Materials Problems in QPT Systems: Their Non-Negligible Effect and the Struggle to Avoid/Minimize Them

Kavli Institute, April 12, 2005

I. Need low temperature data

- A. Because a broad temperature range is necessary to determine behavior
- B. Theories typically (but not always) only predict the limiting, T→0, response

Caveat: Beware data that are only down to 1.4 K, and demand data *<u>at least</u>* *down to 0.3 K. 0.05 K or lower is best.*

II. "Single" crystals vs polycrystalline samples – mosaic spread, inclusions, solubility of flux, . . .

III. Metamagnetic transitions as a pathway to nFl behavior/Quantum Criticality –

- A. importance of ρ_0 in $Sr_3Ru_2O_7$ – Perry et al. found *one* metamagnetic transition in $\rho_0 = 2.8\ \mu\Omega$-cm material while Ohmichi et al. 1 ½ years later found *two* metamagnetic transitions in $\rho_0 = 0.8 - 2.0\ \mu\Omega$-cm material
- B. Consider $CeIrIn_5$

IV. Caution – Field Driven QCP can be different than using x or P.

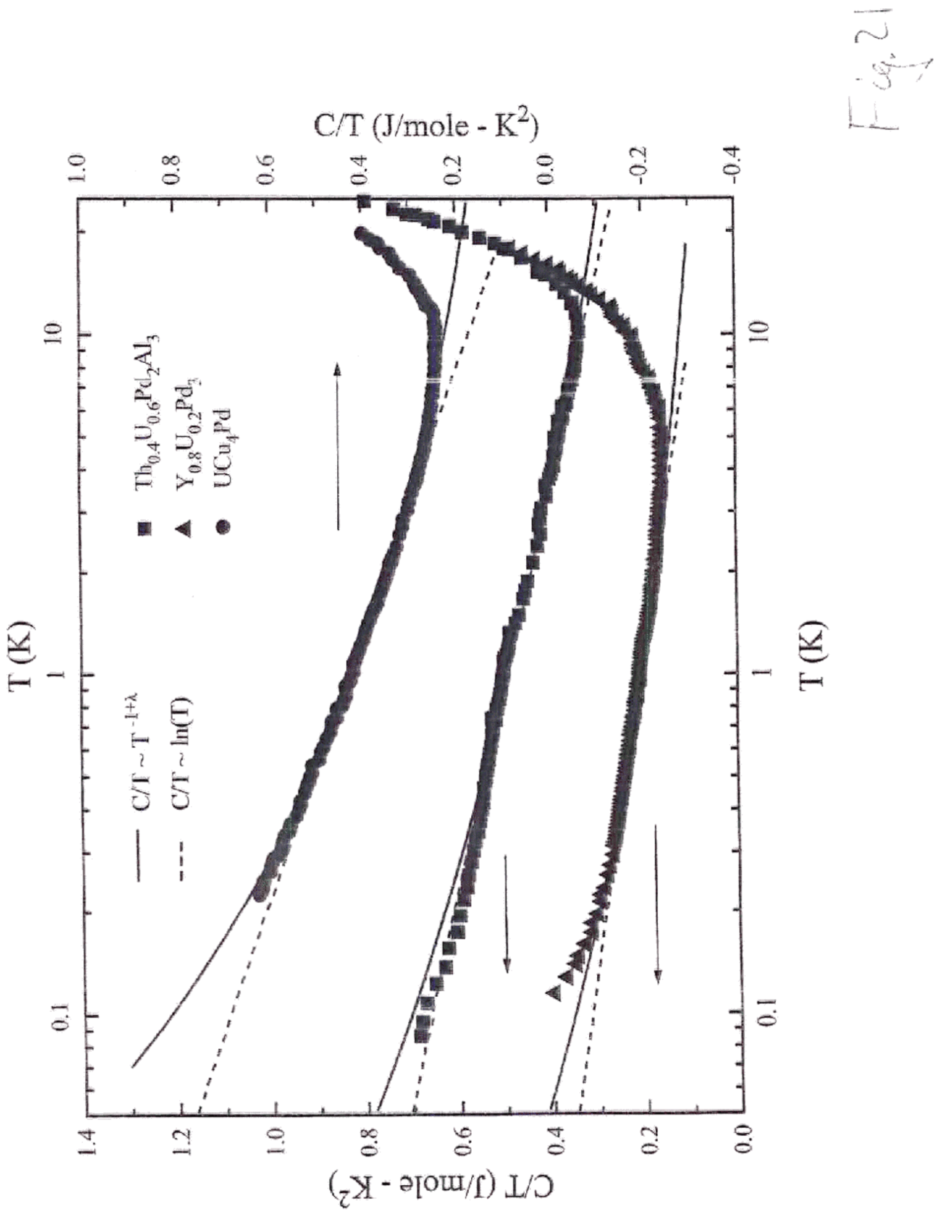
V. There exist materials issues (homogeneity, second phase) that are often important

VI. Low temperature properties (see I. above) are widely known to be sample dependent

- e. g., presence of bulk superconductivity in $CeCu_2Si_2$
- Using C/T as an example, consider the low T limiting behavior in $Y_{0.8}U_{0.2}Pd_3$, $CeNi_2Ge_2$, and $YbRh_2Si_2$

