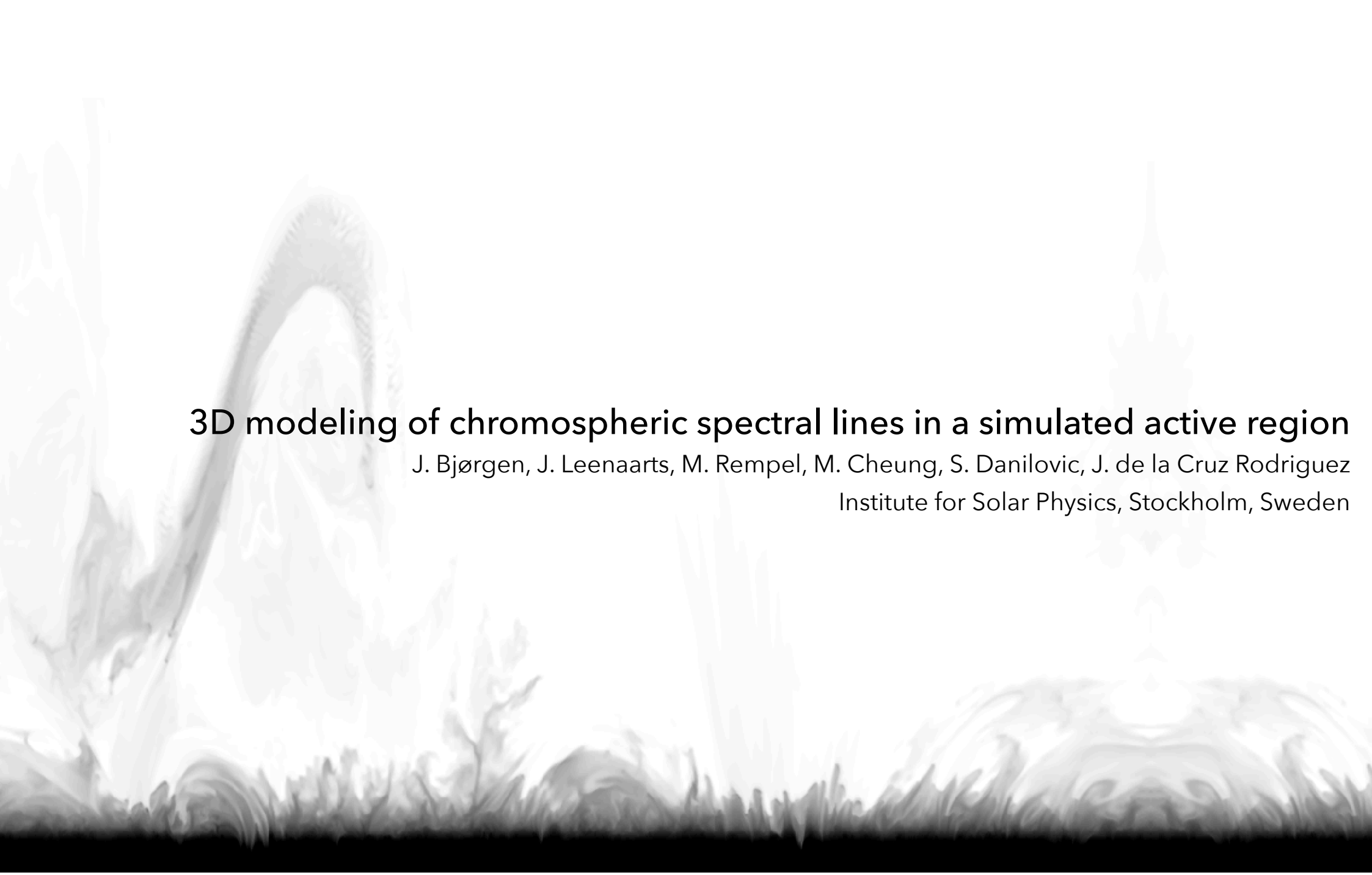

3D modeling of chromospheric spectral lines in a simulated active region

J. Bjørgen, J. Leenaarts, M. Rempel, M. Cheung, S. Danilovic, J. de la Cruz Rodriguez

Institute for Solar Physics, Stockholm, Sweden

IRIS-9, Göttingen, 25-29 June 2018

Contributed Talk

2. Chromospheric heating and dynamics

Three-dimensional modeling of chromospheric spectral lines in a simulated active region

J. P. Bjørgen[1], J. Leenaarts[1], M. Rempel[2], M. C. M. Cheung[3], and S. Danilovic[1]

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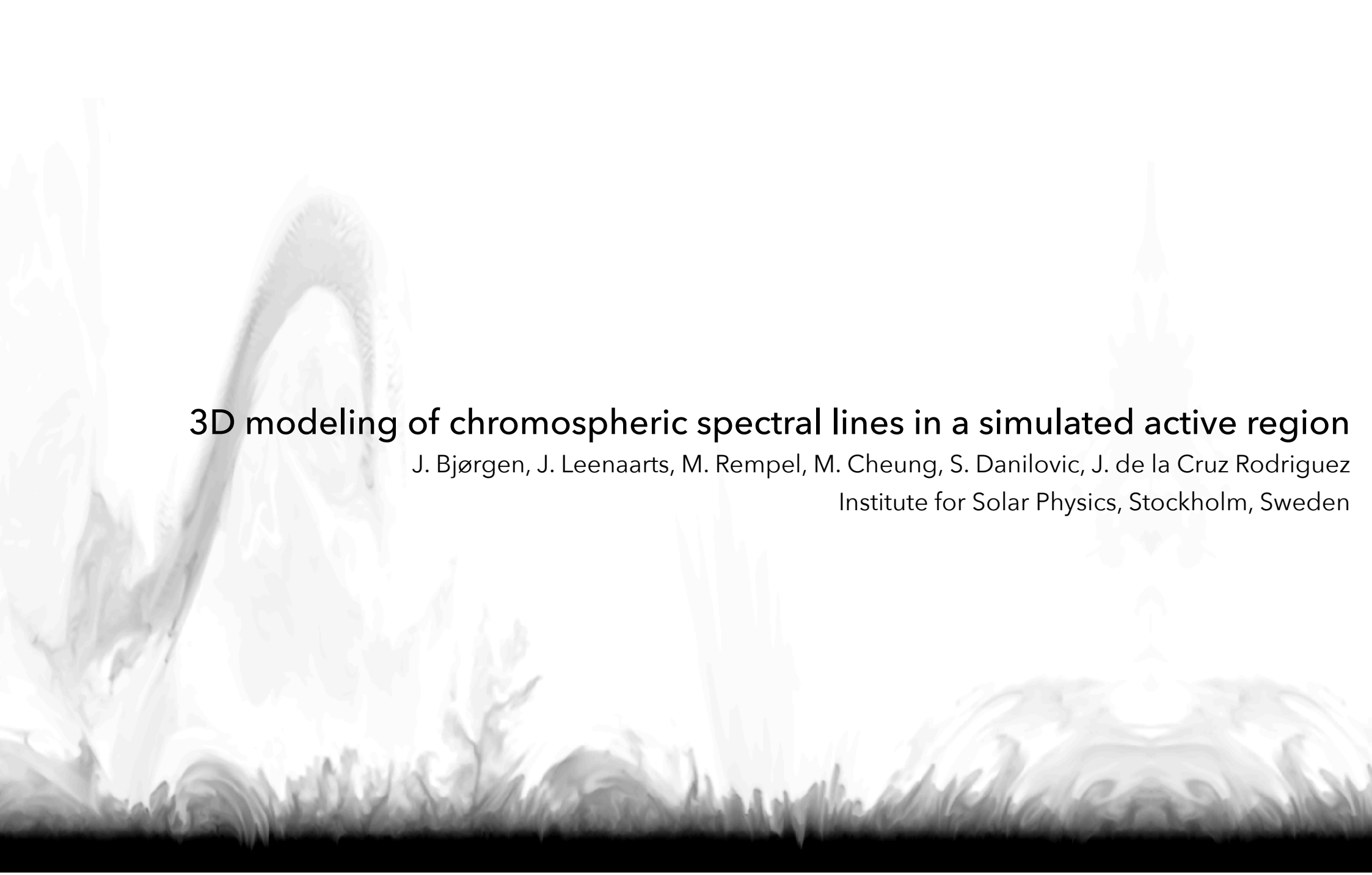
[3] *Lockheed Martin Solar and Astrophysics Laboratory, USA*

Recently, the 3D MHD code Muram was extended to include the corona (Rempel, 2017). A simulation was run that included an active region containing sunspots and a solar flare. We present for the first time 3D non-LTE radiative transfer calculations from this active region simulation.

We synthesized Ca II H&K/8542 Å, Mg II h&k, and Hα using the Multi3D code, where we included horizontal radiative transfer (3D effects). For hydrogen, we solved the charge conservation equation and statistical equilibrium simultaneously to obtain NLTE electron densities. For Ca II and Mg II we included partially-coherent scattering of photons (PRD effects).

This simulation reproduces long fibrils that span the active regions and shows structures in Hα that look like flare ribbons. We compare our results to high resolution observations.



