



The Design, Discovery, Growth and Physical Properties of Novel Intermetallic Compounds

TUNING MAGNETISM

Paul C. Canfield

Distinguished Professor,

Department of Physics

Senior Physicist, Ames Laboratory

Iowa State University

2nd European School in Material Science,

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To set the stage (part 1)...

Correlated electronic ground states have been one of the focuses of Solid State Physics for the past several decades. Such correlations range from Stoner enhancements in nearly ferromagnetic Fermi liquids, all the way to heavy fermions and quantum criticality. This field, like so many others in condensed matter physics, has depended on the development and discovery of new compounds to drive it.

In this talk, we will examine two systems that allow for a degree of tuning across parts of this phase space.

RAgGe (*part of E. Morosan's thesis*)

$\text{RT}_2\text{Zn}_{20}$ (*part of S. Jia's thesis*)



To set the stage (part 2)...

Motivations for making a sample:

Want a specific material

Want a specific effect or ground state

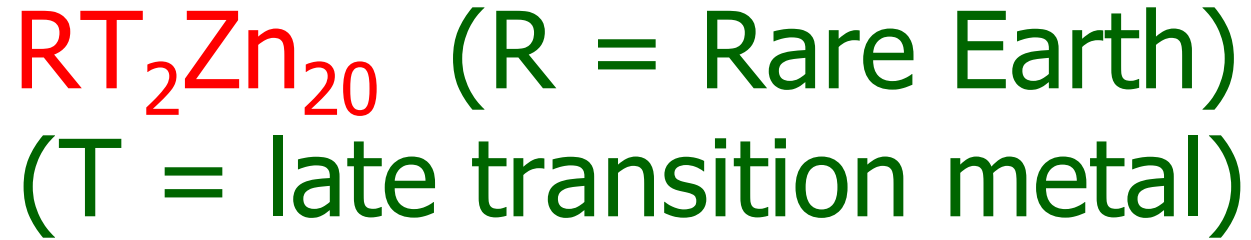
Want to explore phase space (chemical / physical)

If you get what you wanted...get to work

When you find something new or unexpected, is it interesting?

Once you get to know specific compounds / series well, use them as model systems.

These motivations can often blur and evolve. In this final lecture let me deconstruct our research agendas on two families of materials.



Motivations

- (i) Play around in physical phase space**
- (ii) Explore new and rich structure class**
- (iii) Create and use model systems**



Dilute, rare earth bearing, intermetallic compounds.

I wanted to see if I could find interesting physics in intermetallics with very dilute rare earths *that are still fully occupying a unique crystallographic site.* (To some extent this points toward large unit cells.)

This offers the possibility of studying local moment as well as hybridizing R closer to the single ion limit, but while still preserving periodicity.

It also provides a rationalization for exploring some new chemical and structural spaces.

I made a very comprehensive list of R-bearing, large unit cell compounds and started sorting through it.

(For experts, start at the end of one of the Pearson indexes and work backwards....)



RT₂Zn₂₀

The RT₂Zn₂₀, (T = Fe, Co, Ni, Ru & Rh) family was discovered by T. Nasch, et al. *Z. Naturforsch.* 52b 1023(1997).

There were virtually no physical characterization measurements made on its members, probably due to (i) issues of purity in polycrystalline form and (ii) a prejudice that the transition temperatures would be very low, if detectable. E.g. we have also grown isostructural GdTi₂Al₂₀ and GdV₂Al₂₀ samples for which T_N ~ 2.5 K.

hydrogen 1 H 1.0079																		helium 2 He 4.0026																			
lithium 3 Li 6.941		beryllium 4 Be 9.0122		Key: element name atomic number symbol atomic weight (mean relative mass)																boron 5 B 10.811		carbon 6 C 12.011		nitrogen 7 N 14.007		oxygen 8 O 15.999		fluorine 9 F 18.998		neon 10 Ne 20.180							
sodium 11 Na 22.990		magnesium 12 Mg 24.305																		aluminum 13 Al 26.982		silicon 14 Si 28.086		phosphorus 15 P 30.974		sulfur 16 S 32.065		chlorine 17 Cl 35.453		argon 18 Ar 39.948							
potassium 19 K 39.098		calcium 20 Ca 40.078		scandium 21 Sc 44.956		titanium 22 Ti 47.867		vanadium 23 V 50.942		chromium 24 Cr 51.996		manganese 25 Mn 54.938		iron 26 Fe 55.845		cobalt 27 Co 58.933		nickel 28 Ni 58.693		copper 29 Cu 63.546		zinc 30 Zn 65.39		gallium 31 Ga 69.723		germanium 32 Ge 72.61		arsenic 33 As 74.922		selenium 34 Se 78.96		bromine 35 Br 79.904		krypton 36 Kr 83.80			
rubidium 37 Rb 85.468		strontium 38 Sr 87.62		yttrium 39 Y 88.906		zirconium 40 Zr 91.224		niobium 41 Nb 92.906		molybdenum 42 Mo 95.94		technetium 43 Tc [98]		ruthenium 44 Ru 101.07		rhodium 45 Rh 102.91		palladium 46 Pd 106.42		silver 47 Ag 107.87		cadmium 48 Cd 112.41		indium 49 In 114.82		tin 50 Sn 118.71		antimony 51 Sb 121.76		tellurium 52 Te 127.60		iodine 53 I 126.90		xenon 54 Xe 131.29			
caesium 55 Cs 132.91		barium 56 Ba 137.33		lanthanum 57 La 138.91		cerium 58 Ce 140.12		praseodymium 59 Pr 140.91		neodymium 60 Nd 144.24		promethium 61 Pm [145]		samarium 62 Sm 150.36		europium 63 Eu 151.96		gadolinium 64 Gd 157.25		terbium 65 Tb 158.93		dysprosium 66 Dy 162.50		holmium 67 Ho 164.93		erbium 68 Er 167.26		thulium 69 Tm 168.93		ytterbium 70 Yb 173.05		lutetium 71 Lu 174.97		hafnium 72 Hf 178.49			
francium 87 Fr [223]		radium 88 Ra [226]		actinium 89 Ac [227]		thorium 90 Th 232.04		protactinium 91 Pa 231.04		uranium 92 U 238.03		neptunium 93 Np [237]		plutonium 94 Pu [244]		americium 95 Am [243]		curium 96 Cm [247]		berkelium 97 Bk [247]		californium 98 Cf [251]		einsteinium 99 Es [252]		fermium 100 Fm [257]		mendelevium 101 Md [258]		nobelium 102 No [259]		lawrencium 103 Lr [262]		rutherfordium 104 Rf [261]			

*lanthanoids

**actinoids

lanthanum 57 La 138.91	cerium 58 Ce 140.12	praseodymium 59 Pr 140.91	neodymium 60 Nd 144.24	promethium 61 Pm [145]	samarium 62 Sm 150.36	europium 63 Eu 151.96	gadolinium 64 Gd 157.25	terbium 65 Tb 158.93	dysprosium 66 Dy 162.50	holmium 67 Ho 164.93	erbium 68 Er 167.26	thulium 69 Tm 168.93	ytterbium 70 Yb 173.04
actinium 89 Ac [227]	thorium 90 Th 232.04	protactinium 91 Pa 231.04	uranium 92 U 238.03	neptunium 93 Np [237]	plutonium 94 Pu [244]	americium 95 Am [243]	curium 96 Cm [247]	berkelium 97 Bk [247]	californium 98 Cf [251]	einsteinium 99 Es [252]	fermium 100 Fm [257]	mandeleevium 101 Md [258]	nobelium 102 No [259]

We have expanded this phase space to include T = Os, Ir, Pt (and also some Mn substitution); over 70 compounds have been made.



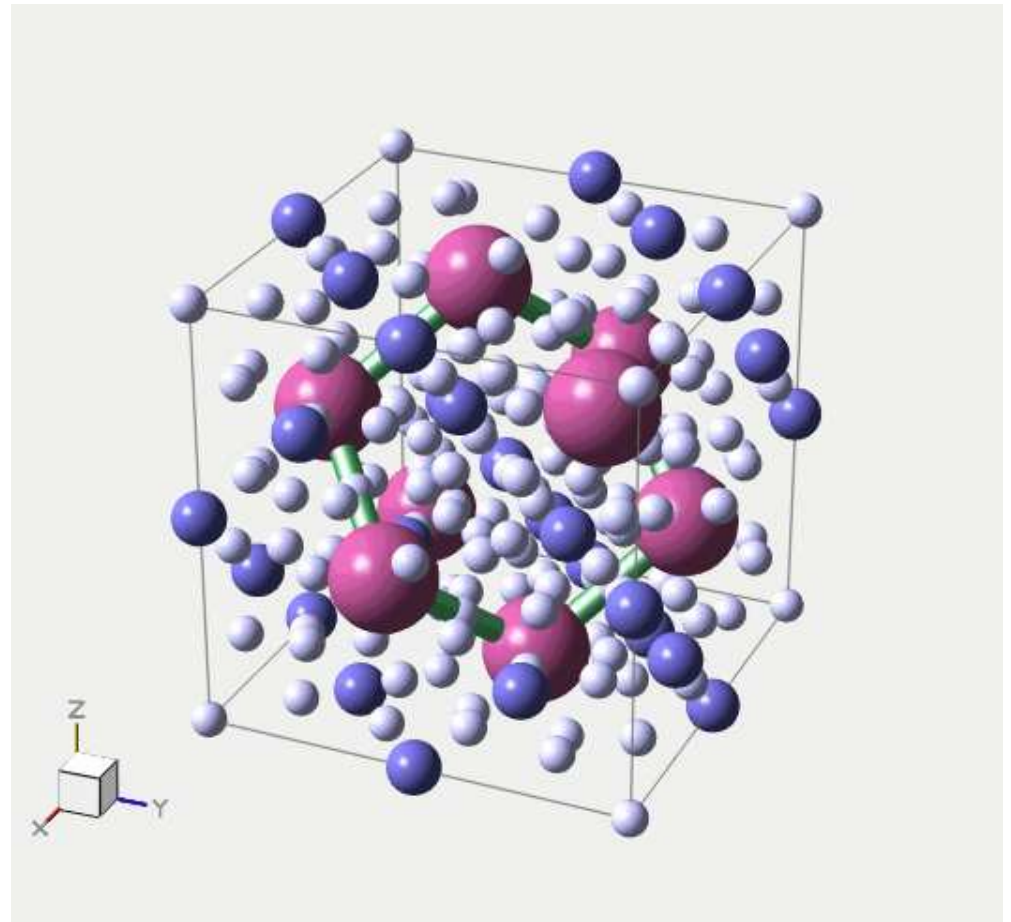
The RT_2Zn_{20} series offer the opportunity to study dilute, rare earth intermetallic compounds: compounds that are less than 5 atomic percent R, but are fully ordered.

--Cubic unit cells, $a \sim 14 \text{ \AA}$
(cF184---Z = 8)

--Single unique
crystallographic R site
with cubic point symmetry

--R – R distance $\sim 6 \text{ \AA}$

--All nearest neighbors for
R and for T are Zn



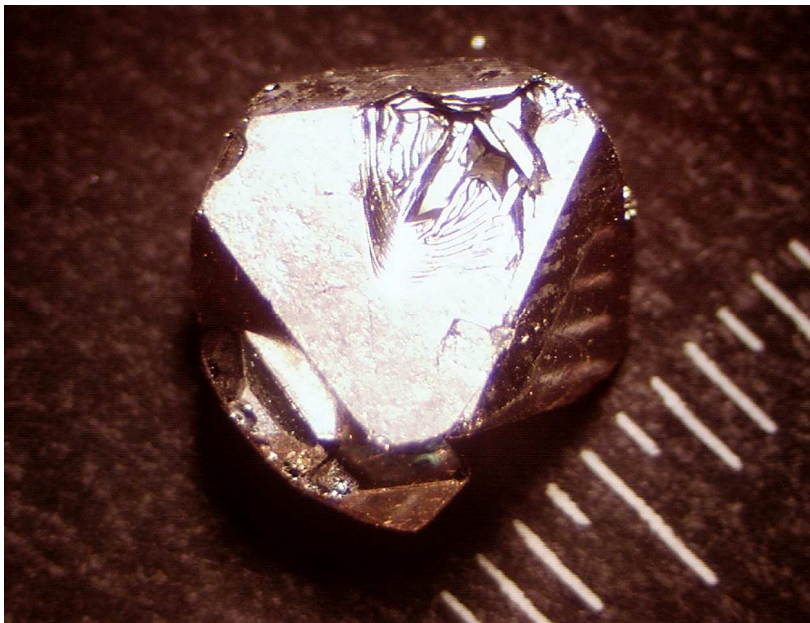
RT_2Zn_{20} Unit Cell

Large spheres: R Medium spheres:
TM Small spheres: Zn

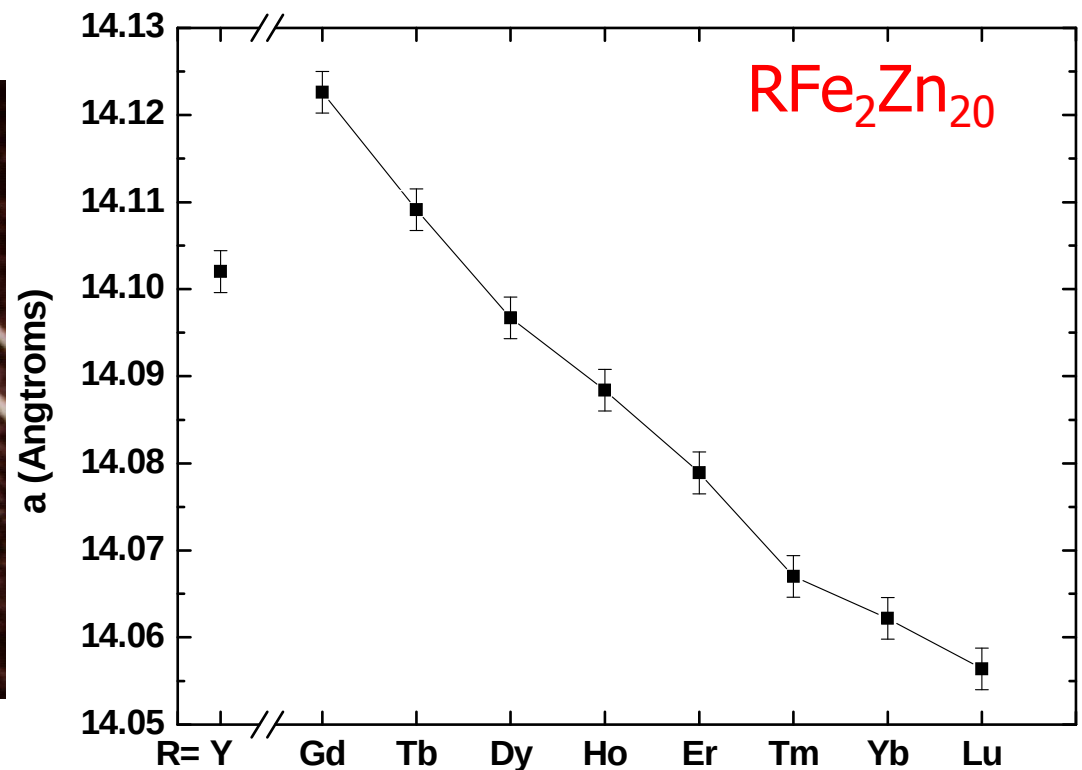


Sample Basics:

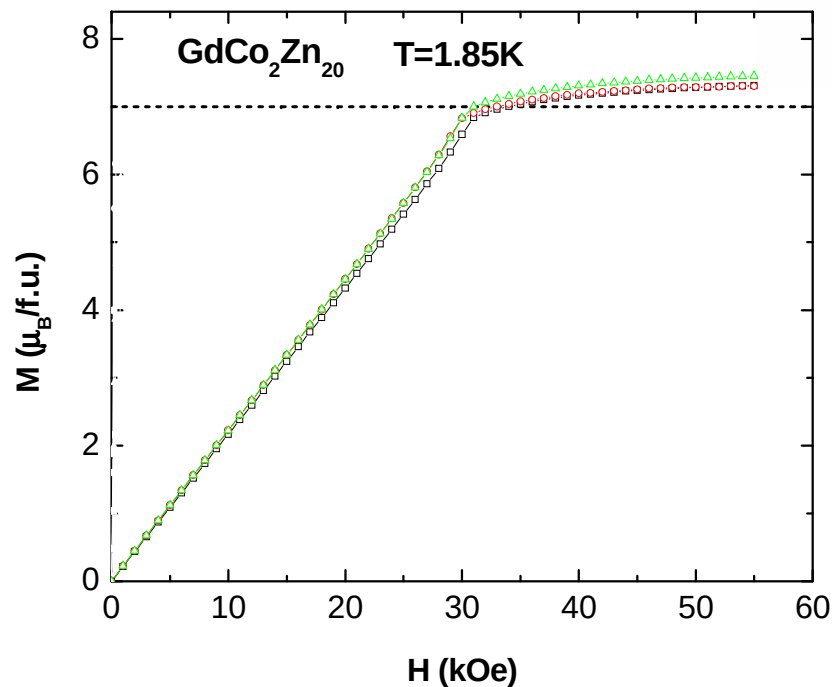
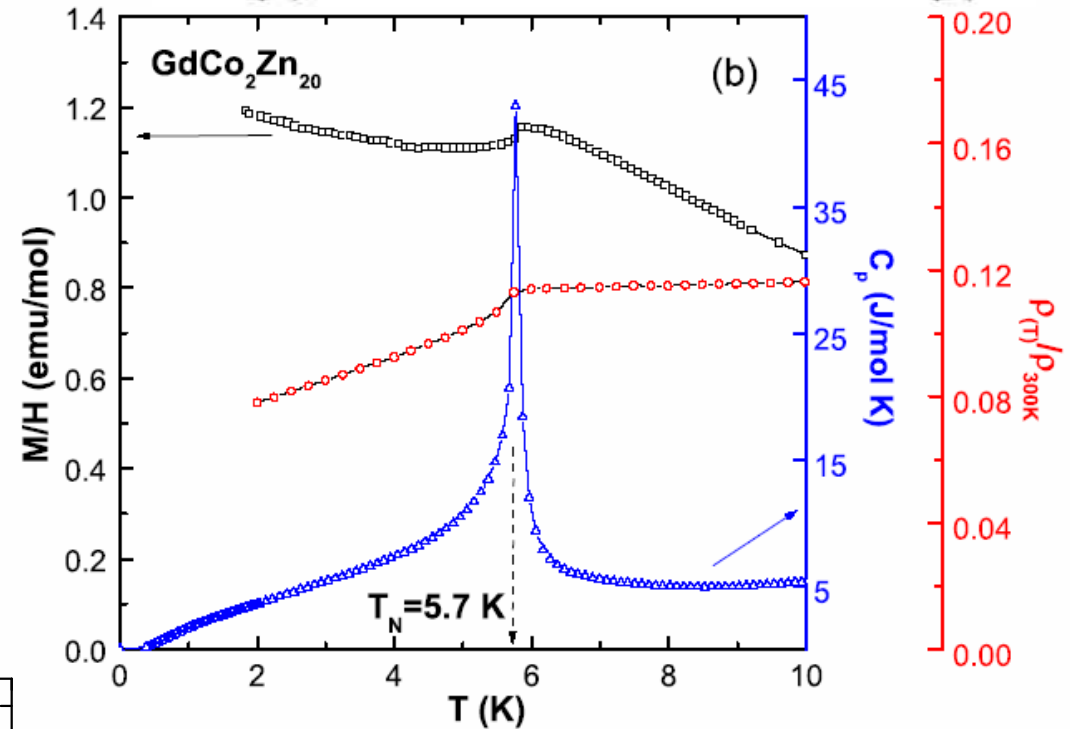
- Crystals grown from Zn self-flux
- Large single crystals with clear 111 facets
- Lattice constants follow lanthanide contraction



$\text{YFe}_2\text{Zn}_{20}$ single crystal



$\text{GdCo}_2\text{Zn}_{20}$ orders antiferromagnetically just below 6 K and is not far removed from the ~ 3 K ordering temperatures of the $\text{GdT}_2\text{Al}_{20}$ compounds.

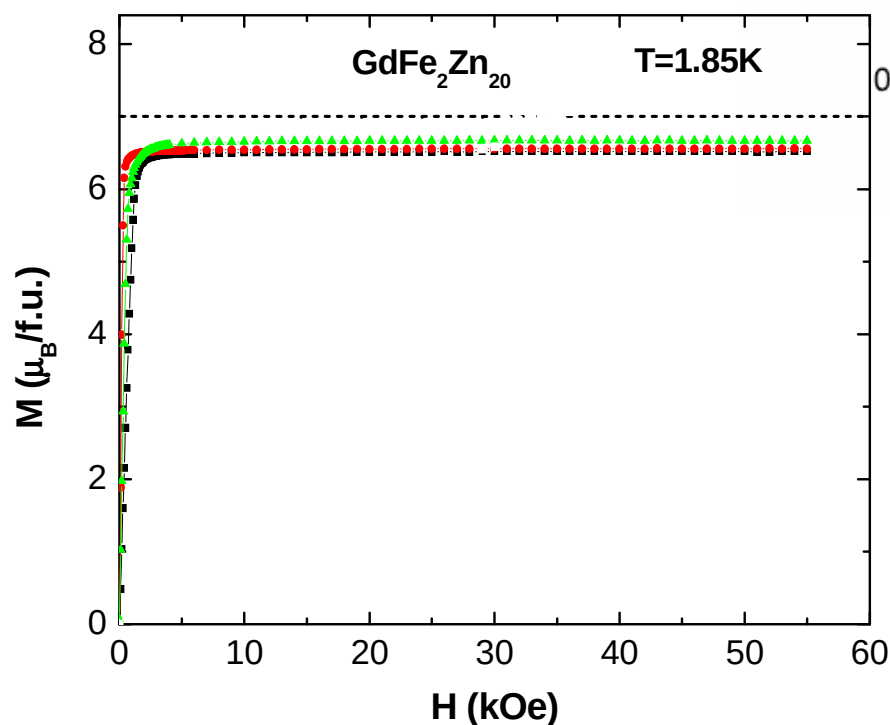
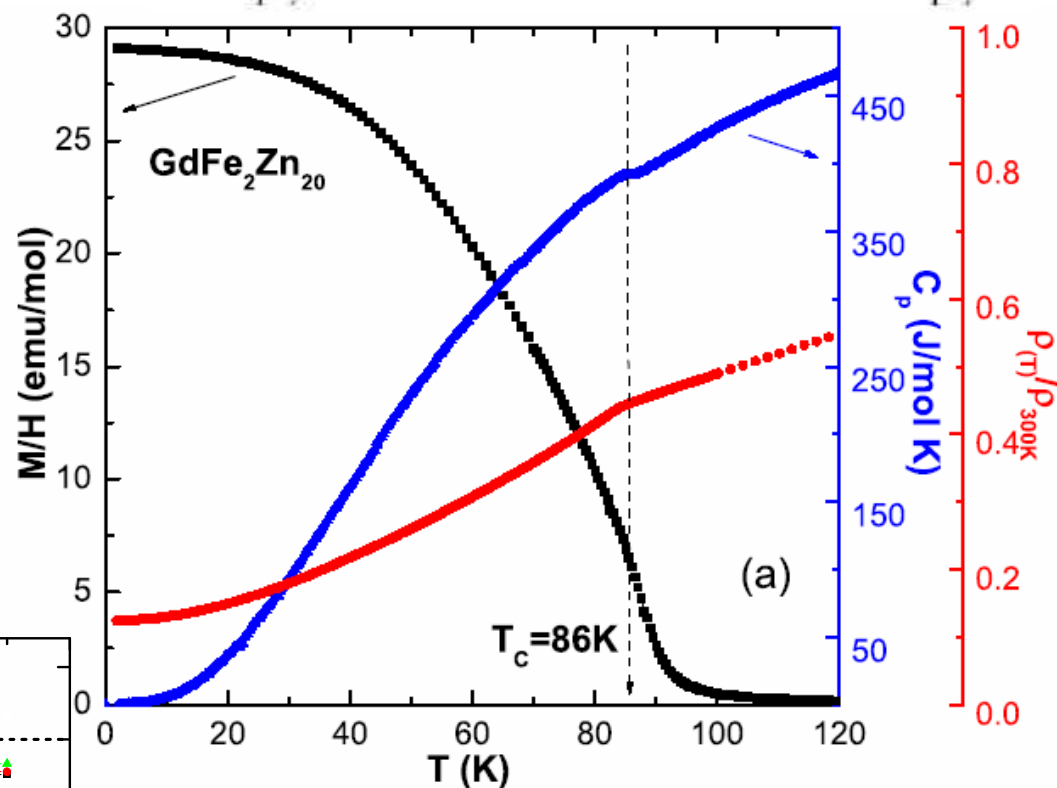


This compound behaves more or less the way one would guess, low temperature ordering that is close to the ordering temperature of elemental Gd divided by the dilution of 1/23.