VII. UCu_4Pd – Disordered systems require even *more* care

VIII. Suggestion for a "better" disordered system

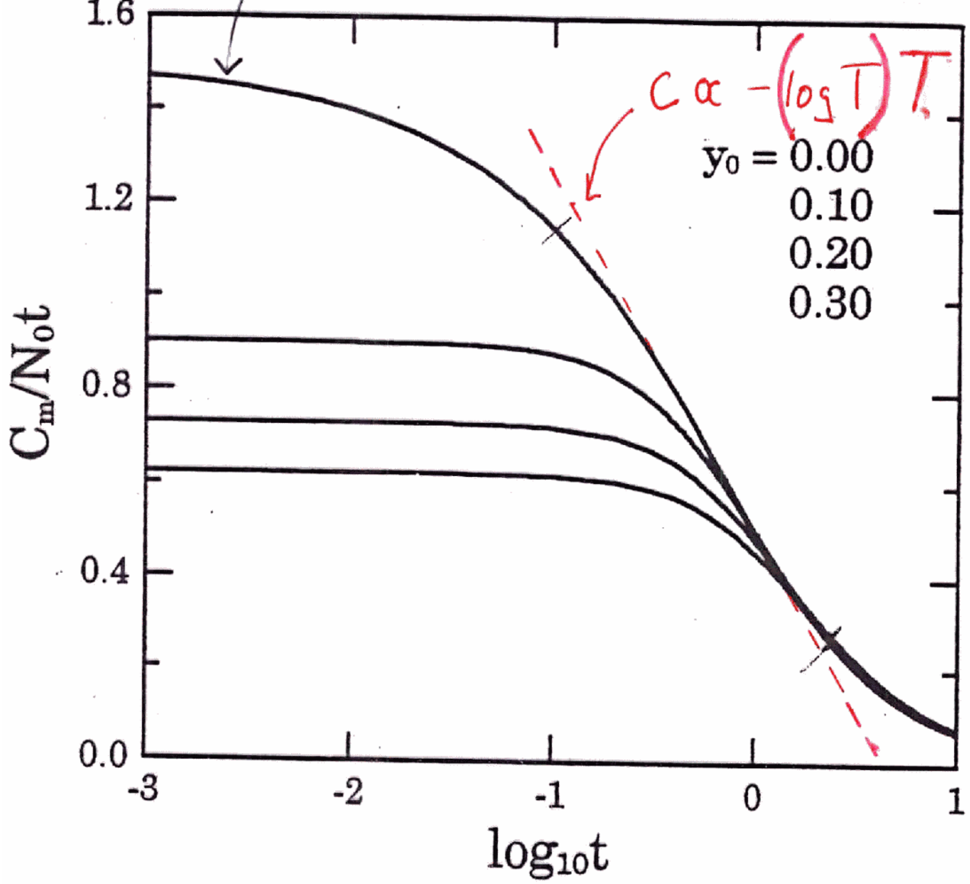


Moriya + Takimoto 3d afm

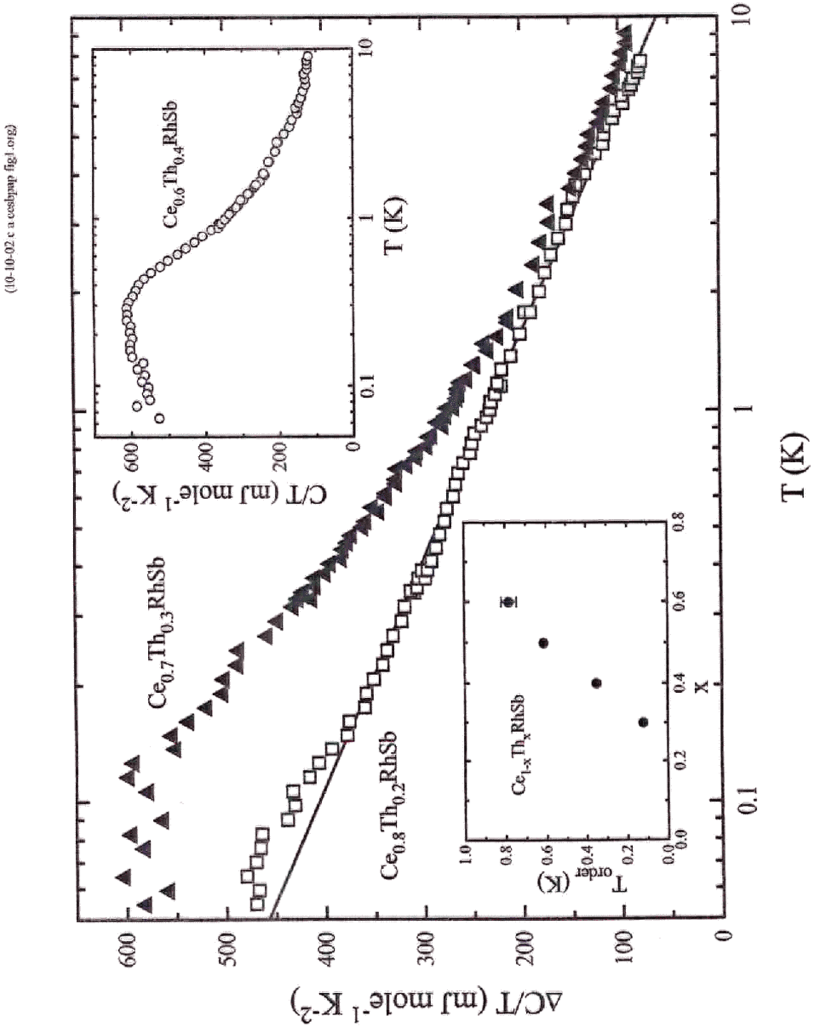
CROSSOVER BEHAVIOR

$\frac{C(T\to 0)}{T} \propto \gamma_0 - T^{+1/2}$

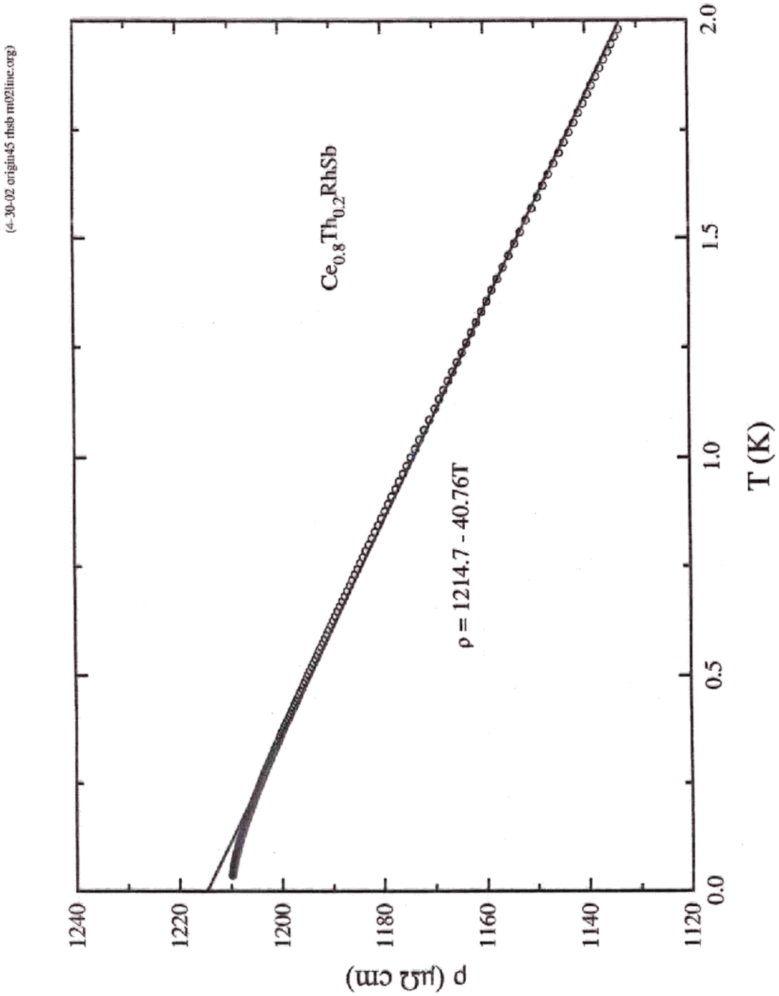
$C \propto -(\log T)\,T$

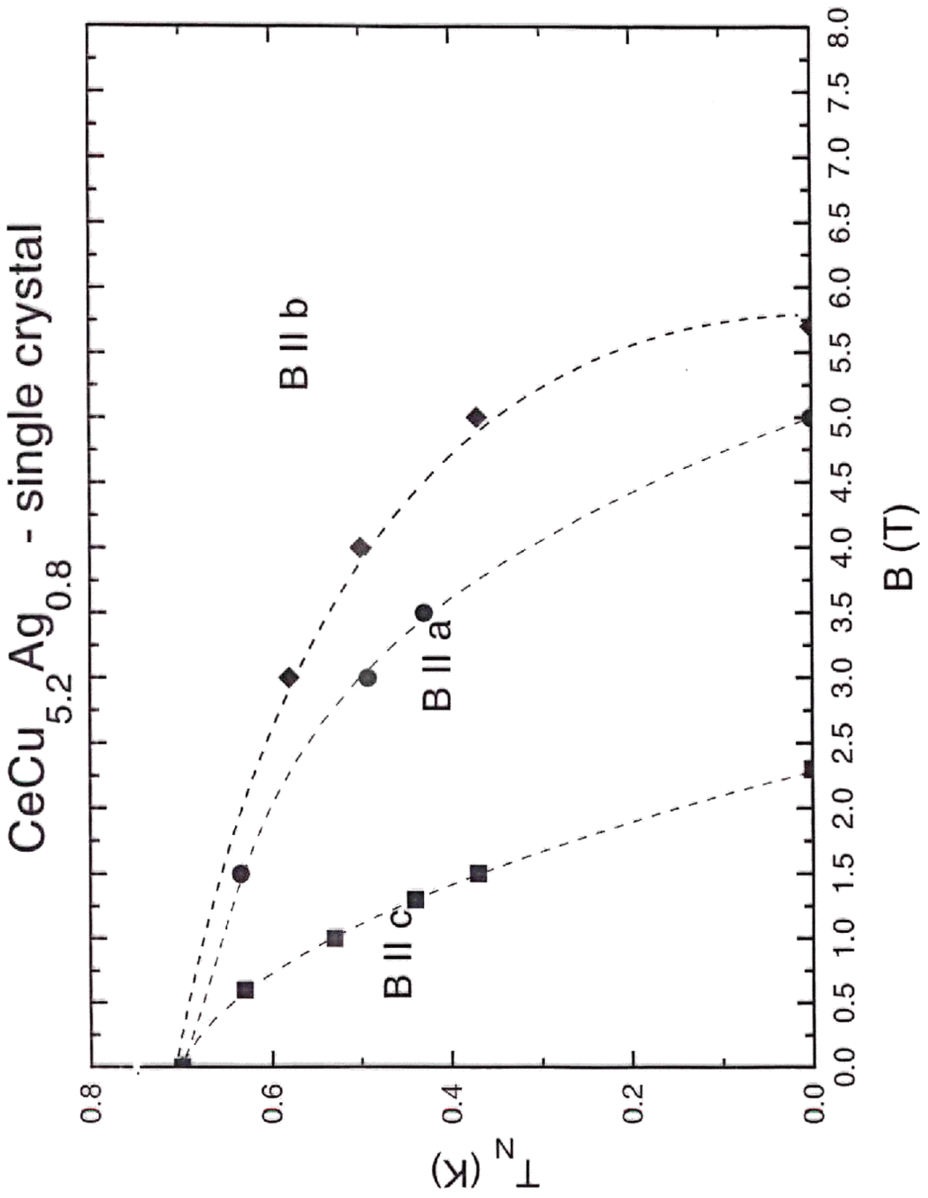


1


(10-10-02 c a ceshypap fig1.org)
