Experimental Status Report on Disordered QPT's

χ(T), M vs H, and C(H)/T for 3 disordered systems (one away from a QCP, two at a QCP) will be presented. Primary theory used for comparison is the Griffiths phase model of Castro Neto and Jones.

The data *sometimes* fit the model, but the experimental situation is quite complex.

Theories of Disorder QPT's

I. Kondo Disorder

$k_B T_K = \varepsilon_F \exp[-1/N(0)J]$, disorder introduces a distribution of T_K's (Dobrosavljevic, Kirkpatrick, Kotliar{1992}; Bhatt and Fisher {1992}; Bernal et al. (fit to exp.){1995}; Miranda et al. {1996,1997}

II. Interplay of spin fluctuations and disorder near a QCP, resistivity (Rosch {1999}), **C and χ** (Fischer and Rosch, '04)

III. Quantum Spin Glass (Georges, Parcolet, Sachdev {2000})

IV. Griffiths phase

Tunneling within rare spin clusters (Castro Neto, Castilla, Jones {'98}; Castro Neto and Jones {'00})

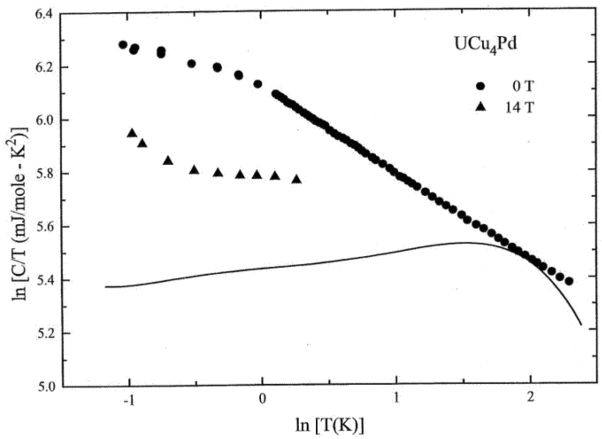
χ and $C/T \sim T^{-1+\lambda}$, $M \sim H^{\lambda}$ above $H_{threshold}$,

also $C(H)/T \sim (H^{2+\lambda/2} / T^{3-\lambda/2})\exp[-\mu_{eff}H/T]$

(peak in C(H)/T above $H_{threshold}$)

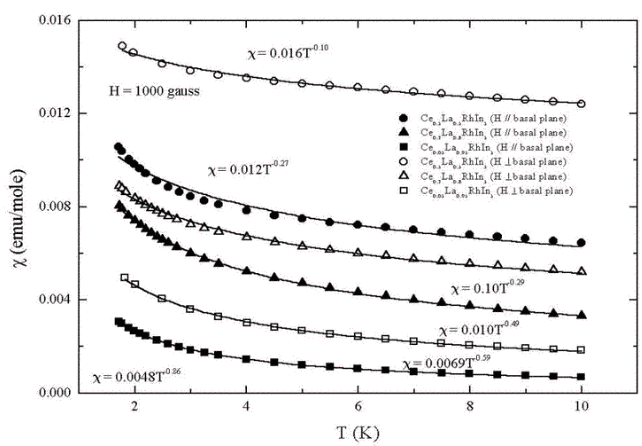
Focus on C(H)

Disordered Kondo model does address C(H) but does not, e. g., fit UCu_4Pd data - no $C/T \sim T^{-1+\lambda}$ and no peak in C/T with applied field so Griffiths phase model <u>also out</u>. (*Is* UCu_4Pd disordered??)



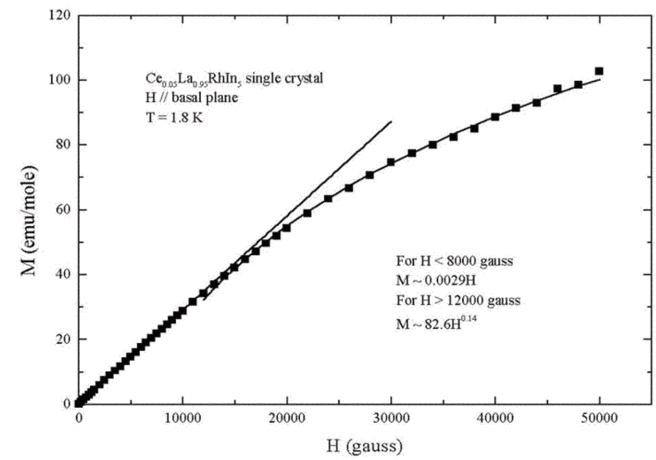
Data from Andraka and Stewart, PRB 47, 3208 (1993)

Work on Disordered nFl Systems $Ce_{1-x}La_xRhIn_5$ (PRB 66, 134418 {'02'}), $Ce_{1-x}Th_xRhSb$ (PRB 67, 184401 {'03}), and $UCu_{5-x}Ni_x$



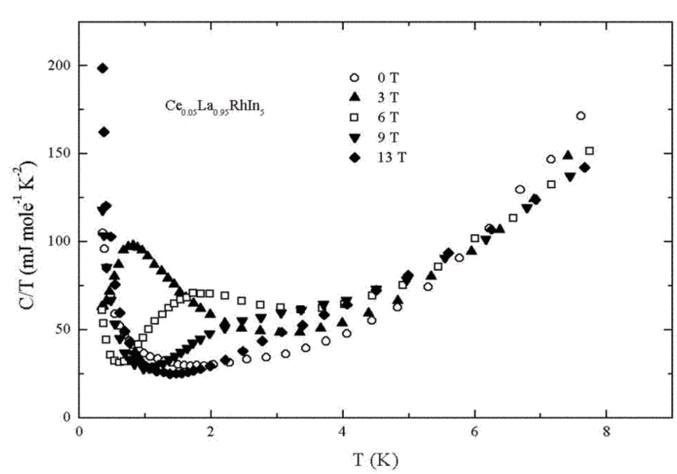
χ vs T for $Ce_{1-x}La_xRhIn_5$ showing power law dependence $T^{-1+\lambda}$. $T_N \rightarrow 0$ for $x > 0.32$

$Ce_{0.05}La_{0.95}RhIn_5$ M vs H_basal plane



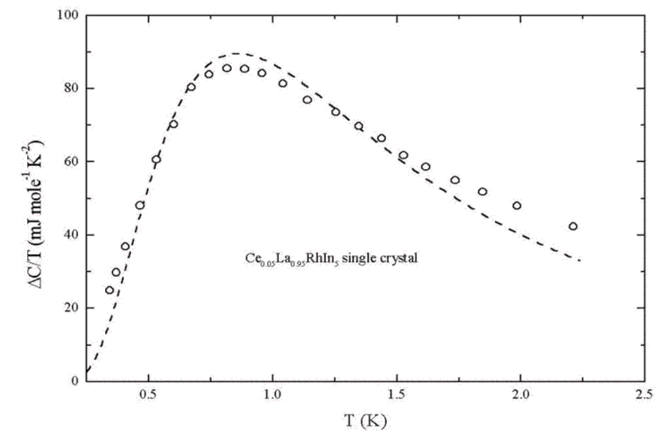
Get <u>same</u> value of λ from M vs H as from χ vs T in last slide.

