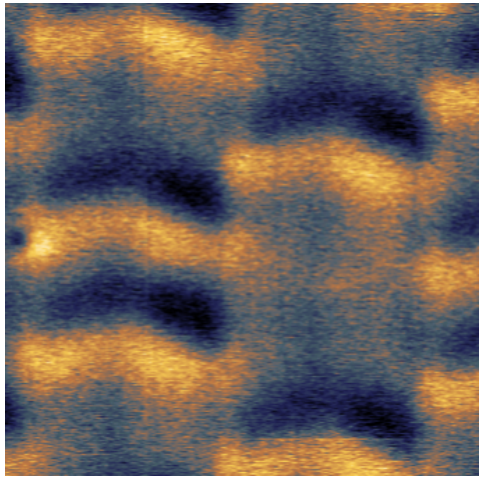
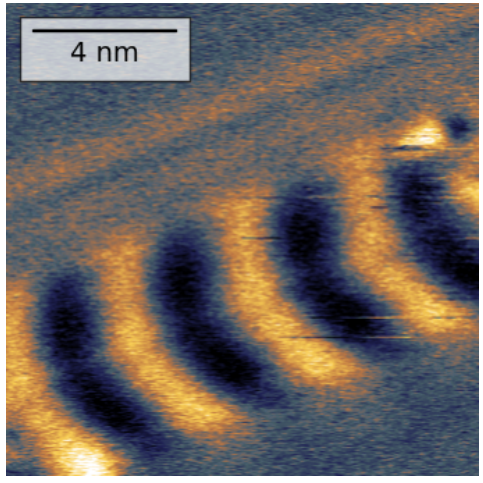
Universität Hamburg

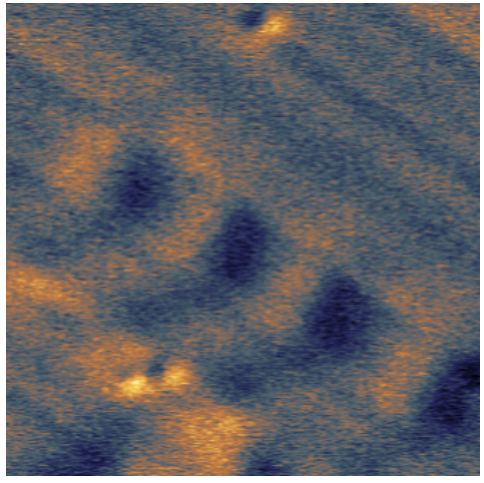
MA 28.4: Non collinear magnetic order at room temperature

Aurore Finco, Pin-Jui Hsu, Niklas Romming, Thomas Eelbo, Lorenz Schmidt, André Kubetzka, Kirsten von Bergmann and Roland Wiesendanger

University of Hamburg, Germany



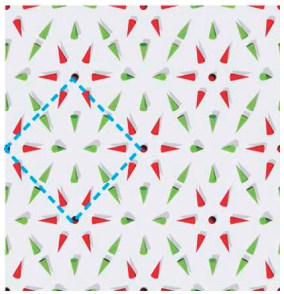


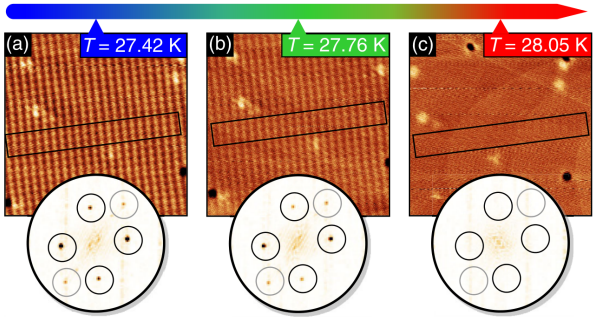


Skyrmions in ultrathin films

- Skyrmions: topologically non trivial magnetic objects
- Interesting for spintronics applications (racetrack memories)
- Stabilized in ultrathin films by the interface-induced **Dzyaloshinskii-Moriya interaction**

Fe/Ir(111): nanoskyrmion lattice





Nanoskyrmion lattice visible until 28 K

How to improve thermal stability?

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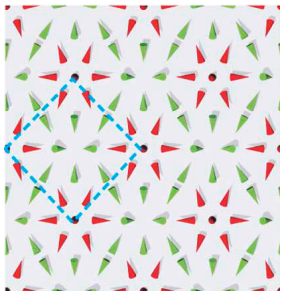

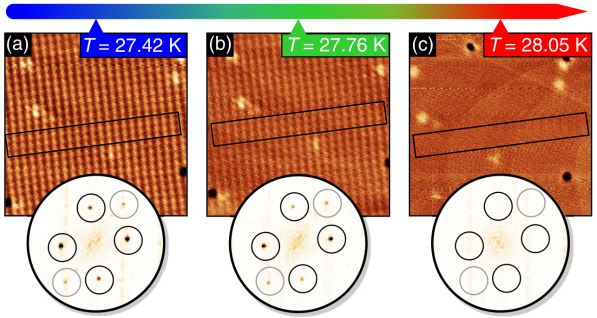

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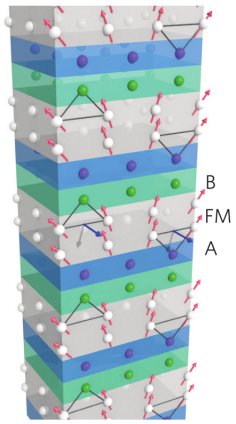

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Multilayer stacks
e.g. $(Ir/Co/Pt)_x$

Room temperature skyrmions observed

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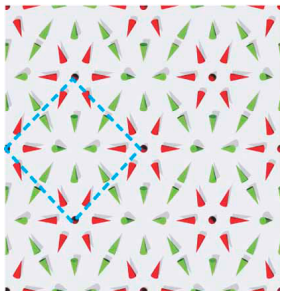

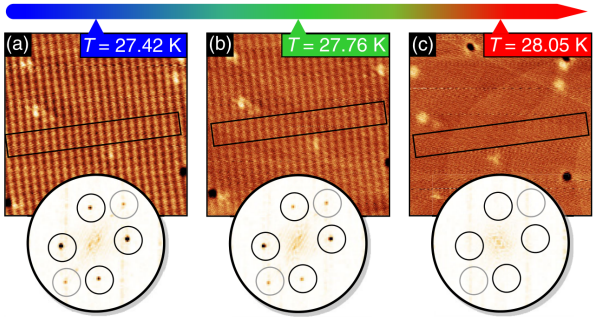

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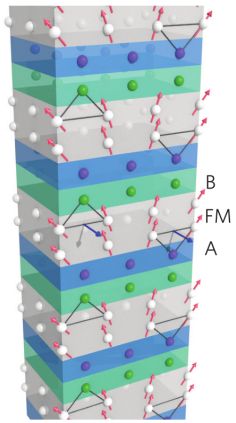

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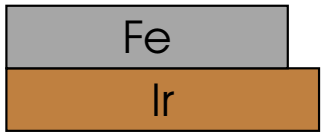

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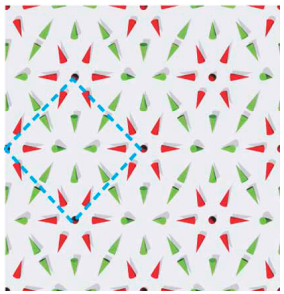

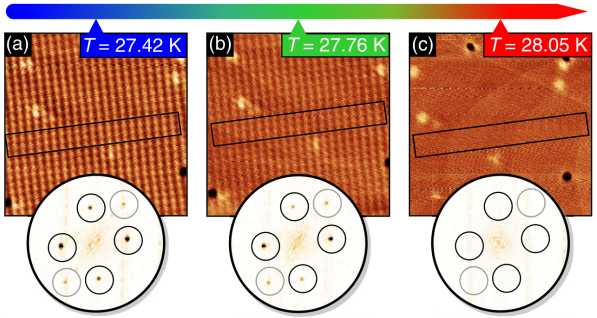

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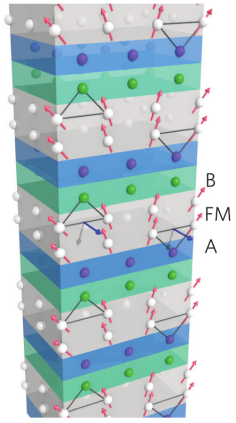

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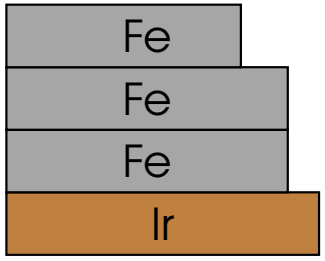

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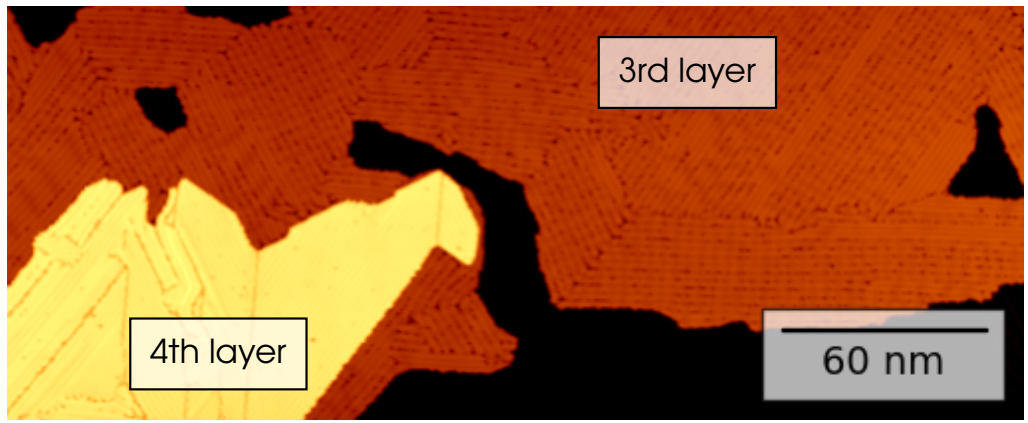
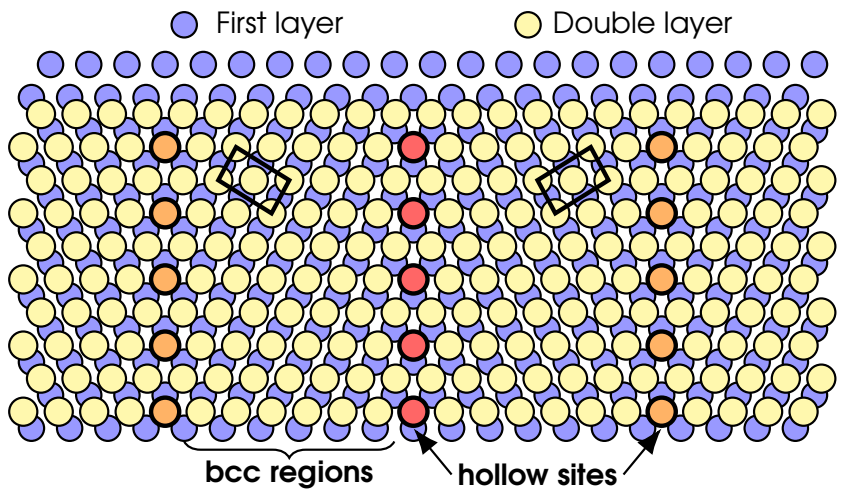
Morphology of the Fe films on Ir(111)

