Coronal Heating from Alfvén Wave Turbulence in Solar Coronal Loops

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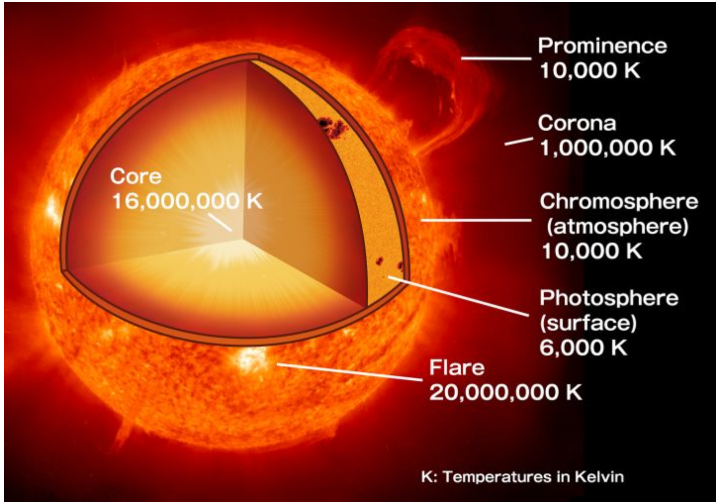
The Big Picture

- Coronal Loops are giant arc-like magnetic field lines that extend from the surface of the Sun into the Sun's corona, visible due to the plasma that runs along the magnetic field lines.
- The Sun's Corona is at least 200 times hotter than the surface of the Sun. It is believed that the solar corona is heated by non-thermal processes.
- The objective of this project is to model Coronal Loops and investigate how the corona is heated.

TRACE - Nov. 6th, 1999



What is a Magnetic Potential Field?

- $\beta = \frac{plasma\ pressure}{magnetic\ pressure}$ ← Very high in the corona!
- We are using "force-free/current-free" potential field extrapolations.
- "Current-free" potential fields mean that there is no electric current density.
- Therefore, coronal magnetic potential fields = "current-free" fields.

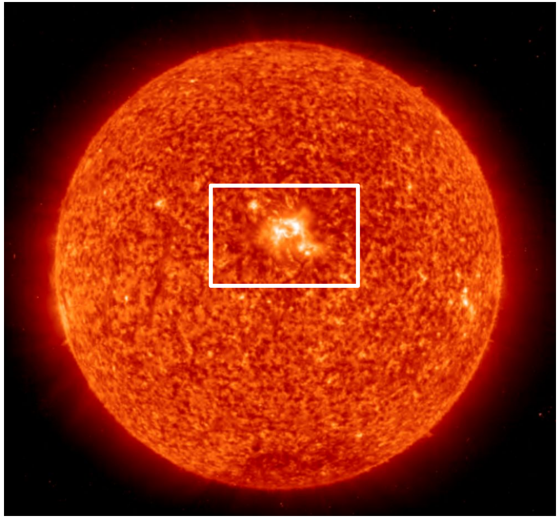
$$\mathbf{j} = \frac{1}{4\pi}(\nabla \times \mathbf{B}) = \frac{1}{4\pi}(\nabla \times \nabla\phi) = 0$$

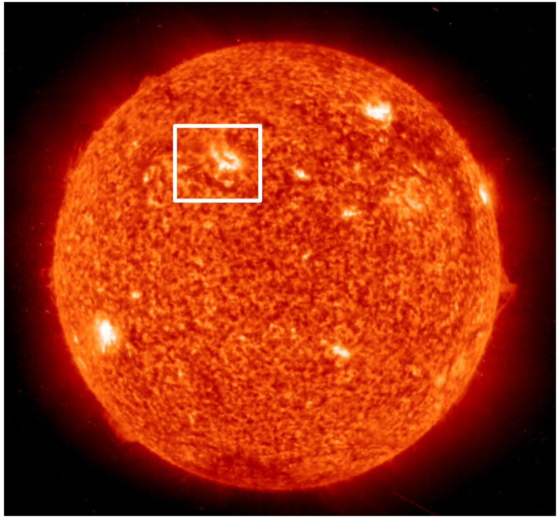
- j = electric current density, $\nabla\phi$ = magnetic potential.

Coronal Modeling Software (CMS)

- We used an idl Coronal Modeling Software (Cms2, Asgari & Van Ballegooijen 2012) to model potential fields of two active regions.

