Physically consistent simulation of chromospheric and coronal magnetic fields

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Issue

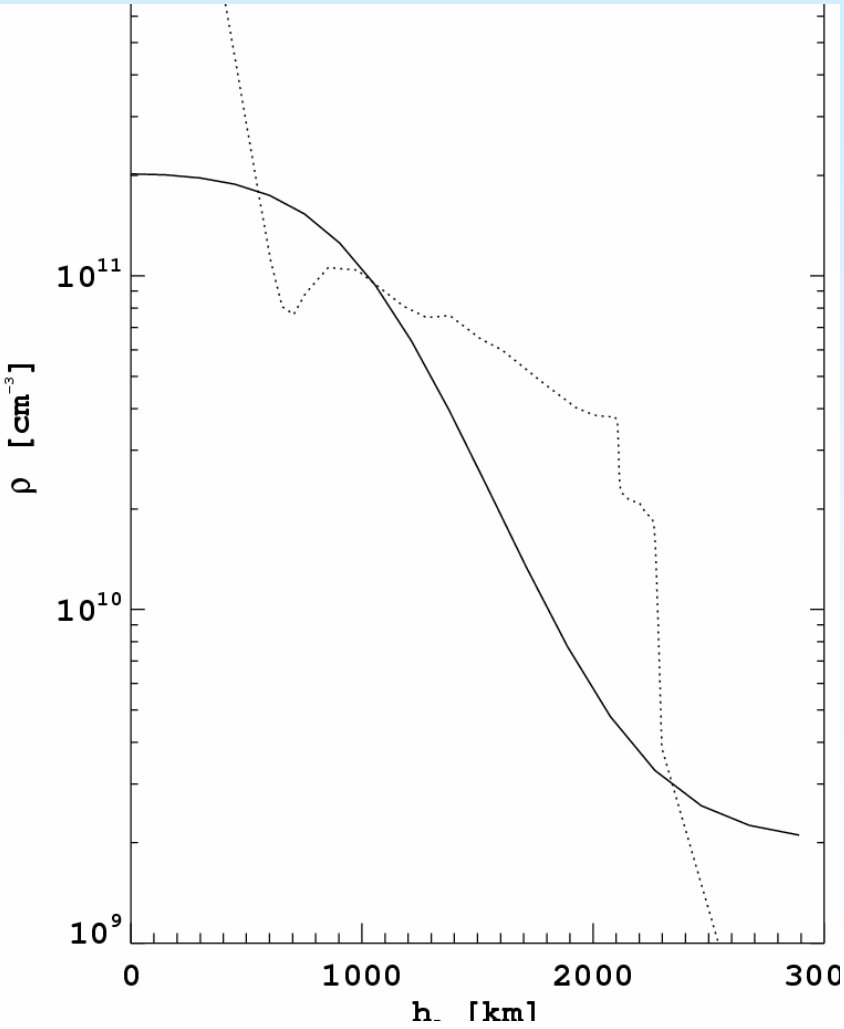
- Magnetic fields couple photosphere, chromo-sphere and corona, but their measurement is restricted mainly to the photosphere
- Hence, the usual approach is force-free extrapolation, neglecting J perpendiular to B
- Questions:
  - What are the limits of this approach?
  - How important are perpendicular currents?

Our approach

- Currents in chromosphere and corona
  - are driven by plasma motion and
  - are closely related to the magnetic field geomet and / or even the topology
- Our method of investigation of the currents:
  - MHD simulation based on observed photosphe B fields and plasma motion
- Here: results of case studies based on observed
  - chromospheric current sheet (Solanki et al.03)
  - quiet sun – EUV bright point (Brown et al. 01)
  - coronal hole (Tu et al., 2005)

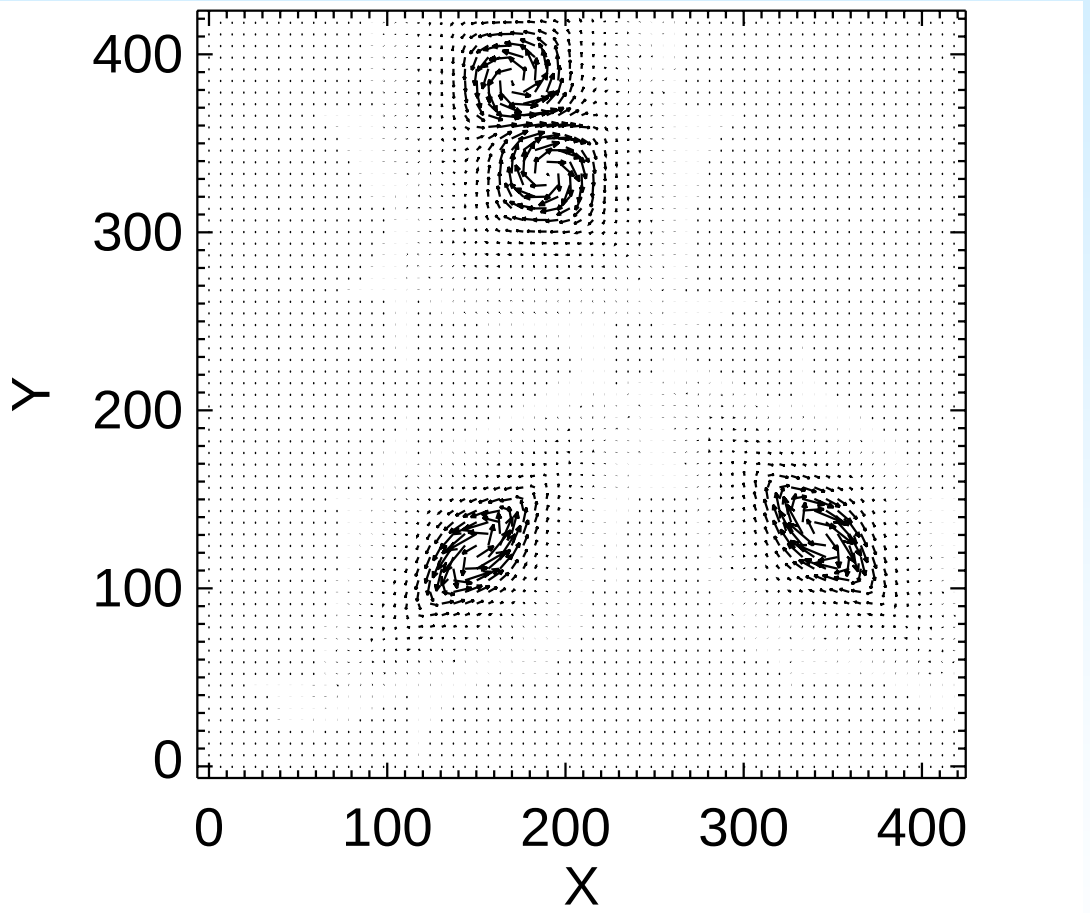
Initial & boundary conditions

Initial condition: Force free B-field and MHD equilibrium



Ex.: Density stratification at t=0

Boundary condition: photospheric plasma motion:



A resistivity is locally switched on after the current carrier velocity exceeds a plasmaphysically detremined threshold

Neutral gas-plasma coupling

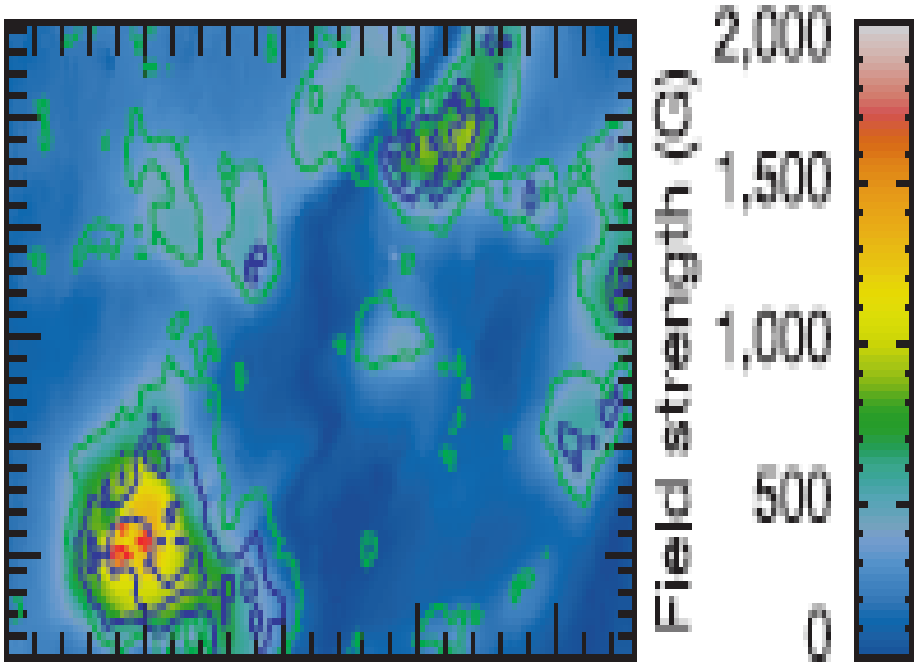
$$
\begin{aligned}
\frac{\partial \rho}{\partial t} &= -\nabla \cdot \rho \mathbf{u} - \nu(\rho - \rho_0) \\
\frac{\partial \rho \mathbf{u}}{\partial t} &= -\nabla \cdot \rho \mathbf{u}\mathbf{u} - \frac{1}{2}\nabla p + \mathbf{j} \times \mathbf{B} - \mu\rho(\mathbf{u} - \mathbf{u}_0) \\
&= -\nabla \cdot \left[\rho \mathbf{u}\mathbf{u} + \frac{1}{2}\left(p + B^2\right)\underline{\underline{1}} - \mathbf{B}\mathbf{B}\right] - \mu\rho(\mathbf{u} - \mathbf{u}_0) \\
\frac{\partial \mathbf{B}}{\partial t} &= \nabla \times (\mathbf{u} \times \mathbf{B} - \eta \mathbf{j}) \\
\frac{\partial p}{\partial t} &= -\nabla \cdot p\mathbf{u} - (\gamma - 1)p\nabla \cdot \mathbf{u} + 2(\gamma - 1)\eta \mathbf{j}^2 - \kappa n k_B (T - T_0) \\
with \quad & \mathbf{E} = -\mathbf{u} \times \mathbf{B} + \eta \mathbf{j} \\
& \nabla \times \mathbf{B} = \mathbf{j}
\end{aligned}
$$

Neutral gas in the chromosphere:

