Chiral Edge Mode in the Coupled Dynamics of Magnetic Solitons

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Vortex ground state of a permalloy microdisk

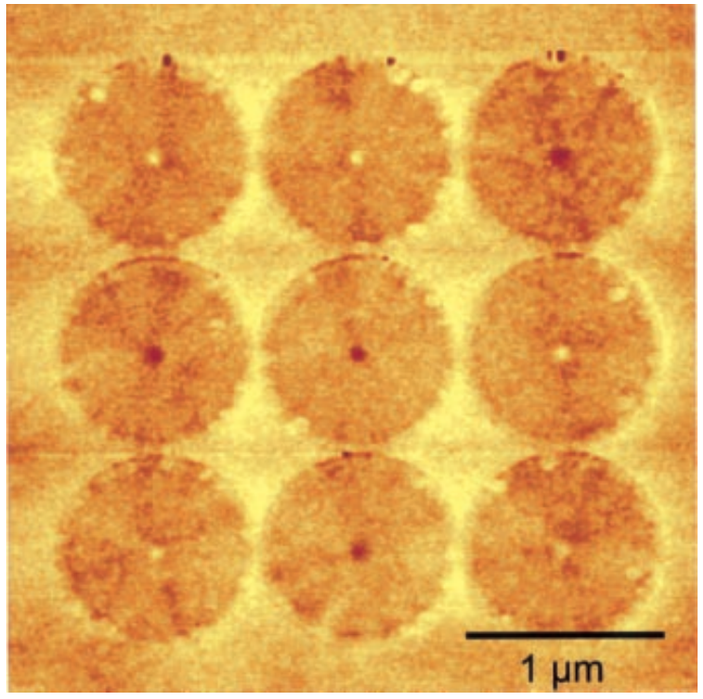
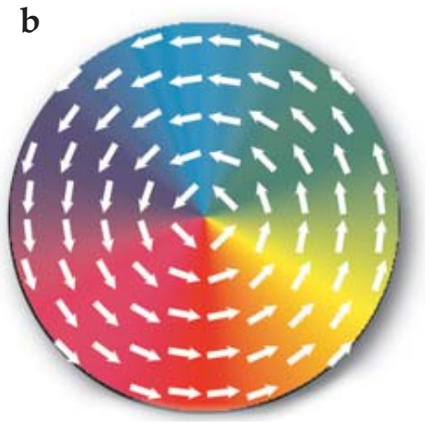


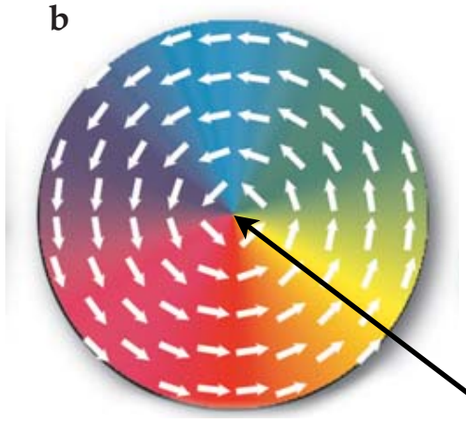
Fig. 2. MFM image of an array of permalloy dots 1 μm in diameter and 50 nm thick.

Shinjo et al, *Science* (2000)



Chien et al, *Physics Today* (2007)

