The A-phase in MnSi

in light of neutron scattering

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MnSi problems

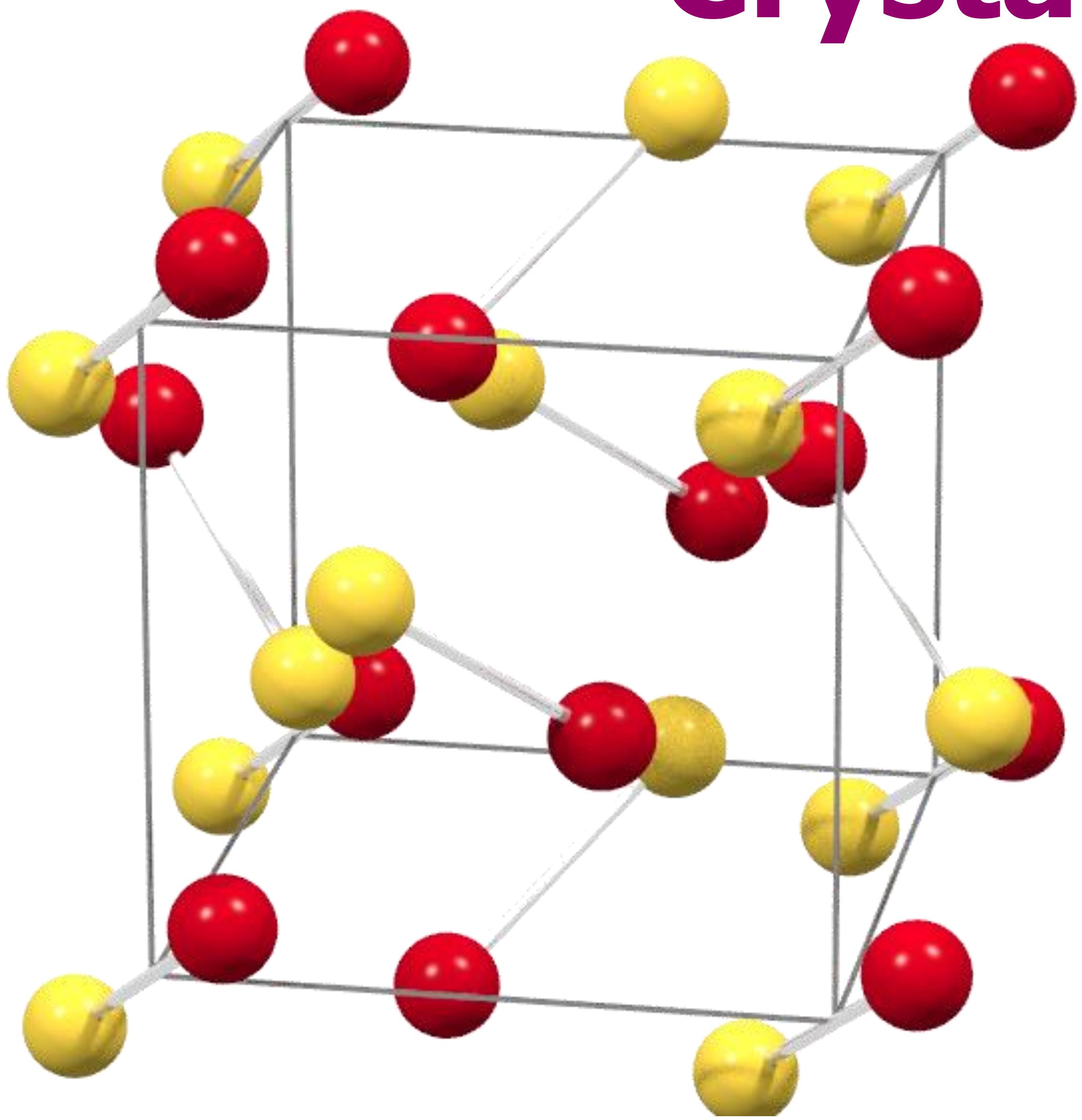
1) Crystallographic Handedness and Spin Chirality.

2) Complex nature of the thermal phase transition.

3) T-P phase diagram: quantum phase transition.

4) H-T phase diagram, appearance of A-phase (k-flop and skyrmion lattice).

Crystal structure



MnSi, FeSi, CoSi,
$Mn_{1-y}Fe_ySi$, $Fe_{1-x}Co_xSi$,
$Mn_{1-y}Co_ySi$,

FeGe, MnGe, $Fe_{1-x}Mn_xGe$

- B20-type cubic single crystal
- Space group $P2_13$
- a = 4.55 Å
- 4 Me and 4 Si(Ge) <u>atoms</u> are inside a unit cell positions (u,u,u), (1/2+u,1/2-u,u), (1/2-u,-u,1/2+u), (-u,1/2+u,1/2+u) with u_{Mn} = 0.138 and u_{Si} = 0.845

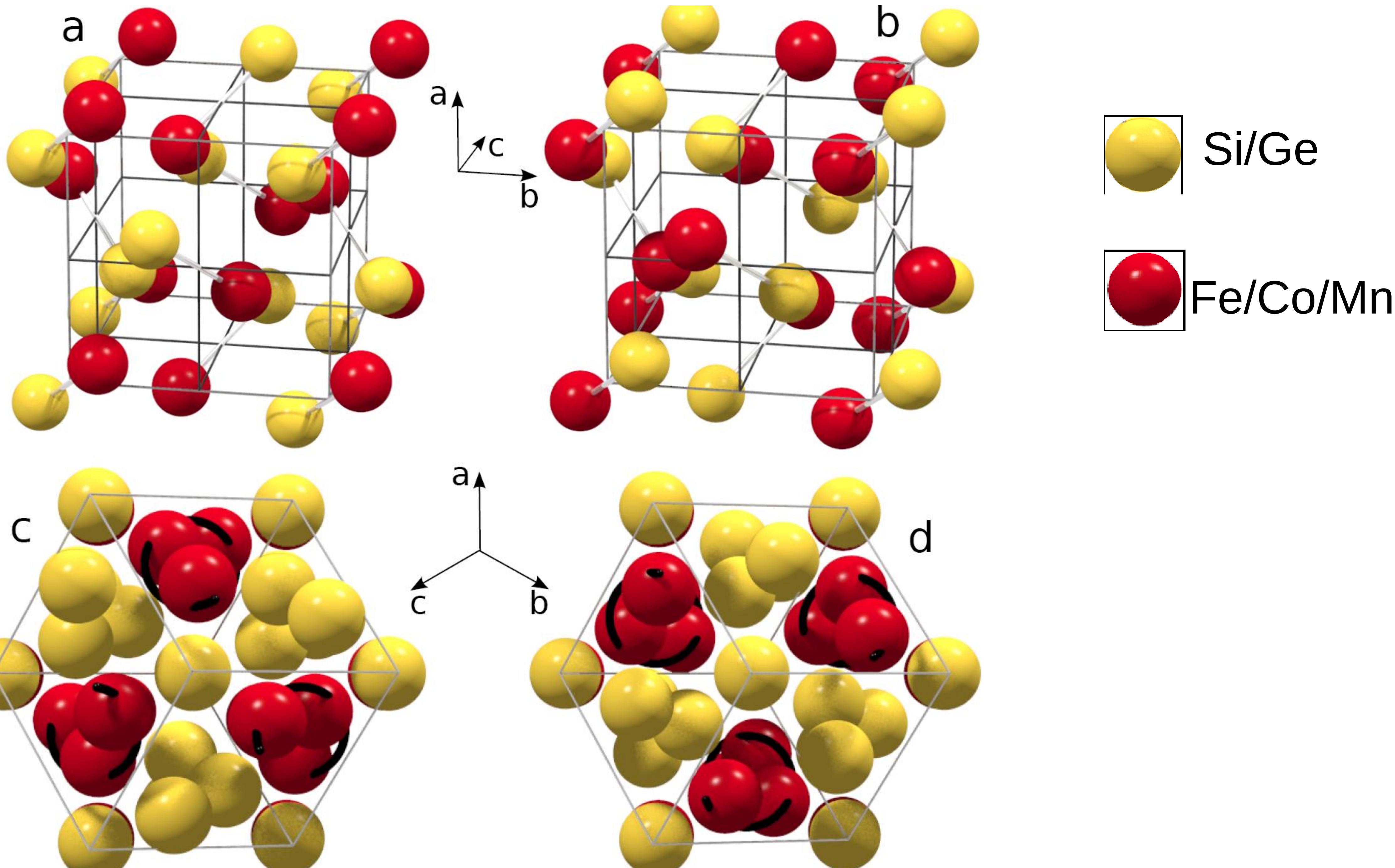
What is structural handedness?

(u,u,u), (1/2+u,1/2-u,u),
(1/2-u,-u,1/2+u) (-u,1/2+u,1/2+u)

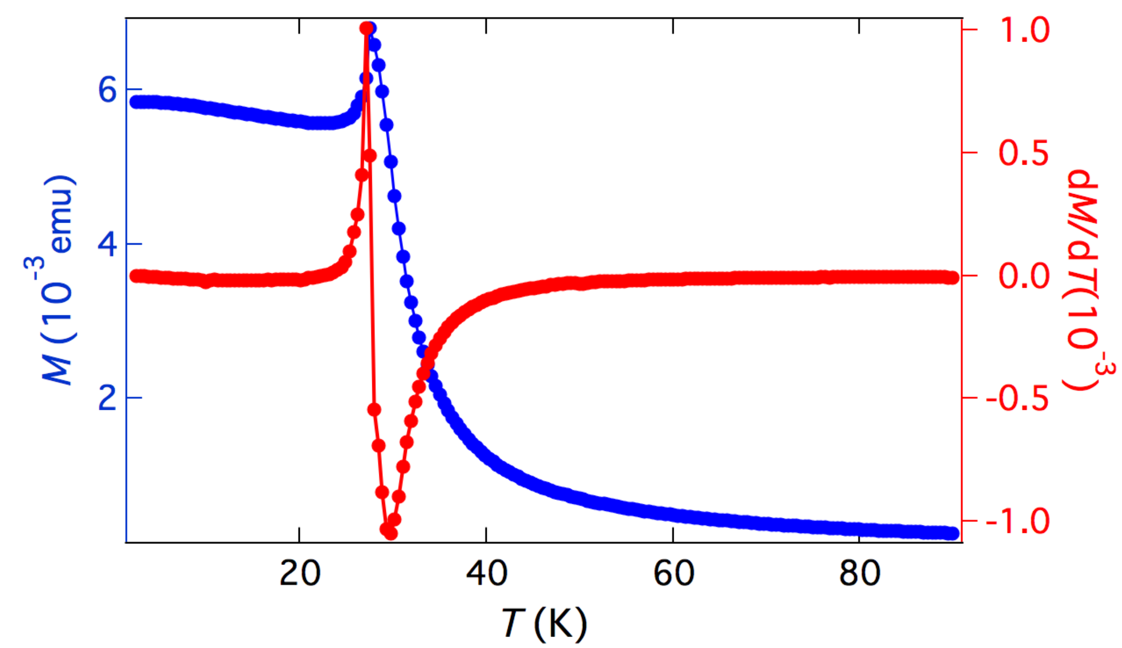
with u_{Me} = 0.138 и u_{Si} = 0.845.

(u,u,u), (1/2+u,1/2-u,u),
(1/2-u,-u,1/2+u) (-u,1/2+u,1/2+u)

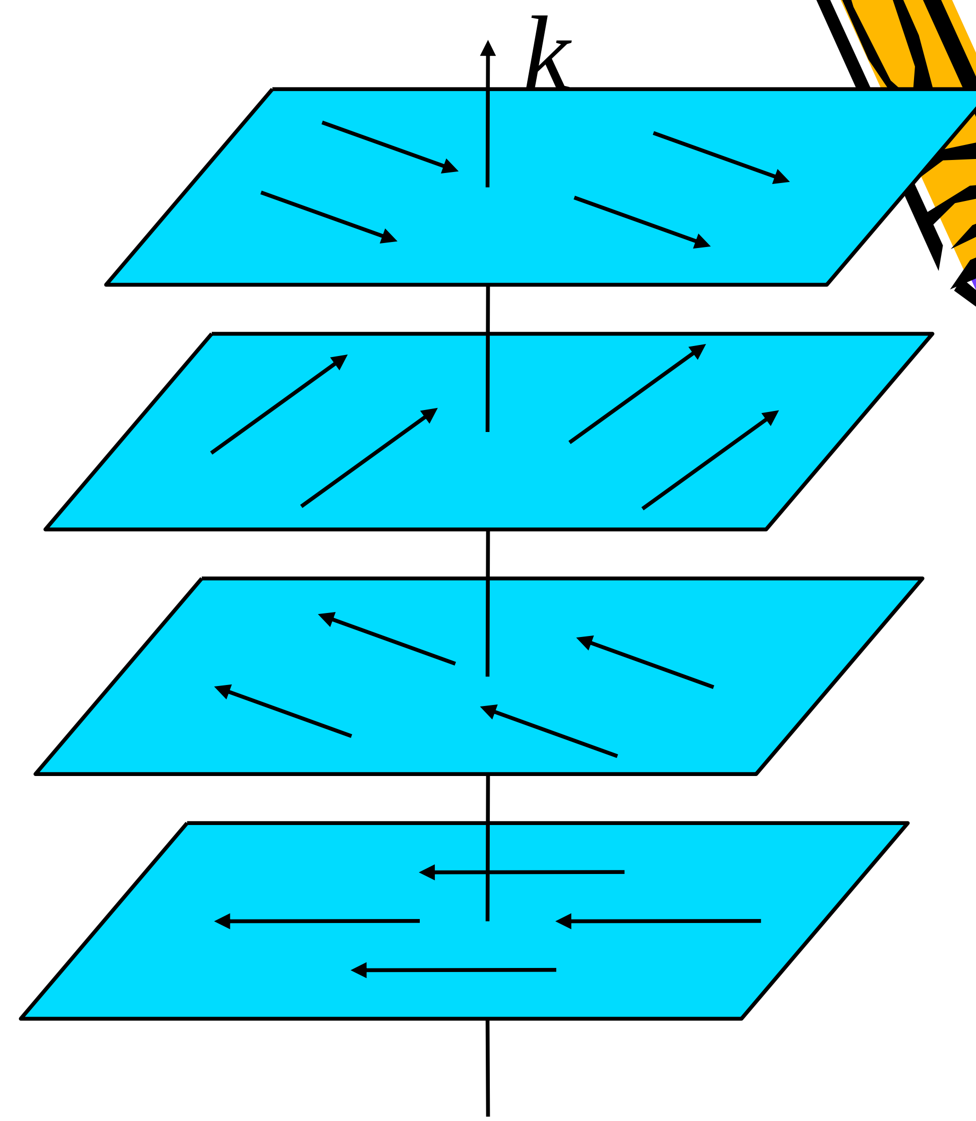
with u_{Me} = 0.862 и u_{Si} = 0.155.



