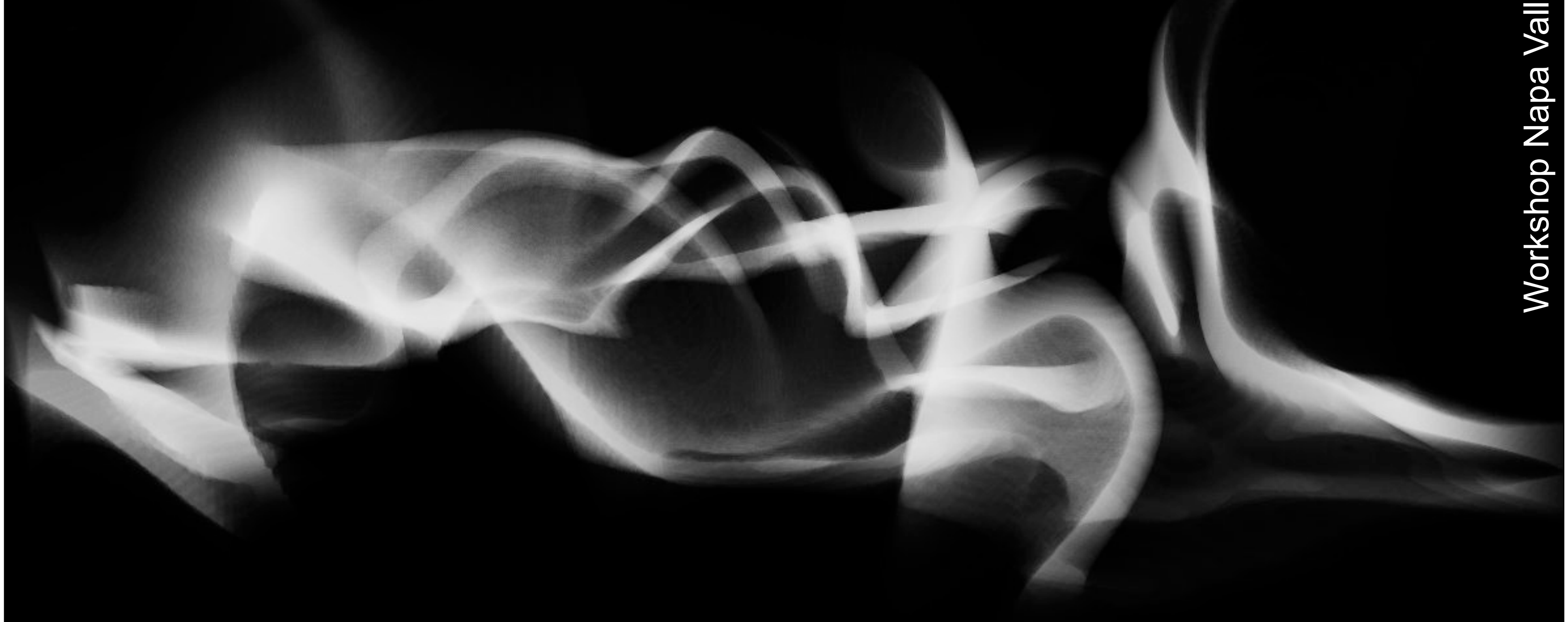
Magnetic connectivity and coronal dynamics

Hardi Peter, *Sven Bingert*, *Pia Zacharias*

Kiepenheuer-Institut für Sonnenphysik, Freiburg

peter@kis.uni-freiburg.de

Workshop Napa Valley



iLoops seen in Ne VIII (770 Å) – $\lesssim 10^6$ K – from a 3D MHD coronal simulation

KIS

1D vs 3D

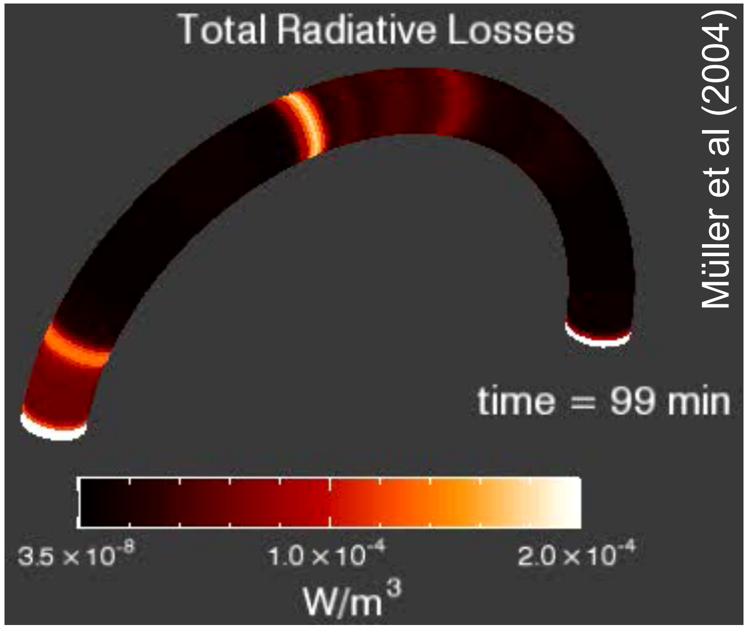
1D lop models

+ good description of thermal evolution (heat conduction & radiative losses)
- limited self-consistent heating
- assumes loops are individuals

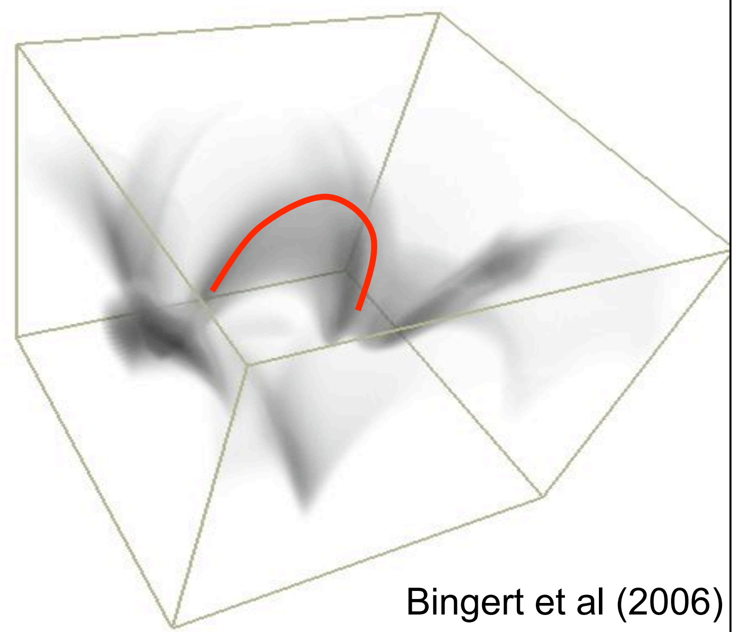
3D models

+ account for spatial complexity: interaction of structures
+ heat input as fct of space and time (but…)
- limited resolution (heat conduction…)

1D loop model



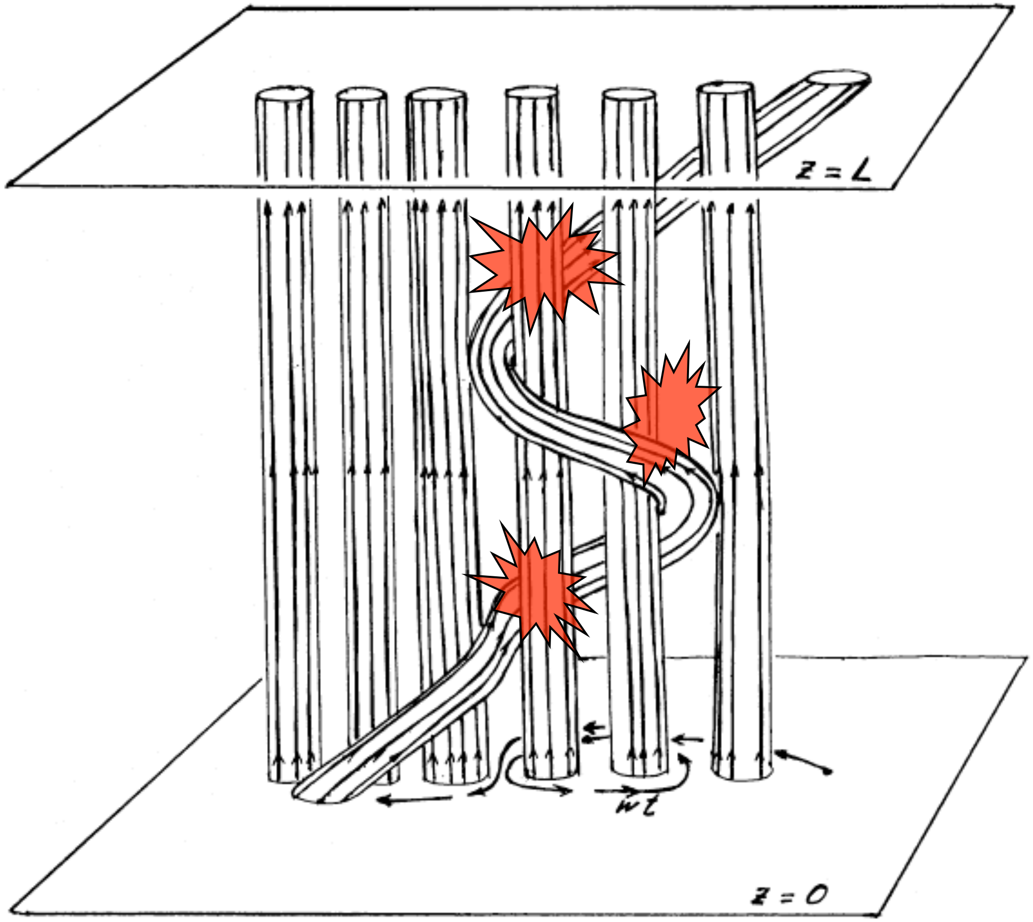
3D model pseudo emission ≈ 650 000 K



Bingert et al (2006)

