

**Scanning Hall imaging of the
magnetic phase transitions in
 Gd_5Ge_4 and $\text{Gd}_5\text{Si}_2\text{Ge}_2$**

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This work is supported by the Leverhulme Foundation and the EPSRC

Track Record

- **Superconductors**

Bugoslavsky Y *et al.*, Vortex Dynamics in Superconducting MgB2 **Nature** **410** (2001) 563 - 565

Bugoslavsky Y *et al.*, Enhancement of the high magnetic field critical current density of superconducting MgB2 by proton irradiation, **Nature** **411** (2001) 561-563

- **Spin Polarised Heuslers**

Branford WR, Clowes SK, Syed MH, *et al.*, Large positive magneoresistance in nonstoichiometric NiMnSb thin films on Si, **Appl Phys Lett** **84** (2004): 2358-2360

Miyoshi Y *et al.*, Comparison of free surface polarization of NiMnSb and Co₂MnSi, **Appl Phys Lett** **88** (2006)142512

- **Meta Magnets**

Roy SB, Perkins GK, Chattopadhyay MK, *et al.*, First order magnetic transition in doped CeFe₂ alloys: phase coexistence and metastability, **Phys Rev Lett** **92** (2004) 147203

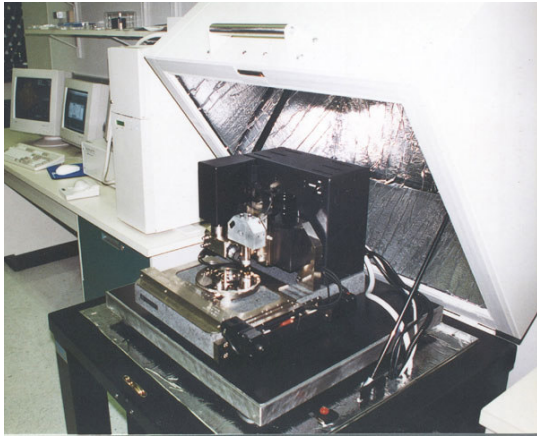
Moore JD *et al.*, Reducing the operational magnetic field in the prototype magnetocaloric system Gd₅Ge₄ by approaching the single cluster limit, **Appl Phys Lett** **88** (2006) 072591

Moore JD *et al.*, Correlating the local magnetic properties of the magnetic phase transition in Gd₅Ge₄ using scanning Hall probe imaging, **Phys Rev B** **73** (2006) 144426

Electrical transport

Tools

MFM



VSM



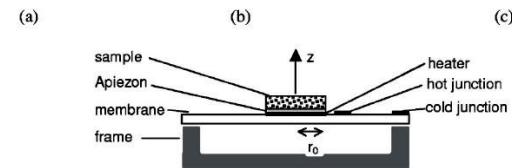
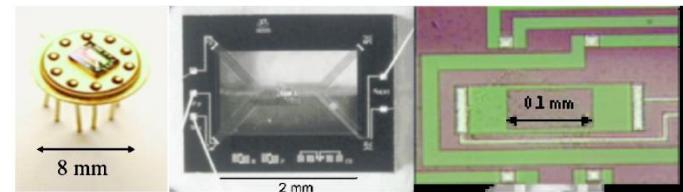
Point contact spectroscopy



Hall probe imaging



Membrane sensor for *ac-calorimetry and latent heat*



(d)

Outline of talk

- Motivation
- Scanning Hall rig
- 1. Imaging of Gd_5Ge_4
 - *MH* loop behaviour in bulk / fragments
 - Summary
- 2. Imaging of single crystal $\text{Gd}_5\text{Si}_2\text{Ge}_2$
 - Summary

