IRIS observations and modeling of the chromosphere and TR/corona

Bart De Pontieu
Lockheed Martin Solar & Astrophysics Laboratory

Thanks to Juan Martinez-Sykora, Milan Gosic, Don Schmit, Ineke De Moortel

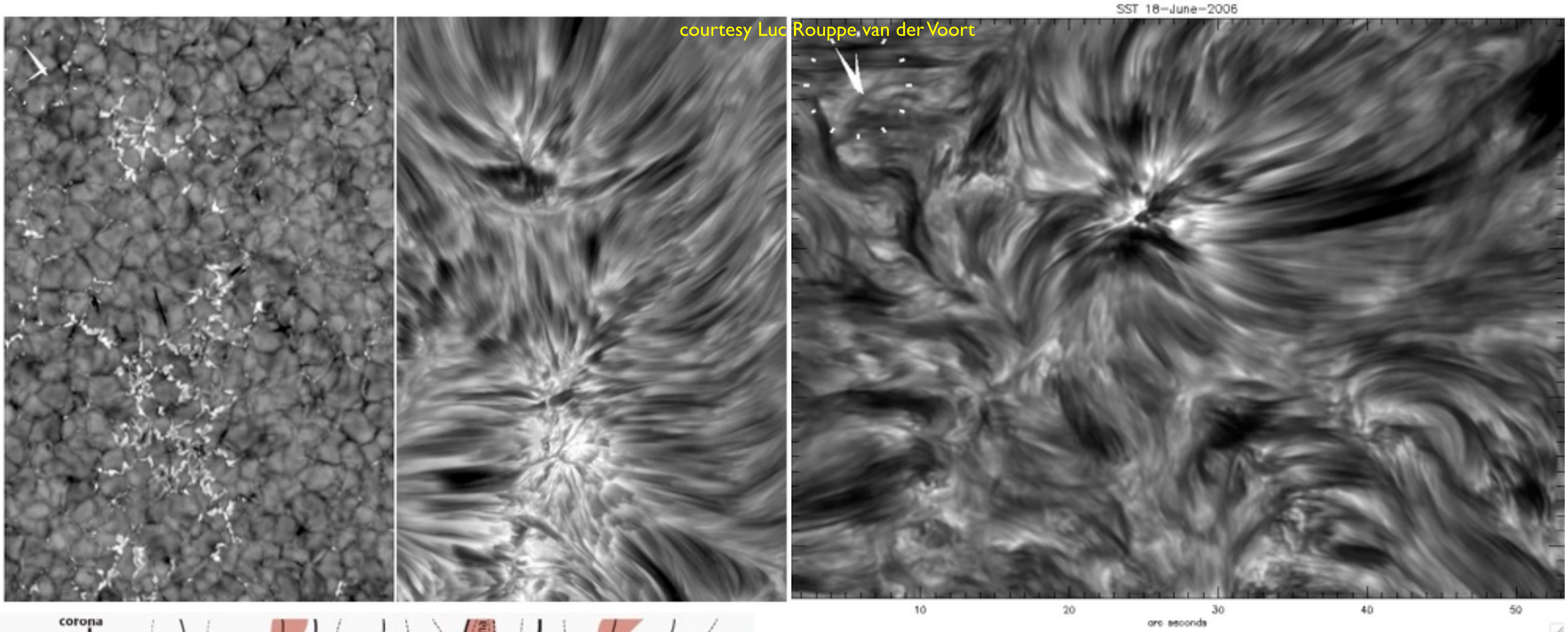
Outline of the Talk

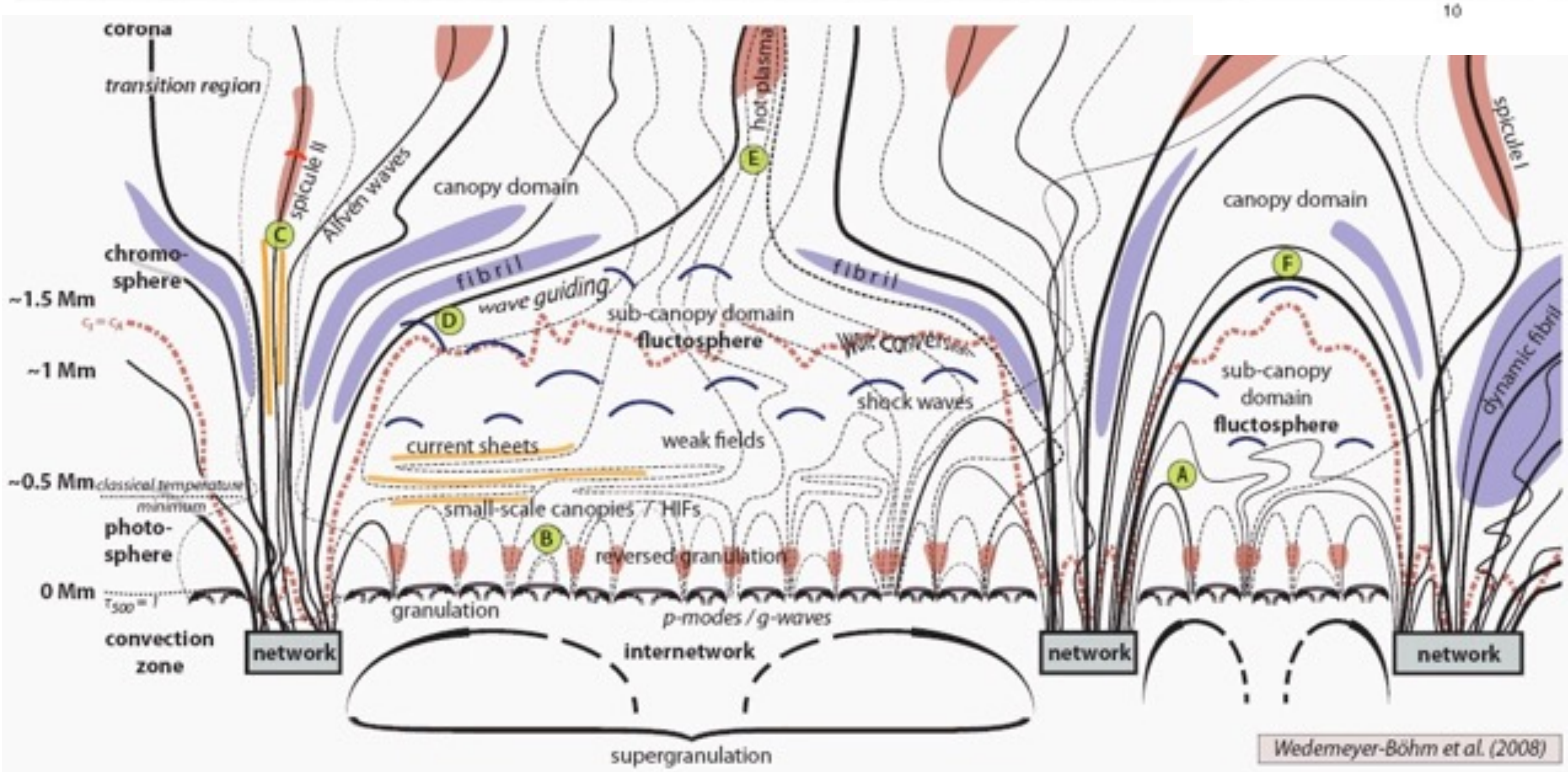
1. Quiet Sun Dynamics and Heating
   a. Magneto-acoustic shock waves
   b. Granular-scale magnetic fields

2. Active Region Dynamics
   a. Magneto-acoustic shock waves and dynamic fibrils
   b. Chromospheric dynamics and non-equilibrium TR ionization

3. Spicules and Alfven Waves
   a. Formation of spicules
   b. Heating to coronal temperatures
   c. Alfven wave generation

Chromospheric Dynamics (1/2)





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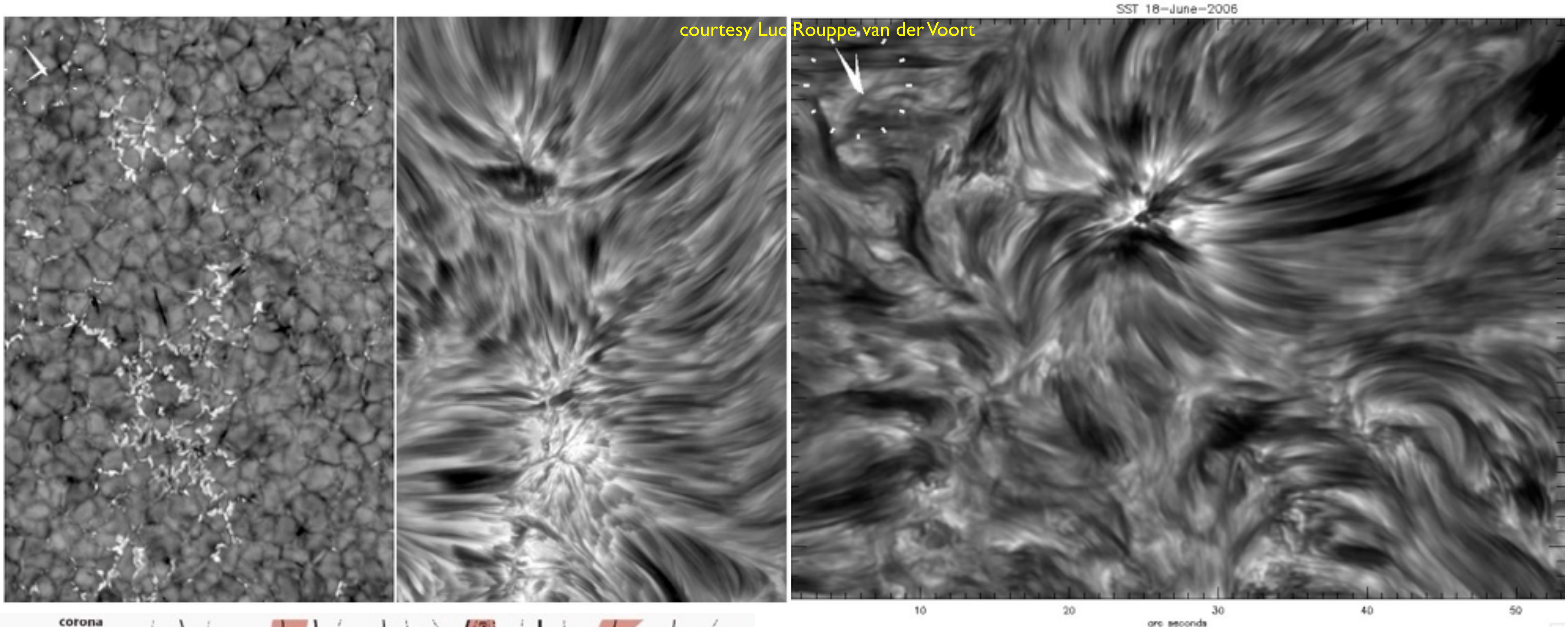

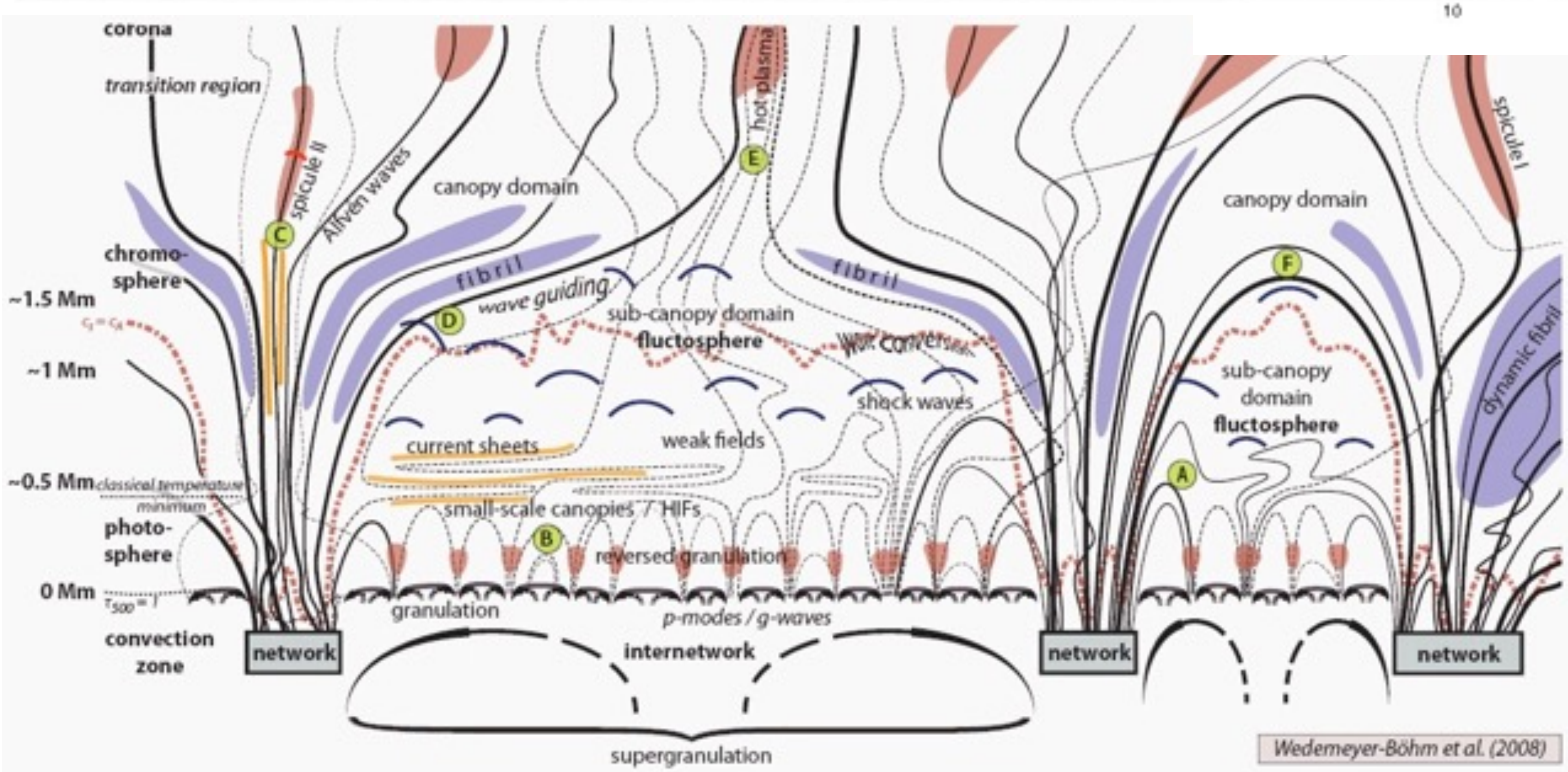

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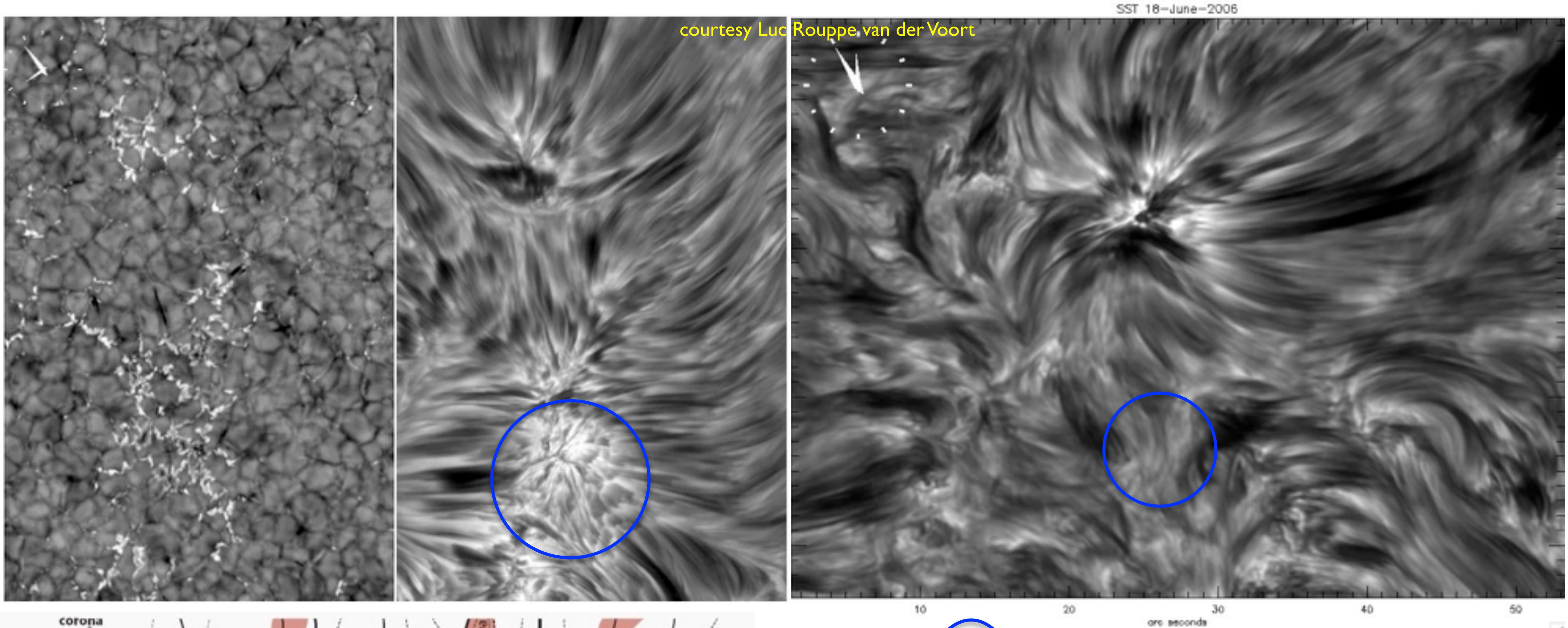
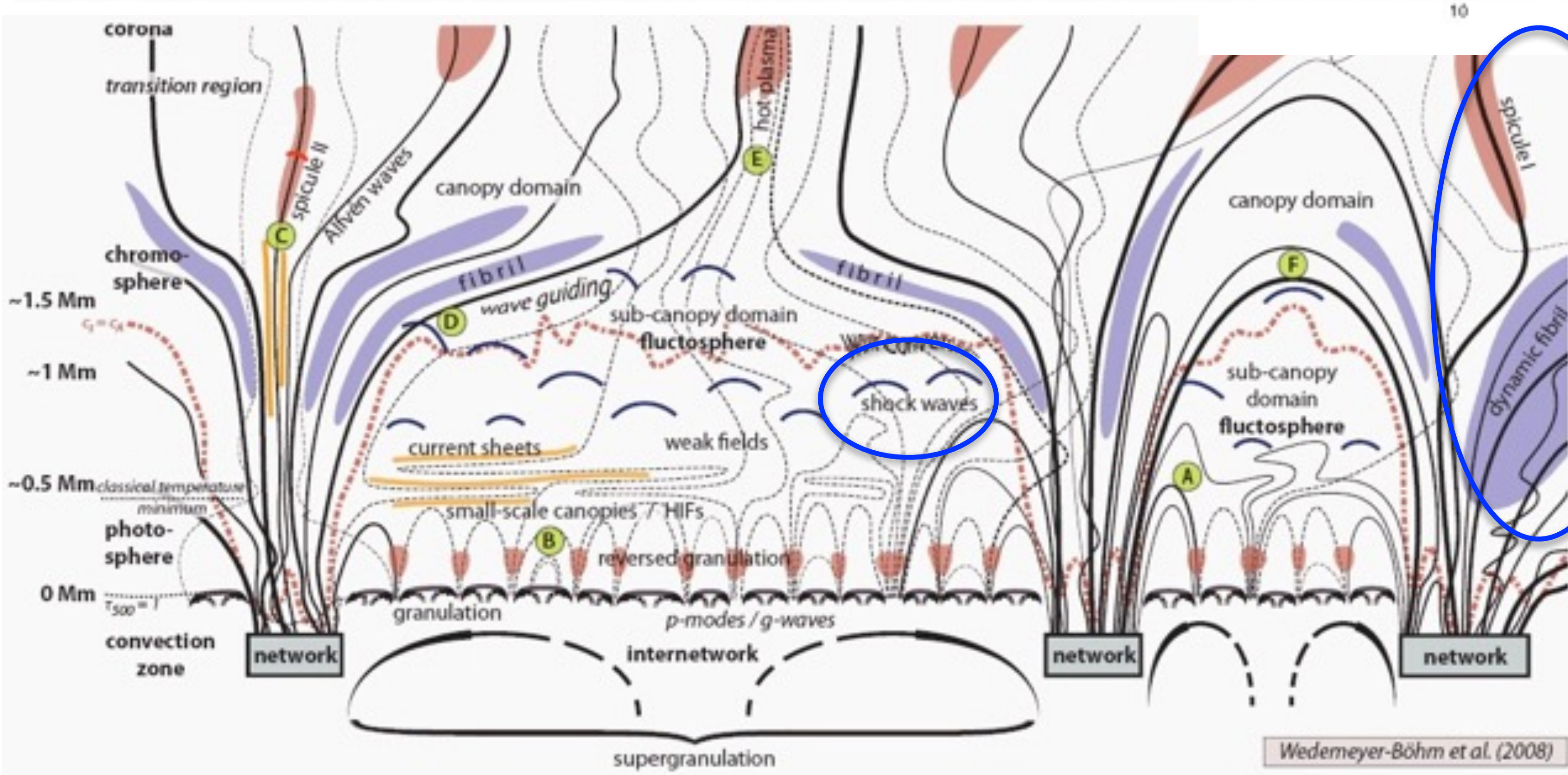
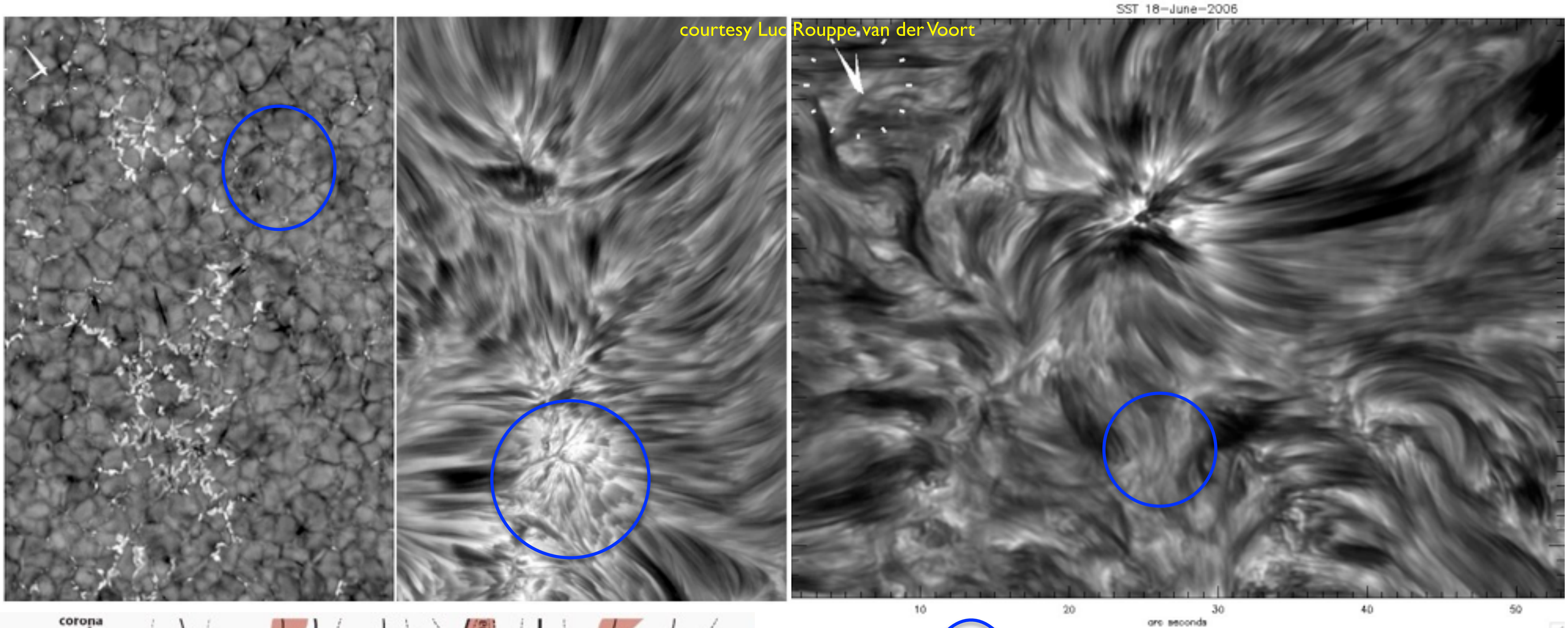
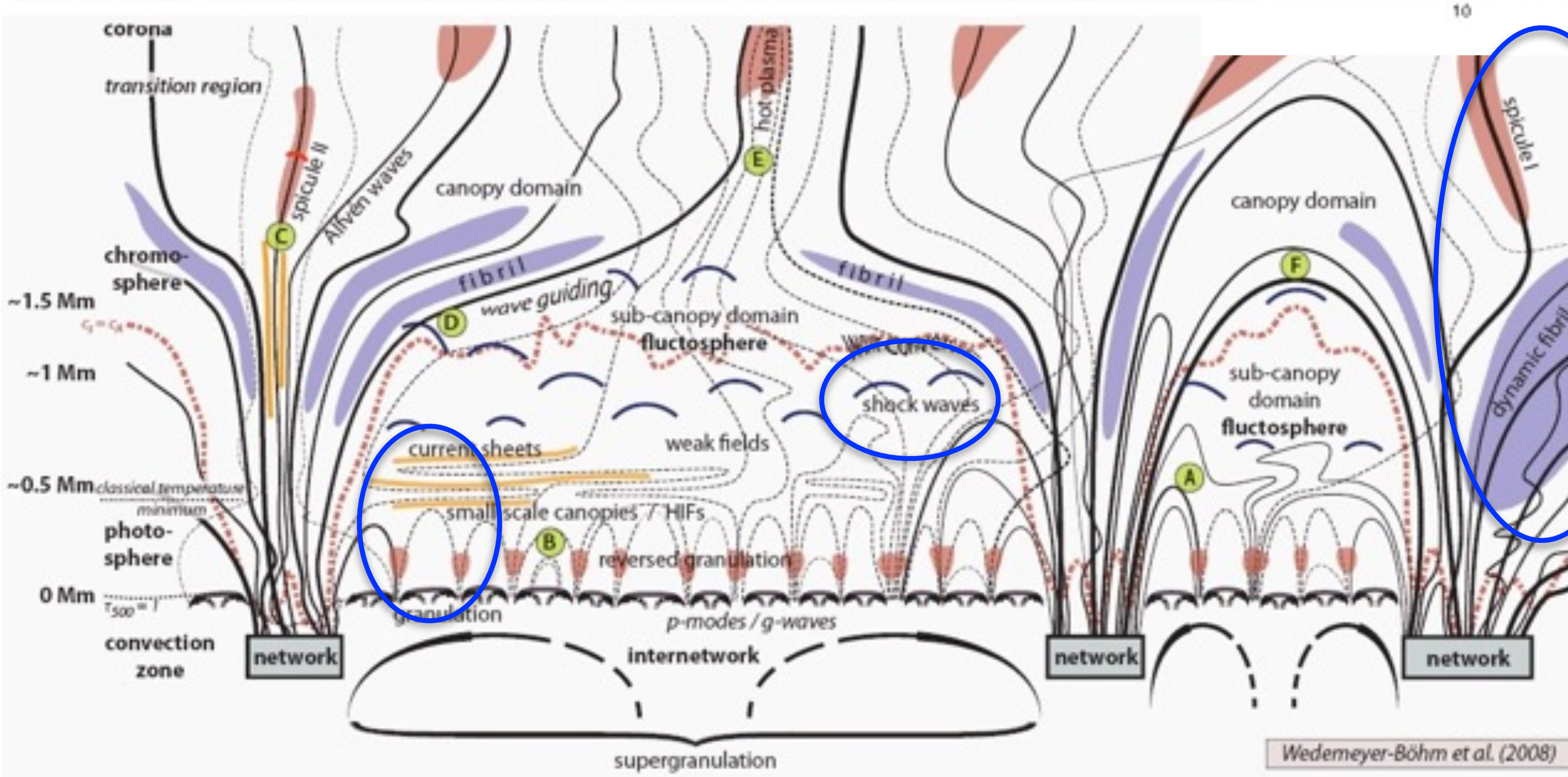




Magneto-acoustic shock waves
(energetic impact on chromo network and internetwork, and TR/corona)

Chromospheric Dynamics (1/2)





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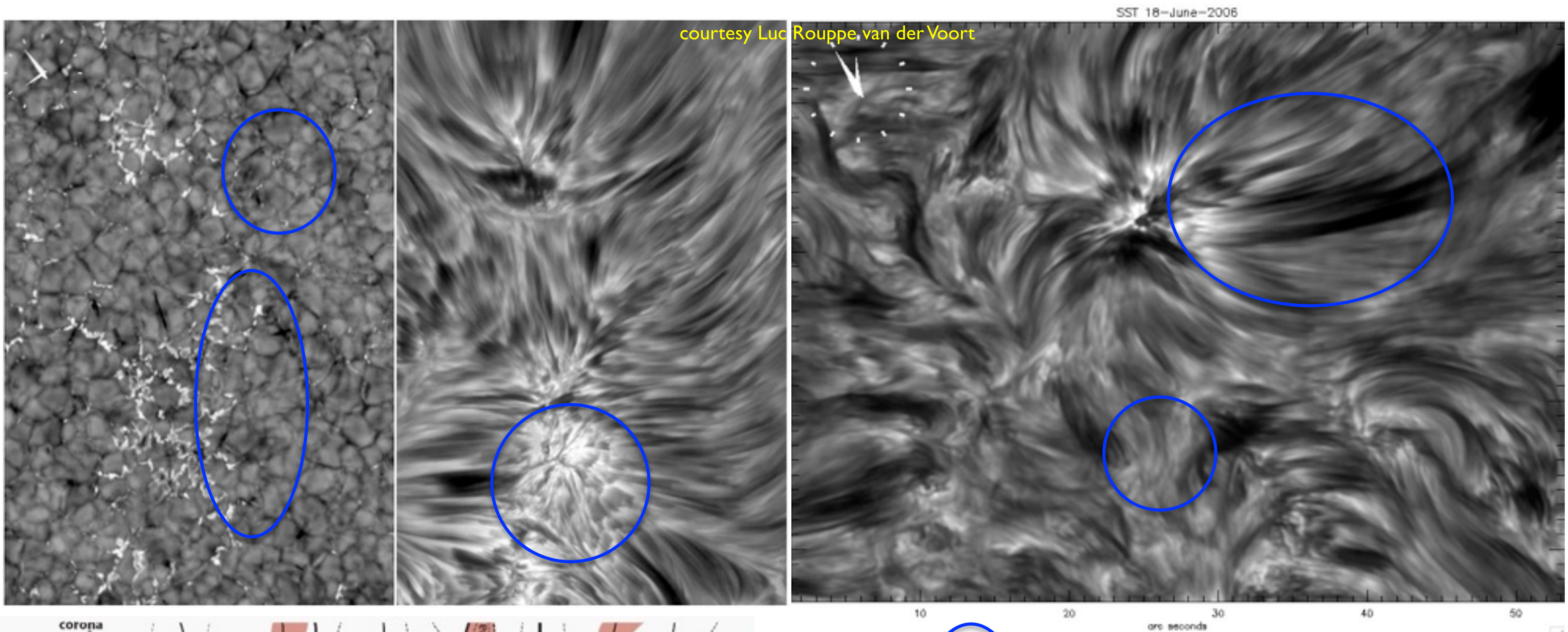
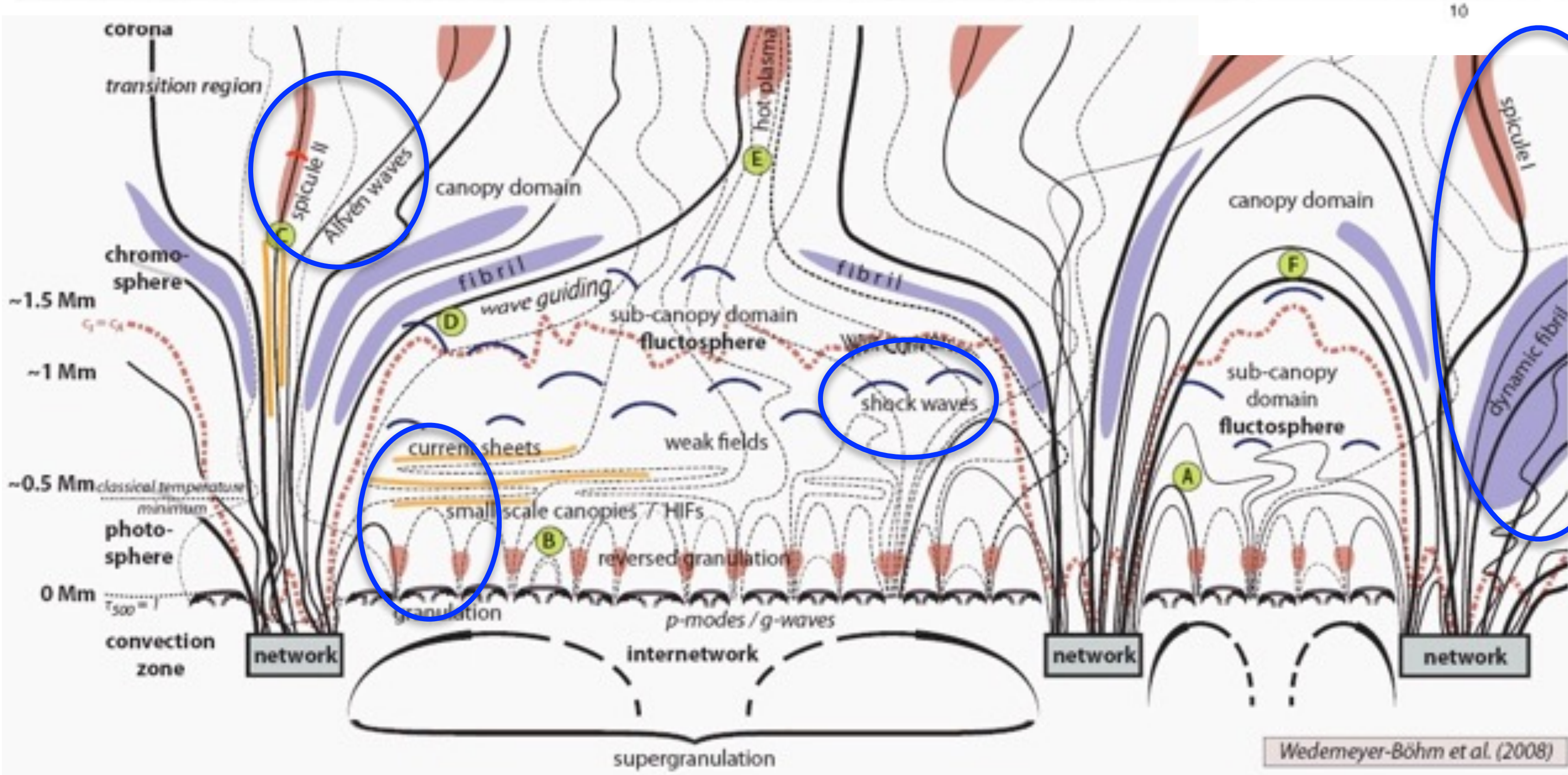
Weak fields
(granular flux emergence, impact)

Chromospheric Dynamics (1/2)





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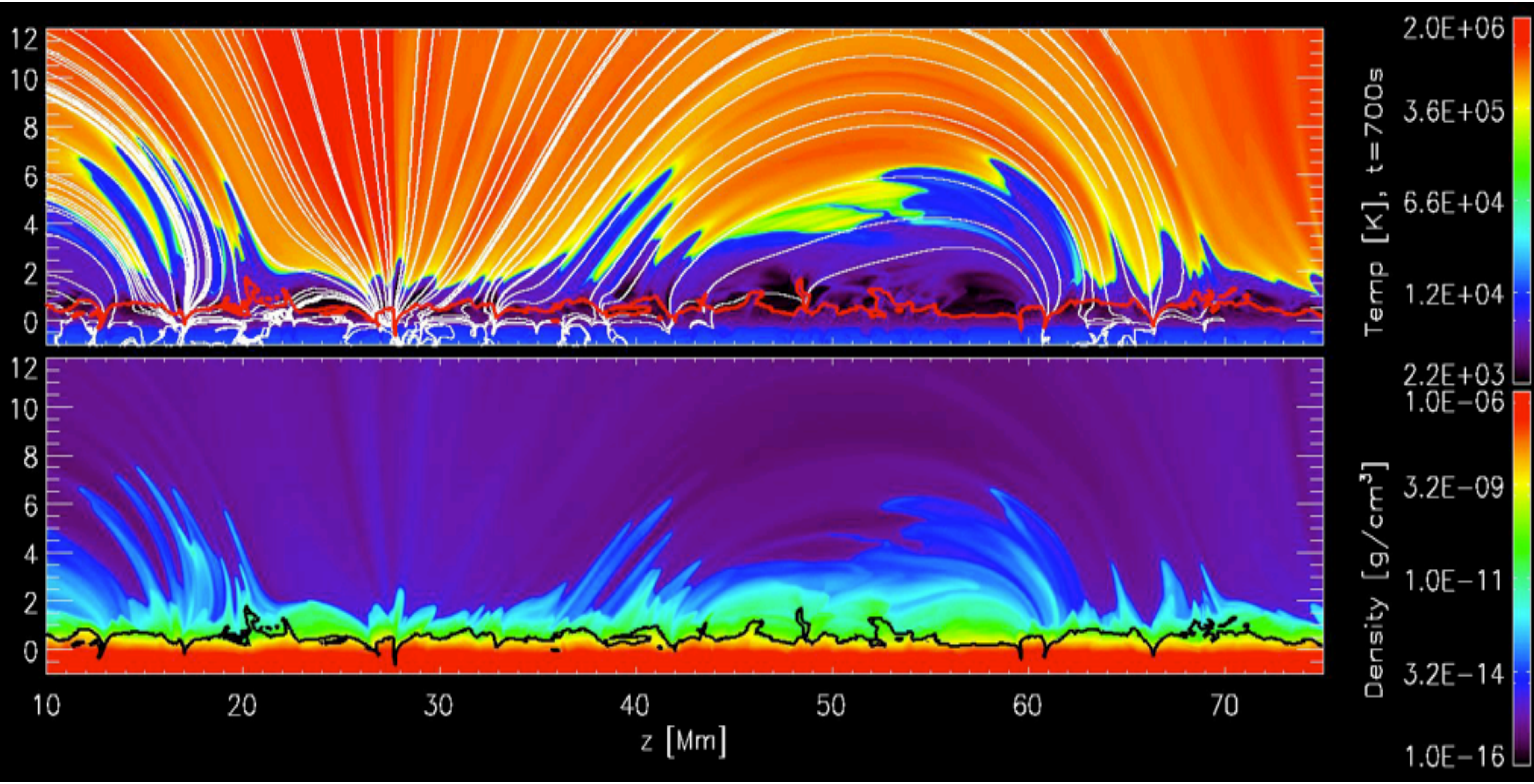
(energetic impact on chromo network and internetwork, and TR/corona)

Spicules & Alfven waves
(generation, impact on TR/corona)

Weak fields
(granular flux emergence, impact)

Chromospheric Dynamics (2/2)



Martinez-Sykora et al., 2016
See talk by Juan Martinez-Sykora

2D radiative MHD simulations including ion-neutral interactions reproduce many chromospheric observations

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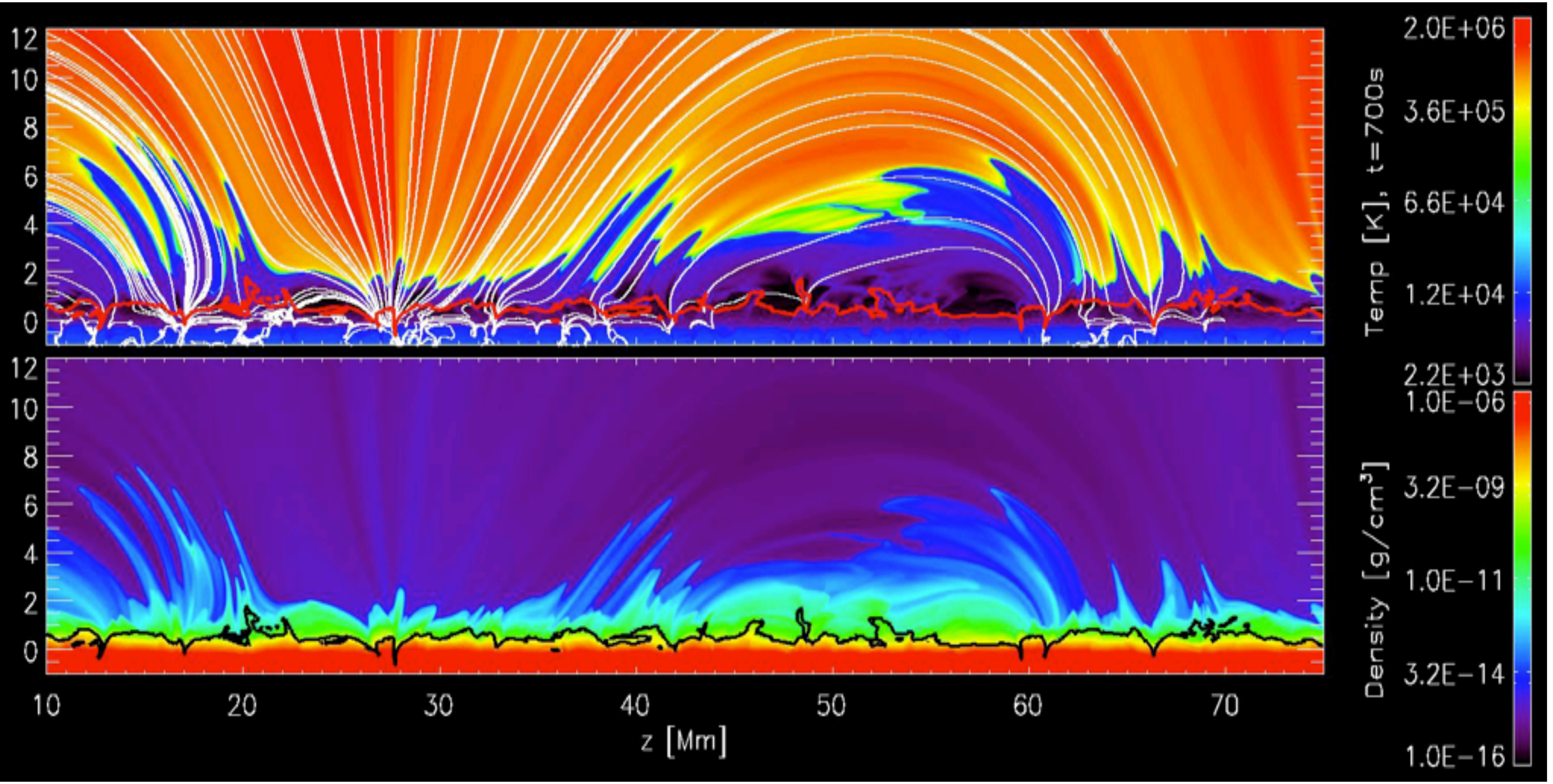

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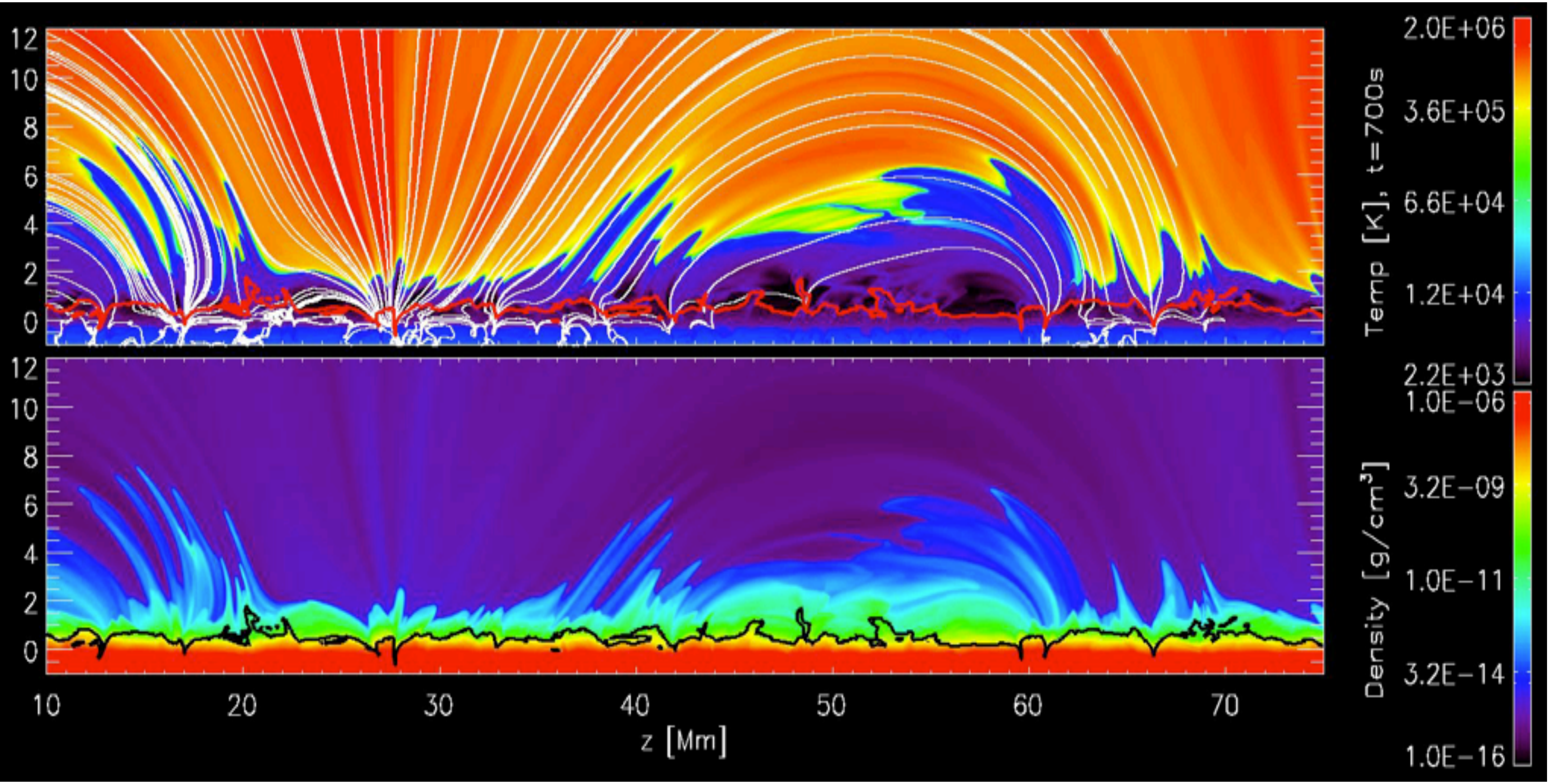