C(H)/T for $Ce_{0.05}La_{0.95}RhIn_5$ H_basal plane



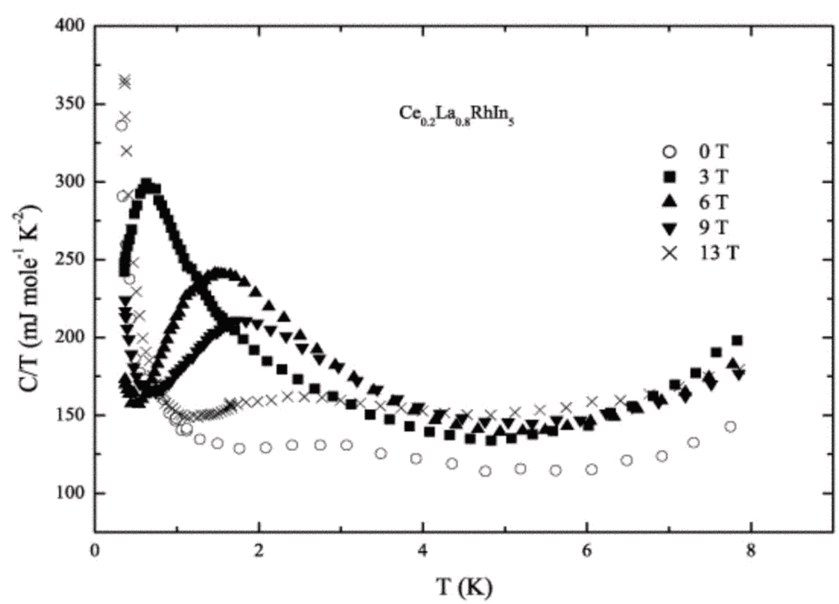
Upturns at low T in field are due to splitting of nuclear levels. This effect is subtracted off in the next slide.

C(3 T)/T for $Ce_{0.05}La_{0.95}RhIn_5$ fit to C.N.-J. Griffiths Phase Theory

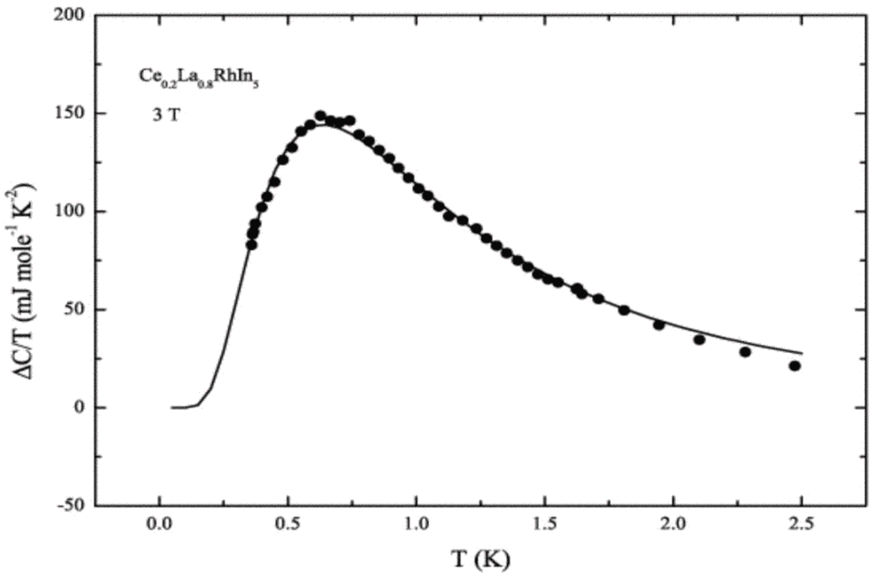


Fit to ΔC uses $\lambda=0.14$ from the χ vs T (<u>and</u> M vs H) fits and thus has only two free fitting parameters.