So what is the noise about?

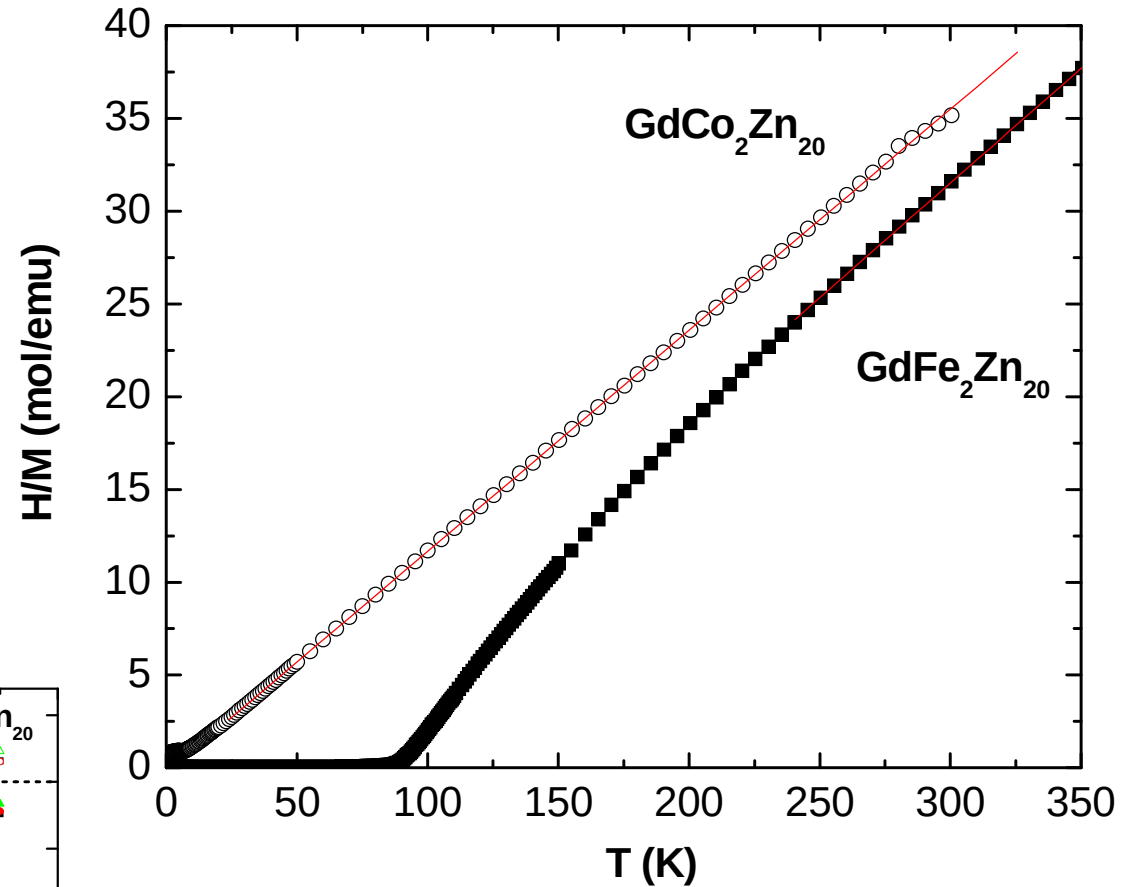
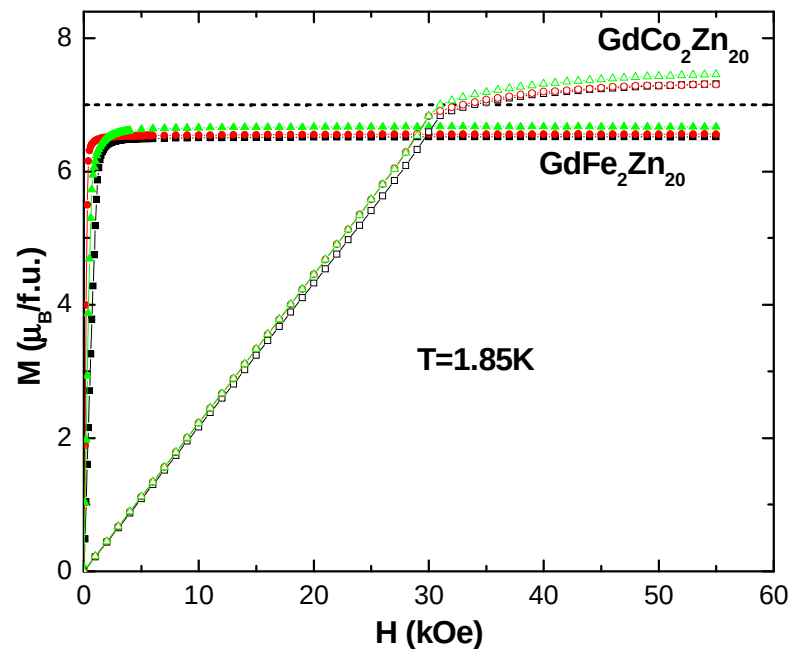


$\text{GdFe}_2\text{Zn}_{20}$ orders
ferromagnetically at a
remarkably high 86 K.



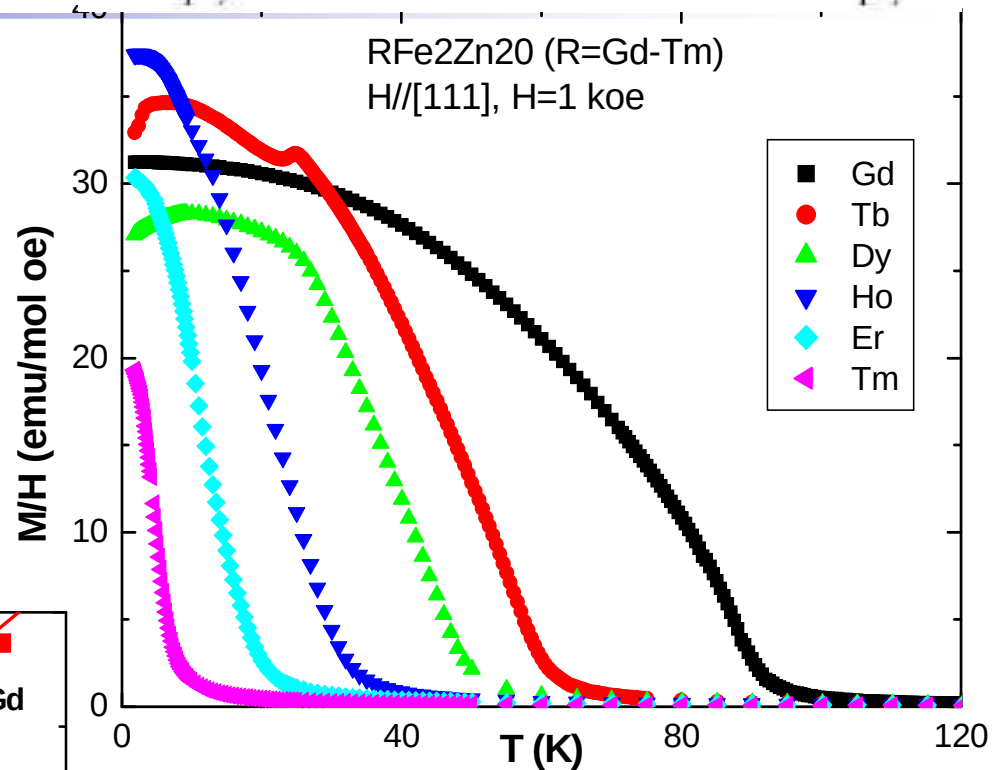
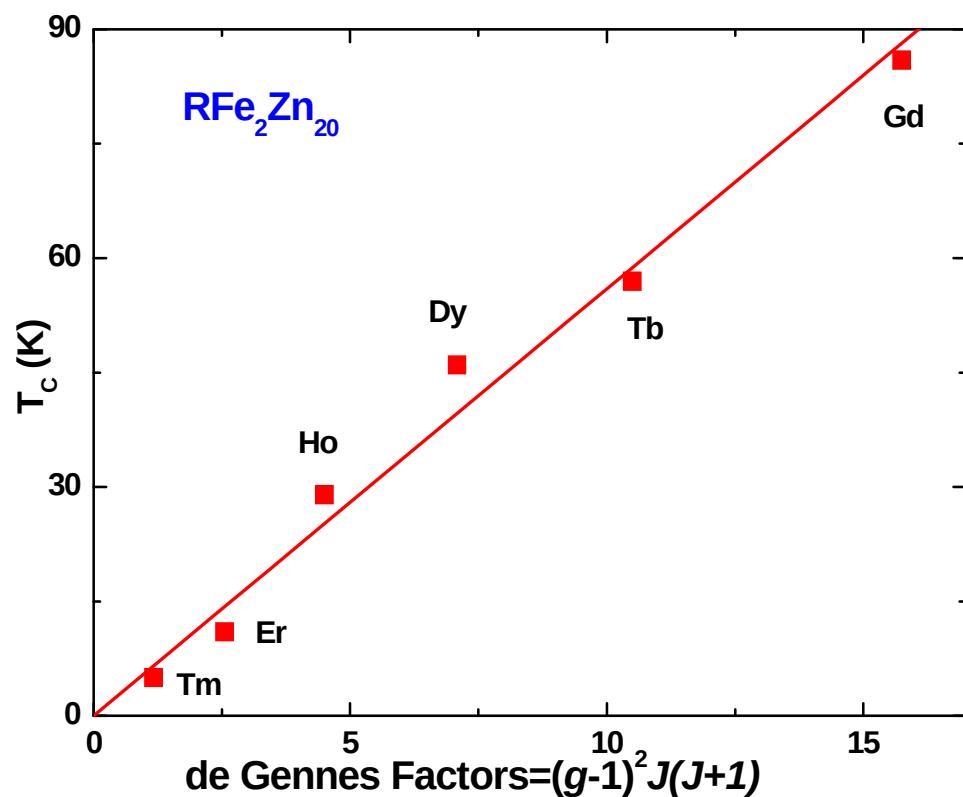
This is a very high
temperature for a
compound with 1 local
moment bearing Gd
out of 23 atoms per
formula unit.

Both $\text{GdCo}_2\text{Zn}_{20}$ and $\text{GdFe}_2\text{Zn}_{20}$ manifest high temperature, effective moments consistent with Gd^{+3}



And, as seen already, both have low temperature, saturated moments close to 7 μ_B

The whole RFe_2Zn_{20} series has enhanced T_C values that deGennes scale well.



The question is, "Why does the RFe_2Zn_{20} series manifest such high ordering temperatures?"



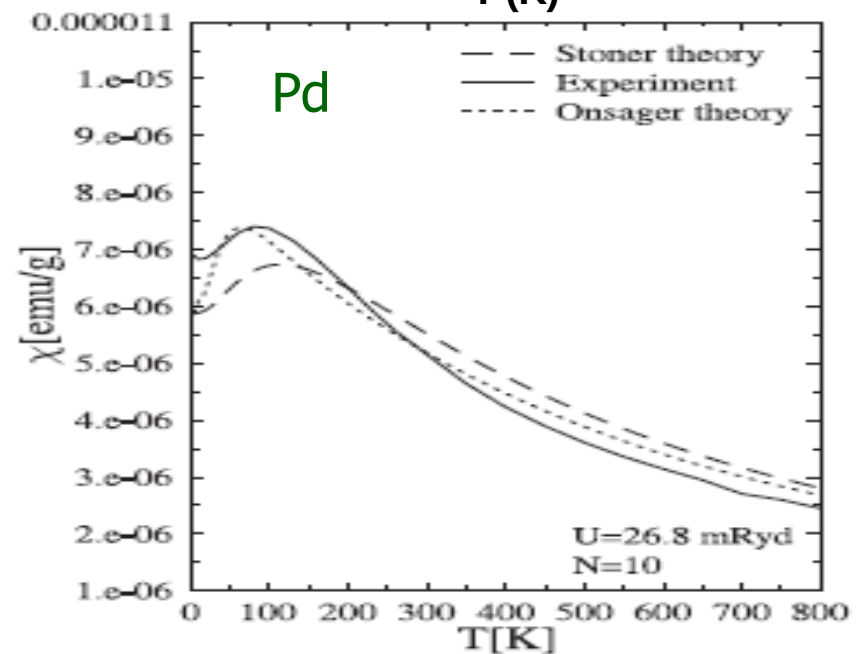
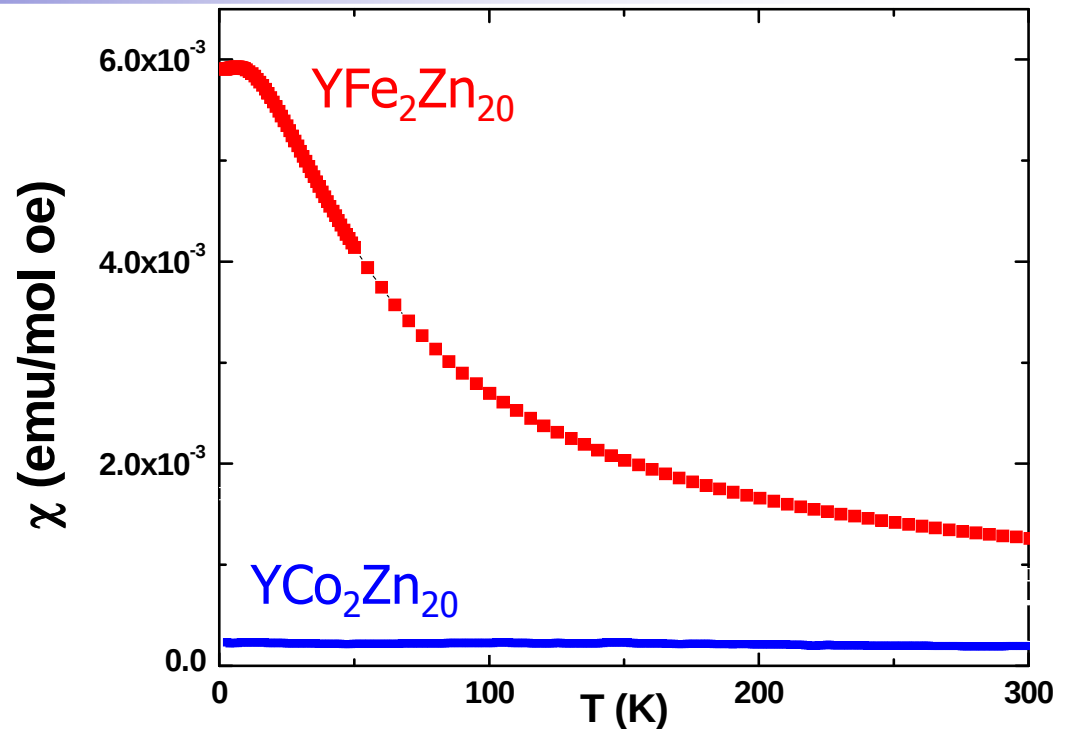
*Let's remove
the local moment
magnetism and look
at a "simpler" system*

In terms of magnetic
susceptibility

$\text{YFe}_2\text{Zn}_{20}$ is very similar to
 Pd

$\text{YCo}_2\text{Zn}_{20}$ is more like Cu.

If this is the case, can we
think of $\text{YFe}_2\text{Zn}_{20}$ as being
close to the Stoner limit
(like Pd is)?



Stoner enhancement of $\text{YFe}_2\text{Zn}_{20}$

$$\chi = \mu_0^2 N(E_F) / (1-Z) \quad Z = 1/2 U N(E_F)$$

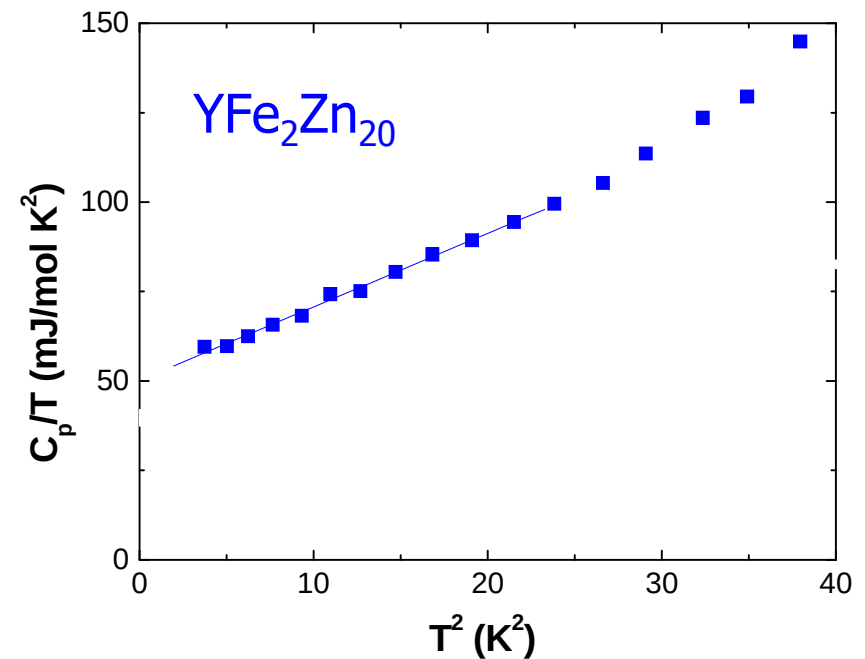
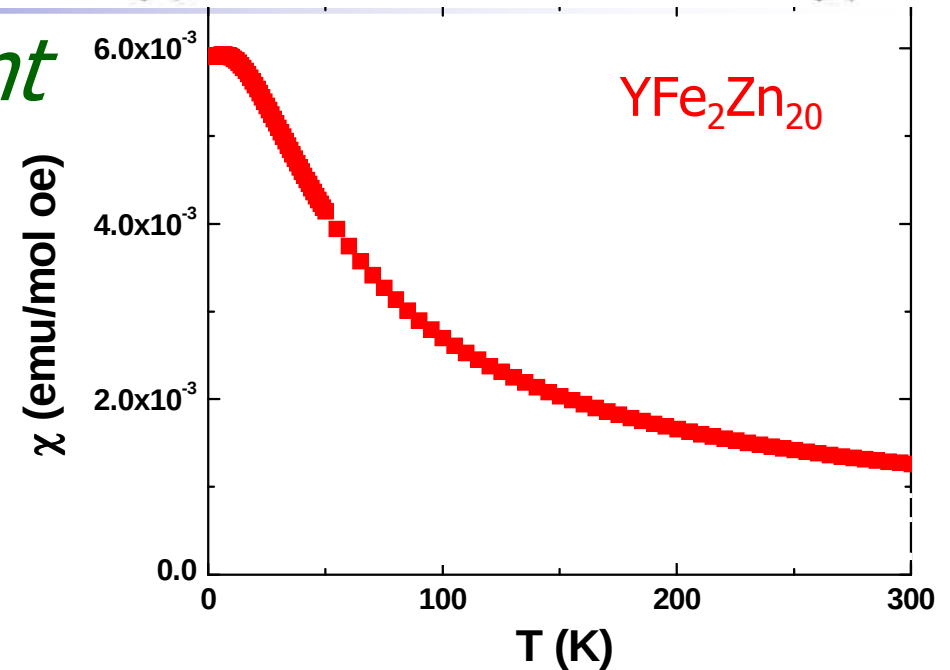
$$\gamma = \pi^2 k_B^2 N(E_F) / 3$$

Using experimental values of low temperature χ and γ we can determine the value of Z

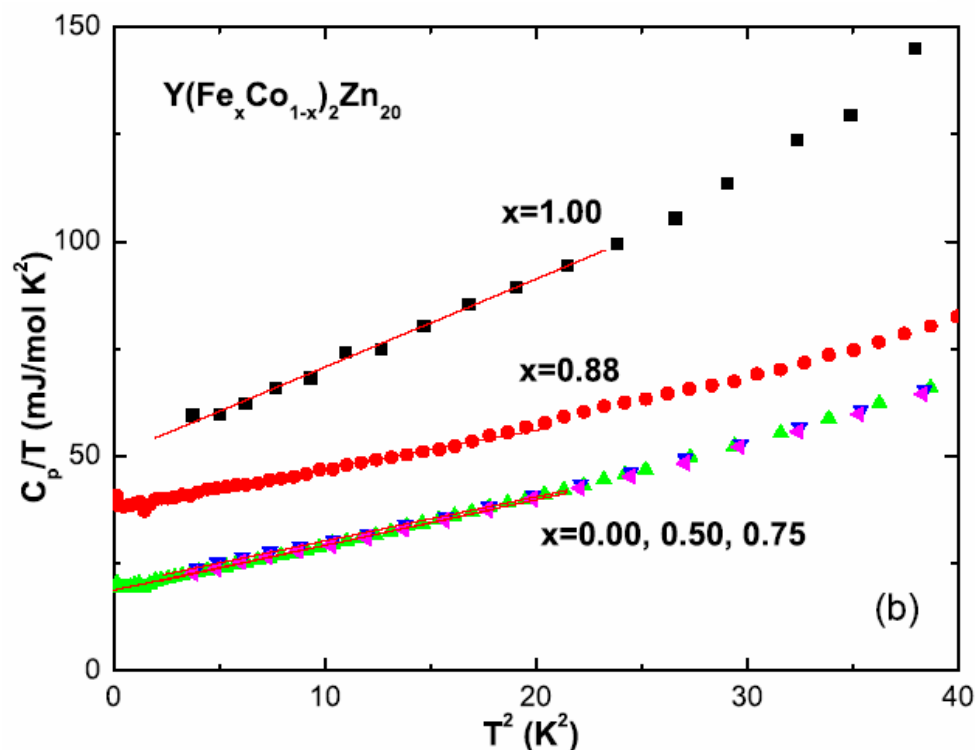
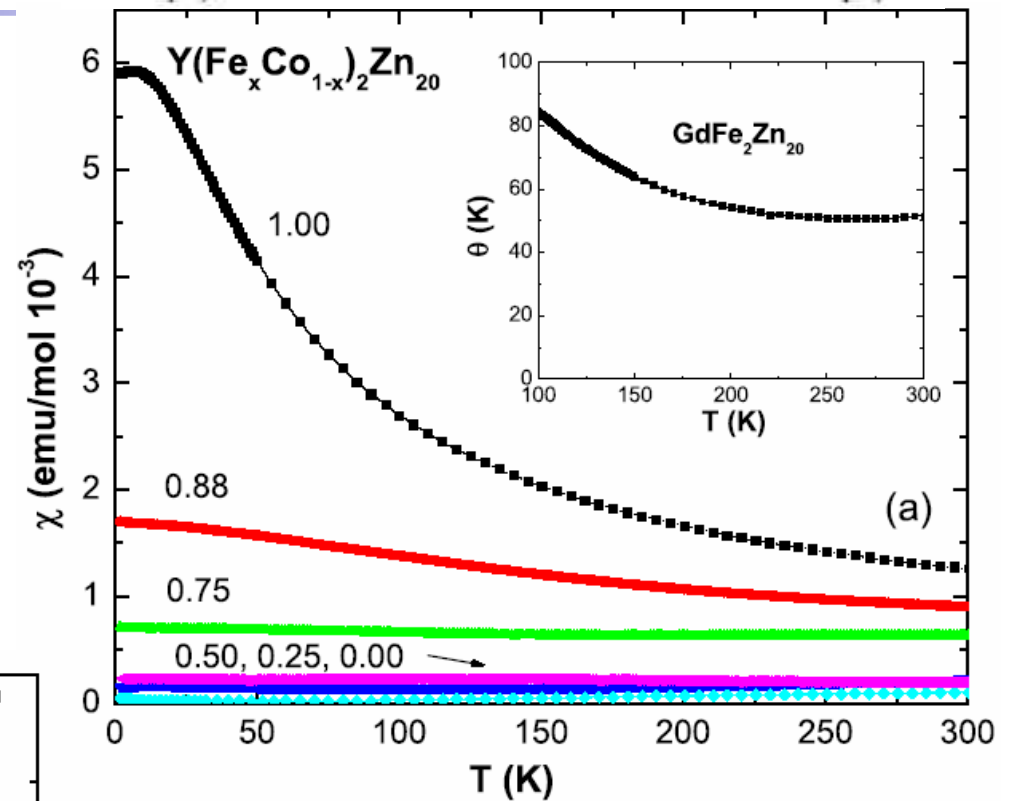
$$Z = 1 - (3\mu_0^2 \gamma / \pi^2 k_B^2 \chi)$$

The enhanced $N(E_F)$ of the $\text{YFe}_2\text{Zn}_{20}$ helps to put it very close to the Stoner limit. Using magnetization and specific heat data the Stoner enhancement can be found to be $Z \sim 0.87$.

