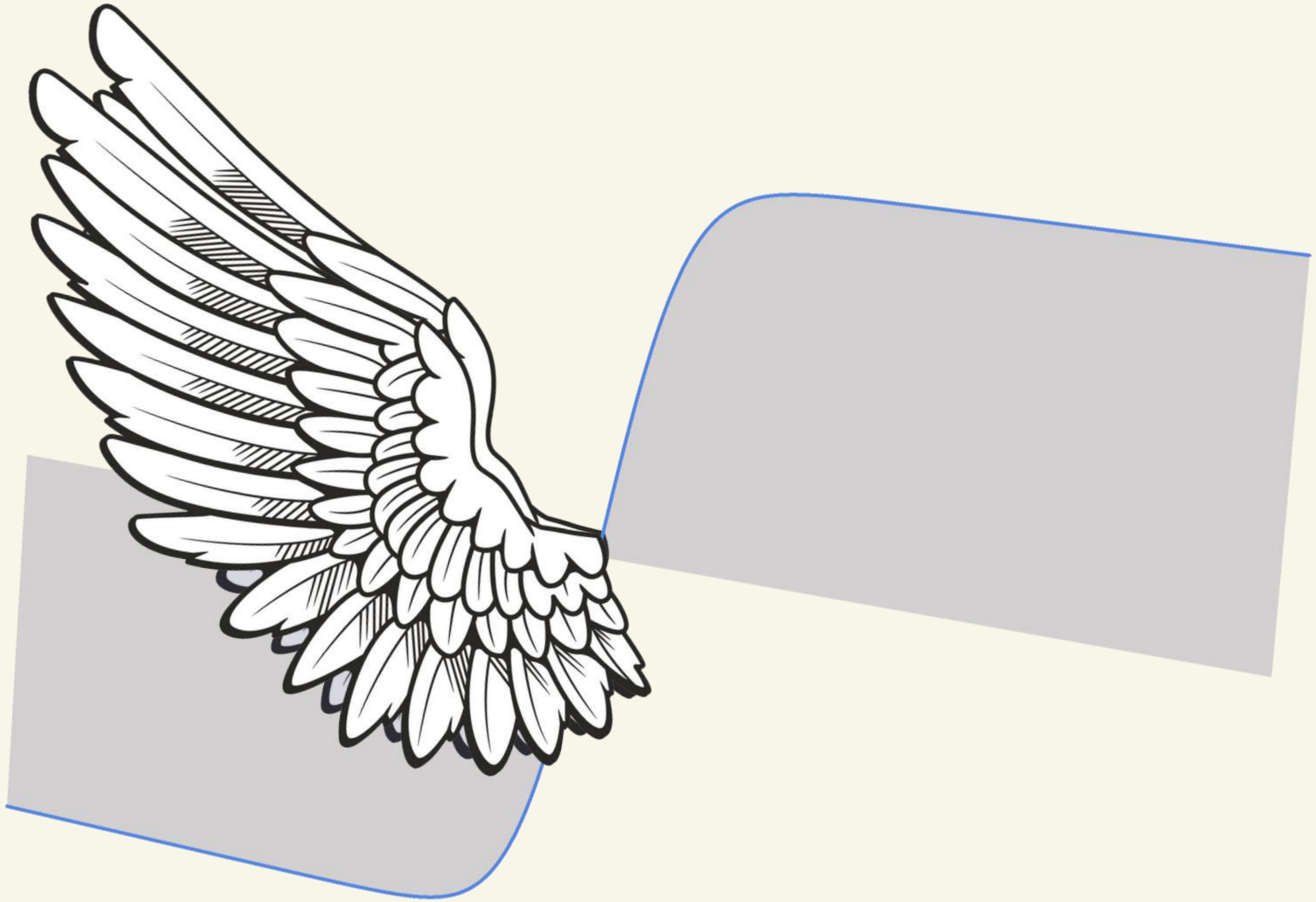
Flying Domain Walls in Driven Magnets

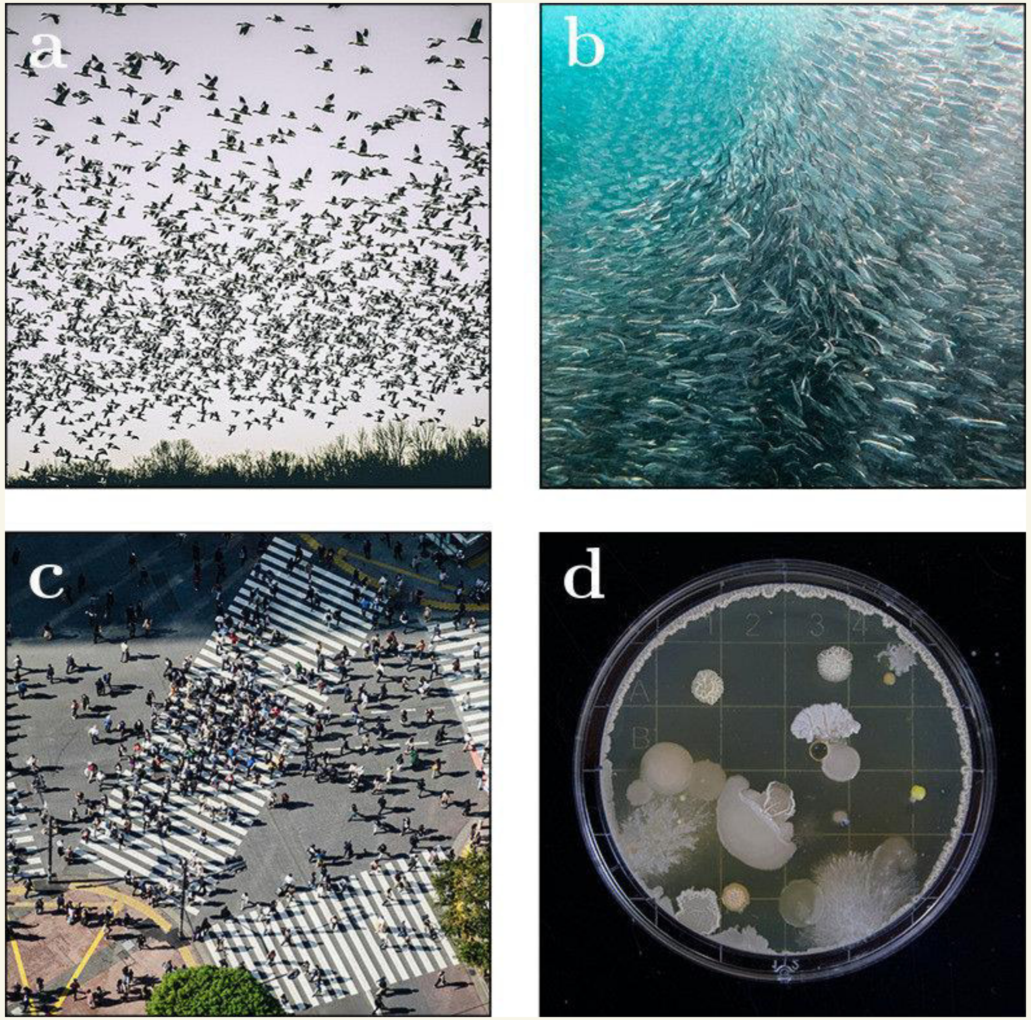
Active

Dennis Hardt & Achim Rosch



7/27/2023

Active Matter



Schmidt, Falko. (2020).

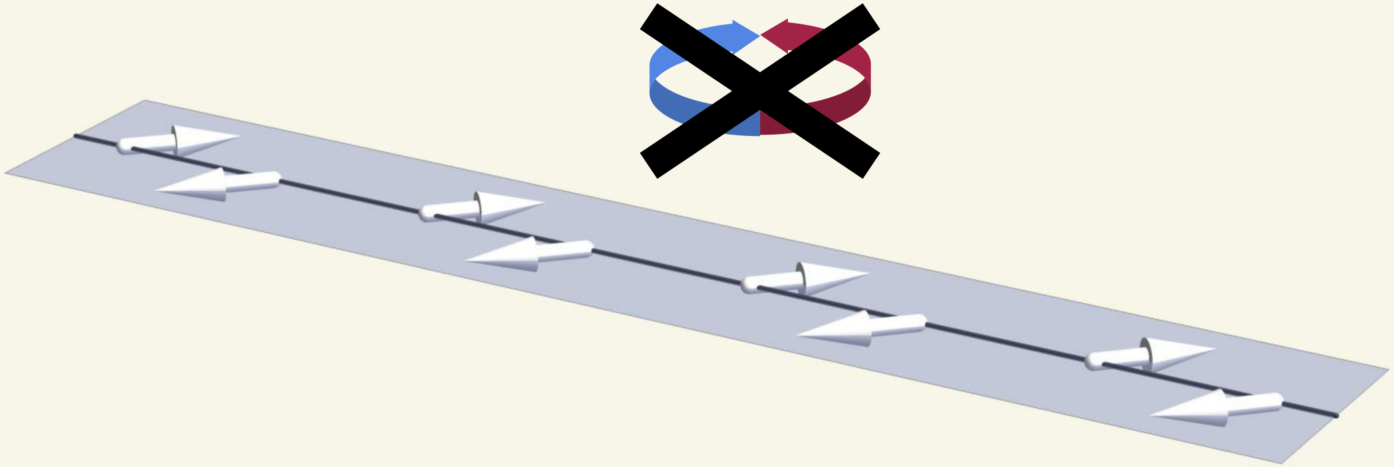
emergent collective behaviour

Can we find similar in magnets?

XY-Model: Starting Point

