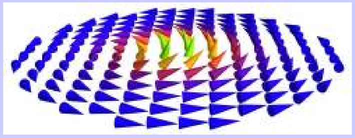
Resonant modes of coupled magnetic nanodisks



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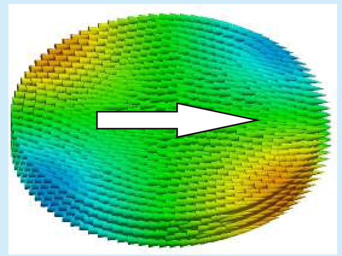
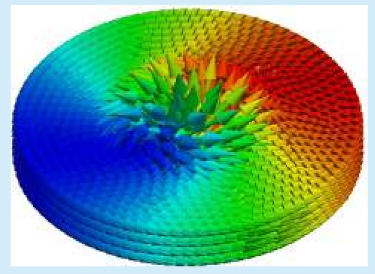
Motivation

Interacting magnetic nano-elements with tailored magnetic configurations [1] have a wide range of applications, from magnetic logic [2] to radio-frequency and microwave signal generation, in particular if they are incorporated into spin torque nano-oscillators (STNOs). [3,4]. Here we study the stability and resonant modes of metastable states in coupled nanodisks in view of these applications.

Ground states of individual nanodisks



Quasi-uniform state (small diameter)

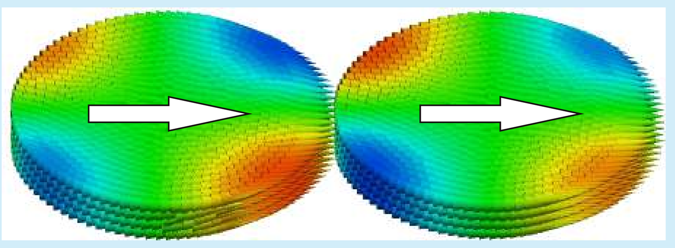


Vortex state (larger diameter)

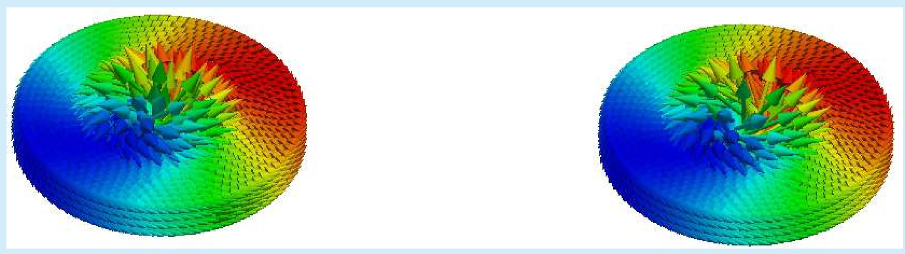
There exists a transition region of intermediate diameter where both states are metastable.

Pairs of nanodisks: metastable coupled states

- Uniform state is stabilized in closely spaced disks through flux closure of the stray fields near the edges:

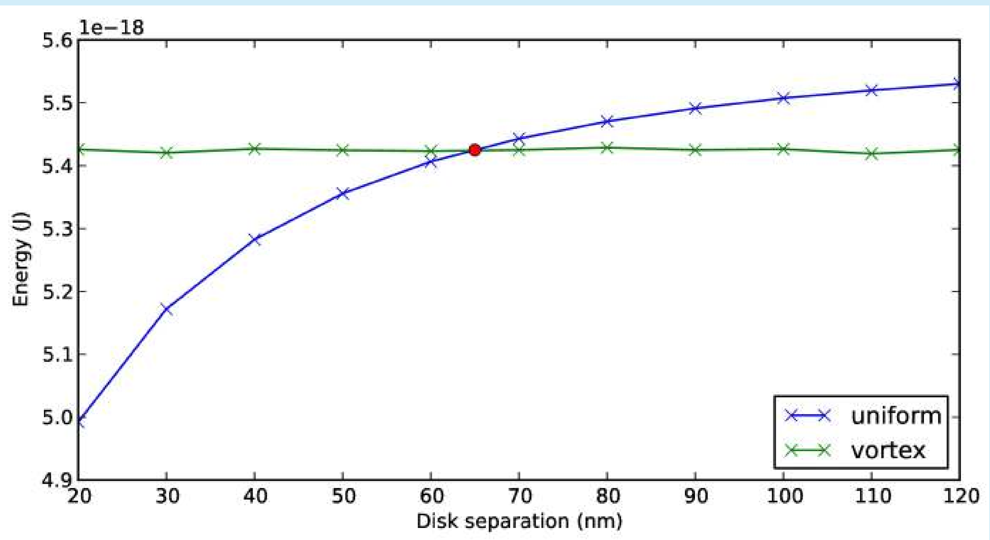


- Vortex state is favourable in disks that are far apart:



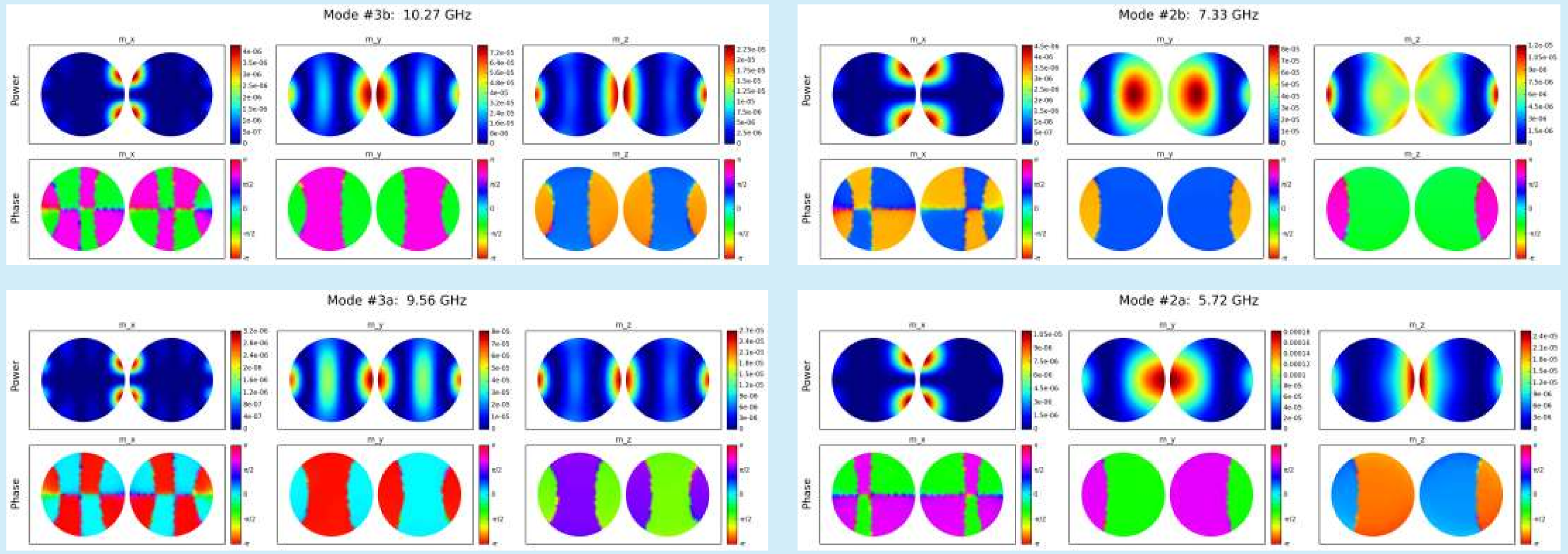
Dependence of coupled disk energy on distance

