Coronal Heating of an Active Region Observed by XRT on May 5, 2010

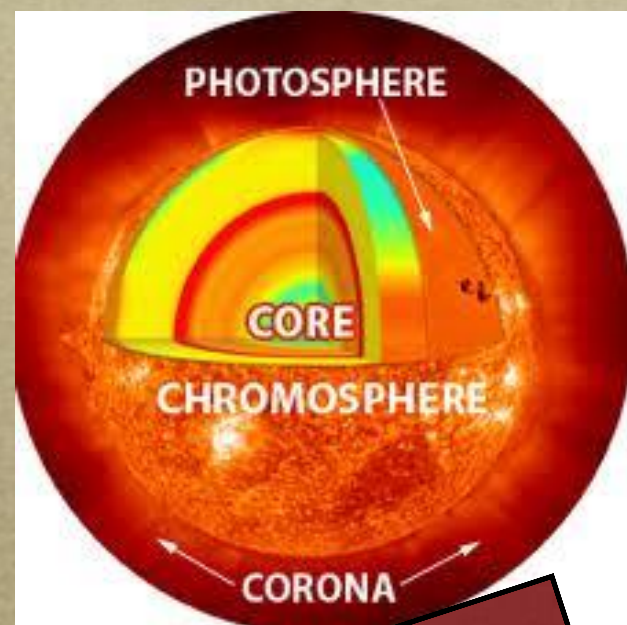
A Look at Quasi-static vs Alfven Wave Heating of Coronal Loops

Amanda Persichetti
Aad Van Ballegooijen

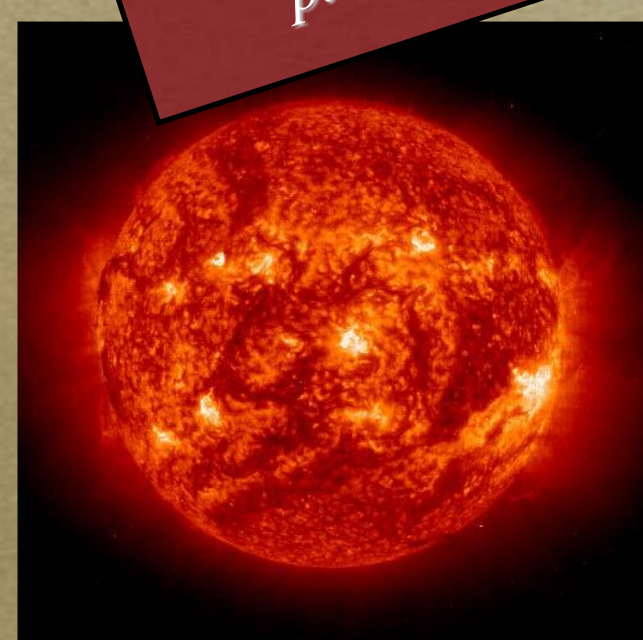
... Meet the Corona

Plasma:
"The 4th State of Matter"
~ An ionized gas consisting of electrons that have been pulled free of atoms and ions, in which the temperature is too high for neutral, un-ionized atoms to exist

As a result of plasma motion, magnetic fields are generated in the sun



Electrically neutral plasma



High Temperatures

Low Densities

Dominated by Magnetic Fields

X-ray Radiation

B-Field Frozen-in to Plasma

Coronal Heating

Why do we Study it?

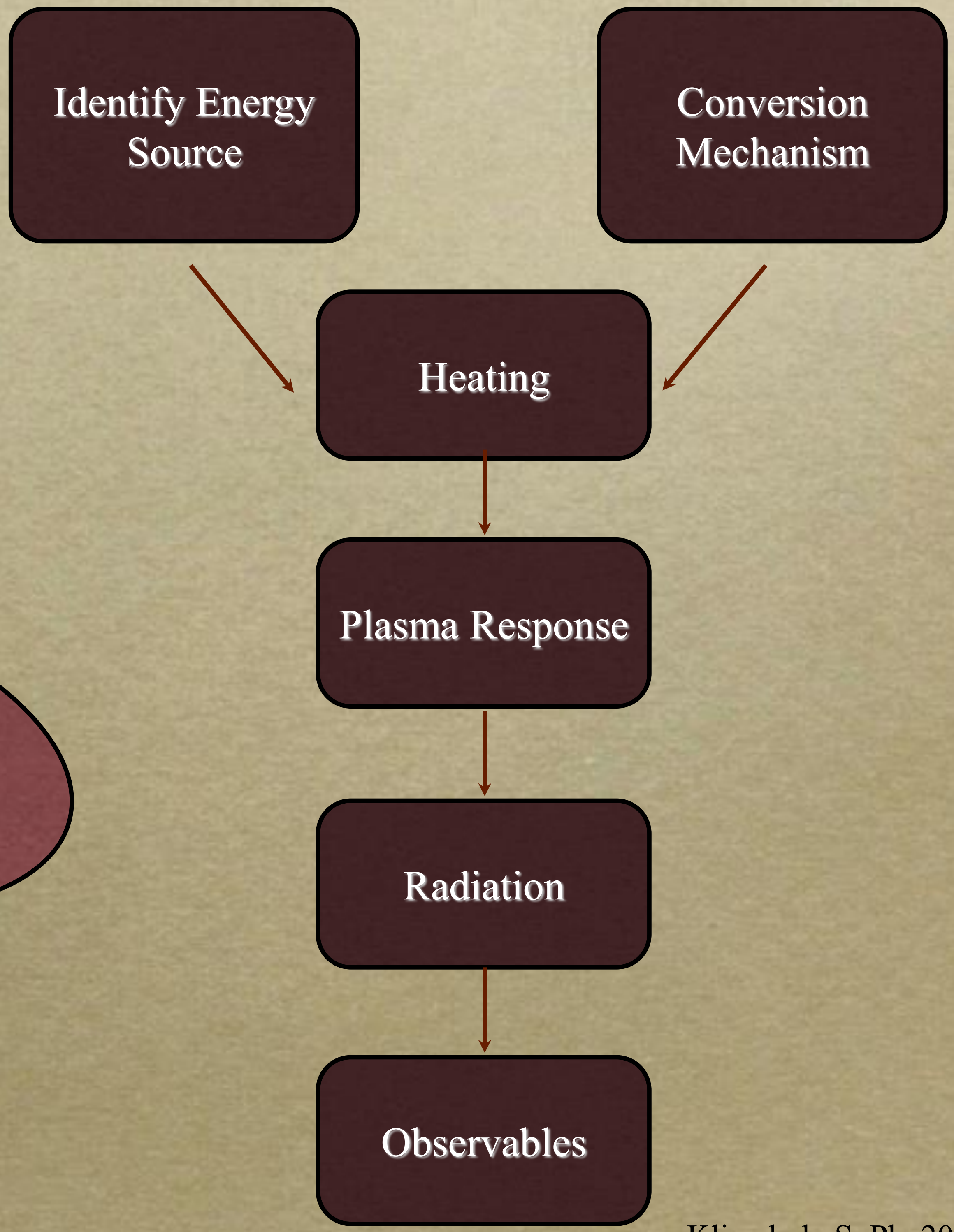
it defies expectations
--> hundreds of times hotter than photosphere
Thermodynamics

