Nonlinear Force-Free Field Modeling of a Small but Dynamic Active Region

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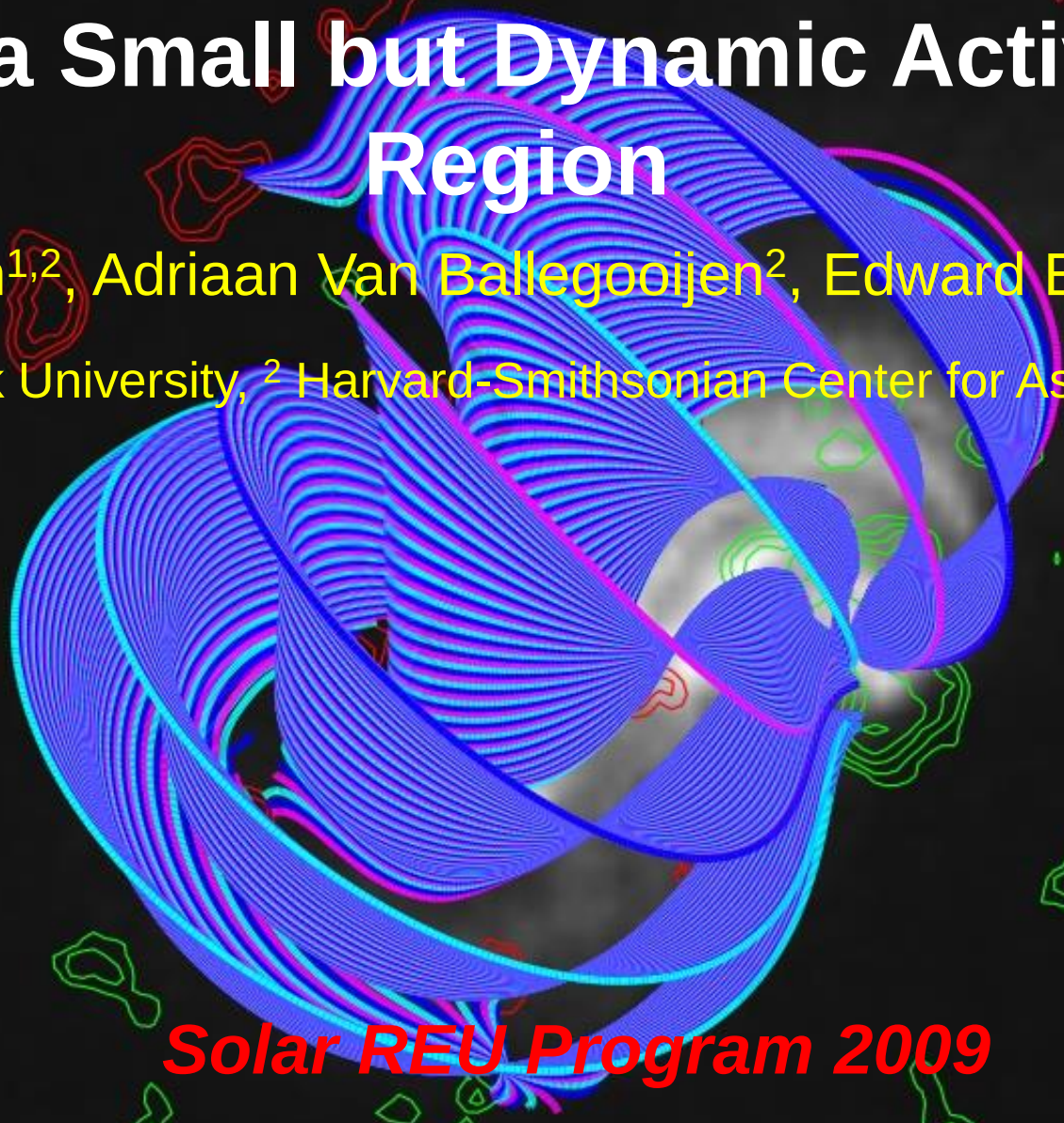
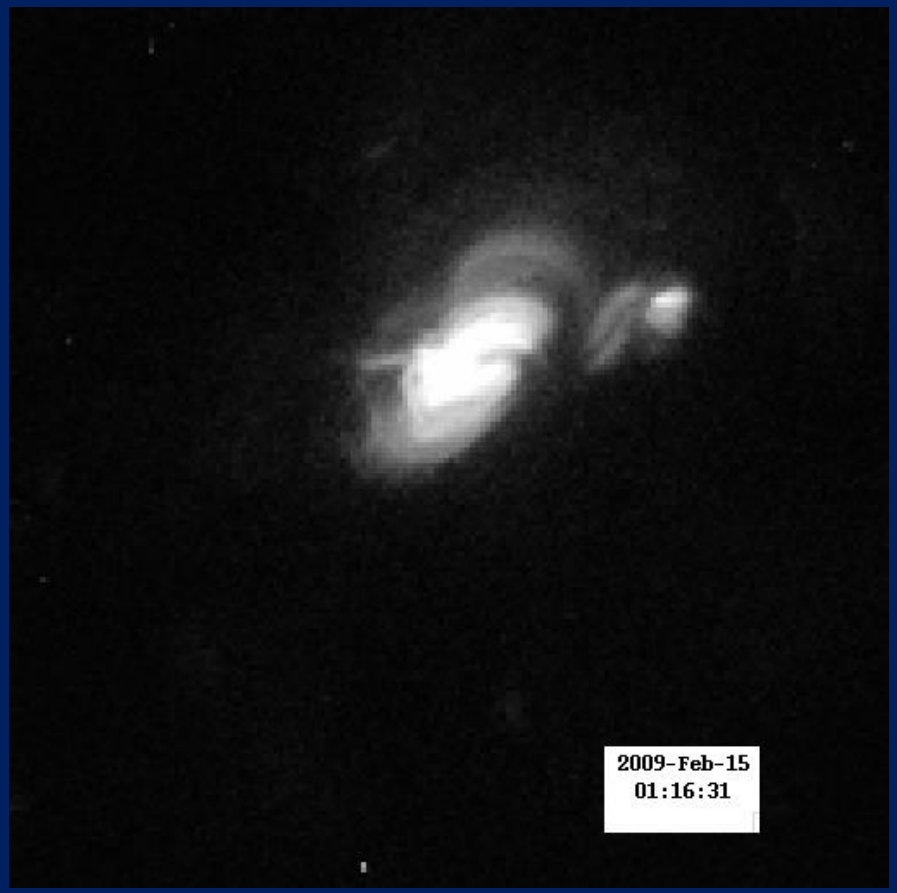
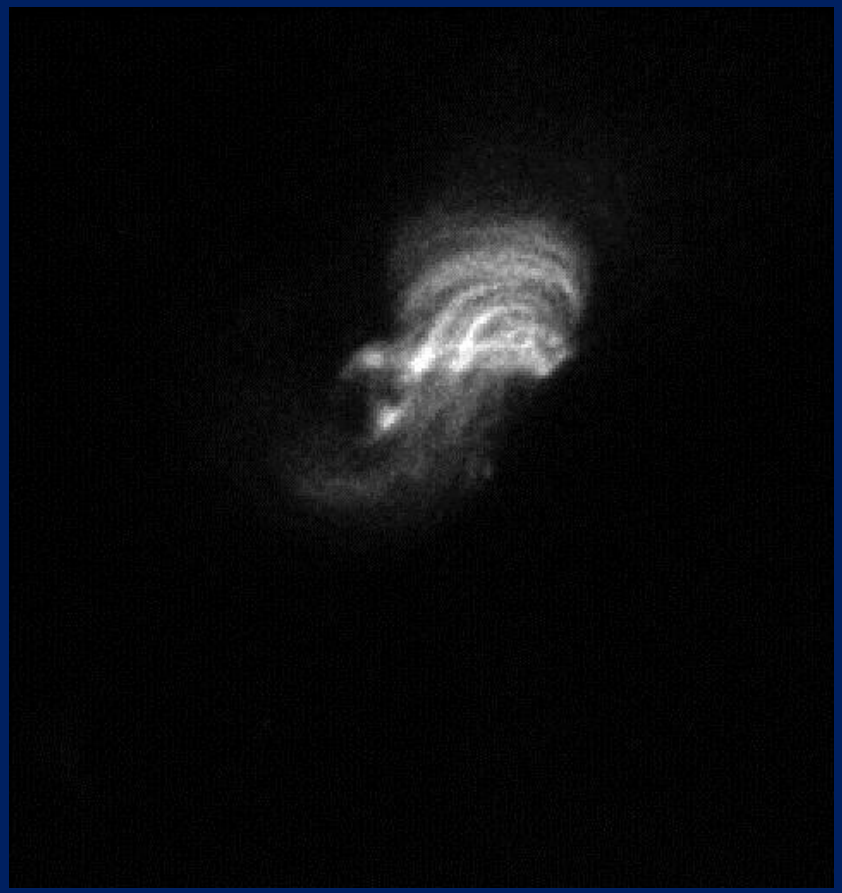


