



# **Different Signatures of Chromospheric Evaporation in Two Solar Flares *Observed with IRIS***

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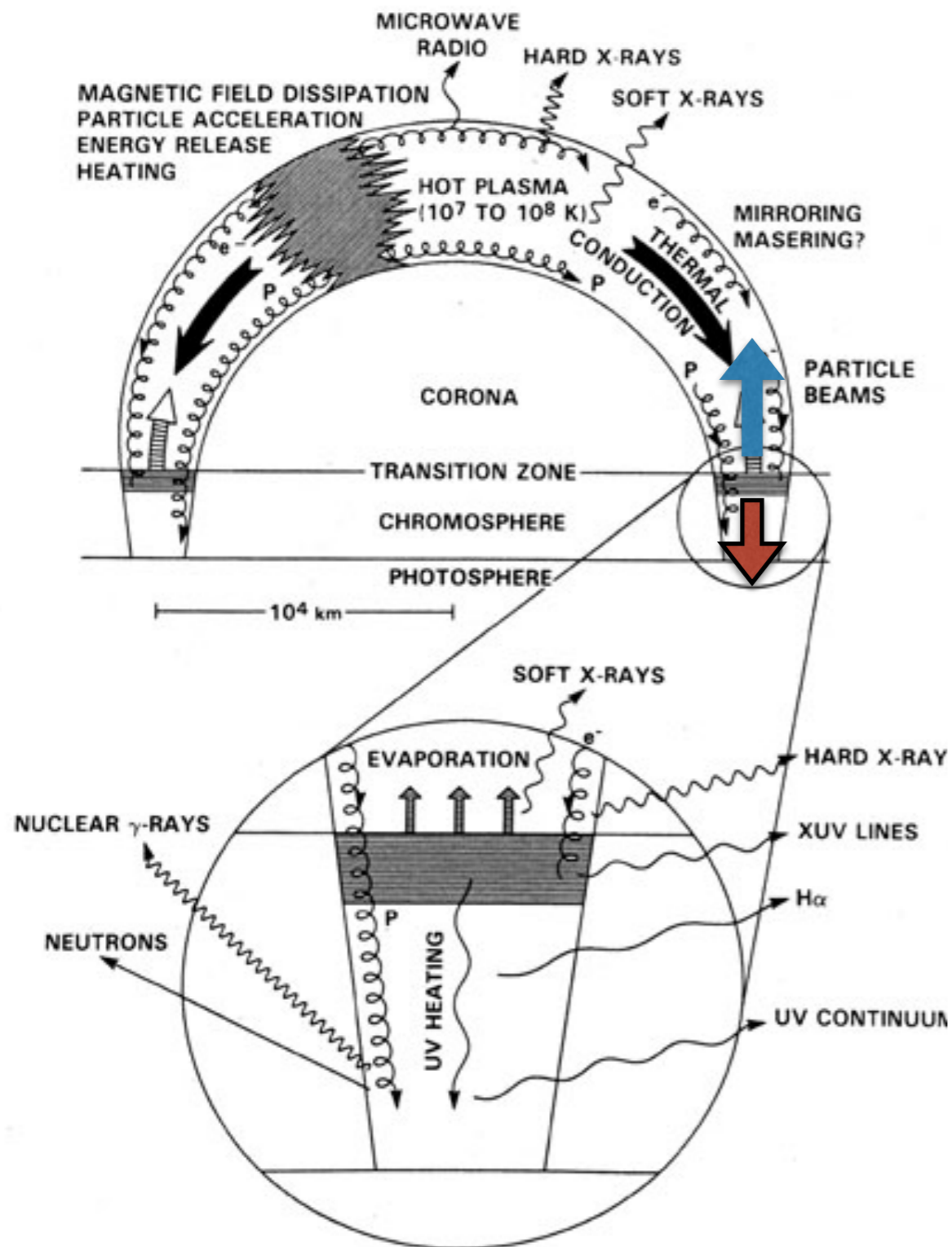
**November 7, 2019**

# Background

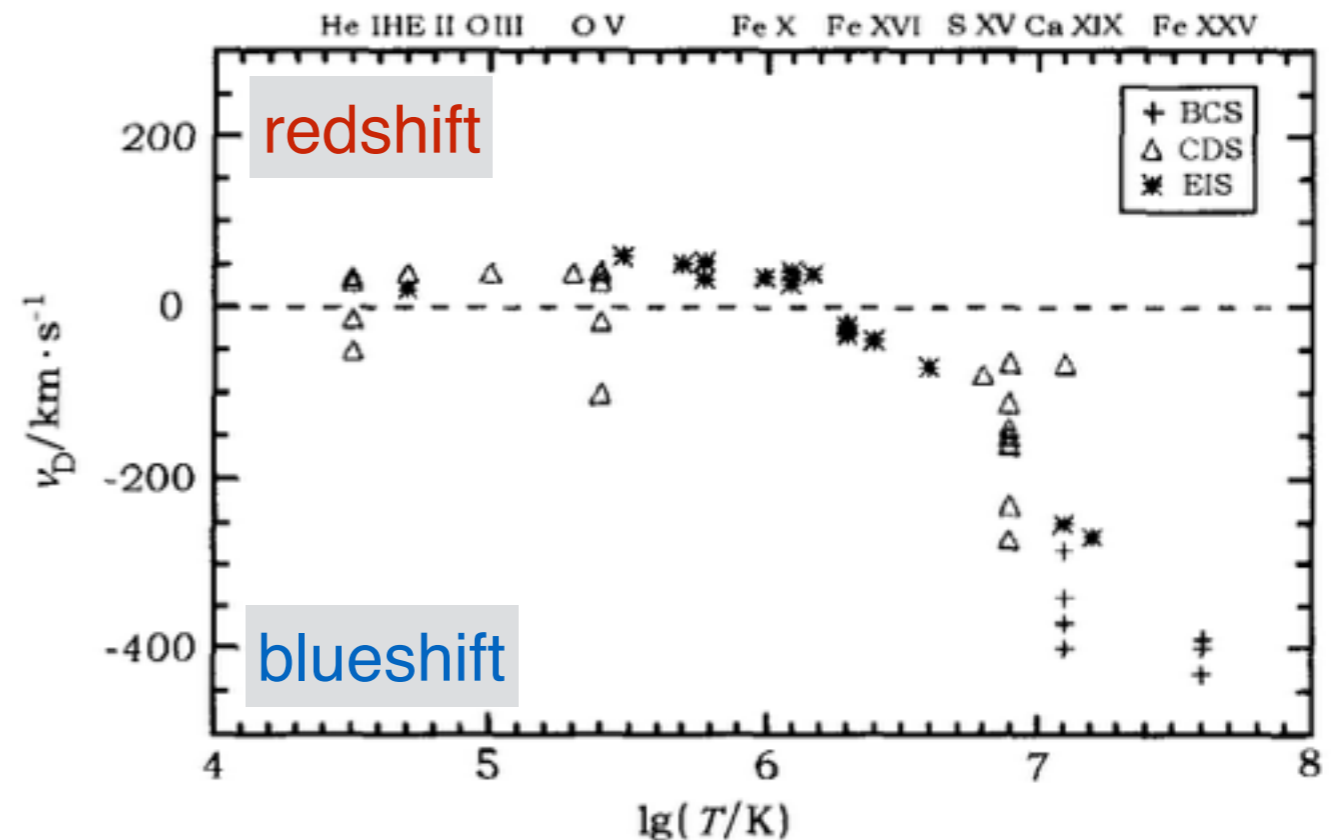
## Chromospheric evaporation

- **upward mass motions** at flare ribbons due to thermal pressure  
(Feldman et al. 1980; Antonucci 1982; Schmieder et al. 1990; Doschek et al. 2013; ...)
- also **downward motions** (condensation) conservation of momentum  
(Canfield et al. 1990; Fisher et al. 1985; ...)

