Evolution of MHD waves in low layers of a Coronal Hole

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Motivation

The formation of small scales in coronal holes has already been studied by several authors: e.g., Matthaeus et al. 1999; Verdini and Velli, 2007; Verdini et al., 2009; Verdini et al. 2010.

All these studies consider the formation of small scales in a wide region extending beyond the sonic point, considering a unipolar magnetic field.

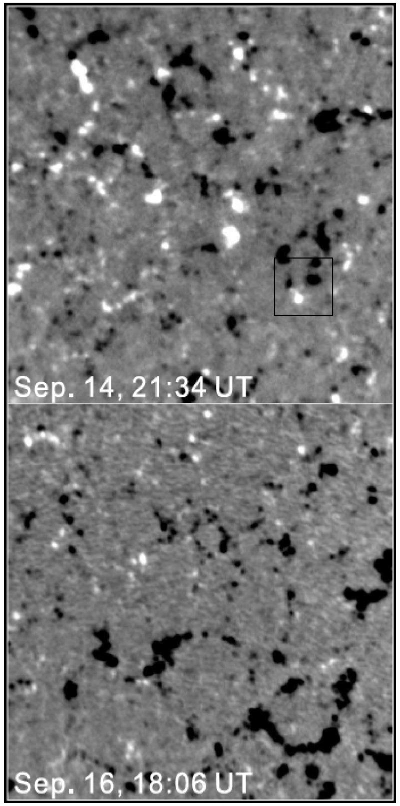
We would like to investigate if inhomogeneities at the base of the Corona could be responsible for small scale formation at low altitudes.

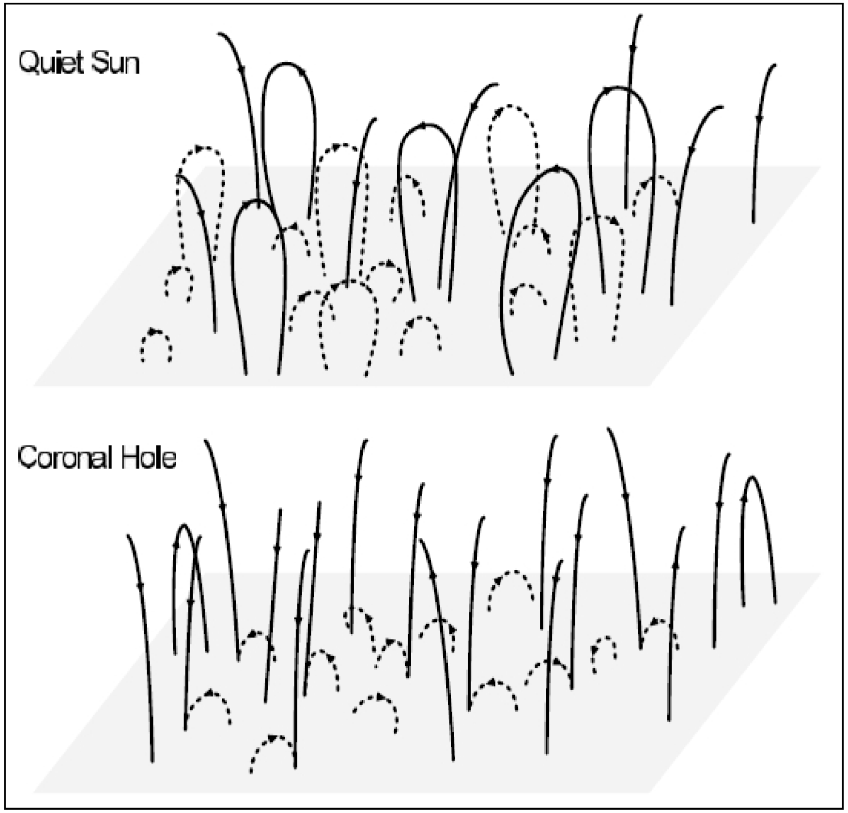
Coronal holes

Coronal holes are low density regions of the solar Corona, mainly situated at poles, where the magnetic field has a dominant polarity but with the presence of regions in the photosphere with inverted polarity.

Quiet Sun

Coronal Hole

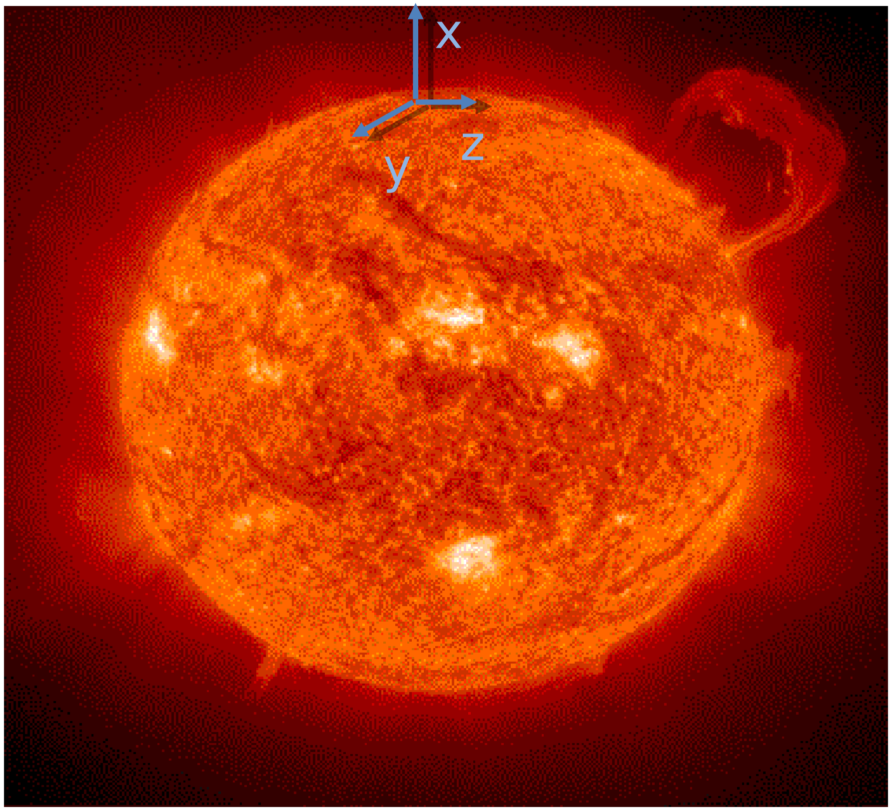




A magnetogram (on the left) and a cartoon (on the right) of the magnetic field in a Quiet Sun region and in a Coronal hole. (Zhang, Ma & Wang, ApJ 2006)

A model for the magnetic field in a coronal hole

The reference frame we are considering is situated in this way:



We make two assumption:

- equilibrium potential magnetic field (null current)