Motivation

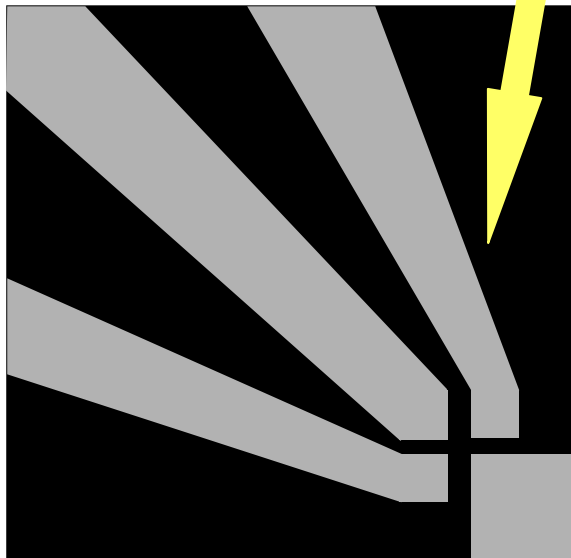
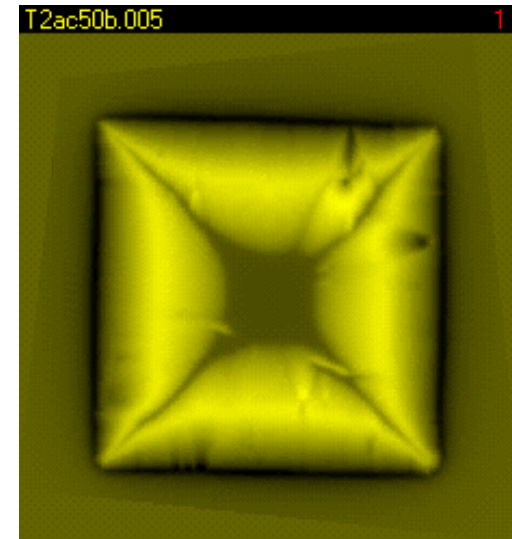
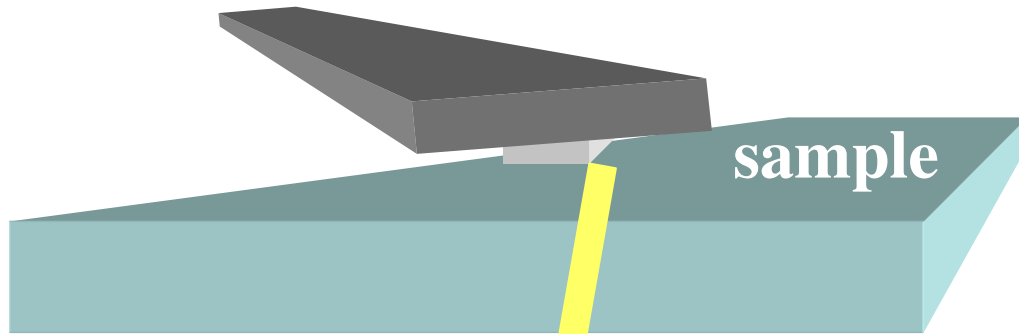
Clausius Clayperon equation for a first-order transition

$$\Delta T \propto [T/C_H] \Delta M \frac{\partial H_c}{\partial T}$$

- For magnetocaloric applications vital to:
 - lower the operating transition field H_c
 - sharpen the transition in field
 - minimise hysteresis

OUR MOTIVATION - to understand the underlying behaviour of the transition in the example systems studied. What aspects determine macroscopic physical properties?

Scanning Hall probe technique



5 μ m Hall sensor (InSb on GaAs)