ΔC/T (mJ mole-1 K-2)
T (K)
0
100
200
300
400
500
600
0.1
1
10
Ce0.7Th0.3RhSb
Ce0.8Th0.2RhSb
C/T (mJ mole-1 K-2)
Ce0.6Th0.4RhSb
0
200
400
600
0.1
1
10
T (K)
Ce1-xThxRhSb
T order (K)
x
0.0
0.2
0.4
0.6
0.8
1.0
0.0
0.2
0.4
0.6
0.8

5

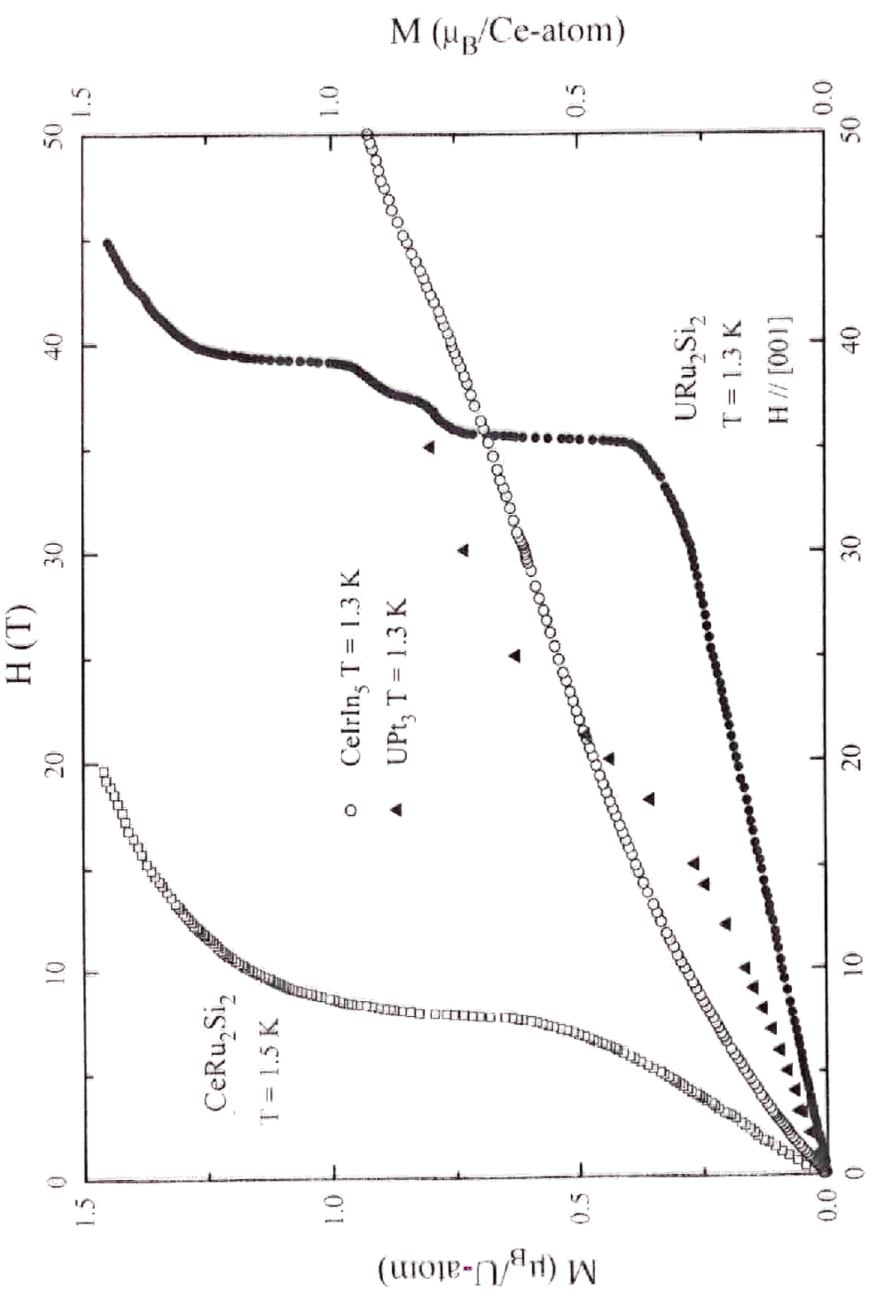

(4-30-02 origin45 rhsb m02line.org)
Ce0.8Th0.2RhSb
ρ = 1214.7 - 40.76T
ρ (μΩ cm)
T (K)
1120
1140
1160
1180
1200
1220
1240
0.0
0.5
1.0
1.5
2.0

