The formation and heating of chromospheric fibrils in a radiation-MHD simulation

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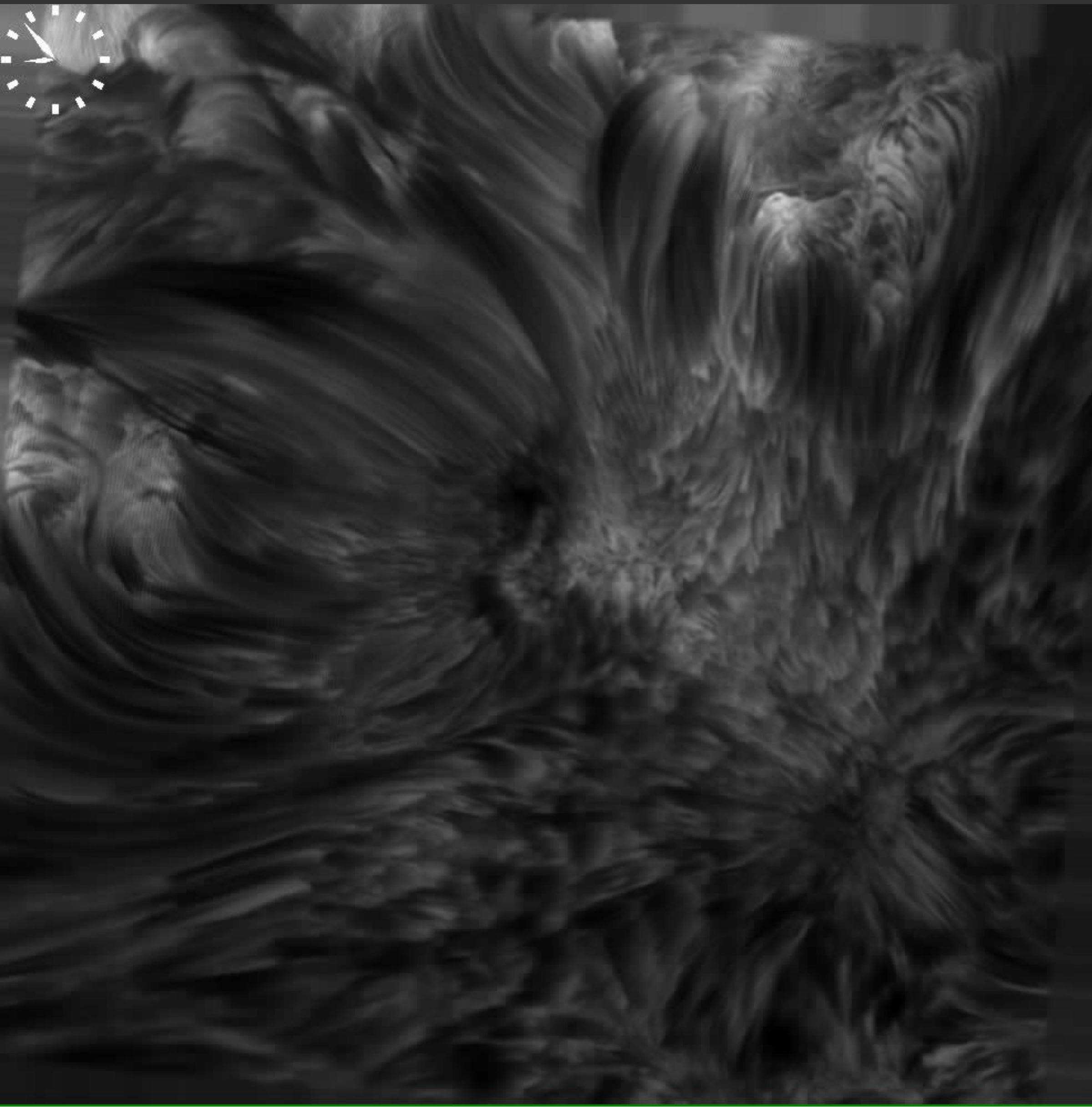


Obs phenomenon in chromospheric lines

Long (500-20000 km)
Narrow (180 km)

Lifetime:
Individual (200-400s)
Groups (much longer!)