- lattice mismatch between Fe and Ir (34% between bulk fcc Ir and bulk bcc Fe)
- Fe deposition at elevated substrate temperature (around 200 °C)
- 1st layer **pseudomorphic** (strained)
- **reconstruction lines** along the 3 equivalent crystallographic directions on the thicker layers (uniaxial strain release)

Topography, $U = 200\,\mathrm{mV}$, $I = 1\,\mathrm{nA}$, $T = 4\,\mathrm{K}$, $B = 0\,\mathrm{T}$, W tip



Topography, $U = -700\,\mathrm{mV}$, $I = 1\,\mathrm{nA}$, $T = 4\,\mathrm{K}$, $B = 2.5\,\mathrm{T}$, Cr bulk tip



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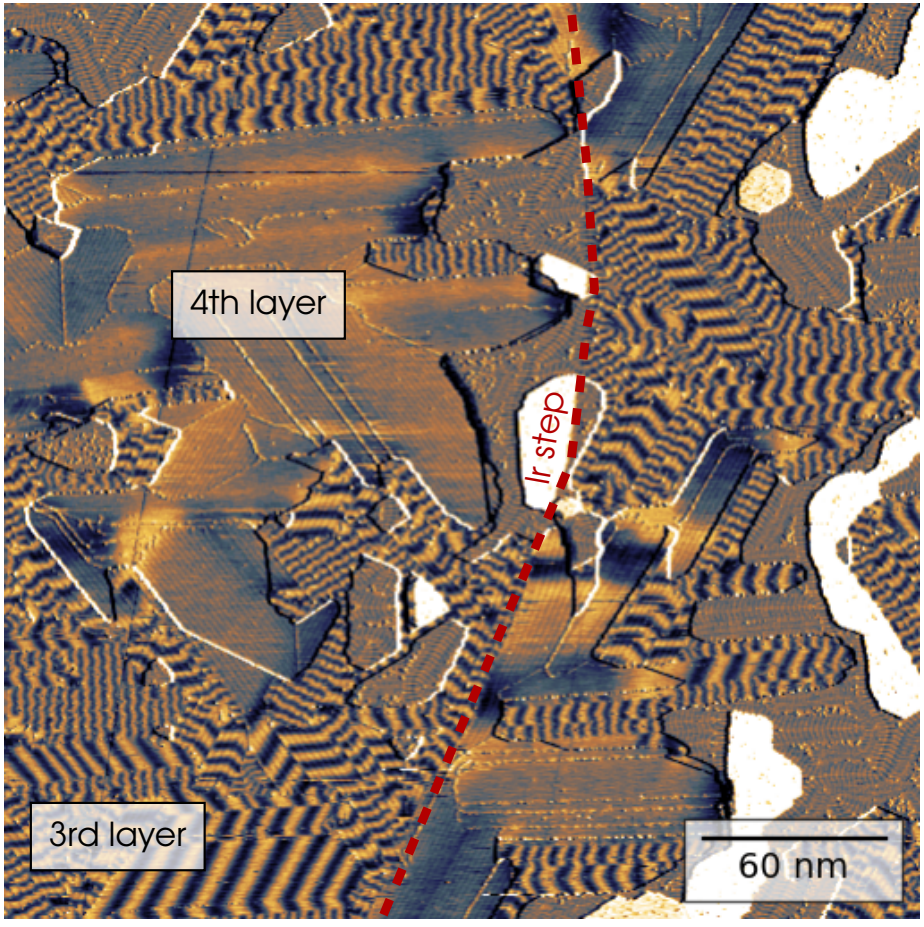
Non-collinear magnetic structure, low T, no external field

Strong influence of the surface structure on the magnetic order



Differential conductance, $U = -700\,\mathrm{mV}$, $I = 1\,\mathrm{nA}$,
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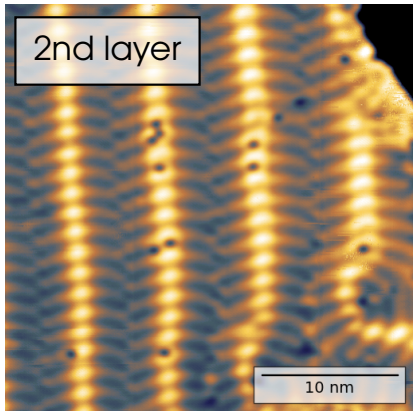

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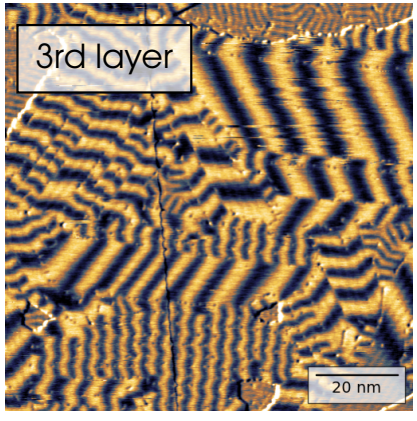

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- **Ferromagnetic domains on the 4th layer**

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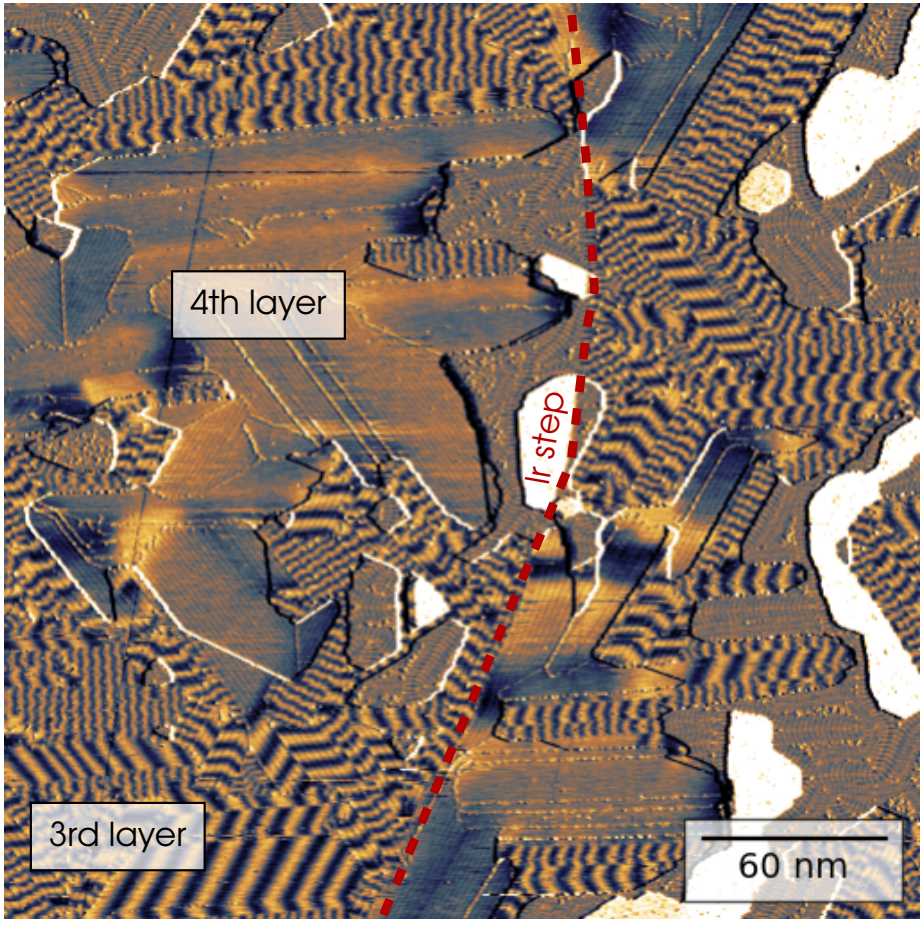

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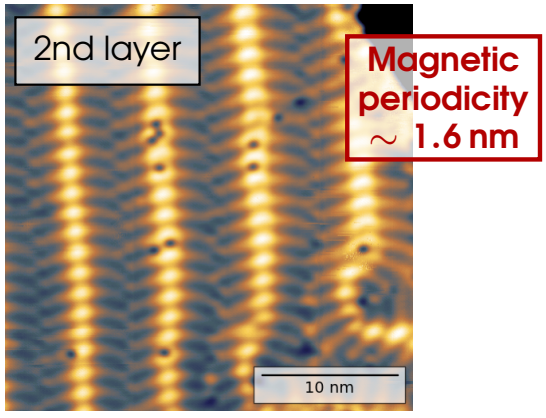

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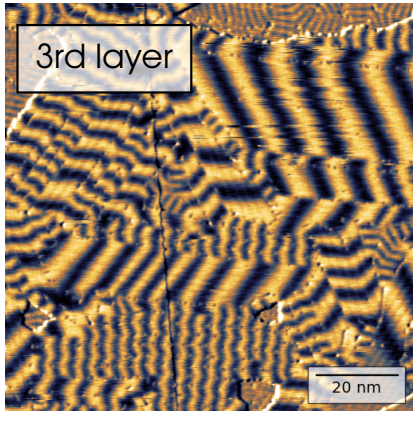

