^{55}Mn NMR investigation on Mn_2GaC nanolaminated thin film

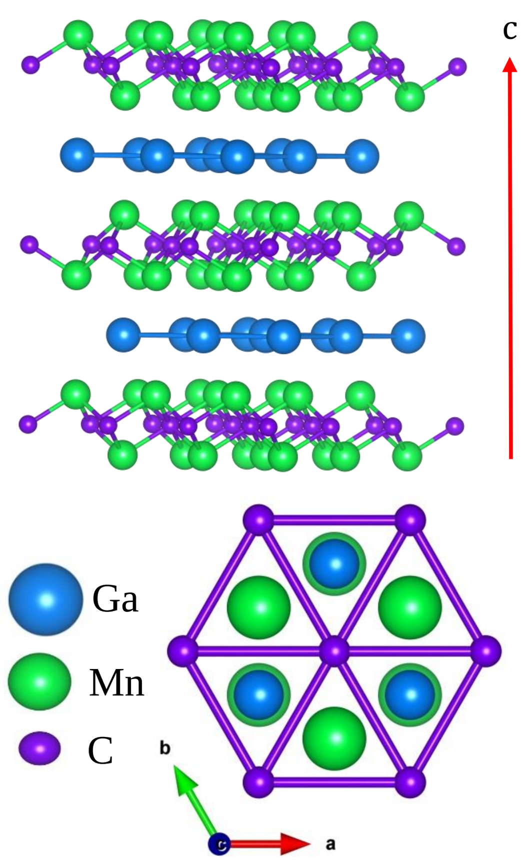
J. Dey[1], R. Kalvig[1], E. Jędryka[1], M. Wójcik[1], U. Wiedwald[2], M. Farle[2], and J.Rosen[3]
[1]Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warszawa, Poland
[2]Faculty of Physics and Center for Nanointegration (CENIDE), University of Duisburg-Essen, 47057, Duisburg, Germany
[3]Thin Film Physics, Department of Physics, Chemistry and Biology (IFM), Linköping University, SE-581 83, Linköping, Sweden

INTRODUCTION

Background

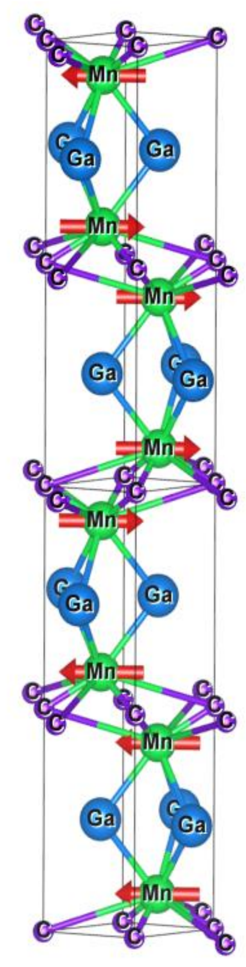
$M_{n+1}AX_n$ **(MAX)** phases
M →early transition elements,
A→ IIIA and IVA group elements,
X →either carbon or nitrogen,
n (1, 2 or 3) is the number of layers.

Mn_2GaC
Consisted of only one transition metal element, has been synthesized in thin film(nanolaminated) form to understand the fundamental structural and magnetic properties.
It belong to **hexagonal** crystal structure symmetry of space group $P6_3/mmc$.



Neutron reflectometry on Mn_2GaC

- Long range anti-ferromagnetic structu (AFM[0001]$^A{}_4$)
- Strong intralayer ferromagnetic coupling between Mn-C-Mn → Supermoment model
- Long range magnetic repetition distanc ~25Å(nearly two structural unit cell)
- Inconsistence with the previous VSM results showing remanent magnetization.

