Laboratoire Léon Brillouin

Fédération Française de Diffusion Neutronique

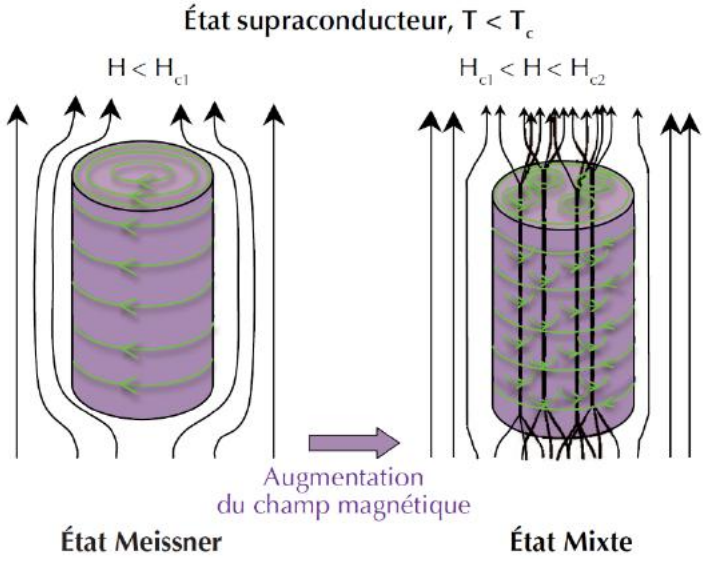
Magnetic textures and neutron scattering

Nicolas Martin

Journée de lancement de la 2FDN
16/05/2017

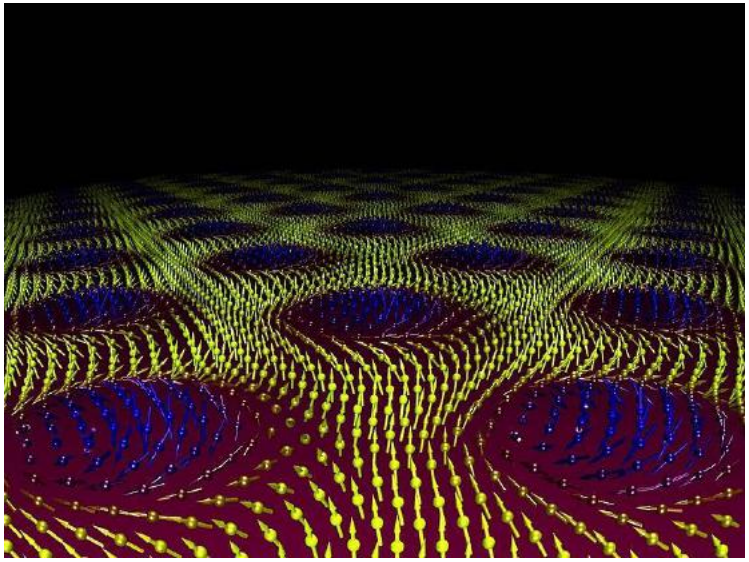
Magnetic textures and neutron scattering

Vortex lattices in type II superconductors



Prediction: Abrikosov, JETP **32**, 1442 (**1957**)

Skyrmion lattices in chiral magnets



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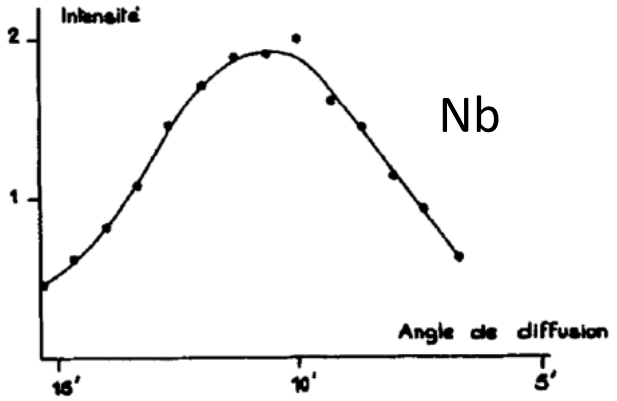
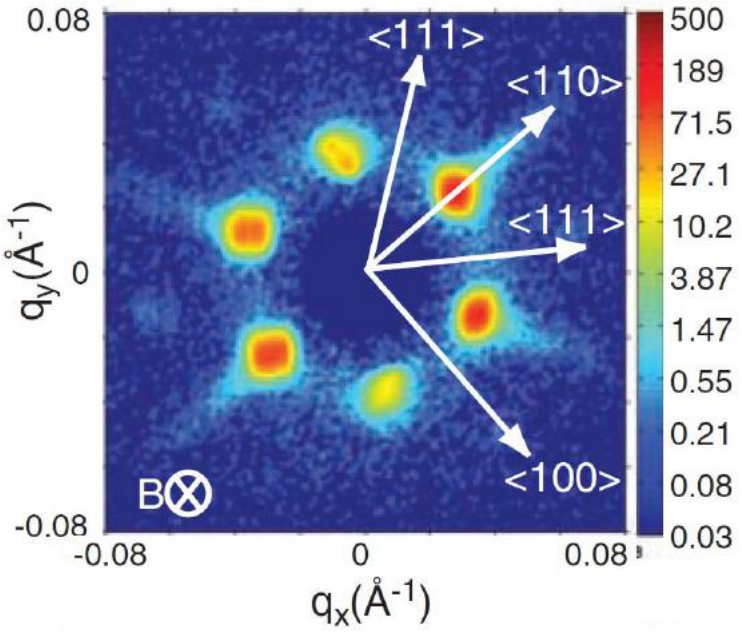


Fig. 2. Pic de Bragg observé avec l'échantillon recuit et un champ appliqué de 1620 Oe. La largeur du pic correspond au pouvoir de résolution de l'appar eil.

Prediction: Abrikosov, JETP **32**, 1442 (**1957**)
Discovery: Cribier *et al.*, Phys. Lett. **9**, 106 (**1964**)

Skyrmion lattices in chiral magnets



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

Magnetic textures and neutron scattering

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Neutron scattering

- Extended Q-range:

→ structures with typical size 1 Å ≤ d ≤ 0.1 µm

- High penetration power:

→ probe bulk samples

- Extreme sensitivity to magnetism:

→ the best (vectorial) magnetometer on the market

Pred

Disc

(**1989**)

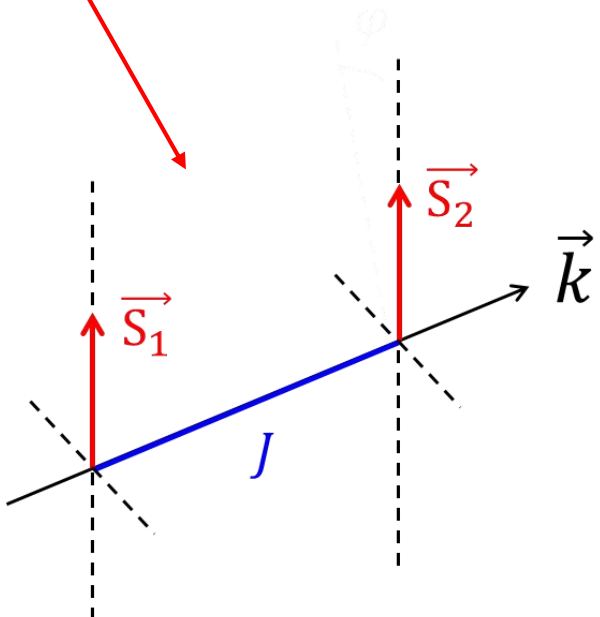
009)

