

# INFERRING RECONNECTION ENERGY RELEASE FROM UV/EUV SIGNATURES IN FLARES

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# Outline

- General background (Magnetic reconnection)
- Project outline
- Model
- Results and comparison with observations
- Summary

# Magnetic Reconnection

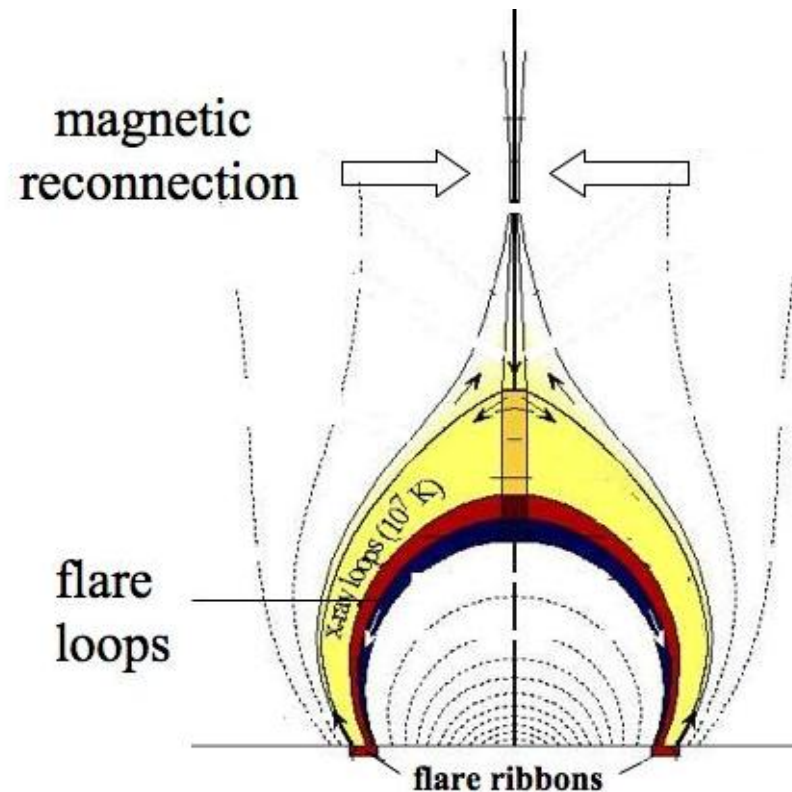
Main phase of flare:

Oppositely directed field lines **reconnect**

This brings the system to a **lower energy state**

Energy released -

- heats chromosphere
  - forming flare ribbons—**observable in UV**
  - outlines feet of coronal flare loops
- 
- Infer magnetic reconnection rates and energy release rates from time series of flare images



(adapted from Forbes & Acton, 1996)

# Heat Flux ( $F_H$ )

**Heat flux** - from hot corona to the chromosphere

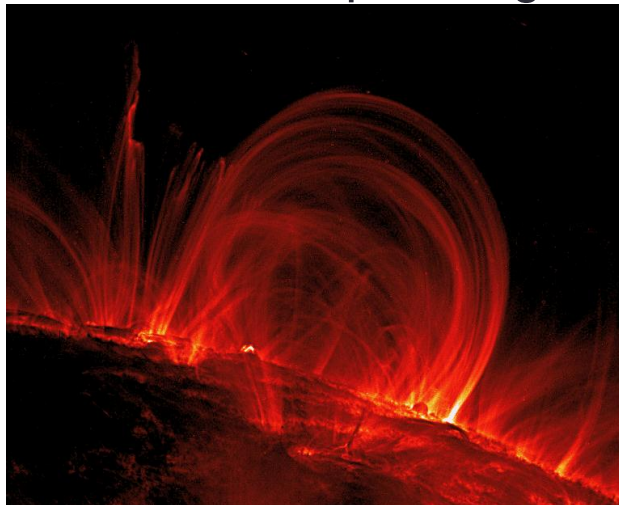
Initial Stage –  $F_H >$  radiation flux (excess heat flux)

-drives **chromospheric evaporation**

- Heated plasma transferred from chromosphere to corona

Later stage -  $F_H <$  radiation flux (deficient heat flux)

Plasma is drained from coronal loop through cooling – **coronal condensation**



# Project Outline

Aim: Study evolution of flare radiation at foot-points, measure parameters for reconnection and search for a better understanding of the relationship between reconnection and energization of plasmas in flux tubes

- **Magnetic reconnection** (observe through UV signatures)
- **Energy release** (**heating functions** inferred from UV light curve)
- **Plasma Evolution** (modelled by EBTEL)
- **Flare radiation** (measured by AIA)
  
- Modelling radiation output using EBTEL to compare with AIA observations
- Key parameter - **energy loss through TR** (new model)

# Measuring Magnetic Reconnection

- **Conservation of magnetic flux** - infer magnetic reconnection flux by measuring magnetic flux present in newly formed flaring regions in the chromosphere
- Measure the **reconnection rate**:

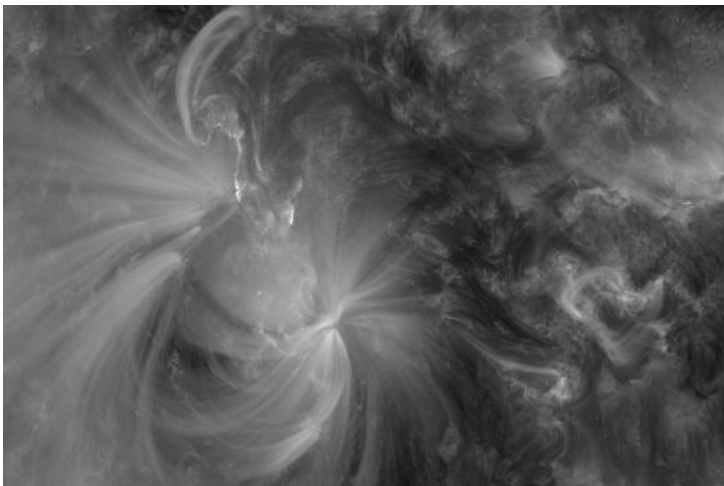
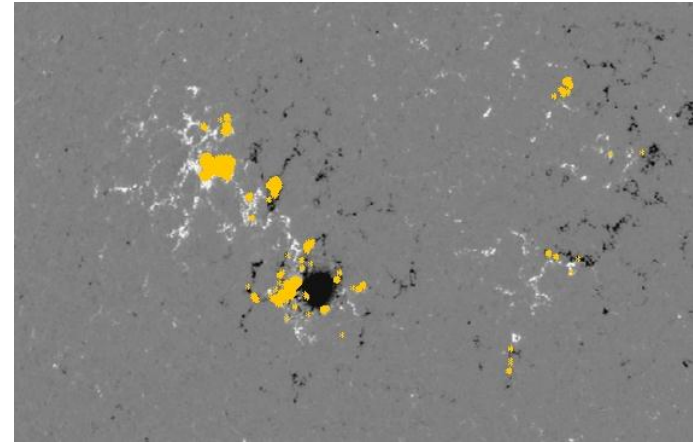
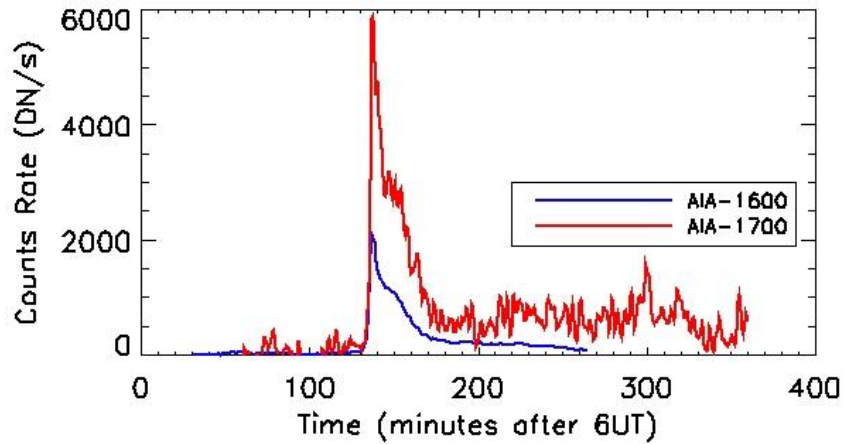
$$\frac{\partial \phi}{\partial t} = \frac{\partial}{\partial t} \left( \int \vec{B} \cdot d\vec{a} \right) \approx \frac{\partial}{\partial t} (\Sigma B_i a_i)$$

- **Faraday's Law**  $\oint \vec{E} \cdot d\vec{l} = - \frac{\partial \phi}{\partial t}$

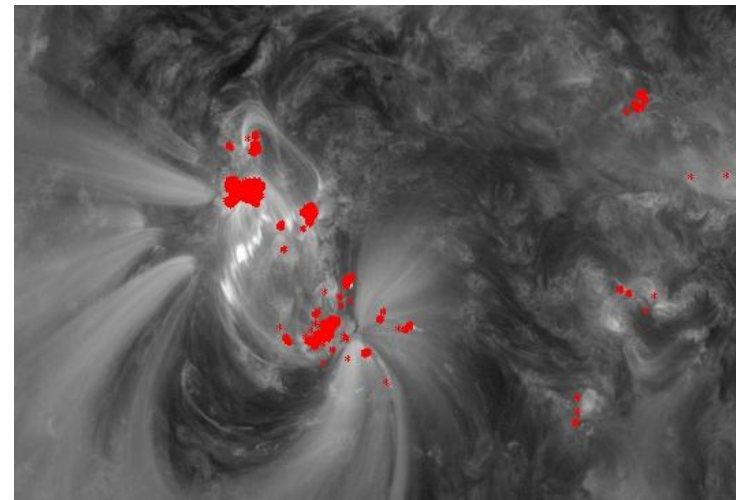
- **Energy release rate per unit flux**  $I(t) = \frac{\int H(t) dt}{\phi}$

# Observations

C3.2 flare obtained by AIA/SDO on 1<sup>st</sup> August 2010



Time: 8UT



Time: 10:20 UT

# Heating Function

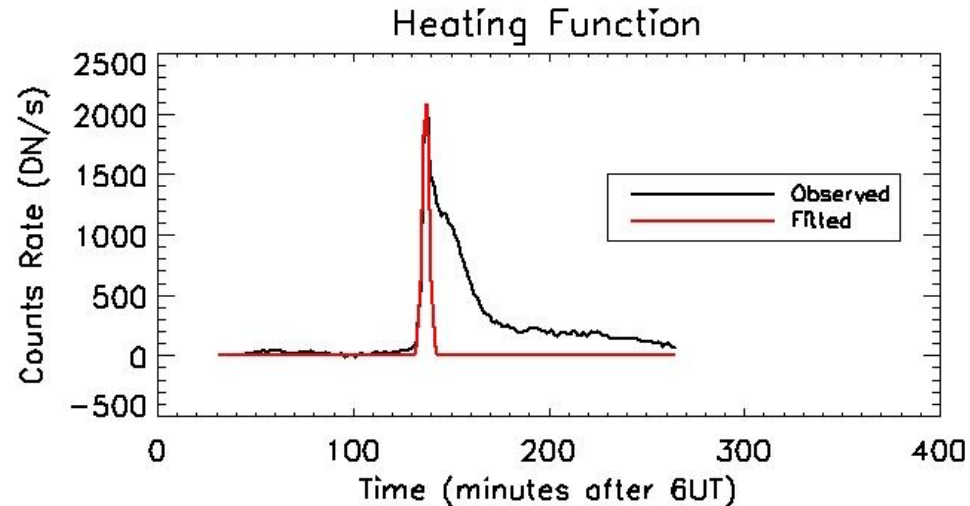
- UV light curve of individual pixels reflect **timing, amplitude and duration** of individual energy release events.

