Bipolar region formation in stratified two-layer turbulence

Warnecke et al 2013 & 2015

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together with:

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Negative Effective Magnetic Pressure Instability

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NEMPI

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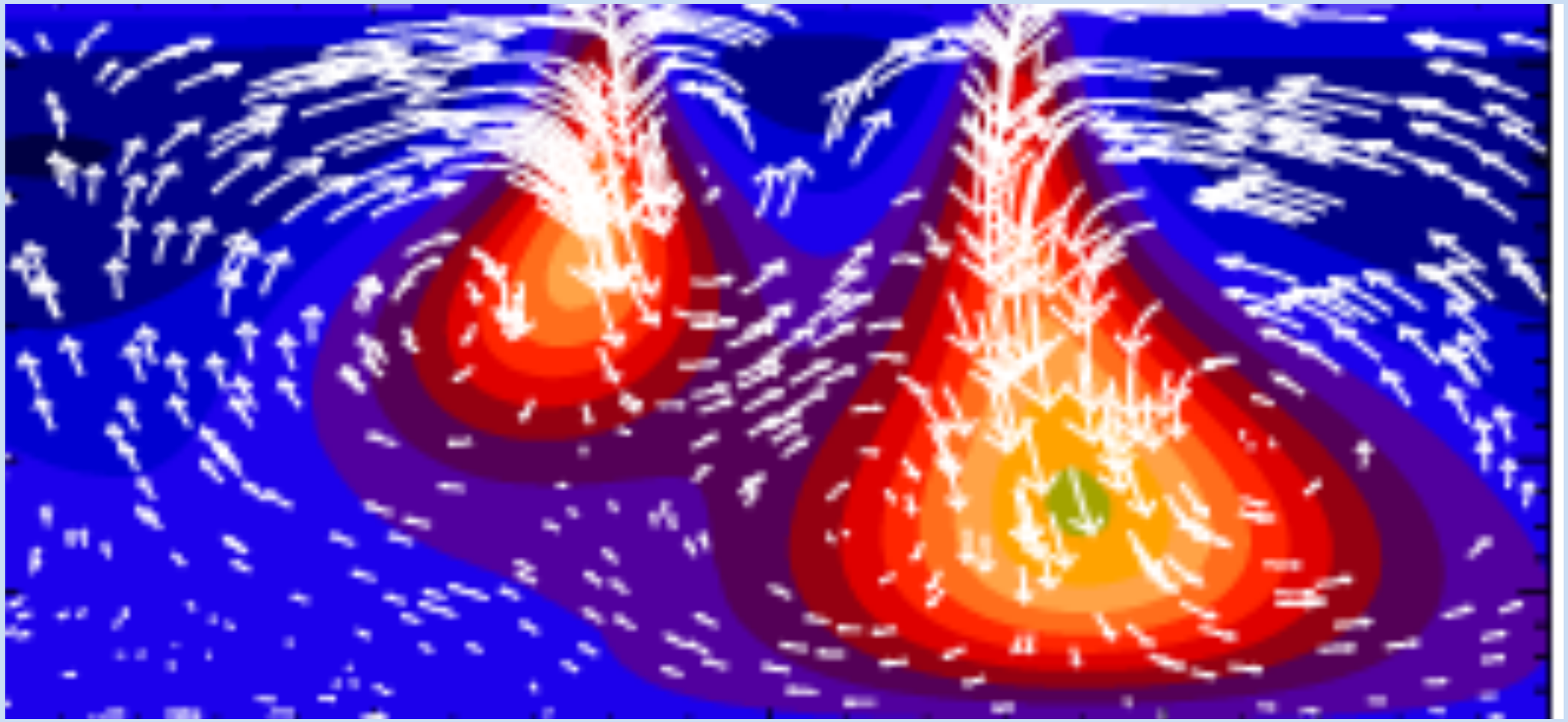

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Negative Effective Magnetic Pressure Instability NEMPI

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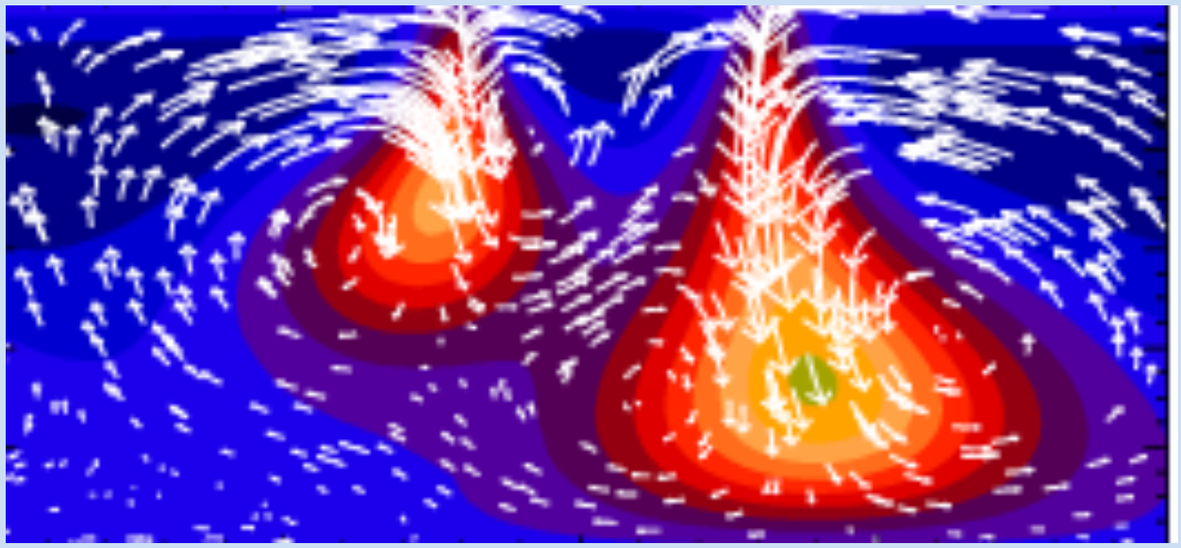
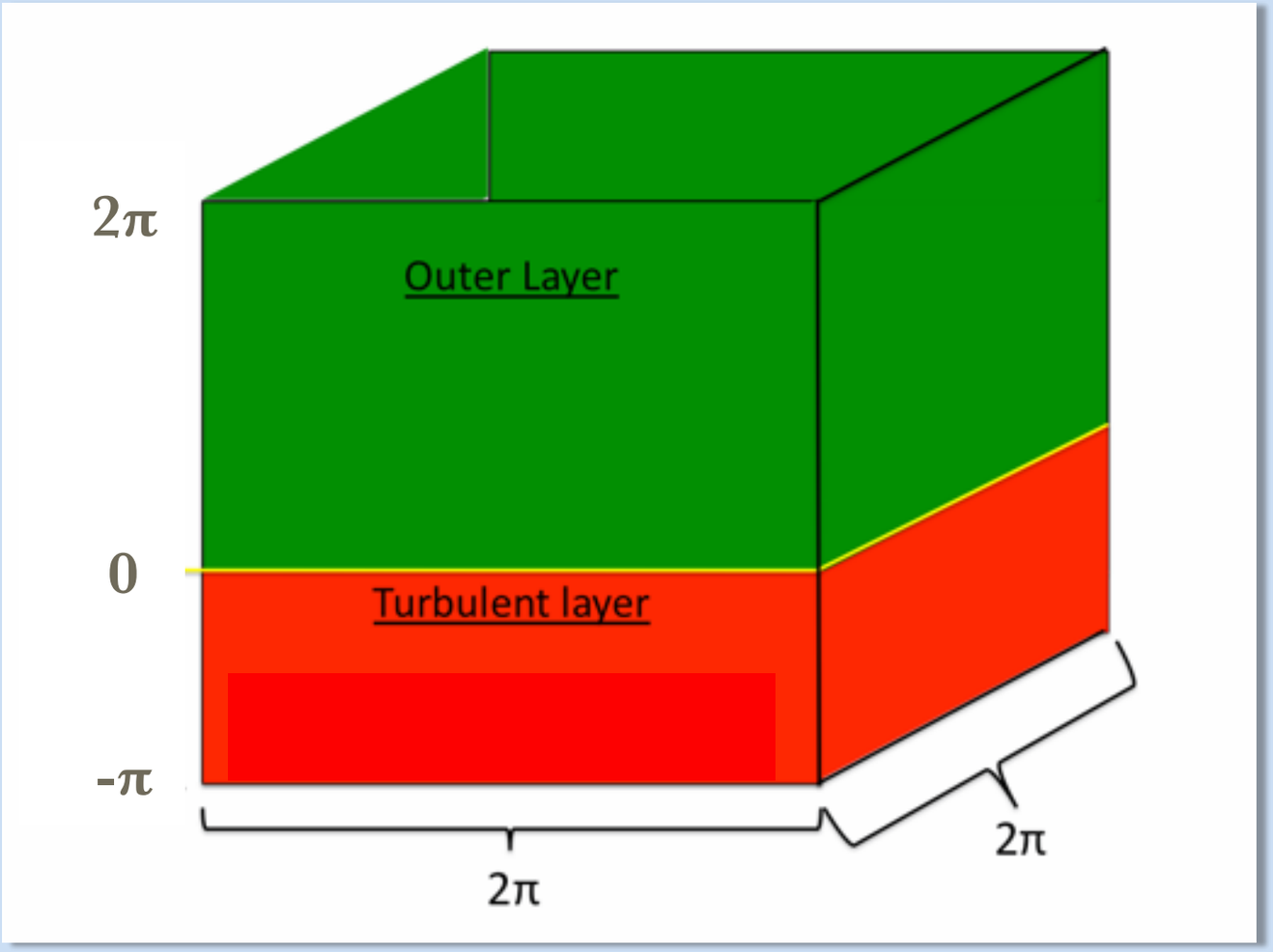


Kleeorin et al. 1989, 1990
Brandenburg et al., 2011, 2012, 2013
Kemel et al. 2012a,b, 2013a,b

Cartesian Setup

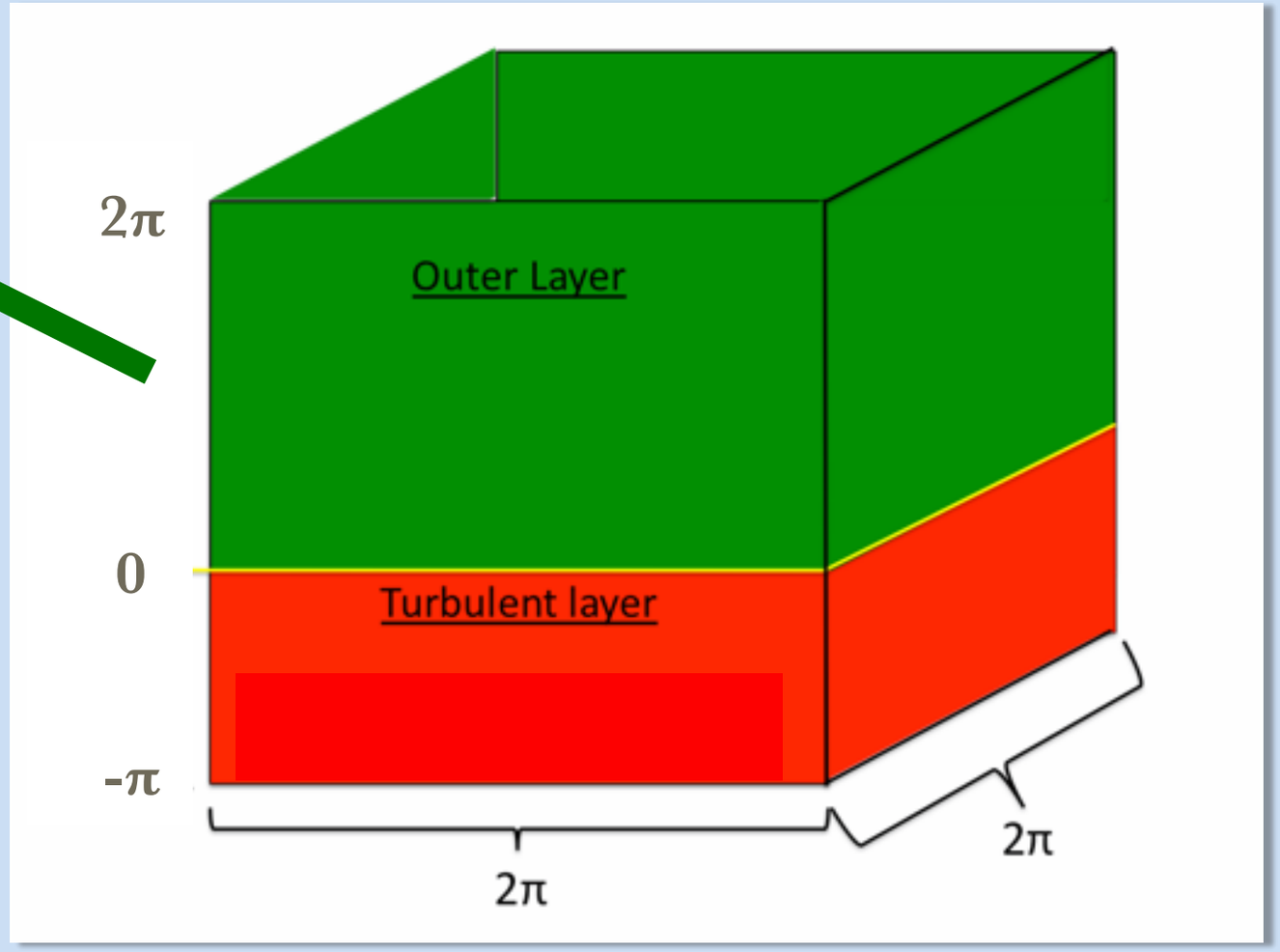


Cartesian Setup

Simplified corona:

Isothermal density stratification

Imposed magnetic field: $B_y = B_0 = 0.02\, B_{eq0}$



Equations:

$$\frac{\partial A}{\partial t} = U \times B + \eta \nabla^2 A$$

$$\frac{D \ln \rho}{Dt} = -\nabla \cdot U$$

$$\frac{DU}{Dt} = g + \theta_w(z) f + \frac{1}{\rho}[-c_s^2 \nabla \rho + J \times B + \nabla \cdot (2\nu \rho S)]$$

