



南京大學  
NANJING UNIVERSITY

# **Spectroscopic** Diagnostics of **Chromospheric Evaporation** *Using IRIS and Hinode/EIS*

**Ying Li (李瑛)**

M. D. Ding & J. Qiu

**SCHOOL OF ASTRONOMY AND SPACE SCIENCE  
NANJING UNIVERSITY**

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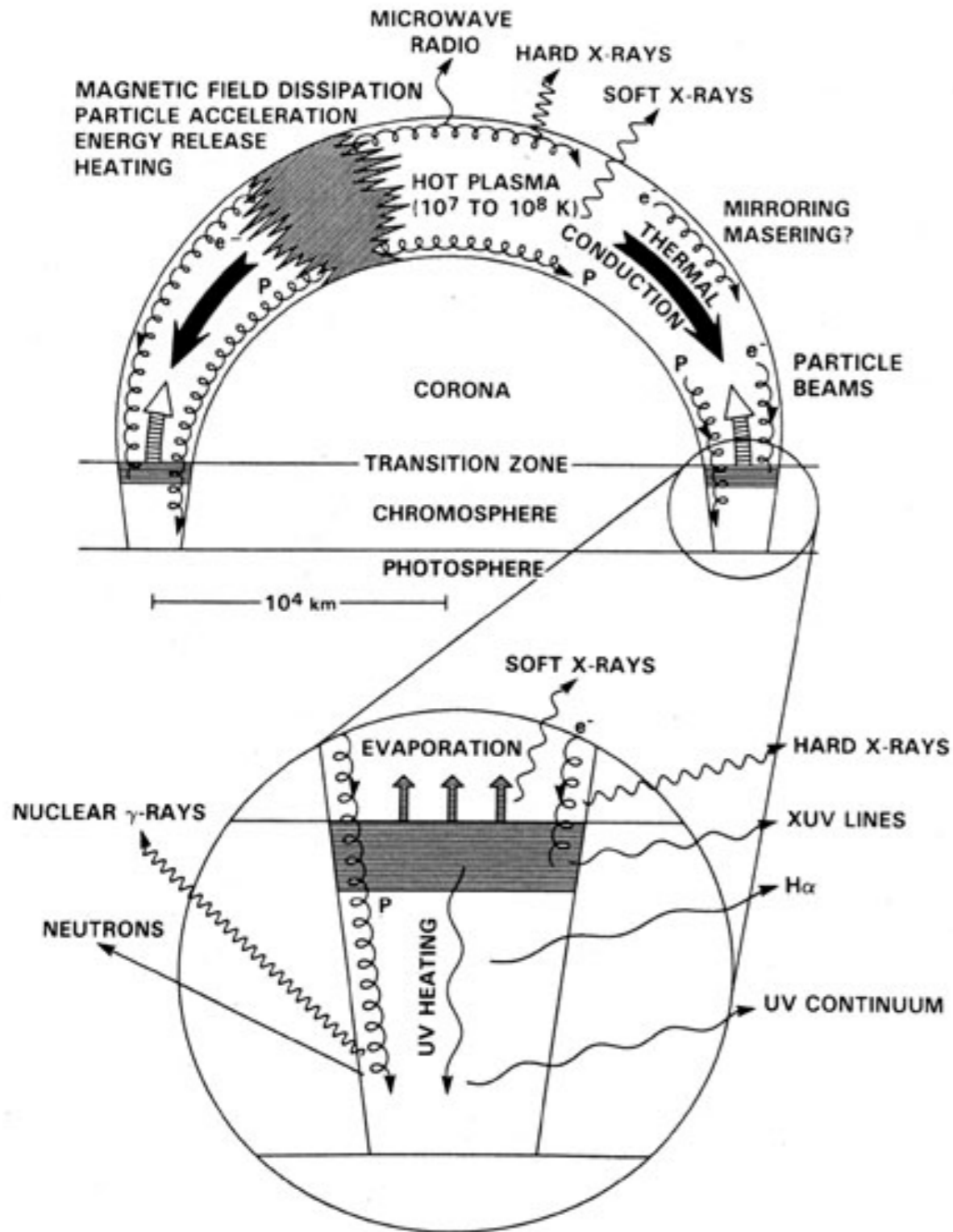
**Summary & Discussion**

# Background (1/3)

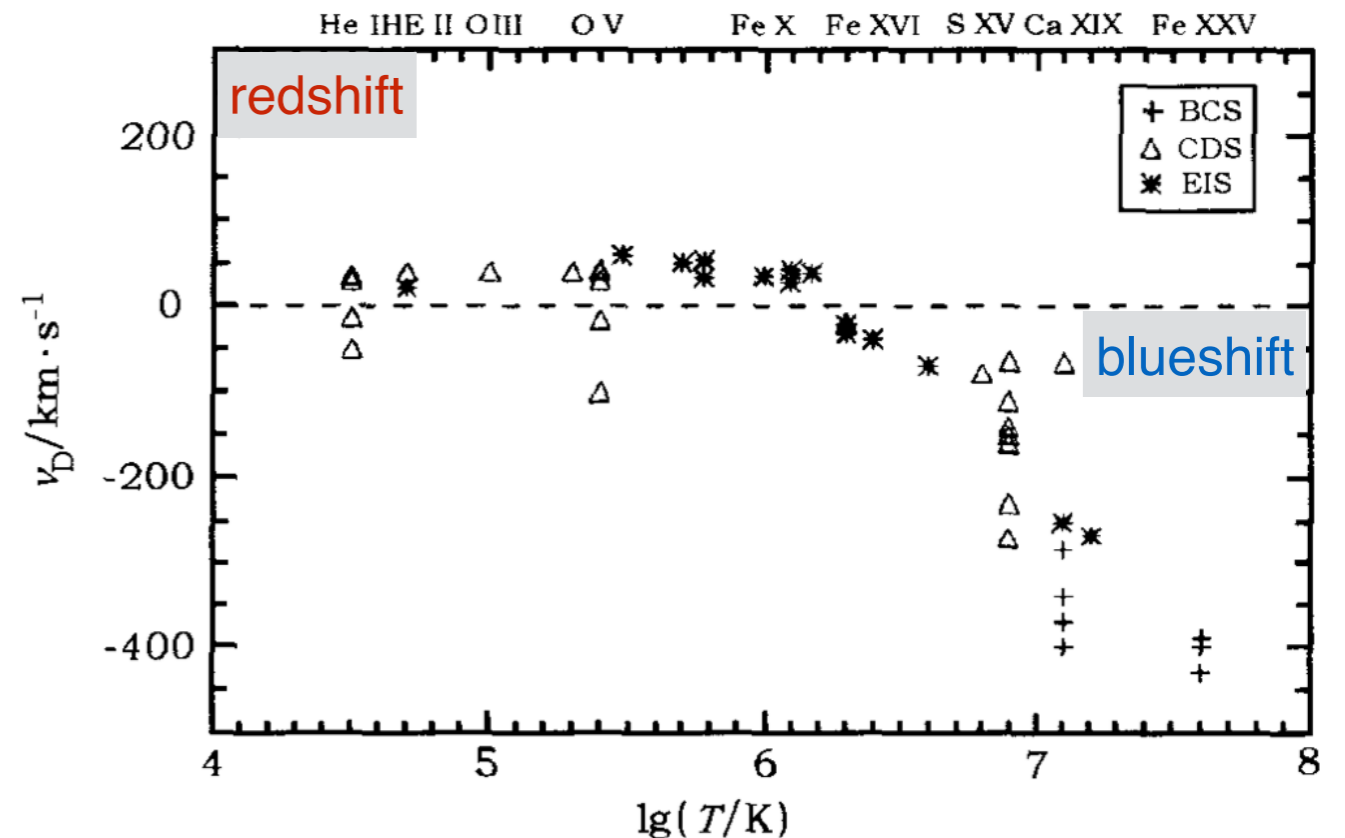
## Chromospheric evaporation

- **upward mass motions** in a flaring process due to thermal pressure  
(Feldman et al. 1980; Antonucci 1982; ...)
- also **downward motions** (condensation) conservation of momentum  
(Canfield et al. 1990; Fisher et al. 1985; ...)

in observations



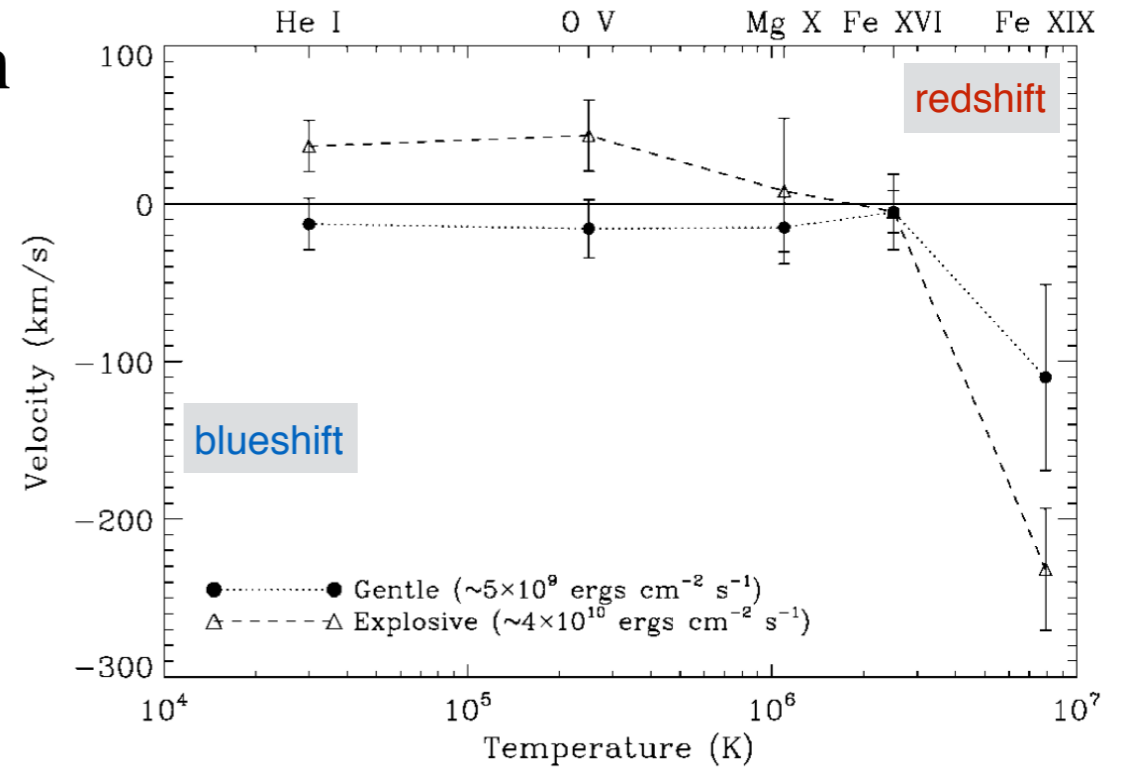
(Dennis & Schwartz 1989)



