Simulations of chromospheric heating: progress and challenges

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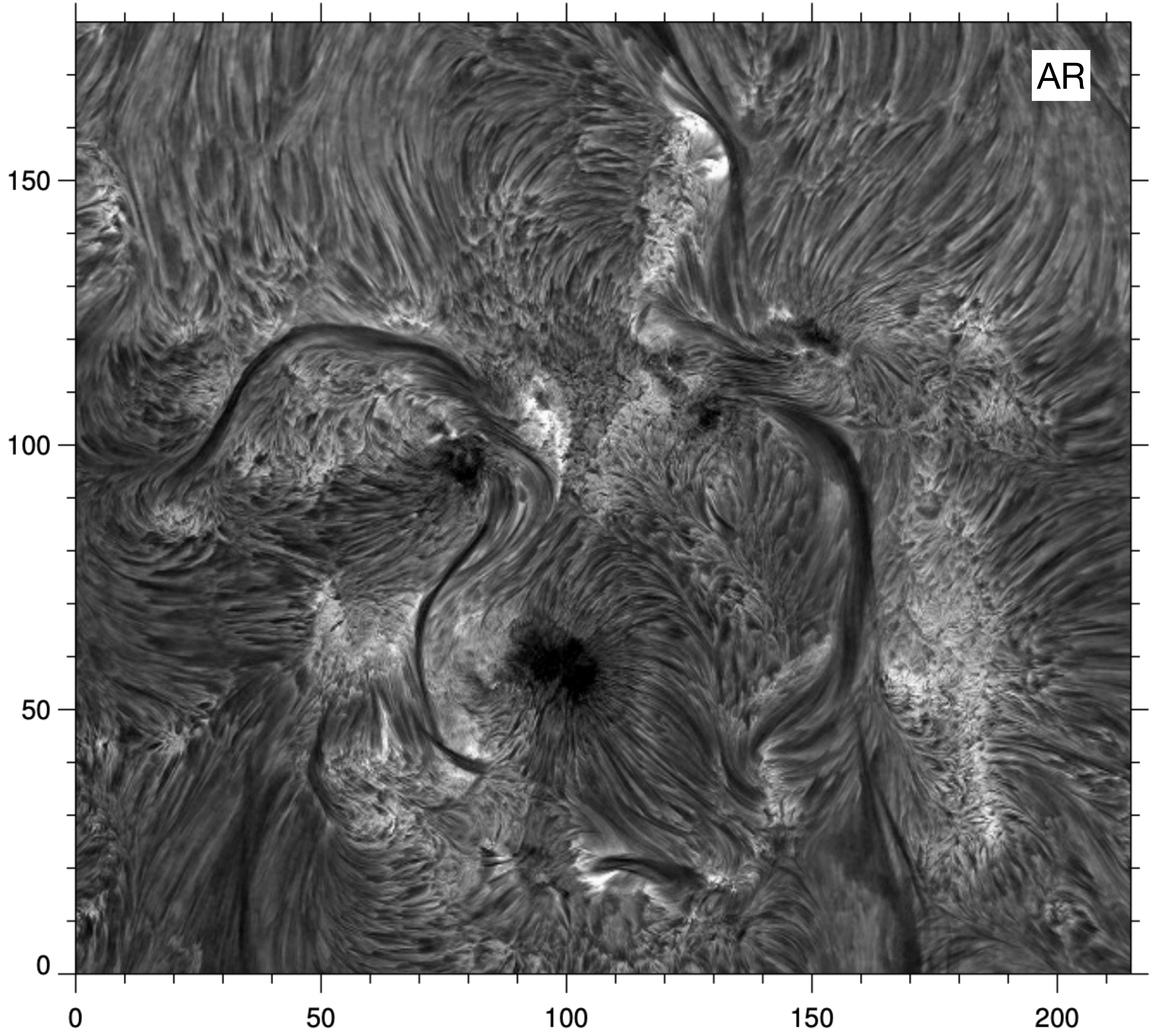
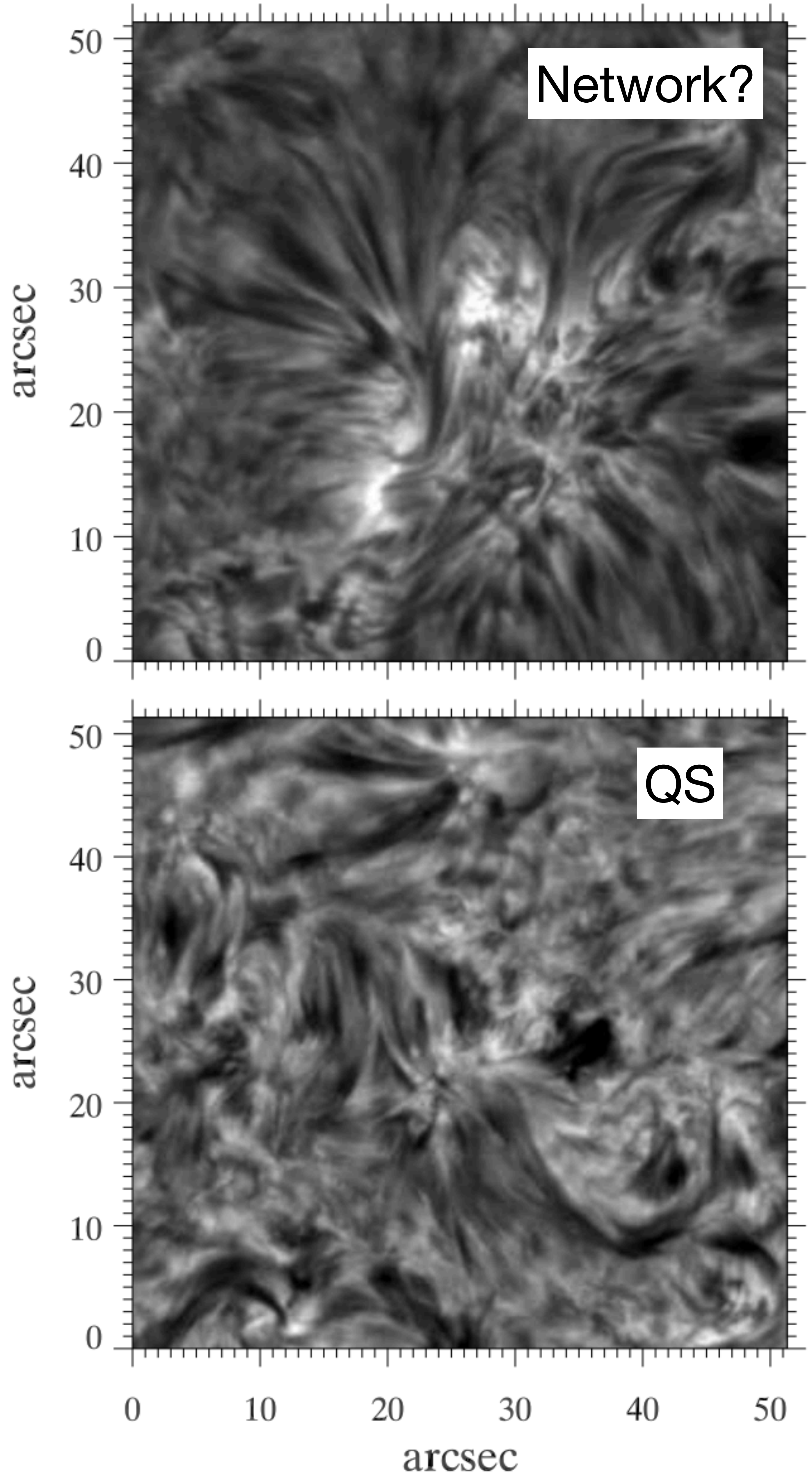
Thanks to:
Adur Pastor Yabar, Jaime de la Cruz Rodriquez, Joao da Silva Santos, Jorrit Leenarts, Matthias Rempel and Damien Przybylski

Observed chromosphere



Dutch Open Telescope (DOT) Hα, passband 0.25Å

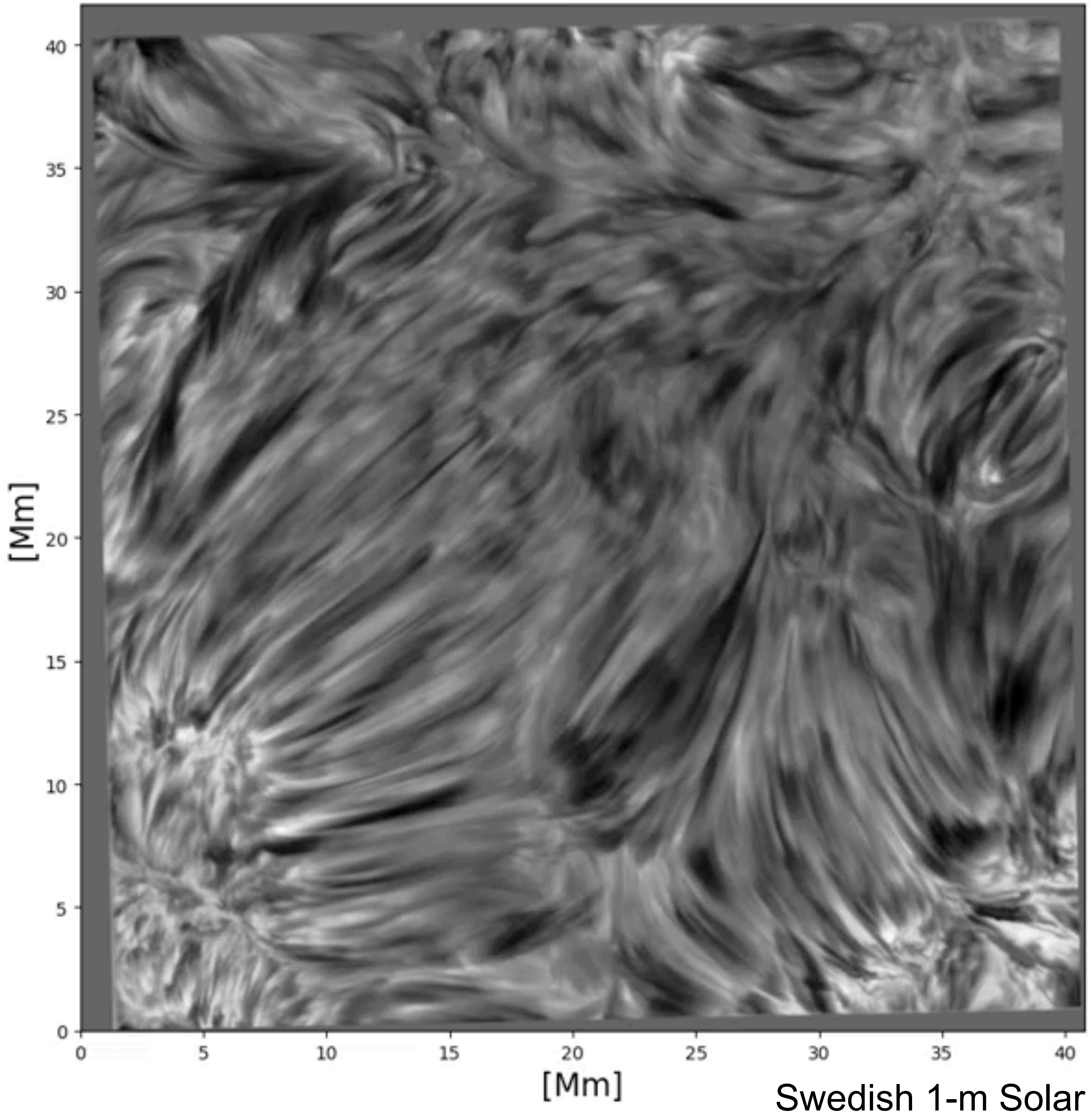


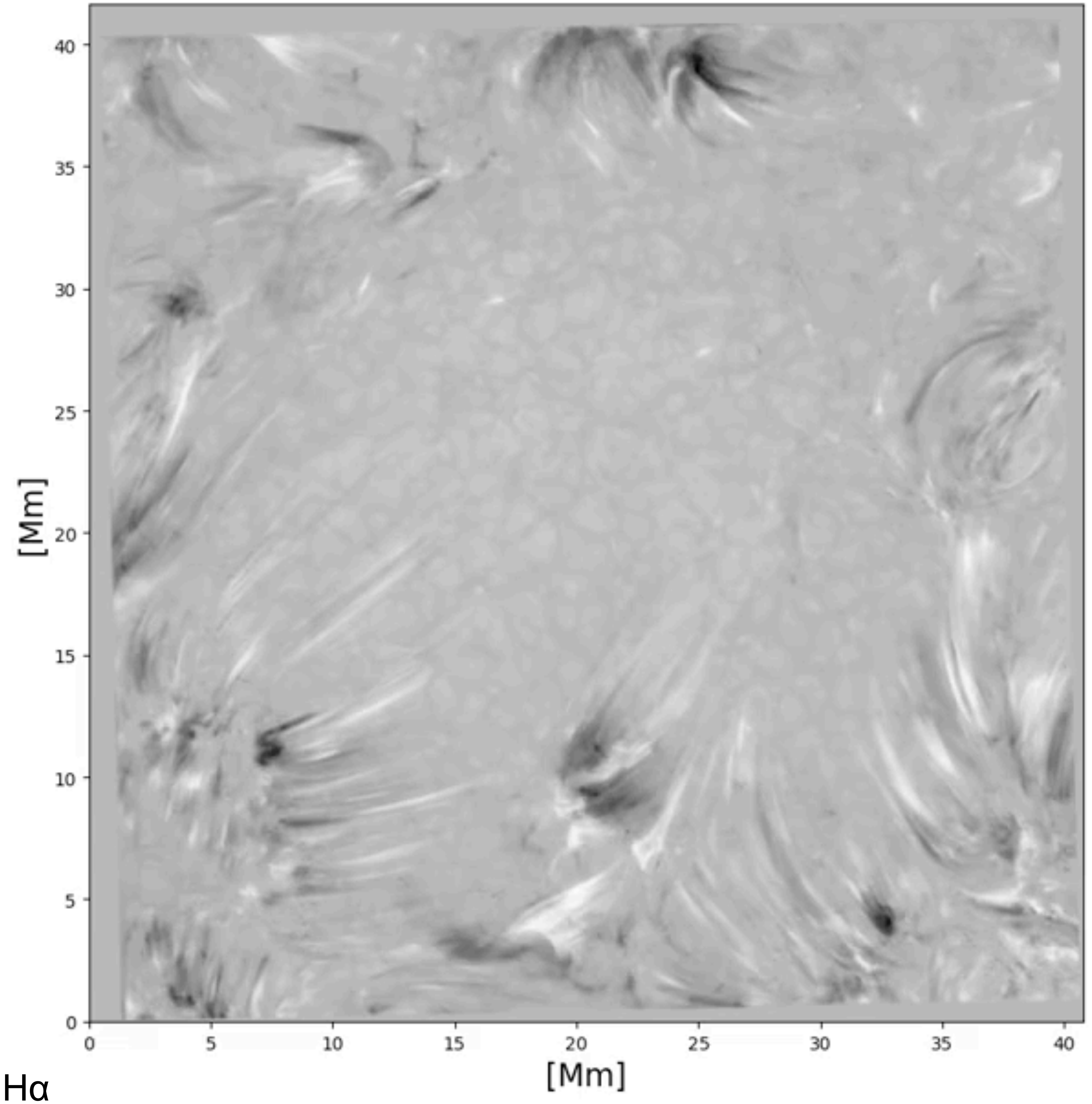
Dunn Solar Telescope, IBIS

Observed chromosphere

Duration ~ 7 min
Cadence ~ 2 s
Dopplegrams +-36 km/s

Highly dynamic - Pietarila et al. 2009; Reardon et al. 2011, Rutten & Rouppe van der Voort 2017, De Pontieu et al. 2007, 2012; McIntosh et al. 2008, Kuridze et al. 2012, 215,216, Sekse et al. 2014, Pereira et al. 2016, Samanta et al. 2019, Jafarzadeh et al. 2017, Gafeira et al. 2017