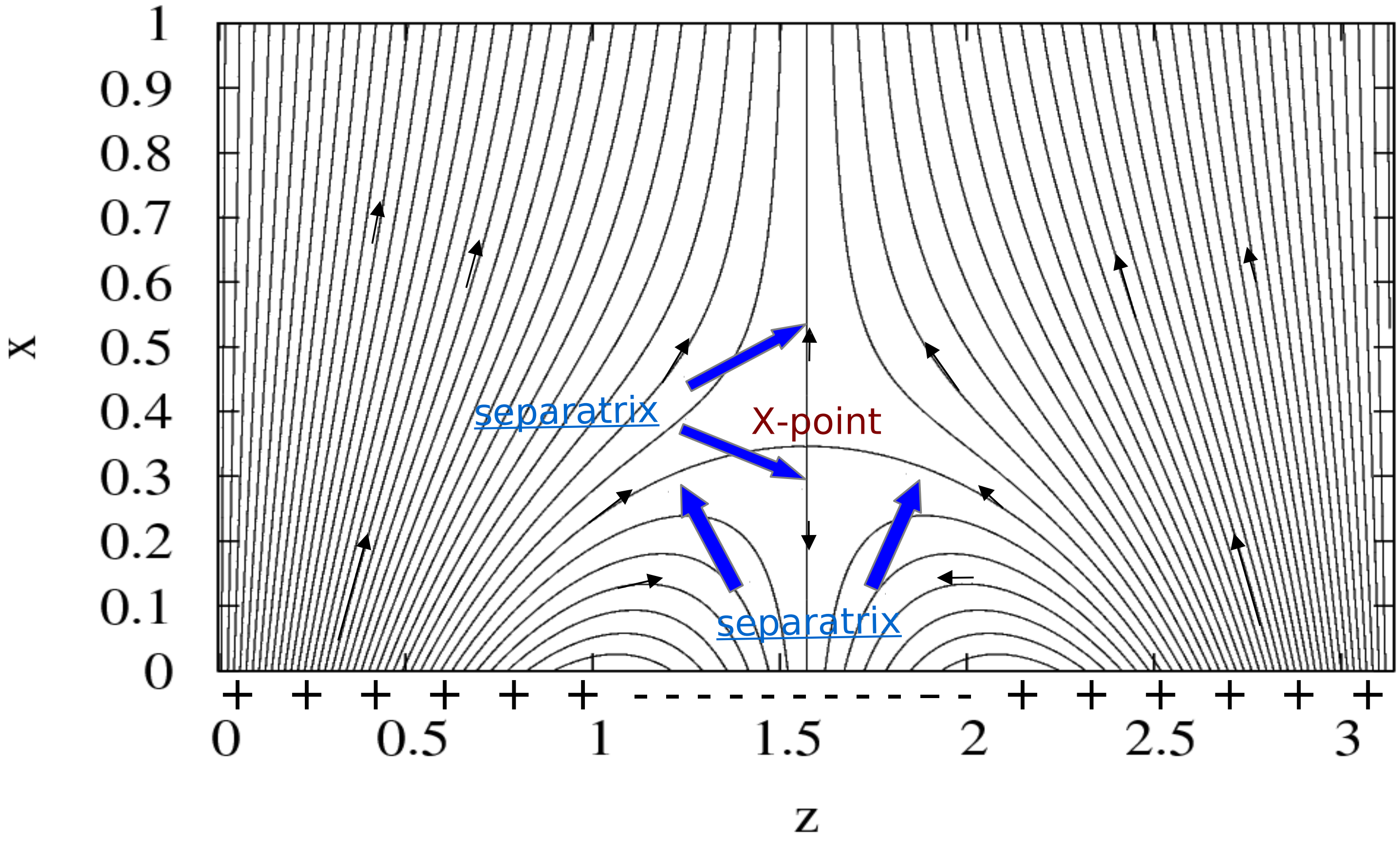
$$\vec{B} = -\nabla\phi \quad \Rightarrow \quad \nabla^2\phi = 0$$

- negligible curvature (cartesian coordinates)

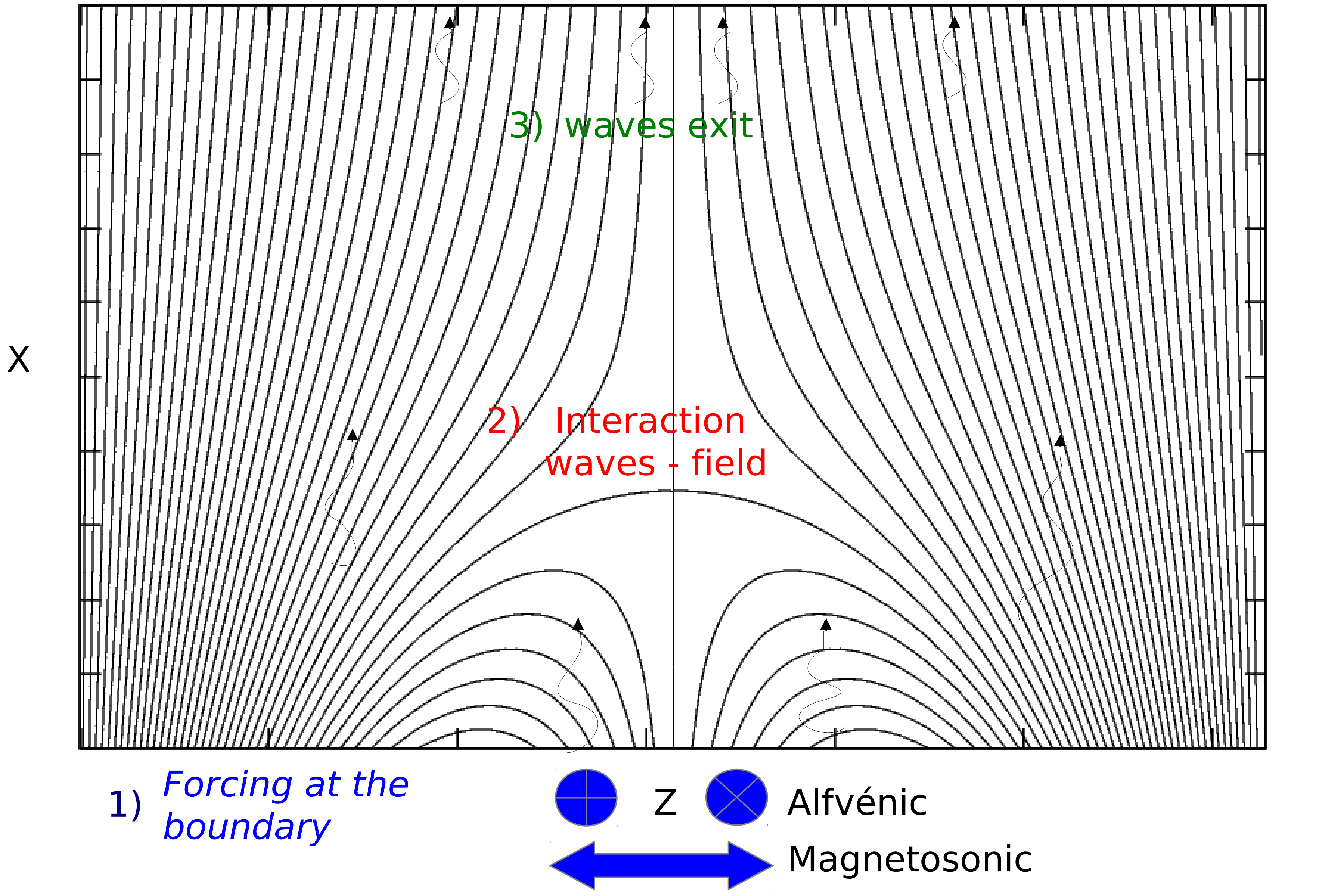
A model for the magnetic field in a coronal hole

A simple two dimensional solution of the problem is represented by the field:

$$B_x = 2\cos(2z)\, e^{-2x} + 1$$
$$B_z = 2\sin(2z)\, e^{-2x}$$



What do we do?



