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Hysteresis of nanocylinders with DMI and the role of demagnetisation effects

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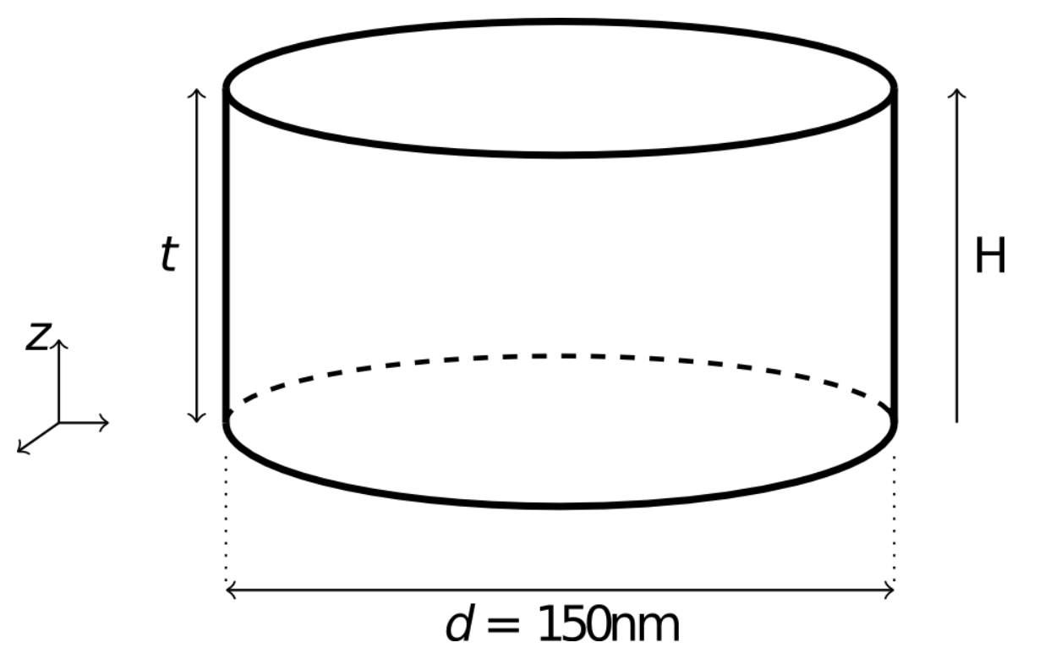
Introduction

- Topologically stable skyrmions, which arise due to the Dyzaloshinskii-Moriya Interaction (DMI), hold great potential for **new, efficient data storage methods**.
- Recent work demonstratres confined **nanodisk geometries aid skyrmion stablization** [1,2], with skyrmions being found stable at zero-field and in the absence of magnetocrystalline anisotropies [2].
- Further work on non-confined geometries shows system **thickness enhances skyrmion stablility** [3].
- Here we **study nanocylinders through their hysteresis**, avoiding the need to find minimum energy states. Consequently, **all states presented are accessible experimentally**.

Method

- **FeGe nanocylinders**:



- 3D finite element micromagnetic simulation using **finmag.**
- Maximum mesh discretisation of **3nm.**
- Thickness, *t*, varied between **10-80nm**.
- Magnetisation dynamics govenered by **LLG equation**.
- **Interaction energies**:

$$\underbrace{A(\nabla\mathbf{m})^2}_{\text{Exchange}} + \underbrace{D\mathbf{m}\cdot(\nabla\times\mathbf{m})}_{\text{DMI}} - \underbrace{\mu_0\mathbf{H}\cdot\mathbf{m}}_{\text{Zeeman}} - \underbrace{\frac{\mu_0}{2}\mathbf{H}_D\cdot\mathbf{m}}_{\text{Demag}}$$

- **System initialised** with saturating external field in **–z direction** of -4M$_s$.
- Hysteresis field swept up to +4M$_s$ and back down in steps of 0.02M$_s$.
- **State type determined** at each field step.