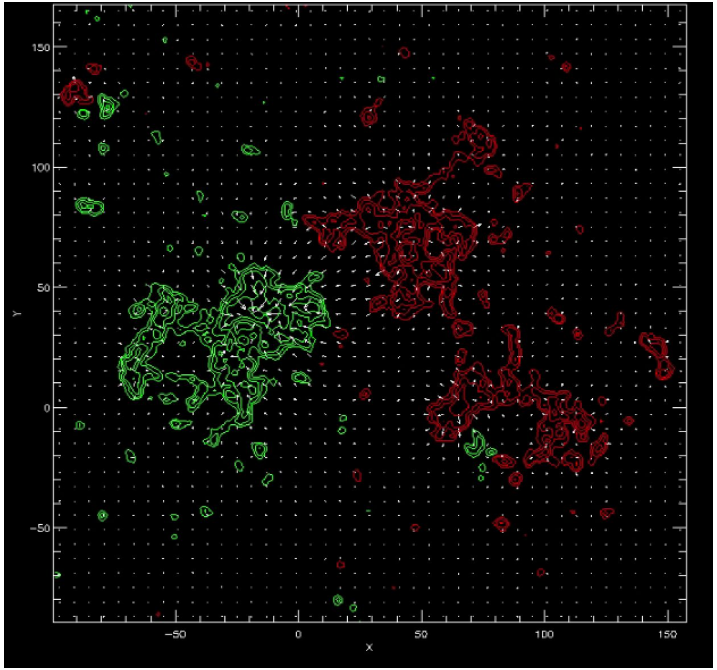
AR10938 on January 1st, 2007 & AR11067 on May 5th, 2010



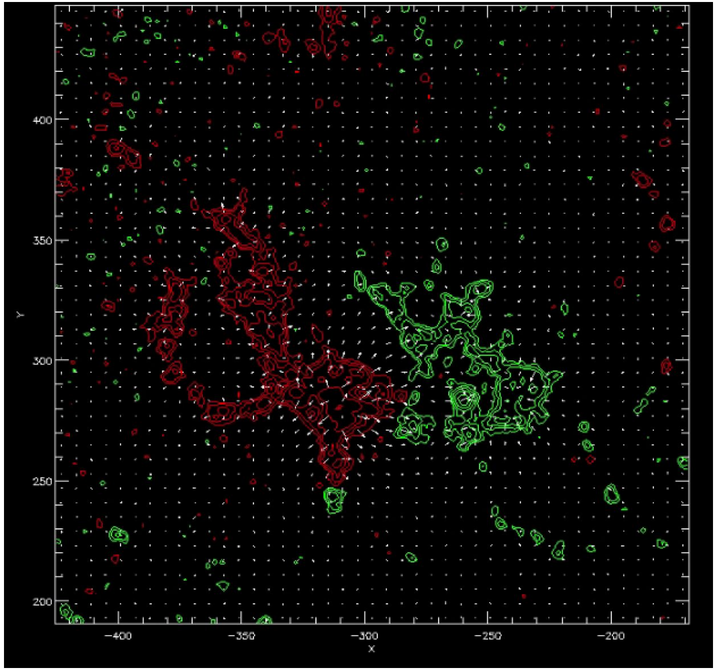


Magnetic Potential Field Modeling

Potential Field Model for AR10938 on 1-18-2007



Potential Field Model for AR11067 on 5-5-2010

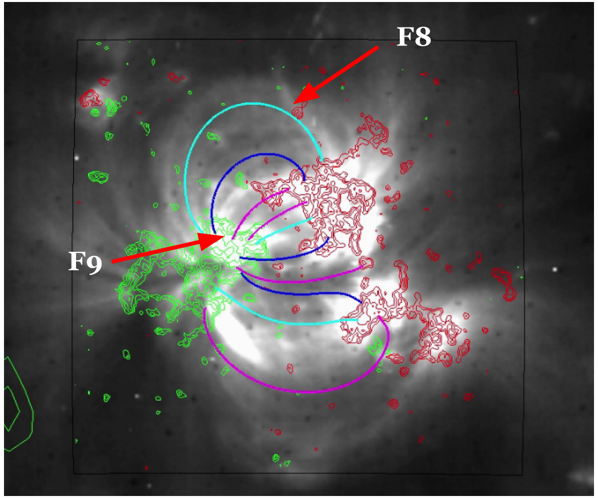


- Two poles; red = positive polarity, green = negative polarity; flow from positive to negative
- X & Y axes = position of active region