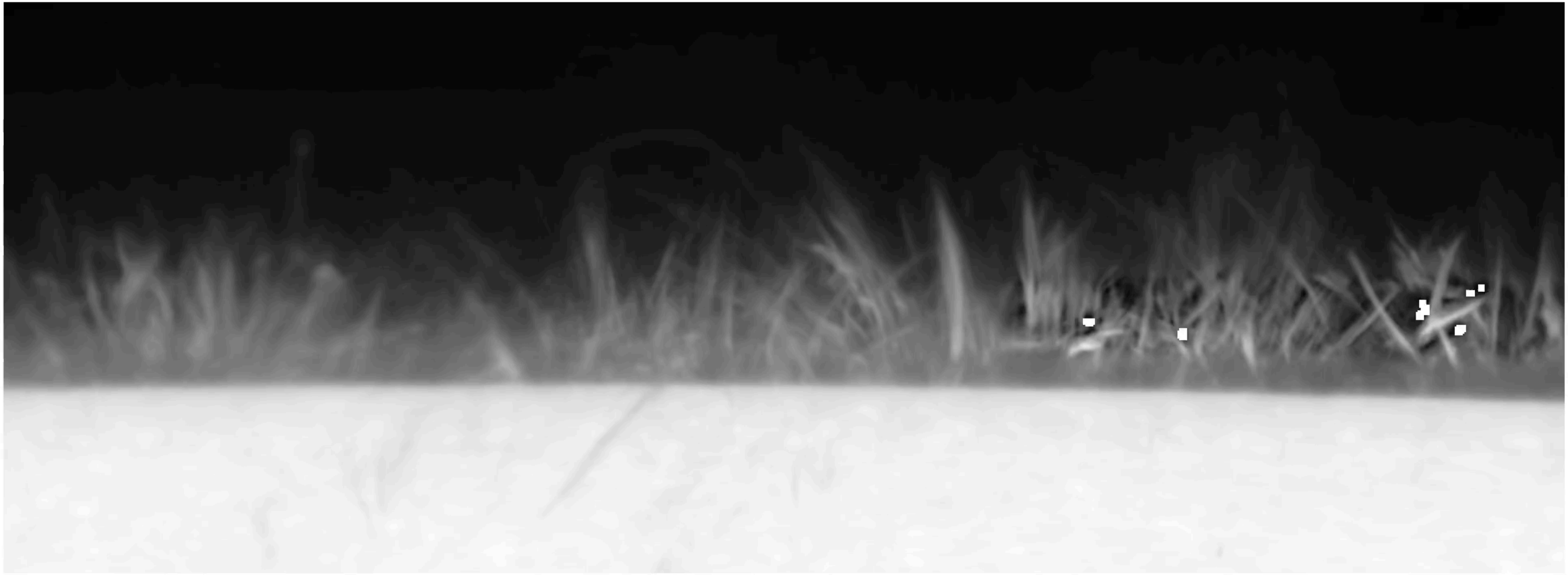


Swedish 1-m Solar Telescope Hα

Observed chromosphere

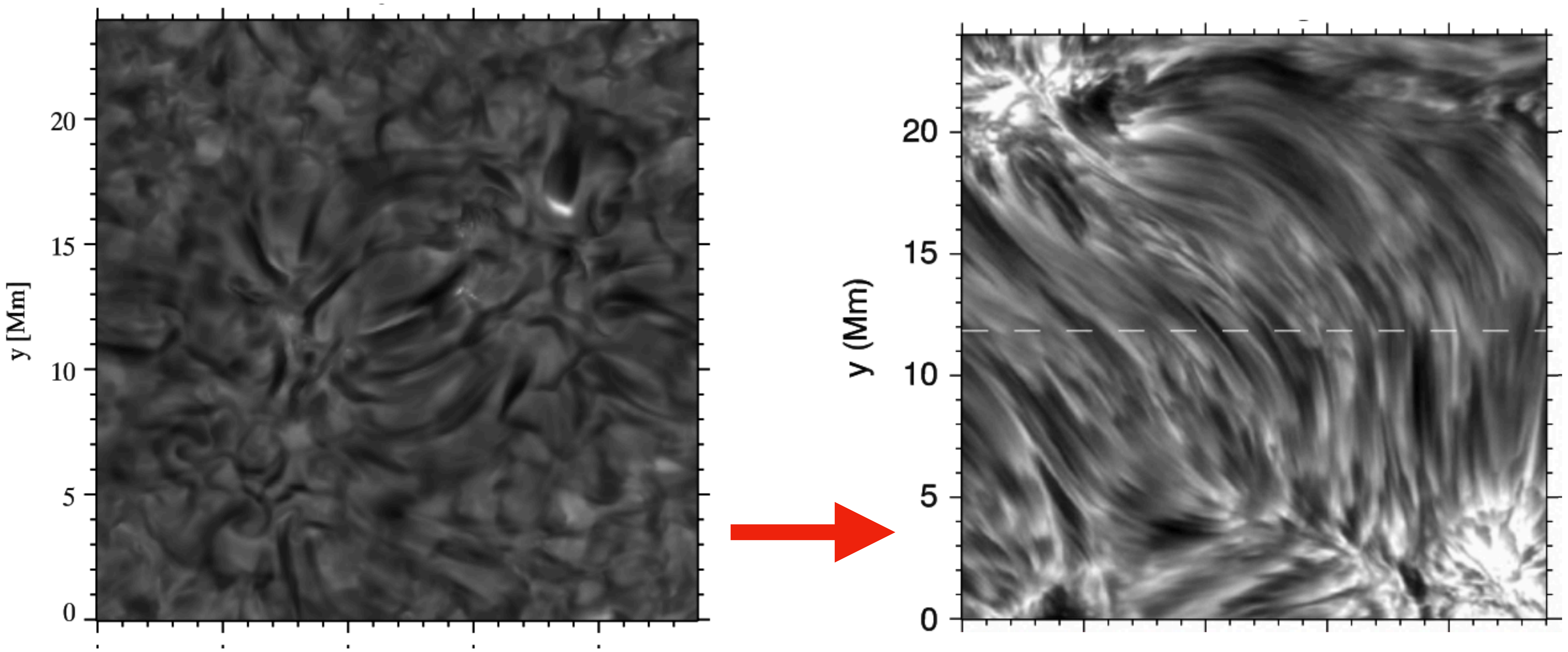
Duration ~ 5 min
Cadence ~ 10 s
@ -50 km/s

Highly dynamic - Pietarila et al. 2009; Reardon et al. 2011, Rutten & Rouppe van der Voort 2017, De Pontieu et al. 2007, 2012; McIntosh et al. 2008, Kuridze et al. 2012, 215,216, Sekse et al. 2014, Pereira et al. 2016, Samanta et al. 2019, Jafarzadeh et al. 2017, Gafeira et al. 2017



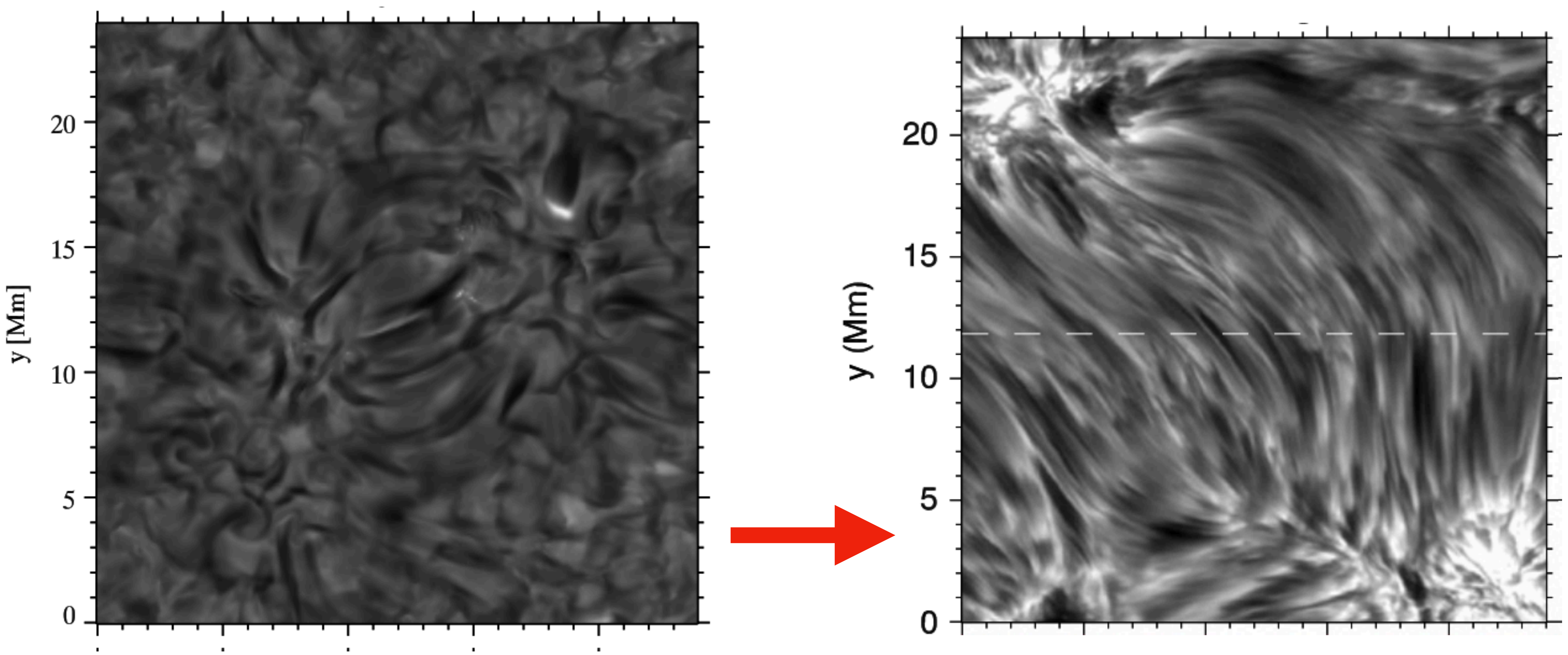
Swedish 1-m Solar Telescope Hα

Chromospheric modelling - what do we need?



Leenaarts et al. 2015

Chromospheric modelling - what do we need?

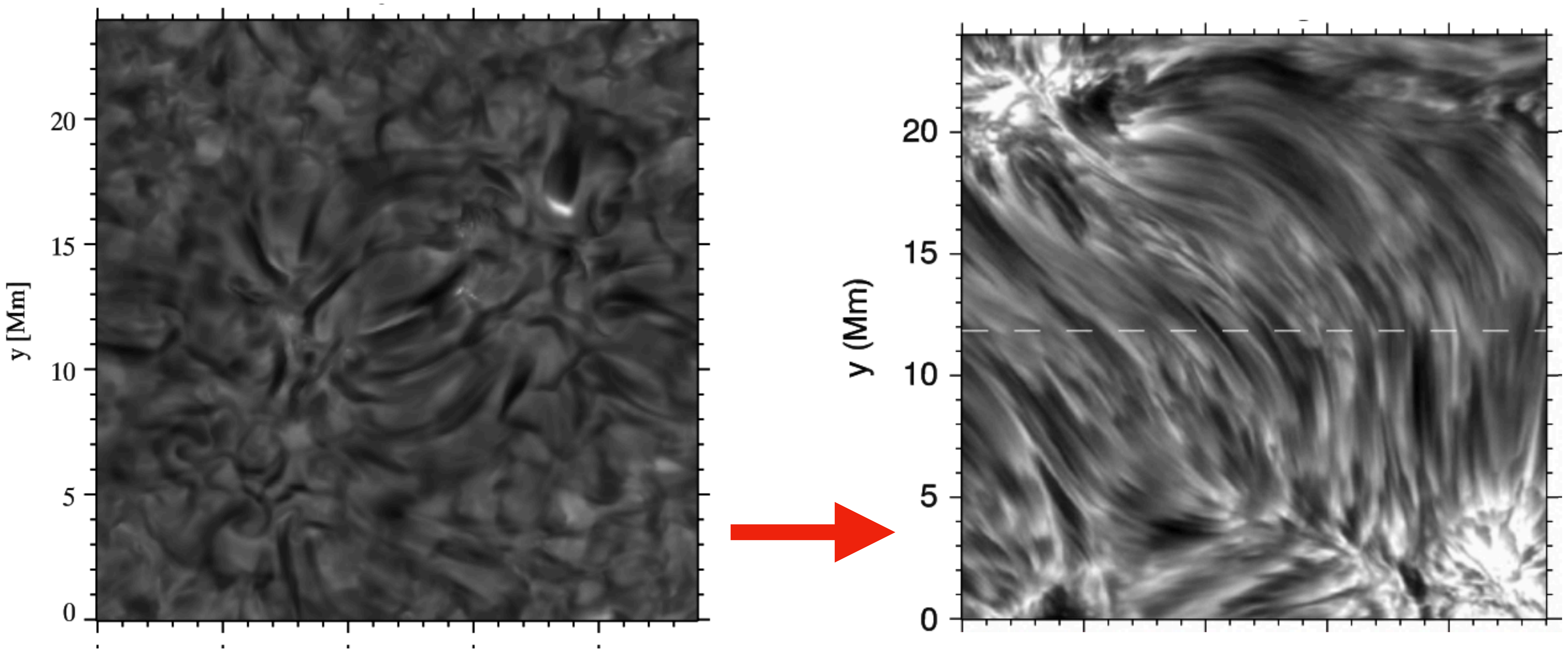


Leenaarts et al. 2015

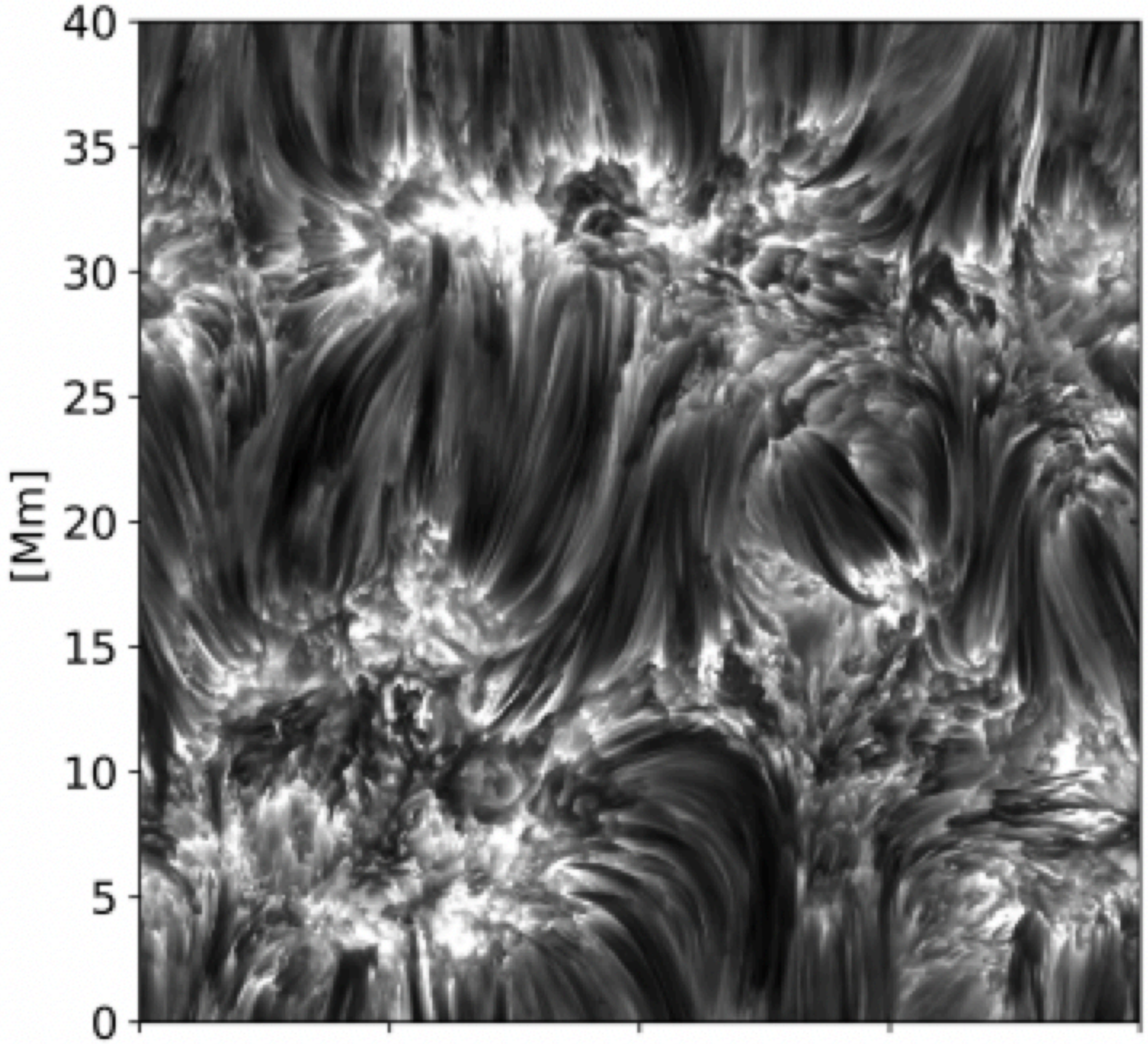
The configuration of the magnetic field is an important factor in controlling the energy losses.

Withbroe & Noyes 1977

Chromospheric modelling - what do we need?



