



MSU Solar Physics REU Jennifer O'Hara

Heating of Flare Loops With
Observationally Constrained Heating
Functions

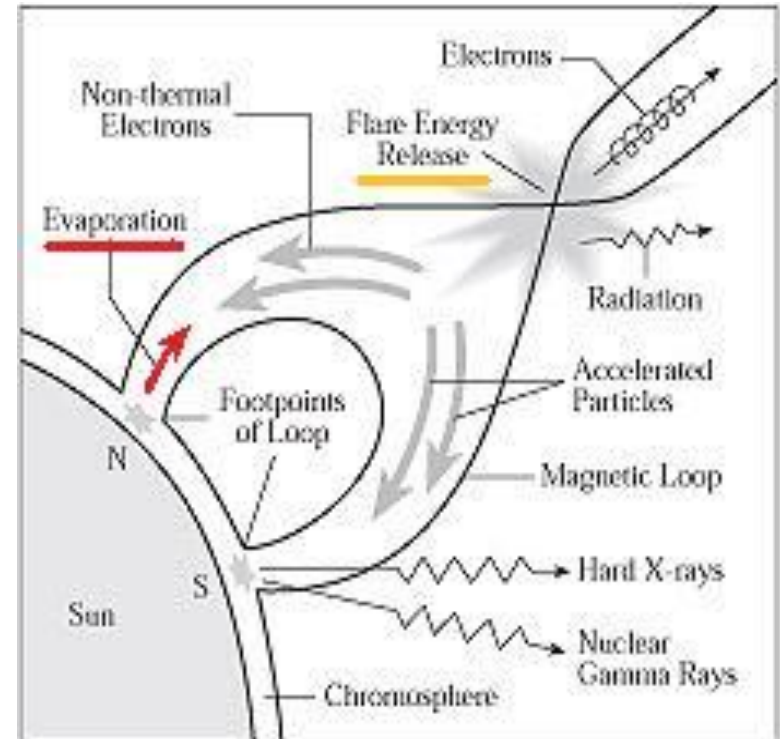
Advisors
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- ✿ Background: Reconnection
- ✿ Project summary
- ✿ Method
- ✿ Data Analysis
- ✿ Conclusions

Magnetic Reconnection in Solar flares

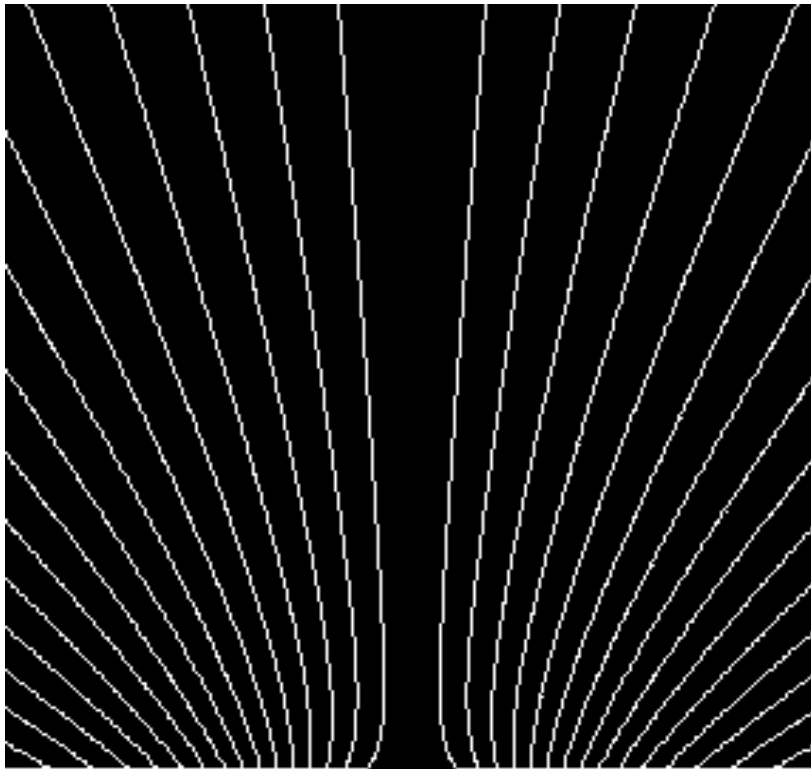
- Where oppositely directed field lines are brought in close proximity and reconnect
- Become a lower energy state: -> **energy release**
- Thermal and non-thermal electrons channelled down the loop -> emit **hard and soft X rays**
- Heat flux along flux tubes heat Chromosphere -> **UV**



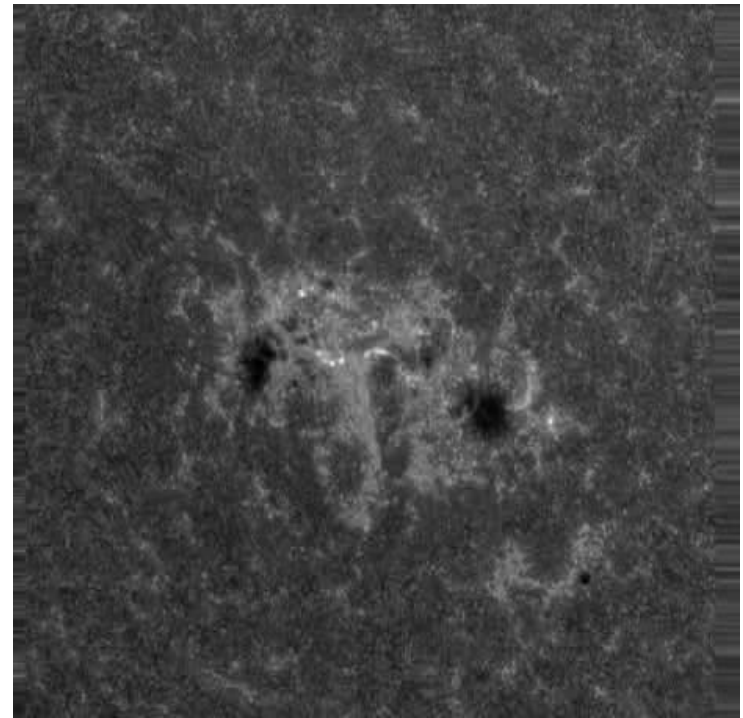
- Heated plasma in Chromosphere can rise into the loop - **Chromospheric evaporation**
- plasma cools and drains – **Chromospheric condensation**