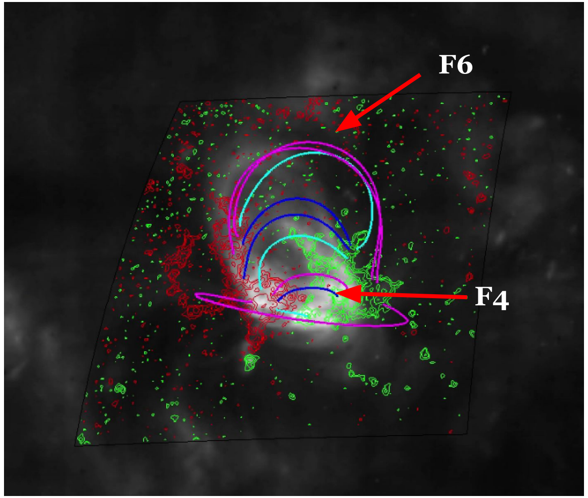
Modeling Coronal Loops from Potential Field Models

- Gathered magnetic synoptic maps and magnetograms from SDO and SOHO instrument data on the active regions to allow CMS to layer EUV images of the Sun on the two dates underneath the potential field lines.
- Applied the software to trace magnetic field lines within these regions.

January 1st, 2007



May 5th, 2010

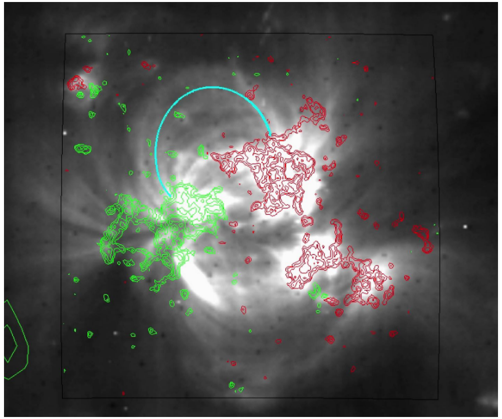


Significance of Field Lines Modeling

- Each magnetic field line traced has specific positional and magnetic field measurements at every point along the line.
- Needed these field line measurements to run through the Alfvén Wave Turbulence Model to further investigate the heating.

