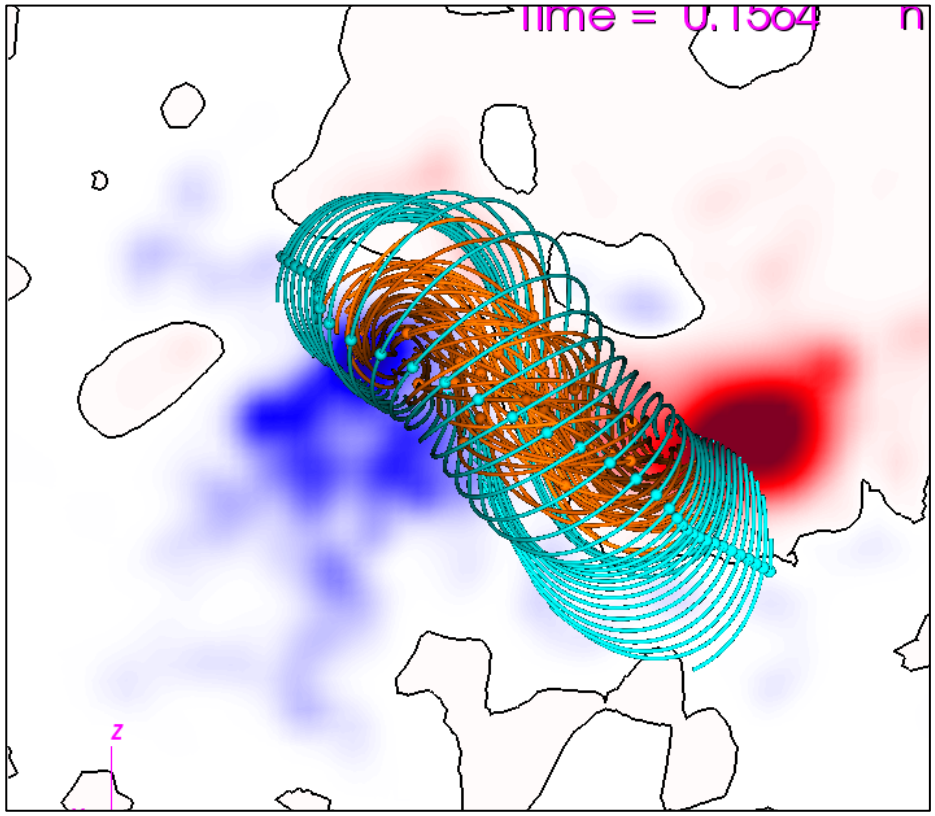


Run Visualization: Stable Case (Bp frac 0.6)

- **Now:** Easy to qualitatively compare to readily available data.
- **Future:** Leverage Helioviewer API to automatically get images and make co-aligned comparisons.