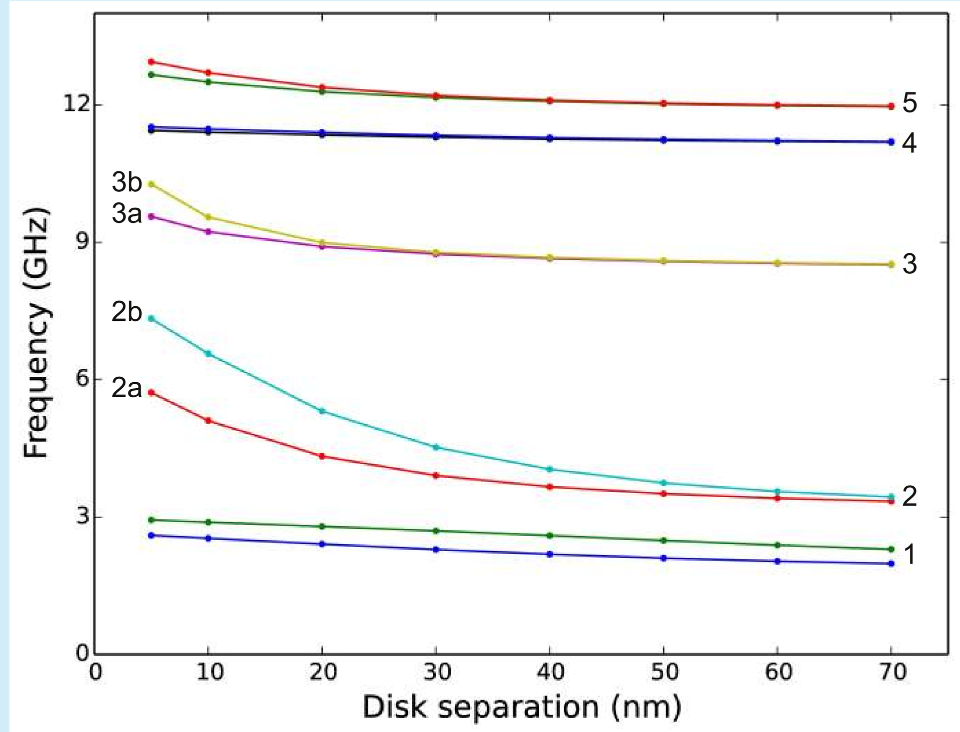
(diameter: 85 nm, thickness: 10 nm)

