The puzzles of $CeCu_{6-x}Au_x$

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Magnetic instability in $CeCu_{6-x}Au_x$

Classical vs. quantum phase transitions

Magnetic fluctuations by neutron scattering

Pressure vs. magnetic-field tuning

B. Bogenberger	A. Schröder
F. Huster	M. Sieck
C. Pfleiderer	O. Stockert
T. Pietrus	T. Trappmann
H.G. Schlager	B. Will

M. Loewenhaupt, N. Pyka, G Aeppli	neutron scattering
H. Wilhelm, D. Jaccard	high pressures
K. Grube, W. Fietz	compressibility
P. Coleman, A. Ramazashvili,	
A. Rosch, P. Wölfle	theory

Quantum Phase Transition in $CeCu_{6-x}Au_x$

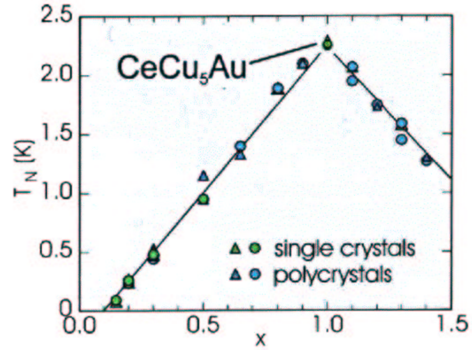
$CeCu_6$: heavy fermions with $\gamma = 1.6$ J/molK^2

non-magnetic groundstate

Onuki, … Amato

short lived AF correlations

Aeppli, Rossat-Mignod



Alloying with Au: long-range AF order

"negative lattice pressure" explains $T_N(x)$ for $x < 1$

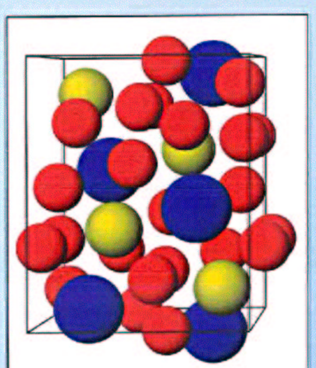
Onset of AF order at $x_C = 0.1$: quantum phase transition

Non-Fermi liquid behavior:

$$\frac{C}{T} = a \ln\left(\frac{T_0}{T}\right), \quad \rho = \rho_0 + AT, \quad T_N \sim x - x_C$$

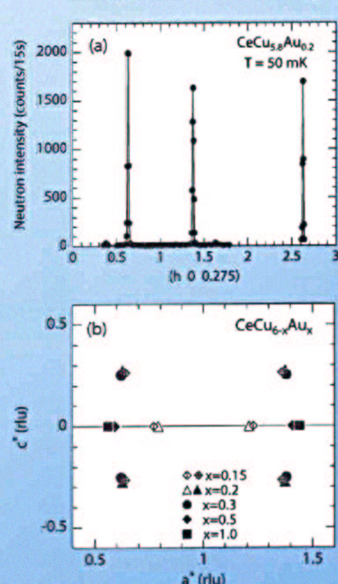
Crystal structure and magnetic order of $CeCu_{6-x}Au_x$

Orthorhombic structure
Pnma

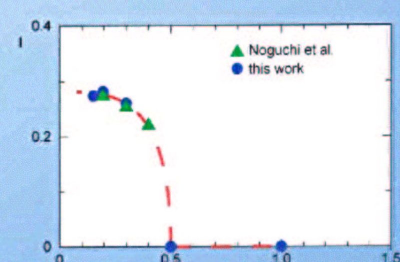


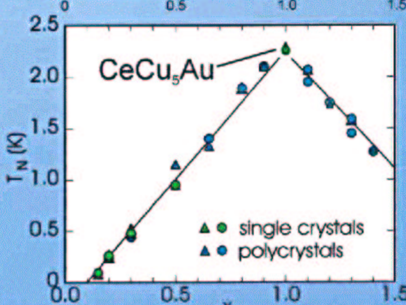
$CeCu_6$:
small monoclinic distortion suppressed for $x > 0.15$