in observations (in pre-IRIS era)



(Dennis & Schwartz 1989)



# Background

## Two types of evaporation

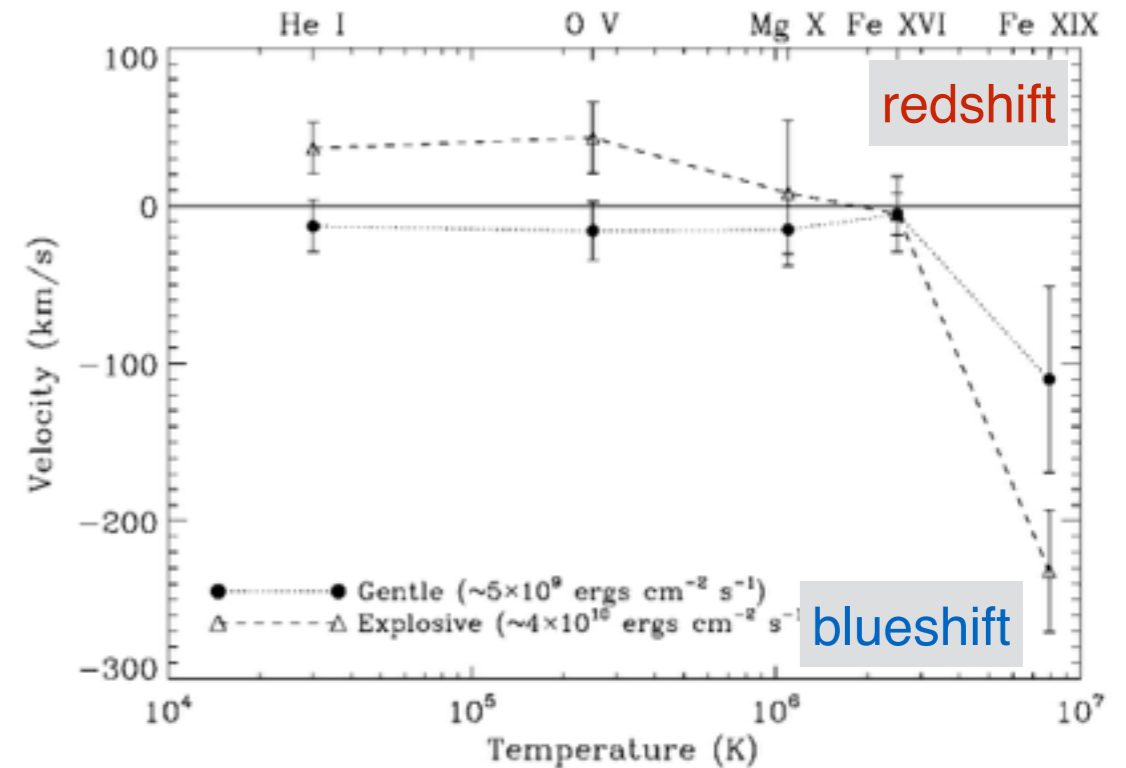
(Fisher et al. 1985a,b,c)

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

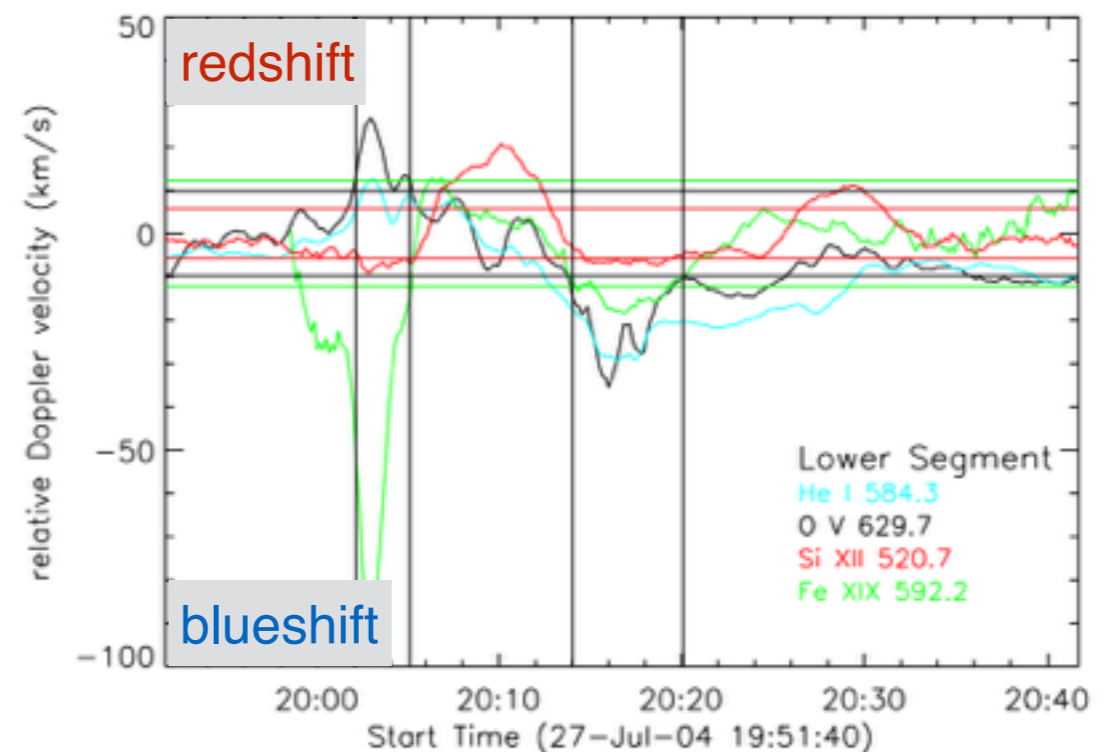
**threshold** of electron flux

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

**Conversion from explosive to gentle evaporation**



(Milligan et al. 2006a,b)



(Brosius 2009)

# Background

in IRIS era

wholly blueshifted  
Fe XXI line profile  
(well consistent with  
theoretical models)

explosive evaporation  
observed in general  
(gentle evaporation  
rarely reported)