Tool to study coronal structure & dynamics

field line braiding – Parker (1972) ApJ 174, 499
or flux tube tectonics – Priest et al (2002) ApJ 576, 533



Parker (1972) ApJ 174, 499

braiding of magnetic field lines through **random motions** on the stellar surface

→ braided magnetic field in chromosphere and corona

→ currents $j \sim \nabla \times B$

→ Ohmic dissipation $H \sim \eta j^2$

→ heating of the corona through continuous reconnection

can be studied in 3D MHD models:

► resolution cannot match 1D loop models (of course)

► self consistent description of structure, dynamics and evolution

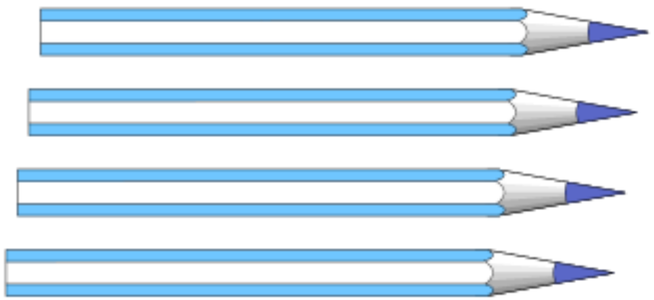
Gudiksen & Nordlund (2002, 2005)
ApJ 572, L113; 618, 1020

3D MHD model including spectral synthesis

3D MHD model: ***The Pencil Code***

Brandenburg & Dobler (2002) Comp Phys Comm 147, 471

- ► high-order finite-difference code for compressible 3D MHD
- ► highly modular
- ► efficiently under MPI on massively parallel shared- or distributed-memory computers



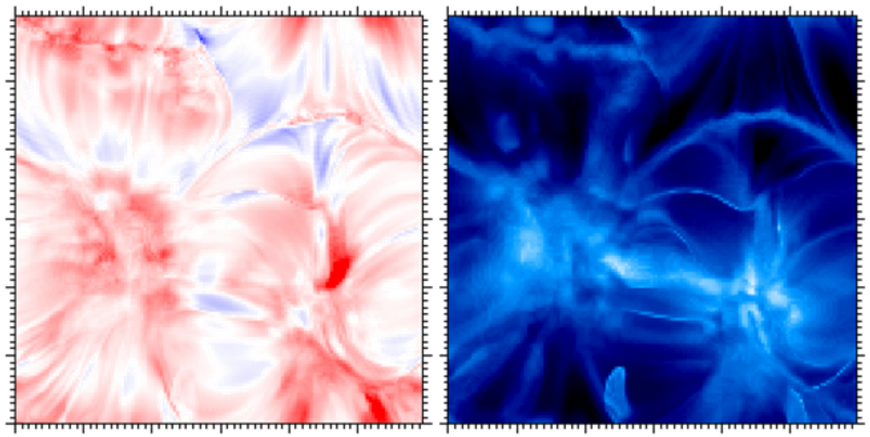
- ► Box: 256^3 grid : 50 x 50 x 30 Mm^3 horizontally periodic, open top
- ► horitontal motions in photosphere close to solar convevtion pattern
- ► Ohmic heating concentrated in chromsophere and low corona

proper inclusion of energy balance:

- ► radiative losses
- ► heat conduction

essential to get proper coronal pressure

→ only then reliable determination of EUV and X-ray emission !



- ► emissivity at each grid point (CHIANTI)
- ► integration of EUV and X-ray spectral line profiles

→ maps in intensity and Doppler shift
→ direct comparison to observations

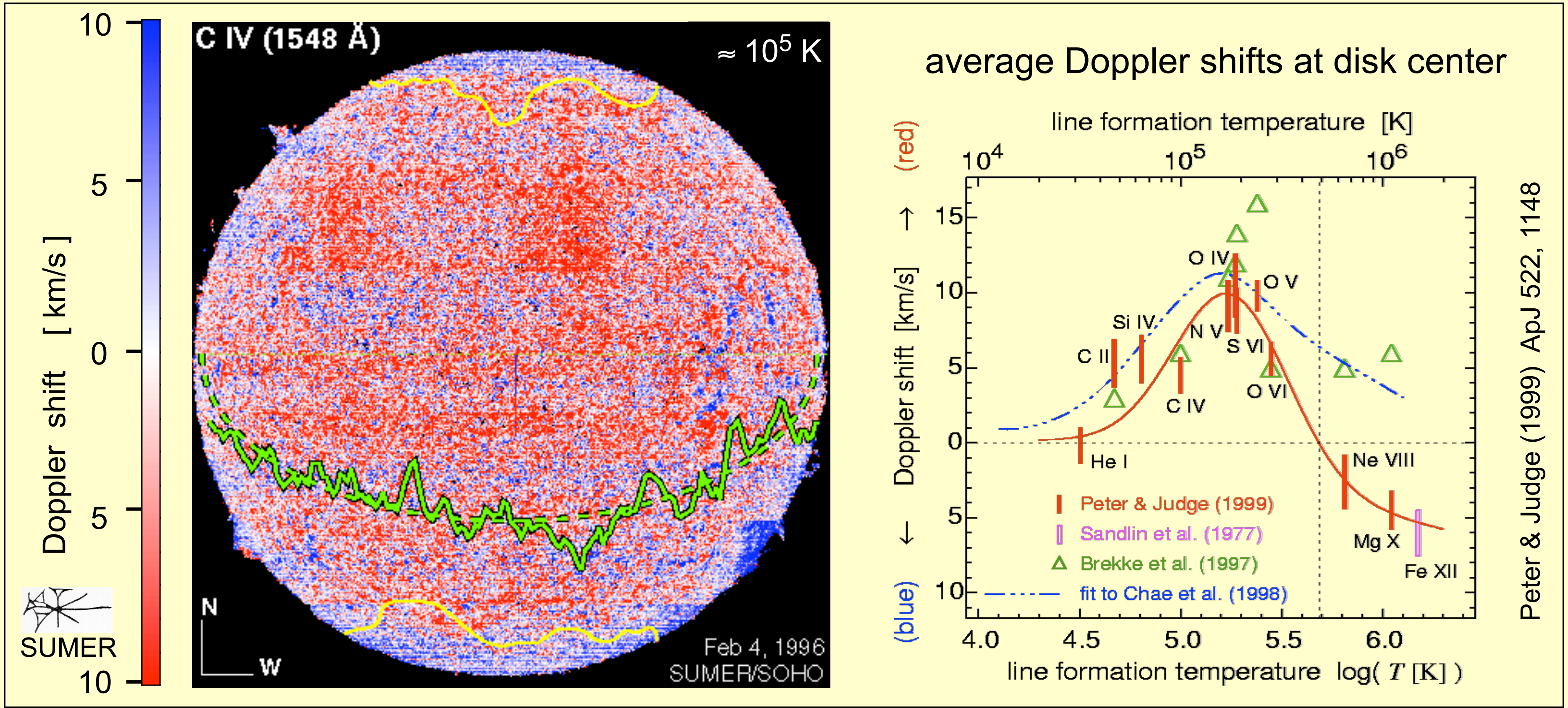
Overview

-- global properties / ensemble averages

-- individual loops

-- what are loops -- or what can they be?

