Spin fluctuations in MnGe chiral Magnet

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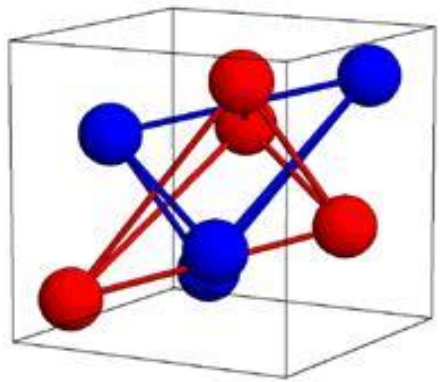
Summary

- ***The B20 family***
  - A hierarchy of interactions
  - Spin fluctuations, skyrmions, and quantum critical points
  - MnGe : a case in point
- ***chiral fluctuations in MnGe***
  - the different probes
  - **MuSR**
  - Which type of fluctuations?
  - Consequences on the elastic and electric properties

The B20 family

non centrosymétric space group $P2_13$



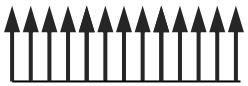
MnSi, FeGe, $Fe_{1-x}Co_xSi$, ..,MnGe

itinerant magnetism, tuned by a hierarchy of interactions

MnSi

θ_{cw}~J~30K

Ferro exchange



D~Ja/λ~0.75K
λ~180Å
a=4.5 Å

DM Anisotropy

$E_c=g\mu_B H_c$~10^{-3}K
H_c=0.1T

Crystal Anisotropy

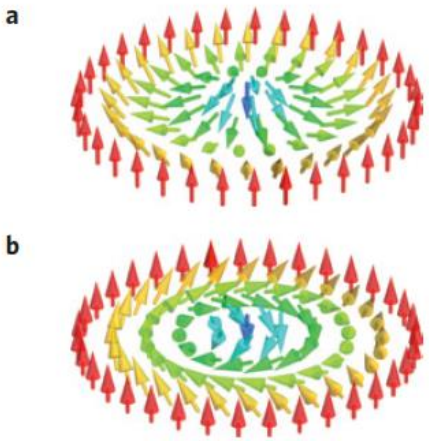
long period helixes

In bulk materials

- Quantum critical points
- Skyrmions

Spin fluctuations

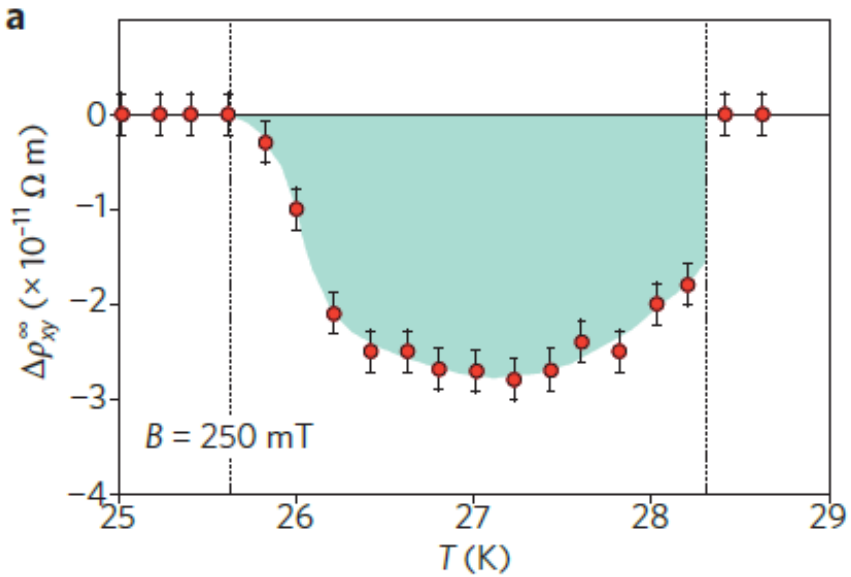
Skyrmions



A. Fert review (2013)

$$\rho_{xy} = \rho^{o}_{xy} + \rho^{a}_{xy} + \rho^{t}_{xy}$$

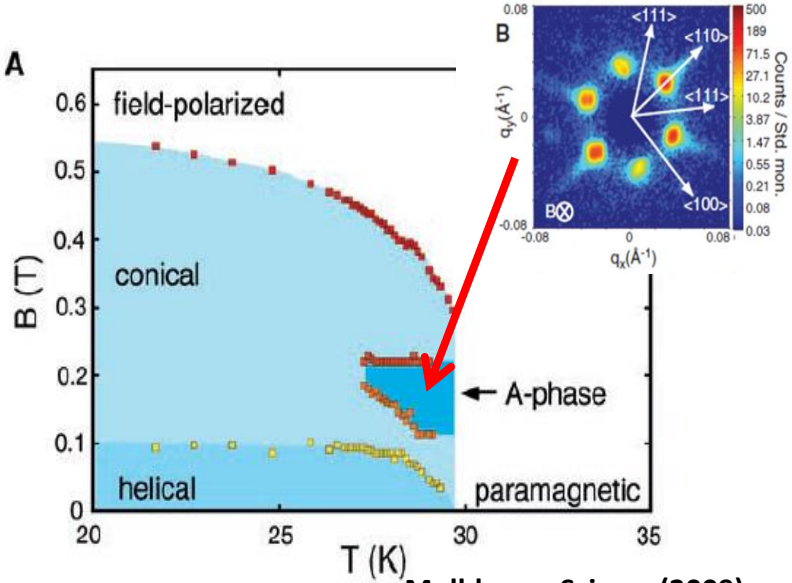
$R_0\mu_0 H$ $R_s M$ **THE**



Schultz Nature (2012)

Negative THE in MnSi

Bulk MnSi



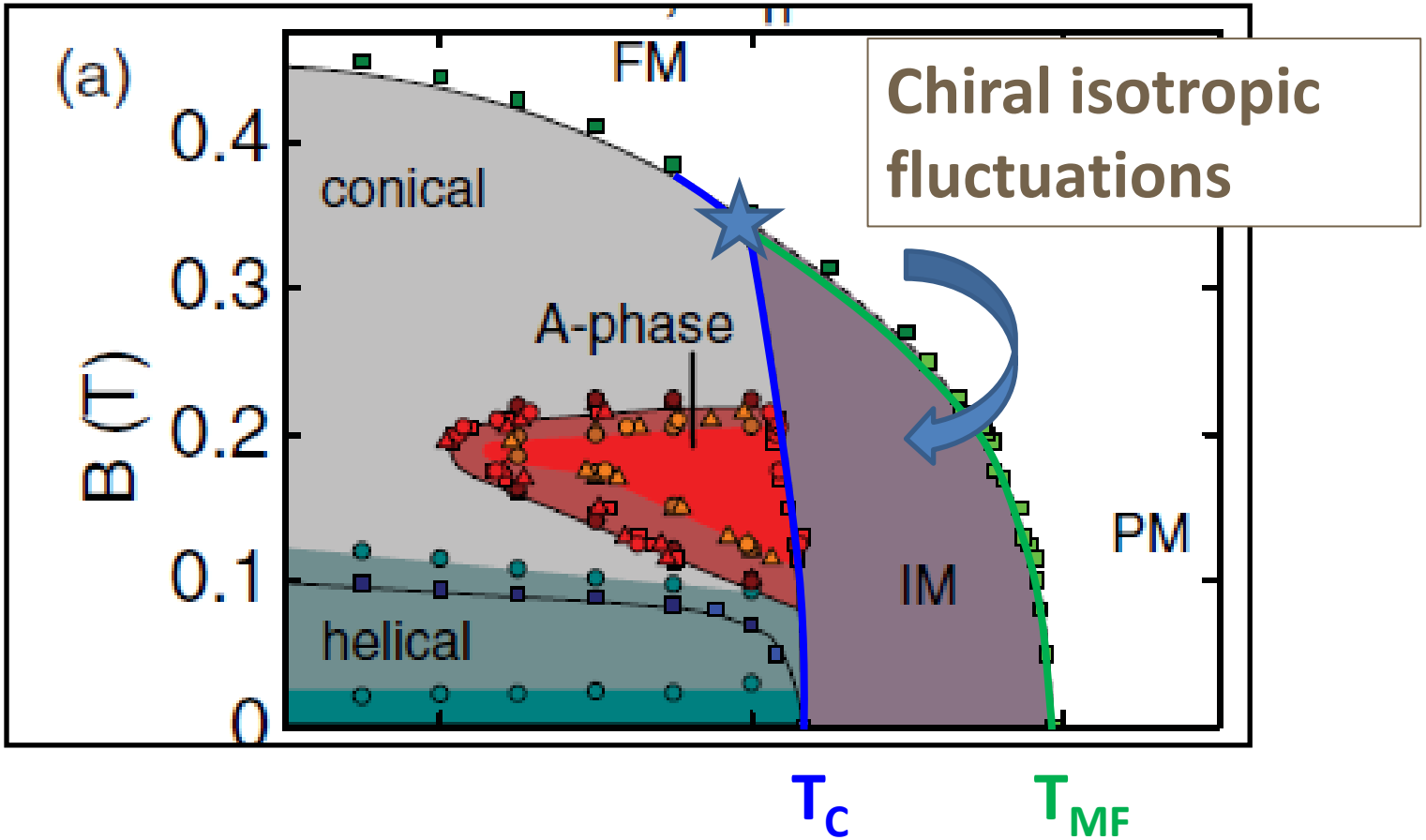
Mulhbauer Science(2009)