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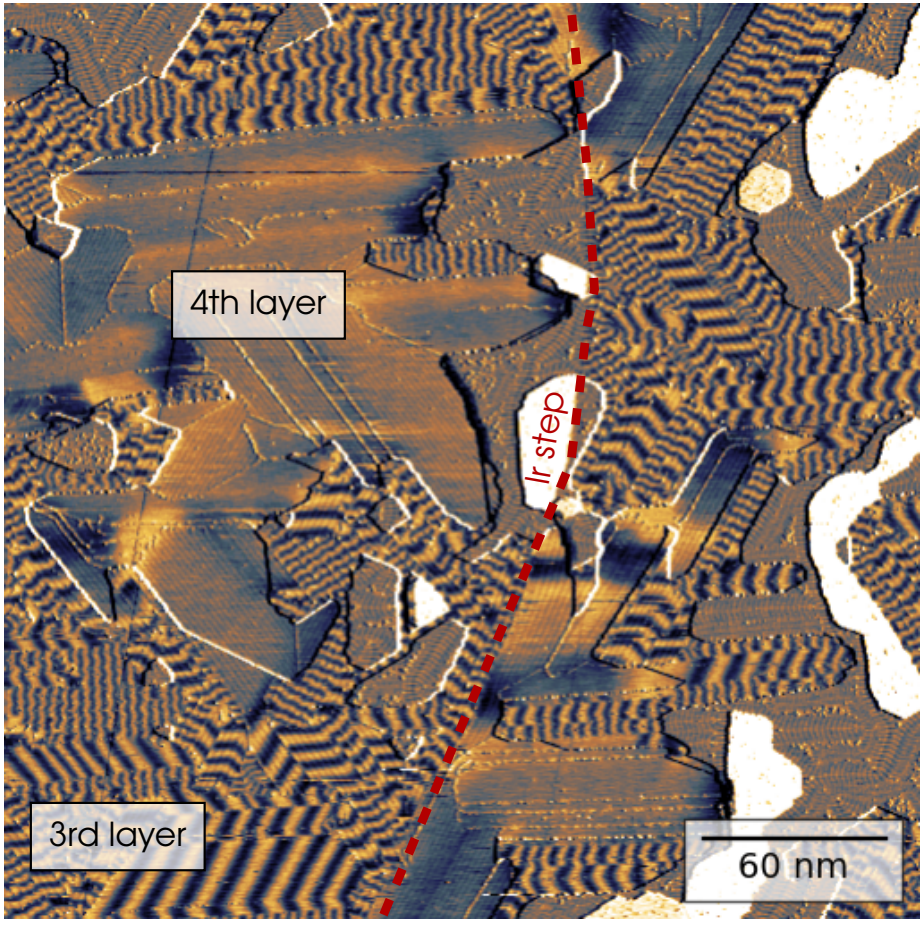

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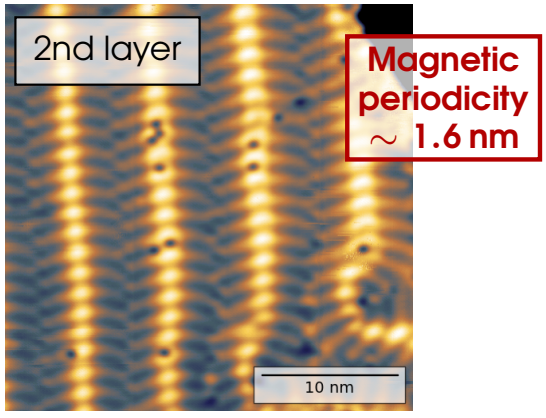

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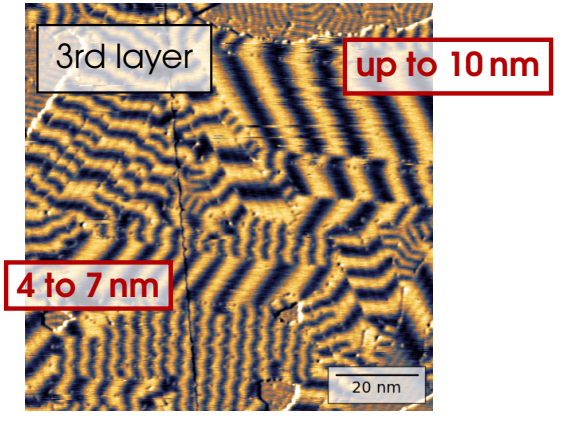

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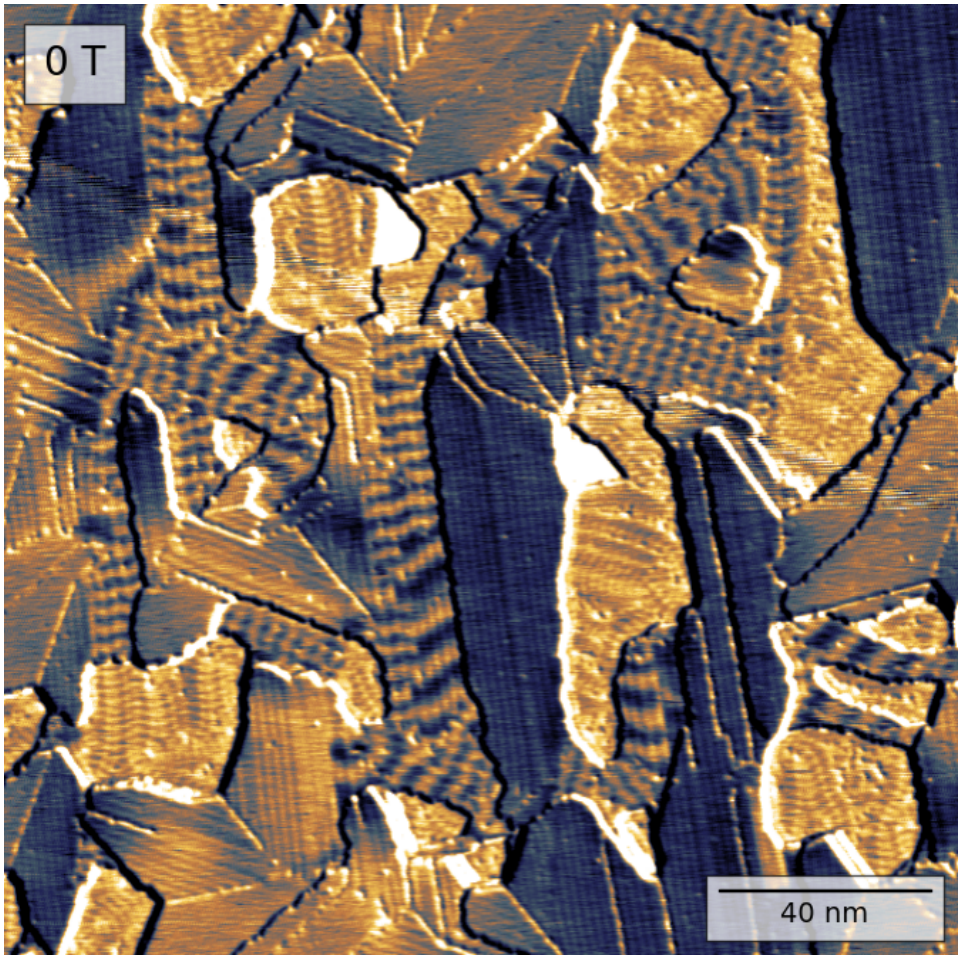
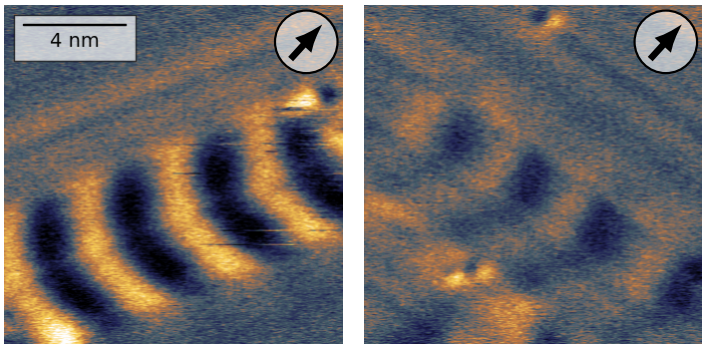
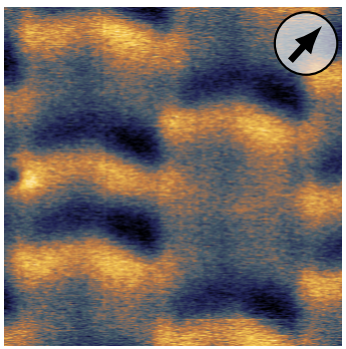
Application of an external out-of-plane magnetic field

- No effect on the 2nd layer up to 9 T.
- On the 3rd layer, single magnetic objects appear around 1.5 T.

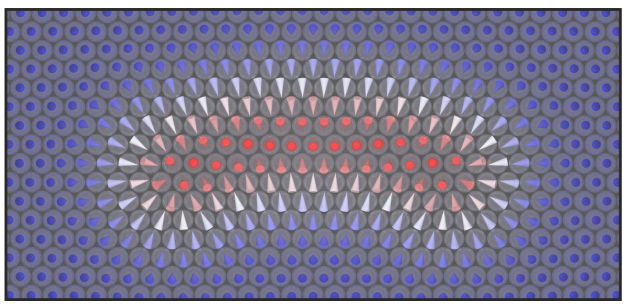


Differential conductance, $U = -500\,\mathrm{mV}$, $I = 1\,\mathrm{nA}$, $T = 4\,\mathrm{K}$, Cr bulk tip with out-of-plane magnetic sensitivity





Differential conductance, $U = -700\,\mathrm{mV}$, $I = 1\,\mathrm{nA}$, $T = 8\,\mathrm{K}$, $B = -2.5\,\mathrm{T}$, Cr bulk tip



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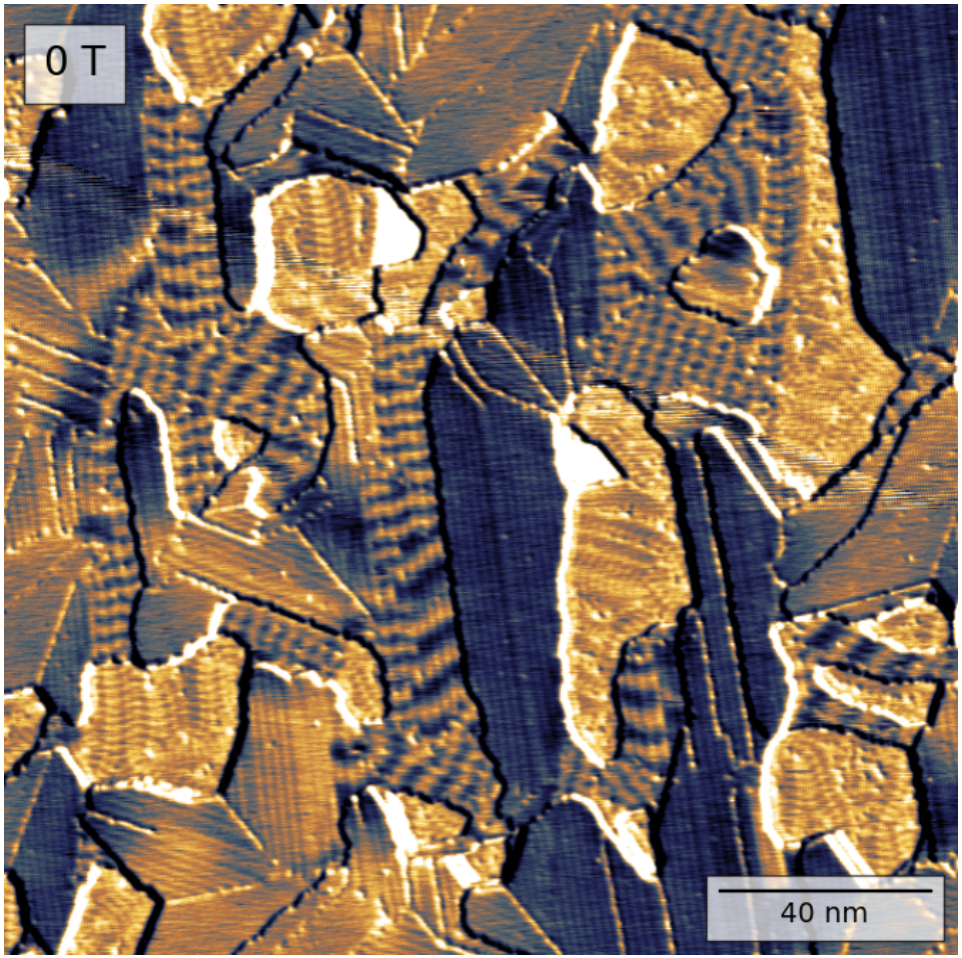