XY-antiferromagnet $H_0 = J\sum_j \left(S_j^x S_{j+1}^x + S_j^y S_{j+1}^y\right)$

weak driving field in z direction



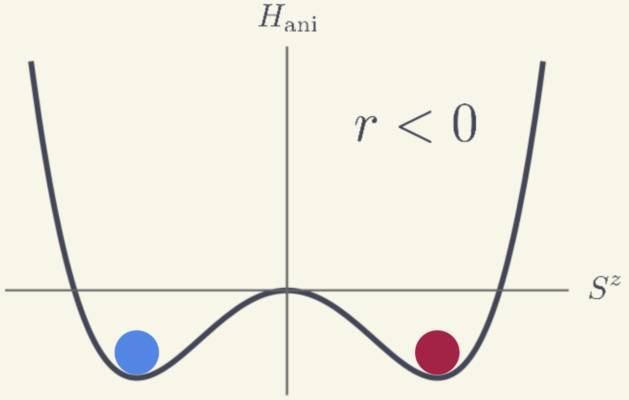
oscillations but…
no net rotation activated!

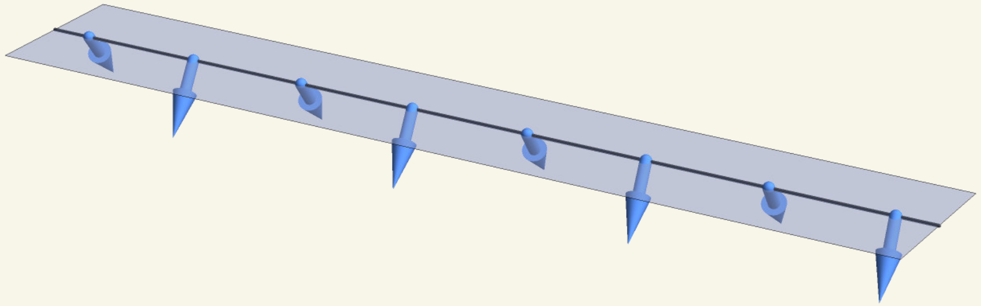
Ferrimagnet

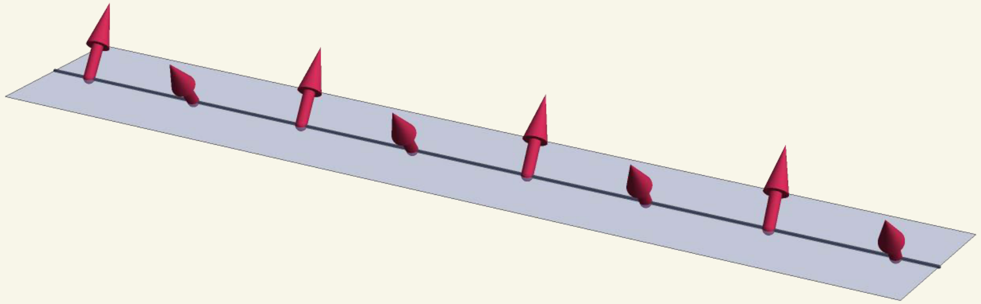
$$H_0 = J \sum_j \left(S_j^x S_{j+1}^x + S_j^y S_{j+1}^y - S_j^z S_{j+1}^z \right)$$