Leenaarts et al. 2015



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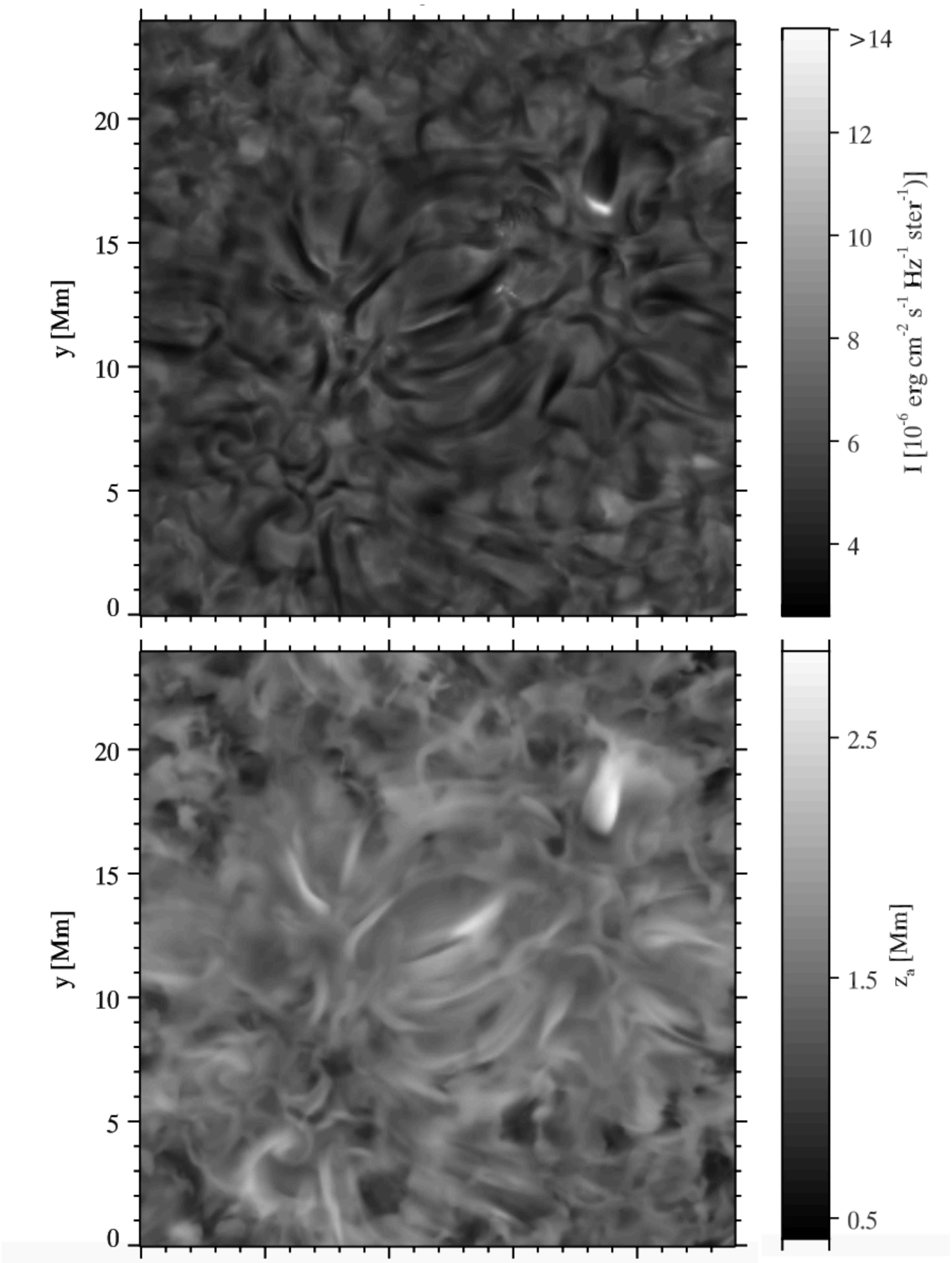
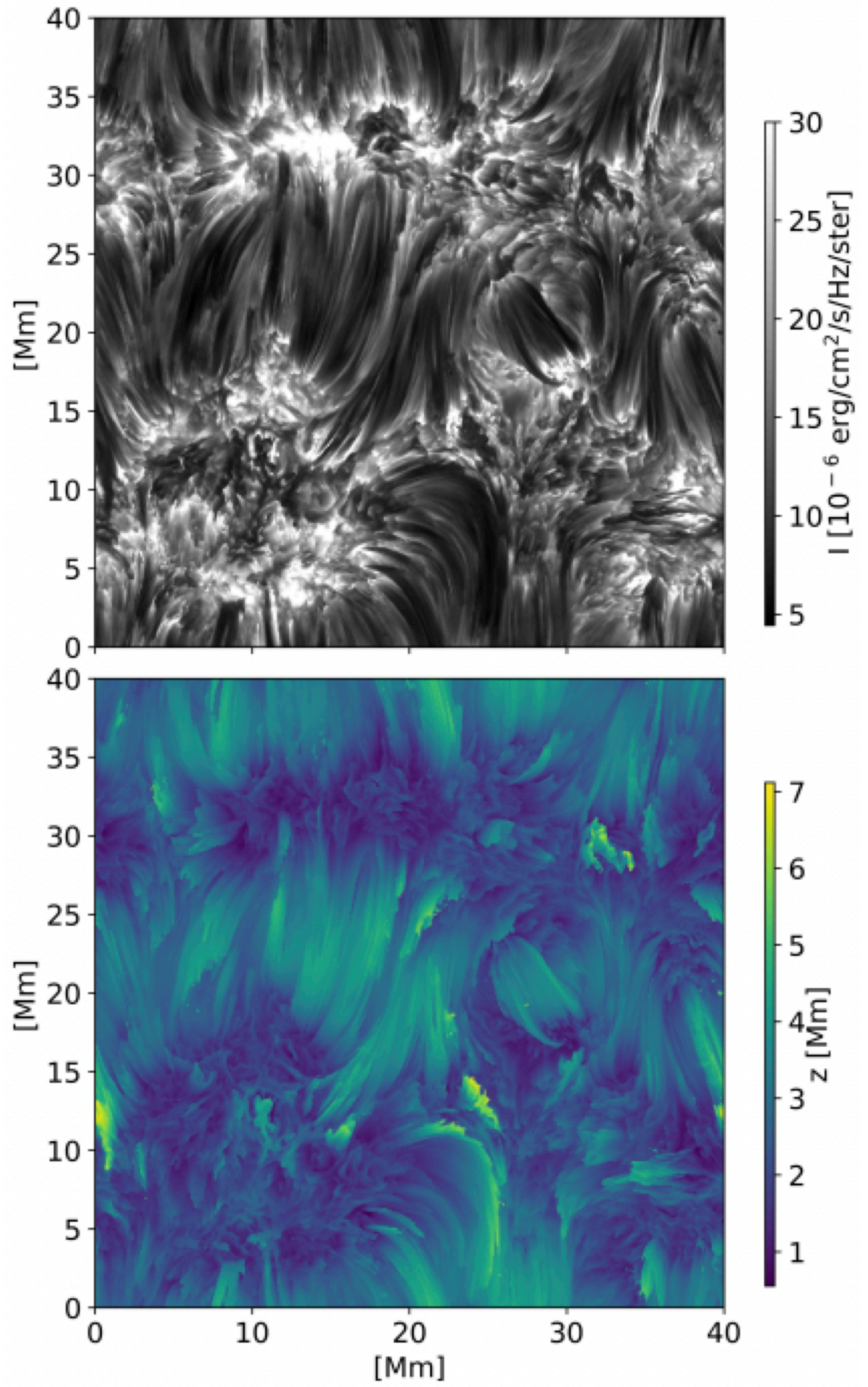
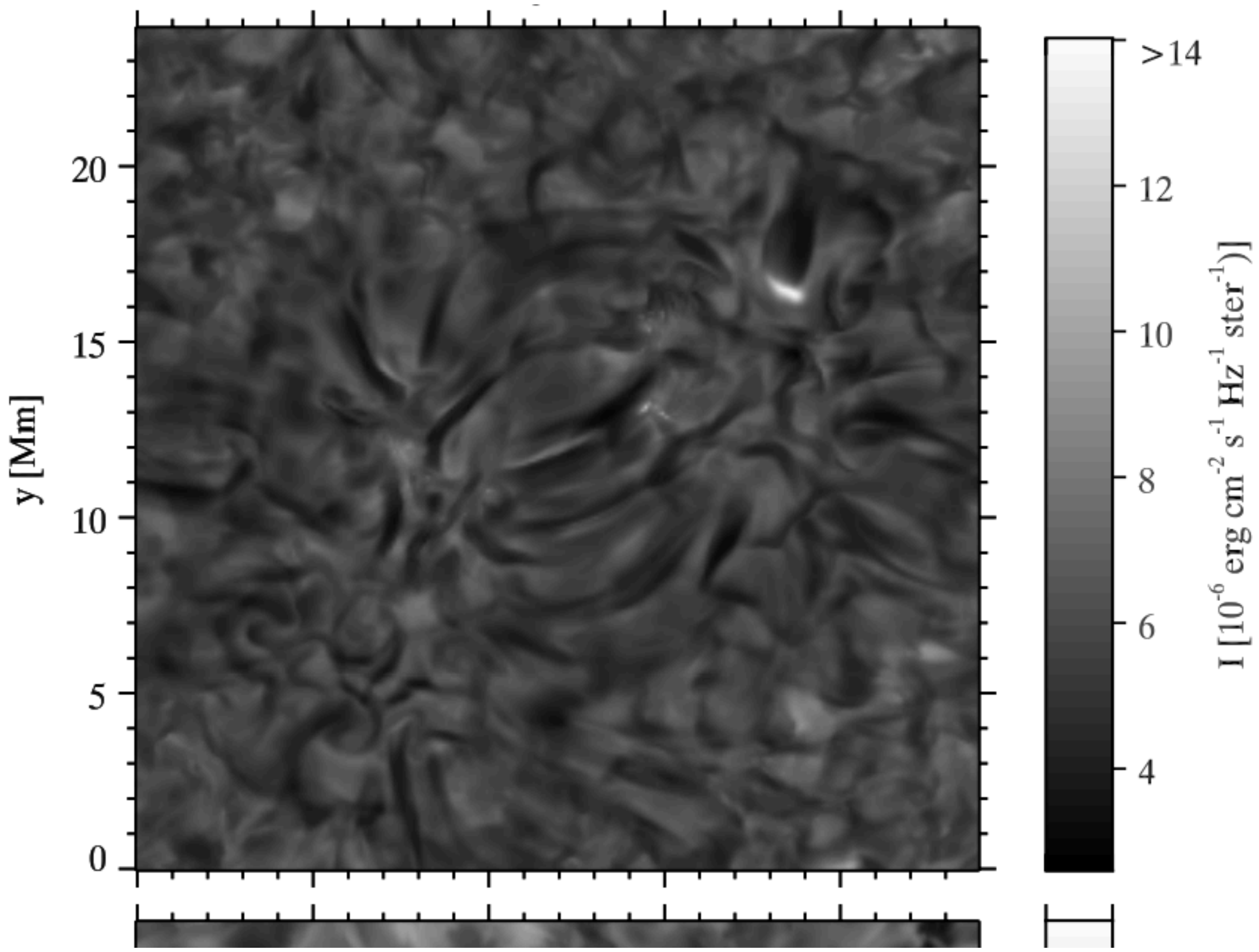
Withbroe & Noyes 1977



Some of the differences:

- domain size
  (24 × 24 × 16.8 Mm vs
  40 × 40 × 22 Mm)
- mean unsigned field
  (30 G vs 180 G)
- field configuration
  (bipolar vs complex)





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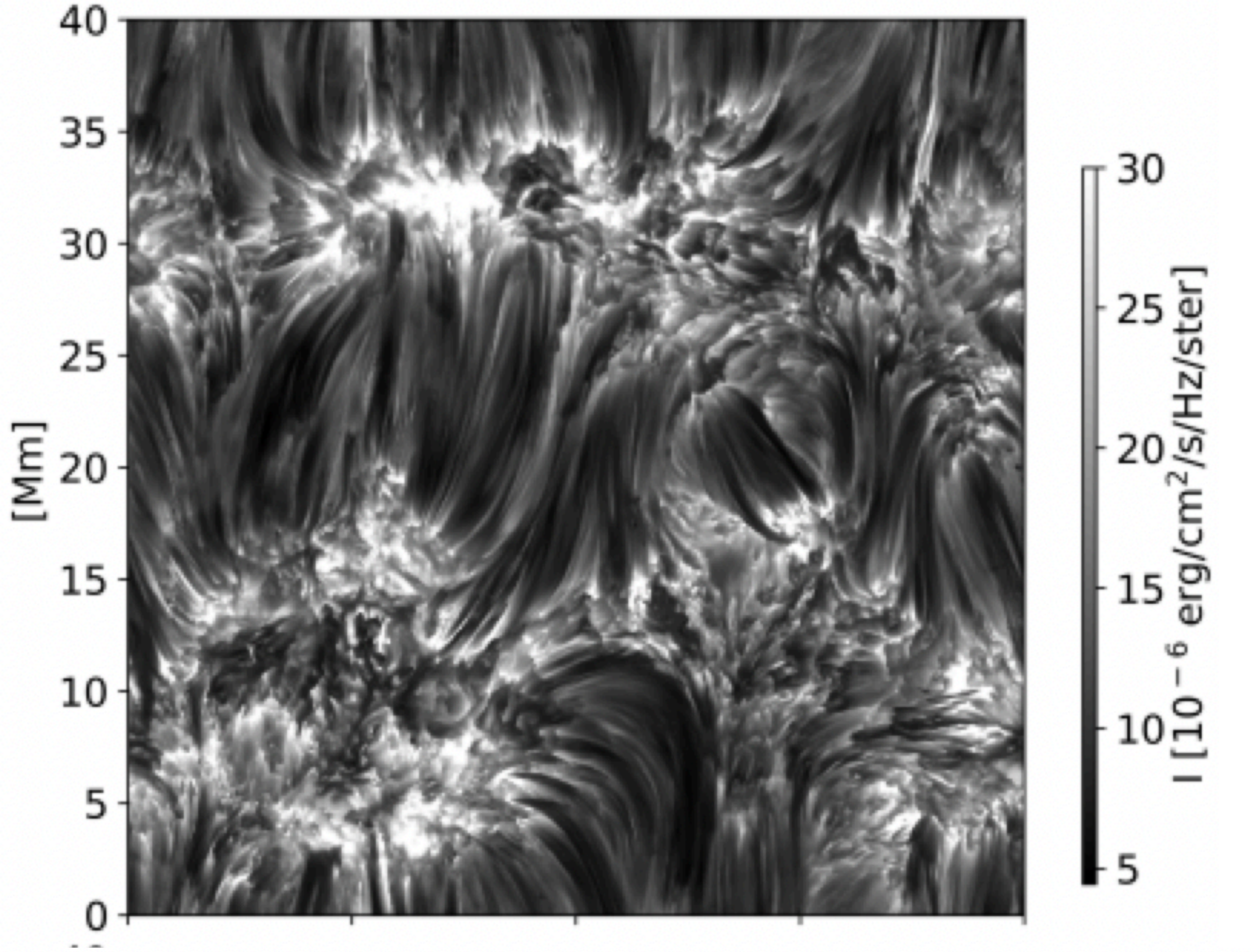
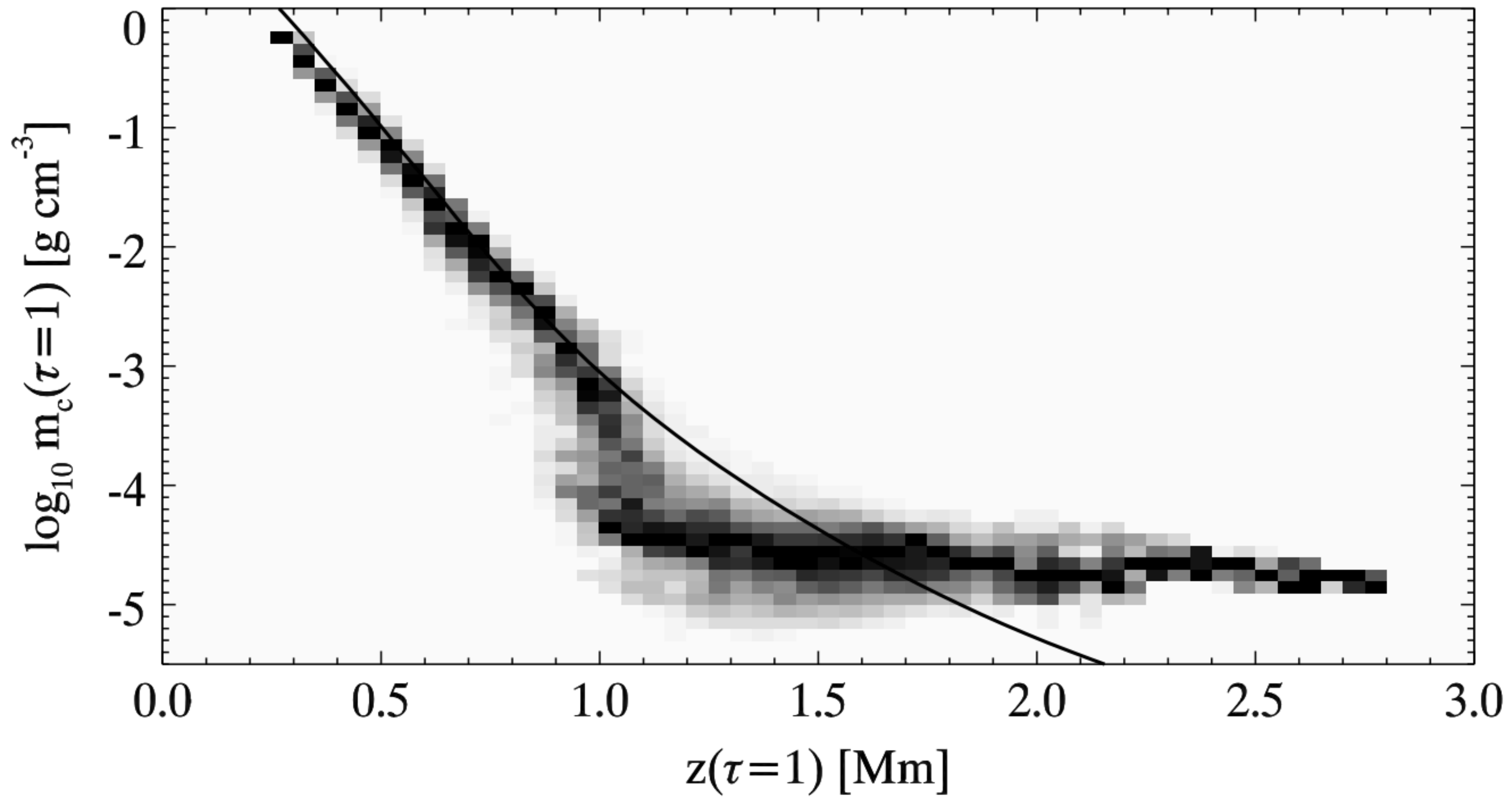
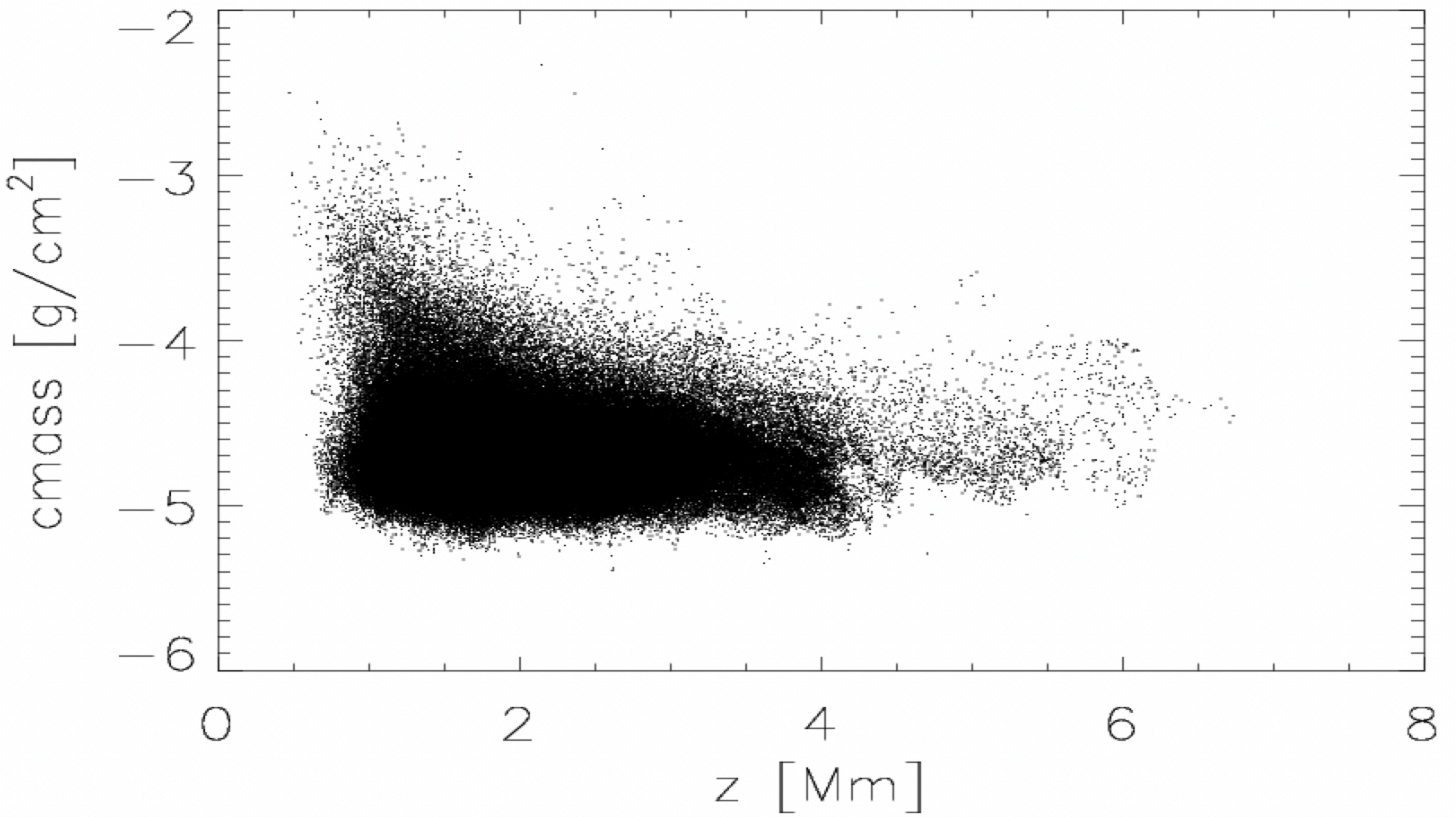
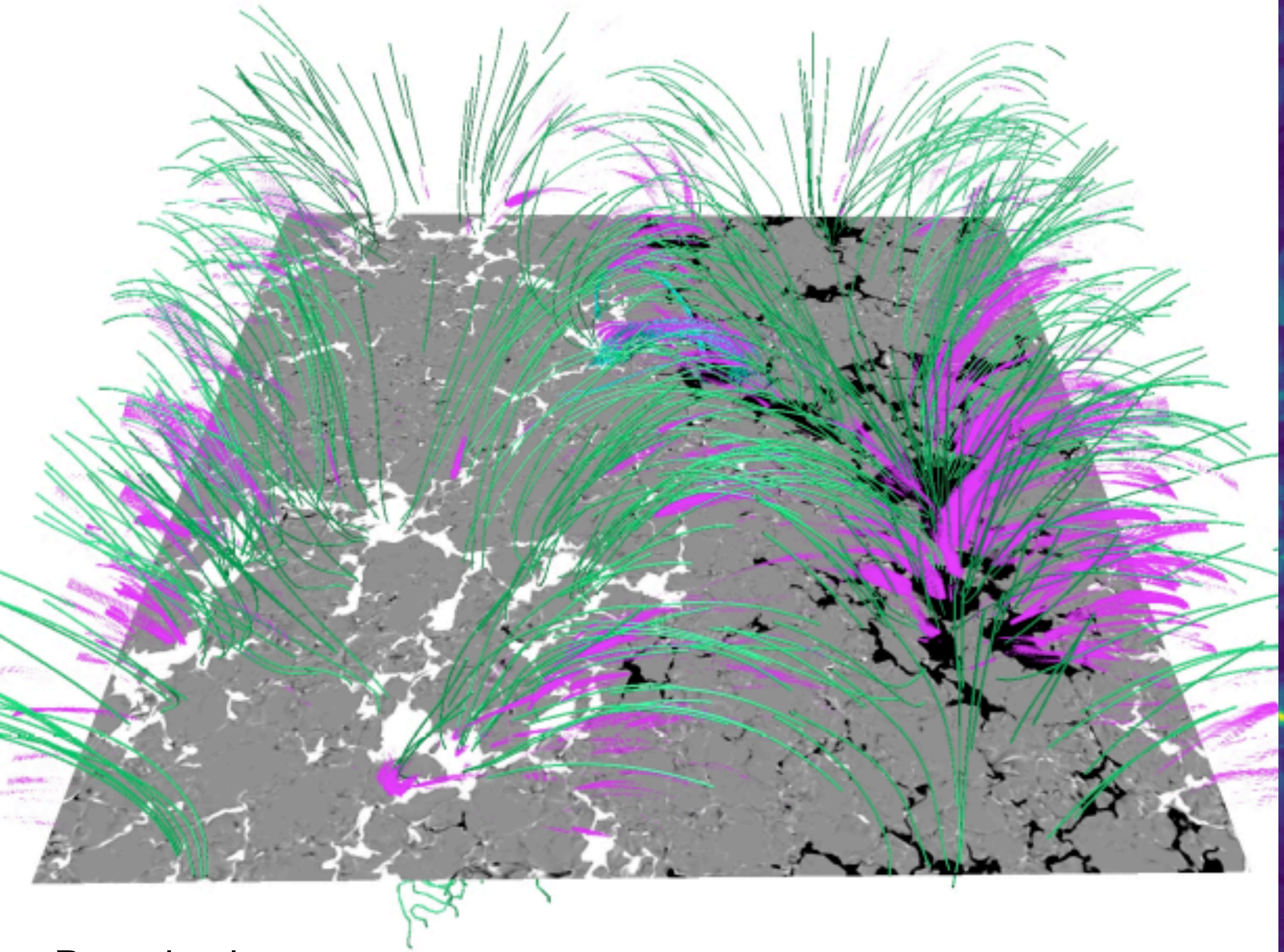


