Observation of chiral fluctuating state in $Mn_{1-x}Fe_xSi$ above T_C

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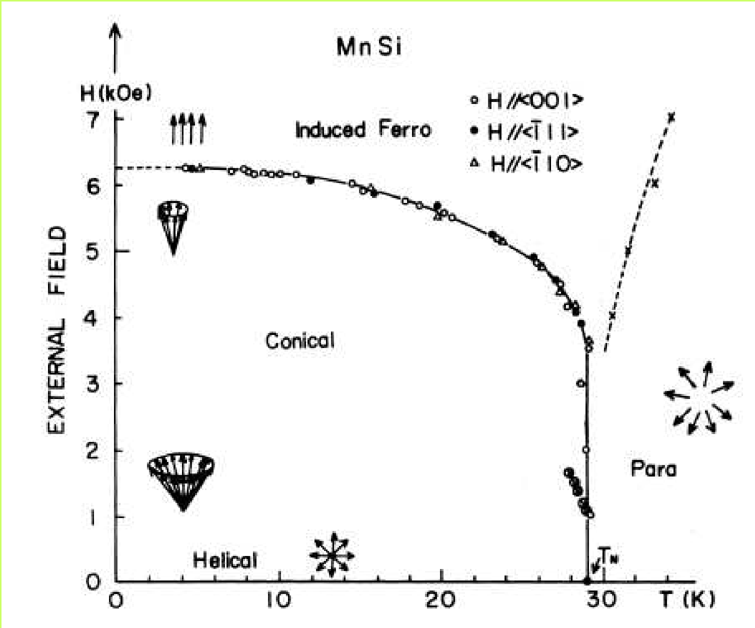
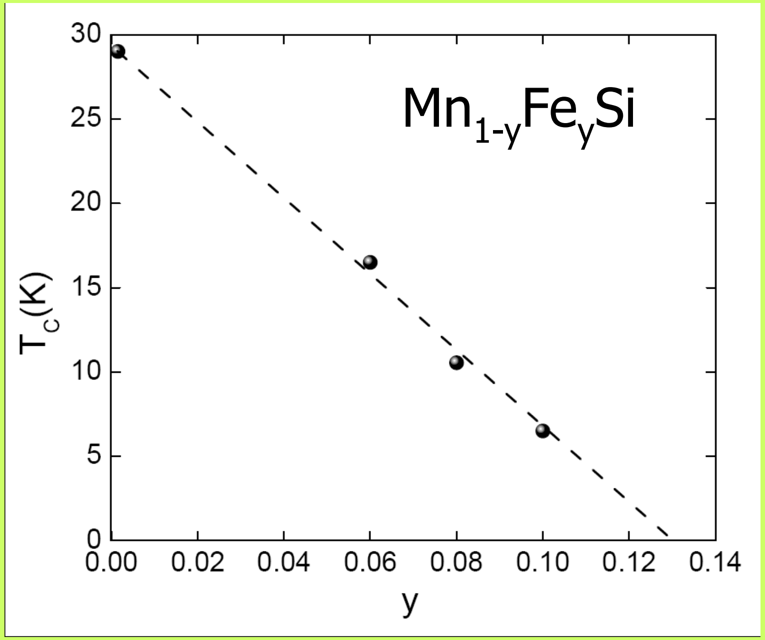
Magnetic order in **$Mn_{1-y}Fe_ySi$**





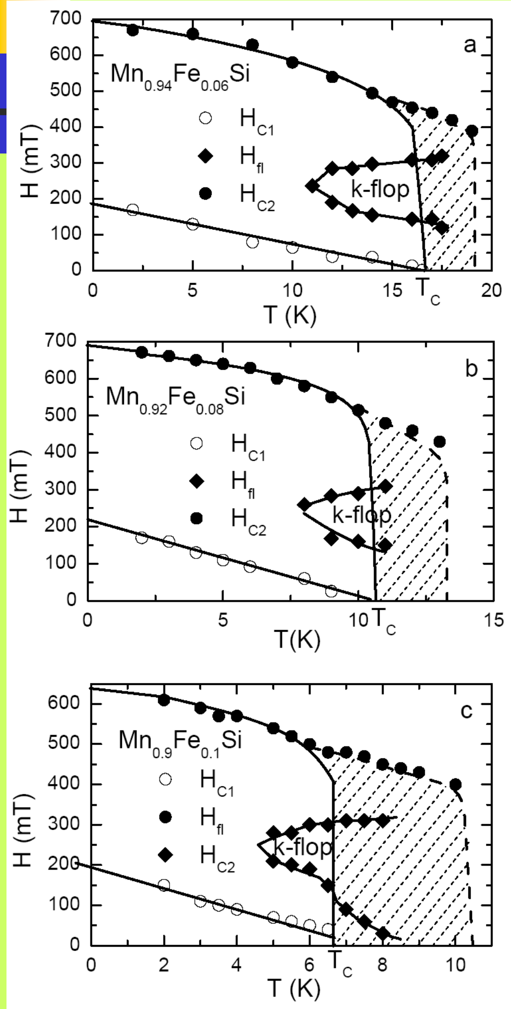
[1] Y. Ishikawa, G. Shirane, J.A. Tarvin, M. Kohgi, Phys.Rev.B **16** (1977) 4956.

1) period 18 - 10 nm for $Mn_{1-y}Fe_ySi$.

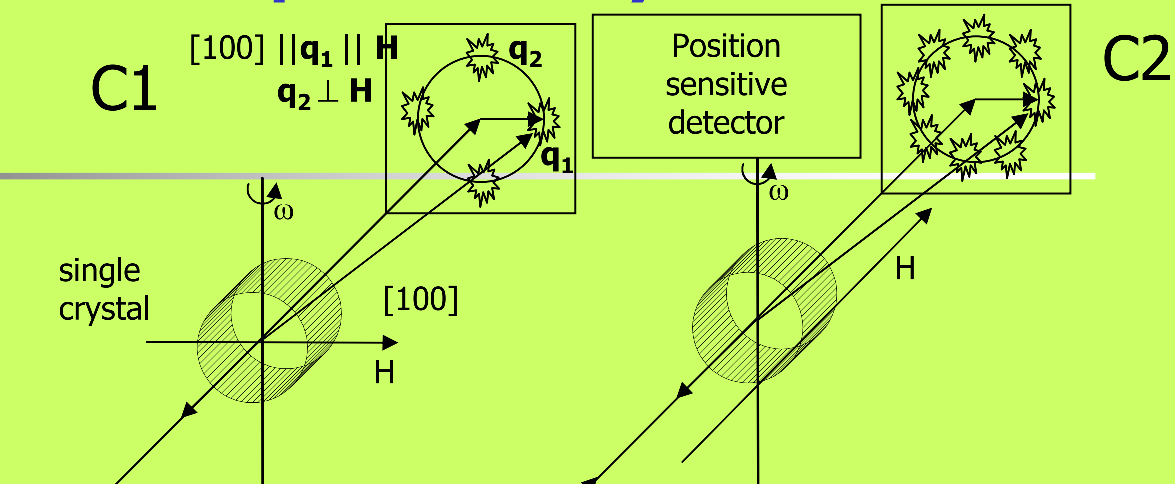
2) μ_S (Me) ≈ 0.25 – 0.40 μ_B for $Mn_{1-y}Fe_ySi$