Solar REU Program 2009

Active Region in the Quiet Sun

XRT Images





Purpose of Study

- Scientific
  - magnetic topology of coronal structure
  - insight into photosphere-corona interaction
  - evolution of structural changes (static)
  - physical parameters: energy, helicity

- Methods
  - NLFFF (nonlinear force-free field modeling)
  - advancing techniques of extrapolating magnetic structure from photospheric observation

Nonlinear Force-Free Field Modeling: Concept and Theory

$$\rho\frac{Dv}{Dt} = -\nabla p + \rho g + J \times B$$

$$\vec{J} \times \vec{B} = 0 \Rightarrow force - free$$

$$\nabla \times \vec{B} = \alpha \vec{B} \Rightarrow \vec{J} // \vec{B}$$

$\alpha = 0 \Rightarrow$ potential field solution

$\Rightarrow$ no currents

$\alpha \neq 0 \Rightarrow$ non - zero constant for whole region

$\Rightarrow$ *linear* force - free fields

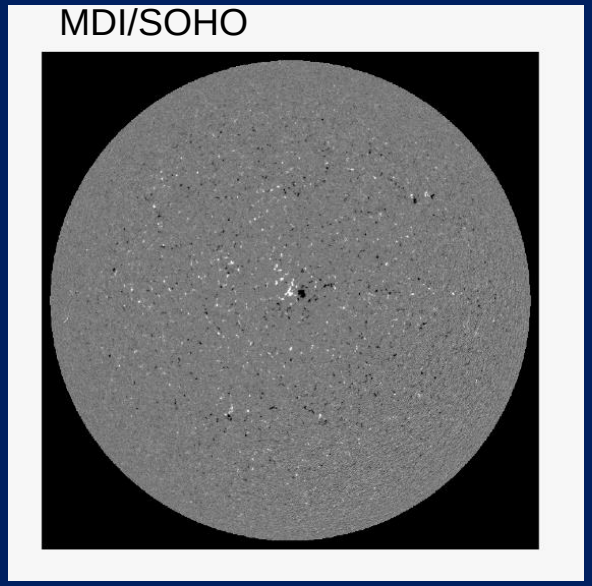
$\Rightarrow$ free - energy

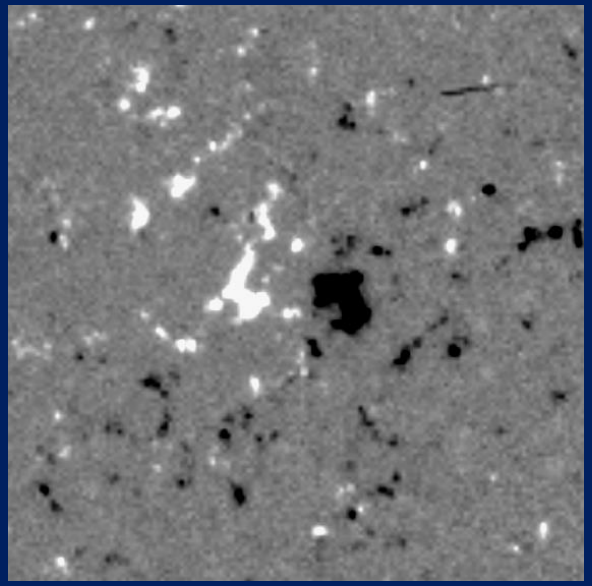
$\alpha \neq 0 \Rightarrow$ non - zero and not a constant

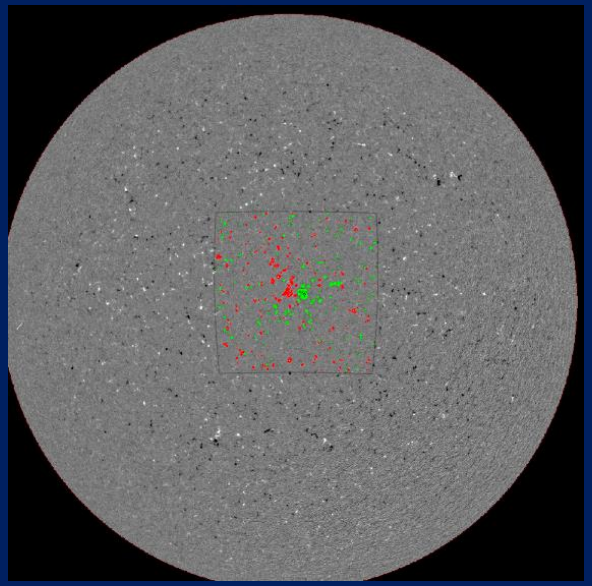
$\Rightarrow$ *nonlinear* force - free fields

