Magnetism with a twist - Topology and zoology of skyrmions

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Outline

- Skyrmions and Topology in magnetism
- Room temperature skyrmion host $Co_{10-x}Zn_{10-y}Mn_{x+y}$
  - Room temperature skyrmions
  - Meta-stability
  - “Square skyrmion” lattice
  - Skyrmions in zero field at room temperature
- Magnetoelectric skyrmion host Cu_2OSeO_3
  - E-field control of skyrmion phase
    - SANS
    - Theory
    - Direct observation (LTEM)
  - Lattice defects and melting, hexatic phase?

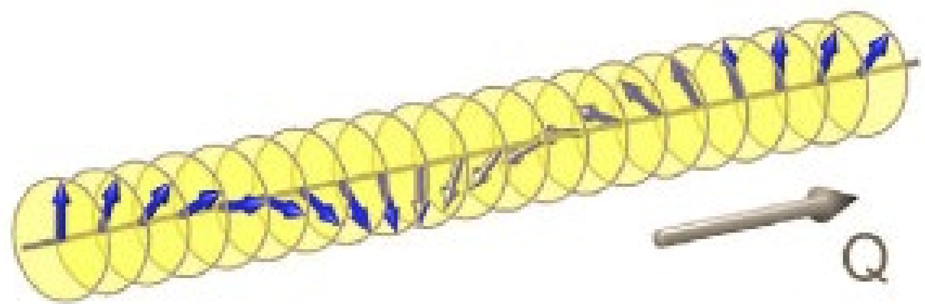
Dzyaloshinskii-Moriya helices

$H = -\Sigma\ J_{ij} S_i \cdot S_j + D_{ij} \cdot (S_i \times S_j)$

J favors parallel spins

J>0 Ferromagnet

J<0 Antiferromagnet



D favor perpendicular spins

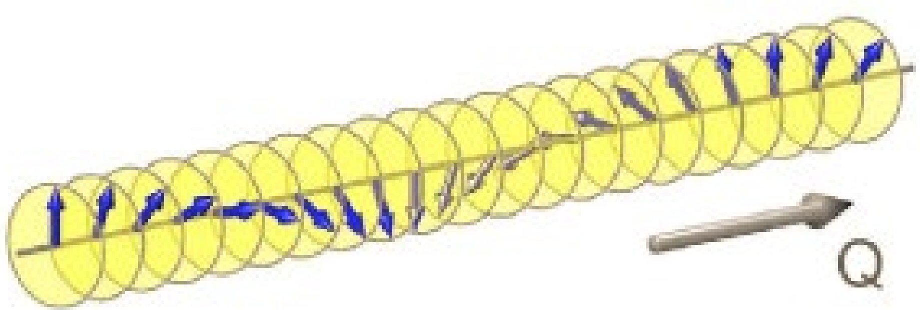
J & D: twist spins by angle $\tan\Theta = D/J$

Helix with period $Q = 2\pi a\ J/D$

Symmetry

- D_{ij} allowed on bonds without inversion symmetry
- Comes from spin-orbit interaction, 1-10% of J
- Mostly $\Sigma D_{ij} = 0$ per unit cell.
- Chiral crystal structures $\Sigma D_{ij} \equiv D \neq 0$

- So "ferromagnets" with chiral structure unstable towards long-period helical structure



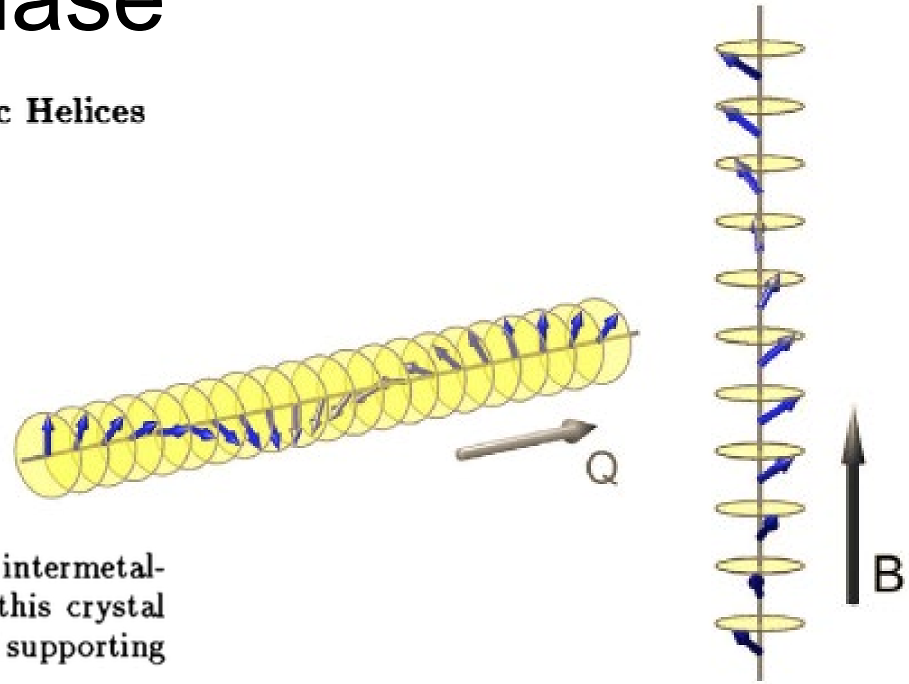
Helical, conical and "A-phase"

Magnetic Ordering in Nearly Ferromagnetic Antiferromagnetic Helices

1993

Bente LEBECH

Department of Solid State Physics, Risø National Laboratory,
DK-4000 Roskilde, Denmark

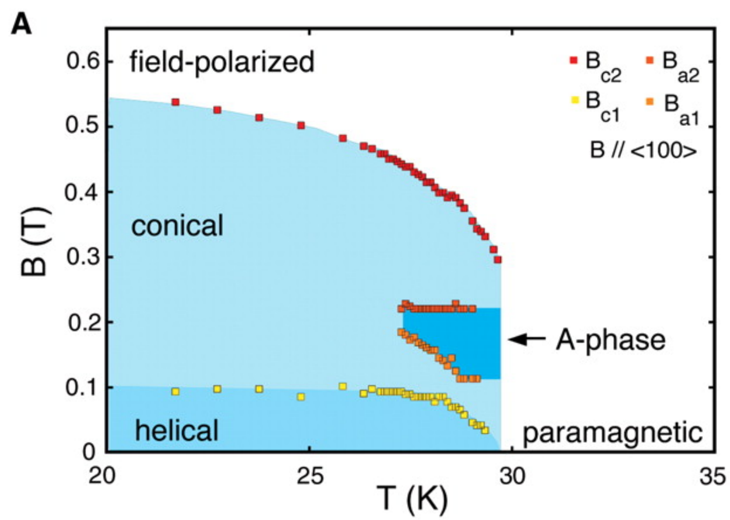


Abstract

The cubic polymorph of FeGe and MnSi belong to a class of magnetic intermetallic compounds with the B20 crystal structure ($P2_13$). Materials with this crystal structure lack inversion symmetry; they have chirality and are capable of supporting

5. Conclusion

The present paper has considered various aspects of the magnetic phase diagram of cubic FeGe and MnSi and correlated the results of neutron small-angle scattering data to the existing theoretical treatments of Dzyaloshinskii-Moriya helices. The neutron scattering data agree reasonably well with the predictions of the present day theories. However, in the neutron diffraction data for both FeGe and MnSi there are indications that the magnetically ordered structure could be a single domain multi-q structure rather than a multi-q single domain structure. If the ordered structure is a multi-q structure, it may be necessary to revise the theoretical description outlined above.

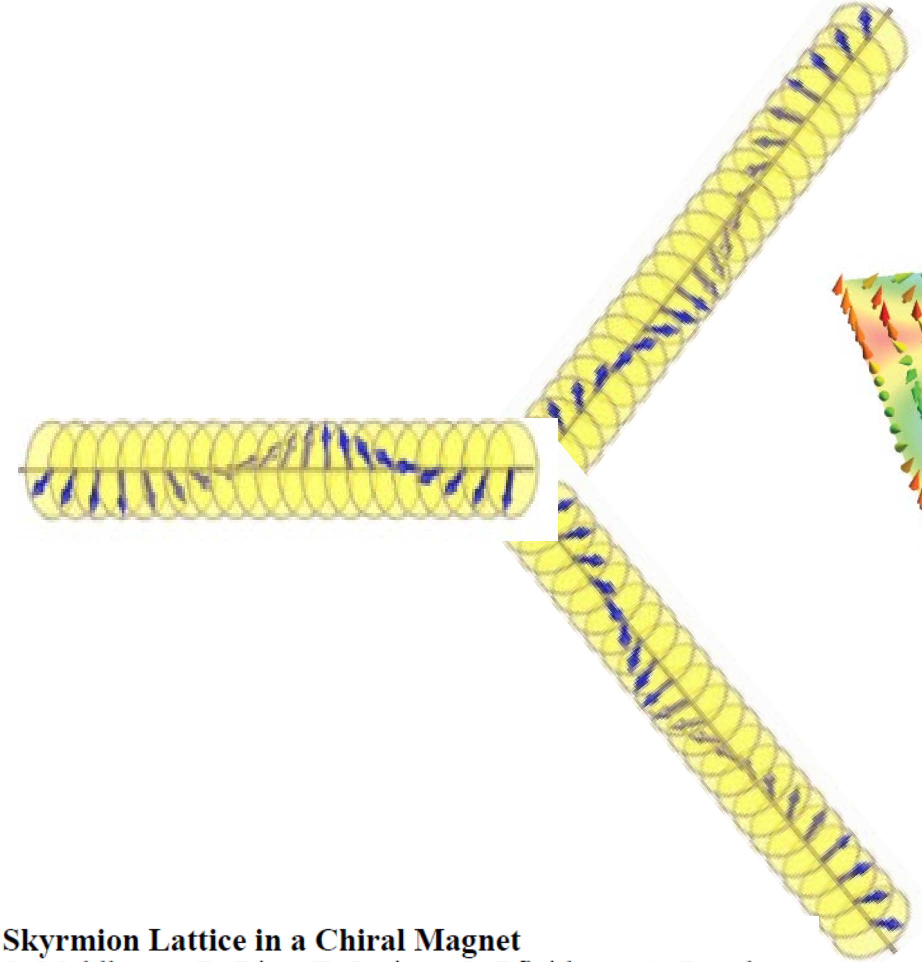


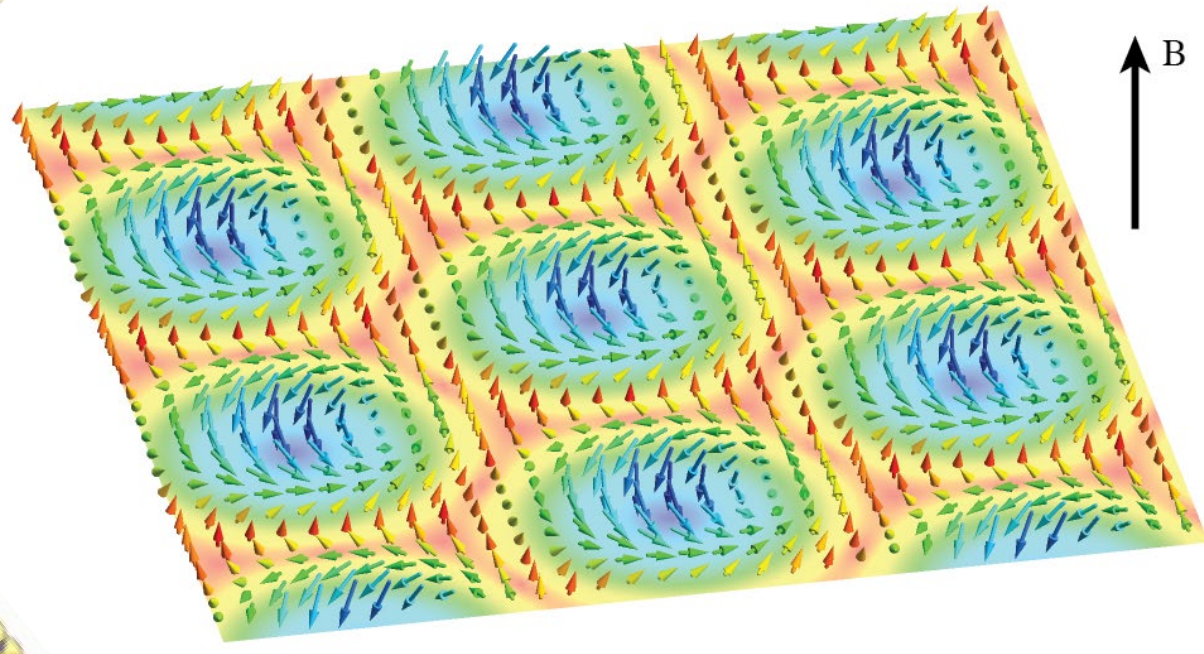
3Q structure

- Superpose 3 helices:

$$\mathbf{M}(r) \approx \mathbf{M}_f + \sum_{i=1}^{3} \mathbf{M}^h_{\mathbf{Q}_i}(\mathbf{r} + \Delta \mathbf{r}_i) \qquad (3)$$

where $\mathbf{M}^h_{\mathbf{Q}_i}(\mathbf{r}) = A[\mathbf{n}_{i1}\cos(\mathbf{Q}_i\mathbf{r}) + \mathbf{n}_{i2}\sin(\mathbf{Q}_i)\mathbf{r}]$





Looks like “spin vortices”

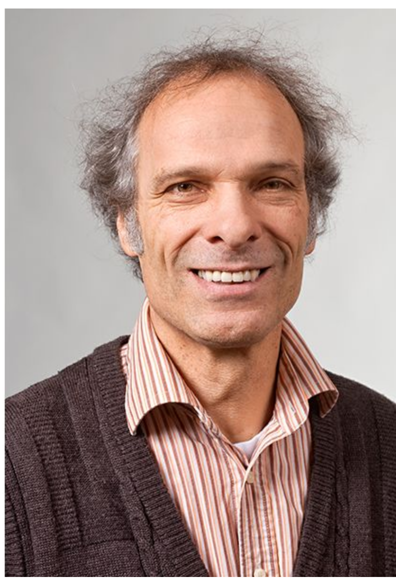
Skyrmion Lattice in a Chiral Magnet
S. Mühlbauer, B. Binz, F. Jonietz, C. Pfleiderer, A. Rosch, A. Neubauer, R. Georgii and P. Böni (February 13, 2009)
Science **323** (5916), 915-919. [doi: 10.1126/science.1166767]

2016 EPS CMD Europhysics Prize

The Condensed Matter Division of the European Physical Society is proud to announce the award of the 2016 European Physical Society Condensed Matter Division Europhysics Prize to:

Peter Böni, Aleksandr N. Bogdanov, Christian Pfleiderer, Achim Rosch and Ashvin Vishwanath

"for the theoretical prediction, the experimental discovery and the theoretical analysis of a magnetic skyrmion phase in MnSi, a new state of matter."

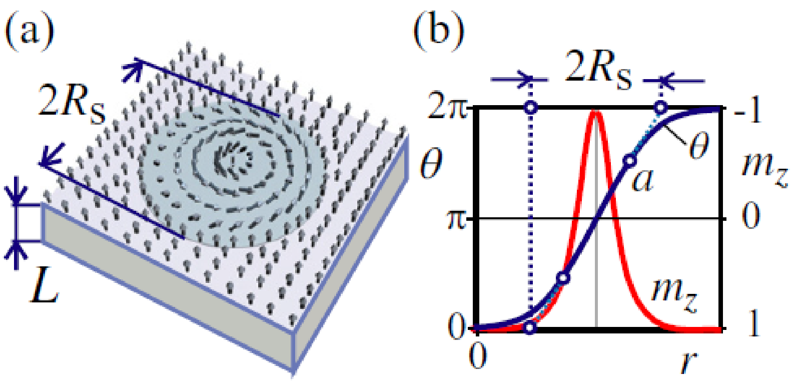


Thermodynamically stable magnetic vortex states in magnetic crystals

A. Bogdanov *, A. Hubert

Institut für Werkstoffwissenschaften VI der Universität Erlangen-Nürnberg, Martensstr. 7, D 91058 Erlangen, Germany

Received 14 February 1994



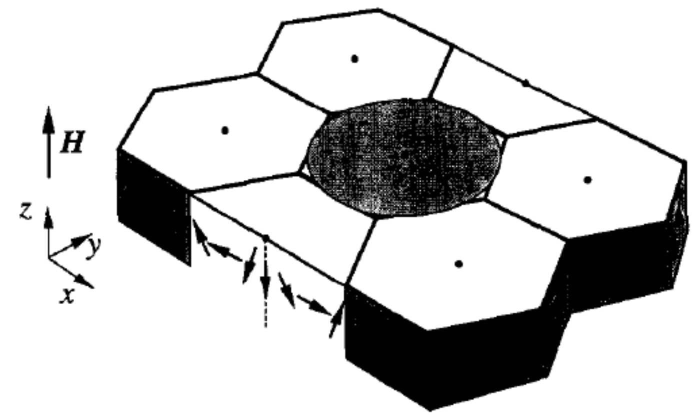


Fig. 1. Schematic view of a sample with a vortex lattice. In the cross-section a Néel-like rotation is indicated (see Section 2.5).

"spin vortices" as local solitonic solution to continuum model

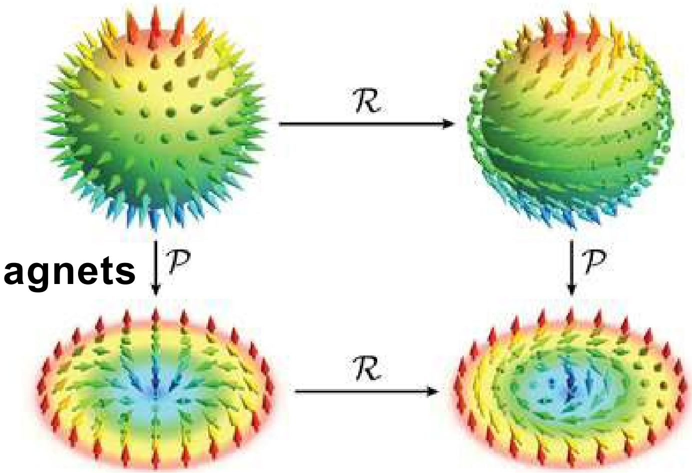
$$\mathcal{H}_{JDh} = J(\nabla \mathbf{S})^2 + D\mathbf{S} \cdot (\nabla \times \mathbf{S}) - \mathbf{h} \cdot \mathbf{S}$$

Skyrmion lattice of individual skyrmions $\Longleftrightarrow$ 3-Q magnetic structure

Magnetic skyrmions: non-trivial topology in real-space

Tony Skyrme

Nucl. Phys. **31** 556 (1962)



http://www.christophschuette.com/physics/skyrmions.php

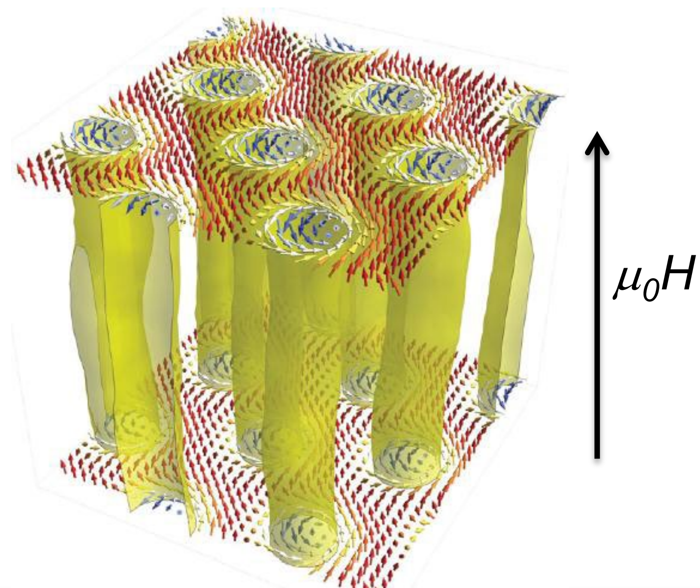
•Skyrmion → a local excitation of a smooth mesonic field

•Excitations interpreted to be baryon *particles*

•Characterised by a *topological charge*.