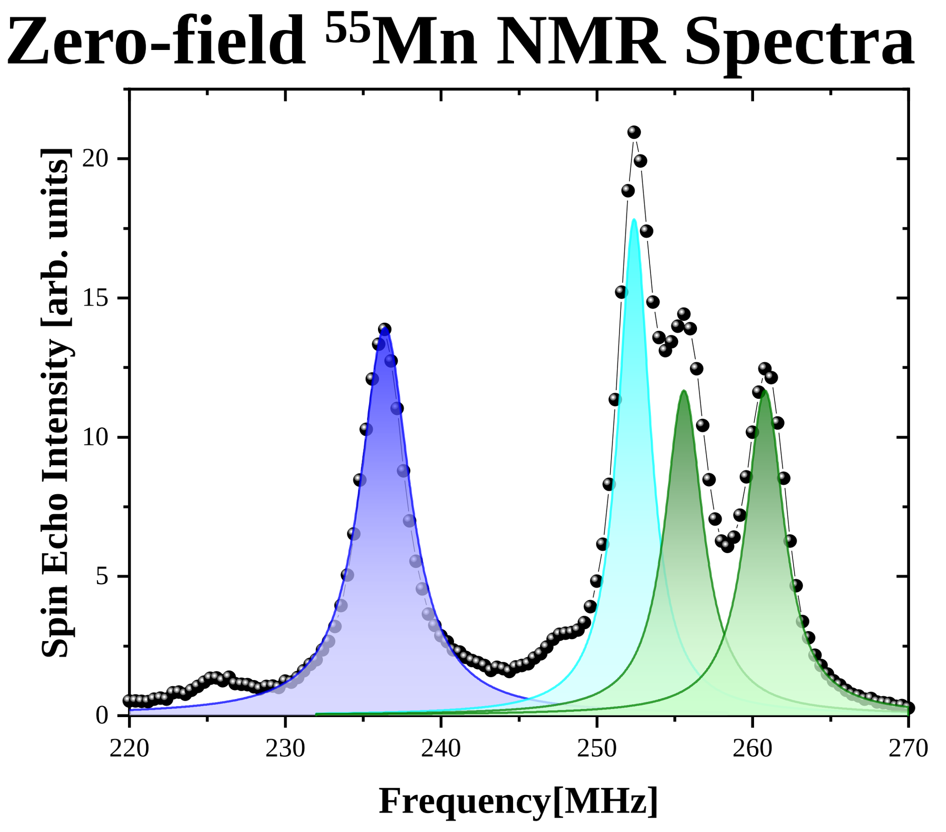


Motivation

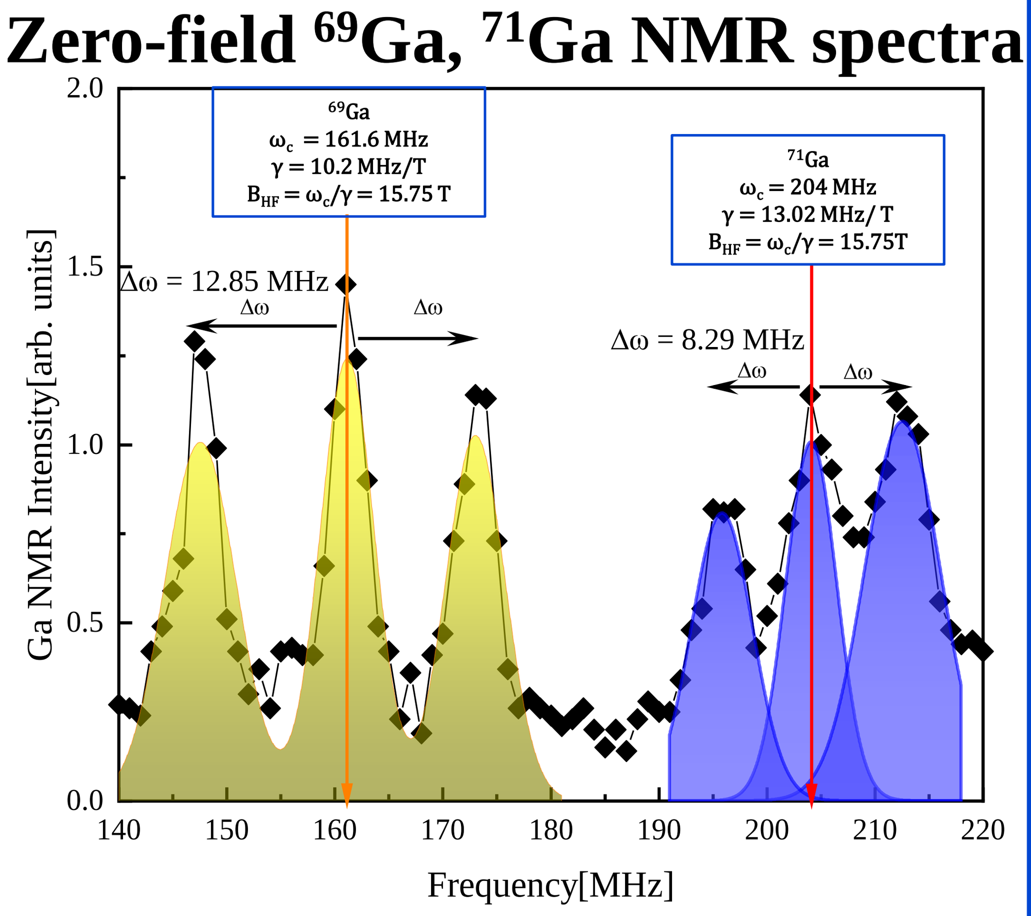
- Theoretical prediction of complex magnetic structure with competing ferromagnetic and antiferromagnetic interactions.
- Lack of explanation of previously observed remanent magnetization from macroscopic magnetic measurement in predicted AFM[0001]$^A{}_4$ structure from neutron reflectometry produce inconclusive structural information for Mn_2GaC.
- Nuclear magnetic resonance (NMR) in **MgO(111)/Mn_2GaC** 100nm thin film in both zero-field(ZF) and External magnetic field (B_{ext}) will provide an microscopic insight into the magnetic structure of the system.

