

Spectroscopic Diagnostics of Chromospheric Evaporation *from IRIS*

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Outline

Background
(chromospheric evaporation)

Instrument & Spectra
(IRIS & UV lines)

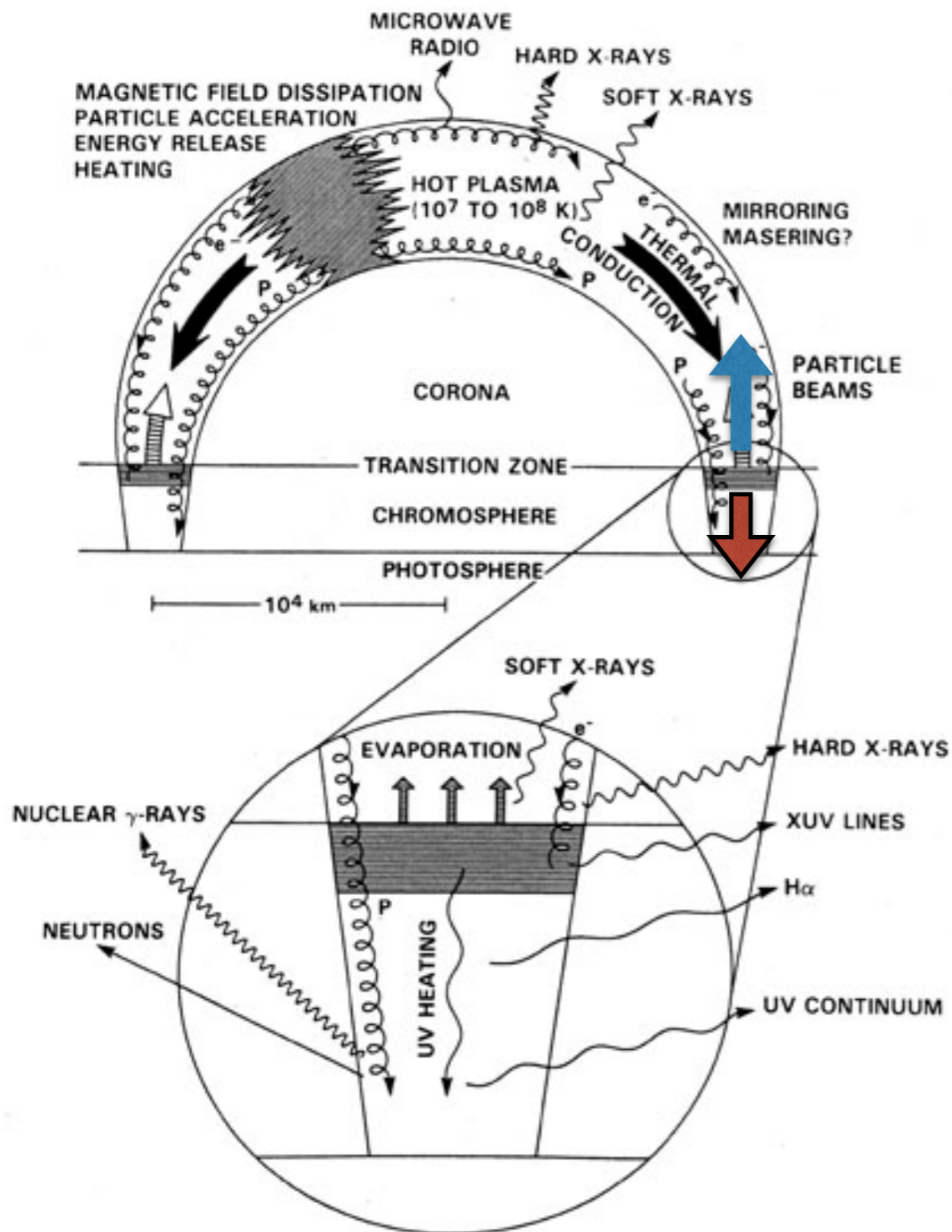
Observations & Results
(3 flare events)