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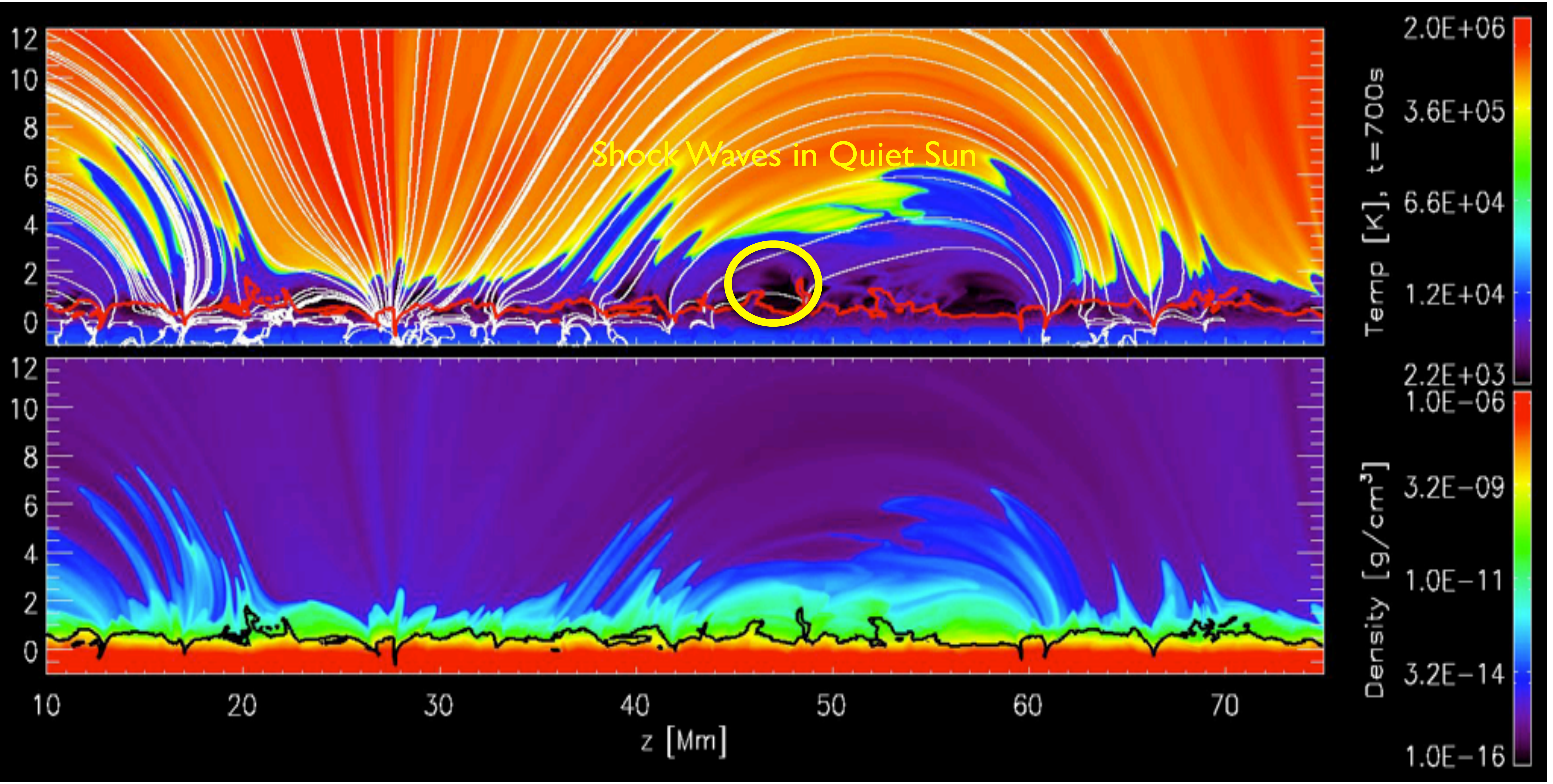

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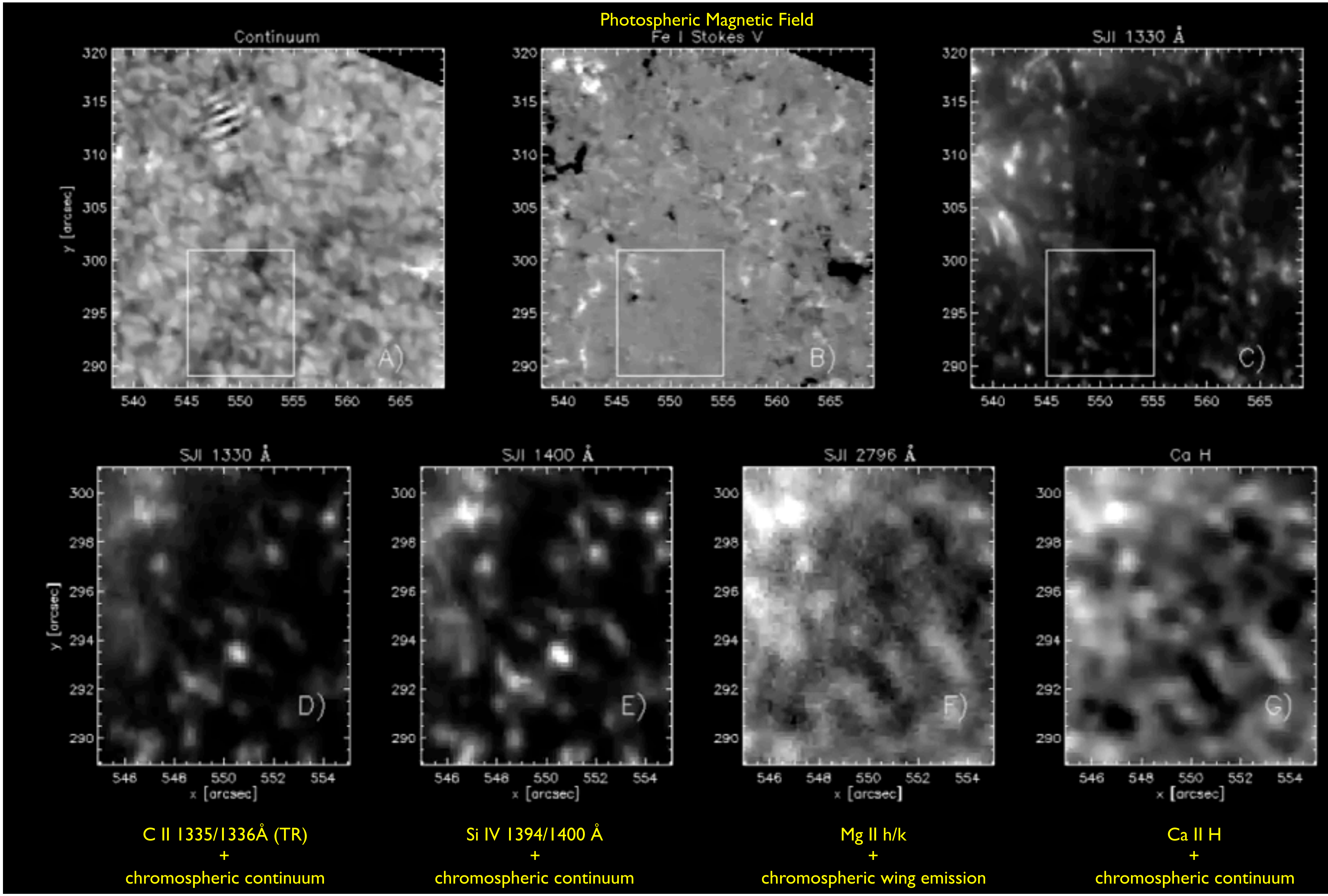
IRIS slit-jaw images dominated by short-lived brightenings



Brightenings similar in all SJIs and Ca II H (SST)

Martinez-Sykora et al., 2015

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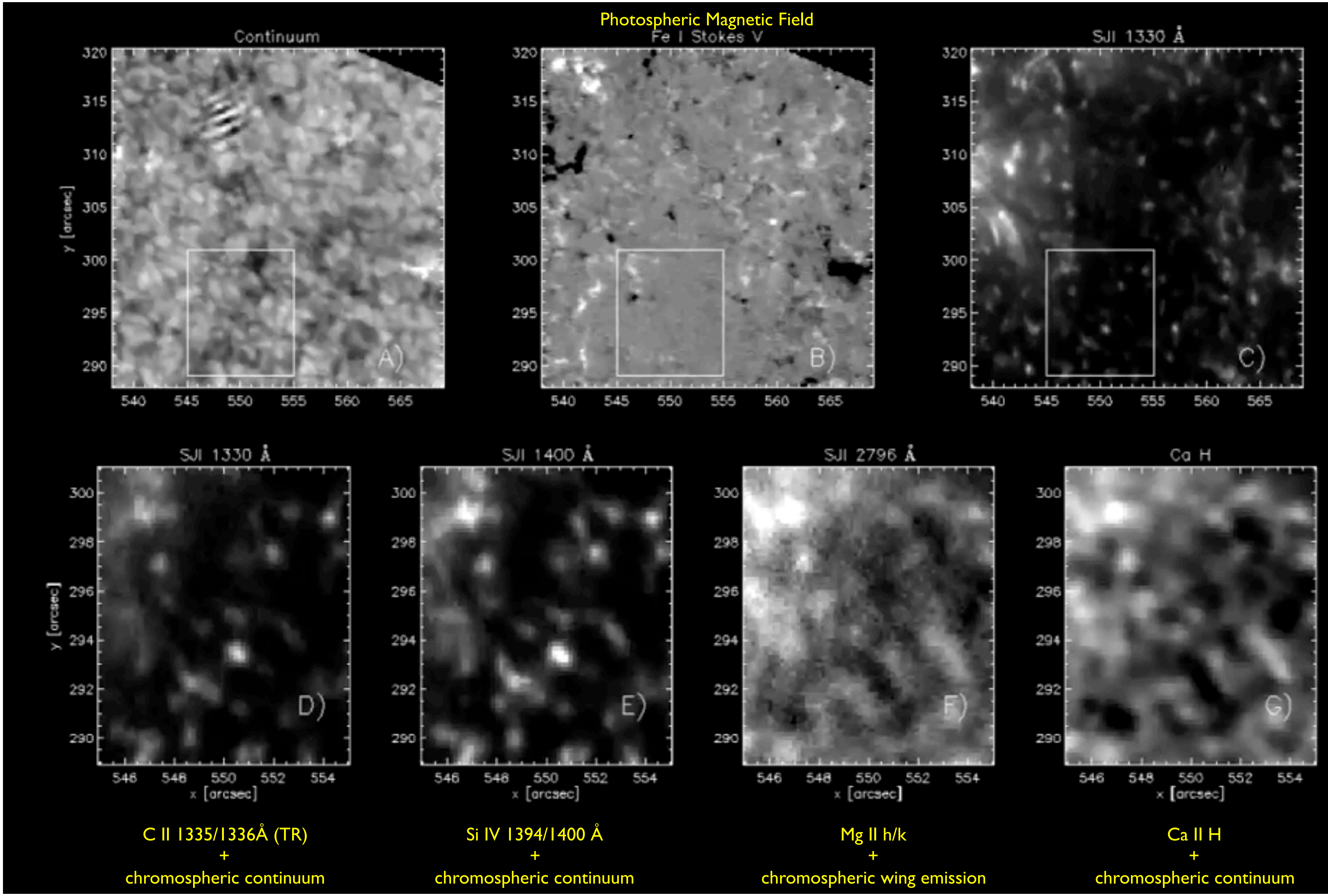

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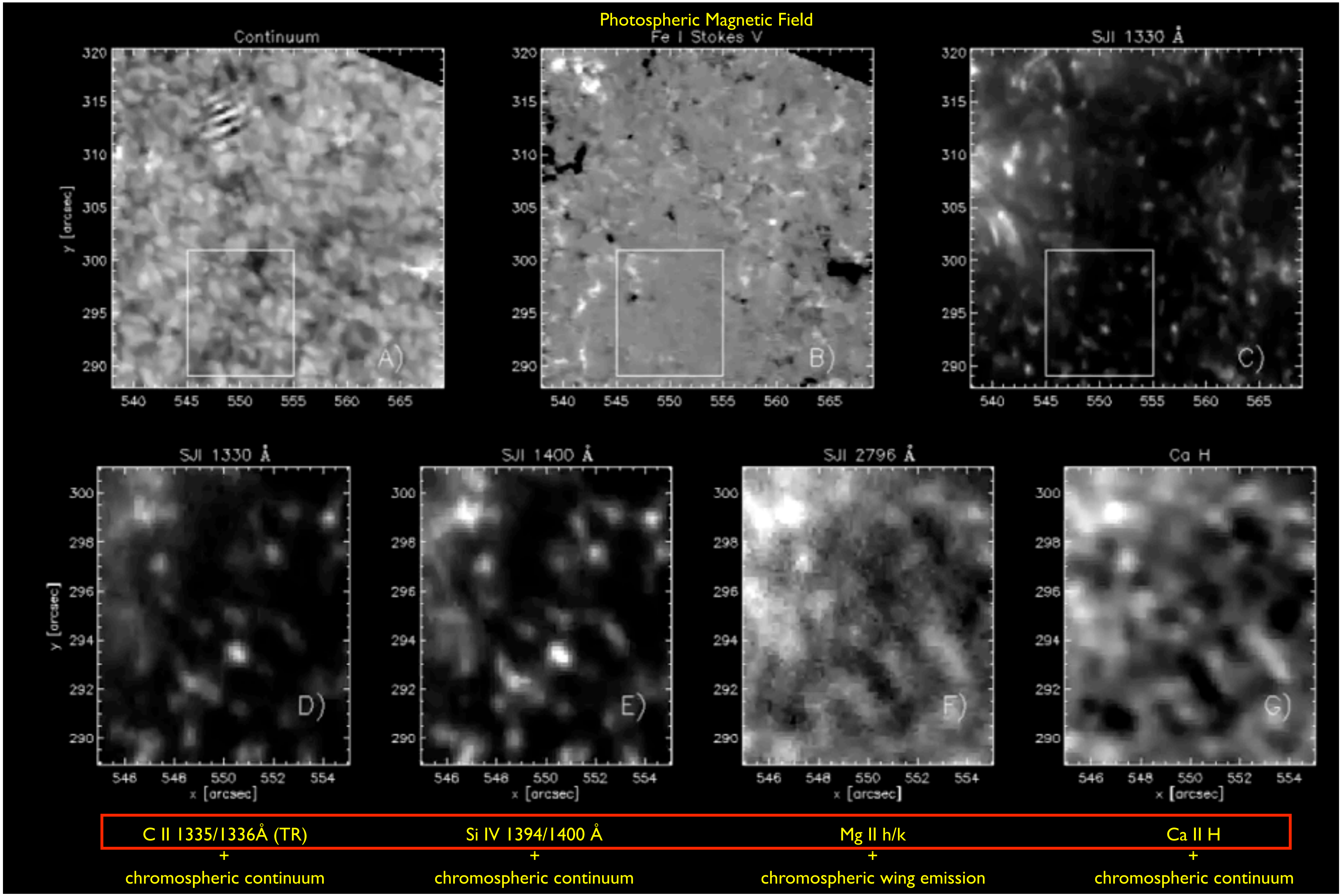

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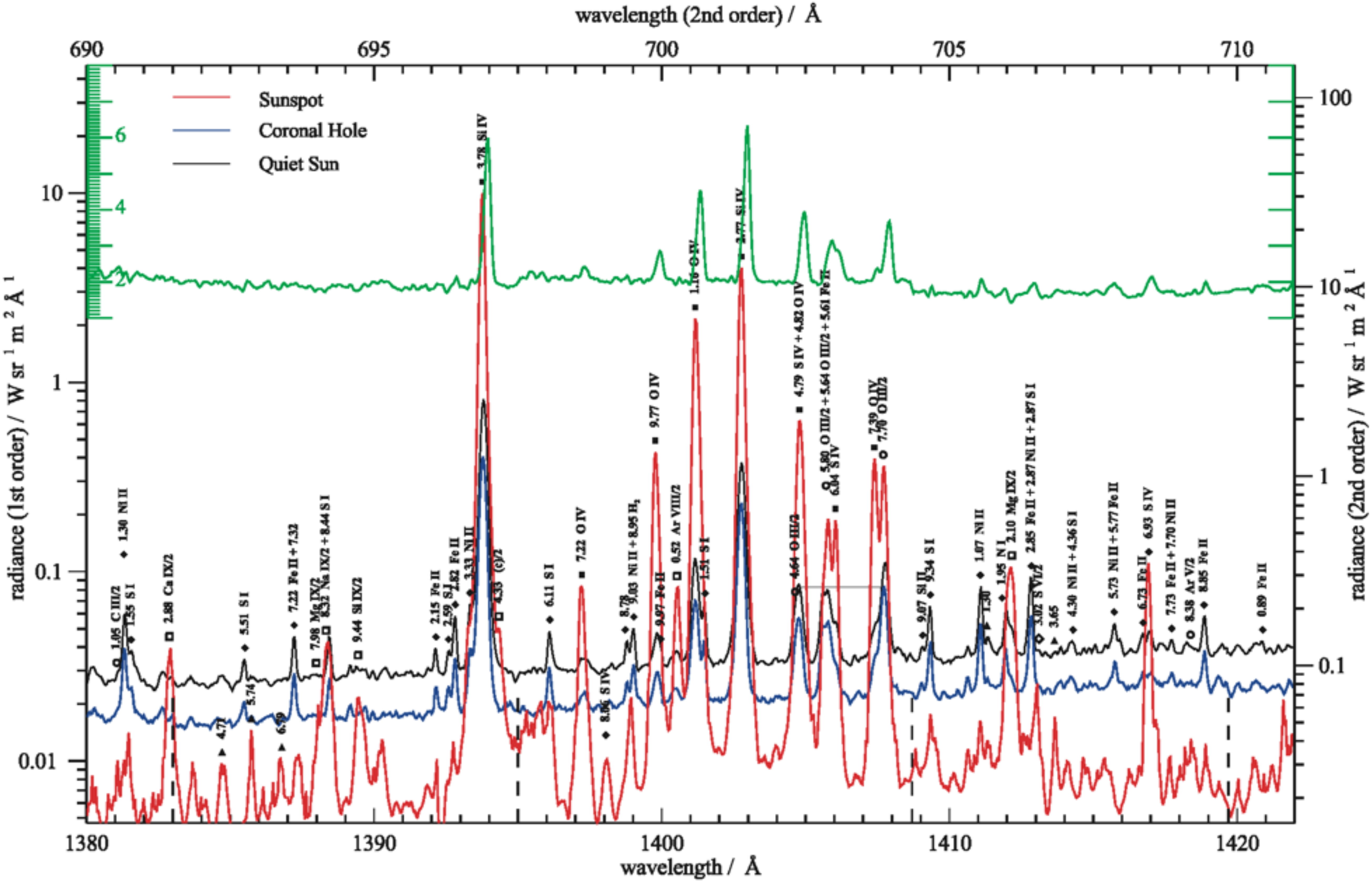

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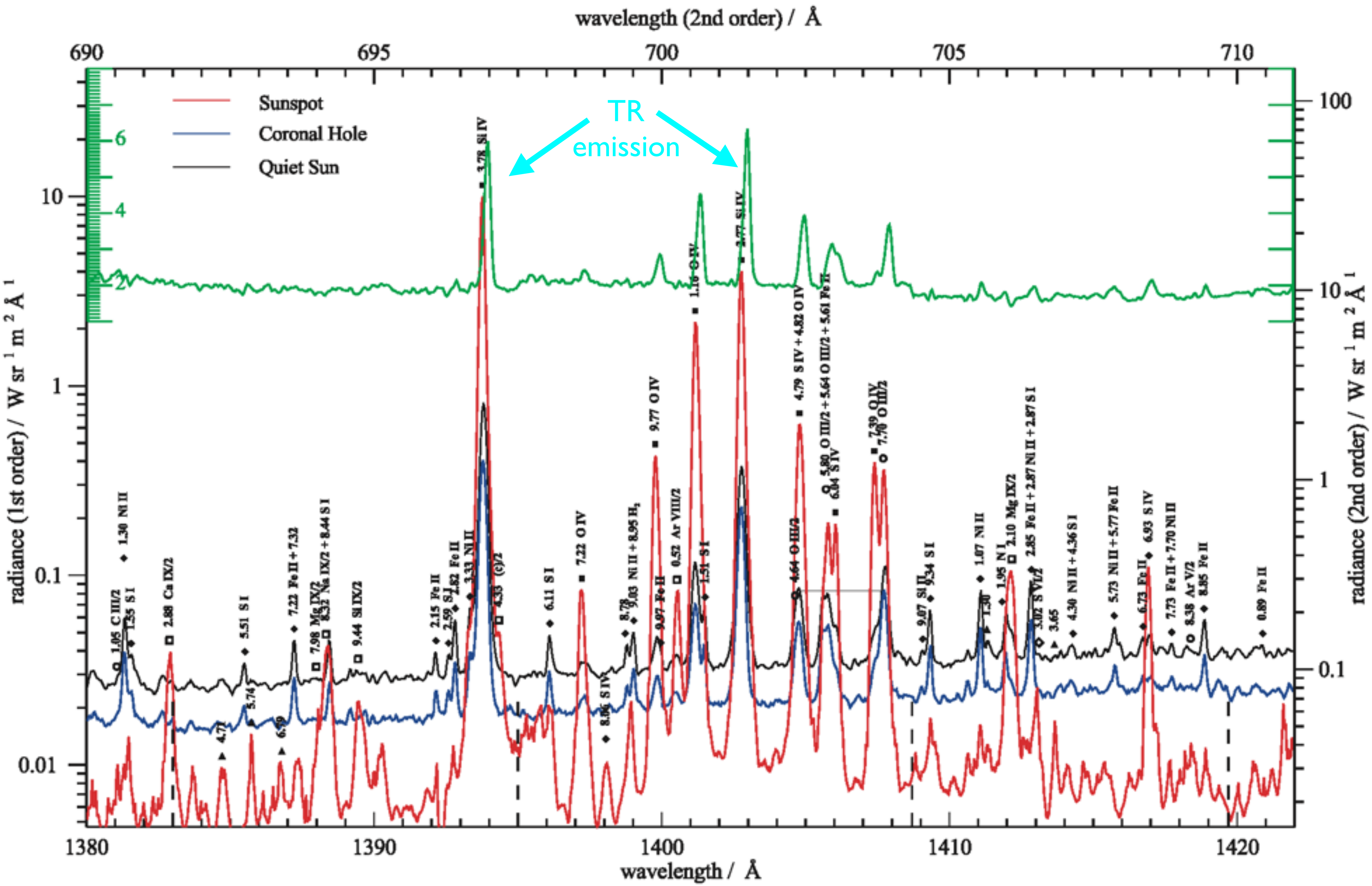

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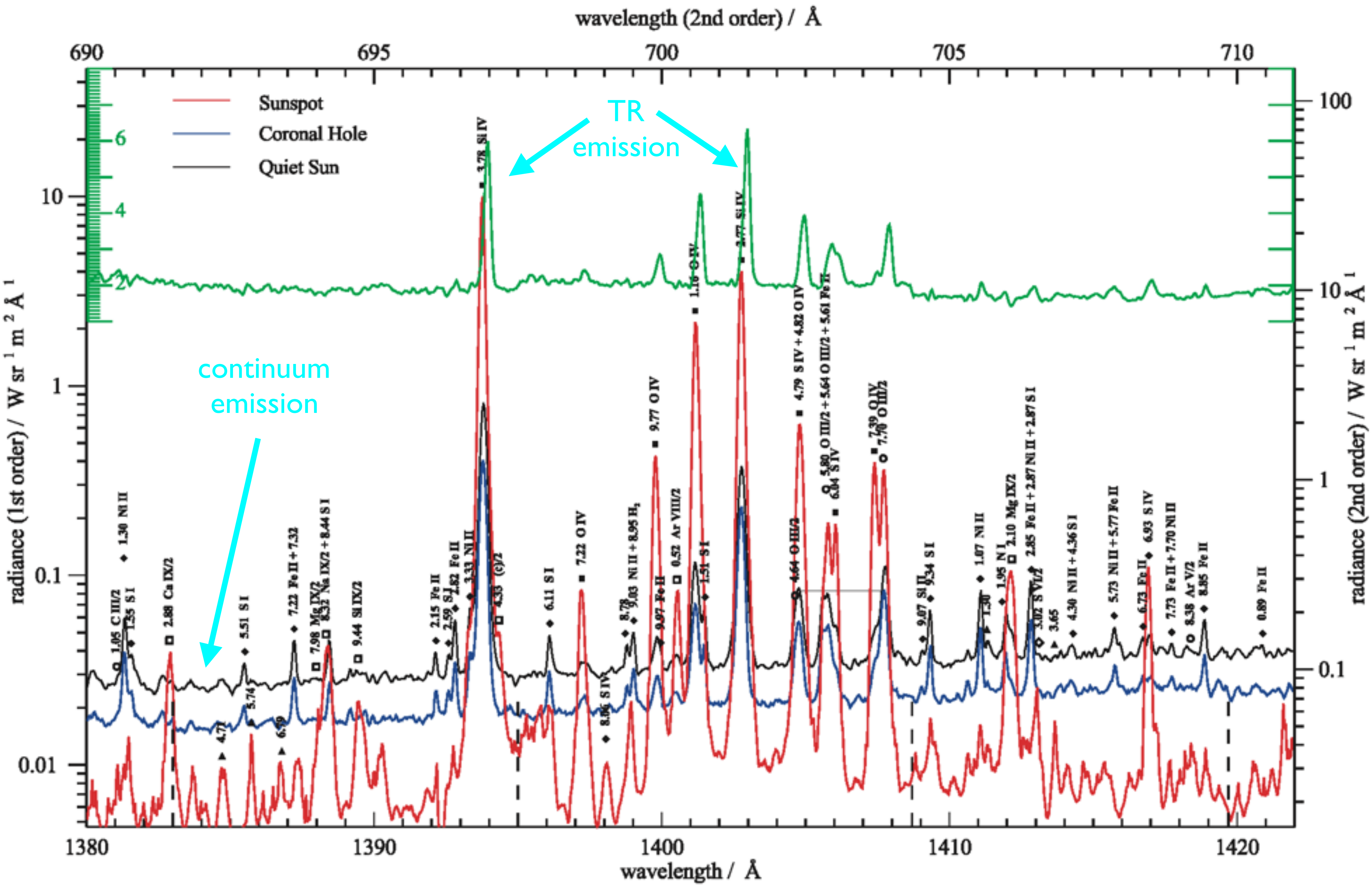

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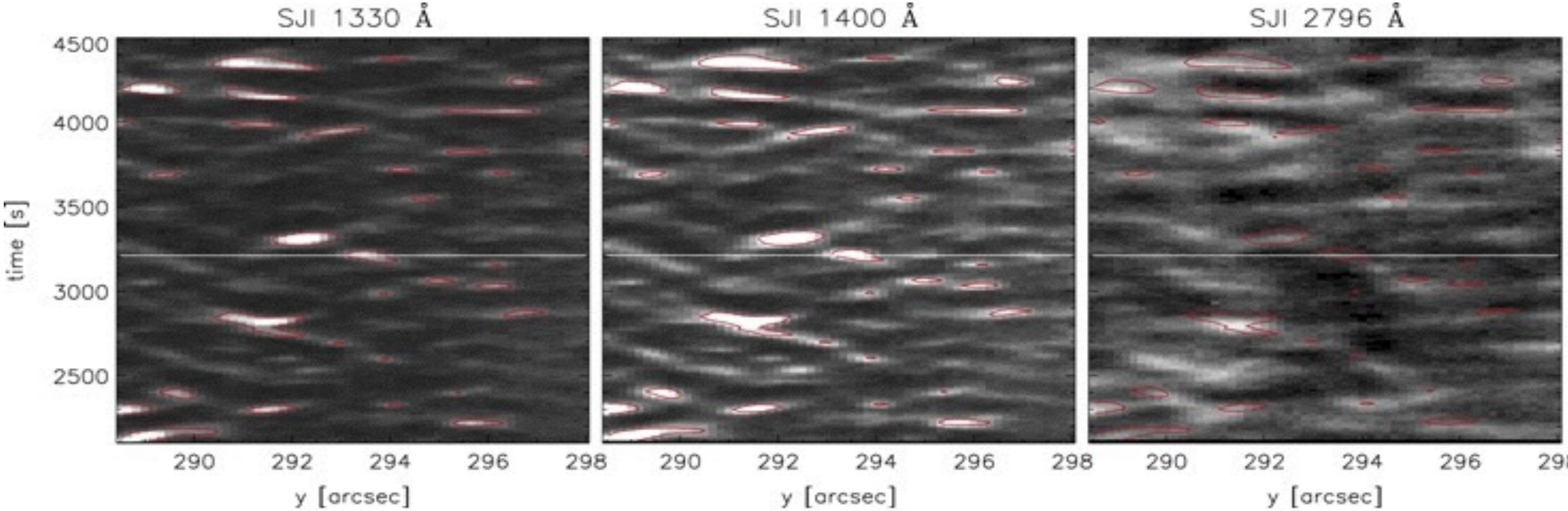
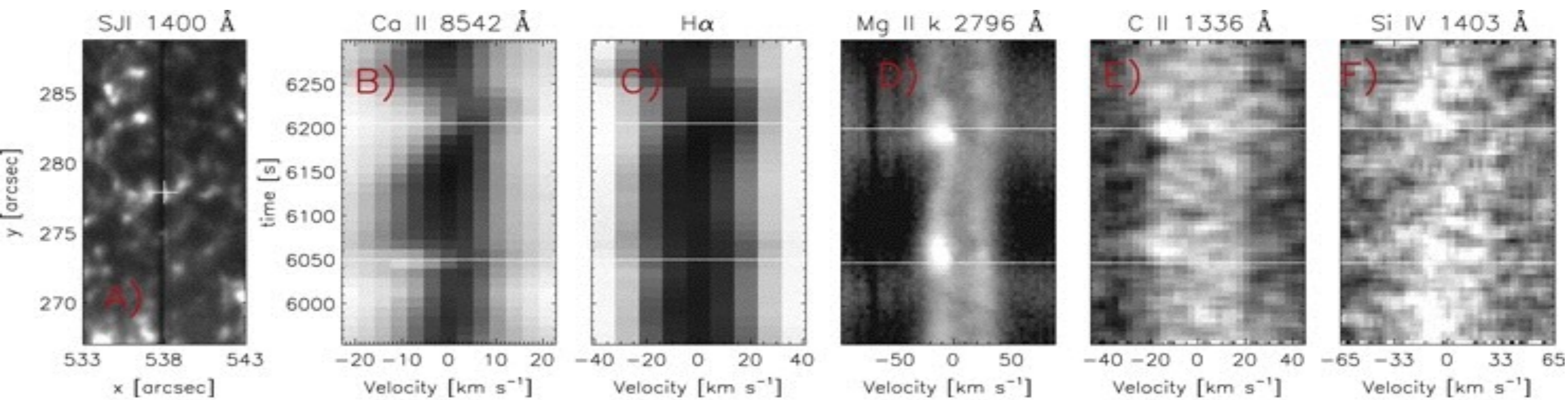
Many brightenings caused by chromospheric shock waves



No significant time delays between brightenings

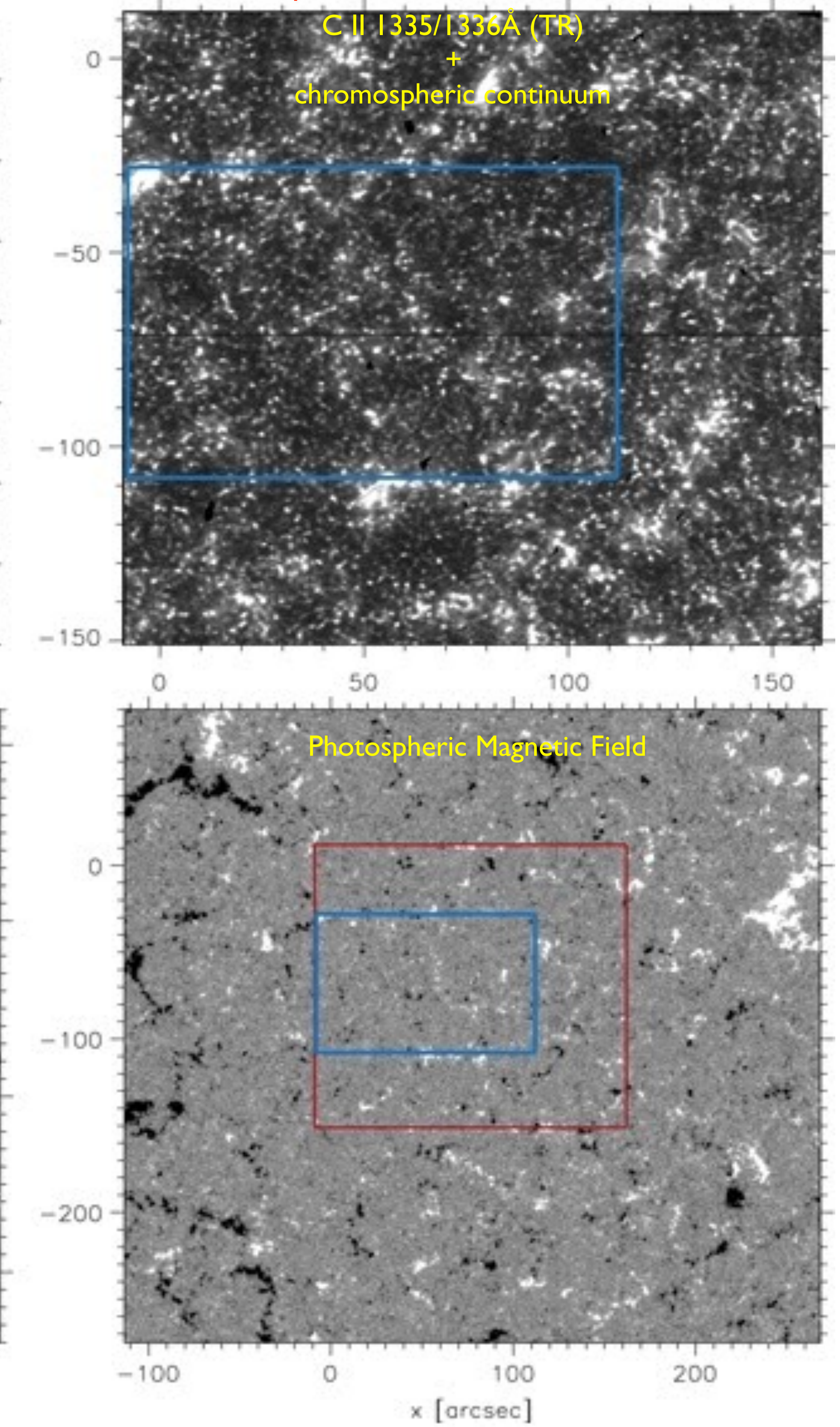


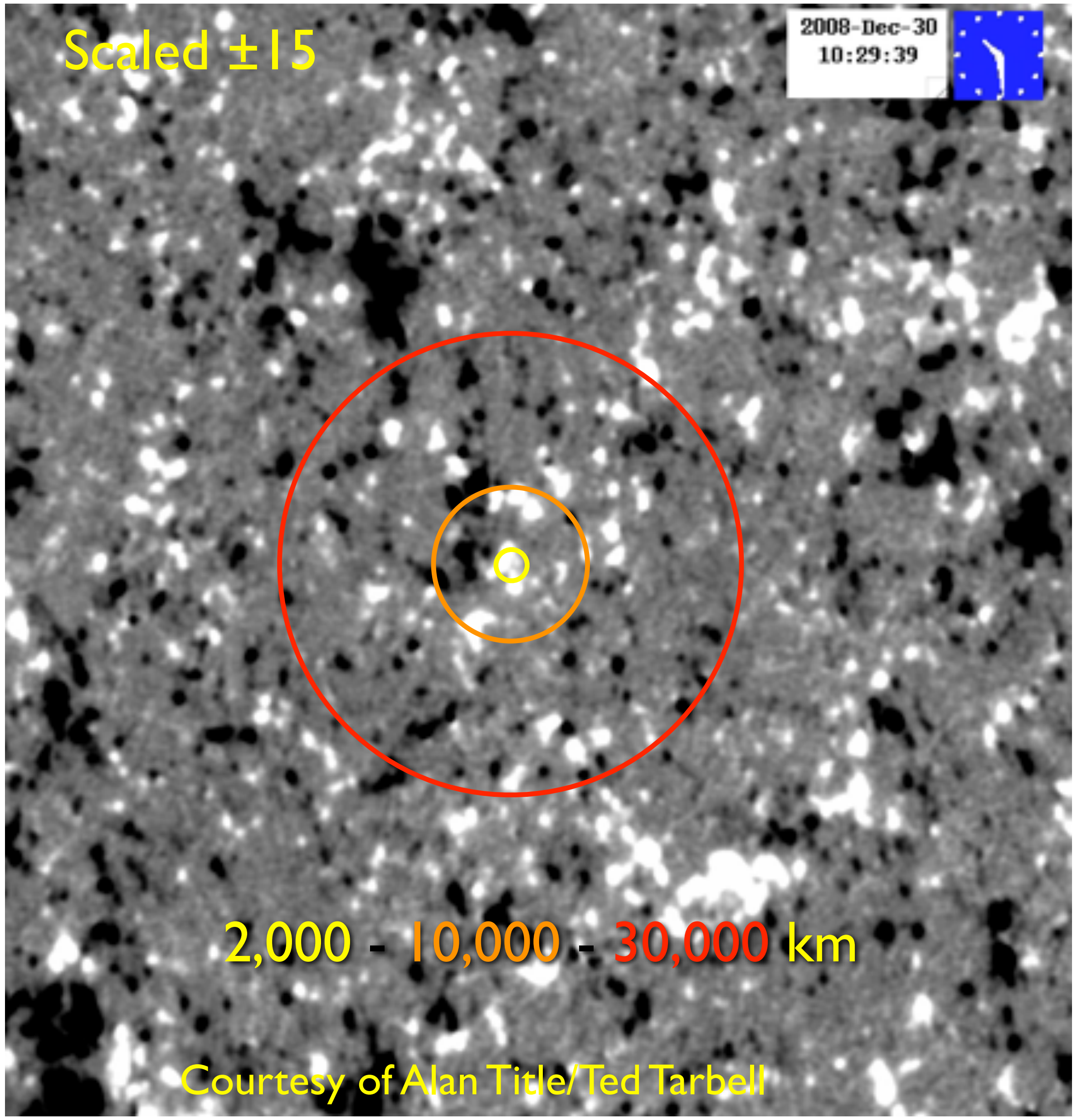
Typically very little TR emission: chromospheric (continuum) shocks

Martinez-Sykora et al., 2015

Do weak granular-scale magnetic fields play a role?

