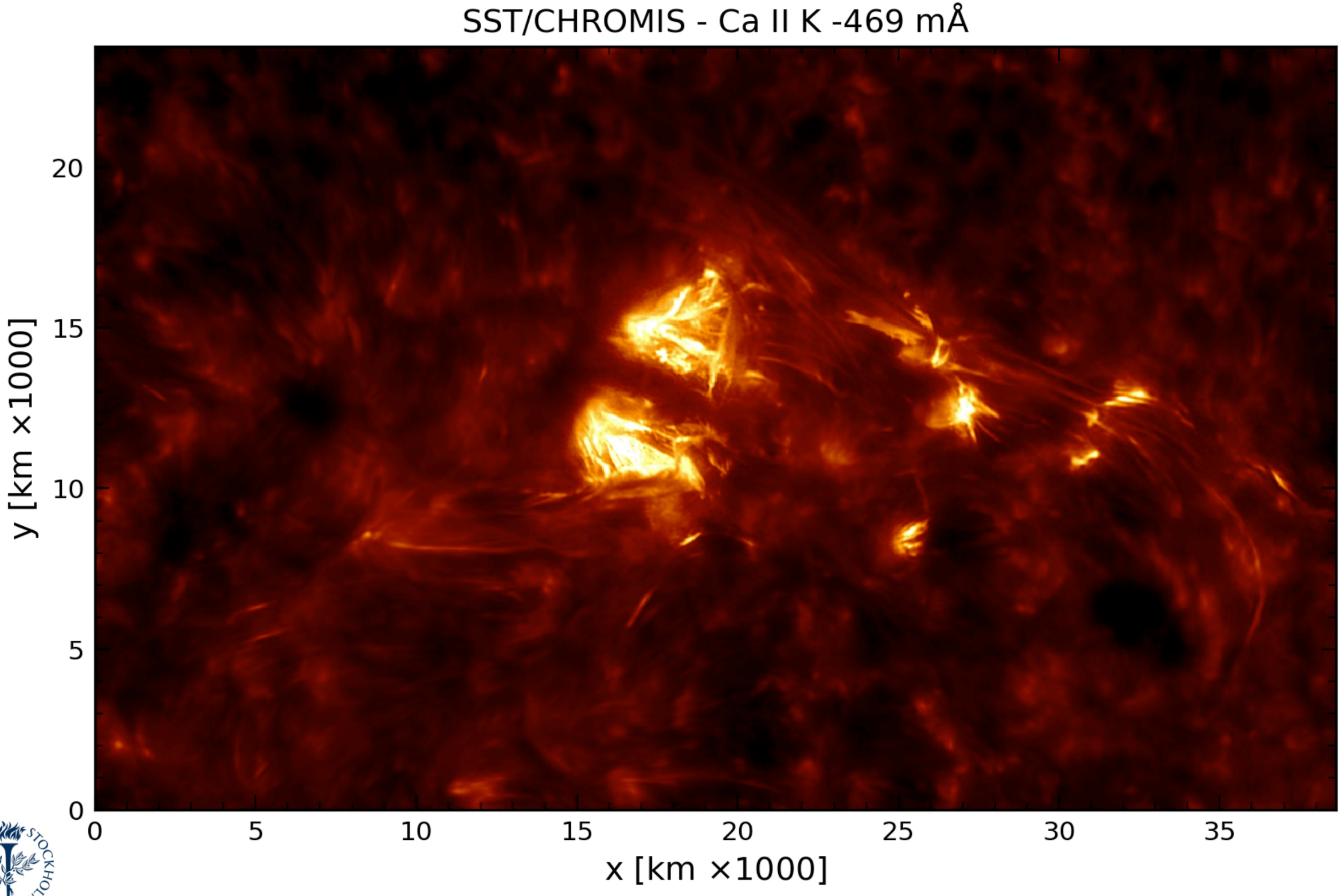
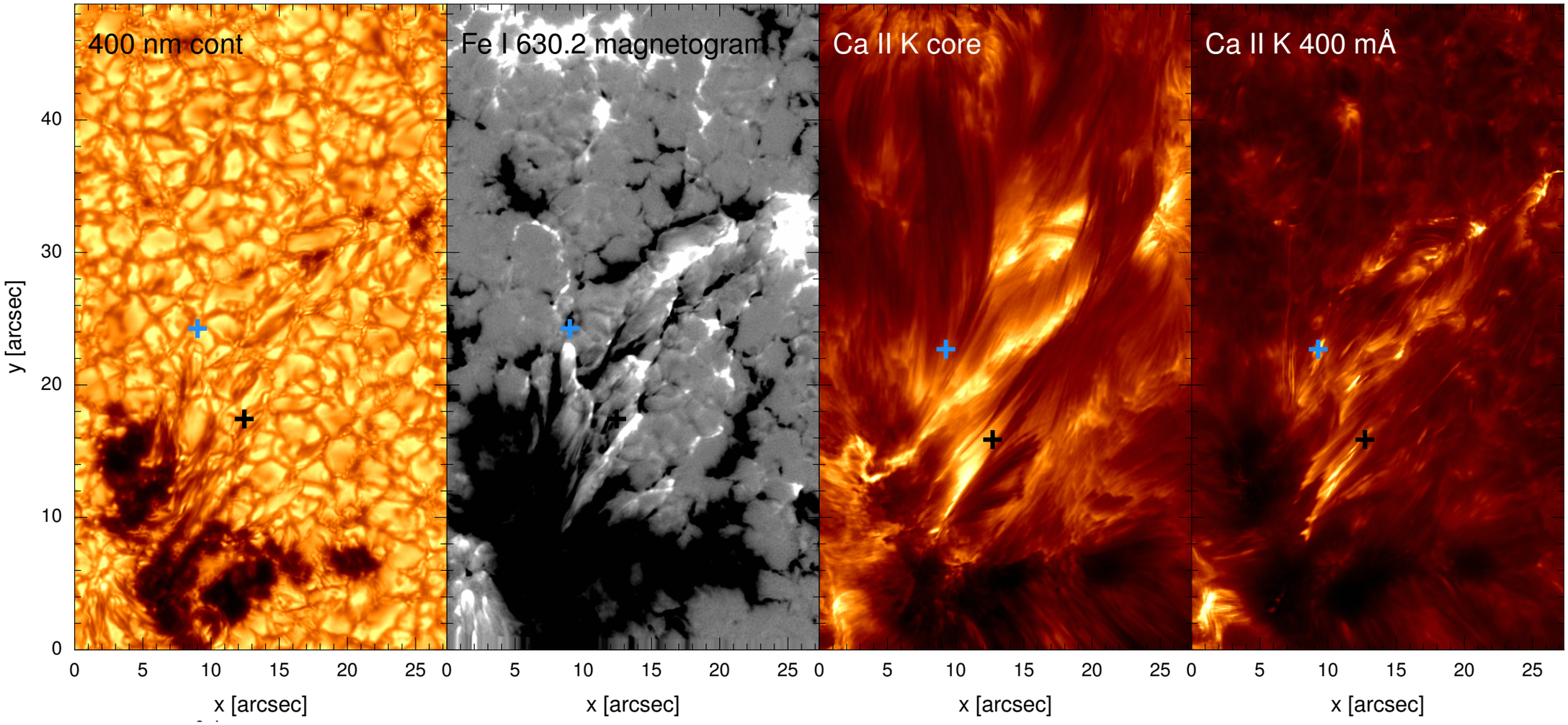
Chromospheric diagnostics: a personal selection



Stockholm University

Jaime de la Cruz Rodríguez

The chromosphere: energy transport and deposition

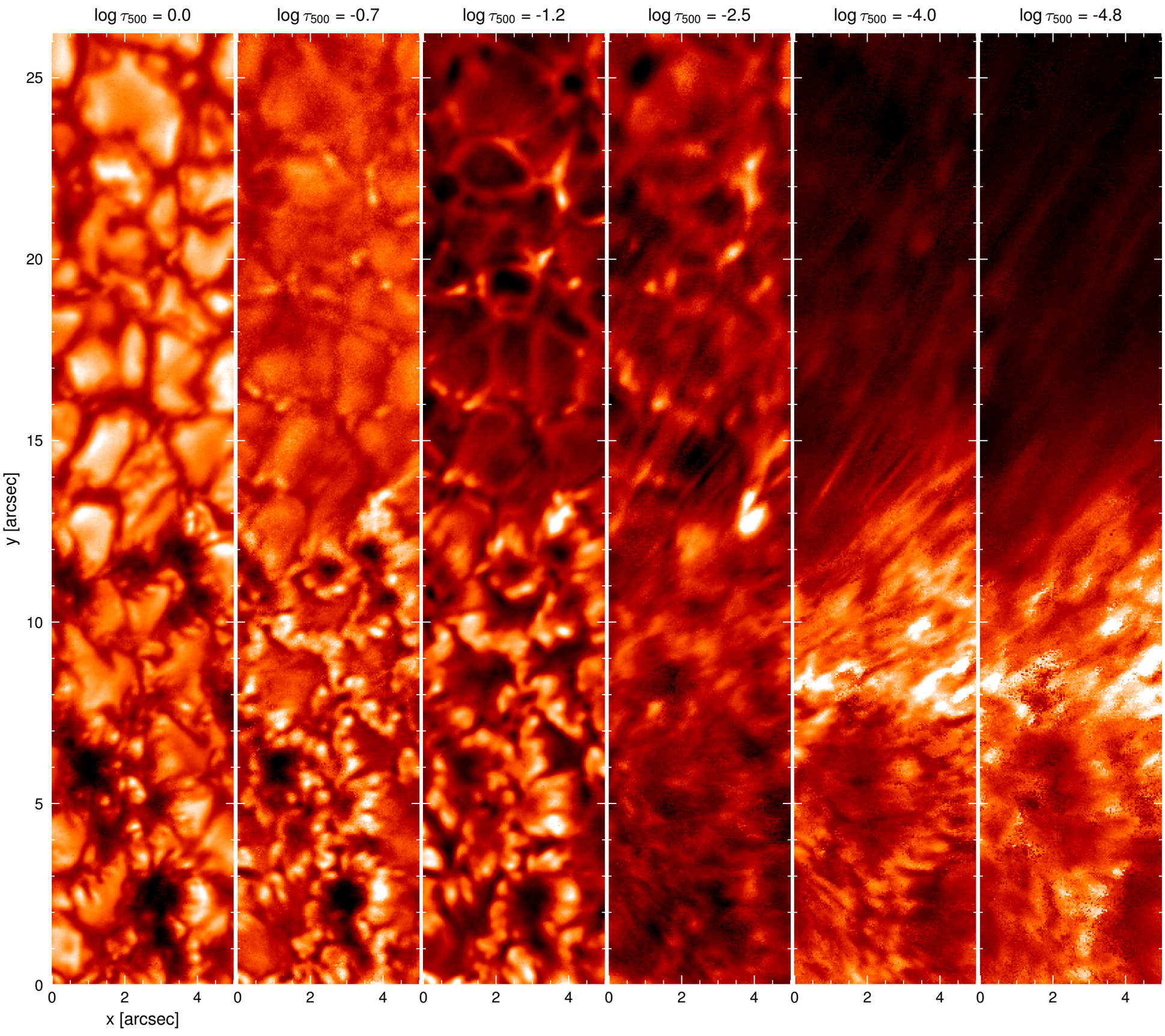


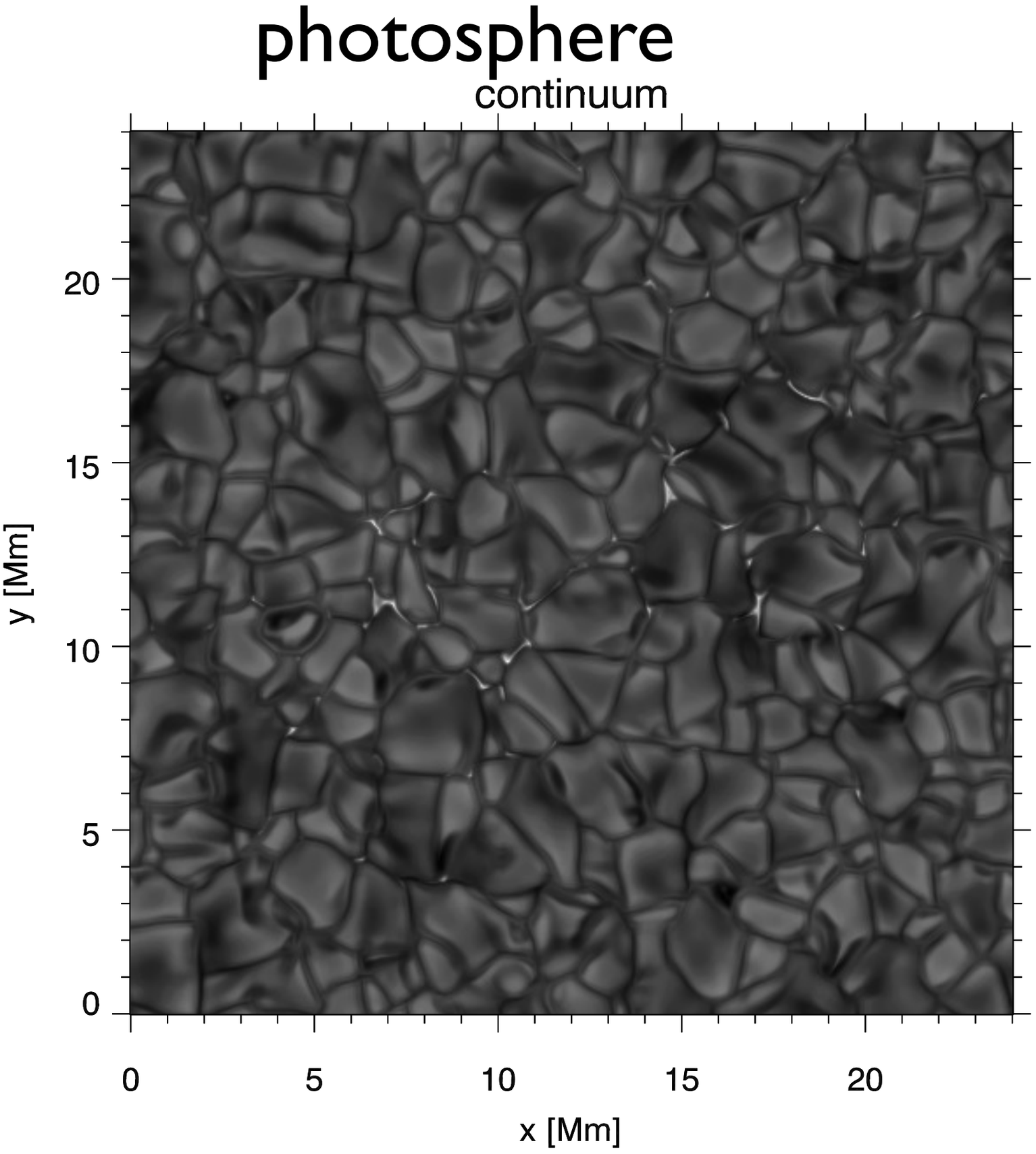
The **chromospheric heating problem:** what mechanisms *transport and release energy* into the outer layers of the Sun?

Unlike in the photosphere:

- The energy necessary to **sustain** the observed radiative cooling rates must be provided, both in quiet-Sun and active regions.
- There are very **few measurements of the magnetic field vector** in the chromosphere.

