Attractive Magnon Polarons

Chensong Hua (华辰松), Chongzhou Wang (汪崇州), and Weichao Yu (余伟超)

22110190020@m.fudan.edu.cn

Institute for Nanoelectronic devices and Quantum computing, Fudan University, Shanghai 200433, China.

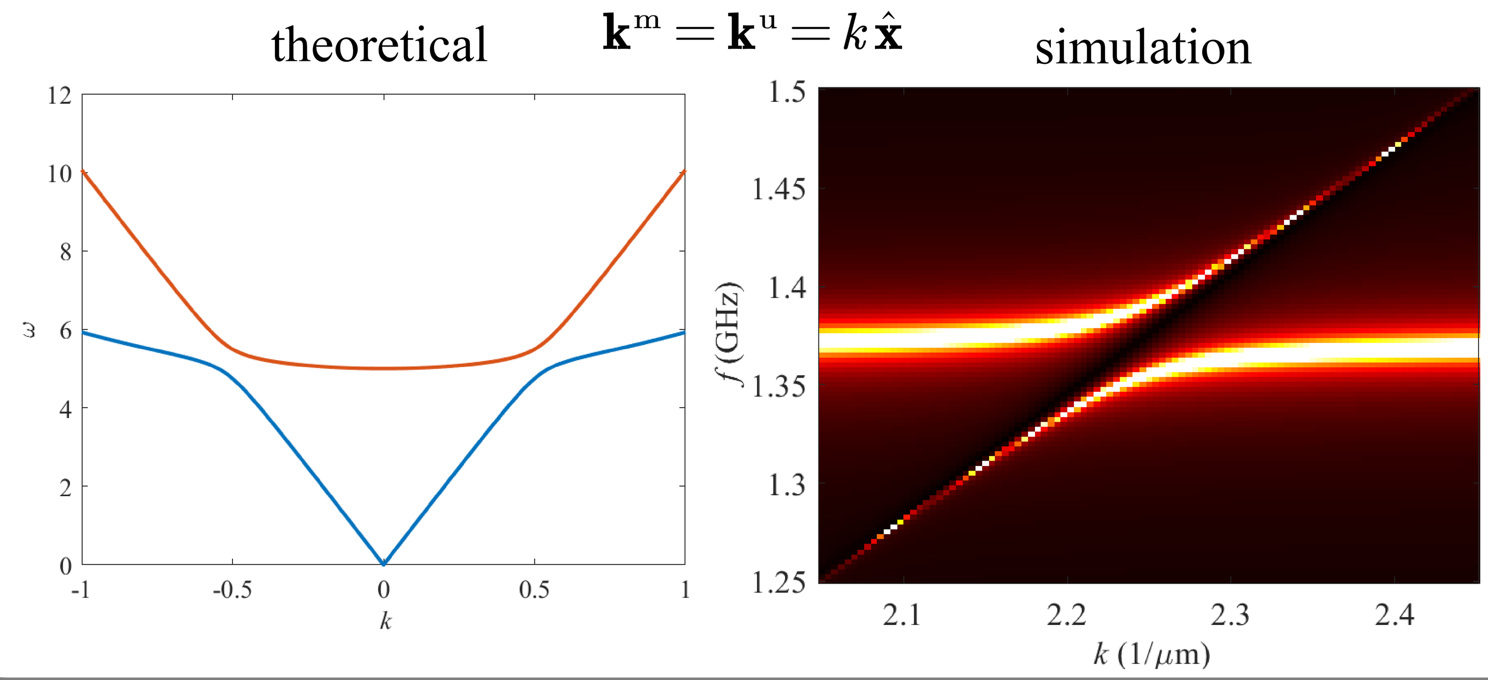
Abstract: Magnon polarons are the hybrid excitation modes between magnons and phonons, which tend to form repulsive level anti-crossings in spectra. Here we proposed a level attraction mechanism for the magnon polaron system. With a transverse attenuation in the magnon mode, the propagating magnon polaron will show a chiral level attraction in the reciprocal space. This model can be mapped to three different finite size magnonic systems: the easy-axis surface anisotropic magnons, the magnetostatic surface magnons, and the topological edge magnons in the skyrmion lattice. This finding may pave the way for the research in non-Hermitian magnonic band structures.