In bulk MnSi , the SK lattice is stable in a small (T, H) region : A phase

Skyrmions and spin fluctuations

First order transition induced by strong fluctuations

MnSi

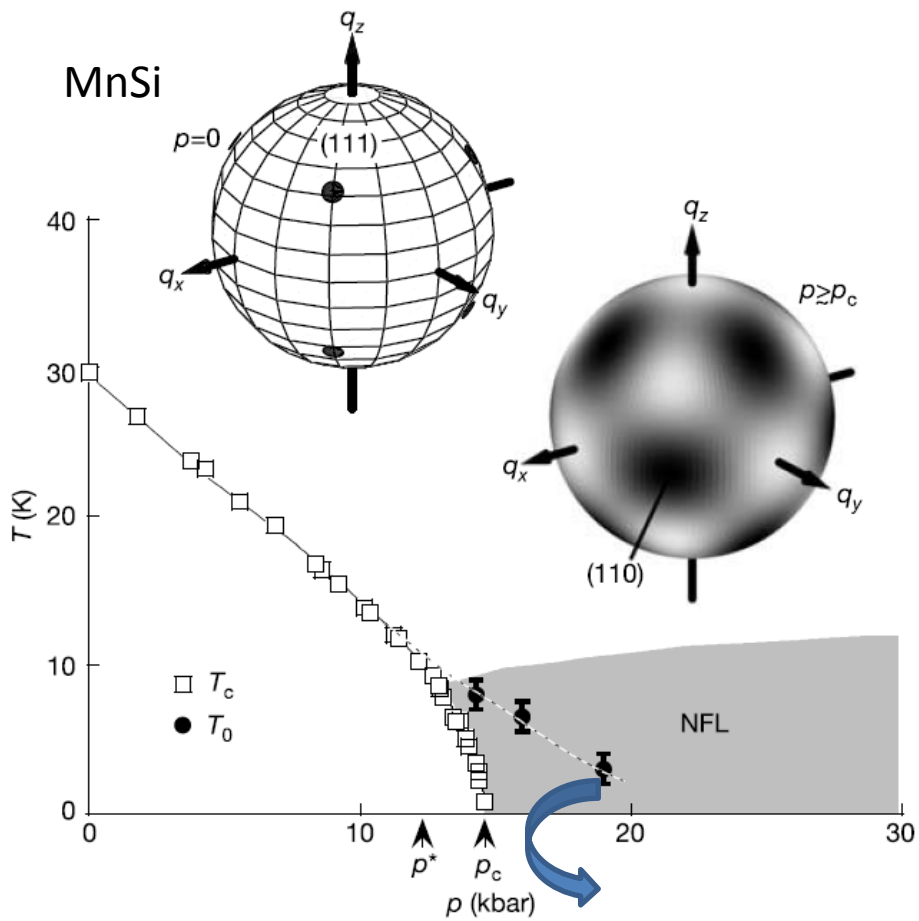


Bauer, Gast, Pfleiderer PRL(2013)
Janoschek et al PRB(2014)

Quantum critical points and spin fluctuations

Under pressure

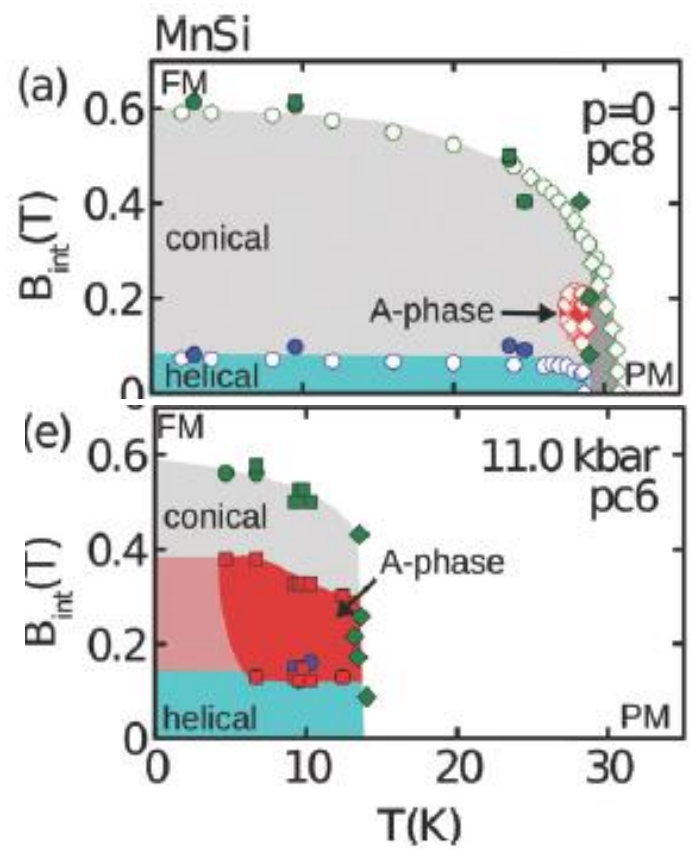
Partial ordered phase



No Cp or χ anomaly

Pfleiderer *et al* , Nature (2004)

under magnetic field

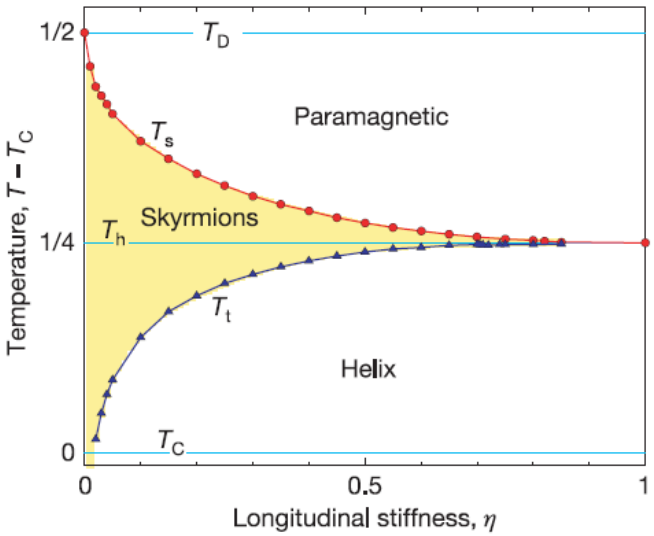


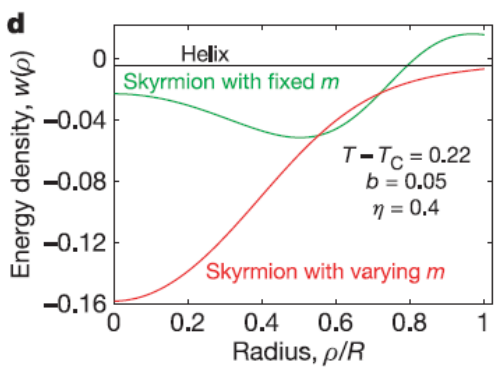
Ritz *et al.* PRB(2013)

Potential mechanisms

Longitudinal fluctuations of the magnetic moment

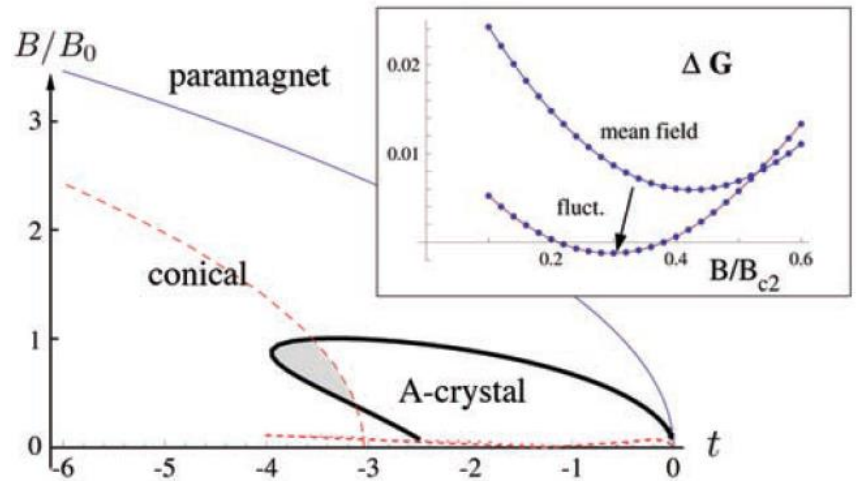
Spontaneous skyrmions (H=0)

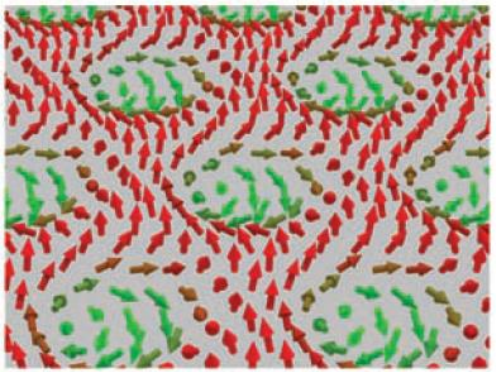




Roessler Nature (2006)

Skyrmion lattice in applied field





Mulhbauer Science (2009)

MnGe : a case in point (1)

Two possible sources for the spin fluctuations

- ***Short pitch***

compound	MnSi	FeGe	MnGe
T_N (K)	29.5	279	170
L_D (nm)	18	68-70	**3**
P_C (GPa)	1.3	**19**	**7 and ~13**

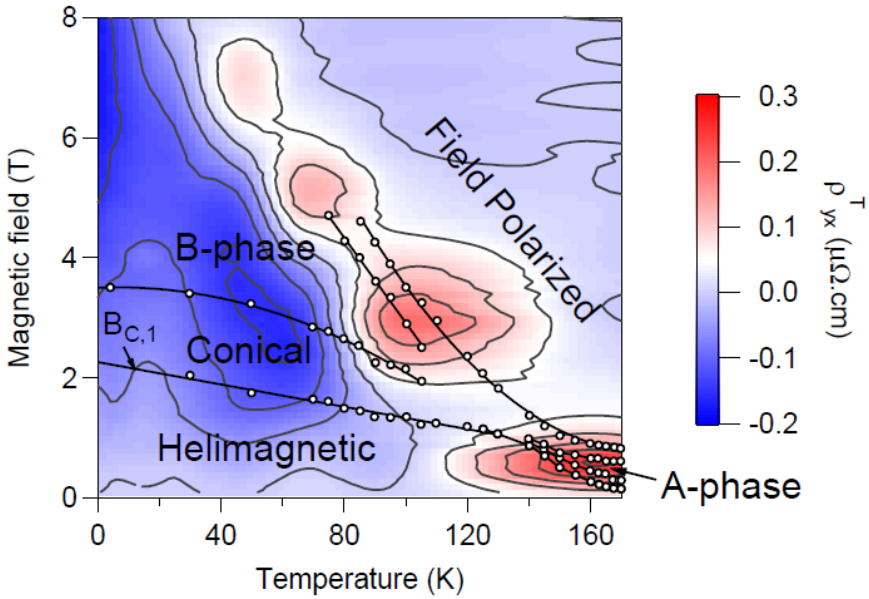
O. Makarova et al PRB(2012)
Kanazawa et al PRL(2011)

