Topological structures in patterned nanomagnets

Olle Heinonen[1,2] and C. Phatak[1]

[1]Materials Science Division, Argonne National Laboratory

[2]Department of Physics and Astronomy, Northwestern University

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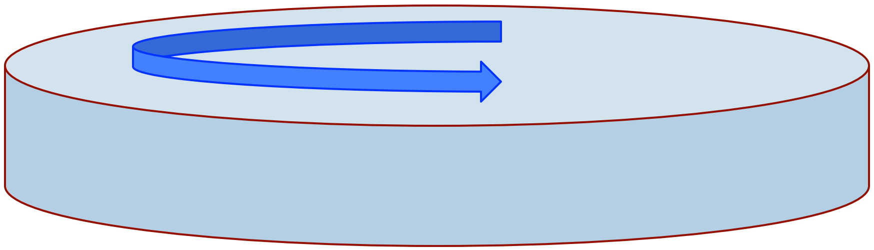
Outline

- Competing interactions and frustration – vortices, spin-ice lattices
- Experimental system
- Lorentz images in zero applied field
- Quasi-static response
- Micromagnetic modeling – statics
- Micromagnetic modeling – dynamics
- Summary

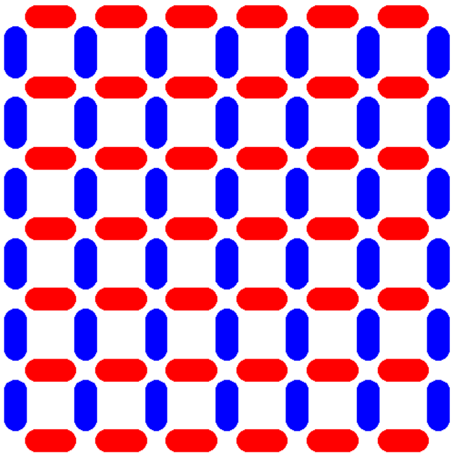
Frustration and competing interactions

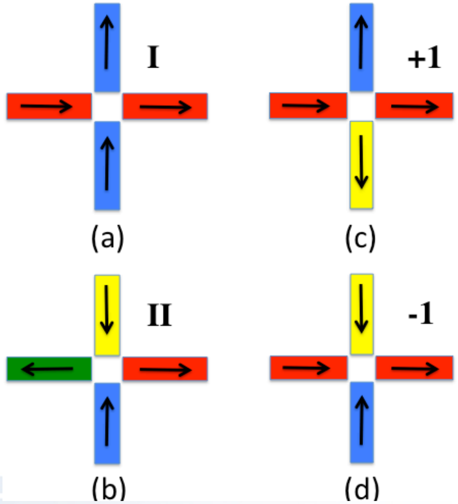
Micron- or nano-sized systems can be engineered to have competing interactions

In a thin, micron-sized disk, the magnetization forms a vortex.
Exchange interactions want to keep the magnetization uniform
but demagnetizing fields are minimized when poles are avoided
at the edges



