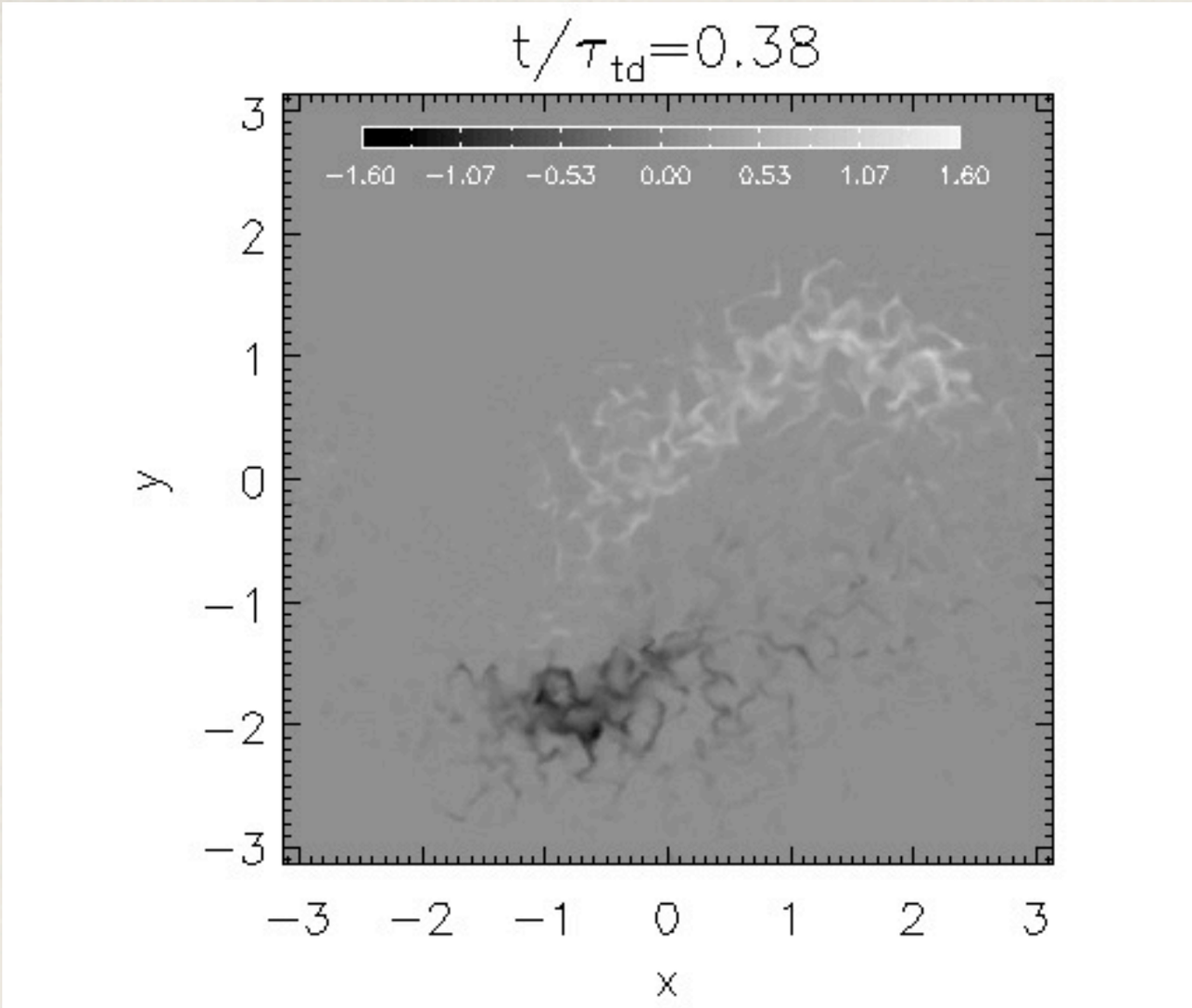
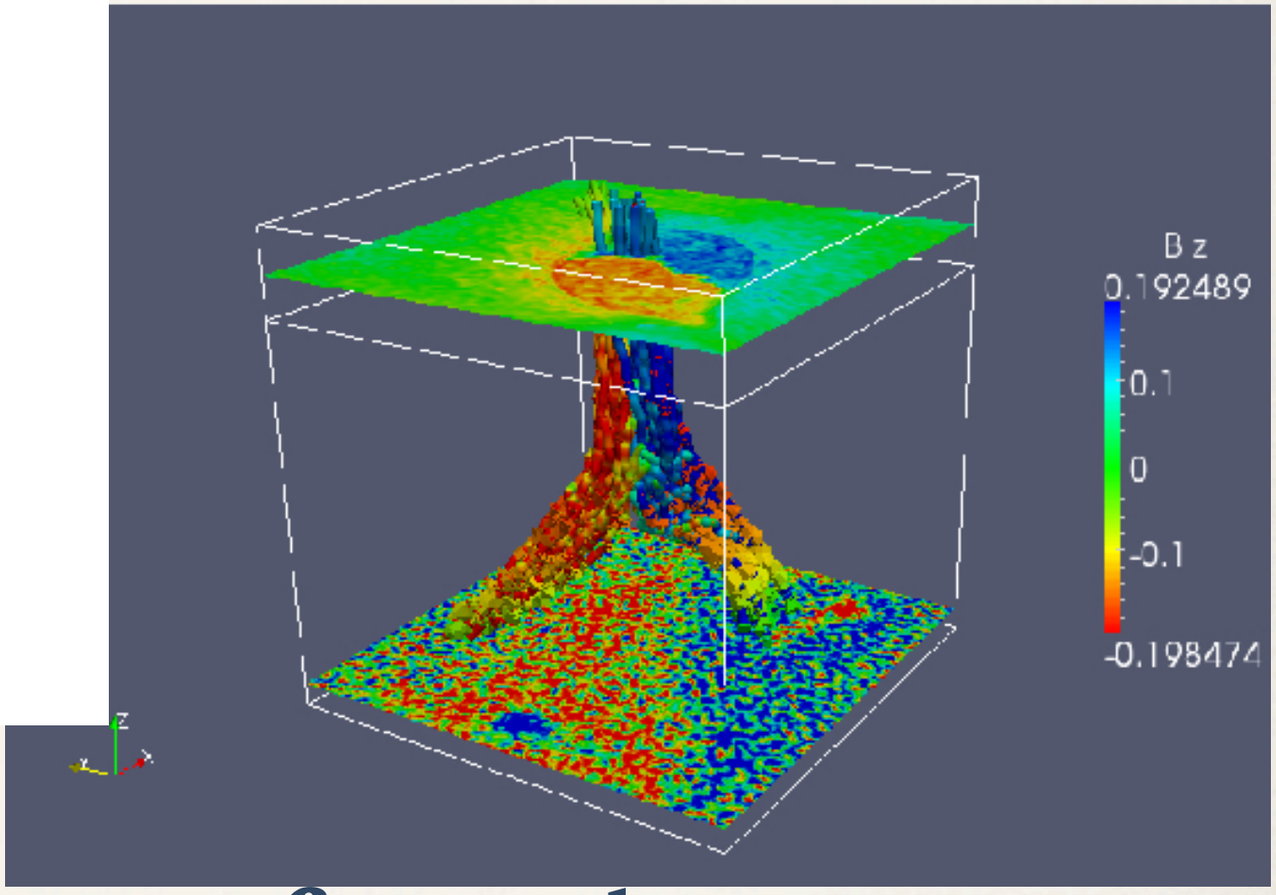




