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Information Transfer by Vector Spin Chirality in Finite Magnetic Chains

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Vector spin chirality is one of the fundamental characteristics of complex magnets. For a one-dimensional spin-spiral state it can be interpreted as the handedness, or rotational sense of the spiral. Here, using spin-polarized scanning tunneling microscopy, we demonstrate the occurrence of an atomic-scale spin spiral in finite individual bi-atomic Fe chains on the $(5 \times 1) - \mathrm{Ir}(001)$ surface. We show that the broken inversion symmetry at the surface promotes one direction of the vector spin chirality, leading to a unique rotational sense of the spiral in all chains. Correspondingly, changes in the spin direction of one chain end can be probed tens of nanometers away, suggesting a new way of transmitting information about the state of magnetic objects on the nanoscale.

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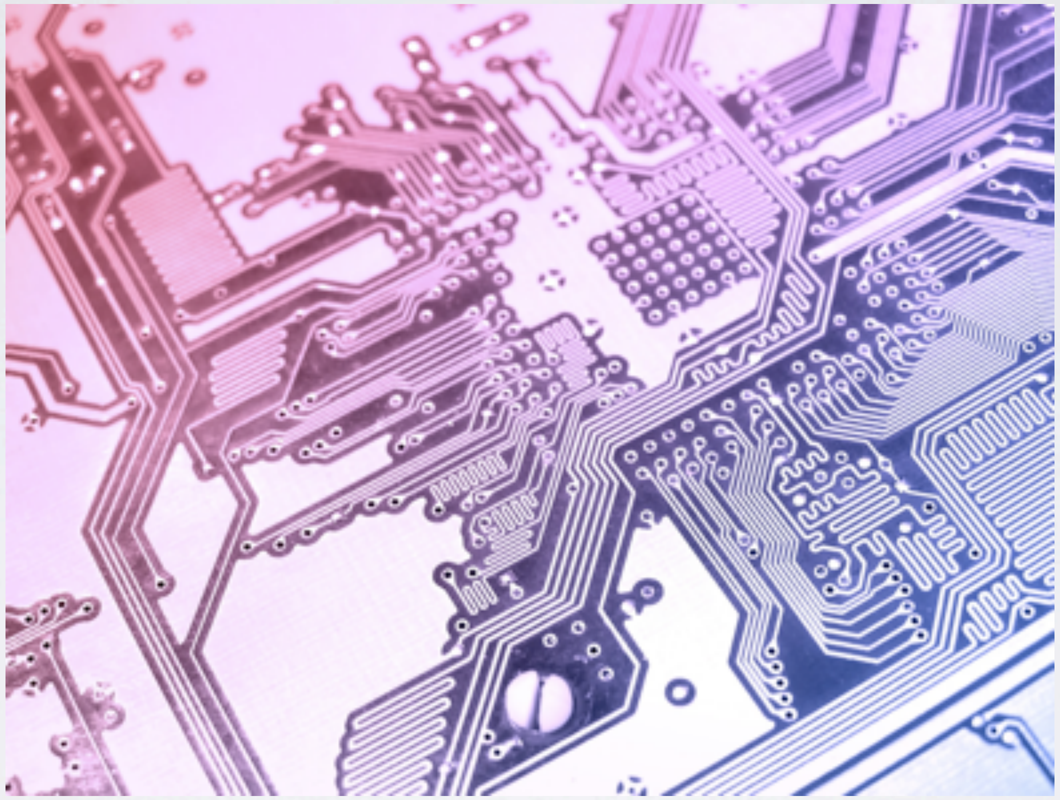
INTEREST IN THESE SYSTEMS

This guy...



