Heating of an erupting prominence associated with a solar coronal mass ejection on 2012 Jan 27

Jin-Yi Lee[1], John C. Raymond[2], Katharine K. Reeves[2],
Yong-Jae Moon[1], and Kap-Sung Kim[1]

[1]Kyung Hee University, Korea

[2]Harvard-Smithsonian Center for Astrophysics, USA

Lee et al. ApJ 2017 844,3

Introduction

- In this event, EUV observations show that the absorption features of prominence change to emission features during its eruption, which indicates that the erupting plasma is being heated.
- We discuss the heating and energy budget of the erupting prominence and loops using AIA and XRT observations.
- **The energy budget is central to understanding the eruption process.** It is not trivial to determine the local heating rate even if the mass, temperature, and speed of the plasma are known, because **thermal conduction can redistribute the energy, and radiative or adiabatic cooling can keep the temperature low in spite of intense heating.**
- However, it is possible to estimate **the importance of their effects and determine at least approximately how energy is partitioned among its kinetic, thermal, and heating components.**

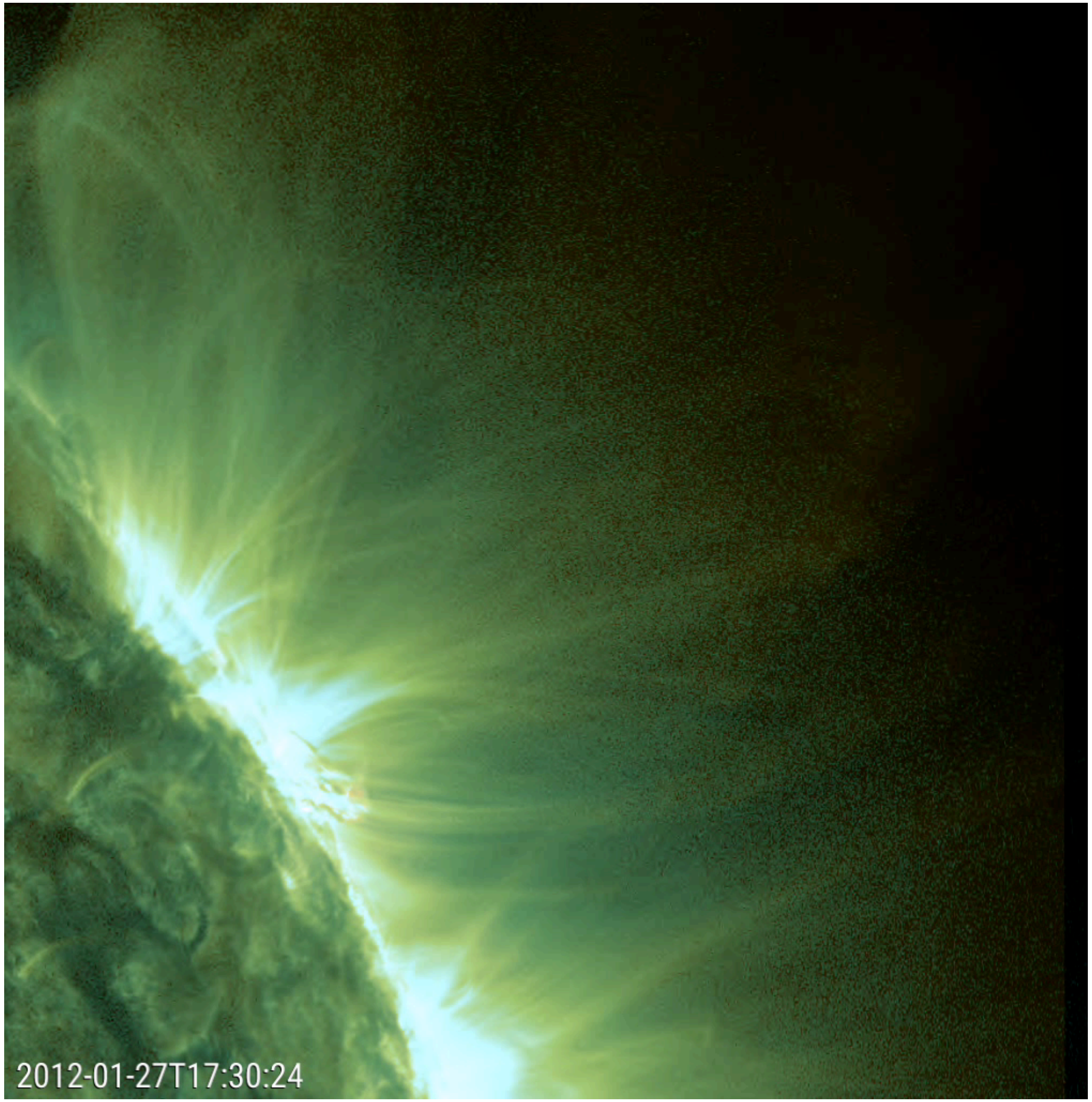
Observations

GOES
- X 1.7 flare (2012. 01. 27)
 (17:37 - 18:36 – 18:56 UT)

SDO/AIA
- EUV observations (0.5-20 MK)

Hinode/XRT
- X-ray observations (>1MK)
- flare mode observation
- 17:47-17:58 UT
- passbands: Be_thin, Al_med

