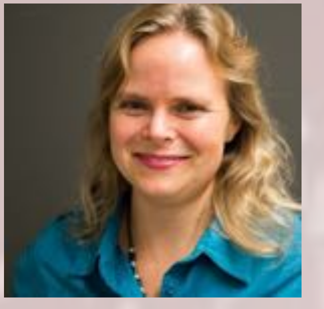
Effective description of topological magnetic textures

Davi R Rodrigues, Ben McKeever, Karin Everschor-Sitte, Matthias Sitte, Jairo Sinova, Artem Abanov

October 24, 2017– INSPIRE GROUP SEMINAR

MS,KES,TV,DRR,JS, AA - PRB, 2016
DRR,KES,OT,JS, AA - PRB, 2017
…


Outline

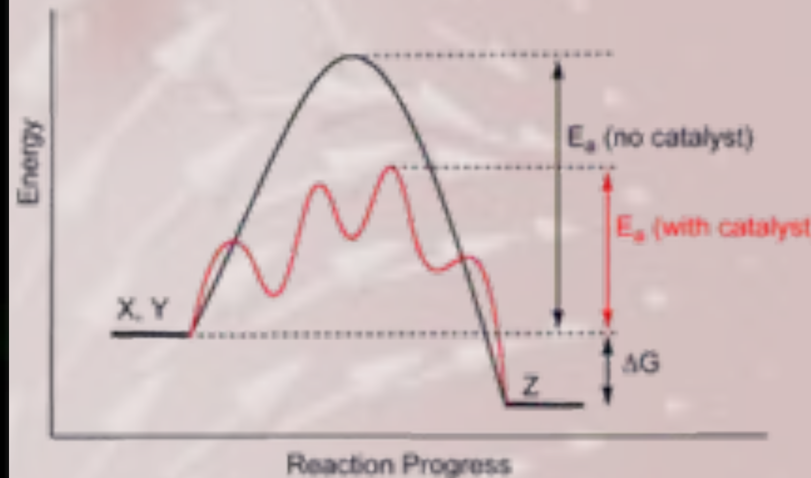
- Introduction;
- Creation of topological textures;
- Effective description of Domain walls;
- Effective description of Skyrmions;
- Summary and future research;

Motivation – An analogy:

Is it useful?

Probably.

What do we need to have fire?



- Lazyness → Minimum requirements;
- Macroscopic aspects;

What can we do with fire?

It’s hot. → Warming? Cooking?

It’s powerful.→Weapons?

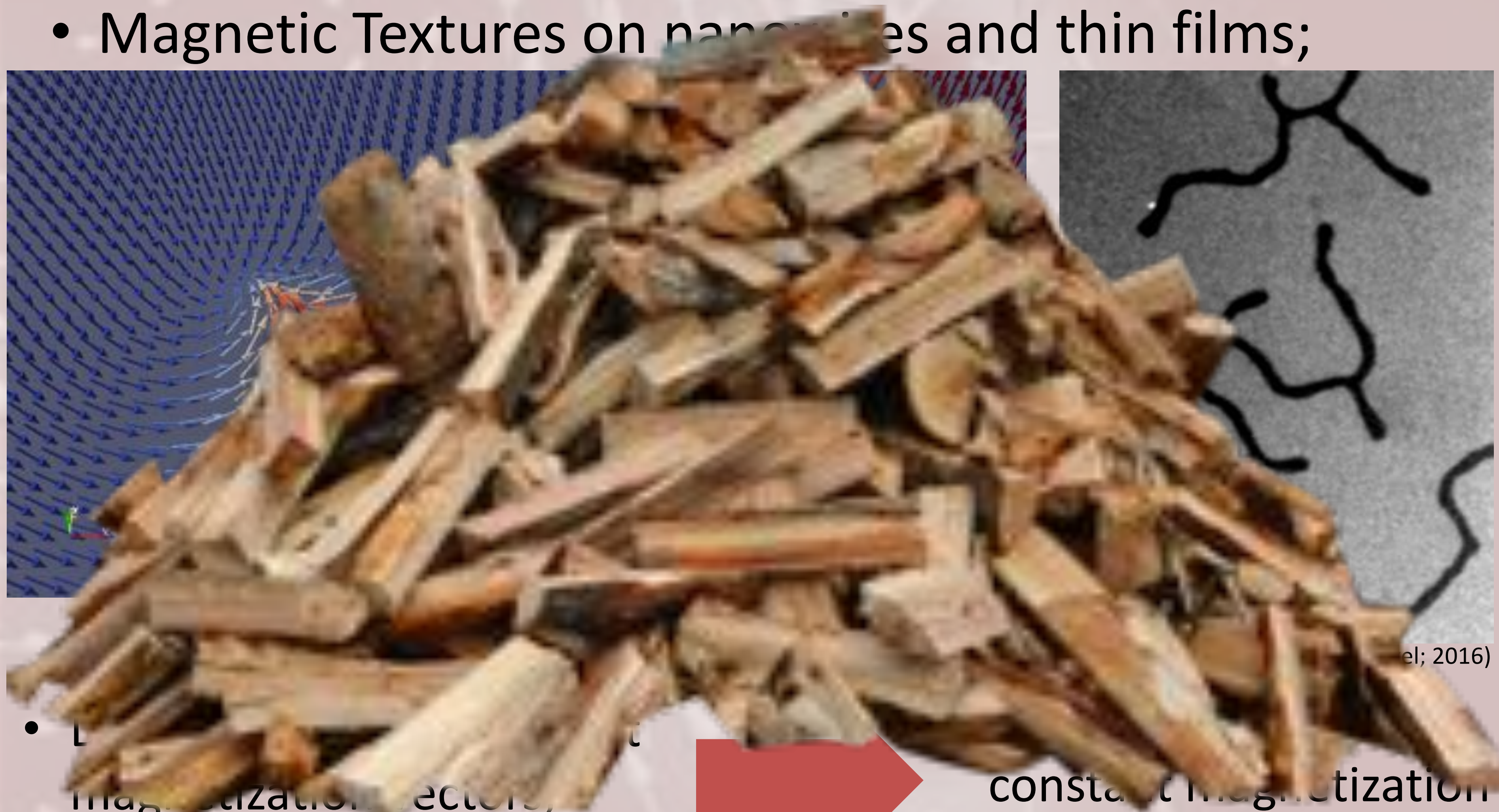
Enough about fire. I’m out of time.