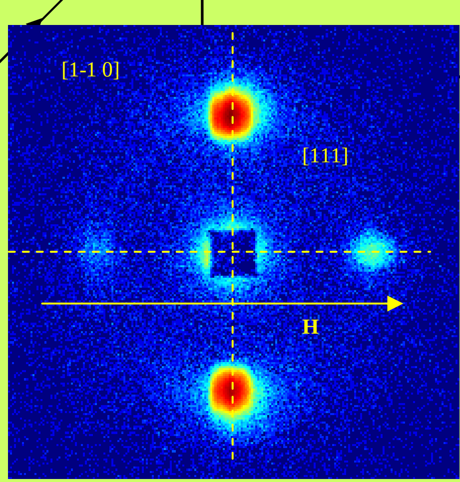
2. H-T phase diagram, appearance of A-phase: spirals or skyrmions ?

$Mn_{1-y}Fe_ySi$



S. V. Grigoriev, V. A. Dyadkin, E. V. Moskvin, D. Lamago, Th. Wolf, H. Eckerlebe, and S. V. Maleyev, Phys.Rev. B **79** (2009) 144417





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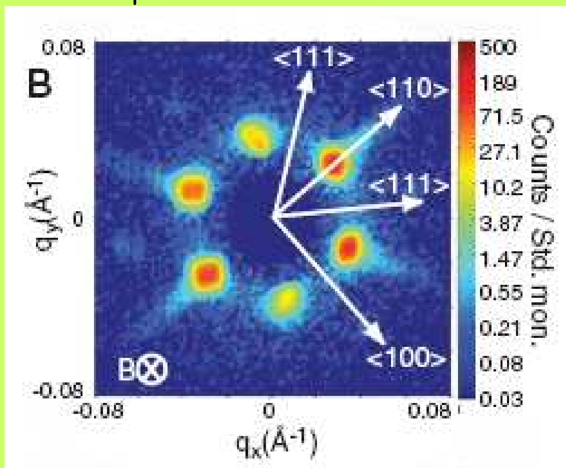
B. Lebech in "Recent Advances in Magnetism of Transition Metal Compounds" p. 167-178 ed. A.Kotani, N Suzuki (1993)

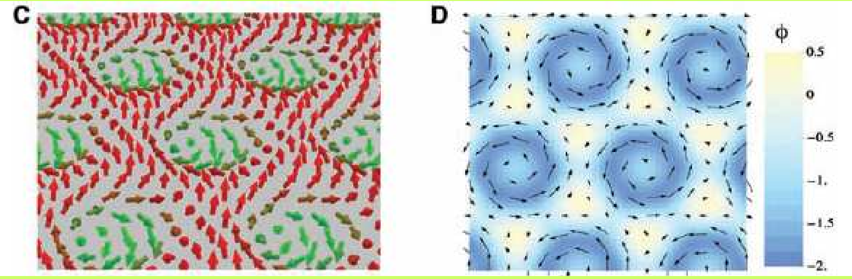


S. Mühlbauer, B. Binz, F. Jonietz, C. Pfleiderer, A. Rosch, A. Neubauer, R. Georgii, P. Böni, Science 323 (2009) 915.

Skyrmion lattice

Real-space observation of a two-dimensional skyrmion crystal
X. Z. Yu, Y. Onose, N. Kanazawa, J. H. Park, J. H. Han, Y. Matsui, N. Nagaosa, Y. Tokura
Nature 465 (2010) 901.

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



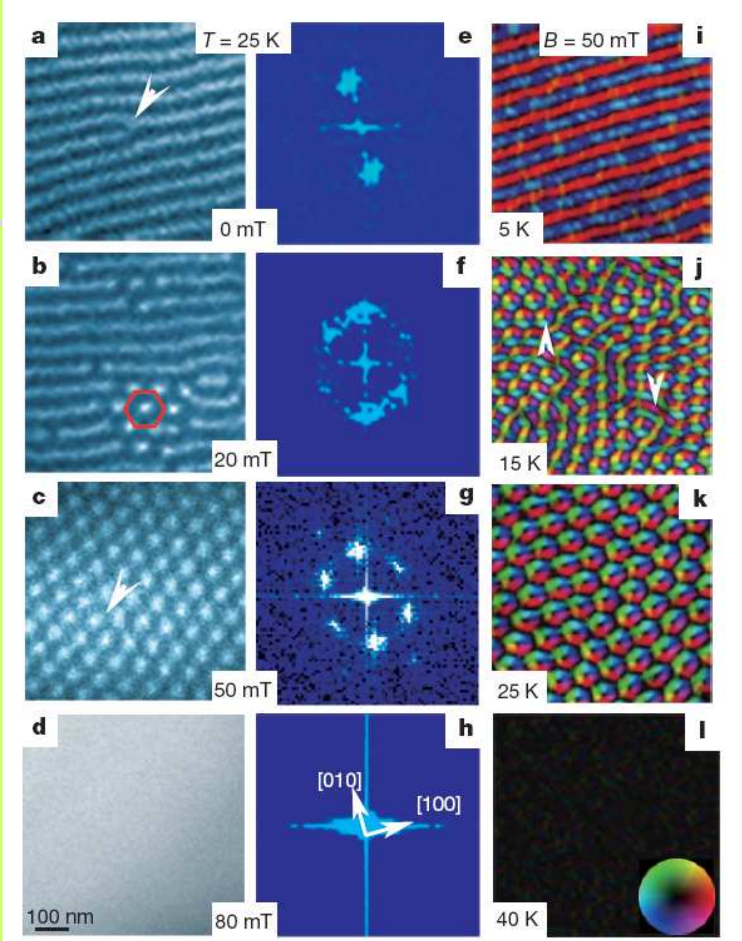


Figure 2 | Variations of spin texture with magnetic field and temperature in $Fe_{0.5}Co_{0.5}Si$. **a–d**, Magnetic-field dependence of the spin texture, in real-space Lorentz TEM (overfocus) images. **e–h**, FFT patterns corresponding to **a–d**. **i–l**, Temperature profiles of the distribution map 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.