A few studied Mechanisms

~Quasi-static

~Alfven Wave Turbulence

~Micro/Nano Flares



Klimchuk, SoPh, 2006

Magnetohydrodynamics (MHD)

Equation of Motion $\rho \frac{D\mathbf{v}}{Dt} = \mathbf{j} \times \mathbf{B} - \nabla p + \rho \mathbf{g}$

Force Free Condition

$$\mathrm{j} \times \mathbf{B} = 0$$

Ampere's Law

$$\nabla \times \mathbf{B} = \mu \mathbf{j} = \alpha \mathbf{B}$$

A function of position that describes the twist of the field and must be constant along field lines.

Cases

α = 0 Potential Field

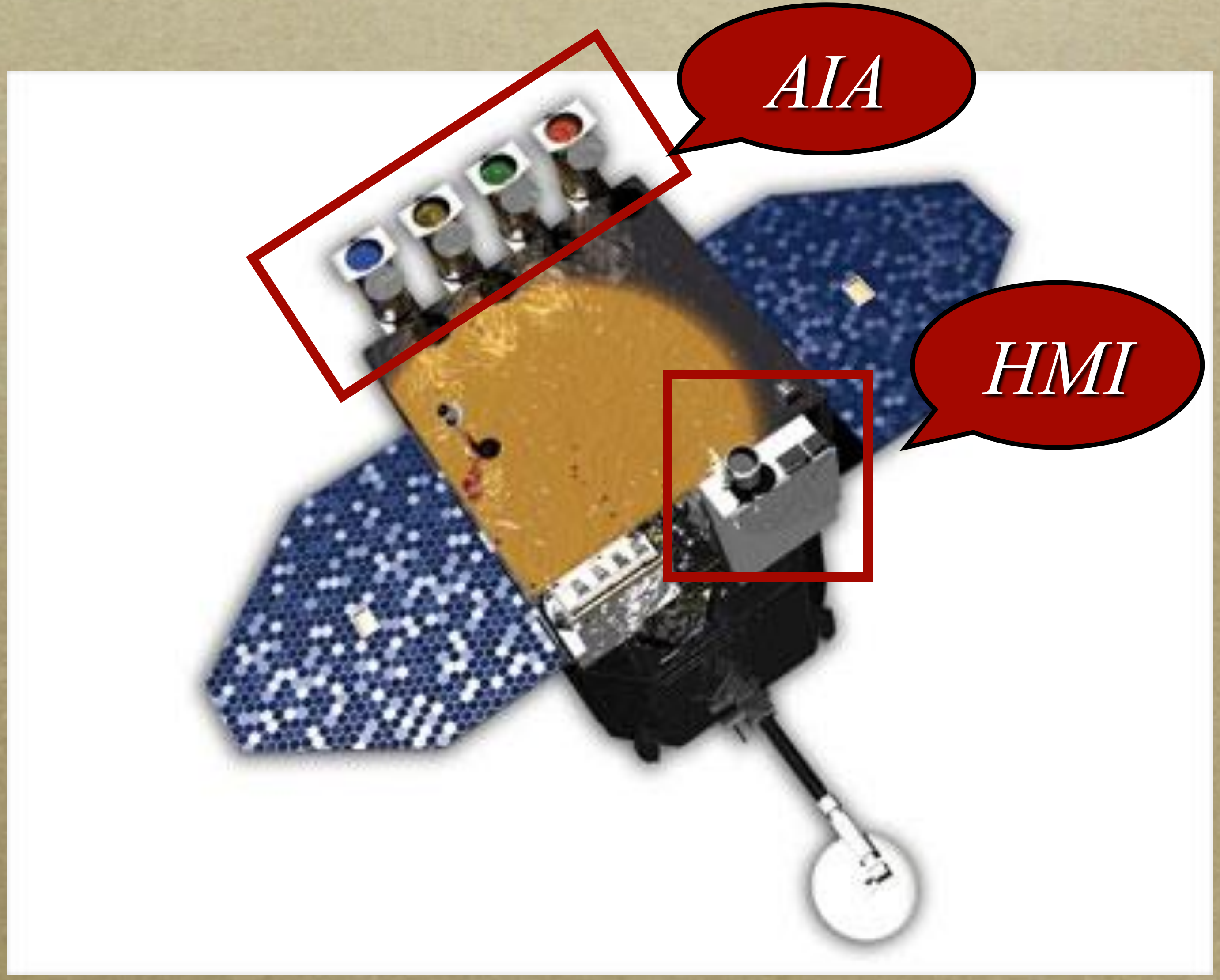
α = constant Linear FFF

α(r) Non-Linear FFF

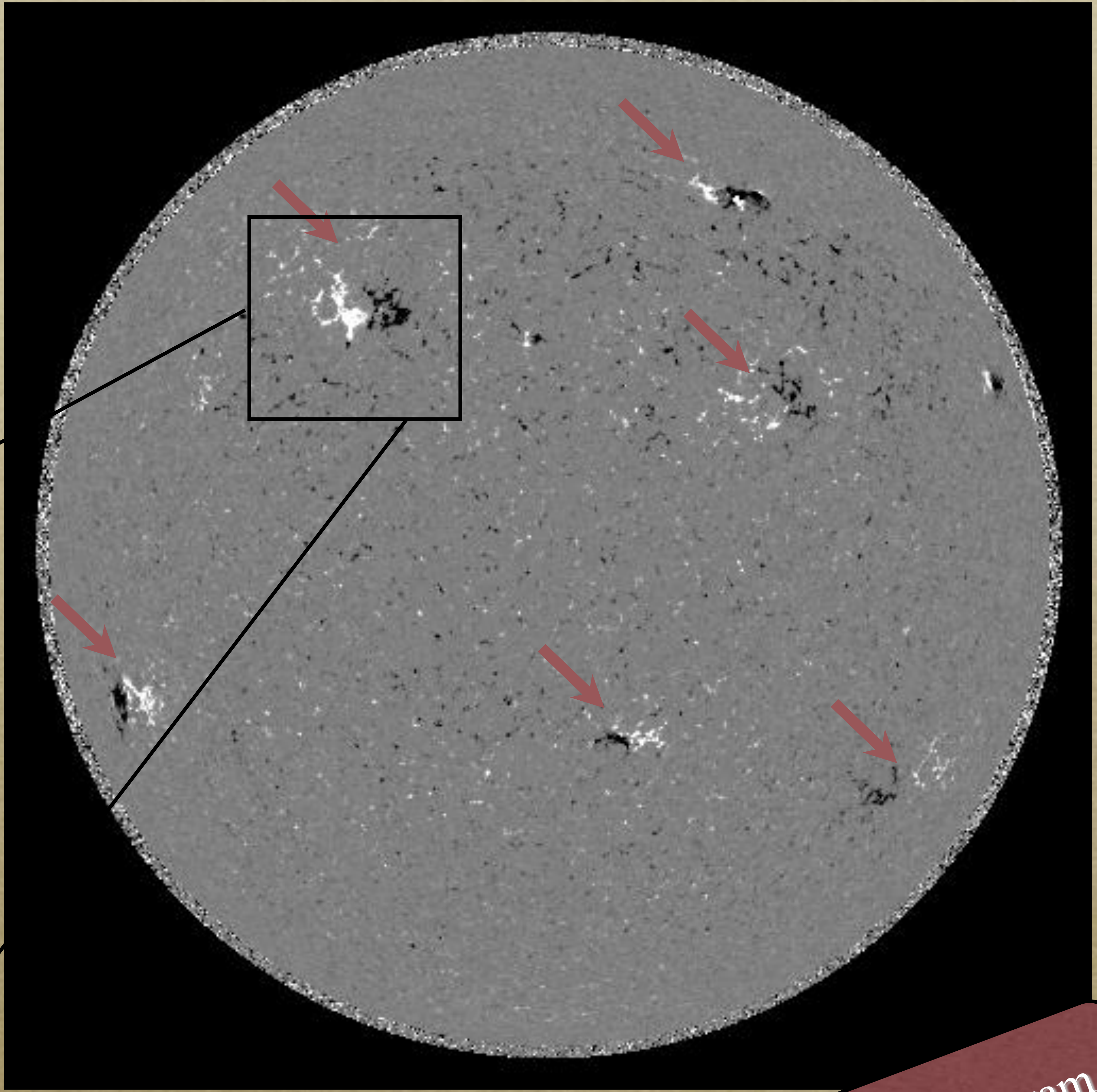
Instruments

XRT (Hinode)

Solar Dynamics Observatory (SDO)



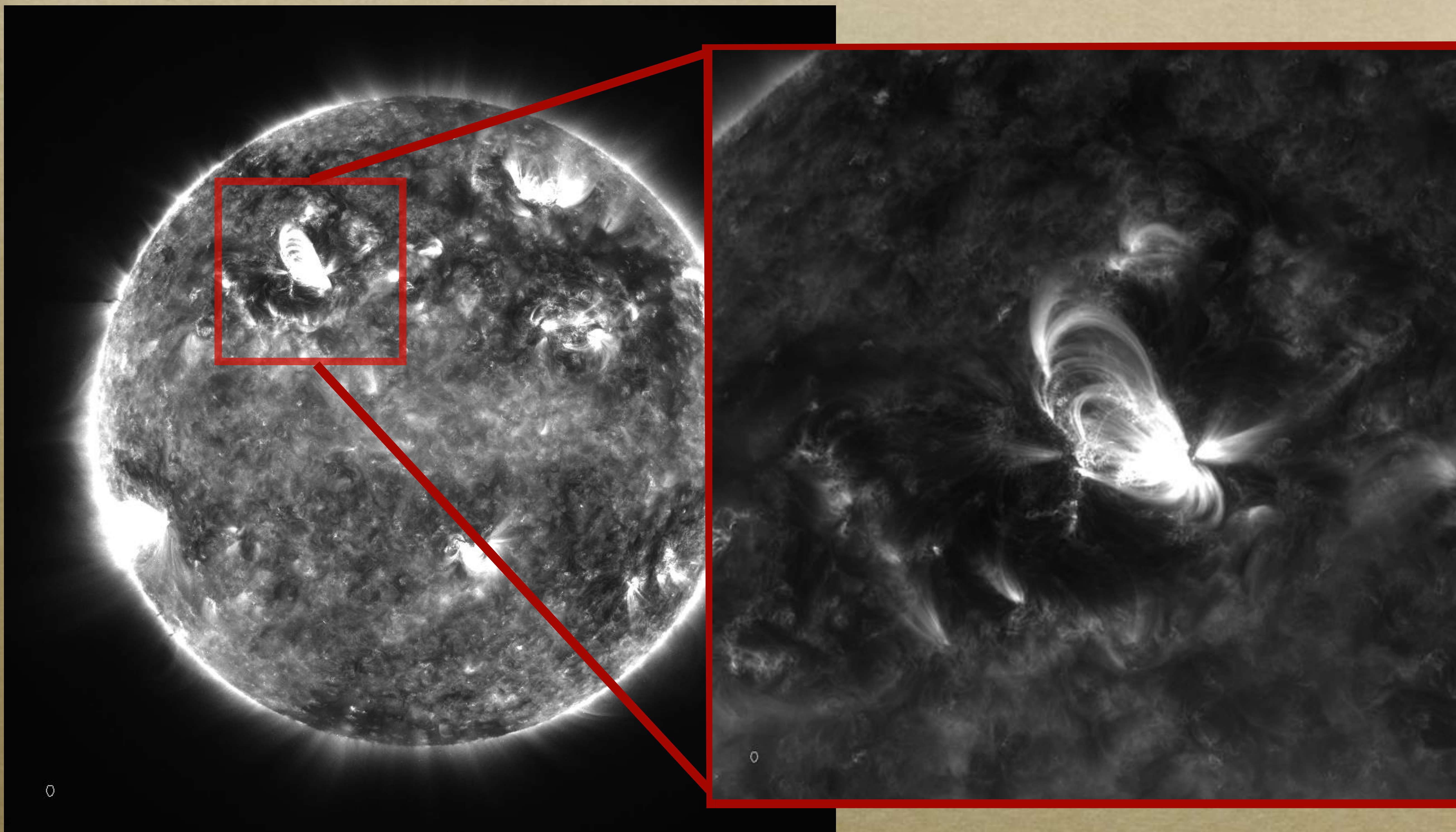
Active Region: a region in the solar atmosphere, from the photosphere to the corona, that develops when strong magnetic fields emerge from inside the sun. Magnetized realm in and around sunspots.