3D modeling of chromospheric spectral lines in a simulated active region

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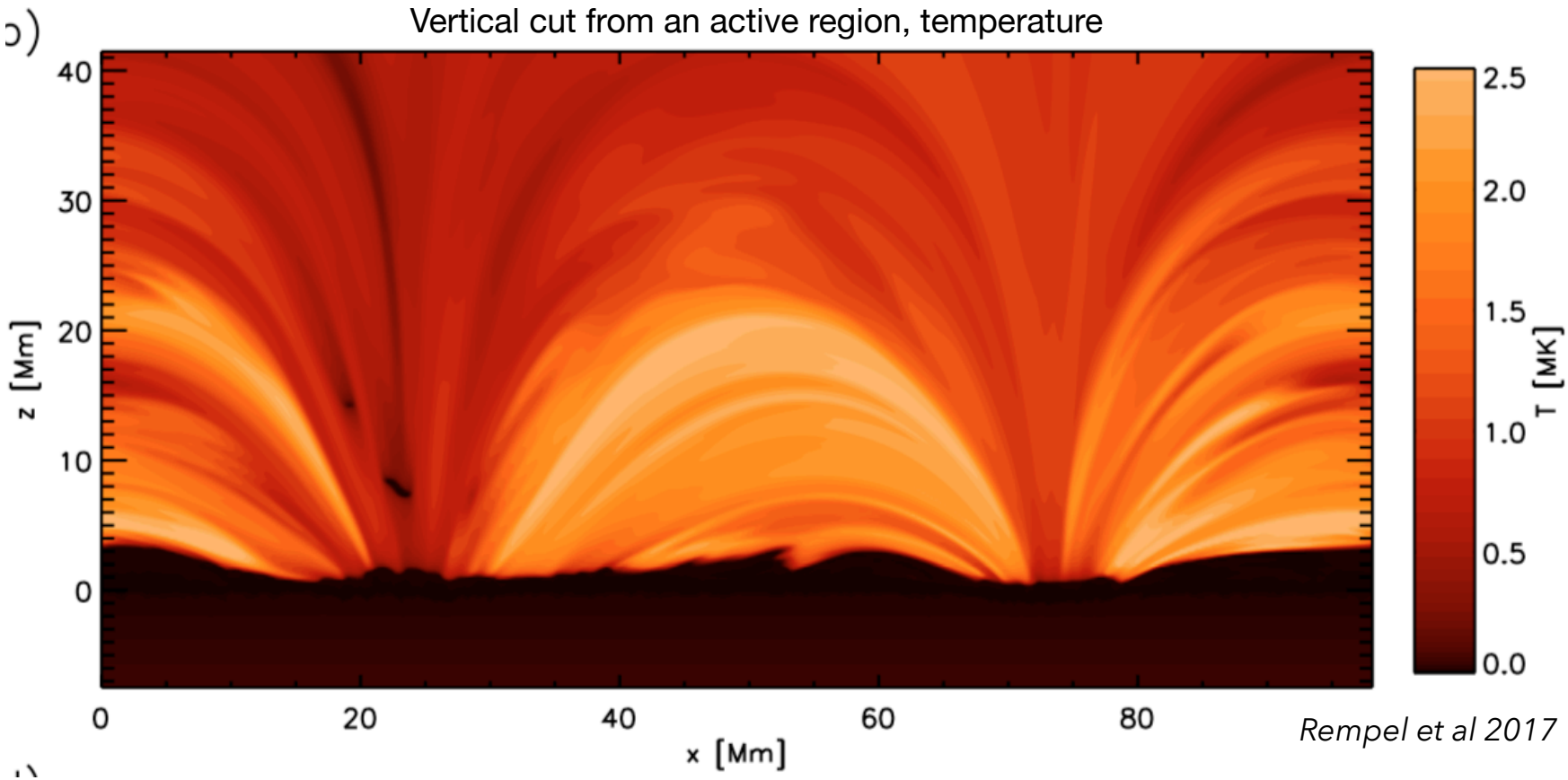
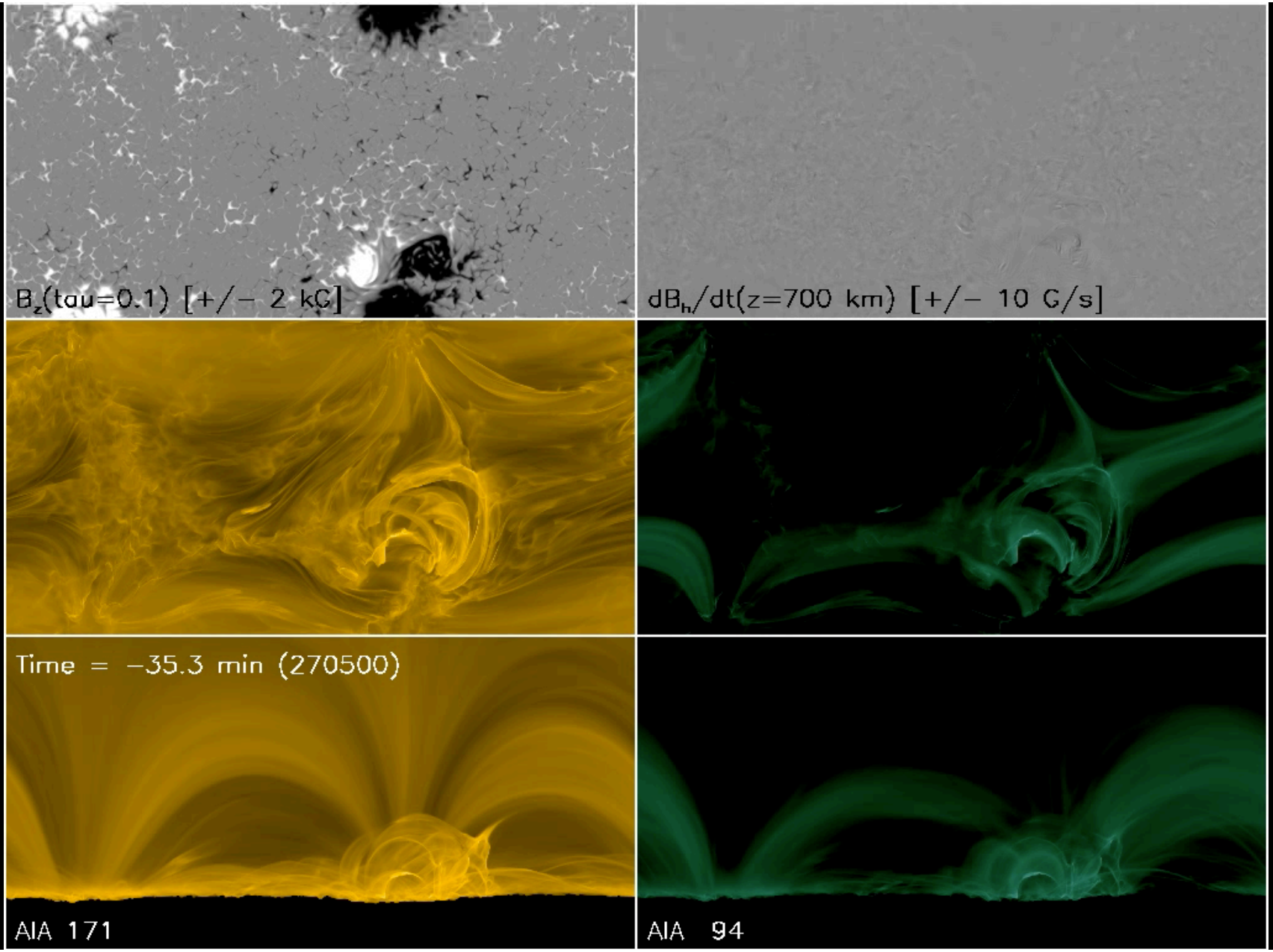
MuRam: Chromosphere/corona



Rempel et al 2017

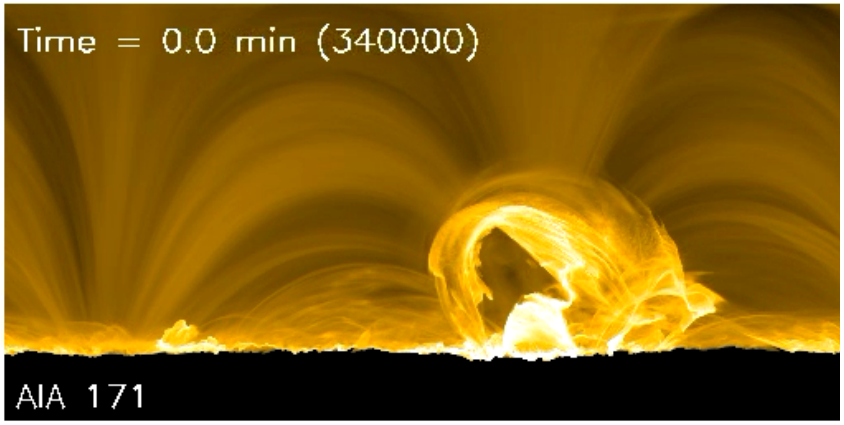
Simplifications:

- The chromosphere is treated in LTE + equilibrium ionization equation of state
- «Boris Correction»: reduced speed of light.



Courtesy from M. Rempel

MuRam: Simulation of a Solar Flare



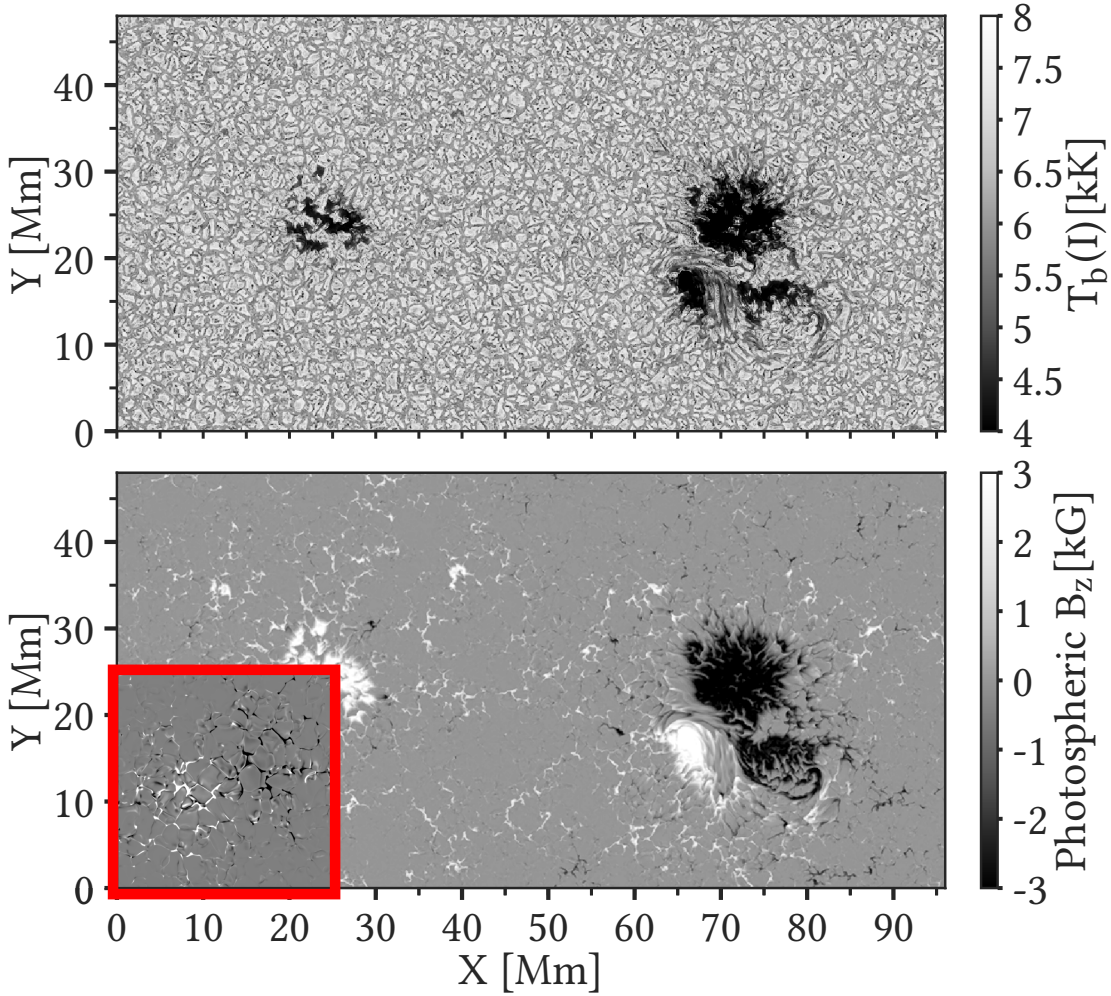
Model atmosphere:

$$1024 \times 512 \times 1536$$

$$98\ \text{Mm} \times 49\ \text{Mm} \times 49\ \text{Mm}$$

$$\Delta x, y = 96\ \text{km}$$

$$\Delta z = 32\ \text{km}$$



Public snapshot from Bifrost; *Carlsson et al (2016)*

Multi3D: non-LTE radiative transfer

- Multilevel Accelerated Lambda Iteration
- Short-charaterstic solver
- Charge conservation: non-LTE n_e
- CRD/PRD *Sukhorukov & Leenaarts (2017)*