Question	Answer
What will I be working with?	Topological magnetic textures;
What do I want to know about it?	General dynamics, independent of microscopic aspects;

In a single sentence: “The goal is to understand how topological textures move and how to move them.”

What do I mean by fire?

- Magnetic Textures on nan... es and thin films;



...el; 2016)

- L... t mag... tizatio... ectors;

constan... t ma... etization vectors;

Can you be more specific?

- Hamiltonian:

$$H = \sum_{<ij>} -J\mathbf{S}_i \cdot \mathbf{S}_j \qquad \text{“} -\lambda(\mathbf{S}_i \cdot n_i)^2 \text{“}$$

- Exchange interaction;
- Anisotropy;

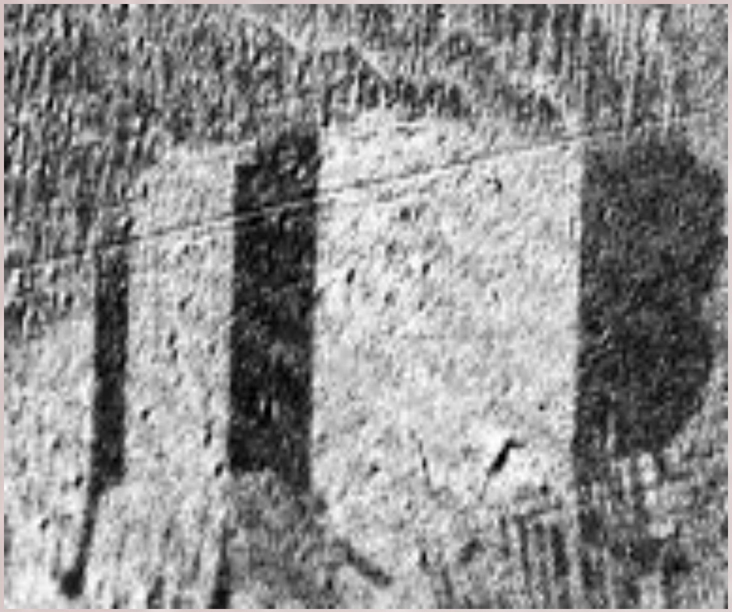
DOMAINS!

Reduces symmetry & Doubly degenerate;

(Zureks, Chris; 2008)

What can happen then?

- Stability.



