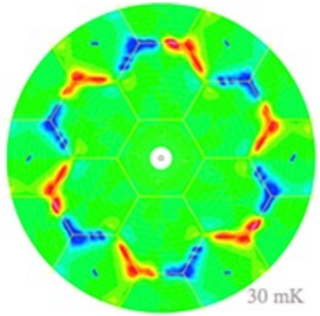
Chiral spin liquid ground state in $YBaCo_3FeO_7$

PHYSICAL REVIEW X 12, 021029 (2022)



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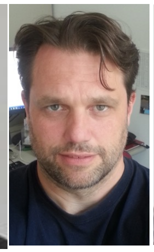


The system $YBa\color{green}{Co_3^{2+}Fe^{3+}}O_7$

S=3/2, 5/2

mineral $SbNaBe_4O_7$

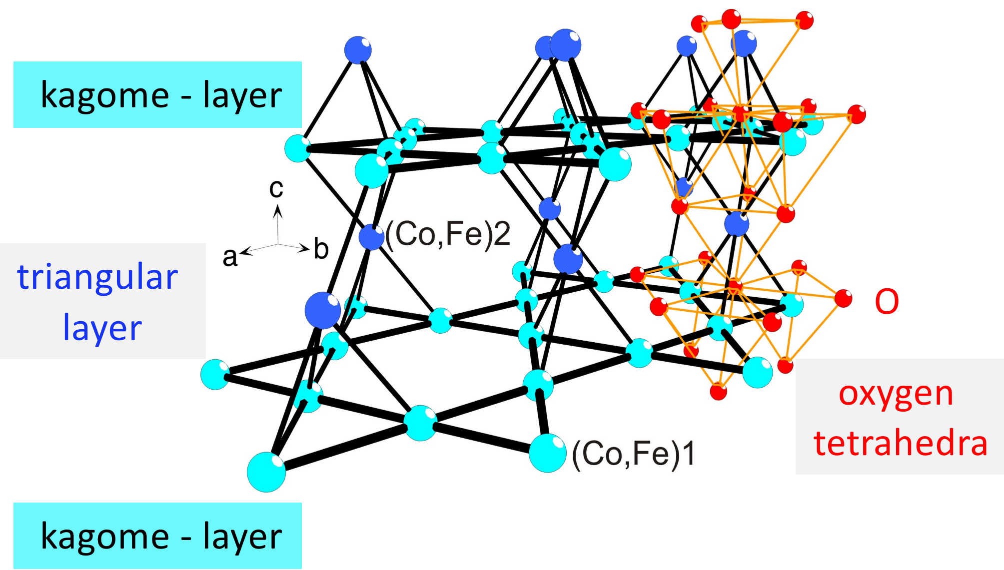
structure Aminoff 1933, Pauling 1935

Structure

layered kagome-system