References

[1] S. Rohart & A. Thiaville, Phys. Rev. B, 88(18), 184422 (2013)

[2] Beg, Marijan, et al. "Ground state search, hysteretic behaviour, and reversal mechanism of skyrmionic textures in confined helimagnetic nanostructures." Sci. Rep. 5, 17137 (2015)

[3] Rybakov, F. N., et al., Phys. Rev. B, 87(9), 094424 (2013)

Acknowledgements

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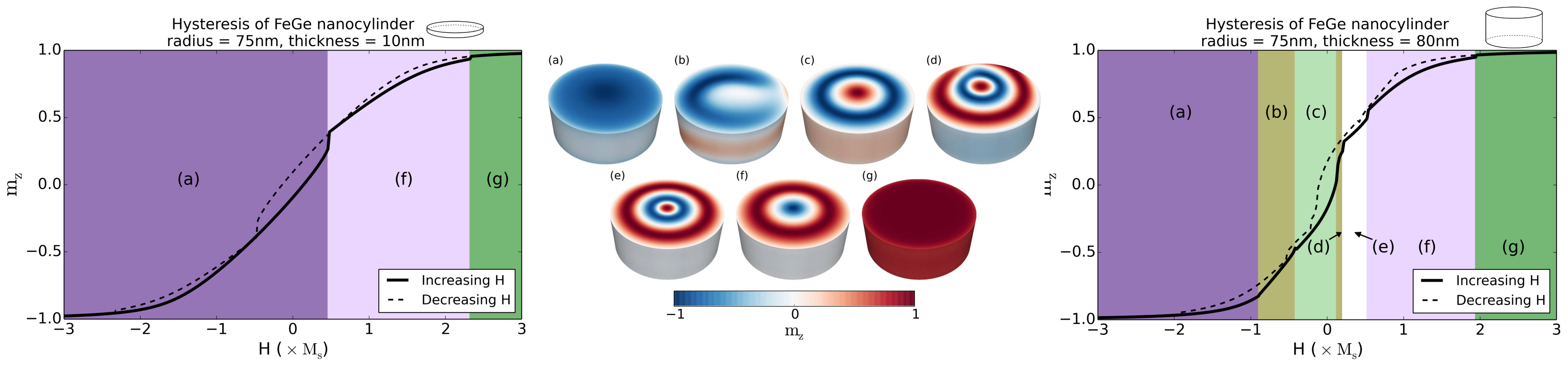
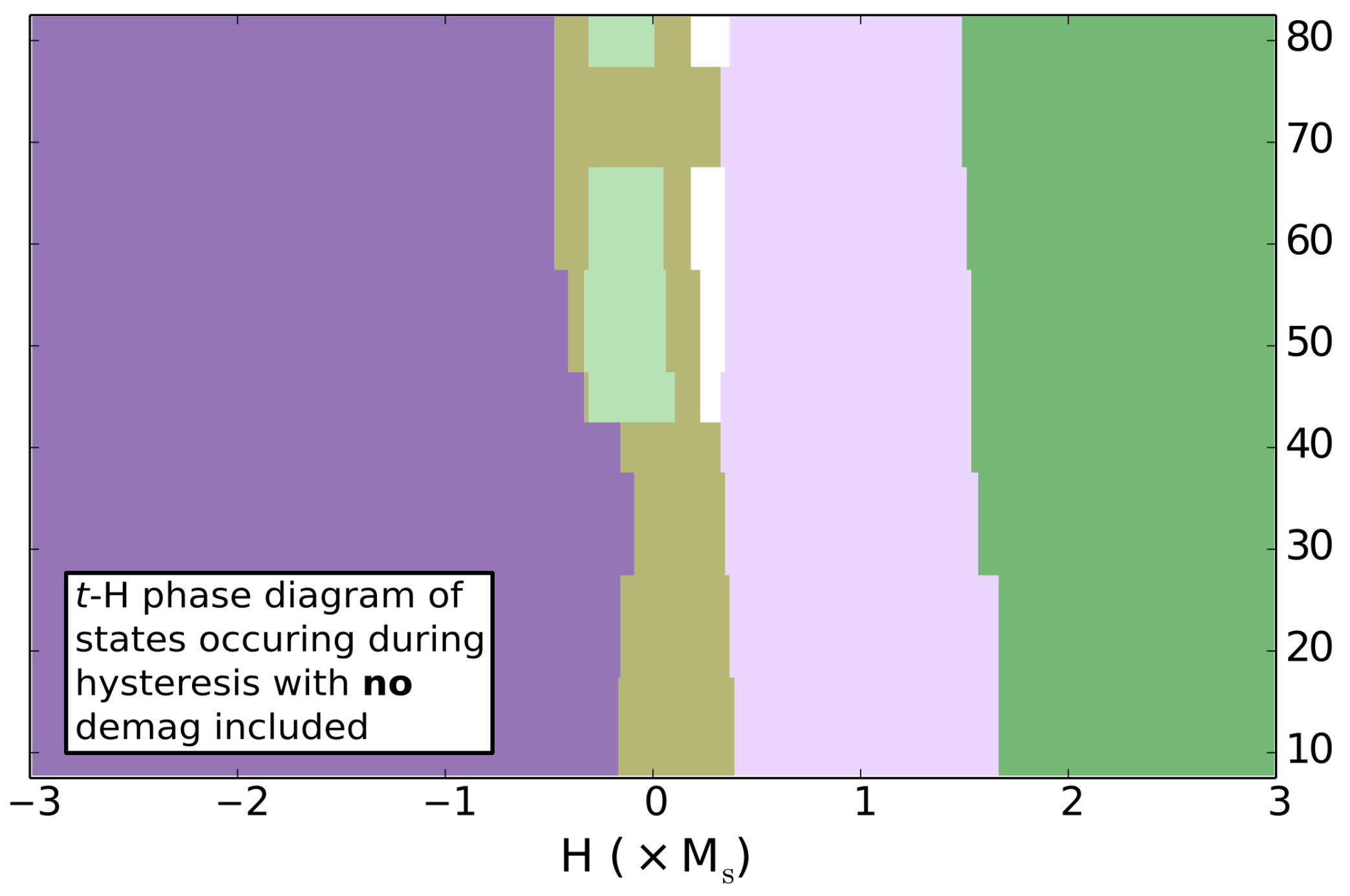
Hysteresis