Magnon Polaron: Level Repulsion (LR)

The dynamics of magnons can be illustrated by the Landau-Lifshitz-Gilbert (LLG) equation, while the phonons can be described by the Navier-Lamé (NL) equation. The magnetoelastic coupling energy connects these two quasiparticles and forms hybrid excitations called the magnon polarons. Homogenous plane wave magnon polarons will show repulsive energy anti-crossings.

- **Magnon - LLG:** $i\omega\delta\mathbf{m} = \gamma\mathbf{m}_0\times\delta\mathbf{h} + \gamma\delta\mathbf{m}\times\mathbf{h}_0 + i\omega\alpha\mathbf{m}_0\times\delta\mathbf{m}$
- **Phonon - NL:** $-\rho\omega^2\delta\mathbf{u} = \mu\lambda\nabla^2\delta\mathbf{u} + (\lambda+\mu)\nabla(\nabla\cdot\delta\mathbf{u}) + \delta\mathbf{f}$

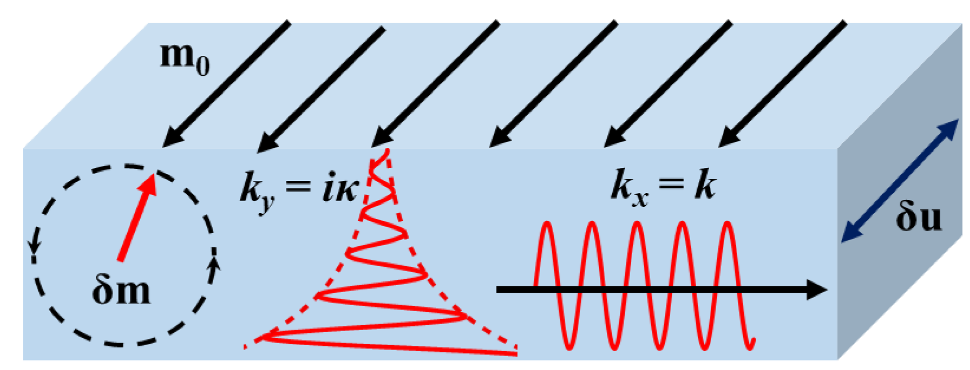
theoretical $\mathbf{k}^{\mathrm{m}} = \mathbf{k}^{\mathrm{u}} = k\hat{\mathbf{x}}$ simulation

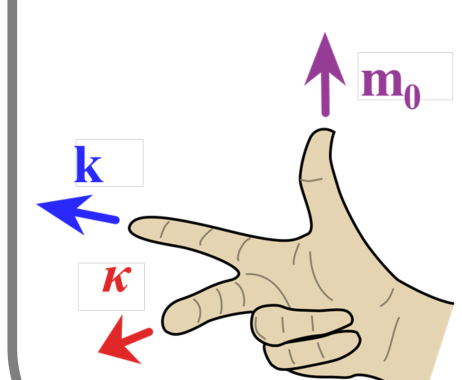


Magnon Polaron: Level Attraction (LA)