Summary & Discussion

Background

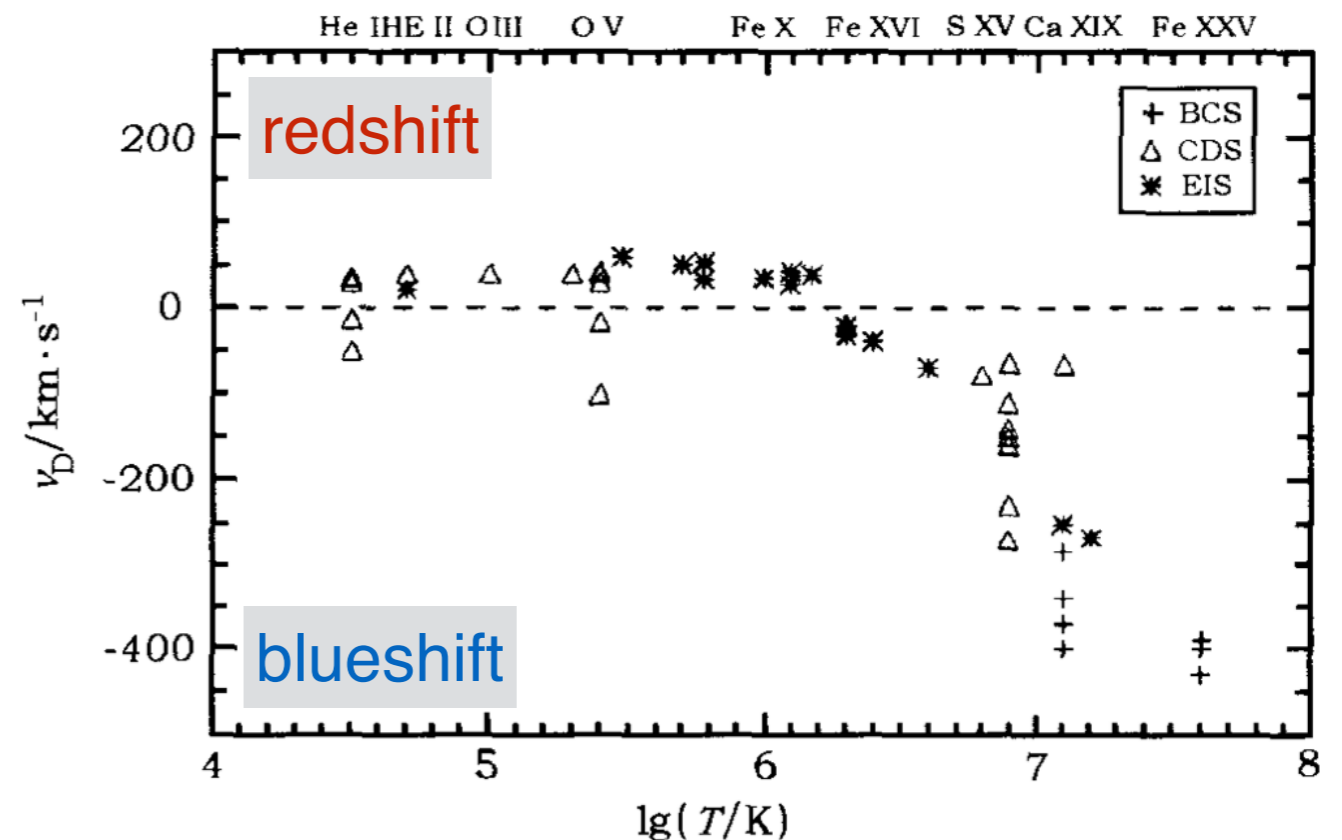
Chromospheric evaporation

- **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; ...)



(Dennis & Schwartz 1989)

in observations



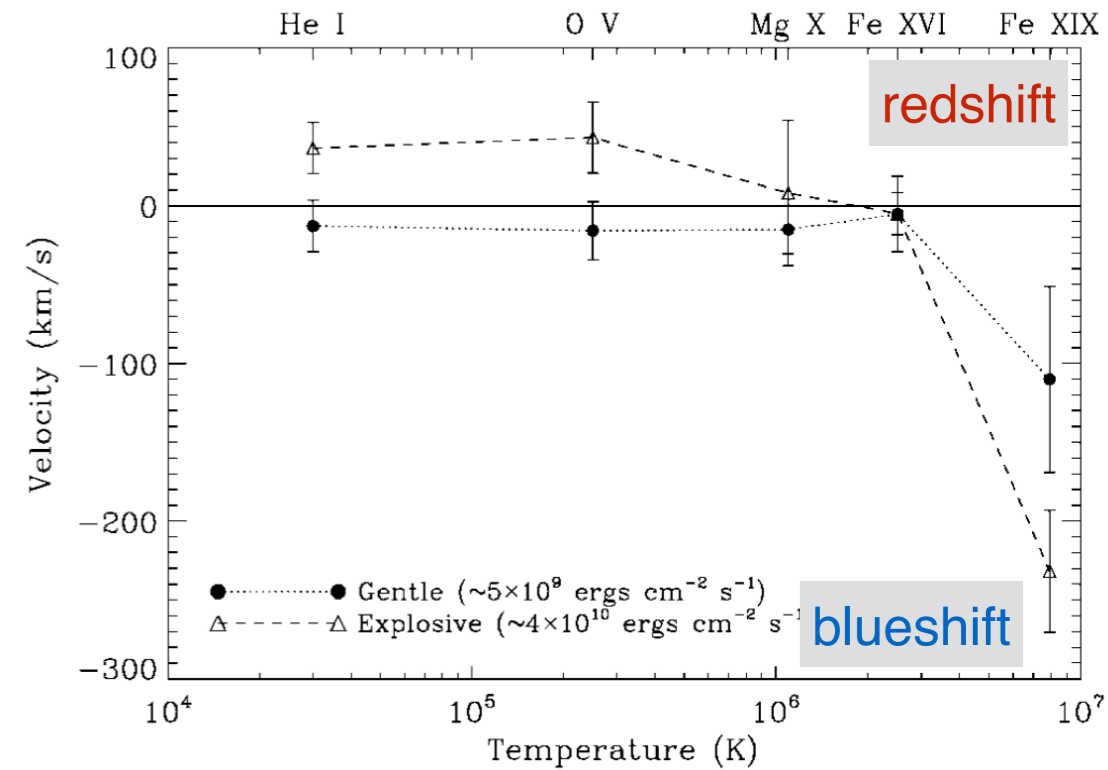
Background

Two types of evaporation

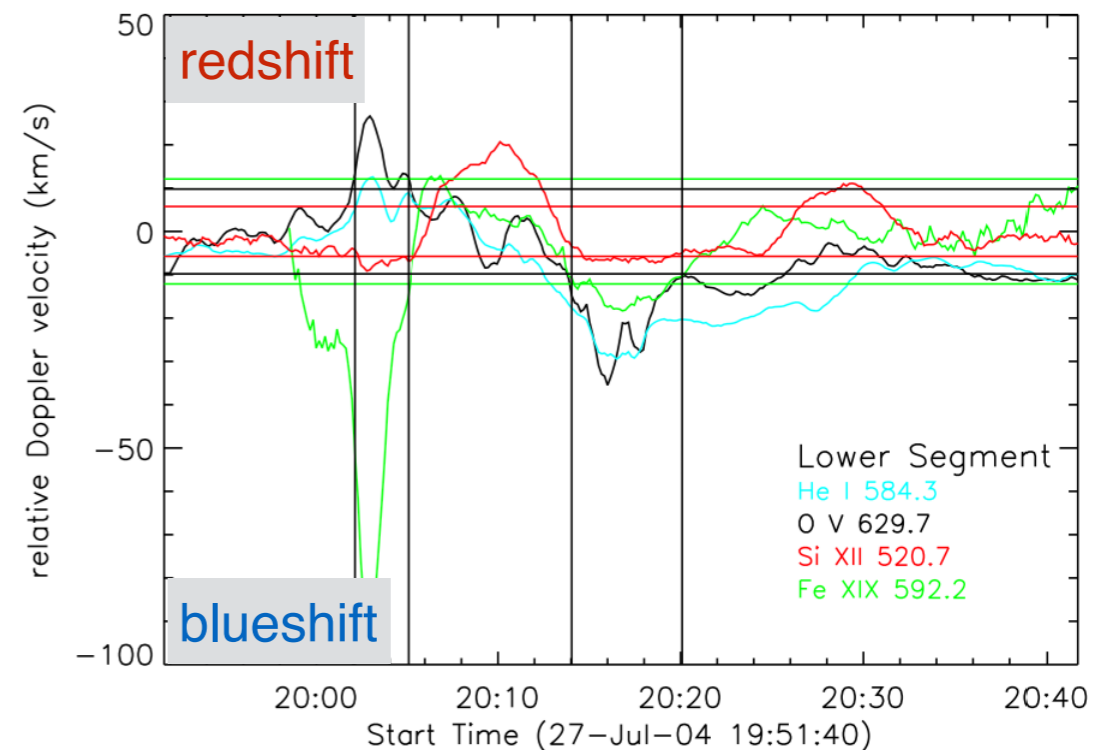
(Fisher et al. 1985a,b,c)