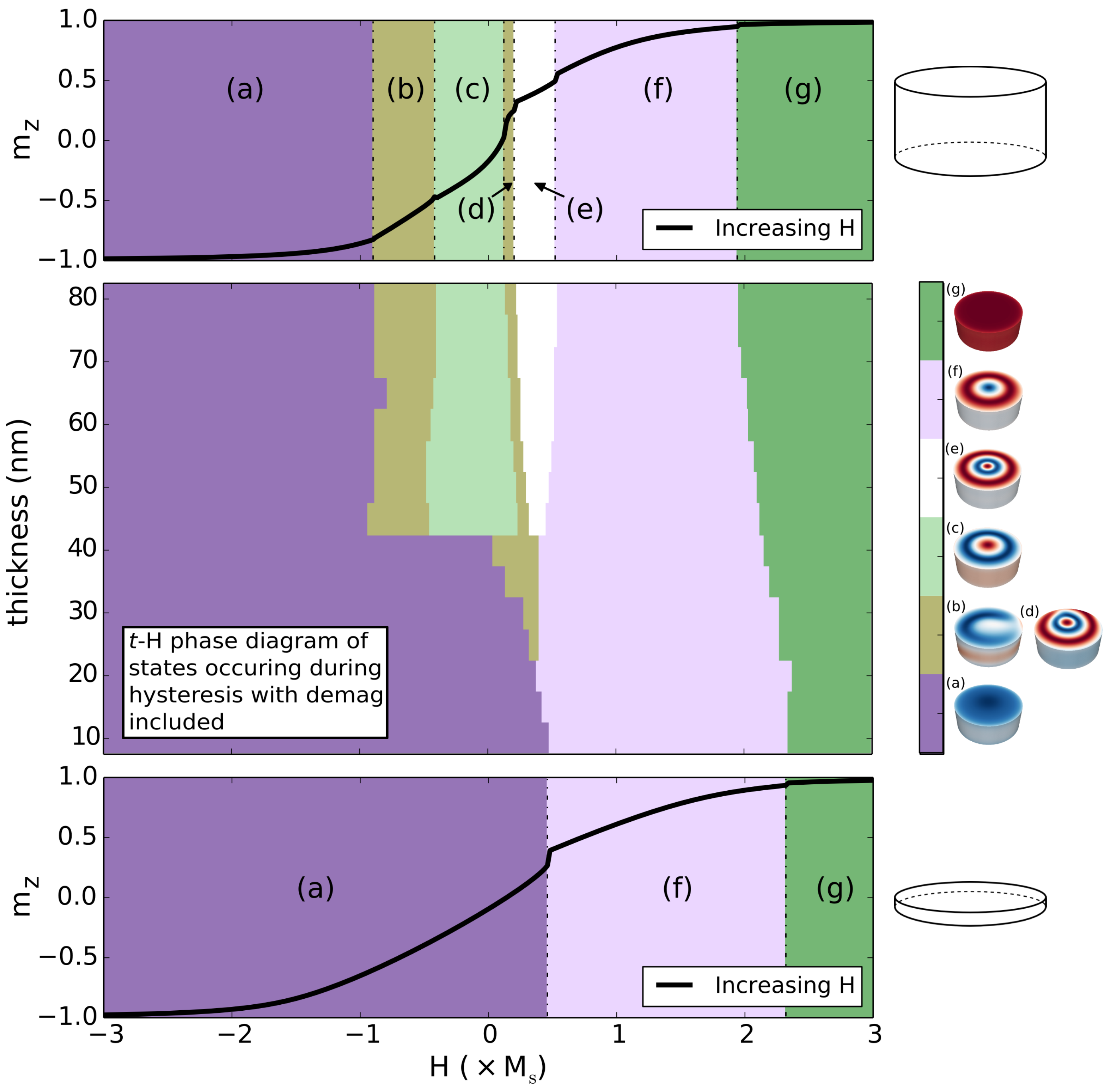
- The divisions (green, purple, olive) on the hysteresis plots indicate the regions where the different states occured during the hysteresis when the external field was increasing.
- Further states occur with increased sample thickness.