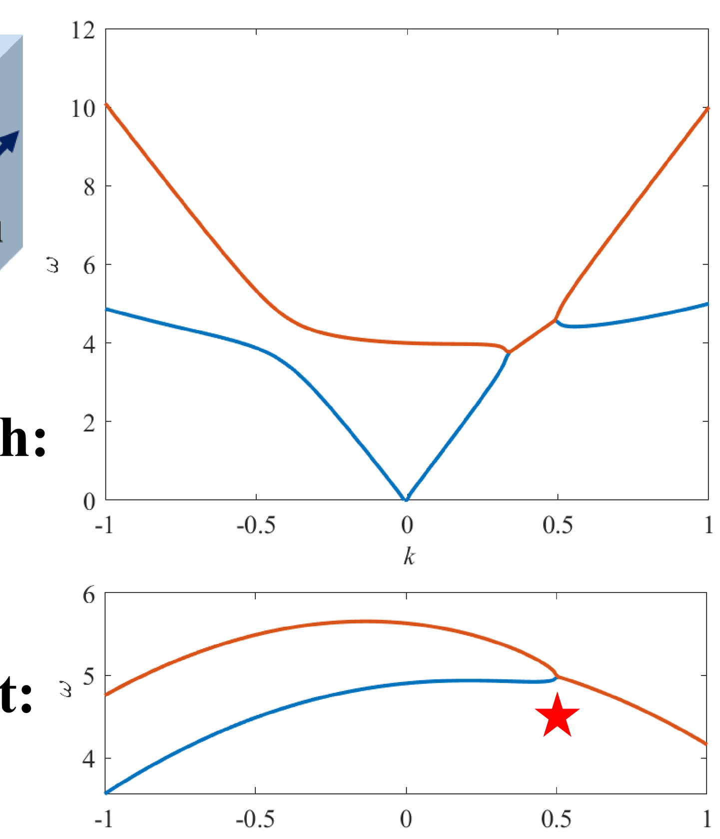
Level attraction will happen when the magnon mode has a specific transverse attenuation where the propagating direction, the evanescent direction, and the magnetization direction satisfy the right-handed chirality. In such a situation the magnon-phonon coupling strength can be purely imaginary and thus the system is a non-Hermitian one.

- **Magnon:** $\mathbf{k}^{\mathrm{m}} = k\hat{\mathbf{x}} + i\kappa\hat{\mathbf{y}}$
- **Phonon:** $\mathbf{k}^{\mathrm{u}} = k\hat{\mathbf{x}}$



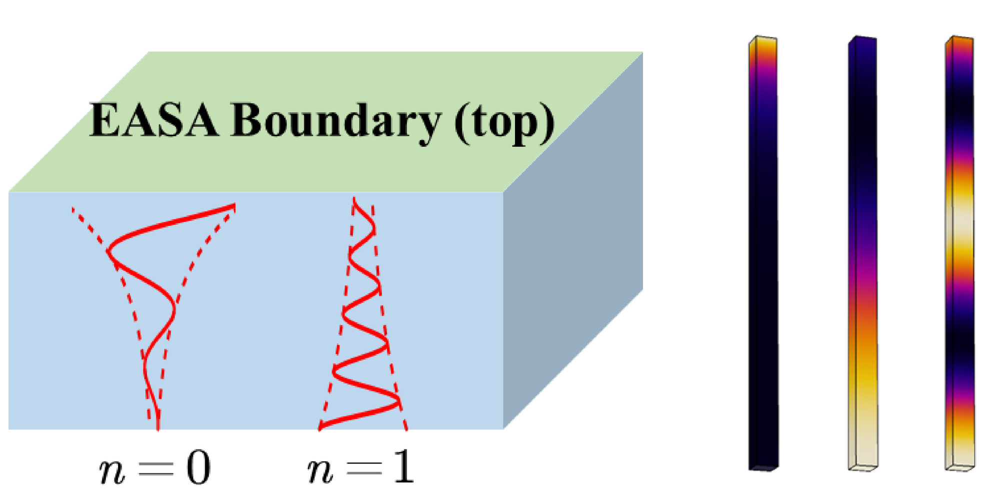


- **Coupling Strength:** $g = b_2\sqrt{\dfrac{\gamma k(k-\kappa)}{2\rho\mu_0 M_s}}$
- **Exceptional Point:** ★ $\kappa_0 = \dfrac{\gamma h_0}{c}$