Model input:

$T_{\rm gas}, \rho, \vec{v}$

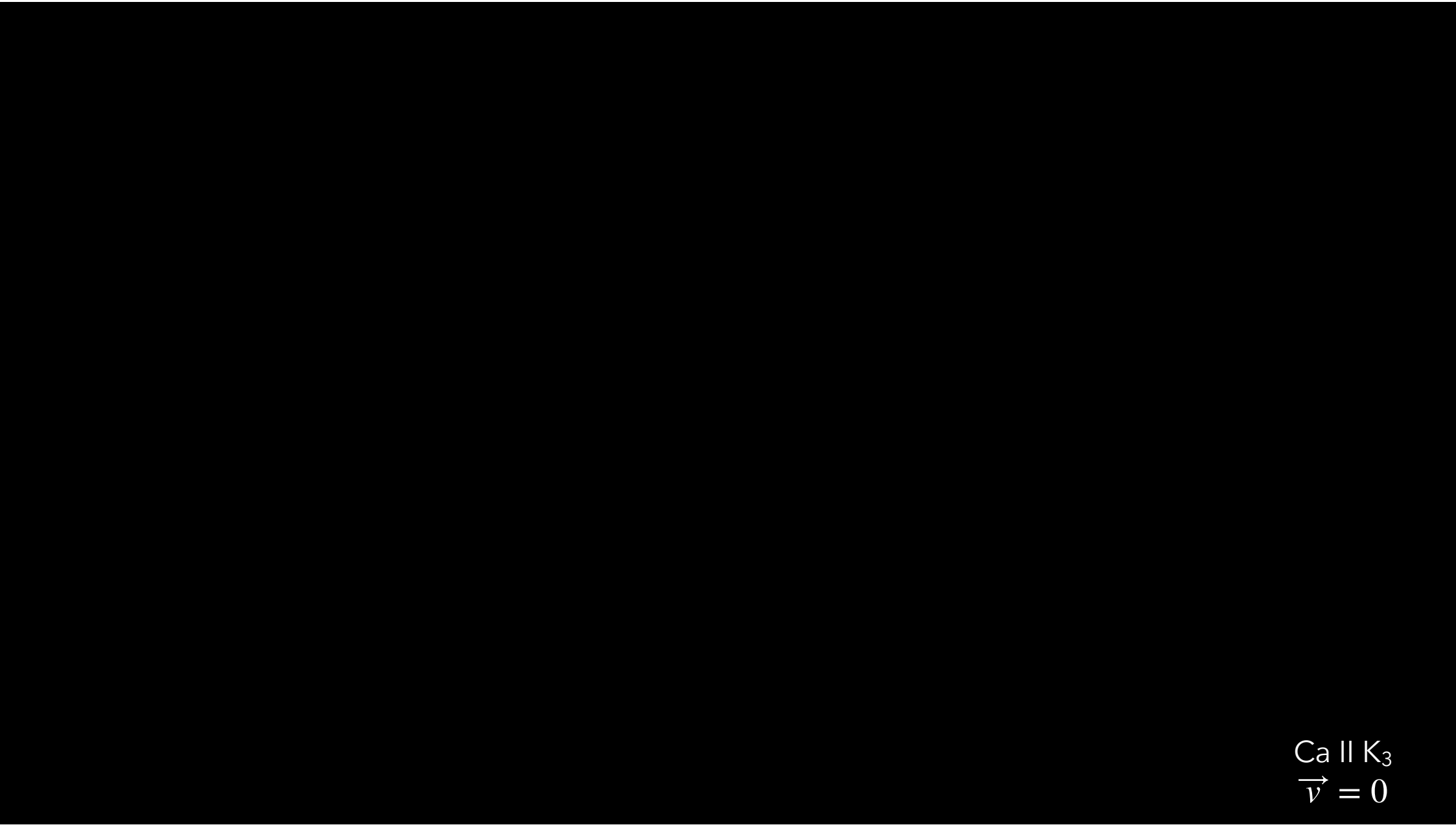
Model atoms:

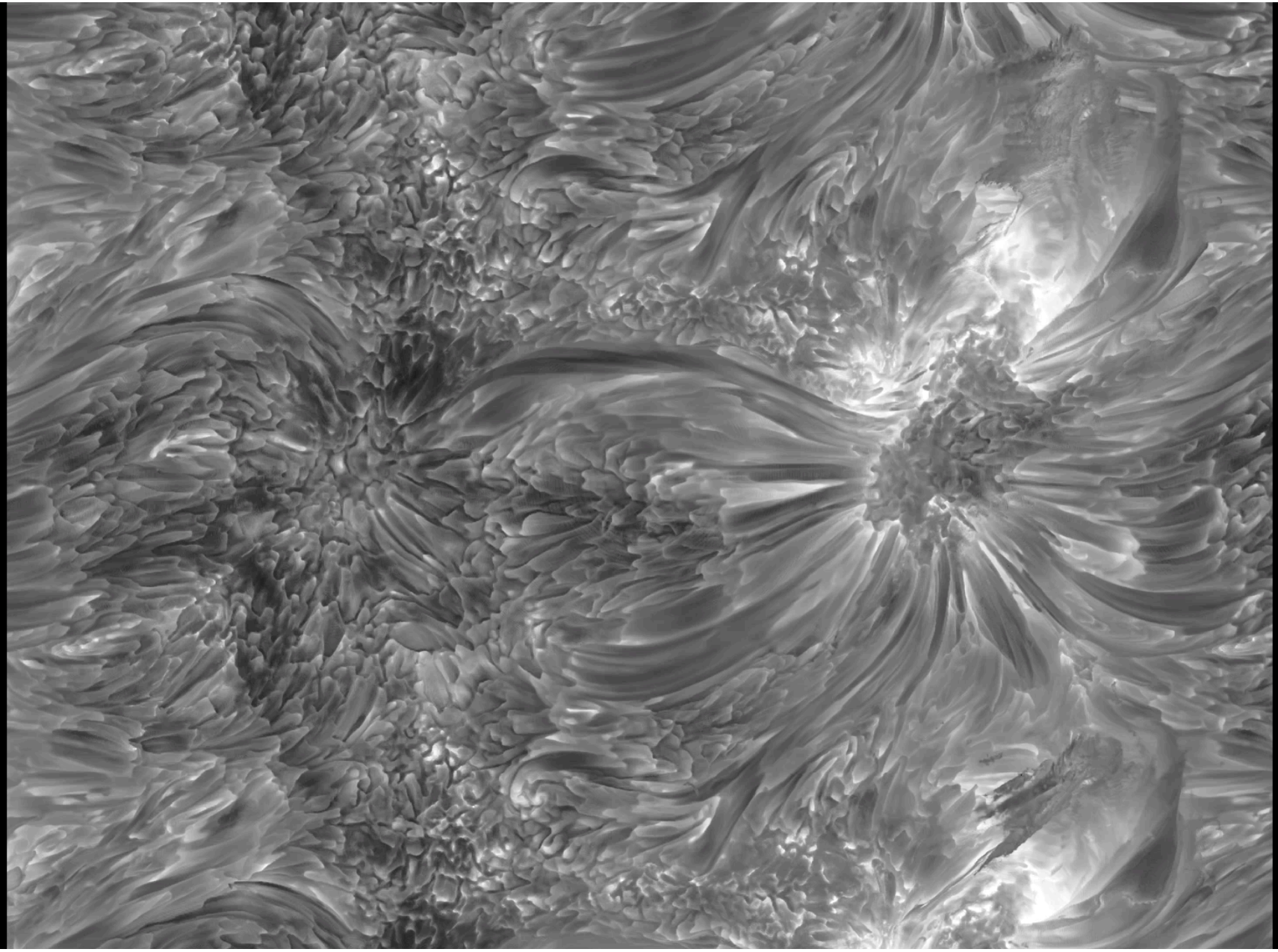
H / Ca / Mg

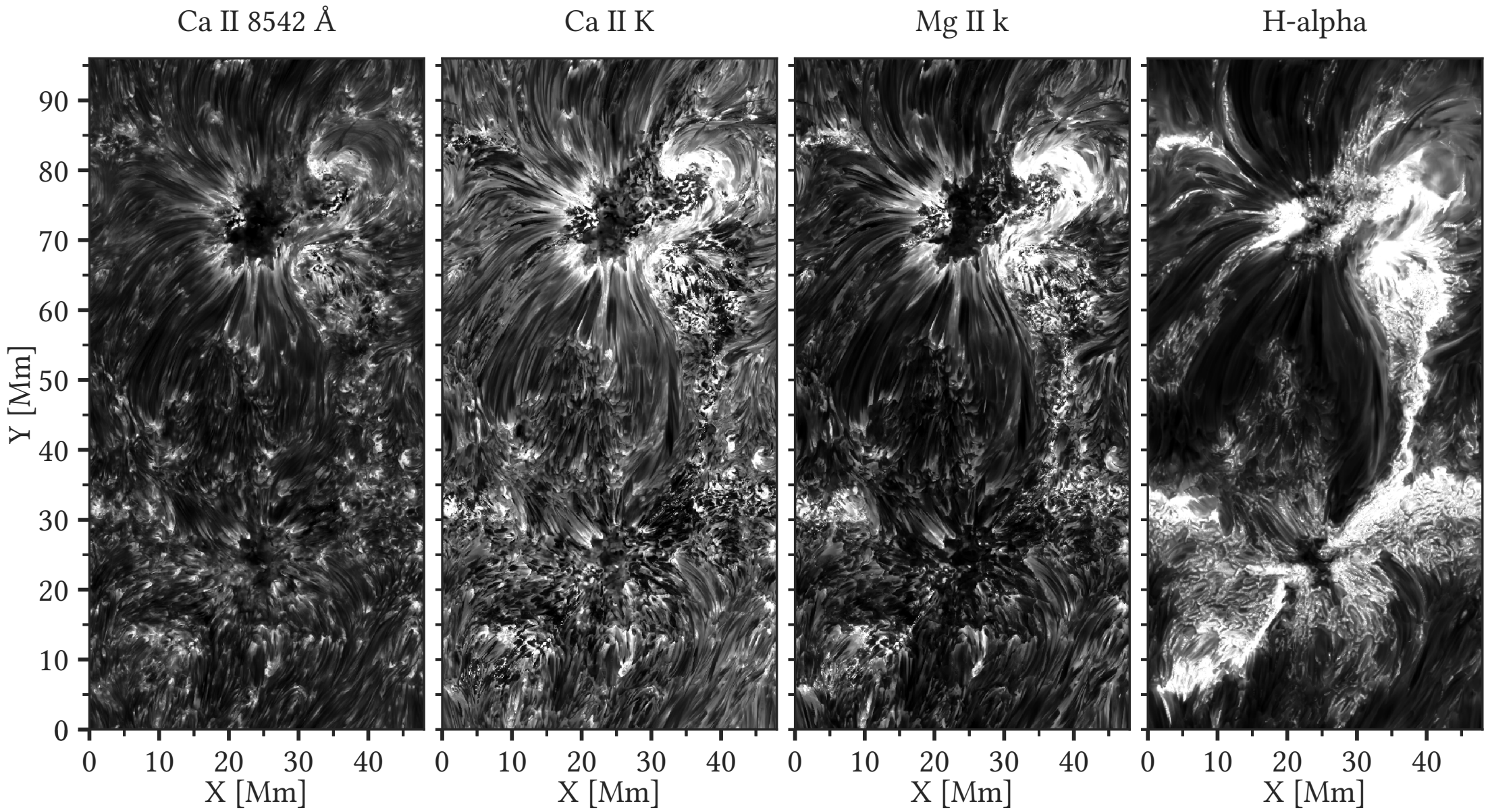
Statistical equilibrium	Particle conservation	Charge conservation
$n_i \sum_{i,i\neq j} P_{ij} - \sum_{j,i\neq j} n_j P_{ji} = 0$	$n_{\rm tot} = \sum_i n_i$	$n_e = n_p + \sum_k^{\rm metals} \alpha_k \sum_{j=1}^{\rm ion} j f_{jk}$

