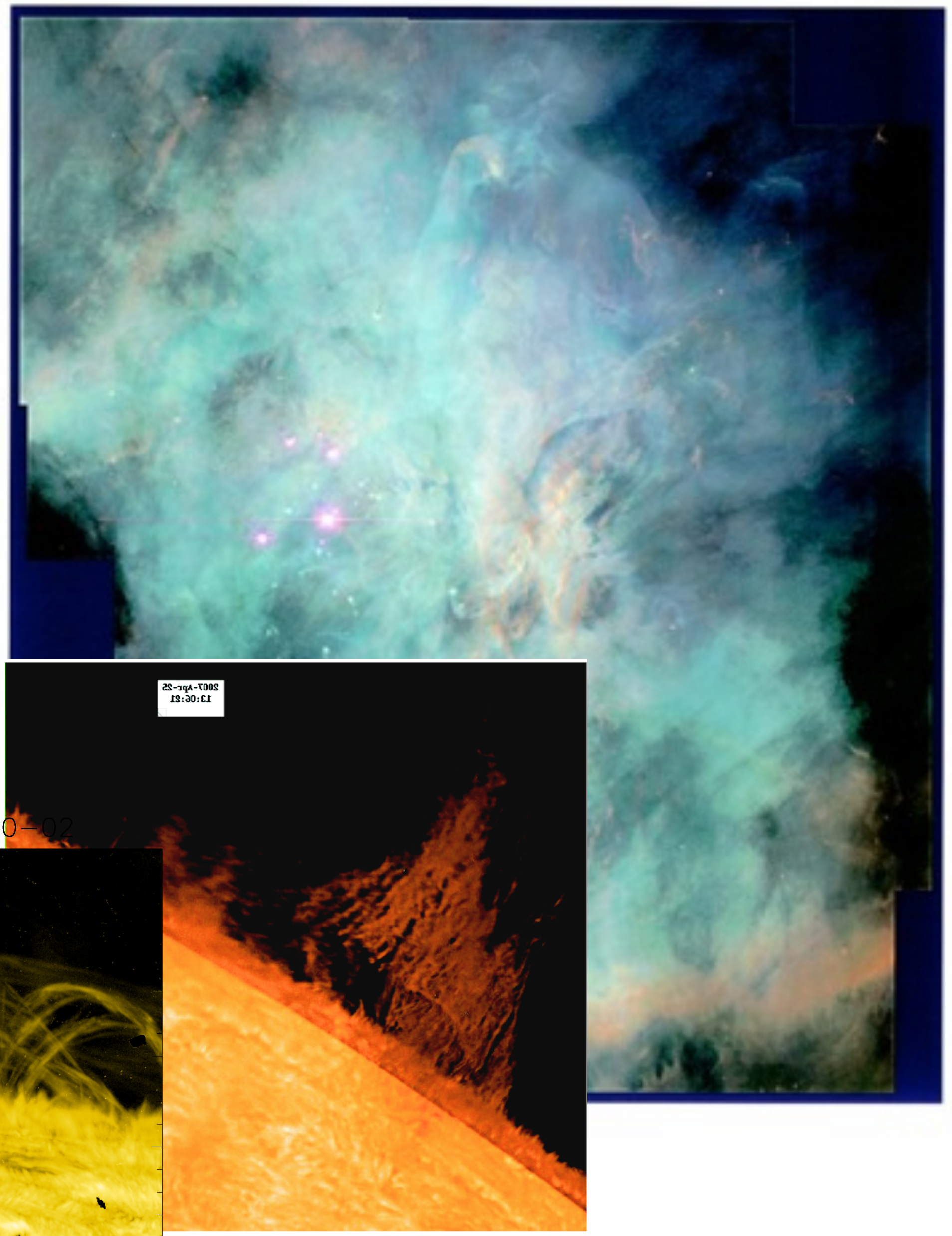
Prominences & coronal rain
- Similarities and differences -

Wei Liu (LMSAL/Stanford) and Patrick Antolin (NOAJ)

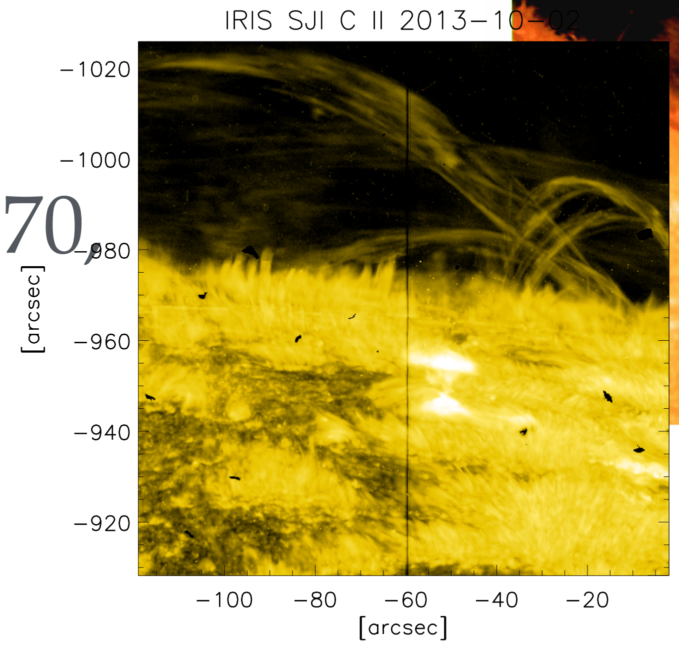
Plasma condensations in the universe

- Filamentary structure in interstellar medium (Cox 1972)
- Planetary nebulae (Zanstra 1955)
- Spiral arms of galaxies (Spitzer 1956)
- Prominences (Parker 1953)
- Coronal rain (Kawaguchi 1970, Leroy 1972)

Orion Nebula

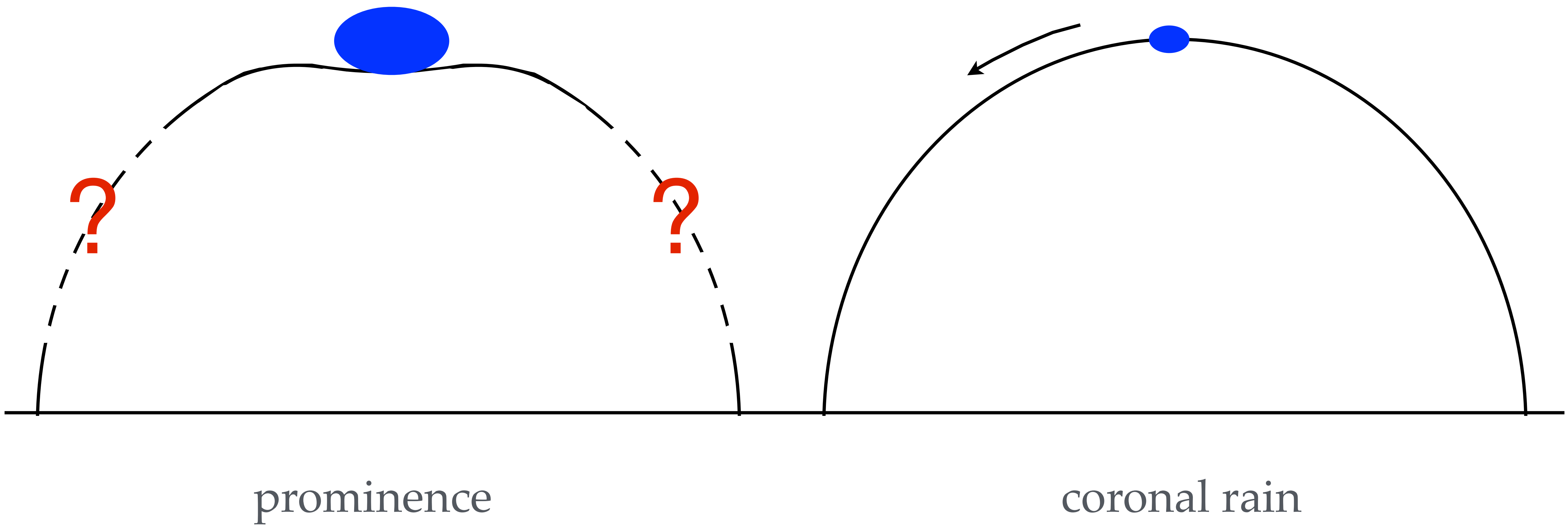


coronal rain



QS prominence

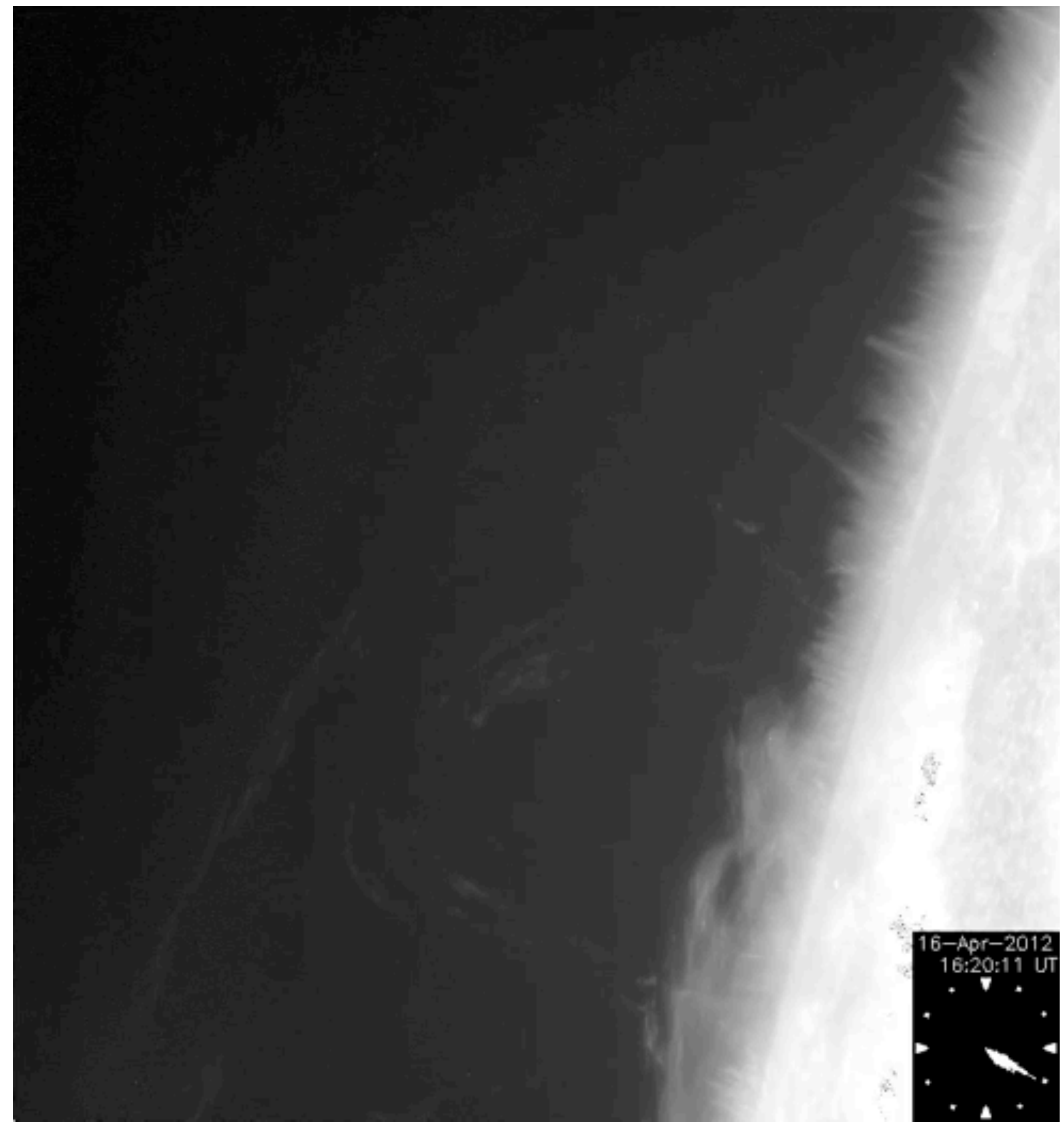
Magnetic field topology & plasma state



Different magnetic field topology may lead to different plasma state (e.g. Mackay 2010, Gilbert et al. 2002, 2007)

Cool material falling from coronal heights

- Three kinds in solar atmosphere:
  - "standard" AR rain (non-flare related)
  - Erupted prominence material failing to escape
  - Rain in post-flare loops (flare related)
- Morphology differences
  - pre-eruptive prominence flows appear more continuous
  - coronal rain & post-eruptive return material appears more clumpy
- Dynamics
  - Prominence: ≲40 km/s
  - Fall-backs: close to free-fall
  - Rain: [30,200], ~80 km/s



Return flows of Chromosphere–corona Mass Cycle: prominence and coronal rain

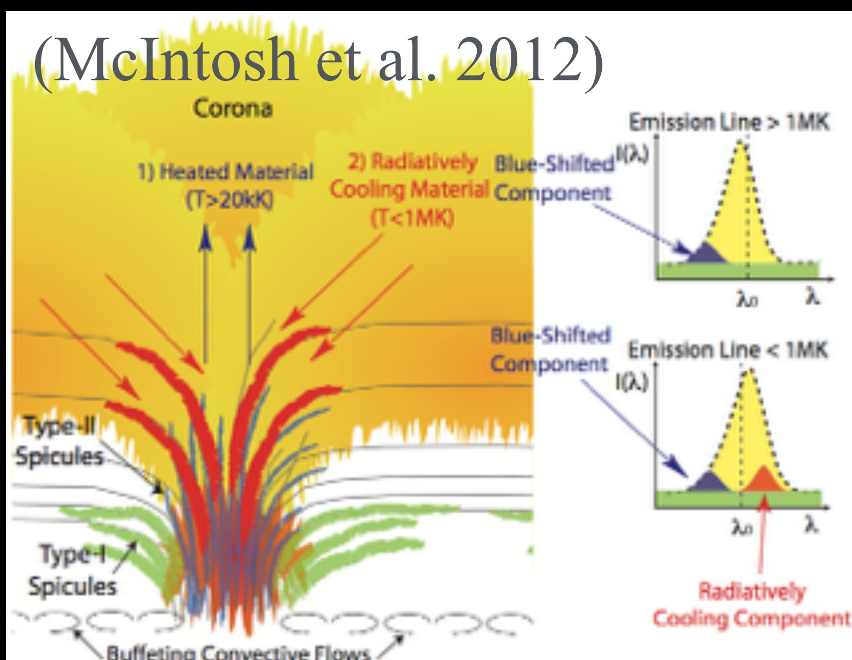
(1) Hot mass/Magnetic flux Up:

- Spicules, footpoint upflows, flux emergence (e.g., bubbles/plumes)