- Rise phase - half Gaussian:

$$I(t) = I_0 \exp\left(-\frac{(t-t_0)^2}{2\tau_r^2}\right) \quad (0 < t < t_0)$$

- Decay phase - exponential:

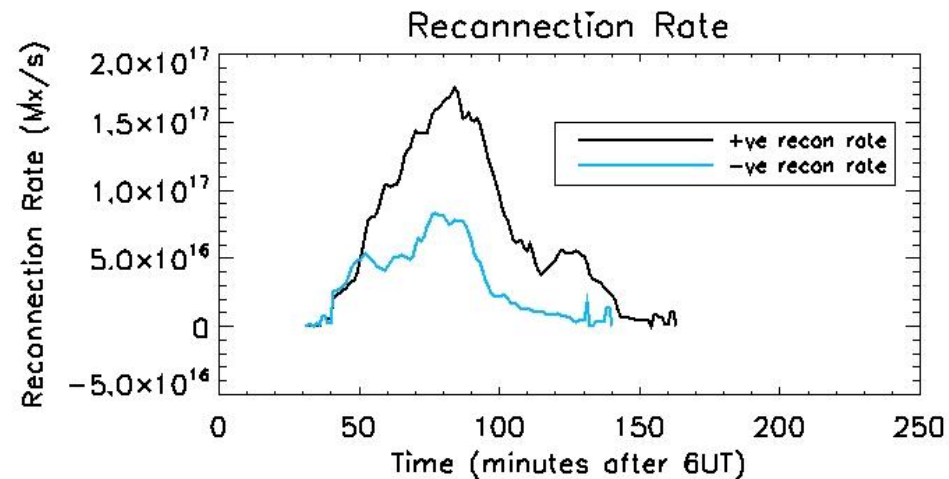
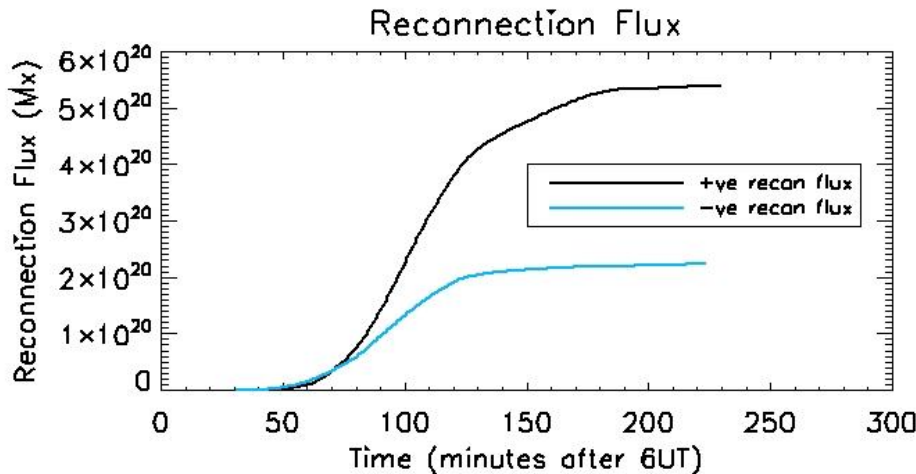
$$I(t) = I_0 \exp\left(-\frac{t-t_0}{\tau_d}\right) \quad (t > t_0)$$



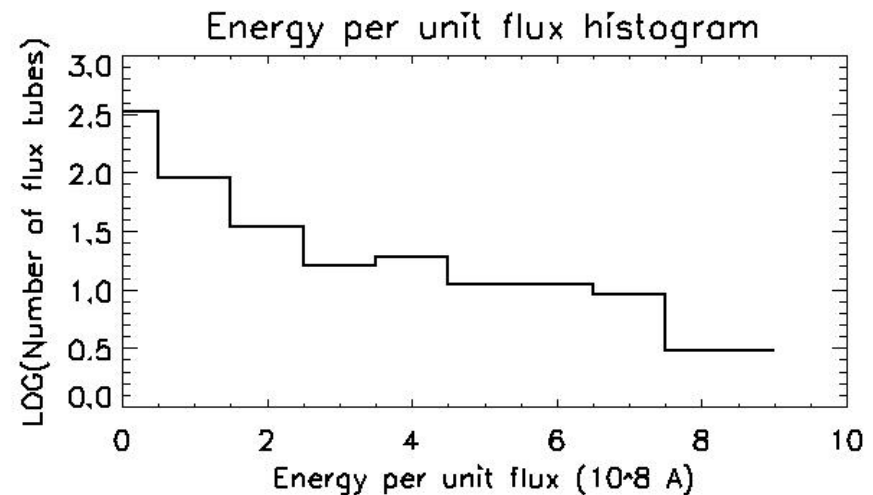
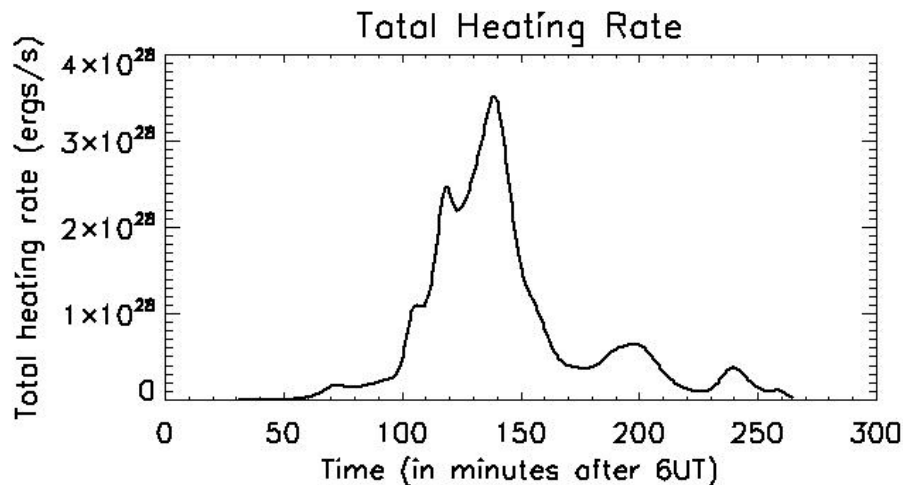
- $H(t) = \lambda I(t)$  where  $\lambda$  is the total heating factor
- Long decay phase cannot be explained by conductive or radiative cooling -> **overlying coronal radiation**



