GdNi/MoGe transport studies

a.k.a. 'what I have learnt this week'

Chris et al 8/2/6

Outline

- Nothing about equal trilayers, $T_C(d_S)$ and $T_C(d_S)$ etc (- Jan's job)
- Spin valves/switches – Tagirov etc etc
- Our Gd-Ni – magnetic properties
- AMR and MR around T_C
- Bloch domains, flux flow, I-Vs
- Problems and newer experiments
- Conclusions

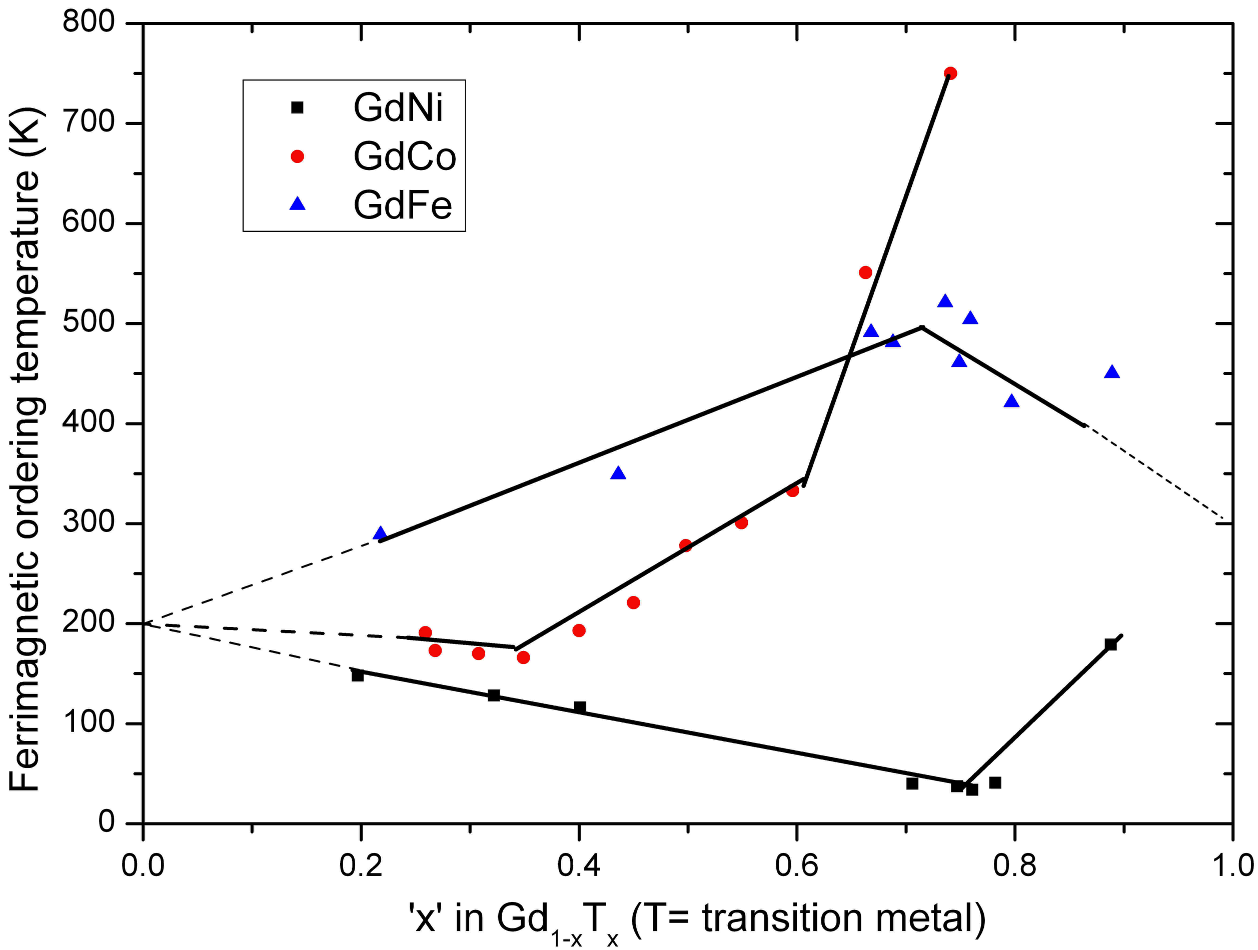
Starting point: The spin valve / Tagirov spin switch / spin accumulation effect(s)

F/S/F trilayer: two simple ideas to start with:

For Cooper pairs in S surrounded by F with weak/low polarisation **antiparallel** F layers gives HIGHER T_C than **parallel**. (Tagirov theory, Gu in CuNi experiment, and Birge's group with Ni (and Py?!))

For higher polarisation the trapped (quasi)-electrons become important: in the **anti-parallel** case a spin from one F can't escape to the other – it's trapped in S and **suppresses** the Cooper pairs and therefore T_C.
(for example Py/Nb/Py stuff here)

A reminder of GdNi

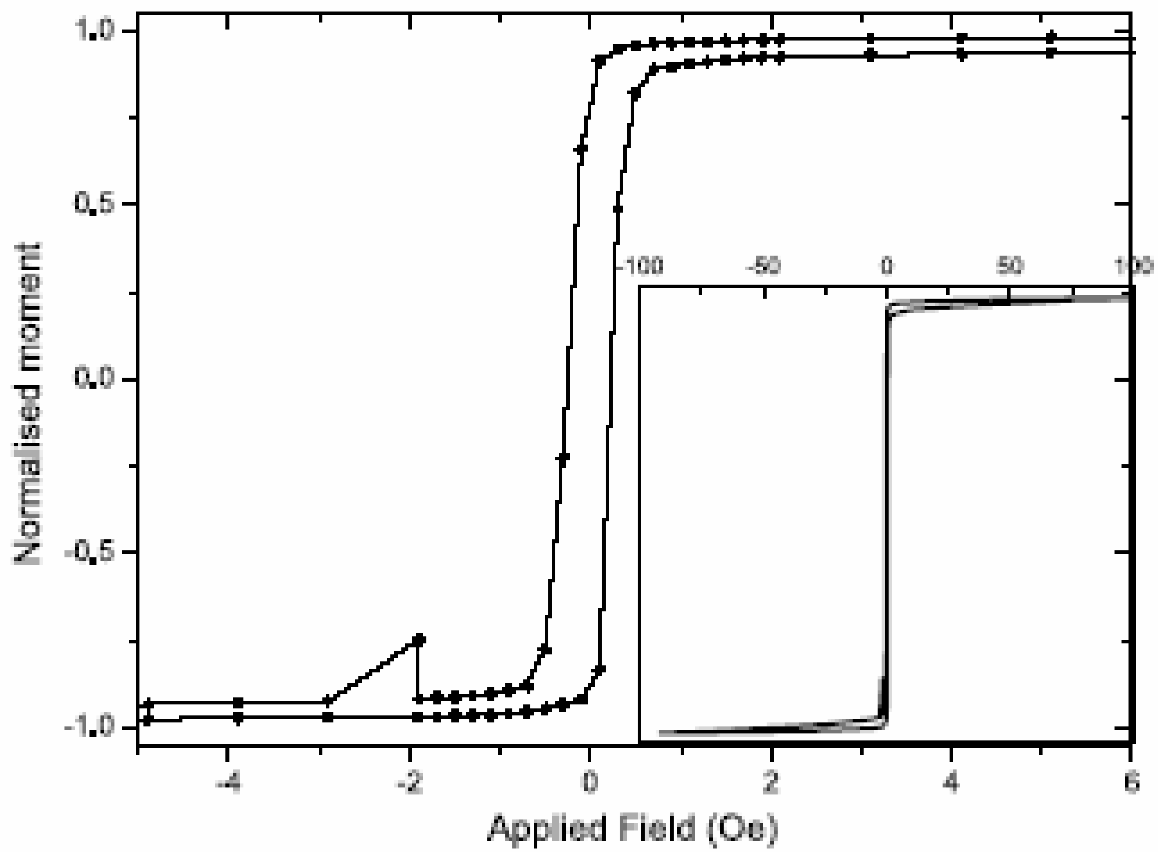


Same thing in Gd-Fe: Orehotsky and Schröder, J. Appl. Phys. **43**, 2413 (1972).

Both are co-linear ferrimagnets

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

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

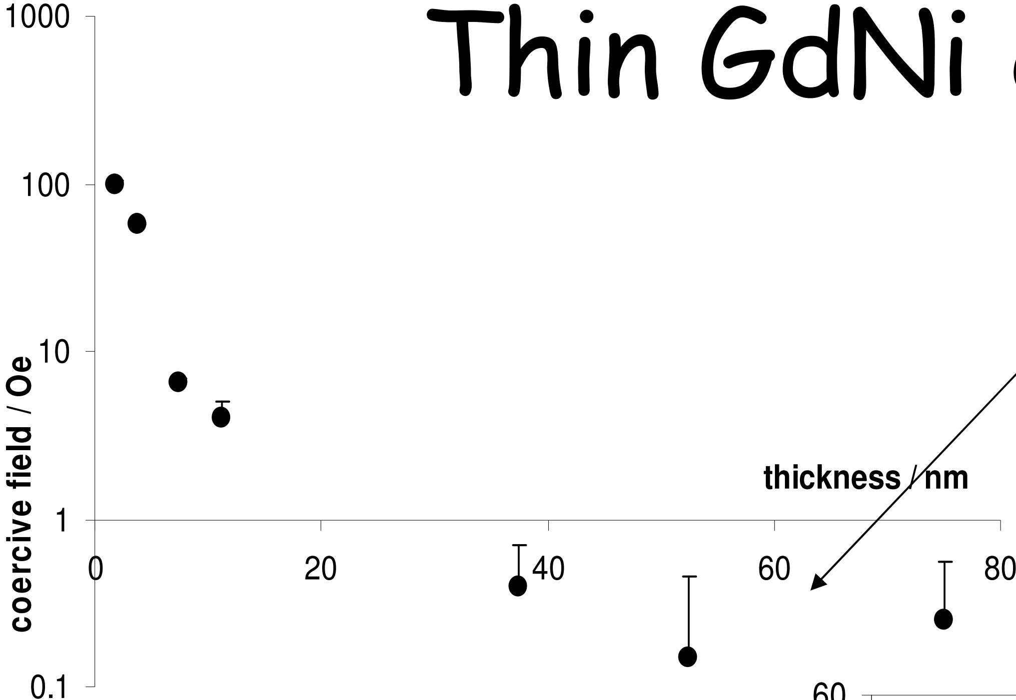
No grain boundaries: no domain wall pinning: domain motion and therefore H_C can be very small