In artificial spin ice lattice, frustration is engineered by geometry

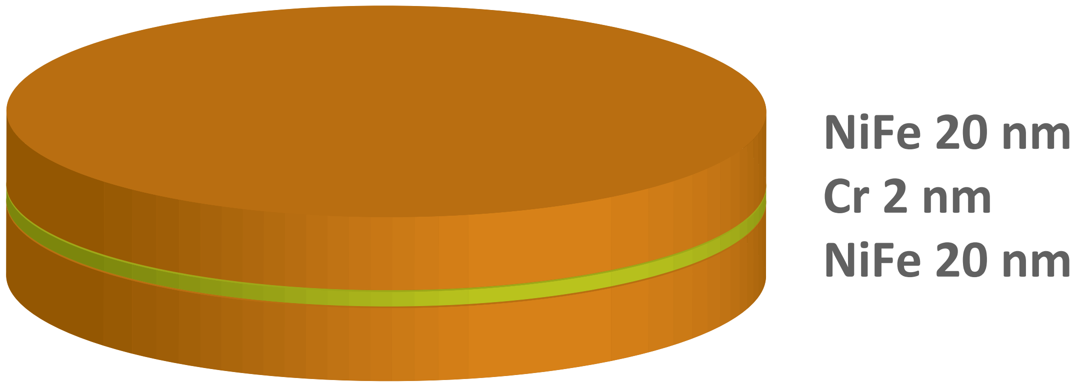




Experimental system

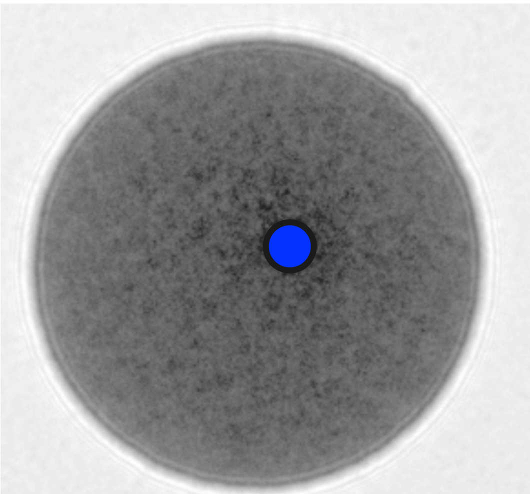
- What effect do engineered inter-layer exchange have on the magnetization in coupled stacked discs?

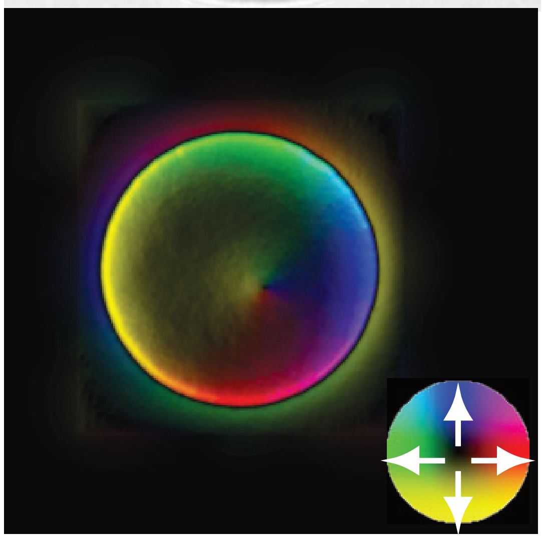
Two Permalloy discs, 2 μm diameter, 20 nm thick, separated by 2 nm Cr
The Cr promotes a weak anti-ferromagnetic coupling between the Py discs



What are the equilibrium magnetization configurations?
What are the dynamical magnetization modes?