Intense bipolar structures from dynamos

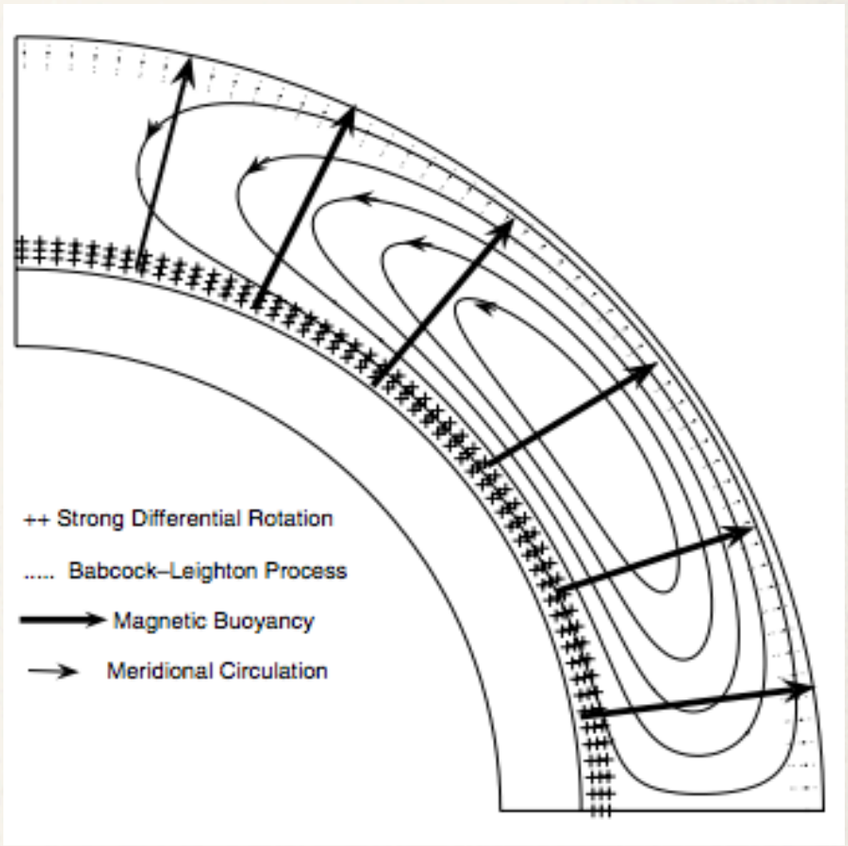
Dhrubaditya Mitra, NORDITA

March 2015 NORDITA, Stockholm

Solar magnetic activity: present dogma

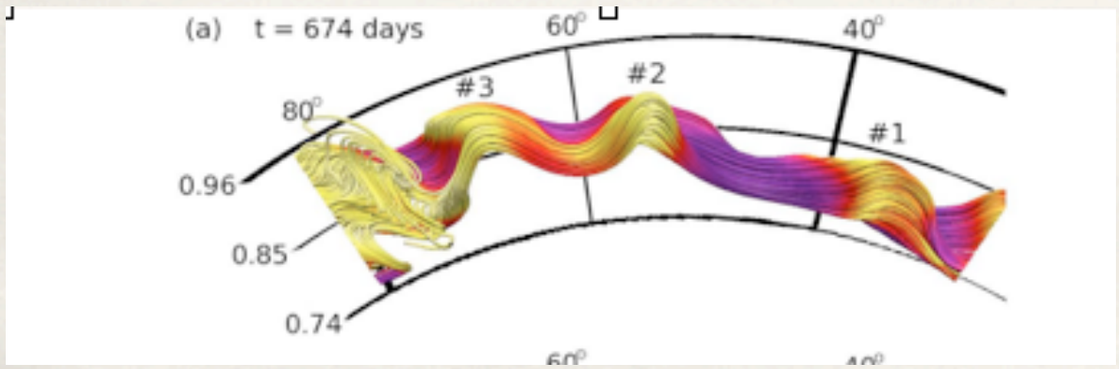
* **Standard model**: Dynamo is described by the flux-transport dynamo model. The magnetic field at the bottom of the convection zone becomes unstable by the magnetic buoyancy instability, rises and emerges at the surface to form active regions and sunspots.

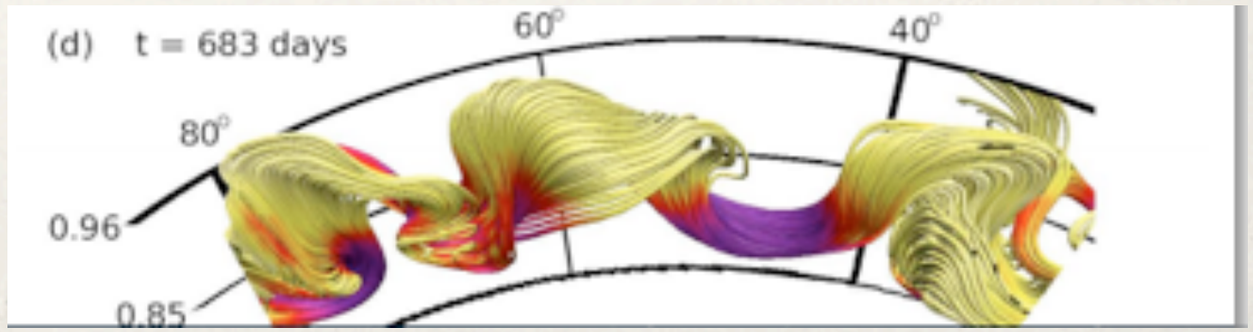
P. Charbonneau, Living Reviews of Solar Physics



* **Criticisms**: Too far from eqns. of MHD (among many other ones)

Fan and Fang 2014



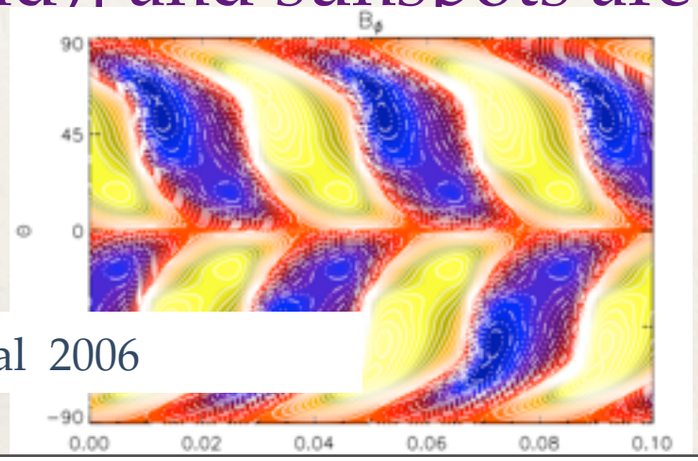


non-standard model ?

- Solar dynamo operates at the bulk of the convection zone obeying mean-field dynamo equations.

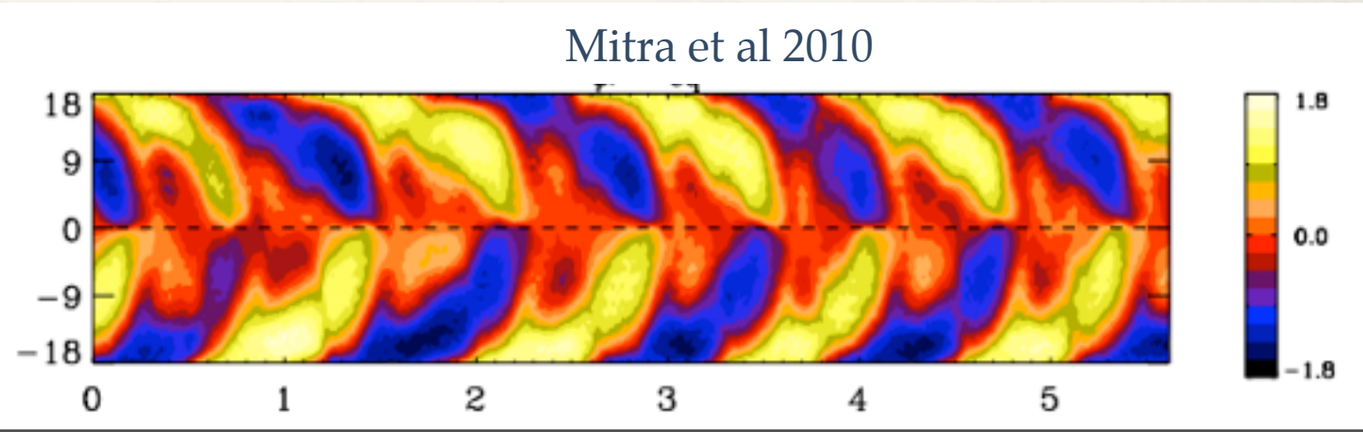
- At the surface, near-surface-shear layer makes it go equatorward (Brandenburg 2005) ; or it is an alpha-square dynamo with different signs of alpha, hence propagates equatorward (Mitra et al . 2010).

- From this large-scale dynamo generated field, active regions [at smaller scales (but larger than the energy-containing scale of the fluid)] and sunspots are formed.



Kapyla et al 2006

Mitra et al 2010



Near-surface flux concentration

- Observed in radiative-convection simulations, (e.g., Stein and Nordlund, Rempel and Cheung)

- May be necessary to invoke even within the "standard model" as fluxtubes weaken as they rises.

- What is the mechanism of near-surface flux concentration ? It has to concentrate magnetic field from a weaker background field in the presence of turbulence. It could be the NEMPI that we are hearing so much about or even the radiative mechanism of Kitchatinov and Mazur.

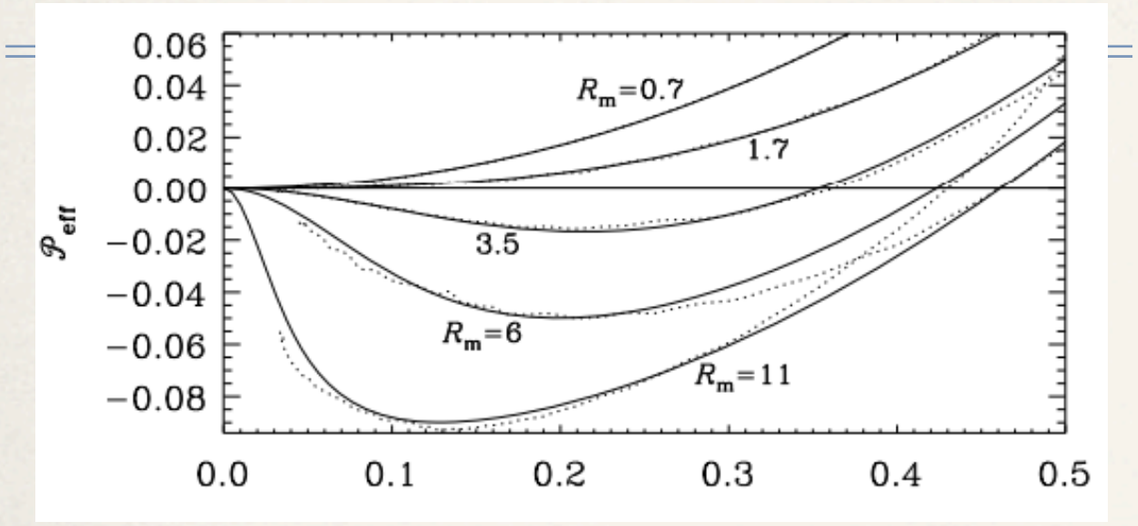
What is NEMPI ?