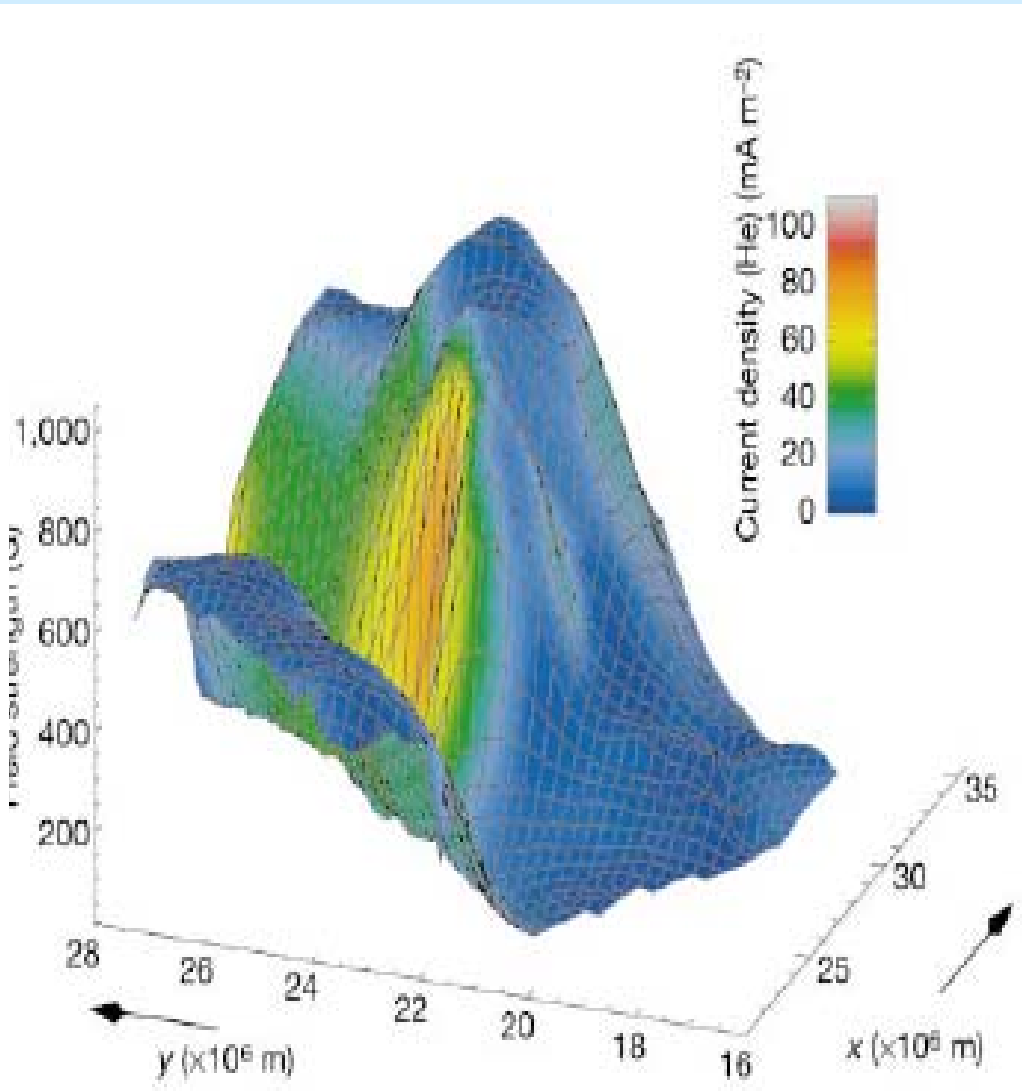
$n_n \approx 10^{13}\, to\, 10^{14}\ \mathrm{cm}^{-3}, v_{th} = 7 \cdot 10^3\ \mathrm{m/s}$ $\nu_{in} = n_n \sigma_n v_{th}$ with $\sigma_n \approx 10^{-15}\ \mathrm{cm}^2$.

1. Chromospheric current sheet

Chromospheric magnetic field map (Solanki et al., Nature 2003):



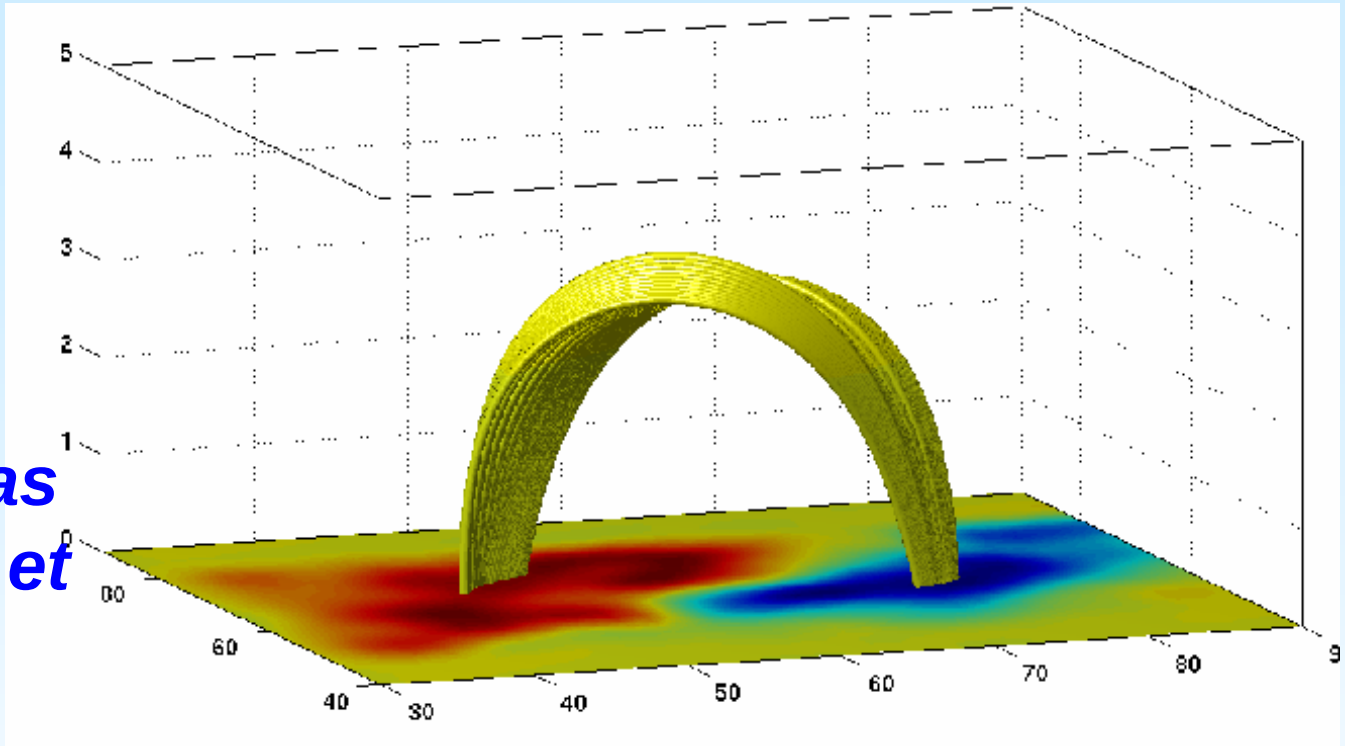
Derivation of a chromospheric current sheet from the observed chromospheric magnetic field (Solanki et al., Nature 2003) ->



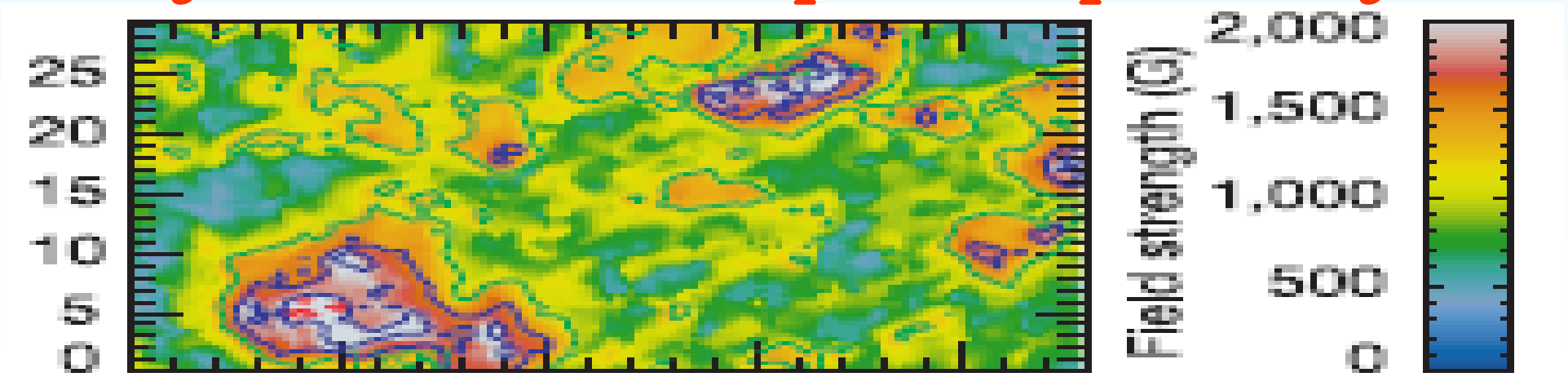
Force-free field extrapolation:

Force free extrapolation:
(Jperp =0 assumed)

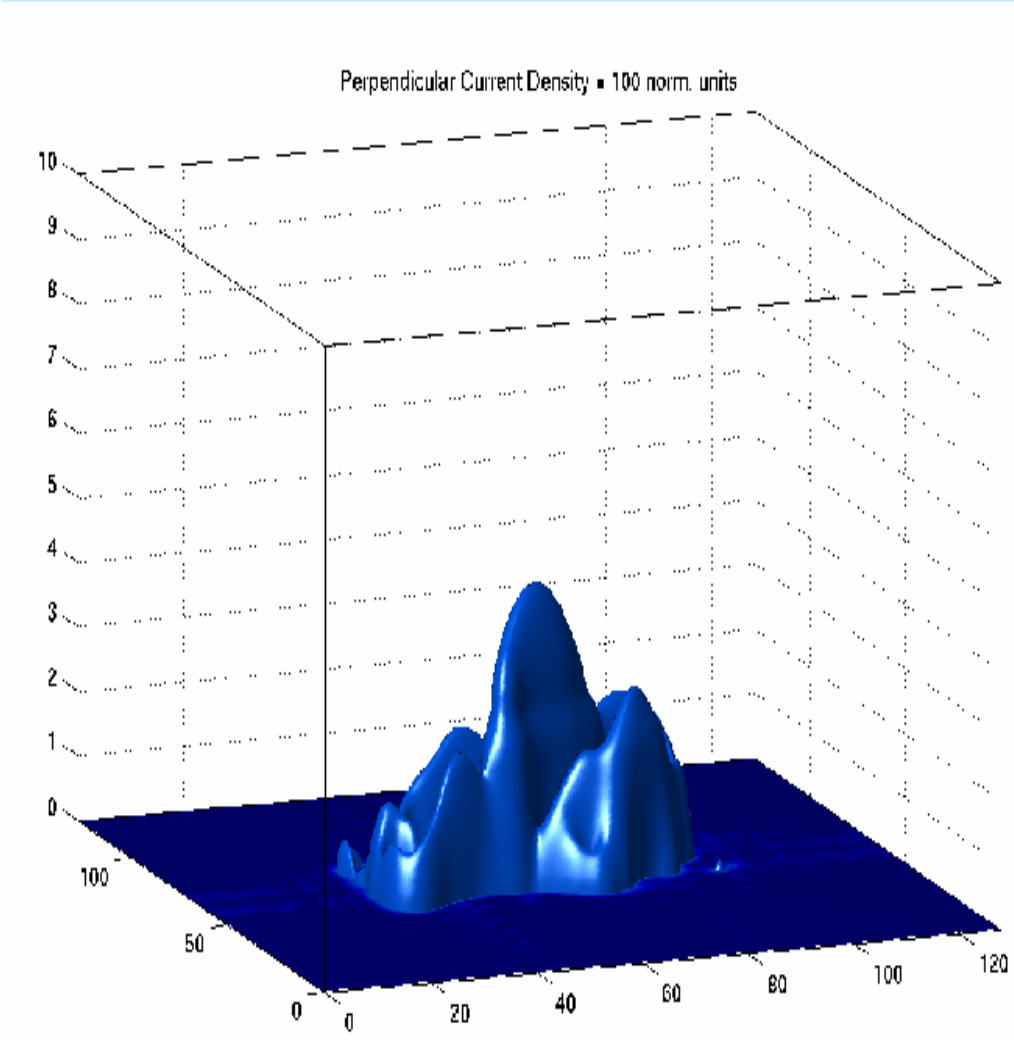
-> No place for a Jperp current sheet as observed by Solanki et al. 2003 (Nature)