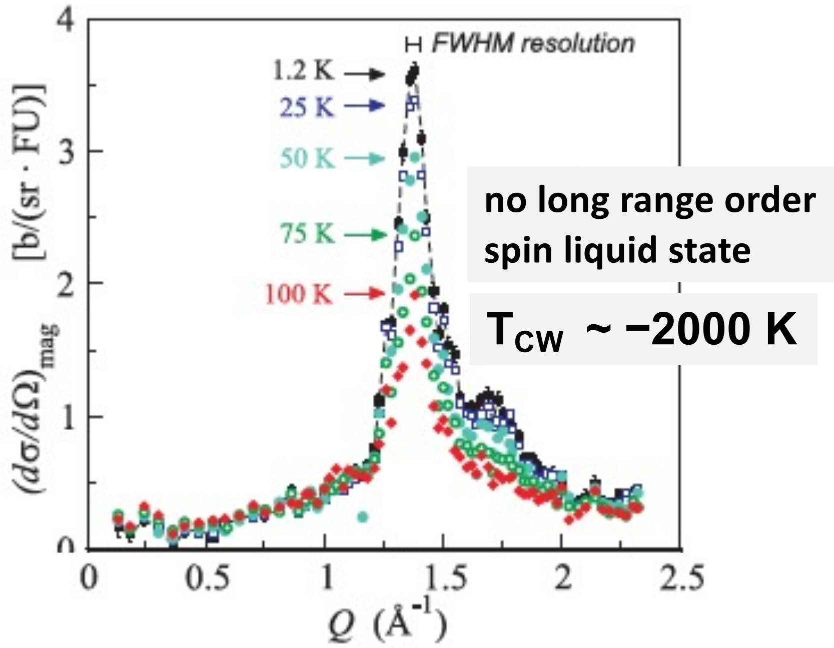
Swedenborgite structure

hexagonal *P*6_3*mc*



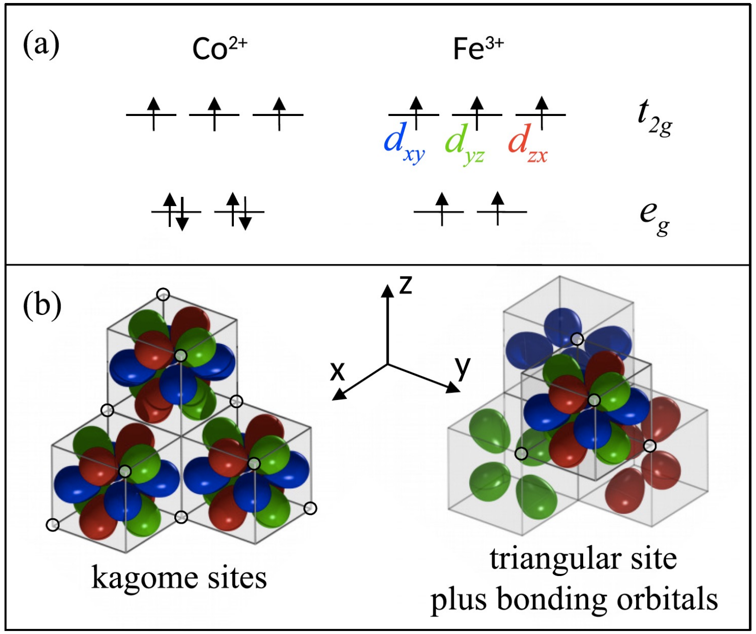
Spin correlations

polarized diffuse magnetic neutron scattering from powder



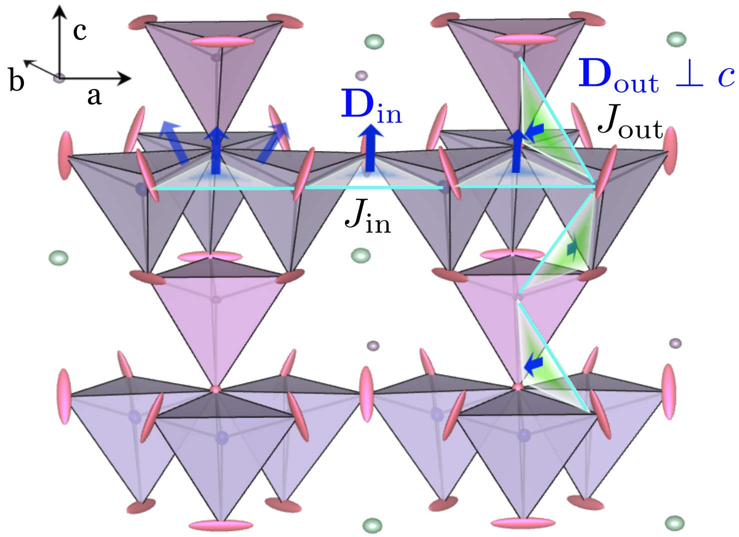
Valldor et al., Phys. Rev. B 84, 224426 (2011).

Exchange interactions



Super-exchange
between half-filled $t2_g$ *orbitals*

Reim et al., Phys. Rev. B 97, 144402 (2018)