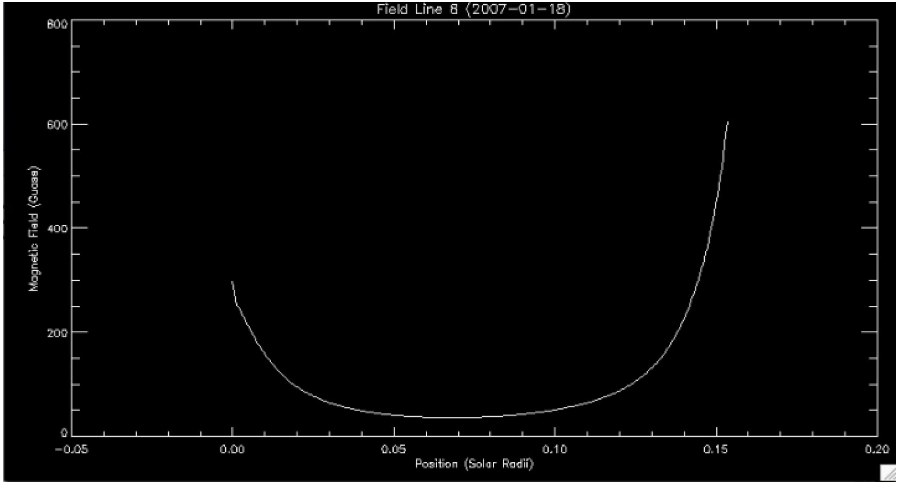
AR10938 on January 1st, 2007

Field Line 8

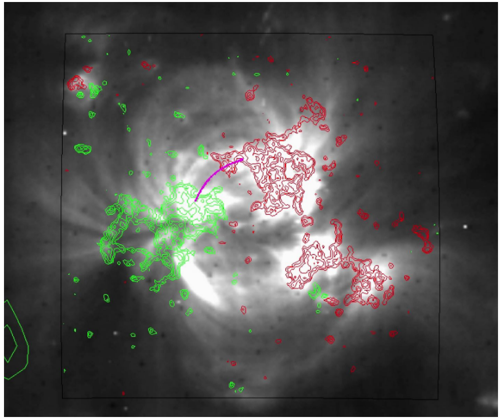


- Min mag. field strength = 35.7050G
- Max mag. field strength = 603.761G

Magnetic Field Strength vs. Position along Magnetic Field Line

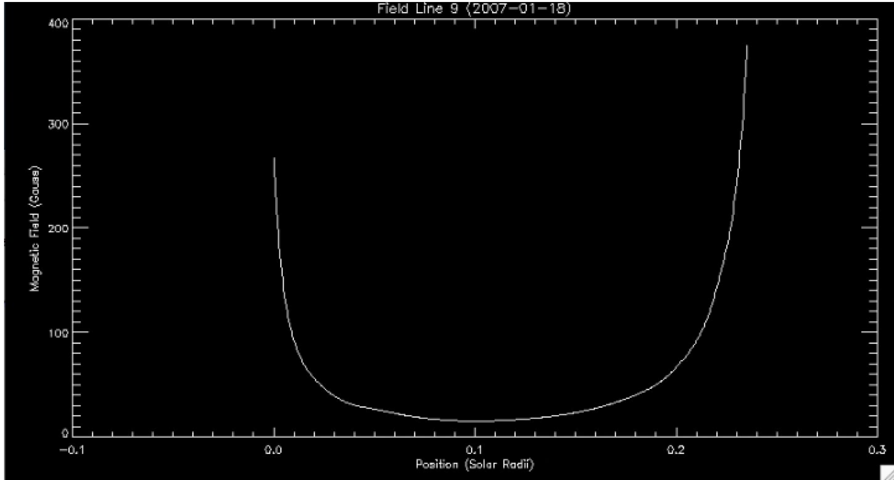


Field Line 9



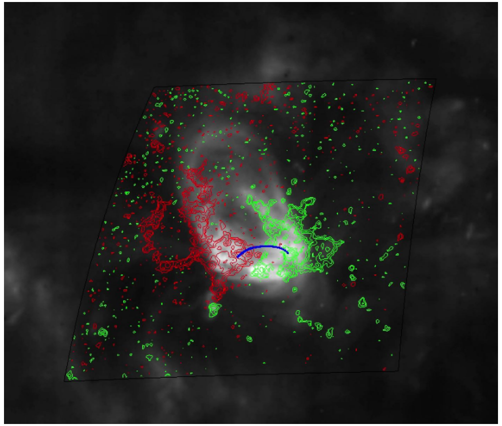
- Min mag. field strength = 14.9956G
- Max mag. field strength = 374.186G