# Measuring Magnetic Reconnection



Total recon: +ve =  $7.7 \times 10^{20}$  Mx, -ve =  $-2.6 \times 10^{20}$  Mx



Total heating energy =  $1.6 \times 10^{30}$  ergs

# EBTEL Model

- **0D Enthalpy Based Thermal Evolution Of Loops** Model describes average temperature, density and pressure across a coronal strand (Klimchuk et al. 2008 and Cargil et al. 2012)
- Equate enthalpy flux of evaporating and condensing plasma with any excess or deficit in  $F_H$  relative to  $R_{TR}$ .

$$\frac{d\bar{n}}{dt} = -\frac{c_2}{5c_3kL\bar{T}}(F_0 + \mathcal{R}_{tr}),$$

$Q$ : volumetric heating rate ( $\text{erg s}^{-1} \text{cm}^{-3}$ )

$L$ : loop half-length (cm)

$F_0$ : thermal conduction flux ( $\text{erg s}^{-1} \text{cm}^{-2}$ )

$\mathcal{R}_c$ : coronal radiation rate ( $\text{erg s}^{-1} \text{cm}^{-2}$ )

$\mathcal{R}_v$ : energy loss rate through transition region ( $\text{erg s}^{-1} \text{cm}^{-2}$ )

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

Where  $Q = \frac{H}{L}$  and it is assumed that  $R_{TR} = c_1 R_c$  where  $\mathcal{R}_c \approx \bar{n}^2 \Lambda(\bar{T})L$

# Modification to EBTEL Model

- Unrealistic to scale  $R_{TR}$  to  $R_C$ . Best guess is to scale  $R_{TR}$  with pressure.

- **Static Equilibrium Case**

$$R_{TR} = \int_{10^4}^{10^6} \Lambda(T) DEM(T) dT$$

$$DEM(T) = g(T)P$$

$$g(T) = \sqrt{\frac{\kappa_0}{8k_B^2} T^{\frac{1}{2}} \left[ \int_{T_0}^T T'^{\frac{1}{2}} \Lambda(T') dT' \right]^{-\frac{1}{2}}}$$

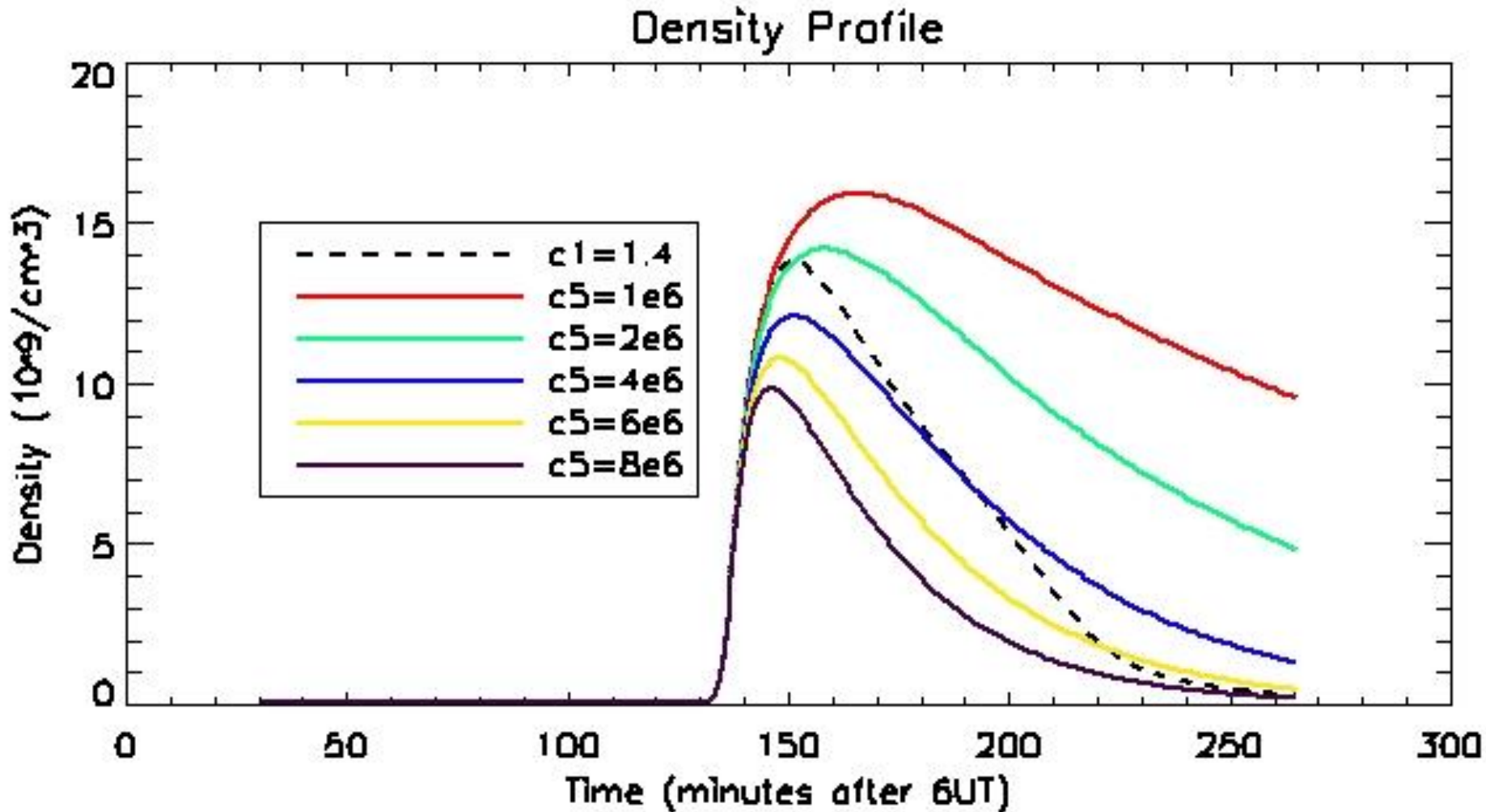
$$R_{TR} = P \int_{10^4}^{10^6} \Lambda(T) g(T) dT$$