Magnetic properties

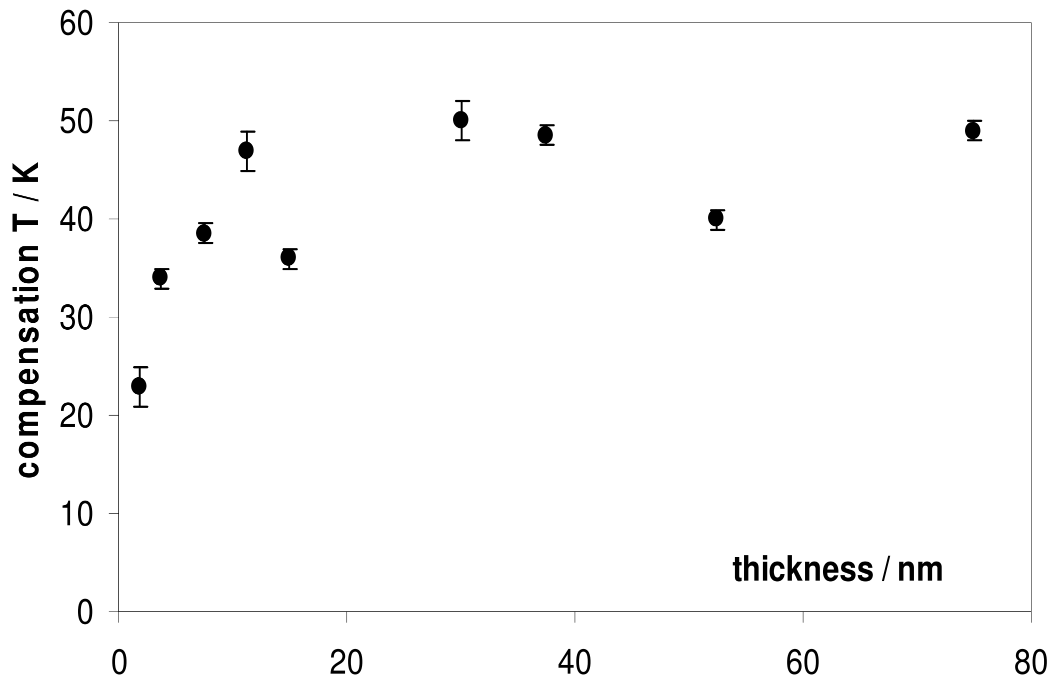
- T_{Curie} (and $T_{Compensation}$) reduced at low d_F
- H_C also increases (as you'd expect)
- Would like to work with a trilayer with top and bottom ~same T_{Curie}, but different H_C

.....not so easy

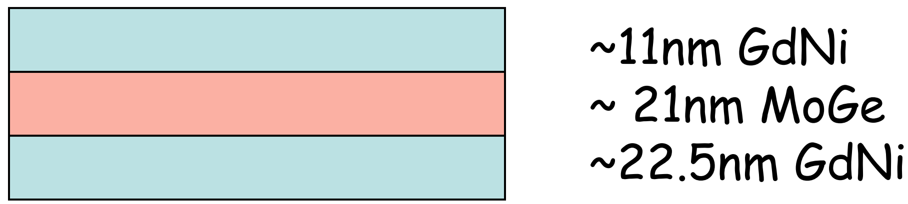
Thin GdNi changes…



Hard to measure in SQUID

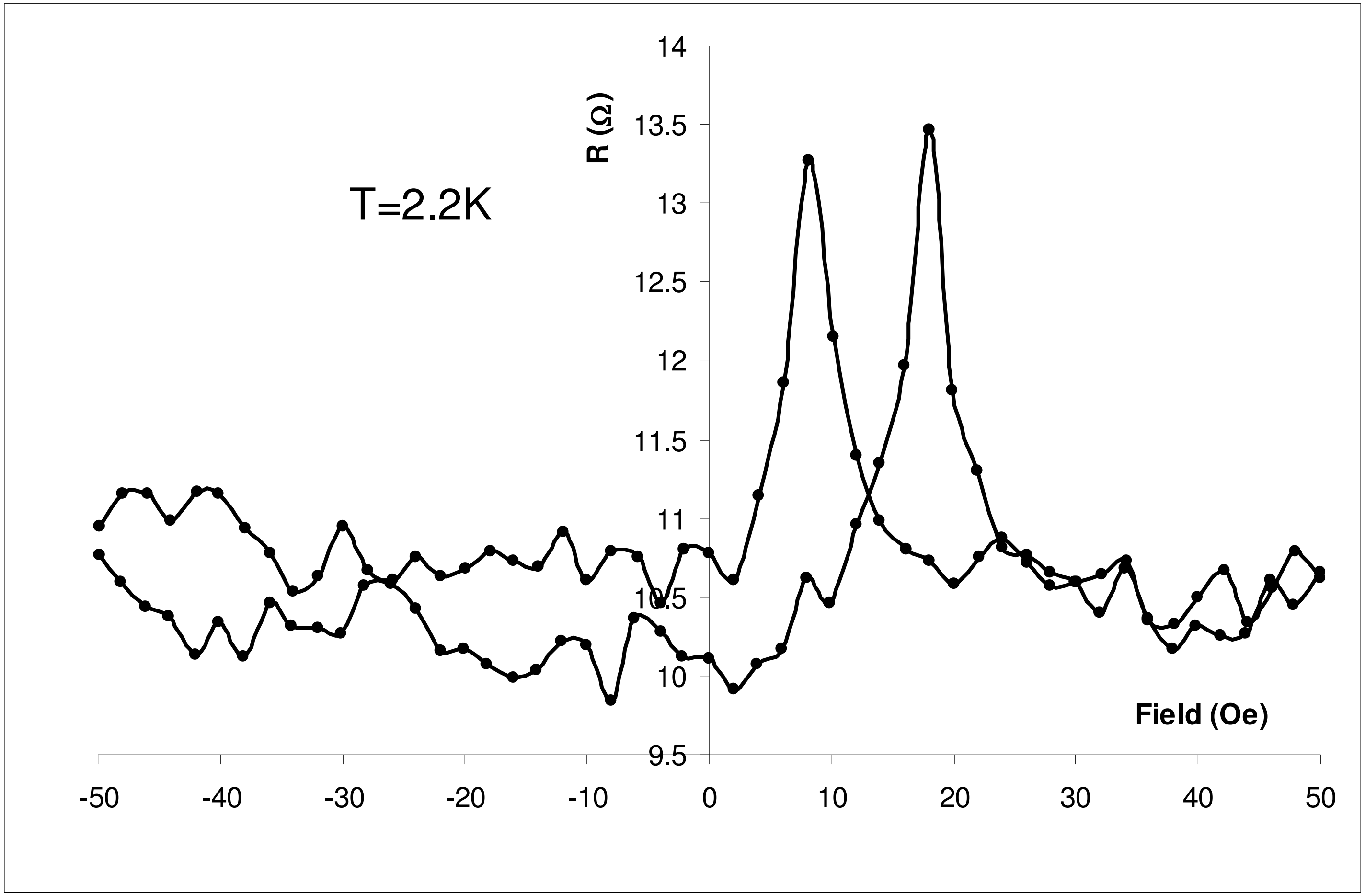


First samples



- From previous $H_C(d_F)$ data this should show spin valve behaviour
- Actual SQUID measurement wasn't very clear
- Doubled the sample size for extra signal, but not re-measured yet

Original PPMS data



Not good enough to measure AMR at higher T

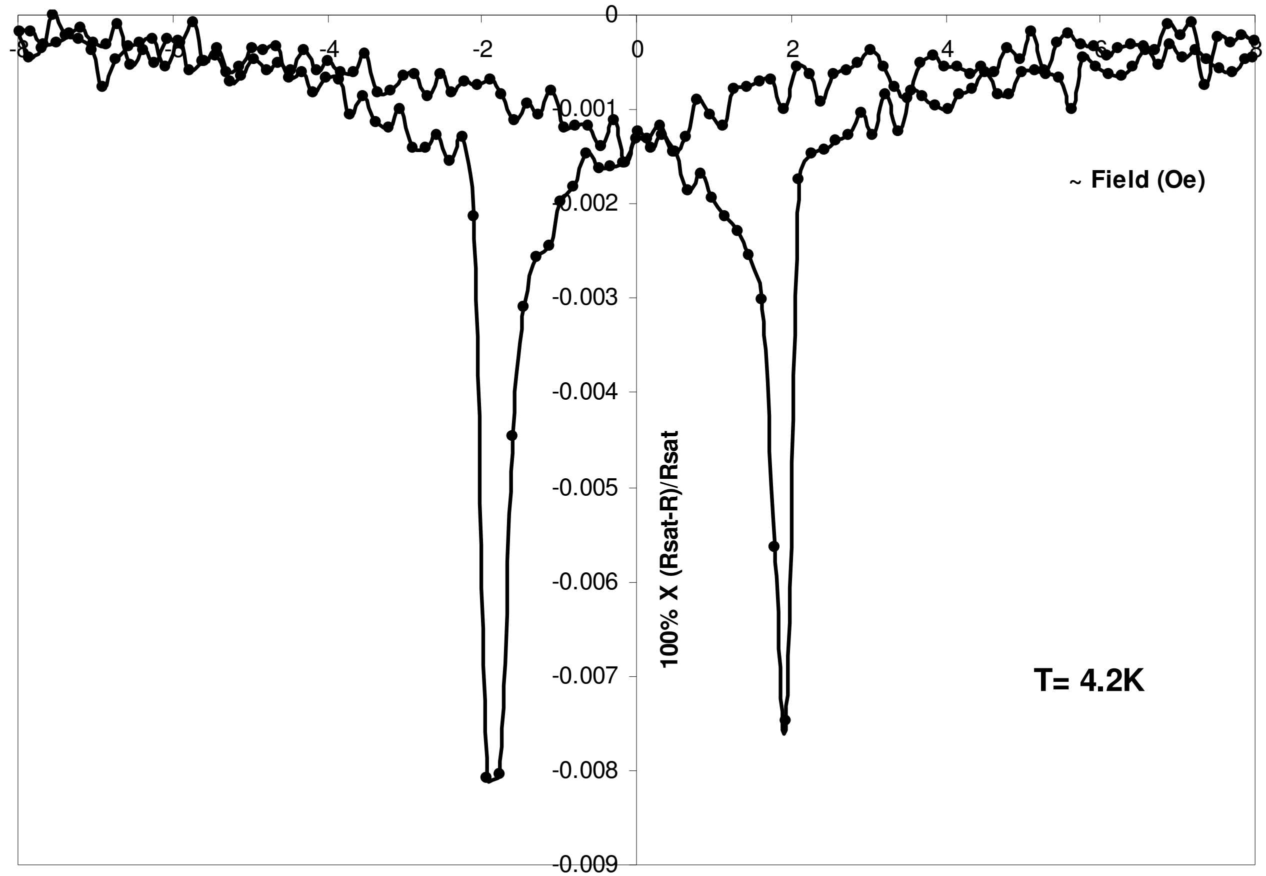
Offset field and small steps in H hard

Noisey (probably T fluctuations)

Still promising, so

use cryostat instead!

