Universität Hamburg
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Funded by the Horizon2020 Framework Programme of the European Union

MA 43.4:

Structure and magnetism of an hydrogenated Fe monolayer on Ir(111)

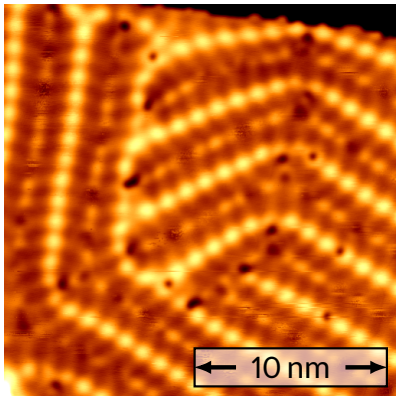
Aurore Finco, Pin-Jui Hsu, André Kubetzka, Kirsten von Bergmann and Roland Wiesendanger

University of Hamburg

The hydrogenated double layer Fe on Ir(111)

Previous talk: MA 43.3 by Levente Rózsa

tip ⊙



Constant current map, 200 mV, 1 nA, 5 K, 4 T

Pristine double layer Fe:

- Dislocation lines
- Spin spirals, period about 1.5 nm
- No skyrmions!

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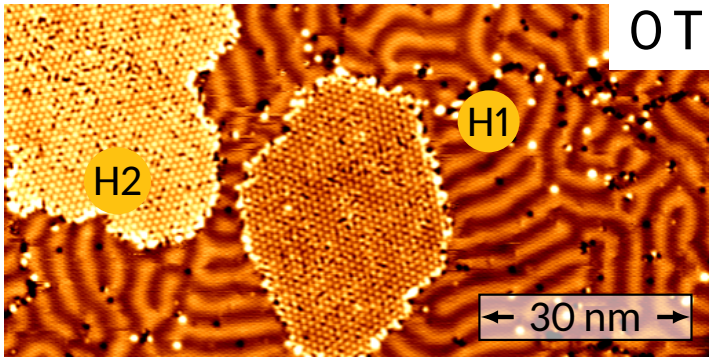
tip ⊙

With H incorporation:

- 2 phases found
- hexagonal superstructures
- H2: 0.98 nm period $\rightarrow$ FM
- H1: $p(2 \times 2)$ 0.54 nm period
  - Spin spiral period about 3.5 nm



Constant current map, −700 mV, 1 nA, 4 K, Cr bulk tip

P.-J. Hsu *et al.* Guiding Spin Spirals by Local Uniaxial Strain Relief. *Physical Review Letters* 116.1 (2016), p. 017201.

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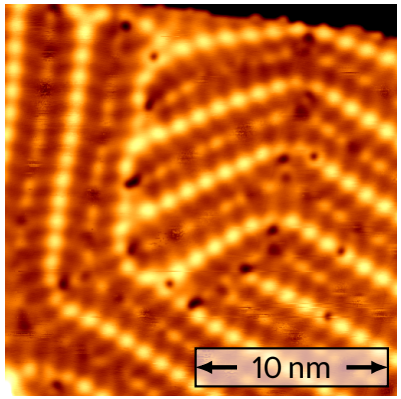

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With H incorporation:

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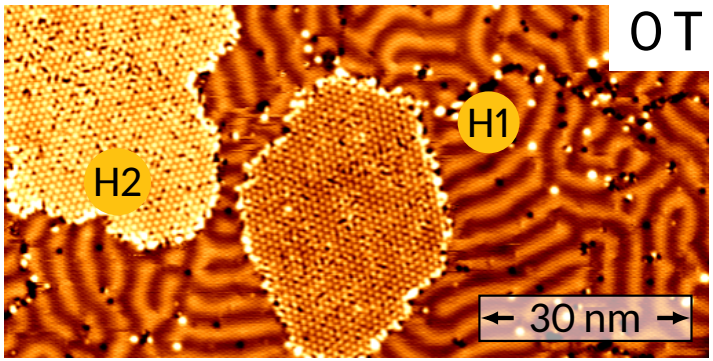
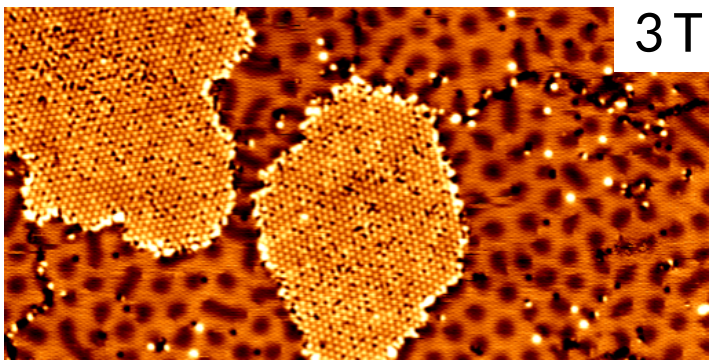
- 2 phases found
- hexagonal superstructures
- H2: 0.98 nm period → FM
- H1: $p(2 \times 2)$ 0.54 nm period
  - Spin spiral period about 3.5 nm
  - Skyrmions appears under magnetic field





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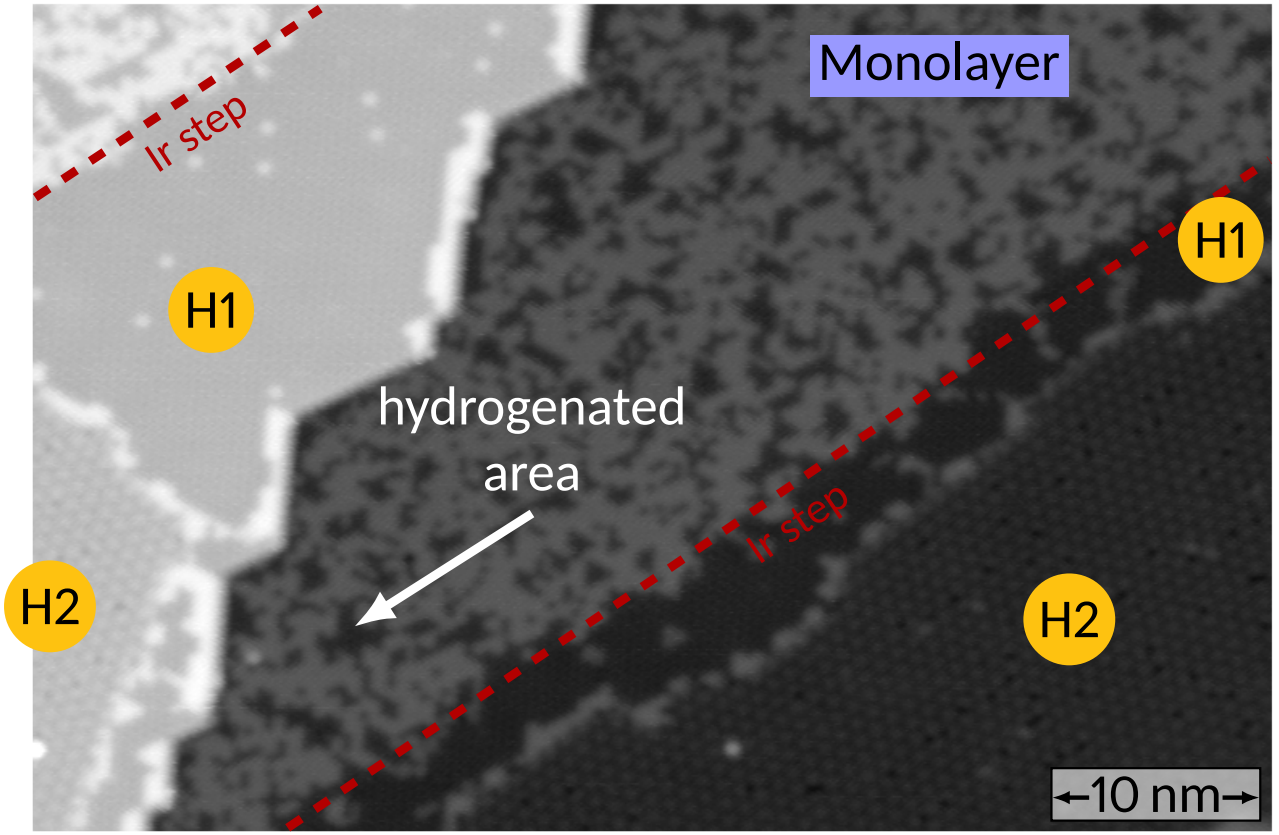
H atoms are also incorporated in the monolayer



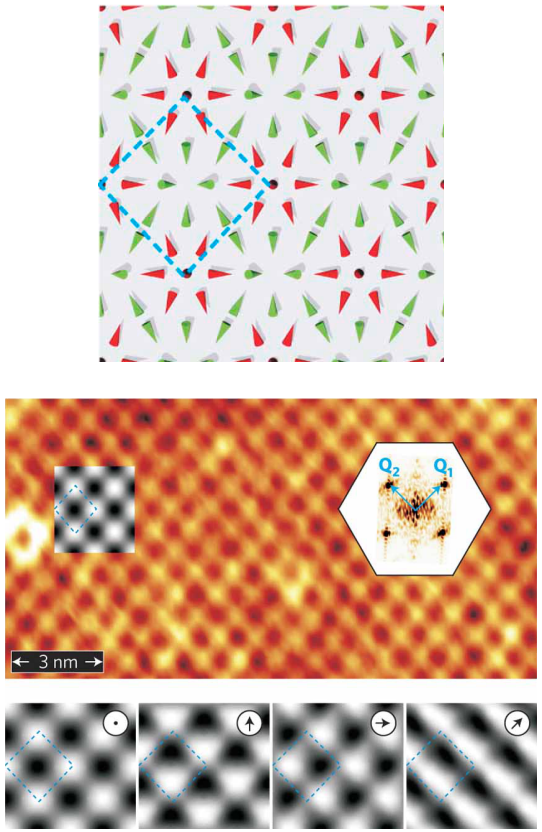
Constant current map, −700 mV, 1 nA, 8 K, 0 T

- Sample exposed to atomic H at room temperature
- Then post-annealed at 300 °C

The nanoskyrmion lattices in the monolayer Fe on Ir(111)