- **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
 $\sim 10^{10} \text{ ergs cm}^{-2} \text{ s}^{-1}$ (Fisher et al. 1985a)

**Conversion from explosive
to gentle evaporation**



(Milligan et al. 2006a,b)



(Brosius 2009)

Background

Studies from IRIS

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

explosive evaporation
observed in general
(rare gentle evaporation)

line Profiles of
Si IV, C II & Mg II
heating mechanisms??

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)

Instrument & Spectra

IRIS (Interface Region Imaging Spectrograph)

wavelength: $\sim 1400 \text{ \AA}$ & $\sim 2800 \text{ \AA}$ (FUV/NUV)

spectral line: $\log T = 3.7\text{--}7.0 \text{ K}$ (chromos., TR, coronal lines)

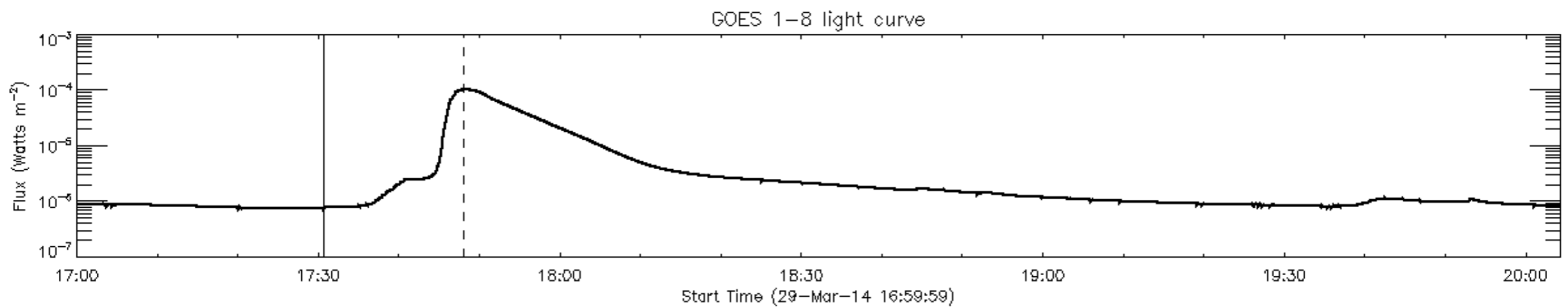
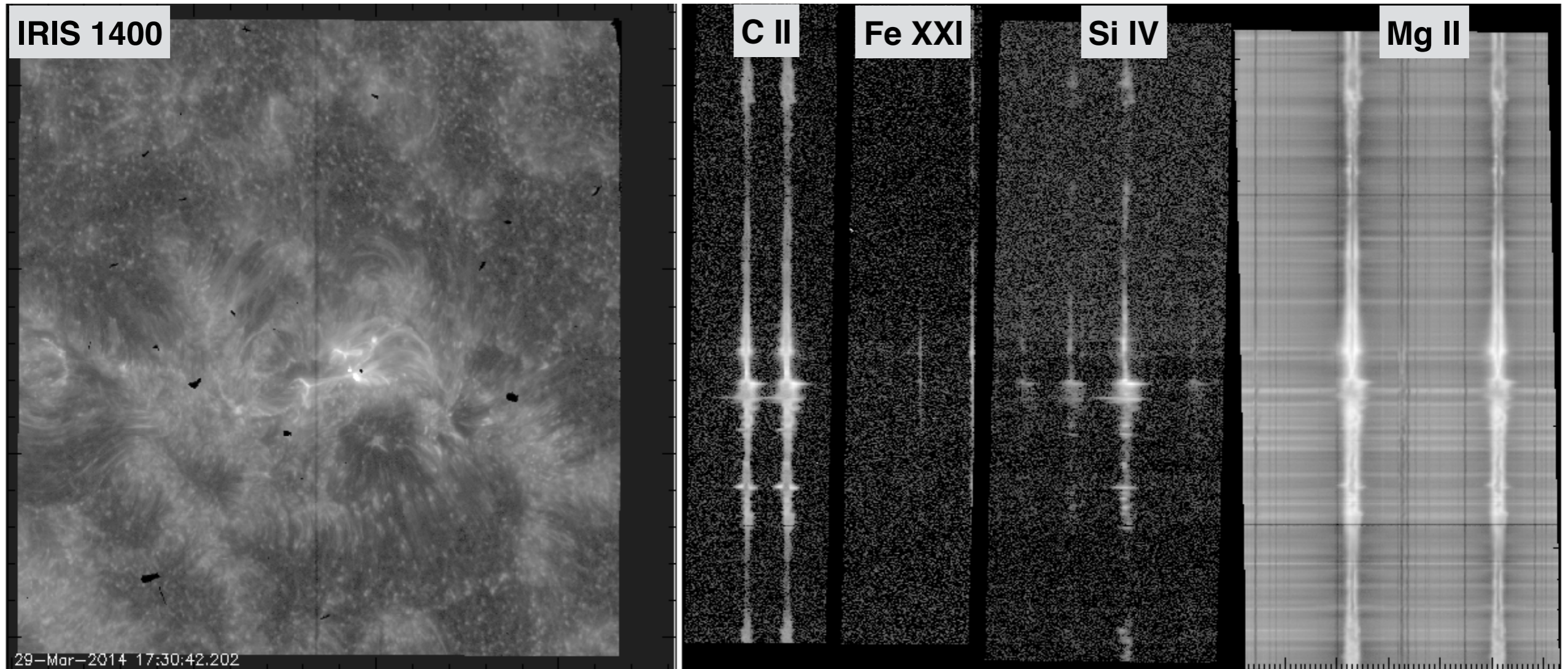
resolution: $\sim 0.33''$, $\sim 2 \text{ sec to min}$, 0.025 \AA/pixel

mode: raster scan & sit-and-stare (also slit jaw images)