Magnetogram from HMI

XRT Image

May 5, 2010 Active Region



171Å AIA Image

One hour movie of 171Å images

Modeling Magnetic Fields

CMS

~A software package that allows you to construct models of the solar corona based on photospheric magnetograms from HMI and coronal images from AIA

~Models provide information about the coronal magnetic field that cannot already be directly observed from SDO data.

Purpose MS

Accurately model the magnetic field lines of the active region based on data from SDO. This gives us a better idea of the properties of the region in order to make more educated conclusions, in our case, about the heating.

Program Approach

Non-Potential Field

1) Construct potential field

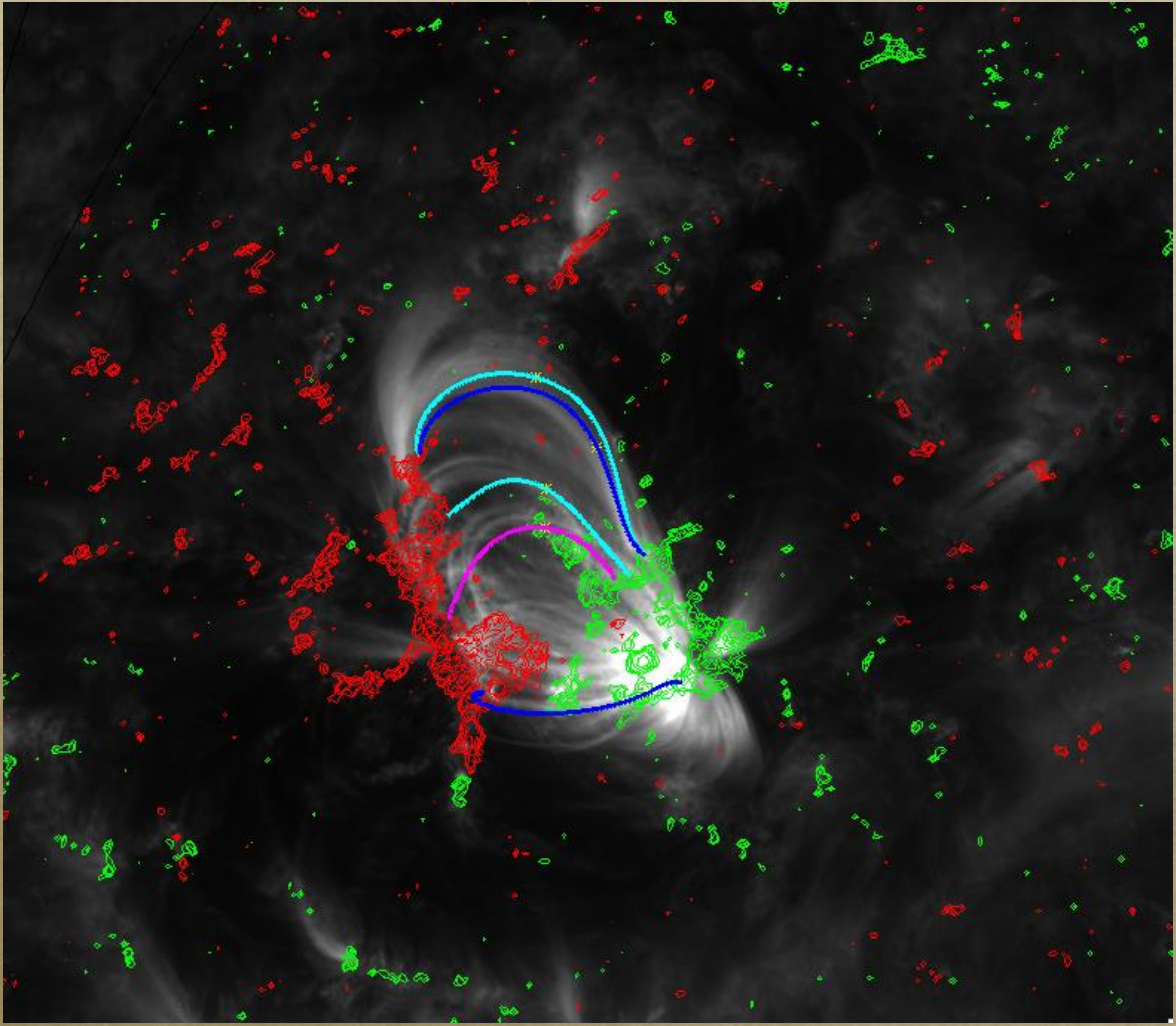
2)Insert flux rope in model along manually selected path

3)Apply magneto-frictional relaxation

van Ballegooijen et al. (2010 in prep)