$C_5$

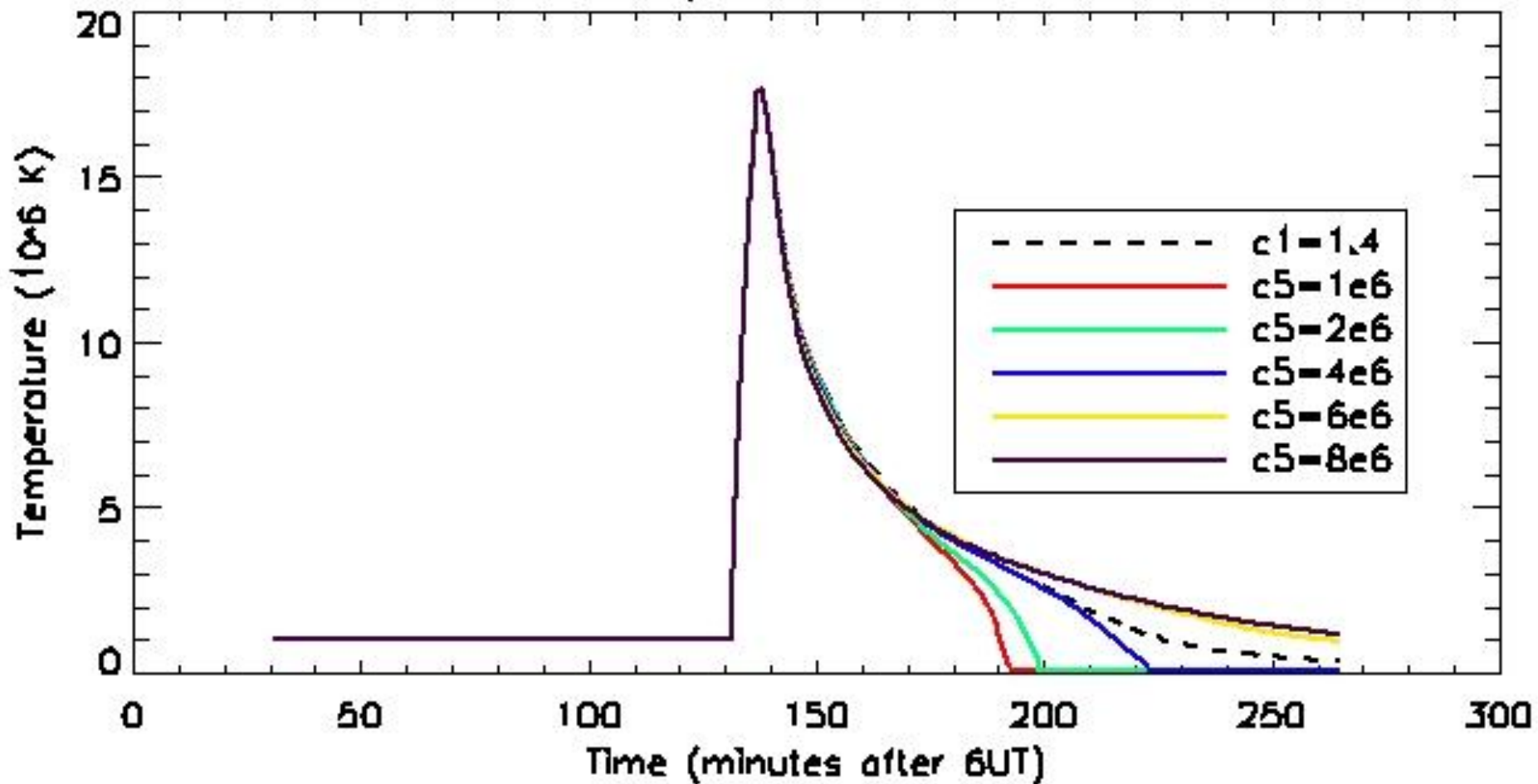
# Results

Pressure gauge method –  $c_5 = 2 \times 10^6$

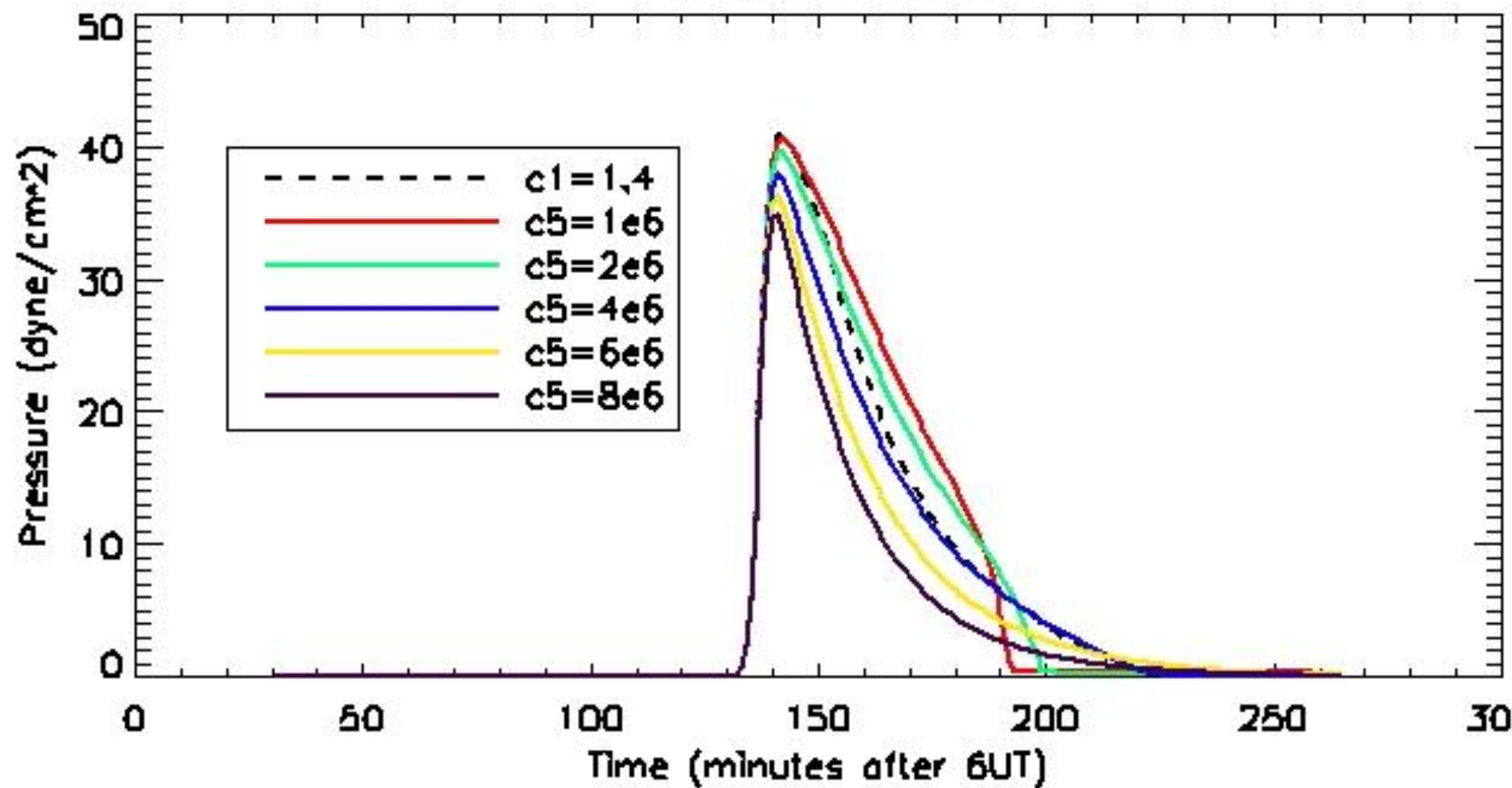
Scaling with coronal radiation –  $c_5 = 2.8 \times 10^6$