X
3) waves exit
2) Interaction
waves - field
1) *Forcing at the boundary*
Z
Alfvénic
Magnetosonic

The MHD equations

$$\frac{\partial \rho}{\partial \tau} + \nabla \cdot (\rho \mathbf{v}) = 0,$$

$$\frac{\partial \mathbf{v}}{\partial \tau} + (\mathbf{v} \cdot \nabla)\, \mathbf{v} = -\frac{1}{\rho} \nabla p + \frac{1}{\rho} (\nabla \times \mathbf{b}) \times \mathbf{b} + \frac{\nu}{\rho} \nabla \cdot \vec{\vec{\sigma}},$$

$$\frac{\partial \mathbf{b}}{\partial \tau} = \nabla \times (\mathbf{v} \times \mathbf{b}) + \eta \nabla^2 \mathbf{b},$$

$$\frac{\partial p}{\partial \tau} + \nabla \cdot (p \mathbf{v}) + (\gamma - 1)\, p\, (\nabla \cdot \mathbf{v}) =$$

$$\kappa \nabla^2 \left(\frac{p}{\rho} \right) + (\gamma - 1) \left[\eta (\nabla \times \mathbf{b})^2 + \frac{\nu}{2} \vec{\vec{\sigma}} : \vec{\vec{\sigma}} \right]$$

ρ = ionic density
v = velocity
B = magnetic field
P = pressure
J = current
T = temperature
ν = viscosity
η = resistivity
κ = thermic conducibility

All the variables are non dimensional and normalized to these quantities:

$$\rho_0 = 5 \cdot 10^{-16} g/cm^3,\ c_{A0} = 2.5 \cdot 10^7 cm/s,\ B_0 = c_{A0} \sqrt{4\pi\rho_0} = 5.6G$$

$$P_0 = \rho_0 {c_{A0}}^2 = 0.3 \frac{g}{cms^2},\ L_0 = 10^9 cm,\ T_0 = L_0 / c_{A0} = 40s$$

BOUNDARY AND INITIAL CONDITIONS

- periodical boundary conditions along y and z:

$$f(x,0,z,t) = f(x,2\pi,z,t)\ ,\ \forall x \in [0,1]\ ,\ \forall z \in [0,\pi]\ ,\ \forall t \geq 0$$

$$f(x,y,0,t) = f(x,y,\pi,t)\ ,\ \forall x \in [0,1]\ ,\ \forall y \in [0,2\pi]\ ,\ \forall t \geq 0$$

- "characteristics" method implemented on the boundary along the x direction to treat incoming and outgoing perturbations dynamically.

FORCING AT THE BASE OF THE CORONA:

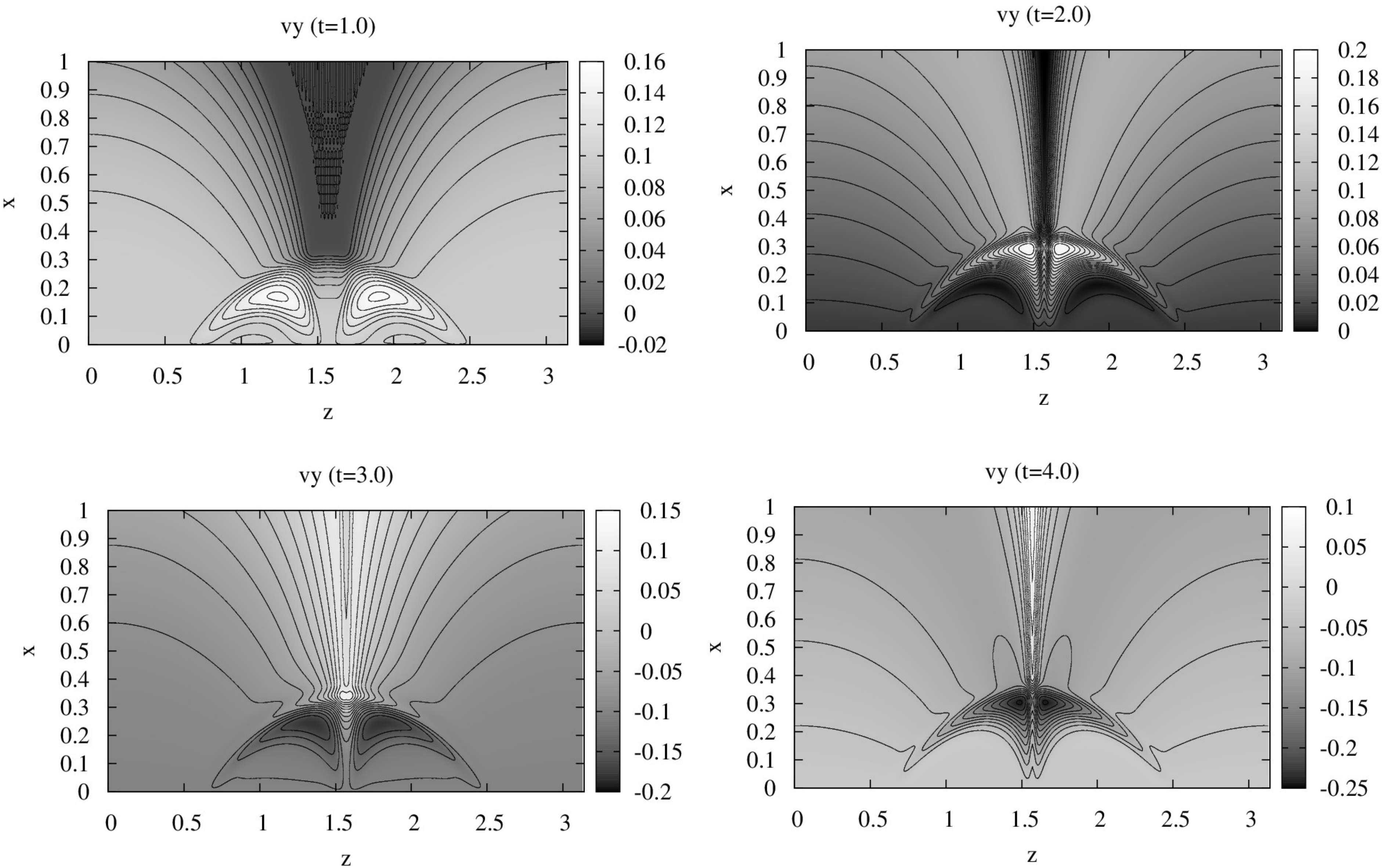
$$\mathbf{v}(x=0,z,\tau) = v_1 \sin(\omega\tau)\mathbf{e}_y$$ Alfvénic