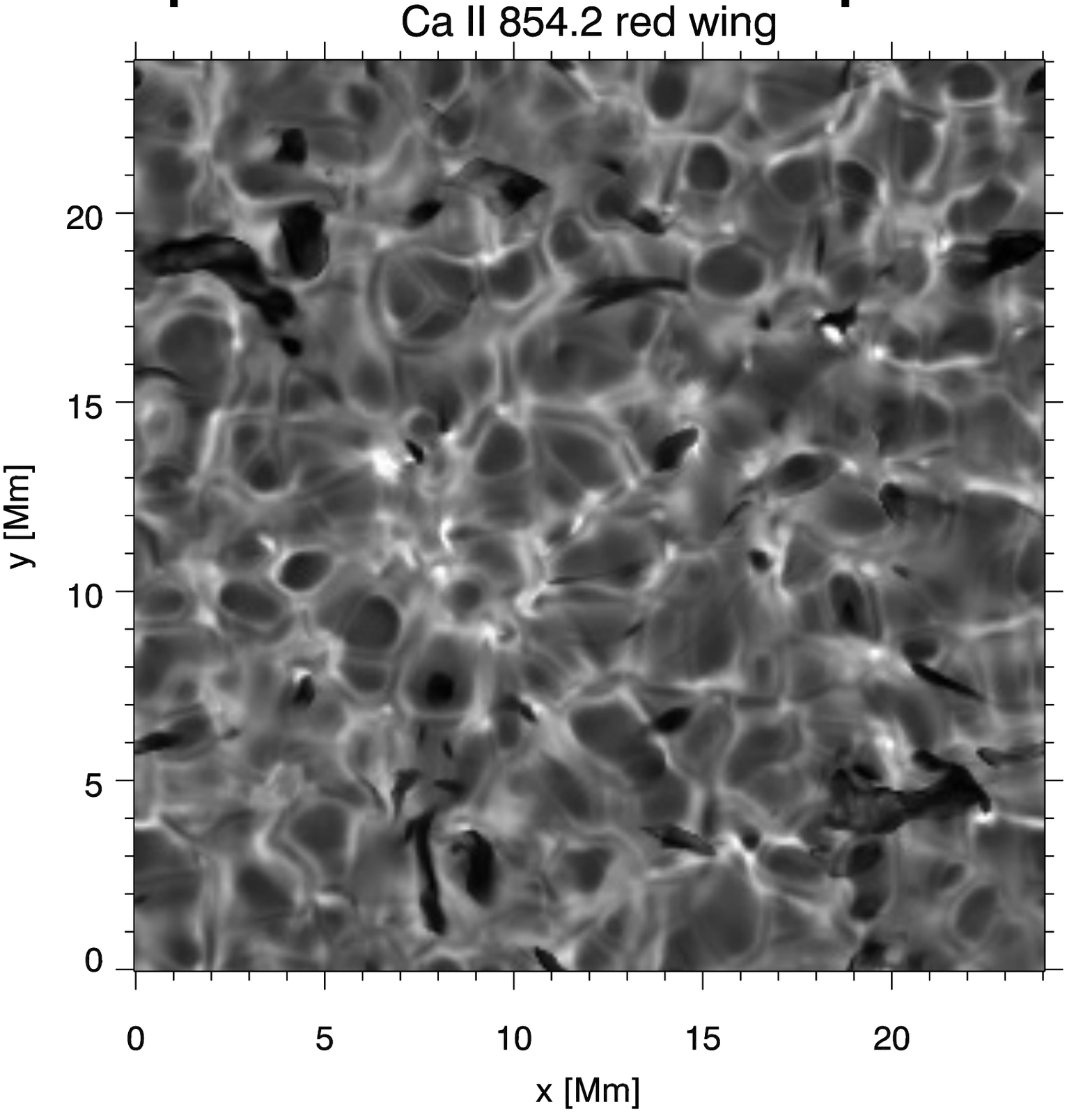
The chromosphere: energy transport and deposition





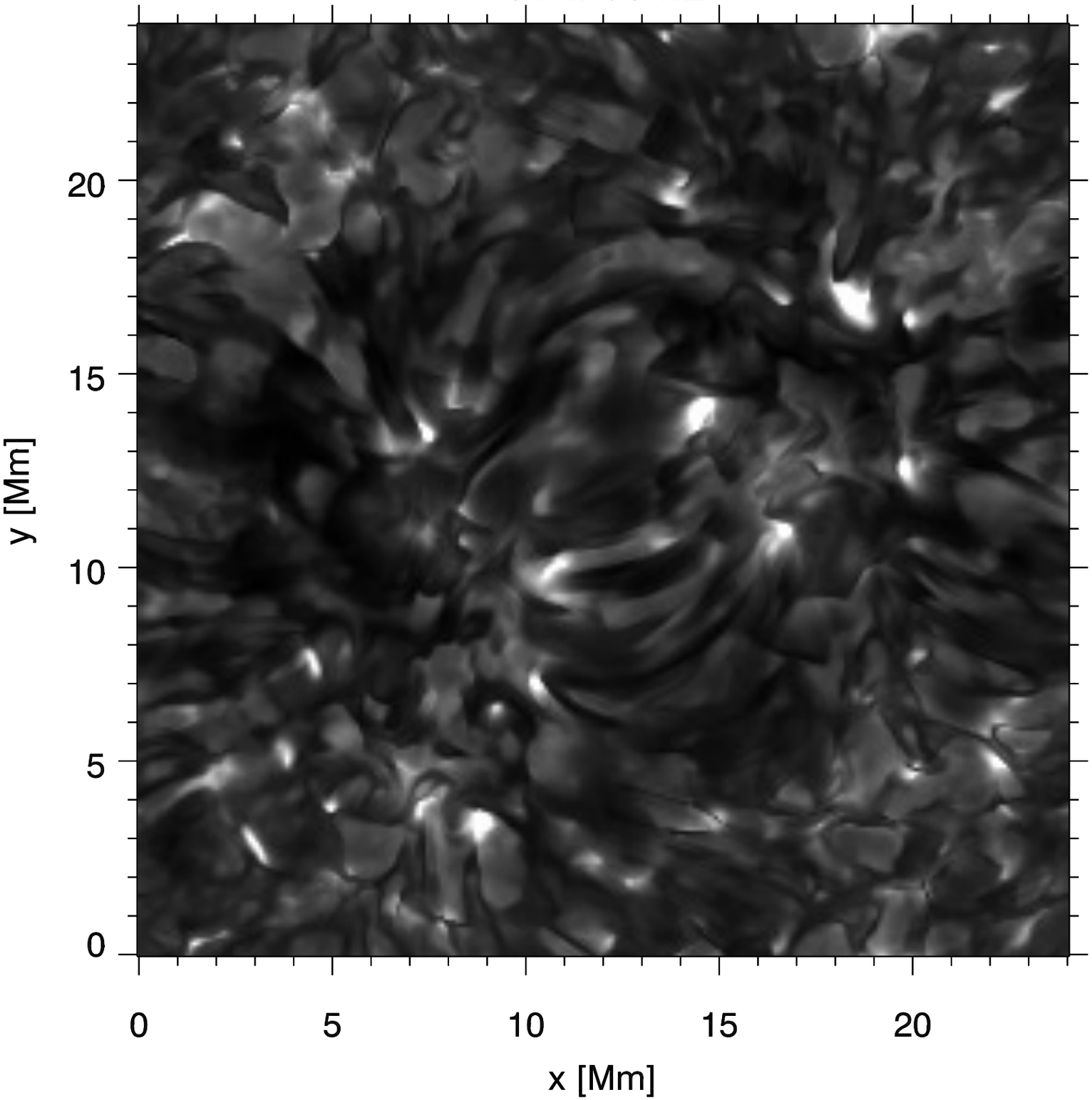
Courtesy J. Leenaarts

photosphere-low chromosphere



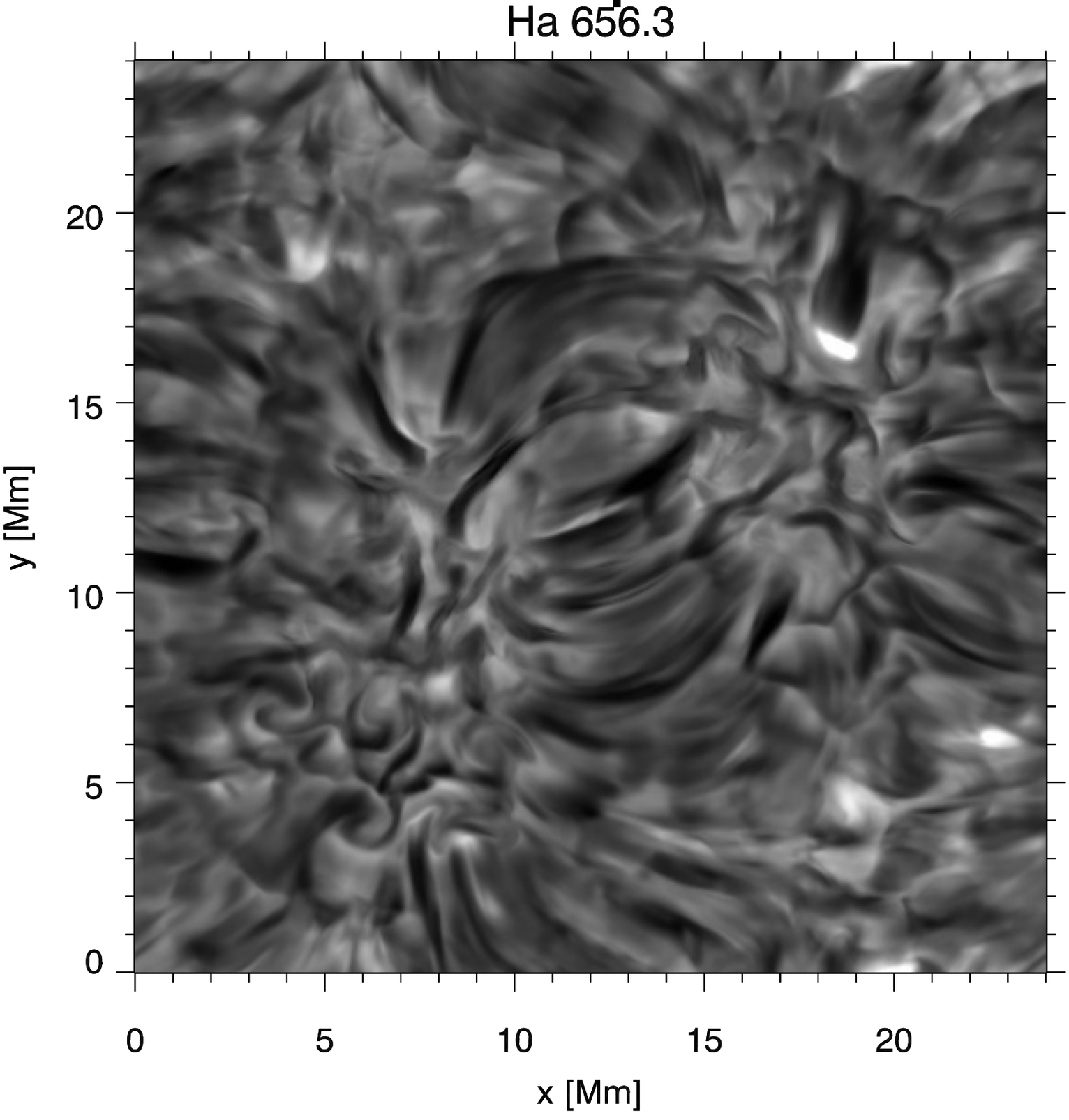
Courtesy J. Leenaarts

mid chromosphere



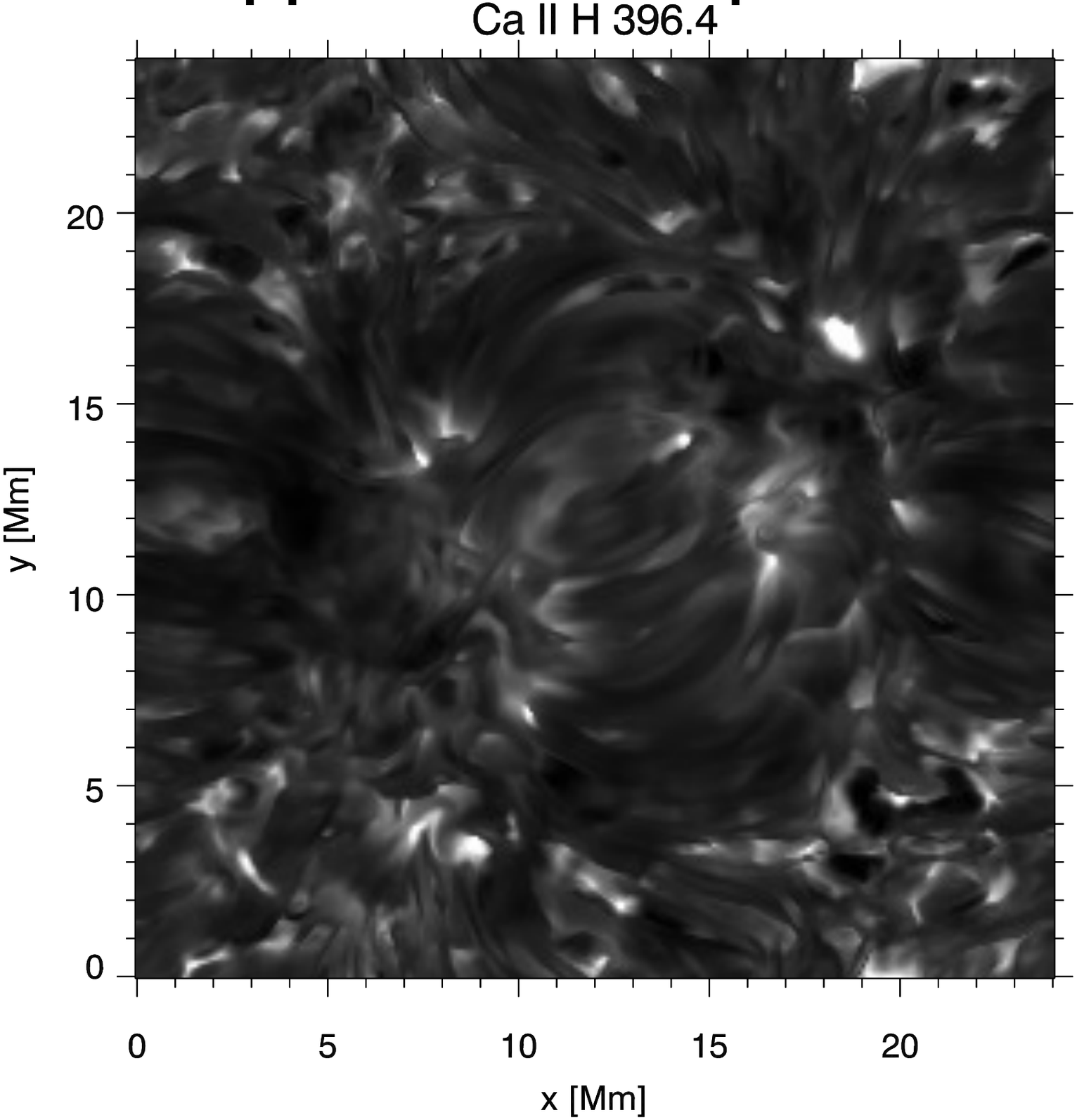
Courtesy J. Leenaarts

mid chromosphere



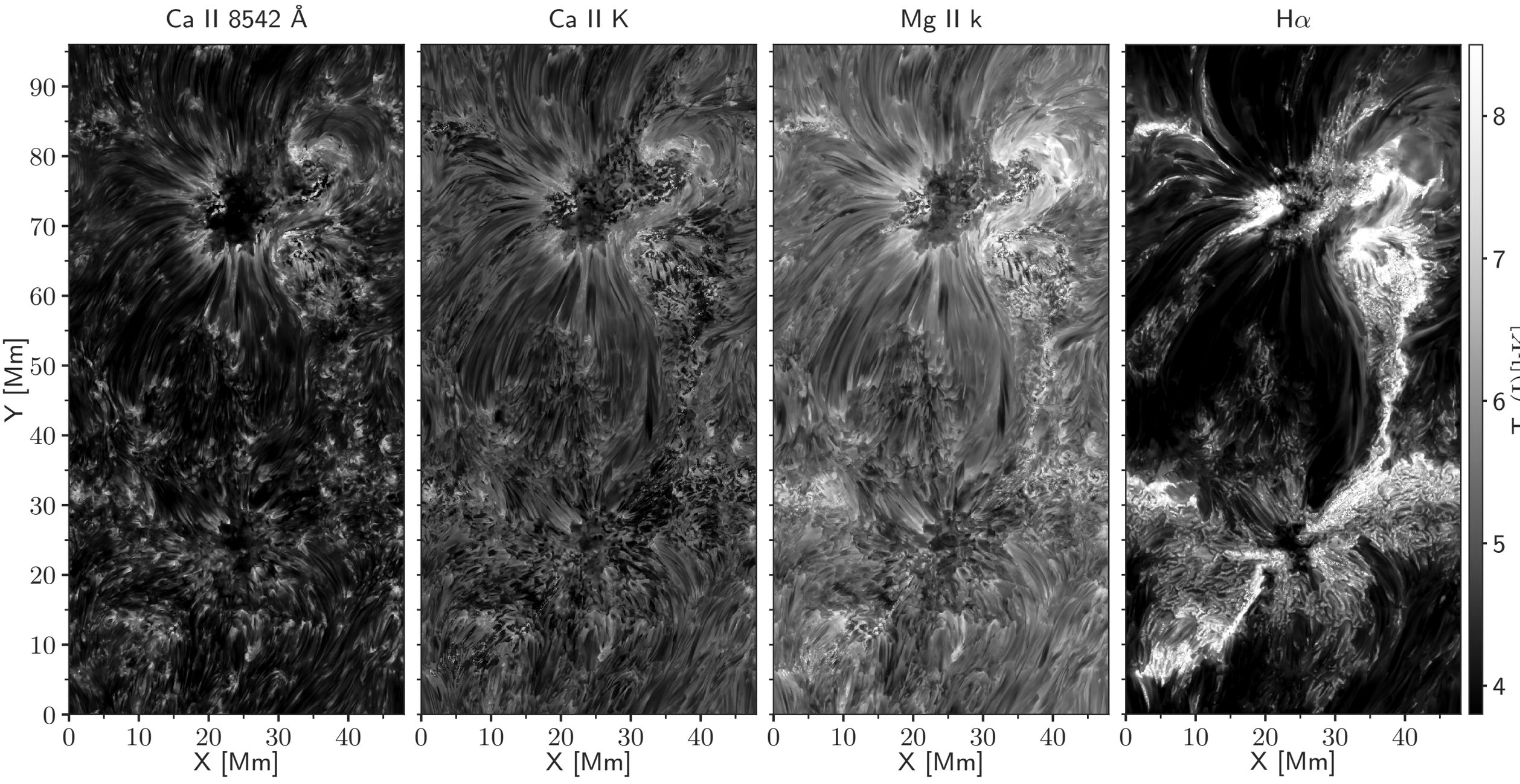
Courtesy J. Leenaarts

mid-upper chromosphere



Courtesy J. Leenaarts

An example of a 3D MHD simulation (Muram)

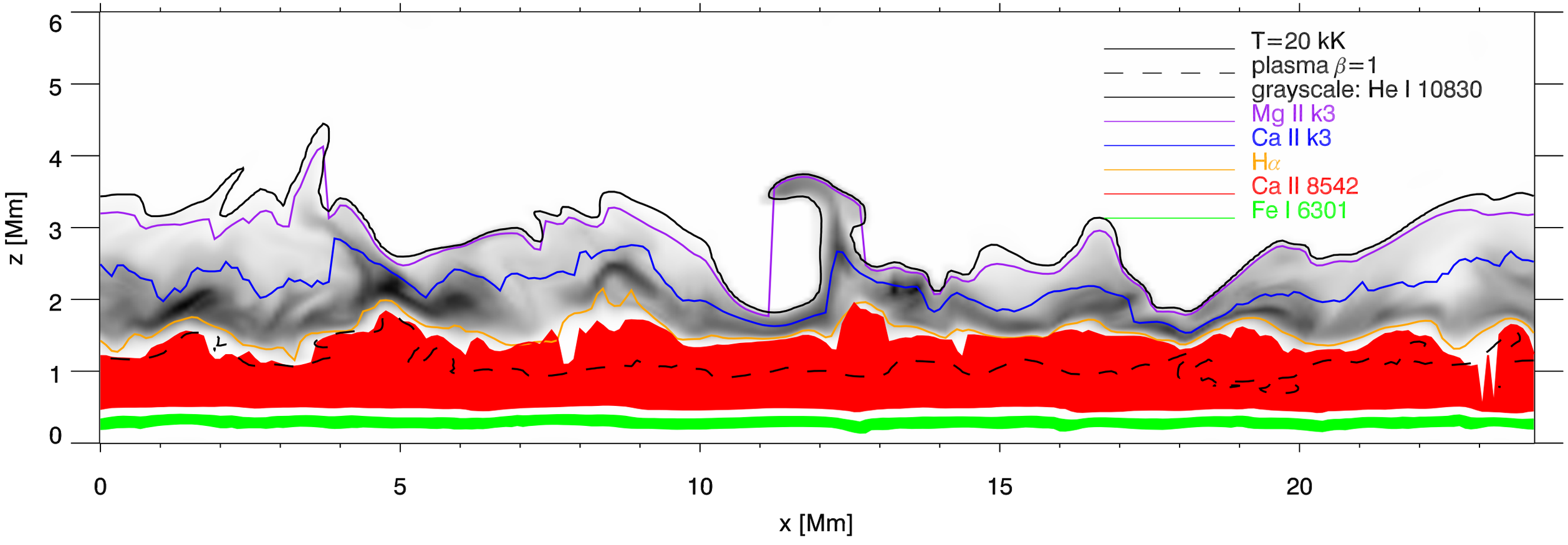


Using 3D radiative transfer we recover elongated fibril structures, and something that looks like ribbon in Halpha.