# Background (2/3)

**Two types of chromospheric evaporation** according to the observed Doppler velocity

- **explosive evaporation:** blueshifts & redshifts  
(e.g., Milligan et al. 2006a)
- **gentle evaporation:** only blueshifts detected  
(e.g., Milligan et al. 2006b)

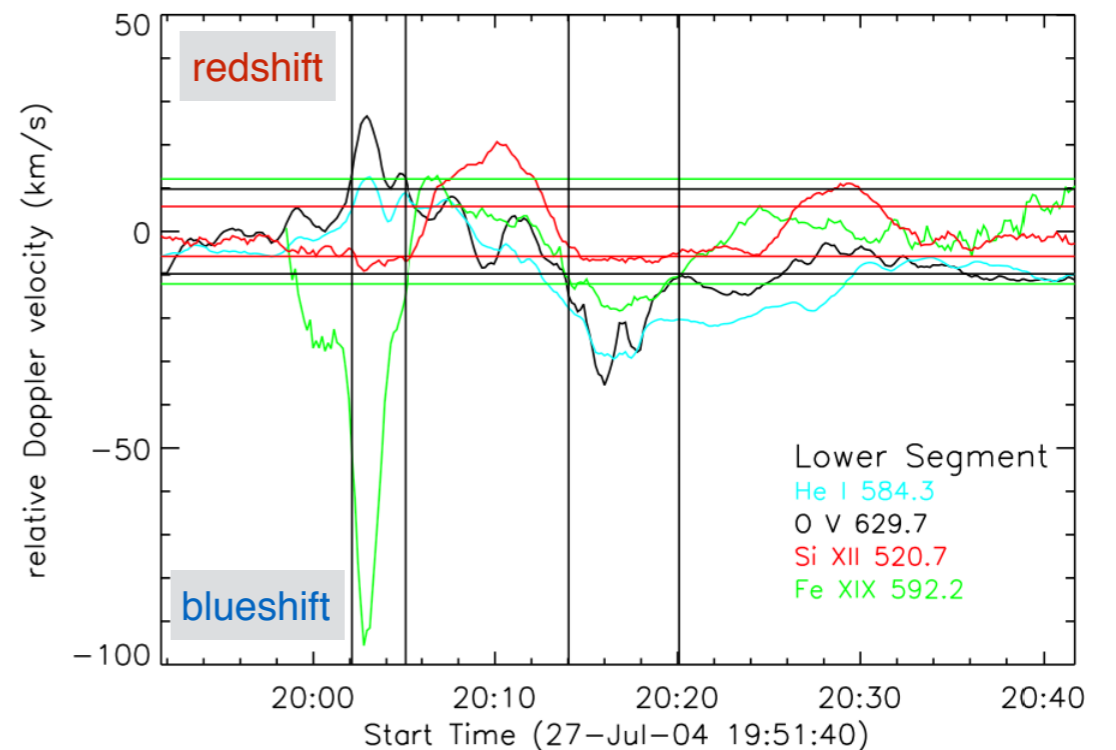


(Milligan et al. 2006a,b)

**conversion** from explosive to gentle chromospheric evaporation

**threshold** of electron flux

$\sim 10^{10}$  ergs cm<sup>-2</sup> s<sup>-1</sup> (Fisher et al. 1985)



(Brosius 2009)

# Background (3/3)

## Some problems (discrepancies between observations and models)

before/in EIS (pre-IRIS) era

### — dominant stationary component in high T ( $\geq 10$ MK) lines

(Ding et al. 1996; Milligan & Dennis 2009)

explanations:

- (1) moving perpendicular to the line-of-sight (Falewicz 2009)
- (2) from the top of the flare loop (Doschek & Warren 2005)
- (3) multi-strand flare loop model (Brosius 2013)
- (4) instrument not sensitive (Doschek & Warren 2005)

*solved in the IRIS era?*

### — high temperature downflows

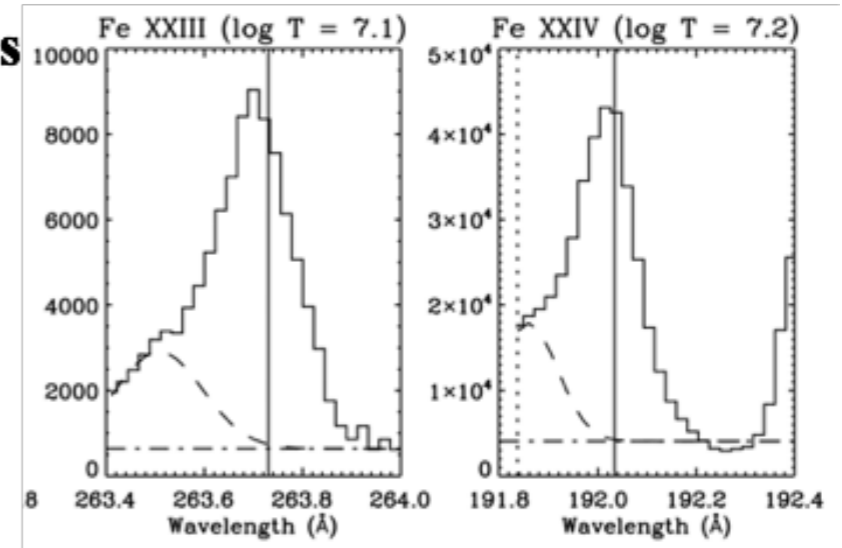
reversal temperature from blueshift to redshift

$\leq 1$  MK (Kamio et al. 2005)

2 MK (Milligan 2008)

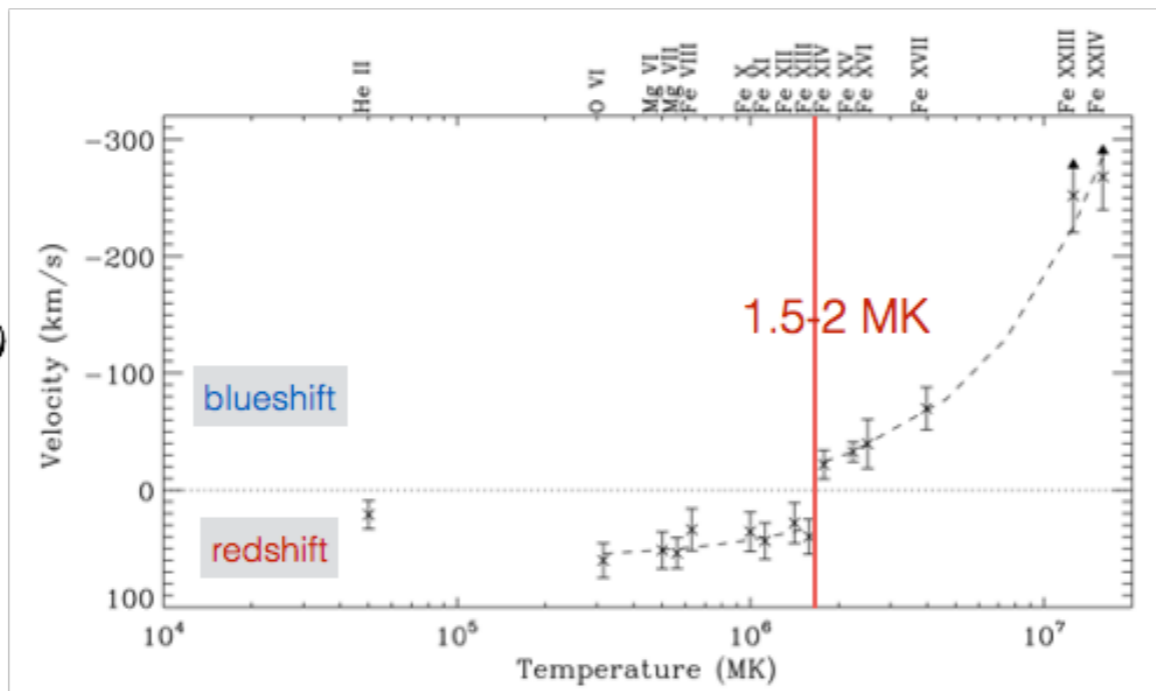
2.5-5 MK (Li & Ding 2011)

rather high energy deposition site?? *(further investigated in numerical modeling???)*

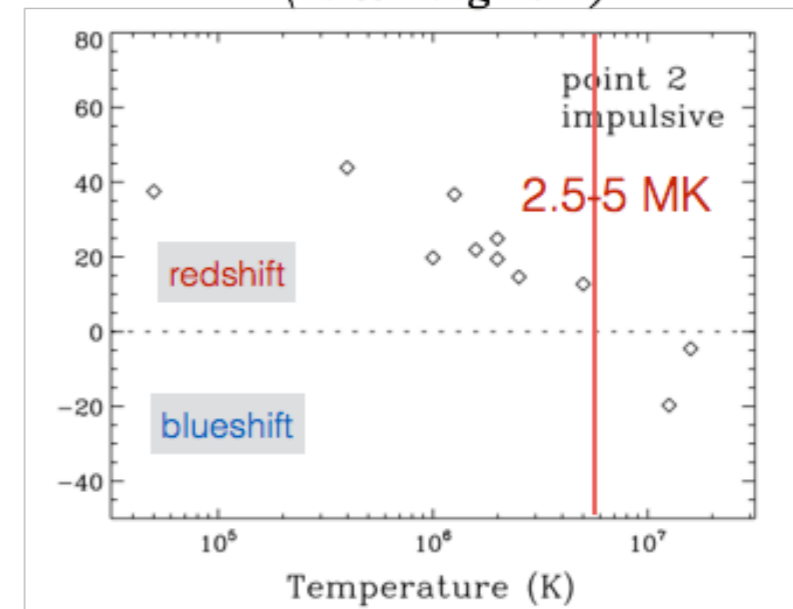


(Milligan & Dennis 2009)

(Milligan & Dennis 2009)



(Li & Ding 2011)



# Instruments

## **Hinode/EIS** (since 2006)

**Extreme-ultraviolet Imaging Spectrometer**

wavelength: 170–210 Å & 250–290 Å (EUV)

spectral line:  $\log T = 4.7\text{--}7.2$  K (coronal & flaring lines)

resolution:  $\sim 1''$ ,  $\sim$ sec to min, 0.022 Å/pixel

mode: raster scan & sit-and-stare

## **IRIS** (since 2013)

**Interface Region Imaging Spectrograph**

wavelength:  $\sim 1400$  Å &  $\sim 2800$  Å (FUV/NUV)

spectral line:  $\log T = 3.7\text{--}7.0$  K (chromospheric lines)

resolution:  $\sim 0.167''$ ,  $\sim$ sec to min, 0.025 Å/pixel

mode: raster scan & sit-and-stare (SJI)