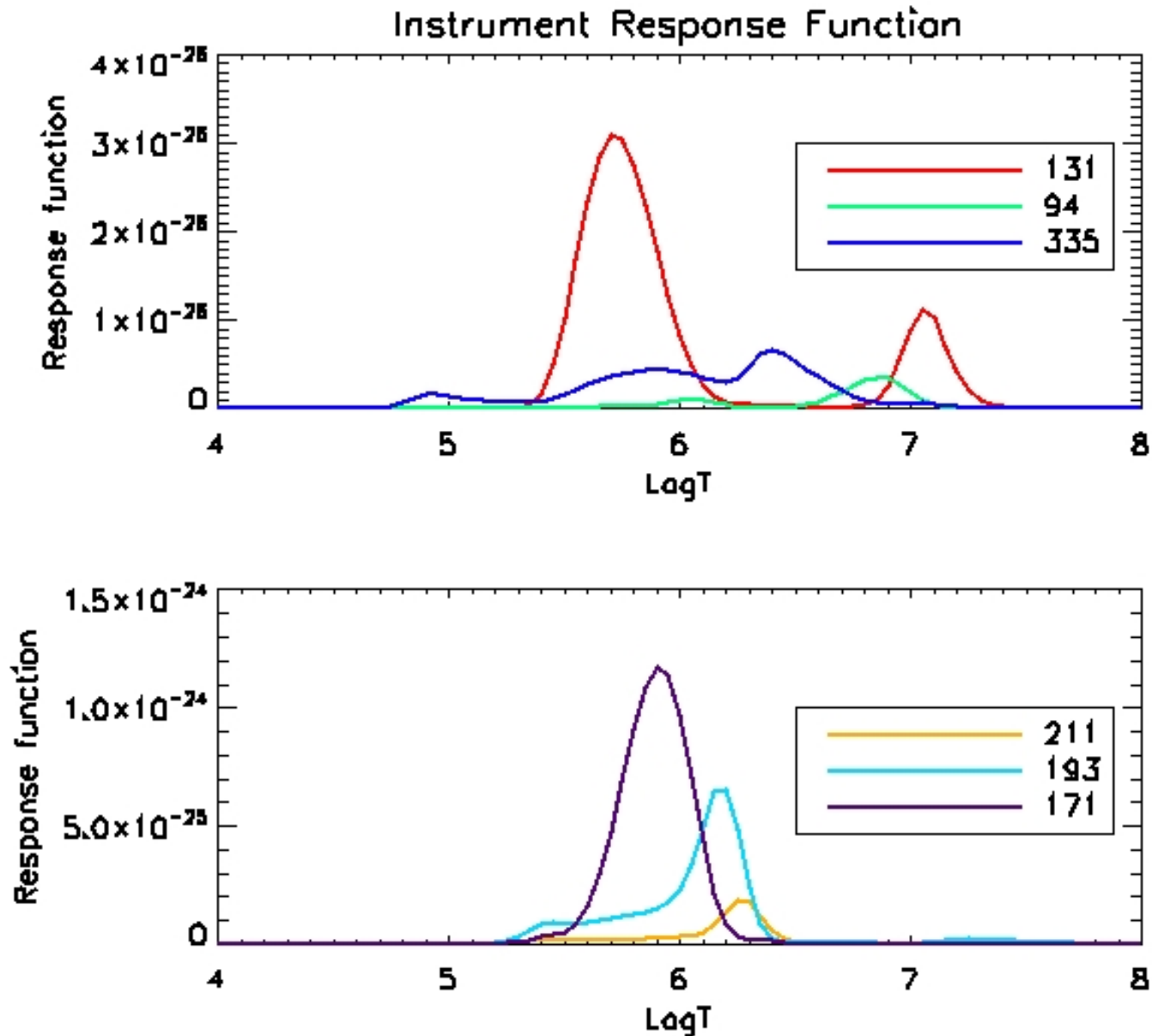
### Temperature Profile



## Pressure Profile

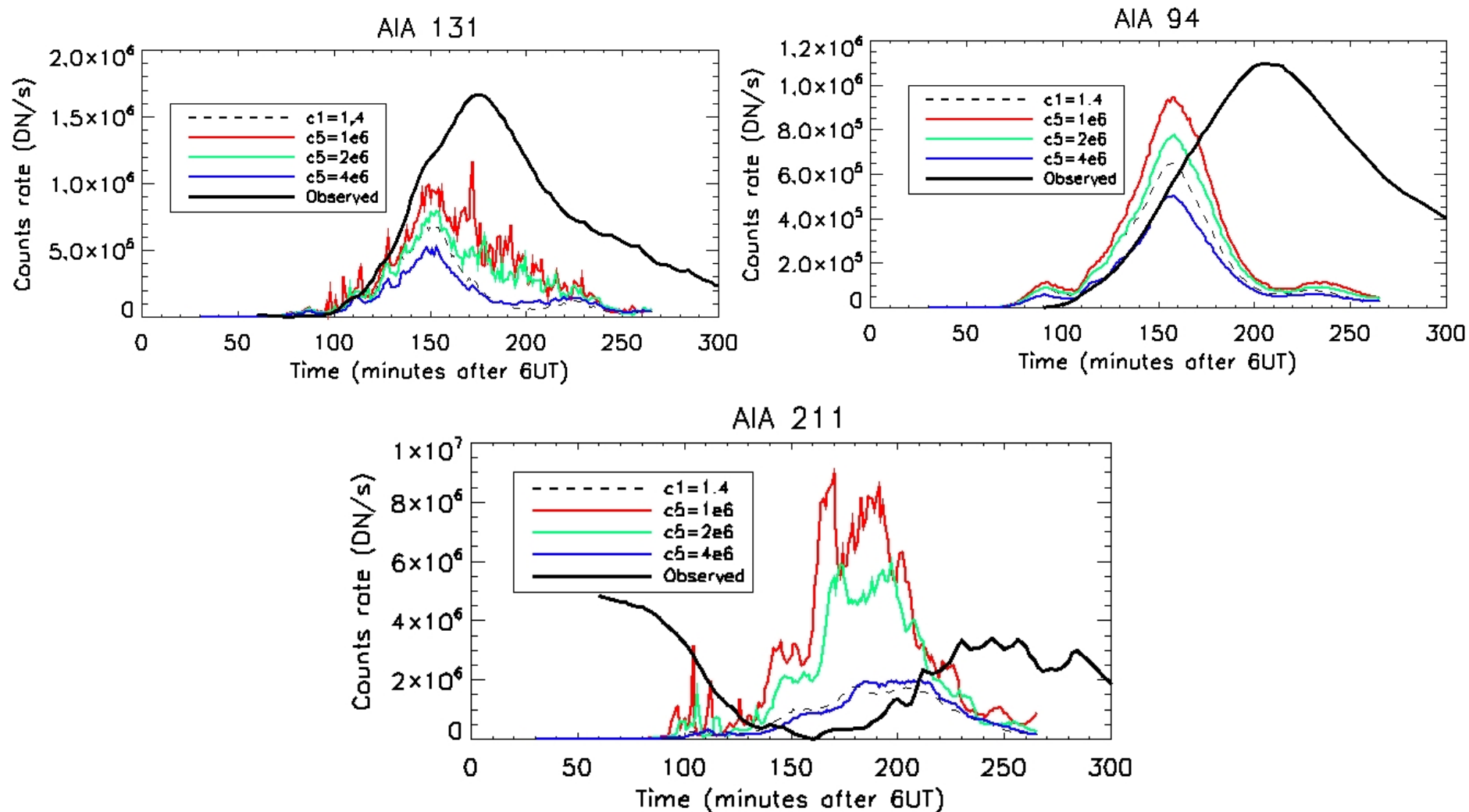