Bjørgen, Danilovic, Leenaarts, Rempel (in prep.)

Few chromospheric diagnostics

Line	PRD/SE	Polarization	Max. formation
Na I D1	SE	Zeeman	Upper photosphere
Mg I 517 nm	SE	Zeeman	Upper photosphere
Ca II IR triplet	SE	Zeeman + Scatt.	Lower chromosphere
H I 656 nm	SE	Zeeman + Scatt.	Middle chromosphere
He I D3	SE	Zeeman + Scatt.	Mid/up chromosphere
He I 1083 nm	SE	Zeeman + Scatt.	Mid/up chromosphere
Ca II H & K	PRD	Zeeman + Scatt. (?)	Upper chromosphere



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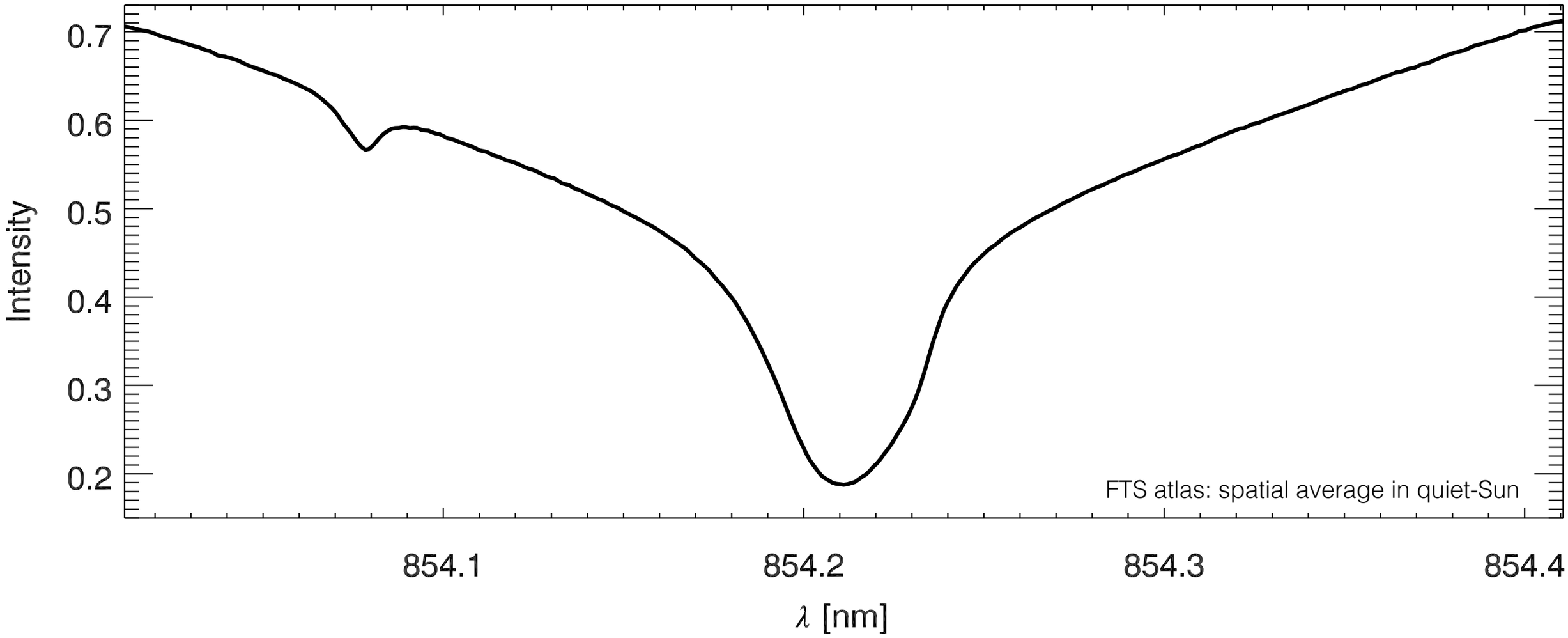
He I 1083 nm	SE	Zeeman + Scatt.	Mid/up chromosphere
Ca II H & K	PRD	Zeeman + Scatt. (?)	Upper chromosphere

Difficulties:

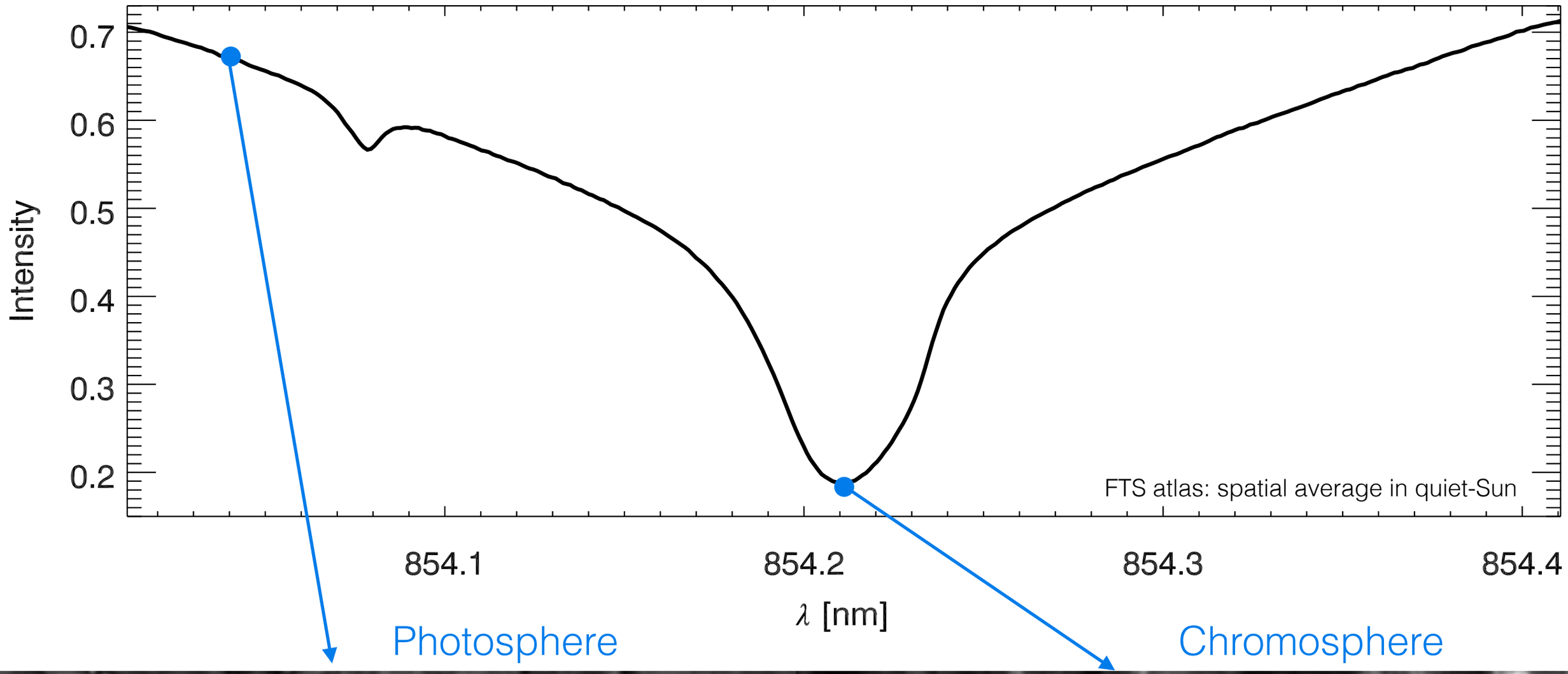
- Statistical equilibrium + Zeeman polarization in the best case.
- In the upper chromosphere we need to include PRD.
- Very large macroscopic and turbulent velocities.
- Very low signal-to-noise ratio.
- Very few 3D simulations available*.

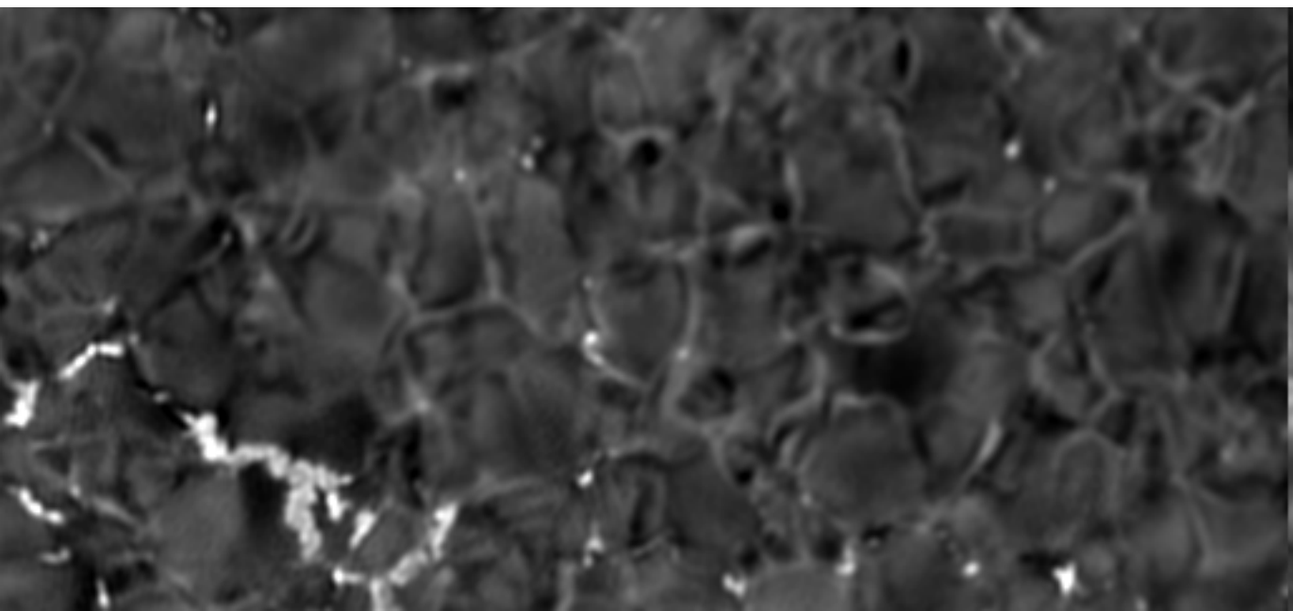
Ca II 854.2 nm

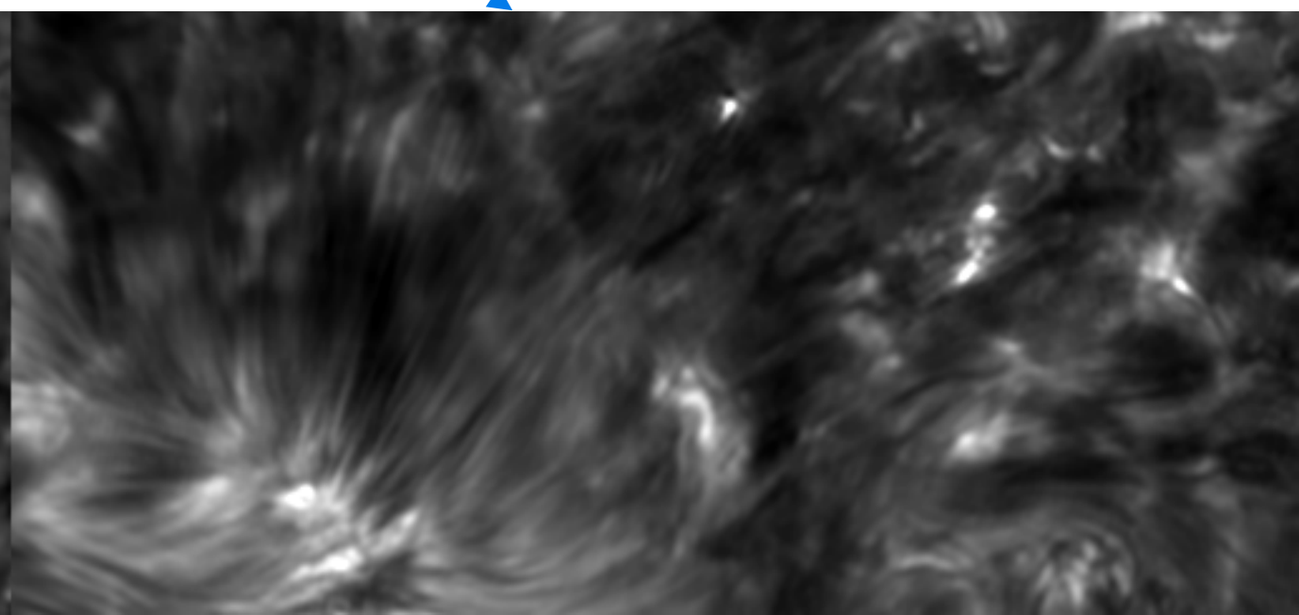
Ca II 854.2 nm


0.7
0.6
0.5
0.4
0.3
0.2
Intensity
FTS atlas: spatial average in quiet-Sun
854.1
854.2
854.3
854.4
λ [nm]