- Domain walls has fixed size
  → Domain wall width

Natural length parameter

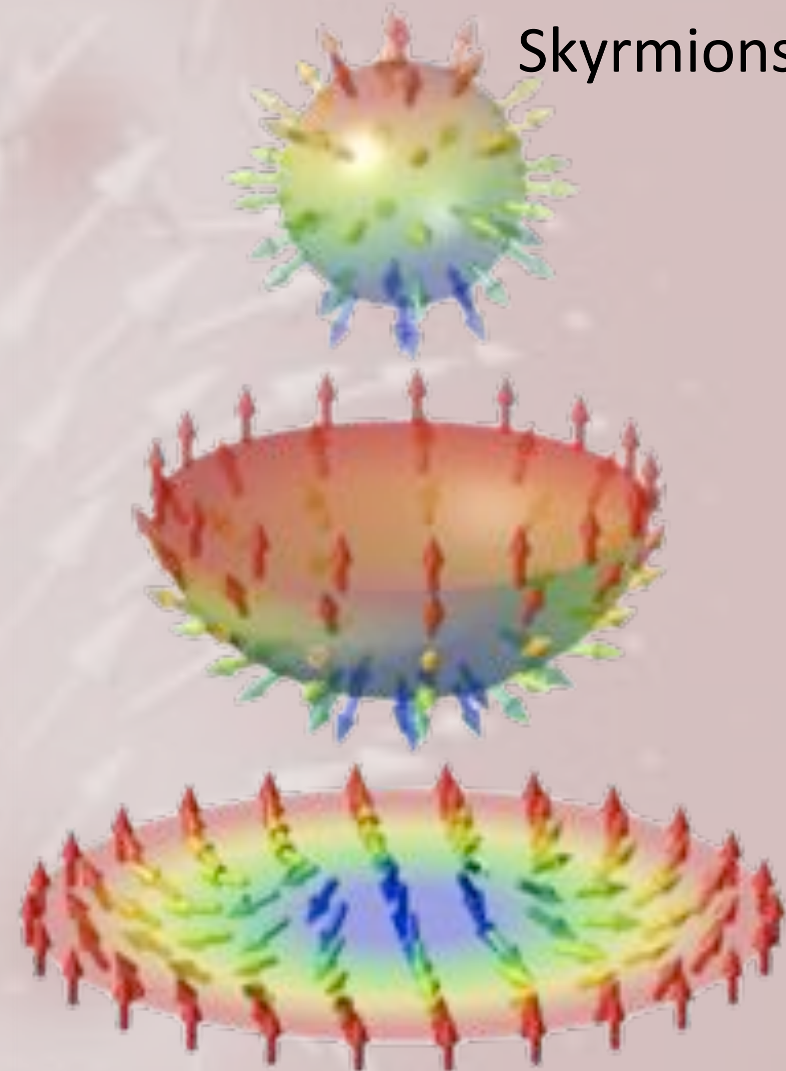
$$\Delta = \sqrt{J/\lambda}$$

Rigid structures

What about fire balls?

- Topological structures

  Continuous approximation



(Sitte, KES, J. Applied Physics 2014)

Topological charge

$$Q = \frac{1}{4\pi}\int \mathbf{m}\cdot\left(\partial_x \mathbf{m}\times\partial_y \mathbf{m}\right)dxdy$$

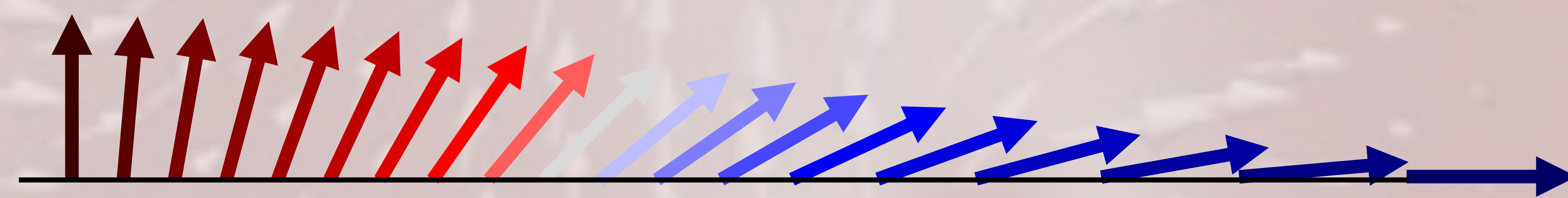
How to create Domain walls?

- We want to avoid magnetic fields (too strong)

Electrical means preferred $j_a \partial_a \vec{S}$

Minimal requirements!!!