Ensemble averages



Doppler shifts

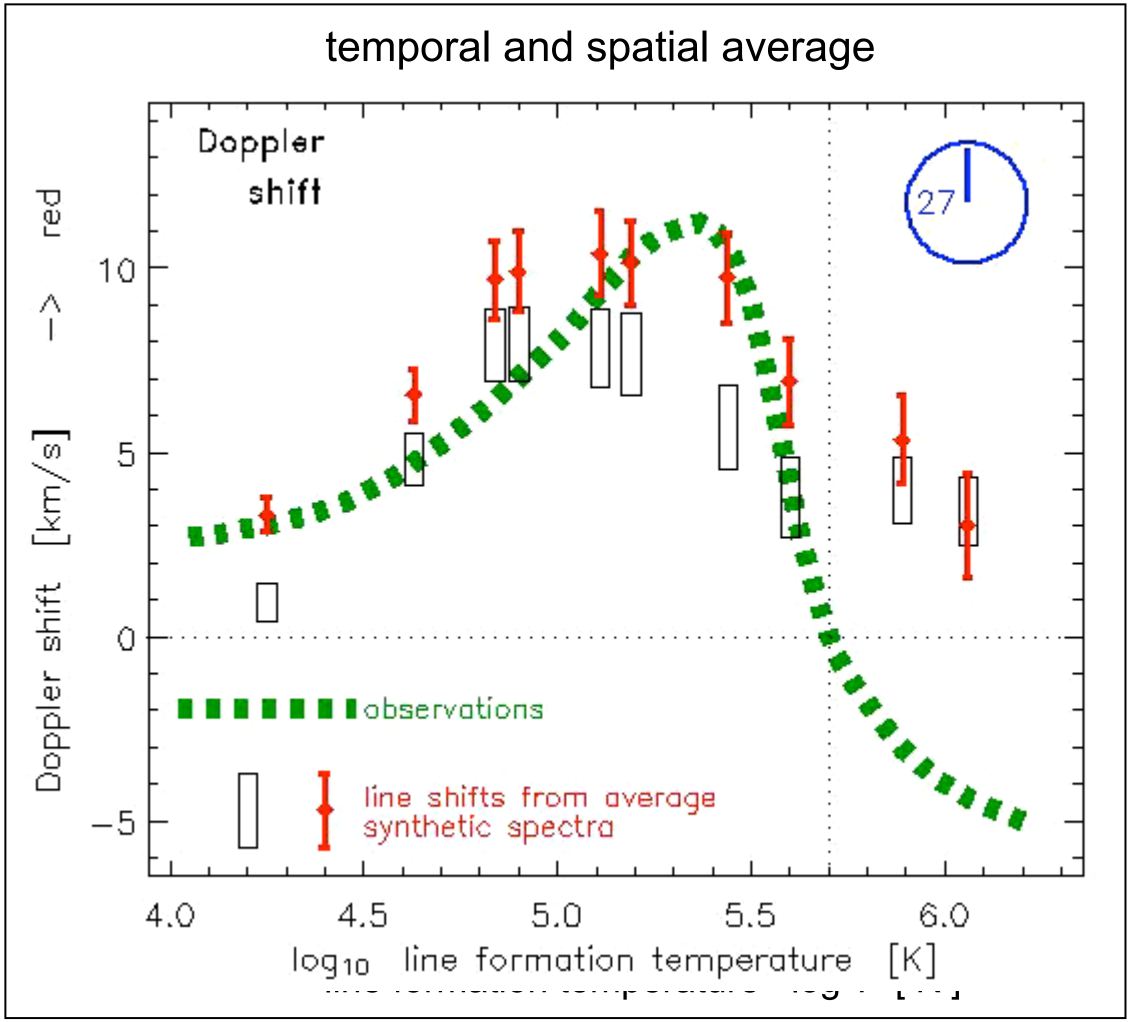
spatial averages

- very good match in TR
- overall trend v_D vs. T quite good
- still no match in low corona

  → boundary conditions?
  → missing physics?

temporal variability

- high variability as observed
- for some times almost net blueshifts in low corona!



Peter, Gudiksen & Nordlund (2004) ApJ 617, L85

➡ **no “fine-tuning” applied !**

➡ **best over-all match of models so far**

Emission measure

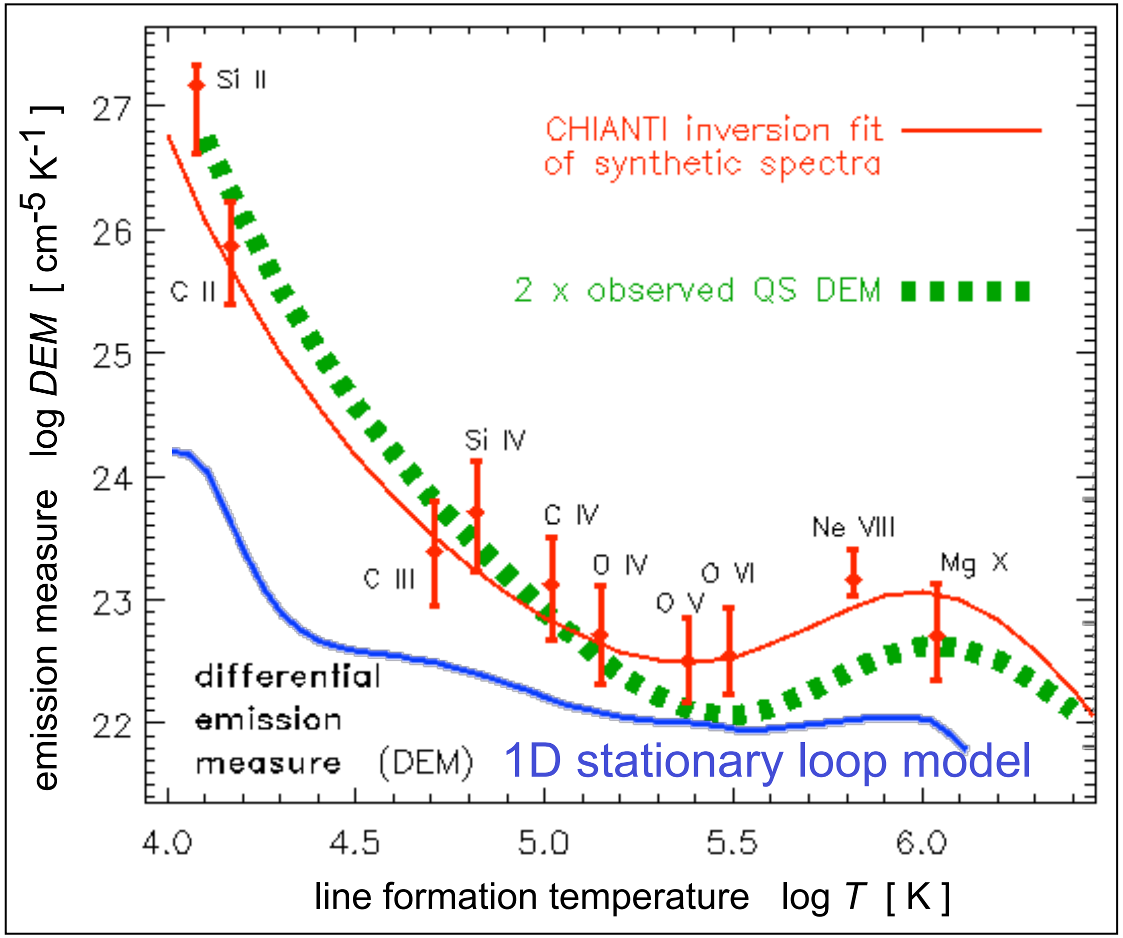
$$DEM = n_e^2 \frac{dh}{dT}$$

DEM inversion using CHIANTI:

1 – using synthetic spectra derived from 3D MHD model

2 – using solar observations (SUMER, same lines)

➡ good match to observations!! DEM increases towards low T in the model !

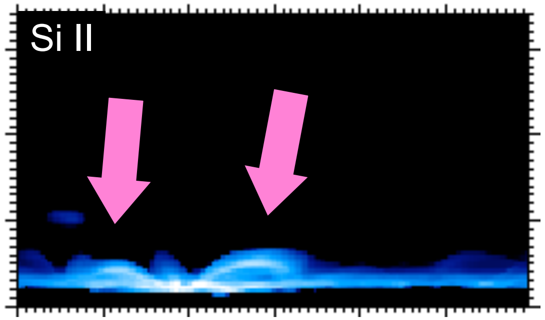


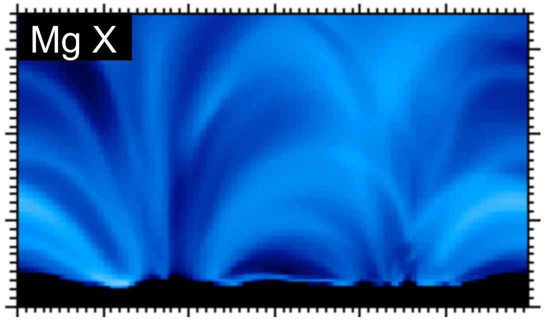
Peter, Gudiksen & Nordlund (2006) ApJ 638, 1166

Supporting suggestions that numerous cool structures cause increase of DEM to low *T*

AND:

velocities reduce *grad T* !