anisotropy

$$H_{\text{ani}} = \frac{r}{2} \sum_j (S_j^z)^2 + \frac{1}{4} \sum_j (S_j^z)^4$$





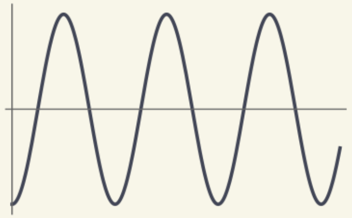


Driven Magnets: Illustrative Case

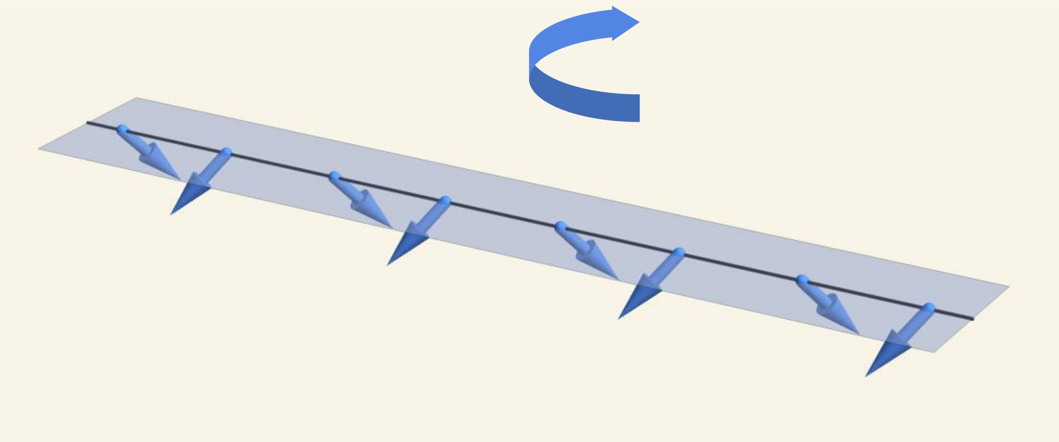
$$H_0 = J \sum_j \left(S_j^x S_{j+1}^x + S_j^y S_{j+1}^y - S_j^z S_{j+1}^z \right)$$

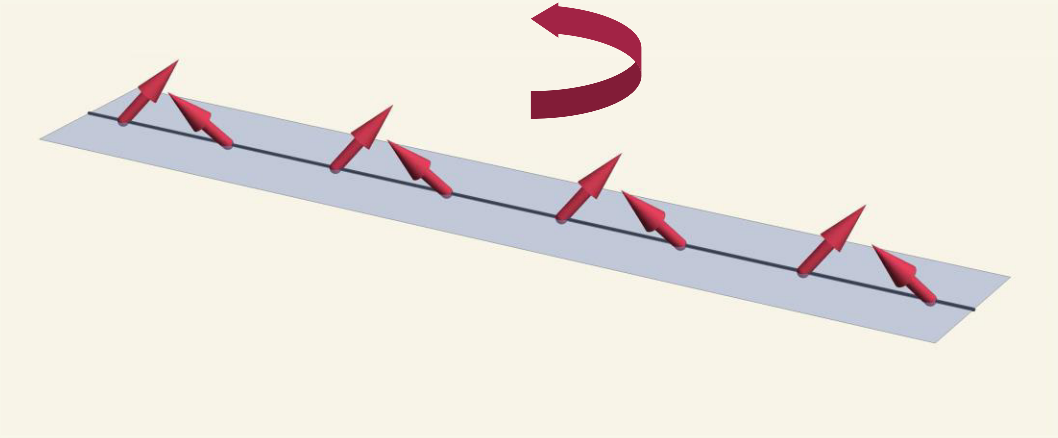
$$H_{\text{ani}} = \frac{r}{2} \sum_j (S_j^z)^2 + \frac{1}{4} \sum_j (S_j^z)^4$$

$$H_{\text{drive}} = -B_0 \cos(\Omega_d t) \sum_j g_j S_j^z$$



staggered $g_j = \begin{cases} g_e, & \text{even } j \\ g_o, & \text{odd } j \end{cases}$





pumped Goldstone mode $\langle \phi_{e/o}(t) \rangle = \alpha S^z t$

2. order in driving field

$$\alpha \propto (g_o^2 - g_e^2) B_0^2$$

Activated Goldstone Modes

$SO(3)$

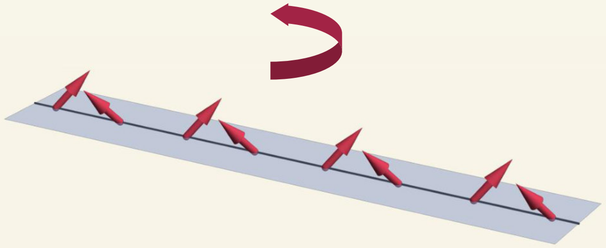
rotations in space

anisotropy

continuous symmetry broken

$U(1)$ $\mathbb{Z}_2$

rotations in xy-plane – reflection along z



Coarse Grained Model

driving

$$\lambda \partial_t \phi = \lambda \alpha m_z + \nabla^2 \phi - \dot{m}_z + \eta_\phi$$

