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Magnon driven domain wall motion with Dzyaloshinskii-Moriya interaction

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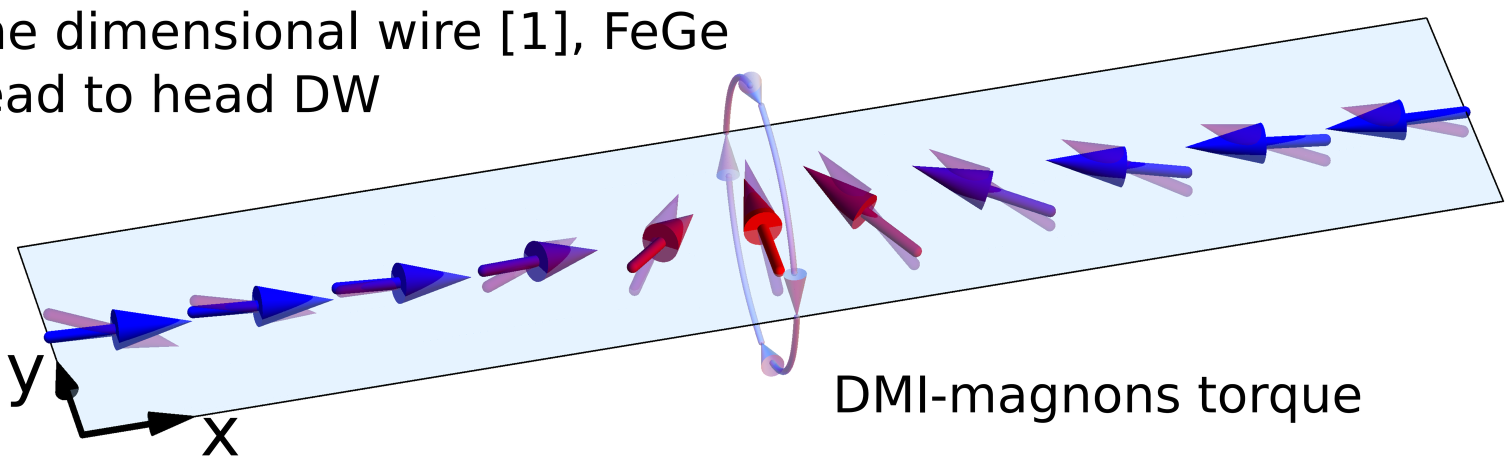
Motivation

Spin waves (magnons) and domain wall (DW) motion:

- Angular momentum conservation.
- Spin waves dispersion is biased by DMI.
- How does the DMI influence the DW motion?