Magnetic order in **FeGe and MnSi**



MnSi



1) spiral period 18 nm for MnSi.

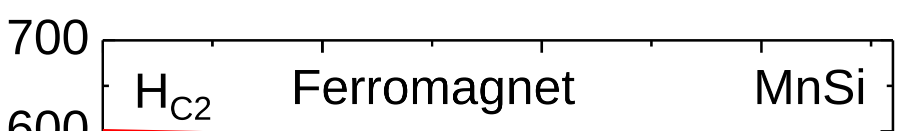
2) μ_S (Me) ≈ 0.40 μ_B for MnSi

H-T phase diagram

PHYSICAL REVIEW B **83**, 224405 (2011)

Magnetic fluctuations and correlations in MnSi: Evidence for a chiral skyrmion spin liquid phase

C. Pappas,[1,2,*] E. Lelièvre-Berna,[3] P. Bentley,[3] P. Falus,[3] P. Fouquet,[3] and B. Farago[3]



$T = T_C + 0.2K$

PHYSICAL REVIEW B **83**, 224411 (2011)

Chiral criticality in the doped helimagnets $Mn_{1-y}Fe_ySi$

Sergey V. Grigoriev,[1] Evgeny V. Moskvin,[1] Vadim A. Dyadkin,[1] Daniel Lamago,[2,3] Thomas Wolf,[3]
Helmut Eckerlebe,[4] and Sergey V. Maleyev[1]

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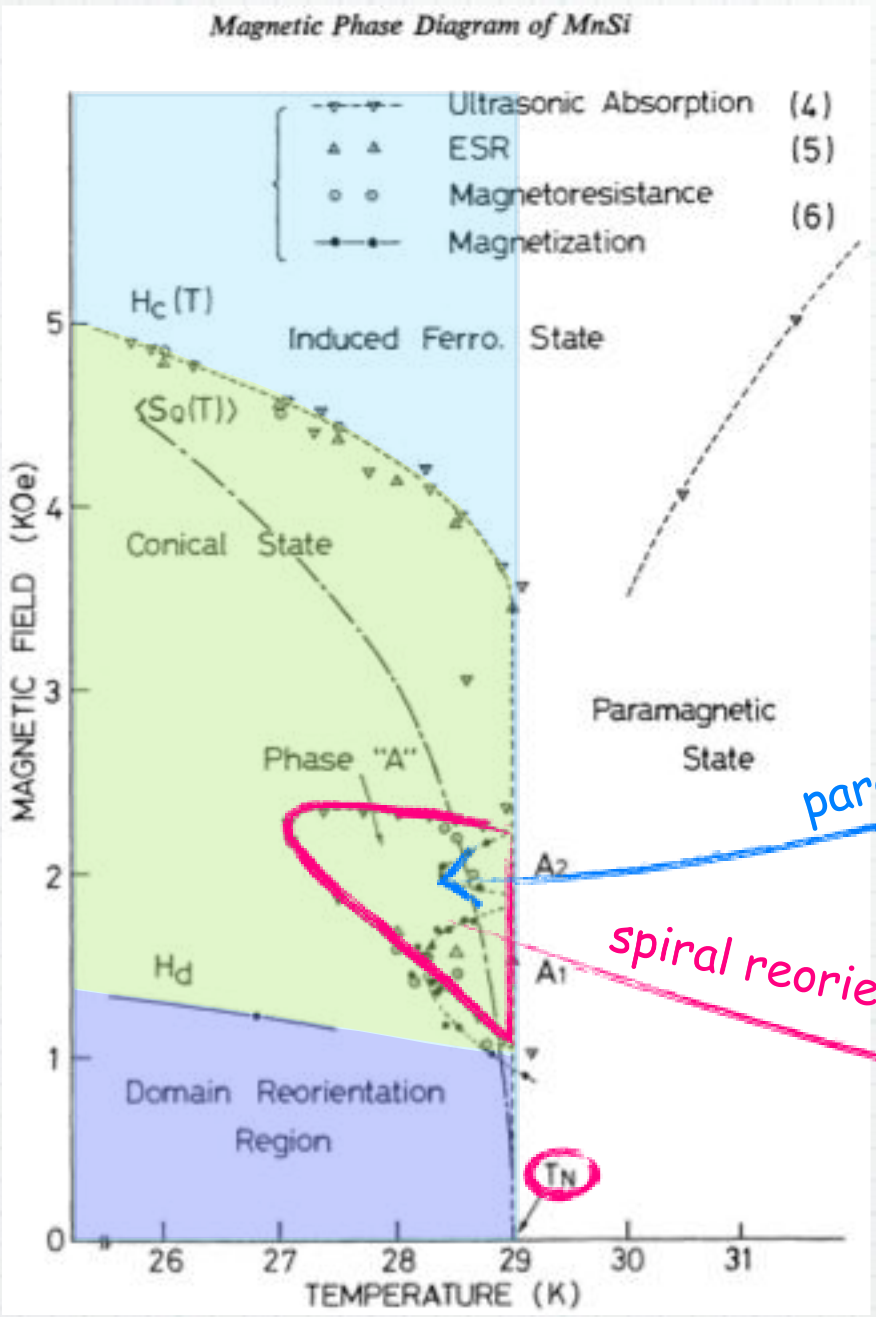
PRL **107**, 037207 (2011) PHYSICAL REVIEW LETTERS week ending 15 JULY 2011

Magnetic Blue Phase in the Chiral Itinerant Magnet MnSi

A. Hamann,[1,3] D. Lamago,[1,2] Th. Wolf,[1] H. v. Löhneysen,[1,3] and D. Reznik[1,4]

S. ... Jonietz, C. Pfleiderer, A. Rosch, A. Neubauer, R. Georgii, P. Böni, Science 323 (2009) 915.

A-phase in MnSi

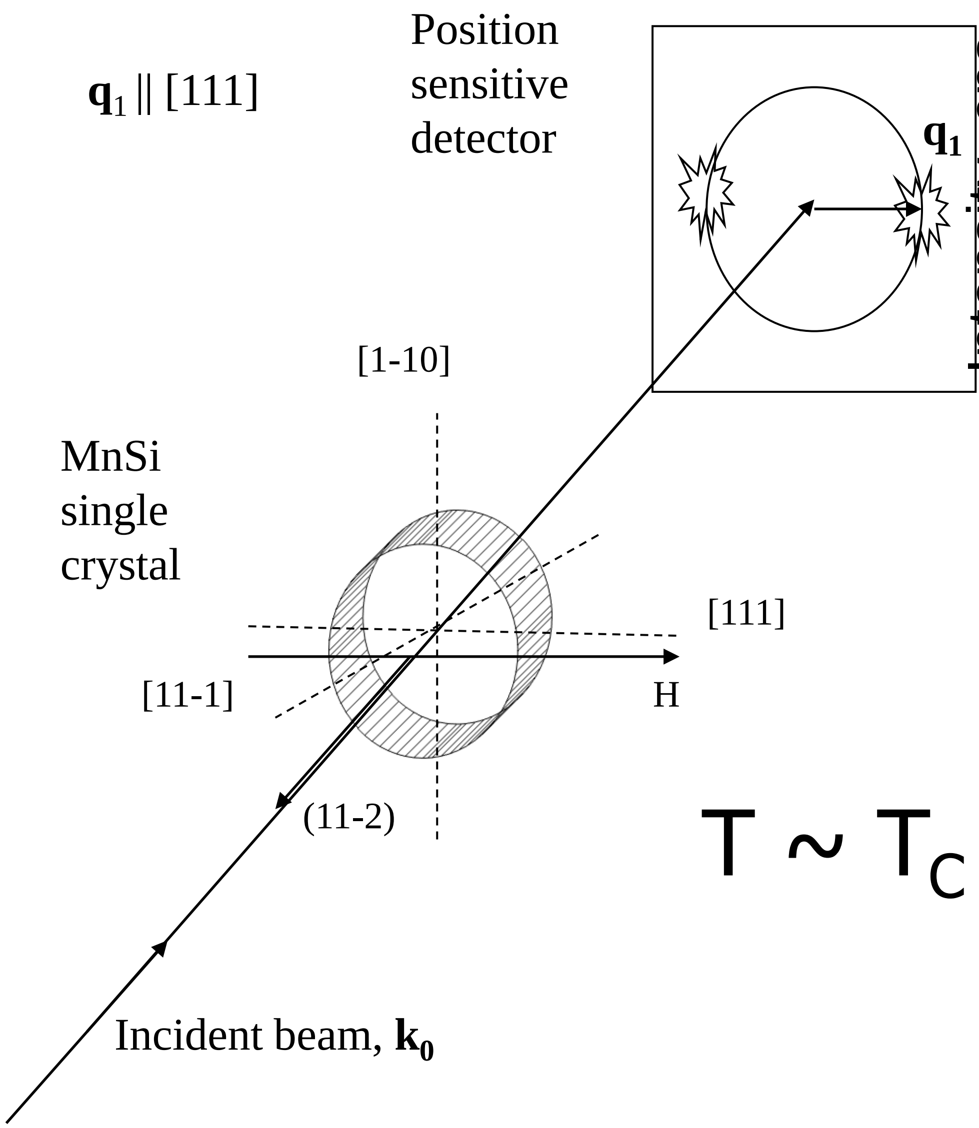


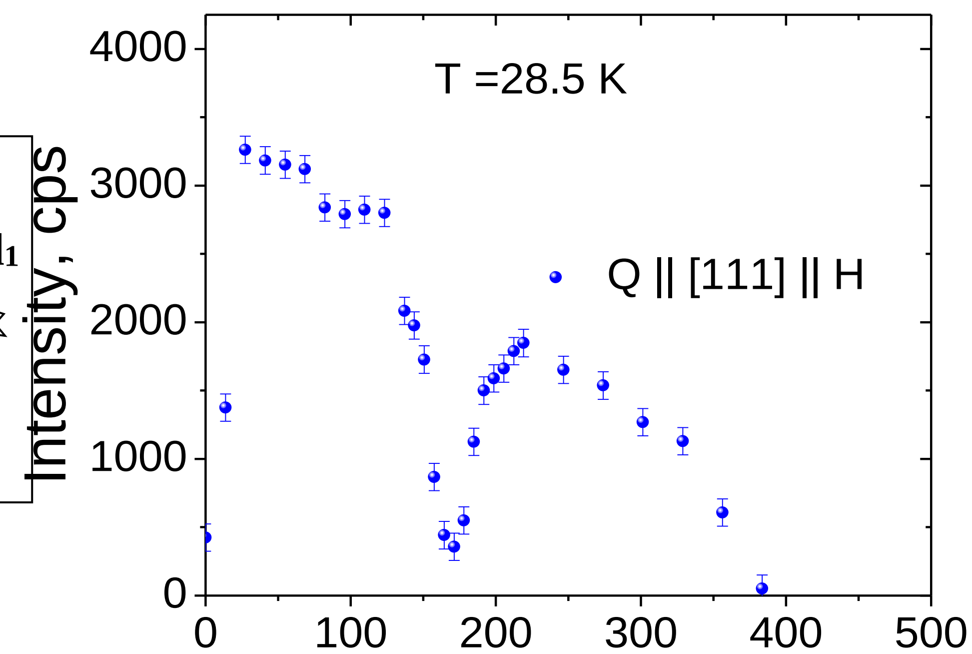
(4) S. Kusaka et al. Solid State Commun. **20** (1976) 925
(5) M. Dante et al. J. Phys. Soc. Jpn. **42** (1977) 1555
(6) T. Sakakibara et al. J. Phys. Soc. Jpn. **51** (1982) 2439

Y. Ishikawa and M. Arai. J. Phys. Soc. Jpn. **53** (1984) 2726

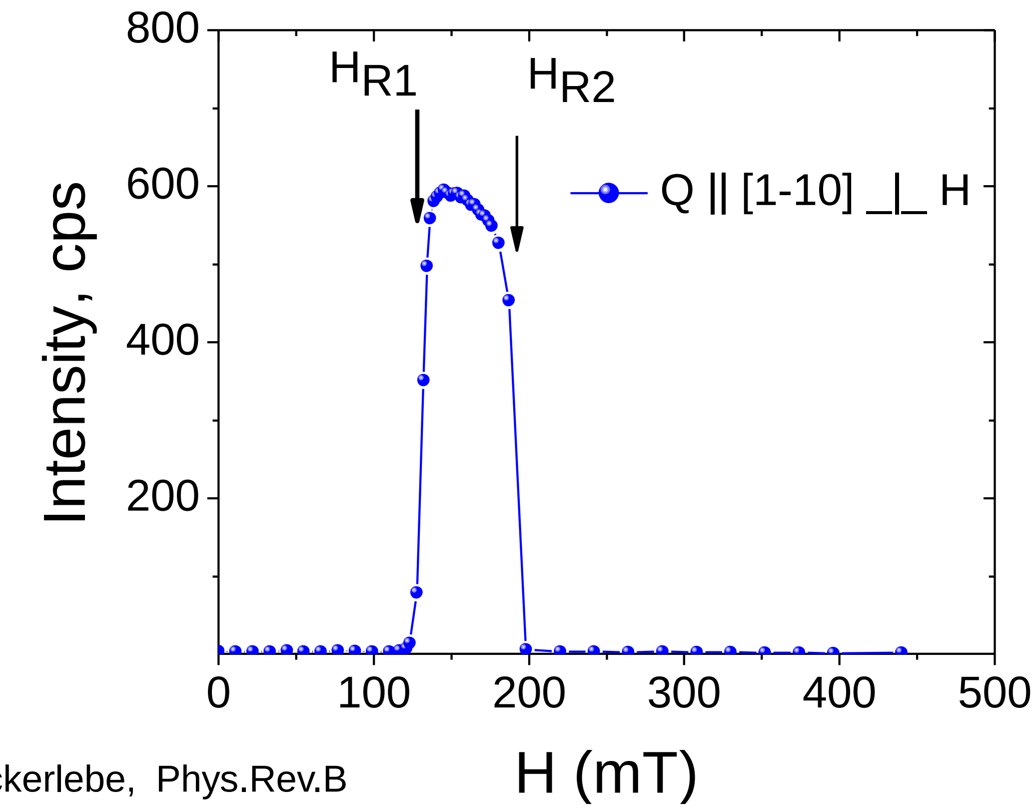
B. Lebech, et al J. Magn. Magn. Mater., **140-144** (1995) 119