Magnetic Field Strength vs. Position along Magnetic Field Line



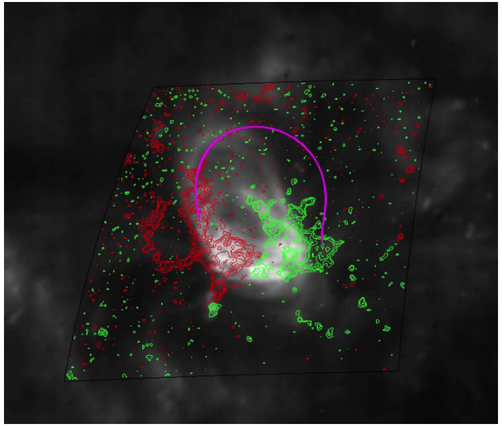
AR11067 on May 5th, 2010

Field Line 4



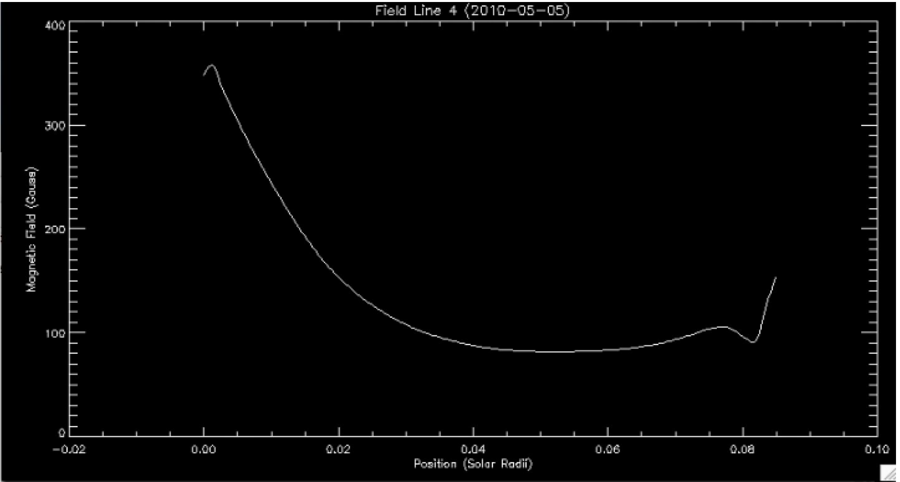
- Min mag. field strength = 81.3935G
- Max mag. field strength = 357.421G

Field Line 6

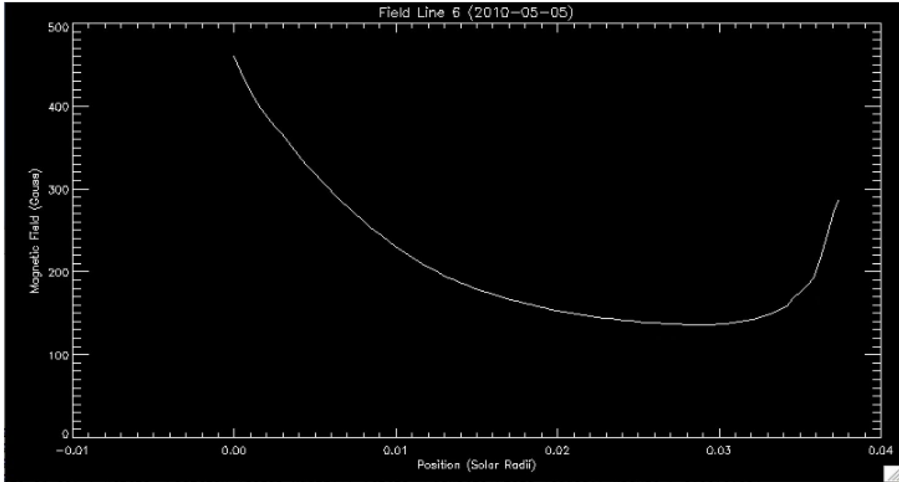


- Min mag. field strength = 136.239G
- Max mag. field strength = 459.942G

Magnetic Field Strength vs. Position along Magnetic Field Line



Magnetic Field Strength vs. Position along Magnetic Field Line

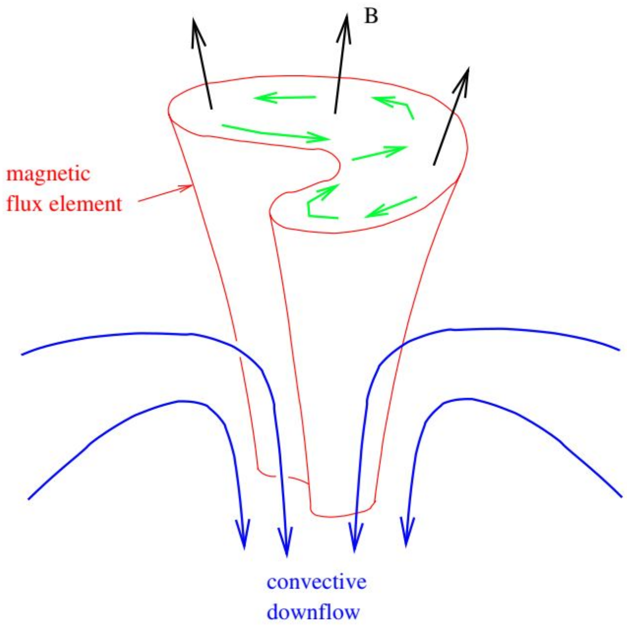


What are Alfvén Waves?

- The discovery of the existence of these waves came about in 1942 while Hannes Alfvén was researching the coronal heating problem.
- One of many different waves produced in the Sun due to its plasma structure.
- Result from the interaction between magnetic fields and plasma.
- Our project focused on the turbulence created by these waves within coronal loops and how that turbulence may result in the heating of the corona.