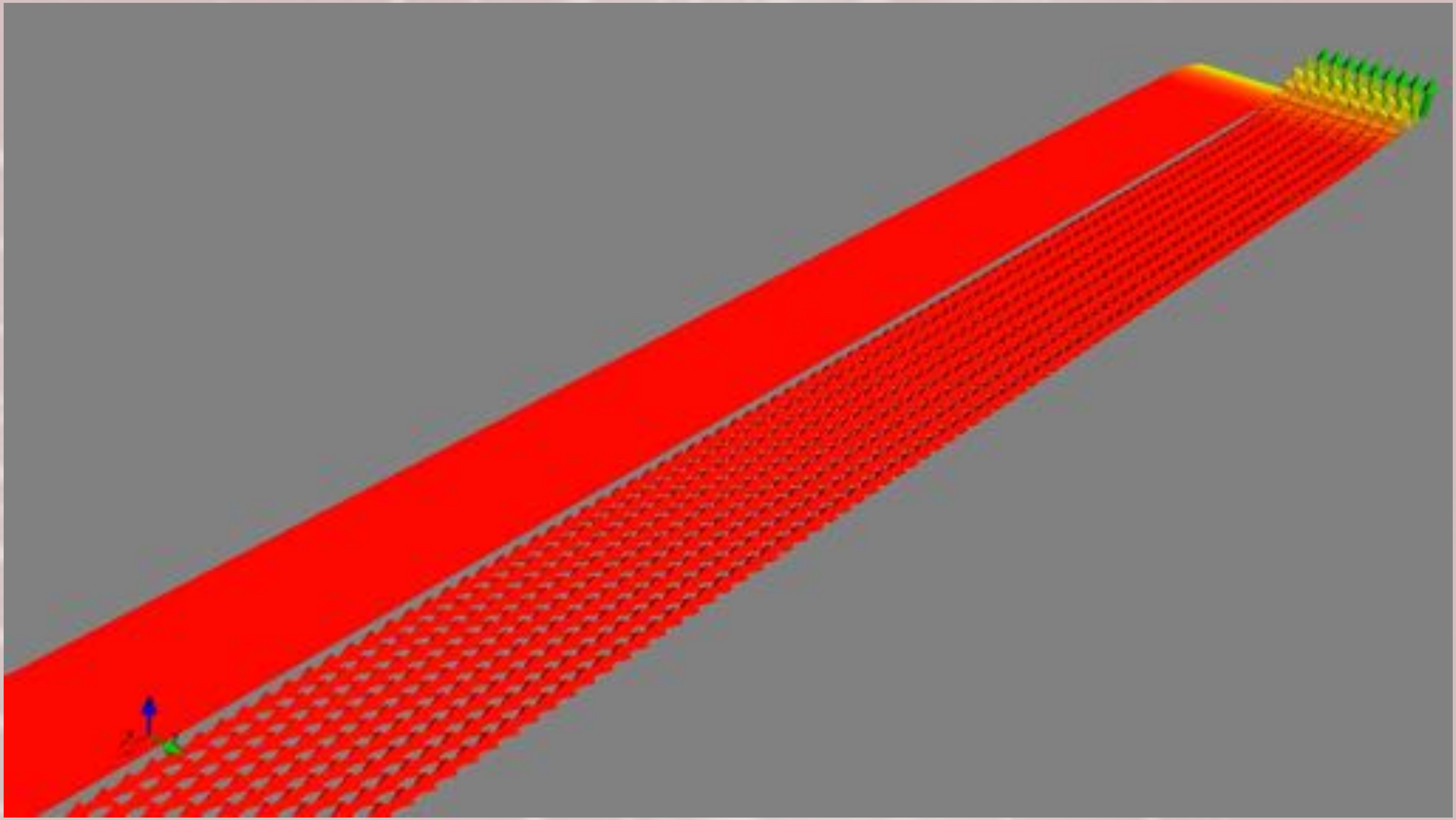
Breaking translational symmetry



$j < j_c$ $j < j_C$

$$j_c < j_C$$

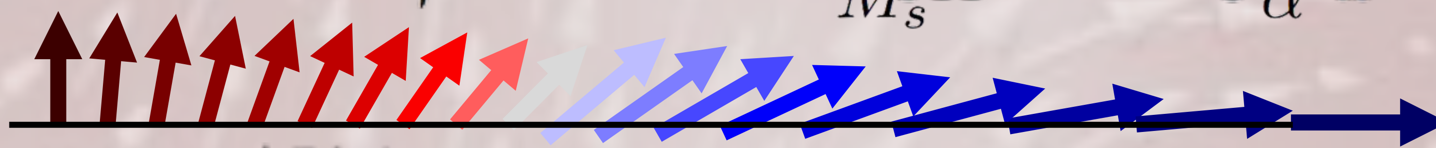
What happens then?