Martinez-Sykora et al., 2015





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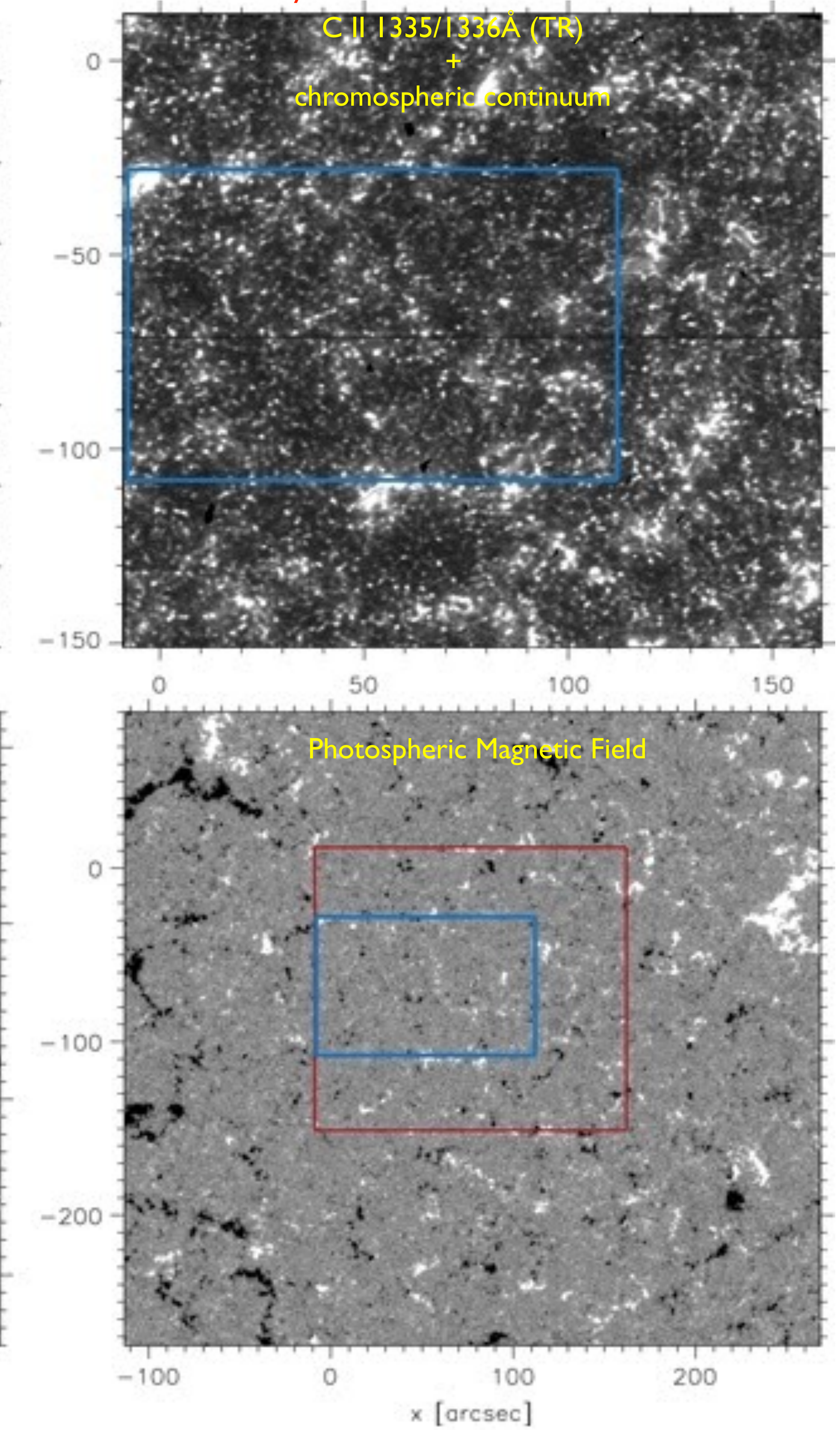

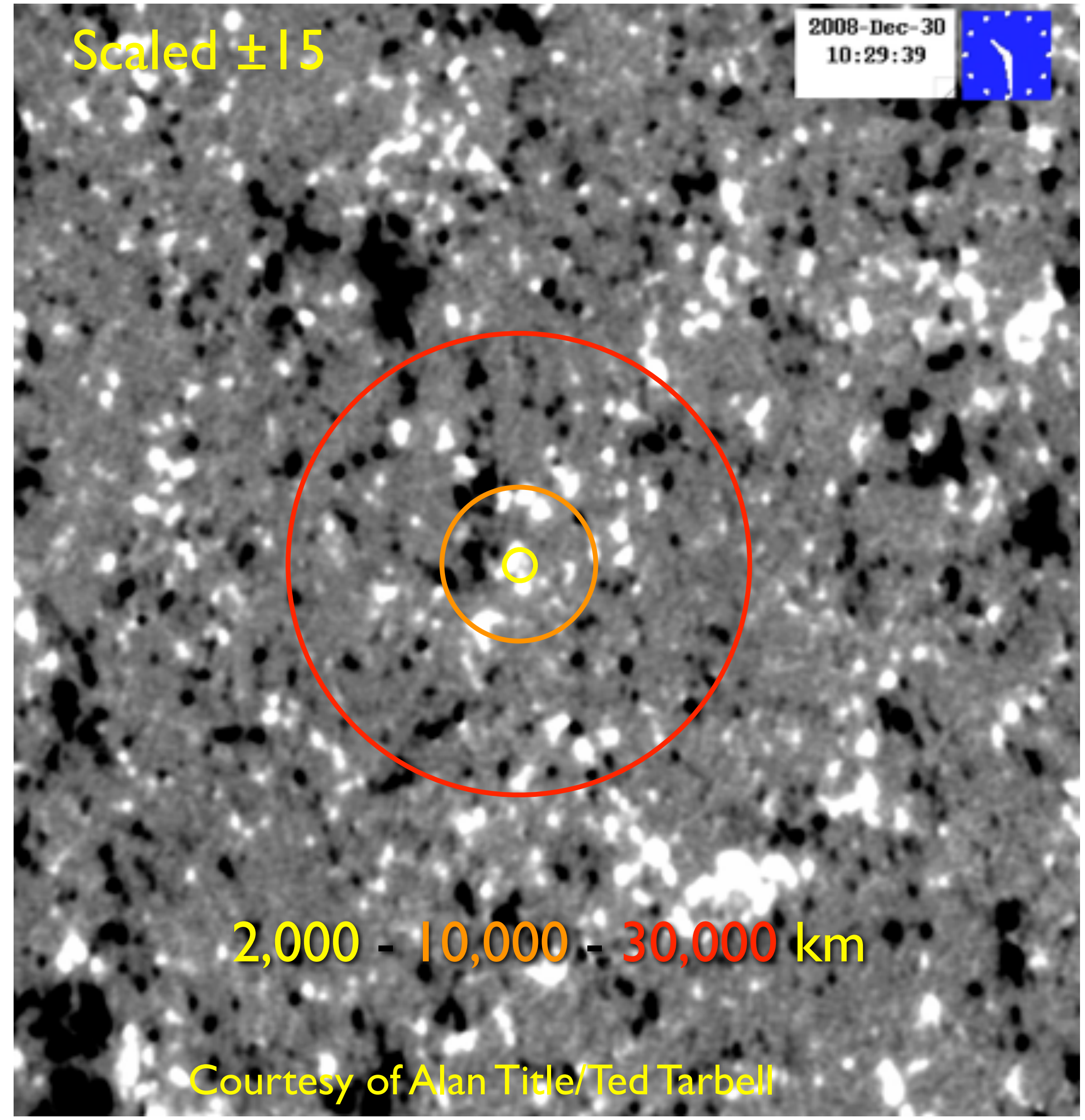

Granular fields are weak, but total flux emerging over whole Sun is enormous

Martinez Gonzalez & Bellot Rubio (2009), Ishikawa et al. (2009,2010)

Significant fraction of granular fields estimated to reach chromosphere within 5 min: chromospheric energy flux density of 10^6-10^7 erg/cm^2/s (Martinez-Gonzalez et al., 2010)

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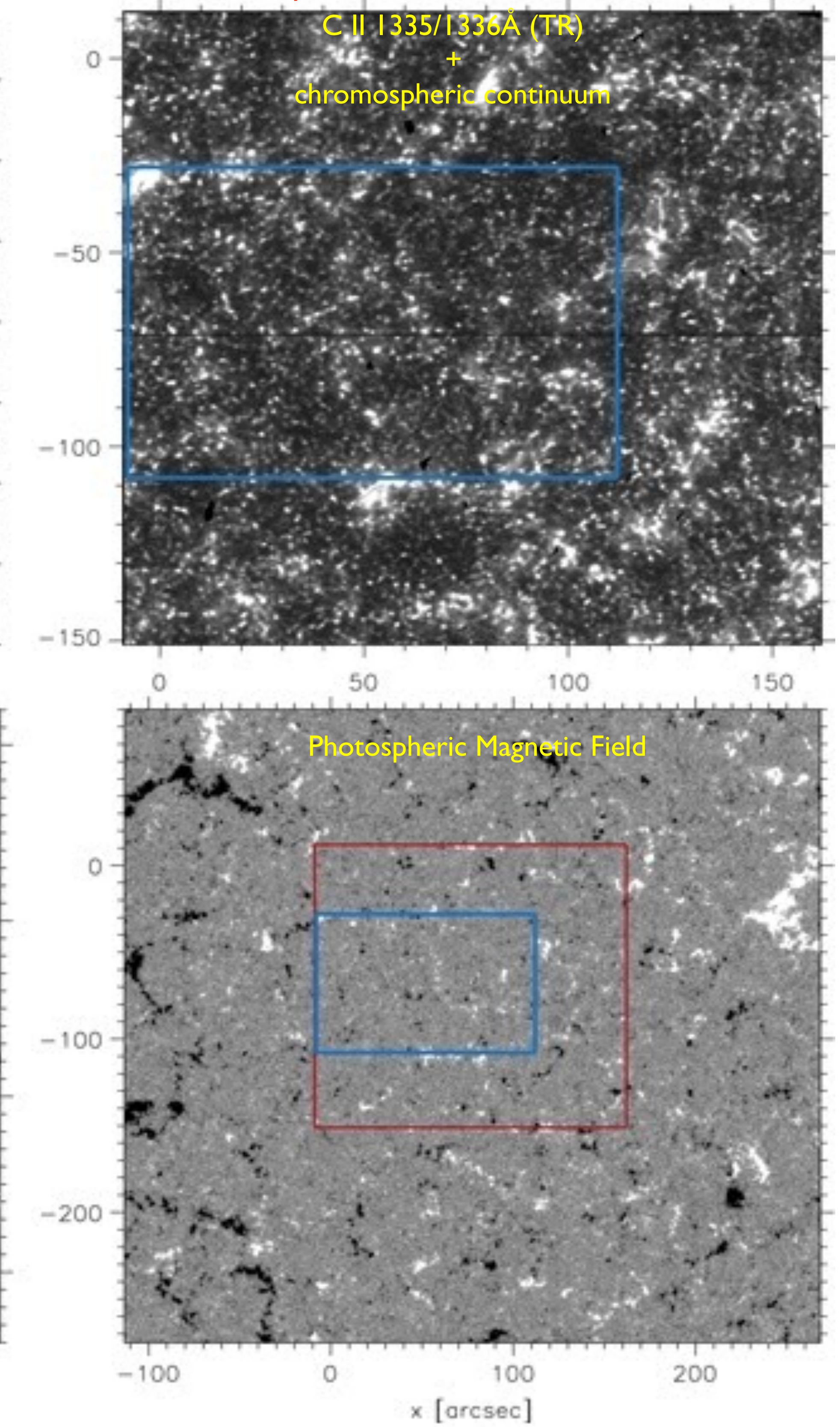

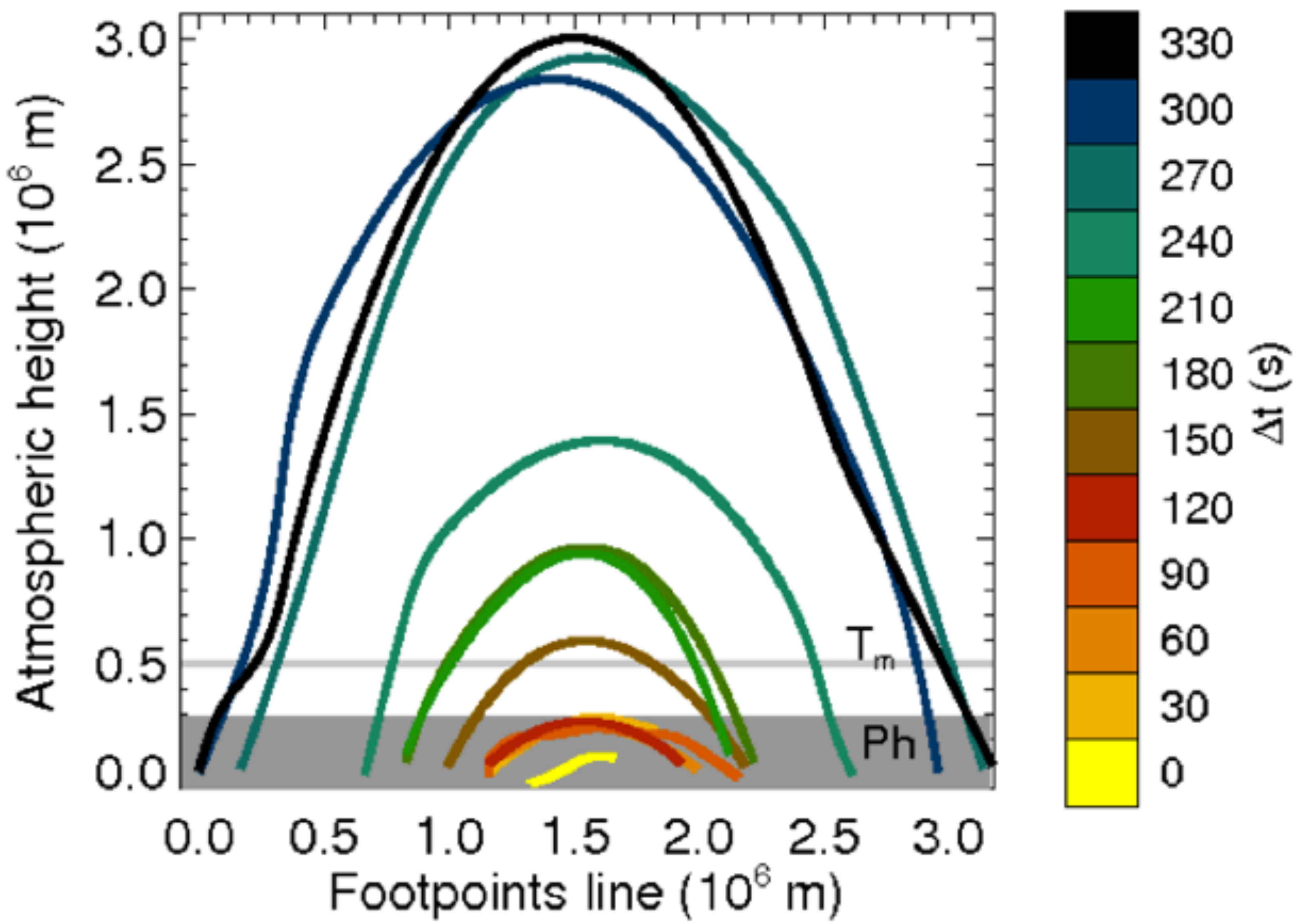

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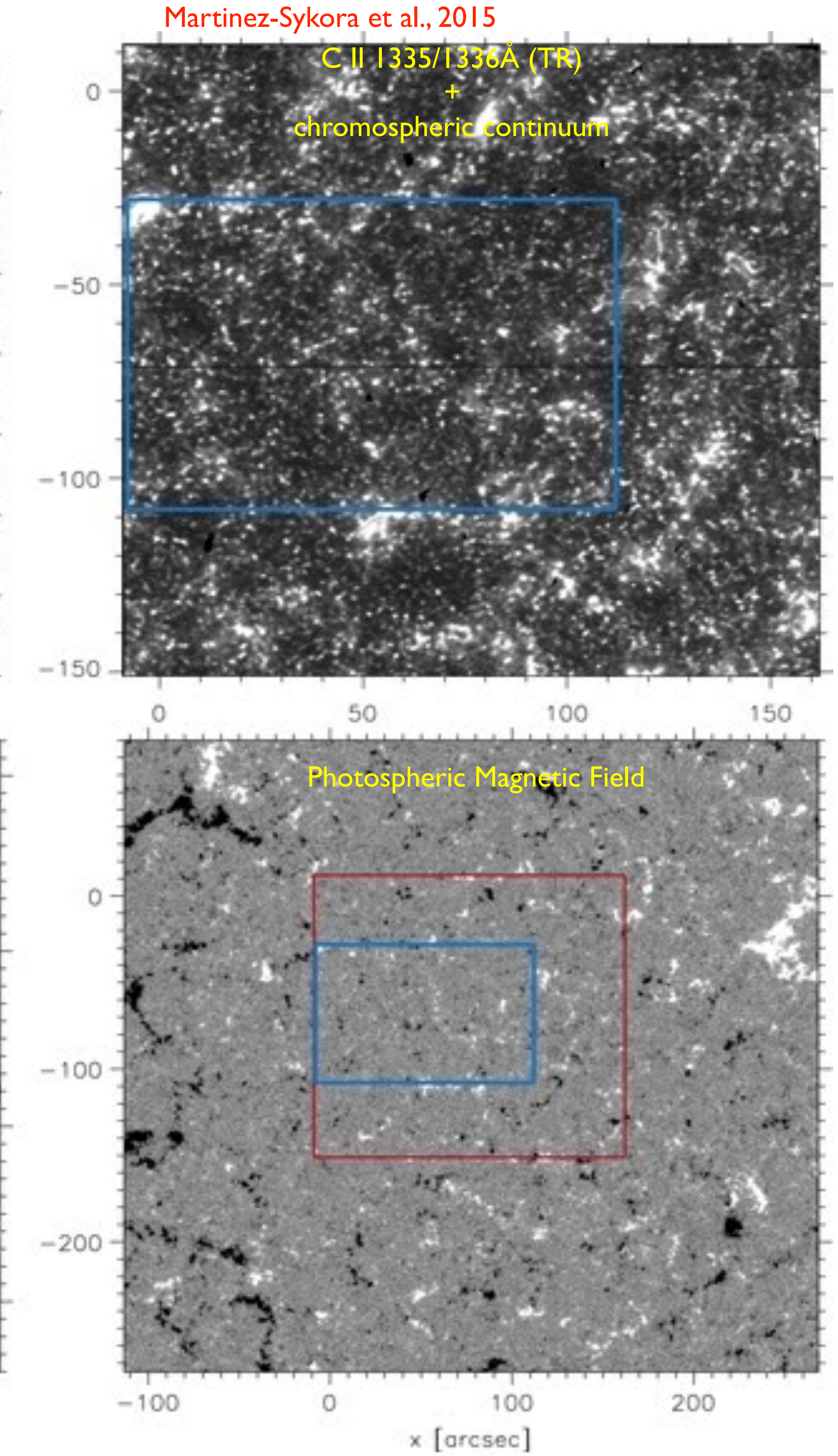

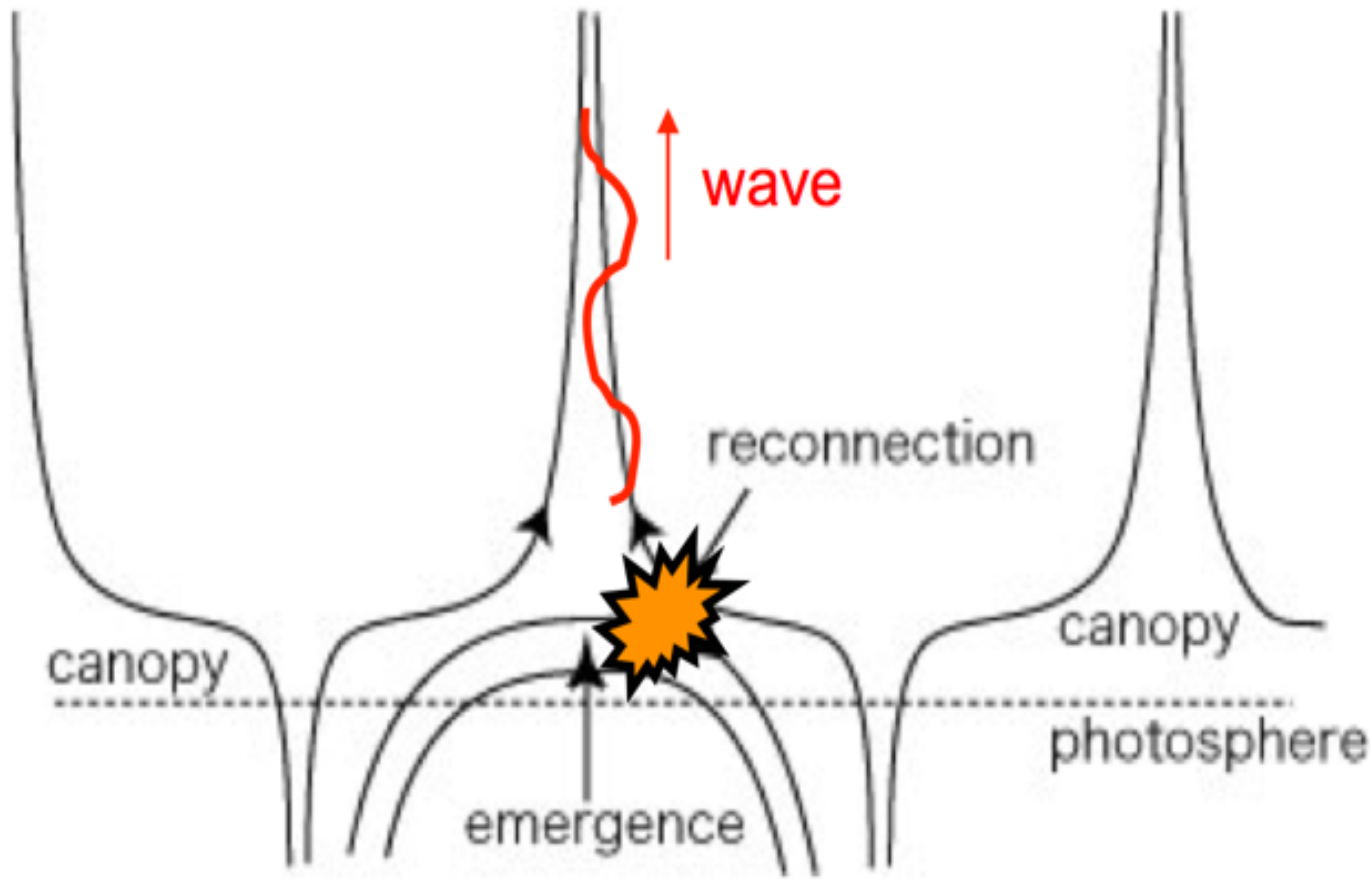

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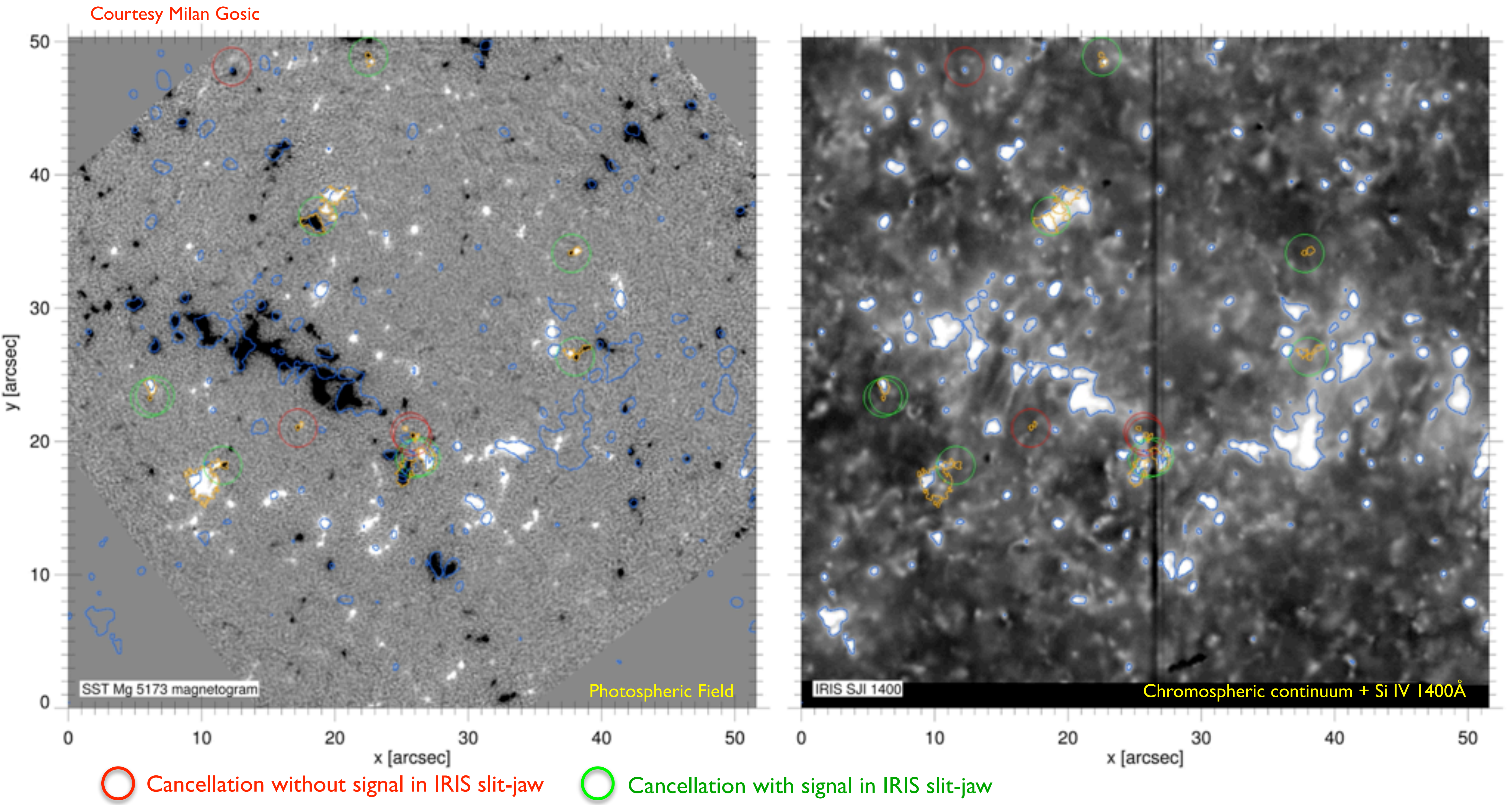
Chromospheric impact of granular-scale fields from cancellation



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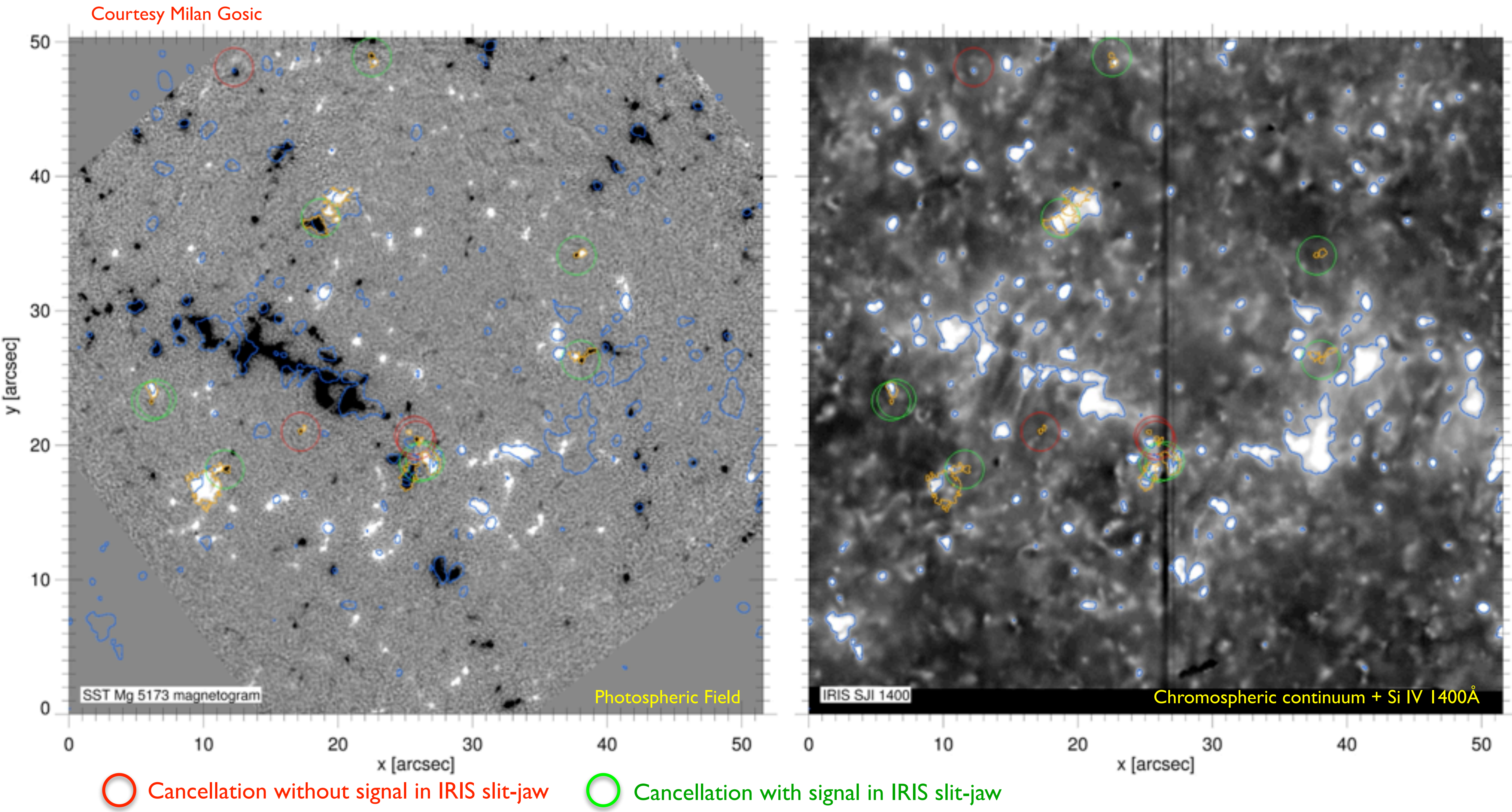
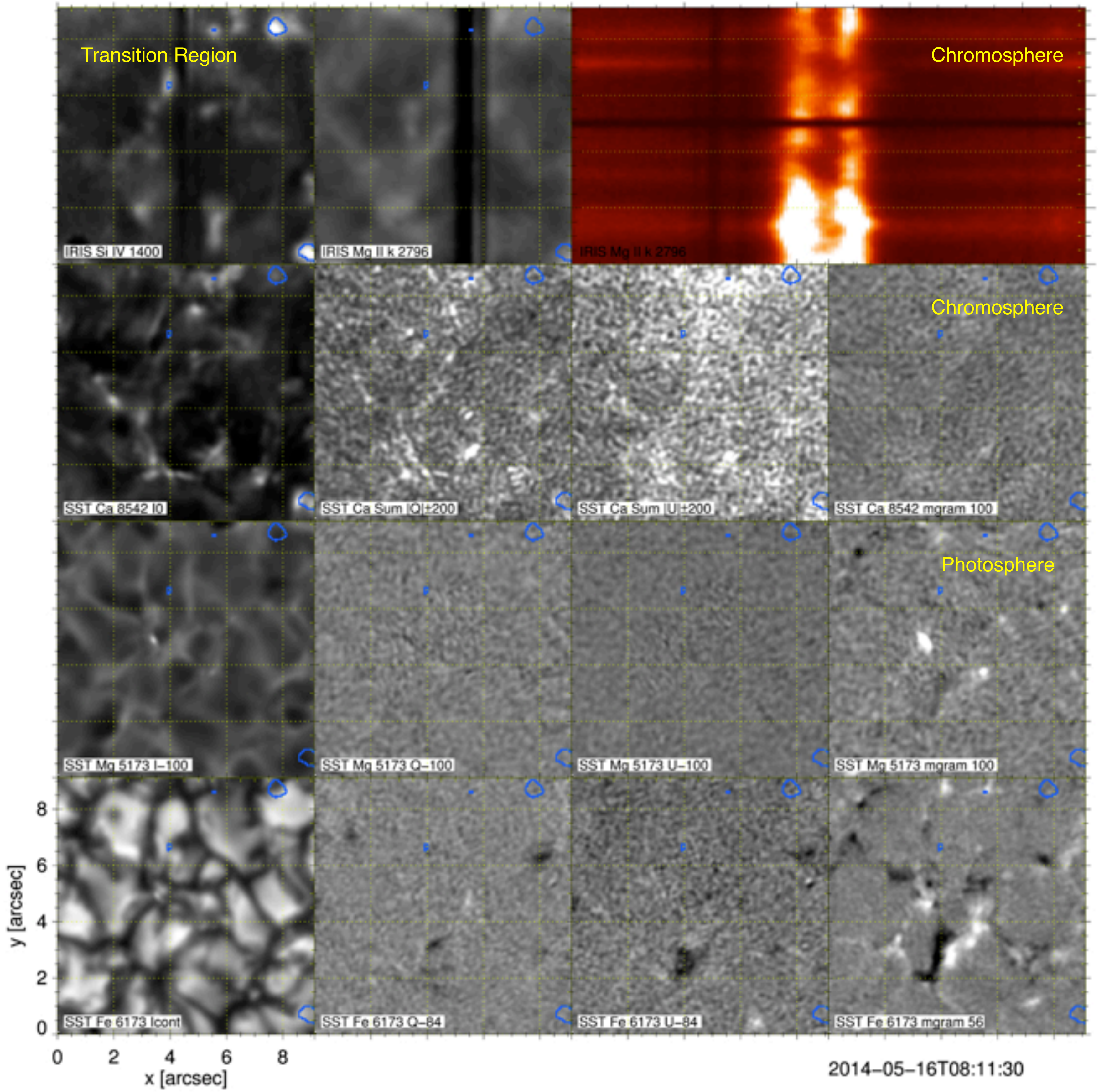


Automated tracking of photospheric magnetic fields shows that: in addition to emergence, cancellation plays a significant role in the chromospheric dynamics

Impact of granular fields on chromospheric dynamics/energetics

courtesy of
Milan Gosic



Cancellation leads to significant heating in IRIS slit-jaw channels (chromospheric continuum? Si IV TR?)
Brightenings typically precede photospheric cancellation by several minutes

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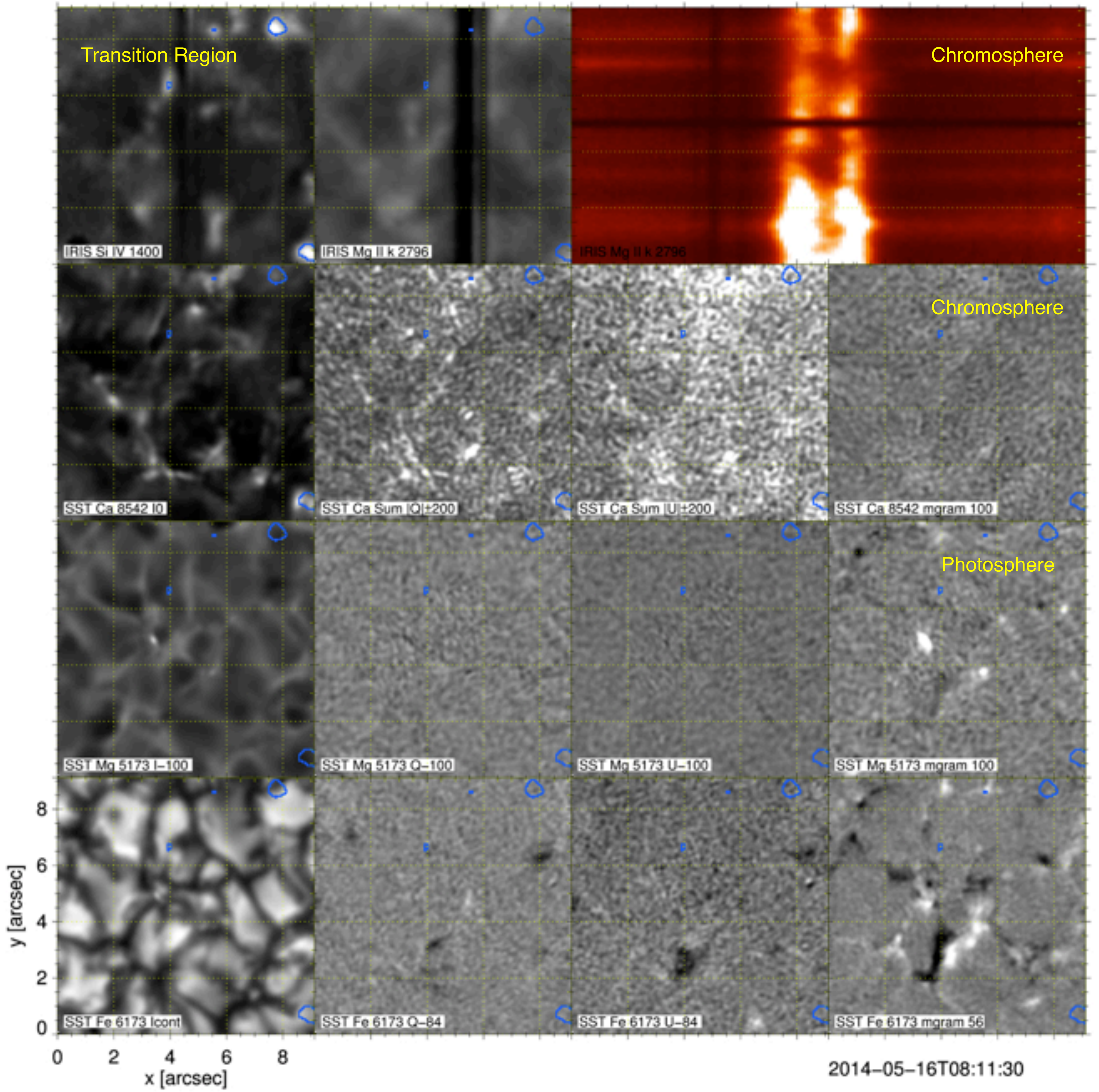

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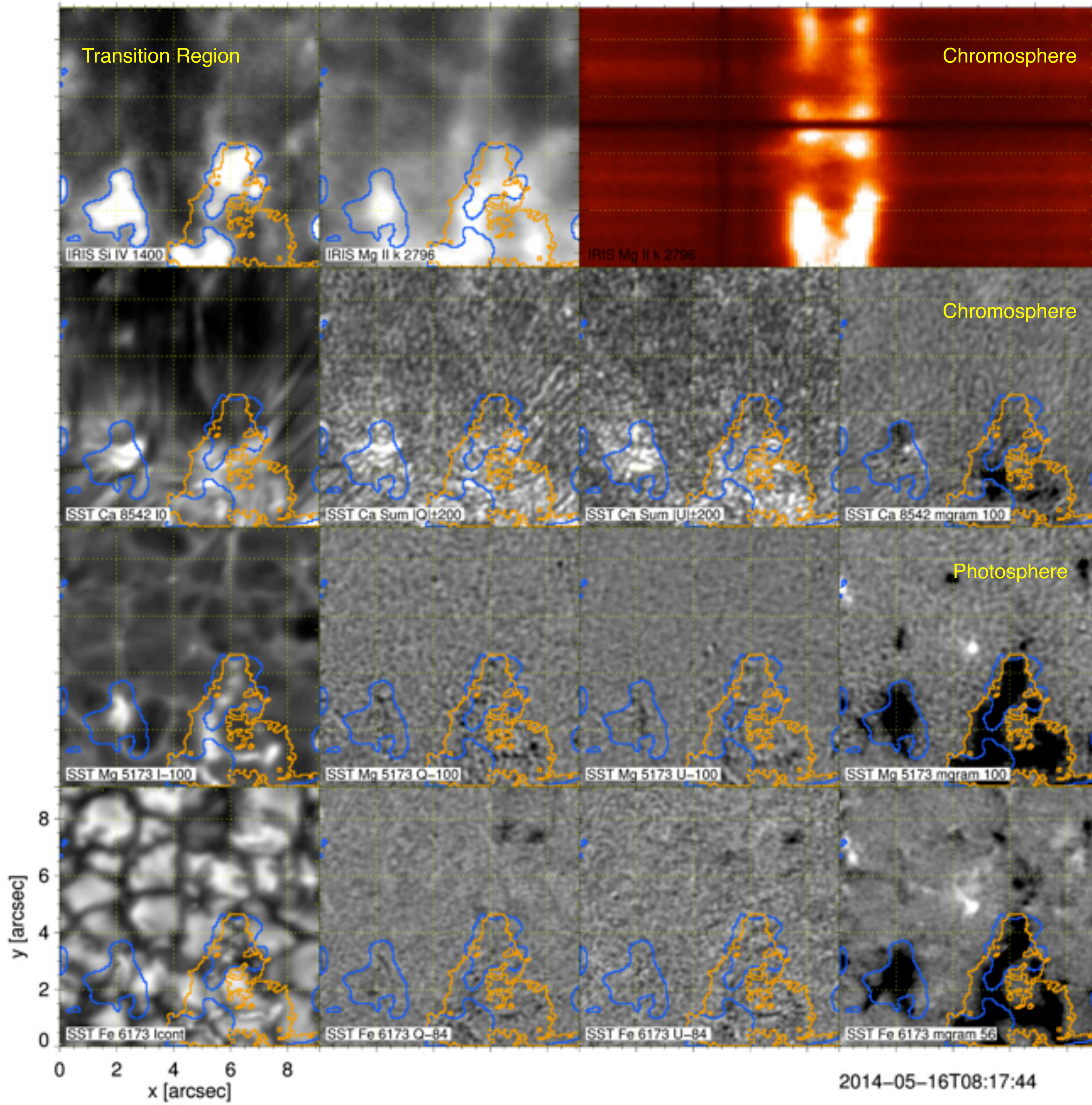

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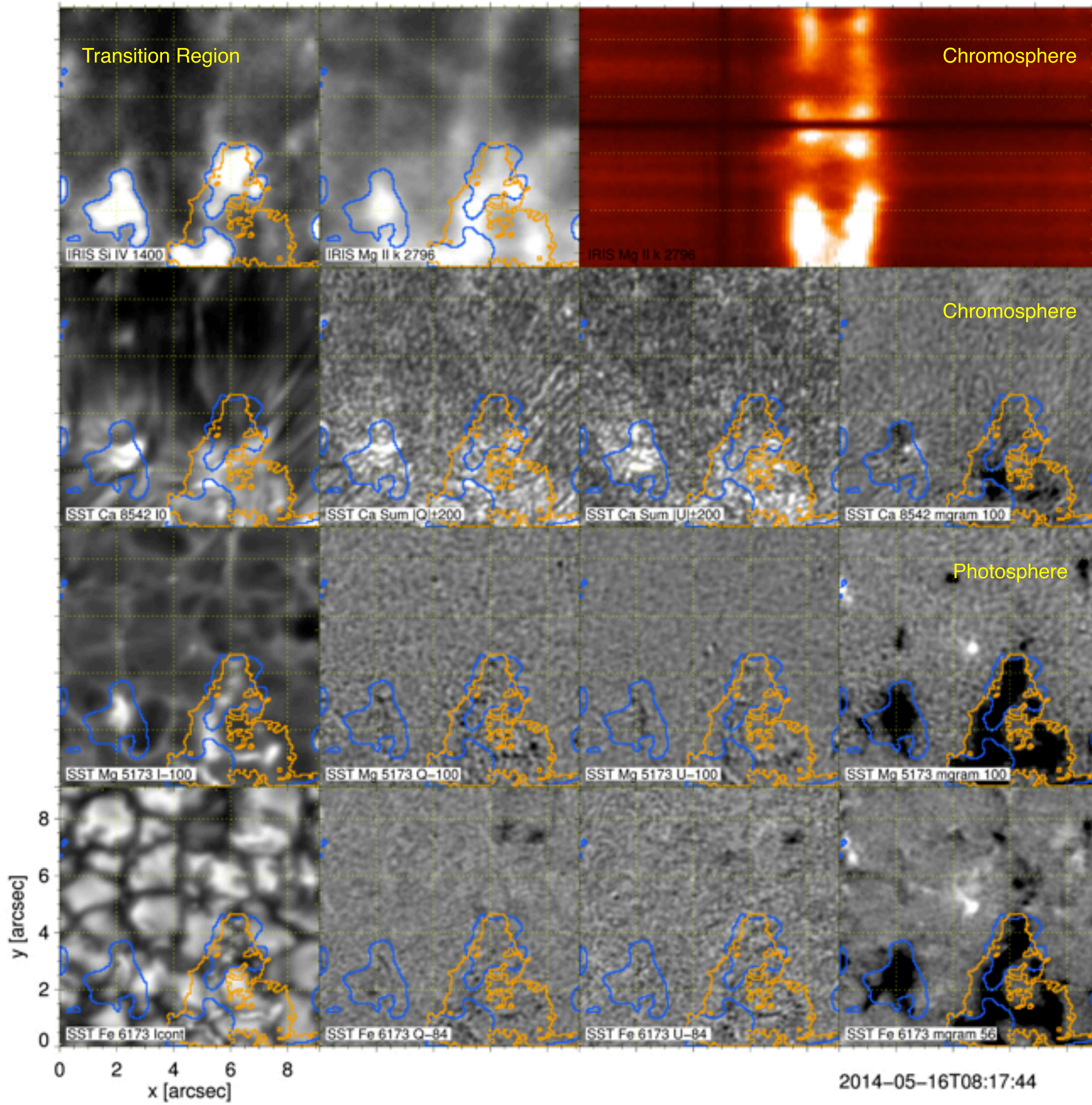

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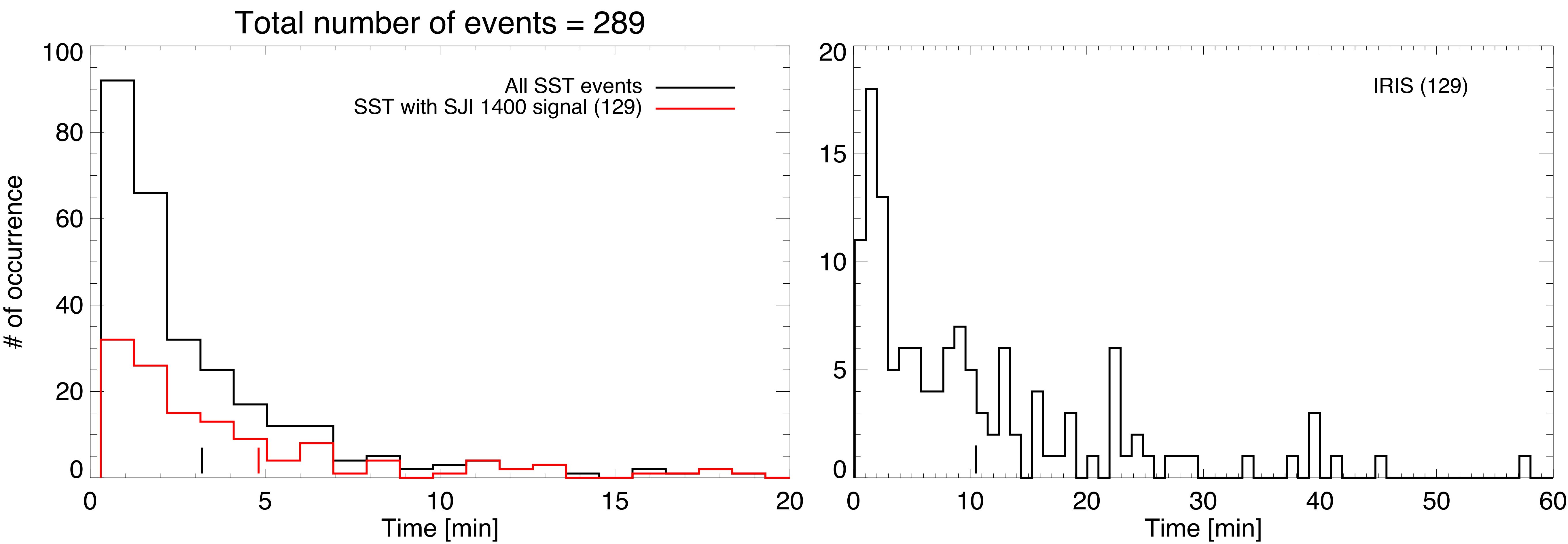
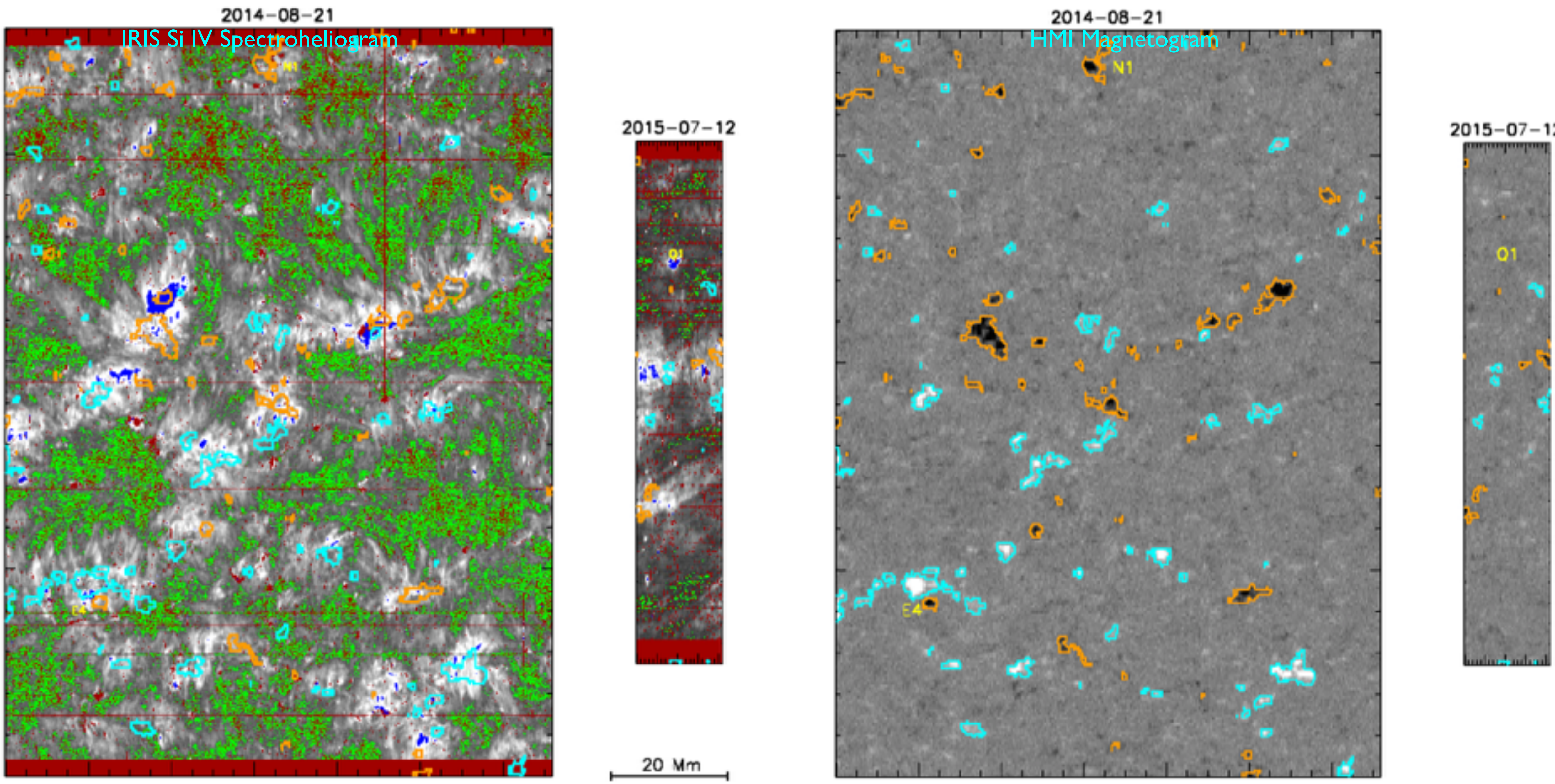


courtesy of Milan Gosic

- 44% of cancellations lead to brightenings in IRIS slit-jaw channels
- Typical lifetimes of order 5 minutes
- Suggests at least chromospheric heating, possibly TR heating

