FMR identification of skyrmionic states in confined helimagnetic nanostructures

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Introduction

- Skyrmionic states can be the **ground state** in confined helimagnetic nanostructures at zero external field and in absence of magnetocrystalline anisotropy [1].

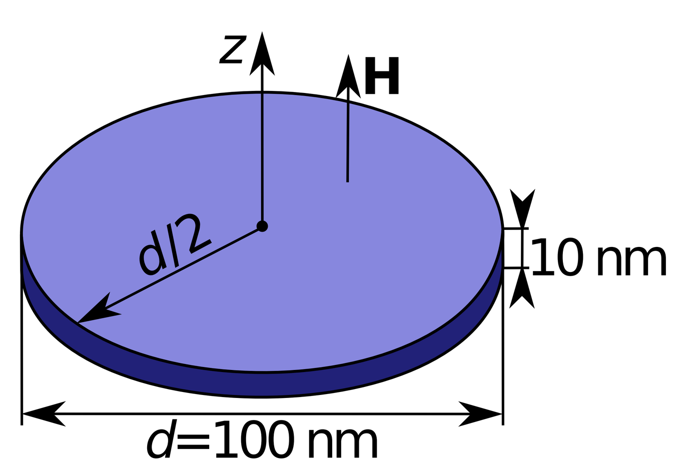
- Skyrmionic ground states emerge in the form of **incomplete Skyrmion (iSk)** and **isolated Skyrmion (Sk)** states [1].

- In this work [2], we study dynamic properties (**resonance frequencies and corresponding eigenmodes**) of both iSk and Sk states and compare their power spectral densities.

- Systematic results in this study can guide the **experimental identification** of skyrmionic states in confined helimagnetic nanostructures by measuring resonance frequencies.

Methods

- Geometry and **material parameters**



FeGe [1]:

M_s = 384 kA/m

A = 8.78 pJ/m

D = 1.58 mJ/m^2

- Hamiltonian

$$w = A(\nabla \mathbf{m})^2 + D\mathbf{m} \cdot (\nabla \times \mathbf{m}) - \mu_0 M_s \mathbf{H} \cdot \mathbf{m} + w_d$$

(symmetric exchange; Dzyaloshinskii-Moriya; Zeeman; demagnetisation)

- Dynamics (LLG equation)

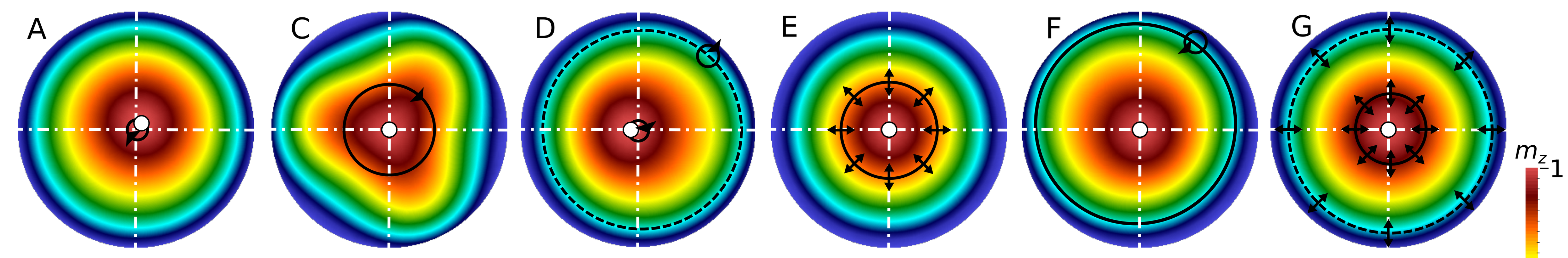
$$\frac{\partial \mathbf{m}}{\partial t} = -\gamma_0^* \mathbf{m} \times \mathbf{H}_{\text{eff}} + \alpha \mathbf{m} \times \frac{\partial \mathbf{m}}{\partial t}$$

(precession; damping)

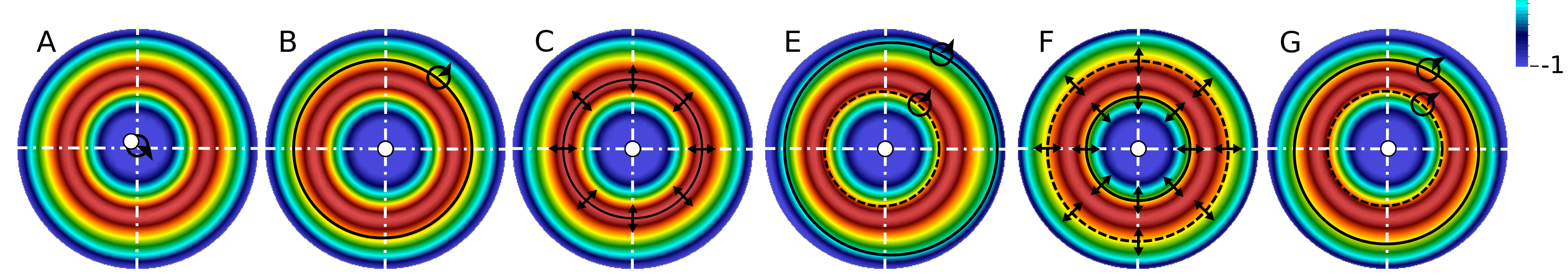
- **Full 3D finite elements** simulation model.
- **No** assumption about **translational invariance** in the out-of-plane direction.
- **Eigenvalue method** [3] allows us to compute all existing eigenmodes.
- We perform the **ringdown method** [4] to determine what eigenmodes can be excited using a particular experimentally feasible excitation.
- All frequencies in the ringdown method are excited approximately equally in the [0, 100 GHz] range using **cardinal sine wave excitation.**
- The magnetisation is evolved for 20 ns and recorded every 5 ps.
- We **compare** the power spectral densities in a 100 nm thin film FeGe disk at different external magnetic fields.