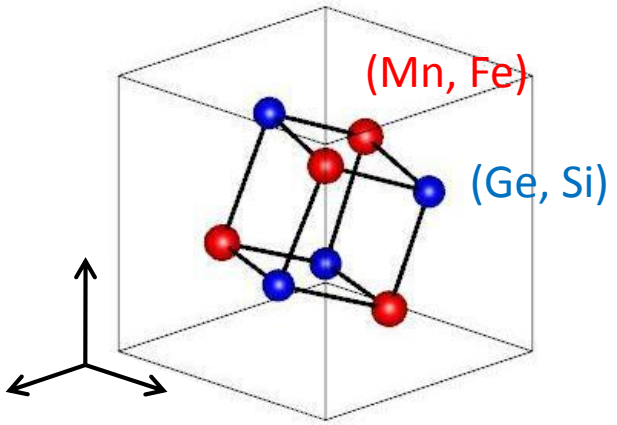
The B20 chiral magnets

General properties

- Non centrosymmetric chiral space group $P2_13$
- Some examples: MnSi, FeGe, $Fe_xCo_{1-x}Si$, **MnGe**…
- Hierarchy of energy scales:

$$\mathcal{H} = -J\,\vec{S_i}\cdot\vec{S_j} + \vec{D_{ij}}\cdot\vec{S_i}\times\vec{S_j} + \sum_k \alpha^k_{\mathrm{cub}}\nabla\vec{S_i}\nabla\vec{S_j} - g\mu_B\sum_i \vec{H}\cdot\vec{S_i}$$





Bak and Jensen, J Phys C **13**, L881 (1980)

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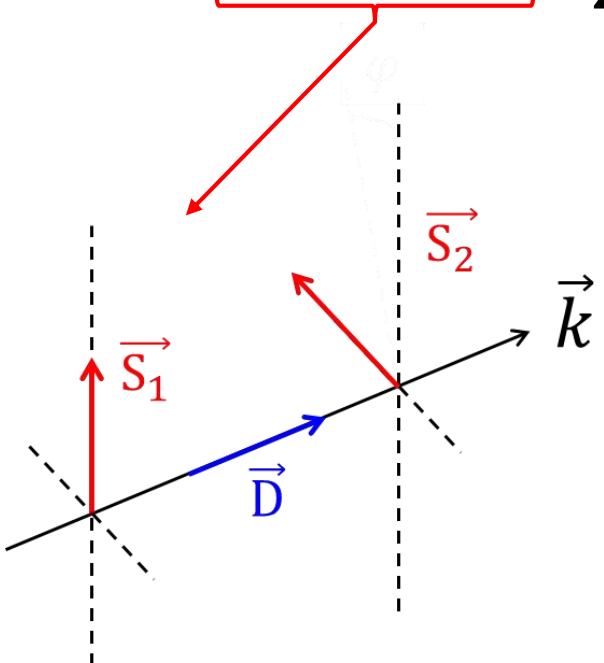

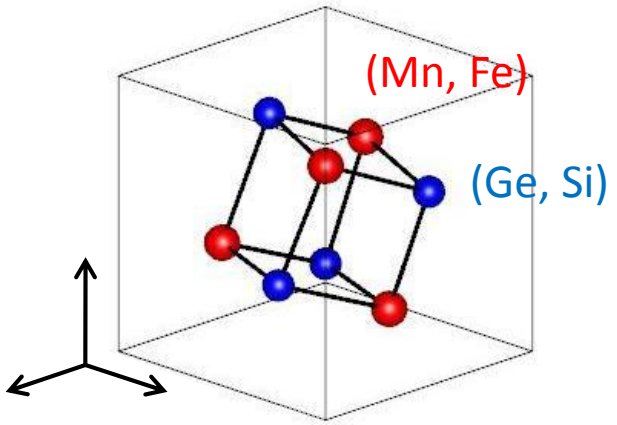

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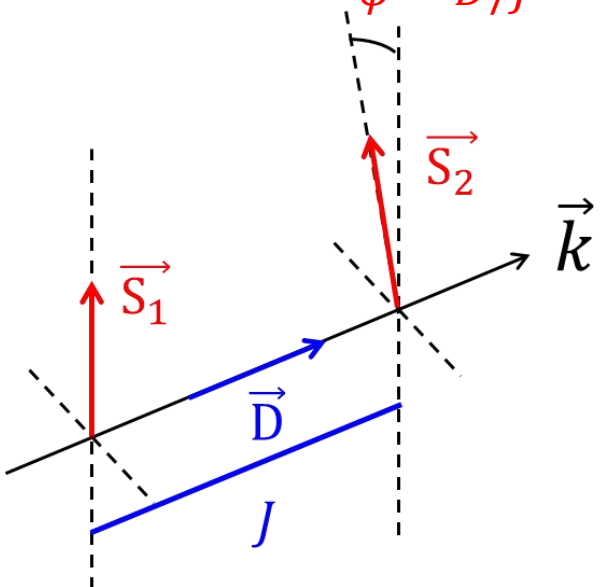

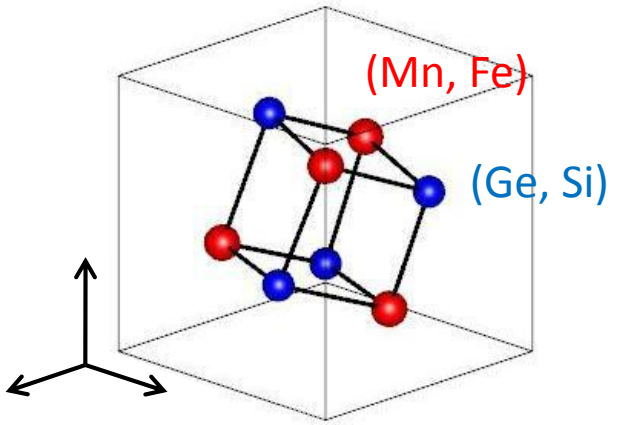

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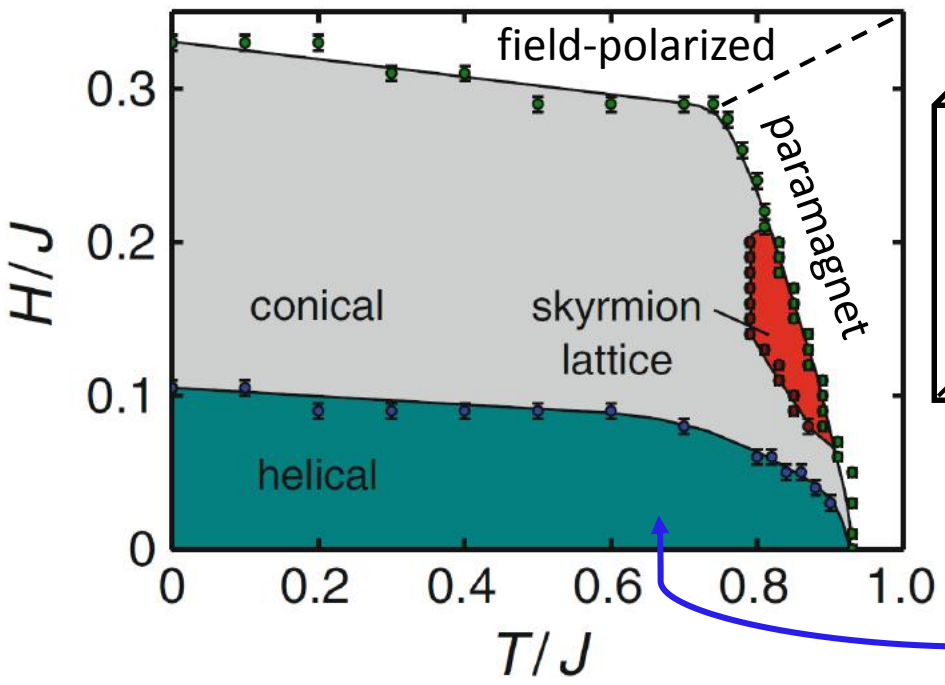
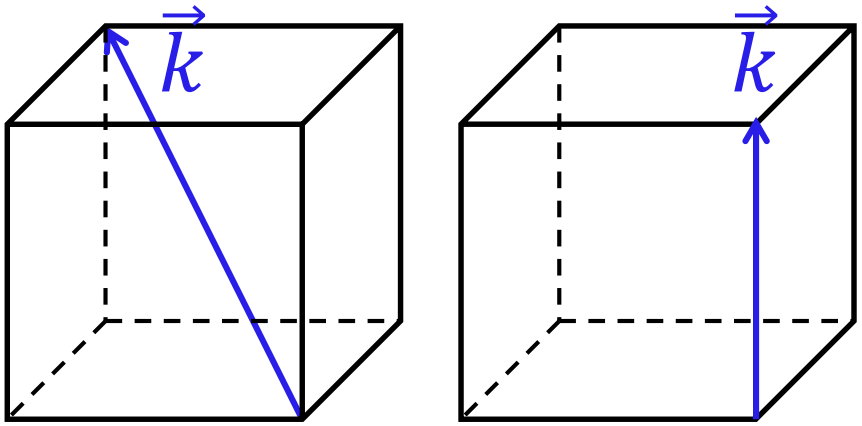
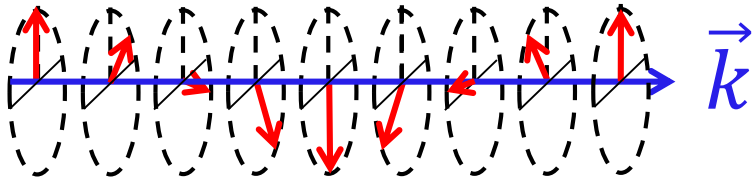
The B20 chiral magnets