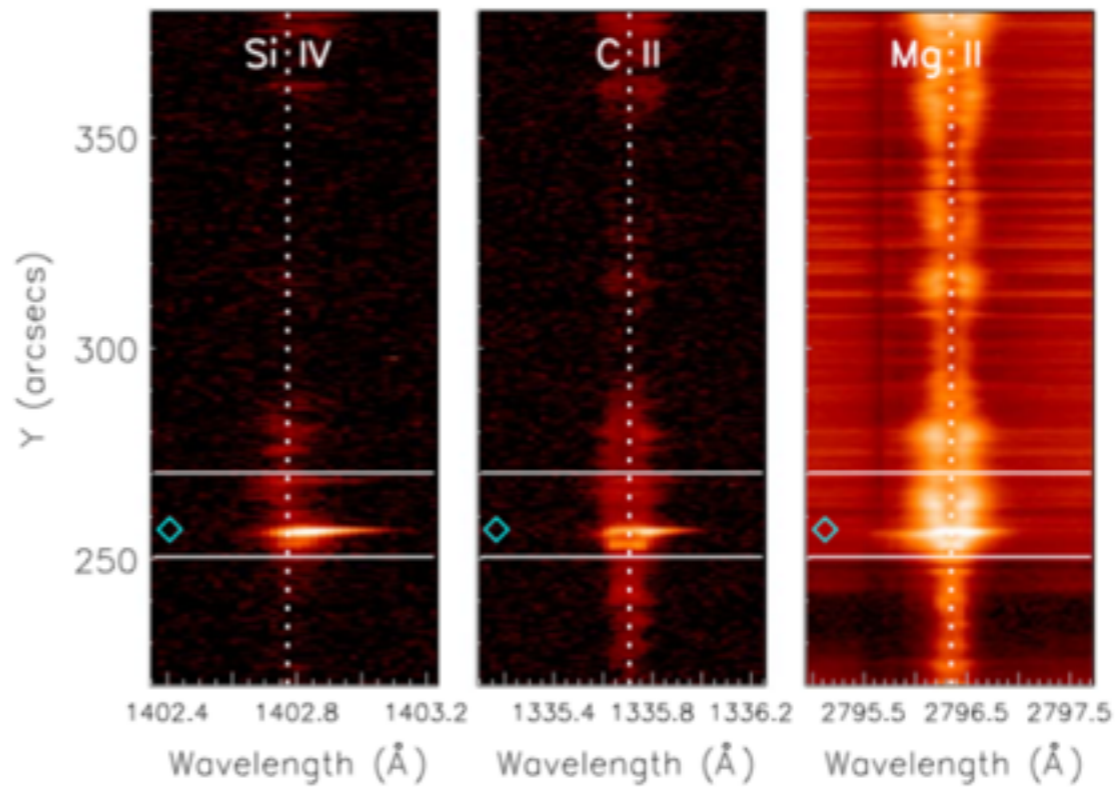
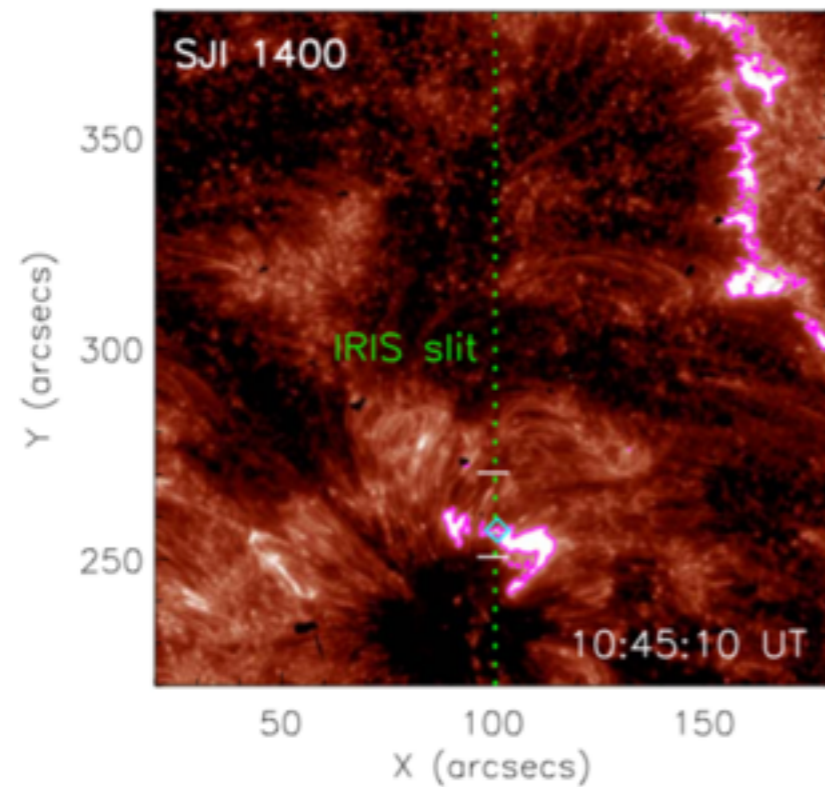
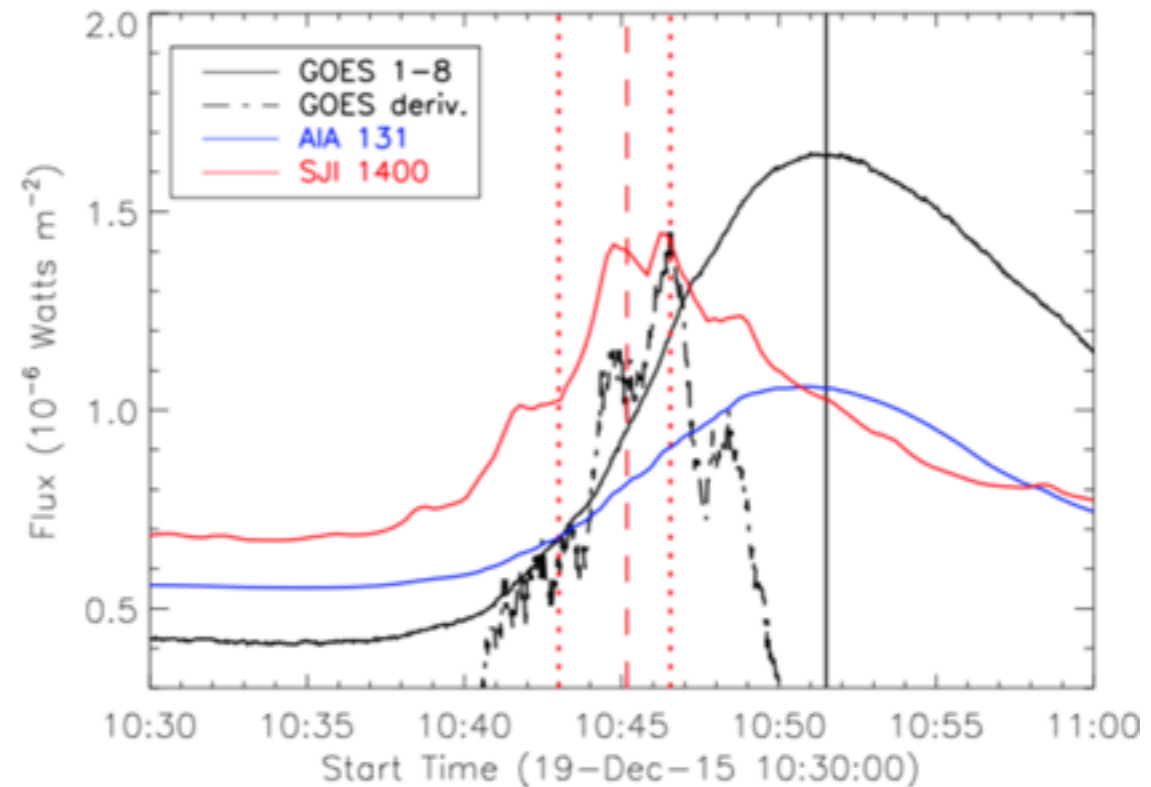
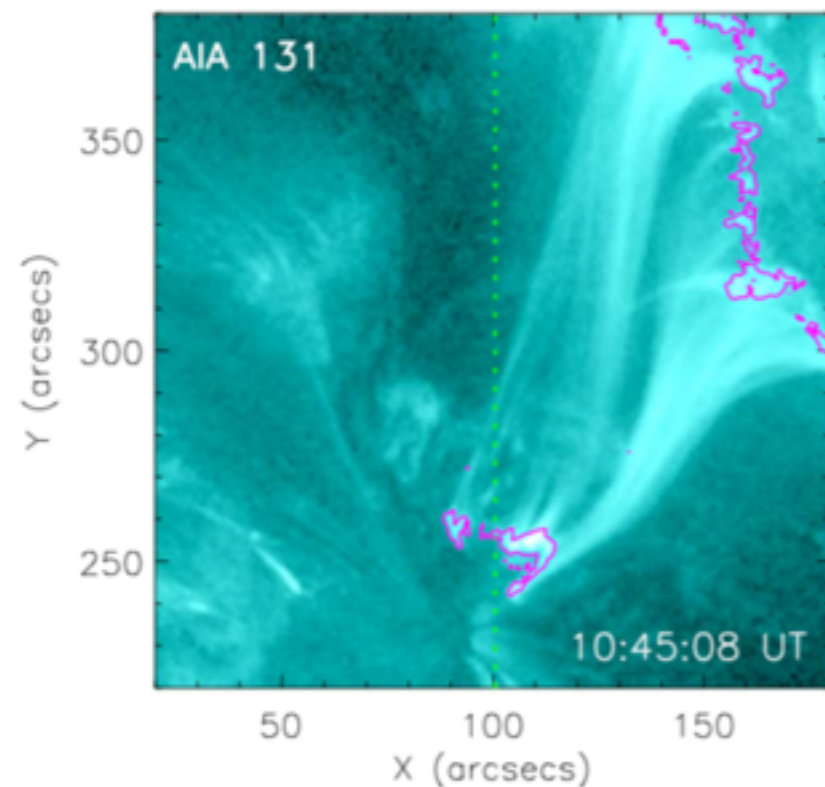
line Profiles of  
Si IV, C II, Mg II  
(heating information?)