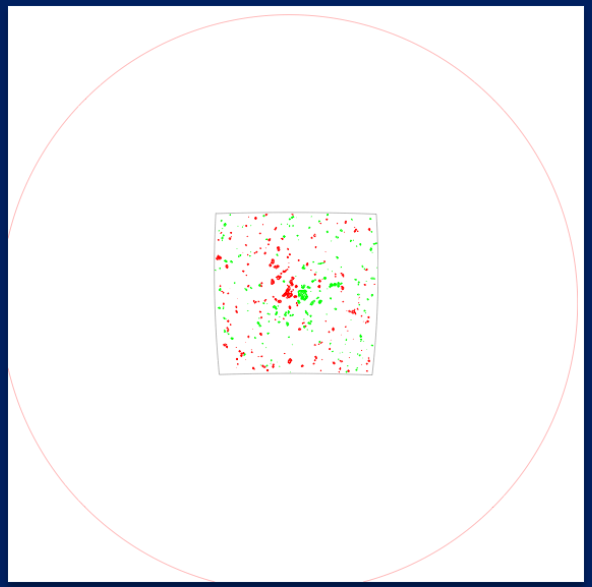
$\Rightarrow$ constant on a given field line but each field line a different constant

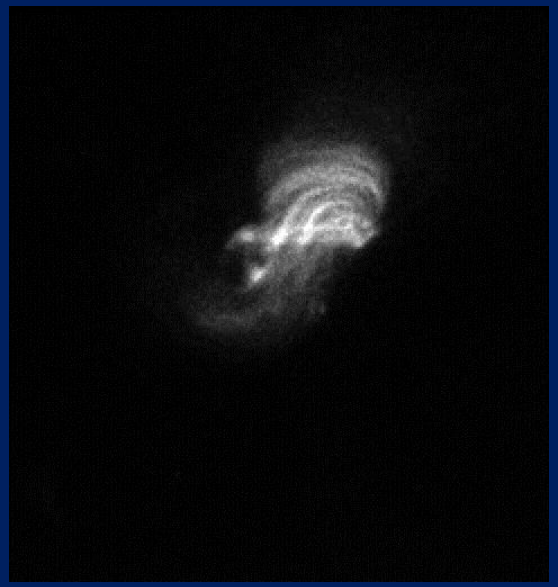
Generating NLFFF Models: The Data

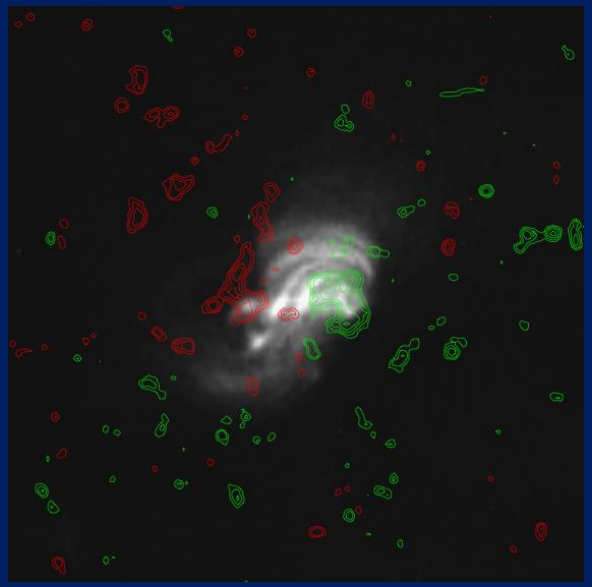












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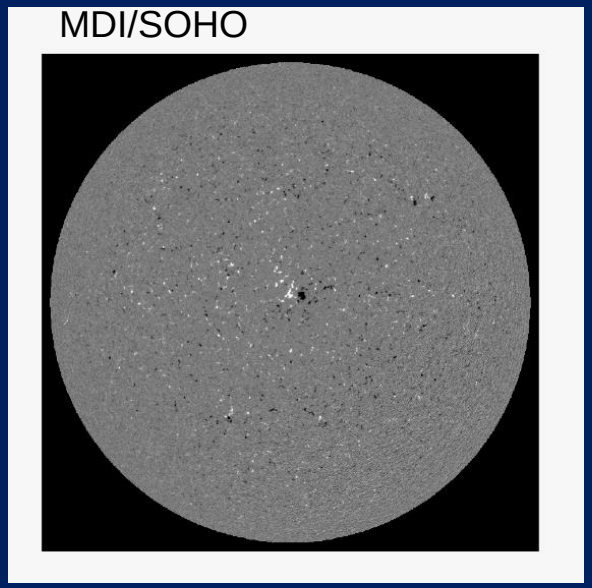
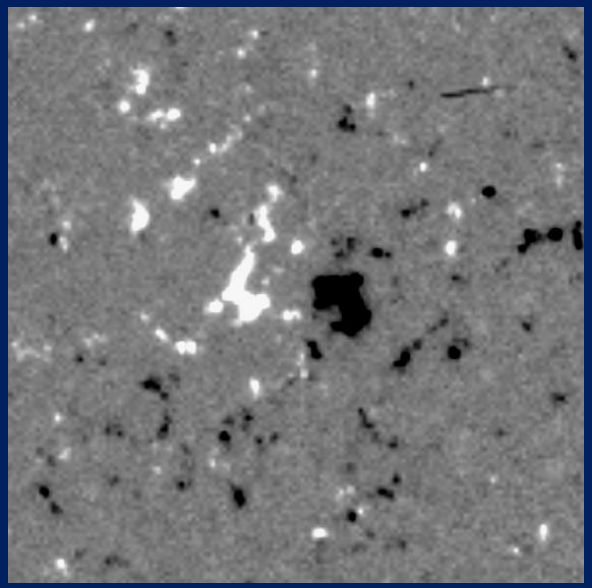
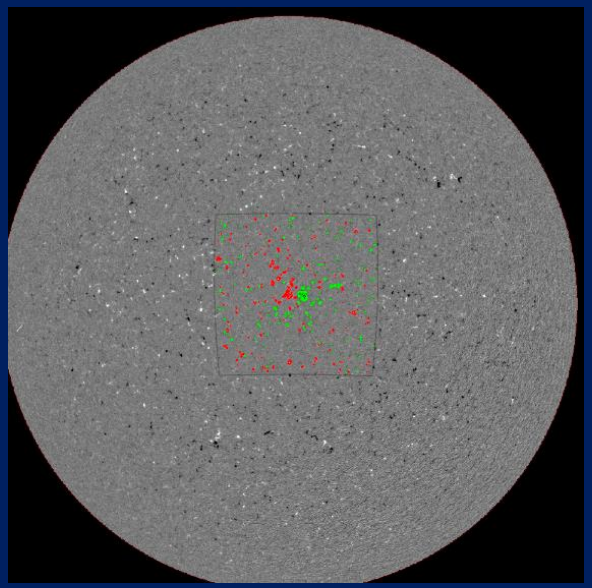
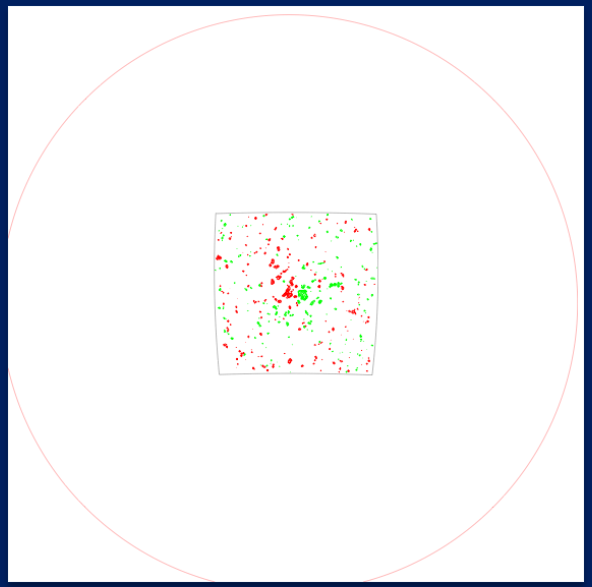
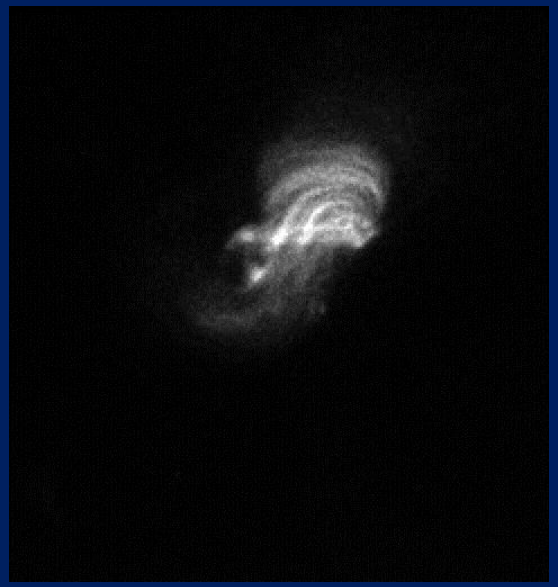
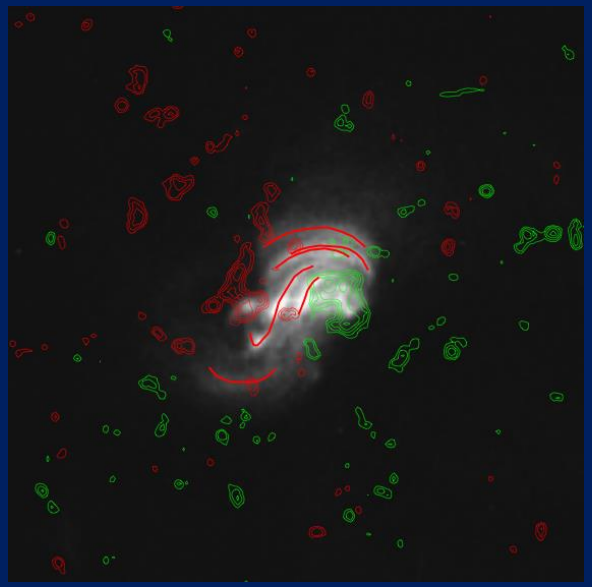