Lorentz image in zero applied field

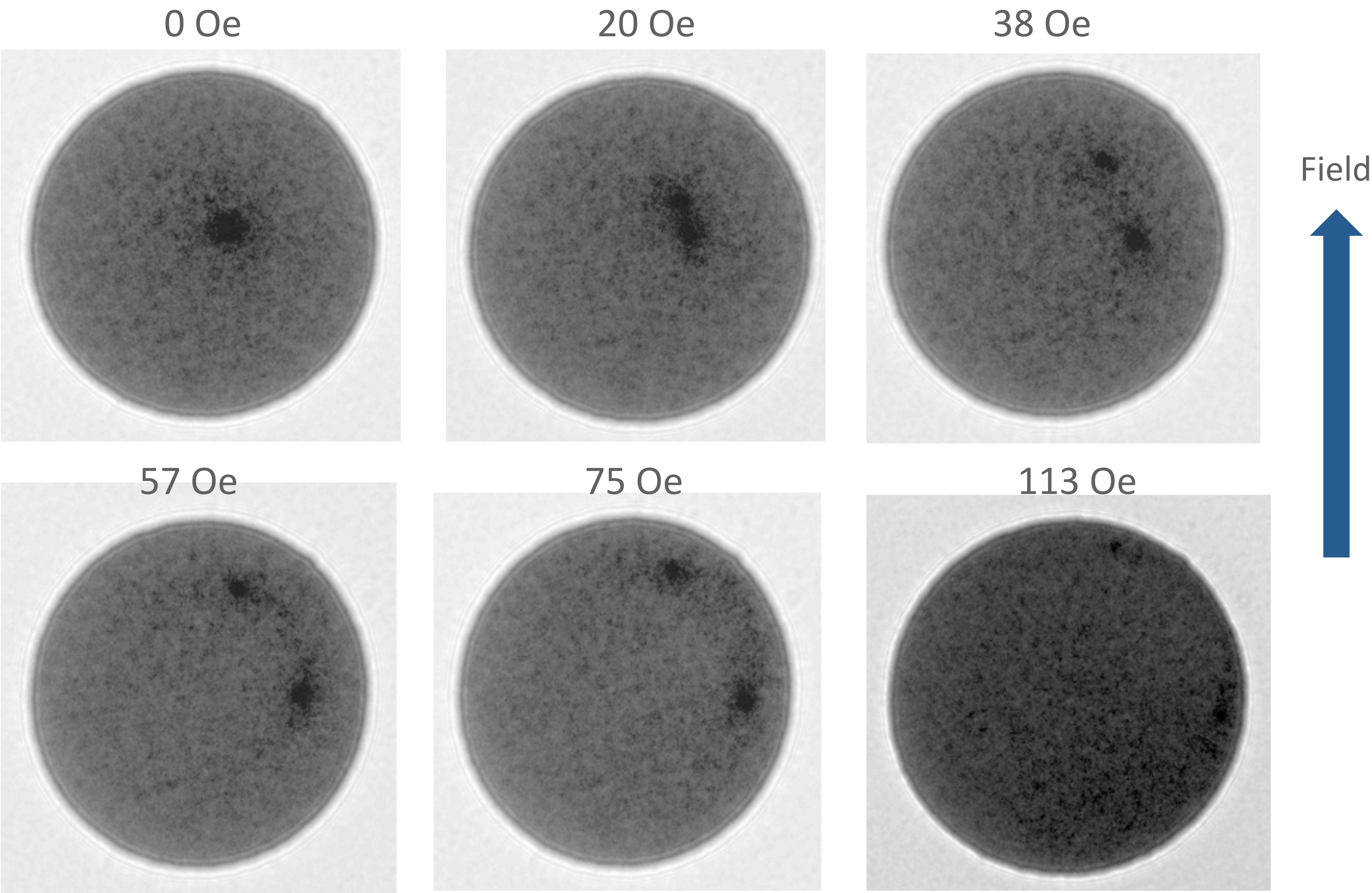




Under-focused Lorentz image. Dot (colored blue) is typical of vortex structure. Indicates two vortices on top of one another.

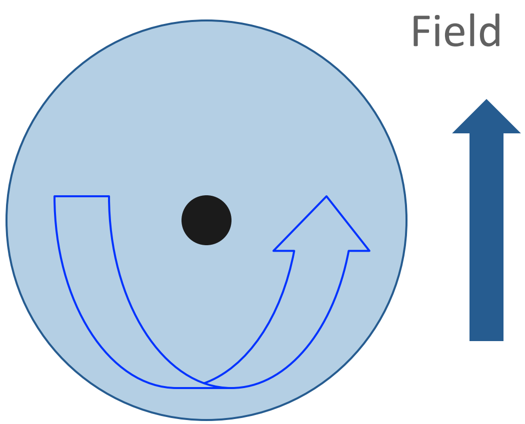
Reconstructed magnetic induction color map – the details are not quite consistent with two stacked vortices.