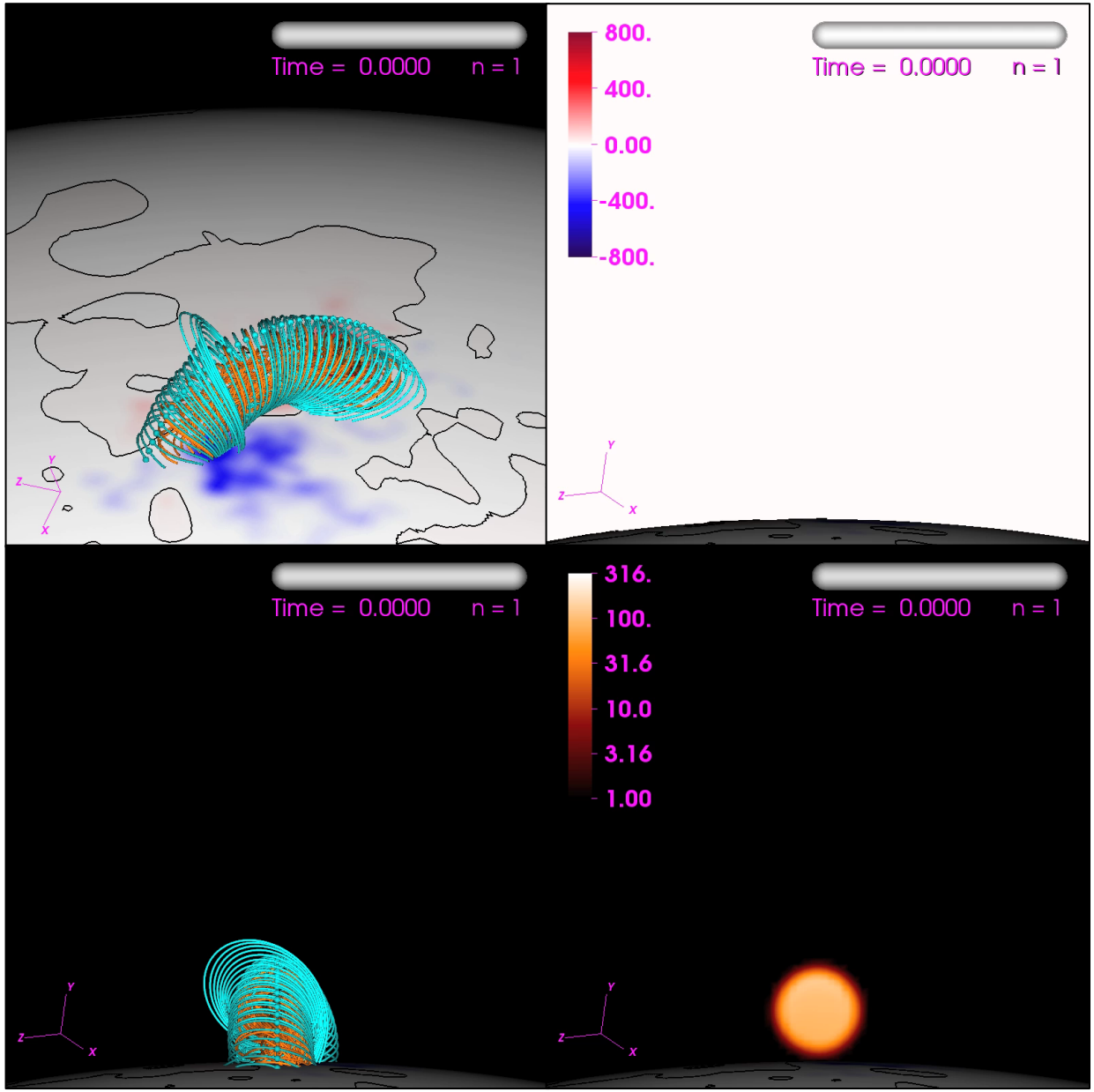


SDO AIA 193 (from jHelioviewer)



TDm Top Down view

Run Visualization: Unstable Case (Bp frac 0.8)



Summary / Next Steps

- We have a developed a production ready version of the TDm Designer interface for CME generation.
- The webapp gets you from map selection all the way to run generation, and has save/load functionality.
- Just pass the output to the main CORHEL-CG script and it will launch a batch MPI job.
- The automatic diagnostics/movies are made in the same job, placed in a self contained archive with all the .html for viewing inside.
- We have delivered the interface to CCMC.

Next Steps?:

- Make CCMC version of TDm Designer / CORHEL-CG live.
- Use TDm interface to power thermodynamic MHD runs [end goal].
  - Once you like a zero-beta solution, can try it in the full physics model
  - This is much more computationally intensive, and requires new techniques to make feasible (run-remeshing/interpolation, time-dependent background]

