Amorphous ferromagnetism

(a progress report in understanding & experiments)

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Outline

- Introduce amorphous materials[1]
- How magnetism might change – new types of magnetism
- One and two sub-networks
- Domains and anisotropy
- Gd-Transition metal literature
- Our Gd-Ni
- Outlook

1. Mostly taken from: J. M. D. Coey, J. Appl. Phys. **49**, 1646 (1978) and/or R. C. O'Handley, *Modern Magnetic Materials* (Wiley, 2000).

Key features of amorphousness

- No long range order
- Short range order -> NOT random!
- Bond lengths change (generally increase – looser packing)
- Concentrate on metallic bonding
- Very small ‘grains’ ~ a few nm

How do you make amorphous materials?

- Splat cool
- Sputtering etc
- Add metalloid elements (Si, B, C or P)
- Bombard with high energy ions (e.g. FIB)

Different types of magnetism

- Ferromagnet
- Antiferromagnet
- ~~Paramagnet~~
- ~~Diamagnet~~
- Speromagnet
- Asperomagnet
- Sperimagnet
- ~~Helimagnet~~
- ~~Mictomagnet~~
- ~~Superparamagnet~~
- Ferrimagnet
- ~~Metamagnet~~
- ~~Parasitic ferromagnet~~
- ~~Spin glass~~

Want to get to a concentrated system of GdNi eventually – ignore stuff like RKKY oscillatory exchange through a non-magnetic spacer in a dilute system.

How might magnetism change?

(passing note: For BCS superconductors: atoms random: trouble for phonons = big changes in T_C But nothing really new)

Not such a obvious link for magnetism to atomic positions:

$$\mathscr{H} = -\sum \mathbf{J}(r_{ij})\, \mathbf{S}_i \cdot \mathbf{S}_j$$

Weird things can happen: e.g. the sign of $\mathbf{J}(r_{ij})$ for Fe changes for $r \sim 3Å$

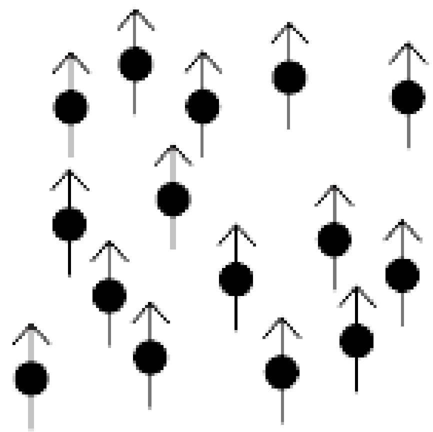
(Clearly with RKKY oscillation too things can get even more complicated: don't go there today)

One sub-network

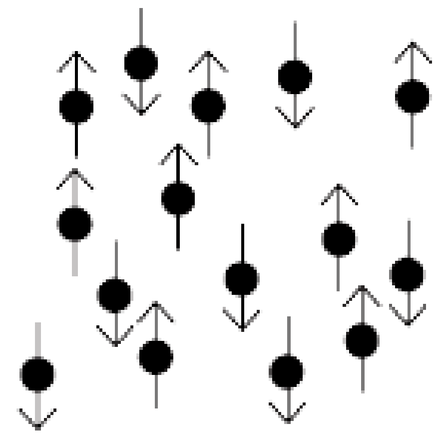
(same or similar atoms)

(a) Ferromagnet

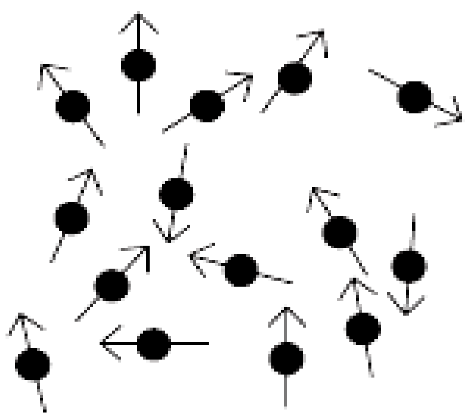
(b) Antiferromagnet
(hard to get – frustration:
many AFs become FM in
Amorphous state)



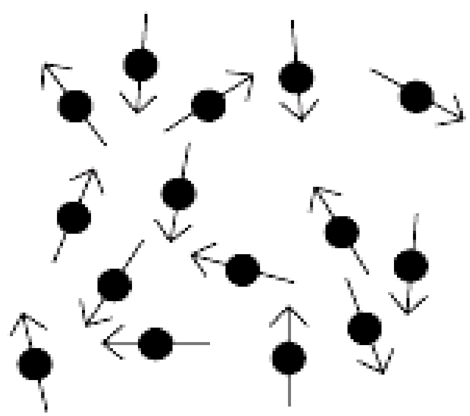
(a)



(b)



(c)

