Ground state skyrmion and helical states in confined FeGe nanostructures

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Introduction

- **Magnetic Skyrmions** an exciting avenue for physics research in recent years, after theoretical predictions of their presence in materials with broken inversion symmetry.
- Potential engineering applications to magnetic storage devices and MRAM.
- Nanodisk systems containing skyrmions have previously been studied [1]. However, because of the radial symmetry in disk systems, it is not clear that these results apply to polygonal systems where the magnetisation can be geometrically frustrated.
- We study skyrmionic textures in **confined polygonal nanogeometries** of the B20 material **FeGe** with finite element micromagnetics.

Methods

- We simulate **triangular and square nanogeometries** of **side length d** (nm) and of thickness 10 nm.
- We relax the systems under the LLG equation, in the presence of the exchange, bulk Dzaloshiinski Moriya and Zeeman interactions, with parameters [1]
  - $A = 8.78 \times 10^{-12}$ J/m
  - $M_s = 3.85 \times 10^5$ A/m
  - $D = 1.58 \times 10^{-3}$ J/m^2
  - **B = 0 - 800 mT, applied out-of-plane**

  We also include the demagnetising field calculations.
- The systems are **relaxed from a range of initial states**, into metastable states. The energy of these is computed, with the lowest energy state for each geometry chosen as the ground state.

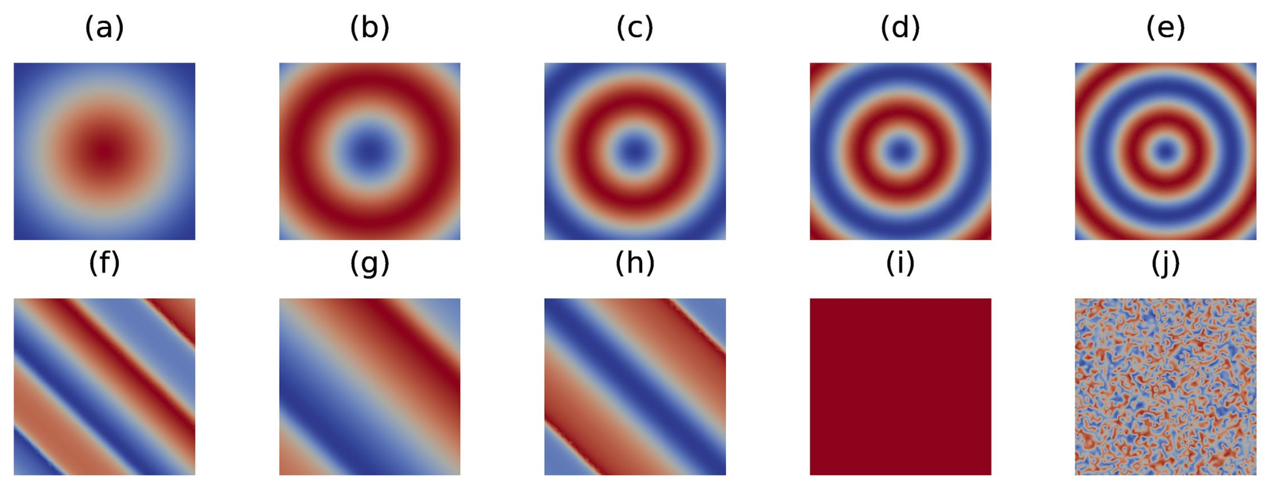

Figure 1: All geometries are relaxed from a range of initial states (shown here in square geometries). These are (a) Incomplete Skyrmion (b - e) Skyrmionic (f-h) helical (i) Uniform (j) 3x Random Magnetisation