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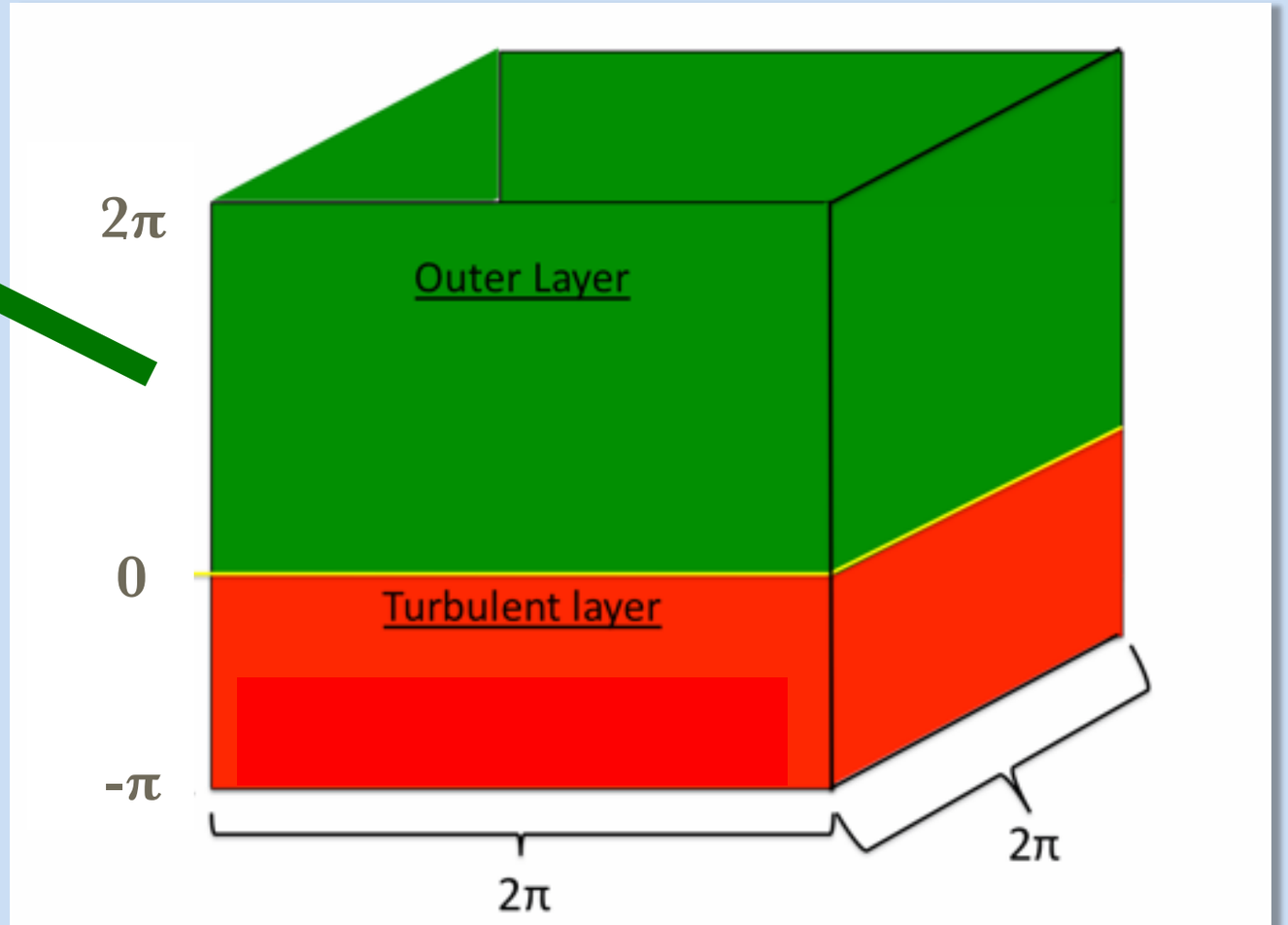

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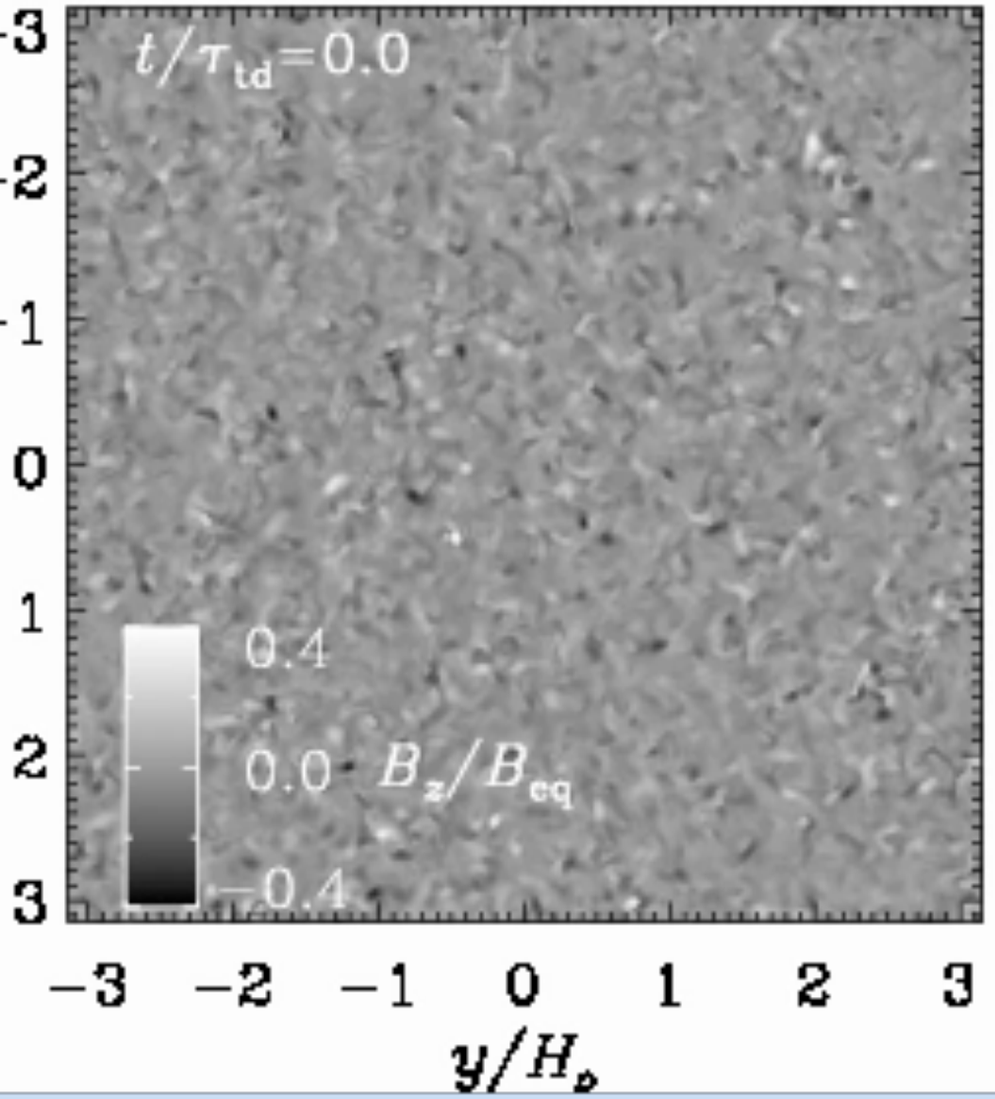
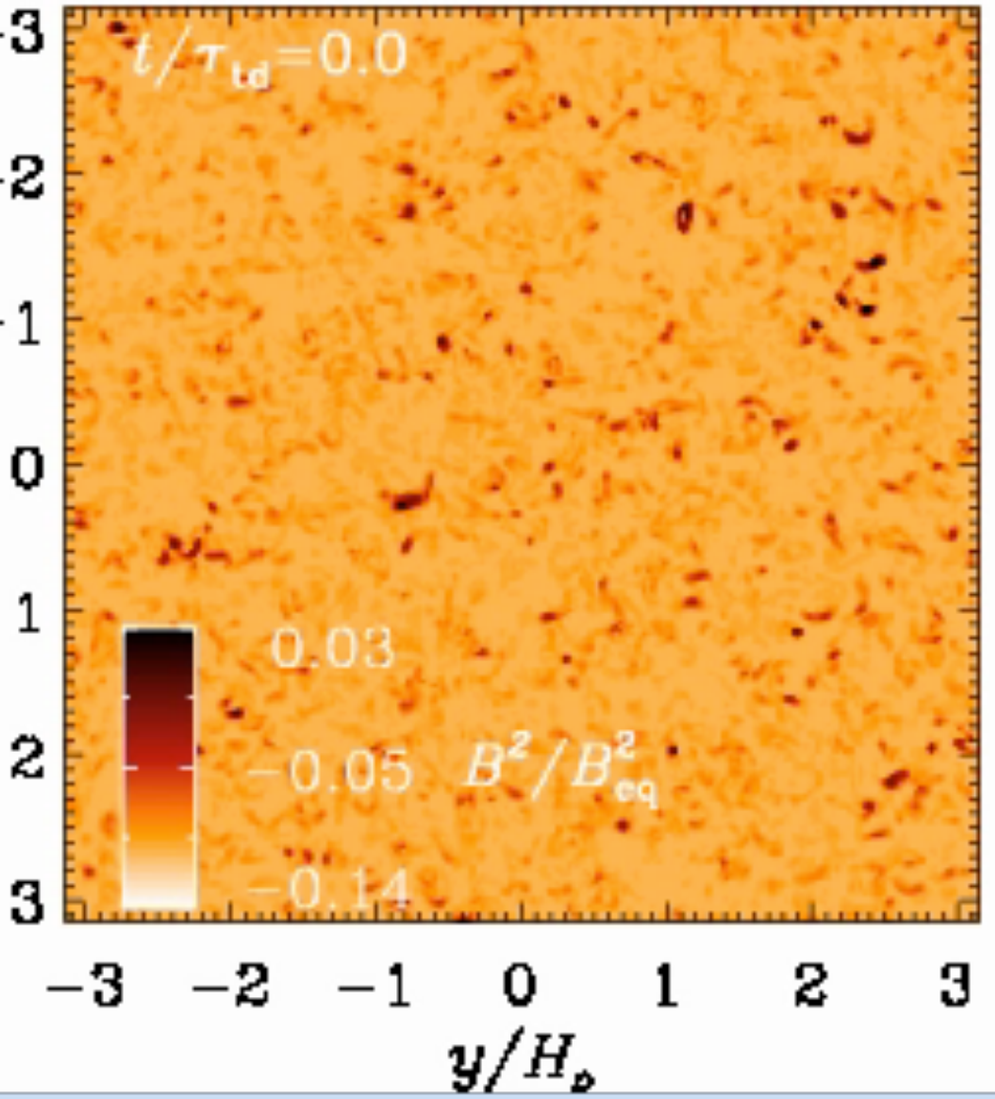
$$\Theta_w(z) = \frac{1}{2}\left(1 - \mathrm{erf}\frac{z}{w}\right)$$

Forcing f with non-helical transverse plane waves with wave numbers around $k_f = 30$.