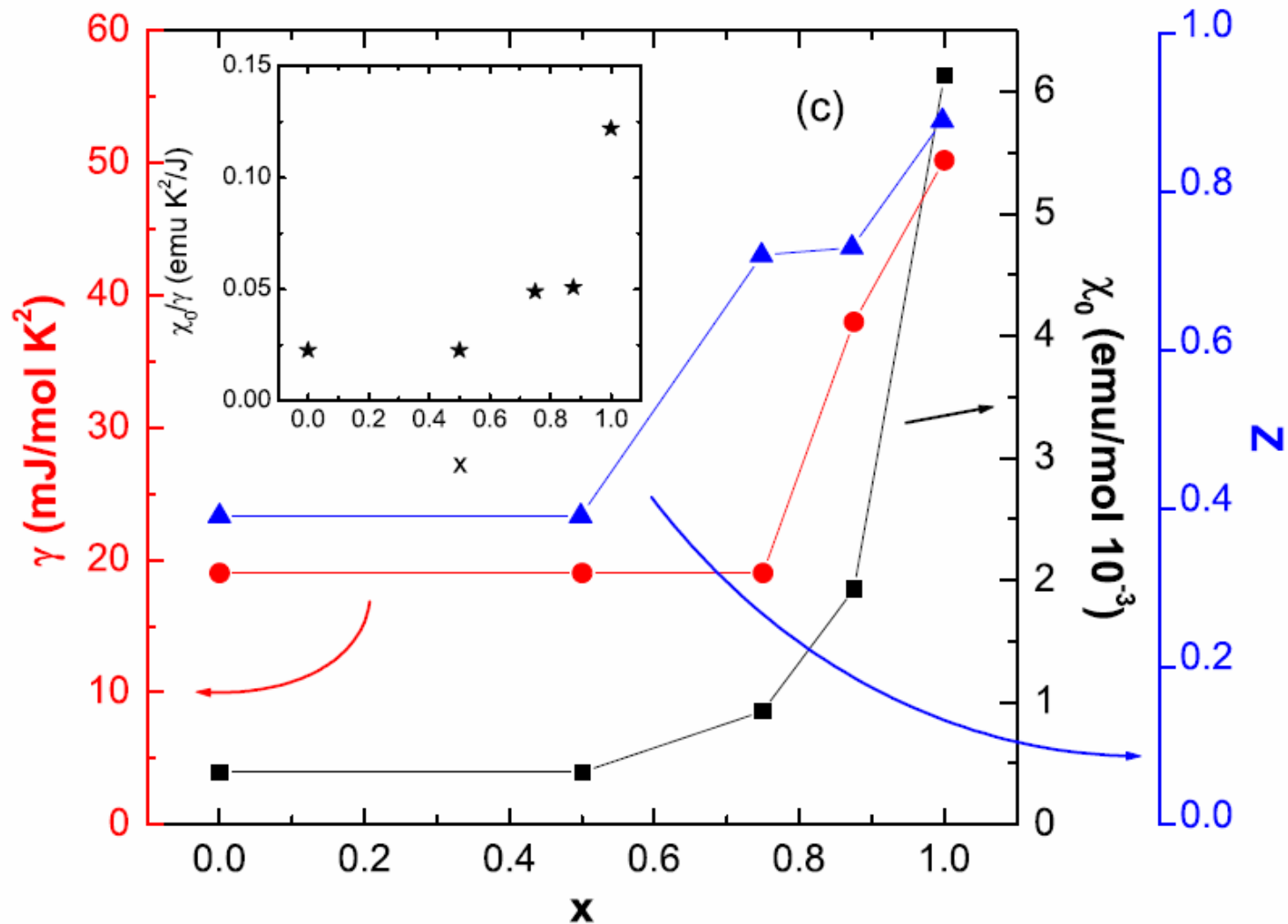
n.b. for Pd, $Z \sim 0.83$



$\text{Y}(\text{Fe}_x\text{Co}_{1-x})_2\text{Zn}_{20}$ can be tuned from a polarizability similar to Cu to one that is greater than Pd.

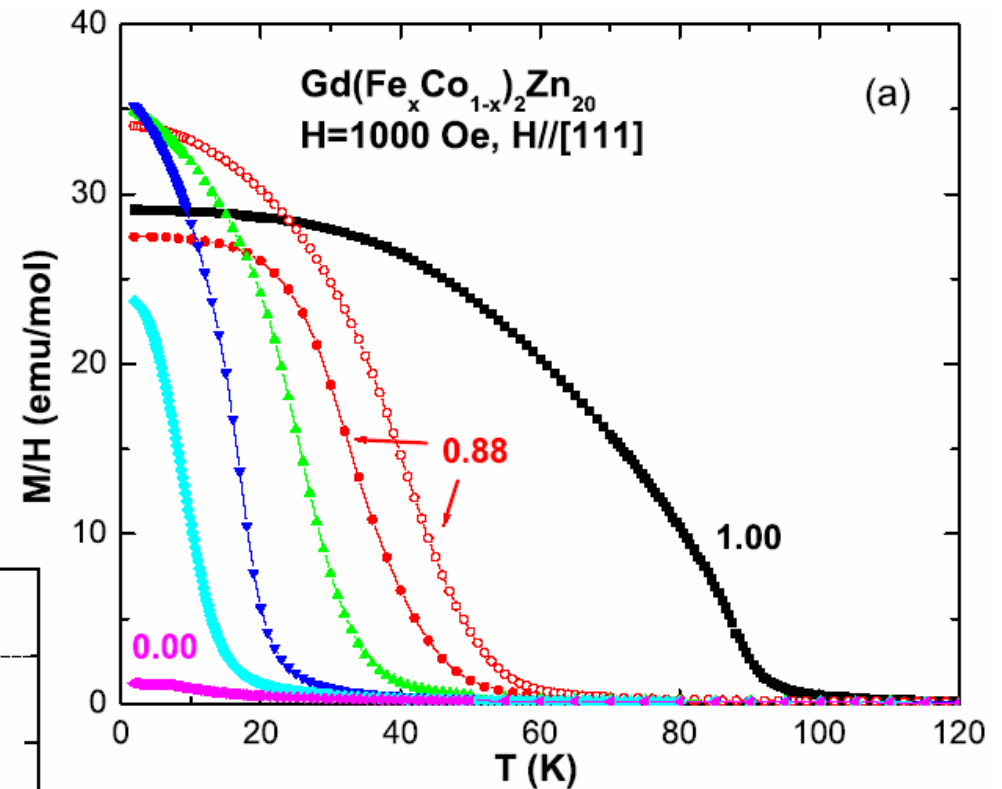
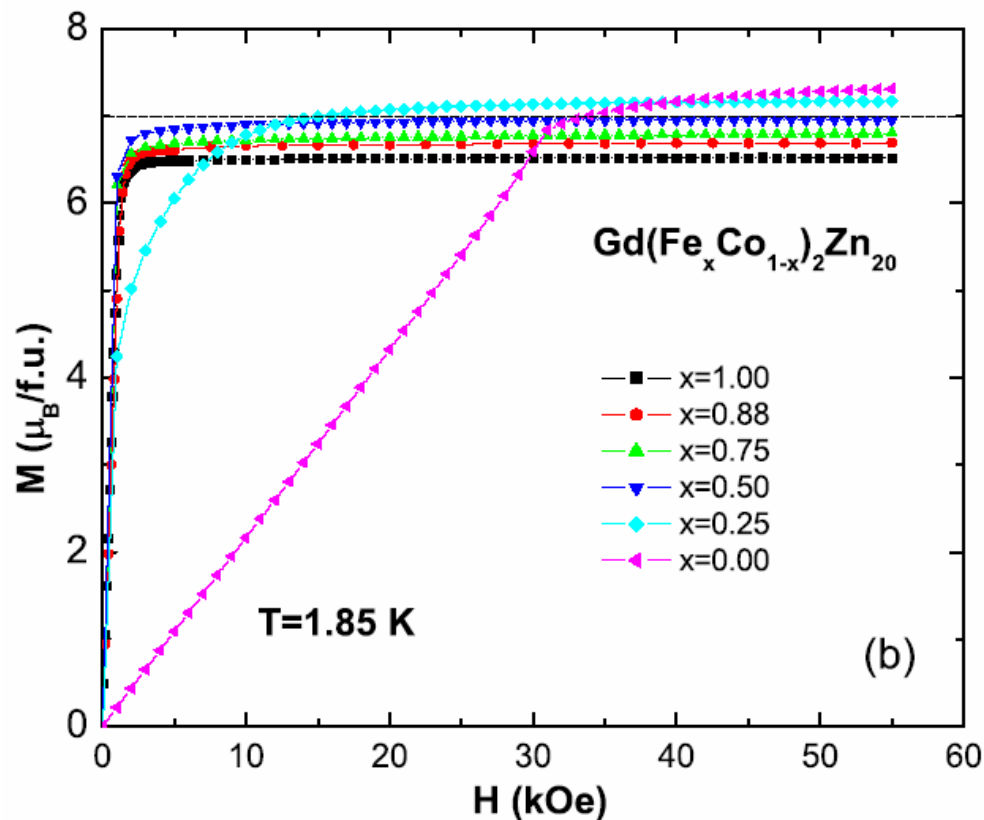


There is a monotonic, but non-linear change in both gamma and chi as Co/Fe ratio is changed. How does this manifest itself in Z , the Stoner parameter?



Z can be calculated from $\text{Y}(\text{Co}_{1-x}\text{Fe}_x)_2\text{Zn}_{20}$ thermodynamic data (must account for the core diamagnetism). We can tune the material right up to the edge of the Stoner limit!!

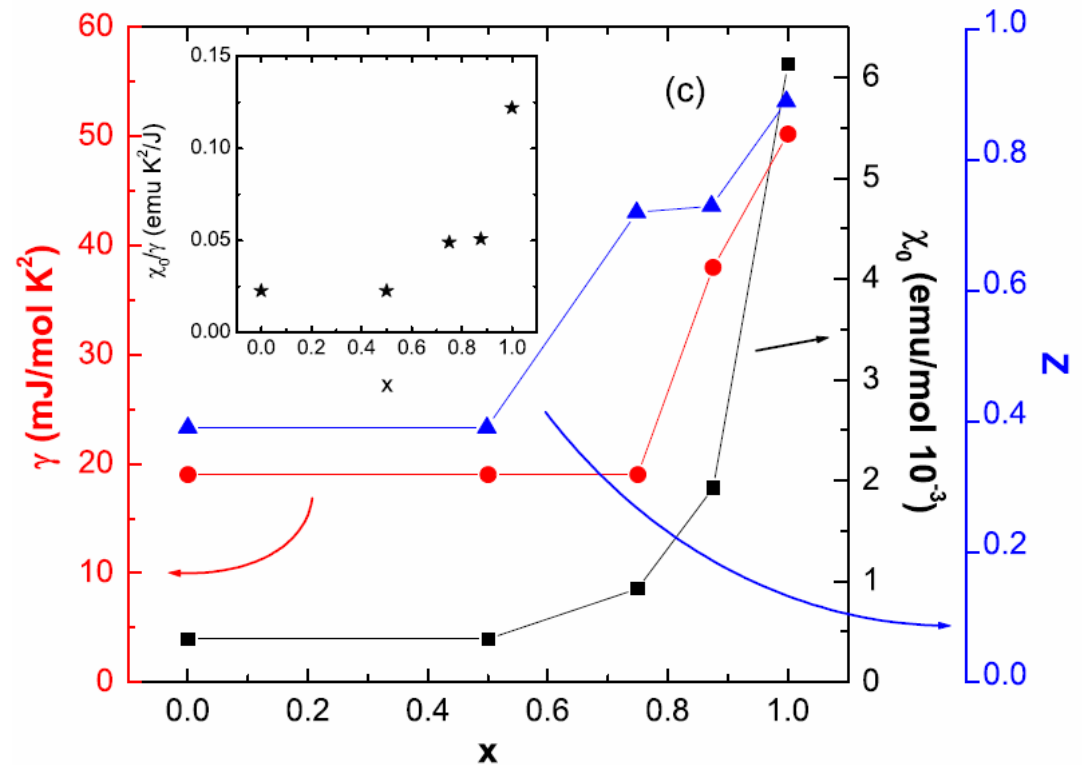
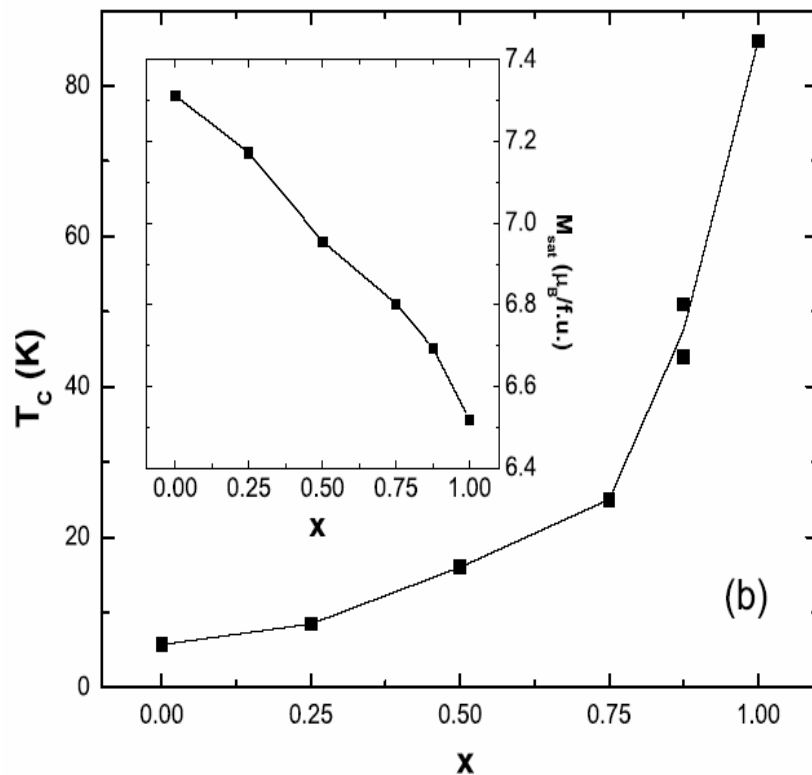
By placing Gd (large S , local moment) into such a highly polarizable medium, $\text{GdFe}_2\text{Zn}_{20}$ attains a very large T_C .



As the system is moved away from the Stoner criterion by Co doping T_C drops rapidly.



T_C for $\text{Gd}(\text{Co}_{1-x}\text{Fe}_x)_2\text{Zn}_{20}$ qualitatively follows X_0 and γ data from $\text{Y}(\text{Co}_{1-x}\text{Fe}_x)_2\text{Zn}_{20}$ host.



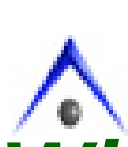
By increasing the amount of Fe, the electronic system is brought closer and closer to a ferromagnetic Fermi liquid and the Gd finds itself in an increasingly polarizable media and T_C increases dramatically.



WAIT!!!! *Don't leave the series yet!*

As we examined the RT_2Zn_{20} series in detail we checked the Yb-member with special care. This is because Yb-based intermetallics can often show Kondo-lattice behavior, with some or all of the entropy of the Yb^{3+} ion being transferred over to the electronic channel, leading to a greatly enhanced electronic specific heat, γ , and reduced moment (or total absence of) magnetic order.

This is standard operating procedure when exploring a new R-intermetallic series. Specific R-members are predisposed to certain types of physics: for Ce and Yb (Sm and Eu to lesser extents) you should always check for Kondo / heavy fermion physics.



What about “the other type of correlated electron material”?

What happens when you allow $R = \text{Yb}$ (or Ce) in $\text{RT}_2\text{Zn}_{20}$?

--Hybridizing members of the $\text{RT}_2\text{Zn}_{20}$ series are examples of ordered Kondo Lattices that are approaching a single ion impurity concentration level.

--For $R = \text{Fe}, \text{Co}, \text{Ru}, \text{Rh}, \text{Os}, \text{Ir}$ we have discovered **SIX NEW** Yb-based heavy fermion compounds. *(Formally, doubling the number of such compounds!)*

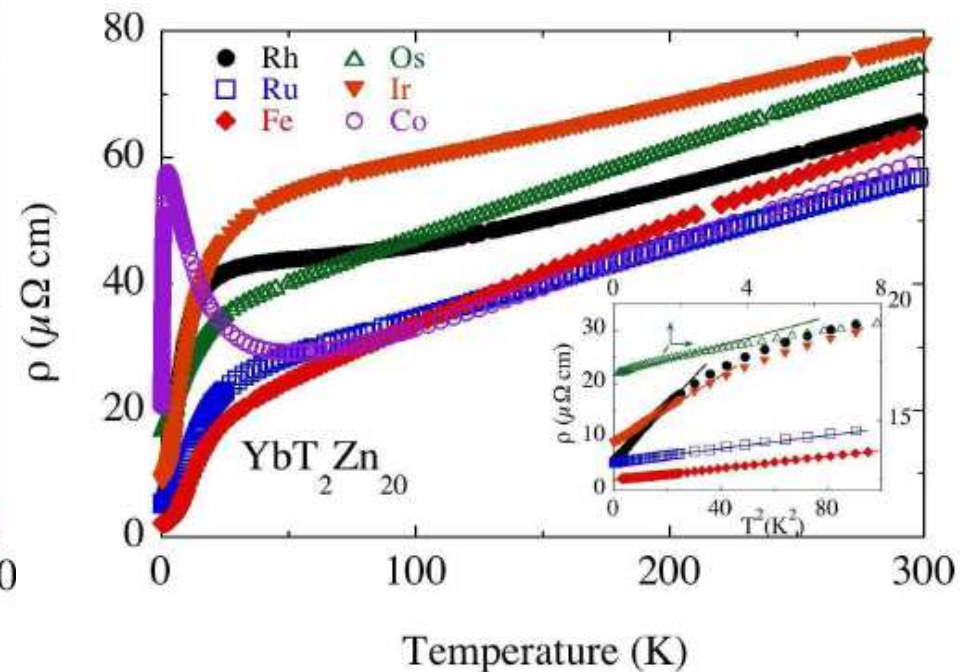
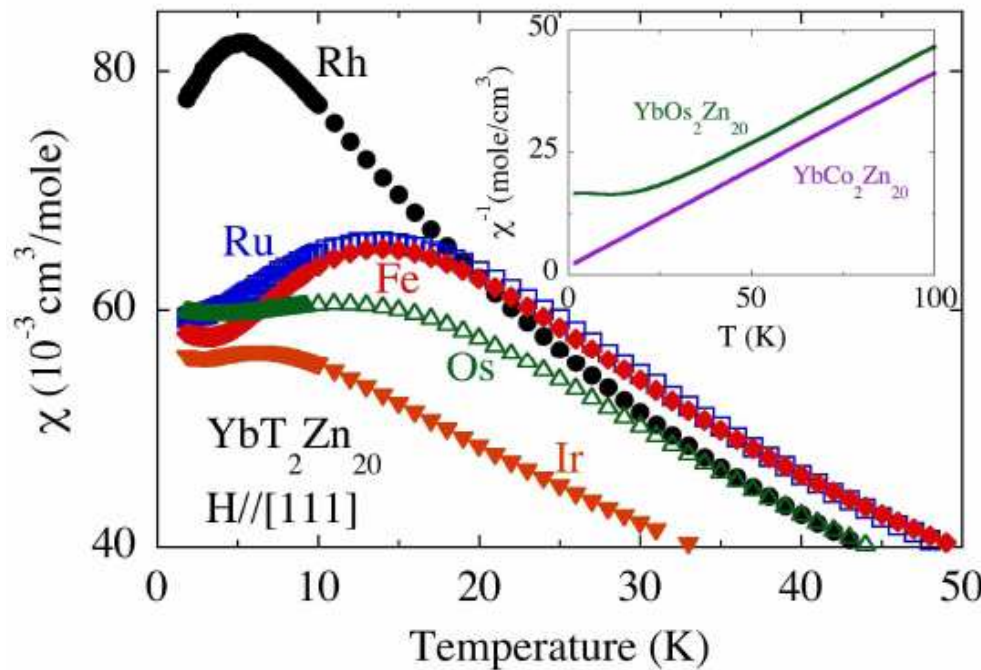
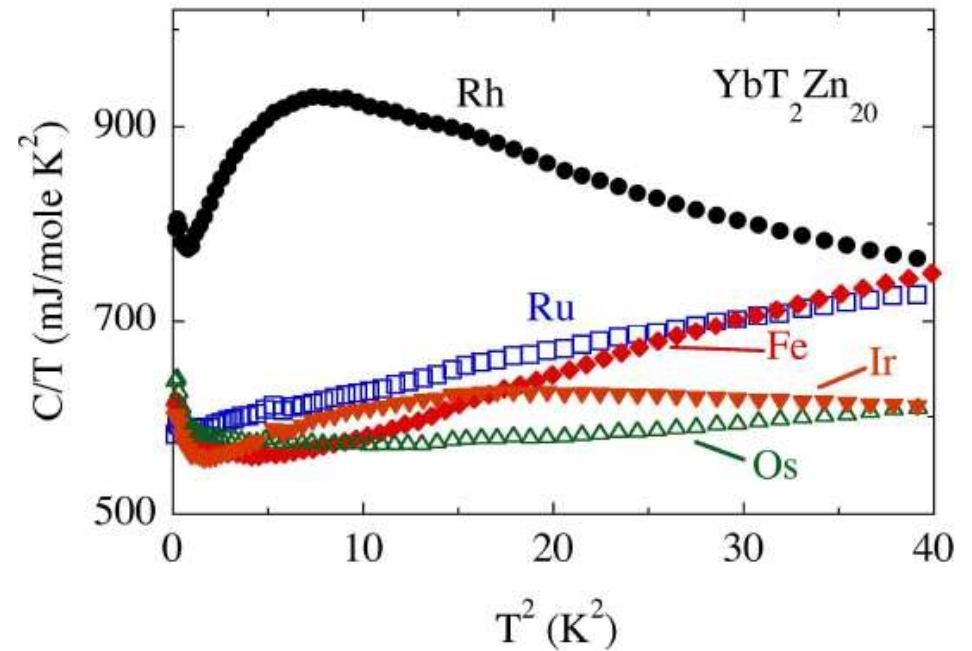
--Given that (i) the 4 nearest neighbors and 8 next nearest neighbors of the Yb are Zn and (ii) the lattice parameter varies by less than 1% between these six compounds, this half dozen new systems allows for comparison of the thermodynamic and transport properties between very closely related heavy fermion compounds.