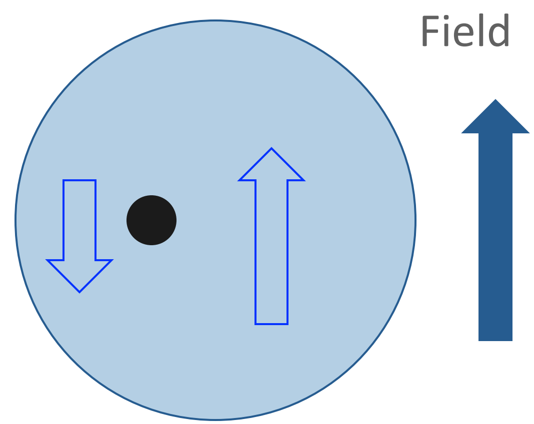
Quasi-static response

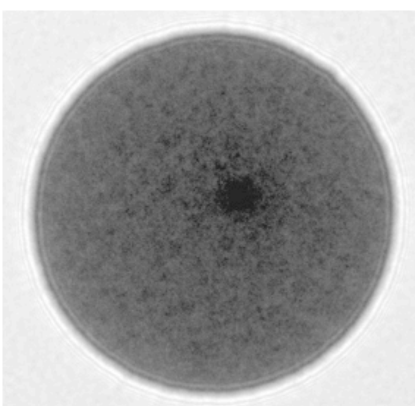


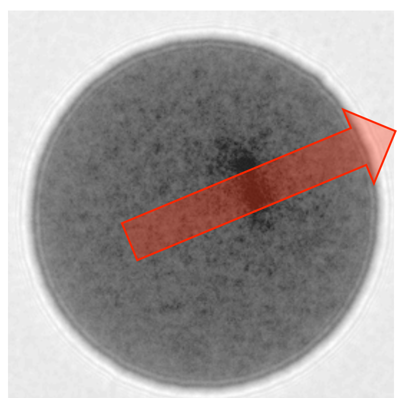
What gives???

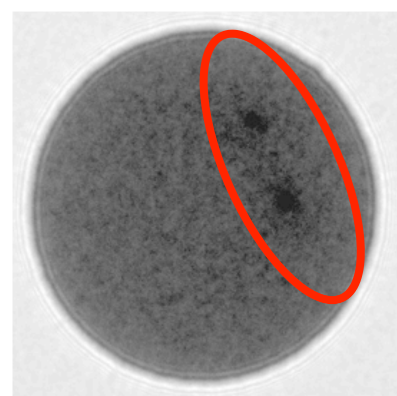
Vortices in a magnetic field: the core should move **perpendicularly** to the applied field!











Summary observations:

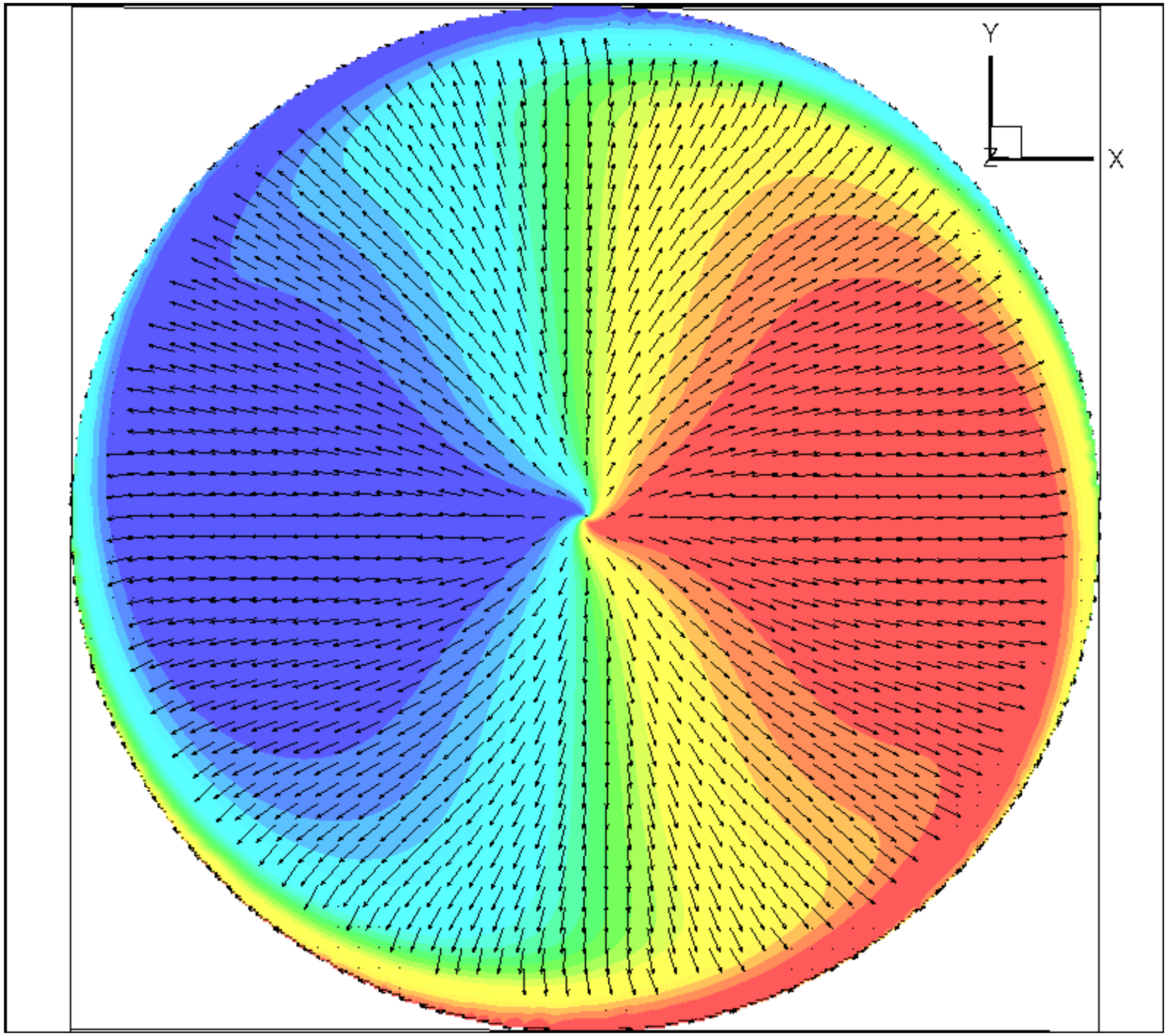
- Zero field: Dot consistent with stacked vortices, but details do not quite agree with vortex configuration
- Static field response: dot moves about 45° to field direction. Vortex core should move perpendicularly to field direction
- Dots split apart and move away from 45° direction
- This is not consistent with vortex configurations