AMR at 4.2K

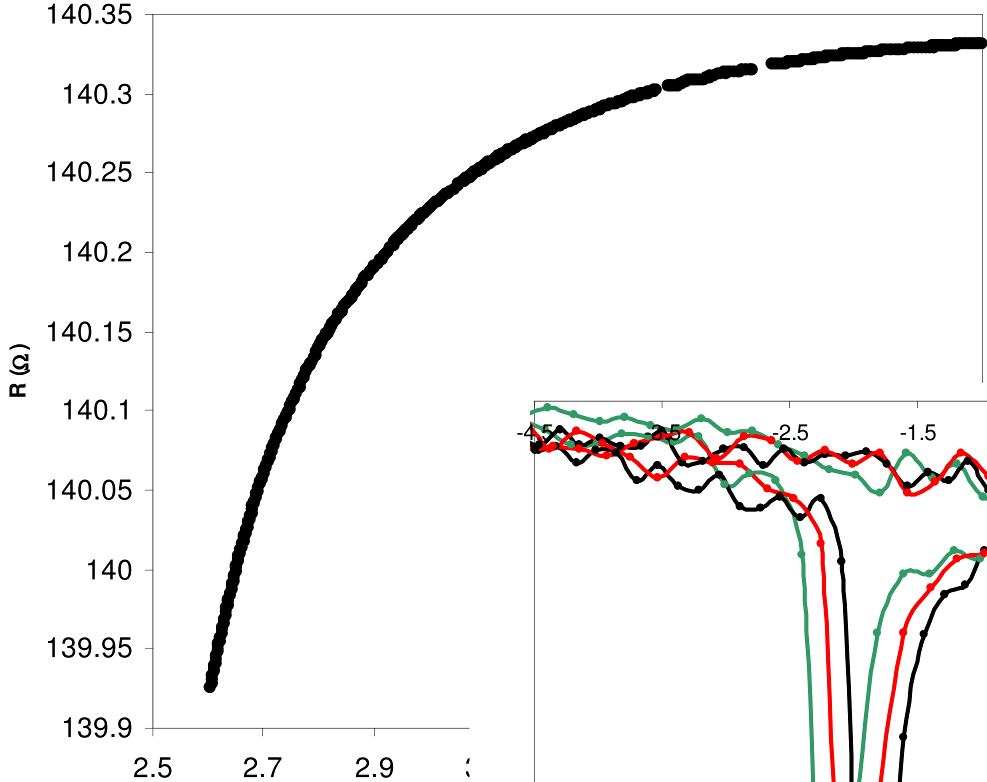


Noise ~ 1 part in 100,000

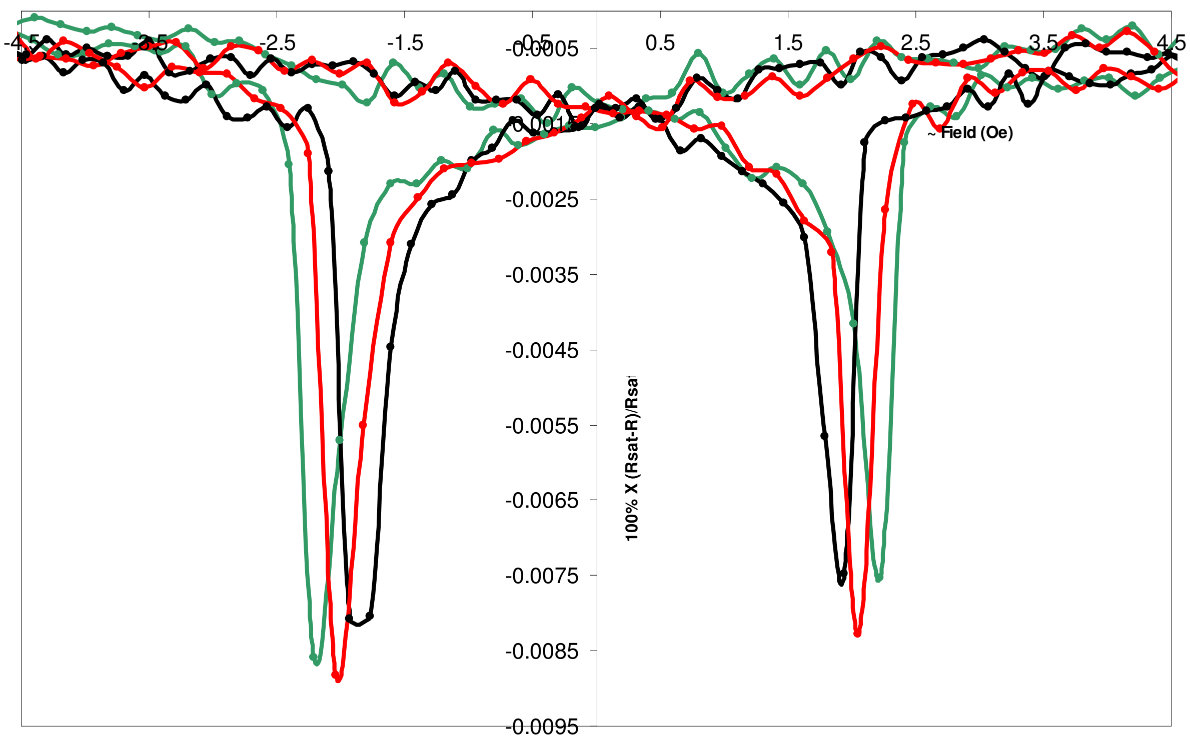
Bias current 250μA on a optically patterned film

H // I, so ‘normal’ AMR – dips in R around the coercive field of the GdNi

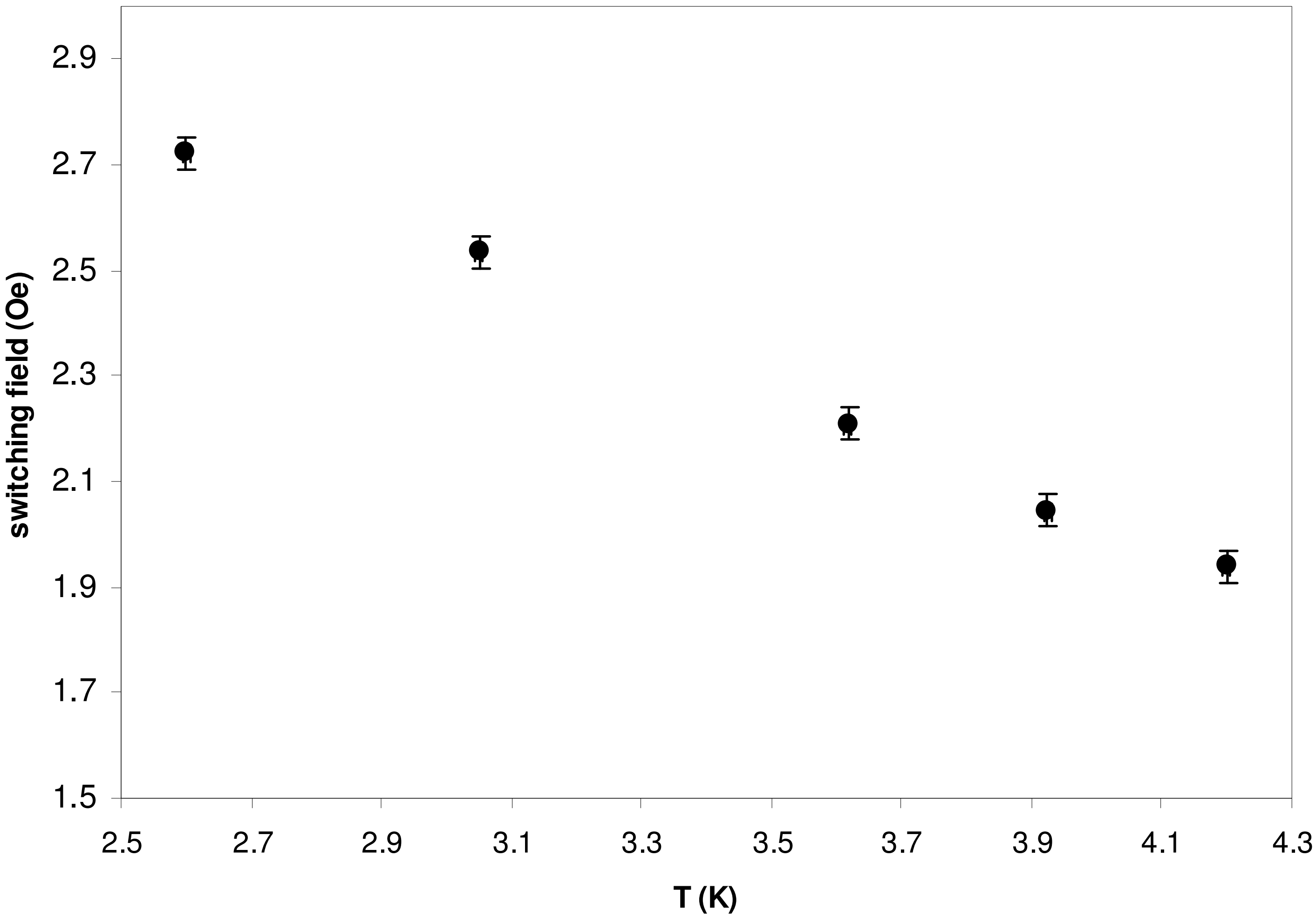
AMR at lower T



In this regime dR/dT is relatively small (see later), and we can stabilize T well enough to measure AMR at various T

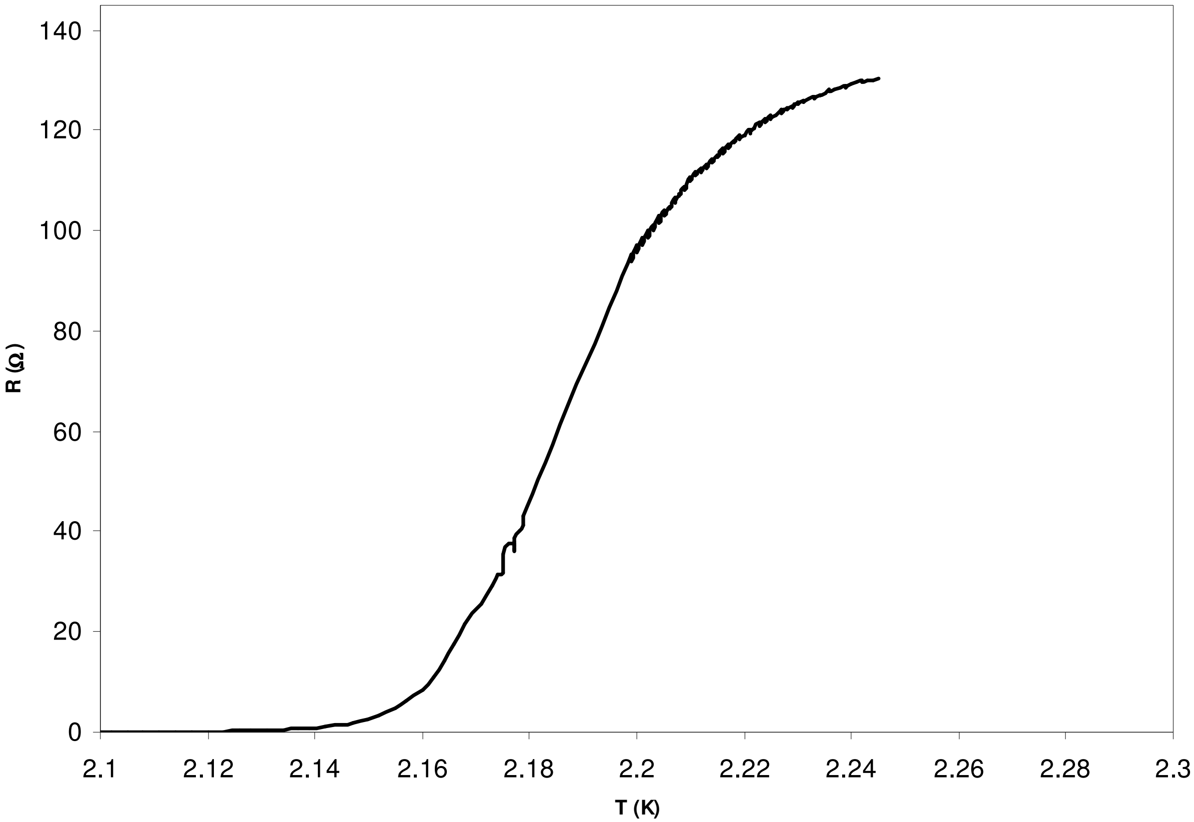


AMR at lower T



Nothing surprising – but useful later…..