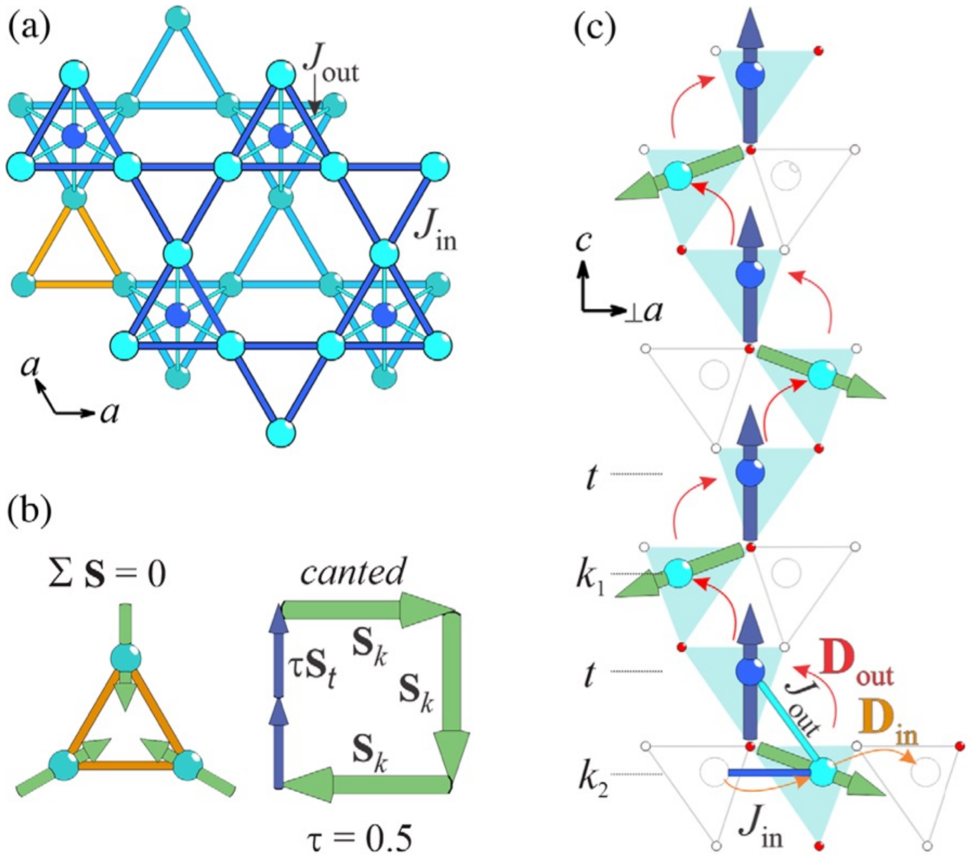
Dzyaloshinskii-Moriya interactions

3

D => vector chirality $\mathbf{C} = \langle \mathbf{S} \times \mathbf{S}' \rangle \neq 0$

$\mathbf{D_{in}}$ *ab*-plane anisotropy

Frustration and sum rules



MCS

$J_{\rm in} = 2J_{\rm out}$

ferro-chains on *t*-sites

$\mathbf{D}_{\rm out}$

t-site anisotropy $\parallel c$

$\mathbf{D}_{\rm in}$

k-site anisotropy towards *ab* -plane

weak anisotropies

Manuel et al., Phys. Rev. Lett. 103, 037202 (2009).

Possible Chiral Spin-Liquid Phase in Noncentrosymmetric $RBaCo_4O_7$
Khalyavin et al., Phys. Rev. B 85, 220401(R) (2012).

XYZ-polarisation analysis
of diffuse magnetic neutron scattering from single crystals