Extra Slides

Run Optimization

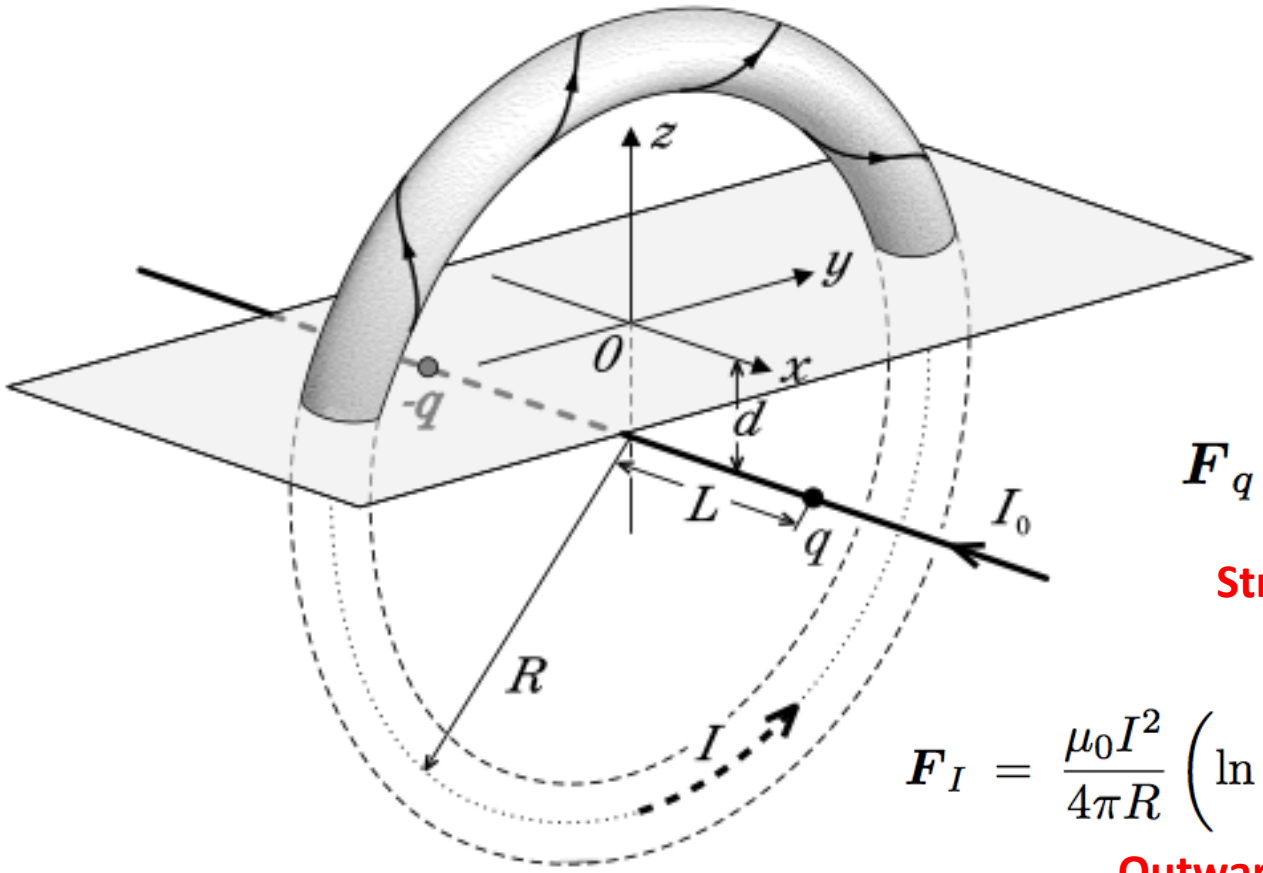
- Optimize zero-β mesh for speed.
  - Modest resolution for selected AR region (defualt ds = 0.004 R_s = 3Mm) .
  - Finer resolution in rope region only, set by the minor radius: ds=a/10.
  - Mesh spacing grows exponentially outside region of interest.

- Run time controlled by Alfvén timescale for the region.
  - 10x Alfvén crossing times for the FR length (before insertion).
  - Could probably go lower, usually its clear if stable/non-stable.

- This run was 137x184x234 and took ~10min on 140 cores
  - Scales to ~1hr 20min on 24 cores.
  - This is already fast, but we are exploring GPU optimization so that rapid (<20 min) runs can be done on a local workstation.
  - Could probably coarsen things as well (more testing needed).