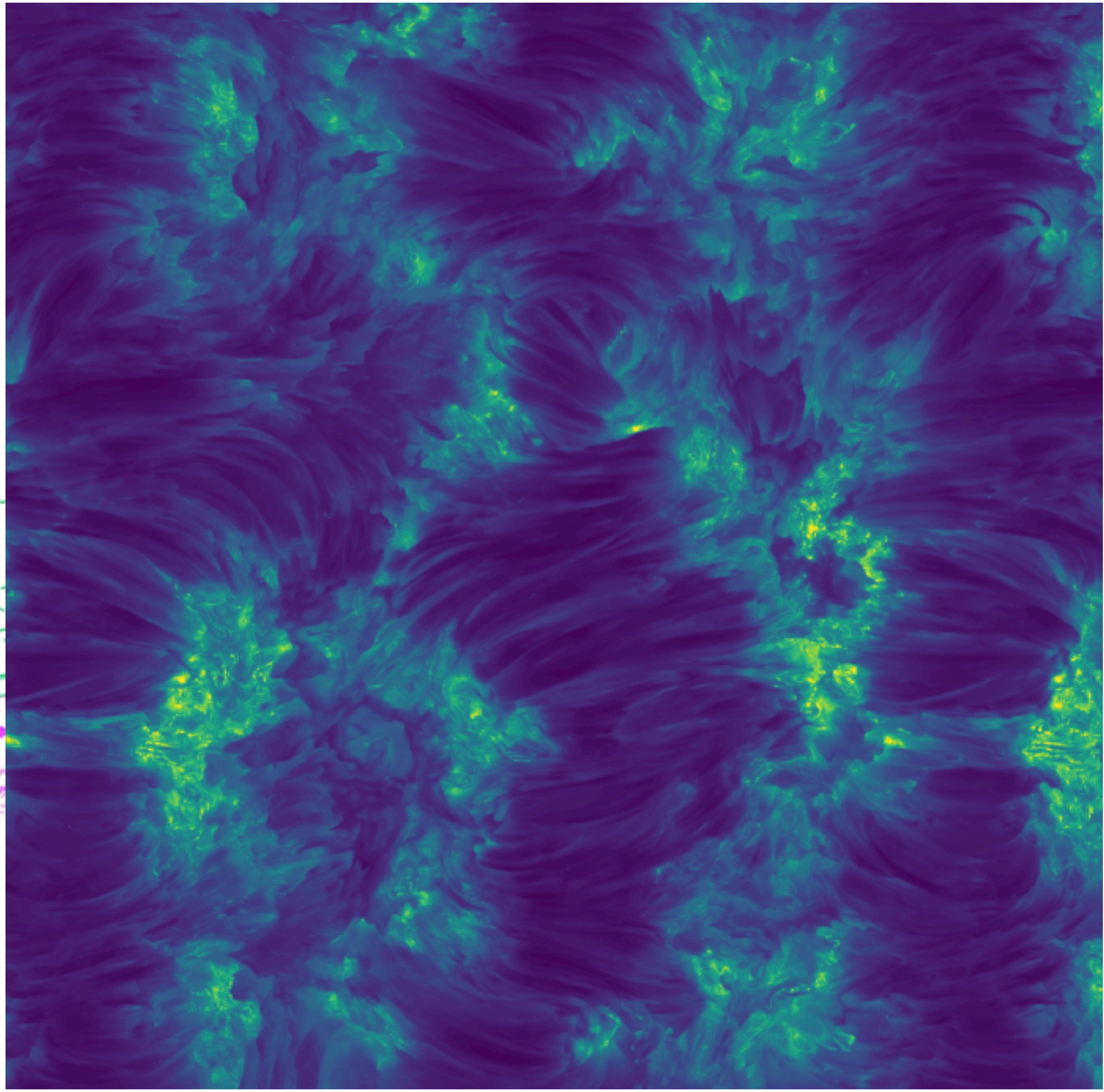


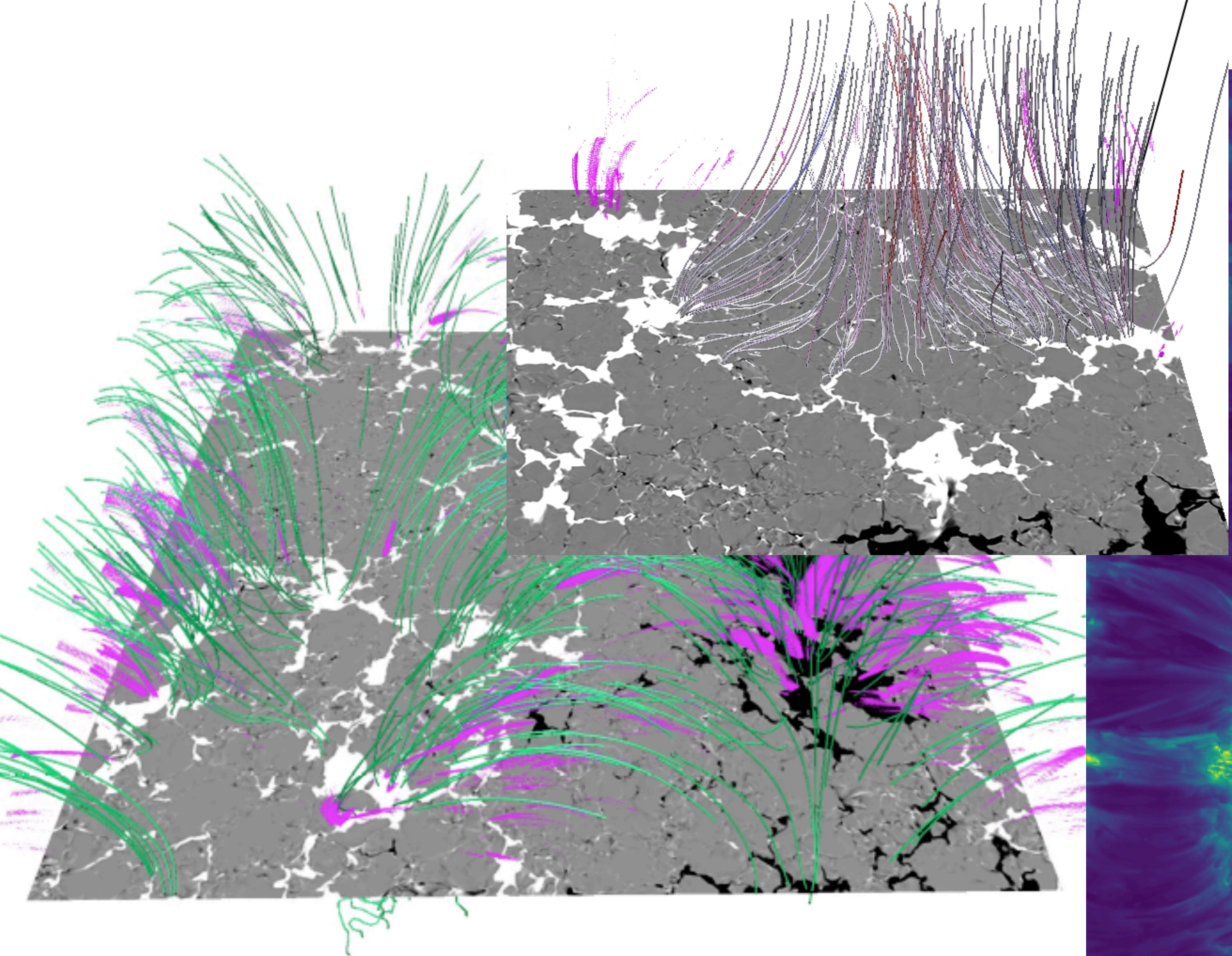




Domain size:
40x40x22 Mm

green - magnetic field lines
purple - high current density





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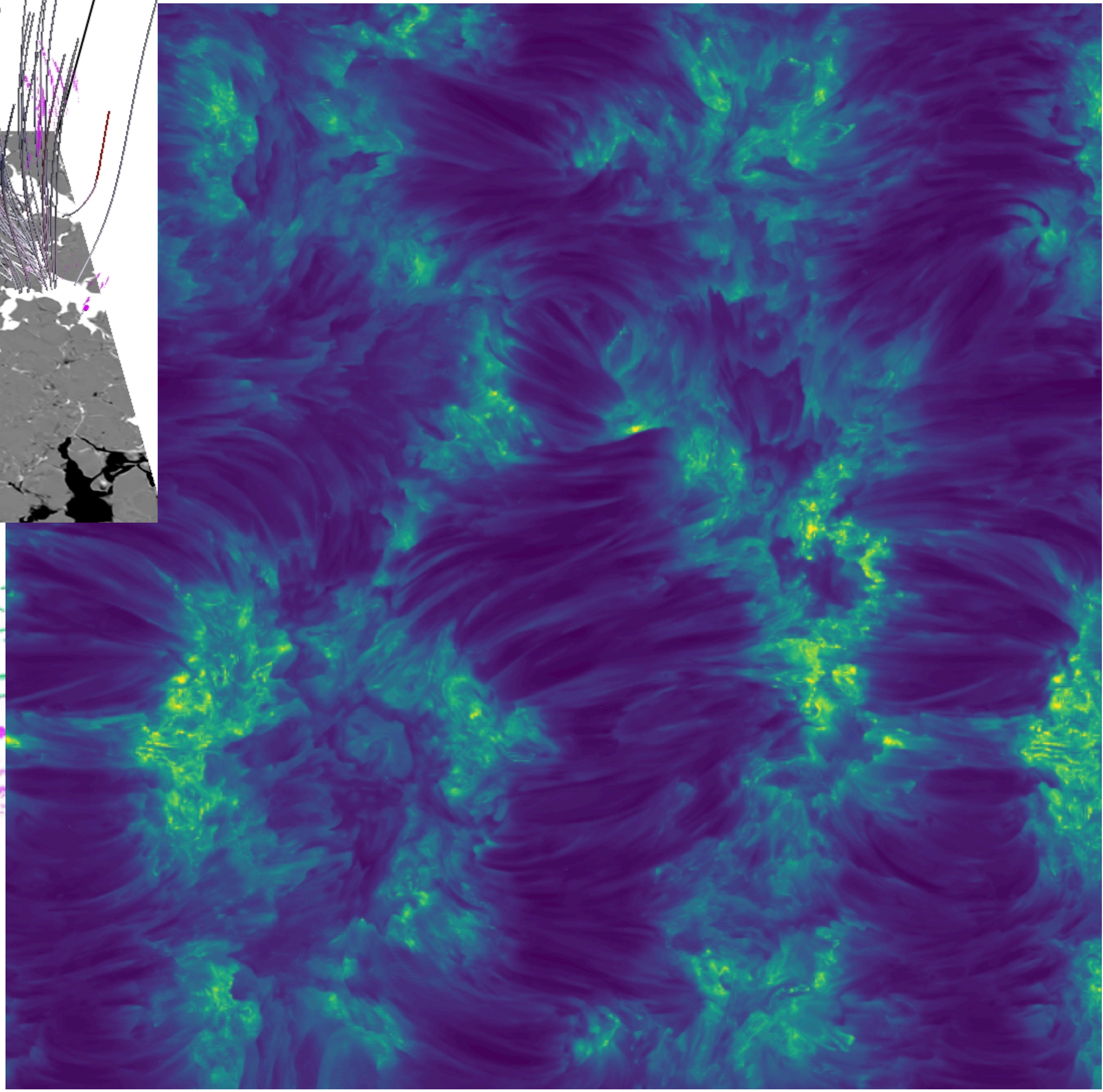
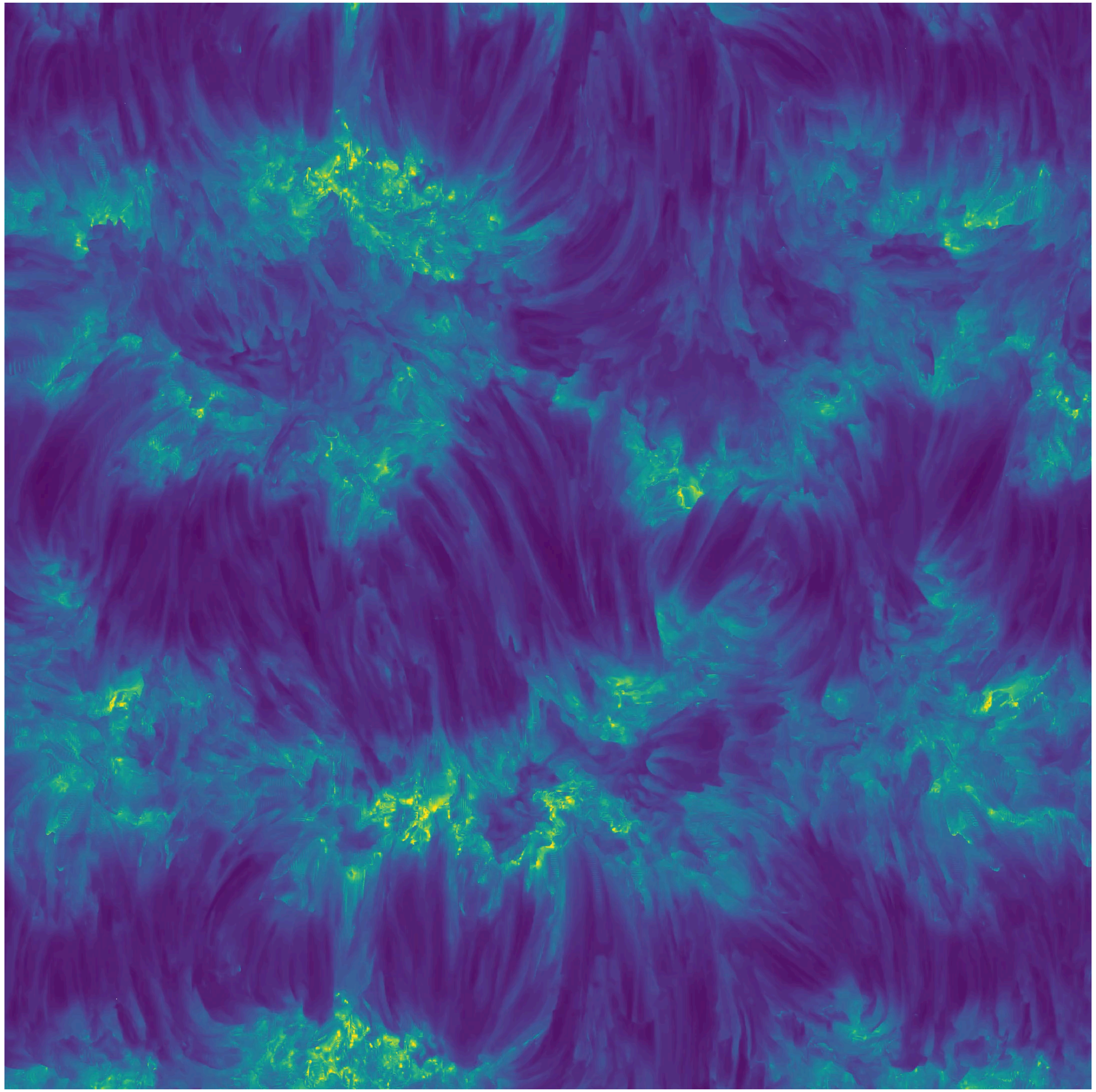
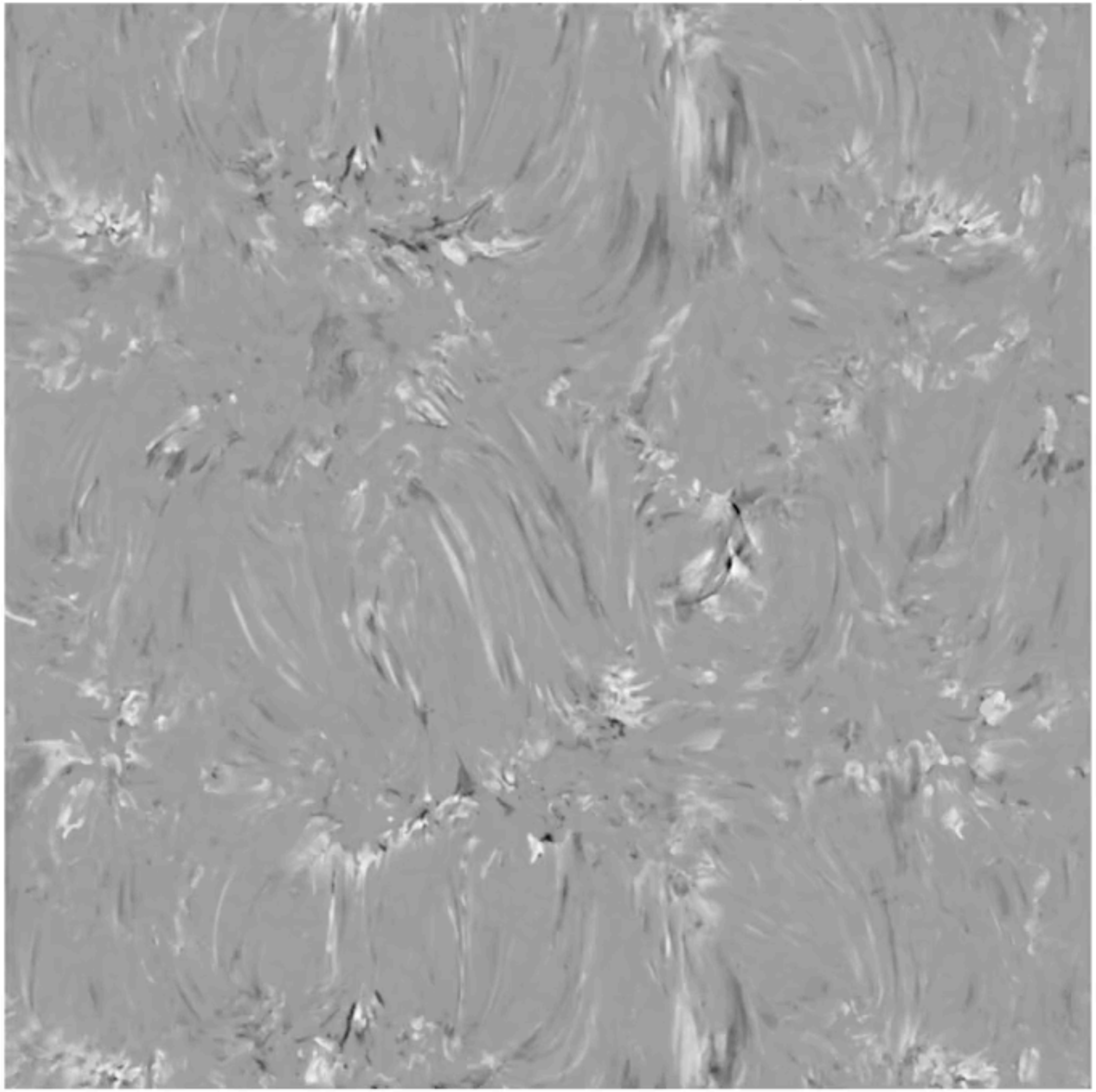


Synthetic chromosphere

Features reproduced: long fibrils, short and long dynamic fibrils, surges, Rob’s events, RREs and RBEs, spicule.

Duration ~ 5 min
Cadence ~ 10 s
Dopplegrams +-36 km/s





Synthetic chromosphere

Features reproduced: long fibrils, short and long dynamic fibrils, surges, Rob’s events, RREs and RBEs, spicule.

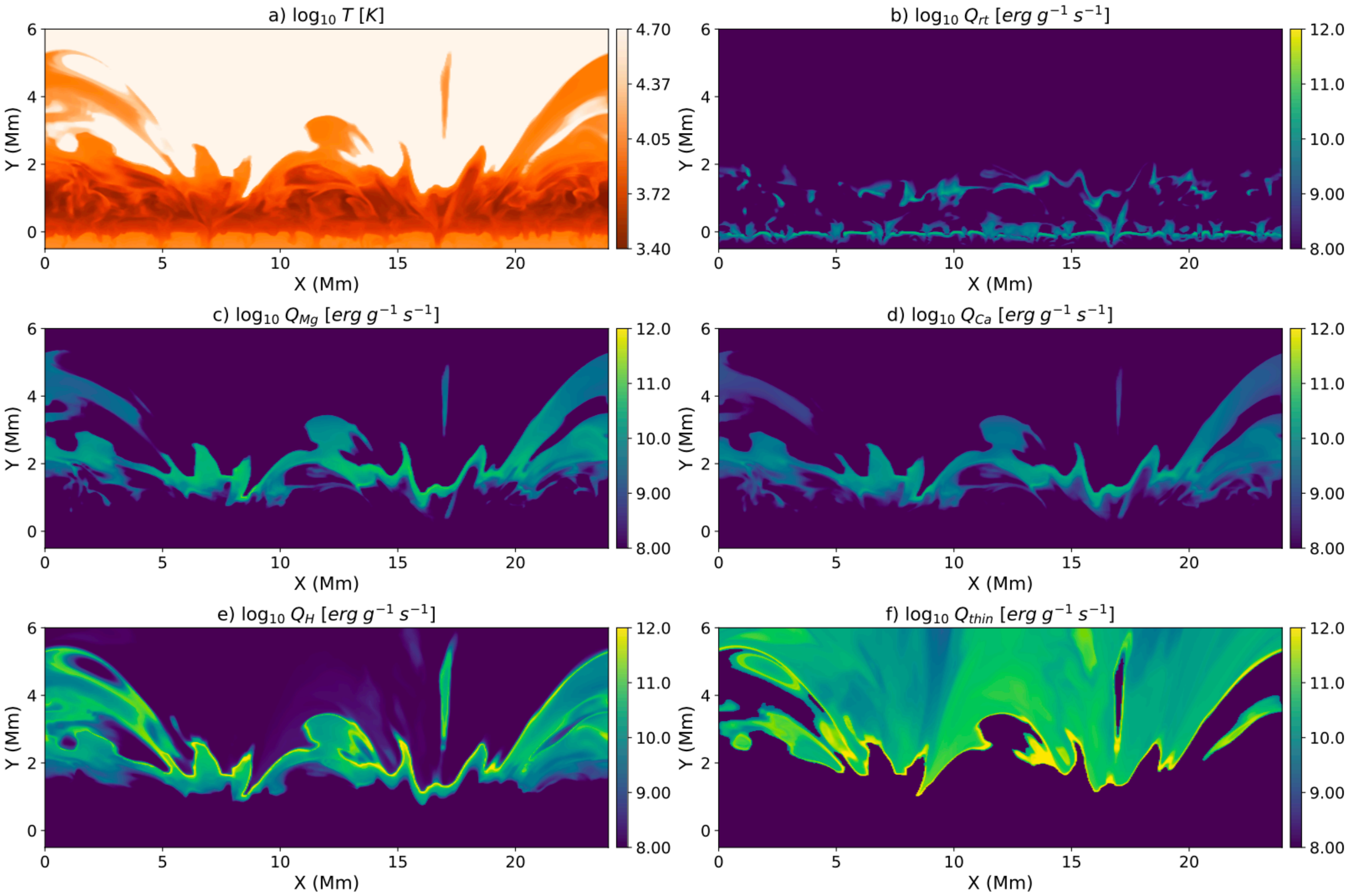