Ground State Phase Diagrams

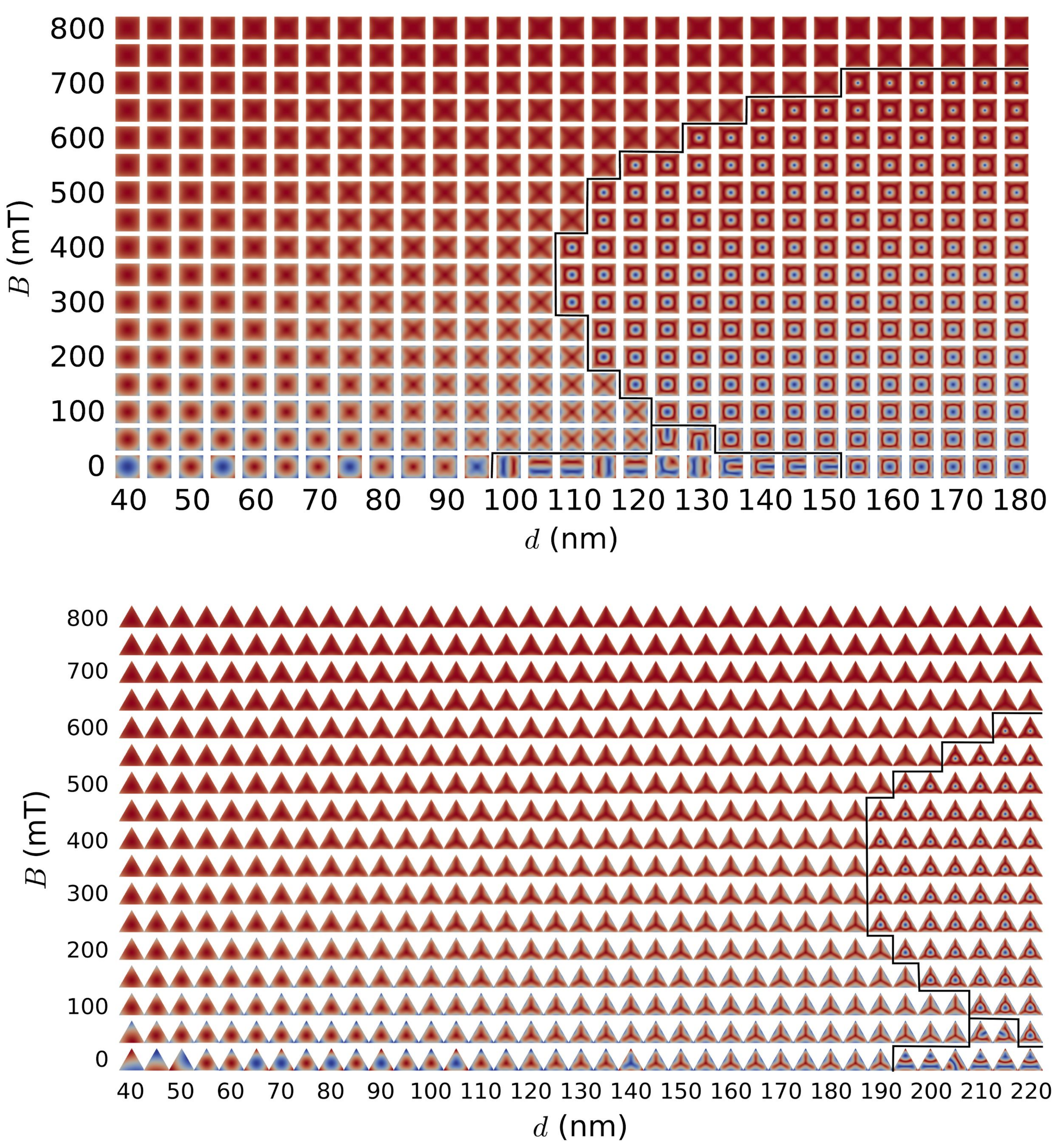

Figure 2: "Phase diagrams" of square and triangle nanostructures with side length *d* and with an applied field *B*.