EXPERIMENTAL RESULTS

Zero-field ^{55}Mn NMR Spectra



Zero-field ^{69}Ga, ^{71}Ga NMR spectra

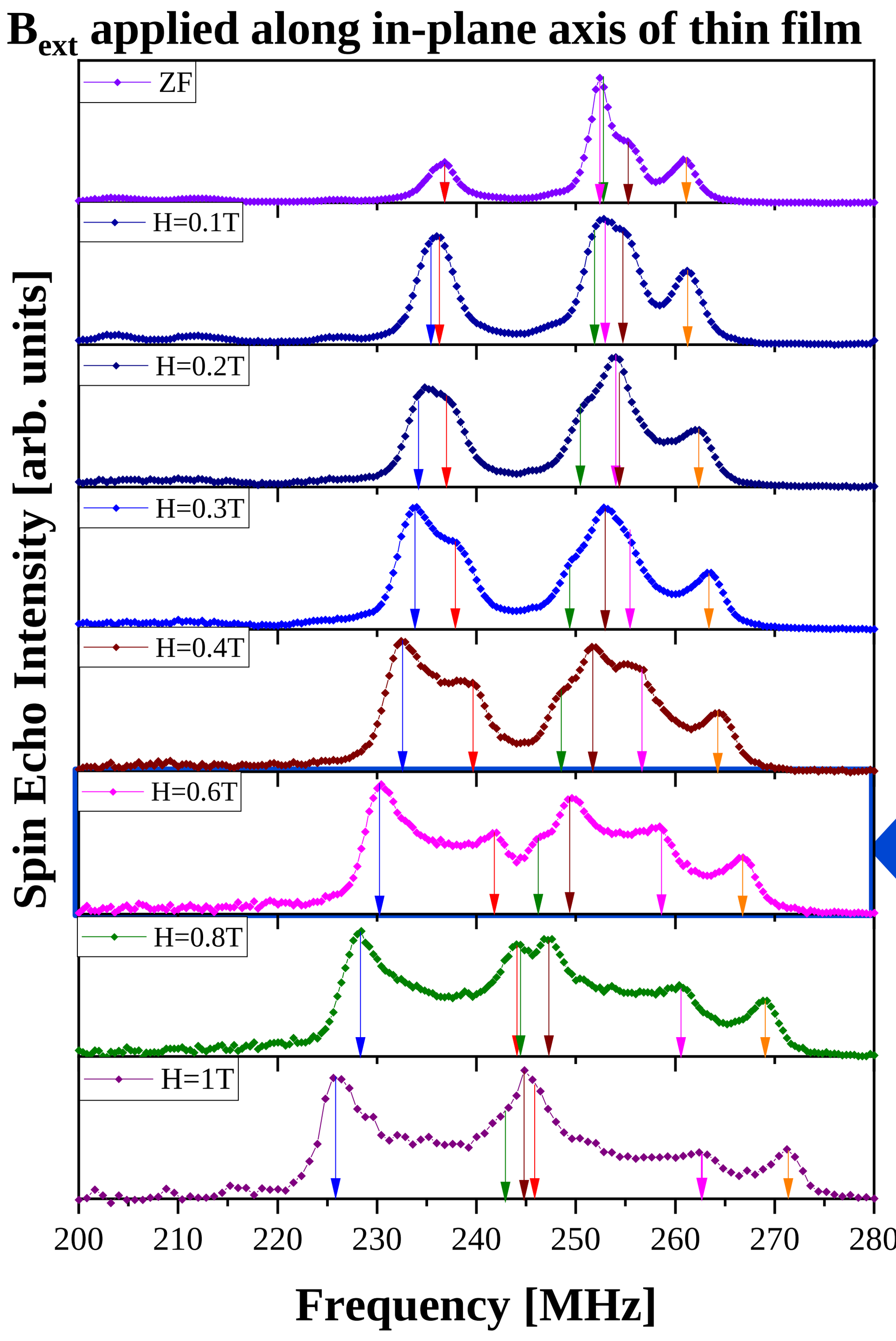


- Triplets are result of coupling between Electric field gradient (EFG) and nuclear quadrupole moment (Q), which are expected in the case of nuclear spin (I) = 3/2.

$$\Delta\omega = 2\pi\omega_Q(3\cos^2\theta - 1)$$
$$where,\ Quadrupolar\ frequency(\omega_Q)$$
$$= 2\pi\left[\frac{3e^2qQ}{h2I(I-1)}\right]$$

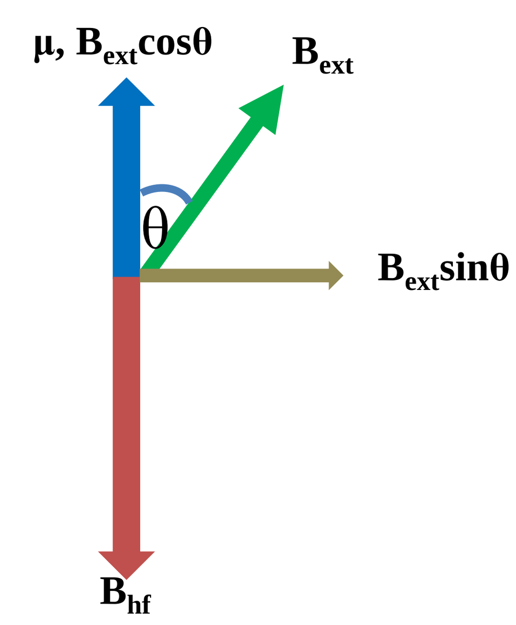
- ^{69}Ga, ^{71}Ga corresponds to single hyperfine field (B_{hf}) = 15.75 T.
- The large hyperfine field at Ga is due to the transferred hyperfine field from surrounding Mn-magnetic moments.