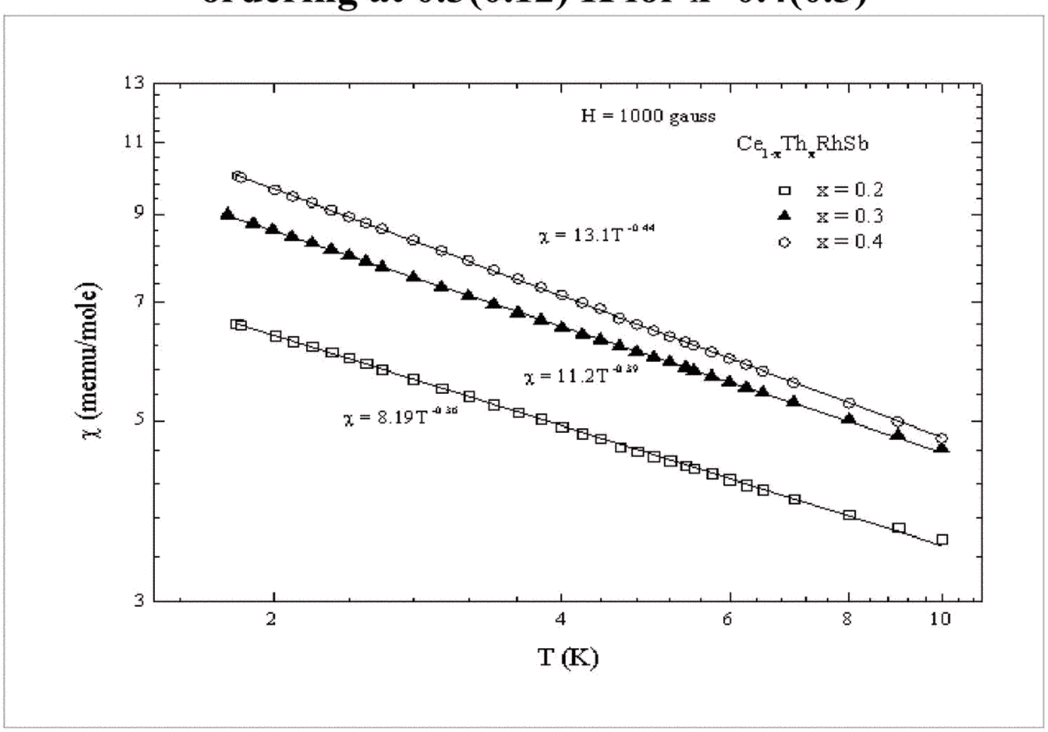
C(H)/T for $Ce_{0.2}La_{0.8}RhIn5$



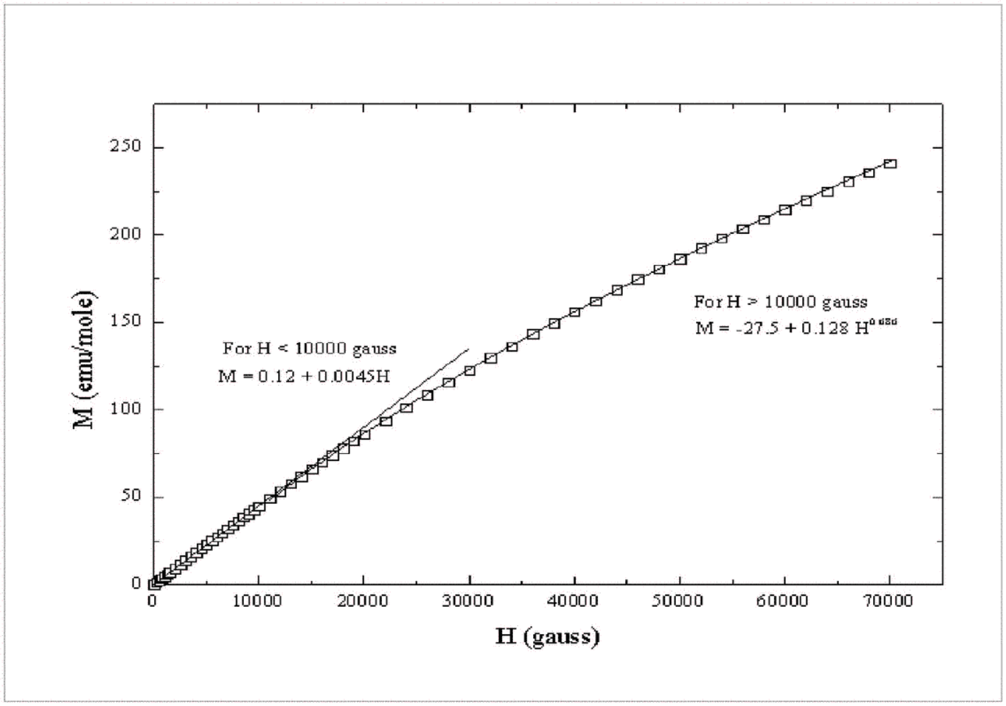
C(3 T)/T $Ce_{0.2}La_{0.8}RhIn_5$ fit to C.N.-J. Griffiths Phase Theory



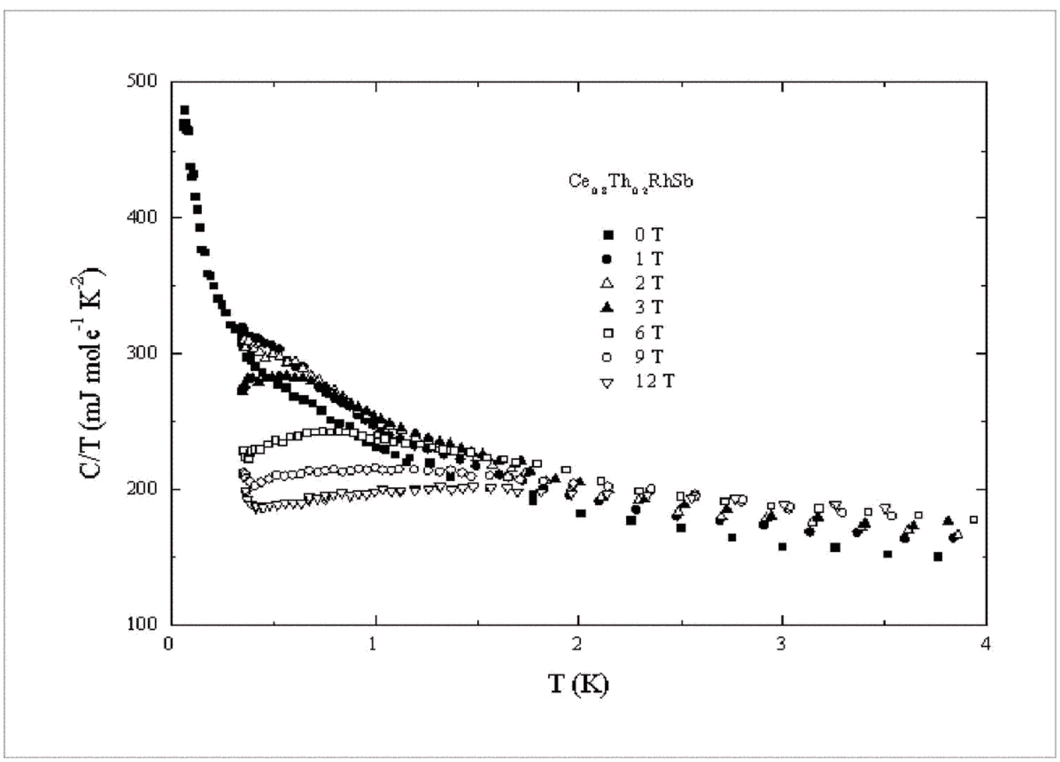
χ vs T for $Ce_{1-x}Th_xRhSb$ (disorder on the f-electron site) showing power law dependence $T^{-1+\lambda}$, $T_N \rightarrow 0$ at x ~ 0.2, some remanent ordering at 0.3(0.12) K for x=0.4(0.3)