•Skyrmion excitation in the solid state:
Liquid crystals, QHE, BEC, magnets

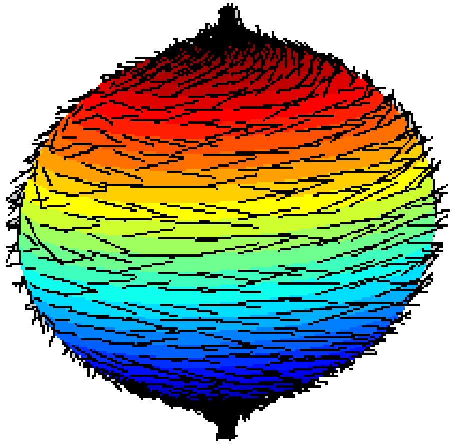
Topologically non-trivial (countable objects)
Closed particle-like state (physical stability)



P. Milde *et al.*, Science 340, 1076 (2013)

The hairy ball theorem

- "you can't comb a hairy ball flat without creating a cowlick“



- Topology concern non-local properties !

The Nobel Prize in Physics 2016

Photo: A. Mahmoud
David J. Thouless
Prize share: 1/2

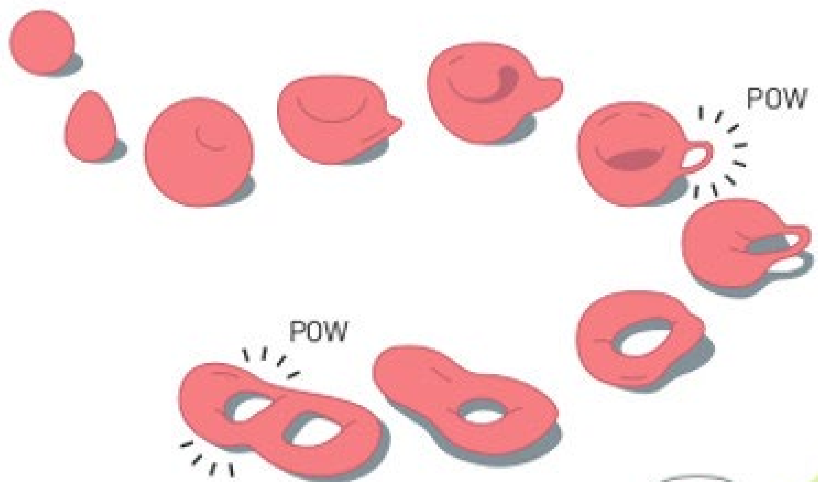
Photo: A. Mahmoud
F. Duncan M. Haldane
Prize share: 1/4

Photo: A. Mahmoud
J. Michael Kosterlitz
Prize share: 1/4

The Nobel Prize in Physics 2016 was awarded with one half to David J. Thouless, and the other half to F. Duncan M. Haldane and J. Michael Kosterlitz *"for theoretical discoveries of topological phase transitions and topological phases of matter"*.

Topological phase transitions

Topological phases of matter



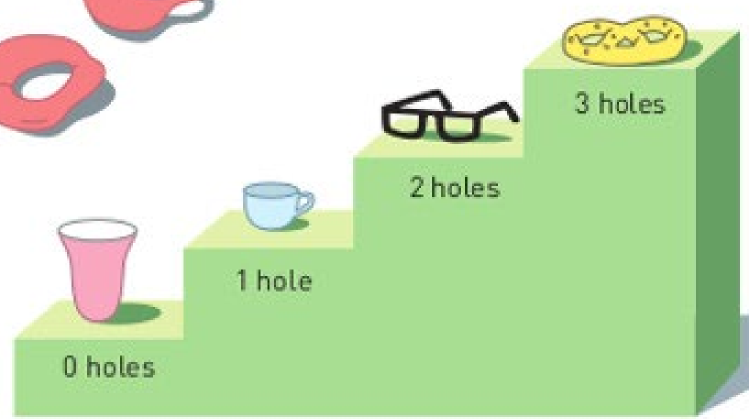
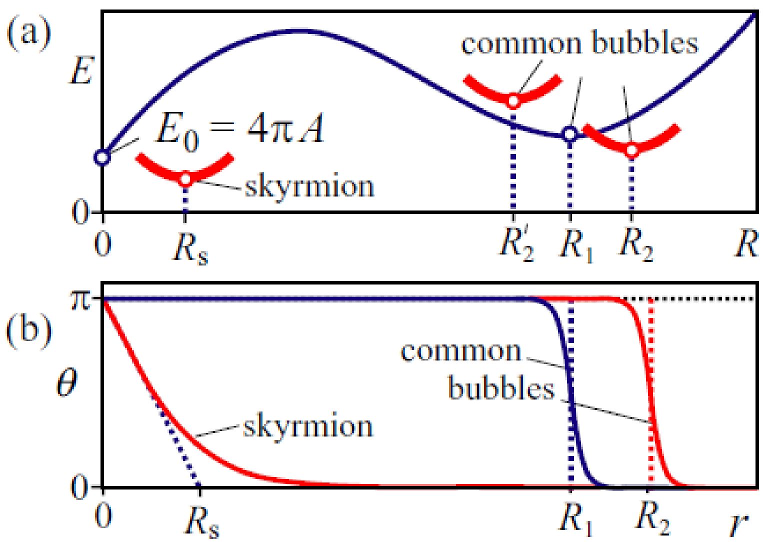
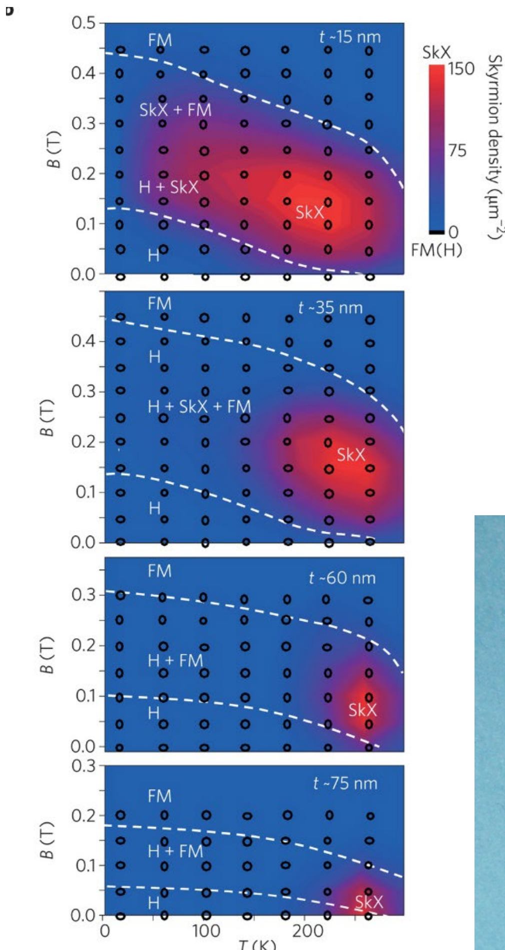


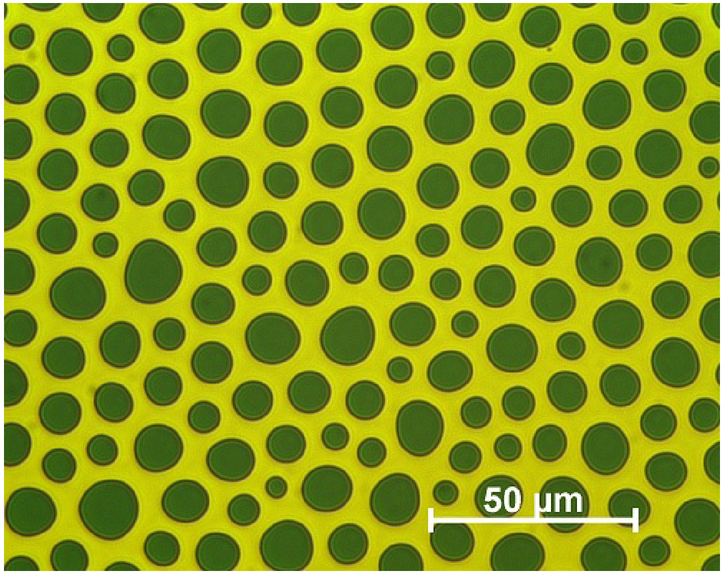
Illustration: ©Johan Jarnestad/The Royal Swedish Academy of Sc

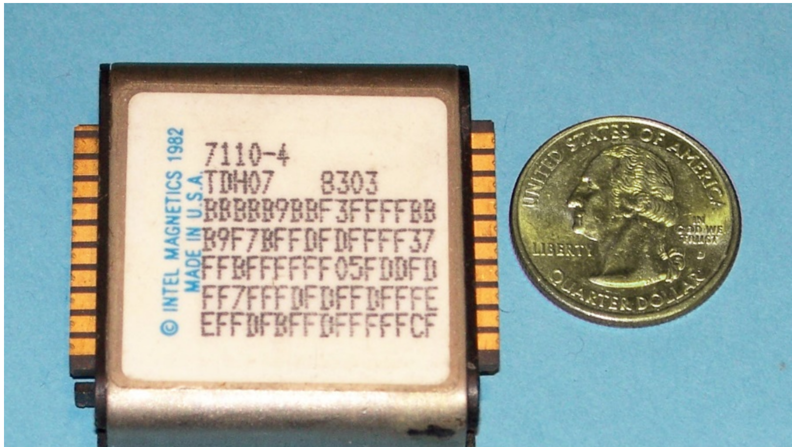
Skyrmions and magnetic bubbles

- In plate-geometry bubbles are stabilized by dipole fields









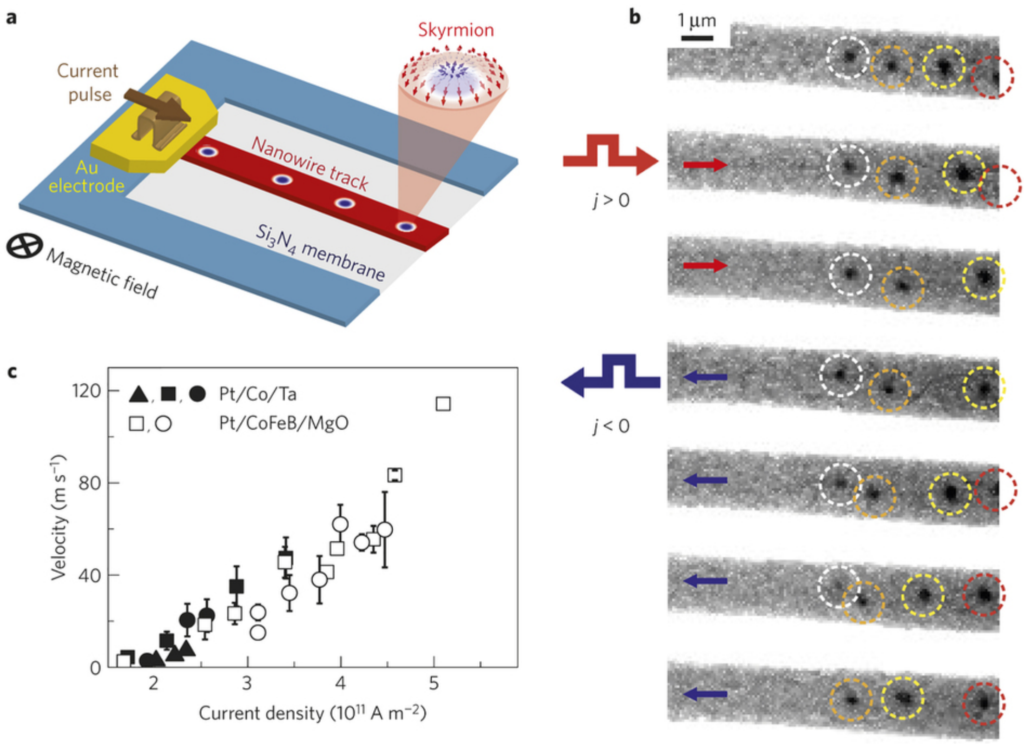
Intel 1Mbit bubble memory

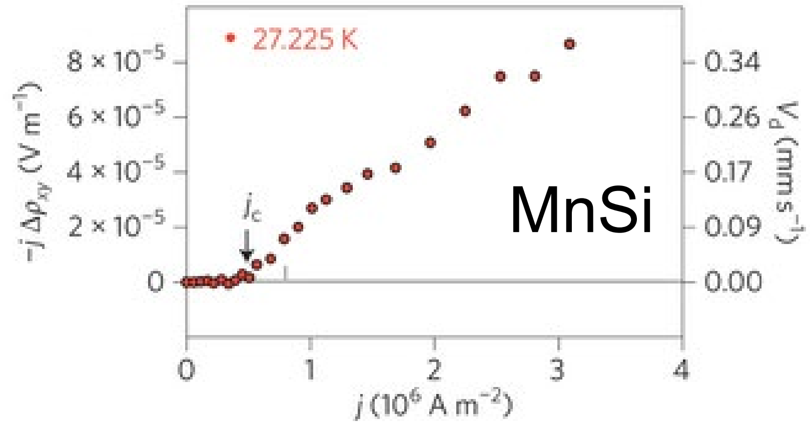
Skyrmions on the track

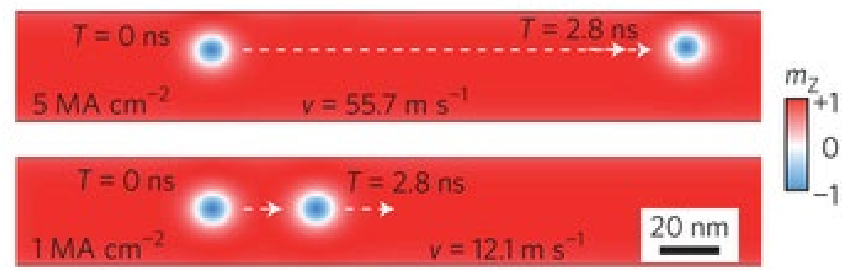
Albert Fert, Vincent Cros and João Sampaio

Magnetic skyrmions are nanoscale spin configurations that hold promise as information carriers in ultradense memory and logic devices owing to the extremely low spin-polarized currents needed to move them.

- Skyrmions move in small currents
- Race-track memory…

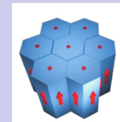




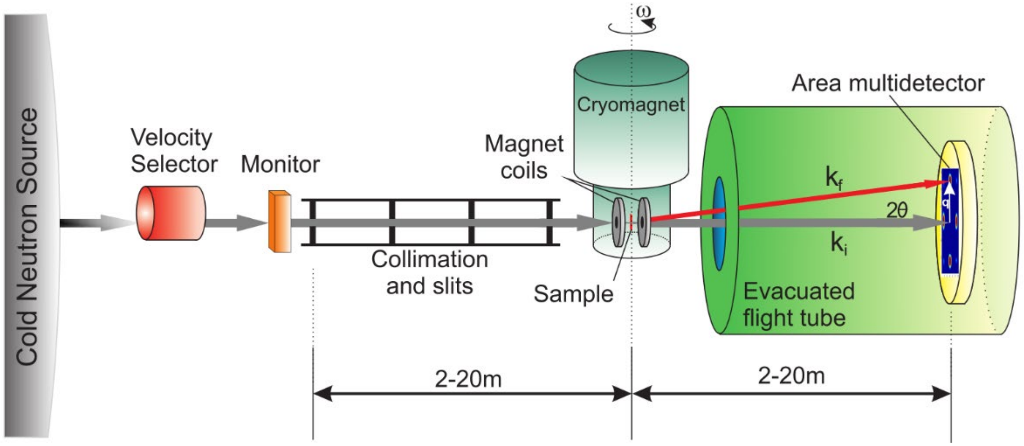


simulation

Many phenomena, large interest, growing list of materials

Material	SG	Ordering Temp	Helimag. Period	Transport property	Skyrmion motion	SkL Dimension	References
MnSi	$P2_13$	30 K	18 nm	Metallic	j_c~10^6A.m^{-2} ΔT	2D 	S. Mühlbauer *et al.*, Science **323**, 915 (2009) F. Jonietz *et al.*, Science **330**, 1648 (2010) M. Mochizuki *et al.*, Nat. Mater. **13**, 241 (2014)
FeGe	$P2_13$	280 K	70 nm	Metallic	j_c<10^6A.m^{-2}	2D	X.Z. Yu *et al.*, Nat. Mater. **10**, 106 (2010) X.Z. Yu *et al.*, Nat. Comm. **3**, 988 (2012)
$Fe_{1-x}Co_xSi$	$P2_13$	11 – 36 K	40-230 nm	Metal / semi-conductor		2D	W. Münzer *et al.*, PRB **81**, 041203(R) (2010) X.Z. Yu *et al.*, Nature **465**, 901 (2010)
$Mn_{1-x}Fe_xSi$	$P2_13$	7-16.5 K	10-12 nm	Metallic		2D	S.V. Grigoriev *et al.*, PRB **79,** 144417 (2009)
$Mn_{1-x}Fe_xGe$	$P2_13$	150-220 K	5 - 220 nm	Metallic		2D	K. Shibata *et al.,* Nature Nano. **8,** 723 (2013)
$Co_xZn_yMn_z$	$P4_132$	140-480K	110-190nm	Metallic		2D	Y. Tokunaga *et al.,* Nat. Com. **6,** 7638 (2015)
GaV_4S_8	C_{3v}	13 K	22nm Neel type	Semi-conductor		2D anisotrop	I. Kezsmarki *et al.*, Nat Mat **14,** 1116 (2015)
Cu_2OSeO_3	$P2_13$	58 K	50 nm	Insulating Magneto-electric	ΔT E<10^5 V/m	2D	S. Seki *et al.*, Science **336,** 198 (2012) T. Adams *et al.*, PRL **108**, 237204 (2012) M. Mochizuki *et al.*, Nat Mat **13**, 241 (2014)
MnGe	$P2_13$	170 K	3 nm	Metallic		3D?	N. Kanazawa *et al.*, PRL **106**, 156603 (2011) N. Kanazawa *et al.*, PRB **86**, 134425 (2012)

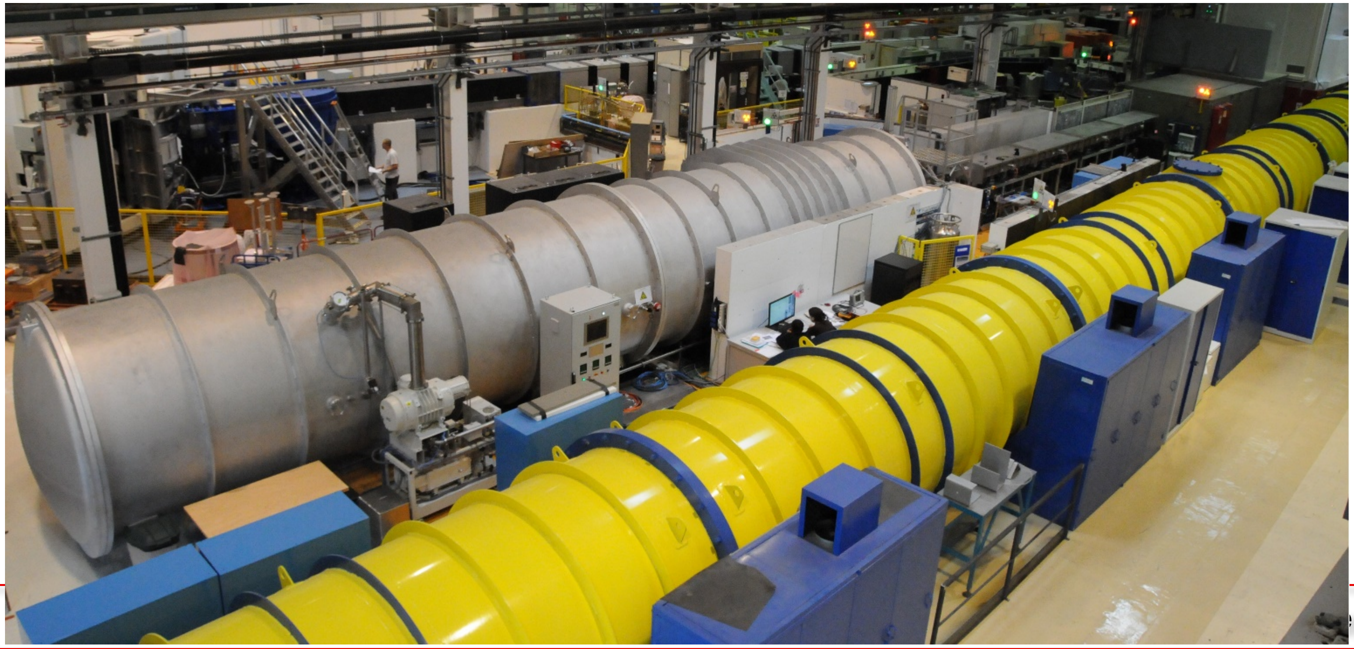
Small-angle neutron scattering (SANS)