The dynamics of a vortex core

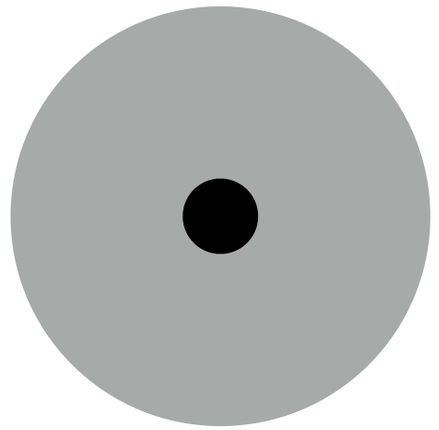


$$\mathbf{R}(t) = (X(t), Y(t))$$

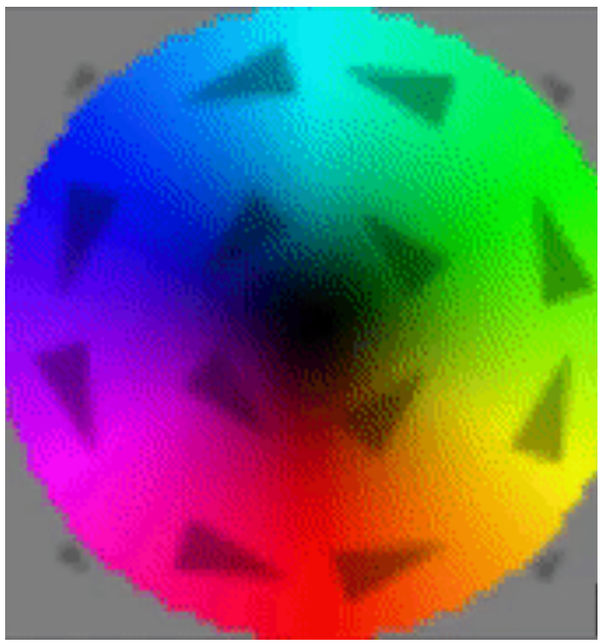
The low-energy dynamics of a vortex disks can be captured by the dynamics of the vortex-core position.

Pinning potential: $U(\mathbf{R}) = K\mathbf{R}^2/2$

Force: $F = -K\mathbf{R}$



The gyrotropic dynamics of a vortex core



Force: $\mathbf{F} = -K\mathbf{R}$

Velocity: $\frac{d\mathbf{R}}{dt} \perp \mathbf{F}$

Why is the velocity perpendicular to the force?

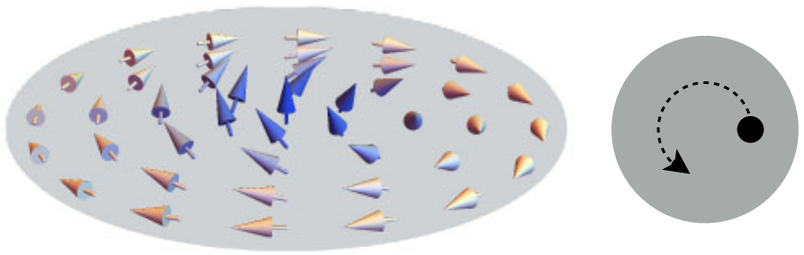
* video credit: Magnetic Kaleidoscope: https://www.youtube.com/watch?v=Lw-N25yclaQ

The gyrotropic dynamics of a vortex core

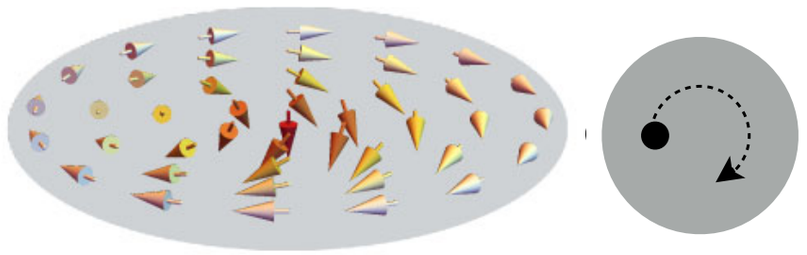
equations of motion: $G\frac{d\mathbf{R}}{dt} \times \hat{\mathbf{z}} = \mathbf{F} = -K\mathbf{R}$ resonant frequency: $\omega \equiv K/G$