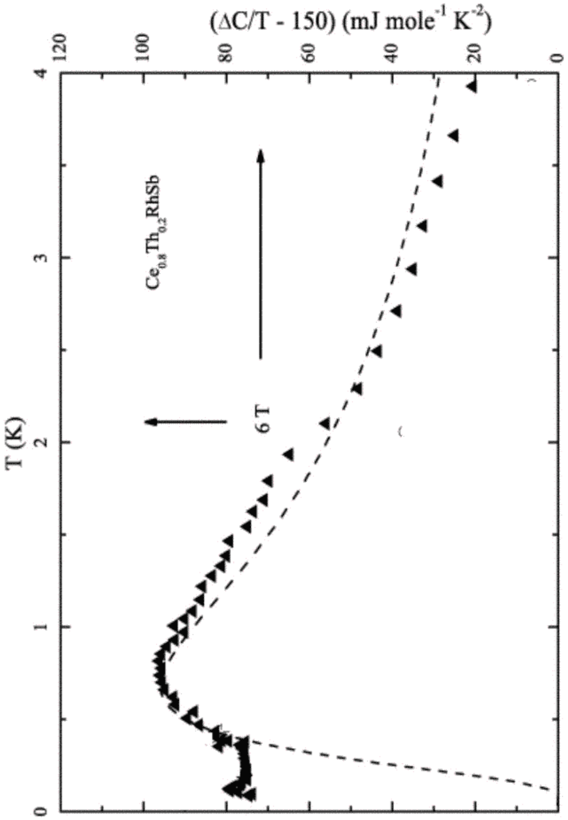
M vs H for $Ce_{0.8}Th_{0.2}RhSb$ fit to C.N.-J. Griffiths Phase



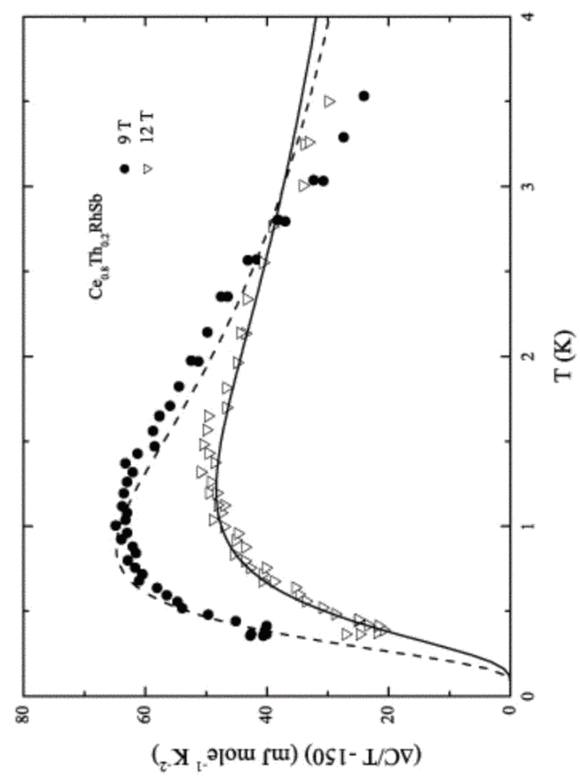
C(H)/T for $Ce_{0.8}Th_{0.2}RhSb$



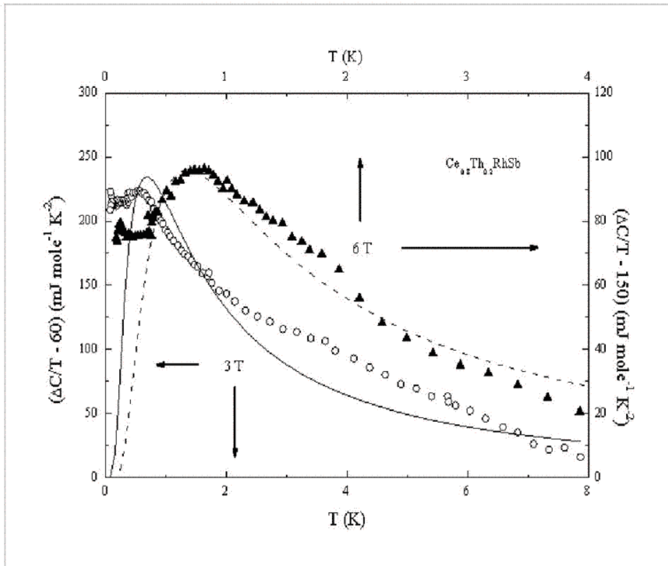
C(6 T)/T for $Ce_{0.8}Th_{0.2}RhSb$ fit to C.N.-J. Griffiths Phase



C(9, 12 T)/T for $Ce_{0.8}Th_{0.2}RhSb$ fit to C.N.-J. Griffiths Phase

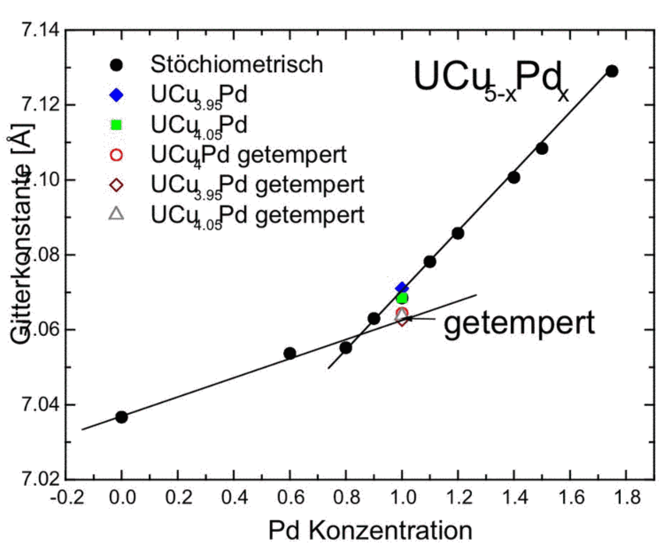


$Ce_{0.8}Th_{0.2}RhSb$ but . . .