Impact of demagnetisation

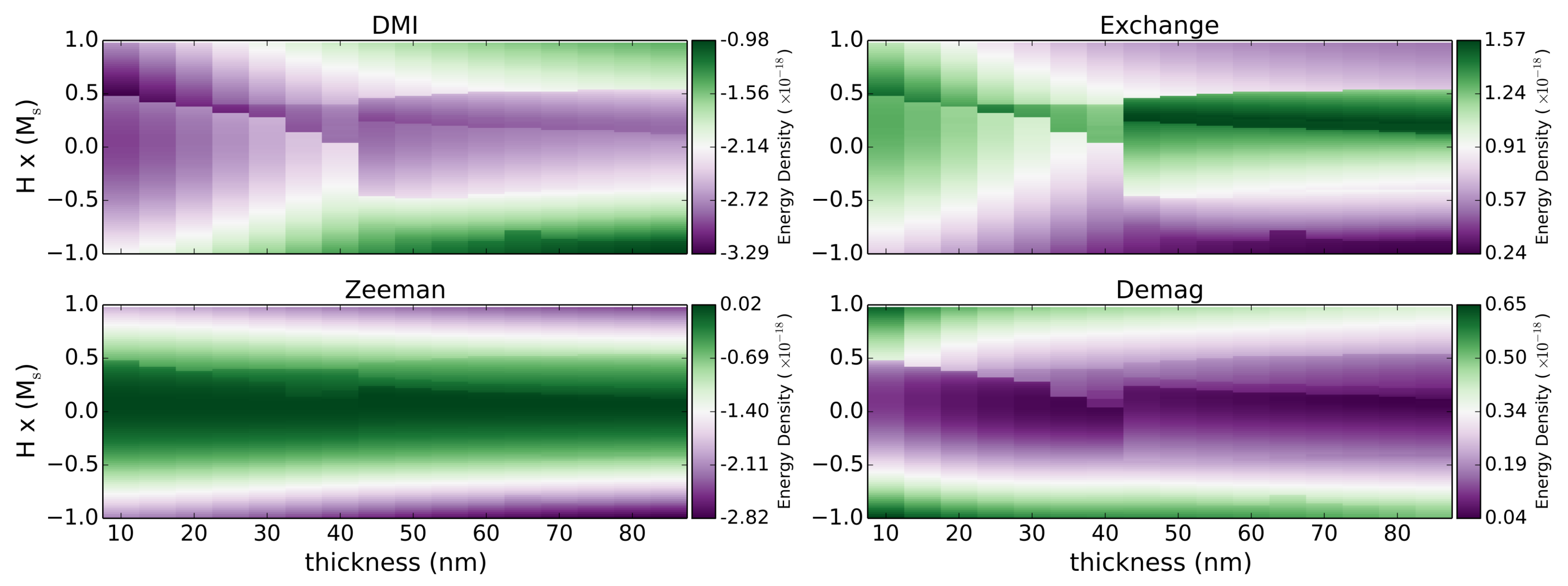
- *t*-H phase diagrams indicate different states which occur during hysteresis for **increasing field only.**
- **Phase change** at *t*=45nm where additional states occur in hysteresis.



- **Demagnetisation is a stabilising factor**, prolonging the region in which a state is stable.
- Demagnetisation allows states (a) and (c) to exist **at unfavourable external field** values.



Energies



- **DMI energy density decreases** significantly at the phase change.
- Occurs with a marked **increase in exchange energy** density.
- **State (e)** decreases the energy density.
- **Phase change** due to DMI.

Conclusions

- In the hysteresis of nanocylinders with DMI, thickness impacts the range of field values at which states occur.
- Increased thickness also allows additional states to become accessible.
- This is due to the DMI interaction.
- The additional states occur with reduced DMI energy density and increased exchange energy density.
- Demagnetisation in these geometries prolongs the region of field values at which states remain stable.
- Demagnetisation allows for specific states to remain stable into unfavaourable external field values.