Giant precursor phase

$$\Delta T \sim \frac{A}{D} \sim \frac{1}{L_D^2}$$

MnSi : ΔT~4K
FeGe 4K
MnGe **50-300K !**

- ***High skyrmion density?***
- ***Giant THE***



Viennois et al, EPL (2015)
Kanazawa, PRL 2011

MnGe : a case in point (2)

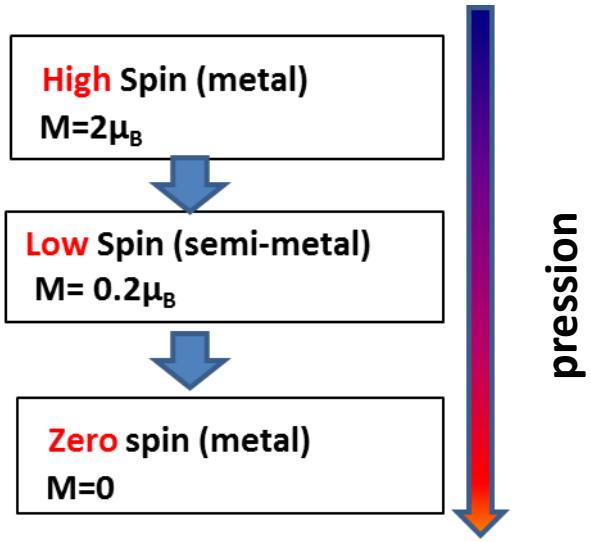
Two possible sources for the spin fluctuations

- ***Two Quantum Critical points***

compound	MnSi	FeGe	MnGe
T_N (K)	29.5	279	170
L_D (nm)	18	68-70	**3**
P_C (GPa)	1.3	**19**	**7 and ~13**

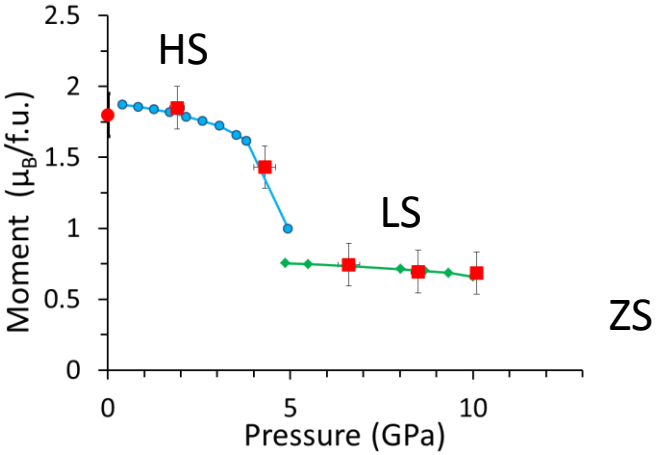
O. Makarova et al PRB(2012)
Kanazawa et al PRL(2011)

- ***Anomaly of the density of state***
- ***HS et LS metastable spin states***
- ***Slow « Invar-like » fluctuations ?***



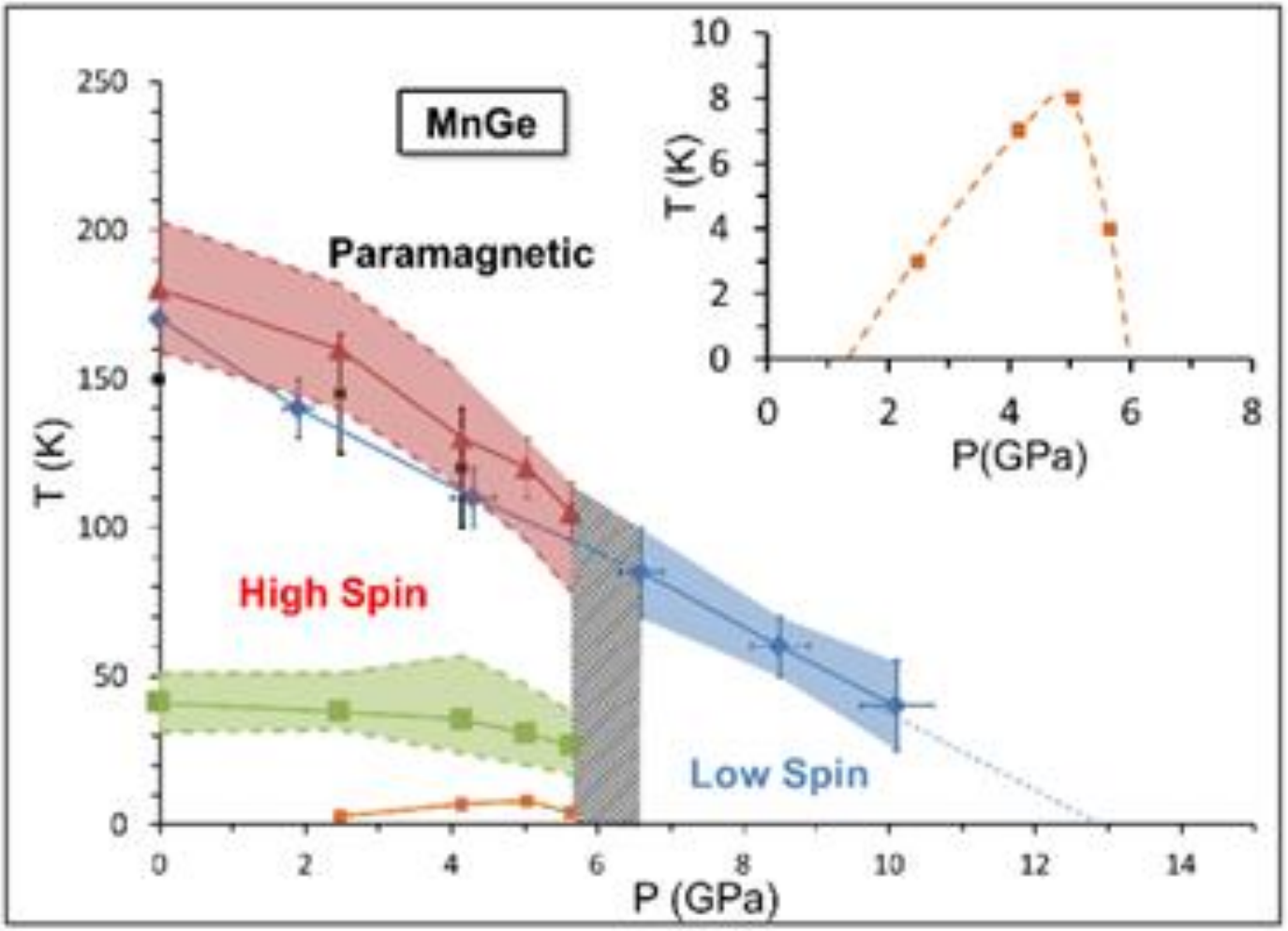
ab initio prediction
U. Roessler (2011)

M. Deutsch et al PRB RC (2014)



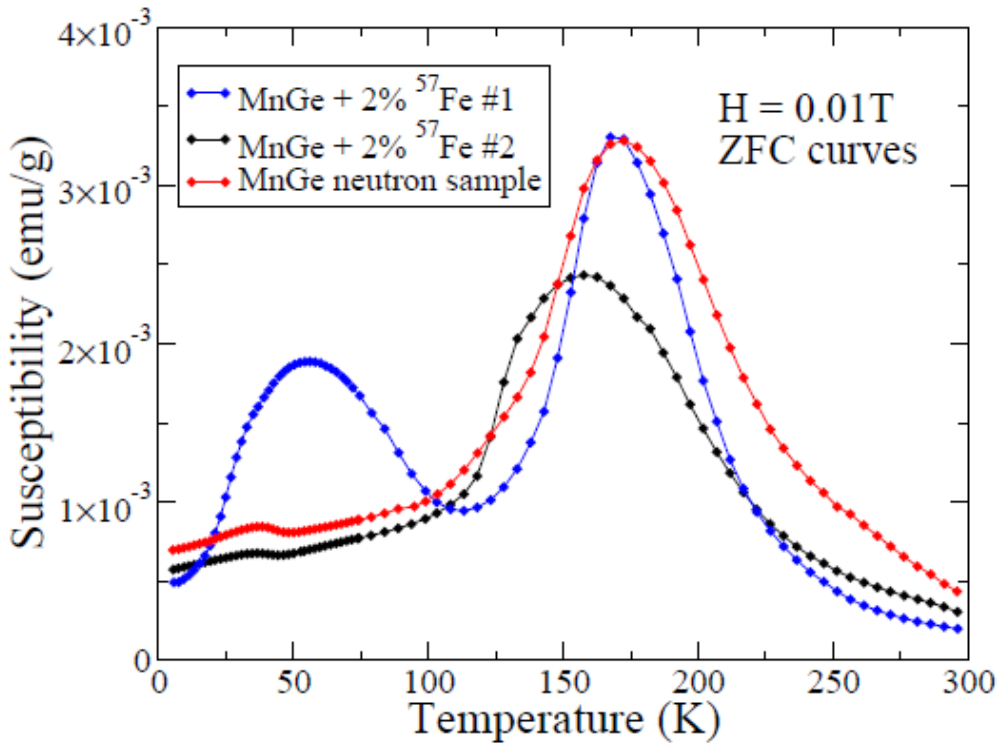
MnGe : High pressure phase diagram

M. Deutsch et al PRB **89**, 180407R, (2014)



MnGe :static susceptibility

low magnetic field



	MnGe	MnSi
	a=4.8Å	4.5Å
	J~280K	30K
	D~46K	0.75K
	Ea~3.4K	2 10^{-3}K

Deutsch et al PRB (2014)

In MnGe, spin fluctuations extend over a huge T range: $T_N \pm 70K$
and exist below T_N
Sample dependence: the susceptibility peak scales the fluctuating region

Probing the spin fluctuations

Which probes ?