LASCO CME Catalogue
- Halo (2508 km/s)
- 18:27 UT in C2



Jhelioviewer 171Å + 131Å (17:30-18:15 UT)

Analysis

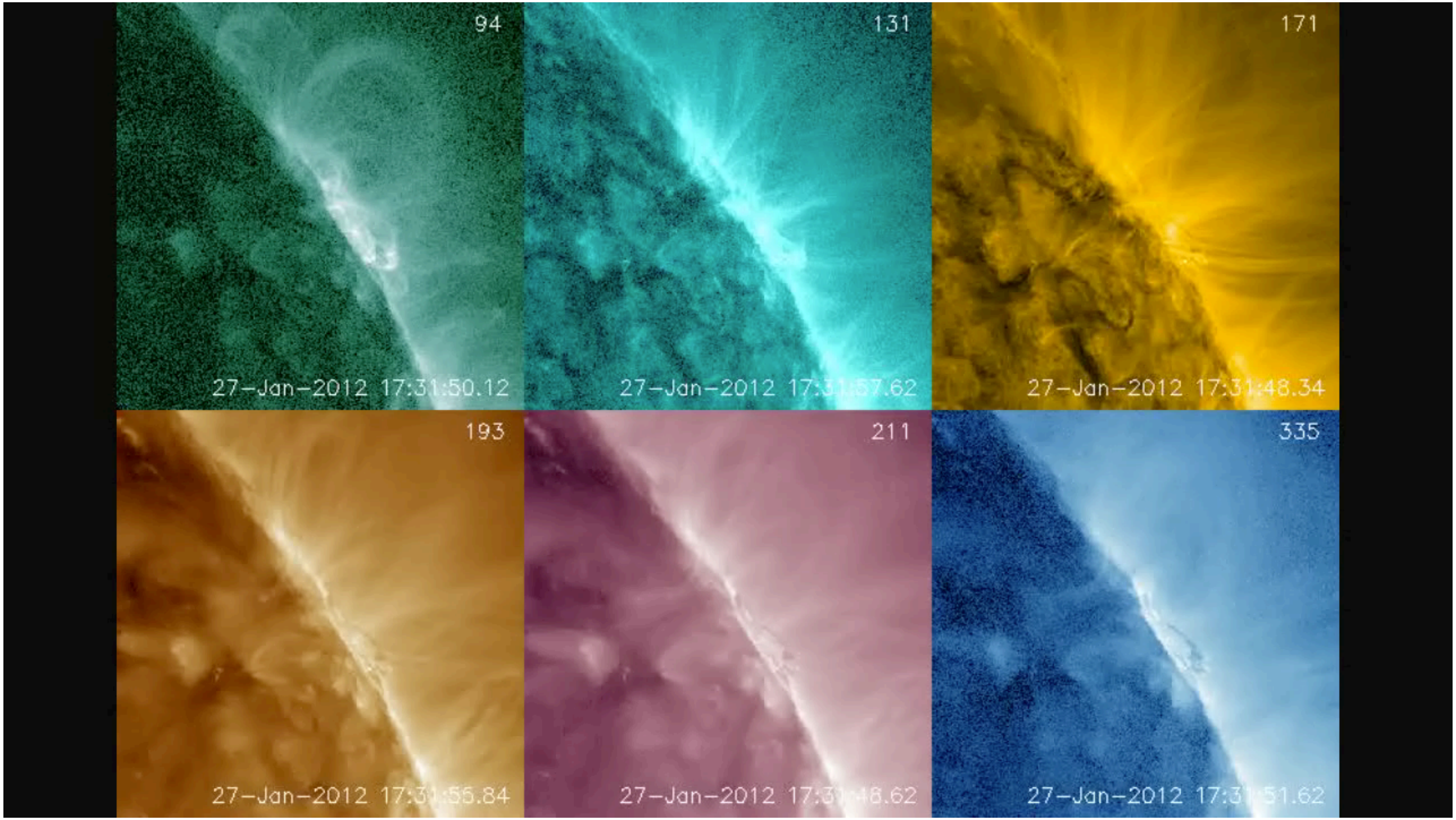
- Prominence at the beginning of eruption: Absorption feature
- Prominence with a writhe motion: Emission feature
- Erupting loops at three times: Emission features