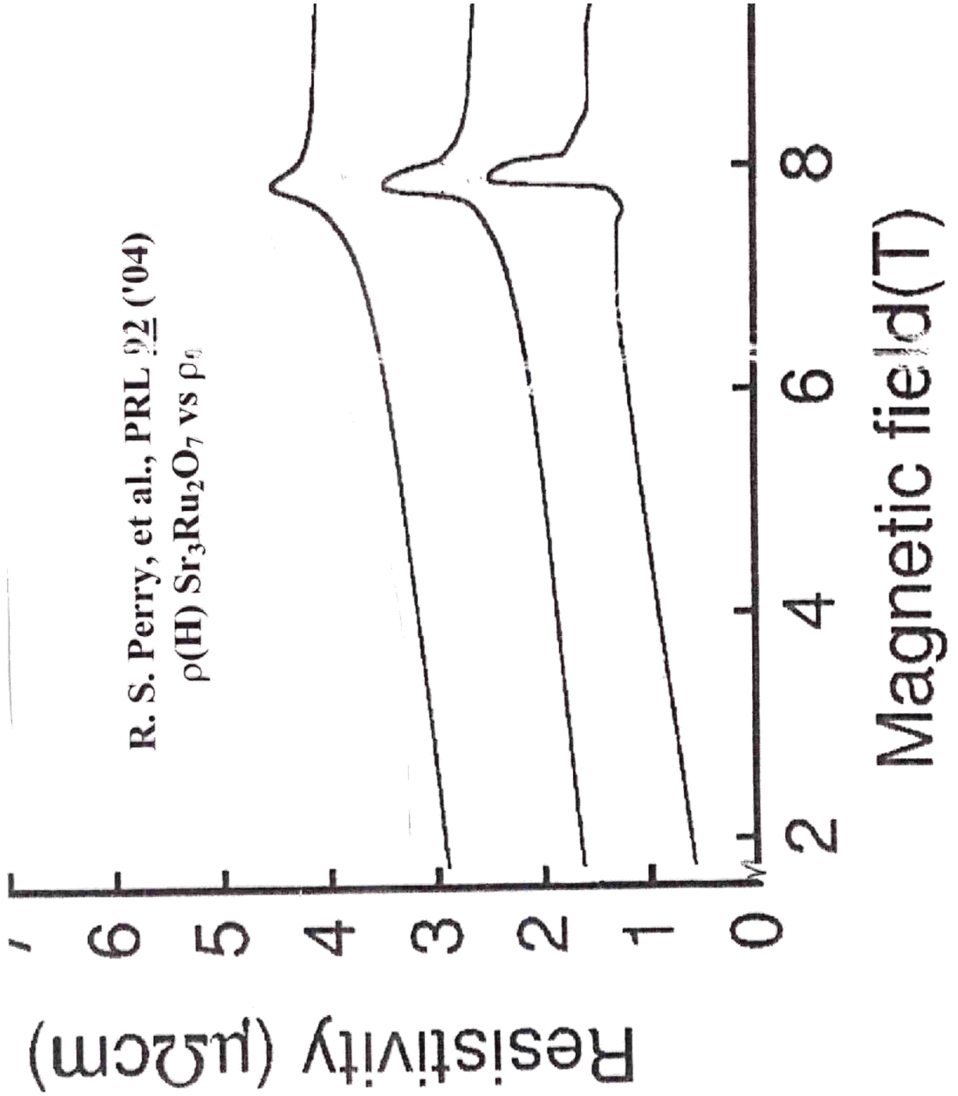


III

SYSTEMS WITH METAMAGNETIC TRANSITIONS

COMPOUND	$H_{metamag}$(T)	$\Delta M(\mu_B$/Ce,U-atom)
$CeRu_2Si_2$	7.7	0.65
UPd_2Al_3	18.5	1
UPt_3	20.5	0.2
URu_2Si_2	35.8,36.5,39.6	0.45,0.1,0.45
$CeIrIn_5$	42	0.05





R. S. Perry, et al., PRL 92 ('04)
ρ**(H) Sr$_3$Ru$_2$O$_7$ vs** ρ_9

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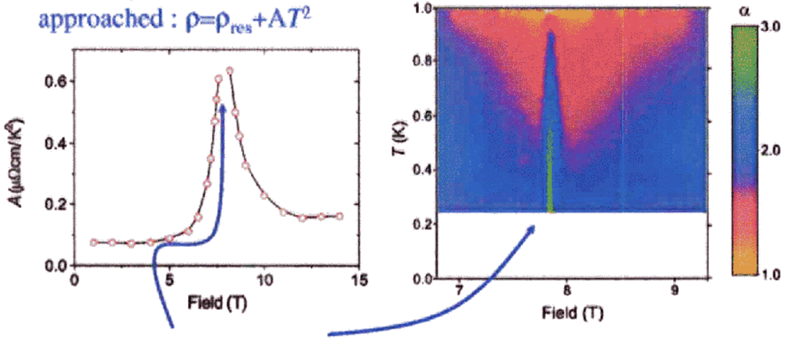
Transport studies of the quantum critical phase diagram of '2nd generation' $Sr_3Ru_2O_7$: a closer look

Diverging *A* coefficient as the metamagnetic transition is approached : $\rho=\rho_{res}+AT^2$

$\rho = \rho_{res} + AT^{\alpha}$, *H*//*c*



Fit no longer possible here because ρ no longer varied as T^2. In fact, more like T^3 – hard to understand. Could it be due to finite purity?

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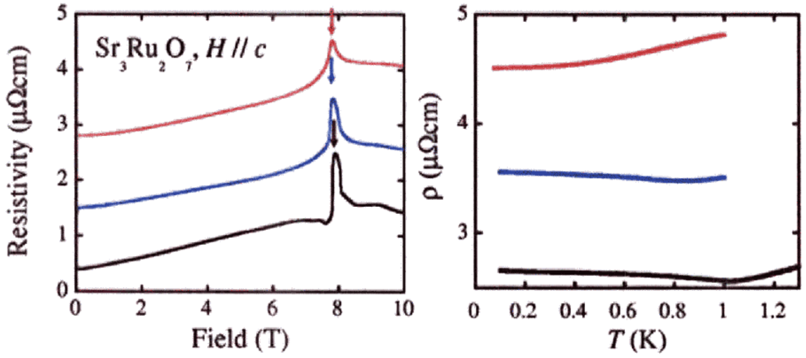
Flat T^3 seen in old crystals becomes a distinct *minimum* in the new generation of high-purity crystals



Also minimum moves to higher *T* with increasing sample purity!

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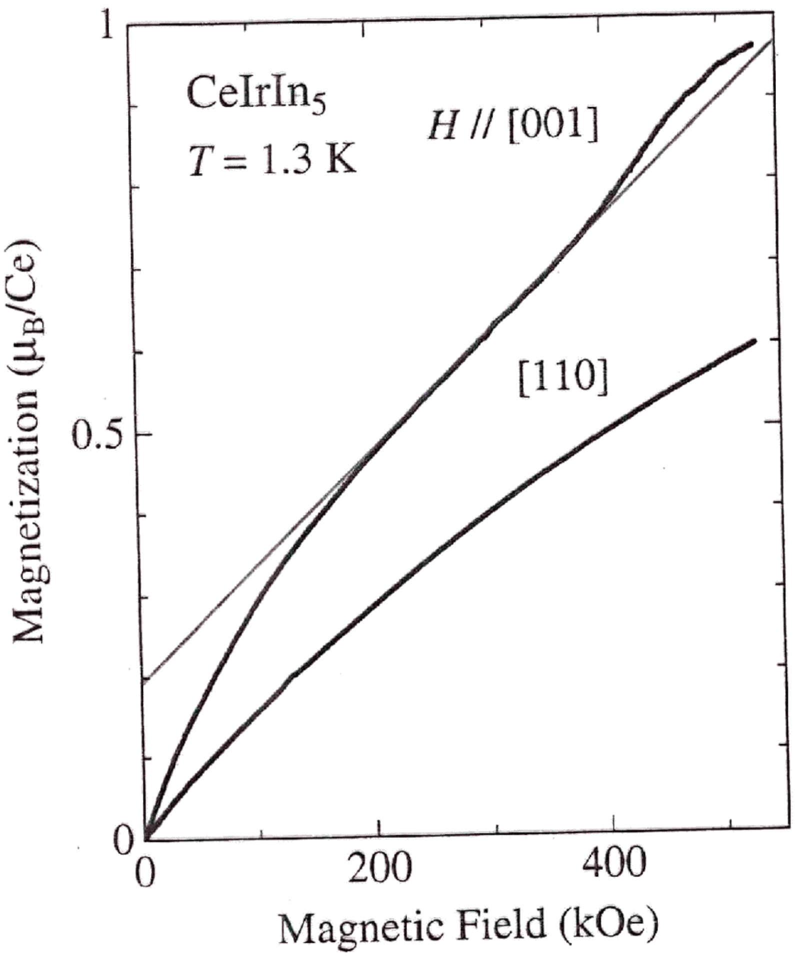


High-field magnetization of $CeIrIn_5$ measured at 1.3 K.

FIELD DRIVEN QCP'S

Overall question: **Do such systems show the full range of behavior found via doping or pressure?**

Outline

I.) Metamagnetism *can* be one route to QCP's.
e. g. UPt_3 , $Sr_3Ru_2O_7$ (ref. talk of A. Schofield)

II.) Can use field in some cases to reach QCP at $T_N(B) \to 0$ (Reminder: doping and pressure also only work in some cases.)