$$\mathbf{v}(x=0,z,\tau) = v_1 \sin(\omega\tau)\mathbf{e}_z$$ Magnetosonic

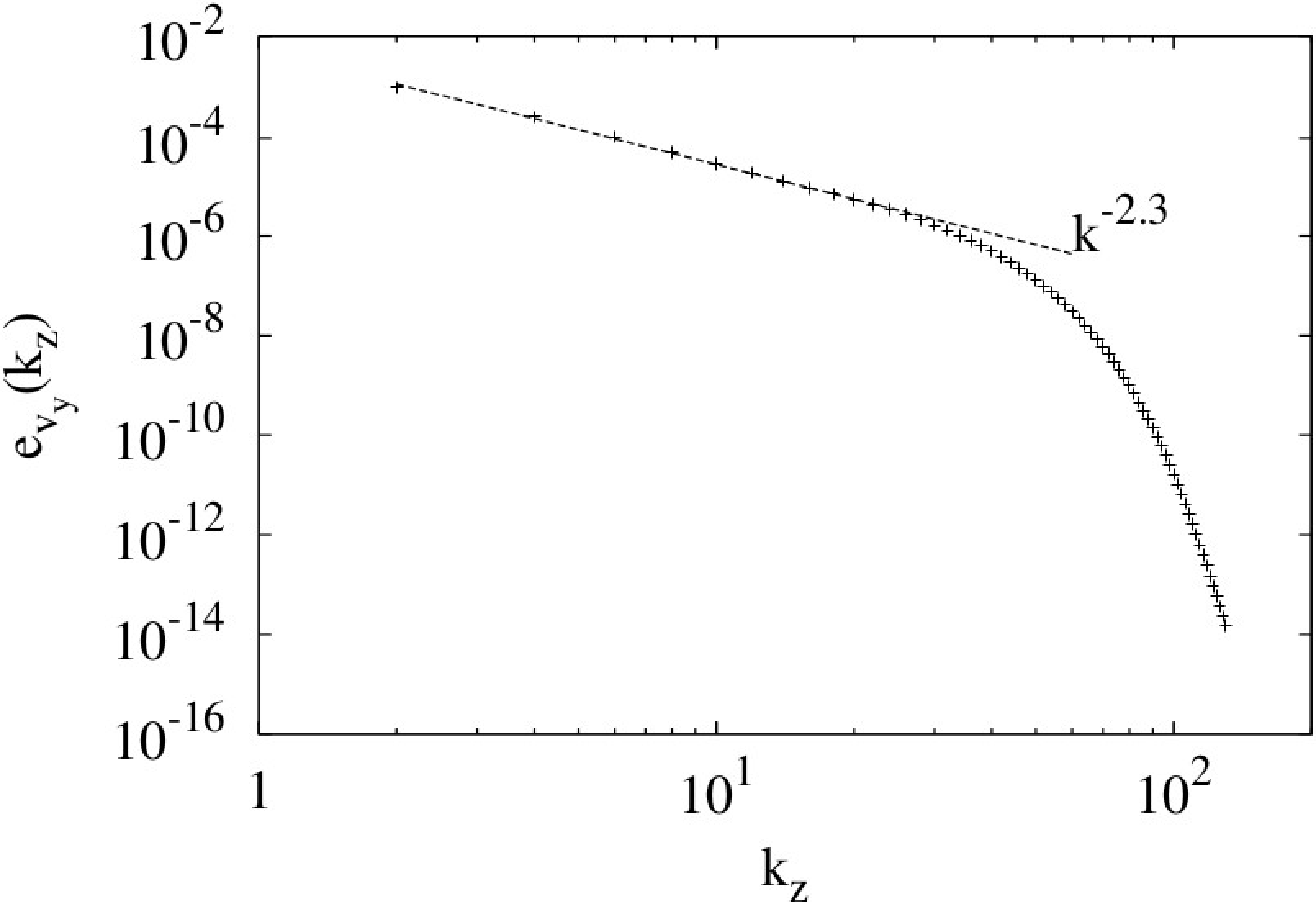
v_1=0.1
(small amplitude)
T=160s

Pressure and density are homogeneous all over the domain at t=0.