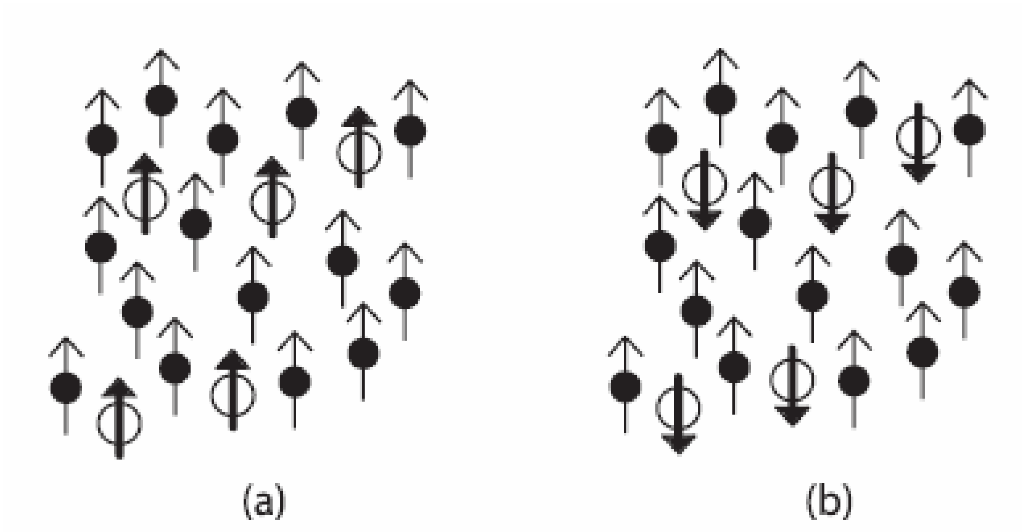


(d)

(c) Asperomagnet
(net M)

(d) Speromagnet
(no net M)