←**Comparison of behavior (ρ, χ, C/T) for B vs x,P**→
in selected antiferromagnets

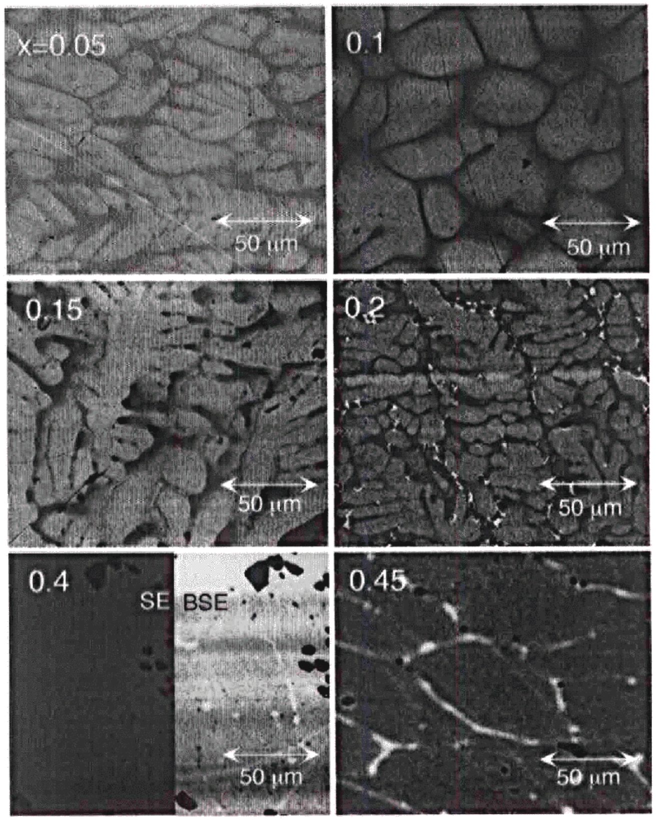
- A.) $CeCu_{6-x}Ag_x$ - some differences B vs x,P
- B.) $CeCu_{6-x}Au_x$ - also some differences, but also between x and P
- C.) $YbRh_2Si_2$ - difference in *temperature range* of $\rho = \rho_0 + aT$ between x and B
- D.) $YbCu_{5-x}Al_x$ - the reverse of $CeCu_{6-x}M_x$
- D.) Usage of B≥0 to tune near a general QCP

Comparison of ρ, χ, C/T for B_{crit} vs x_{crit}, P_{crit}

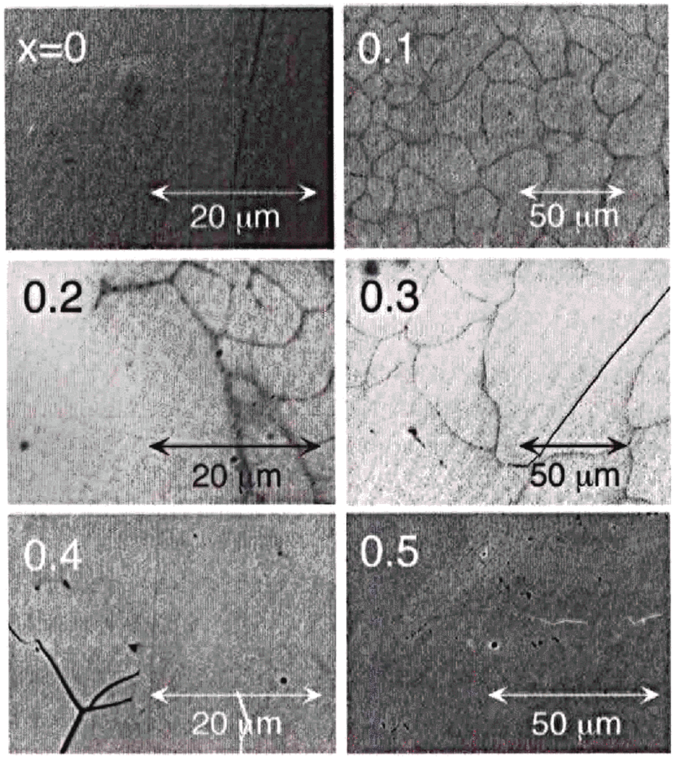
System	$\rho = \rho_0 + aT^{\alpha}$ $\alpha(B_c/x_c,P_c)$	C/T($B_c/x_c,P_c$)	$\chi^{-1} - \chi_0^{-1} = T^{\beta}$ $\beta(B_c/x_c,P_c)$
$CeCu_{6-x}M_x$	1.5/1.3,<1*	γ-a$\sqrt{T}$/logT	1/0.8
$YbRh_2Si_2$	1* / 1	logT "+"/logT "+"	-/0.75
$YbCu_{5-x}Al_x$	1.5/1.3	logT/γ-a$\sqrt{T}$	0.89/0.74

