Heating of the Solar Corona by Alfvén Wave Turbulence

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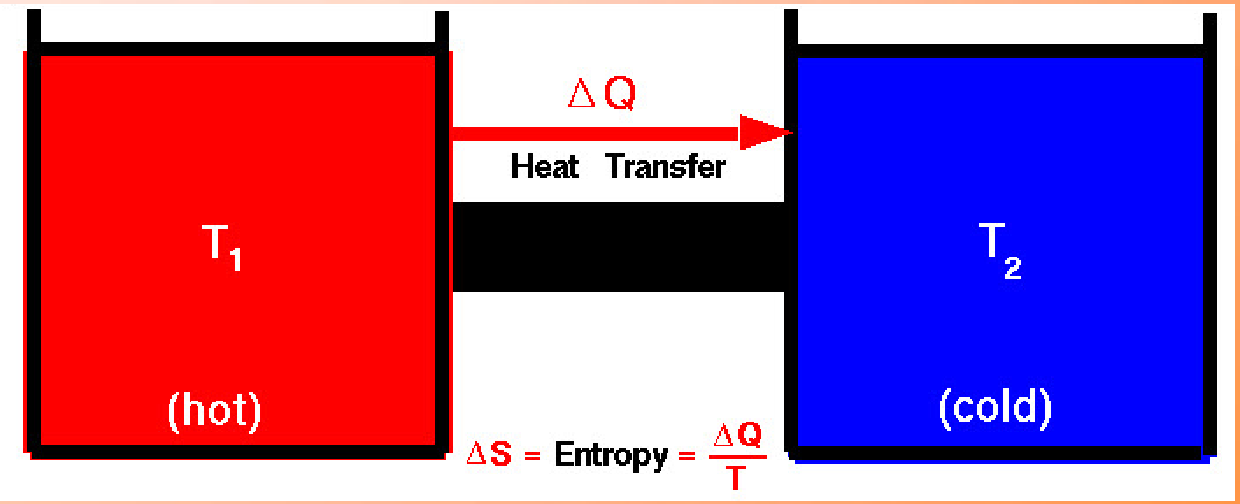
The Coronal Heating Problem

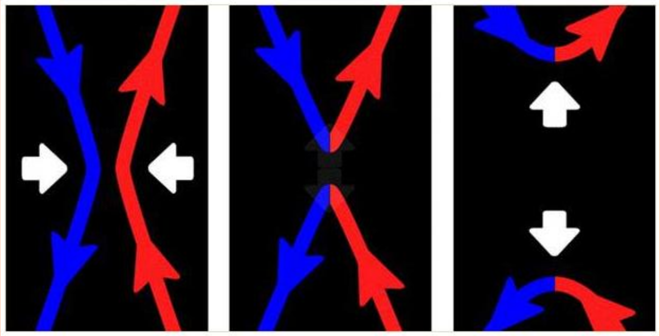
- Corona has a temperature significantly higher than that of the photosphere
- Seems to violate 2nd Law of Thermodynamics



Two possible solutions:

Nanoflares

- Random motion of coronal loop footpoints causes braiding
- Stress builds up
- Magnetic field lines break up and reconnect, releasing energy



Alfvén Wave Turbulence

- Random footpoint motions cause Alfvén waves to propagate along coronal loops
- Waves meet at centre of loop
- Interact nonlinearly, releasing energy

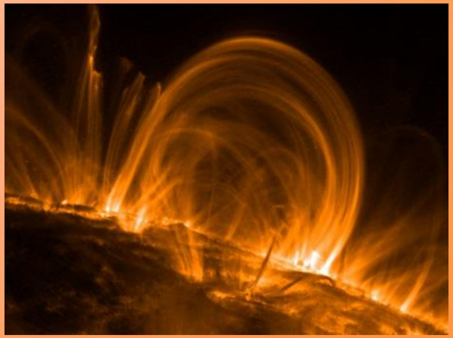


Image courtesy of TRACE/NASA (Nov 1999)

Aims of This Project

- To conduct comprehensive studies of generation and dissipation of Alfvén waves in the solar atmosphere in observed open and closed field lines using analytical and numerical tools.
- To interpret observations and compare them to the modeling results.

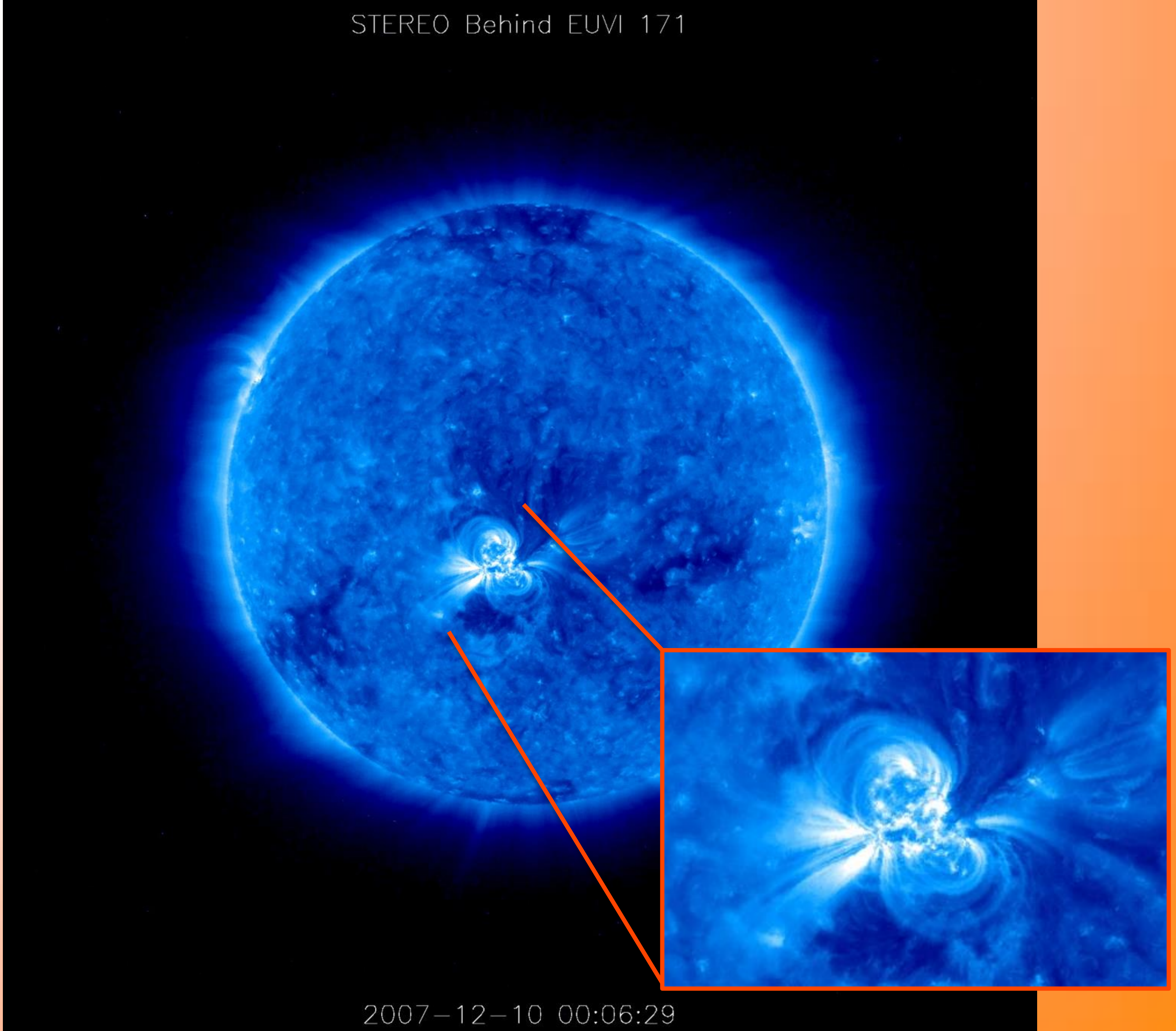
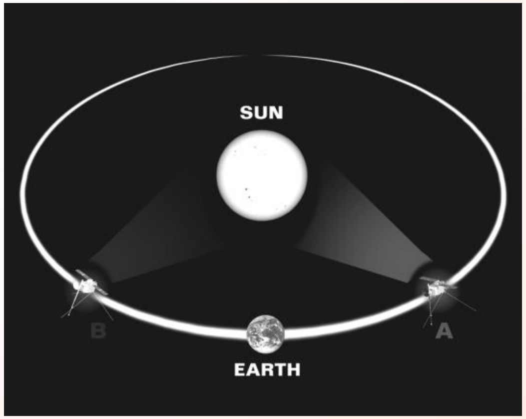