Model

One dimensional wire [1], FeGe
Head to head DW

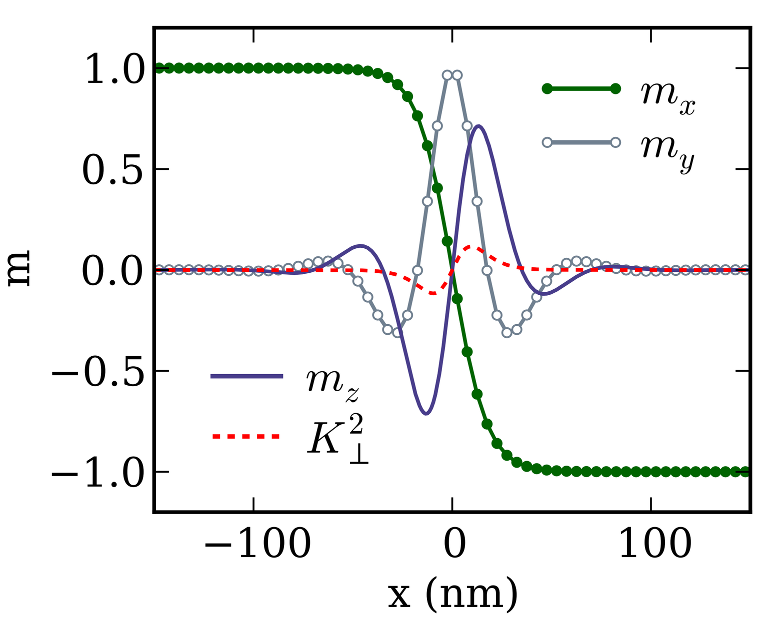


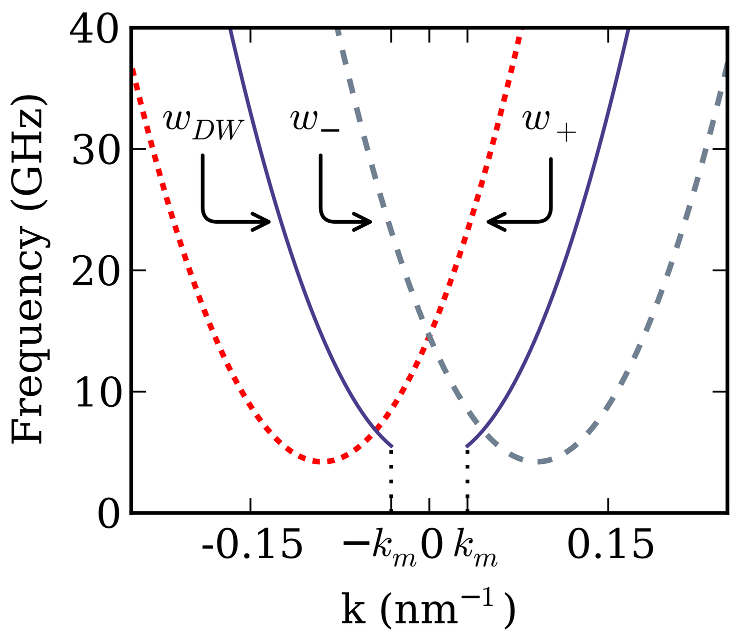
$$E = \int \left[A(\nabla \mathbf{m})^2 - K m_x^2 + K_\perp m_z^2 + D\mathbf{m} \cdot (\nabla \times \mathbf{m}) \right] \mathrm{d}x,$$

exchange anisotropy DMI

Spin waves are excited locally by $\mathbf{h}(t) = h_0 \sin(\omega t)\mathbf{e}_y$

Domain wall profile and spin waves excitation





The magnetization unit vector

$$\mathbf{m} = (\cos\theta, \sin\theta\cos\phi, \sin\theta\sin\phi)$$

For static profile, by minimizing *E*,

$$2A\theta'' = \sin 2\theta(A\phi'^2 + K(1+\kappa\sin^2\phi) - D\phi'),$$
$$\sin\theta(2A\phi'' - K_\perp \sin 2\phi) = 2\cos\theta(D - 2A\phi')\theta'.$$

For $K_\perp = 0$, we obtain,

$$m_x = -\tanh(x/\Delta),$$
$$m_y = \mathrm{sech}(x/\Delta)\cos(x/\xi + \Phi),$$
$$m_z = \mathrm{sech}(x/\Delta)\sin(x/\xi + \Phi),$$

Δ is the DW width, $\xi = 2A/D$

Φ is the DW tilt angle

Small fluctuation $\psi = u - iv$

$$\mathbf{m} = \mathbf{m}_0 + [u(x)\mathbf{e}_\theta + v(x)\mathbf{e}_\phi]e^{-i\omega t},$$

Linearize the LLG equation,

$$\hat{H}\psi(\zeta) = (1+q^2)\psi(\zeta),$$
$$\hat{H} = -d^2/d\zeta^2 + 1 - 2\,\mathrm{sech}^2(\zeta)$$
$$\zeta = x/\Delta$$