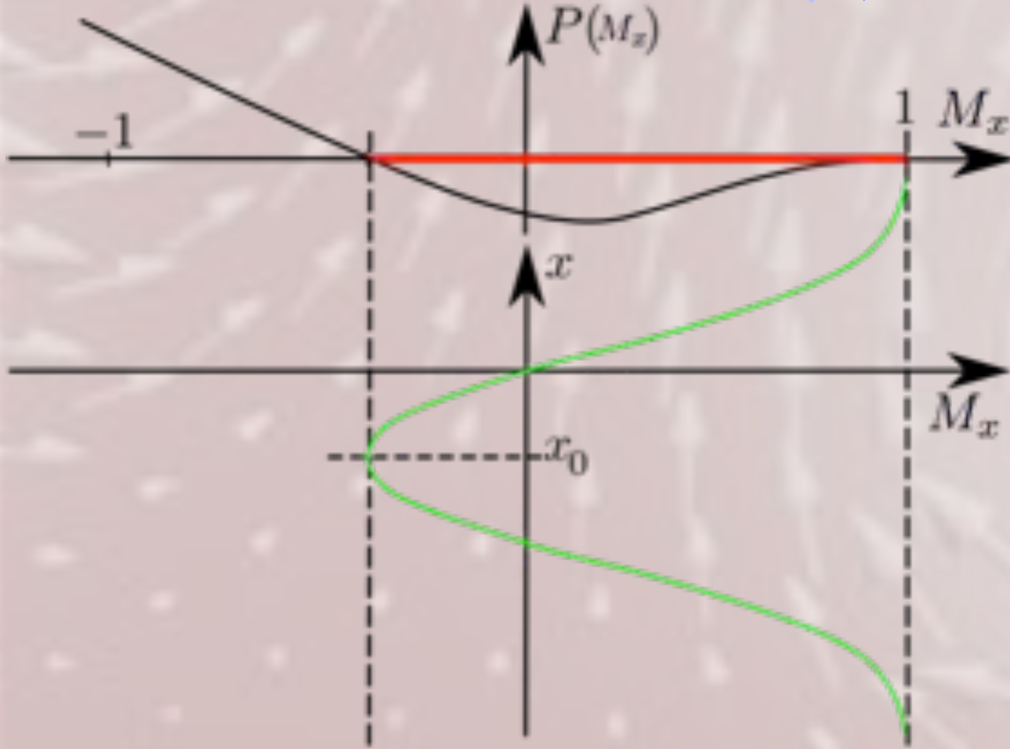


A bit of math...

- LLG equation:

$$(\partial_t + v_s \partial_x)\boldsymbol{M} = -\gamma \boldsymbol{M} \times \boldsymbol{H}_{\text{eff}} + \frac{\alpha}{M_s} \boldsymbol{M} \times \left(\partial_t + \frac{\beta}{\alpha} v_s \partial_x\right)\boldsymbol{M}$$





- Solutions parametrized by x_0

- Time dependence:

$$\boldsymbol{M}(x,t) = \boldsymbol{M}_0(x - x_0(t); v_{s_{x_0(t)}})$$

- Solution:

$$T \sim (j - j_c)^{-1/2}$$

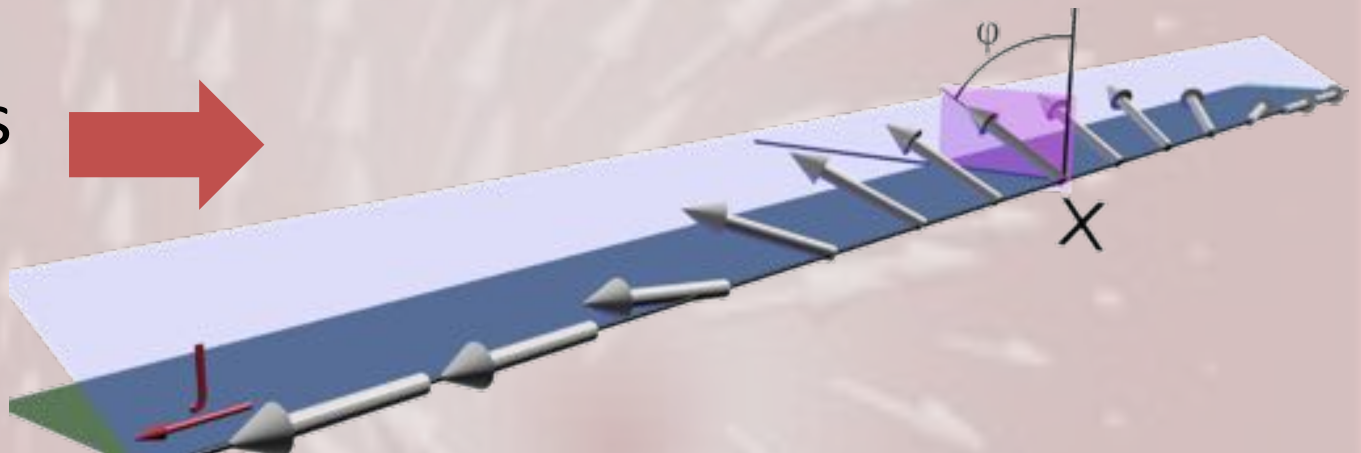
“Avoid complications.”

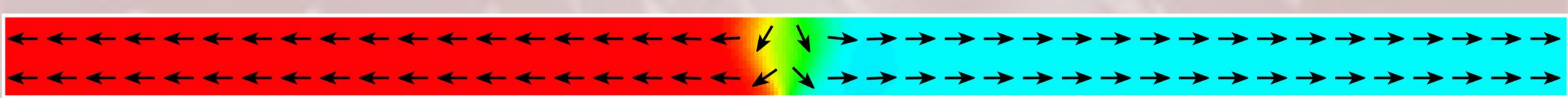
Landau-Lifshitz-Gilbert equation

$$(\partial_t + v_s\partial_x)\boldsymbol{M} = -\gamma\boldsymbol{M}\times\boldsymbol{H}_{\mathrm{eff}} + \frac{\alpha}{M_s}\boldsymbol{M}\times(\partial_t + \frac{\beta}{\alpha}v_s\partial_x)\boldsymbol{M}$$

Too complicated!!!