STEREO Behind EUVI 171
2007-12-10 00:06:29

Image:http://cse.ssl.berkeley.edu/stereo_solarwind/mission.html

Image: http://orbiterchspacenews.blogspot.com/2012/07/sounding-rocket-mission-to-observe.html

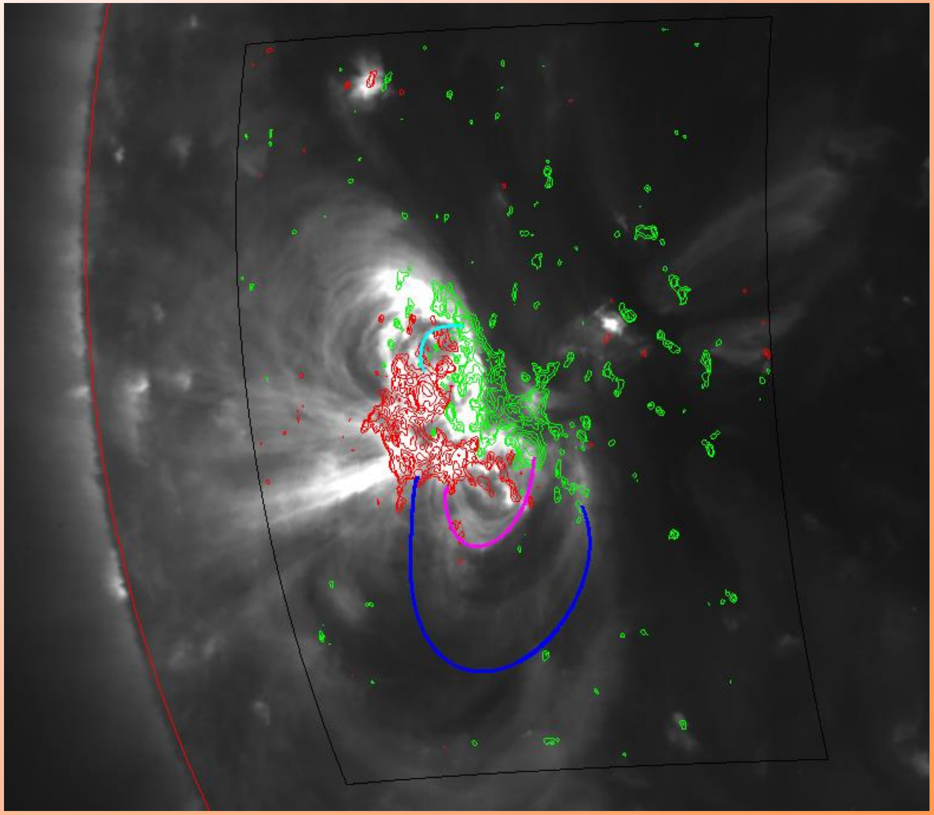


Data Sources

- STEREO – employs two nearly identical space based observatories, one ahead of the earth and one behind
- MDI – an instrument on the SOHO spacecraft, measures height of the transition region and magnetic field strength
- EIS – a spectrometer on Hinode, provides monochromatic images of the TR and corona

Part One: Modeling

- Coronal Modeling System (CMS2) program used to select and model a closed loop



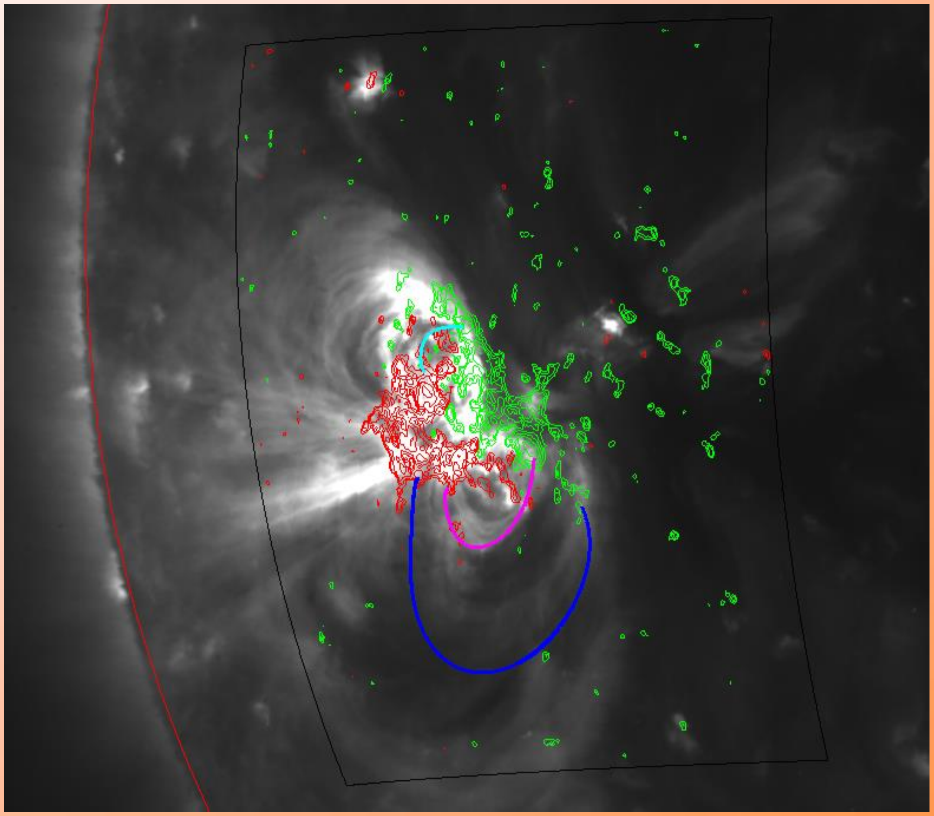
- evolve.f90 program used to solve differential equations