Flare Class	Date	Cadence (s)	Blueshifts (Evaporation)	Redshifts (Condensation)	References
C1.6	2014-04-19	31	Fe XXI	Si IV, C II, Mg II	Tian et al. (2014)
C1.9	2014-11-19	9.5	-	Si IV, C II, Mg II	Warren et al. (2016)
C3.1	2014-03-15	16.5	Fe XXI	Si IV, C II	Brosius & Inglis (2017)
C3.1	2015-10-16	6	-	Si IV	Zhang et al. (2016b)
C4.2	2015-10-16	9.4	Fe XXI	Si IV	Zhang et al. (2016a)
C6.5	2014-02-03	75	Fe XXI	-	Polito et al. (2015)
M1.0	2014-06-12	21	Fe XXI	C II	Sadykov et al. (2015, 2016)
M1.1	2014-09-06	9.5	Fe XXI	Si IV	Tian et al. (2015)
M1.6	2015-03-12	5.2	Fe XXI	Si IV, Mg II	Tian & Chen (2018)
			Fe XXI	Si IV	Brannon (2016)
M1.8	2014-02-13	42	-	Mg II	Kerr et al. (2015)
M2.3	2014-11-09	37	Fe XXI	Si IV, C II, Mg II	Li et al. (2017b)
M3.7	2017-09-09	9.4	Fe XXI	Si IV, C II, Mg II	Brosius & Inglis (2018)
M7.1	2014-10-27	16.2	Fe XXI	Si IV	Li et al. (2017a, 2018)
M7.3	2014-04-18	9.4	Fe XXI	Si IV, O IV, C I	Brosius & Daw (2015)
			-	Si IV	Brannon et al. (2015)
X1.0	2014-03-29	75	Fe XXI	Si IV, C II, Mg II	Battaglia et al. (2015)
			Fe XXI	Si IV, C II, Mg II	Li et al. (2015b)
			Fe XXI	-	Young et al. (2015)
			-	Fe II	Kowalski et al. (2017)
X1.6	2014-09-10	9.4	Fe XXI	Si IV	Tian et al. (2015)
			Fe XXI	Mg II	Graham & Cauzzi (2015)
			Fe XXI	-	Dudík et al. (2016)
			Fe XXI	C I	Li et al. (2015a)
X1.6	2014-10-22	131	Fe XXI	C I	Li et al. (2015a)
			Fe XXI	Si IV	Lee et al. (2017)
X2.0	2014-10-27	26	Fe XXI	Si IV	Polito et al. (2016)

## IN OUR WORK

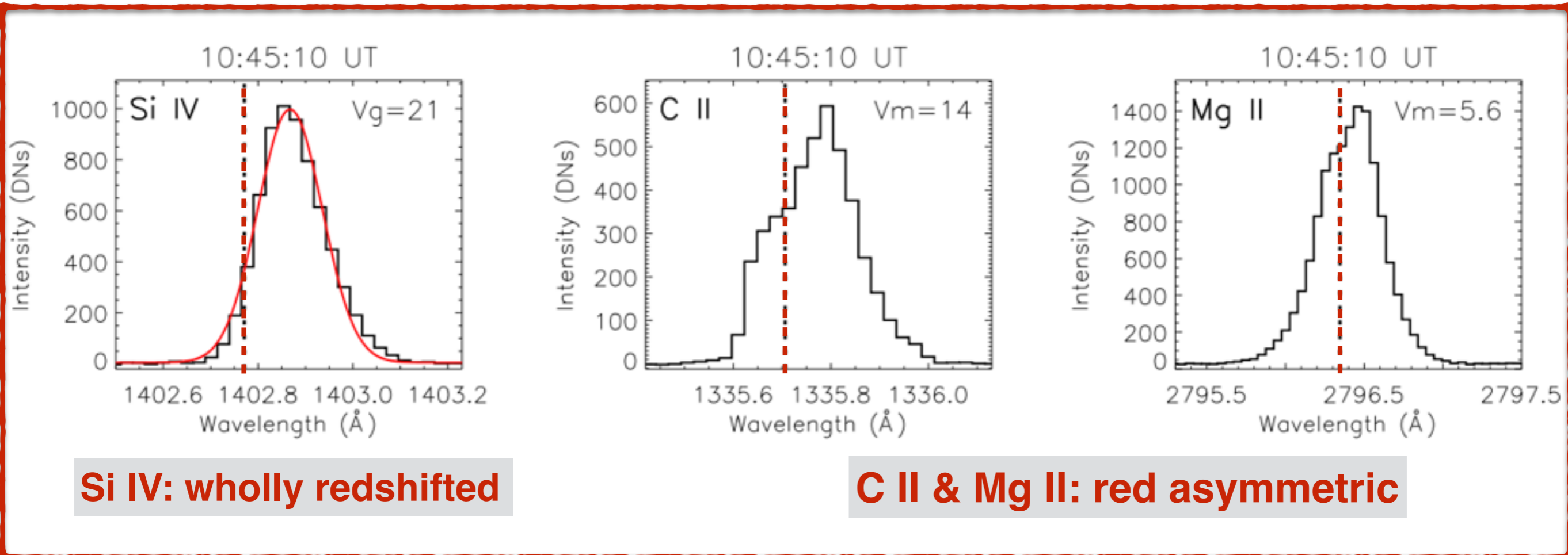
- study two flare events: a C1.6 & a B1.6
- focus on: the cool Si IV, C II, Mg II lines at flare ribbons
- method: single Gaussian fitting for Si IV  
moment analysis on C II & Mg II