Results

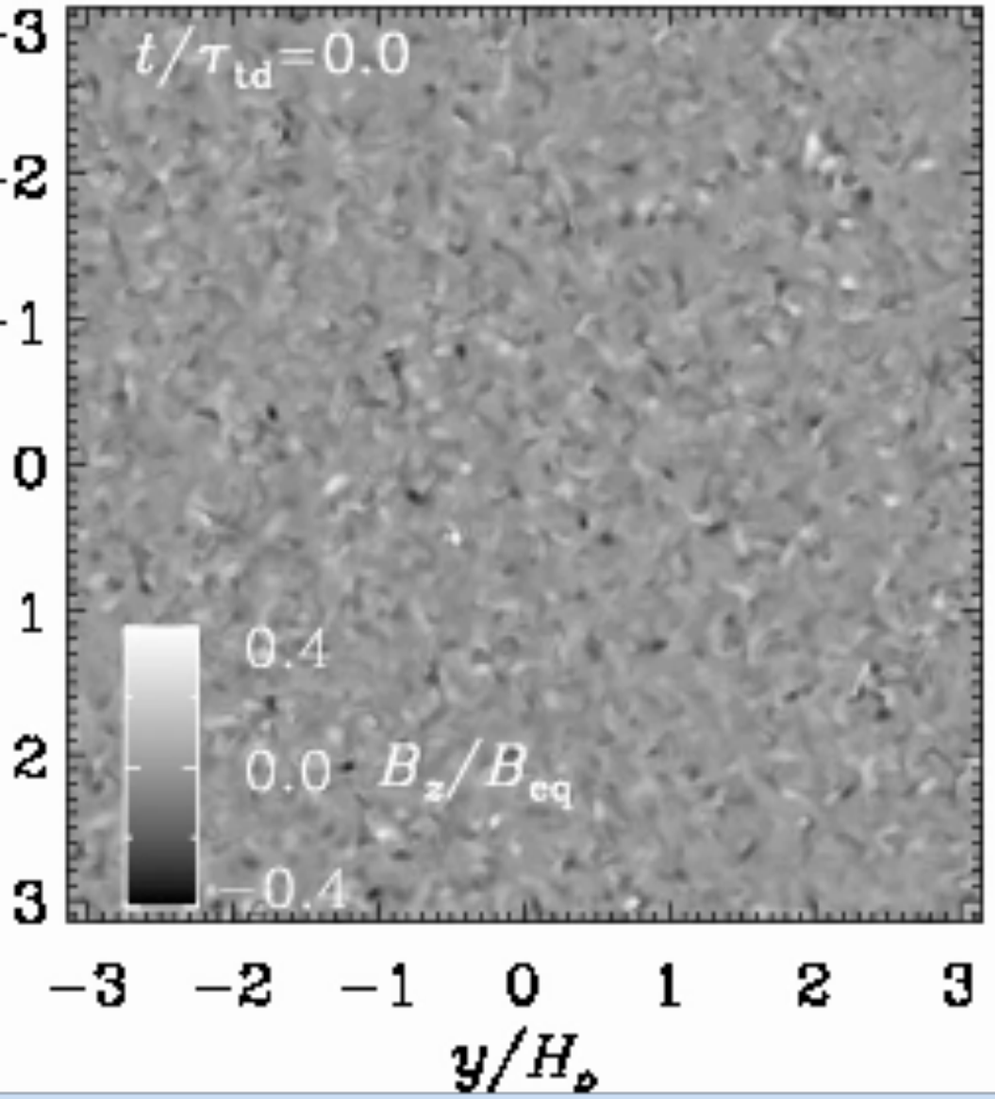


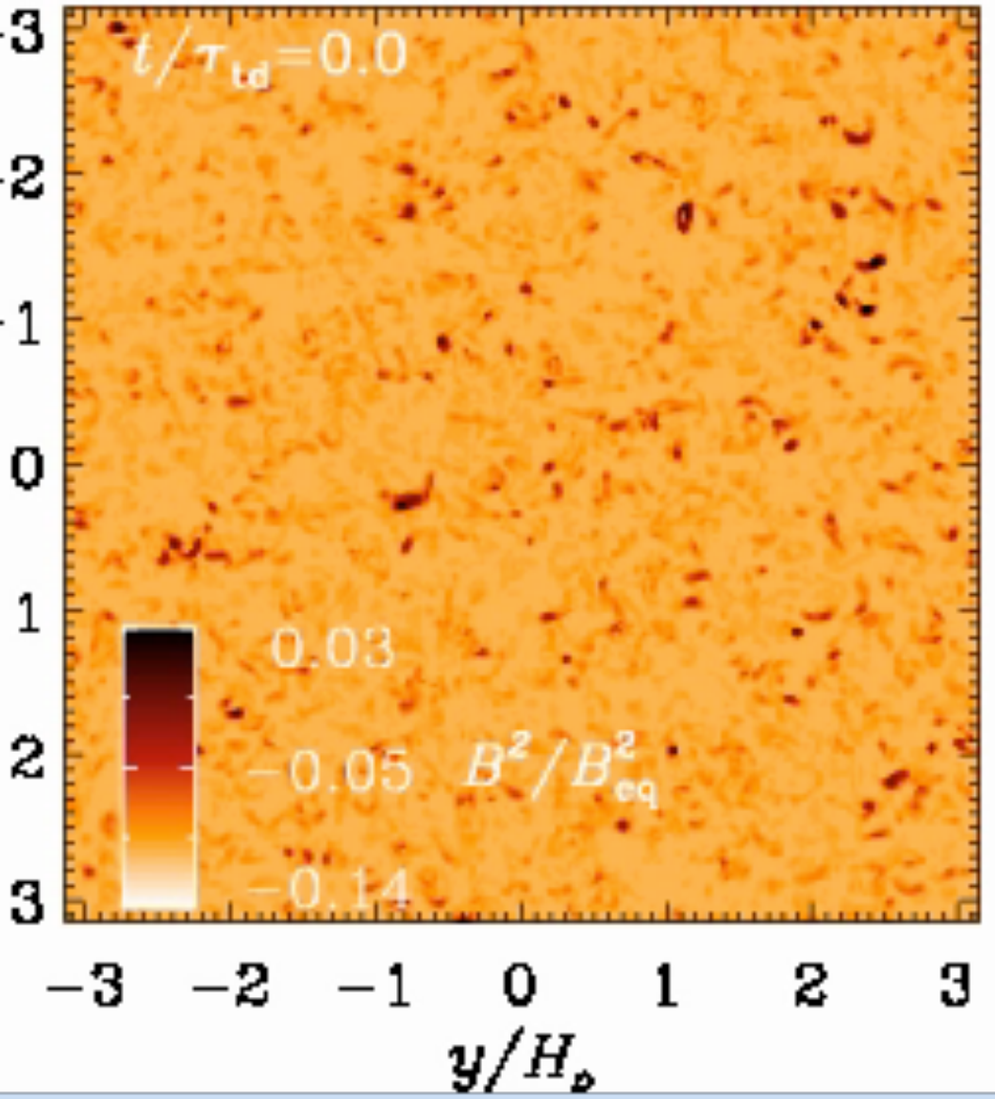


B_z B^2

$\tau_{td}=3k_f/(urms\ k_1^2)$

Results





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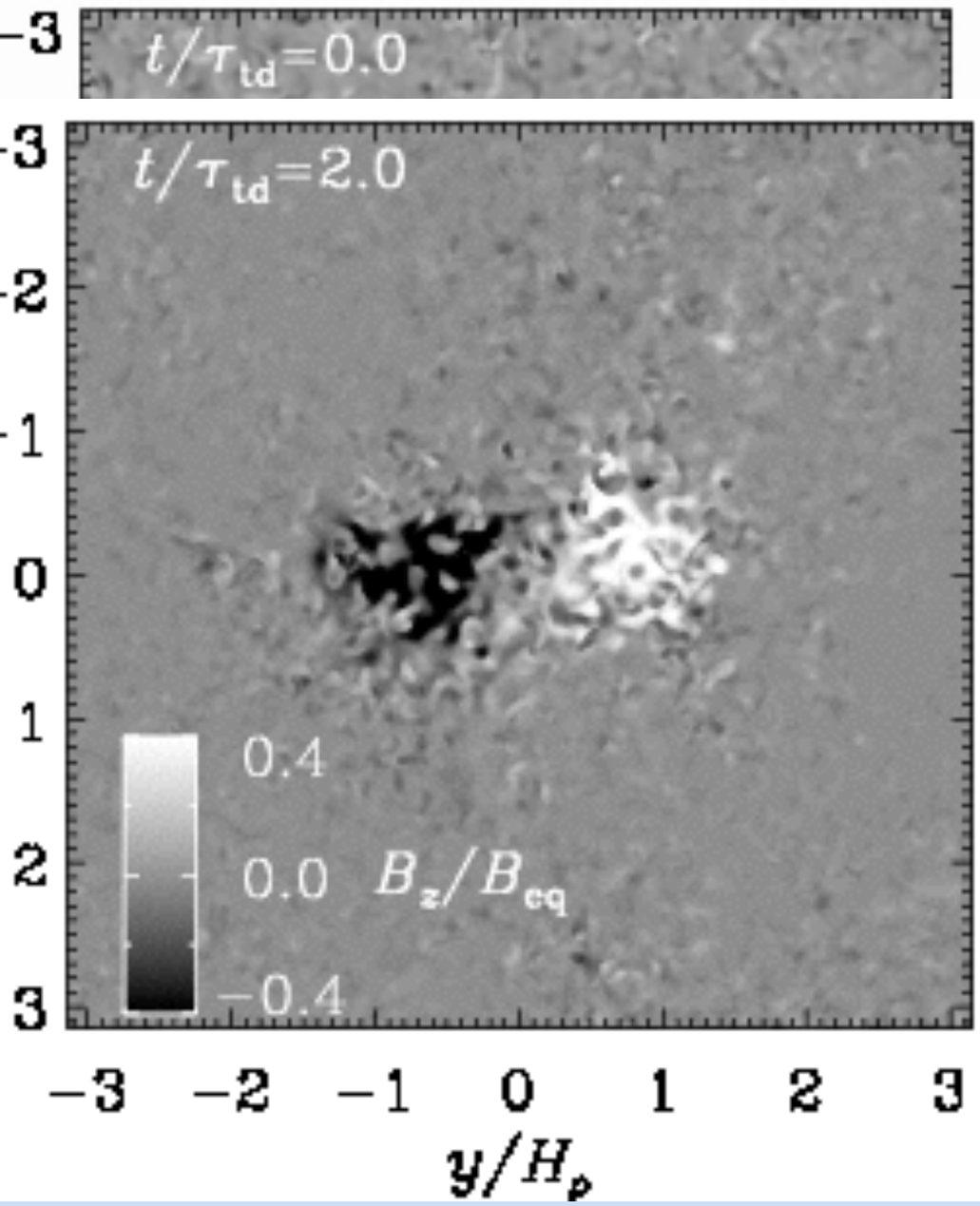

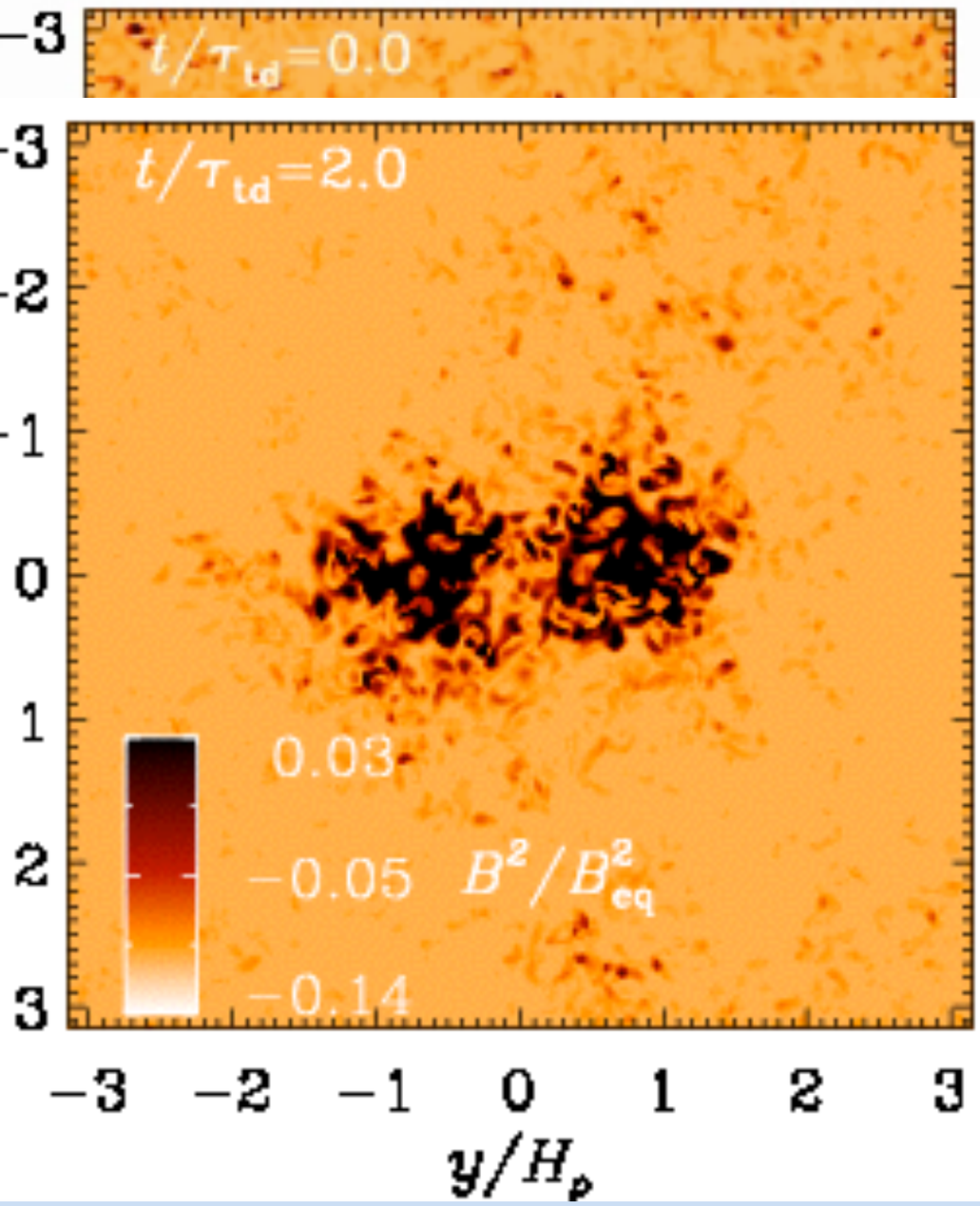

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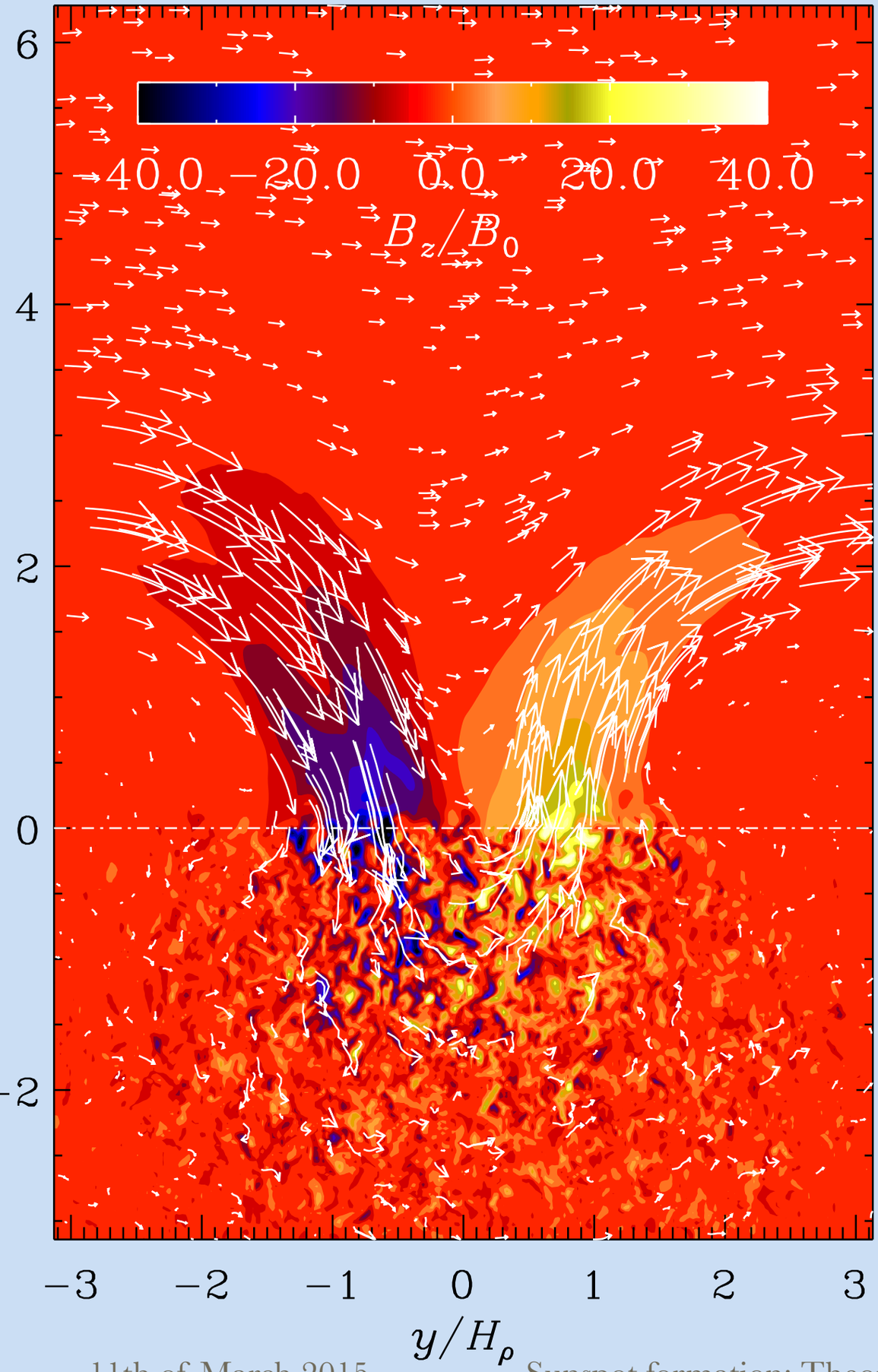
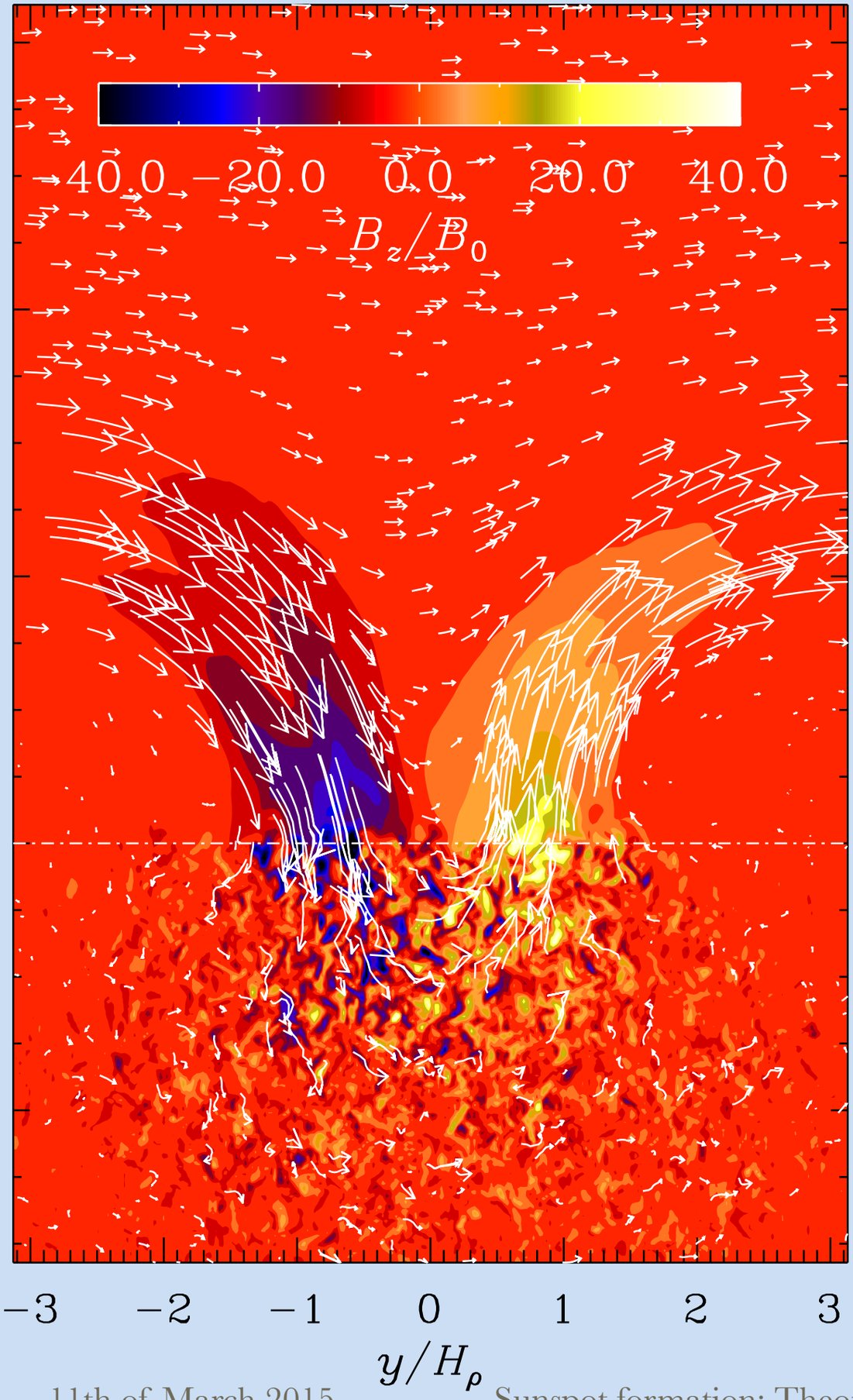
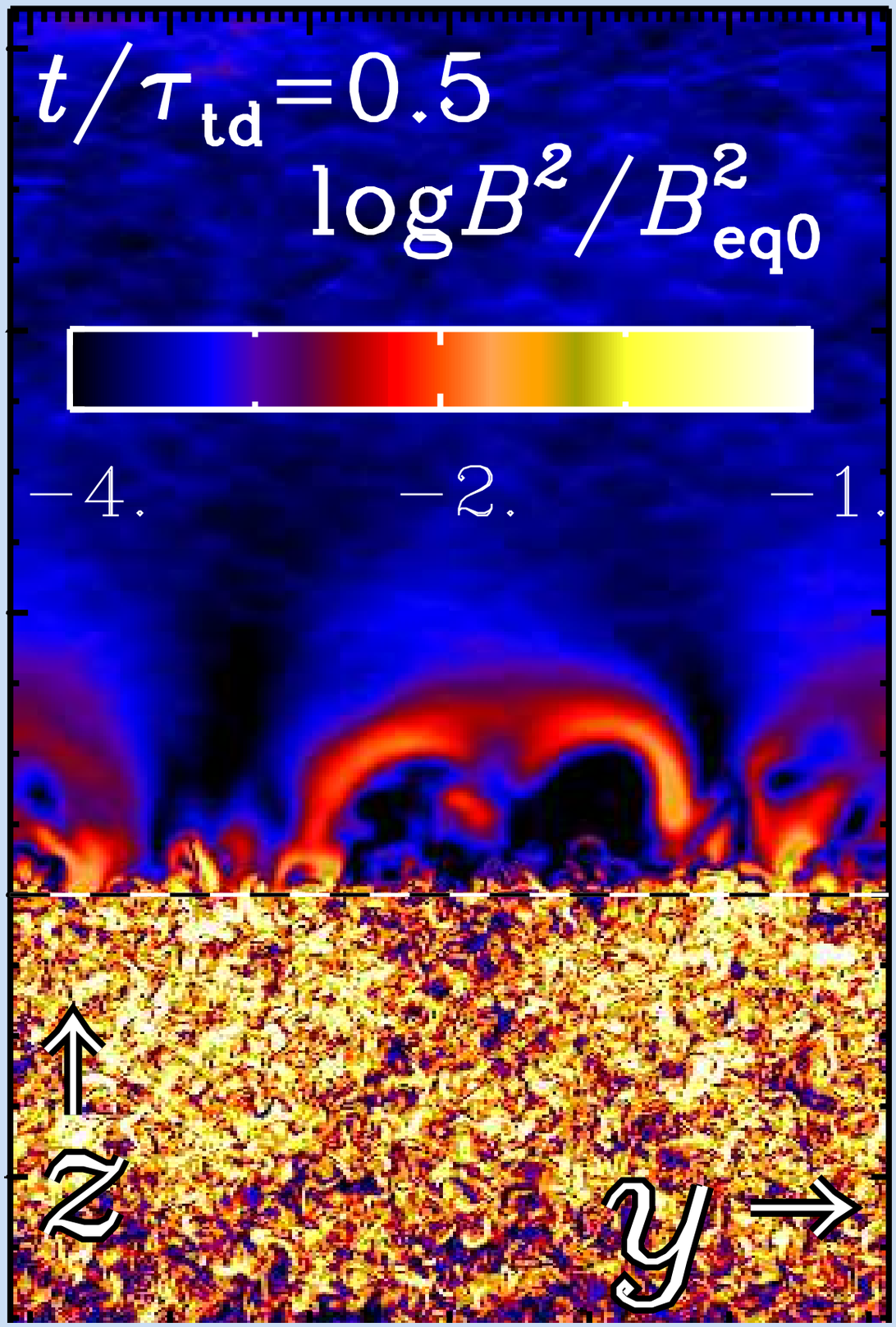
Coronal extend