(H,T)-phase diagram

$$\mathcal{H} = -J\,\vec{S_i}\cdot\vec{S_j} + \vec{D_{ij}}\cdot\vec{S_i}\times\vec{S_j} + \sum_k \alpha^k_{\mathrm{cub}}\nabla\vec{S_i}\nabla\vec{S_j} - g\mu_B\sum_i \vec{H}\cdot\vec{S_i}$$







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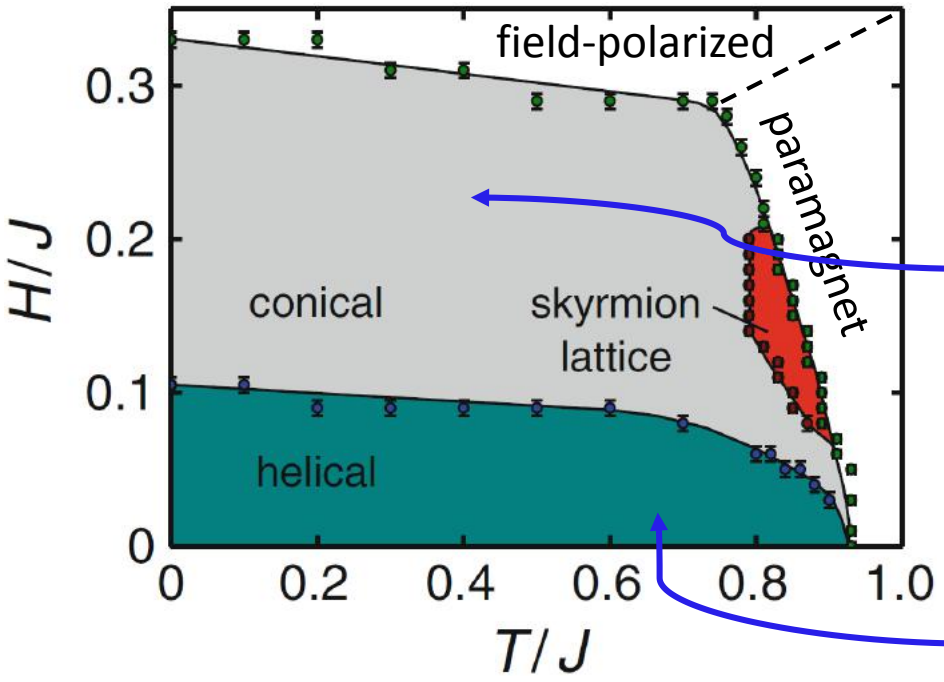

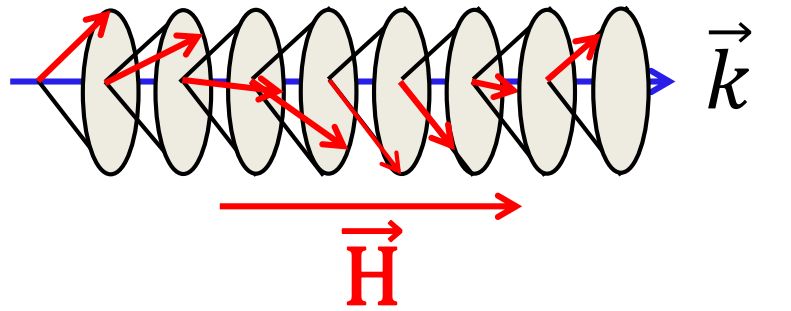

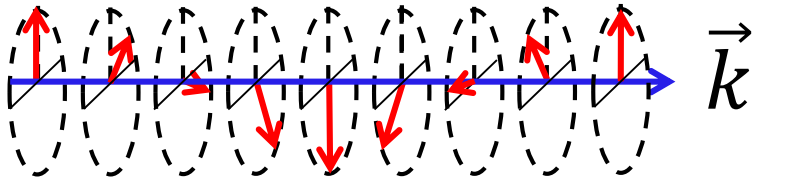

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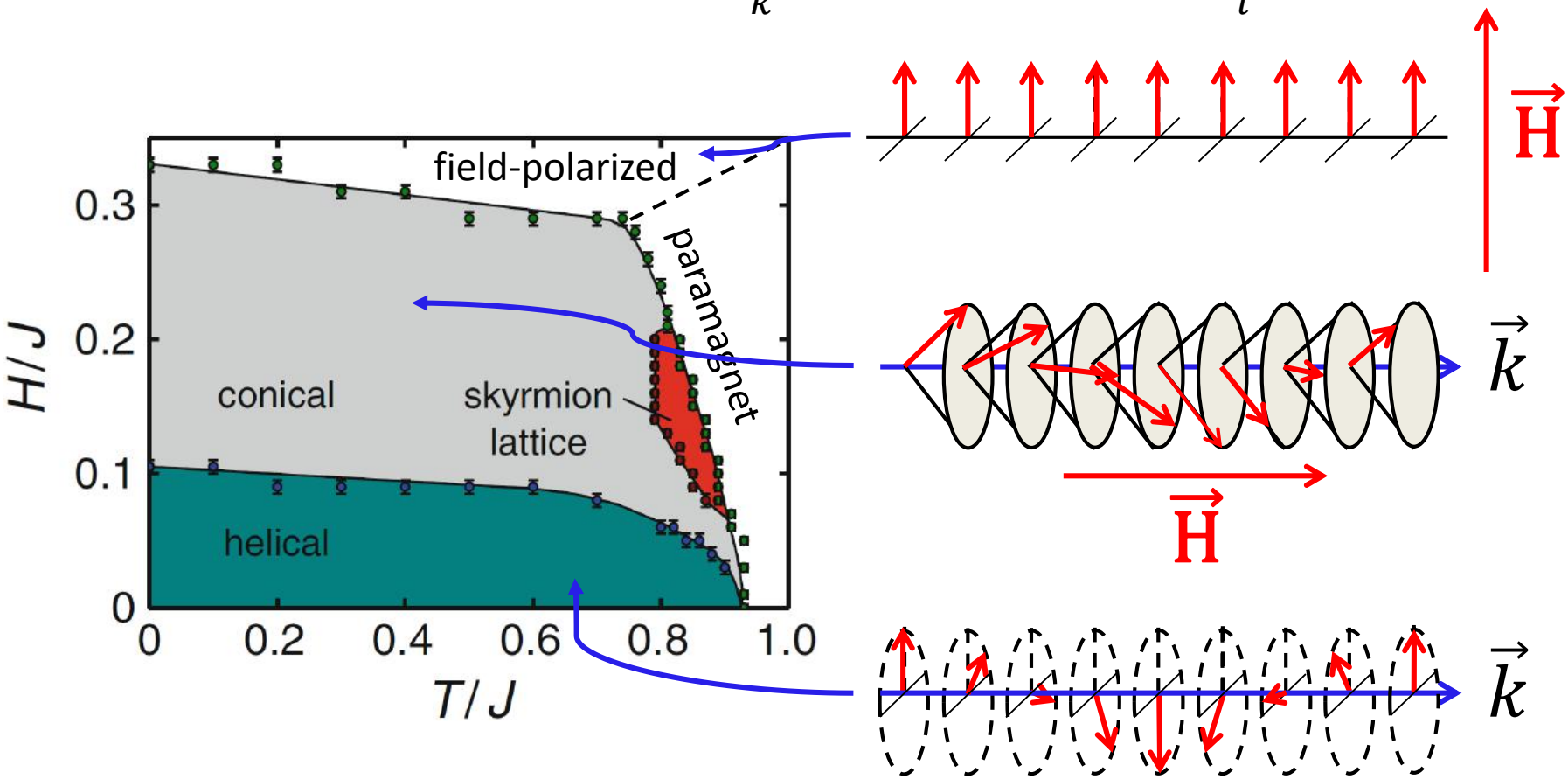

