Thermal coupling through the atmosphere

Tiago M. D. Pereira

Rosseland Centre for Solar Physics

Invited Talk

3. Magnetic coupling and mass flux through the atmosphere

Thermal coupling through the atmosphere

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Energy flows through the solar atmosphere in mysterious ways. Structures may appear out of nowhere through rapid heating or cooling, plasma can evaporate or condense quickly. Understanding the thermal coupling through the atmosphere is key to uncover the origin of many solar phenomena. To probe different temperatures, we must combine spectral lines formed over a wide range of plasma properties, a challenging task. The advent of the *IRIS* mission has made this task easier by providing a broad thermal coverage and high spatial resolution. Combining *IRIS* with other observatories has significantly improved our understanding of phenomena as diverse as spicules, penumbral micro-jets, Ellerman bombs, the unresolved fine structure, and many others in both quiet and active regions. I will cover some of *IRIS*'s successes in mapping the thermal coupling between the chromosphere and transition region. More generally, I will argue how the multi-instrument approach is becoming an essential tool to understand phenomena that can no longer be regarded as separate manifestations in different layers, and are intrinsically multi-thermal.

Thermal coupling through the atmosphere

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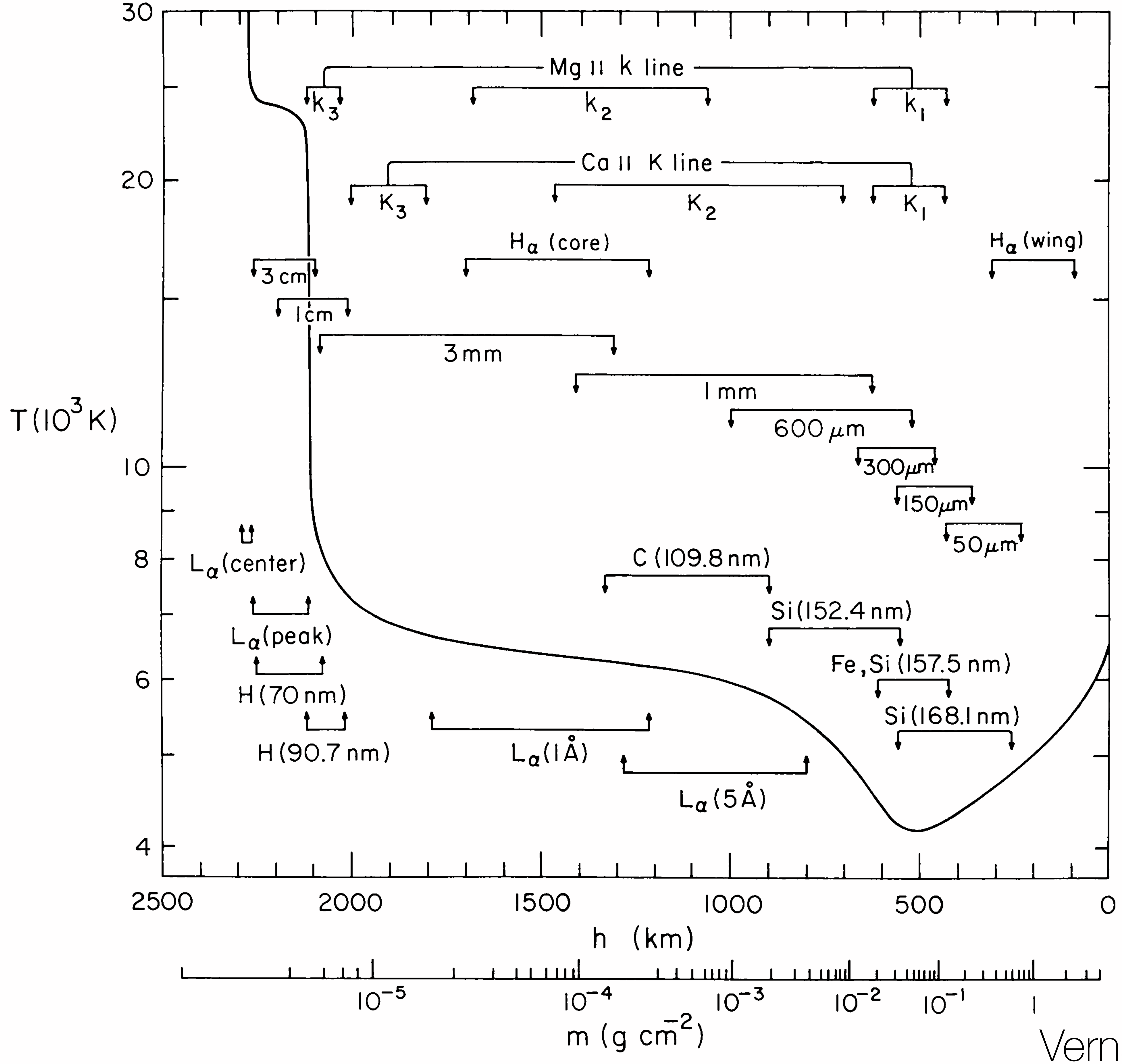
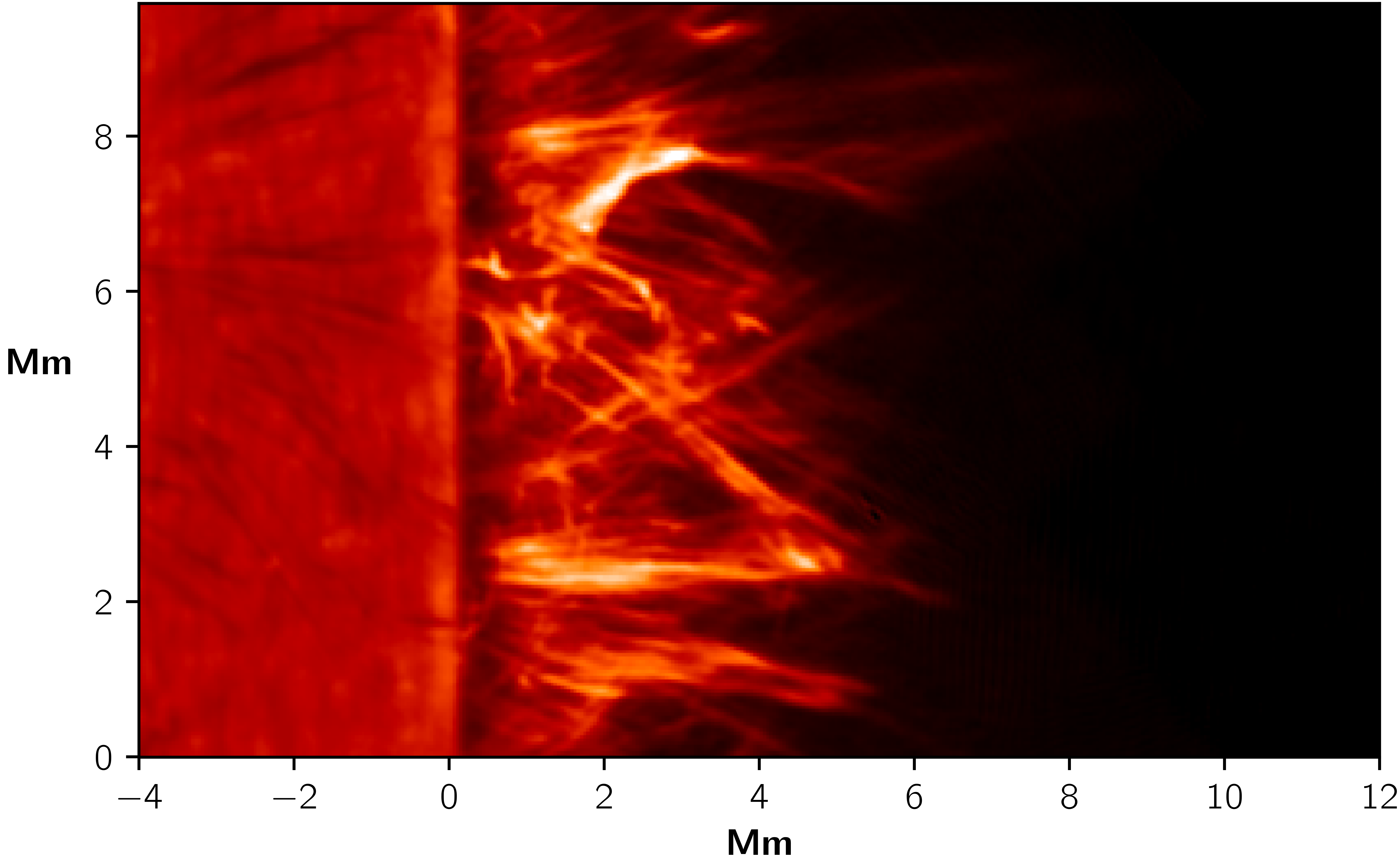


Vernazza et al. (1981, ApJS 45)



Mm
8
6
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2
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−4
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6
8
10
12
Mm

Mm
8
6
4
2
0
–4
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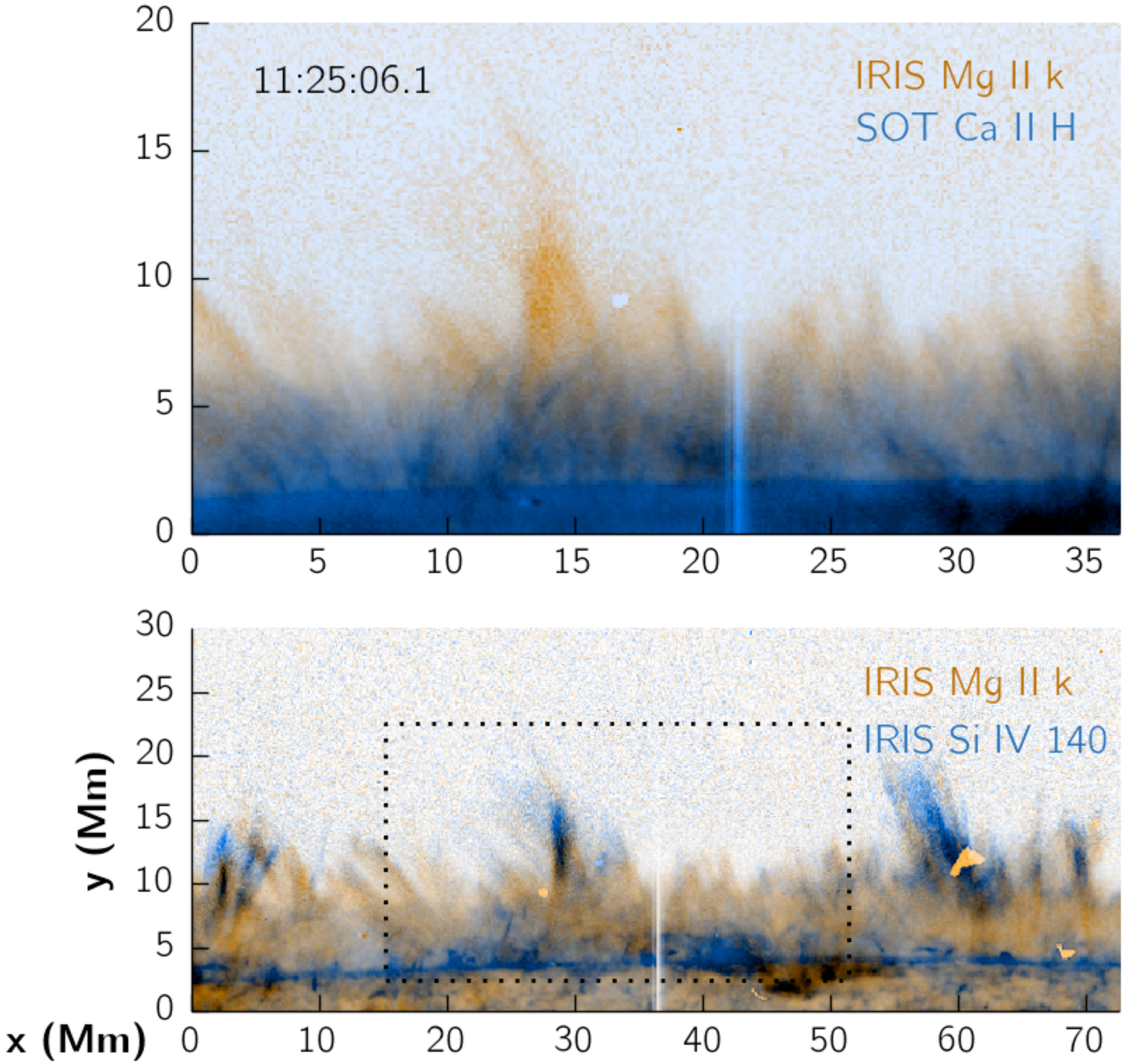
0
2
4
6
8
10
12
Mm
10^5
10^4
T (K)