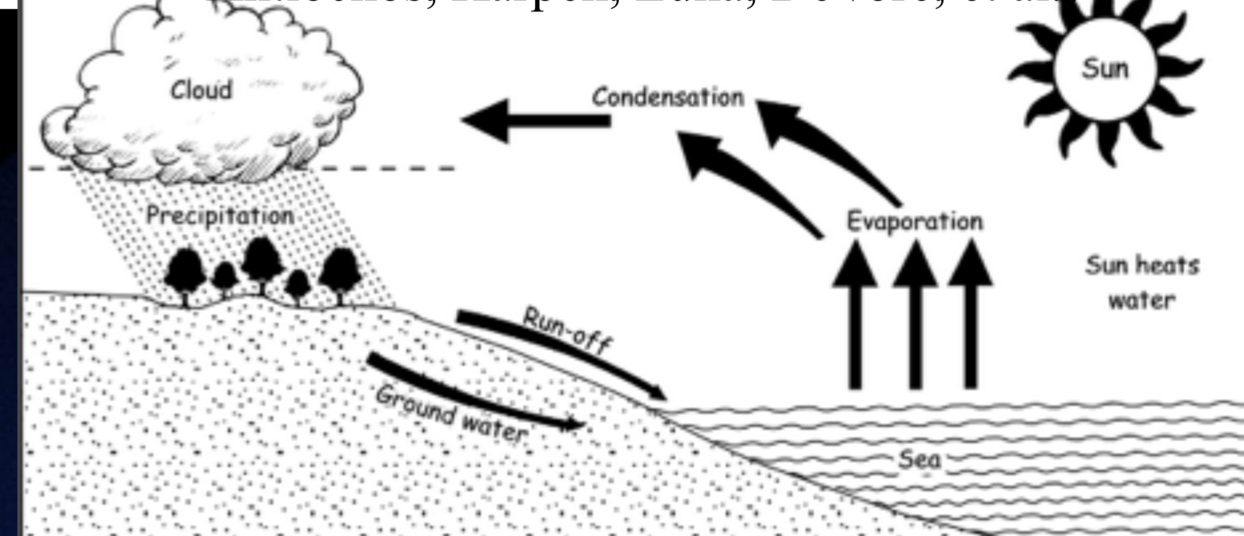
(2) Cool mass down:

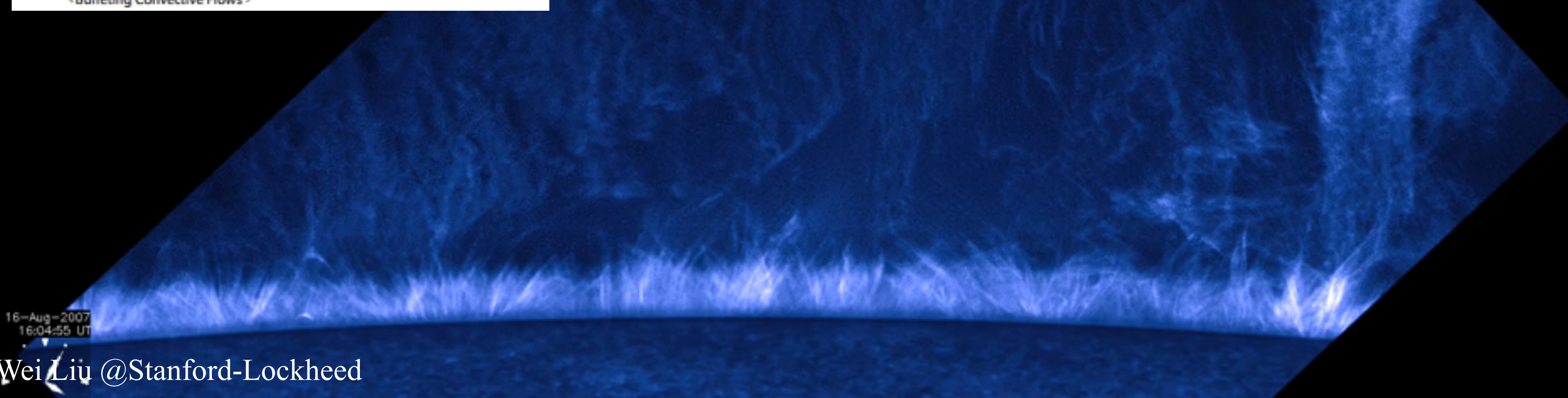
- **Prominences, Coronal rain**

(McIntosh et al. 2012)



Coronal condensation (thermal non-equilibrium; Antiochos, Karpen, Luna, DeVore, et al.)





Significance of return flows

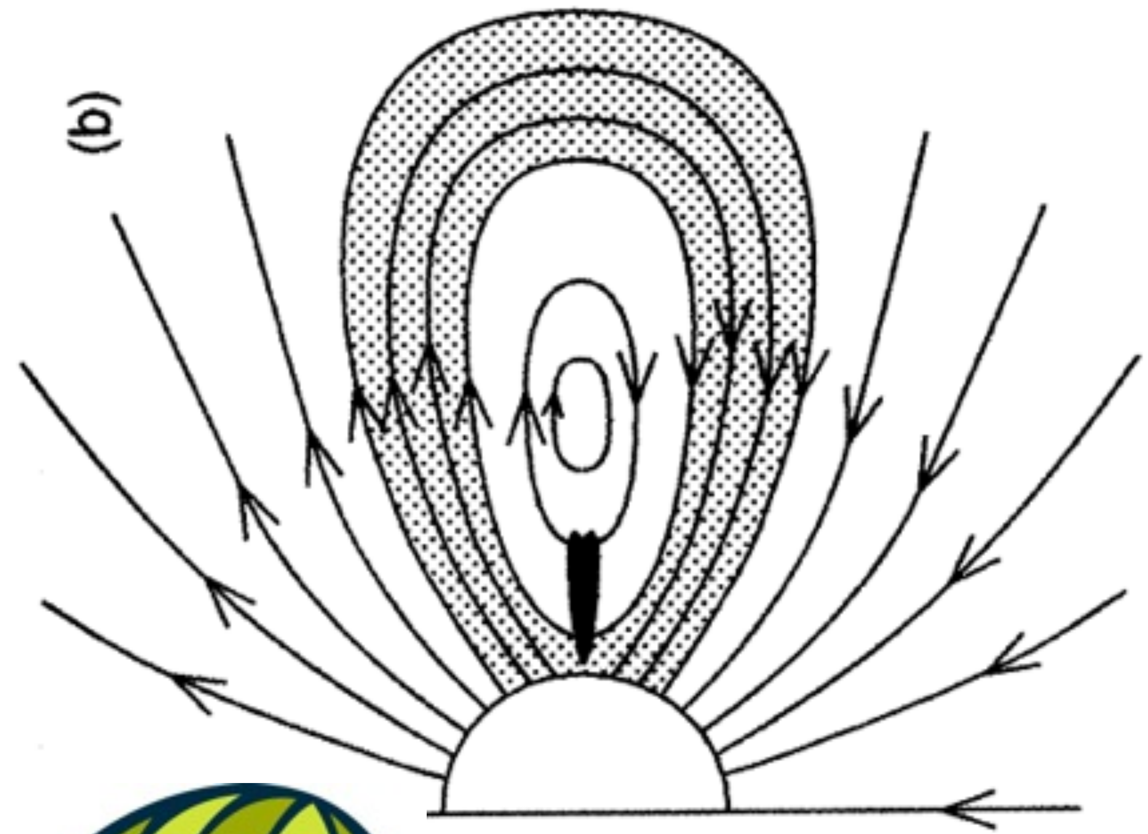
1. Where, when, & how catastrophic **cooling** occurs – implications for **coronal heating** (e.g., Antolin+ 2010, Viall & Klimchuk 2012).

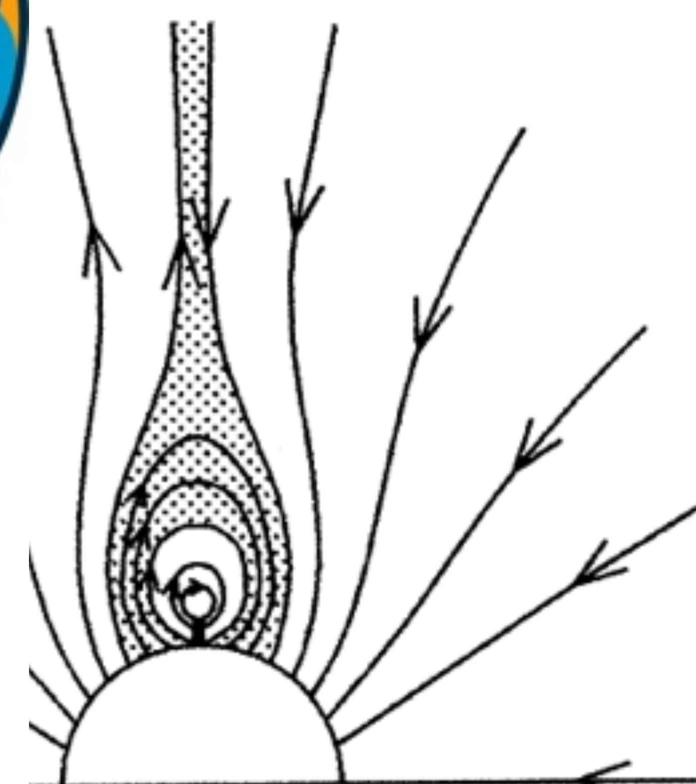
2. **CME initiation**

a) Emerging flux and helicity accumulates in the coronal cavity.

b) Drainage unloads mass (~10^{15} g/day, Liu+ 2012; Antolin & Rouppe van der Voort 2012).

➔ buoyantly unstable
➔ CME liftoff (likely for quiescent prominence eruptions/CMEs; cf., Nat Gopalswamy's talk this morning)



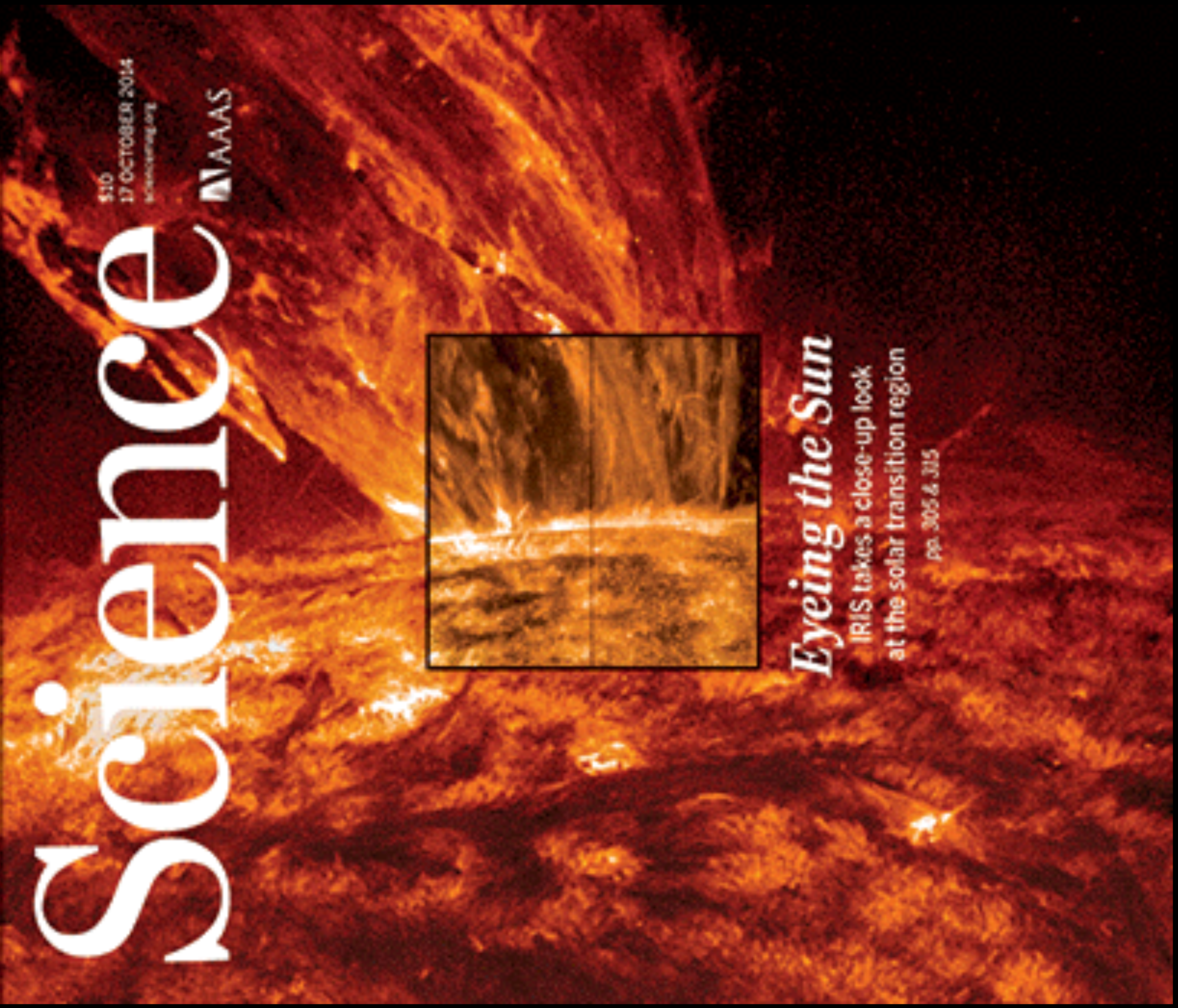


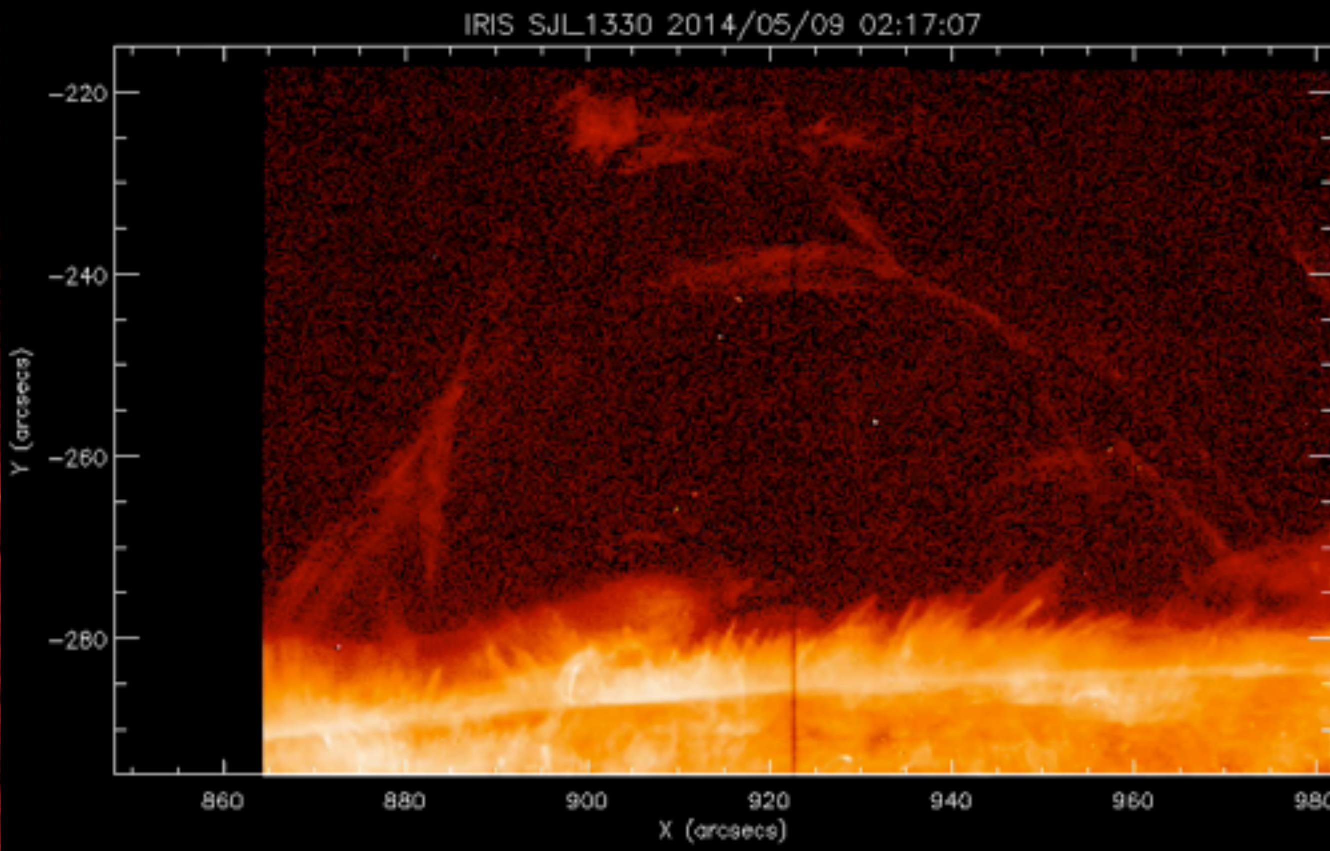
Low (2001)