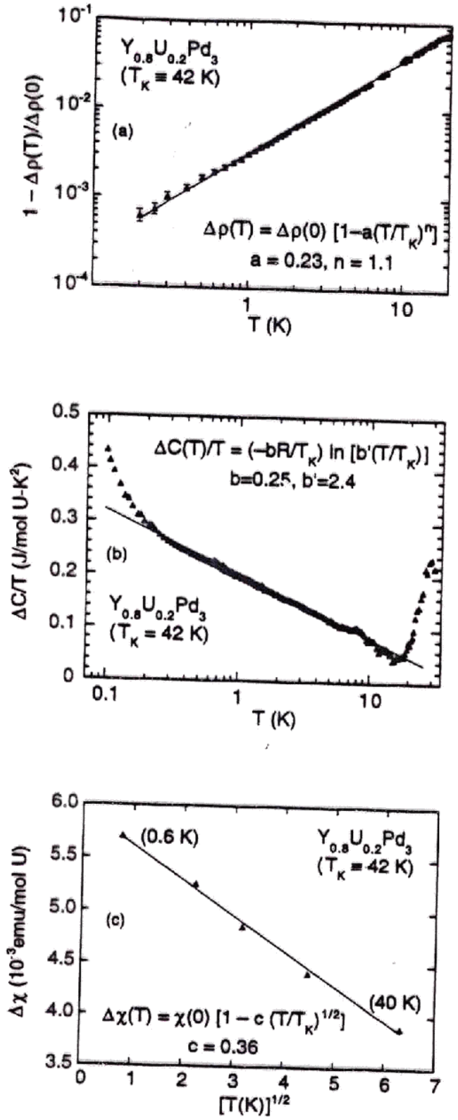
*restricted, T<0.2 K, temperature range

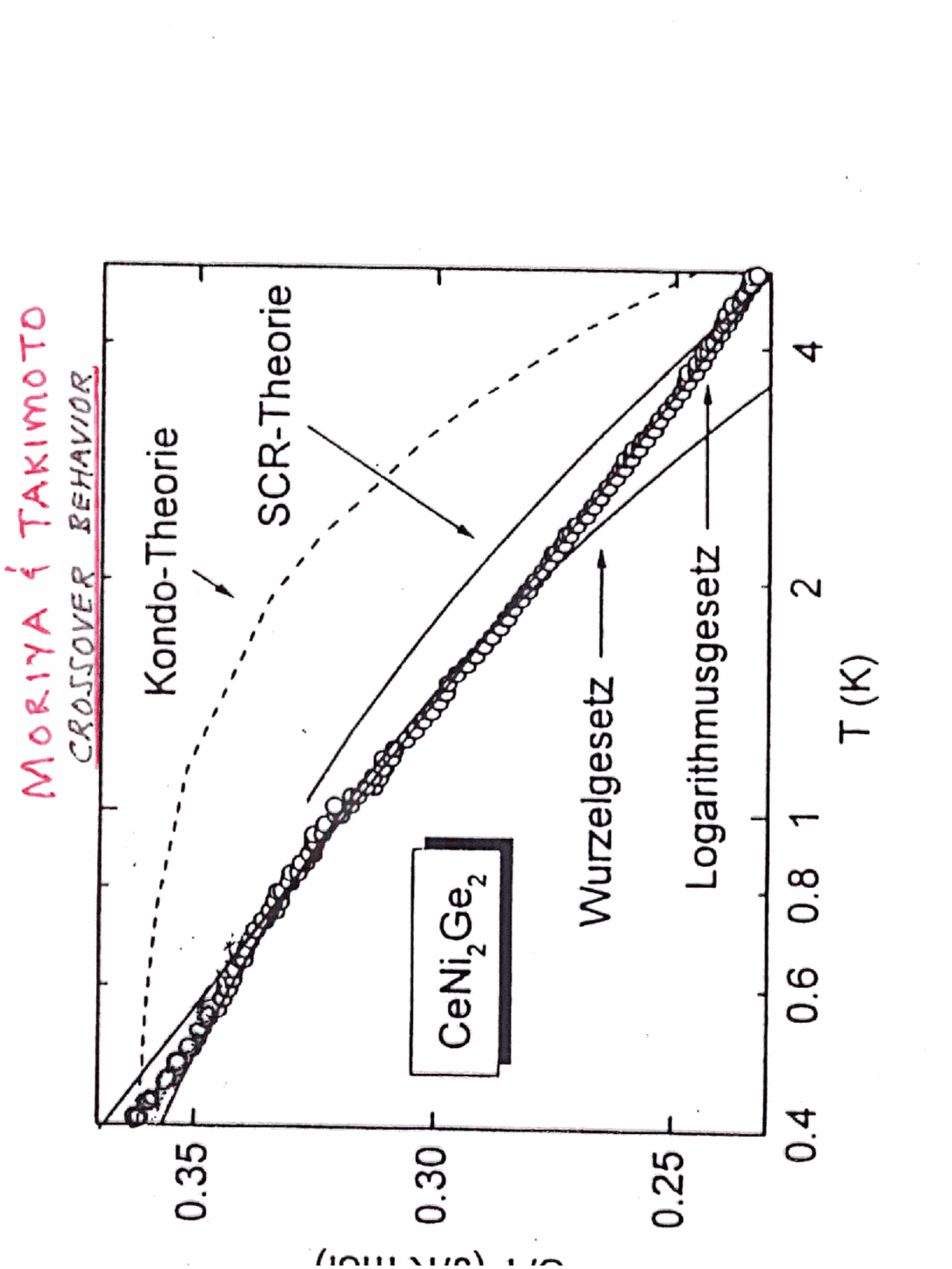
$U_x Y_{1-x} Pd_3$ (Gajewski, et al. PRB 62, '00)