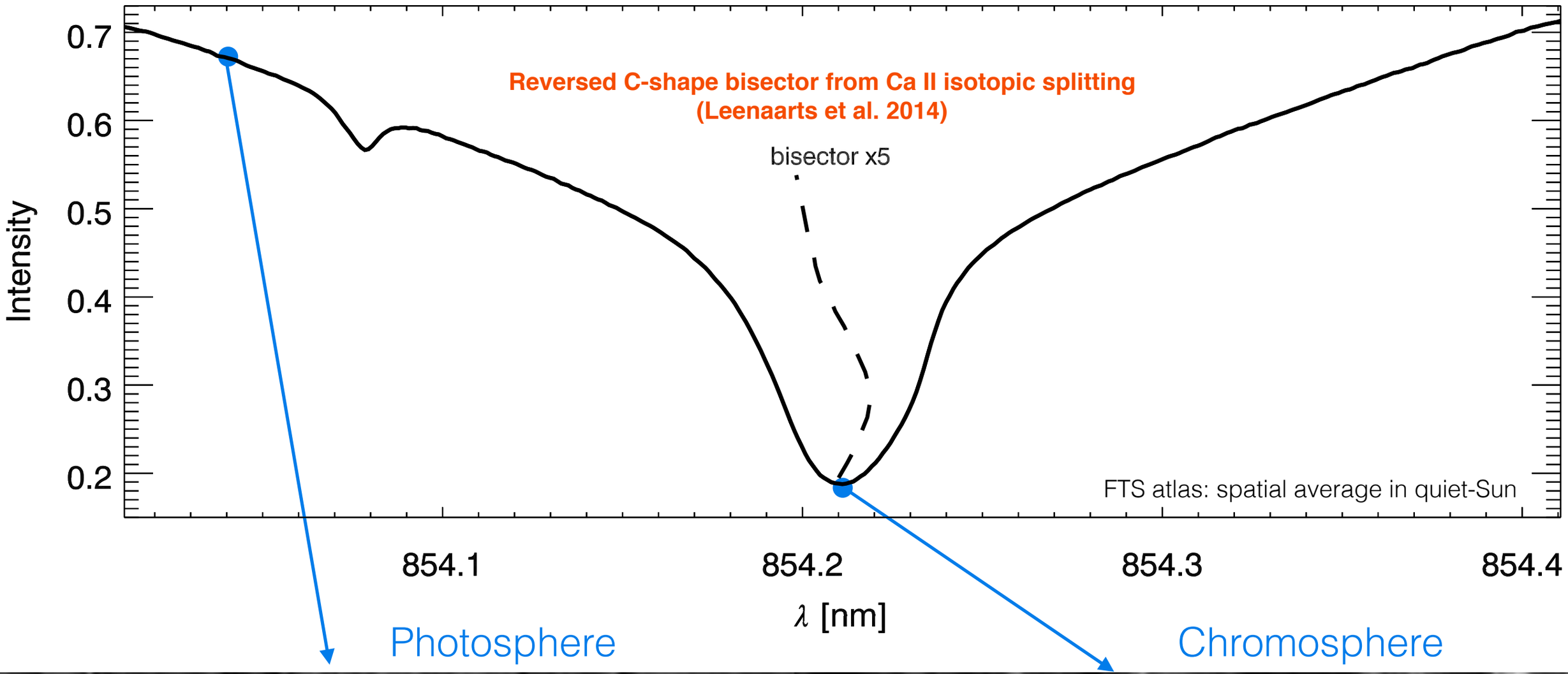
Ca II 854.2 nm

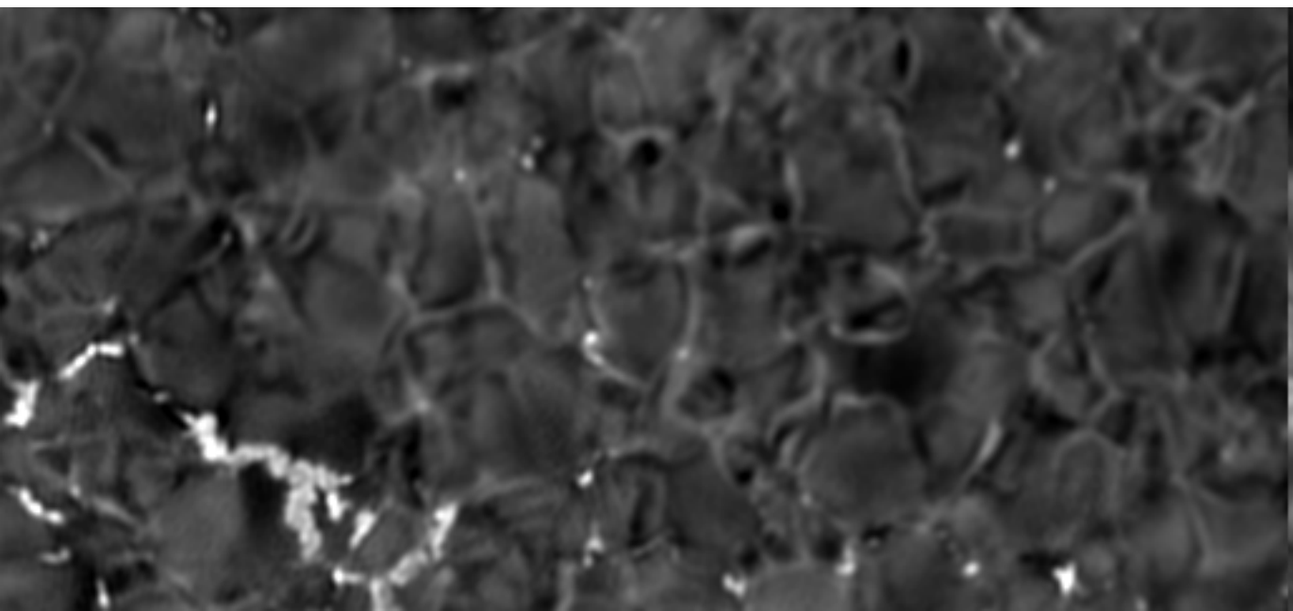

0.7
0.6
0.5
0.4
0.3
0.2
Intensity
FTS atlas: spatial average in quiet-Sun
854.1
854.2
854.3
854.4
λ [nm]
Photosphere
Chromosphere

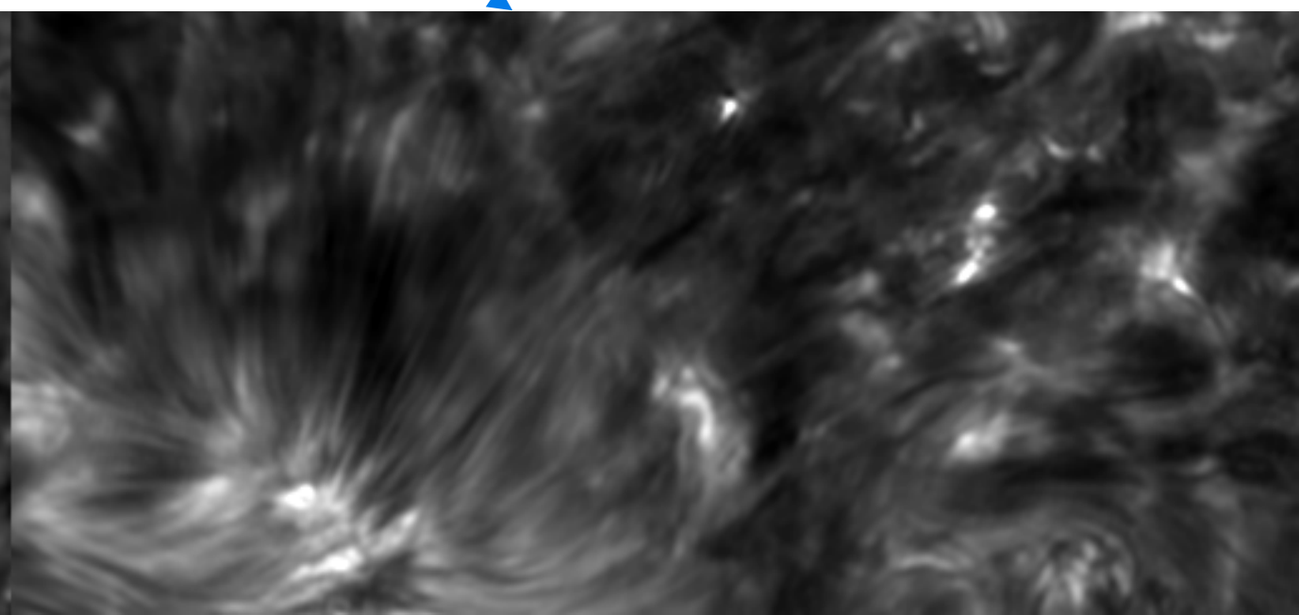




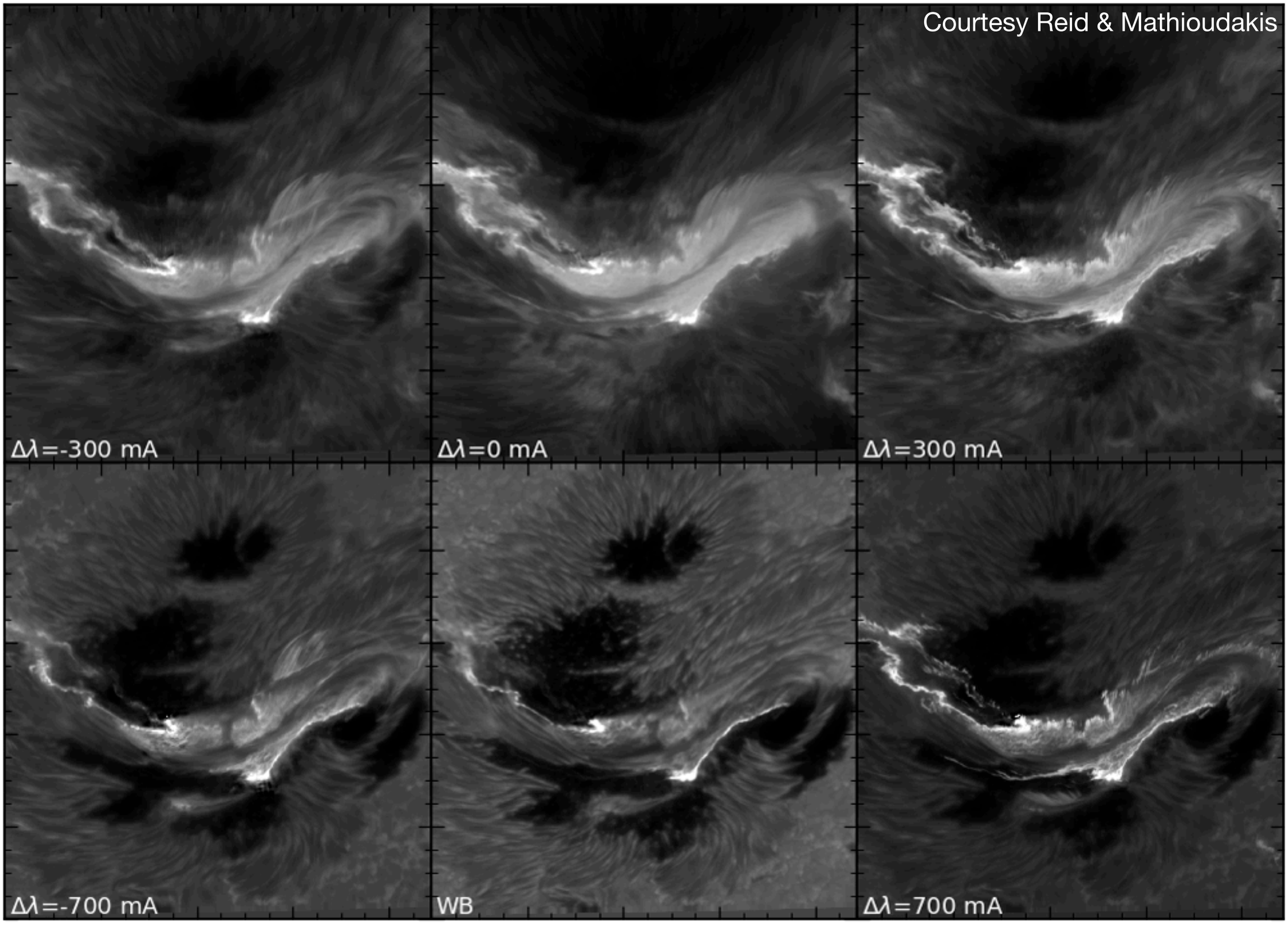
Ca II 854.2 nm


Reversed C-shape bisector from Ca II isotopic splitting
(Leenaarts et al. 2014)
bisector x5
FTS atlas: spatial average in quiet-Sun
Intensity
0.7
0.6
0.5
0.4
0.3
0.2
854.1
854.2
854.3
854.4
λ [nm]
Photosphere
Chromosphere

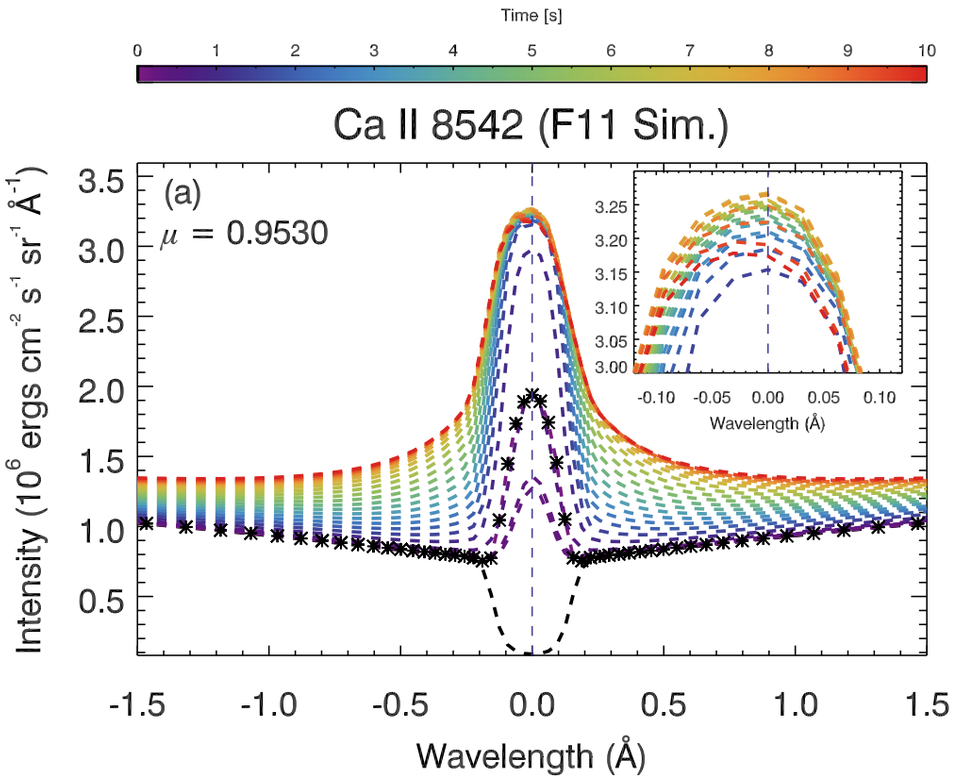


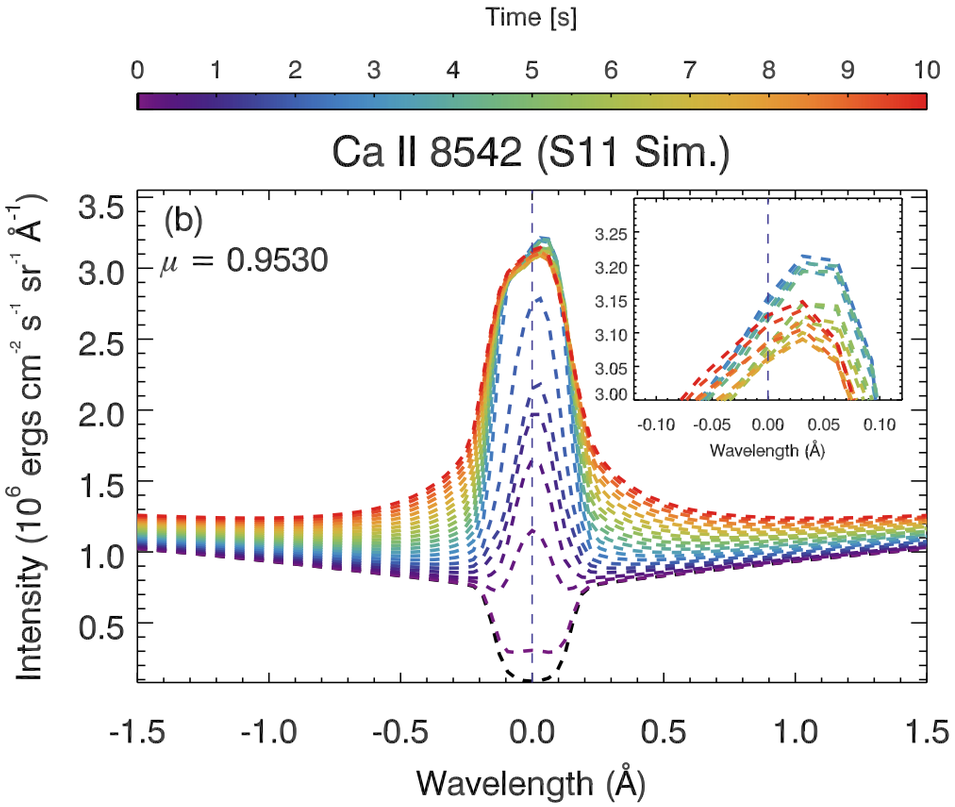


Ca II 854.2 nm


Courtesy Reid & Mathioudakis
Δλ=-300 mA
Δλ=0 mA
Δλ=300 mA
Δλ=-700 mA
WB
Δλ=700 mA