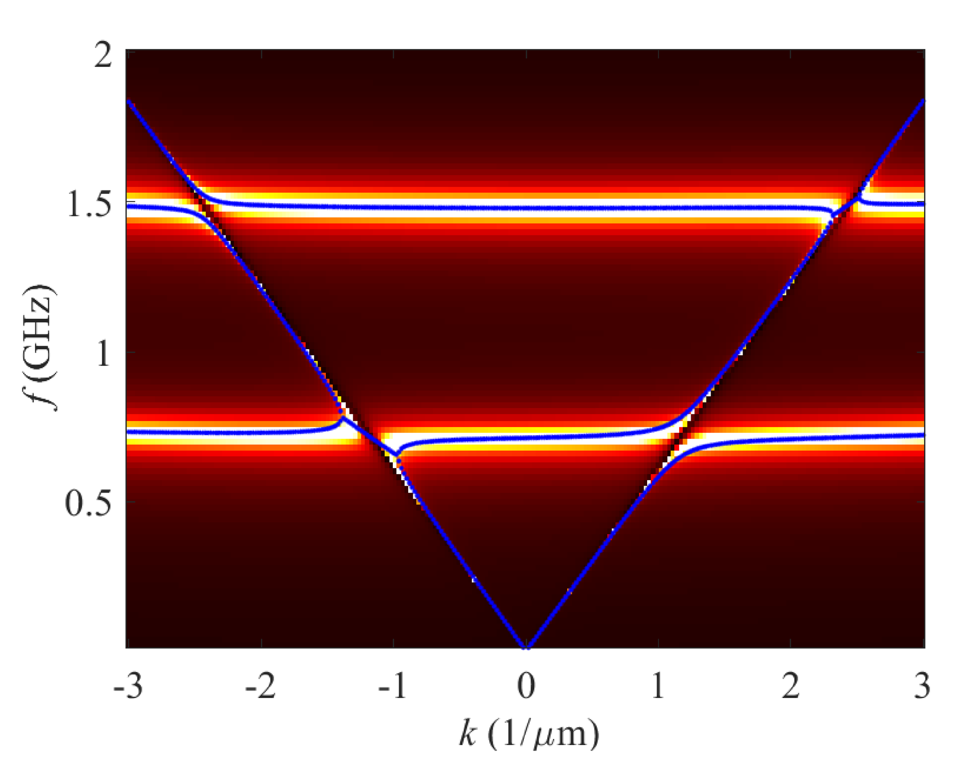
Easy-axis Surface Anisotropy

The easy-axis surface magnetic anisotropy (EASA) introduces an extra easy axis in the normal direction, thus generating surface spin wave modes on the boundary for small mode numbers n. For a specified EASA boundary, magnon polarons propagating along different directions show different LR/LA properties.



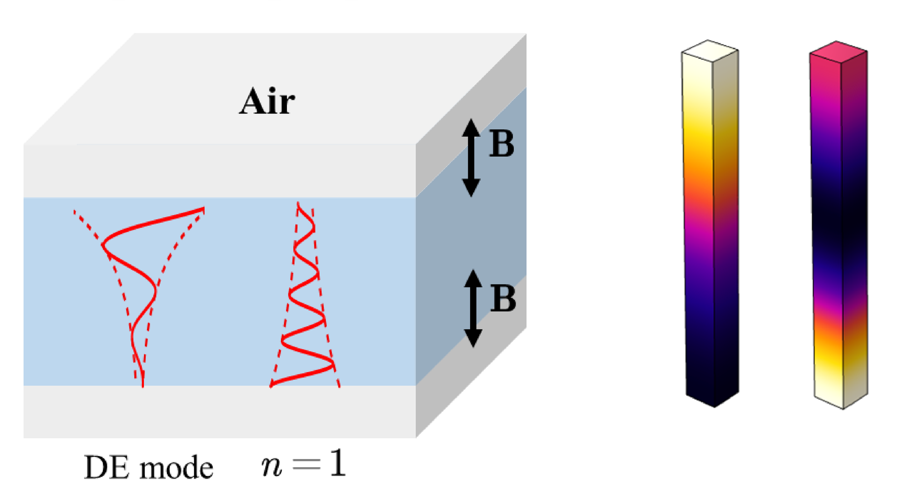
$$A\,\mathbf{m}\times\frac{\partial\mathbf{m}}{\partial\mathbf{n}} - K_s(\mathbf{m}\cdot\mathbf{n})\mathbf{m}\times\mathbf{n} = 0$$

$$\omega_n = \gamma\sqrt{[A(k^2+k_{y1}^{(n)2})+h_0]\,[A(k^2+k_{y2}^{(n)2})+h_0]}$$