# AIA Instrument Response Function



# Coronal Observations

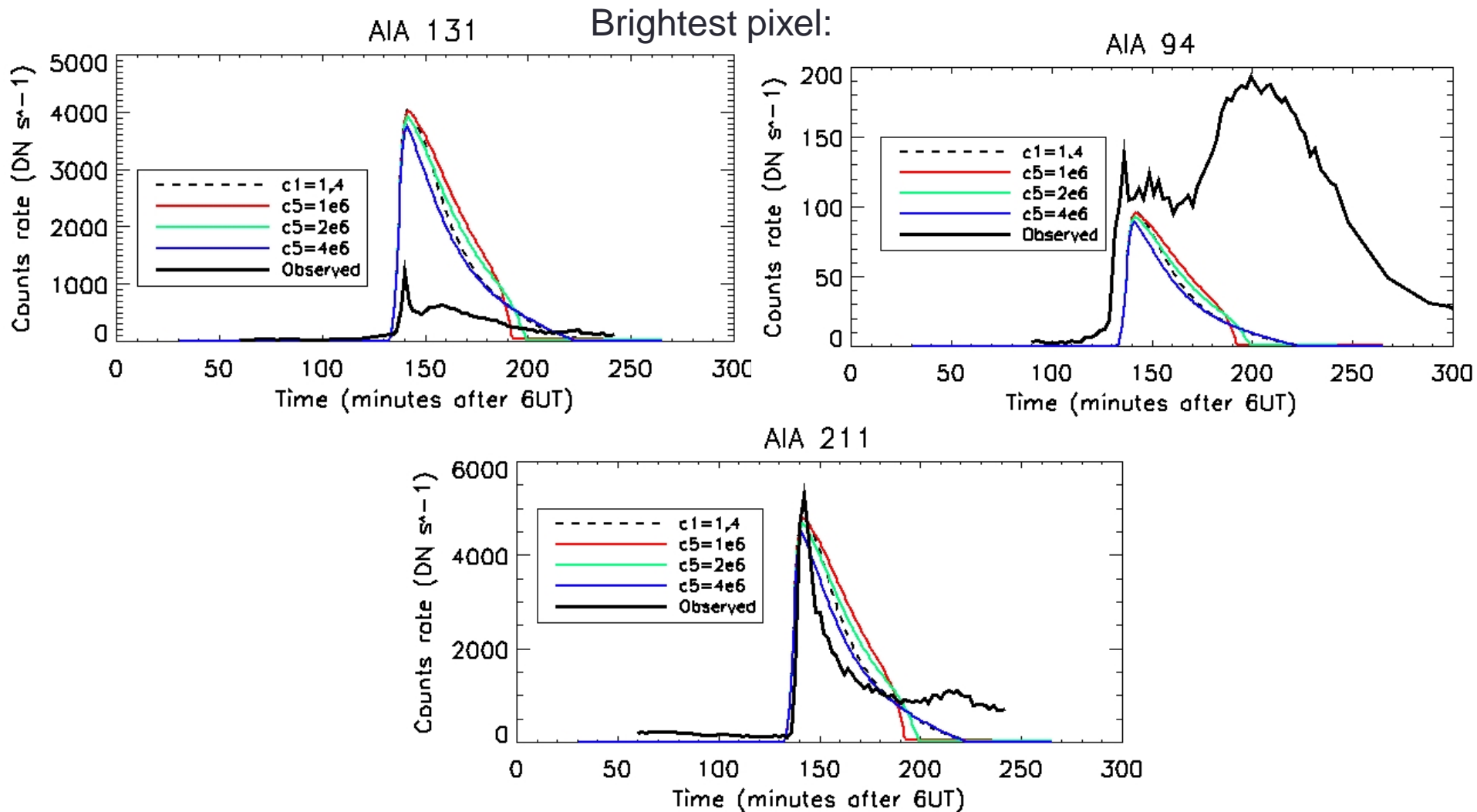
$$\text{Coronal radiation} = \sum_i n(T_i)^2 L(T_i) R(T_i)$$





