Quantum skyrmions in the antiferromagnetic triangular lattice

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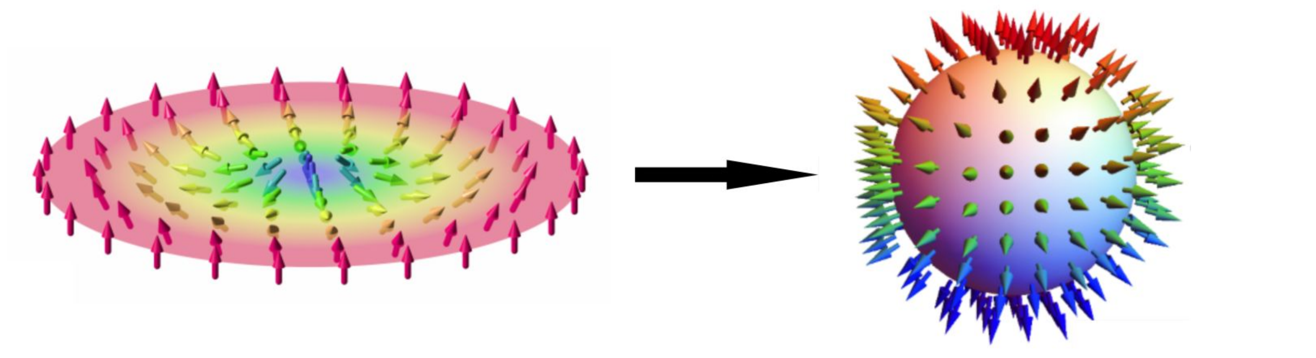
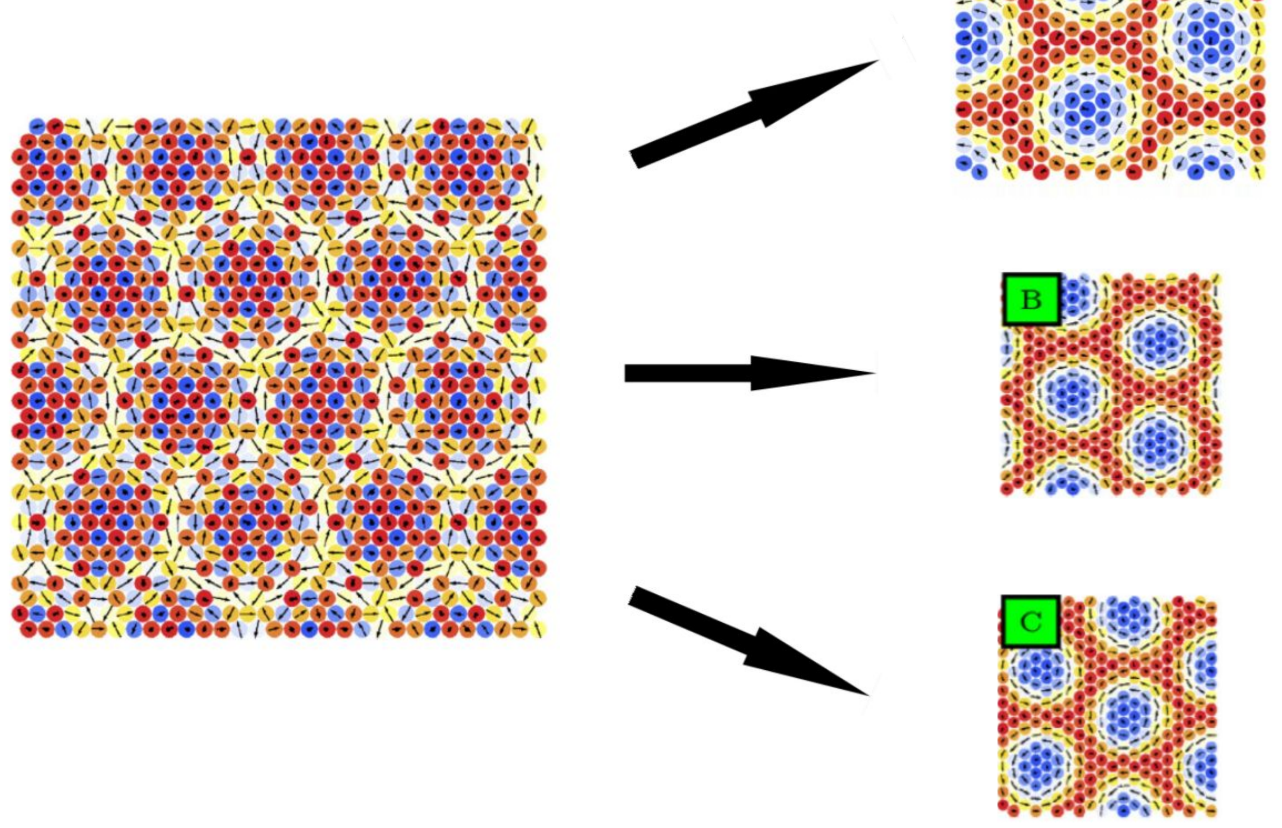
Introduction