$$\frac{d\mathbf{B}}{dt} \approx \nabla \times (\mathbf{v} \times \mathbf{B})$$

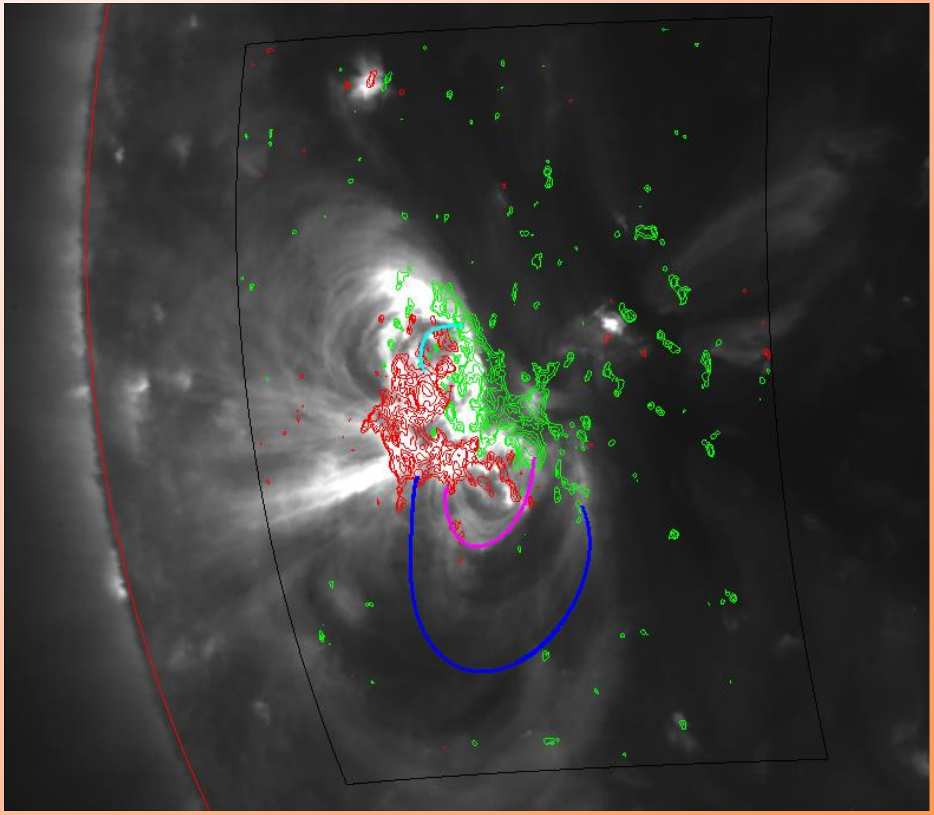
Magnetic Induction Equation

$$\rho \frac{D\mathbf{v}}{Dt} = -\nabla p - \rho \mathbf{g} + (\mathbf{j} \times \mathbf{B}) + \mathbf{F}_{visc}$$

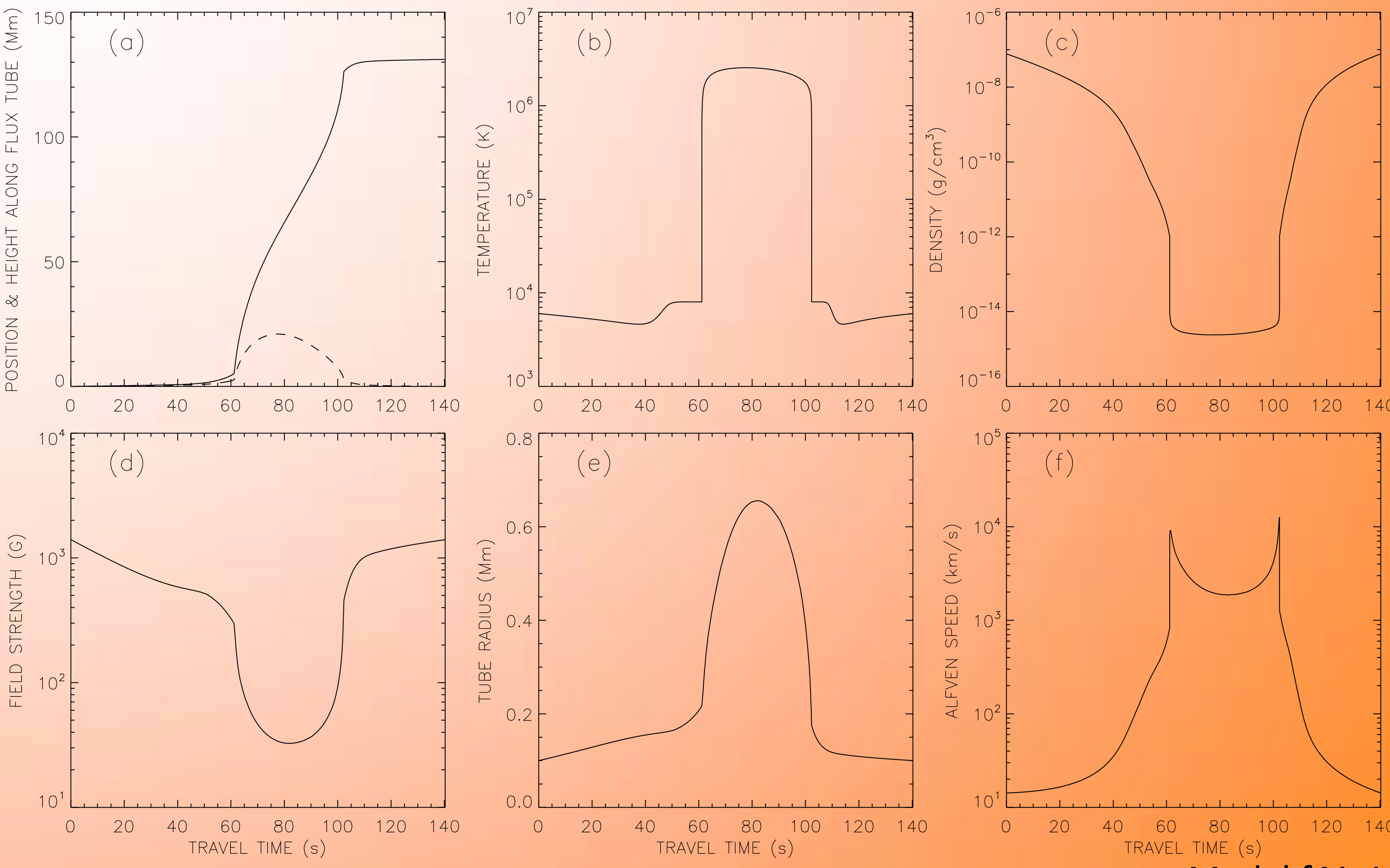
Plasma Equation of Motion



- Braid program used to analyse the results
- Computes temperature, pressure, magnetic field strength, average heating rate and other parameters along the loop