Ubiquitous

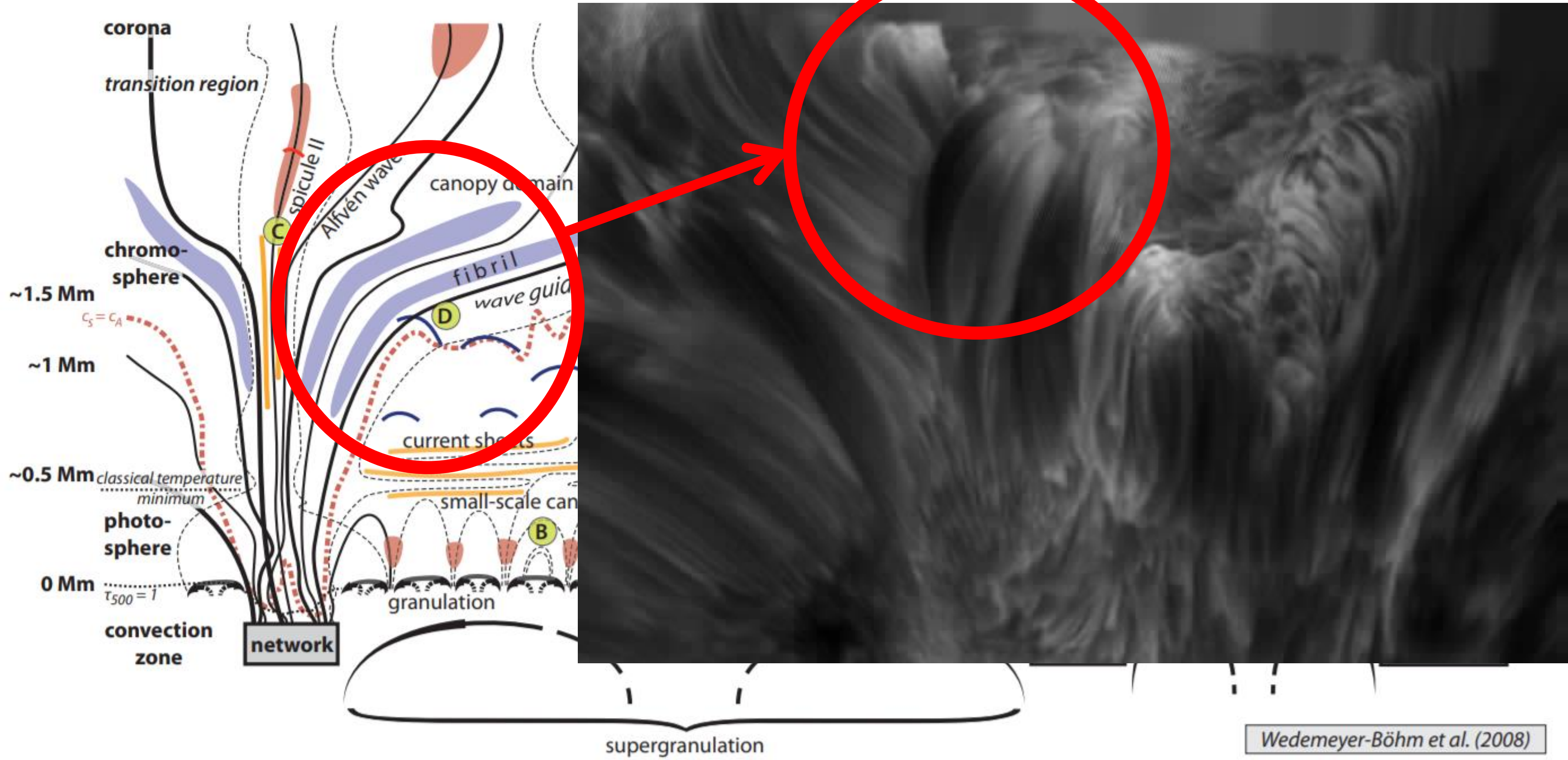
Left: Fibrils obs with SST.
L. Rouppe van der Voort & M. van Noort (University of Oslo 2005)

2007 De Pontieu, 2006 Hansteen, 2010 Wiegelmann, 2017 Gafeira, 2017 Mooroogen 2017 Jafarzadeh

Theories of fibrilar formation

1) p-mode at photophere → 2) material near footpoints rises → 3) Relatively static B-field acts as a guide

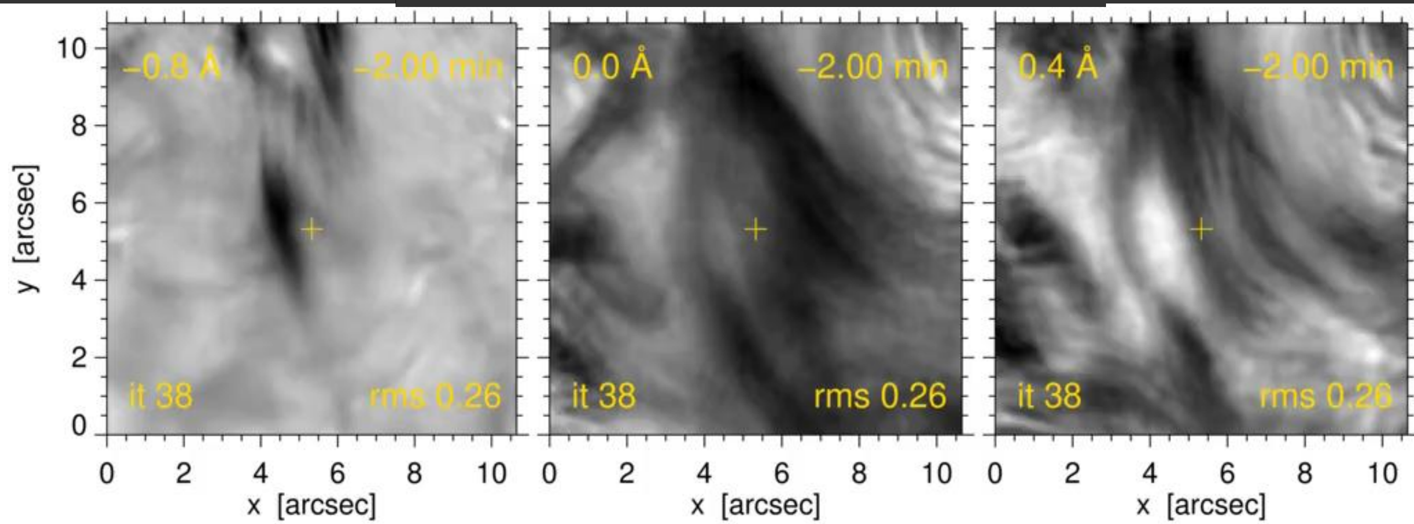
Hansteen et al 2006
De Pontieu et al 2007