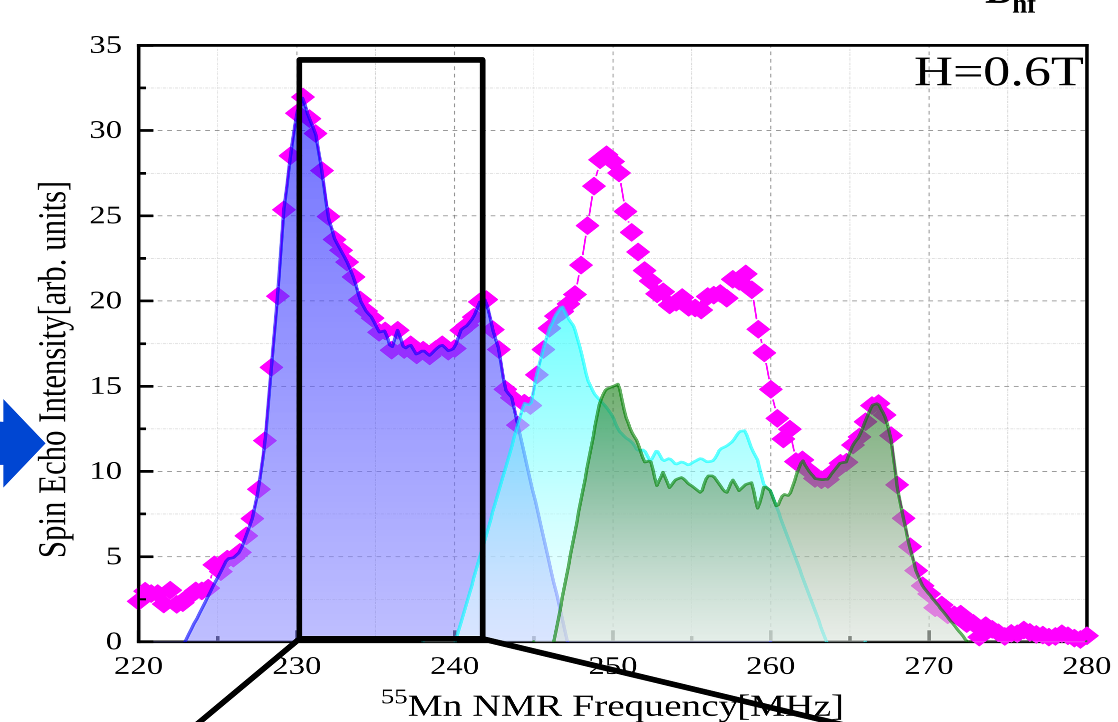
Evolution of ^{55}Mn NMR spectra of MgO(111)/ Mn_2GaC thin film when 0-1T B_{ext} applied along in-plane axis of thin film