$$G = -2\pi stp$$

spin density — **polarity** (odd in time reversal) — disk thickness



$p = +1$

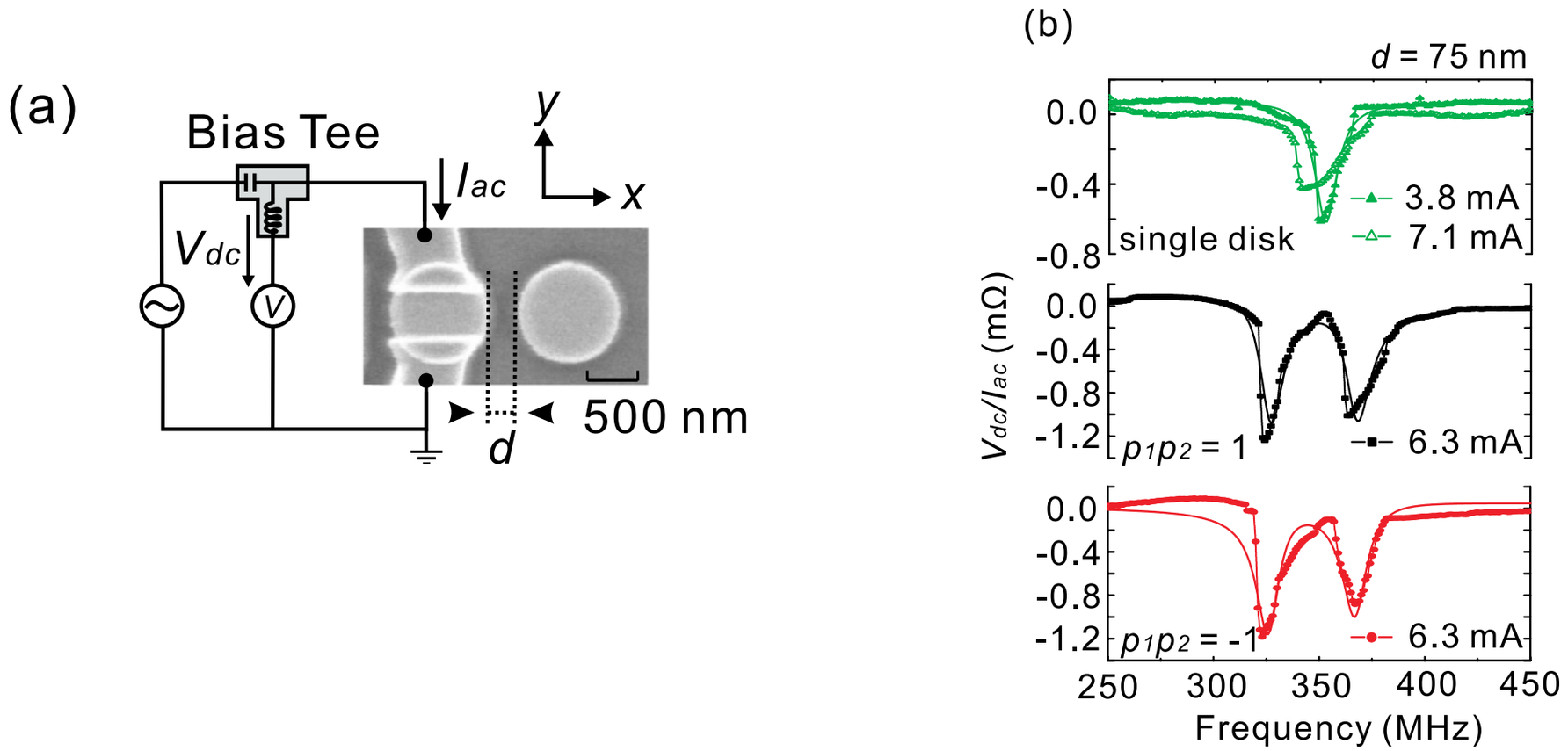


$p = -1$

The **polarity** of a vortex determines the **gyration direction**.

Thiele, *PRL* (1972)

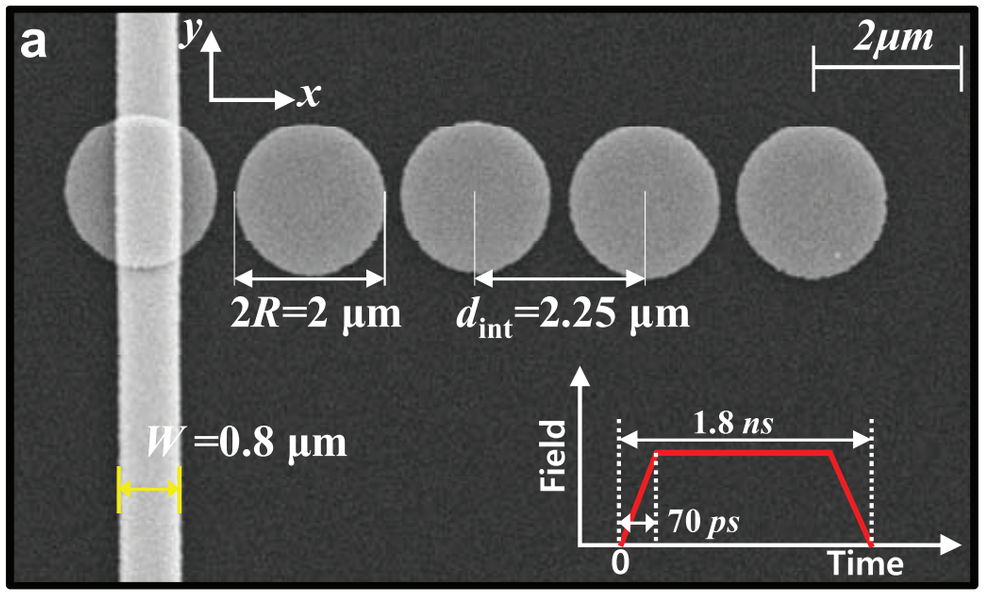
The dipolar-coupled dynamics of two vortices