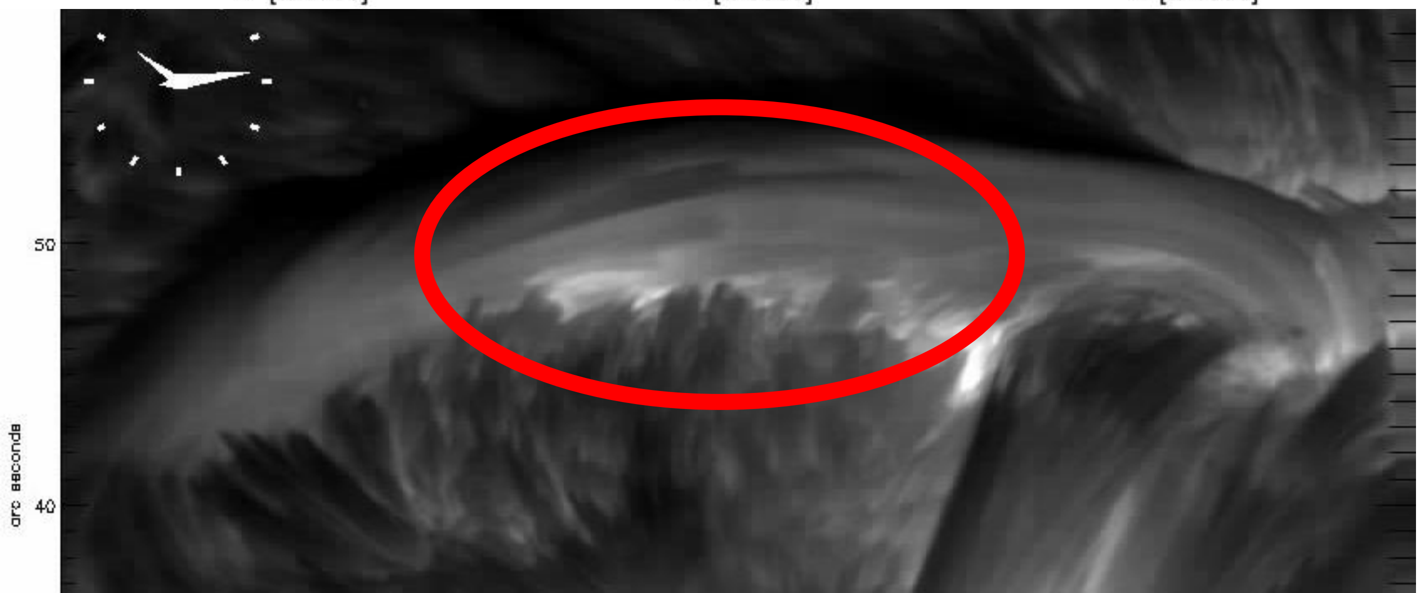


Wedemeyer-Böhm et al. (2008)