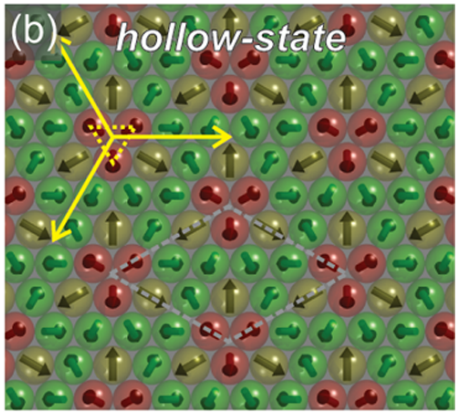
fcc stacking

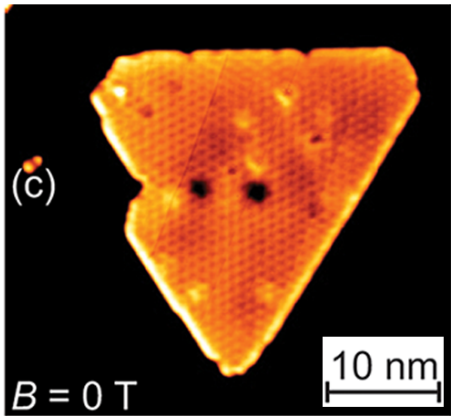
square nanoskyrmion lattice



hcp stacking

hexagonal nanoskyrmion lattice



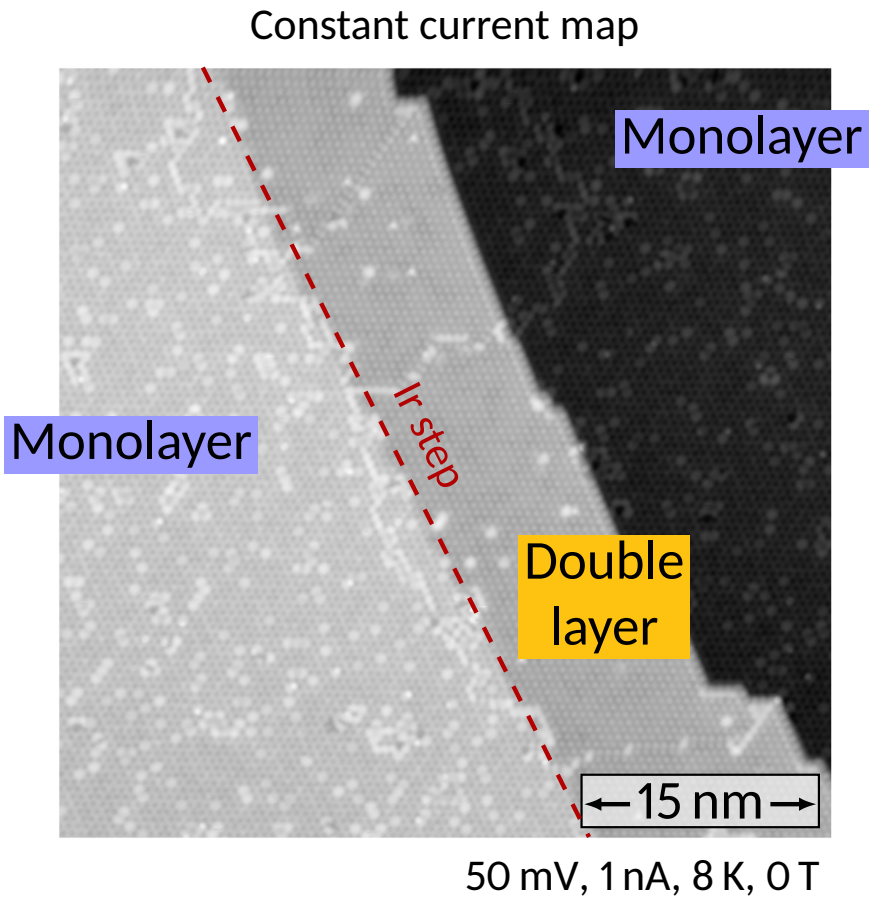


S. Heinze *et al.* Spontaneous atomic-scale magnetic skyrmion lattice in two dimensions. *Nature Physics* 7.9 (2011), pp. 713–718.

K. von Bergmann *et al.* Influence of the Local Atom Configuration on a Hexagonal Skyrmion Lattice. *Nano Letters* 15.5 (2015), pp. 3280–3285.

The hexagonal phase

When enough atomic H is incorporated in the Fe monolayer, an hexagonal superstructure is produced on the whole surface.



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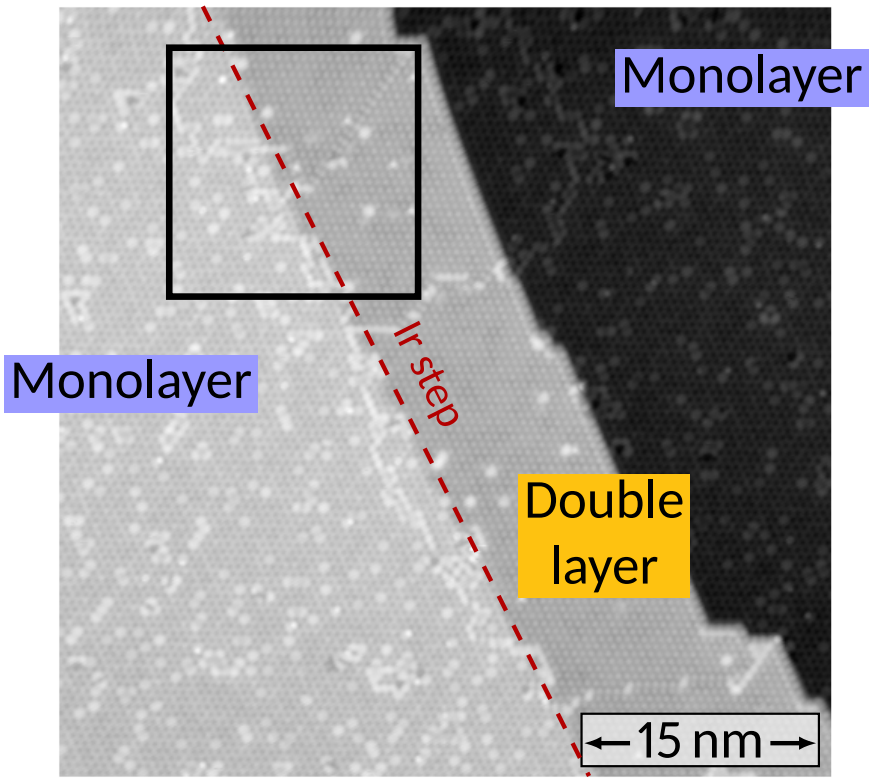
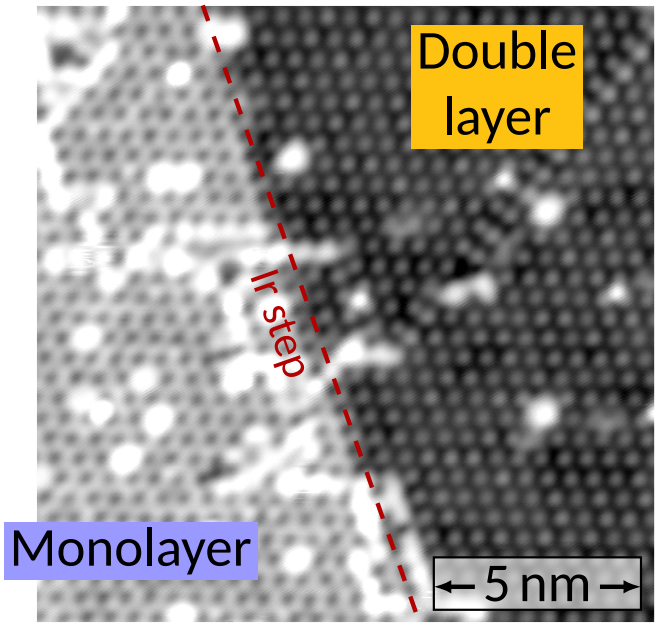


50 mV, 1 nA, 8 K, 0 T

Zoom in



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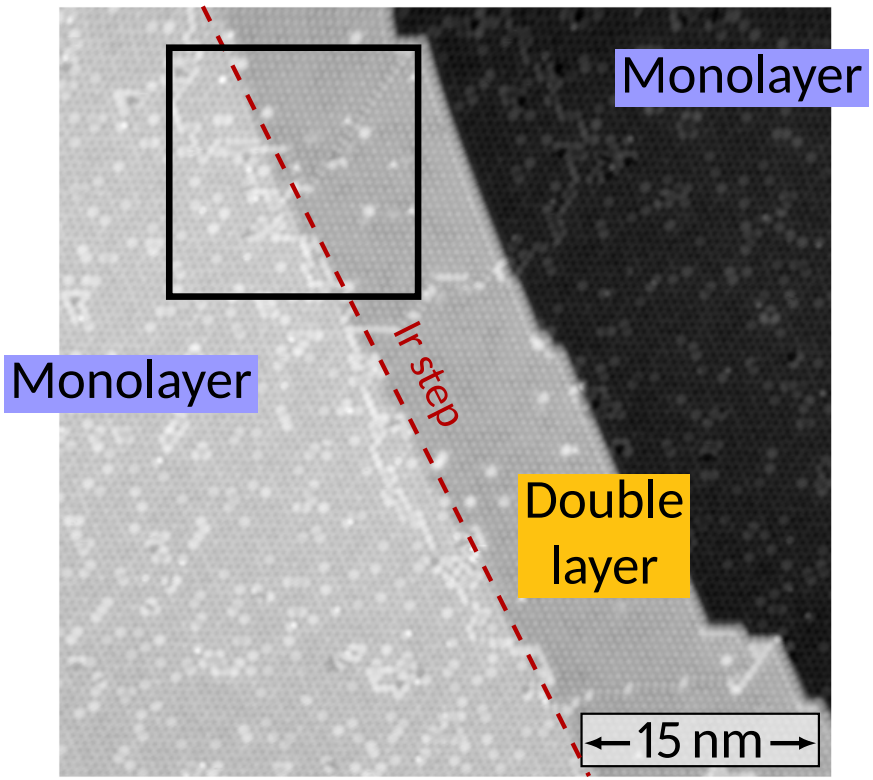

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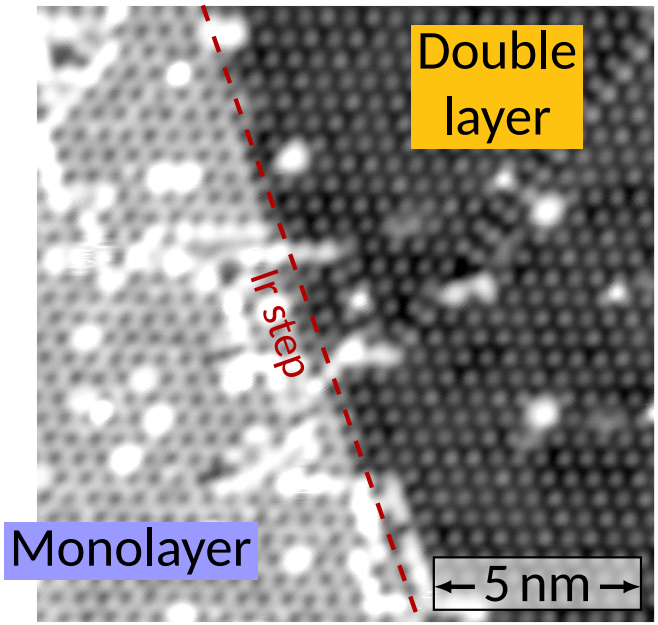

- Same size and orientation than in the double layer
- $p(2 \times 2)$ superstructure, size 0.54 nm
- Bright protrusions = H vacancies
  $\Longrightarrow$ Dark dots = H atoms?