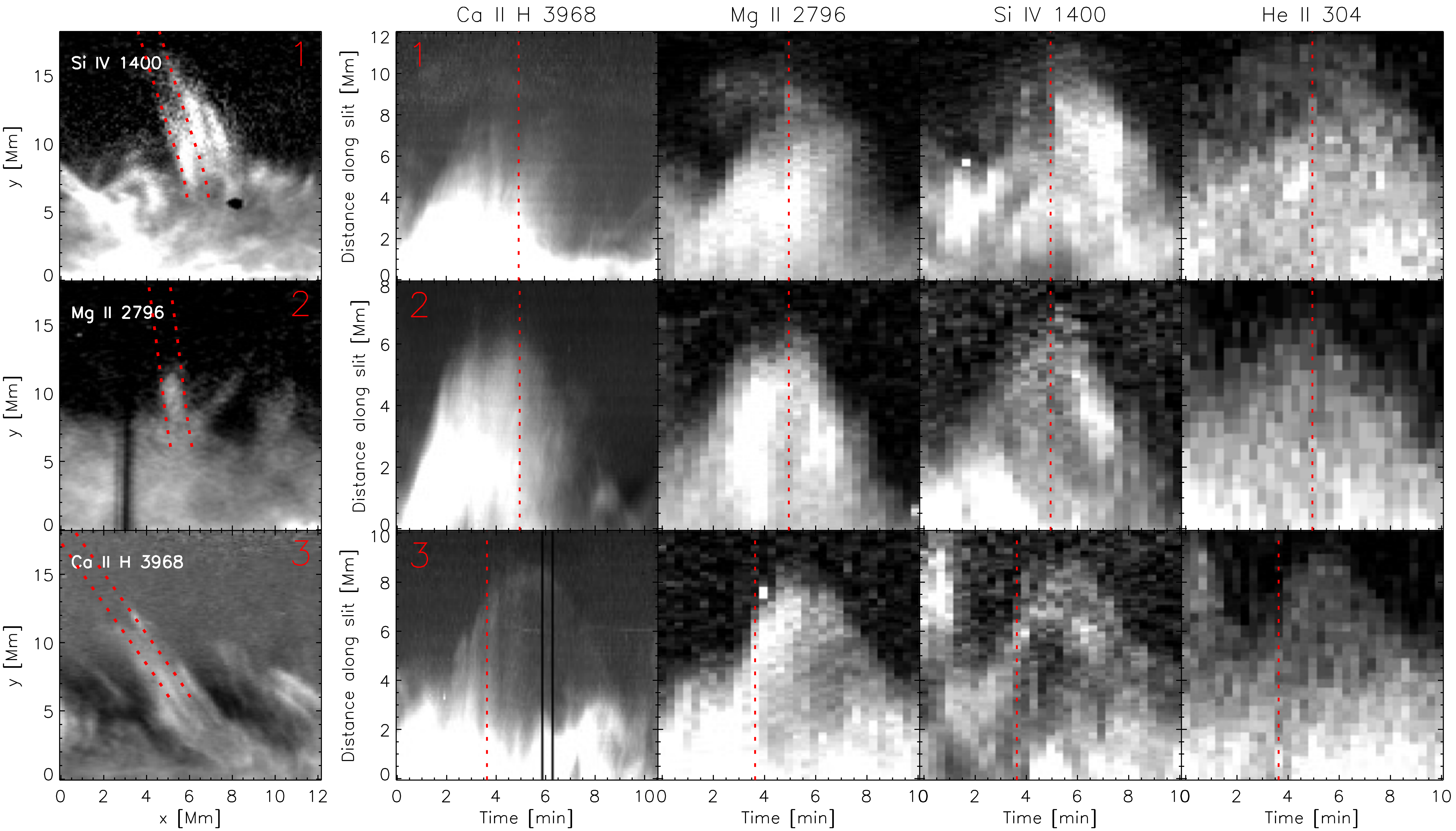
Spicules

Spicules



TMDP et al. (2014, ApJL 792)

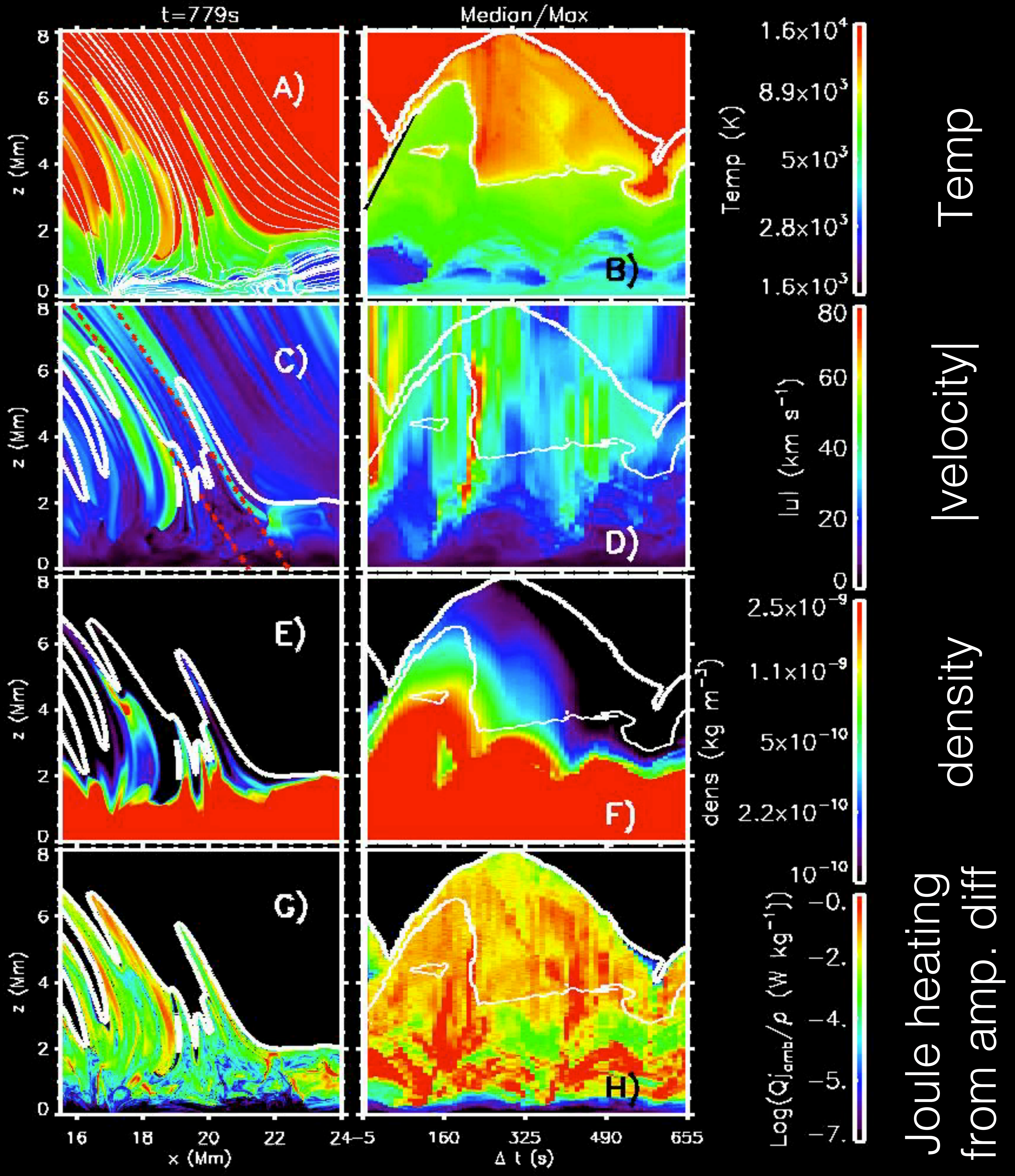
57.0 s
170.9 s
284.8 s
398.8 s
512.7 s
626.7 s
SOT Ca II H
IRIS Mg II k
IRIS Si IV
AIA He II
80 km s^{-1}
Mm
Length (Mm)
Time (s)
TMDP et al. (2014, ApJL 792)



Skogsrud et al. (2015, ApJ 806)

Spicules reproduced in Bifrost 2.5D model with ion-neutral effects

Martínez-Sykora et al. (2017, Science 6344)