Magnetic Reconnection

- Reconnection continues, new loops form above old, higher in corona
- Loops : 100's of individual strands **heated separately**
- Footpoints move apart



(Forbes)



We can measure reconnection rate with

$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial t} \left(\int \vec{B} \cdot d\vec{a} \right) \approx \frac{\partial}{\partial t} (\Sigma B_i a_i)$$

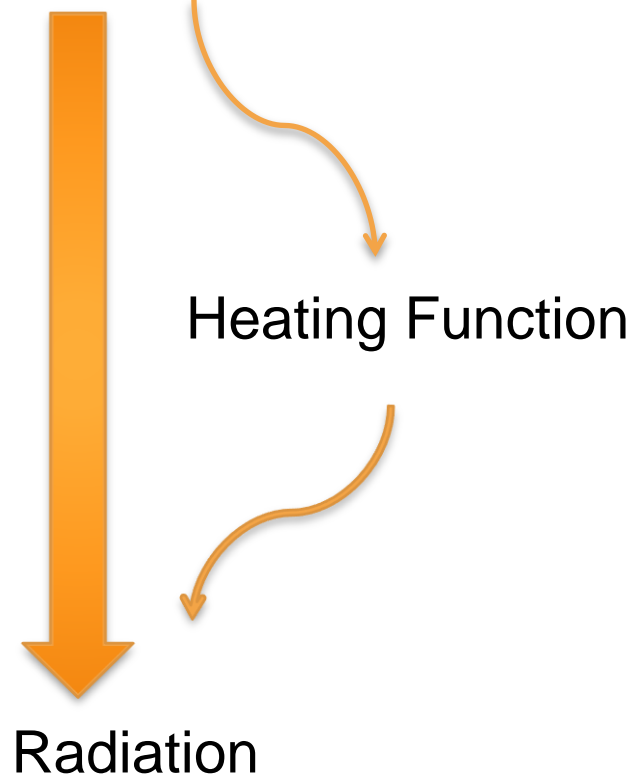
$$\oint \vec{E} \cdot d\vec{l} = - \frac{\partial \phi}{\partial t}$$

Project Summary

Big picture: Understanding the relationship between reconnection and energy release.

- What we know:
 - ✓ **know flux:** can measure reconnection
 - ✓ **Know radiation** (measured by GOES and AIA)Want to know link :how this energy is released!
- Specific Question:
Link is : **HEATING FUNCTION**
- Guess that UV pixel observations reflect heating -> know times and place of heating.
- Use model with heating function input to calculate radiation outputs and compare with GOES and AIA observations to see if our assumption is true.

Magnetic Reconnection



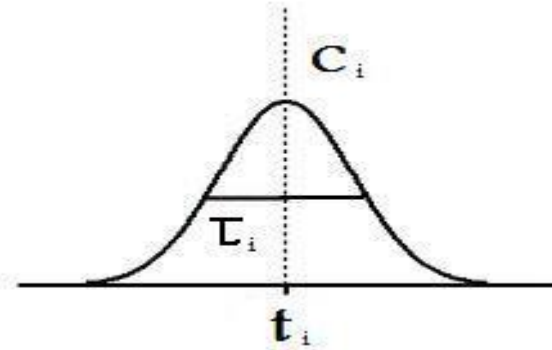
Constructing a heating function

- ✿ Model that each flare is made up of hundreds (thousands) of ind. Strands - each base is a pixel.
- ✿ Formed and heated at **different times**.
- ✿ Very bright **U.V observations** at feet of loops appear almost **instantaneously**
- ✿ So can use U.V to deduce **reconnection rate** and can also calculate an **individual heating function** for each strand.

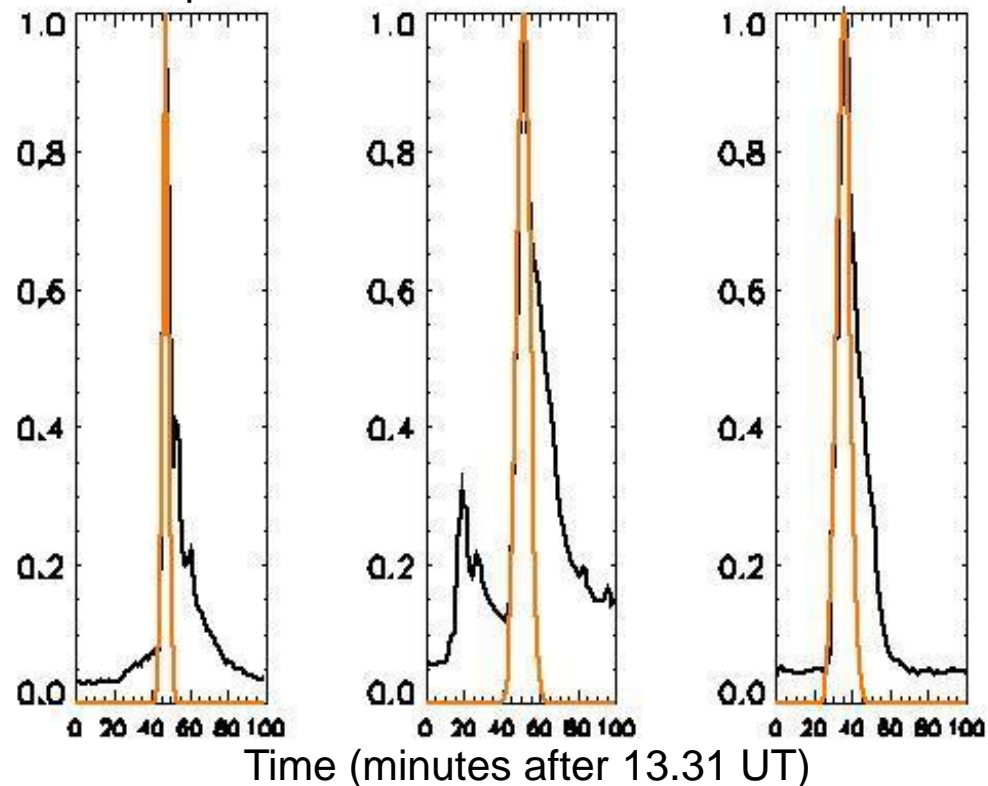
Constructing Heating Function cont'd

- Each pixel has an individual UV light curve and we want individual heating function to model rise time for each.
- Can use different shapes to model UV rise: Gaussian, Linear ect.
- For our purposes we used Gaussian:

Observed UV
Heating Function



Comparison of Observed UV and Heat function



$$H_i = Q_i L_i = \lambda \left[C_i \exp \left(- (|t - t_i|)^2 / 2\tau_i^2 \right) \right]^\alpha \text{ (ergs/s/pixel)}$$

$$\alpha = 1$$

H_i : discrete energy (heating) flux in each flux tube;

Q_i : volumetric heating rate (what we want to input in model)

L_i : loop length;

C_i : UV peak count rate;

t_i : peak time; τ_i : rise time;

λ : Total heating scaler (in ebtel model)

$C1$: R_{tr}/R_c (in ebtel model)

Other initial constraints (energy in = energy out):

$$\int H dt = \int (\sum H_i) dt = \int (R_c + R_{tr}) dt = (1 + C1) \int R_{GOES} dt \text{ (ergs)}$$

R_c, R_{tr} : coronal and transition region radiation rates

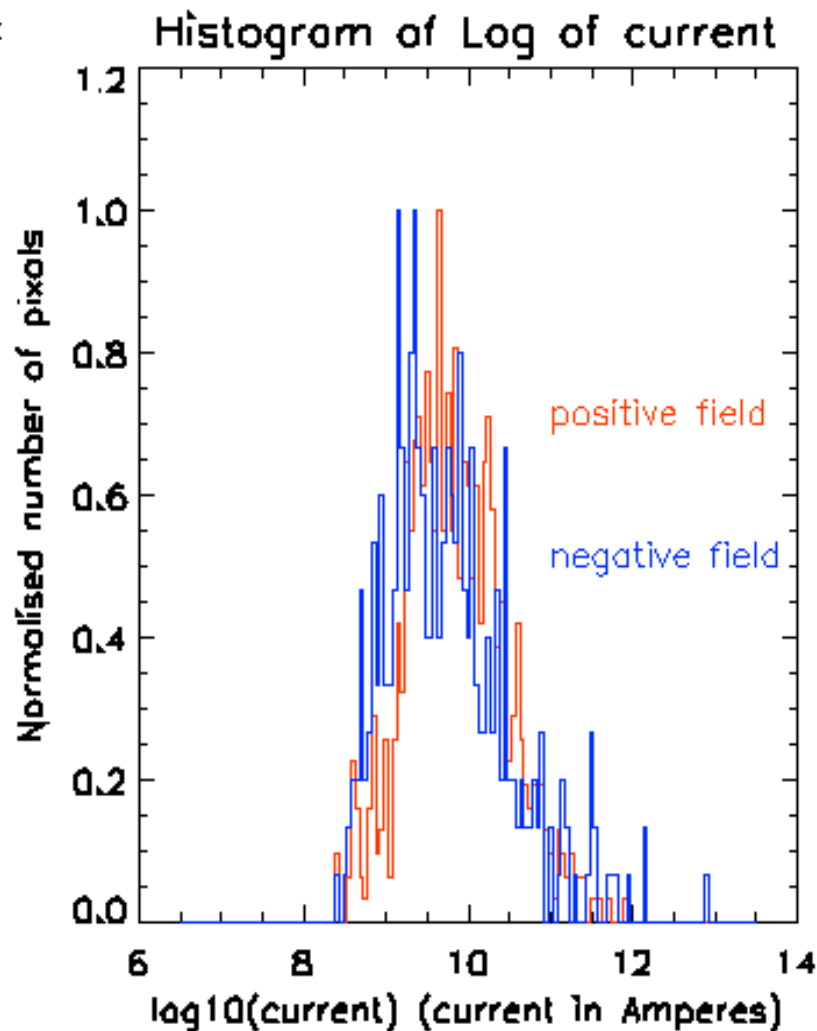
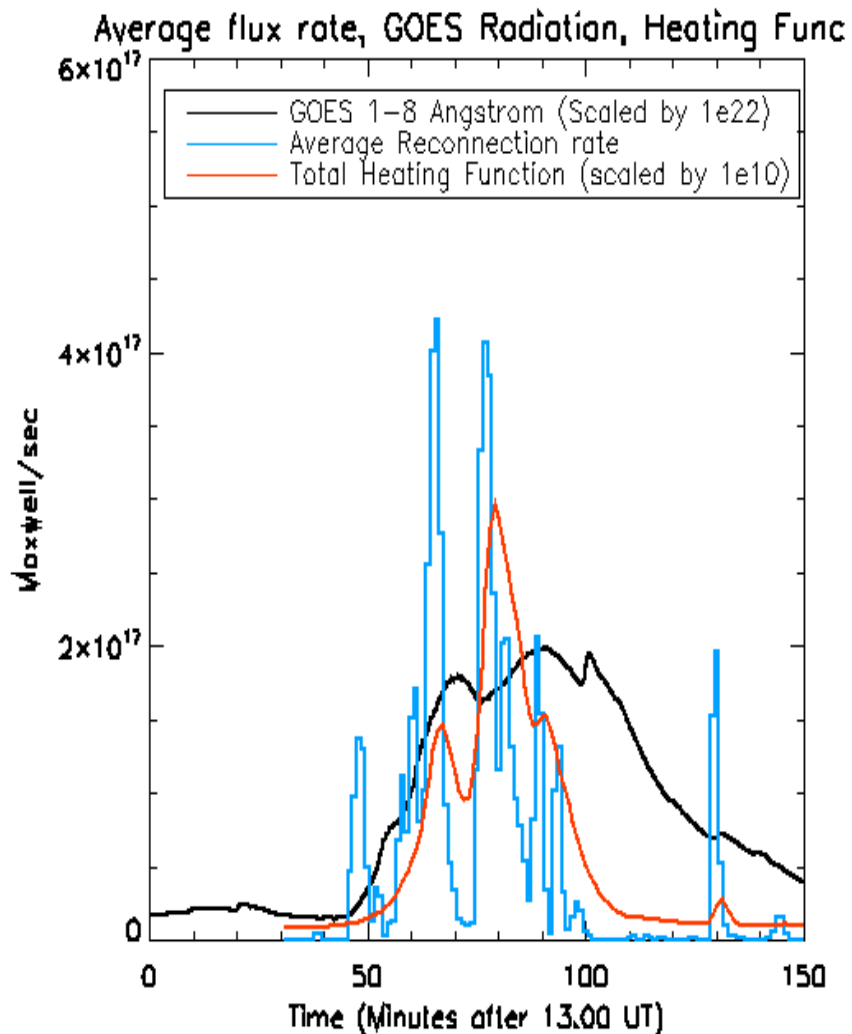
$$R_{tr} = C1 R_c$$