Magnetic skyrmion in a classical spin system:



Antiferromagnetic skyrmion lattice on the triangular lattice [1]:

on each sublattice: ferromagnetic skyrmion lattice



For skyrmions, $|N_{\text{Sk}}| = 1$

On a triangular lattice:

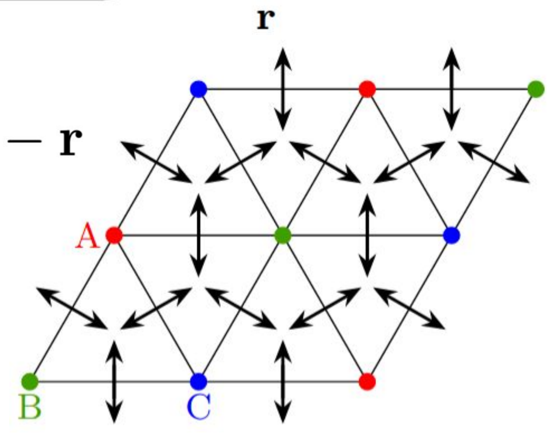
$$Q_{\text{clas}} = \frac{1}{8\pi} \sum_{(i,j,k)\in\triangle/\nabla} \mathbf{S}_i \cdot (\mathbf{S}_j \times \mathbf{S}_k)$$

Model and methods

$$\hat{H} = \sum_{\langle \mathbf{r},\mathbf{r}'\rangle} [J\hat{\mathbf{S}}_{\mathbf{r}} \cdot \hat{\mathbf{S}}_{\mathbf{r}'} + \underbrace{\mathbf{D}_{\mathbf{r}'-\mathbf{r}} \cdot (\hat{\mathbf{S}}_{\mathbf{r}} \times \hat{\mathbf{S}}_{\mathbf{r}'})}_{\text{DM}}] - \sum_{\mathbf{r}} B\hat{\mathbf{e}}_z \cdot \hat{\mathbf{S}}_{\mathbf{r}}$$

- J > 0 (AF)
- D/J = 0.8
- N ~ 100 spins
- DMRG [2], $\chi \leq 300$

$\mathbf{D}_{\mathbf{r}'-\mathbf{r}} \perp \mathbf{r}' - \mathbf{r}$



Ferromagnetic case was previously studied [3,4].

Conclusions and future work

- Signatures of the emergence of AF skyrmions on the triangular lattice for a wide range of magnetic fields B
- Entanglement present between its constituents
- Phase arises independently of lattice boundary shape
- Other entanglement measurements?

References

[1] H. D. Rosales, D. C. Cabra, and P. Pujol. Three-sublattice skyrmion crystal in the antiferromagnetic triangular lattice. Phys. Rev. B, 92:214439, 2015.

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[4] O. M. Sotnikov, V. V. Mazurenko, J. Colbois, F. Mila, M. I. Katsnelson, and E. A. Stepanov. Probing the topology of the quantum analog of a classical skyrmion. Phys. Rev. B, 103:L060404, 2021.