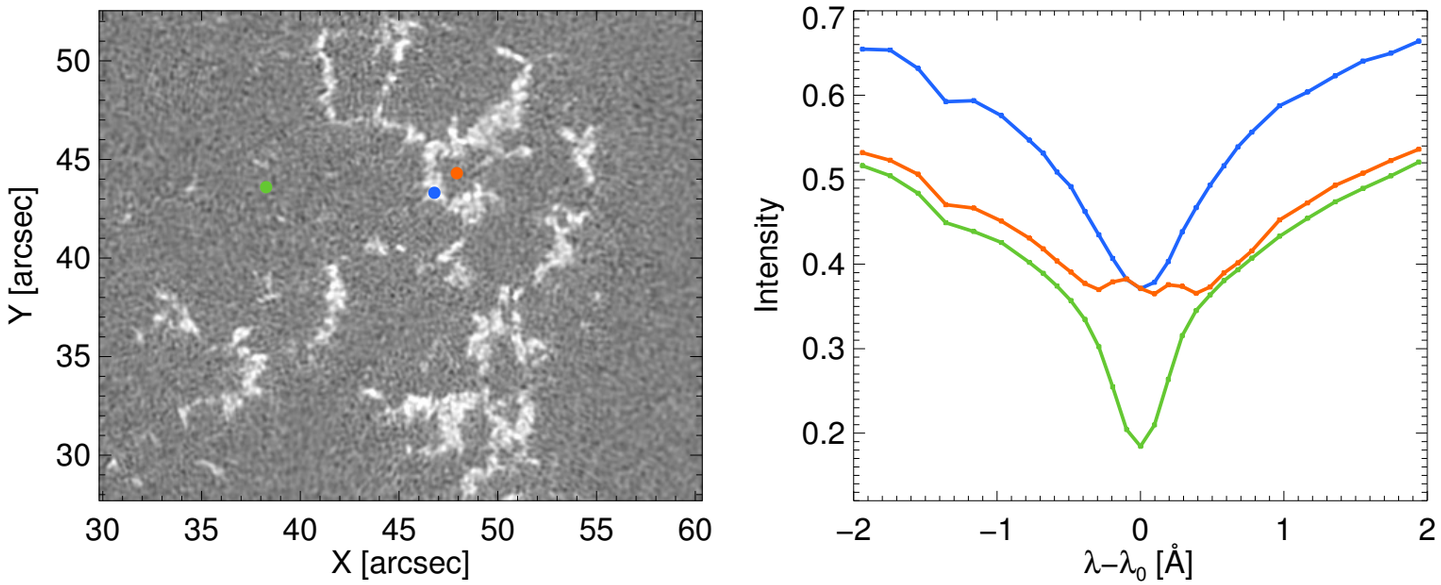
Ca II 854.2 nm





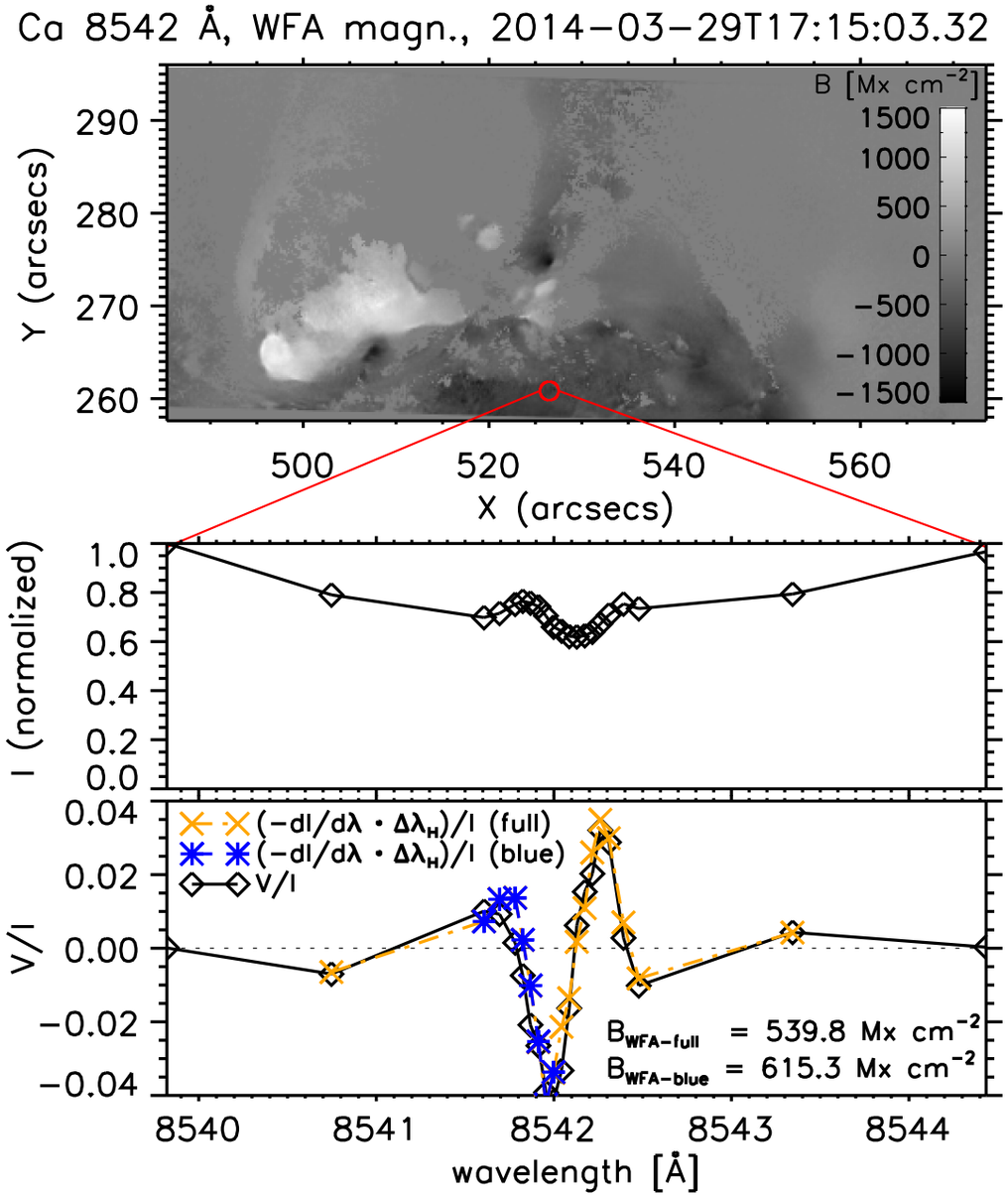
Kerr et al. (2016)

- 8542 is sensitive to the lower chromosphere.
- Limitations to discern between heating models (see Kerr et al. 2016).
- Greatly sensitive to temperature*.
- Not a very good velocity diagnostic in many applications



de la Cruz Rodriguez et al. (2013)

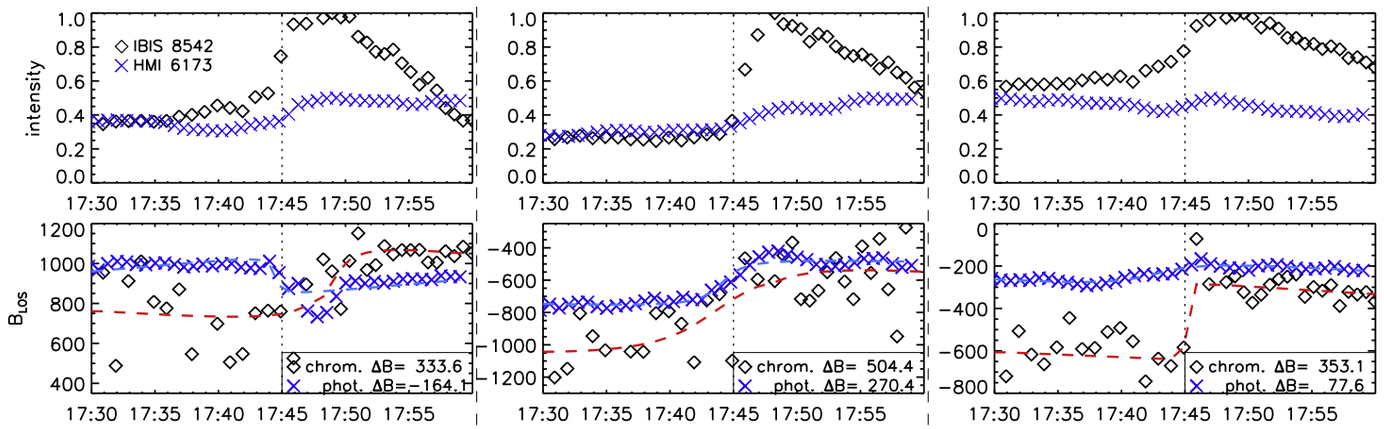
Ca II 854.2 nm



Kleint (2016)

- 8542 is usually in the weak field regime.
- Easy and fast estimation of B from obs.

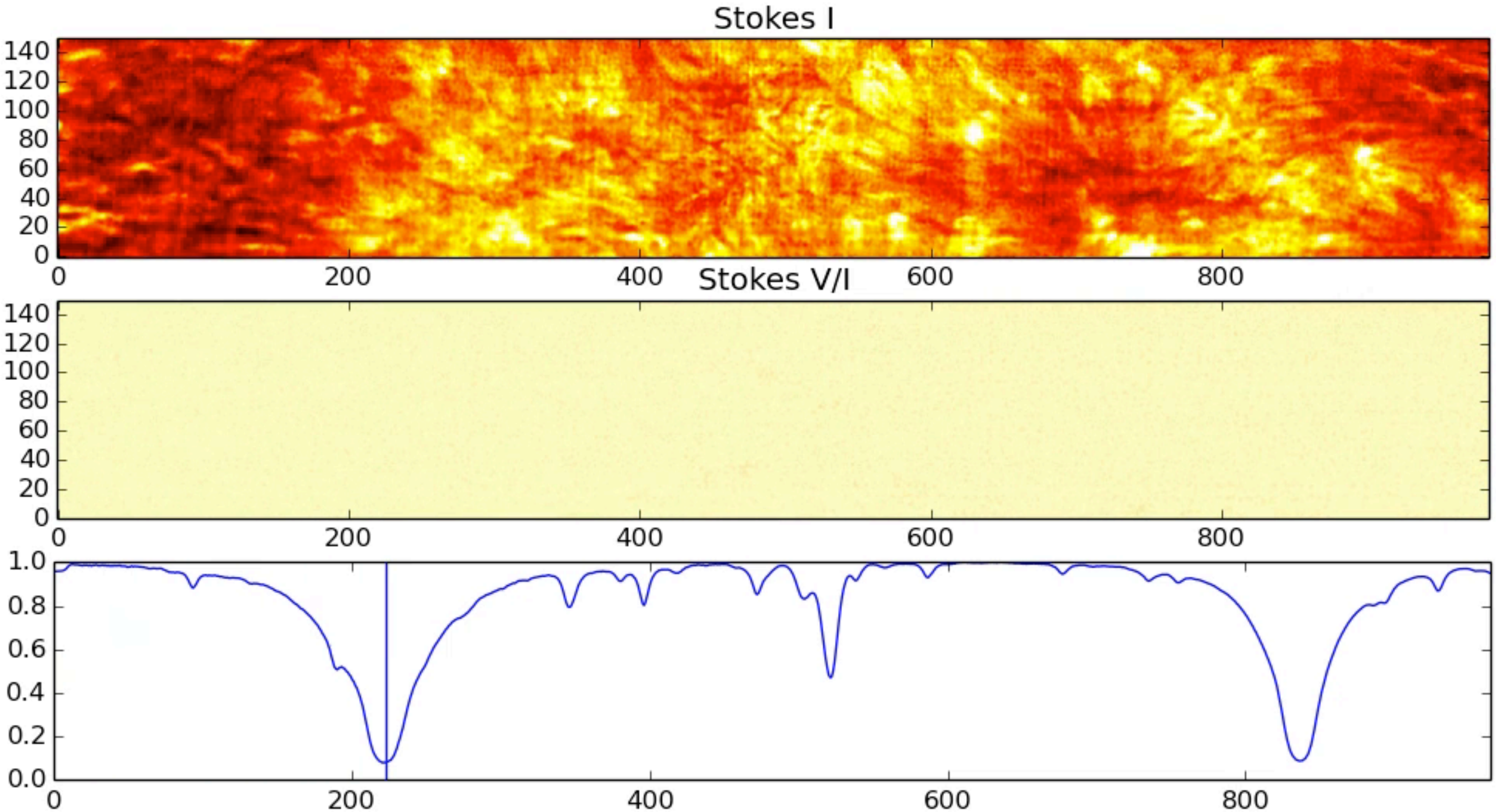
$$V(\lambda) = -CB_{\mathrm{l.o.s}} \frac{\partial I(\lambda)}{\partial \lambda}$$



Kleint (2016)

