From DC current heating to 3D reconnection - the modes of magnetic energy conversion in chromosphere and corona - Numerical simulations based on Hinode observations

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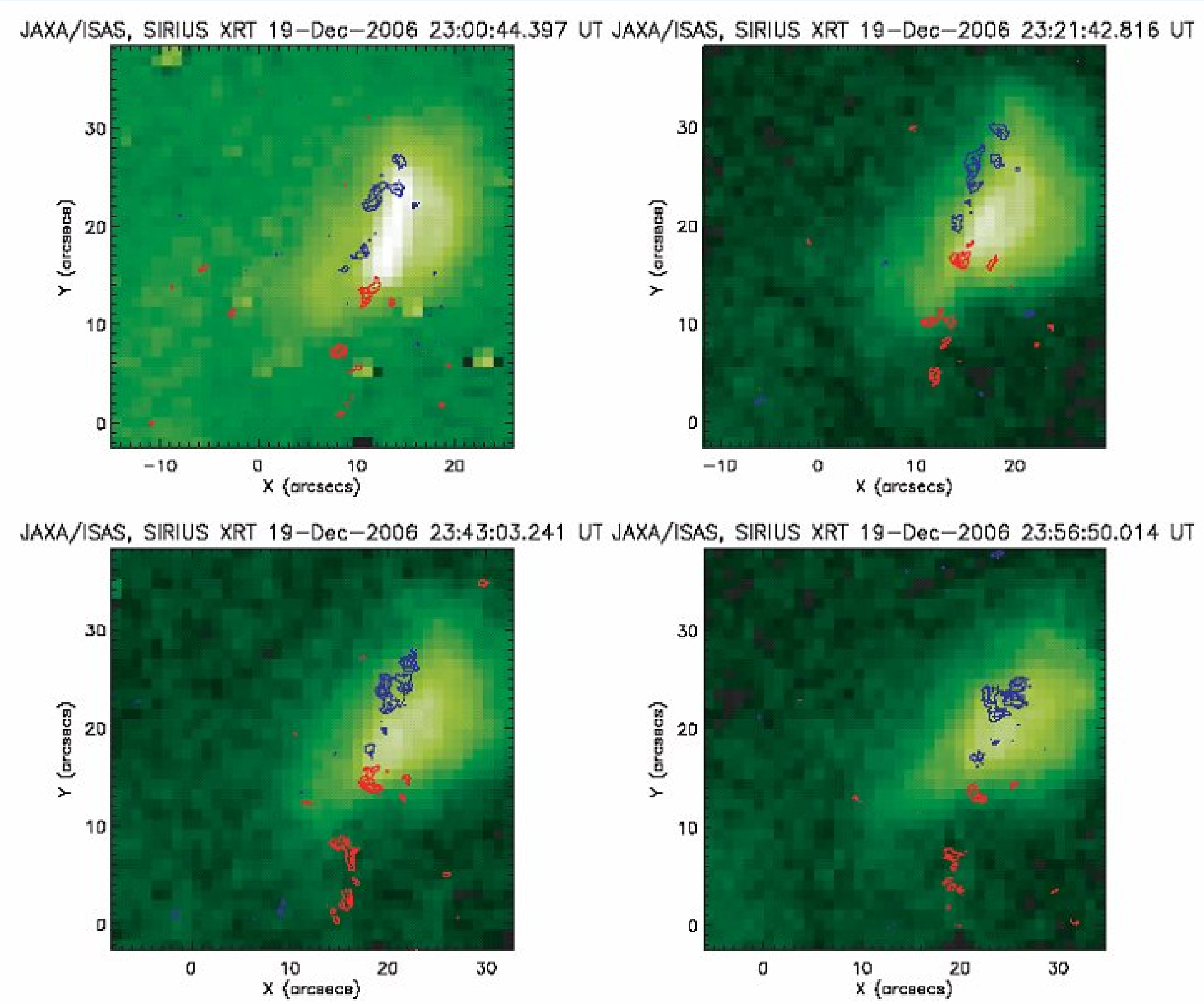
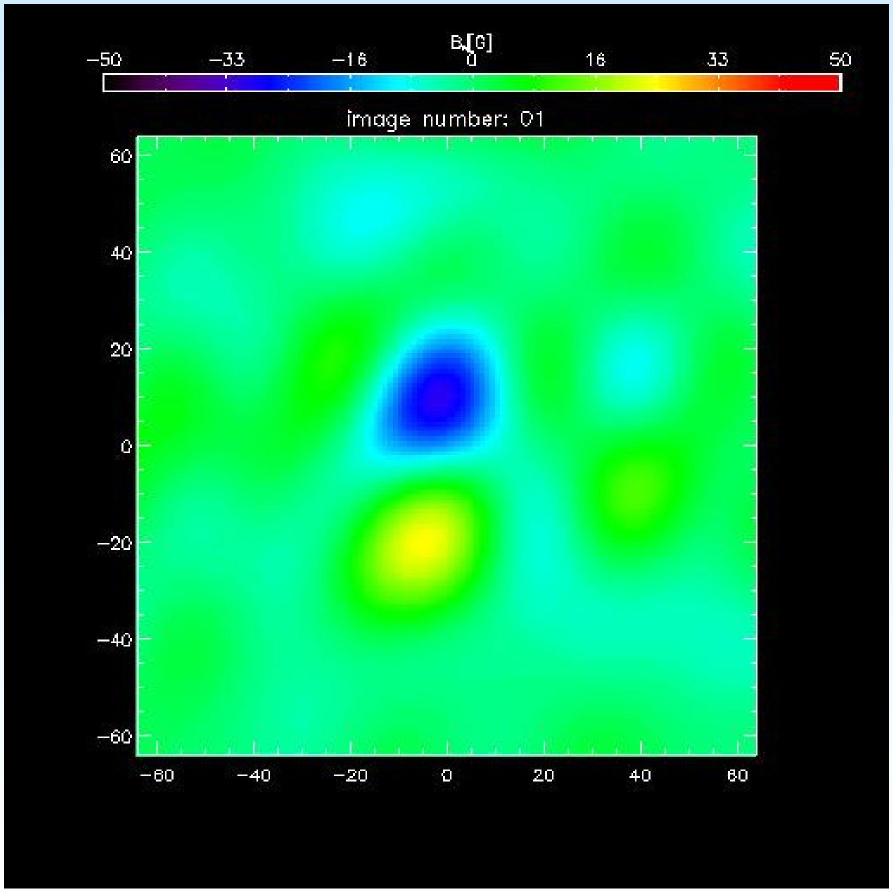
XRT and SOT observations