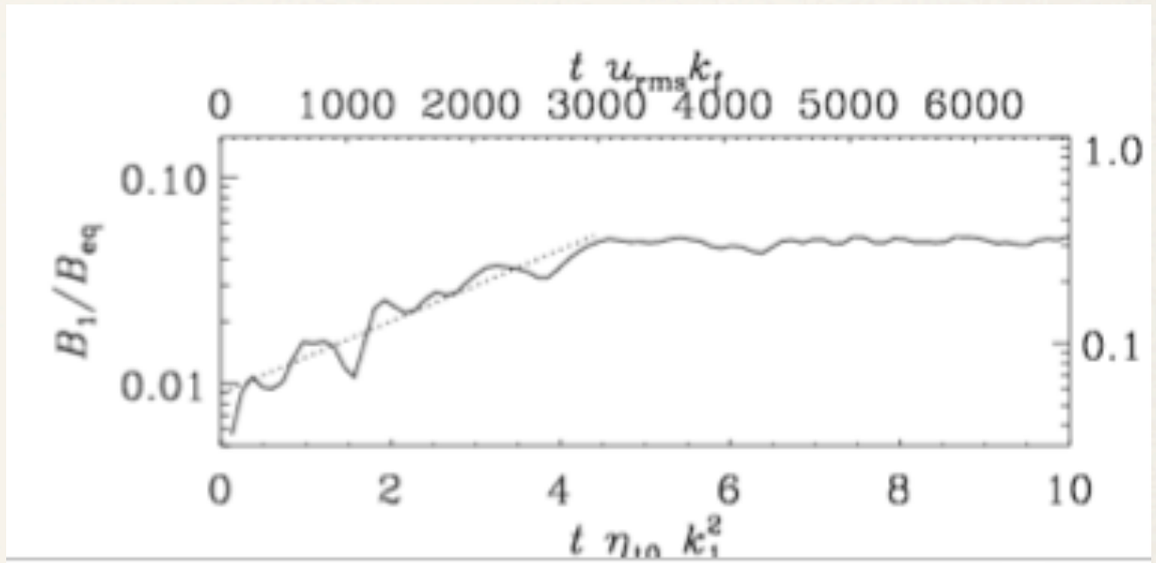
$$\rho\left[\partial_t \boldsymbol{u} + \boldsymbol{u}\cdot\boldsymbol{\nabla}\boldsymbol{u}\right] = \mu\nabla^2\boldsymbol{u} \quad - \quad \boldsymbol{\nabla}\mathcal{P} + \boldsymbol{J}\times\boldsymbol{B} + \rho\boldsymbol{g}$$

- Pressure (high school physics)
- Magnetic Pressure (undergraduate)
- Effective Magnetic Pressure (graduate studies)

$$\mathcal{P} \quad = \quad \frac{c_{\rm s}^2}{\gamma}\rho + p_{\rm eff}(B^2,\rho)$$

Can effective magnetic pressure be negative ?





$$\mathcal{P}_{\rm eff}(\beta) = \frac{1}{2}\left[1 - q_{\rm p}(\beta)\right]\beta^2 \quad \textit{versus} \quad \beta \equiv |\overline{\mathbf{B}}|/B_{\rm eq}$$

$$\sigma = \frac{k_\perp}{k}\frac{\sqrt{-2C_{\rm B}}c_A}{H_\rho}$$

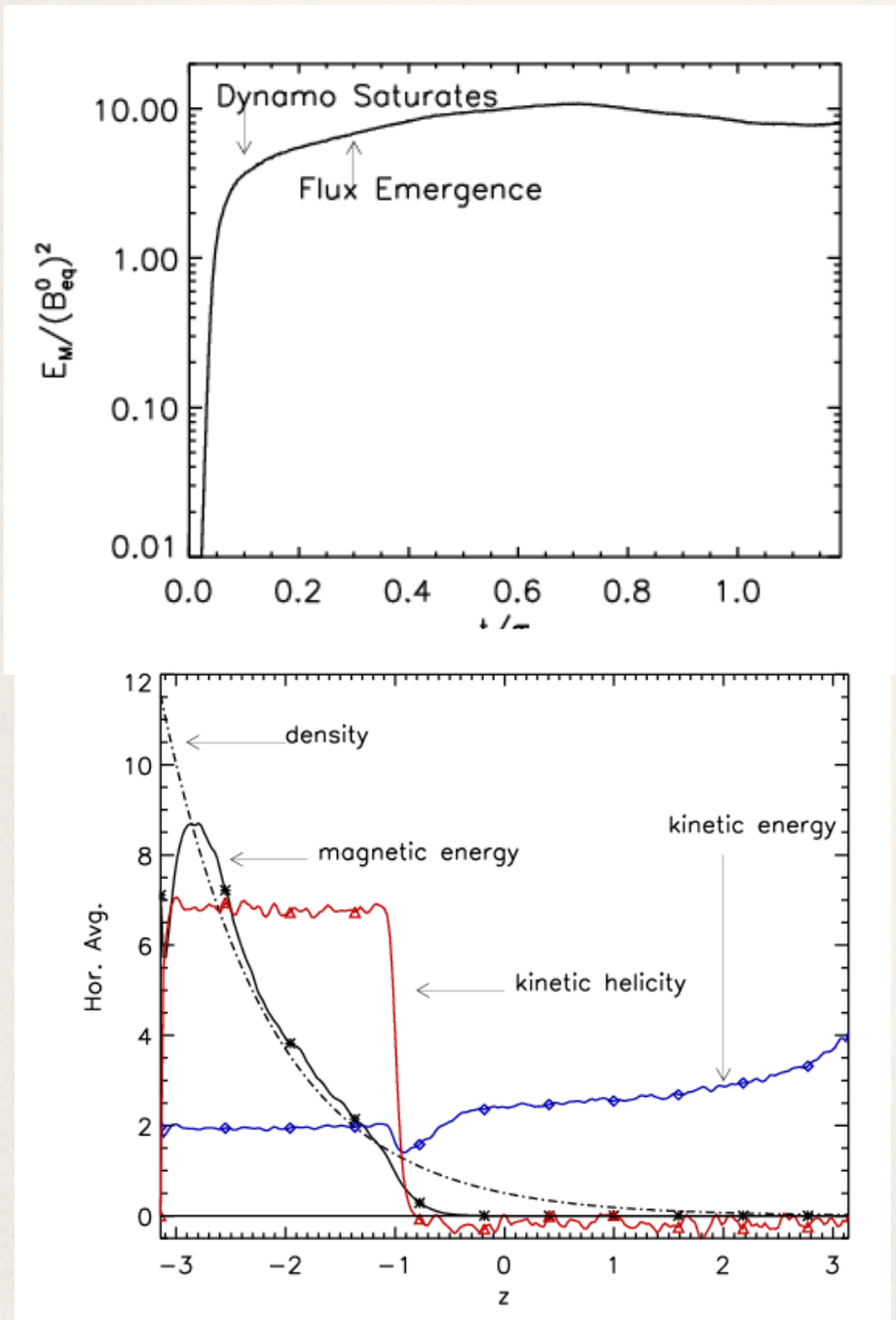
- Sign cannot be determined by symmetry arguments. For small Re the effective magnetic pressure is positive. The calculation of effective pressure from direct numerical simulations (through calculation of Reynolds and Maxwell's stresses) is the only way.

- If it is negative, it can give rise to an *instability that grows on top of a turbulent state* !