Impact of granular fields on TR dynamics/energetics



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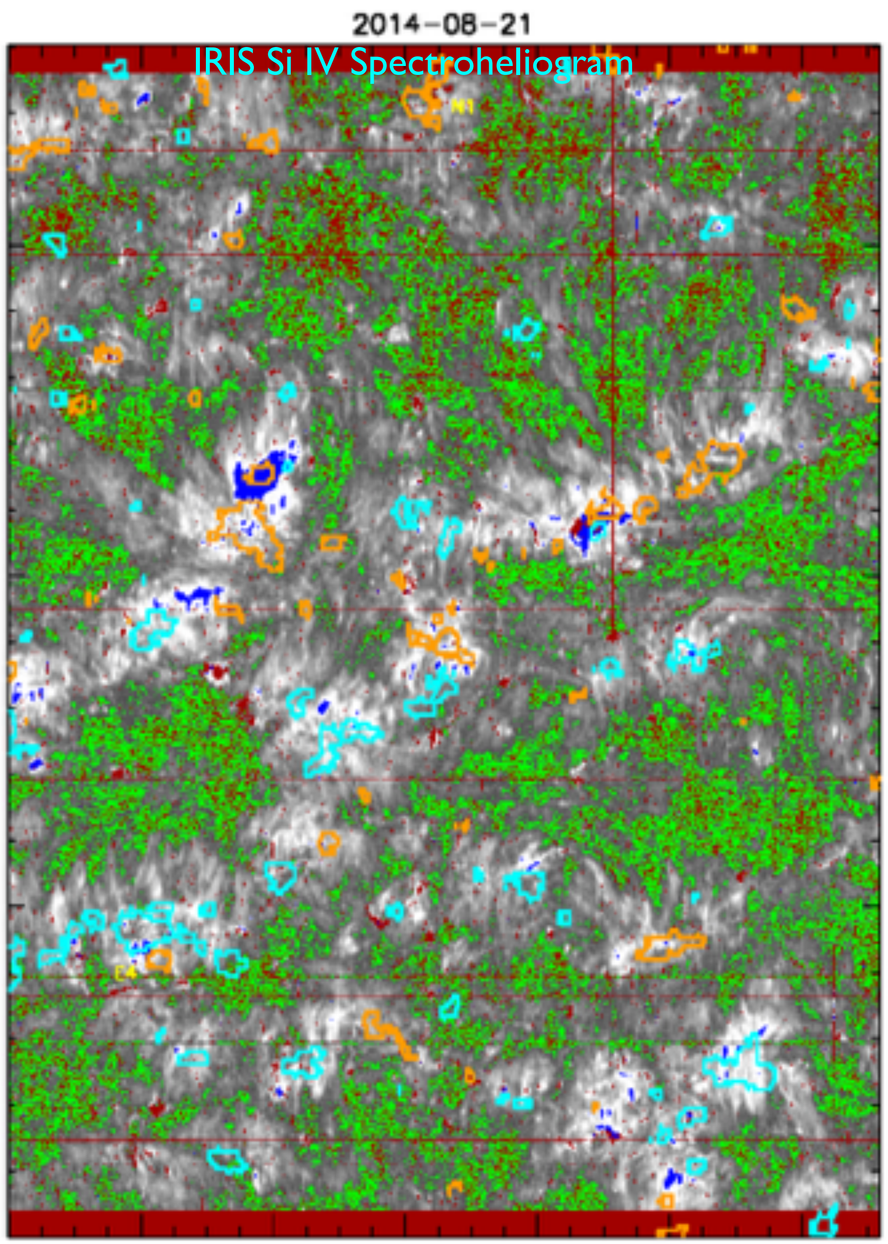

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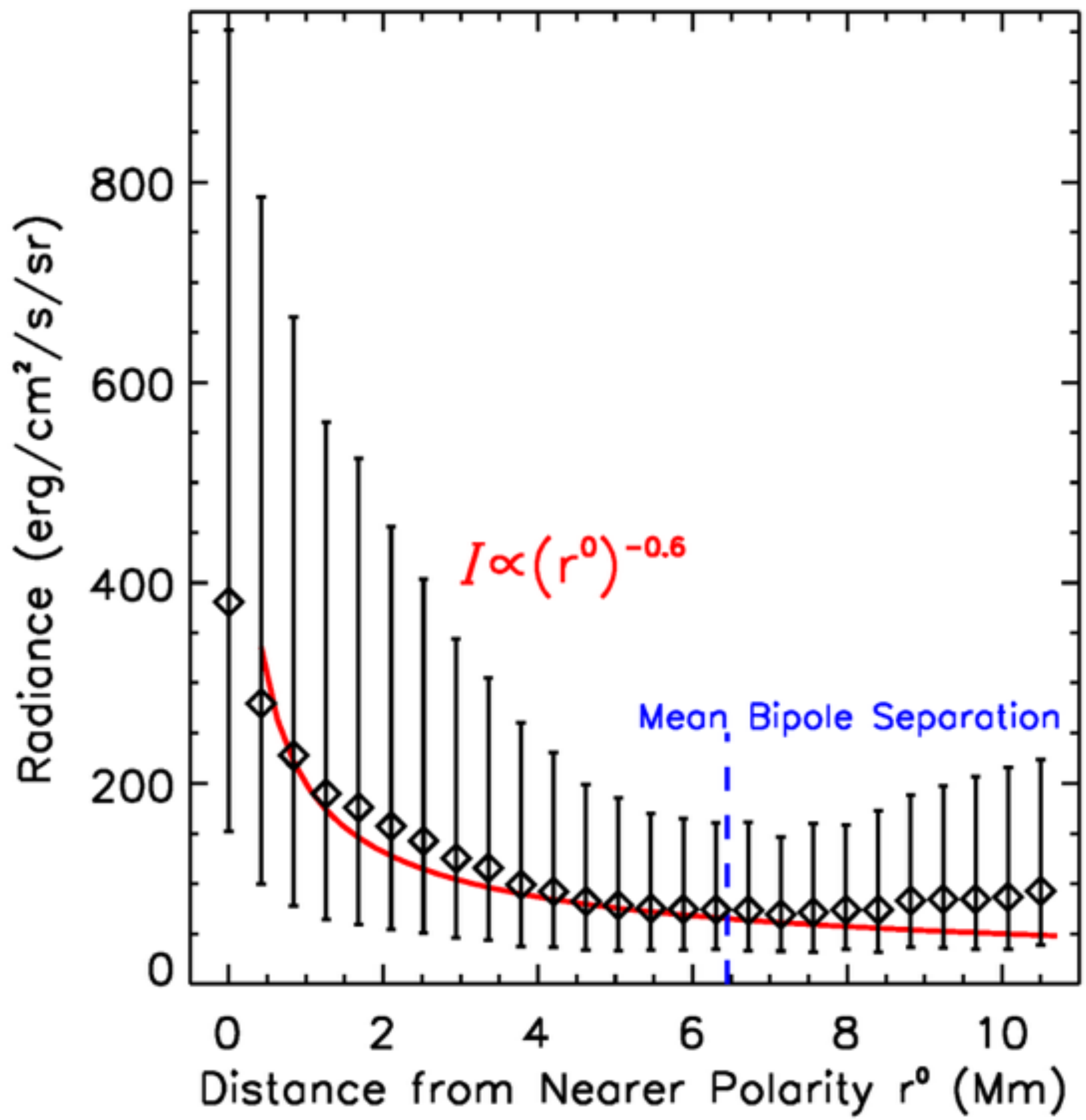

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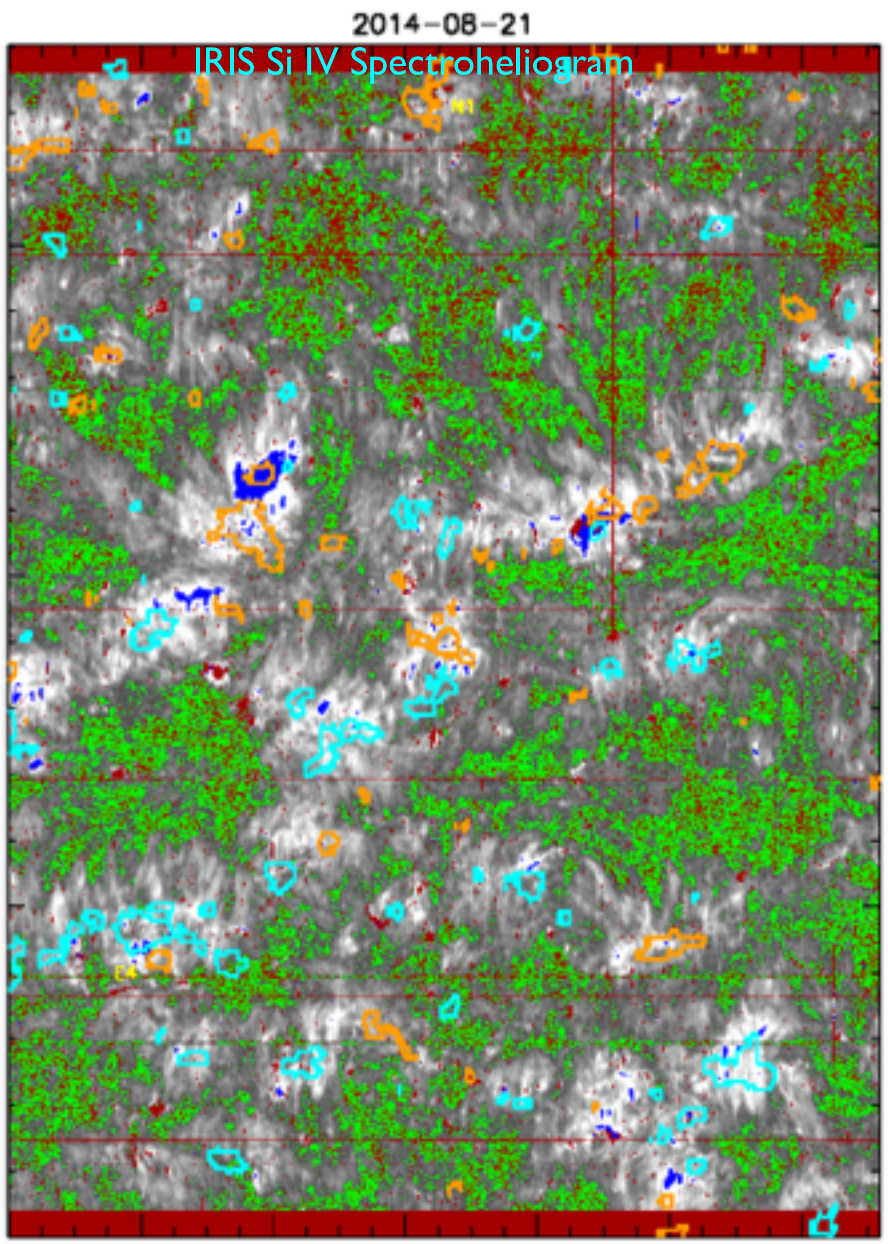

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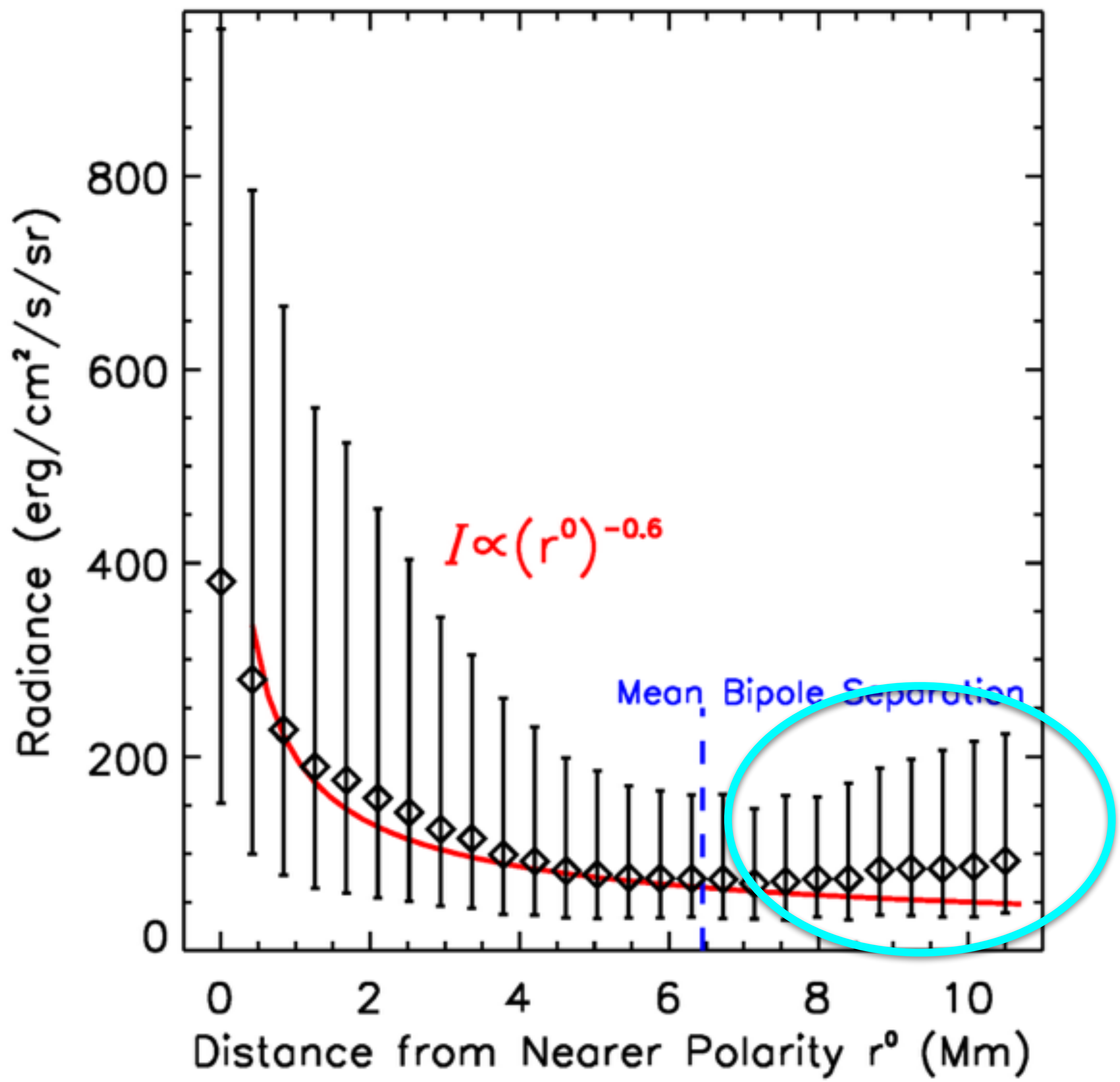
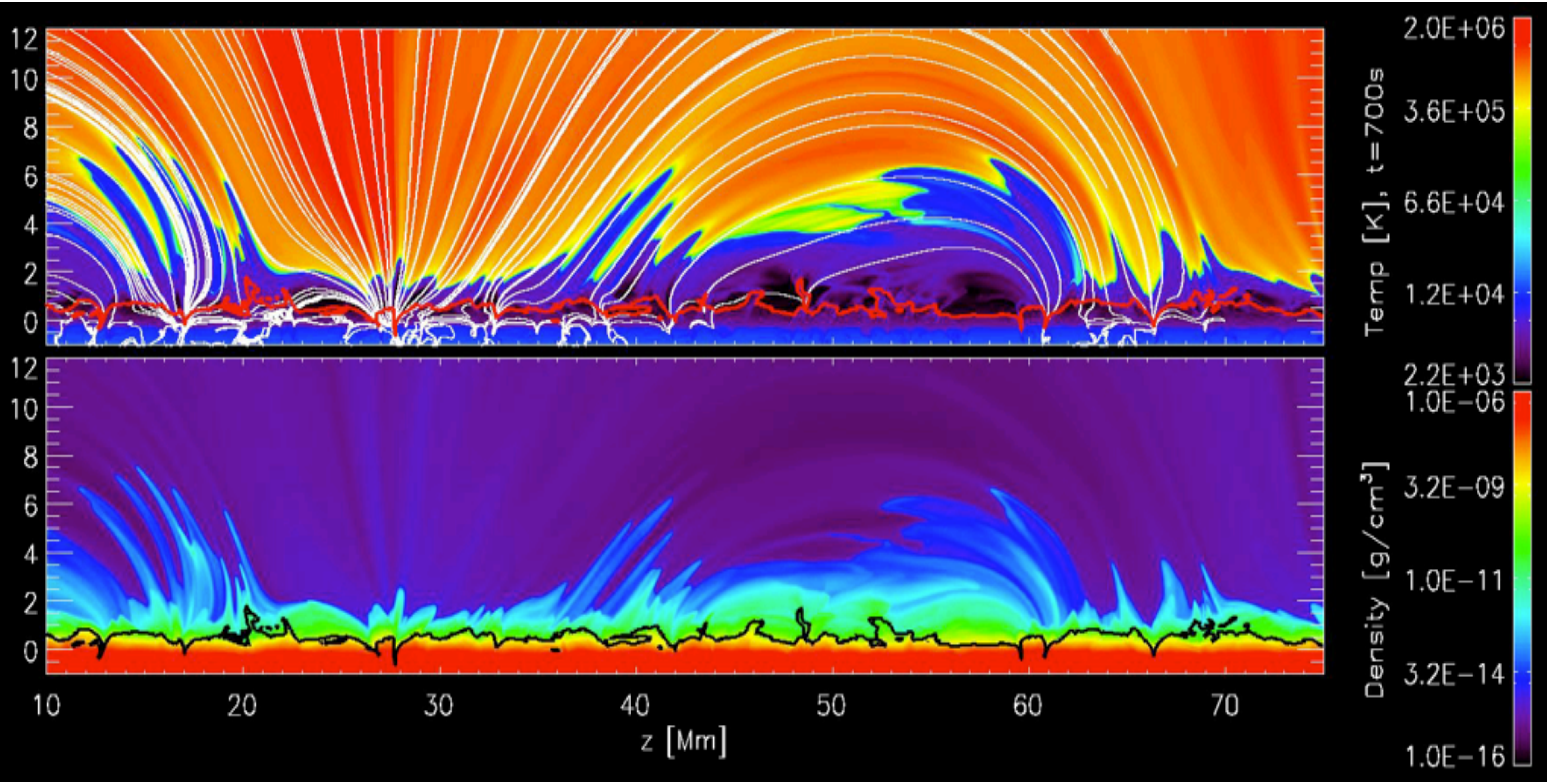


Si IV brightness in QS strongest near network

But significant rise far away from network: *effect of weak fields?*

Both types of spicules…



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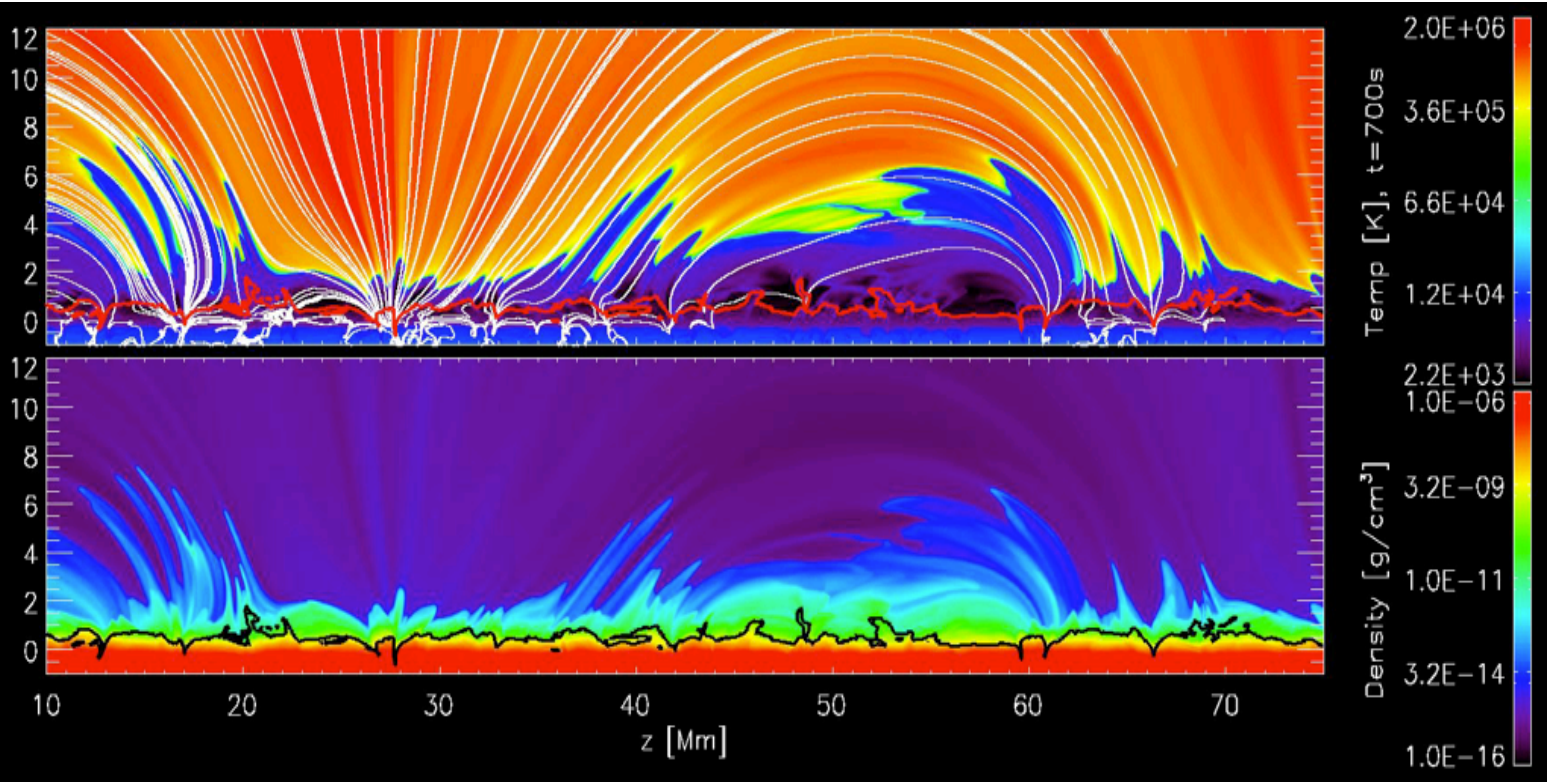

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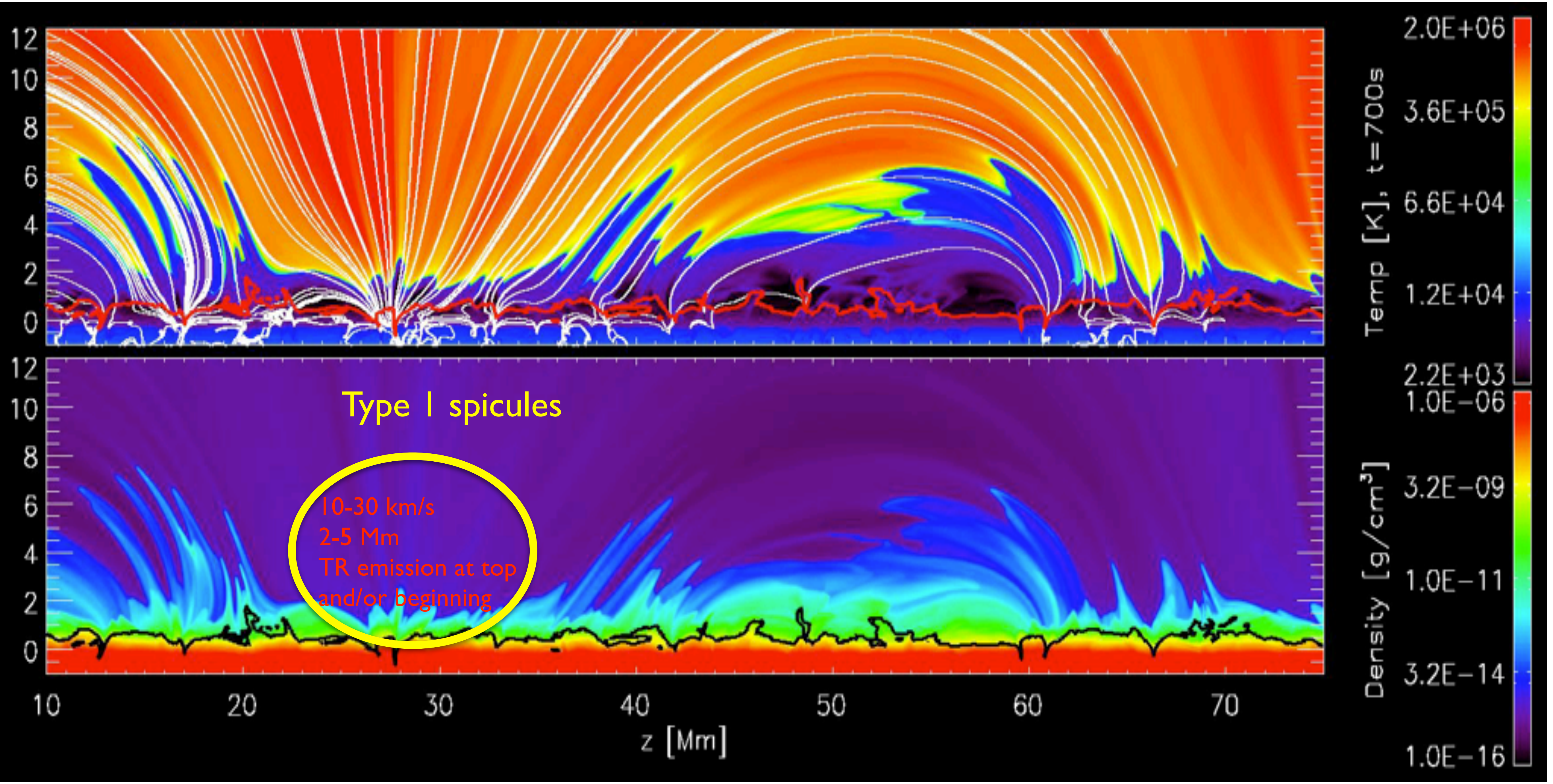

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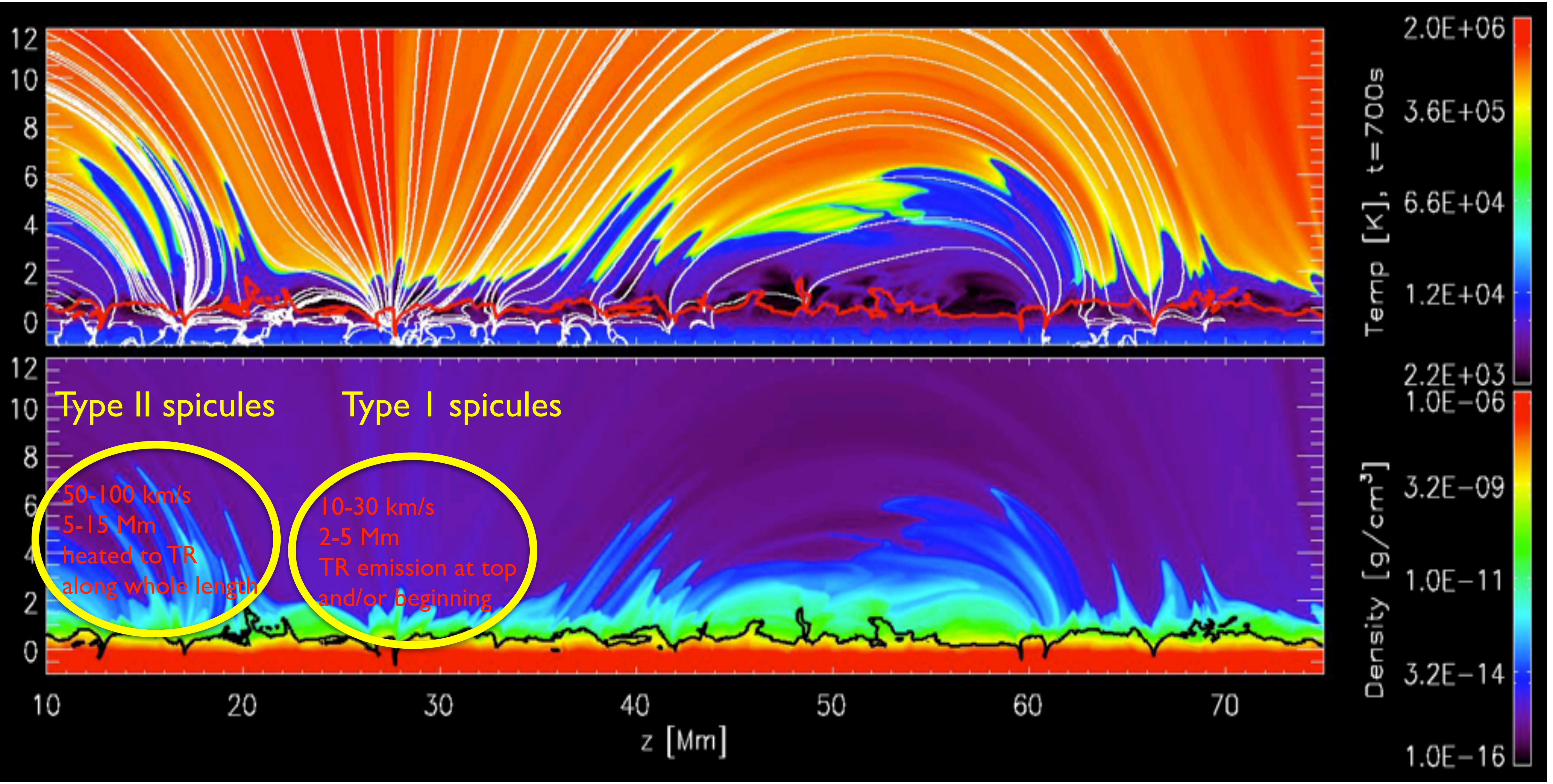

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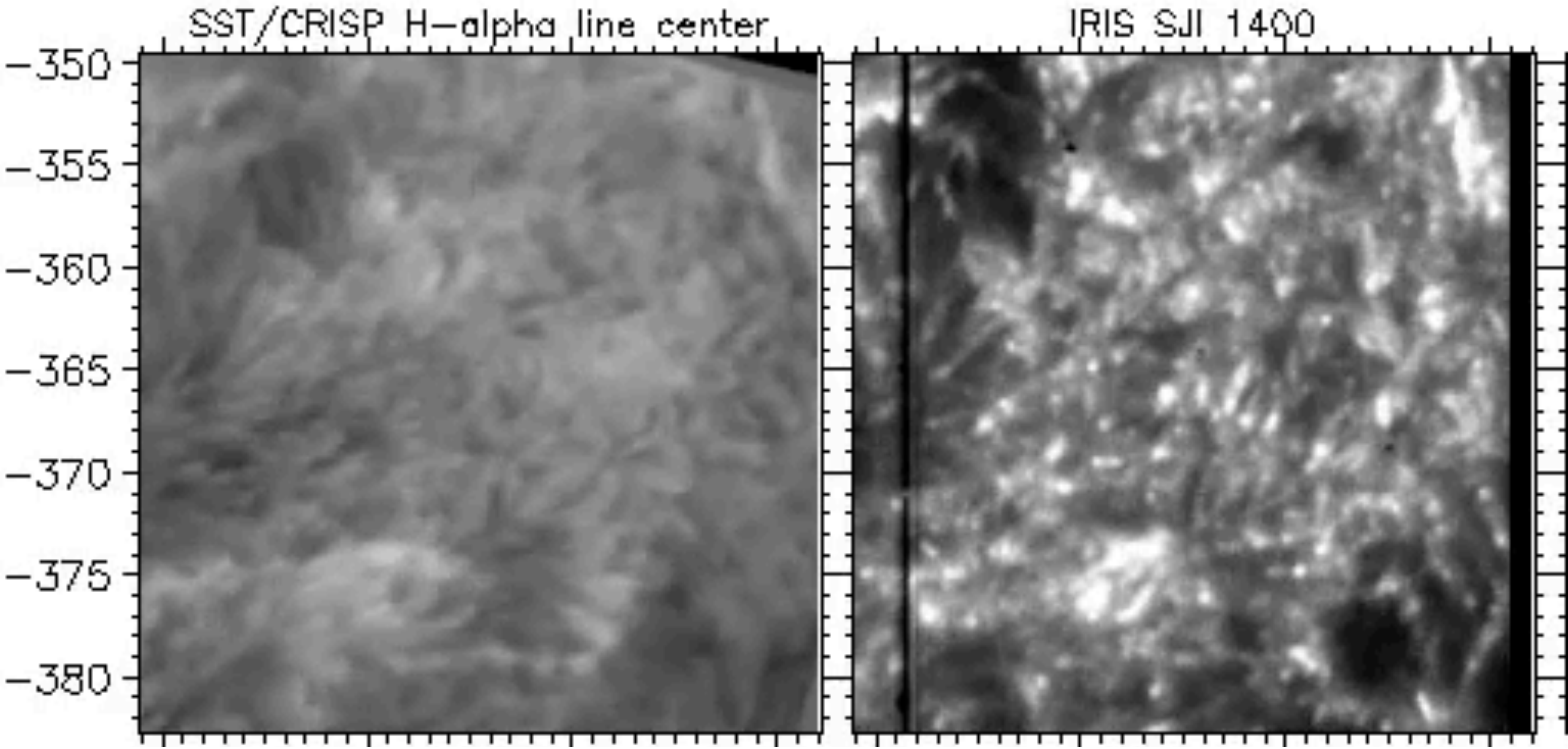
Impact of the chromosphere on the outer atmosphere

What drives the dynamics of the transition region spectral lines?



Active region plage: dynamic fibrils (type I spicules)
often associated with Si IV brightenings

Skogsrud et al., 2015

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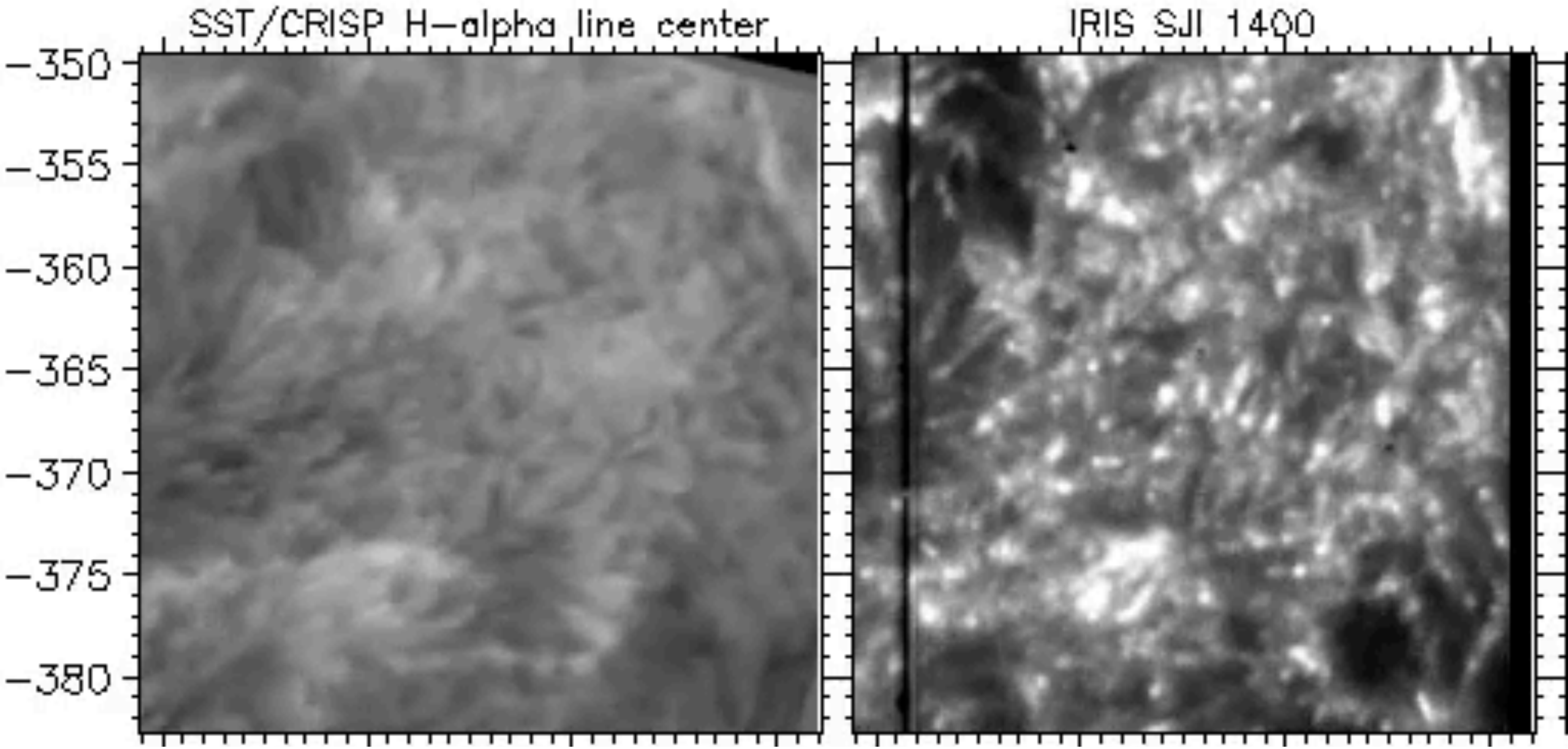

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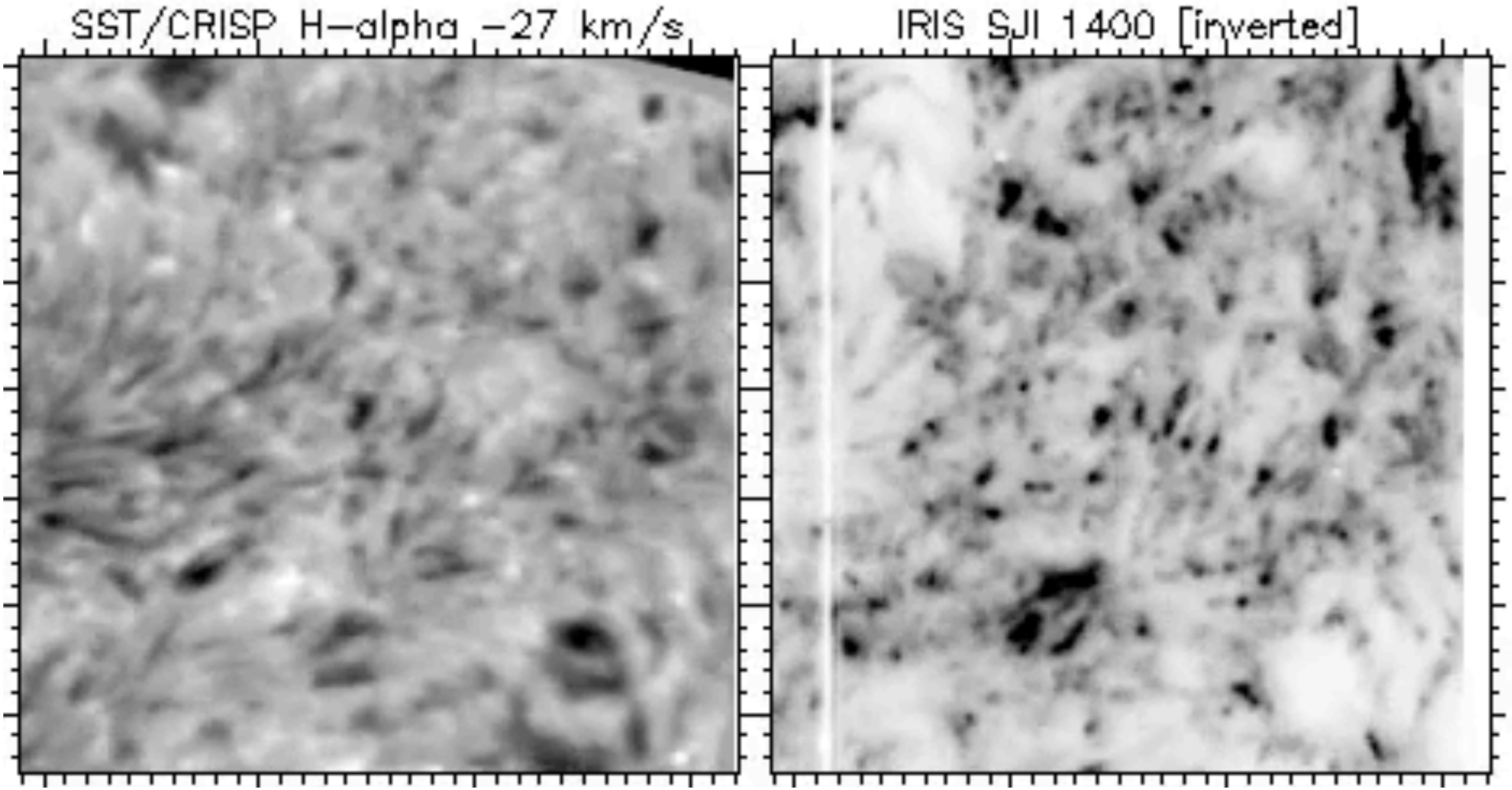

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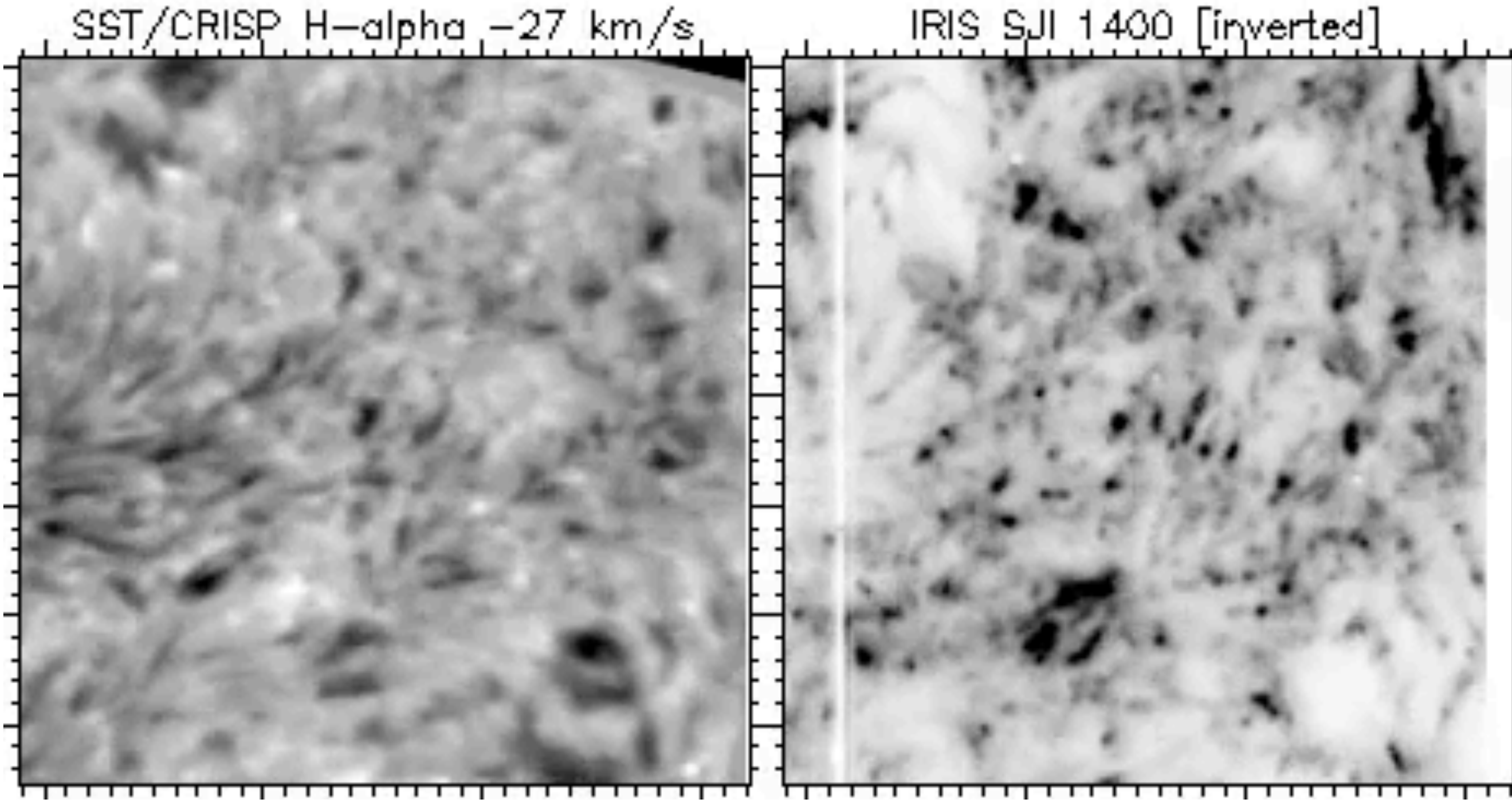