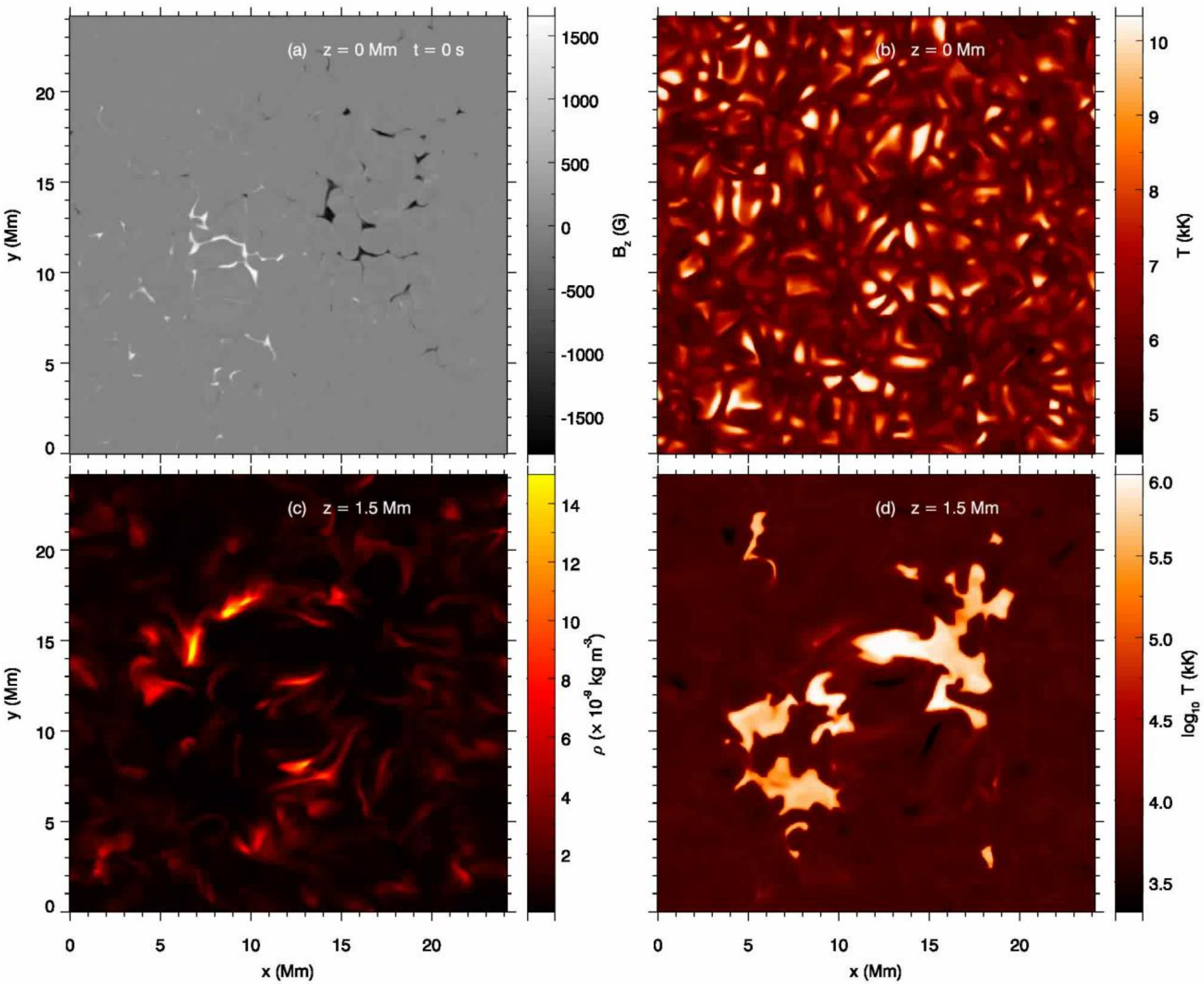
Theories of fibrilar formation

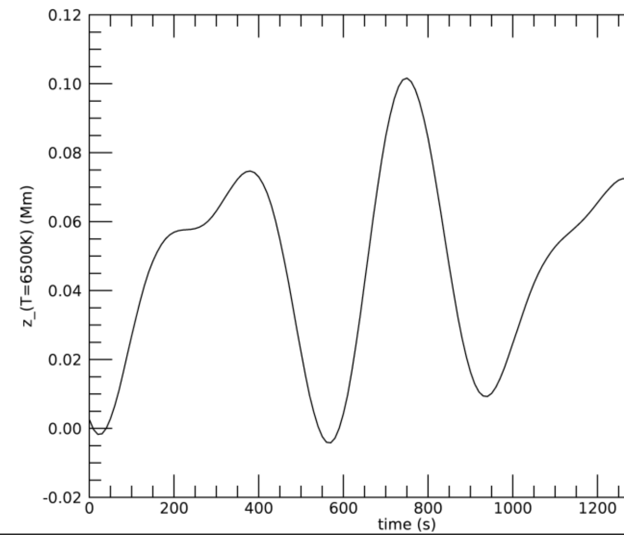
1) Heating event (Brightening) → 2) Material rises (blue shifted) → 3) In aftermath dark fibril forms





Experiment Description





Above: p-mode (Box osc) vs t

Bifrost (Gudiksen 2011) solves MHD eqs on a staggered grid. 6^{th} order differential operator & Hyman time stepper.

Small bipolar region

Grid: $504 \times 504 \times 512$

z extent: -2.4 to 14.4 Mm

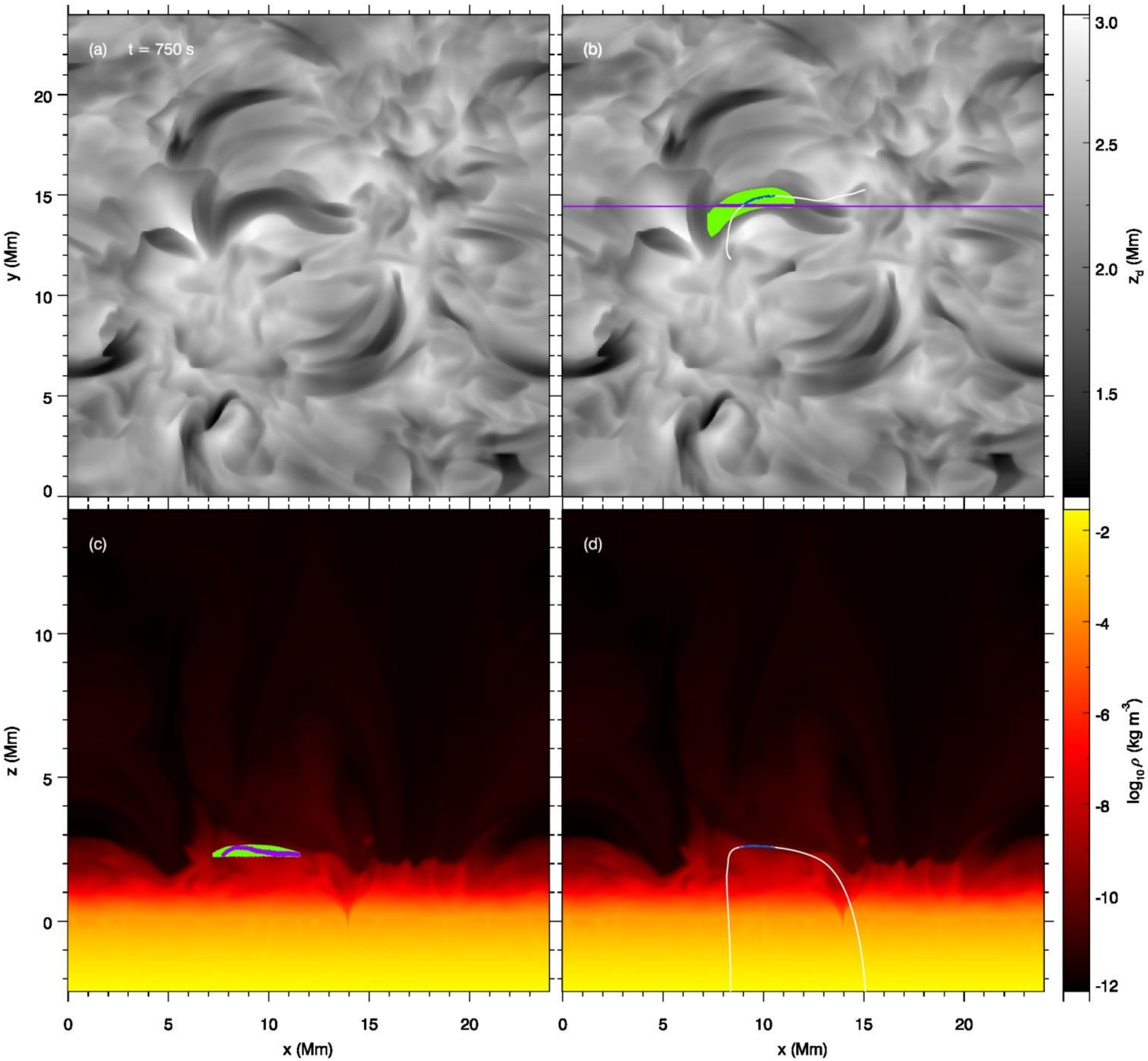
Time: 1270 s

(a) Bz (b) T (kK) $z = 0$ (photosphere)

(c) ρ (d) T (kK) $z = 1.5$ Mm chromosphere

See Carlsson et al 2016, Leenaarts et al. 2012, 2015

Studying mass loading using tracer particles



Corks:

- Passive tracer particles
- Flow with the fluid
- Motions updated with HD timesteps

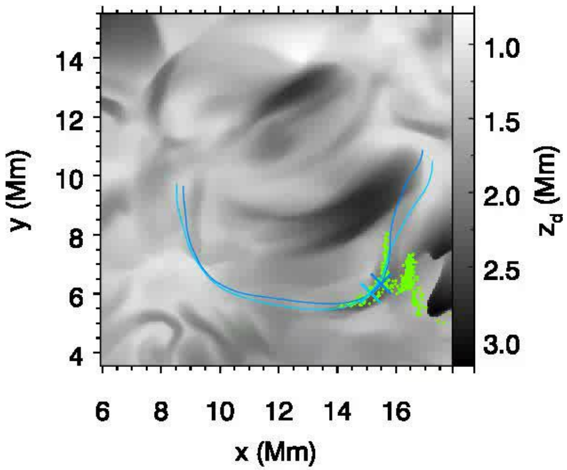
Selecting corks in fibrils:

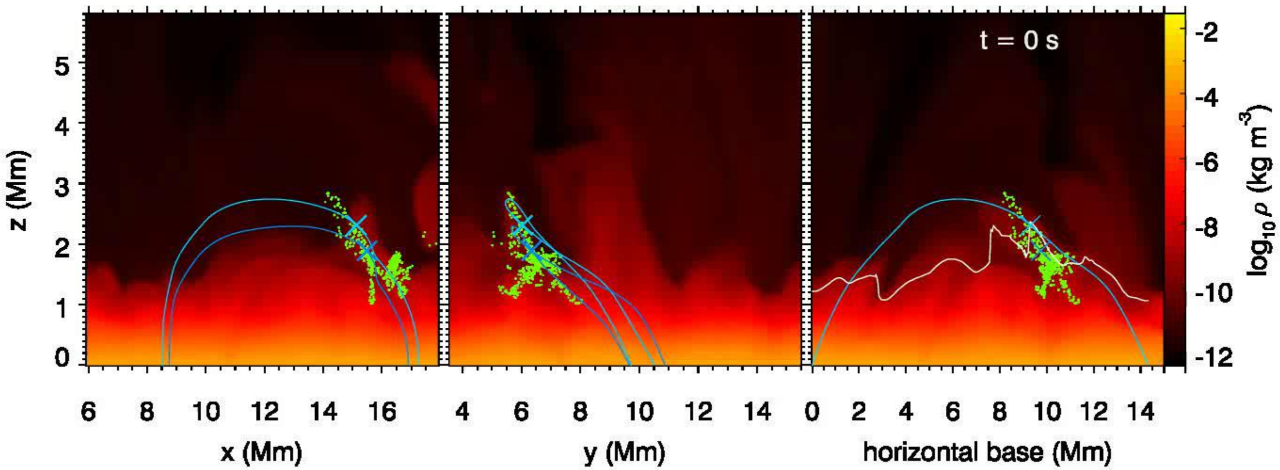
- Hα core formation z_d "height" greater (dark)
- Spatial box
- Corks $< \pm 100$ km of z_d

Closer inspection:

- Cork centrally located
- Fieldline through
- Select corks < 1 grid square from fiedline (~ 30 km) @ t_{seed}