Rigid structures



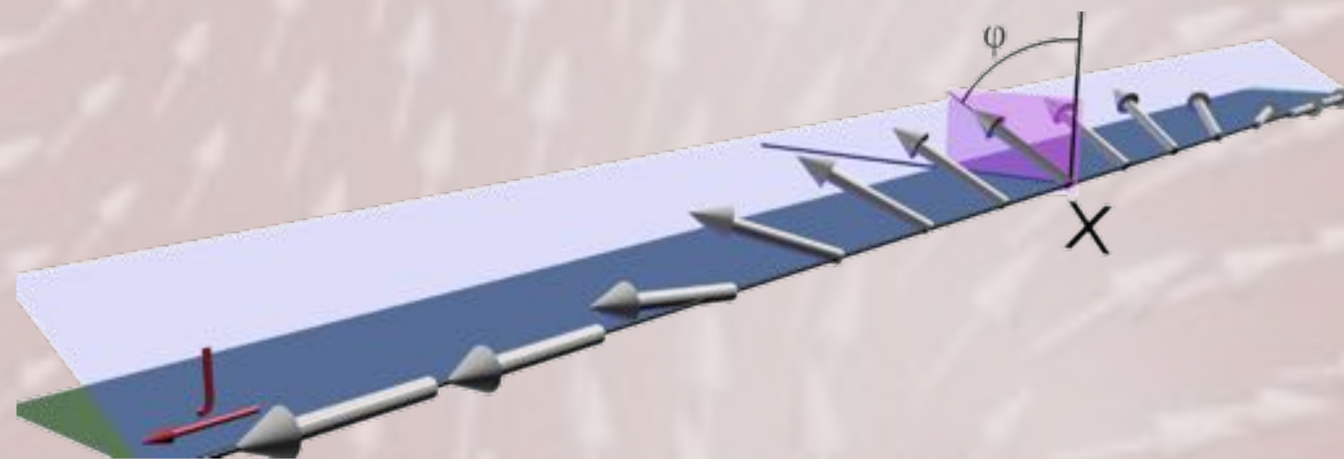


Kim at al (Nature Comm., 2014)

Simpler is always better

Soft modes:

$$\boldsymbol{\xi}(t) = \{\xi_1(t), \ldots, \cancel{\xi_N(t)}\} \Rightarrow \{X, \phi\}$$



$$\frac{d\hat{\boldsymbol{M}}}{dt} = \{\hat{\boldsymbol{M}}, H\} + \gamma_{\hat{\boldsymbol{M}}} \Rightarrow \dot{\xi}_i = \{\xi_i, E\} + \gamma_{\xi_i}$$

But how?

LLG equation: $\frac{d\hat{\boldsymbol{M}}}{dt} = \{\hat{\boldsymbol{M}}, H\} + \gamma_{\hat{\boldsymbol{M}}}$

Soft modes: $\frac{d\hat{\boldsymbol{M}}}{dt} = \sum_{i=1}^{N} \frac{\partial \hat{\boldsymbol{M}}}{\partial \xi_i} \frac{d\xi_i}{dt},$