W. Schweika, J. Phys.: Conf. Ser. ***211***, 012026 (2010)

Powder samples

Otto Schärpf †13.6.2019

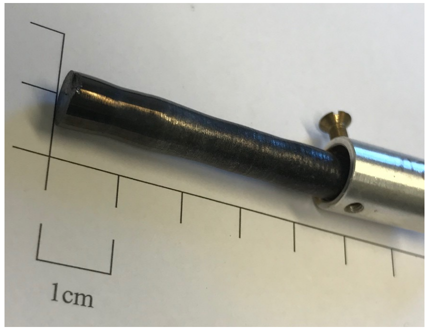
XYZ method 1993

D7 - ILL

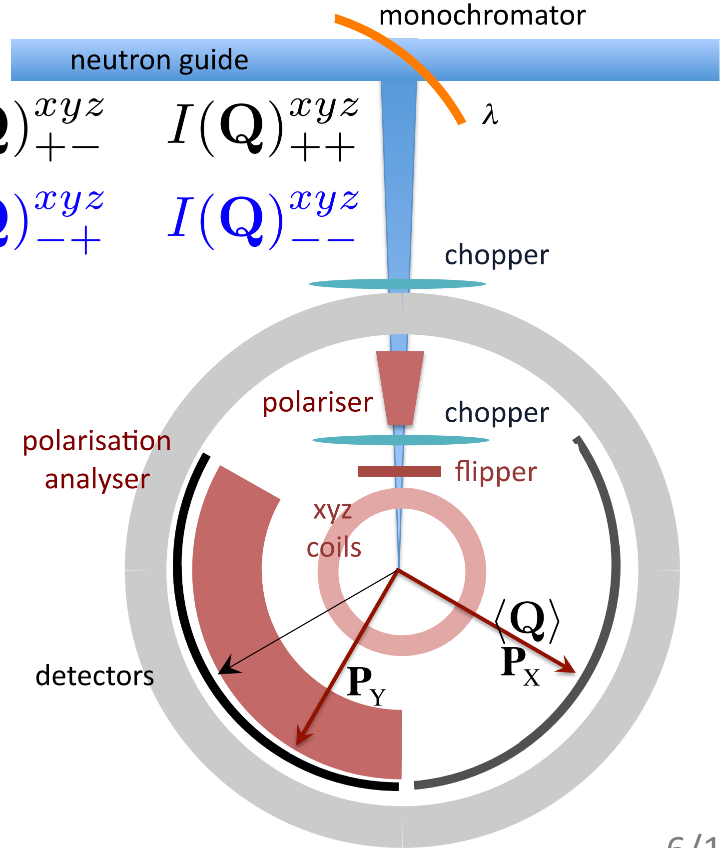
XYZ-polarisation analysis

of diffuse magnetic neutron scattering from **single crystals**

W. Schweika, J. Phys.: Conf. Ser. ***211***, 012026 (2010)

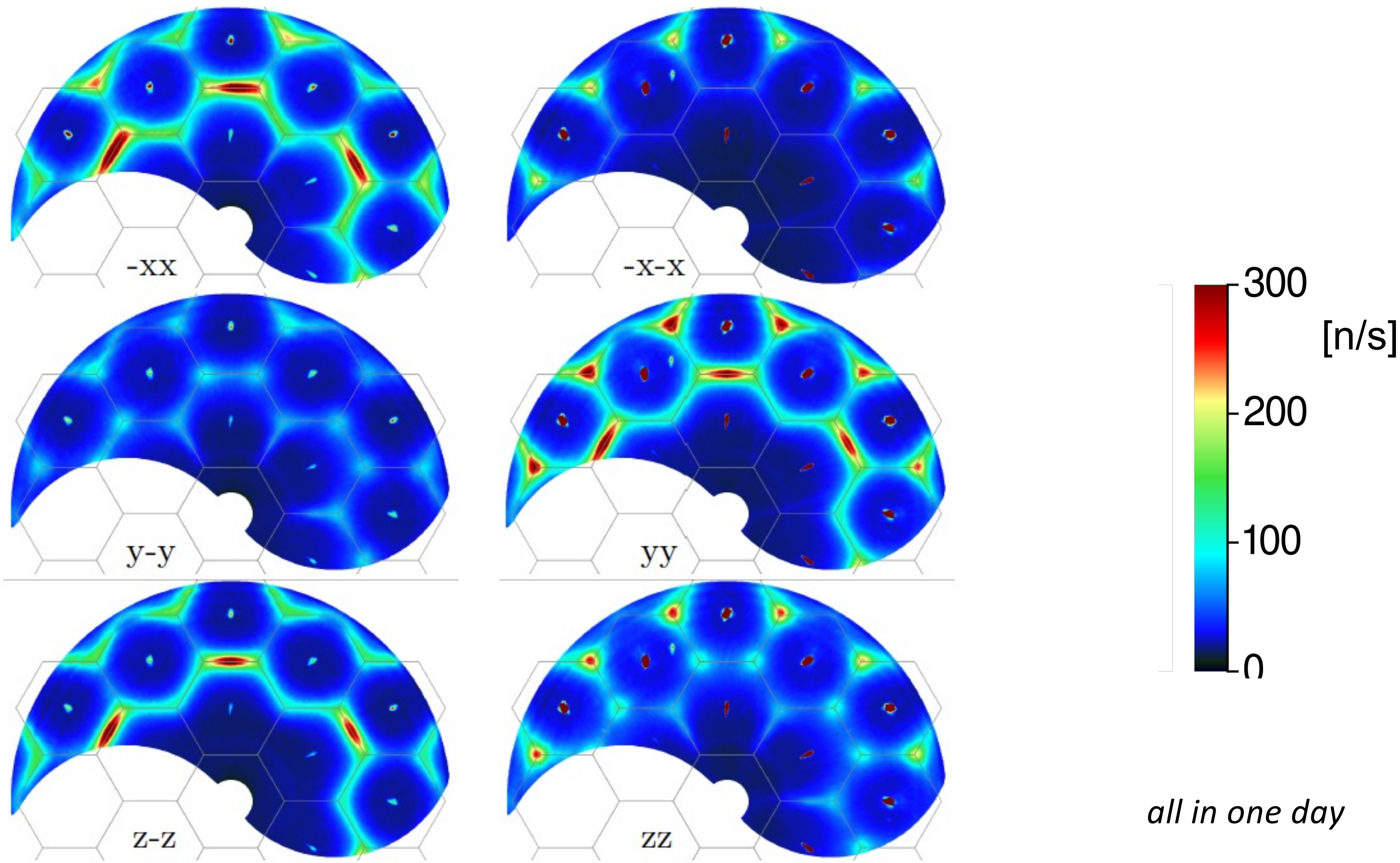


$$I(\mathbf{Q})^{xyz}_{+-} \quad I(\mathbf{Q})^{xyz}_{++}$$
$$I(\mathbf{Q})^{xyz}_{-+} \quad I(\mathbf{Q})^{xyz}_{--}$$