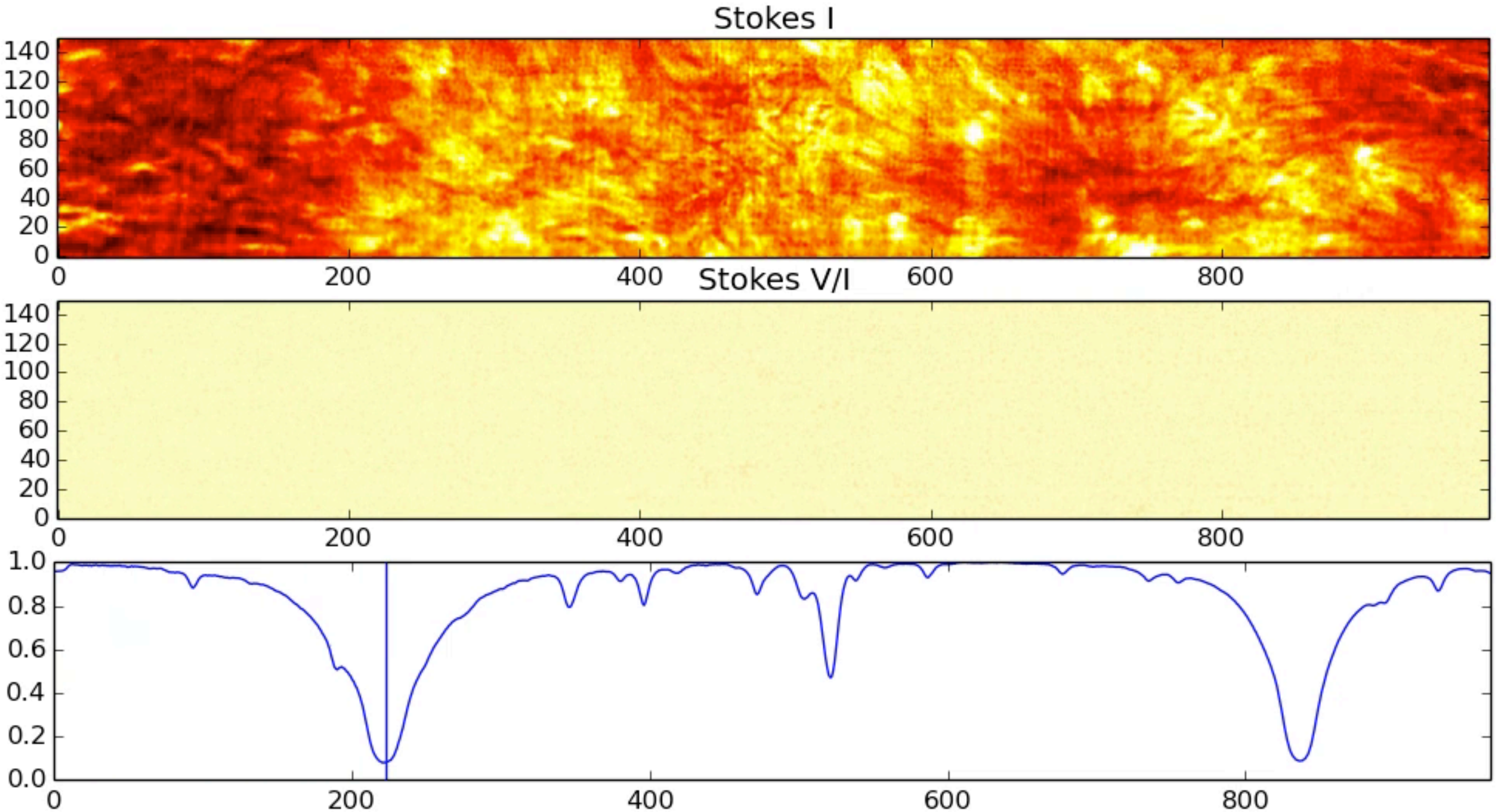
Na I D_1 & D_2

Na I D_1 & D_2



SST/Trippel observation, courtesy of I. Milic & M. Van Noort

Na I D_1 & D_2



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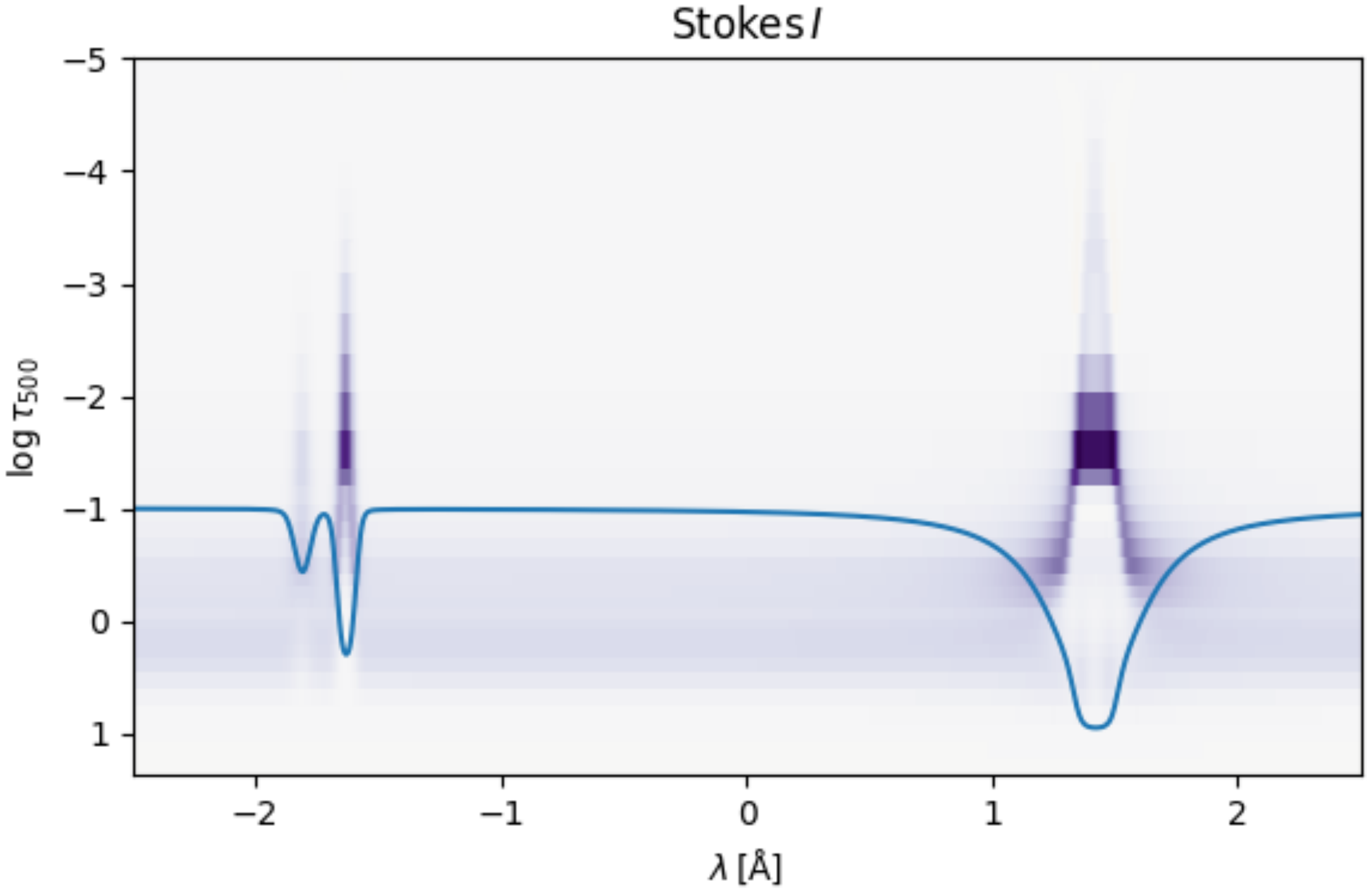
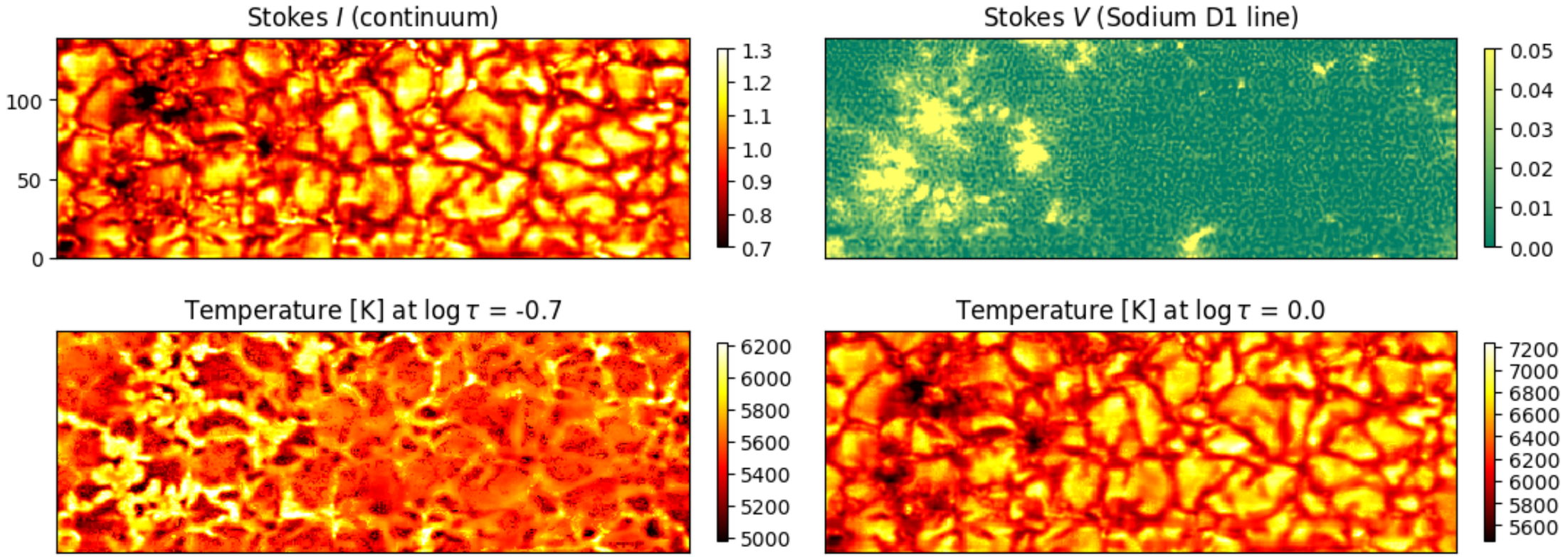