List of parameters for the energy budget investigation

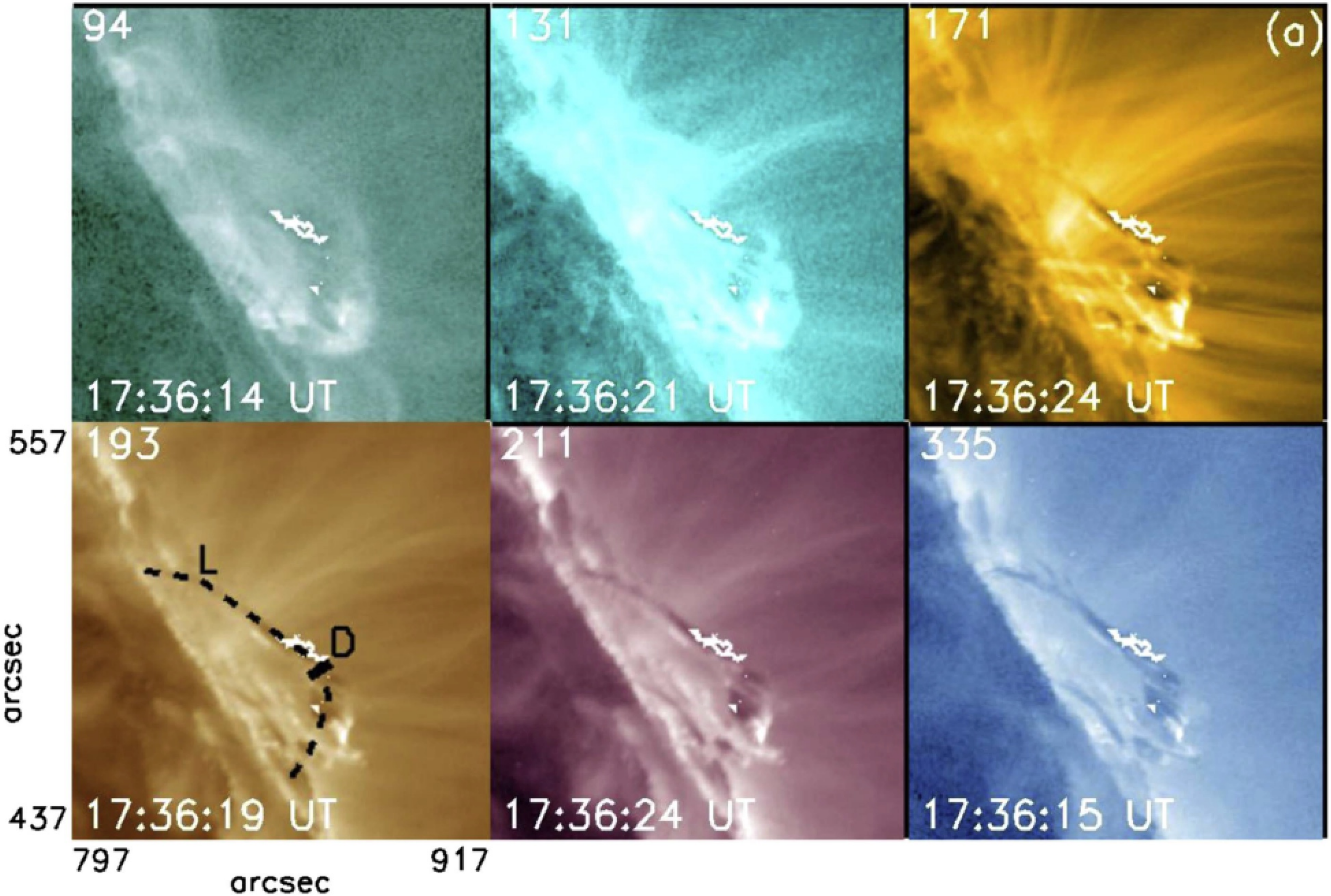
Parameter	Description
TE	Thermal energy (erg)
KE	Kinetic energy (erg)
L_r	Radiative loss energy (erg)
F_c	Thermal conduction energy (erg)
H	Heating energy (erg)
$\tau_{\rm rad}$	Radiative loss timescale (s^{-1})
$\tau_{\rm cond}$	Thermal conduction timescale (s^{-1})
$L_{\rm rad}$	Radiative loss rate (erg cm^{-3} s^{-1})
L_a	Cooling rate by adiabatic expansion (erg cm^{-3} s^{-1})
dq	Cooling rate by thermal conduction (erg cm^{-3} s^{-1})
H_r	Heating rate (erg cm^{-3} s^{-1})

Prominence eruption seen as absorption features

17:31 – 17:45 UT



Prominence seen as absorption features



Analysis: Absorption features

- Assumes a single value of covering factor for both neutral and ionized particles.

$$I_{obs} = I_b(f_{clear} + f_{dark}e^{-\tau}) + I_f$$

$$\frac{I_{obs}}{I_0} = 1 - G(1 - e^{-\tau})$$

I_0: average of 50 images between 17:10 and 17:19 UT

$I_0 = I_b$ (background emission)+ I_f (foreground emission)