Transition region: Thin region between Chromosphere and Corona, where most radiation is emitted.

Resultant Heat Function

March 7th 2011, M1.7 class Flare, 13.45 UT

Theoretical current = energy / mag flux



EBTEL model

- Models evolution of plasma in a single strand.
- 0D model : average T , n , P for each strand.
- Equates the enthalpy flux with excess deficit of heat flux relative to transition region loss rate.

Q - volumetric heating rate
n - electron number density
T - Temperature
P - Pressure
L - Length of strand
F₀ - F_c Heat flux

$$\frac{d\bar{P}}{dt} \approx \frac{2}{3} \left[\bar{Q} - \frac{1}{L} (\mathcal{R}_c + \mathcal{R}_{tr}) \right].$$

$$\frac{d\bar{n}}{dt} = - \frac{c_2}{5c_3 k L \bar{T}} (F_0 + \mathcal{R}_{tr}),$$

$$\frac{d\bar{T}}{dt} \approx \bar{T} \left(\frac{1}{\bar{P}} \frac{d\bar{P}}{dt} - \frac{1}{\bar{n}} \frac{d\bar{n}}{dt} \right).$$

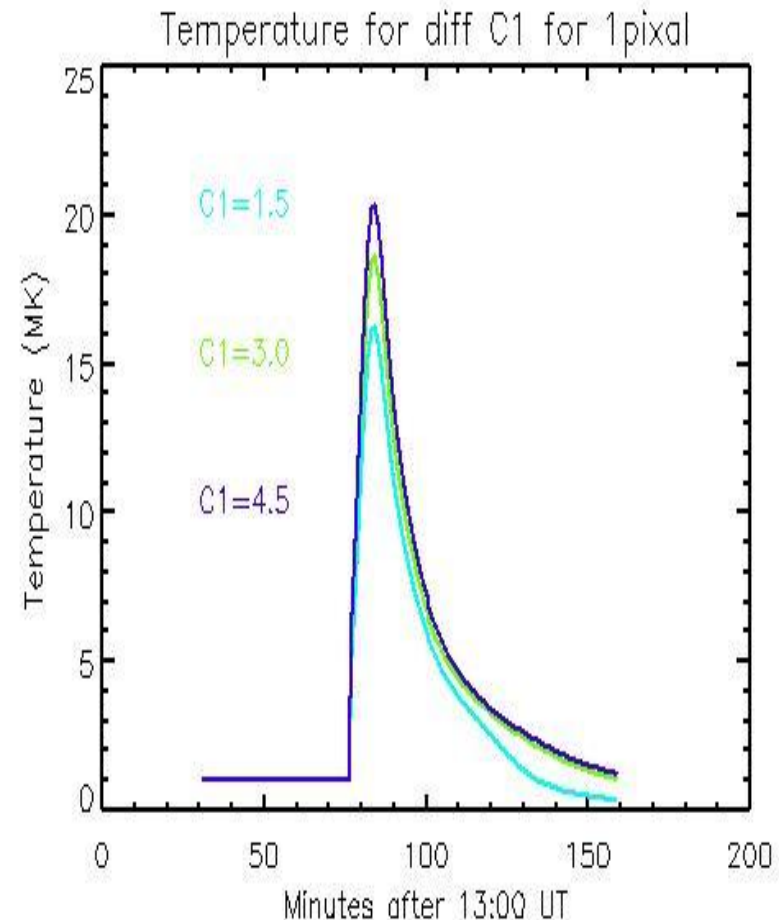
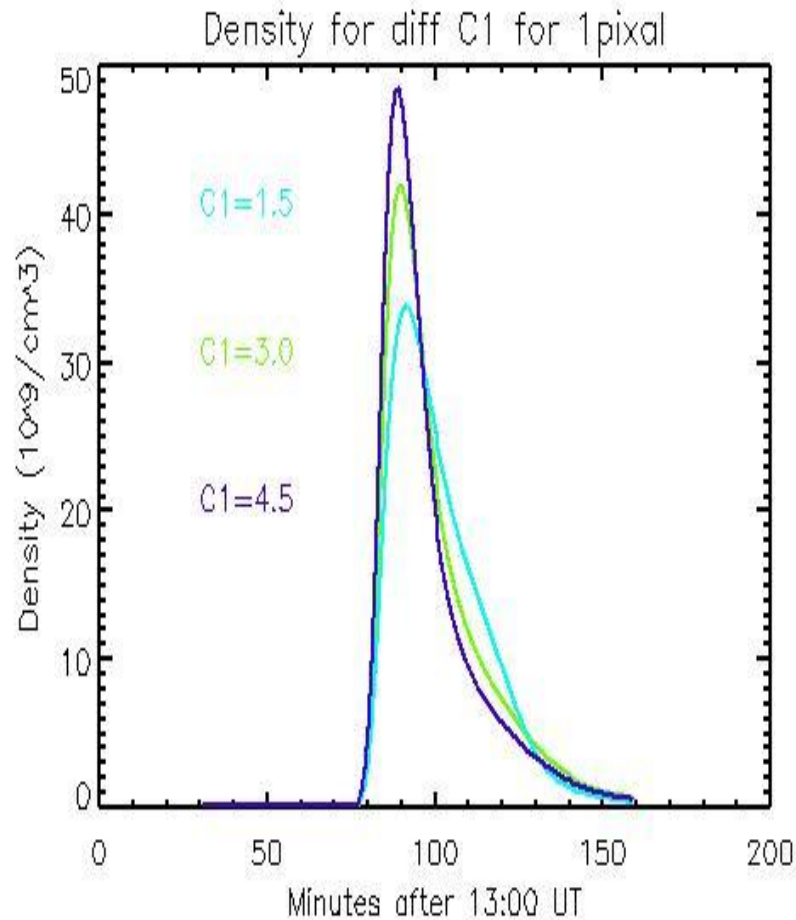
EBTEL model cont'd

