

Thermodynamics of a flare related on-disk active region sigmoid

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Overview

- Introduction to sigmoids
- Study of on-disk sigmoid observed on Dec. 26 and 28, 2015
- Temperature investigation of a flaring sigmoid
- Summary

Thermodynamics of a flare related on-disk active region sigmoid

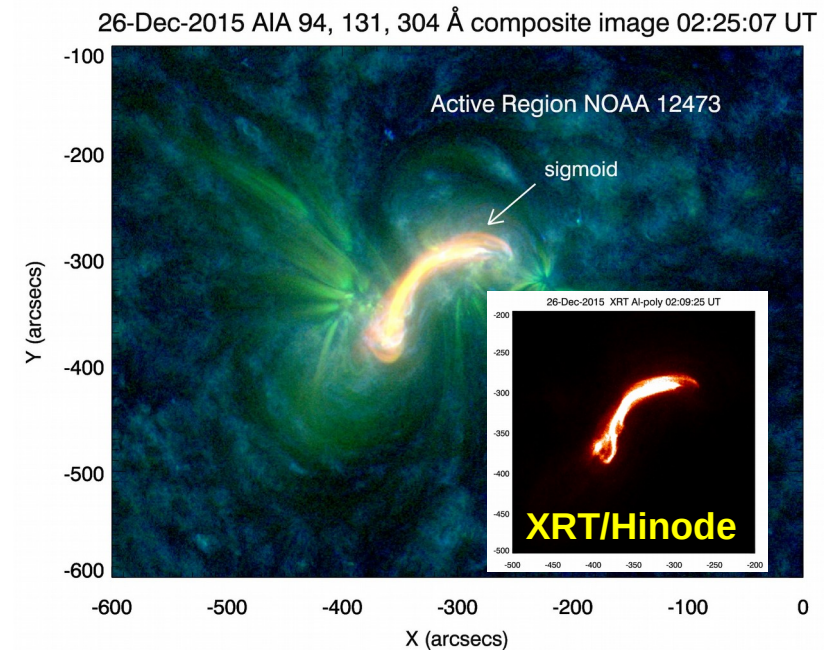
Mulay, S. et al. in preparation for MNRAS

Sigmoids

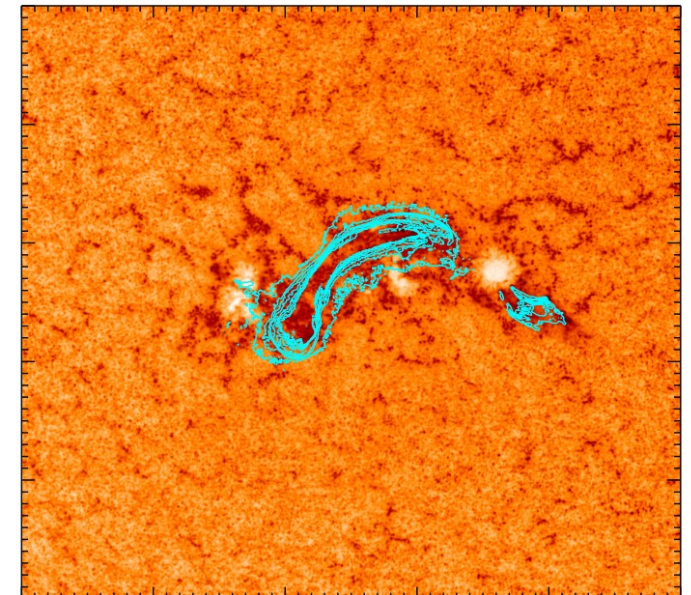
- Show **S-shaped** (reverse S or two J-shaped) structures
- **Highly sheared and twisted loops** that are formed along the polarity inversion line
- Considered to be one of the **best pre-eruption signatures**

Objective of my research

- **Investigation of temperature of a sigmoid** during their lifetime on solar disk
- **Relationship between sigmoids and solar flares**
- How temperature of a sigmoid varies during the impulsive, peak and decay phase of flares



AIA 1600 Å 02:25:03 UT



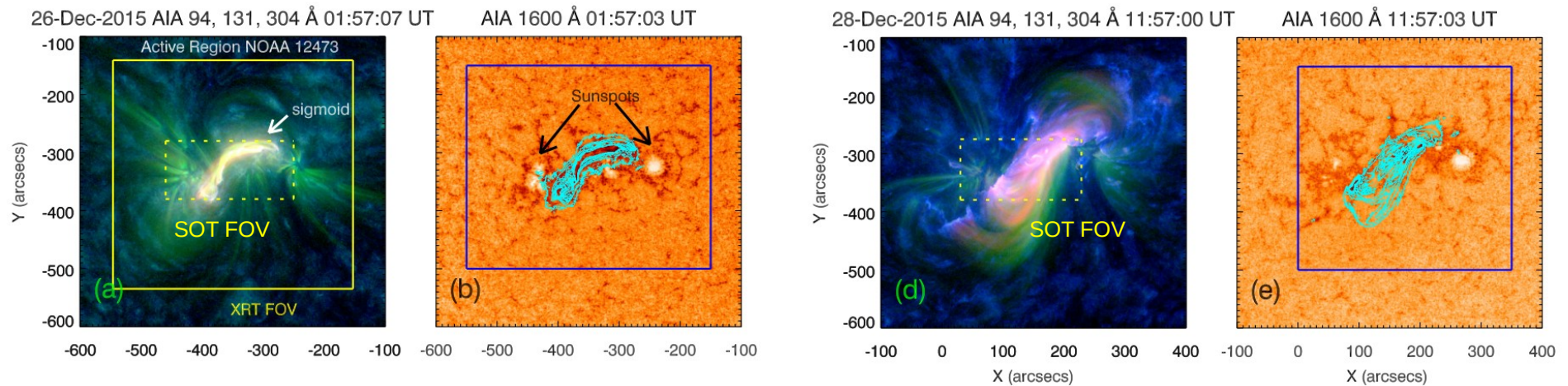
Data collection

- Using X-ray (Hinode/XRT) and EUV (SDO/AIA) imaging observations
- Full disk XRT images from the Solar Monitor website, XRT event archive
- On-disk sigmoids between +/- 50° longitude - 2010 – 2018 - > 50 events

Methodology

- Temperature analysis using different methods such as
- **Filter ratio** – two XRT channels, AIA 94 and 131 Å channels,
GOES X-ray fluxes from two filters
- **Emission measure analysis** using AIA observations – Cheung et al. 2015
- Study of **Fe XVIII emission in sigmoids from AIA 94 Å channel** (Del Zanna 2013)
- **Dec. 24 – 28, 2015 – Sigmoid - NOAA AR 12473 - 4 B, 11 C and 2 M X-ray class**
 - 1) Dec. 26, 2015 – C1.6 GOES flare – only brightening along sigmoid
 - 2) Dec. 28, 2015 – M1.8 GOES flare – sigmoid eruption