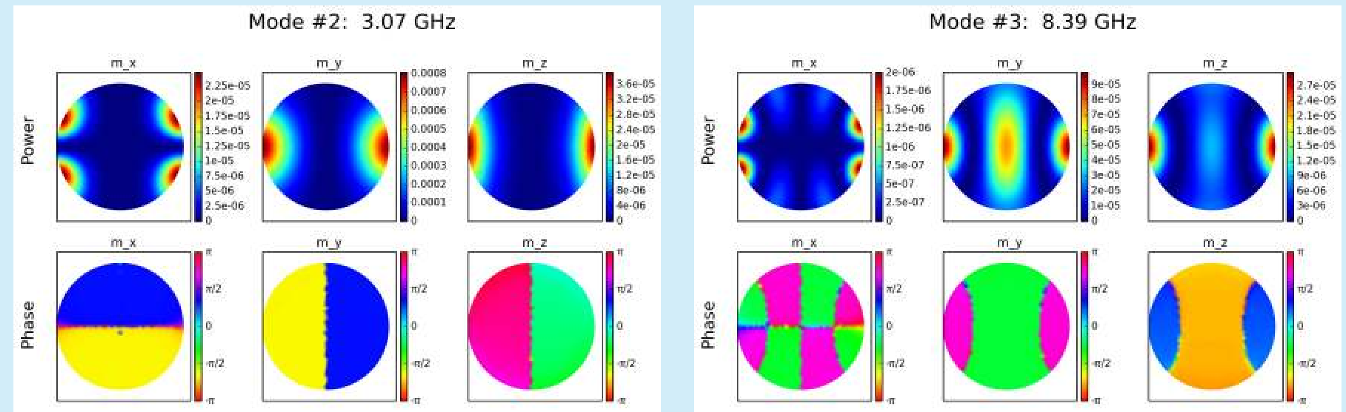


Strong coupling: frequency splitting and mode deformation

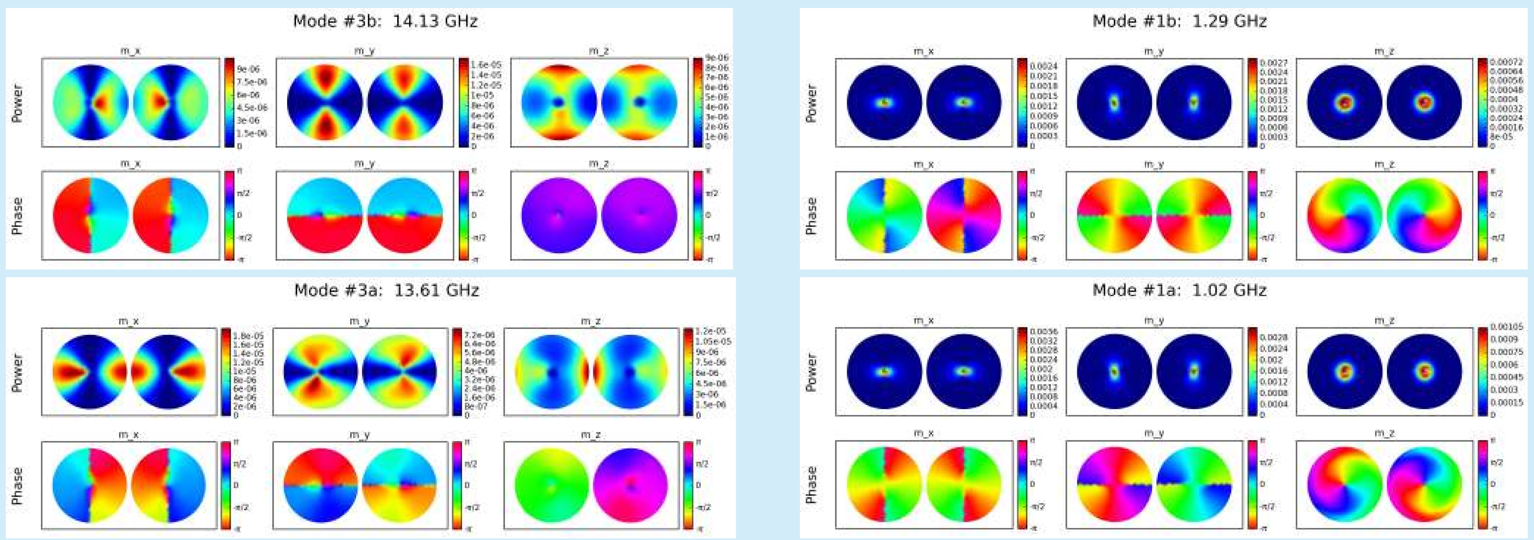
Uniform state

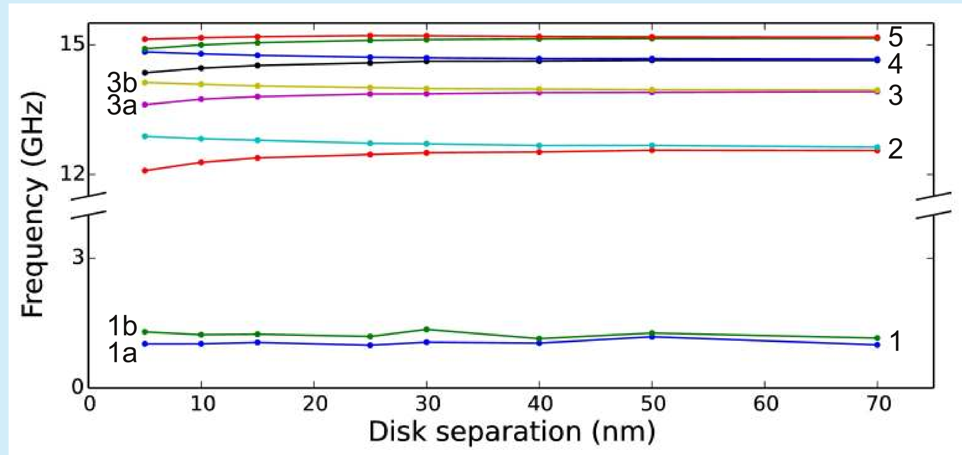


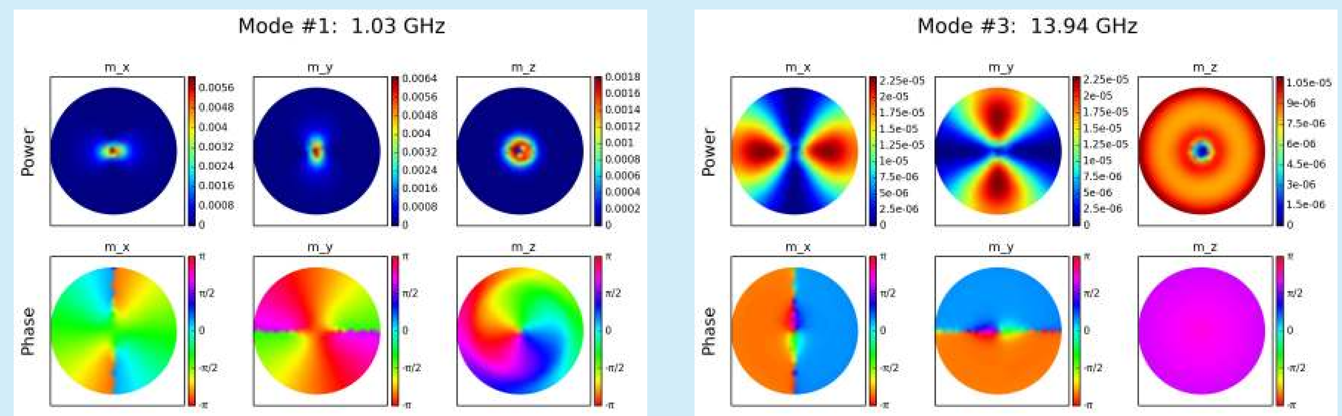




Vortex state







Computation of resonant modes

All calculations were performed using the finite-element based micromagnetic simulation framework "Finmag" (successor of Nmag [5]).

(i) **Ringdown method:** [6]

- Relax into desired equilibrium state in presence of small perturbing field.
- Switch off field & record dynamics as m relaxes back into equilibrium.
- Compute power spectrum via Fourier transform of magnetisation dynamics.

(ii) **Eigenvalue method**: [7]

- Linearize Landau-Lifshitz-Gilbert equation around equilibrium state m_0.
- Sinusoidal ansatz solution for Δm (where $m = m_0 + \Delta m$) leads to a (generalized) eigenvalue problem.
- The resulting eigenvalues and eigenvectors yield the resonant frequencies and mode profiles.

Conclusions

- Dipolar coupling between closely spaced nanodisks leads to stabilization of the single-domain state.
- Magnetostatic coupling also results in deformations of the resonant modes & frequency splitting (=> in-phase vs. out-of-phase oscillations of neighbouring edges) — both in the uniform and vortex state.
- Coupled modes converge towards the single-disk modes as the disk separation increases.
- Stronger coupling effects & mode alterations are observed for uniform configuration than vortex configuration.

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