Emergence of zero-field non-synthetic single and interchained antiferromagnetic skyrmions in thin films

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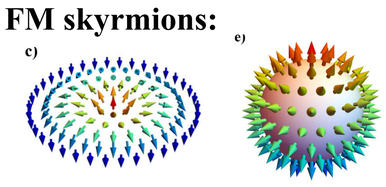
Abstract

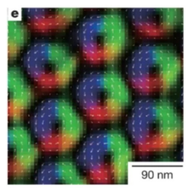
Antiferromagnetic (AFM) skyrmions are envisioned as ideal localized topological magnetic bits in future information technologies. In contrast to ferromagnetic (FM) skyrmions, they are immune to the skyrmion Hall effect, might offer potential terahertz dynamics while being insensitive to external magnetic fields and dipolar interactions. Although observed in synthetic AFM structures and as complex meronic textures in intrinsic AFM bulk materials, their realization in non-synthetic AFM films, of crucial importance in racetrack concepts, has been elusive. Here[1], we unveil their presence in a row-wise AFM Cr film deposited on PdFe bilayer grown on fcc Ir(111) surface. Using first principles, we demonstrate the emergence of single and strikingly interpenetrating chains of AFM skyrmions, which can co-exist with the rich inhomogeneous exchange field, including that of FM skyrmions, hosted by PdFe. Besides the identification of an ideal platform of materials for intrinsic AFM skyrmions, we anticipate the uncovered knotted solitons to be promising building blocks in AFM spintronics.

Magnetic skyrmions

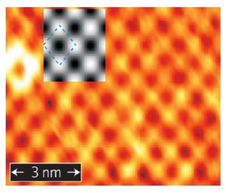
➢ **FM skyrmions:**



- Topological protection[2]

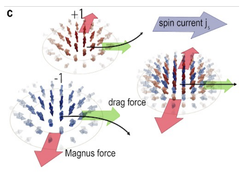


- FM skyrmions in bulk magnets[3]

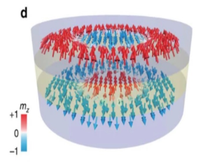


- FM skyrmions in ultra-thin films [4]

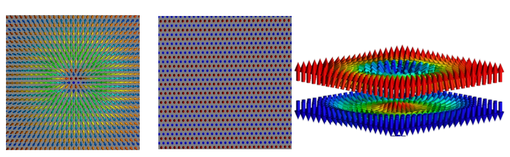
➢ **AFM skyrmions:**



- No skyrmions Hall angle[5]



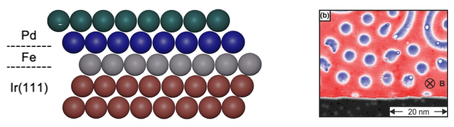
- Synthetic AFM skyrmions[6]



- Intrinsic AFM skyrmions are anticipated to emerge on AFM background

Methods

➢ **Multiscale modelling approach**



[7]

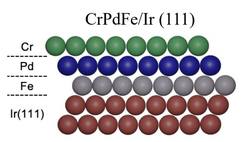
- Optimizing the structures[8]
- Magnetic interactions[9]
- Spin dynamics[10]

QUANTUMESPRESSO → JuKKR → spirit

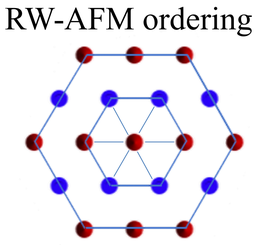
$$H = -\sum_{ij} \mathbf{J}_{ij}\mathbf{S}_i \cdot \mathbf{S}_j - \sum_{ij} \mathbf{D}_{ij} \cdot (\mathbf{S}_i \times \mathbf{S}_j) - \sum_{i} \mathbf{K}_i (\mathbf{S}_i^z)^2 - \sum_{i} \mathbf{B} \cdot \mathbf{S}_i$$

AFM magnetic layered system

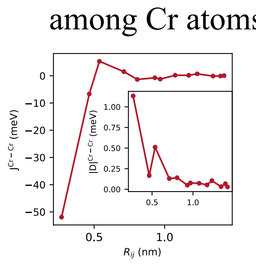
- The magnetic system



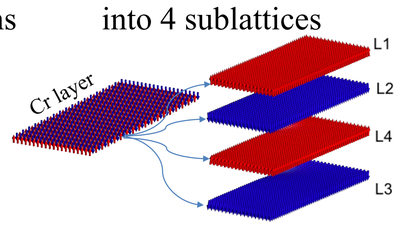
- Triangular lattice with RW-AFM ordering