# Spectral Lines

Ion	Wavelength (Å)	$\log T_{max}$ (K)
He II	256.32	4.7
Fe VIII	185.21	5.8
Fe X	184.54	6.0
Fe XII	195.12	6.1
Fe XIII	202.04	6.2
Fe XIV	274.20	6.3
Fe XV	284.16	6.3
Fe XVI	262.98	6.4
Ca XVII	192.82	6.7
Fe XXIII	263.76	7.1
Fe XXIV	192.03	7.2

**from EIS**  
*(for the 1st flare event)*

Ion	Wavelength (Å)	$\log T_{max}$ (K)
Mg II h	2803.5	4.0
Mg II k	2796.4	4.0
C II	1334.5	4.3
C II	1335.7	4.3
Si IV	1402.8	4.8
Fe XXI	1354.1	7.0

**from IRIS**  
*(+EIS for the 2nd flare event)*

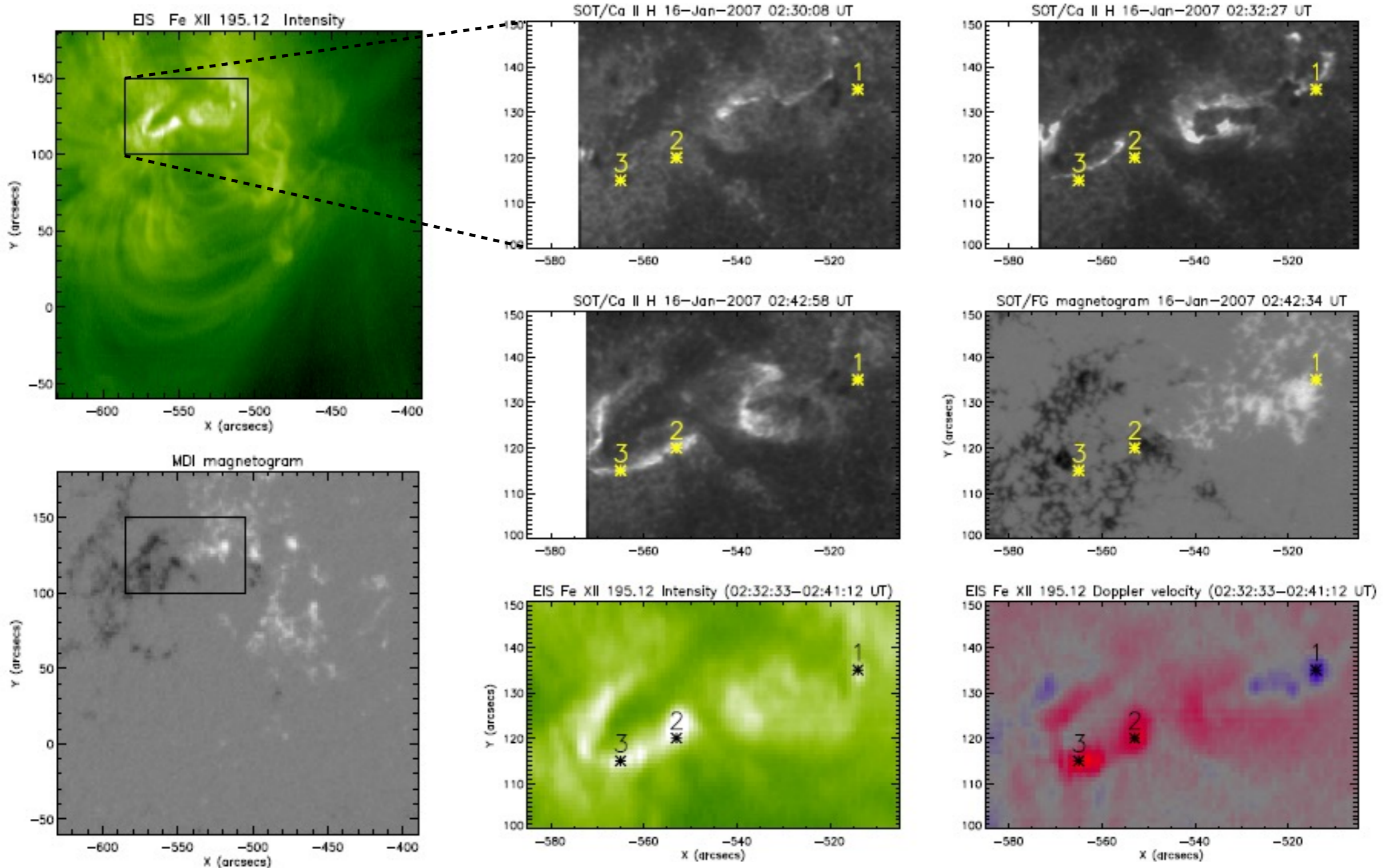
**the 1st flare event**  
in the EIS (pre-IRIS) era

[Li & Ding, 2011, ApJ, 727, 98](#)

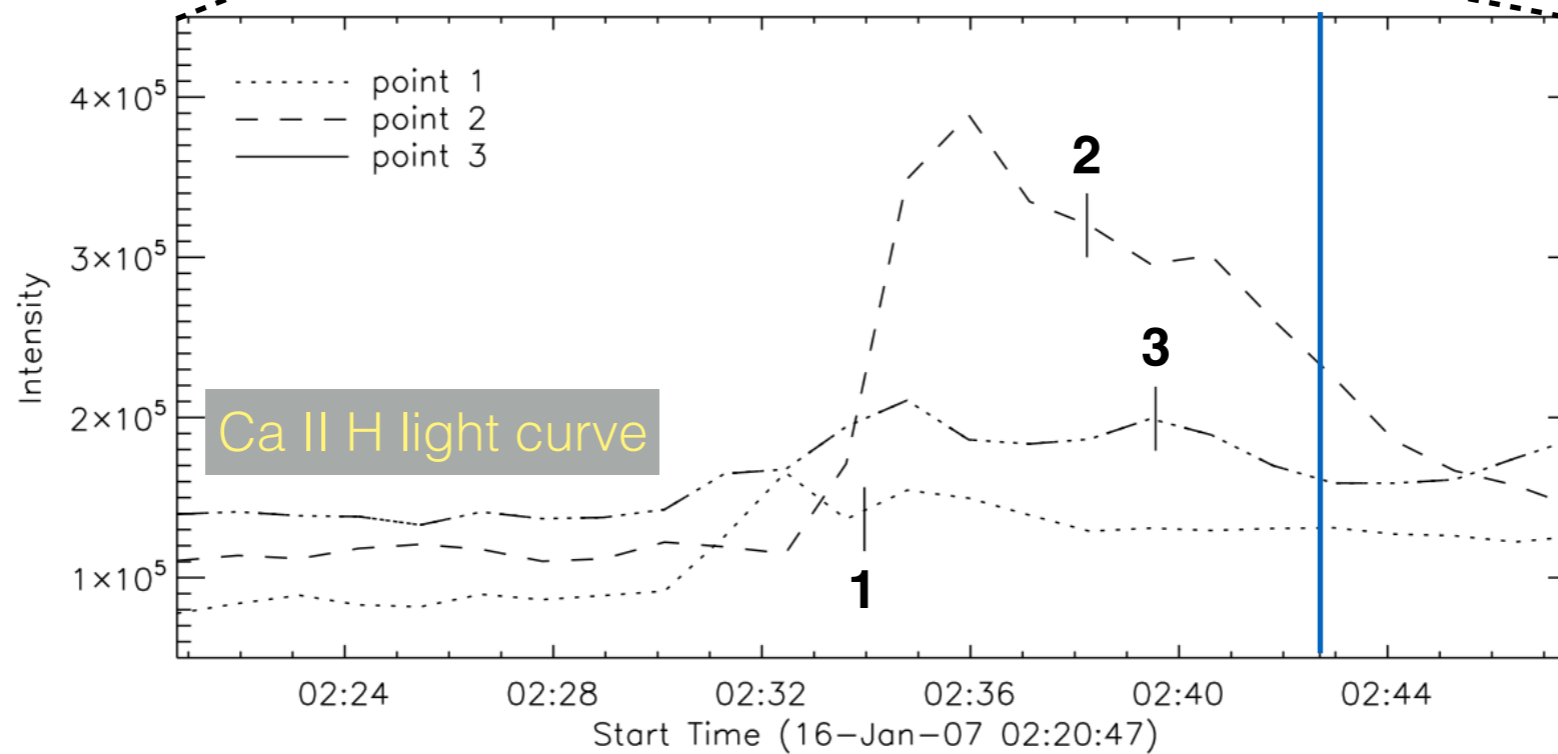
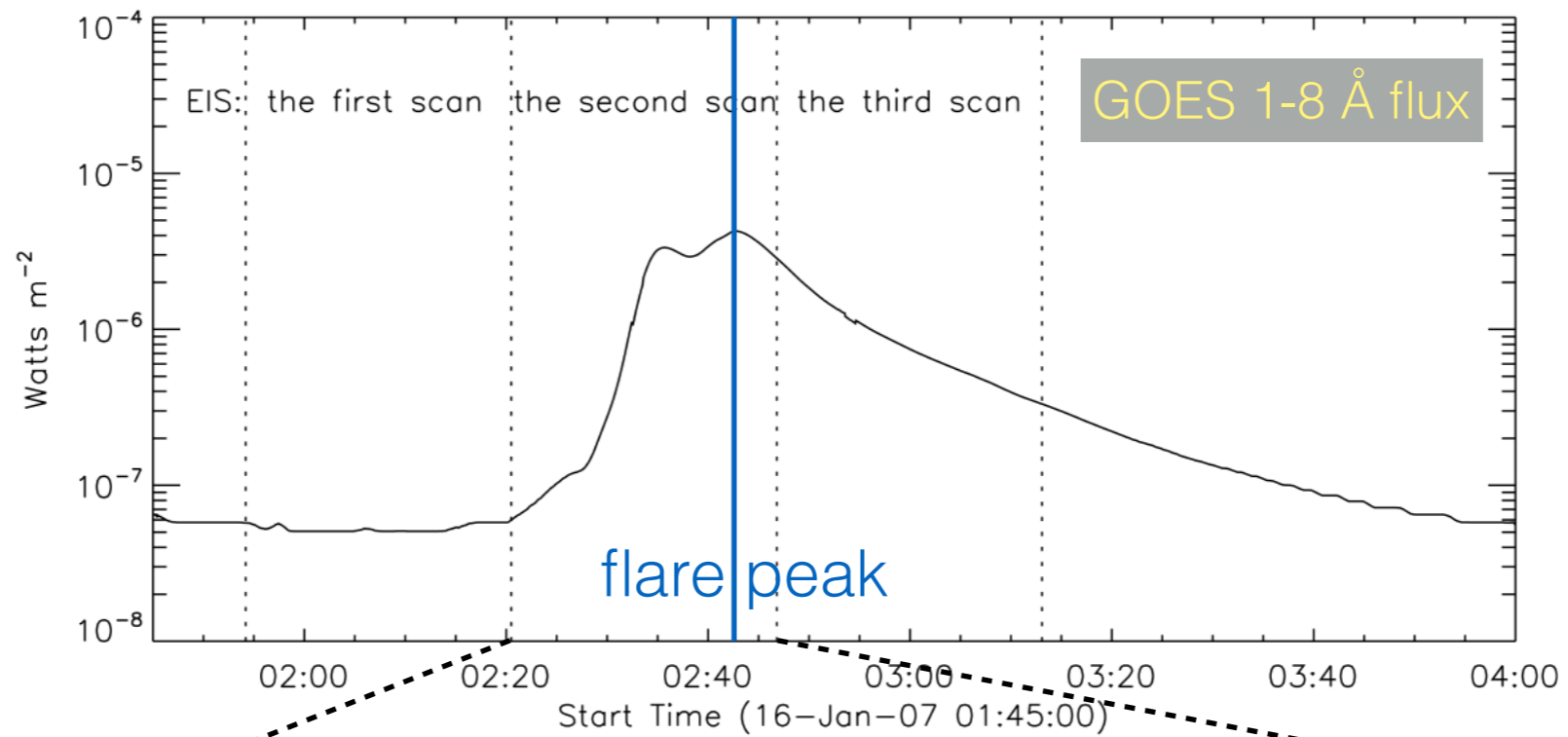