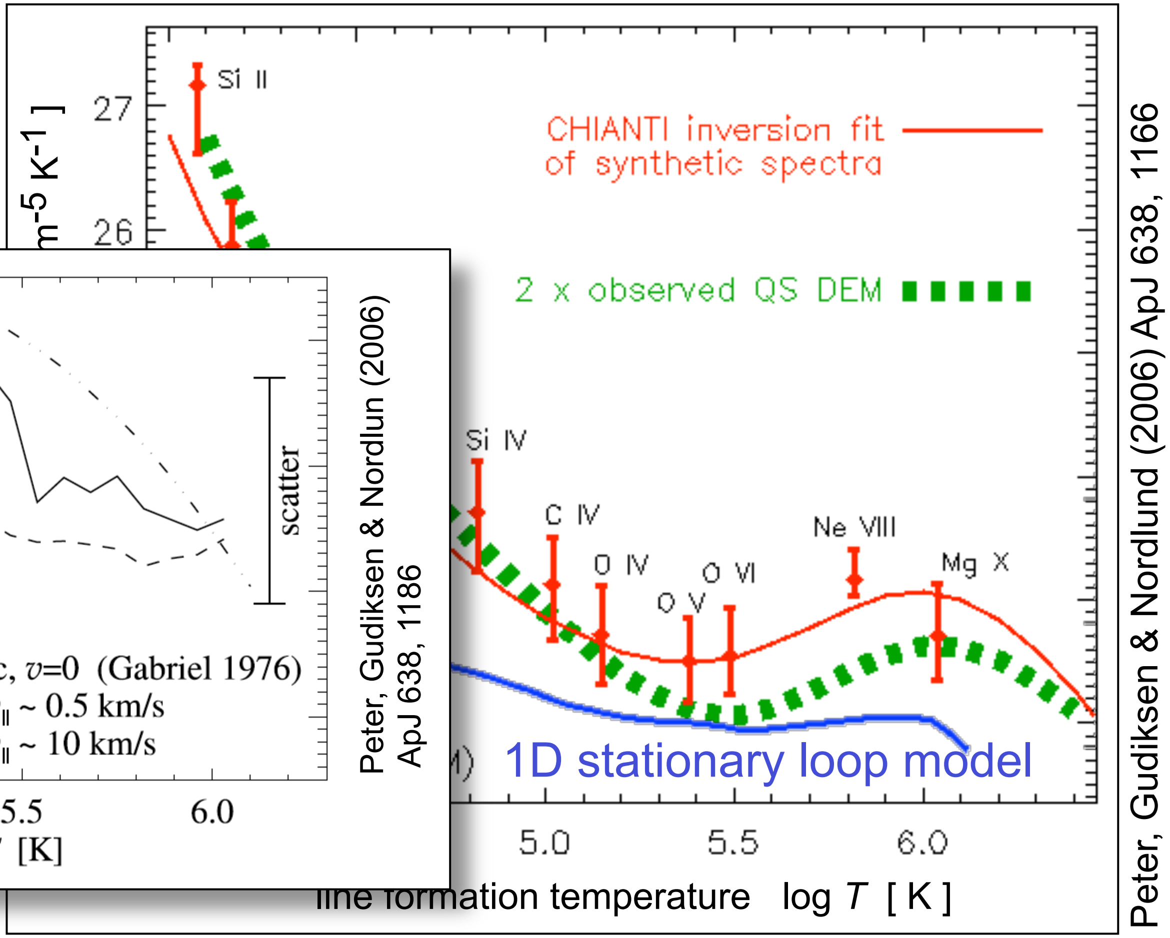
Emission measure

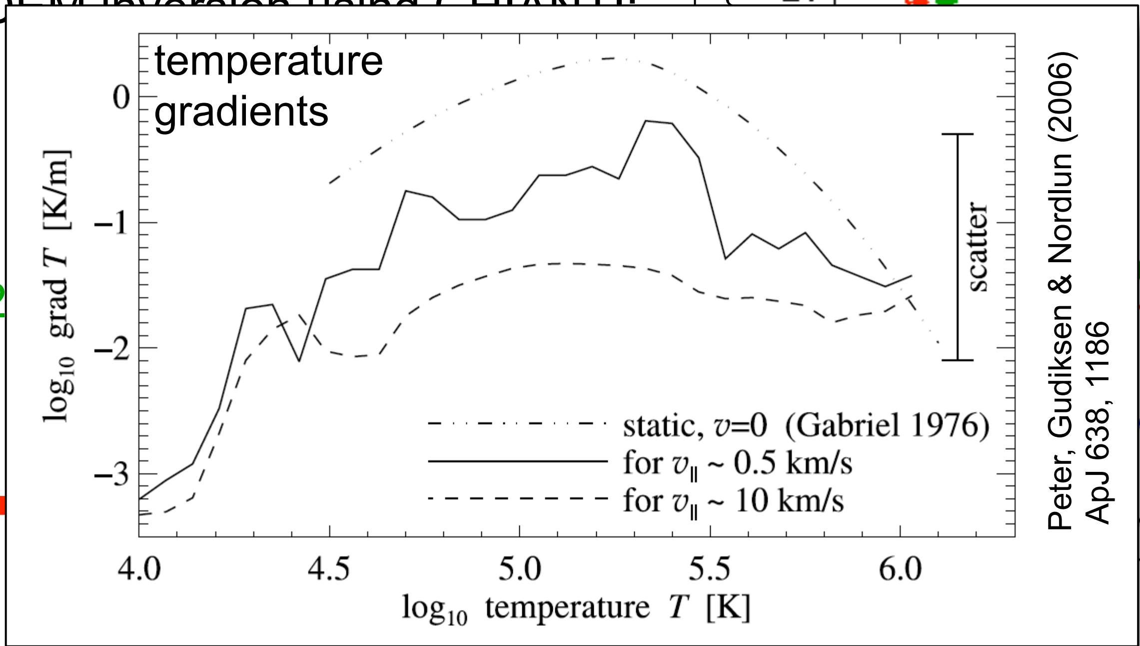
$$DEM = n_e^2 \frac{dh}{dT}$$

DEM inversion using CHIANTI:

1

2





Supporting suggestions that numerous cool structures cause increase of DEM to low *T*

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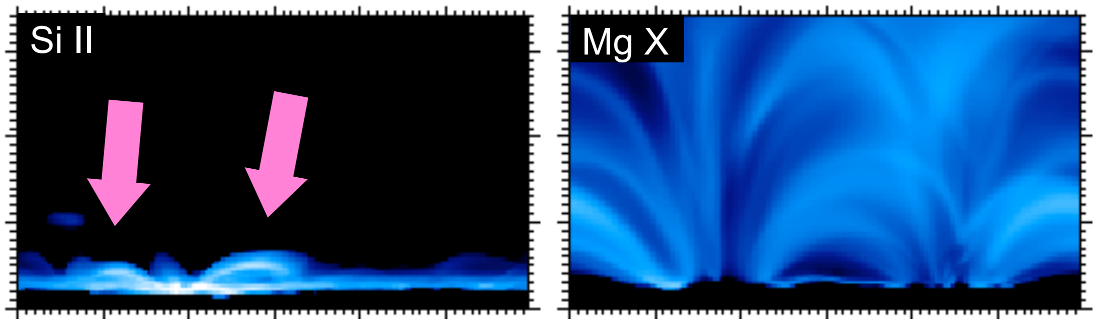


Temporal variability: average properties

observations:

[Brković, Peter & Solanki (2003), A&A 403, 725]

- rms intensity fluctuations have pronounced peak at ~10^5 K
- rms Doppler shift variations increase monotonically

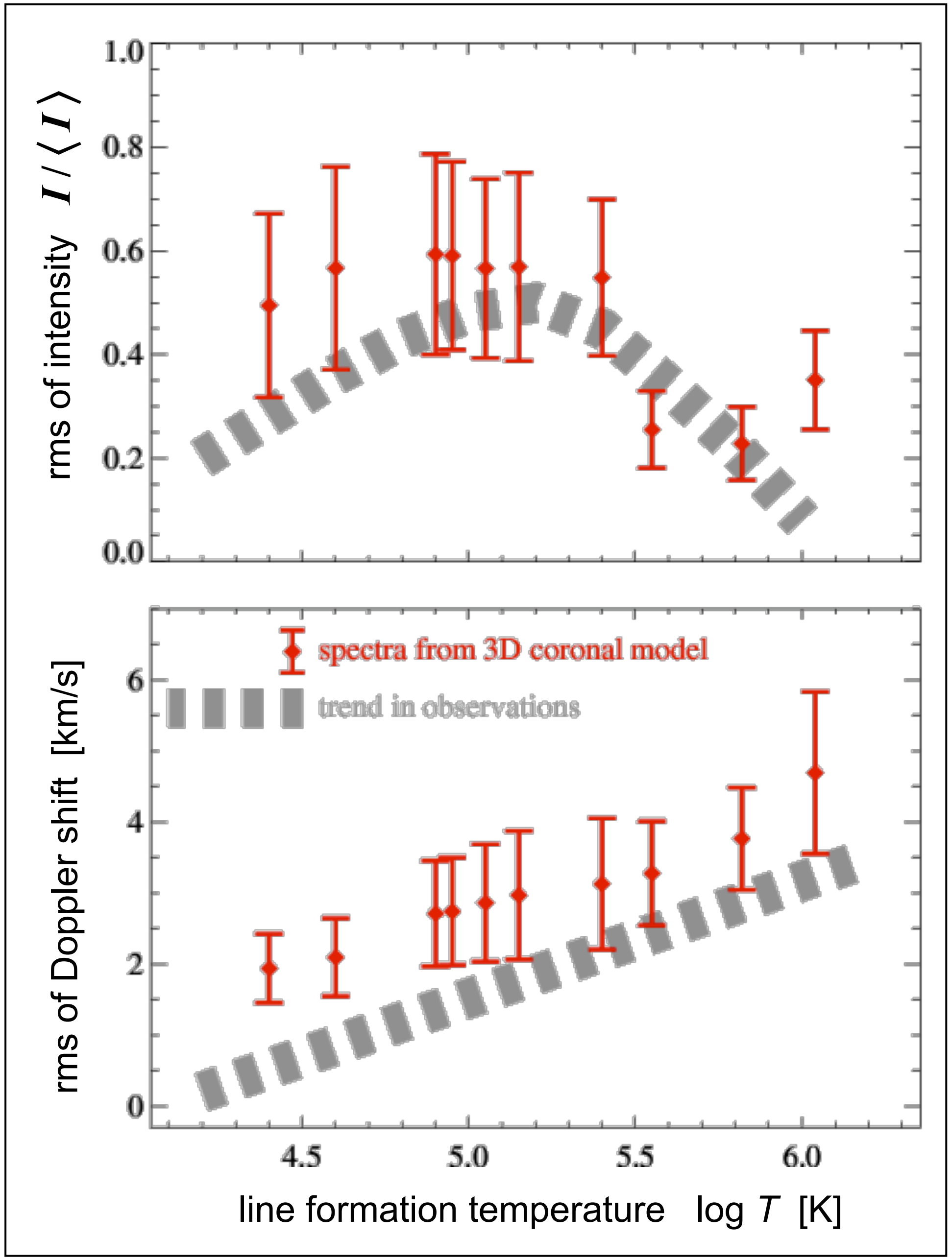
synthetic spectra from 3D model

+ very good match of observed trend(s)

+ correct description of "overall" variability

– real Sun shows variations on much shorter times (seconds)