damping

diffusion

couplings

white noise

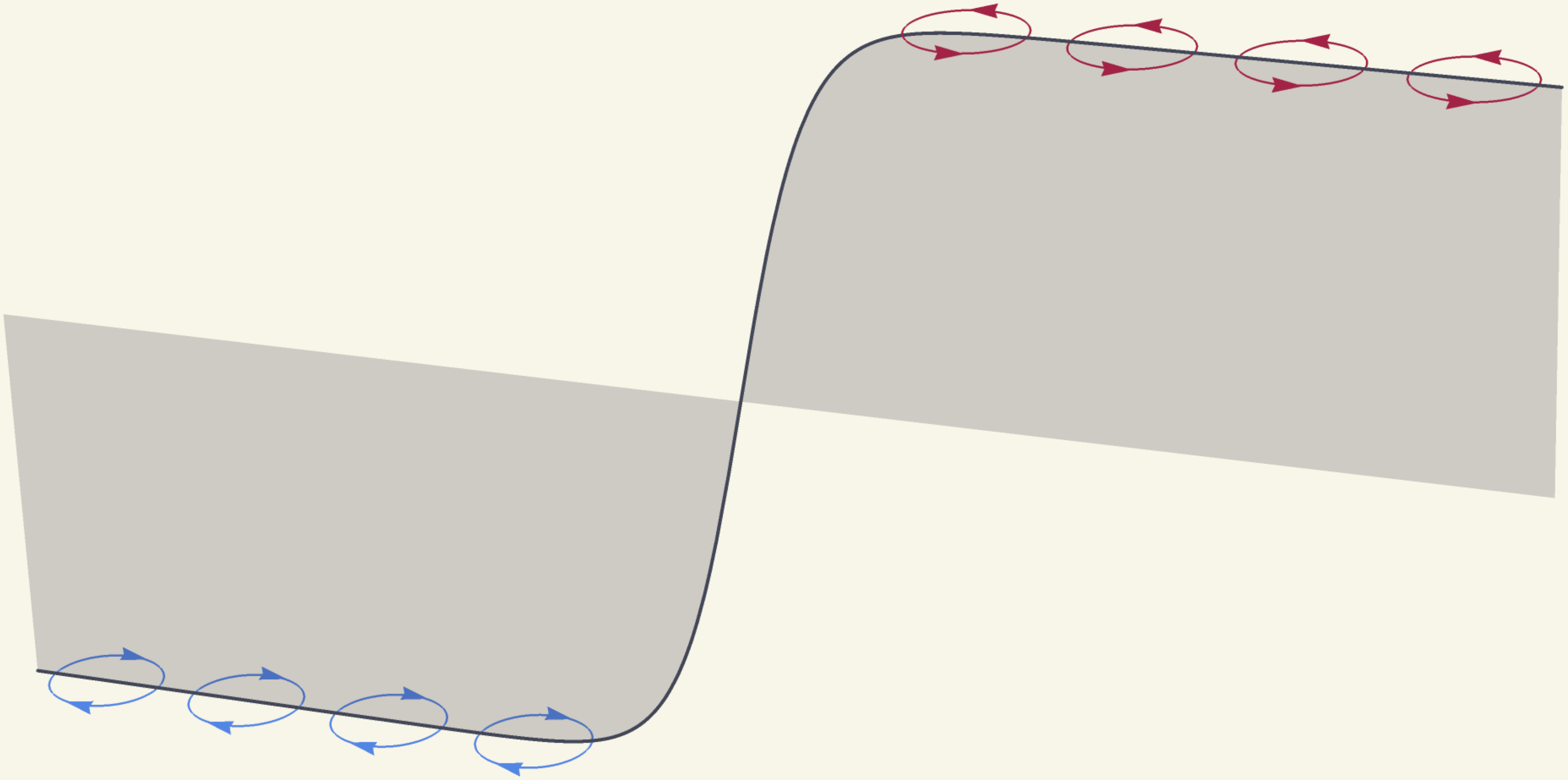
$$\lambda \partial_t m_z = -r m_z - m_z^3 + \nabla^2 m_z + \dot{\phi} + \eta_{m_z}$$

anisotropy

$$\boldsymbol{S}_i = \begin{pmatrix} \sqrt{1 - m_z^2}\,\cos(\phi) \\ \sqrt{1 - m_z^2}\,\sin(\phi) \\ m_z \end{pmatrix}$$

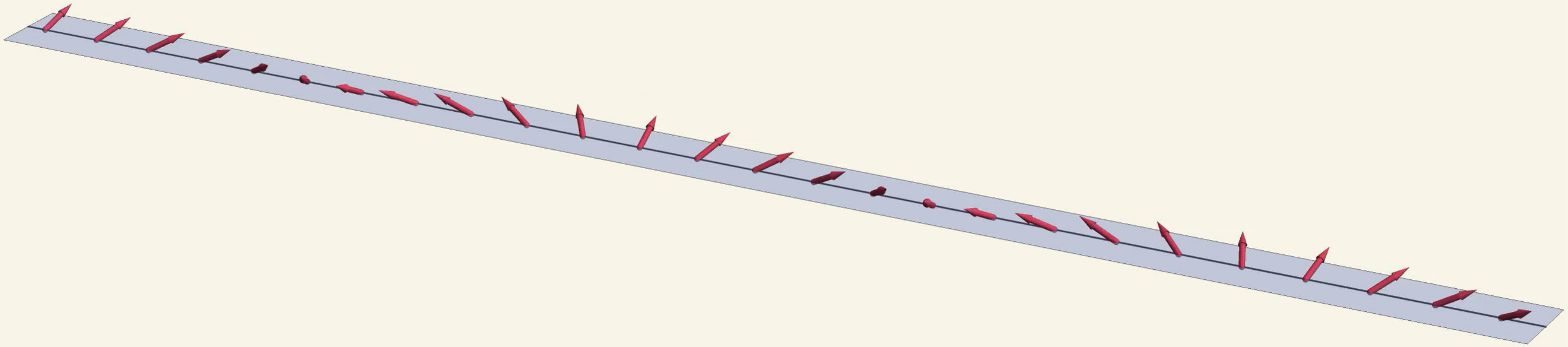
long wavelength limit

What is the Fate of Domain Walls?