red contour s = pos Bfield

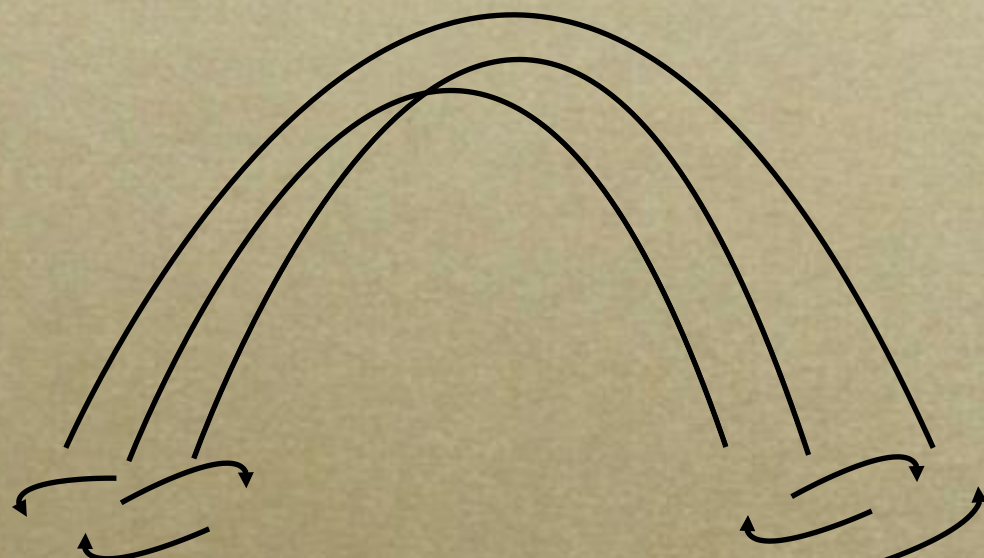
green contou rs = neg Bfield



Can see distinct loops in 171 A image

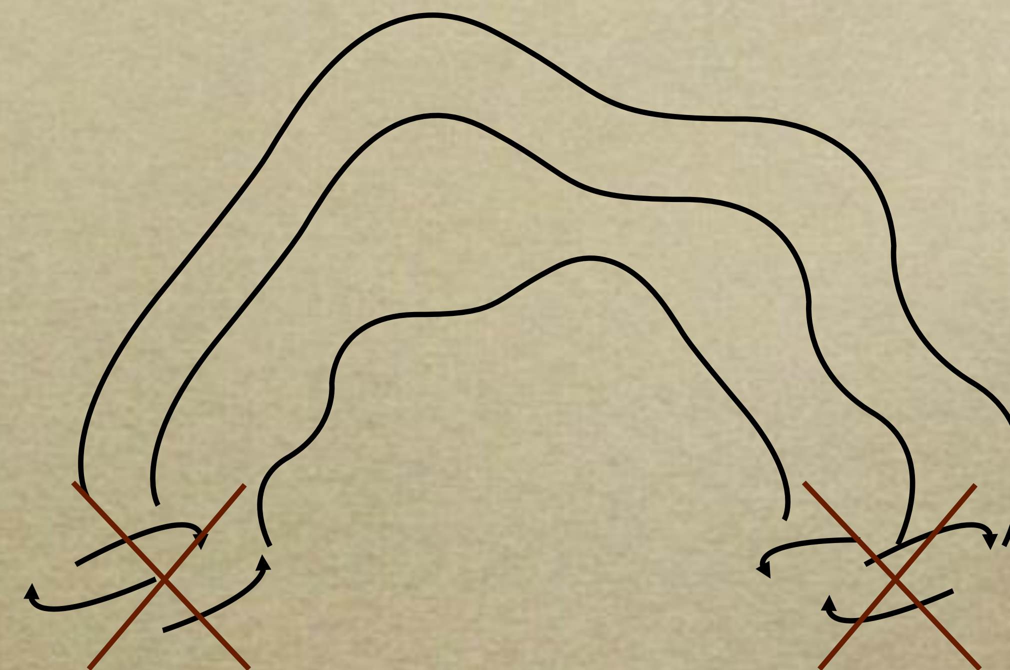
adjust model so field lines match loops

Heating of Coronal Loops



Quasi-Static Response
to foot-point motions

$$\frac{L}{v_A} << \tau_p$$



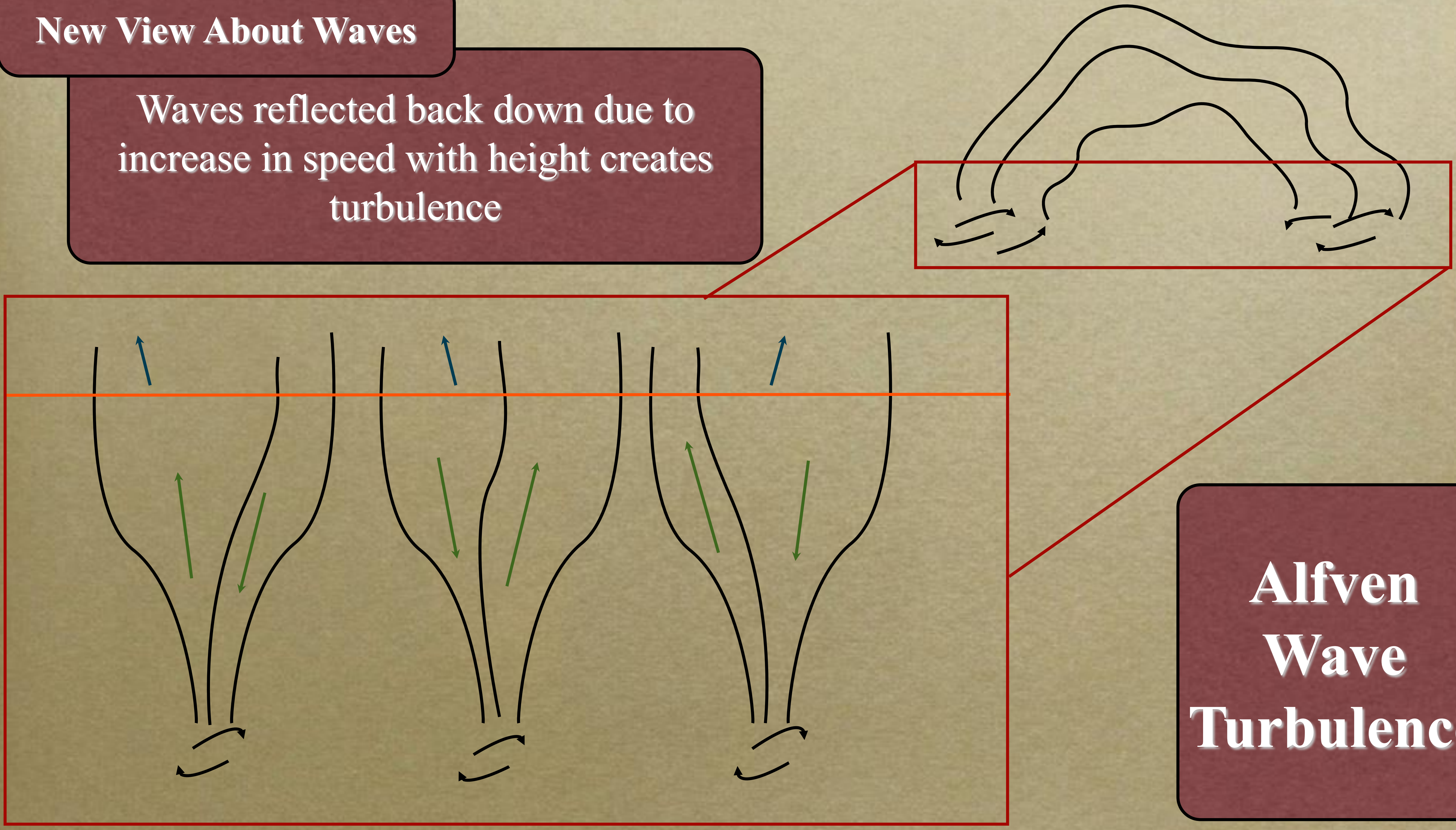
Alfven Waves

$$\frac{L}{v_A} >> \tau_p$$

Chromosphere

New View About Waves

Waves reflected back down due to increase in speed with height creates turbulence