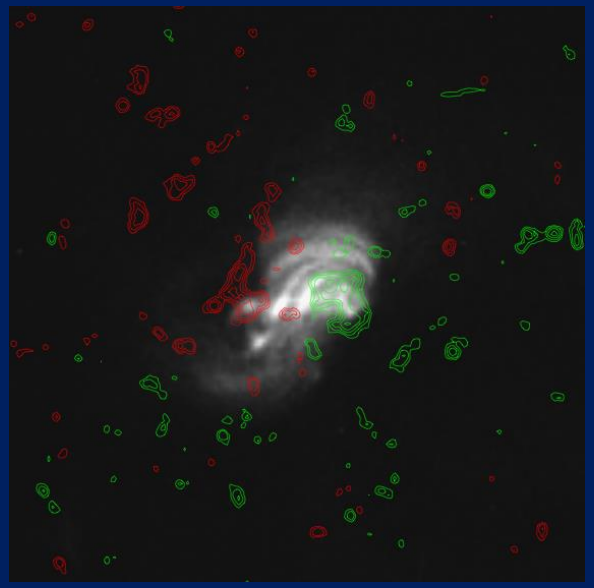


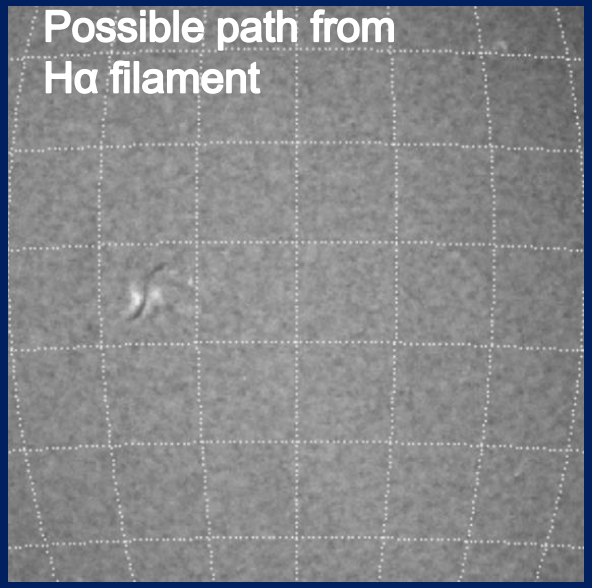


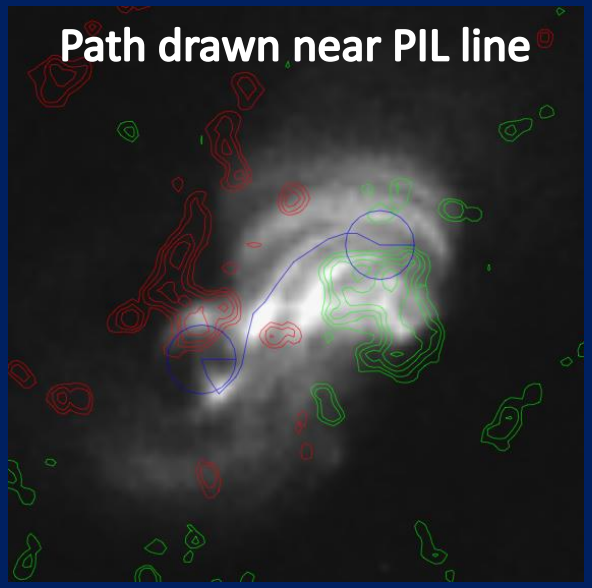


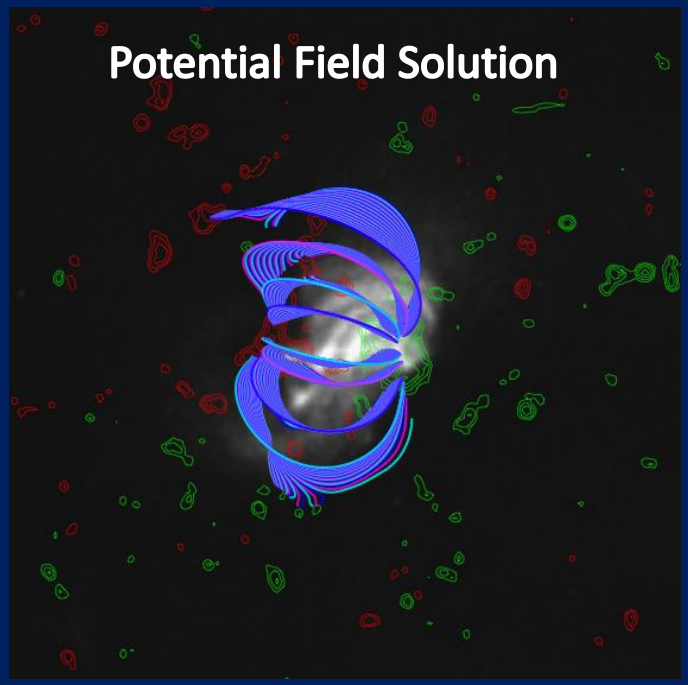


Generating NLFFF Models: Flux Rope Insertion Method





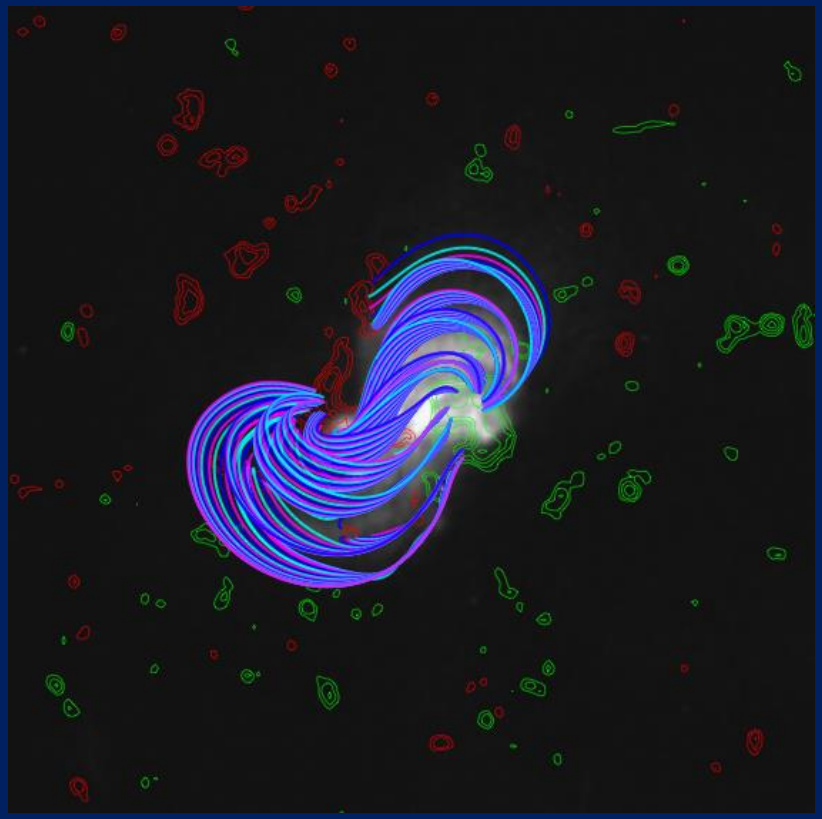


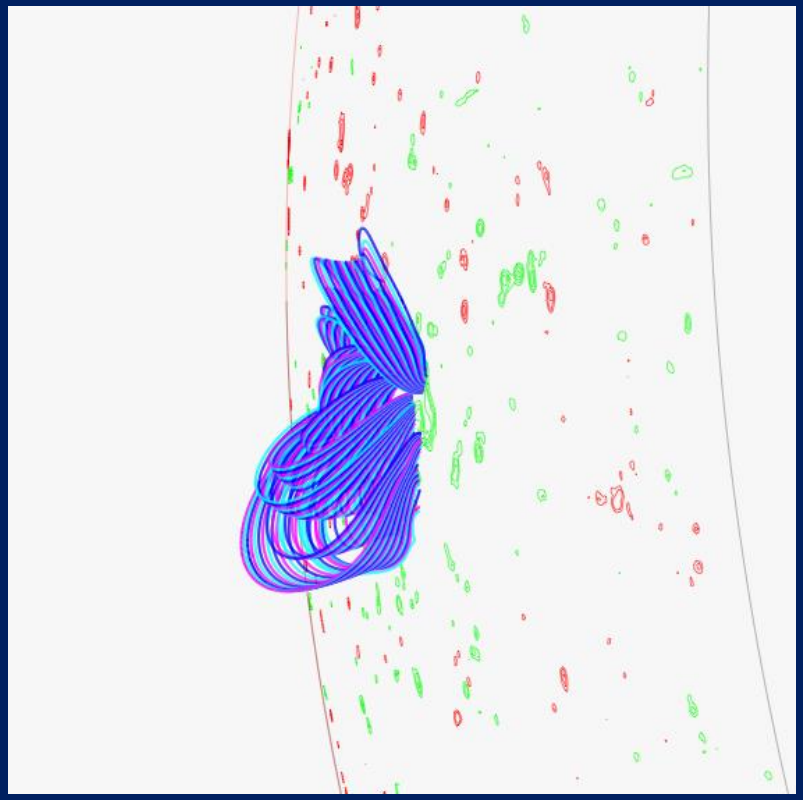