f_{dark}: covering factor, $f_{clear} = 1 - f_{dark}$

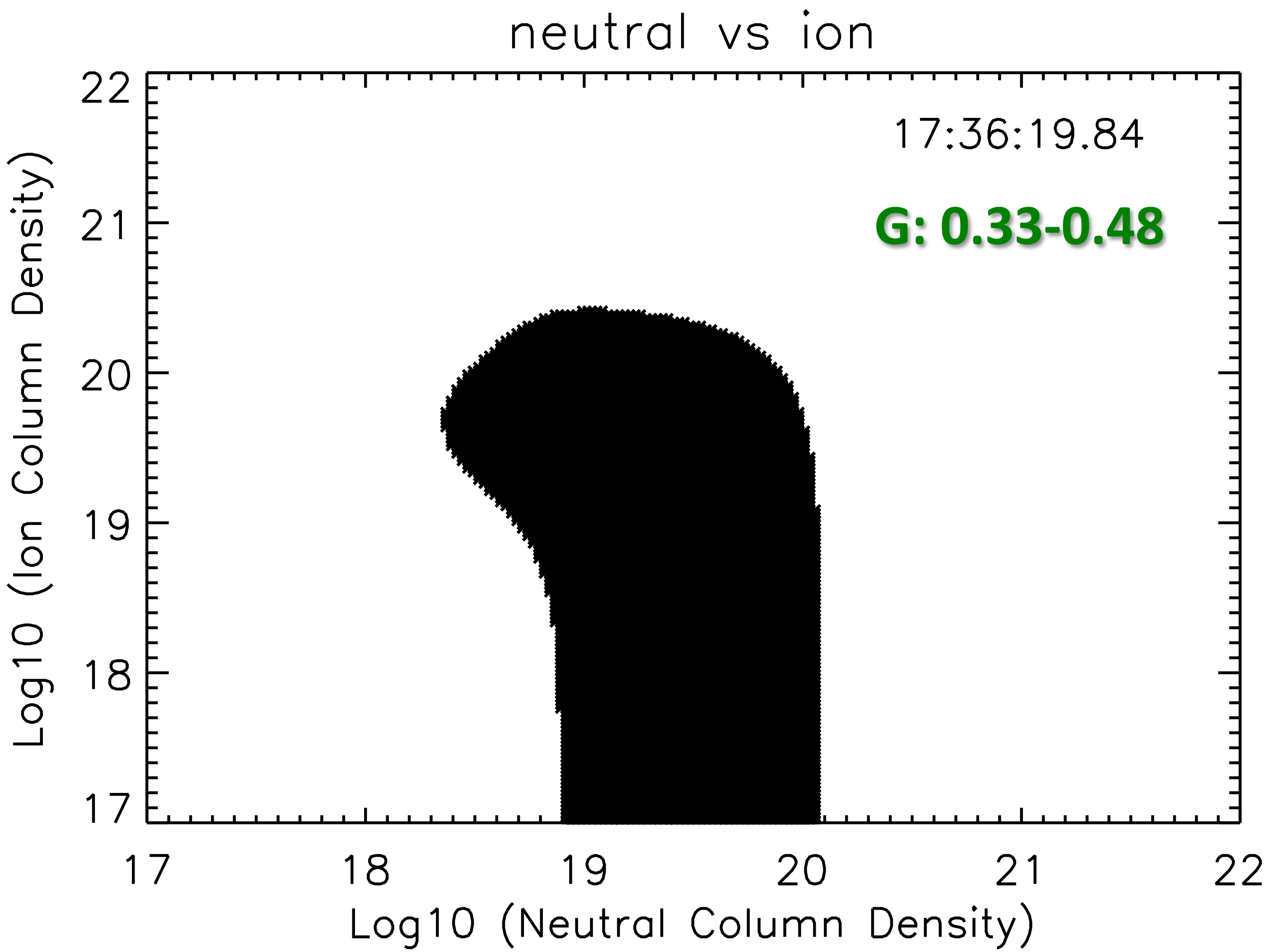
$$G = f_{dark}\frac{I_b}{I_0}(0 \leq G \leq 1)$$

$$\tau = N_{neutral}(\sigma(H,\lambda) + \sigma(He,\lambda)) + N_{ion}\sigma(He^+,\lambda)$$

σ: absorption cross section

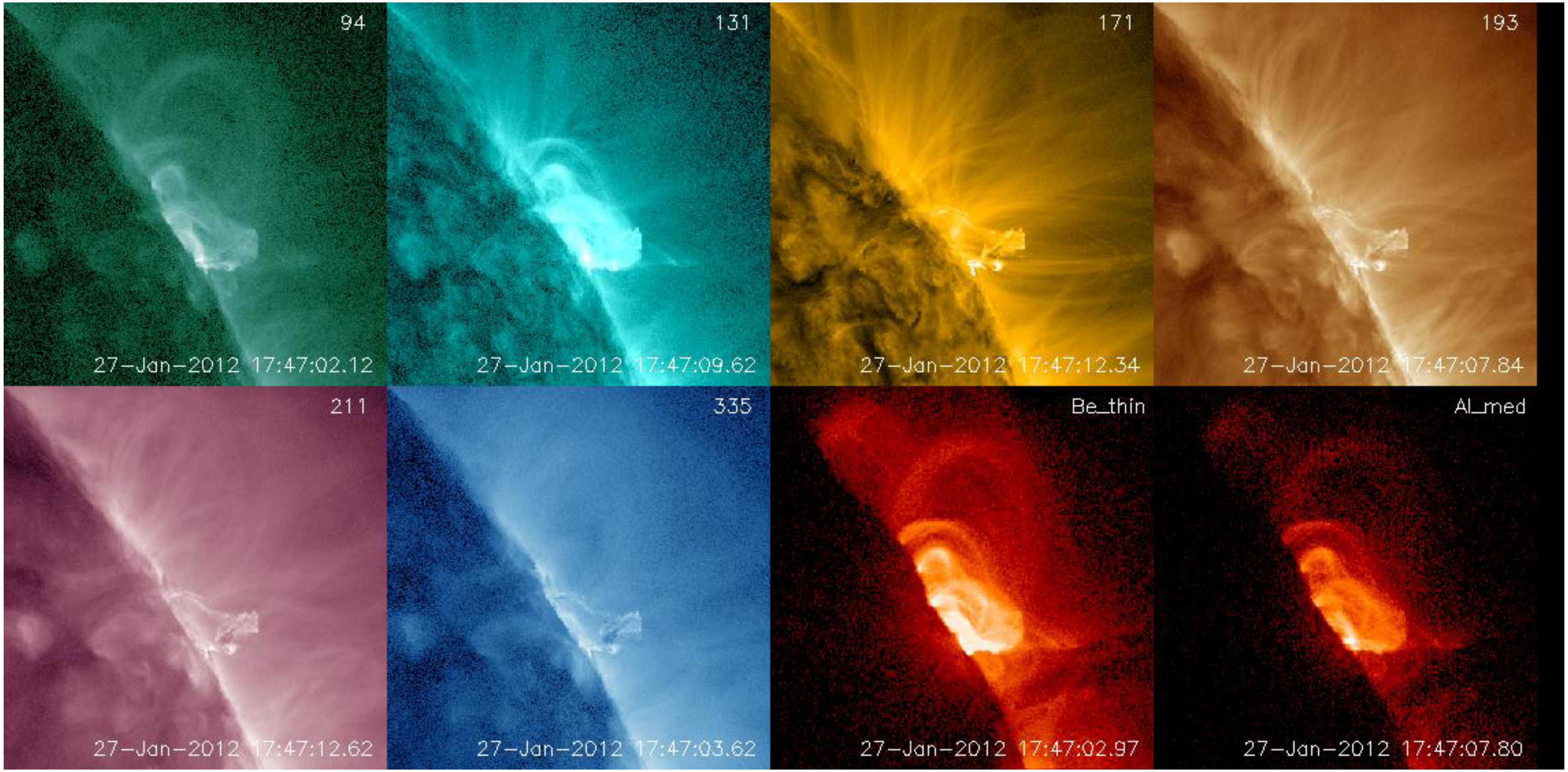
$N_{neutral}$ and N_{ion}: neutral and ion column densities (10^{17}-10^{22}cm^{-2})