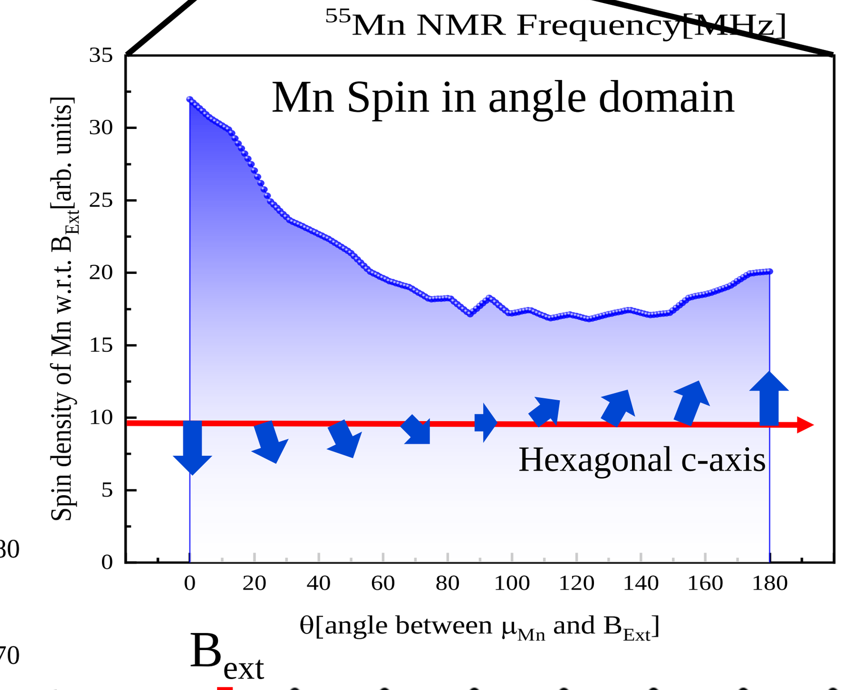


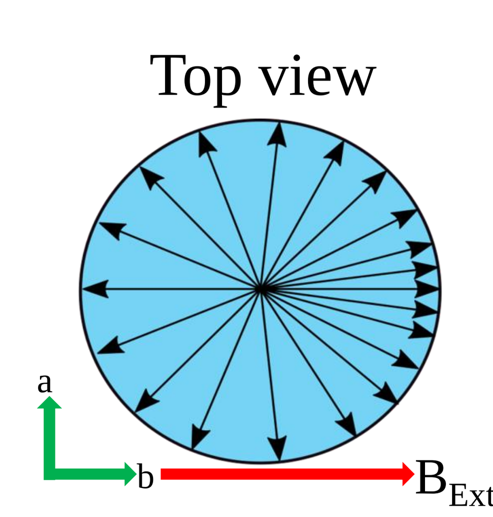
NMR Theory

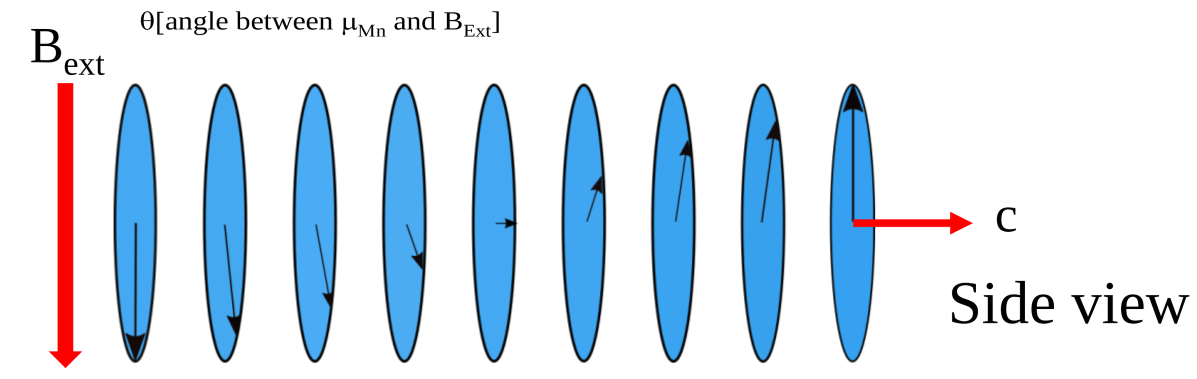
NMR frequency(ω)
$$= \gamma\left|\vec{B}_{hf} + \vec{B}_{ext} + \vec{B}_{dem}\right|$$
$$= \gamma\left[B_{hf} - B_{ext}\cos\theta\right]$$
for B_{Ext} applied along in-plane axis of thin film
$B_{dem} = 0$