sensitivity $\sim 1\mu\text{T}/\sqrt{\text{Hz}}$

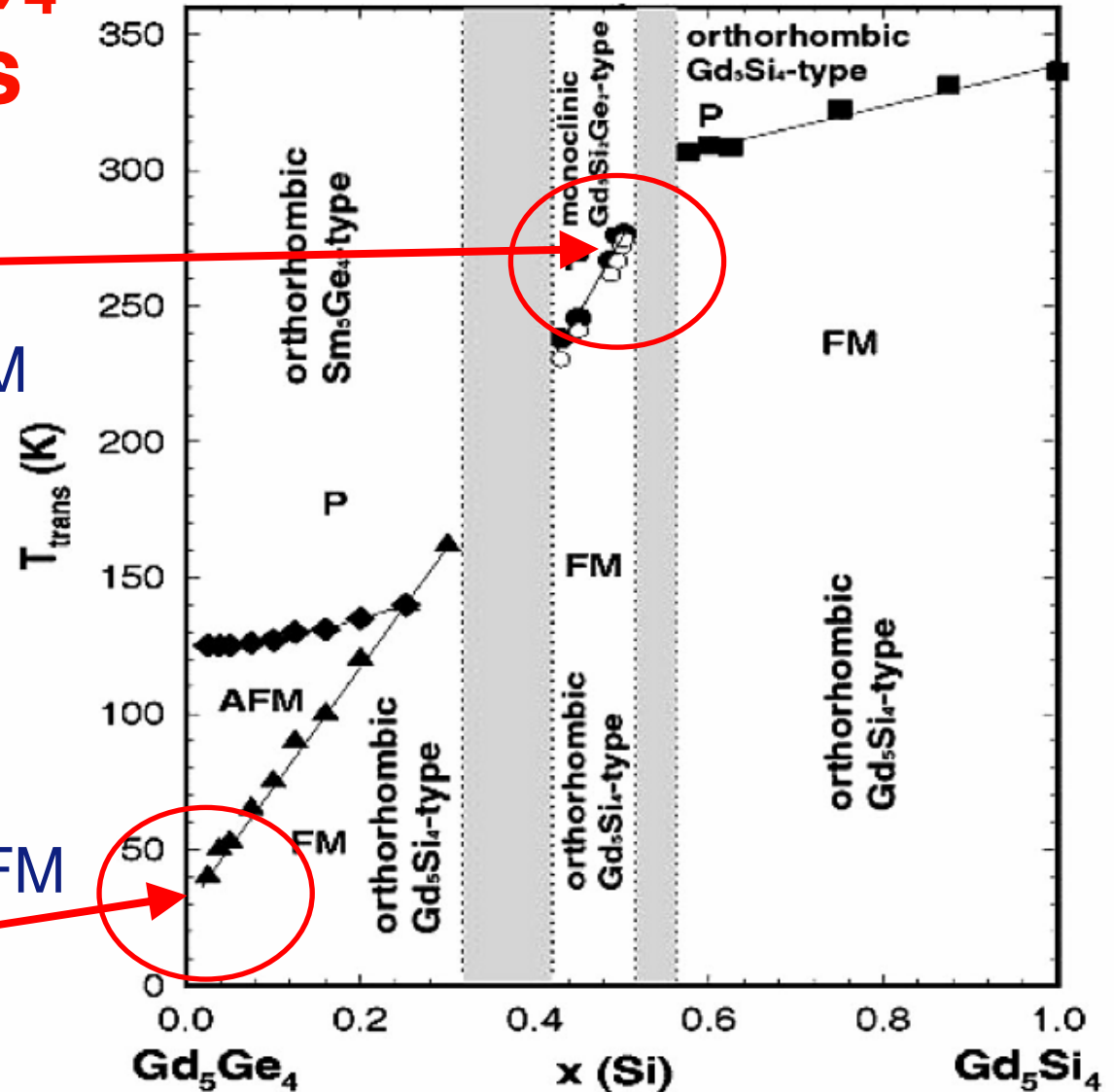
**operating range 5-300K,
0-4 Tesla**

**Typical image time ~ 10 mins
(300 pixels per second)**

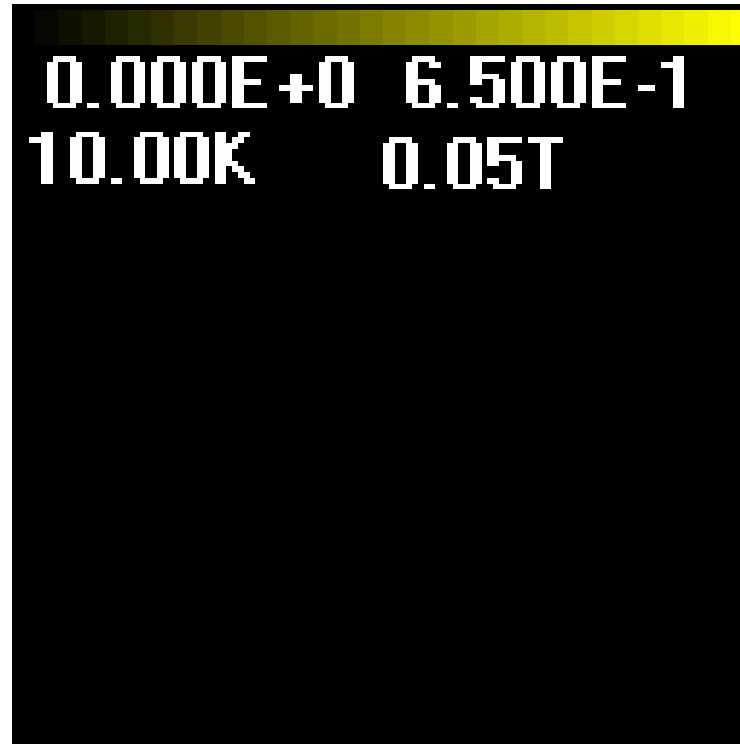
Gd₅(Si_xGe_{1-x})₄ compounds

Magnetic & crystallographic phases
H = 0T

- Gd₅Si₂Ge₂
 - First-order PM to FM transition at 280K
- Gd₅Ge₄
 - First-order AFM to FM transition at 35 K