Magnetostatic Surface Mode

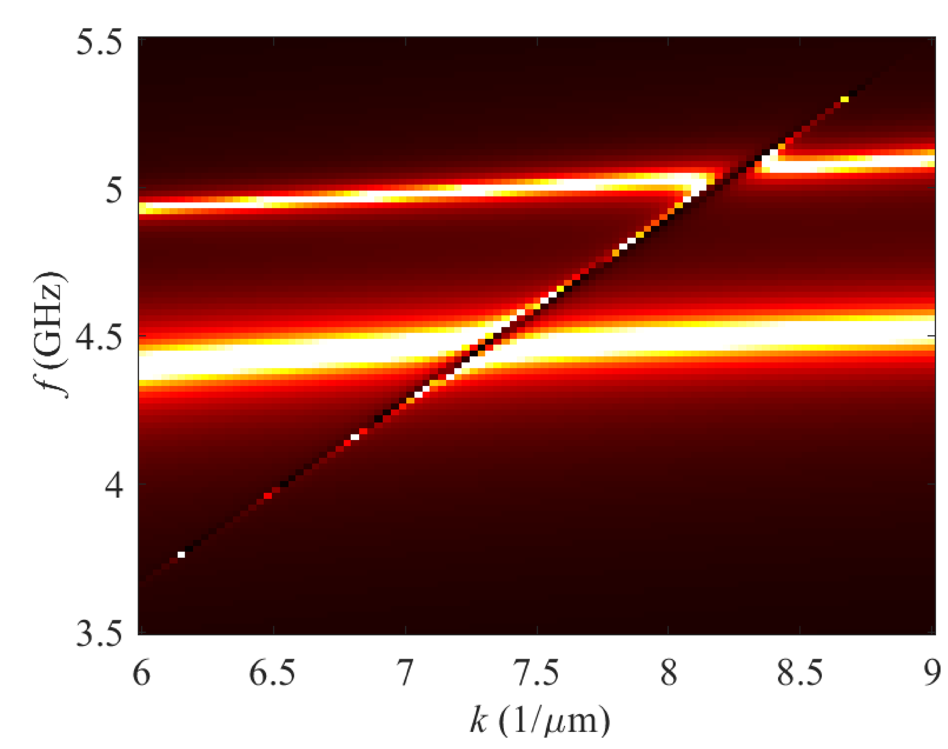
The magnetostatic surface mode is caused by the boundary conditions of the magnetic dipolar fields around the magnetic films. Because of the locked relations between the propagating direction and the evanescent direction, magnon polarons show the same LR/LA spectra properties in the same mode.



$$\mathbf{n}\cdot(\mathbf{B}_{\mathrm{in}} - \mathbf{B}_{\mathrm{out}}) = 0 \qquad \mathbf{n}\times(\mathbf{H}_{\mathrm{in}} - \mathbf{H}_{\mathrm{out}}) = 0$$

$$\omega_{\mathrm{DE}} = \gamma\sqrt{(h_0+M_s/2)^2 - (M_s/2)^2 e^{-2kd}}$$

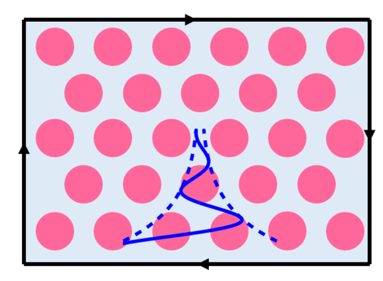
$$\omega_n = \gamma\sqrt{[h_0 + Ak^2 + A(n\pi/d)^2]\,[M_s + h_0 + Ak^2 + A(n\pi/d)^2]}$$