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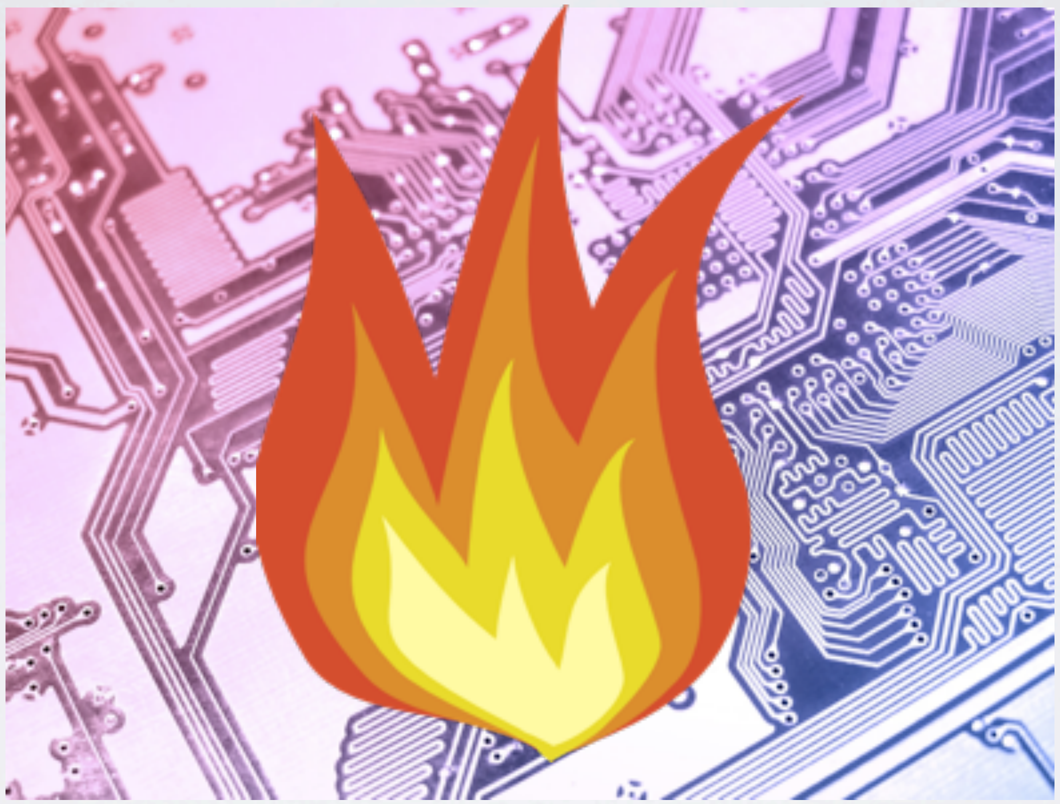

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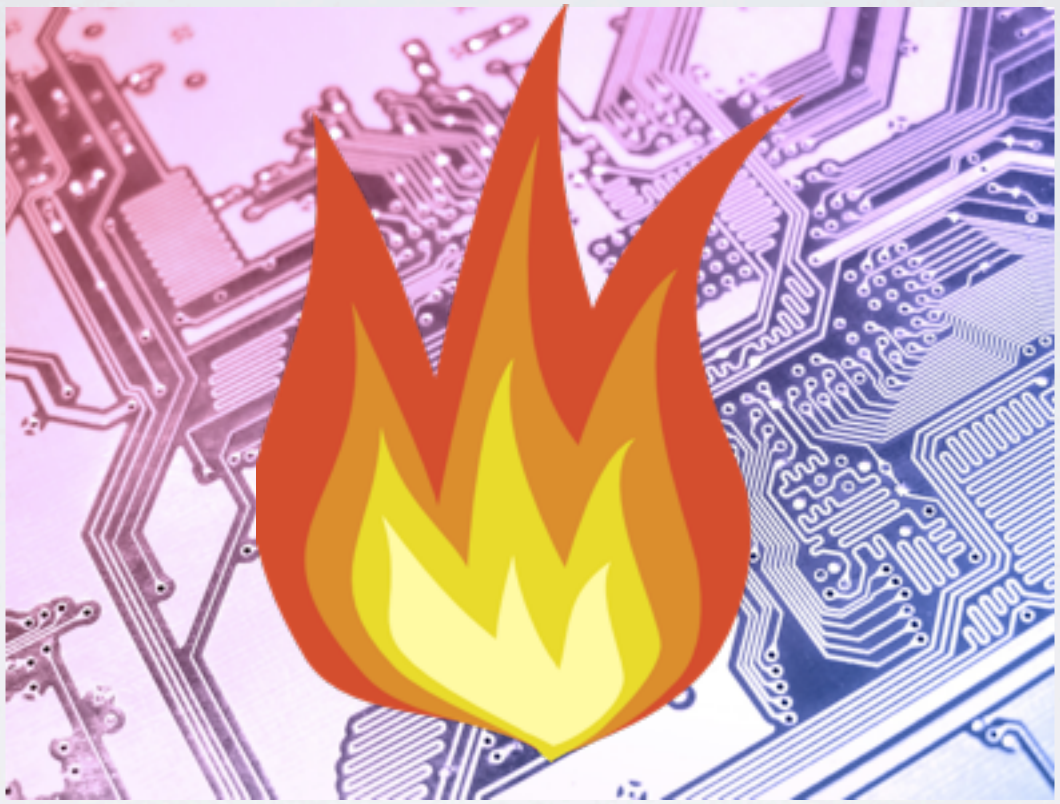