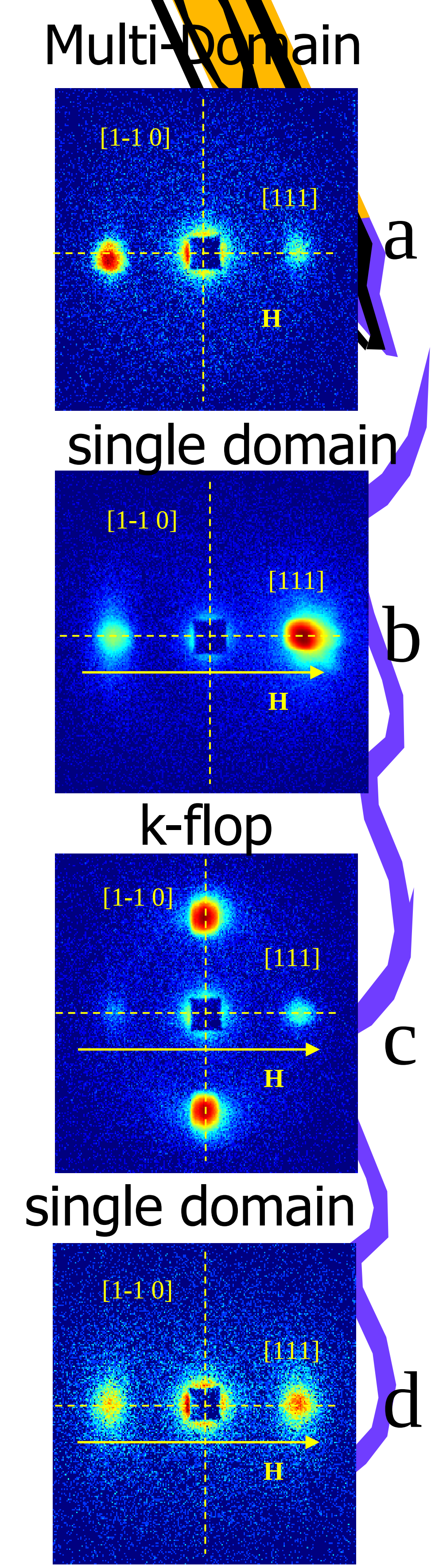
Field induced k-flop in MnSi near T_C and skyrmion lattice





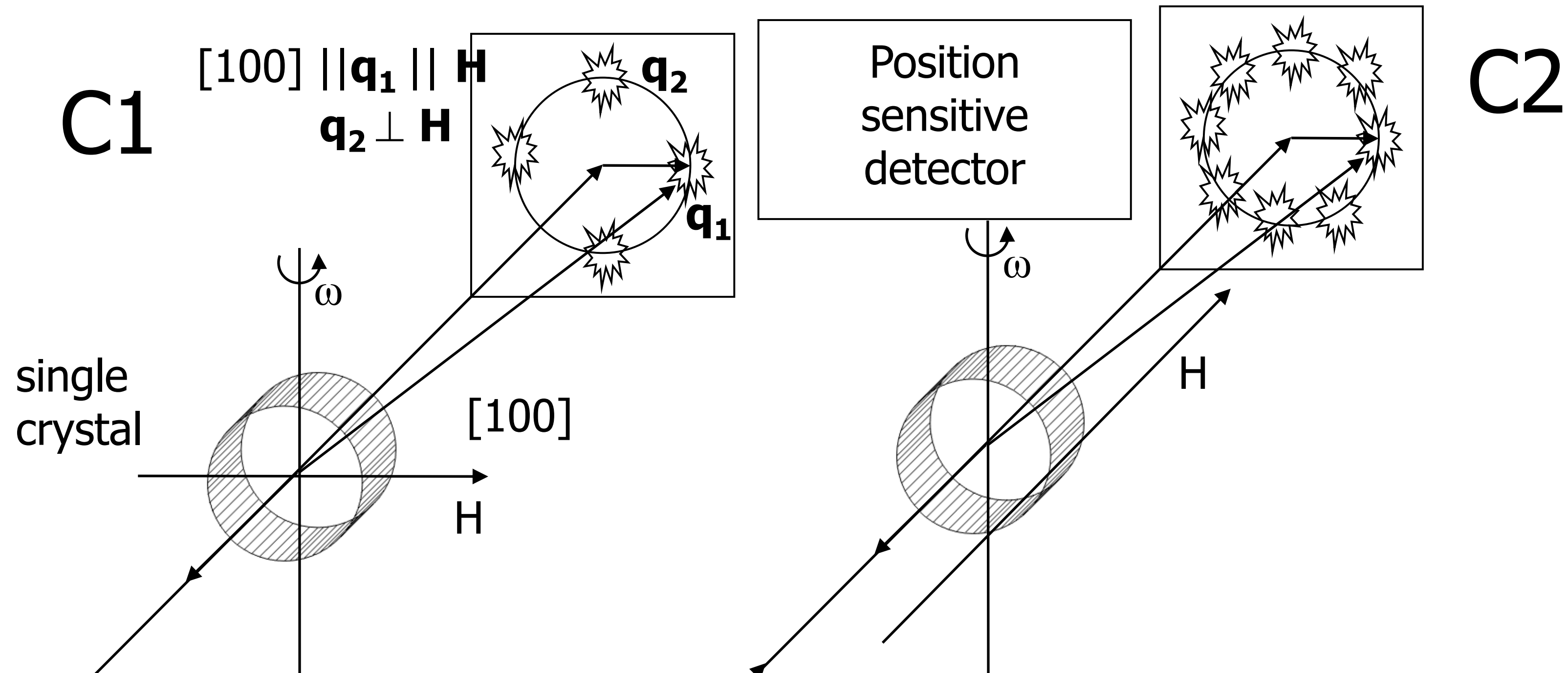
$T \sim T_C$





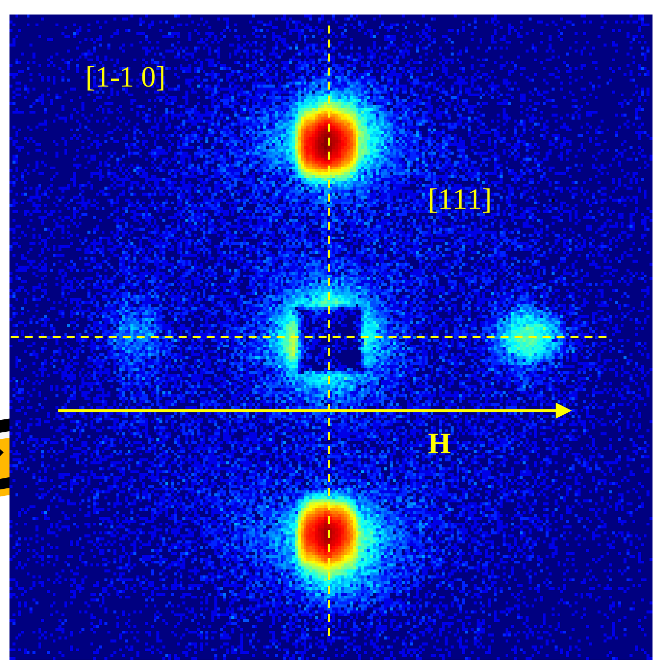
S.V. Grigoriev, S.V. Maleyev, A.I. Okorokov, Yu.O. Chetverikov, H. Eckerlebe, Phys.Rev.B **73** (2006) 224440.

k-flop or Skyrmion lattice?

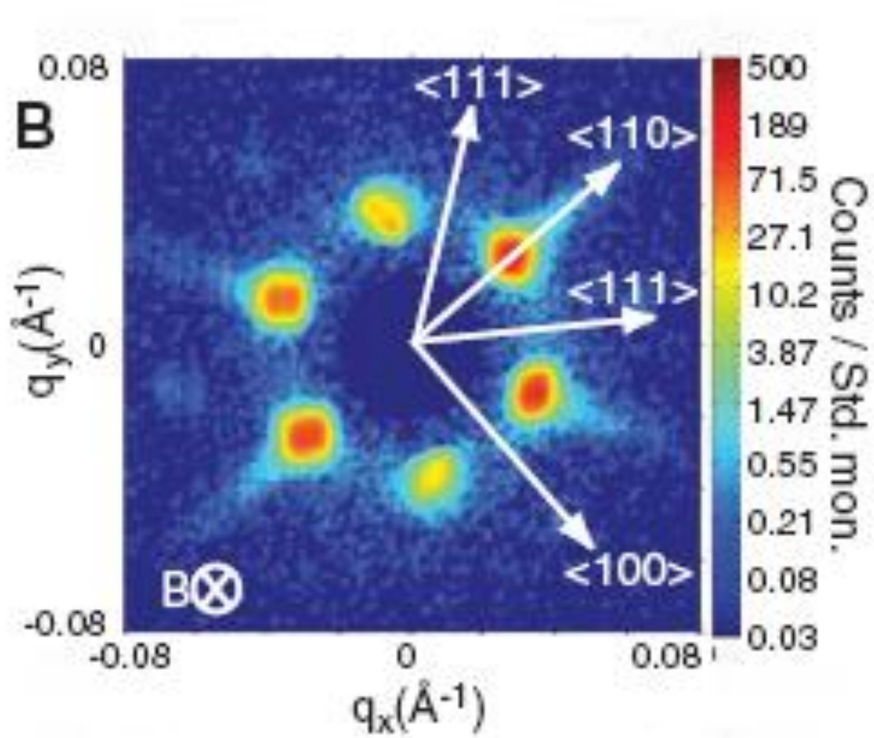


S.V. Grigoriev, S.V. Maleyev, A.I. Okorokov, Yu.O. Chetverikov, H. Eckerlebe, Phys.Rev.B **73** (2006) 224440.