Two sub-networks



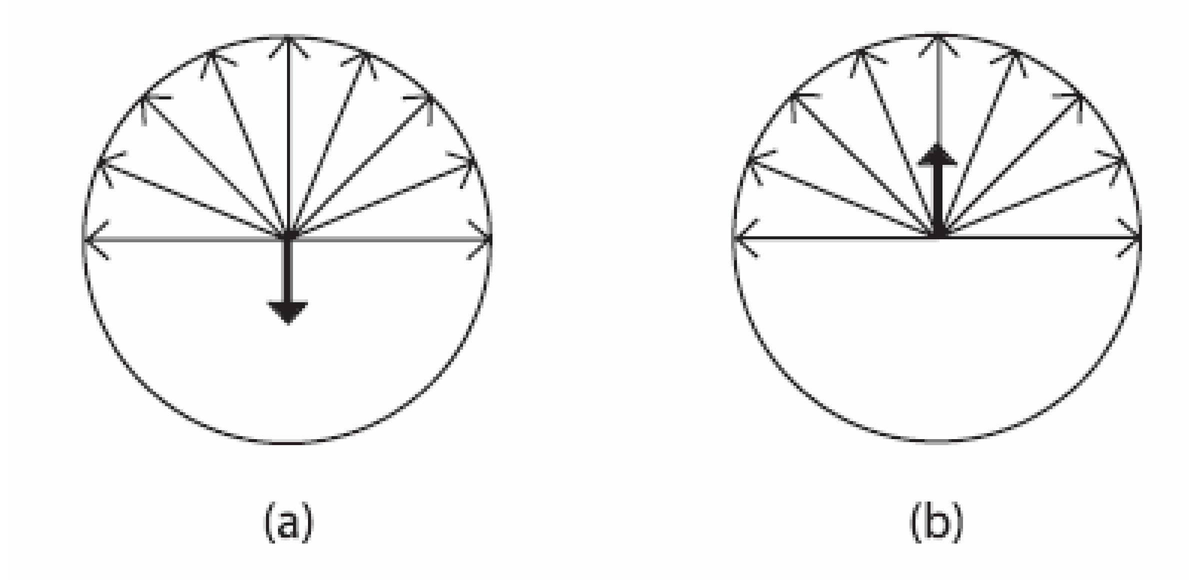
(a) Ferromagnetism

(b) Ferrimagnetism

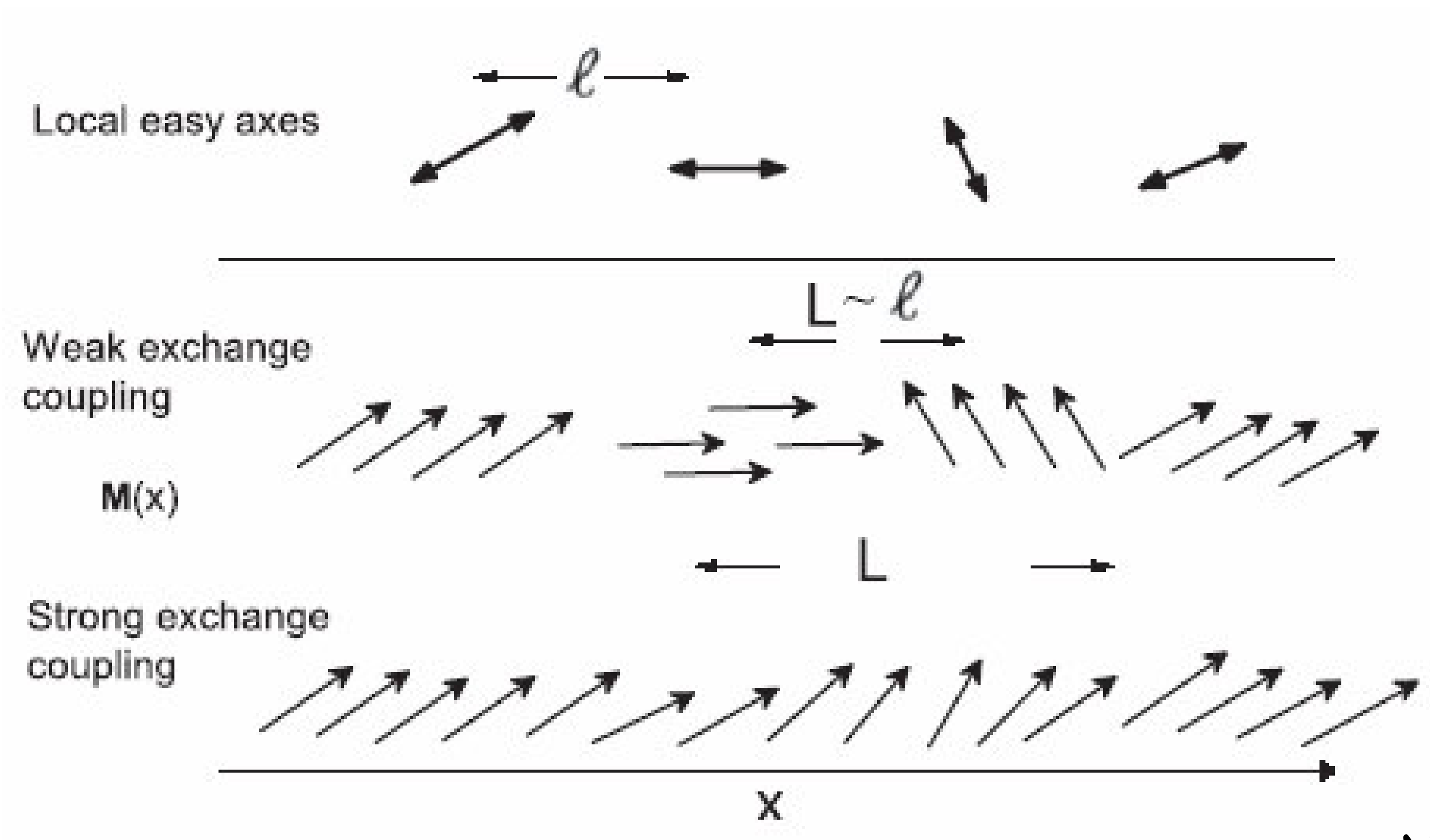
ALL DEPENDS ON DETAILS OF THE INTER AND INTRA-NETWORK COUPLING

(a) Speromagnetism

(b) Sperimagnetism



Local 'random' anisotropy



For 3d systems is turns out L ~ 20μm
For 4f (non-S-state) L ~ 20nm

But this is what Gd is!

Non-trivial, but remember by comparing localisation 4f shell diameter ~0.3Å

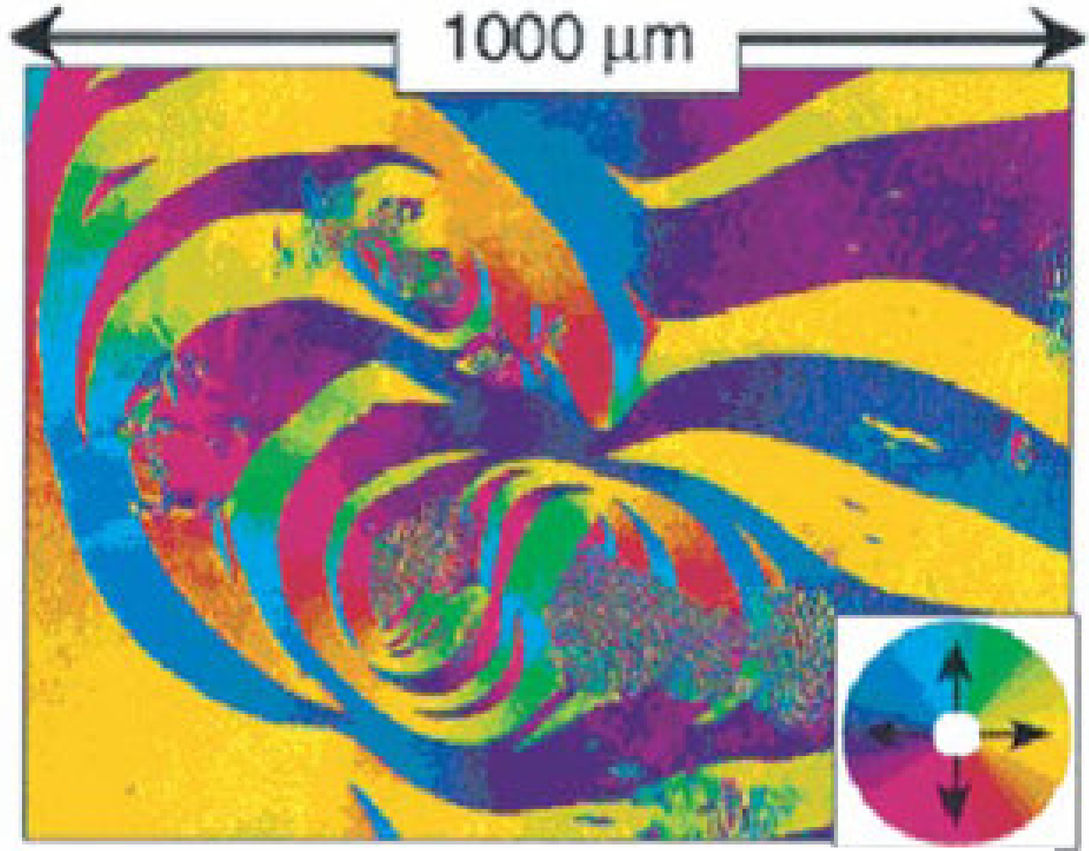
Domains

If local anisotropy is weak:

Only shape and stress etc control 'domain's' direction not rectilinear

For very strong local anisotropy, the 'domain' is a few hundred atoms.

For the speromagnet, the word domain is not really sensible at all.