- ***Time-frequency scales***
- ***length-Q scales***

Static susceptibility
τ~1s

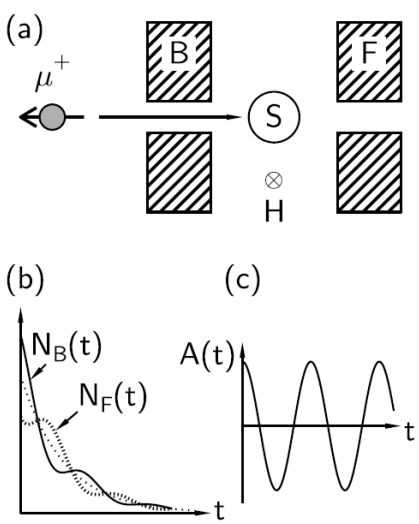
MuSR
τ~10^{-7}_10^{-5}s

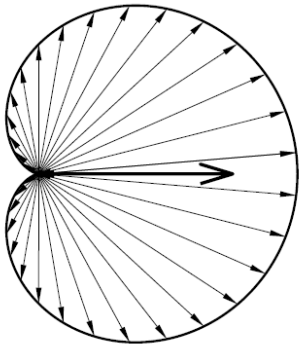
Mössbauer effect
τ ~10^{-8}s

Resonant
Neutron spin-echo
τ ~10^{-11}_10^{-12}s

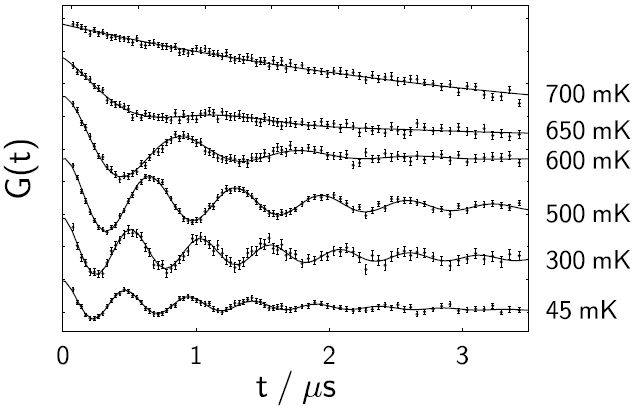
a MuSR experiment

Blundell, review (2002)

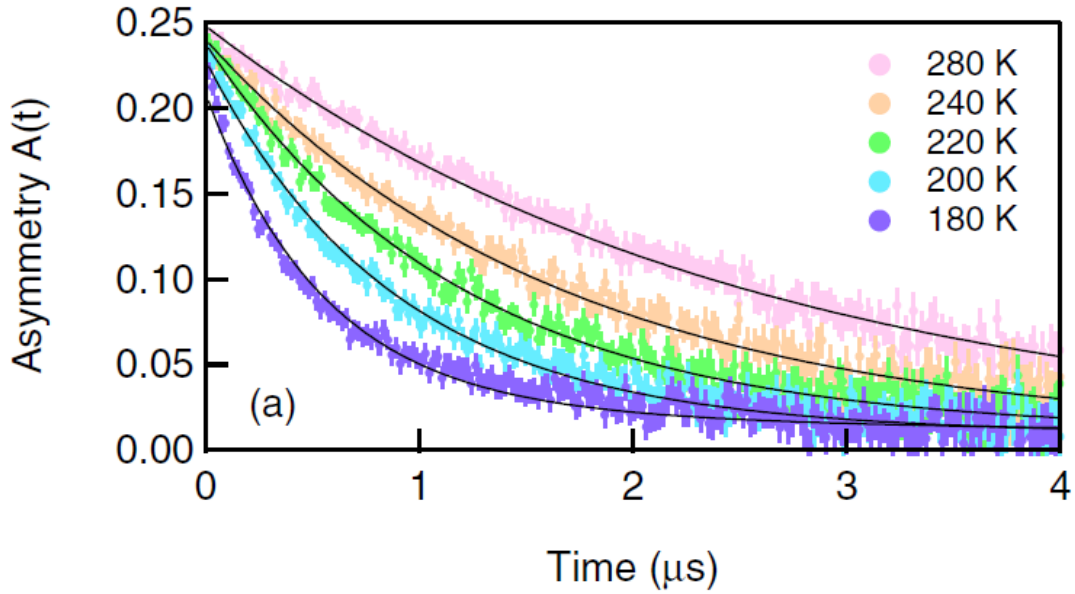




$$A(t) = \frac{N_B(t) - N_F(t)}{N_B(t) + N_F(t)}$$



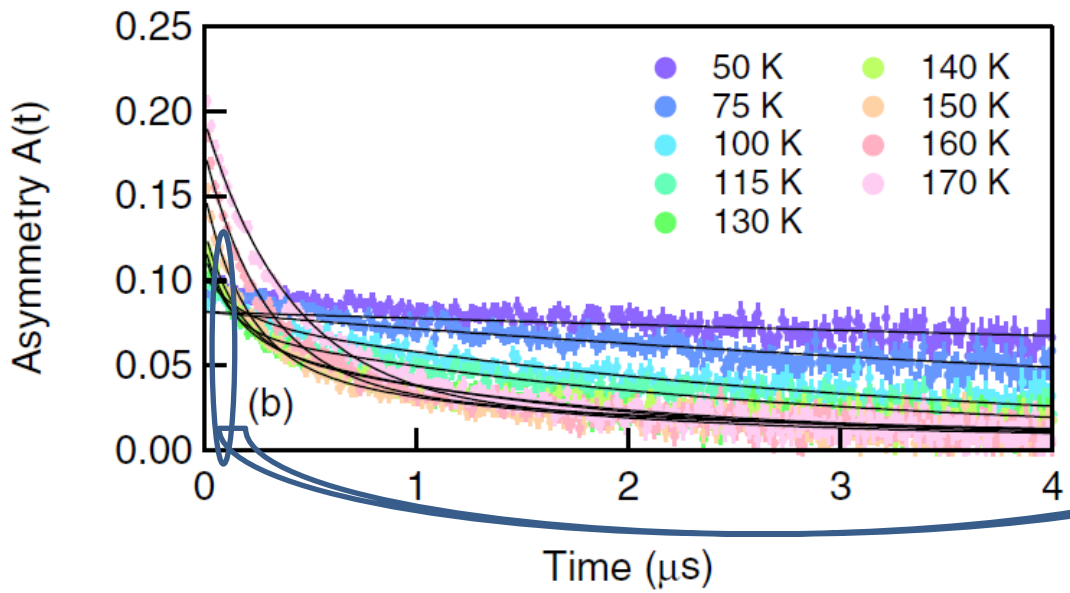
MnGe: MuSR

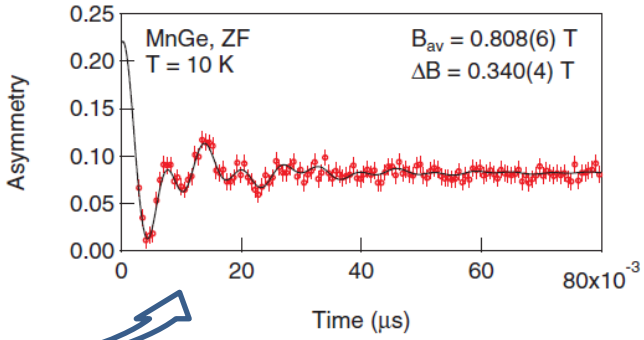


$T>T_N$

$T<T_N$

Strong depolarization from static dipolar fields





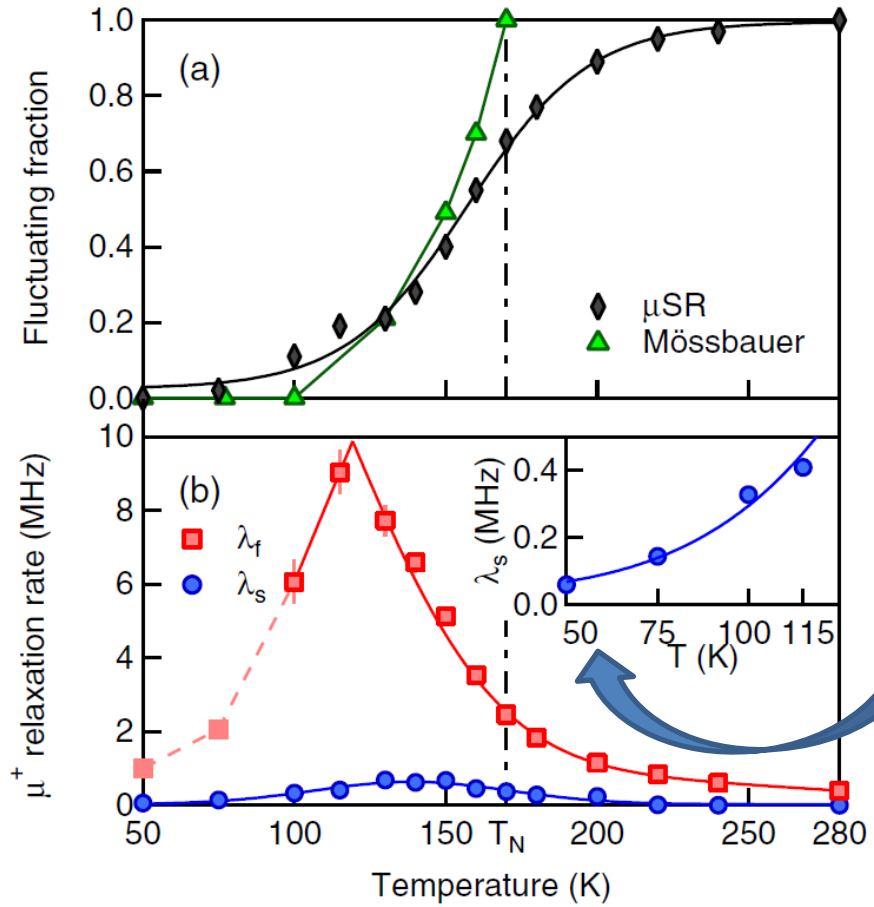
MnGe: MuSR

$$A(t) = (A_{\text{tot}} - b)\left[\frac{1-f}{3}e^{-\lambda_s t} + f e^{-\lambda_f t}\right] + b,$$