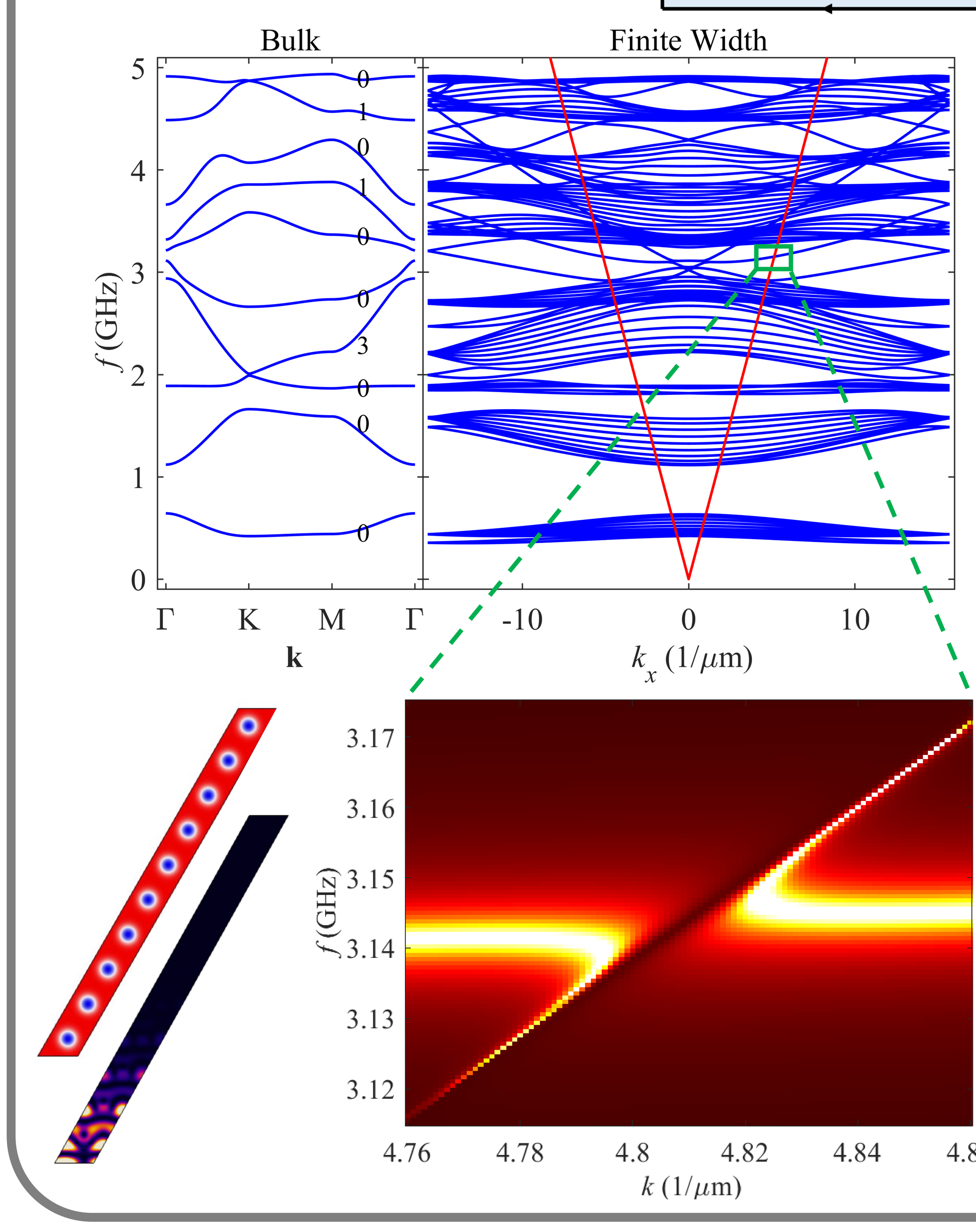


Topological Edge States in SkX

The skyrmion crystals (SkX) can support rich topologically non-trivial magnonic bands, which are described by the Chern numbers. In finite size systems, robust edge states appear because of the bulk-boundary correspondence. The relevant edge magnon polarons will show attractive spectra.