Micromagnetic modeling

- 2 µm diameter Py discs (H_K=0), thickness 20 nm, A=1.3 erg/cm
- Antiferromagnetically coupled through infinitely thin layer; coupling=-0.025 erg/cm^2 (-15.6 Oe coupling field)
- Demagnetizing field calculated using fast Fourier transforms on 5 nm x 5 nm x 5nm mesh
- Damping typically α=0.25 (statics), time-integration using a modified Bulirsch-Stoer adaptive integrator

Zero-field magnetization states

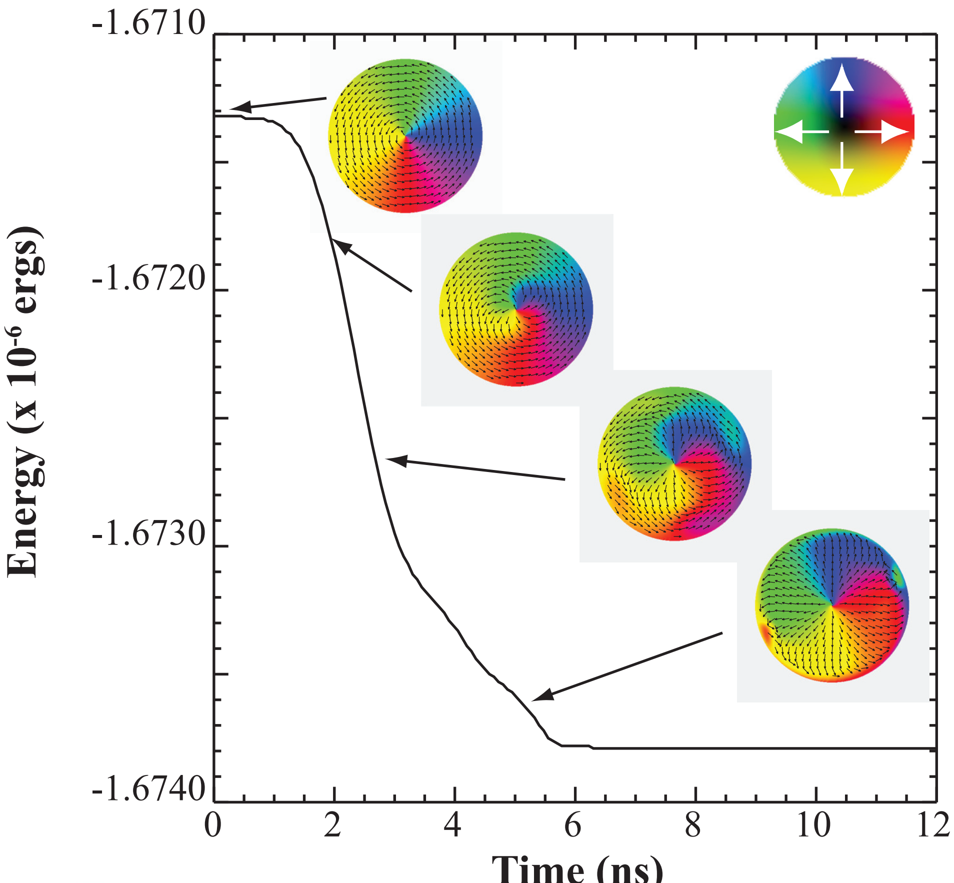
Initial state is vortices with **same** chirality, AFM interlayer coupling