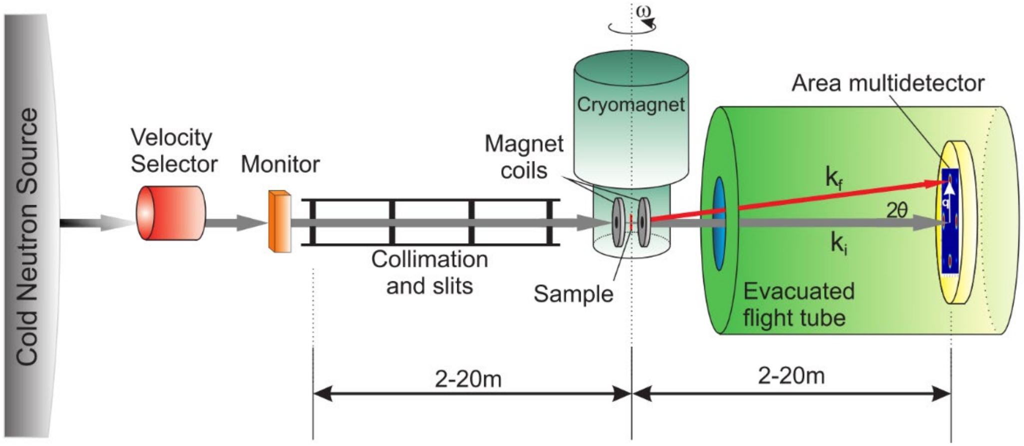
D33 @ ILL

Large period $\lambda = 2d\sin\theta$ **structures (~3 to 500 nm) → low *q* → SANS**

- Length of instrument: 4-40 m
- Scattering angle: ~1-5°
- Low ***q***: 0.002 to 0.3 Å^{-1}.
- Non-destructive bulk probe
- Neutron spin polarisation analysis

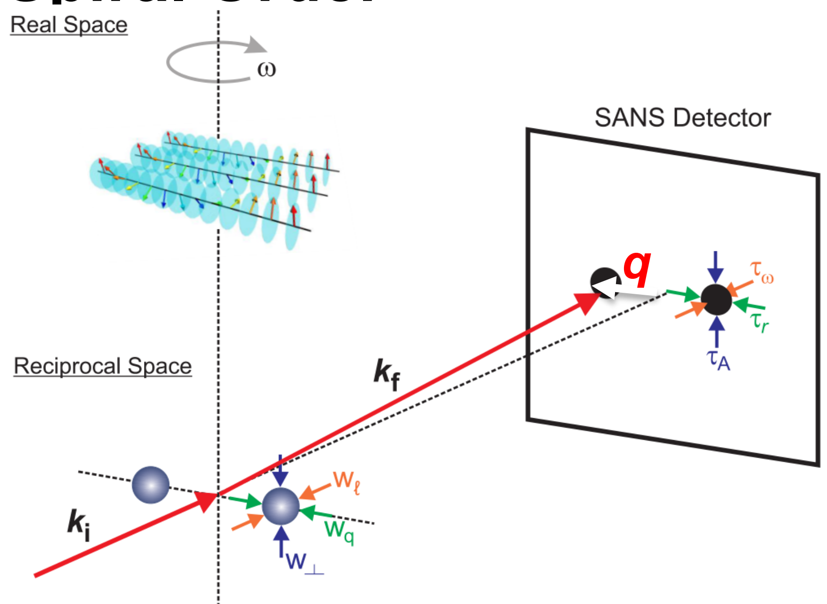


Small-angle neutron scattering (SANS)



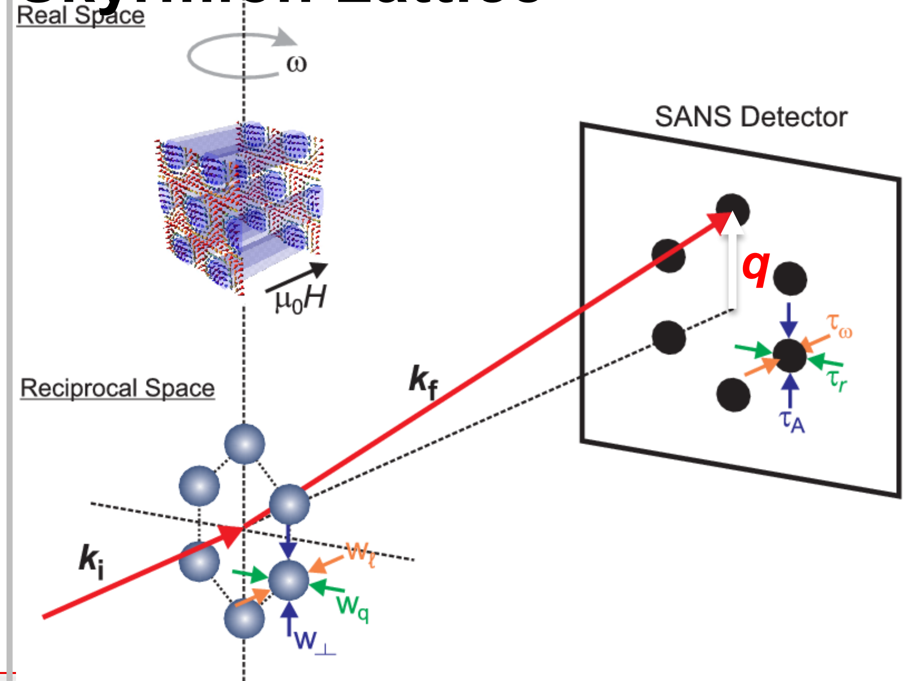
Large period $\lambda = 2d\sin\theta$ structures (~3 to 500 nm) → low *q* → SANS

Spiral Order



$$\left.\frac{d\sigma}{d\Omega}\right|_{mag,el} = N(\gamma r_0)^2\frac{(2\pi)^3}{v_0}\sum_{\mathbf{G}}\sum_{\mathbf{k}}\sum_{\alpha,\beta}(\delta_{\alpha\beta}-\hat{q}_\alpha\hat{q}_\beta)F_M^{\mathbf{k}\alpha\dagger}F_M^{\mathbf{k}\beta}\delta(\mathbf{q}-\mathbf{k}-\mathbf{G})$$

Skyrmion Lattice



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  - Lattice defects and melting, hexatic phase?

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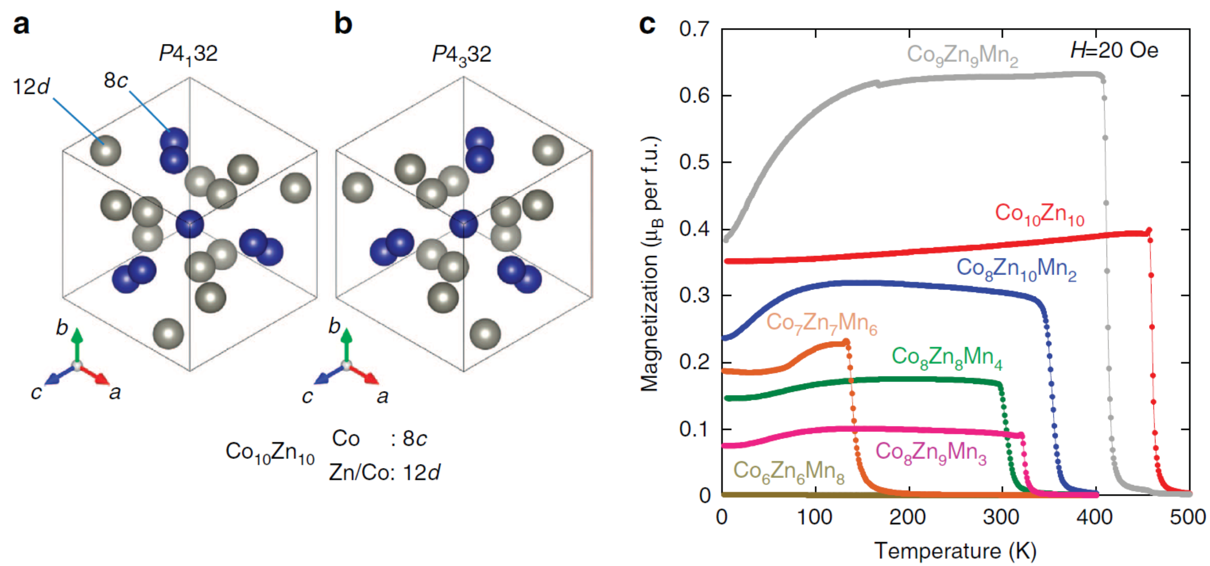
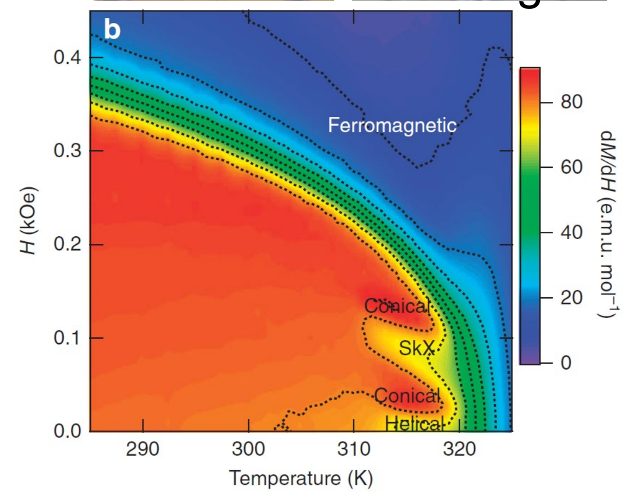
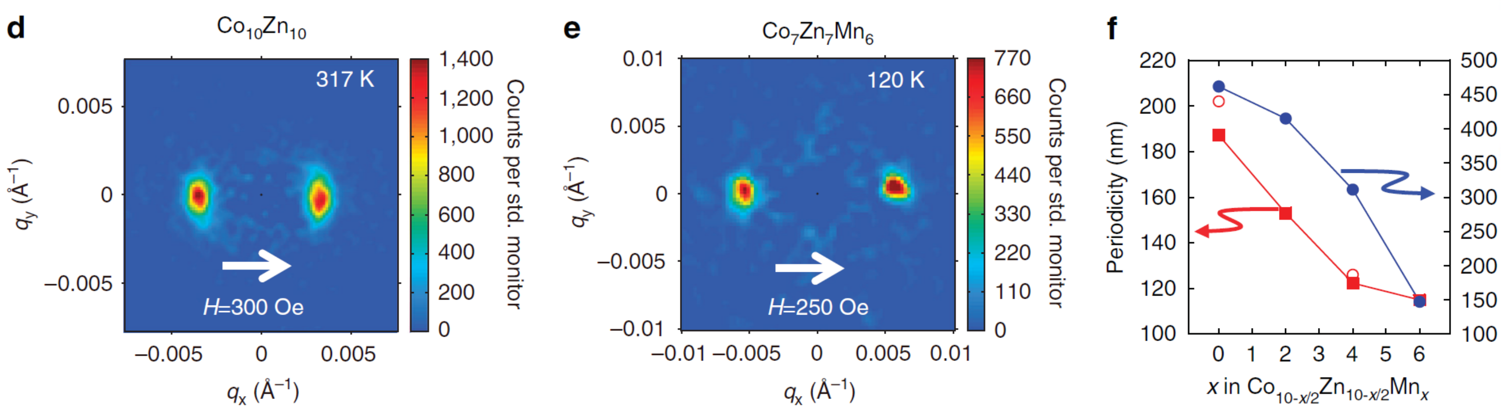
OPEN

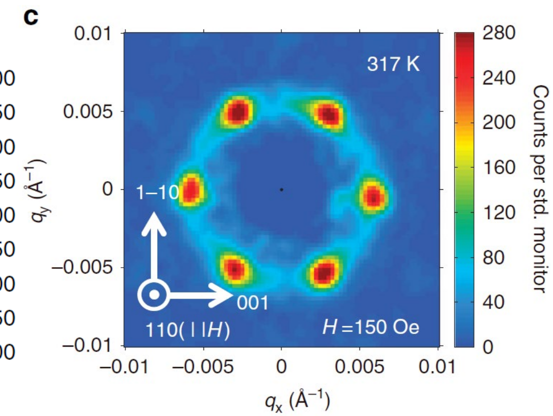
A new class of chiral materials hosting magnetic skyrmions beyond room temperature

Y. Tokunaga[1,†], X.Z. Yu[1], J.S. White[2], H.M. Rønnow[1,3], D. Morikawa[1], Y. Taguchi[1] & Y. Tokura[1,4]









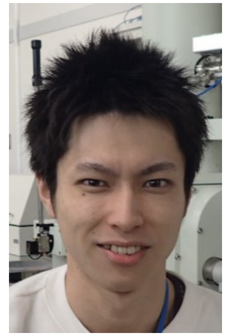
Robust metastable skyrmions and their triangular–square lattice structural transition in a high-temperature chiral magnet

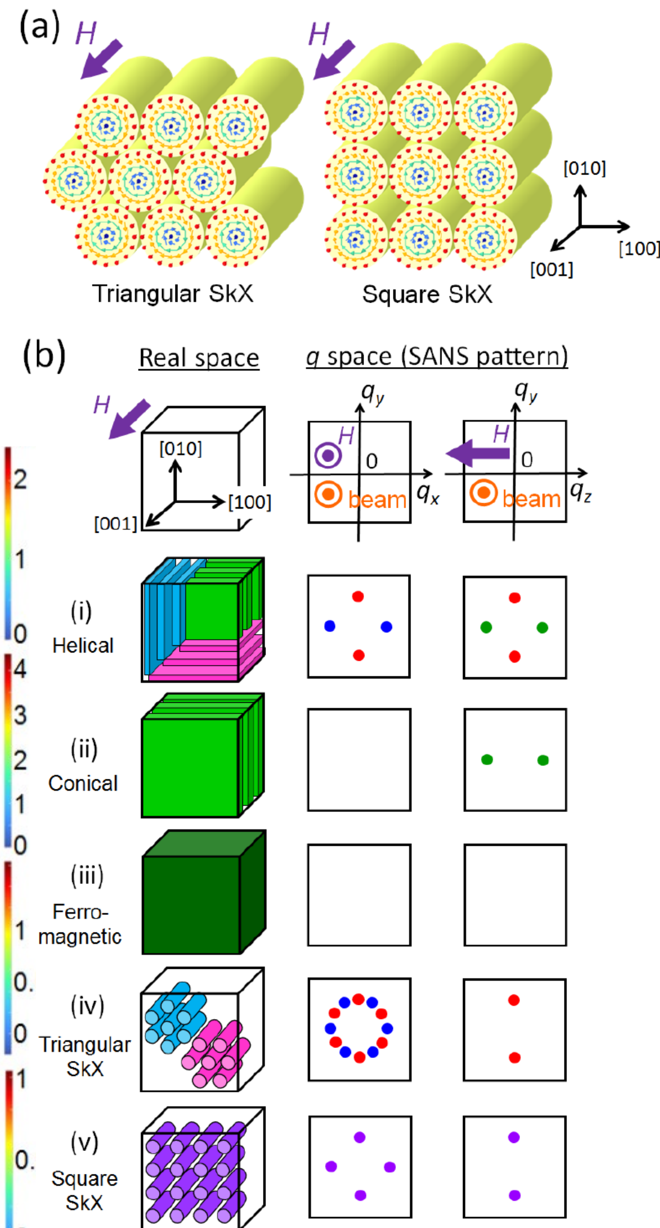
K. Karube, J. S. White, N. Reynolds, J. L. Gavilano, H. Oike, A. Kikkawa, F. Kagawa, Y. Tokunaga, H. M. Rønnow, Y. Tokura & Y. Taguchi

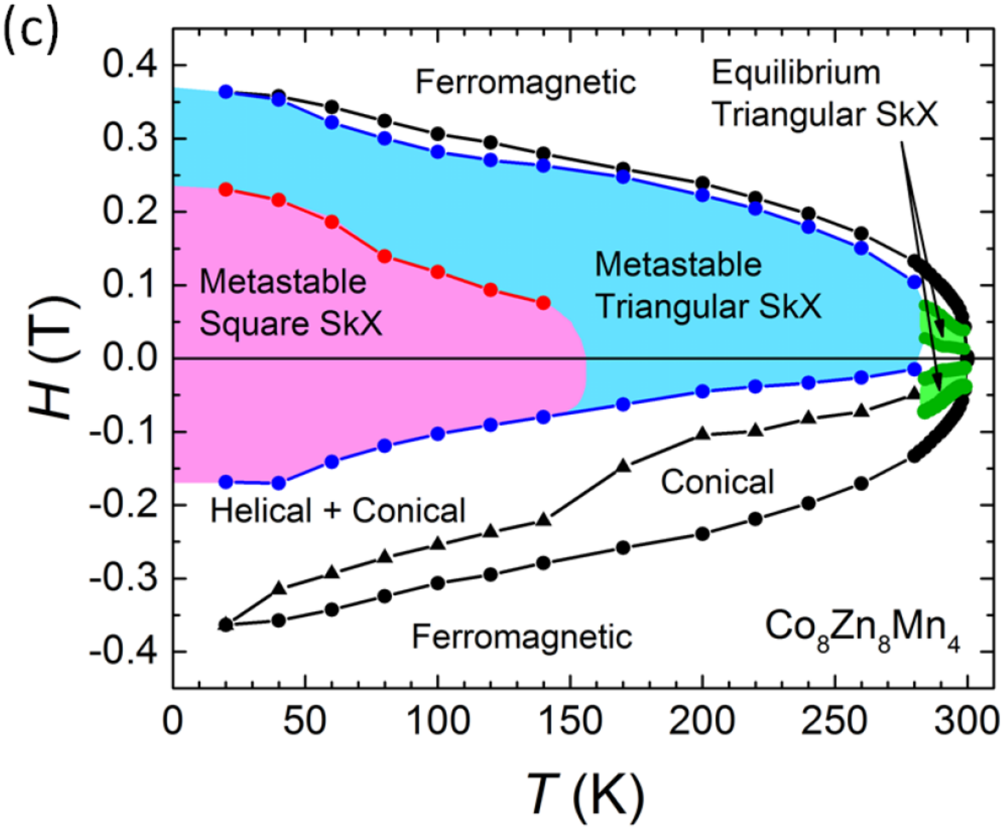
Affiliations | Contributions | Corresponding author

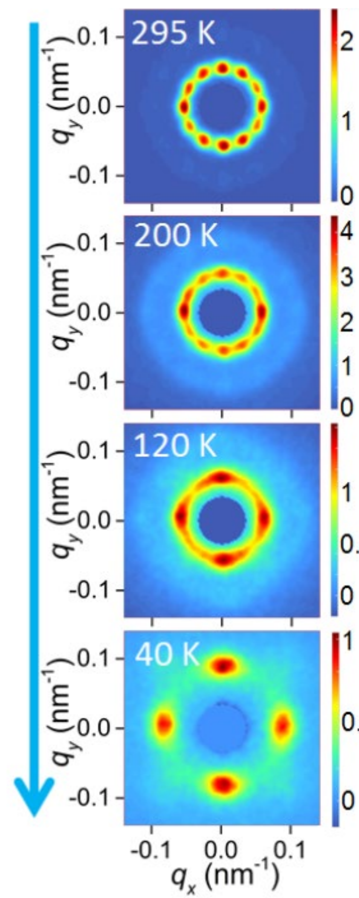
Nature Materials (2016) | doi:10.1038/nmat4752