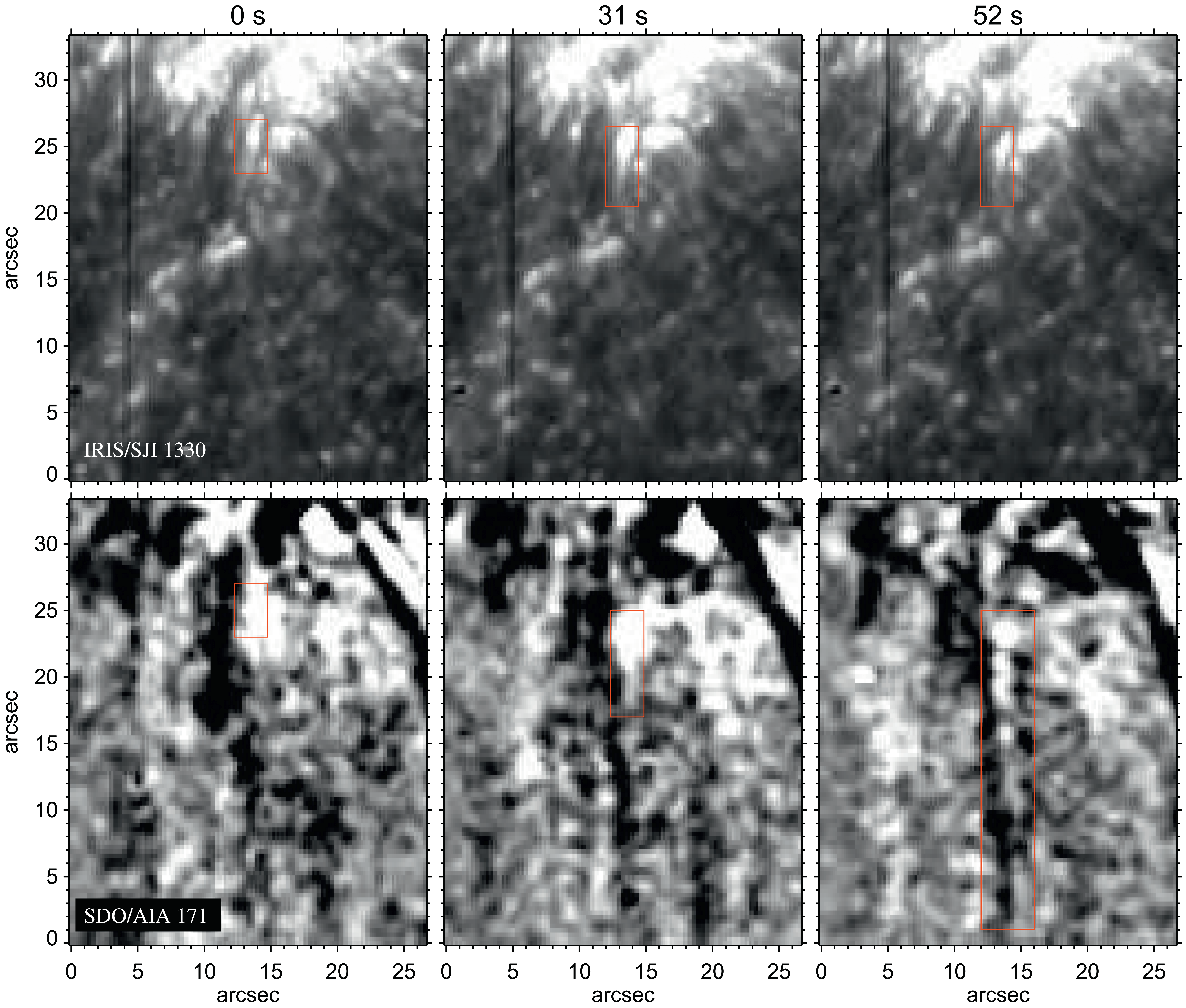


Heating of spicules to at least TR temperatures occurs naturally in radiative MHD simulations

Ambipolar diffusion in low-density spicular environment has a key role

Martínez-Sykora et al. (2017, Science 6344)

Propagating Coronal Disturbances (PCDs)



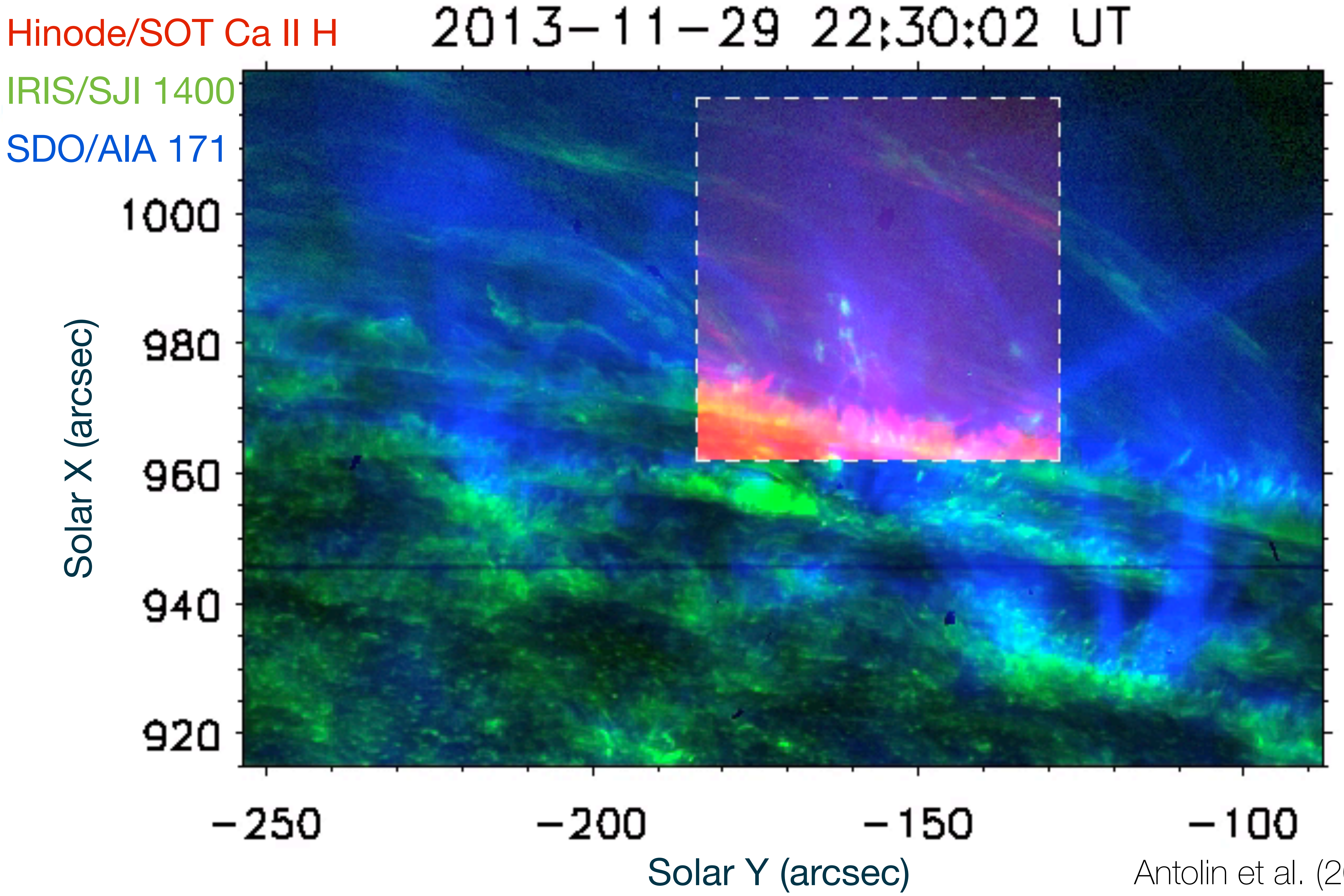
Krzysztof Barczynski's talk earlier today

See Bart De Pontieu's and Ineke De Moortel's talks later today!

Bryans et al. (2016, ApJL 829)

Coronal rain

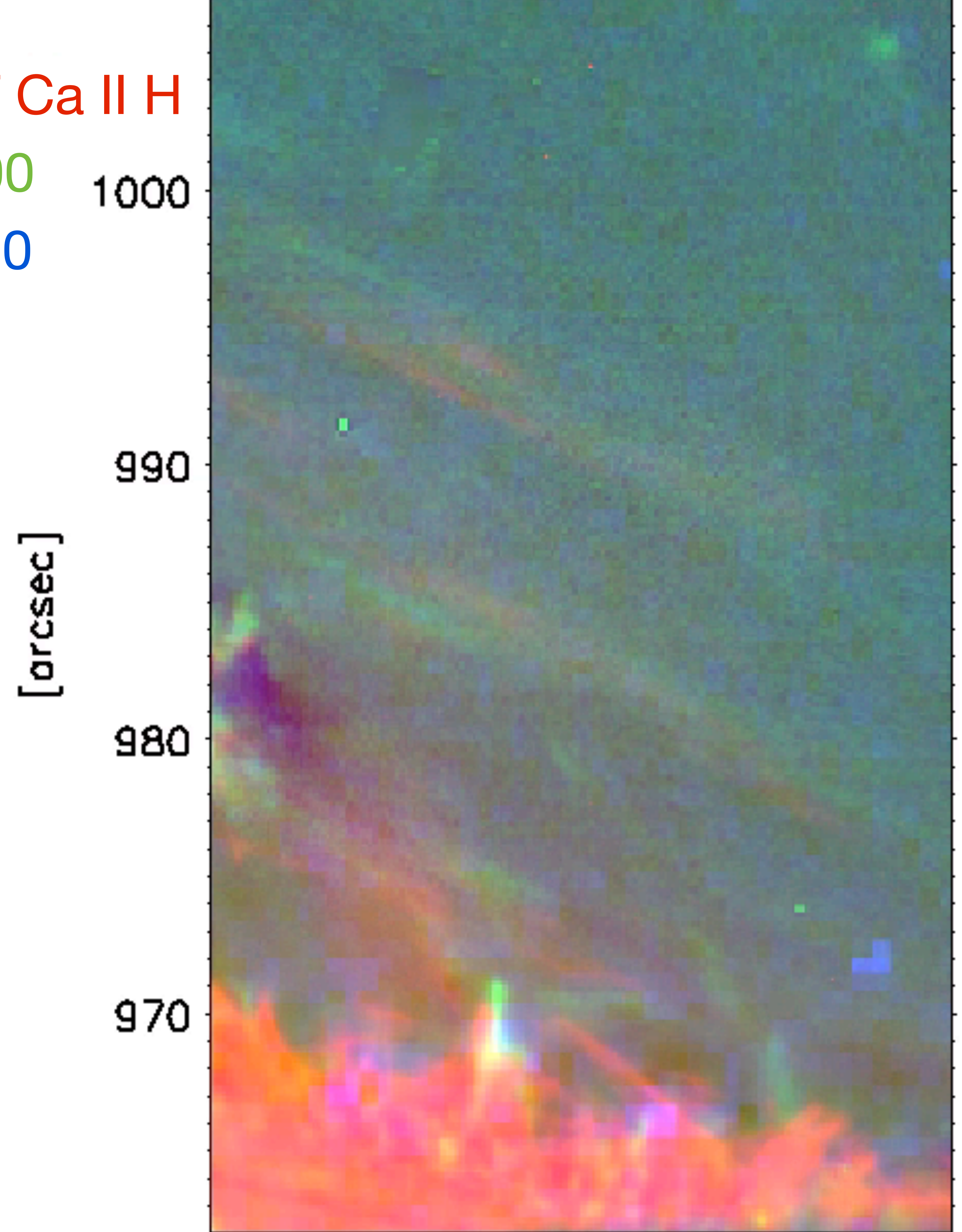
Coronal Rain



Antolin et al. (2015, ApJL 806)