Reflectionless potential

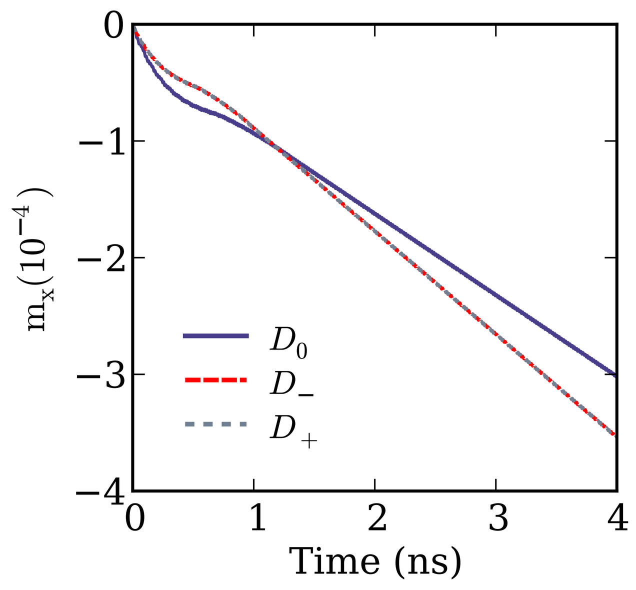
Dispersion relation inside the DW,

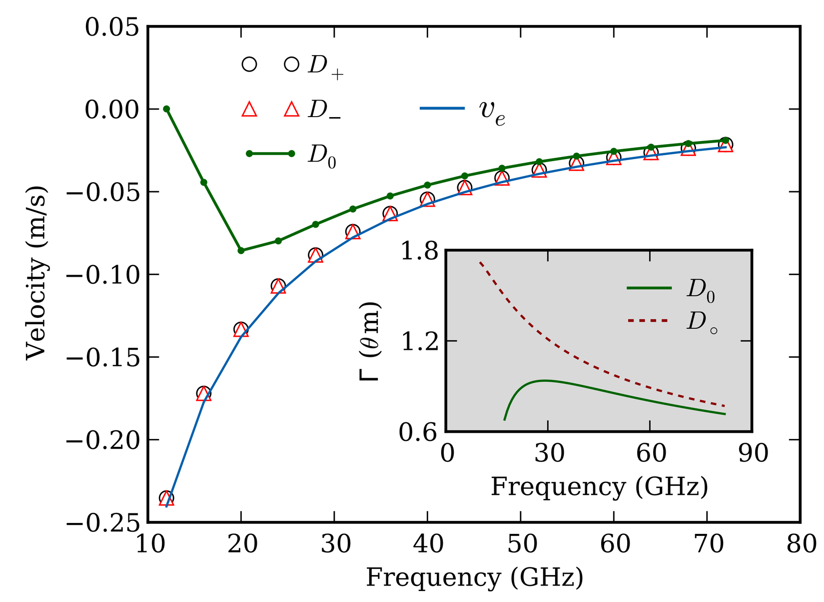
$$\omega_{DW} = \gamma_0(\tilde{K} + Ak^2)$$

Outside the DW,

$$\omega_\pm = \gamma_0(K + Ak^2 \pm Dk).$$

DW motion without easy plane anisotropy





The conservation of angular momentum [2]