Results

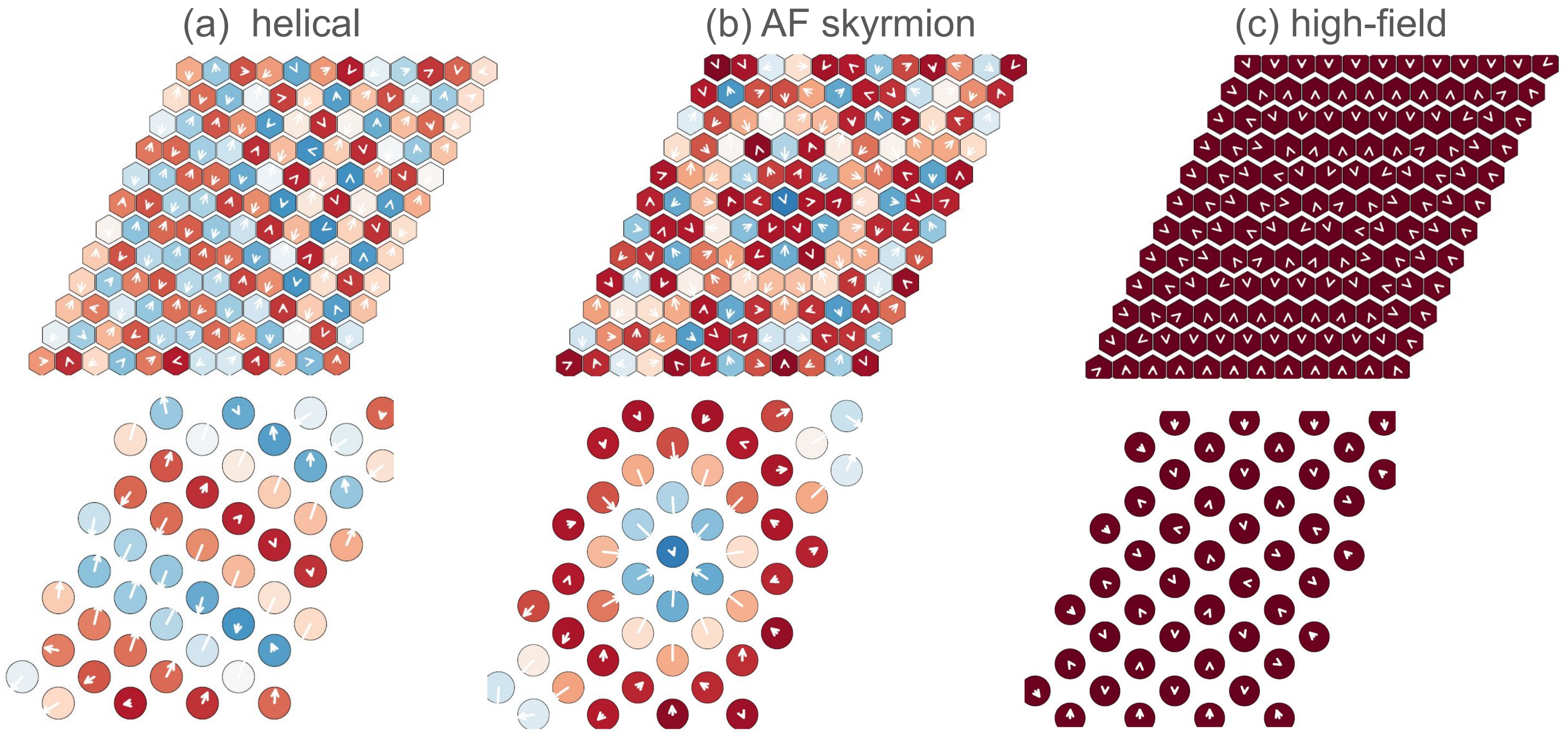

Fig. 1: Local magnetization of ground states of H for B/J = (a) 0.8, (b) 1.76, (c) 5.6. We plot expectation values of S_x, S_y and S_z for the entire triangular lattice (top) and a sublattice (bottom). Sublattice profiles are similar to results from [3].