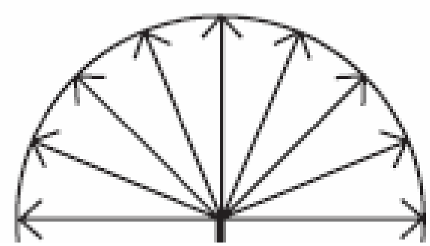
A. Gavrin and J. Unguris, J. Magn. Magn. Mater. **213**, 95 (2000).

- Distinction between domains and domain walls becomes blurred….
- Similarly since there can be only very weak anistropy – domain walls can be very wide

Domains 2

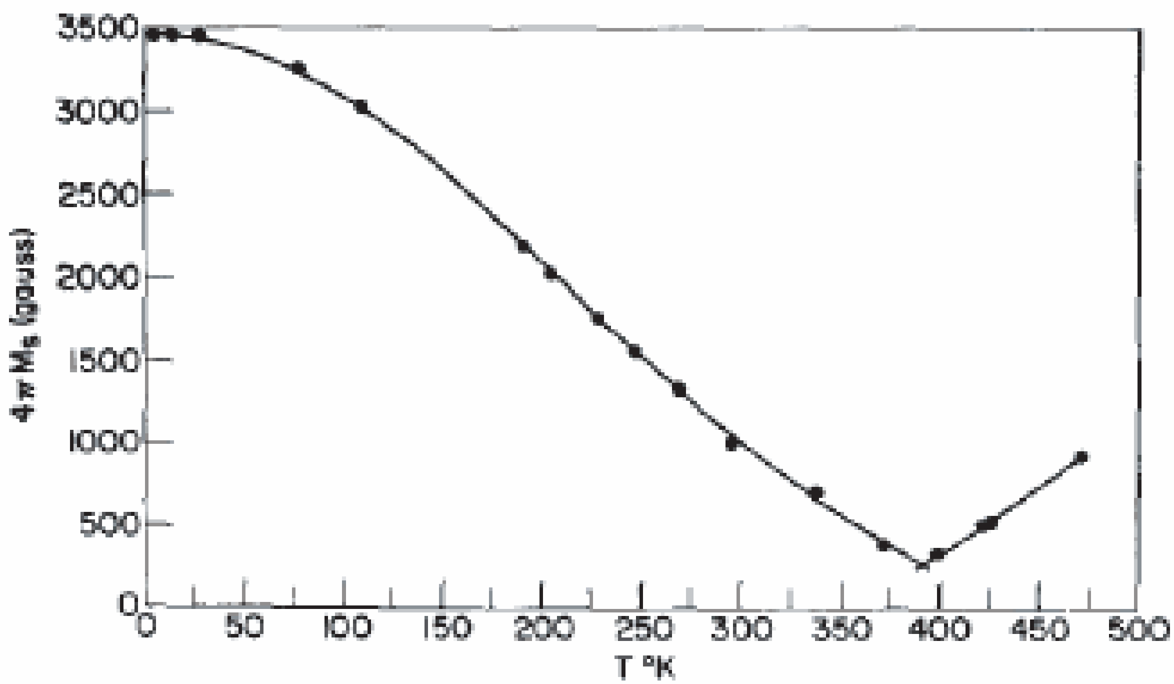
- Also given no grain boundaries: no domain wall pinning: domain motion and therefore H_C can be very small

• However if you have some local anistropy, e.g. asperomagnet, the first half is easy (wall motion), then you have to close the 'umbrella' of spins – can be very hard!