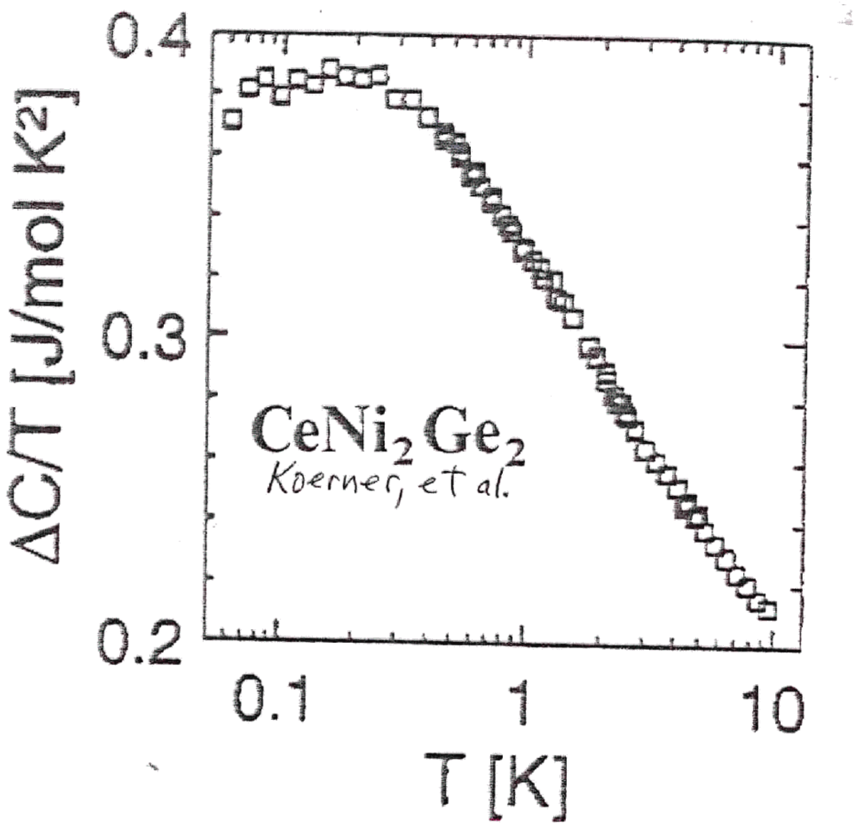


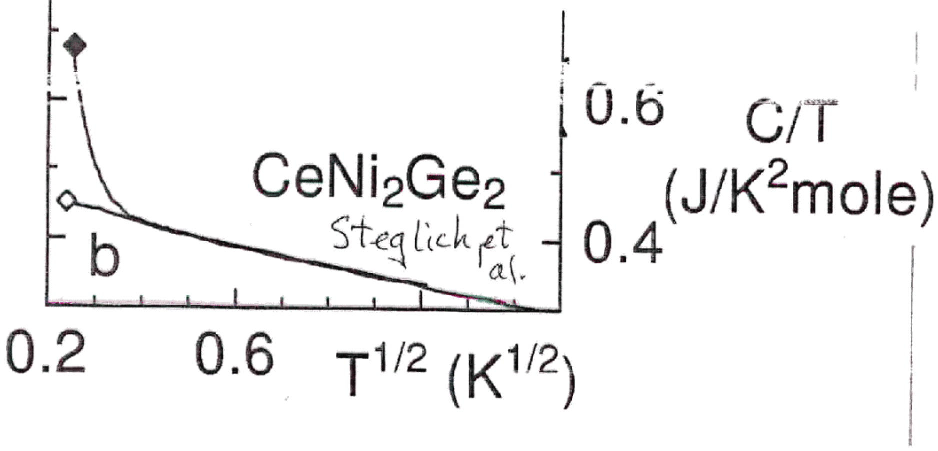
$U_x Sc_{1-x} Pd_3$

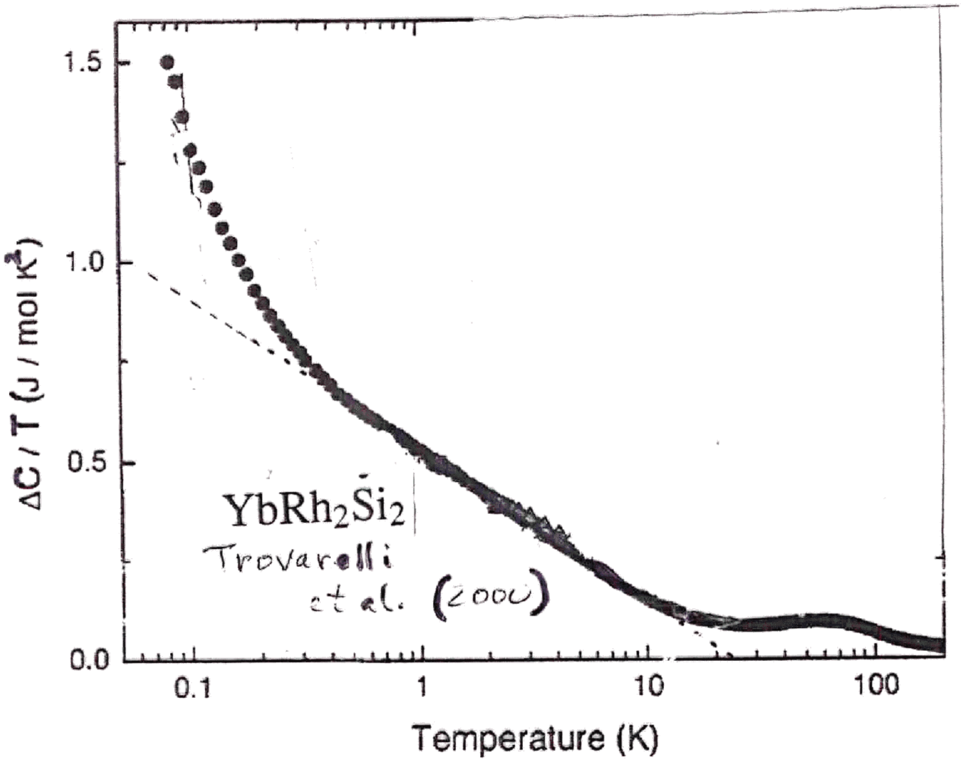

x=0
20 µm
0.1
50 µm
0.2
20 µm
0.3
50 µm
0.4
20 µm
0.5
50 µm


Y0.8U0.2Pd3
(TK = 42 K)
(a)
1 − Δρ(T)/Δρ(0)
10^-1
10^-2
10^-3
10^-4
Δρ(T) = Δρ(0) [1−a(T/TK)^n]
a = 0.23, n = 1.1
1
10
T (K)
ΔC(T)/T = (−bR/TK) ln [b'(T/TK)]
b=0.25, b'=2.4
(b)
Y0.8U0.2Pd3
(TK = 42 K)
ΔC/T (J/mol U-K²)
0
0.1
0.2
0.3
0.4
0.5
0.1
1
10
T (K)
(0.6 K)
Y0.8U0.2Pd3
(TK = 42 K)
(c)
Δχ (10^-3 emu/mol U)
3.5
4.0
4.5
5.0
5.5
6.0
Δχ(T) = χ(0) [1 − c (T/TK)^1/2]
c = 0.36
(40 K)
0
1
2
3
4
5
6
7
[T(K)]^1/2

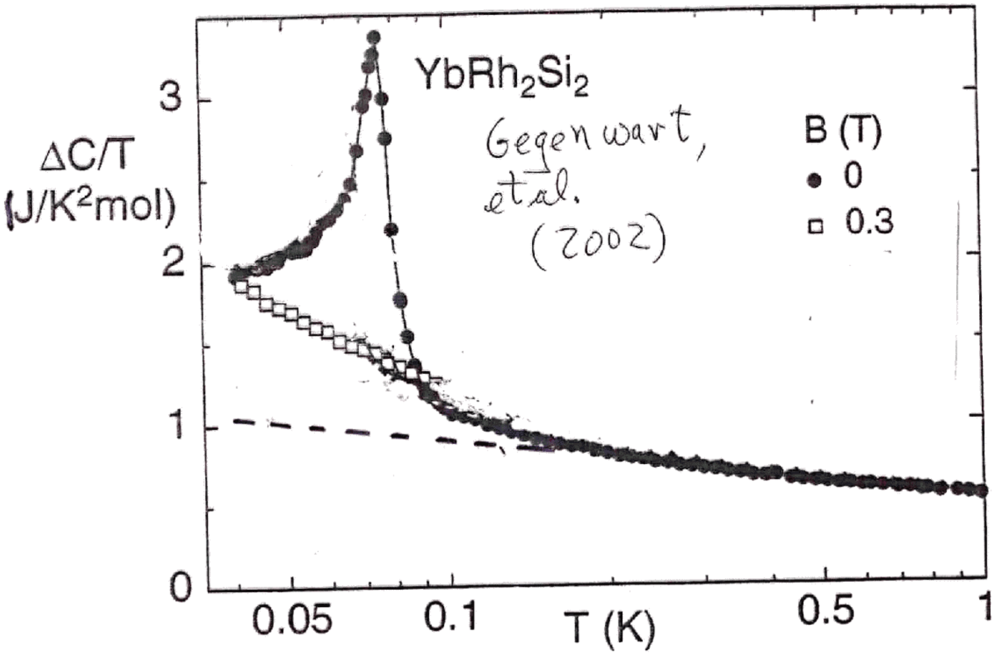

MORIYA & TAKIMOTO
CROSSOVER BEHAVIOR
Kondo-Theorie
SCR-Theorie
$CeNi_2Ge_2$
Wurzelgesetz
Logarithmusgesetz
0.35
0.30
0.25
0.4
0.6
0.8
1
2
4
T (K)


0.4
0.3
0.2
ΔC/T [J/mol K²]
$CeNi_2Ge_2$
Koerner, et al.
0.1
1
10
T [K]


$CeNi_2Ge_2$
Steglich et al.
b
0.6
0.4
C/T
(J/K²mole)
0.2
0.6
$T^{1/2}$ ($K^{1/2}$)

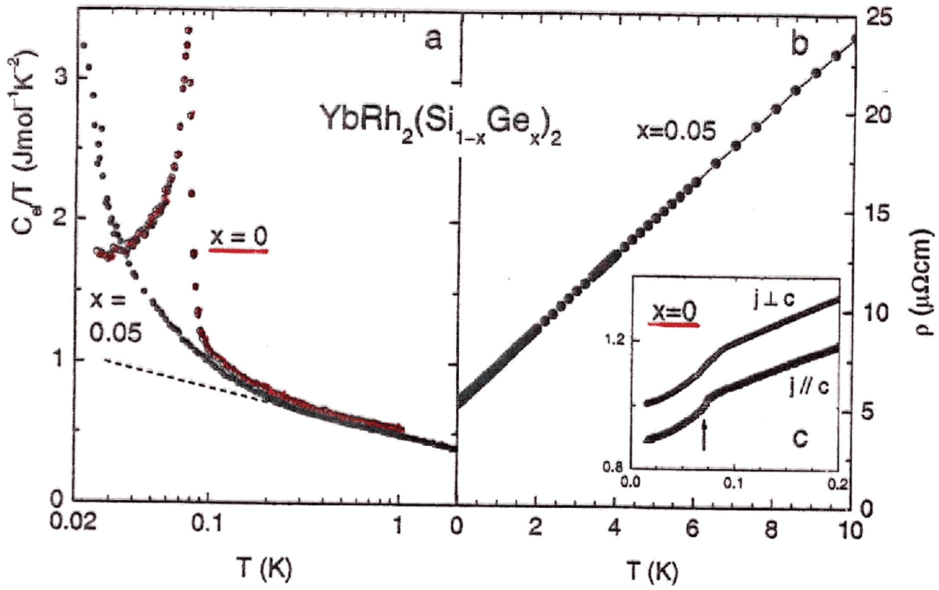


Trovarelli et al. (2000)



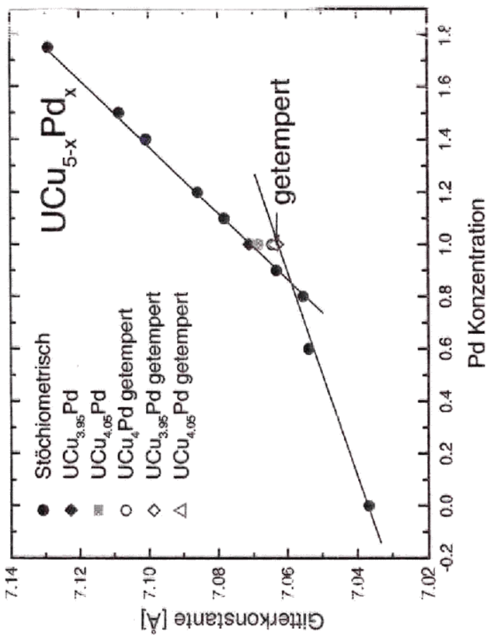
Gegenwart, et al. (2002)