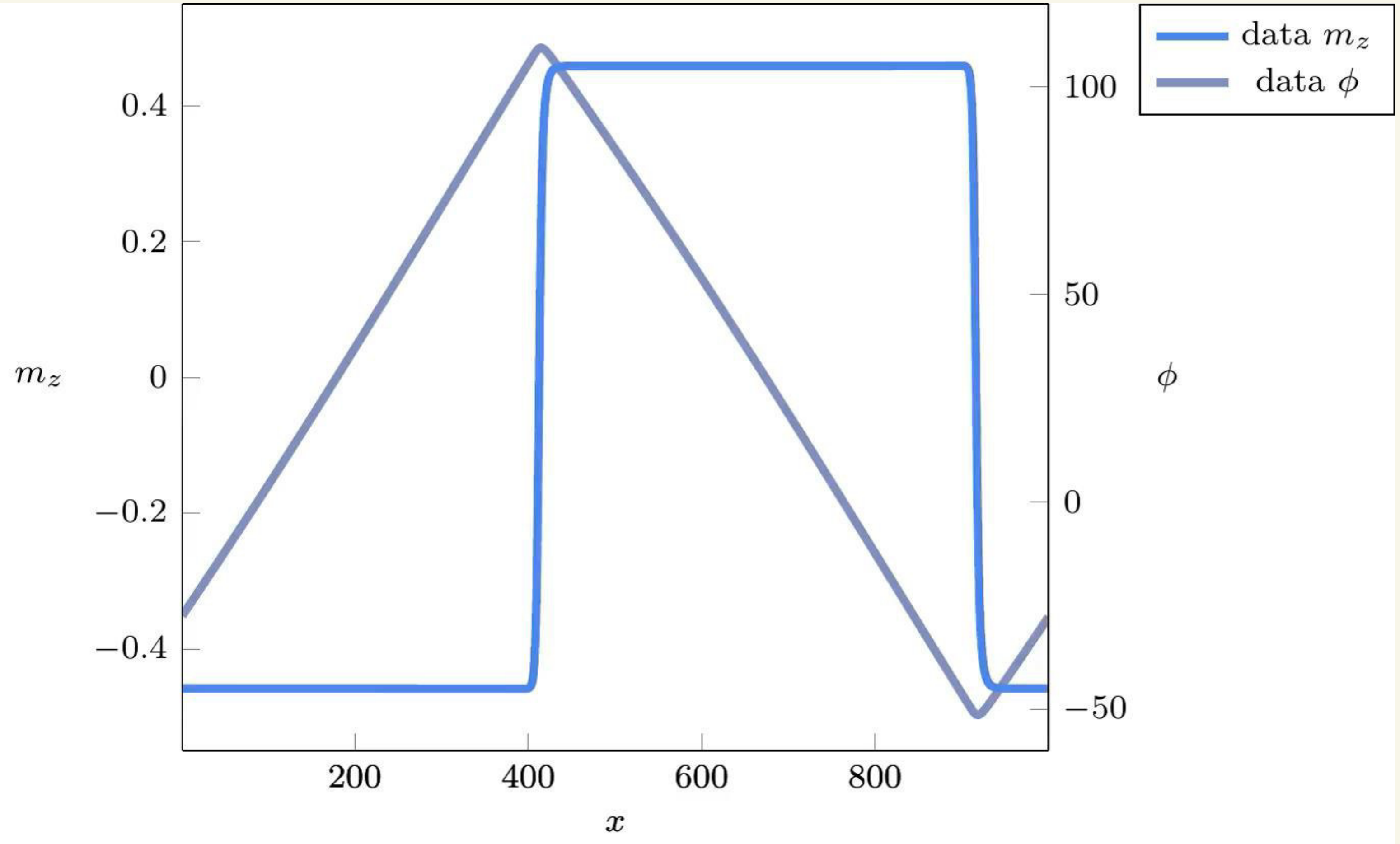


Are they active?

Domain Walls Fly Through the System



Domain Walls Shape



moving solution:

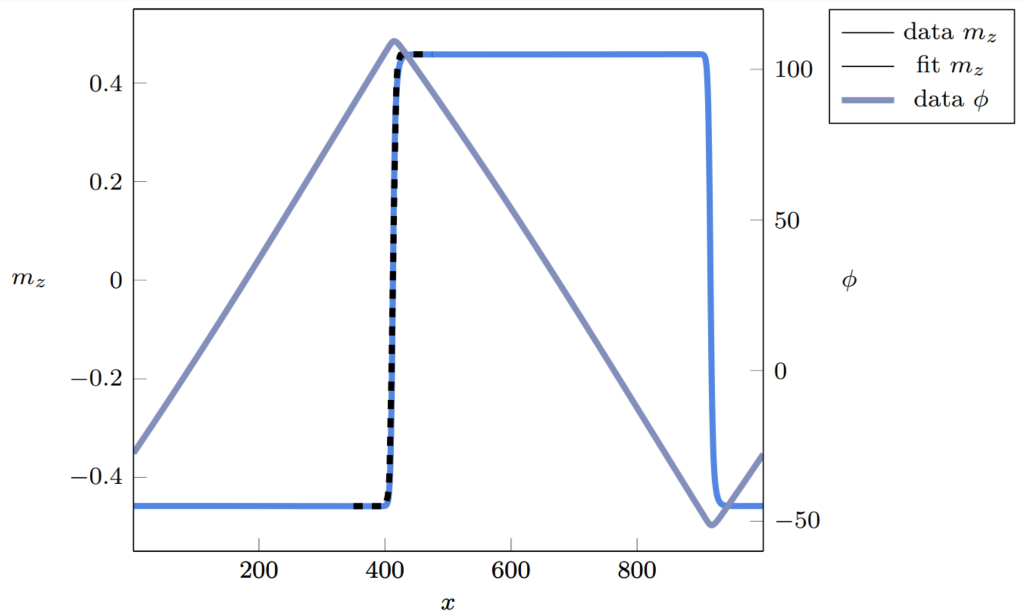
$$\phi(x,t) \to \phi(x-vt)$$
$$m_z(x,t) \to m_z(x-vt)$$