$$\mathcal{R}_c \approx \bar{n}^2 \Lambda(\bar{T}) L. \quad F_c \approx -\frac{2}{7} \kappa_0 \frac{T_a^{7/2}}{L}, \quad c_1 = \frac{\mathcal{R}_{tr}}{\mathcal{R}_c}.$$

- Inputs:
 - initial temp, density and pressure
 - scalar parameters **c1**, and total heating **λ**
 - Loop **length (L)**: interpolated so increases for different strands
- EBTEL:
 - Calculates initial R_c from equation above
 - Use C_1 to calculate R_{tr} .
 - Sub into 3 diff eq.'s to find rate of change and new average n , P , T , then repeat
- Output:
 - **Average T, n, P at each time for each individual flux tube.**
- Use to make calculations and compare with observations

Single Flux Tube Analysis

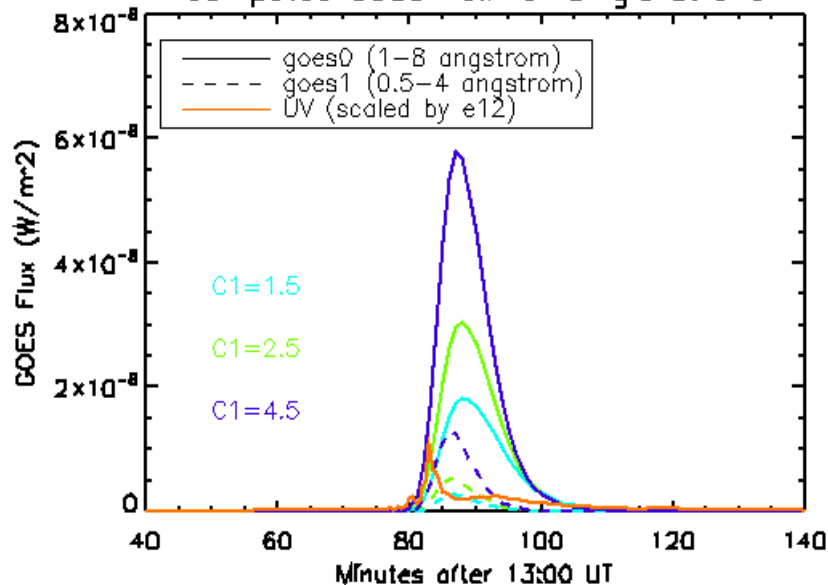
$$c_1 = \frac{R_{tr}}{R_c}$$



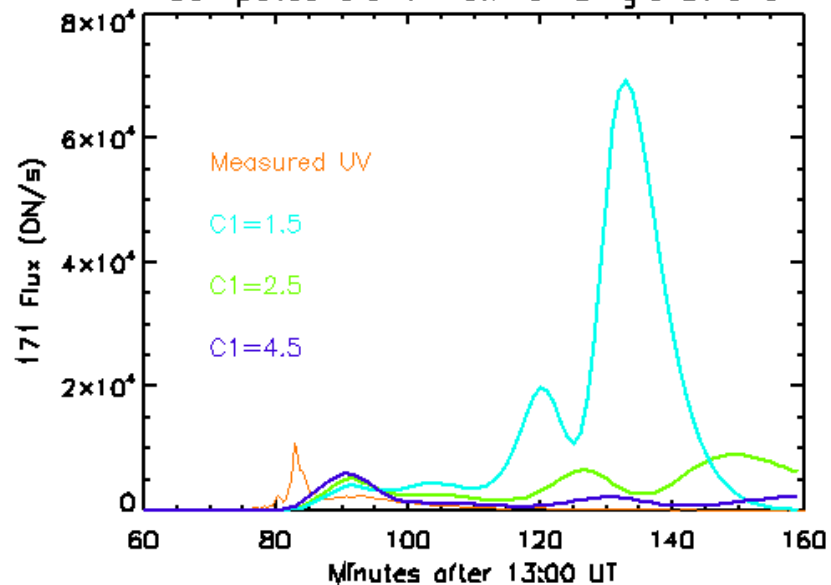
- Increased C1 → Greater total energy input
 - Greater R_{tr} to R_c ratio
 - After heating see less density: as less plasma as less evaporation
 - Less R_c : cools more slowly