Constraints of neutral and ion column densities



Prominence and loops seen as emission features

17:47 – 17:58 UT

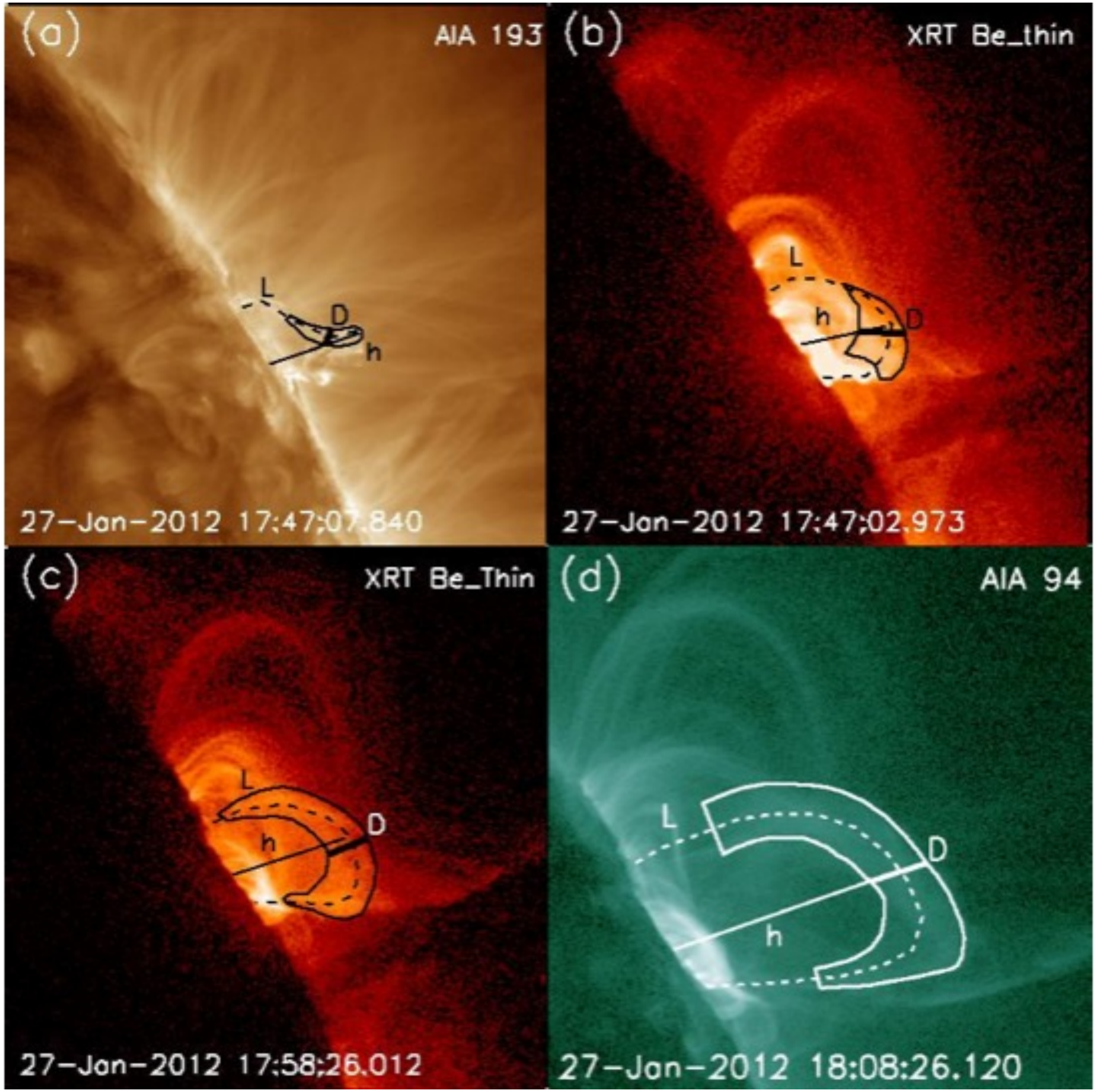


Analysis: Emission features

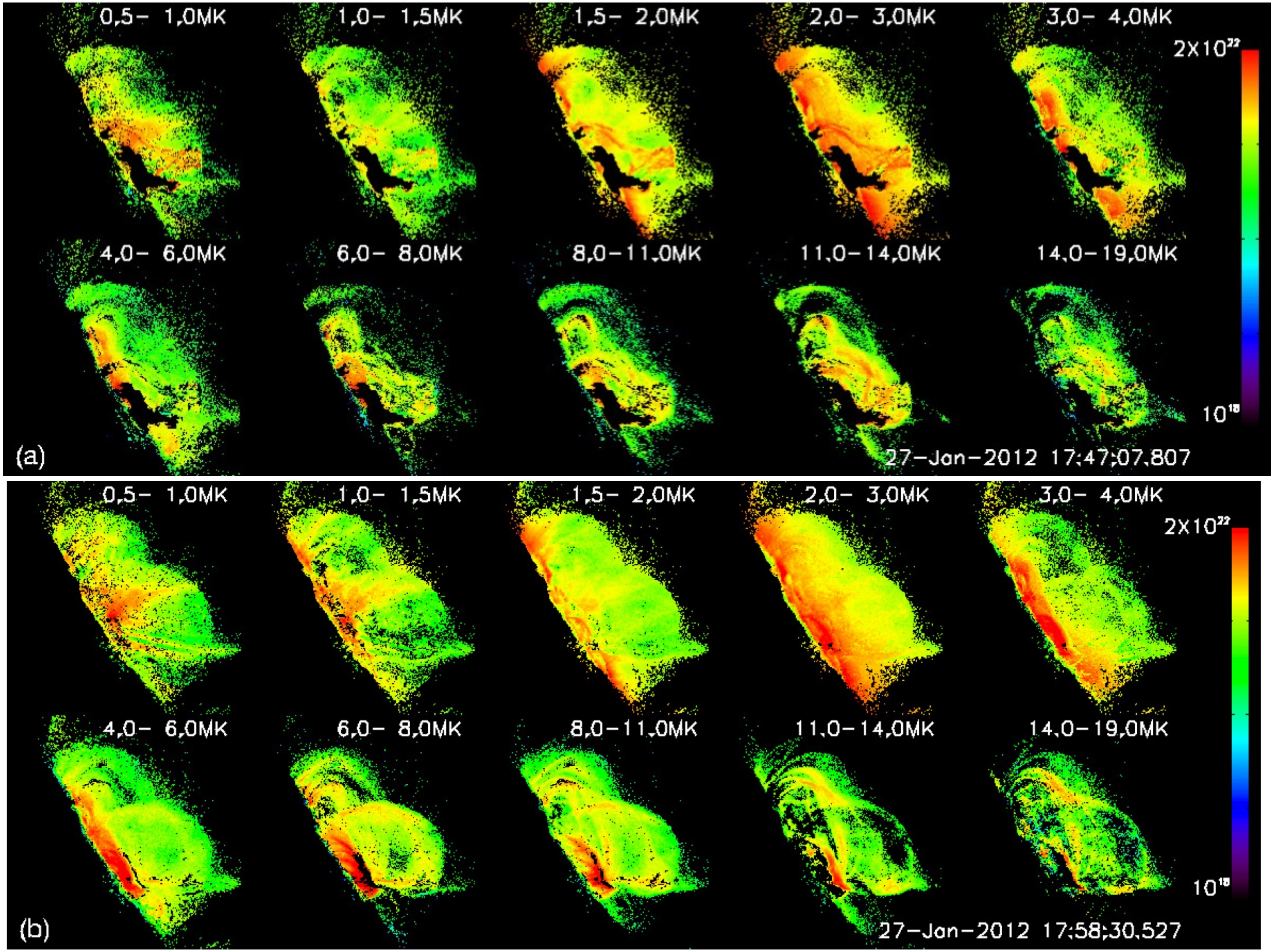
- Differential Emission Measure
  - Hannah and Kontar 2012, 2013
  - http://www.astro.gla.ac.uk/~iain/demreg/map/

  (optimized and faster version, performs a zeroth order regularization)
- Revise to use with Hinode/XRT observations
  - AIA 6 passbands (94 Å, 131 Å, 171 Å, 193 Å, 211 Å, 335 Å)
  - XRT 2 passbands (Be_thin, Al_med)
- Image deconvolution using point spread function
- Comparisons of DEMs with various solar spectra
  - AIA default spectra
    - Coronal abundance (Feldman et al. 1992), Chianti 7.1.3
    - Using standard AIA response function software with options (chiantifix, evenorm, noblend)
  - Spectra with chianti version 8 (Del Zanna et al. 2015)
    - Coronal abundance (Feldman et al. 1992)
    - Coronal abundance (Schmelz et al. 2012)
    - Photospheric abundance (Caffau et al. 2011)