S. Mühlbauer, B. Binz, F. Jonietz, C. Pfleiderer, A. Rosch, A. Neubauer, R. Georgii, P. Böni, Science 323 (2009) 915.



C

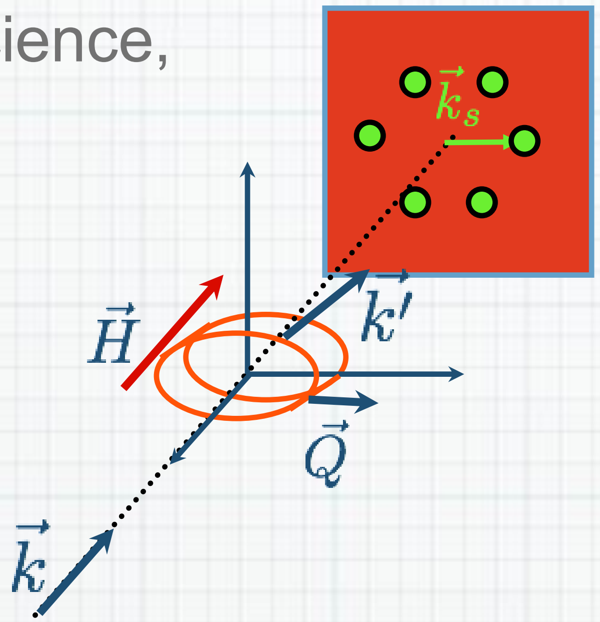


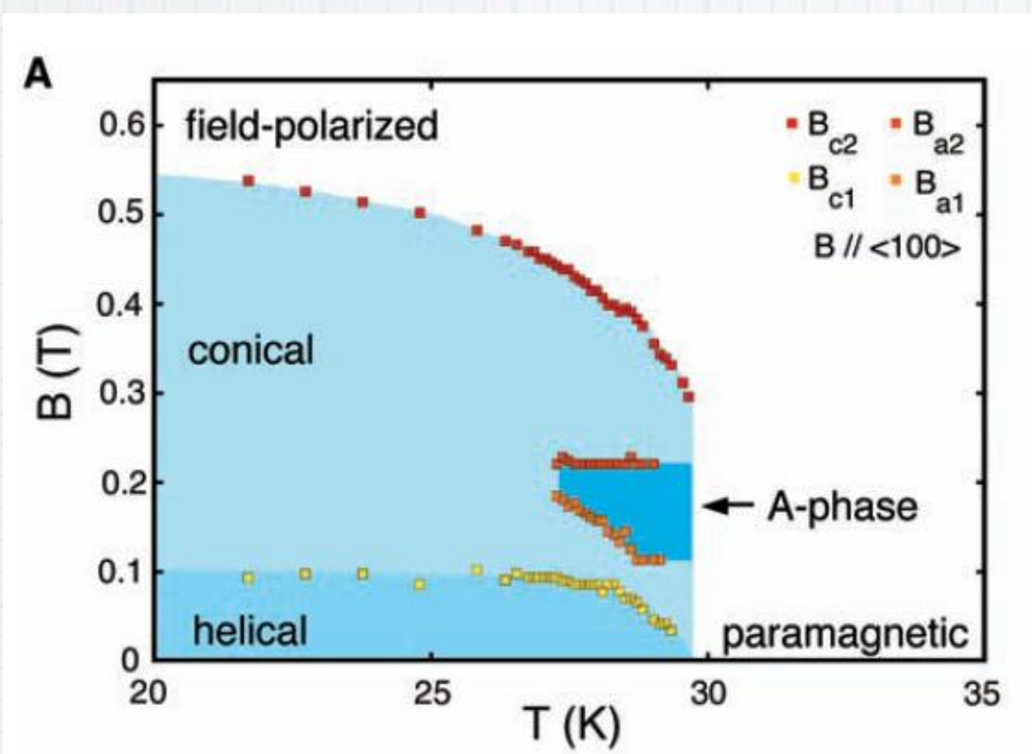
Neutron scattering in MnSi

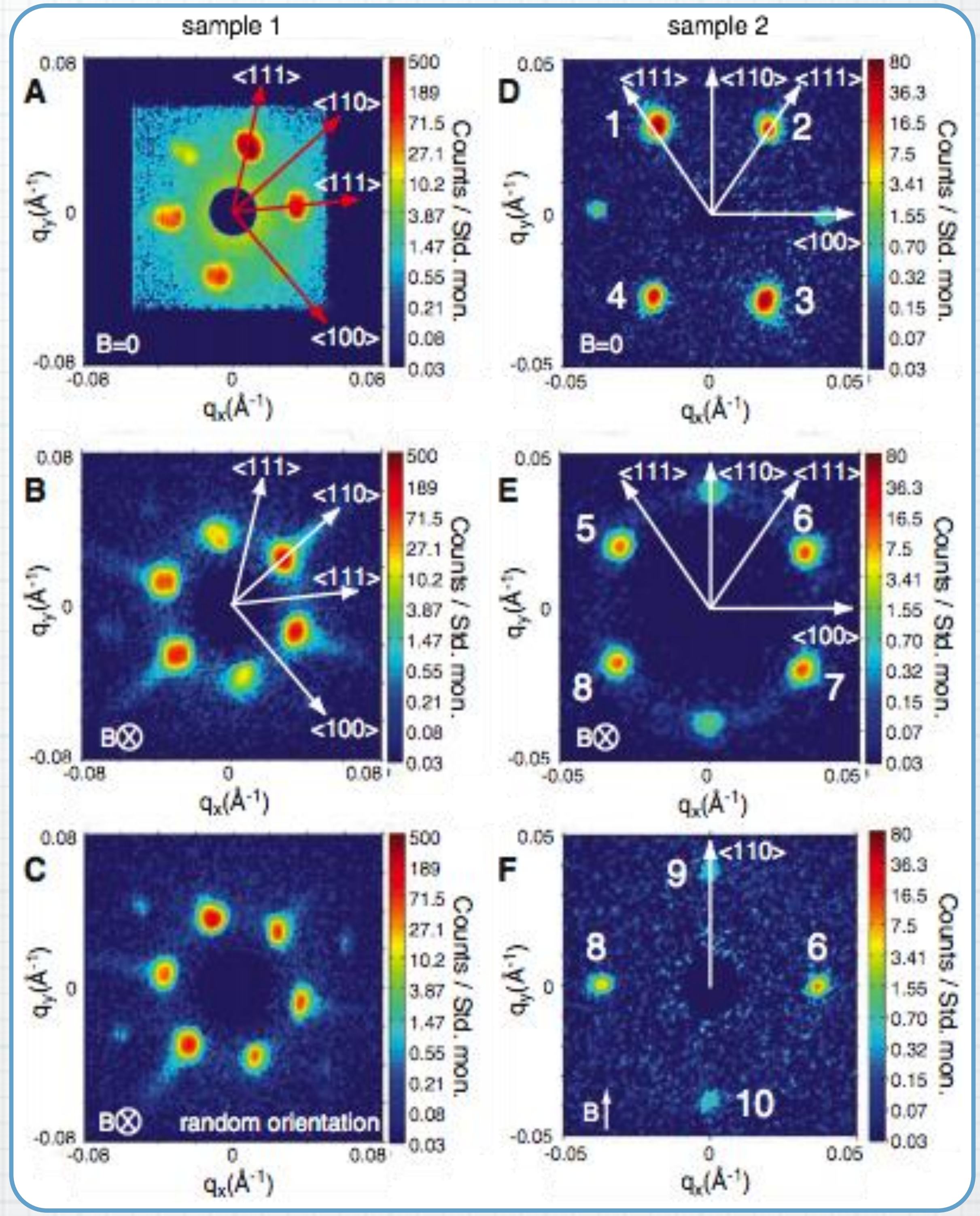
S. Mühlbauer et al. Science, **323** (2009) 915.

longitudinal geometry

$$\vec{k} \,||\, \vec{H}$$

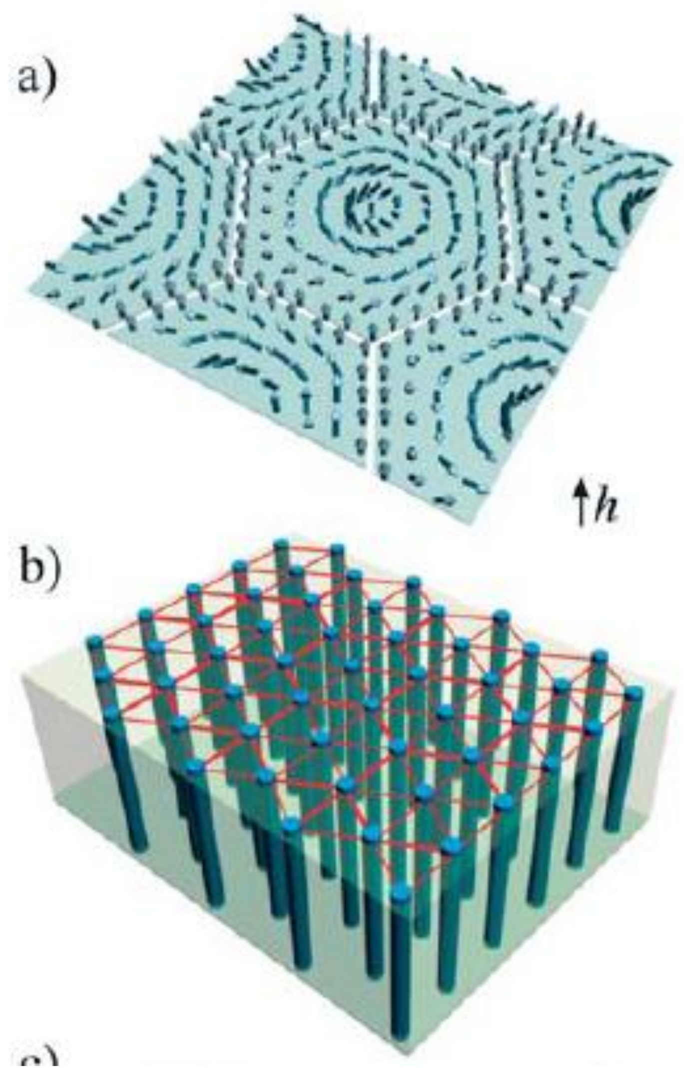


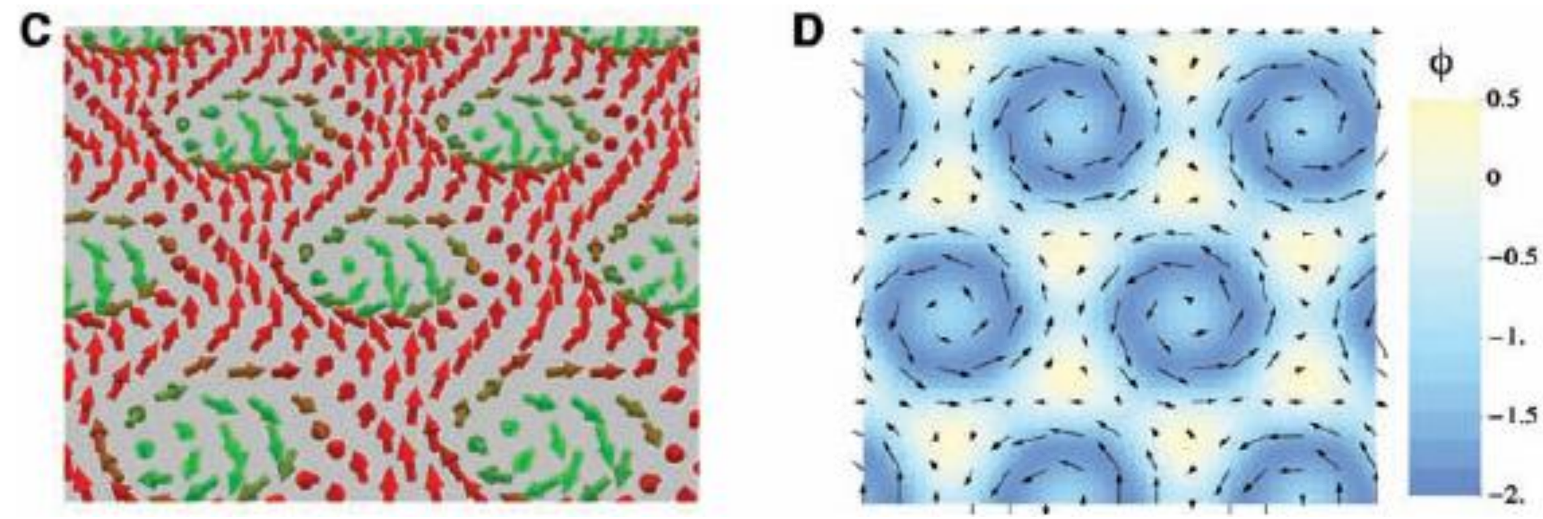




Skyrmion lattice

S. Mühlbauer, B. Binz, F. Jonietz, C. Pfleiderer, A. Rosch, A. Neubauer, R. Georgii, P. Böni, Science 323 (2009) 915.





Skyrmions and chirality selection in noncentrosymmetric magnets

U. K. Rößler, A. A. Leonov, A. B. Butenko, A. N. Bogdanov

Skyrmions in Thin Films $Fe_{0.5}Co_{0.5}Si$

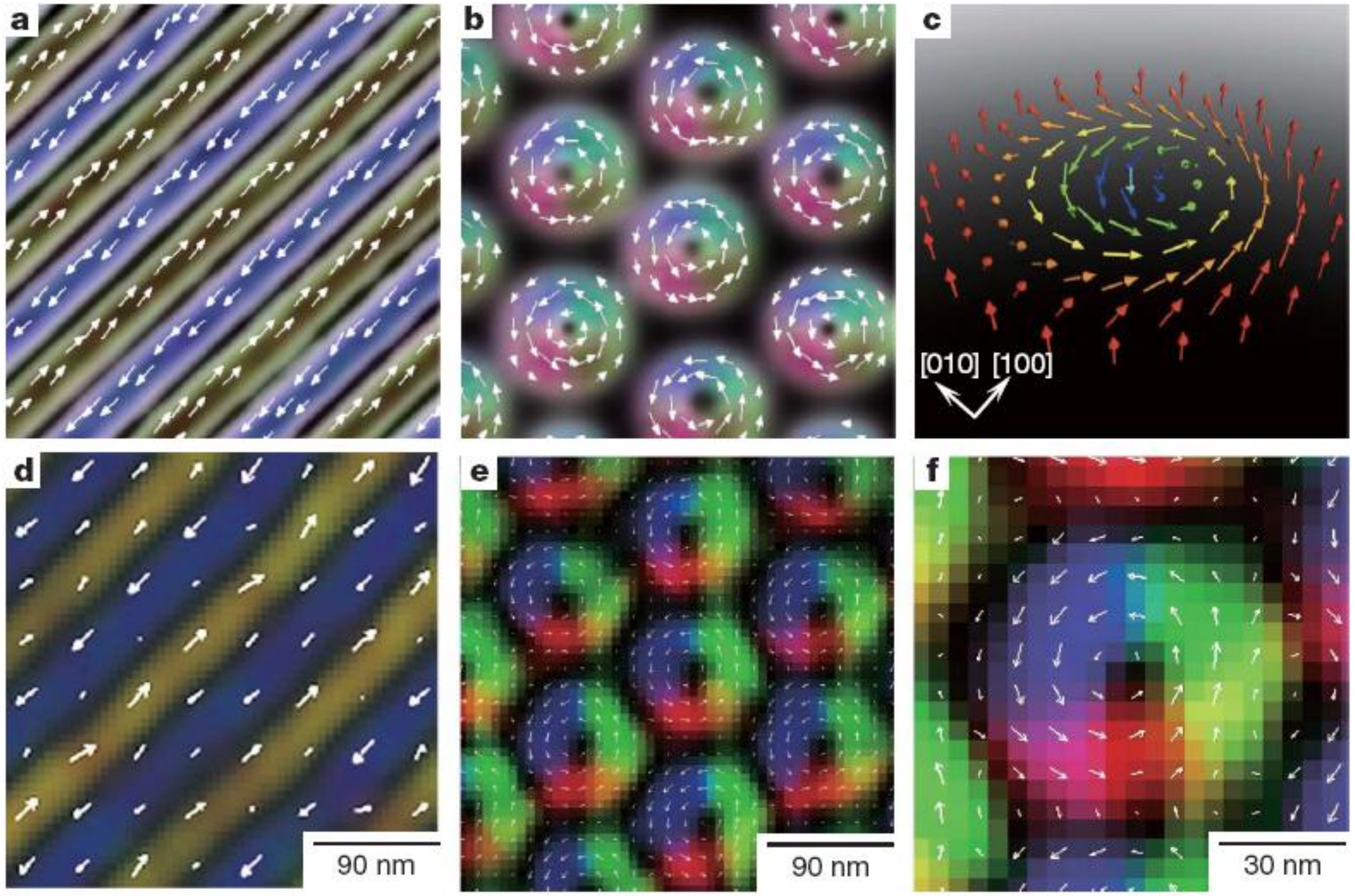


Figure 1 | Topological spin textures in the helical magnet $Fe_{0.5}Co_{0.5}Si$. **a**, **b**, Helical (**a**) and skyrmion (**b**) structures predicted by Monte Carlo simulation. **c**, Schematic of the spin configuration in a skyrmion. **d**–**f**, The experimentally observed real-space images of the spin texture, represented by the lateral magnetization distribution as obtained by TIE analysis of the Lorentz TEM data: helical structure at zero magnetic field (**d**), the skyrmion crystal (SkX) structure for a weak magnetic field (50 mT) applied normal to the thin plate (**e**) and a magnified view of **e** (**f**). The colour map and white arrows represent the magnetization direction at each point.