Coronal Rain

Hinode/SOT Ca II H
IRIS/SJI 1400
IRIS/SJI 1330

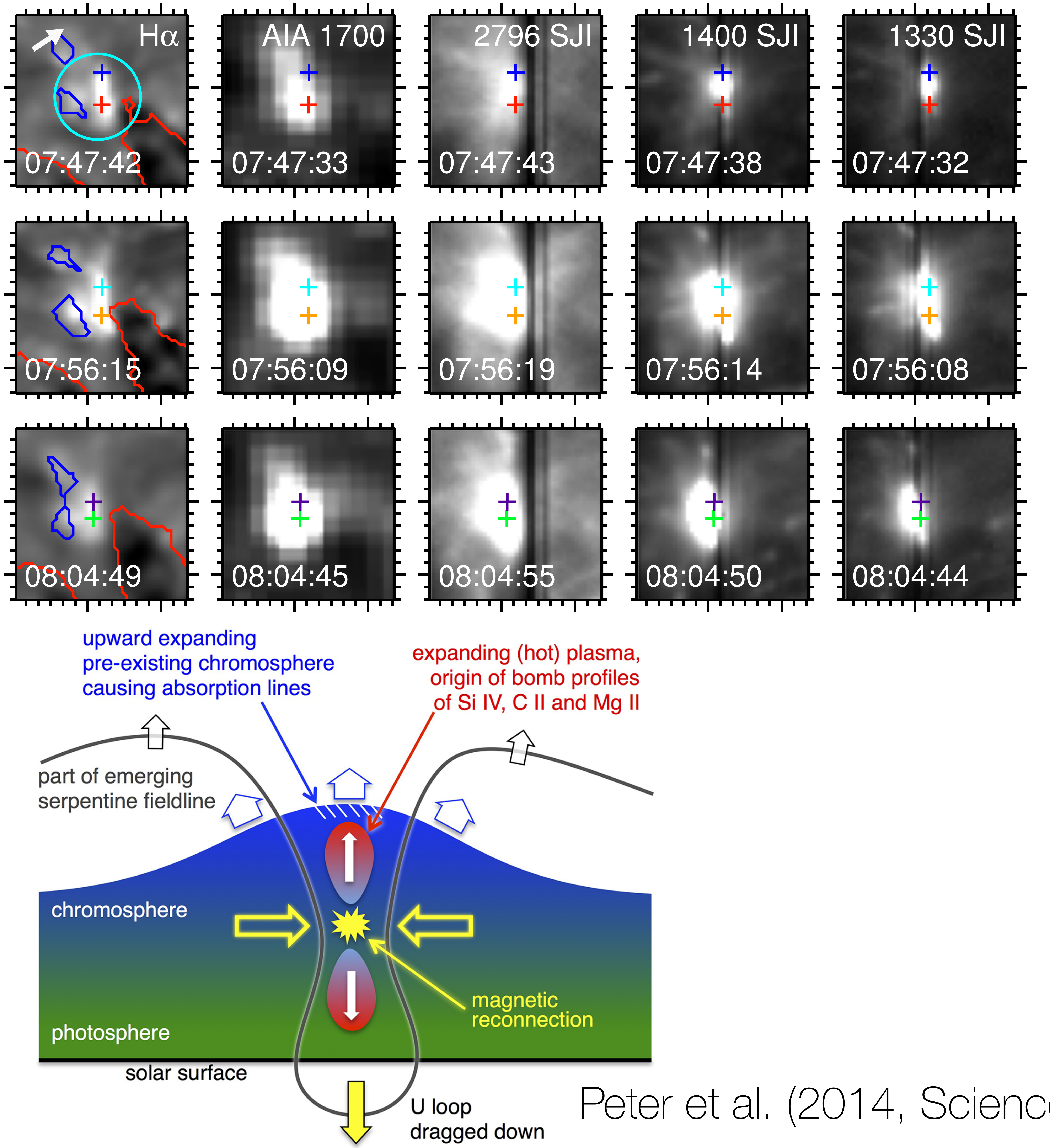


- Progressive cooling from TR to chromosphere
- Significant cooling before clumps reach the surface
- Still some plasma co-exists at coronal temperatures
- Thin layer (<0.33”) from chromosphere to TR temperatures

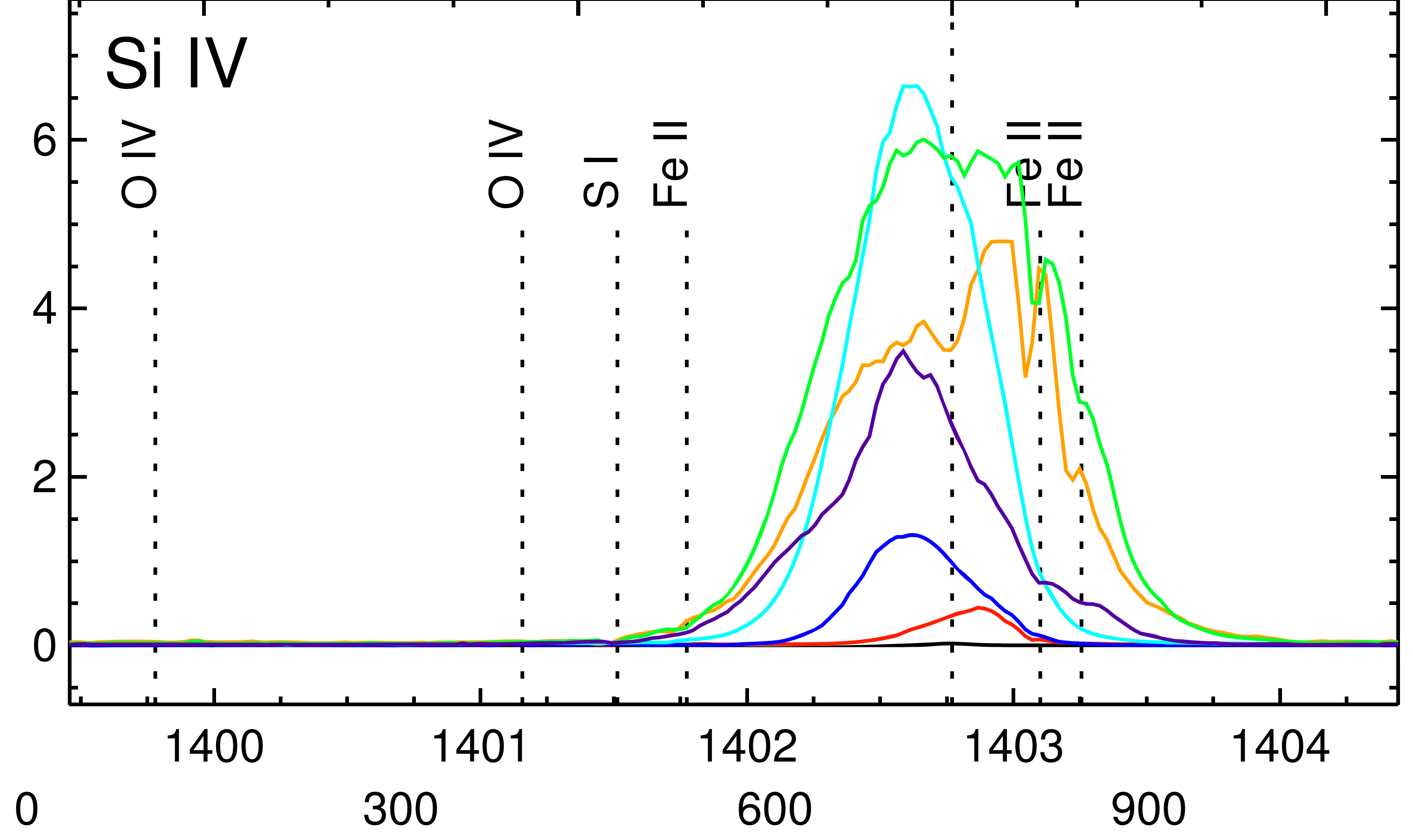
Antolin et al. (2015, ApJL 806)