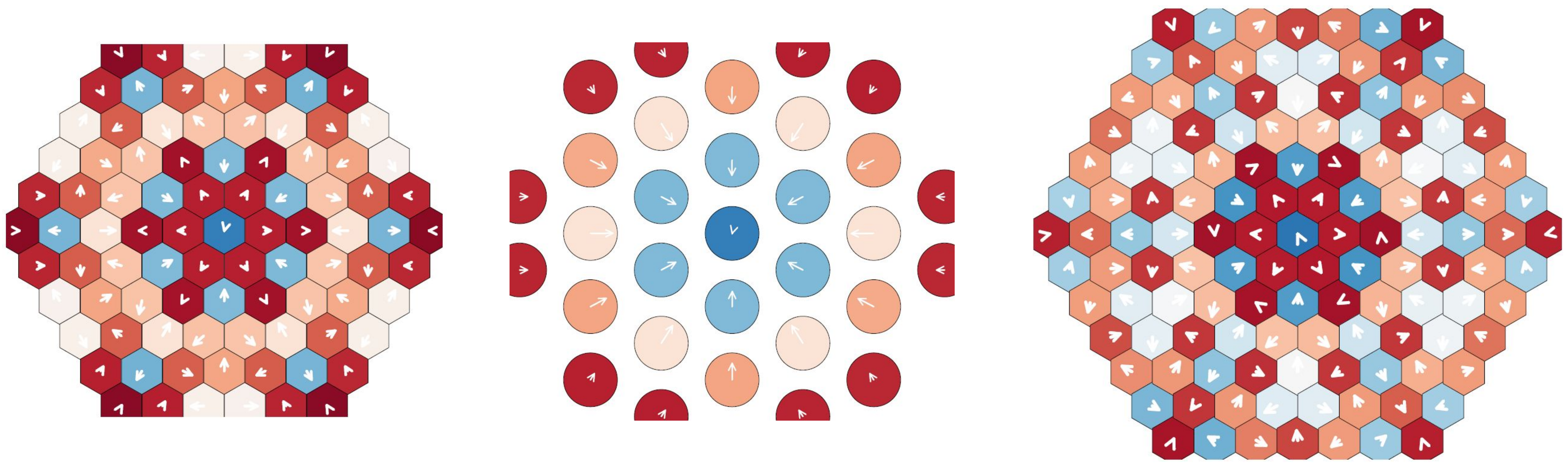

Fig. 2: Local magnetization of ground states of H on a disk-shaped triangular lattice for different values of D/J. We plot lattice (left) and sublattice (center) local magnetization for B/J=1.76 and D/J=0.8. If we fix B/J=1.2 and D/J=0.6, the ground state magnetization profile (right) presents a similar pattern.

$$Q = \frac{1}{\pi} \sum_{(i,j,k)\in\triangle/\nabla} \langle \hat{\mathbf{S}}_i \cdot (\hat{\mathbf{S}}_j \times \hat{\mathbf{S}}_k)\rangle$$

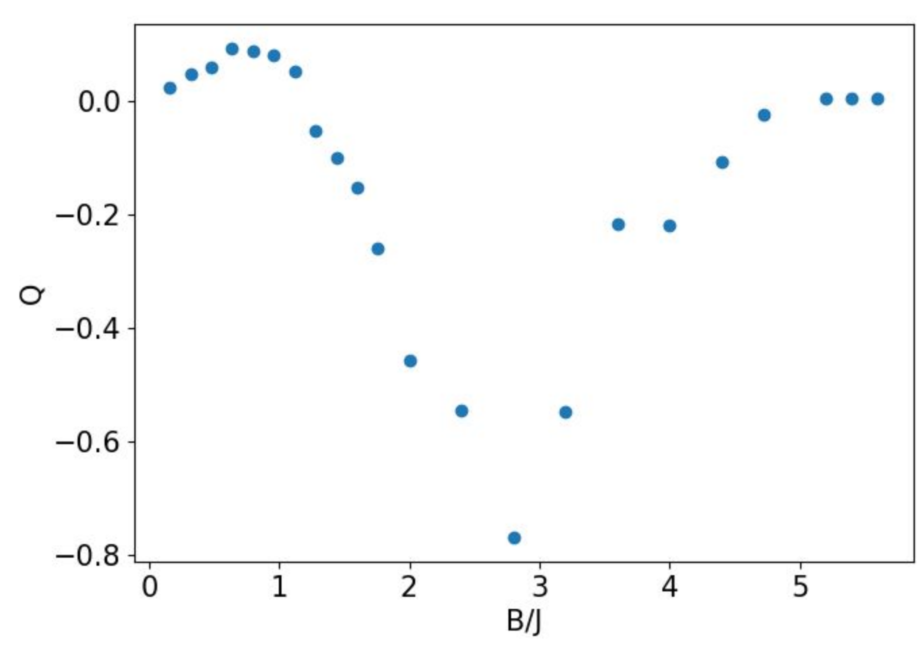

Fig. 3: Chirality Q v. B/J for each corresponding ground state of H.