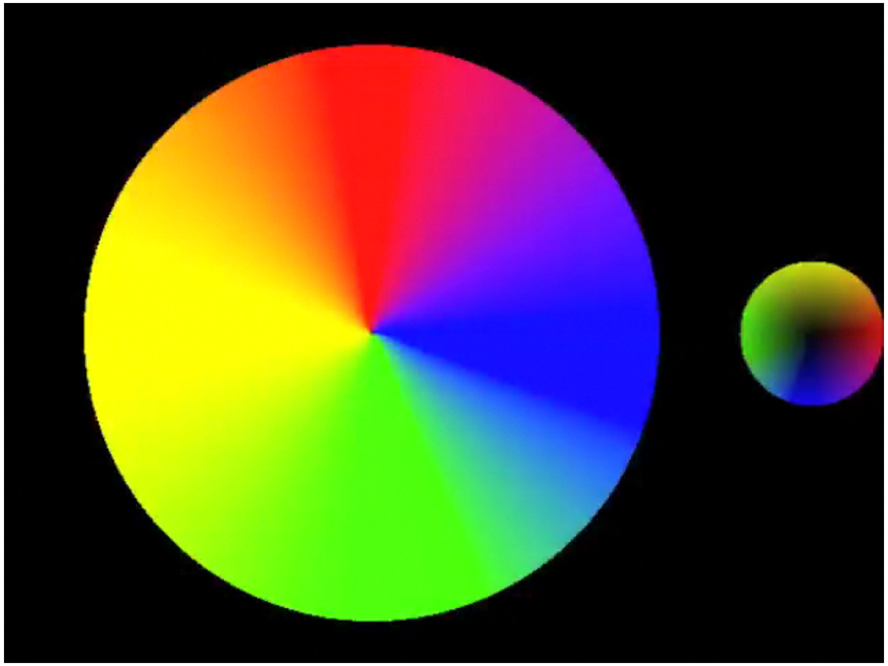


It's a meron!