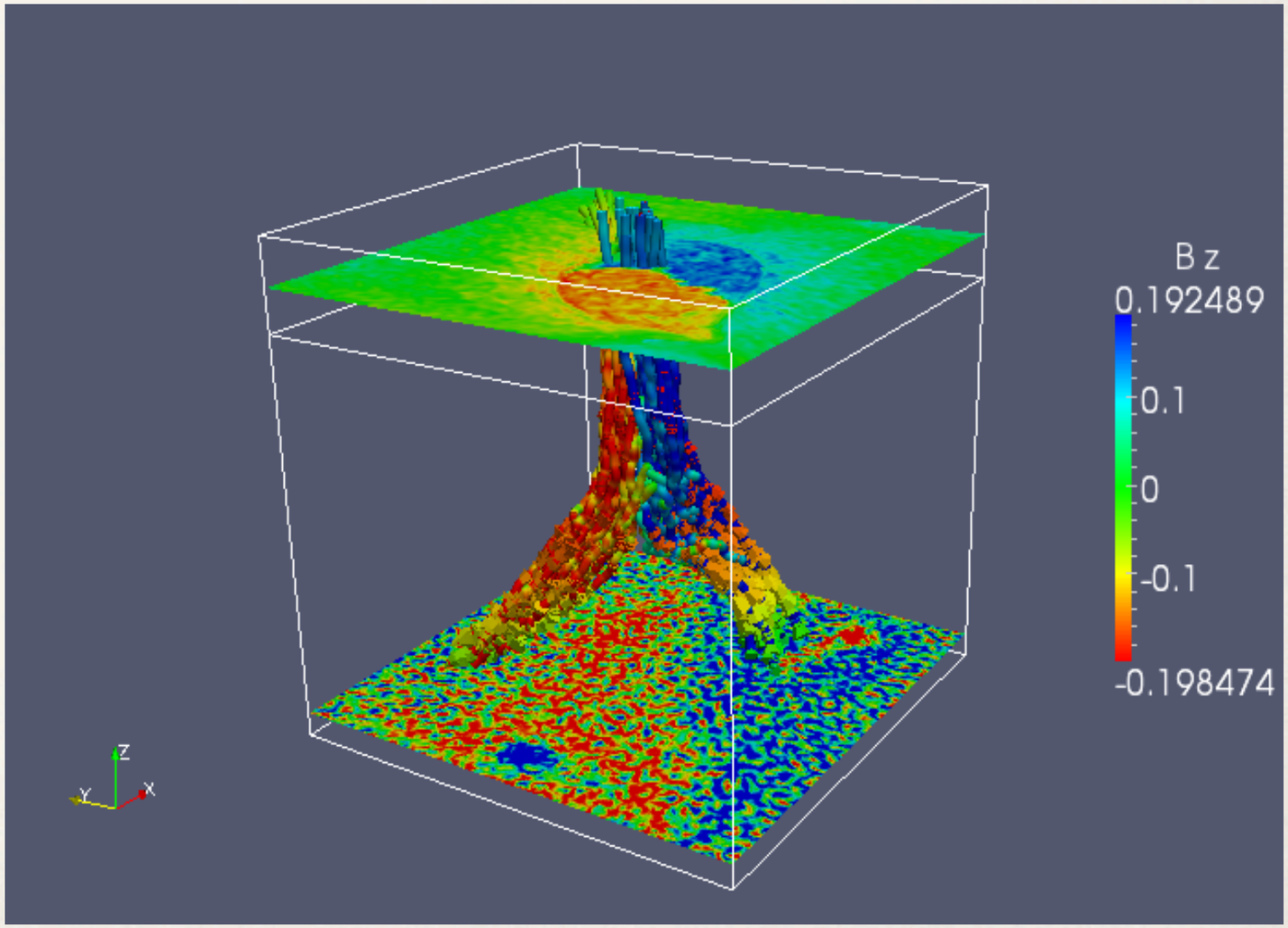
NEMPI is various avatars:

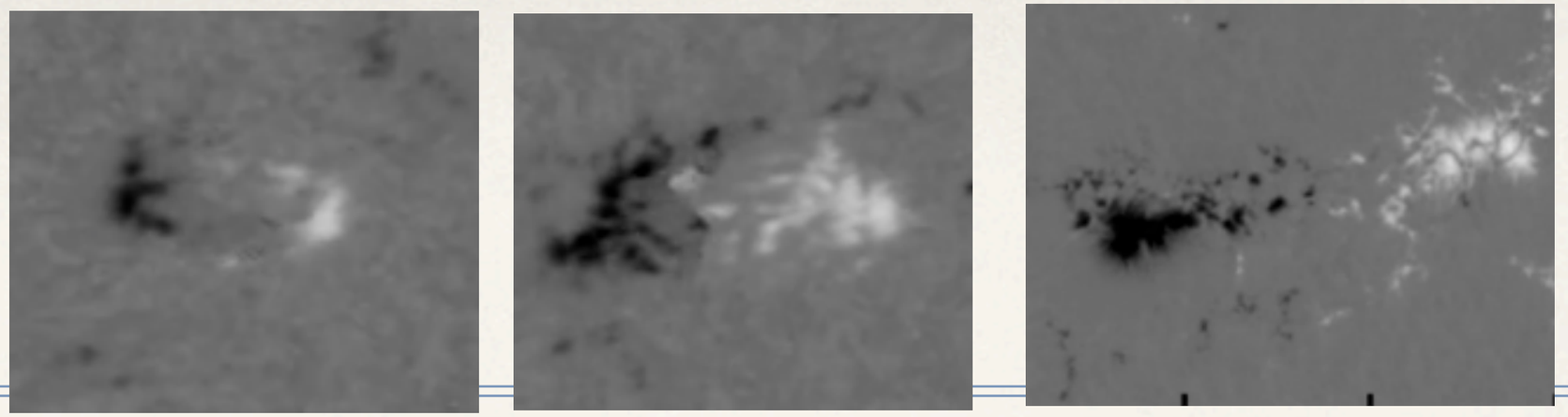
- Effective magnetic pressure can be negative under various circumstances (Kemel, Brandenburg, Kleeorin, Rogachevski, Kapyla, Kapyla)
- Demonstration that the instability operates in forced turbulence simulations (Brandenburg ..., Kemel,...) and its linear stability theory.
- NEMPI with background vertical and horizontal magnetic fields.
- What happens to NEMPI under rotation ... ? (Illa, ..)
- NEMPI generates bipolar structures (Joern, ...)
- NEMPI in spherical coordinates (Sarah,..)

NEMPI and dynamo

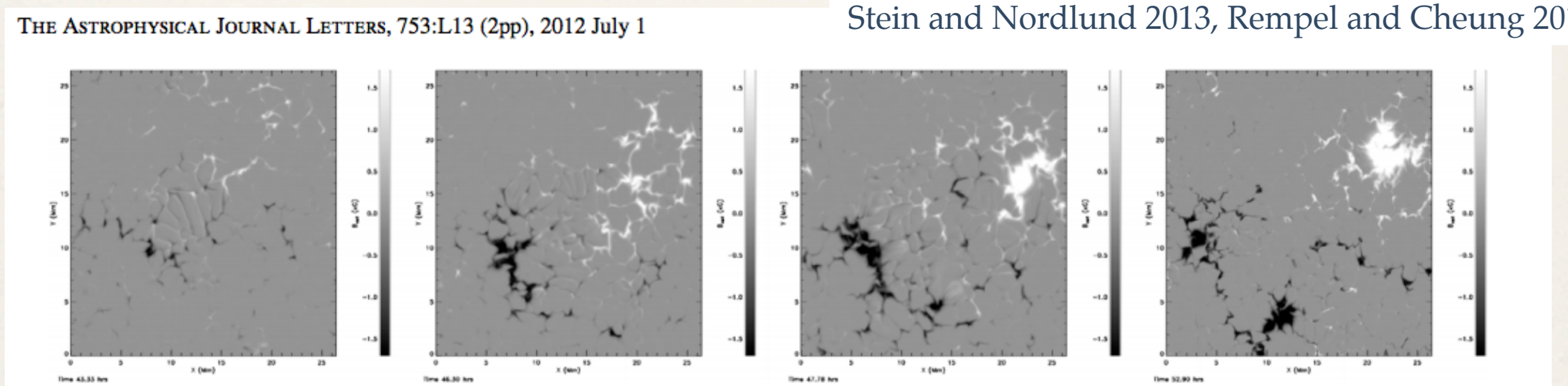


"Everything should be made as simple as possible but no simpler" A. Einstein, (never!)



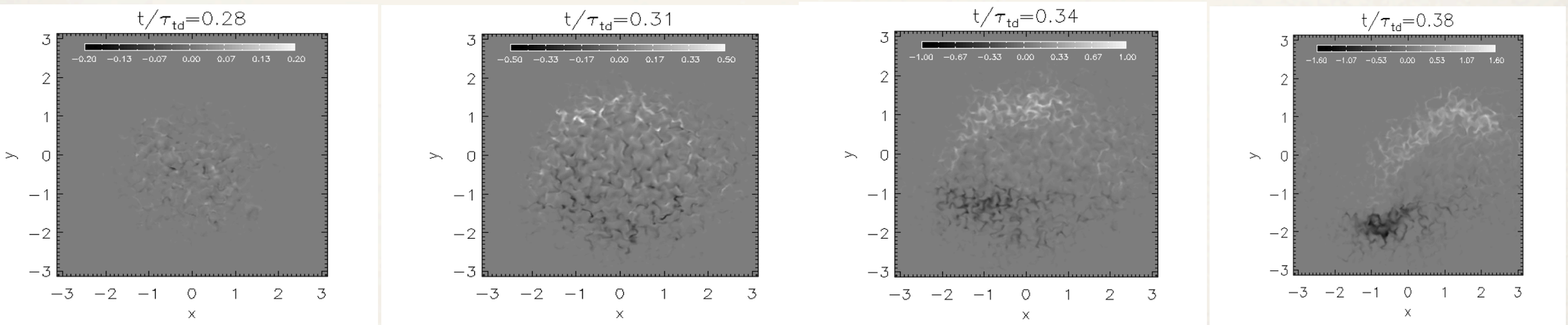


Stein and Nordlund 2013, Rempel and Cheung 2014



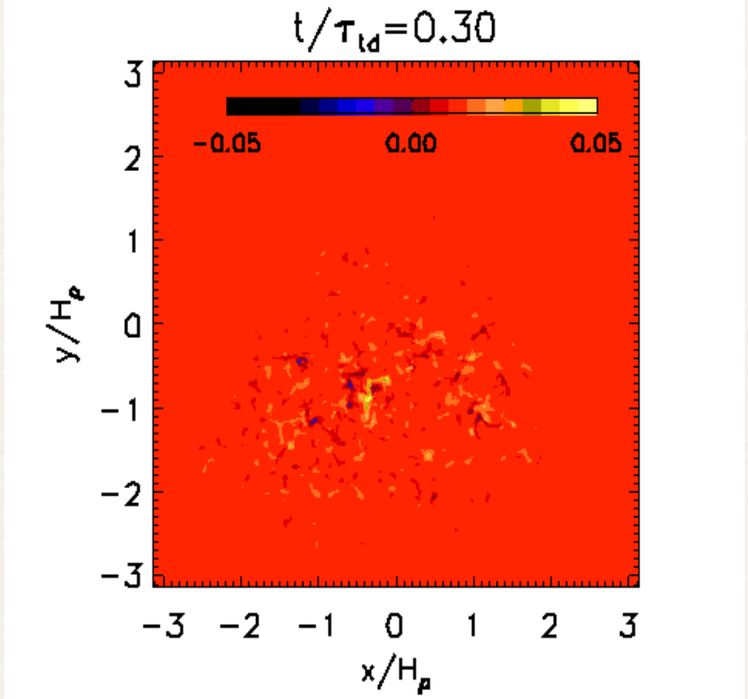
THE ASTROPHYSICAL JOURNAL LETTERS, 753:L13 (2pp), 2012 July 1