Sigmoid location in AIA, SOT and HMI images



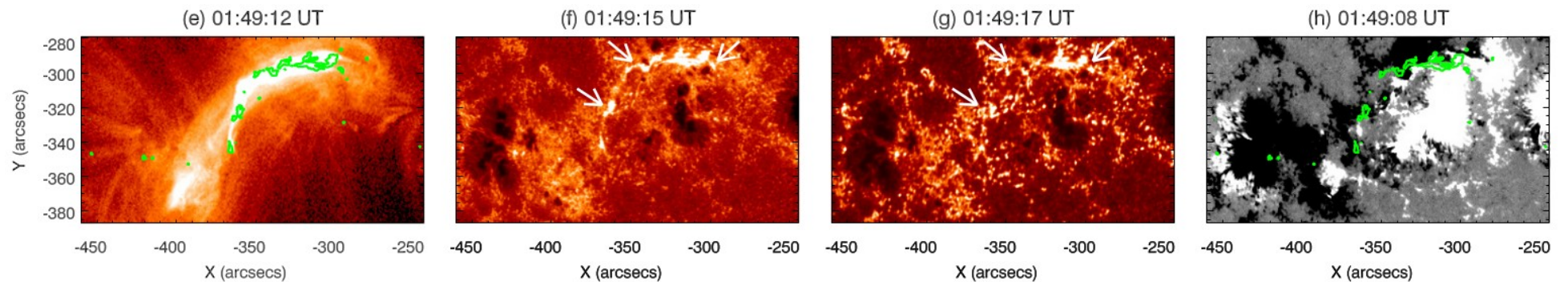
AIA 94 Å

SOT Ca II 3968 Å

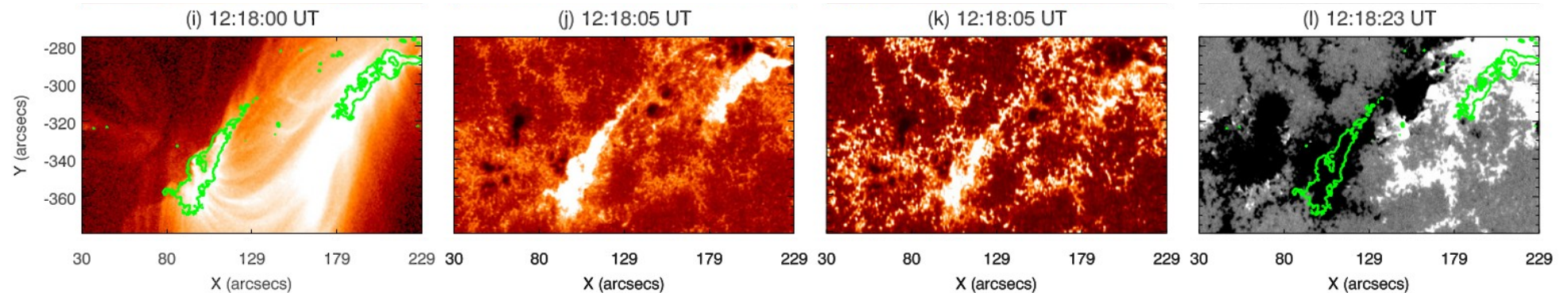
AIA 1700 Å

HMI LOS +/- 100 G

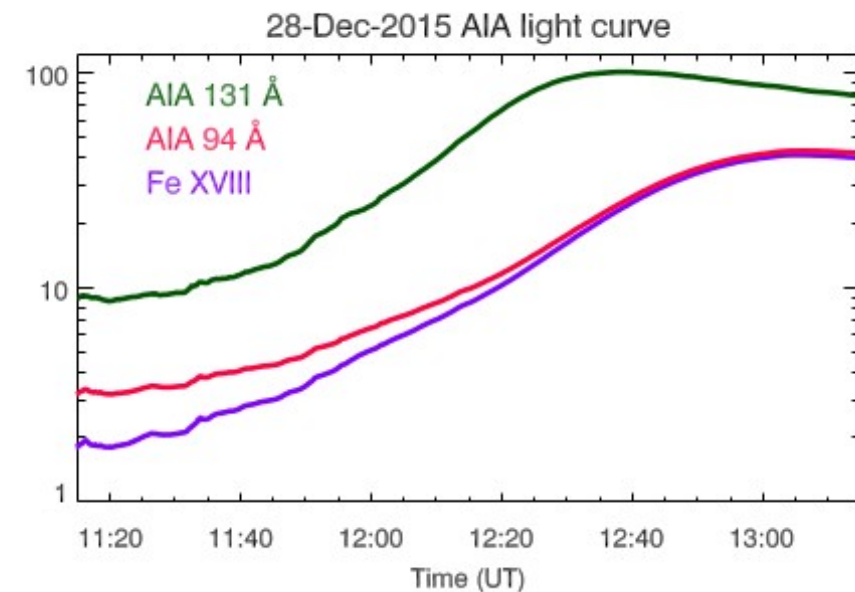
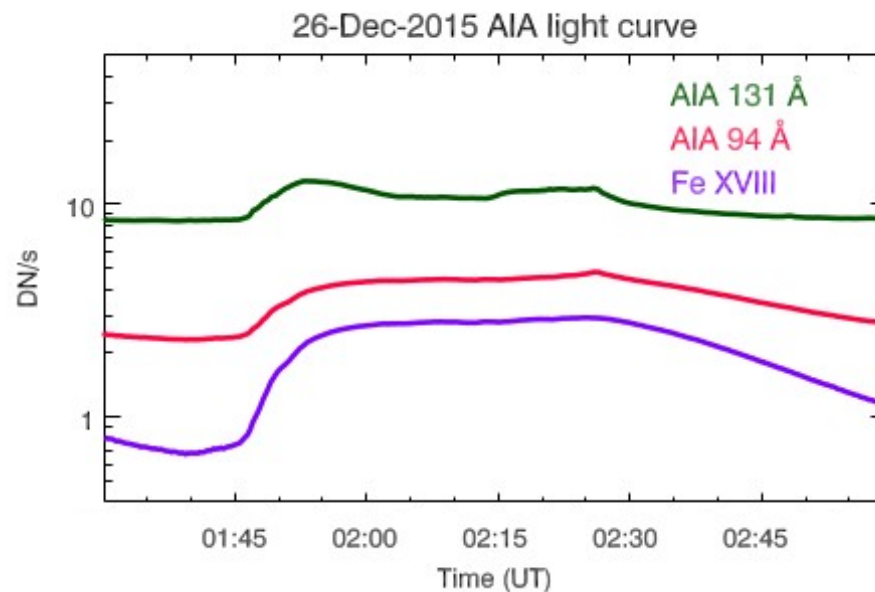
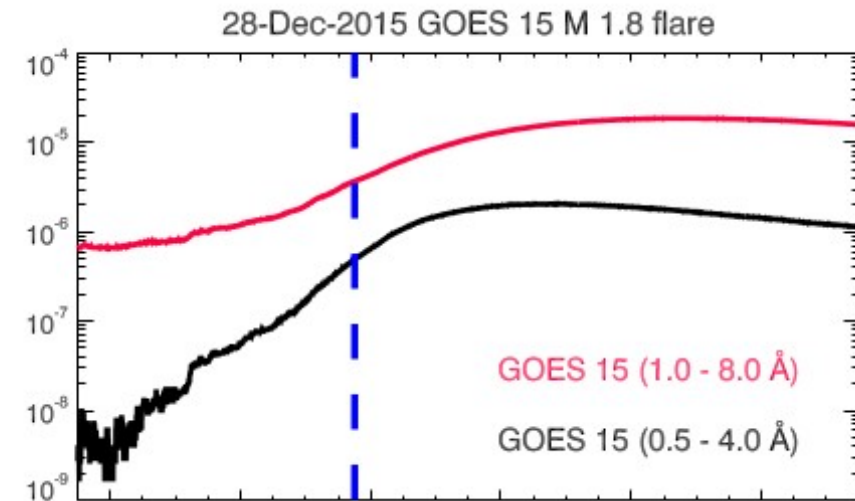
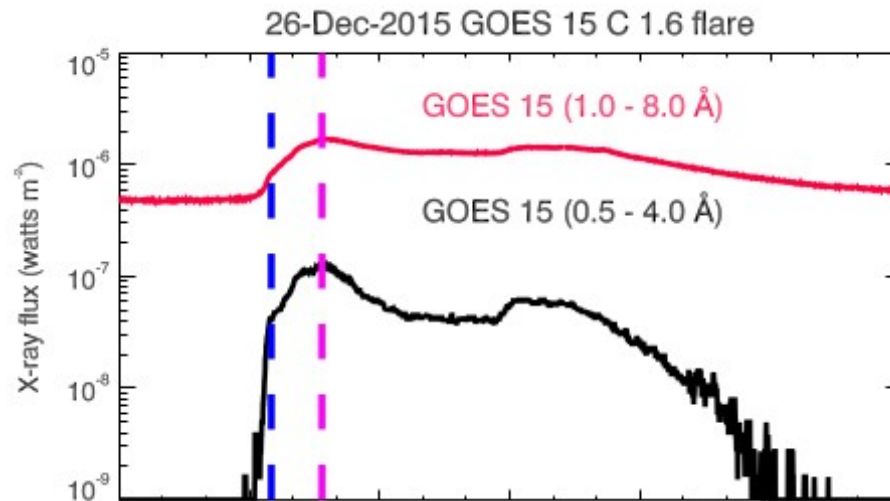
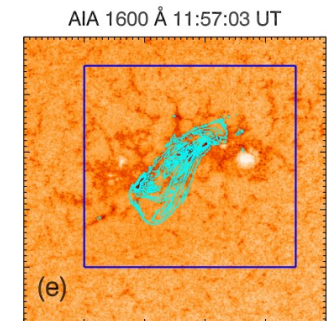
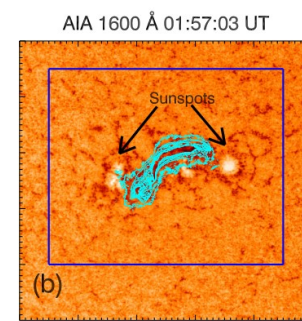
26-Dec-2015