Geometry assumption (cylinder structure)



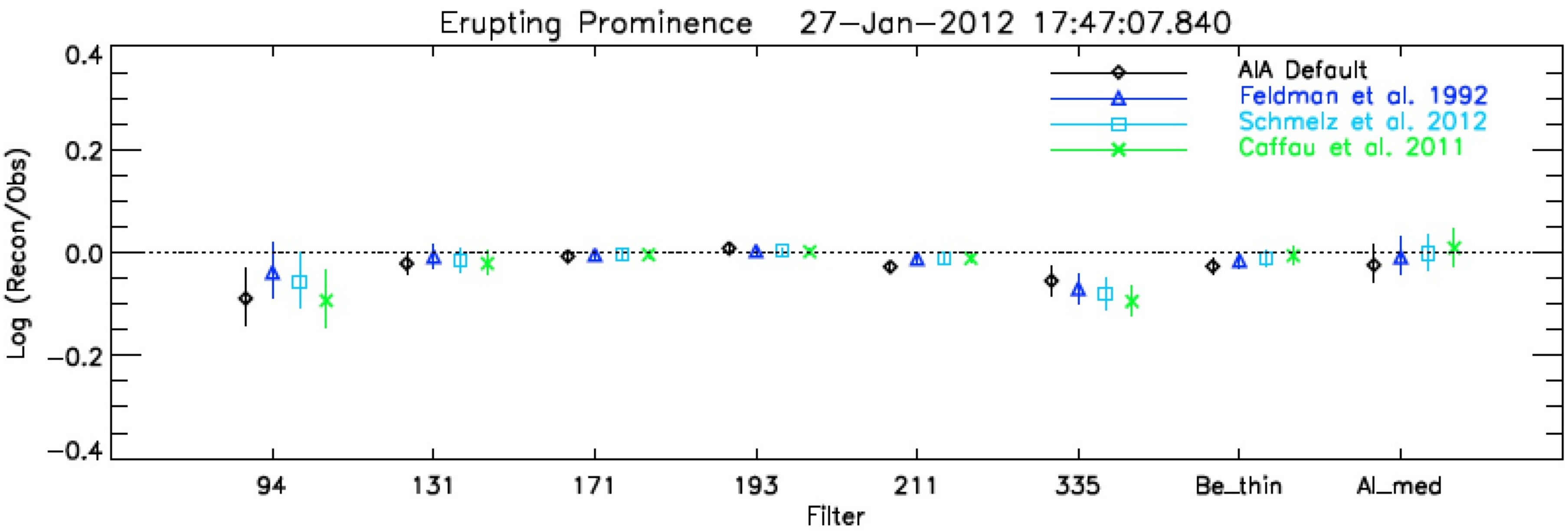
DEM maps



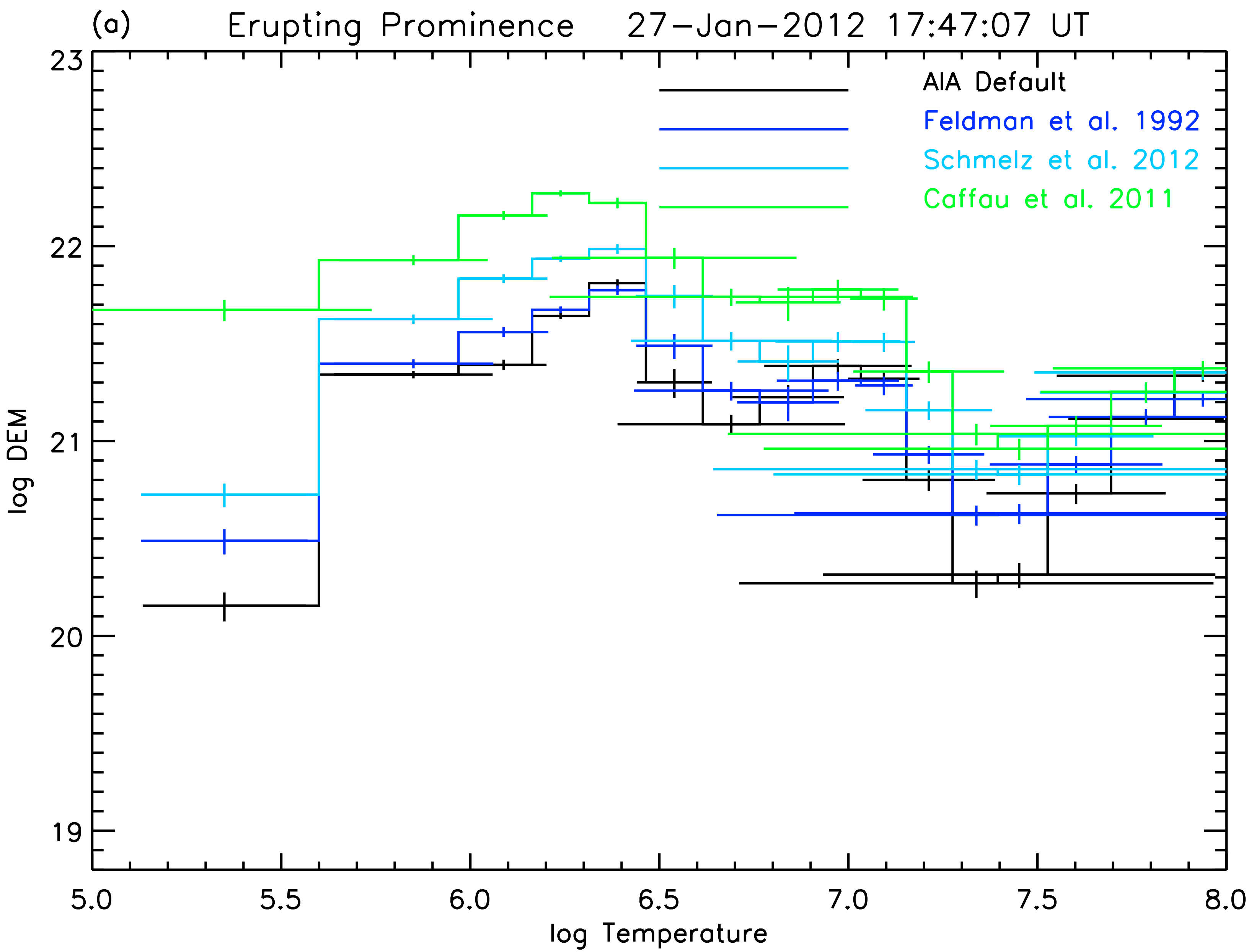
0.5- 1.0MK
1.0- 1.5MK
1.5- 2.0MK
2.0- 3.0MK
3.0- 4.0MK
4.0- 6.0MK
6.0- 8.0MK
8.0-11.0MK
11.0-14.0MK
14.0-19.0MK
$2X10^{22}$
10^{18}
(a)
27-Jan-2012 17:47:07.807
0.5- 1.0MK
1.0- 1.5MK
1.5- 2.0MK
2.0- 3.0MK
3.0- 4.0MK
4.0- 6.0MK
6.0- 8.0MK
8.0-11.0MK
11.0-14.0MK
14.0-19.0MK
$2X10^{22}$
10^{18}
(b)
27-Jan-2012 17:58:30.527

DEM reconstruction errors

Erupting Prominence 17:47 UT



DEM (Erupting prominence)



Heating energy

- Energy equation

cooling heating

$$\frac{5}{2}(n_e + 0.8n_e)k\frac{dT}{dt} = -(dq + L_{rad} + L_a - H)$$

radiation

thermal conduction adiabatic expansion

$$L_{rad} = n_e n_e 0.8 * P(T)$$

radiative loss function

$$L_a = \frac{5}{2}(n_e + 0.8n_e) * k * (2T_0 \frac{v_h}{h})$$

h: loop height, v_h: expansion velocity

T_0: temperature in the earlier time

$$H = H_{wave} + H_{mag} + H_{cond} + H_{shock}$$

- The H includes all contributions to the heating, such as wave dissipation, magnetic reconnection, turbulent heating or the divergence of conductive flux, or shock waves generated by the reconnection outflow.

Energy Budget of the erupting prominence and loops

	Time	τ_{rad}	τ_{cond}	L_{rad}	L_a	dq	H_r
	UT	10^3 sec		10^{-2} erg cm^{-3} sec $^{-1}$			
Prom	17:47	0.5-1.0	65-120	1.3-4.4	0.1	0.0	5-10
Loop	17:47	5.3-9.5	1.2-2.1	0.4-1.1	3.1-5.6	2.8	9-14