- Tension from overhead field lines pushing down balances flux rope expanding up to achieve NLFFF equilibrium

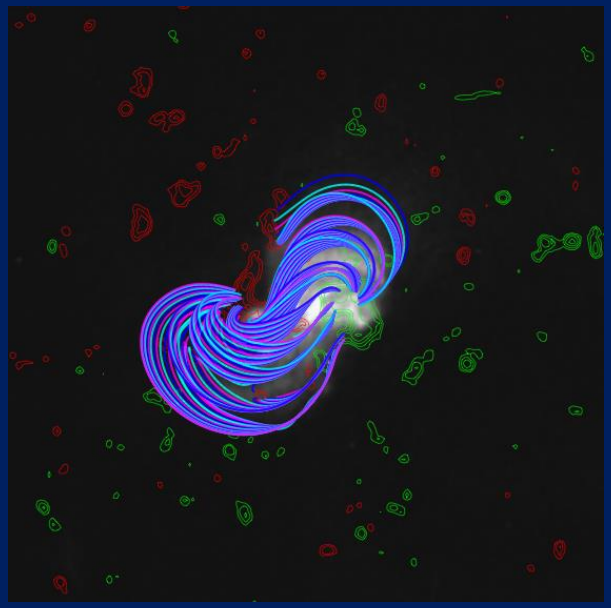
- magnetofrictional relaxation process -> force-free
  - solve induction equation: $\frac{\partial \vec{B}}{\partial t} = \nabla \times \left(\vec{v} \times \vec{B} \right)$
  - $\vec{v} \propto \vec{J} \times \vec{B}$