28-Dec-2015

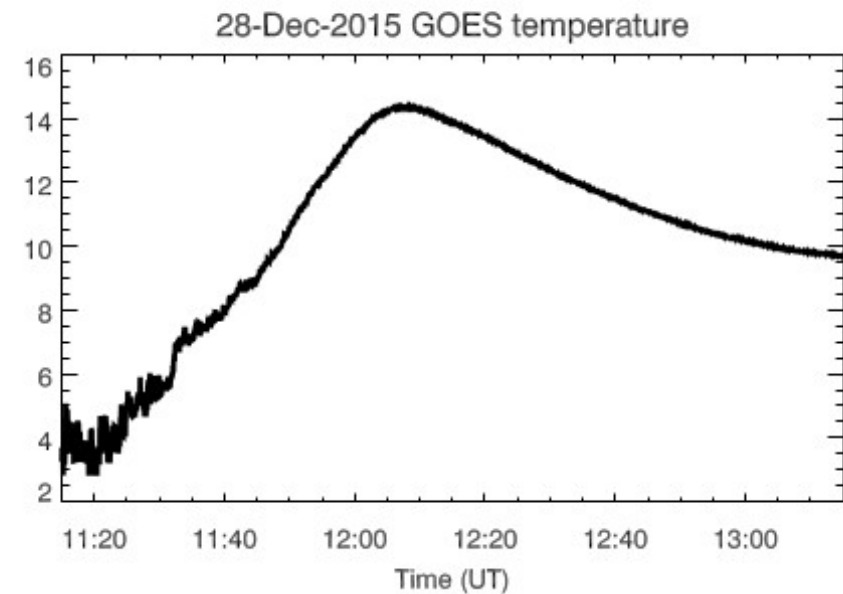
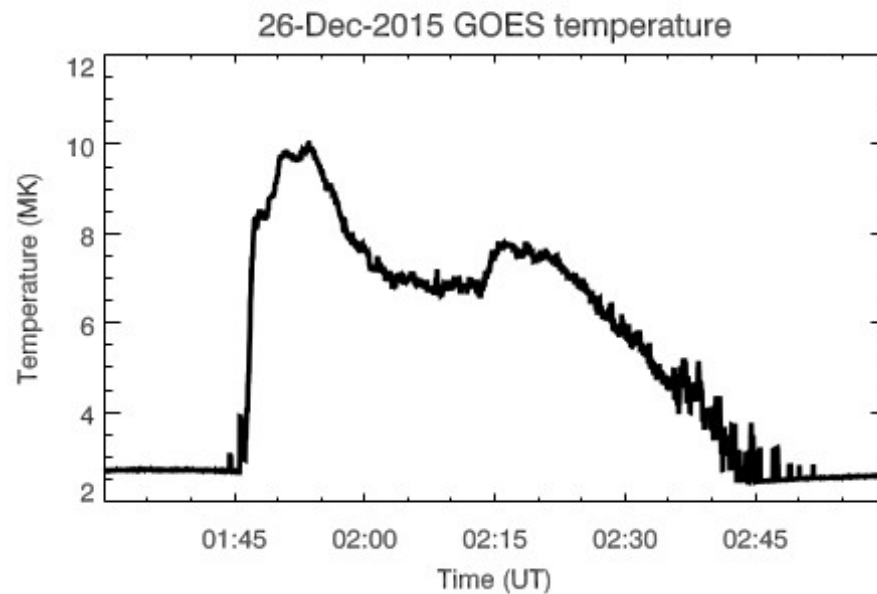
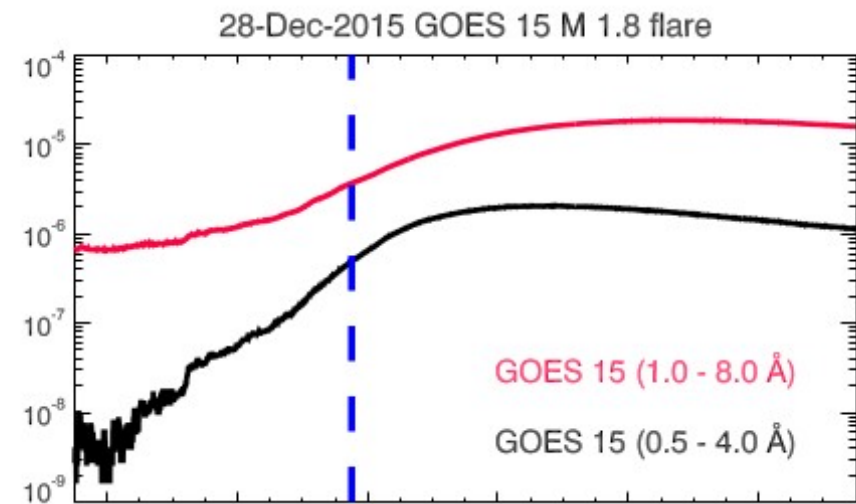
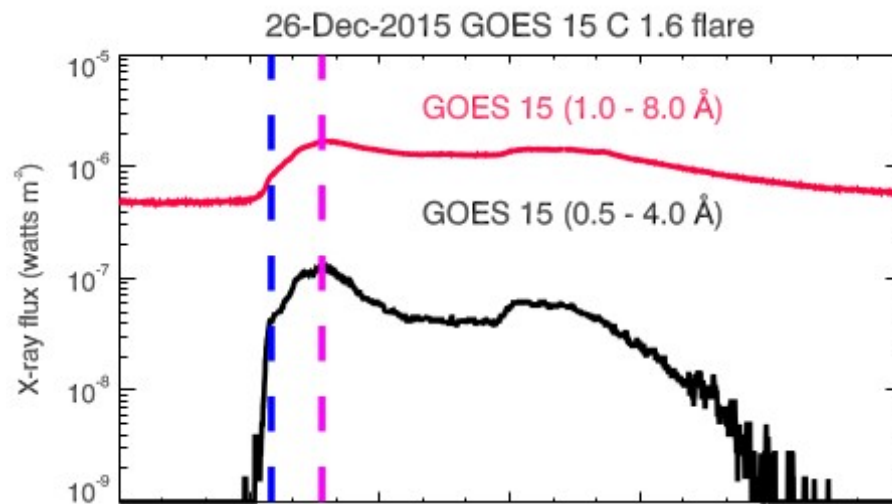


