

DYNAMICS & MAGNETORESISTANCE OF 1D DOMAIN WALLS & SKYRMIONS

Martyna Sedlmayr[†], N. Sedlmayr[†], J. Berakdar[○], and V. Dugaev[†]

[†]Department of Physics and Medical Engineering, Rzeszów University of Technology, Rzeszów, Poland

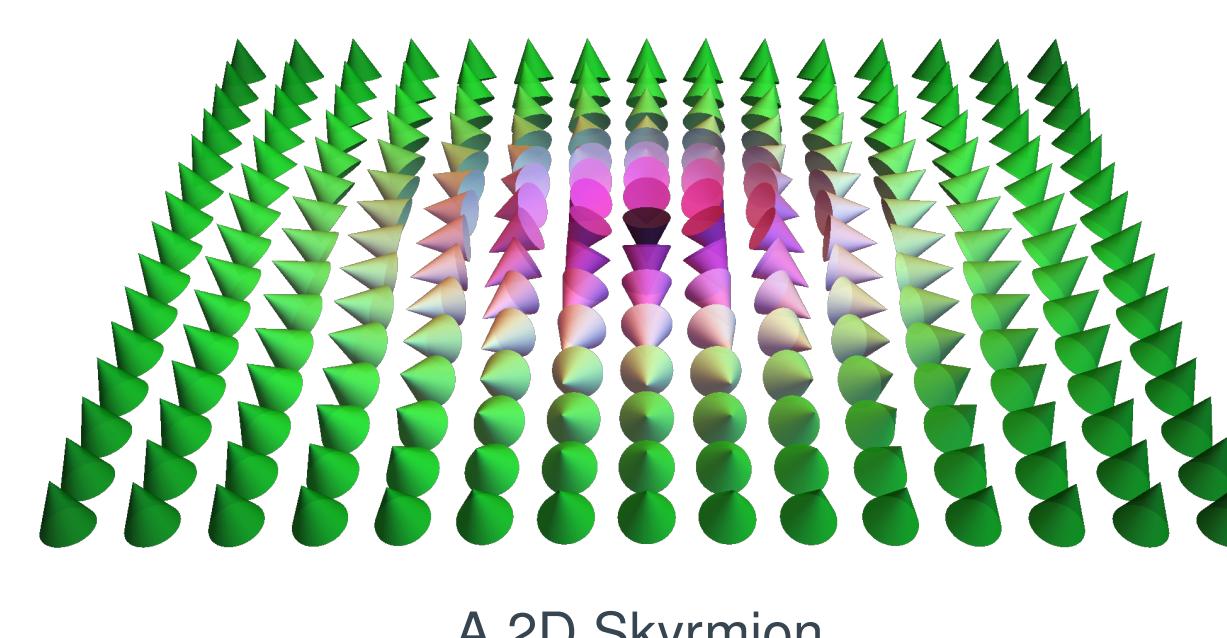
[○]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, Halle (Saale), Germany