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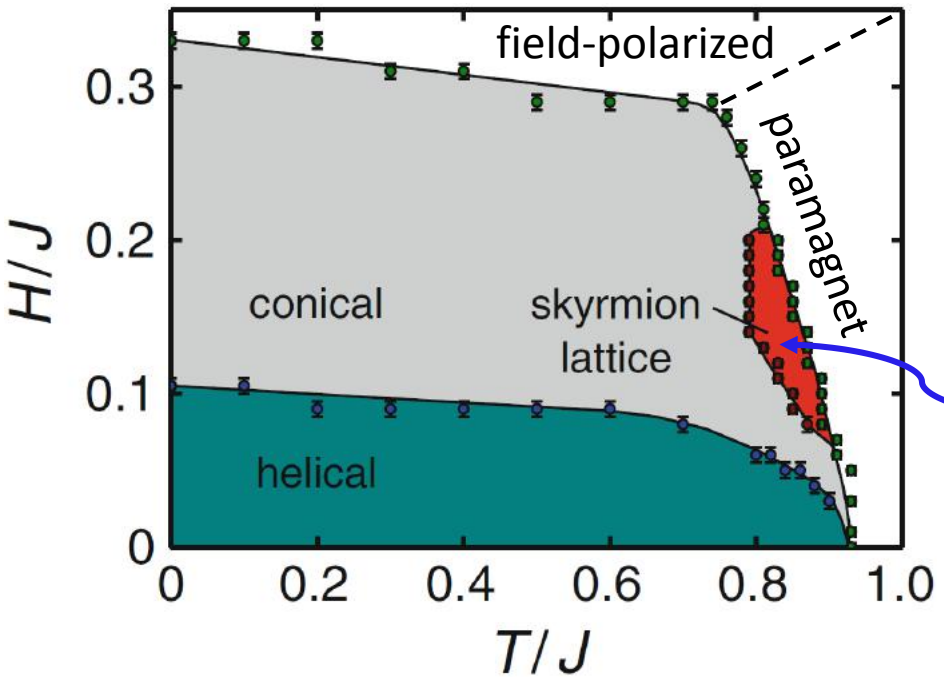

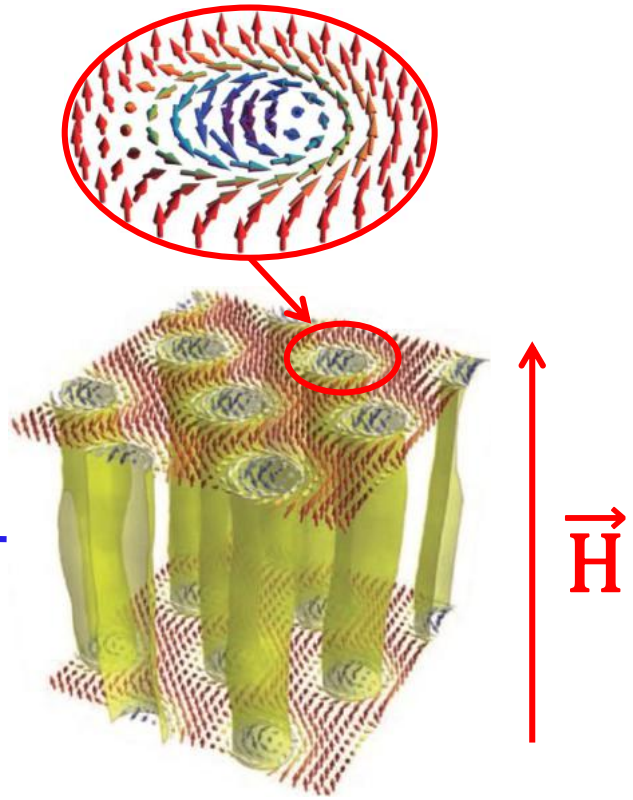

S. Mühlbauer *et al.*, Science **323**, 915 (2009)

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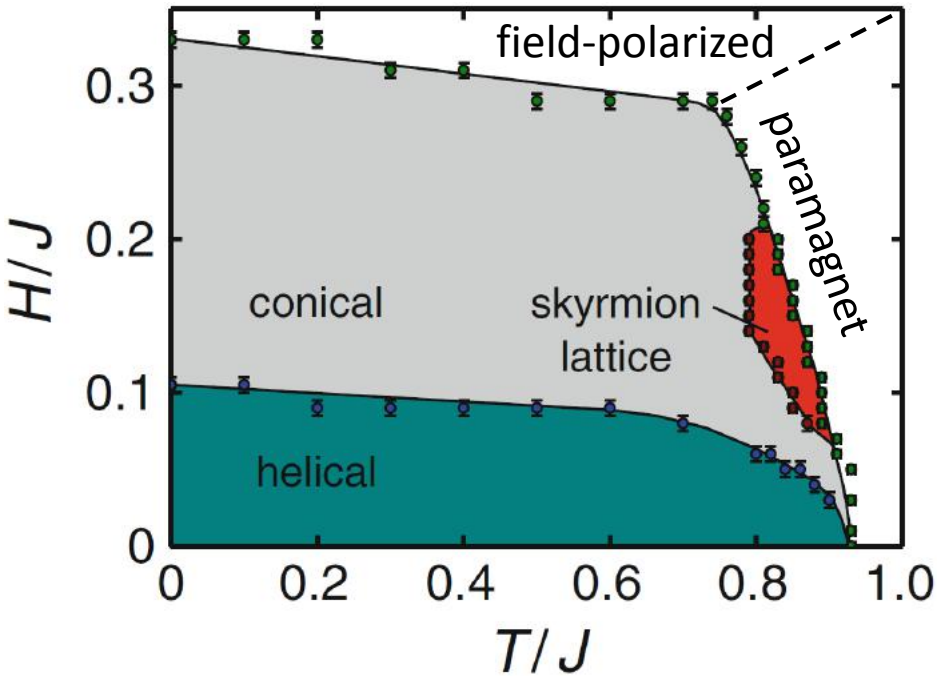
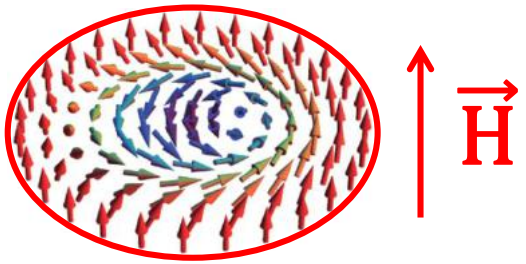
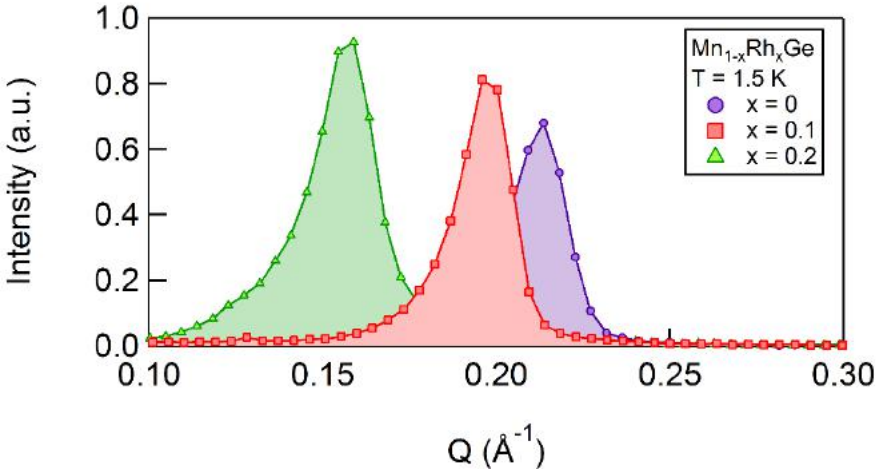