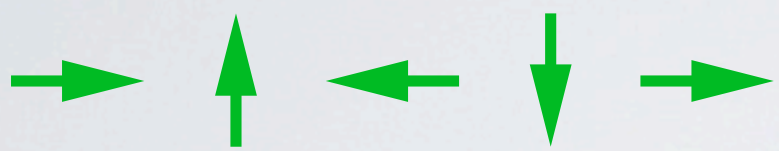
Opportunities spintronics in non-itinerant systems

- No moving charges
- Small signals → Less power dissipation
- Different operation

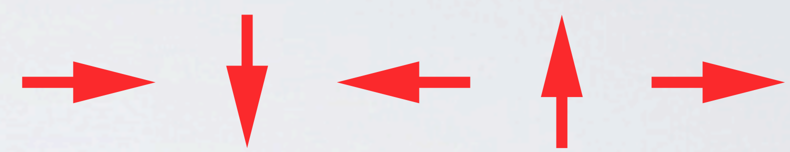
DEFINITION CHIRALITY

In 1-D systems, chirality is about the handedness of a spiral state

$$\mathbf{C}_i \propto \mathbf{S}_i \times \mathbf{S}_j$$



$C_z = 1$



$C_z = -1$

Chirality is related to current in Heisenberg systems

$$I_s = \frac{\mathrm{d}S_i^z}{\mathrm{d}t} \propto [J \sum_{ij} \mathbf{S}_i \cdot \mathbf{S}_j, S_i^z] \propto J \left[S_i^+ S_j^- - S_i^- S_j^+\right] \propto C_i^z$$

However, this does not always mean that nonzero chirality = finite current.

CHIRALITY AND SPIN CURRENT

Example: magnets with DM interaction $\boldsymbol{D}_{ij} \cdot (\boldsymbol{S}_i \times \boldsymbol{S}_j)$ can have nonzero equilibrium chirality. Does this mean there is a nonzero equilibrium current?

$$H = \sum_{ij} \frac{\tilde{J}_{ij}}{2} \left[e^{i\alpha_{ij}} S_i^+ S_j^- + e^{-i\alpha_{ij}} S_i^- S_j^+ \right] + J_{ij} S_i^z S_j^z$$

With the parameter $\tilde{J}_{ij} e^{i\alpha_{ij}} = J_{ij} + iD_{ij}$. Assume spin parametrized by