# Observations — a C1.6 flare on 2015-12-19



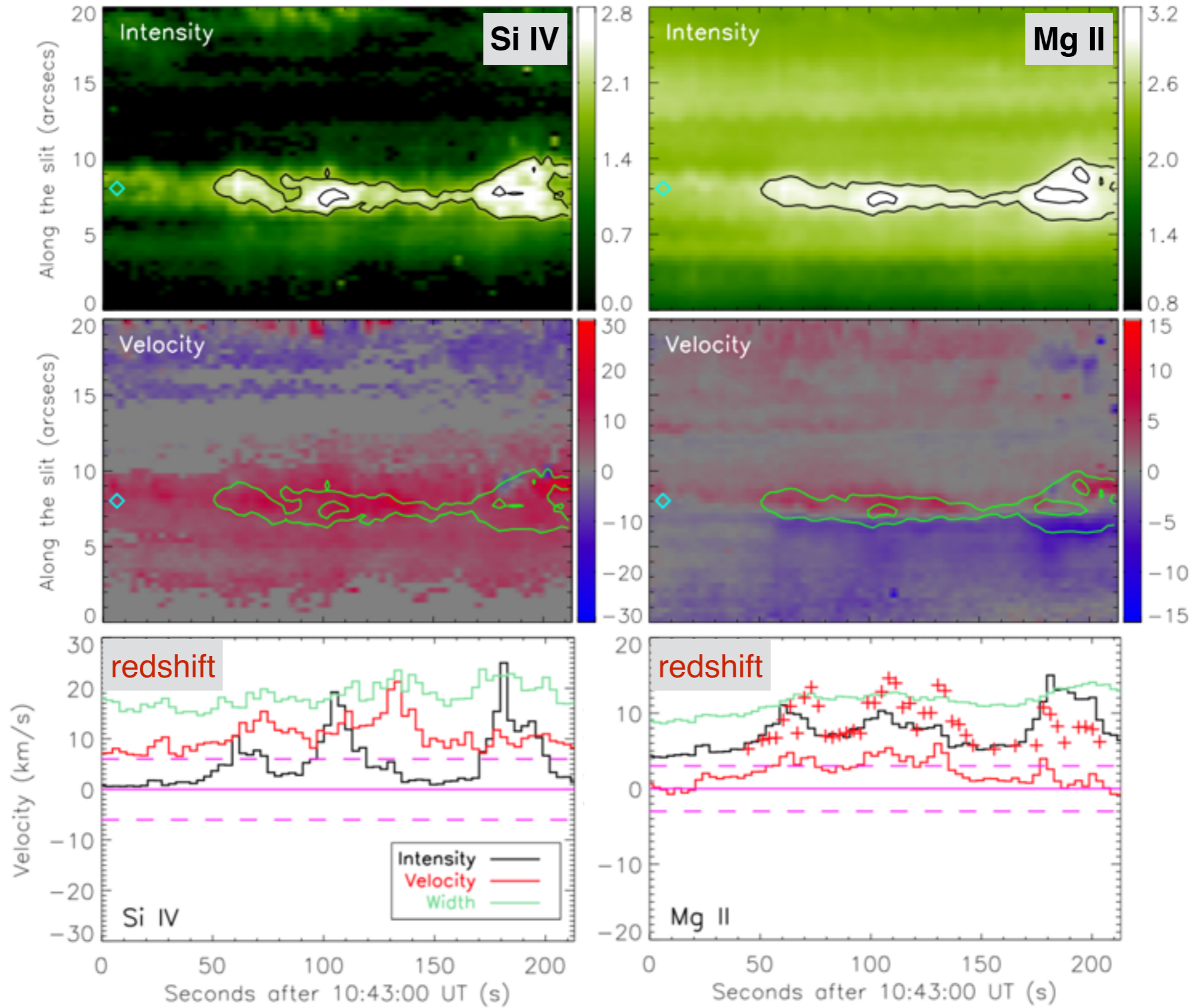
**IRIS slit cuts across one of the flare ribbons, where all the cool lines show redshifts.**