2-fractions model

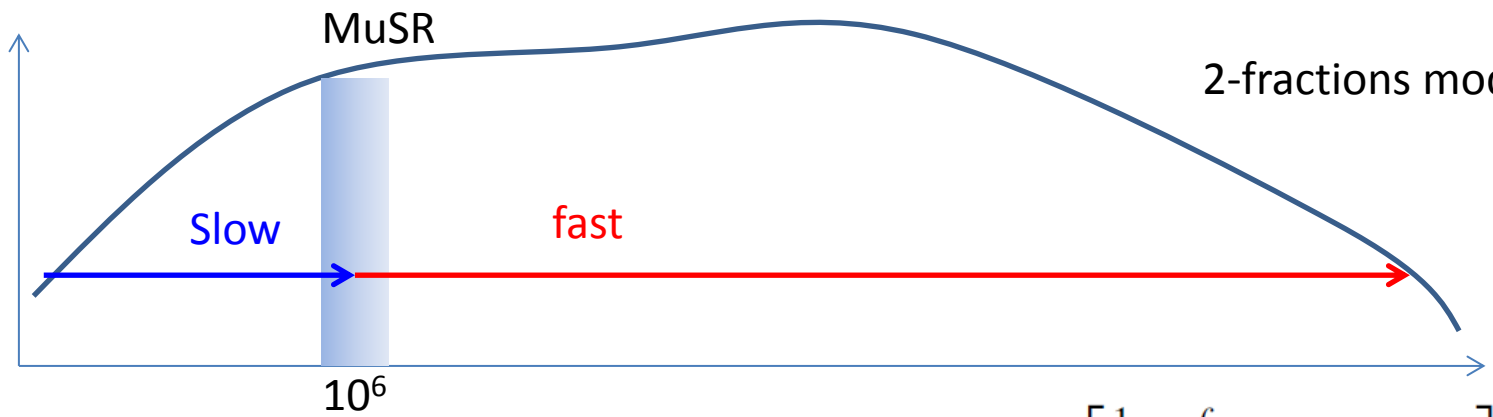
f: fast (λ_f)
1-f: slow (λ_s)

b: small fixed background



Slow fluctuations in the ordered phase

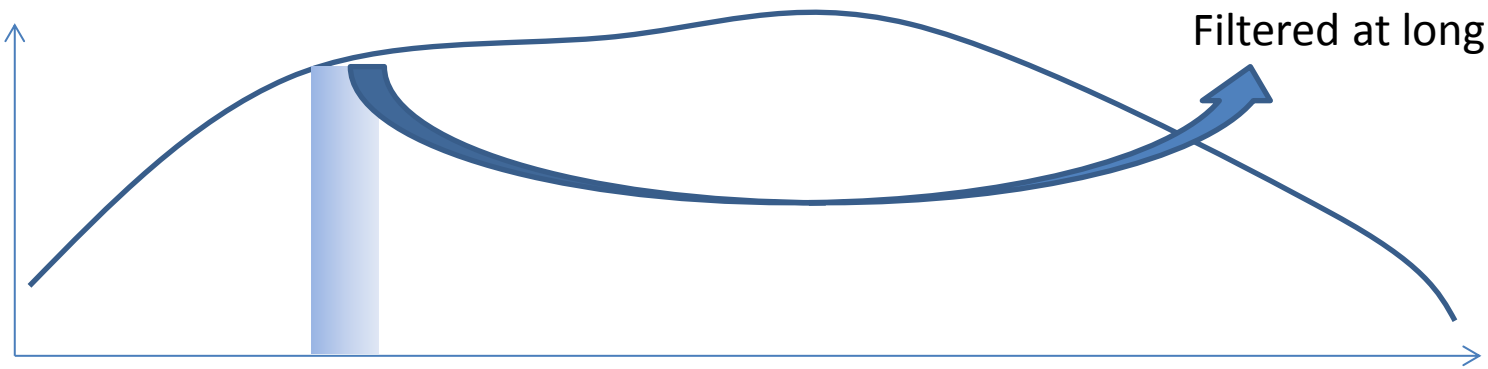
MnGe: MuSR



2-fractions model

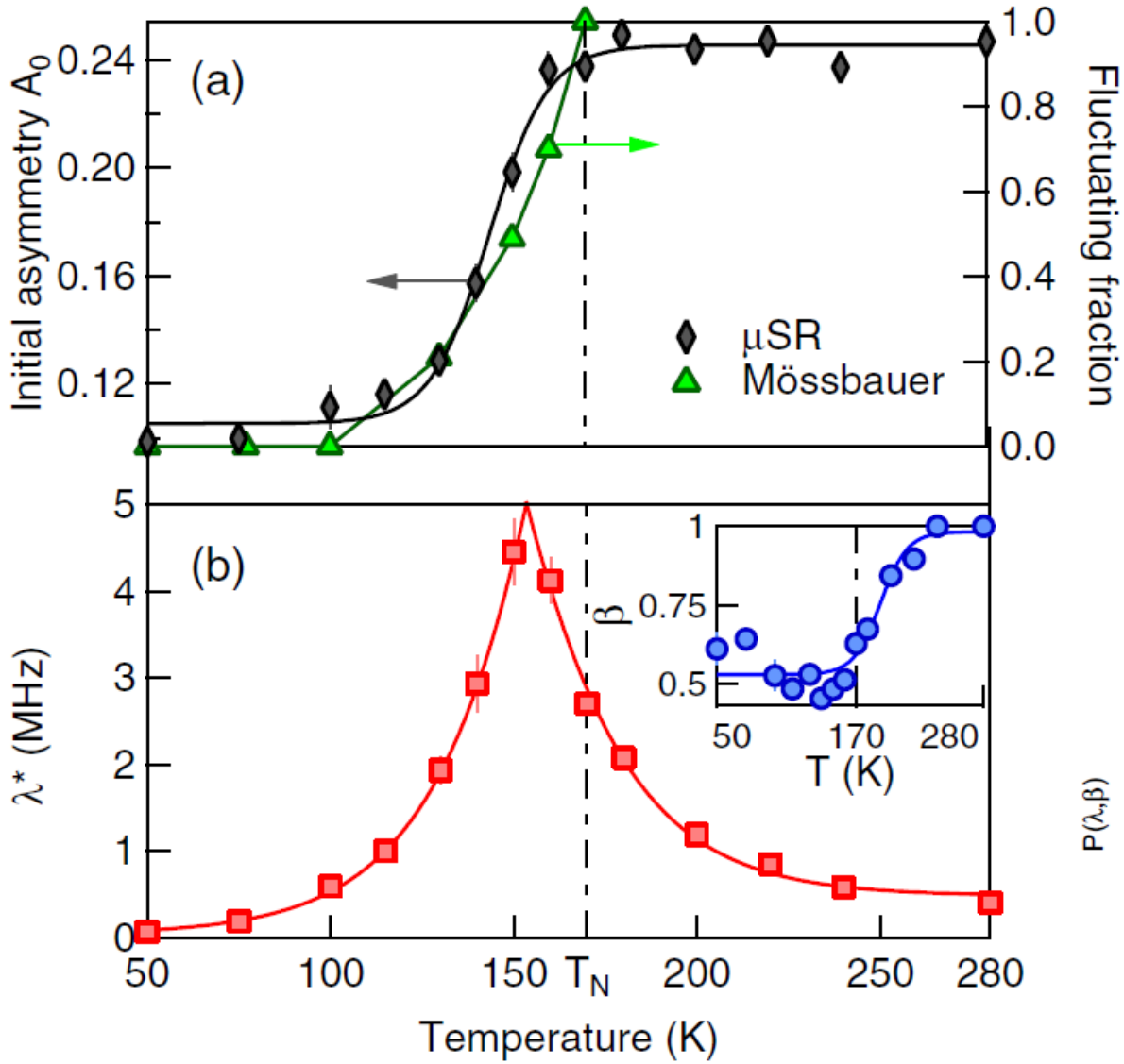
$$A(t) = (A_{\text{tot}} - b)\left[\frac{1-f}{3}e^{-\lambda_s t} + f e^{-\lambda_f t}\right] + b,$$

Continuous distribution
of relaxation rates
Filtered at long times



$$A(t) = (A_0 - b)e^{-(\lambda^* t)^\beta} + b,$$

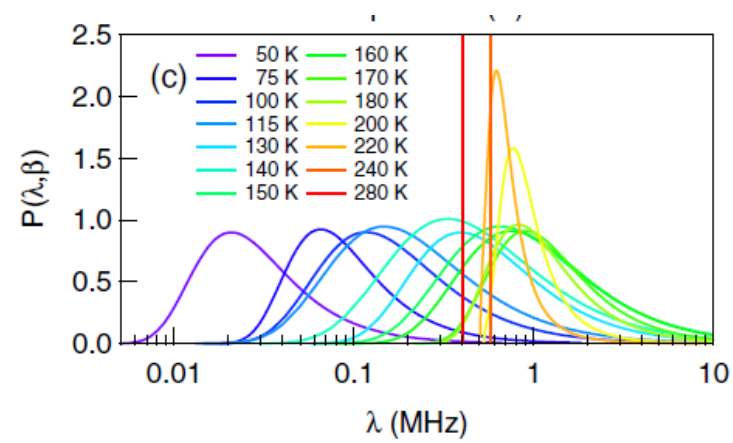
MnGe: MuSR



Continuous model

Broad distribution of independent relaxation channels (λ*, β)

$$\frac{1}{\lambda^*}\int_0^\infty P(\lambda,\beta)e^{-\lambda t}\,d\lambda = e^{-(\lambda^* t)^\beta}$$

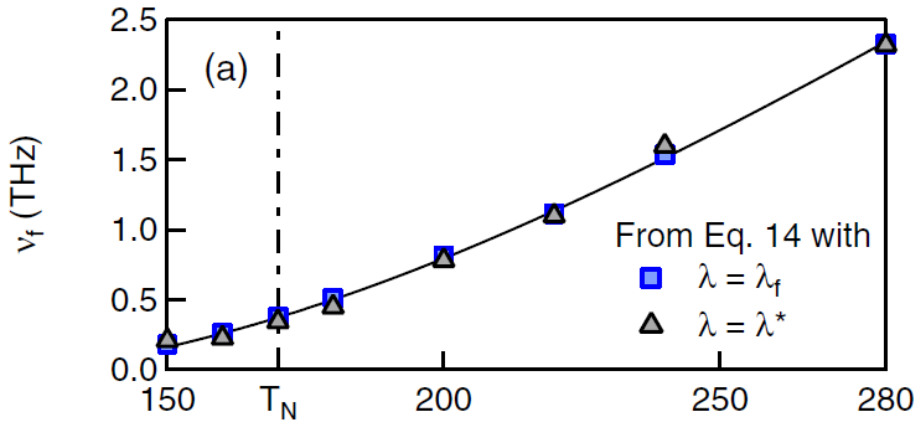


frequencies of the spin fluctuations?