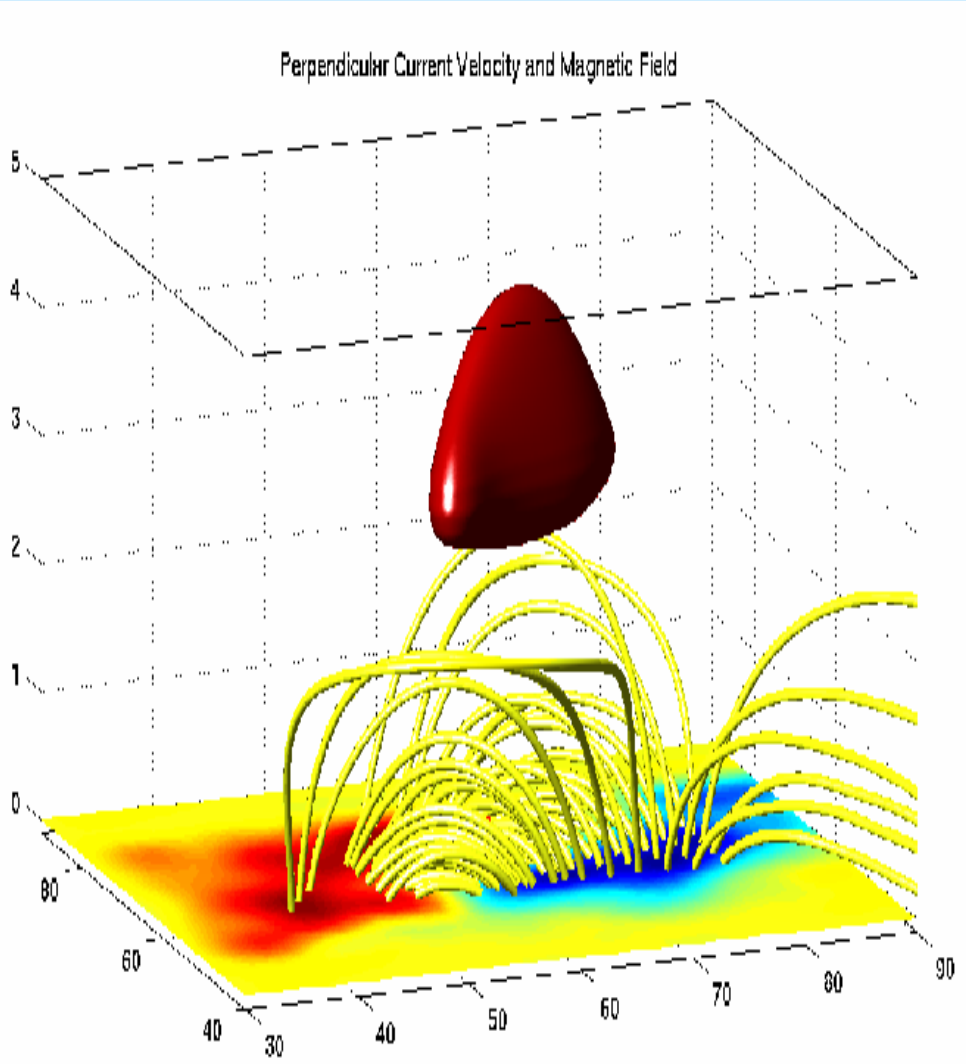


… of the observed photospheric field:



Simulation-> Jperp current sheet



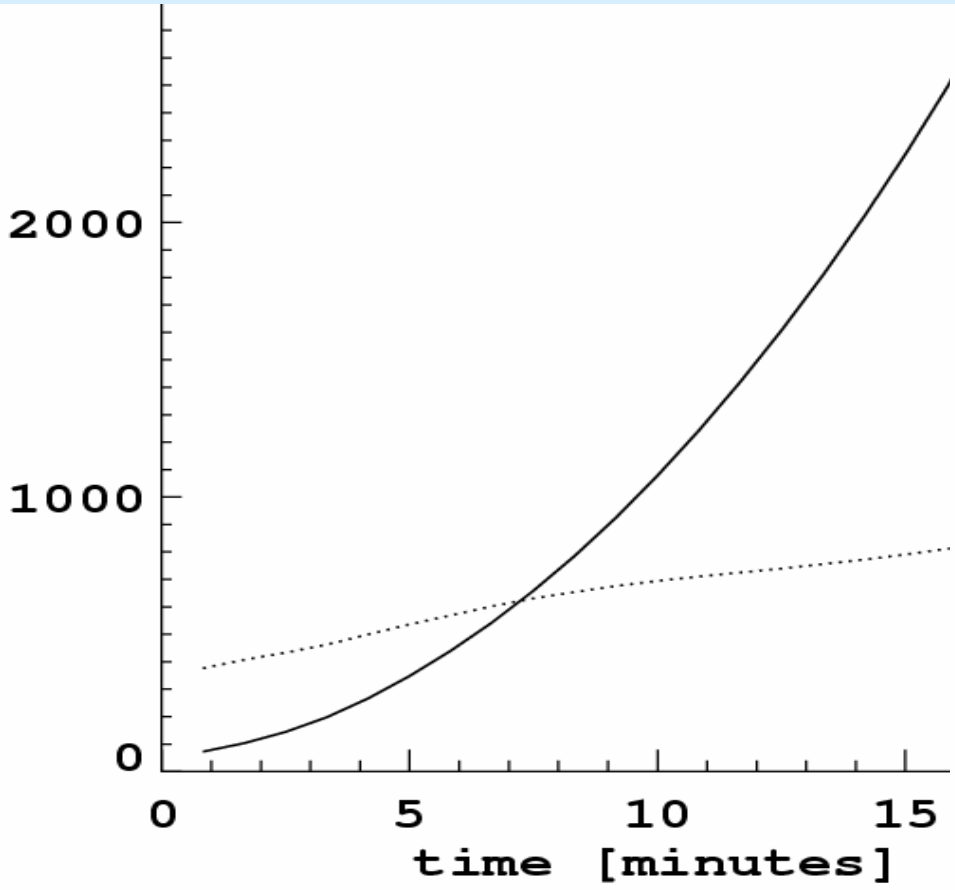


Isosurface of Jperp=const., i.e. of perpendicular current density

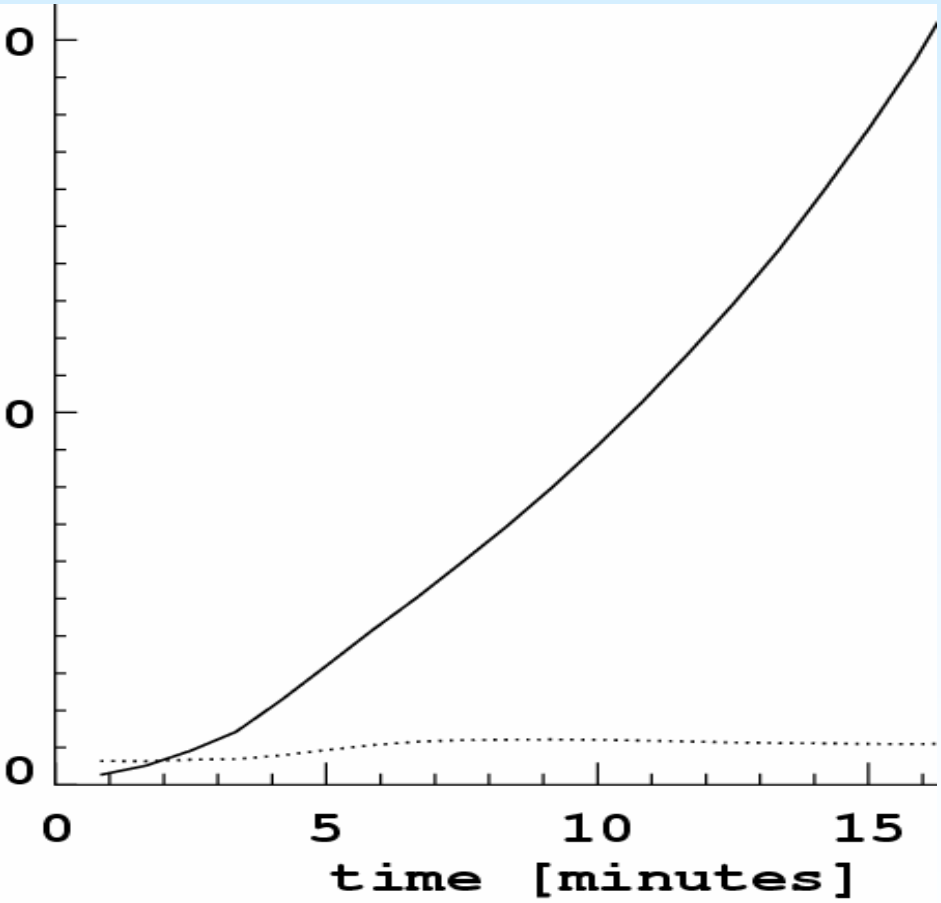
Higher isosurface of Jperp=const., and resulting disturbed B field

Ideal current evolution (i.e. there is no resistivity switched on):

j^2 in the chromosphere (< 3 Mm)