Effective Domain Wall Equation

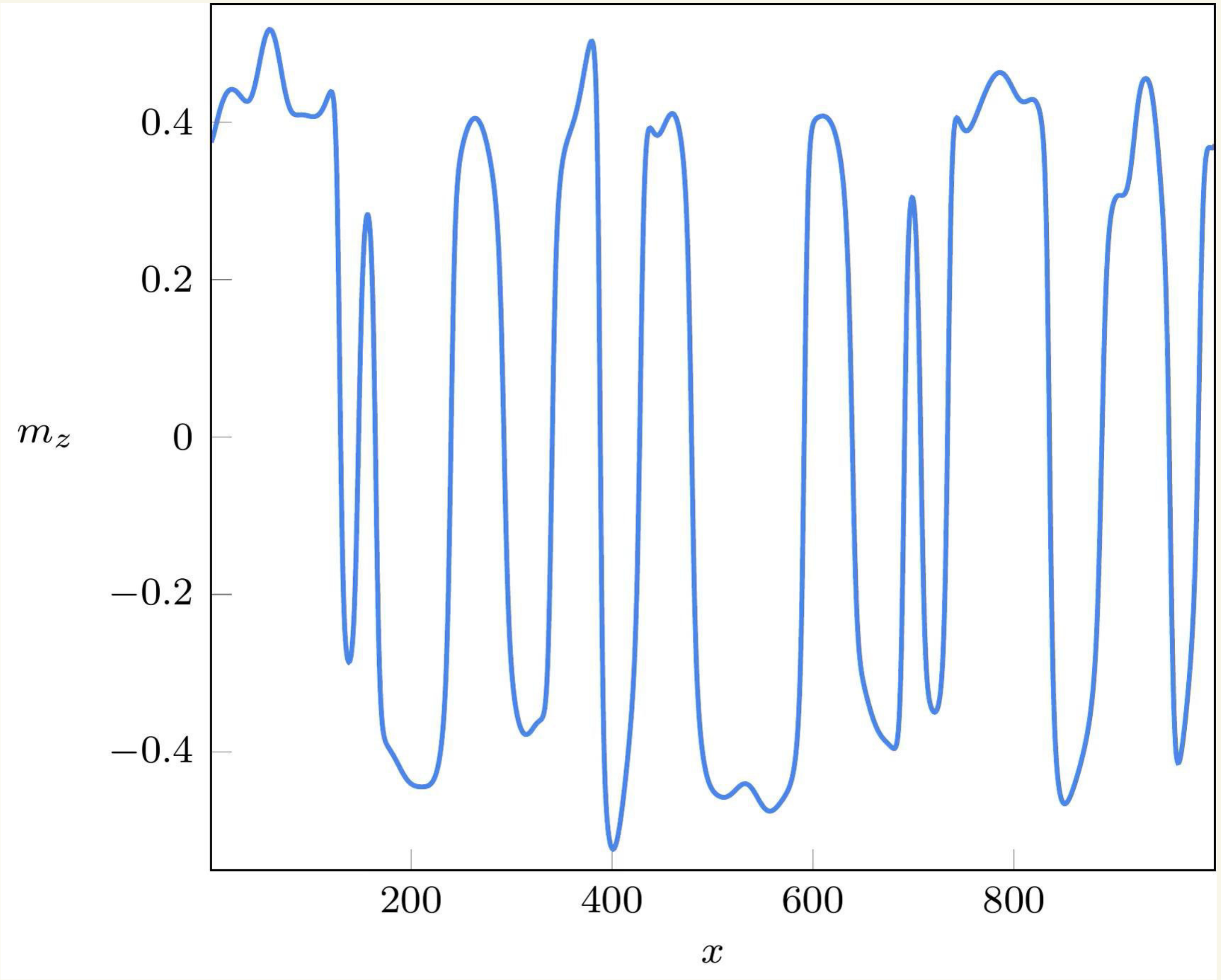
$$0 = (\alpha - r)m_z - m_z^3 + 2\nabla^2 m_z + \frac{\sqrt{1+\lambda^2}}{\sqrt{\alpha}\lambda}\nabla^3 m_z + \ldots$$

$$v = \pm\sqrt{\frac{\alpha}{1+\lambda^2}}$$

$$m_z = \sqrt{\alpha - r}\,\tanh\left(\frac{\sqrt{\alpha - r}}{2}(x - x_0)\right)$$