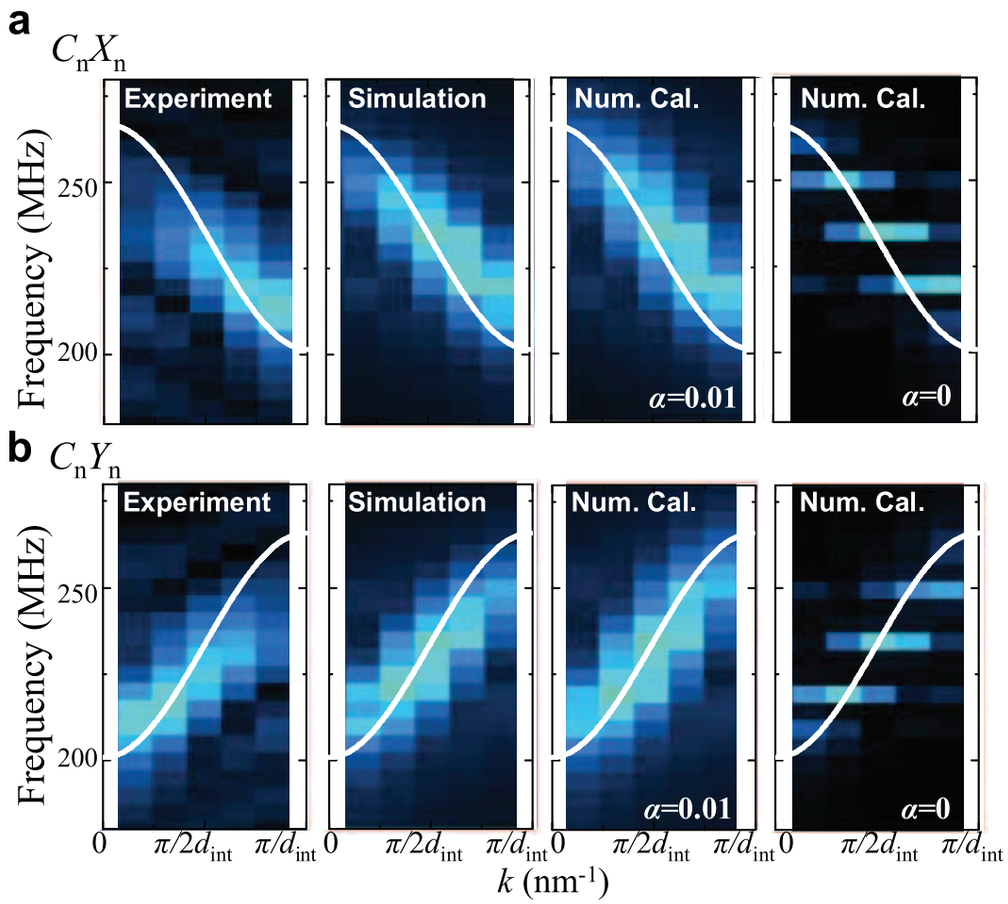


Sugimoto et al, *PRL* (2010)