Hall probe imaging of AFM \rightarrow FM in Gd_5Ge_4



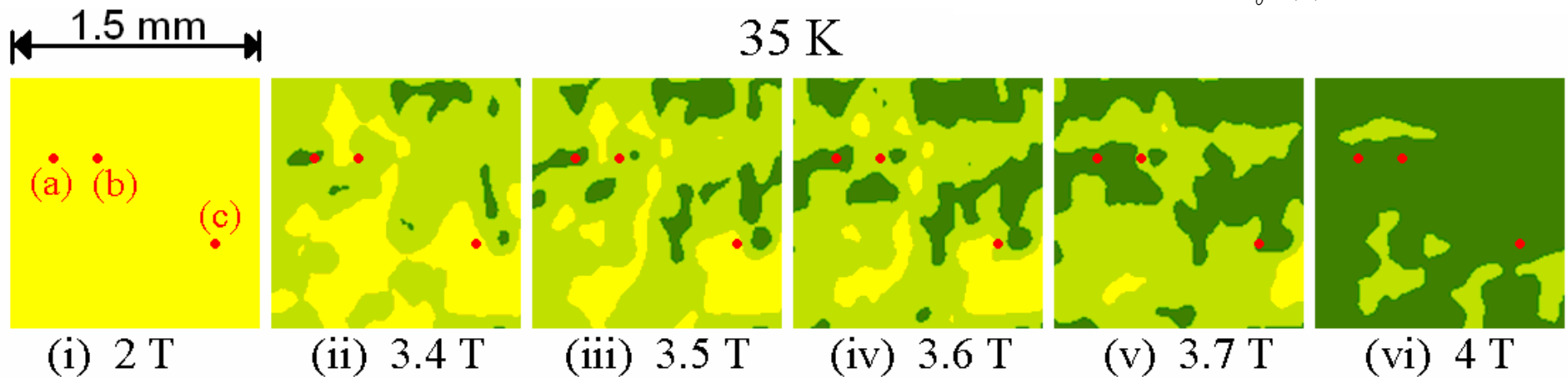
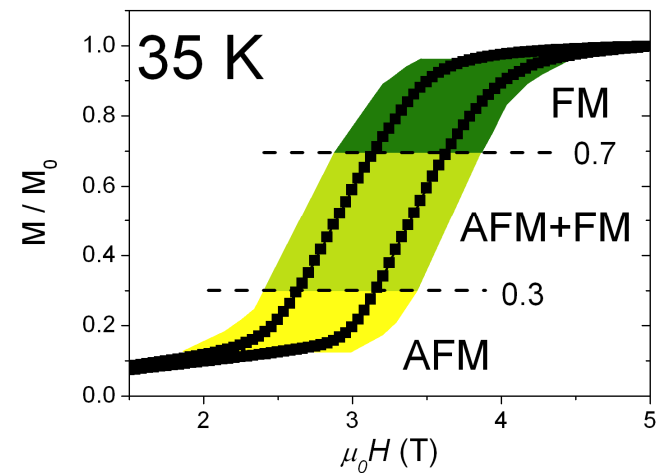
- Classic nucleation and growth of one phase in another
- Regions switch quickly suggesting the local loops are sharp