Lower in the transition



Transition width ~ 0.1K

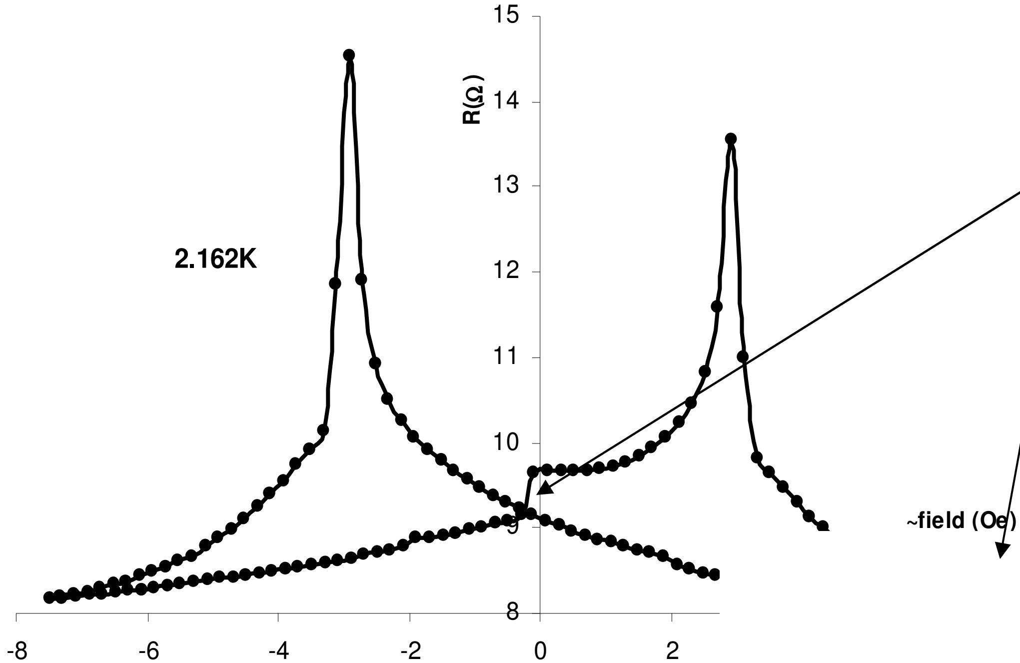
R_N ~140 Ω

dR/dT ~ 1400 Ω/K

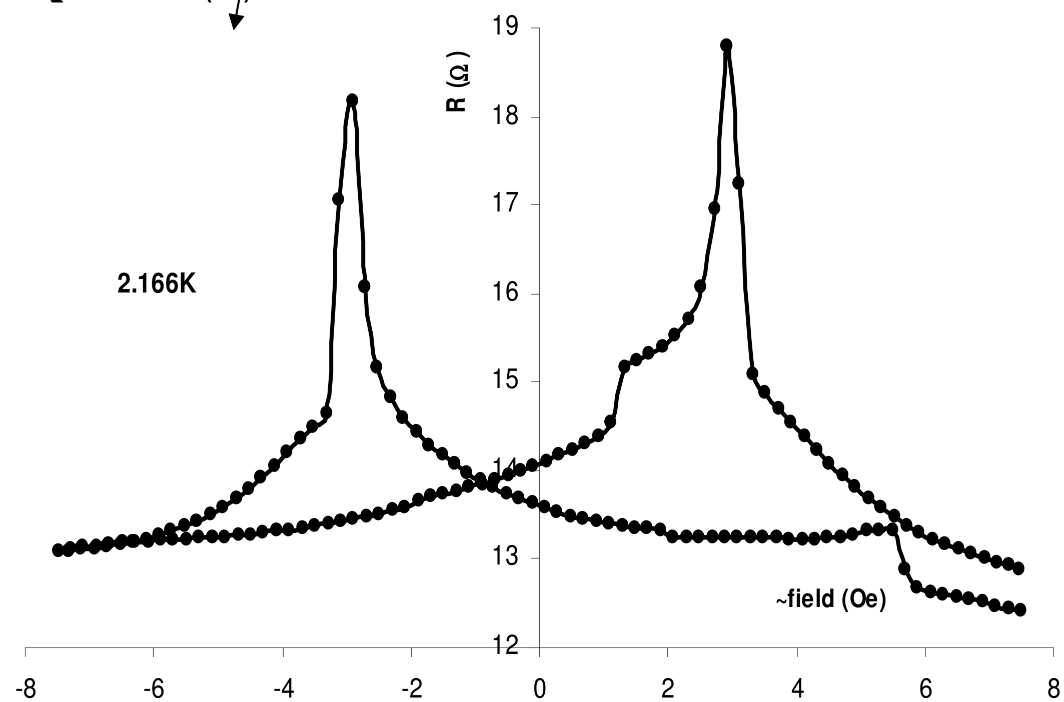
To see AMR of 1 part in 10,000 means ΔT better than 10μK…. err no.