- ***In the paramagnetic range T>> T_N***

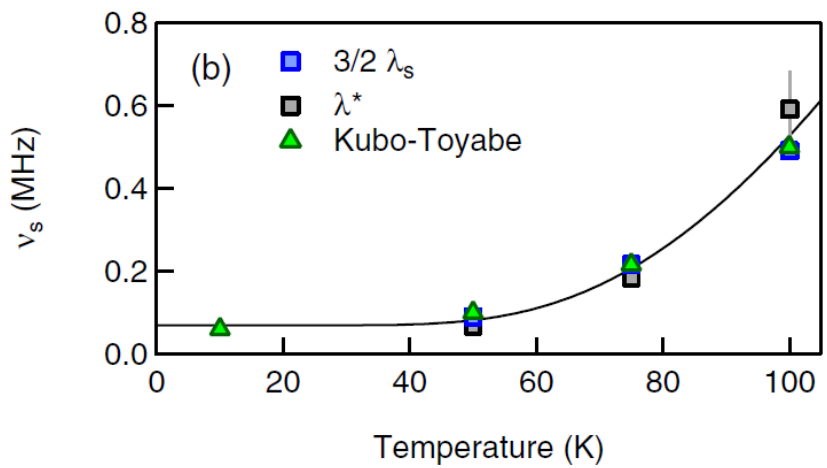
$$\lambda = \frac{2\gamma_\mu^2 \langle B^2 \rangle}{\nu_f},$$

$\langle B^2 \rangle = \langle B_{av}^2 \rangle$ with B_{av}=0.8T



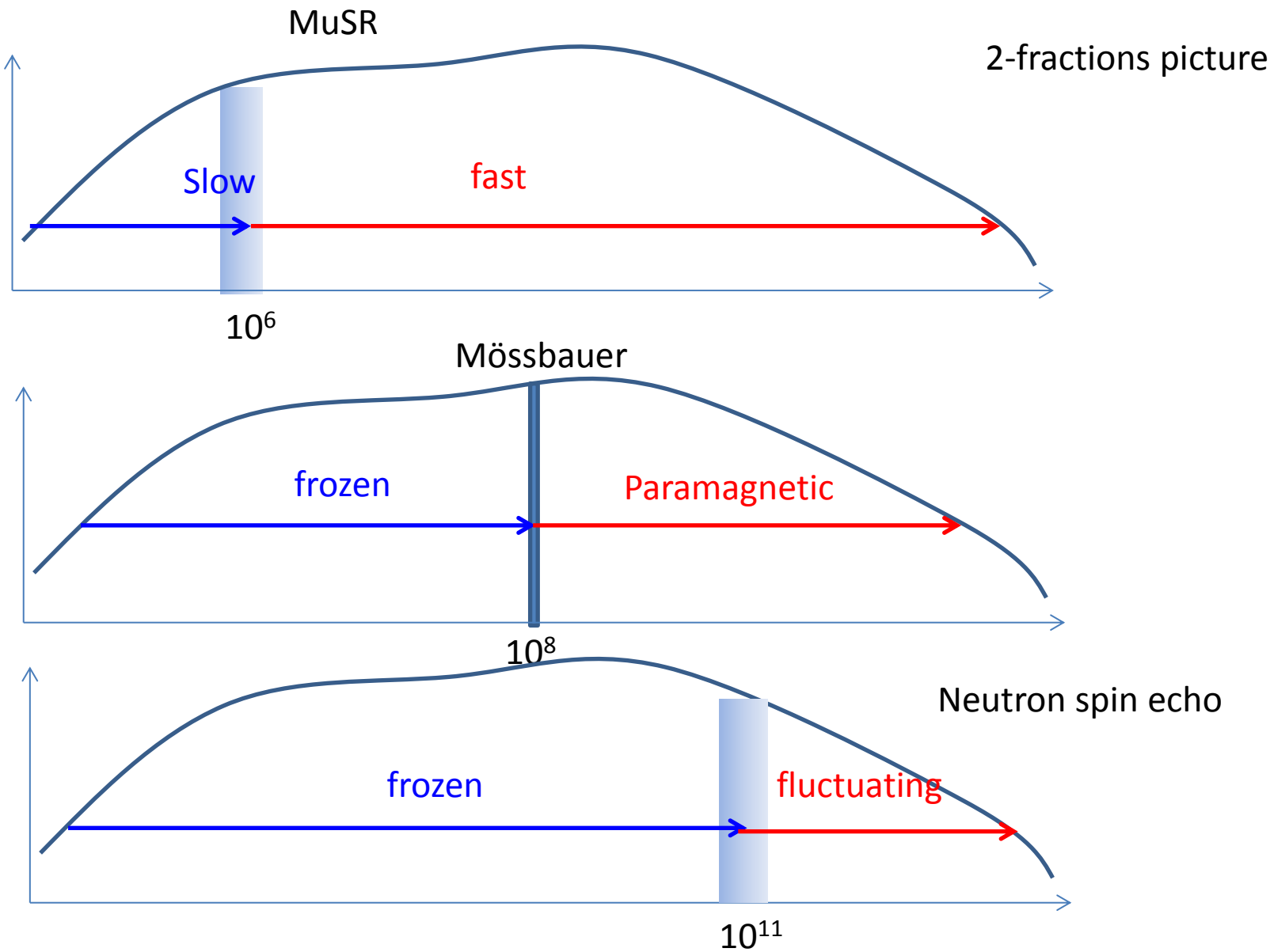
- ***Deep in the ordered phase T<<T_N***