$$\mathbf{S}_i = S(\cos\phi_i, \sin\phi_i, 0)$$

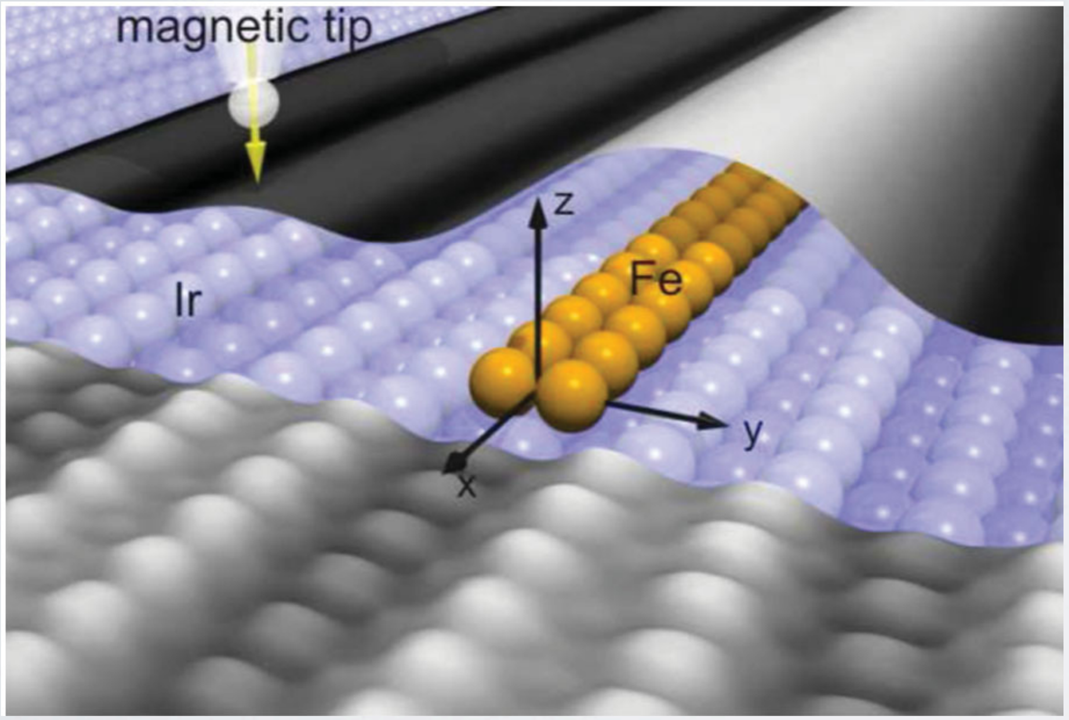
Spin current then given by (again from commutator)

$$I_S \propto JS^2 \sin(\phi_i - \phi_j - \alpha_{ij})$$

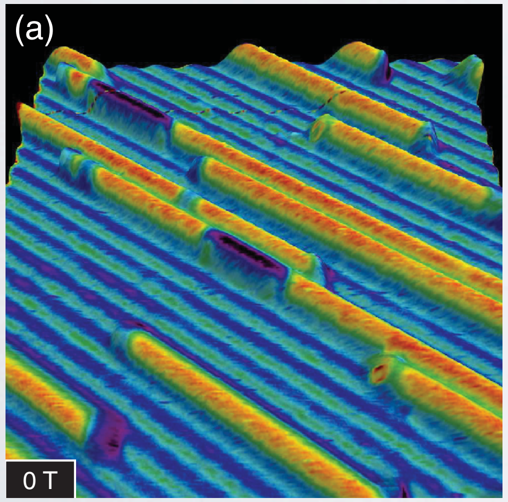
But minimization of energy gives constraint $\phi_i - \phi_j - A_{ij} = 0$.

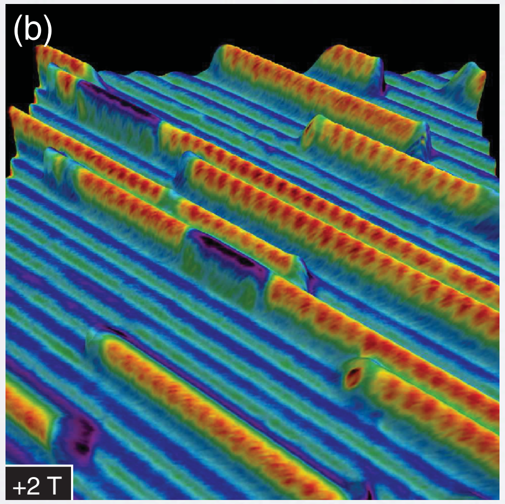
So spin current is zero even when chirality is not.