Single Flux Tube Analysis

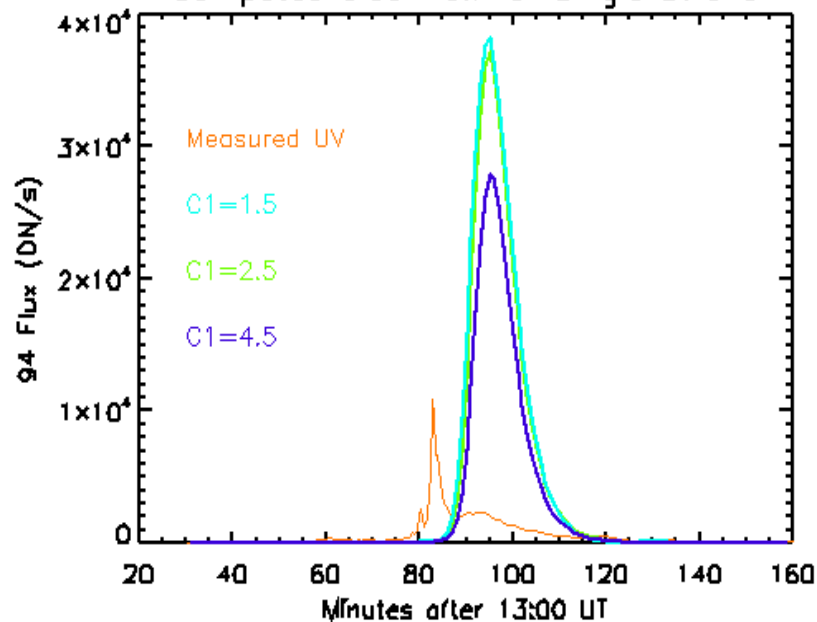
Computed GOES flux for Single Strand



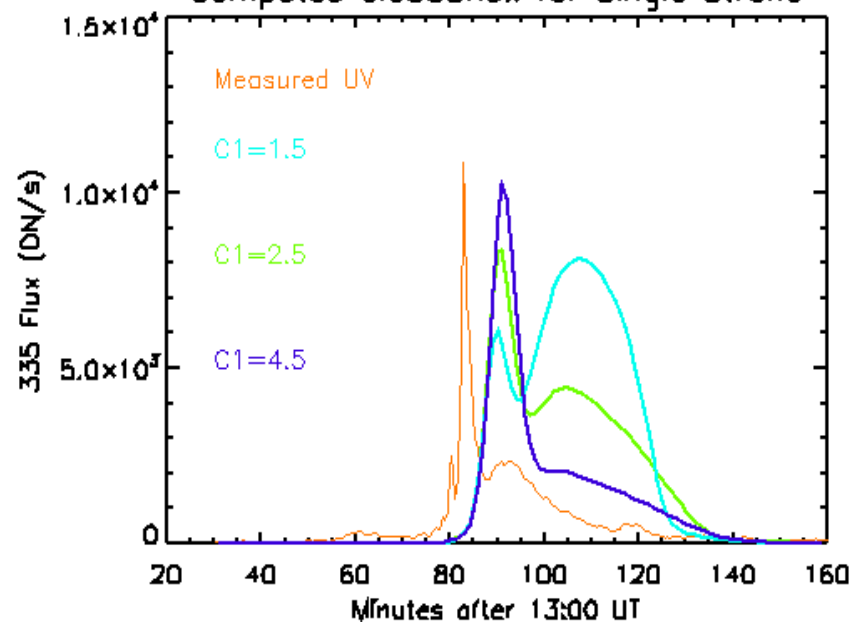
Computed aia171flux for Single Strand



Computed aia94flux for Single Strand

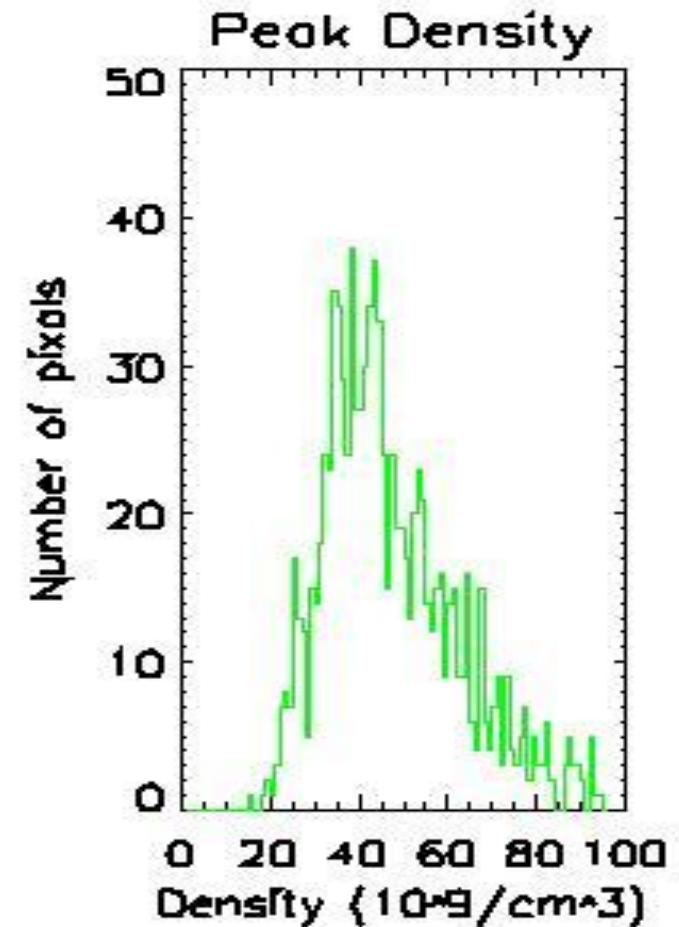
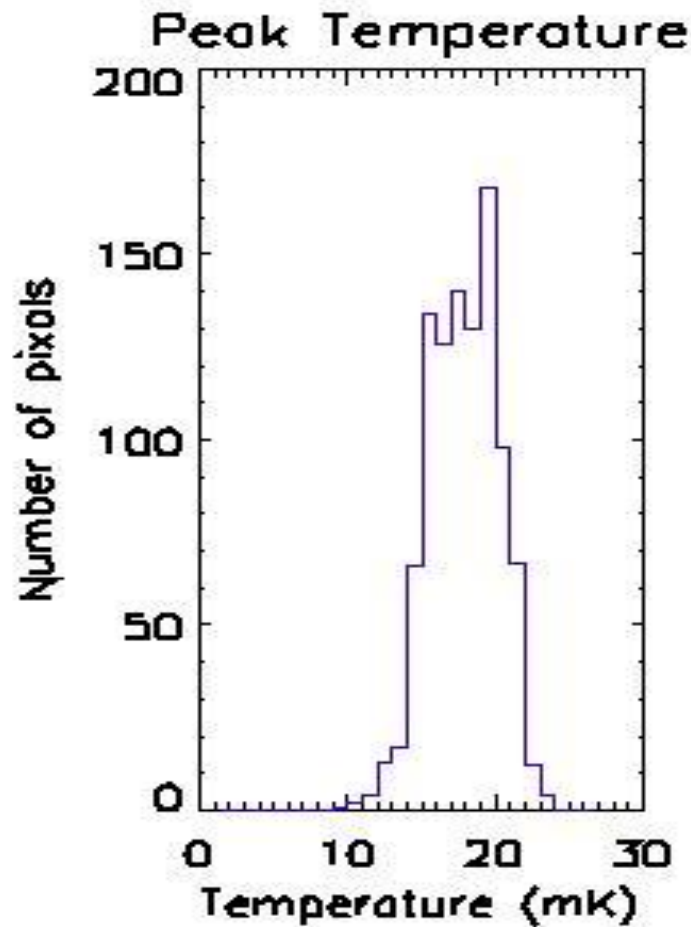