Results



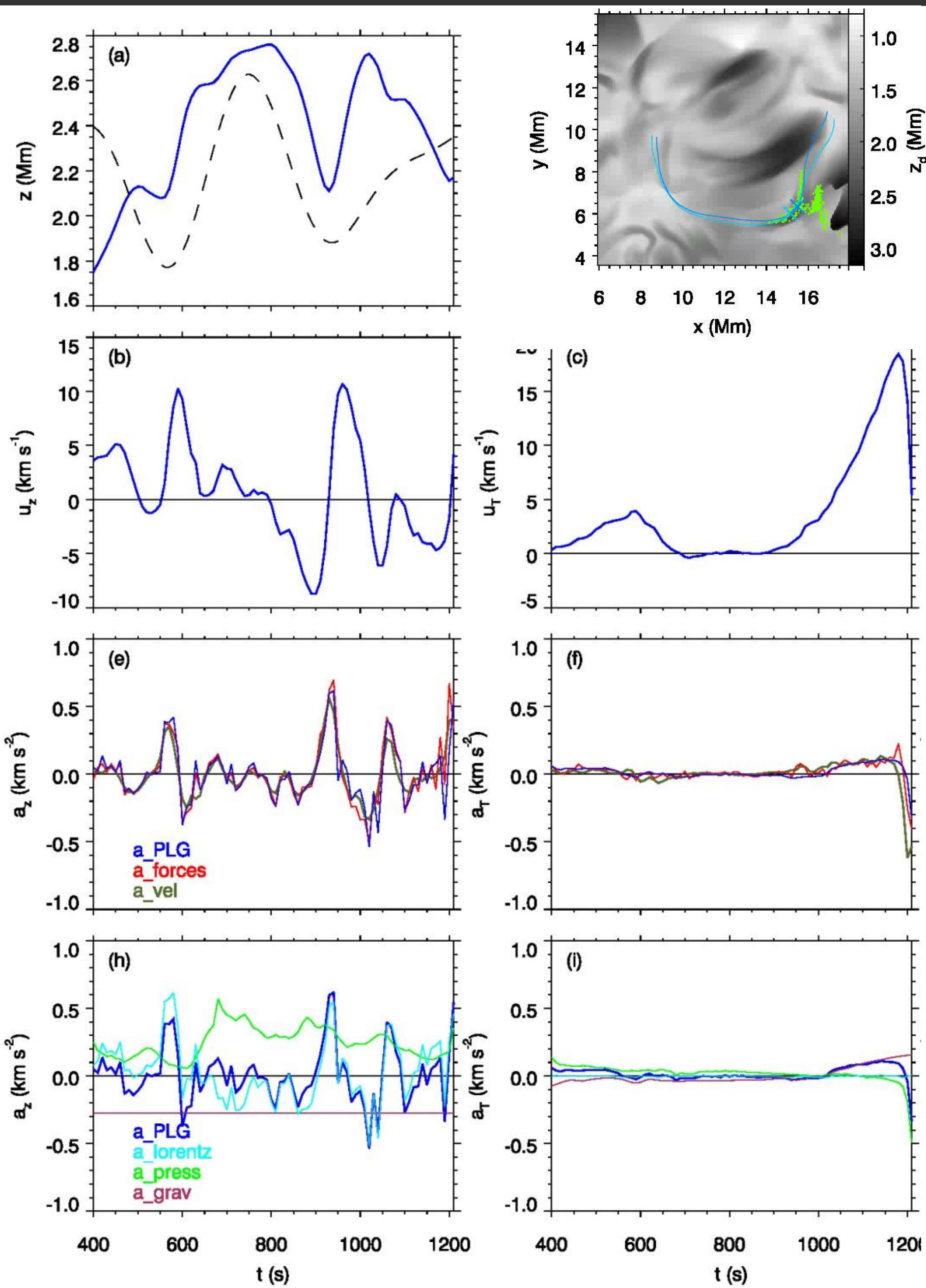


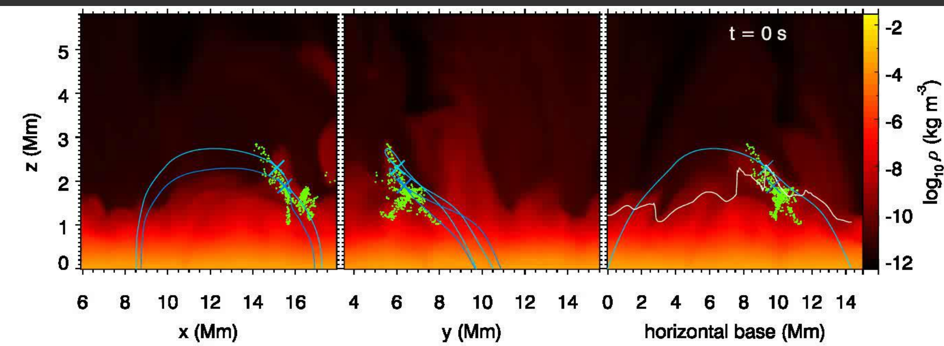
Fibrilar mass loading:

- From low chromosphere
- Field lines with flattened tops rise and untwist
- Not from footpoints, closer to loop apex

- Material begins draining under gravity

Results: Mass loading





Fibrilar mass loading:

- From low chromosphere
- Field lines with flattened tops
- Not from footpoints

- Raising occurred with

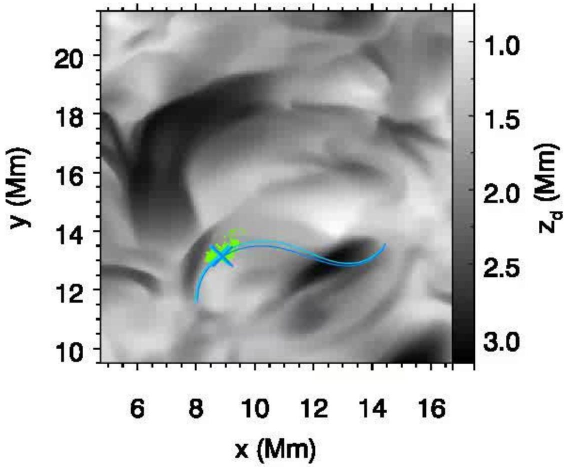
Field lines untwist & become more parabolic

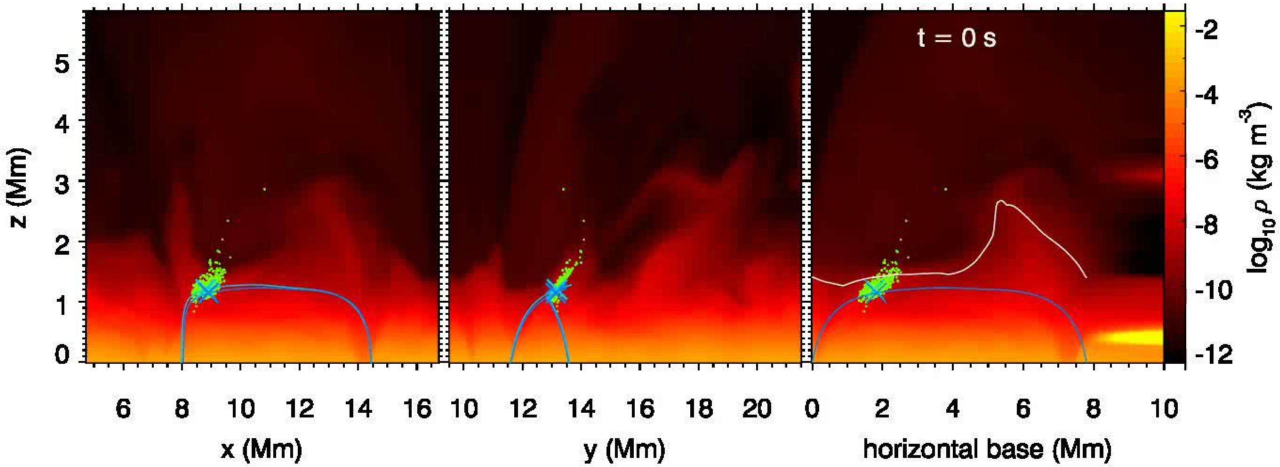
box osc. (p-modes)

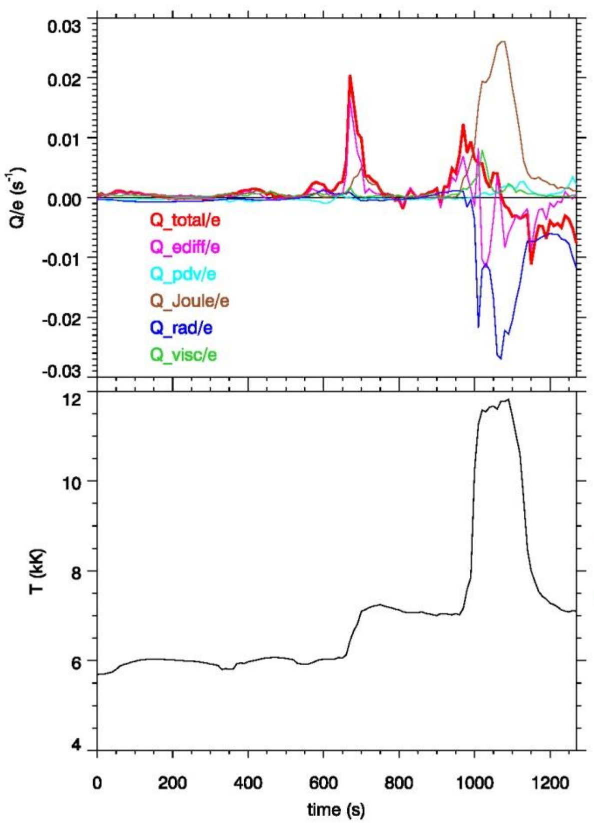
- Direct influce raising material: Lorentz force
- Ridge of dense cool material high in atmos