# Results — typical line profiles at the ribbon (C1.6 flare)



signatures of chromospheric condensation, or explosive evaporation

# Results — evolution of line intensity & Doppler velocity

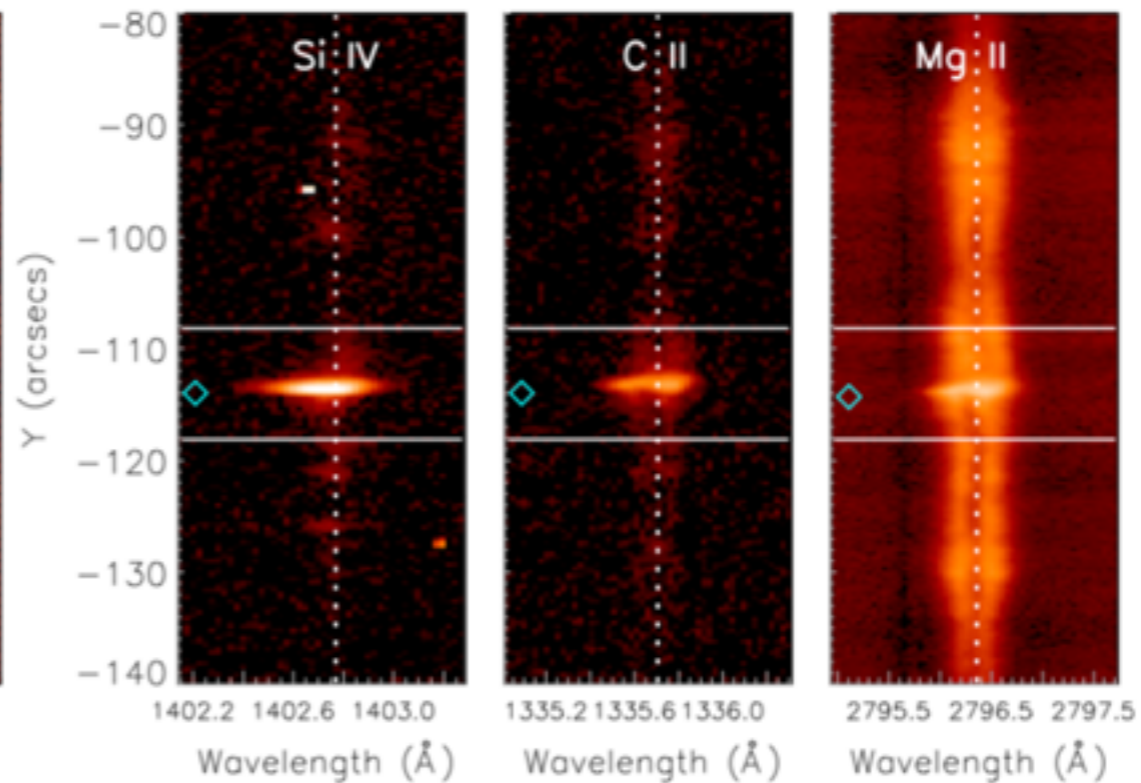
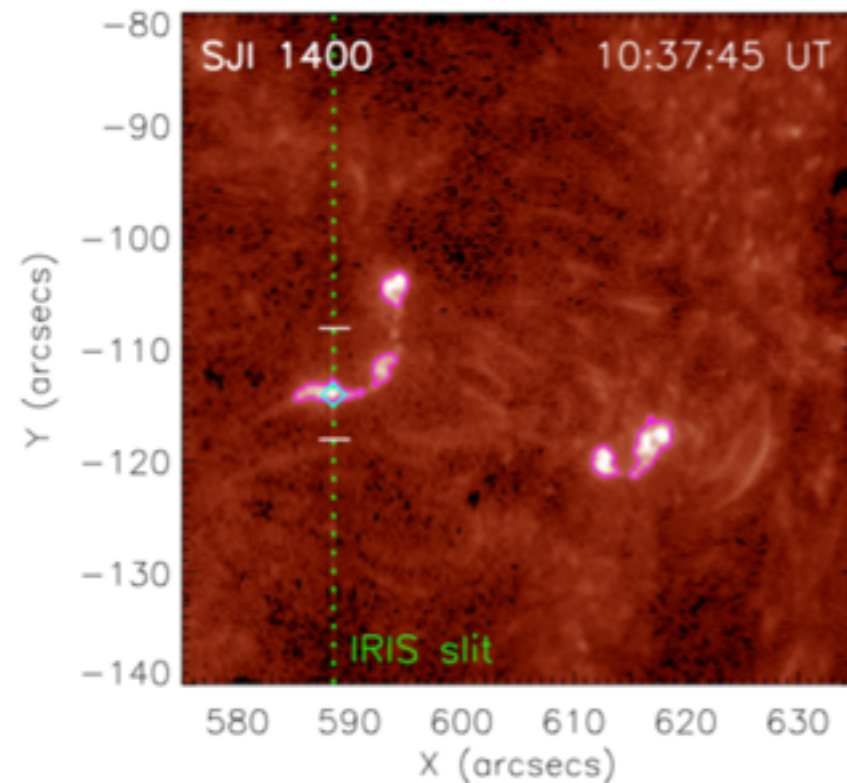
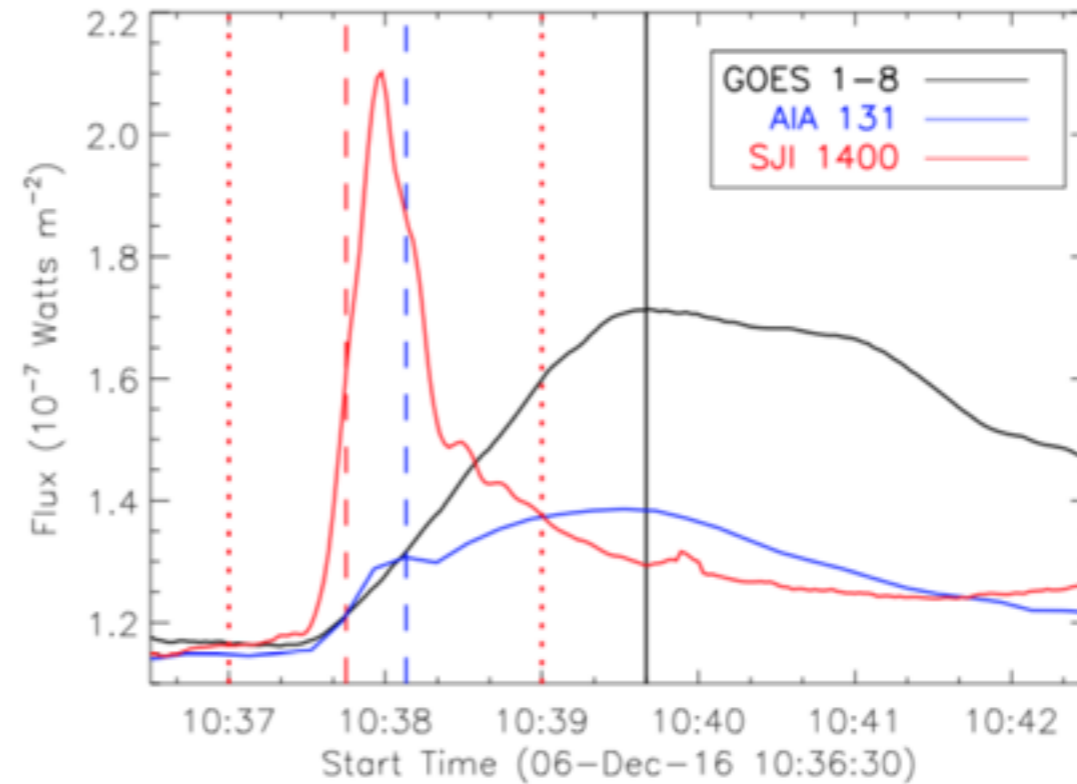
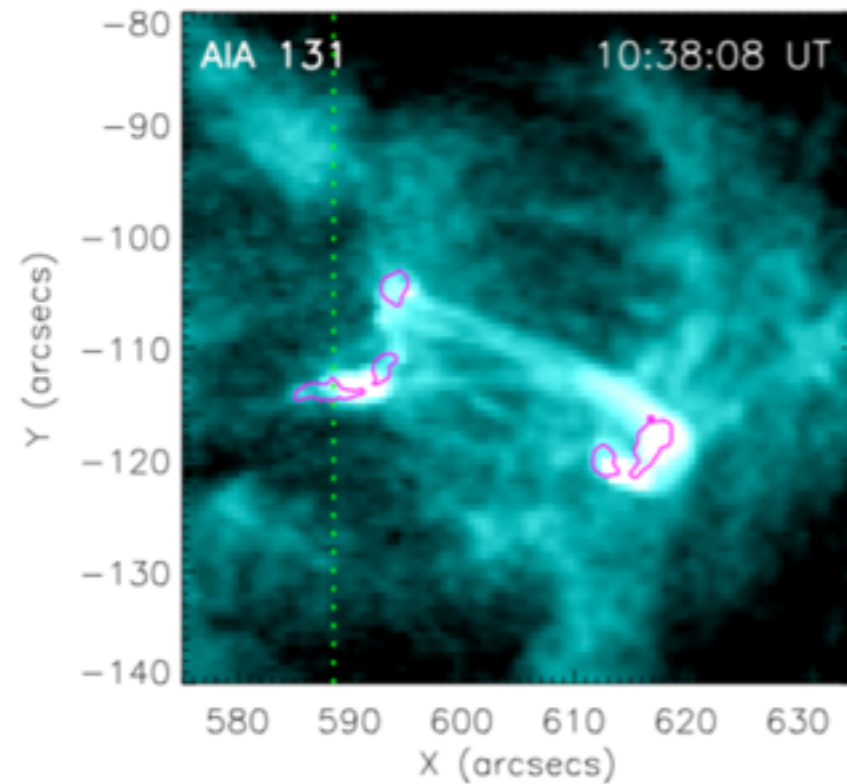