XYZ-polarisation analysis
of diffuse magnetic neutron scattering from single crystals

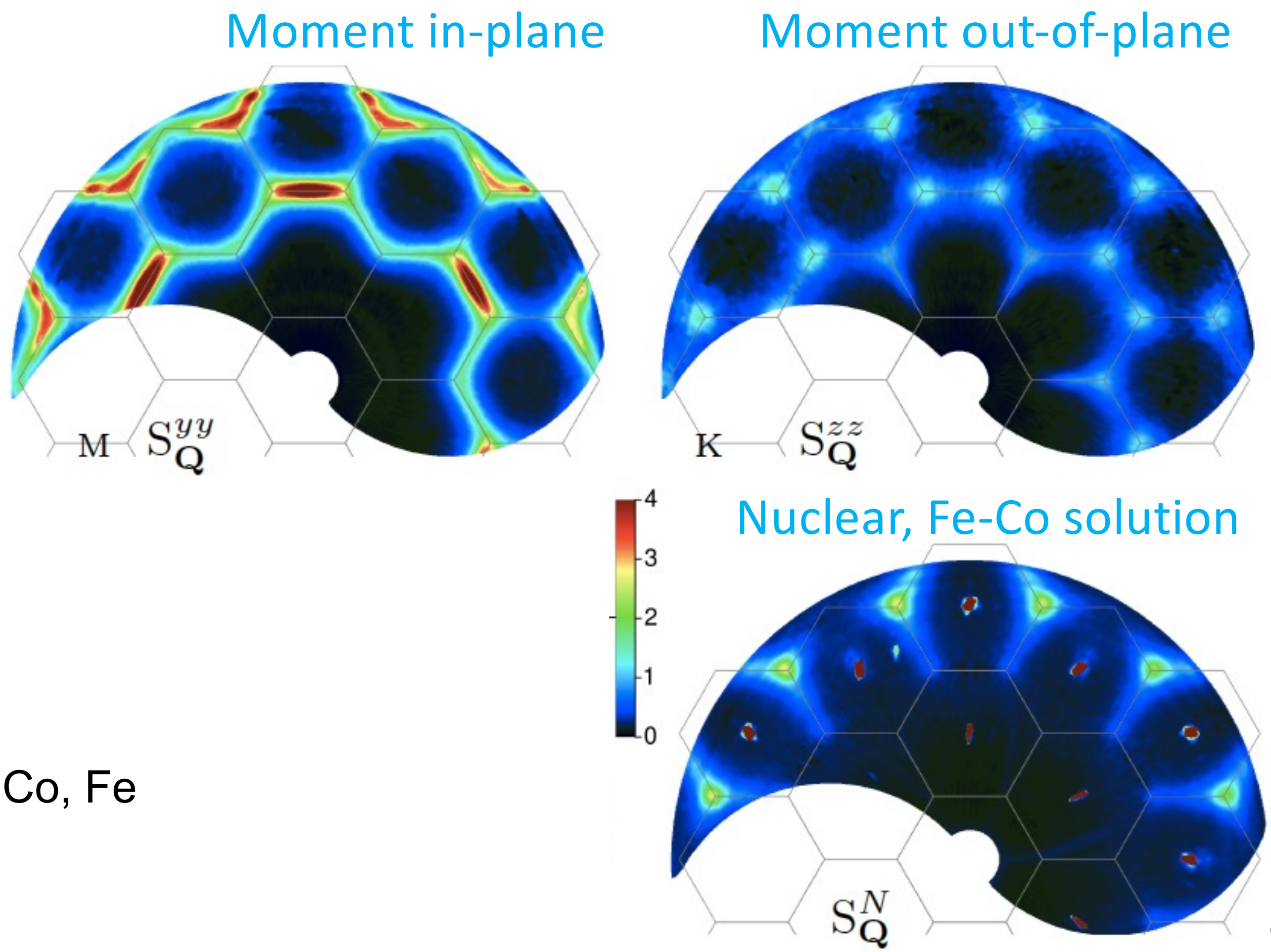
W. Schweika, J. Phys.: Conf. Ser. ***211***, 012026 (2010)