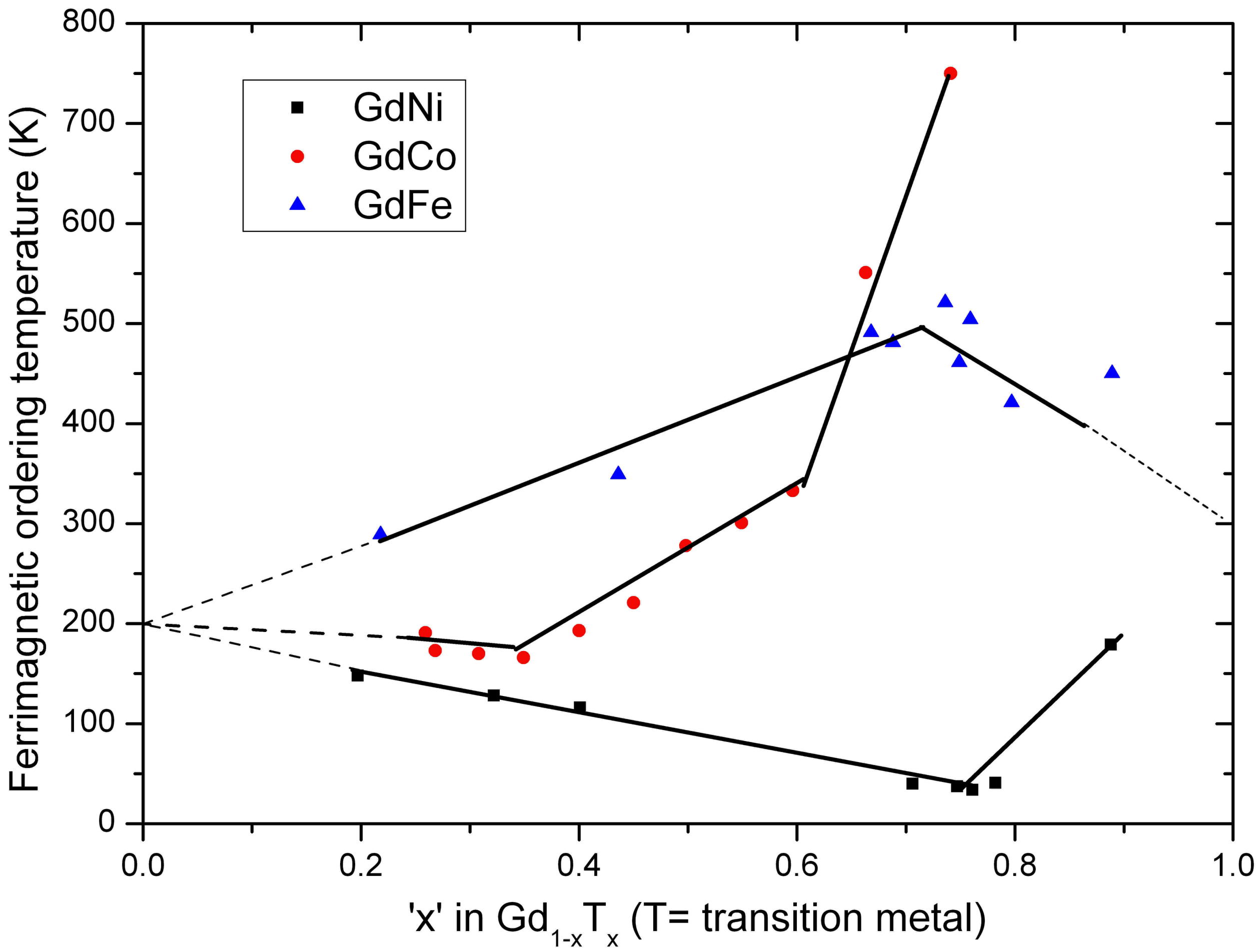


Literature of Gd with transition metals (TM)

- Compensation of antiferromagnetically coupled Gd-Co: ferrimagnet.
  - (Gd-Co bonds weaker than Co-Co bonds and Gd-Gd not important at large x)



P. Chaudhari, J. J. Cuomo, and R. J. Gambino, Appl. Phys. Lett. **22**, 337 (1972).



Same thing in Gd-Fe: Orehotsky and Schröder, J. Appl. Phys. **43**, 2413 (1972).

Both are co-linear ferrimagnets

Weaker moment in Ni, and I've never seen a compensation plot either…
(c.f. PdNi vs PdFe??)

GdNi not the same as other Ni-Rare earths [1,2]

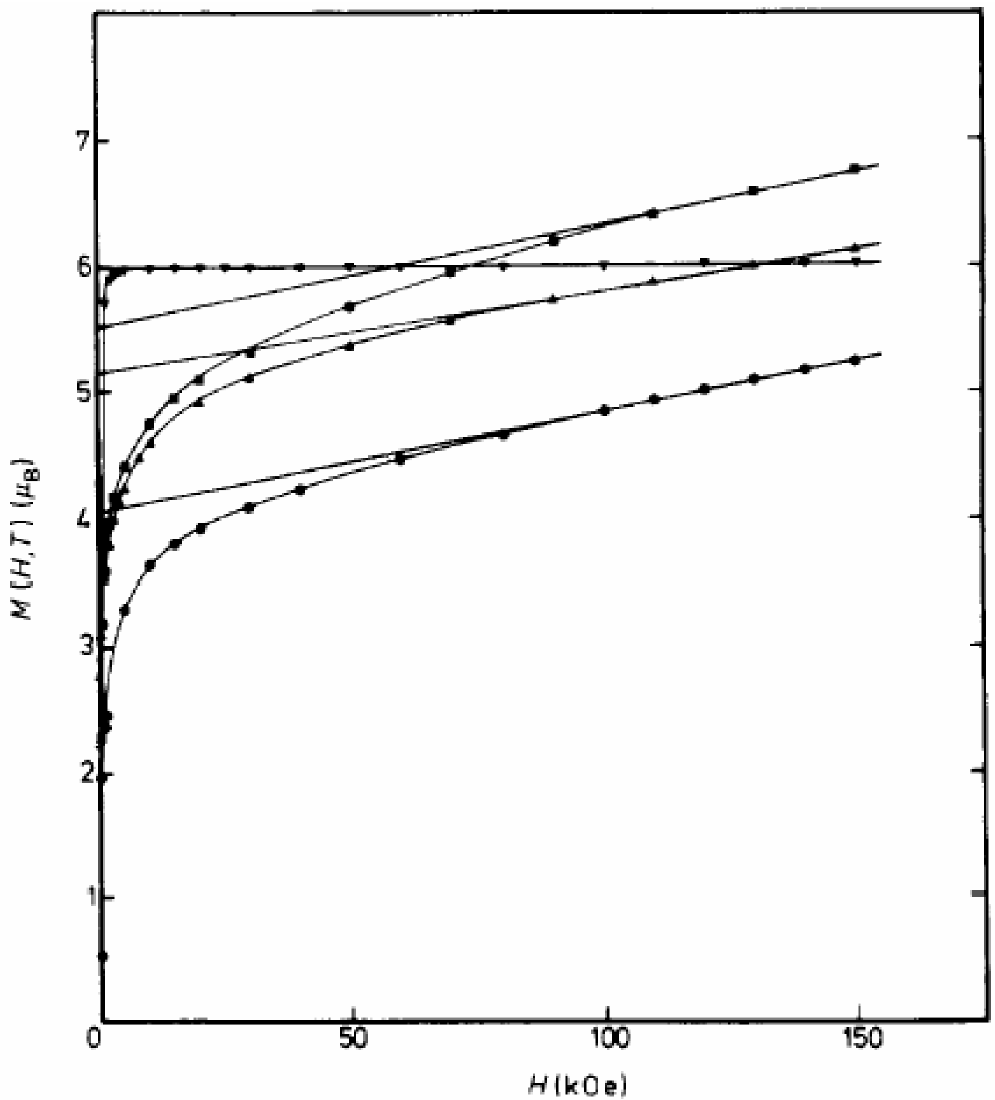
Other rare earths such as $Ni_{3.4}Ho$, $Ni_{3.2}Dy$, $Ni_{3.0}Er$