Ion	Wavelength (\AA)	$\log T_{max}$ (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

- moment analysis
- bisector method
- Gaussian fitting (single/multiple)

Observations — an X1.0 flare on 2014-03-29



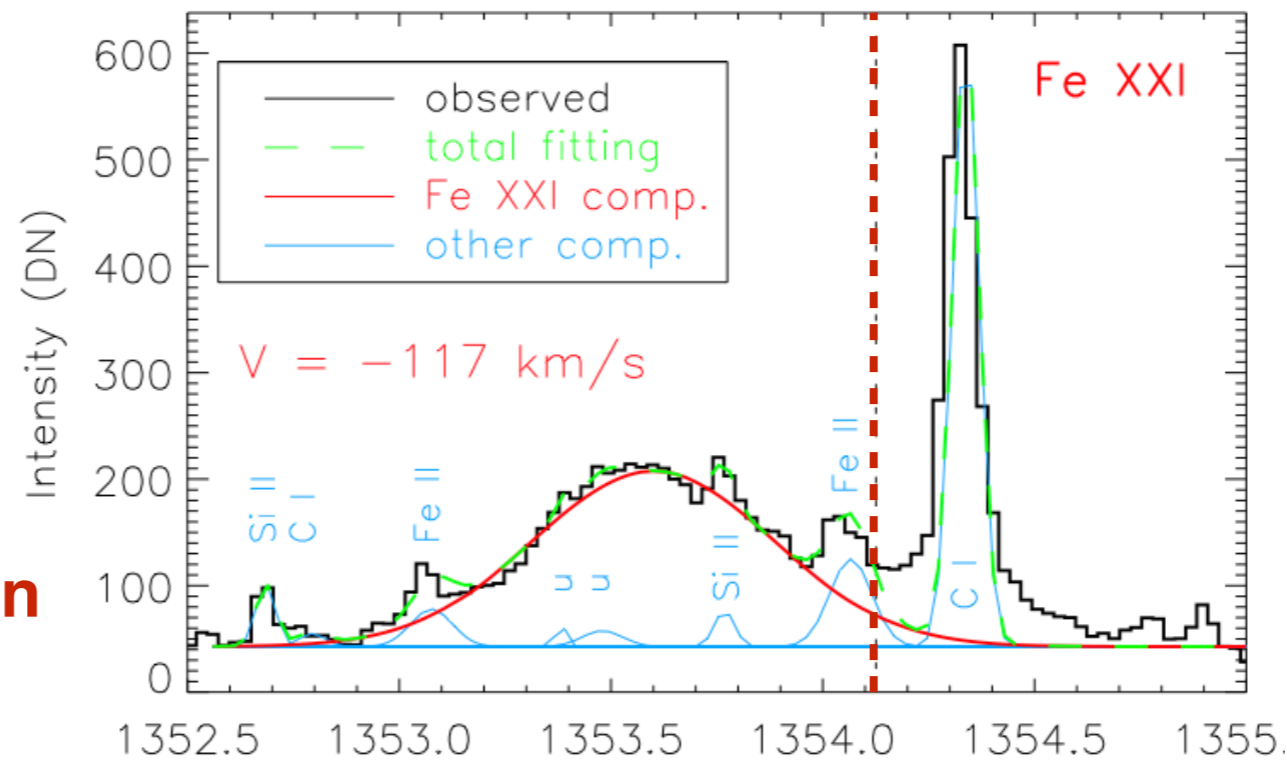
Results — profiles of hot (≥ 10 MK) lines (IRIS vs. EIS)

at the flare ribbon

IRIS Fe XXI

quite symmetric & wholly blueshifted

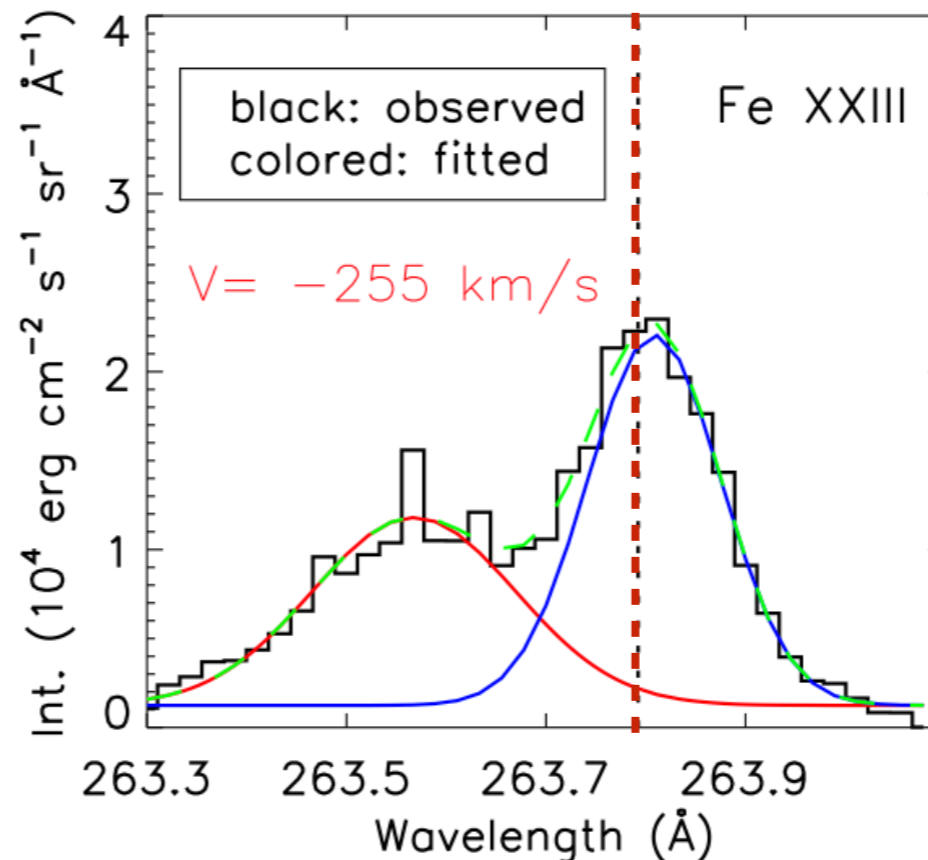
— well match the prediction of evaporation models



using multiple Gaussian fitting (with blending)