# Observations (1/2) — a C4.2 flare on 2007-01-16

three points at the flare ribbons with different magnetic polarities

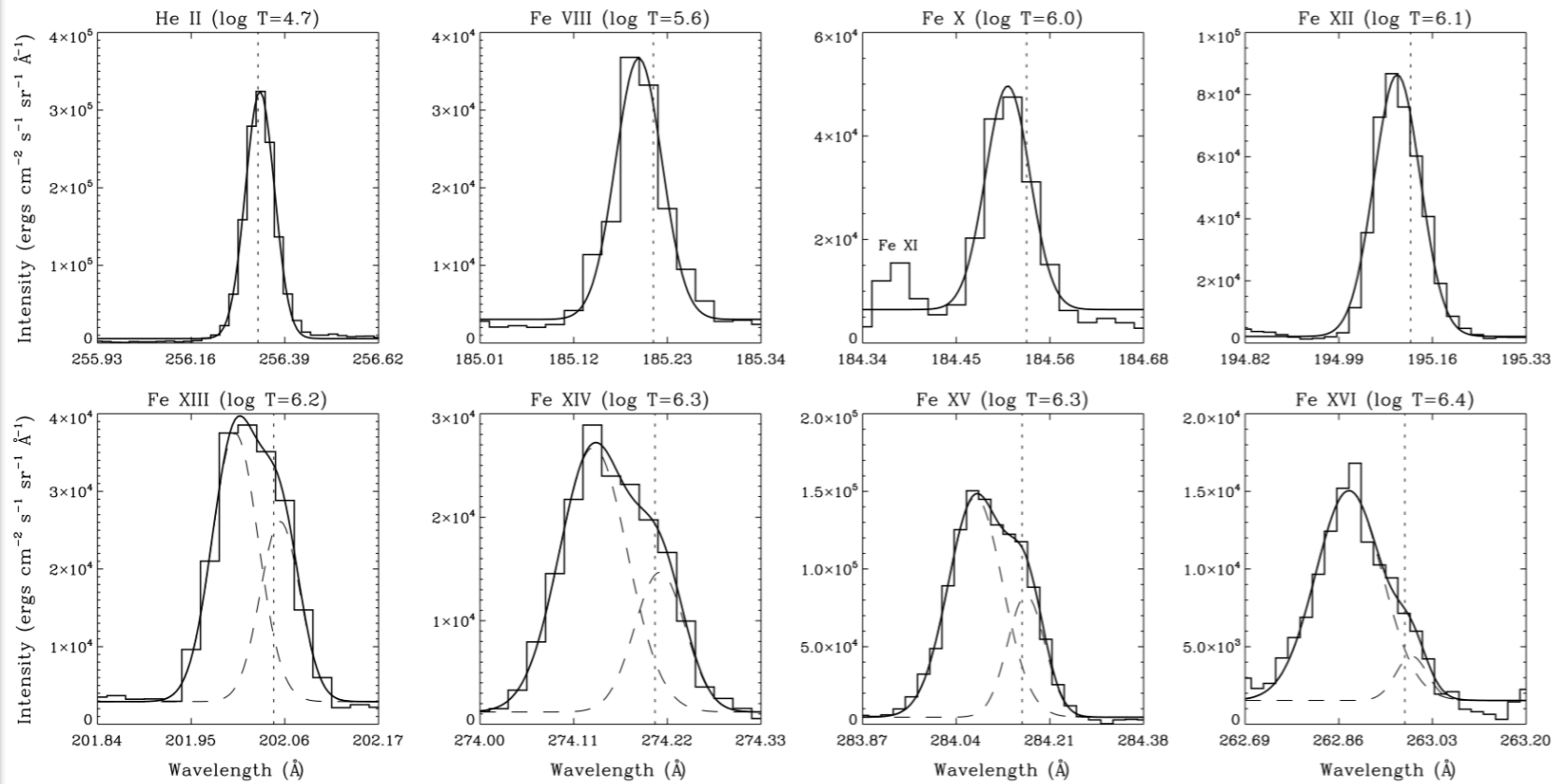


# Observations (2/2) — a C4.2 flare on 2007-01-16



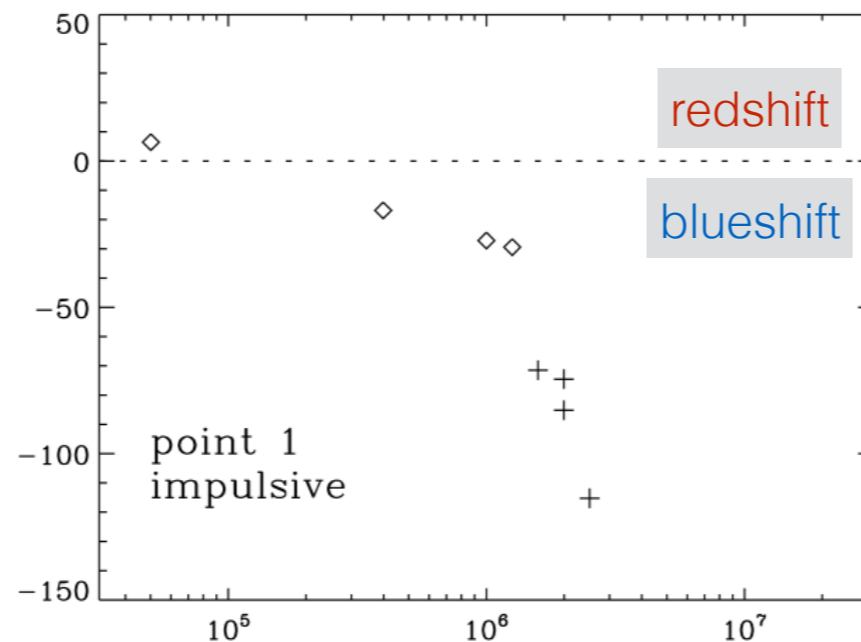
# Results (1/2) — point 1 at the positive polarity

## impulsive phase

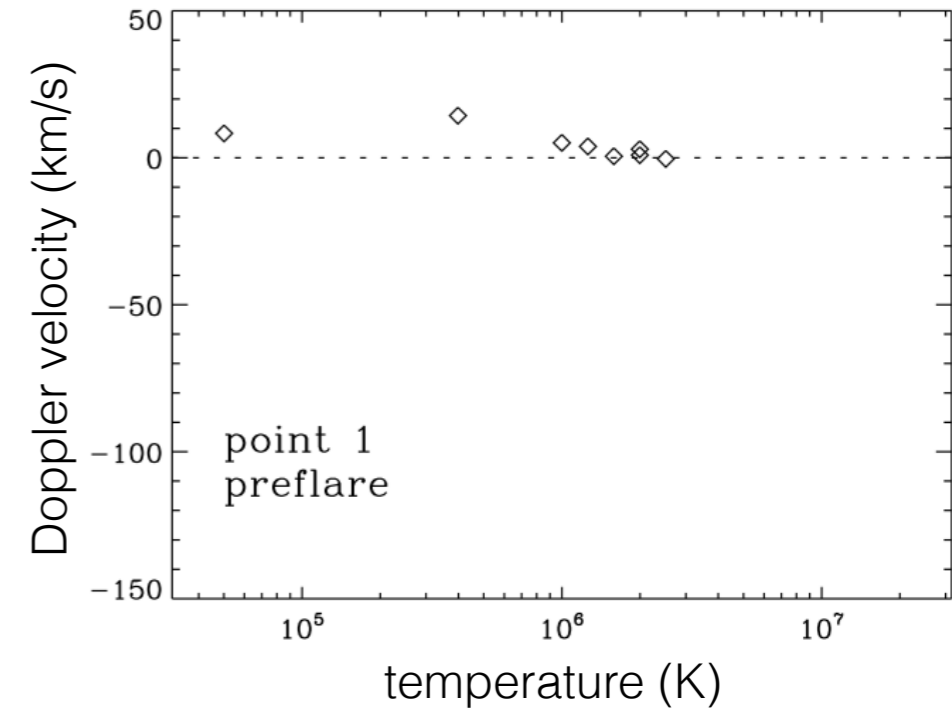


## dominant blue-components

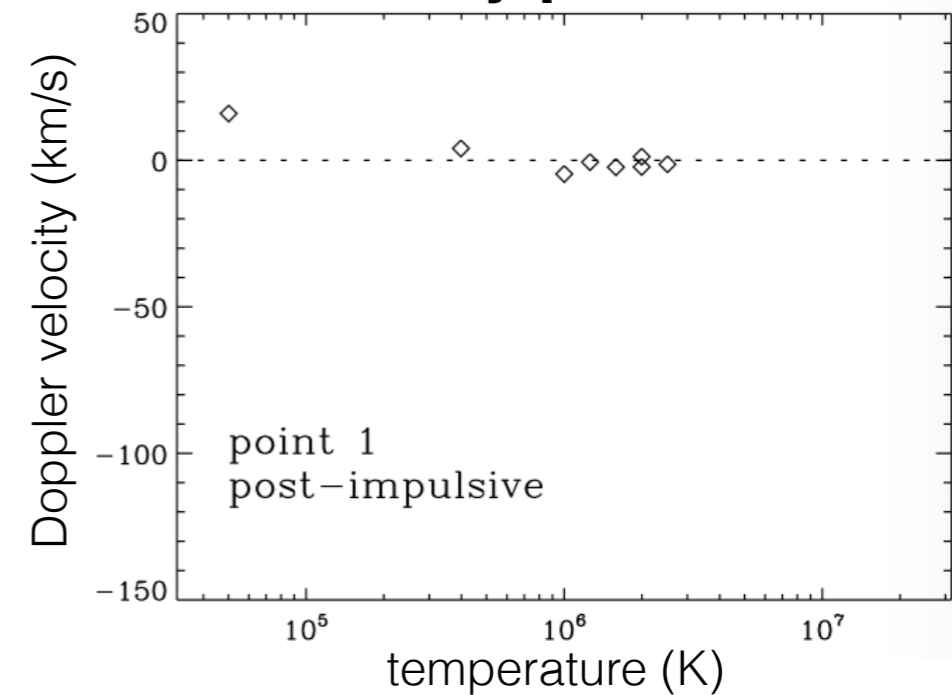
Ion	$V_d$ ( $\text{km s}^{-1}$ )	Ratio
He II	+5	
Fe VIII	-28	
Fe X	-36	
Fe XII	-37	
Fe XIII	-68	1.72
Fe XIV	-80	2.53
Fe XV	-89	2.64
Fe XVI	-116	9.95