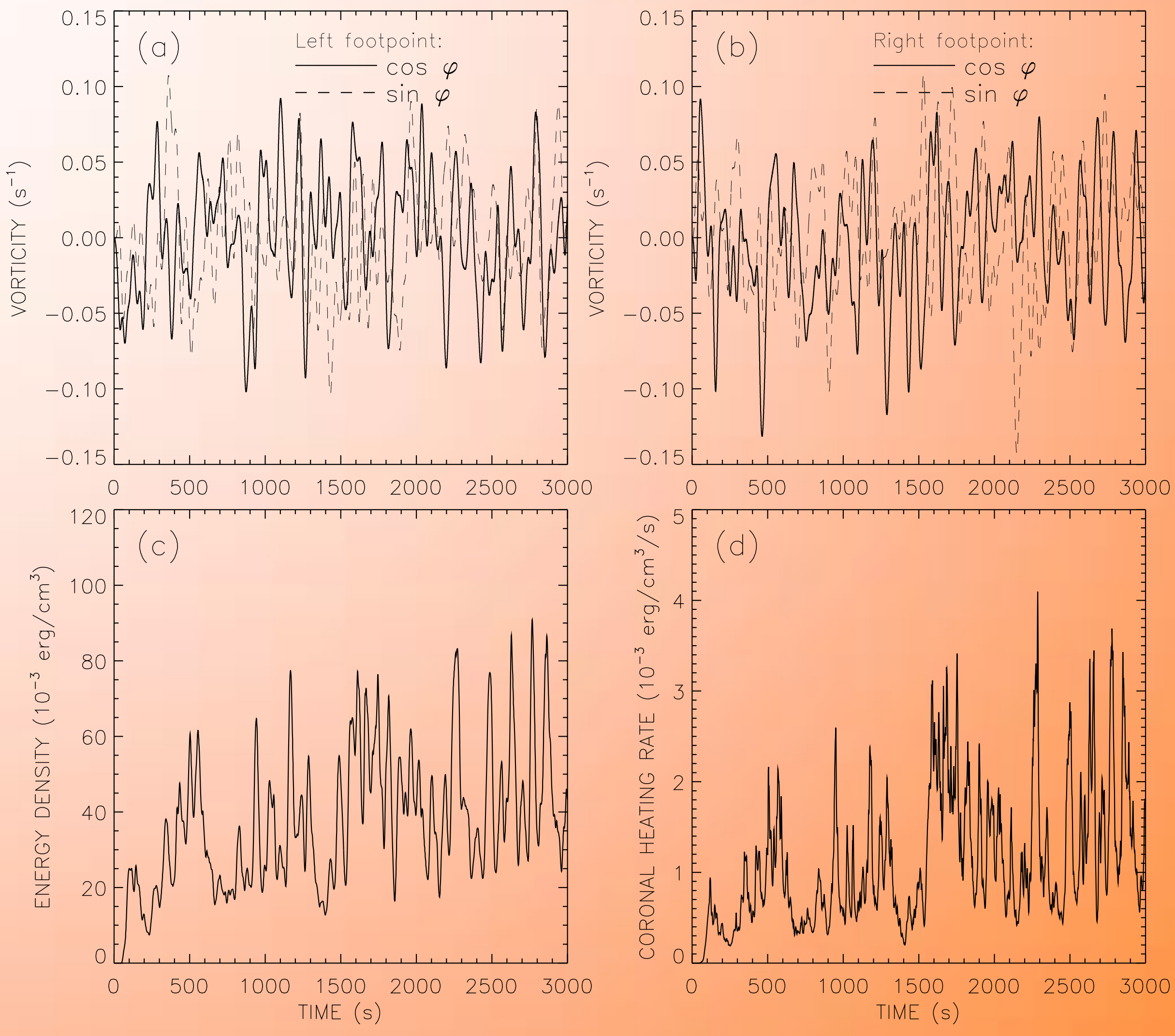


Results



Model f41r1

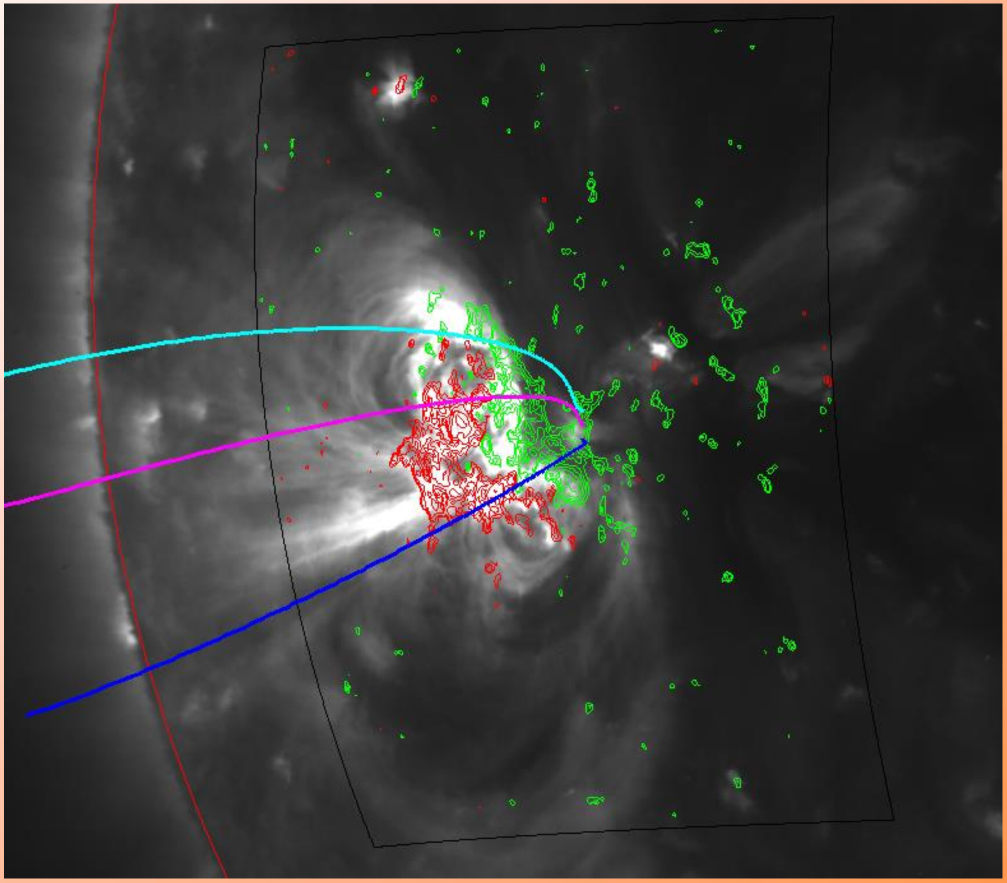
Results



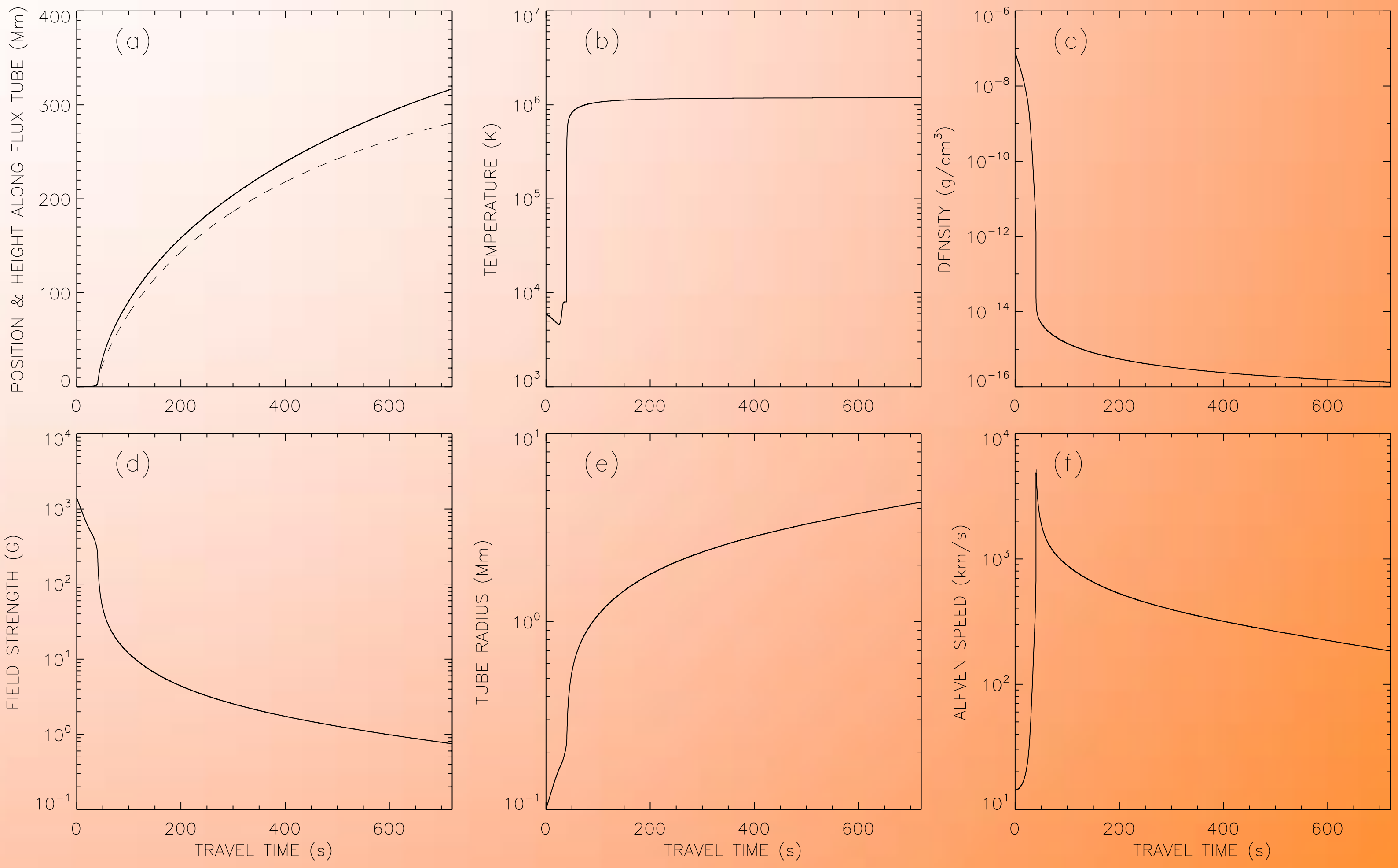
Model f41r1

Open Field Line

- Same analysis repeated for open field lines



Results



Model f47r1

Part Two: Observations

- EUV Imaging Spectrometer (EIS) – combination of multilayer telescope and spectrometer in 170-210 Å and 250-290 Å
- Spectral observations used to infer plasma motions

Image: http://orbiterchspacenews.blogspot.com/2012/07/sounding-rocket-mission-to-observe.html