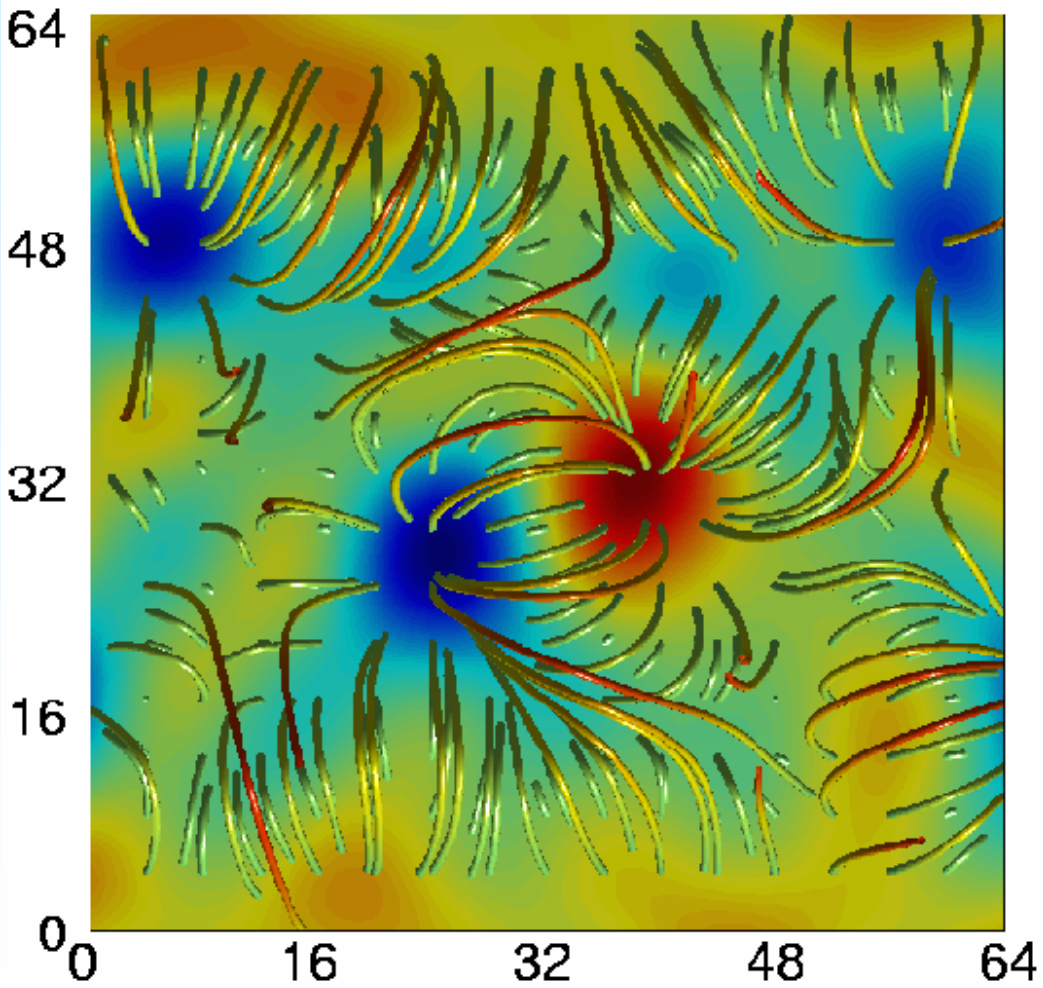


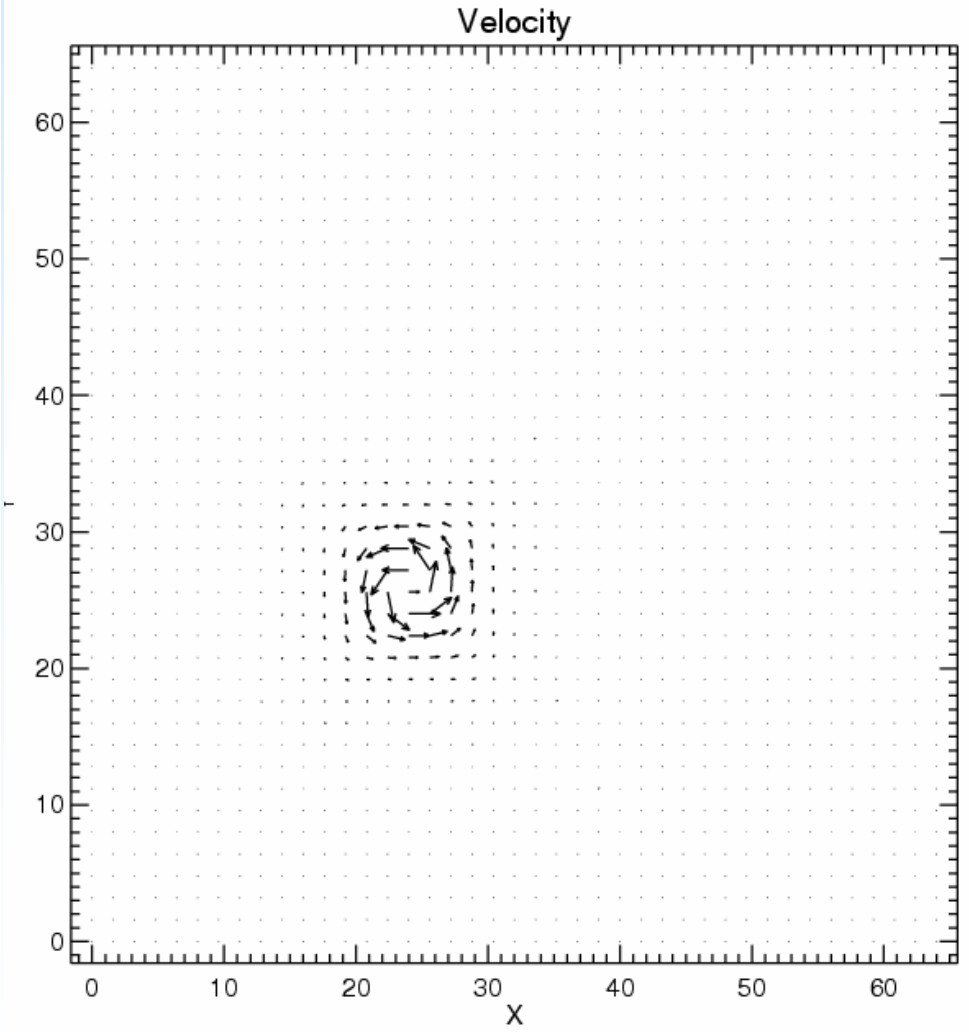
j^2 in the corona (> 4 Mm)



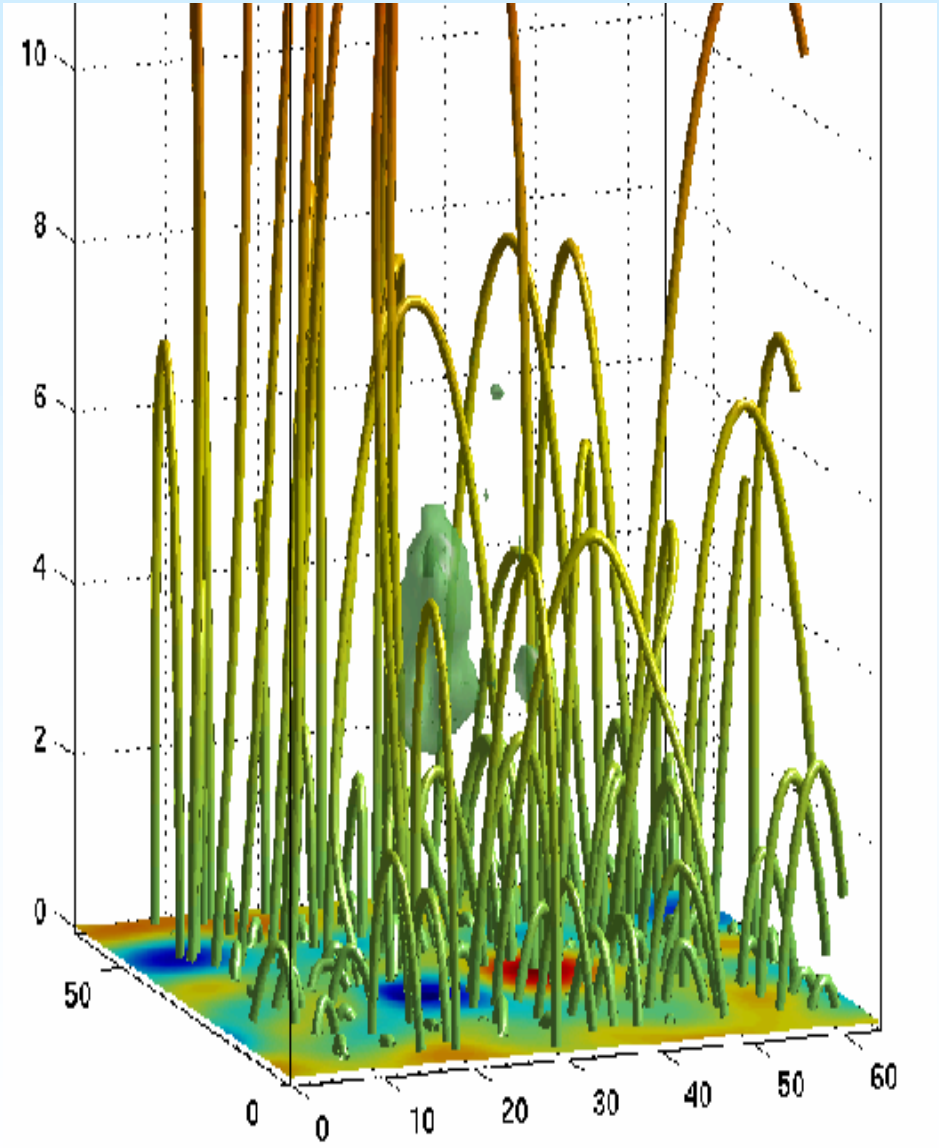
Solid lines: Jpar^2; Dotted lines: J_perp^2

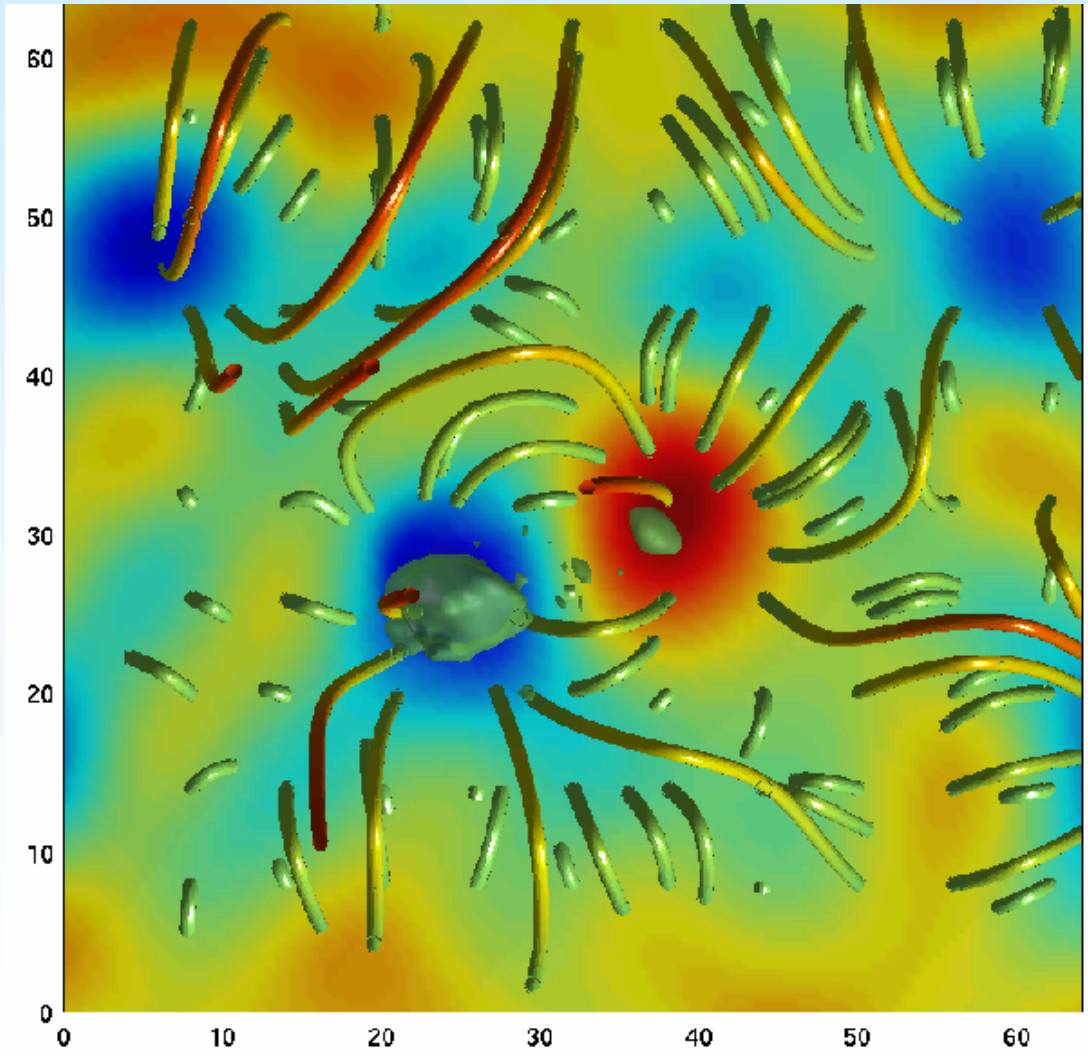
2. Quiet Sun EUV Bright Point (14.6.98, 14:00 UT)