[1] Bogdanov, A. N. & Yablonskii, D. A. Thermodynamically stable 'vortices' in magnetically ordered crystals. The mixed state of magnets. Sov. Phys. JETP 68, 101–-103 (1989).
[2] Bogdanov, A. New localized solutions of the nonlinear field-equations. JETP Lett. 62, 247–-251 (1995).
[3] Bogdanov, A. N., Rossler, U. K., Pfleiderer, C. Modulated and localized structures in cubic helimagnets. Physica B 359–-361, 1162–-1164 (2005).
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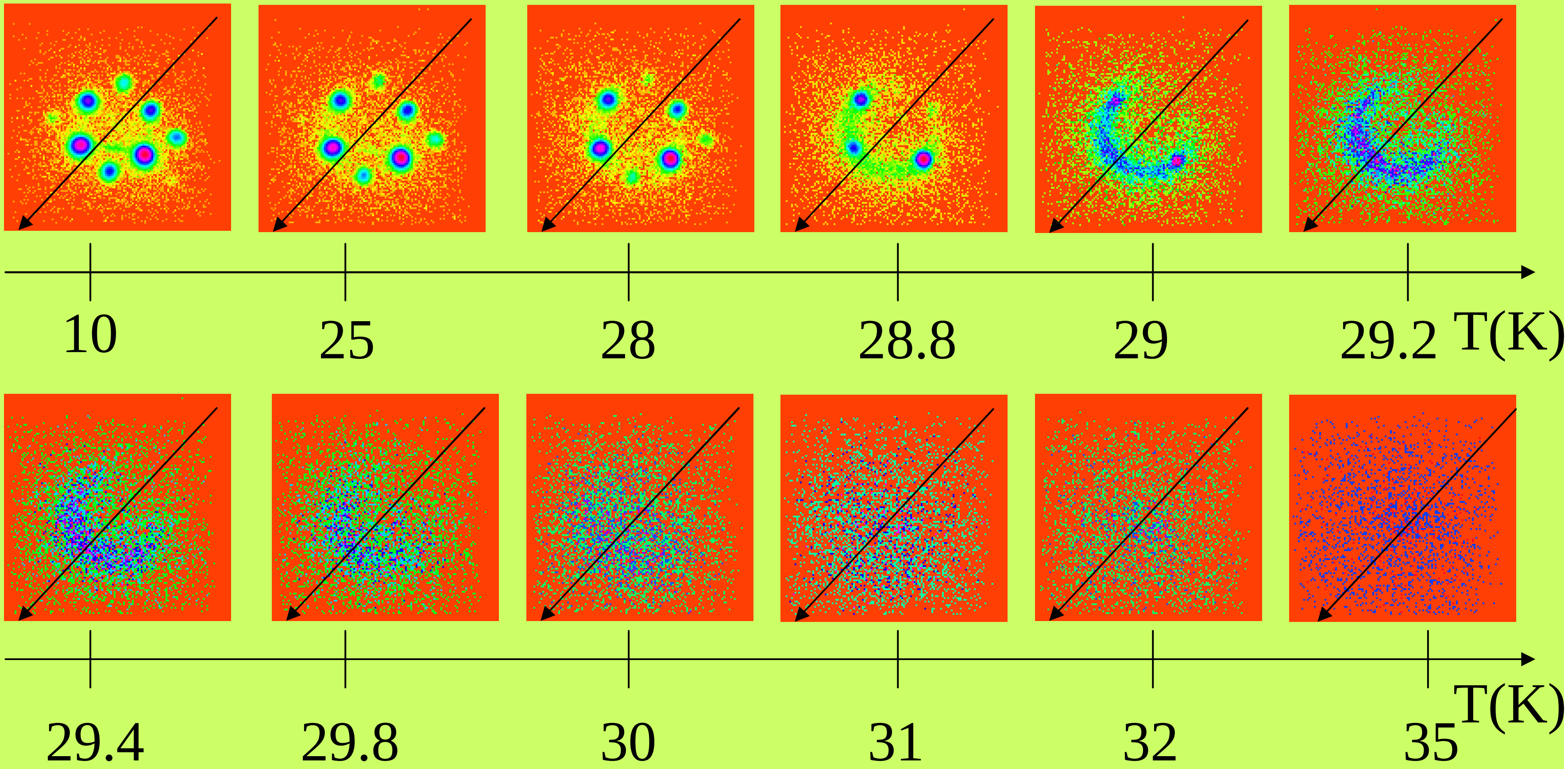
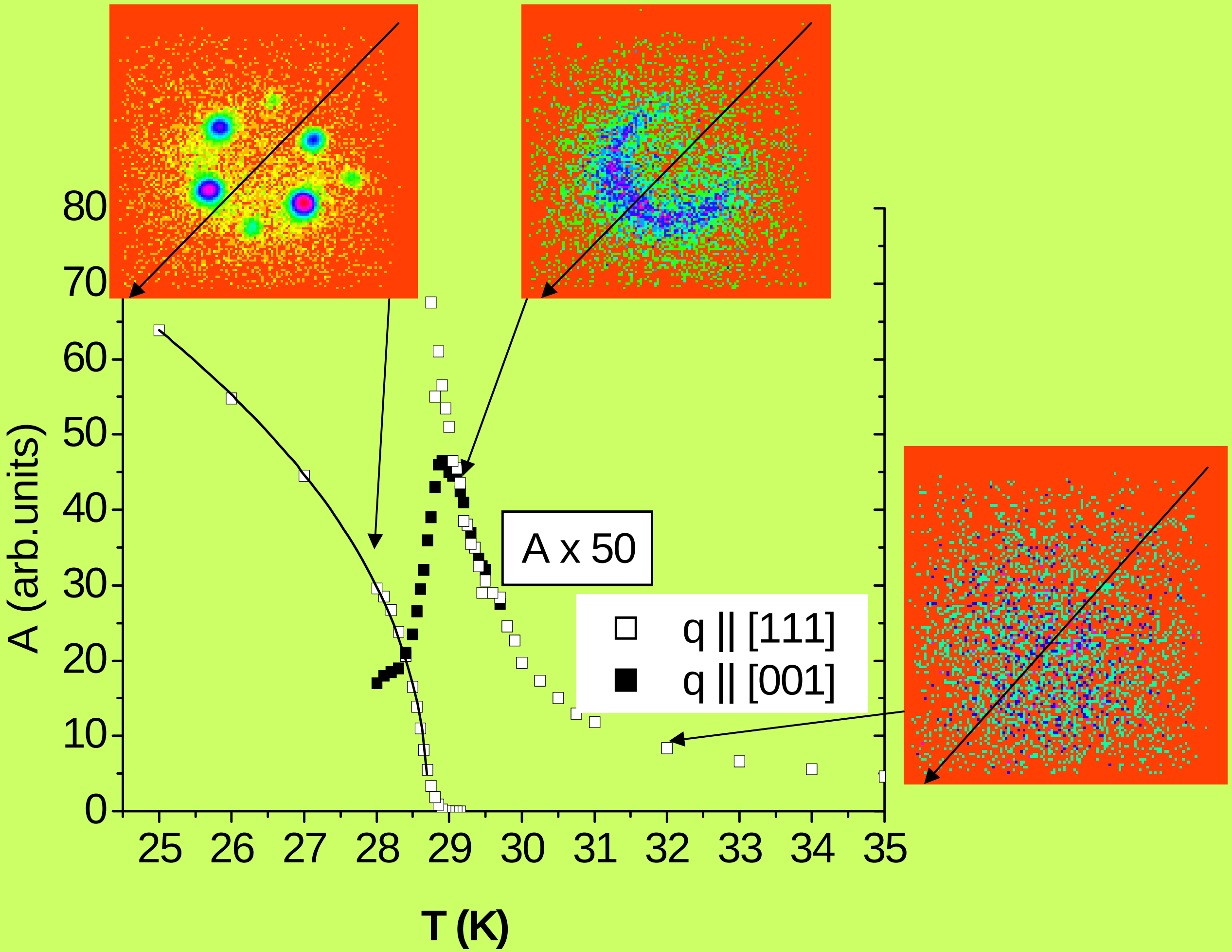
Thermal phase transition in MnSi