High-resolution Spectroscopic Observations by IRIS of a Spectacular Fast CME/Prominence Eruption on 2014-May-09

Wei Liu (Stanford/LMSAL), Bart De Pontieu (LMSAL), Jean-Claude Vial (Univ. Paris), Alan Title (LMSAL), Mats Carlsson (Univ. Oslo), Han Uitenbroek (NSO), Takenori Okamoto (ISAS), Thomas Berger (NOAA), Patrick Antolin (NOAJ)

ApJ, accepted

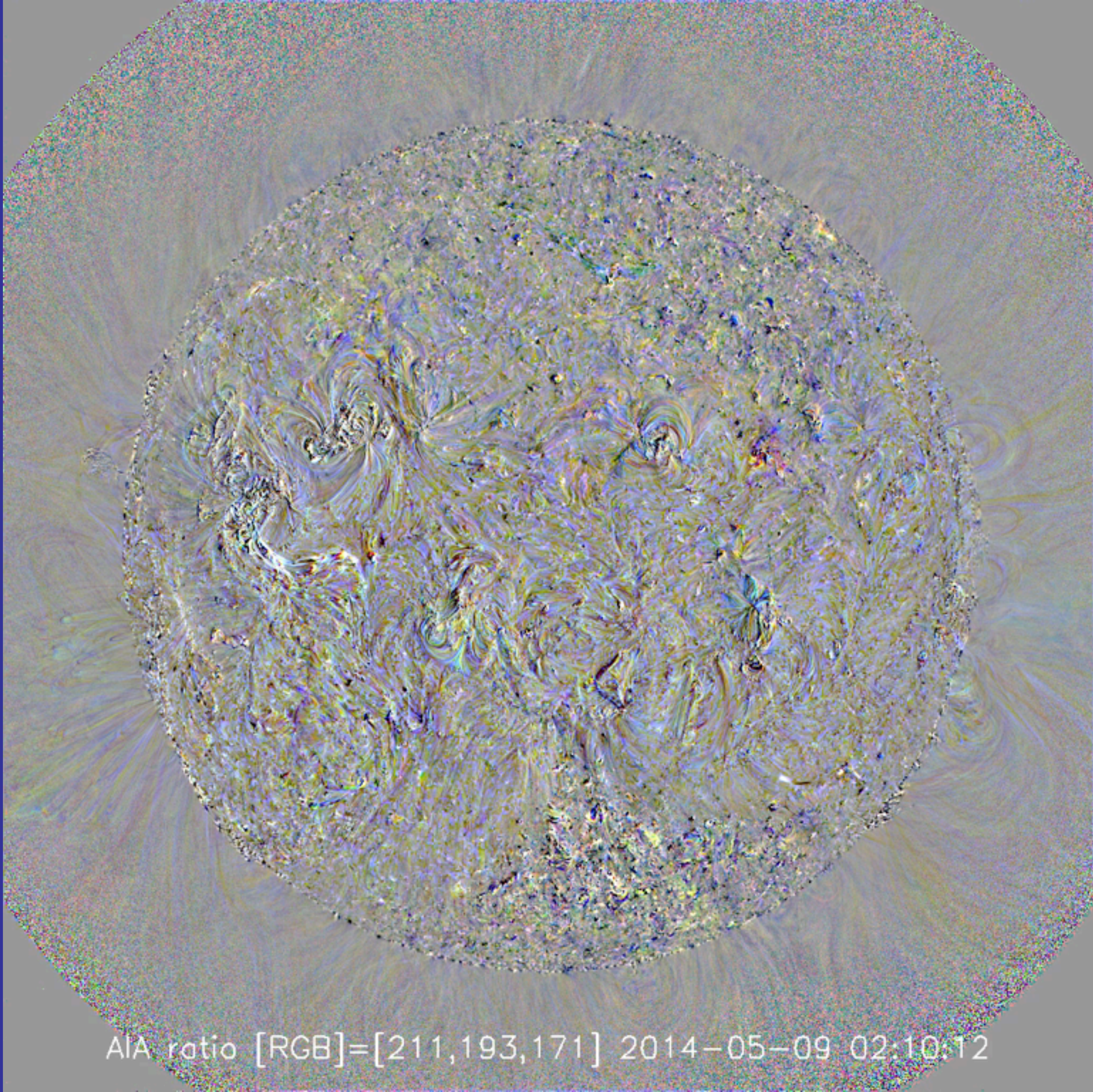




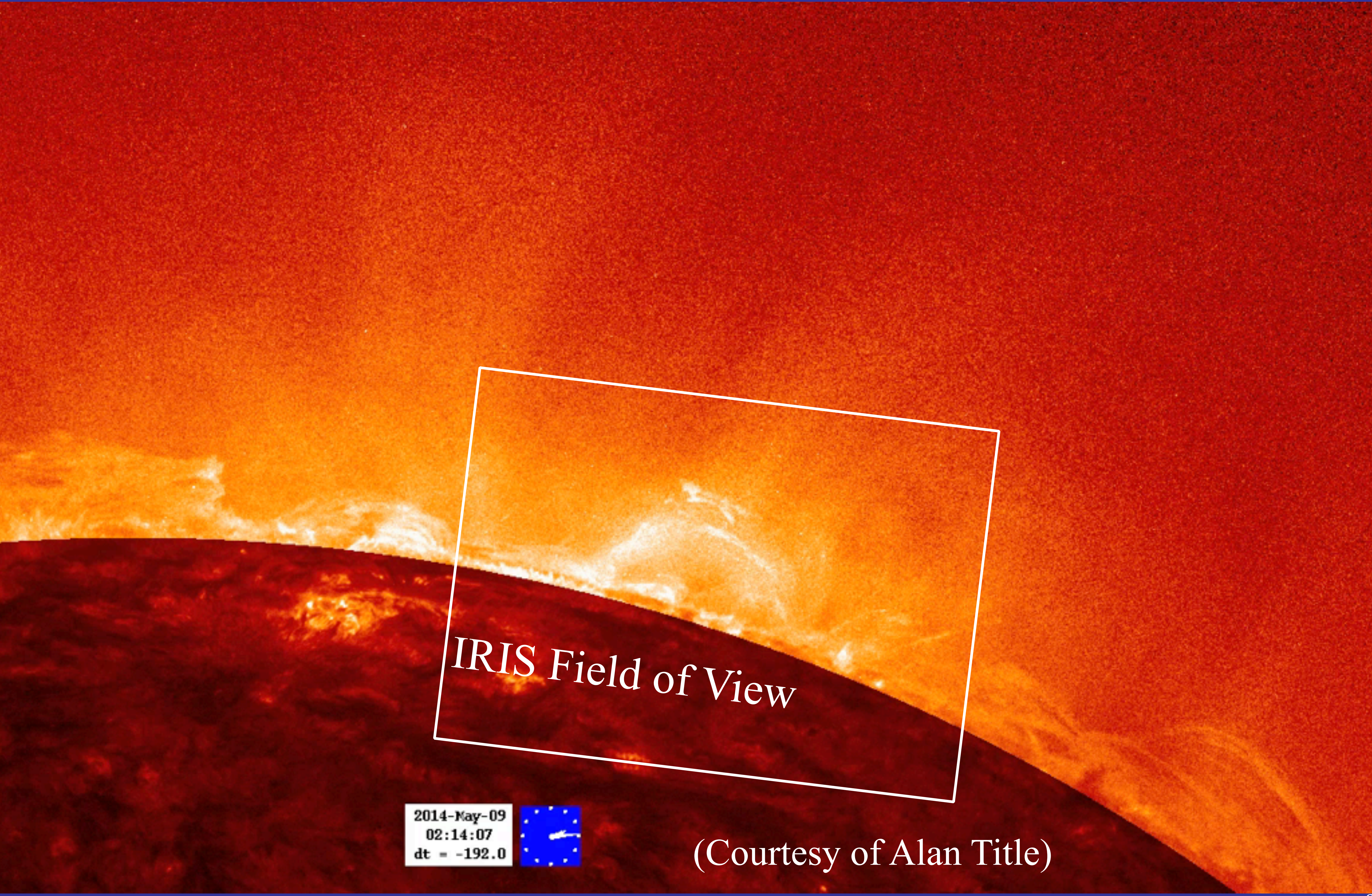
CME,
EUV wave,
Prominence
Eruption,

AIA tri-color
ratio movie
(Courtesy of
Marc DeRosa)

X1.6 flare

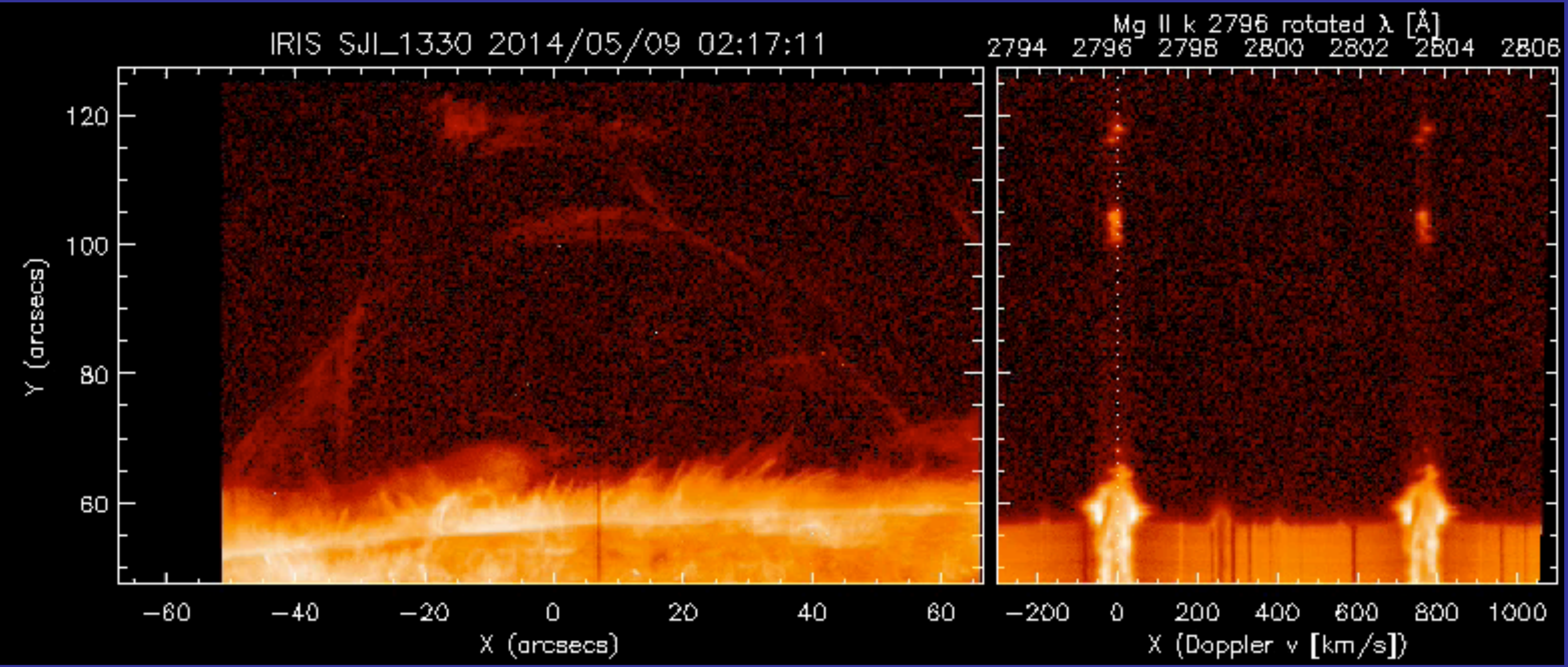


Prominence Eruption, SDO/AIA He II 304 Å (logT~4.7 K)