Kosuke Karube

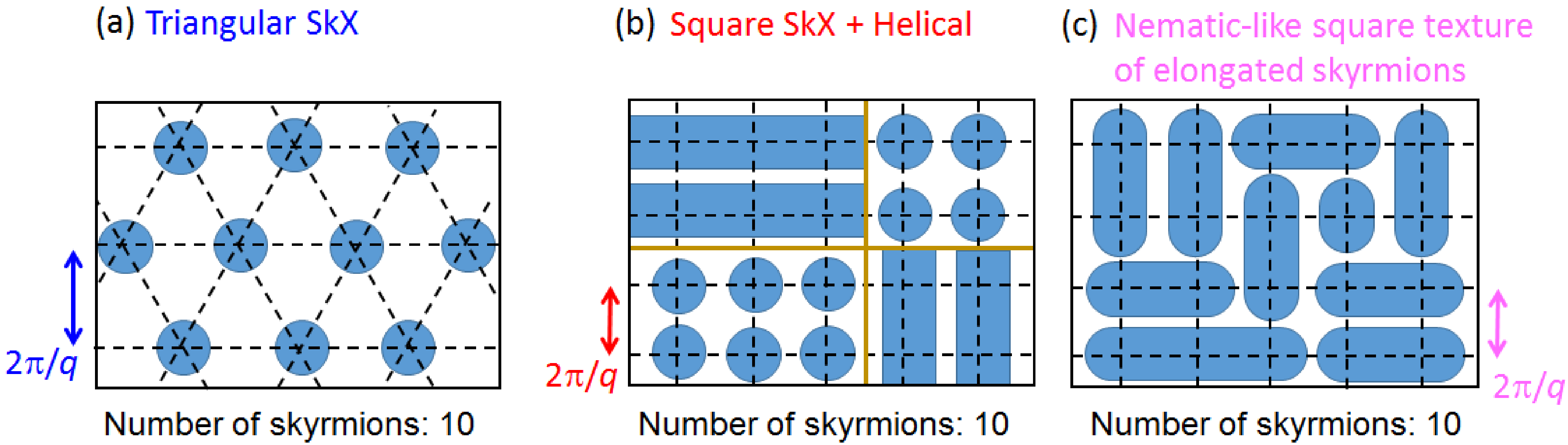








Topological protection + D/J(T) => long skyrmions



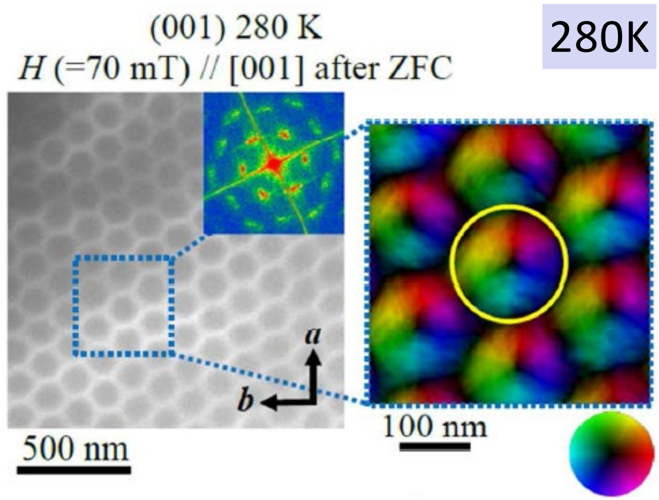
- Consequence:
  - Relationship helical domains / elongated skyrmions
  - Edges of helical domains carry half-skyrmions = merons
  - Crossing phase transition can pump skyrmions

Confirmation from real-space imaging

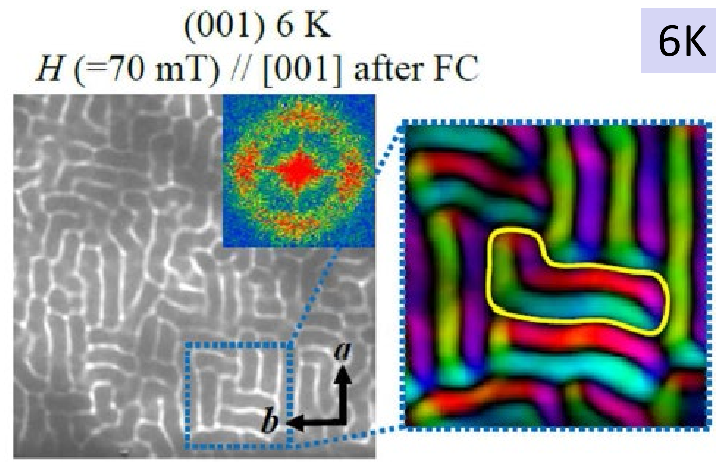
D. Morikawa *et al.*, Nano Letters, Just Accepted Manuscript (2017)

$Co_8Zn_8Mn_4$ – 150nm thick plate

280K

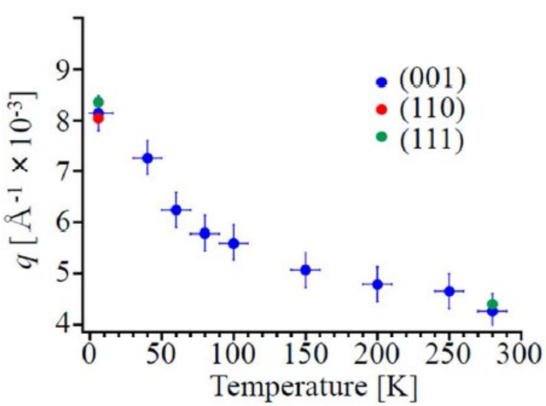


6K

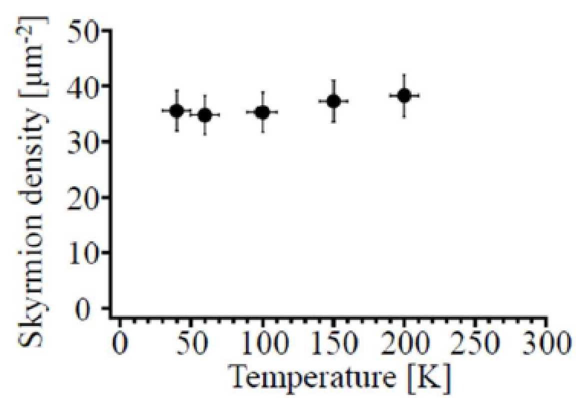


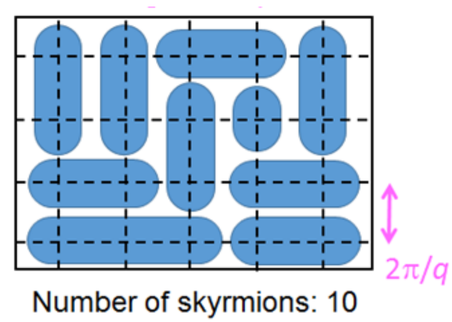
Metastable skyrmions deform upon cooling

_T_-dependence of q



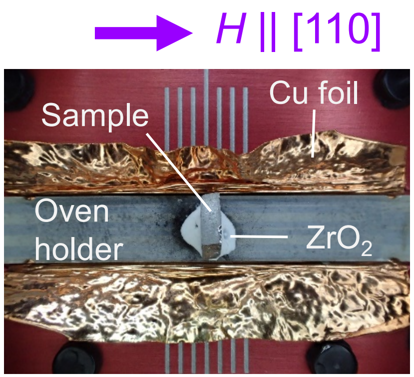
Skyrmion density



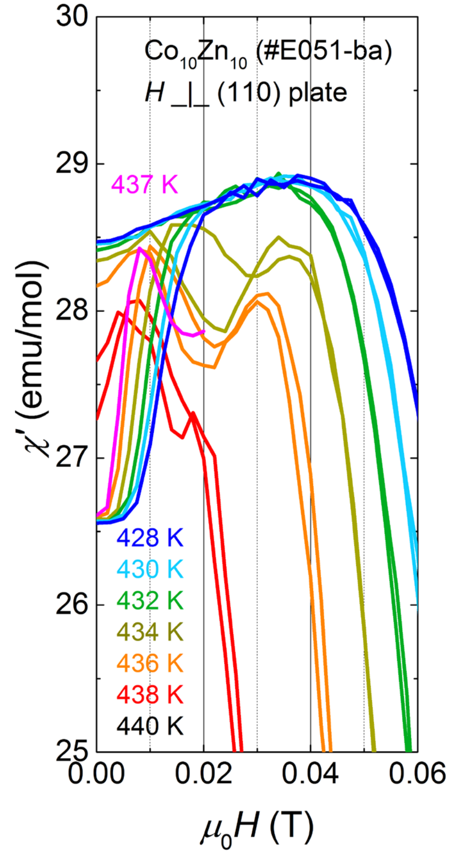


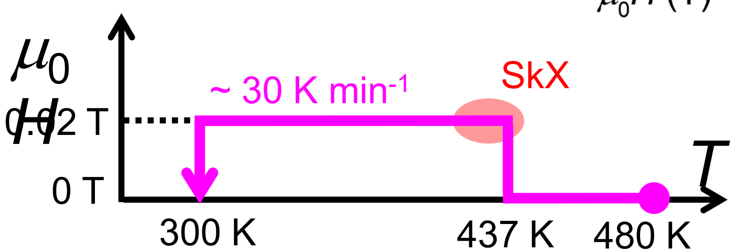
Open Q: Does a similar deformation take place in bulk samples?

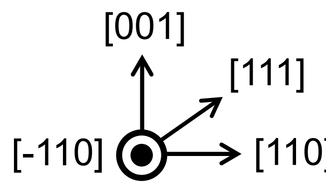
SANS measurement : Room-T zero-H SkX quenched at RIKEN

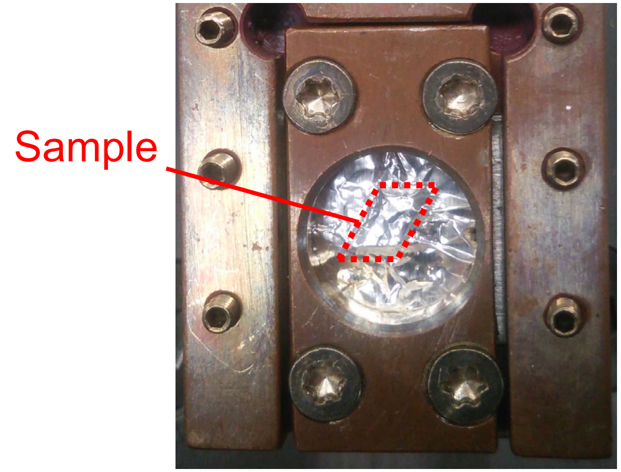


MPMS3 oven stick @ RIKEN



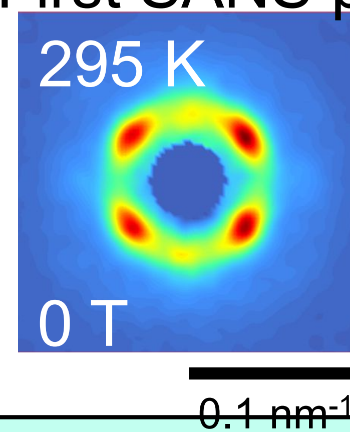


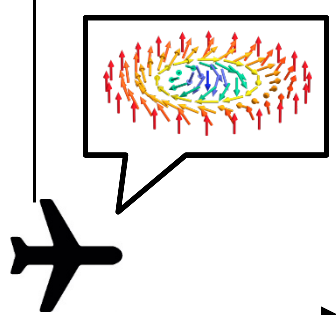




SANS oven stick @PSI

First SANS pattern



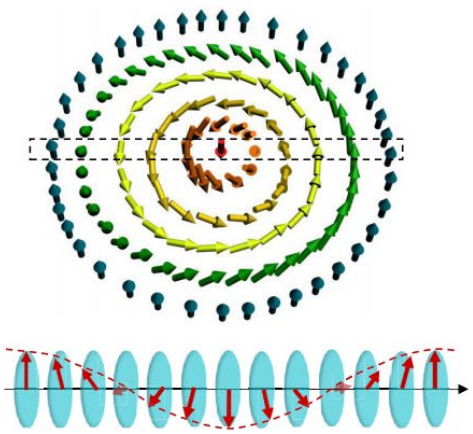


RIKEN (Japan) → PSI (Switzerland)

Travel of SkX !!!

Skyrmion types

Bloch-type

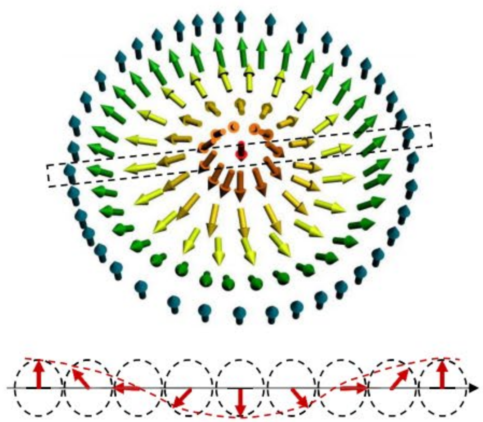


Chiral (not polar)

Cubic - P2$_1$3 - T
MnSi (2009)
FeGe (2010)
$Fe_{1-x}Co_xSi$ (2010)
Cu_2OSeO_3 (2012)

Cubic - P4$_1$32 - O
Co-Zn-Mn (2015)
$(Fe,Co)_2Mo_3N$ (2016)*

Néel-type



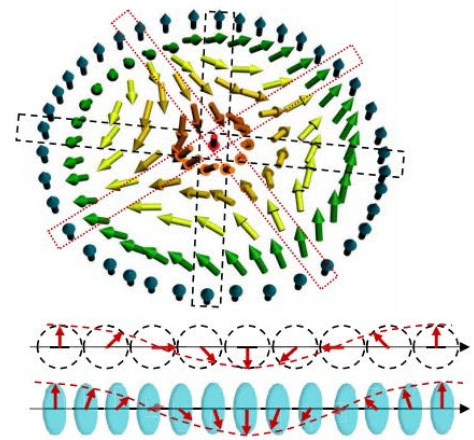
Polar (not chiral)

***Rhom. - R*3m - C_{3v}**
GaV_4S_8 (2015)
GaV_4Se_8 (2017)

***Tetr. - P4cc* - C_{4v}**
$VOSe_2O_5$ (2017)

PdFe on Ir(111)*
Ir/Co/Pt multilayers* …

'anti-skyrmion'



A.K. Nayak et al., Nature **548**, 561 (2017)

Neither chiral, nor polar
Tetr. - $I42\bar{m}$ - D_{2d}
$Mn_{1.4}Pt_{0.9}Pd_{0.1}Sn$ (2017)*

* **Not bulk** - Thin film/plates or multilayers

No inversion symmetry
→ Dzyaloshinskii-Moriya interactions

$$\int \vec{M} \cdot (\nabla \times \vec{M})$$

→ long-period twisted spin structures

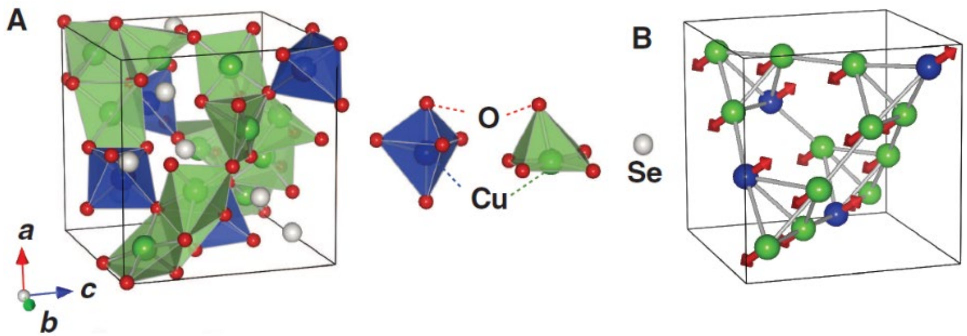
Outline

- Skyrmions and topology in magnetism
- Room temperature skyrmion host $Co_{10-x}Zn_{10-y}Mn_{x+y}$
  - Room temperature skyrmions
  - Meta-stability
  - “Square skyrmion” lattice
  - Skyrmions in zero field at room temperature

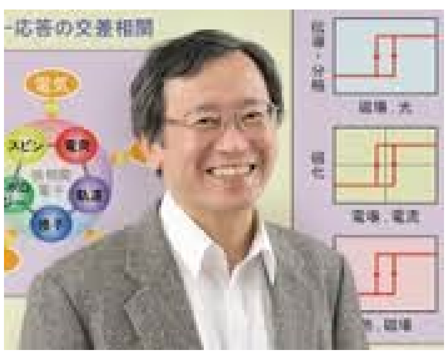
- Magnetoelectric skyrmion host Cu_2OSeO_3
  - E-field control of skyrmion phase
    - SANS
    - Theory
    - Direct observation (LTEM)
  - Lattice defects and melting, hexatic phase?

Skyrmion hosting insulator Cu_2OSeO_3

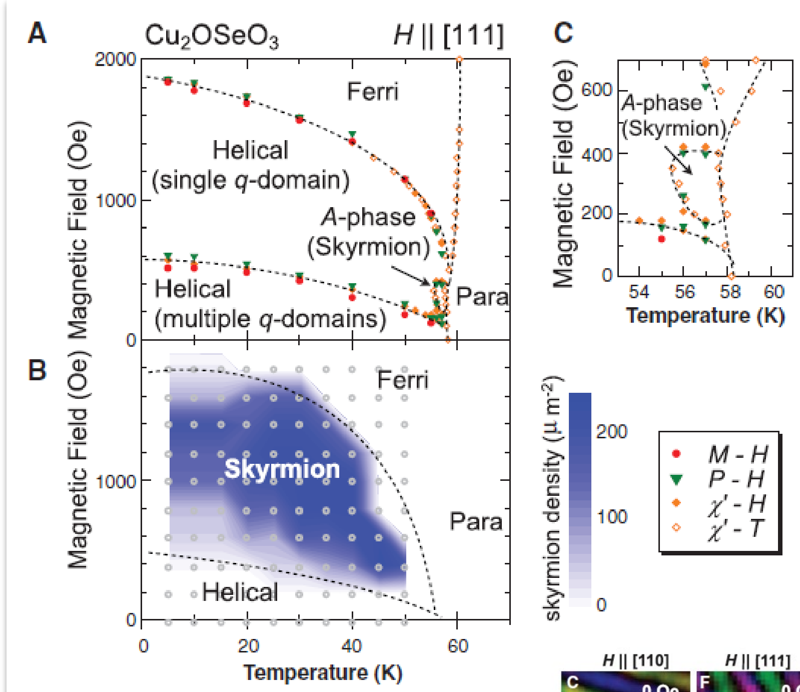
Crystal structure, $P2_13$, no inversion symmetry

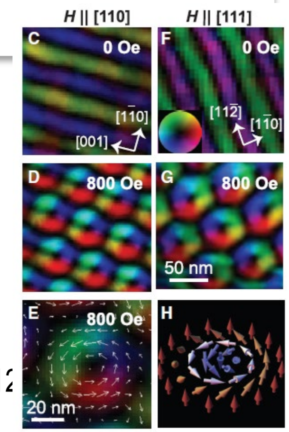


Cubic unit cell contain 16 Cu^{2+} S=1/2
4 tetrahedra forming “3-up-1-down” S=1
Total S=4 per unit cell
No inversion => net DMI per unit cell