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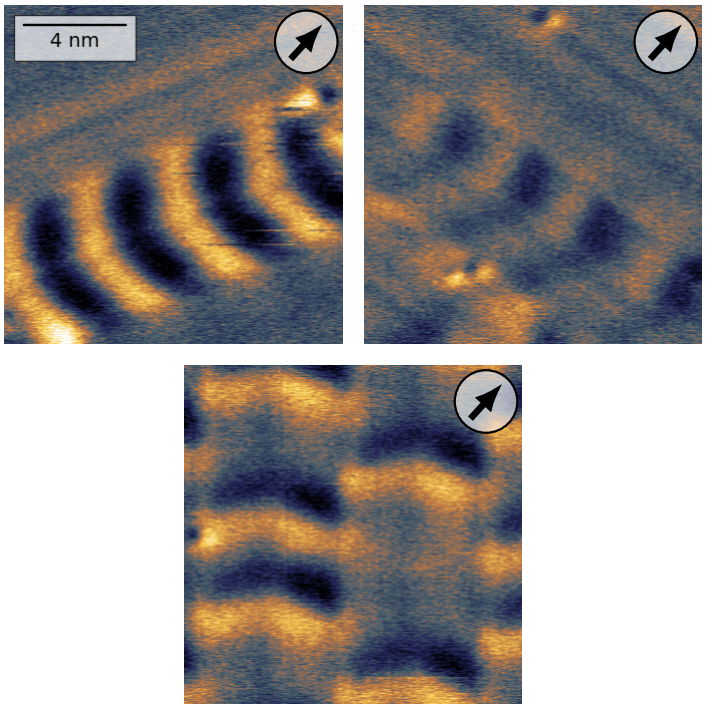

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Distorted skyrmions
MA 5.5, MA 15.6

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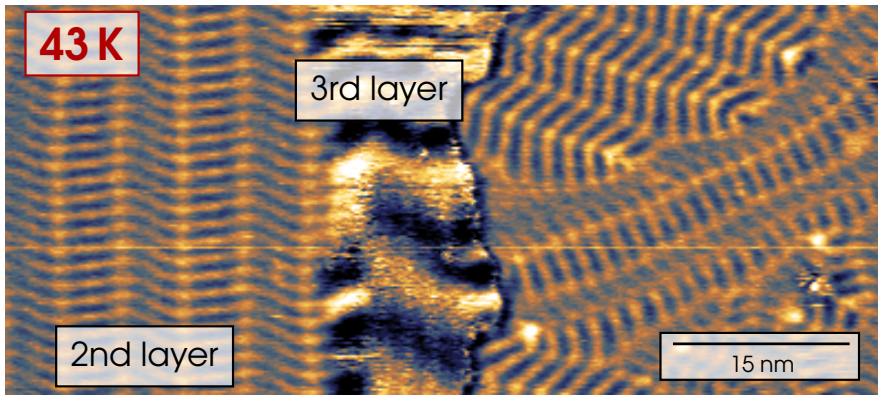
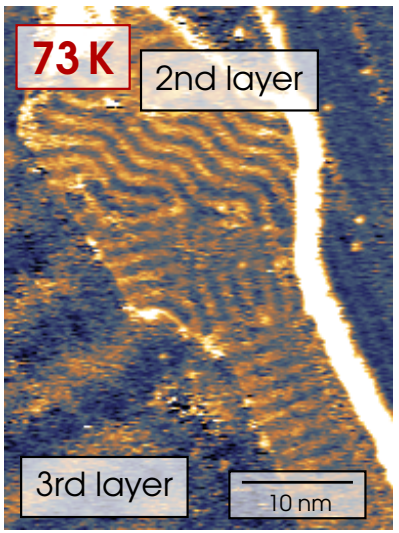
Temperature dependence of the 2nd layer

No external magnetic field

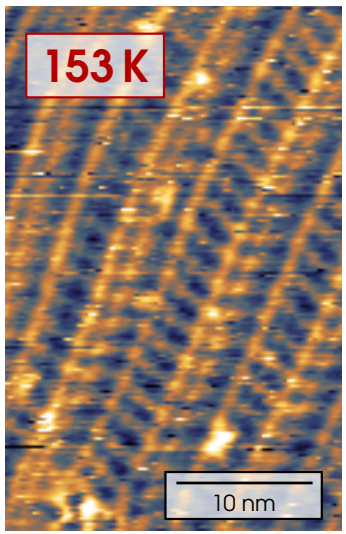
- Spin-polarized measurements with a Fe coated W tip
- Temperature increased in several steps



Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 0.7\,\mathrm{nA}$



Differential conductance, $U = -1.3\,\mathrm{V}$, $I = 1.5\,\mathrm{nA}$



Differential conductance,
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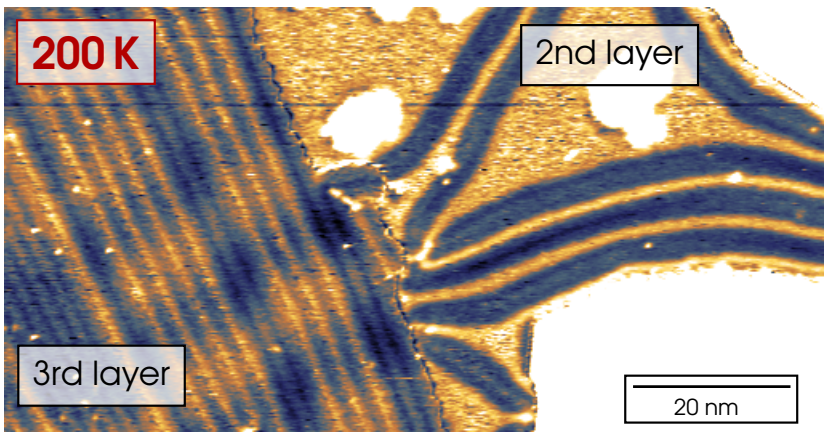

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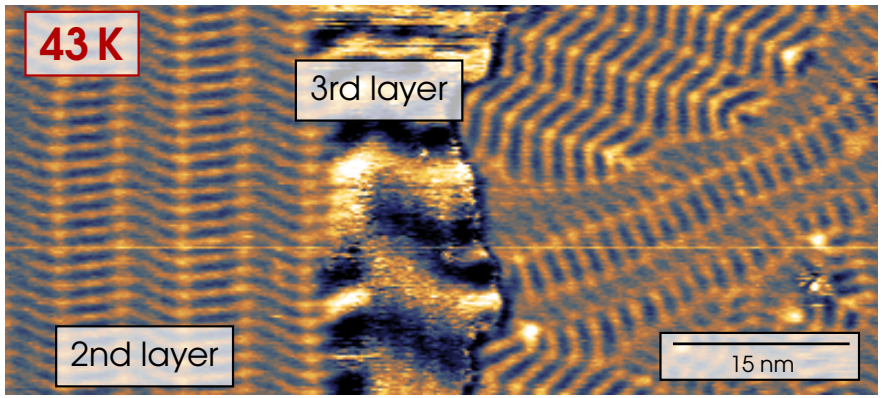

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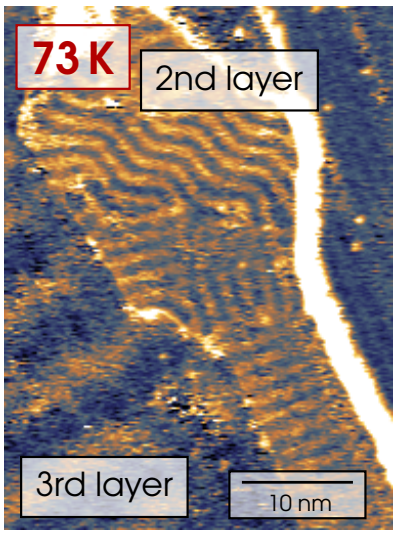

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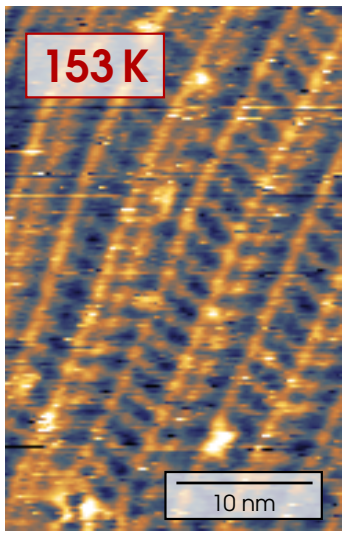

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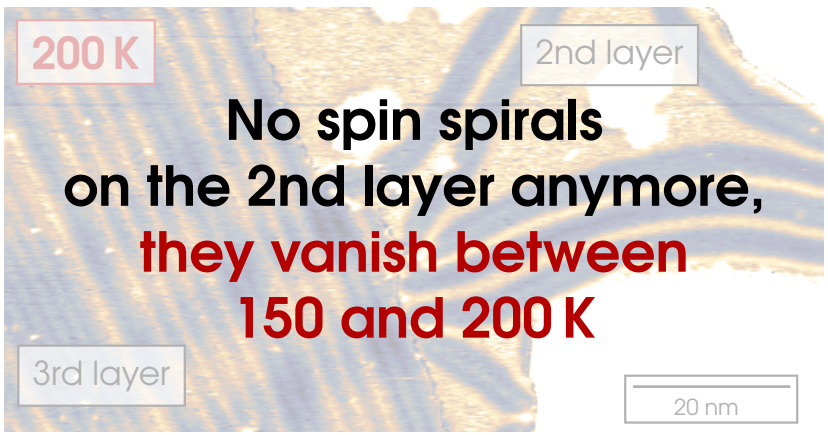