Coronal extend





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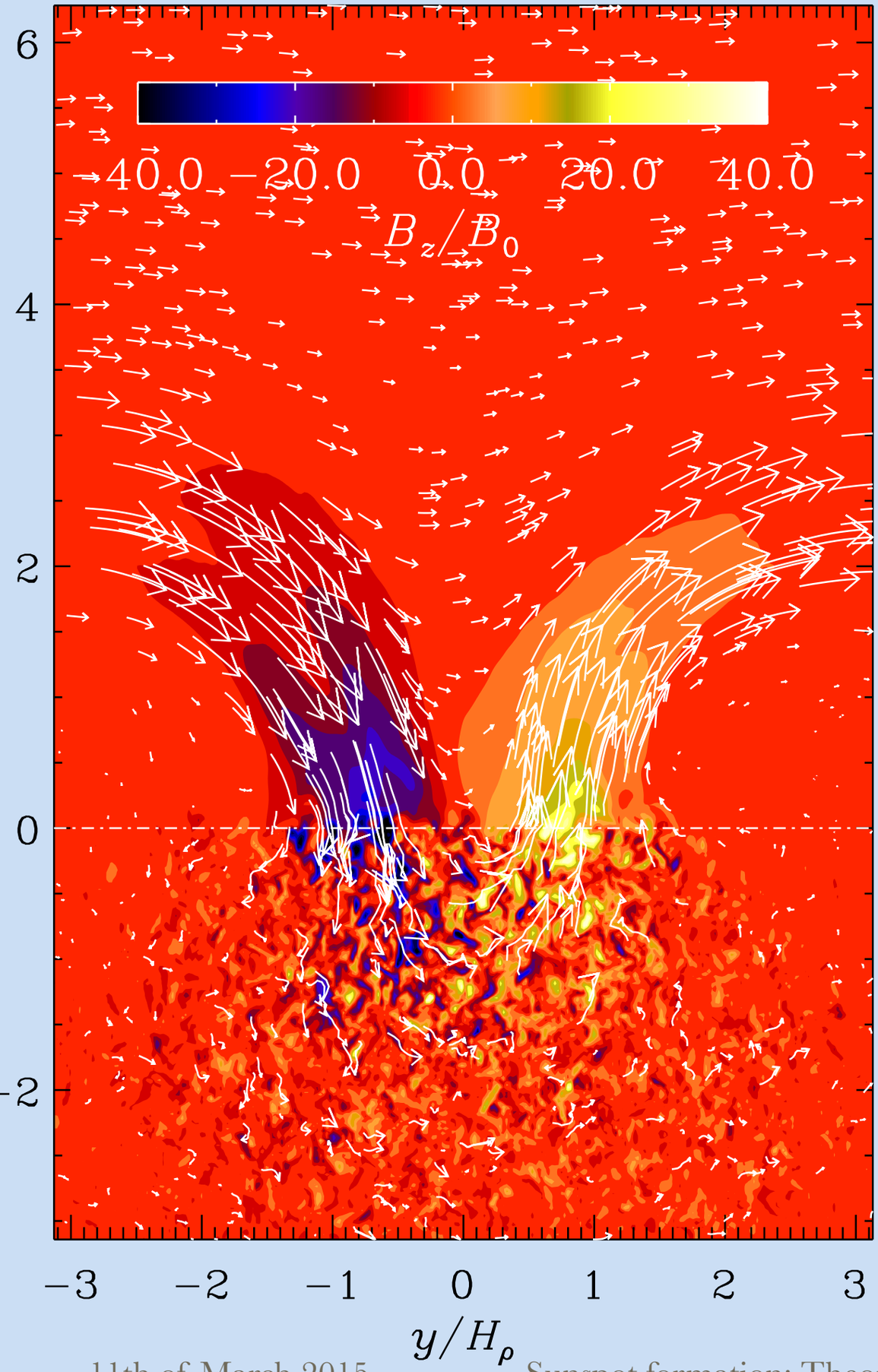