m.sedlmayr@prz.edu.pl

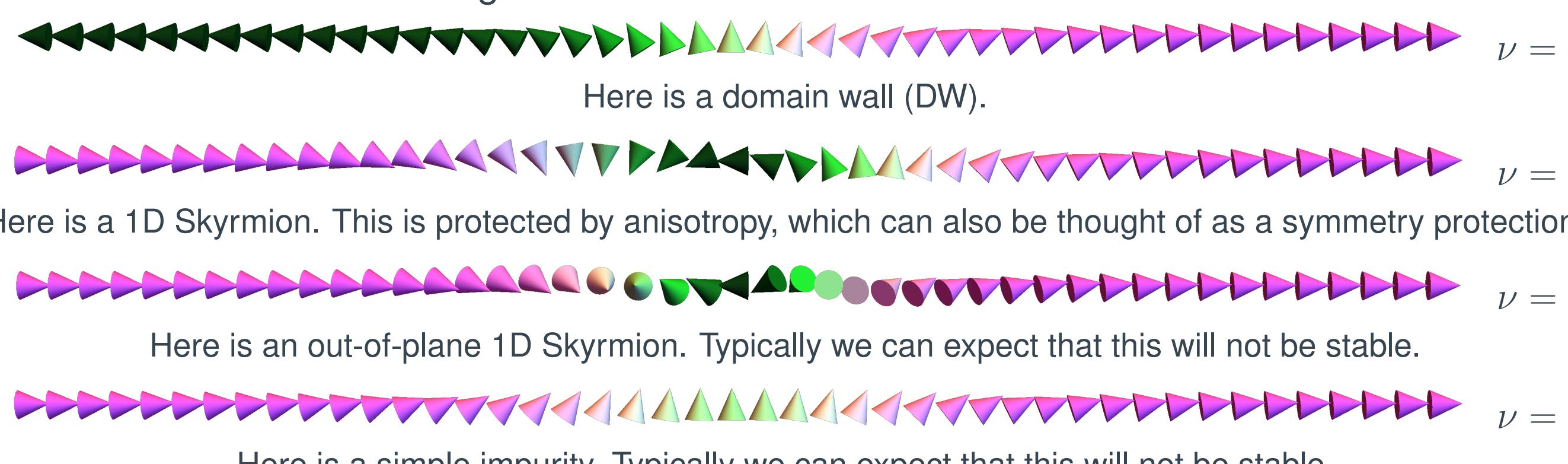
In one dimensional ferromagnetic wires domains of collinear ferromagnetic order can be separated by different types of topological, and non-topological, domain walls. Domains of opposite orientation are typically separated by either Bloch or Neel domain walls, whereas domains of the same orientation can be separated by magnetic impurities, or by a one dimensional equivalent of a skyrmion which may be found in quasi-one dimensional wires. We consider the different current induced dynamics and stability of these various magnetic deformations. We will go on to make a thorough investigation of the different magnetoresistance which can be caused by these various forms of domain walls, paying particular attention to the one dimensional skyrmion.

Motivation

Skyrmions are well known topological objects in 2D magnetic condensed matter systems of a special type. In 1D materials it is also possible to find a variety of twists and separating regions of collinear magnetization. These can also be protected "topologically" between bulk orientations. Indeed one can even define a winding number to categorize them.



In 1D we can find various configurations.



In terms of the classical bulk magnetization \vec{M} we can define a winding number

$$\nu = \frac{1}{2\pi} \int dz \phi_z \quad \text{where} \quad \vec{M}(z) = M(\sin[\phi_z] \cos[\theta_z], \sin[\phi_z] \sin[\theta_z], \cos[\phi_z])$$

We want to know what the magnetoressistance is for these various textures, how they interact, how they move, and how stable they are.

We consider the 1D magnetic wire with a certain profile of magnetization $M(x)$ which changes direction in the $x-y$ plane. The Hamiltonian for the conduction electrons is, neglecting the Coulomb interaction,

$$H = -\frac{\hbar^2}{2m} \frac{d^2}{dz^2} - g \vec{\sigma} \cdot \vec{M}(z)$$

where g is the coupling constant.

Dynamics and Stability

Landau-Lifschitz-Gilbert Equations with relaxation[1] and non-adiabatic torque[2]:

$$\partial_t \vec{M} = -\frac{1}{1+\alpha^2} \left[\gamma \vec{M} \times \mathcal{H} + \frac{\alpha \gamma}{M} \vec{M} \times (\vec{M} \times \mathcal{H}) + \frac{b_j(1+\alpha\xi)}{M^2} \vec{M} \times (\vec{M} \times (\vec{j}_e \cdot \nabla) \vec{M}) + \frac{b_j(\xi-\alpha)}{M} \vec{M} \times (\vec{j}_e \cdot \nabla) \vec{M} \right]$$

\mathcal{H} is the effective field:

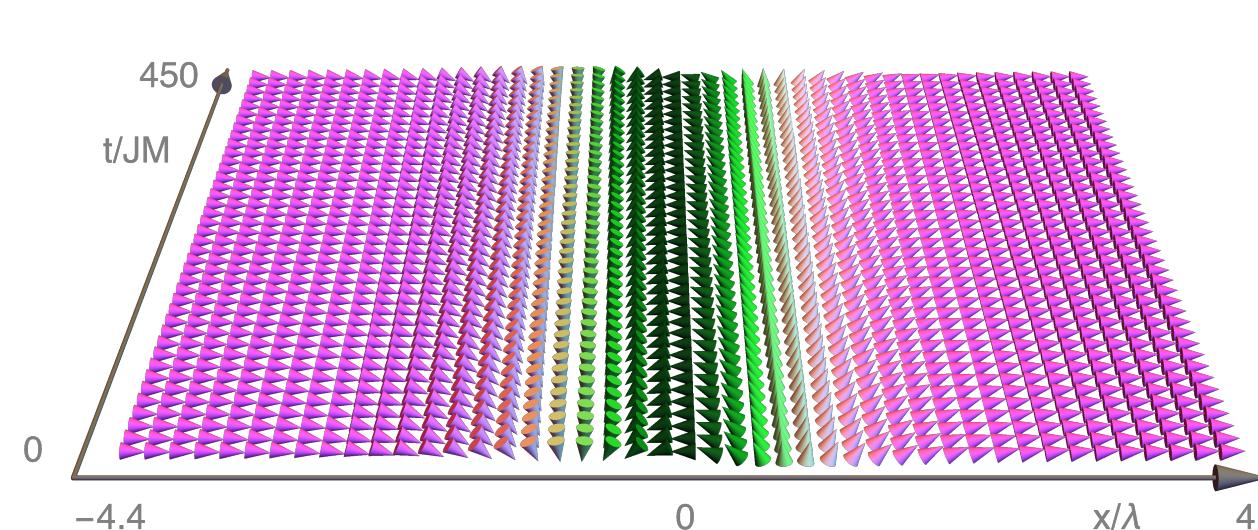
$$\mathcal{H} = J \vec{S} + \alpha_{ik} \frac{\partial^2 \vec{M}}{\partial x_i \partial x_k} + K M_x \vec{x}$$