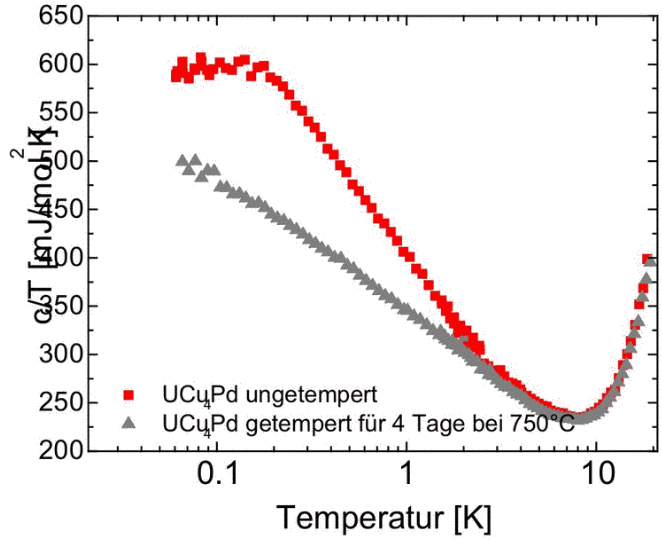
Retrospective on UCu_4Pd – should we treat it as ‘disordered’?

I. **Annealing <u>clearly</u> 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)**



Retrospective on UCu_4Pd - continued

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

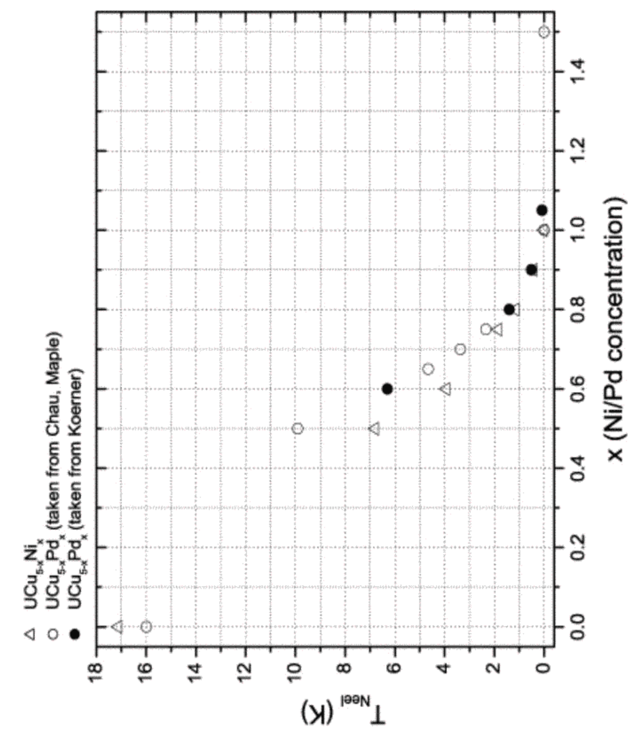


Retrospective on UCu_4Pd - end

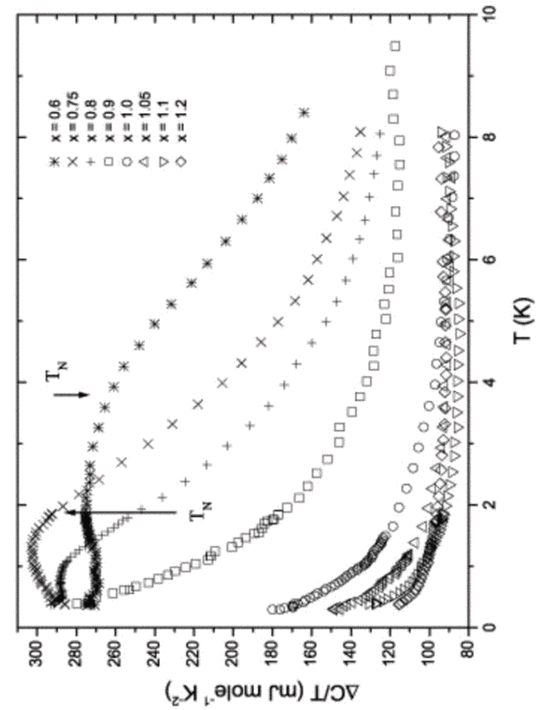
Conclusion: **EXAFS and lattice parameter data show that UCu_4Pd is 'partly' ordered, and the specific heat shows that slight differences in Be I sublattice ordering (from ~ 73% Pd occupation in unannealed to ~ 81 % Pd occupation in annealed material – Booth et al., PRB 66, 140402 {2002}) are important.**

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

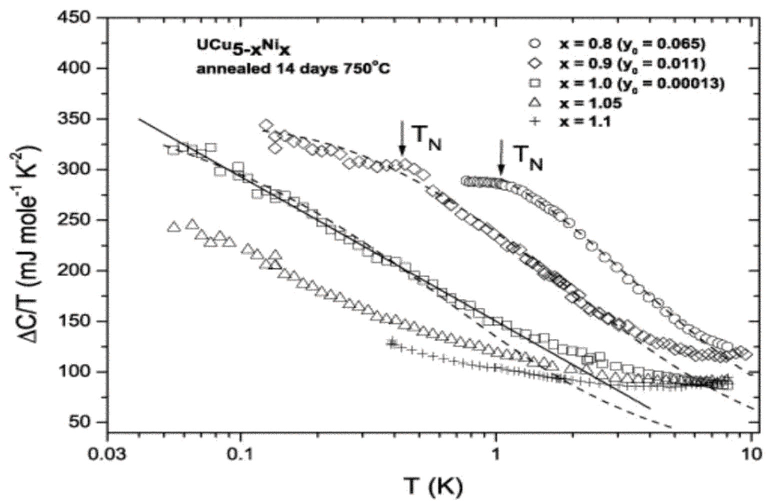
$UCu_{5-x}Ni_x$ (T_N vs x) (Also $UCu_{5-x}Pd_x$)



$UCu_{5-x}Ni_x$ (C/T near x_{QCP})

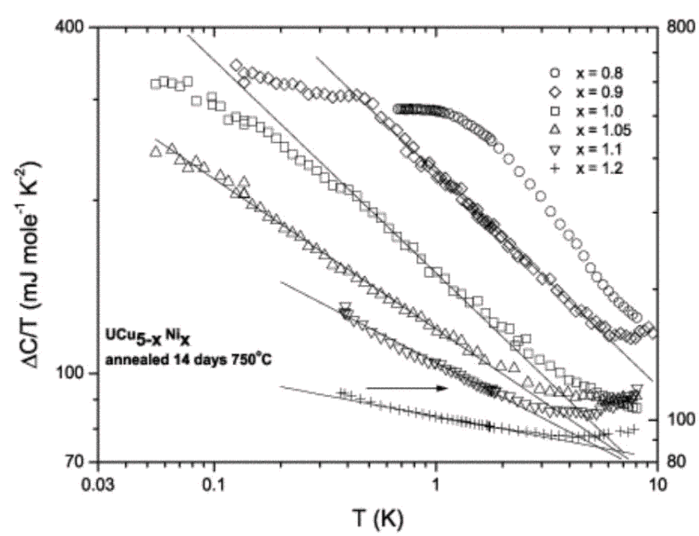


$UCu_{5-x}Ni_x$ (C/T vs logT)