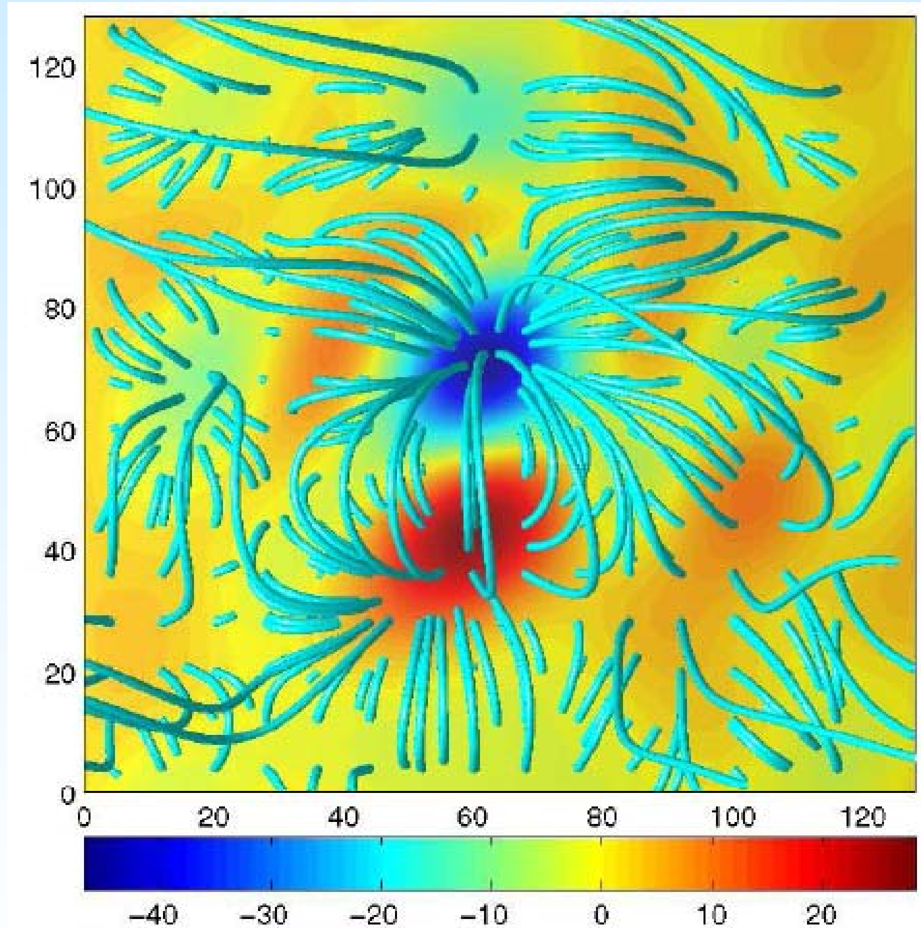


XRT- X-ray images taken between 23:00 UT and 23:56 UT on December 12, 2006 as well as SOT photospheric B-fields from [Kotoku et al., 2007]

-> What causes the brightening?

LOS photospheric B-field around the observed Xray-BP (23:00 UT)