EIS Fe XXIII

blueshifted plus stationary components



double Gaussian (no blending)

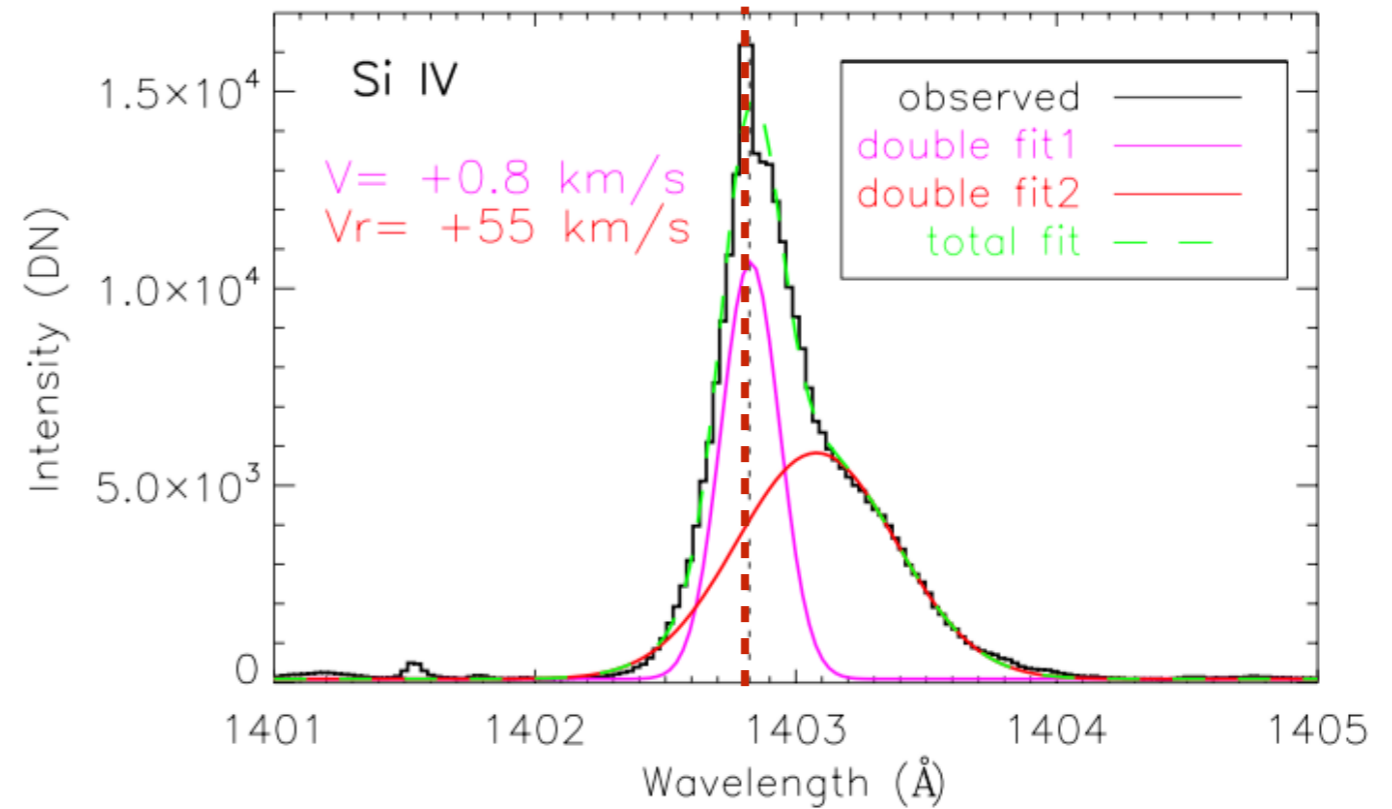
Li et al. 2015
ApJ, 811, 7

Results — profiles of cool lines from TR & chromosphere

TR Si IV