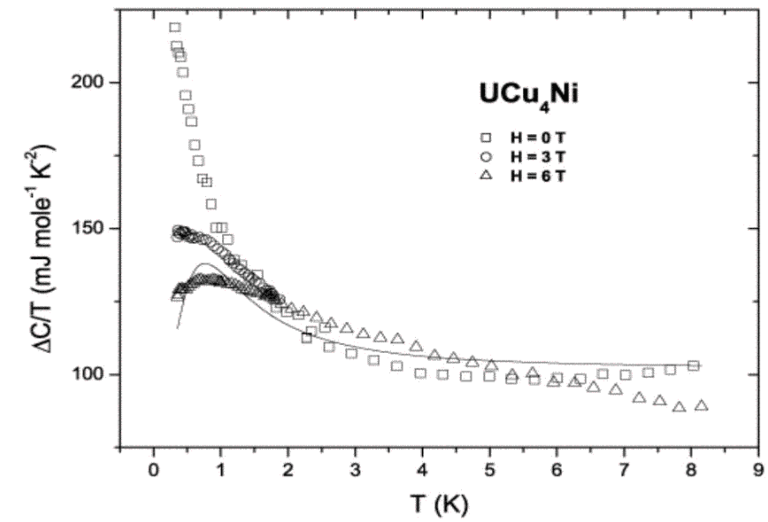
Dashed lines are fits to Moriya's theory of data down to T_N; $y_0 \rightarrow 0$ at QCP. Solid line through the x=1.0 data shows that logT is a better fit to the data at the QCP

$UCu_{5-x}Ni_x$ (logC/T vs logT)

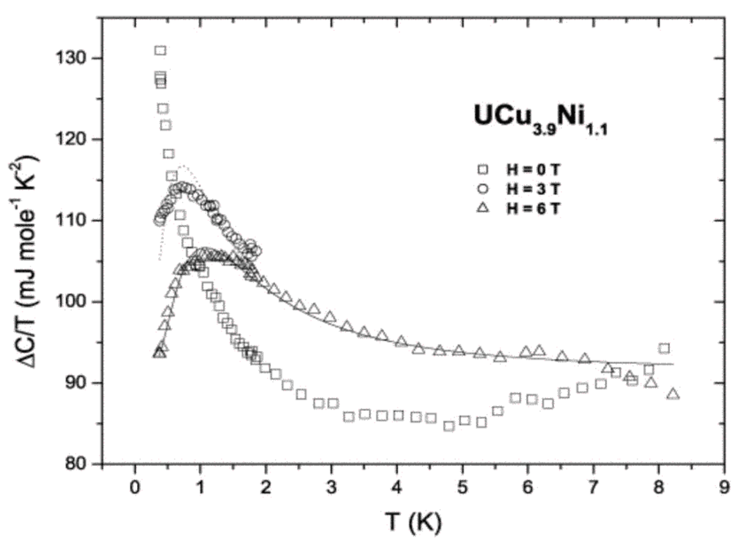


Straight, solid line (⇔Power law, Griffiths phase) is *not* a good fit at x=1.0, QCP, but *is* slightly away from x=1.0

$UCu_{5-x}Ni_x$ Field dependence of C/T does *not* (as expected) match C.N.-J. Griffiths phase at x=1.0 (where there is QCP logT behavior) but does at x=1.1