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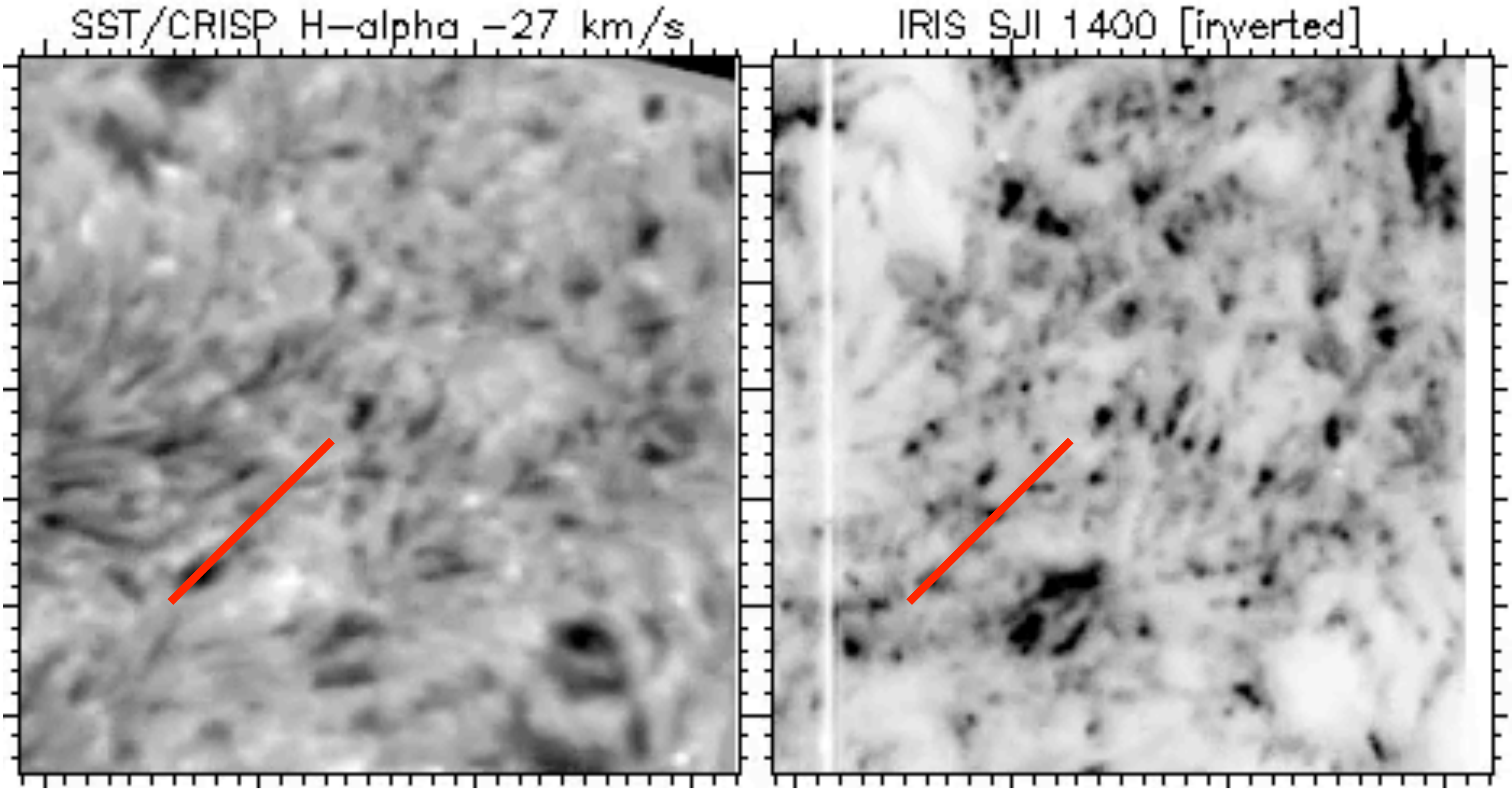

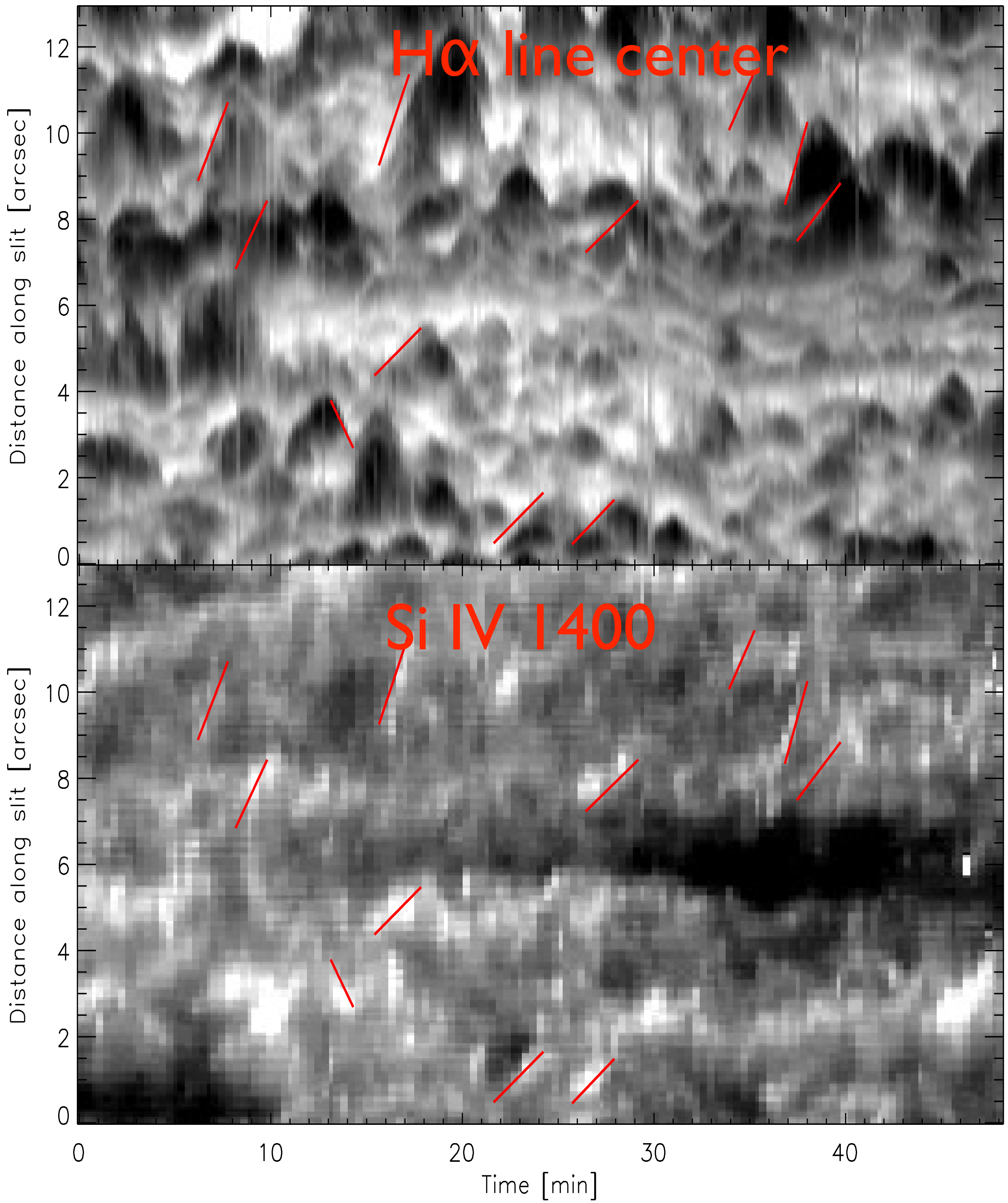

Dynamic fibrils (type I spicules)
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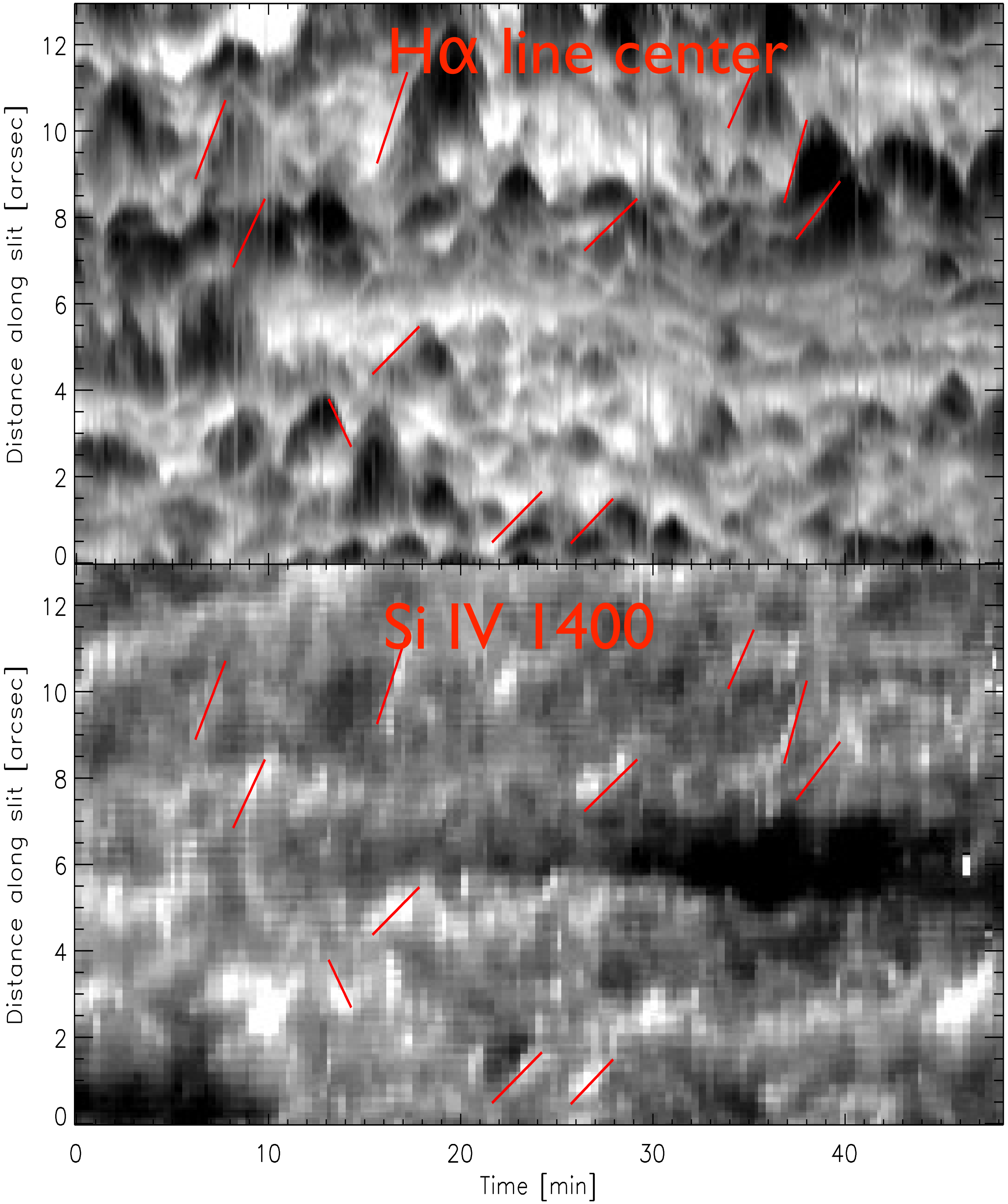

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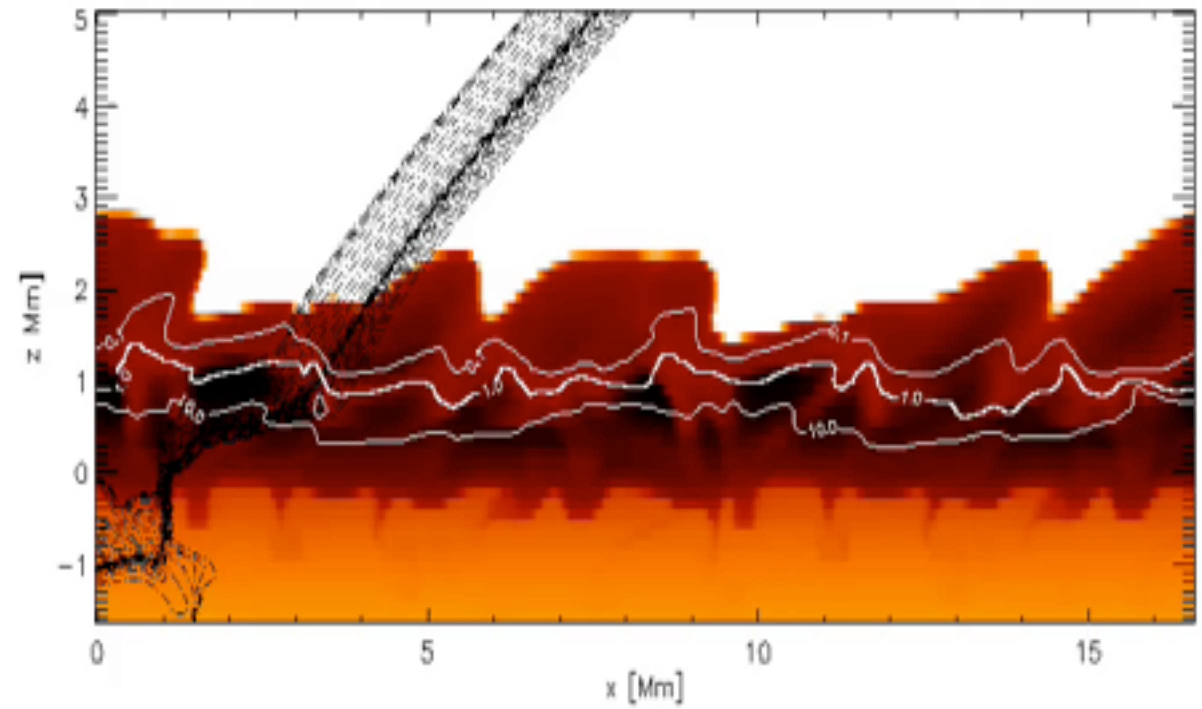
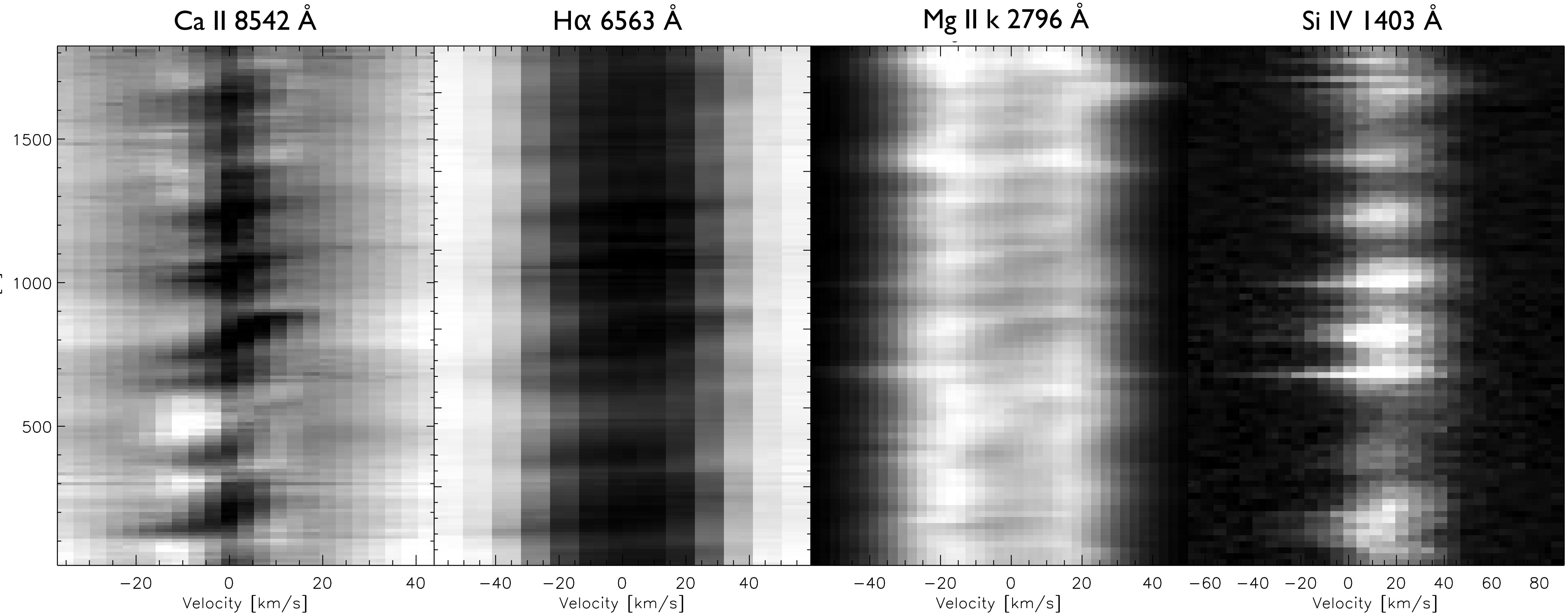
Numerical Simulations



2D/3D radiative MHD simulations show that magneto-acoustic slow-mode shocks in low-beta environment lead to dynamic fibrils and quiet Sun mottles

(Hansteen et al., 2006, De Pontieu et al., 2007, Rouppe van der Voort et al., 2007, Martinez-Sykora et al., 2009)

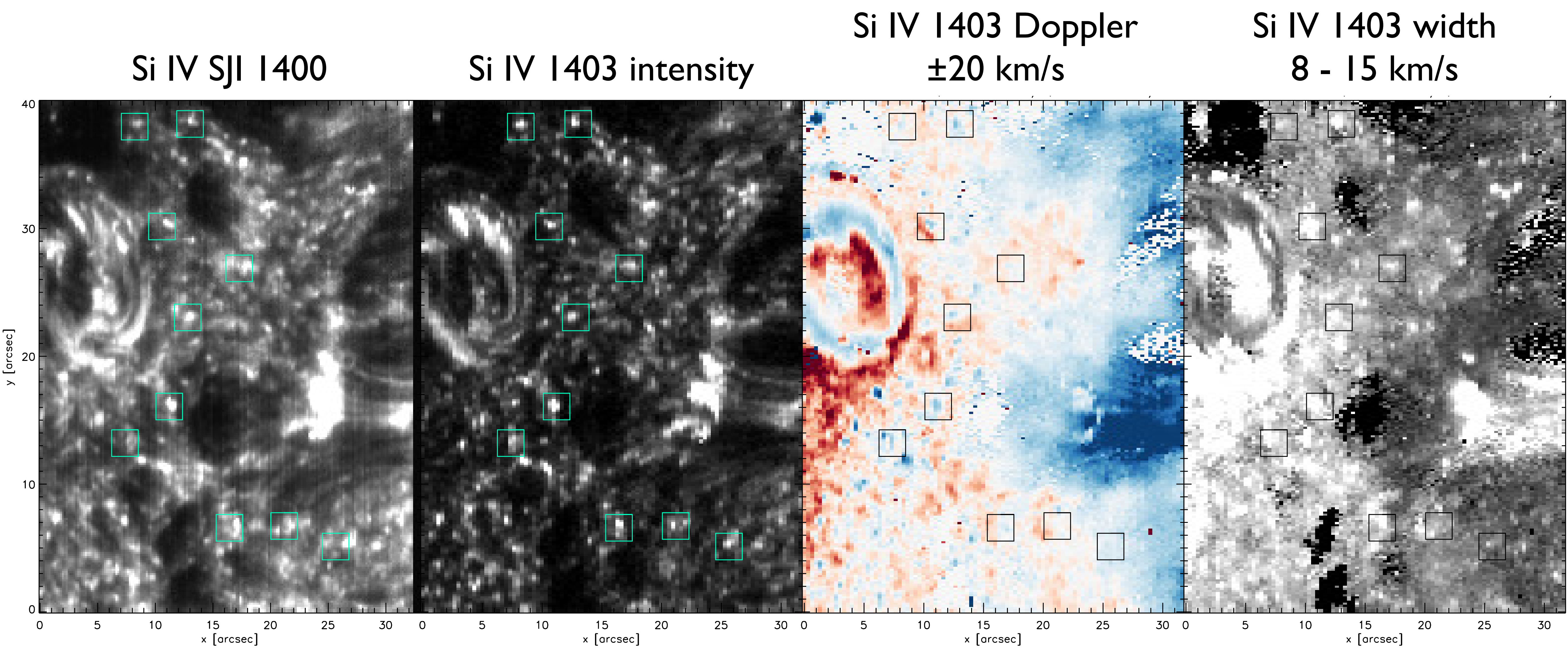
Transition Region response to dynamic fibrils: Si IV brightening, blueshift and line broadening



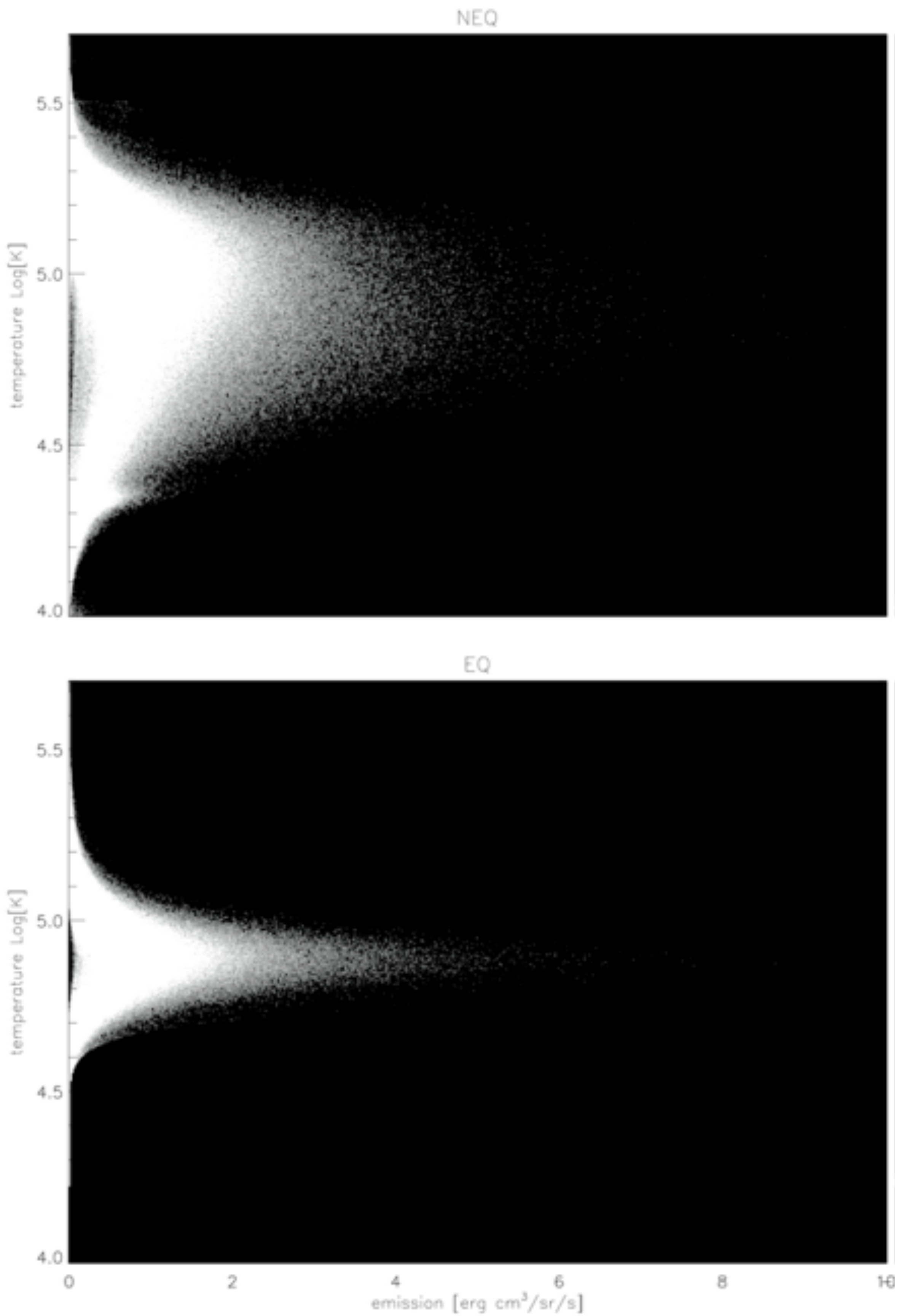
Si IV spectra clearly related to magneto-acoustic shock waves in chromosphere

Combined λ-t plots of Mg IIh and Si IV reveal a frequent connection of Si IV emission/ broadening with shock passage in magnetized regions.

Transition Region response to dynamic fibrils: Si IV brightening, blueshift and line broadening



Non-equilibrium ionization leads to Si IV formation over wider temperature range



Temperature

Non-equilibrium ionization

Temperature

Ionization equilibrium

Emission

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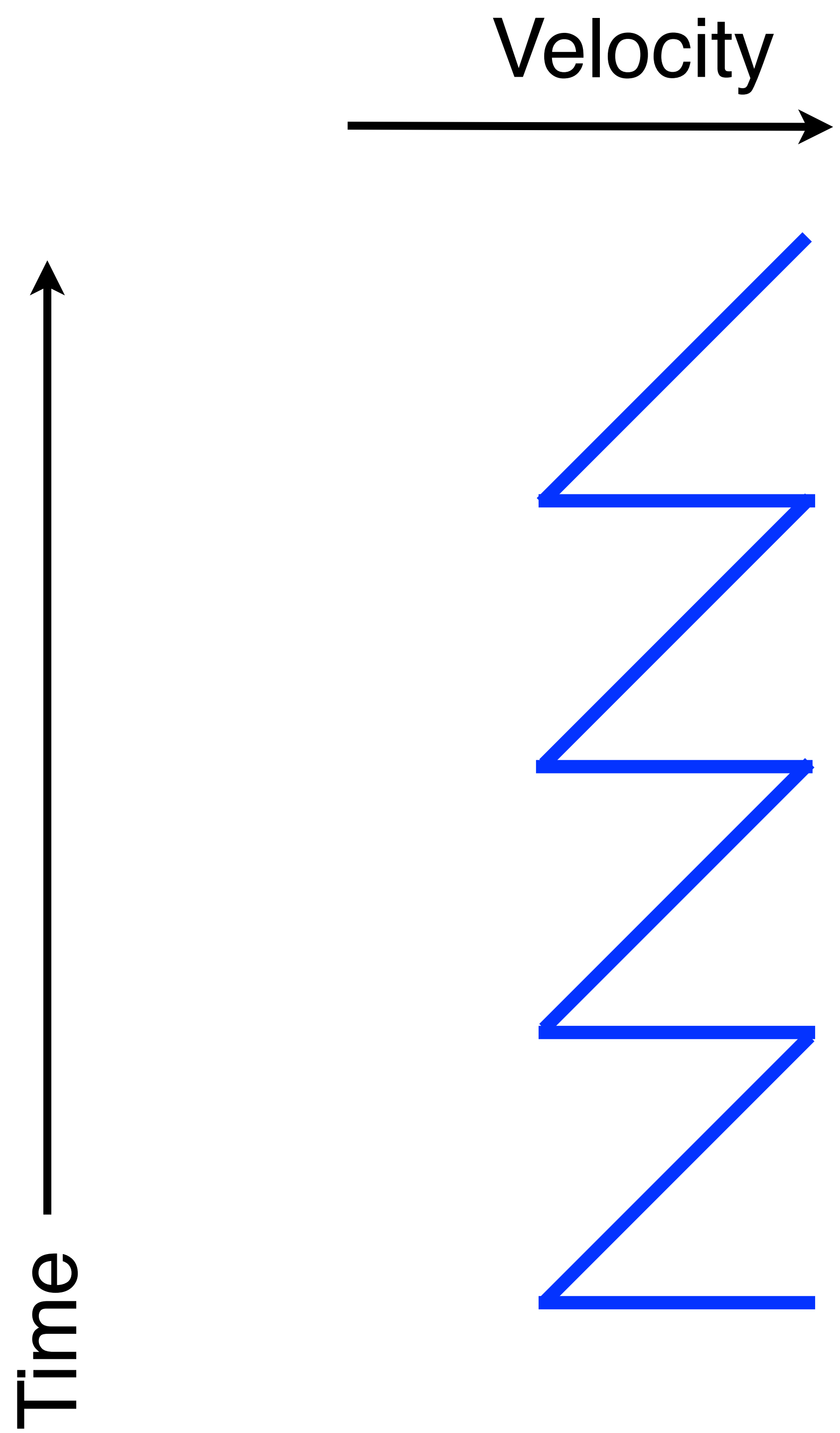

Wider temperature range leads to larger range of velocities along line-of-sight, and thus non-thermal line broadening, especially during shock passage

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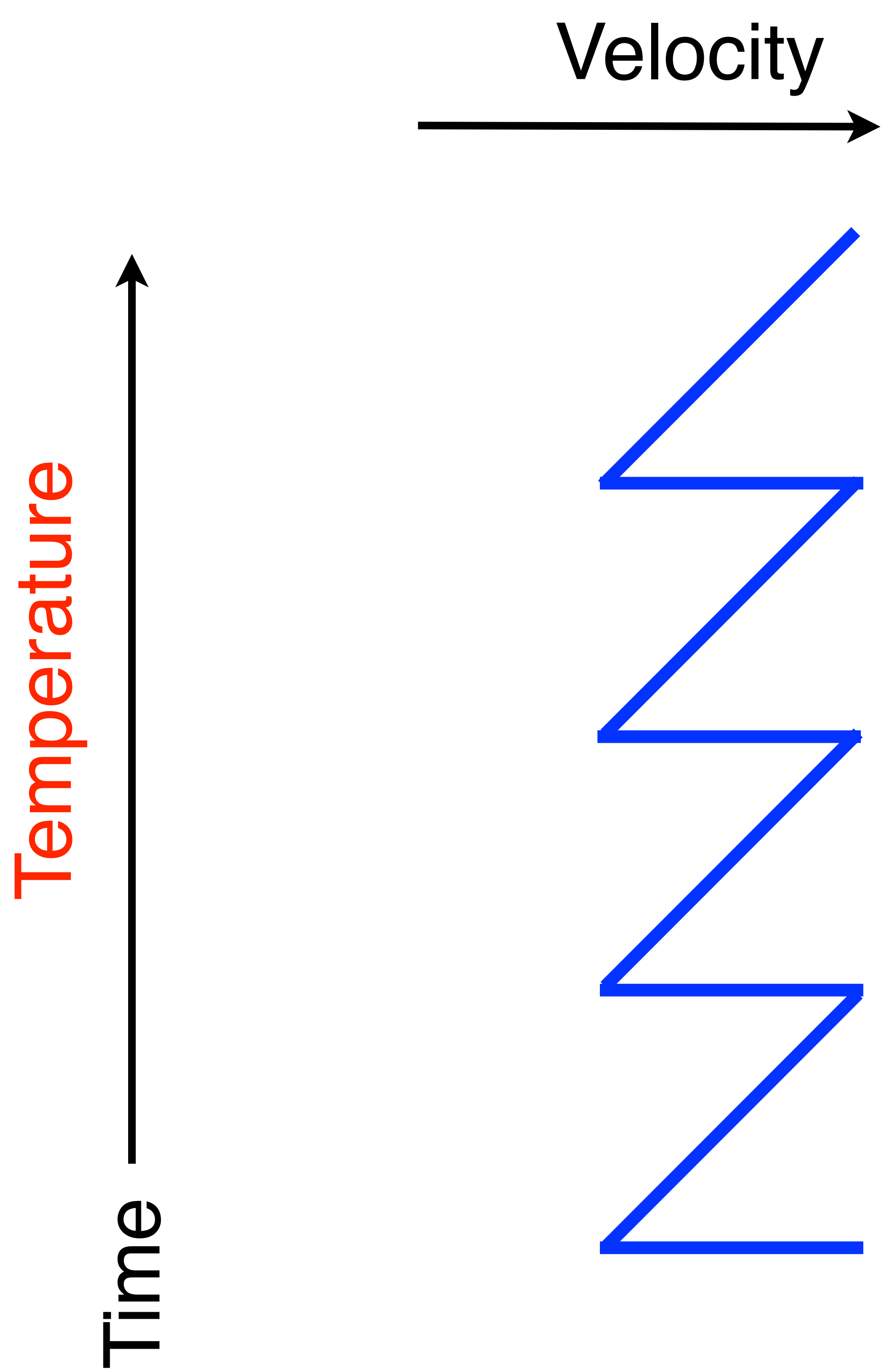

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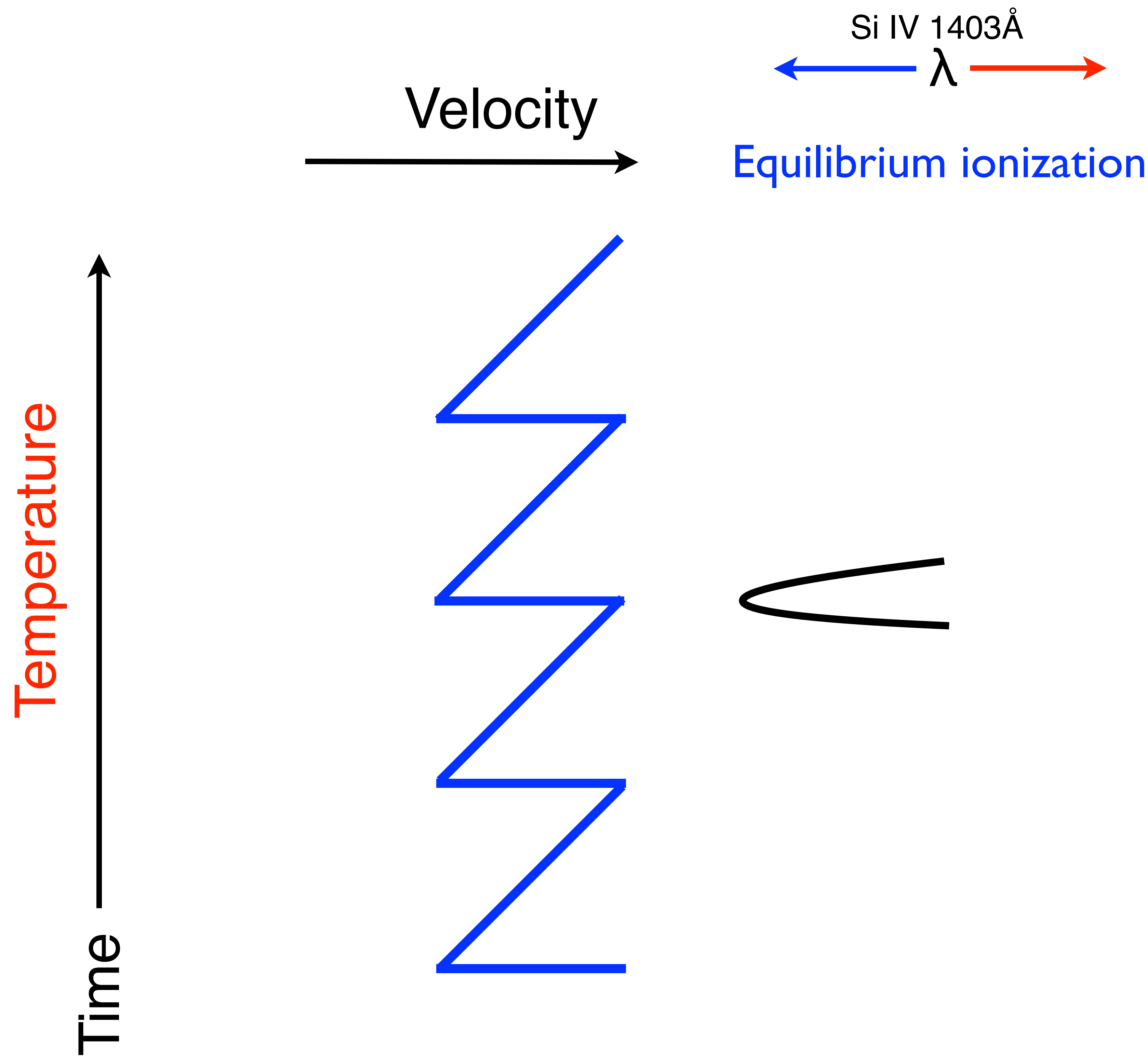

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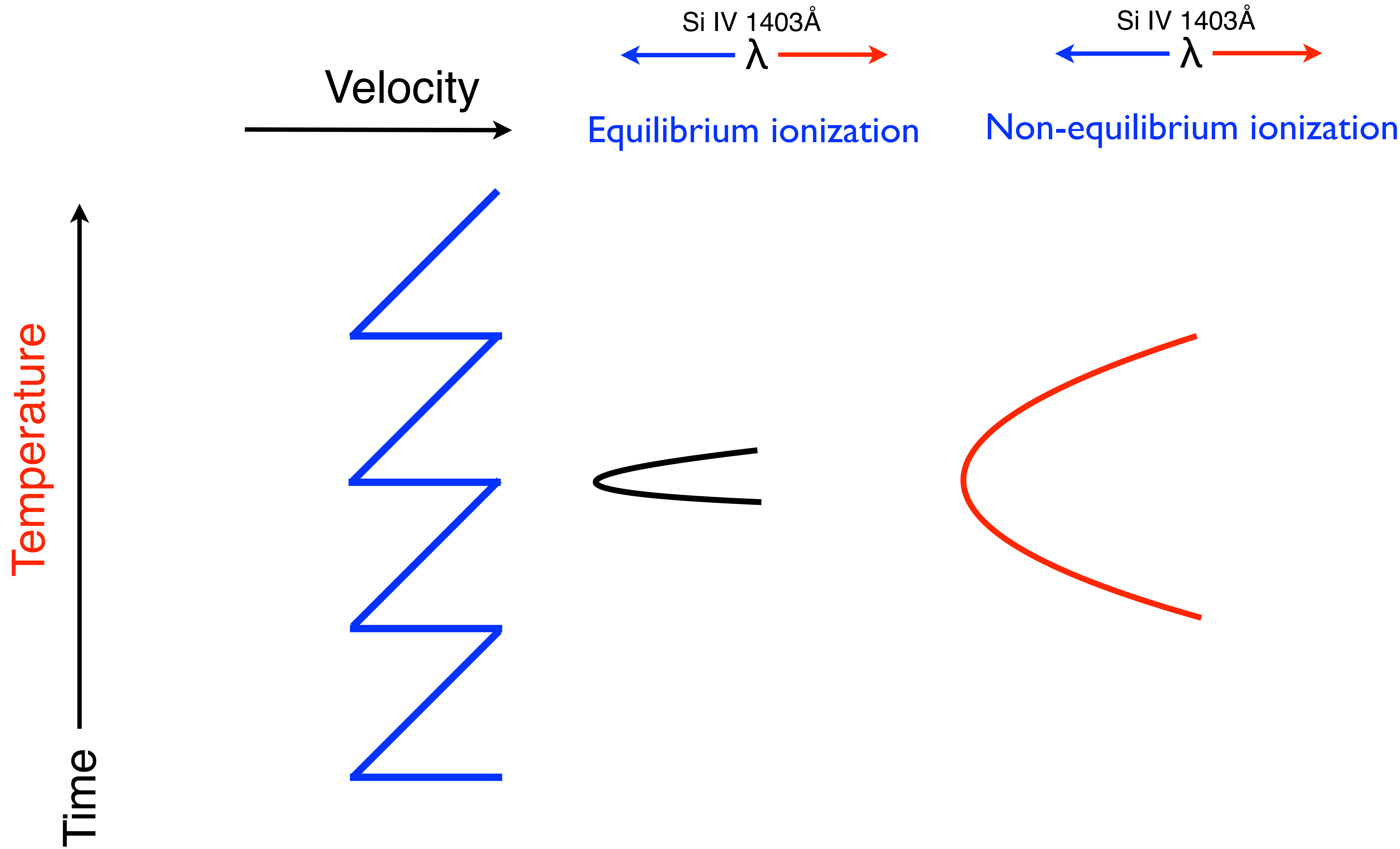

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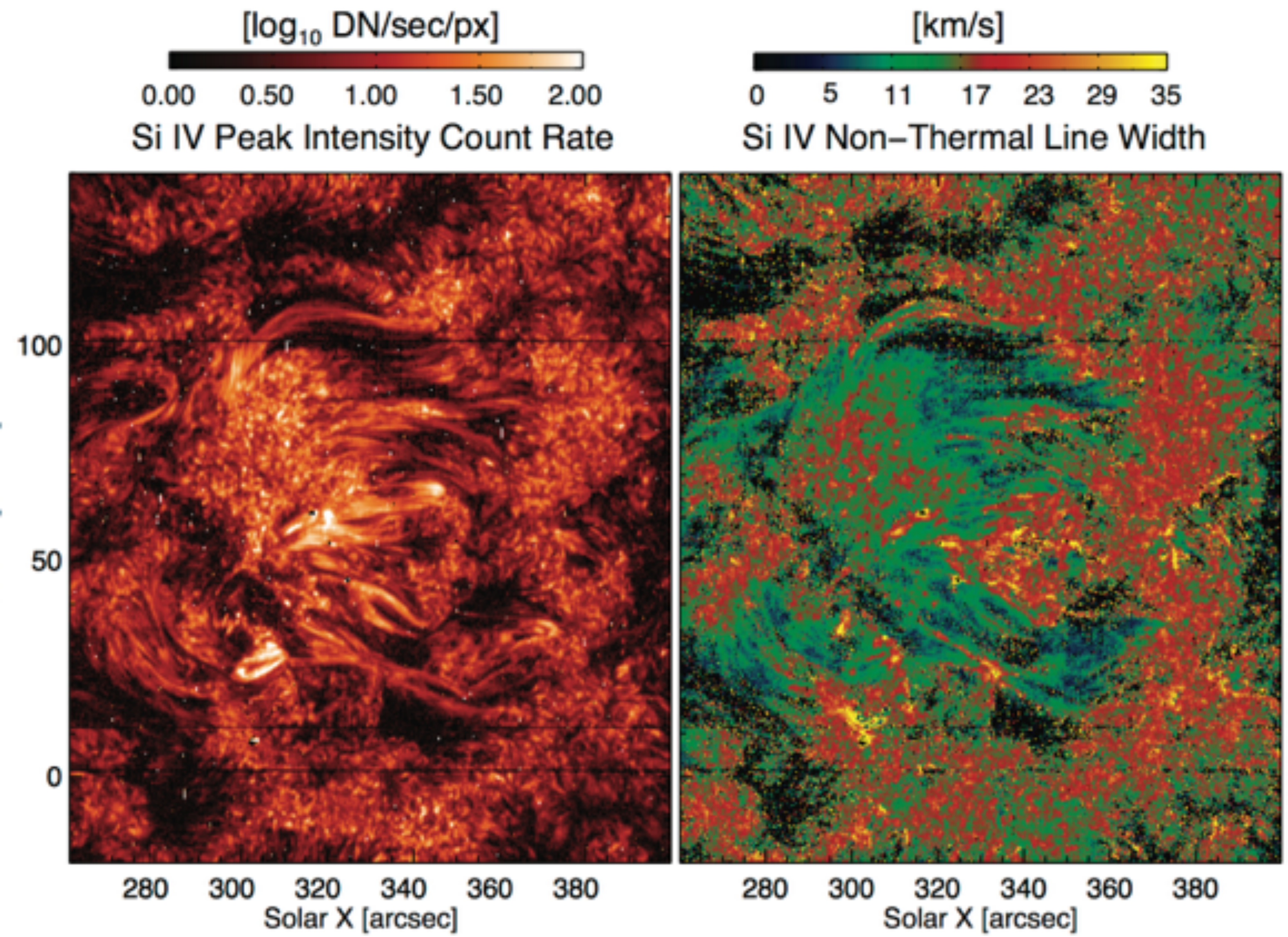
Chromospheric dynamics from type I spicules lead to non-equilibrium ionization in transition region



De Pontieu et al., 2015

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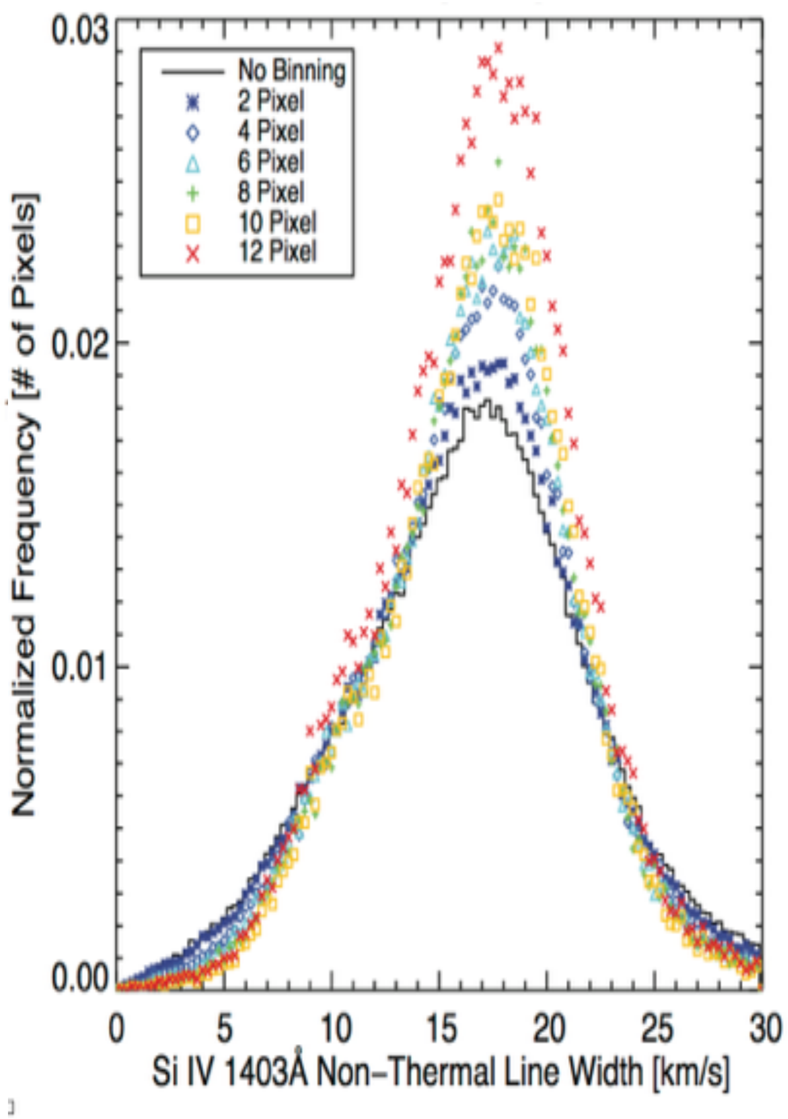