X. Z. Yu, Y. Onose, N. Kanazawa, J. H. Park, J. H. Han, Y. Matsui, N. Nagaosa, Y. Tokura, Nature 465 (2010) 901 -904.

Skyrmions in Thin Films $Fe_{0.5}Co_{0.5}Si$

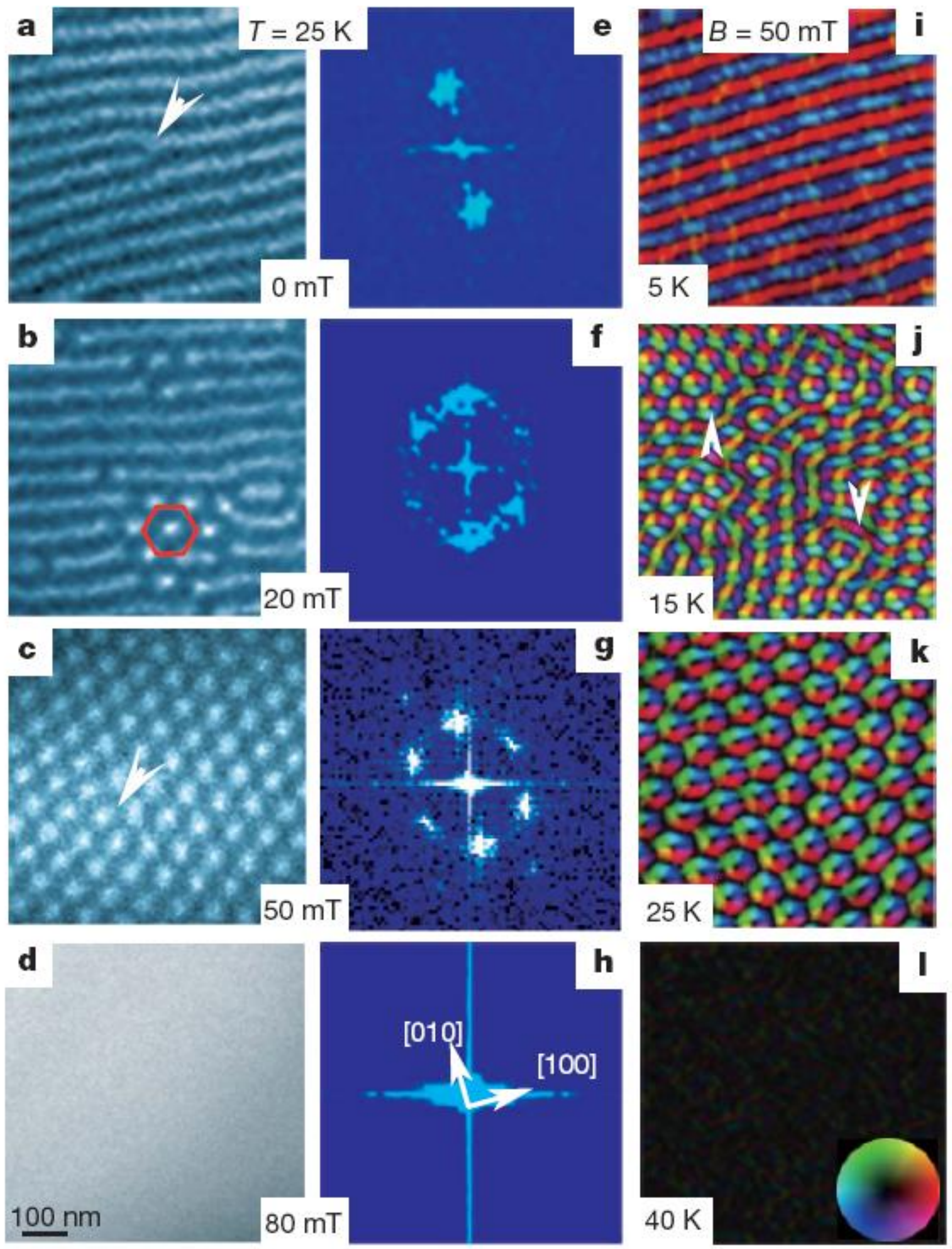
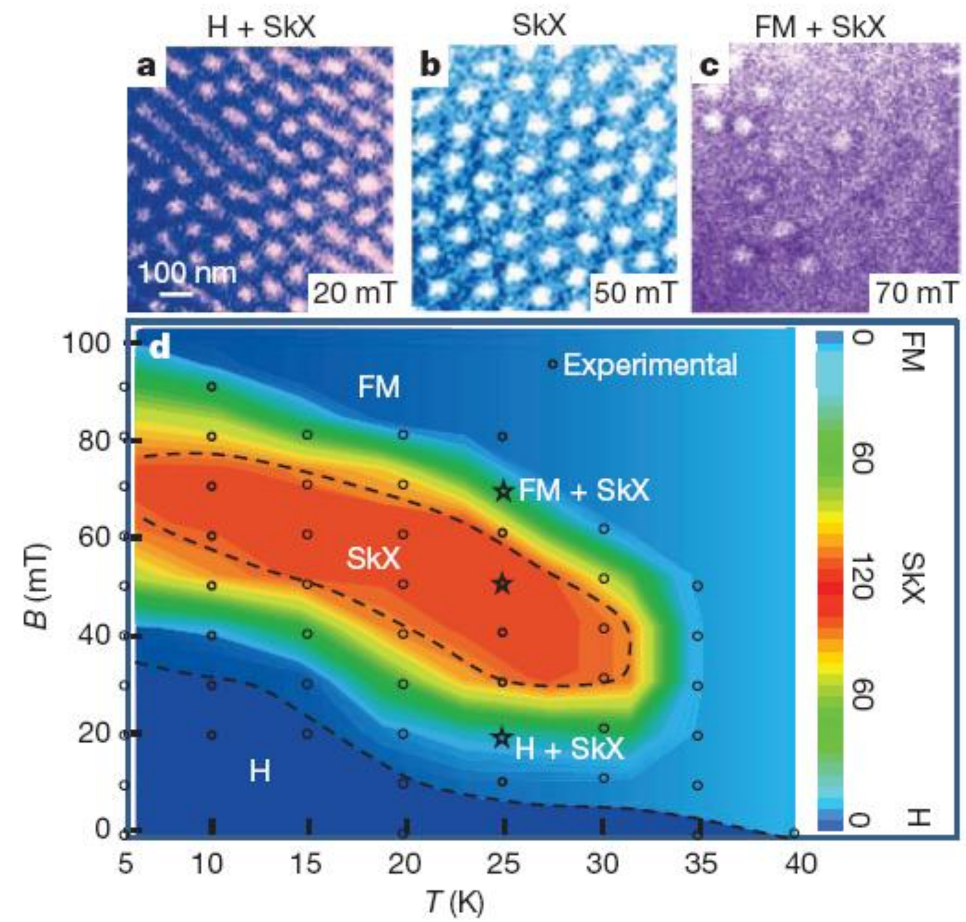
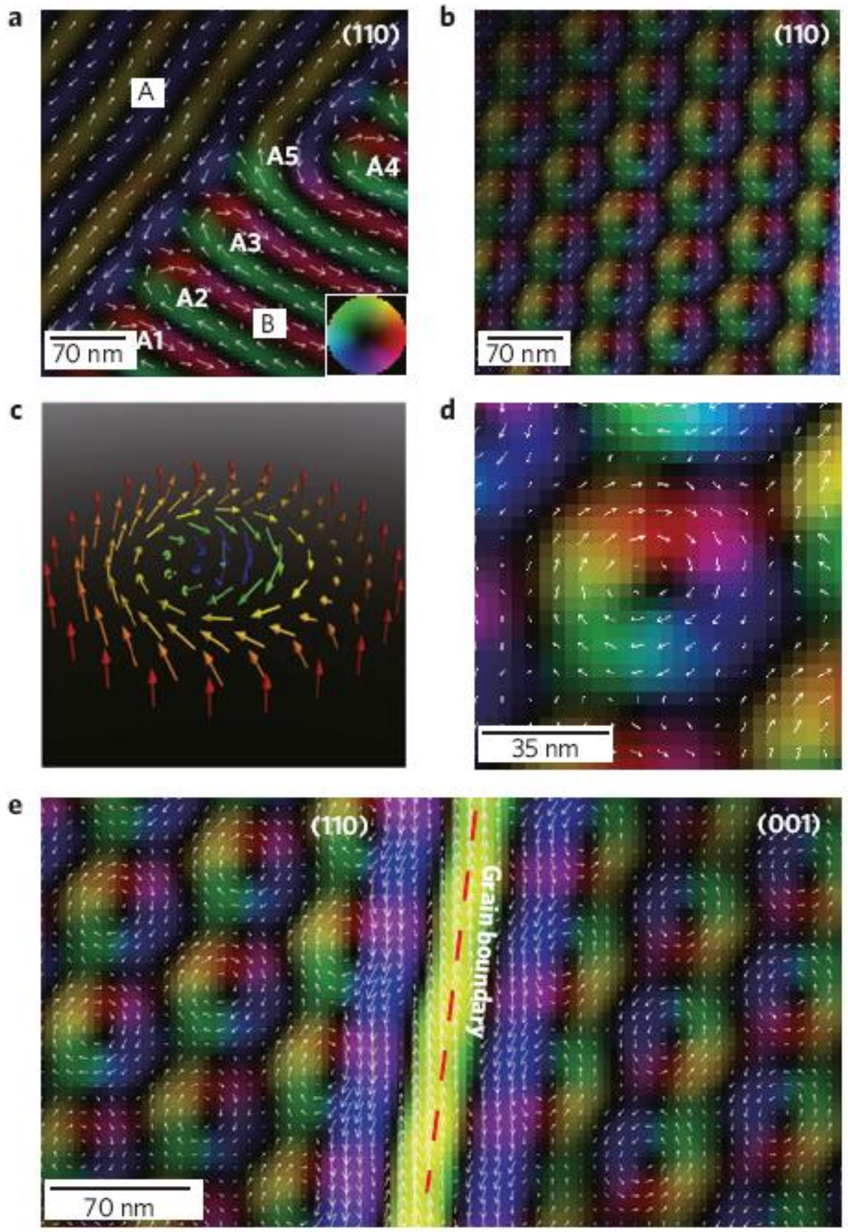
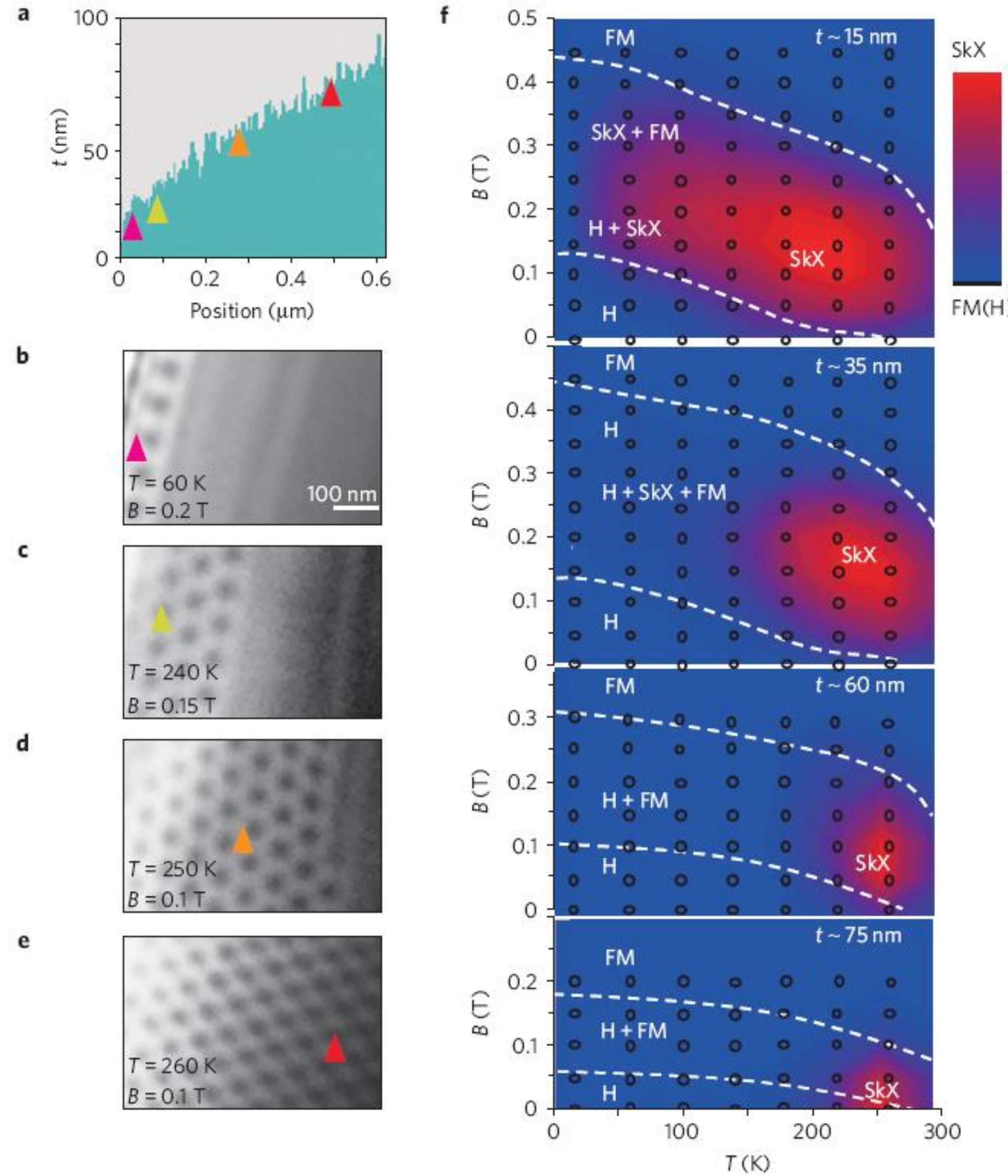


Figure 2 | Variations of spin texture with magnetic field and temperature in $Fe_{0.5}Co_{0.5}Si$. **a–d**, Magnetic-field dependence of the spin texture, in real-space Lorentz TEM (overfocus) images. **e–h**, FFT patterns corresponding to **a–d**. **i–l**, Temperature profiles of the distribution map of the lateral magnetization for a magnetic field of 50 mT. Magnetic fields were applied normal to the (001) thin film. The colour wheel represents the magnetization direction at every point.



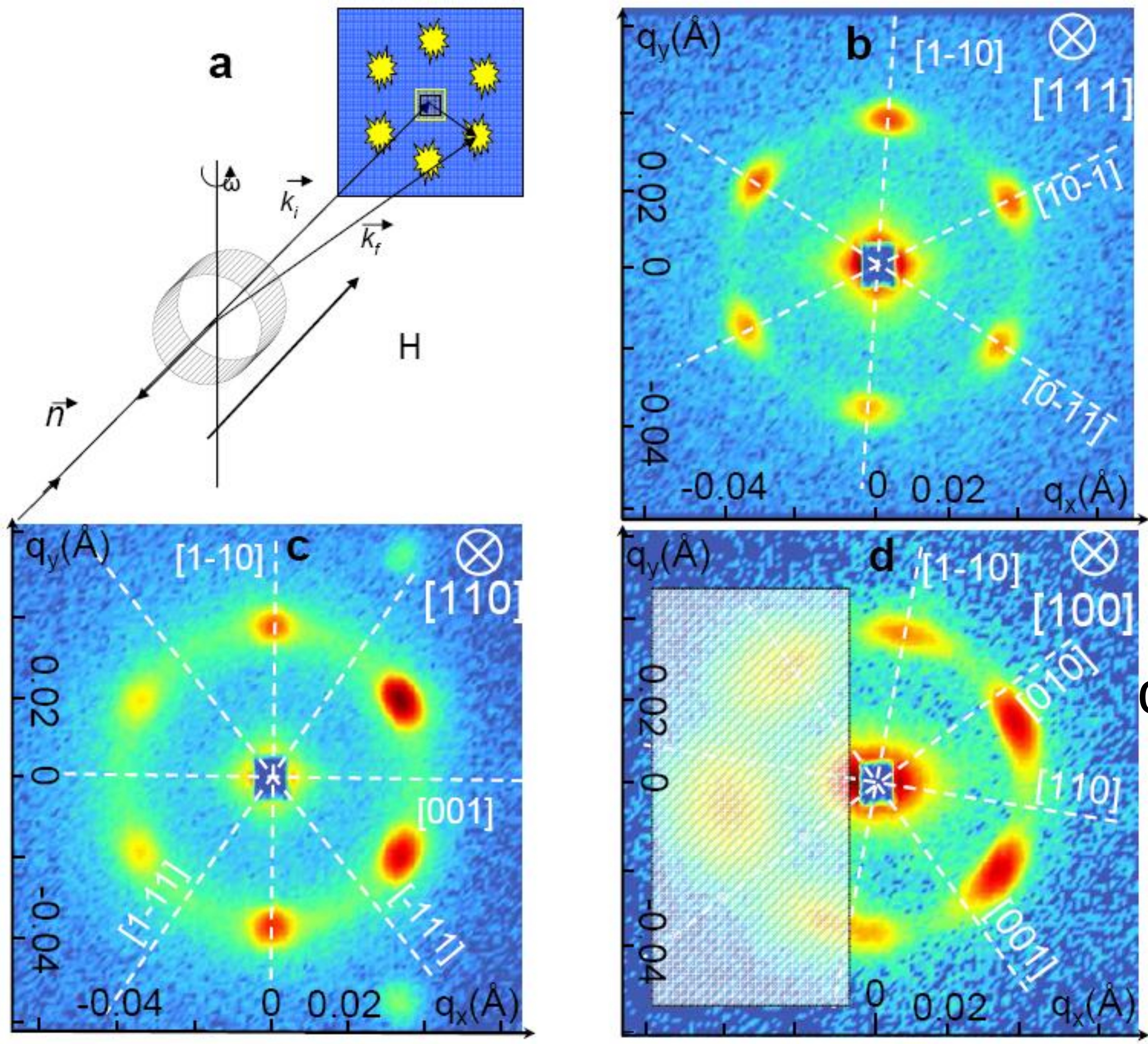
Skyrmions in Thin Films FeGe





X. Z. Yu, N. Kanazawa, Y. Onose, K. Kimoto,W. Z. Zhang, S. Ishiwata, Y. Matsui and Y. Tokura, Nature Materials 10 (2011) 106-109