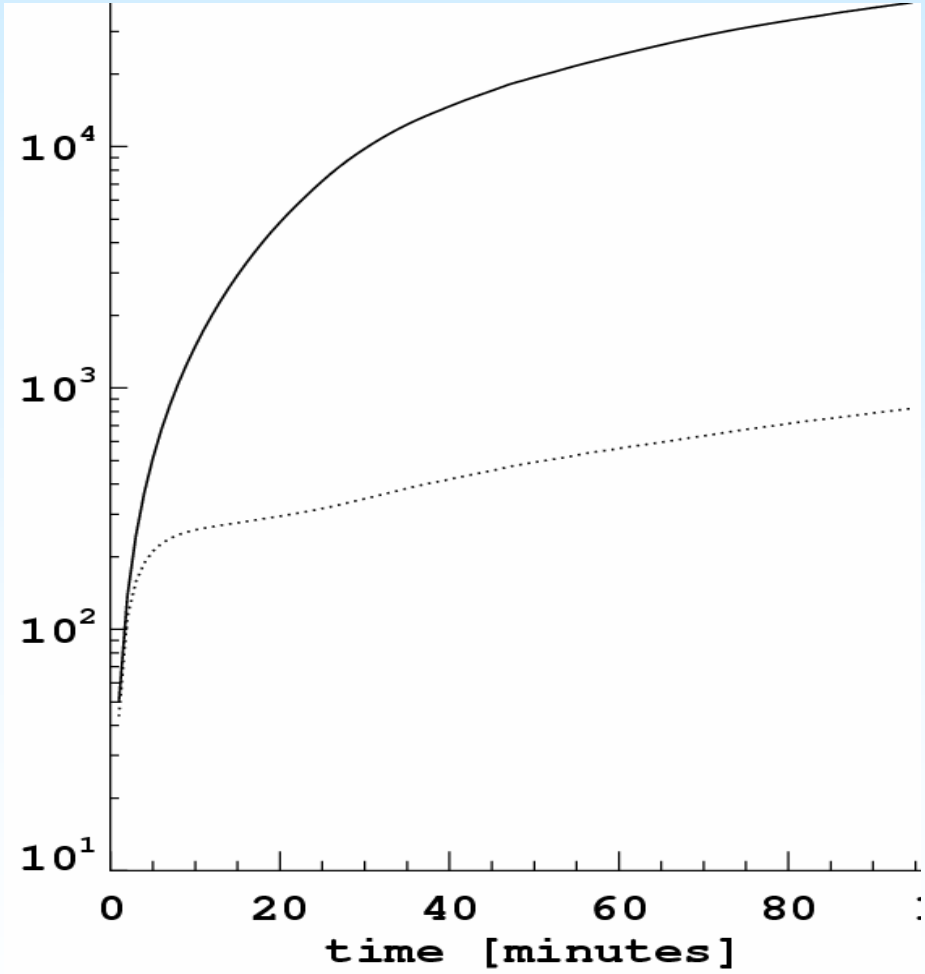
Localized Jperp current sheets



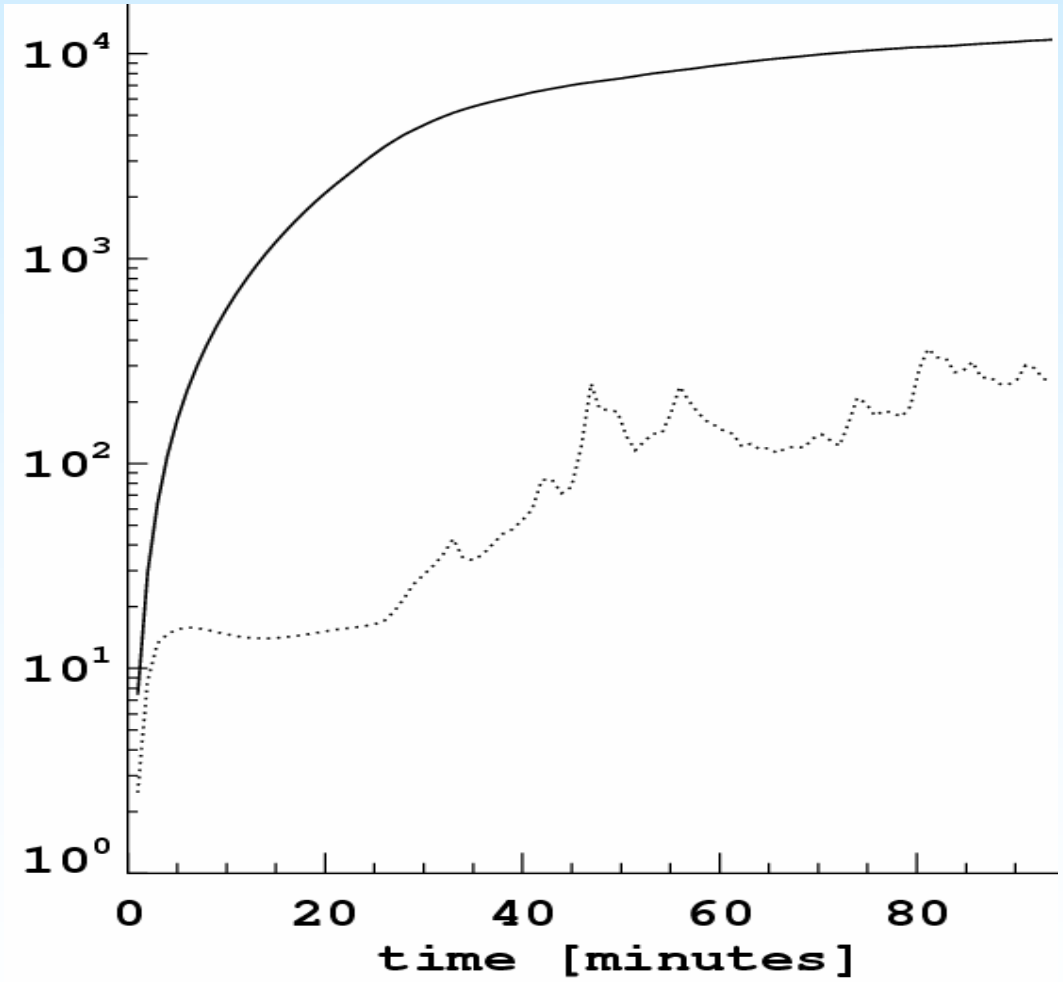


Currents in the Bright Point case

j^2 in the chromosphere (< 3 Mm)

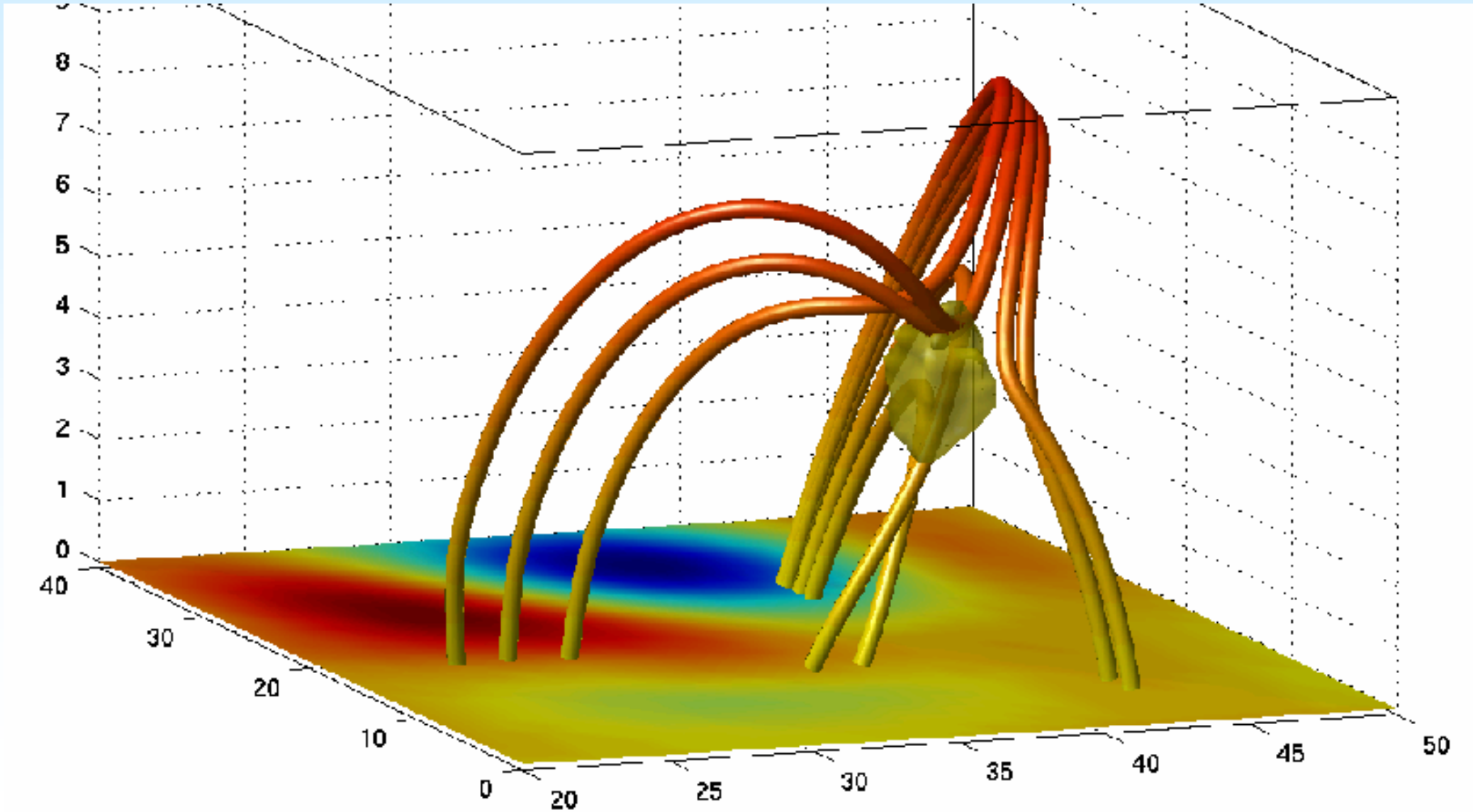


j^2 in the corona (> 4 Mm)



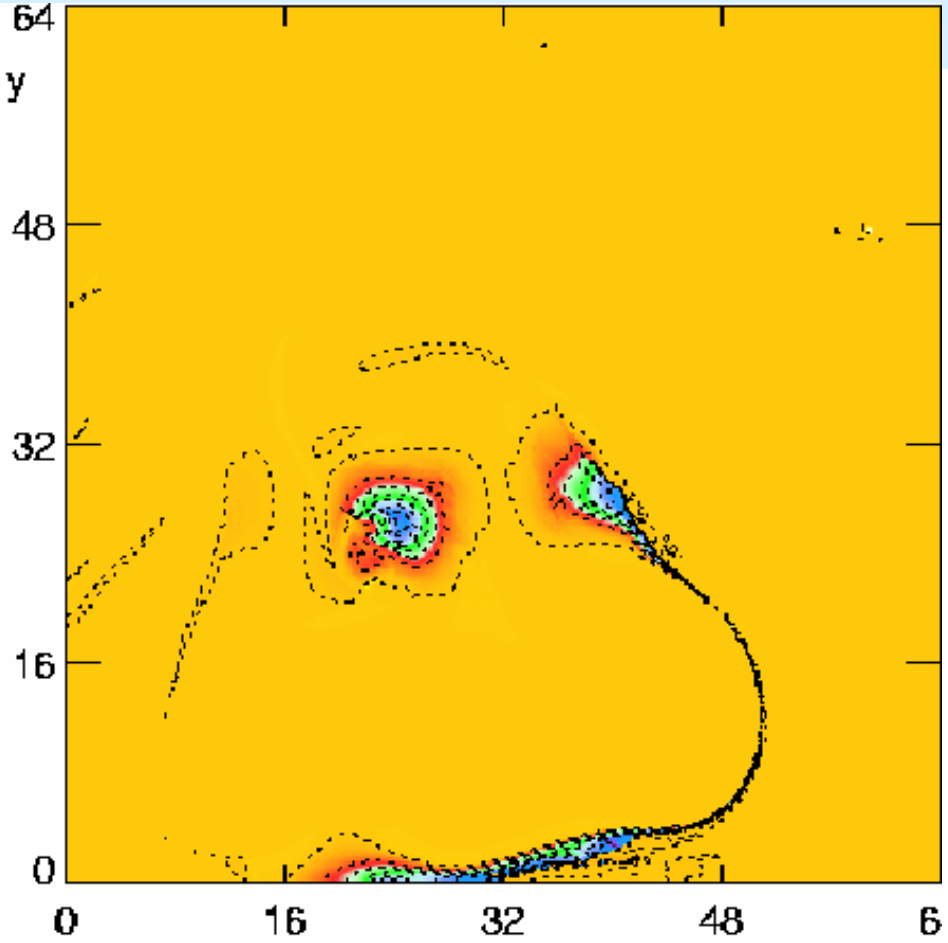
(Solid lines: Jpar^2; dotted lines: J_perp^2)