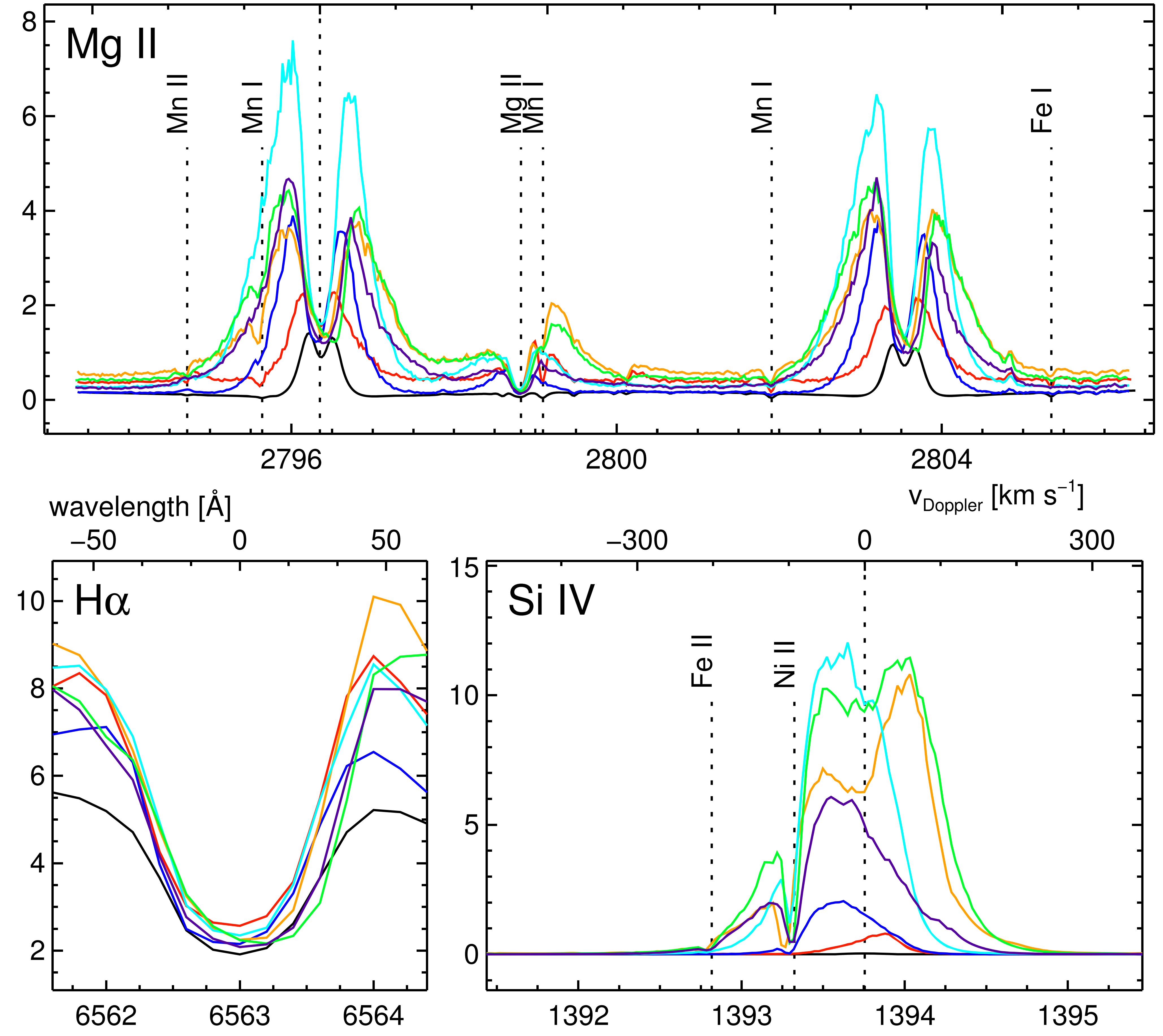
UV bursts

UV Bursts



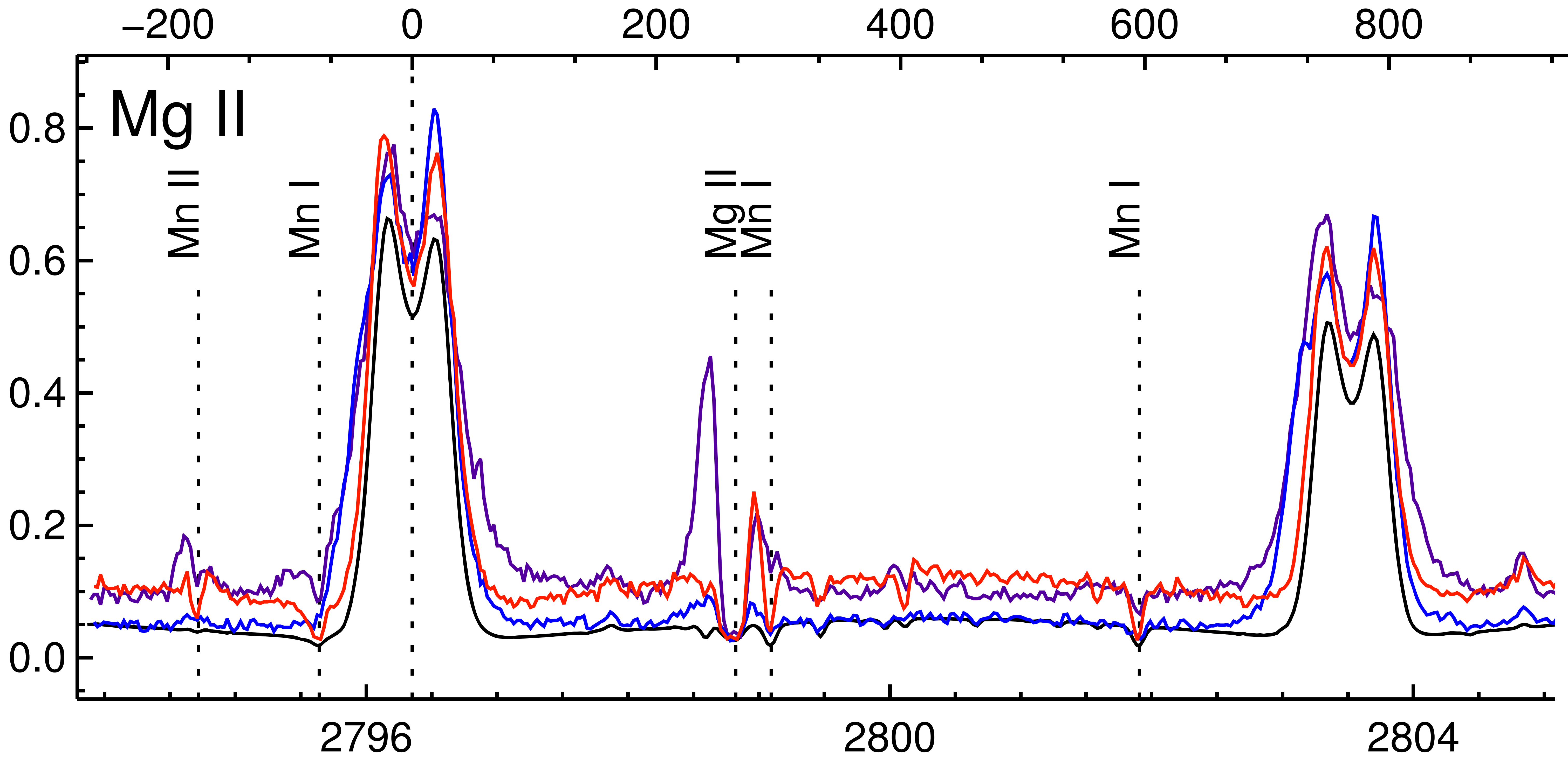
Peter et al. (2014, Science 6207)

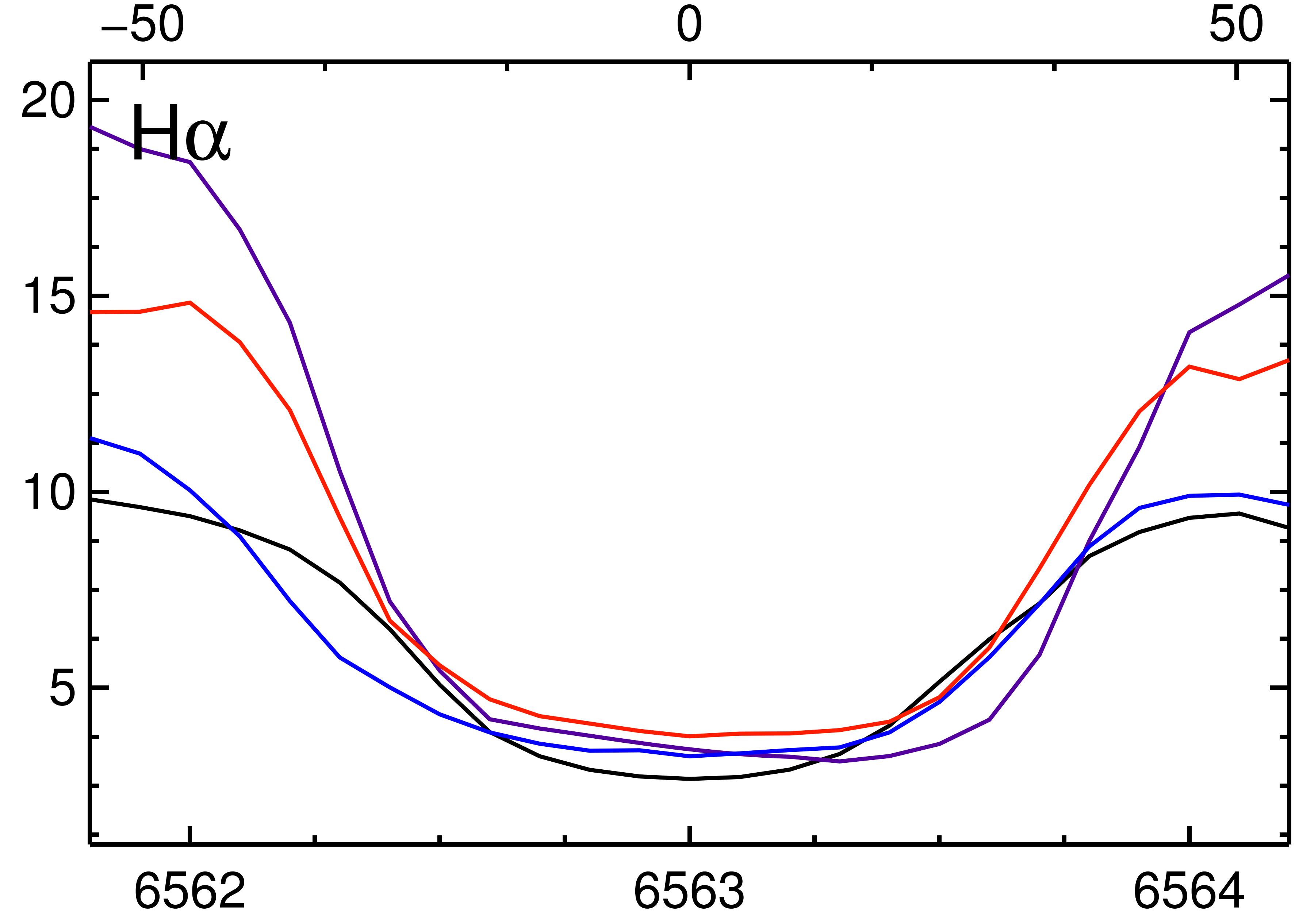




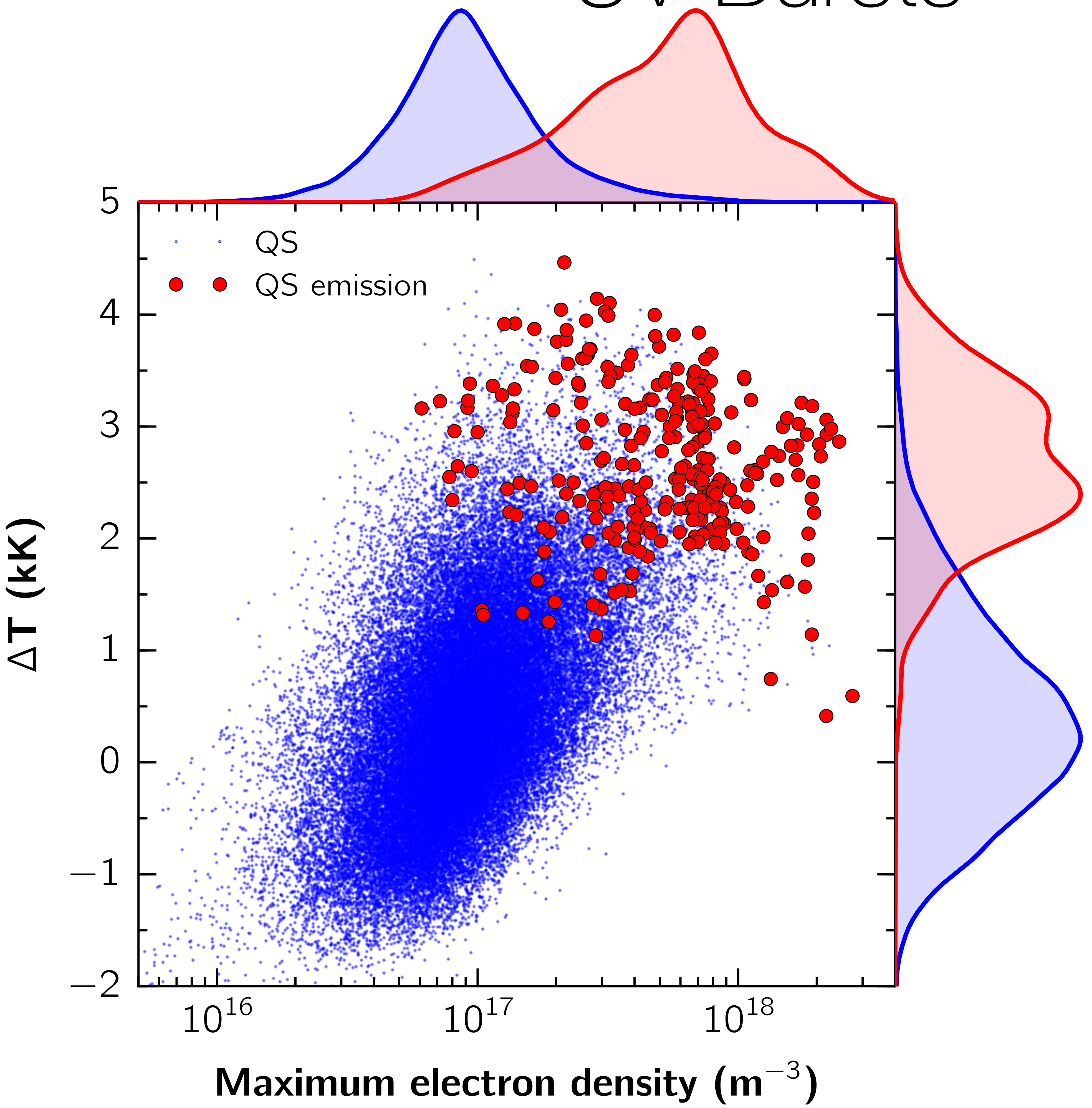
Vissers et al. (2015, ApJ 812)

UV Bursts





Vissers et al. (2015, ApJ 812)