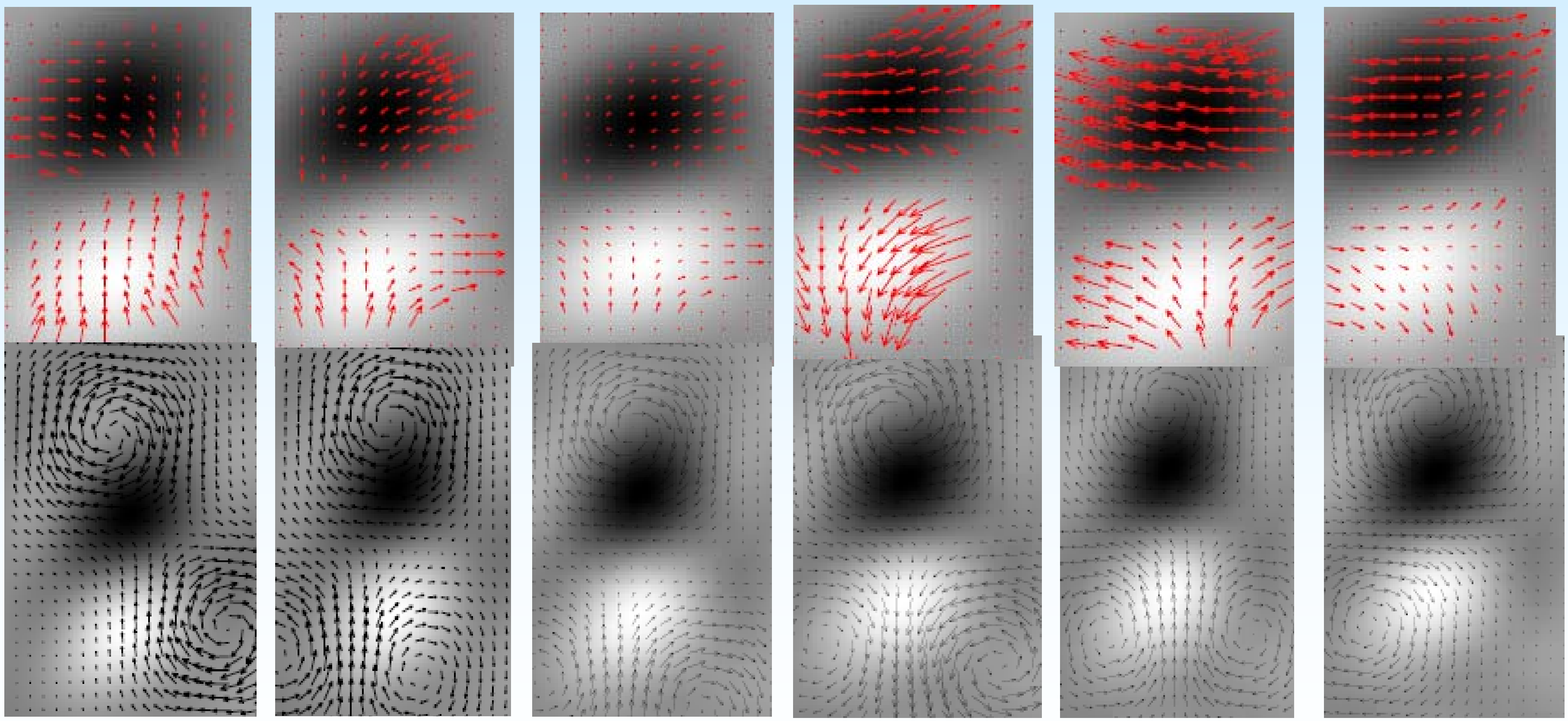


Basic 8 spatial modes of the photospheric B-fields (LOS)

The potential B field shows Strong connection changes

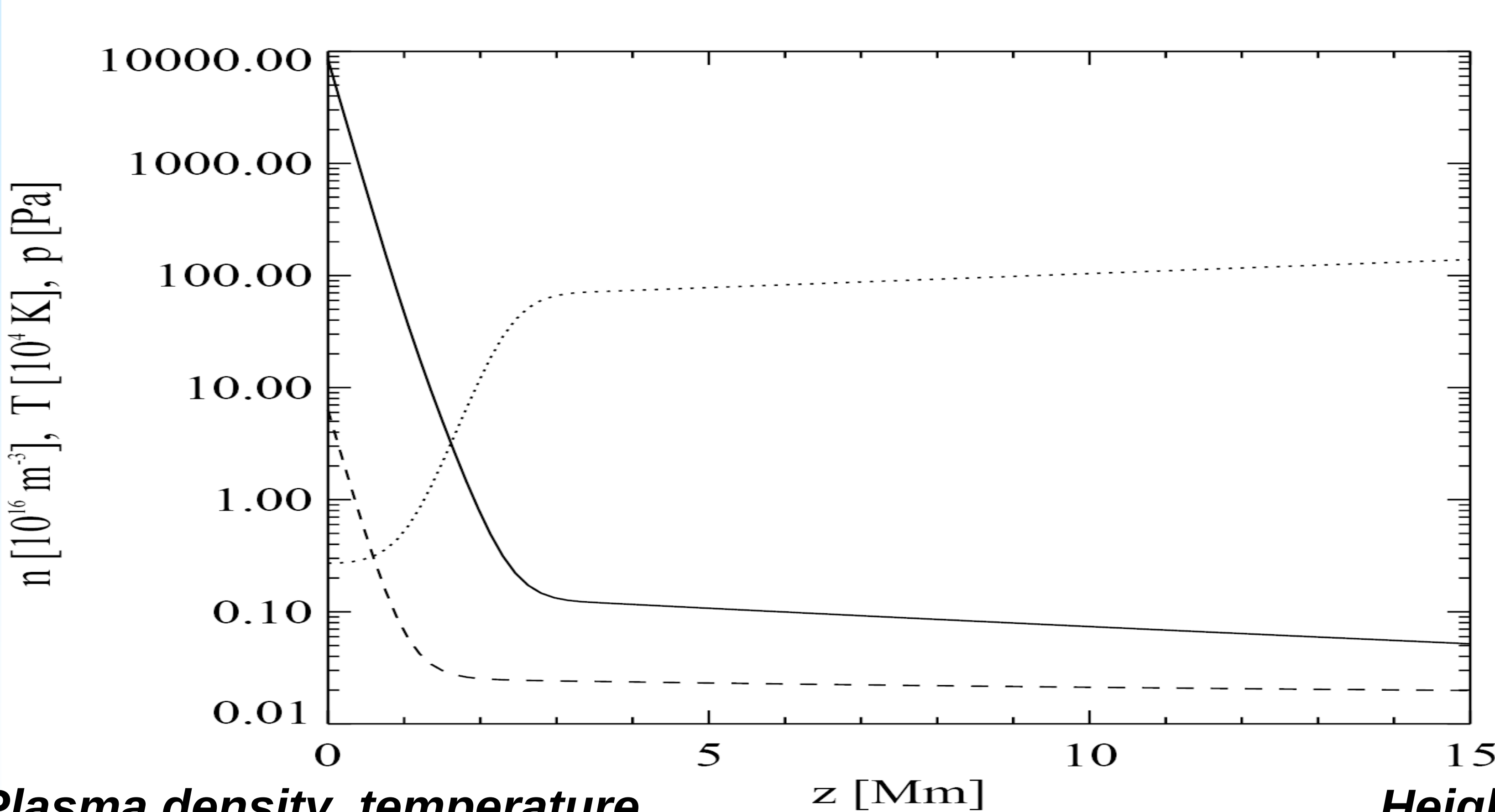
LCT -> Patterns of photospheric plasma motion change with time