Complex nature of the thermal phase transition in MnSi



The neutron cross-section at T > T_C

Bak-Jensen model and bilinear part of the free energy density

$$W(\mathbf{Q}) = \left[\frac{B}{2}\left(Q^2+\kappa_0^2\right)\delta_{\alpha\beta} + iD\epsilon_{\alpha\beta\gamma}Q_\gamma\right] S^\alpha_{\mathbf{Q}} S^\beta_{-\mathbf{Q}} + \frac{F}{2}\left(Q_x^2|S^x_{\mathbf{Q}}|^2 + Q_y^2|S^y_{\mathbf{Q}}|^2 + Q_z^2|S^z_{\mathbf{Q}}|^2\right),$$

Neglecting DMI and anisotropic exchange

$$\chi^F_{\alpha\beta}(\mathbf{Q}) = \frac{T}{B(Q^2+\kappa_0^2)}\delta_{\alpha\beta},$$

In real space

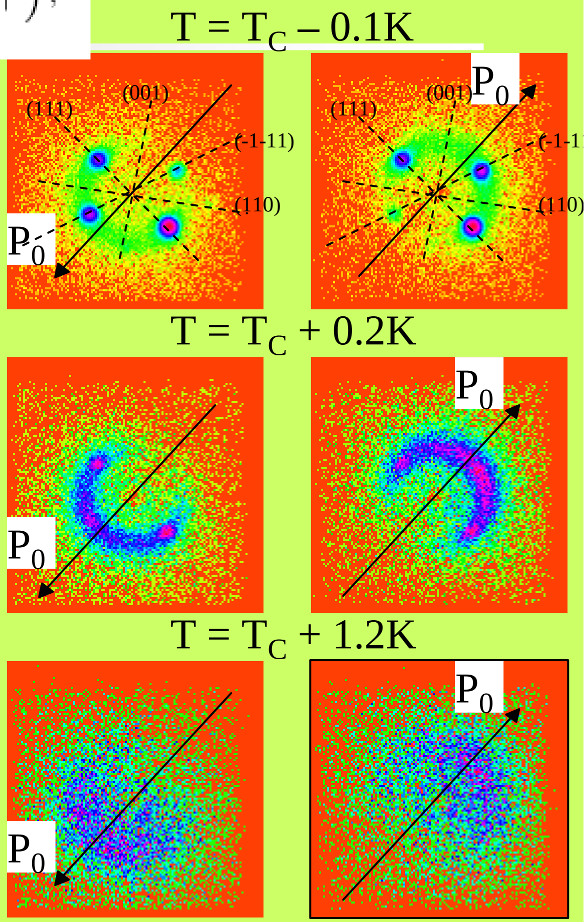
$$\chi^F_{\alpha\beta}(\mathbf{r}) = \frac{1}{(2\pi)^3}\int \chi^F_{\alpha\beta}(\mathbf{Q}) e^{-i\mathbf{Qr}} d^3\mathbf{Q} = \frac{T}{4\pi B}\frac{e^{-\kappa_0 r}}{r}\delta_{\alpha\beta}.$$

Accounting for DMI and anisotropic exchange

$$\chi_{\alpha\beta}(\mathbf{Q}) = \frac{T\left[\left(Q^2+k^2+\kappa_1^2\right)\delta_{\alpha\beta} - 2ik\left(D/|D|\right)\epsilon_{\alpha\beta\gamma}Q_\gamma - 4k^2 Q_\alpha Q_\beta/\left(Q^2+k^2+\kappa_1^2\right)\right]}{B\left\{\left[(Q+k)^2+\kappa_1^2\right]\left[(Q-k)^2+\kappa_1^2\right] - 4(F/B)k^2Q^4\left\{\hat{Q}^4\right\}/\left(Q^2+k^2+\kappa_1^2\right)\right\}},$$

with the corresponding neutron cross section

$$\frac{d\sigma}{d\Omega} = \frac{2r^2T}{B}\frac{Q^2+k^2+\kappa_1^2+2k(D/|D|)(\mathbf{Q}\cdot\mathbf{P}_0)}{[(Q+k)^2+\kappa_1^2][(Q-k)^2+\kappa_1^2]+k^2\kappa_A^2(\mathbf{Q})}$$