---**M. S. Torikachvili, S. Jia, E. D. Mun, S. T. Hannahs, R. C. Black, W. K. Neils, Dinesh Martien, S. L.**

Bud'ko, P. C. Canfield cond-mat/0608422 *In press PNAS*

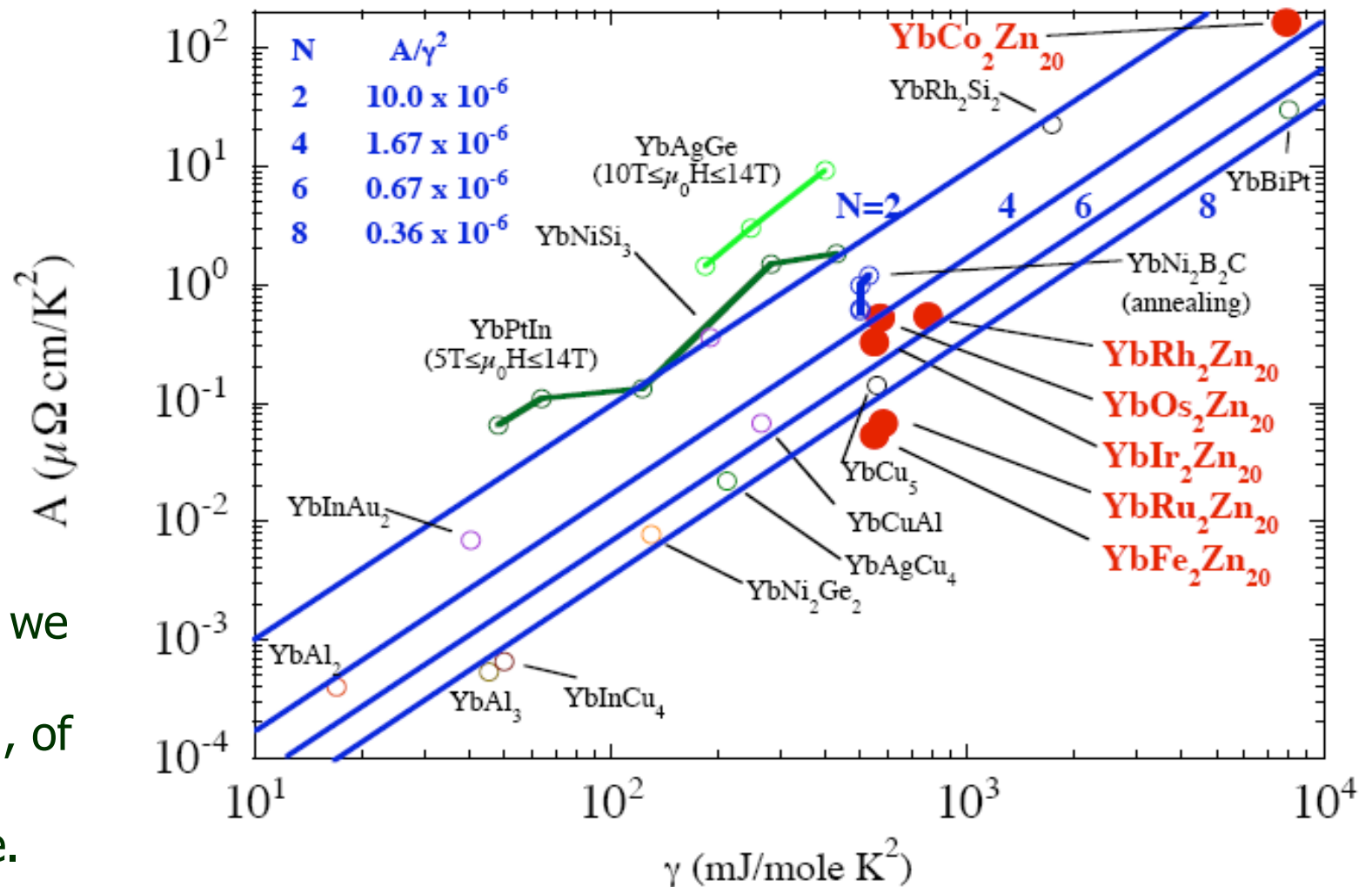


These six compounds manifest classical heavy fermion behavior in ρ , χ and C_p data. For T = Fe, Ru, Rh, Os, Ir the χ and γ data, as well as the Wilson ratio are very similar. On the other hand, although the gross ρ data is similar the low temperature, AT^2 term is very different.





We can plot the data for our six new $\text{YbT}_2\text{Zn}_{20}$ heavy fermions on a Kadowaki-Woods plot with some other Yb-based systems. We see that for $T = \text{Fe, Ru, Rh, Os, Ir}$ there is a vertical spread that implies a significant difference in the Yb ion degeneracy for $T \sim T_K$. E.g. for $T = \text{Fe, Ru}$ have higher $T_K / T_{\Delta\text{CEF}}$ ratios.



By choosing T we can tune the degeneracy, N , of the Kondo screened state.



Tuning magnetism in RT_2Zn_{20} materials

The RT_2Zn_{20} system offers a highly tunable system for the study of the interaction between correlated electrons and local, as well as hybridizing, moments.

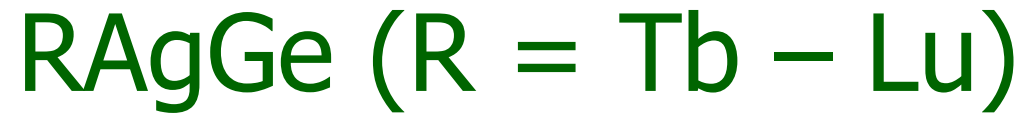
--We have discovered a system that allows us to tune the conduction electrons to the edge of a Stoner instability while maintaining an ordered, dilute, local moment lattice.

--The remarkably high ferromagnetic ordering of RFe_2Zn_{20} can be understood within this framework.

--These series offer the possibility to tune $N(E_F)$ and also, by substitution or dilution the R – R distance over an unprecedented range.

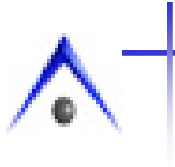
--By choosing $R = Yb$ we have found a half dozen new Yb-based heavy fermions which have degeneracies ranging between $N = 4$ to $N = 8$.

--By studying $(Lu_{1-x}Yb_x)Fe_2Zn_{20}$ and $(Lu_{1-x}Yb_x)Co_2Zn_{20}$ we are starting to examine the effects of extremely dilute Yb in a nearly ferromagnetic Fermi liquid .



Motivations

- (i) Play around in chemical phase space**
- (ii) Look for specific physics**
- (iii) Create and use model system**

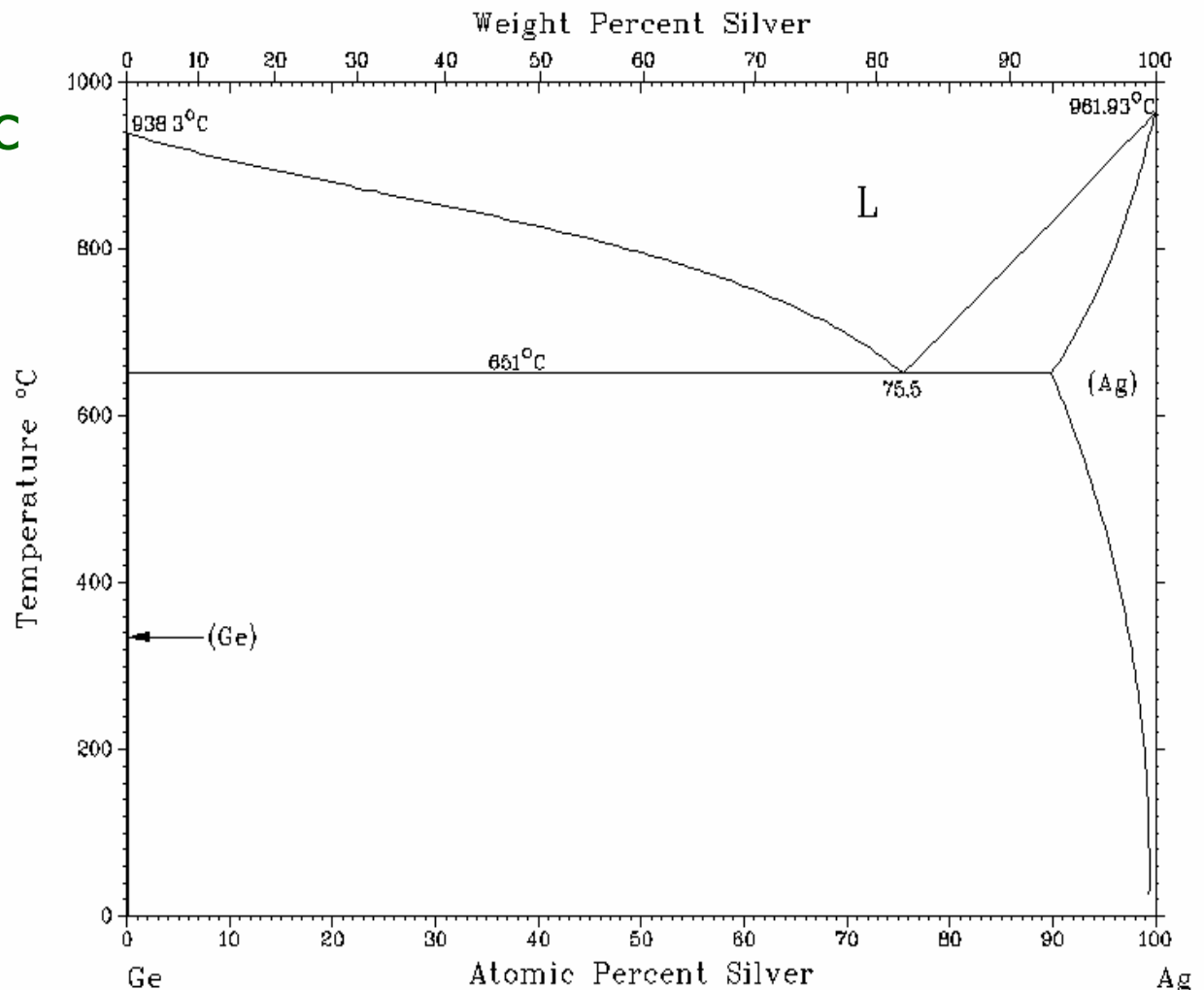


Sometimes Eutectics are compelling:
they offer easy access to liquid.

Relatively low eutectic

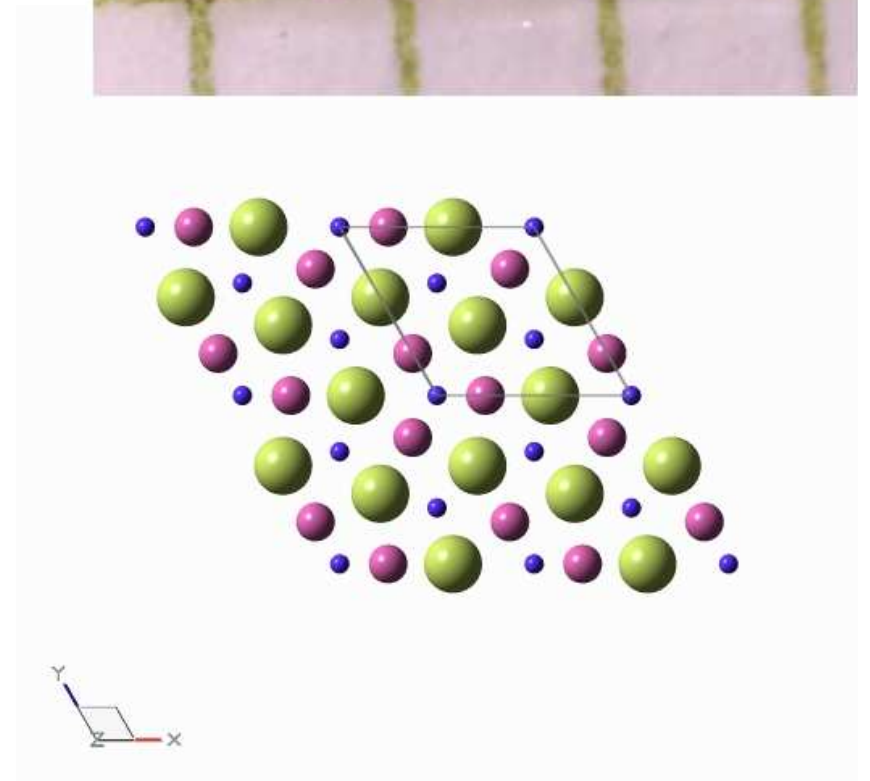
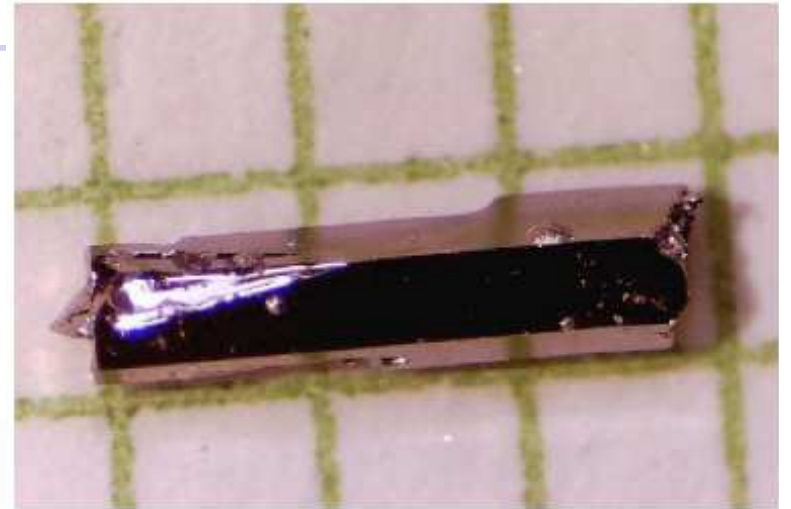
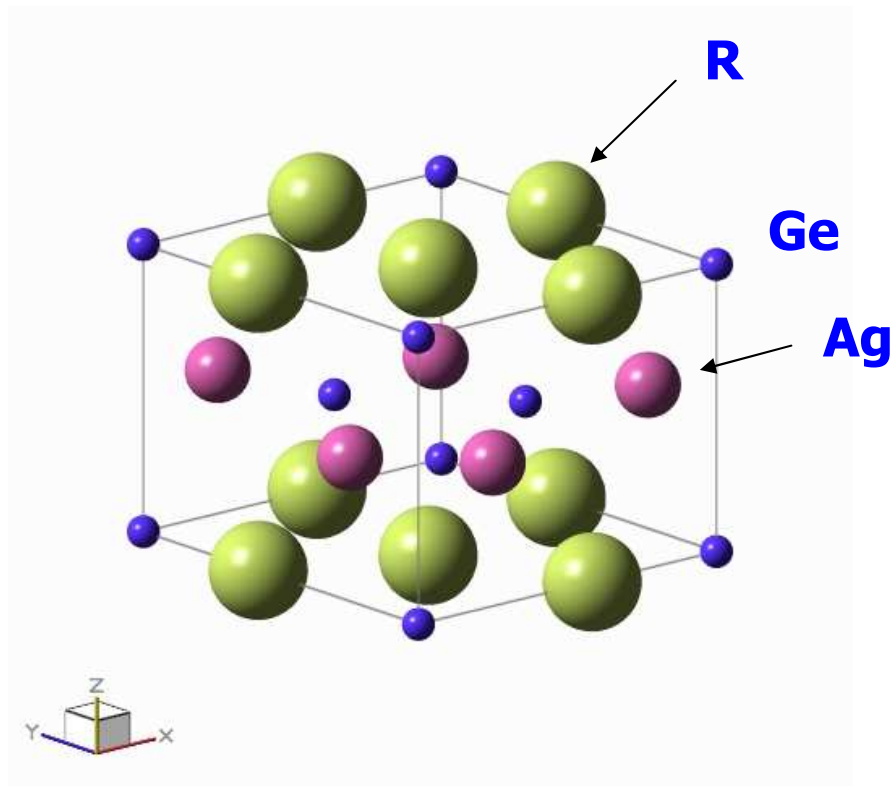
No binary second
phases to cause
problems

Looks promising for
seeing what sorts of
R-Ag-Ge compounds
can be grown





RAgGe - structure

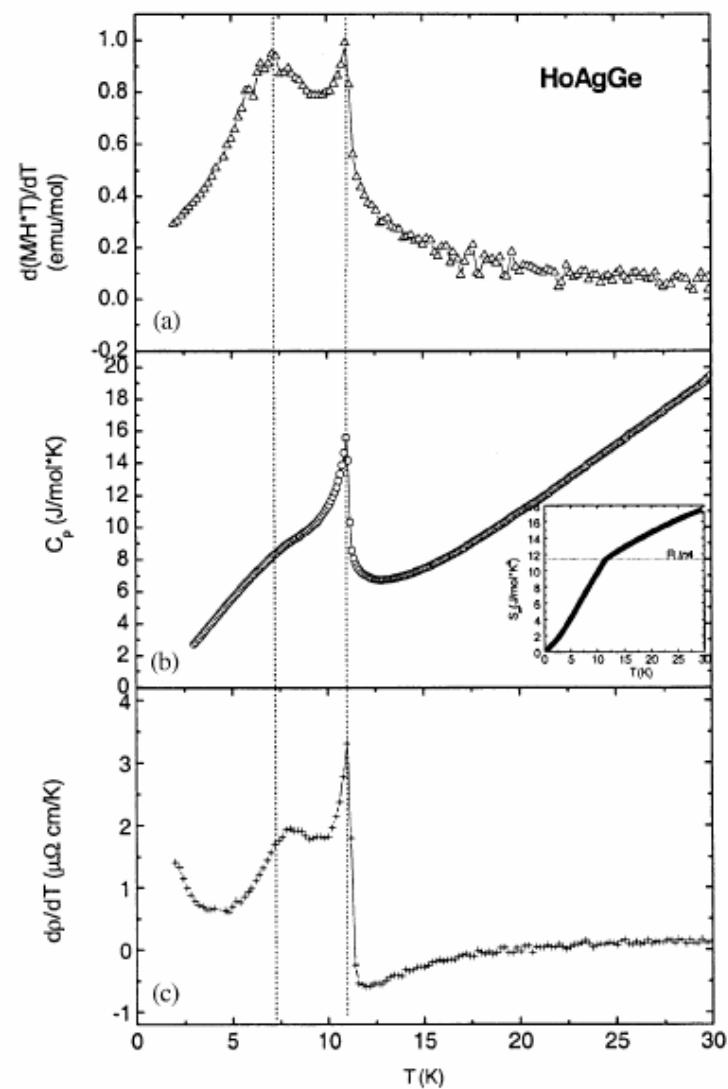
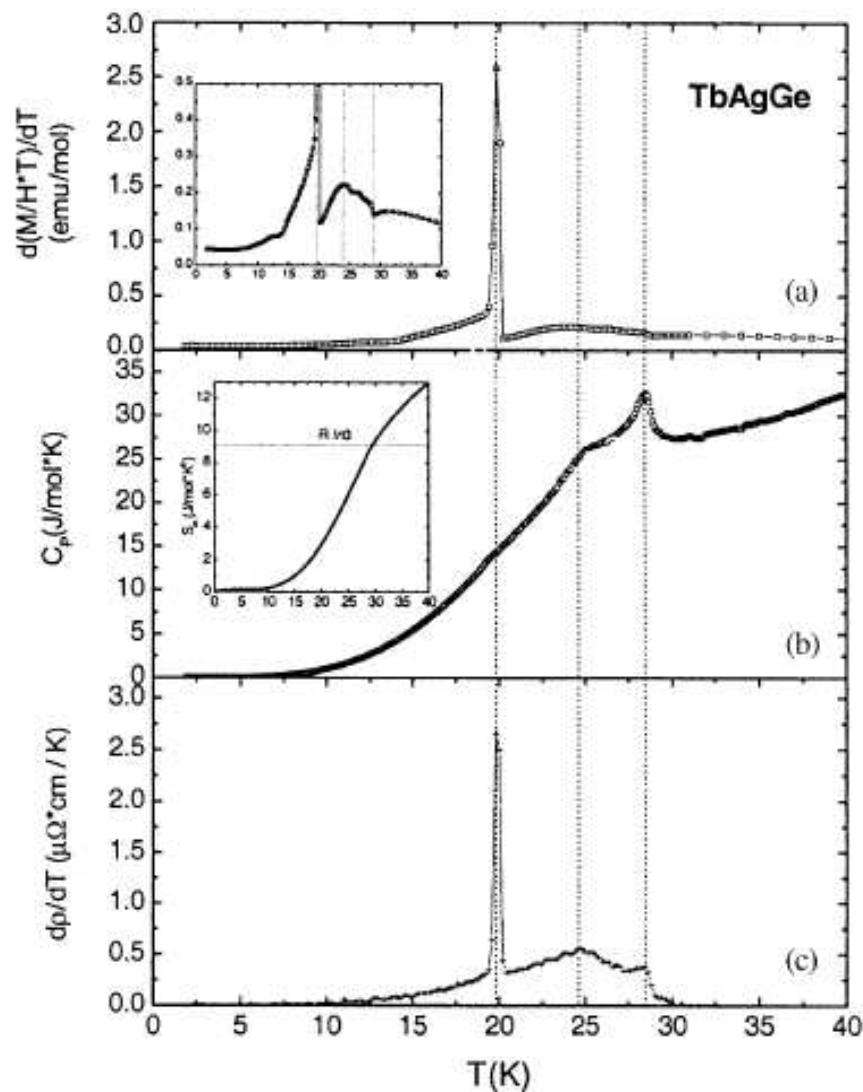


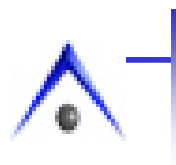
Hexagonal P-62m, R in orthorhombic point symmetry



RAgGe (R = Tb – Lu)

We studied the basic electronic and magnetic properties, mapping transition temperatures as well as anisotropies.