coupled pair of vortices = diatomic molecule with bonding and antibonding states

The dipolar-coupled dynamics of five vortices

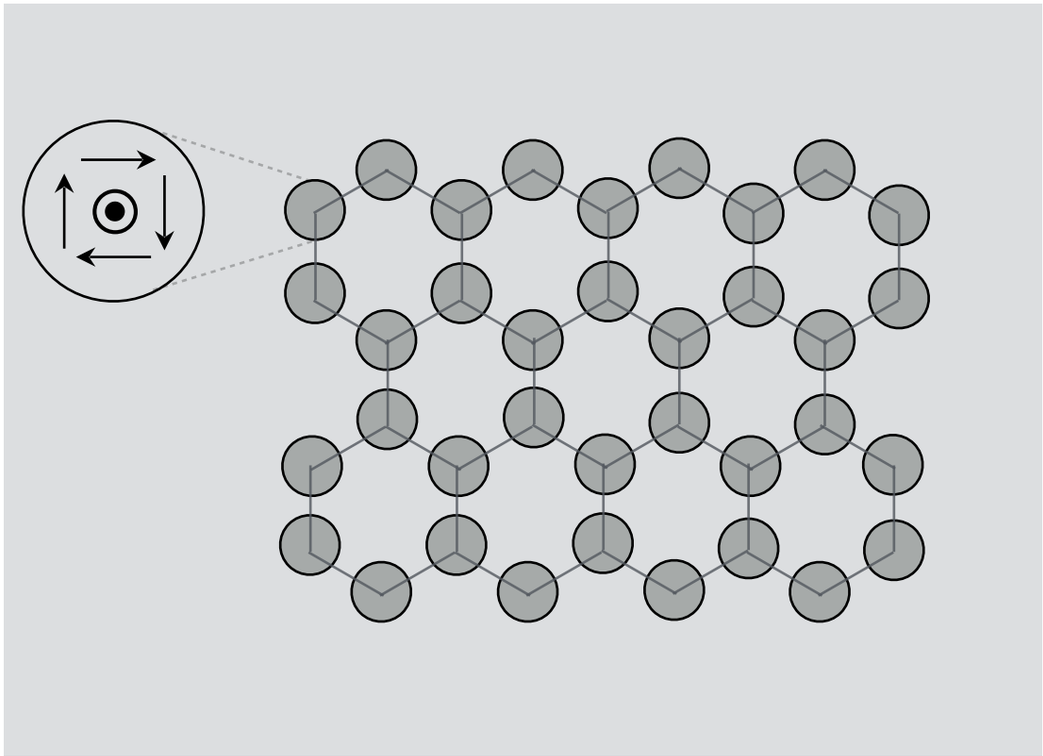




dispersion relation of the coupled dynamics

Han et al, *Sci. Rep.* (2013)

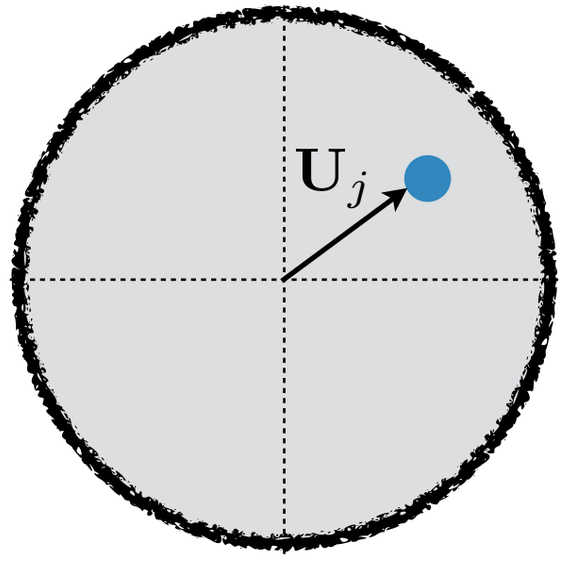
The dipolar-coupled dynamics of many vortices?



SKK and Tserkovnyak, *PRL* (2017)

The dipolar-coupled dynamics of many vortices?

equations of motion for jth vortex core: $G\hat{\mathbf{z}} \times \dfrac{d\mathbf{U}_j}{dt} + \mathbf{F}_j = 0$