A-phase in MnSi: revisited

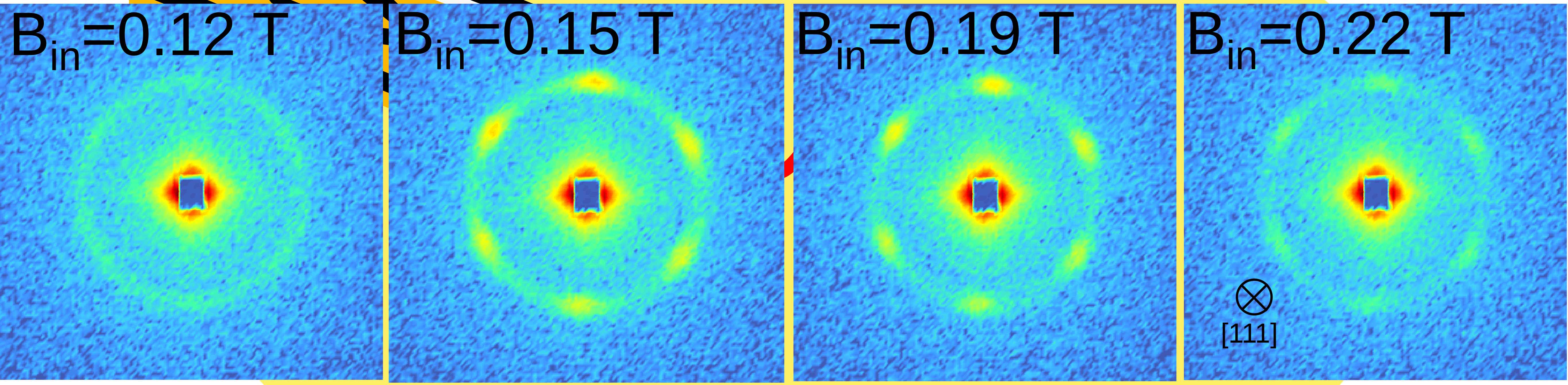


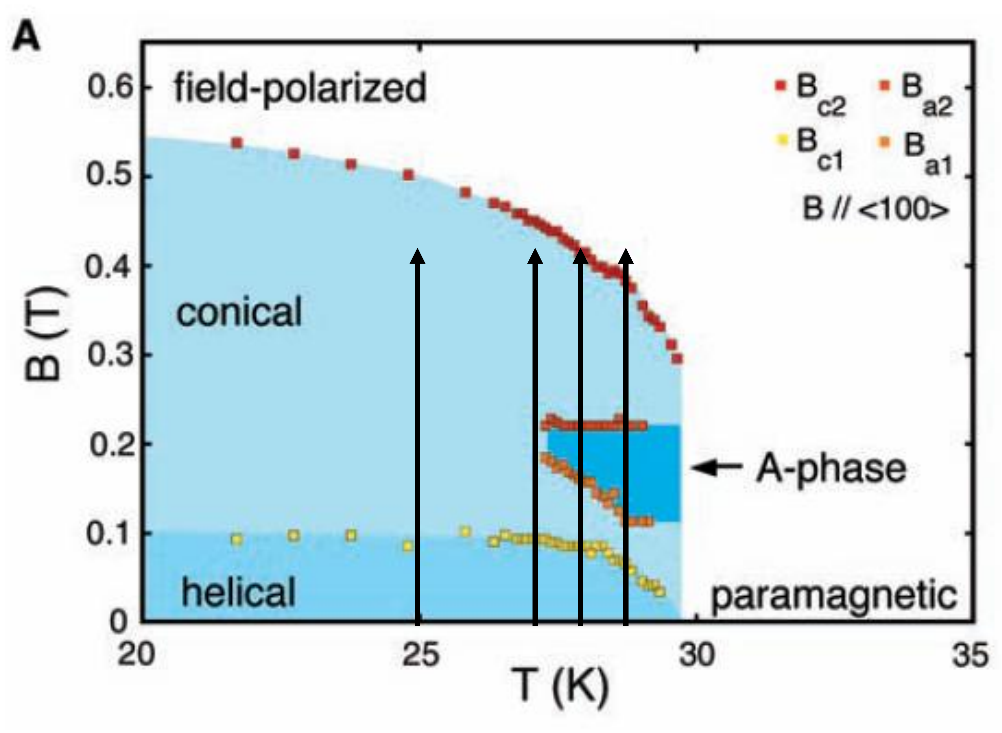
1) Hexagonal structure is insensitive to the crystal orientation.

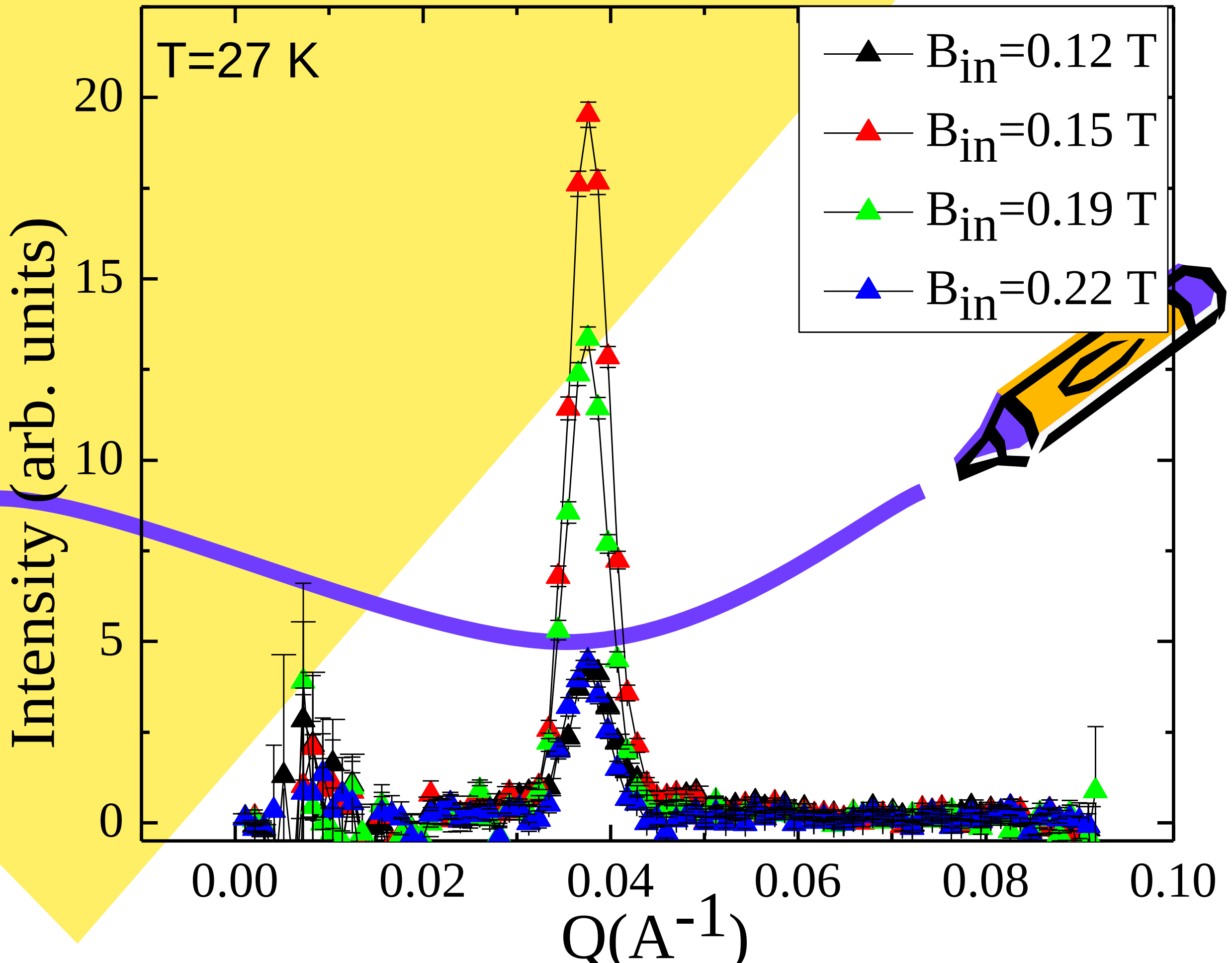
2) Hexagonal structure is stable in sense of (a) translation and (b) orientation on the scale of sample of 1 cm^2, the wavevector of spiral, cone and hexagonal phase