23:02 UT	23:07 UT	23:12 UT	23:17 UT	23:22 UT	23:27 UT



Corresponding boundary conditions for simulation

Equilibrium plasma conditions: density and temperature stratification



Plasma density, temperature, pressure in the solar gravitation

Height

Set of RMHD equations, solved

(subscript 0 for neutrals)

$$
\begin{aligned}
\frac{\partial \rho}{\partial t} &= -\vec{\nabla}\cdot\rho\vec{u} - \mu(\rho\ ) \\
\frac{\partial \rho\vec{u}}{\partial t} &= -\vec{\nabla}\cdot\rho\vec{u}\vec{u} - \vec{\nabla}p + \vec{j}\times\vec{B} - \nu\rho(\vec{u}-\vec{u}_0) \\
&= -\vec{\nabla}\cdot\left[\rho\vec{u}\vec{u} + \left(p + \frac{B^2}{2\mu_0}\right)1 - \frac{\vec{B}\vec{B}}{\mu_0}\right] - \nu\rho(\vec{u}-\vec{u}_0) \\
\frac{\partial \vec{B}}{\partial t} &= \vec{\nabla}\times(\vec{u}\times\vec{B} - \eta\vec{j}) \\
\frac{\partial p}{\partial t} &= -\vec{\nabla}\cdot p\vec{u} - (\gamma-1)p\vec{\nabla}\cdot\vec{u} + (\gamma-1)\eta j^2 - \kappa n k_B (T - T_0)
\end{aligned}
$$

$$
\begin{aligned}
\vec{E} &= -\vec{u}\times\vec{B} + \eta\vec{j} \\
\vec{\nabla}\times\vec{B} &= \mu_0\vec{j}
\end{aligned}
$$

$$
\hat{\eta}^* = \begin{cases} \eta_{\mathrm{a}}^* \left(\frac{|v_{\mathrm{dr}}|}{v_{\mathrm{thr}}} - 1\right); & |v_{\mathrm{dr}}| \geq v_{\mathrm{thr}}, \\ 0; & |v_{\mathrm{dr}}| < v_{\mathrm{thr}}. \end{cases}
$$

$$p = 2n\kappa_B T$$

RMHD simulation results

- **Simulated heating is maximum at BPs position**

- **The heating is robust, does not depend on the details of the photospheric plasma motion.**

- **Most important for heating are geometrical features of the magnetic field, in particular strong changes in the B-field connectivity**

- **A consequence of connecticity changes if footpoint motion applies: current generation**

To understand current dissipation:
-> kinetic theories have to be applied

Current dissipation

If the resistivity is parametrized by an „effective collision frequency“ as

$$\eta = \frac{\nu}{\epsilon_0 \omega_{pe}^2}$$

then in the chromosphere binary particle collisions dissipate currents [Spitzer–Härm]:

$$\nu_{coll} \cong \frac{\omega_{pe}}{n\lambda_D^3}$$

However, in the transition region and corona -> binary collisions become inefficient->micro-turbulent dissipation:

Threshold: current carrier velocity or gradients > critical

Quasi-linear estimate [Sagdeev et al.]

$$\nu_S \cong 0.01\omega_{pe} \frac{T_e}{T_i} \frac{u_D}{v_{te}}$$

Nonlinear->kinetic simulations needed for solar conditions [Büchner & Elkina]