**multiepisode explosive evaporation in the C1.6 flare**



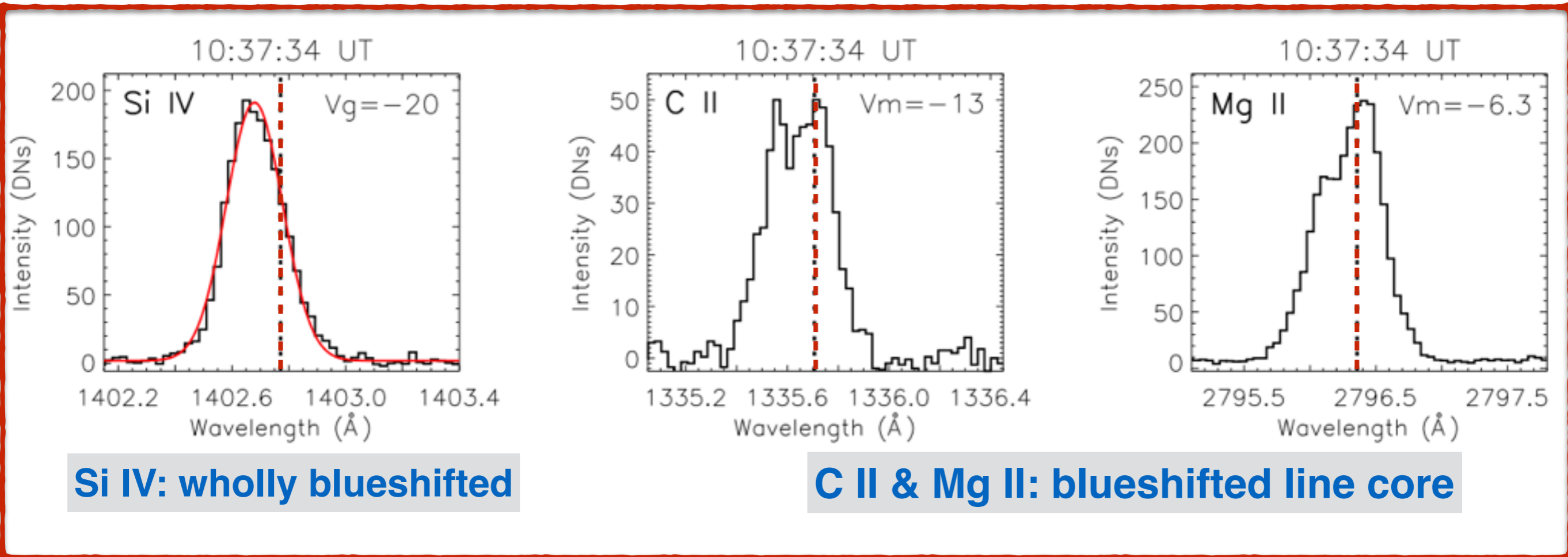
# Observations — a B1.6 flare on 2016-12-06

(also analyzed by Jeffrey et al. 2018)



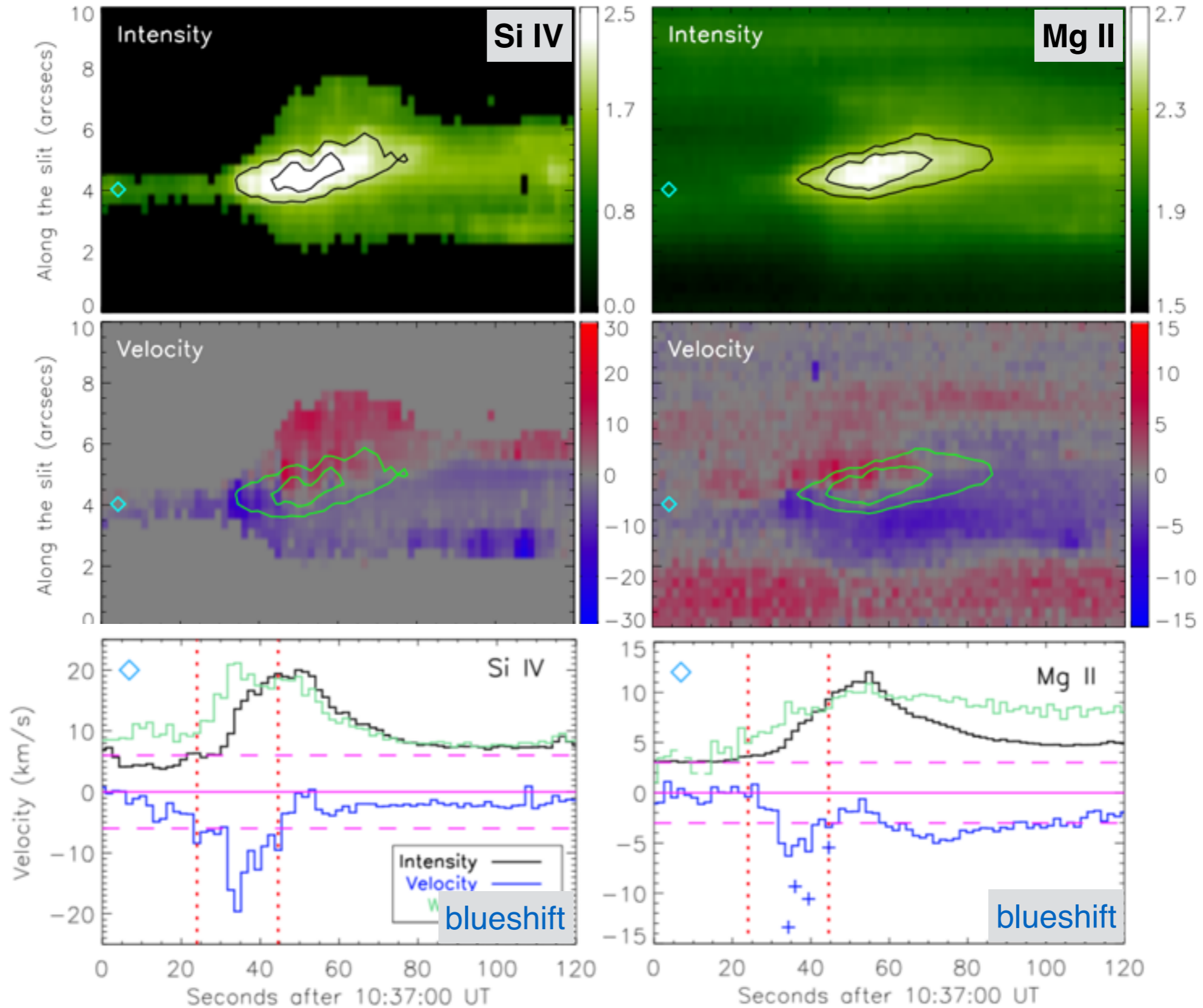
IRIS slit cuts across one of the flare ribbons, where all the cool lines show blueshifts.