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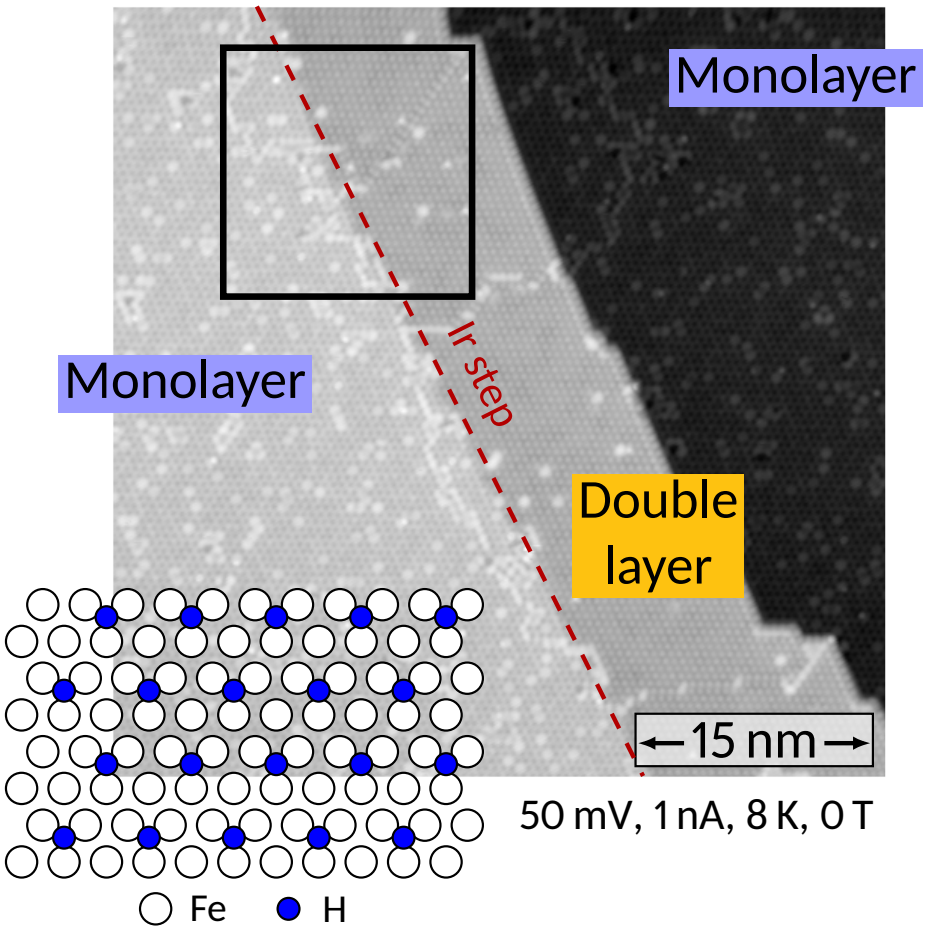

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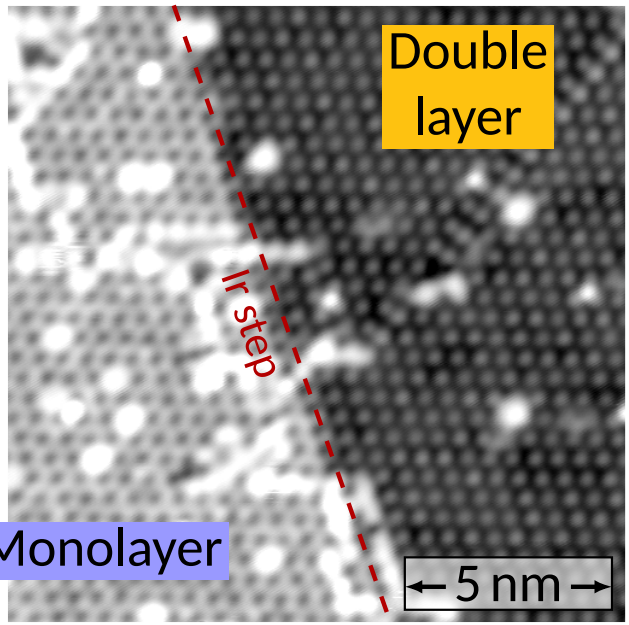

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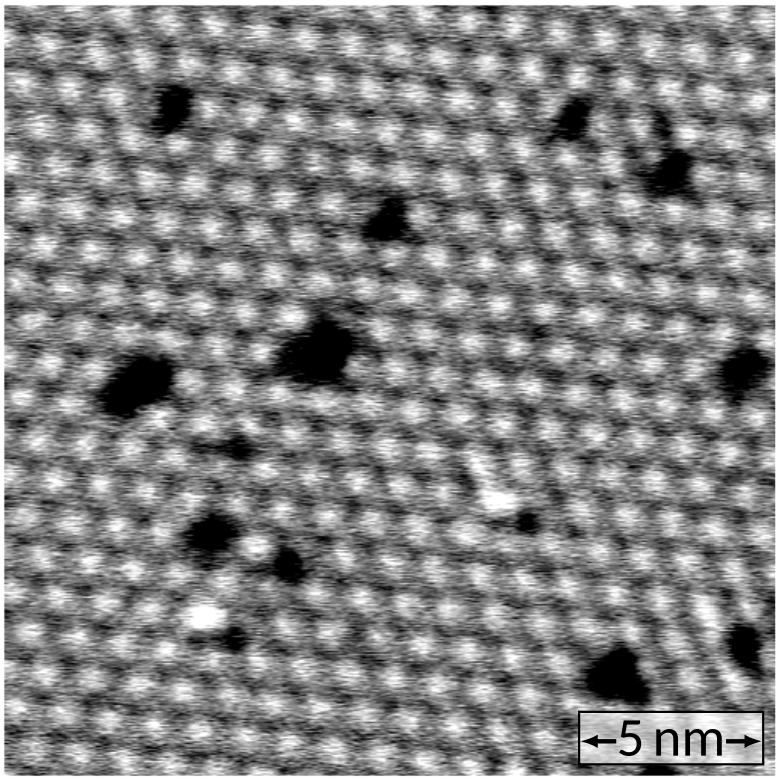
Magnetism of the hexagonal phase

Differential conductance map

tip



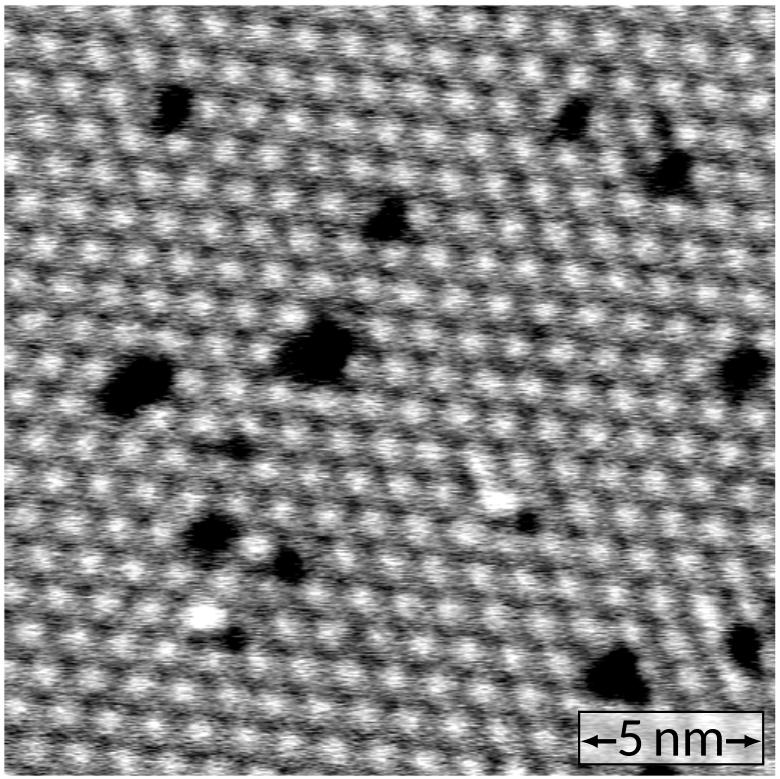
−1 V, 1 nA, 4 K, 0 T

- Hexagonal pattern
- Size measured 1.06 nm
- About twice the size of the $p(2 \times 2)$ superstructure

Magnetism of the hexagonal phase

Differential conductance map

tip ⊙



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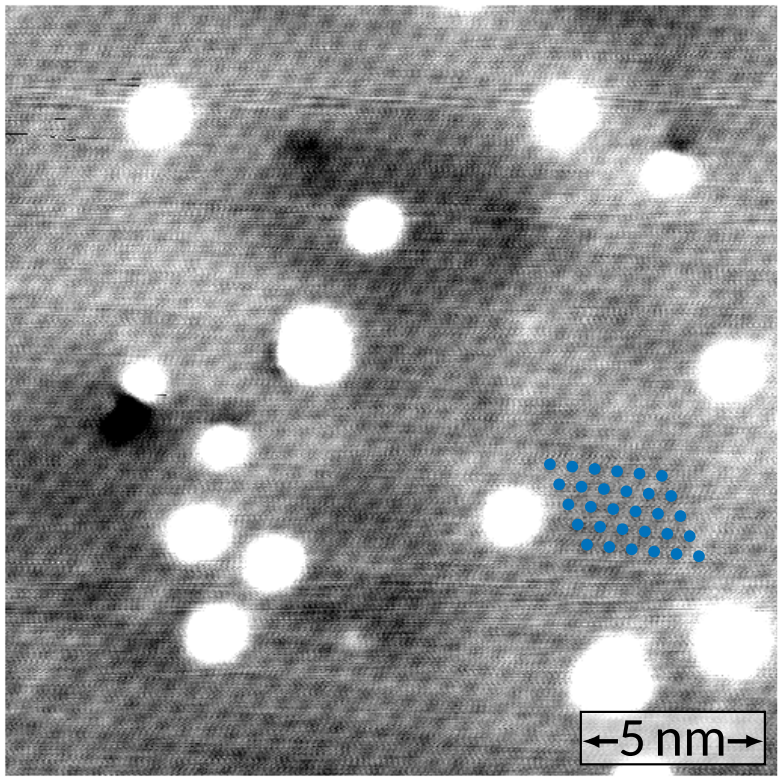

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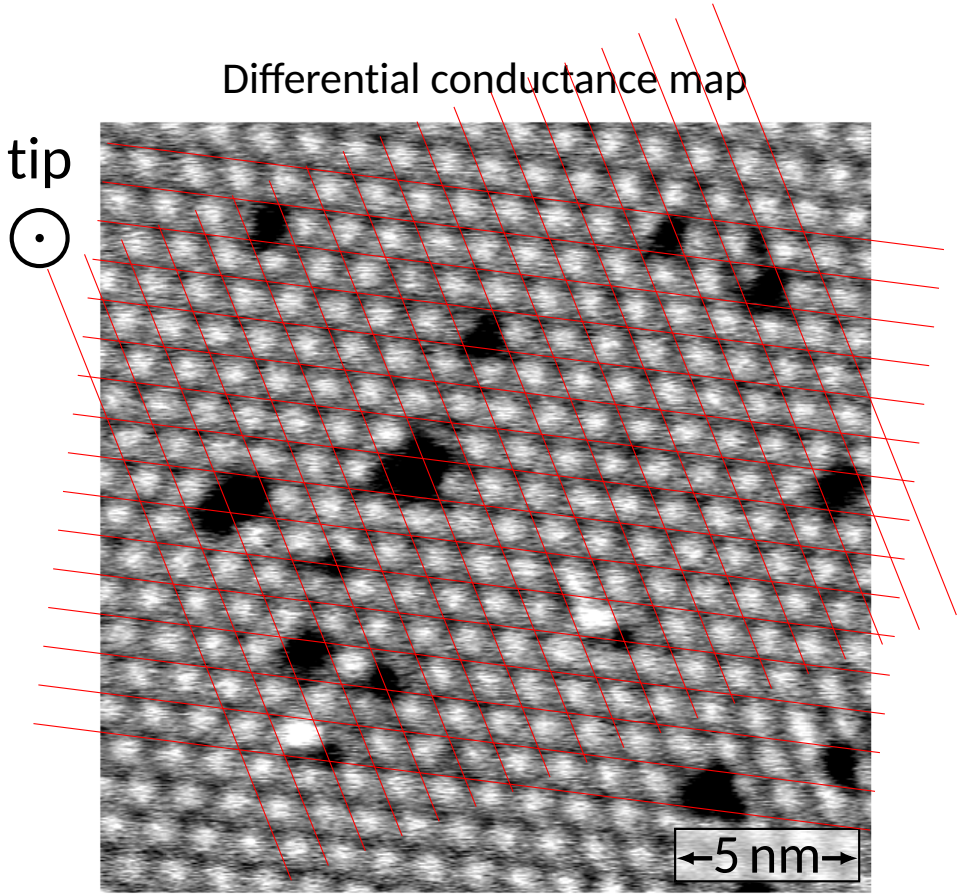