Can only look for effects much bigger than AMR

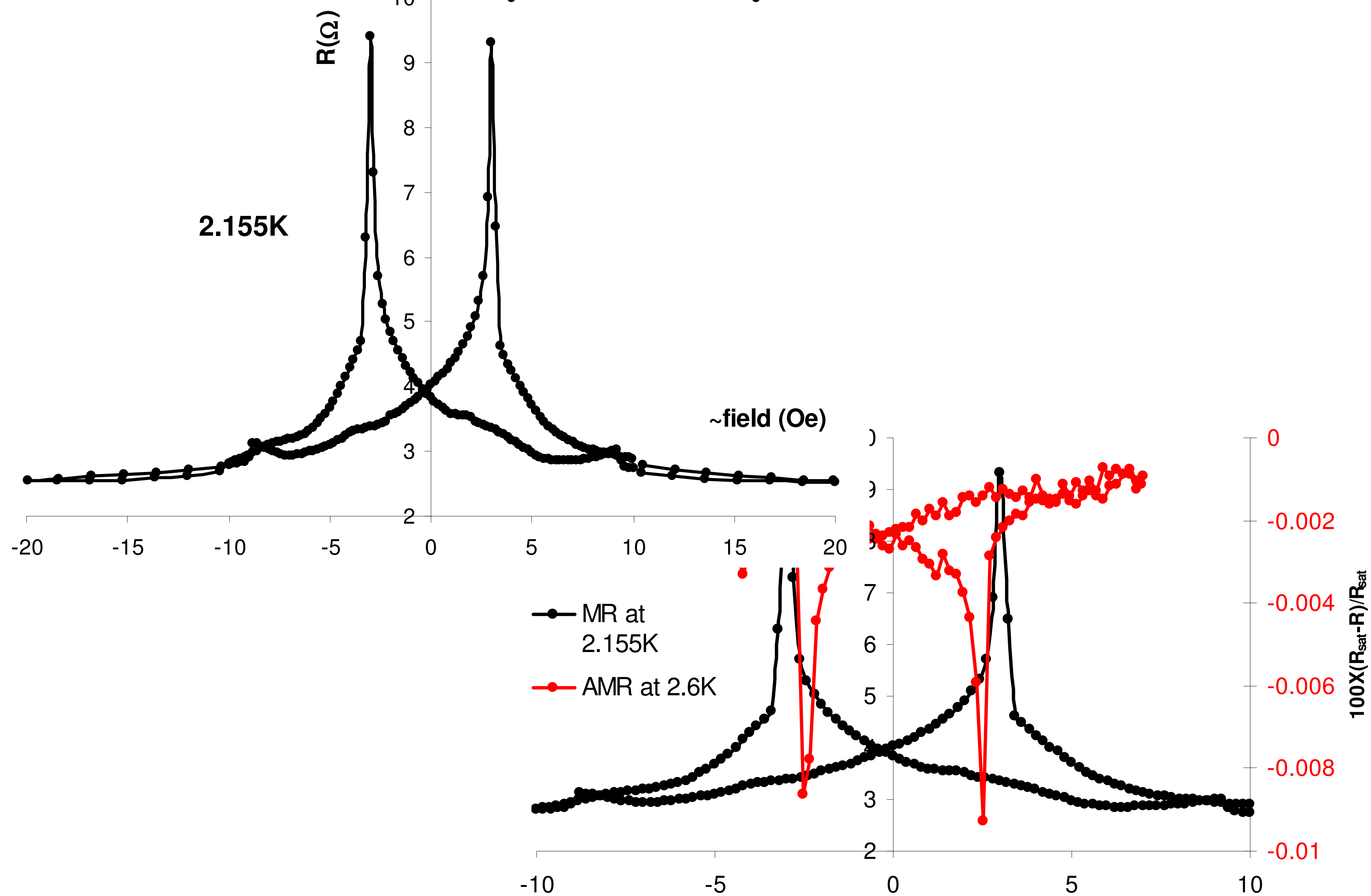
MR at foot of transition



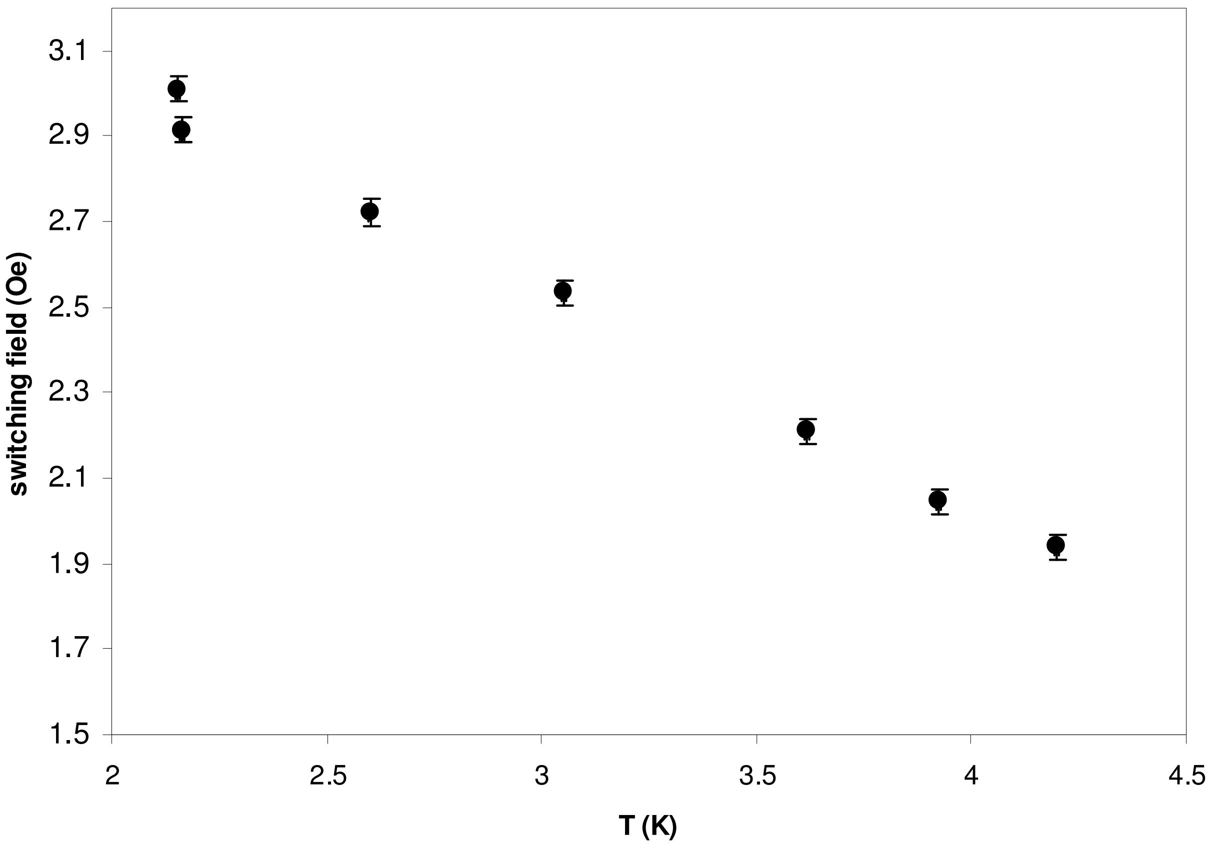
Jumps are fluctuations in T of the order 0.3mK



MR at foot of transition



Switching field vs T

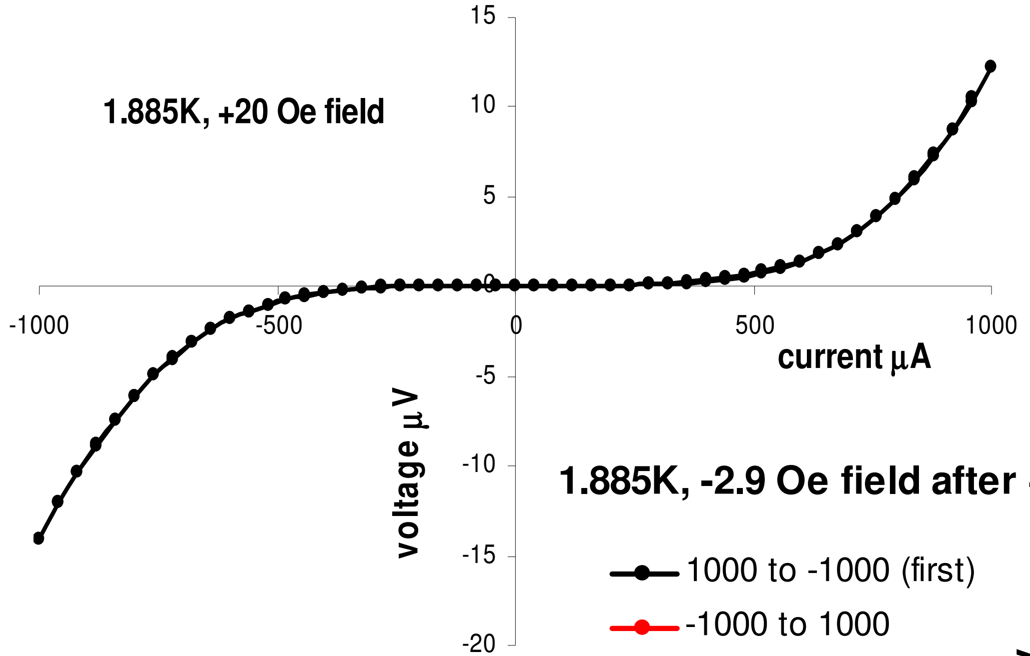


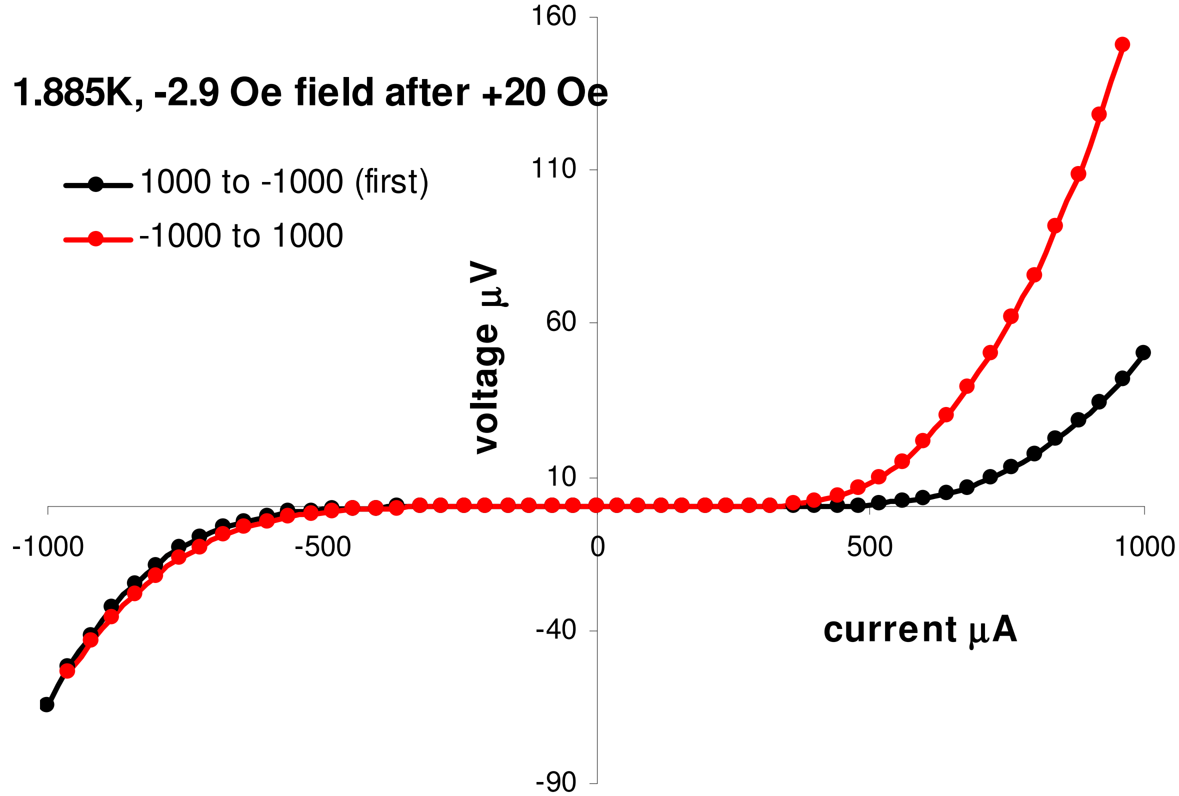
Switching fields fit in with the trend further above T_C – so nothing is really different – the relatively huge PEAKS in MR are at the same field as the DIPS in AMR (if we could measure it)

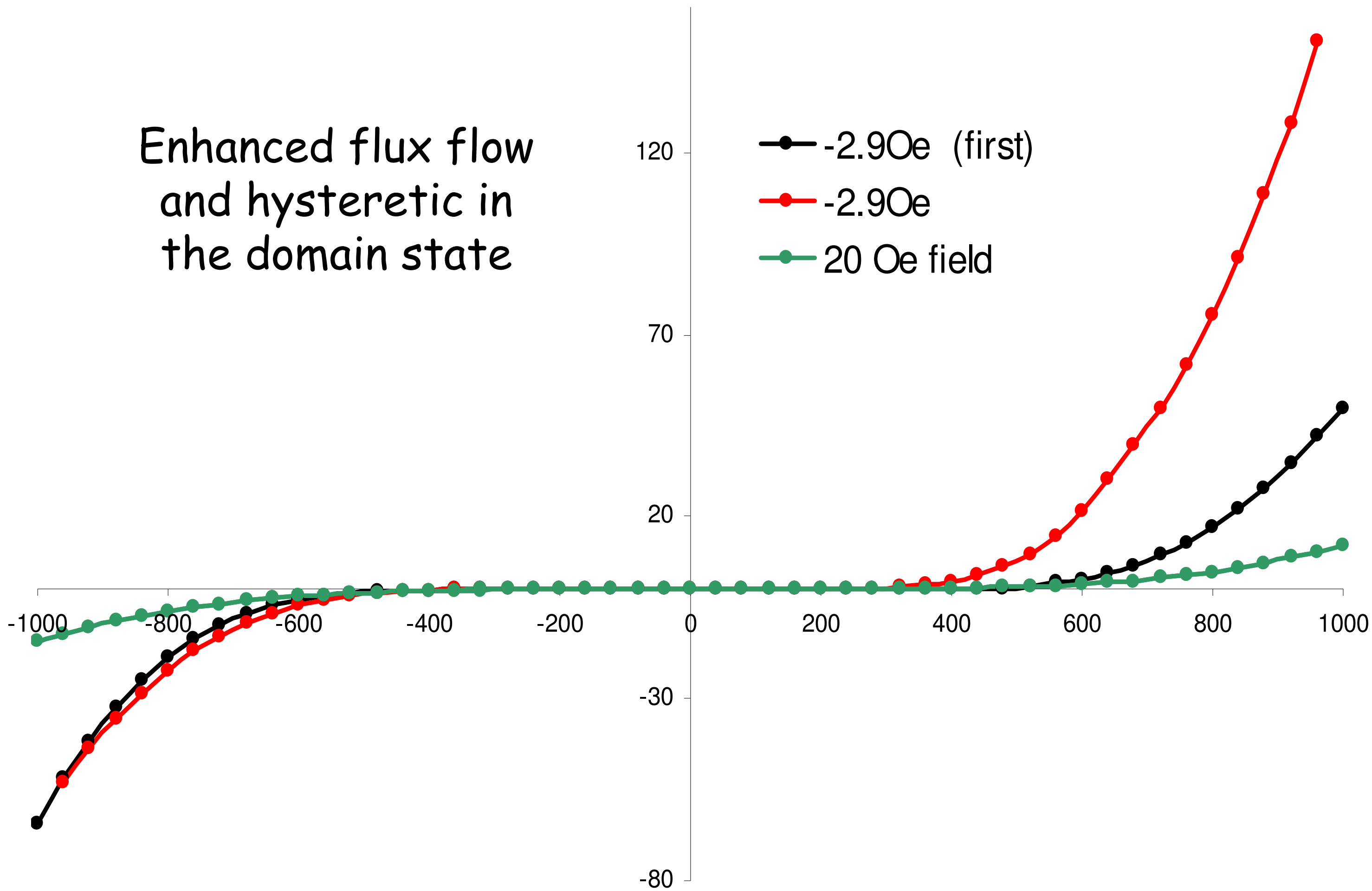
Wasn't this done before?