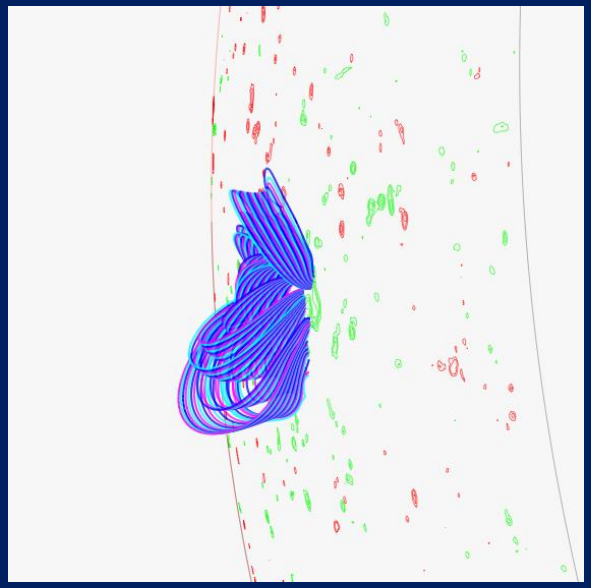
Resulting NLFFF Model

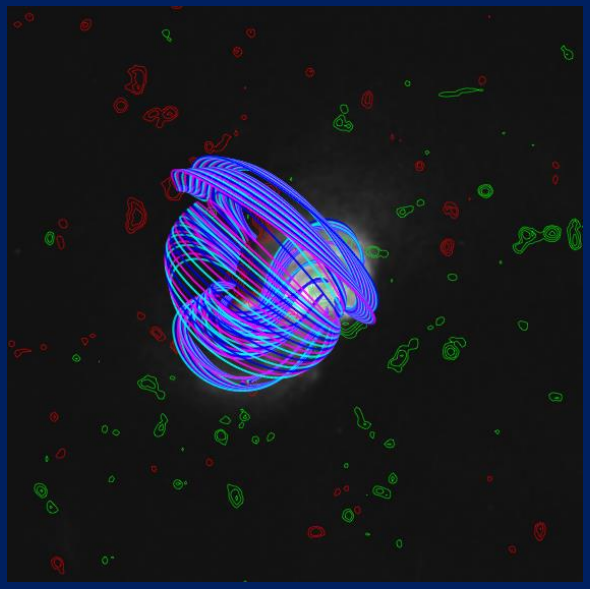


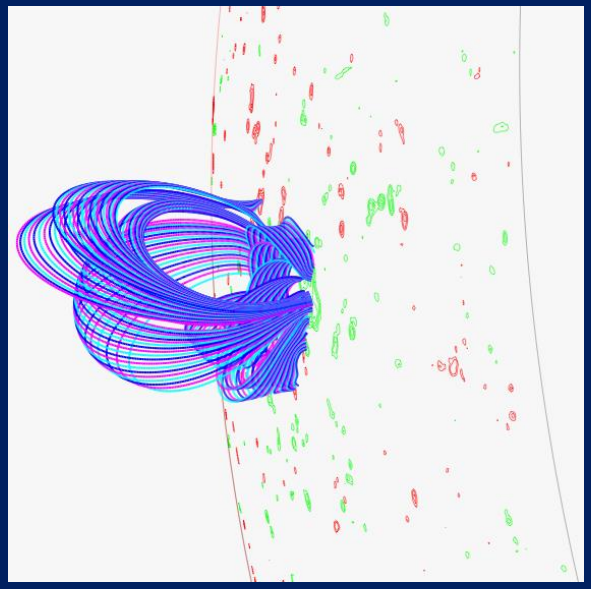


Resulting NLFFF Model

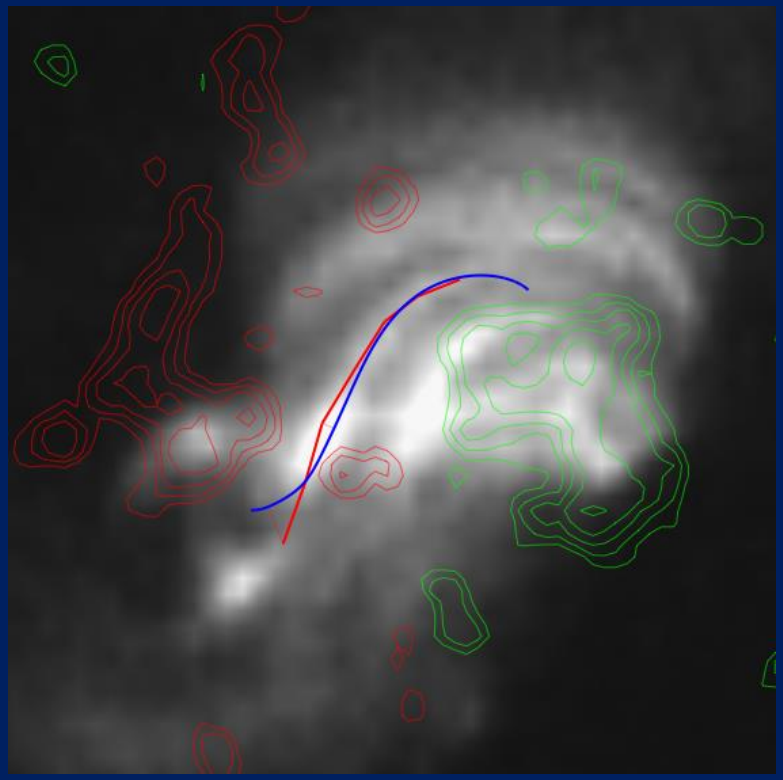


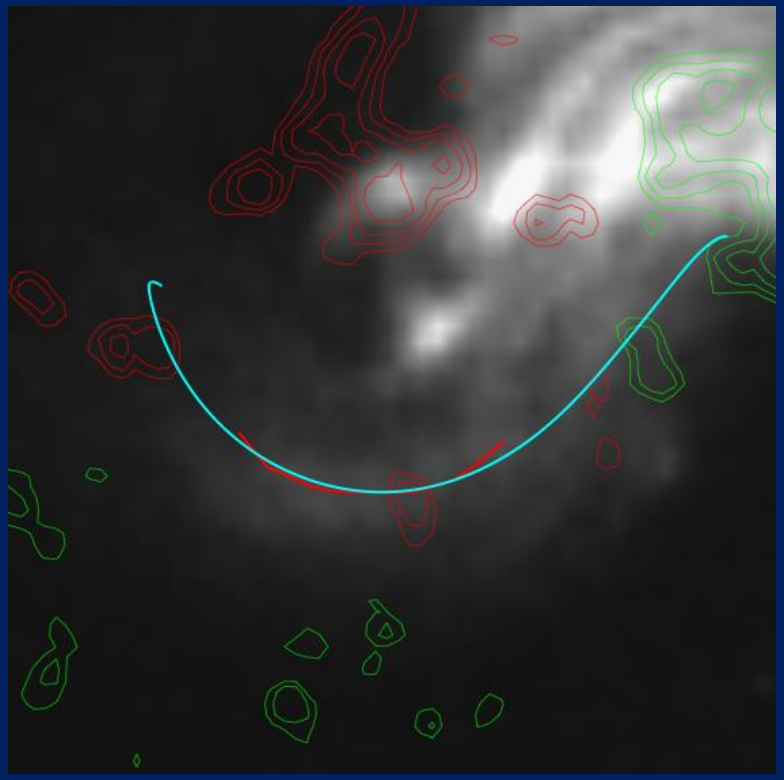






Fitting the NLFFF Model to Observations

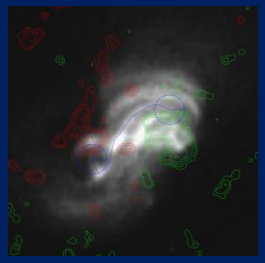




Selecting Best Fit Model and Determining Model Properties

- Suite of Models to Test: 4 flux ropes X 5 axial fluxes x 4 poloidal fluxes
- Varied shape of flux insertion ropes
- Axial flux: 2.0e20 – 4.0e20 Mx
- Poloidal flux: 1.0e9 – 1.0e10 Mx/cm