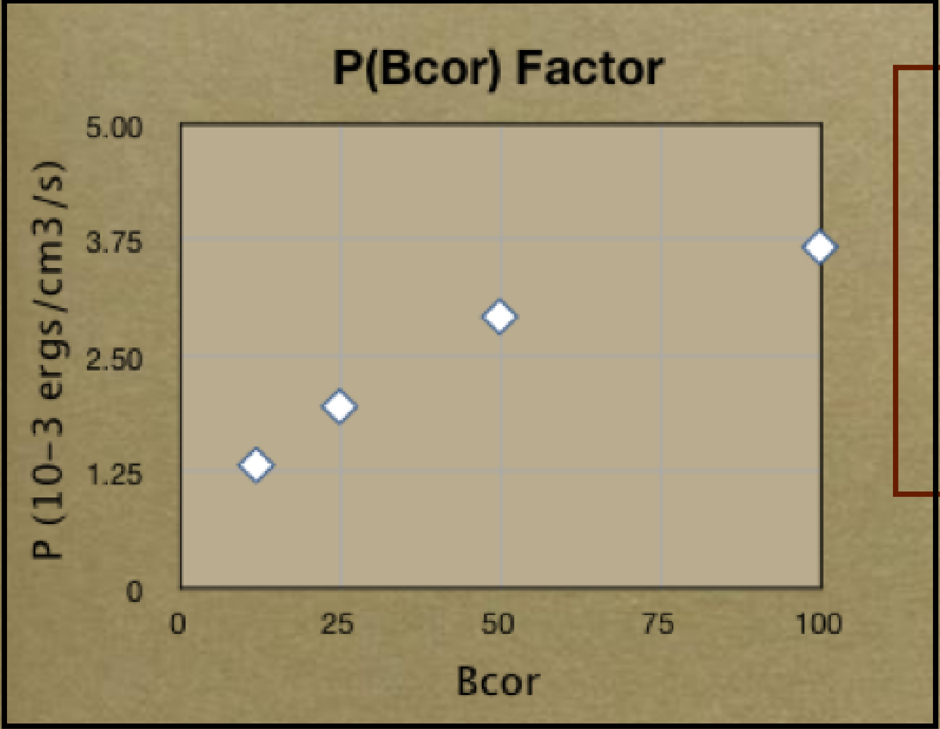
Alfven Wave Turbulence

Heating Rates

Quasi-Static
Heating Rate per unit volume

$$Q_{cor} \approx \frac{B_{cor}^2 u_0^2 \tau_0}{8\pi L_{cor}^2}$$

Quasi-Static heating dependent on magnetic field, loop length, and properties of foot-point motions.

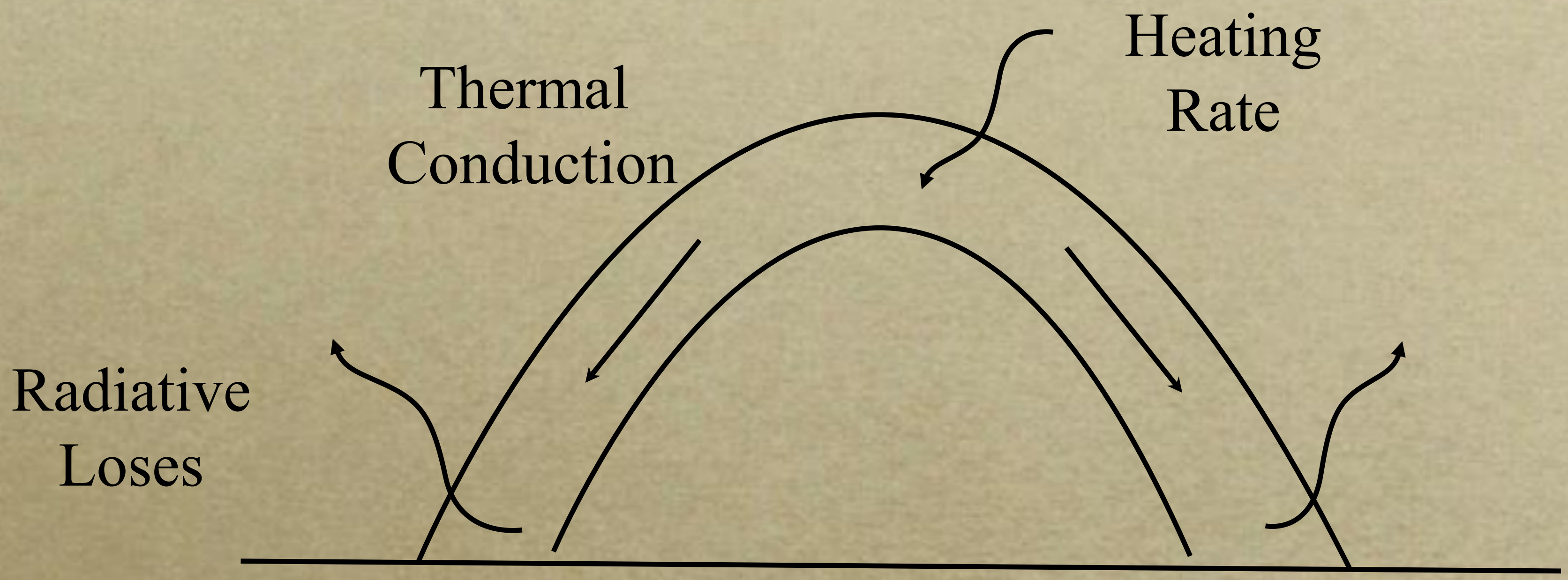


Alfven Wave
Heating Rate

$$Q_{cor} \approx \left(\frac{u_0}{1.5km/s}\right)^{1.65}\left(\frac{L_{cor}}{50Mm}\right)^{-0.92} P(B_{cor})$$

Alfven Wave heating is based on numerical simulations.