$$A(t) \sim \frac{A_{tot}}{3} \exp(-2/3\nu_s t),$$



A very large range of frequencies

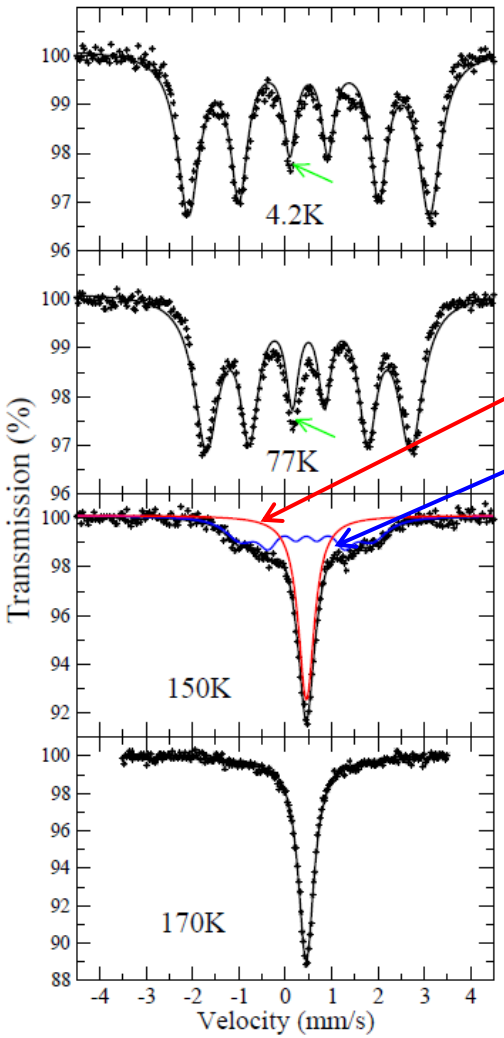
MnGe: MuSR, M.E, NSE



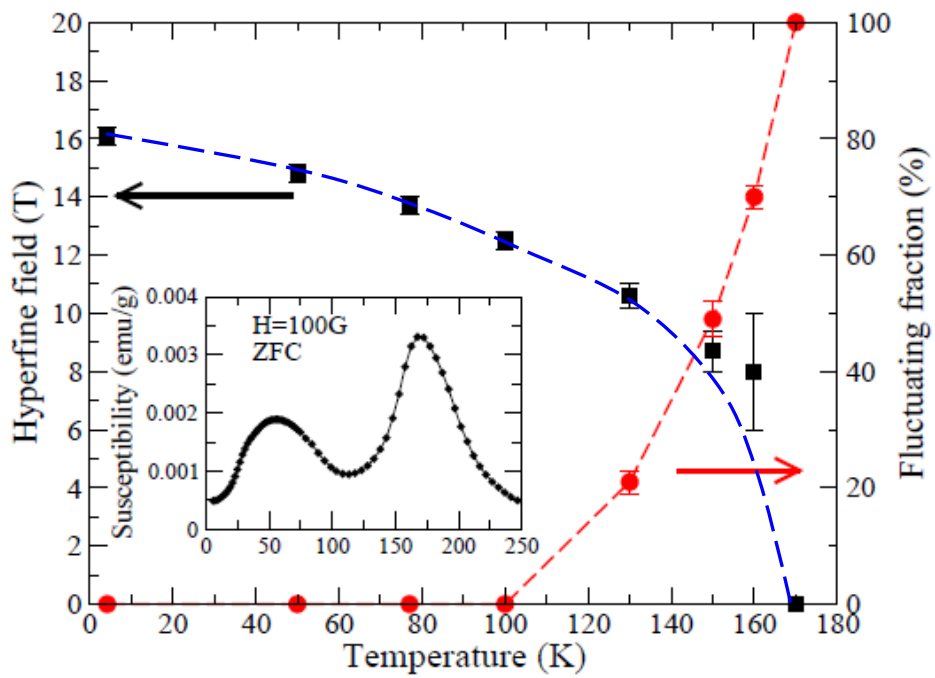
^{57}Fe-doped MnGe: Mossbauer study

P. Bonville

M. Deutsch et al PRB (2014)

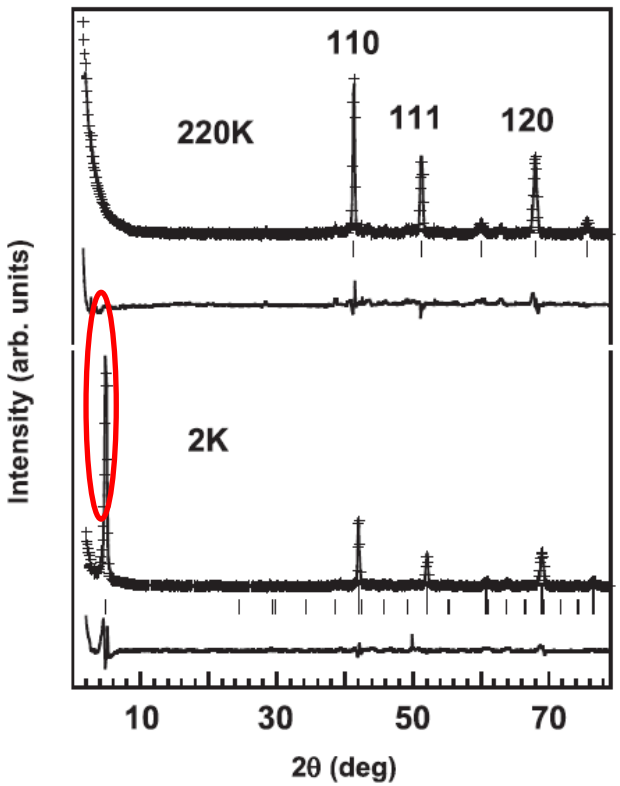


Coexistence of
fluctuating (seen as paramagnetic)
and
Frozen (seen as ordered)
signals



MnGe: Neutron diffraction

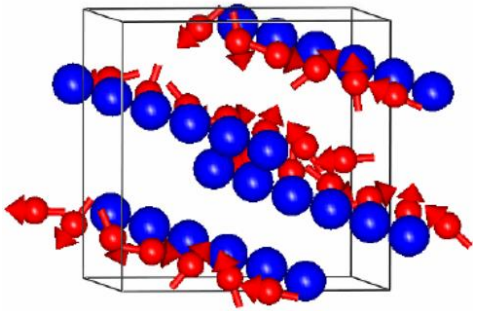
Probes the helical order and scales the ordered moment of the helix

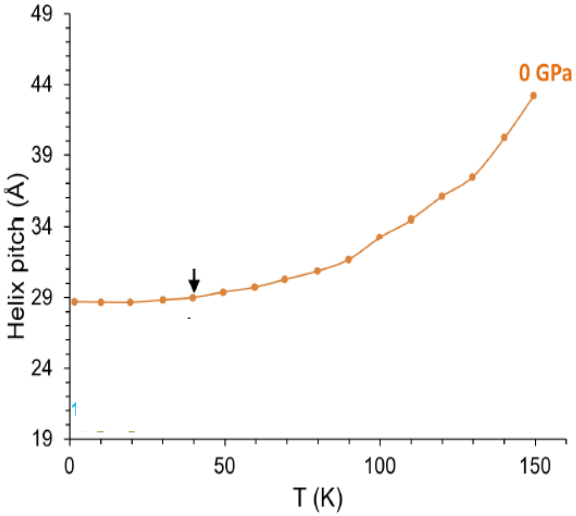


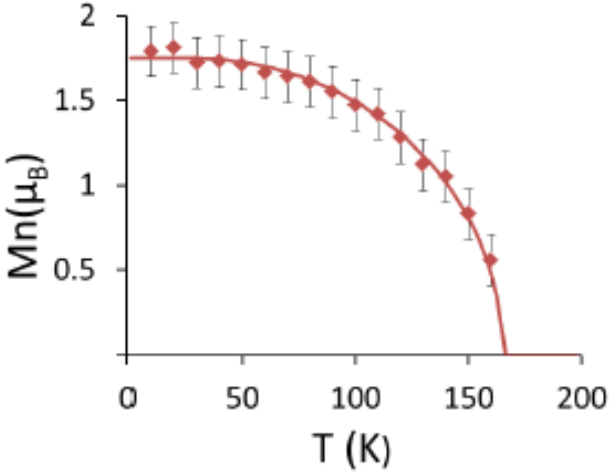
Intense zero satellite

Position → **period**

Intensity → **Moment**

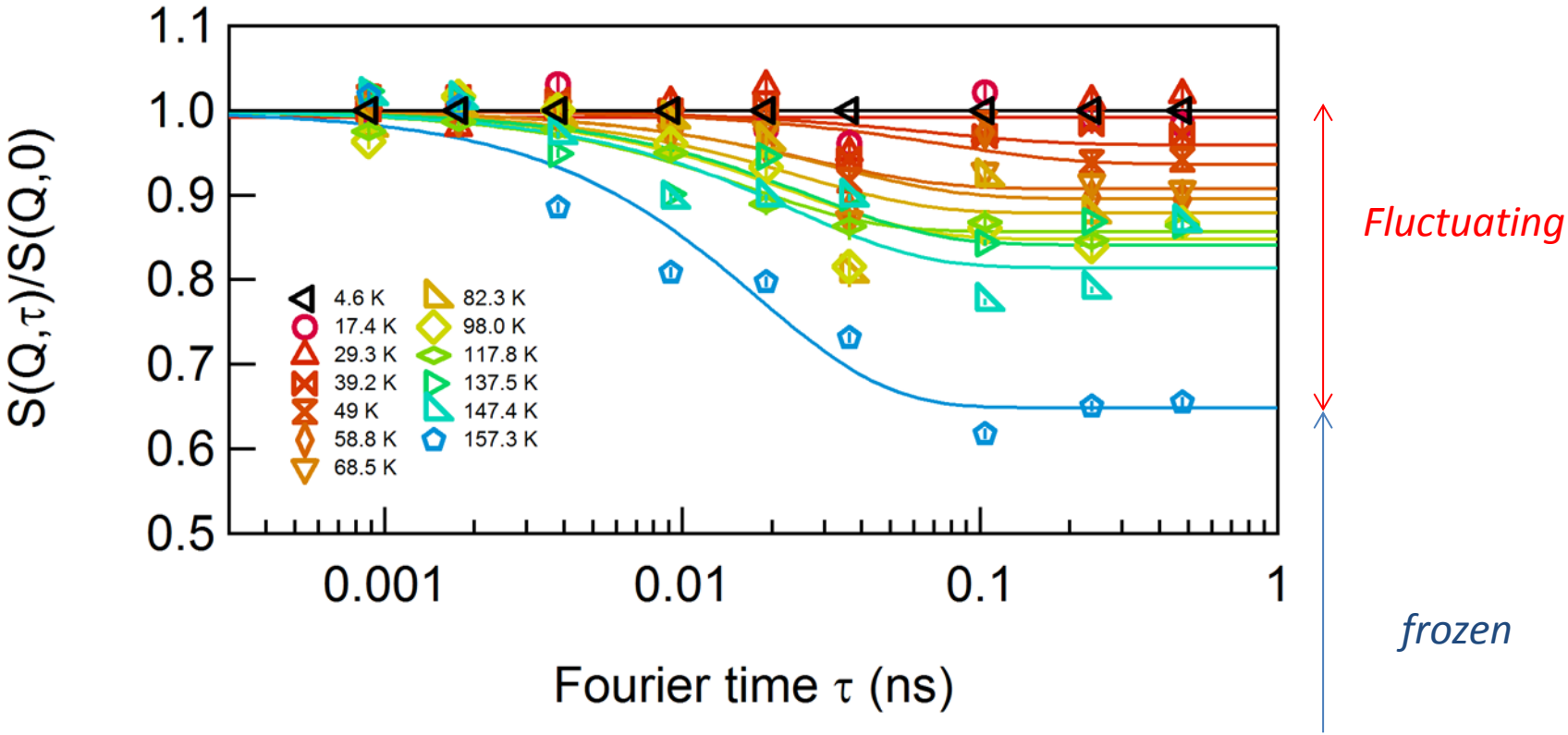






MnGe: Resonant Neutron Spin echo

Mieze technique (resonant spin echo) @ Reseda (HMI, Munich)