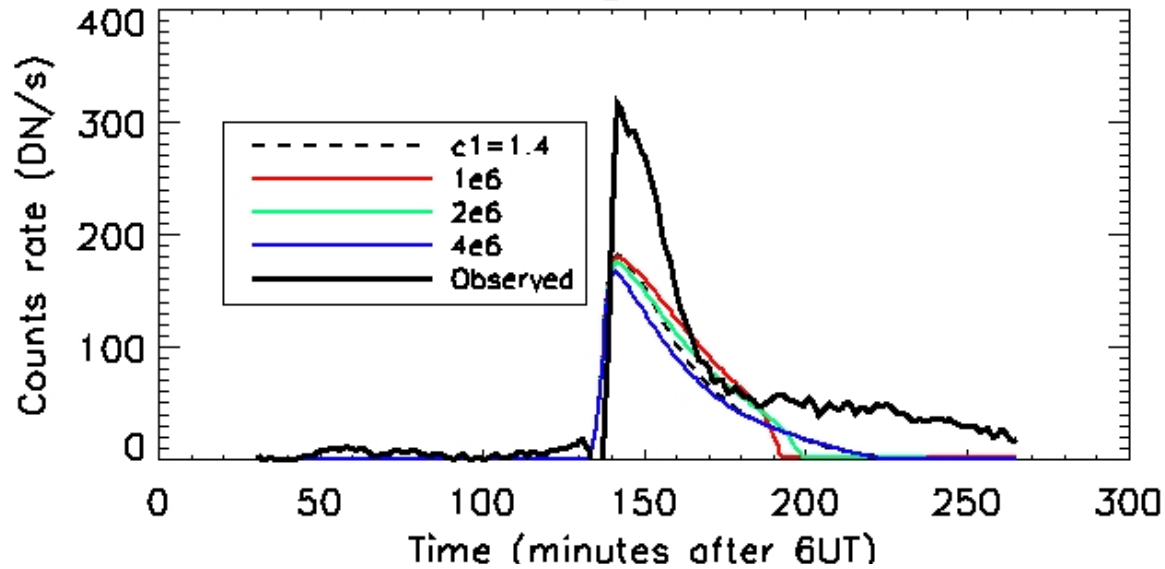
# Foot-point Observations

$$\text{Footpoint emission} = \int_{10^4}^{10^6} DEM(T)R(T)dT \quad \text{where } DEM(T) = g(T)P$$

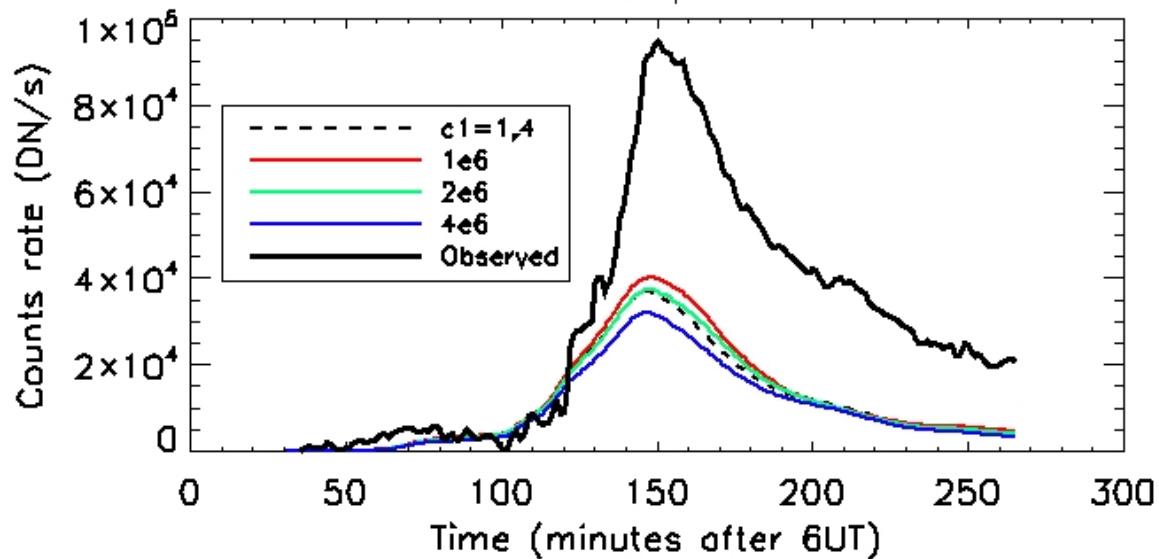


# Carbon 4 Comparison

CIV Brightest Pixel



CIV



# Summary

- UV footpoint emission -> calculate **heating rate** -> **energy release rate**
- Total heating energy =  $1.6 \times 10^{30}$  ergs Total reconnection flux =  $5.15 \times 10^{20}$  Mx
- Established connection between reconnection, energy release and loop heating
  
- Modified EBTEL model –  $R_{TR} = c_5 P$
- **Physically motivated** approach
- Early decay slowed down
- **In future** - modify heating function?
  
- Calculated **coronal radiation** fits reasonably well in heating phase
- Calculating **foot-point radiation** using pressure-gauge method fits reasonably well with observations
- **In future** – 1D model connecting foot-point to coronal loop?

Thanks for your attention!