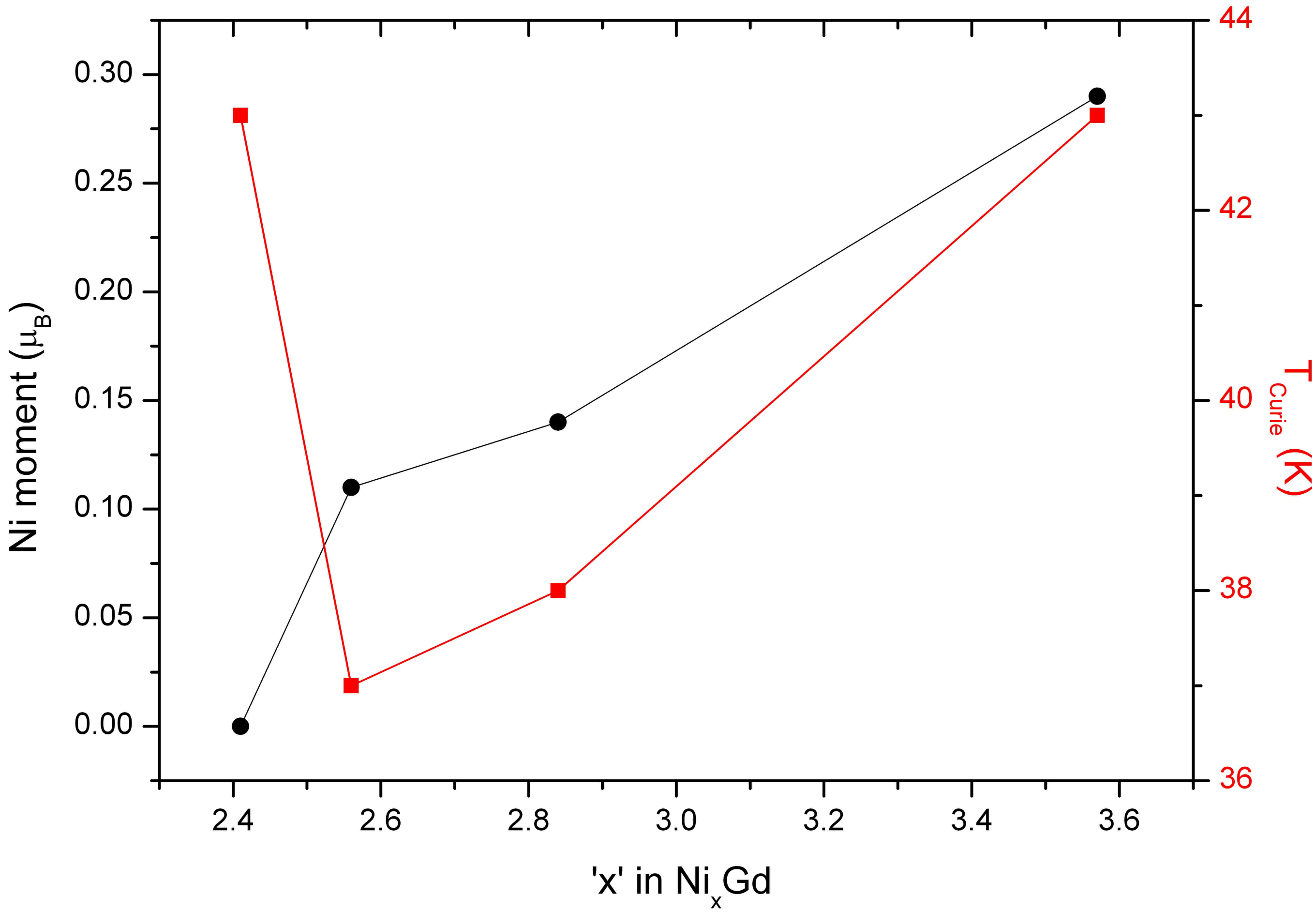
Show speromagnetic order of the RE with antiparallel weak Ni moment: hard to saturate!

Ni_3Y is non-magnetic! (more Ni will eventually work)

NiGd: Negative *and* positive MR seen - difference between near to T_{Curie} and well below… discuss another time