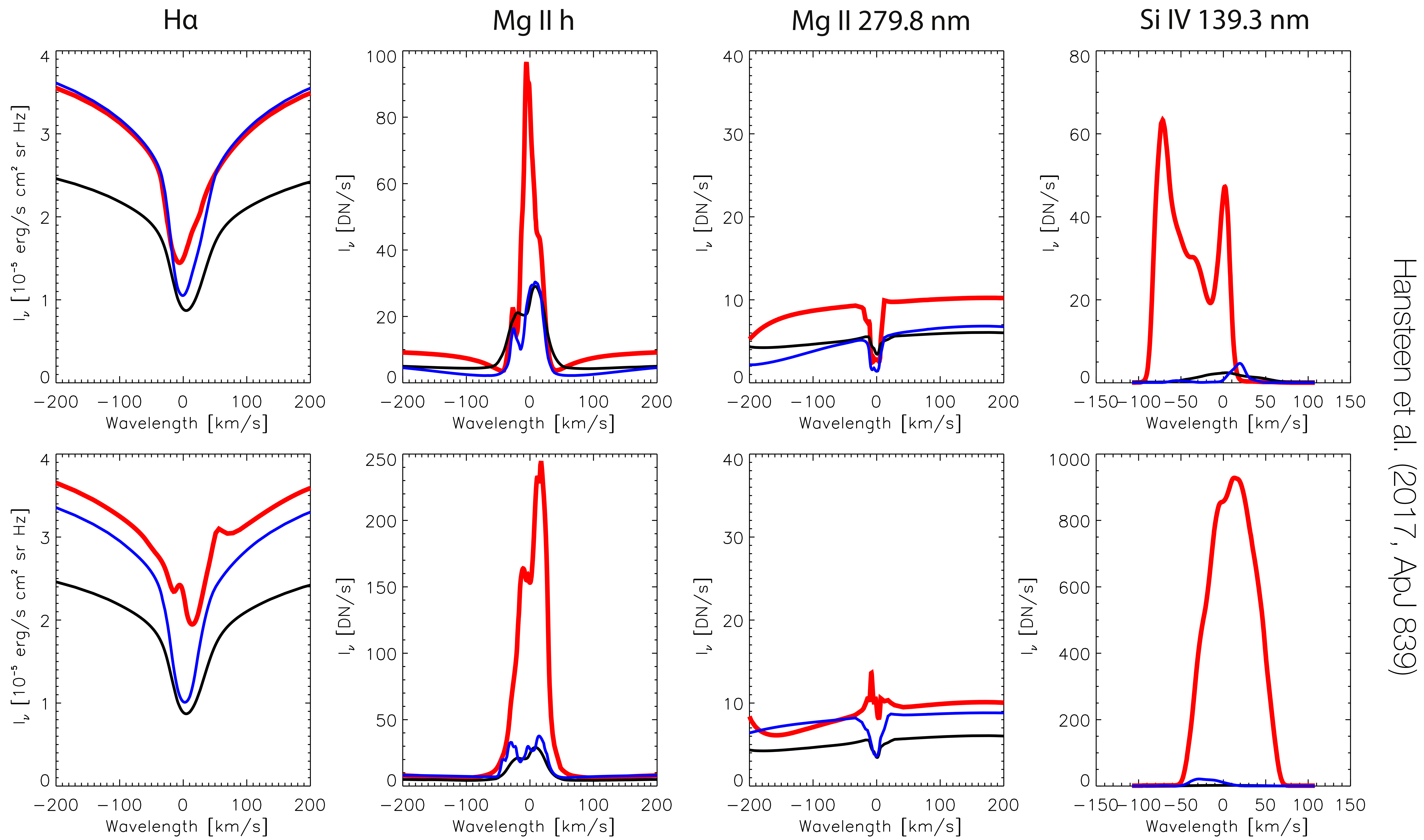


TMDP et al. (2015, ApJ 806)

Hansteen et al. (2017, ApJ 839)

Also, Sanja Danilovic talk earlier today.

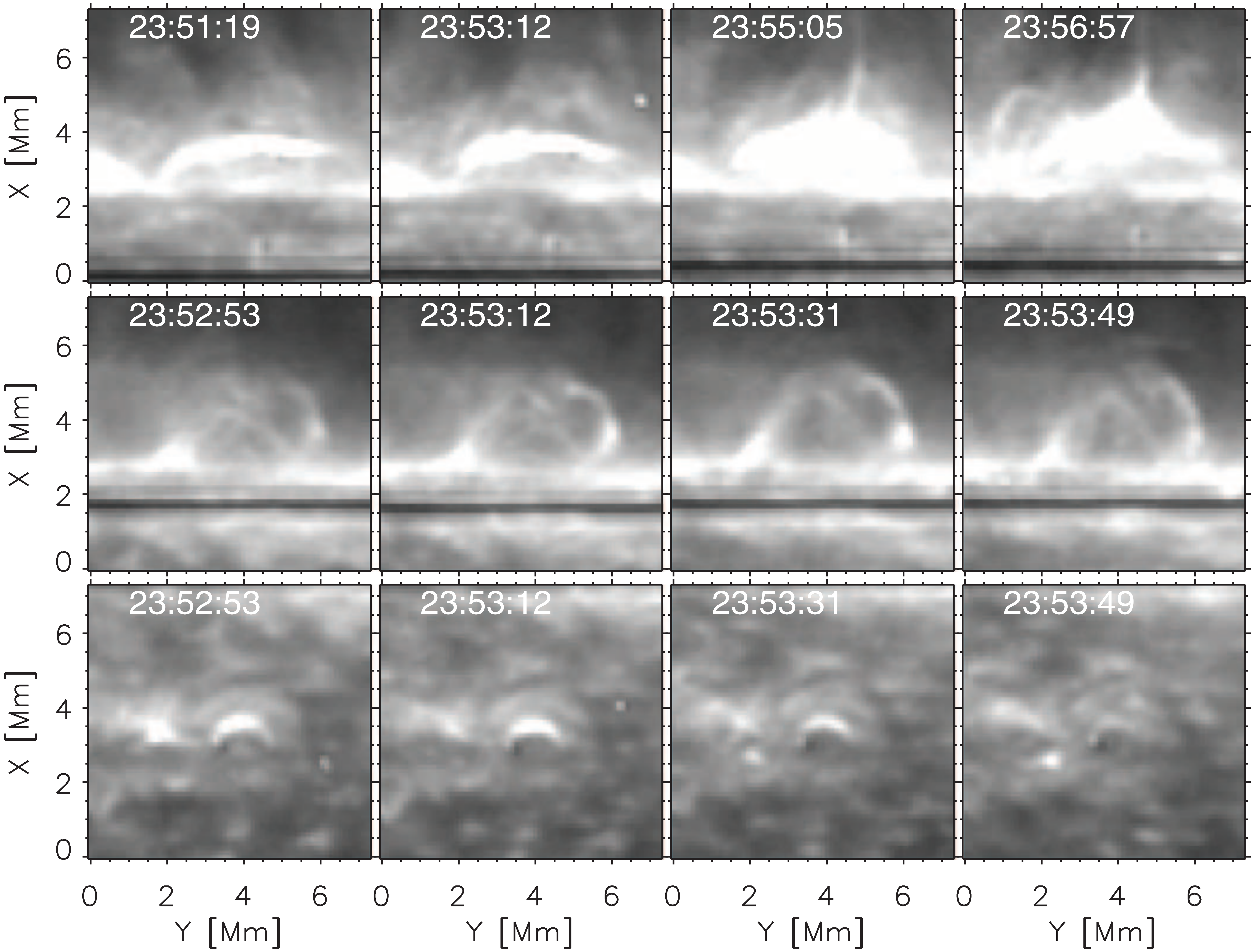
See Viggo Hansteen's talk tomorrow at 09:30.



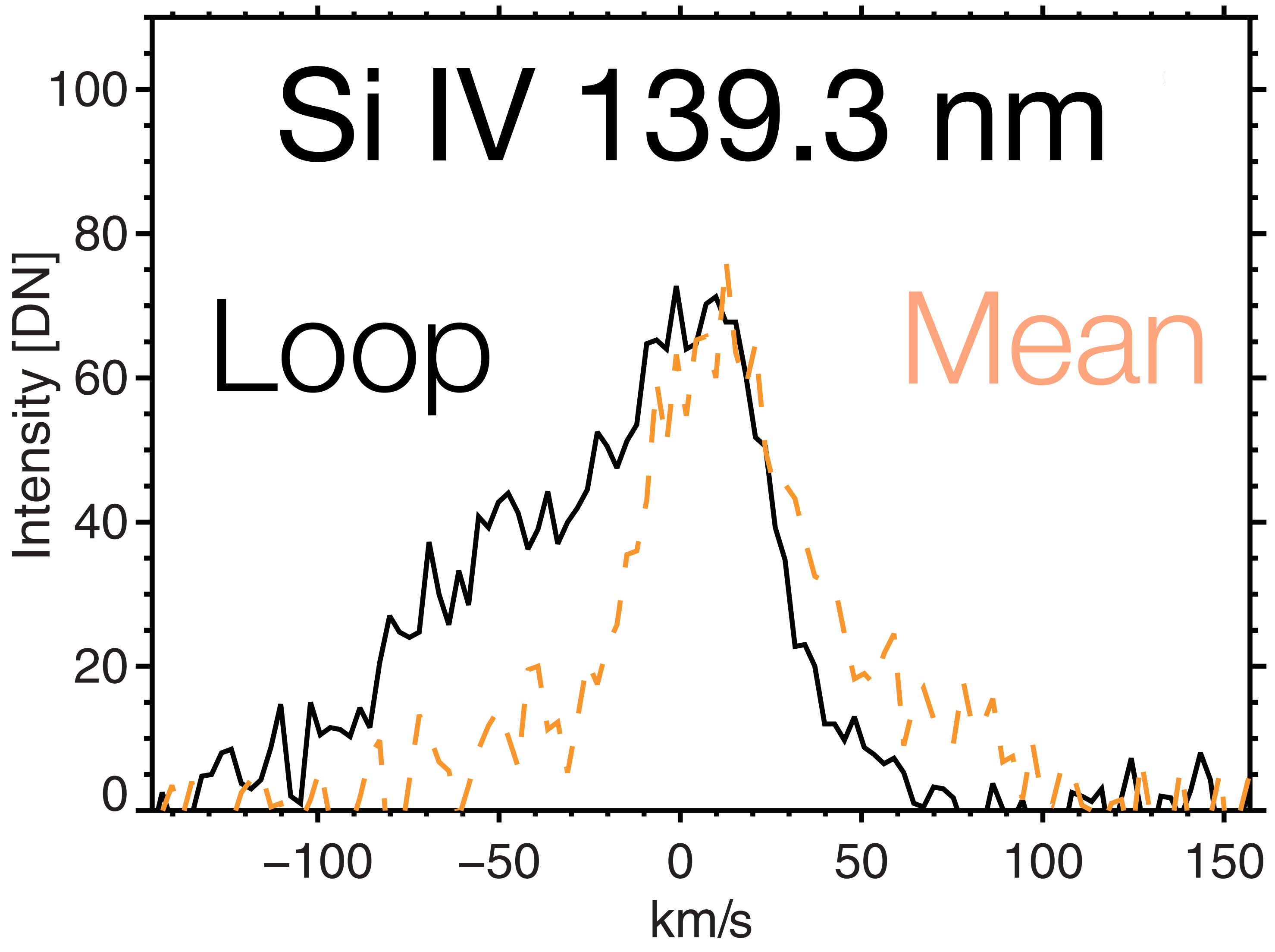
Hα
Mg II h
Mg II 279.8 nm
Si IV 139.3 nm
I_ν [10^{-5} erg/s cm² sr Hz]
I_ν [DN/s]
Wavelength [km/s]
Hansteen et al. (2017, ApJ 839)