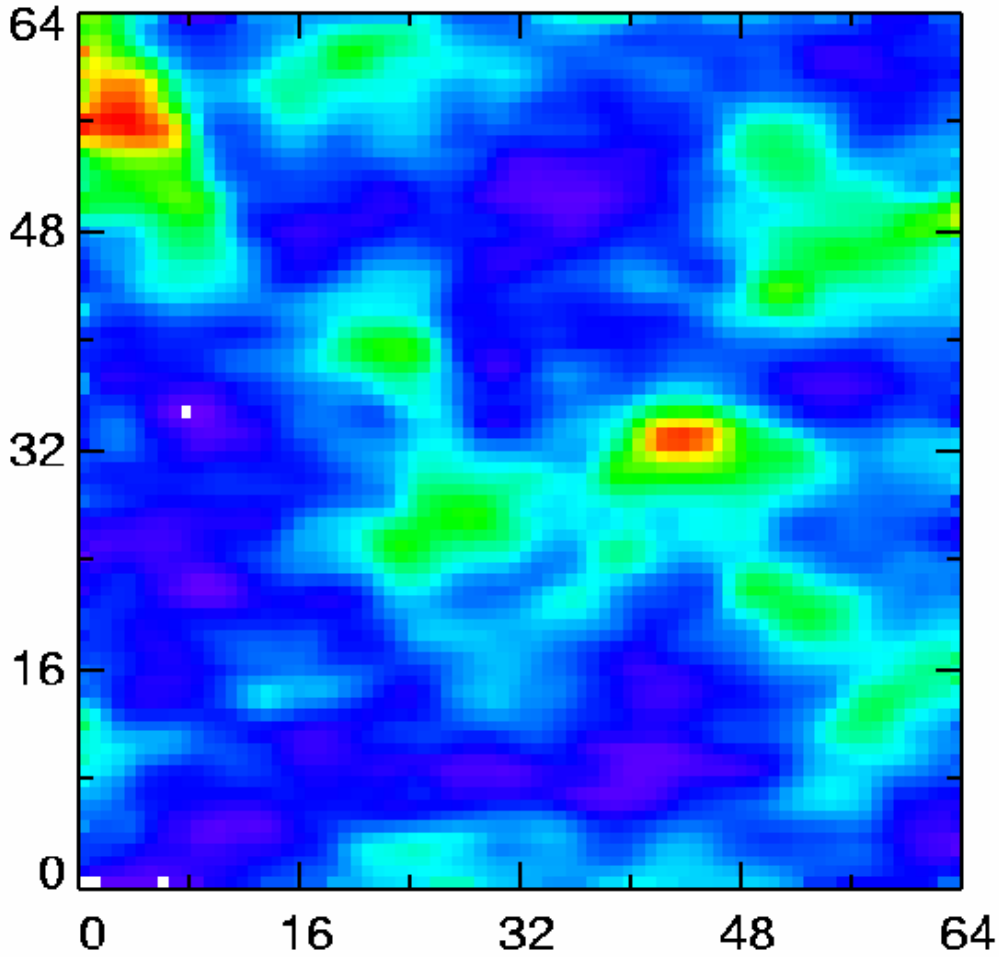
Reconnection dynamics: magnetic flux switching over a region of nonideal plasma (enhanced current -> resistivity)



Mapped down to the photosphere sheet currents

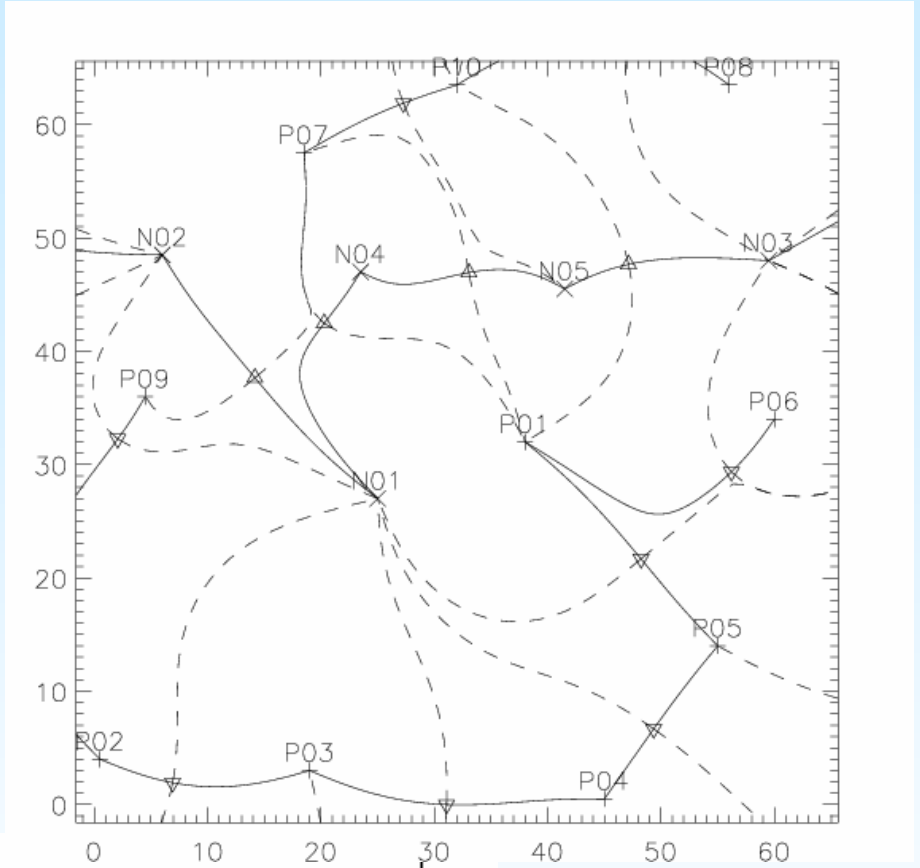
vs. TRACE observations

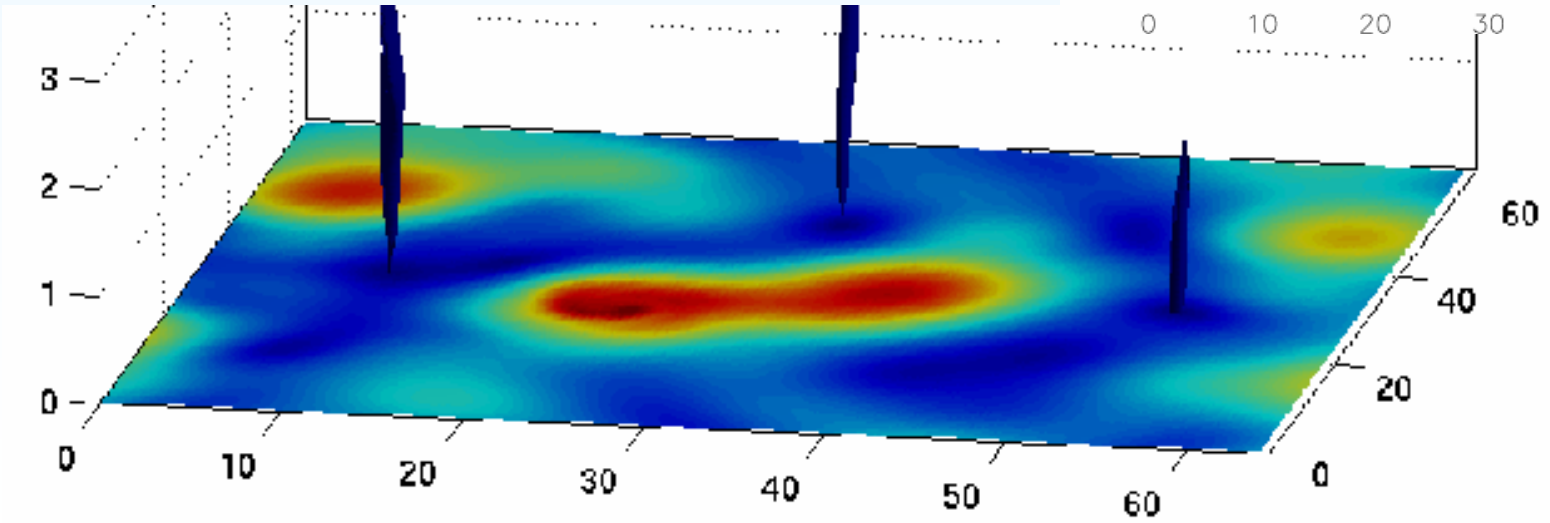




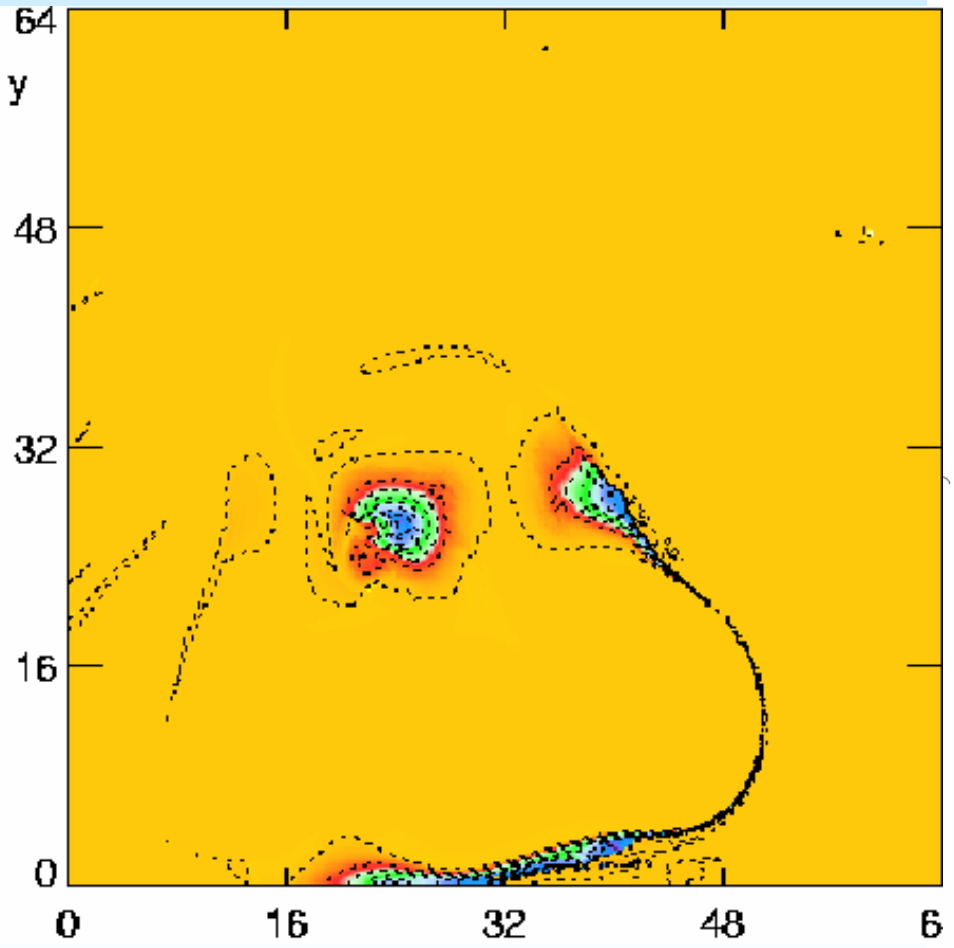
Magnetic topology – skeleton approach

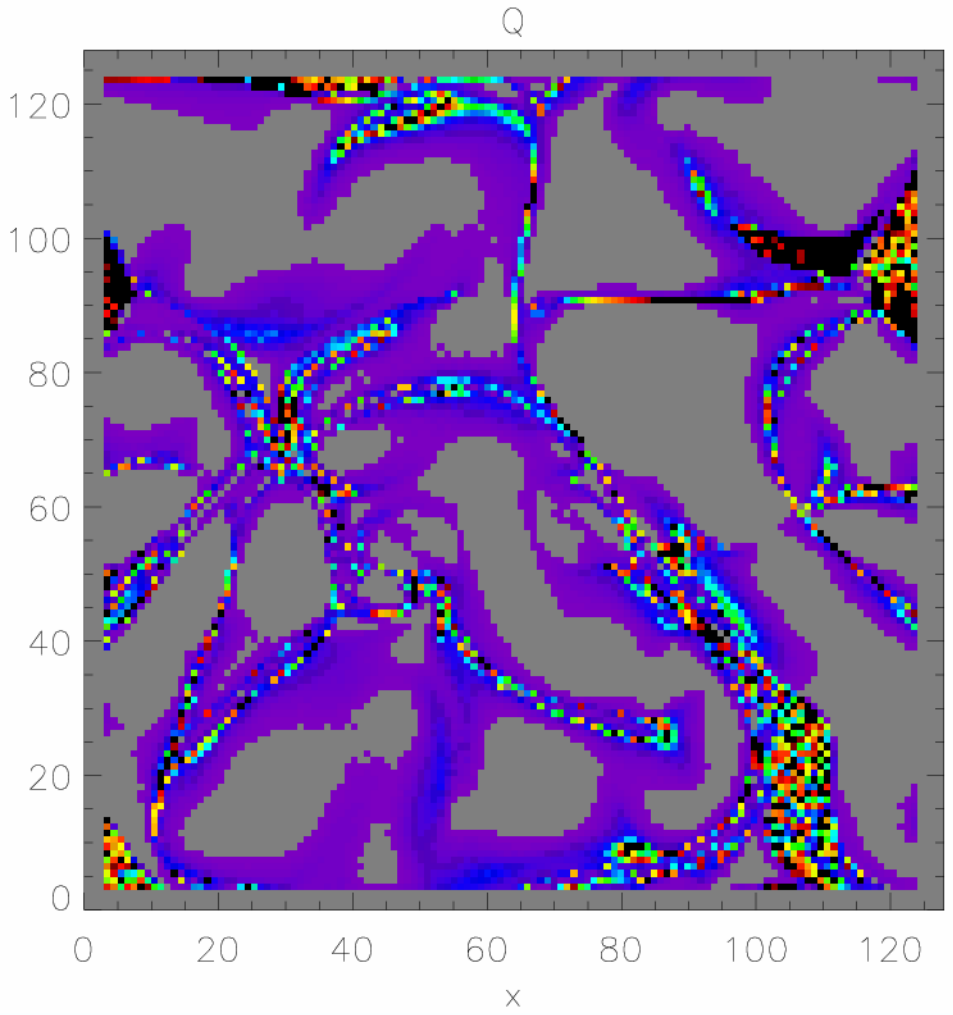
Photospheric poles, nulls, separators and separatrices for discrete sources ->
and
Coronal Nulls in the extrapolated B field:





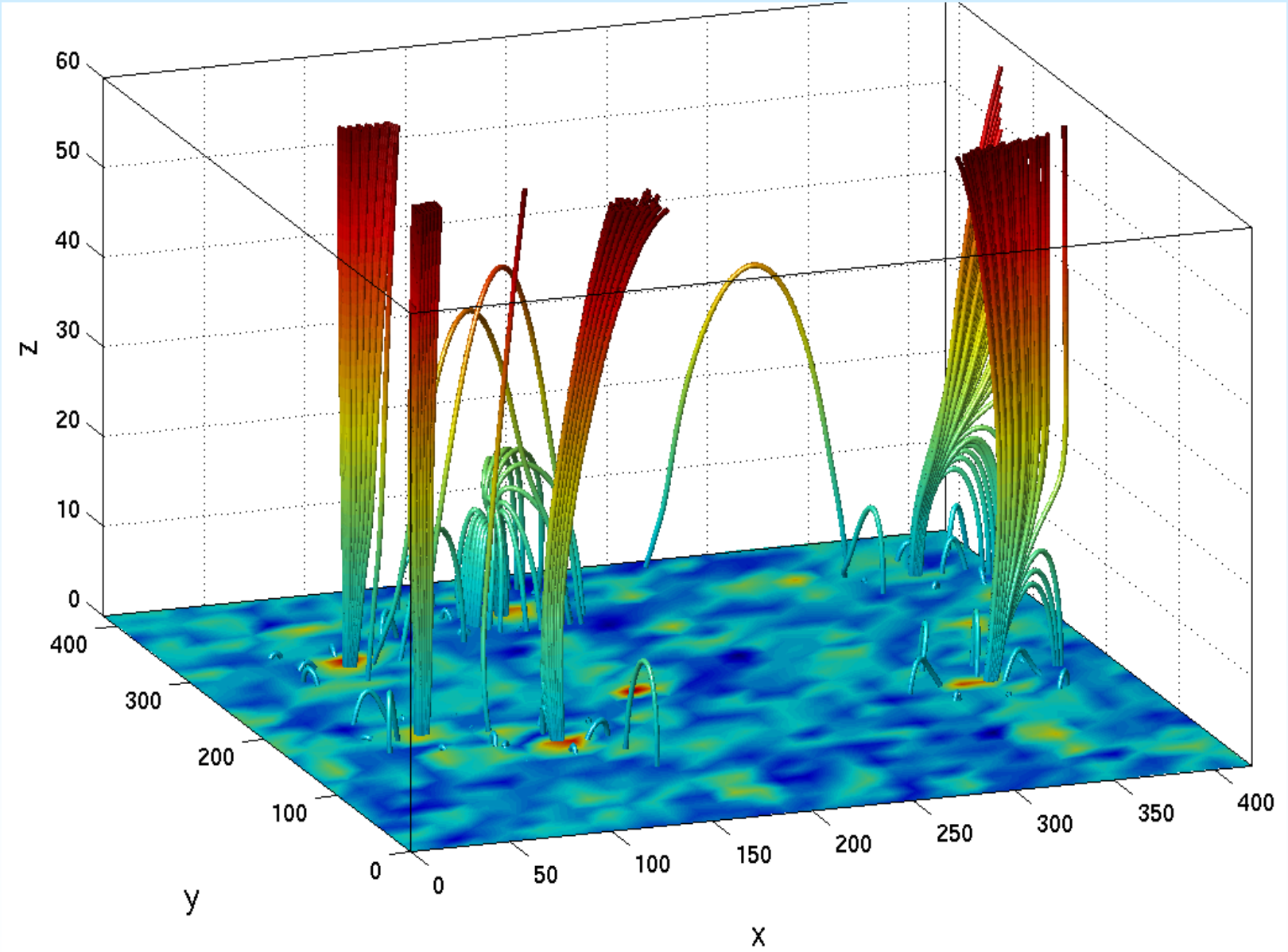
Current sheet mapping vs. Q





The hyperbolic flux tube indicator Q (right panel) correctly predicts the areas of enhanced current flows (left panel)

3. Coronal hole

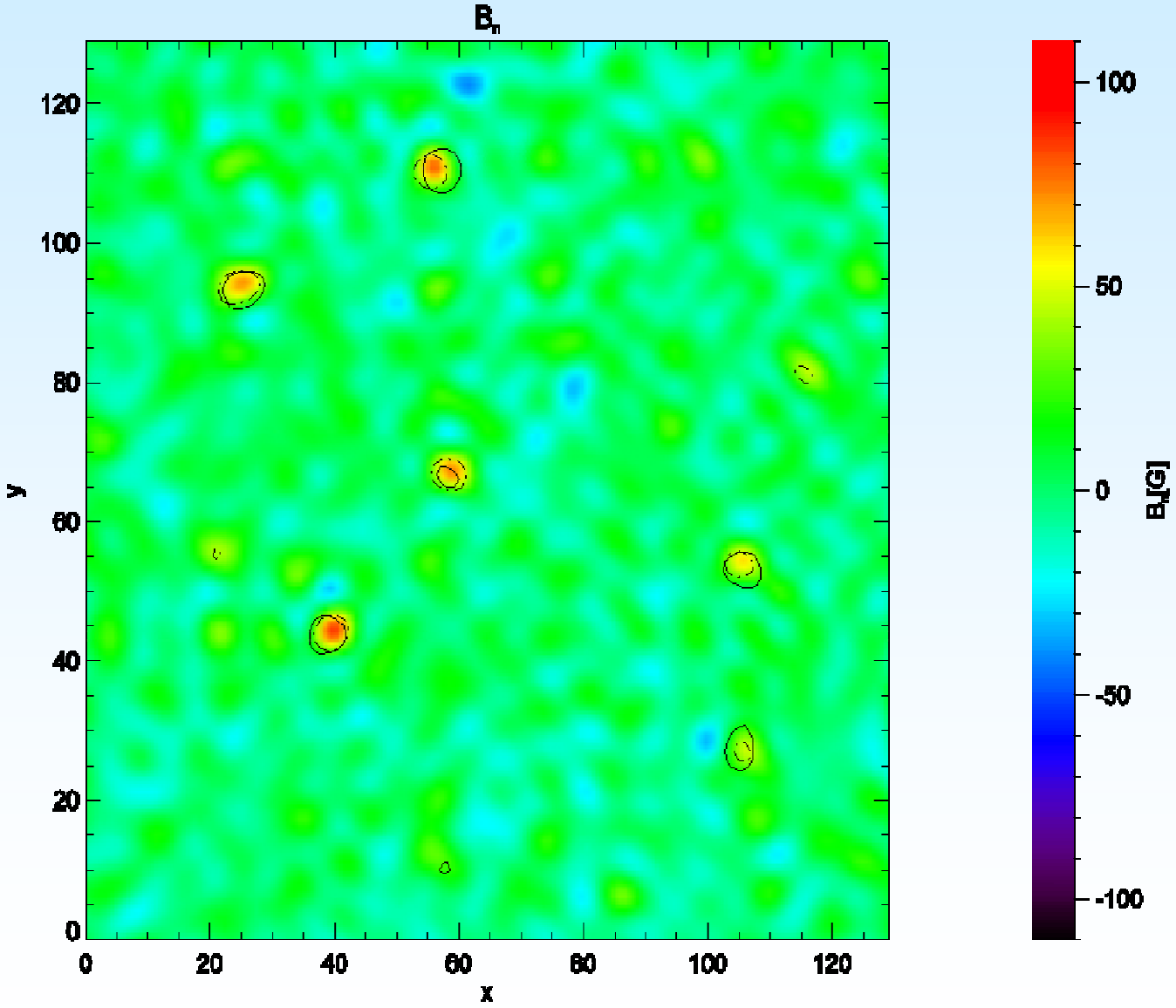


Force free extrapolated magnetic field: Funnels and small loops

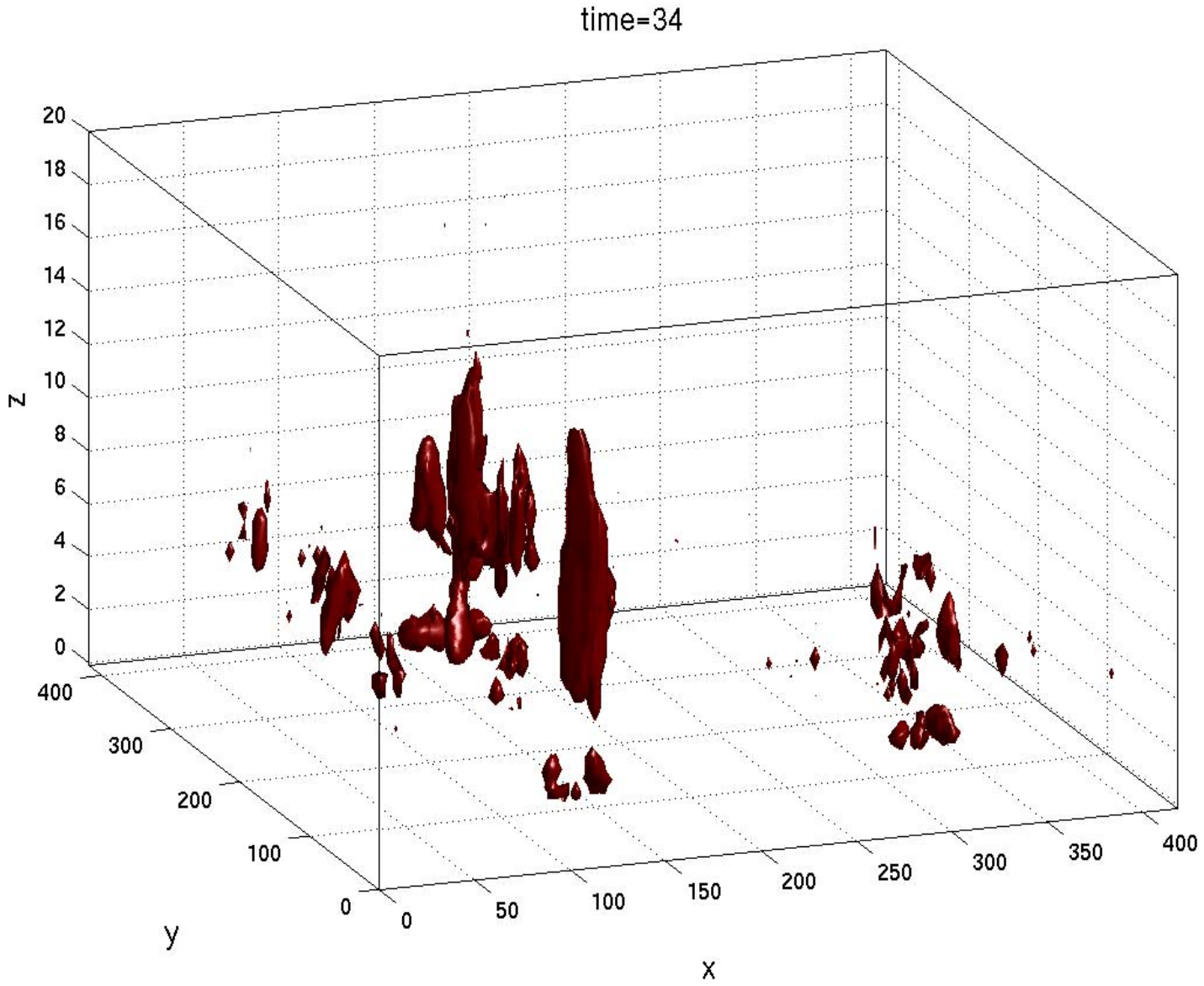
Footpoint motion between 1:36 and t=3:12 on 21.6.96