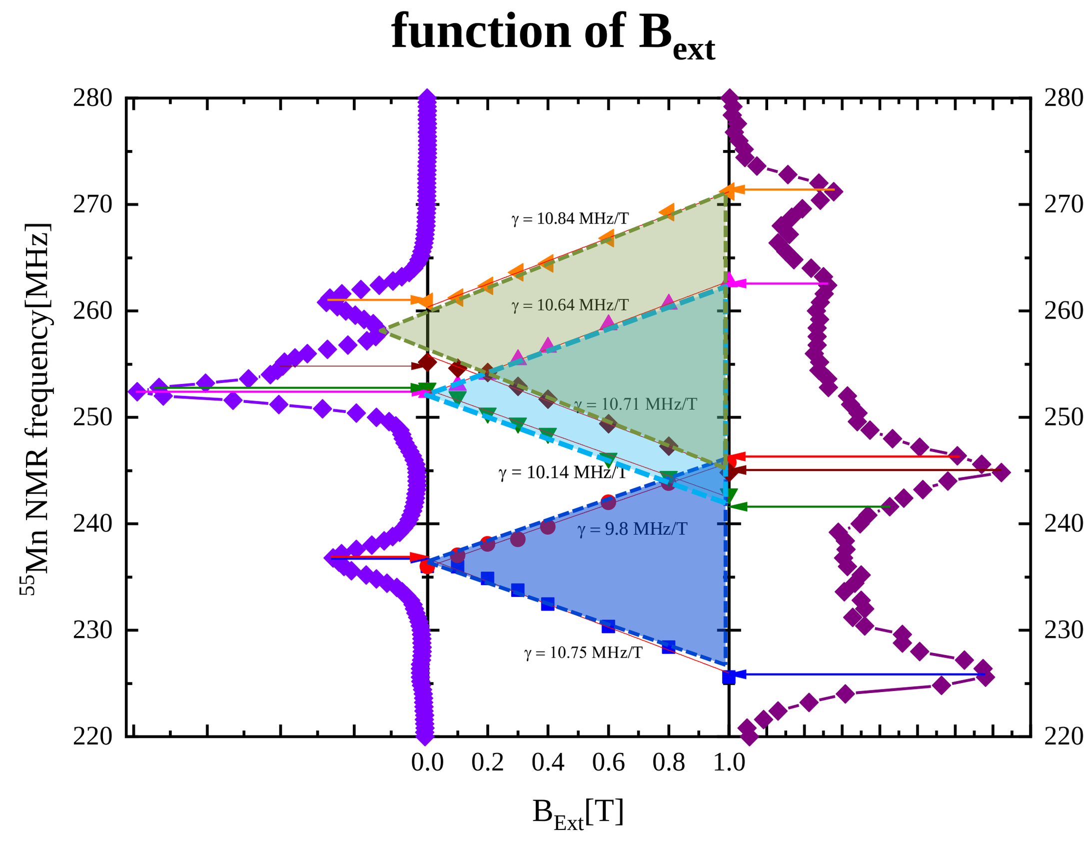








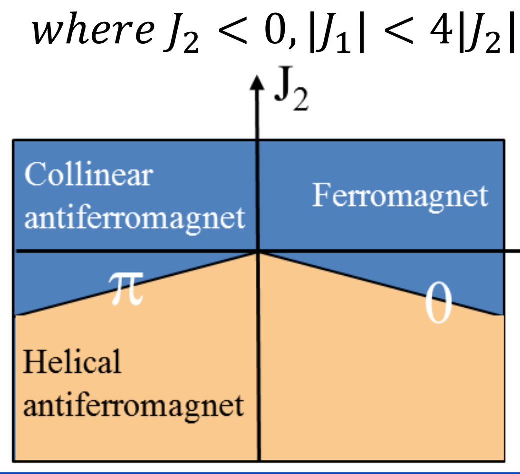
^{55}Mn NMR frequency as a function of B_{ext}