Computed aia335flux for Single Strand



Temperature and Density Distribution

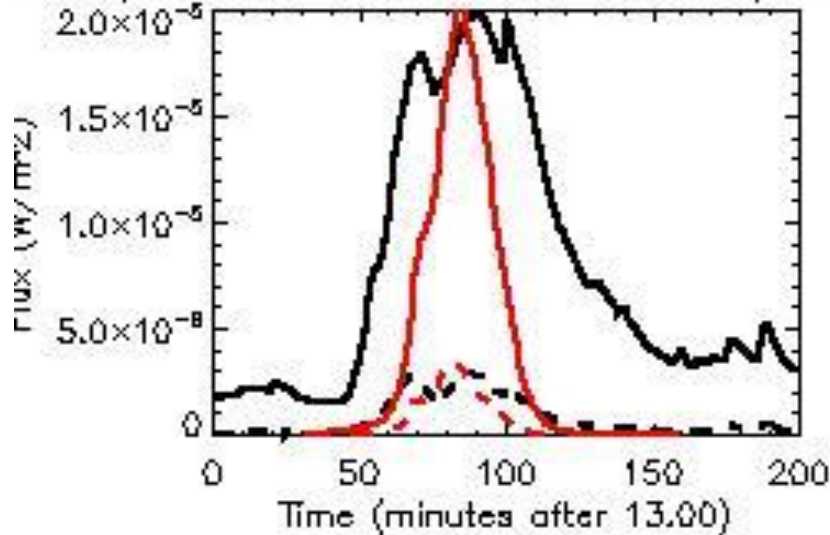
- 982 flux tubes
- Ranges are consistent with expected values
- Use T and n for each flux tube to calculate expected radiation and compare with obs.



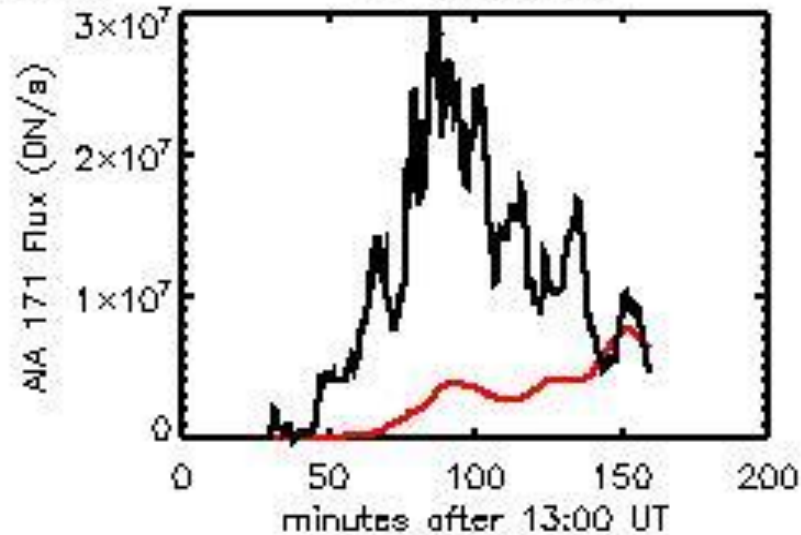
Comparison With Observed Data

— Goes0 1-8 angstrom
- - - Goes1 0.5-4 angstrom

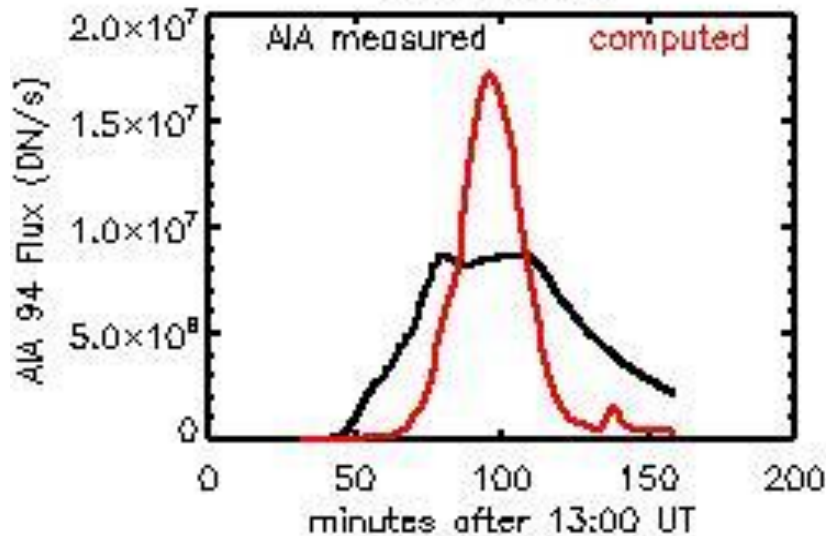
Comparison of measured and computed Goes