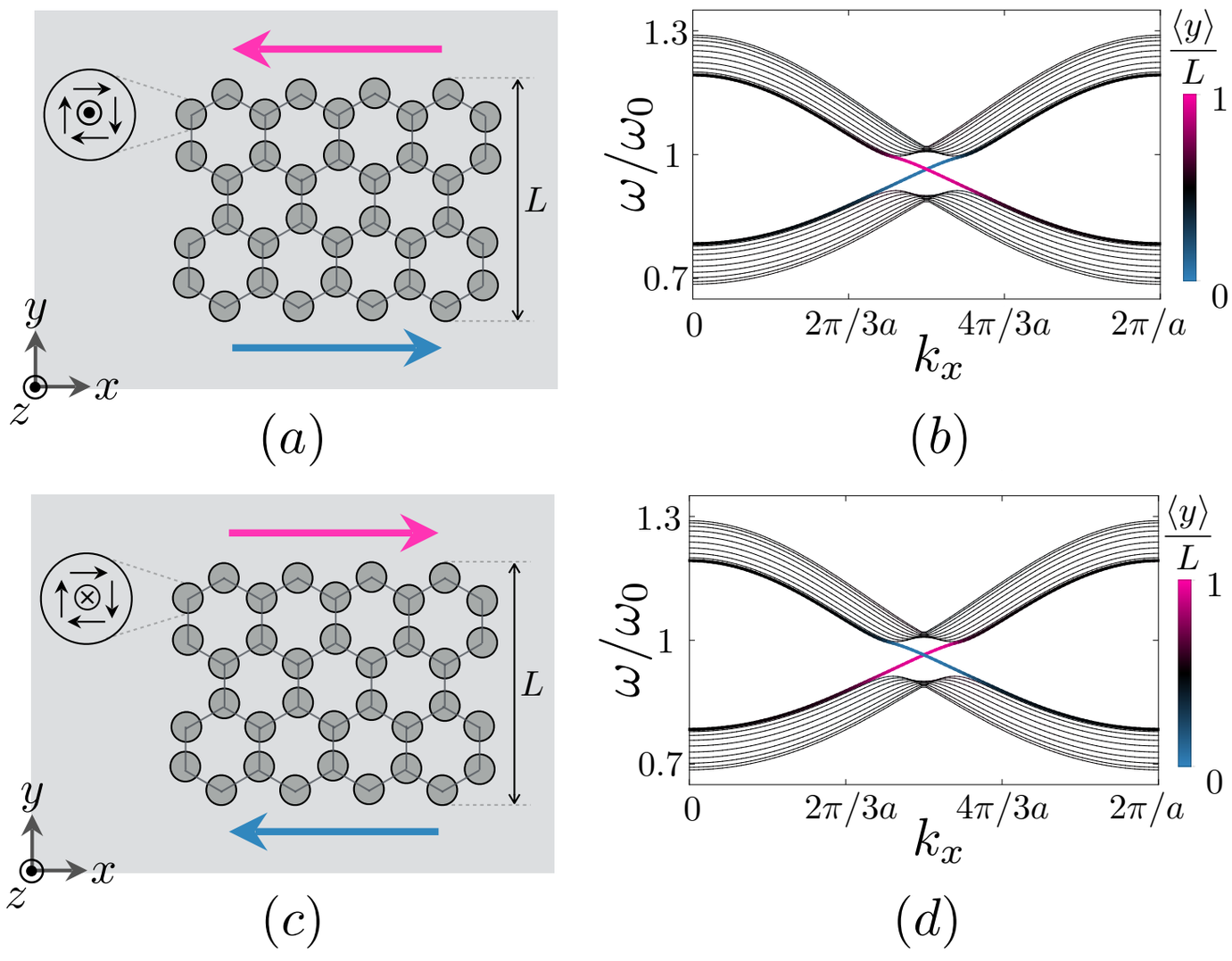
core displacement: $\mathbf{U}_j = \mathbf{R}_j - \mathbf{R}_j^0$

conservative force: $\mathbf{F}_j = \dfrac{\partial U}{\partial \mathbf{U}_j}$

potential energy: $U = \sum_j K\mathbf{U}_j^2/2 + \sum_{j\neq k} U_{jk}/2$

SKK and Tserkovnyak, *PRL* (2017)