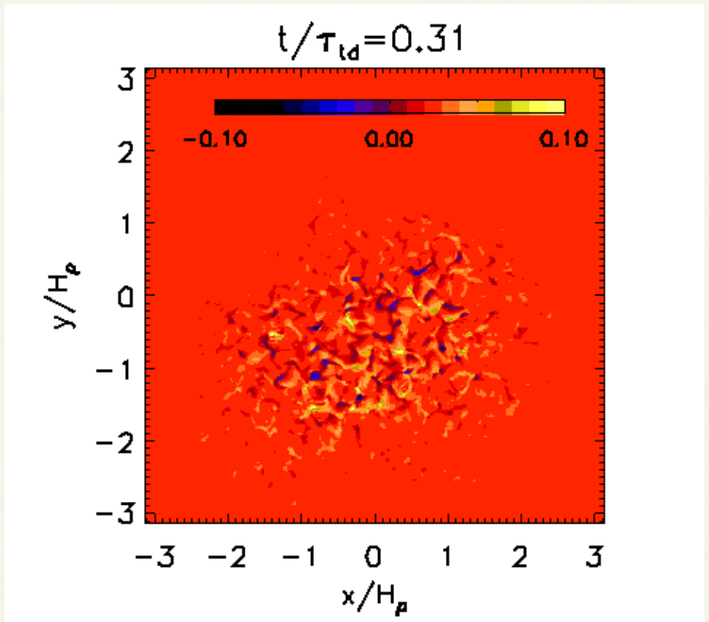
Figure 1. Vertical magnetic field. The images are clipped at ±1.7 kG, but the actual range is ±3 kG. The *x*-axis is the east–west axis. The field entered in the upflows at the bottom at an angle 30° to the *x*-axis. The active region approximately maintains this orientation. The separation of the pores is approximately the size of the supergranule-scale convective cells near the bottom of the domain.

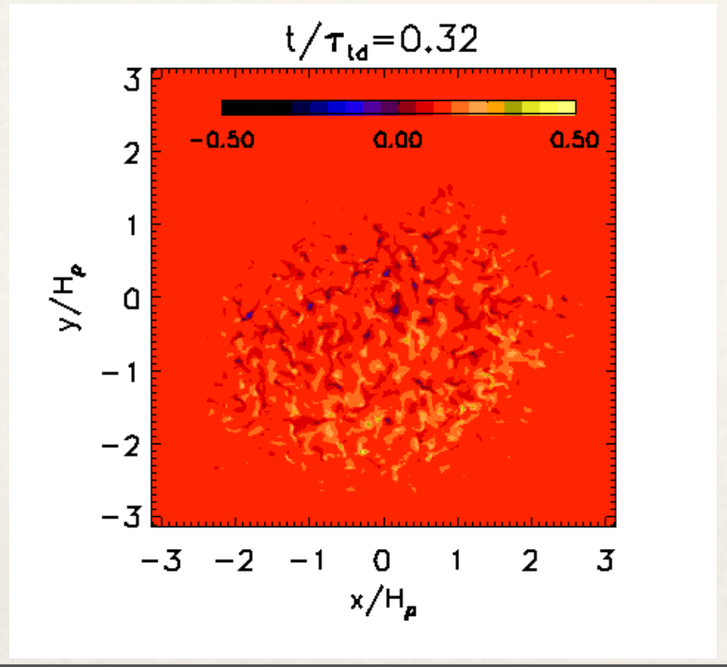


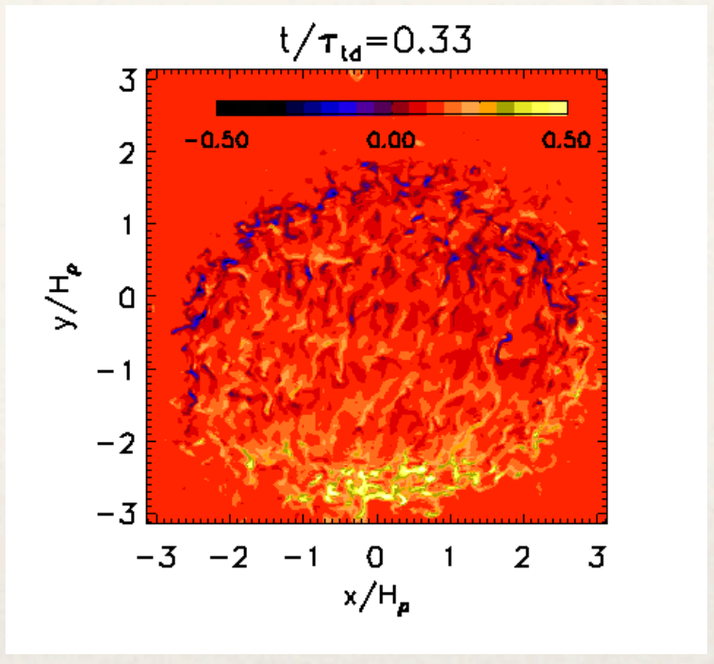
Mitra et al 2014

Flux emergence from another run







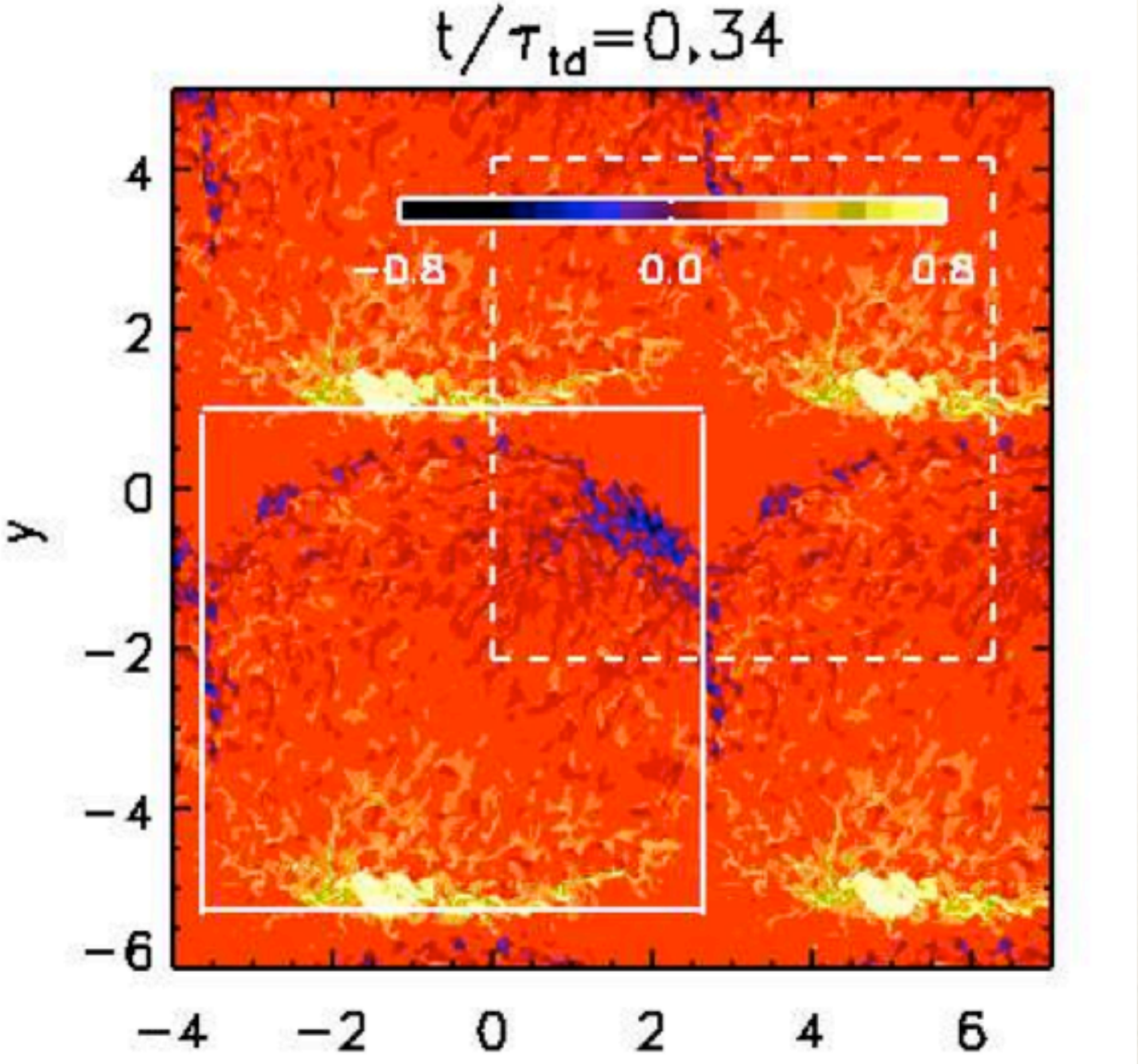


Are you suffering from NEMPI ?