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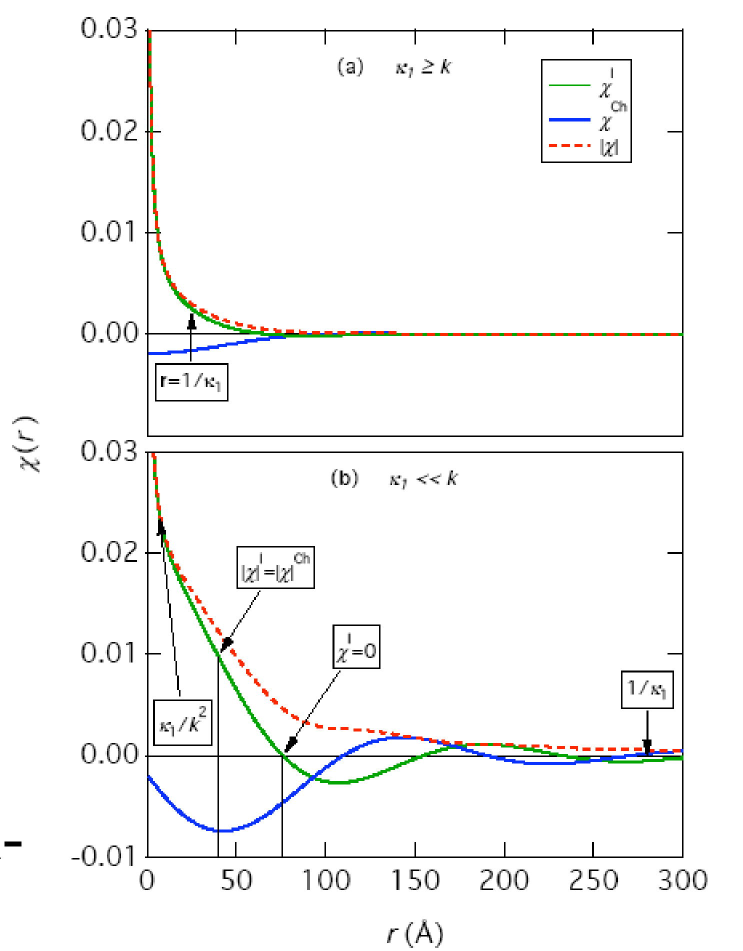
In real space

$$\chi^{I}_{\alpha\beta}(r) = \frac{T}{4\pi B}\frac{e^{-\kappa_1 r}}{r}\left(\cos kr + \frac{k}{\kappa_1}\sin kr\right)\delta_{\alpha\beta},$$

$$\chi^{Ch}_{\alpha\beta}(r) = \frac{T}{4\pi B}(D/|D|)\frac{e^{-\kappa_1 r}}{r}\left[\sin kr + \frac{k}{\kappa_1}\left(\frac{\sin kr}{kr} - \cos kr\right)\right]\epsilon_{\alpha\beta\gamma}\hat{r}_{\gamma},$$

$$\chi^{L}_{\alpha\beta}(r) = \frac{T}{4\pi B(k^2+\kappa_1^2)}\nabla_{\alpha}\nabla_{\beta}\frac{1}{r}\left[e^{-\kappa_1 r}\left(\frac{k}{\kappa_1}\sin kr - \cos kr\right) + e^{-r\sqrt{k^2+\kappa_1^2}}\right]$$



k = 0, then ferromagnetic fluctuations

$k < \kappa_1$, then ferromagnetic type diffuse fluctuations (a certain chirality but k is ill-determined)

$k > \kappa_1$, then helical fluctuations with a certain chirality and a well defined k.

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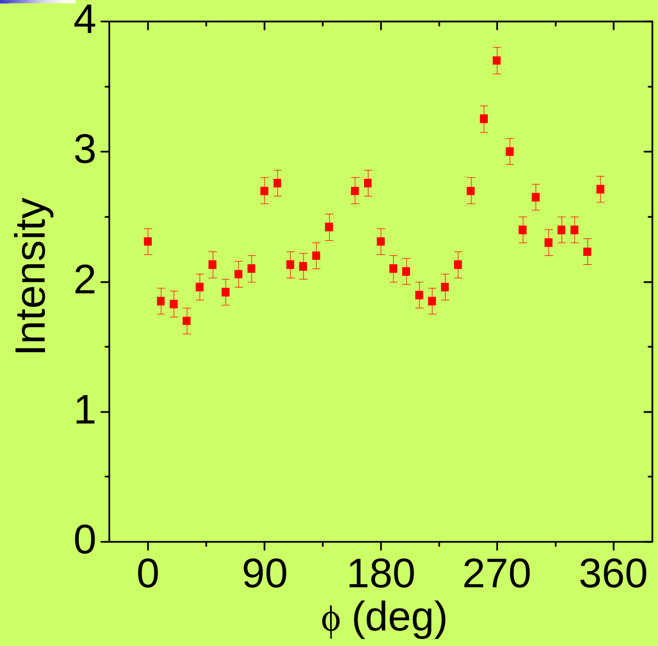
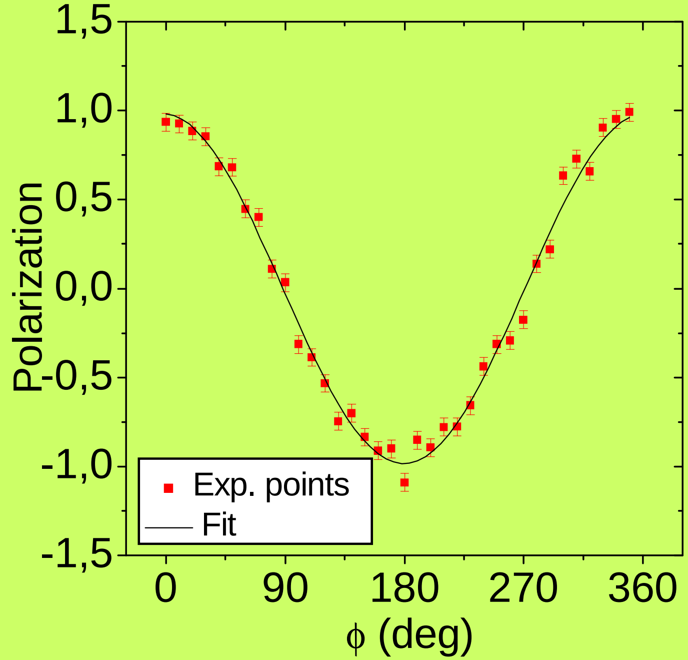
Data analysis: angle dependence

$$\frac{d\sigma}{d\Omega} = \frac{[rF(\mathbf{q})]^2 T}{[B(q+k)^2+\kappa^2]} \frac{k^2+q^2+\kappa^2-2k\mathbf{q}\mathbf{P}_0}{[(q-k)^2+\kappa^2+(|U|k^2/2)(\hat{q}^4-1/3)]}$$

$$P_s = \frac{\sigma(\mathbf{P_0})-\sigma(-\mathbf{P_0})}{\sigma(\mathbf{P_0})+\sigma(-\mathbf{P_0})} = -\frac{2kqP_0\cos\varphi}{q^2+k^2+\kappa^2}$$



Intensity of the scattering at |**q**| = k
I = (I(P_0) + I($-P_0$)) at T = T_C + 0.3 K.