3. Zero field NFL behavior in $YbRh_2(Si_{0.95}Ge_{0.05})_2$

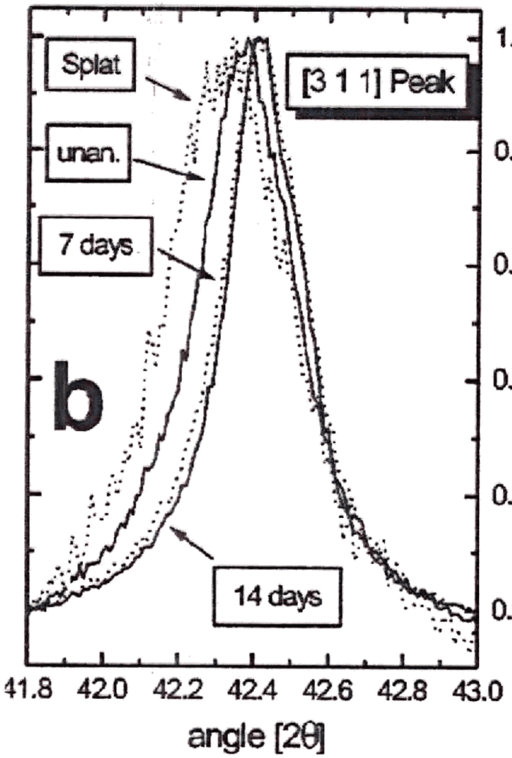


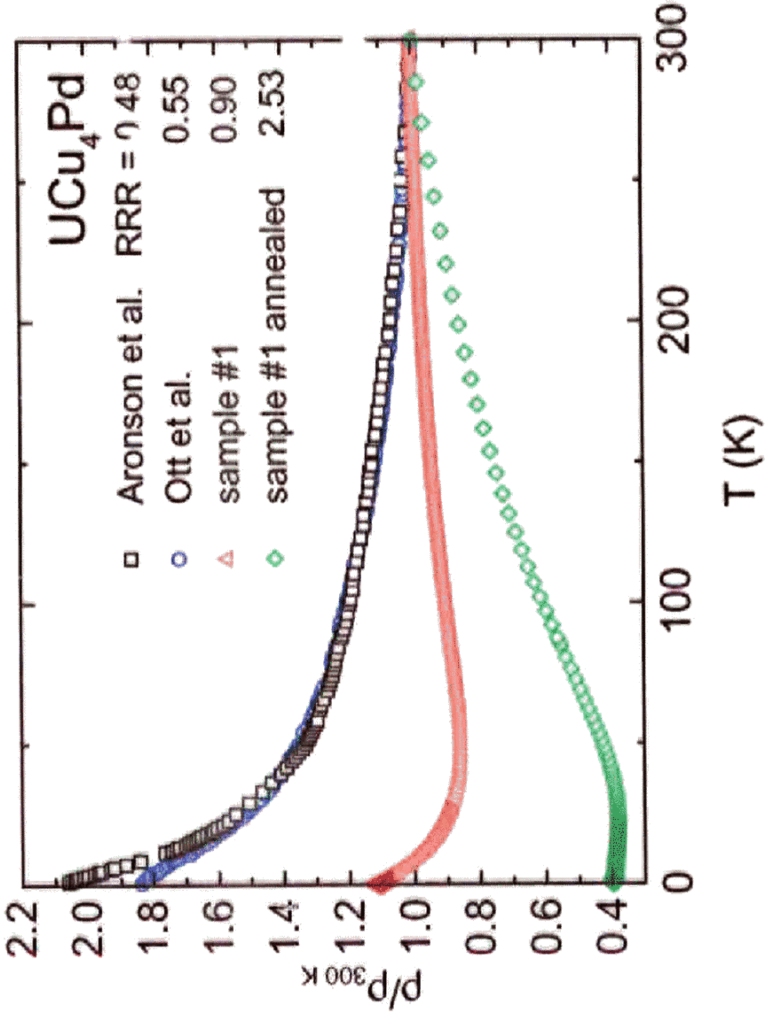
Retrospective on UCu_4Pd – should we treat it as 'disordered'?

I. **Annealing clearly affects order (Weber, et al. PRB 63, 205116 {'01} -discuss $AuBe_5$ structure with one (larger) Be I site and four (smaller) Be II sites. (Pd is *larger* than Cu)**



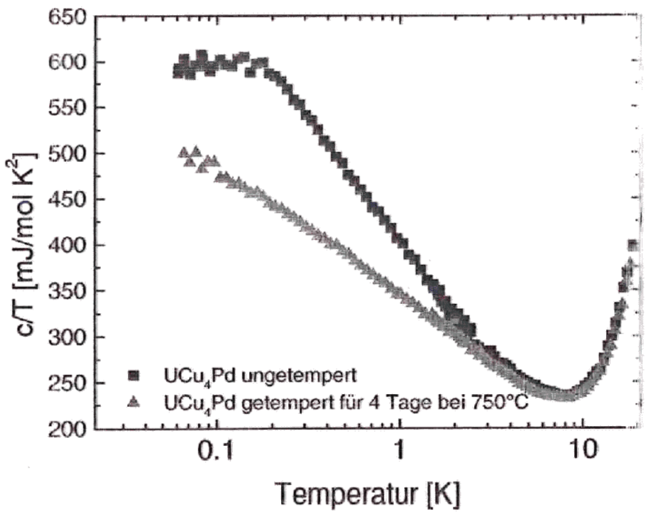
UCu$_4$Pd


Splat
unan.
7 days
14 days
[3 1 1] Peak
b
1.0
0.8
0.6
0.4
0.2
0.0
intensity [a. u.]
41.8
42.0
42.2
42.4
42.6
42.8
43.0
angle [2θ]


UCu$_4$Pd
RRR = 0.48
0.55
0.90
2.53
□ Aronson et al.
○ Ott et al.
△ sample #1
◇ sample #1 annealed
0
100
200
300
T (K)
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
$\rho/\rho_{300\ K}$

Retrospective on UCu_4Pd - continued

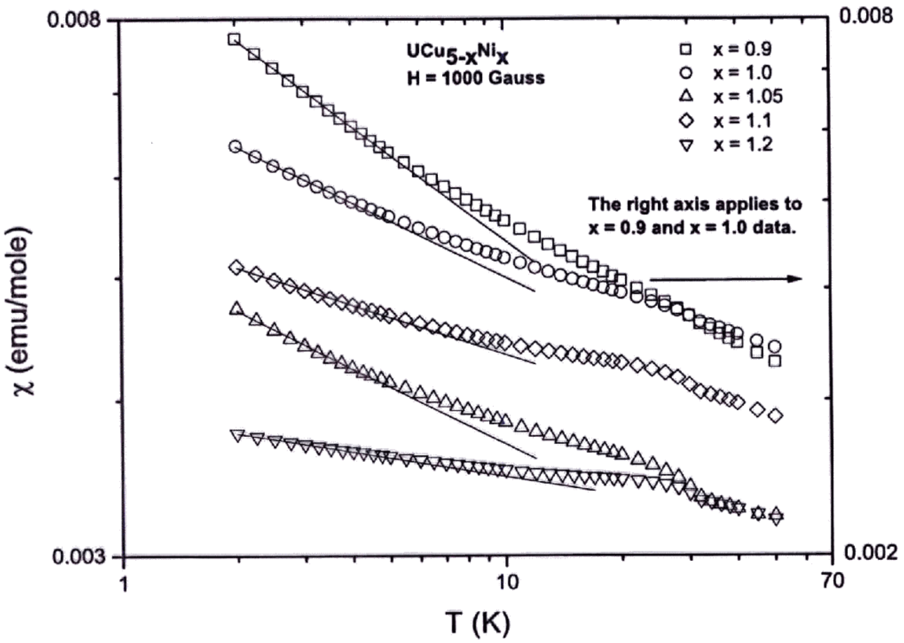
II. Annealing (and better order) affect the specific heat



Retrospective on UCu_4Pd

Conclusion: EXAFS and lattice parameter data show that UCu_4Pd is 'partly' ordered, and the specific heat shows that slight differences in Be I sublattice ordering (from ~ 73% Pd occupation in unannealed to ~ 81 % Pd occupation in annealed material – Booth et al., PRB 66, 140402 {2002}) are important.

⇒ Need to study a system with 'better' disorder near a QCP.



0.008
0.003
0.008
0.002
1
10
70
T (K)
χ (emu/mole)
$UCu_{5-x}Ni_x$
H = 1000 Gauss
□ x = 0.9
○ x = 1.0
△ x = 1.05
◇ x = 1.1
▽ x = 1.2
The right axis applies to x = 0.9 and x = 1.0 data.