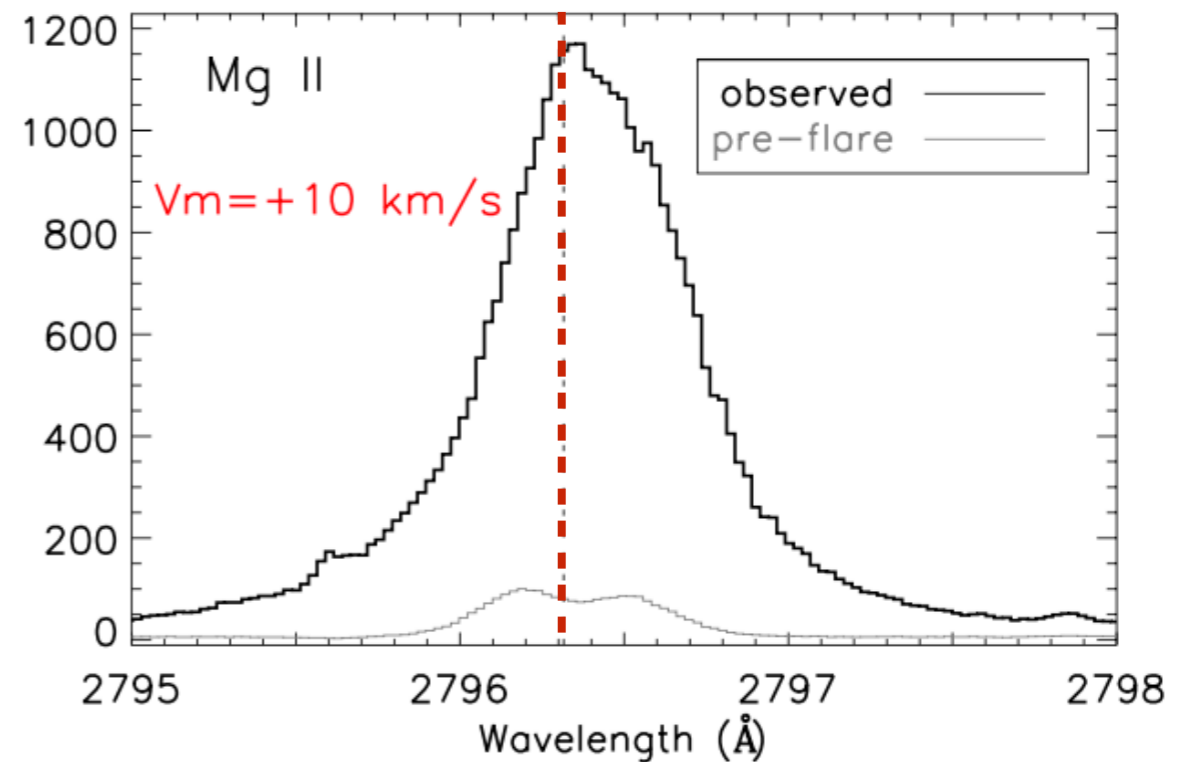
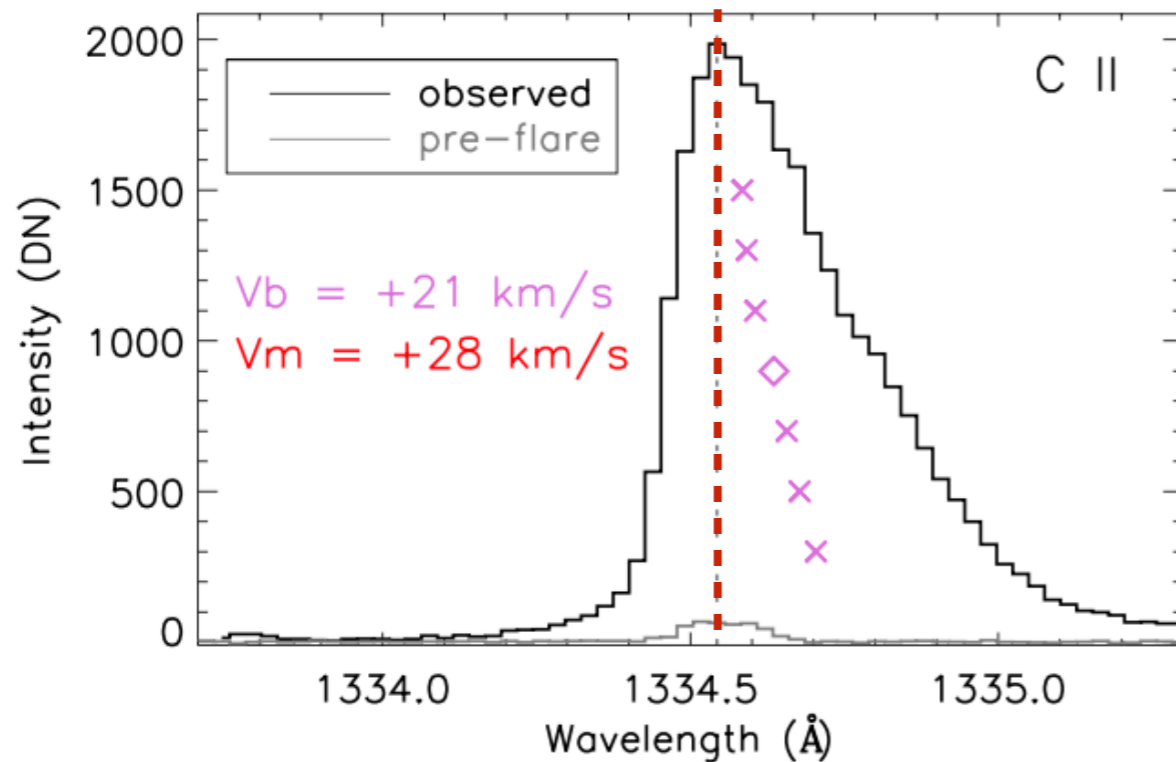
red asymmetry
(with a rest component)

— an explosive evaporation

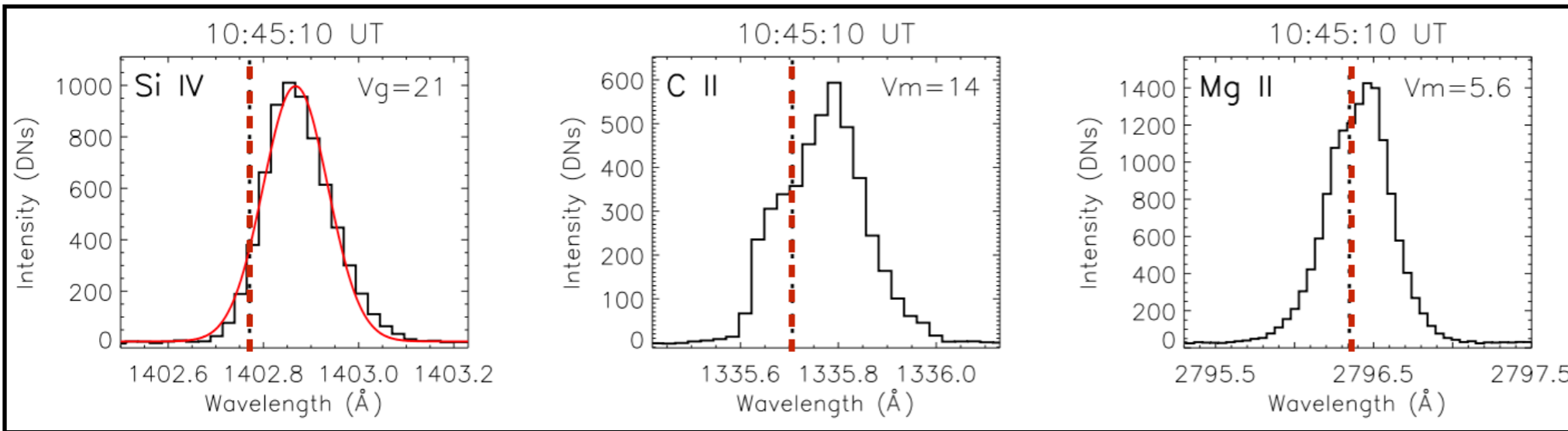
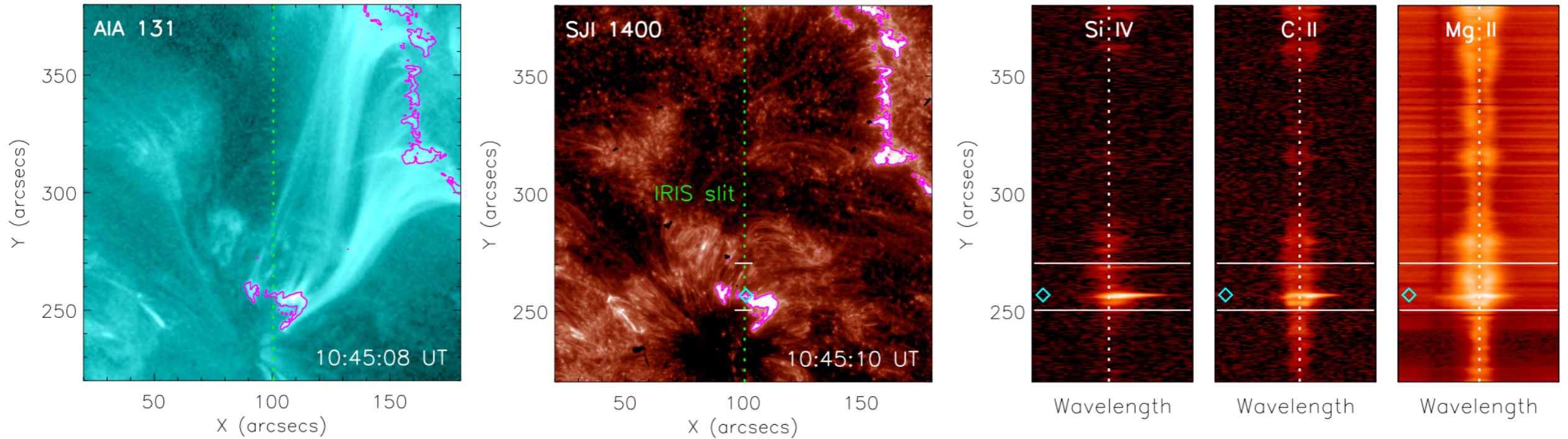