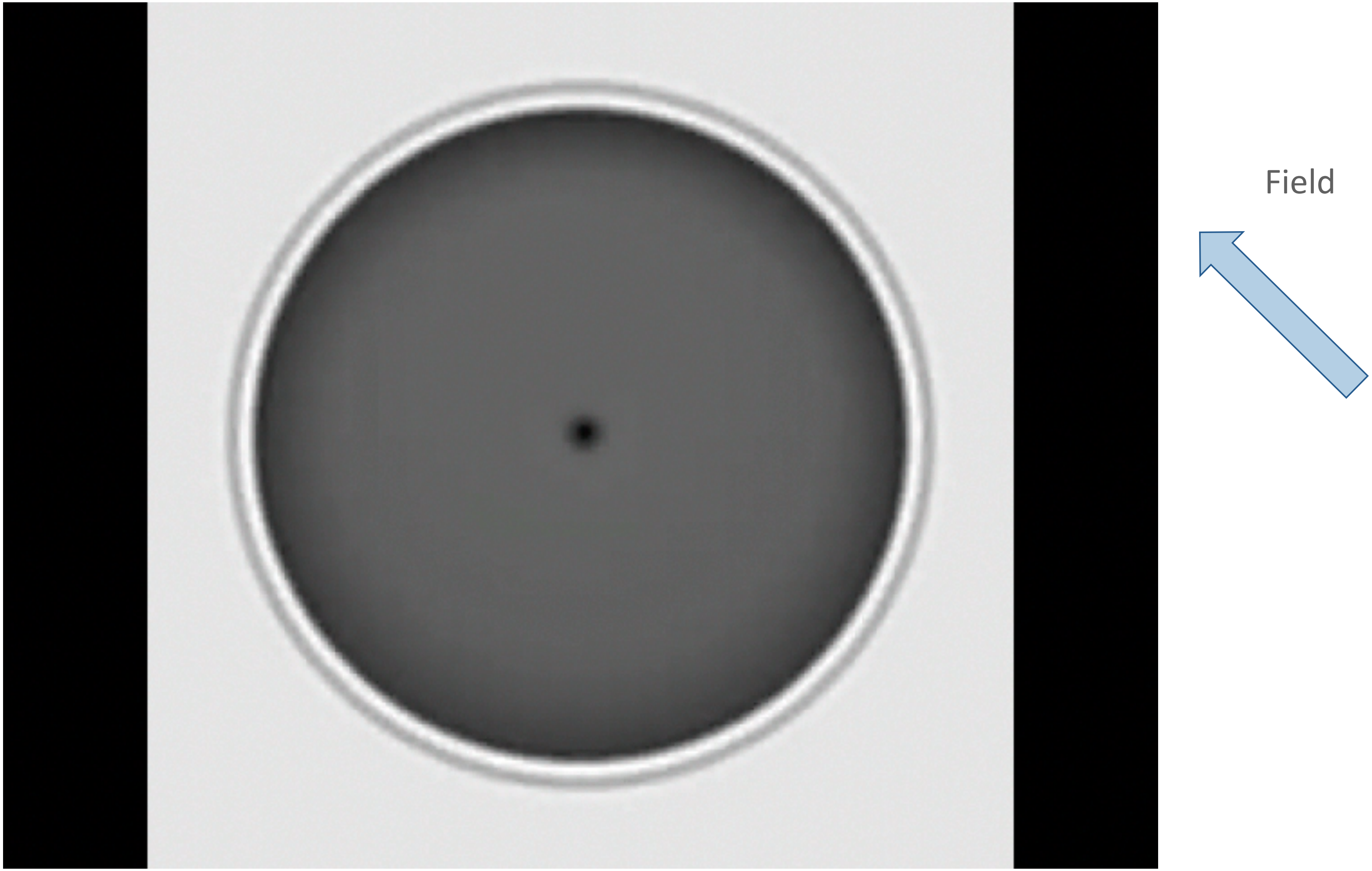
Relaxation from initial FM vortices

Relaxation of initial FM vortices to meron state





Simulated quasi-static response



Summary quasi-static response

- Initial FM vortices will deform to a meron state (two merons) but will not continue to deform to AFM vortices
- Simulated images and quasi-static response are consistent with experimental observations
- Configuration with AFM vortices has **lower** energy than meron state
- Speculate that the deposition process and spatial variations initially align magnetization along edges ferromagnetically – the structure will then deform to a meron state as the deposition continues
- Quasi-static field response is (almost) Goldstone-like – the cores can move along degenerate trajectories; experimental inhomogeneities will pin cores at fixed field. Increasing field and thermal fluctuations will move cores further

Summary and conclusions

- A weak antiferromagnetic coupling between to discs can give rise to an un-anticipated structure – “meron”
- Lorentz TEM images and micromagnetic simulations agree very well
- Meron response to quasi-static field is weird – cores can slide around in a static field
- Meron dynamics is very different from dynamics of FM or AFM vortices – slow breathing-like modes