Heating of Coronal Loops

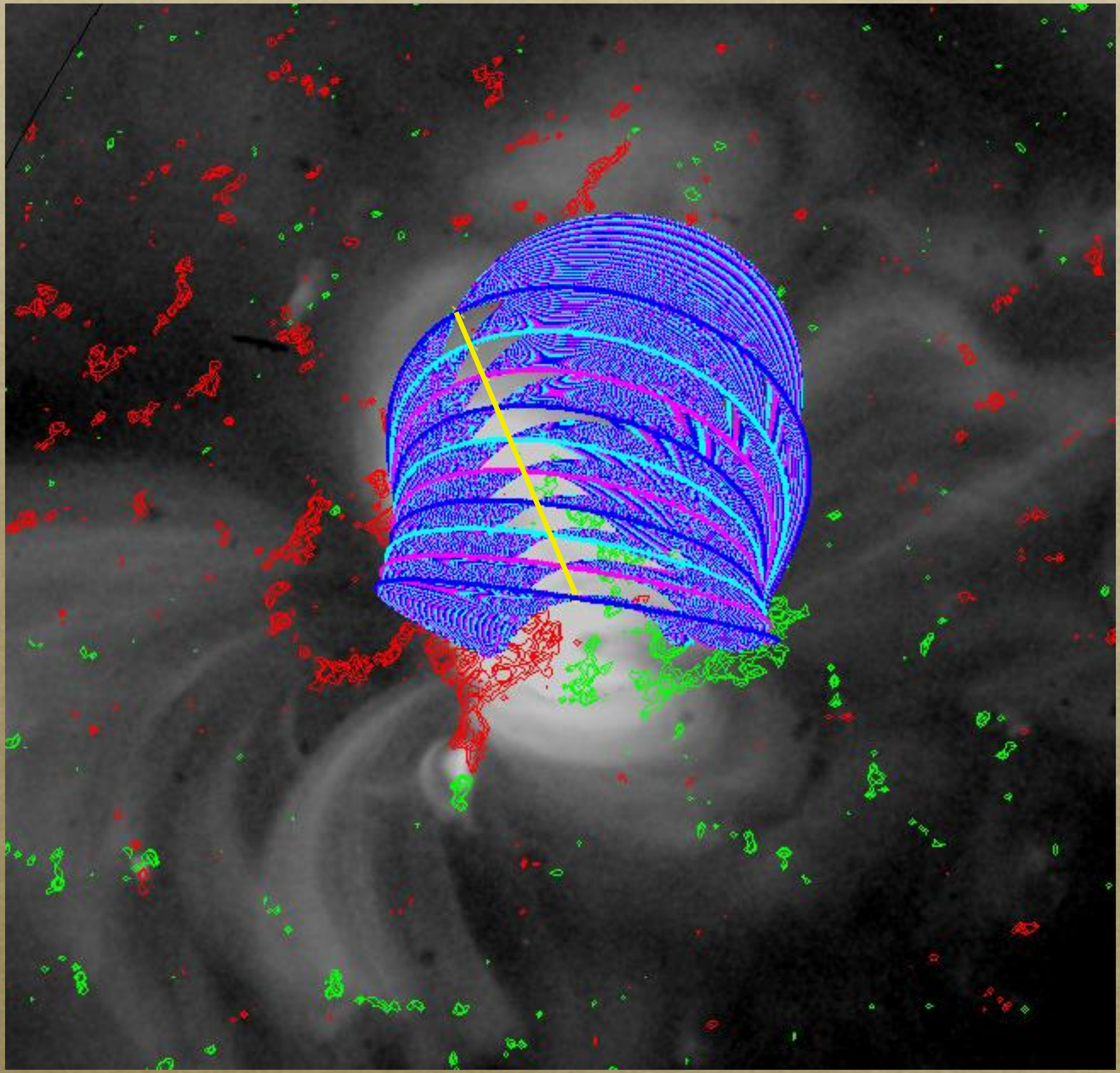


Three processes related to heating present in the corona:
~Heating rate contribution
~Thermal Conduction
~Radiative Loses