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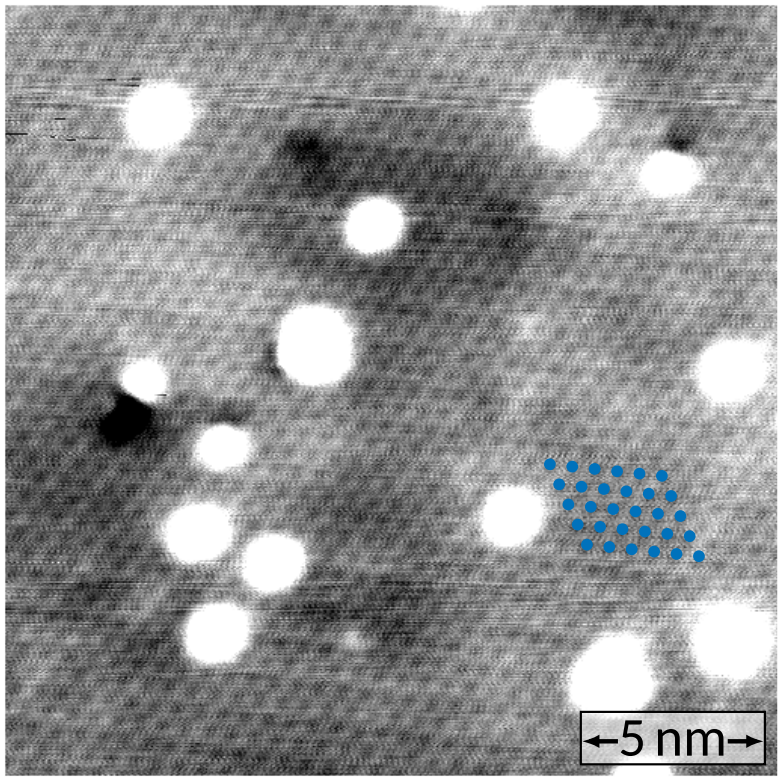

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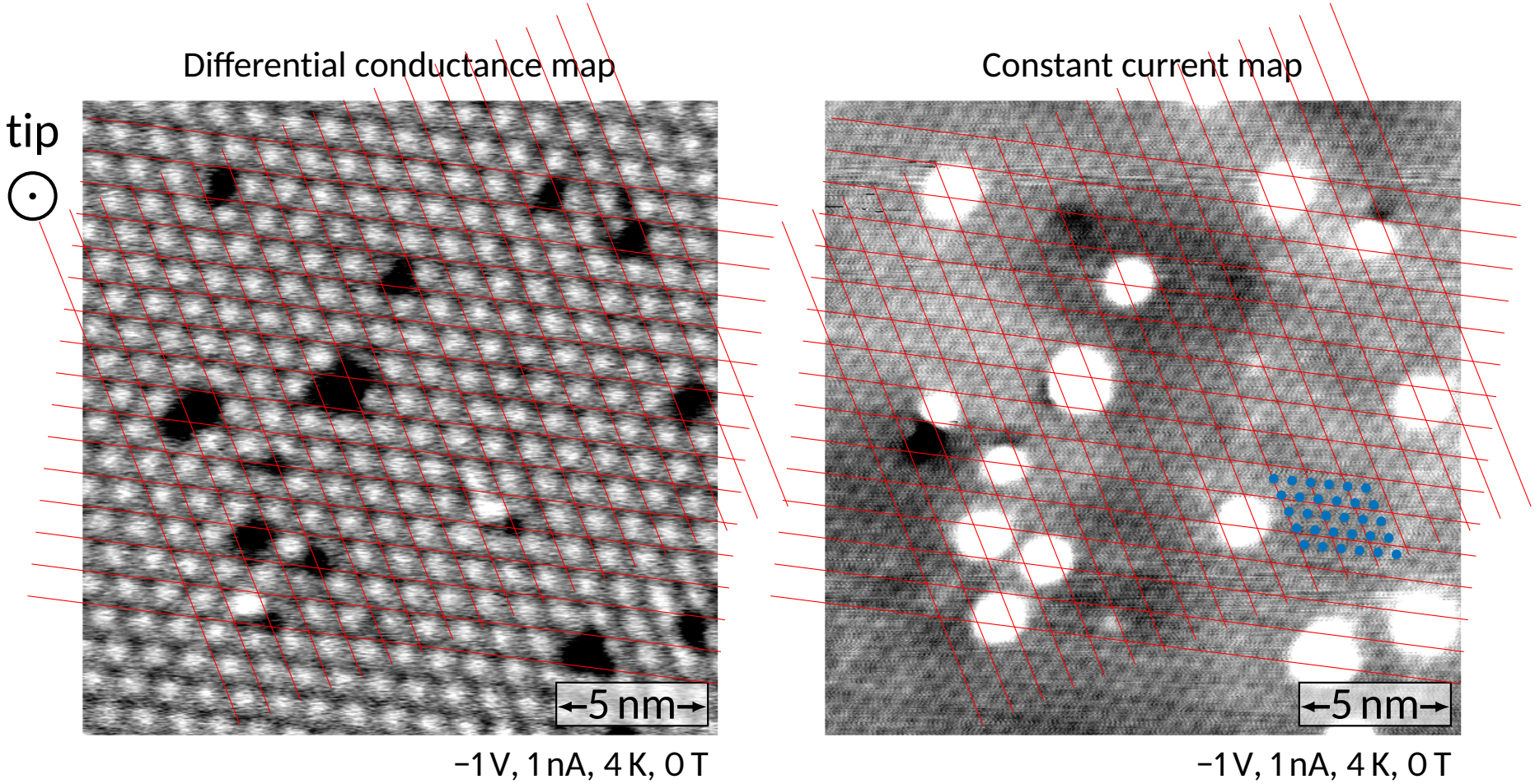

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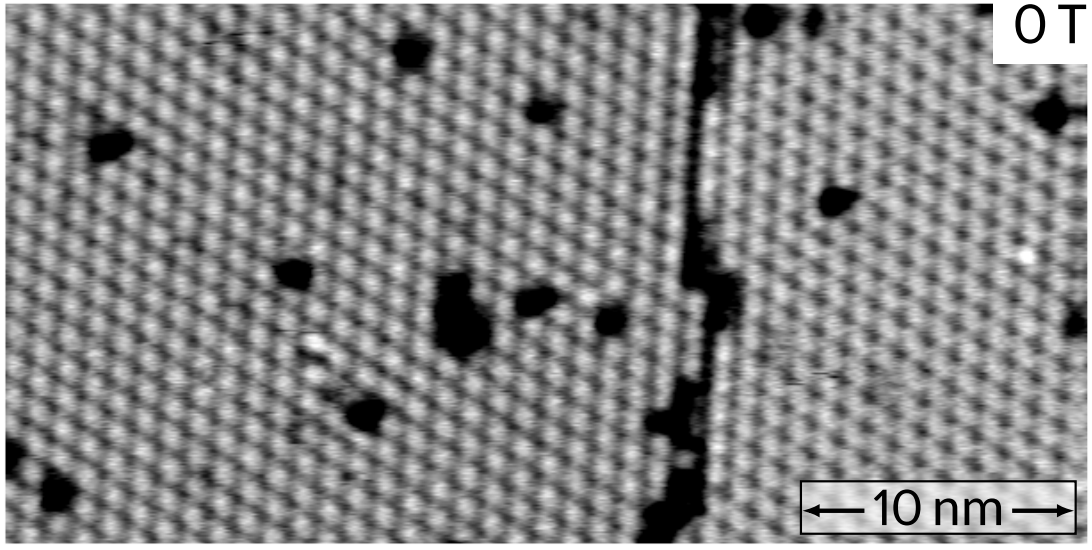
Magnetic structure aligned with the H superstructure

Switching of domains with magnetic field



Differential conductance map, −700 mV, 1 nA, 4 K

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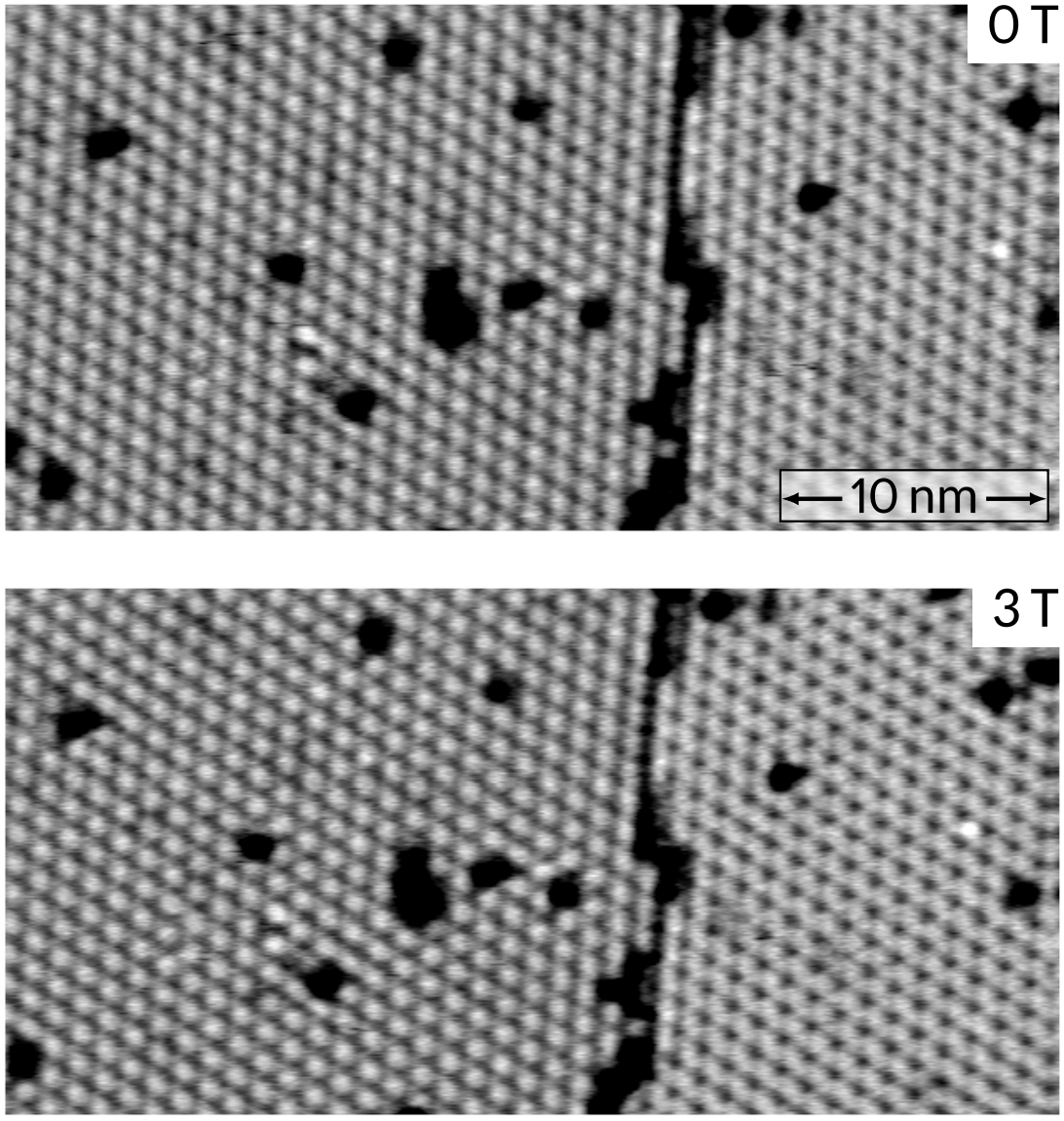