Alfvén Waves and the Heating of the Corona

- Theory: Alfvén waves are created by granulation at the photospheric footpoints, driven upward by the motions inside the photospheric flux, Alfvén Waves from the two footpoints collide at the top of the loop creating the turbulence that deposits energy in the Sun’s Corona, increasing its temperature.



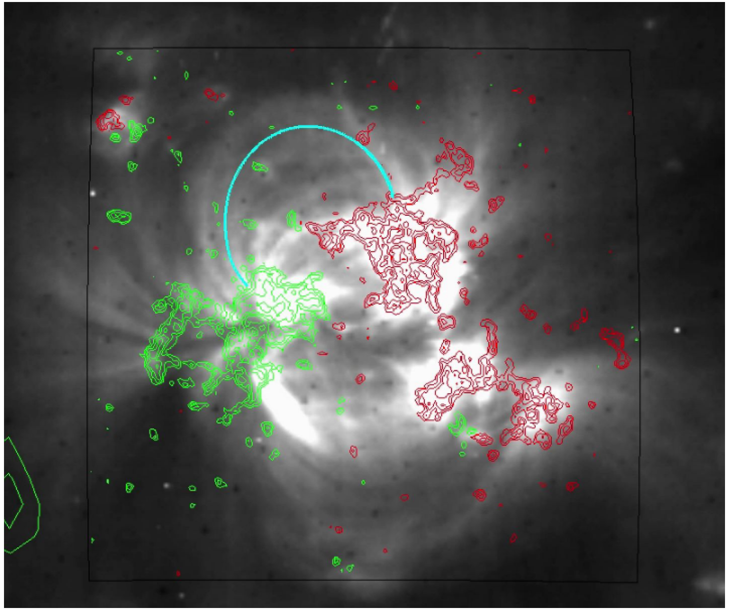
- Alfvén Wave Turbulence Model: The properties of Alfvén waves depends strongly on density as a function of position.