Our tests with traditional model atmosphere:
upper photosphere temperatures

Courtesy of I. Milic & M. Van Noort

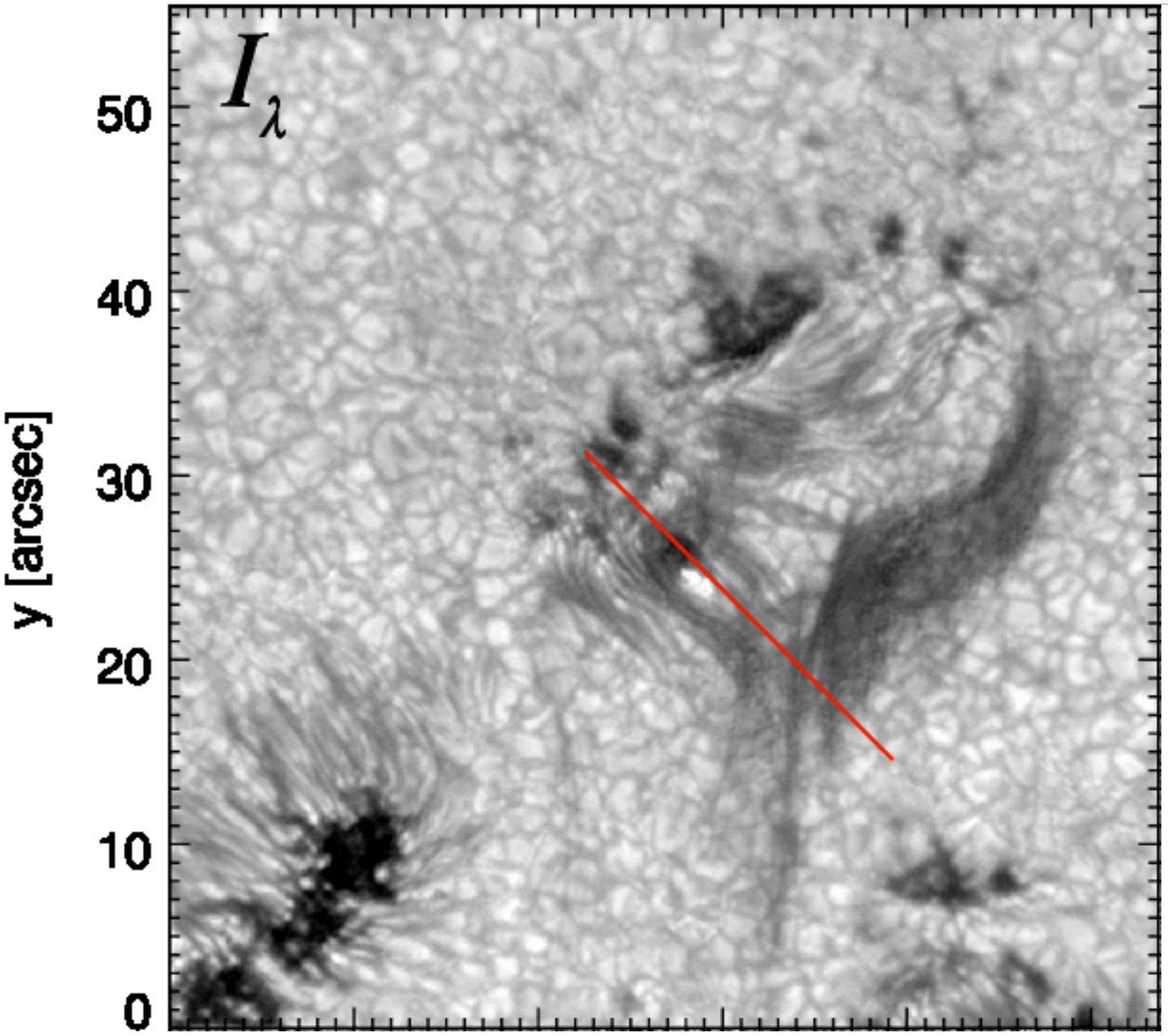
Na I D_1 & D_2



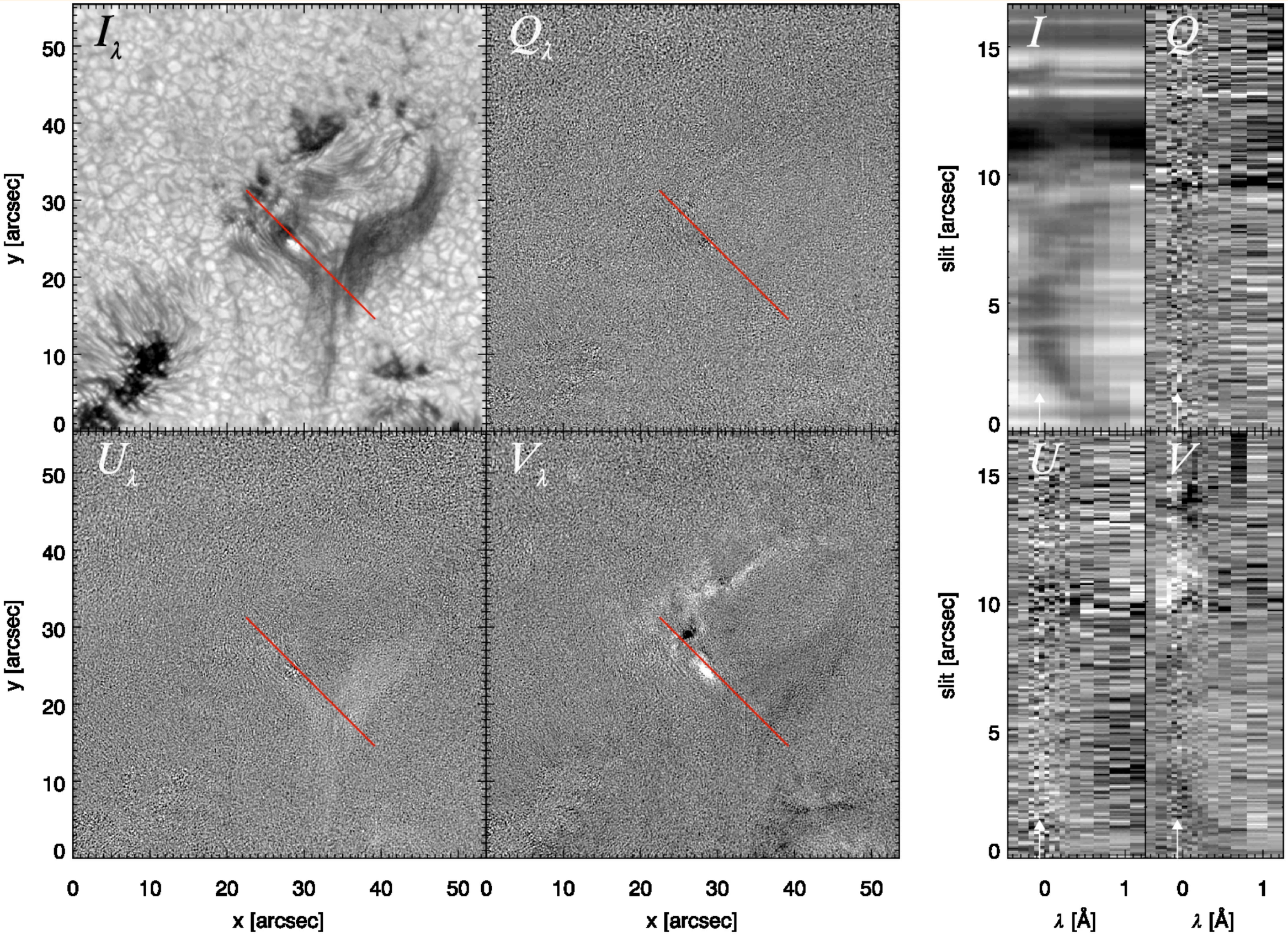
Courtesy of I. Milic & M. Van Noort

He I D_3

He I D_3

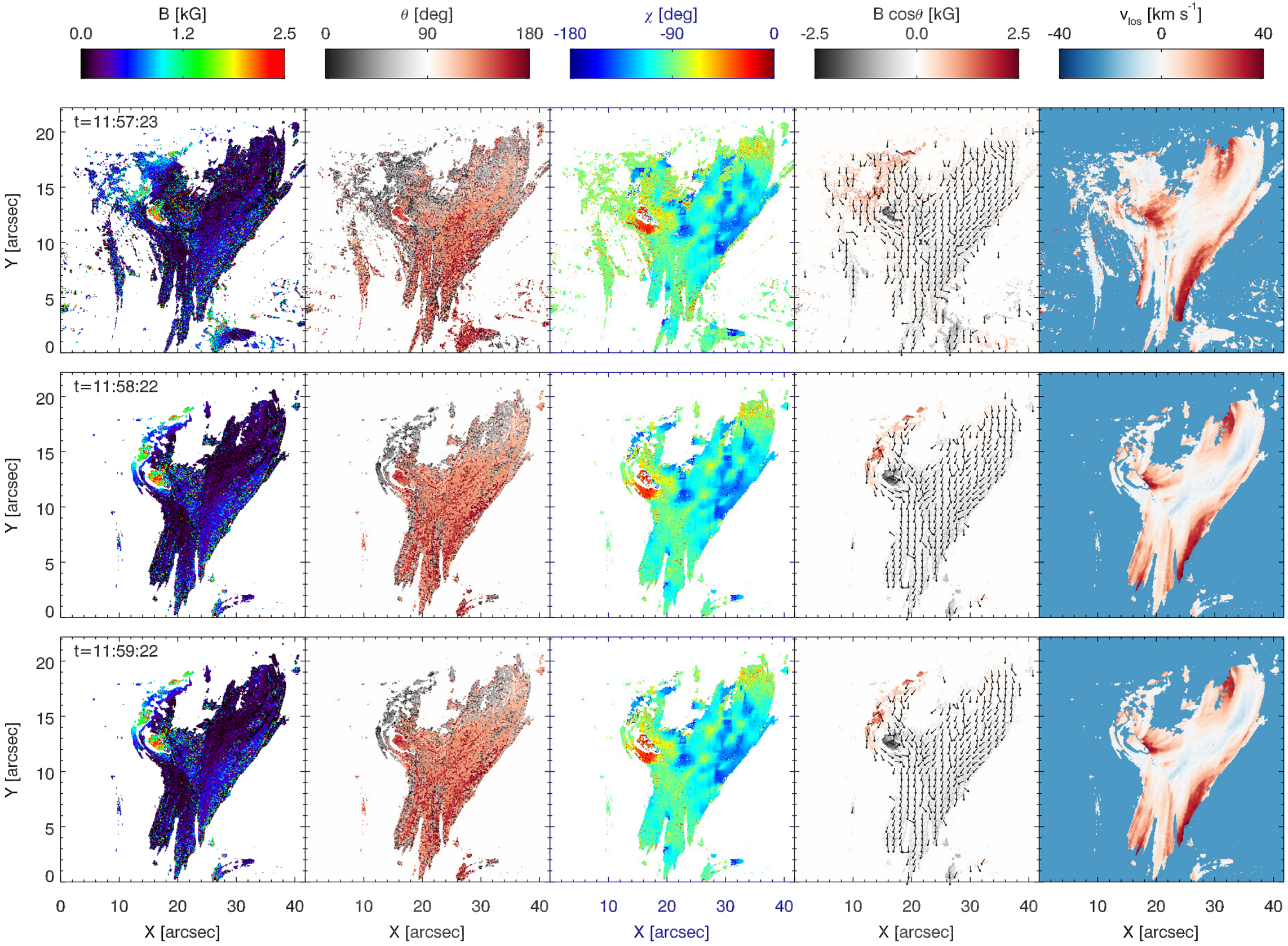


He I D_3



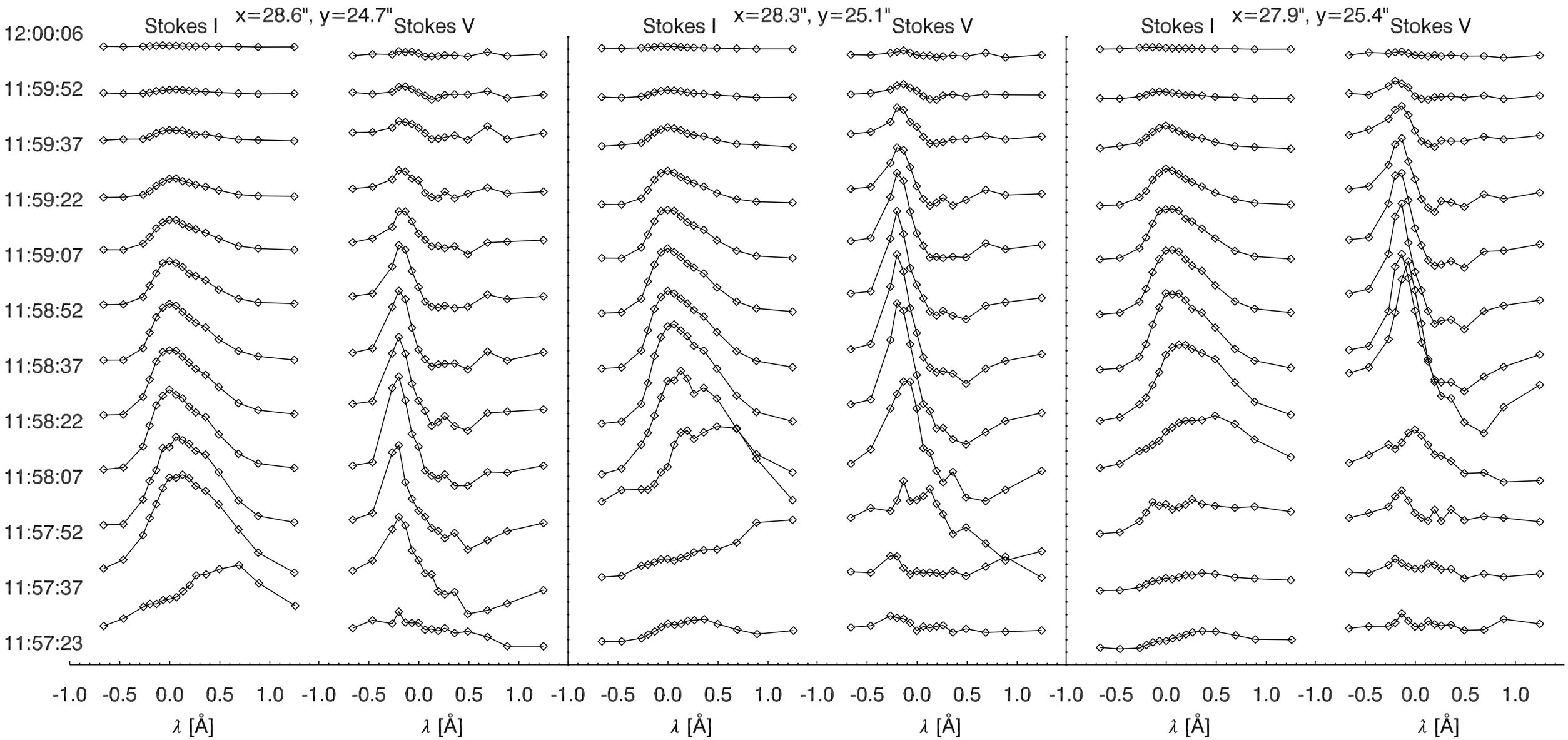
Courtesy of T. Libbrecht

He I D_3



Courtesy of T. Libbrecht

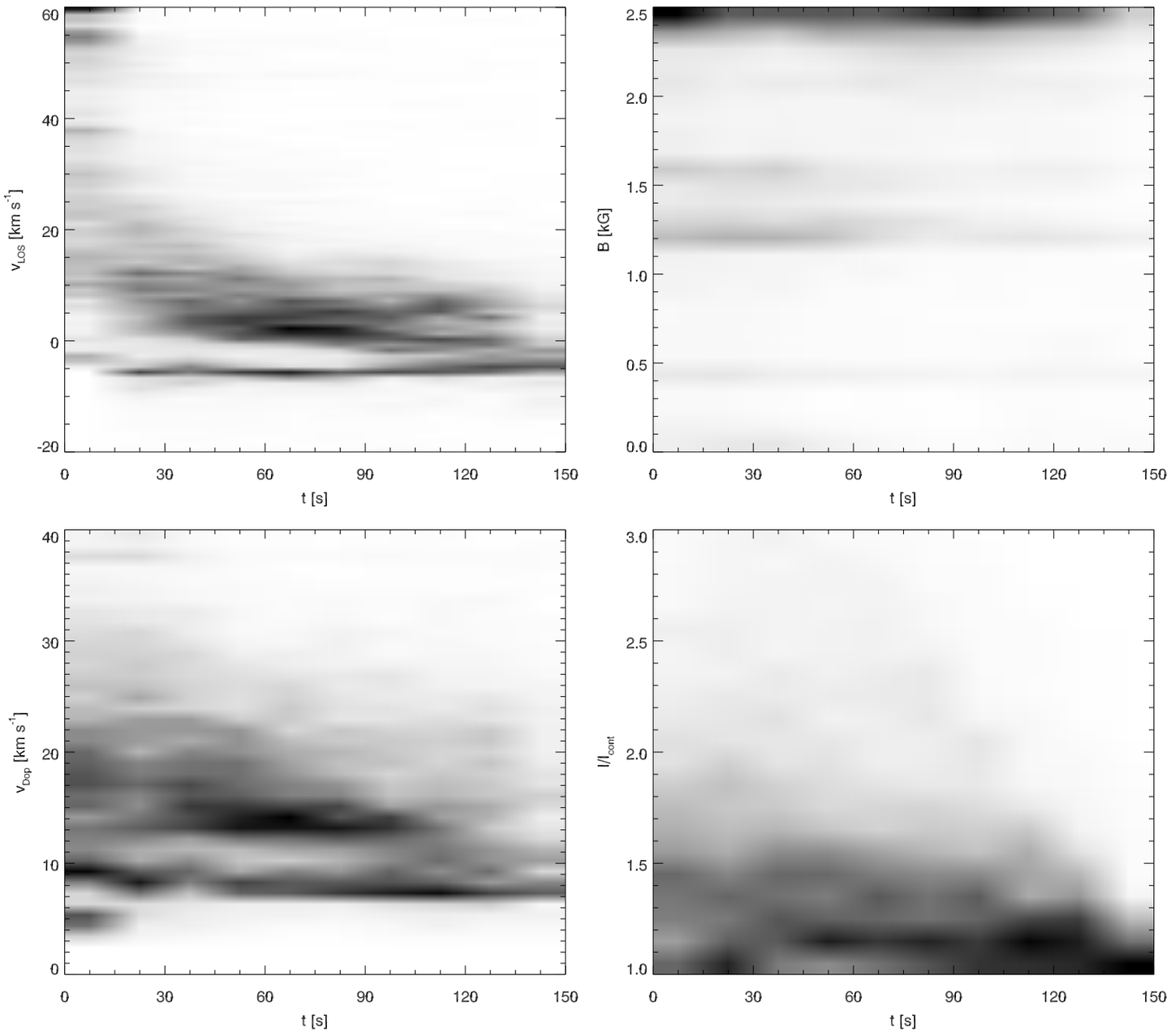
He I D_3



Excellent diagnostic to study chromospheric condensation

Courtesy of T. Libbrecht

He I D_3



Excellent diagnostic to study chromospheric condensation

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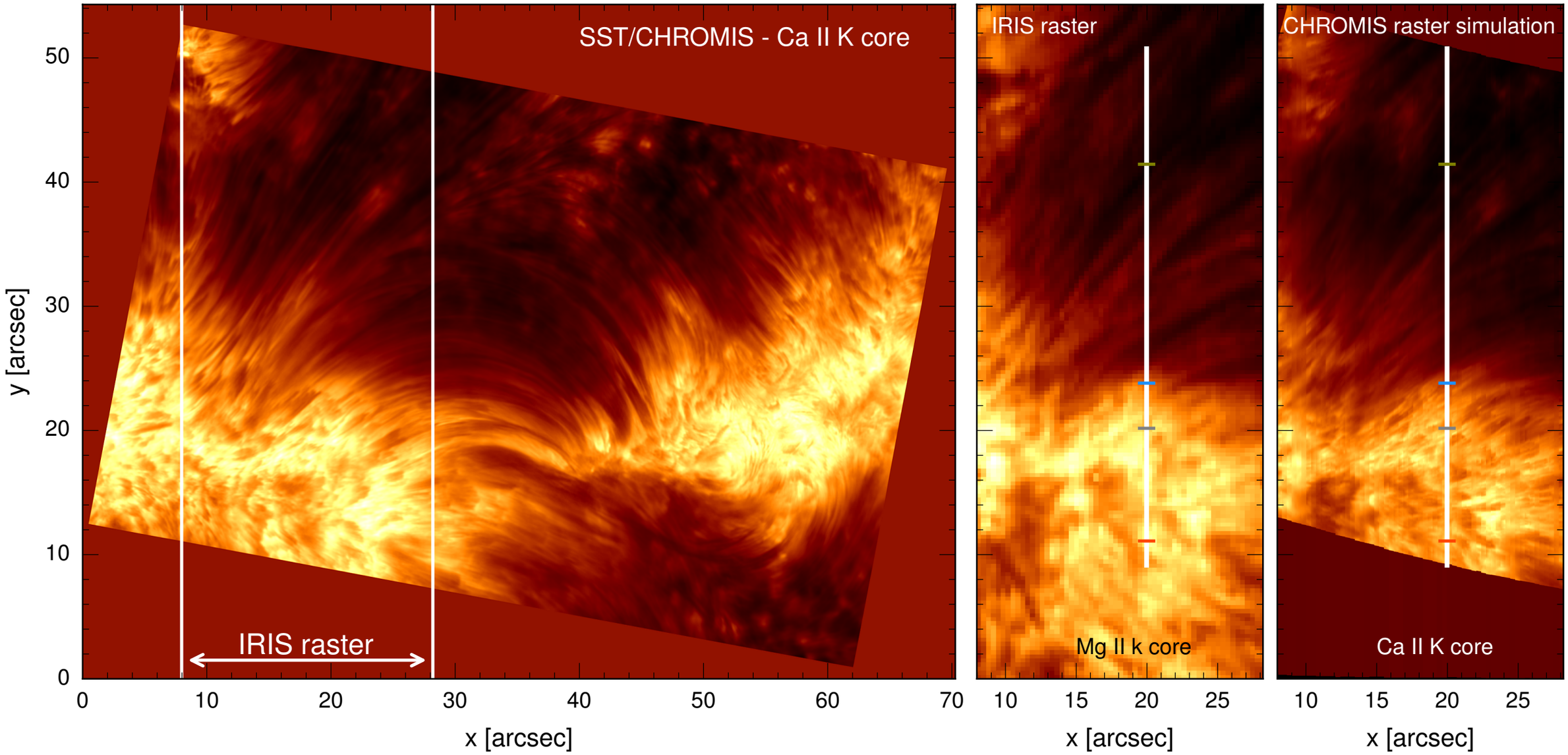
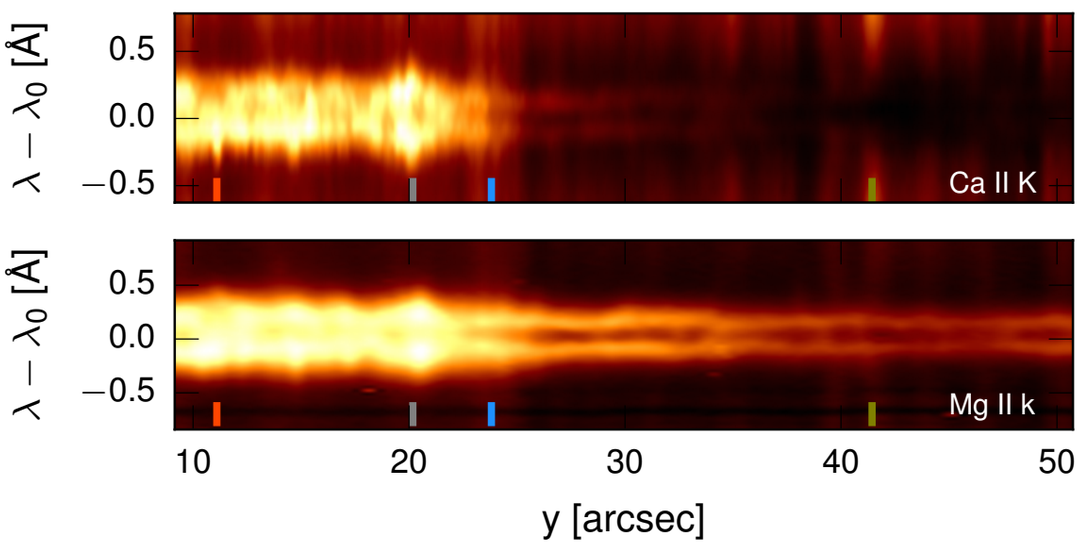
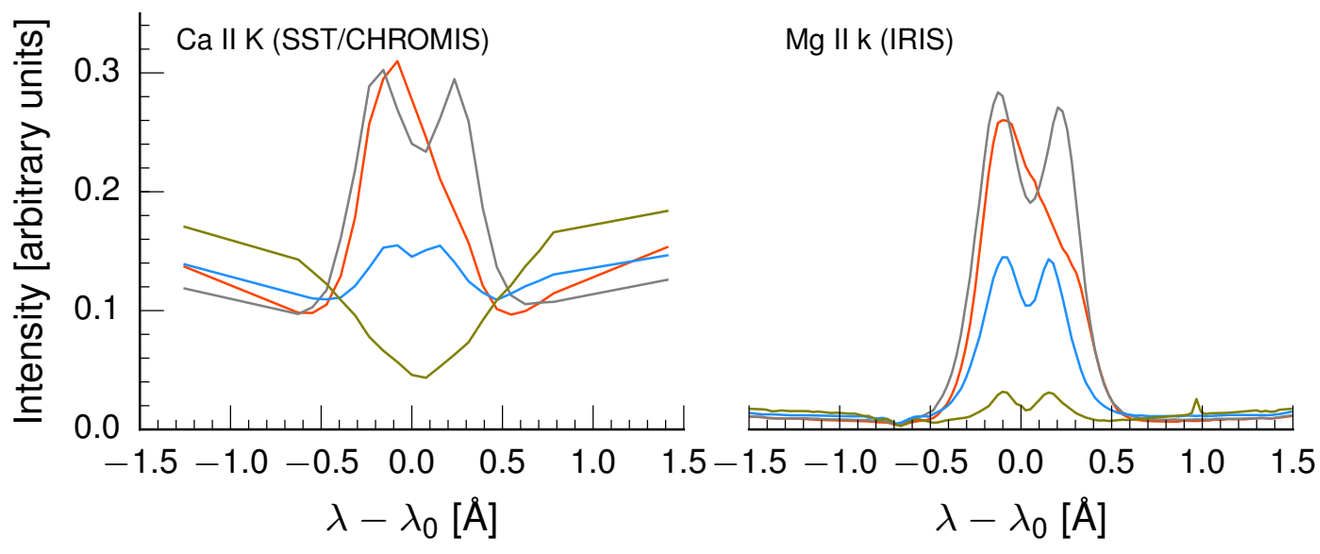
Ca II H & K

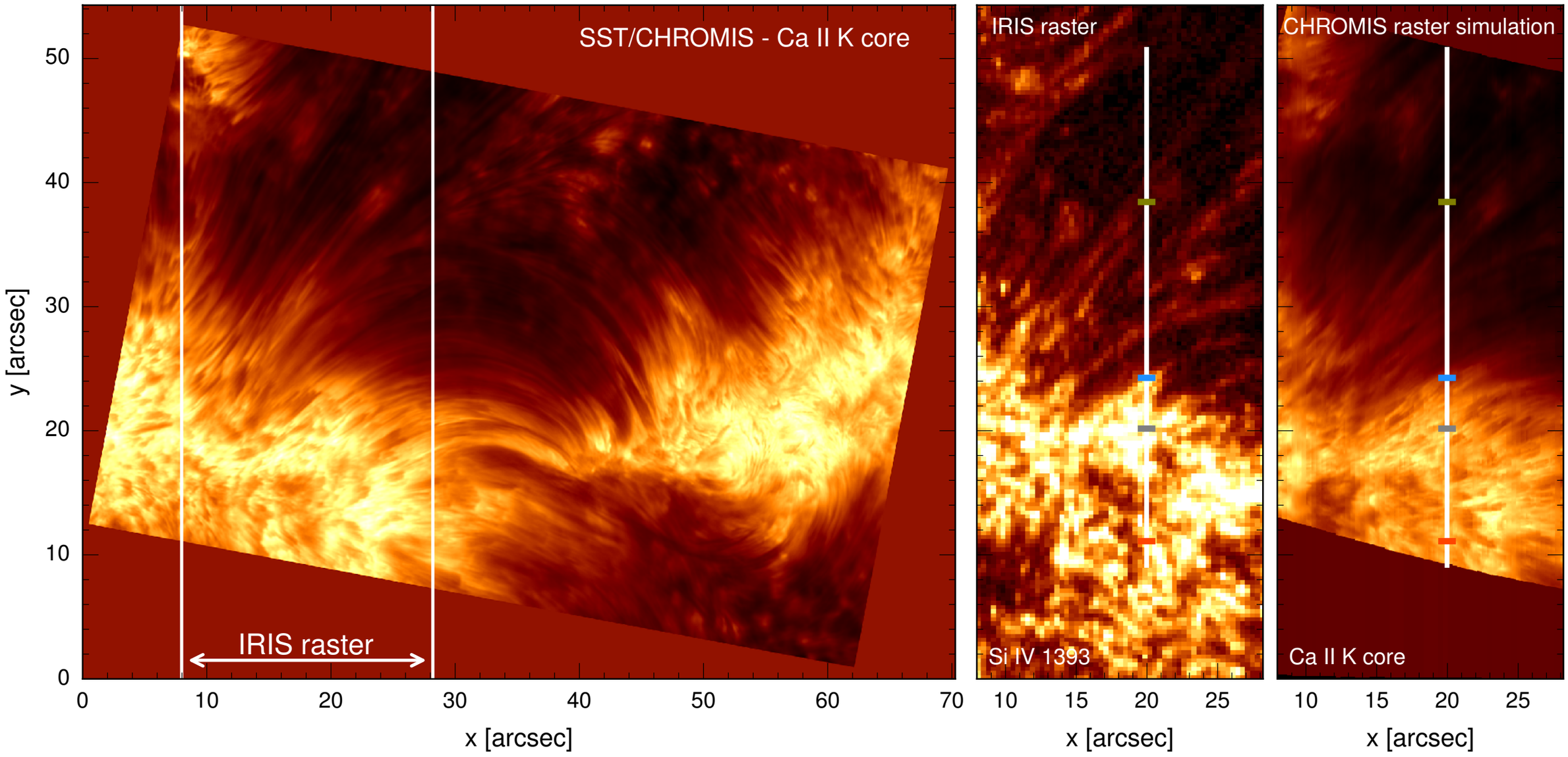
Ca II H & K

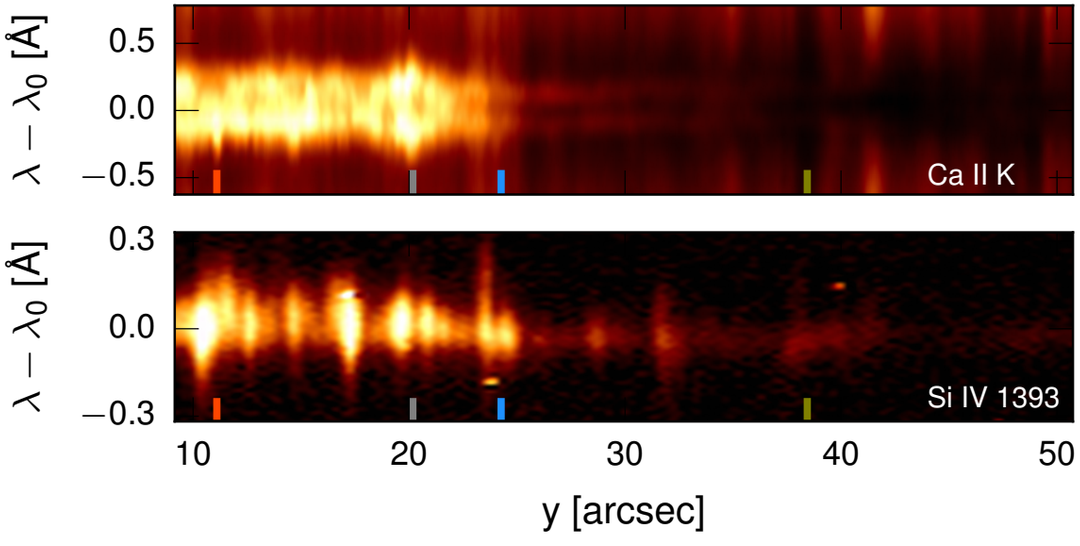

SST/CHROMIS - Ca II K core
IRIS raster
y [arcsec]
x [arcsec]
IRIS raster
CHROMIS raster simulation
Mg II k core
Ca II K core
x [arcsec]
x [arcsec]