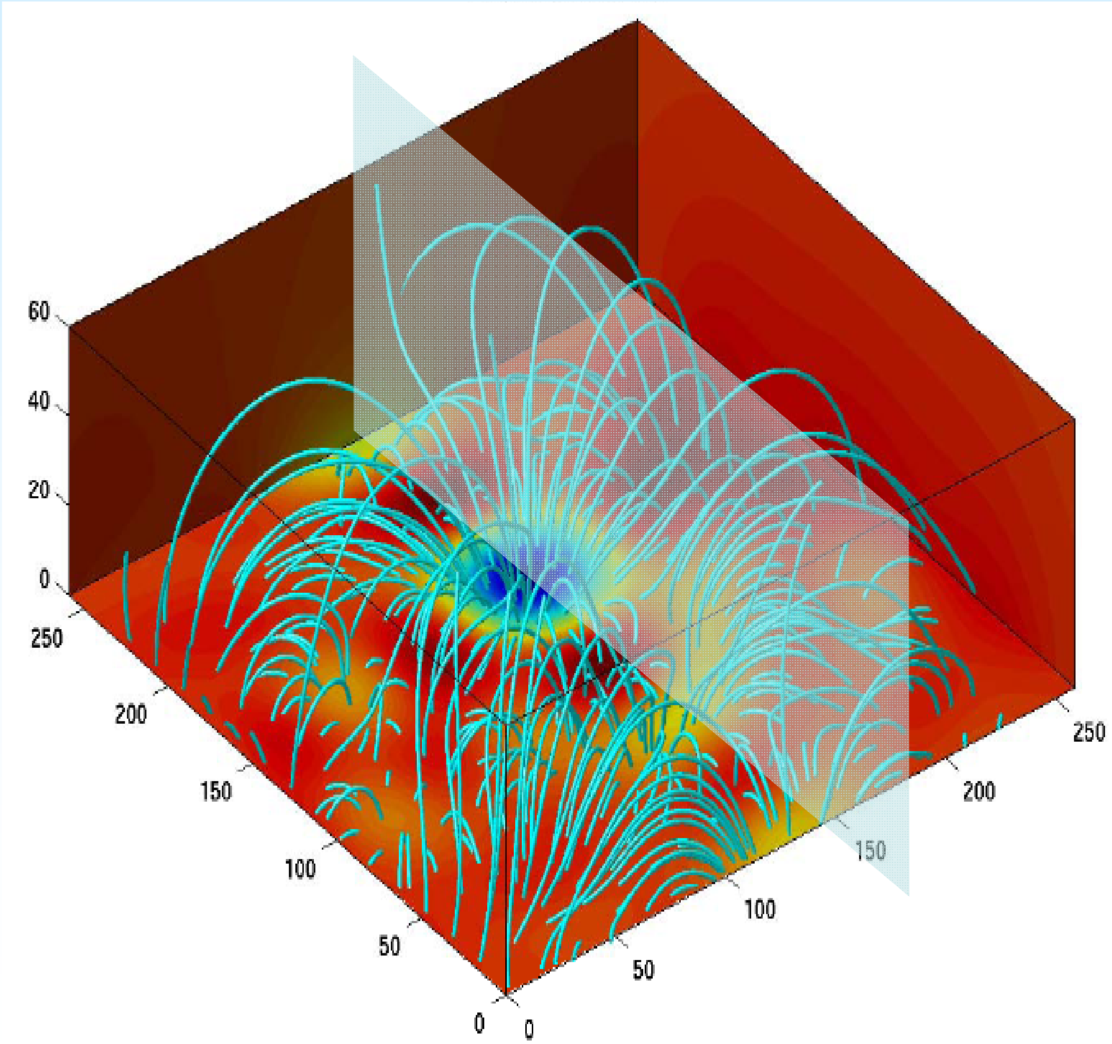
– higher beta -> IA / double layers

– lower beta –> LH turbulence

$$\nu_c \approx \omega_{pi}/2\pi$$

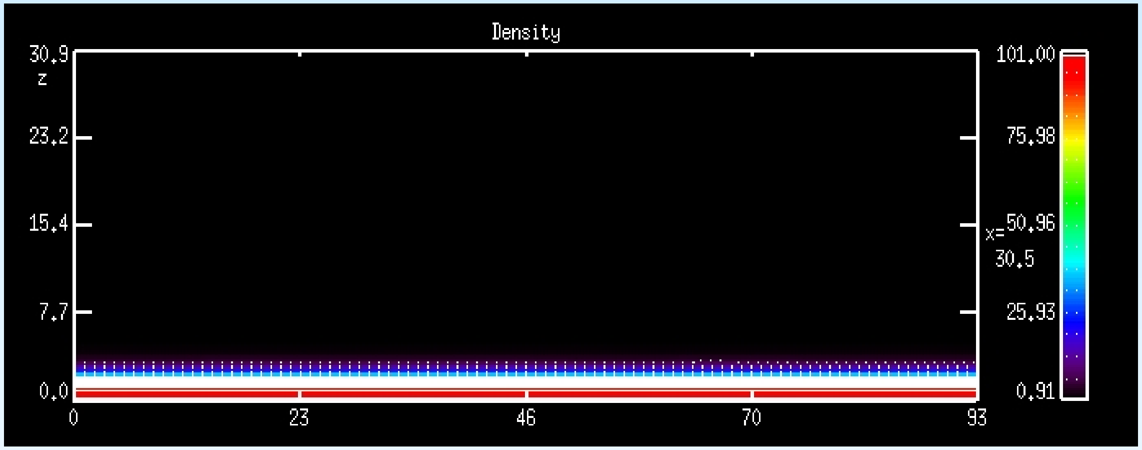
$$\nu_c \approx \Omega_{LH}$$

Results of simulations diagnozed in a vertical plane through the Bmax



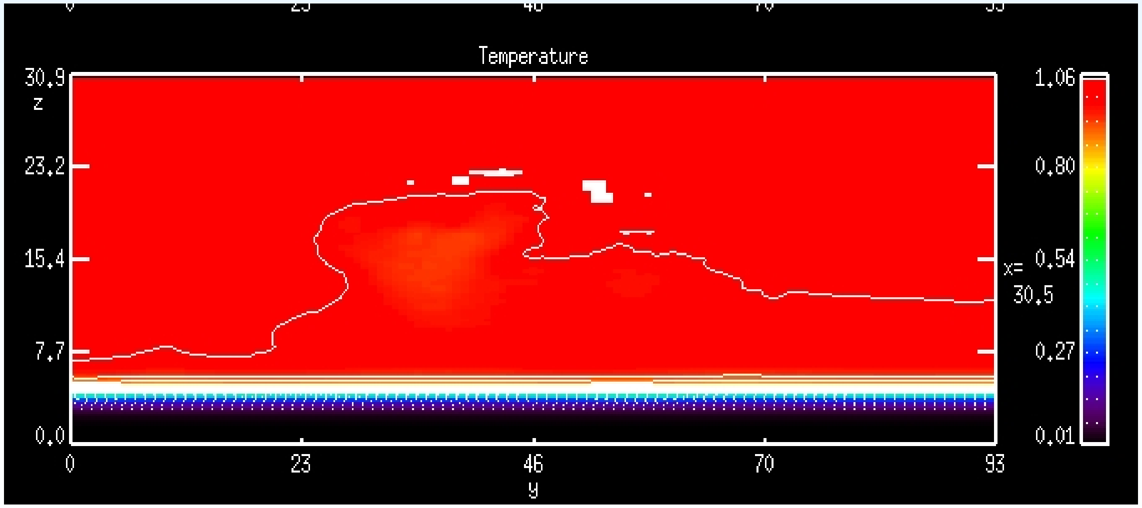
Initial situation

Density (n)