Duration ~ 5 min
Cadence ~ 10 s
@ -60 km/s

Heating

$$\frac{\partial e}{\partial t} + \vec{\nabla} \cdot (e\vec{v}) = \underset{\text{compression}}{-P\,(\nabla \cdot \vec{v})} - \underset{\text{conduction}}{\nabla \cdot \vec{F_c}} - \underset{\text{radiation}}{\nabla \cdot \vec{F_r}} + \underset{\text{magnetism}}{Qres} + \underset{\text{viscosity}}{Qvis}$$

Heating

$$\frac{\partial e}{\partial t} + \vec{\nabla}$$



ty

Przybylski et al. submitted

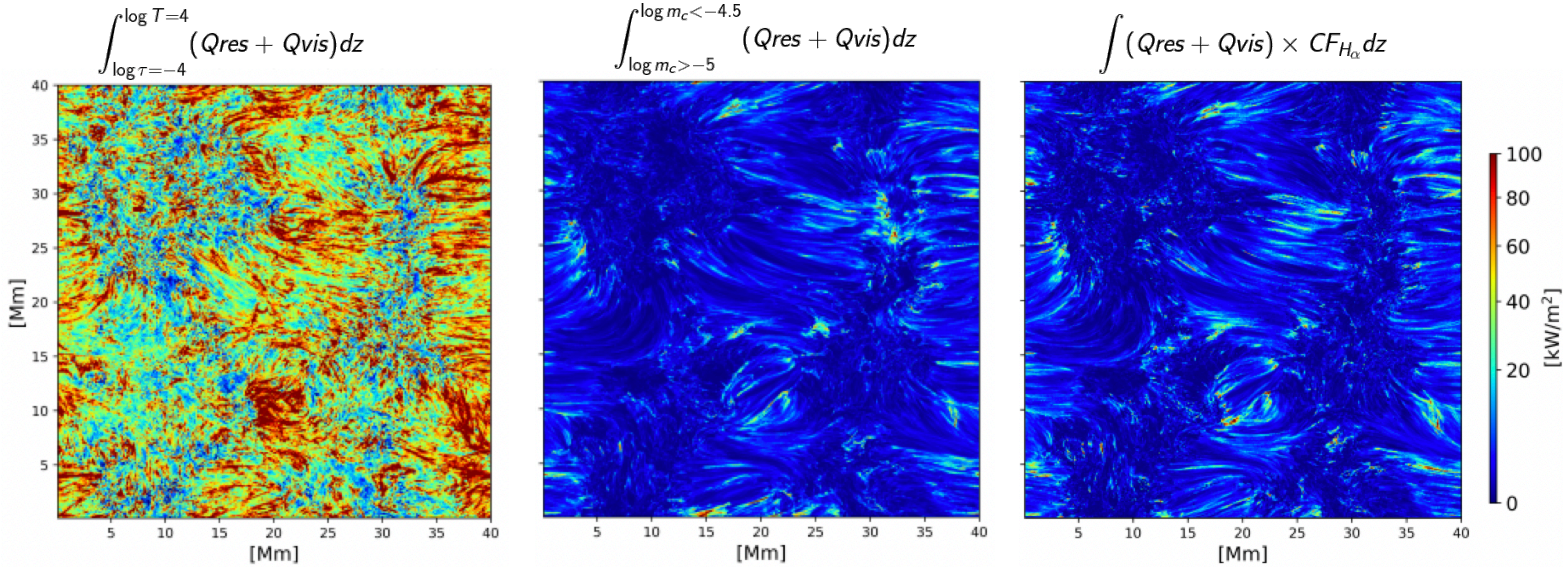
Heating

Canonical values by Withbroe & Noyes 1977

QS: 4 kW/m2   AR: 20 kW/m2

$$\frac{\partial e}{\partial t} + \vec{\nabla} \cdot (e\vec{v}) = -P\,(\nabla \cdot \vec{v}) - \nabla \cdot \vec{F_c} - \nabla \cdot \vec{F_r} + Qres + Qvis$$