- Selected Best Fit Model based on convergence and stability as well as fit

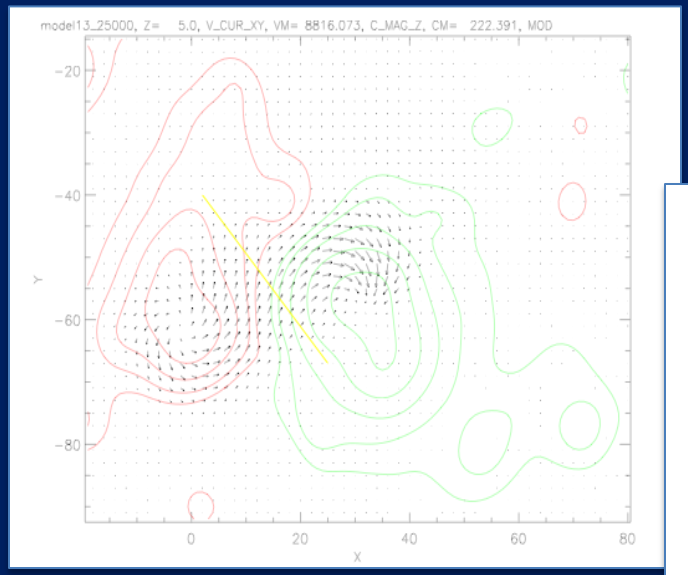
- Best Fit Model:  and axial flux: 3.5e20 Mx
  poloidal flux: 1.0e9 Mx/cm

- Unstable at axial flux: 4.0e20 Mx => 3.5e20 Mx < axial flux < 4.0e20 Mx

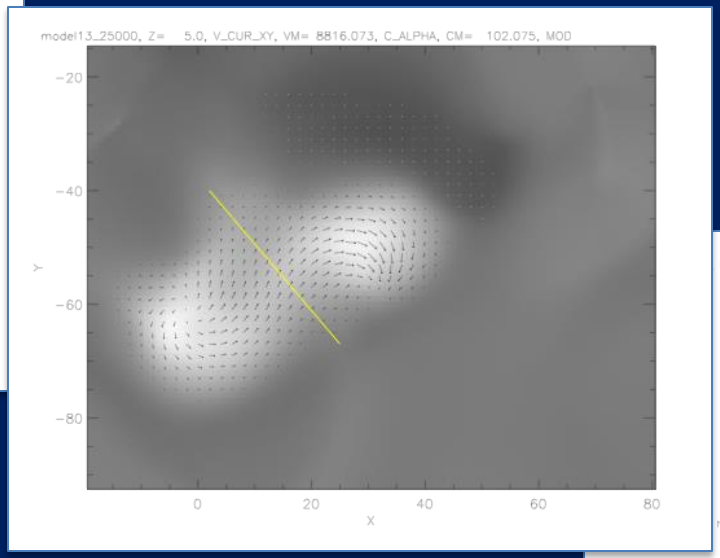
Total energy:
Coronal = 2.3e+31 erg
Potential field = 1.9e+31 erg
Free energy = 4.8e+30 erg
Helicity = 2.9e+41 Mx^2

More Model Properties: α

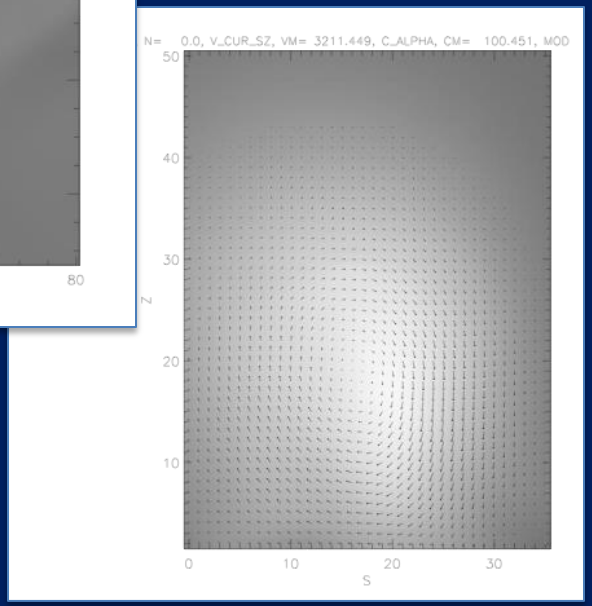
- invariant along field lines, varies from field line to field line => nonlinearity
- how much current along each field line