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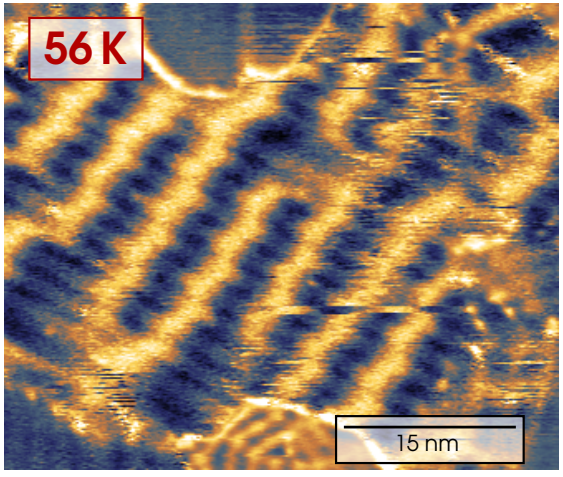
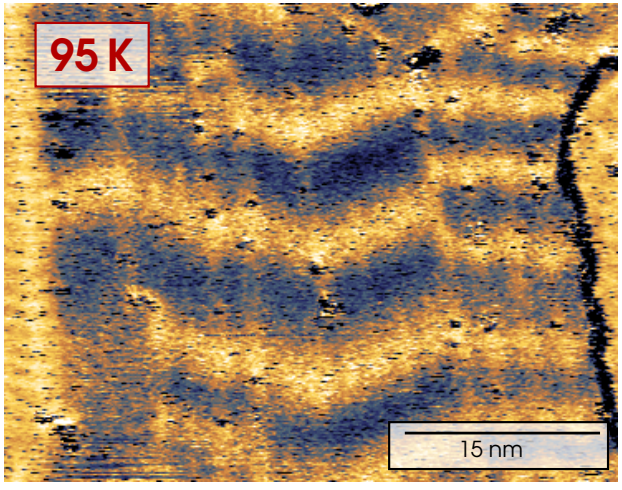
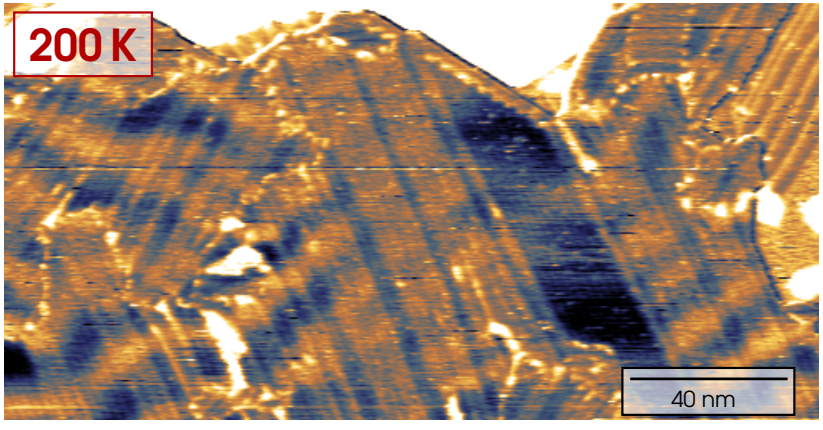


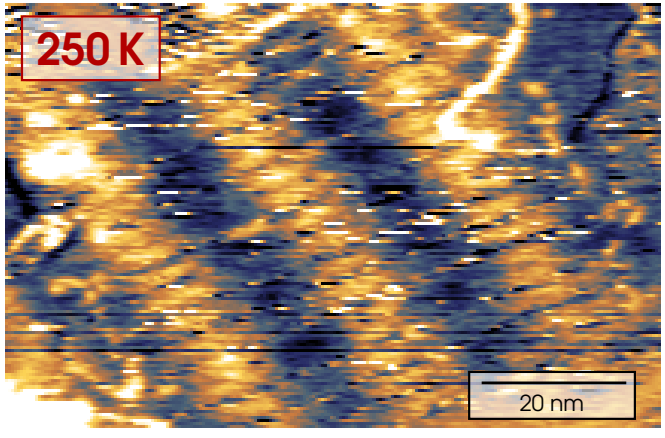
Differential conductance, $U = -1\,\mathrm{V}$, $I = 1\,\mathrm{nA}$



Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 1\,\mathrm{nA}$



Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 2\,\mathrm{nA}$

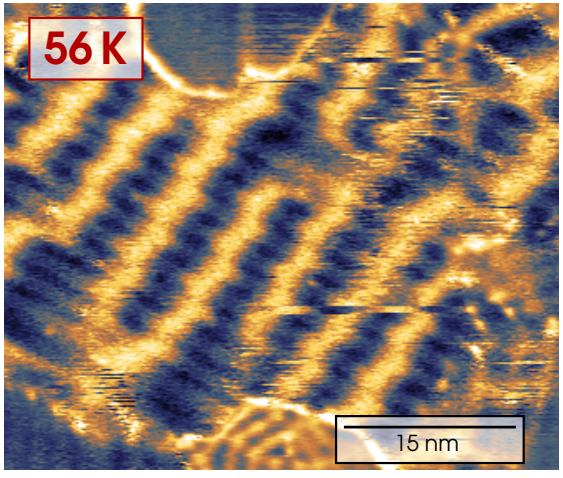


Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 3\,\mathrm{nA}$

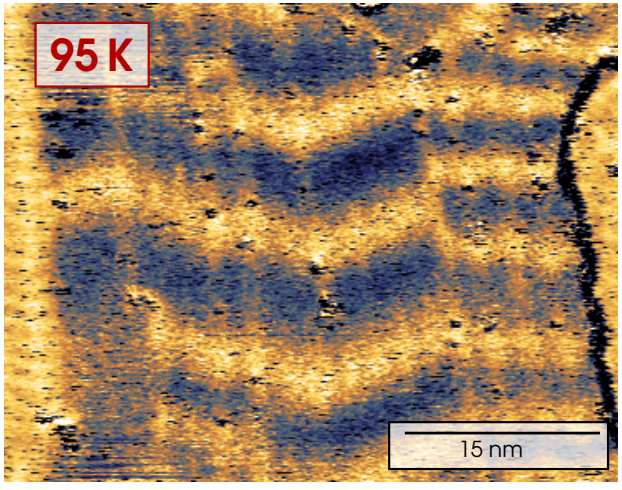
Temperature dependence of the 3rd layer

No external magnetic field

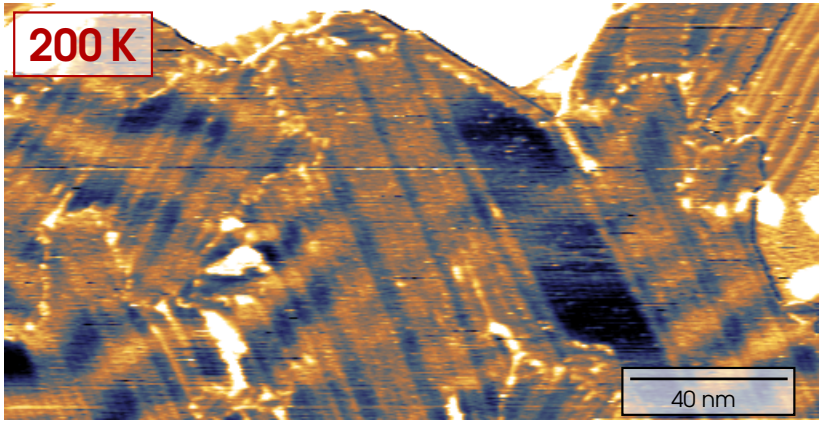
- Spin-polarized measurements with a Fe coated W tip
- Temperature increased in several steps



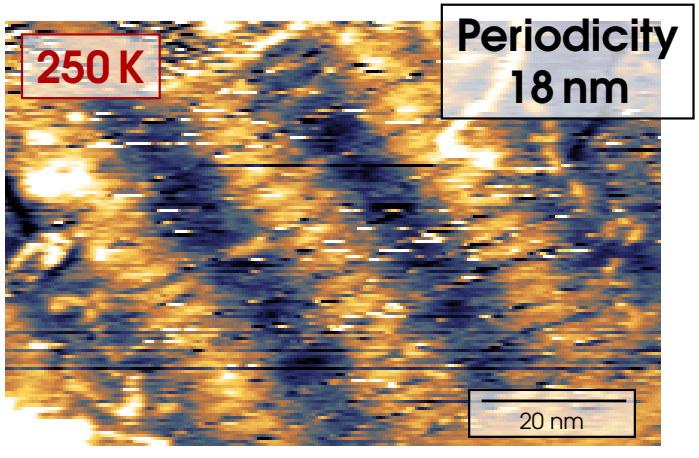
Differential conductance, $U = -1\,\mathrm{V}$, $I = 1\,\mathrm{nA}$



Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 1\,\mathrm{nA}$



Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 2\,\mathrm{nA}$

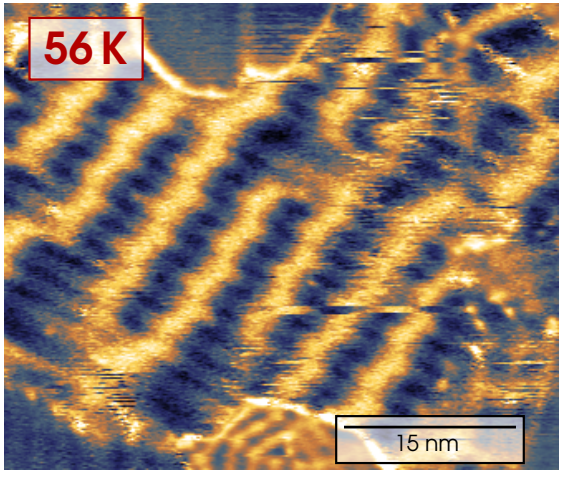


Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 3\,\mathrm{nA}$

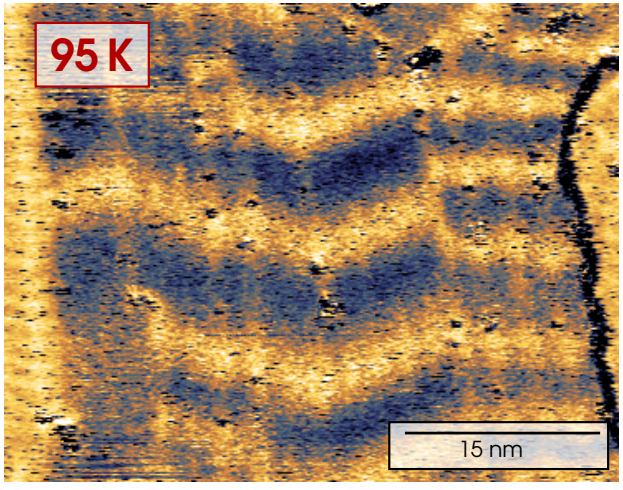
Temperature dependence of the 3rd layer

No external magnetic field

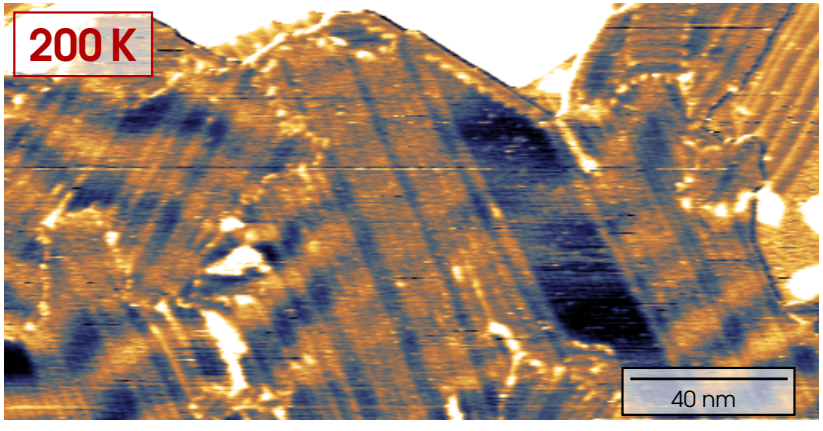
- Spin-polarized measurements with a Fe coated W tip
- Temperature increased in several steps