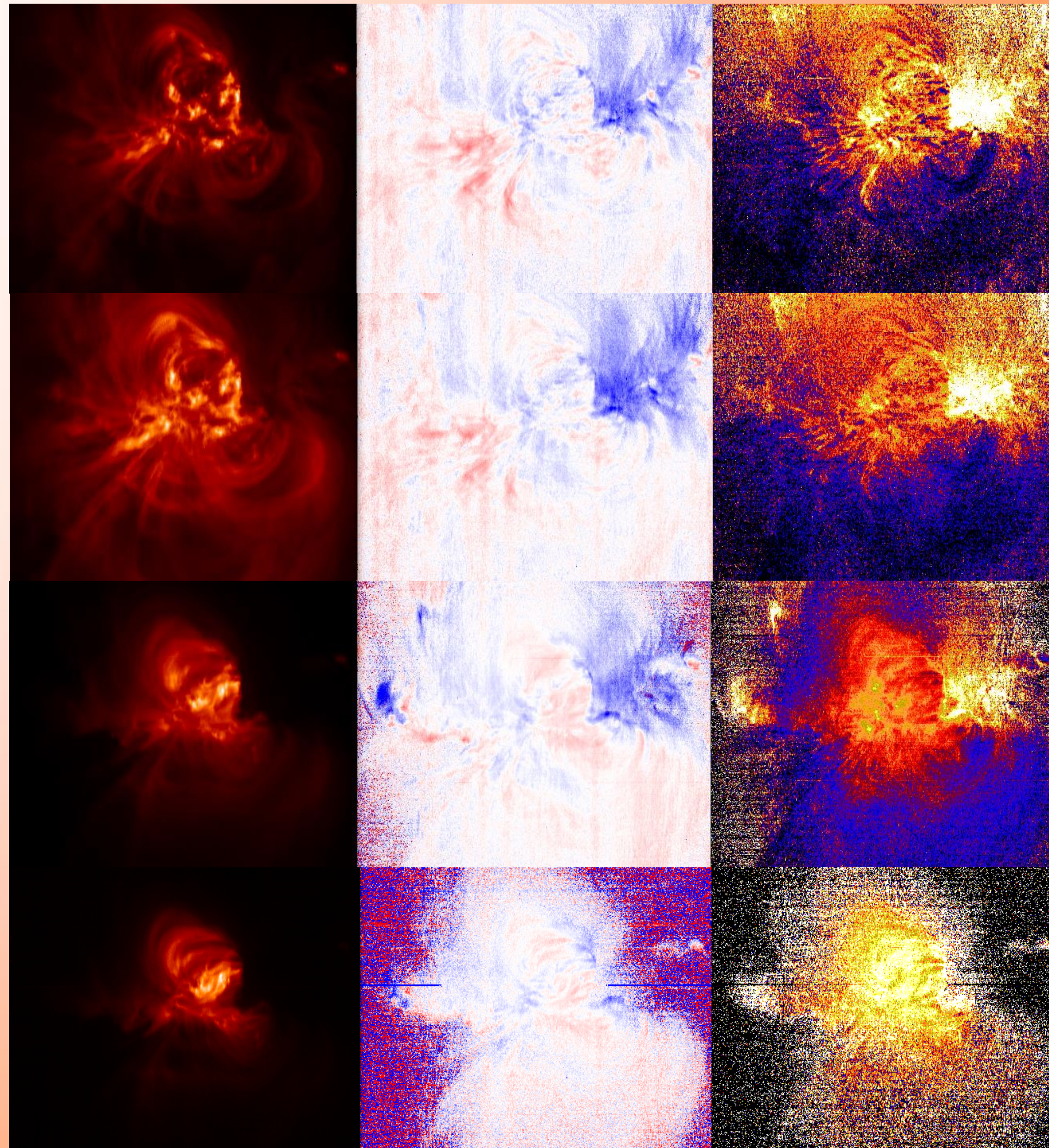
EIS Data

Fe XII – 192.394 Å
1.0×10^6 K

Fe XIII – 202.044 Å
1.6×10^6 K

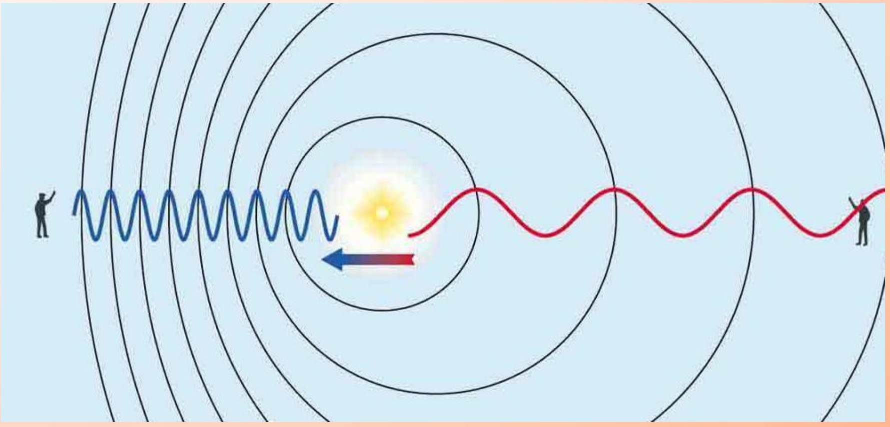
Fe XV – 284.160 Å
2.0×10^6 K

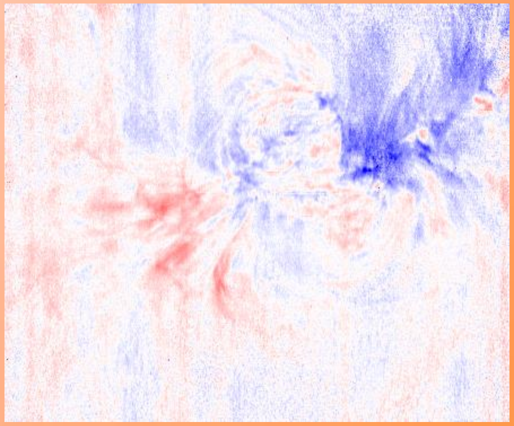
Fe XVI – 262.980 Å
2.5×10^6 K



Doppler Shifts

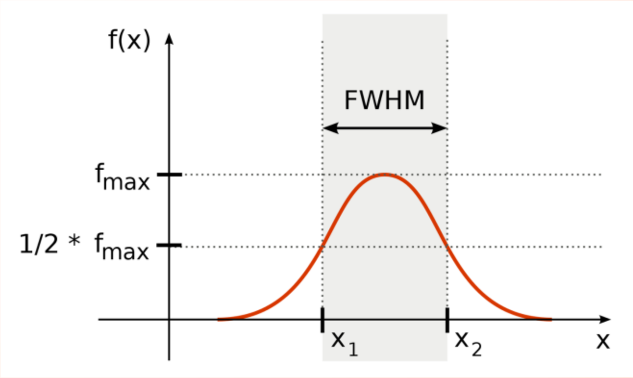
- Source moving with speed v_D relative to the observer
- Emitted frequency f, emitted wavelength λ

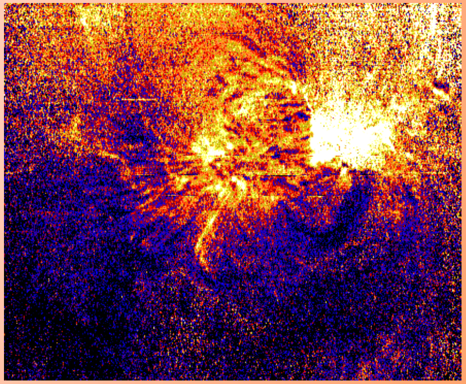




- Observed wavelength = $\lambda \pm v_D/f$
- Change in wavelength $\Delta\lambda_D = v_D/f = \lambda\, v_D/c$

Doppler Width





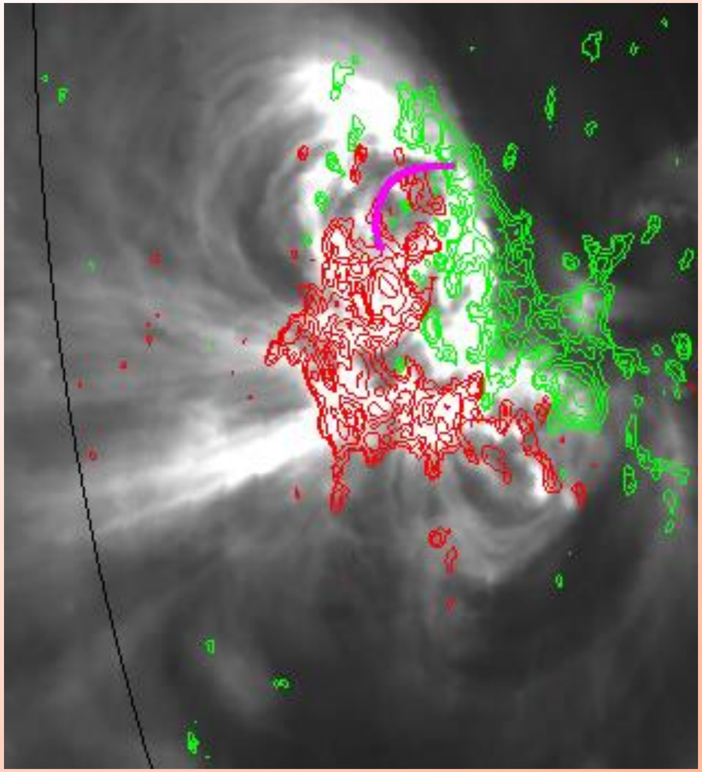
- Sources of line broadening: instrumental, thermal, non-thermal ('microturbulent')
- Total Doppler broadening:

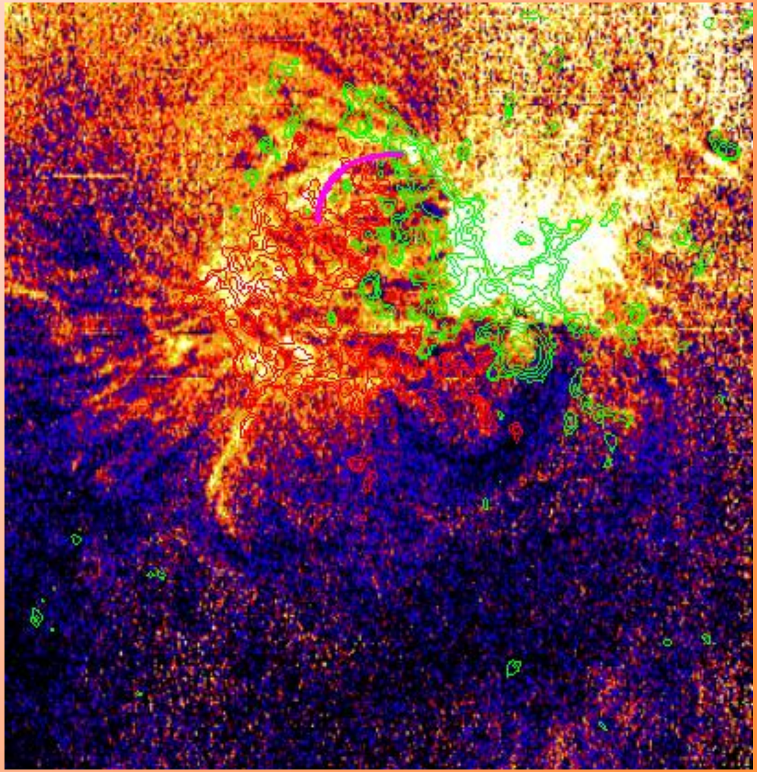
$$v_D = \sqrt{v_{turb}^2 + \frac{2kT}{m}}$$

- FWHM then given by:

$$FWHM = 2\sqrt{2ln2}\Delta\lambda_D \approx 2.355\frac{\lambda}{c}\sqrt{v_{turb}^2 + \frac{2kT}{m}}$$