Newton–Raphson method: $\mathbf{J}\delta x = -F$

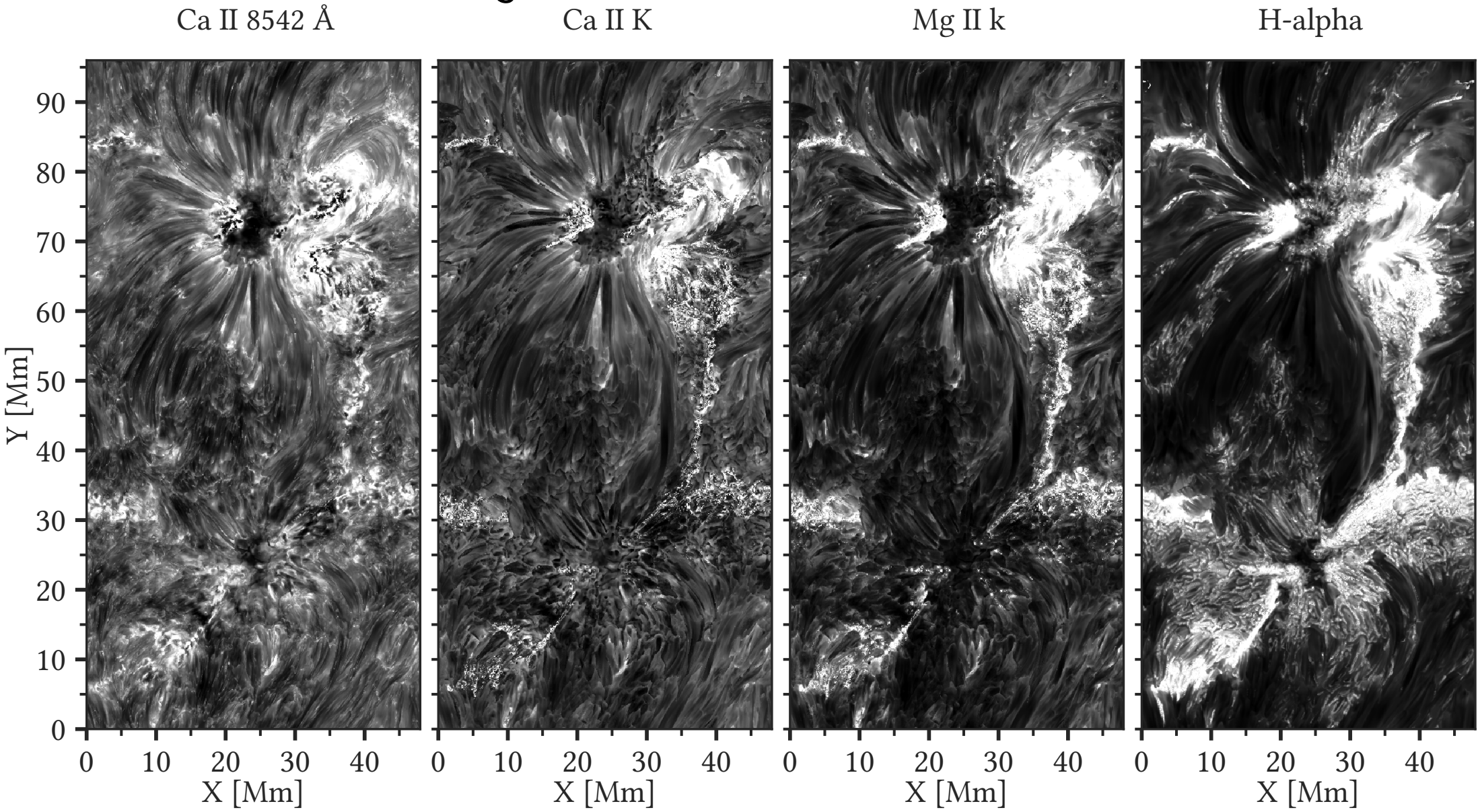
Carlsson & Stein (1992)
Paletou (1995)
Heinzel (1995)


Ca II K_3
$\overrightarrow{v} = 0$

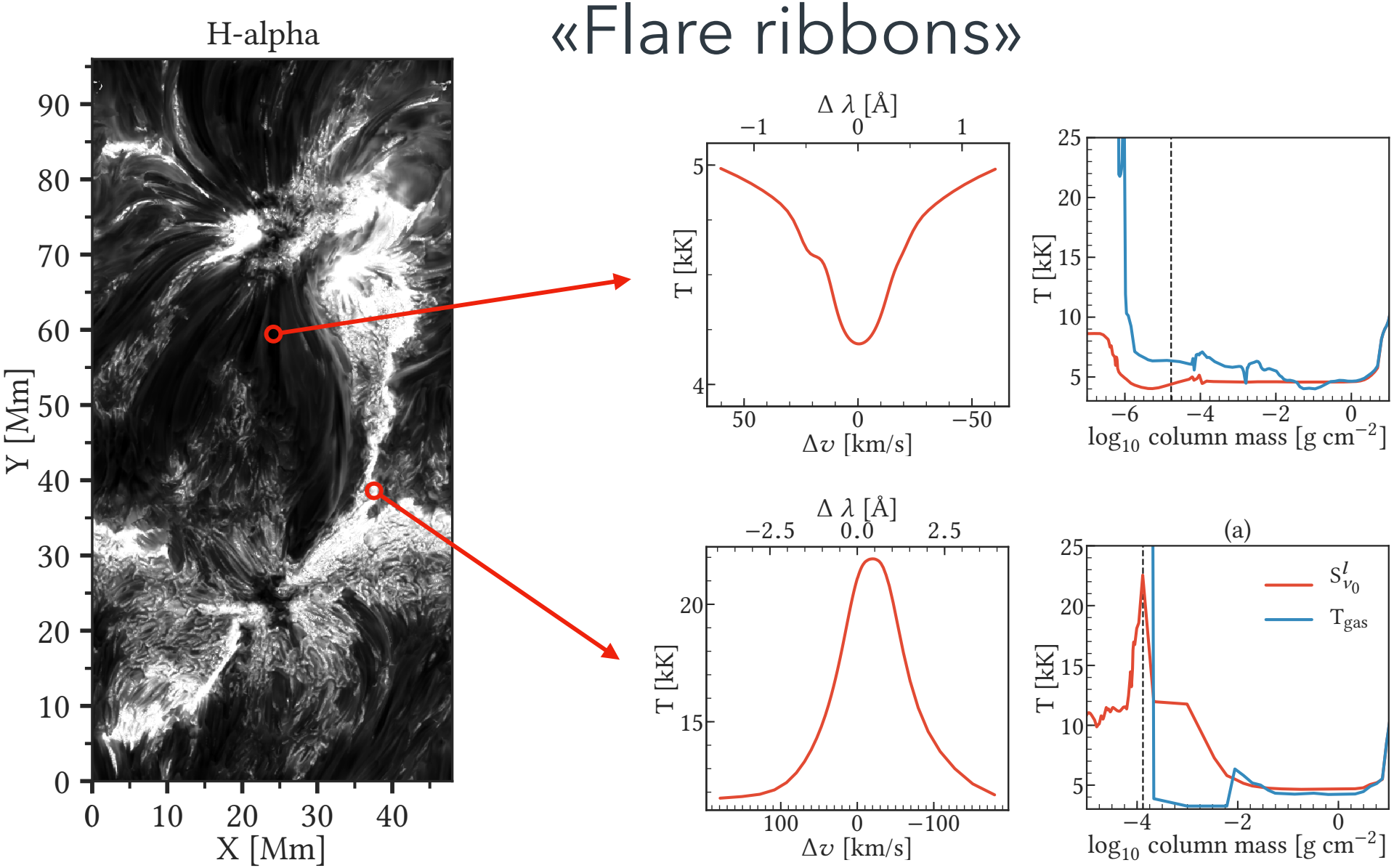

Ca II K_3
$\vec{v} = 0$


Nominal line center
Ca II 8542 Å
Ca II K
Mg II k
H-alpha
Y [Mm]
X [Mm]
0
10
20
30
40
50
60
70
80
90