Temporal and spatial correlation between GOES flares and sigmoid EUV emission



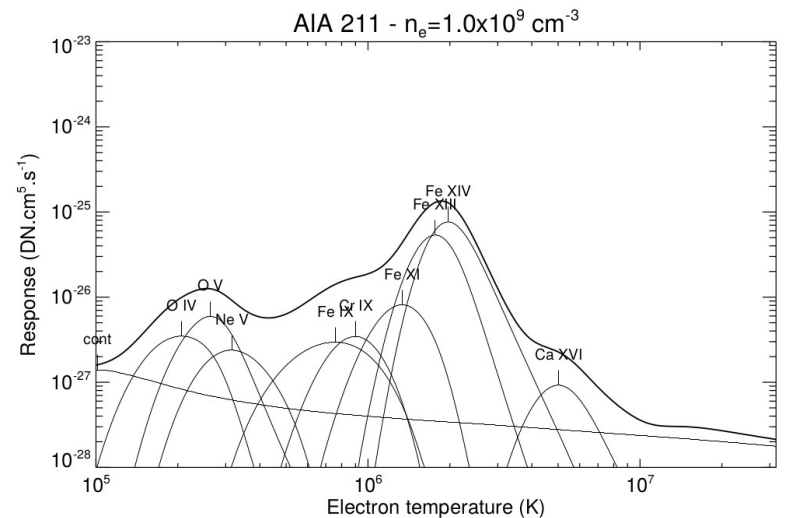
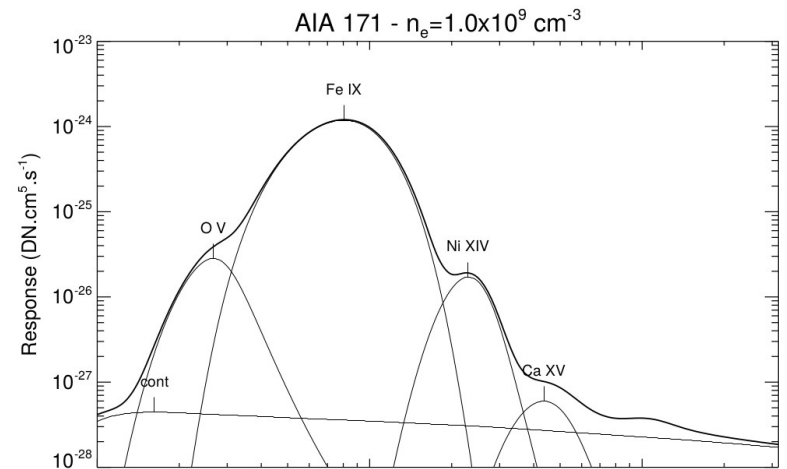
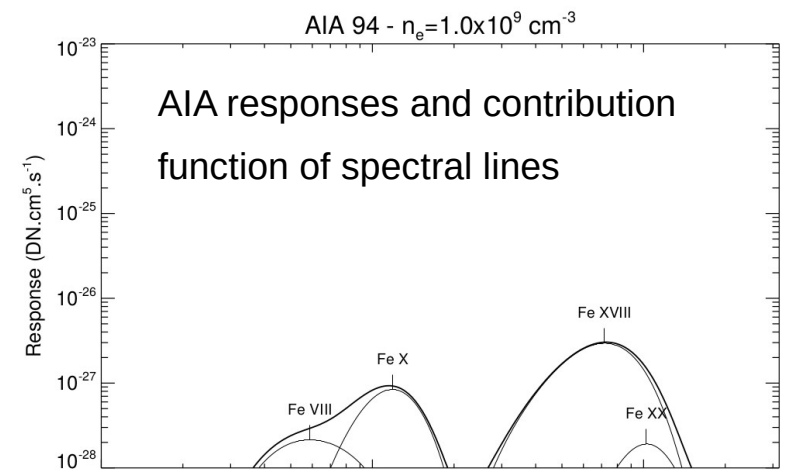
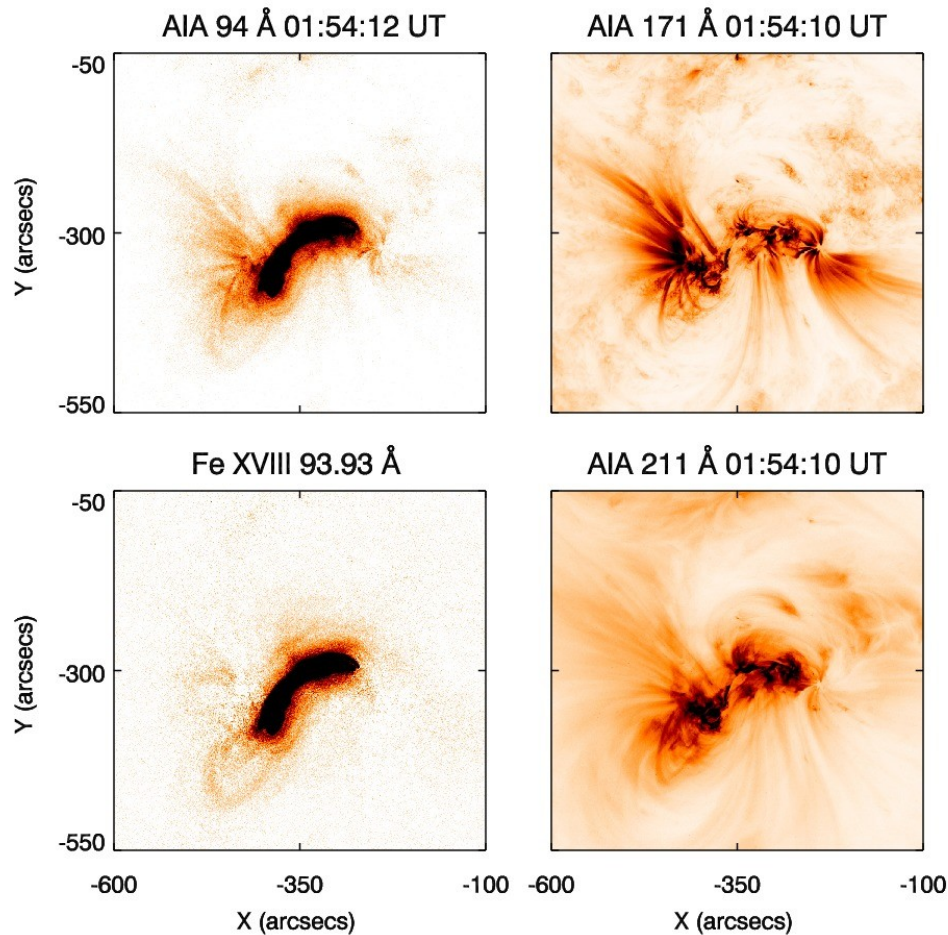
Temperature estimate using GOES filter ratio