$$S = -\operatorname{Tr}(\rho_A \log \rho_A)$$

A: from site 1 to site 72

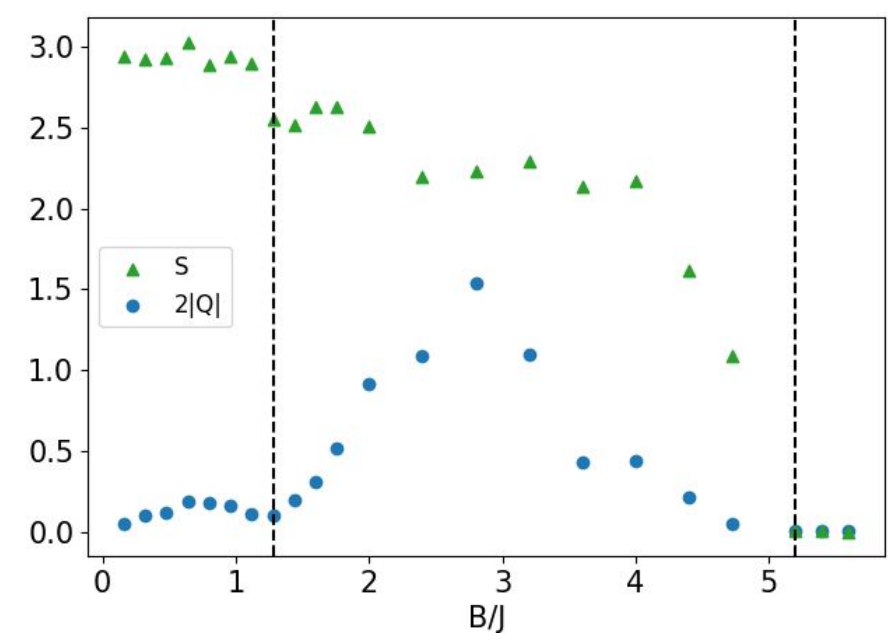

Fig. 4: Entanglement entropy S (green triangles) and rescaled chirality Q (blue dots) v. B/J. Dashed vertical lines signal that Q changes sign.

$$C_{ij} = \max(0, \lambda_1 - \lambda_2 - \lambda_3 - \lambda_4)$$

λ_i: eigenvalues of R

$$R = \sqrt{\rho_{ij}\,\tilde{\rho}_{ij}}$$

$$\tilde{\rho}_{ij} = (\sigma_y \otimes \sigma_y)\rho_{ij}^*(\sigma_y \otimes \sigma_y)$$

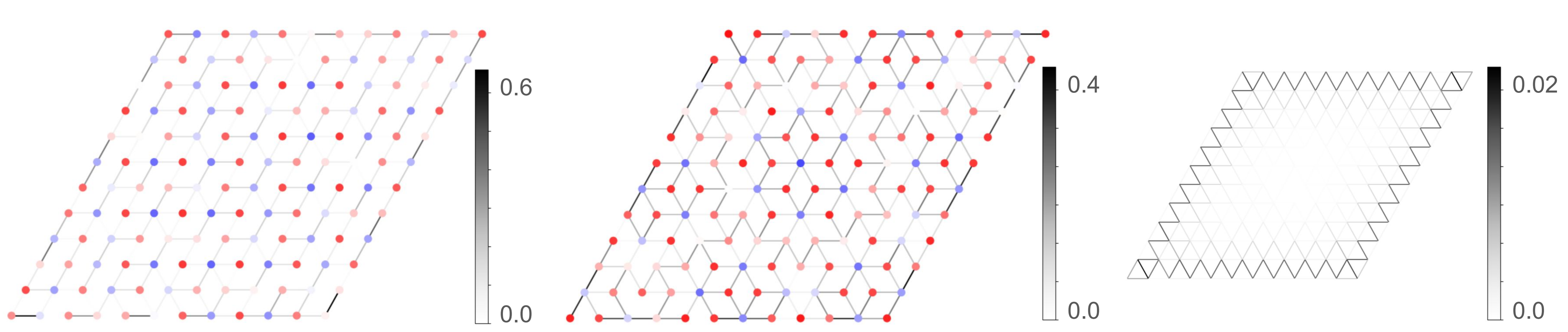

Fig. 5: Concurrence C_{ij} between nearest-neighbor spins i and j for helical (left), AF skyrmion (center) and high-field states (right). These correspond to B/J = 0.8, 1.6, 5.4 and D/J=0.8.