At the maximum formation height

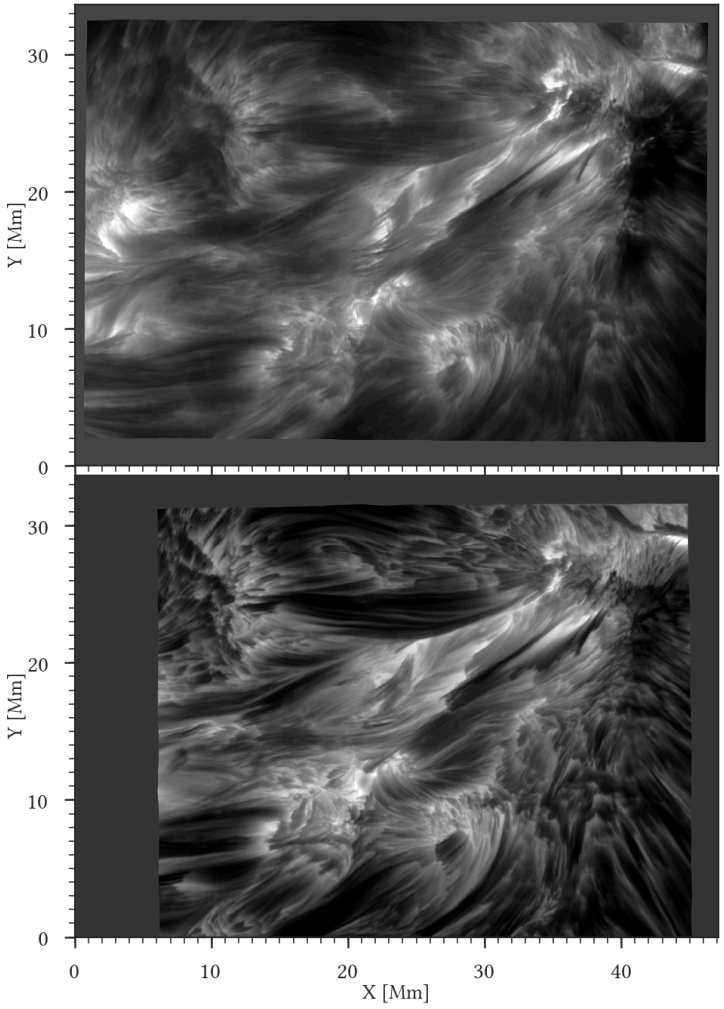


«Flare ribbons»