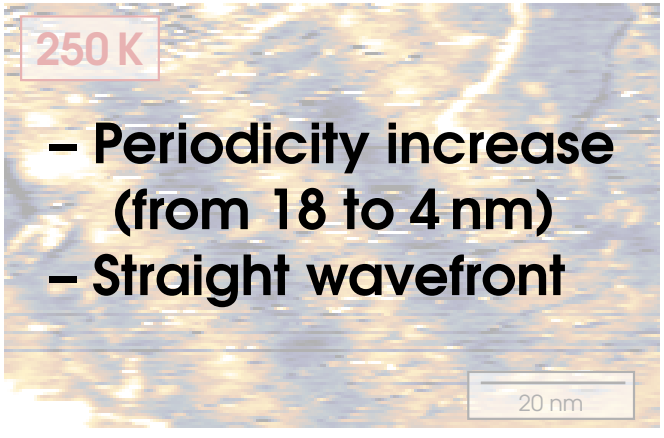
Differential conductance, $U = -1\,\mathrm{V}$, $I = 1\,\mathrm{nA}$



Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 1\,\mathrm{nA}$



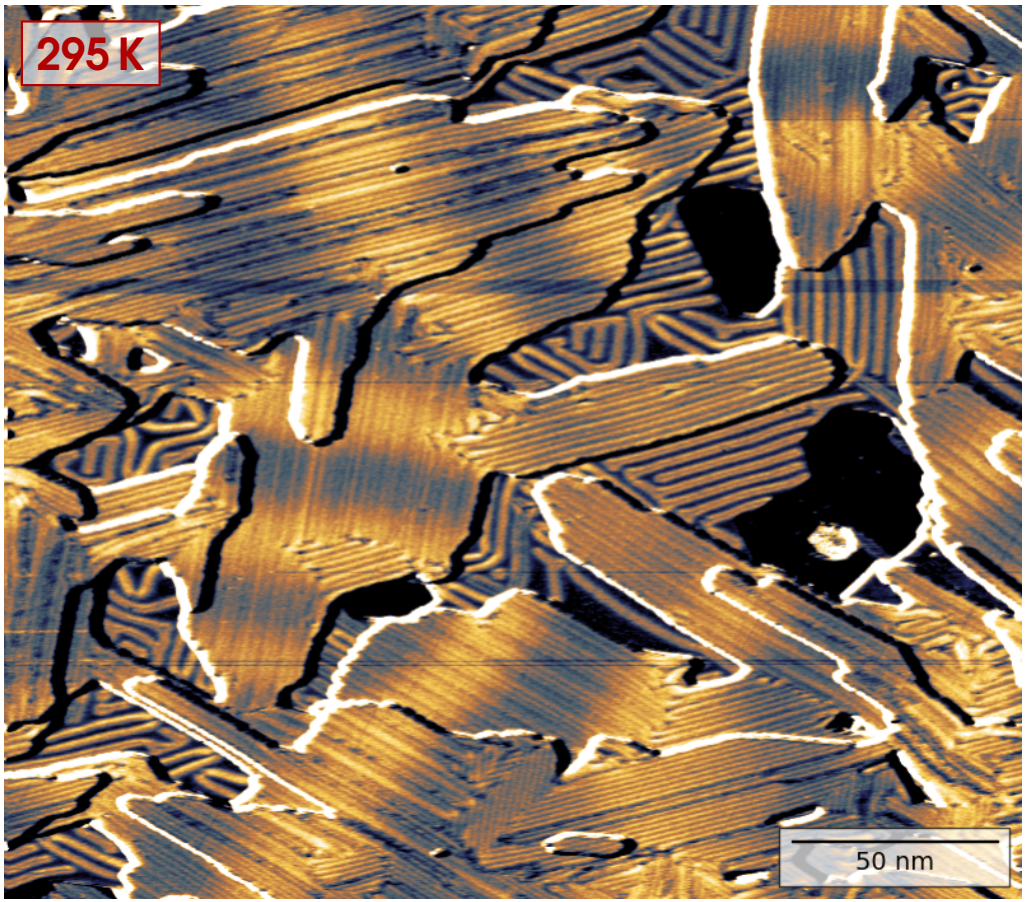
Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 2\,\mathrm{nA}$



Differential conductance, $U = -0.7\,\mathrm{V}$, $I = 3\,\mathrm{nA}$

Non-collinear magnetism at room temperature

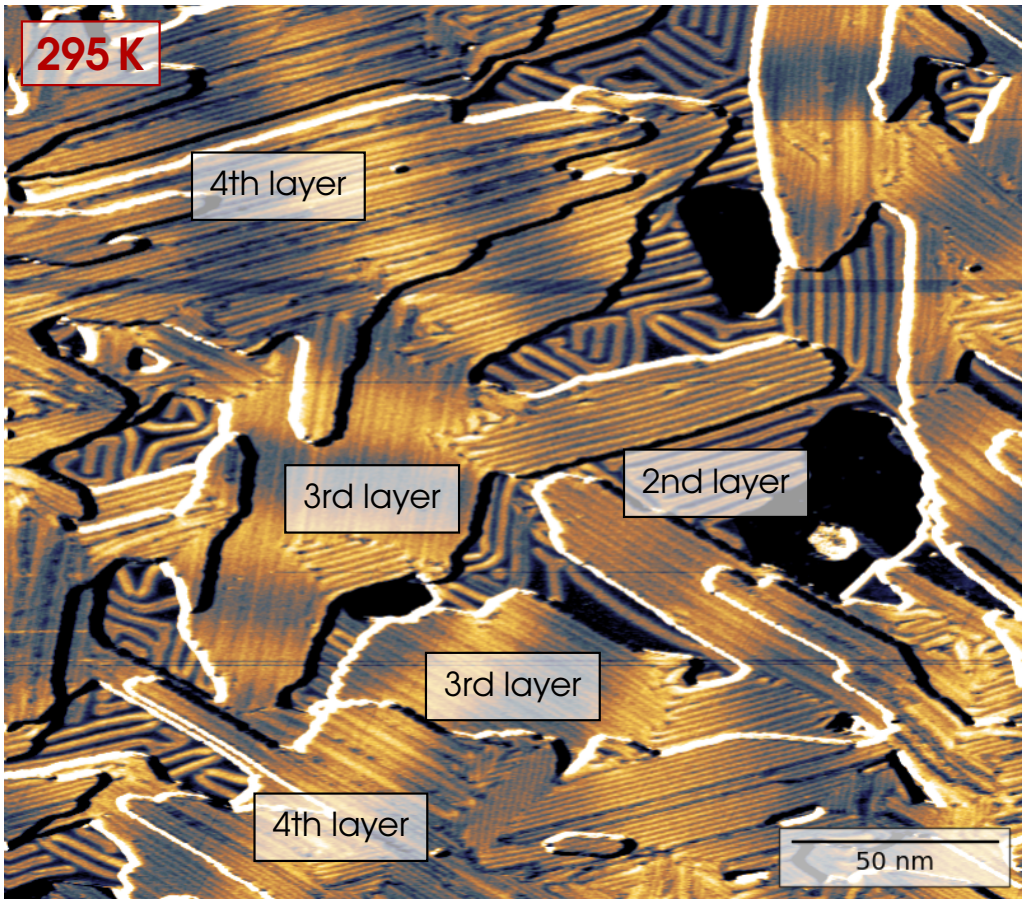
Switch to an antiferromagnetic Cr bulk tip



Differential conductance, $U = -0.5\,\mathrm{V}$, $I = 3\,\mathrm{nA}$, $B = 0\,\mathrm{T}$