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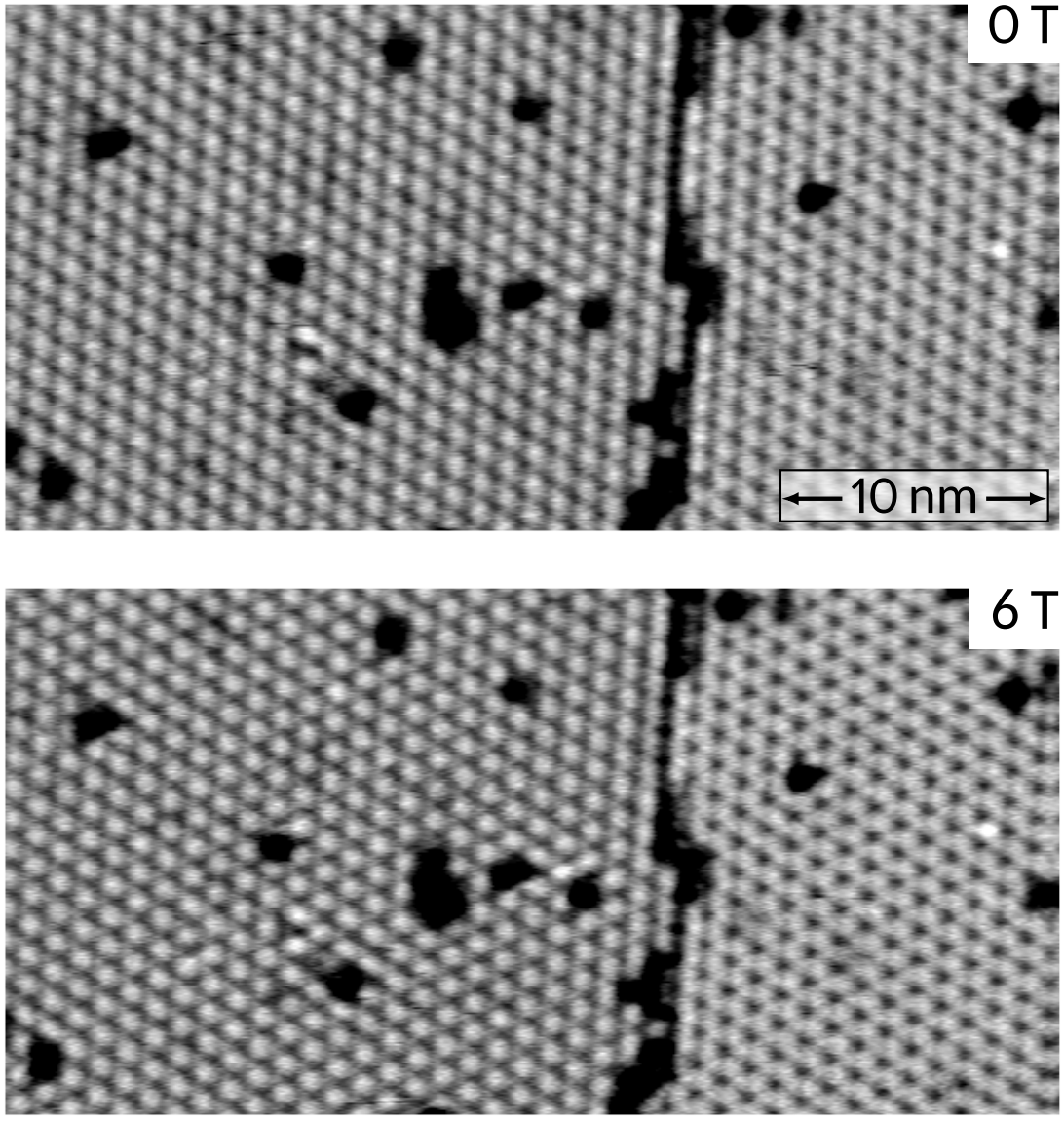

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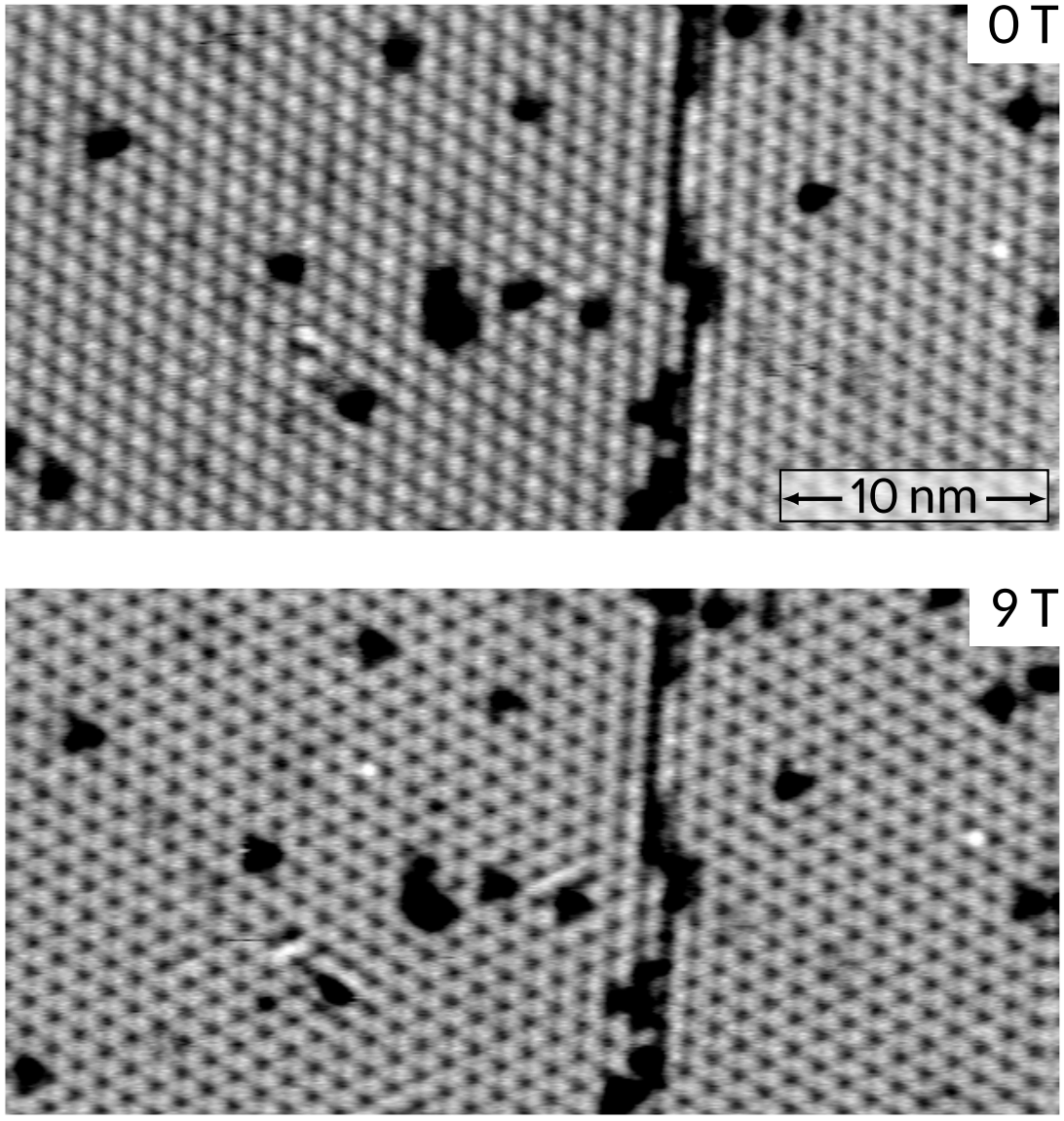
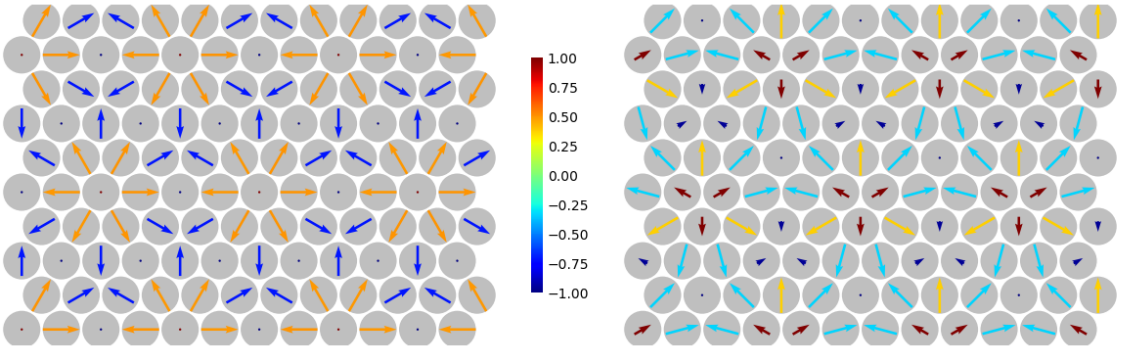


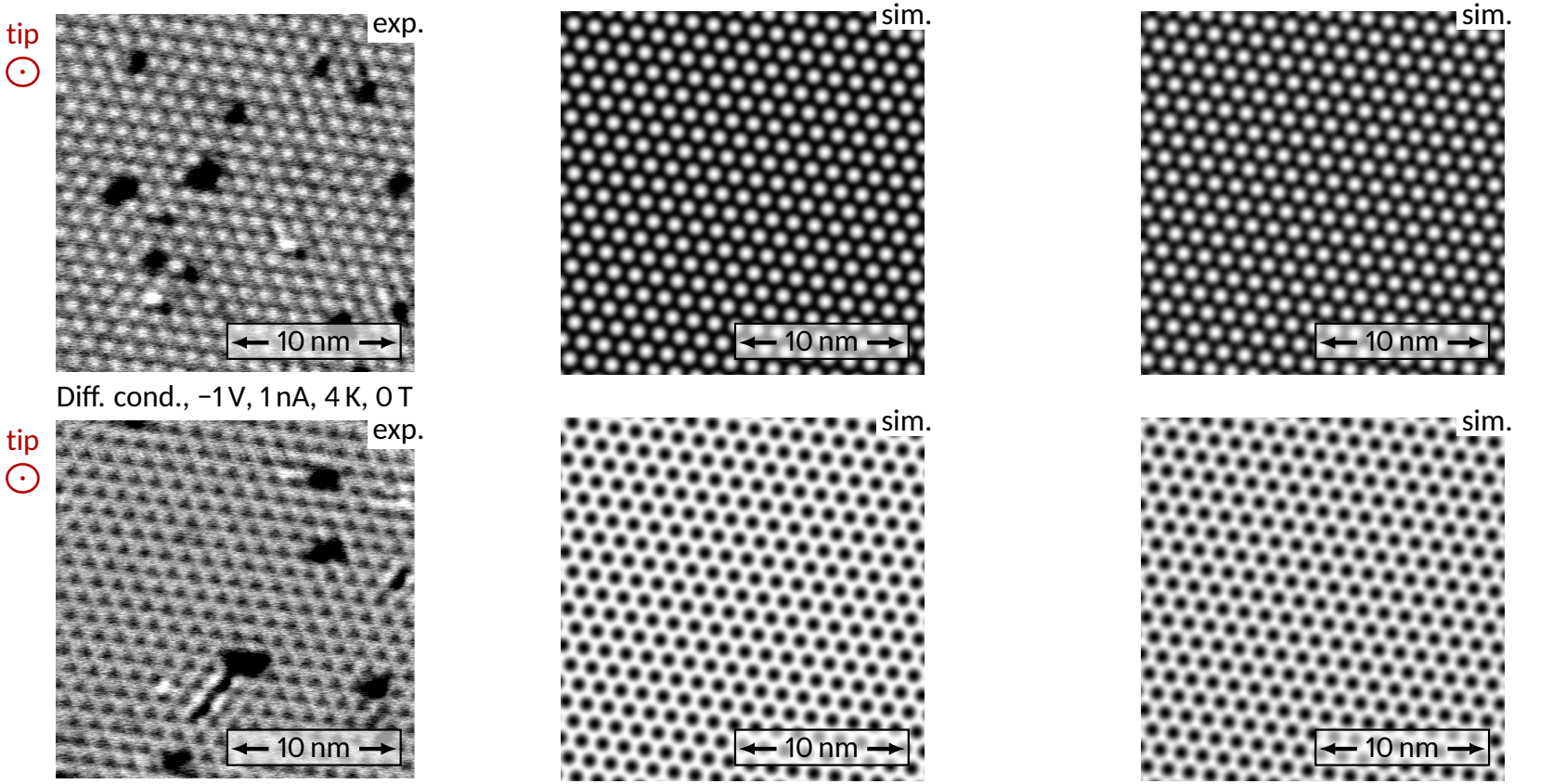
Differential conductance map, −700 mV, 1 nA, 4 K