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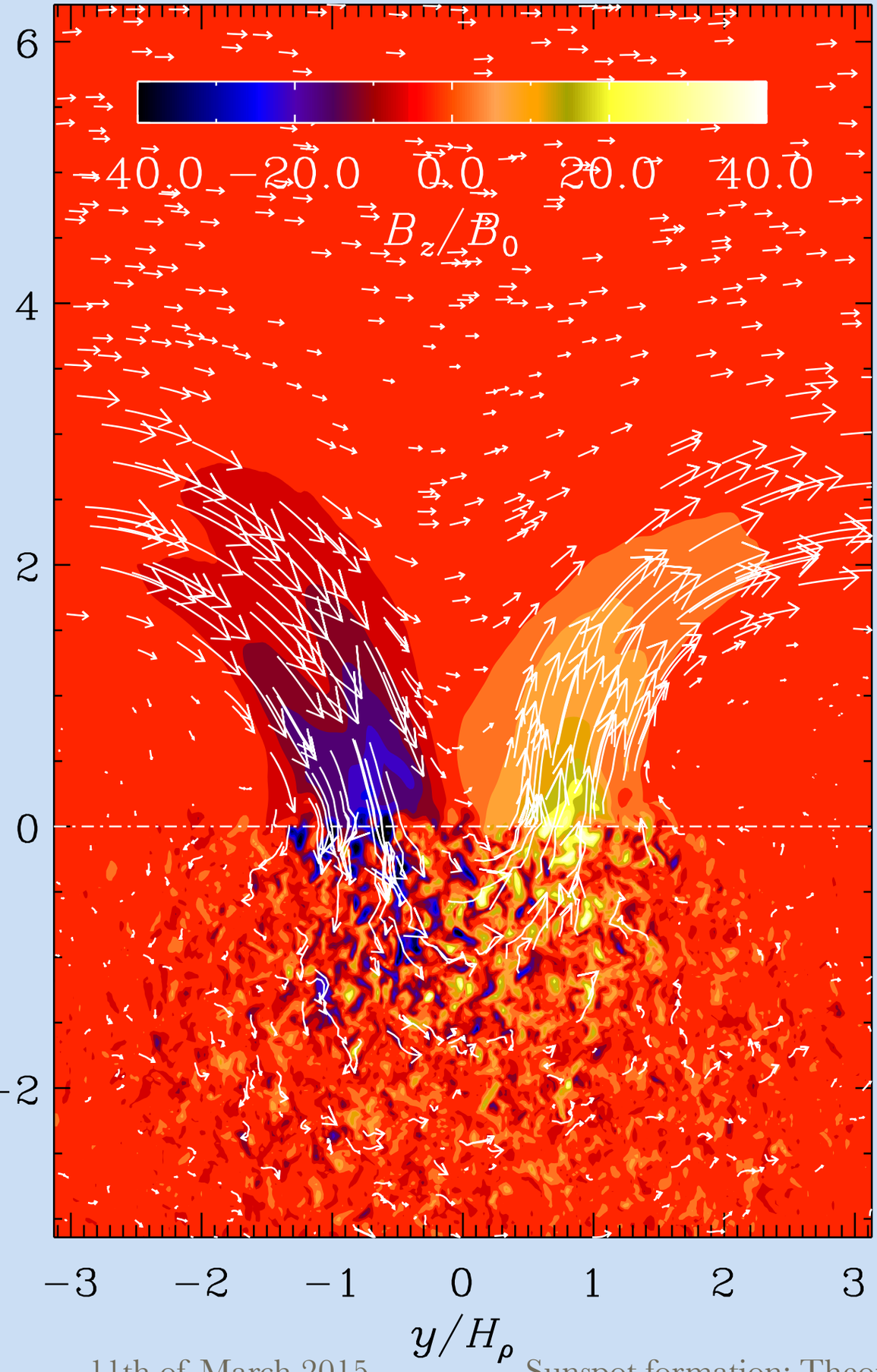
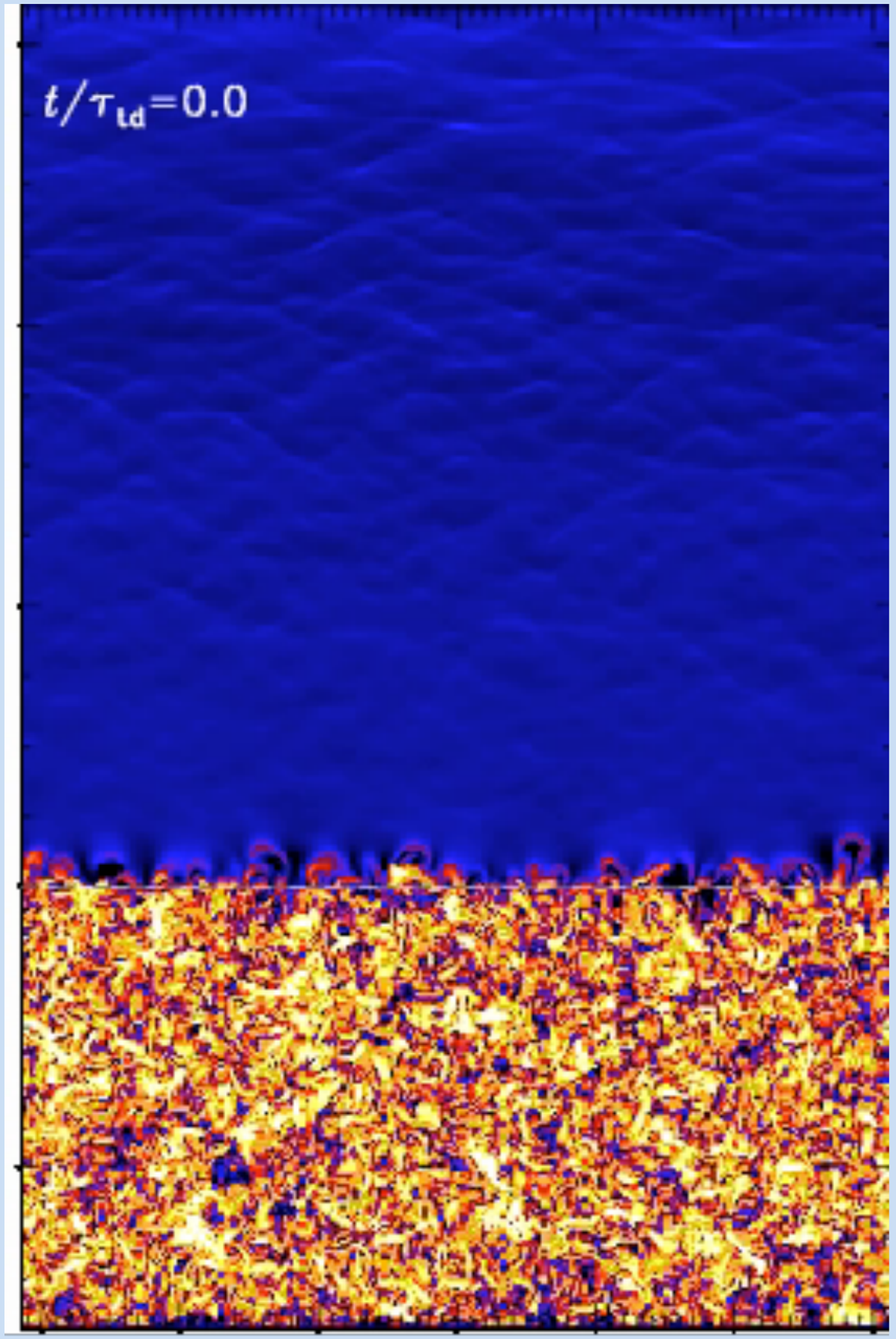
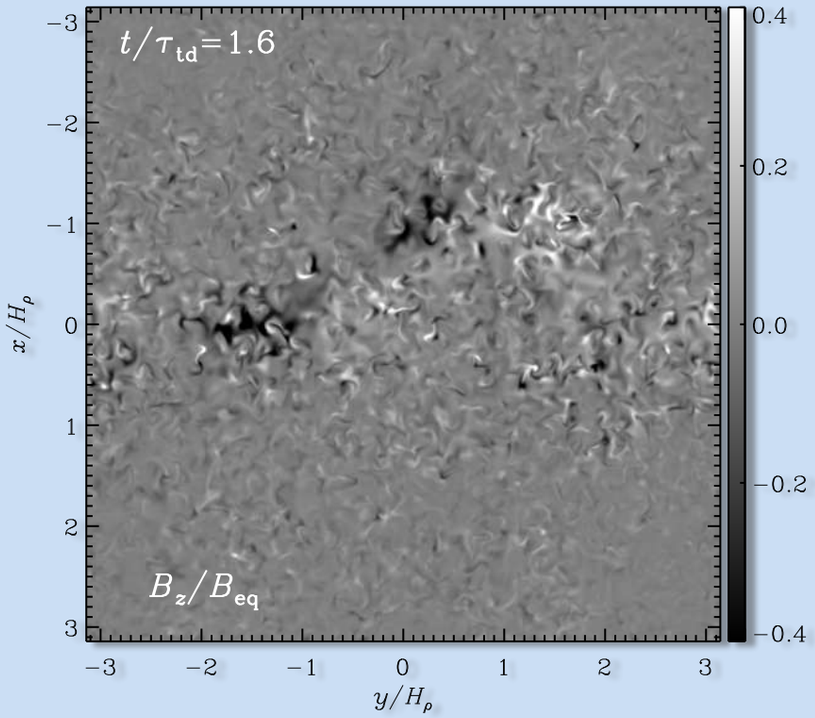
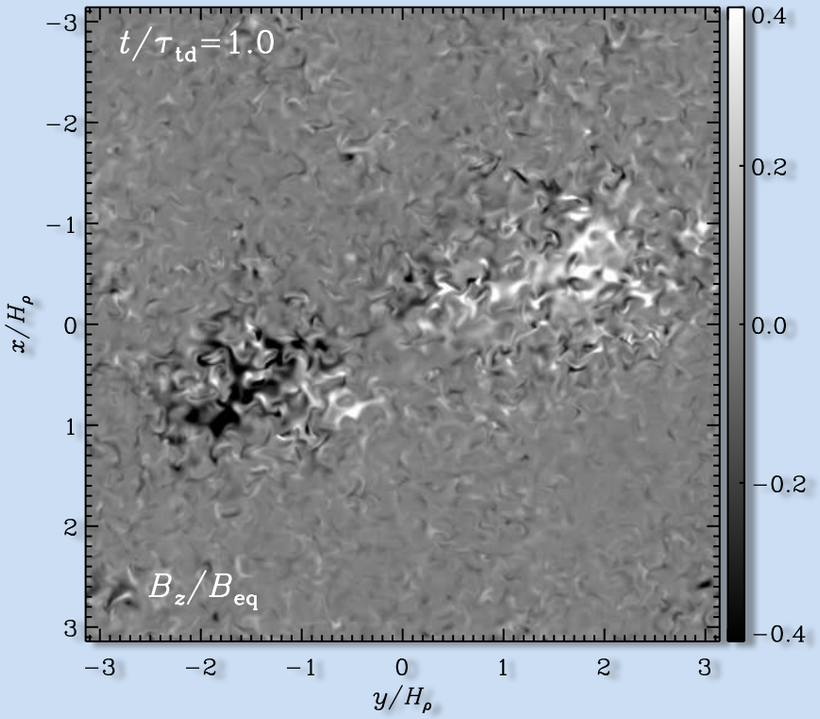
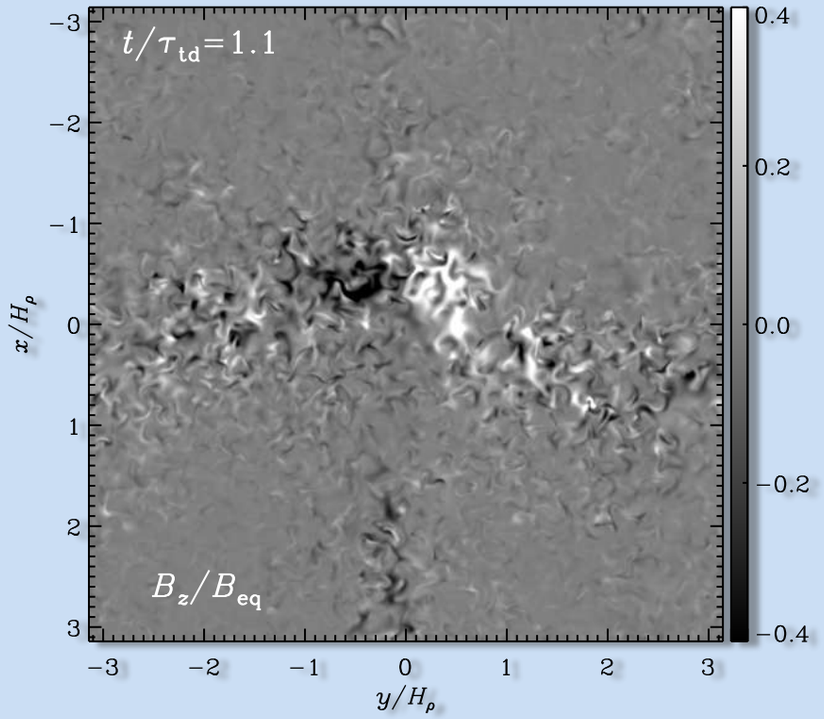