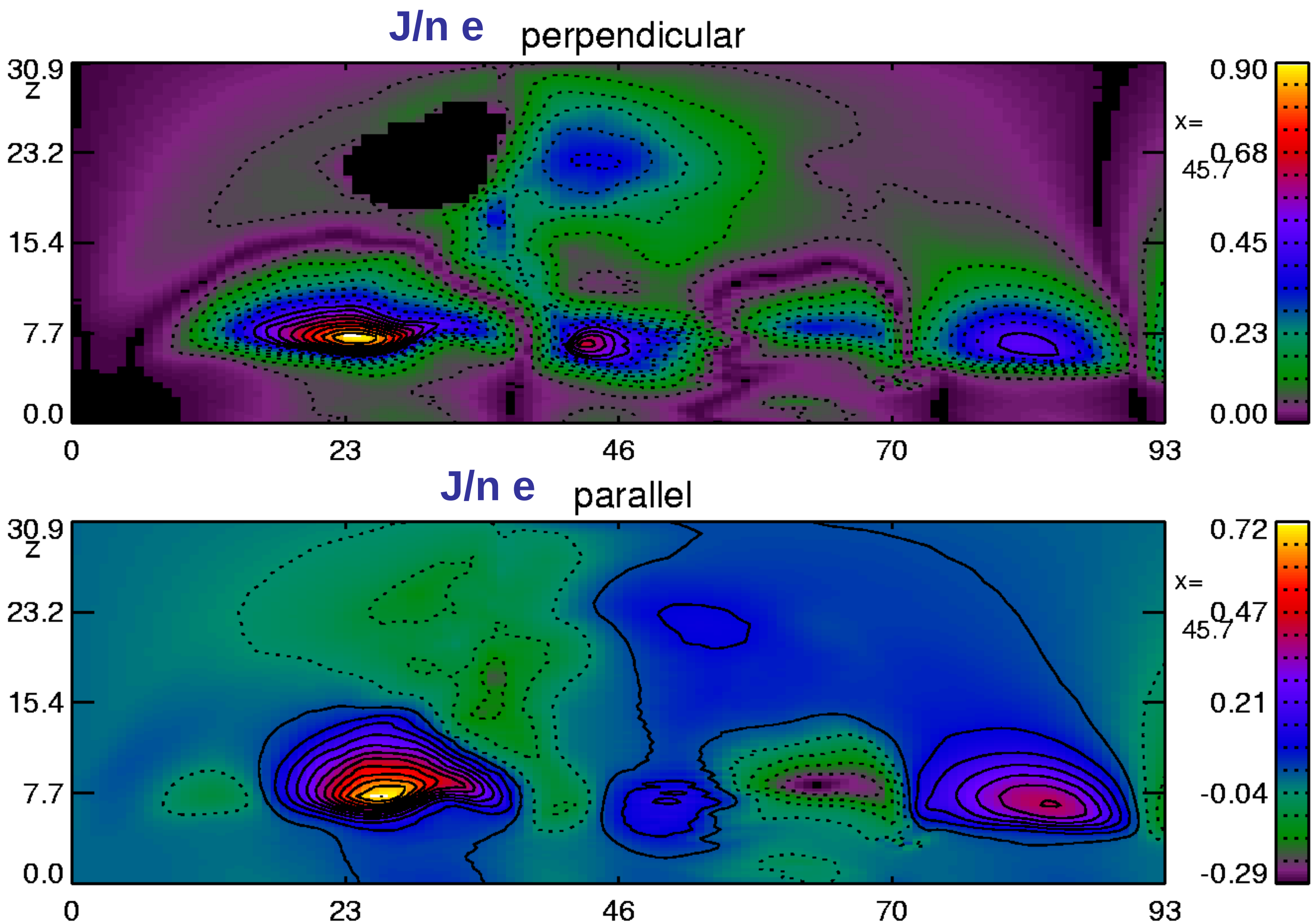


Temperature (T)

(Red = 10^6 K)