# Results — typical line profiles at the ribbon (B1.6 flare)



Quite different from the line profiles in the C1.6 flares!  
signatures of chromospheric evaporation

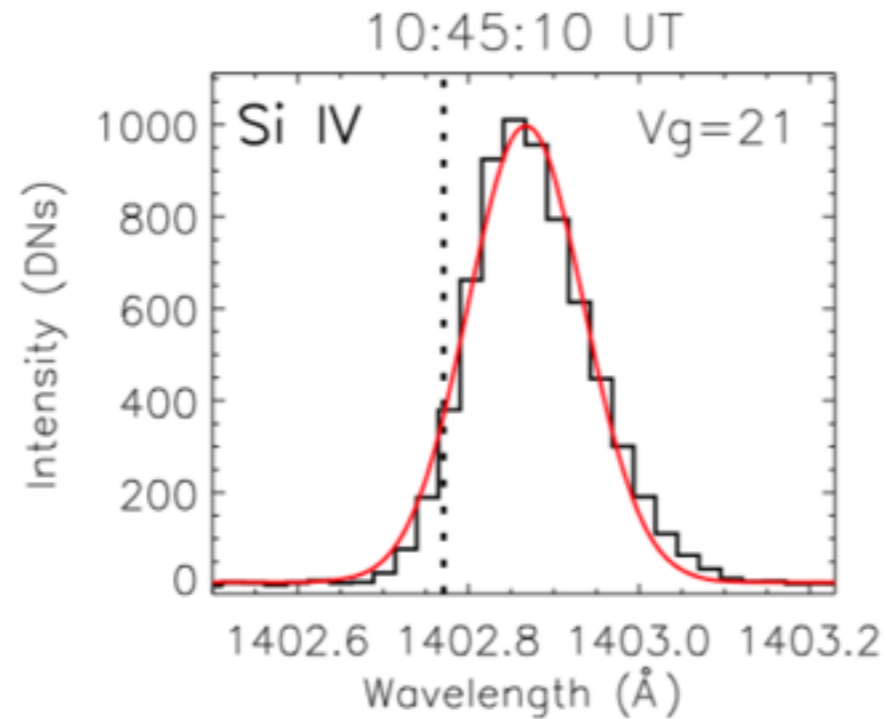
# Results — evolution of line intensity & Doppler velocity



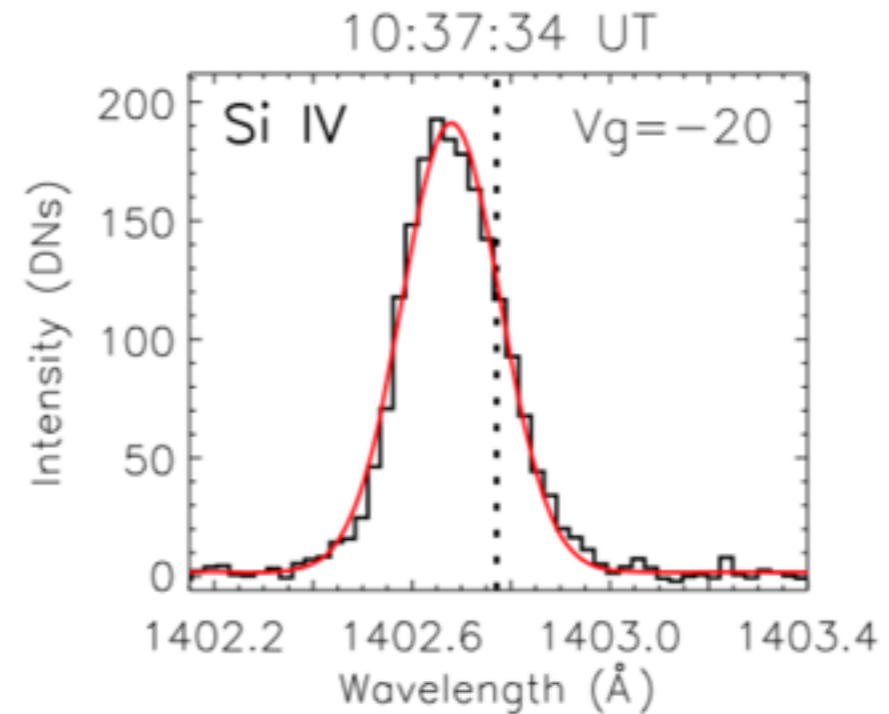
a gentle evaporation in the B1.6 flare!!

# Comparison — Si IV line profiles

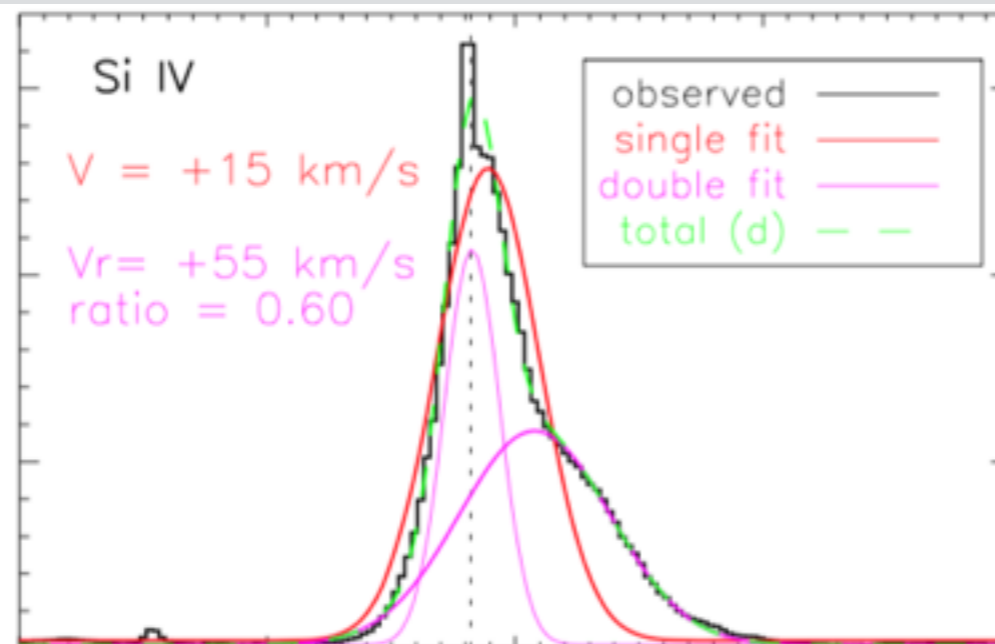
**wholly redshifted in C1.6**  
(weak HXR emission of >25 keV)



**wholly blueshifted in B1.6**  
(HXR emission only up to 12 keV)



**red asymmetric in X1.0, with a rest component**  
(strong HXR emission of >25 keV; Li et al. 2015)



more flare events studied  
in Yu, Li, Ding et al. 2019,  
to be submitted in ApJ

# Summary & Discussion

- **Gentle evaporation has been reported**, for the first time, by using IRIS data. *Note that blueshifts in the Si IV line caused by chromospheric evaporation have actually been reproduced in radiative hydrodynamic simulations (Polito et al. 2018; Kerr et al. 2019).*
- **Different evaporation signatures** have been detected in the cool Si IV, C II & Mg II lines: redshifted / blueshifted.
- **Shapes of Si IV (also C II & Mg II) line profiles:** combining with some other flares, the profiles seem to be related to the nonthermal emission, which may provide some implications on flare heating mechanisms.
- **using radiative hydrodynamic simulations** to study the relationship of Si IV (and also C II & Mg II) line profiles with nonthermal & thermal heating models.

for more details, please see  
Li et al. 2019, ApJ, 879, 30

*Thanks for your attention!*