Rough dG scaling

Good local
moment behavior
for $R = \text{Tb} - \text{Tm}$.

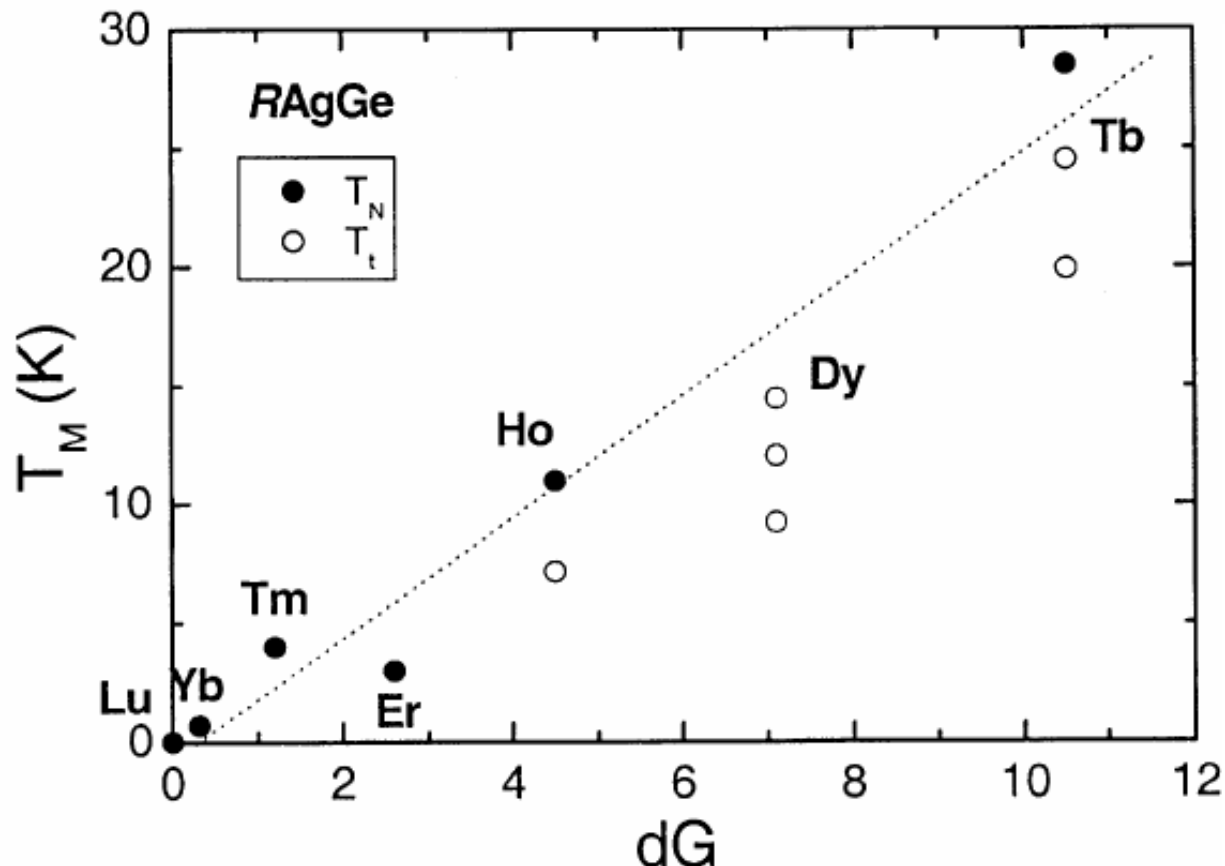
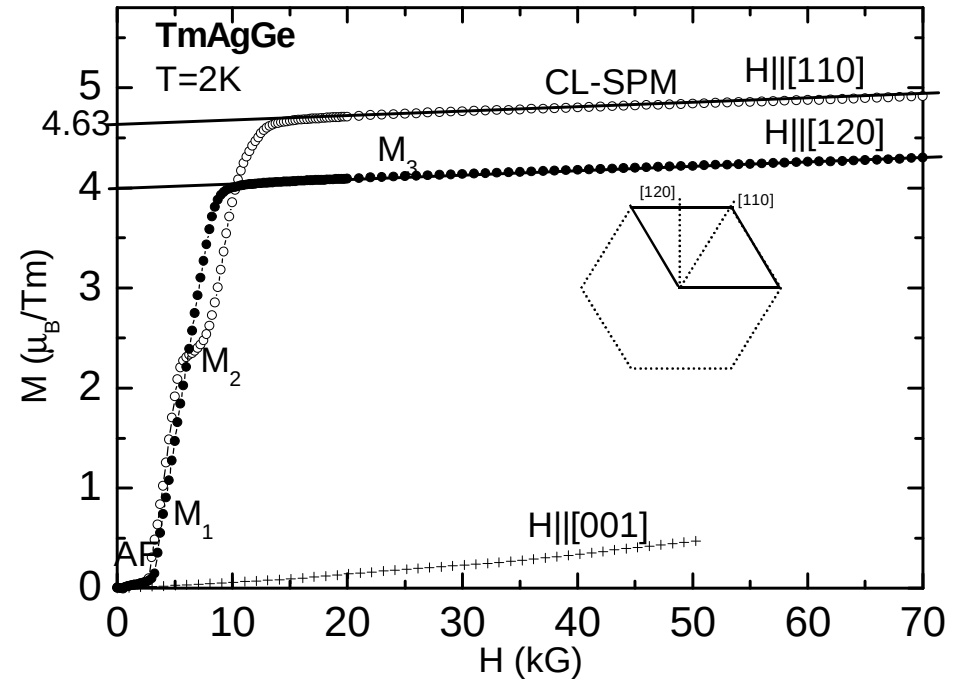
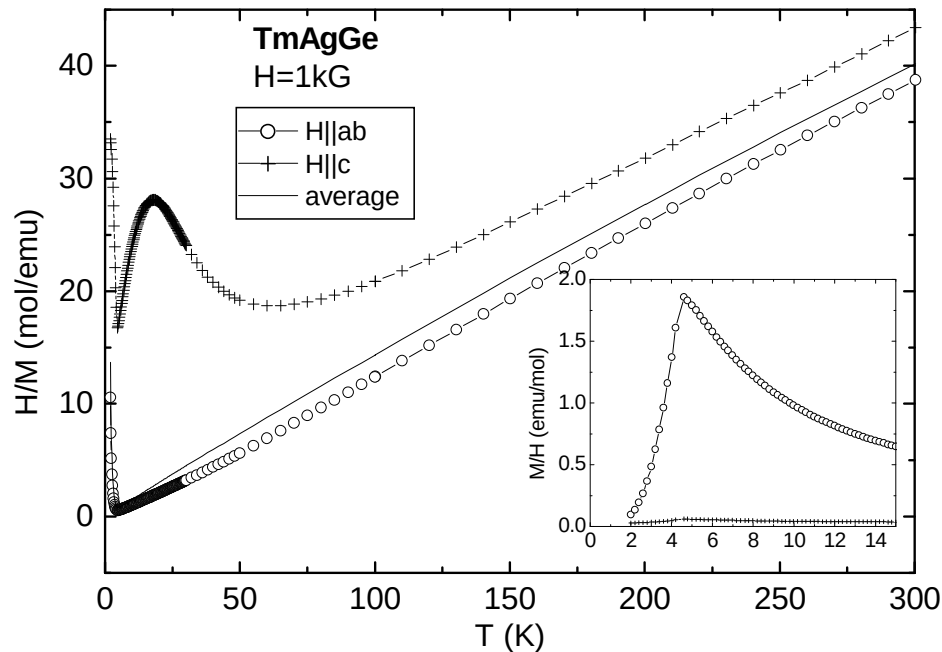


Table 1
Magnetic ordering temperatures T_m , effective magnetic moments and anisotropic paramagnetic Weiss temperatures θ_P

θ_P (K)	Tb	Dy	Ho	Er	Tm	Yb
T_m (K)	28.4 ± 0.1 , 24.6 ± 0.1 , 19.8 ± 0.1	14.5 ± 0.1 , 12.15 ± 0.1	11.0 ± 0.2 , 7.7 ± 0.3	3.1 ± 0.1	4.15 ± 0.15	0.65 ± 0.05 , 0.95 ± 0.05
μ_{eff} (μ_B/R)	9.7	10.4	10.0	9.3	7.9	4.4
θ_{ab} (K)	-53.8	-25.5	-10.1	-3.6	7.5	-15.1
θ_c (K)	1.0	7.4	-1.9	-34.6	-76.3	-83.5
θ_{ave} (K)	-28.3	-10.5	-7.1	-10.9	-14.4	-30.1



We returned to this series when we wanted to study highly anisotropic, local moment metamagnetism compounds with hexagonal unit cells.

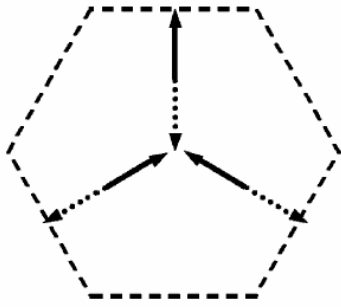


- “Thermodynamic and transport properties of RAgGe ($R = \text{Tb} - \text{Lu}$) single crystals”, E. Morosan *et al.*, Journal of Magnetism and Magnetic Materials 277 (2004) 298–321
- “Angular dependent planar metamagnetism in the hexagonal compounds TbPtIn and TmAgGe ”, E. Morosan *et al.*, PHYSICAL REVIEW B 71, 014445 (2005)

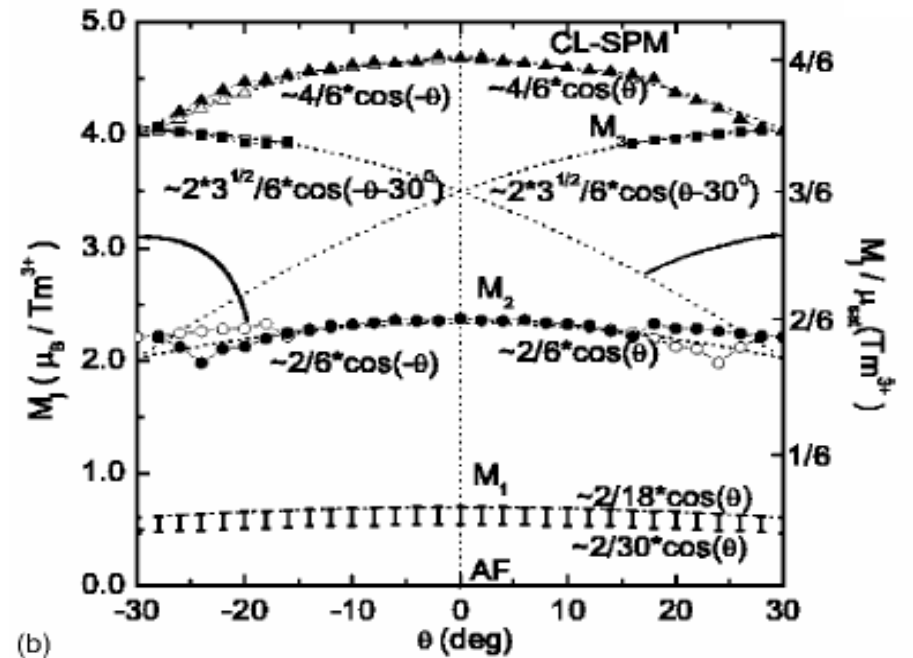
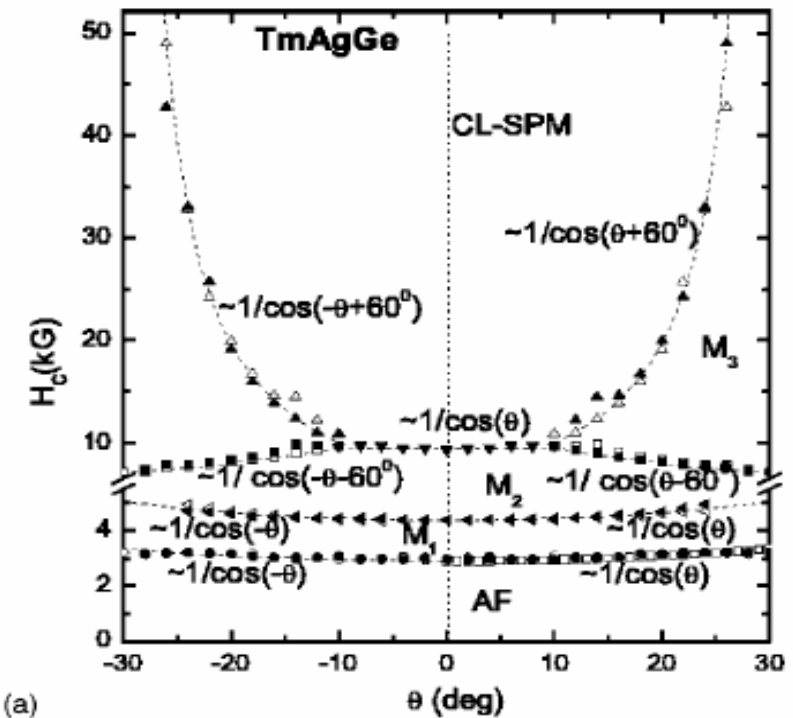


TmAgGe metamagnetism

TmAgGe – extremely anisotropic, planar metamagnetism

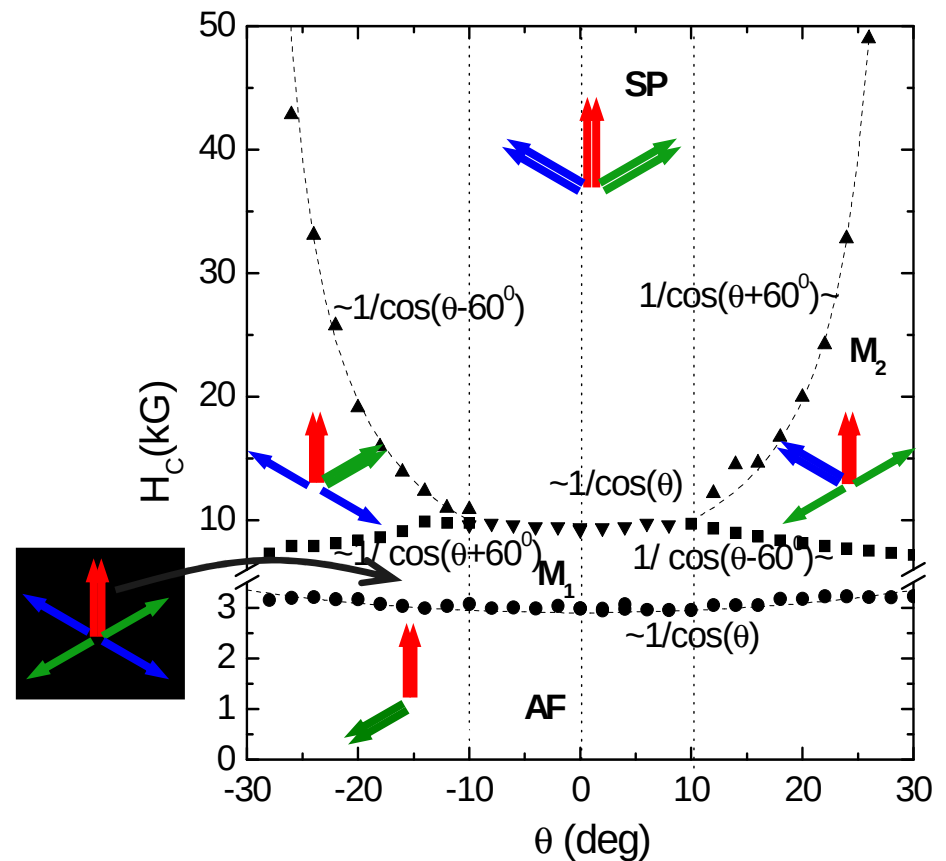
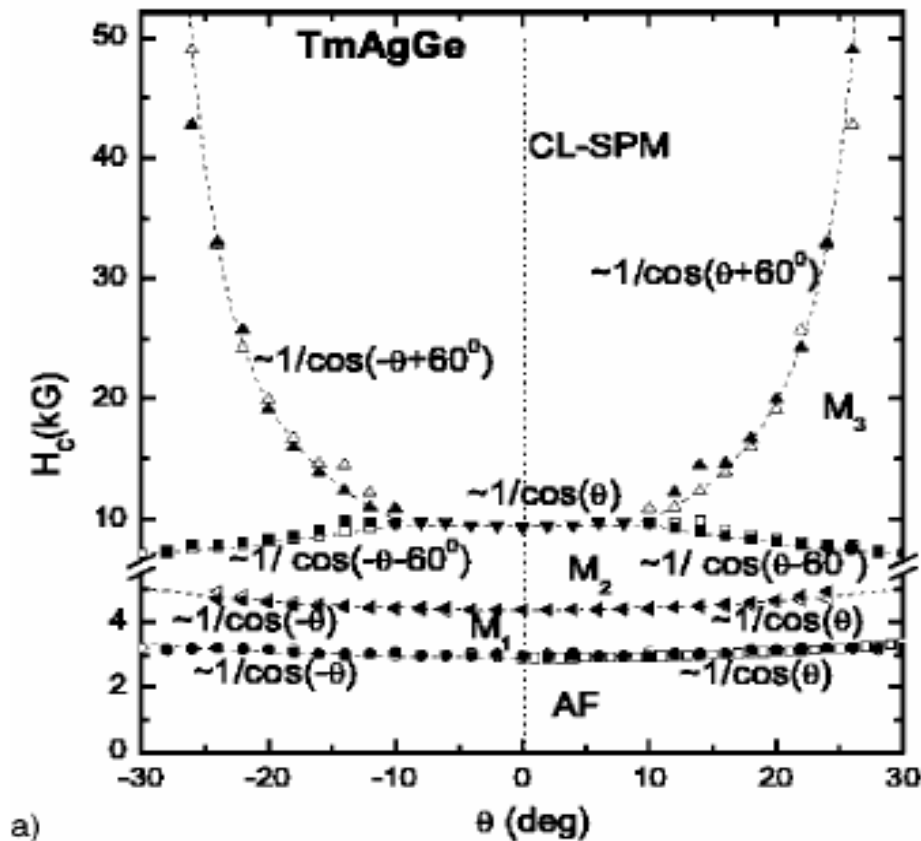


The three Tm in orthorhombic point symmetry act as three Ising-like moments, rotated 60° (120°) with respect to each other





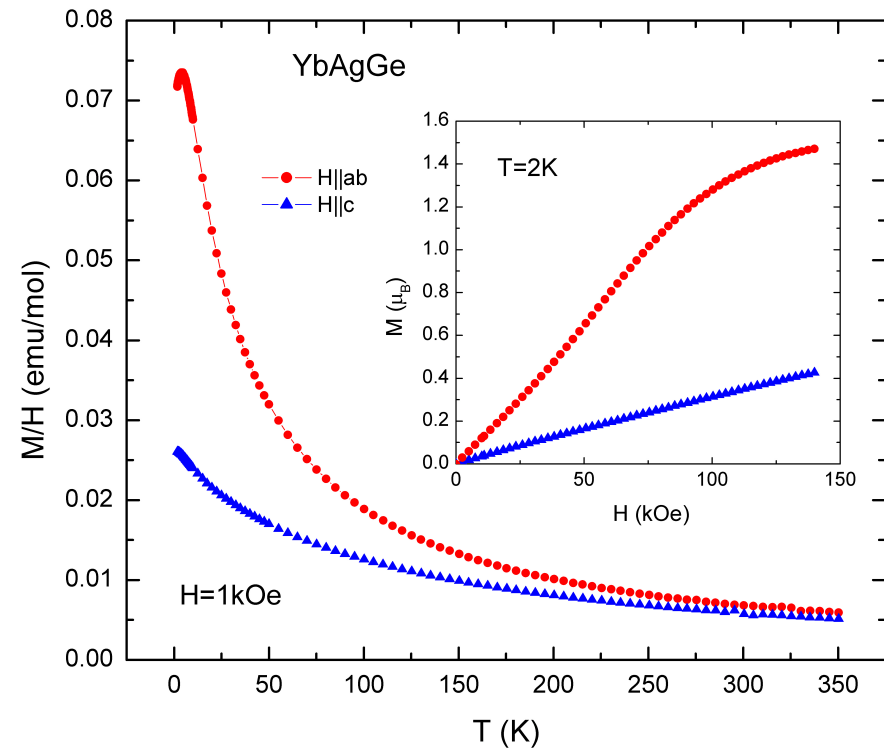
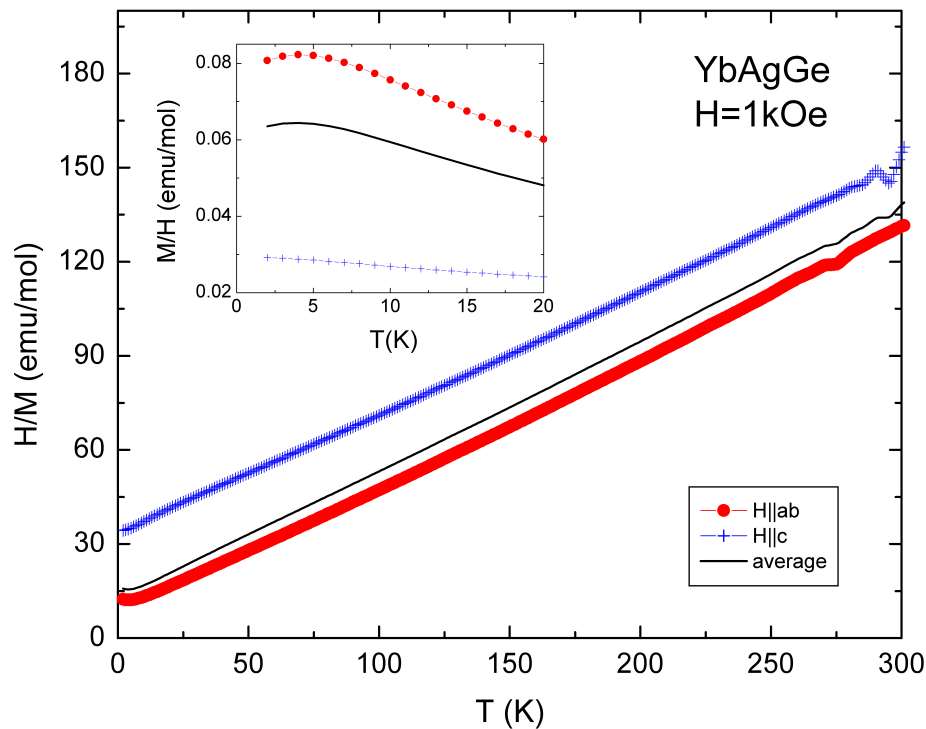
From these data we could infer the net distribution of moments for each metamagnetic state. This study extended our formalism to (i) hexagonal unit cell symmetry (ii) multiple R-sites with lower symmetry.