Another nanoskyrmion lattice

Out-of-plane component

- Superposition of 3 spirals
- 2 magnetic domains
- No rotational domains
- 16 atoms per cell





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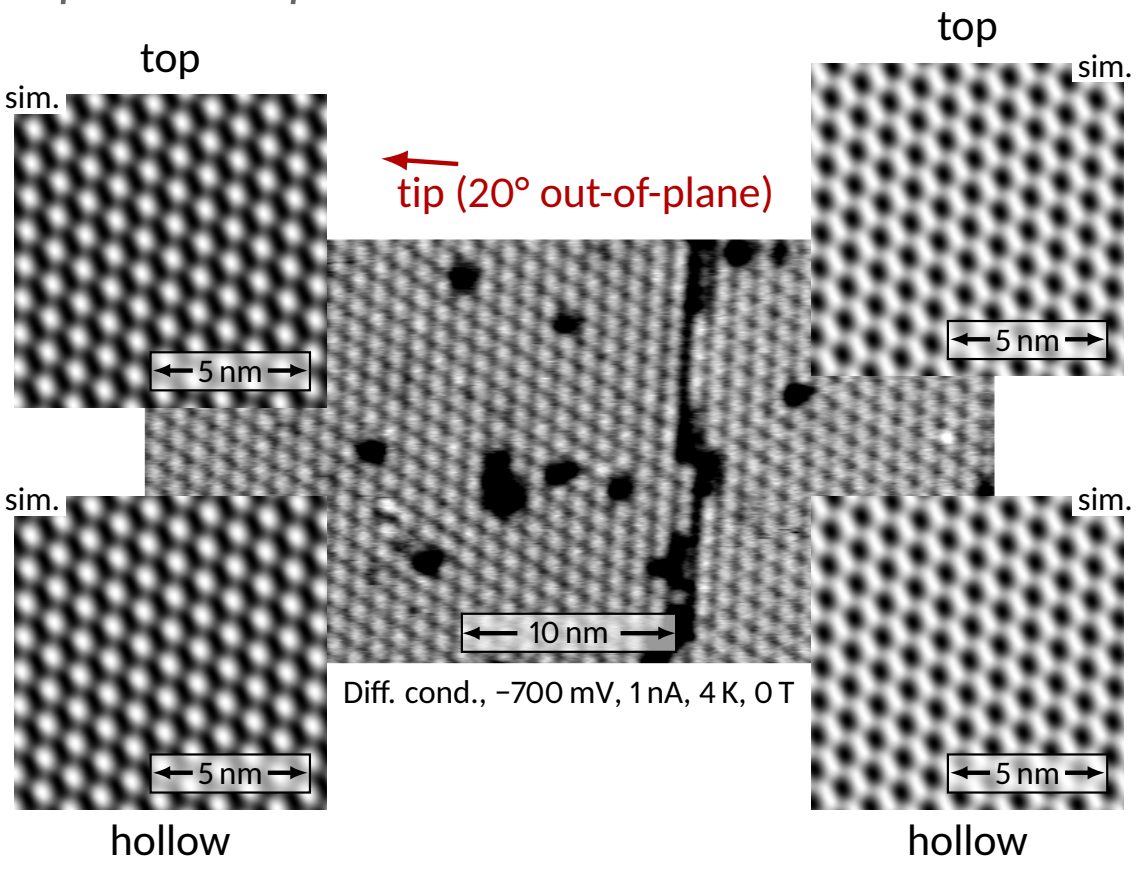
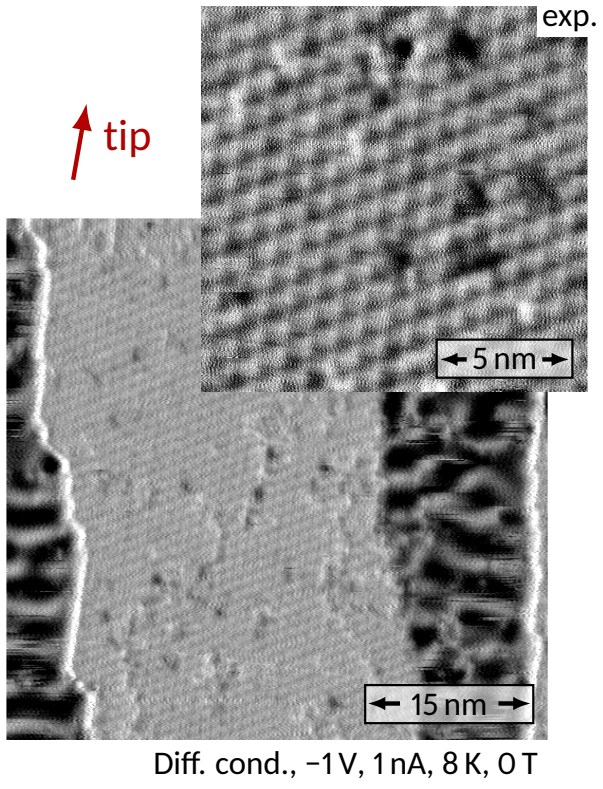
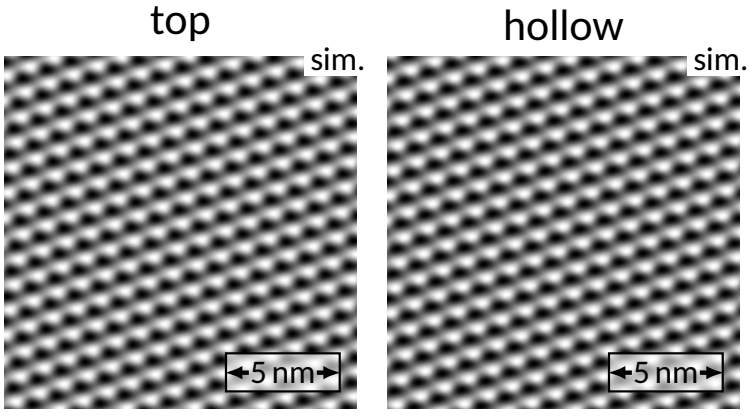




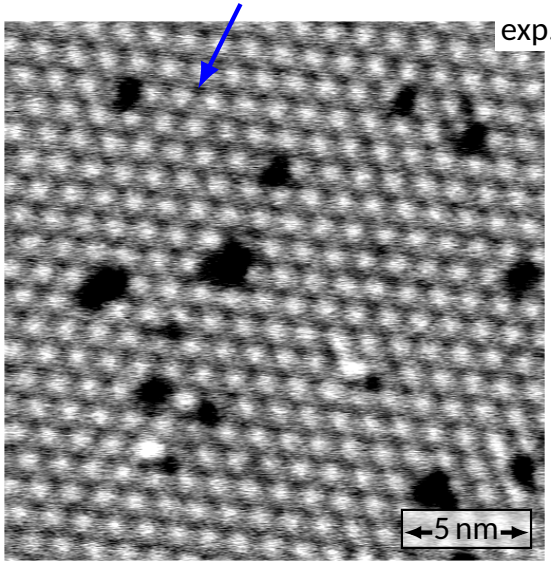


- All the data can be reproduced using the nanoskyrmion lattice
- How to distinguish between the on-top state and the hollow state?

On-top or hollow configuration?

