Dynamics of an incomplete skyrmion state in confined helimagnetic nanostructures

Marijan Beg*, Maximilian Albert, Marc-Antonio Bisotti, David Cortés-Ortuño, Weiwei Wang, Rebecca Carey, Mark Vousden, Ondrej Hovorka, and Hans Fangohr

Faculty of Engineering and the Environment, University of Southampton, Southampton, SO17 1BJ, United Kingdom

**email: m.beg@soton.ac.uk*

Introduction

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

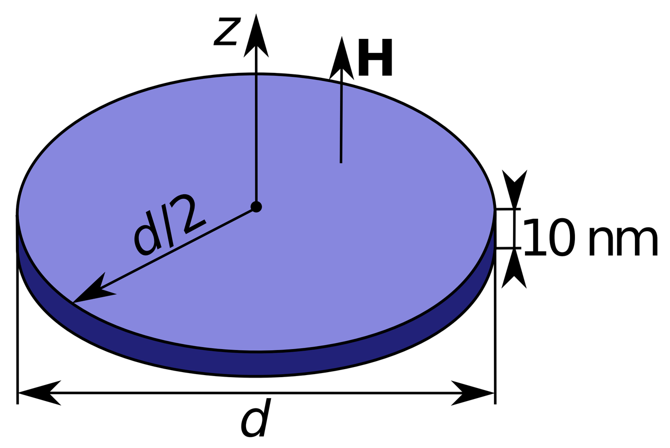
- Skyrmionic ground states emerge in the form of **incomplete Skyrmion (iSk)** and **isolated Skyrmion (Sk)** states [1].

- In this work [2], we study dynamic properties (**resonance frequencies and corresponding eigenmodes**) of an iSk state (in other works called the quasi-ferromagnetic or edged vortex state).

- 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**:

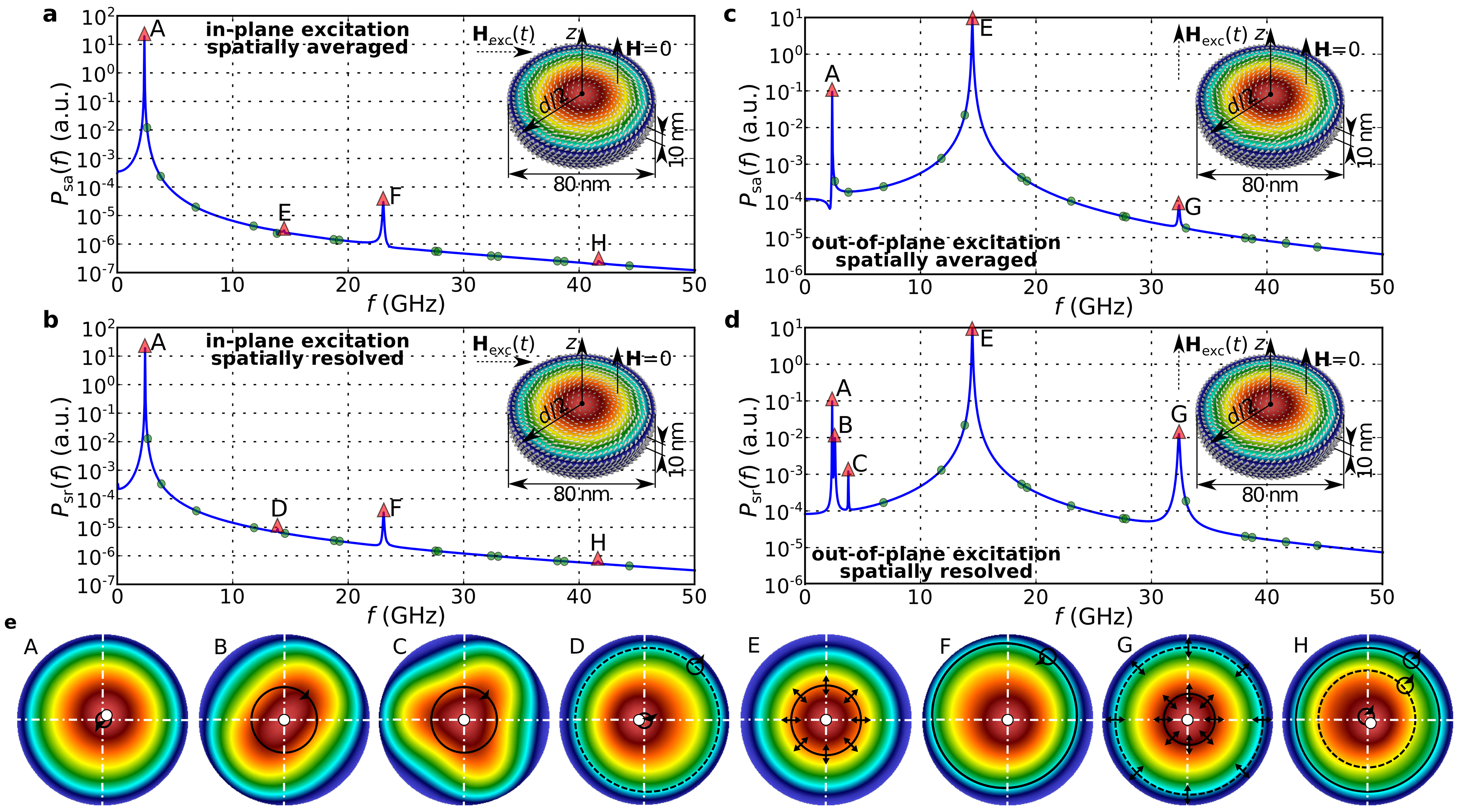
$$w = \overbrace{A(\nabla \mathbf{m})^2}^{\text{symmetric exchange}} + \overbrace{D\mathbf{m}\cdot(\nabla\times\mathbf{m})}^{\text{Dzyaloshinskii-Moriya}} - \underbrace{\mu_0 M_\mathrm{s}\mathbf{H}\cdot\mathbf{m}}_{\text{Zeeman}} + \underbrace{w_\mathrm{d}}_{\text{demagnetisation}}$$