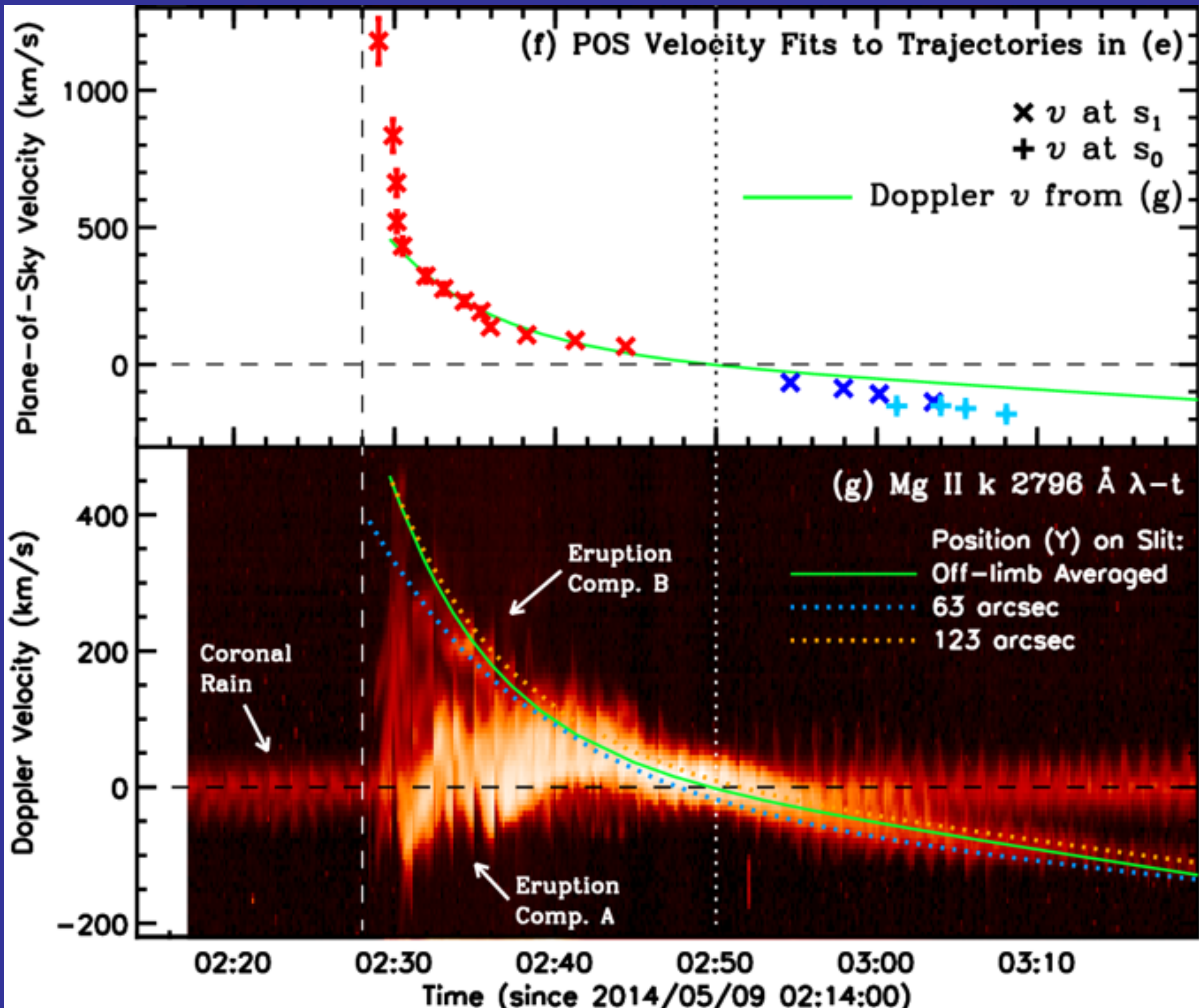


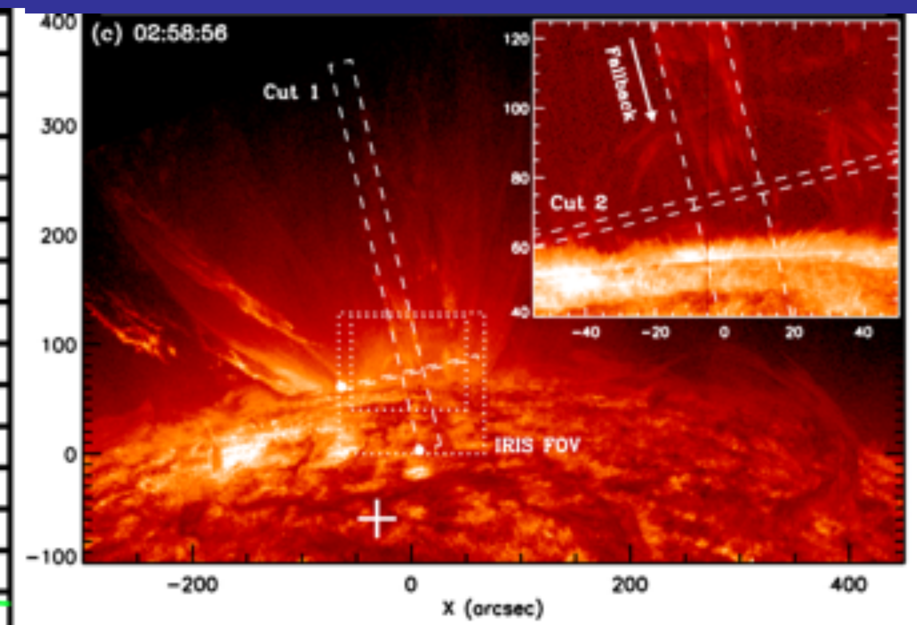
2. IRIS Observations

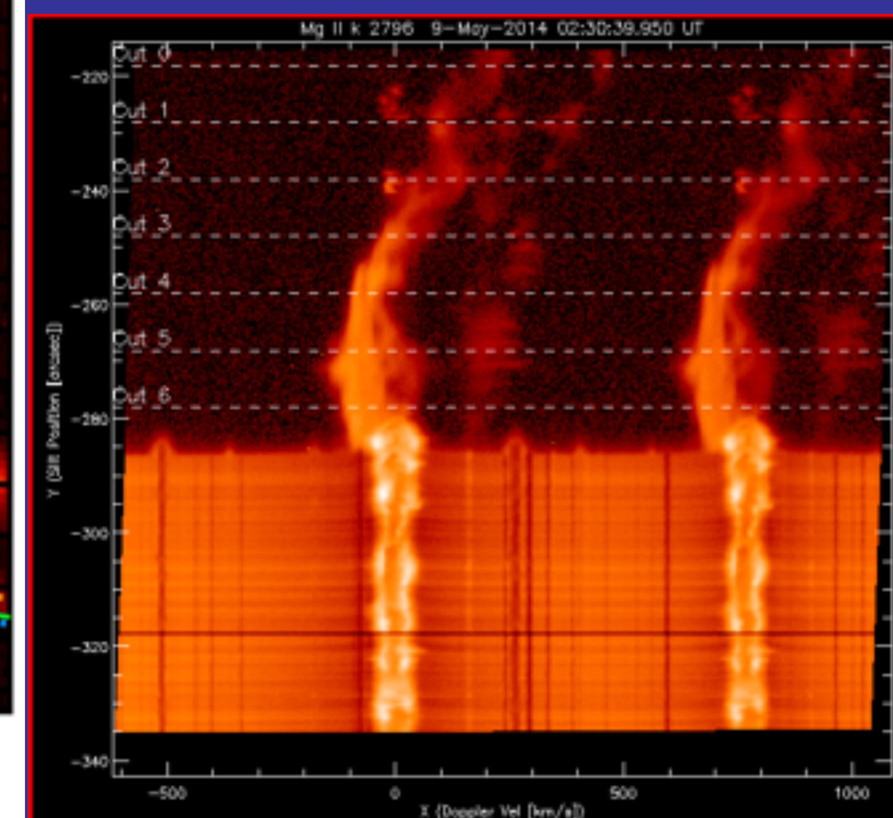
IRIS C II 1330 Å SJI (logT~4.8), Mg II k/h 2796/2803 Å (logT~4.0) spectra



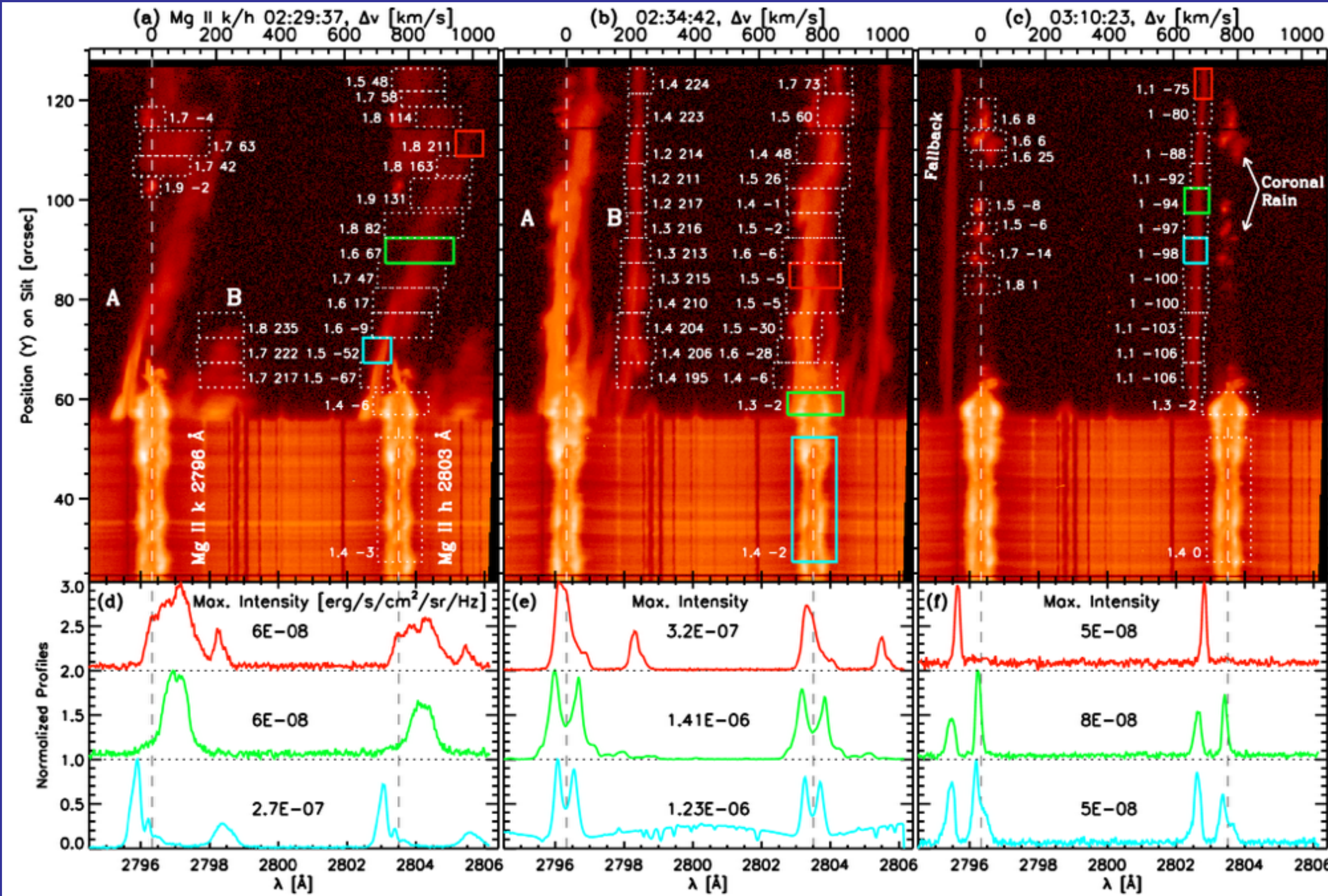
Compare plane-of-sky (AIA) and line-of-sight (IRIS) kinematics