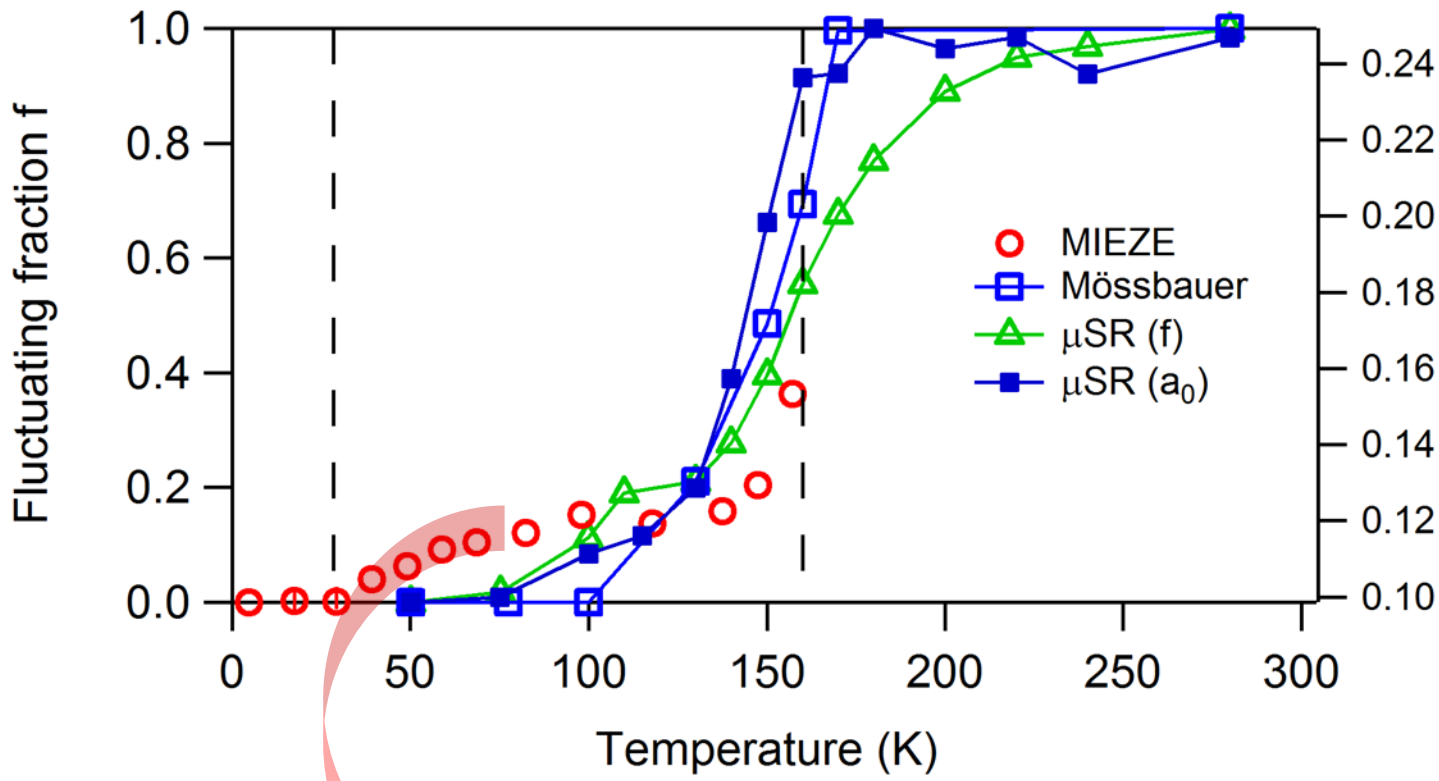


N. Martin et al unpublished

Spin fluctuations at the Bragg peak position

MnGe: Fluctuating fraction

Comparison of the different probes

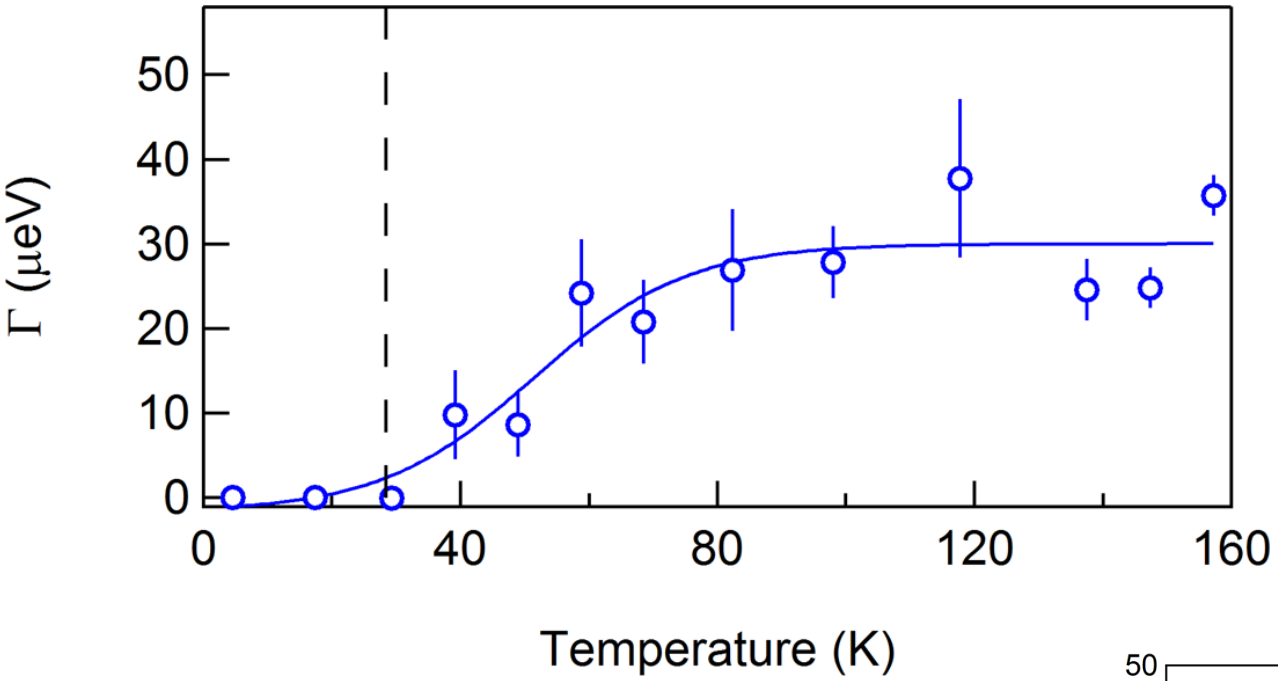


Something new!

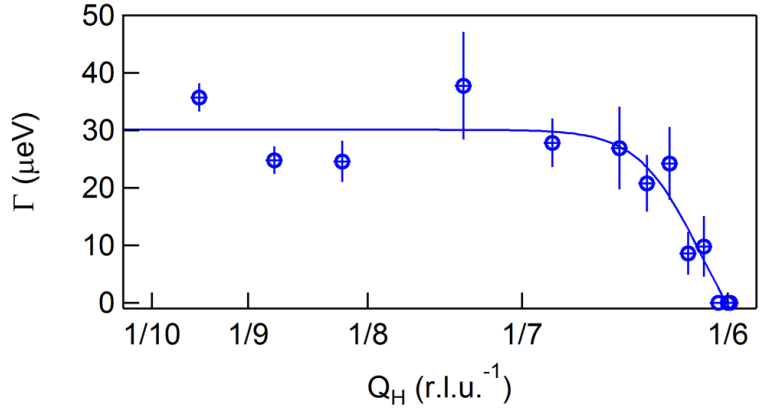
MnGe: Resonant Neutron Spin echo

Quasielastic linewidth

N. Martin et al unpublished



Mieze (2015)



The system becomes « static » (Γ=0) when the helical wave vector locks into a commensurate value 1/6

MnGe: Summary

strong DM interaction

- Short helical pitch
- Huge extension of the fluctuating chiral phase
- Large distribution of spin fluctuating frequencies (10^6-10^{12}Hz)

New movements of the helixes

- seen by NSE in the LRO state
- Locking – unlocking processes?

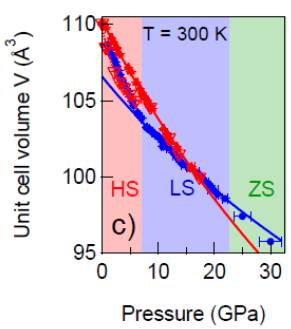
Two possible origins for the spin fluctuations

- Influence on the anomalous ***elastic*** and ***electric*** properties

Slow

- Specific to MnGe (2 QCP)
- HS and LS metastable states

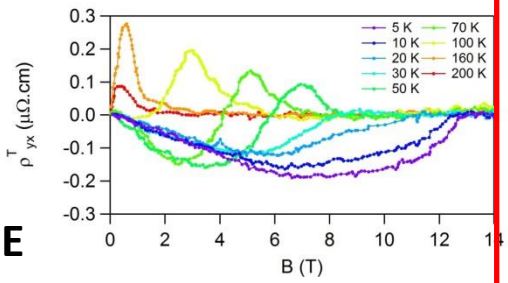
Invar-like behaviour



N. Martin *et al* to appear

Fast

- present in the whole B20 family
- Enhanced in MnGe



Giant THE

Kanazawa PRL 2011

Merci!

et un peu de pub..

RAPID COMMUNICATIONS

PHYSICAL REVIEW B **89**, 180407(R) (2014)

Two-step pressure-induced collapse of magnetic order in the MnGe chiral magnet

M. Deutsch,[1] O. L. Makarova,[1,2] T. C. Hansen,[3] M. T. Fernandez-Diaz,[3] V. A. Sidorov,[4] A. V. Tsvyashchenko,[4,5] L. N. Fomicheva,[4] F. Porcher,[1] S. Petit,[1] K. Koepernik,[6] U. K. Rößler,[6] and I. Mirebeau[1,*]

PHYSICAL REVIEW B **90**, 144401 (2014)

Stress-induced magnetic textures and fluctuating chiral phase in MnGe chiral magnet

M. Deutsch,[1] P. Bonville,[2] A. V. Tsvyashchenko,[3,4] L. N. Fomicheva,[3] F. Porcher,[1] F. Damay,[1] S. Petit,[1] and I. Mirebeau[1,*]

PHYSICAL REVIEW B **93**, 174405 (2016)

Magnetic ground state and spin fluctuations in MnGe chiral magnet as studied by muon spin rotation

N. Martin,[1] M. Deutsch,[2] F. Bert,[3] D. Andreica,[4] A. Amato,[5] P. Bonfà,[6] R. De Renzi,[6] U. K. Rößler,[7] P. Bonville,[8] L. N. Fomicheva,[9] A. V. Tsvyashchenko,[9,10] and I. Mirebeau[1,*]

PHYSICAL REVIEW B **93**, 214404 (2016)

Magnetovolume effect, macroscopic hysteresis, and moment collapse in the paramagnetic state of cubic MnGe under pressure

N. Martin,[1] M. Deutsch,[2,3] J.-P. Itié,[2] J.-P. Rueff,[2,4] U. K. Rössler,[5] K. Koepernik,[5] L. N. Fomicheva,[6] A. V. Tsvyashchenko,[6,7] and I. Mirebeau[1,*]