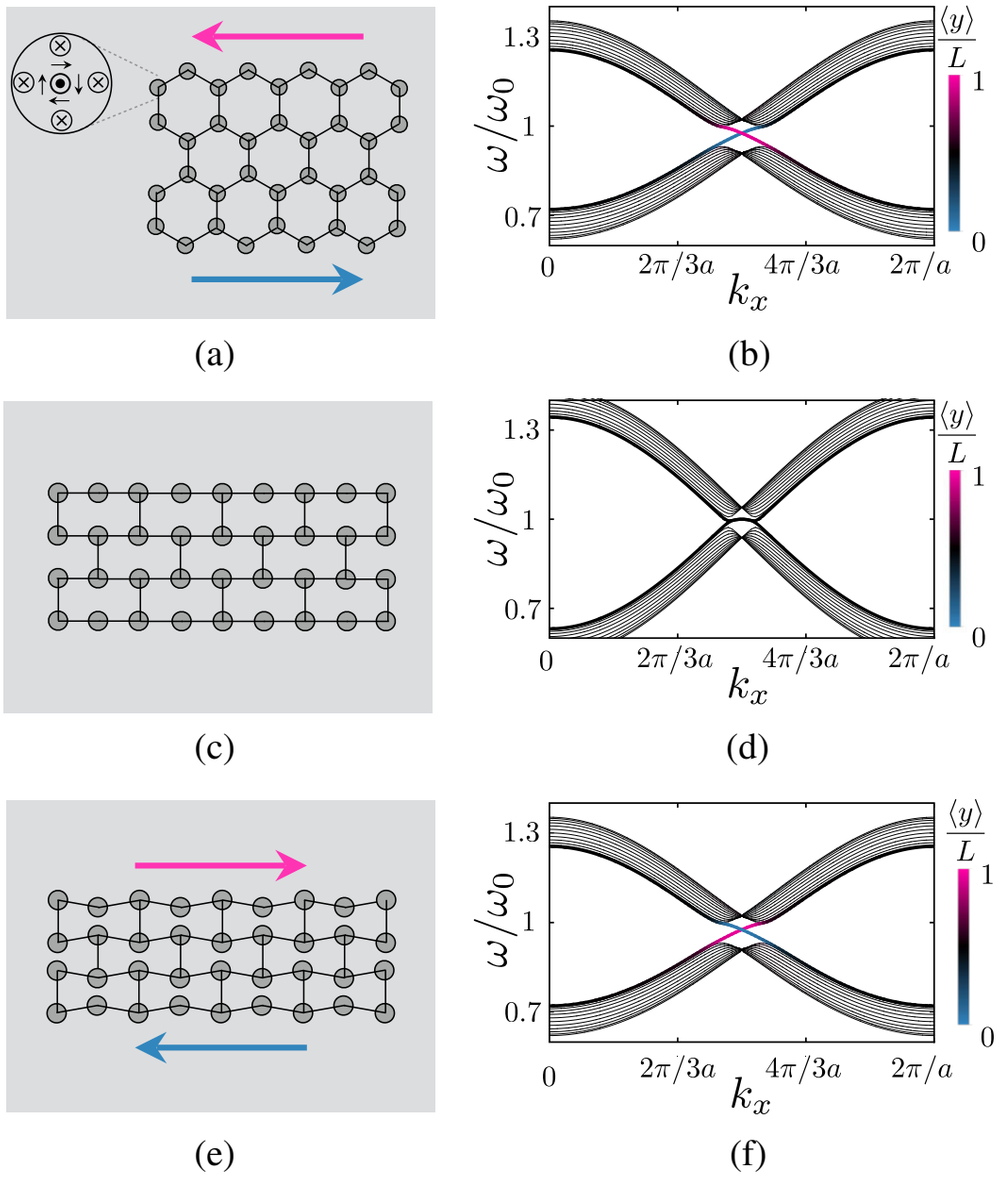
Topological edge mode in honeycomb vortex lattice



The honeycomb lattice of vortex disks supports a **chiral edge mode** in the coupled gyration dynamics. The **chirality** is determined by the **polarity** of the constituent vortices.

SKK and Tserkovnyak, *PRL* (2017)

Topological edge mode in honeycomb skyrmion lattice



The **chirality** can be changed by **distorting** the honeycomb lattice.