$k_S = k_C = k_H$

Magnetic field evolution

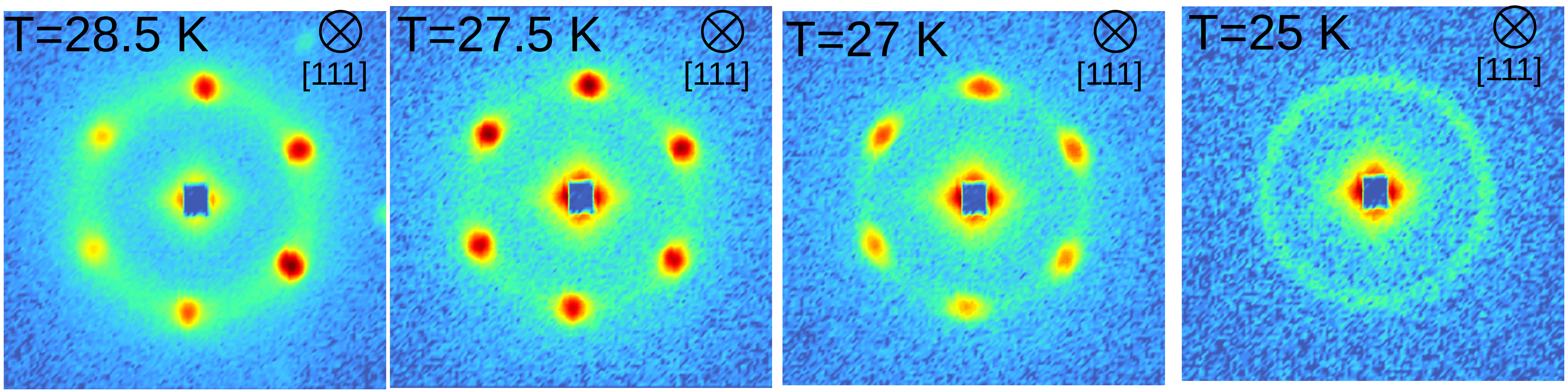


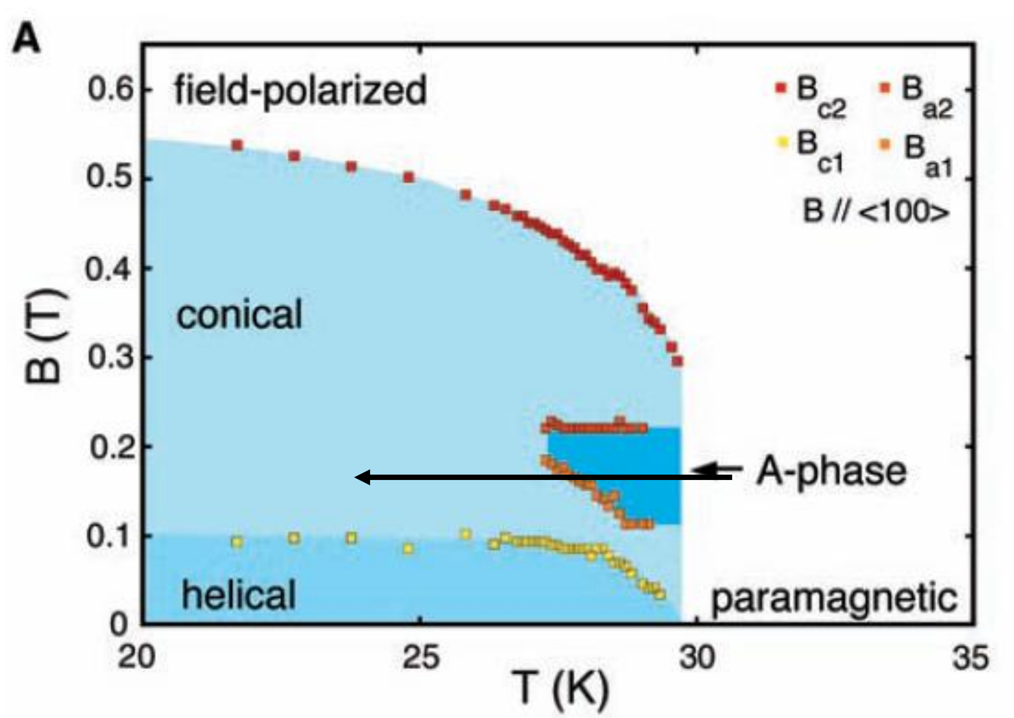


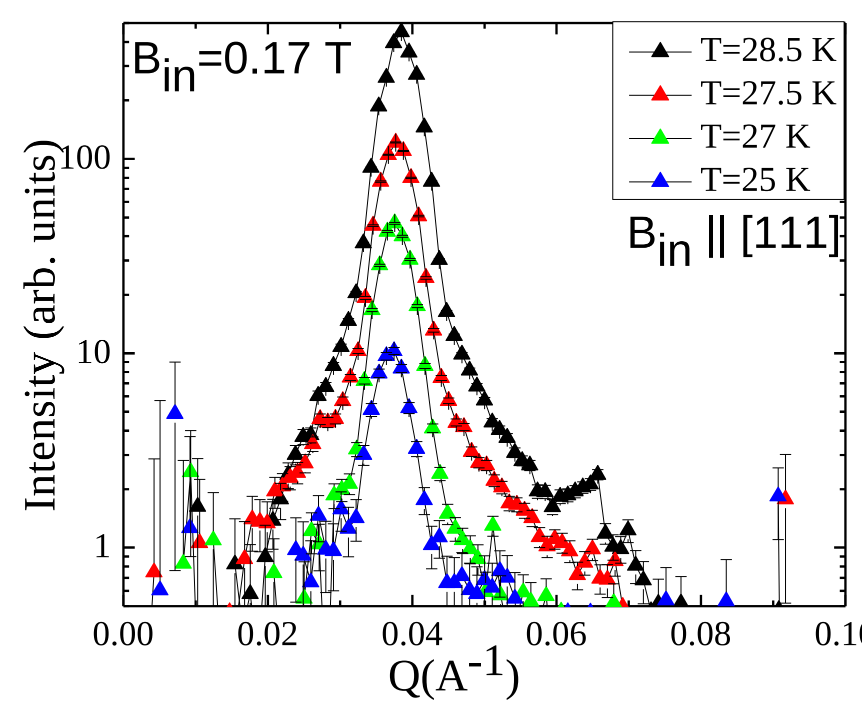


Temperature evolution

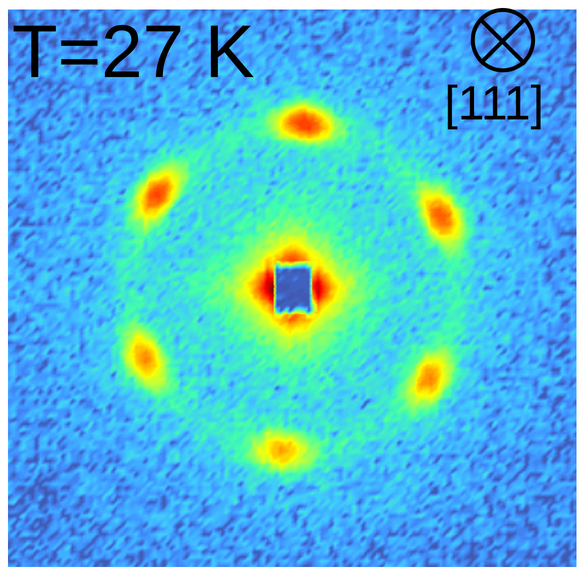
B_{in}=0.17 T

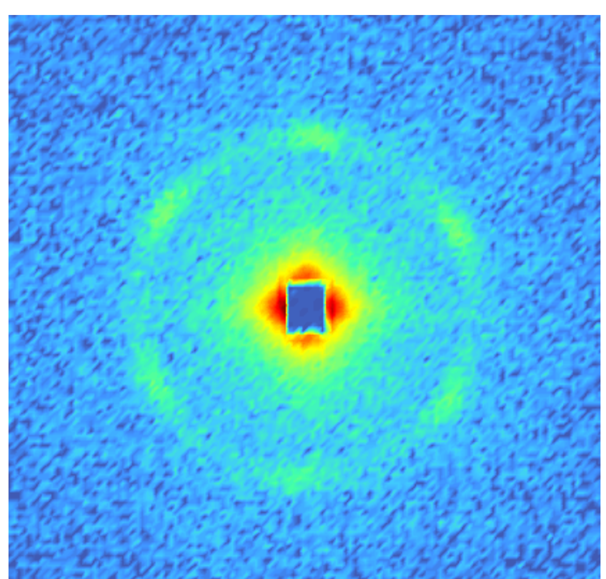


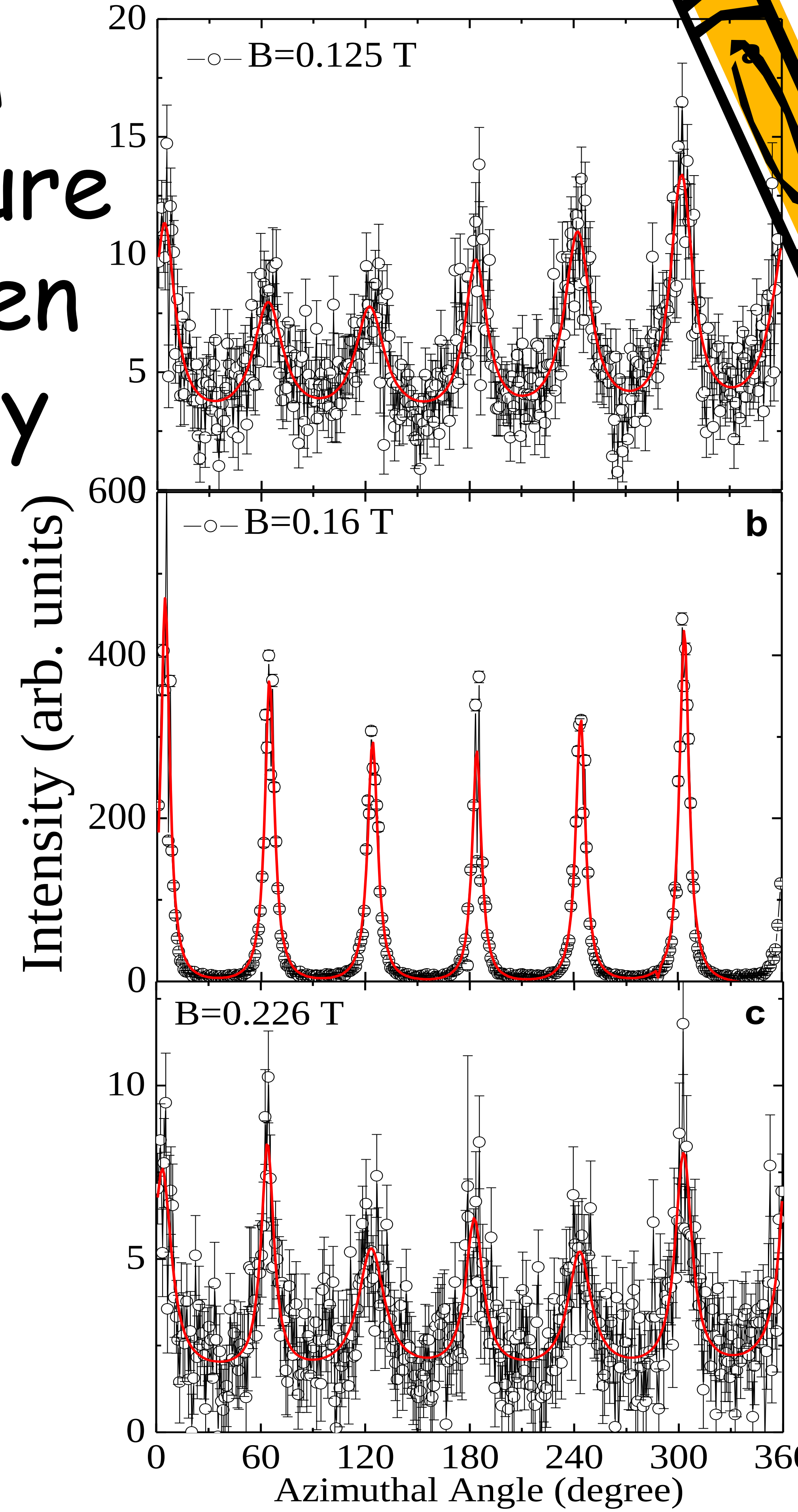




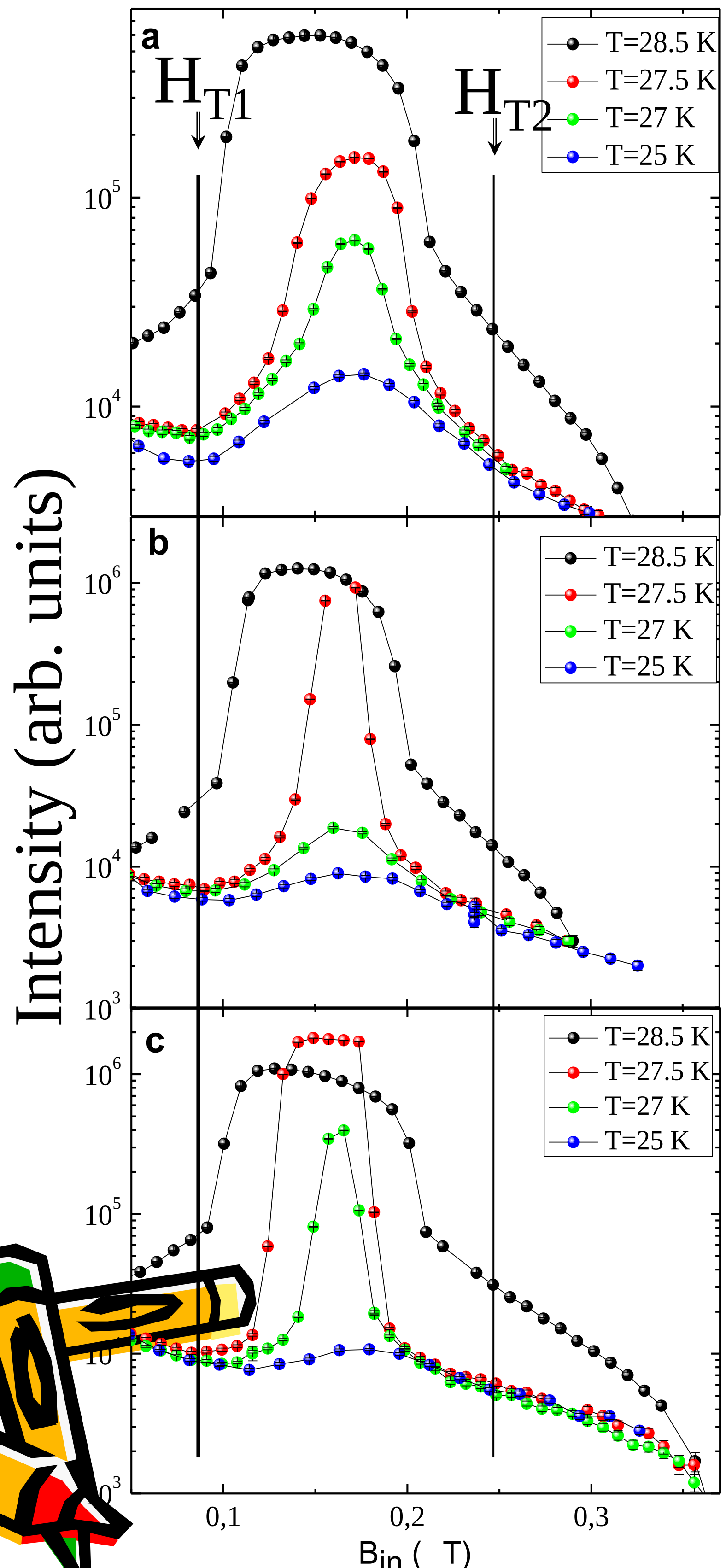
Orientational stability: orientation of hexagon independent on temperature and magnetic field at given field-to crystal geometry