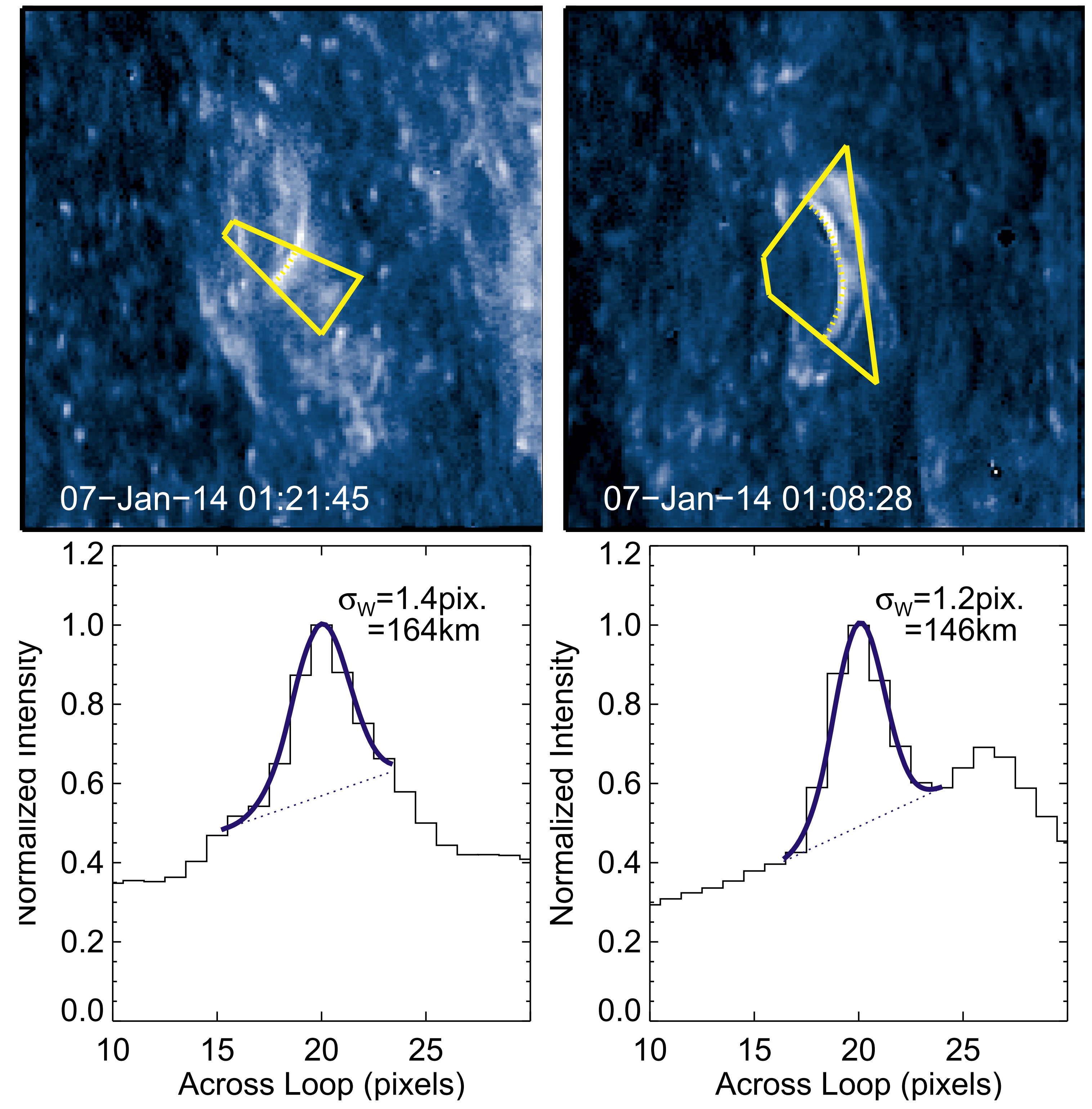
UFS loops

“Unresolved Fine Structure” loops



Hansteen et al. (2014, Science 6207)





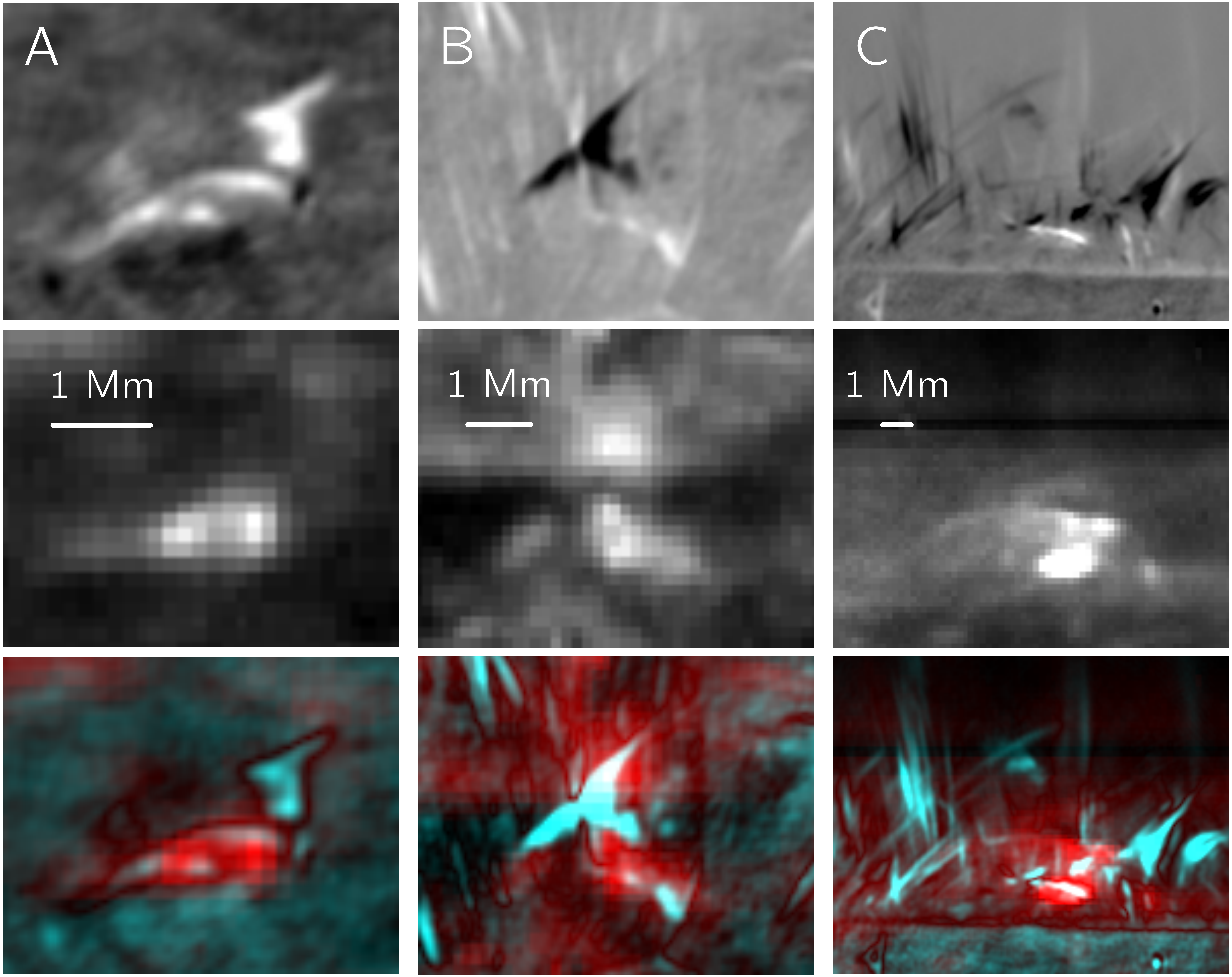
Brooks et al. (2016, ApJL 826)

“Unresolved Fine Structure” loops

TMDP et al. (2018, A&A 612)

“Unresolved Fine Structure” loops

TMDP et al. (2018, A&A 612)



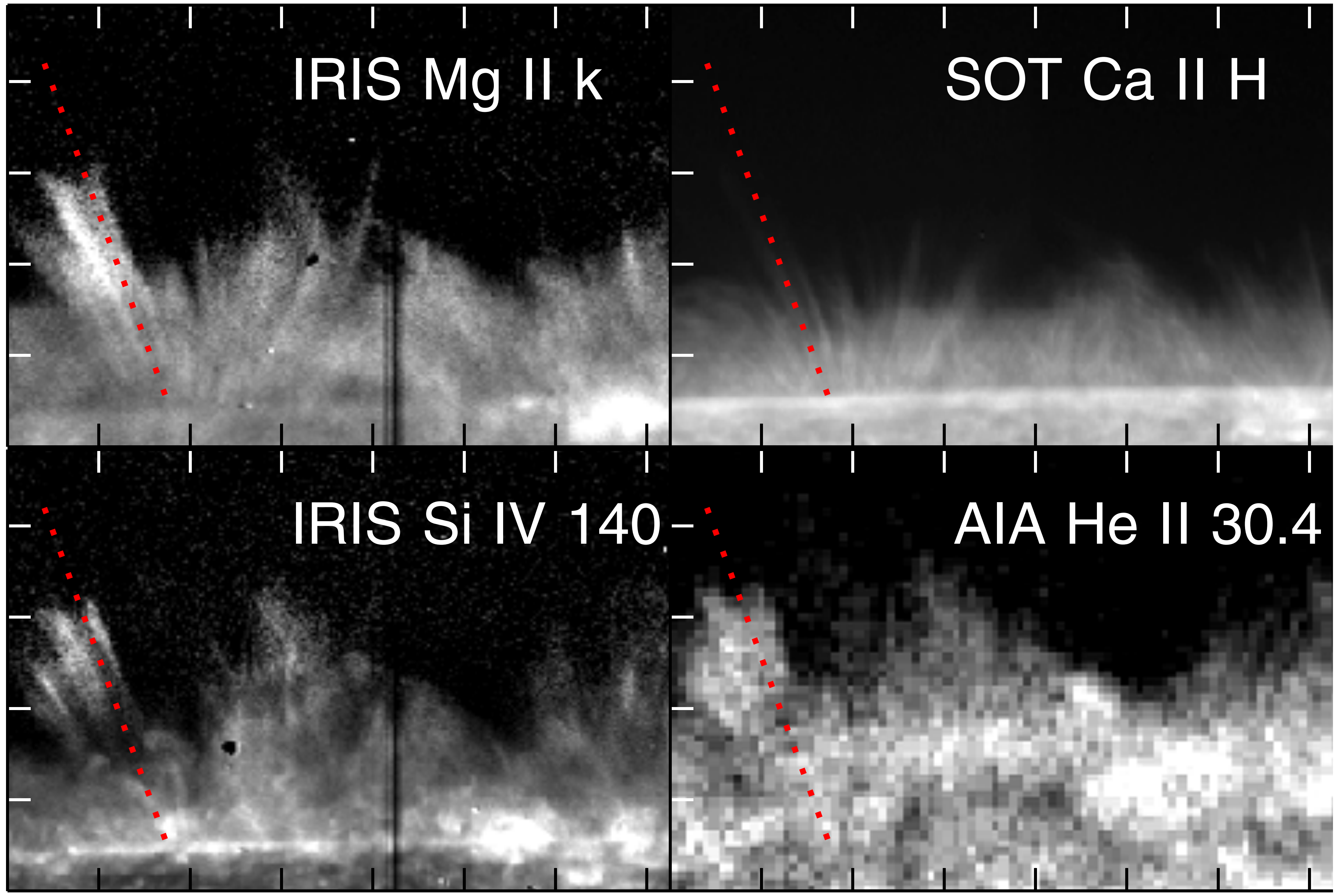
- No obvious heating of chromosphere
- Inverse-Y shape in chromosphere of some loops
- Absence of thermal coupling also important

TMDP et al. (2018, A&A 612)