Loop	17:58	3.5-6.3	3.3-6.0	0.4-1.3	3.2-5.8	0.8	3-5
Loop	18:08	2.9-5.2	30-53	0.2-0.6	3.2-5.7	0.0	0.7-1.5

	Time	TE	KE	L_r	F_c	H
	UT		10^{28} erg			
Prom	17:47	17-30	0.1-0.3	6.9-23	0.8	19-44
Loop	17:47	416-737	0.6-1.0	18-56	111	357-566
Loop	17:58	346-631	0.6-1.1	23-78	36	129-233
Loop	18:08	205-362	4.9-8.7	15-46	2.0	46-96

Discussion and Conclusion

- The neutral column density as seen absorption features is constrained about 4×10^{18} - 9×10^{19} cm^{-2} with the covering factor of 0.33-0.48, while ion column density is hard to constrain.
  - This is because 304 Å and 335 Å are not absorbed by He+, but we don't use 304, and 335 has significant response at short wavelengths and relatively poor signal-to-noise.
- The prominence as seen emission has a peak at about LogT=6.3-6.4, while the DEMs of overlying erupting loops show evidence of a higher peak at around LogT=7.0.
  - **The reconstructions for 94 Å and 335 Å are hard to fit the observations. The choice of abundances does little to solve the discrepancy between AIA and XRT.**
- **The thermal energies are comparable to the heating energies at the earlier time, and the heating rates are larger than any other cooling terms.**
- **This event shows a writhing motion of the erupting prominence, which may indicate a hot flux rope heated by thermal energy release during magnetic reconnection.**

Lee et al. ApJ 2017 844,3

Thank you