- NOT like dips in R caused by averaging of rotating domains over a length scale ξ_S
- In that case superconductivity is LESS suppressed – i.e. R goes down (or I_C goes up)
- How about vortex flow? c.f. MoGe is very weak pinning

I-V measurements below T_C

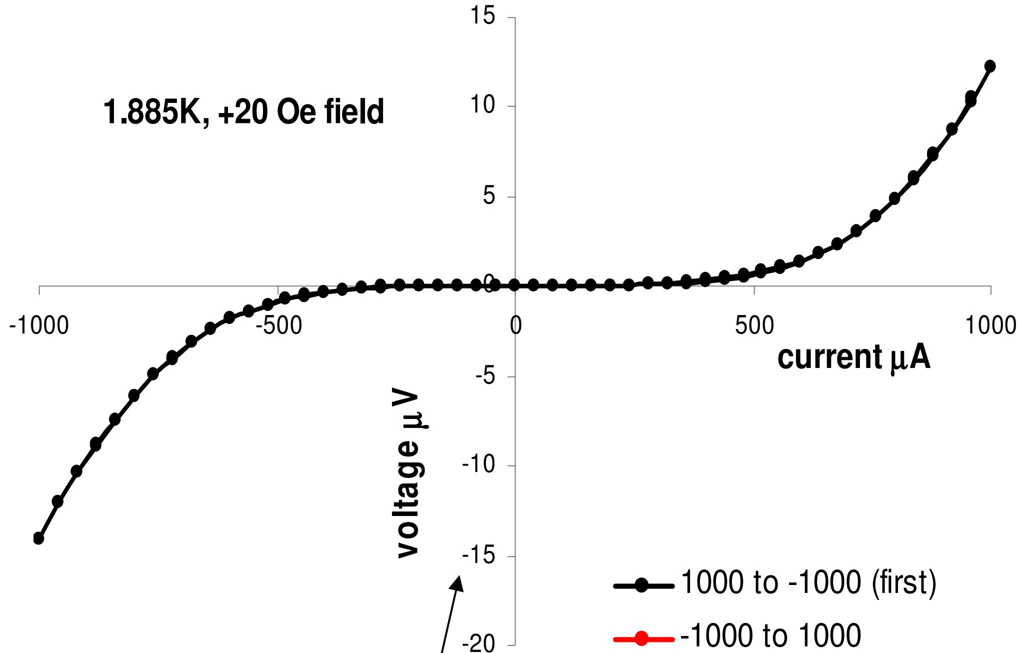




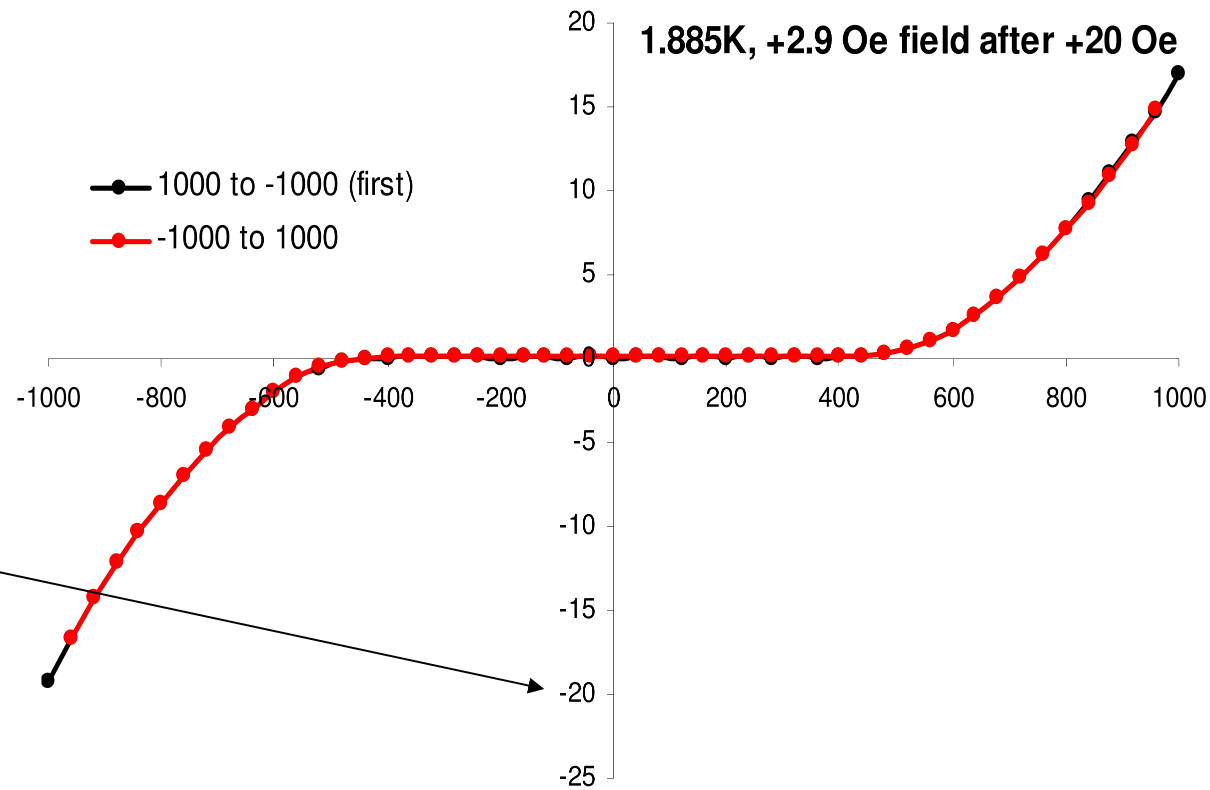


Enhanced flux flow
and hysteretic in
the domain state
-2.9Oe (first)
-2.9Oe
20 Oe field
120
70
20
-30
-80
-1000
-800
-600
-400
-200
0
200
400
600
800
1000

I-V measurements below T_C

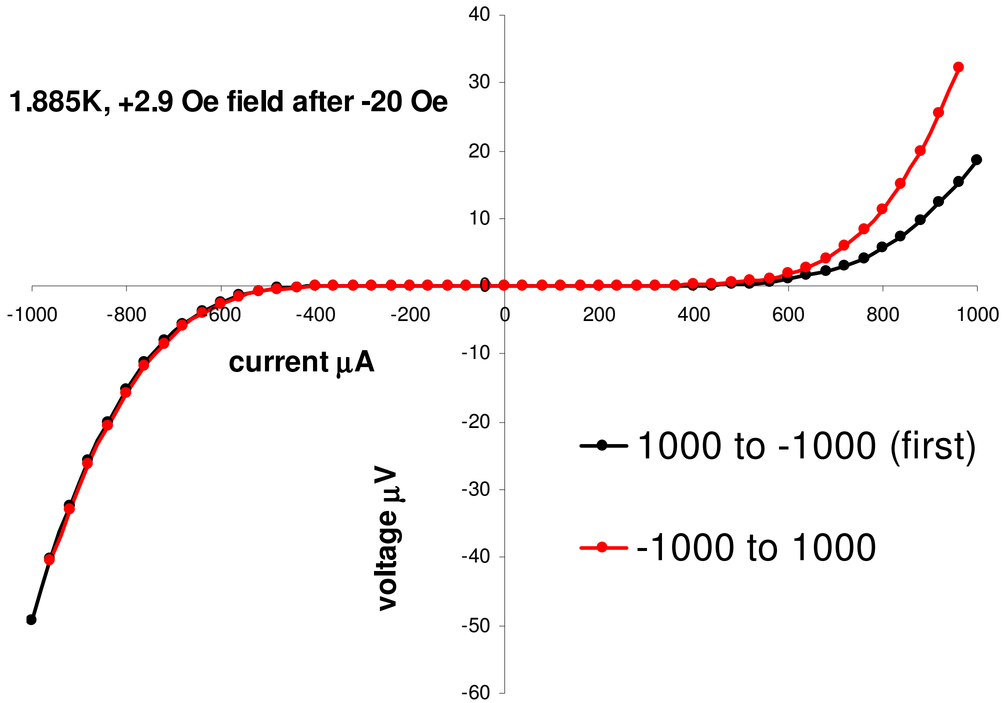


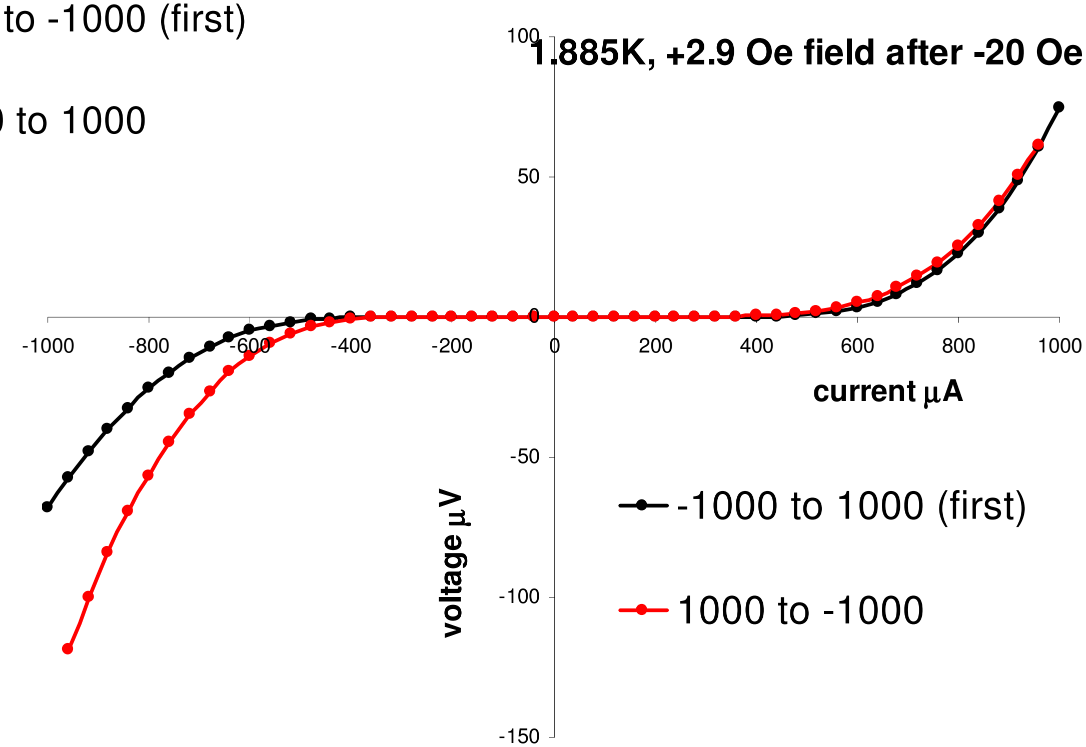
Field history now means NOT in domain state, but at same applied field



