Effective description of topological magnetic textures

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

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...
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 $\rightarrow$ Minimum requirements;
- Macroscopic aspects;

DRY!
What can we do with fire?

It’s hot. → Warming? Cooking?

It’s powerful. → Weapons?
Enough about fire. I’m out of time.

<table>
<thead>
<tr>
<th>Question</th>
<th>Answer</th>
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<tbody>
<tr>
<td>What will I be working with?</td>
<td>Topological magnetic textures;</td>
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<tr>
<td>What do I want to know about it?</td>
<td>General dynamics, independent of microscopic aspects;</td>
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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 nanowires and thin films;
  • Discrete lattice of constant magnetization vectors;
  • Continuous lattice of constant magnetization vectors;

(Hoffmann, Axel; 2016)
Can you be more specific?

- Hamiltonian:
  \[ H = \sum_{\langle ij \rangle} -JS_i \cdot S_j \]
  - Exchange interaction;

  "\(-\lambda (S_i \cdot n_i)^2""

  - Anisotropy;

  Reduces symmetry & Doubly degenerate;

DOMAINS!
What can happen then?

- Stability.

- Domain walls has fixed size
  → Domain wall width

Natural length parameter

\[ \Delta = \sqrt{J/\lambda} \]
What about fire balls?

- Topological structures
  Continuity approximation

Topological charge

\[ Q = \frac{1}{4\pi} \int \mathbf{m} \cdot \left( \partial_x \mathbf{m} \times \partial_y \mathbf{m} \right) dx dy \]

(Sitte, KES, J. Applied Physics 2014)
How to create Domain walls?

• We want to avoid magnetic fields (too strong)

Electrical means preferred

Minimal requirements!!!

Breaking translational symmetry

\[ j_a \partial_a \tilde{S} \]

\[ j < j_c \]

\[ j_c < j_C \]
What happens then?
A bit of math...

- LLG equation:

$$\partial_t \mathbf{M} + \mathbf{v} \cdot \nabla \mathbf{M} = -\gamma \mathbf{M} \times \mathbf{H}_{\text{eff}} \cdot \mathbf{M} \left( \mathbf{v} + \frac{\beta}{\alpha} \frac{\partial}{\partial x} \mathbf{M} \right)$$

- Solutions parametrized by $x_0$

- Time dependence:

$$\mathbf{M}(x, t) = \mathbf{M}_0(x - x_0(t); v_{s|x_0(t)})$$

- Solution:

$$T \sim (j - j_c)^{-1/2}$$
“Avoid complications.”

Landau-Lifshitz-Gilbert equation

\[(\partial_t + v_s \partial_x)M = -\gamma M \times H_{\text{eff}} + \frac{\alpha}{M_s} M \times (\partial_t + \frac{\beta}{\alpha} v_s \partial_x)M\]

Rigid structures

Too complicated!!!
Simpler is always better

Soft modes:

\[ \xi(t) = \{\xi_1(t), \ldots, \xi_N(t)\} \quad \rightarrow \quad \{X, \phi\} \]

\[ \frac{d\hat{M}}{dt} = \{\hat{M}, H\} + \gamma \hat{M} \quad \rightarrow \quad \dot{\xi}_i = \{\xi_i, E\} + \gamma \xi_i \]
But how?

**LLG equation:** \[ \frac{d\hat{M}}{dt} = \{\hat{M}, H\} + \gamma\hat{M} \]

**Soft modes:** \[ \frac{d\hat{M}}{dt} = \sum_{i=1}^{N} \left( \frac{\partial\hat{M}}{\partial \xi_i} \frac{d\xi_i}{dt} \right) \]

- **Thiele Method:**
  1. Project \( \hat{M} \times \partial_{\xi_i} \hat{M} \);
  2. Integrate over volume;

- **Our method:**
  1. Action: \( S = S_B - \int dt H \);
  2. Expand on the soft modes: \( S_{\text{eff}} = \int dt \left( \sum_i p_i q_i - H \right) \);
  3. Poisson Bracket for Soft modes;
  4. Hamiltonian equations: \[ \frac{d\xi_i}{dt} = \{\xi_i, H\}_{q,p} + \gamma\xi_i \]
2 Steps seem simpler than 4...

\[ \frac{d\xi_i}{dt} = \{\xi_i, H\}_{q,p} + \gamma \xi_i \]

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?”

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

\[ \xi(t) = \{\xi_1(t), \ldots, \xi_N(t)\} \rightarrow \{X, Y\} \{\eta, R^2\} \]
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)
You aren’t doing it wrong

if no one knows what you are doing.

Questions?
Thank you for your attention!