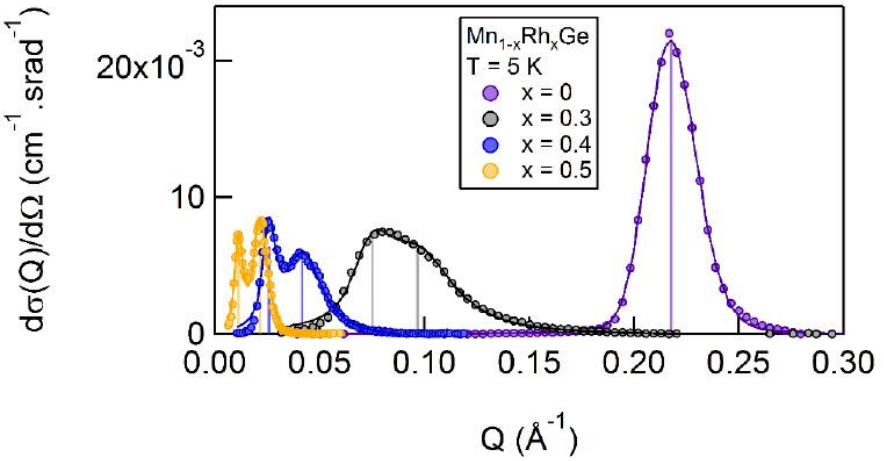
- Magnetic defects with particle-like properties *i.e.* endowed with topological protection
- Potential building blocks of next-generation spintronics (‘*spin orbitronics*’)
- Skyrmion lattice usually observed under applied field → can we stabilize similar defects in zero field?

Effect of Rh-doping in MnGe…

… as seen by neutron scattering in zero-field



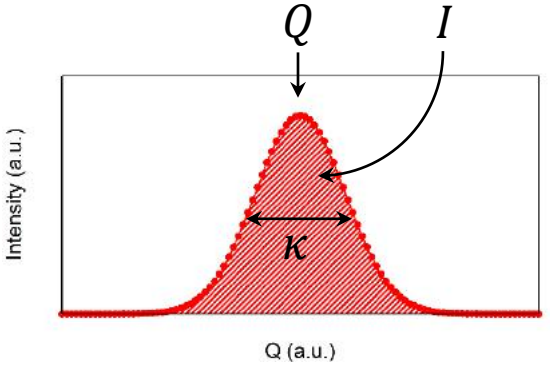
Powder diffraction (G4.1, LLB)



Small angle scattering (PA20, LLB)

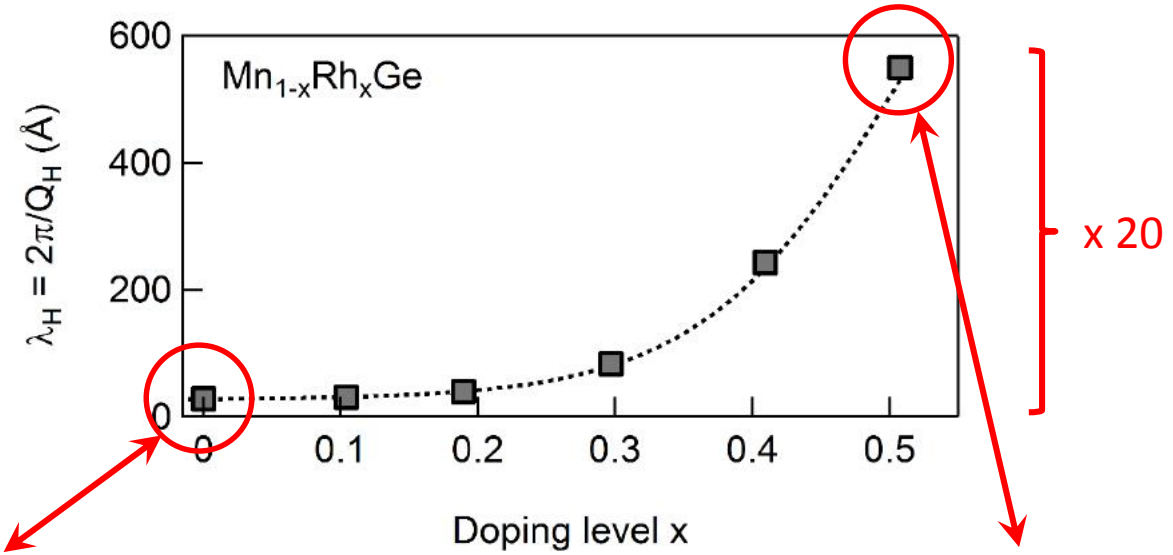
Magnetic diffraction peak parameters

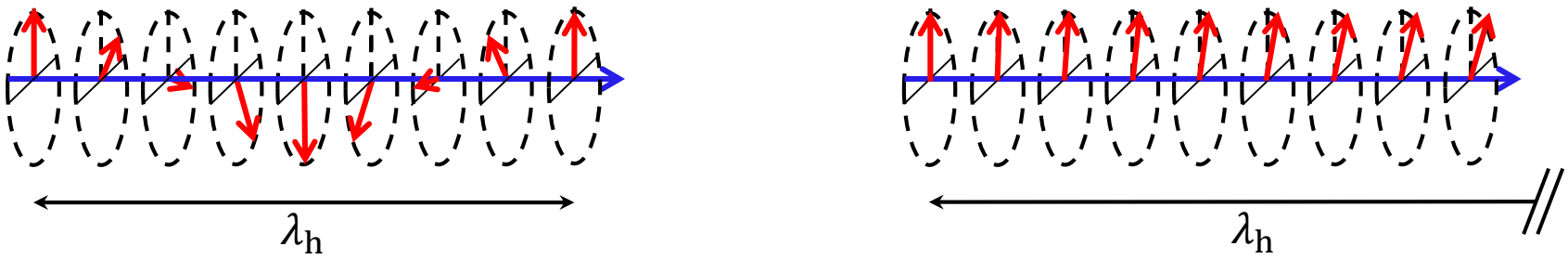
- Position $Q \rightarrow$ magnetic structure periodicity $\lambda = 2\pi/Q$
- Integrated intensity $I \rightarrow$ magnetic moment value $m = \sqrt{I}$
- Width $\kappa \rightarrow$ magnetic structure coherence length $\xi = 1/\kappa$



Magnetic structure of $Mn_{1-x}Rh_xGe$

x-dependence of the helical wavelength





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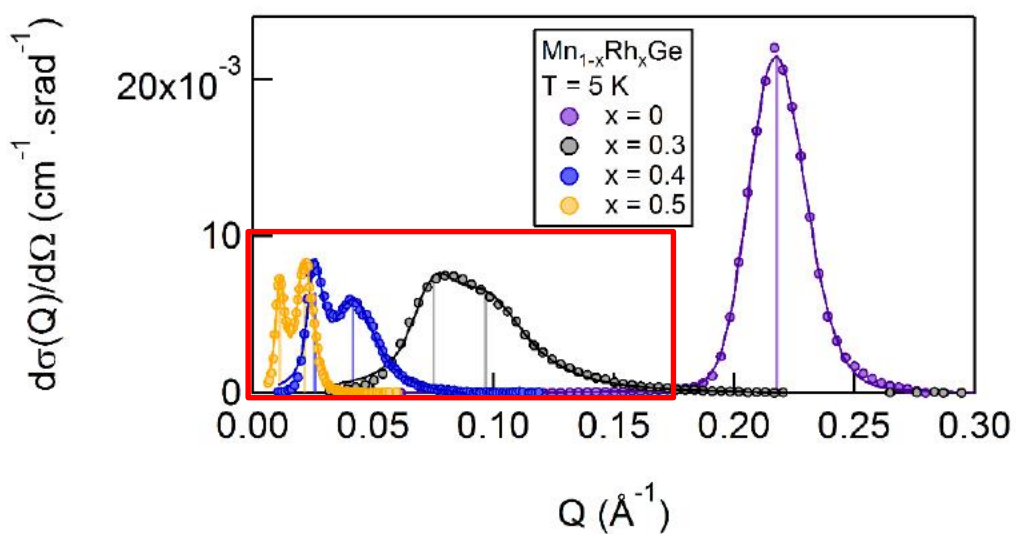
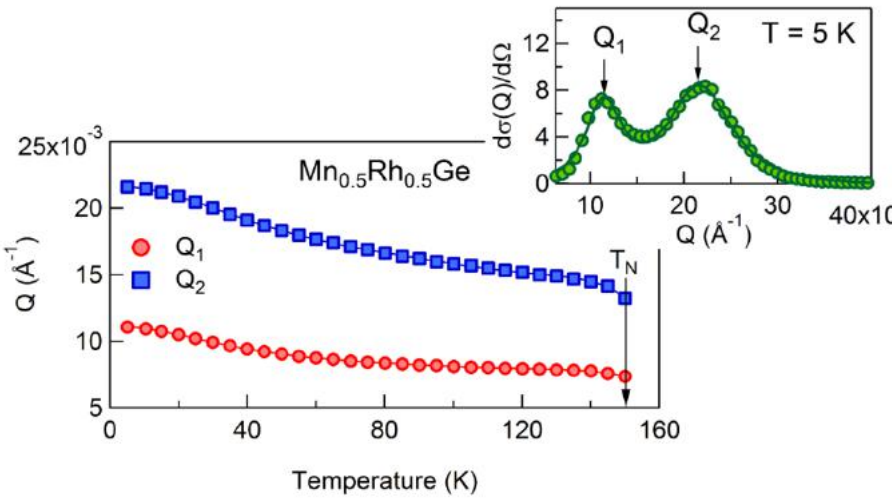
N. Martin *et al.*, arXiv:1702.06511 (2017)