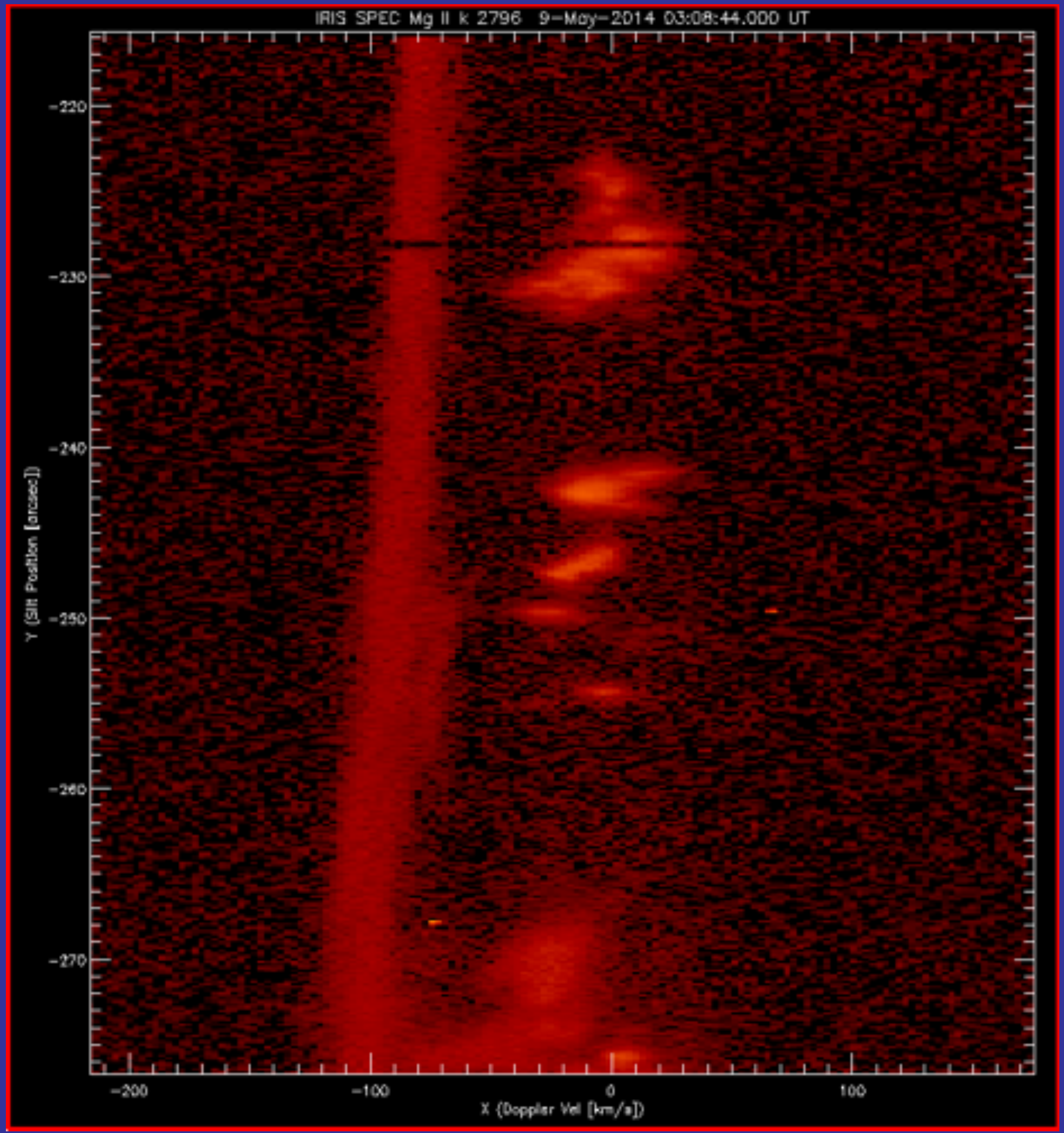


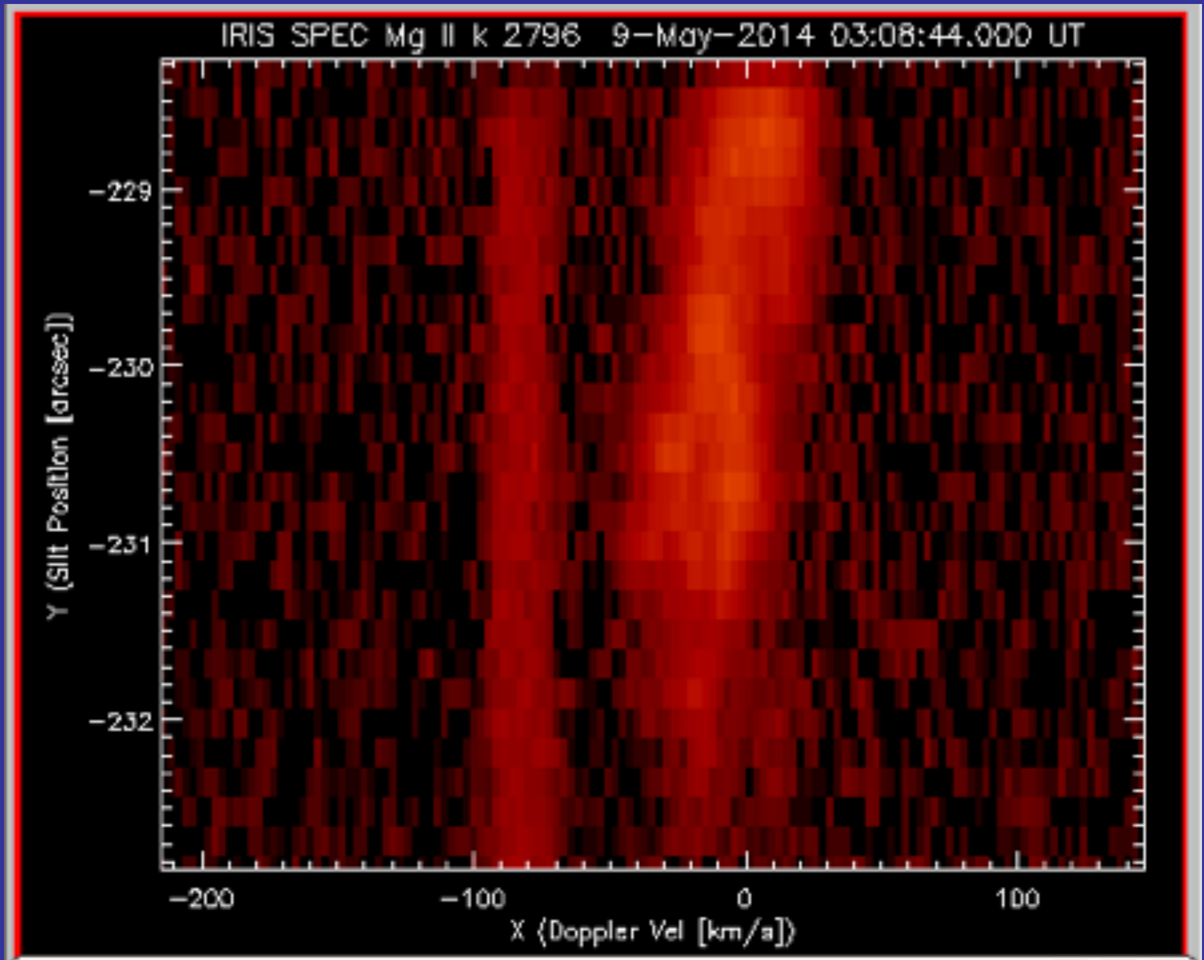
2.2 Mg II k 2796 Å and h 2803 Å integrated line ratio and Doppler velocity

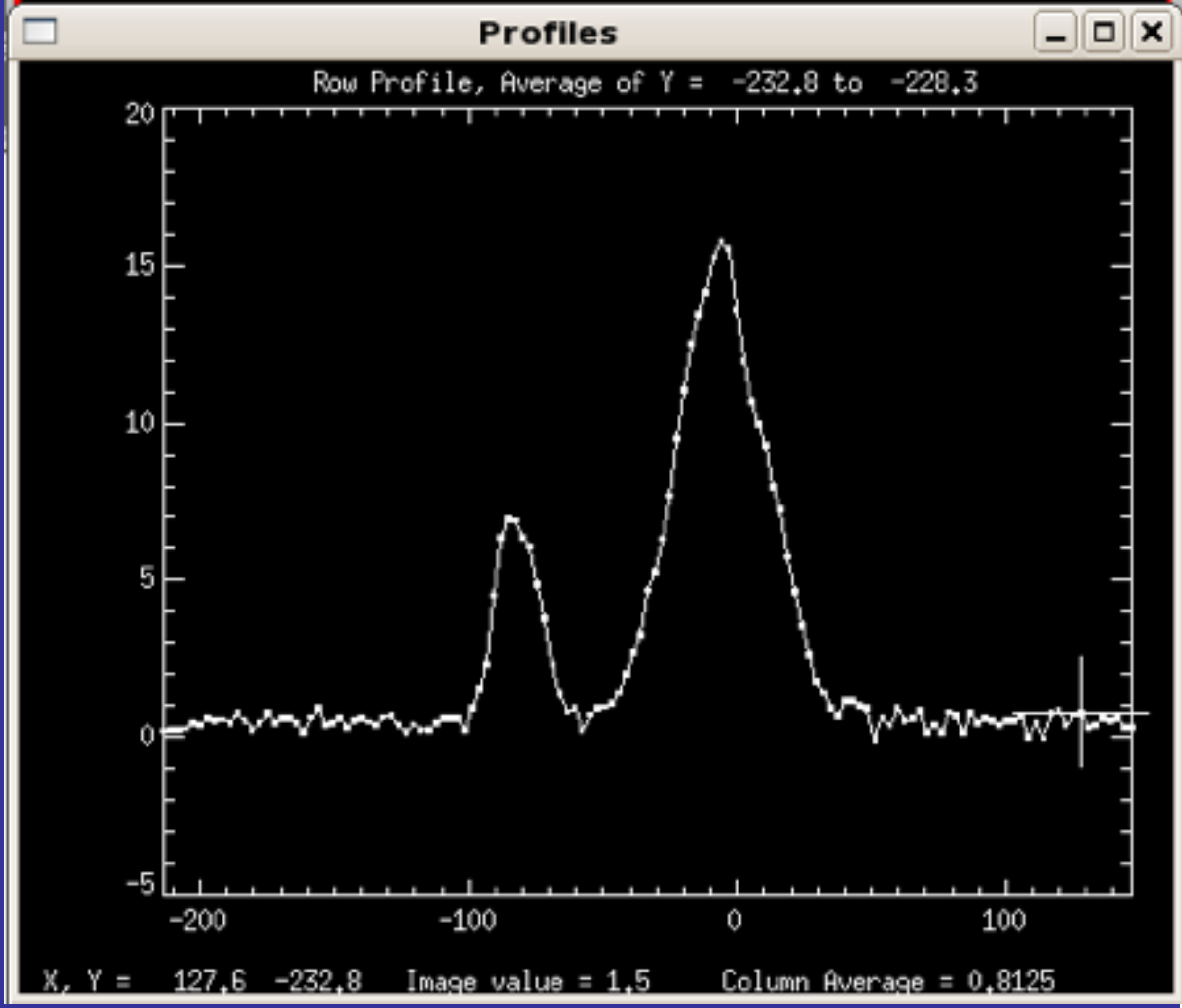


Prominence Eruption
Mg II k 2796 Å (logT=4.0) spectra

Line width: narrow return flows vs. broad coronal rain

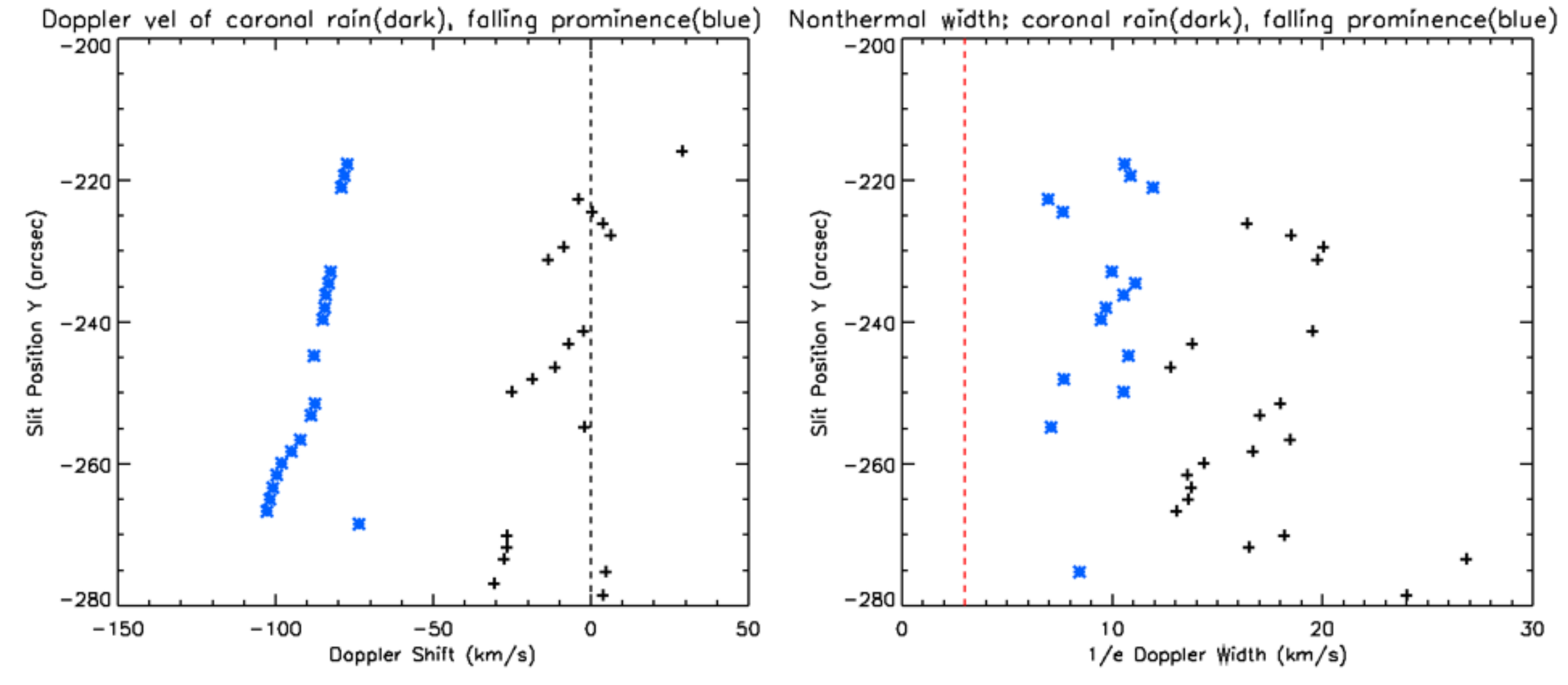




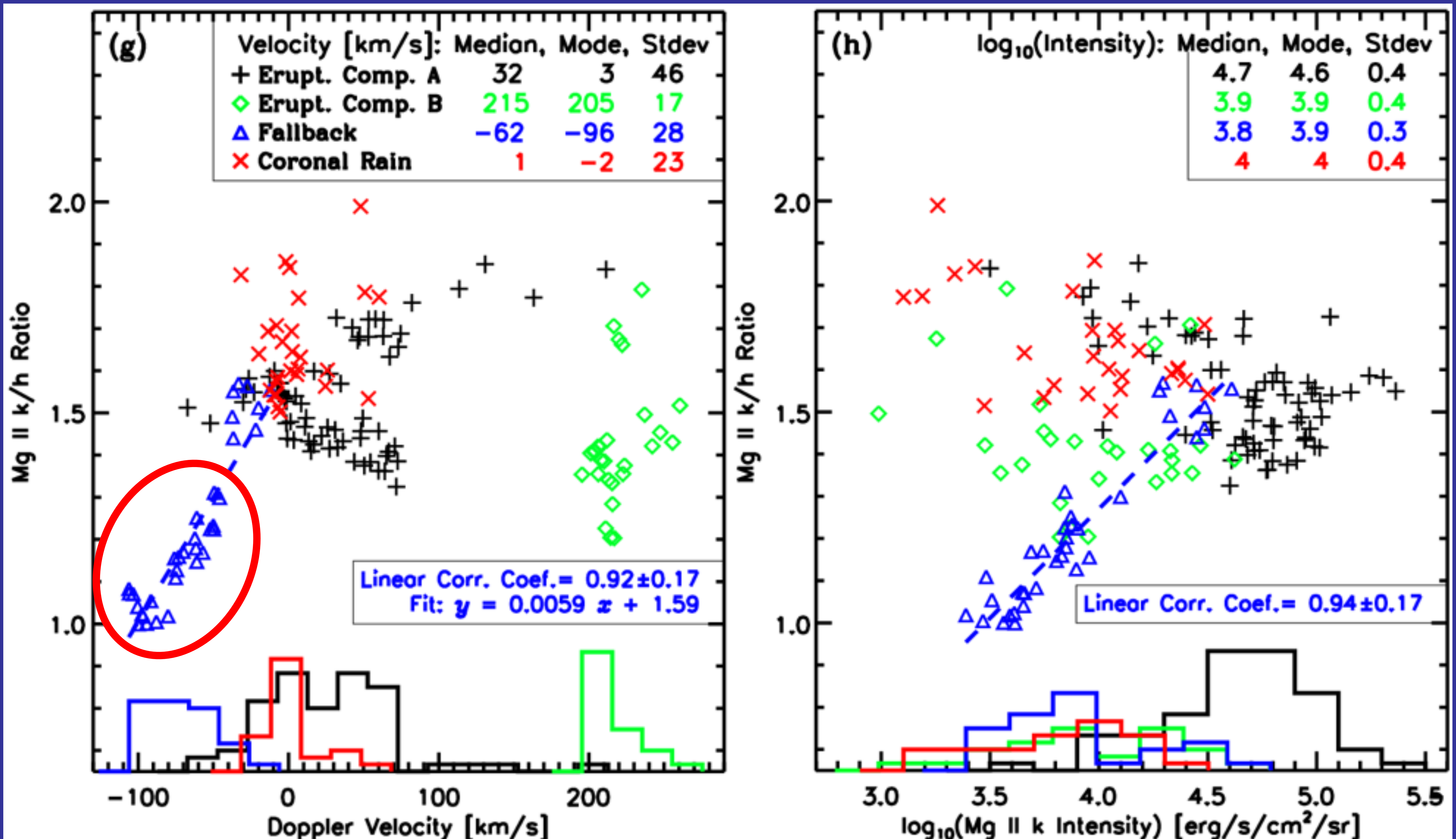


Prominence Eruption; Mg II k 2796 Å spectral fits

	Doppler Velocity	Nonthermal Line width
Return flows of the erupting prominence	***~100 km/s*** ***accelerate with time and distance***	***Narrow, ~10 km/s***
Persistent coronal rain at the loop-top	< 30 km/s	Broad, ~20 km/s