‘Generic’ magnetic phase diagram + SkL phase





S. Seki *et al.*, Science **336,** 198 (2012)

S. Seki *et al.*, Phys. Rev. B **86,** 060403(R) (2012

Outline

- Skyrmions and topology in magnetism
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  - Meta-stability
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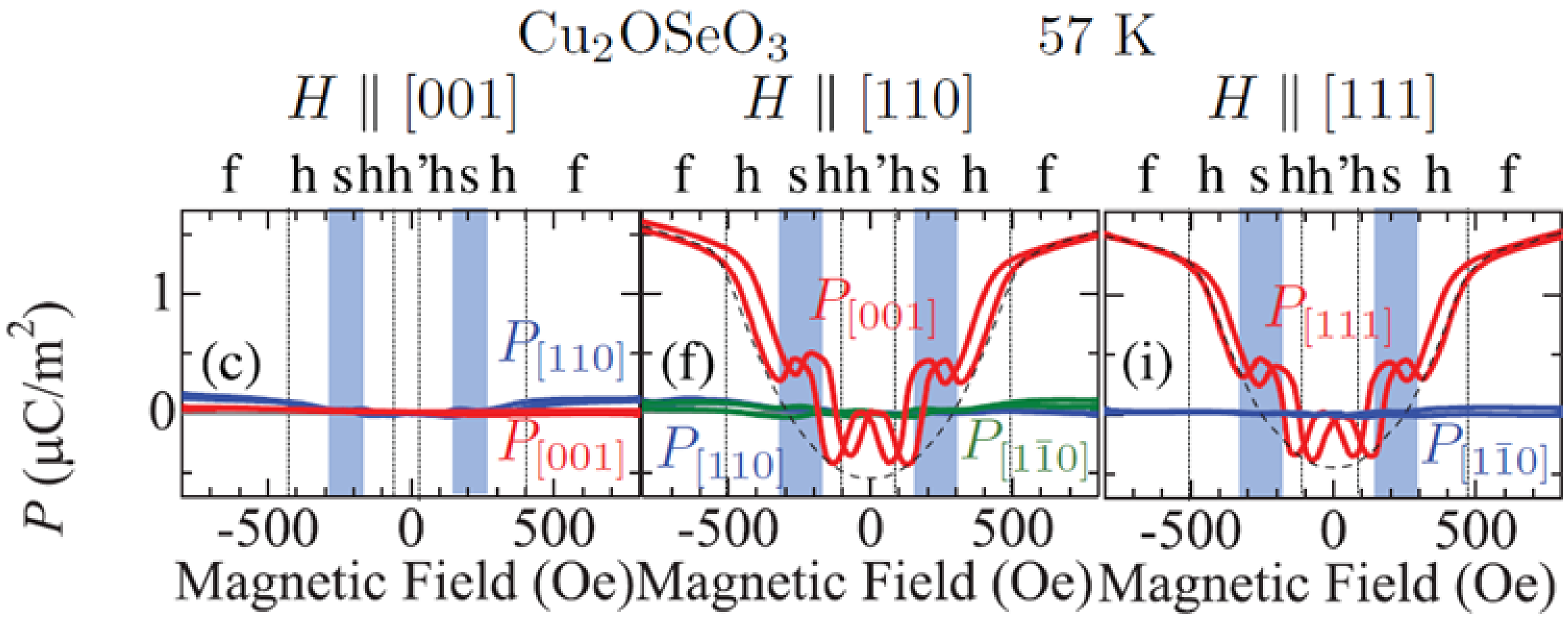
  - Skyrmions in zero field at room temperature

Magneto-electric Cu_2OSeO_3

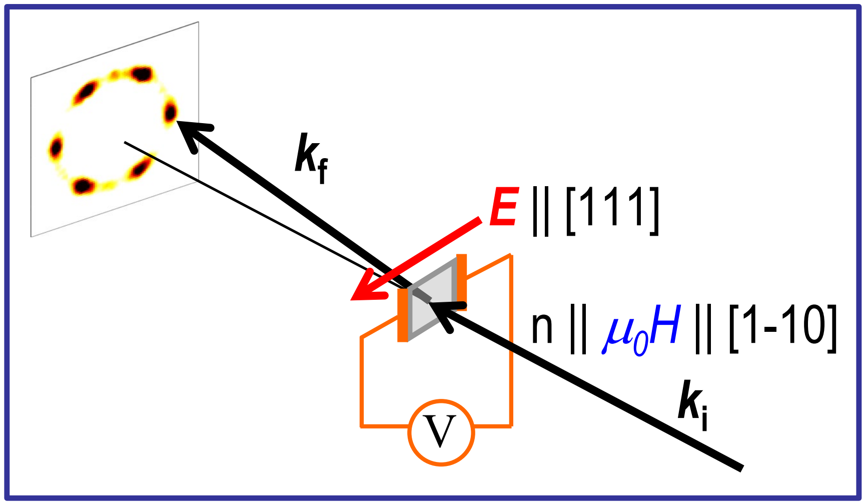


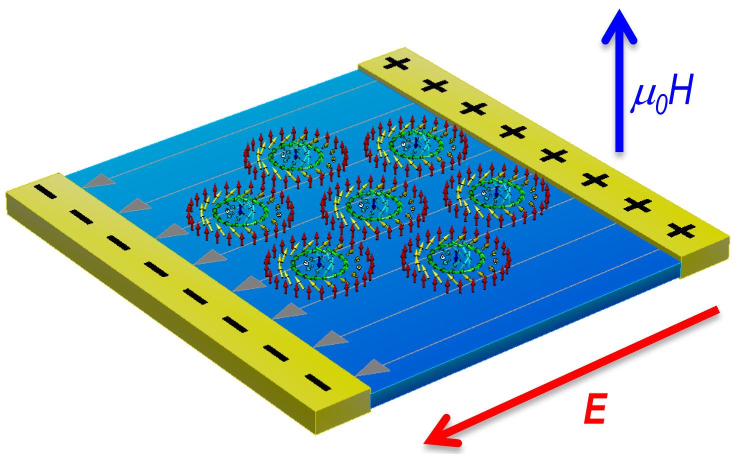
S. Seki *et al.*, Science **336,** 198 (2012)

Question – what is the *E*-field effect on the Skyrmion lattice in insulators?

Small Angle Neutron Scattering with E-field

Experiment Overview

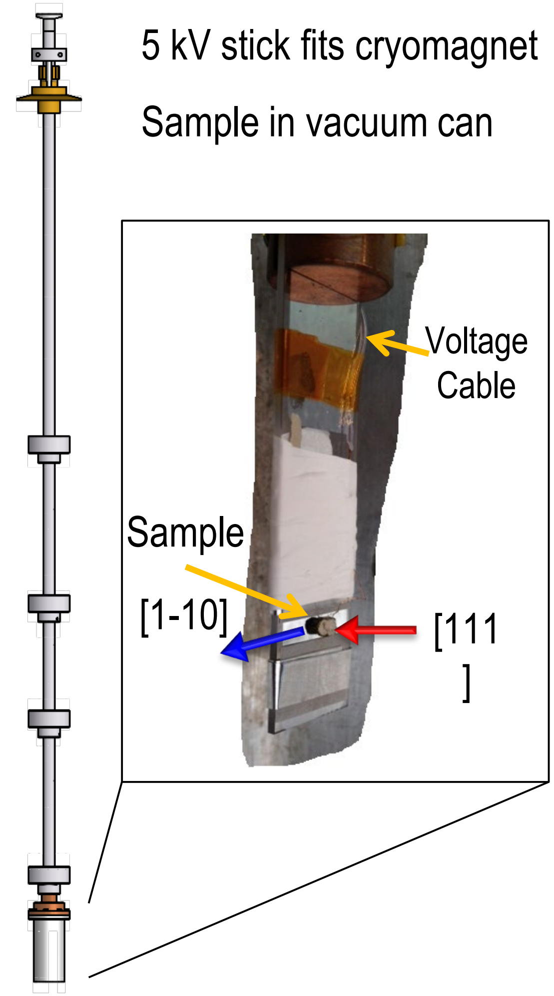




Sample Environment

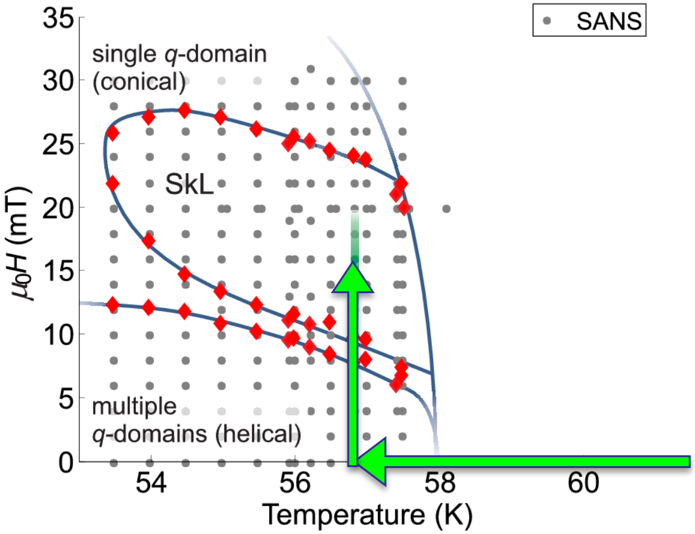
5 kV stick fits cryomagnet

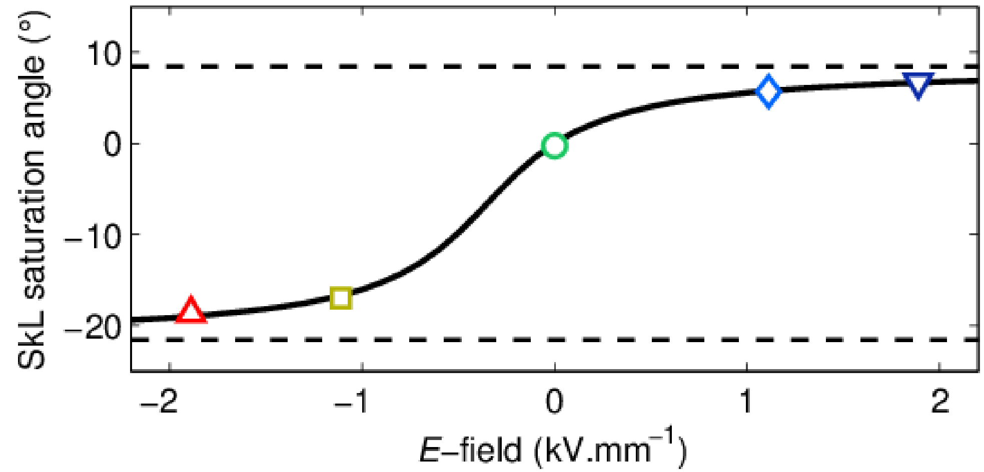
Sample in vacuum can

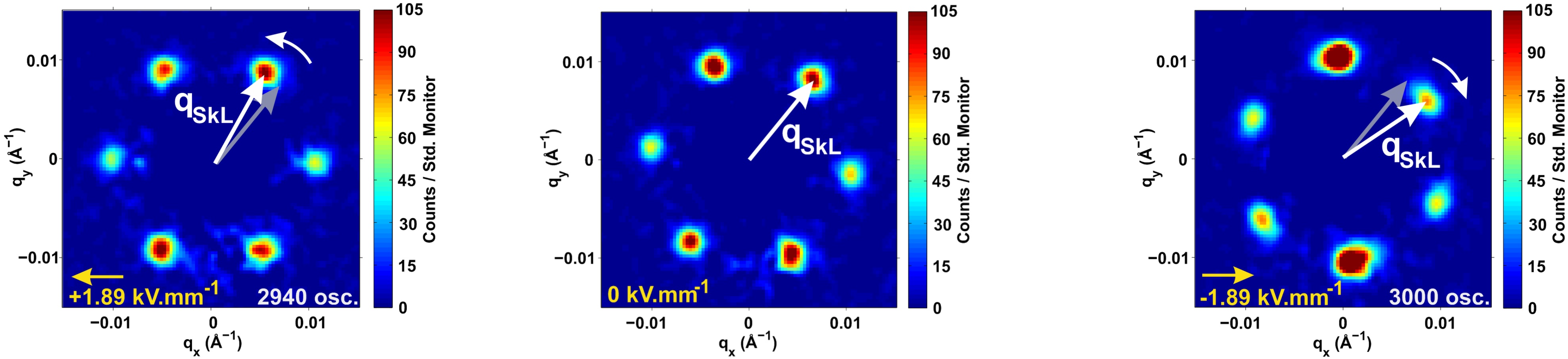


M. Bartkowiak *et al.*, Rev. Sci. Inst. **85**, 026112 (2014)

E-field rotates the skyrmion lattice







J. White *et al*, J. Phys. Cond. Mat **24,** 432201 (2012), PRL**113**, 107203 (2014)

Need perturbation treatment for E-field effect

***E*-field cants the magnetic moments to distort the helices**

$$\mathcal{H} = J(\nabla \mathbf{S})^2 + D\mathbf{S}\cdot(\nabla\times\mathbf{S}) - hS_z + \mathcal{H}_{PE} + \mathcal{H}_A^{(4)} + \mathcal{H}_A^{(6)}$$

First-order correction to the theory → treat the *E*-field as a perturbation.

Obtain the new groundstate under applied *E*-field:

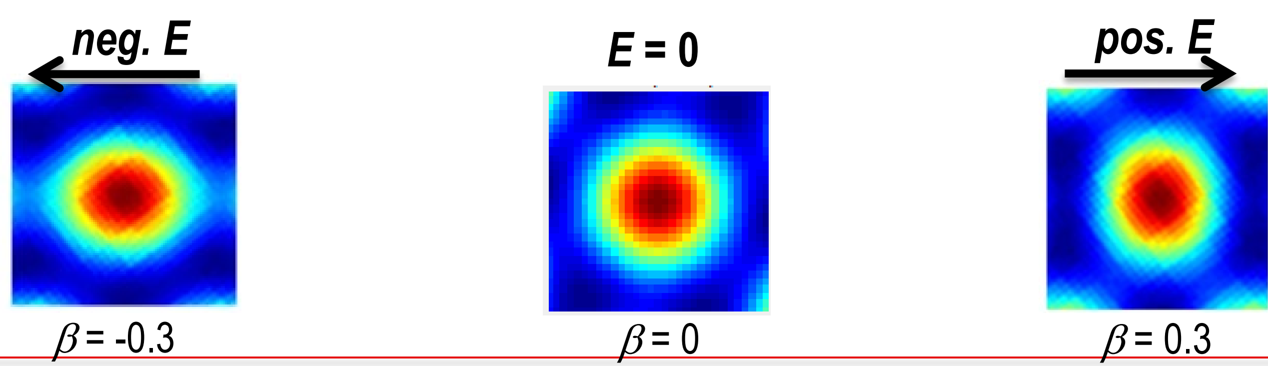
$$|n\rangle = |n^0\rangle + \sum_m \frac{|m^0\rangle\langle m^0|\mathcal{H}_{PE}|n^0\rangle}{\epsilon^{(n)} - \epsilon^{(m)}} \quad \Rightarrow \quad |0\rangle' = |0\rangle + \frac{|1\rangle\langle 1|\mathcal{H}_{PE}|0\rangle}{-Dq} + \frac{|2\rangle\langle 2|\mathcal{H}_{PE}|0\rangle}{-2Dq}$$

$$S^x(q) = -\frac{1}{\sqrt{2}} i\hat{q}_y - \frac{\alpha E}{4Dq_0} i\left(2\hat{q}_x^3 - \hat{q}_x\hat{q}_y^2 - \frac{3\sqrt{2}}{4}\hat{q}_x^2\hat{q}_y - \frac{\sqrt{2}}{2}\hat{q}_y\right)$$

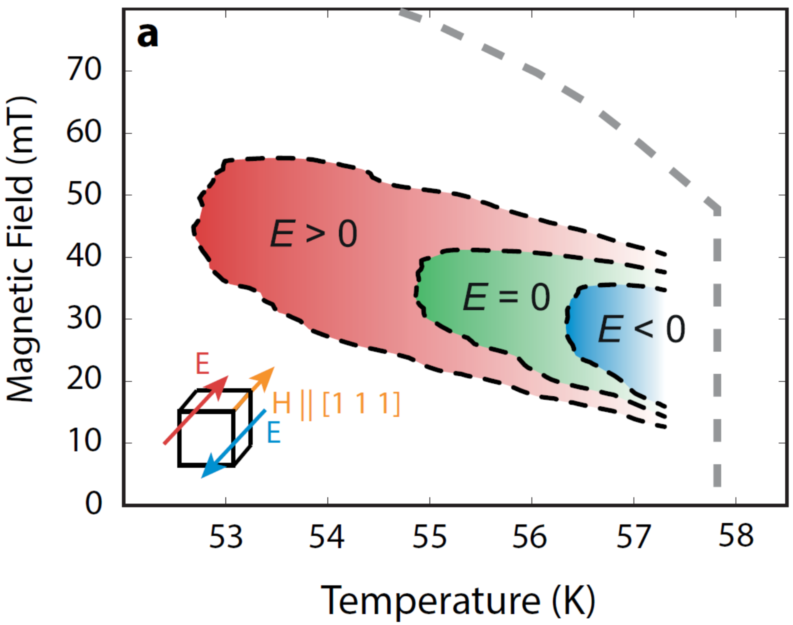
$$S^y(q) = \frac{1}{\sqrt{2}} i\hat{q}_x - \frac{\alpha E}{4Dq_0} i\left(-2\hat{q}_y^3 - \frac{3\sqrt{2}}{4}\hat{q}_x\hat{q}_y^2 + \hat{q}_x^2\hat{q}_y - \frac{\sqrt{2}}{4}\hat{q}_x\right)$$

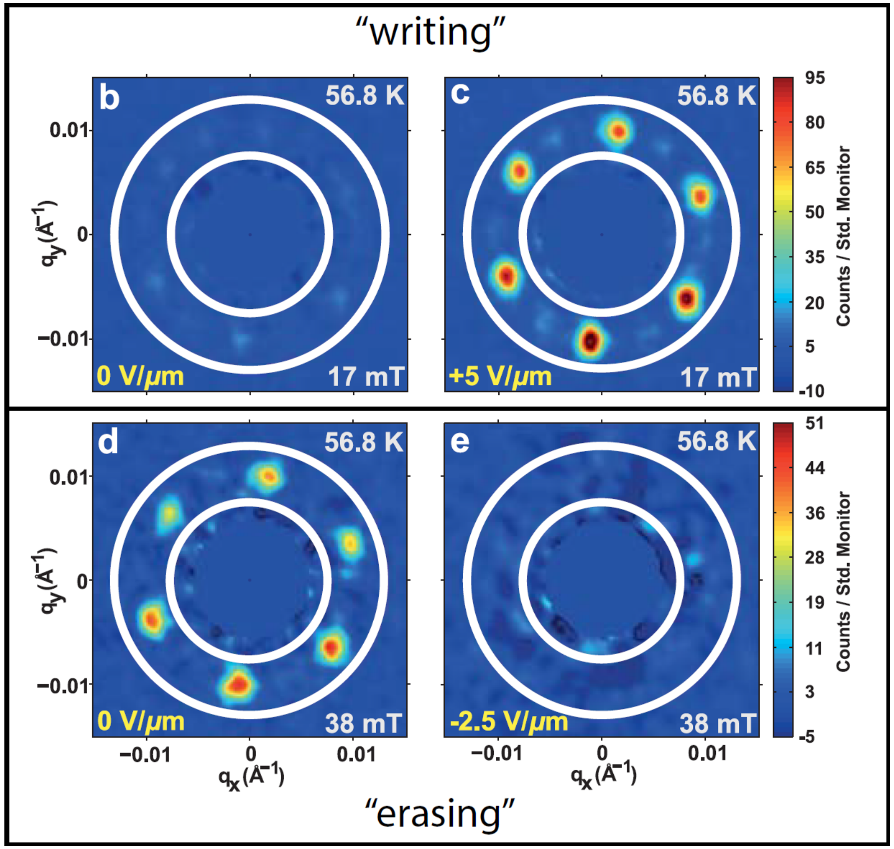
$$S^z(q) = \frac{1}{\sqrt{2}} - \frac{\alpha E}{4Dq_0} i\left(-\frac{\sqrt{2}}{4}\hat{q}_y^2 + \hat{q}_x\hat{q}_y - \frac{\sqrt{2}}{4}\right)$$

- The new groundstate includes **additional** helix components in finite ***E***.
- **The Skyrmion lattice is distorted by *E*.**