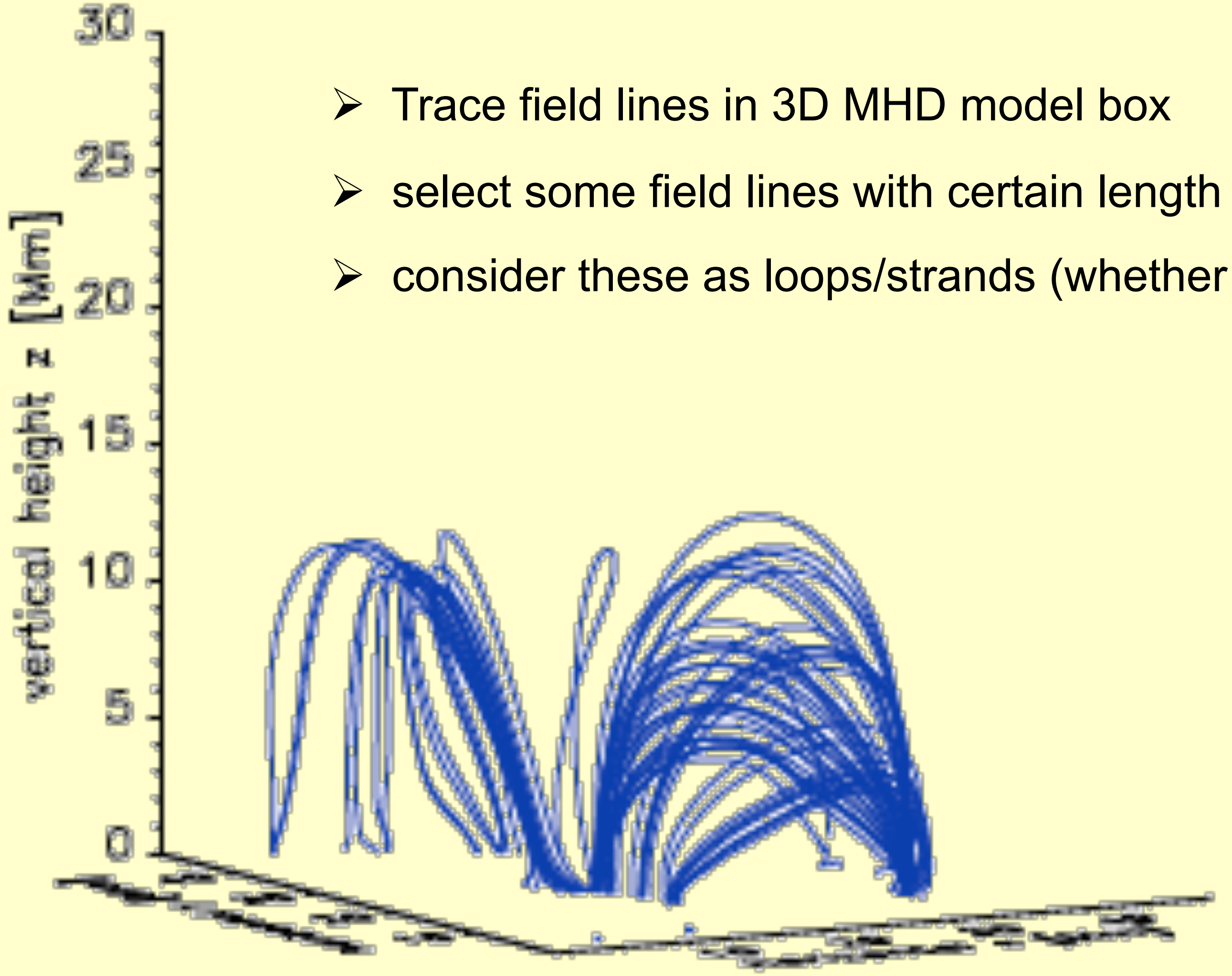
↳ lack of spatial resolution in 3D MHD model ?



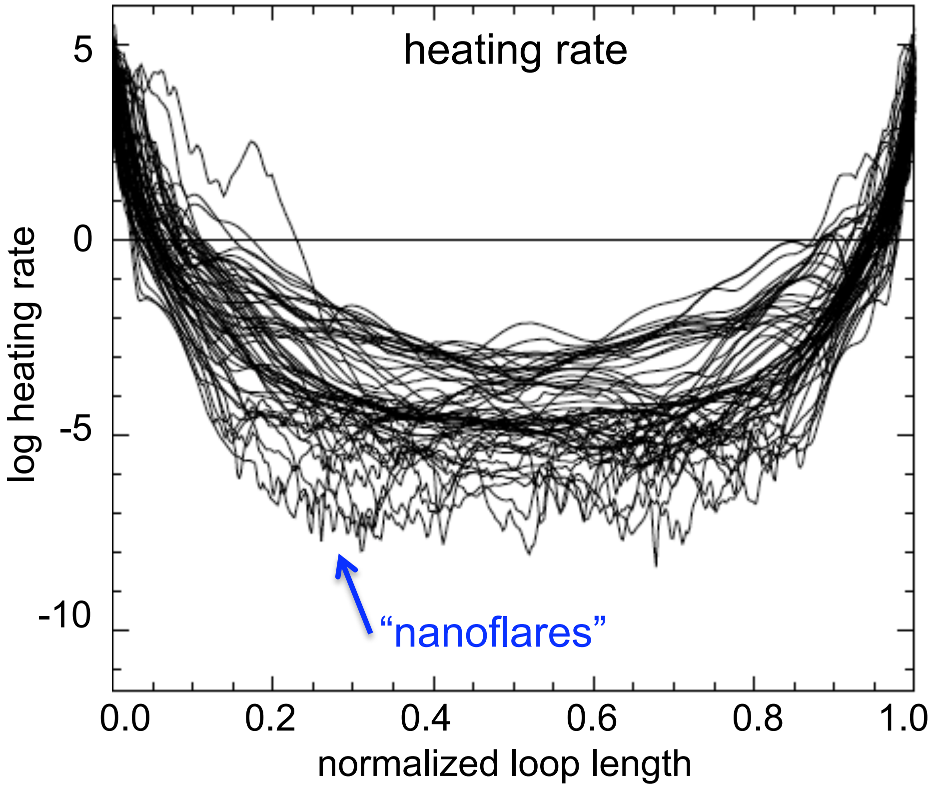
Peter, Gudiksen & Nordlund (2006) ApJ 638, 1086

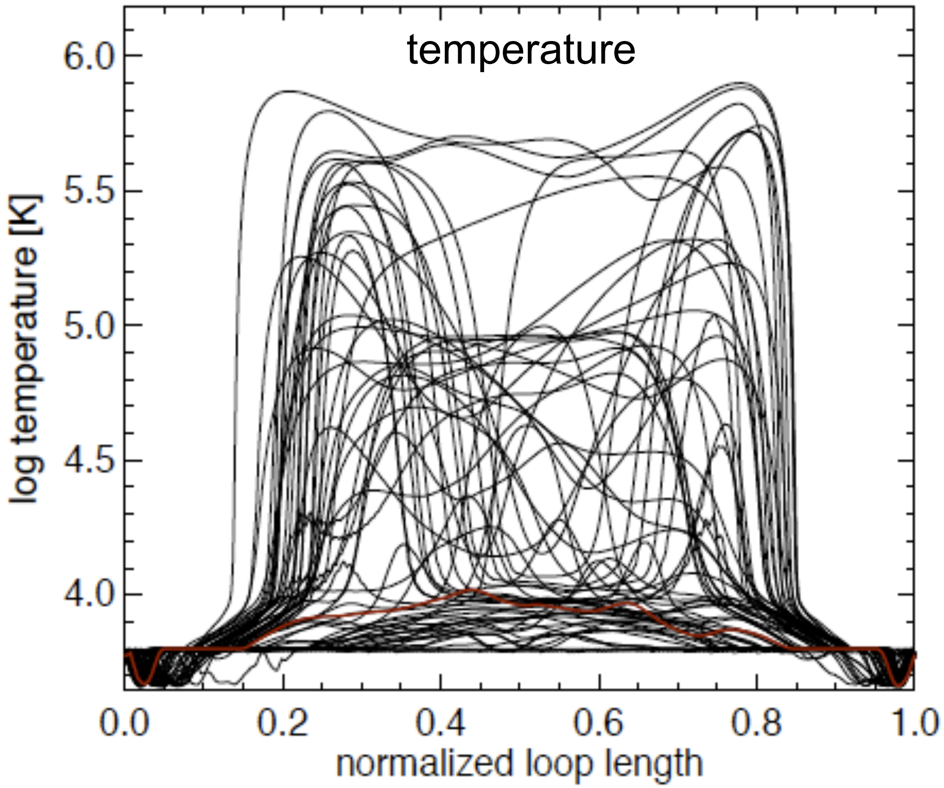
Individual loops

- Trace field lines in 3D MHD model box
- select some field lines with certain length (here 30 Mm)
- consider these as loops/strands (whether bright or not…)



Loop heating and temperatures





Heating:

in coronal part:
exponentially decay of heating rate

individual spikes:
"nanoflares" (individual heating events)