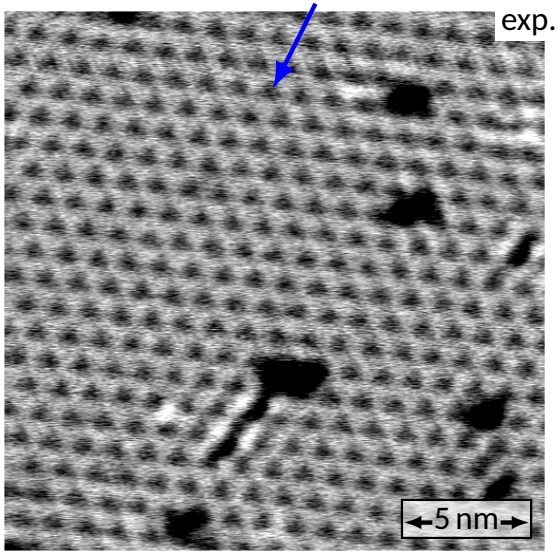
darker dots

tip



Diff. cond., −1 V, 1 nA, 4 K, 0 T

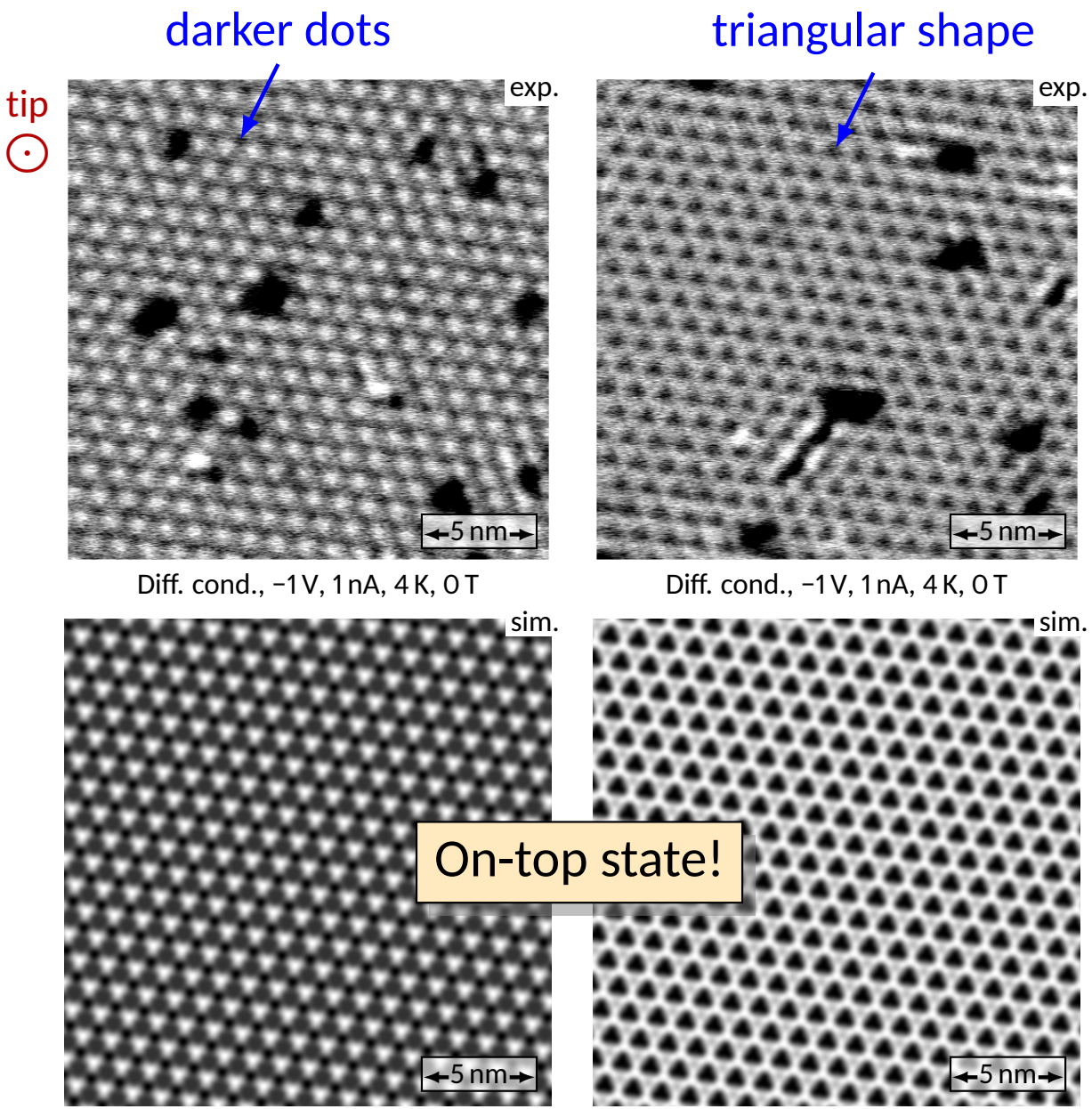
triangular shape



Diff. cond., −1 V, 1 nA, 4 K, 0 T

- H superstructure visible as dark dots at −1 V
- Not the pure magnetic contrast in the differential conductance maps
- Add some dark dots to the simulations, putting the H atoms in the hollow sites

On-top or hollow configuration?



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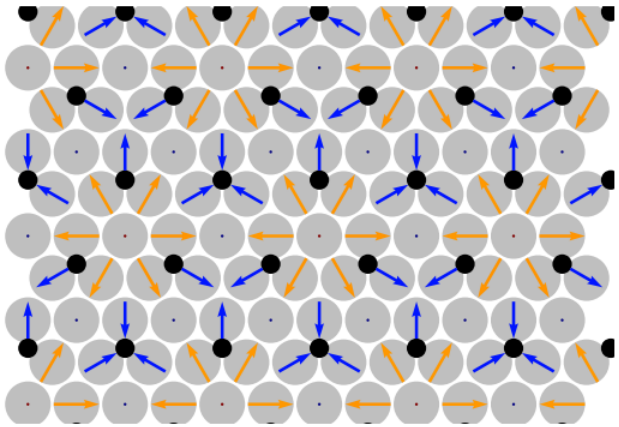
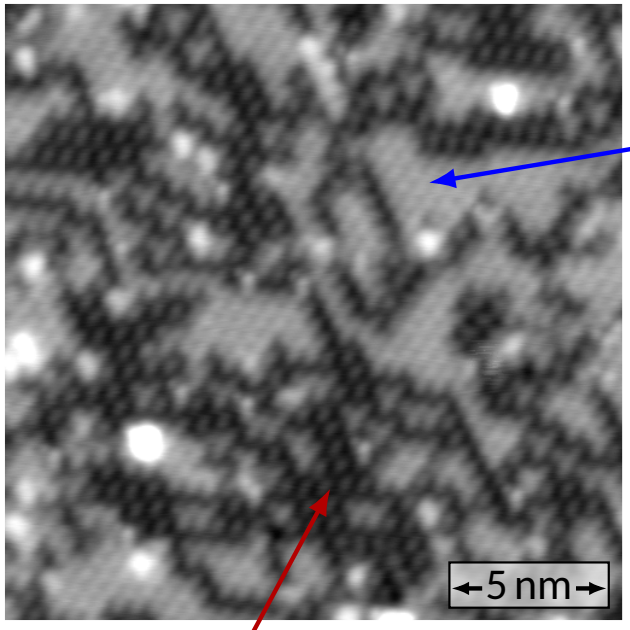


Creation of a square H superstructure

When adding even more H on the sample, another superstructure appears, which can also cover the full monolayer area.

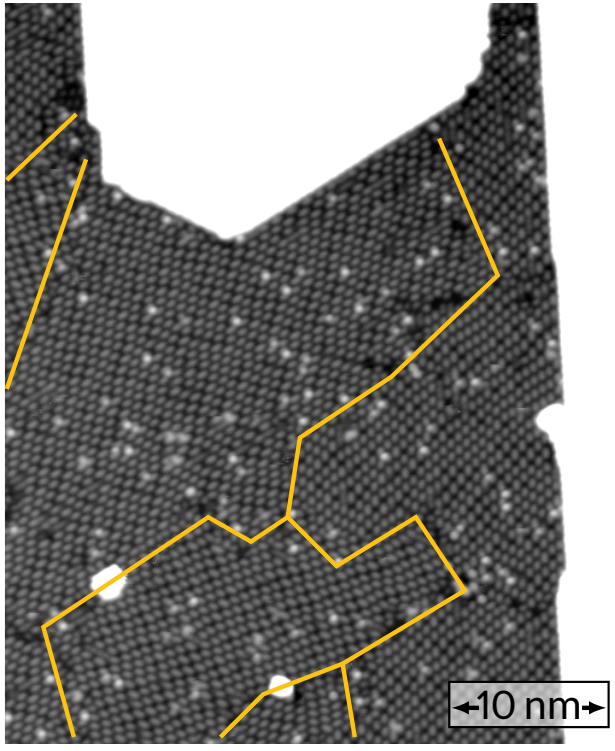
Constant current map



−50 mV, 1 nA, 4 K, 0 T

more H

Constant current map



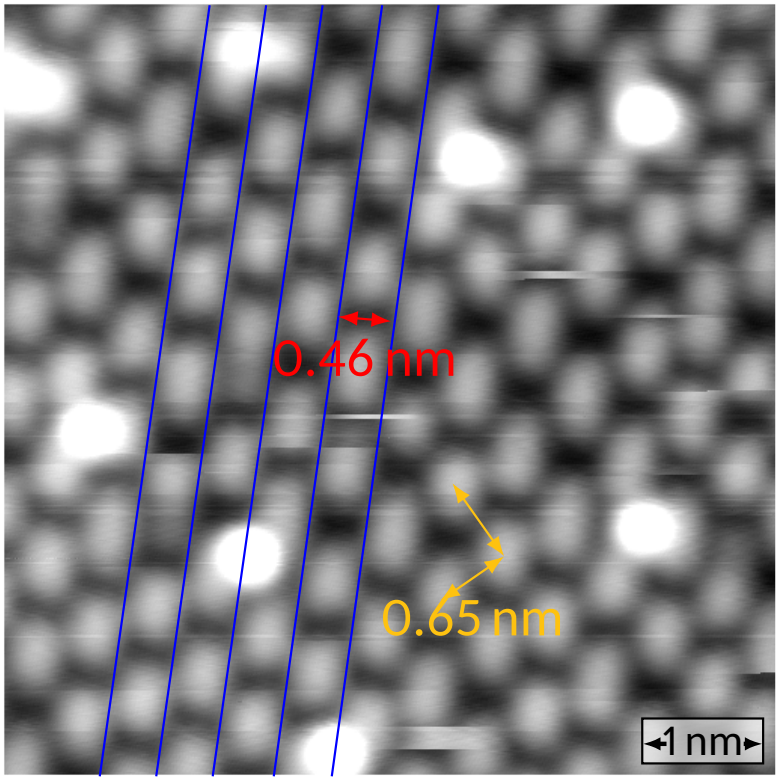
−800 mV, 1 nA, 4 K, 0 T

- Square structure
- Existence of 3 rotational domains

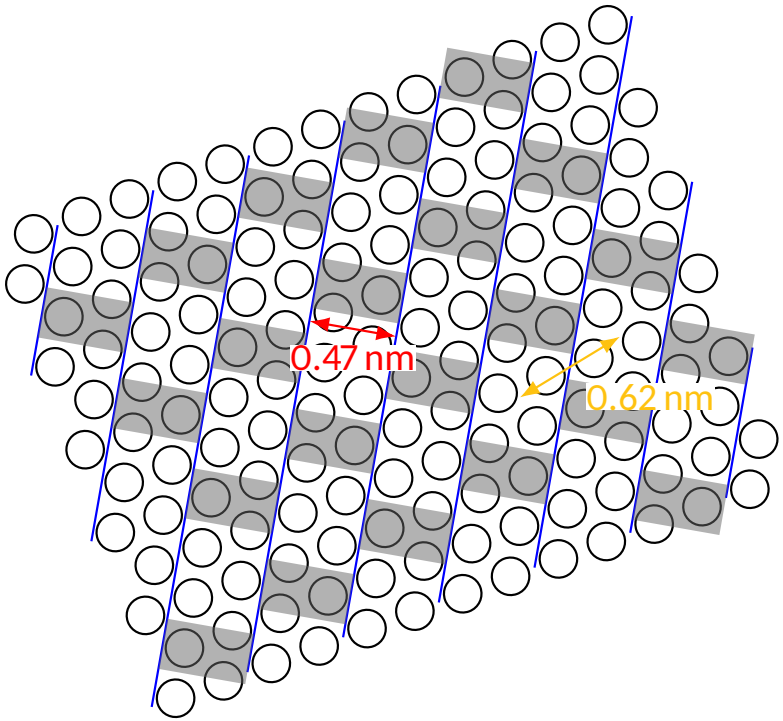
Details of the structure

- Square pattern, not fully periodic
- Very mobile bright protrusions
- Size of the squares about 0.65 nm
- Diagonal of the squares along the close-packed rows of the (111) surface