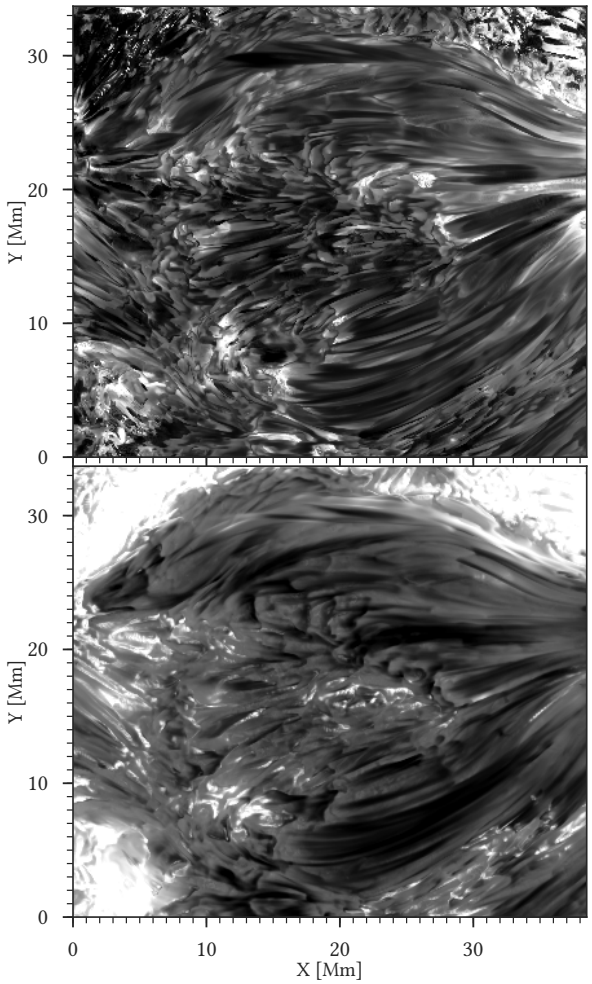


Comparison with H-alpha & Ca II K

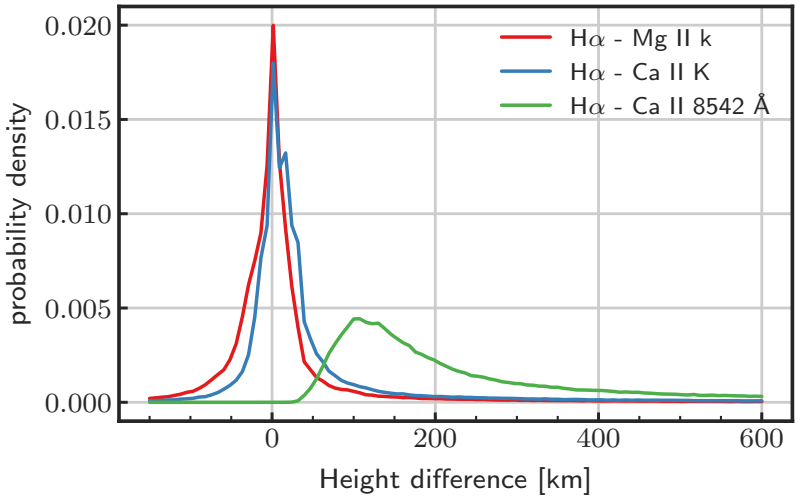
SST - CRISP/CHROMIS

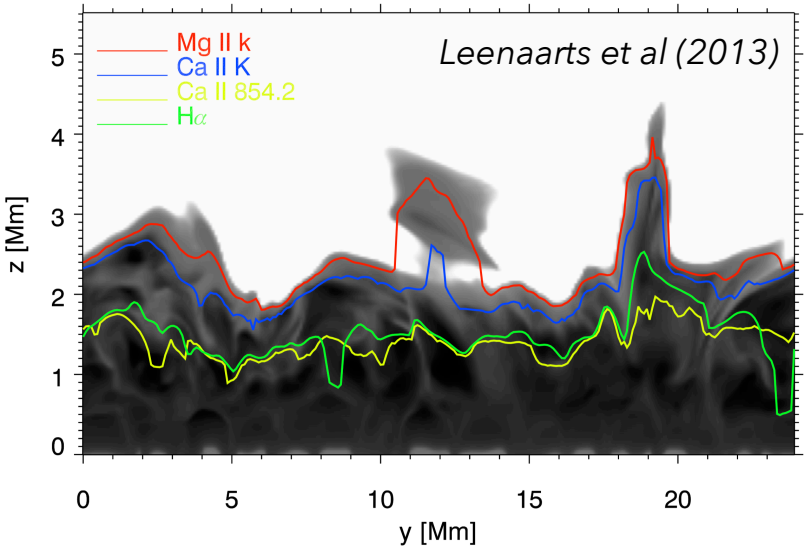


Synthetic



Formation height difference



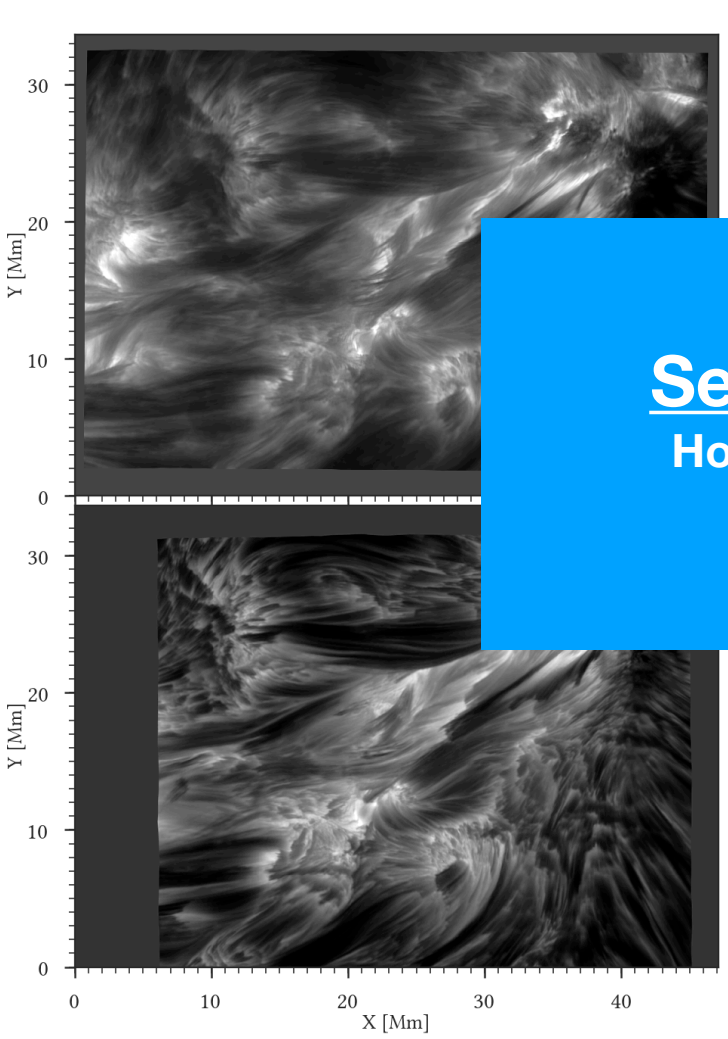


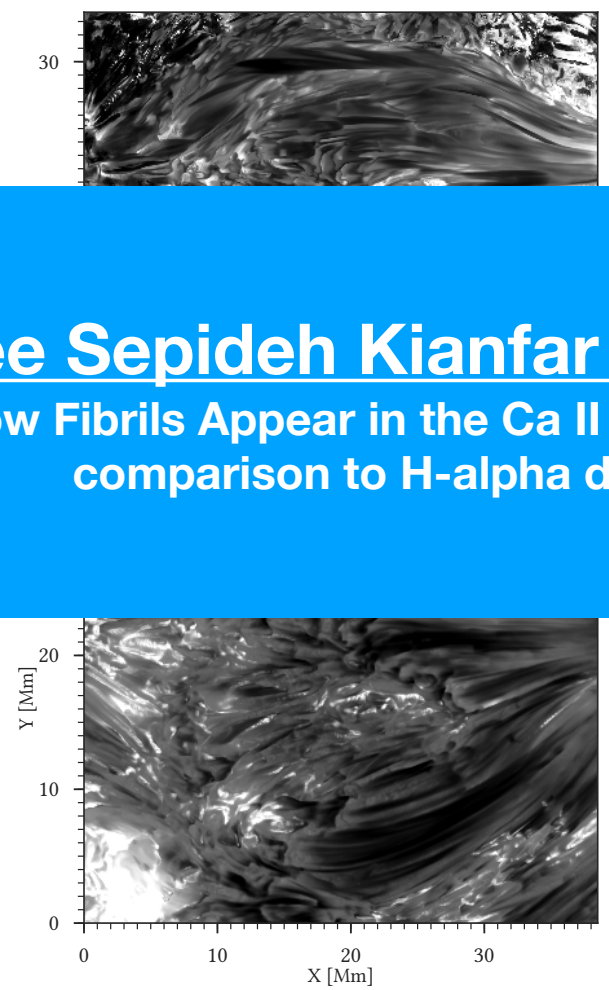
Comparison with H-alpha & Ca II K

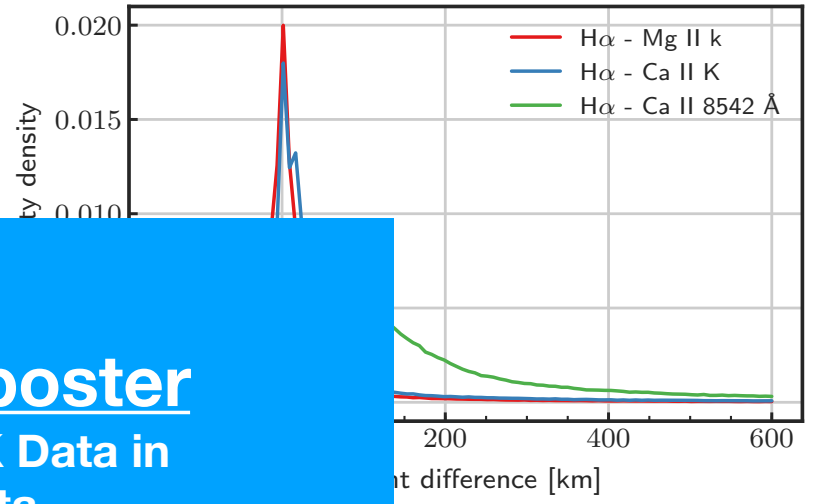
SST - CRISP/CHROMIS

Synthetic

Formation height difference

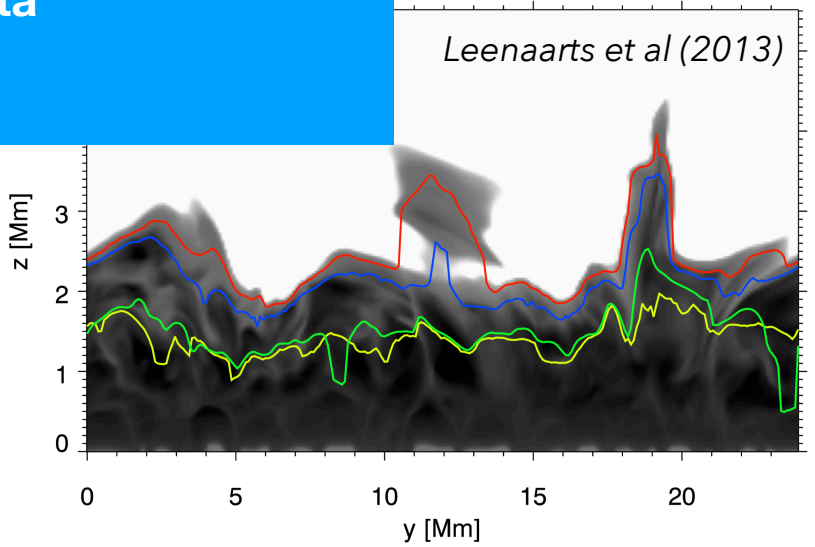






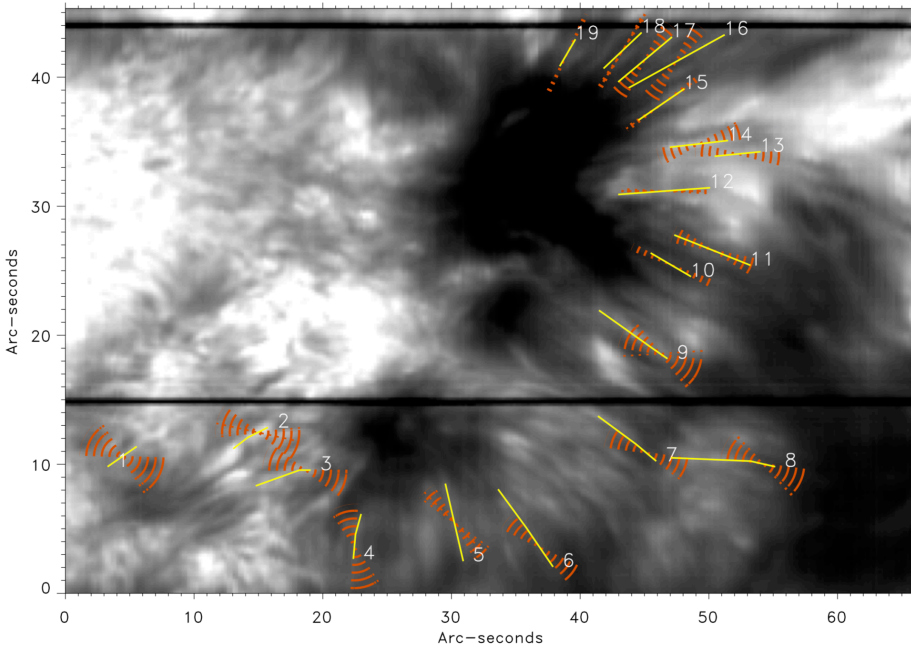
See Sepideh Kianfar poster

How Fibrils Appear in the Ca II K Data in comparison to H-alpha data



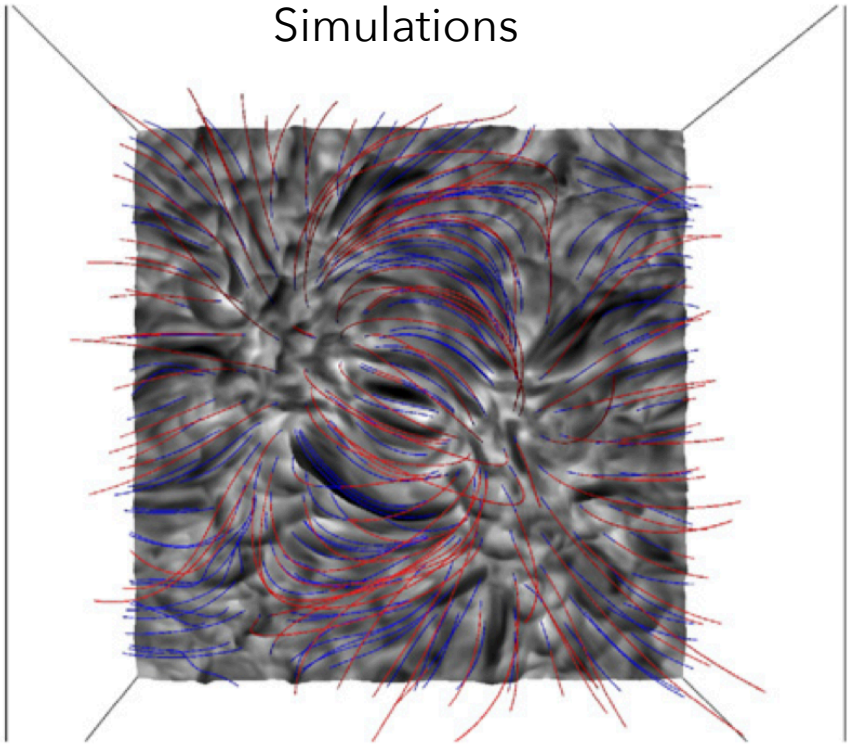
Do fibrils tracing the magnetic filed?

Observations



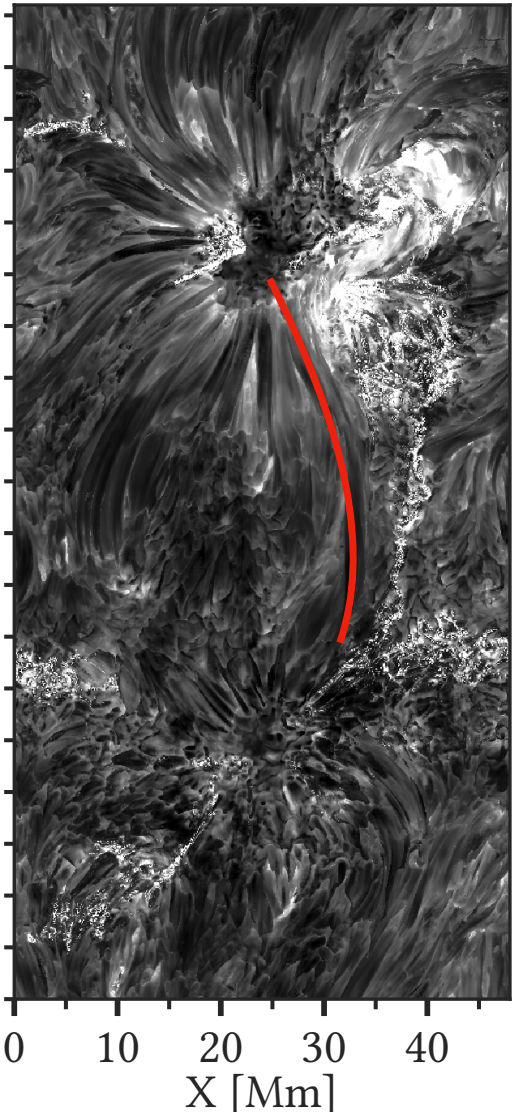
de la Cruz Rodríguez & Socas-Navarro (2013)
Asensio Ramos et al (2017)