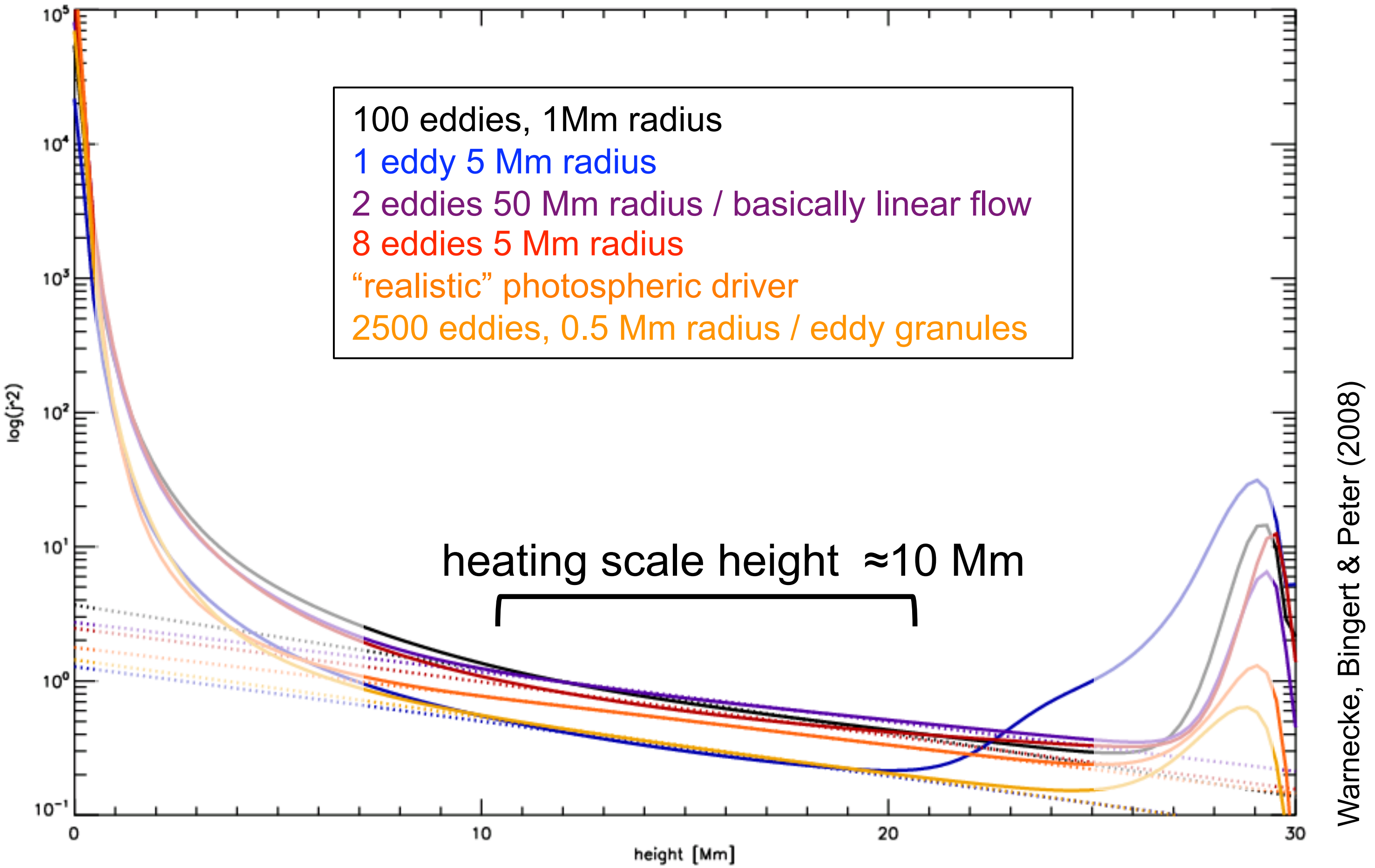
Thermal structure:

coronal loops with flat T-profile

some loops show condensations

3D models as input for 1D loops

Exponentially decreasing heating rate is very robust !!!

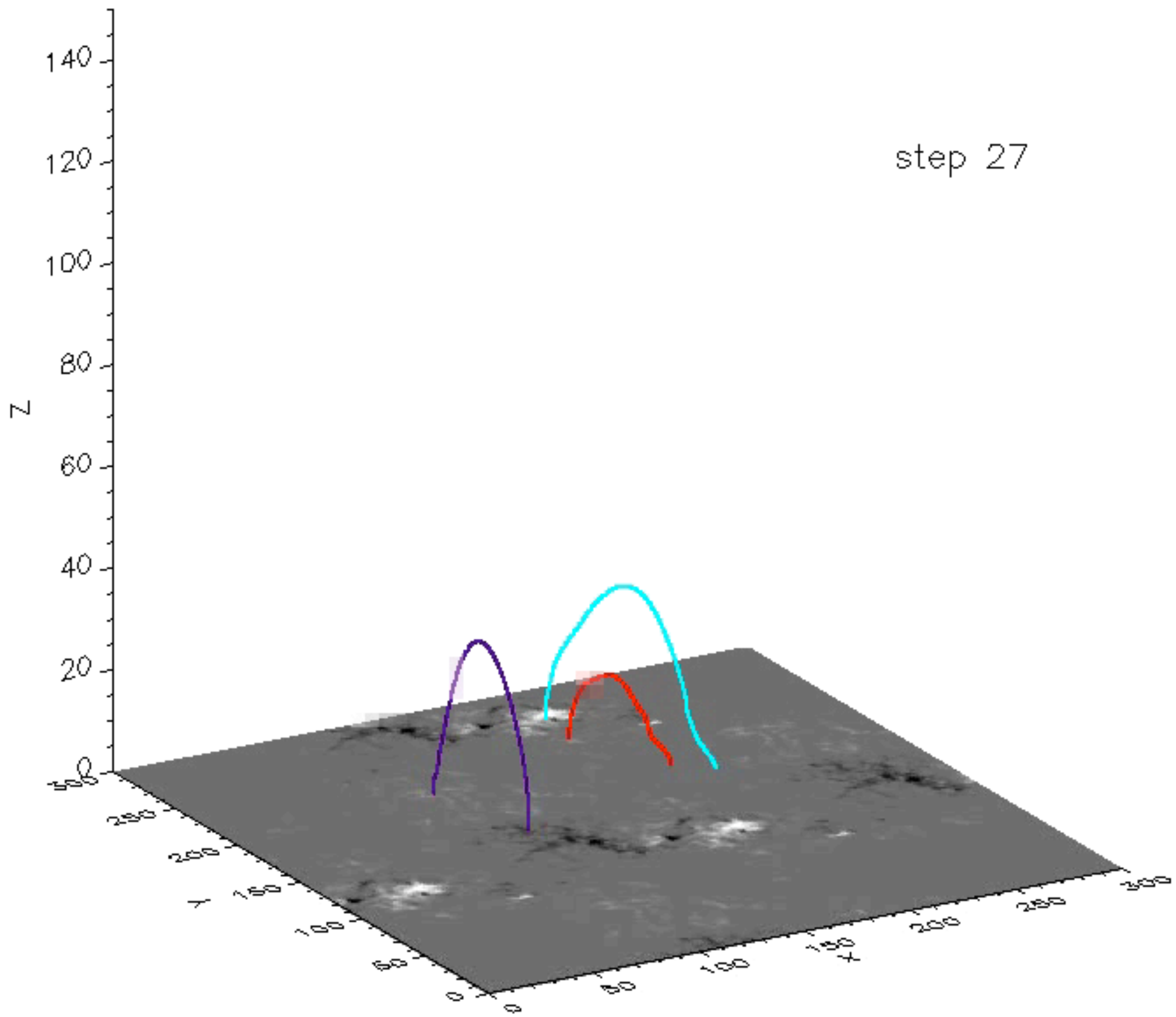


-- independent of photospheric driver heating rate drops exponentially (when smoothed)

-- what about different heating mechanisms?

-- using exp.decay heating rate in 1D loop models seems meaningful

Do loops keep their identity ?



-- some fieldlines are "breathing"

-- some fieldlines are jumping

(approx 40 min)

→ is the concept of loops / strands always justified?

What are loops?

Are loops seen in emission

always along the magnetic field lines?