Hall Probe Imaging of Gd_5Ge_4

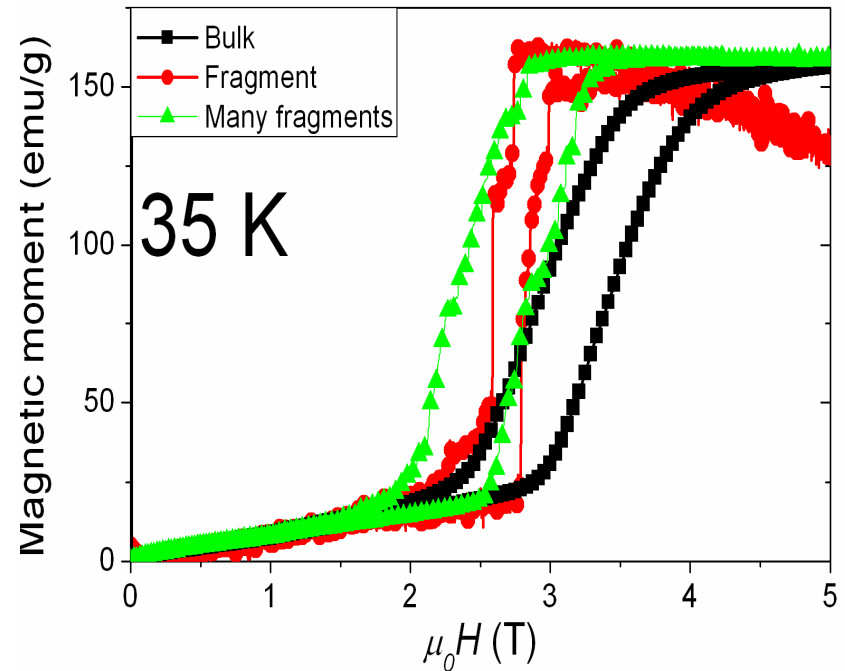
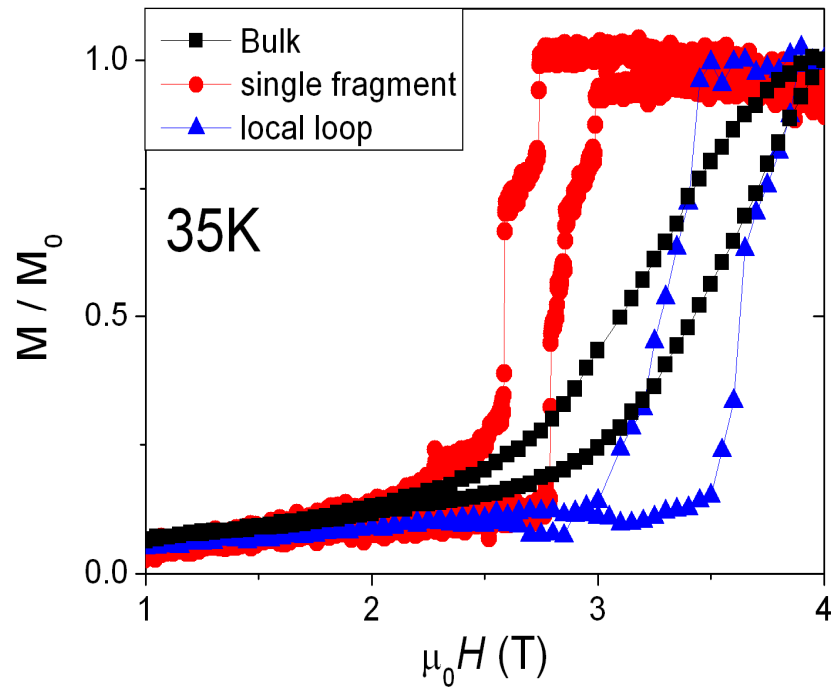
We can look at snap shots of the transition