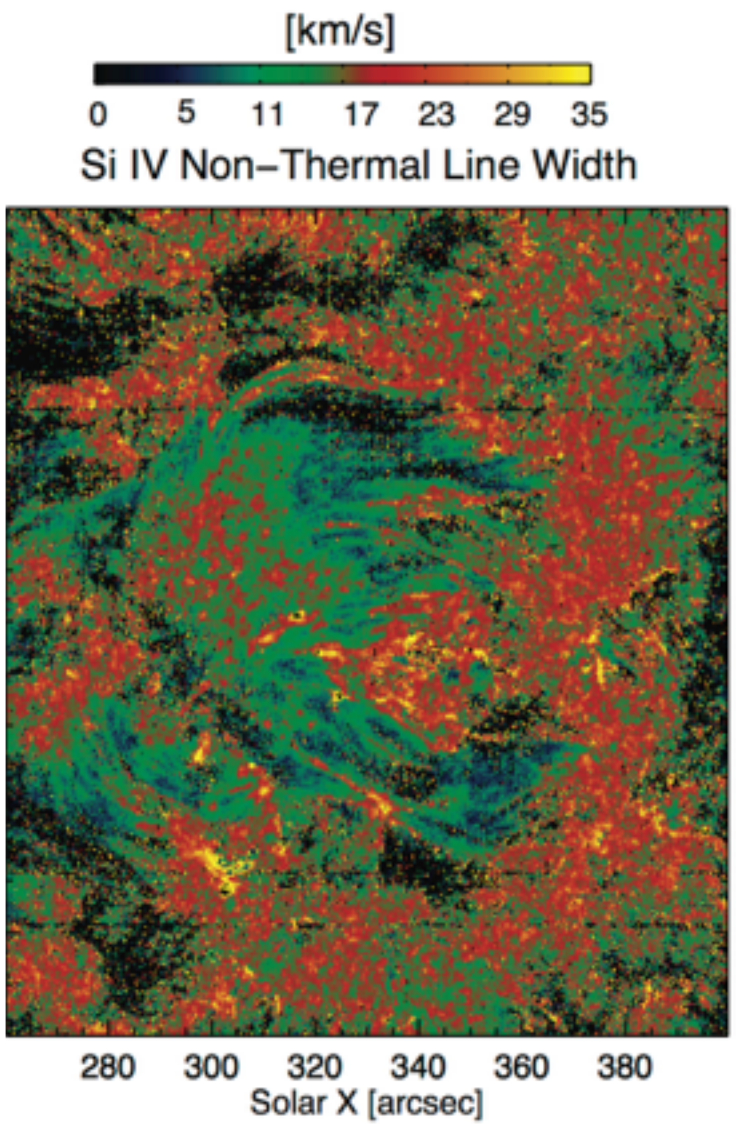

De Pontieu et al., 2015

Impact of chromospheric shocks on TR may help explain:

- apparent invariance of non-thermal line broadening to spatial resolution

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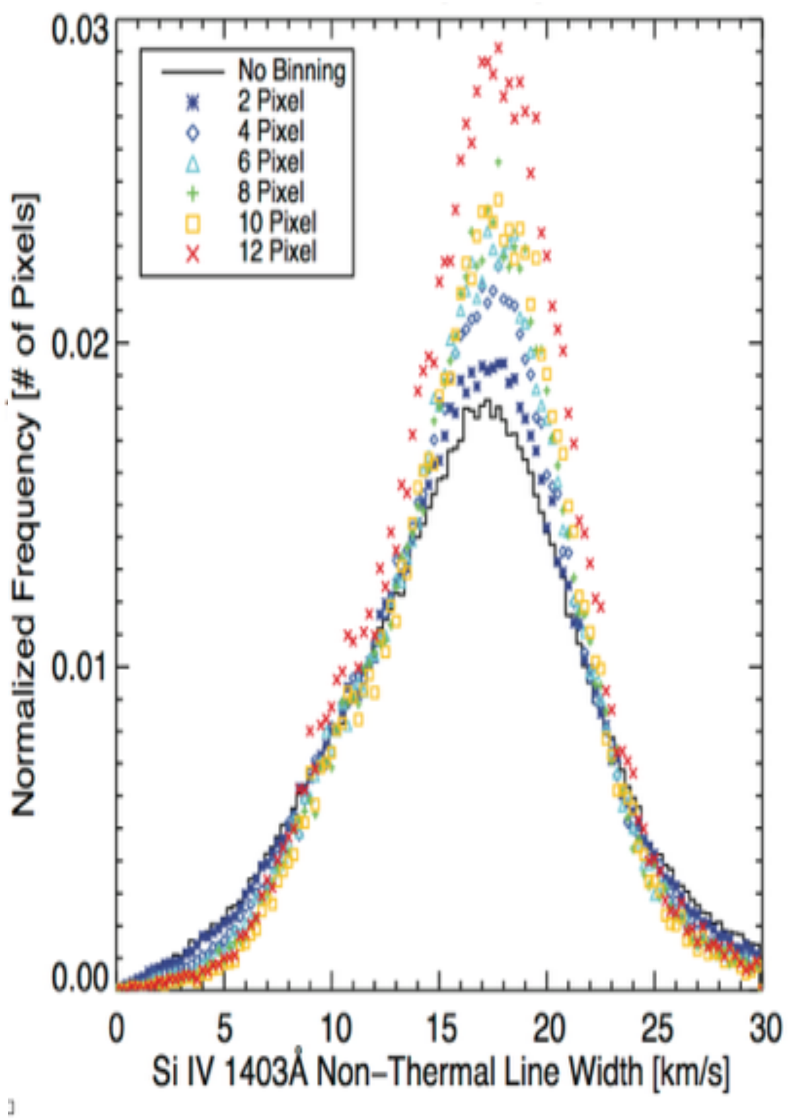

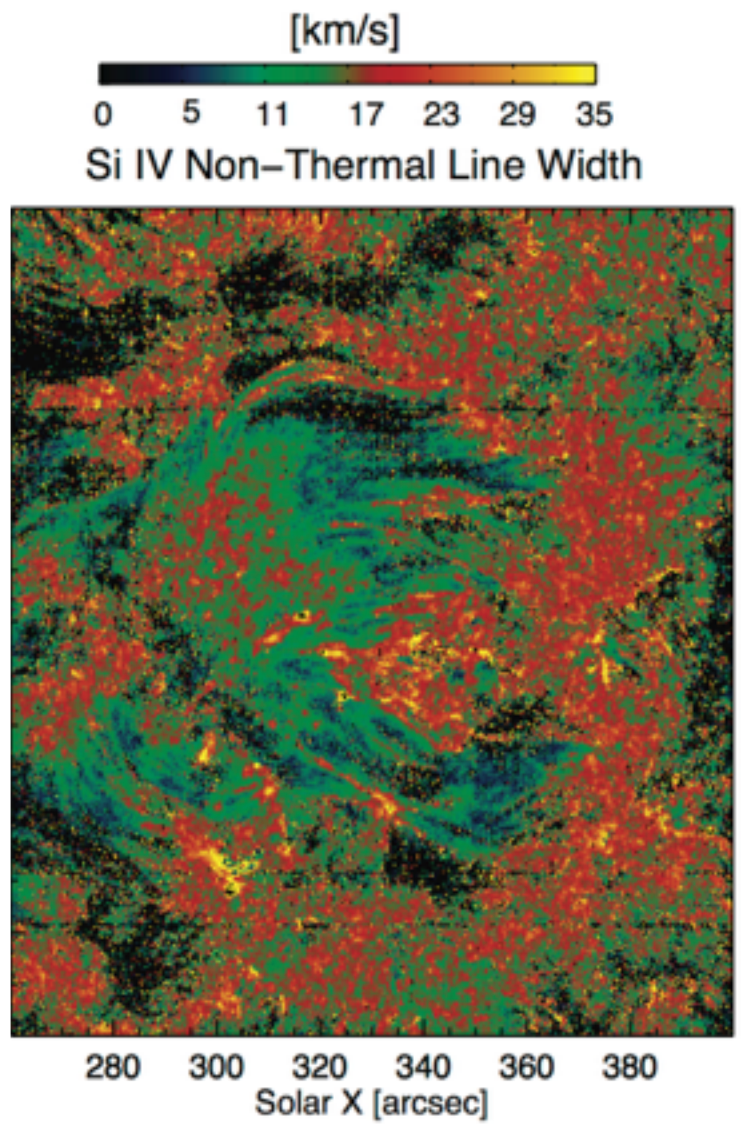

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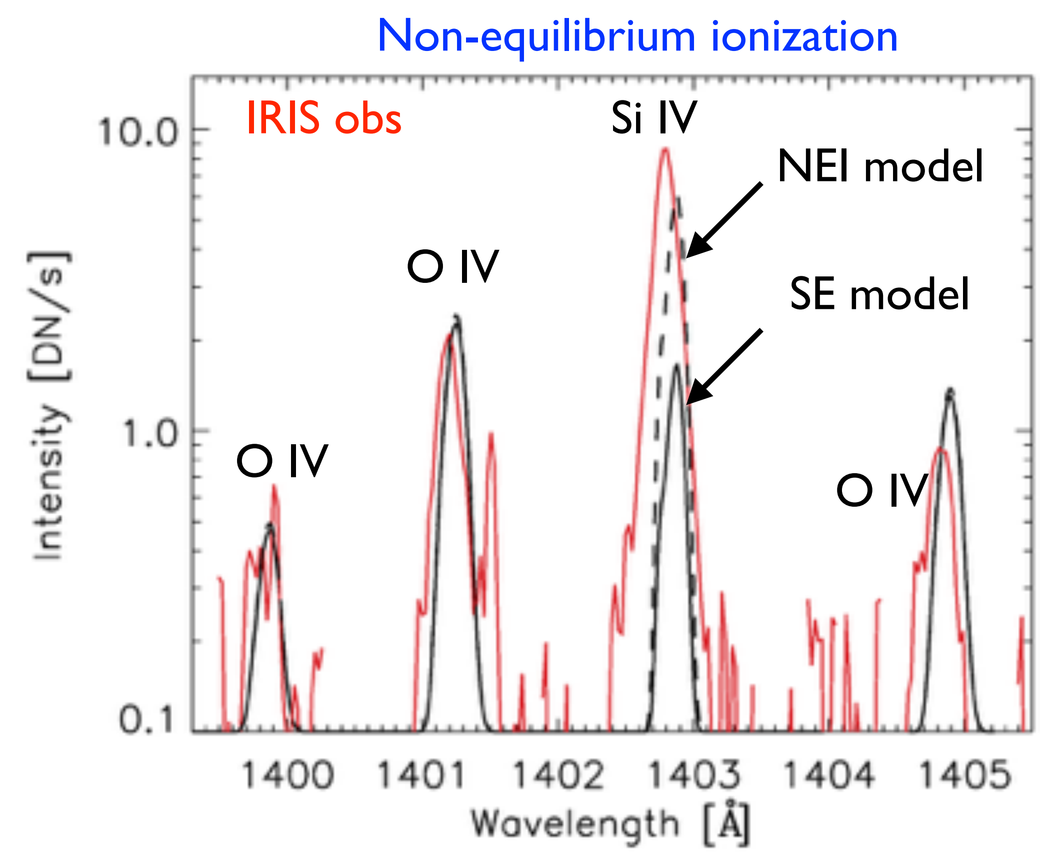
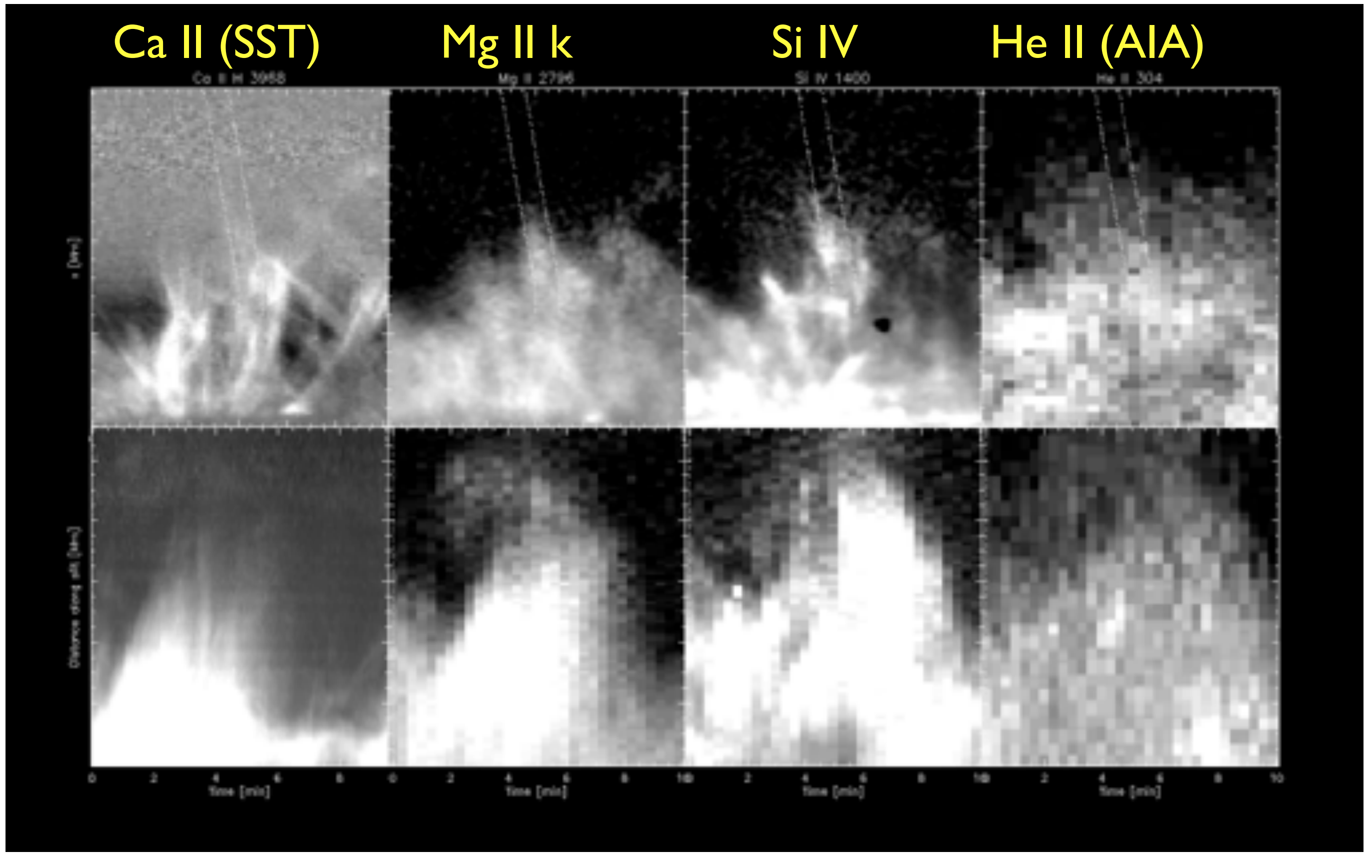


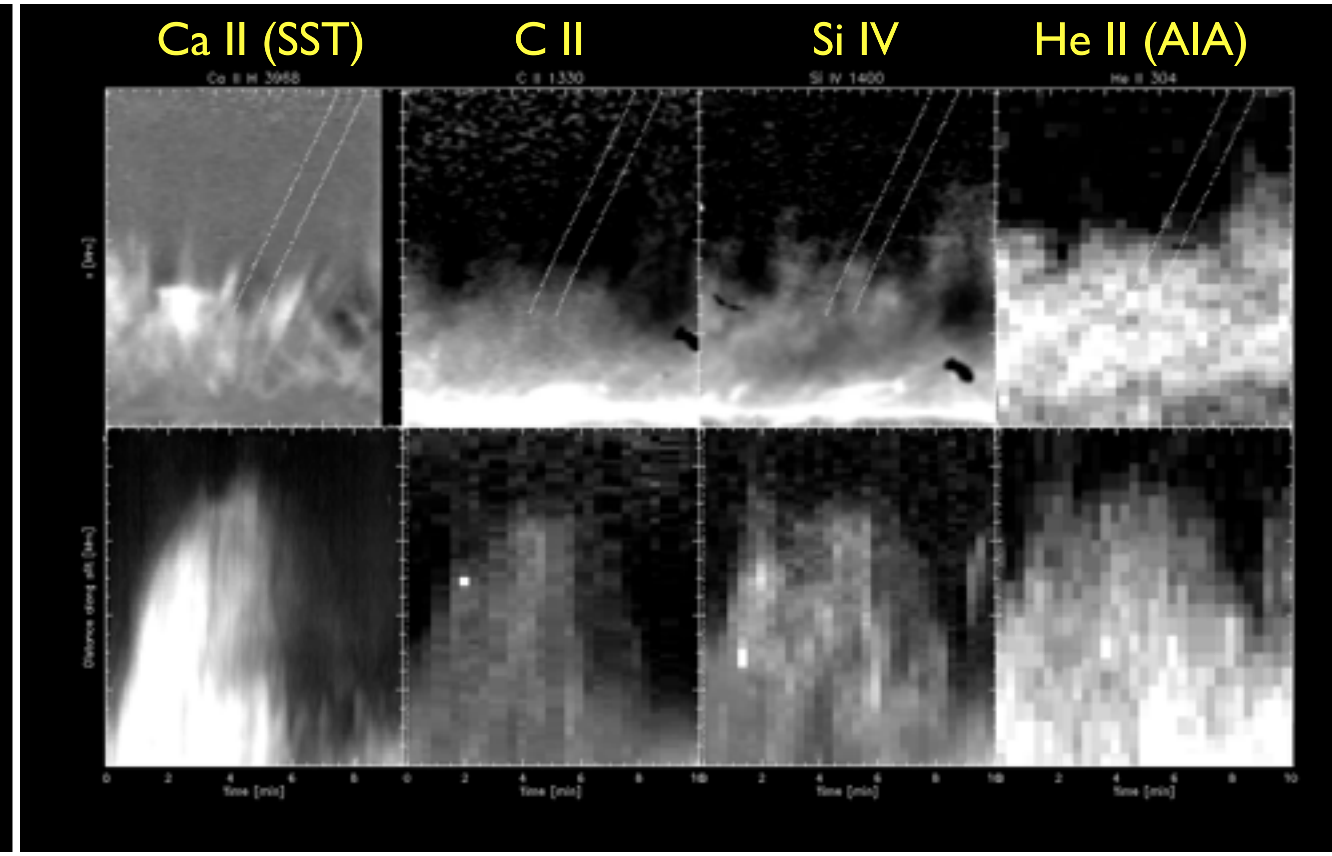
Martinez-Sykora et al., 2016

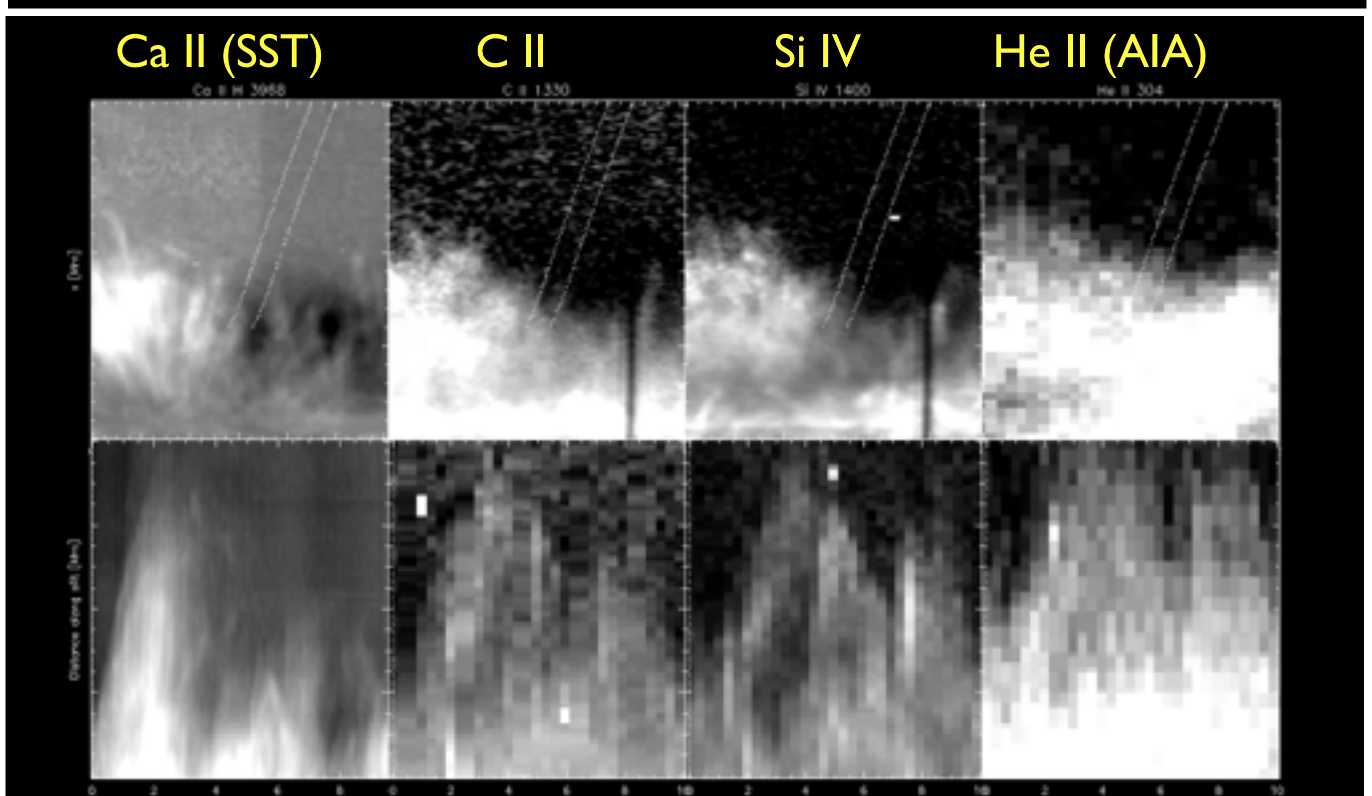
Impact of chromospheric shocks on TR may help explain:

- apparent invariance of non-thermal line broadening to spatial resolution
- non-equilibrium ionization in TR and Si/O intensity anomalies

Chromospheric spicules are heated to transition region temperatures







Skogsrud et al., 2015

Type II spicules are heated and much more violent than type I spicules

Heating timescales of order ~1 min

Ca II H spicules are the initial, rapid phase of violent upward motions…
Followed by Mg II k and Si IV spicules which are the spatio-temporal extensions of Ca II H

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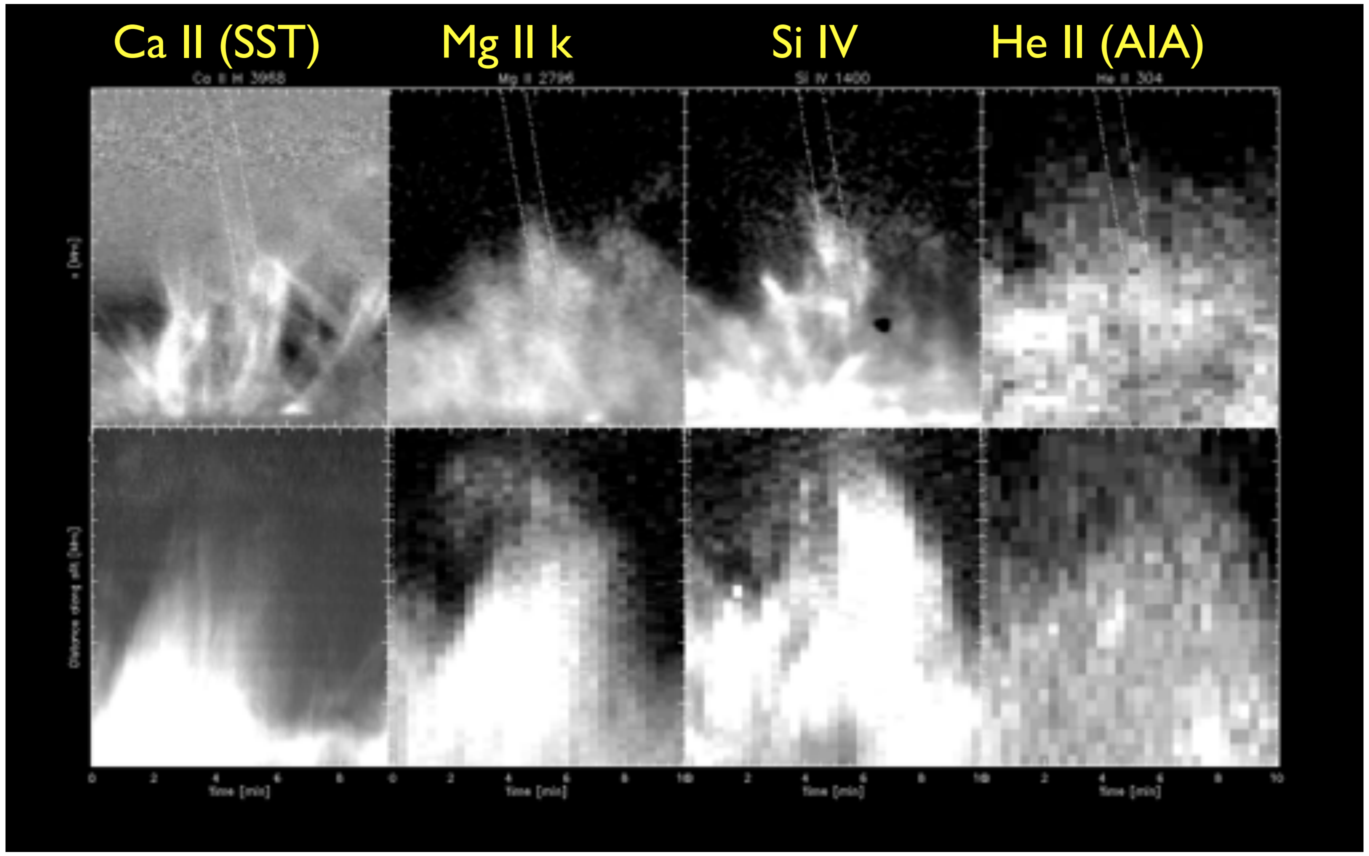

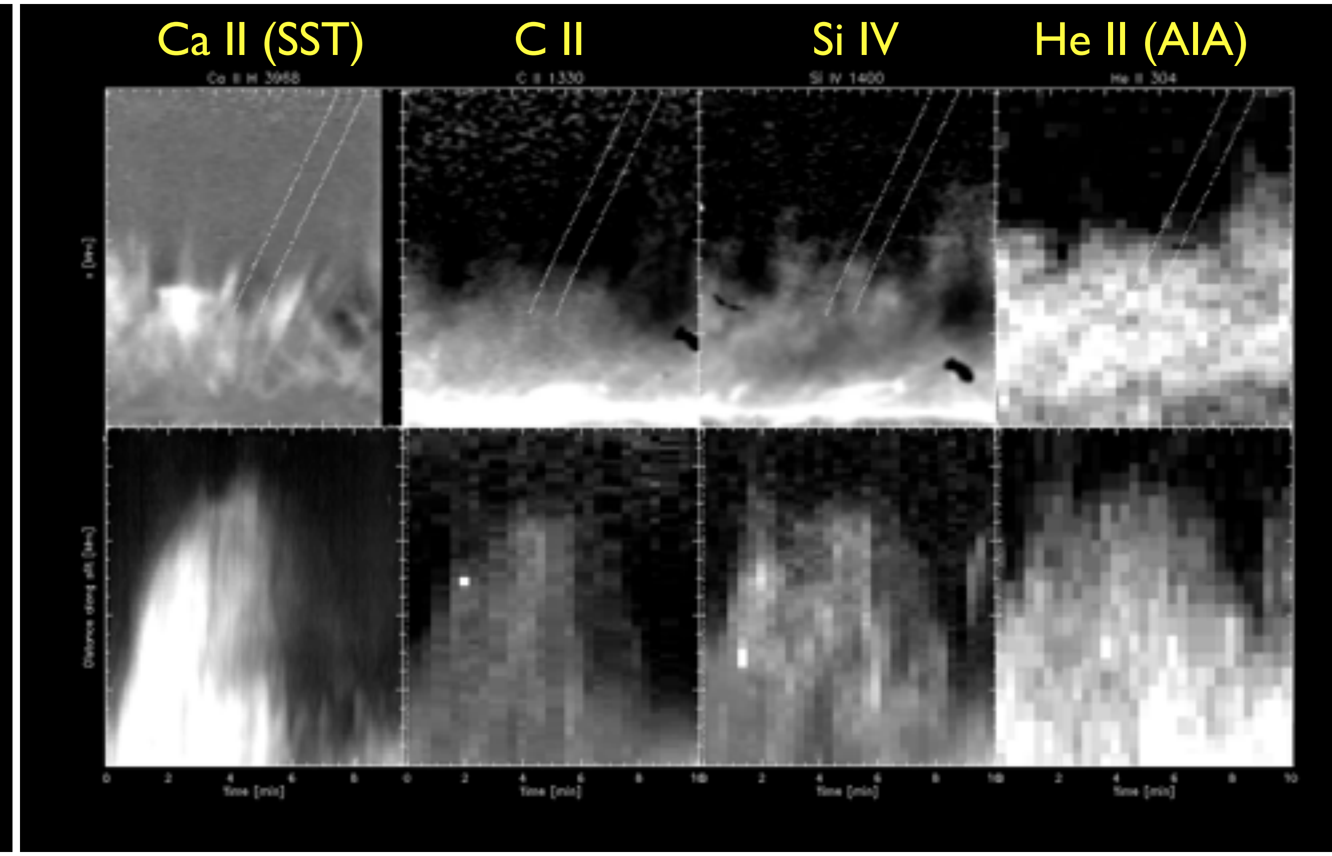

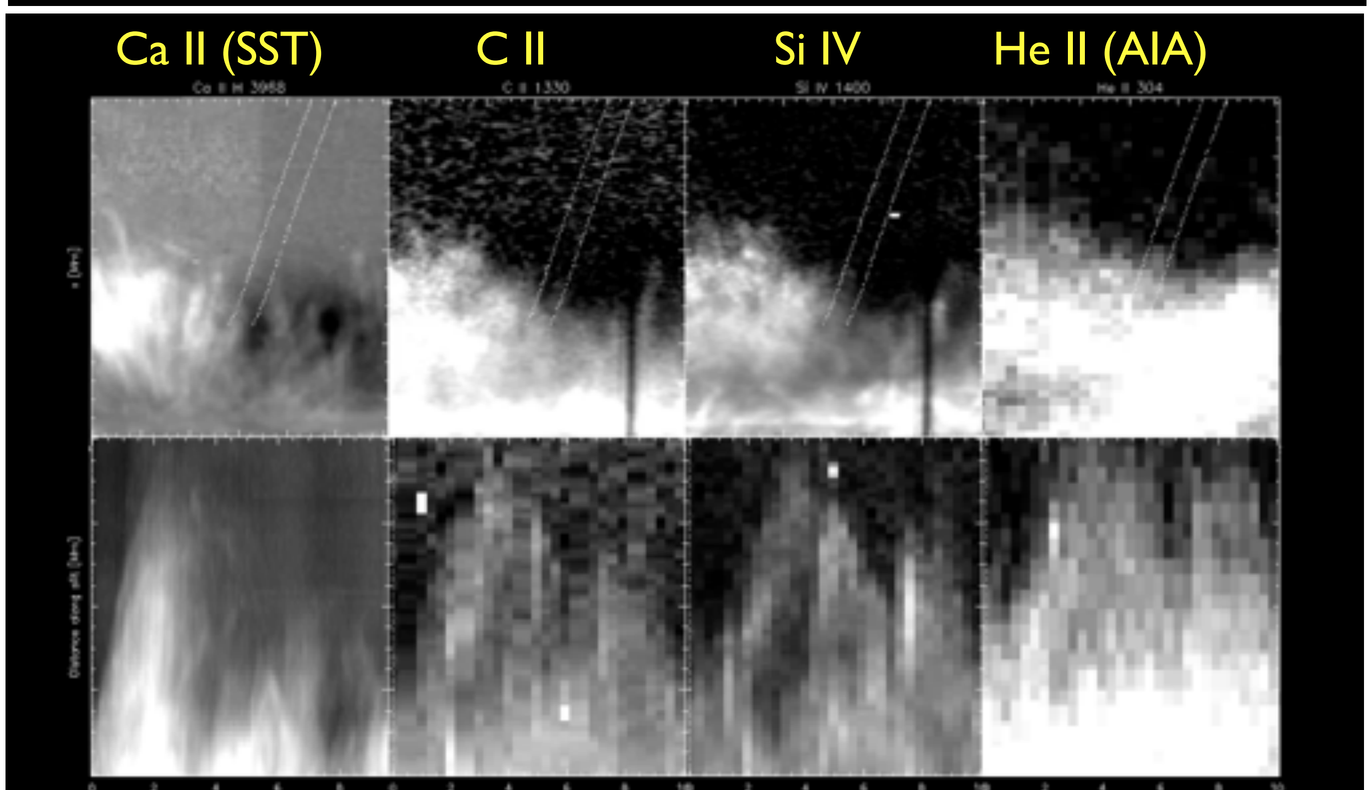

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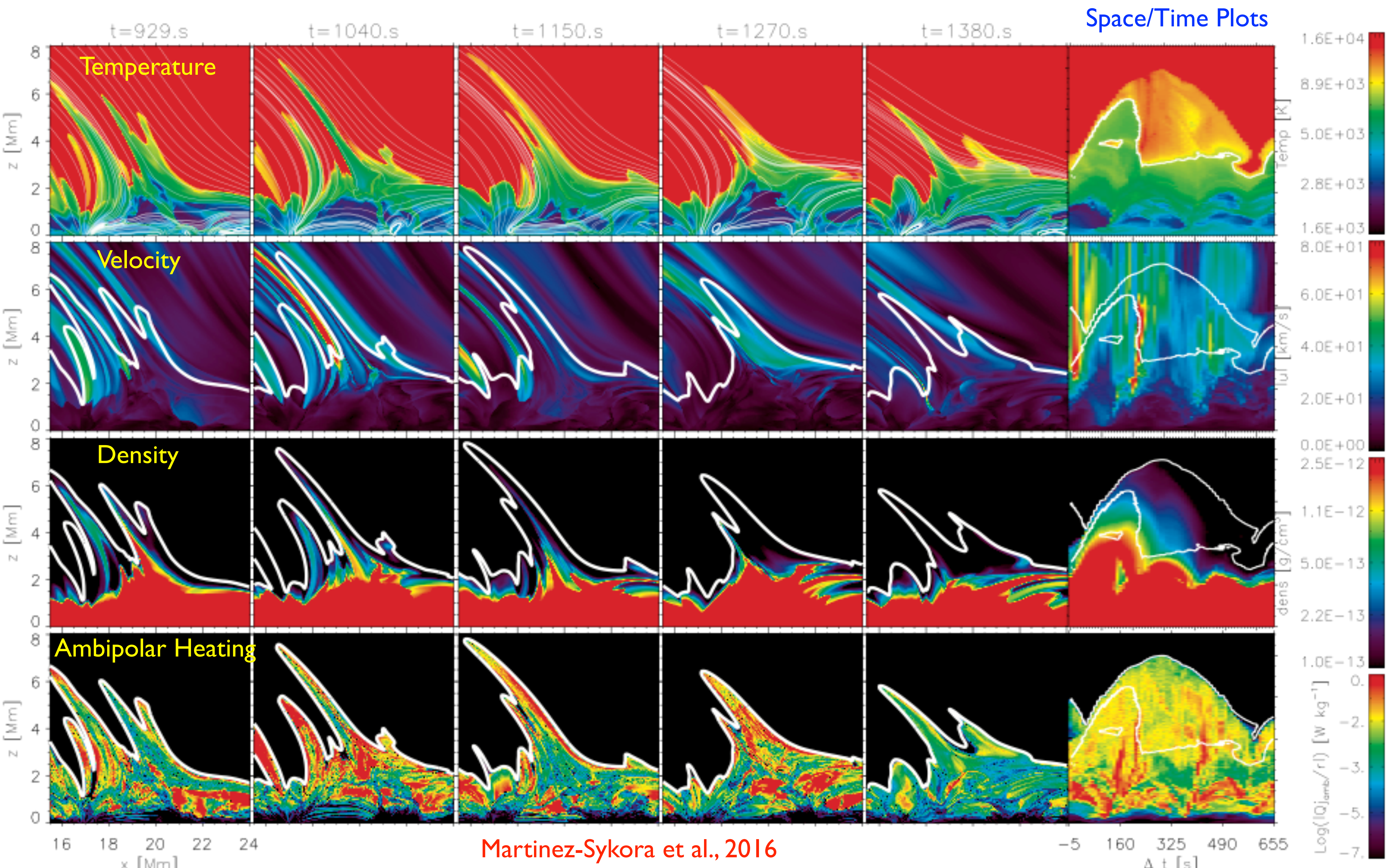

Martinez-Sykora et al., 2016
See talk by Juan Martinez-Sykora

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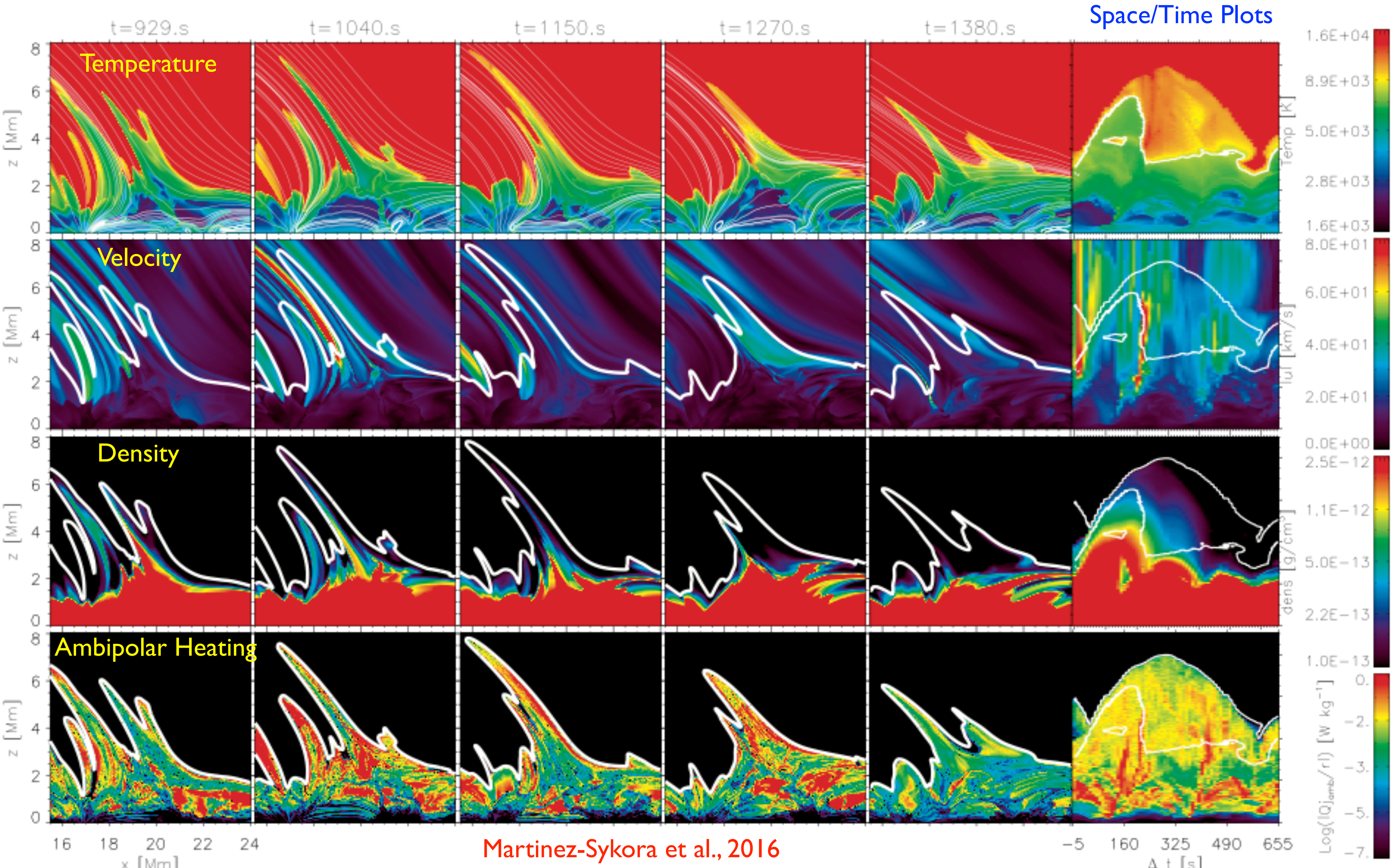

Martinez-Sykora et al., 2016

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… As long as ambipolar diffusion from ion-neutral effects is included

… heating from ambipolar diffusion of perpendicular currents

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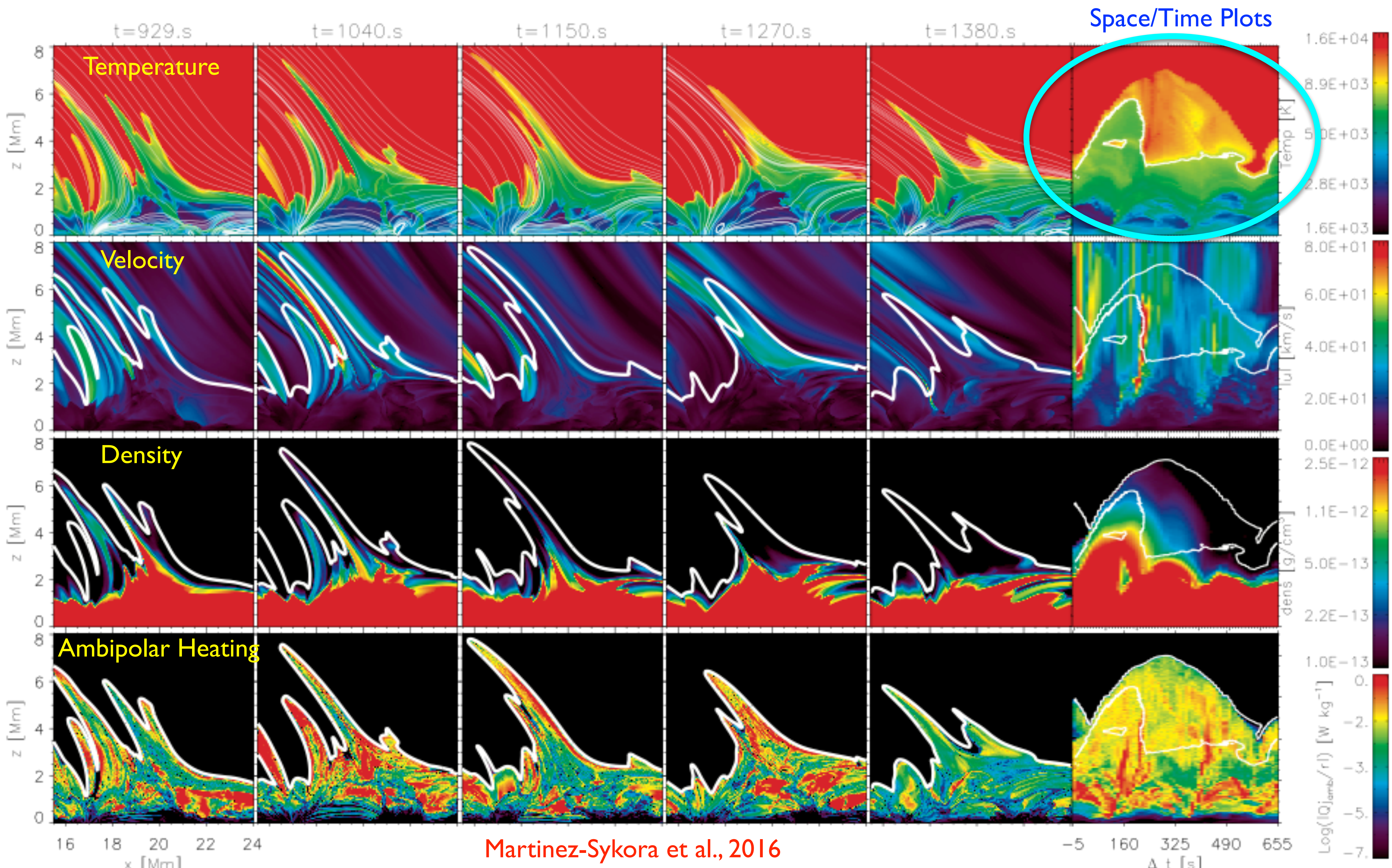