Only very weak increase in flux flow resistivity

Closer look at hysteresis

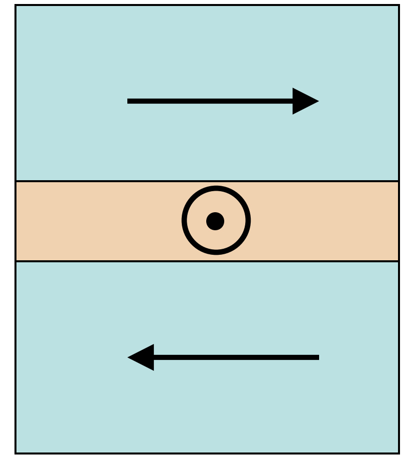




Not self field?!

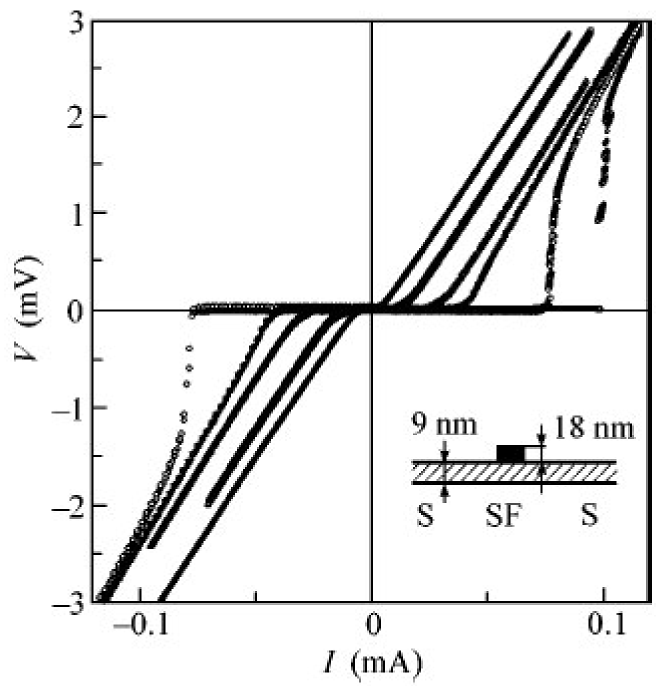
Need to do this at the same T as the AMR data, take more cycles, and think about it more!

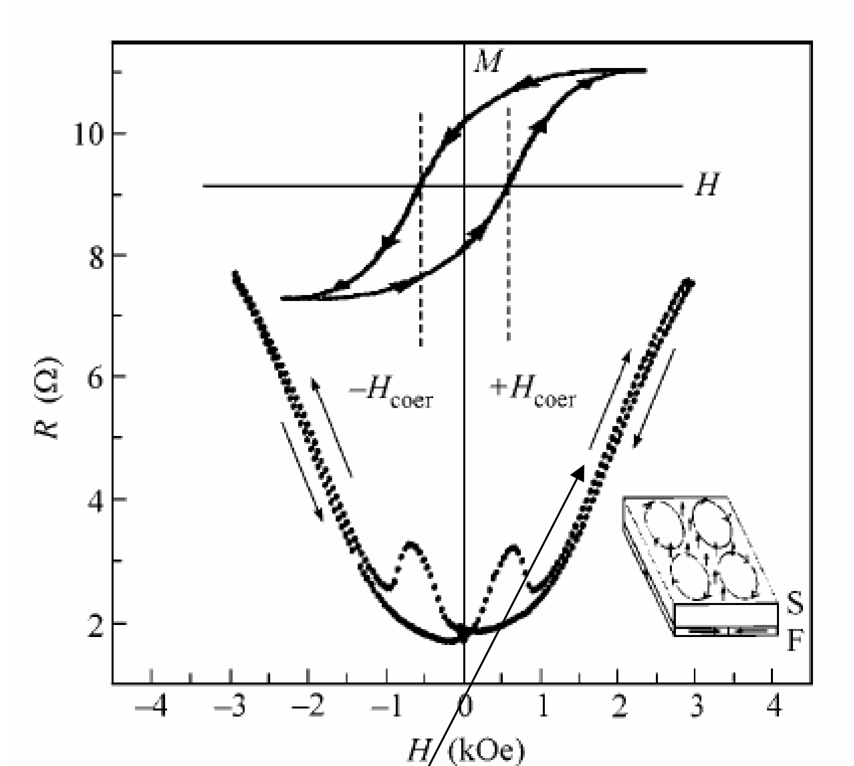
Interpretation



- Just an effect of vortices from Bloch domains?
- Also are the layers switching together? (we see only one AMR peak)
    - •For ferrimagnetic films there may be an out of plane anisotropy (which favours Bloch walls presumably?!) Known for GdCo (PRL **66**, 1086 (1991)) but GdNi has much weaker Ni moment. So perhaps you only see it for very thin films if the surface anisotropy becomes important

Related work





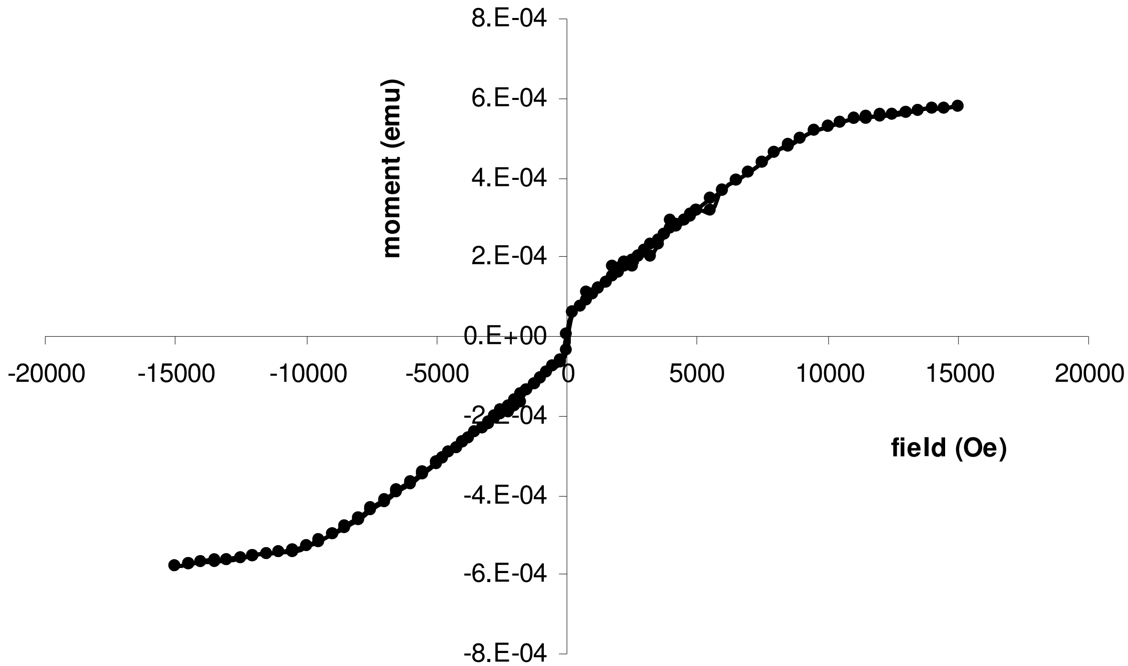
V. V. Ryazanov et al, *JETP Letters* ***77****,* *39 (2003)*

Background is NOT what we see

Side issue: M(H) out of plane

Q: are there Bloch walls?

- 75nm GdNi looks hard axis



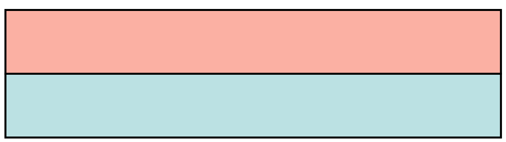
- ~ 5.5 nm film ready to be measured when SQUID is alive again.....

Further things to do

- Try bilayers instead: rule out spin switch effects
  - Direct proximity bilayer: GdNi/MoGe
  - No proximity effect: GdNi/SiO/MoGe
- Take the top (thinner layer) off
- Two problems
  - One physical: Thicker GdNi shows no AMR (see next)
  - One practical: Now the MoGe T_C is higher, (and probably sharper) – harder to stabilize T – grow a thinner MoGe purely for ease of measuring, (later)

Next samples

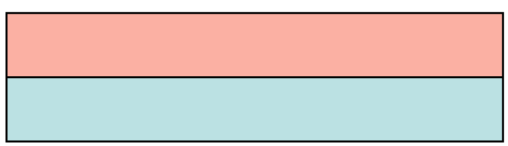
- GdNi nm / MoGe nm with and without SiO isolation:



MoGe
GdNi

MoGe
SiO
GdNi

First sample:



~ 21nm MoGe
~22.5nm GdNi

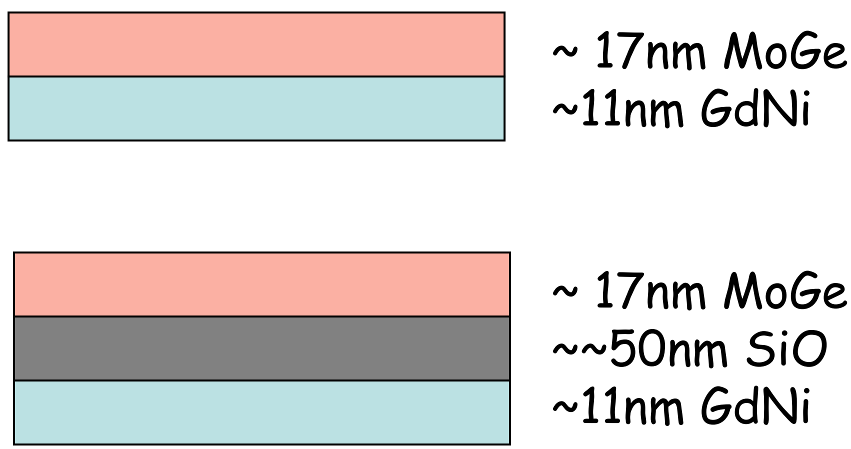
Thicker GdNi has no AMR!
(at 4.2K)

- Probably saw this already with some of Jan's trilayers
- But we had parallel questions about the non-reproducibility of acid etching, and also that you vary the T_C of the trilayer too.
- We know little about monolayers (I've only measured only two samples….