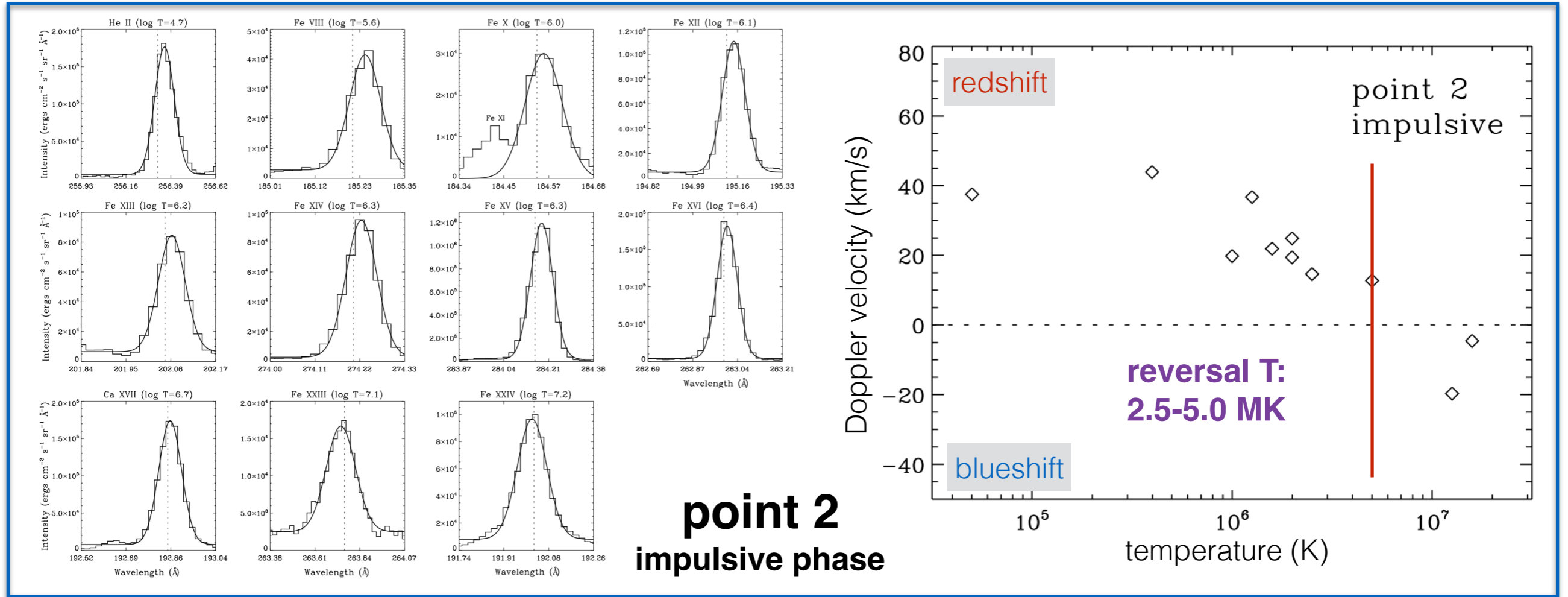
## preflare phase



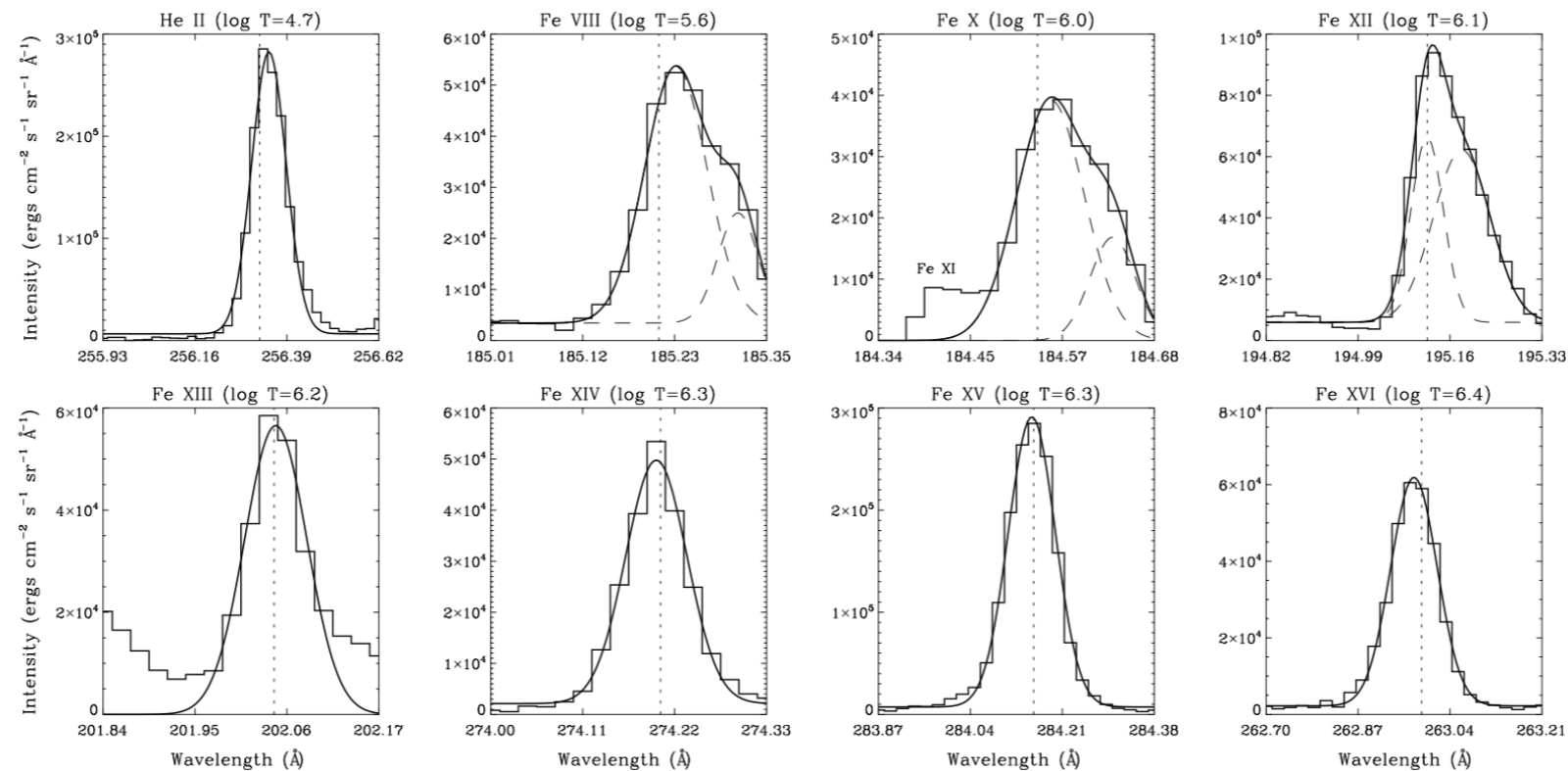
## decay phase



# Results (2/2) — points 2&3 at the negative polarity



**point 3**  
impulsive phase



# Summary — the 1st flare

(1) The line profiles at one ribbon location with positive polarity are **basically blueshifted**. — could be a gentle evaporation.

In particular, **the blueshifted components dominate over the stationary ones** in relatively hot lines. — evaporation region not well resolved?

(2) **Both blueshifts and redshifts** are observed at negative-polarity ribbons. — explosive evaporation;

Particularly, **redshifts are visible** in the lines of relatively high temperatures (**up to 2.5–5.0 MK**). — rather high energy deposition site? (or warm rain?)