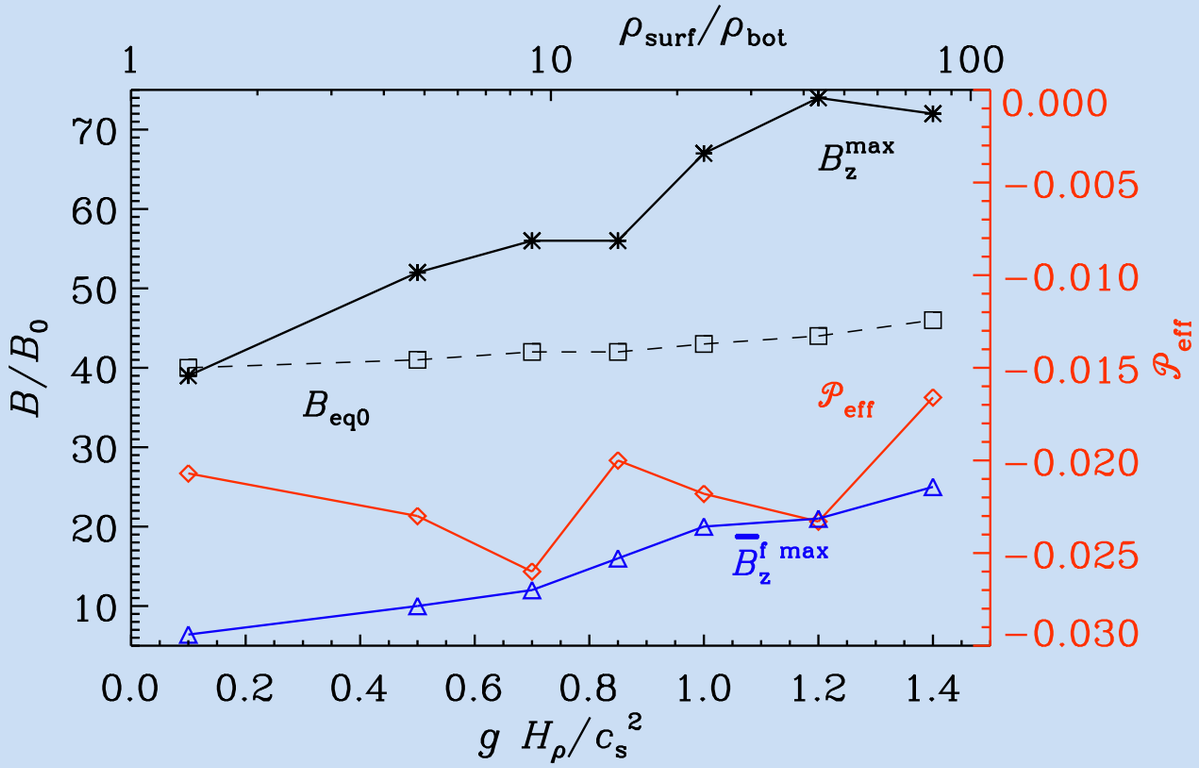
Stratification

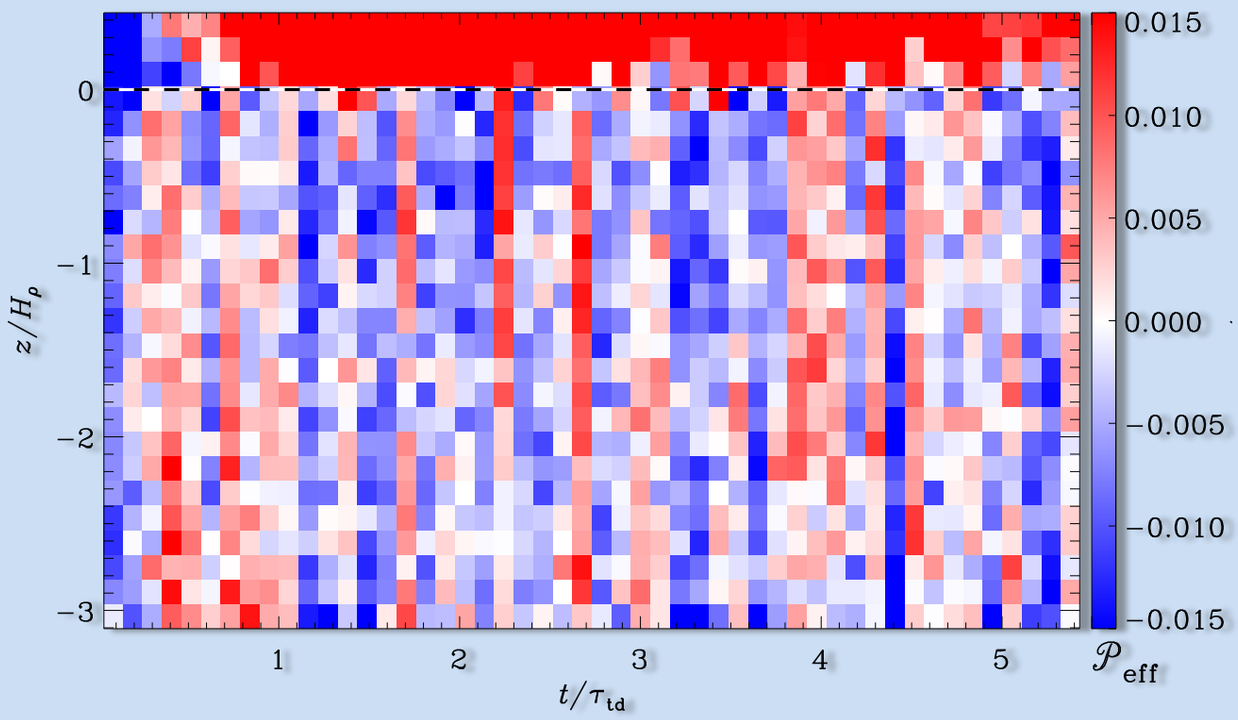




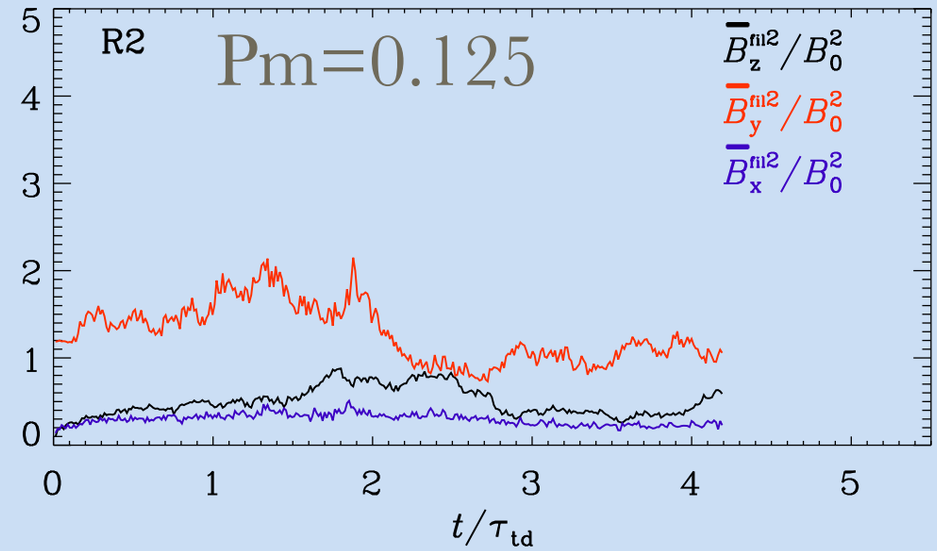


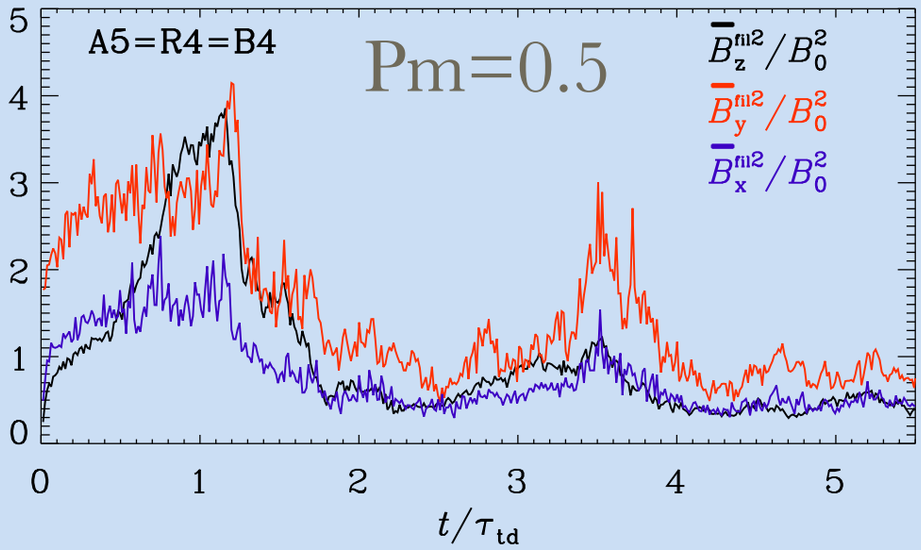
density contrast

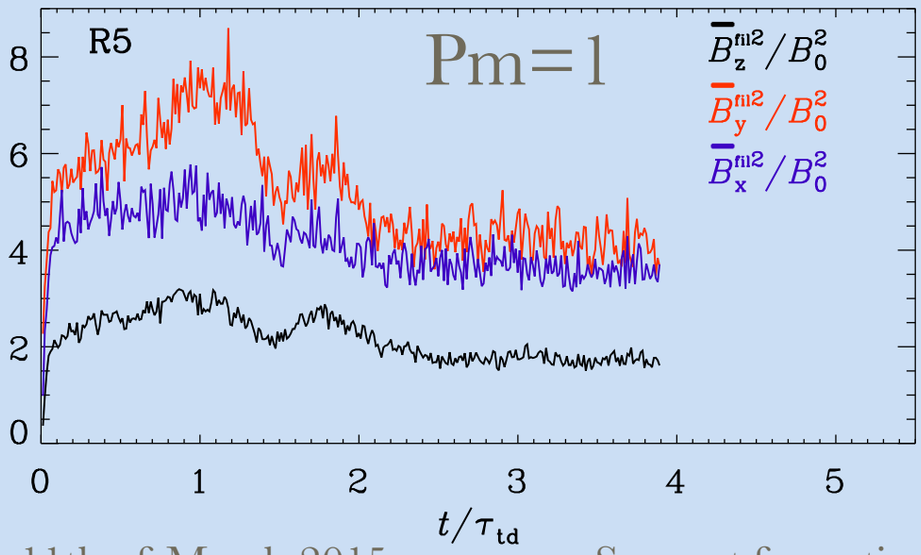




magnetic Prandtl number







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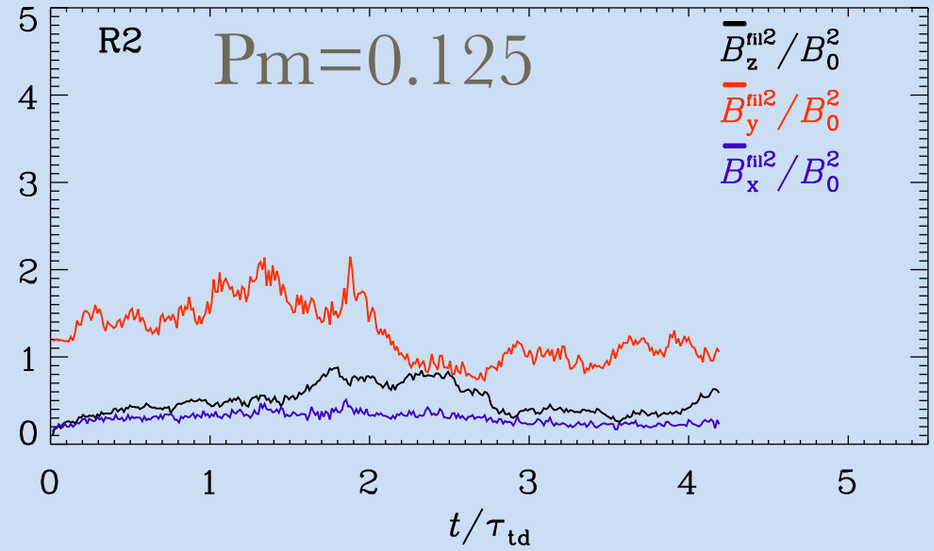
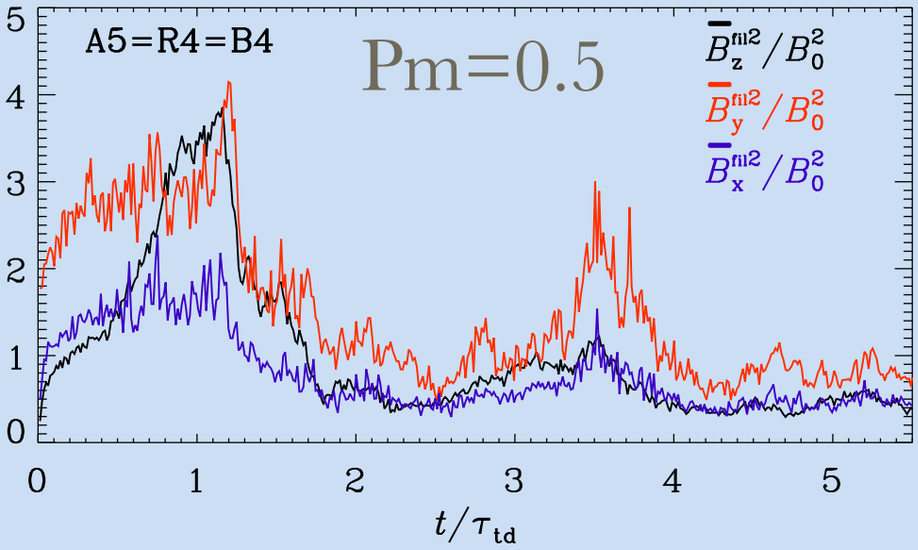
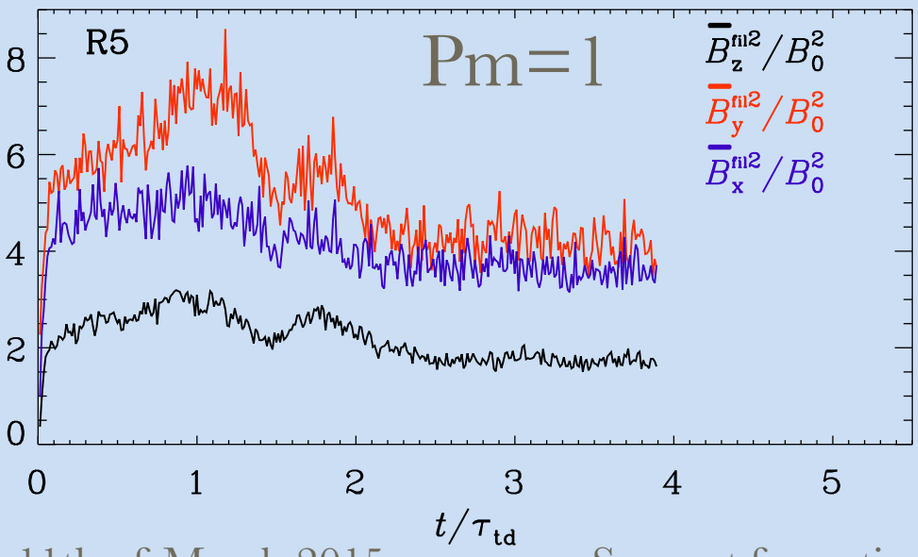
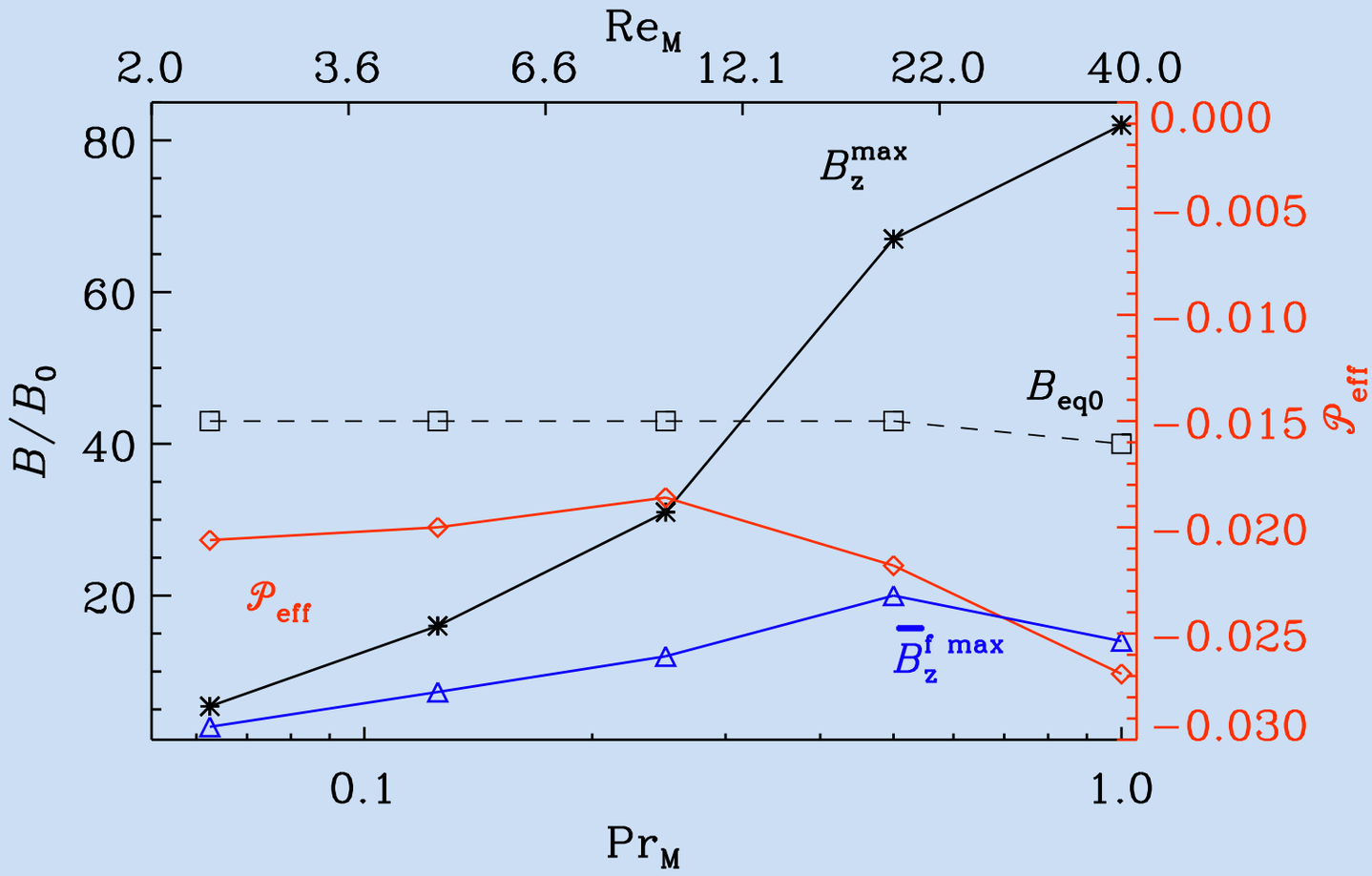
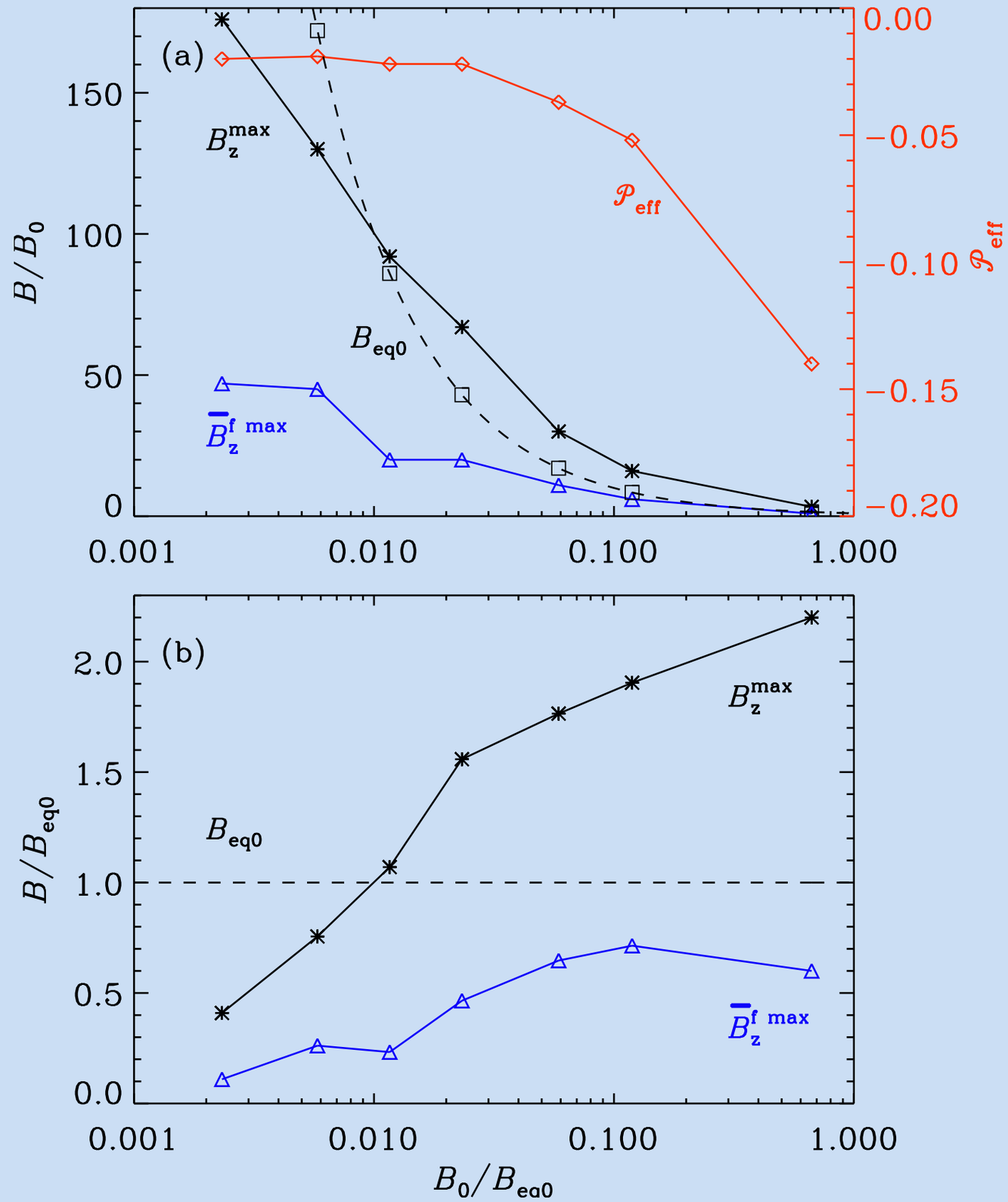