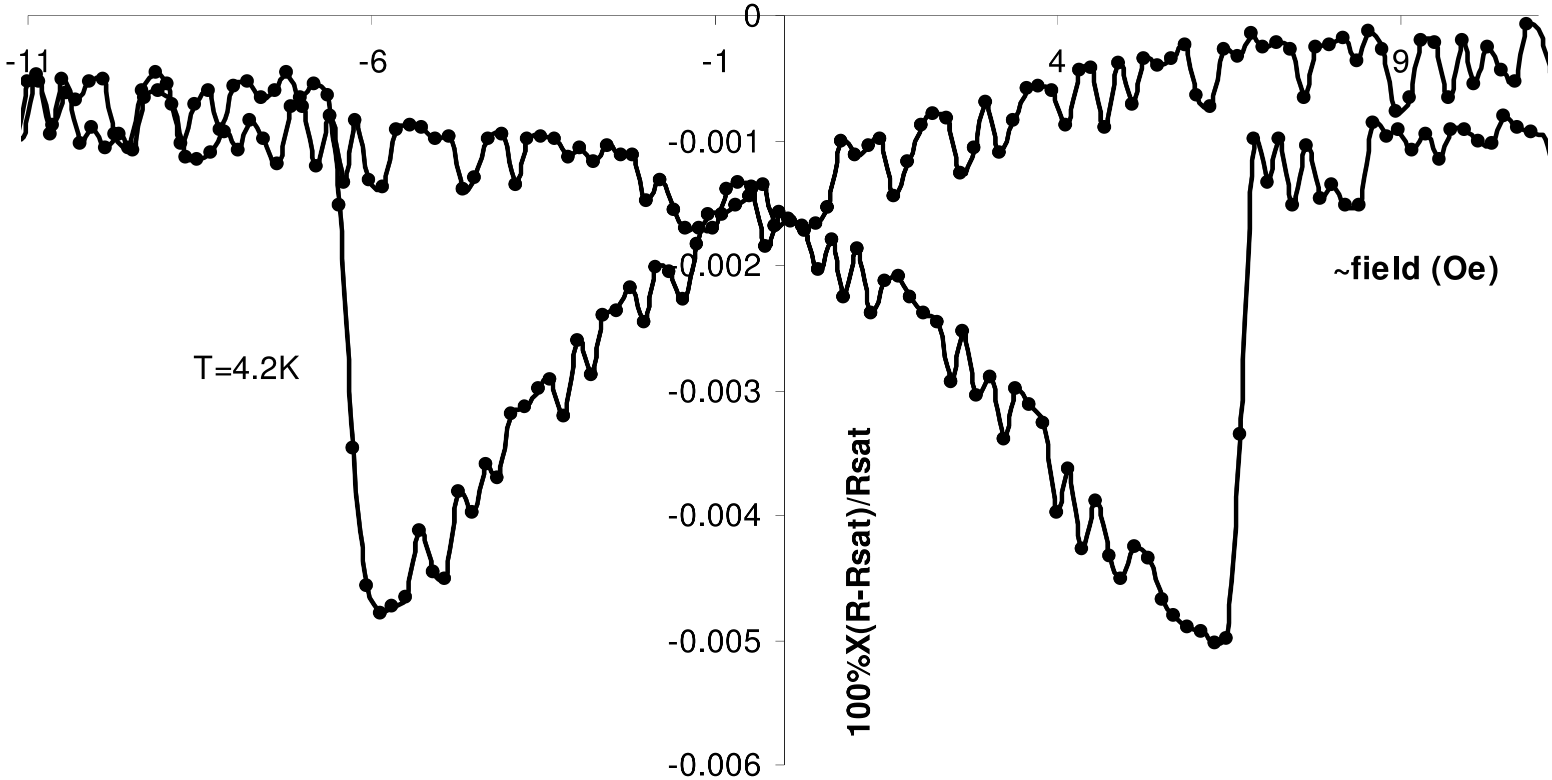
- T_C also very high and hard to hold T stable therefore no MR within the transition
- Didn't even bother to measure the one with SiO isolation…….

Take away the thick GdNi instead!

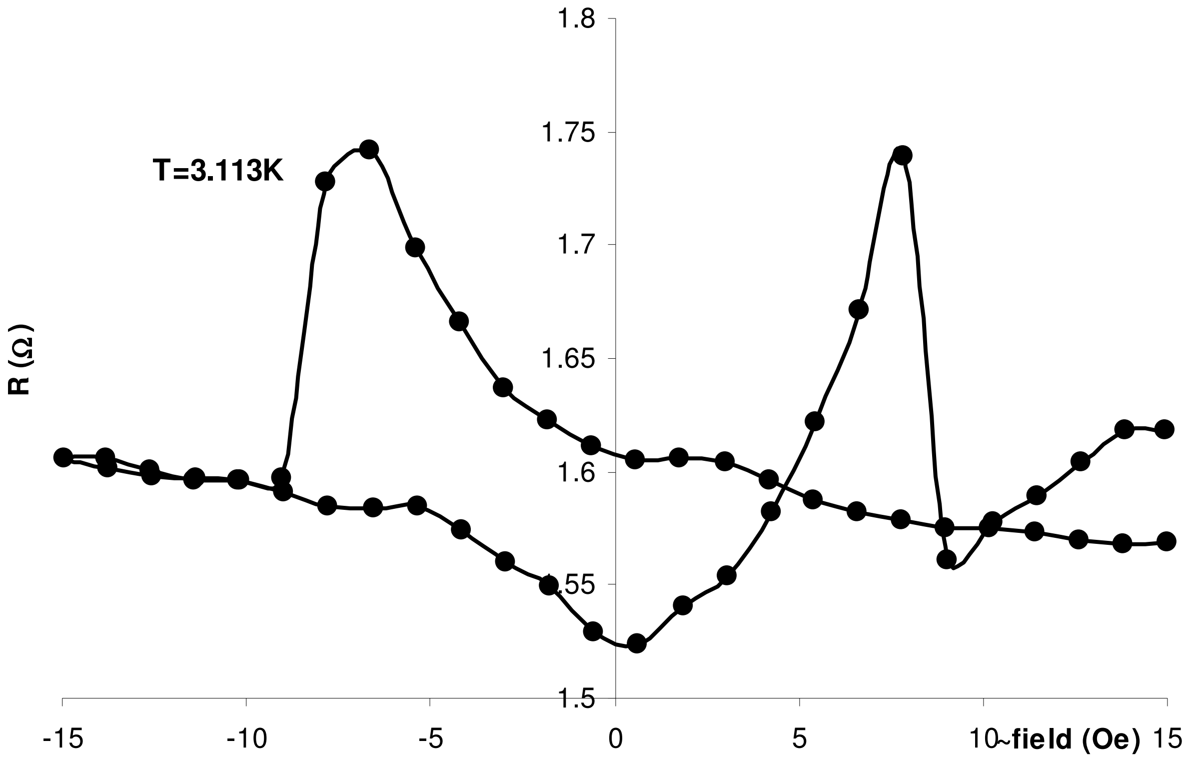
- Again bilayer with and without SiO isolation
- Now MoGe thinner – lower T_C hopefully easier to keep constant



AMR back again!



Within the transition….



- Only weak MR effect inside the transition – nothing like in the trilayers (data not so nice though)
- Even at 3K temperature control not good enough to allow full I-Vs and field sweeps to be made

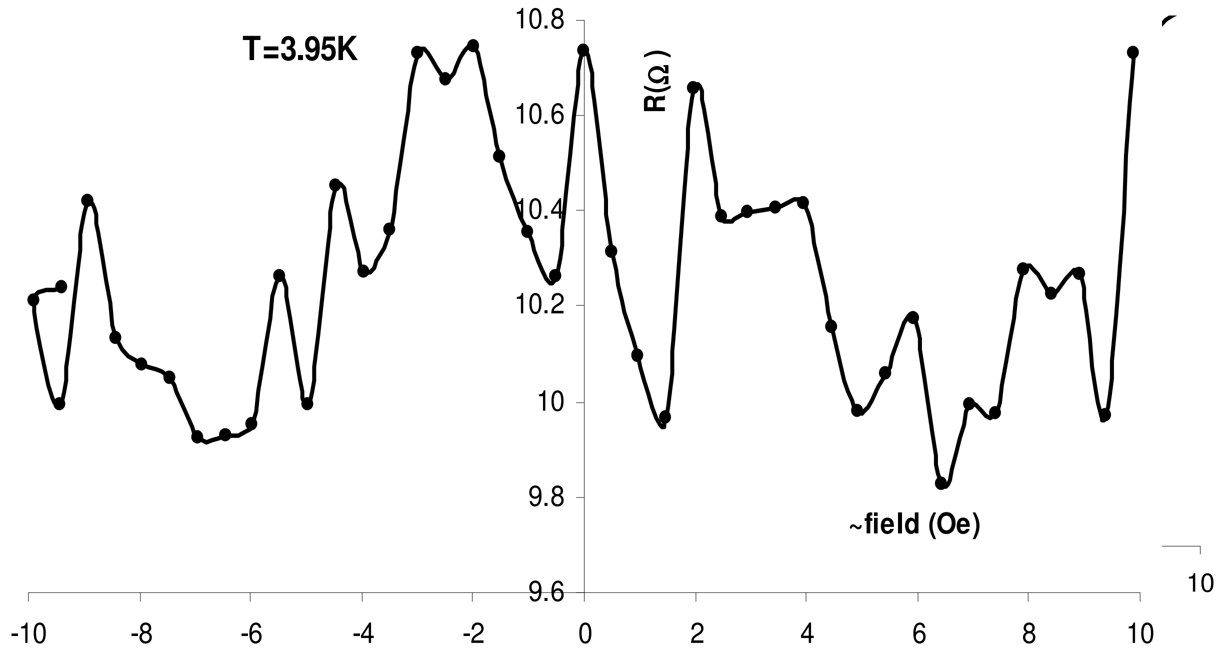
Temperature problem

- T_C still relatively high, hard to stabilize
- Go from working in the liquid to sealed and using PI(D) control on a heater

(didn't have until now)

(one days work – easy enough, as long as you don't 'borrow' useless Labview code from the internet……works now though to ~ 1mK peak to peak stability with not brilliantly optimised P and I)

Now T is easier to stabilize.... back to the thicker GdNi sample



Still no big jumps like in the trilayers, and a strong background MR (and the asymmetry???)

Conclusions

- There is a lot that can possibly be measured!
- Still the bilayer samples need to be optimised for T_C, & things like the peak effect understood, also have SiO samples
- But the cryostat can happily handle mK stability now – so I can take a lot of data in a 0.1K transition width!
- May not be a spin switch, but perhaps one or two interesting things to think about