SYSTEM



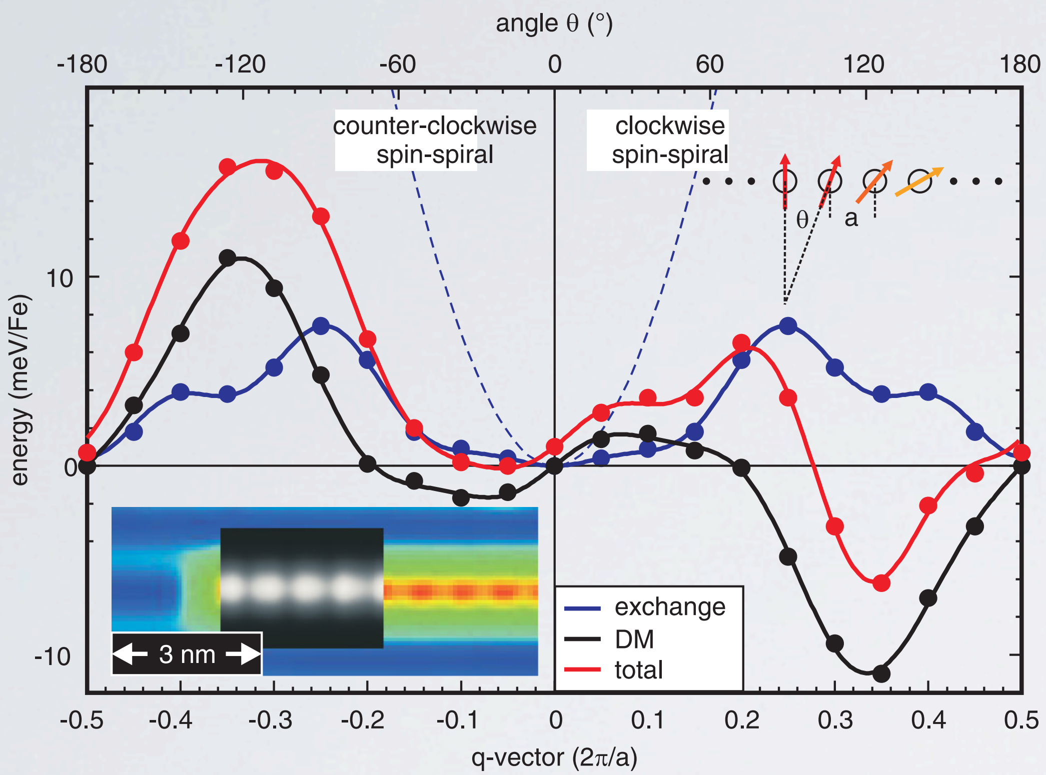
- Bi-atomic Fe chain on Ir(100) surface
- Form by self-assembly
- Typical length ~30 nm (*i.e.* 300 atoms)
- Behave as two parallel identical chains





- Use spin-polarized STM (SPSTM) to measure local magnetization
- Temperature ~8 K
- Magnetic field ~ 2 T

EXPLANATION GROUND STATE



DFT results

- Simplest model is Heisenberg model

$$H = \sum_{ij} J_{ij} \mathbf{S}_i \cdot \mathbf{S}_j$$

- Assumption spiral state

$$\mathbf{S}_i = S(\cos(qai), 0, \sin(qai))$$

- Without SOI, FM state favorable
- Energy quenched from ~75 meV to ~ 1meV due to Ir substrate