Run a numerical experiment…

Two different coronal setups

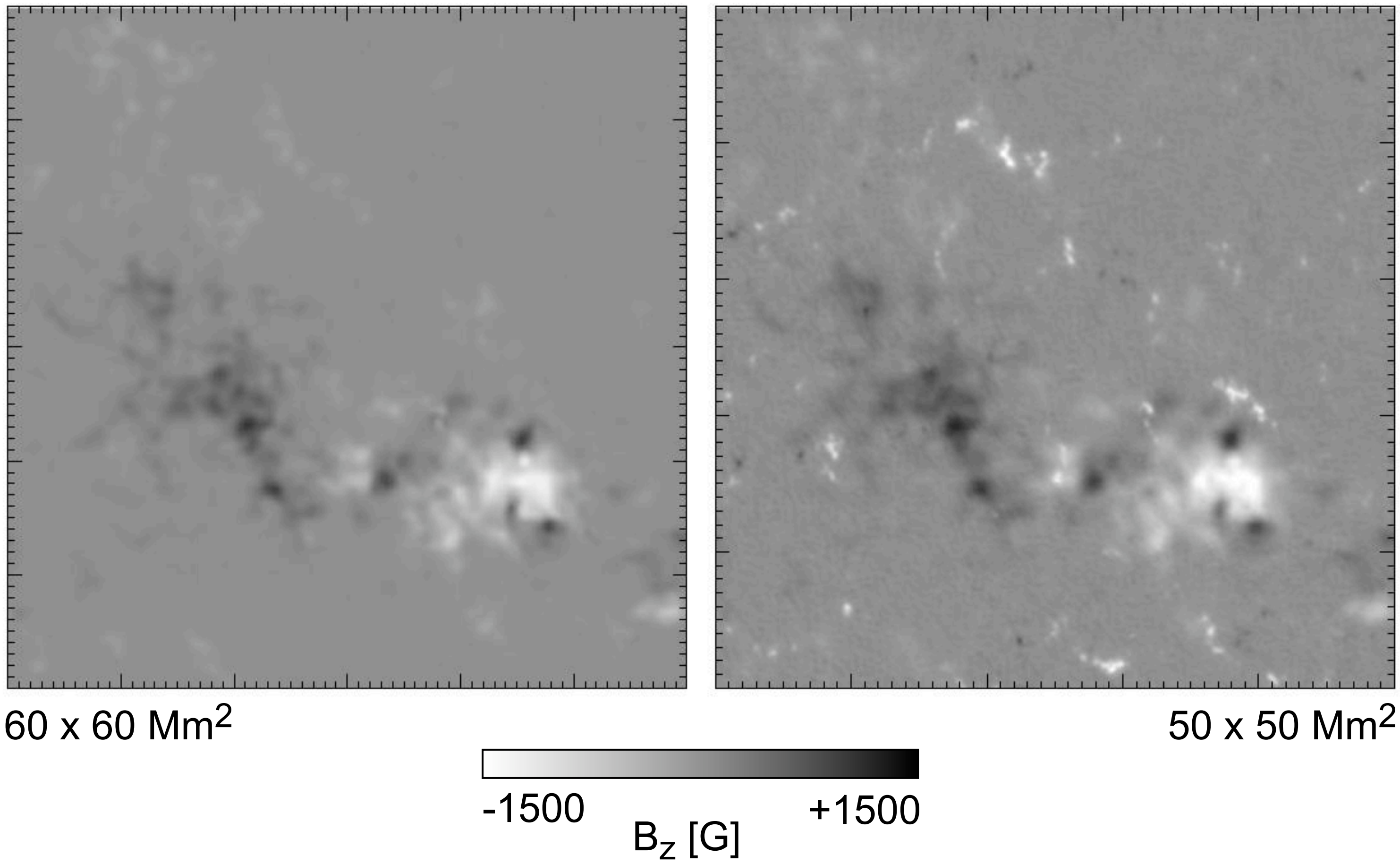
scaled-down active region

- ► two main polarities
- ► no magnetic network

magnetically complex region

- ► scaled-down AR
  plus *enhanced* magnetic network

Magnetic field at lower boundary



Two different coronal setups

scaled-down active region

► two main polarities
► no magnetic network

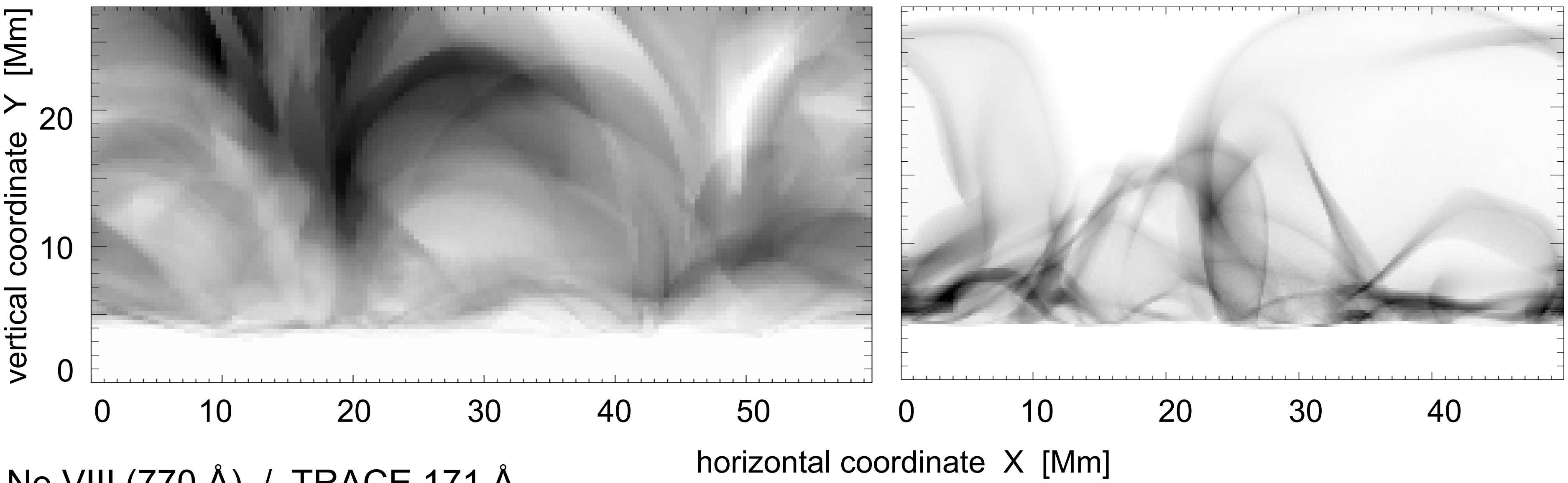
→ large loops systems form
connecting the main polarities

(similar to Gudiksen & Nordlund 2002, 2005)

magnetically complex region

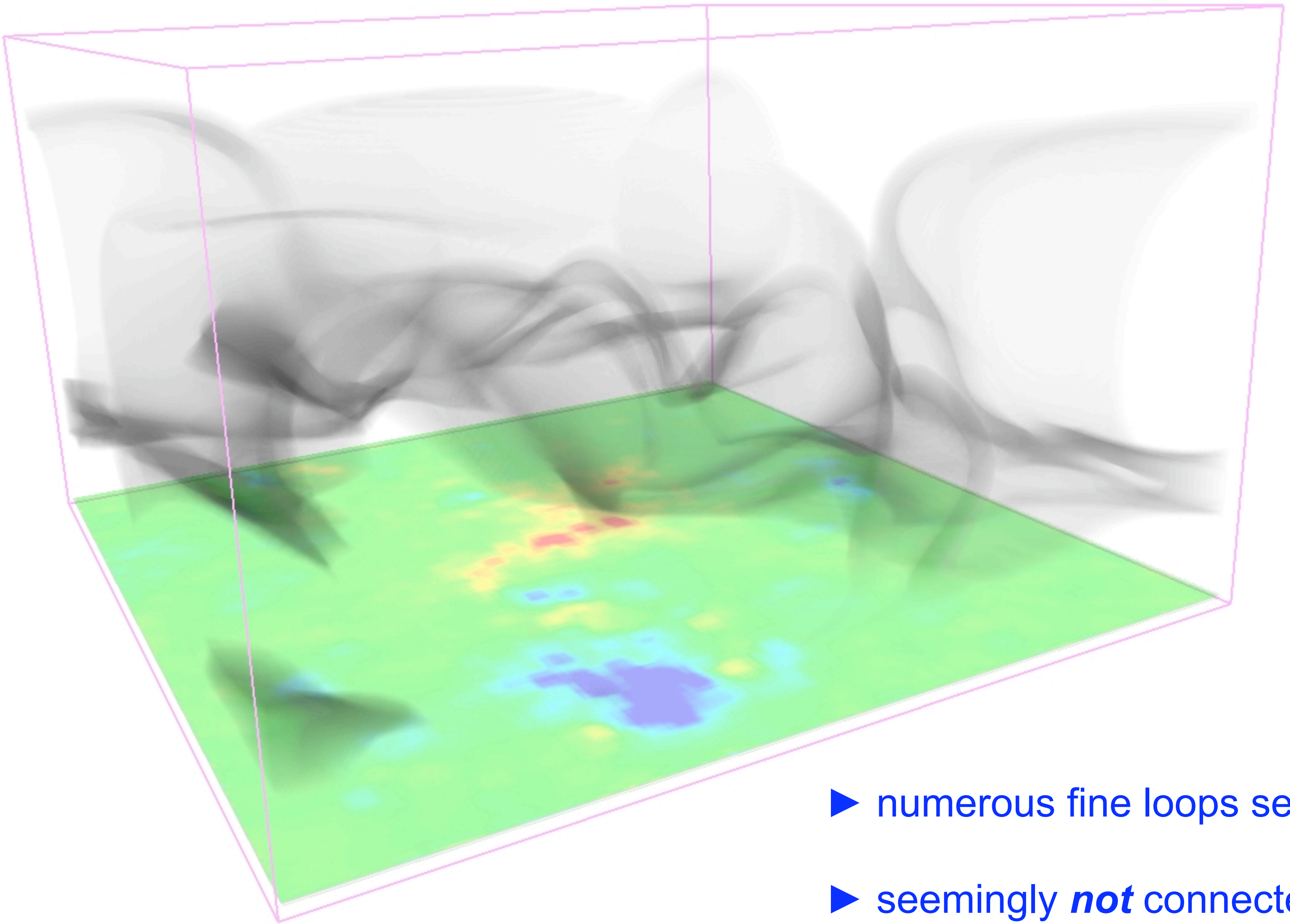
► scaled-down AR
plus *enhanced* magnetic network

→ very fine threads of coronal loops
→ much finer than in previous 3D models
→ fine structures due to high complexity
→ at first sight better match to TRACE