all in one day

W. Schweika, J. Phys.: Conf. Ser. ***211***, 012026 (2010)

Separation of diffuse nuclear and magnetic scattering



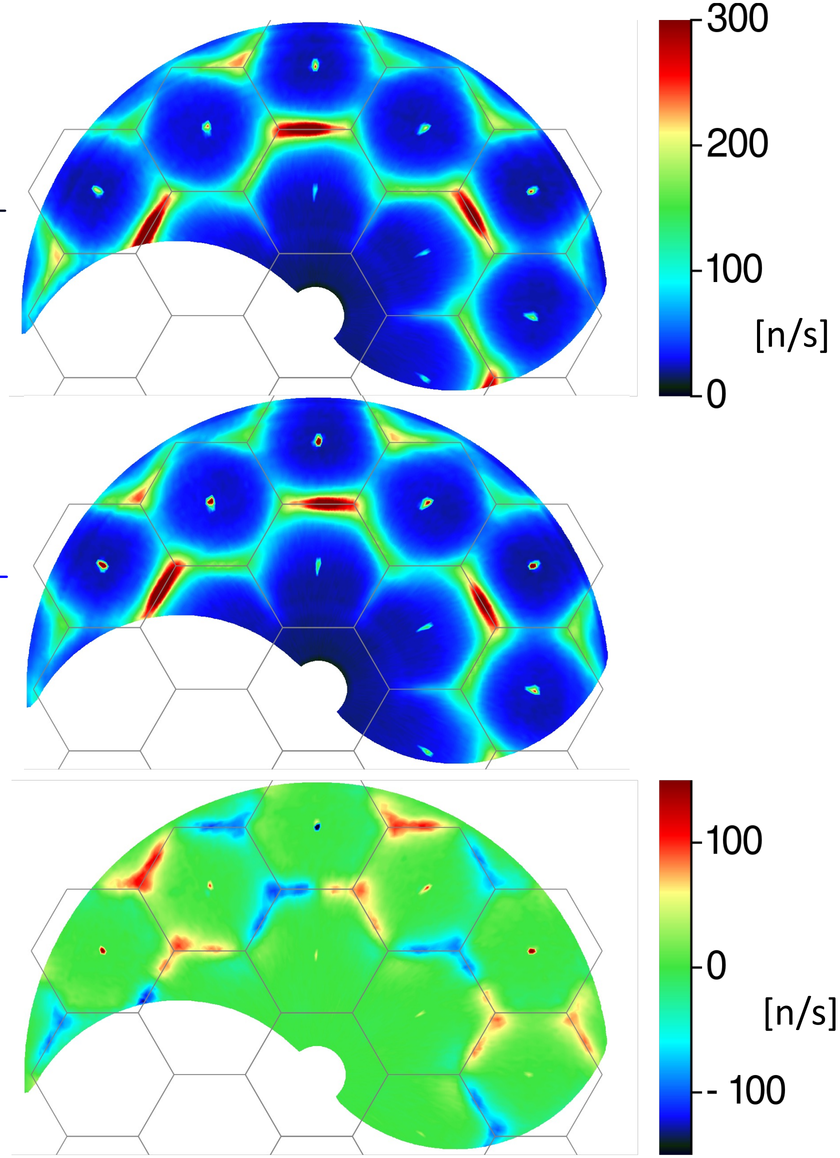
=> S(Q)
include average form factor Co, Fe
scale to S=1

polarization reversal

$$\sigma_{\mathbf{Q}}^{\text{chiral}} = \mathrm{i}\mathbf{P} \cdot (\mathbf{M}_{-\mathbf{Q}}^{\perp} \times \mathbf{M}_{\mathbf{Q}}^{\perp})$$

$I(\mathbf{Q})^{x}_{+-}$

$I(\mathbf{Q})^{x}_{-+}$



Difference: chiral scattering

Magnetic chiral diffuse scattering

$$\sigma_{\mathbf{Q}}^{\text{chiral}} = \mathrm{i}\mathbf{P} \cdot (\mathbf{M}_{-\mathbf{Q}}^{\perp} \times \mathbf{M}_{\mathbf{Q}}^{\perp})$$

Fourier analysis => vector chirality $\mathbf{C} = \mathbf{S}_{\mathbf{R}} \times \mathbf{S}'_{\mathbf{R}'}$ $\quad S^y S^z \quad (\perp \mathbf{Q})$

$$S_{\mathbf{Q}}^{yz} = \mathrm{i}\mathbf{P} \cdot \mathbf{C}(\mathbf{Q})$$

$$= \sum_{\mathbf{r}} \mathbf{e}_{\mathbf{Q}} \cdot \begin{pmatrix} G_{x,\mathbf{r}}^{yz}\, \mathbf{e}_{\mathbf{r}_{\parallel}} \\ G_{y,\mathbf{r}}^{yz}\, \mathbf{e}_{\mathbf{r}_{\perp}^{y}} \\ G_{z,\mathbf{r}}^{yz}\, \mathbf{e}_{\mathbf{r}_{\perp}^{z}} \end{pmatrix} \sin(\mathbf{Q} \cdot \mathbf{r})$$