$$V_A = \frac{B}{\sqrt{4\pi\rho}}$$

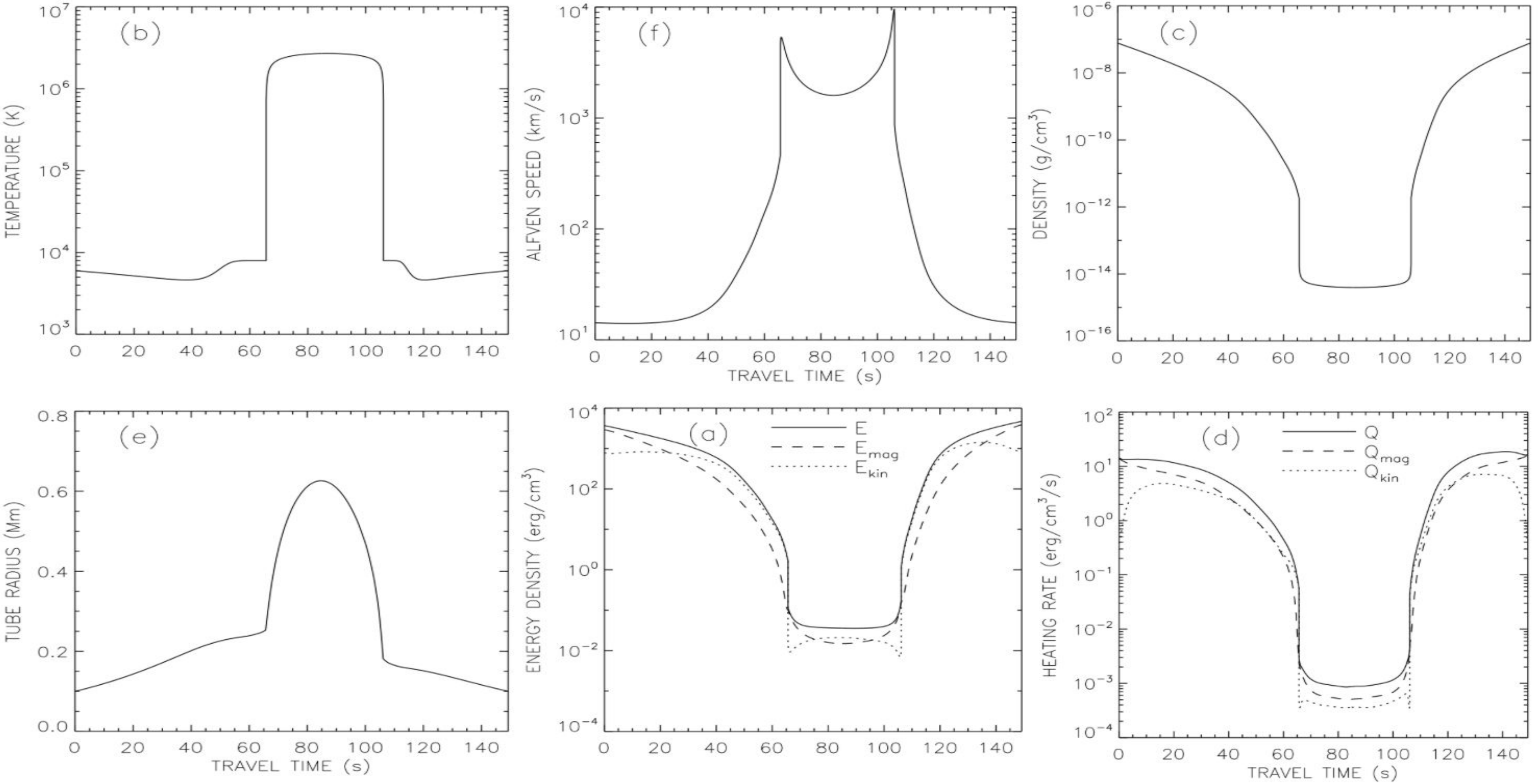
Results

★ Results shown are from modeling Alfvén wave turbulence in F8 on 1-18-2007. These quantities are plotted as a function of Alfvén travel time along the loop.

Field Line 8



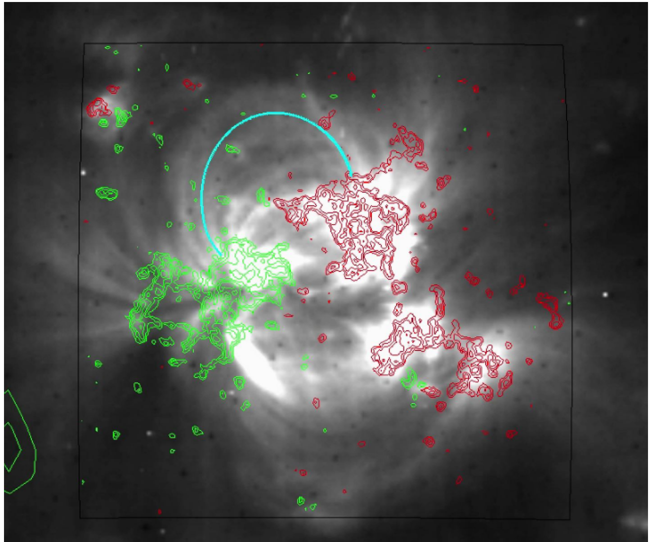
Results:



(b)
TEMPERATURE (K)
(f)
ALFVEN SPEED (km/s)
TRAVEL TIME (s)
(c)
DENSITY (g/cm^3)
(e)
TUBE RADIUS (Mm)
TRAVEL TIME (s)
(a)
E
E_{mag}
E_{kin}
ENERGY DENSITY (erg/cm^3)
(d)
Q
Q_{mag}
Q_{kin}
HEATING RATE (erg/cm^3/s)
TRAVEL TIME (s)

Key Outcomes:

- Modeled loops have peak temperatures in the range of 1-2 MK from Alfvén Wave Turbulence.
- Alfvén speed increases significantly with height along the loops.



Acknowledgements

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★ Thank you, thank you, thank you to everyone involved in making this summer research opportunity possible.

Equations for Figures:

- $$\rho \frac{d\mathbf{v}}{dt} = -\nabla p + \rho \mathbf{g} + \frac{1}{4\pi}(\nabla \times \mathbf{B}) \times \mathbf{B} + \mathbf{D}_v,$$

- $$\frac{\partial \mathbf{B}}{\partial t} = \nabla \times (\mathbf{v} \times \mathbf{B}) + \mathbf{D}_m.$$