SANS: write and erase skyrmion lattice with E-field





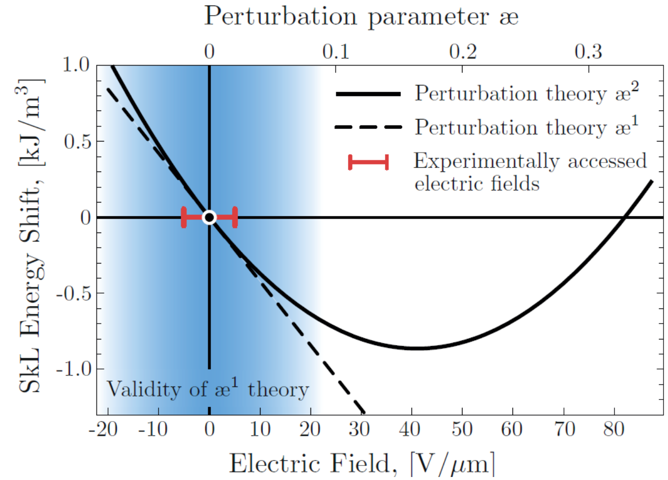
Theory of phase diagram with E-field

- 2^{nd} order perturbation theory

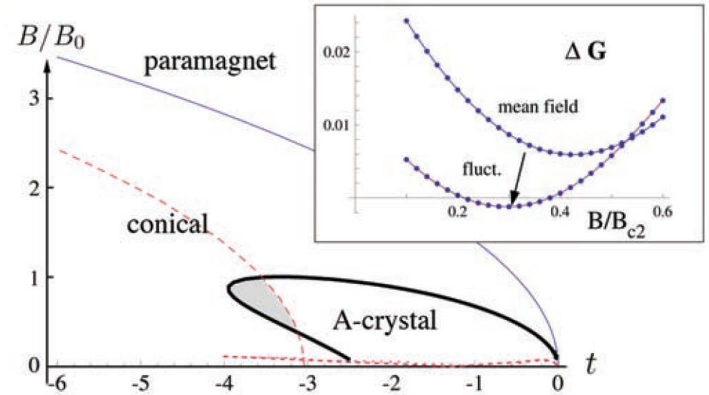
$$\Delta W_1(E) = -\frac{\alpha(2m^2+3\mu^2)M_s^2a^3}{4}E - \frac{189\,\alpha^2\mu^2M_s^2a^3}{64\,Dk_0}E^2, \quad (4.48)$$

$$\Delta W_2(E) = \frac{9\alpha\,A\mu^4M_s^2a^3}{32Dk_0}E\left[\frac{11}{4} - 3\sqrt{2}\frac{\mu}{m} + \frac{\mu^2}{m^2} + \frac{9}{8}(\cos 6\phi_0 + 2\sqrt{2}\sin 6\phi_0)\right], \quad (4.49)$$

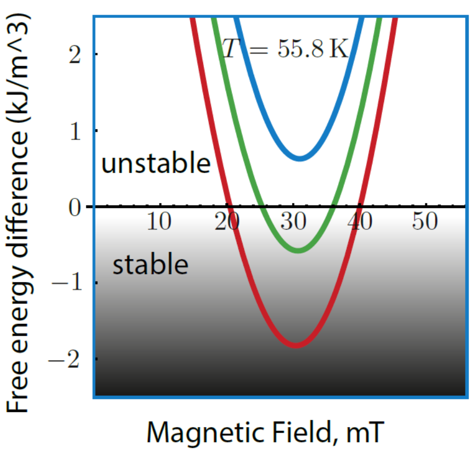
$$\Delta W_3(E) = \frac{27\alpha^2A\mu^4M_s^2a^3}{1024\,D^2k_0^2}E^2 \times \left(f_0 + f_1\cos 6\phi_0 + f_2\sin 6\phi_0\right). \quad (4.50)$$

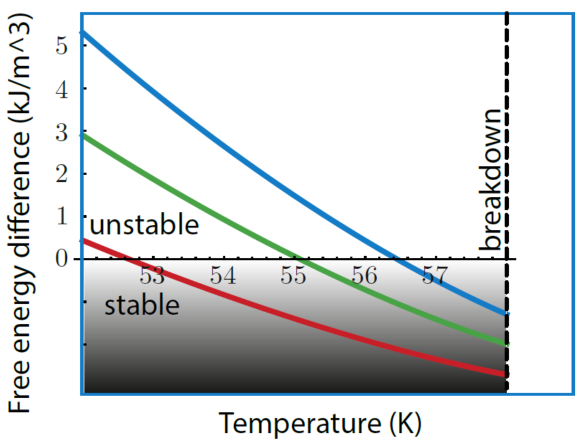


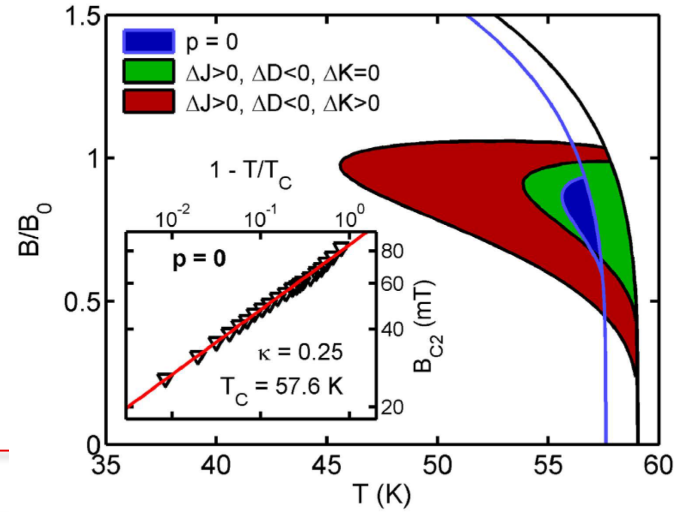
- Landau-Ginzburg approach with improved treatment of Gaussian fluctuations



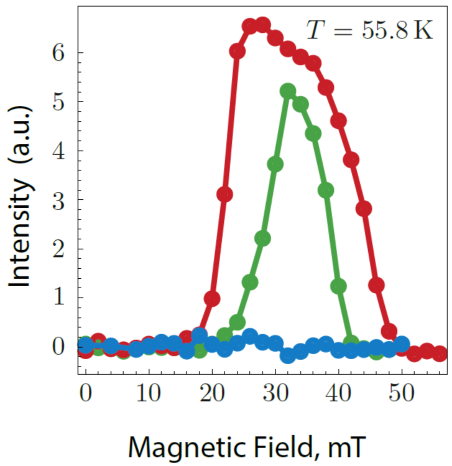
- Use experimental Hc(T) to place Landau-Ginzburg phase diagram on absolute T-scale:

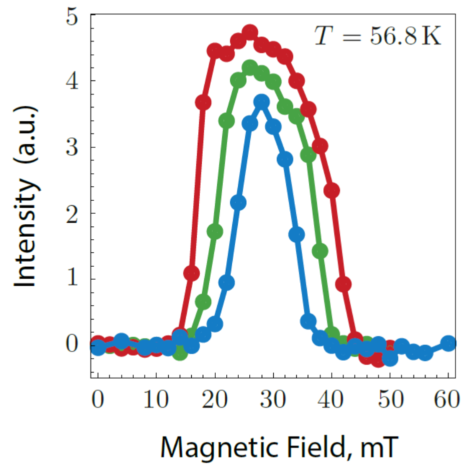


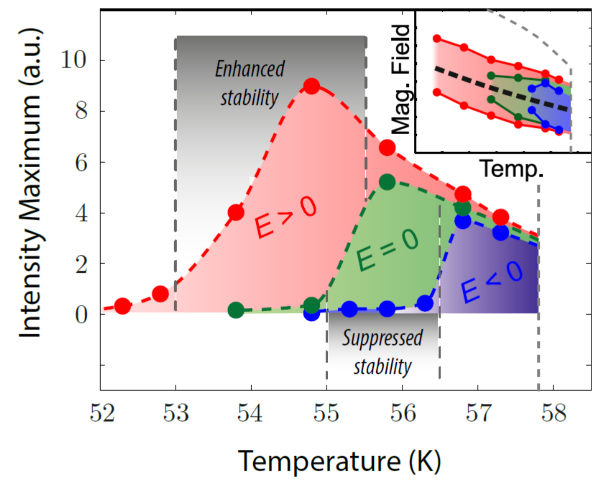


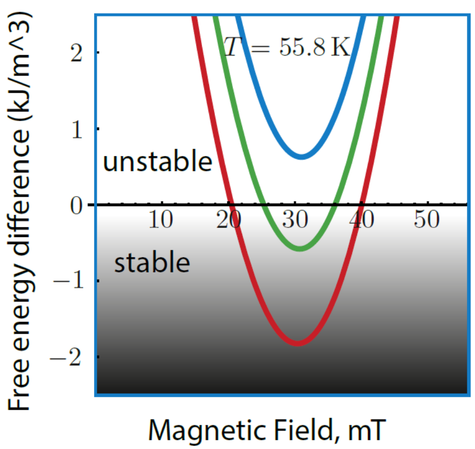


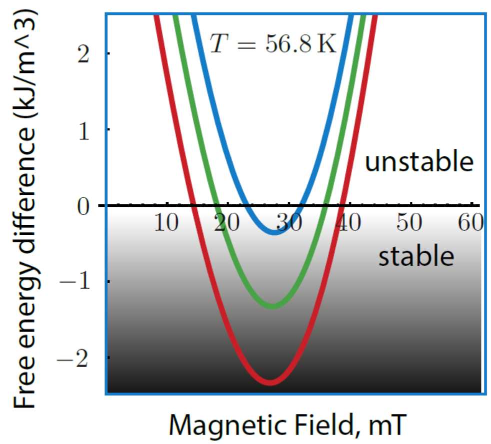
Good agreement with experiment

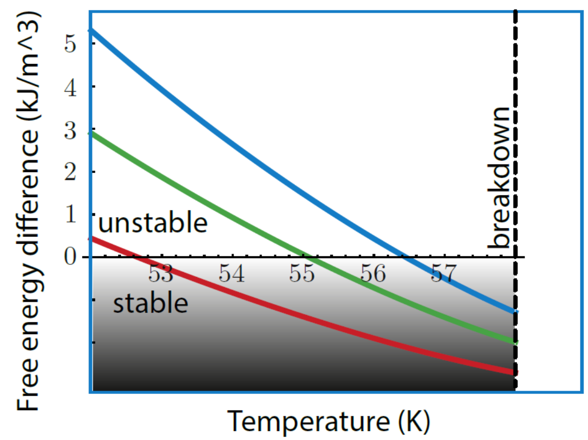








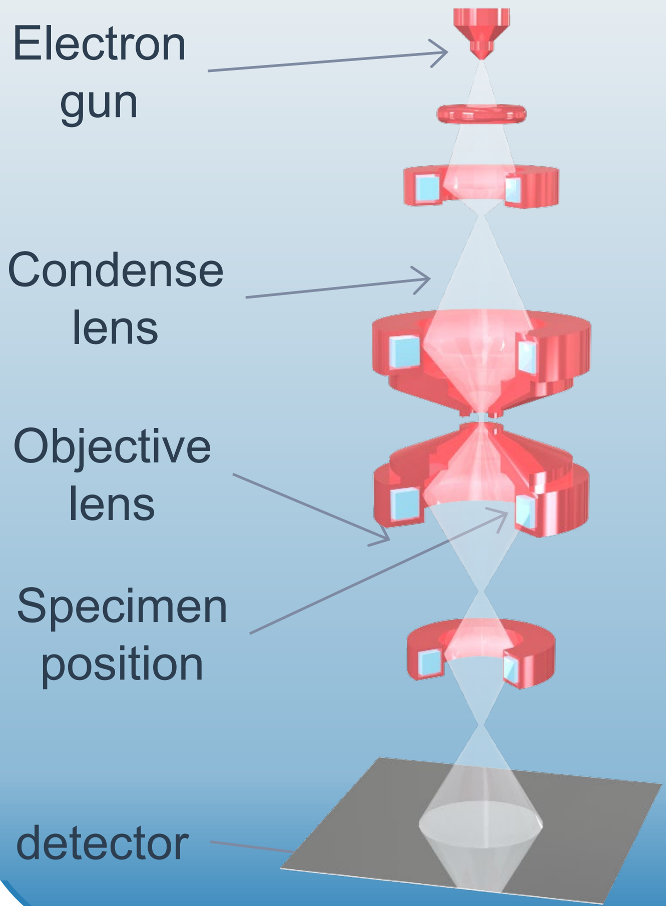




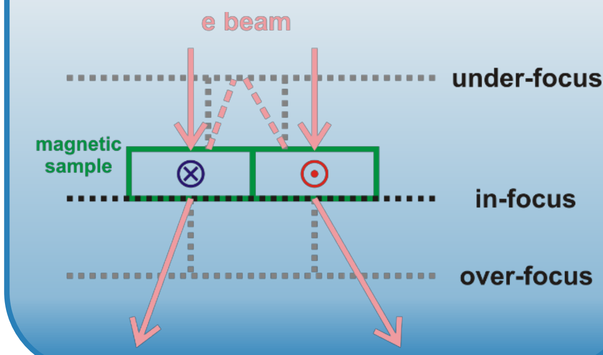
A. Kruchkov et al Sci Rep 8 10466 (2018); White et al PRApp 10, 014021 (2018)

Introduction to Lorenz Transmission Electron Microscopy (LTEM)

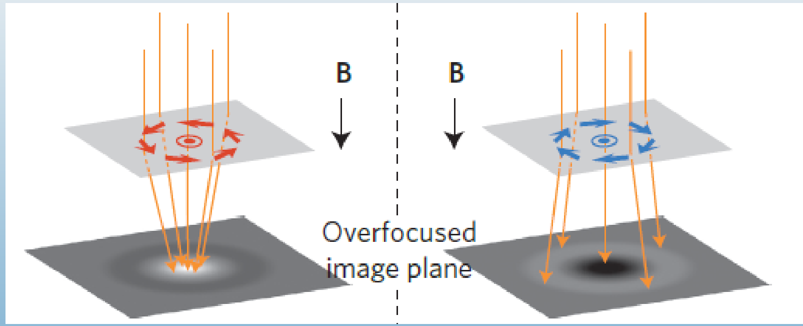
Optics of TEM



Principle of LTEM



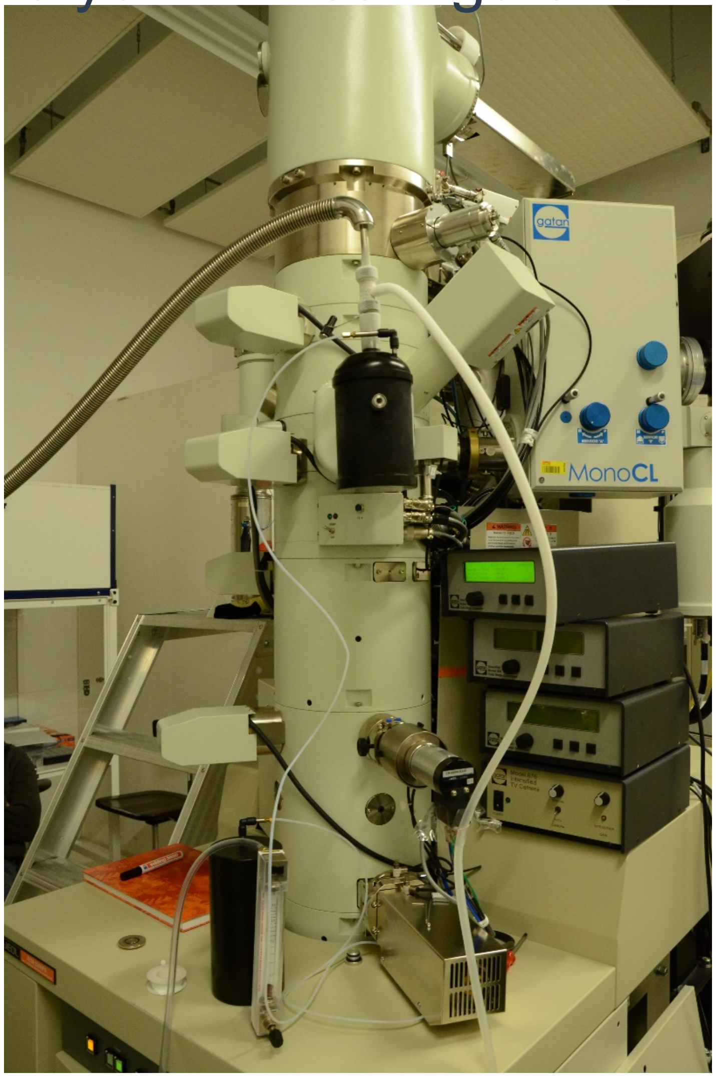
Defocus: Fresnel mode



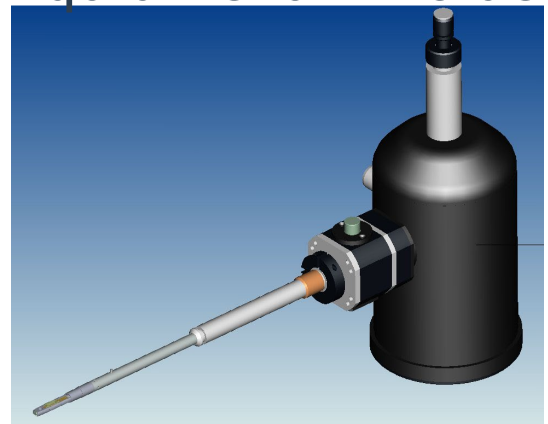
K. Shibada *et al*. Nat. Nanotech. 2013

LTEM experiments

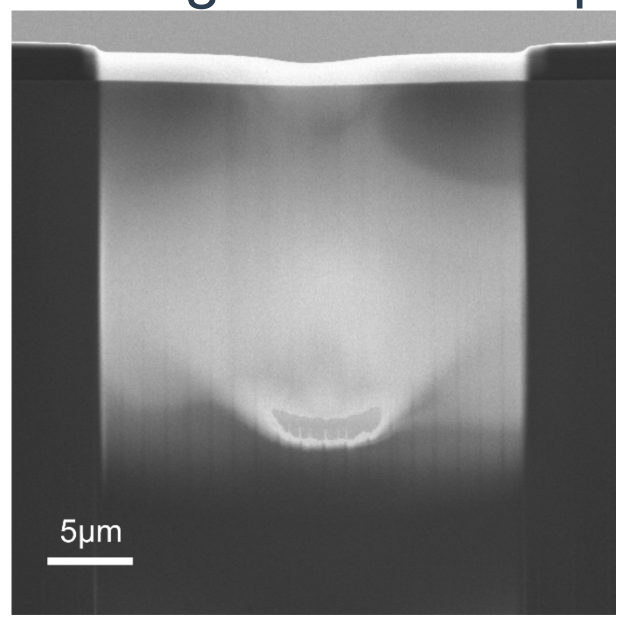
cryo-TEM configuration



Liquid helium holder

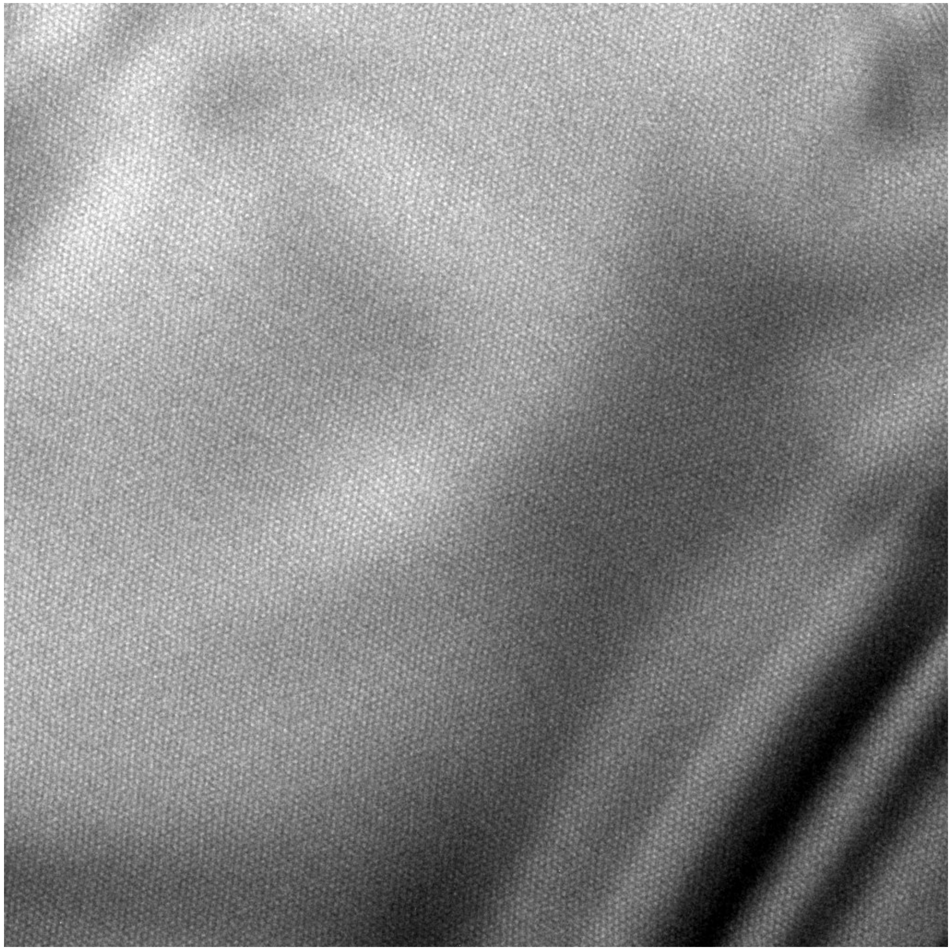


SEM image of the sample region



Cu_2OSeO_3: Lorentz microscopy

- Large sample ⇒ 100000 skyrmions resolved
- Allows quantitative analyses, such as delauney triangulation