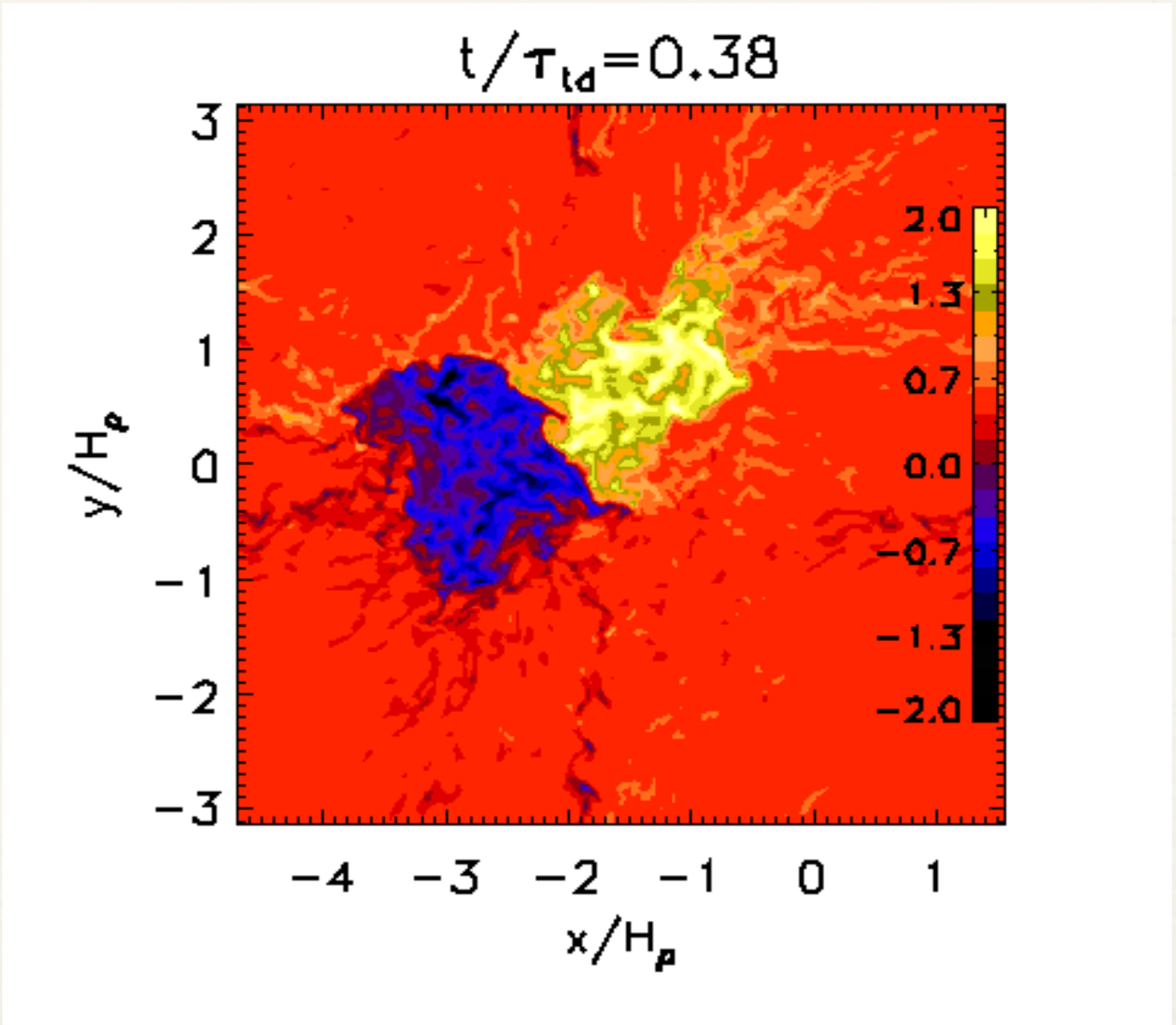
"A revolutionary should be a step ahead of the masses" - V.I. Lenin
"A numerical simulationist should NOT be more than a *half-a-step* ahead of analytical theories" -Uriel Frisch (2003)

- Magnetic field (in units of equipartition) should be order unity.
- Presence of converging flows.
- If you really want to know, calculate the Reynolds and Maxwell's stresses and try to model them with a background magnetic field. *This is not easy*

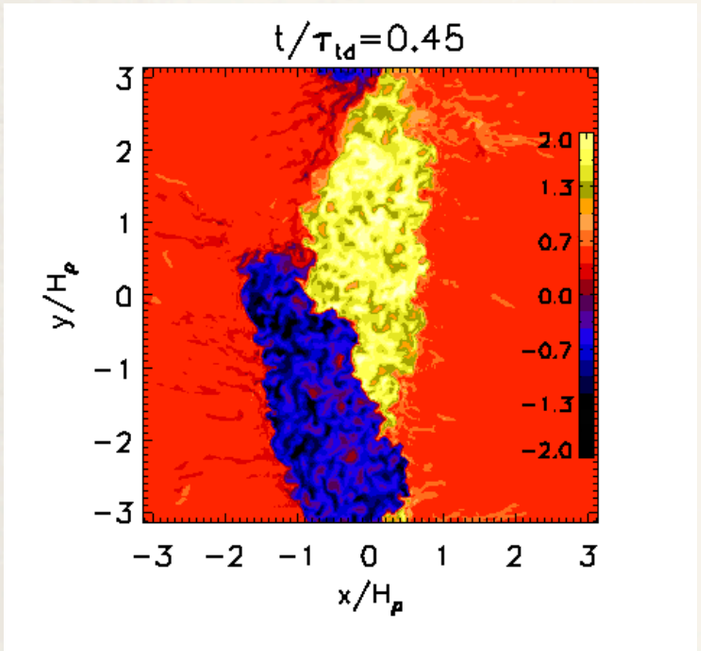
But, periodic boundary condition..

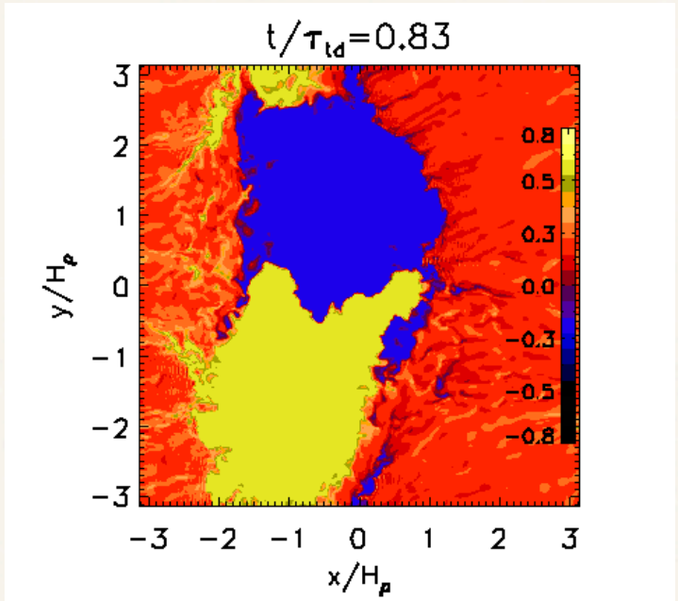


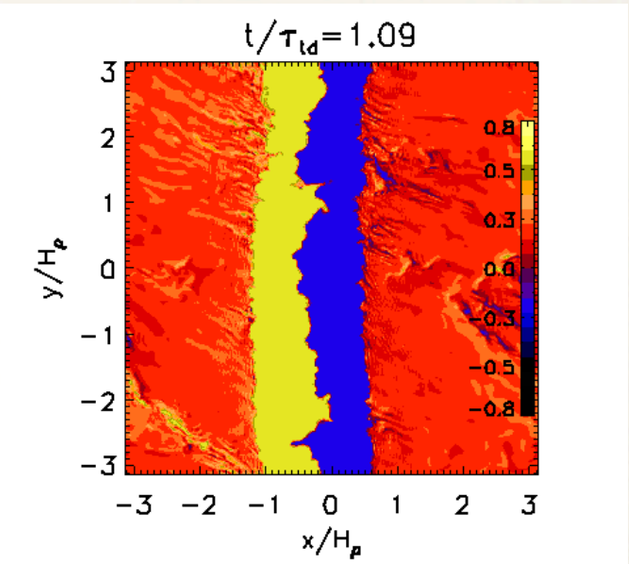
What happens next ?