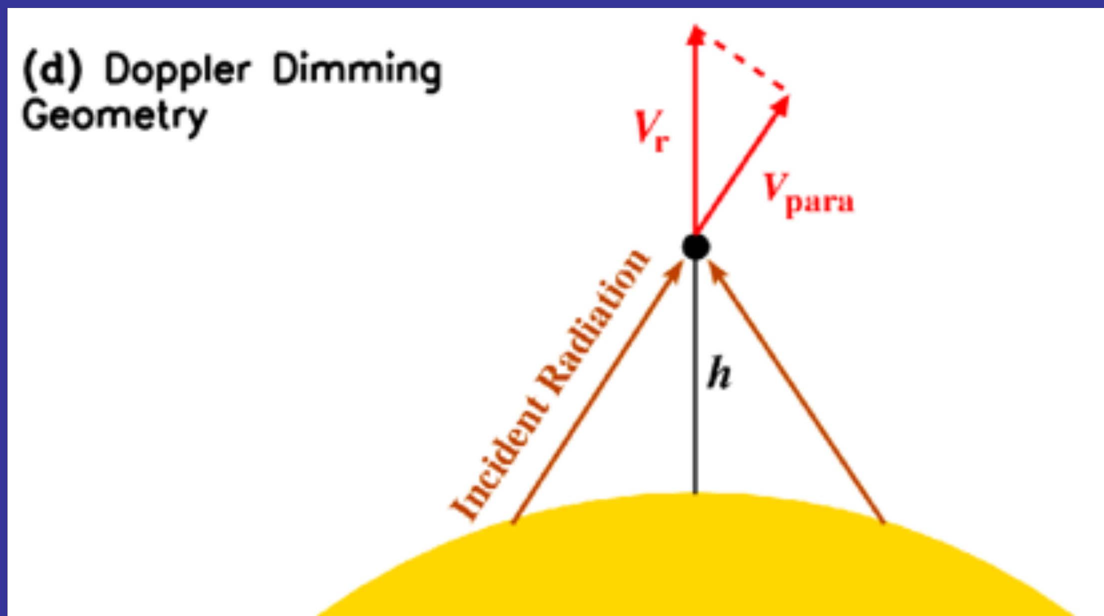


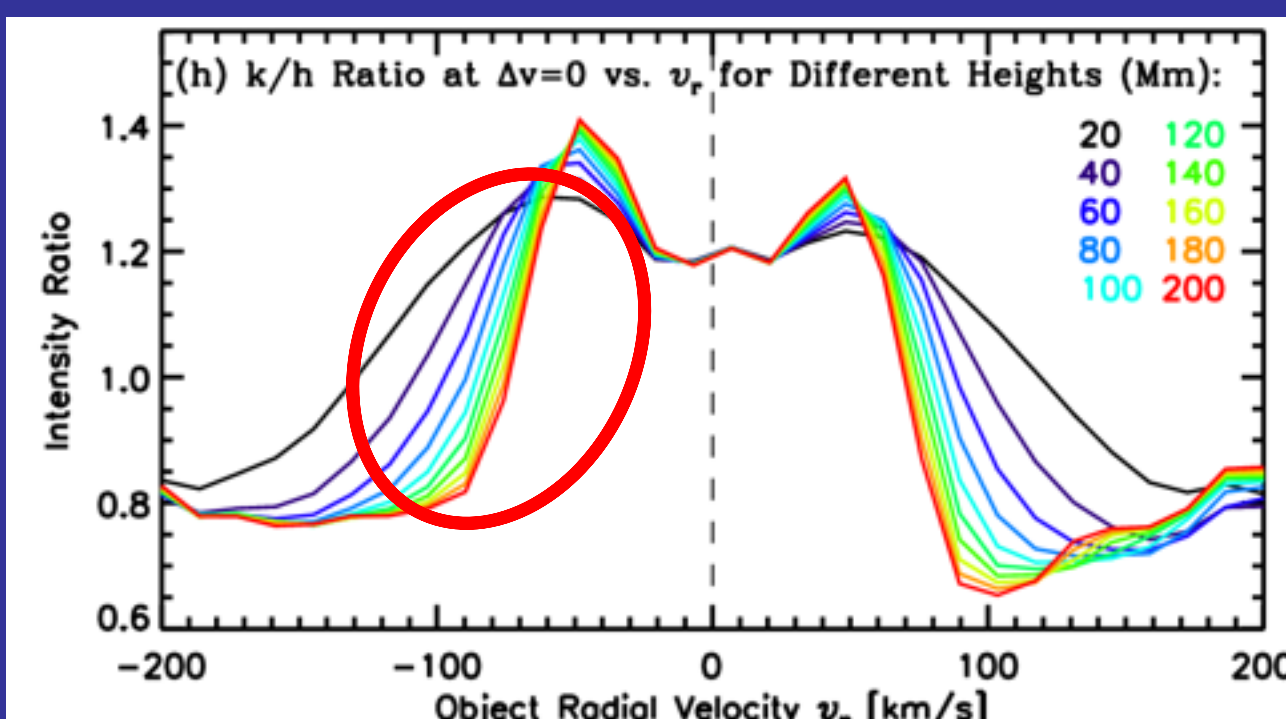
Mg II k 2796 Å and h 2803 Å integrated line ratio vs.
1) Doppler velocity 2) Intensity

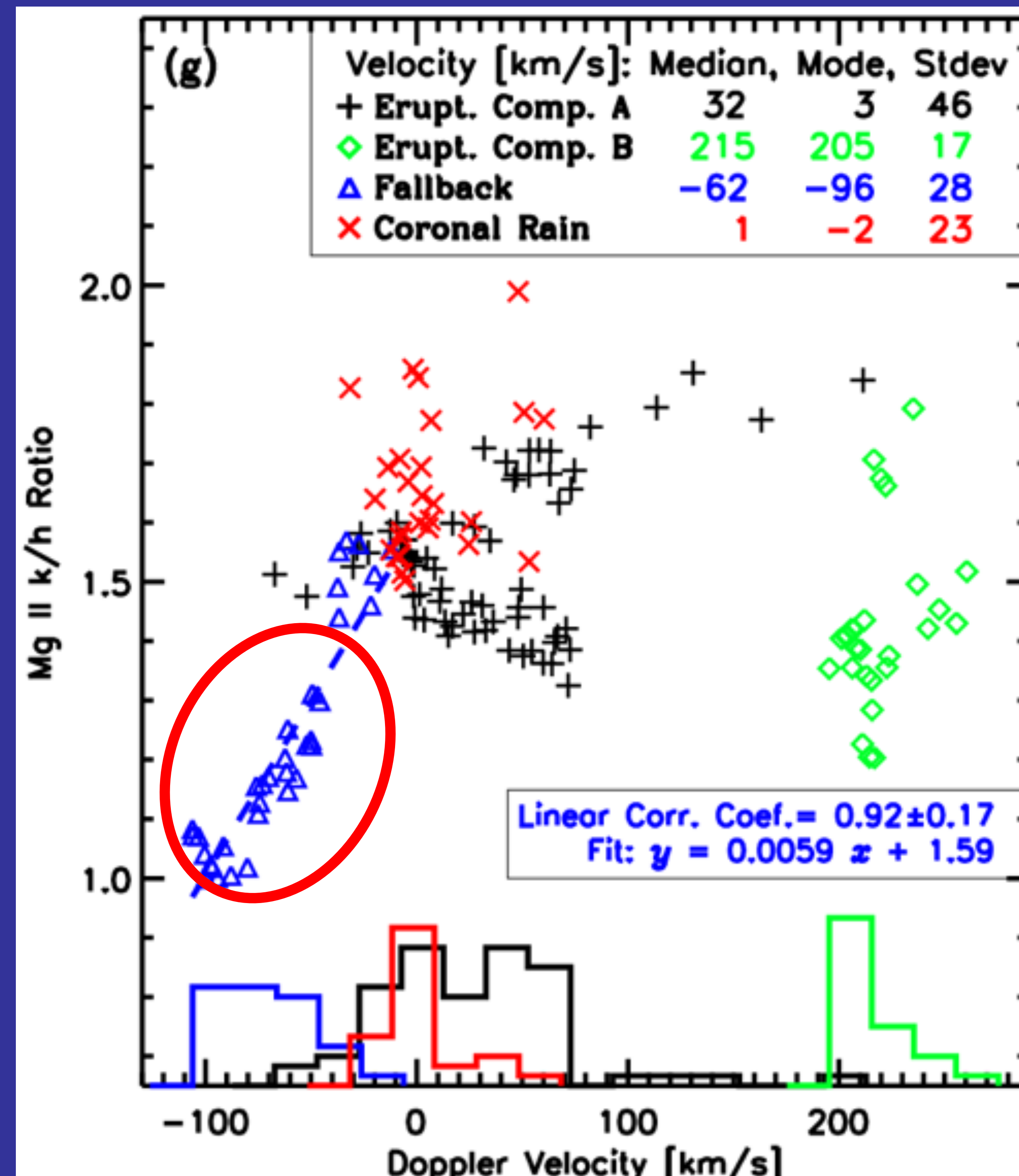


Surprisingly small ratio close to 1
(~2 expected for optically thin regime)

Doppler dimming estimate for Mg II k 2796 Å and h 2803 Å
Compare modeling with observation







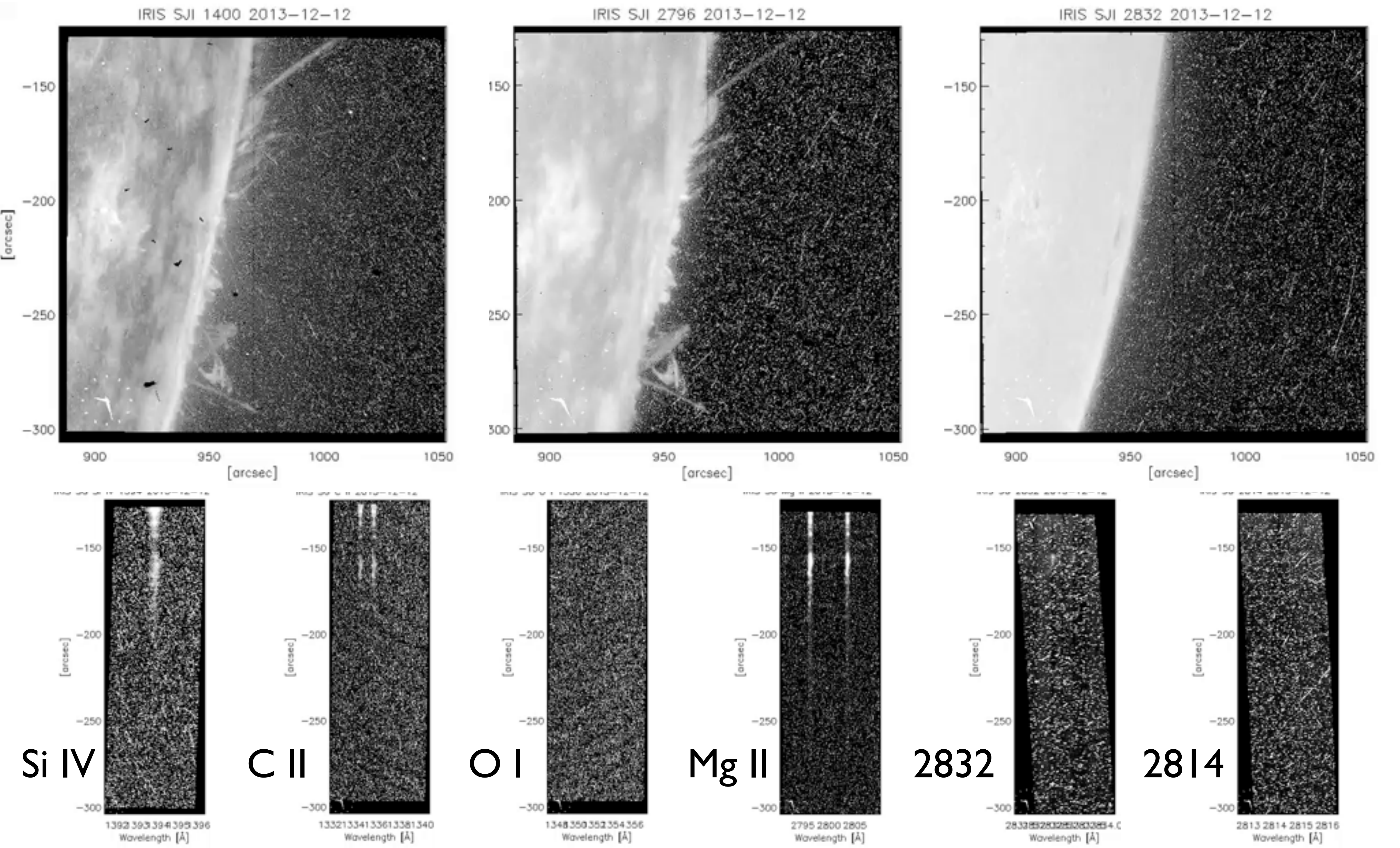
ISSI Team - coronal rain 23-27 February 2015

Non-thermal line broadening in coronal rain

Patrick Antolin

NAOJ

IRIS

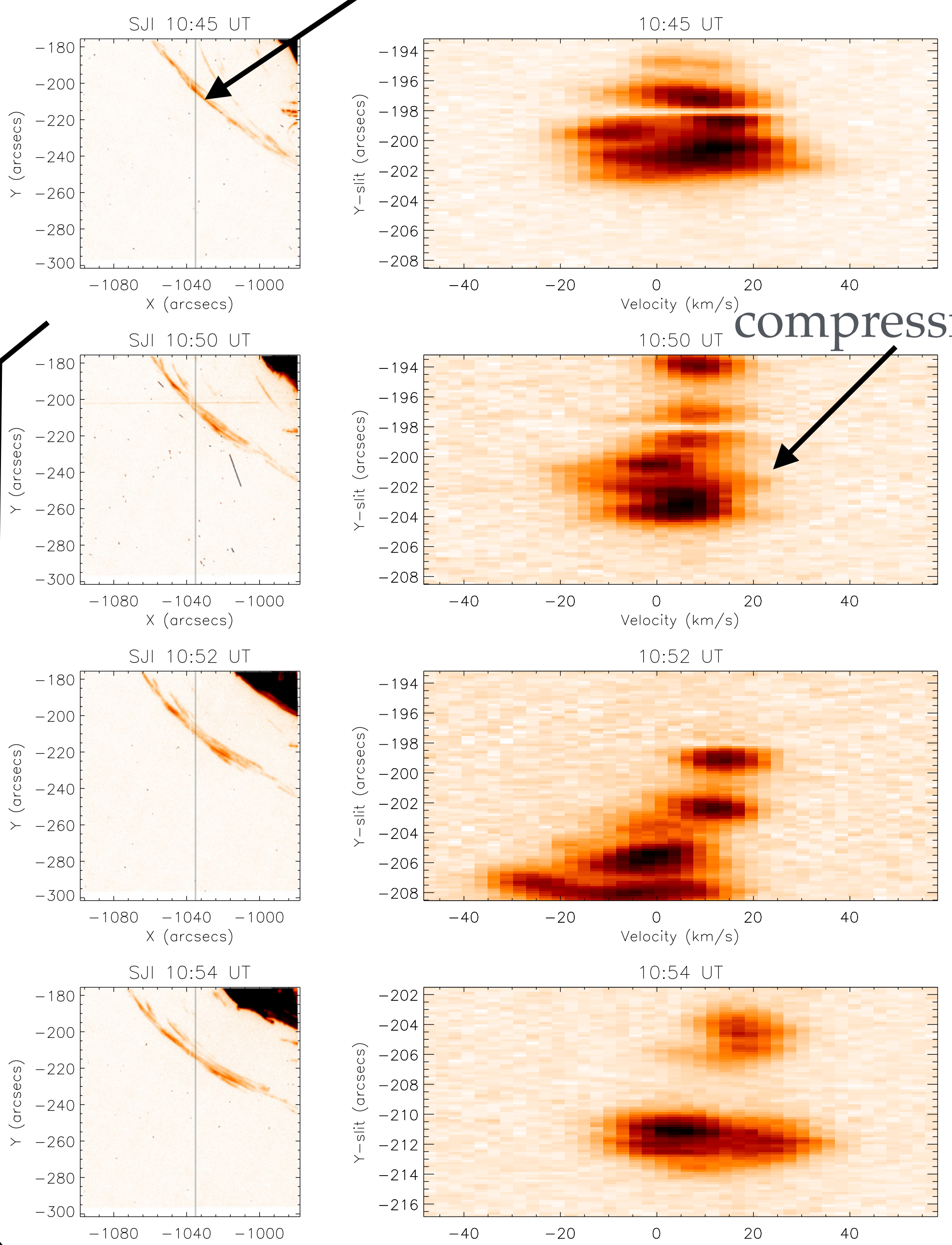

IRIS SJI 1400 2013-12-12
IRIS SJI 2796 2013-12-12
IRIS SJI 2832 2013-12-12
[arcsec]
Wavelength [Å]
Si IV
C II
O I
Mg II
2832
2814