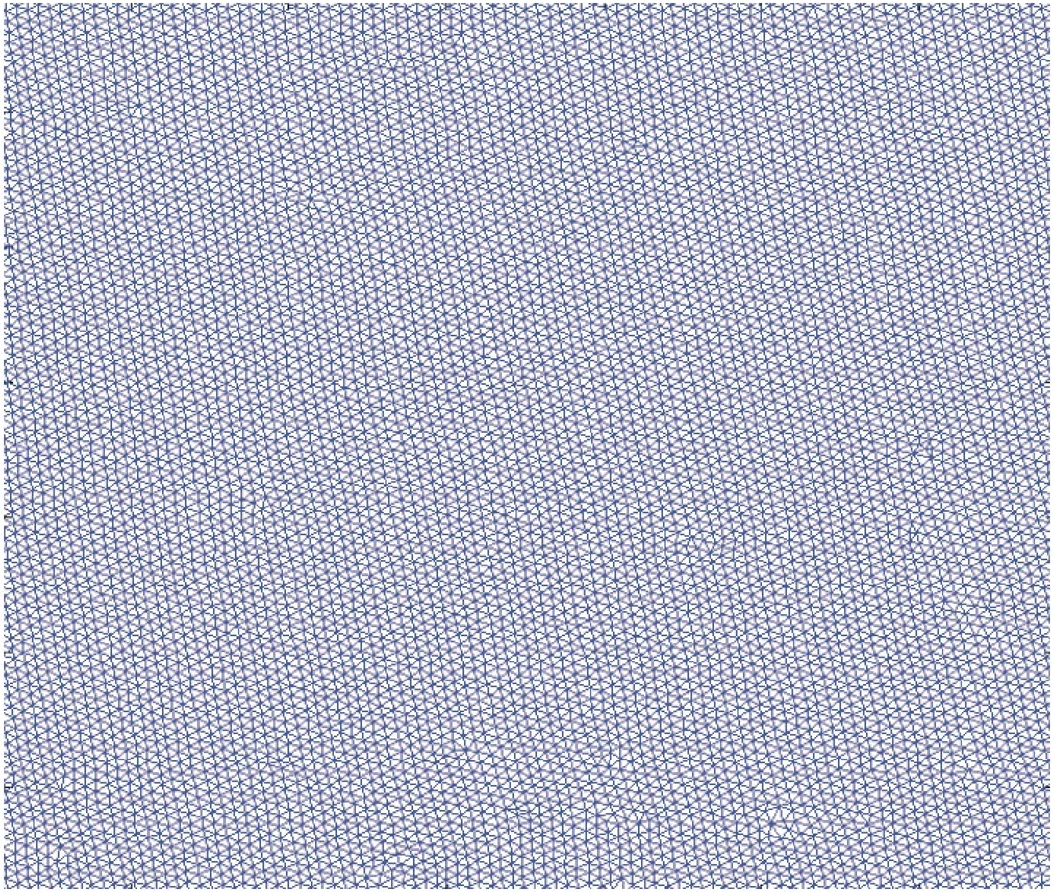
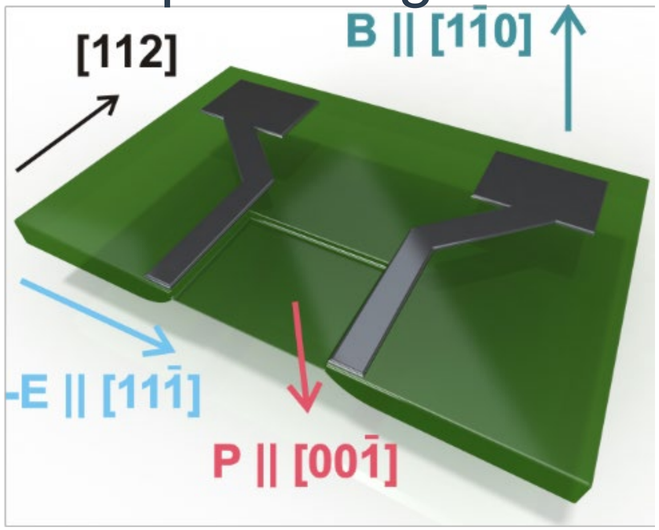


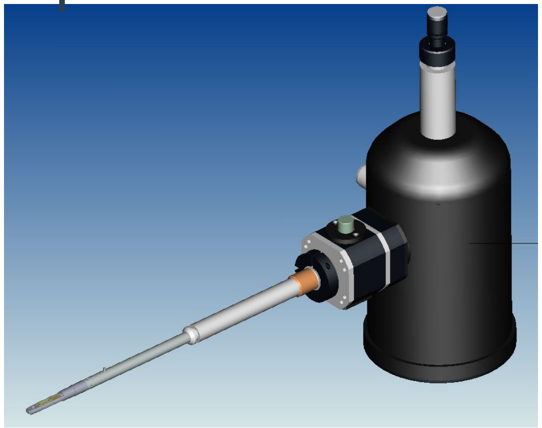
Fig. S4: 7.3x7.3 μm^2 real space image of the skyrmions position at B=192 G obtained by Delauney triangulation.

Magnetic contrast Lorentz transmission electron microscopy with in-situ electric fields

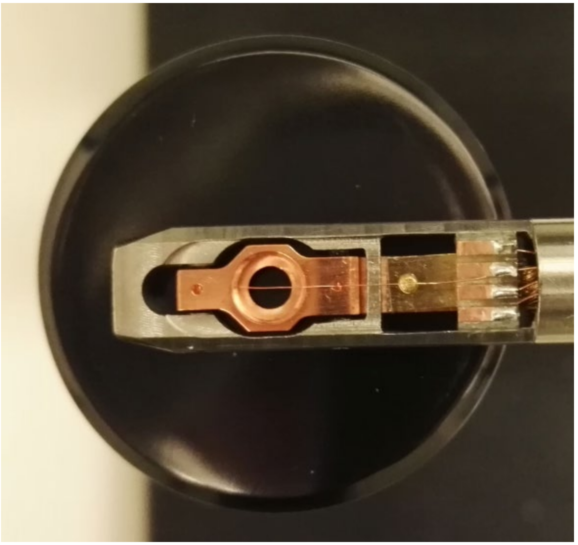
Sample configuration



Liquid helium holder

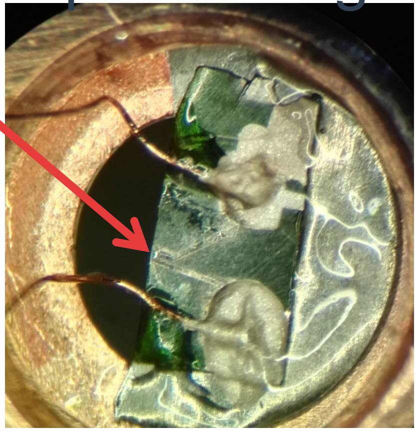


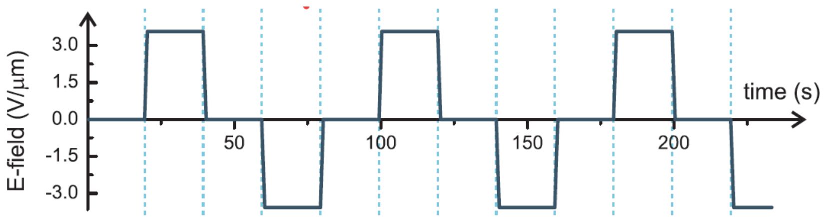
electric connections



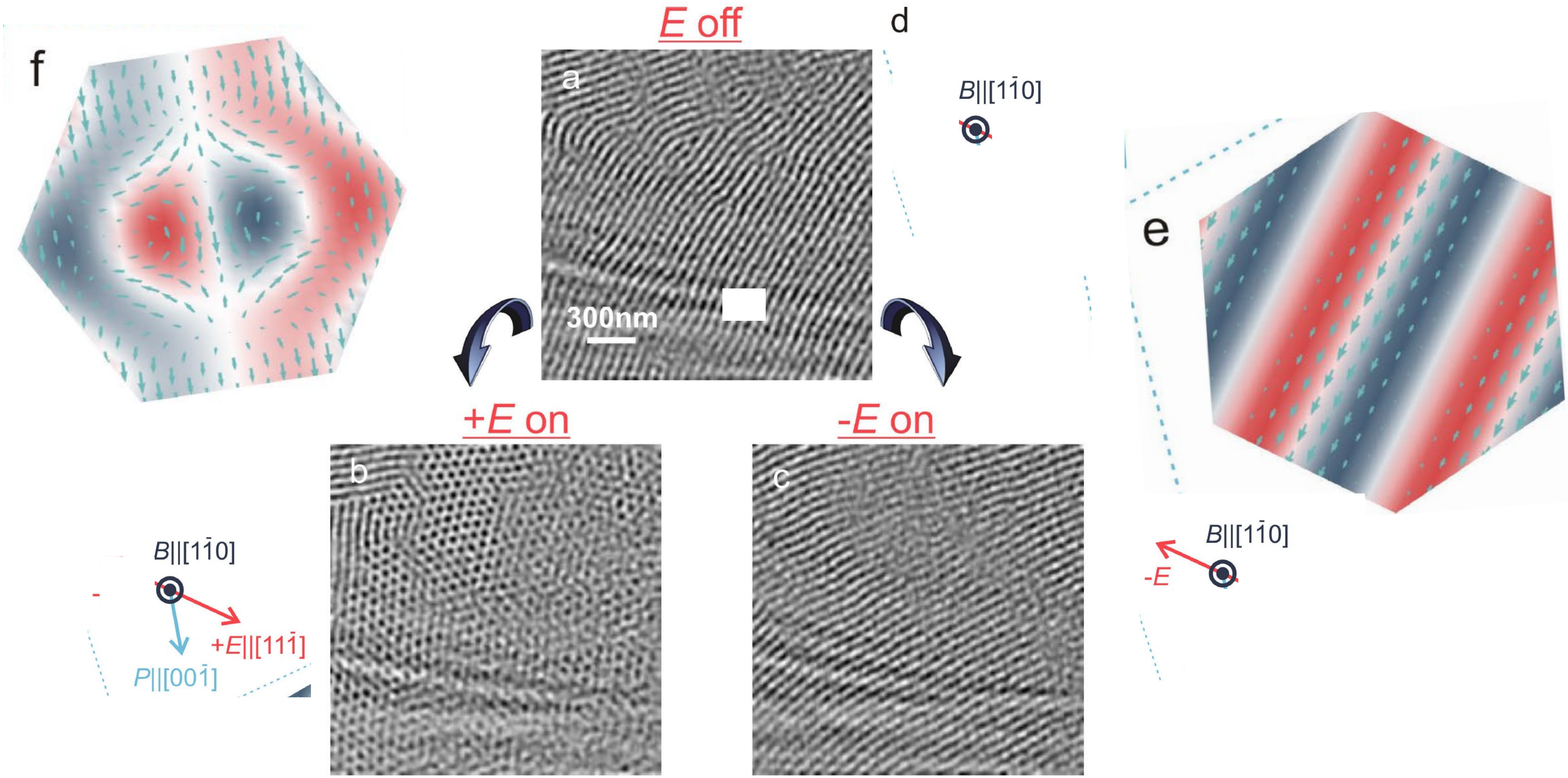
nano-slab region

Optical image





Positive E-field creates skyrmions



ΔEnergy = -P·E

Counting skyrmions in mixed phase

Previous algorithm gets confused

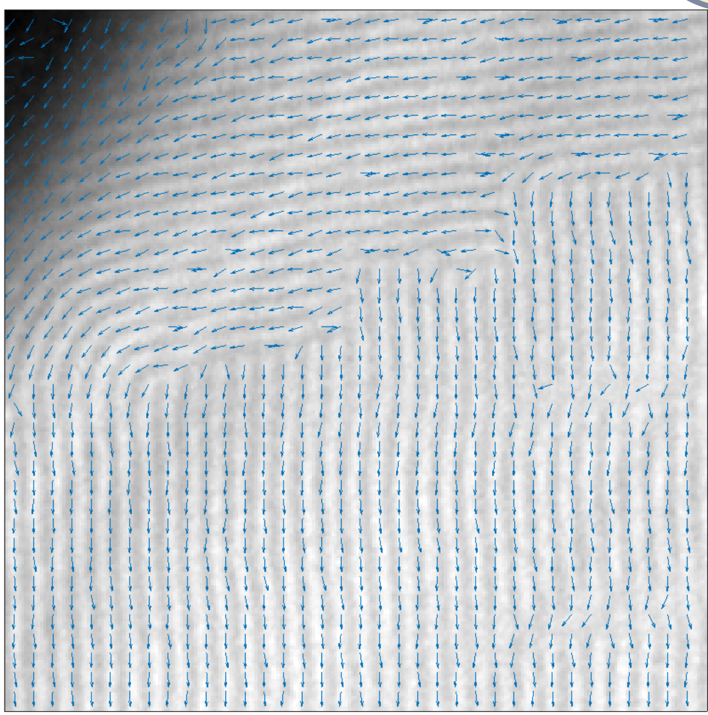
Use orientational map
Inspired by finger-print algorithms

Rau & Schunck 1989

$$V_x(u,v) = \sum_{i=u-\frac{w}{2}}^{u+\frac{w}{2}} \sum_{j=v-\frac{w}{2}}^{v+\frac{w}{2}} 2\partial_x(i,j)\,\partial_y(i,j)$$

$$V_y(u,v) = \sum_{i=u-\frac{w}{2}}^{u+\frac{w}{2}} \sum_{j=v-\frac{w}{2}}^{v+\frac{w}{2}} \left(\partial_x^2(i,j)\partial_y^2(i,j)\right)$$

$$\theta(u,v) = \frac{1}{2}\tan^{-1}\left(\frac{V_y(u,v)}{V_x(u,v)}\right)$$



Inspect frame by hand (worst case)

Skyrmion counts:

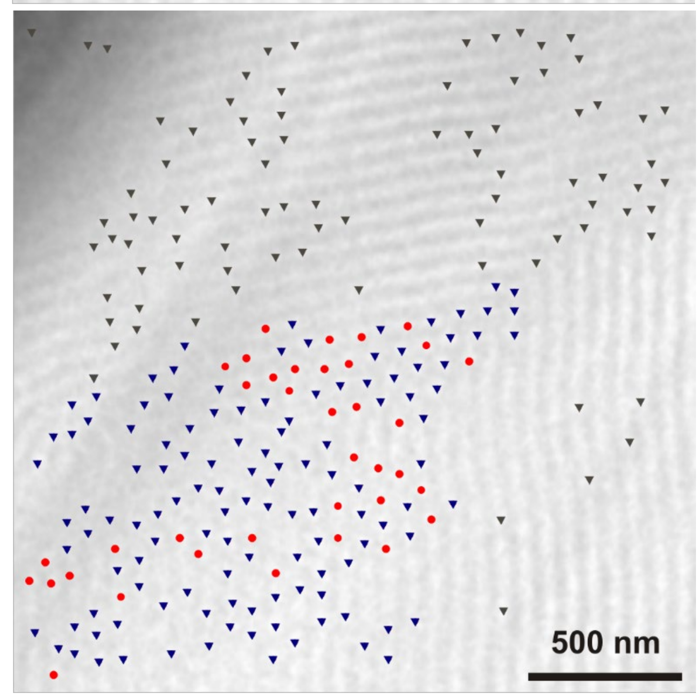
Hand inspection 90

Algorithm: 132

Missed: 37

Extra: 79

So we count skyrmions with an offset



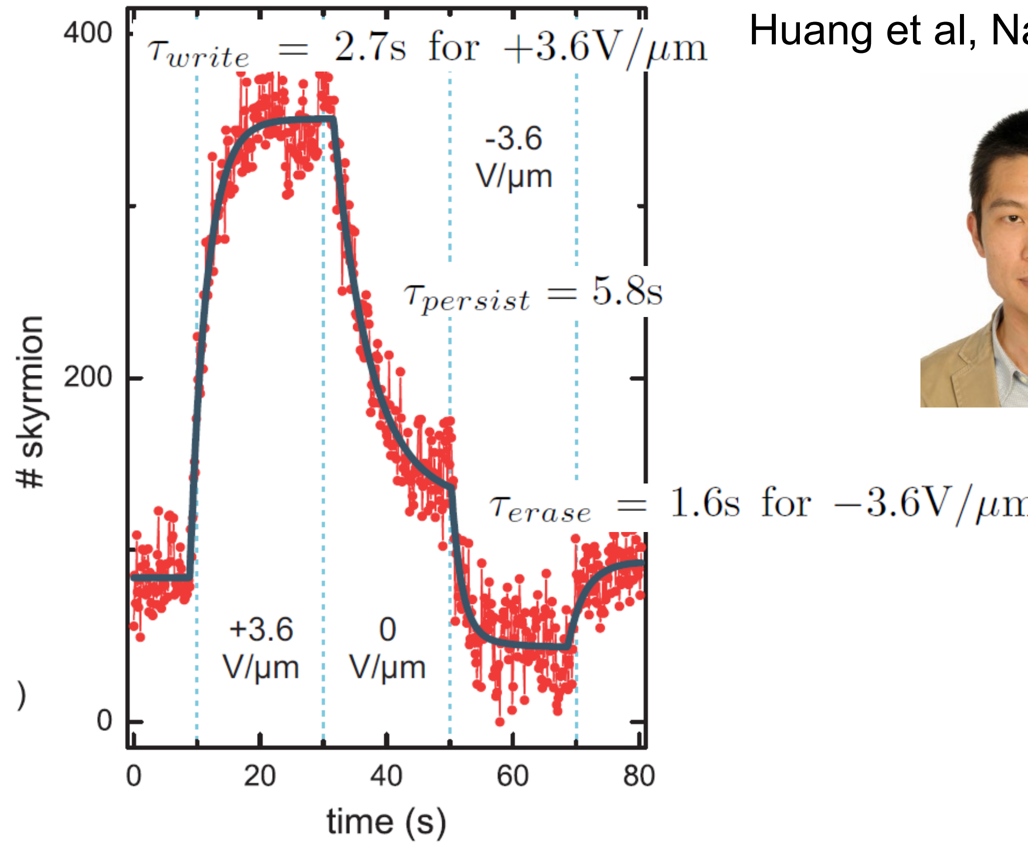
Persistence?