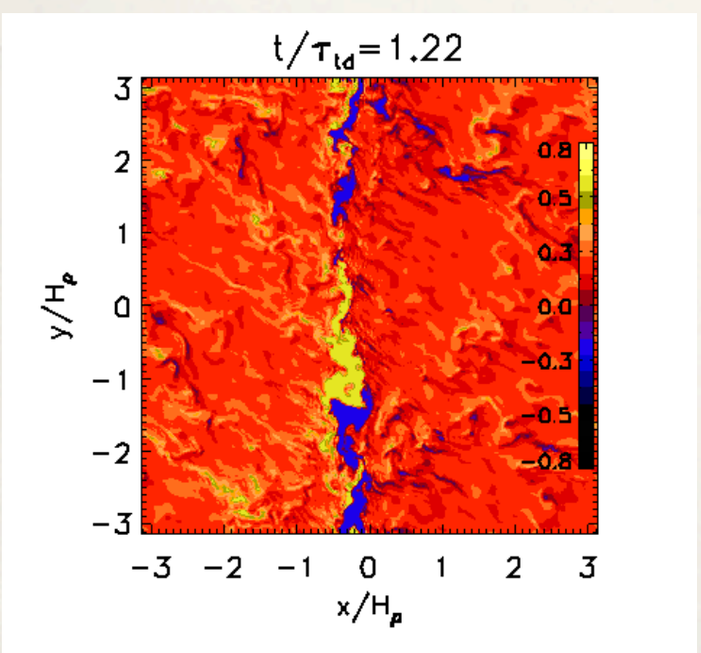


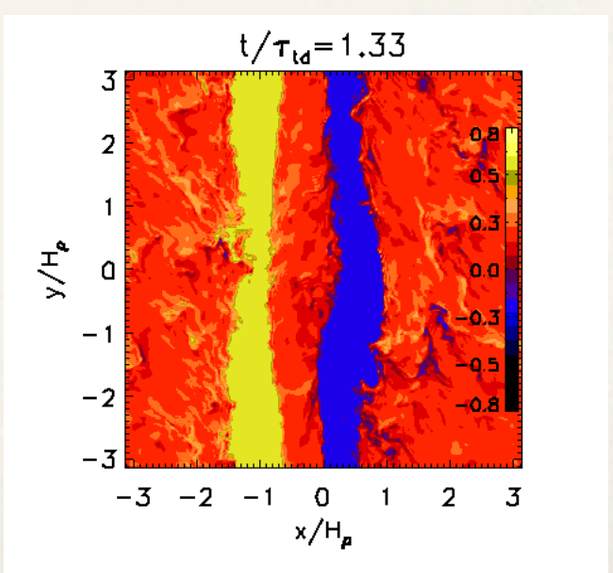
Spots and Bands..