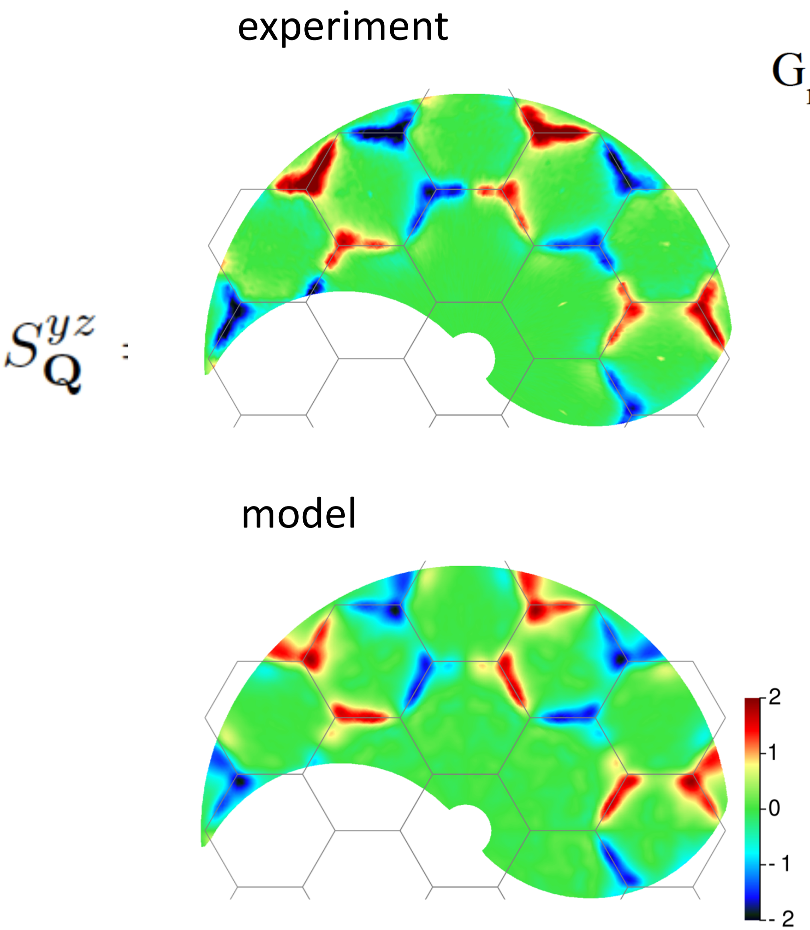
$$= \sum_{\mathbf{r}} \begin{pmatrix} G_{x,\mathbf{r}}^{yz}\, \mathbf{e}_{\mathbf{Q}} \cdot \mathbf{e}_{\mathbf{r}} \\ G_{y,\mathbf{r}}^{yz}\, ||\mathbf{e}_{\mathbf{Q}} \times \mathbf{e}_{\mathbf{r}}|| \\ 0 \end{pmatrix} \sin(\mathbf{Q} \cdot \mathbf{r})$$

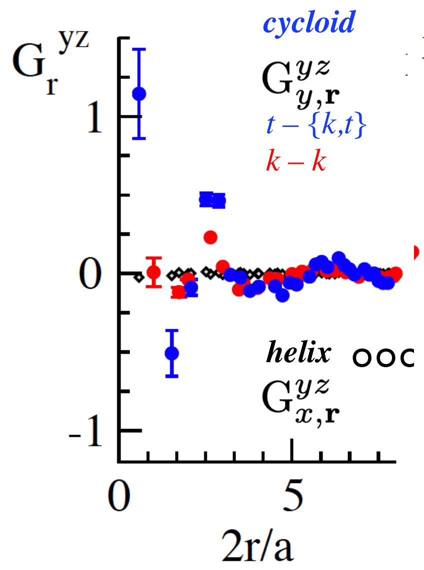
propagation	
x	Helix
y	Cycloid
z	Cycloid
$\parallel \mathbf{Q}$	Helix
$\perp \mathbf{Q}$	Cycloid
$\perp \mathbf{Q}$	(not measured in (hk0))