compression conduction radiation magnetism viscosity

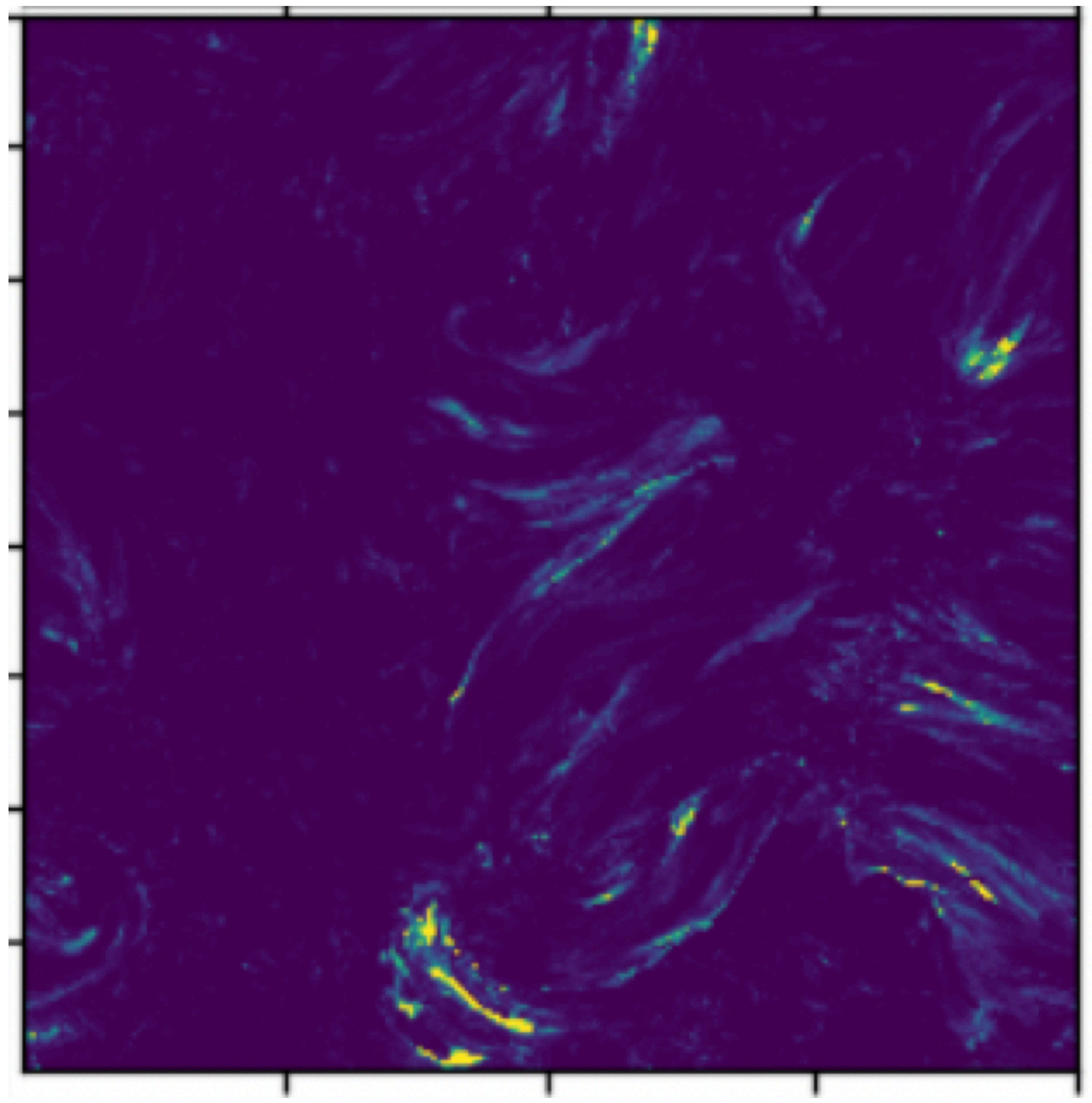


Heating - can be constrained by multiple observables

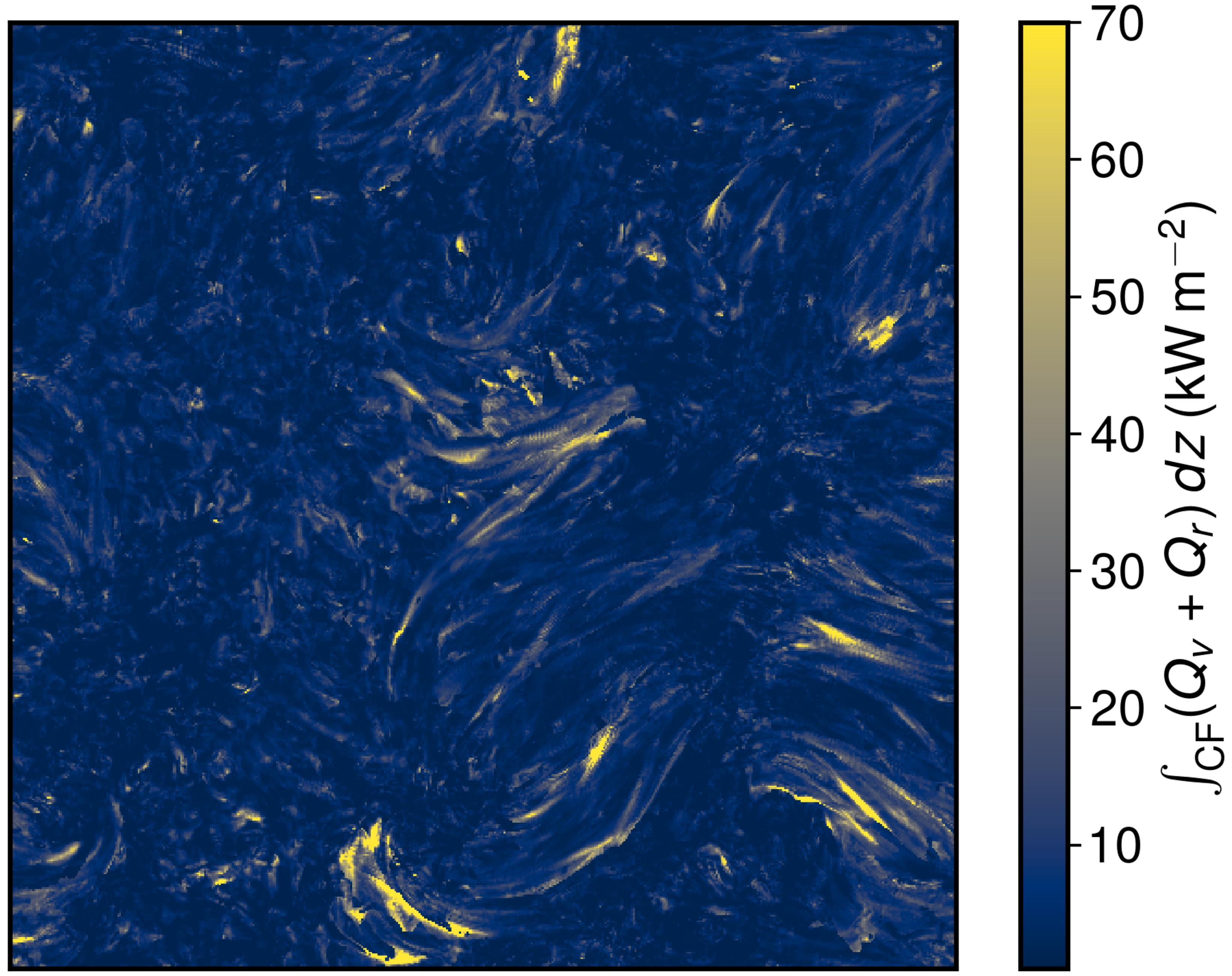
- Heating cannot be observed but losses can
- Retrieved with inversion at 100 km resolution show large variation in space and time ~ 0-160 kW/m2

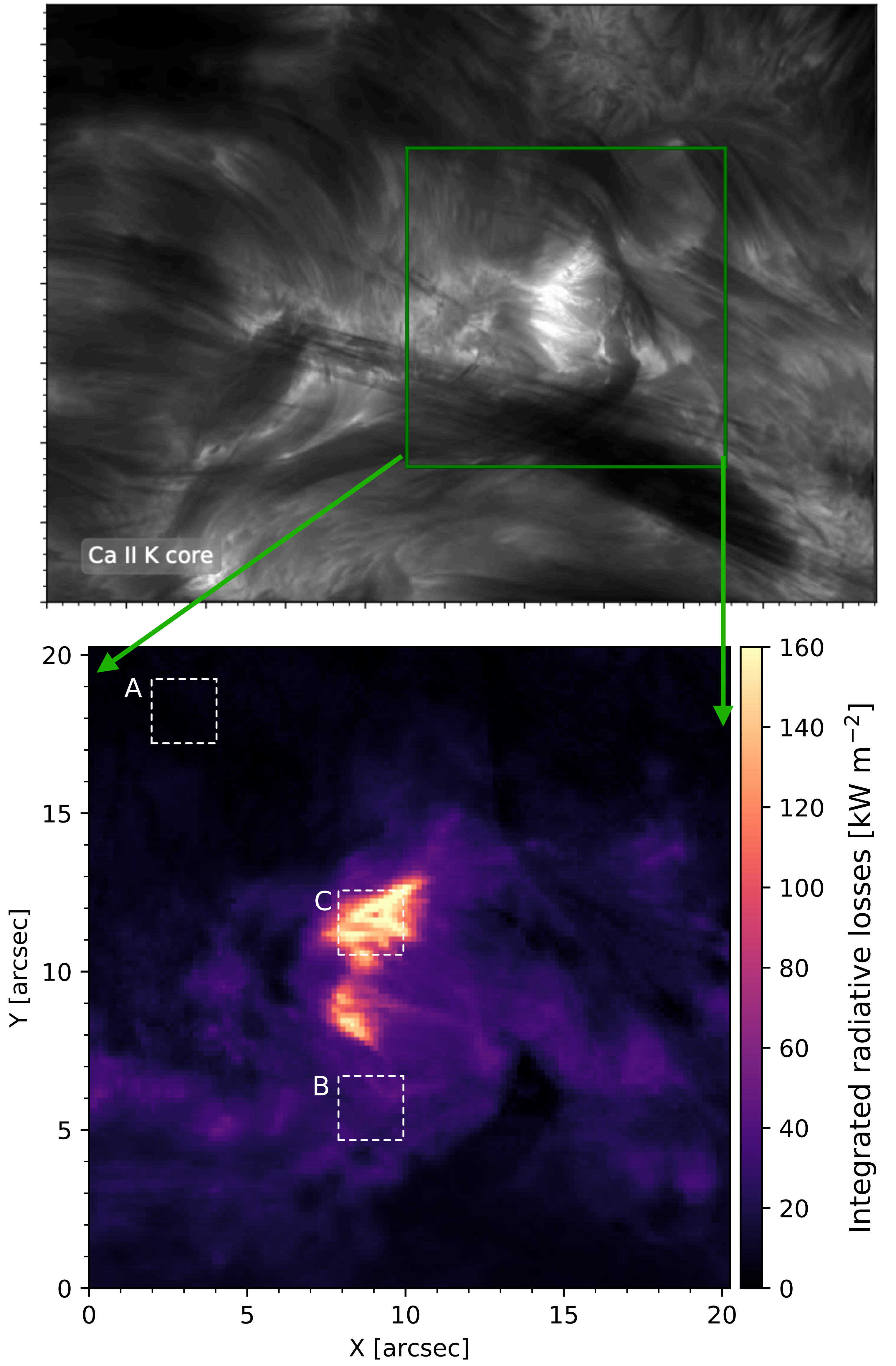
Check out:
Poster Session 4.2 - Jaime de la Cruz Rodriquez - method description
Poster Session 8.5 - Rahul Yadav - application on a flare data (Ca H, Ca K, Ca IR, Mg h, Mg k)
Poster Session 10.2 - Joao da Silva Santos - application on an emerging region data (Alma, Ca IR)

$$\int_{\log m_c > -5}^{\log m_c < -4.5} (Qres + Qvis)\, dz$$



Alma 3 mm





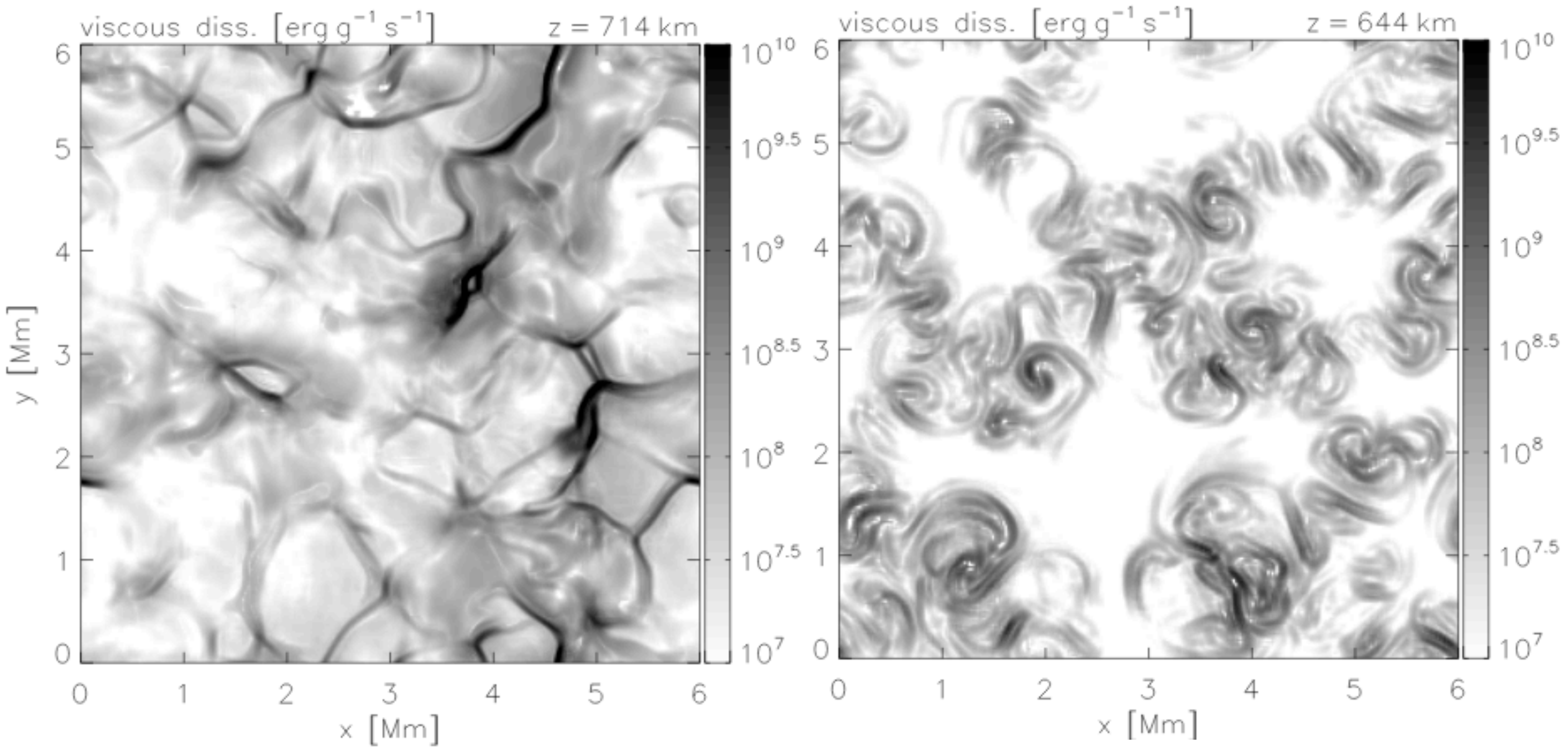
Diaz-Baso et al., 2021

Chromospheric modelling - what do we need?

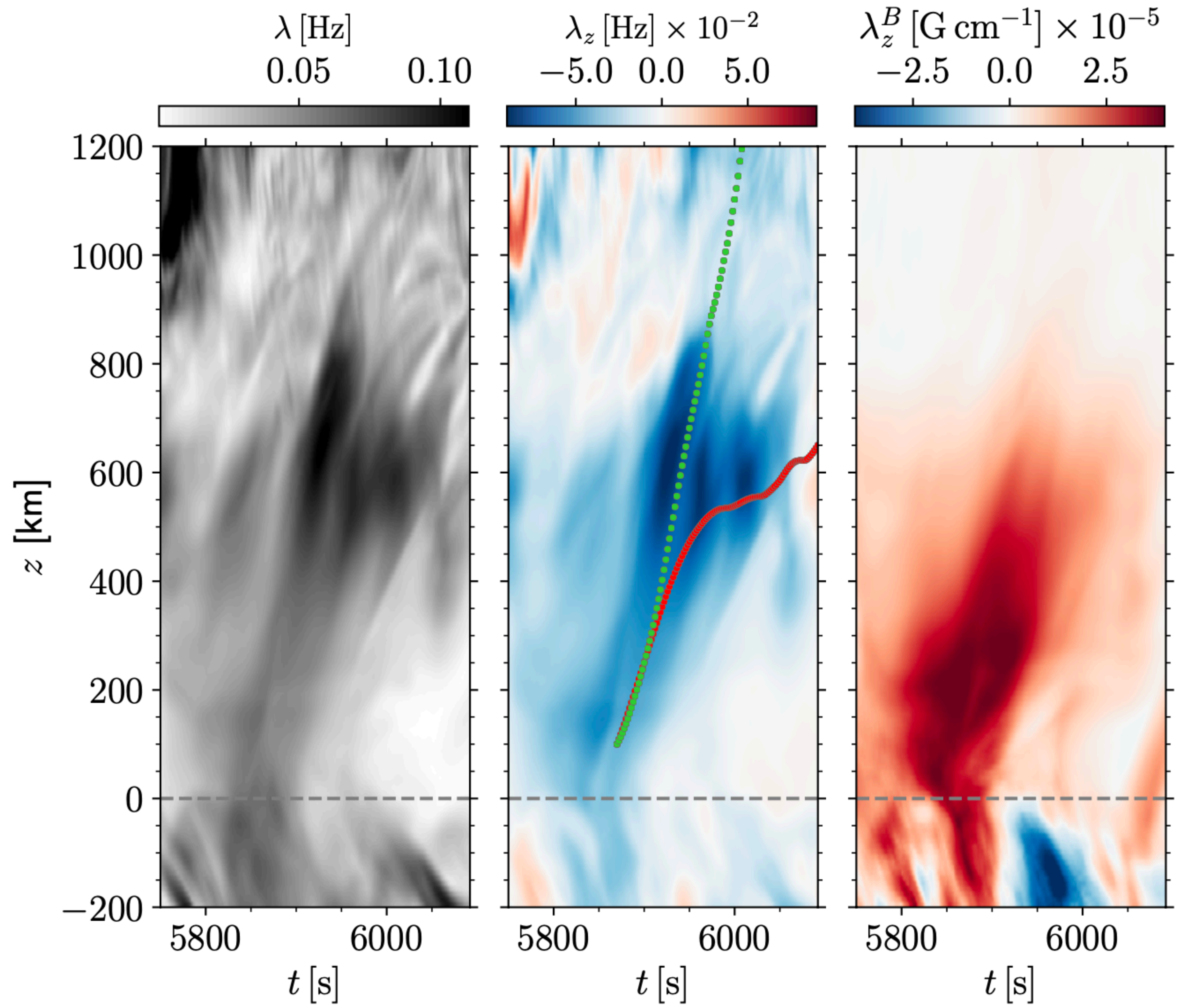
- realistic magnetic configuration
- small scales relevant as large
    - resolve relevant drivers
    - reproduce observed Poynting flux

Vortex flow seems to be relevant:

- Observations - Bonet et al. 2008, Requerey et al. 2017,2018, Wedemeyer & Rouppe van der Voort 2009, Morton et al. 2013, Shetye et al. 2019
- Simulations - Moll et al. 2011, Kitiashvili et al. 2011, Shelyag et al. 2013, Wedemeyer & Steiner 2014, Yadav et al. 2020,2021, Battaglia et al. 2021



Moll et al. 2012



Battaglia et al. 2021

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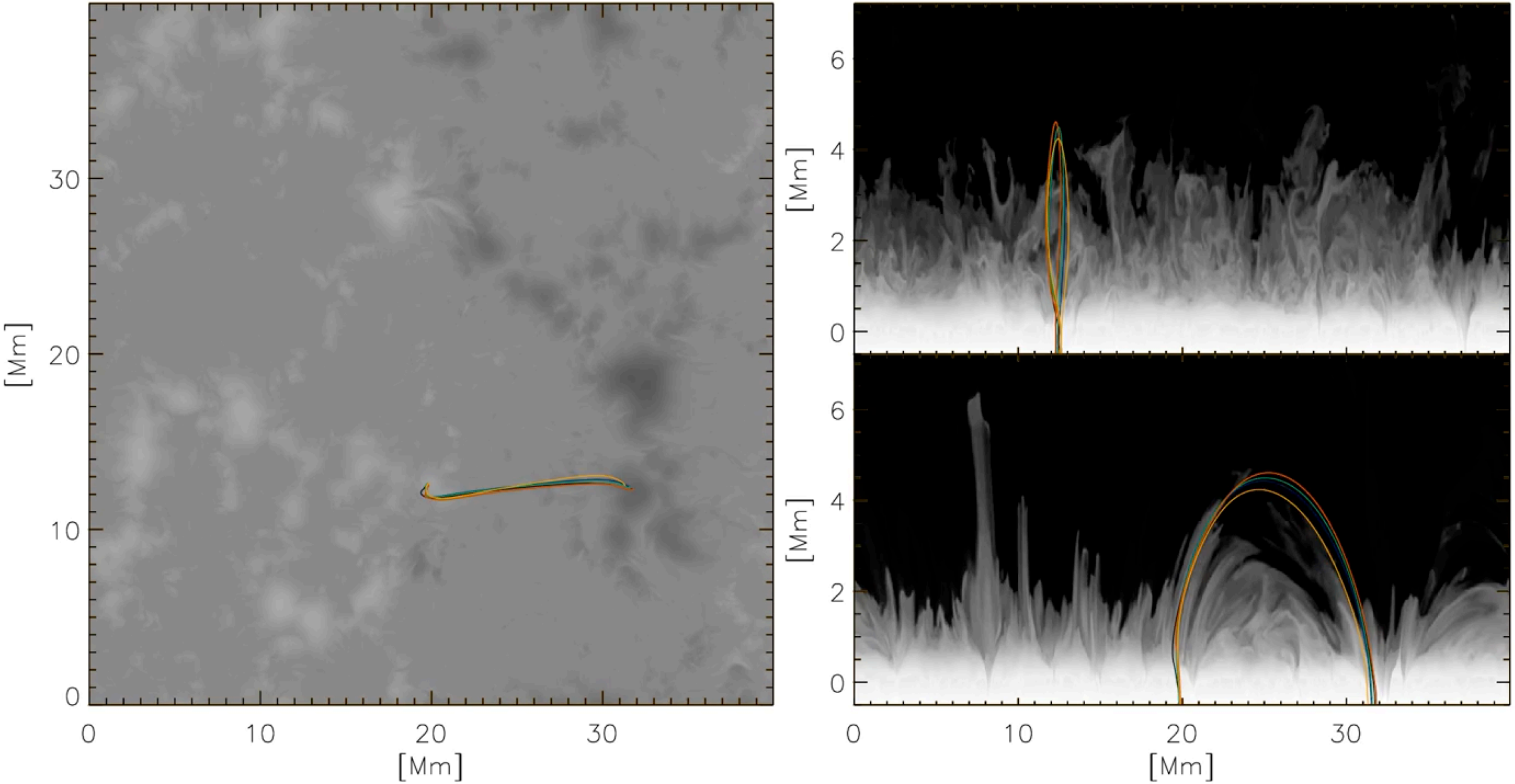
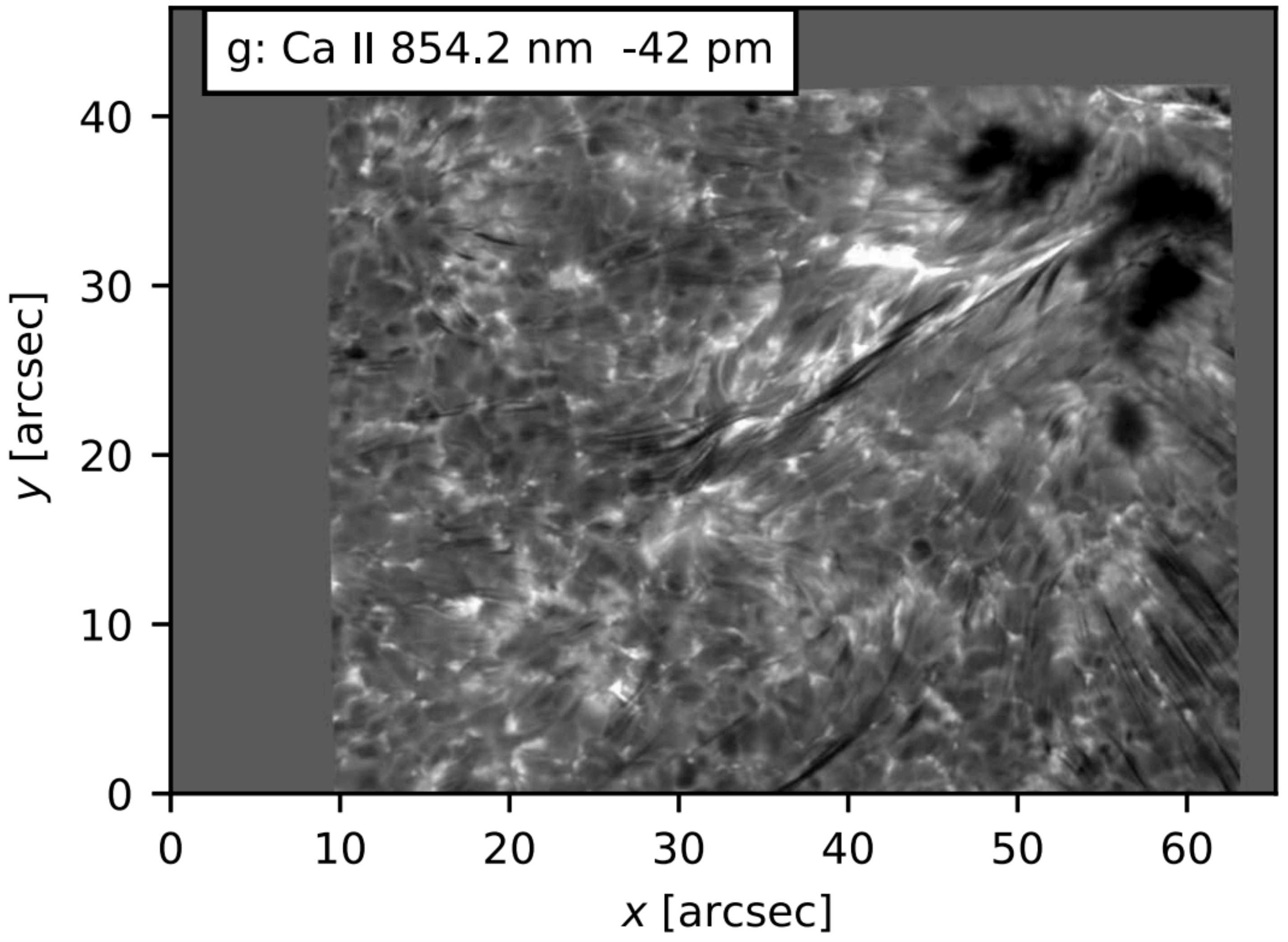
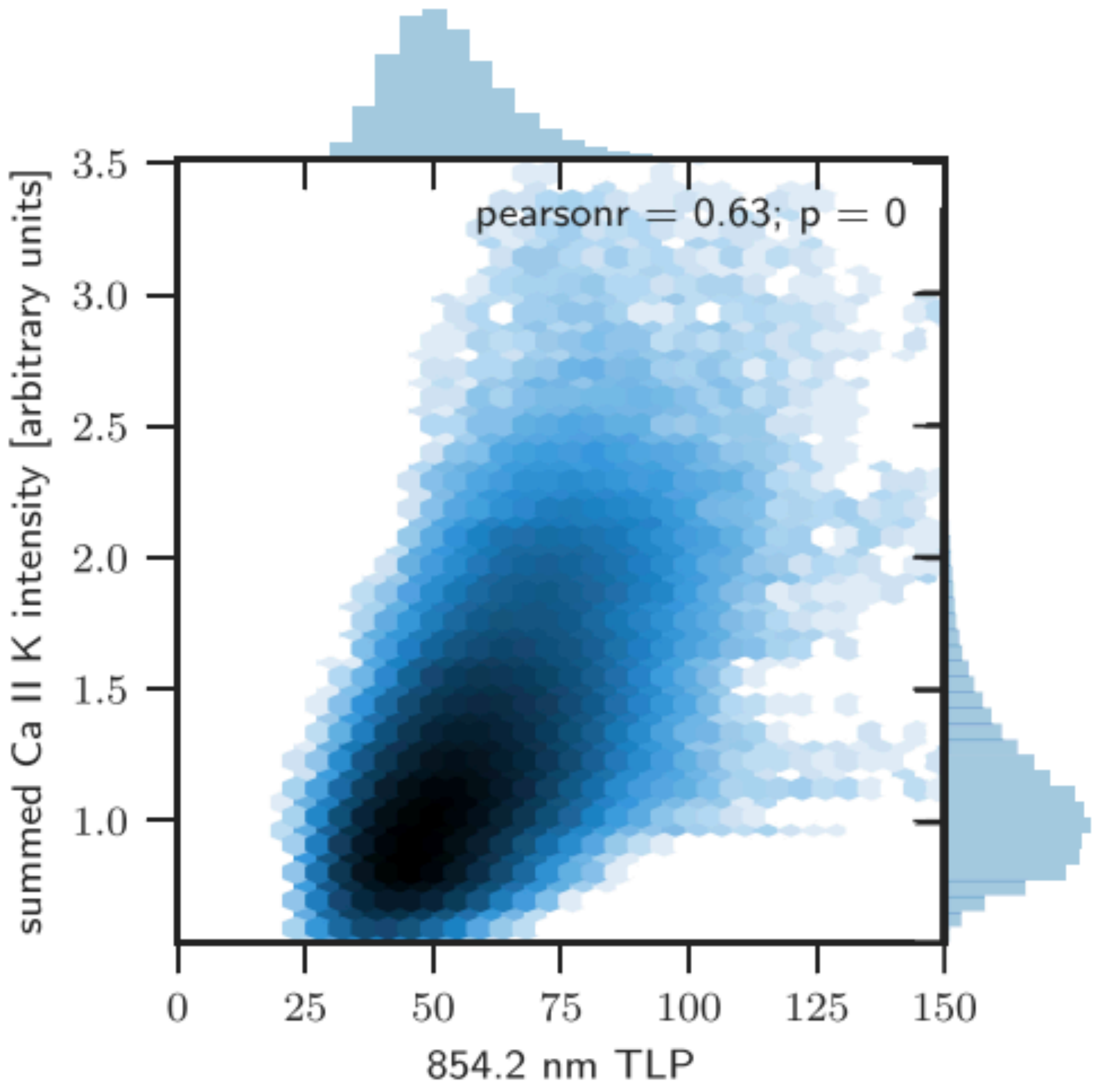


Chromospheric modelling - what do we need?

- realistic magnetic configuration
- small scales relevant as large
- emergence





Leenaarts et al. 2018

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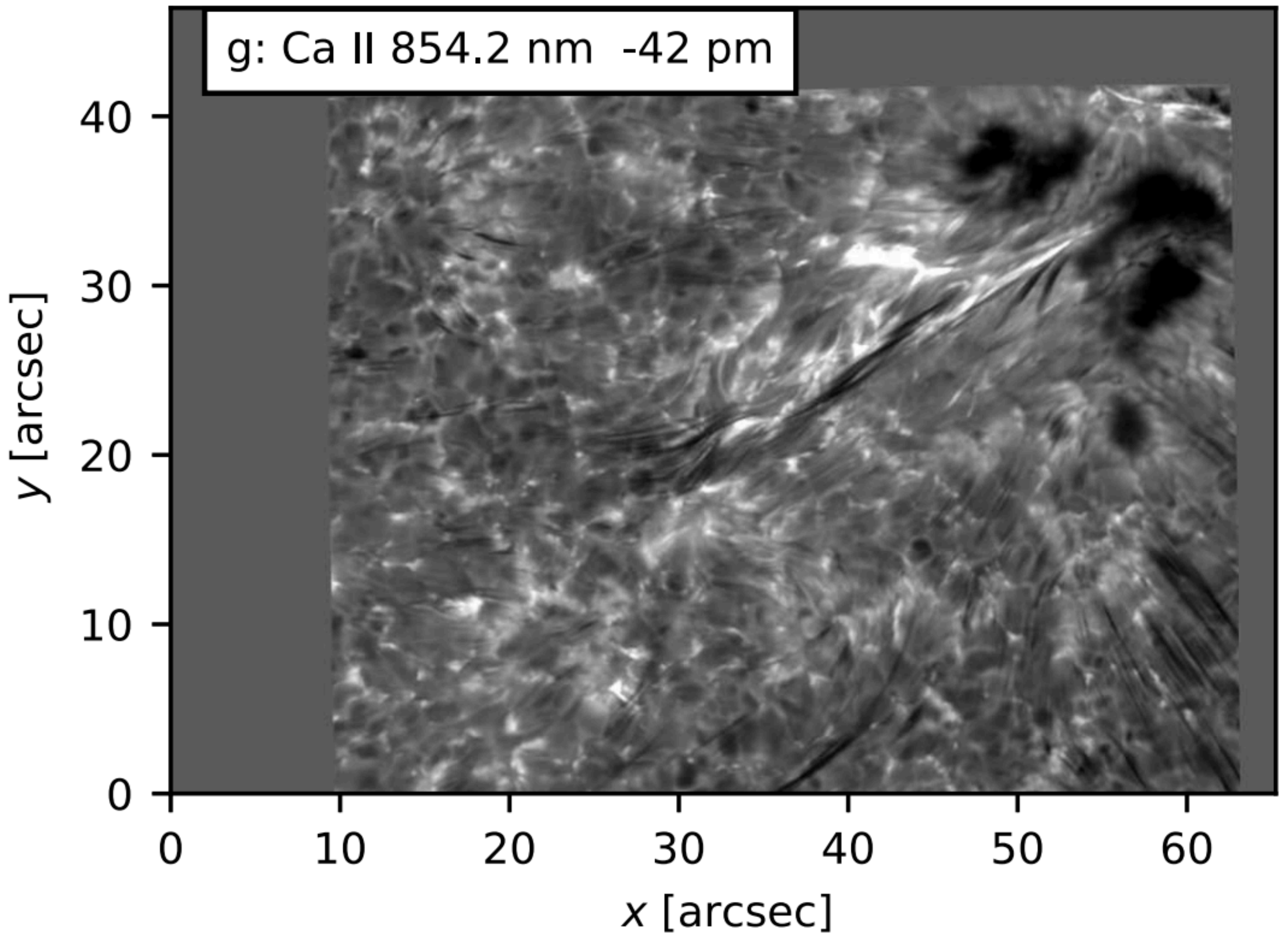
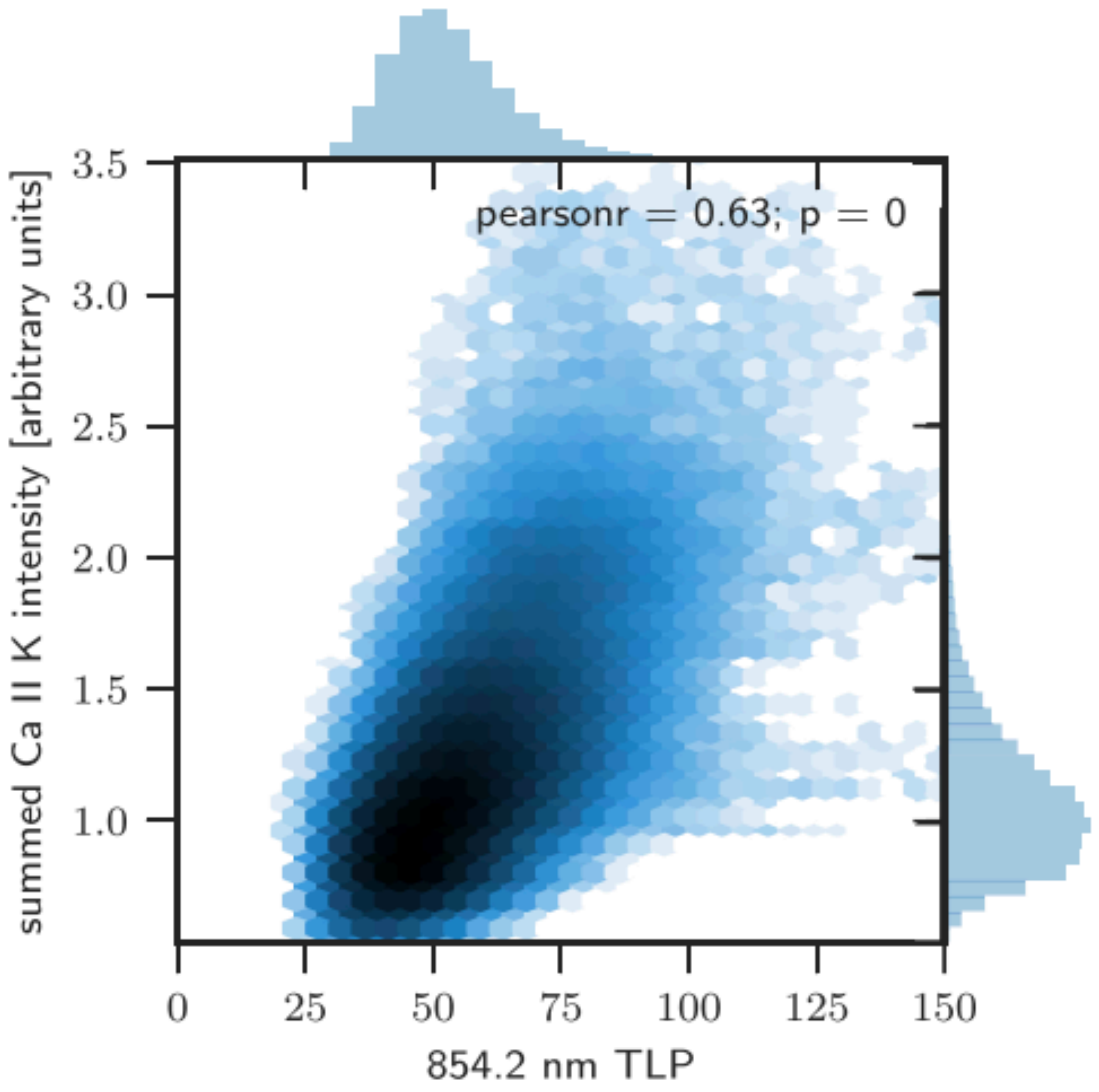
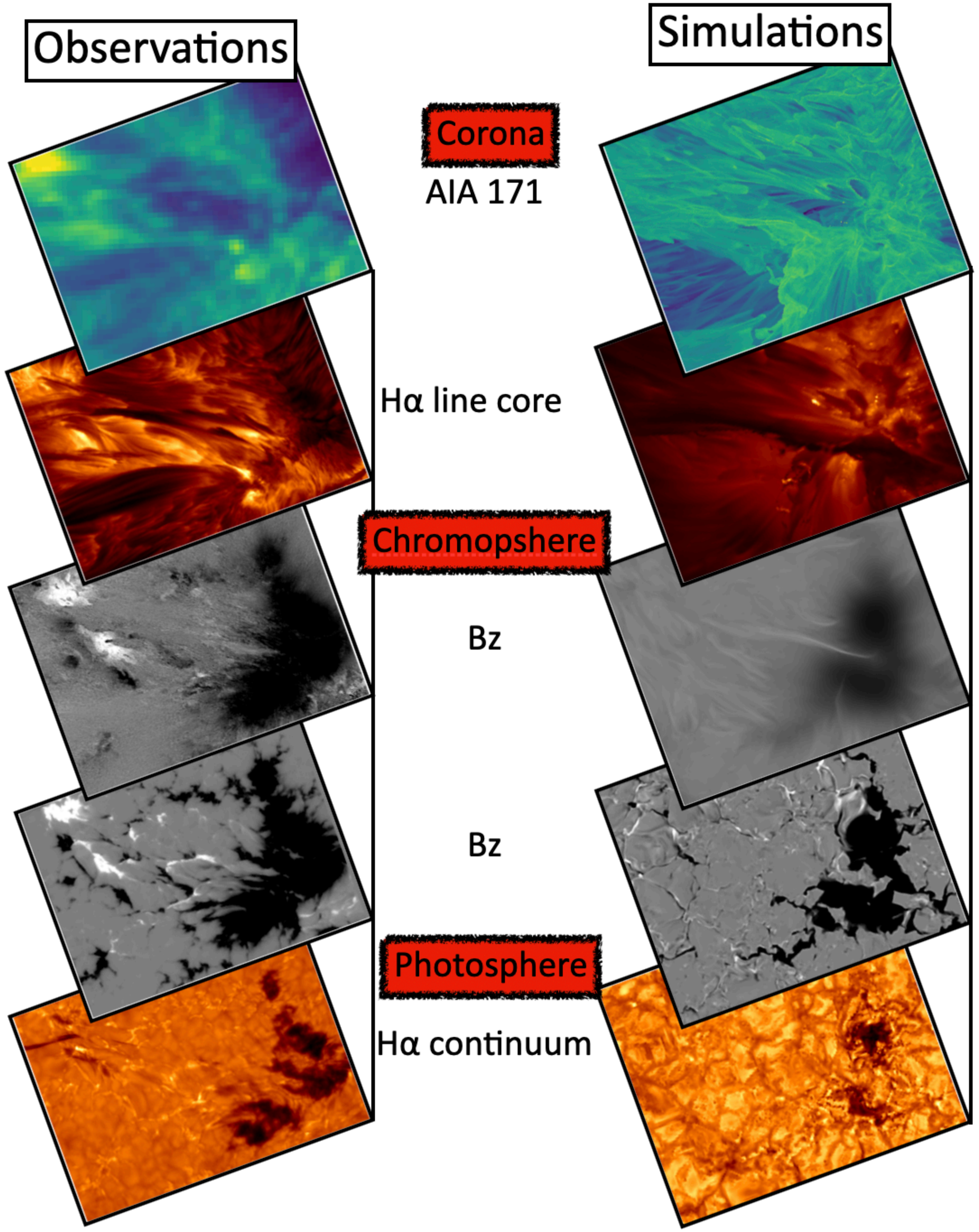