We can study local $M-H$ loop

We can remove cluster size fragments

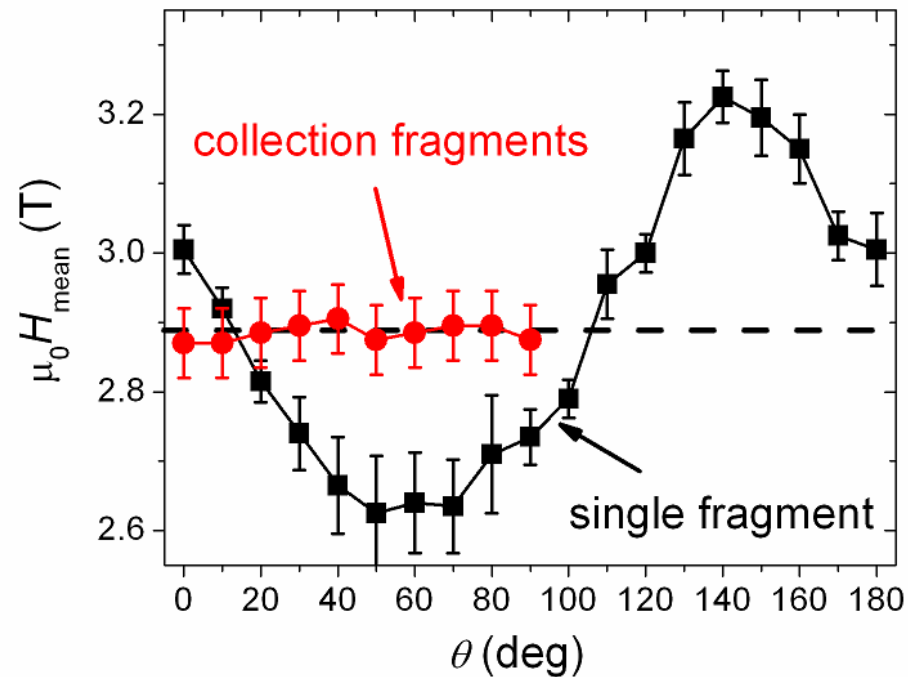


Contrast on local and global scales



- Single fragment switches sharply – a few steps
- Global is not representative of local behaviour
 - Further emphasis is shown later on single crystal

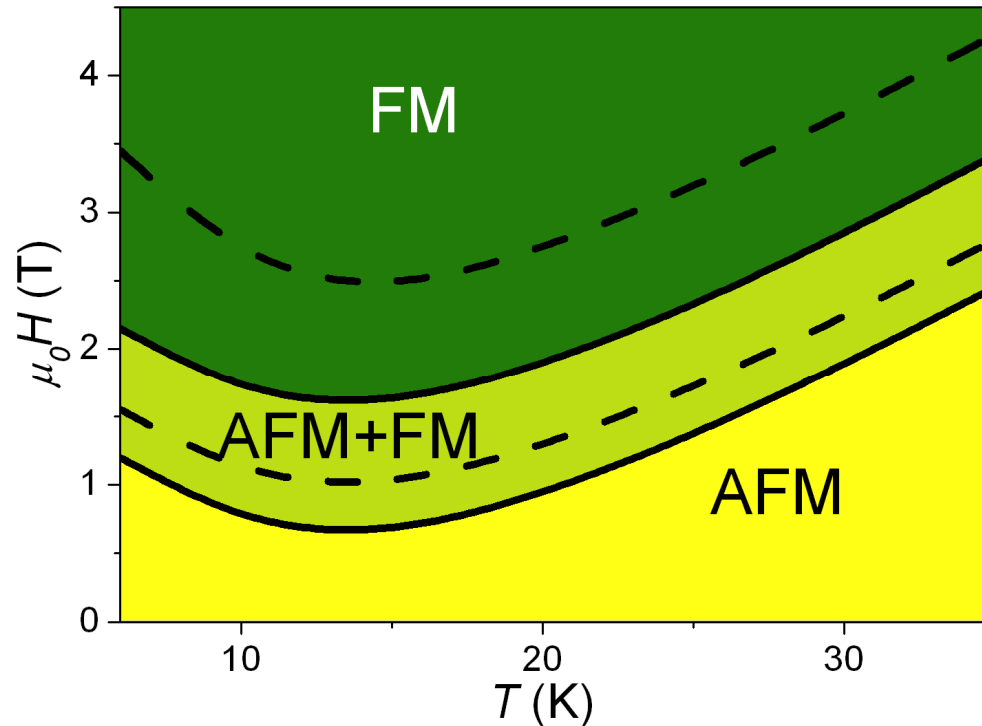
Summary of θ – dependence of H_{mean}



Single fragment shows anisotropy. But collection of fragments does not.

Fragment contains one or a few crystallites.

Comparing the H - T phase diagram of bulk and fragments taken from the bulk



- Fragmentation lowers the operating field and narrows the transition width

Summary 1

- The transition is governed by nucleation and growth of phases.
- Fragmenting the sample to the single cluster nucleation size lowers the critical field.
- Single isolated fragments that are single cluster size and switching of single clusters in the bulk are both single domain one-step transitions.
- We demonstrated that significant changes to the macroscopic properties can be made and indicated the most desirable length scale for fragmentation of the sample 50-100 μm .