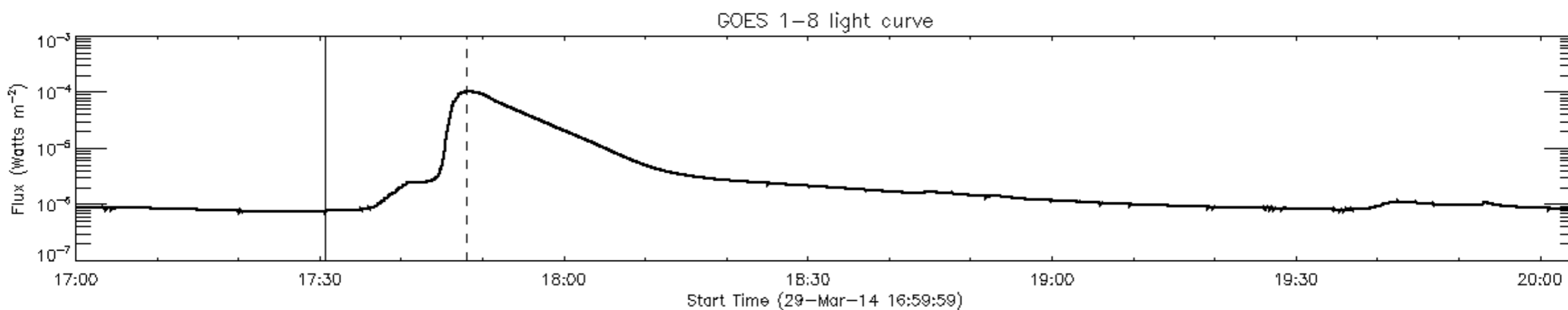
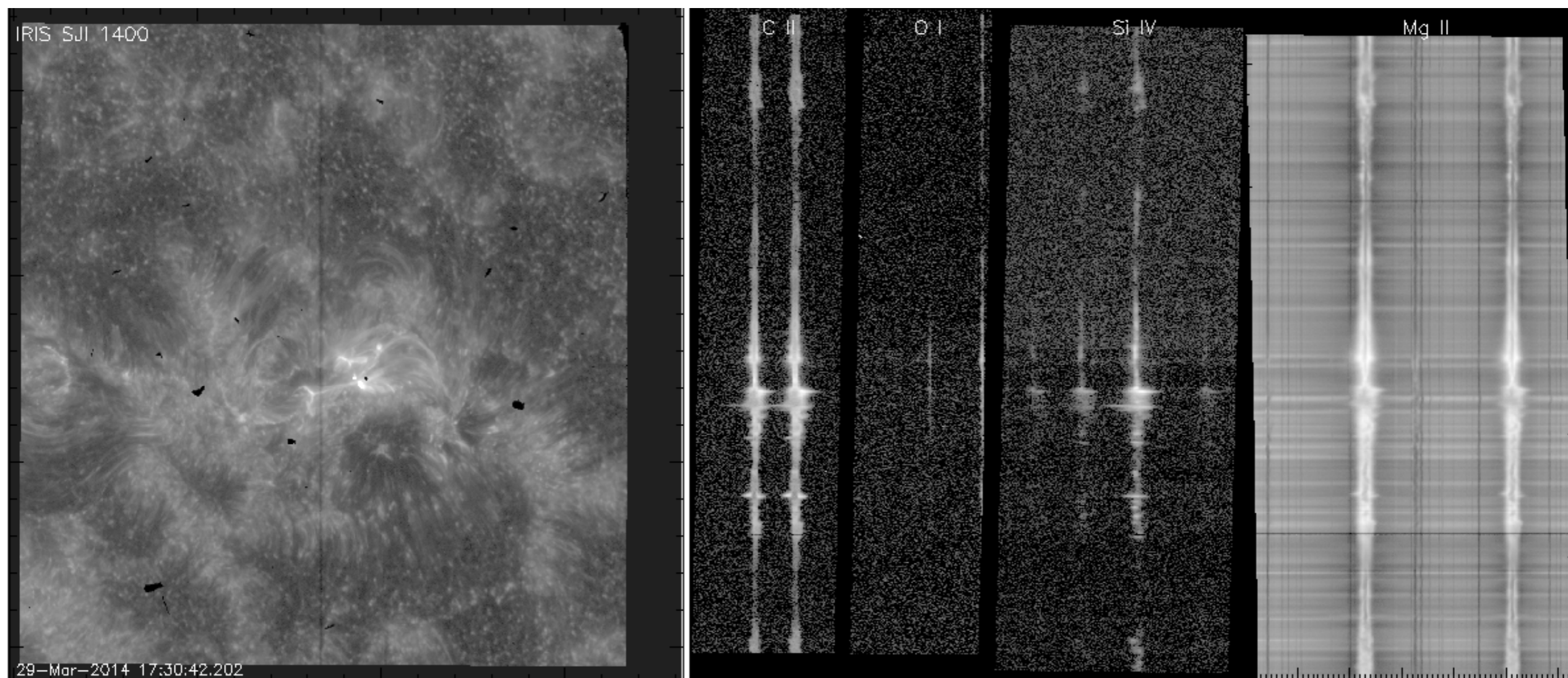
(3) Flaring ribbons with different magnetic polarities show **different types of chromospheric evaporation**.

— The heating mechanisms and atmospheric conditions may vary at different locations.

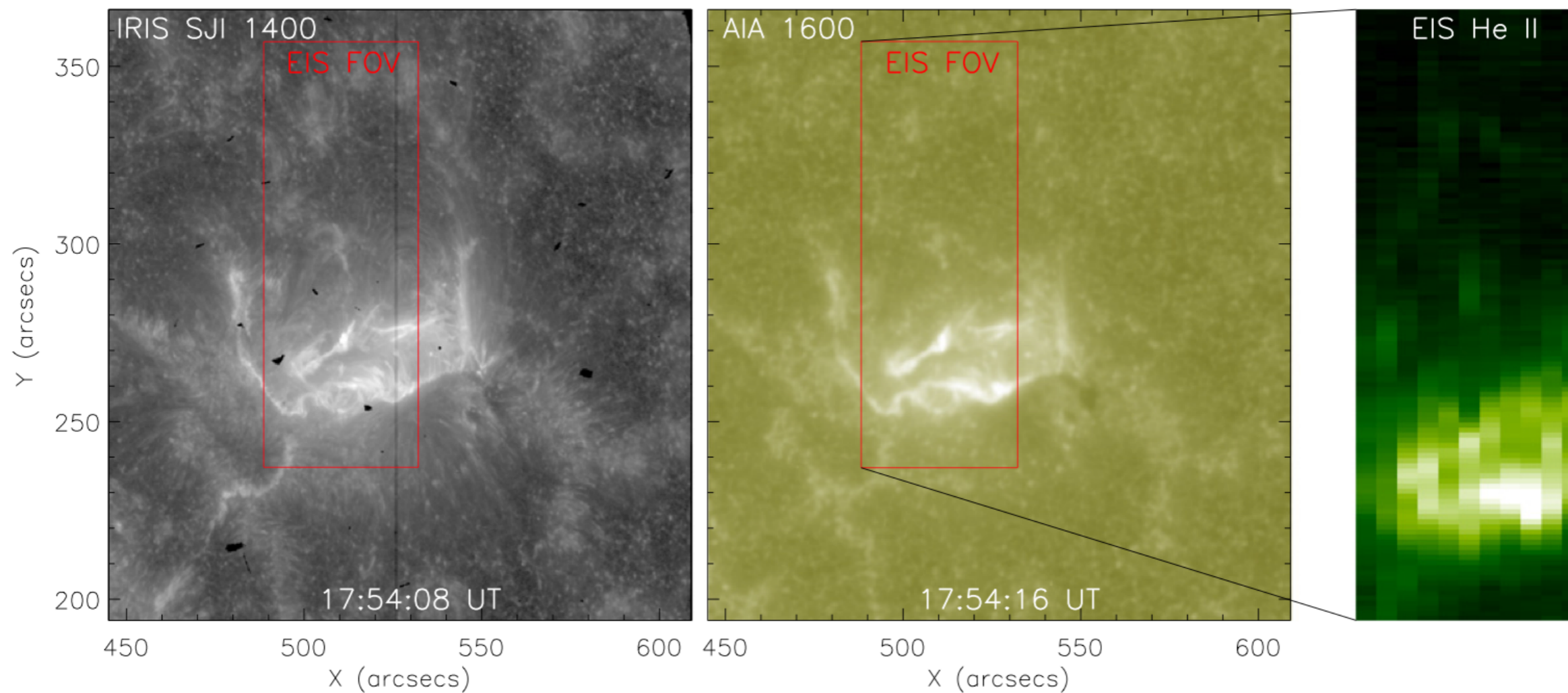
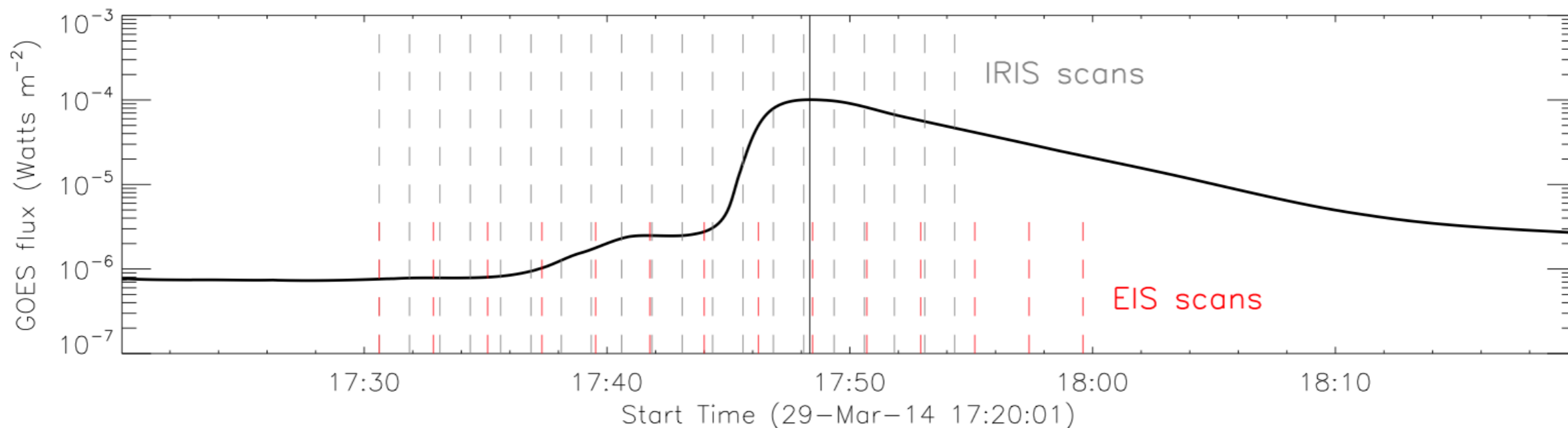
**the 2nd flare event**  
**in the IRIS era (with EIS)**

[Li et al., 2015, ApJ, 811, 7](#)