Thomas et al. (1985), Garcia (1994), Hara et al. (1992)



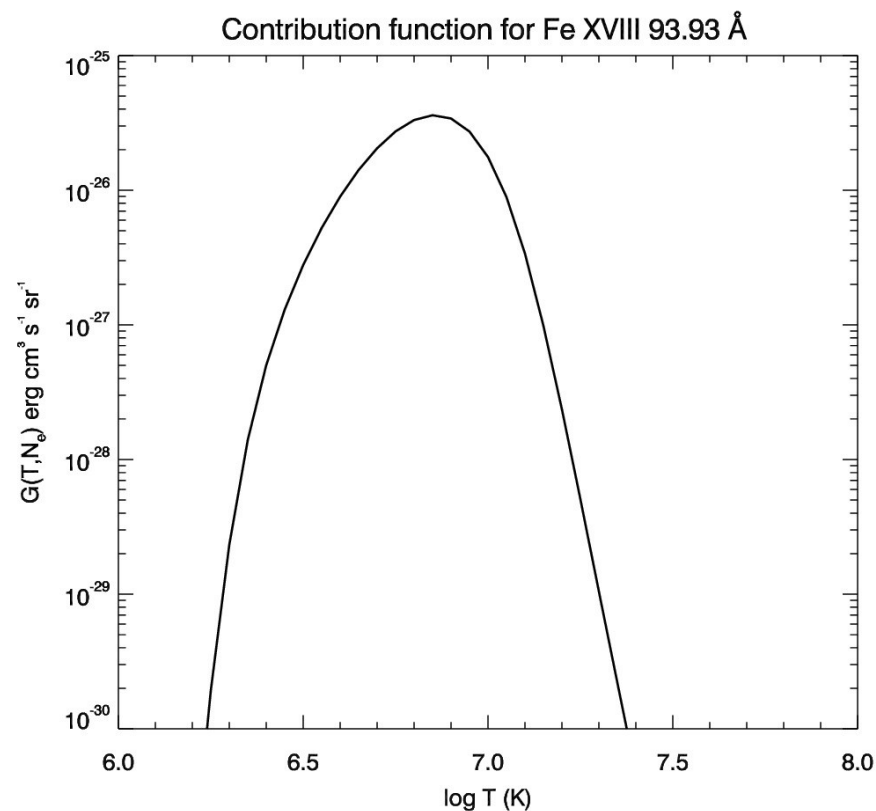
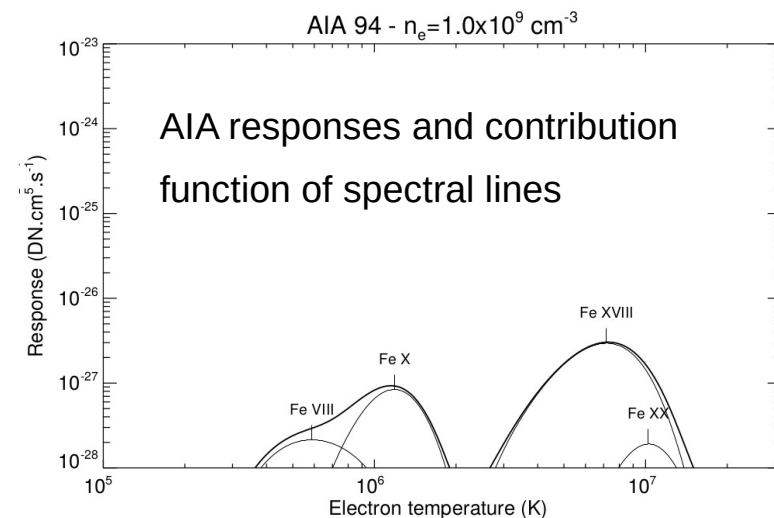
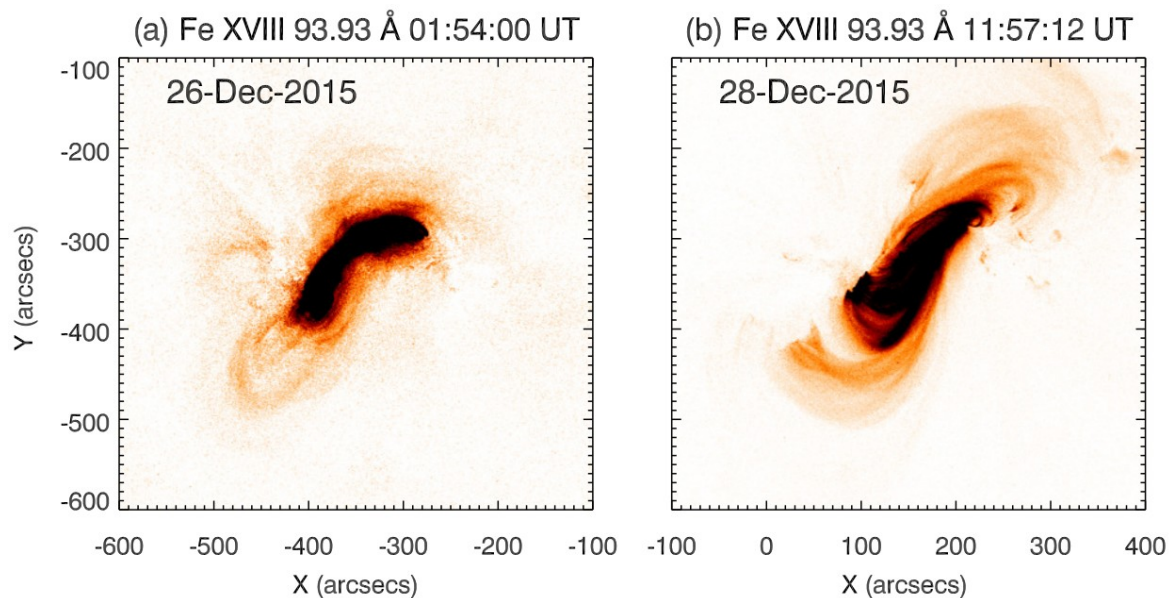
Fe XVIII emission derived using the method by Del Zanna 2013

$$I(\text{Fe XVIII } 93.93 \text{ \AA}) = I(94 \text{ \AA}) - \frac{I(211 \text{ \AA})}{120} - \frac{I(171 \text{ \AA})}{450}$$