Non-collinear magnetism at room temperature

Switch to an antiferromagnetic Cr bulk tip

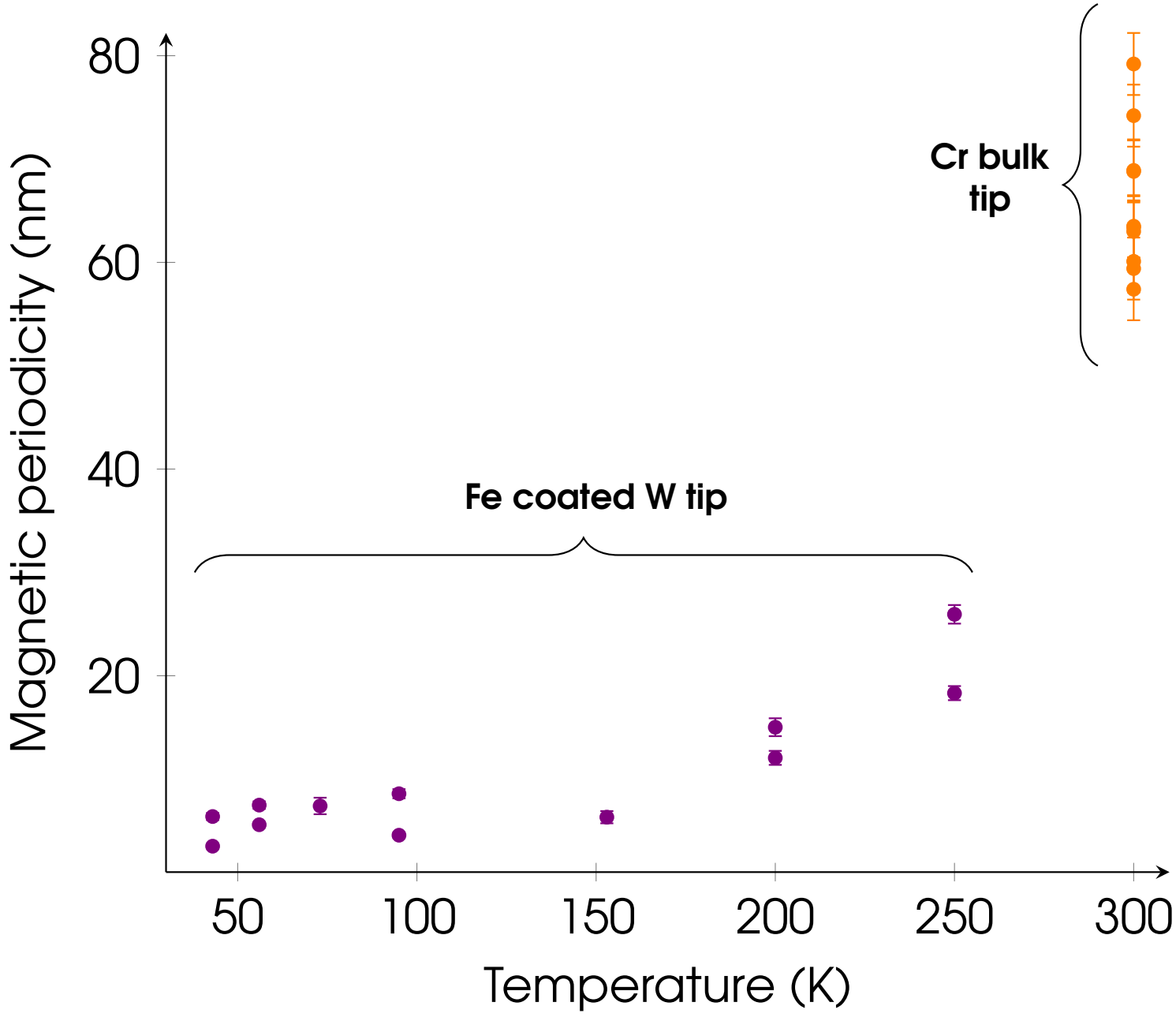


Differential conductance, $U = -0.5\,\mathrm{V}$, $I = 3\,\mathrm{nA}$, $B = 0\,\mathrm{T}$

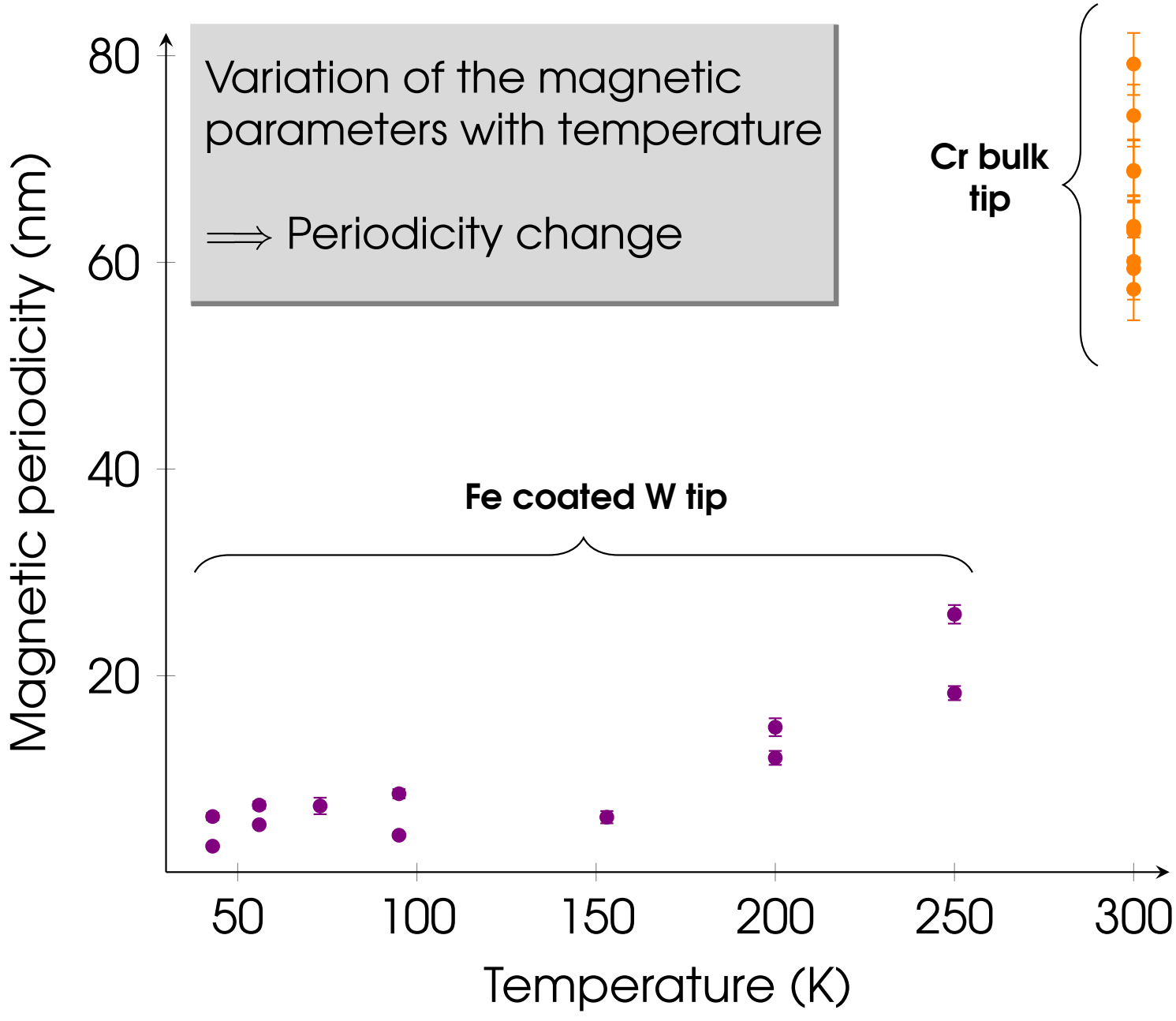
- Spin spirals visible on the 3rd, 4th and 5th layers.
- Direction of the wavevector still given by the reconstruction lines
- Periodicity between 60 and 80 nm
- Straight wavefront perpendicular to the lines
- The spirals are crossing the different layers

- **The local atom arrangement does not impose the shape of the wave front anymore, only the propagation direction.**
- **A coupling between the 3rd, the 4th and the 5th layers seems to become important at room temperature.**

Evolution of the magnetic periodicity on the 3rd layer

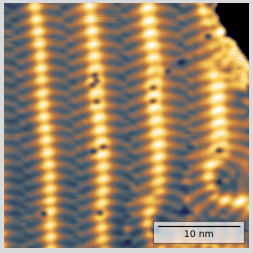


Evolution of the magnetic periodicity on the 3rd layer

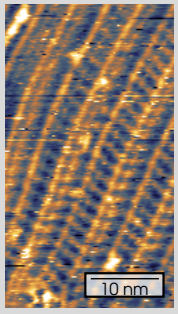


Summary

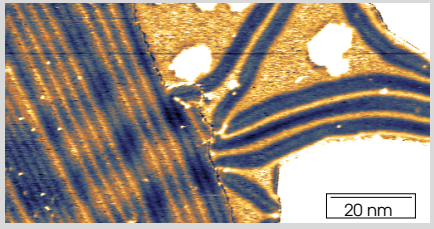
Temperature (no external magnetic field)



Periodicity $\sim$ 1.6 nm
Zigzag wavefront
$T = 4$ K



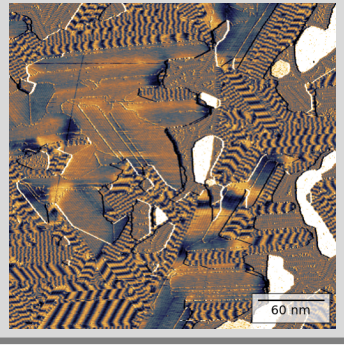
Disparition of the 2nd layer spiral
$T = 150$ K



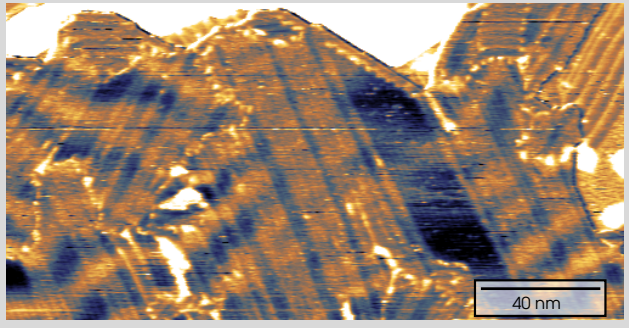
$T = 200$ K

$T = 300$ K

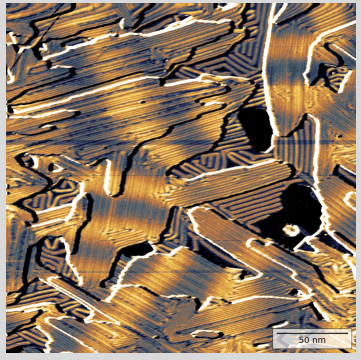
Periodicity $\leq$ 10 nm
Canted or zigzag
wavefront



Periodicity 15 nm
Canted or straight
wavefront



Periodicity 60 – 80 nm
Straight wavefront



Next step:

Apply an external magnetic field at room temperature using a setup with a permanent magnet

$\longrightarrow$ **room temperature skyrmions?**

Acknowledgments

Prof. Dr. Roland Wiesendanger
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Lorenz Schmidt