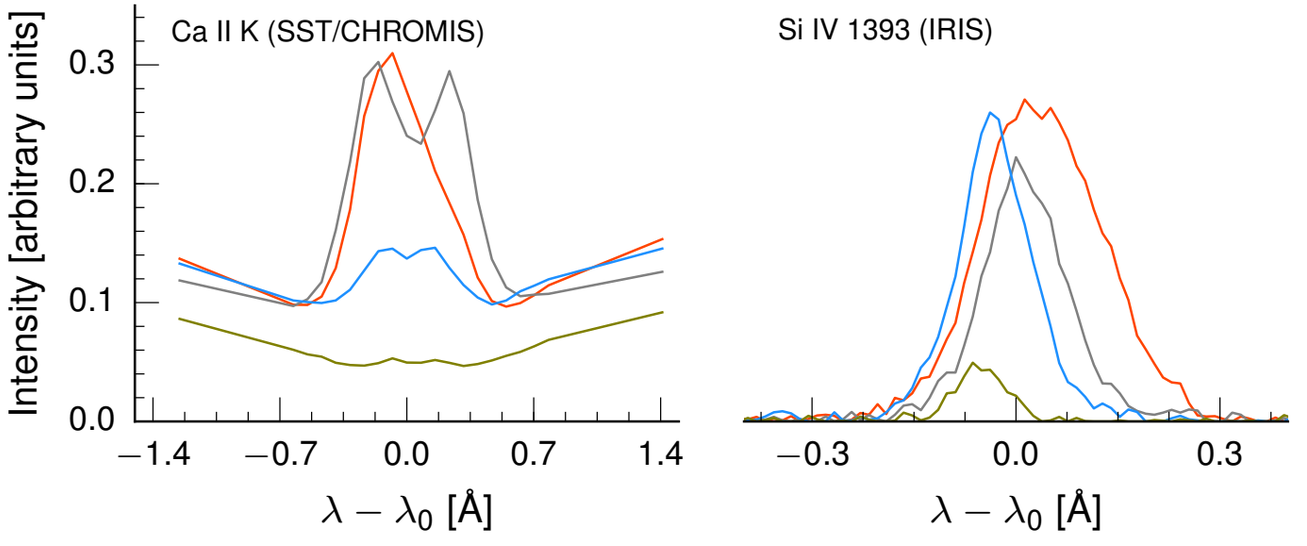

Ca II K
Mg II k
λ − λ0 [Å]
λ − λ0 [Å]
y [arcsec]


Ca II K (SST/CHROMIS)
Mg II k (IRIS)
Intensity [arbitrary units]
λ − λ0 [Å]
λ − λ0 [Å]

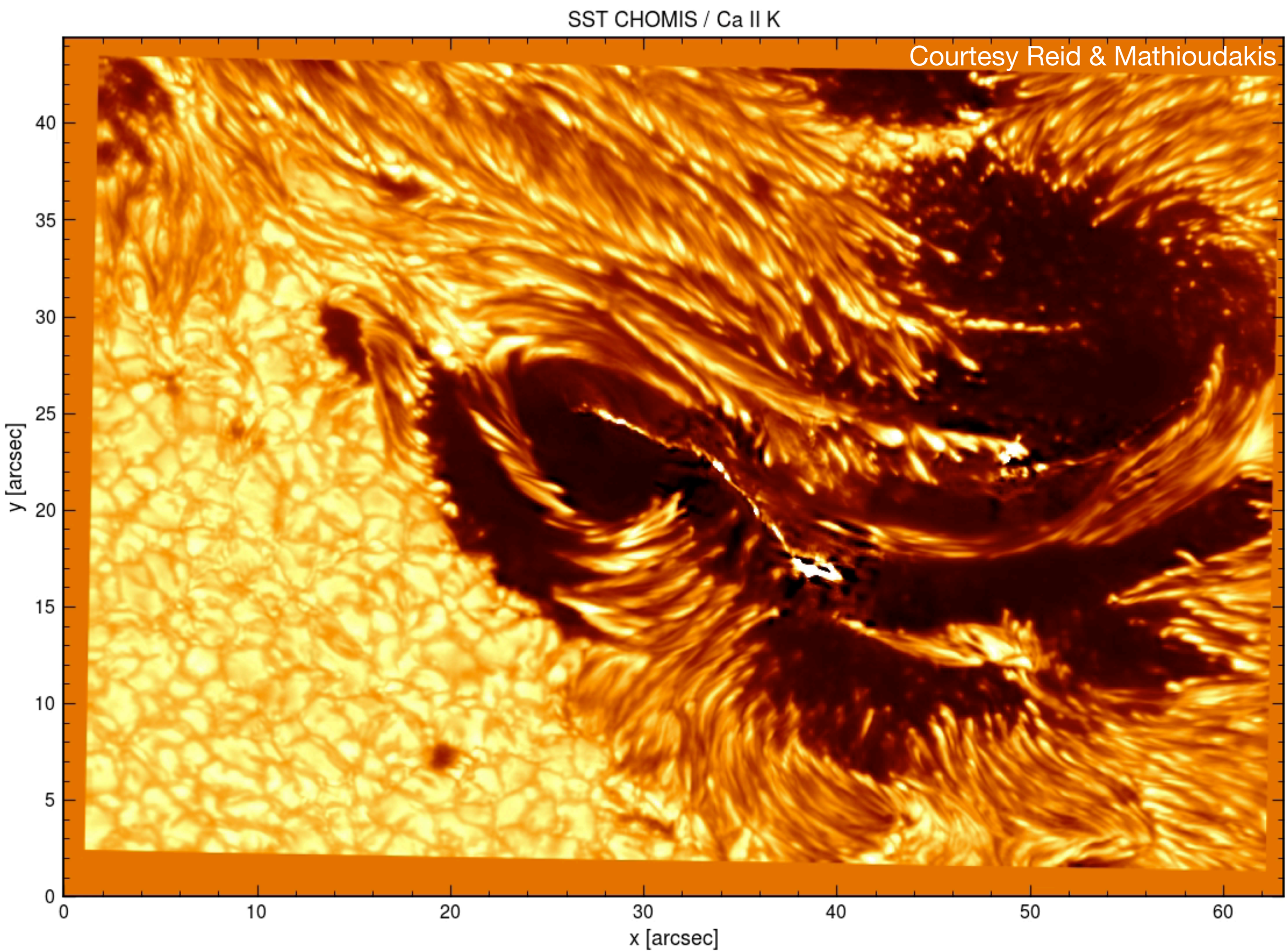
Ca II H & K


SST/CHROMIS - Ca II K core
IRIS raster
y [arcsec]
x [arcsec]
IRIS raster
Si IV 1393
CHROMIS raster simulation
Ca II K core

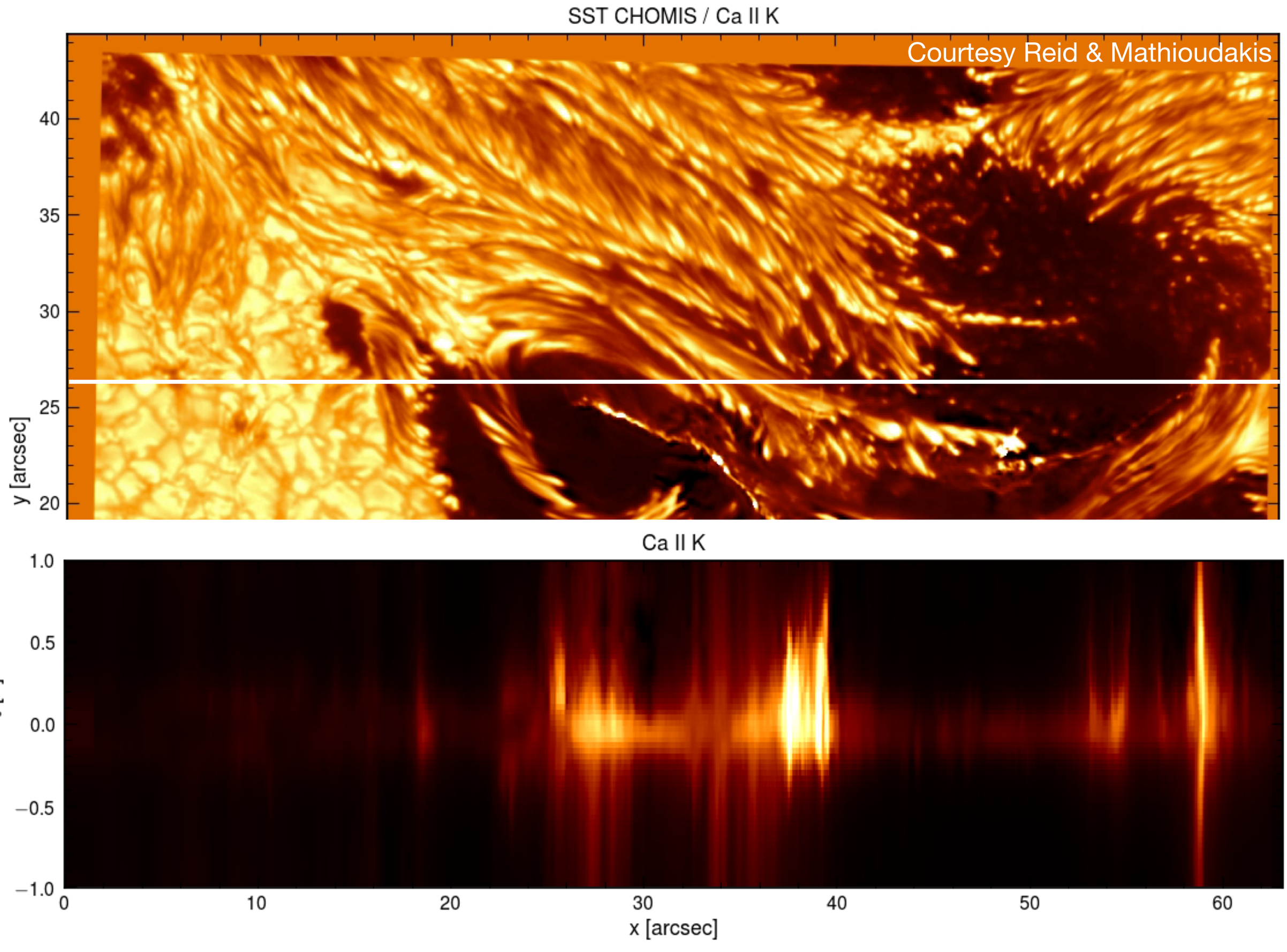

Ca II K
Si IV 1393
λ − λ0 [Å]
y [arcsec]


Ca II K (SST/CHROMIS)
Si IV 1393 (IRIS)
Intensity [arbitrary units]
λ − λ0 [Å]

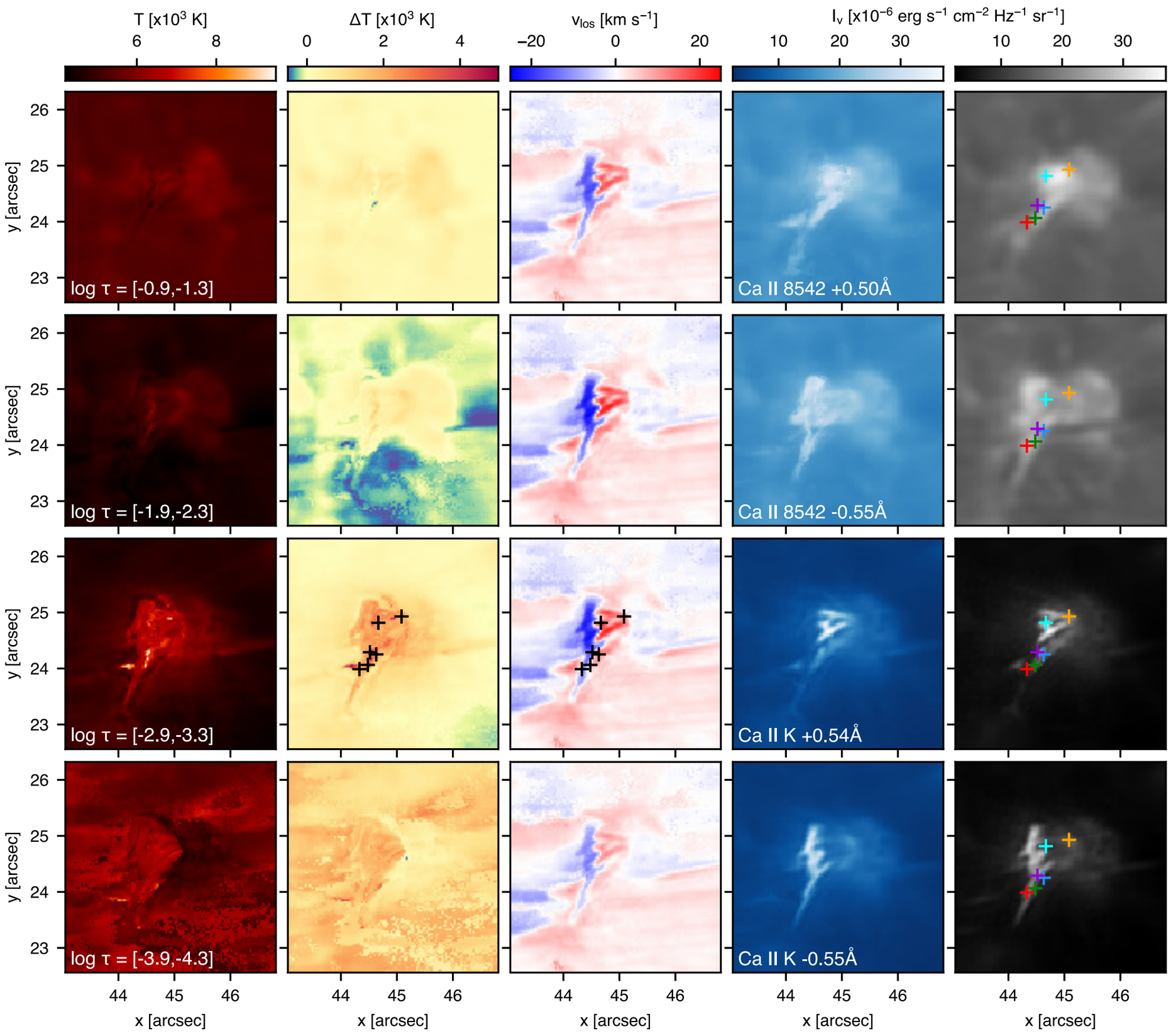
Ca II H & K


SST CHOMIS / Ca II K
Courtesy Reid & Mathioudakis
y [arcsec]
x [arcsec]
0
5
10
15
20
25
30
35
40
0
10
20
30
40
50
60

Ca II H & K


SST CHOMIS / Ca II K
Courtesy Reid & Mathioudakis
y [arcsec]
40
35
30
25
20
Ca II K
$\lambda - \lambda_0$ [Å]
1.0
0.5
0.0
−0.5
−1.0
0
10
20
30
40
50
60
x [arcsec]

Ca II H & K: EB and UV bursts



Vissers et al. in prep.

To take home

- There are very few lines that sample the upper chromosphere.
- From the ground we cannot observe all of them.
- But we can find combinations that cover most of the photosphere and chromosphere: Fe I lines + Mg I 5173 + Ca II 8542 + Ca II K + He I D3/10810.
- B in the upper chromosphere: He I lines!