Constant current map

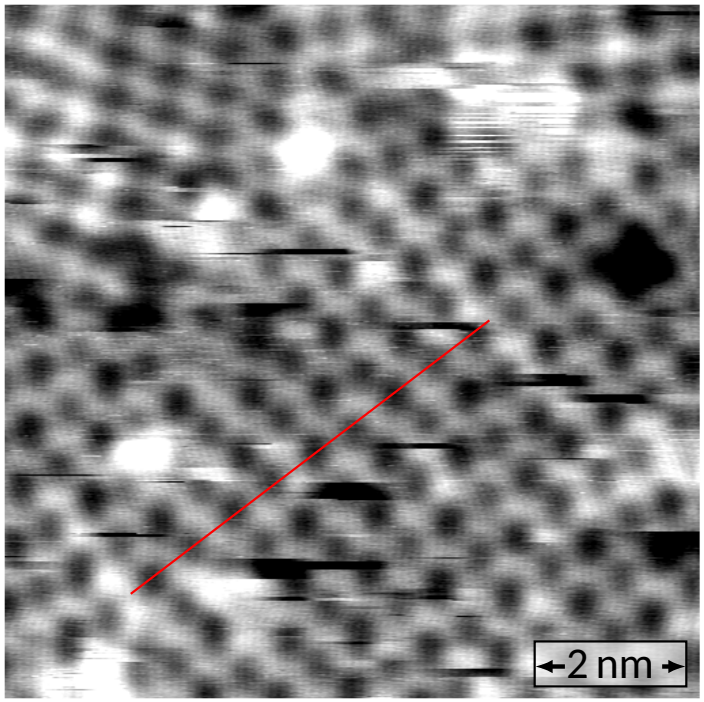


500 mV, 1 nA, 4 K, 0 T

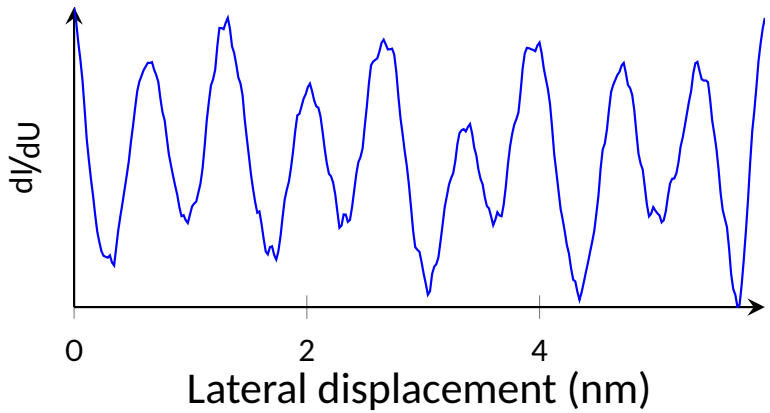


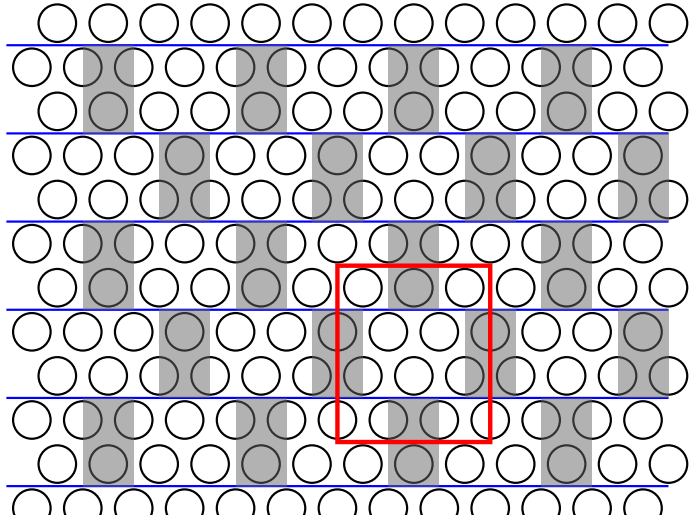
Magnetism of the square phase

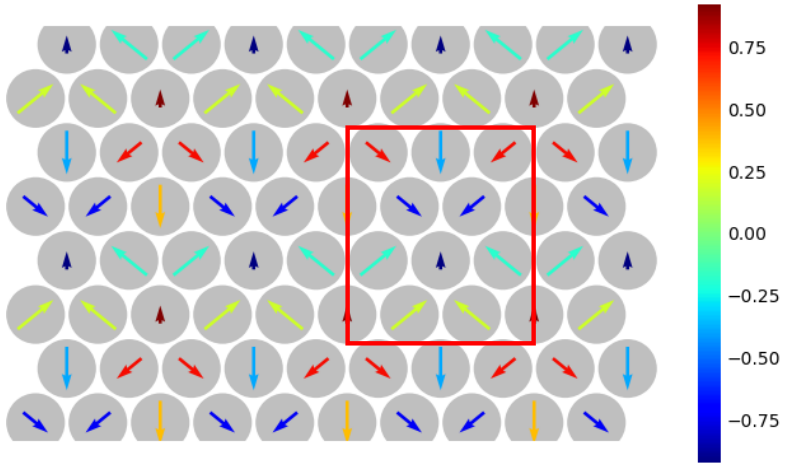
Differential conductance map



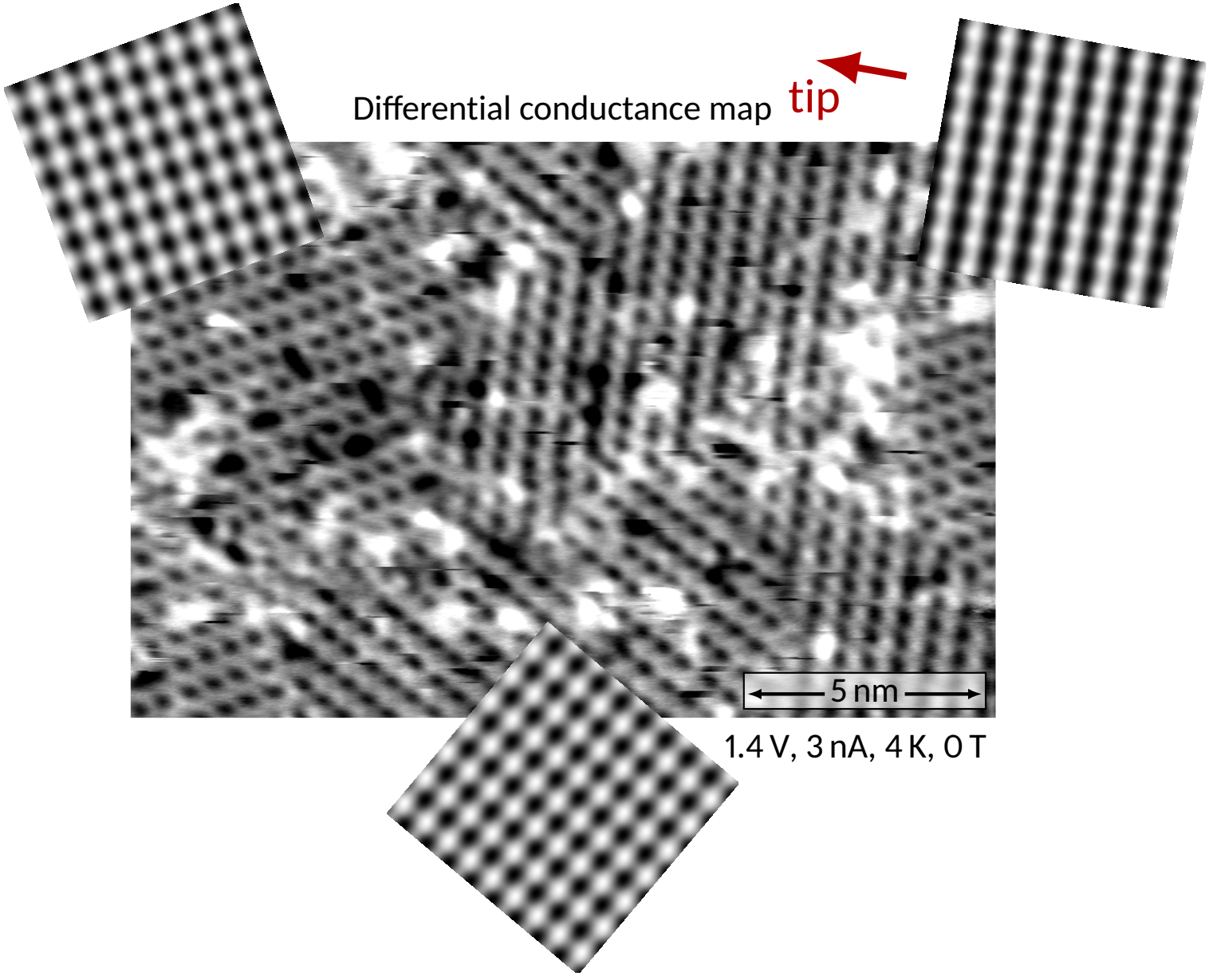
1.4 V, 3 nA, 4 K, 0 T





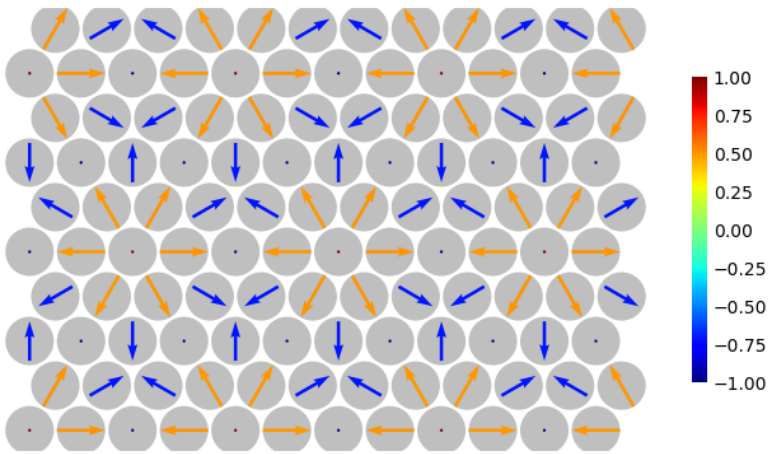


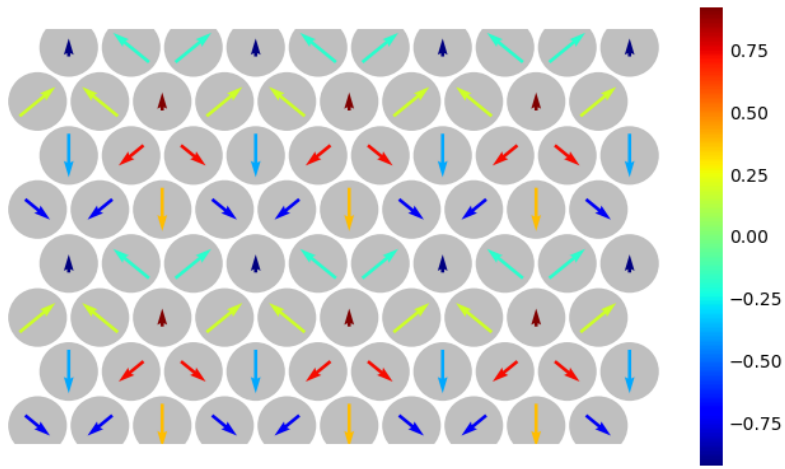
Checking with SP-STM simulations



Summary

- Two different superstructures can be obtained by hydrogenation of the Fe monolayer on Ir(111)
- Phases with different symmetries, hexagonal or roughly square
- Locking of the 2D non collinear magnetic structure on the H superstructure

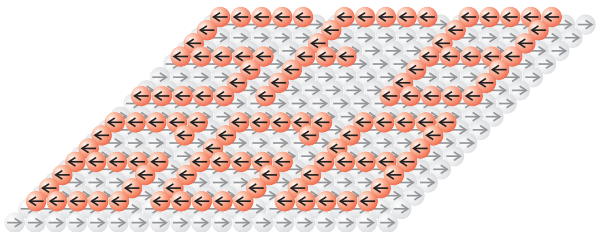




Acknowledgments

Pin-Jui Hsu
André Kubetzka
Kirsten von Bergmann
Roland Wiesendanger

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG



MAGIC Sky

Funded by the Horizon2020 Framework Programme of the European Union