Alfvénic mode

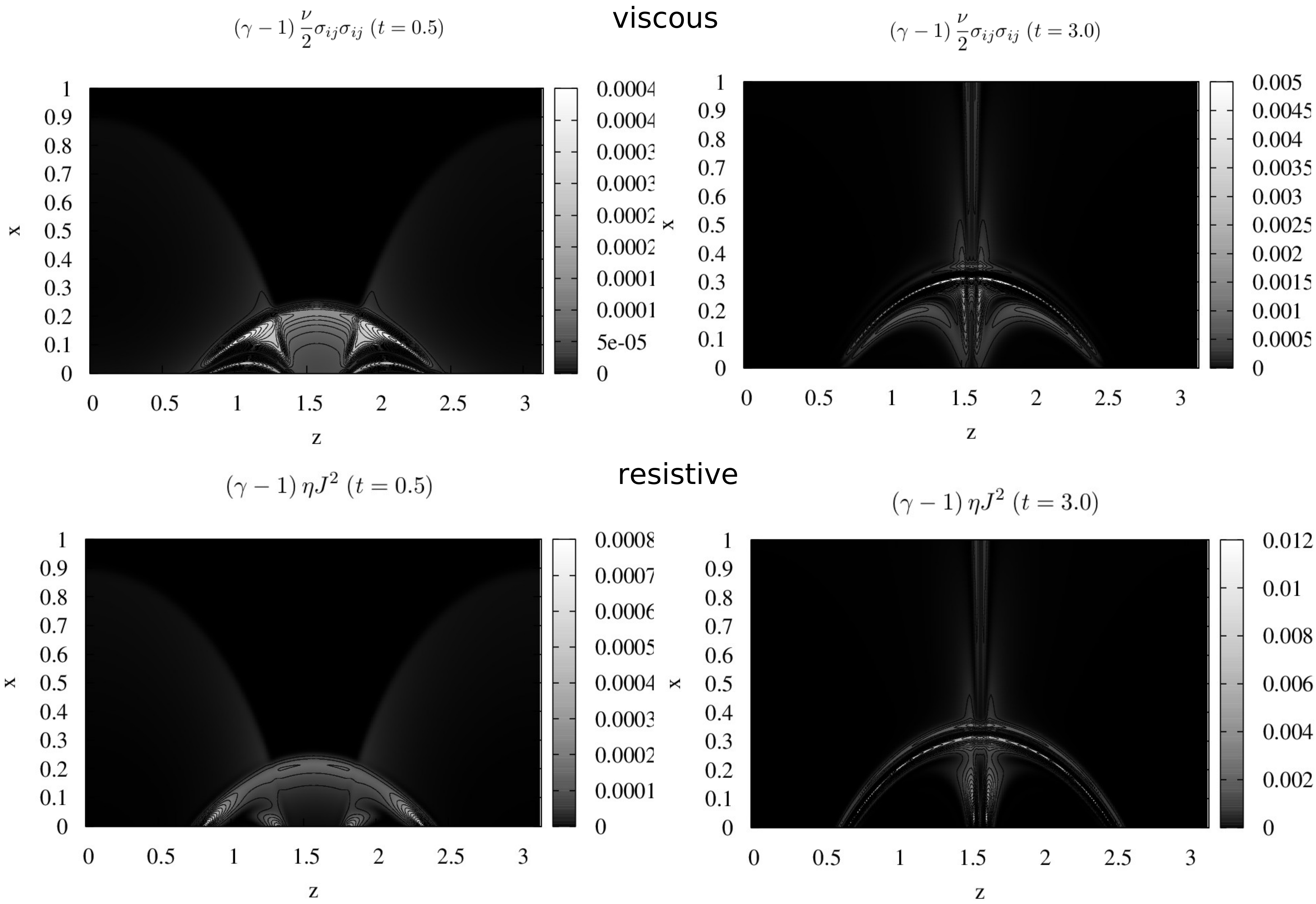


Small scales are concentrated along separatrices

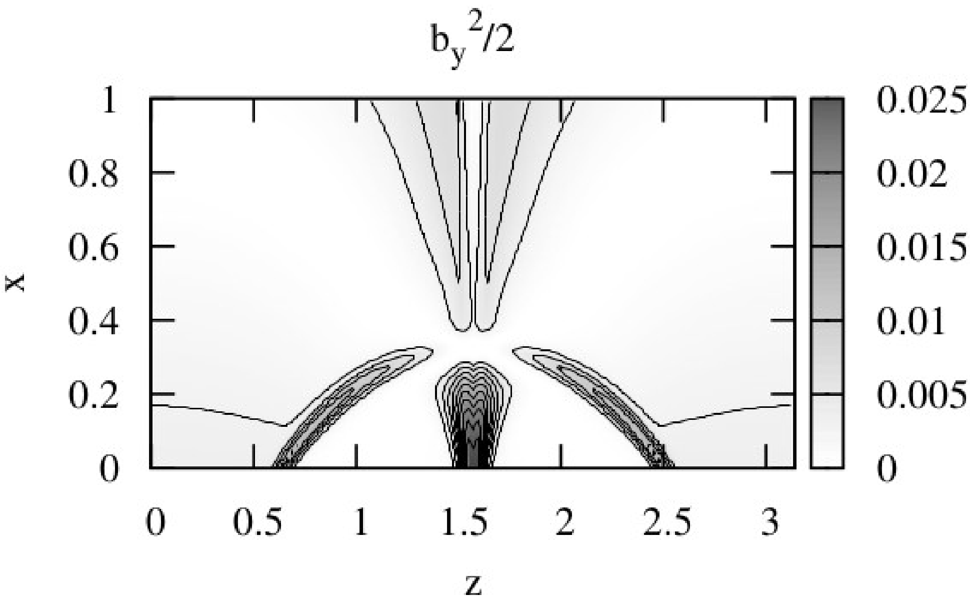


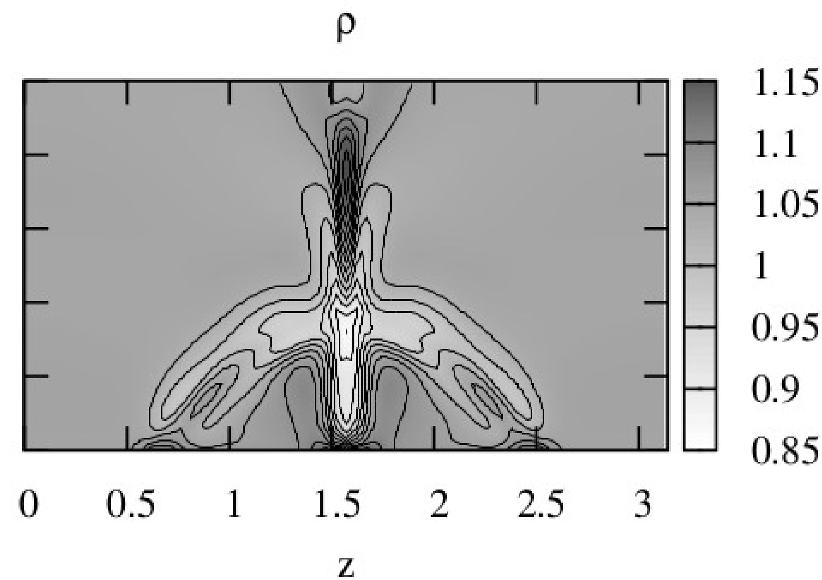
Averaged kinetic energy spectrum of the Alfvénic fluctuation at the top of the domain