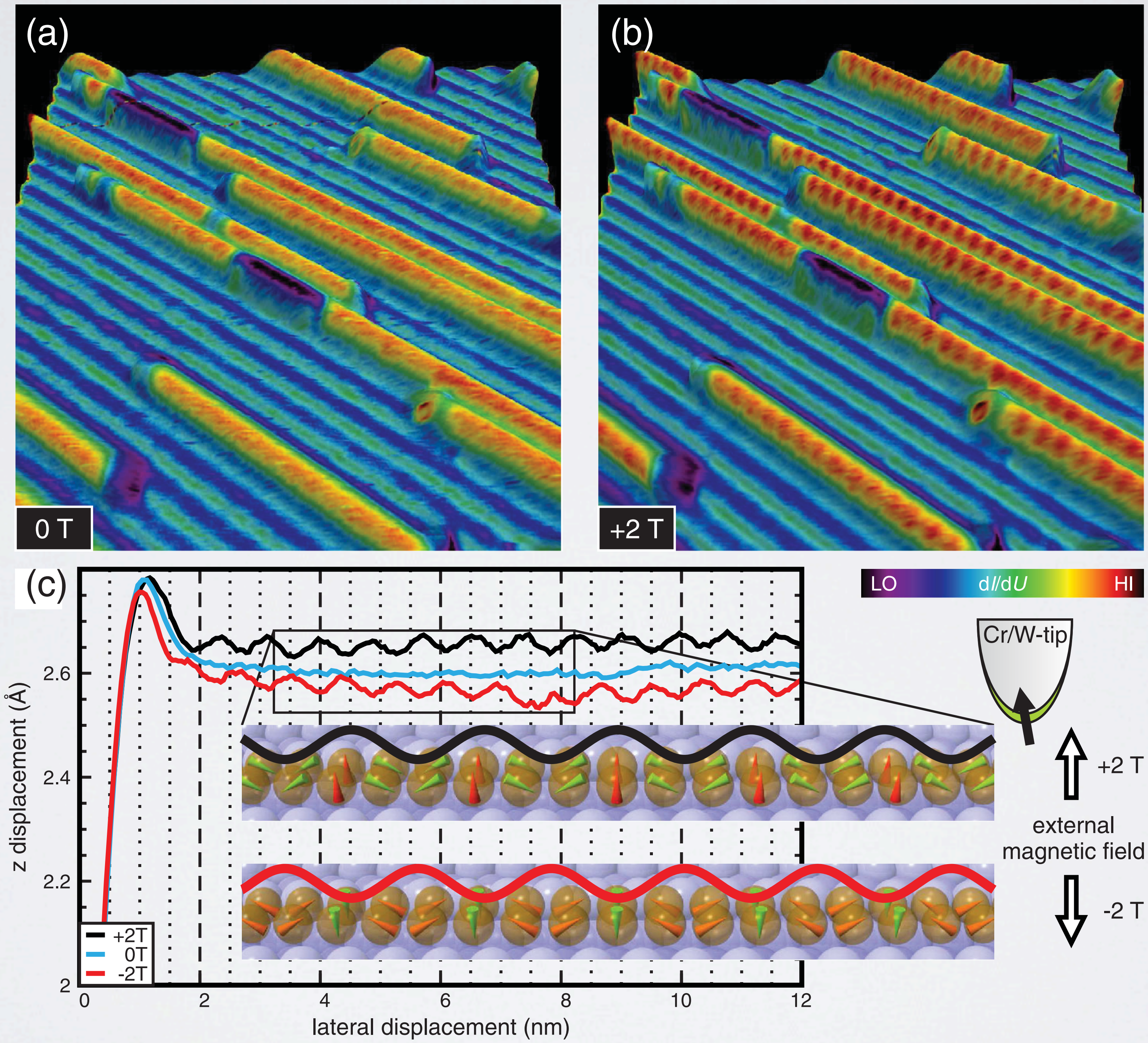
SOI gives rise to Dzyaloshinksii-Moriya interaction ($\mathbf{D}_{ij}$ // *y* axis)

$$H_{\mathrm{DM}} = \sum_{ij} \mathbf{D}_{ij} \cdot (\mathbf{S}_i \times \mathbf{S}_j)$$