TD Flux Rope

Titov & Démoulin 1999



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

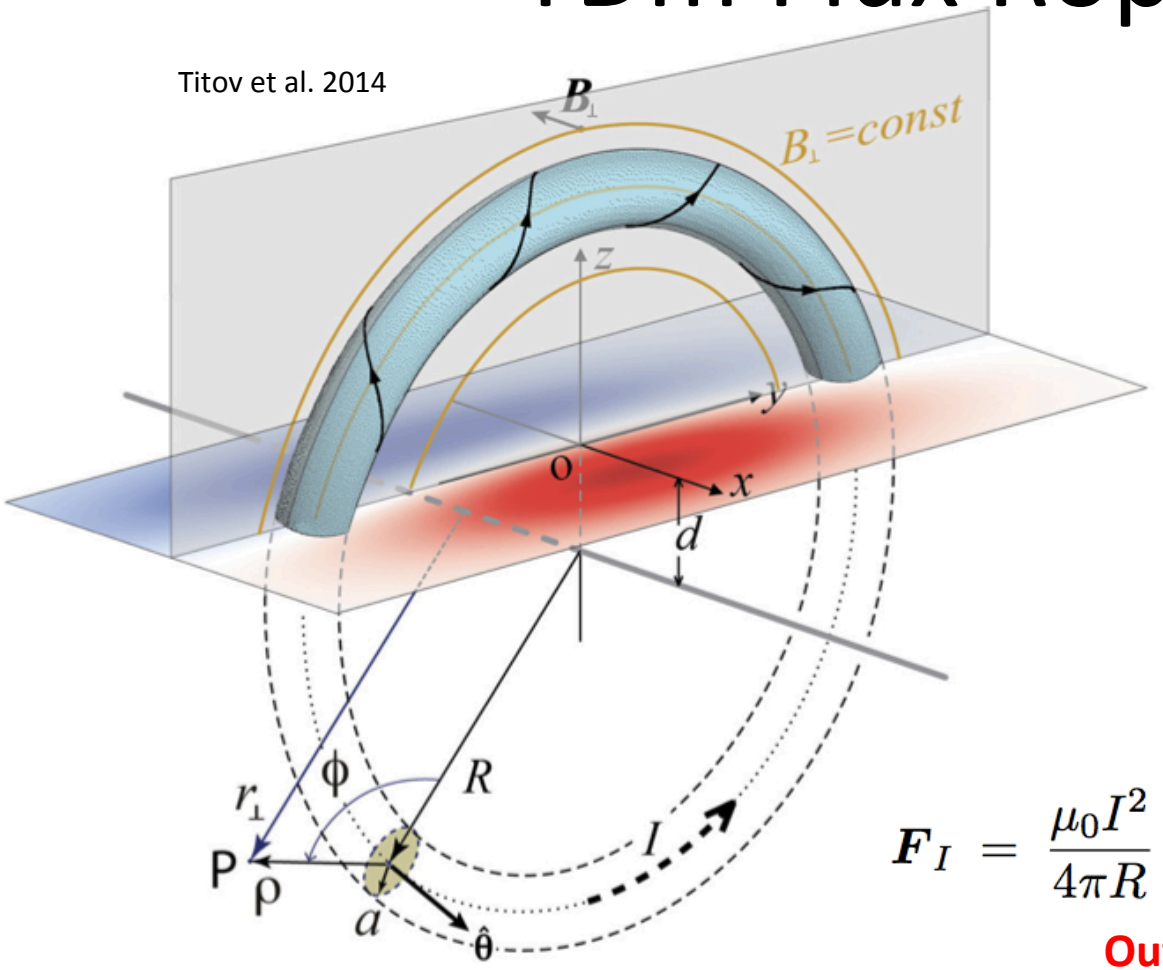
Strapping force from charges

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

Outward force of the Rope

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

TDm Flux Rope



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