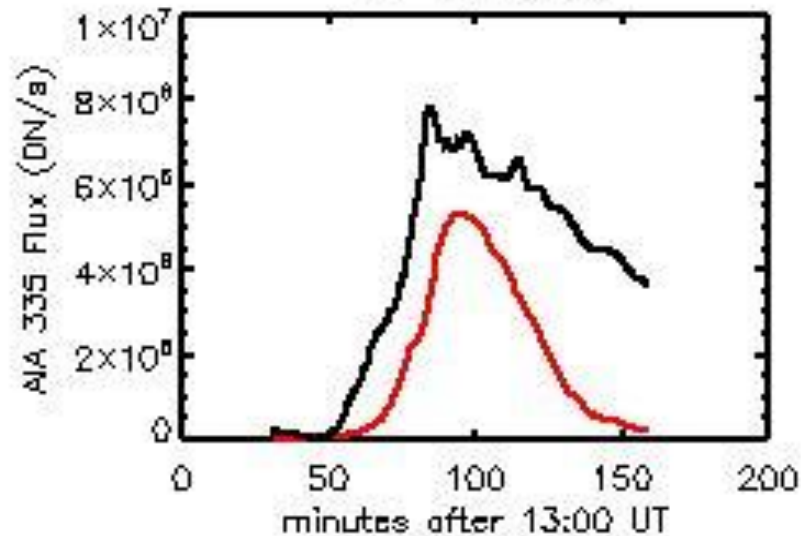
aia 171 flux



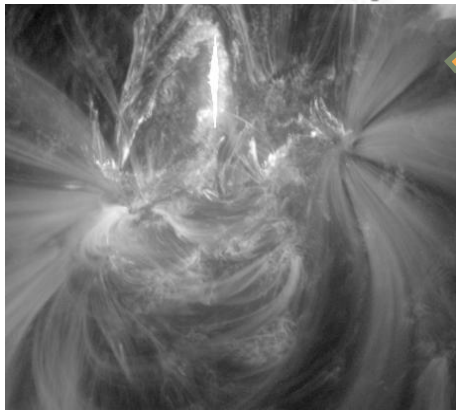
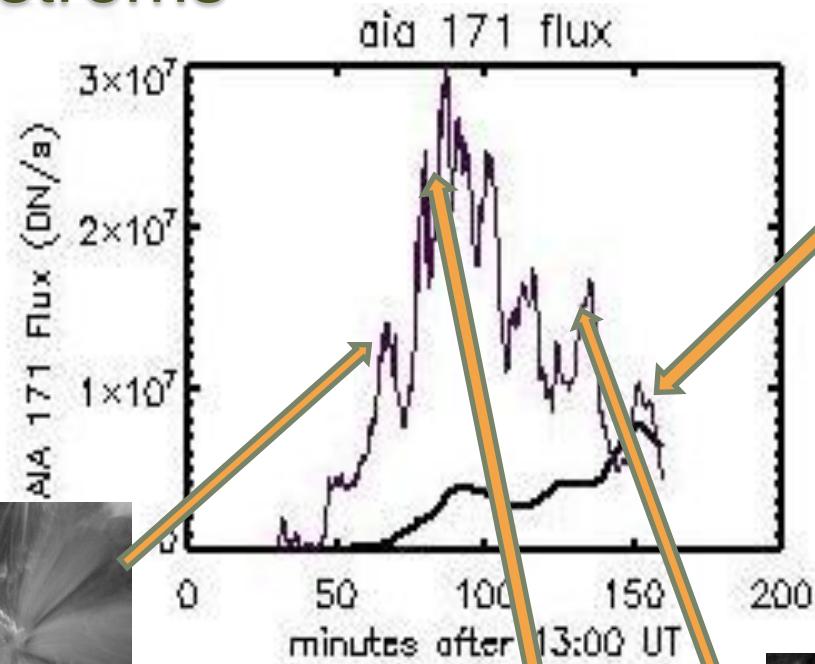
aia 94 flux



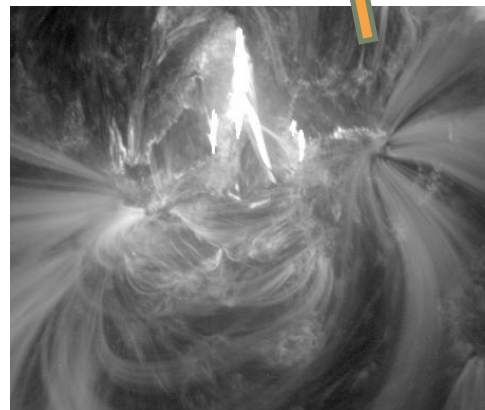
aia 335 flux



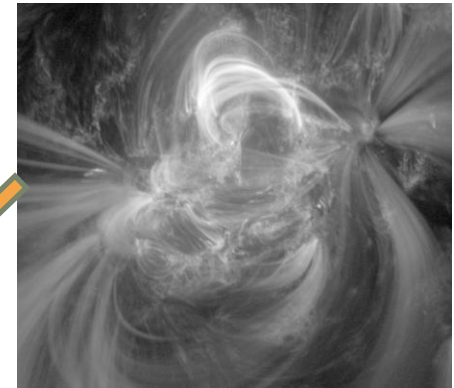
Observed Coronal structures that radiate at 171 Angstroms



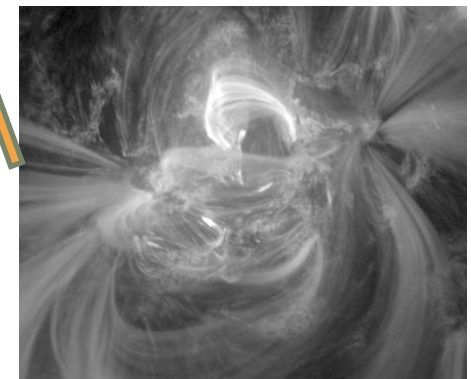
Time: 14.16 UT



Time :14.30 UT



Time: 15.35 UT



Time: 15.10 UT

Conclusions

- Calculated radiation using EBTEL fits reasonably well with observed values

➔ Supports use of Individual strand Heating Function from UV obs.

- Effect of C1 :
Some **wavelengths** more sensitive
- Effect of Inaccurate Response functions
- **In the Future?**
Physical model to determine how C1 should change

References

Klimchuk, A. J., Patsourakos, S., Cargill, P. J. 2008, ApJ, 682, 1351

Longcope, D., Des Jardins, A., Carranza-Fulmer, T., Qiu, J., 2010, Solar Physics, 267, 107

Acknowledgements

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