Exponential

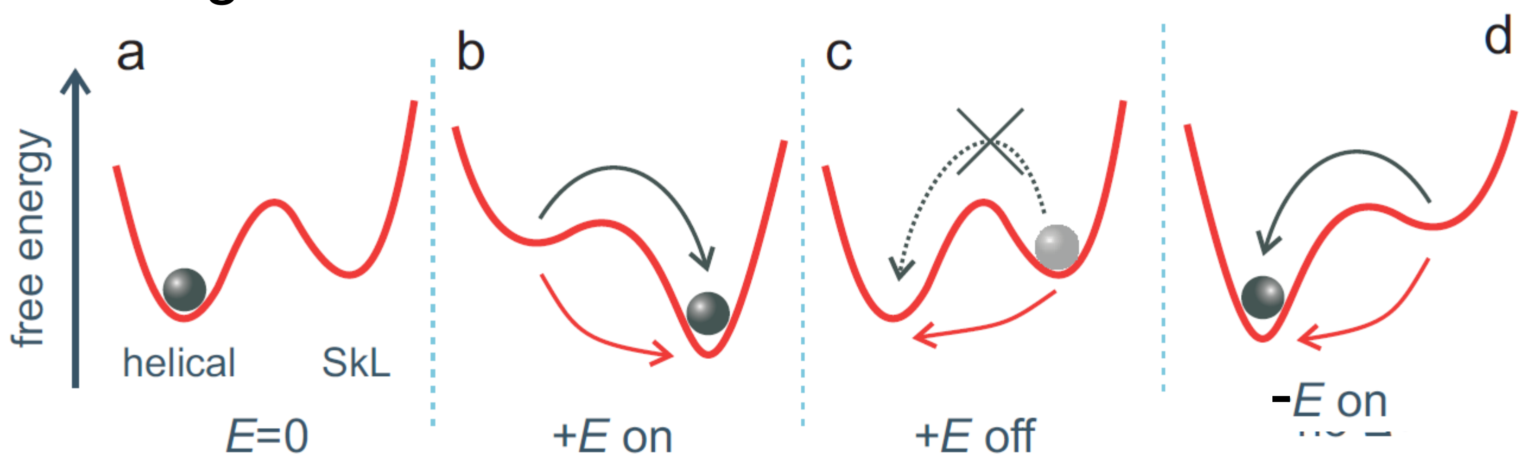
- Write/erase "fast"
- Persist "slow"

True persistence seen in bulk SANS and χ

Room for tuning



Huang et al, Nano Letter *in press*

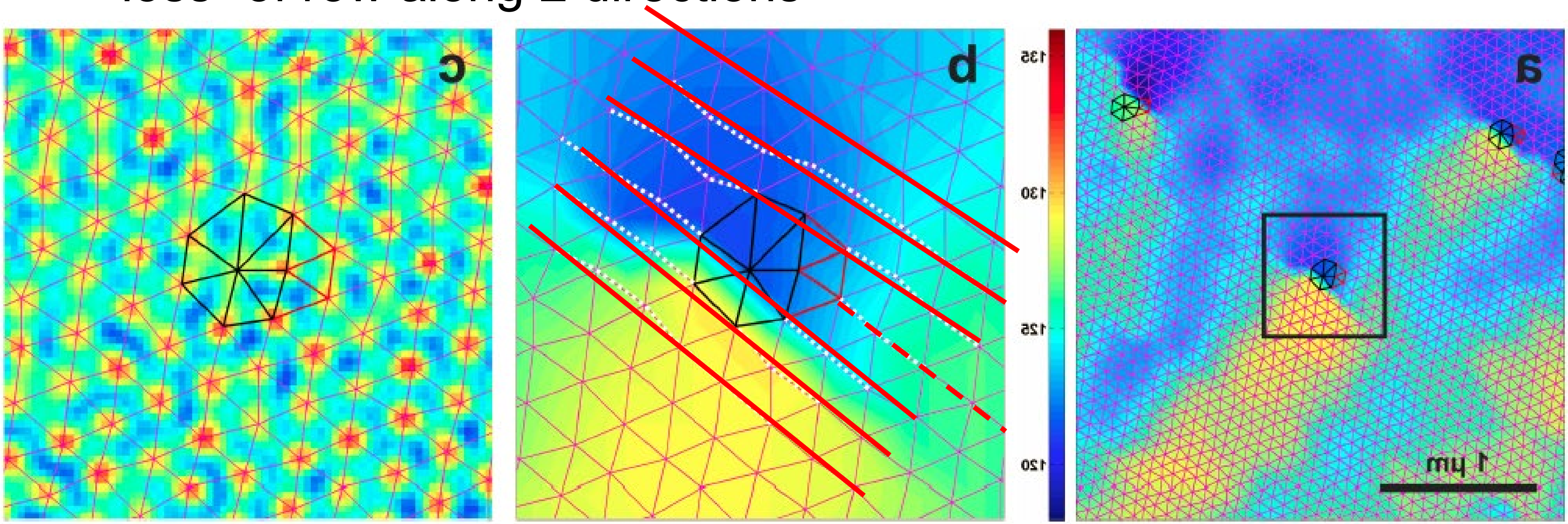


Outline

- Magnetoelectric skyrmion host Cu_2OSeO_3
  - Scaling behaviour
  - E-field control of skyrmion phase
    - SANS
    - Theory
    - Direct observation (LTEM)
  - Lattice defects and melting, hexatic phase?
- Room temperature skyrmion host $Co_{10-x}Zn_{10-y}Mn_{x+y}$
  - Room temperature skyrmions
  - Meta-stability
  - "Square skyrmion" lattice
  - Skyrmions in zero field at room temperature

Defects and angles

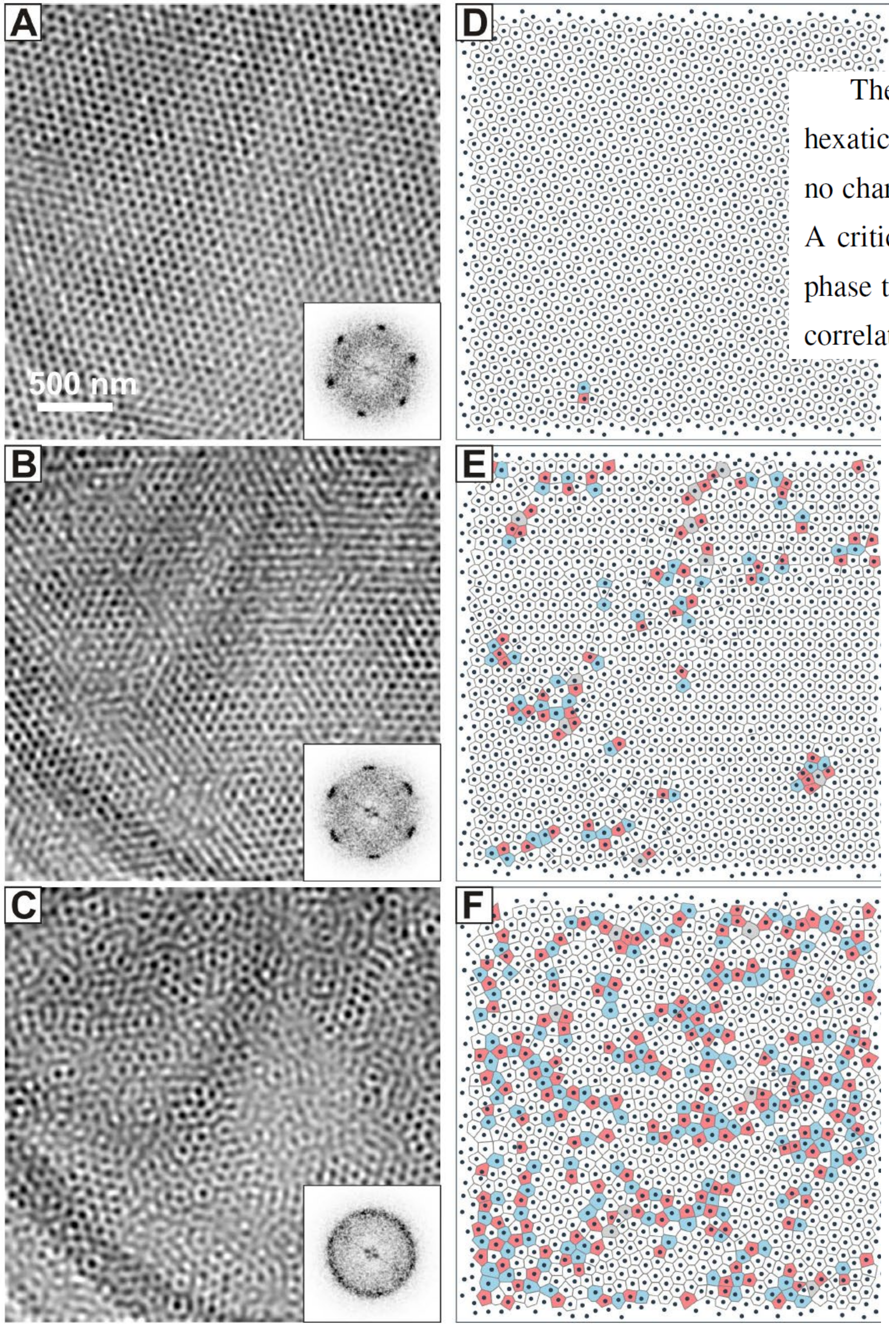
- Defects classifiable – eg a 5-7 or a 5-8-5 defect
  - “loss” of row along 2 directions

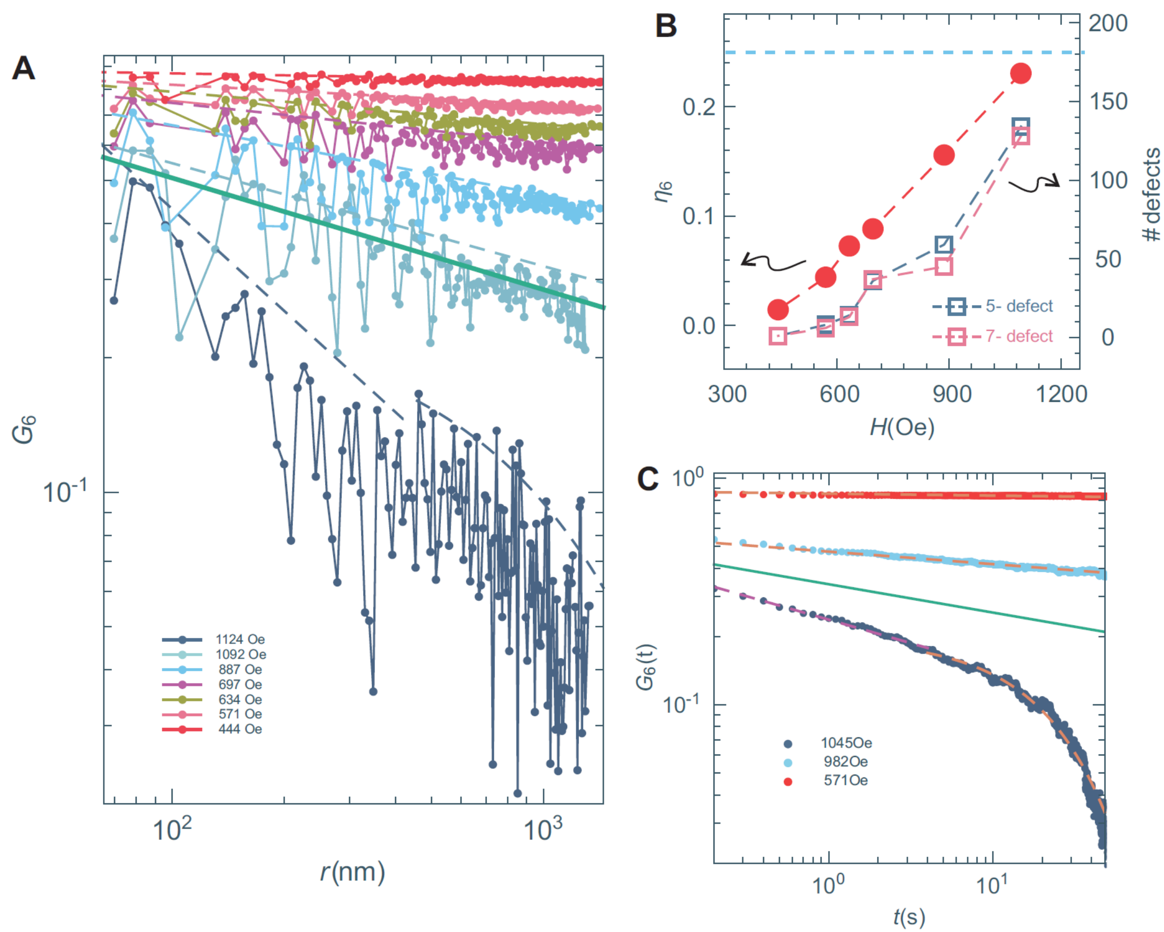


Map SkL angle: $\Psi_6(r_i) = \frac{1}{N_N^i} \sum_k^{N_N^i} e^{i6\theta(r_{ik})}$ or peak in “local Fourrier”

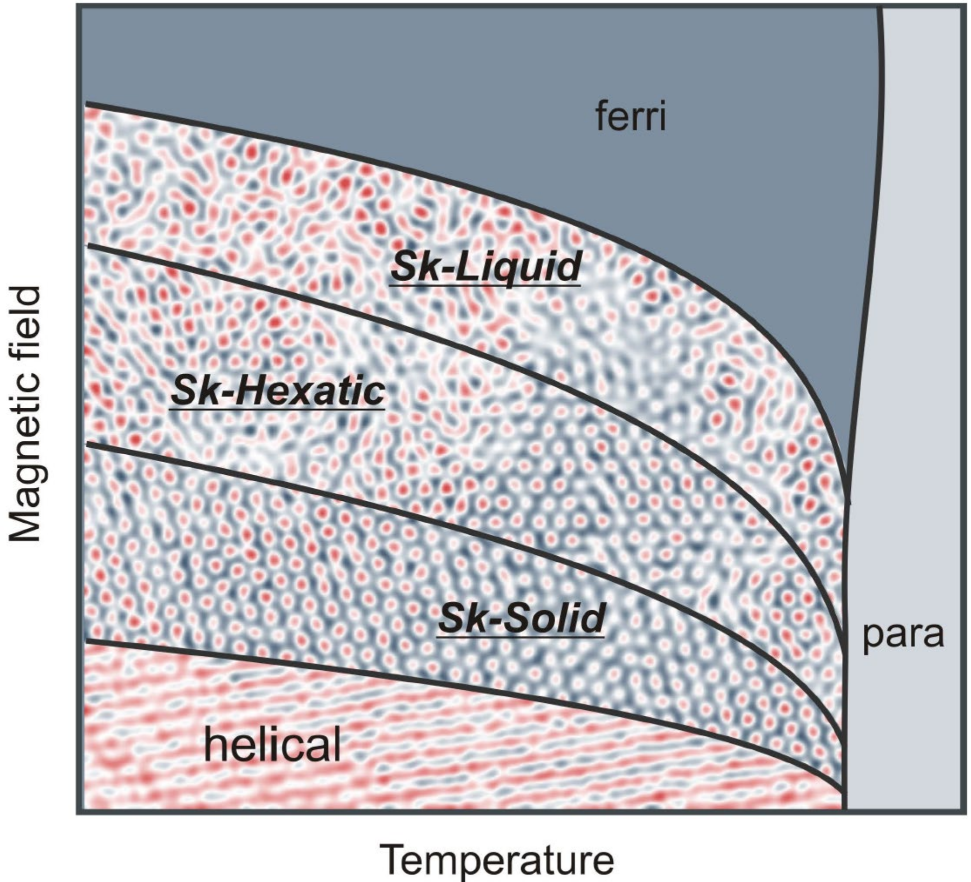
  - Defects creates far-stretching rotations

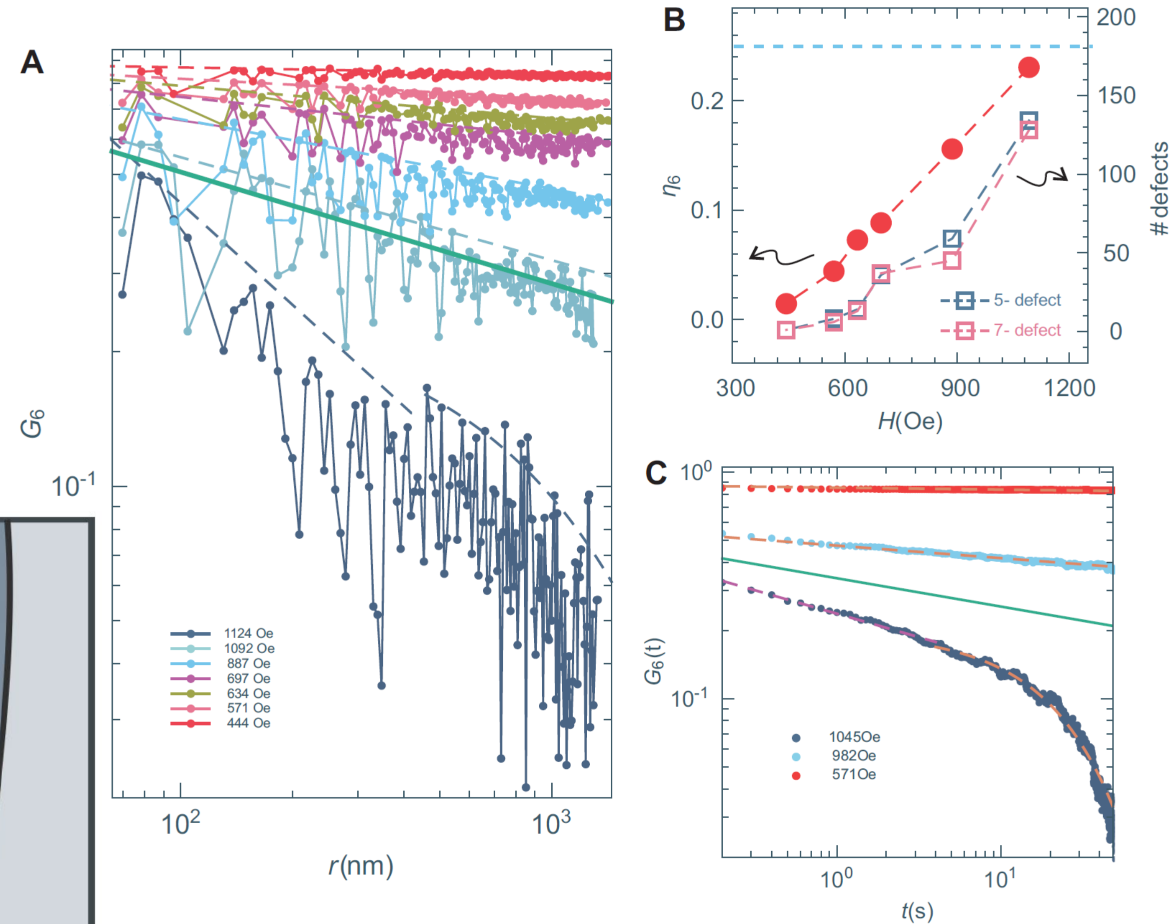
The KTHNY theory predicts a constant $G_6(r)$ close to 1 in the solid phase. When entering the hexatic phase, $G_6(r)$ should decay algebraically $G_6(r) \propto r^{-\eta_6}$. The algebraic decay is slow and there is no characteristic length scale, thus the hexatic phase shows quasi-long range orientational correlations. A critical value of $\eta_6 \to 1/4$ is predicted by the KTHNY theory approaching the hexatic to liquid phase transition. In the liquid phase, exponential decay $G_6(r) \propto e^{-r/\xi_6}$, where ξ_6 is the orientational correlation length, is expected.





Hexatic and liquid skyrmion phases





Outline

- Topology and its limitations
- Magnetoelectric skyrmion host Cu_2OSeO_3
  - Scaling behaviour
  - E-field control of skyrmion phase
    - SANS
    - Theory
    - Direct observation (LTEM)
  - Lattice defects and melting, hexatic phase?
- Room temperature skyrmion host $Co_{10-x}Zn_{10-y}Mn_{x+y}$
  - Room temperature skyrmions
  - Meta-stability
  - "Square skyrmion" lattice
  - Skyrmions in zero field at room temperature

- Skyrmions are fun !

Opportunities at EPFL Institute of Physics:

~~1 Professorship Condensed Matter Physics (expt)~~
~~2 Professorships QST (expt+theory)~~

https://professeurs.epfl.ch/page-158250-en.html

1 Postdoc position	Neutron spectroscopy
~~1 Instrument scientist position~~	~~(CAMEA)~~
2 Postdoc positions	Coupled order and dynamics
2 PhD positions	(ERC SyG HERO)

Fellowships from PhD, Pdoc to Indep. Group Leader