α



α

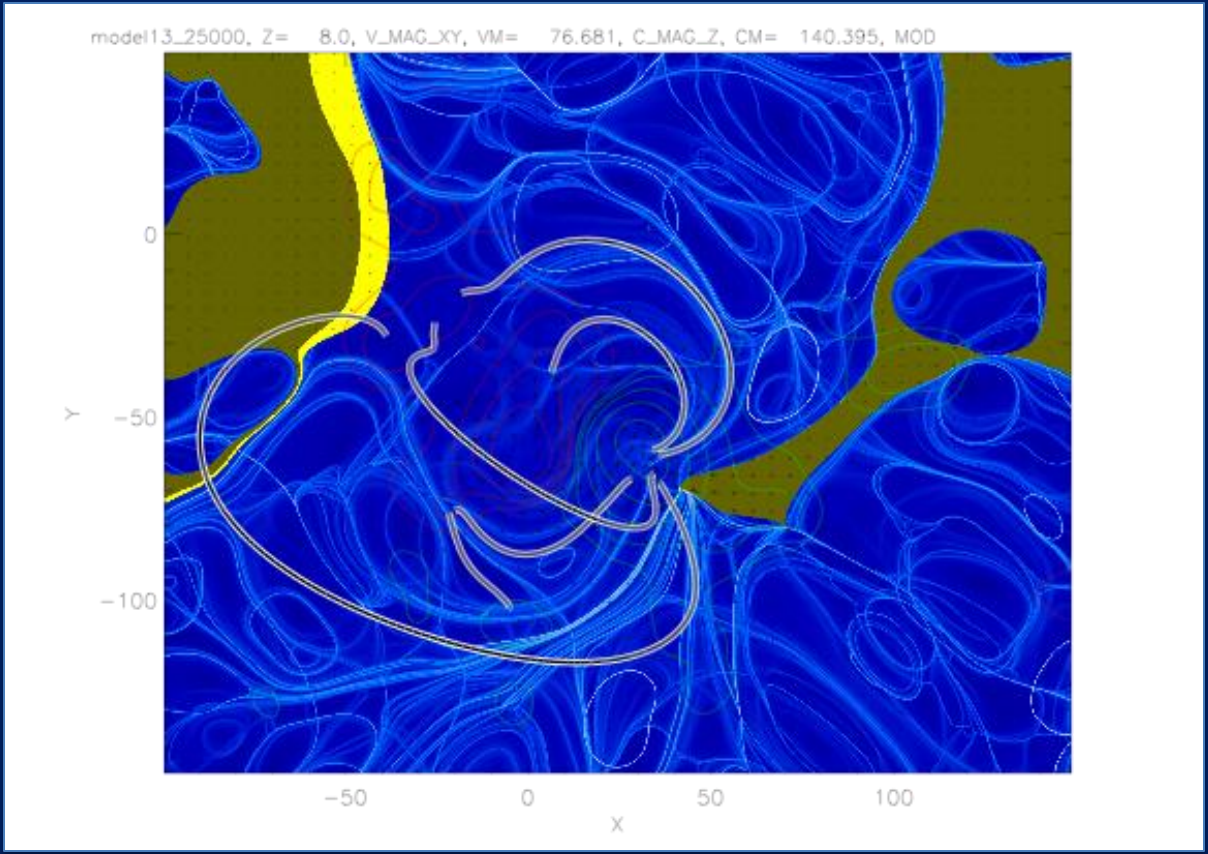


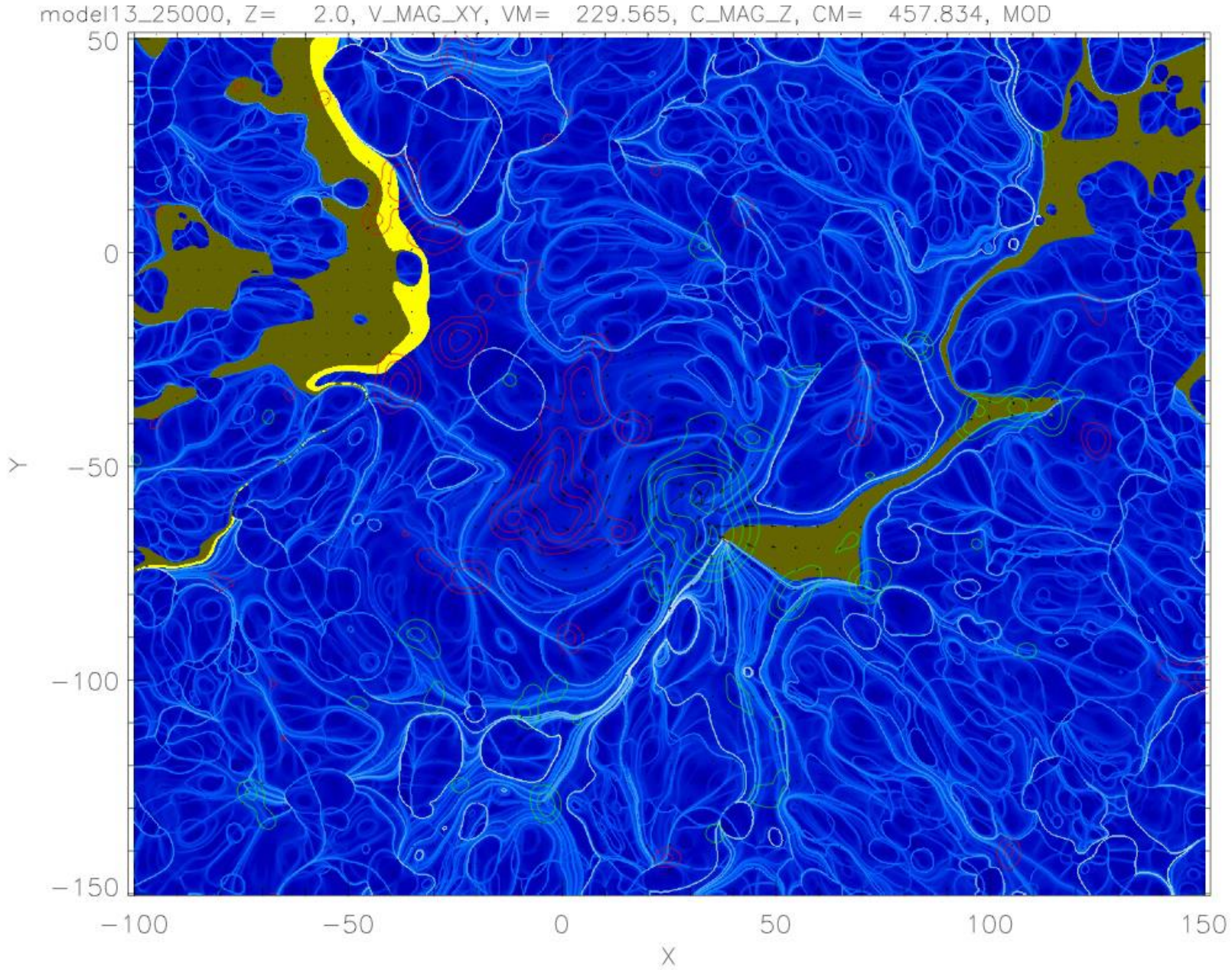
slice perpendicular to flux rope path

QSLs: Quasi- Separatrix Layers

- continuous and large gradients of magnetic linkage over field lines
- possible magnetic reconnection regions but without null point
-

$$\tilde{N}(x,y)=\sqrt{\sum_{i=1,2}\left[\left(\frac{\partial X_i}{\partial x}\right)^2+\left(\frac{\partial X_i}{\partial y}\right)^2\right]} \quad \text{where } \vec{X}_i=(\vec{x}_2-\vec{x}_1)_i$$




model13_25000, Z= 2.0, V_MAG_XY, VM= 229.565, C_MAG_Z, CM= 457.834, MOD
50
0
−50
−100
−150
Y
−100
−50
0
50
100
150
X

Conclusions

- able to use NLFFF modeling to model magnetic topology of coronal structure
  - modeled fields with shear and twist where potential field model could not

- fit model field lines to XRT observations and coronal loops

- determined physical properties of active region:
  - best fit: axial flux of 3.5e20 Mx close to upper limit of 4.0e20 Mx
  - free energy: 4.8e30 erg
  - helicity: 2.9e41 Mx^2
  - alpha: current around flux tube

- QSL maps:
  - complexity of QSL map structure decreasing with height
  - potential field map same features => QSL structural features not current dependent
  - possible small releases of energy prevent large eruptions

Acknowledgements

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- Computer Support: Trae Winter, Alisdair Davey

“Average Deviation”