Martinez-Sykora et al., 2016

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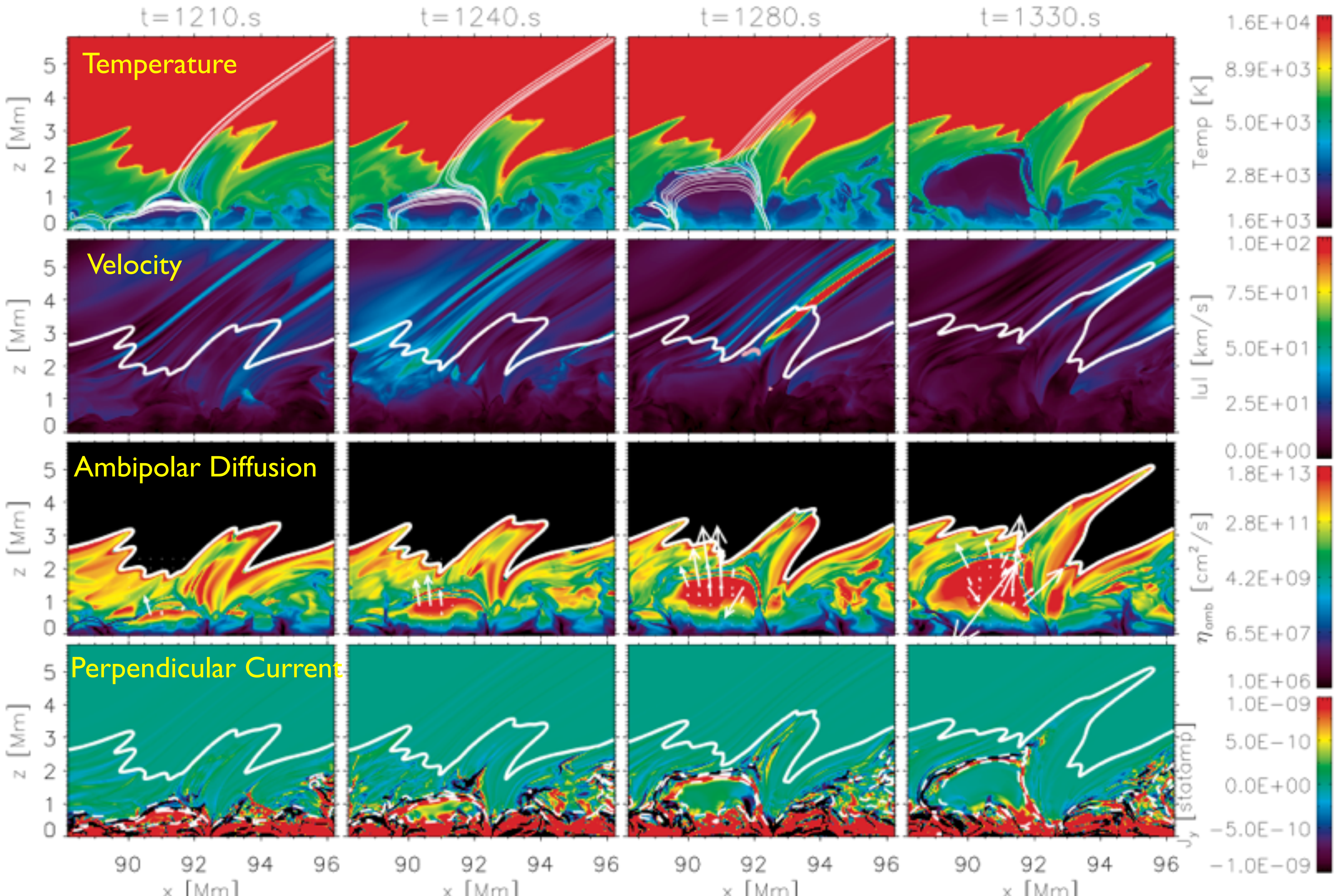
Type II spicules are launched by release of magnetic tension



Martinez-Sykora et al., 2016

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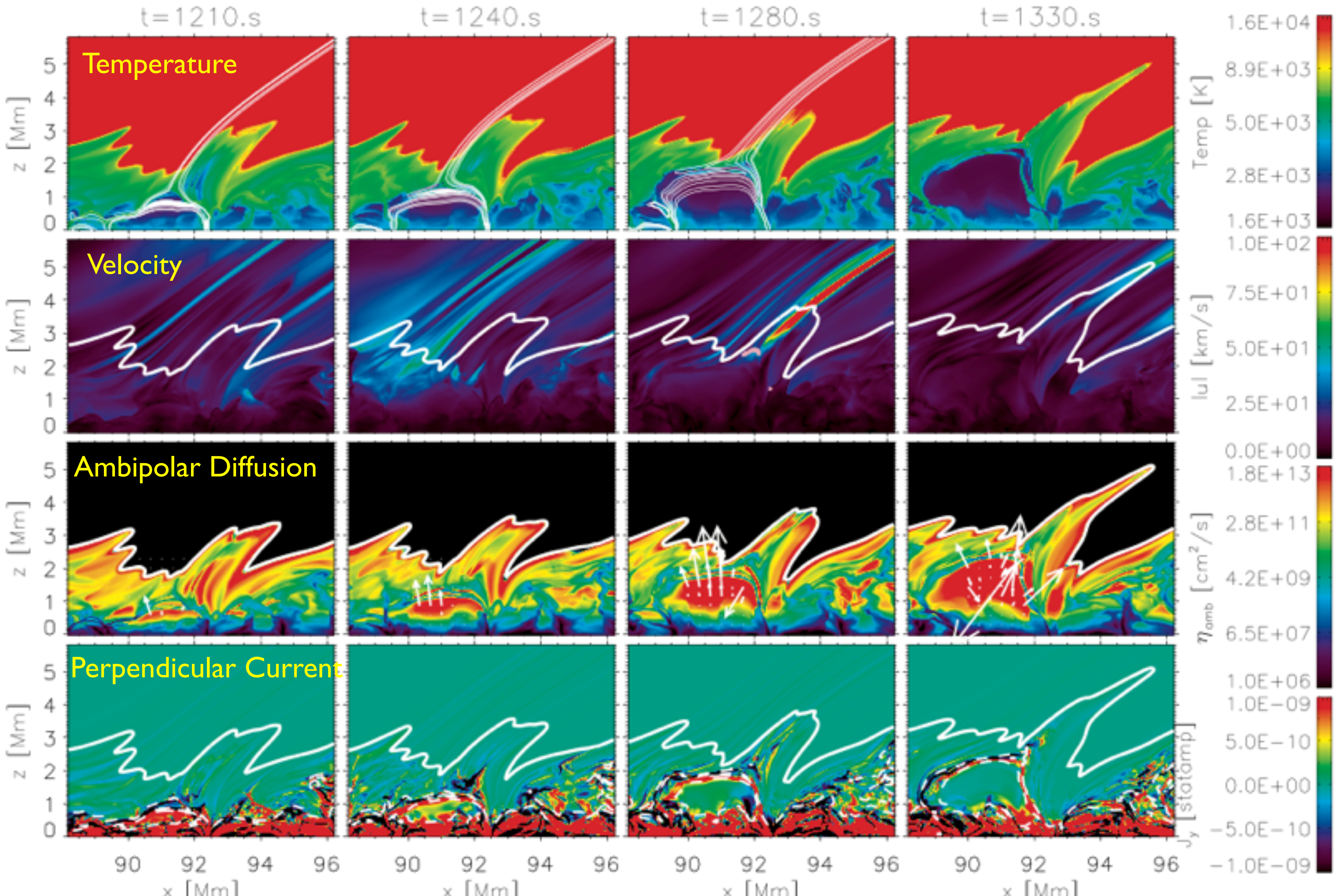
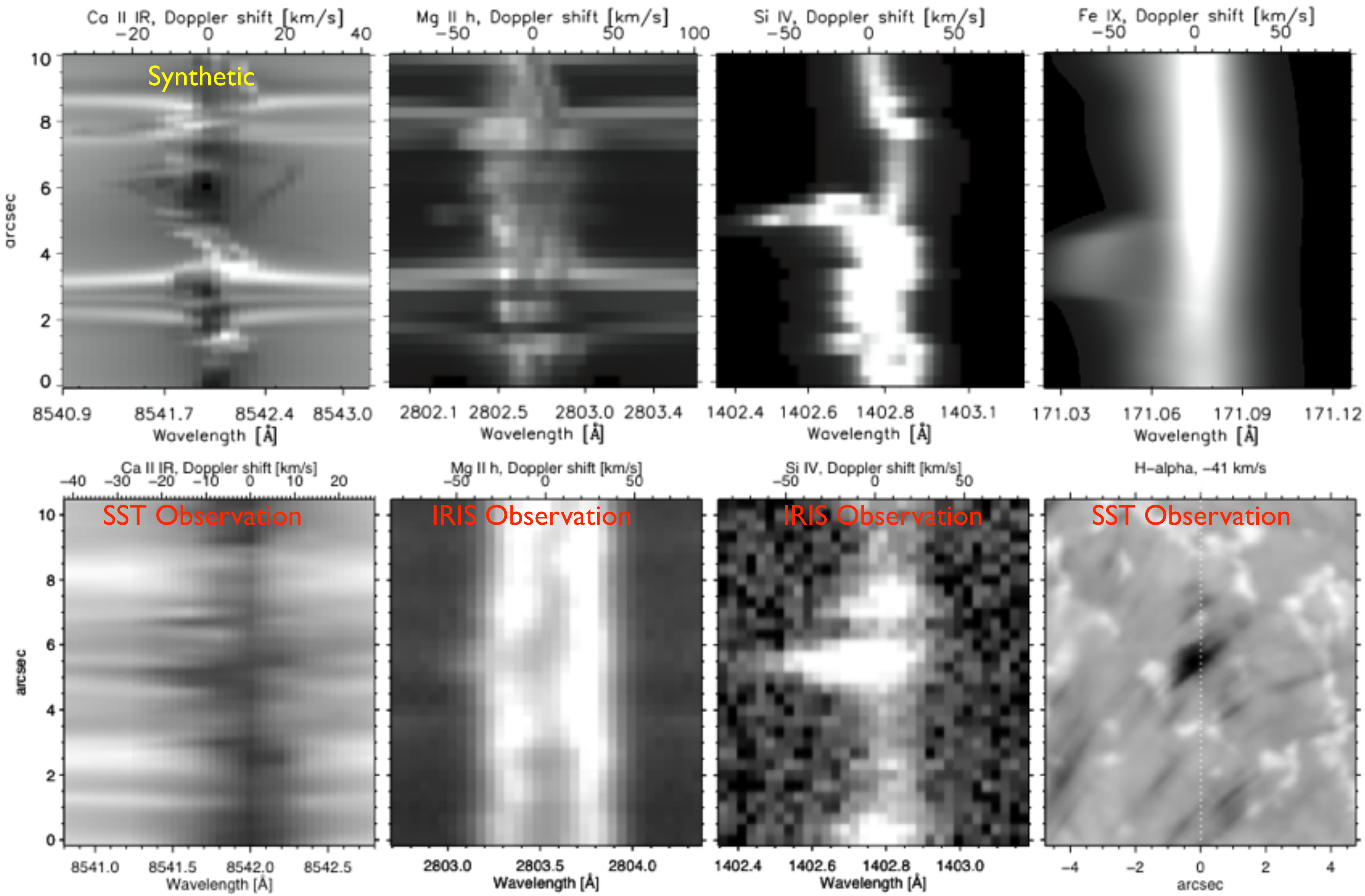


Martinez-Sykora et al., 2016
See talk by Juan Martinez-Sykora

1. created by interaction of weak and network/plage fields in photosphere
2. diffusion of weak fields/tension into chromosphere through ambipolar diffusion
3. amplification of tension because of ambipolar diffusion
4. violent release of tension above beta=1 layer

Synthetic observations from modeled type II spicules match observations



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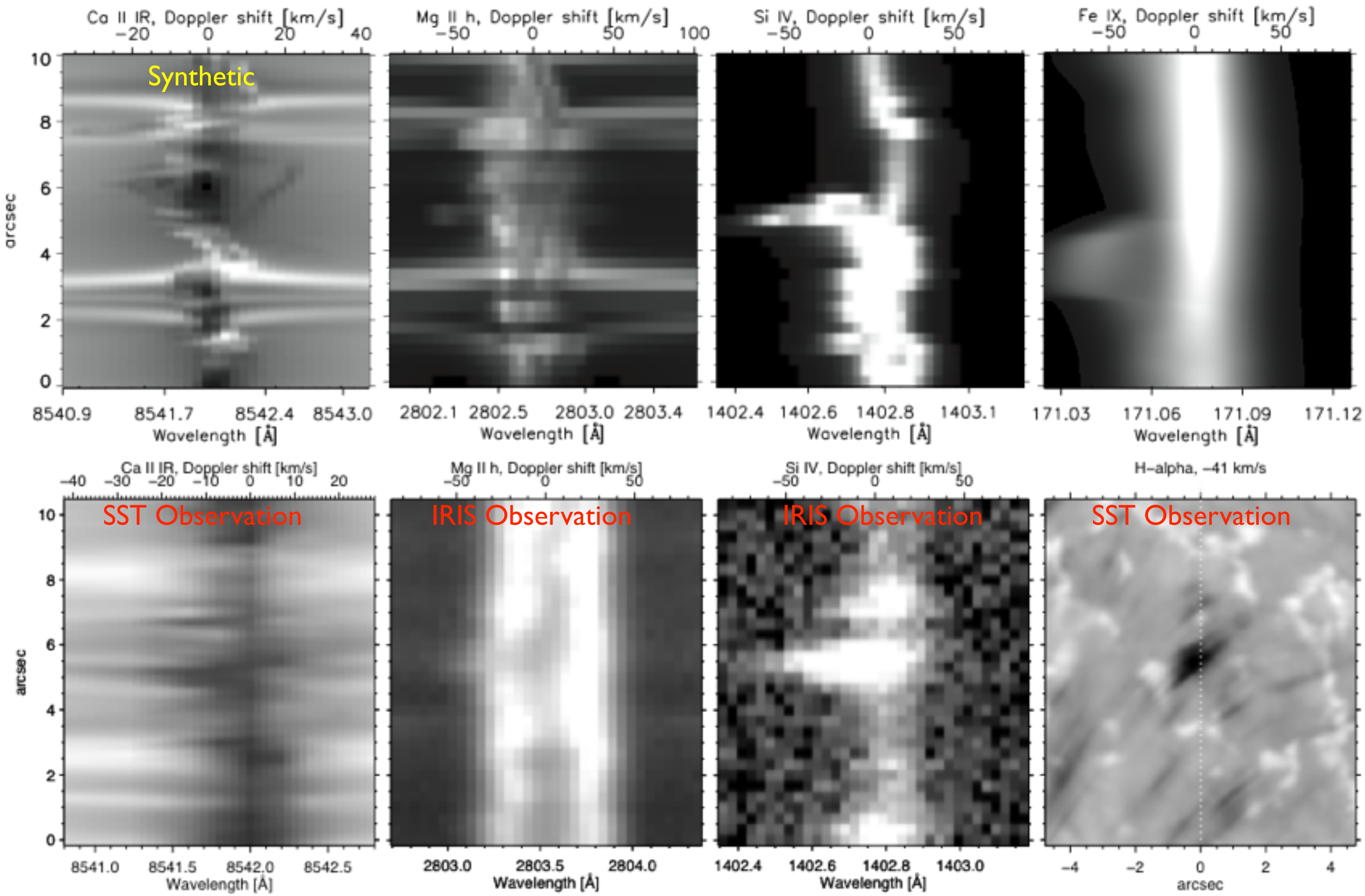

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Model predicts heating of plasma to coronal temperatures…

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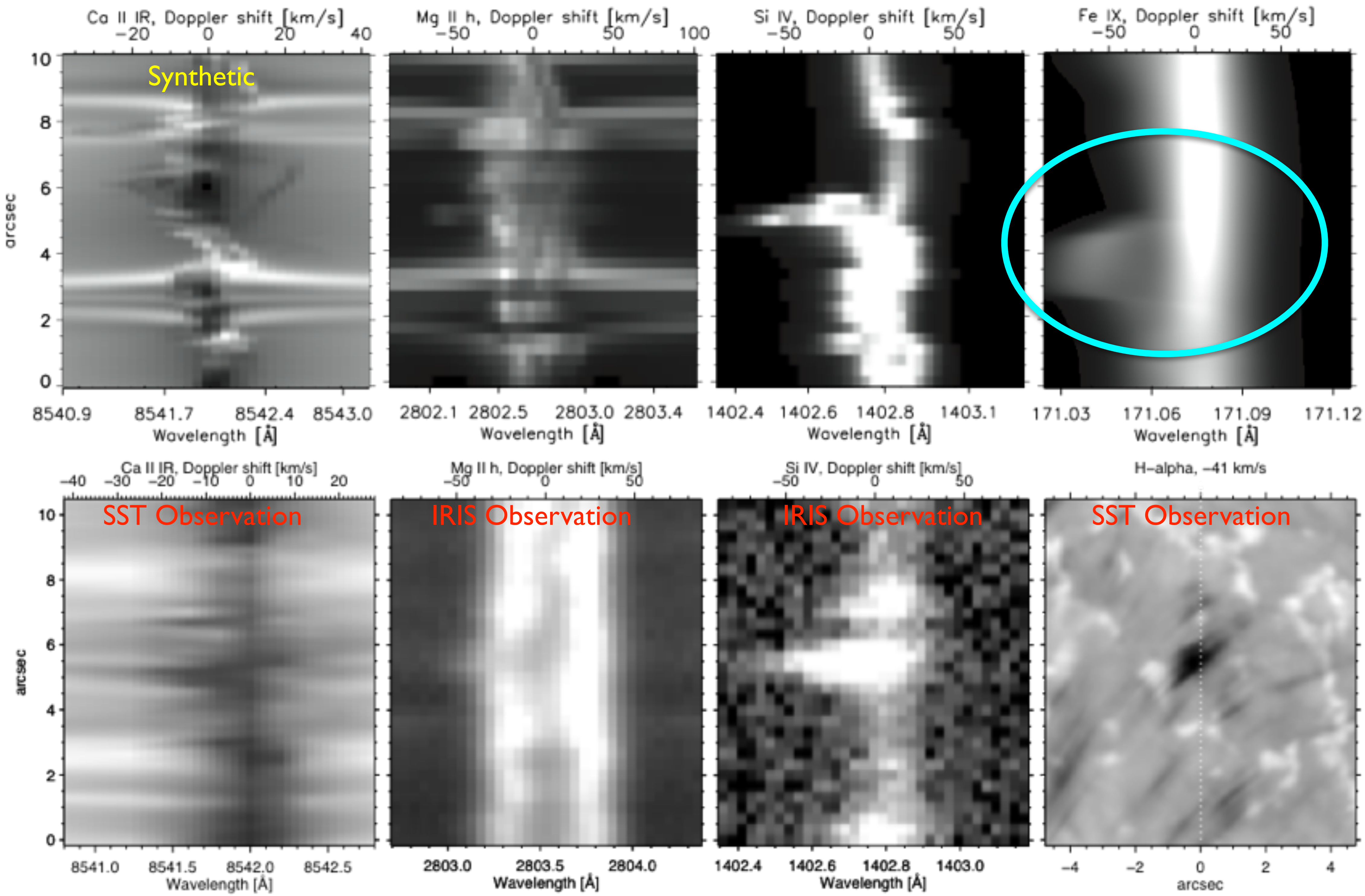

Martinez-Sykora et al., 2016
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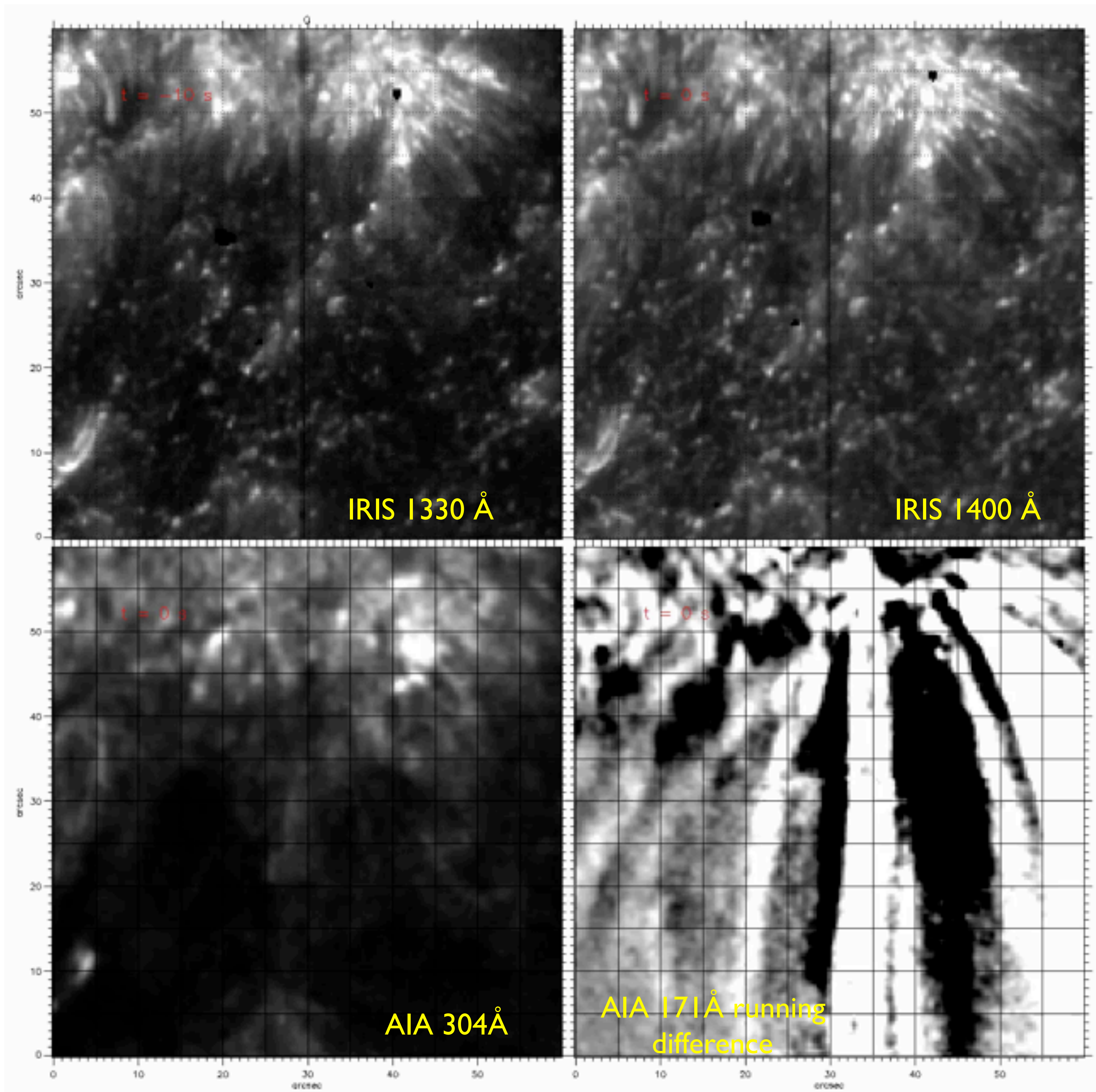
Signatures of type II spicules in the corona?



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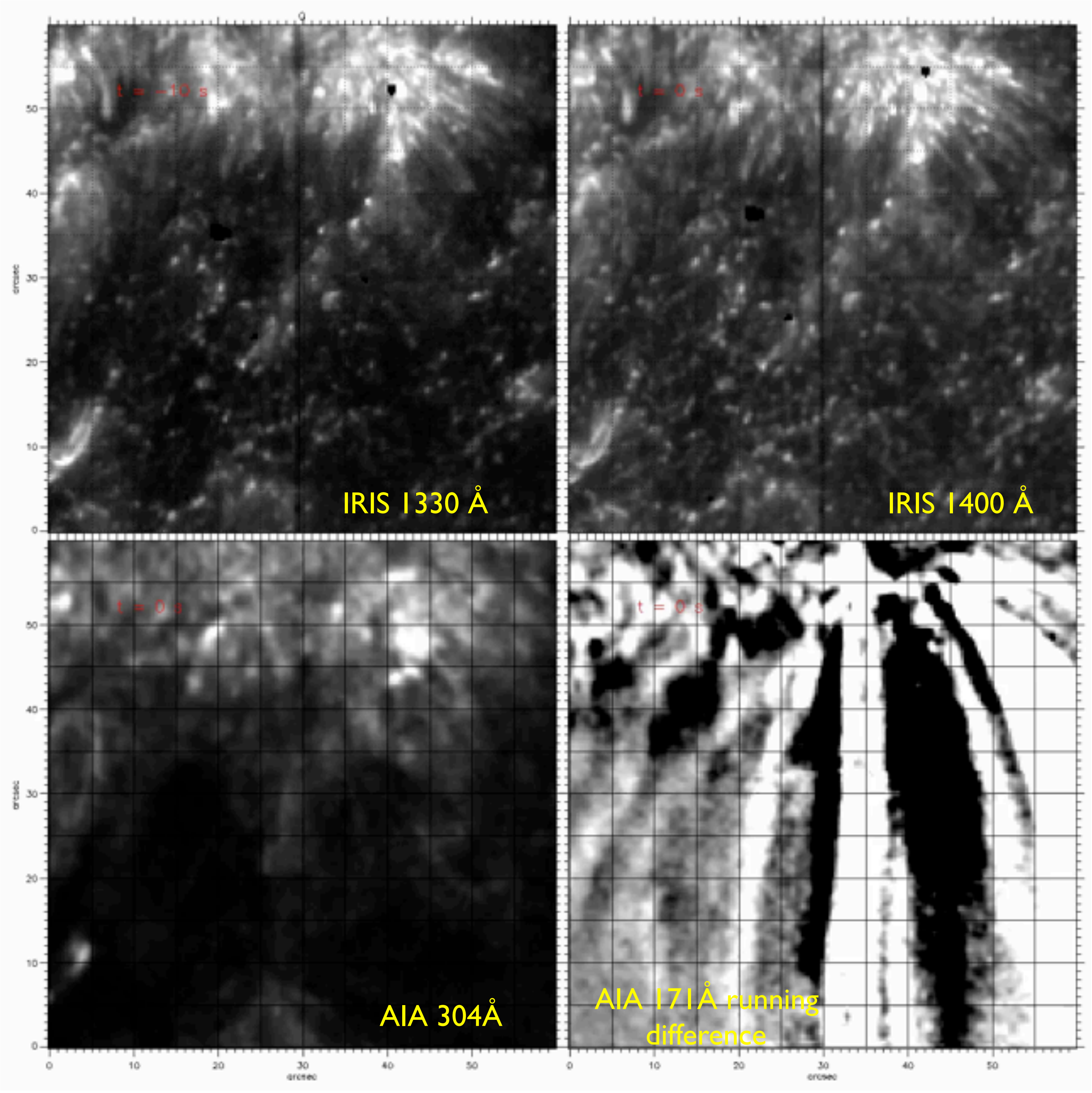

Propagating Coronal Disturbances (PCDs) related to type II spicules?

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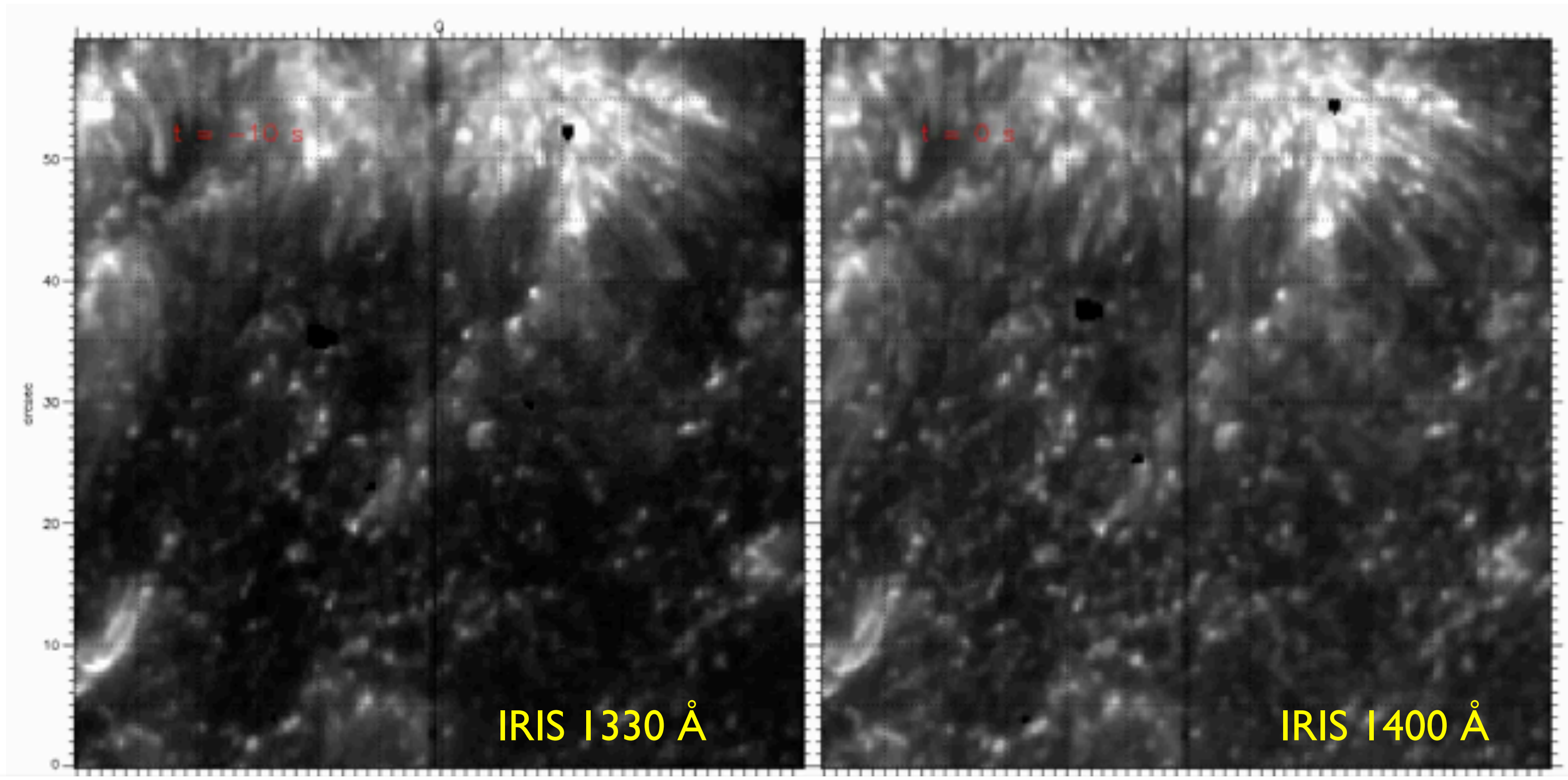

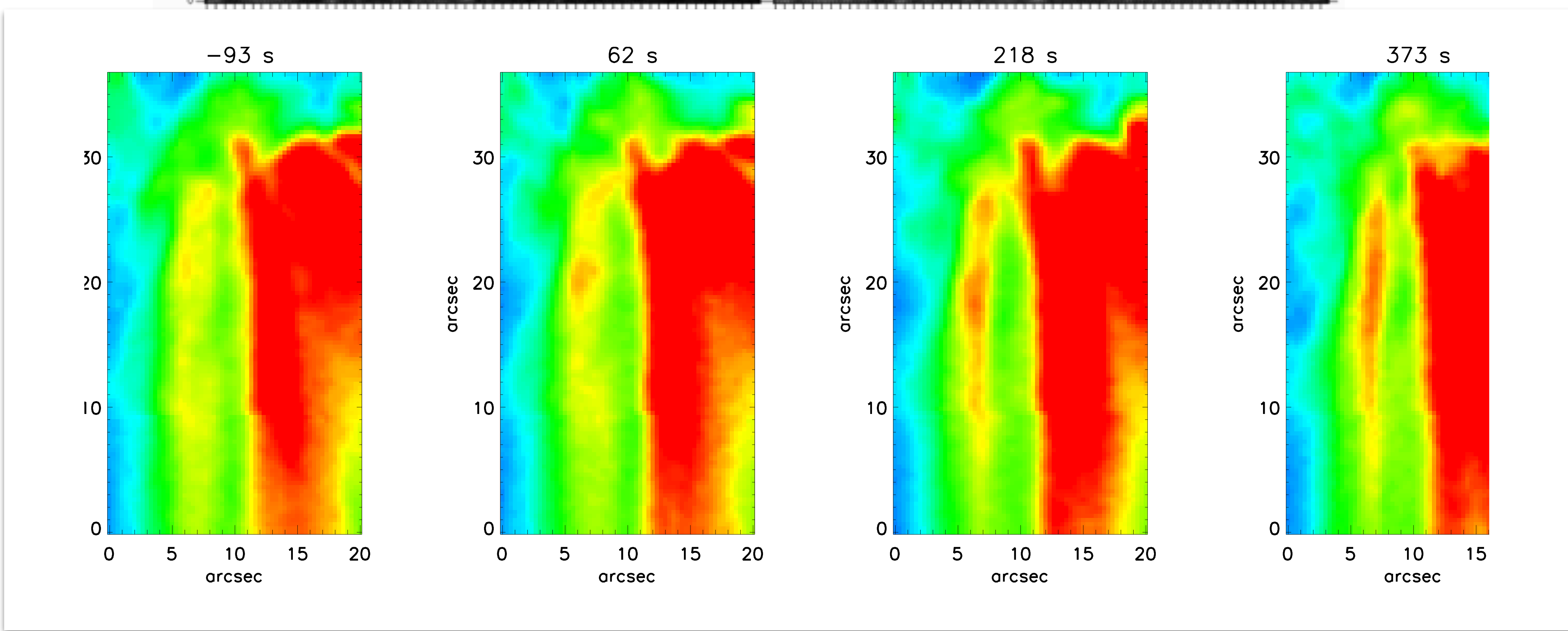

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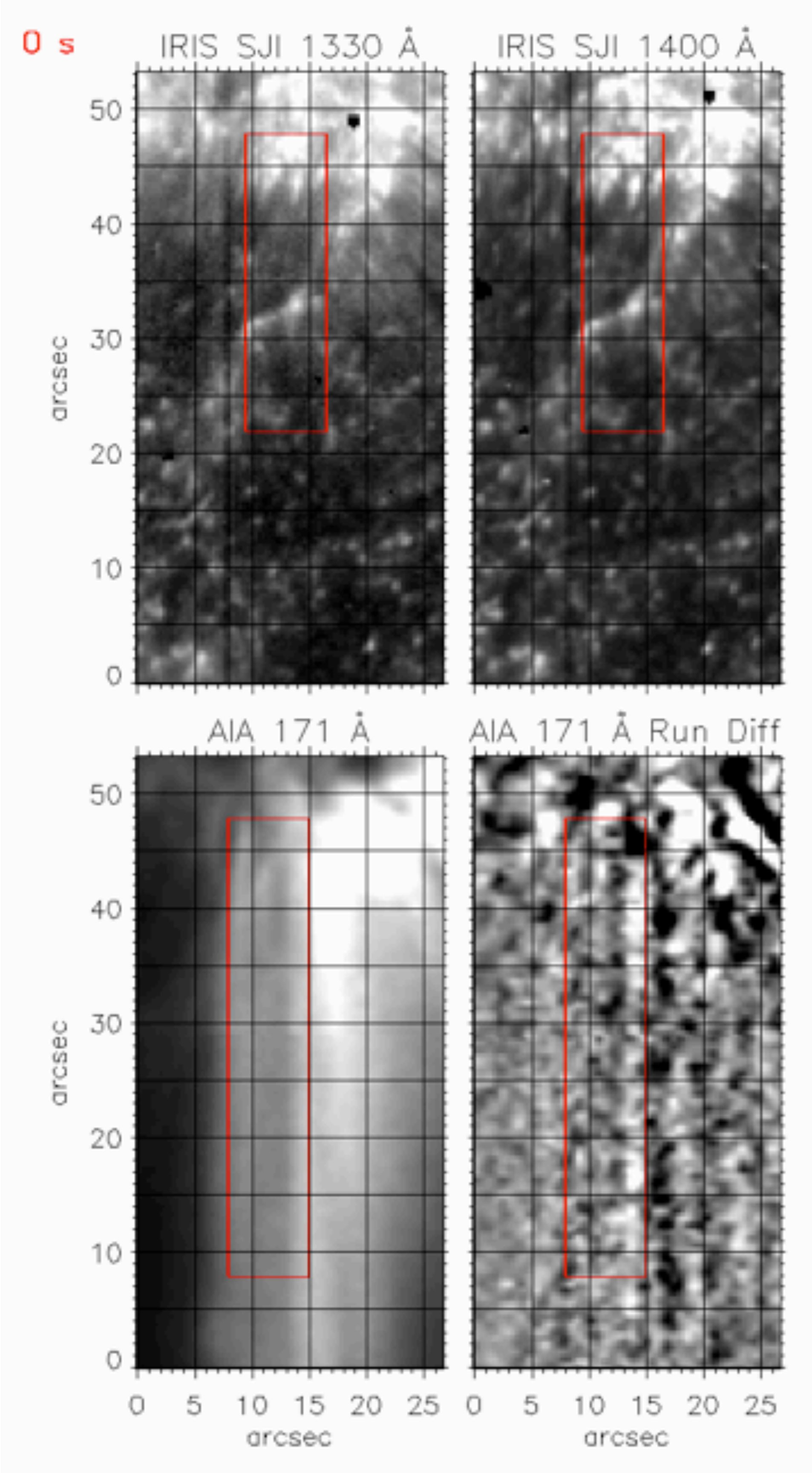

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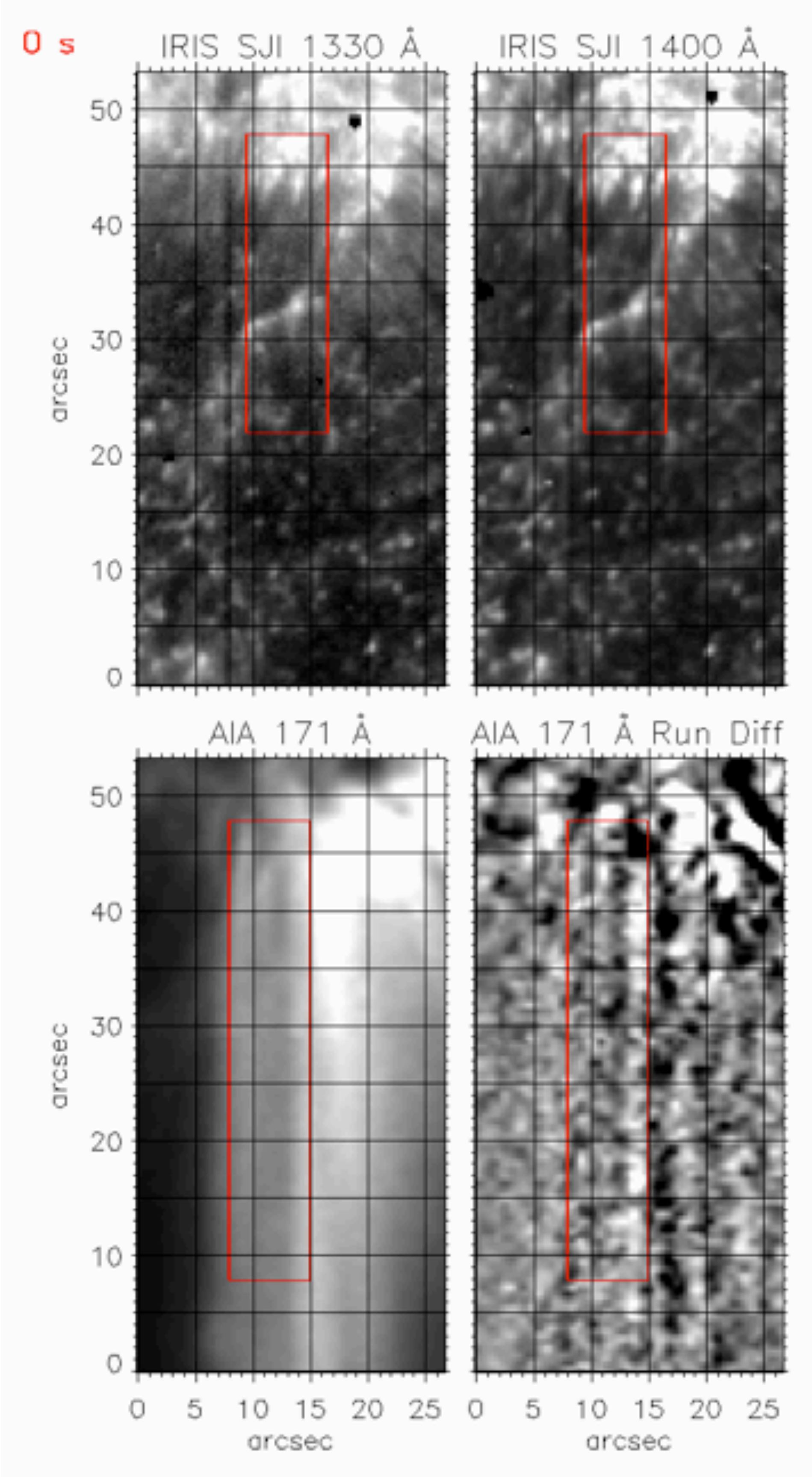

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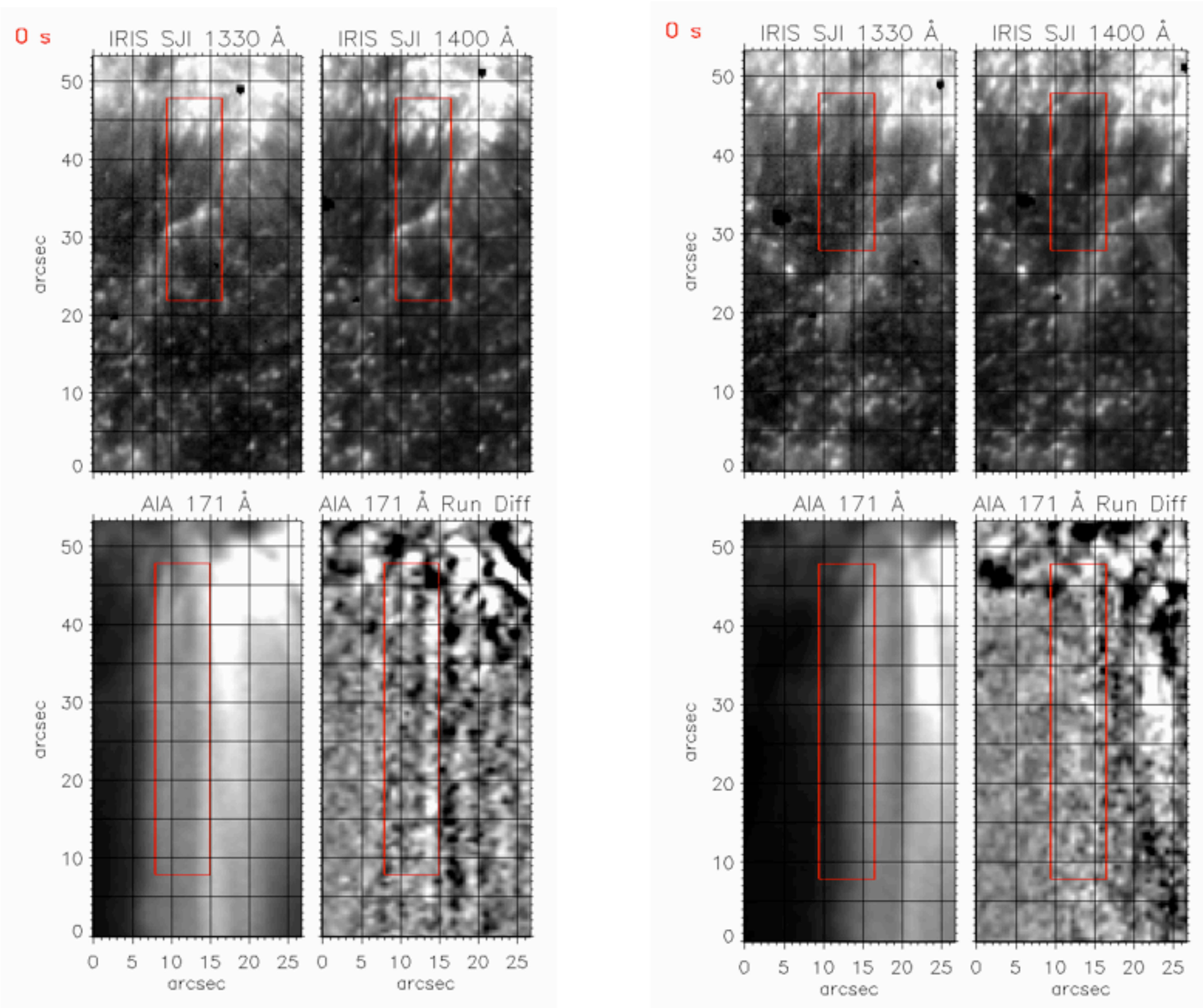