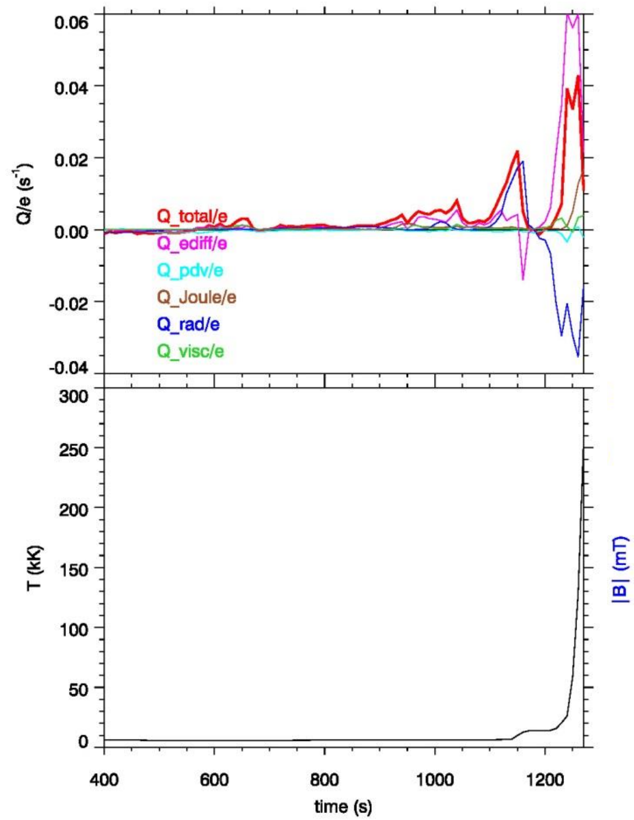
- Material begins draining under gravity

Results: Fibril destruction









- Fibrils drain under gravity, not necessarily with falling box osc.
- Densities drop chromospheric -> coronal.

- Drastic heating can take over when densities are low enough (usually trapped over apex).
- Combination of Joule heating & energy diff.

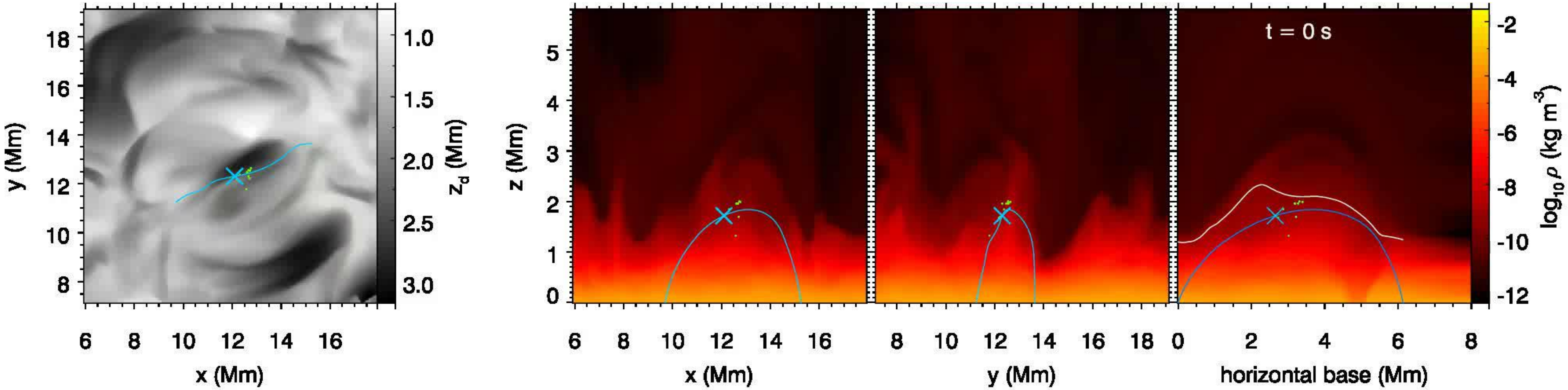
Summary of mass loading

“Lift and drain” scenario

- Mass **from low/mid chromosphere** $(97 - 99\%)$
- Loops with flattened apexes.
- **Loop rise and untwists** to relax, elevating **material above apex** into high chromosphere. (This is dissimilar to previously proposed mass loading scenarios)
- Some untwisting may be triggered by box oscillations (p-modes).

Comments

- Plausible **additional** fibril formation mechanism on the Sun.
- Could be identified in obs from concurrent blueshift along emerging fibrilar length.
- Can appear as parabolic loading up static field: simultaneous horiztonal motions.