- Magnetic interactions among Cr atoms

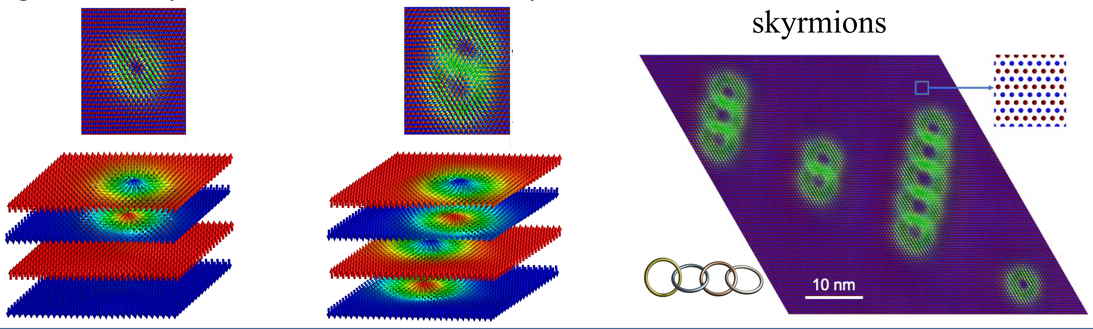


- Cr layer is divided into 4 sublattices

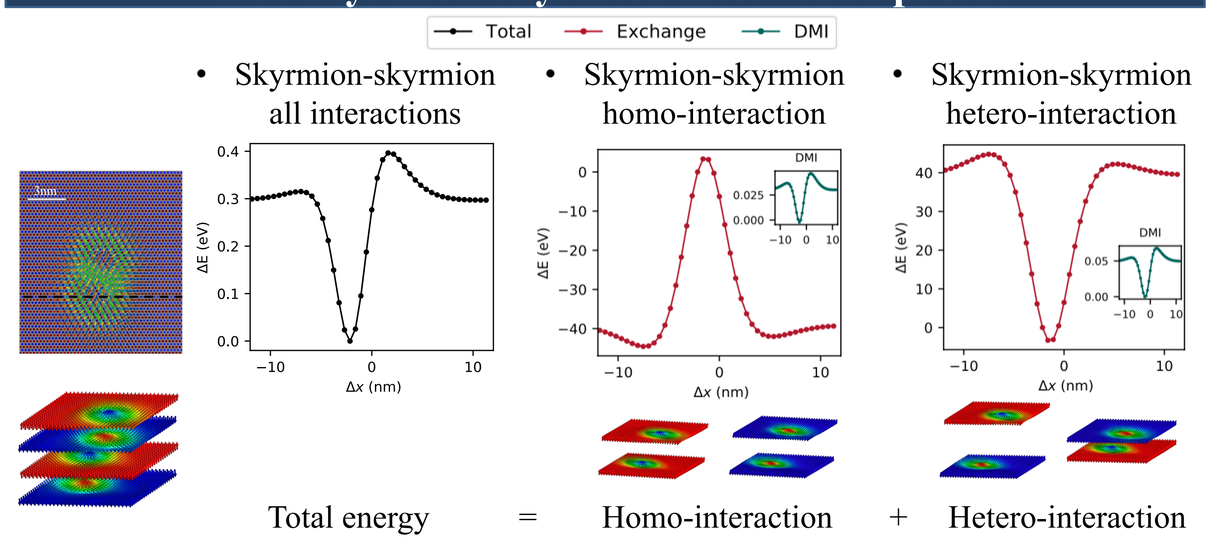


Single & Interchained AFM skyrmions

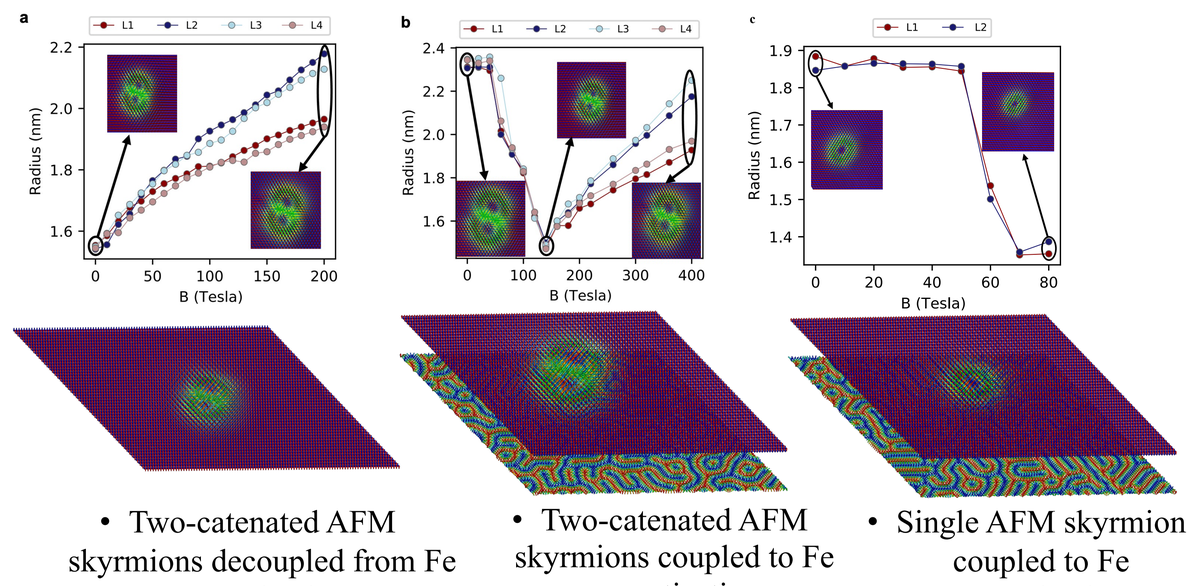
- Single AFM skyrmion
- Double AFM skyrmions
- Plethora of AFM skyrmions



AFM skyrmion-skyrmion interaction profile



Magnetic field effect on the radius of AFM skyrmion

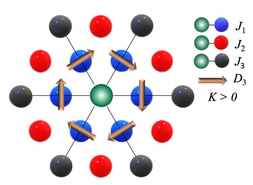


- Two-catenated AFM skyrmions decoupled from Fe magnetizations
- Two-catenated AFM skyrmions coupled to Fe magnetizations
- Single AFM skyrmion coupled to Fe magnetizations

A spin model for intrinsic antiferromagnetic skyrmions[11]

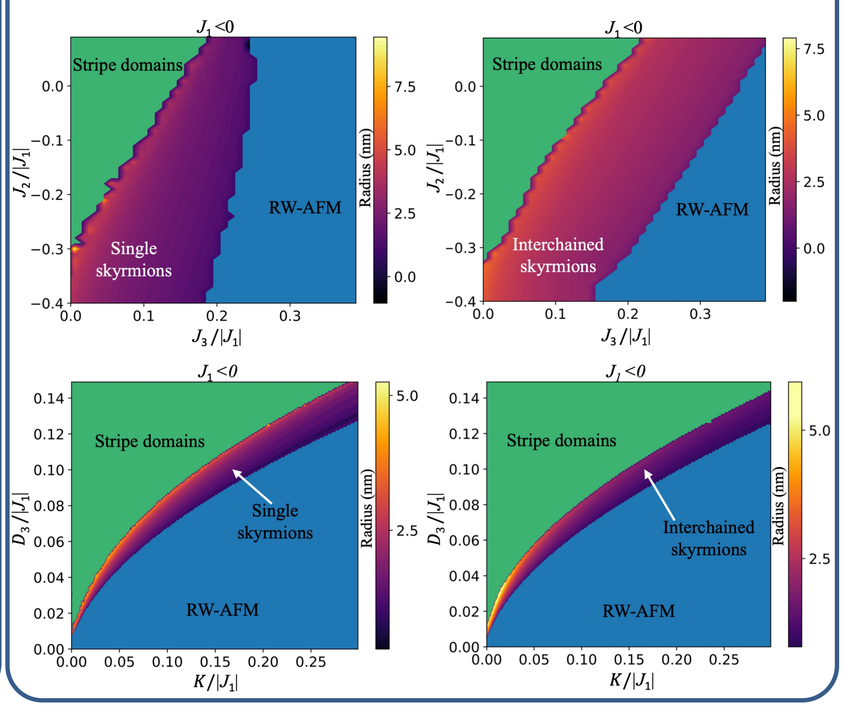
➢ We explore the minimal Heisenberg model enabling the occurrence of single and interchained AFM skyrmions on a triangular lattice

- **The minimum set of Heisenberg interactions**



1. AFM J_1 and J_2 for the realization of the RW-AFM ordering.
2. FM J_3 & in-plane DMI (D_3) for the formation of the FM skyrmions
3. Out-of-plane magnetic anisotropy (K)

- **Phase diagrams**



Conclusion & Outlook

➢ A Plethora of AFM structures is found as metastable states at Cr layer deposited on PdFe/Ir(111).

➢ We explore the minimal Heisenberg model enabling the occurrence of Single and interlinked AFM skyrmions.

➢ These unusual AFM localized entities might become exciting and useful constituents of future nanotechnology devices.

➢ We aim to explore the transport properties of the explored solitons.

Acknowledgment

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