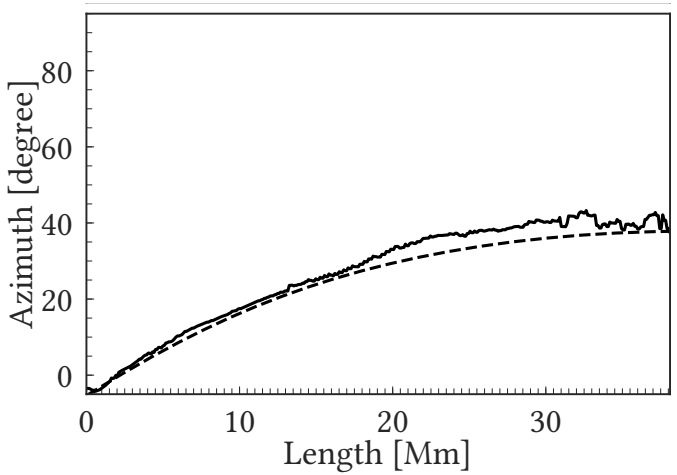
Simulations

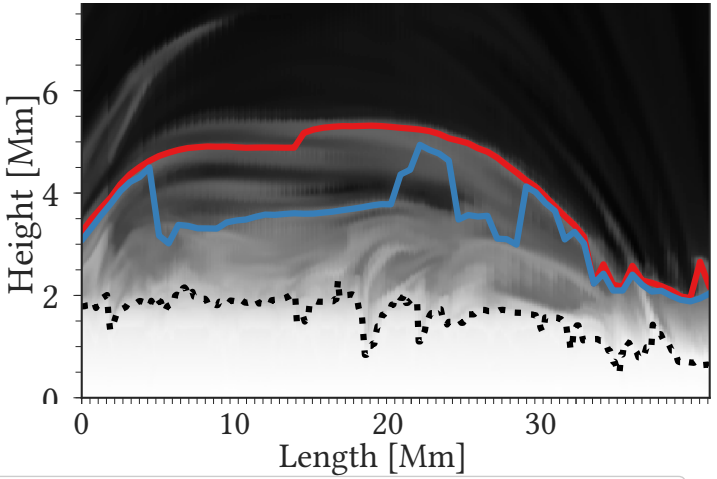


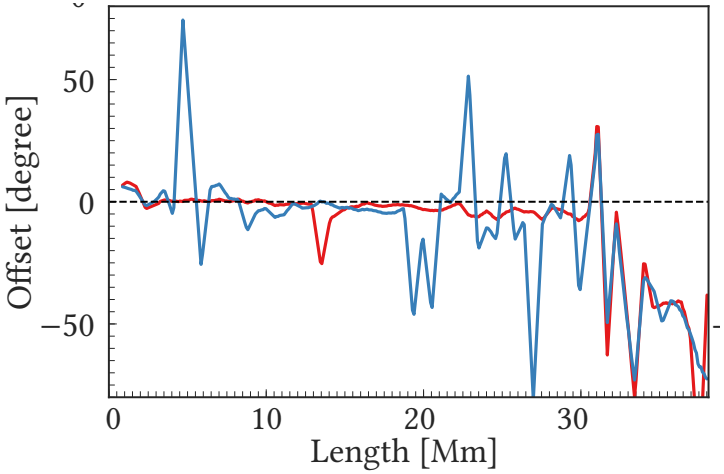
Leenaarts et al (2015)

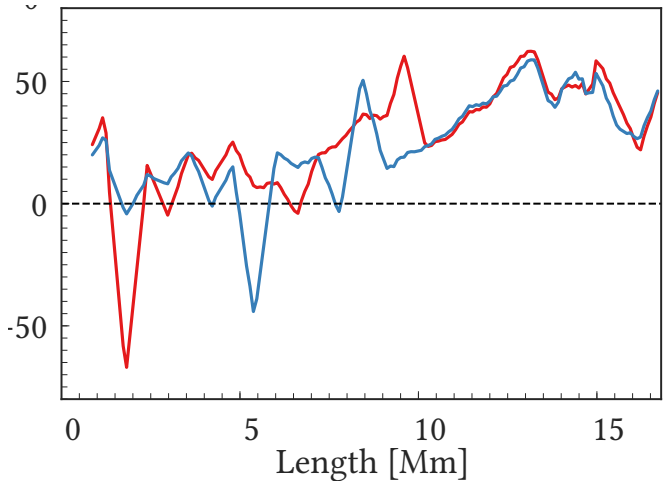
Do fibrils tracing the magnetic filed?

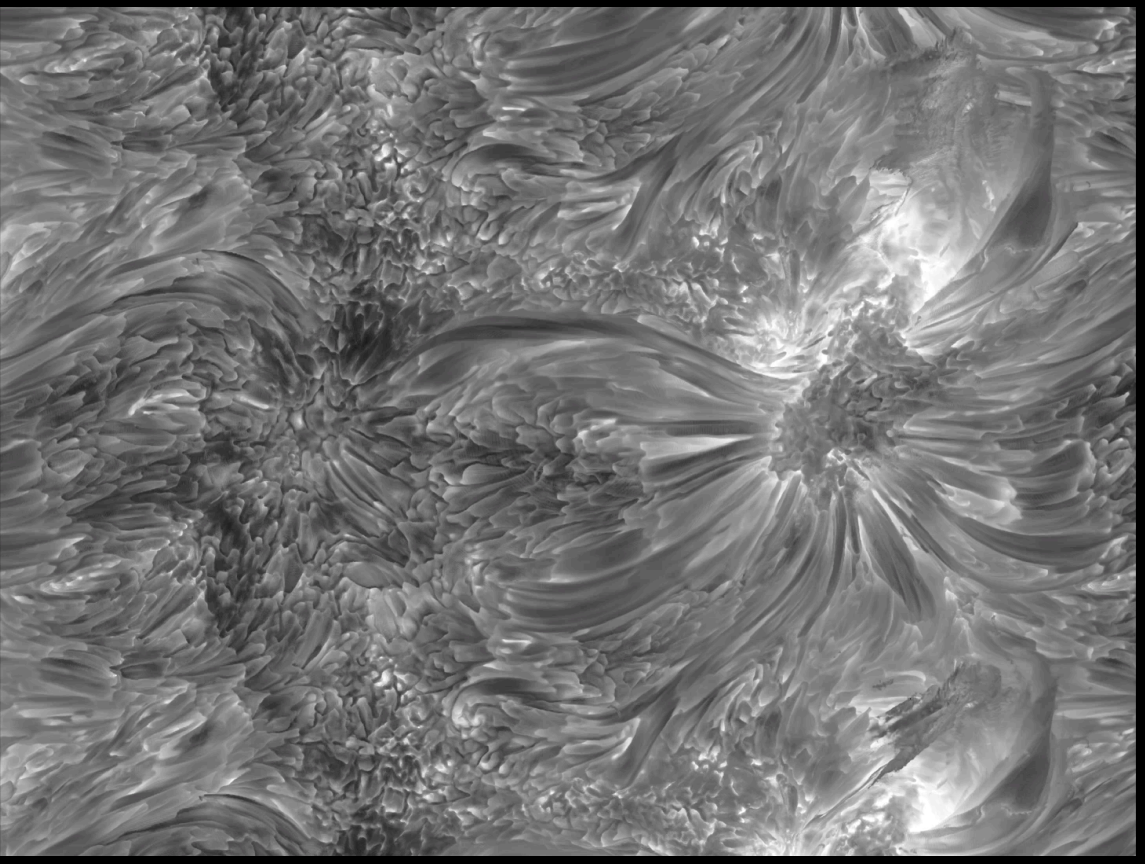










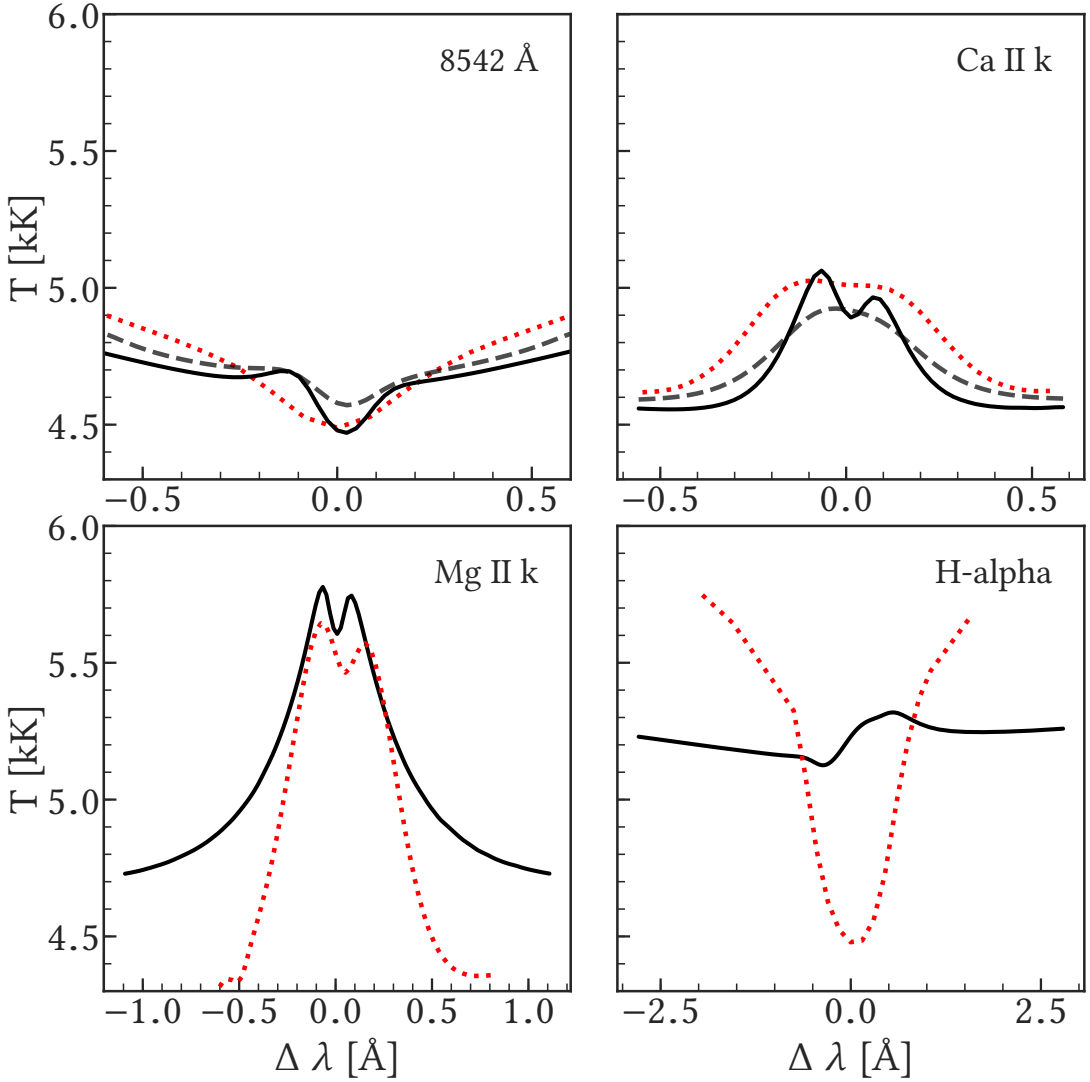


Summary

- Our 3D PRD non-LTE RT code can handle a dynamic simulated active region.
- H-alpha is formed relative close to the Ca II K and Mg II k in this model.
- «Flare ribbons» are caused by a deep temperature rise in the chromosphere.