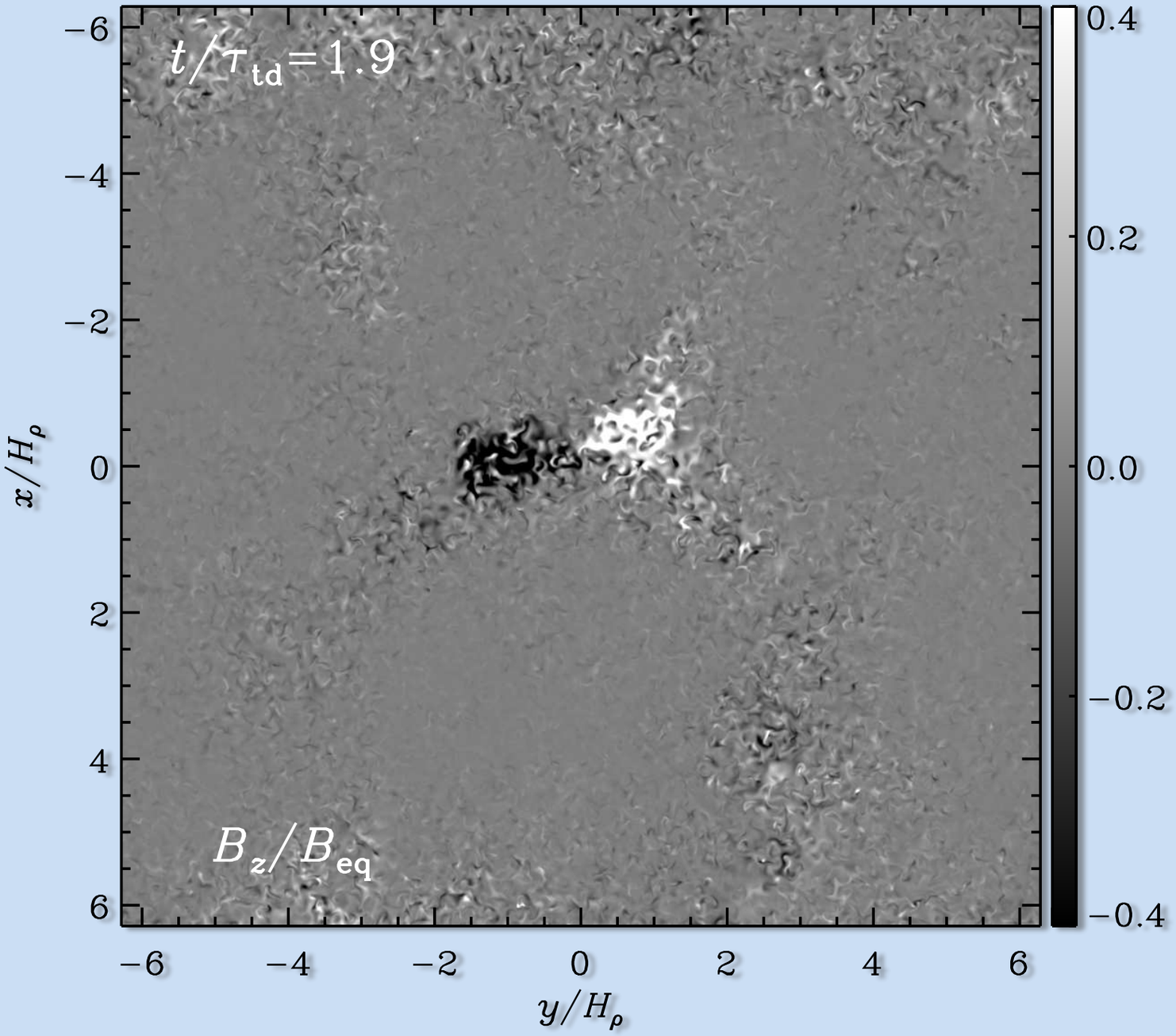




Imposed magnetic field



Horizontal extent



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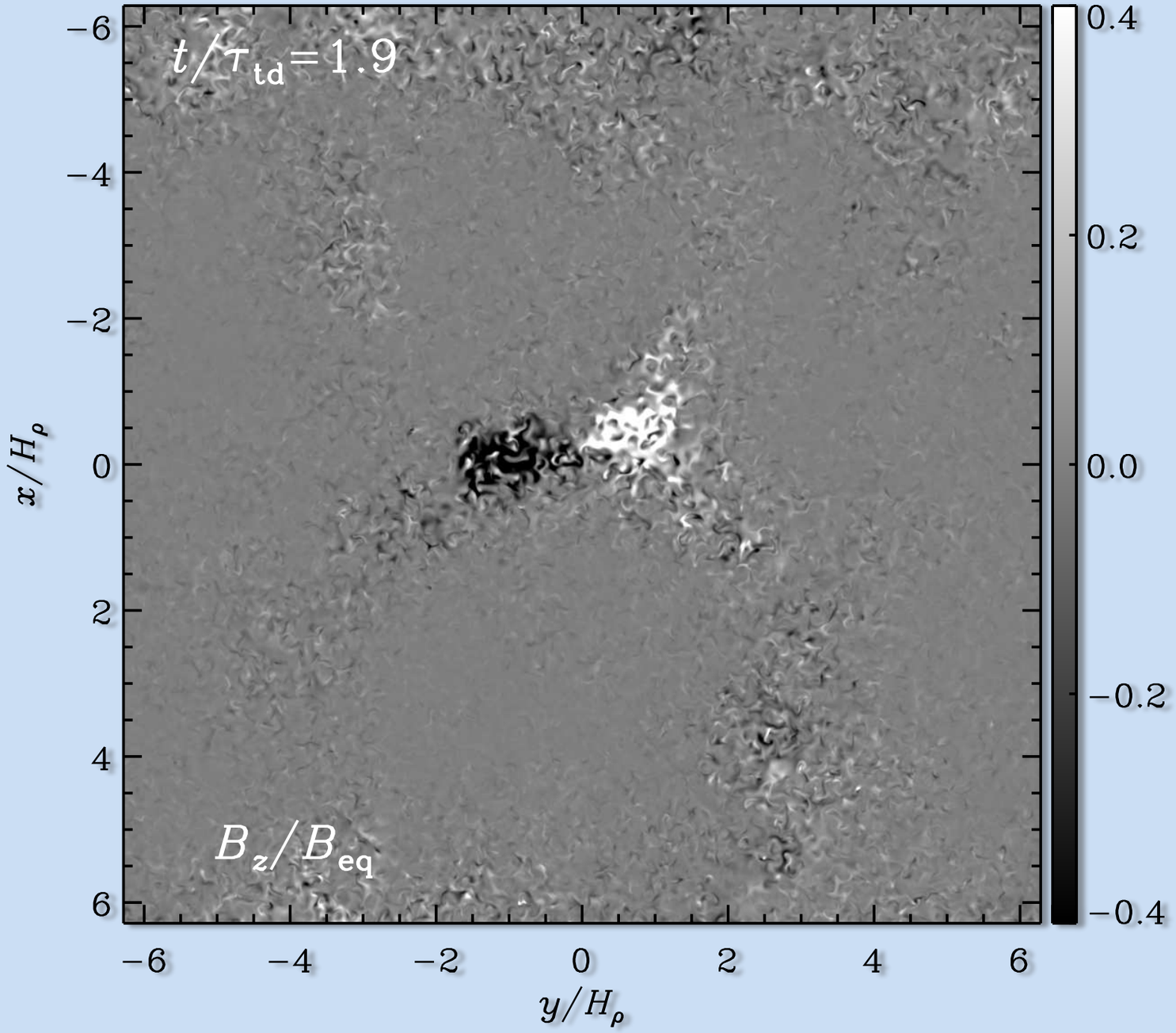
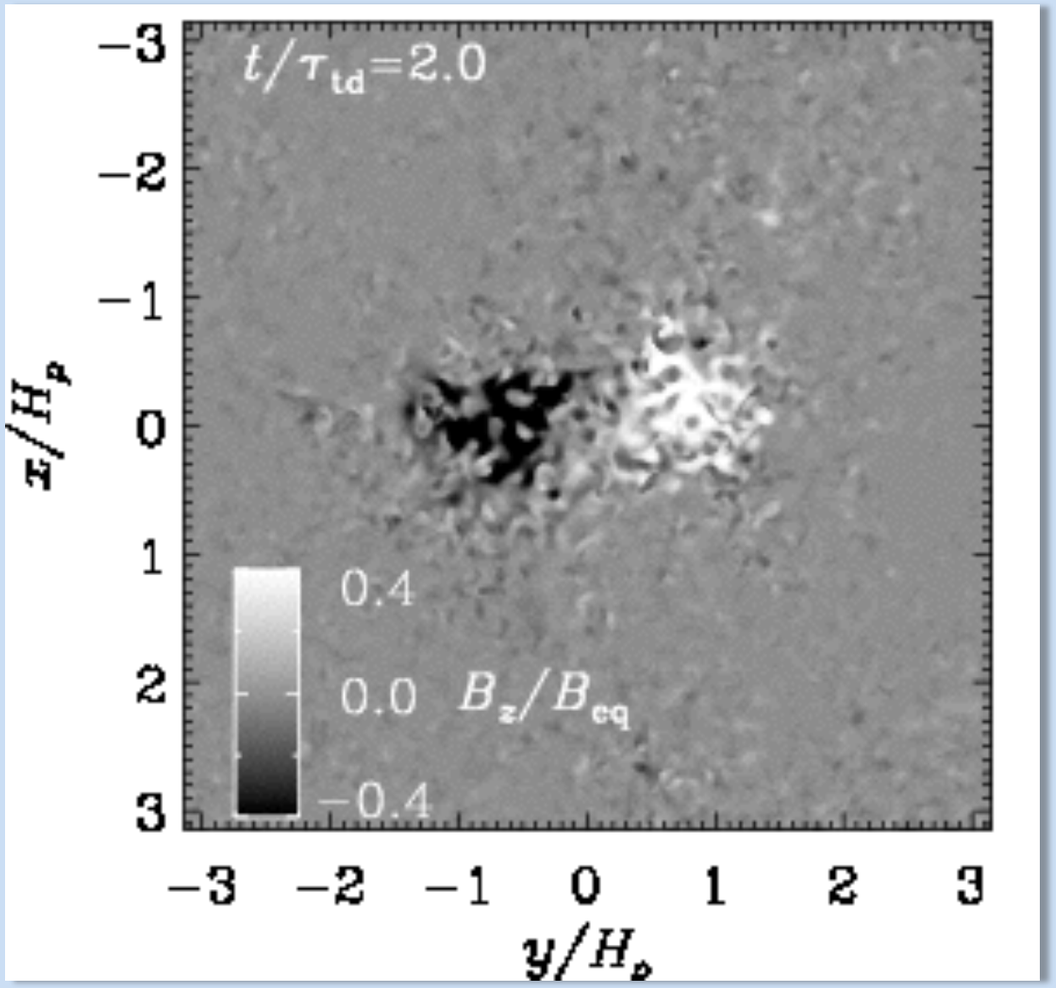
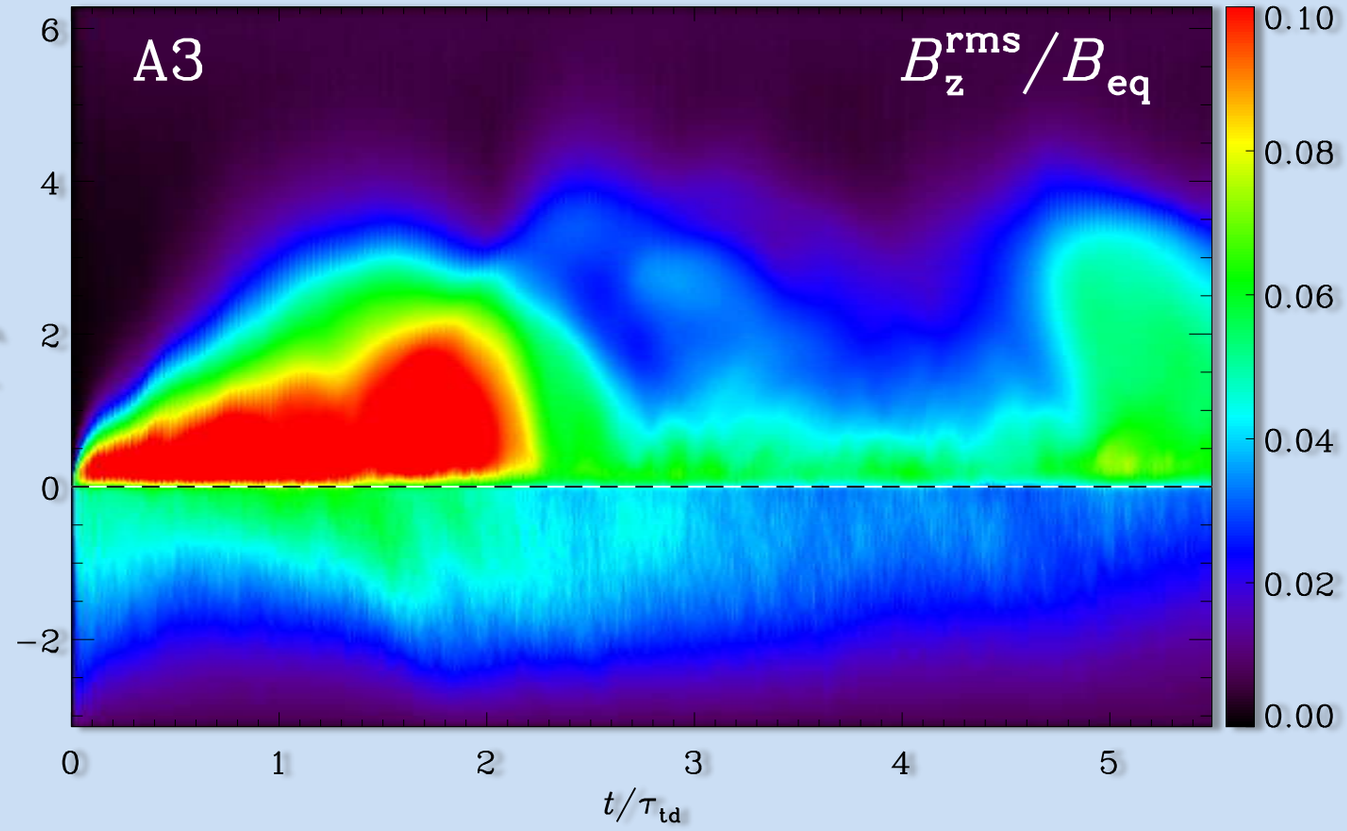
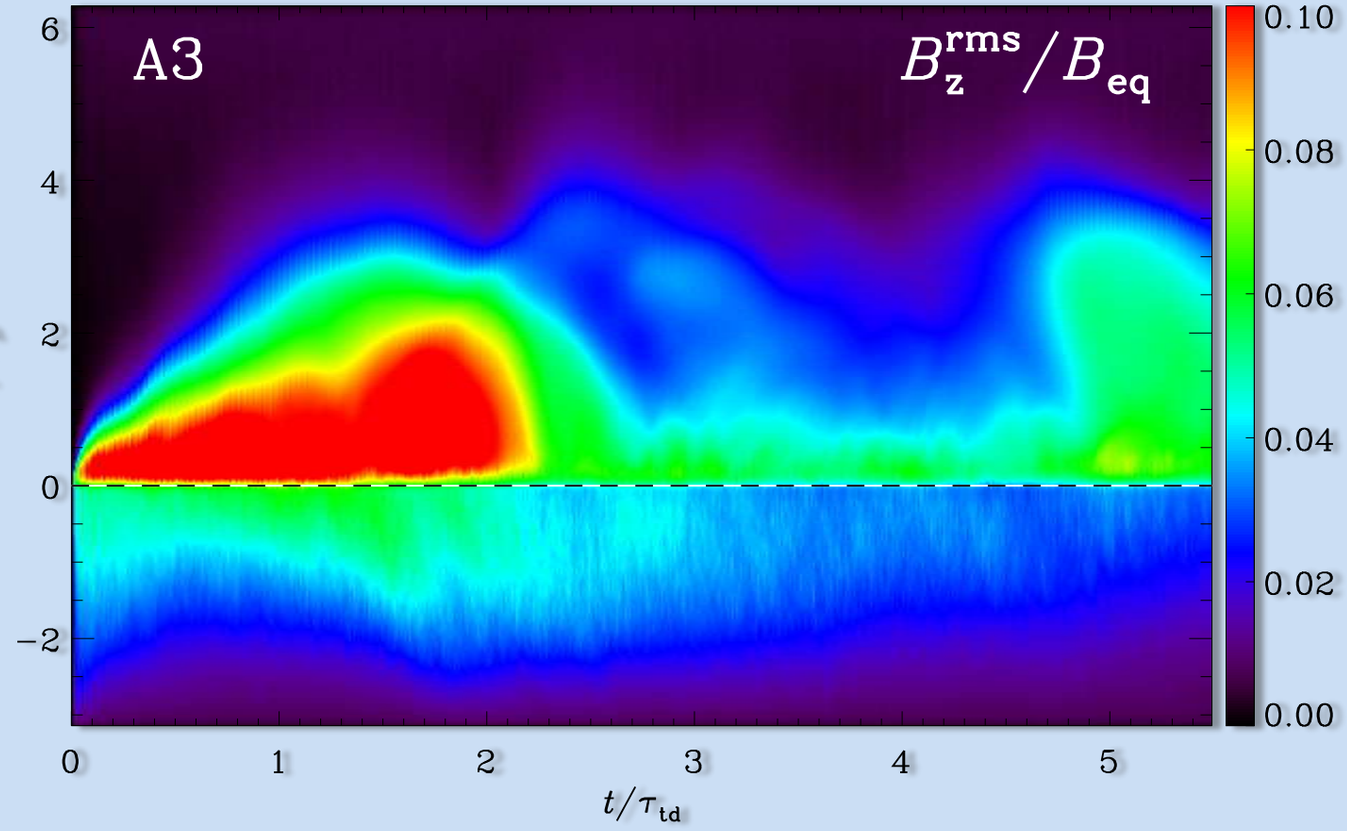