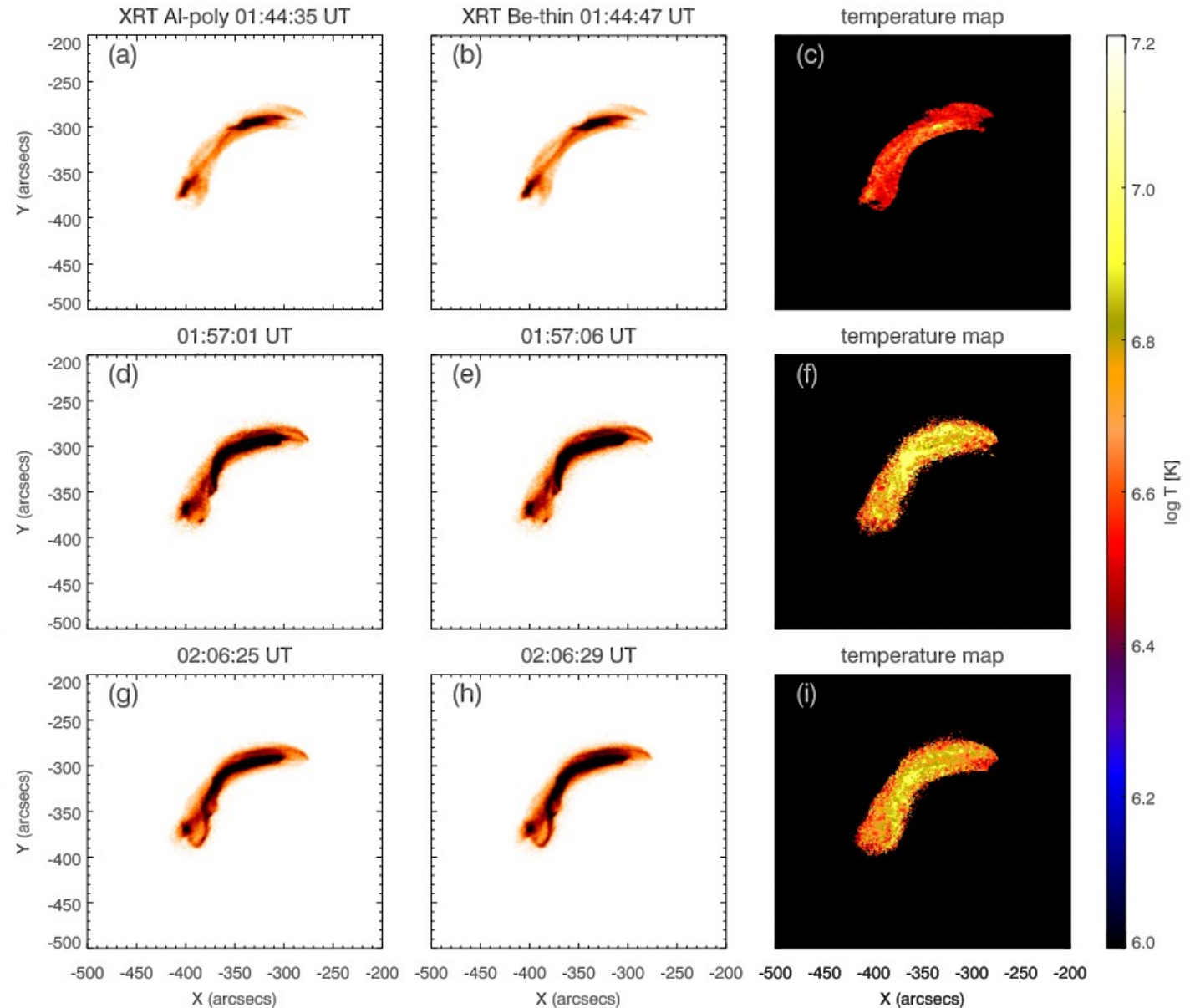
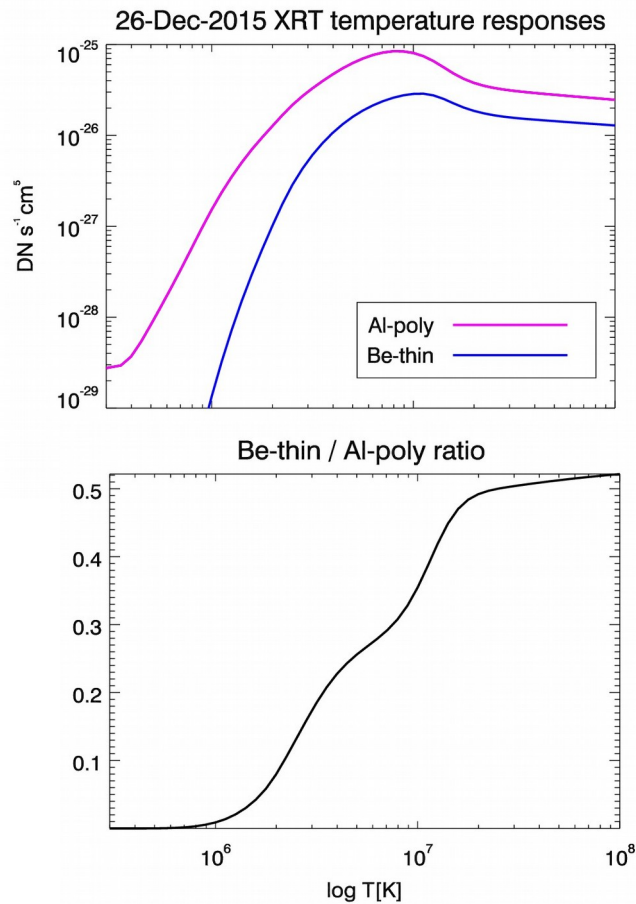
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