Leenaarts et al. 2018



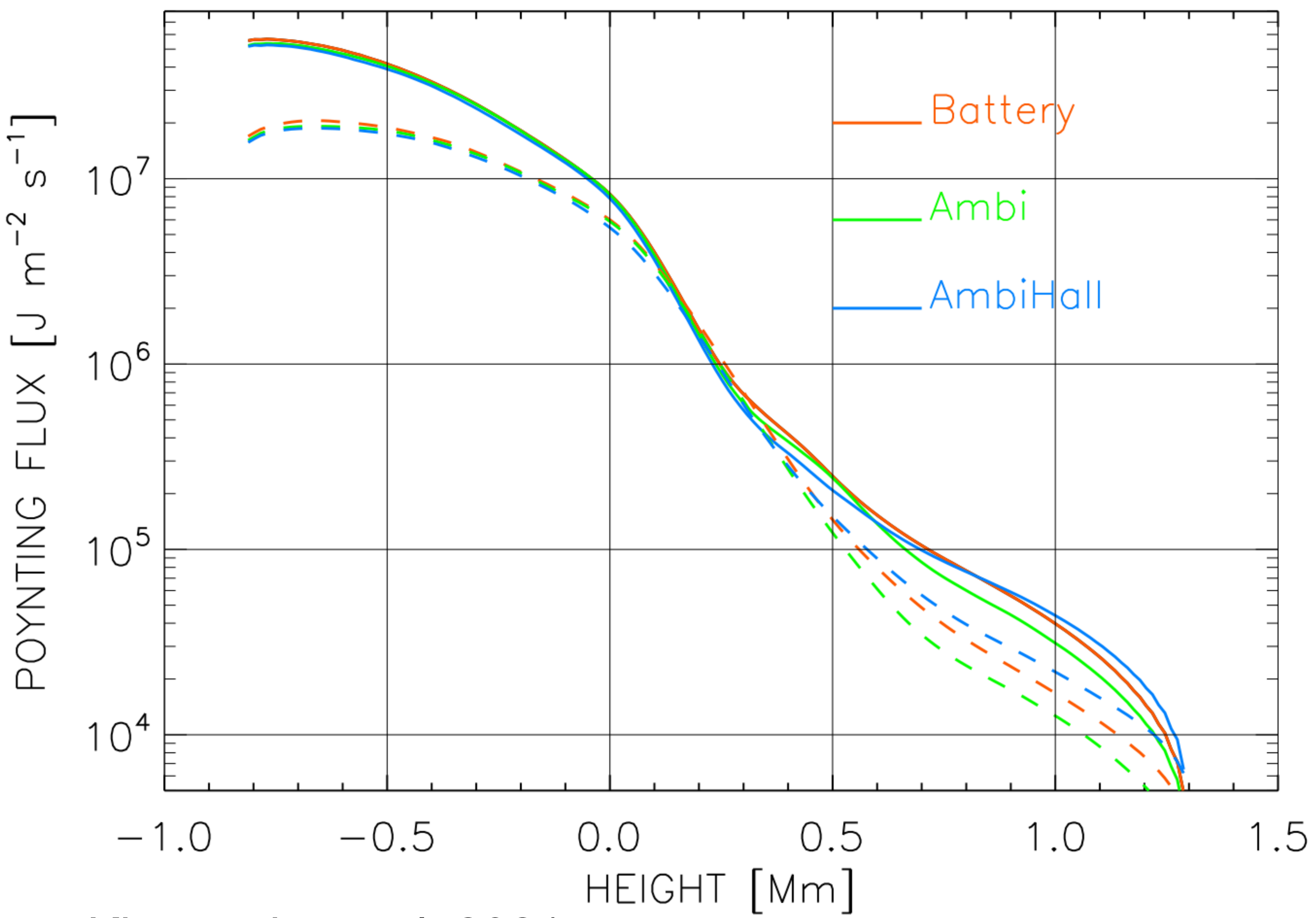
AIA 94
DEM lgT>6
AIA 171
DEM lgT<5
$t = 0.2$ min
Bz @
z=0.5 Mm
dBz/dt
$\int (Qres + Qvis)$
$\int_{\log m_c > -5}^{\log m_c < -4.5}$
with mask
T <1.e4 K
[Mm]
[kW/m2]

Chromospheric modelling - what do we need?

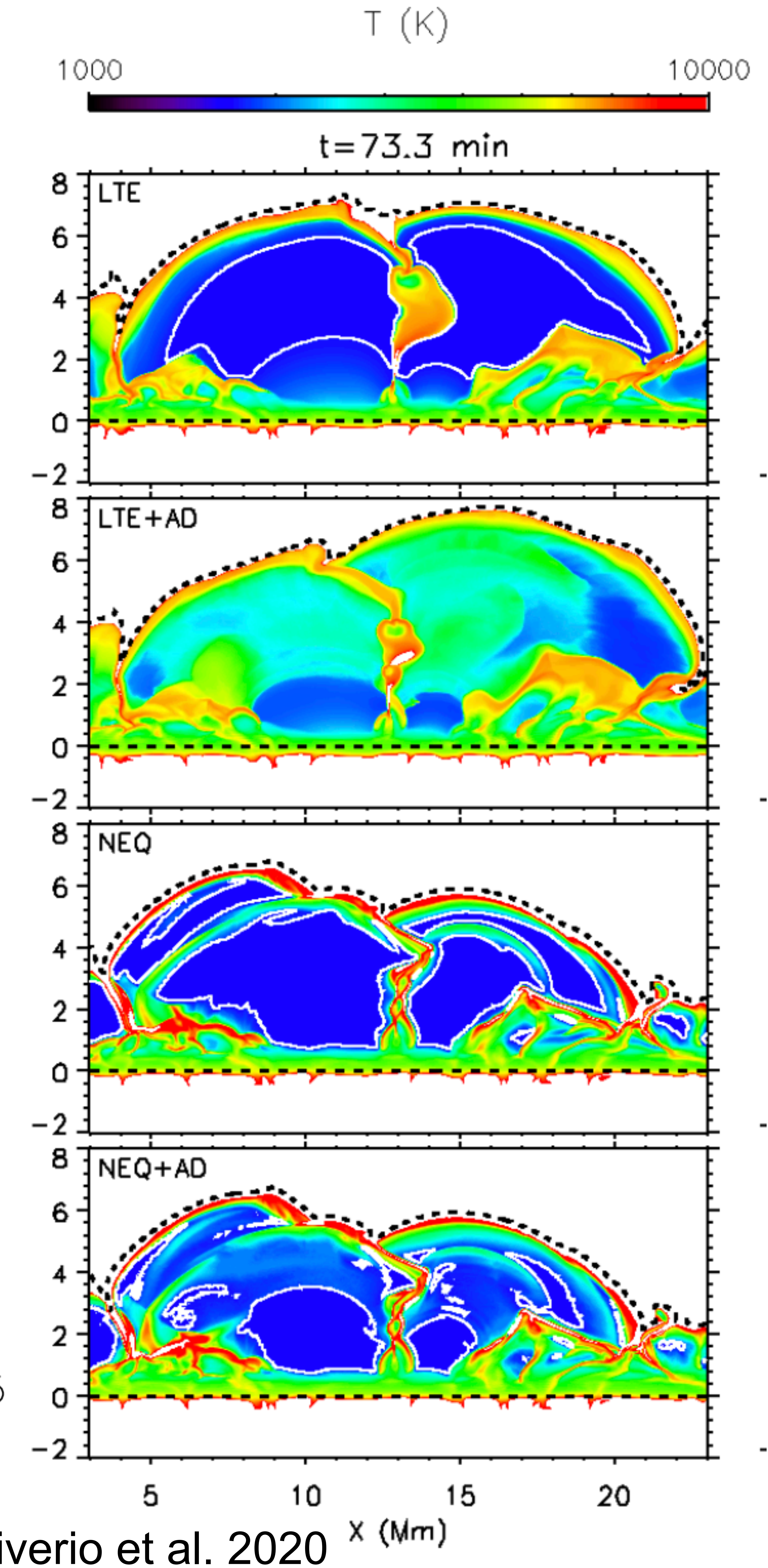
- realistic magnetic configuration
- small scales relevant as large
- emergence
- non-equilibrium ionisation
- ion-neutrals effects

go together

Change atmospheric properties at:
- Shocks
- Contact regions (spicule)
- Emergence
- Reconnection sites
- Poynting flux with height



Khomenko et al. 2021

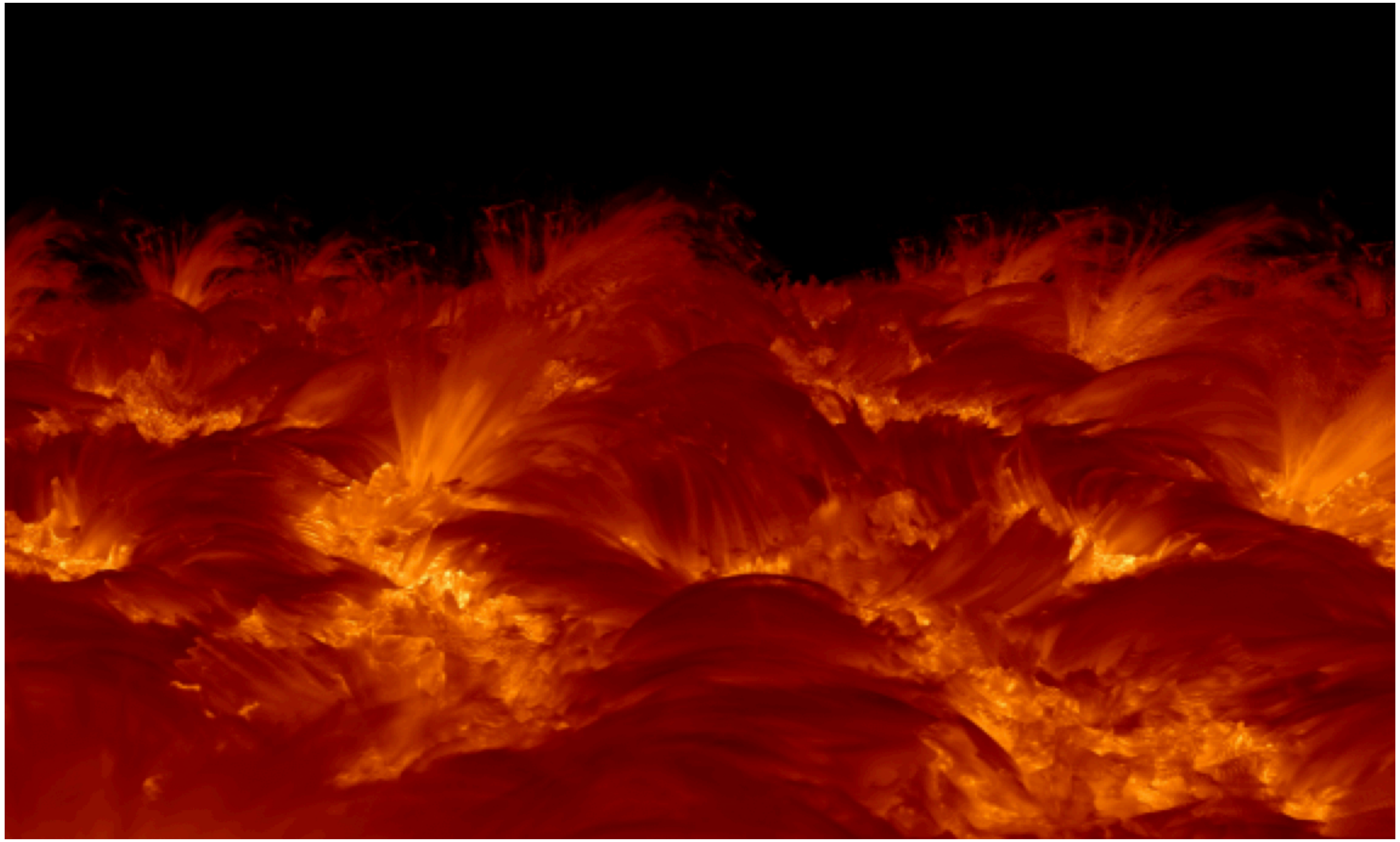


Nobrega Siverio et al. 2020

To take:

Chromospheric modelling - what do we need?

- realistic magnetic configuration
- small scales relevant as large
- emergence
- non-equilibrium ionisation
- ion-neutrals effects



1-to-1 modelling
+
multi-line/continua observations