- Figure 2 shows *d* - *B* "Phase diagrams" of square and triangle nanogeometries.
- In square nanogeometries, we see similar results to nanodisk systems studied in [1]. In large part of the phase diagram we observe 'incomplete skyrmion' or quasi-uniform states.
- However, when no magnetic field is applied, much larger samples are needed to observe skyrmions as the ground state in comparison to disks - **in disks this is observed for diameter 136nm** and above, whereas **we only observe skyrmions as the ground state for squares of side length 155nm and above,** suggesting the boundary plays an important role in the energetics of skyrmionic states in confined geometries.
- We also see several types of helical states in the ground state for smaller sizes. The helical length in FeGe is 70nm. Twisting occurs at the boundary, which means the sample size needs to be somewhat larger in confined geometries in order to fit a full helical period - this explains why we do not see helical states in d < 100nm.
- In triangle samples, **we do not see skyrmions as the ground state at zero applied field in the sample sizes studied.**
- Can be explained by simple geometric arguments. We observe skyrmions in squares of d > 155nm at zero field. The skyrmion radius here is ≈ 100nm.
- Side length from radius of incircle in equilateral triangle given by $d = 2r\sqrt{3}$
- Hence, assuming we might observe skyrmions of similar radius in triangles as in square, **we would need a geometry where *d* ≈ 340nm and above in order to see skyrmions as ground state in triangles** - very large samples to simulate with finite element micromagnetics.

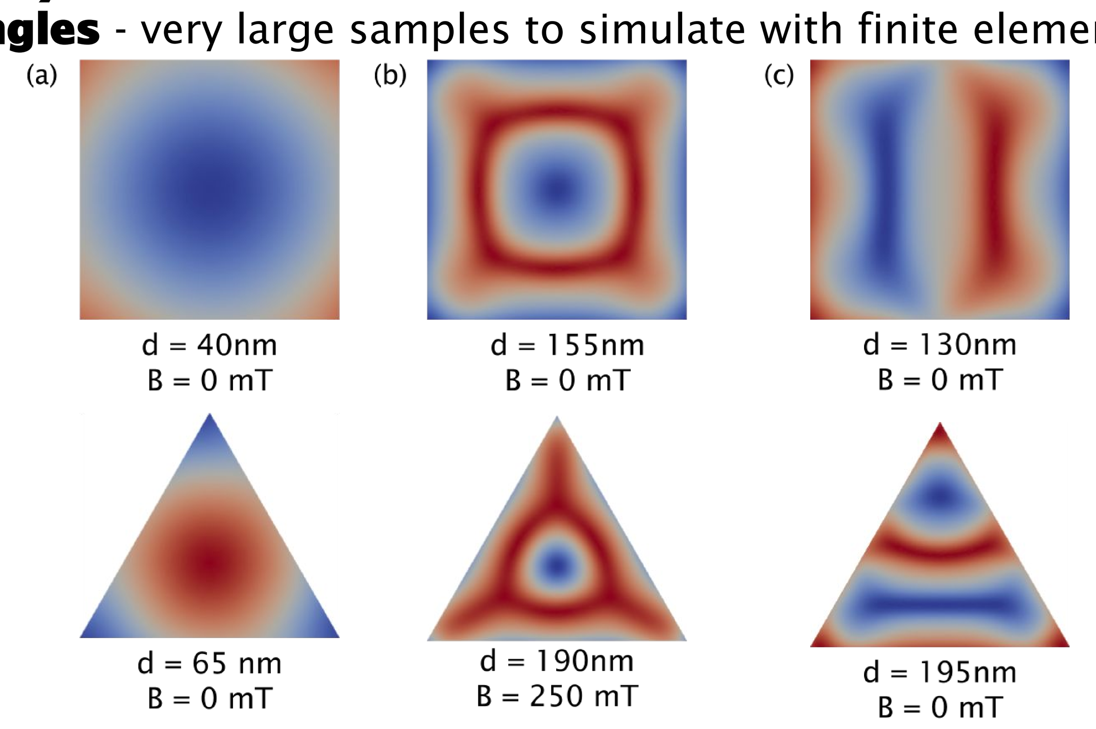

Figure 3: Here we show examples of particular states obtained as the ground state in square and triangular geometries where (a) is the incomplete skyrmion, (b) the skyrmion, and (c) the helical state.