Term is odd in *q*, gives rise to a unique spiral ground state with

$$q = 2\pi/(3a)$$

MEASUREMENT

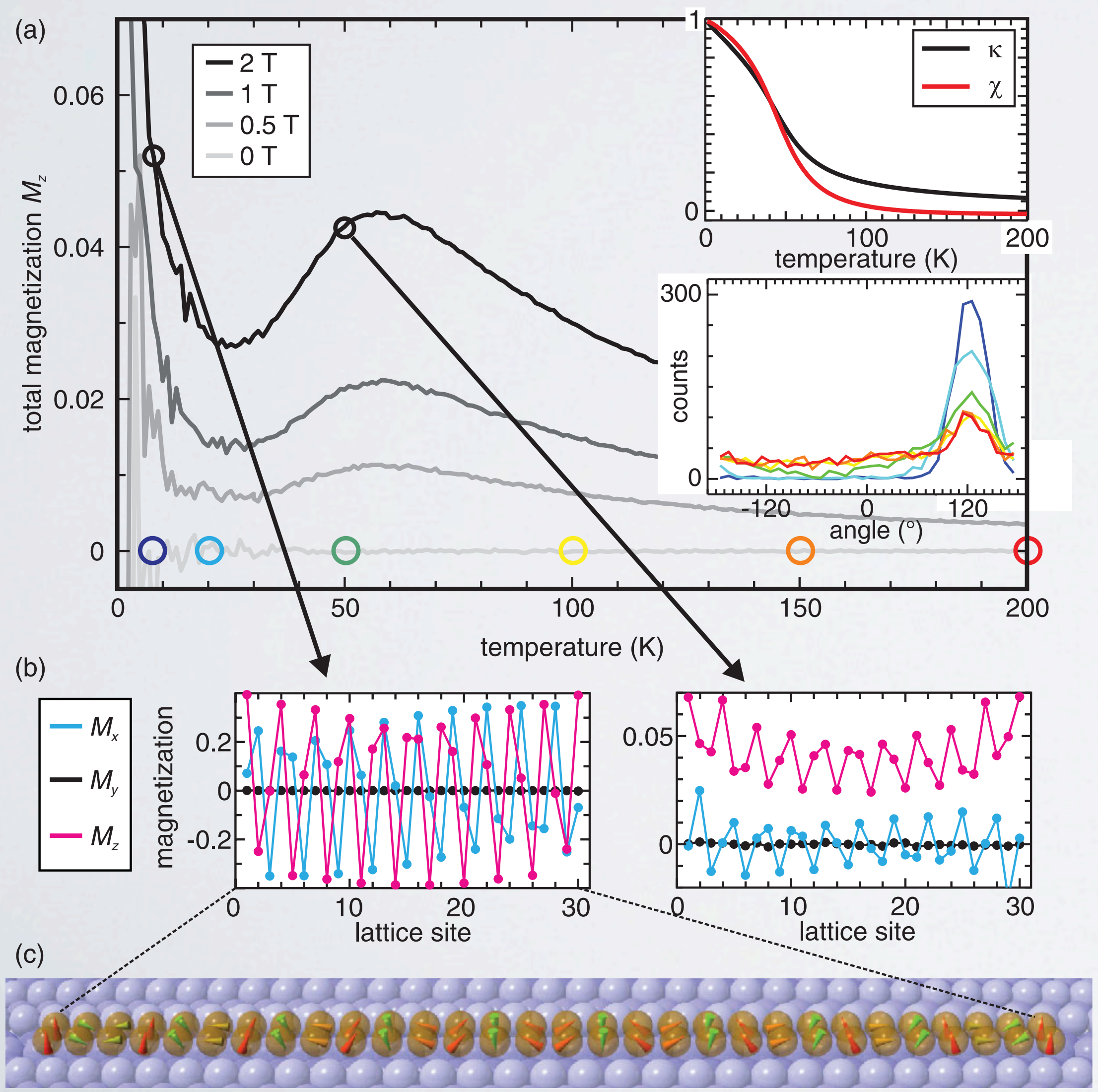


FINITE TEMPERATURES

Heat-bath Monte-Carlo method on complete Hamiltonian

$$H = H_{\rm H} + H_{\rm DM} + H_{\rm ani} + H_B$$

$$H_{\rm ani} = \sum_i K_i \sin^2 \phi_i \qquad H_B = \mu_S B \sum_i S_i^z$$



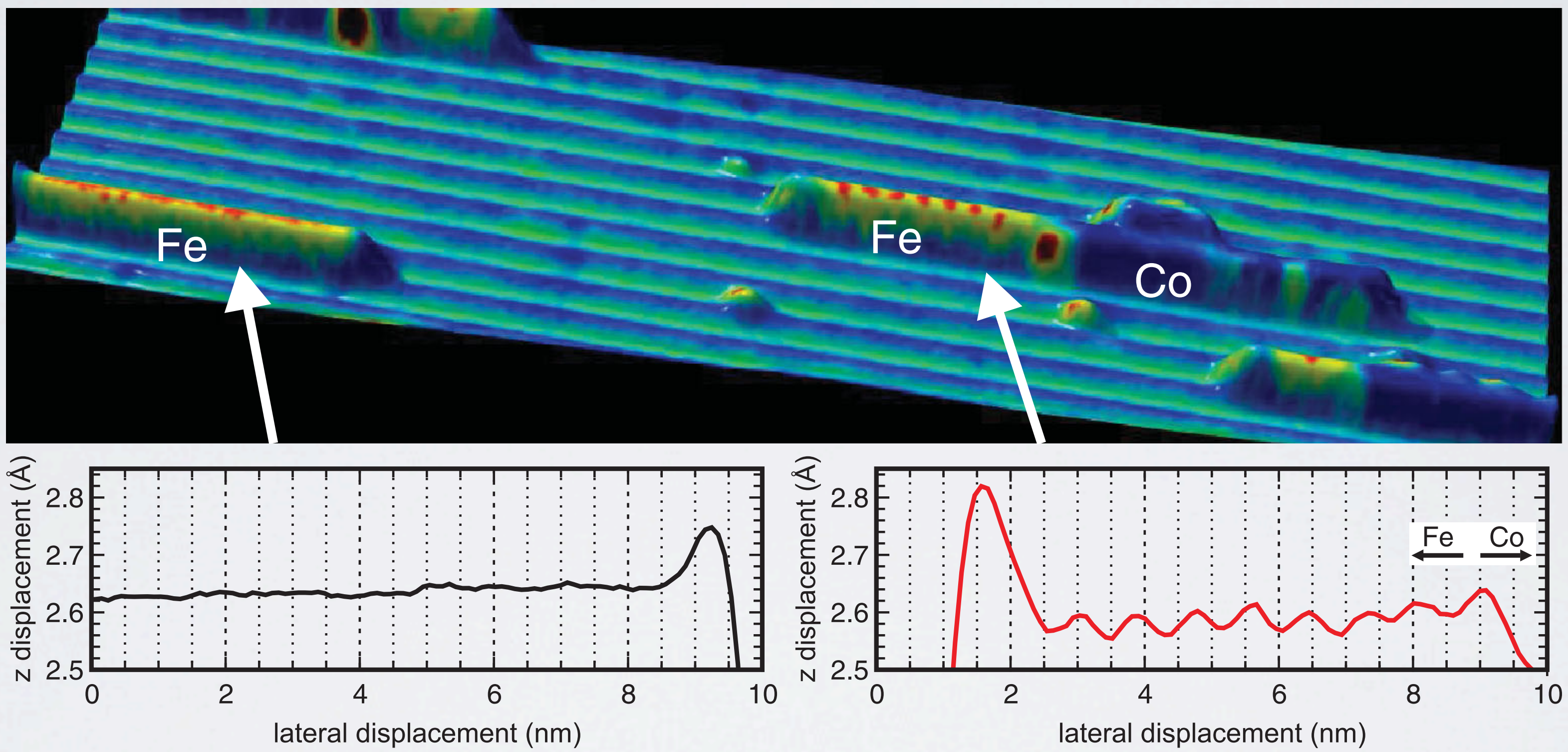
- Local, time-averaged magnetization for finite chain
- At B=0, thermal flucts give <$\mathbf{m}_i$> = 0
- At high T, spiral state destroyed
- Inset shows

$$\kappa \propto \langle (\mathbf{S}_i \times \mathbf{S}_j)_y \rangle \qquad \chi \propto \arccos{(\mathbf{S}_i \cdot \mathbf{S}_j)} - \pi/2$$

- Finite magnetization is finite size effect due to increased susceptibility of end spins

USE IN SPINTRONICS

Propose to use the chiral state to transport information



Exchange-couple Co chain to Fe chain. Depending on the state of the Co chain, the Fe chain will have a different local magnetization, which can be measured at finite distances (~10 nm).

THE END