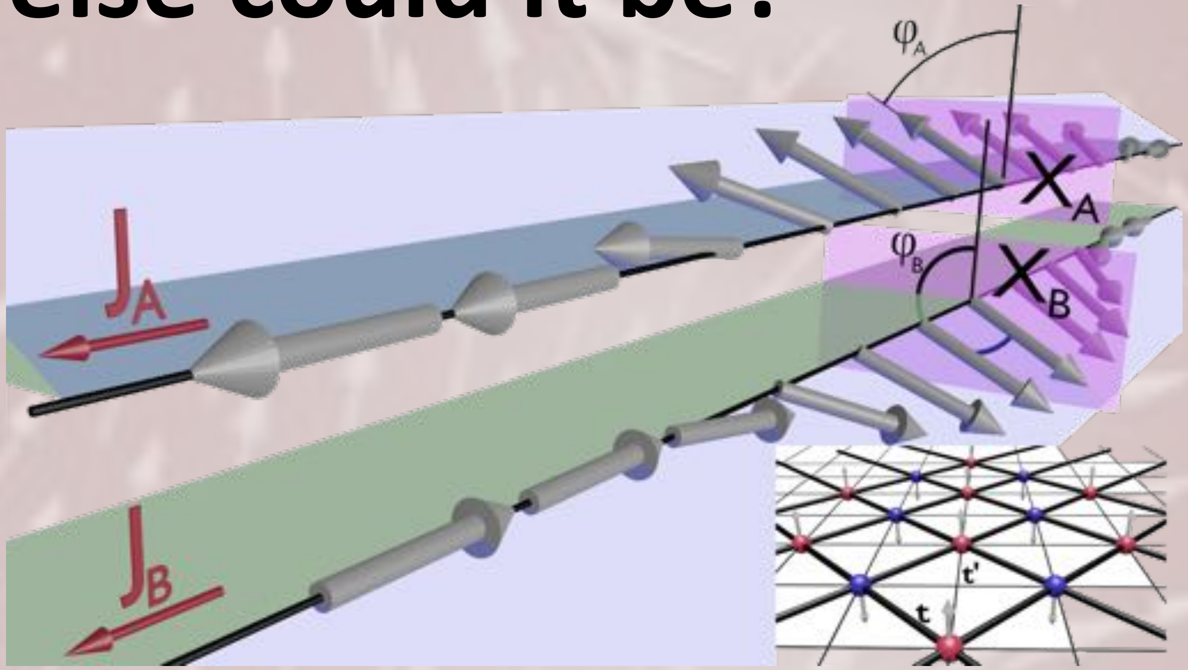
- Thiele Method:
  1. Project $\hat{\boldsymbol{M}} \times \partial_{\xi_i} \hat{\boldsymbol{M}}$;
  2. Integrate over volume;
- Our method:
  1. Action: $\mathcal{S} = \mathcal{S}_B - \int dt H$;
  2. Expand on the soft modes: $\mathcal{S}_{\text{eff}} = \int dt \left(\sum_i p_i \dot{q}_i - H \right)$;
  3. Poisson Bracket for Soft modes;
  4. Hamiltonian equations: $\frac{d\xi_i}{dt} = \{\xi_i, H\}_{\boldsymbol{q},\boldsymbol{p}} + \gamma_{\xi_i}$;

2 Steps seem simpler than 4…

$$\frac{d\xi_i}{dt} = \{\xi_i, H\}_{\boldsymbol{q},\boldsymbol{p}} + \gamma_{\xi_i}$$

1. Independent of microscopic details;
2. Provides good intuition on the relation between soft modes;
3. Natural way to introduce external perturbations (by physical arguments). Examples: Magnetic field, electric current, antiferromagnetic materials

"What else could it be?"



$$2\times\{X,\phi\}$$

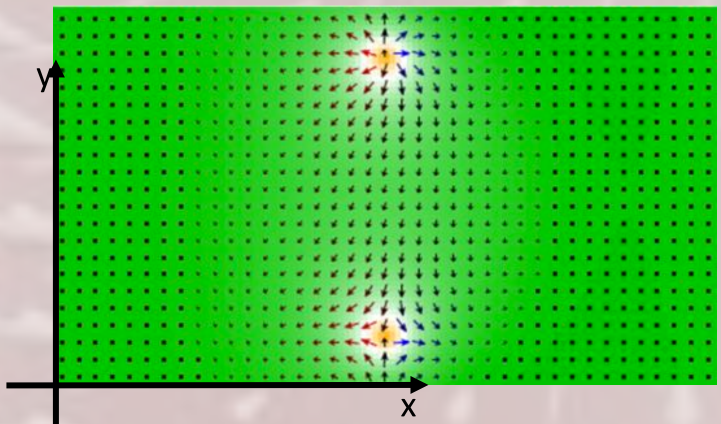
Antiferromagnetic interaction

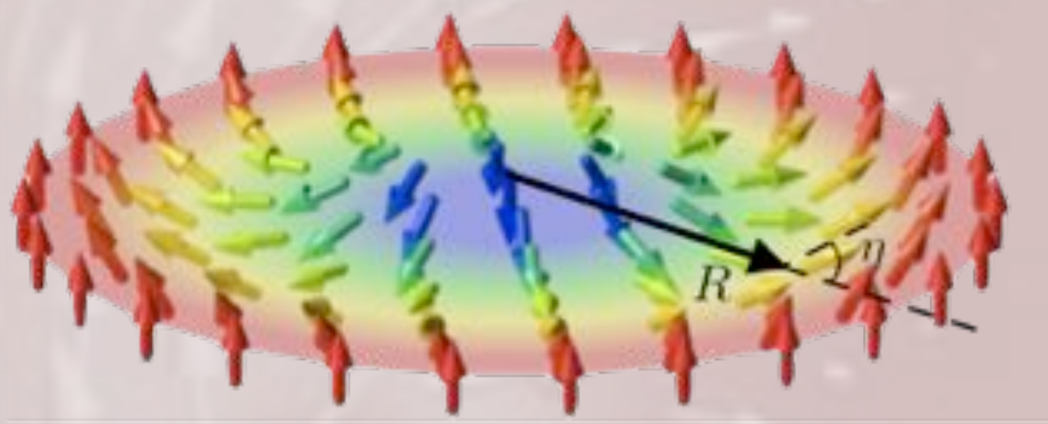
$$E(X_A,\phi_A,X_B,\phi_B)=\frac{\Delta_1}{2}(X_A-X_B)^2+\Delta_2\cos(\phi_A-\phi_B)$$

Same for fireballs?