Proposed Experimental Study

- Grow thin film samples [2, 3] and etch nanogeometry shape
- Apply very strong magnetic field to uniformly magnetise the sample
- Remove/weaken applied field to given value.
- Observe magnetisation states in samples.
- Corresponding simulation results are shown in the figure on the right, to be compared with experimental results.
- Micromagnetic study - simulated under LLG dynamics square nanogeometry from uniformly magnetised sample under applied field B until magnetisation is metastable.
- **At zero field observe skyrmions (110 - 135 nm), target states (140 - 160 nm) and some helical-like states (165 - 180nm).**
- **Simulations suggest this could provide simple way to produce target states and skyrmion states in nanogeometries in the laboratory.**

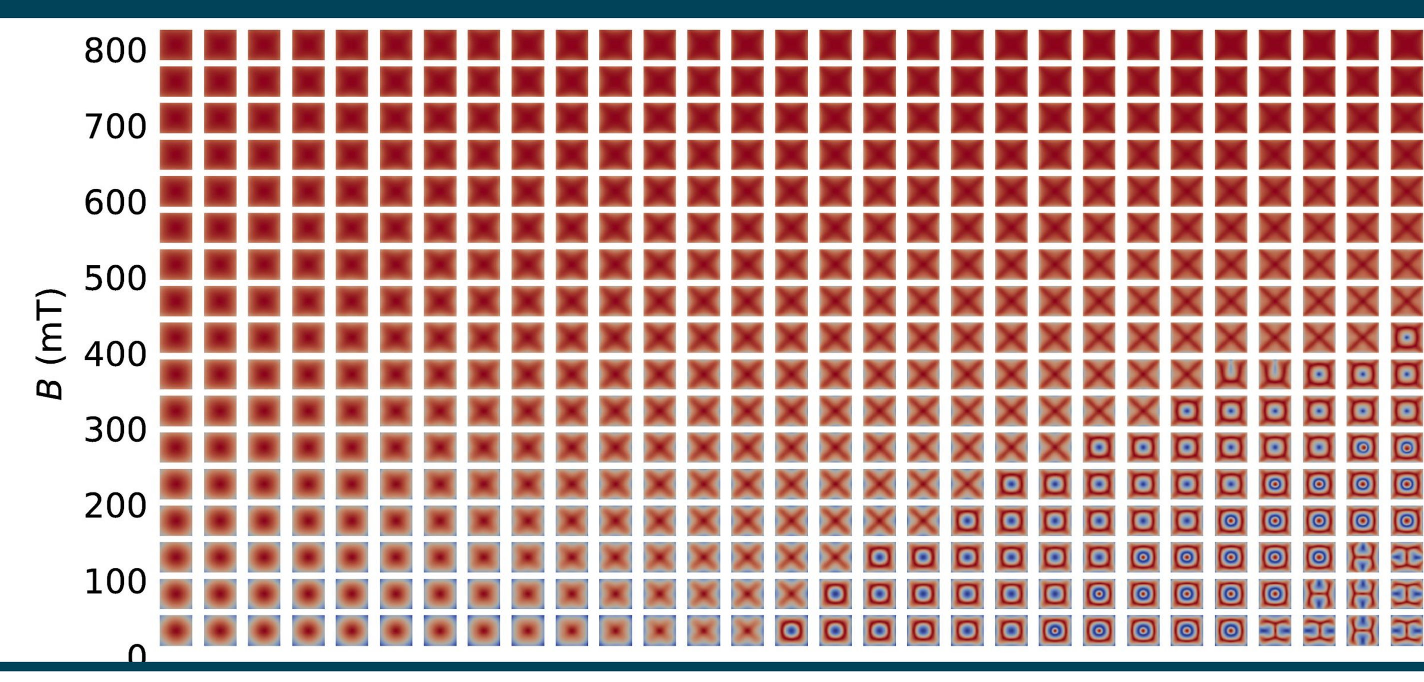

Figure 4: Here we show the states obtained from simulating samples of side length d and with applied in plane field B in an initial uniformly magnetised state.

Acknowledgements

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References

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