Remember to check the Yb-member for Kondo physics....

YbAgGe – basic properties



$$\Theta_{\text{ave}} \approx -30 \text{ K}$$

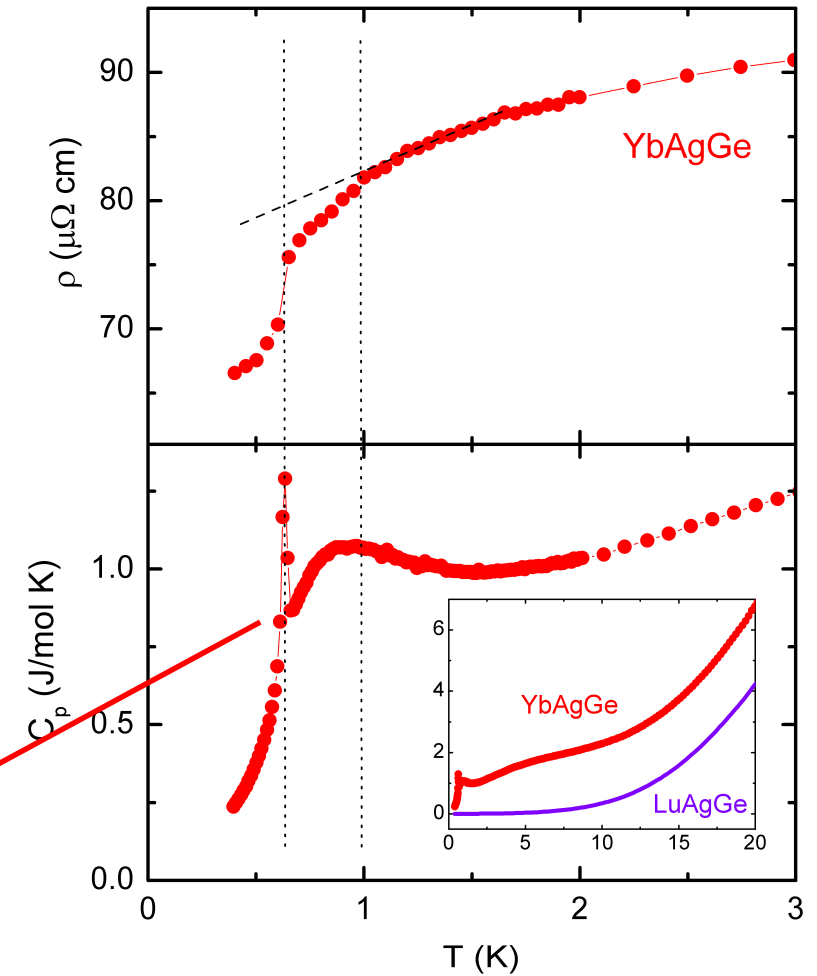
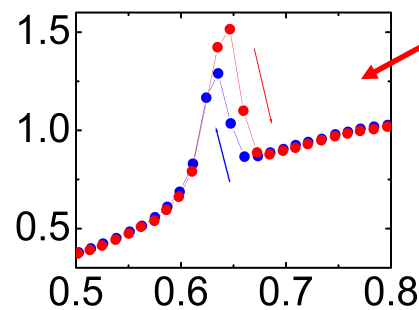
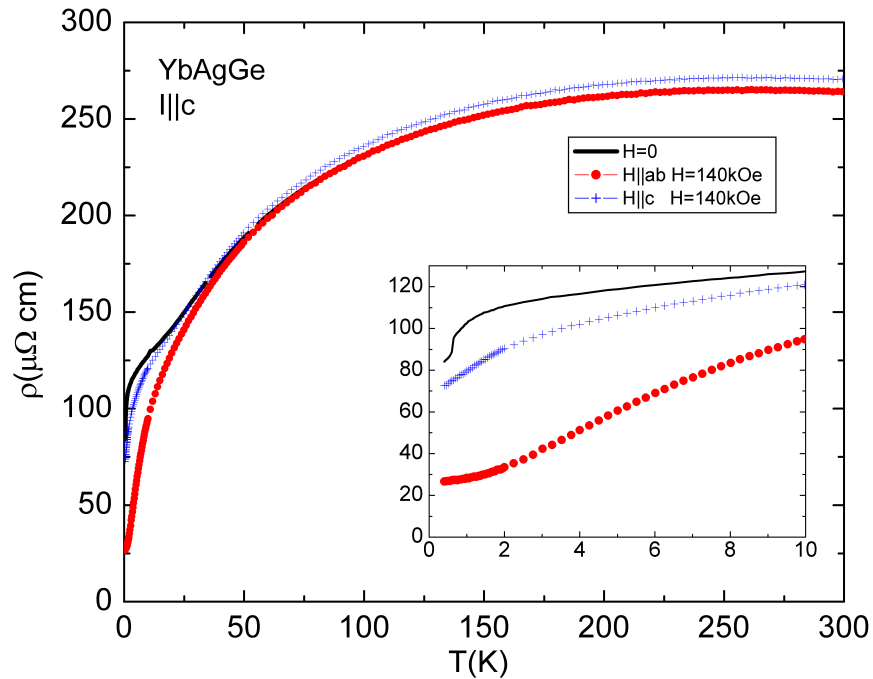
Deviations from CW law in χ_{ave} below $\sim 20 \text{ K}$

Moments are more in plane than along c, but not highly anisotropic like TmAgGe



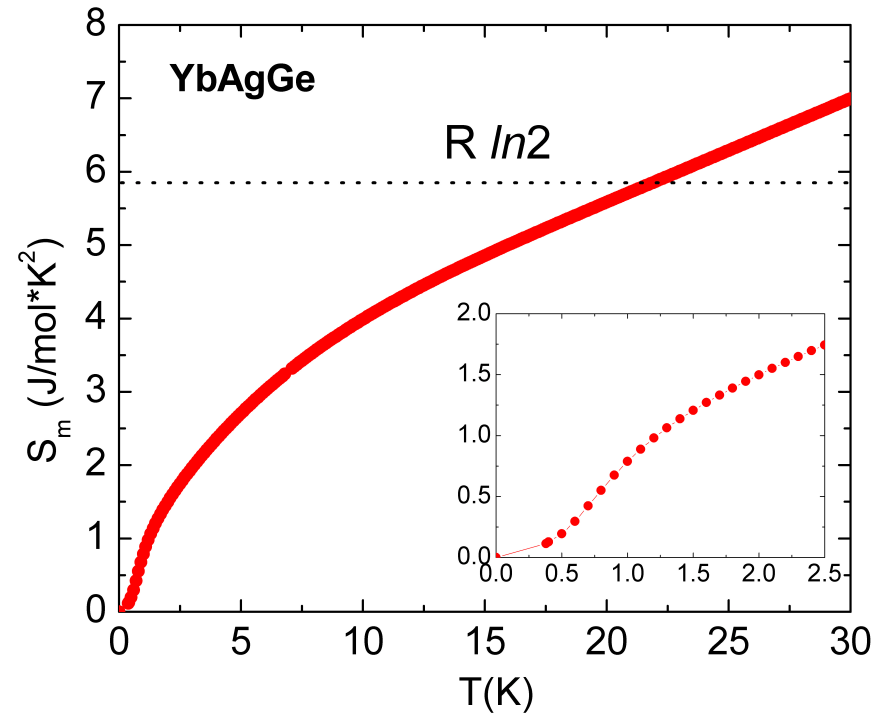
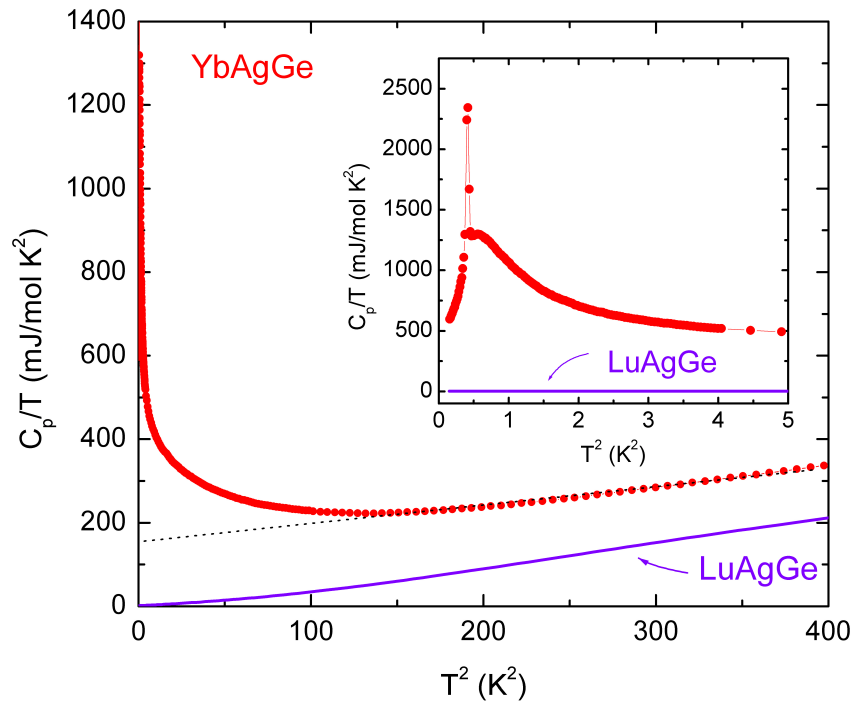
YbAgGe – basic properties

$T_M \approx 0.65\text{K}, 1\text{K}$





YbAgGe – basic properties



$\gamma \approx 150 \text{ mJ/mol K}^2$ from 10K-20K range extrapolation. More realistic estimate: $150 \text{ mJ/mol K}^2 \leq \gamma \leq 1 \text{ J/mol K}^2$

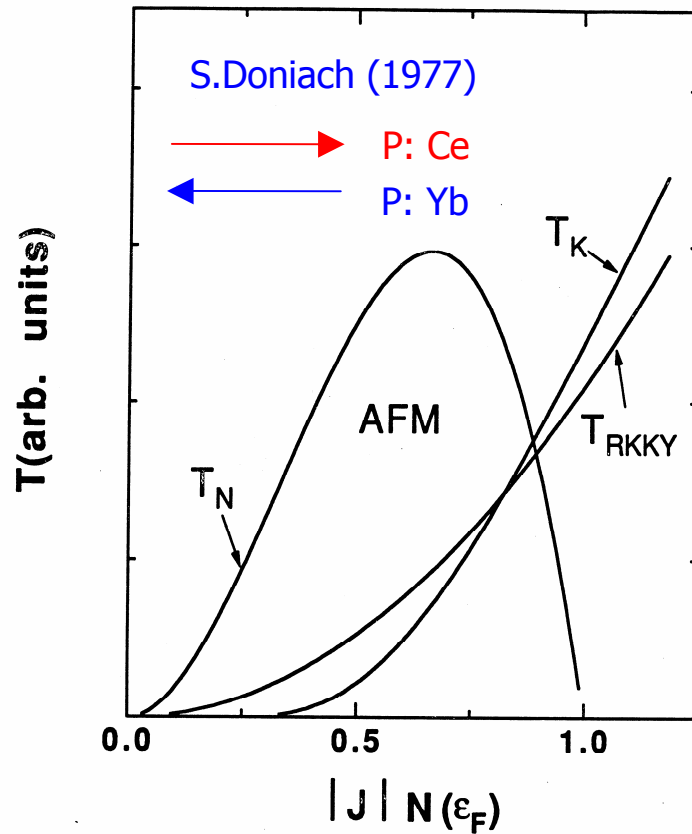
(i) YbAgGe is new Yb-based HF (or close to being HF)

(ii) LRO below 1K, probably small moment ordering

$\Rightarrow$ good candidate for suppression of T_N to QCP

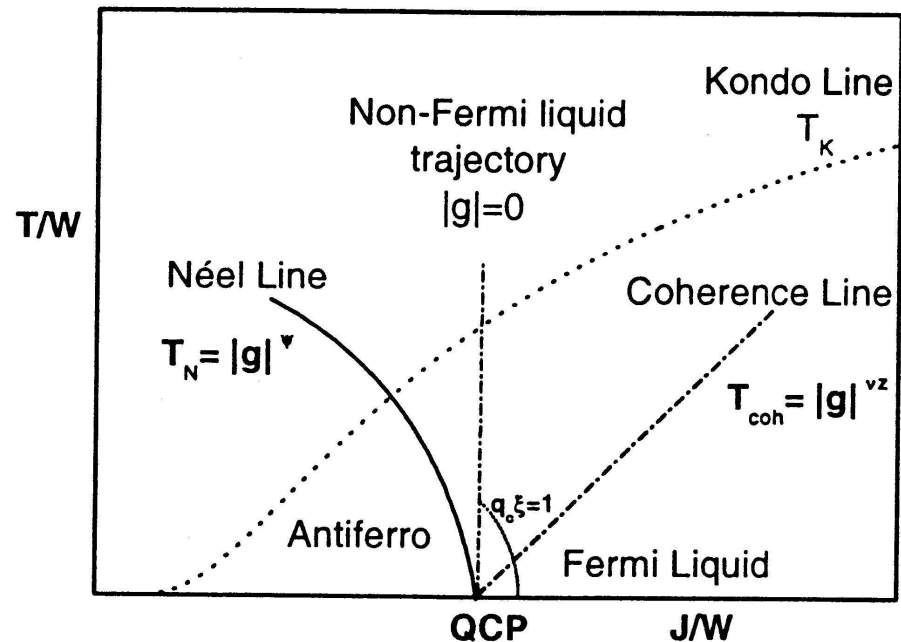


Doniach's phase diagram and QCP



$$T_K \propto E_F \exp(-1/|J|N(E_F))$$

$$T_{RKKY} \propto J^2[N(E_F)]$$



Usually pressure or substitution

M.Continentino (1989) and many others before and mostly after...



Entropy has to be removed.

For local moment regime (even small moment) entropy is removed via ordering (antiferromagnetic in this case).

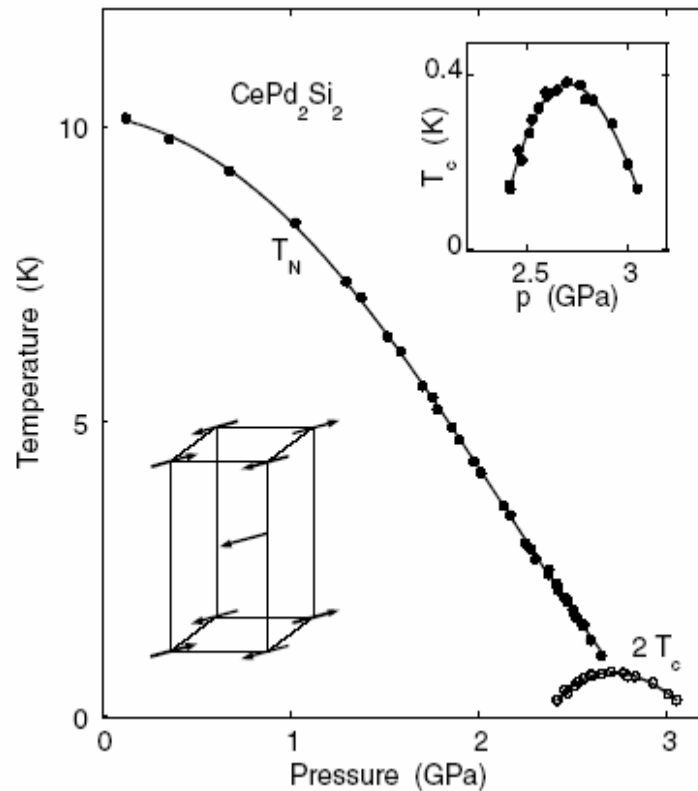
For Fermi liquid regime entropy is removed via heavy electron state (γT_K)

When T_N drops toward 0 K we anticipate a region of phase space in which fluctuations can lead to interesting temperature dependencies of thermodynamic as well as transport properties.

As a gross analogy, think of a mouse trapped in a small, *shrinking* box....It races about in a crazy panic... *It fluctuates*. At the critical field (or pressure or doping) the system does not order and does not yet enter the Fermi liquid regime, but it still needs to remove entropy....*It resorts to fluctuations*.



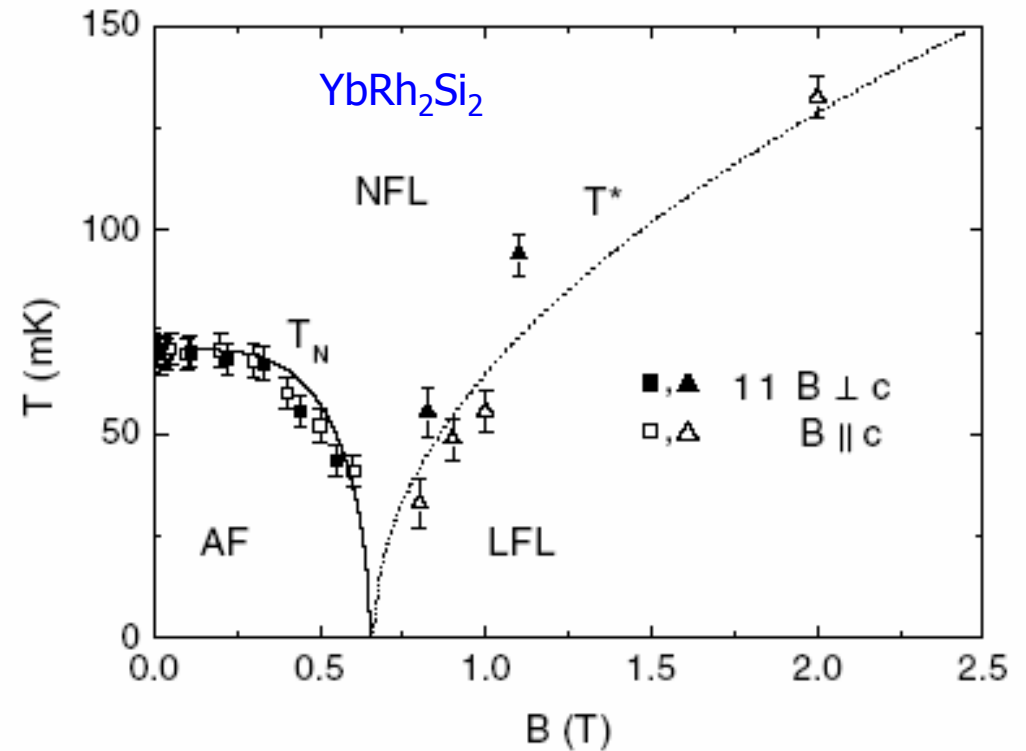
QCP – experimental examples (P, x, H)



Grosche et al., JPCM 13
(2001) 2845

(Similar results for CeIn_3)

→
pressure



Gegenwart et al., PRL 89
(2002) 056402.

→
applied field



QCP – experimental examples

Tune by

substitution $\Rightarrow$ disorder

pressure: discontinuity, difficult

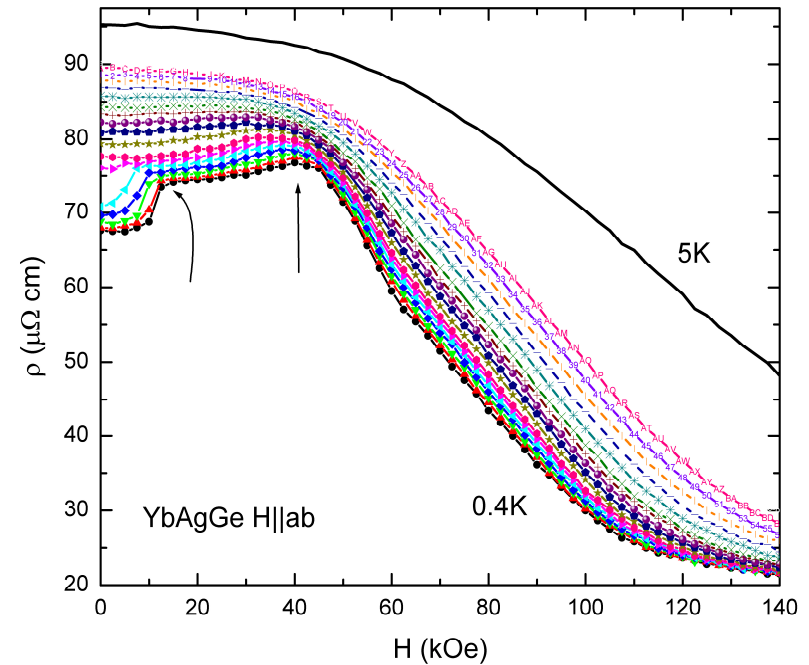
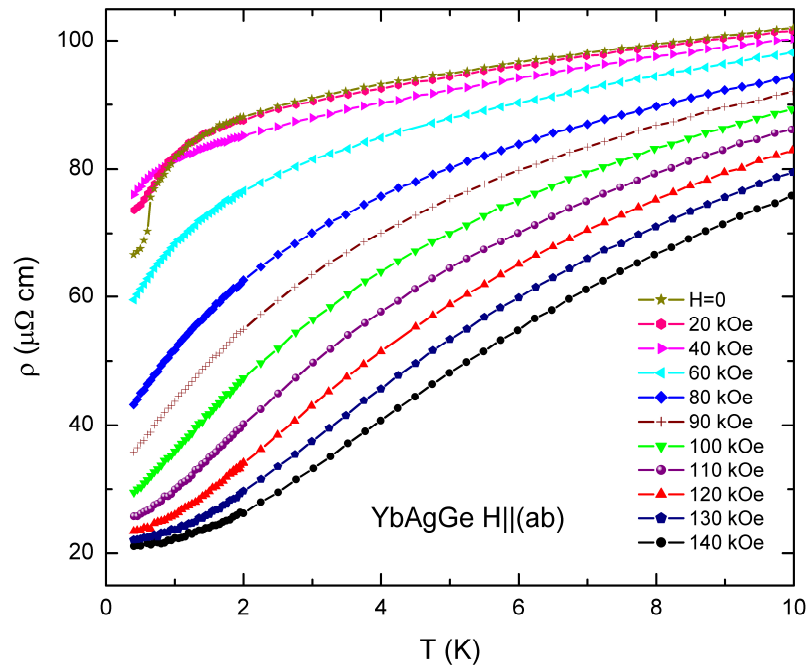
magnetic field: continuous, more
measurements are accessible.

**Are P , x , H “equivalent”? Is there any single,
“universal” picture?**

More, “clean” examples needed!