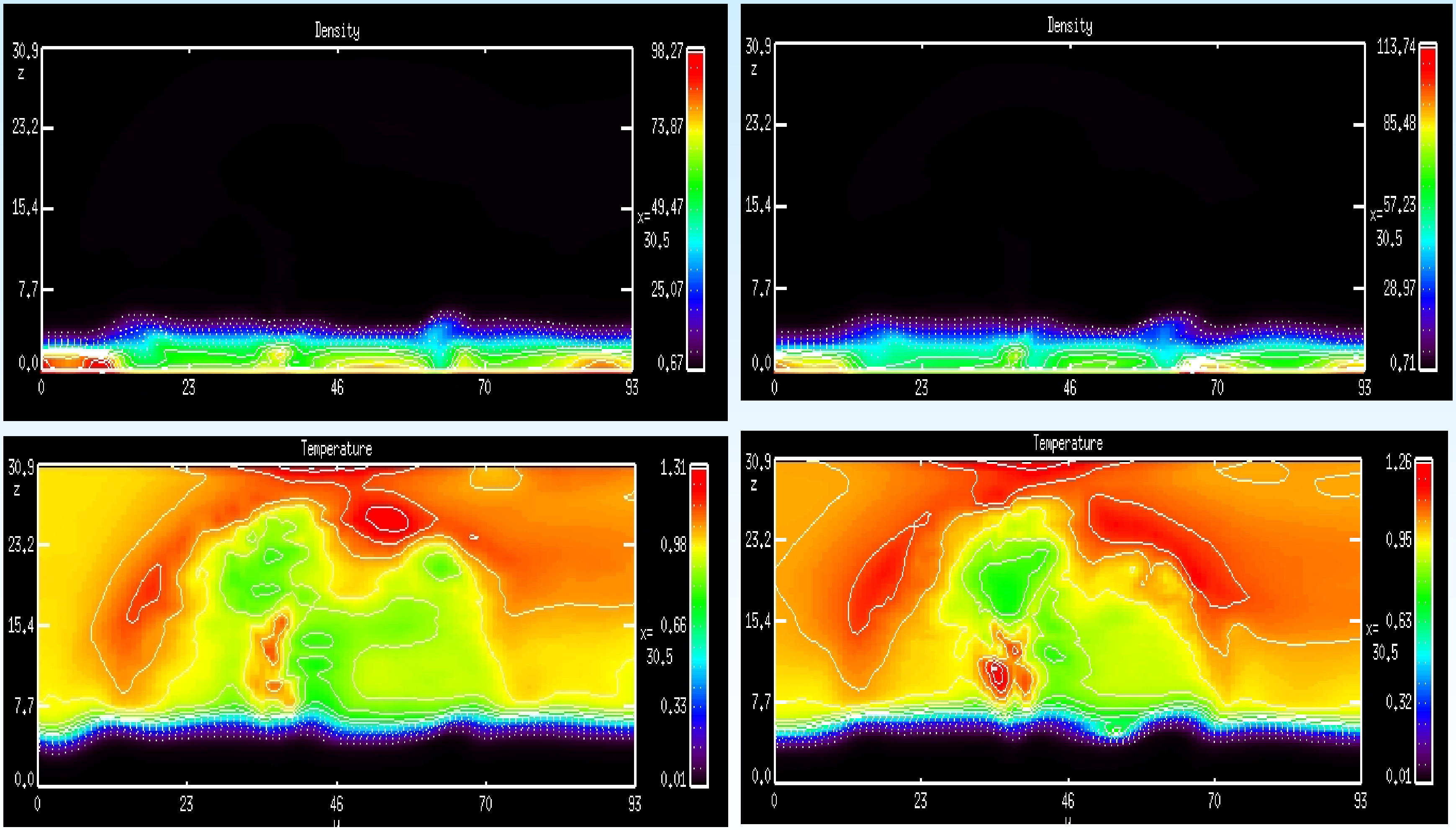


Turbulent current dissipation



j/ne represents the current carrier velocity

Results of 5-minute runs
23:02 – 23:07 & 23:07 – 23:12

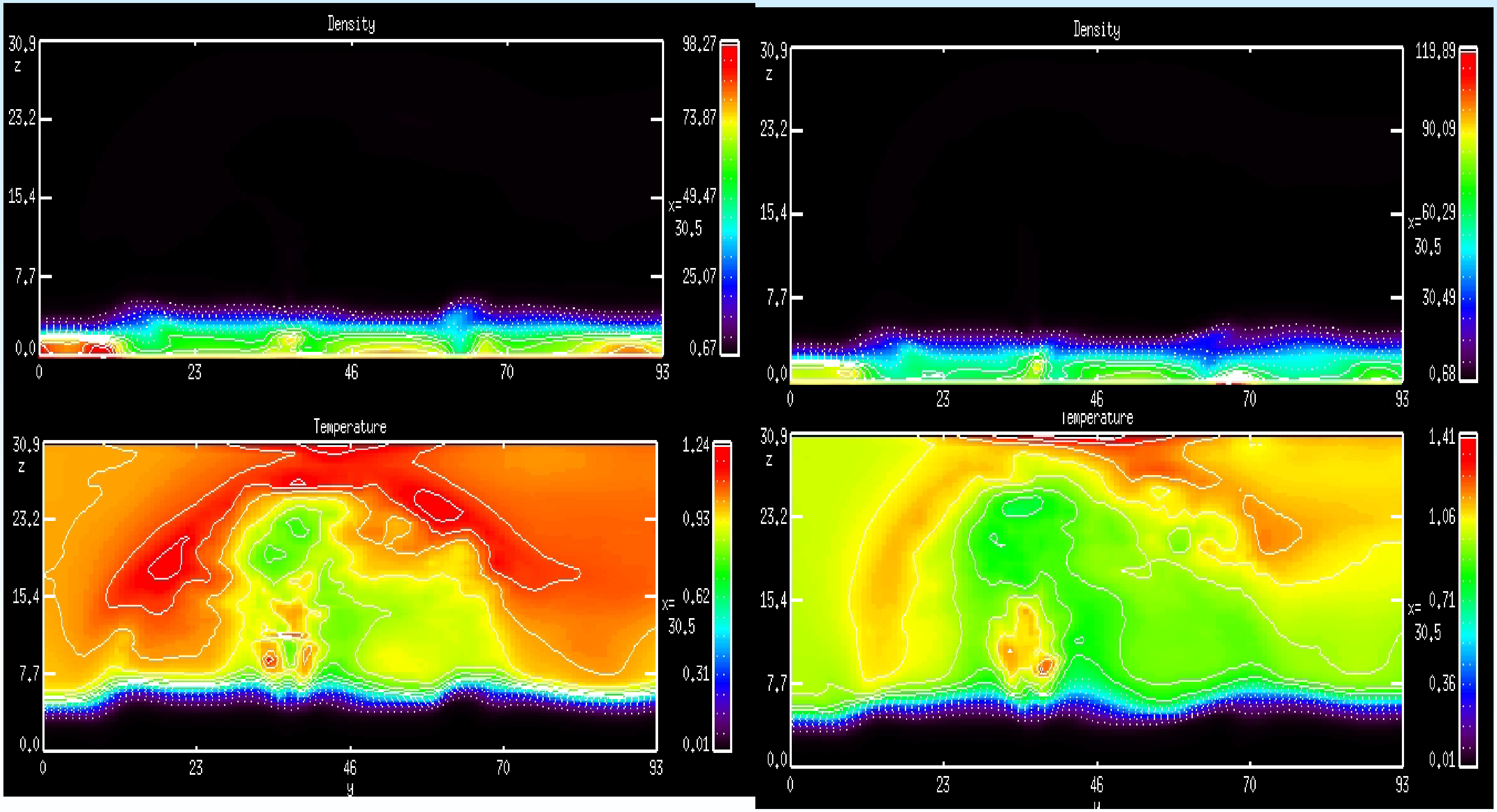


n

T

(Red = 1.3 10^6 K)