Magnetic structure of $Mn_{1-x}Rh_xGe$

Stabilization of magnetic defects in zero-field





- Double peak for $x \geq 0.3$:

  → additional peridocity *i.e.* supermodulation of the spin structure

- Correlated T-dependence of both peak position:

  → competition of interaction terms with almost fixed ratio between them

N. Martin *et al.*, arXiv:1702.06511 (2017)

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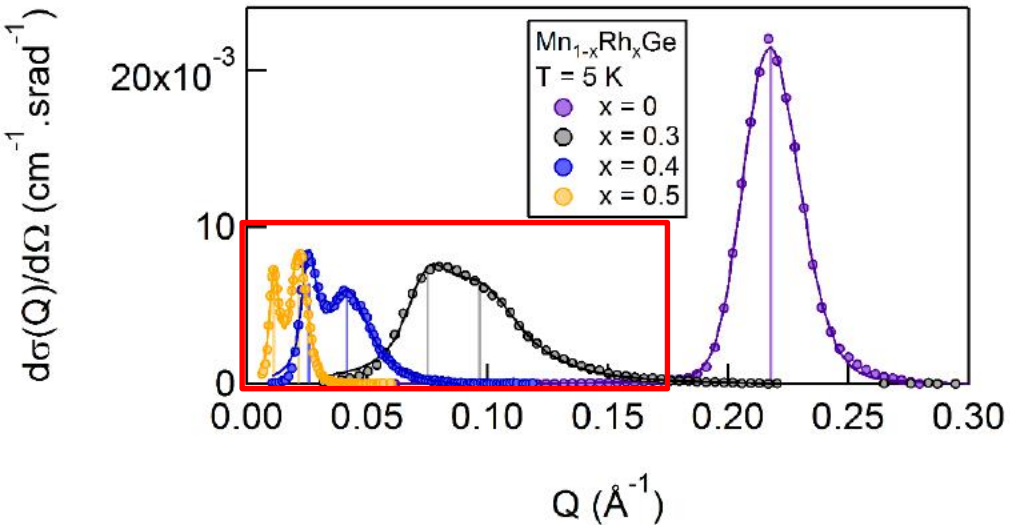

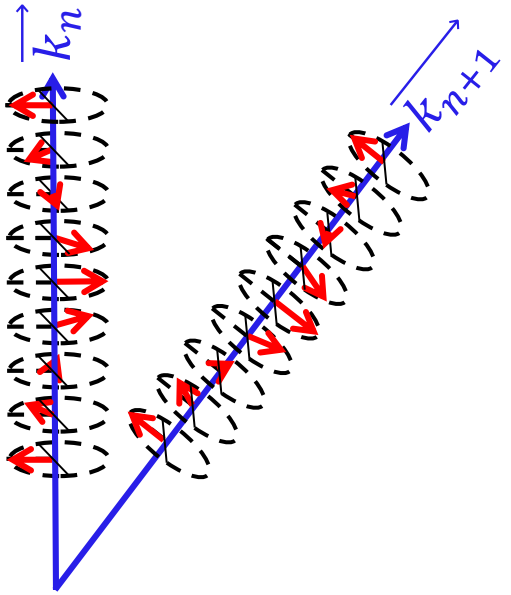

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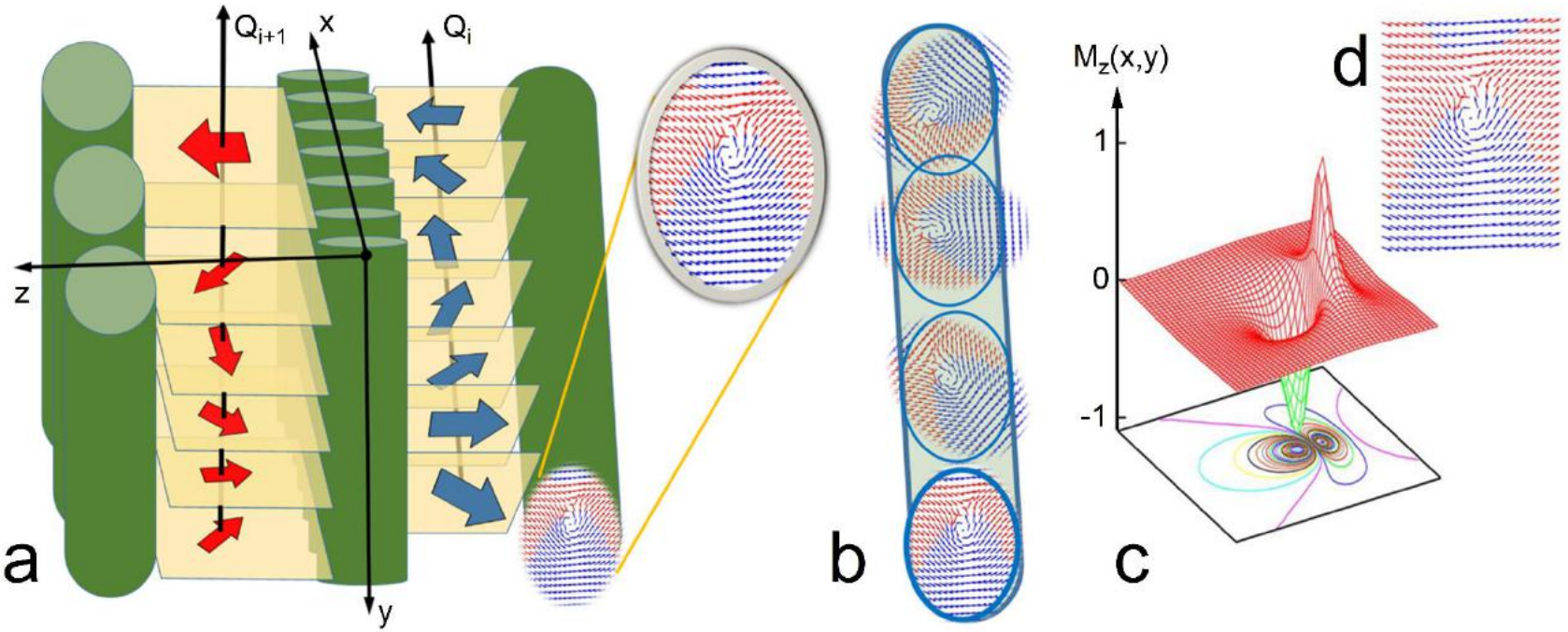
Quenched disorder induced by Rh-doping modifies (local) anisotropy *and* favors changes of spin helix orientation across the sample volume

N. Martin *et al.*, arXiv:1702.06511 (2017)

Magnetic structure of $Mn_{1-x}Rh_xGe$

Stabilization of magnetic defects in zero-field



- Creation of magnetic dislocations whose core is composed of pairs of skyrmions with opposite polarity
- Smooth textures *i.e.* energetically favored against singularities (Bloch points)
- Large scattered intensity → quasi-periodic network

N. Martin *et al.*, arXiv:1702.06511 (2017)

Magnetic structure of $Mn_{1-x}Rh_xGe$

Summary

- 'Dilution' of Mn magnetic ions by non magnetic Rh: control of magnetic structure's peridocity ($30 \leq \lambda_h \leq 600$ Å)
- Quenched disorder: modification of local anisotropy and stabilization of topologically non trivial magnetic defects in zero-field
- Not presented here: negative chemical pressure → control of Mn magnetic moment (from 2 to 4 μ_B / ion!)