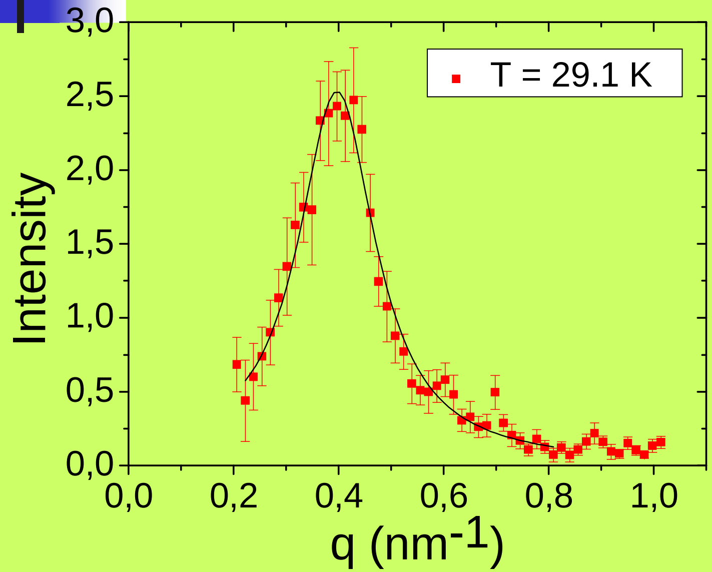


Polarization of the scattering at |**q**| = k
at T = T_C + 0.3 K.

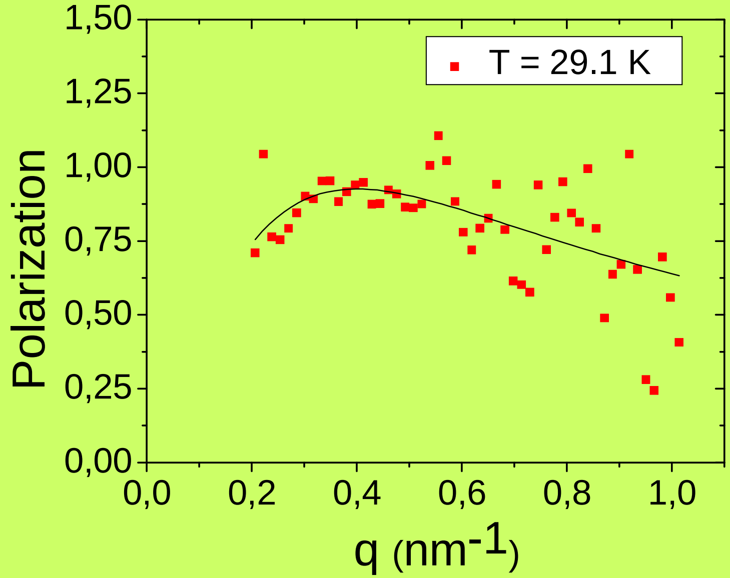
Data analysis: q-dependence

$$\frac{d\sigma}{d\Omega} = \frac{[rF(\mathbf{q})]^2 T}{[B(q+k)^2+\kappa^2]}\frac{k^2+q^2+\kappa^2-2k\mathbf{q}\mathbf{P}_0}{[(q-k)^2+\kappa^2+(|U|k^2/2)(\hat{q}^4-1/3)]}$$

$$P_s = \frac{\sigma(\mathbf{P_0})-\sigma(-\mathbf{P_0})}{\sigma(\mathbf{P_0})+\sigma(-\mathbf{P_0})} = -\frac{2kqP_0\cos\varphi}{q^2+k^2+\kappa^2}$$

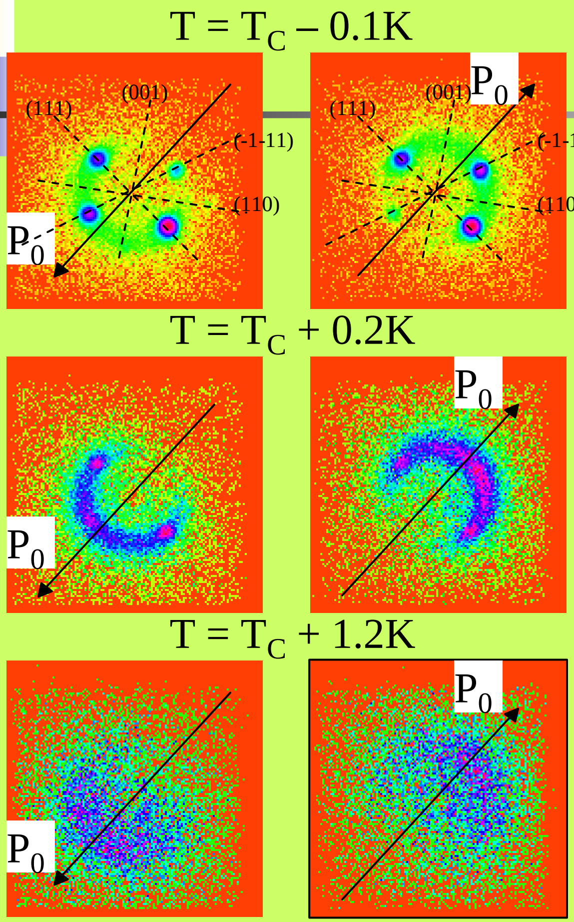


Intensity of the scattering at **q** || $\mathbf{P_0}$
$I(q) = (I(q,P_0) + I(q,-P_0))$