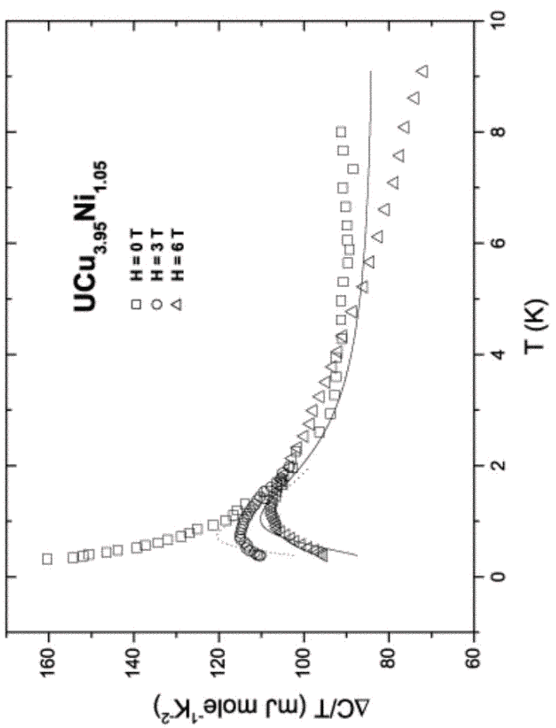


$UCu_{5-x}Ni_x$ C(6 T)/T does fit C.N.-J. for x=1.1

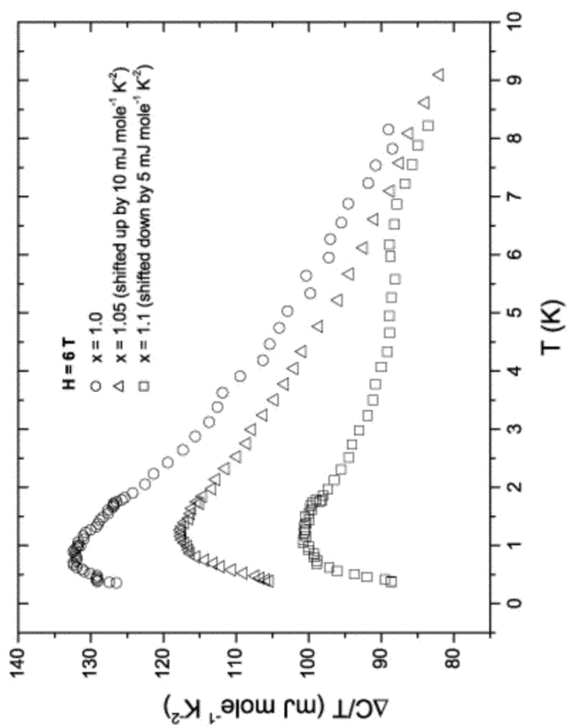


$H_{crossover}$, as determined from M vs H, is ~ 1.9 T for x=1.1

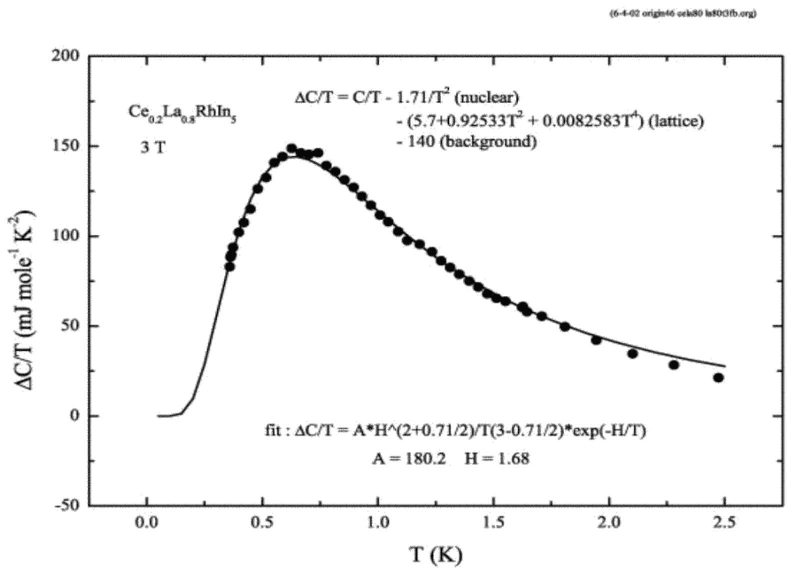
$UCu_{5-x}Ni_x$ But, what about x=1.05?



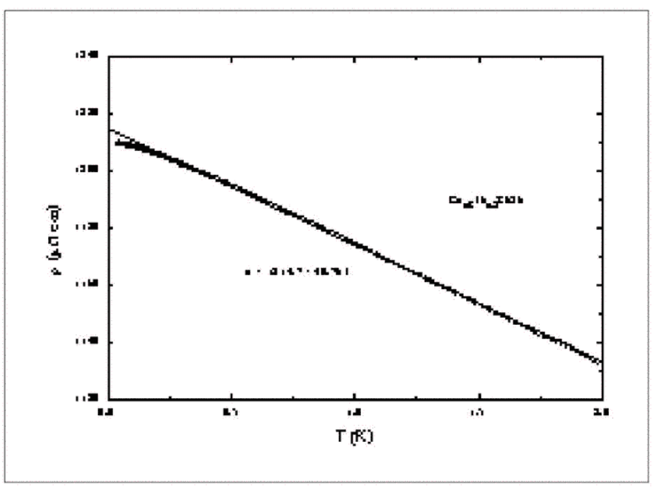
$UCu_{5-x}Ni_x$ Comparison of 6 T data near x_{QCP}