# Observations (1/2) — an X1.0 flare on 2014-03-29



# Observations (2/2) — an X1.0 flare on 2014-03-29



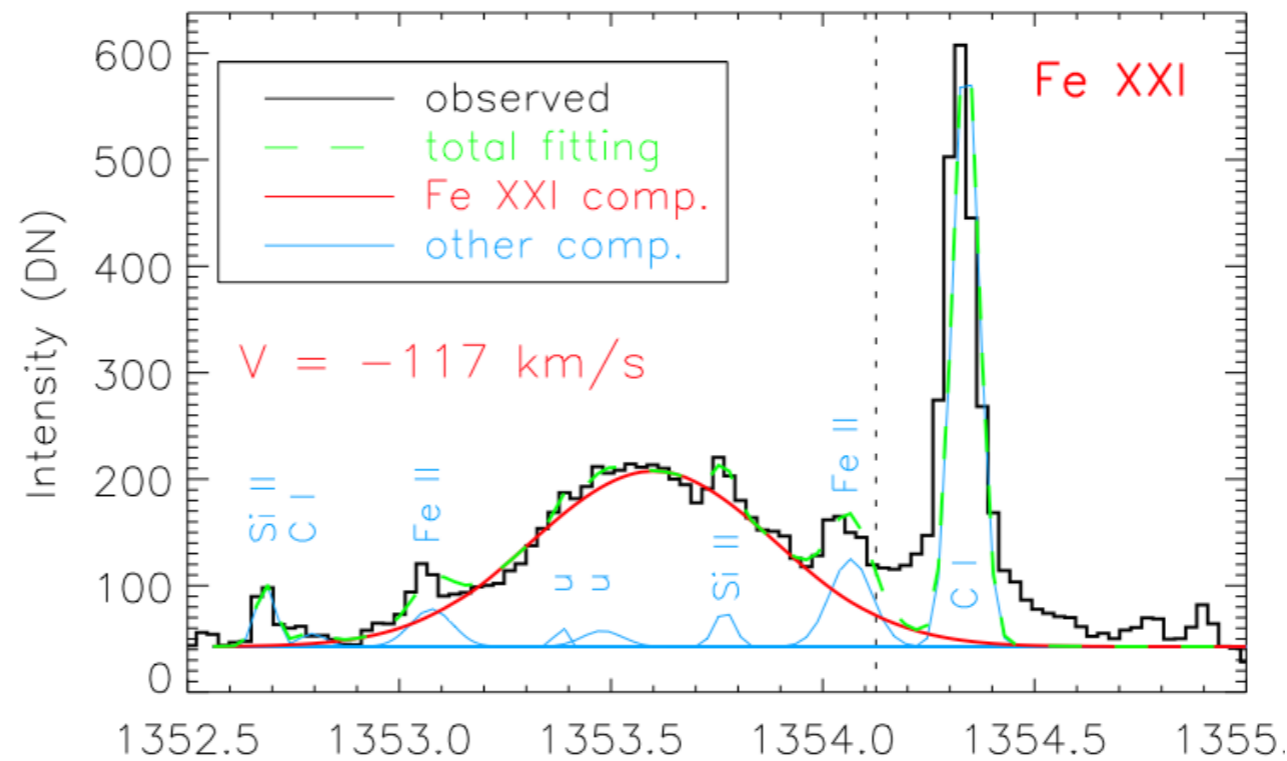


# Results (1/4) — profiles of hot ( $\geq 10$ MK) lines (IRIS vs. EIS)

at the flare ribbons

IRIS Fe XXI

quite symmetric & entirely blueshifted

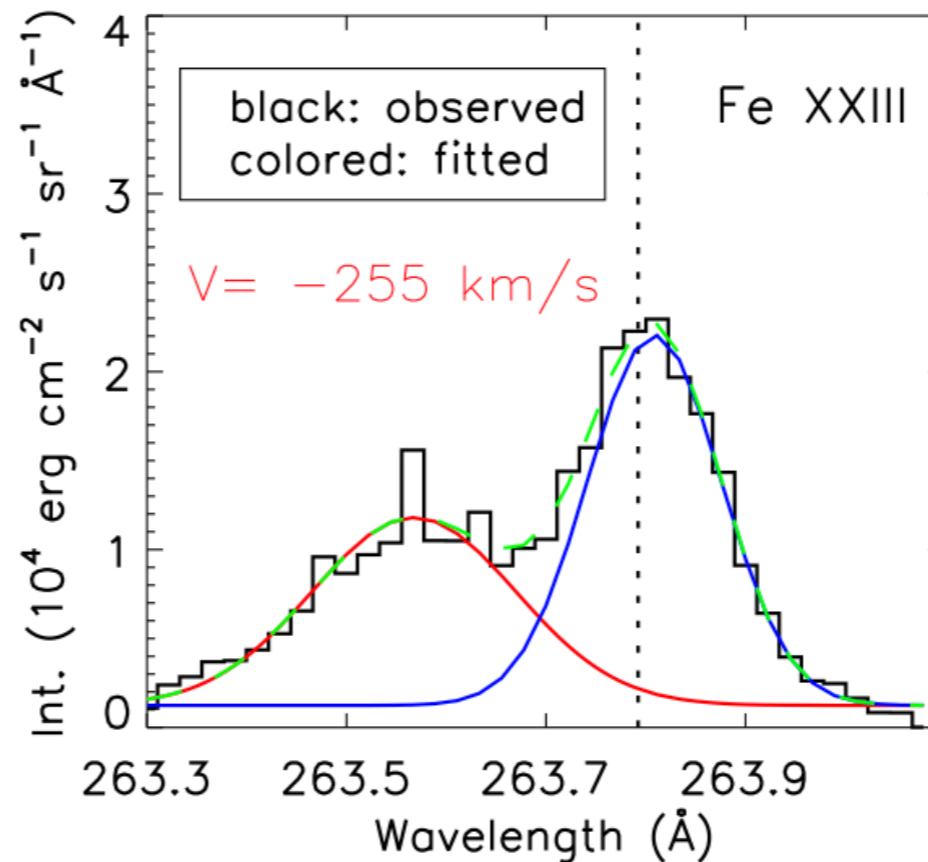


using multiple Gaussian fitting

with blending

EIS Fe XXIII

blueshifted + stationary components

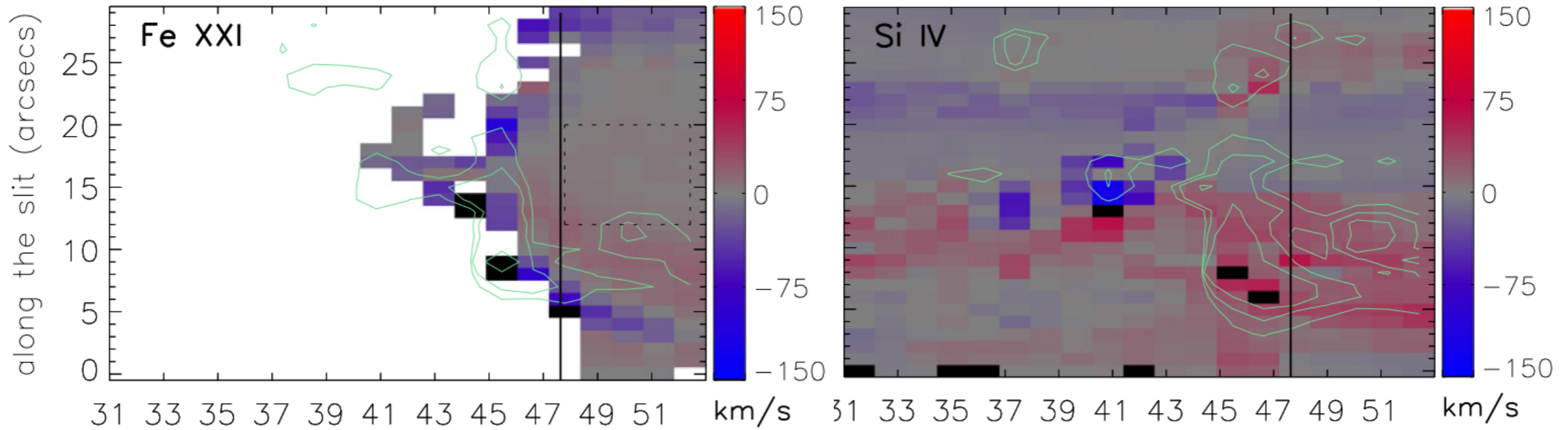


no blending

# Results (2/4) — spatio-temporal variation (IRIS vs. EIS)

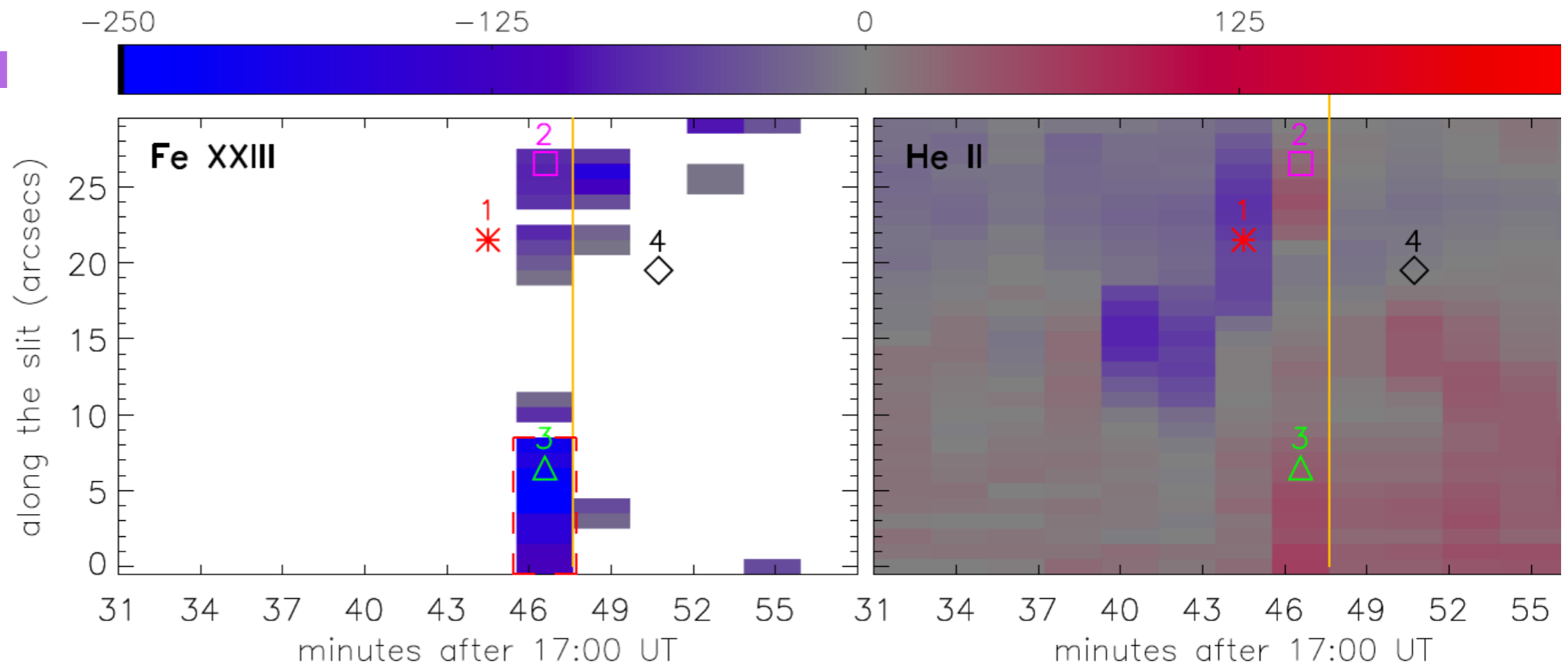
## IRIS Fe XXI & Si IV

a pair of blueshift/redshift fronts cospatial and coincident with separating ribbons