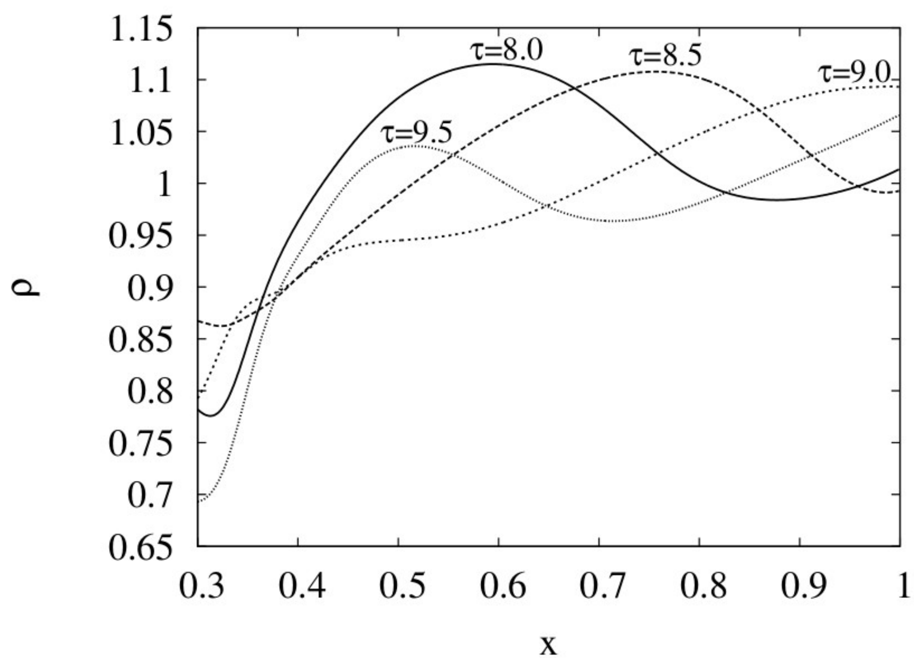
Dissipated power



FORMATION AND EJECTION OF PLASMA BUBBLES



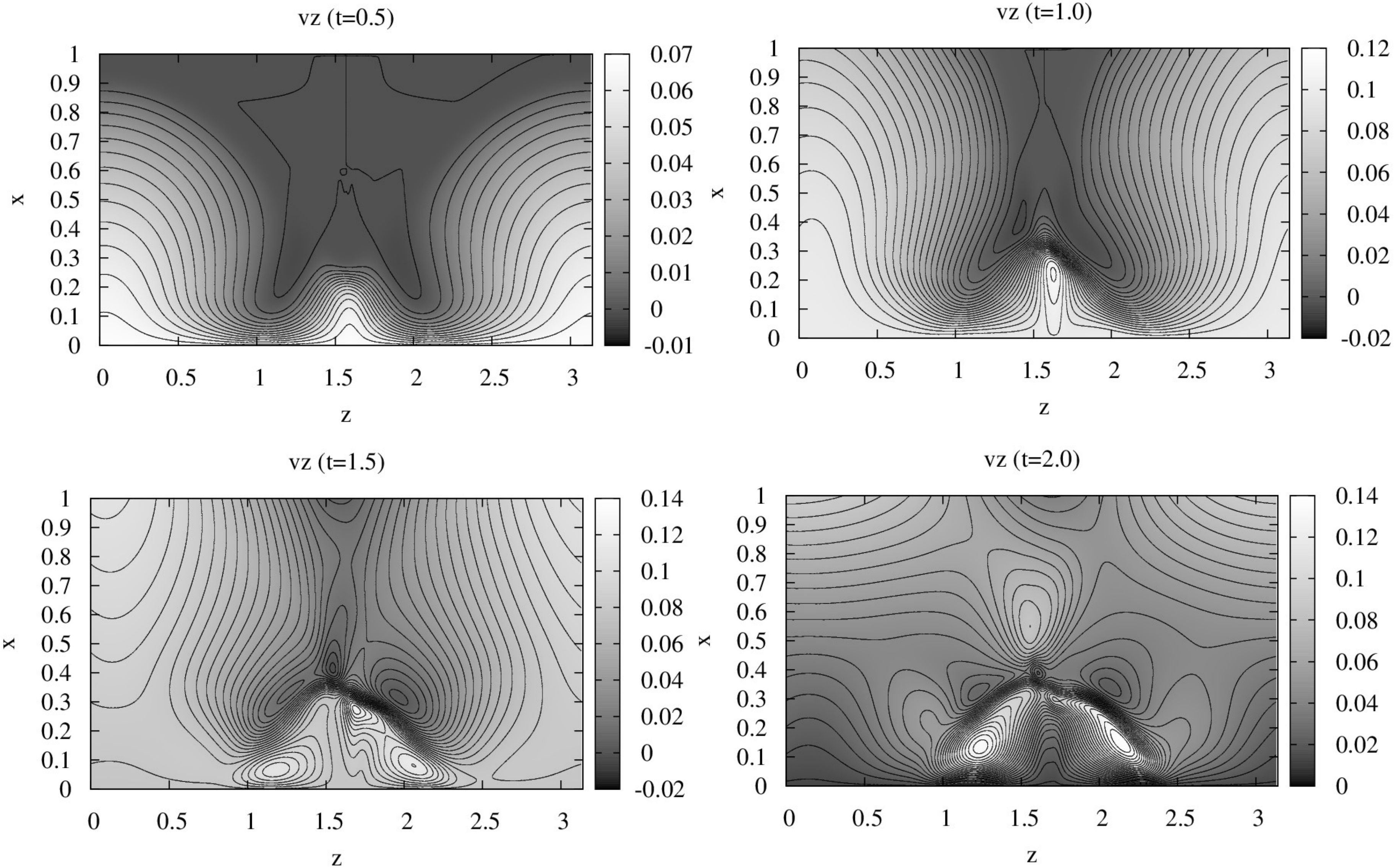




The Alfvén waves pushes matter toward the middle generating plasma bubbles that propagates out through the top at a speed comparable to the Alfvén speed

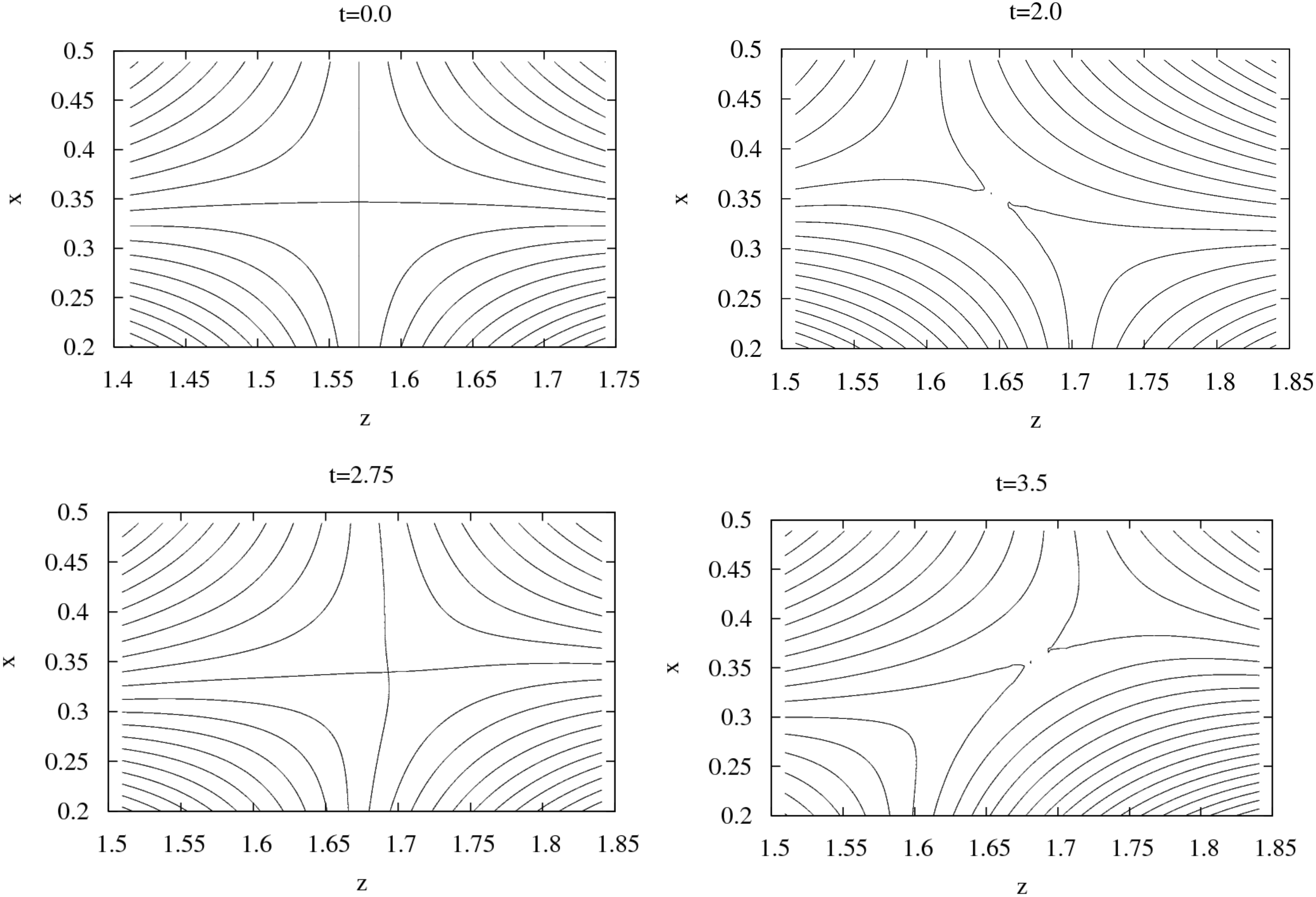
(Pucci et al., 2014)