C II & Mg II

singly peaked & red asymmetry



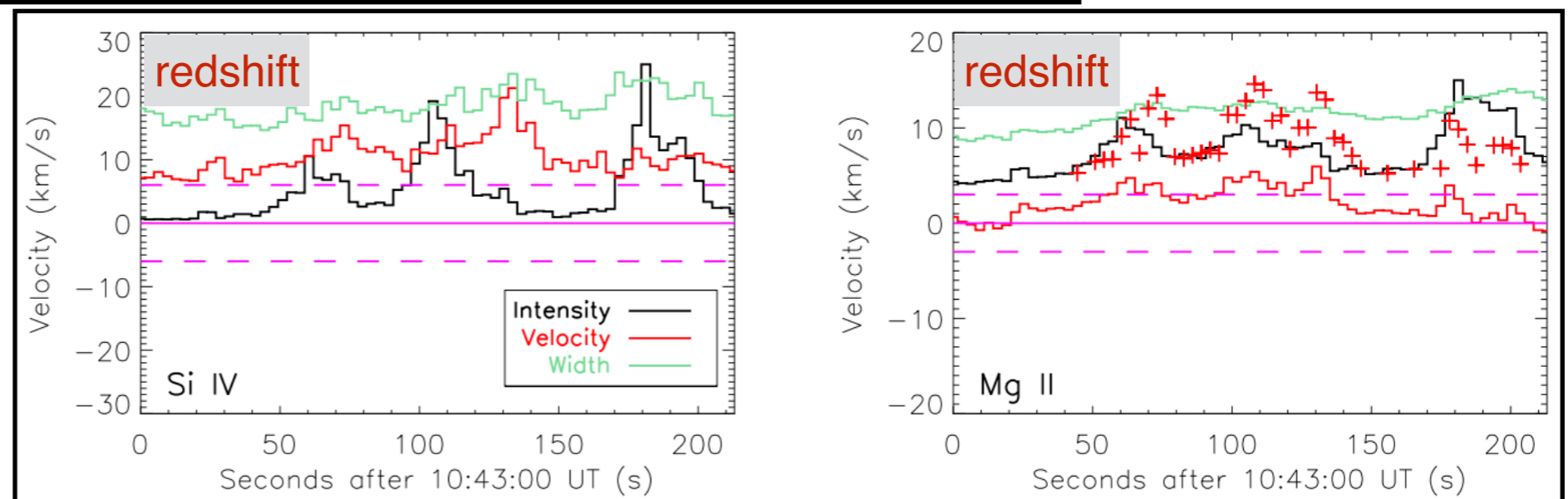
Results — a C1.6 flare on 2015-12-19



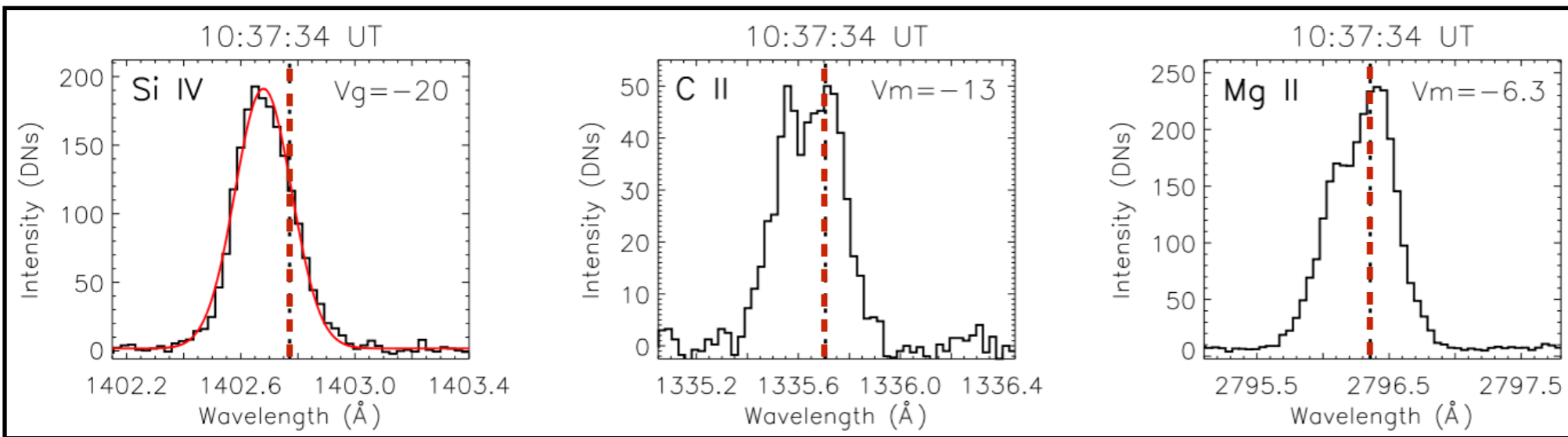
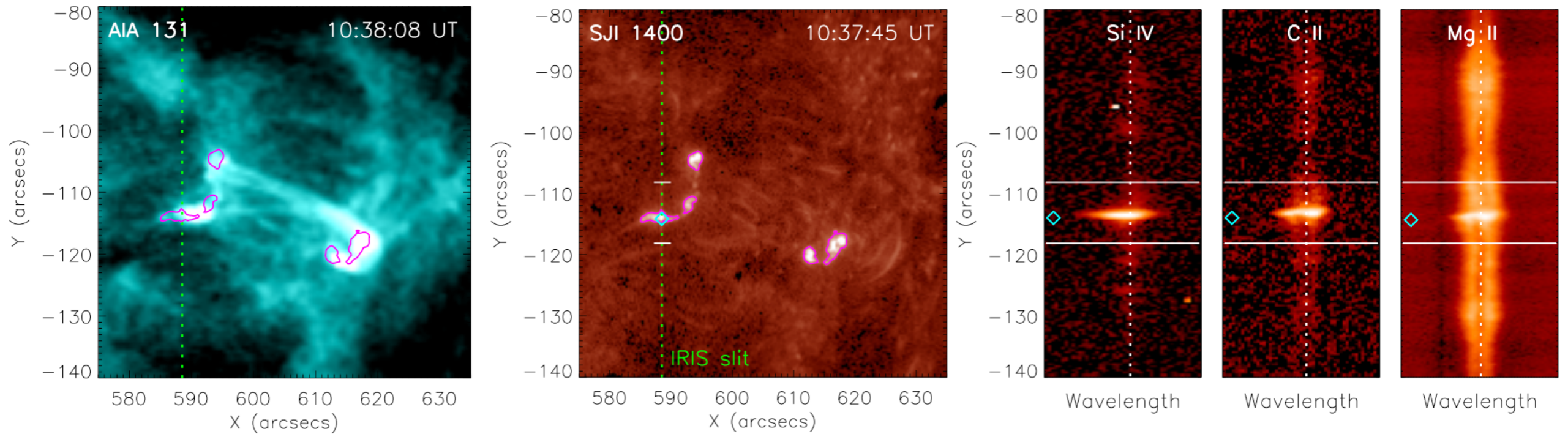
Si IV:
wholly redshifted

C II & Mg II:
a red asymmetry

an explosive evaporation



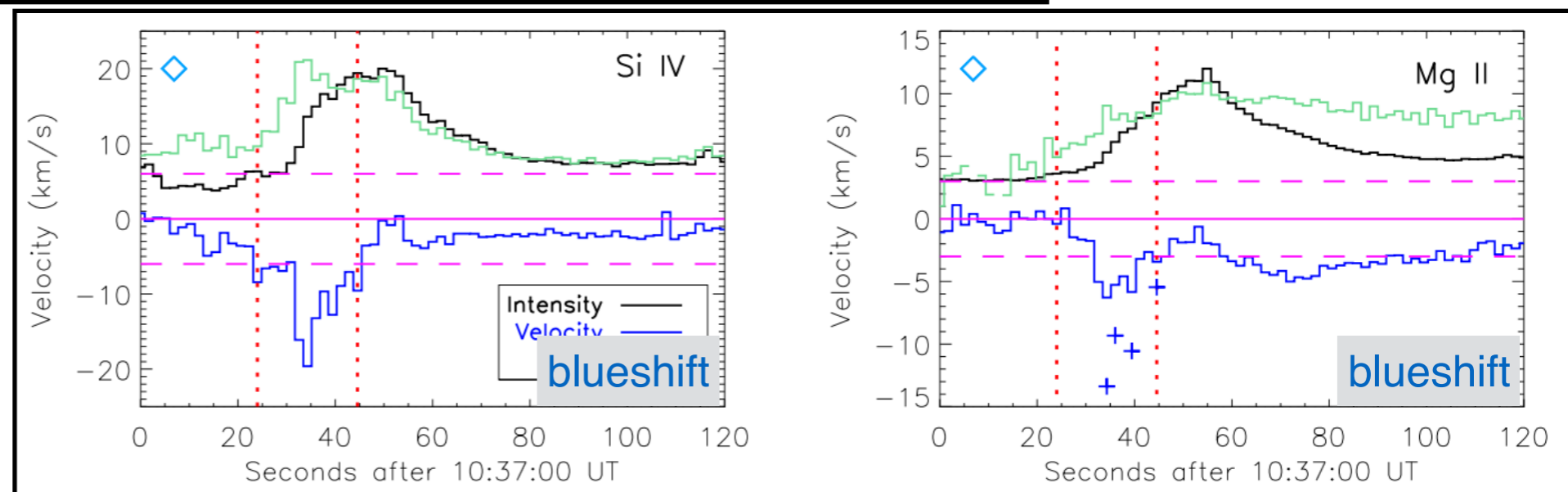
Results — a B1.6 flare on 2016-12-06



Si IV:
wholly blueshifted

C II & Mg II:
blueshifted line core

**a gentle
evaporation**



Summary & Discussion

- **In IRIS flares, wholly blueshifted Fe XXI line profile:** more consistent with the theoretical evaporation models; suggest that the high spatial resolution of IRIS may resolve the evaporation flows (*lots of references*).
- **Gentle evaporation has been reported**, for the first time, by using IRIS data; bring some new insights into chromospheric evaporation in the IRIS era (*Li et al. 2019*).
- **Different evaporation signatures** have been detected in the cool Si IV, C II, & Mg II lines: redshifted / blueshifted (*Li et al. 2019*).
- **Shapes of Si IV (also C II & Mg II) line profiles:** seem to be related to the nonthermal emission, which may provide some implications on flare heating mechanisms (*Yu, Li, Ding et al. 2019, in preparation*).
- **using radiative hydrodynamic simulations** to study the relationship of Si IV (and also C II & Mg II) line profiles with nonthermal & thermal heating models (*Hong, Li, Ding et al. 2019, in preparation*).

Thanks for your attention!