Summary 1/2

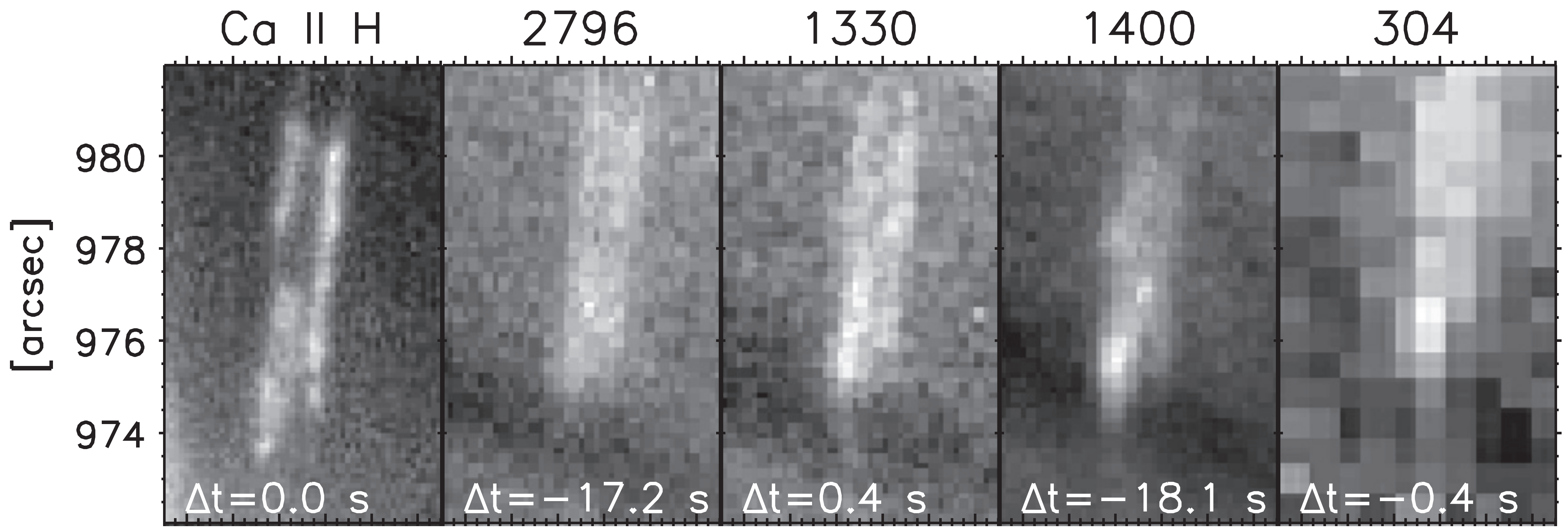
Spicules

- Multi-thermal diagnostics from IRIS and other observatories reveals violent heating history
- Constrains for models of spicule formation
- MHD simulations with ambipolar diffusion big step forward towards first-principle models of spicules



Coronal rain

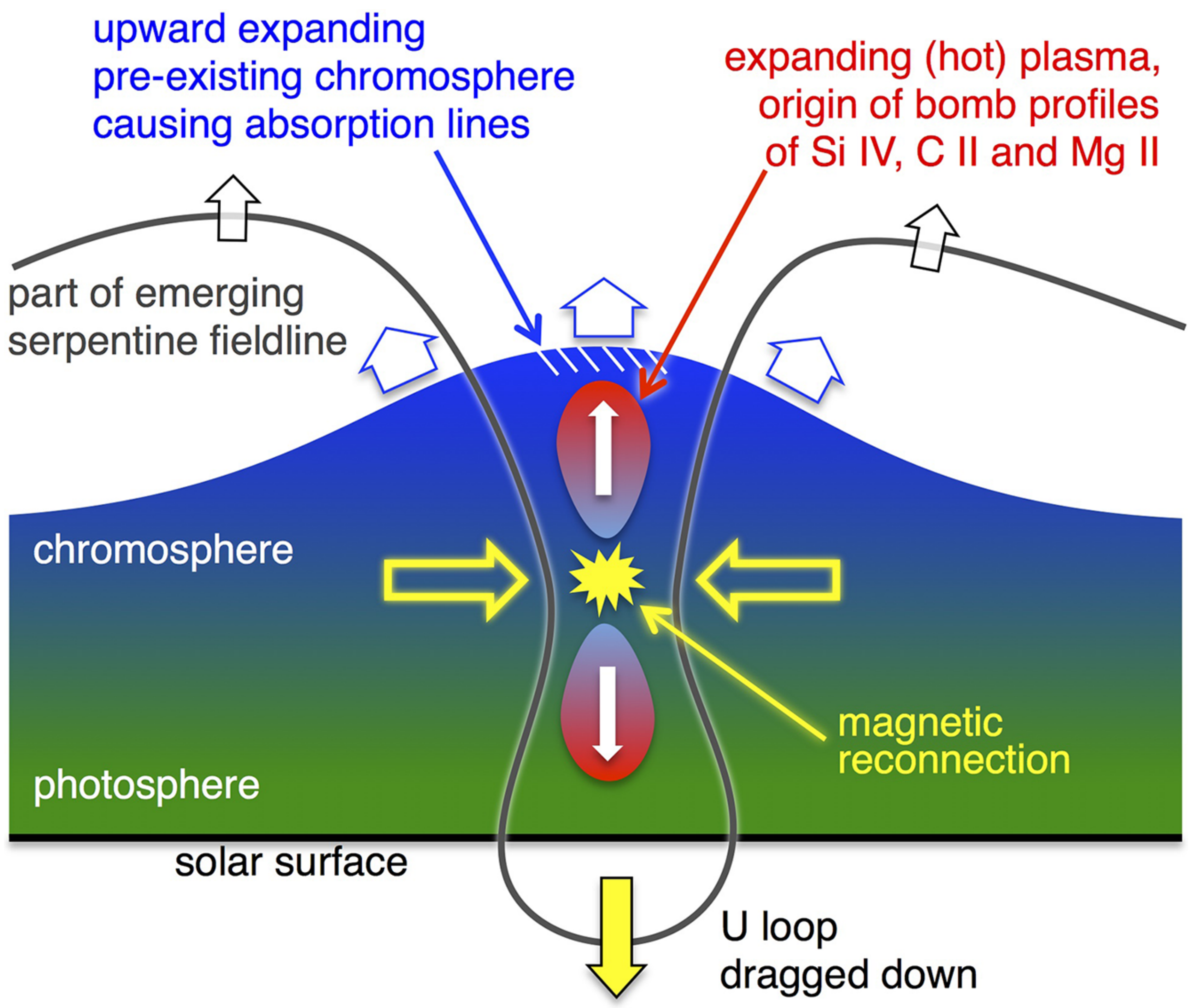
- Multi-thermal diagnostics show significant cooling from TR to chromosphere, until clumps reach surface
- Some plasma still co-exists at coronal temperatures
- Very thin layer separating chromosphere from TR



Summary 2/2

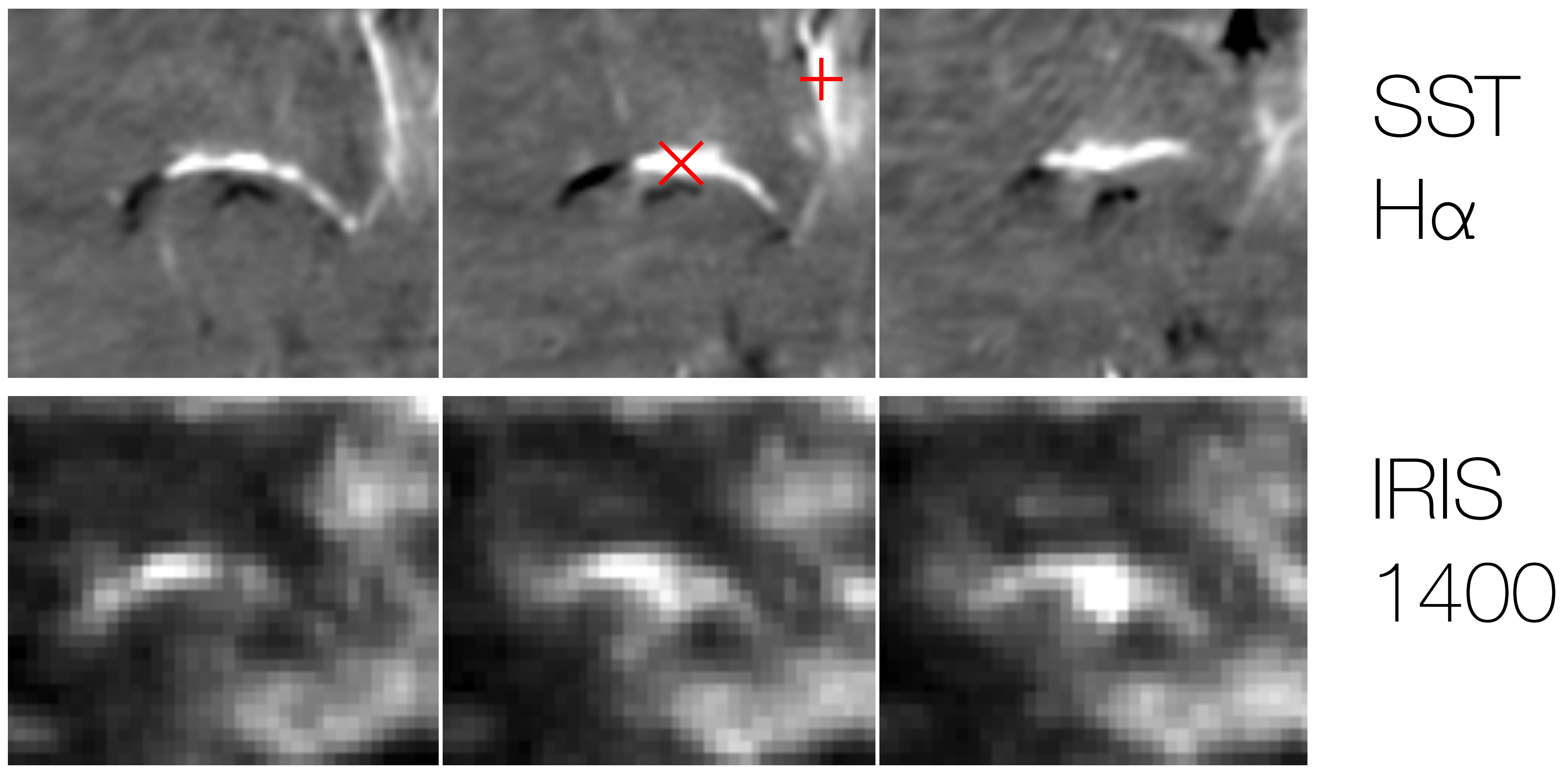
UV bursts / Ellerman bombs

- Combining IRIS with Hα helps decode height of energy release site
- IRIS and co-observations provide constraints for models
- 3D MHD models have reproduced the spectral signatures of UV bursts and EB



UFS loops

- IRIS discovery proposed to be the (previously) unresolved fine structure
- Combining IRIS with SST shows absence of hot chromosphere, loops seen mostly in Dopplergrams
- Suggests disconnect between TR/chromosphere, with some violent ejections possibly reconnection



Conclusions

- Multi-thermal plasma is ubiquitous
- IRIS in unique position to trace thermal history
- Combining IRIS with other observatories greatly increase diagnostic potential:
  - Access to higher resolution, polarimetry, photosphere, corona
  - Some phenomena defined from observations in other lines (e.g. spicules, EB, prominences)
- Forward modelling provides much-needed guidance to interpret complex observations