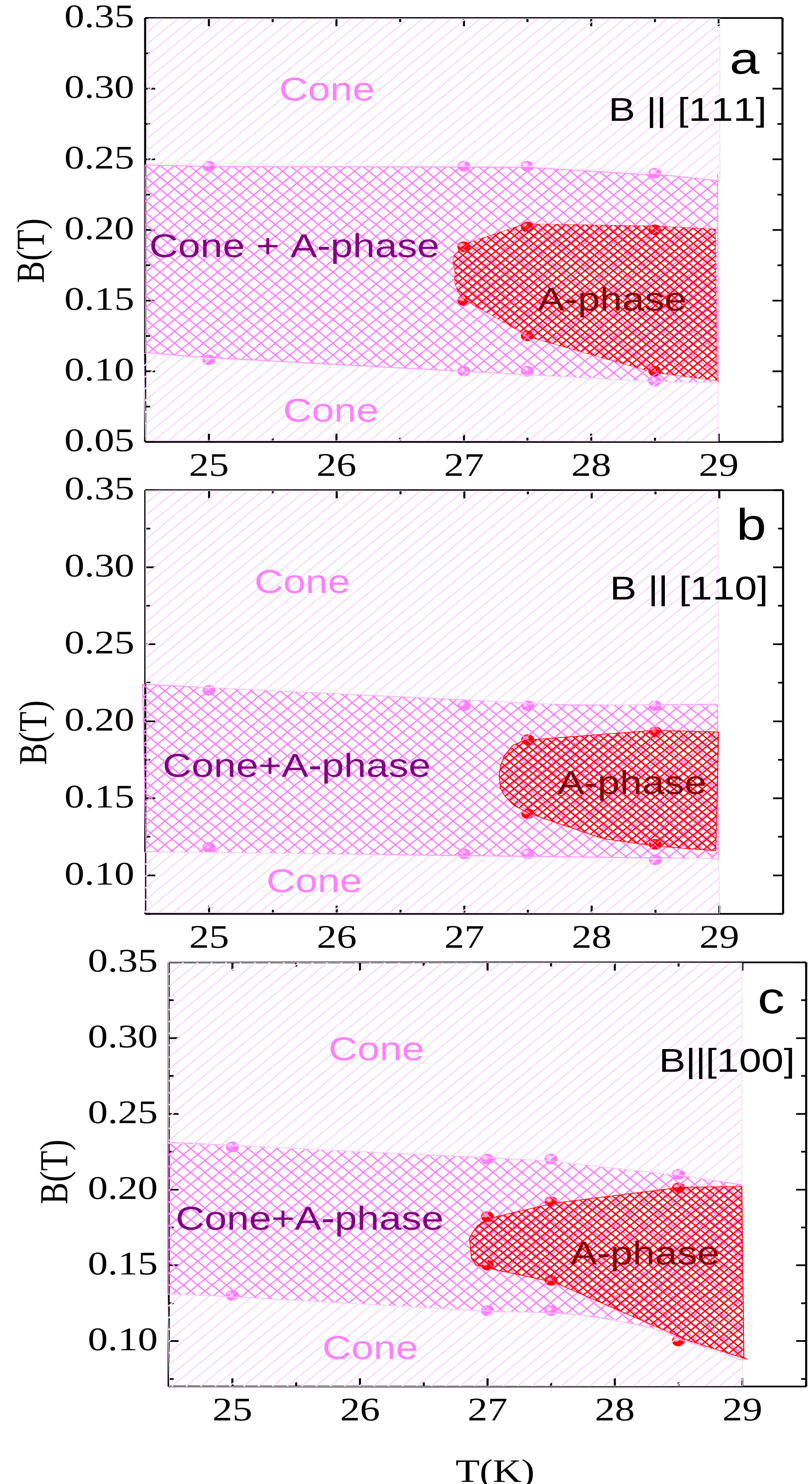






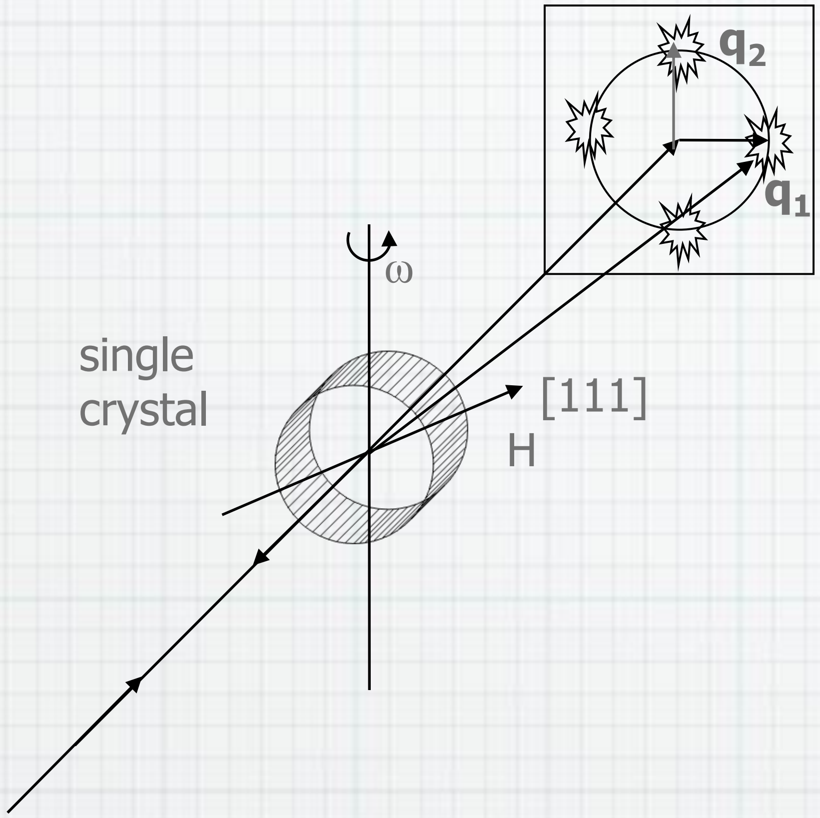
H-T phase diagrams

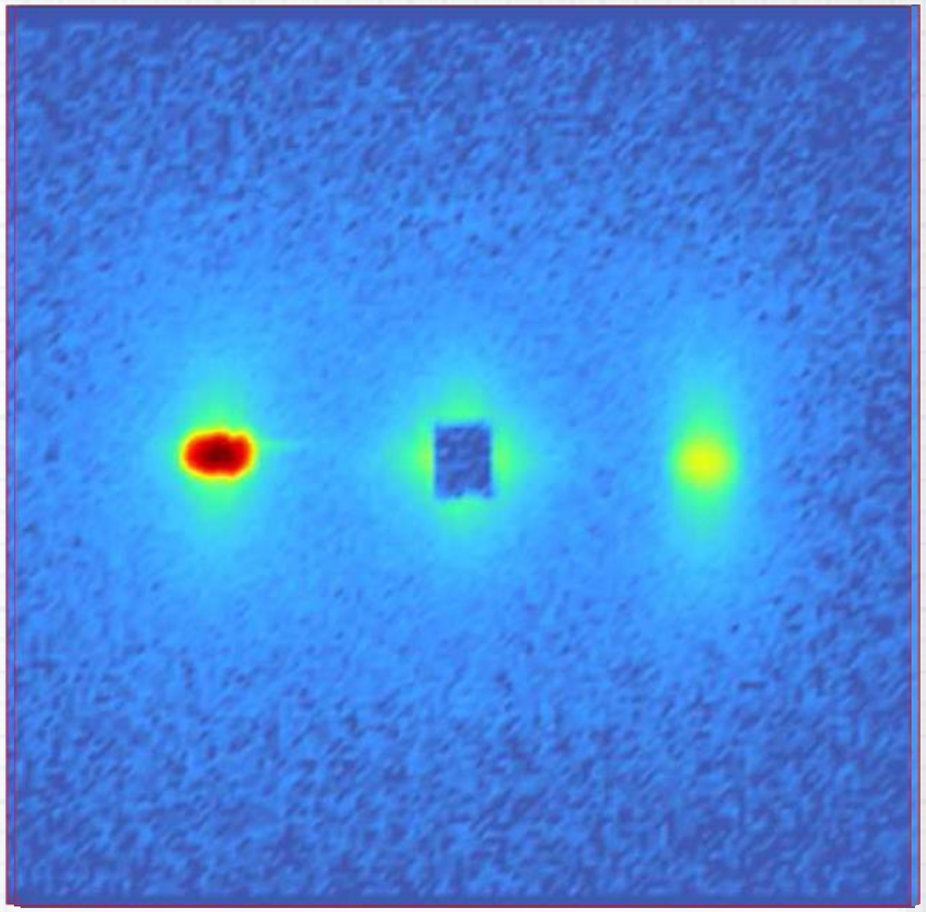




Thermal phase transition in MnSi

T =32K → T =10 K



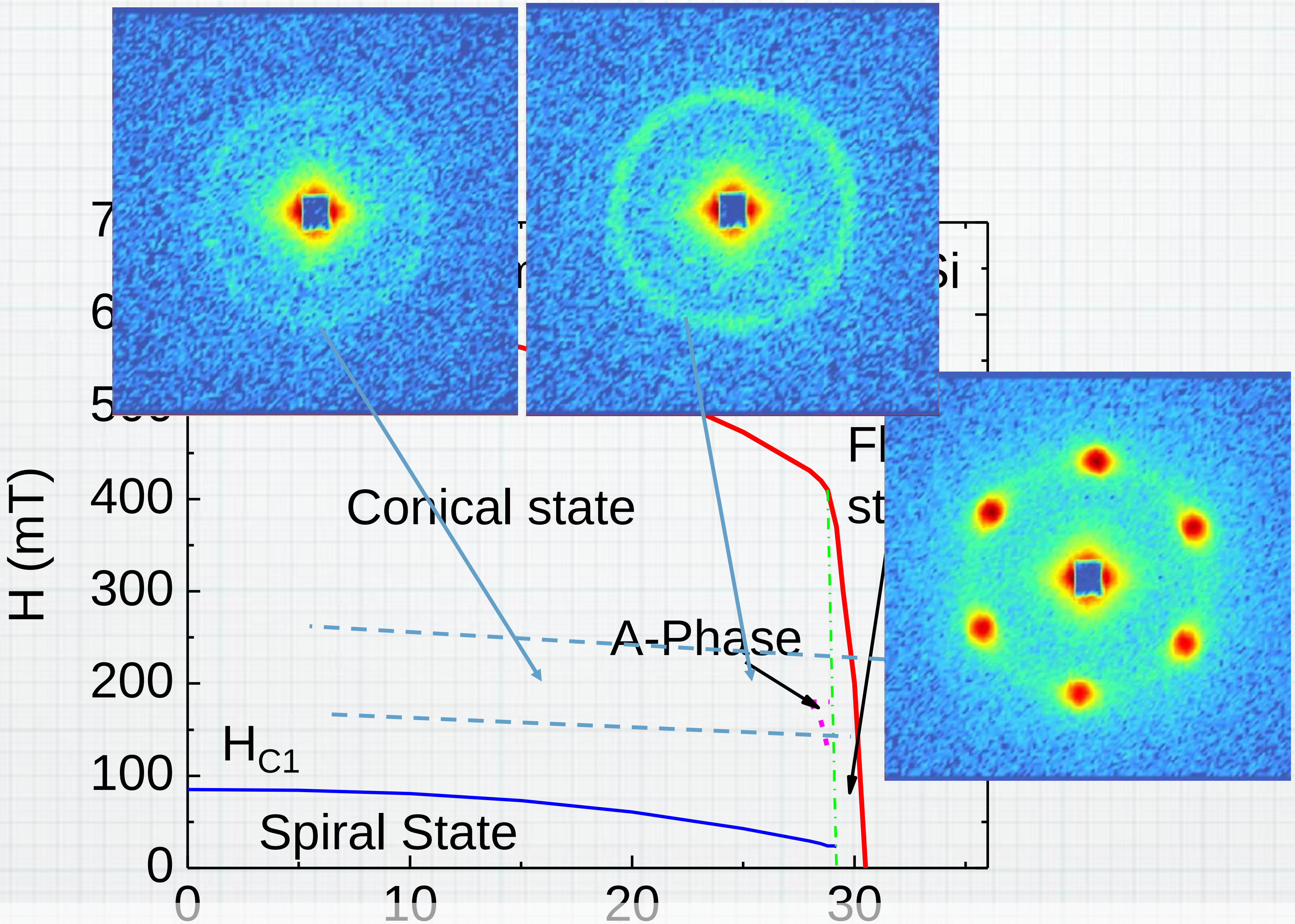


H = 0.16 T

Small angle neutron diffraction experiment on MnSi single crystal

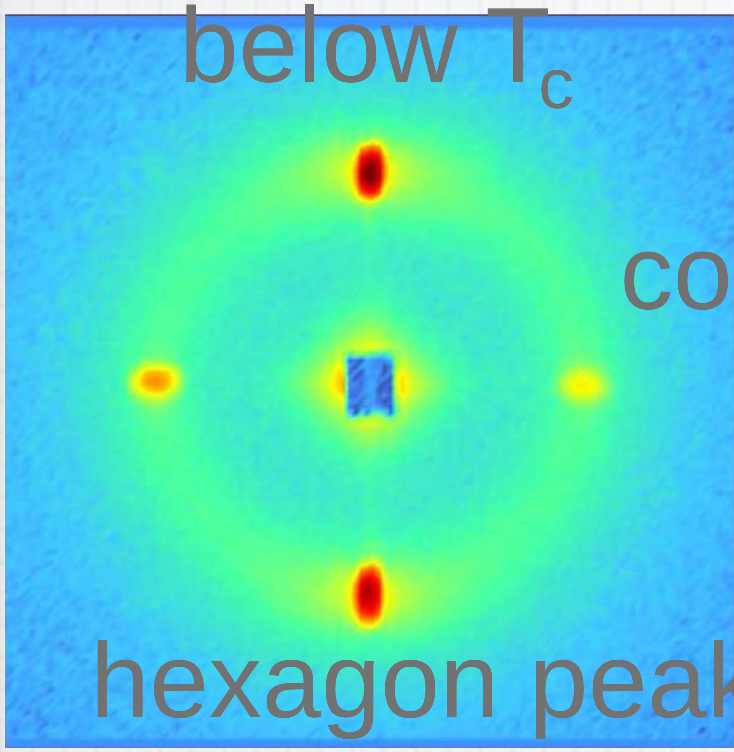
Screen shot of the neutron diffraction picture from MnSi

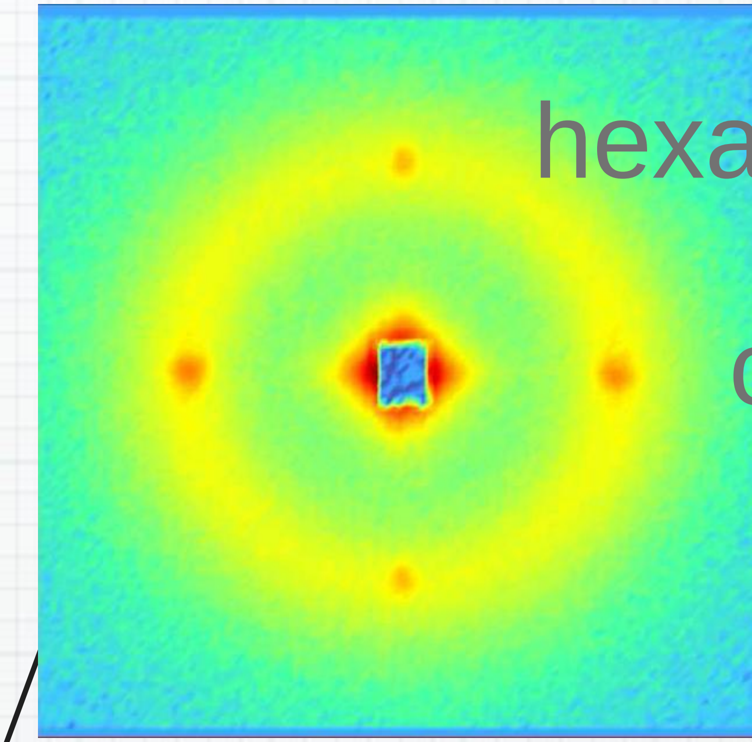
Conclusion 1

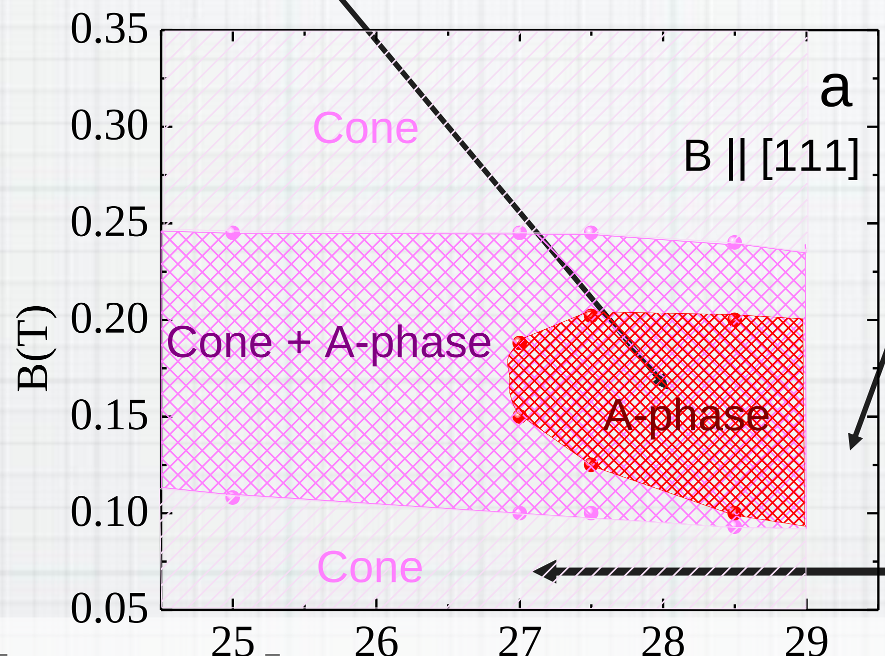


Hexagonal structure ascribed to the A-phase only can be “traced” down to the low temperature range

Conclusion 2







A phase is a structure with coexistence of perpendicular and parallel to field modulations