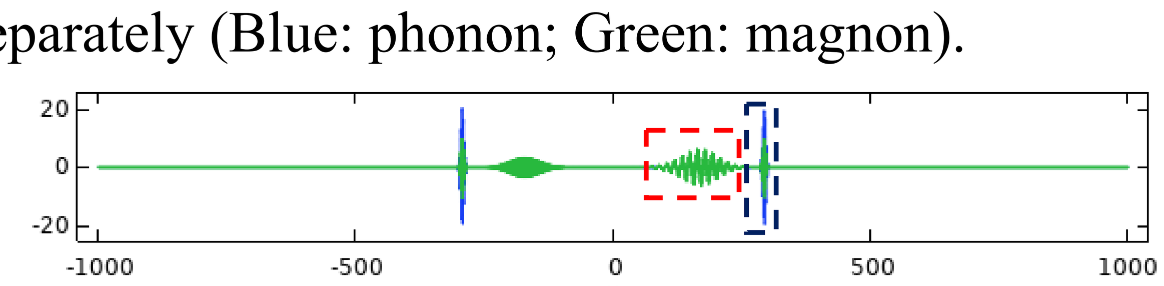
$$C_n = \frac{1}{2\pi}\int_{\mathrm{BZ}} d^2k\,\nabla\times i\langle u|\nabla|u\rangle$$

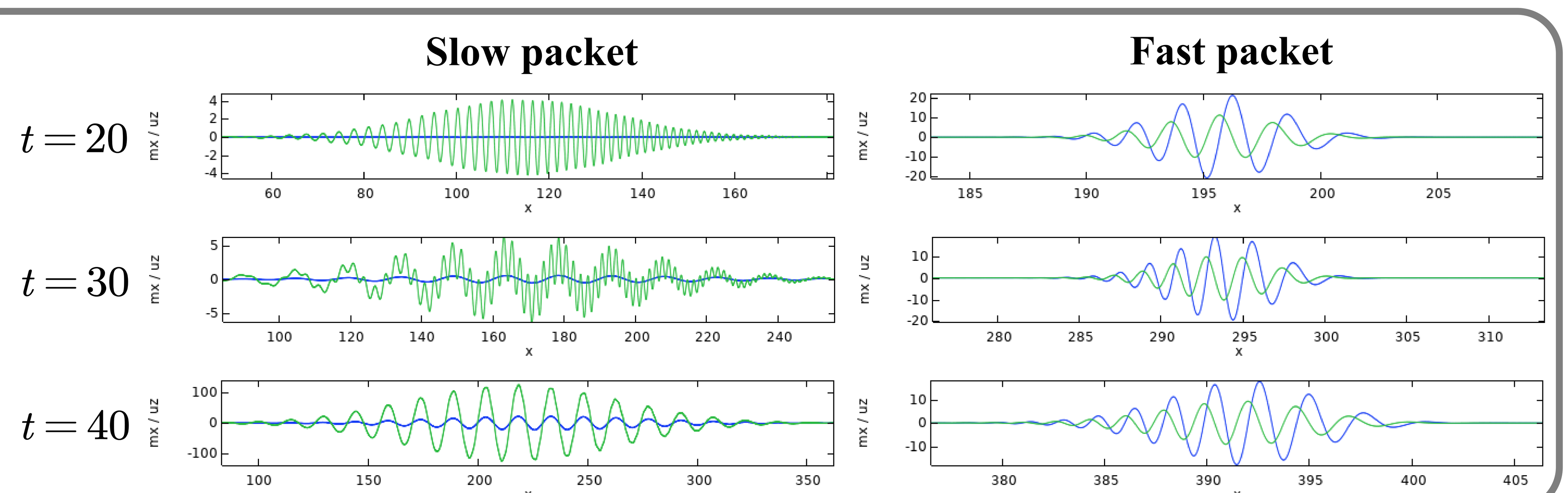




Time Evolution

If a phonon wave packet is generated at the initial time, the attractive magnon polaron will be excited as time evolves. This packet will split into a fast one and a slow one, which show 90° and 0° phase delay separately (Blue: phonon; Green: magnon).





Reference

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- Simulations are performed with the Micromagnetics Module for COMSOL Multiphysics developed by W. Yu et al.

https://cn.comsol.com/blogs/micromagnetic-simulation-with-comsol-multiphysics