Magnetosonic mode

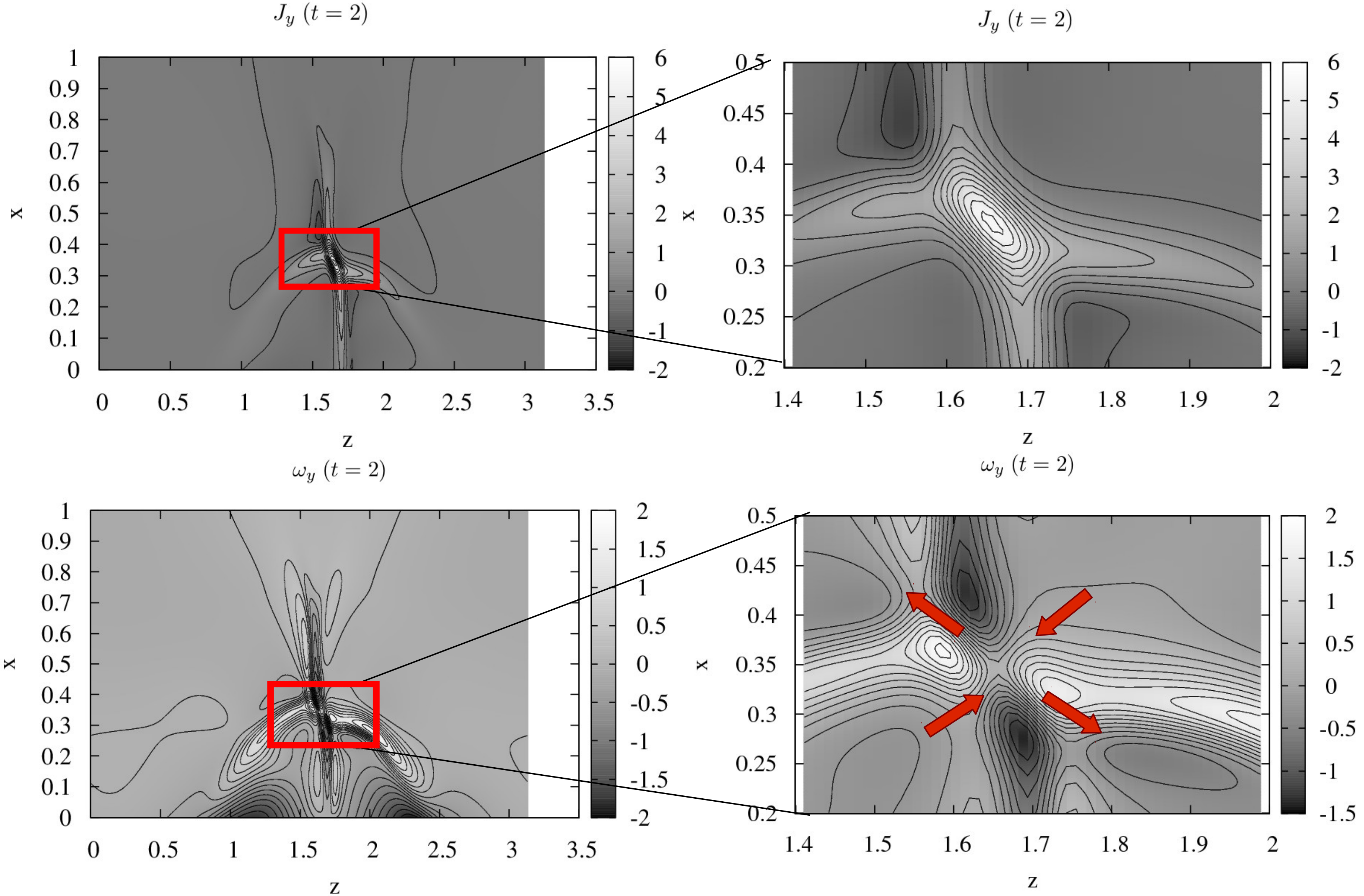


Small scales are concentrated near to the X-point

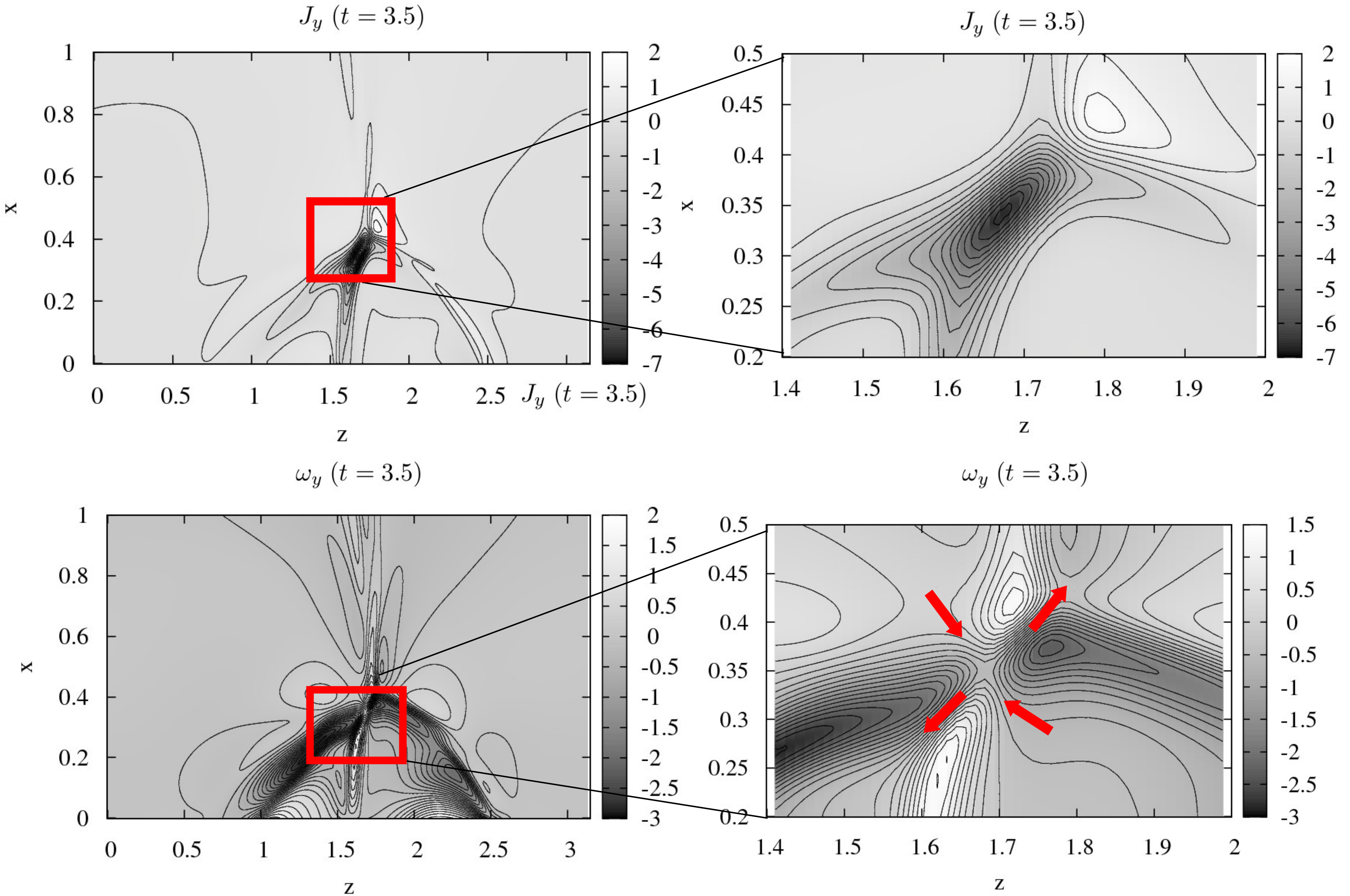
Magnetic fieldlines (Zoom at the X-Point)



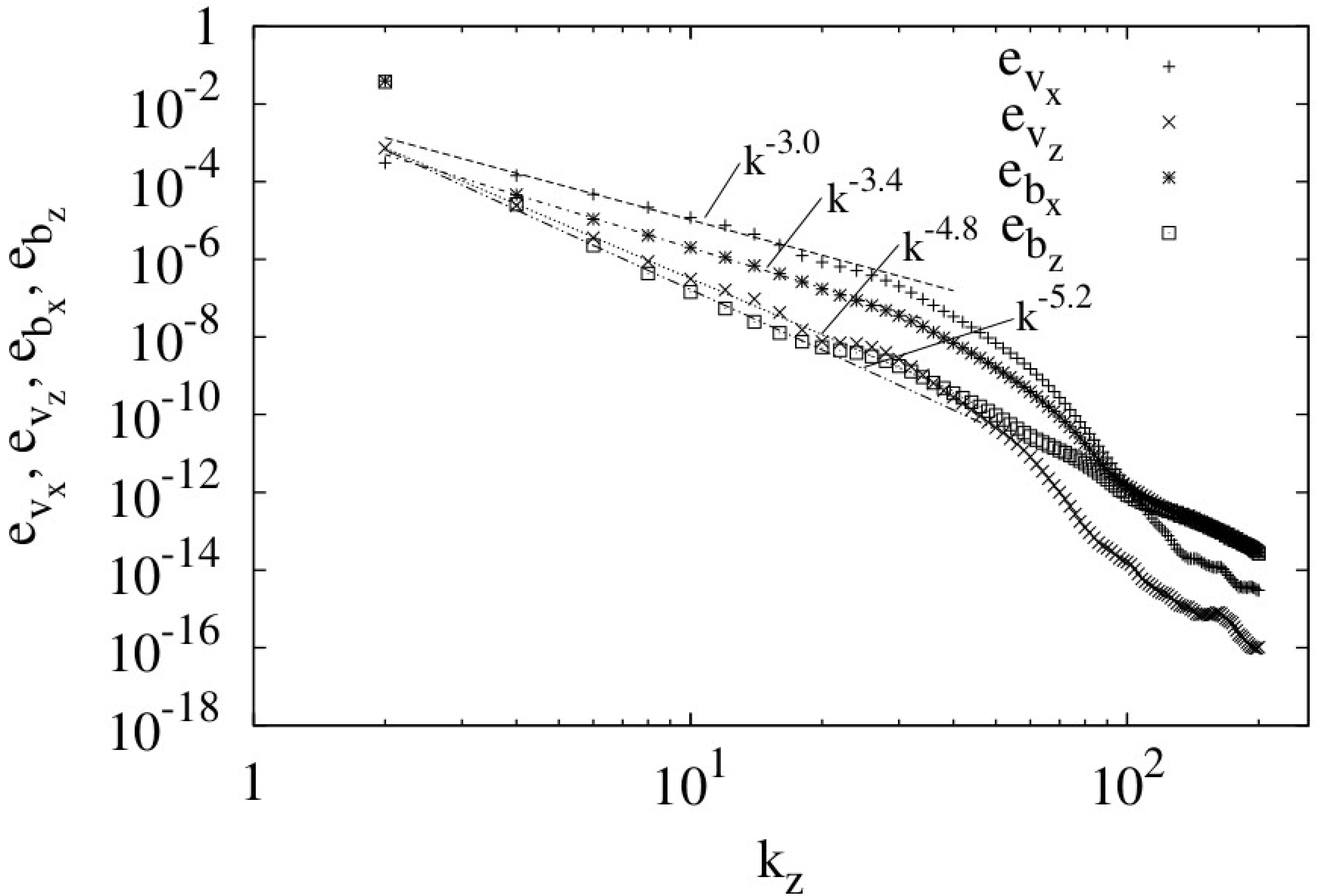
First magnetic reconnection (t=2.0)



Second magnetic reconnection (t=3.5)



Averaged energy spectrum at the top of the domain



Conclusions

-The presence of regions of opposite polarity enhances the small scale formation at low altitudes (h=10^9 cm) in a Coronal Hole.

- In the case of the Alfvén pertubation small scales form along separatrix.

-We see the formation of a power law spectrum at the top of the domain for Alfvén perturbation.

-The magnetic pressure due to the Alfvén waves ejects matter towards the outer atmosphere.

-In the case of the Magnetosonic perturbation small scales form in proximity of the X-point, where magnetic reconnetion takes place.

-We see a weak formation of small scale at the top of the domain for the Magnetosonic perturbation.

Thank you for your attention