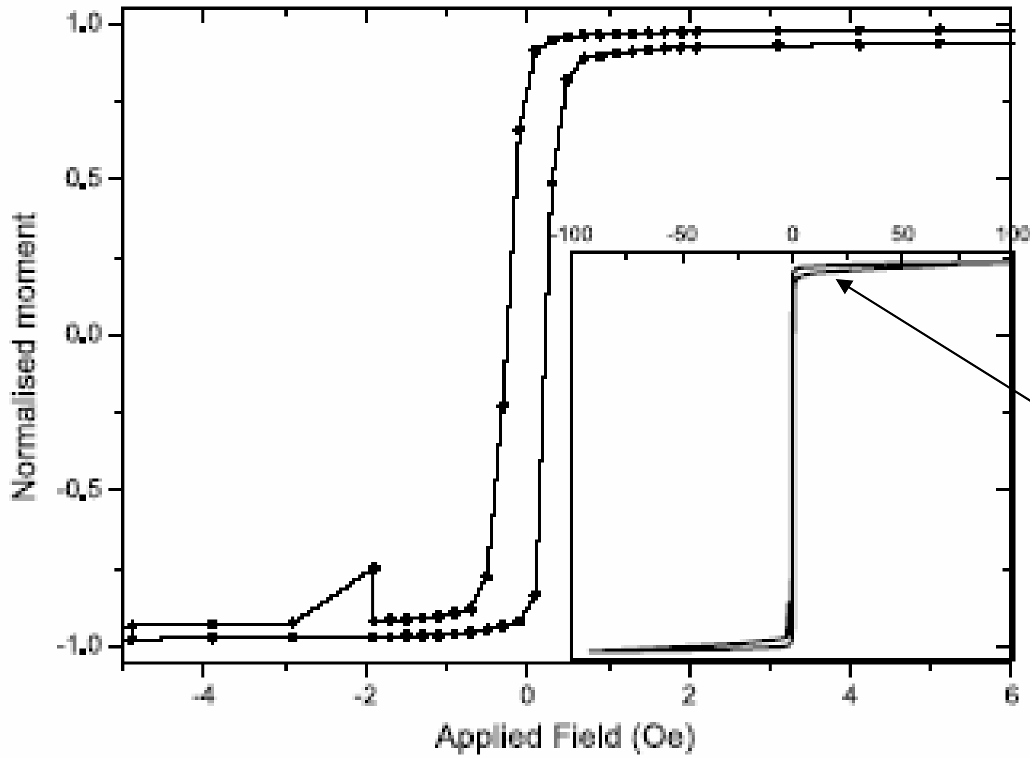
[1] Asomoza *et al* J. Phys. F: Metal Phys. **9**, 349 (1979)
[2] S. von Molnar *et al* J. Appl. Phys. **52**, 2193 (1981).





Also have antiparallel weak Ni moment, but
Gd **not** speromagnetic

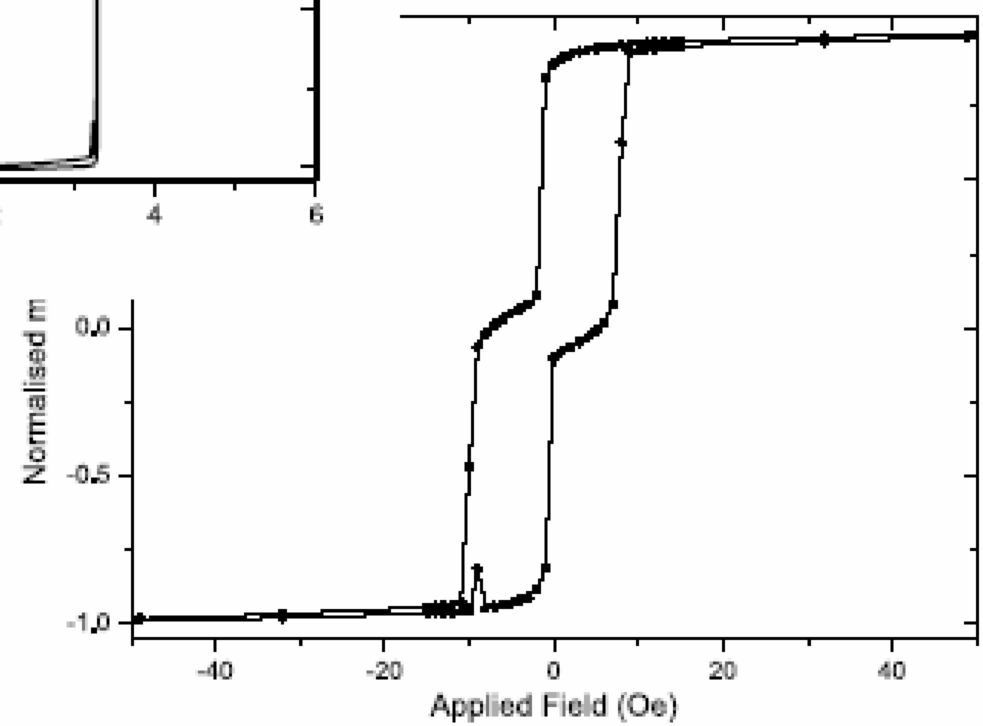
Our $Gd_{\sim 20}Ni_{\sim 80}$: M(H)