## EIS Fe XXIII & He II

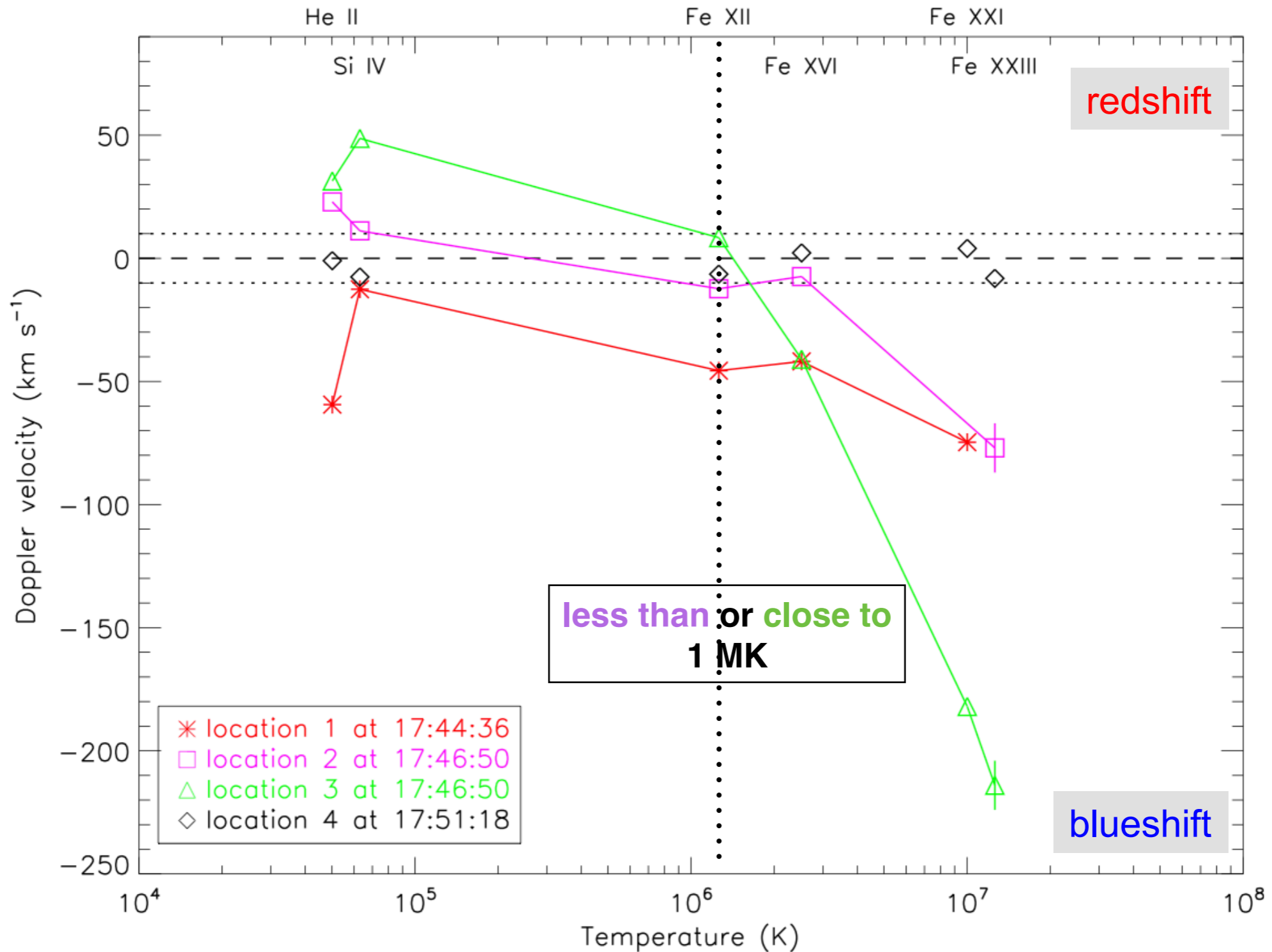
similar trend with a lower resolution



# Results (3/4) — temperature dependence (IRIS + EIS)

## IRIS & EIS multi-T lines

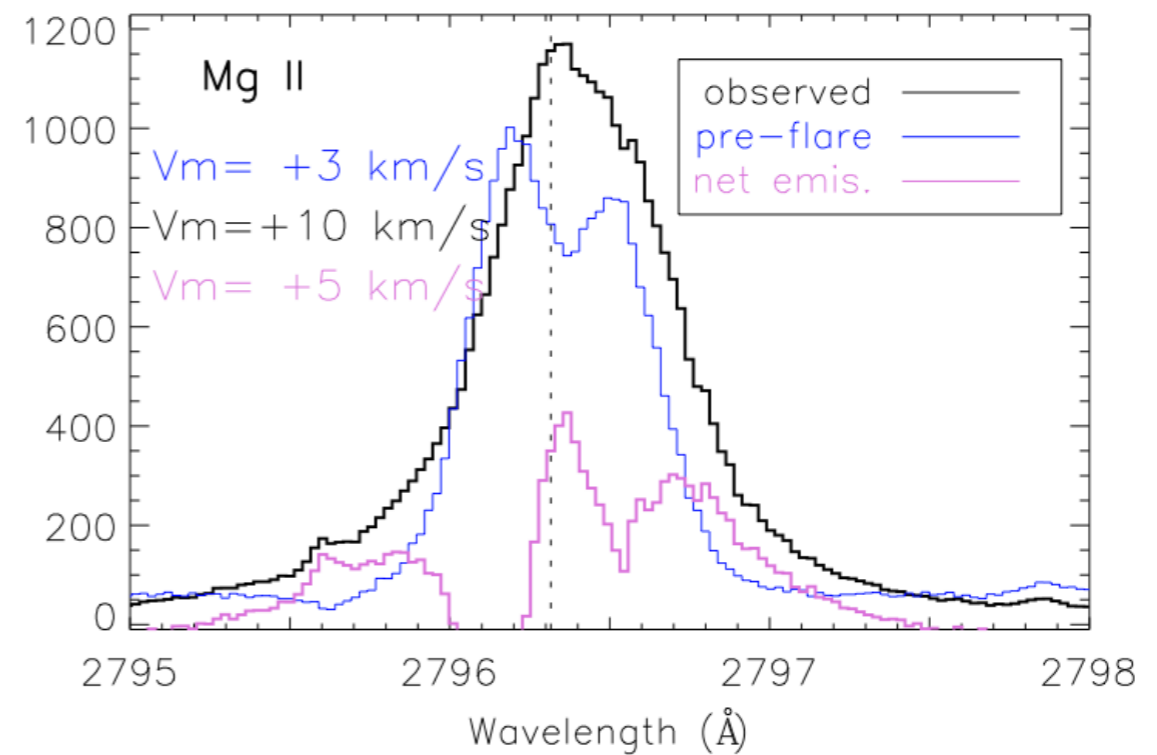
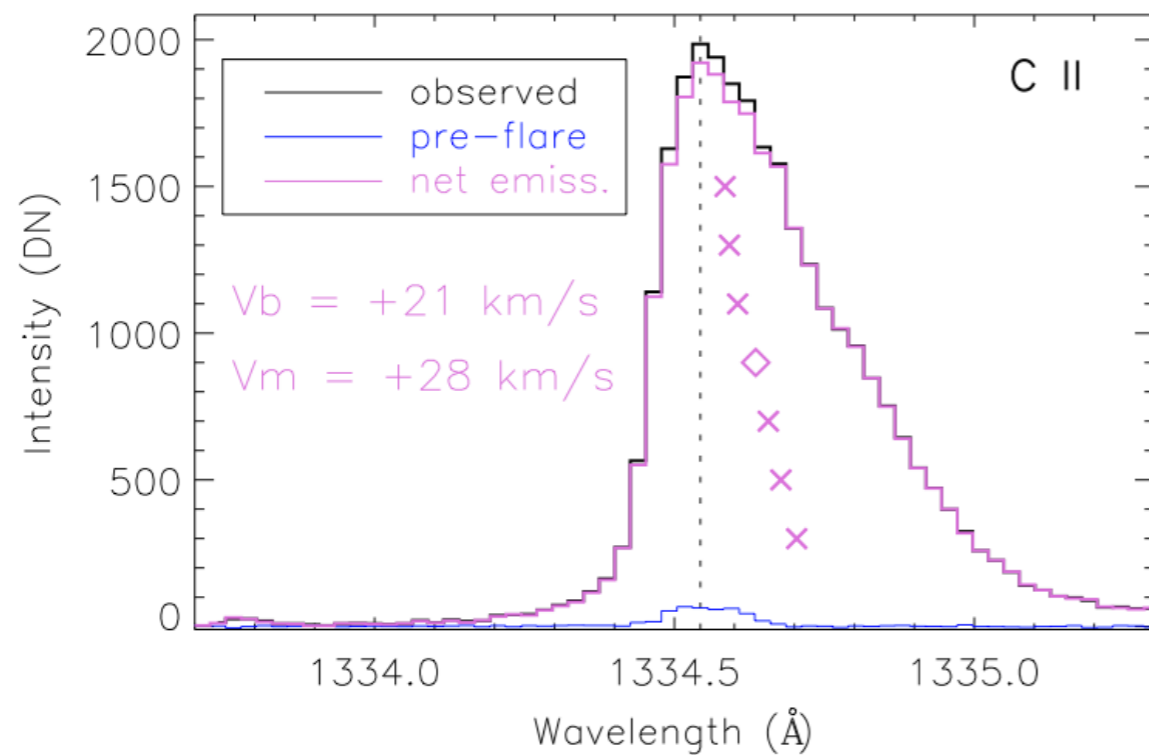
a conversion from gentle to explosive evaporation



# Results (4/4) — profiles of cool lines (from IRIS)

## IRIS C II & Mg II

singly peaked & red asymmetric at the flare ribbon



## Summary — the 2nd flare

Using the high-resolution observations from IRIS:

- (1) We find that **the hot Fe XXI line (~10 MK) is entirely blueshifted** at the flare ribbon, which **well matches the prediction of evaporation model**.
- (2) **The blueshifts are cospatial and coincident with separating ribbons**, suggesting that reconnection/evaporation proceeds well into the decay phase of the flare.
- (3) Different ribbon locations show **different types of evaporation**, and there is **a conversion from gentle to explosive evaporation** as flare evolves.

# Summary for the two flare events

chromospheric evaporation & condensation  
 – *dynamics at the flare ribbons*

event	GOES class	evaporation type	blueshifts (hot lines)	redshifts (cool lines)	flow reversal temperature
1st flare in EIS era	C4.2	gentle & explosive (x)	dominant components (e.g., Fe XXIII)	entirely redshifted (e.g., He II)	2.5–5.0 or ~1 MK
2nd flare in IRIS era	X1.0	gentle & explosive (x, t)	<b>entirely blueshifted (Fe XXI)</b>	red asymmetry (C II & Mg II)	~1 MK

still going on?



also reported by many other nice studies...

# Perspectives in Diagnosing Chromospheric Evaporation (“pros and cons” of EIS & IRIS)

## EIS

**con:** relatively low spatial resolution

**pro:** multiple spectral lines covering a wide T range

—> temperature dependence (energy deposition site)

## IRIS

**con:** few hot spectral lines

**pro:** multiple cool lines (formed in the chromosphere)  
in particular, high spatial and temporal resolution

—> spatio-temporal variation & chromospheric condensation

## EIS + IRIS + modeling

—> help study **flare dynamics** and further  
**flare heating** (function, mechanisms,...)

*Thanks for your attention!*