$$v_e = -\frac{\rho^2}{2} V_g$$

V_g is the group velocity of spin waves

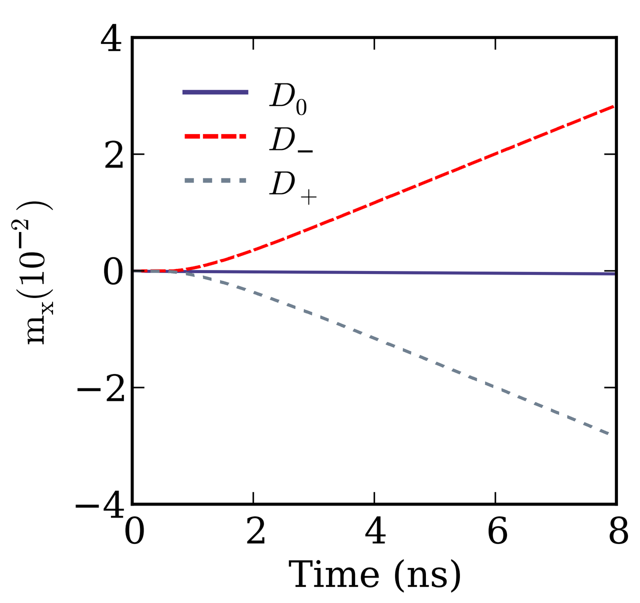
ρ is the amplitude of spin waves

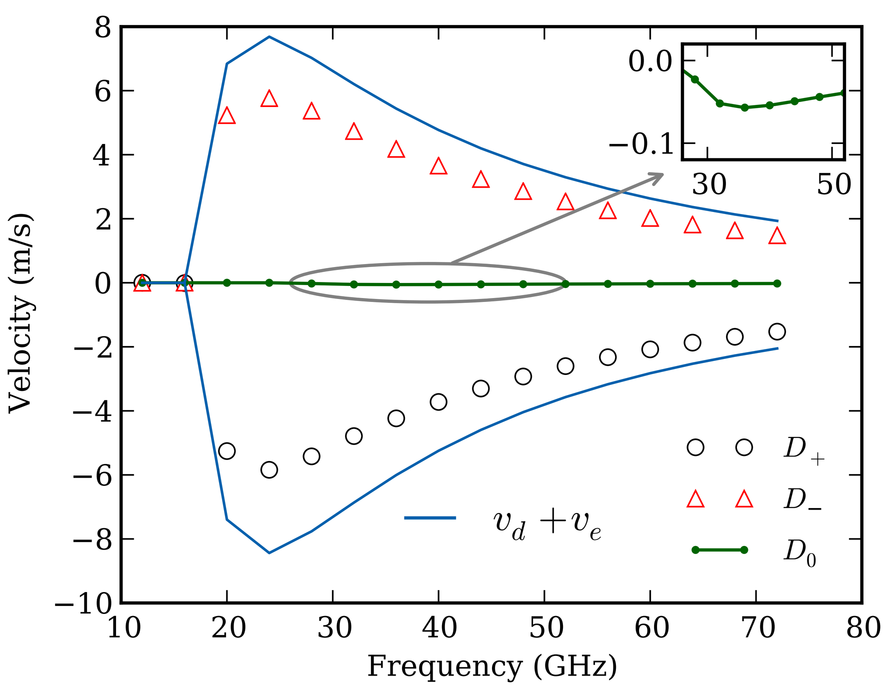
negative

Spin wave decaying

$$\Gamma_\pm = 2/(\alpha\omega)[\gamma_0 Ak \pm D(\omega \mp D\gamma_0 k)/(K_\perp + 2K + 2Ak^2)]$$

DW motion with easy plane anisotropy





The linear momentum of a DW [3]:

$$P_{\mathrm{DW}} = M_s/\gamma \int \phi \sin\theta (\partial\theta/\partial x)\mathrm{d}x = 2\Phi M_s/\gamma$$

The conservation of linear momentum [4]

$$dP_{\mathrm{DW}}/dt = -dP_{\mathrm{magnons}}/dt = -nV_g\delta p \quad \Rightarrow \quad \dot{\Phi} = -\tfrac{1}{4}\rho^2 V_g \delta k$$

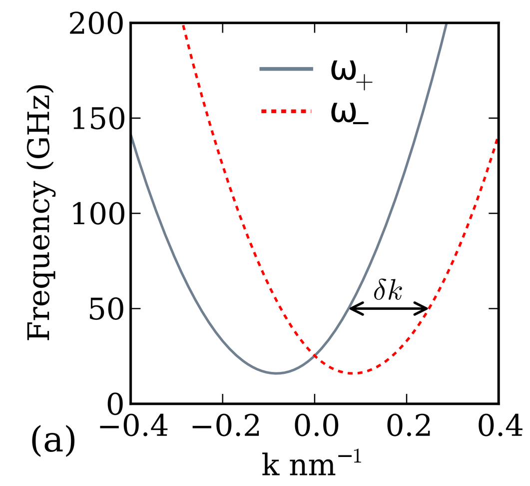
Introduce an external field to describe the DW motion,

$$H_x = \dot{\Phi}/\gamma = -\frac{1}{4}\rho^2\delta k V_g/\gamma$$

$$v_d = \frac{\gamma\Delta H_x}{\alpha} \Big/ \sqrt{1 + \frac{\kappa}{2}\left(1 - \sqrt{1-h^2}\right)}$$

Assume the frequency remains the same, δk can be obtained by

$$\omega_\pm = \gamma_0[\sqrt{(K+Ak^2)(K+K_\perp+Ak^2)} \pm Dk]$$



(a)

Conclusion

The linear momentum exchange is significantly more efficient than angular momentum transfer in moving the DW due to DMI in the presence of easy plane anisotropy [arXiv:1406.5997].

References

[1] W. Wang, et.al.,Magnon driven domain wall motion with Dzyaloshinskii-Moriya interaction http://arxiv.org/abs/1406.5997
[2] P. Yan and X. Wang, Phys. Rev. Lett. **107**, 177207 (2011)
[3] A. Kosevich, B. Ivanov, and A. Kovalev, Phys. Rep. **194**, 117 (1990)
[4] P. Yan, et. al, Phys. Rev. B **88**, 144413 (2013).

Acknowledgements

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