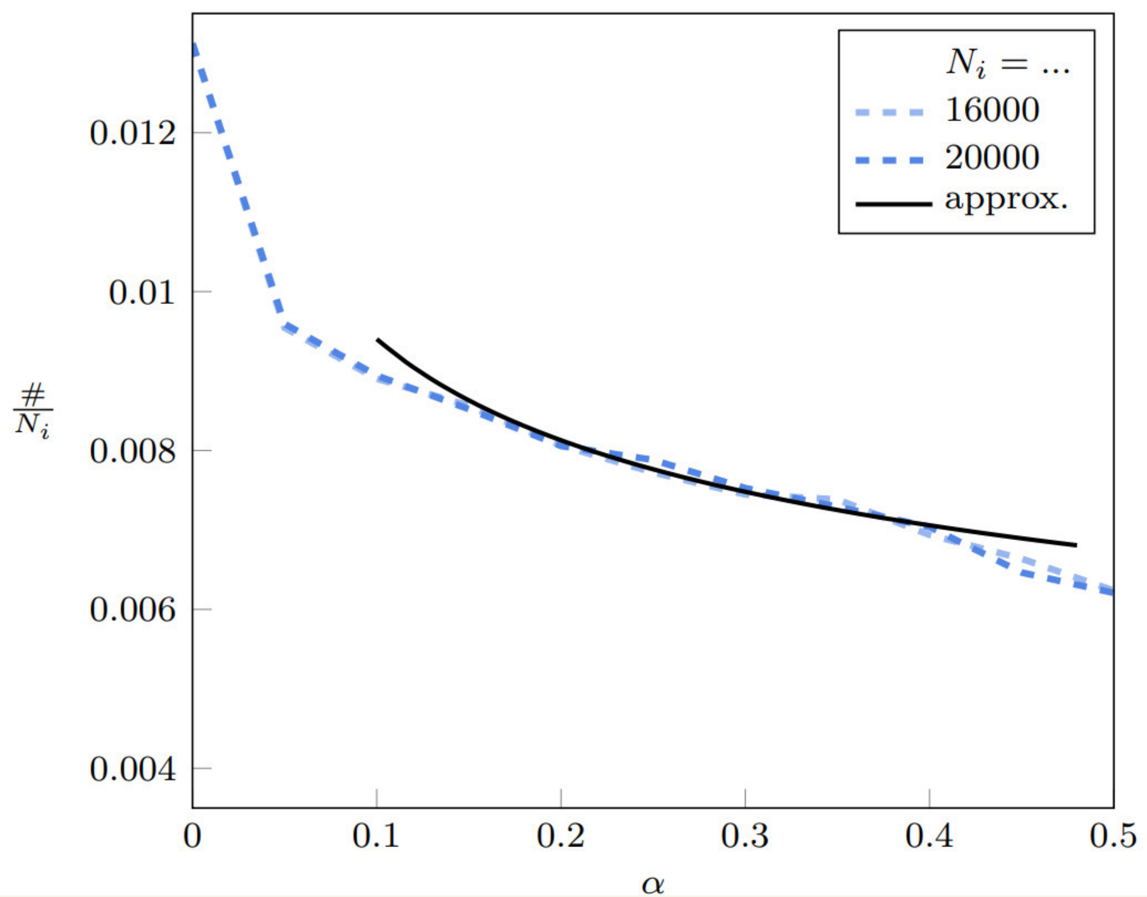


Domain Wall Party ☺



domain walls annihilate each other

Dynamic Duo: Noise & Drive



gain loss

$$\dot{\rho}_{DW} = \Gamma_\eta - \Gamma_\alpha = 0 \qquad \Gamma_\eta = \text{const.}$$

$$\rho_{DW} = \frac{\#}{L} = \frac{1}{\Delta x}$$

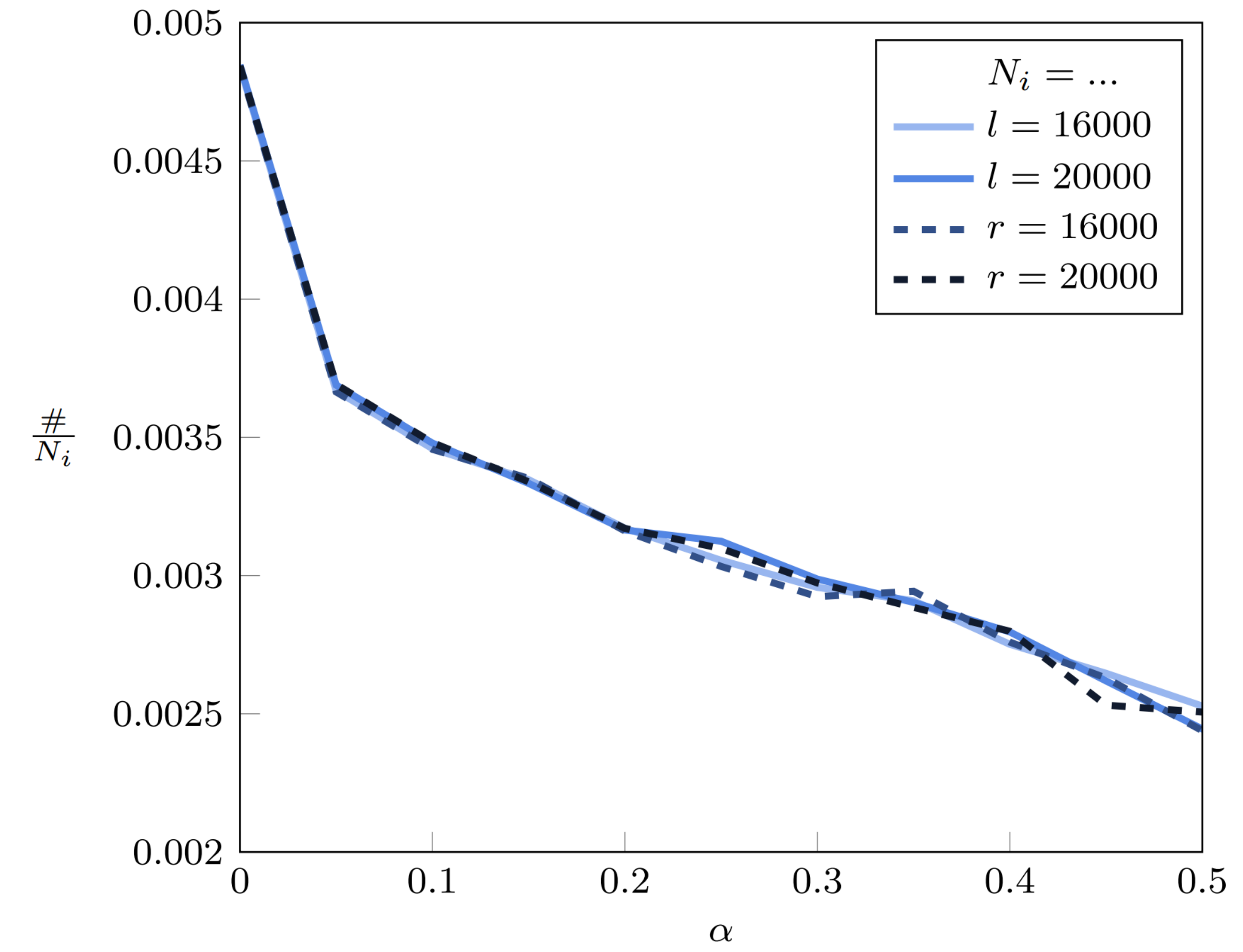
average distance

$$2|v| = \frac{\Delta x}{\Delta t} \longrightarrow \Delta t = \frac{1}{2|v|\rho_{DW}}$$