Eigenmode dynamics

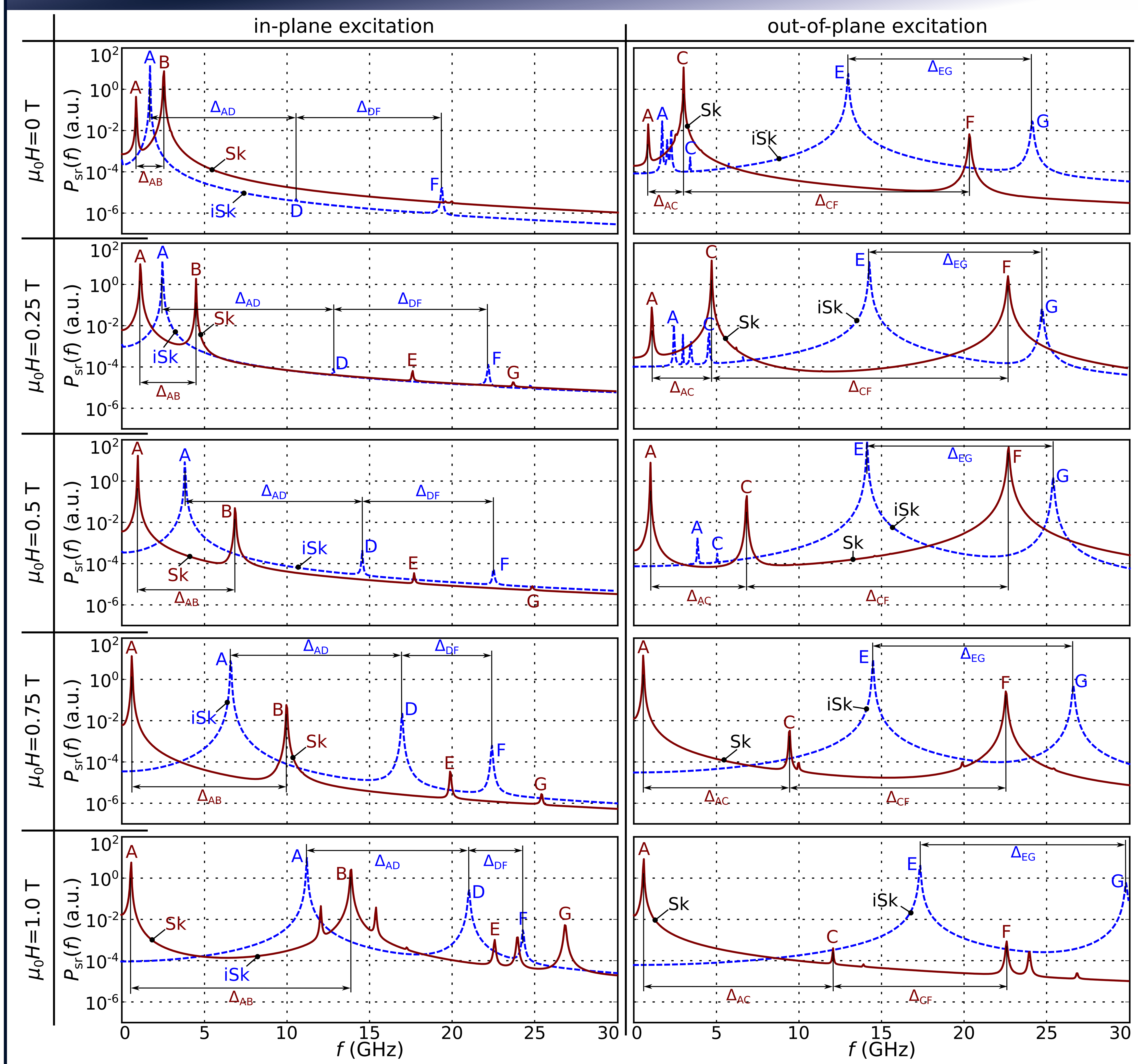
- incomplete Skyrmion (**iSk**)



- isolated Skyrmion (**Sk**)



Comparison of power spectral densities



References

[1] Beg, M. et al., *Scientific Reports* **5**, 17137 (2015).
[2] **Beg, M. et al. *Phys. Rev. B* 95, 014433 (2017).**
[3] D'Aquino, M. et al., *J. Comput. Phys.* **228**, 6130 (2009).
[4] McMichael, R. D. and Stiles, M. D., *J. Appl. Phys.* **97**, 10J901 (2005).

Conclusion

- We computed **all existing eigenmodes** and determined what eigenmodes can be observed using an **experimentally feasible excitation**.
- In a 100 nm diameter sample we compute power spectral densities of both iSk and Sk states and **compare** them.
- We identify several key differences that can **contribute to the identification** of the emerged state by measuring resonance frequencies.
- Our results can be used as an **experimental guide** for the identification of the emerged state.