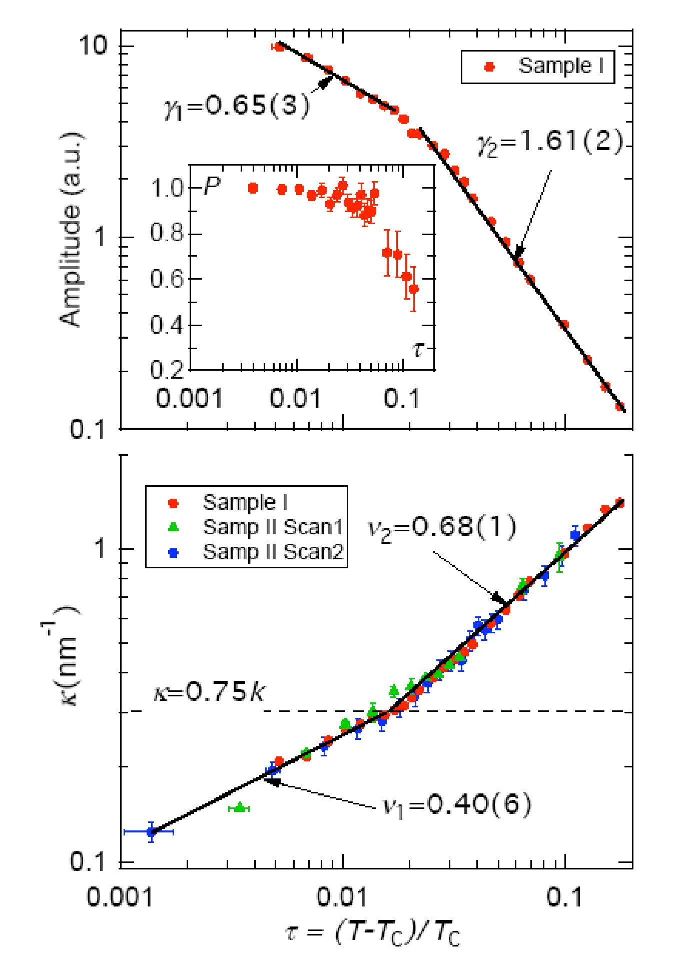


Polarization of the scattering at **q** || $\mathbf{P_0}$
at $T = T_C + 0.3$ K.

Data analysis
temperature dependence

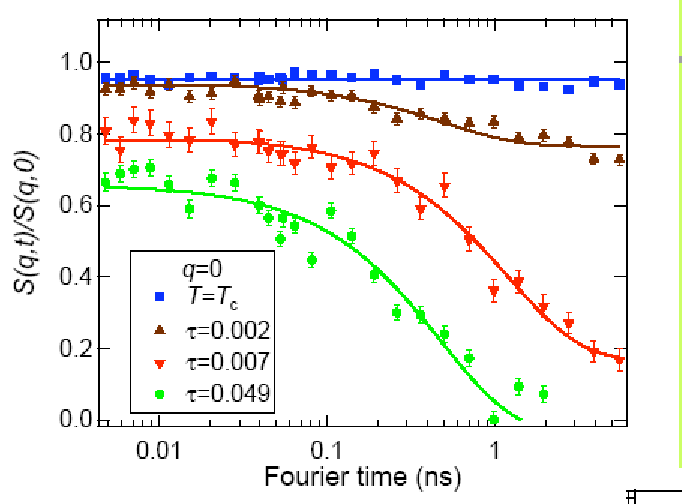


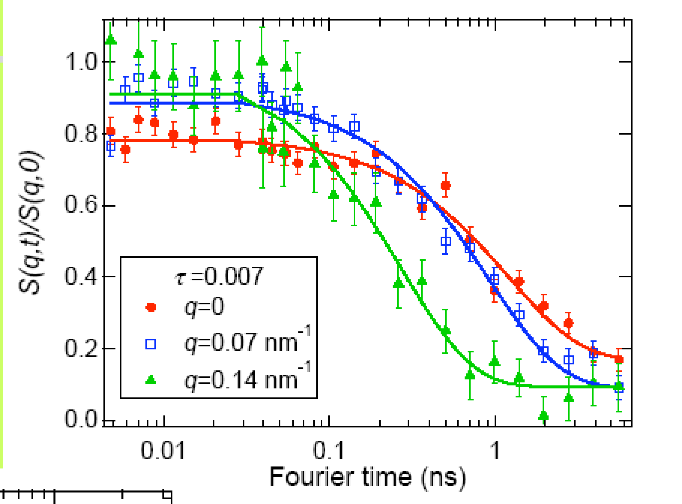
Polarized SANS maps

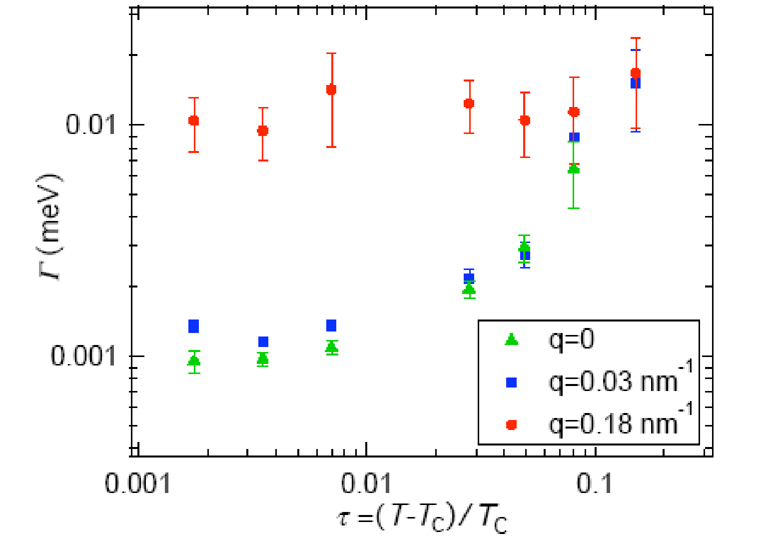


τ- dependence of (a) amplitude of scattering and (b) inverse correlation length.