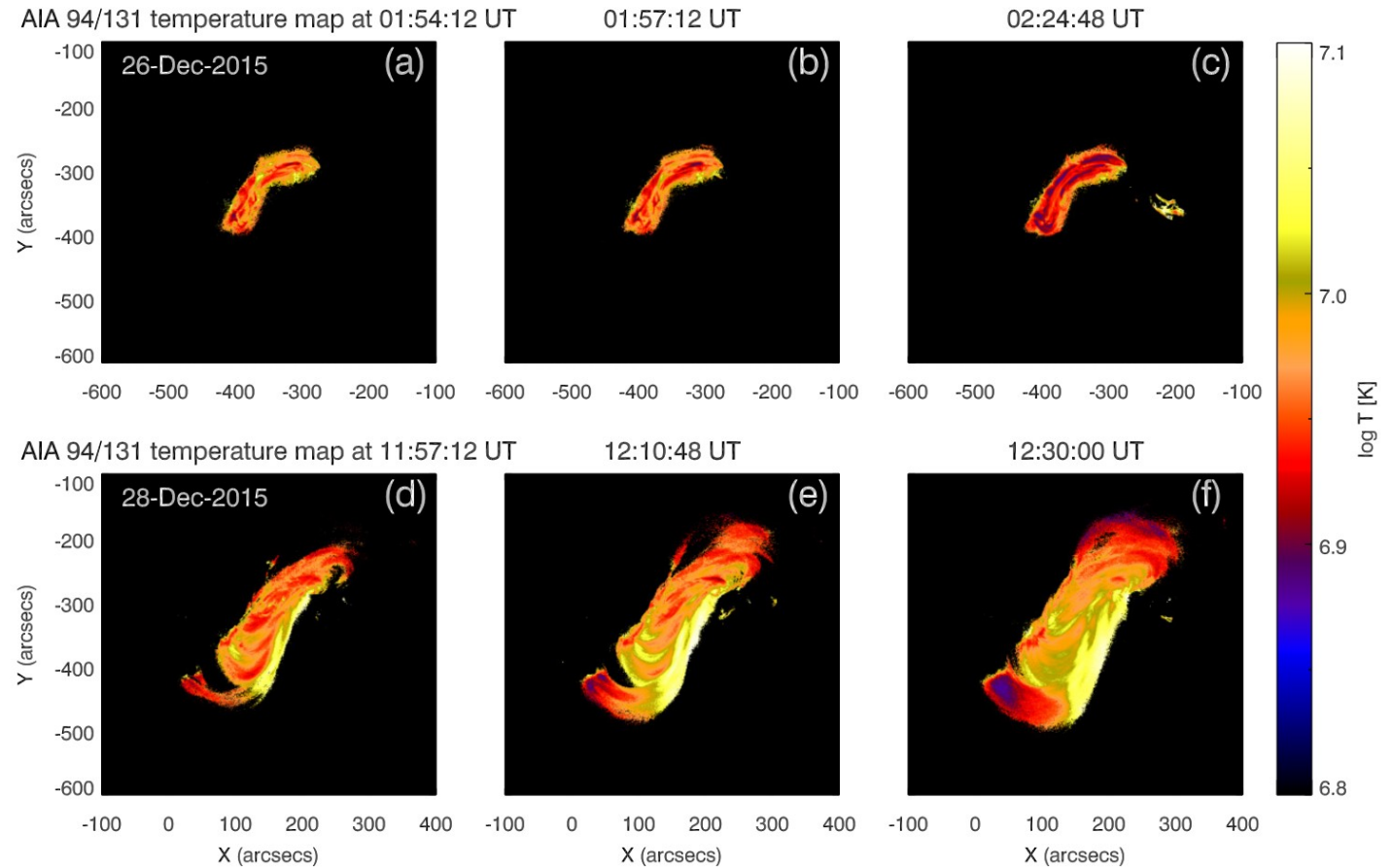
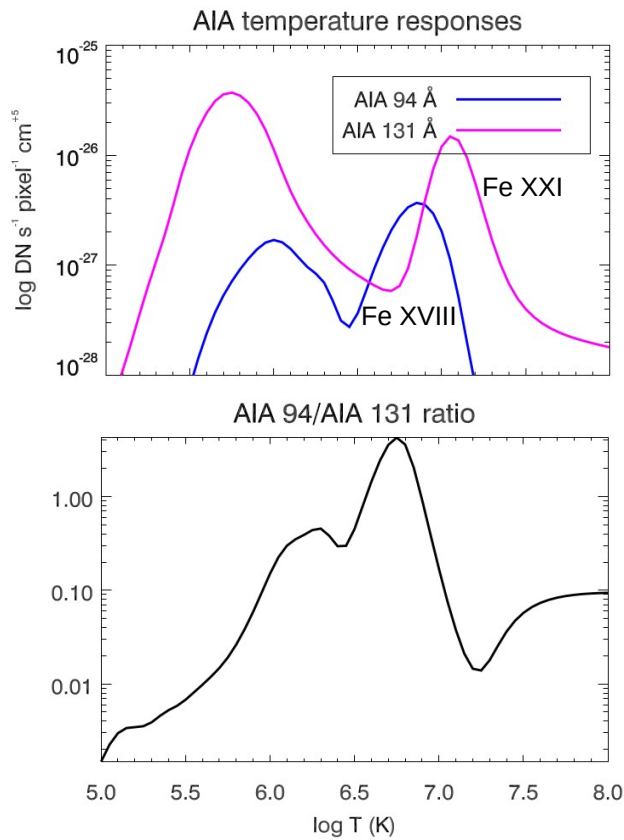
Temperature estimate using XRT filter ratio