Ne VIII (770 Å) / TRACE 171 Å

iLoops – intensity loops in quit Sun network



Emission in
Ne VIII (770 Å)
at log $T \sim 5.8$
(close to
TRACE 171 Å)

and underlying
magnetic field

50 x 50 x 30 Mm^3

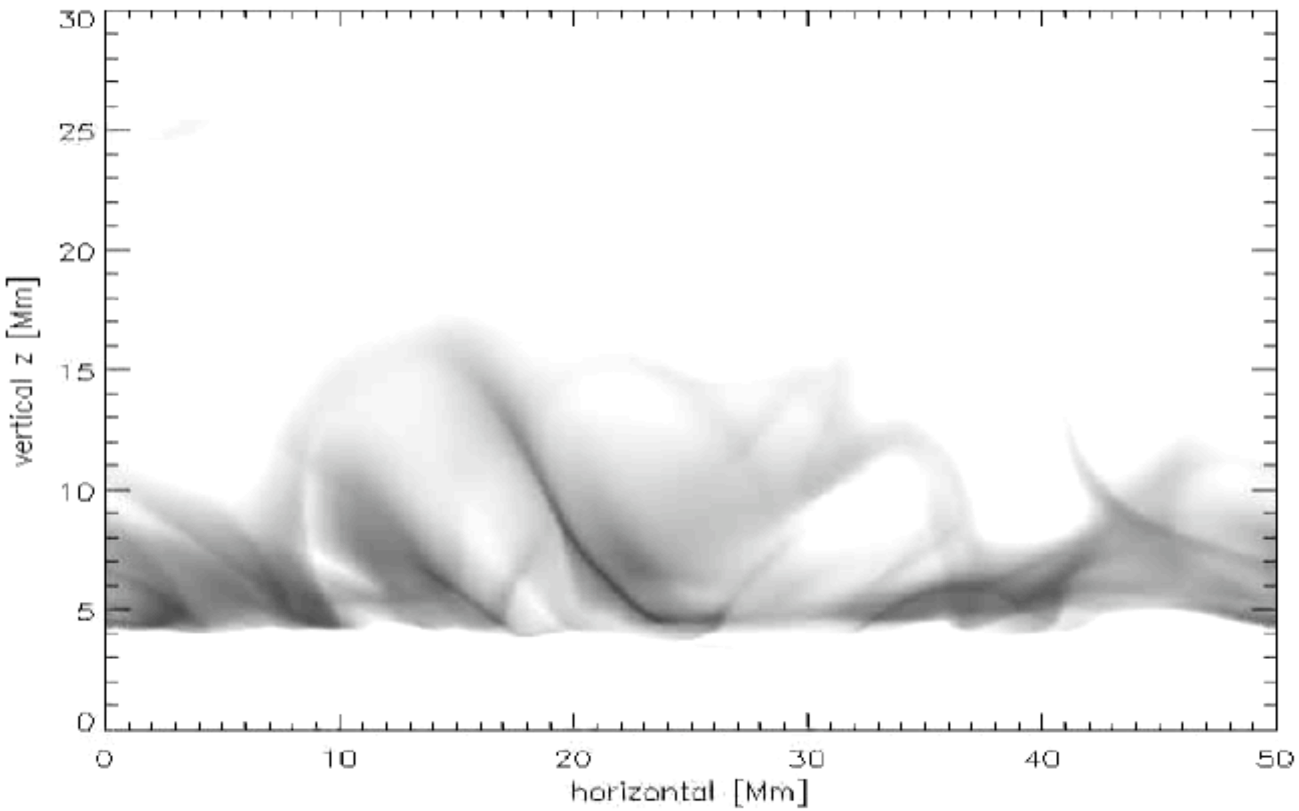
- ► numerous fine loops seen in intensity
- ► seemingly ***not*** connected to underlying magnetic field !!
- ► similar also for “classical” TR lines

iLoops – a projection effect

► we do *not* see loops rotate (or at least not clearly / some might be there…)

► we see iLoops forming and disappearing while the box rotates

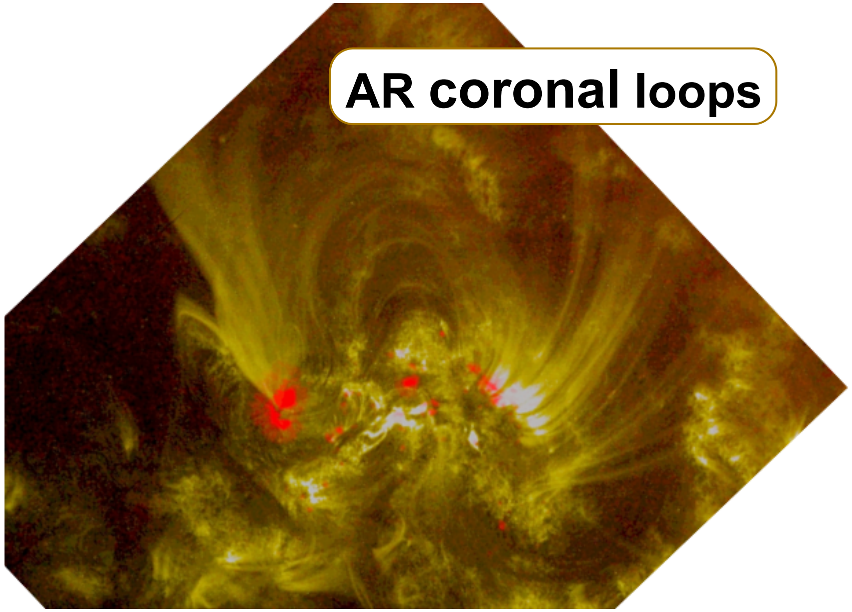
→ these iLoops are (mainly) a projection effect !



looking at the box horizontally from all around…

Emission in Ne VIII (770 Å) at log *T* ~ 5.8 (close to TRACE 171 Å)

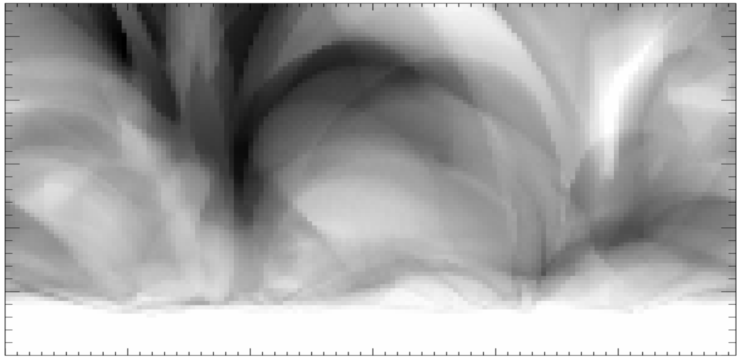
Solar coronal loops

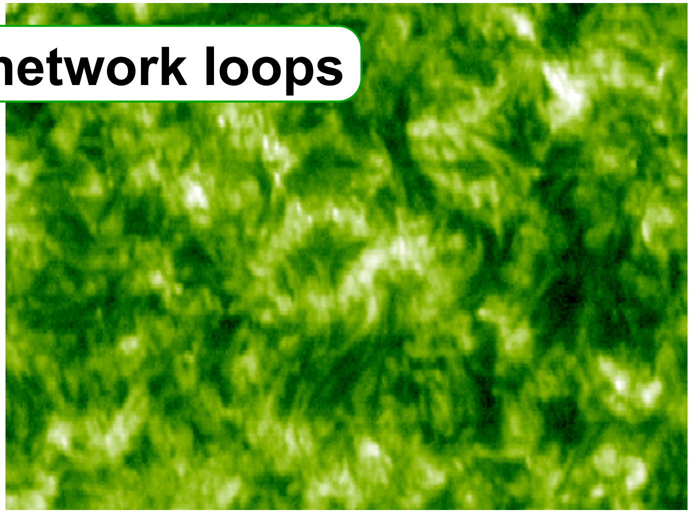


dominated by few magnetic patches

– (large) active regions –

► **bLoops** following magnetic field lines connecting opposite polarities

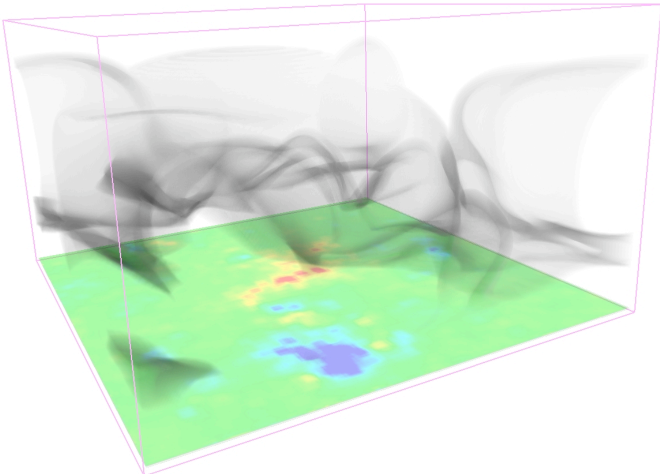




magnetically complex structure:

– magnetic network –

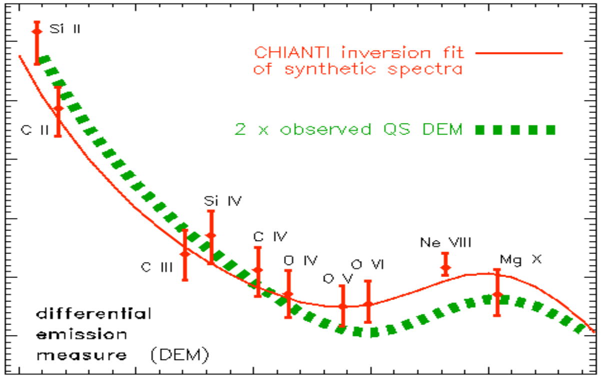
► **iLoops** as projection effects



Conclusions

▶ 3D models for accounting for spatial complexity can account for average properties

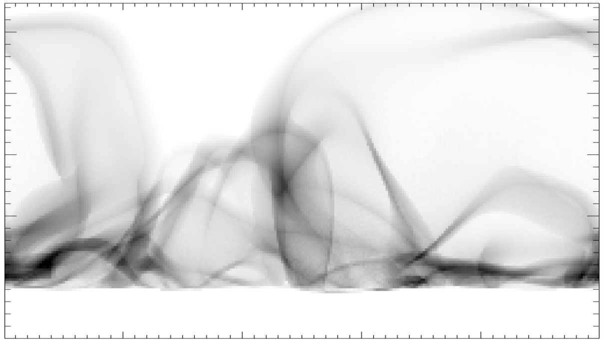
→ Doppler shifts
→ Emission Measure
→ temporal variability



▶ individual loops are heated predominantly at footpoints

→ exponential decay of heating rate

→ spatial distribution of heating not sensitive to details of photospheric driver



▶ probably large part of small "loops" we see in QS cannot described by a traditional loop model!

→ *"iLoops"*