Line profiles

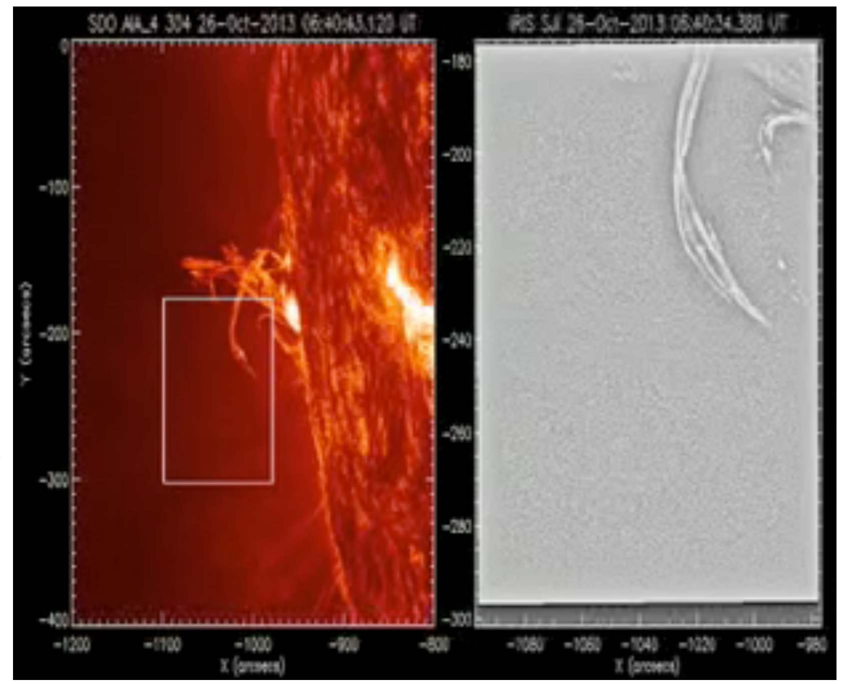
coronal rain

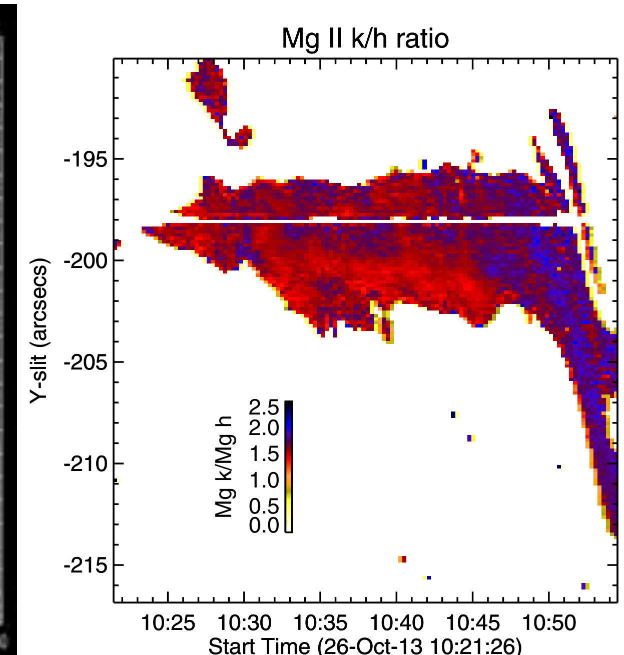
before impact of eruption

during impact



compression?

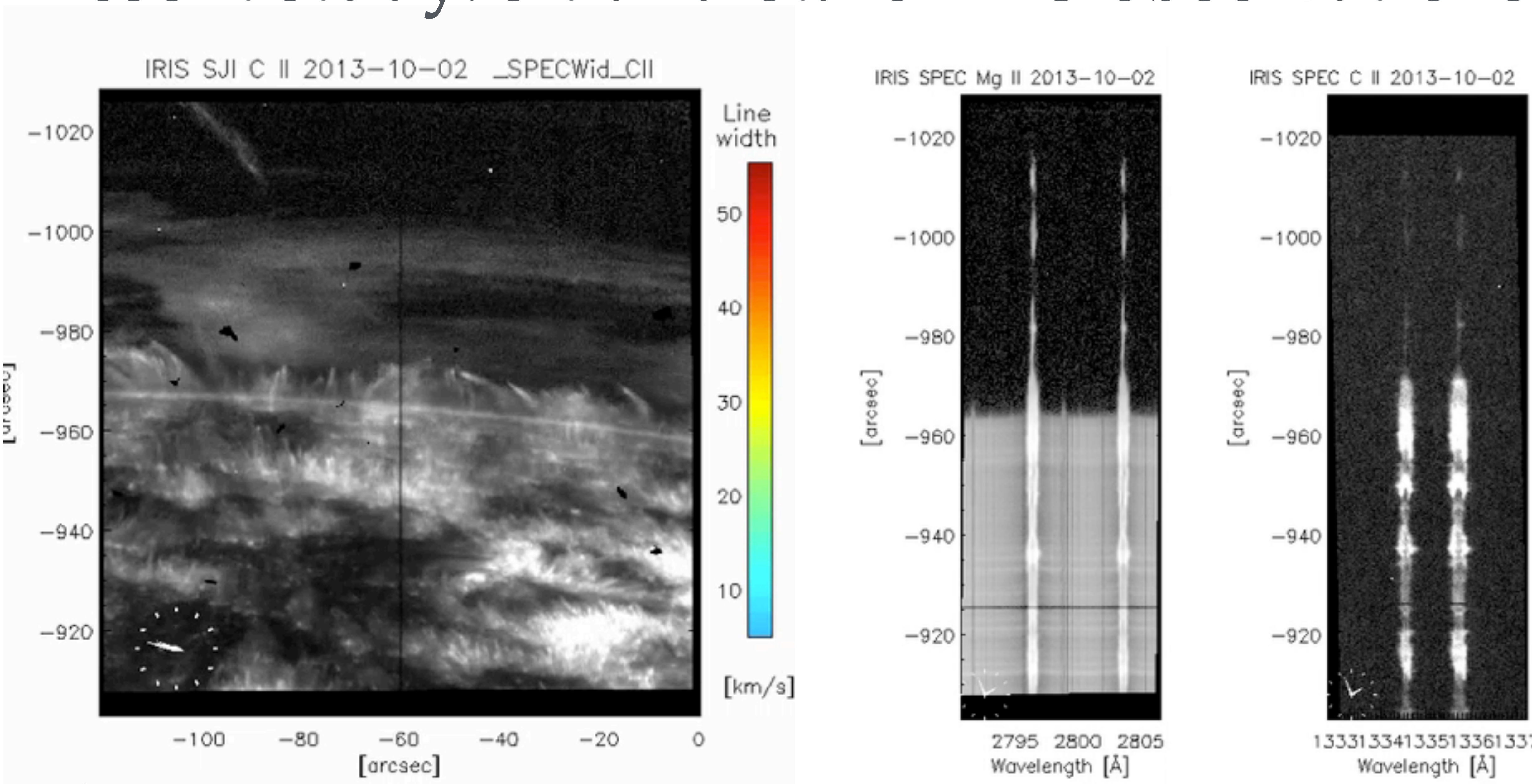




- Complex spectral evolution, mostly due to dynamics
- During impact of eruption: complexity momentarily reduced (compression?).
- k/h ratio increases 1.5->2.
- Significant plasma reorganisation occurs within loops during eruption
- Rain can serve as a probe for turbulence

Harra+ 2014

Present study: sit-and-stare IRIS observations



- IRIS/SJI: 1330 & 2796 (18 s)
- IRIS/SG: Mg II k&h (log T~4-4.2), C II 1334.53 Å & 1335.71 Å (~ log T = 4.3), Si IV 1393.78 Å & 1402.77 Å (log T~4.8) (9 sec)
- Semi-automatic detection of rain (variable intensity, clumpy)/prominence (continuous flow, constant intensity)
- ~ 8 hours -> statistical analysis of spectral characteristics

Estimates of non-thermal line broadening

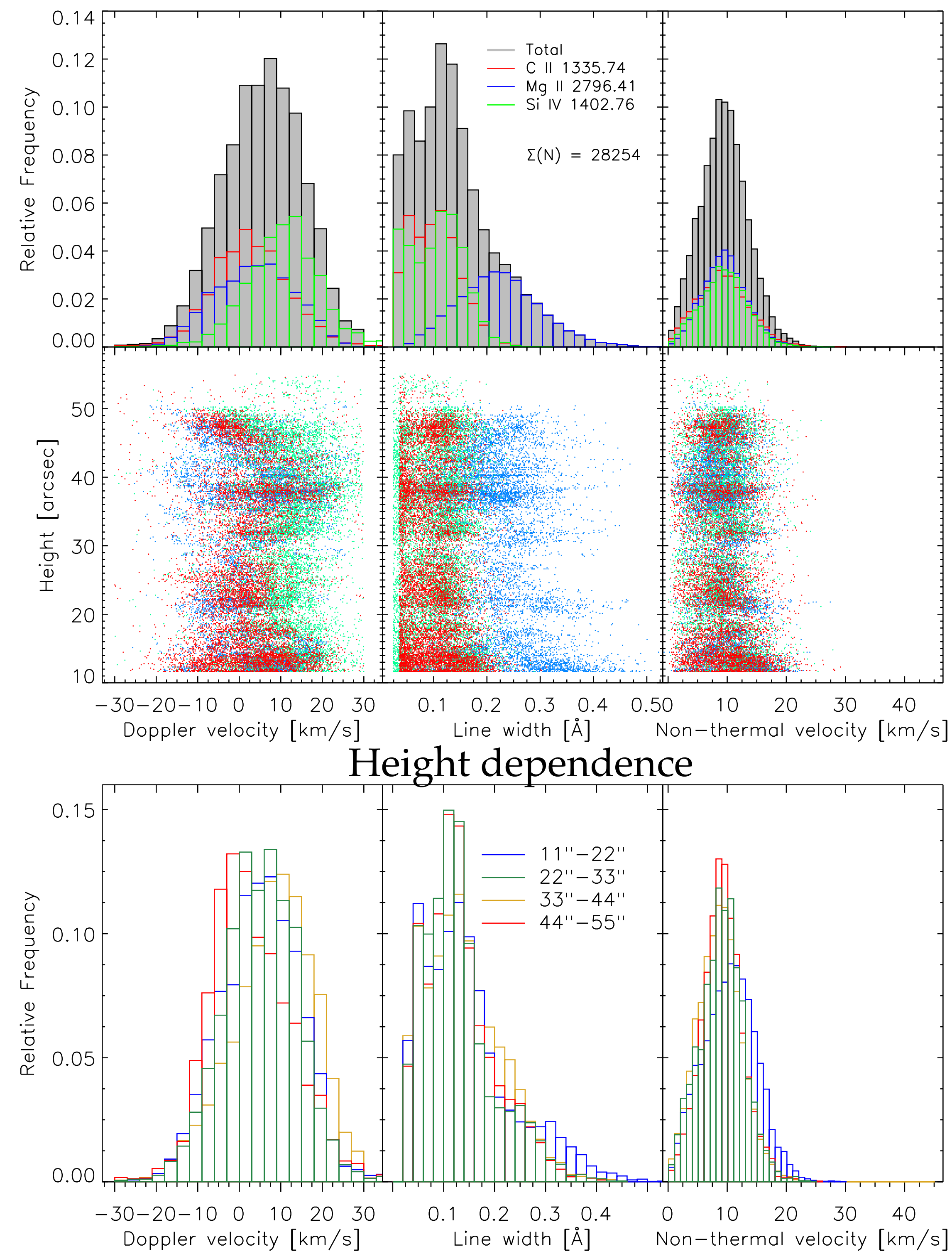
$$\mathrm{FWHM} = \left[\left(2\sqrt{2\log 2}\frac{\lambda_0}{c} \right)^2 \left(\frac{2k_B T}{m} + \xi_{\mathrm{nth}}^2 \right) + \xi_{\mathrm{inst}}^2 \right]^{\frac{1}{2}}$$

- Mostly single emission peaks
- Gaussian-like distribution of non-thermal broadening with values < 25 km/s and a peak ≲10 km/s
- Slightly lower values than previously reported for prominences (Parenti & Vial 2007) despite much higher resolution (similar to De Pontieu + 2014)
- No clear height dependence