(Hara et al. 1992, Narukage et al. 2011)



Using CHIANTI atomic database (Dere et al. 1997, Del Zanna 2015)

Temperature estimate using AIA filter ratio

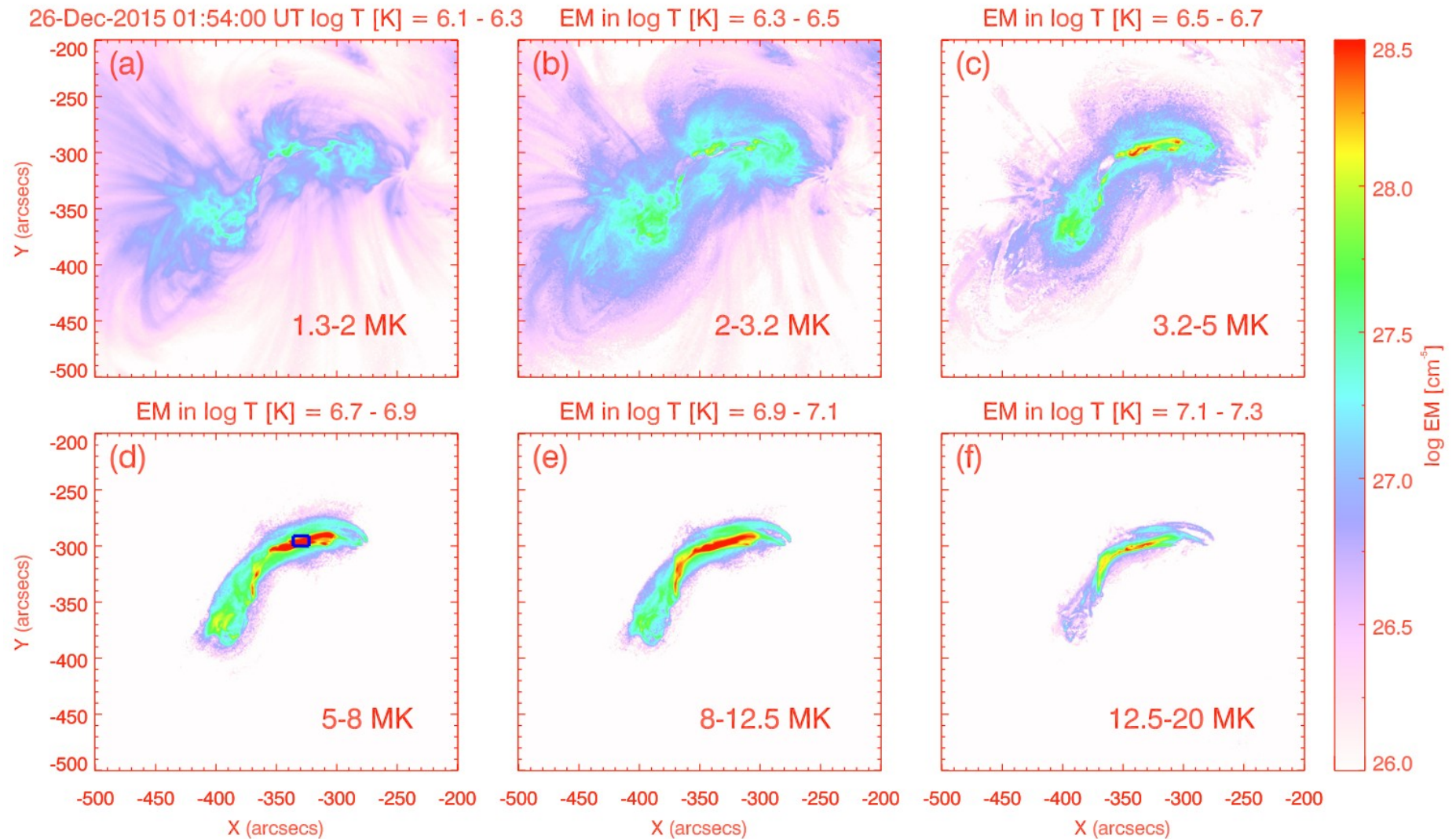


Using CHIANTI atomic database (Dere et al. 1997, Del Zanna 2015)

Temperature estimate using Emission Measure

The amount of plasma along the line-of-sight that emits observed radiation and has temperature between T and $T+dT$.

EM method by Cheung et al. 2015



Temperature estimate using Emission Measure

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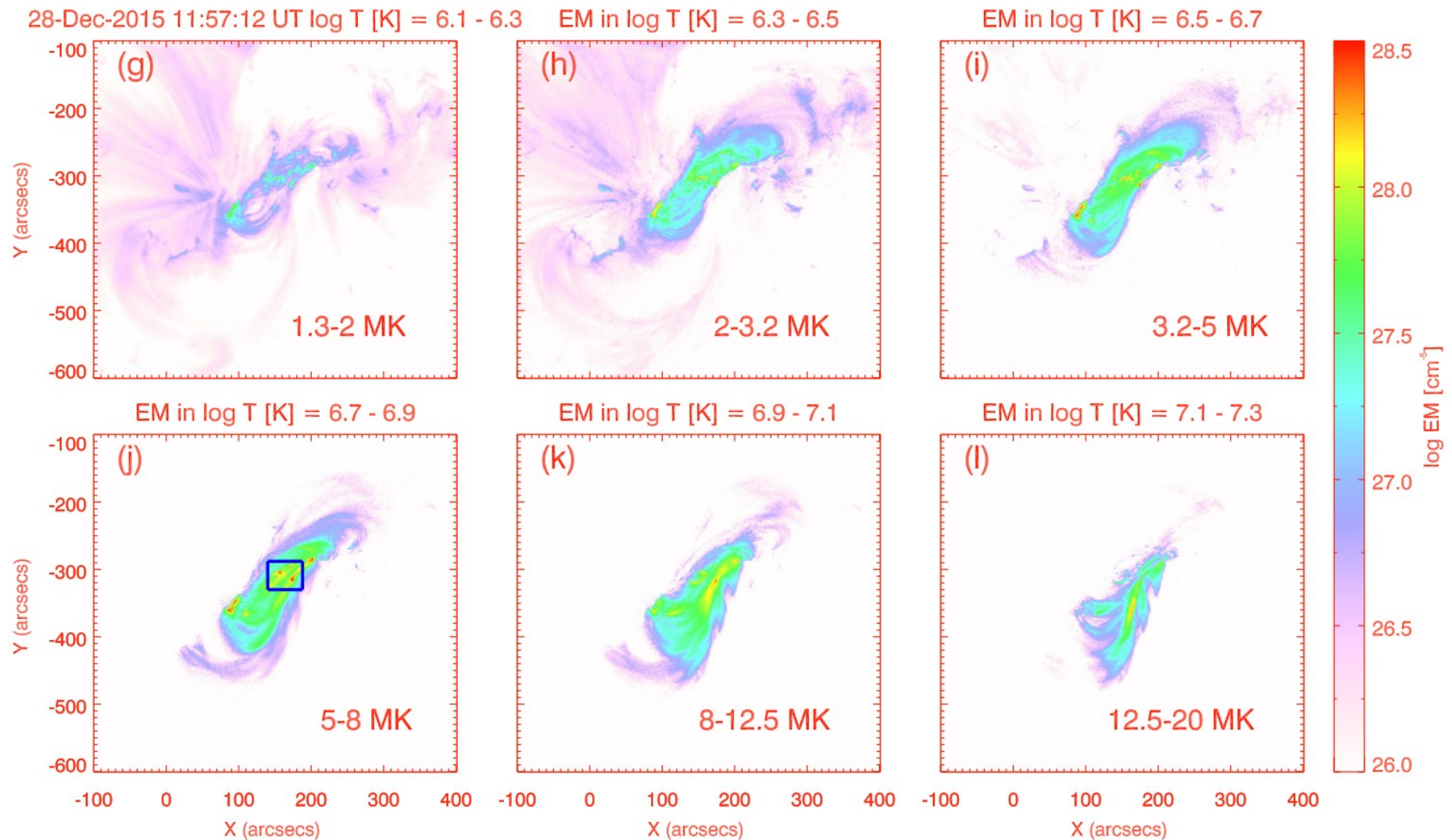


Table 1. Sigmoid and X-ray flare observation details

(Col. 1)	(Col. 2)	(Col. 3)	(Col. 4)	(Col. 5)	(Col. 6)	(Col. 7)	(Col. 8)	(Col. 9)	(Col. 10)	(Col. 11)	(Col. 12)
Date	Flare no.	X-ray Class	Phase of the flare	Time (UT)	GOES temp. (MK)	Time (UT)	Temp. from EM (MK)	Time (UT)	AIA filter-ratio temp (MK)	Time (UT)	XRT filter-ratio temp (MK)
26-Dec-2015	8	C1.6	pre-flare	01:39:00	2.3	01:39:00	2-5	-	-	01:38:35	3.0
AR 12473			start	01:44:00	3	01:44:00	2-5	-	-	01:44:00	2-3.5
S22 E09 ($\beta\gamma$)			peak	01:54:00	10	01:54:00	3-12	01:54:00	8-10	01:57:00	9-10
Jets - 10			end	02:32:00	5.5	02:32:00	3-12	-	-		No XRT data
28-Dec-2015	12	M1.8	pre-flare	11:15:00	4	11:15:00	3-6	-	-		No
AR 12473			start	11:20:00	4	11:20:00	3-6		-		XRT
S22 W18 ($\beta\delta$)			peak	12:45:00	14.5	12:45:00	3-14	12:45:00	8-12		data
			end	14:09:00	8.8	14:09:00	5-9	-	-		available

Multithermal plasma along the sigmoid!

Spectroscopic observations -

- Gibson et al. (1999) and Tripathi et al. (2006) ~ 2 MK (Fe XVI and Si XII lines) - close to the pre-flare sigmoid temperatures
- Del Zanna et al. (2002) - Fe XIX - 8 MK – good agreement with GOES peak flare T_{peak}

EUV imaging observations -

- Cheng et al. (2014) - 10 MK - show good agreement with our results

Study provides important parameters for the thermodynamic modeling!

Mulay, S. et al. in preparation for MNRAS