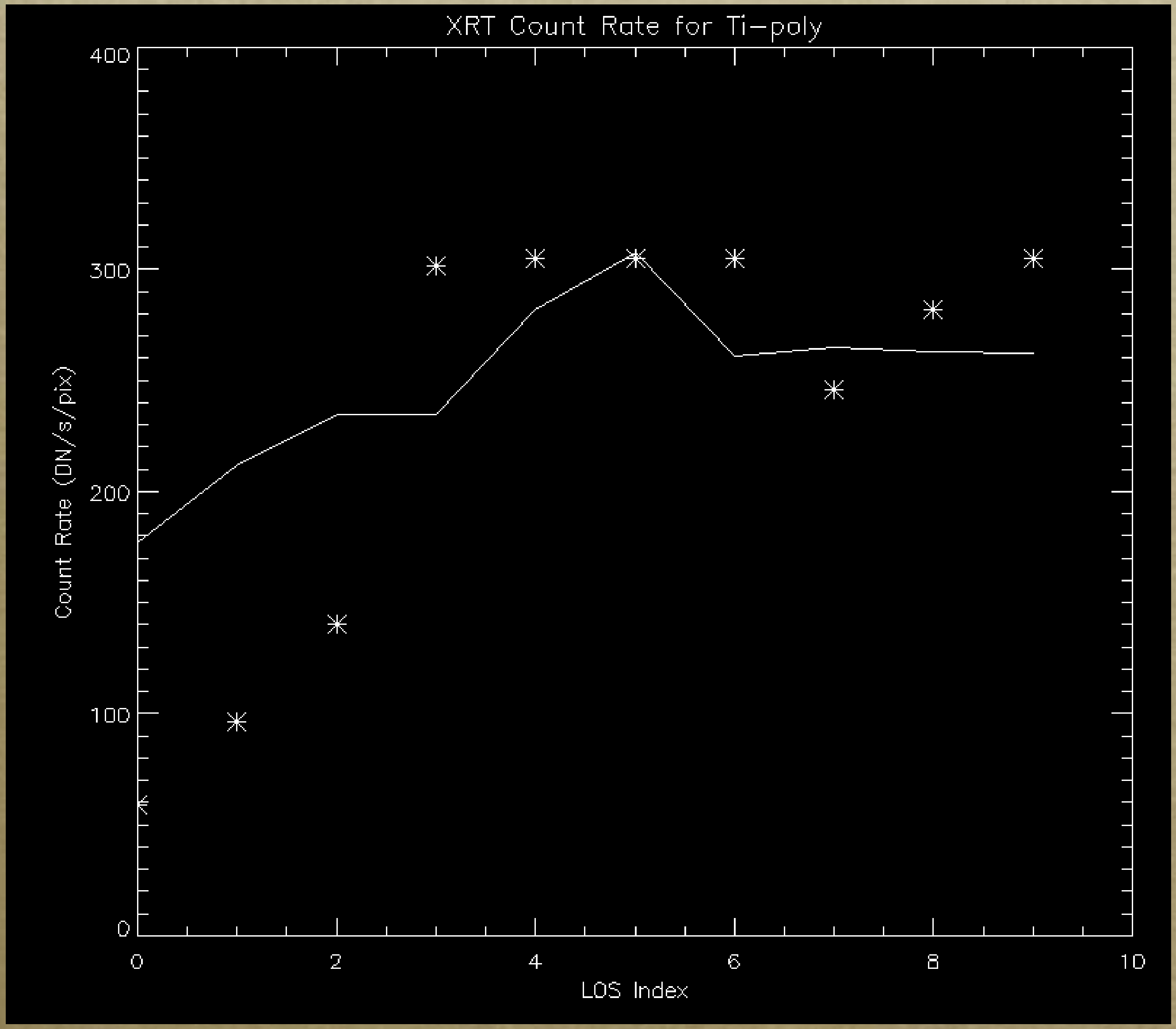
→

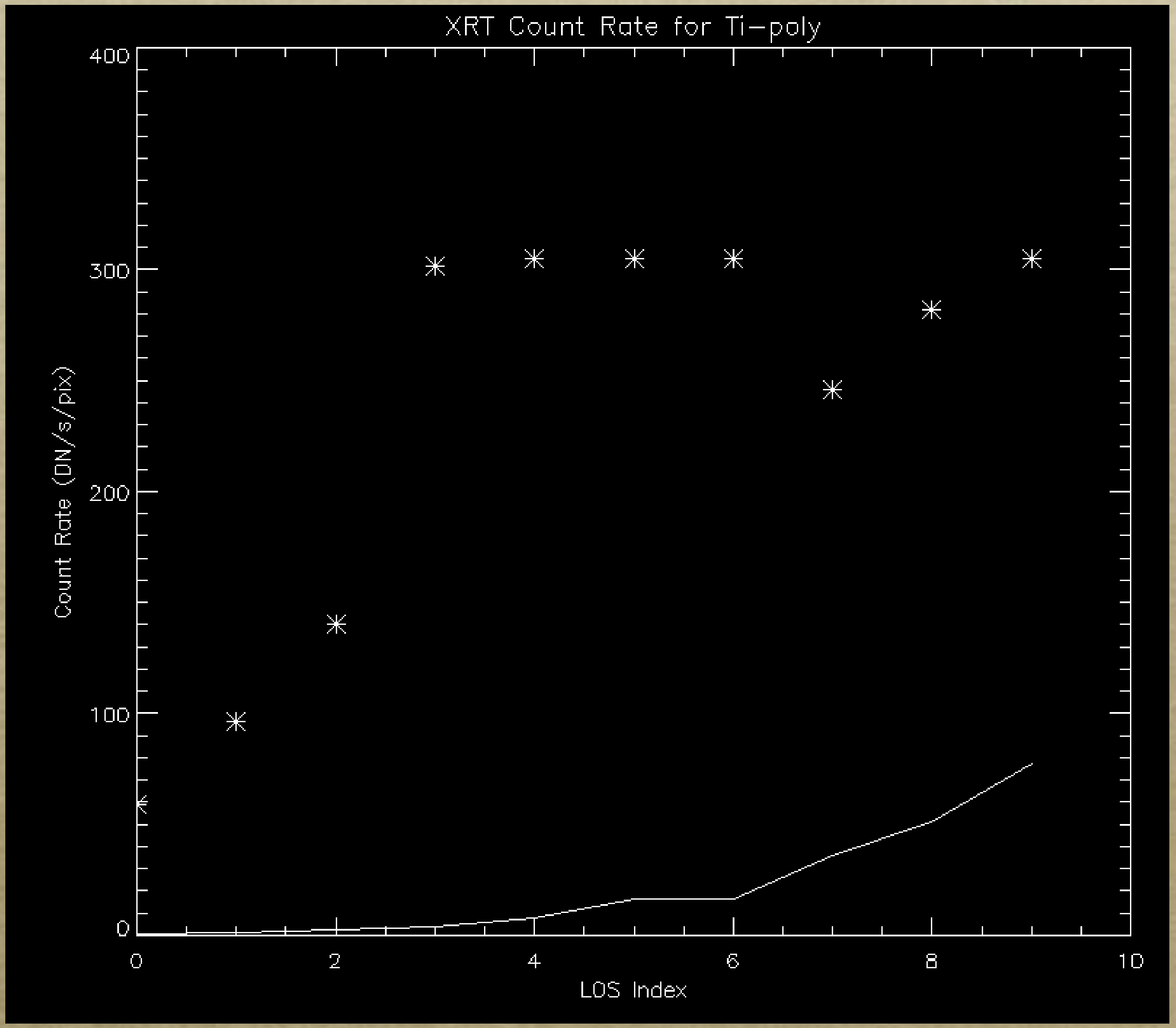
Compute Temperature and Density with respect to position

Solve Coronal Heating Problem for Many Field Lines



Computed and Observed XRT Count Rates





Alfven Wave Turbulence

Alfven velocity = 1.1 km/s

Quasi-Static Footpoint Motion

Foot-point motion time = 40s

Conclusions

- Alfven wave turbulence gives off a lot more heating energy than the quasi-static mechanism producing heat rates on orders of 10^2 greater.
- This made it able for us to get a more accurate fit of calculated intensities to actual intensities for reasonable values of the the foot-point motion parameters.
- The solar corona is so active and constantly changing. When it comes to modeling active regions, each individual one must be modeled with its own individual parameters. They are not consistent for all active regions on surface.

Continued Study

- Apply this analysis to various active regions
- New model involving Alfven wave turbulence
- Consider interactions between neighboring flux tubes including splitting/merging of flux tubes

Special Thanks to

Aad van Ballegooijen

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