Results of 5-minute runs
23:12 – 23:17 & 23:17 – 23:22

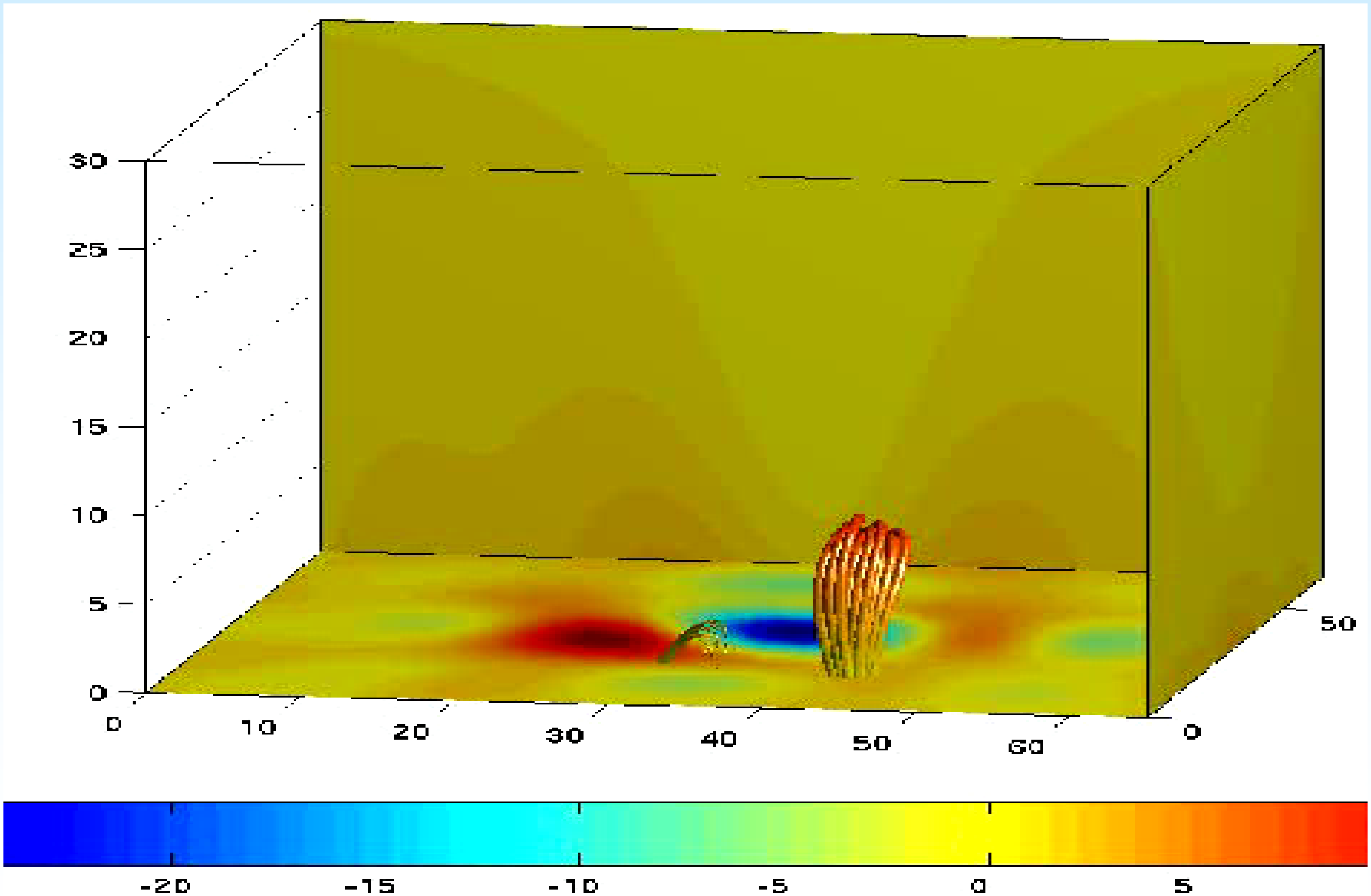


n

T

(Red = 1.4 10^6 K)

Above the chromosphere: 3D reconnection („slipping")



Conclusions

- An observed Hinode X-ray Bright Point location
  - coincides well with the sites of strong B-field connectivity changes, and
  - do not depend much on the exact form of the plasma motion in the photosphere below
- Strong B-field connectivity changes + some plasma motion accross the footpoints

  -> currents, both parallel and perpendicular to B
- While in the chromosphere binary collisions dominate the current dissipation, causing Ohmic heating,
- In the transition region / lower corona main dissipation

  microturbulence-induced 3D „slipping“ reconnection

Outline

- Unprecedented high resolution Hinode observations
- But: Still open, what causes the formation of X-ray and EUV Bright Points
  - coincides well with the sites of strong B-field connectivity changes, and
  - do not depend much on the exact form of the plasma motion in the photosphere below
- Strong B-field connectivity changes + some plasma motion accross the footpoints

  -> currents, both parallel and perpendicular to B
- While in the chromosphere binary collisions dominate the current dissipation, causing Ohmic heating,
- In the transition region / lower corona main dissipation microturbulence-induced 3D „slipping“ reconnection