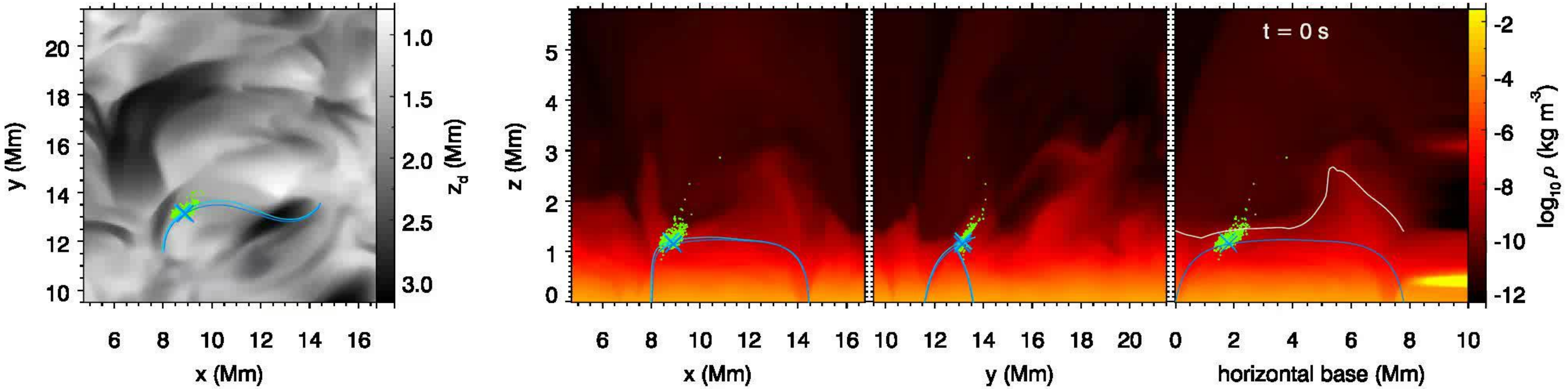
Summary of fibril destruction

Destruction of fibrils

- Fibrils drain under gravity towards footpoints.
- Density of material over apexes drops towards coronal values.
- Effects of Joule heating & energy diff from hot surrounding plasma increase.
- Plasma heats and expands rapidly.
- Mag tension & pressure gradient diverge and separate nearby fieldlines.

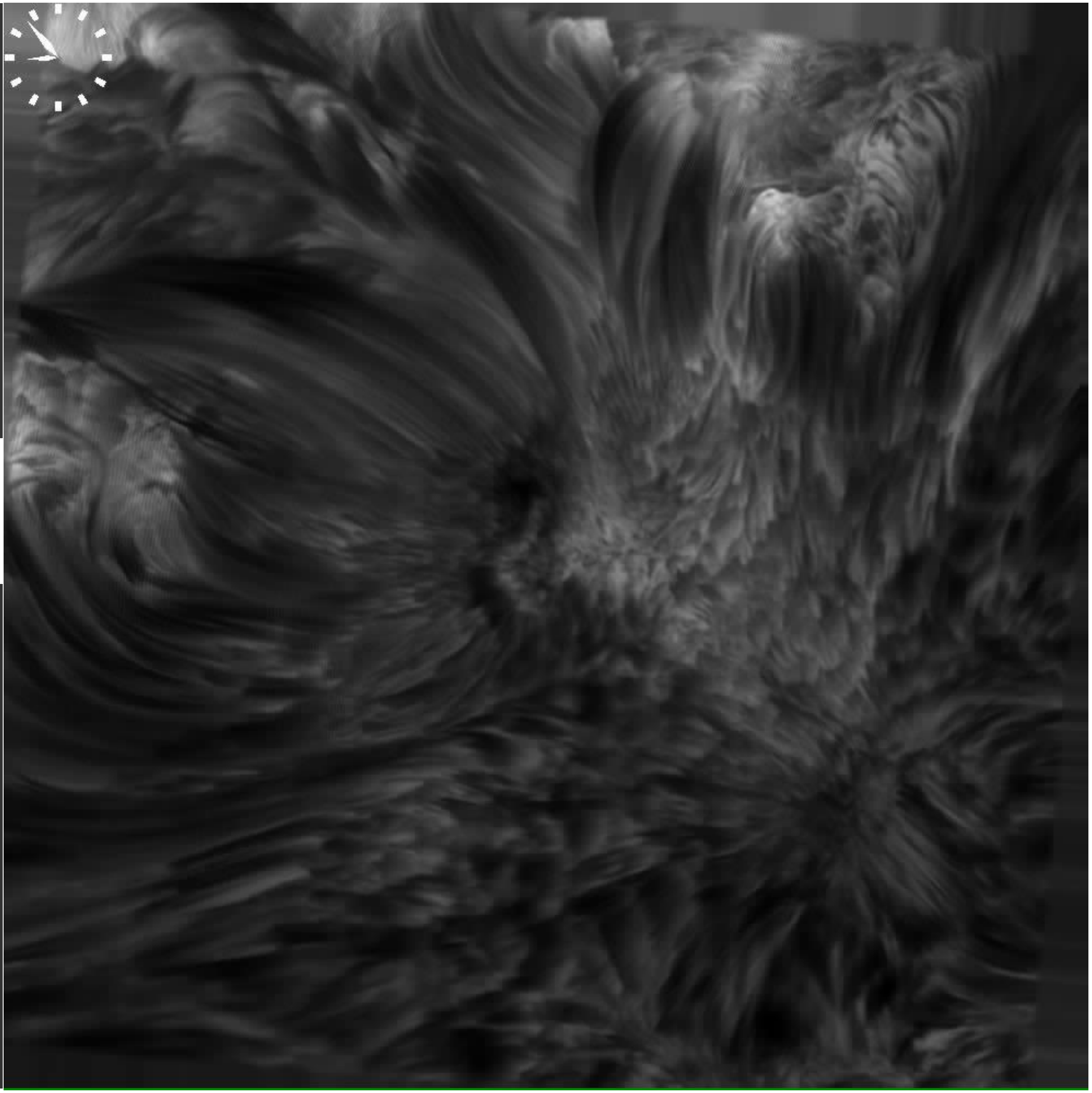
Heating

- Visible tail of the fibril can "drain" much faster than solar gravity due to heating.
- Most fibrils showed transient heating to TR values.
- Possible explanation for transient brightenings of low lying loop sections in TR lines without strong associated footpoint heating (Hansteen et al. 2014, Pereira et al. 2018).
- Sometimes supplied significant mass to corona.



Solar fibrils revisited

1) Feeding up relatively static fieldlines
2) Aftemaths of hot onsets
3) Lift and drain



Making simulated fibrils via methods 1 & 2:

Viscosity
Diffusion
Resolution
Size

Forthcoming paper: Druett, Leenaarts, Carlsson, Szydlarski