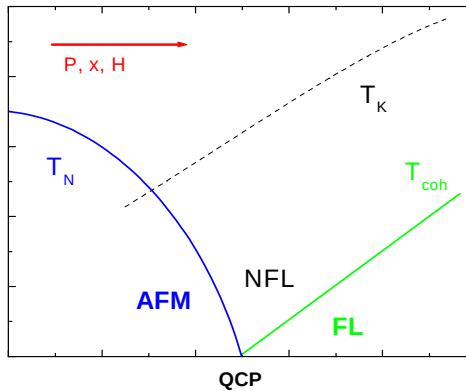
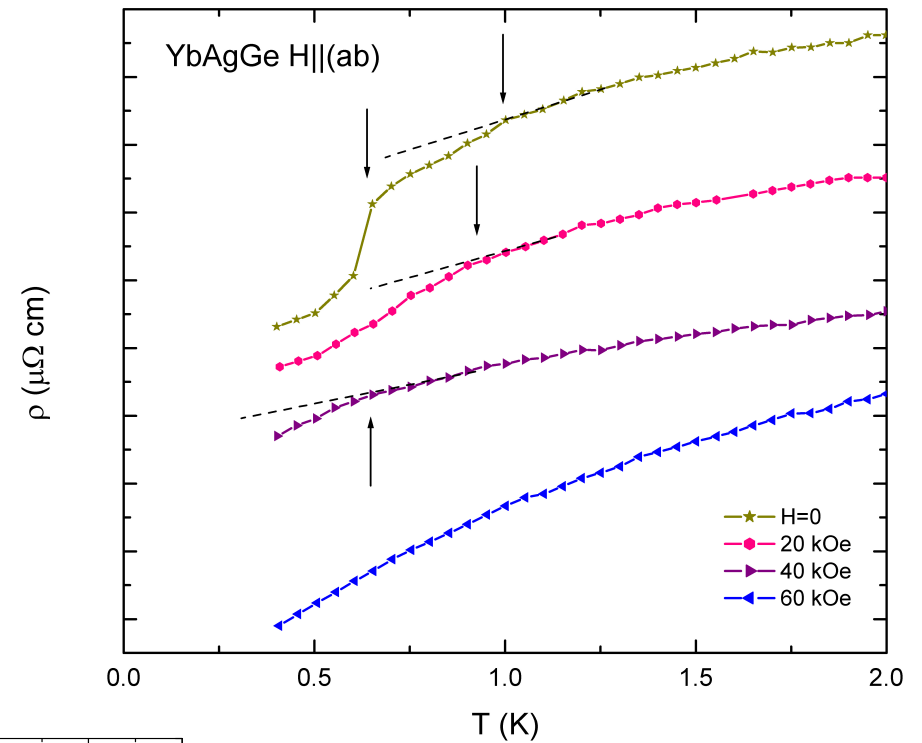
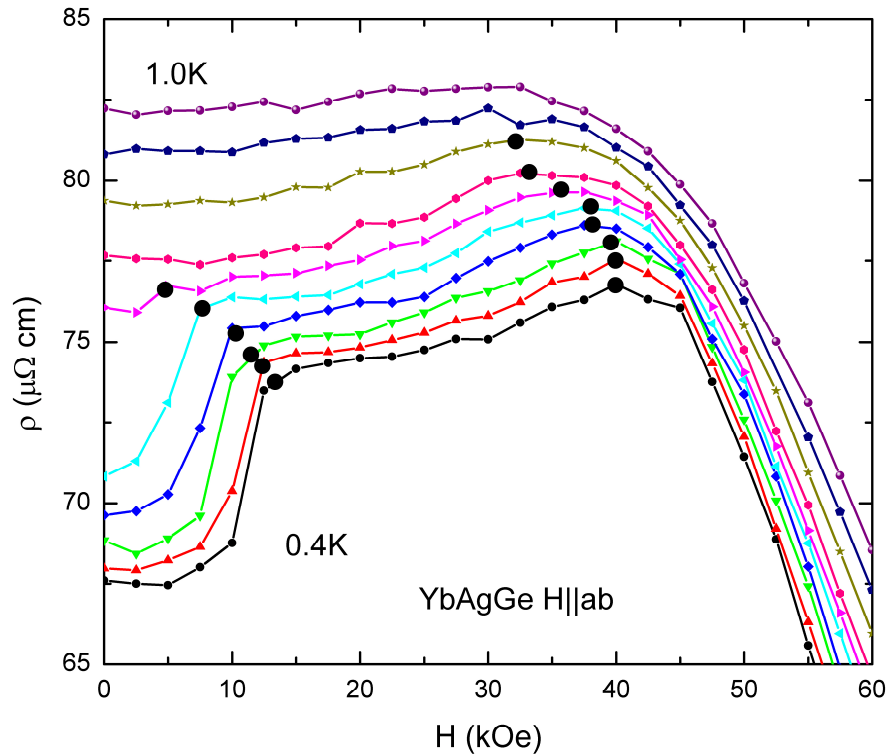
YbAgGe – resistivity in applied field

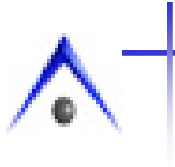


Let us look in more detail

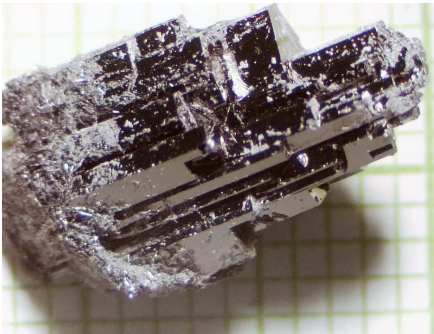


YbAgGe - $\rho(T, H)$: shift of magnetic transitions in applied field





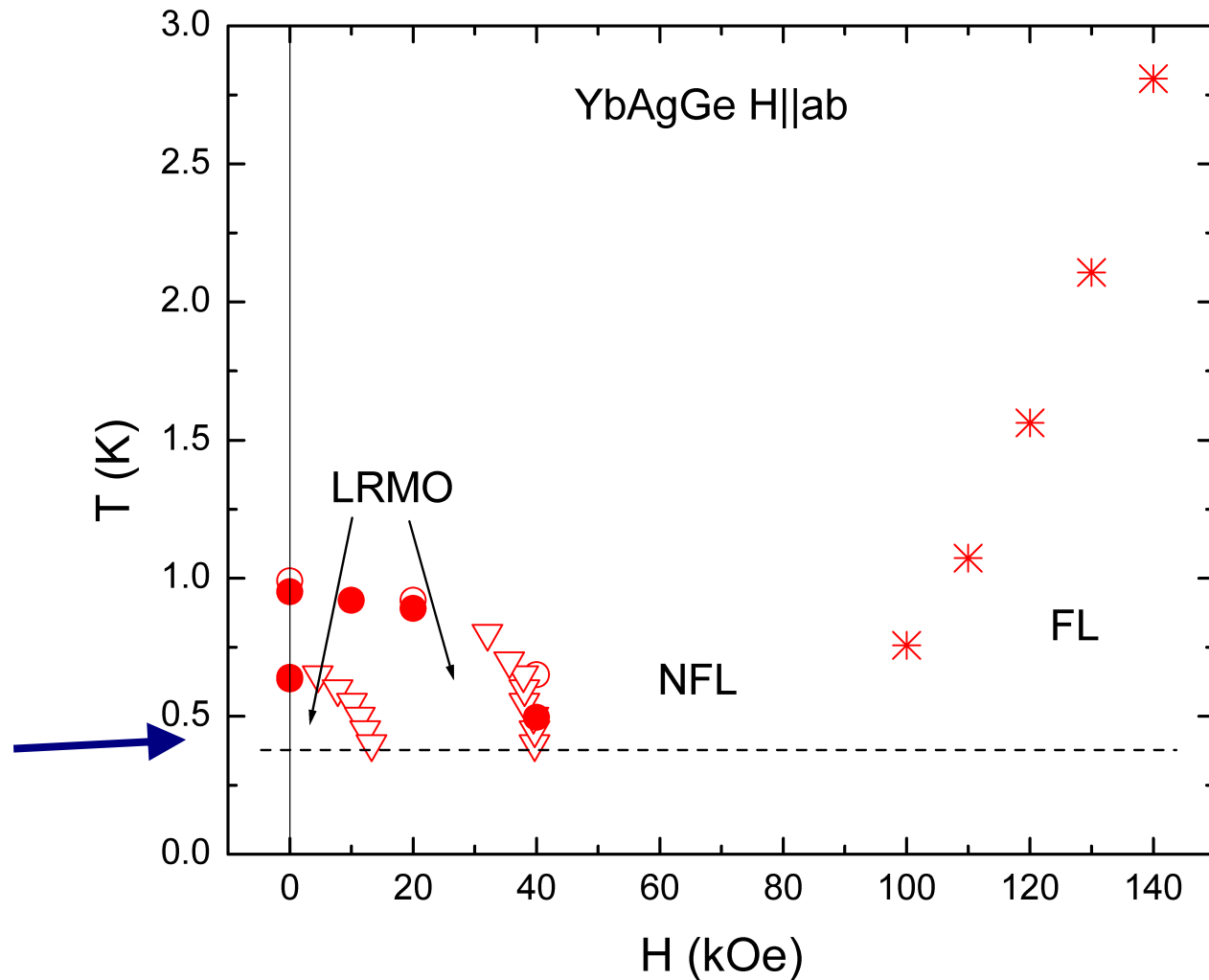
YbAgGe – phase diagram



Note: below
 ~ 0.6 K
neutron
diffraction has
determined a
 $1/3, 0, 1/3$
magnetic
ordering
wave vector

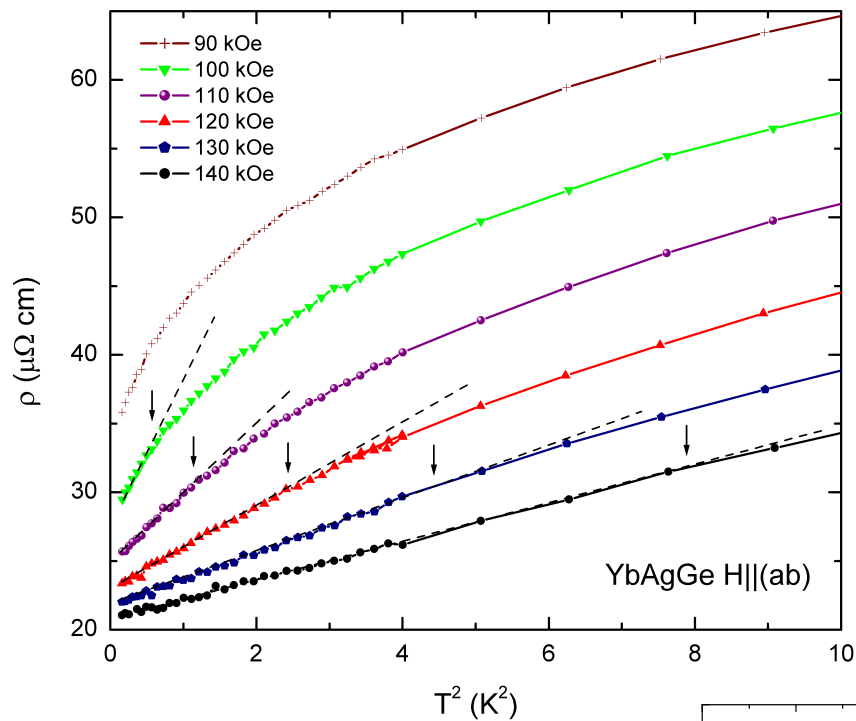
Björn Fåk, Desmond
McMorrow, et al.

JPCM 17 (2005) 301

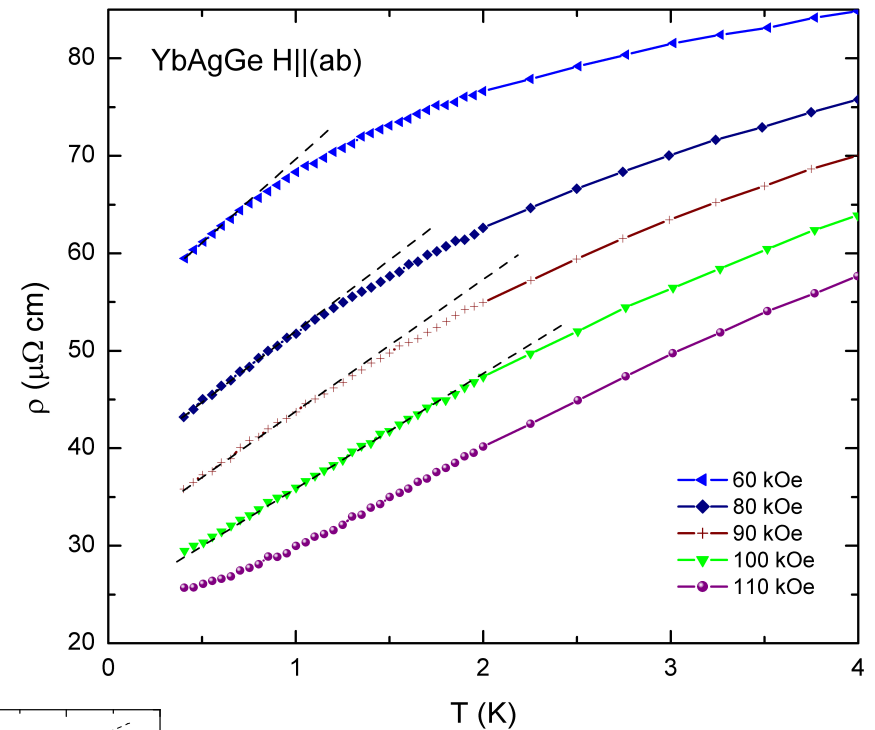




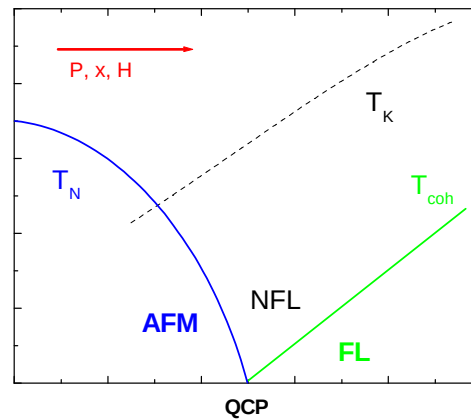
YbAgGe - $\rho(T, H)$: Fermi-liquid vs. non-Fermi-liquid



High fields:
 $\rho = \rho_0 + AT^2$:
FL - like

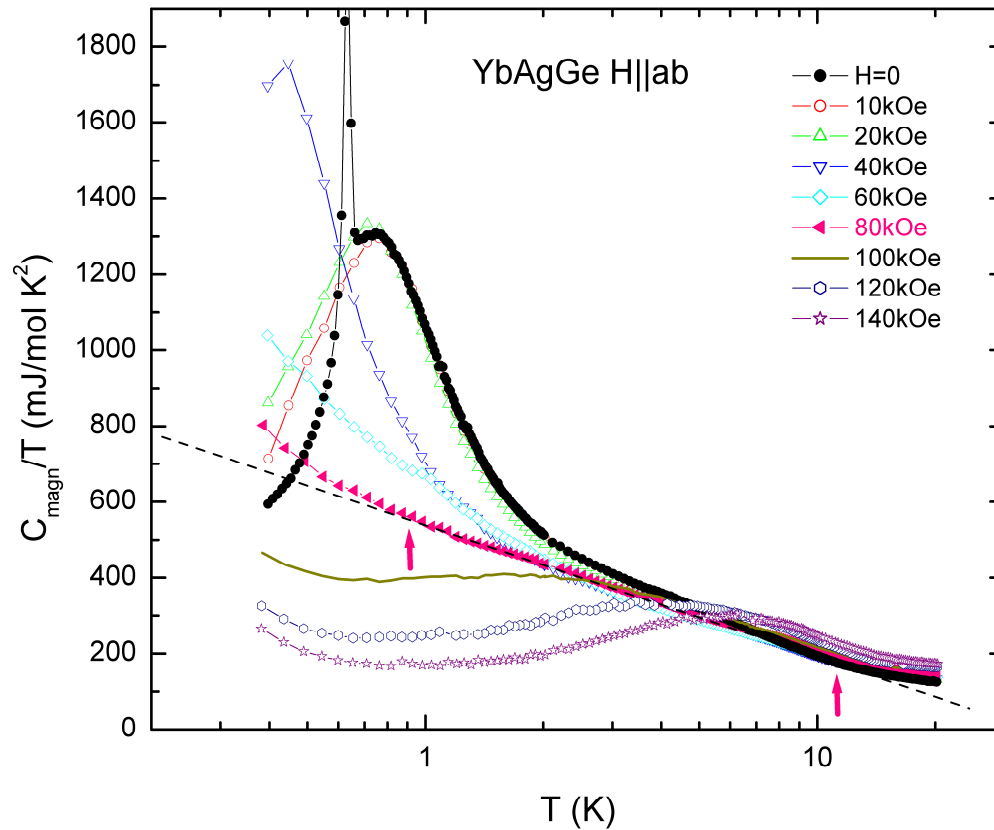


Intermediate fields:
 $\rho = \rho_0 + BT$: **NFL**



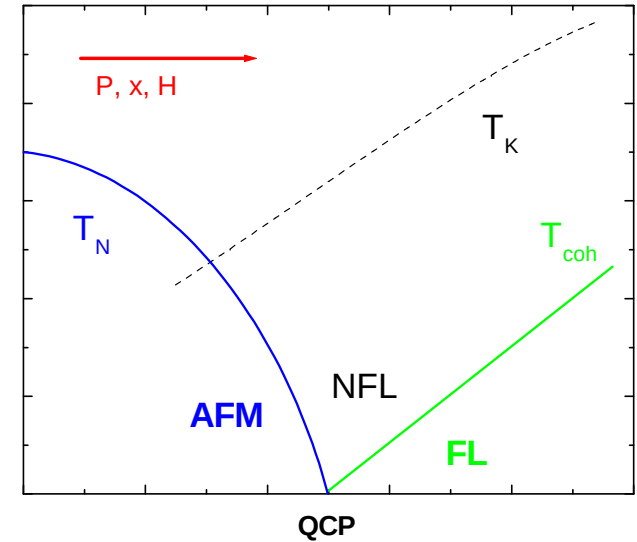


YbAgGe – heat capacity in applied field



H = 80 kOe: $C_{\text{magn}}/T \propto -\ln T$ for over a decade in temperature

$$C_{\text{magn}}/T = \gamma'_0 \ln(T_0/T): \gamma'_0 \approx 144 \text{ mJ/mol K}^2; T_0 \approx 41 \text{ K}$$



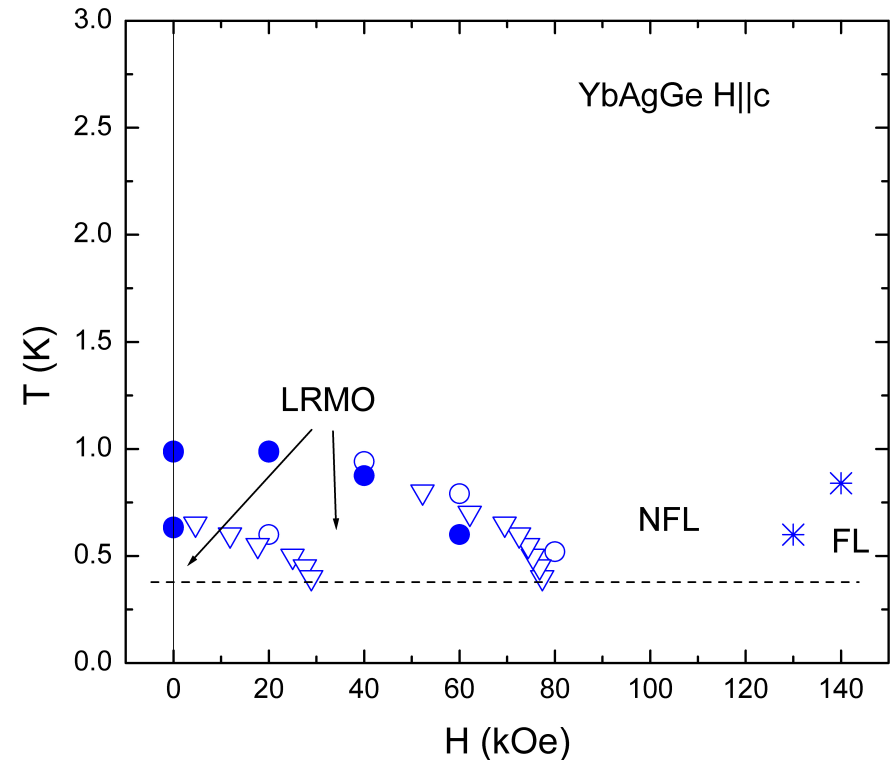
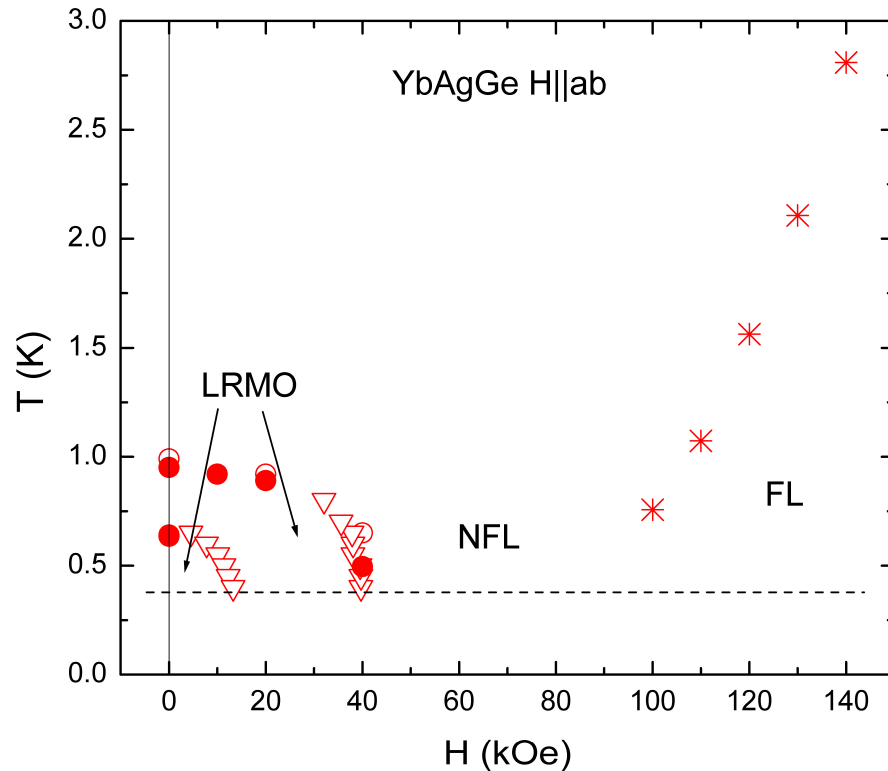
Also: scaling of the specific heat:

$$[C(H)-C(H=0)] \text{ vs. } H/T^\beta, \quad \beta = 1.15$$

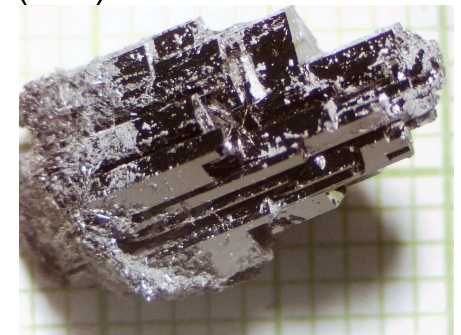
(observed in a number of materials with NFL properties)



YbAgGe – phase diagrams



- (i) Tuning via simple and clean knob – H (not P or x)
- (ii) Only second stoichiometric Yb- compound to show this
- (iii) Like YbRh₂Si₂ the H-T phase diagram appears intriguing, BUT higher T and H scales
- (iv) Unlike YbRh₂Si₂ the crystals can be BIG