$f_0(M)$ homogeneous exchange

α_{ik} inhomogeneous exchange

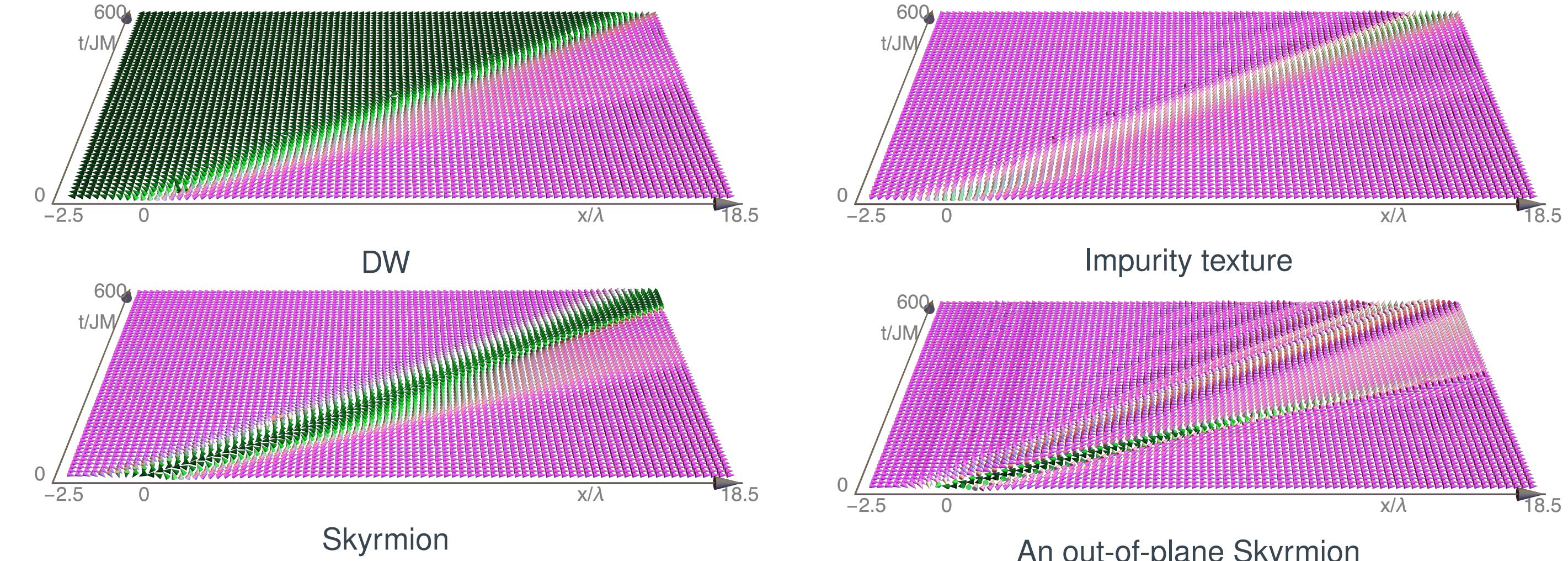
\vec{H}_{ext} external magnetic field

K anisotropy



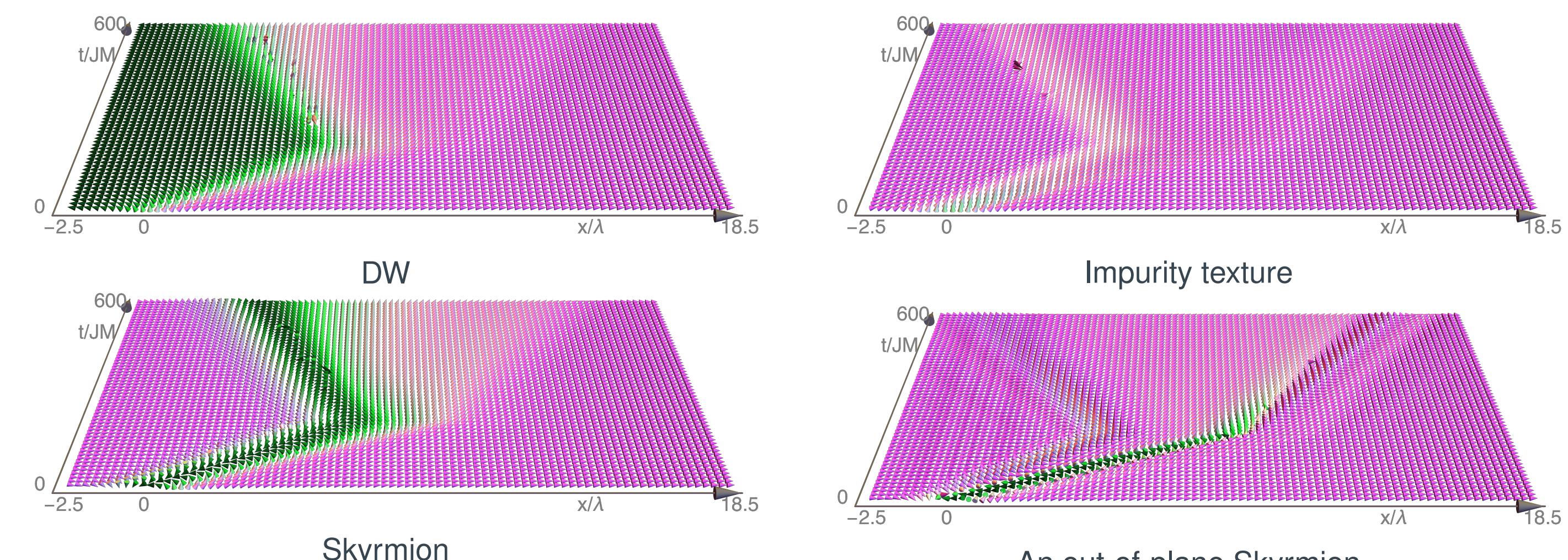
Current Induced Dynamics

Apply constant currents:



Pulsed Current Induced Dynamics

Apply top hat shaped pulsed currents:



The 1D "Skyrmions" can be stabilised using a magnetic field applied along the length of the wire.

Open Questions

- Full catalogue of dynamics for different spin textures
- Electron mediated interactions between the different magnetic structures[3, 4, 5]
- Contribution of bound states at the magnetic texture to the magnetoressistance
- Magnetoresistance from different textures, electron interaction effects?[6, 7]
- Effects on domain wall motion of applied magnetic fields

We have the Schrödinger equation, in a convenient representation,

$$\begin{pmatrix} -\frac{\hbar^2}{2m} \frac{d^2}{dz^2} - \varepsilon & -gM_-(z) \\ -gM_+(z) & -\frac{\hbar^2}{2m} \frac{d^2}{dz^2} - \varepsilon \end{pmatrix} \begin{pmatrix} \varphi(z) \\ \chi(z) \end{pmatrix} = 0$$

where $\varphi(z)$ and $\chi(z)$ are the spinor components of the wavefunction $\Psi(z)$ and $M_{\pm}(z) = M_x(z) \pm i M_y(z)$.

Either by an "exact" numerical solution or by using the semiclassical solution we can find the differential conductance, where r_j is the backscattering in each spin channel $j = 1, 2$.

$$G = \frac{e^2}{2\pi} \sum_j [1 - |r_j|^2]$$

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