SKK and Tserkovnyak, *PRL* (2017)

New research area: soliton-based metamaterial

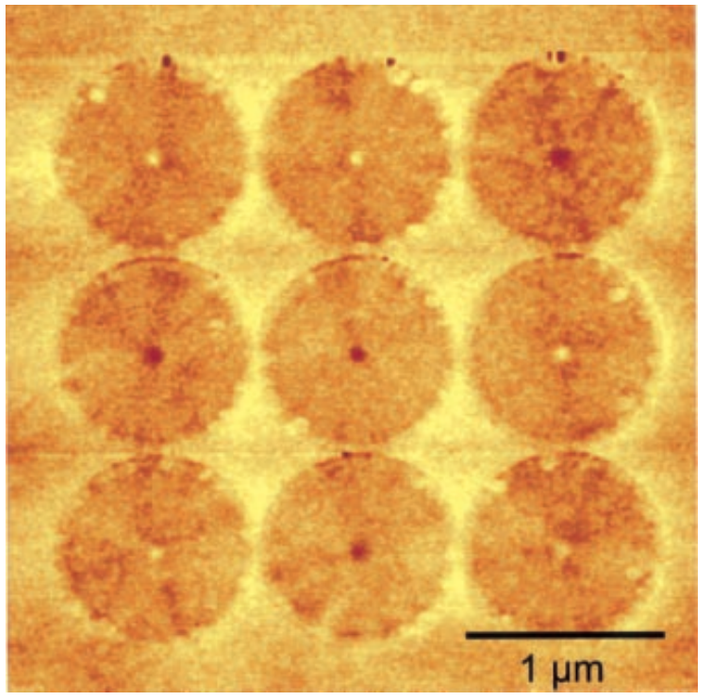
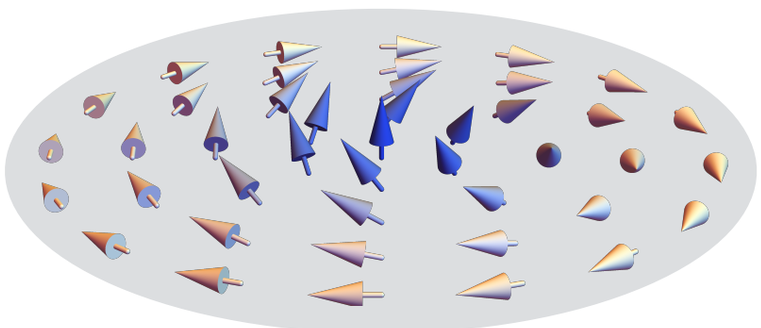


Fig. 2. MFM image of an array of permalloy dots 1 μm in diameter and 50 nm thick.

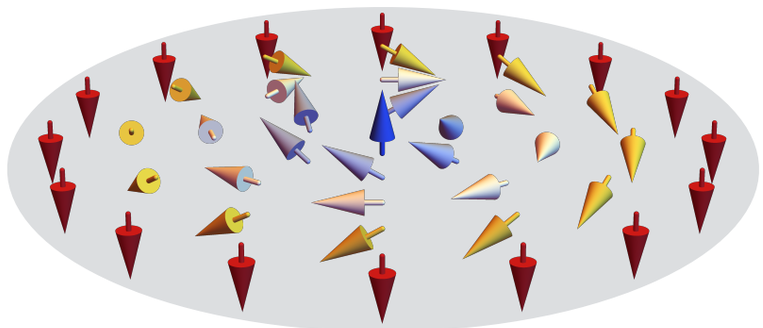
= metataoms with the topological stability

We can create **metamaterials** with **soliton metaatoms**,
which can exhibit novel phases and can provide unusual functionalities.

The new collection of metaatoms

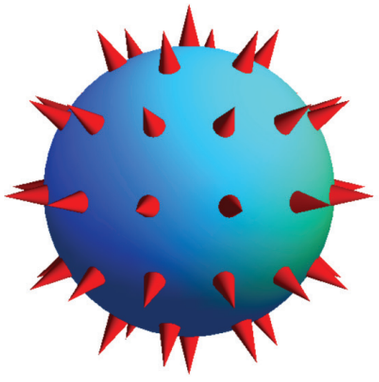


vortex

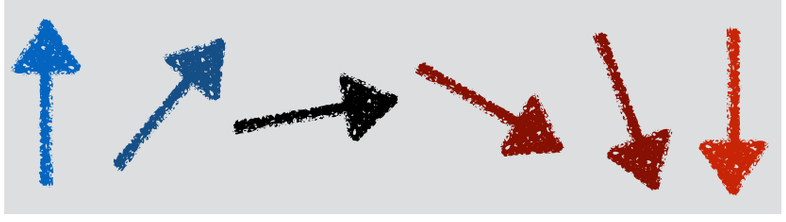


skyrmion

Thank you!



monopole



domain wall