Low field switching for Films 10's of nm thick

Good for FSF: no field effect on S

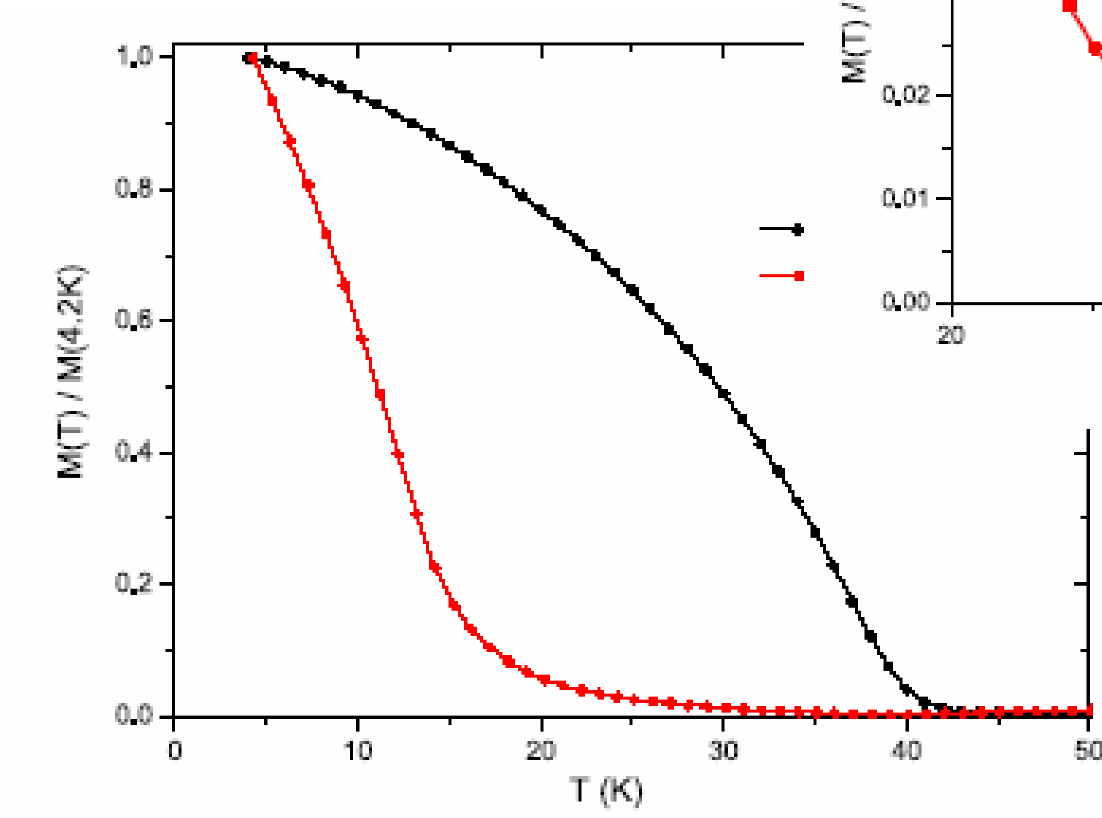
Is this higher field bit the Ni?

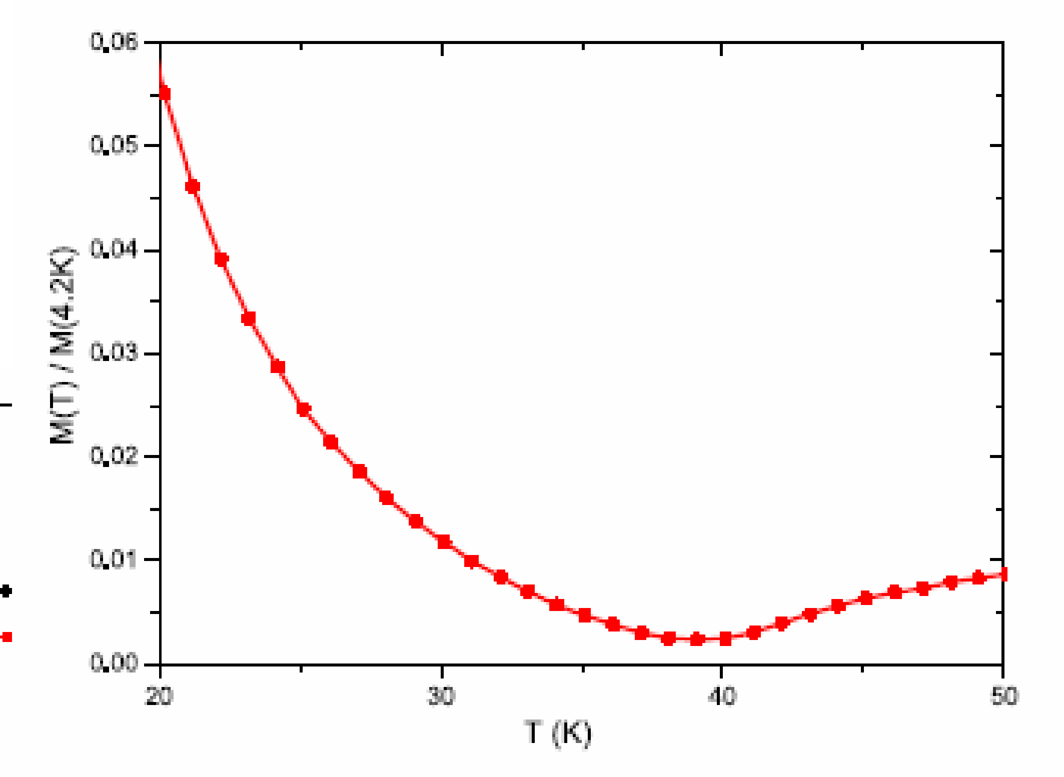


For 7nm thick trilayer is roughness becoming important?! (AFM after SQUID)

Our GdNi: M(T)

- Do we see something like compensation?





T_{Curie} suppressed for thin films, not so surprising

Outlook in literature

Amorphous magnets have been around for a while, but new interest appearing in research:

- Exploit compensation (ferrimagnetism): Gd-Co: measure domain wall magnetoresistance: Prieto et PRB **71**, 214428 (2005).
- Amorphous FM in spin valves: Wu et al, APL **72**, 2176 (1998), Djayaprawira et al, APL **86**, 092502 (2005).
- Amorphous (non-magnetic) spacers in spin valves: Jun et al JMMM **286**, 158 (2005)
- Spin torque with amorphous magnets: Tulapurkar et al, Nature **438**, 339 (2005)

Outlook for us

- Understand what's happening with the M(T) curves (esp. for thinnest films - localisation?) : tomorrow in the SQUID!
- Make & measure FSF spin valves (one is ready)
- Maybe all amorphous CIP and/or CPP FNF structures are also interesting as localisation sets in in the MoGe.

(FSF $\longrightarrow$ FNF $\longrightarrow$ FIF)