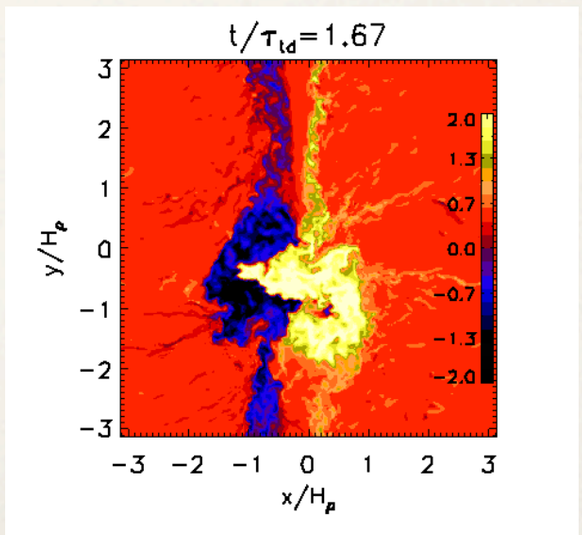




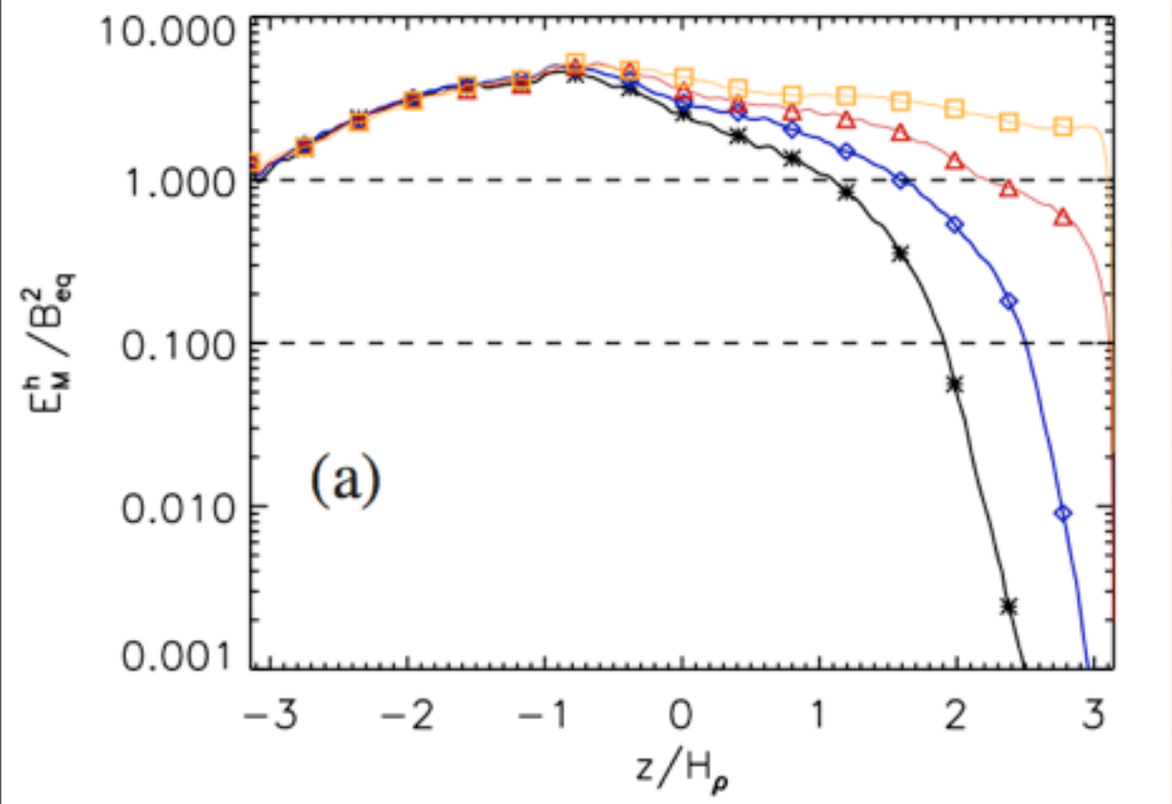


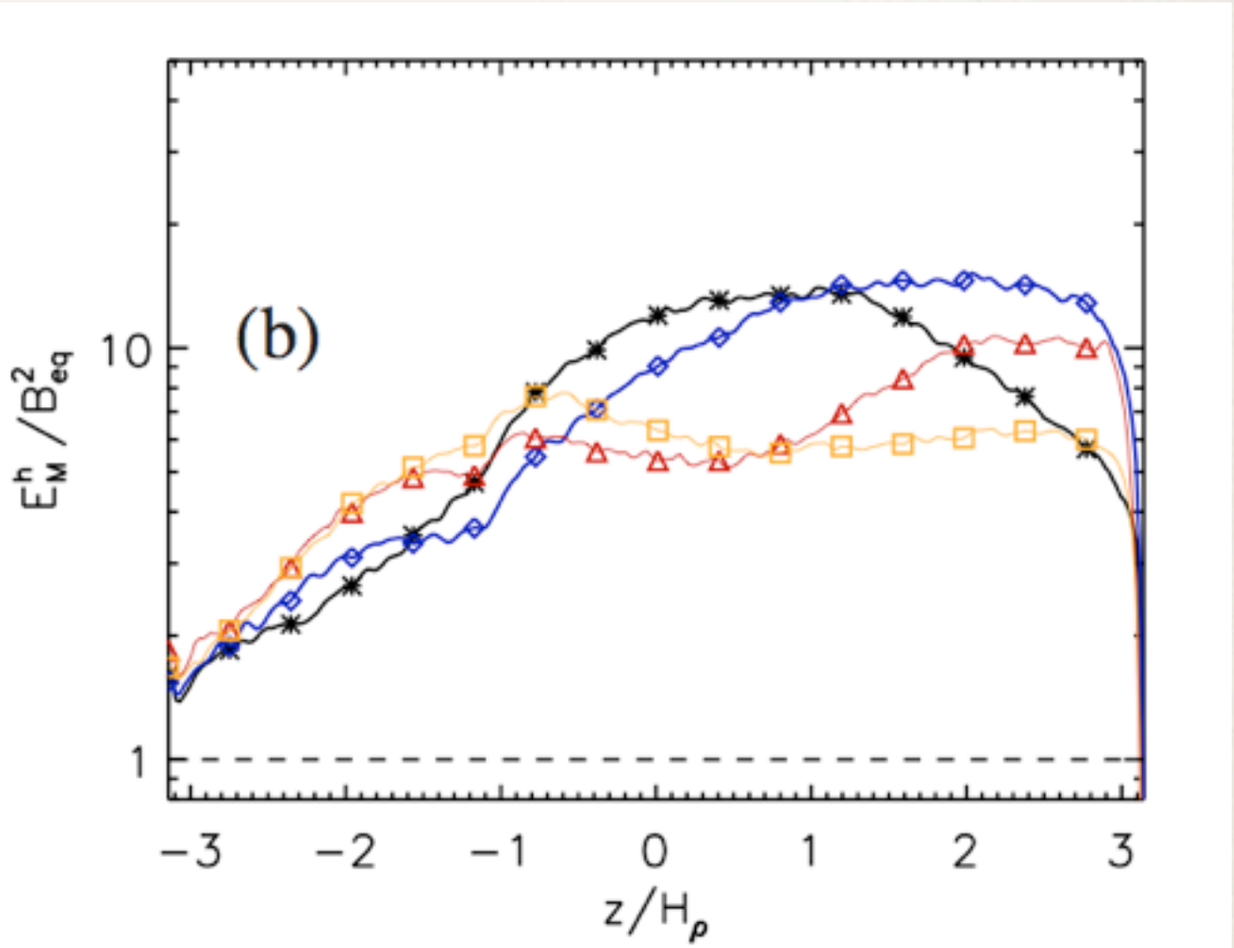




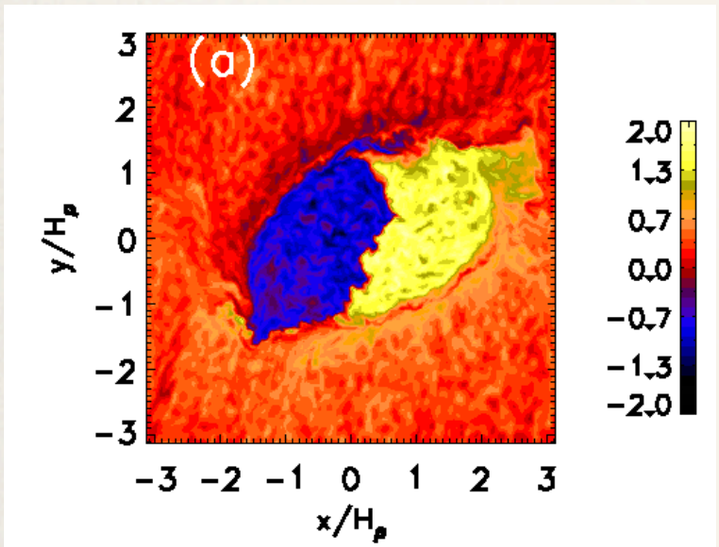


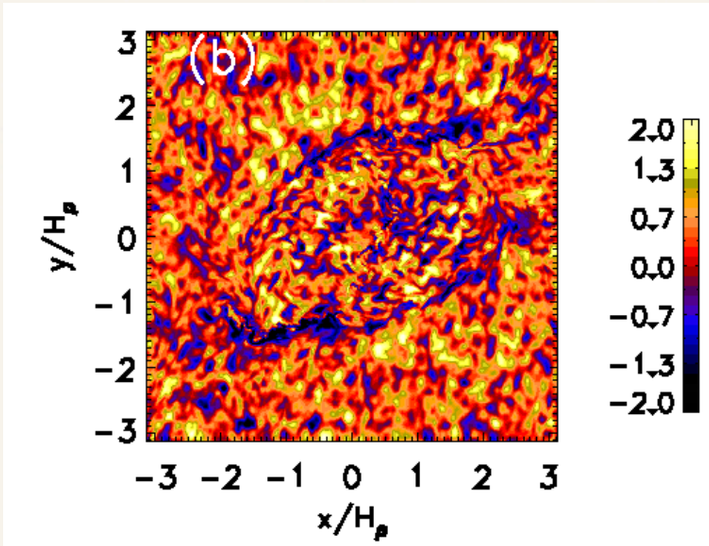
Is NEMPI *the* one ?

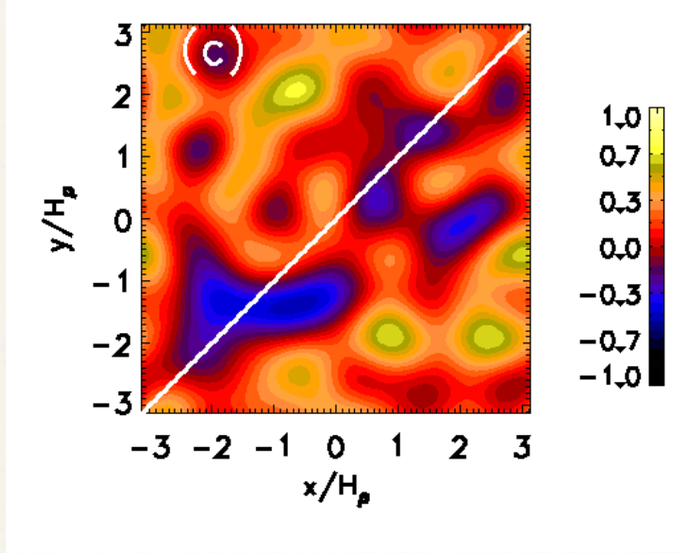


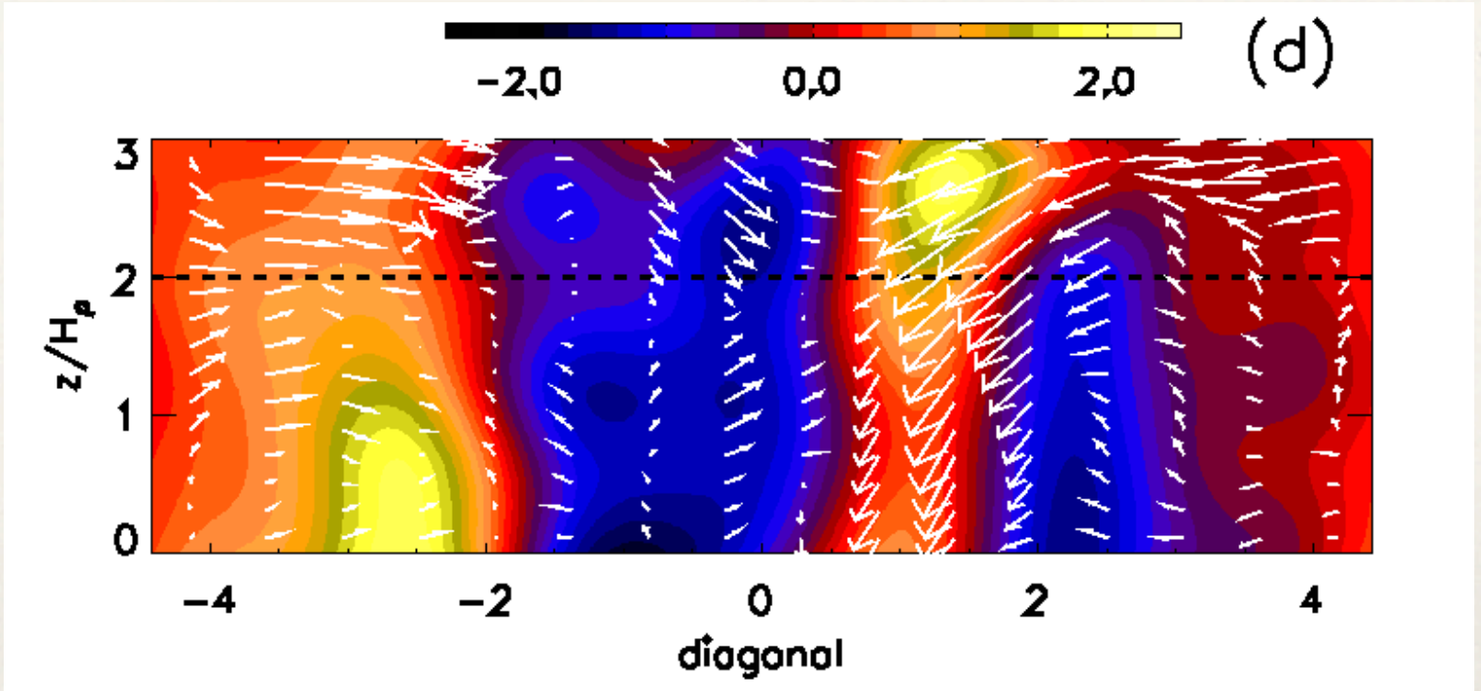


Maybe ..


(a)
y/H_p
x/H_p
3
2
1
0
−1
−2
−3
2.0
1.3
0.7
0.0
−0.7
−1.3
−2.0


(b)
y/H_p
x/H_p
3
2
1
0
−1
−2
−3
2.0
1.3
0.7
0.0
−0.7
−1.3
−2.0


(c)
y/H_p
x/H_p
3
2
1
0
−1
−2
−3
1.0
0.7
0.3
0.0
−0.3
−0.7
−1.0


(d)
−2.0
0.0
2.0
z/H_p
diagonal
3
2
1
0
−4
−2
0
2
4

Conclusions:

- NEMPI may be responsible at the emergence stage of the magnetic field.
- But may or may not be the effect responsible for later-stage pattern formation.
- We need a better theoretical description of NEMPI to be abel to describe it in the presence of a non-constant magnetic field.
- How does the helioseismic signatures of NEMPI and flux-emergence by Parker instability differs ?