Backup

Spatially-averaged profiles



Synthetic

Observation

Spectral degraded synthetic

Instruments:

8542 Å: SST/CRISP

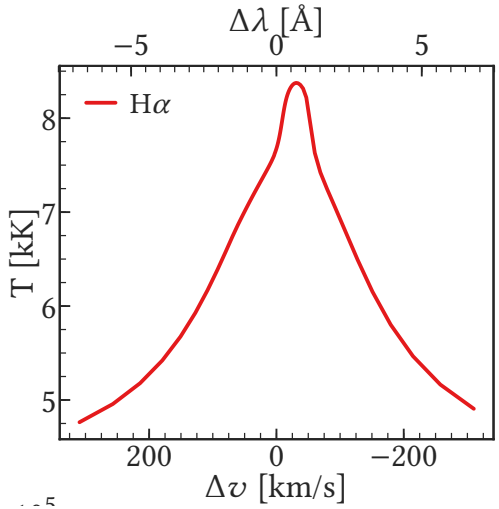
Ca II K: SST/CHROMIS

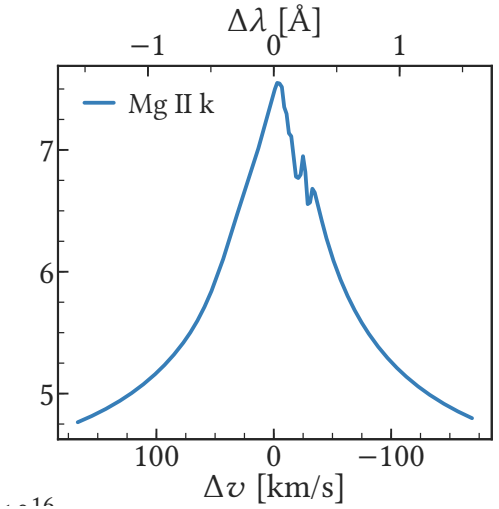
Mg II k: IRIS

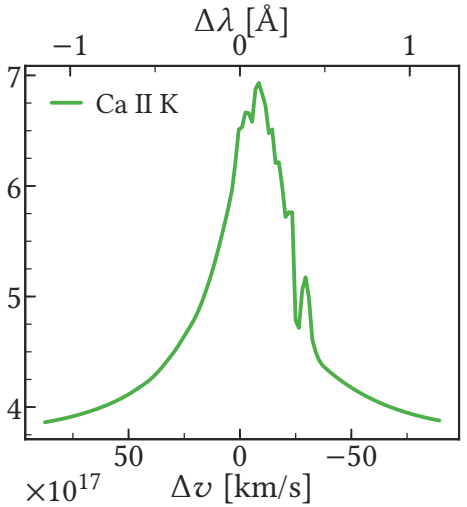
H-alpha: SST/CRISP

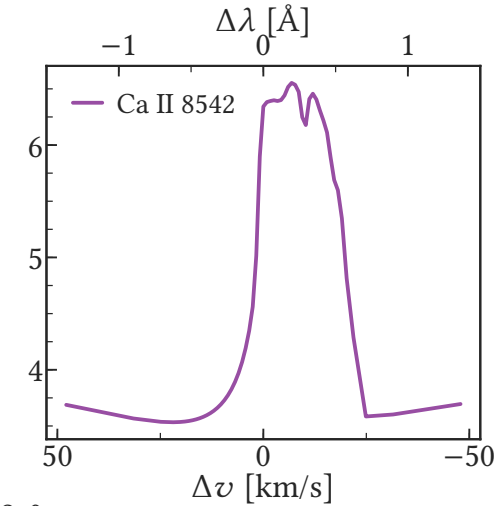
Synthetic profiles

«Flare profiles»

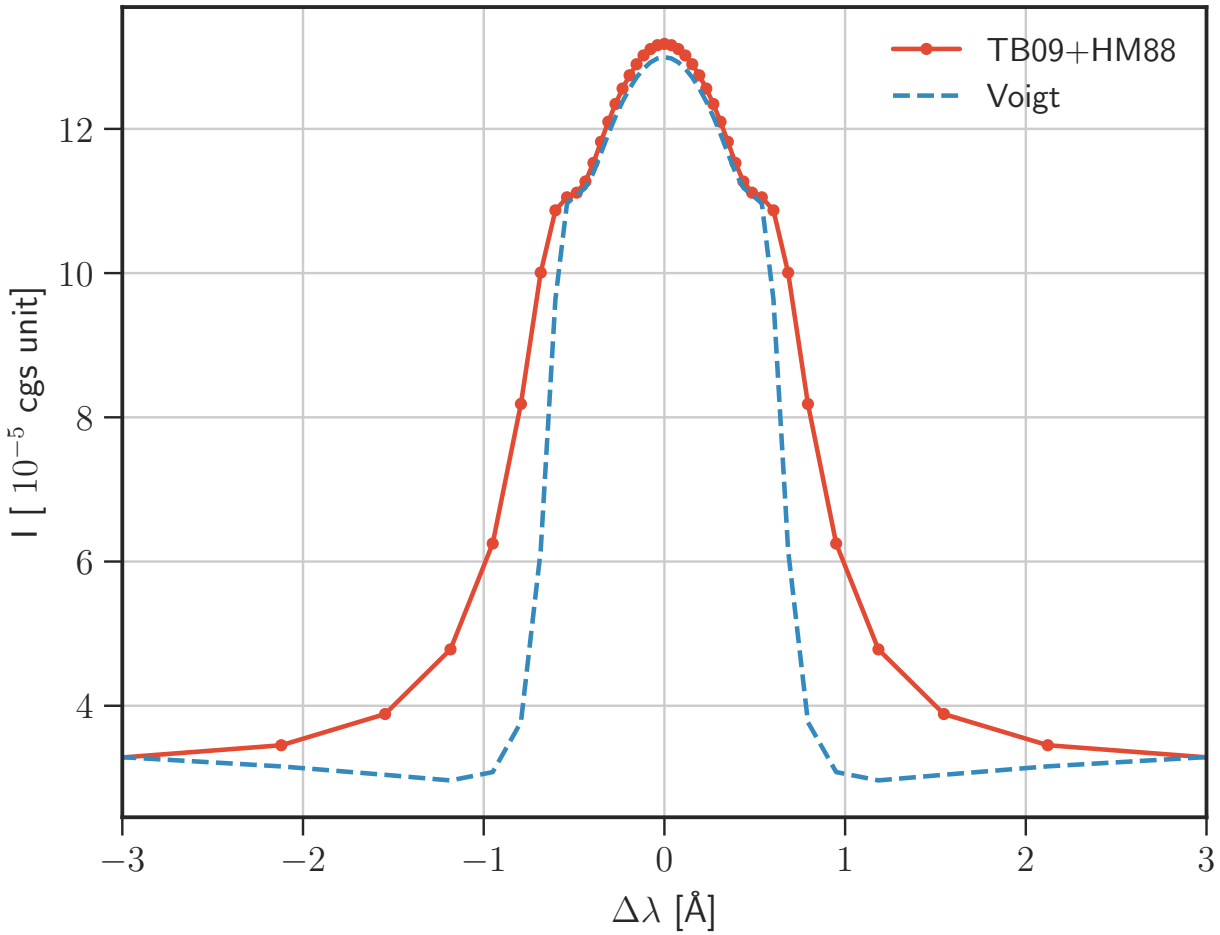




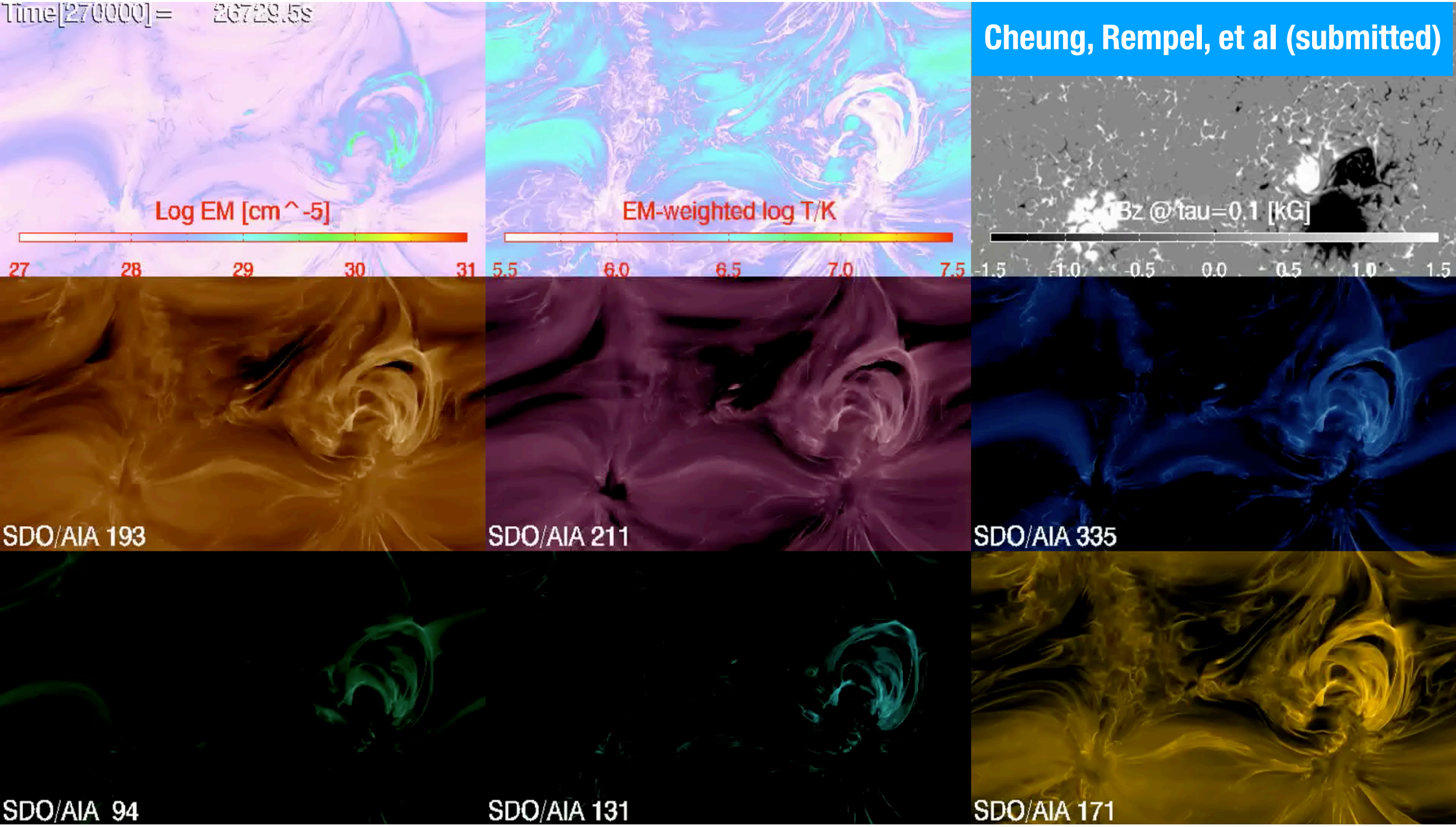




Unified theory of electric pressure broadening



Based on the recipes of Kowalski et al (2017)


Time[270000] = 26729.5s
Log EM [cm^-5]
27
28
29
30
31
EM-weighted log T/K
5.5
6.0
6.5
7.0
7.5
Cheung, Rempel, et al (submitted)
Bz @ tau=0.1 [kG]
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
SDO/AIA 193
SDO/AIA 211
SDO/AIA 335
SDO/AIA 94
SDO/AIA 131
SDO/AIA 171