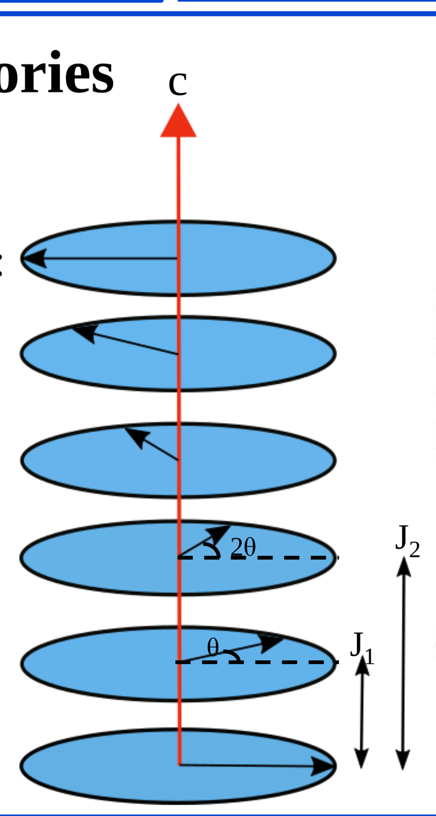


Spiral spin structure related theories

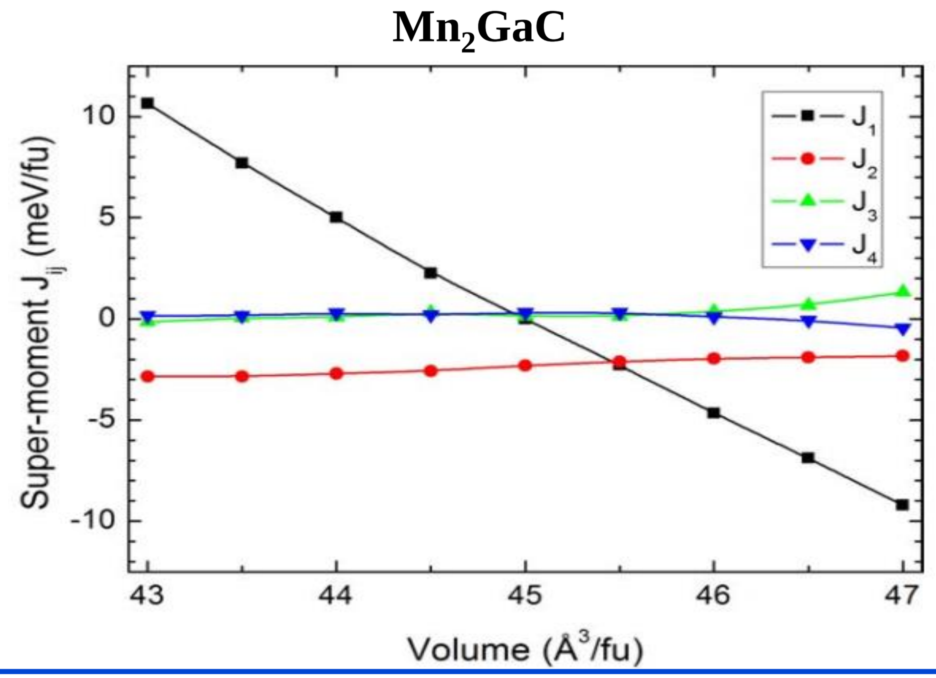
- Assumption: Intralayer ferromagnetic alignment
- Conditions for spiral spin structure to exist:

$$E = -2NS^2[J_1\cos\theta + J_2\cos(2\theta)]$$
$$where\ J_2 < 0, |J_1| < 4|J_2|, J_1 < 0$$





Monte-Carlo simulation of J_i with respect to volume upto four Ga-(Mn-C-Mn)-Ga layer for Mn_2GaC



Conclusion

- From Ga NMR – The uncompensated Mn magnetic moments in neighboring planes excludes the hypothesis of collinear antiferromagnet.
- From zero-field ^{55}Mn NMR – Average Mn Magnetic moment ≈ 2 μ_B
- The evolution of ^{55}Mn spectra in in-plane field suggests the distribution of Mn magnetic moment orientations in subsequent hexagonal base plane suggests the presence of **spiral spin structure** in Mn_2GaC.

References

1. A.S. Ingason, et al. Materials Research Letters, 2:2, 89-93 (2014)
2. A.S. Ingason, et al. Phys. Rev. B 94, 024416 (2016)
3. M. Dahlqvist, et al. Phys. Rev. B 93, 014410 (2016)