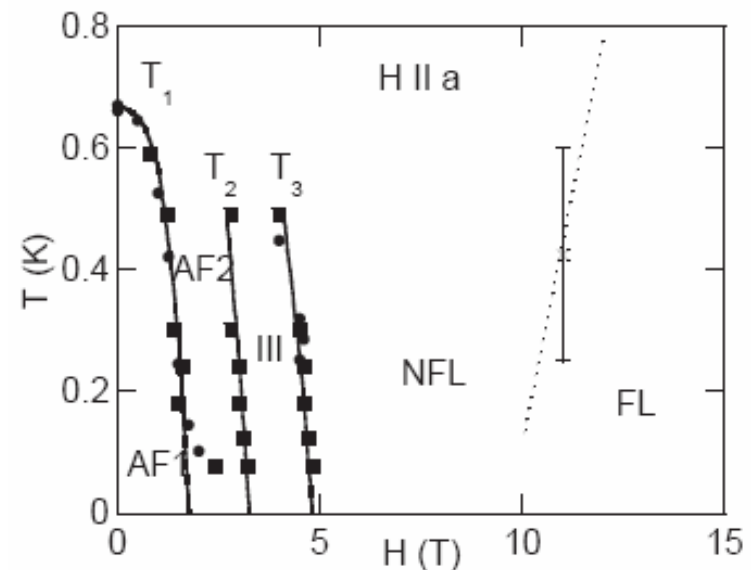
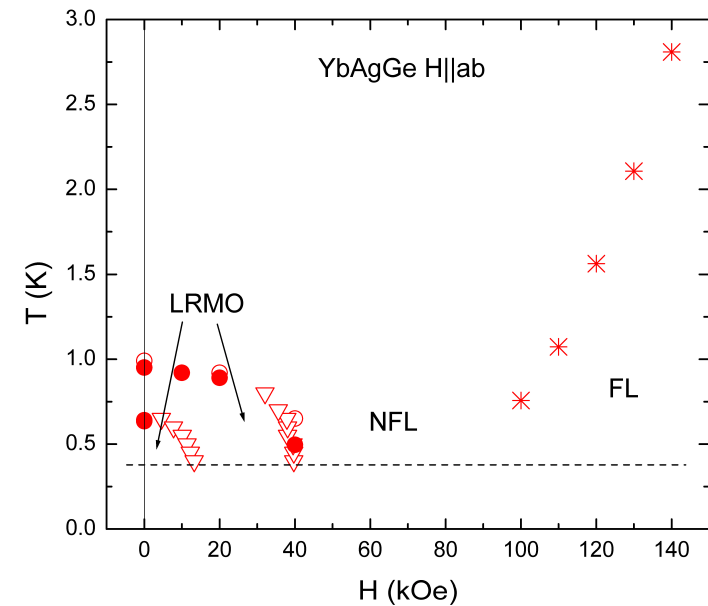
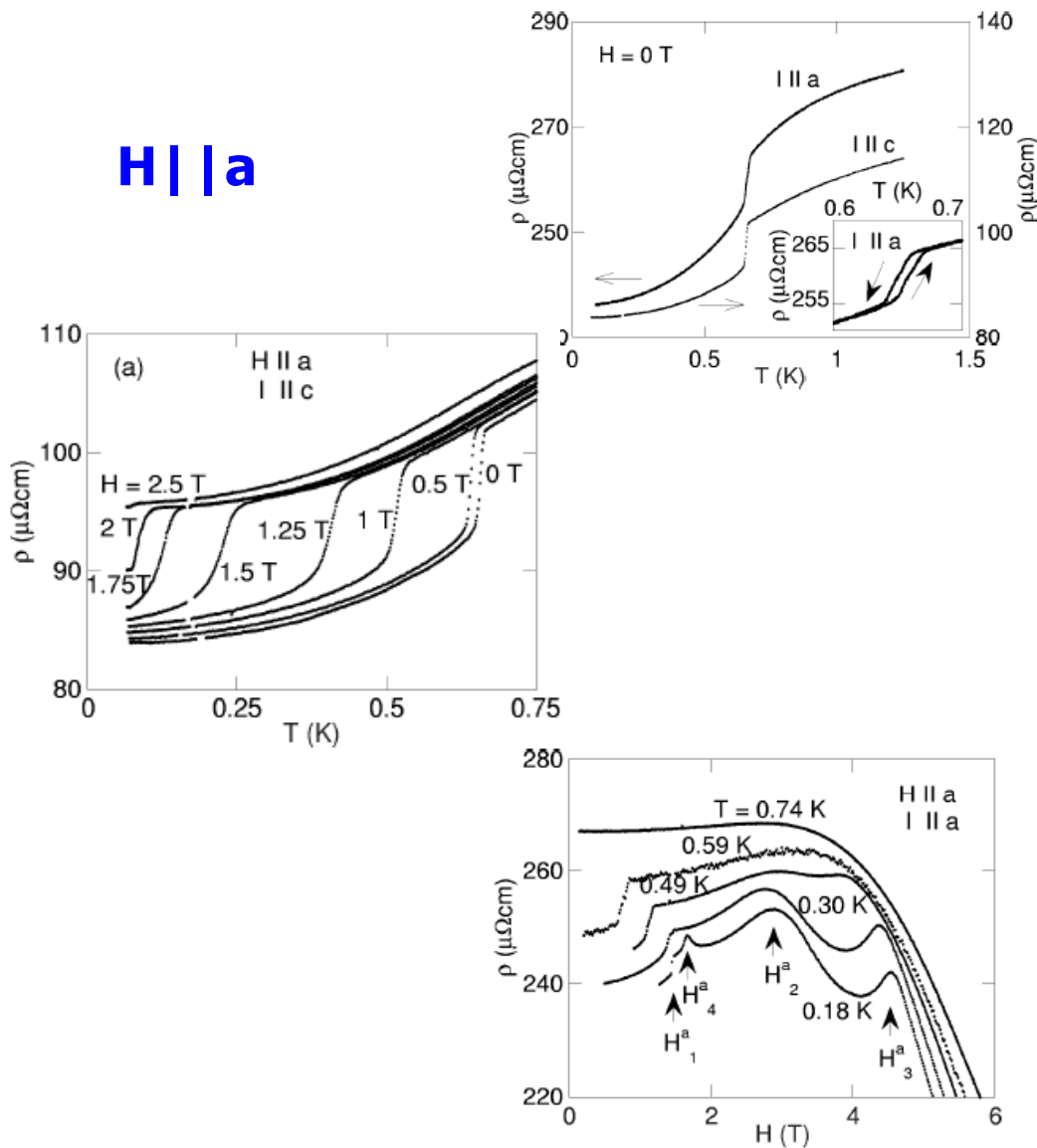
2 gram single crystal for scattering from Yuri Janssen



If we are really interested in QCP we need $T < 0.4$ K

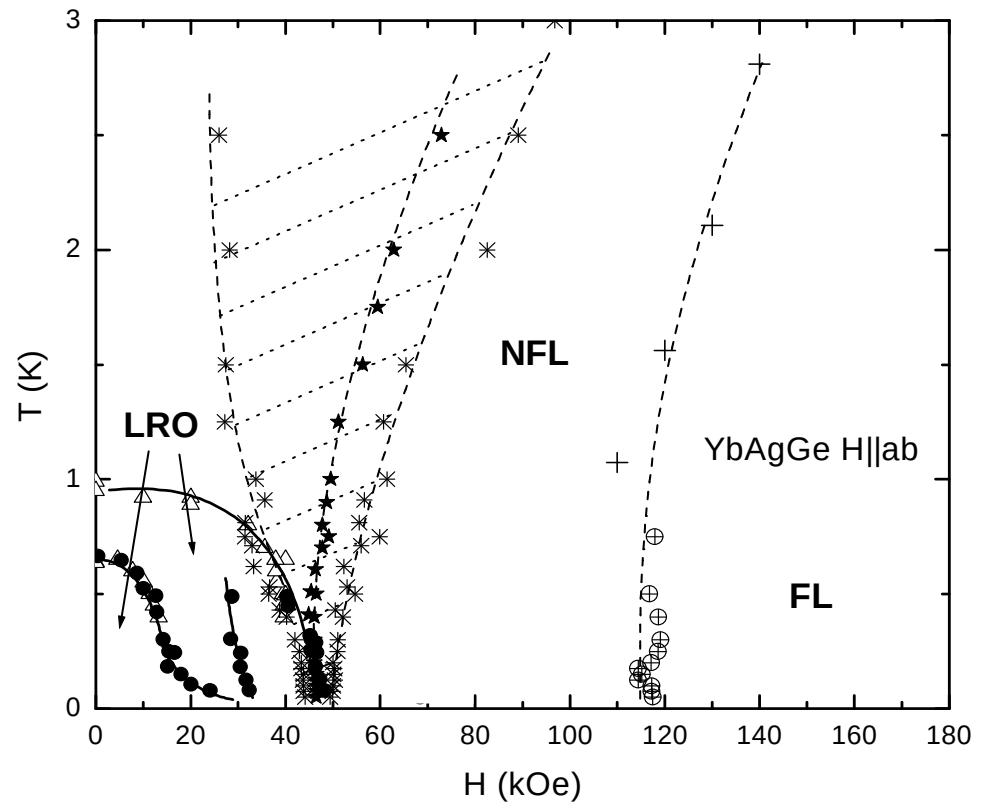
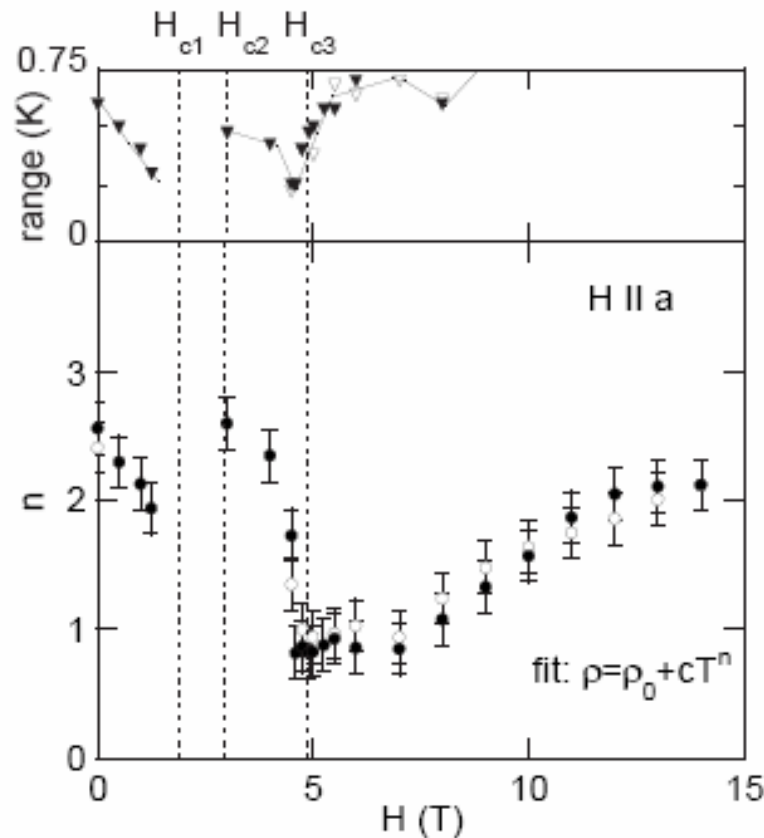
YbAgGe: low temperature magnetotransport

H || a





YbAgGe: low temperature magnetotransport



YbAgGe appears to be a readily accessible example of FI-QCP material, apparently revealing a non-Fermi liquid region even at $T = 0$ K.

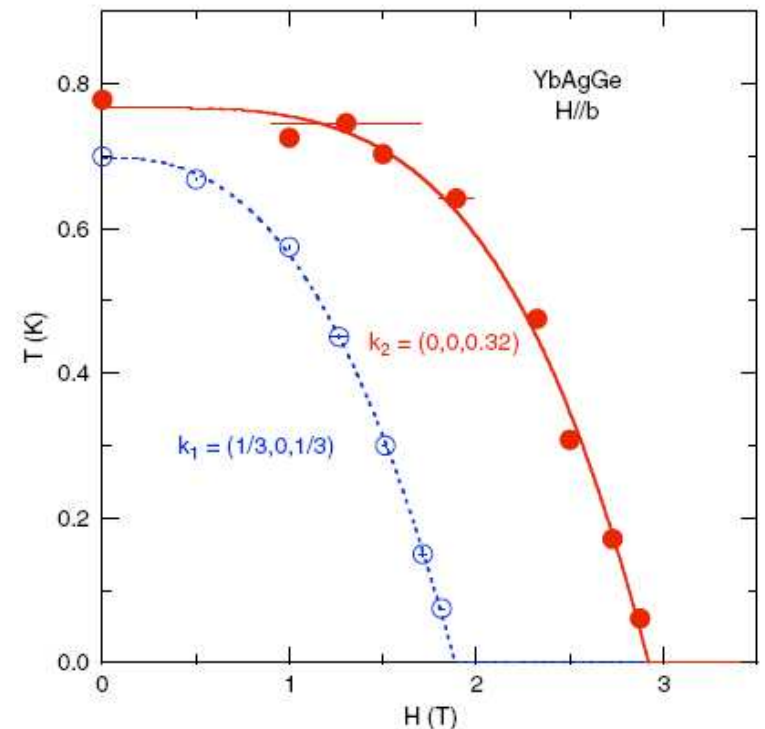
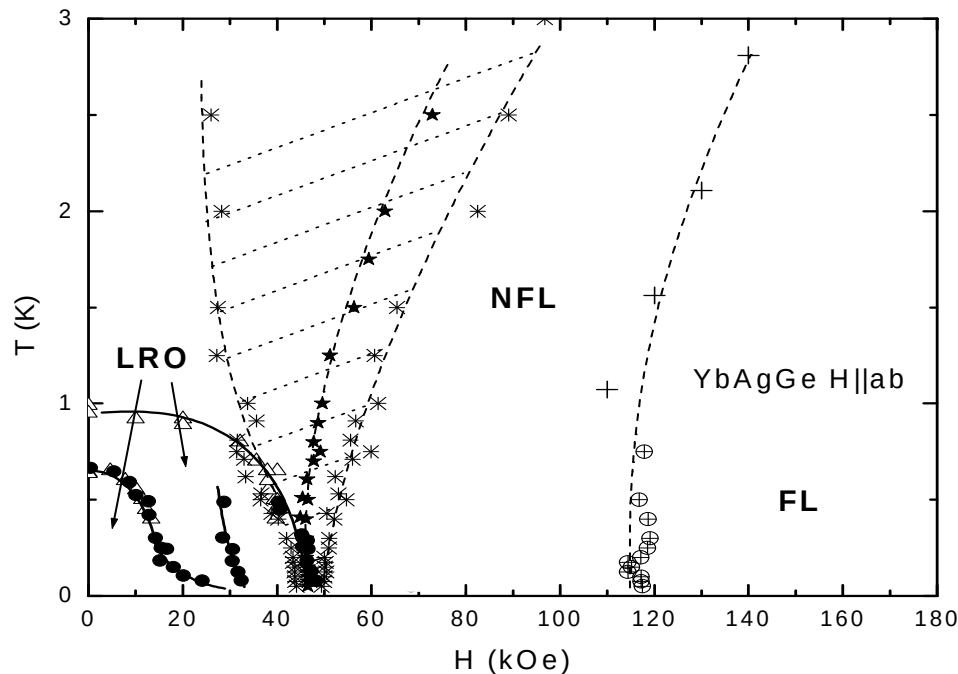
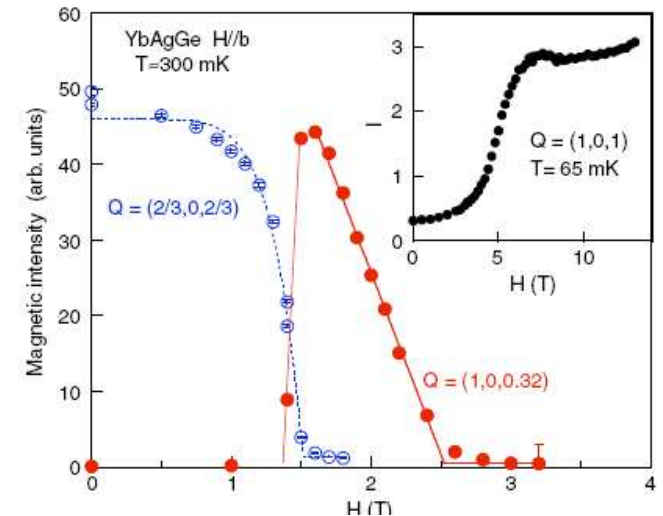


Magnetic phase diagram of heavy-fermion YbAgGe

B. Fåk^{a,*}, Ch. Rüegg^b, P.G. Niklowitz^a, D.F. McMorrow^{b,c}, P.C. Canfield^d, S.L. Bud'ko^d, Y. Janssen^d, K. Habicht^{e,f}

Physica B 378–380 (2006) 669–670

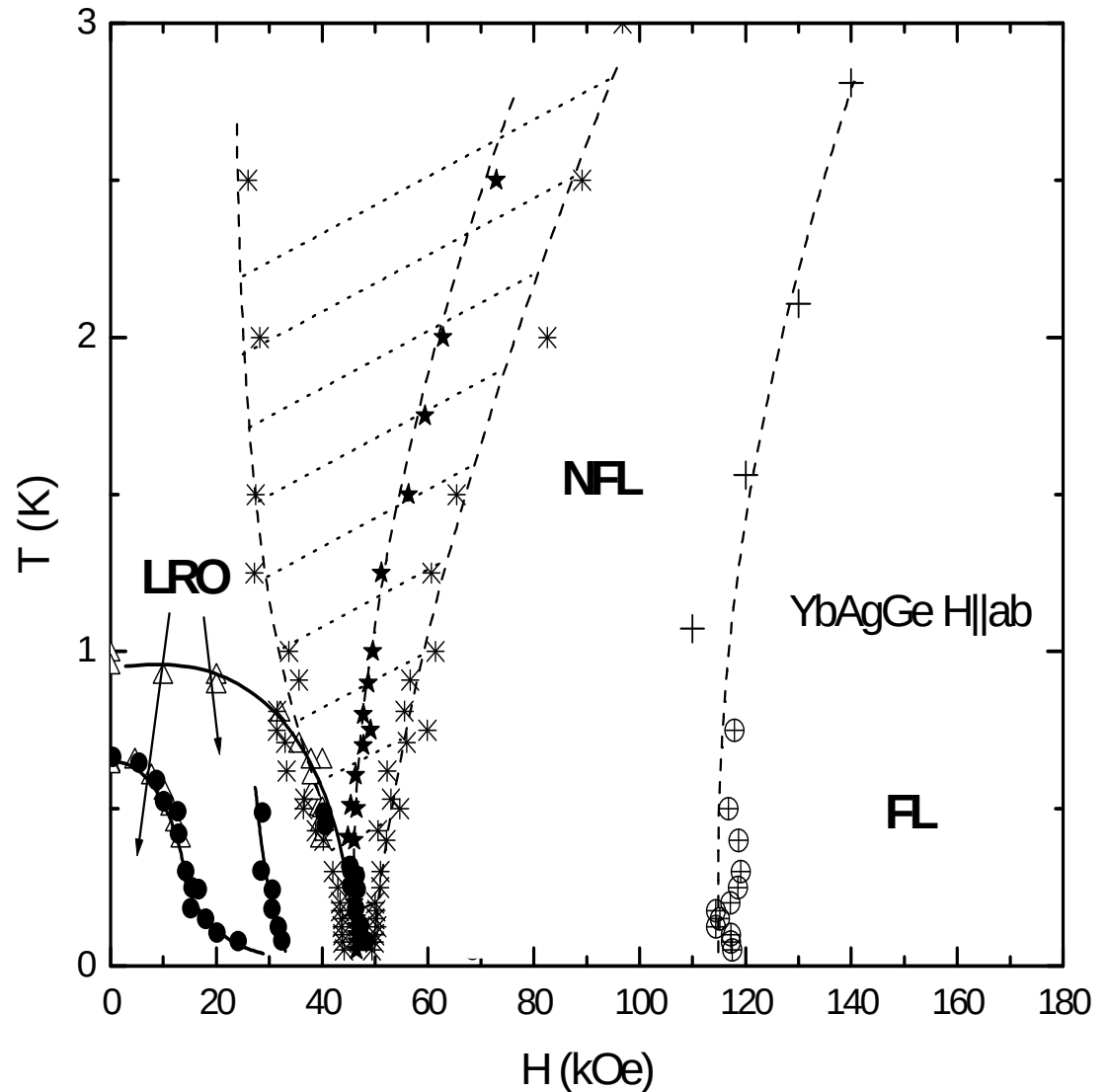
Neutron scattering results as of 5/06 had identified and mapped magnetic order for two lower field / temperature phases. In the past month runs at ILL have found the wave vector of the highest temperature / field phase that defines the outer envelope that ultimately generates the QCP we have been examining. **This means that we now know where to look for the fluctuations that should arising due to the quantum criticality.**

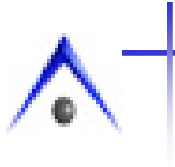




Tuning magnetism in YbAgGe

Experimentally the YbAgGe system allows us to watch as the system progresses from one known limit: a Fermi liquid (strongly correlated electron system), to another known limit: antiferromagnetic order. We can do this at zero temperature by changing an easy to control thermodynamic variable: applied magnetic field. The phase diagram that we have found challenges current theory, specifically the existence of a clear and wide non-Fermi liquid region.





The original motivations for studying the RAgGe and RT_2Zn_{20} series were curiosity about R-Ag-Ge ternaries and desire to study large unit cell, rare earth intermetallics. In both cases, through a series of basic studies, analysis and thought we found model systems that help us study how magnetism and correlated electron systems can be tuned.

Such discoveries are the result of a flexible, new materials research program that is at the heart of basic research in condensed matter physics.



If the material I cover is of interest to you please consider coming to Iowa State University for graduate school or as a Post-doc.

Contact me at "canfield@ameslab.gov" remind me that you were at this school and I will try to help with the application. We have many foreign students and visitors and are delighted to teach more about this vital topic.

 **Novel Materials and Ground States**

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You are here: [Ames Laboratory](#) > [Condensed Matter Physics](#) > [Novel Materials](#)

CANFIELD'S RESEARCH GROUP

Welcome to our web page, where you may learn about who we are and what we do as part of the [Condensed Matter Physics Group](#) of the [Physics and Astronomy Department](#) at [Iowa State University](#) and [Ames Laboratory](#) (a U. S. Department of Energy (DOE) facility). Our group of faculty, staff, post-docs, graduate and undergraduate students is mostly dedicated to the design, discovery, growth and characterization of novel electronic and magnetic compounds - often in single crystal form - and the study of their interesting physical properties.



Here are four of our general review articles:

 Physics Today - October 1998 "New Magnetic Superconductors: A Toy Box for Solid-State Physicists"	 Physics World - January 2002 "Magnesium Diboride: one year on"	 Physics Today - March 2003 "Magnesium Diboride: Better Late than Never"	 Scientific American - April 2005 "Low Temperature Superconductivity Is Warming Up"
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<http://cmpweb.ameslab.gov/personnel/canfield>



For whole lecture series there is no real summary, just gestalt feelings about what works for us...

The design, growth and discovery of novel materials is a powerful tool to use in the study of condensed matter physics.

In our experience it works best when

- (i) Growth and measurements are tightly coupled
- (ii) The reasons for growing a material are allowed to blend and merge into each other.
- (iii) You have fun mucking about with Mother Nature's secrets.



That's All Folks