Universität Hamburg

MAGIC Sky

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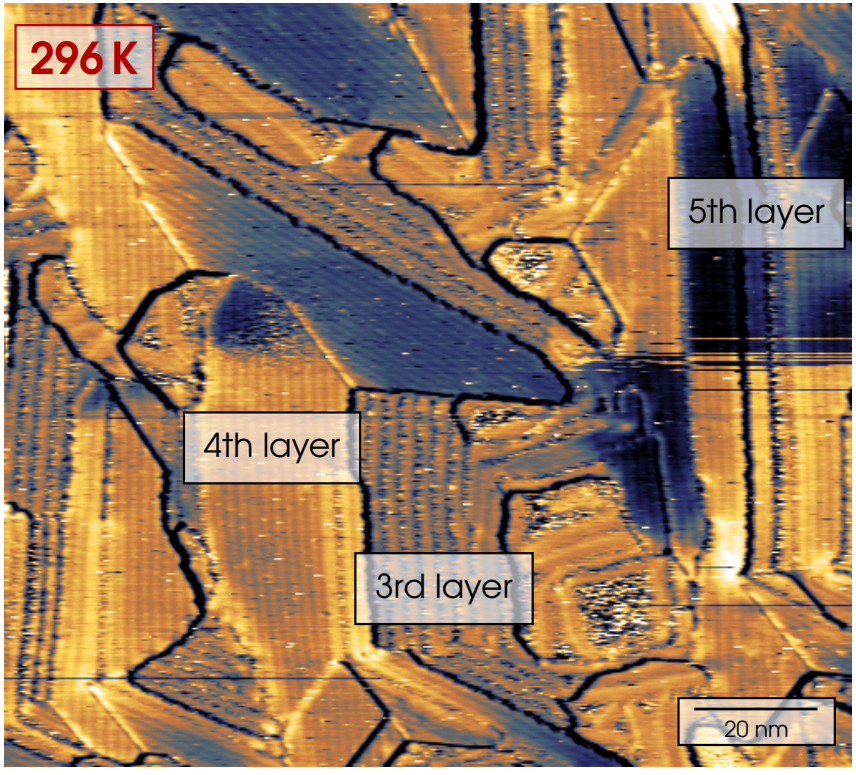
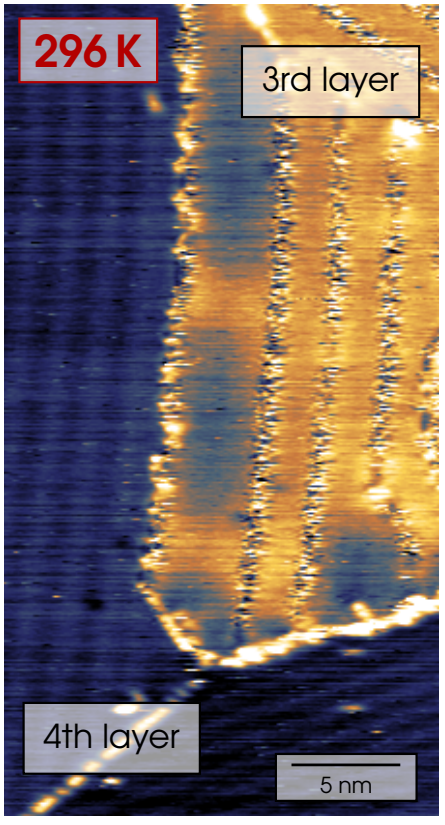
Room temperature magnetic structure



Differential conductance, $U = -0.7$ V,
$I = 1$ nA, $B = 0$ T, Fe coated W tip

- Ferromagnetic domains (and switching) still visible on the 4th and 5th layers
- No spirals visible on the majority of the 3rd layer areas

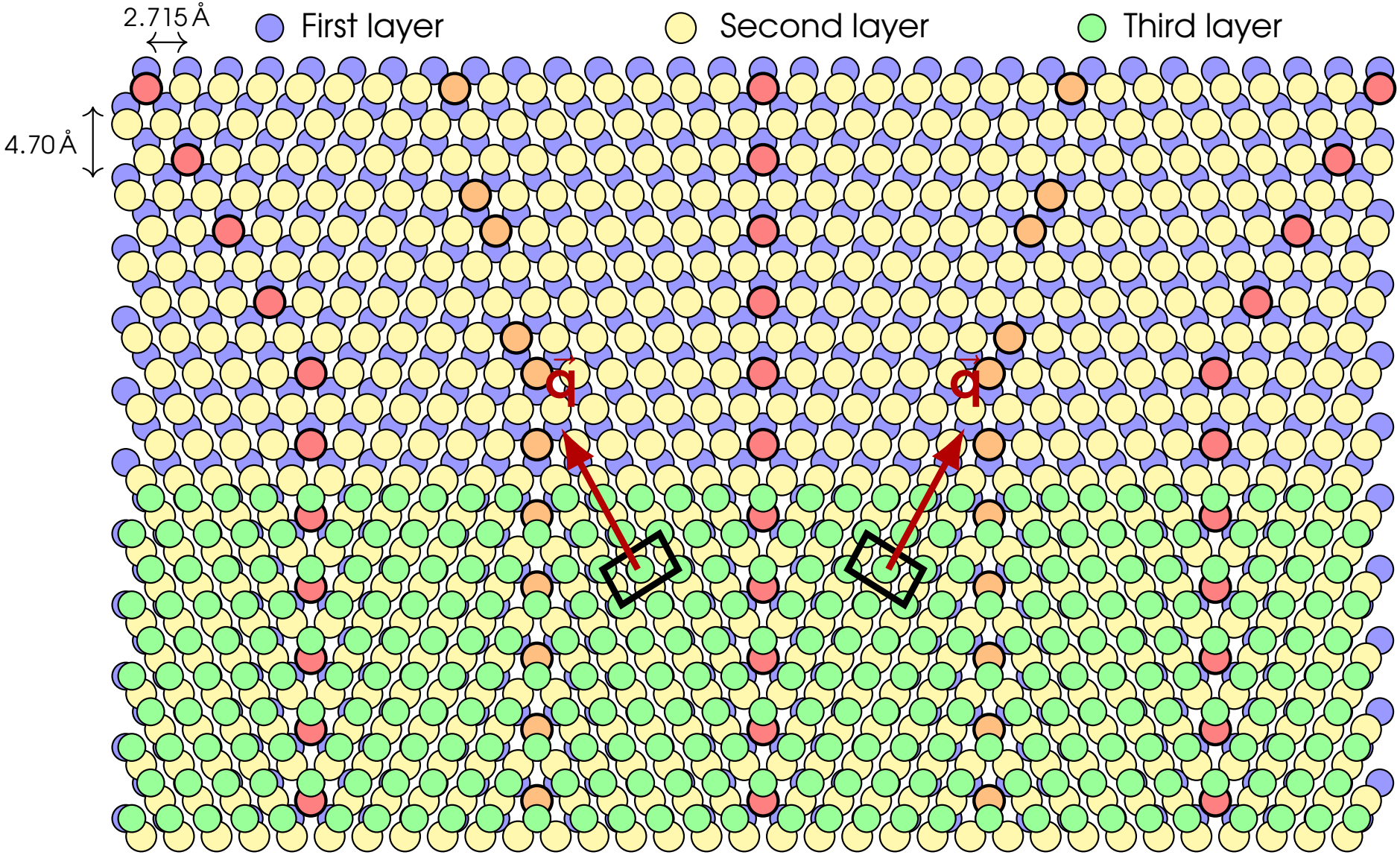


Differential conductance, $U = -0.7$ V,
$I = 1$ nA, $B = 0$ T, Fe coated W tip

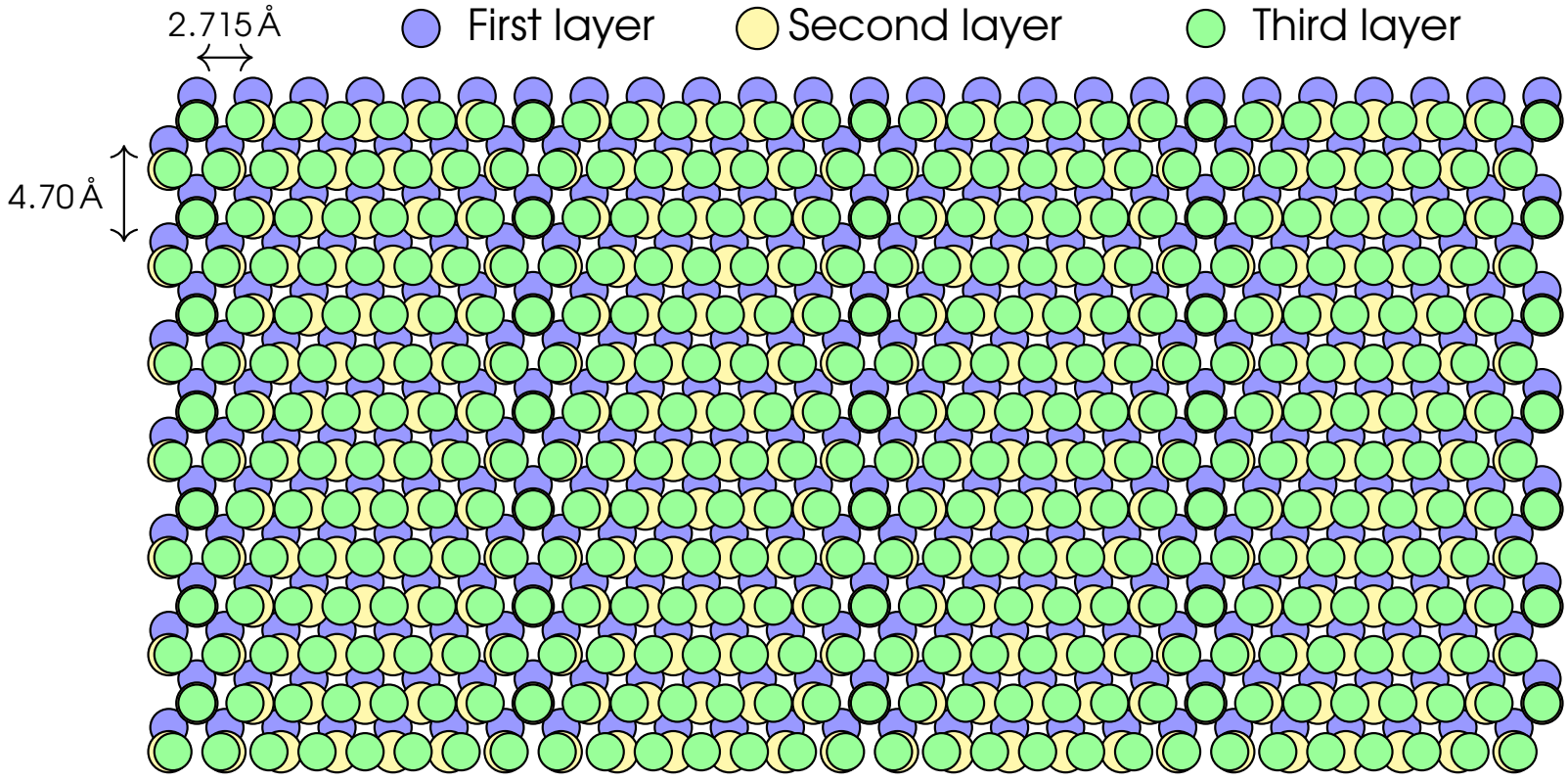
- Only a few small 3rd layer spots exhibit a magnetic pattern

Effect of the stray field of the ferromagnetic tip?

Structural model for the double lines areas on the 3rd layer



Structural model for the dense lines areas on the 3rd layer



- Epitaxial double layer below (non-reconstructed areas)
- Distorted bcc(110) Fe layer on top

Bai An et al. Growth and structural transition of Fe ultrathin films on Ni(111) investigated by LEED and STM. . *Phys. Rev. B* 79 (8, 2009), page 085406.