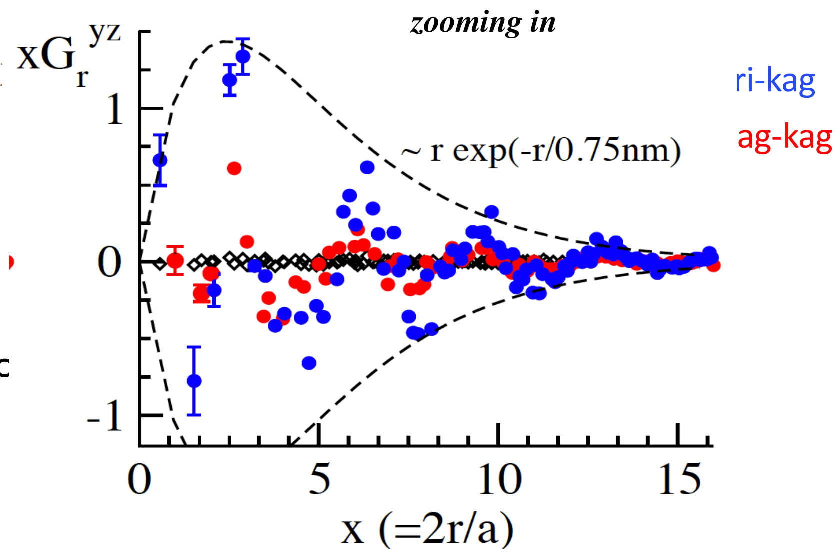
anti-symmetry

Magnetic chiral diffuse scattering

Fourier analysis





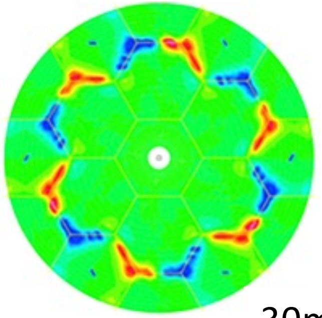


3f-cycloids emanating from ***t***-site

radial cycloidal wave

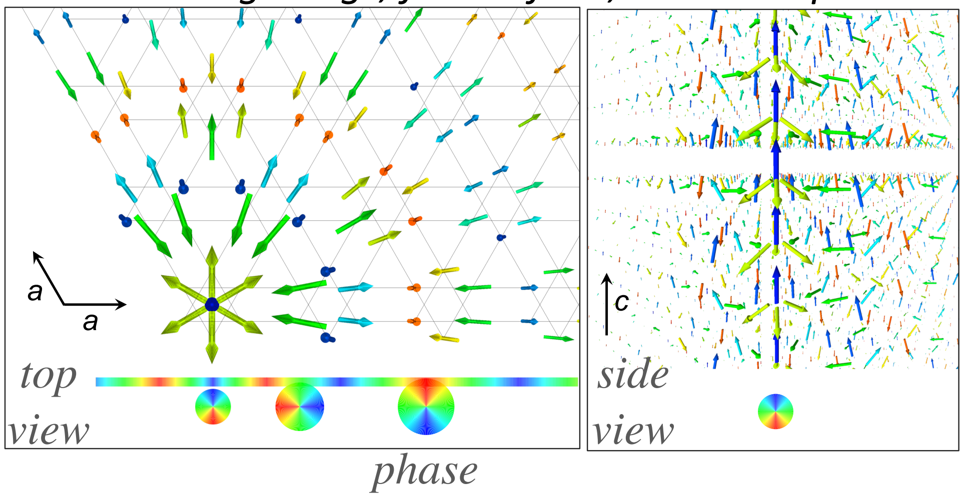
Structure and nature

3*f* - cycloidal structures emanate from *t*-sites
suggesting zero dimensional objects “lumps” stable at lowest T
requiring sufficiently weak anisotropies



30mK

similar to *hedge hogs, flower field, water drops on sea surface*



Could it be
a quantum spin liquid state?
Skyrmions?

Theoretical analysis

Ulrich Rößler (Skyrmion ground states, Nature 2006)

Standard classical theory of magnetic order shows the existence of relevant Lifshitz invariants for the non-centro symmetric and polar structure. Coupling of higher order terms due to chirality may twist the spin structure into an inextricable structure of **short-range entities we term lumps**.

Existence of Lifshitz-type invariants for C_{6v}

cycloids in basal plane $\perp\ c$	$g_{lm}(l_x\partial_x m_z - m_z\partial_x l_x + l_y\partial_y m_z - m_z\partial_y l_y)$
modulation along the c axis	$f_{lm}(l_x\partial_z m_x - m_x\partial_z l_x)$

As in the case of skyrmions in chiral helimagnets, the free energy density in the cores of these lumps is reduced compared to a single spiral, by activating several Lifshitz-terms. **This stabilizes these static solitonic objects and generates an inhomogeneous state that constitutes a classical ground state.**

The present scenario with antisymmetric exchange acting as a frustrating gauge background that stabilizes local spin lumps, is similar to the avoided phase transition in coupled gauge- and matter-fields for sub-nuclear particles, and **may emerge in other non-centro symmetric and highly frustrated systems.**