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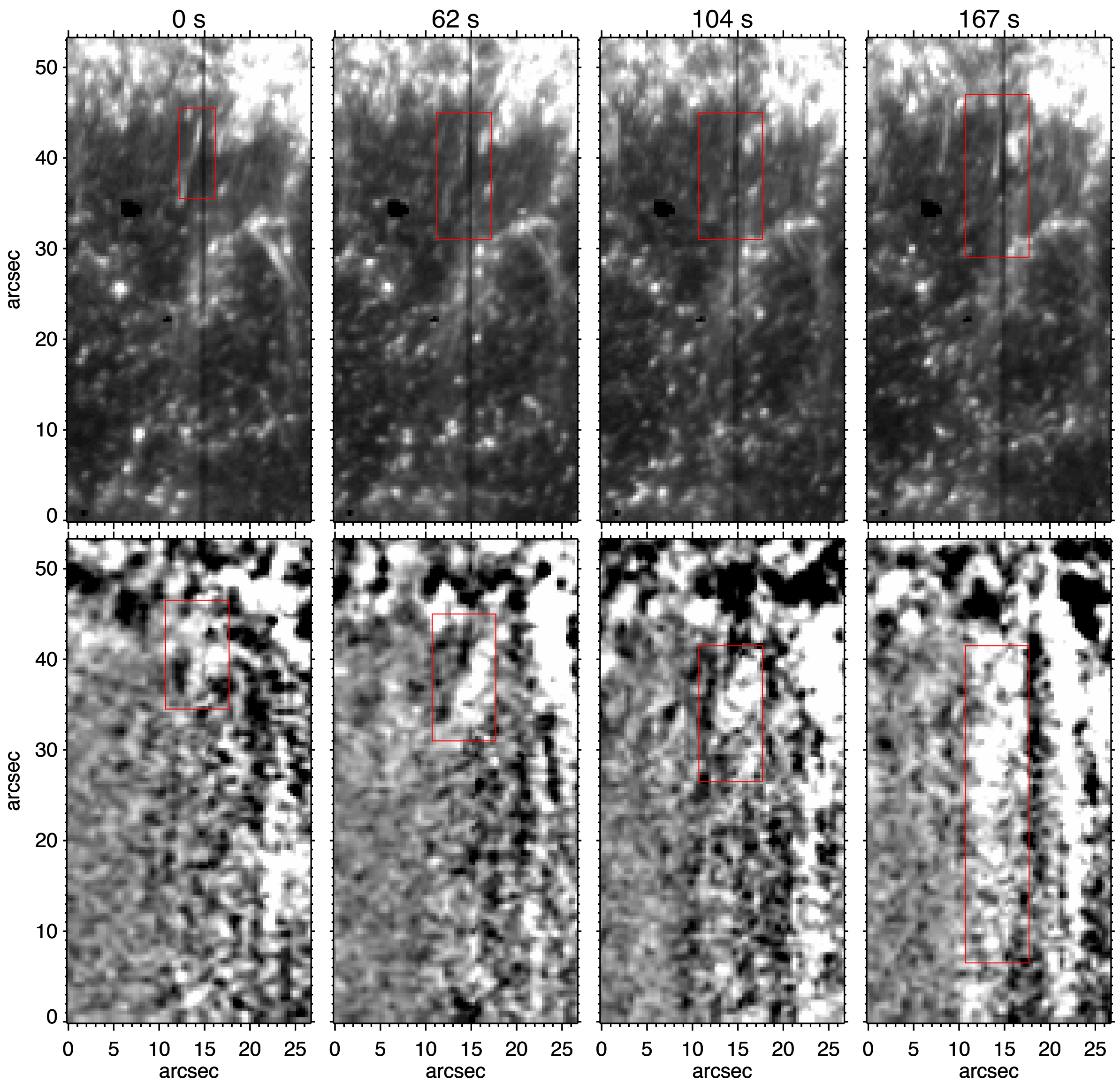

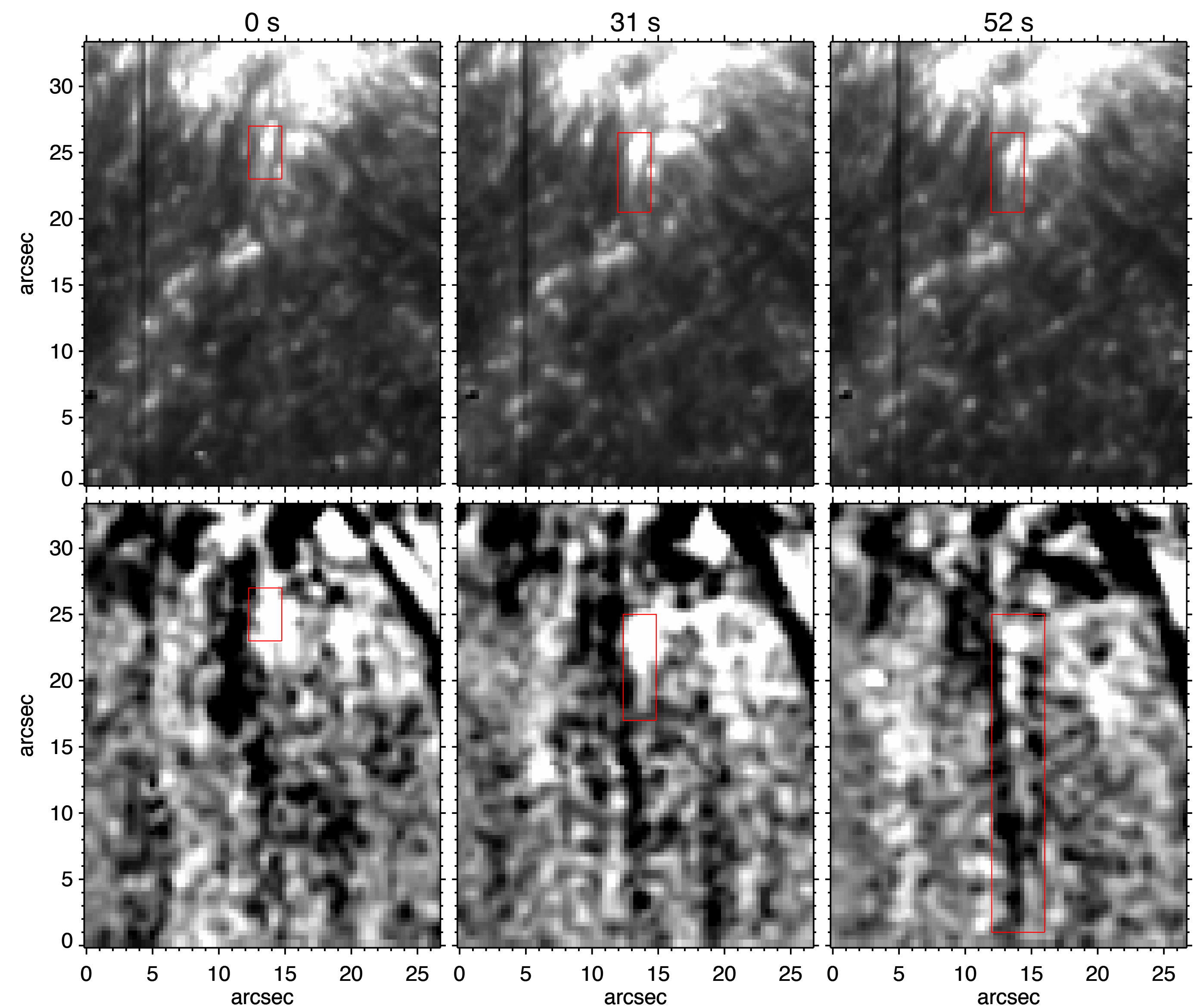

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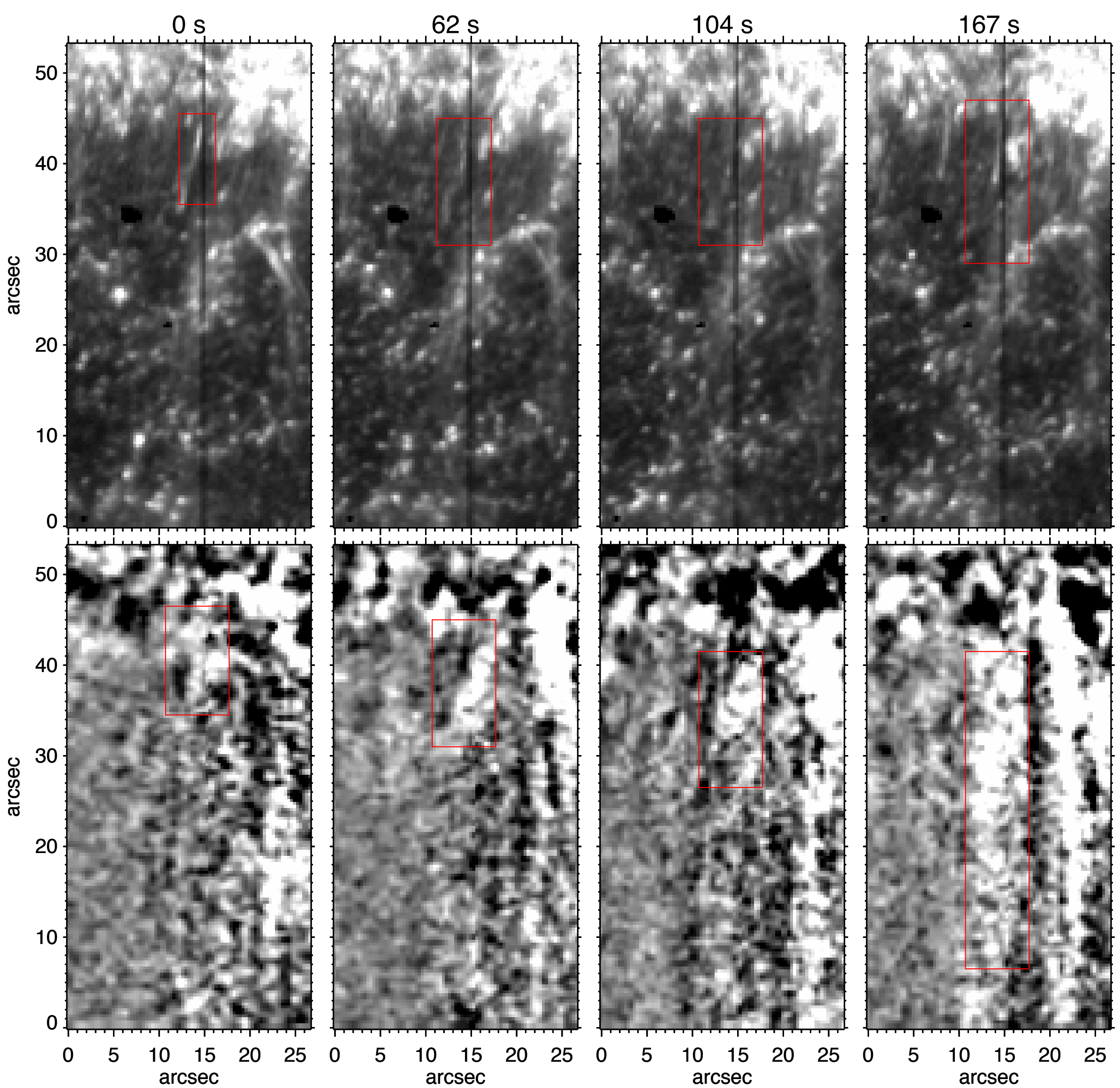
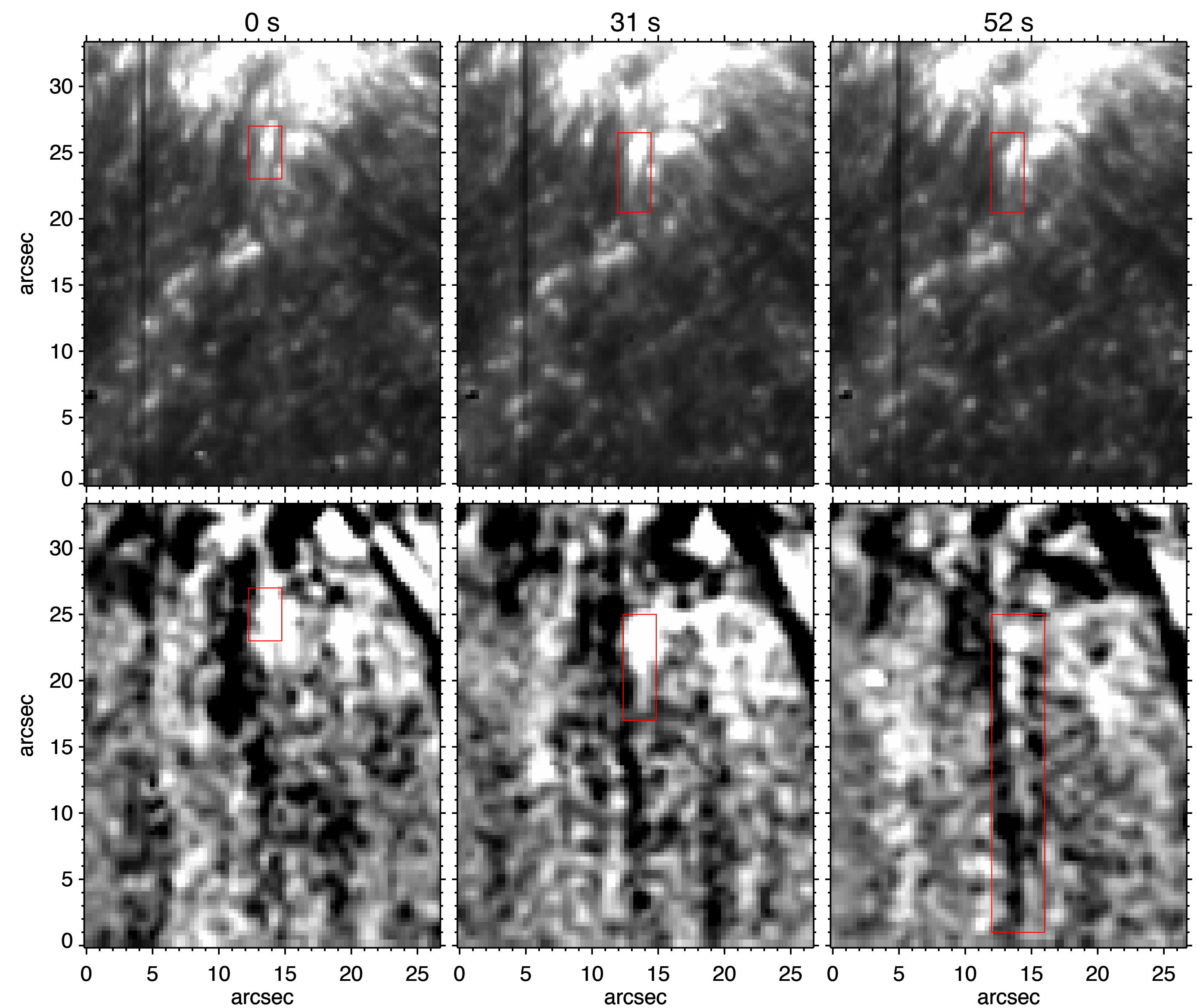
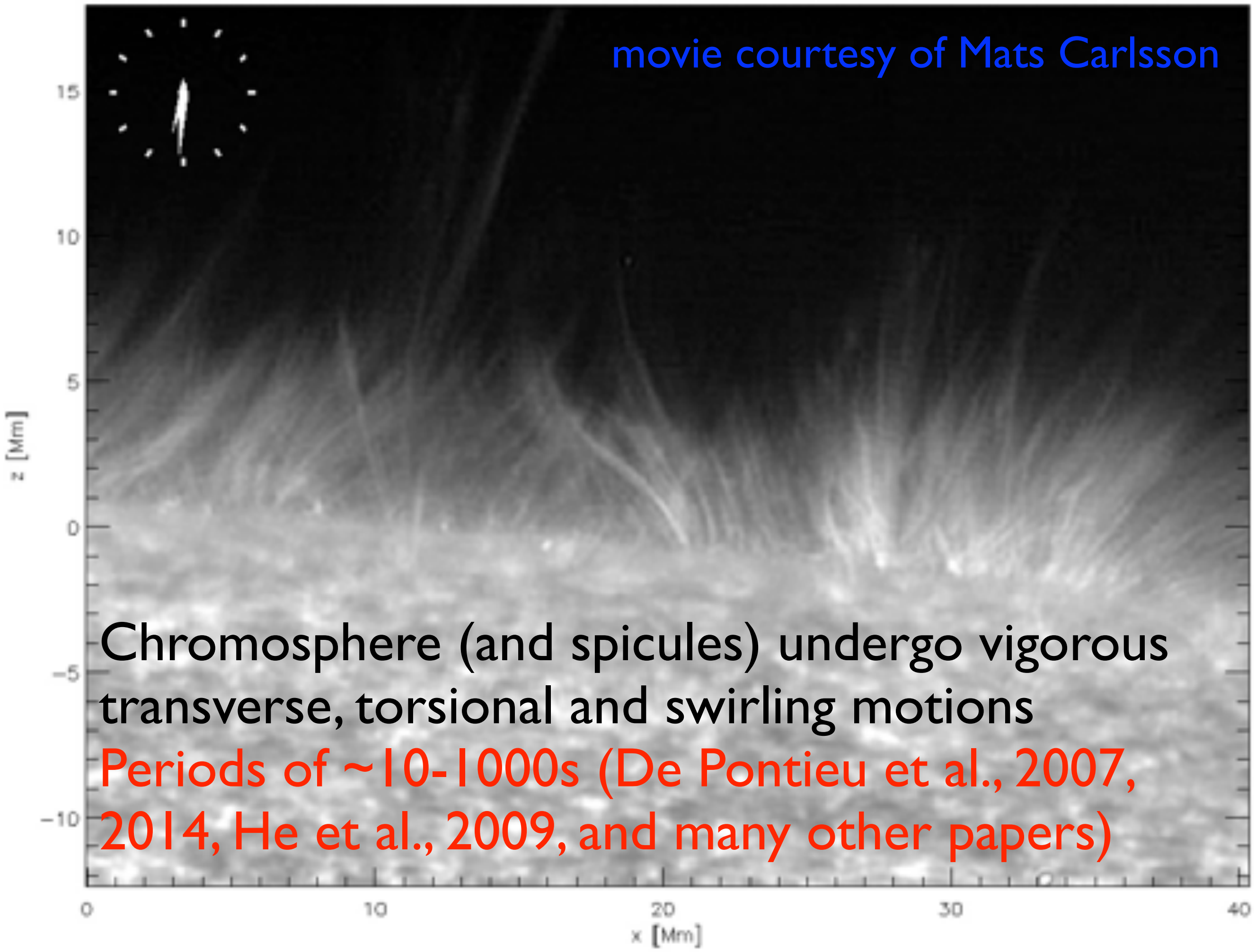




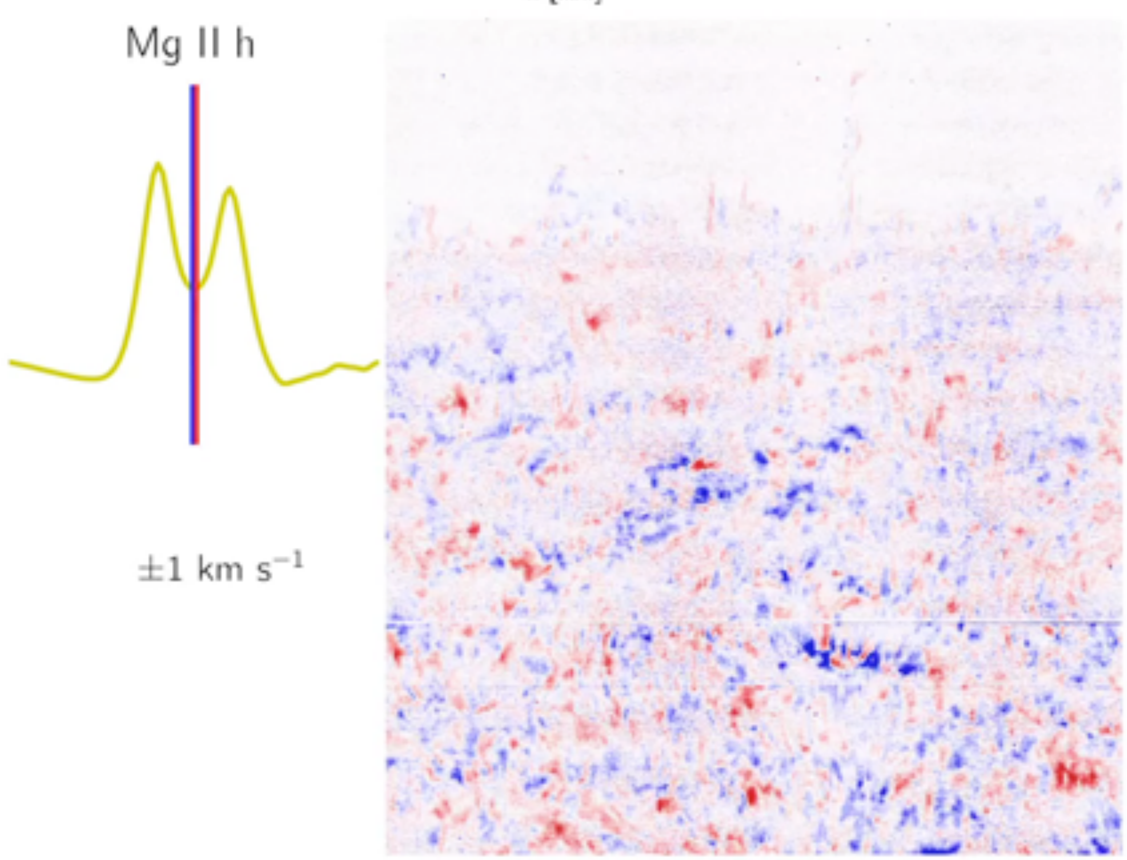
Propagating Coronal Disturbances (PCDs) related to type II spicules!

How are chromospheric Alfven waves generated?

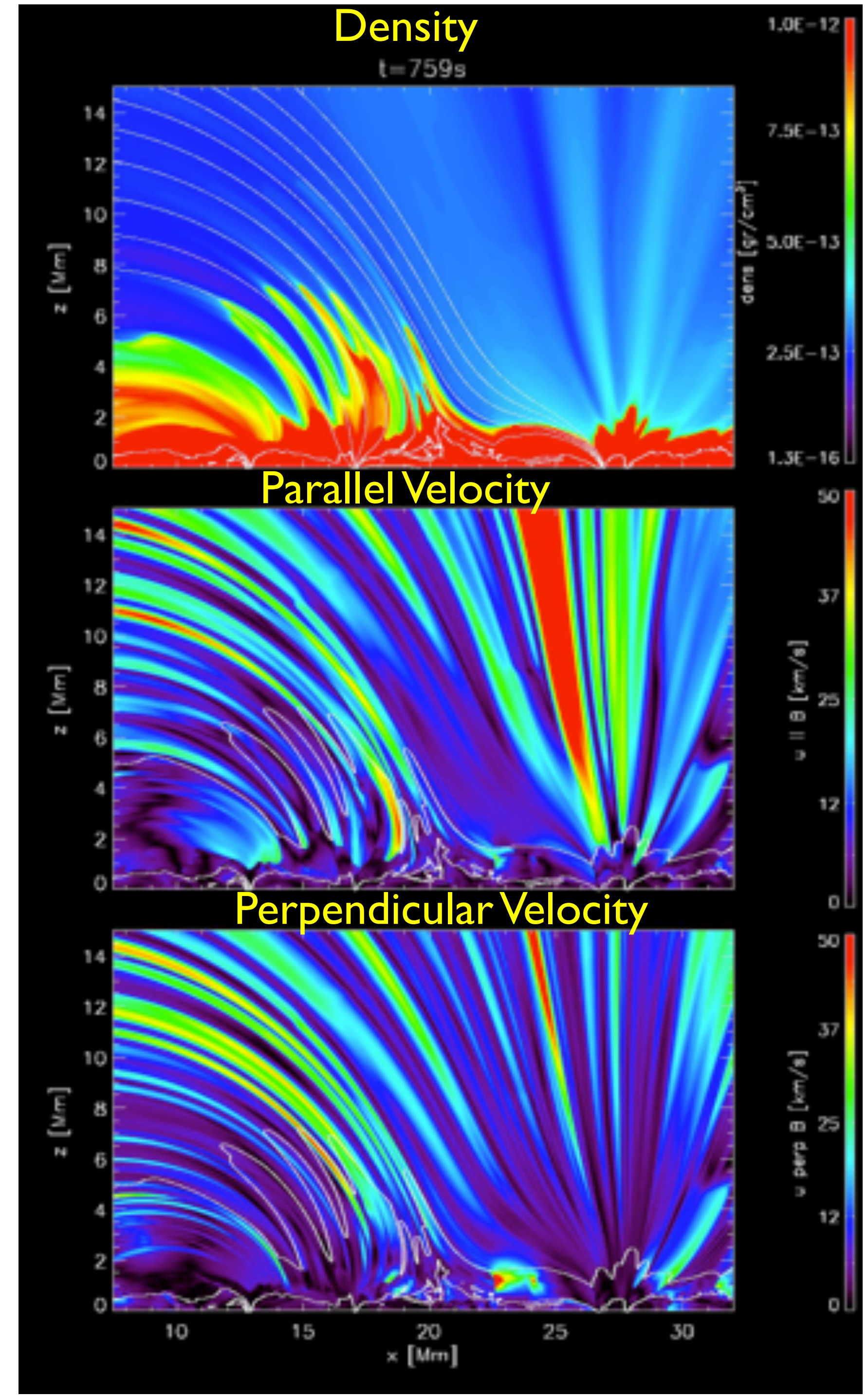


Chromosphere (and spicules) undergo vigorous transverse, torsional and swirling motions

Periods of ~10-1000s (De Pontieu et al., 2007, 2014, He et al., 2009, and many other papers)



De Pontieu et al. 2014 Science, Rouppe van der Voort et al. 2015



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Type II spicules naturally associated with transverse waves from violent realize of magnetic tension

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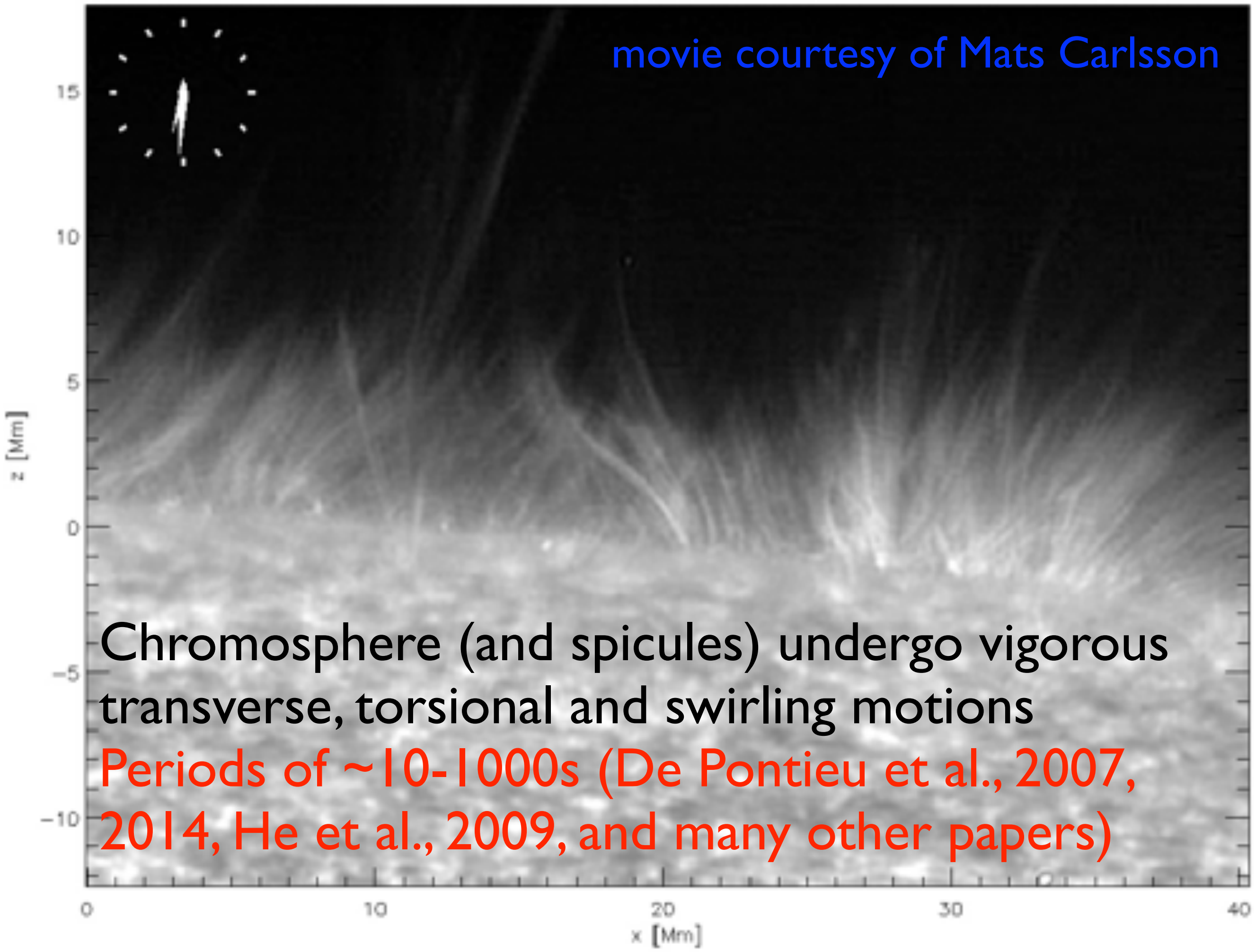

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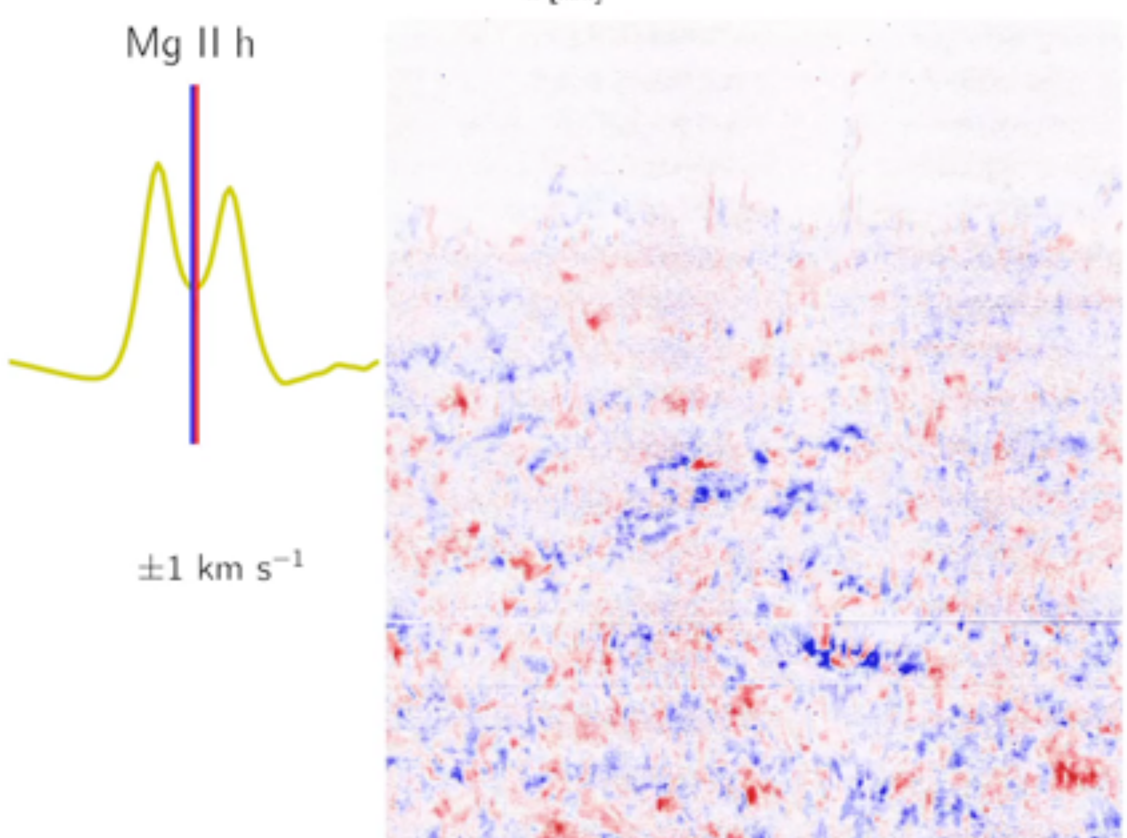

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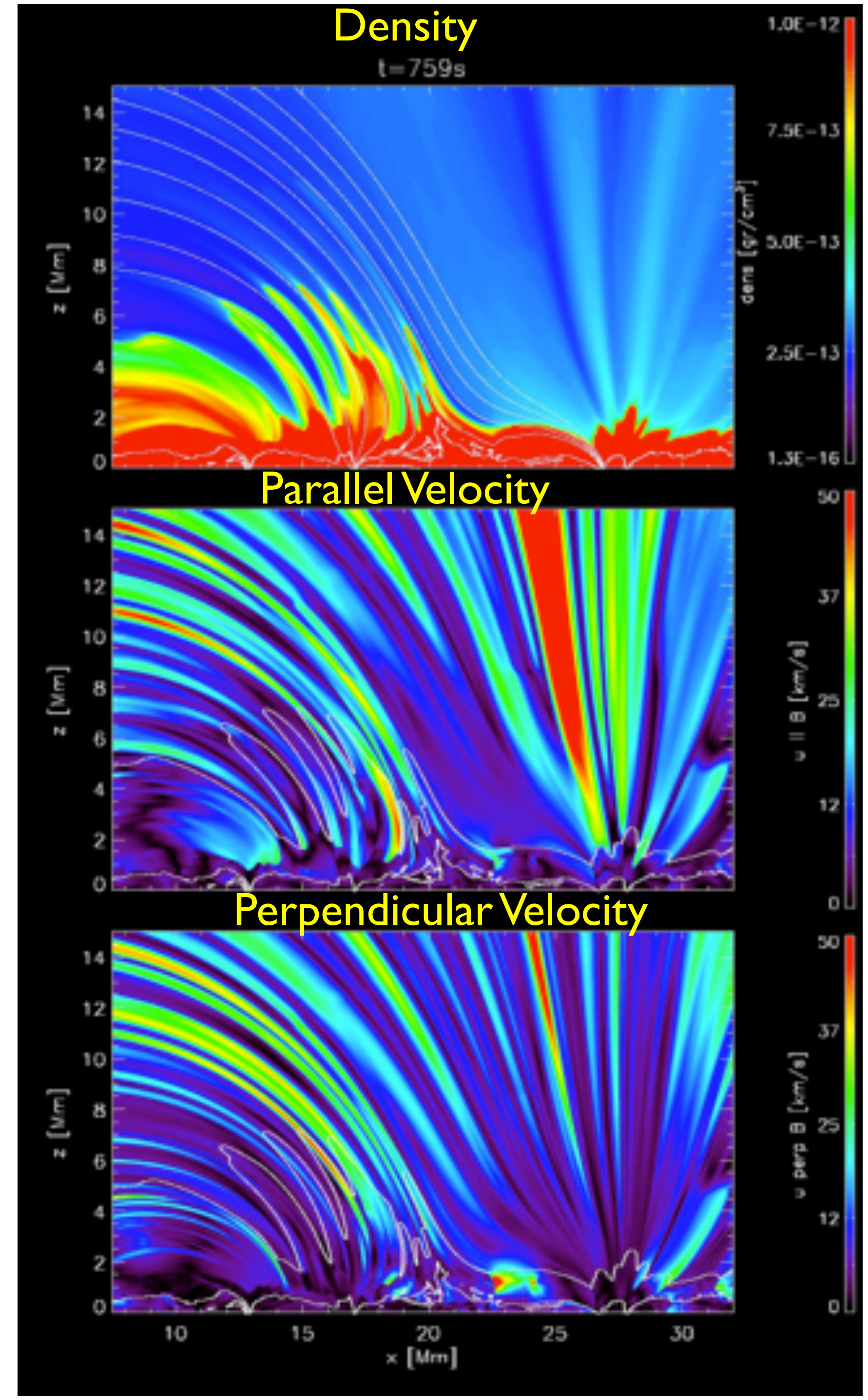

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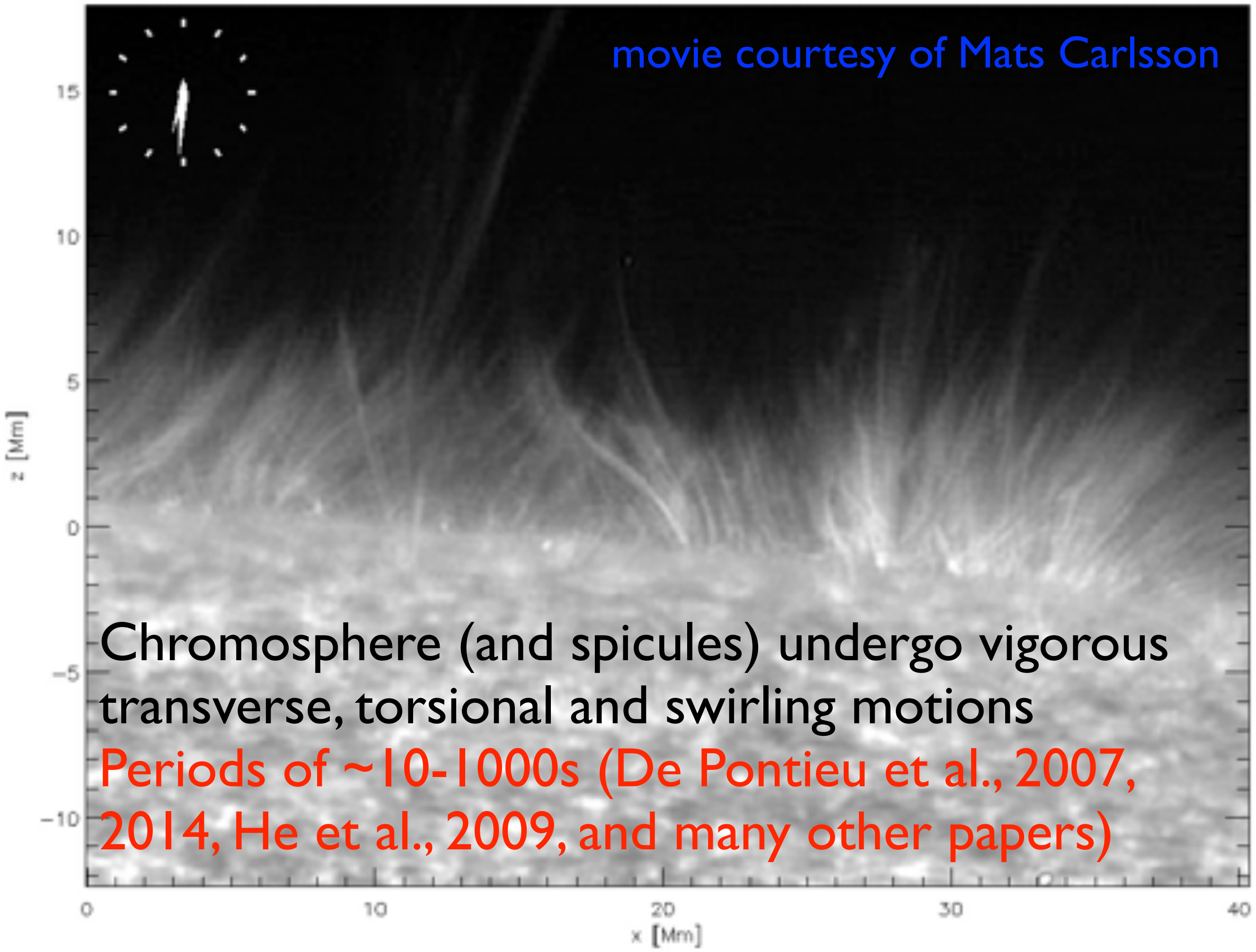

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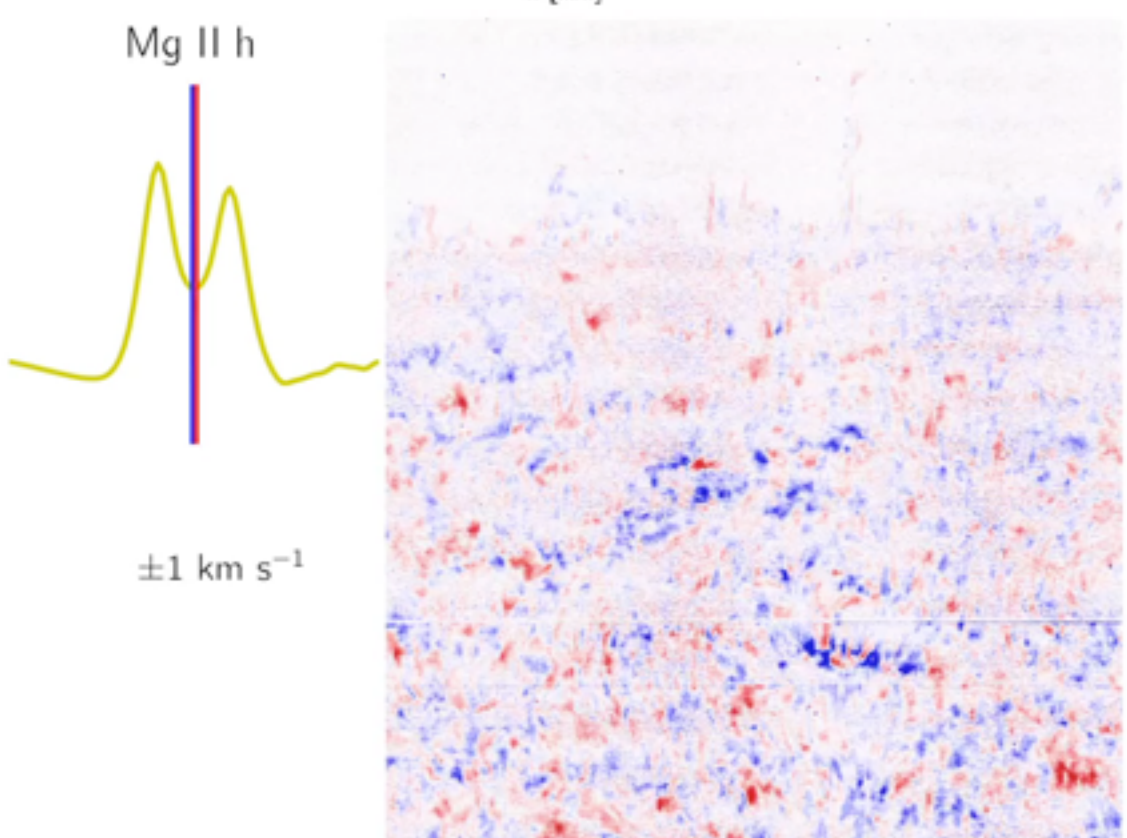

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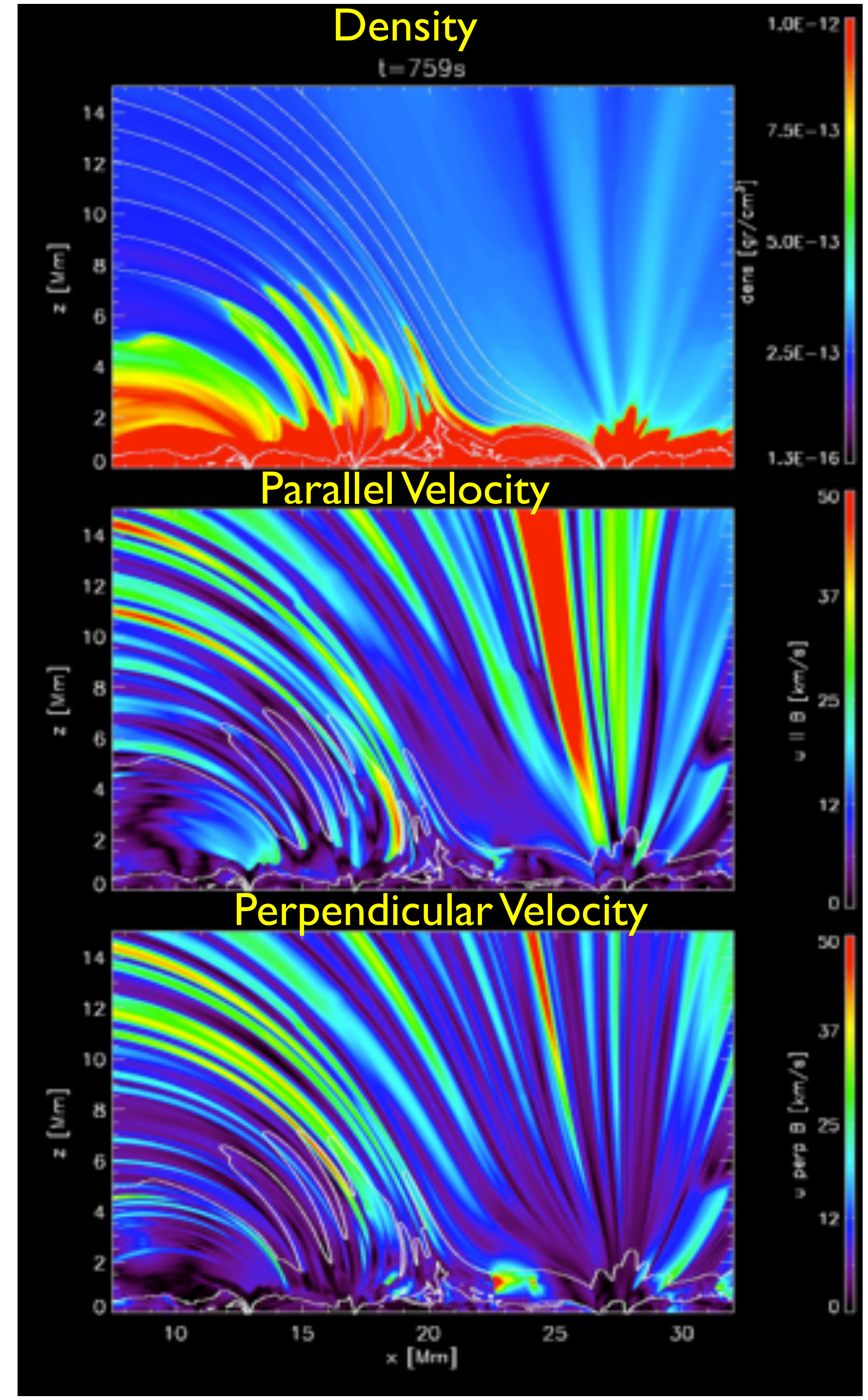

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Conclusions

1. Quiet Sun Dynamics and Heating
   a. Magneto-acoustic shock waves important contributors
   b. Granular-scale magnetic fields lead to chromospheric heating

2. Active Region Dynamics
   a. Magneto-acoustic shock waves and dynamic fibrils
   b. Chromospheric dynamics and non-equilibrium TR ionization

3. Spicules and Alfven Waves
   a. Formation of spicules explained…
   b. Heating to coronal temperatures observed and explained!
   c. Alfven wave generation explained…