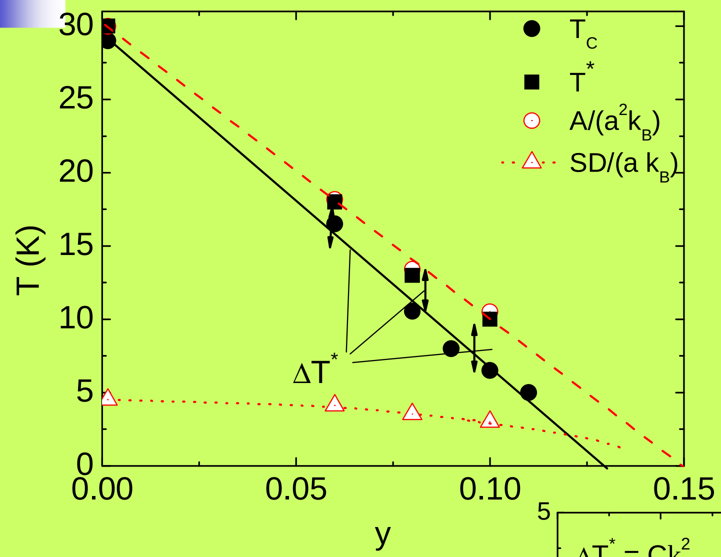
Spin echo measurements of critical fluctuations in MnSi

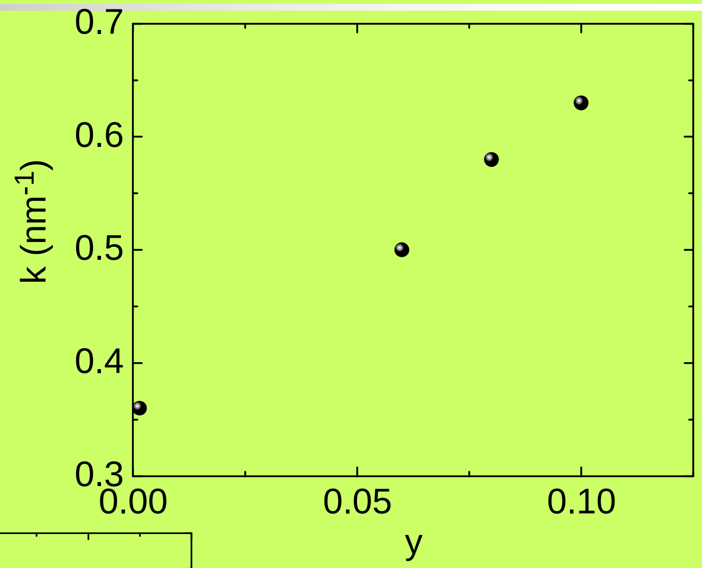


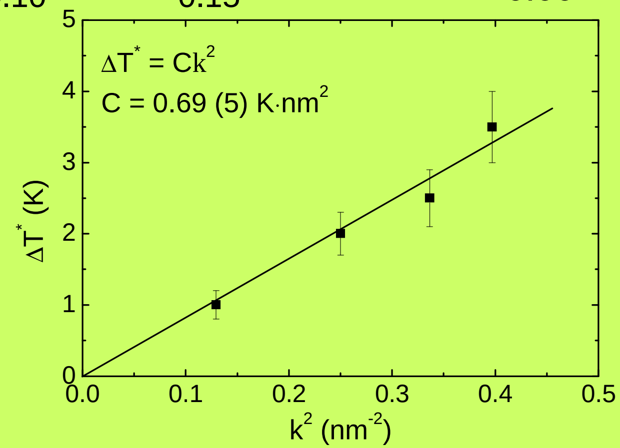




Chiral fluctuating state in $Mn_{1-y}Fe_ySi$ above T_C







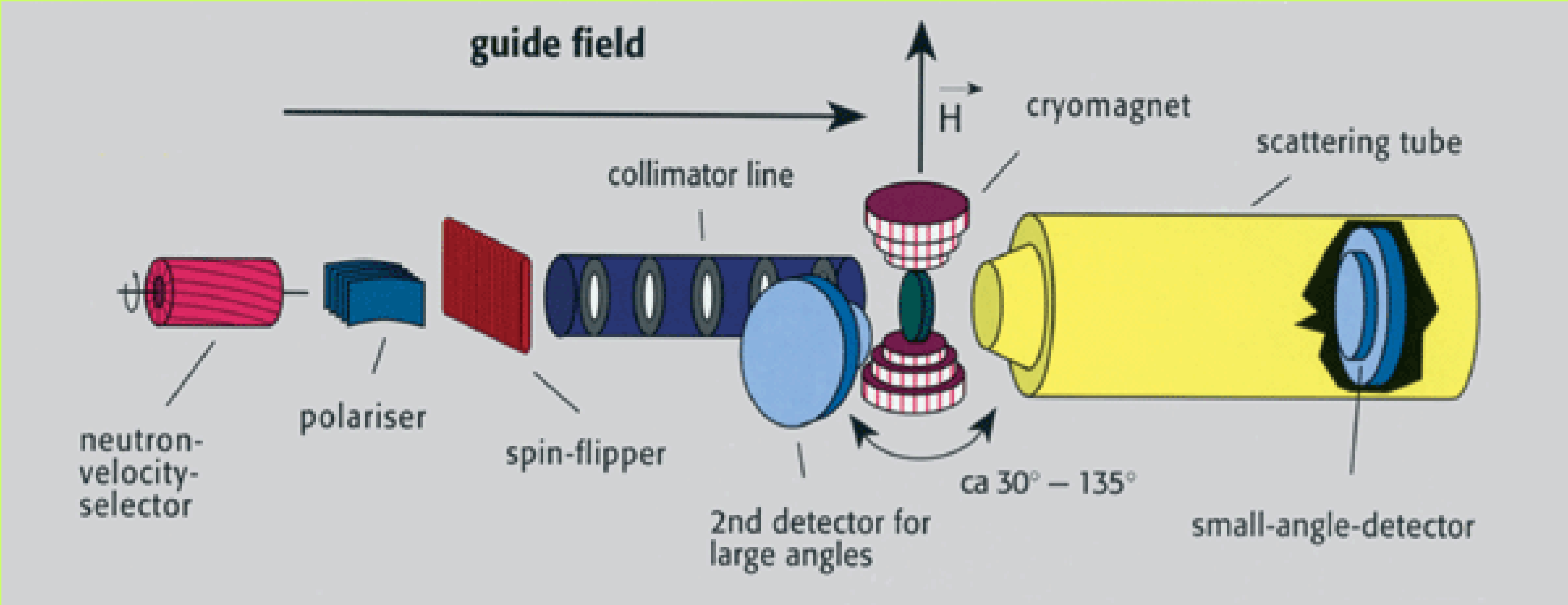
Conclusion

Complex nature of the thermal phase transition has been explained on the basis of MF theory.

The obtained susceptibility and neutron cross section describes the existing set of the experimental data for MnSi.

Acknowledgements

The SANS2 at GKSS in Geesthacht (Germany) (responsible Helmut Eckerlebe).



P_0=0.95,
λ=0.58 nm
(Δλ/λ=0.1)

Acknowledgements

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