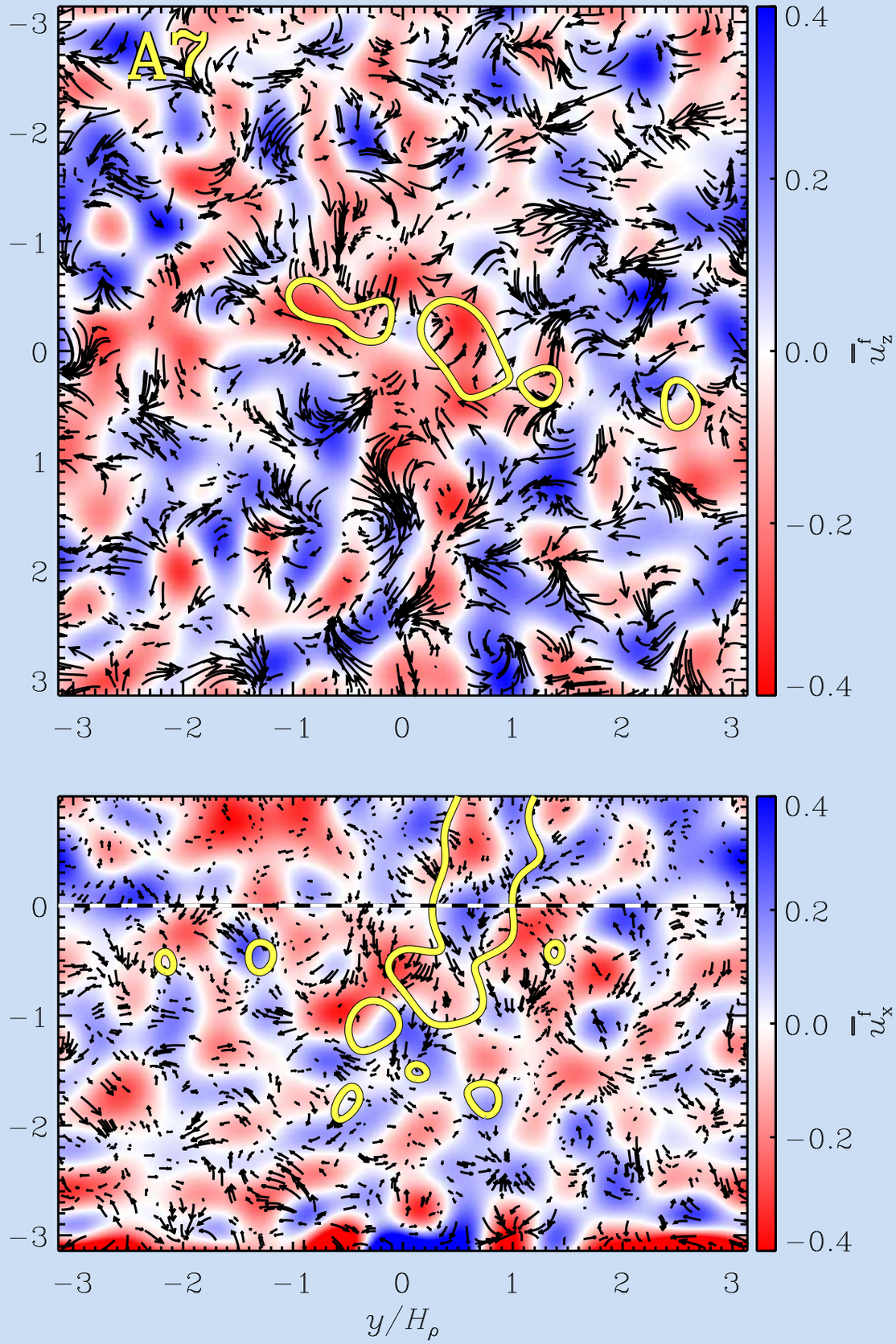




Emergence from the lower layer to the surface

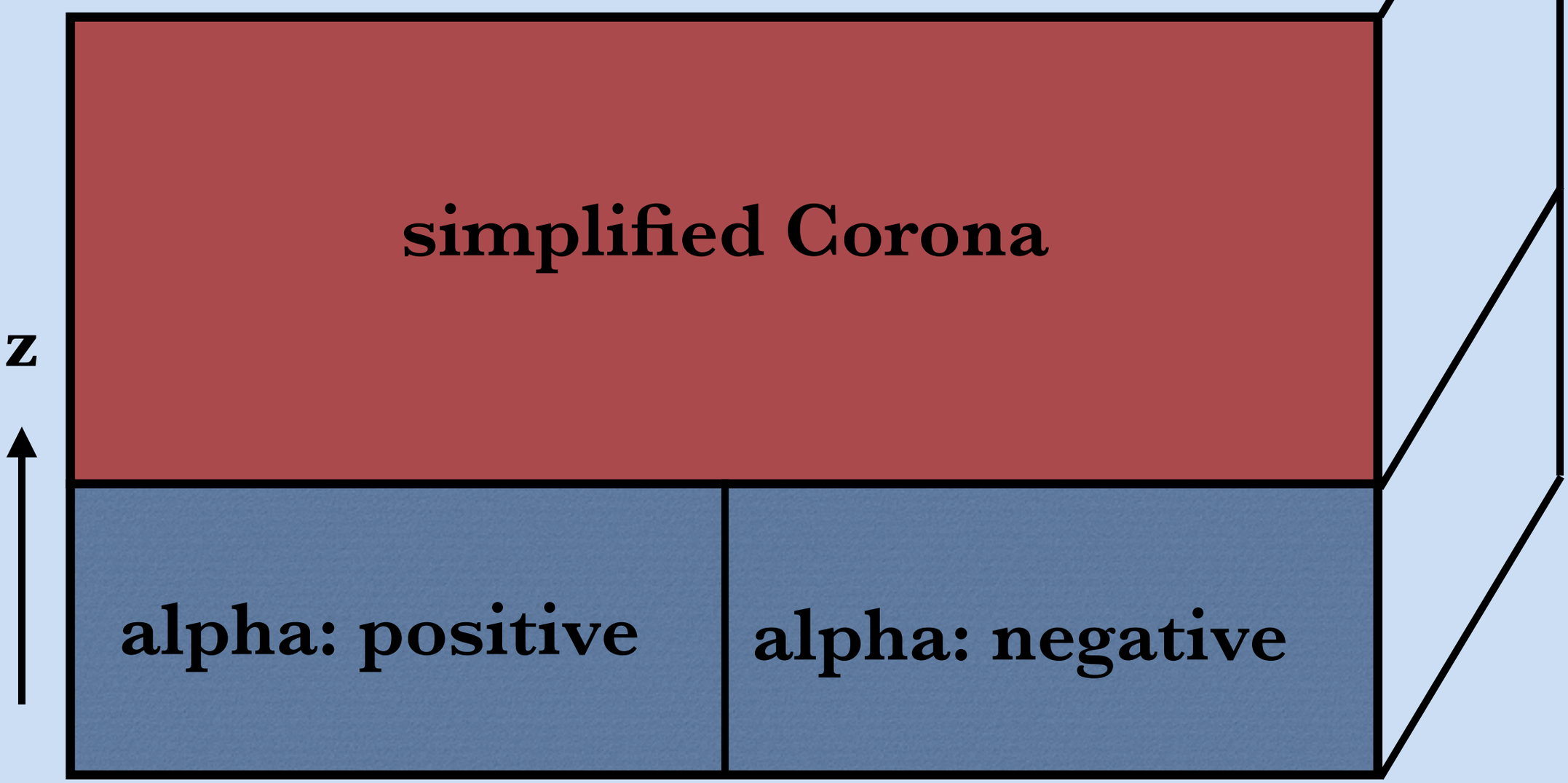
Relation to down flows





Emergence from the lower layer to the surface

Dynamo plus NEMPI



helical forcing => large-scale dynamo

$t/\tau_{\rm td}$
$=0.0$

y/H_ρ

6
4
2
0
−2
−4
−6

−3 −2 −1 0 1 2 3

x/H_ρ

1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5

$t/\tau_{\rm td}$
$=0.0$

y/H_ρ

6
4
2
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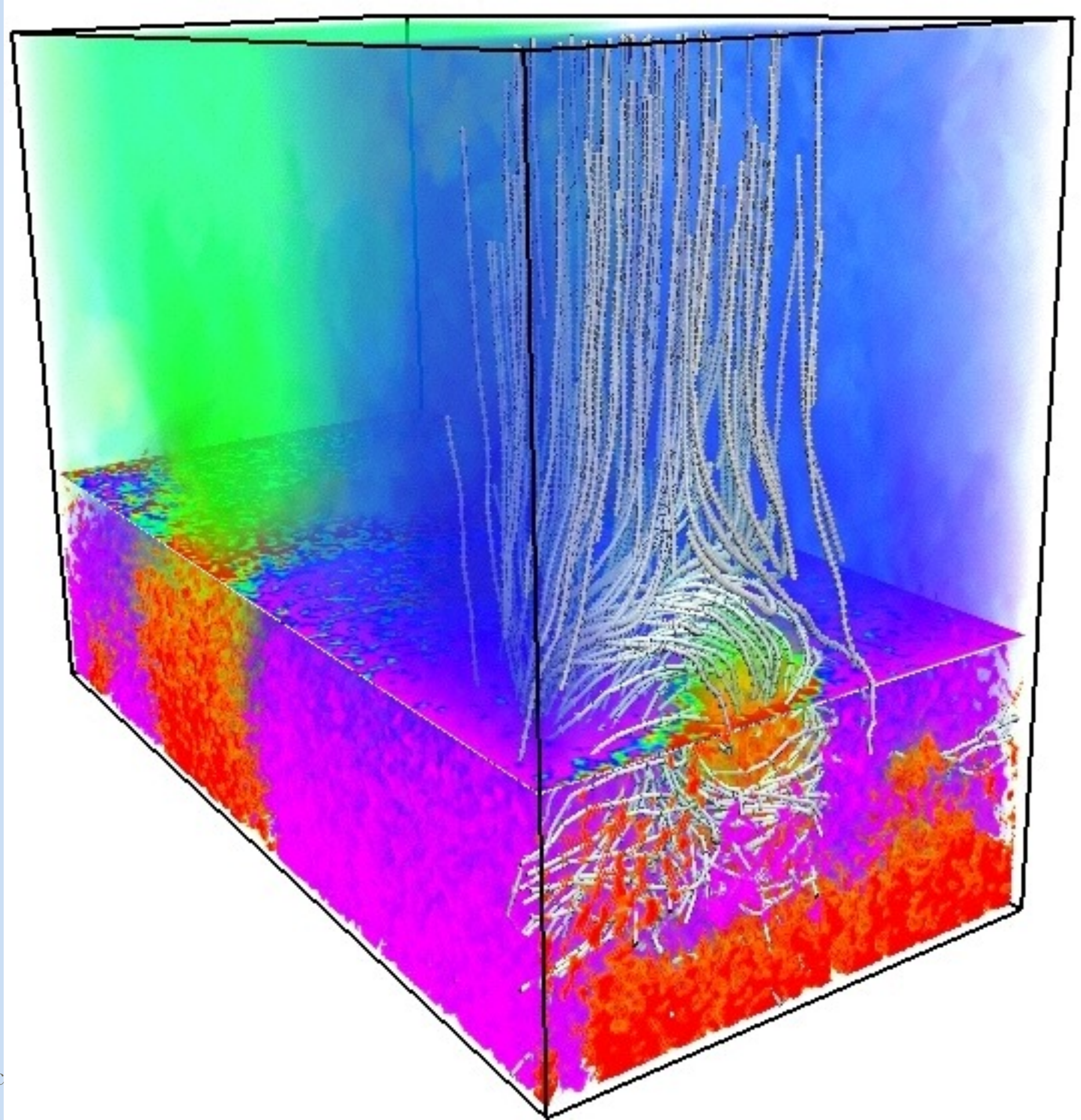

Conclusions

- Generation and decay of bipolar region.
- Super equipartition field strengths.
- NEMPI is most likely responsible.
- Density stratification important.
- Magnetic Prandtl number 0.25-0.5.
- Imposed field should be not too small, and not too large
- Larger horizontal domain helps, same size of poles
- Vertical field rise from lower domain to the surface.
- Correlation with down flows.
- Dynamo generated bipolar regions.