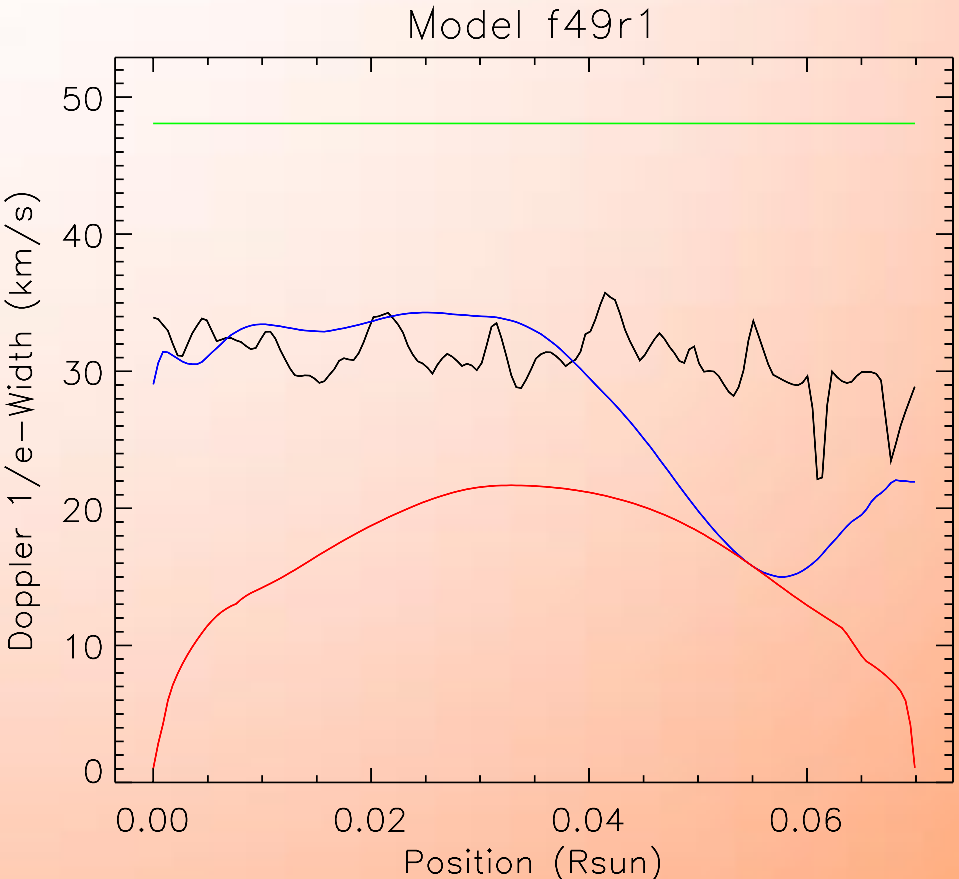
Results – Closed Field Line

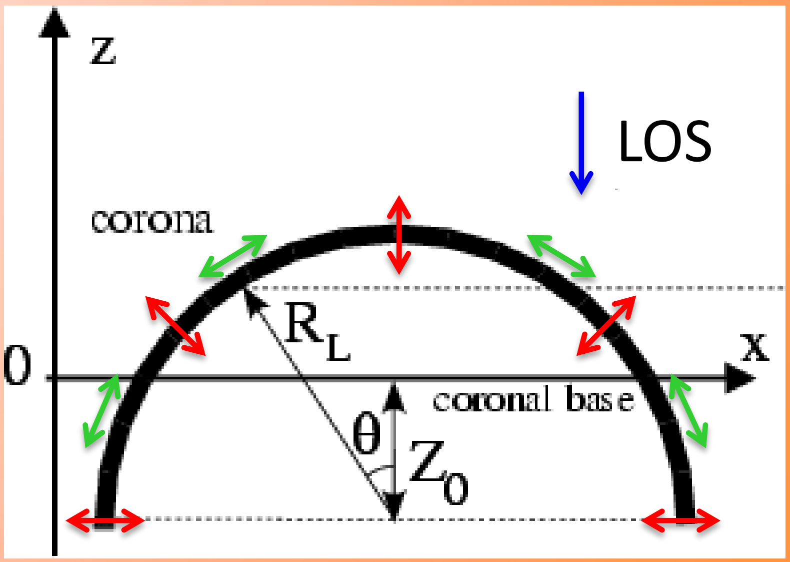




Model f49r1 – Fe XII 192.39

Results – Closed Field Line

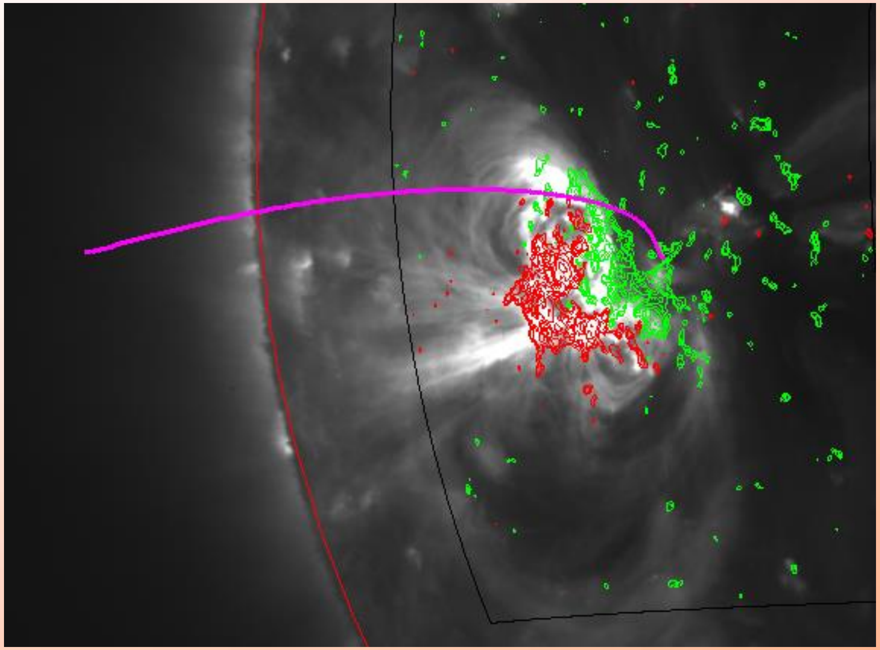


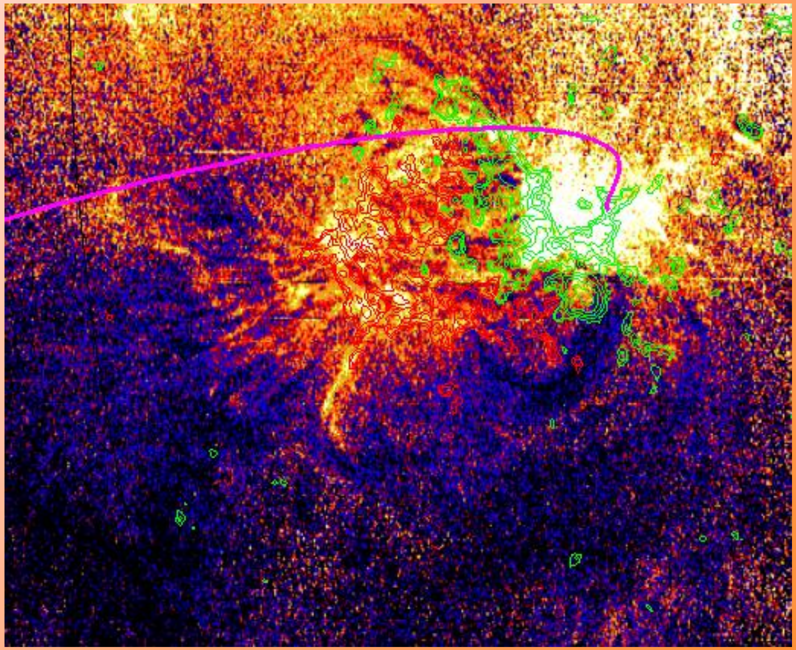


$$V_{LOS}^2 = V_{perp}^2 \cos^2\theta + V_{par}^2 \sin^2\theta$$

Model f49r1 – Fe XII 192.39

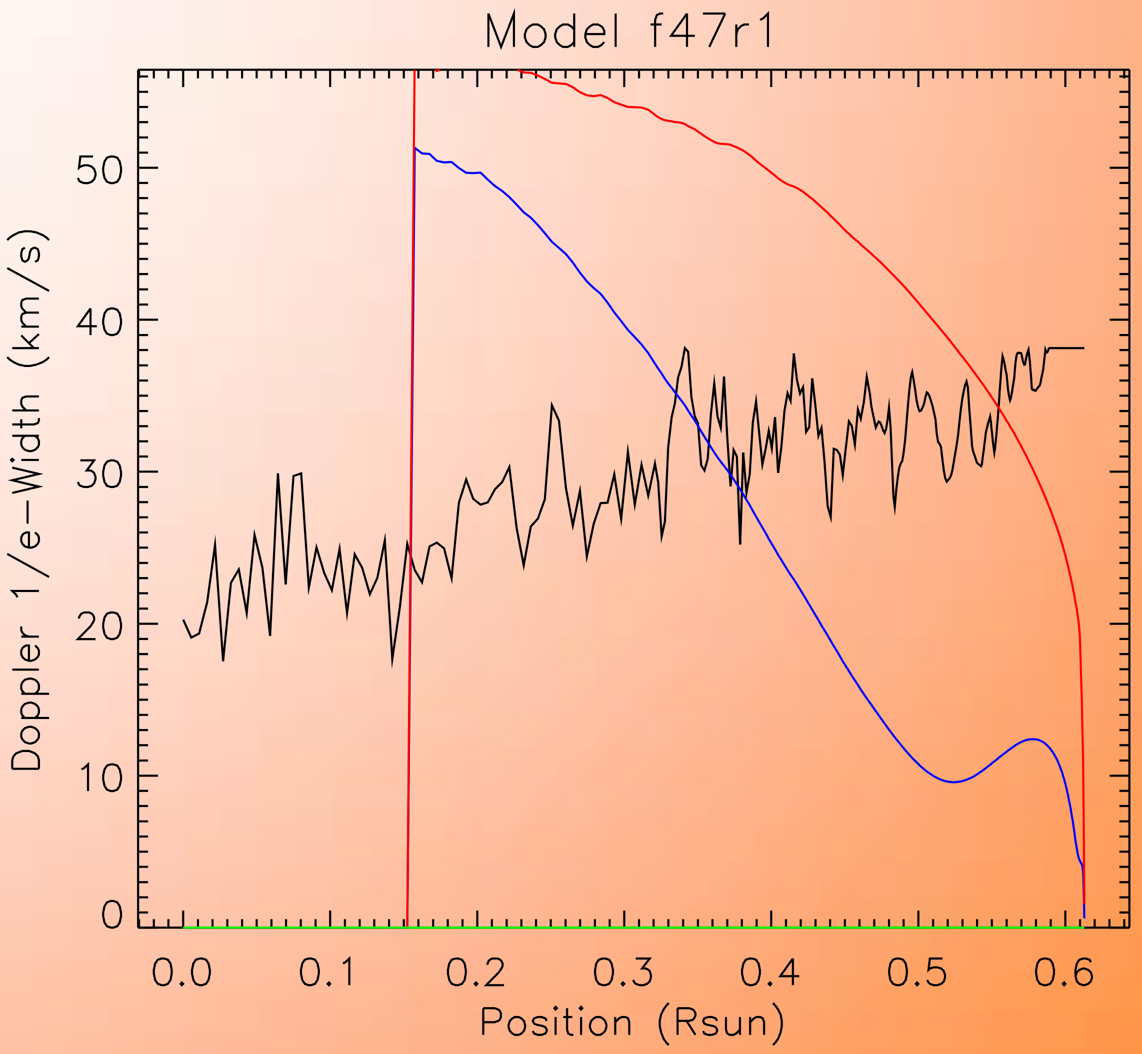
Results – Open Field Line





Model f47r1 – Fe XII 192.39

Results – Open Field Line



Model f47r1 – Fe XII 192.39

Summary and Conclusions

- In this project I modeled Alfvén waves in both closed and open field lines
- I compared the results with data from EIS
- Good agreement for closed field lines
- Next: focus on improving modeling techniques for open field lines and better comparisons with EIS observations

Acknowledgements

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Thank you!