→ Extreme tunability of ground state magnetic properties of the $Mn_{1-x}Rh_xGe$ series: novel insights for potential applications in spintronics?

Conclusions & Outlook

- ✓ Neutron scattering allows discovering new forms of (bulk) magnetic textures…
  - **Here:** spontaneous magnetic defects in chiral magnets
- ✓ …and characterizing their dynamical properties by quasi-elastic/inelastic neutron scattering
- ✓ Application-wise: study the interaction of an electrical current with these defects

Acknowledgments

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Katia Pappas

CEA Saclay - SPEC

Pierre Bonville

Université Paris Sud - ICMMO

Claudia Decorse

Institute for High Pressure Physics, Troitsk, Moscow, Russia

Ludmila Fomicheva
Anatoly Tsvyashchenko

IFW Dresden, Germany

U.K. Rössler

Hiroshima University, Japan:

A.O. Leonov

Competing interactions and modulated structures

- Free energy

$$f_s = f_0[\boldsymbol{s}] + \frac{b}{2}\int d^2r\,|\boldsymbol{\nabla s}|^2 - \frac{\mu^2}{2}\int\int d^2r\,d^2r'\,\boldsymbol{s_r}\,\mathrm{g}(\boldsymbol{r},\boldsymbol{r'})\boldsymbol{s_r}$$

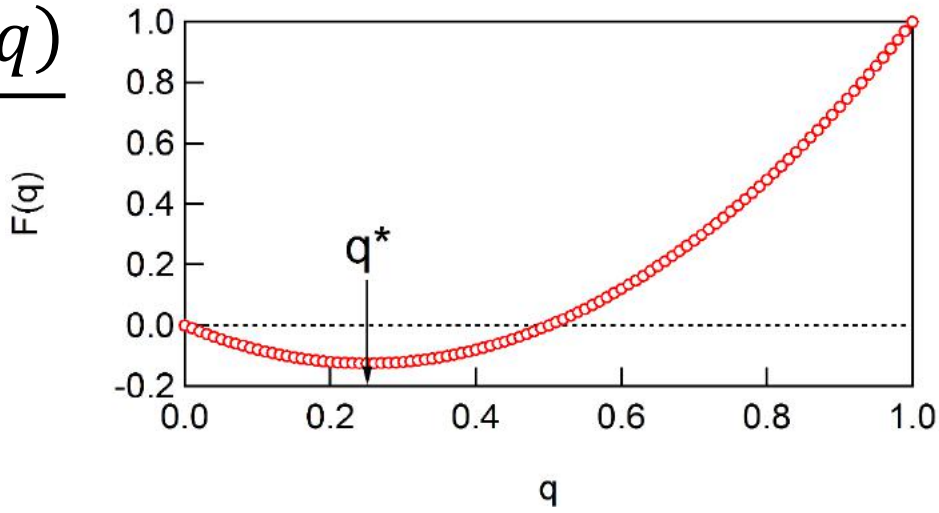
Uniform bulk contribution

Cost of forming domain walls

Dipole-dipole interaction ≈ |1/r|

Fourier transform

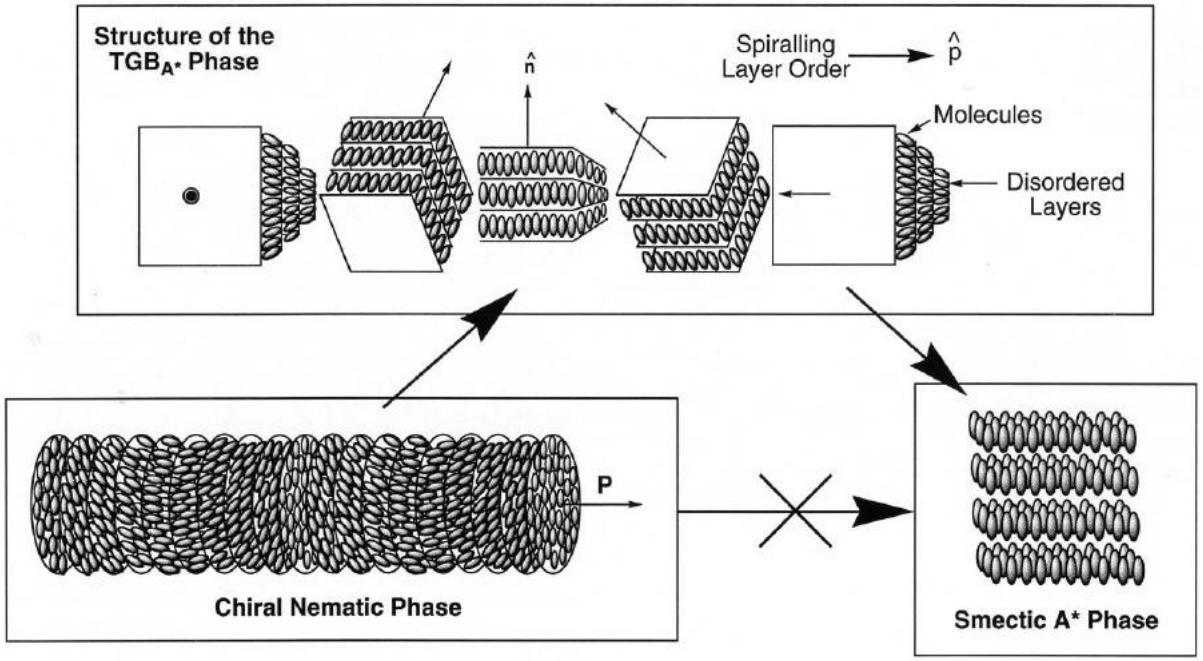
$$\mathrm{F}(q) = \frac{bq^2 - \mu^2\mathrm{G}(q)}{2}$$