The dashed lines are isolines 50 G for the also color-coded MDI line-of sight fields observed at 1:36 UTC on June 26, 1996

The solid lines depict the 50 G level 96 minutes later, i.e. at 3:12 UTC in the co-roated same area



Current sheet formation



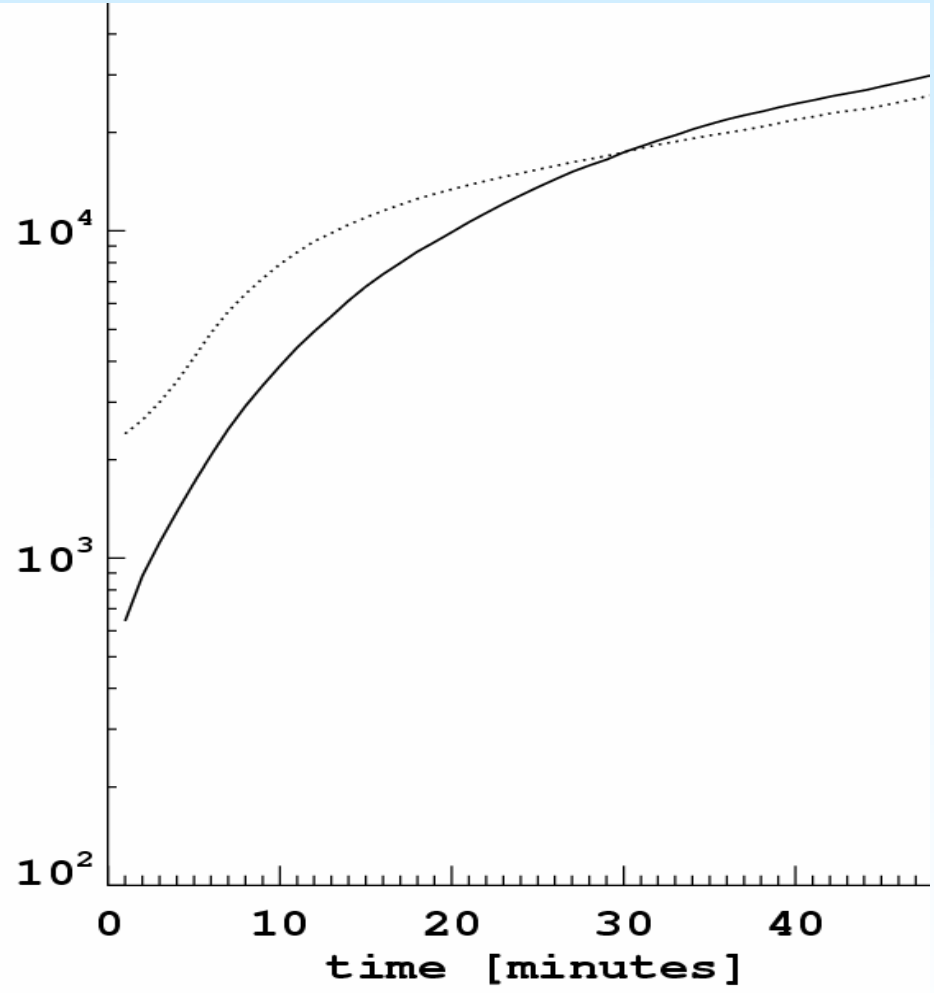
Non force-free current sheets are formed between the small loops and funnels

-> solar wind acceleration

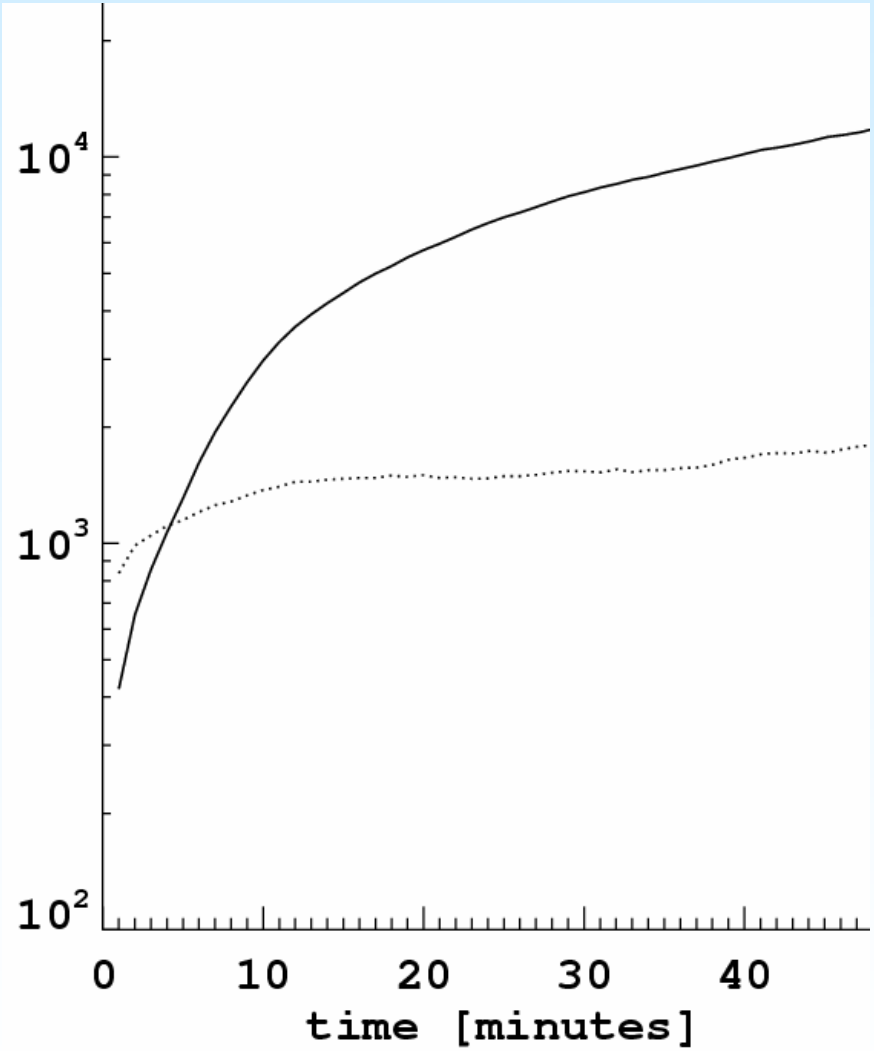
by their reconnection at heights between 5 and 10 Mm

Currents above the coronal hole

I^2 in the chromosphere

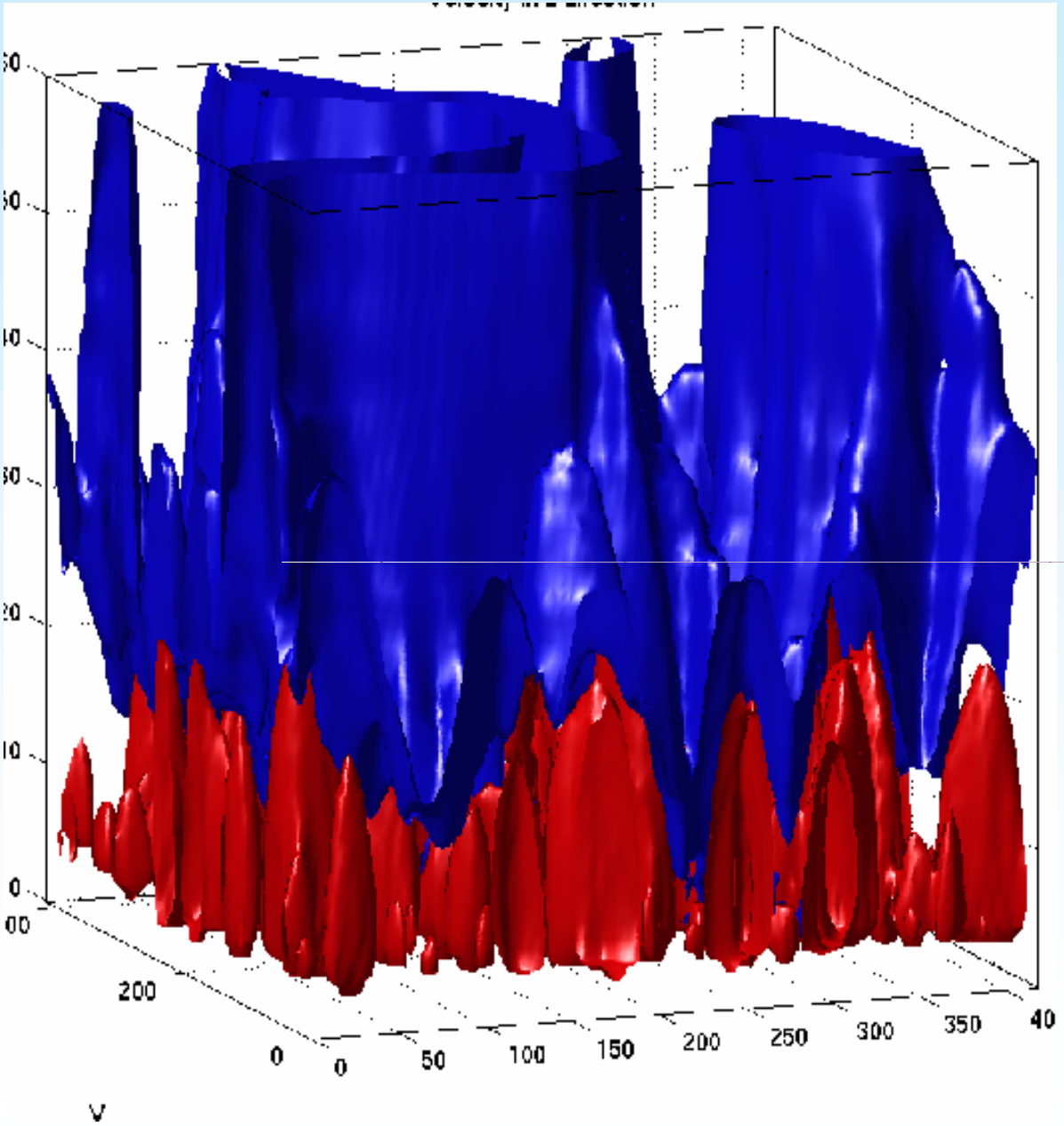


I^2 in the corona



(Solid lines: Jpar^2; dotted lines: J_perp^2)

Accelerated solar wind plasma



The upward (blue) and downward (red) accelerated plasma flows – velocity isosurfaces 10 km/s indicate:

- the upward directed acceleration takes place mainly above 5 Mm and

- at greater heights the accelerated flows fill almost the whole coronal hole area

Summary

- We studied several cases and showed here
  - a chromospheric current sheet
  - a quiet sun bright point
  - a coronal hole
- In all cases non force-free current sheets (CS) form with Jperp
- The non force-free CS disturb the magnetic field properties, violate the force free condition locally, determine the reconnection and acceleration (Epar!) regions
- The locii of the violation of the force free condition correlate well with the prediction of hyperbolic flux tubes in the unperturbed fields
- The latter can be taken as a trial indicator of the violationof the force-free condition