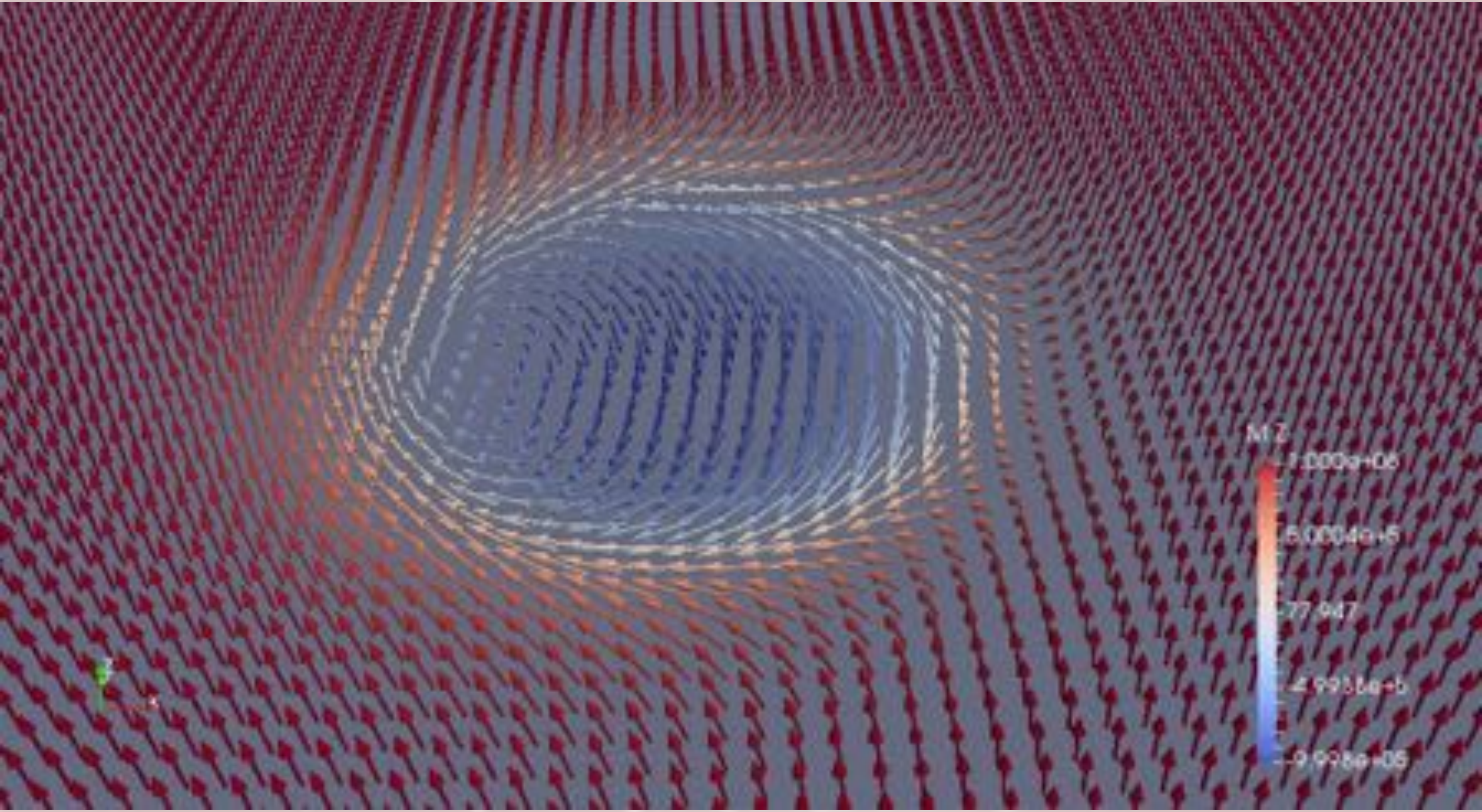
Soft modes

$$\boldsymbol{\xi}(t) = \{\xi_1(t), \ldots, \cancel{\xi_N(t)}\} \longrightarrow \{X, Y\}\{\eta, R^2\}$$





So?



A bit more complicated?

Summary

- There is magnetic topological textures;
- Their existence depend solely on the existence of multiple distinct domains in a sample;
- They have topological properties;
- They have a rigid structure;
- Their long range dynamics is rather simple and requires only a finite number of dynamical variables to describe them; (No need of the full LLG equation)

Questions?

Thank you for your attention!