$Mn_{1-x}(Co,Rh)_xGe$

Magnetic twist-grain boundary phase

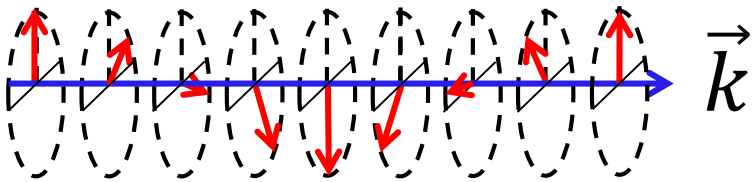
Liquid crystals



Chiral magnets

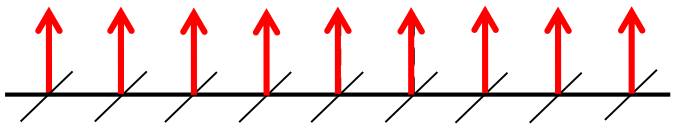
MnGe

Helimagnet



RhGe

(Weak) Ferromagnet



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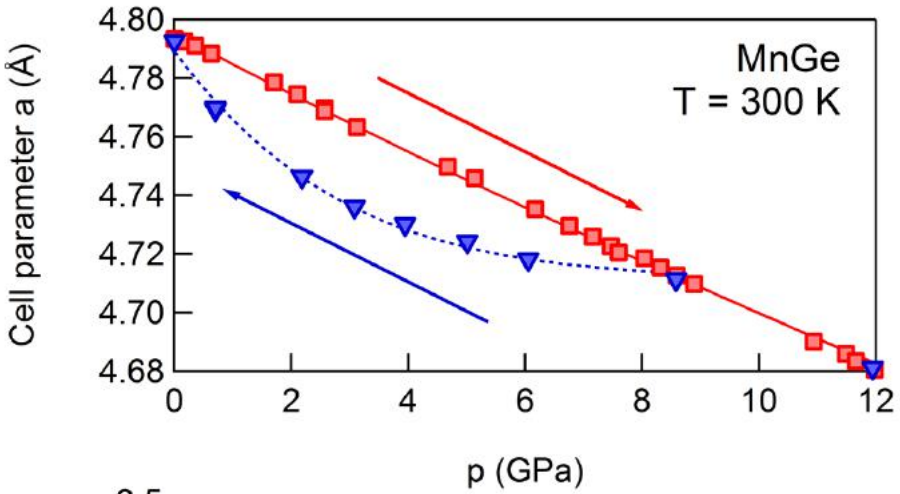
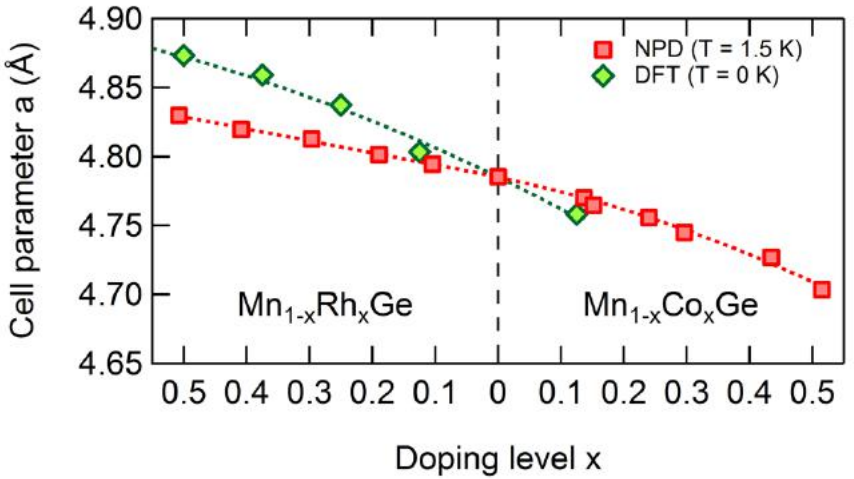
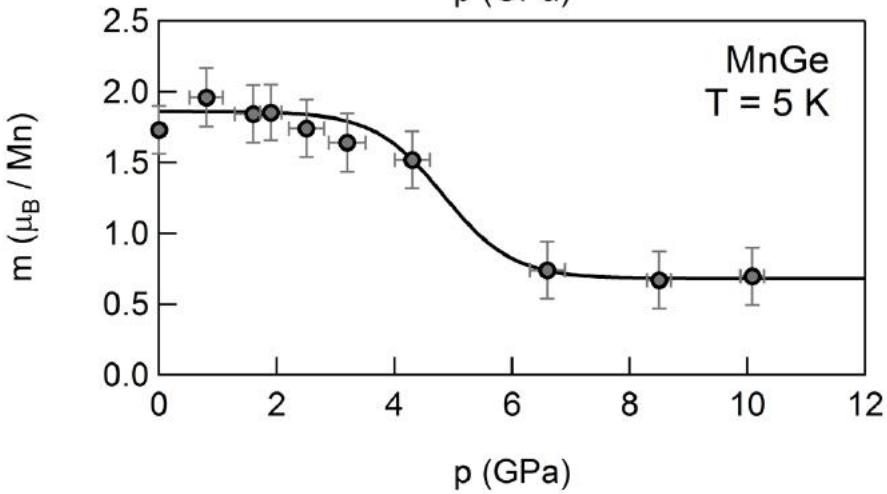
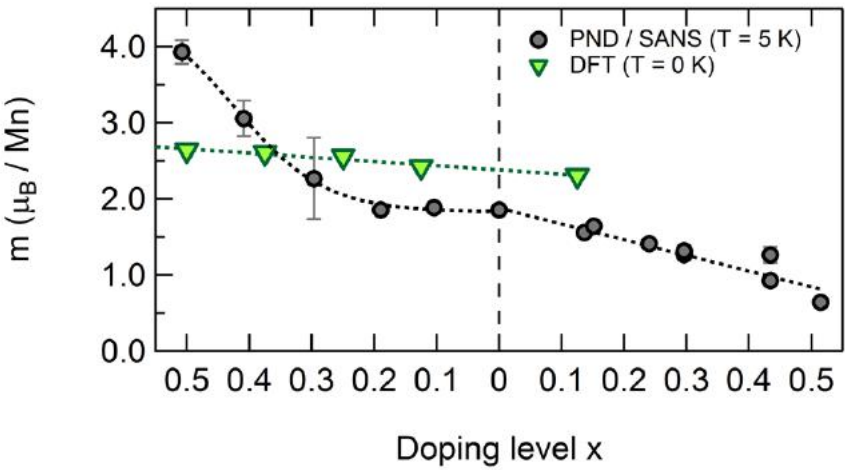
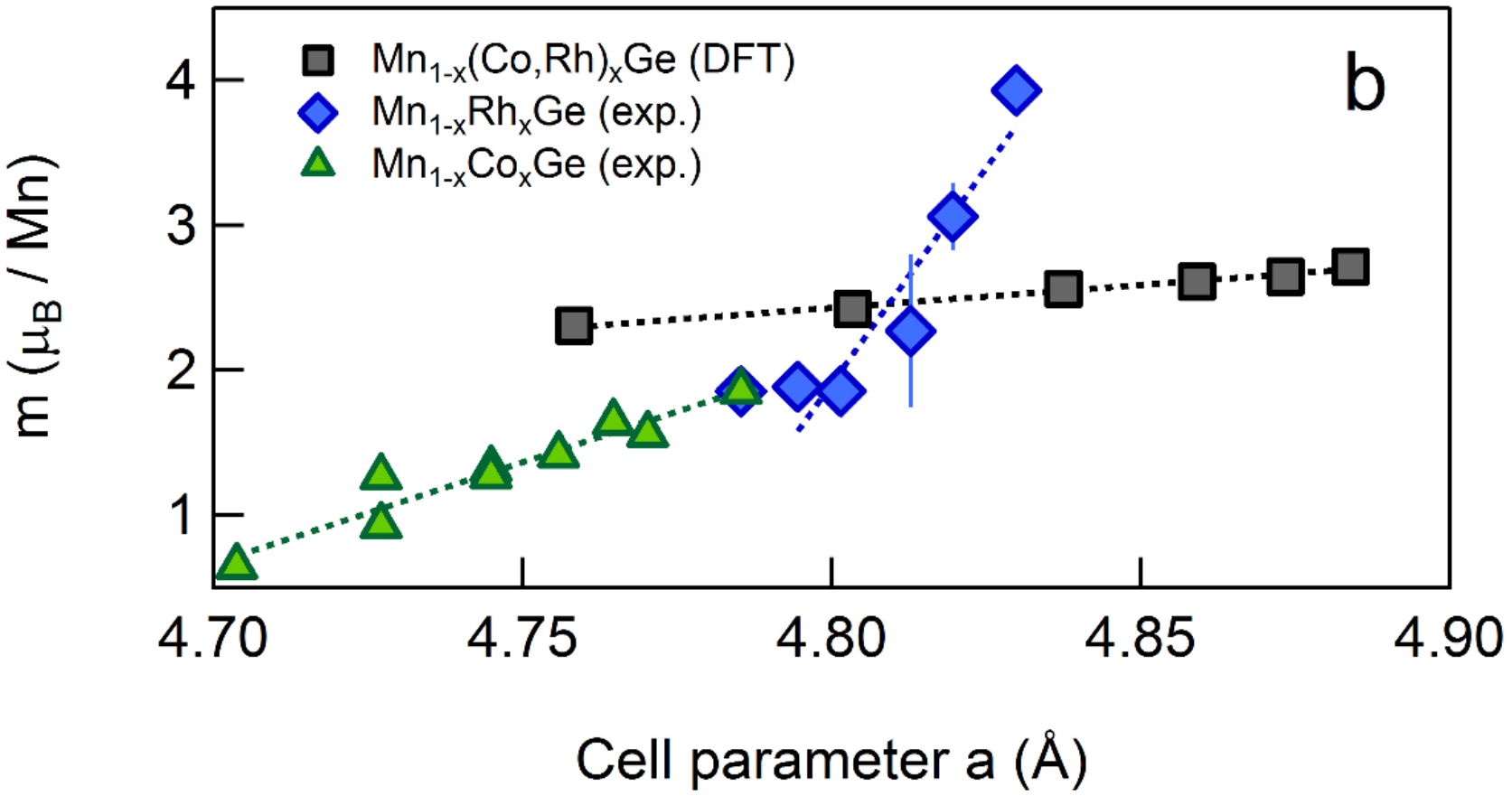
Physical *vs.* chemical pressure









$Mn_{1-x}(Co,Rh)_xGe$

Ordered moment *vs.* lattice parameter