Fitting Parameters for C(H)/T for $Ce_{0.2}La_{0.8}RhIn_5$

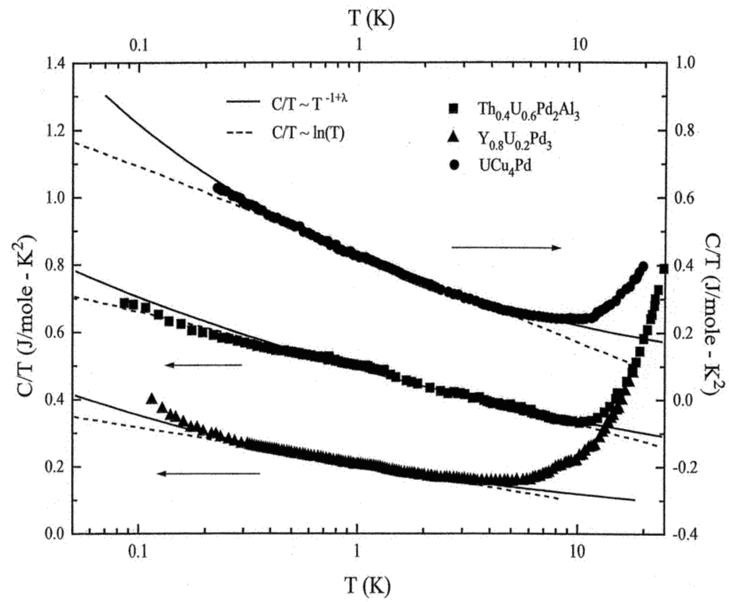


ρ for $Ce_{0.8}Th_{0.2}RhSb$

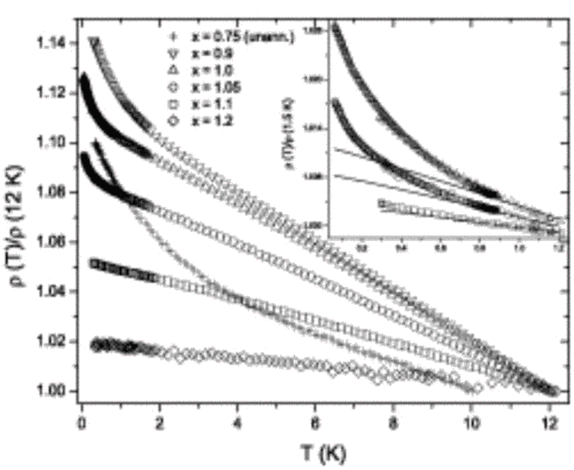


Note deviation from ~ linear behavior at low T as well as large ρ_0

Comparison of logT and $T^{-1+\lambda}$ to C/T data

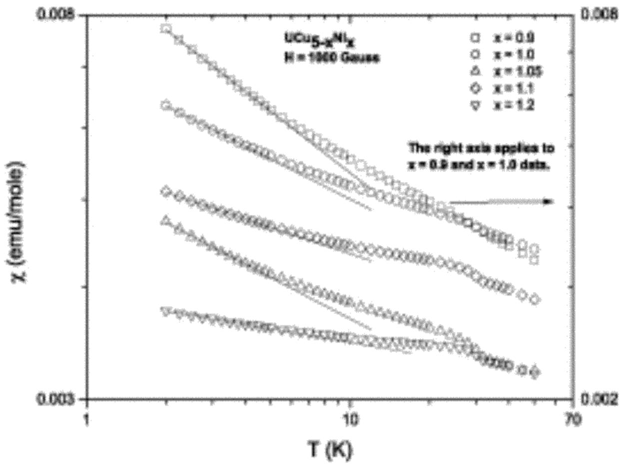


ρ For $UCu_{5-x}Ni_x$

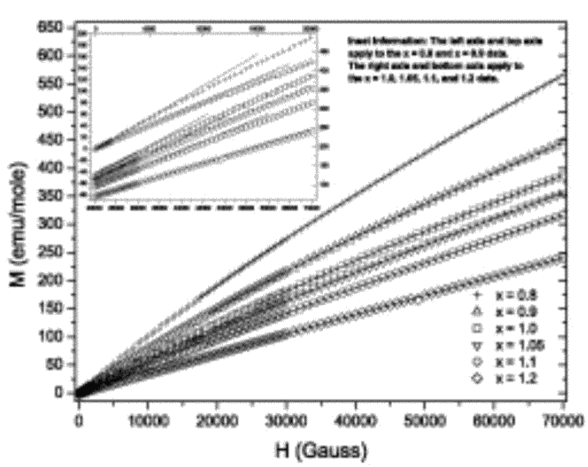


Upturns at low temperatures

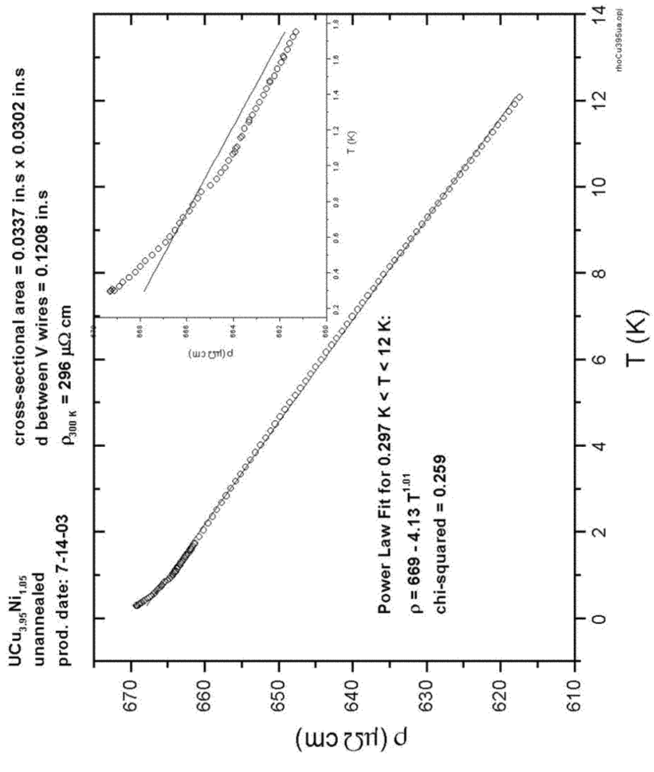
Power Law (Griffiths Phase) Fits to χ for $UCu_{5-x}Ni_x$



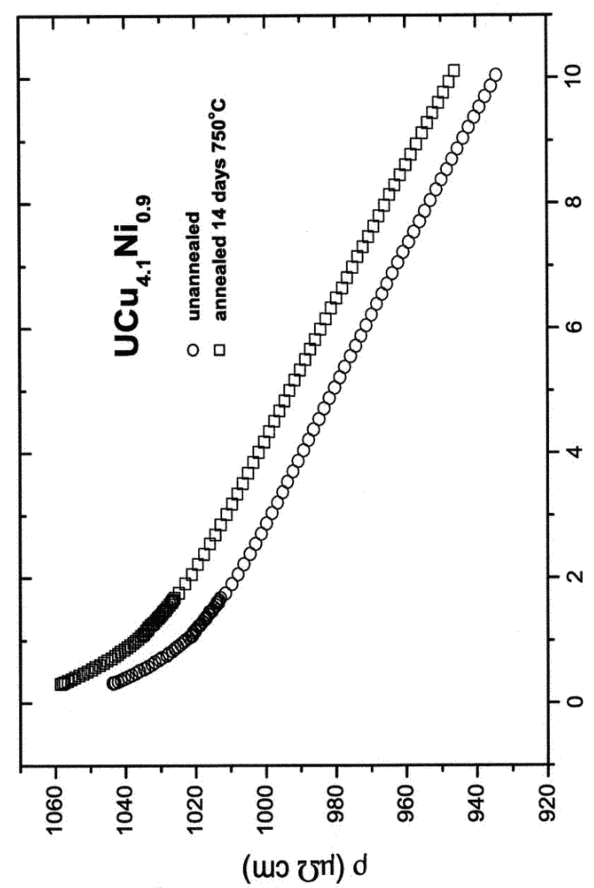
M vs H for $UCu_{5-x}Ni_x$



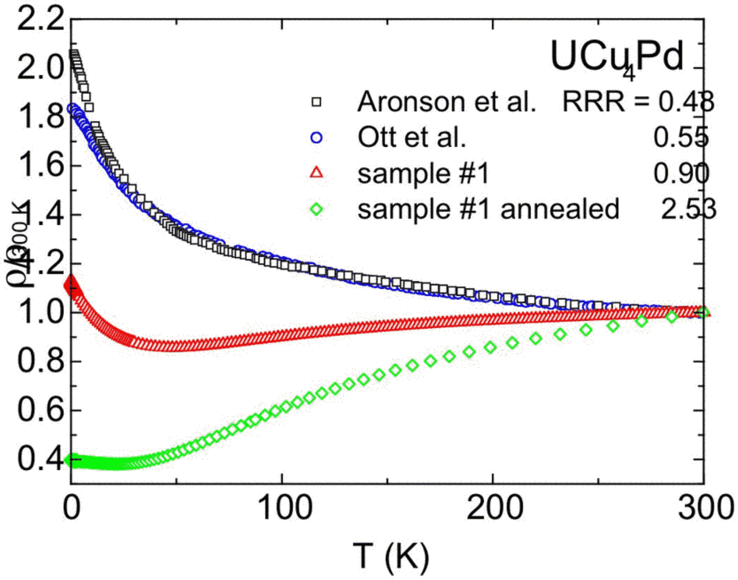
ρ at low T for $UCu_{3.95}Ni_{1.05}$



ρ vs annealing at low T for $UCu_{4.1}Ni_{0.9}$



ρ vs annealing in UCu_4Pd



C(H) for UCu_4Pd