- **Dynamics** (LLG equation):

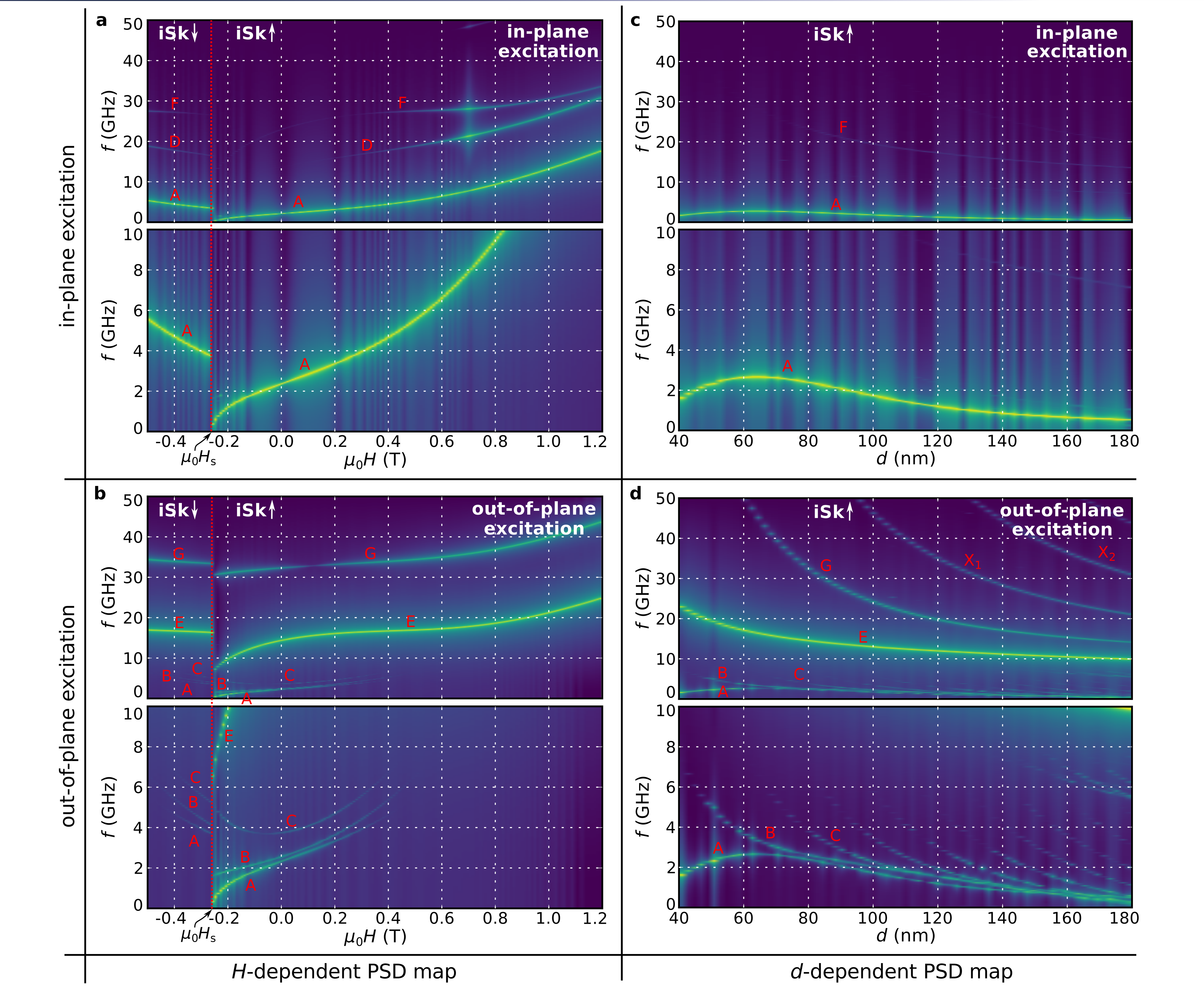
$$\frac{\partial \mathbf{m}}{\partial t} = \overbrace{-\gamma_0^* \mathbf{m}\times\mathbf{H}_\mathrm{eff}}^{\text{precession}} + \underbrace{\alpha\mathbf{m}\times\frac{\partial \mathbf{m}}{\partial t}}_{\text{damping}}$$

- **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
- Power spectral densities are computed using **spatially averaged** and **spatially resolved analyses**

Power spectral densities



Power spectral density maps



References

[1] Beg, M. et al., *Scientific Reports* **5**, 17137 (2015).
[2] **Beg, M. et al. *arXiv* 1604.08347 (2016).**
[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 incomplete skyrmion eigenmodes and determined what eigenmodes can be observed using an experimentally feasible excitation.
- We observe the non-linear dependence of resonance frequencies on disk sample diameter and external magnetic field.
- Near the switching field, the frequency of gyrotropic eigenmode A approaches zero, suggesting that this eigenmode can be the reversal mode.
- Our results can be used as an experimental guide for the identification of emerged state.