average collision time

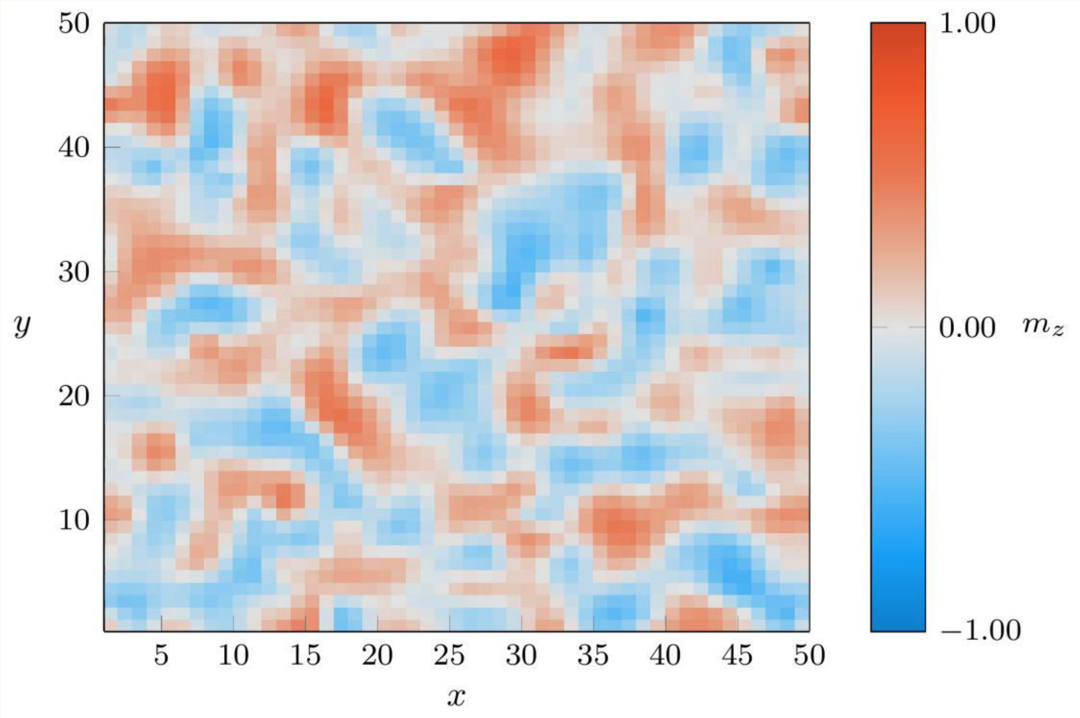
$$\Gamma_\alpha \sim \frac{\rho_{DW}}{\Delta t} \longrightarrow \rho_{DW} \sim \sqrt{\frac{\Gamma_\eta}{2|v|}} \propto \alpha^{-1/4}$$

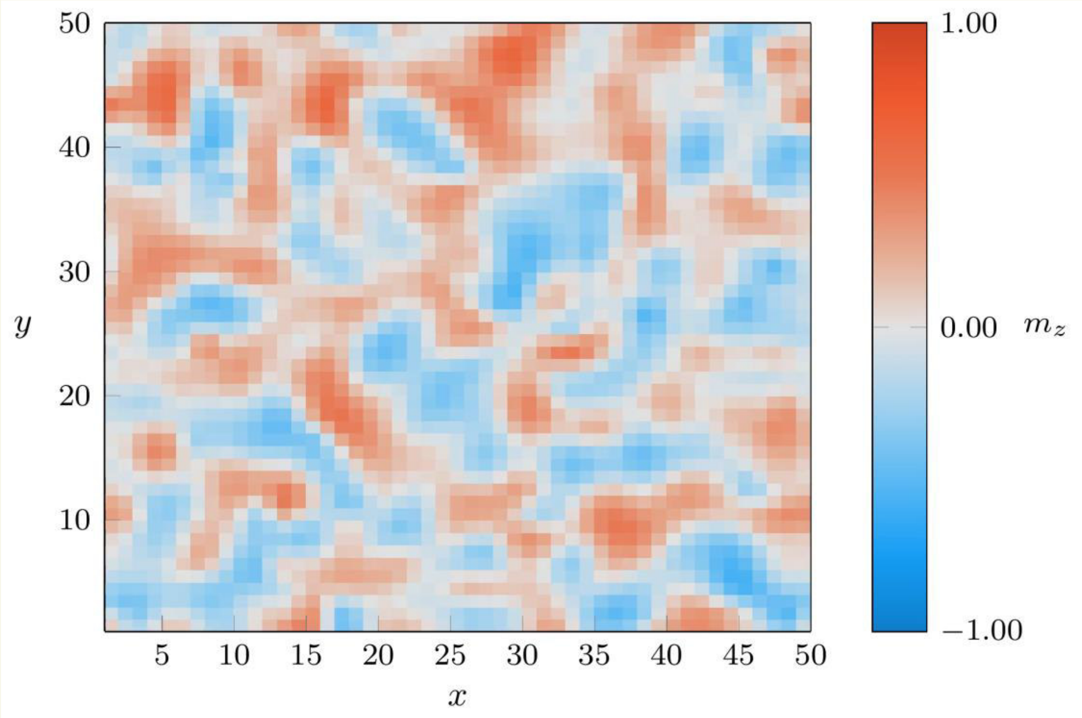
Left or Right ?



no favoured direction!

Fading Domains





driven

more field theoretical perspective – small part active magnets → Zelle, Daviet, Rosch, Diehl. (2023). arXiv:2304.09207.

RECOMMENDED

Summary

Thank you
for your attention