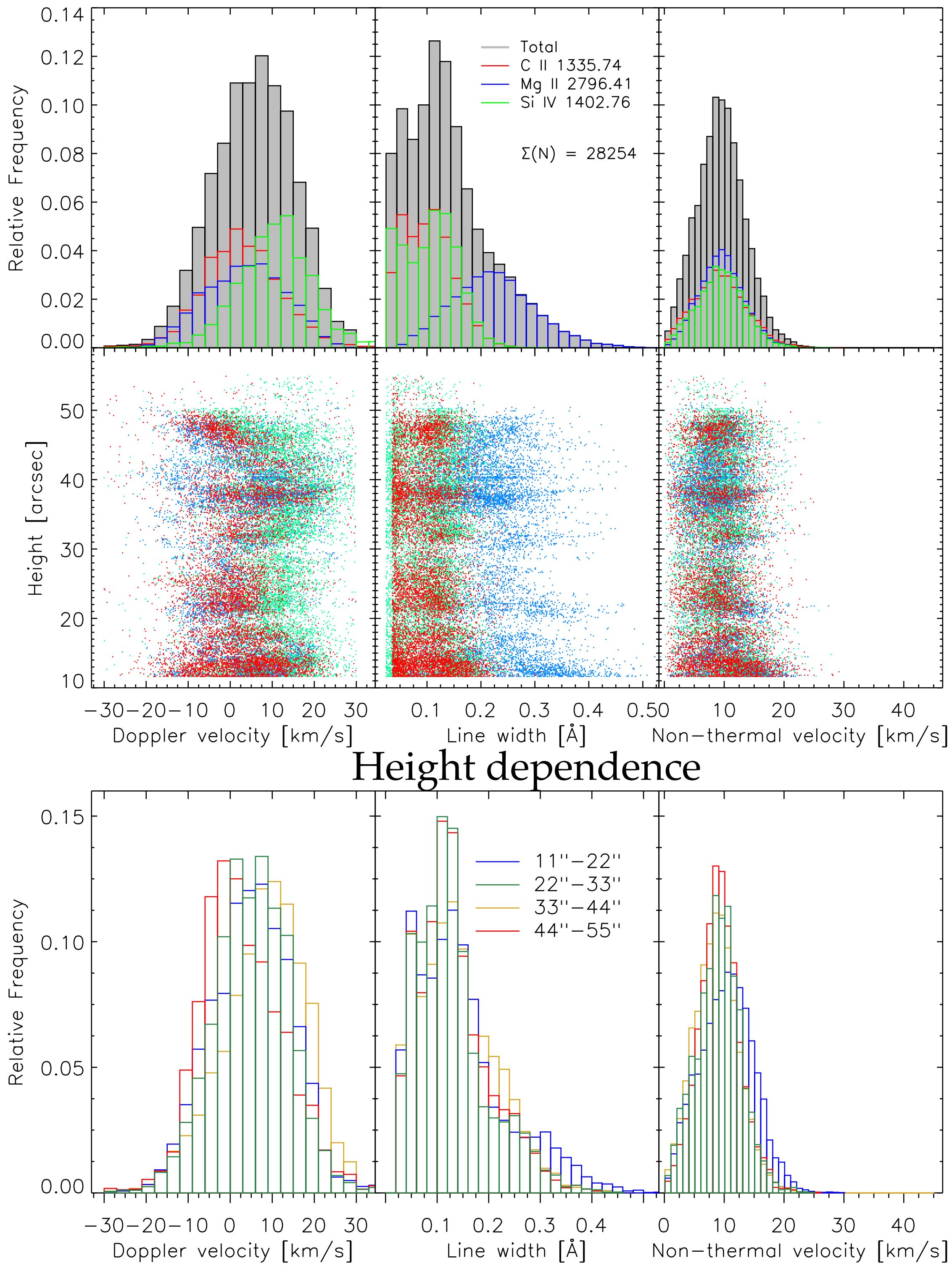
$\log(T_{\mathrm{Si\ IV}}) = 4.8$

$\log(T_{\mathrm{C\ II}}) = 4.3$

$\log(T_{\mathrm{Mg\ II}}) = 4.$

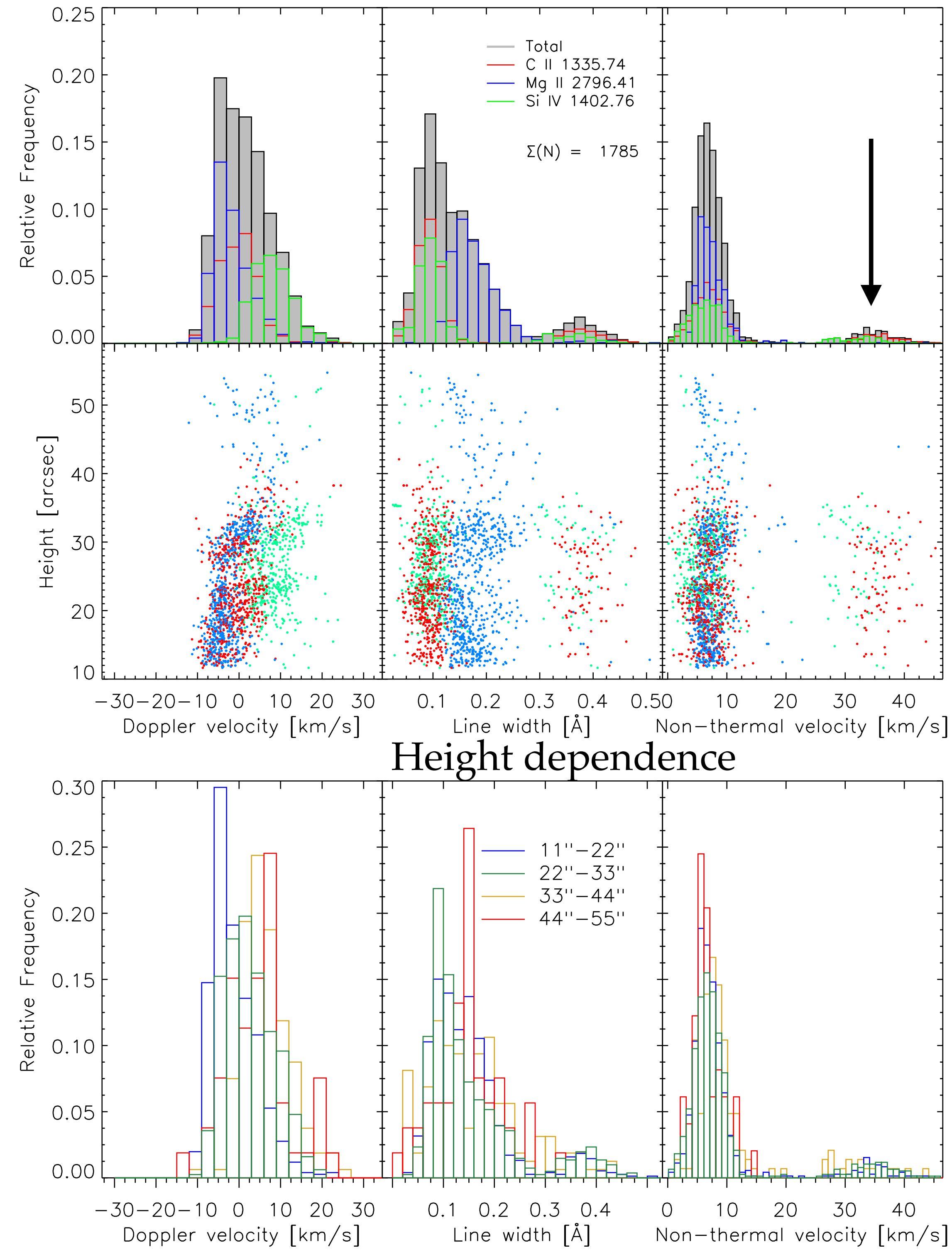


Coronal rain

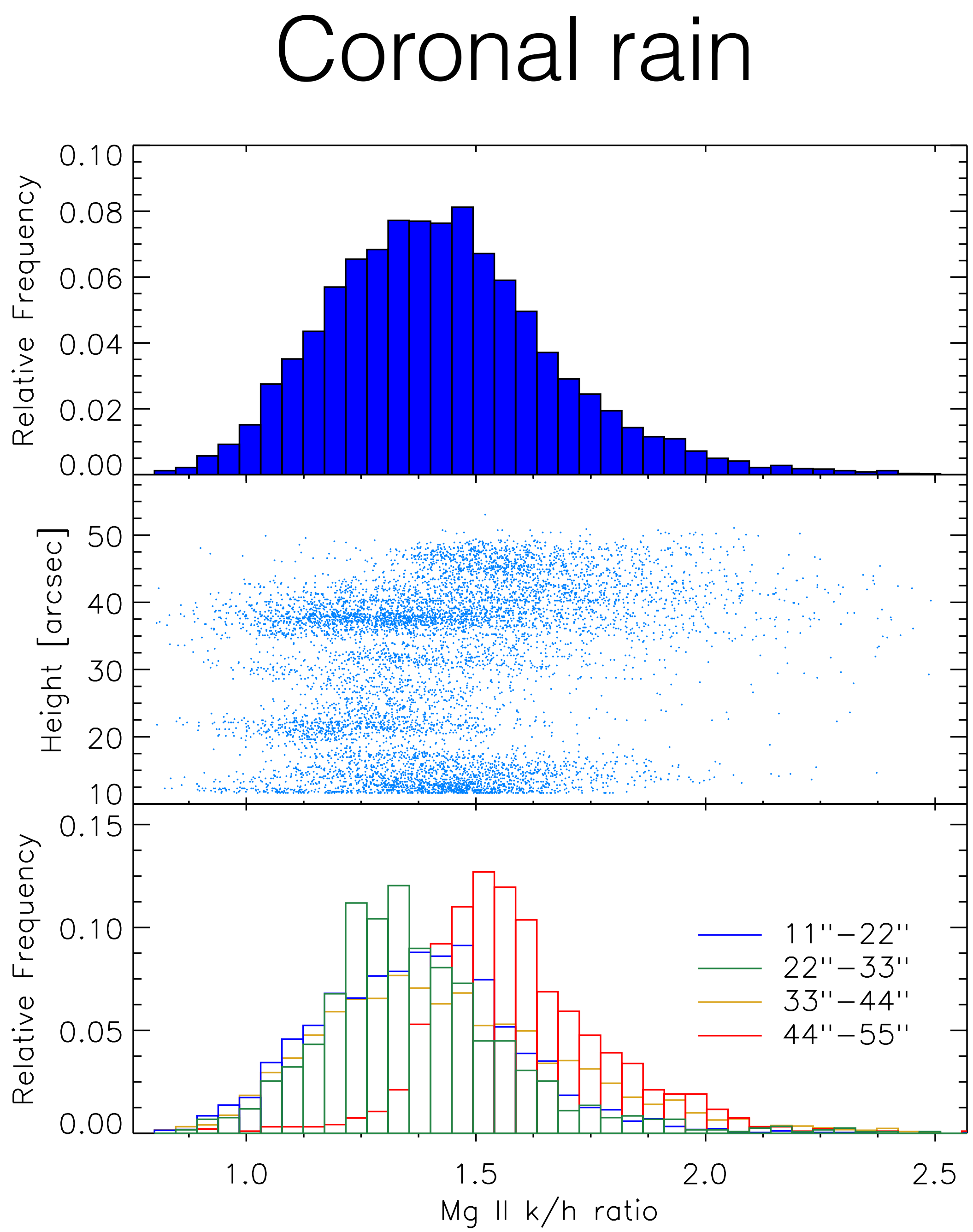


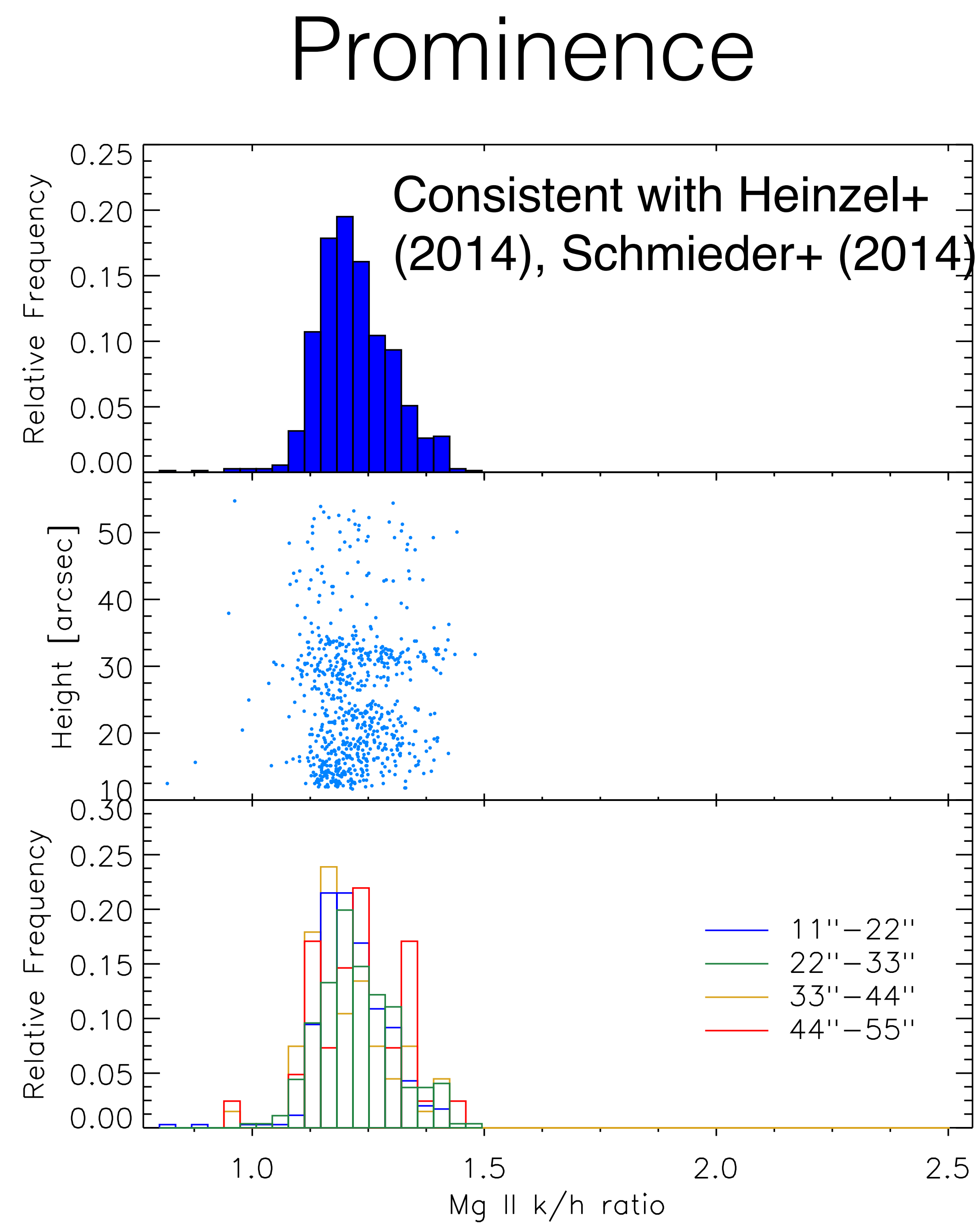
- Uniform with temperature

Prominence



- Double components, dependent on temperature





- k/h ratio decreases with height for coronal rain.
- Large range: very low values (even <1, ~optically thick), to >2 (~optically thin).
- Internal pressure changes in loops? (Harra+ 2014)

Conclusions

Cool material / Characteristic	**Coronal rain**	**Prominence**	**Eruptive fall-back**
Magnetic field	closed	closed	open
dynamics (downward)	Fast (~80 km/s), large range, lower than free-fall	Slow (~30 km/s), smaller range, lower than free-fall	Fast, close to free-fall
lengths	Clumpy (variable)	continuous	Clumpy (variable)
widths	strand-like (↓0.2”)	strand-like (↓0.2”)	strand-like
line profile	Narrow and broad Gaussian (~10-20 km/s)	(non)-Gaussian (reversed) (~10 & 30 km/s)	Narrow gaussian (~10 km/s)
Optical thickness	thin (thick) k/h ~ 1.1-1.7	thick (thin) k/h ~ 1.1-1.5	thick? (dimmed) k/h ~ 1.0-1.4

Thank you!