Incommensurate magnetic ordering

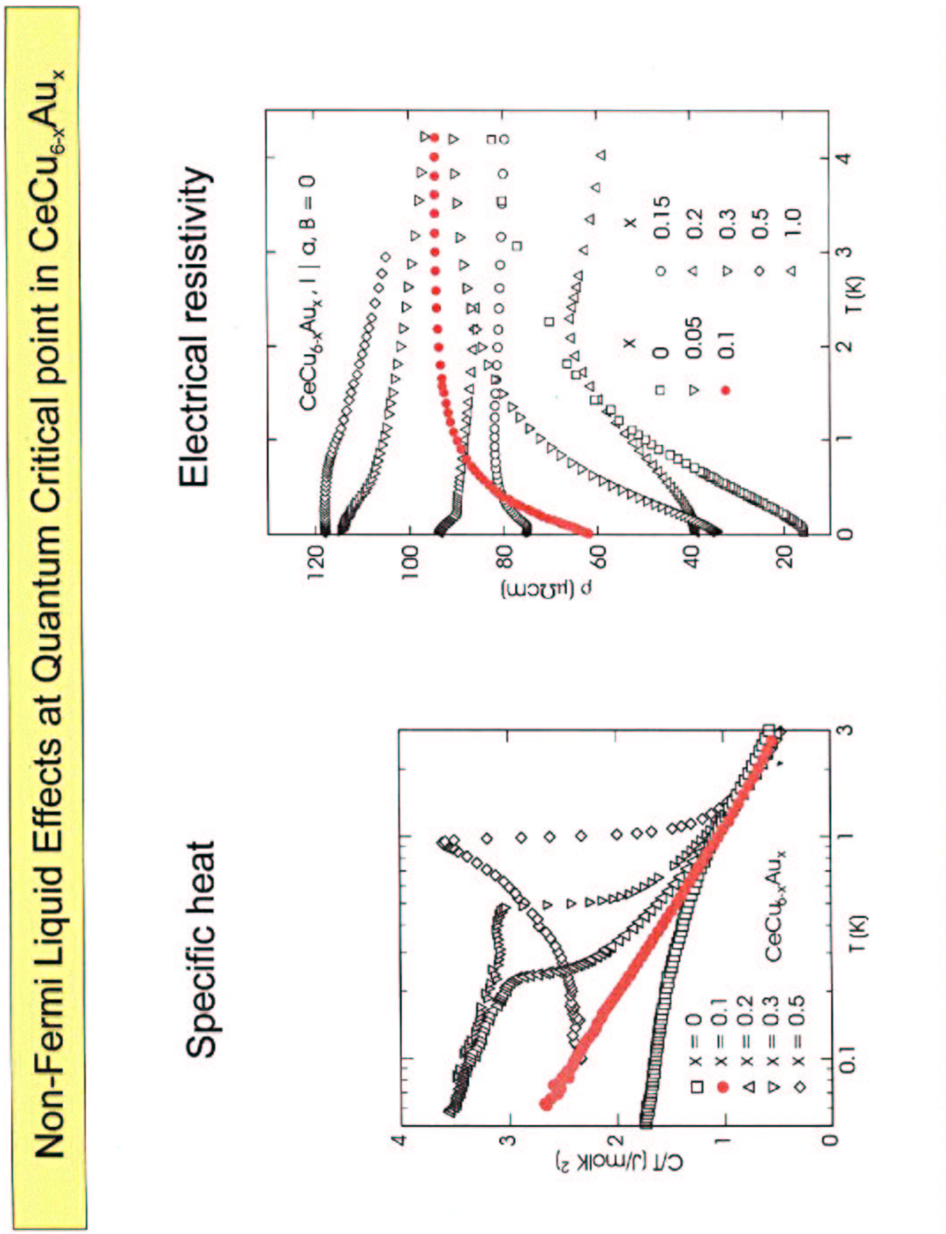


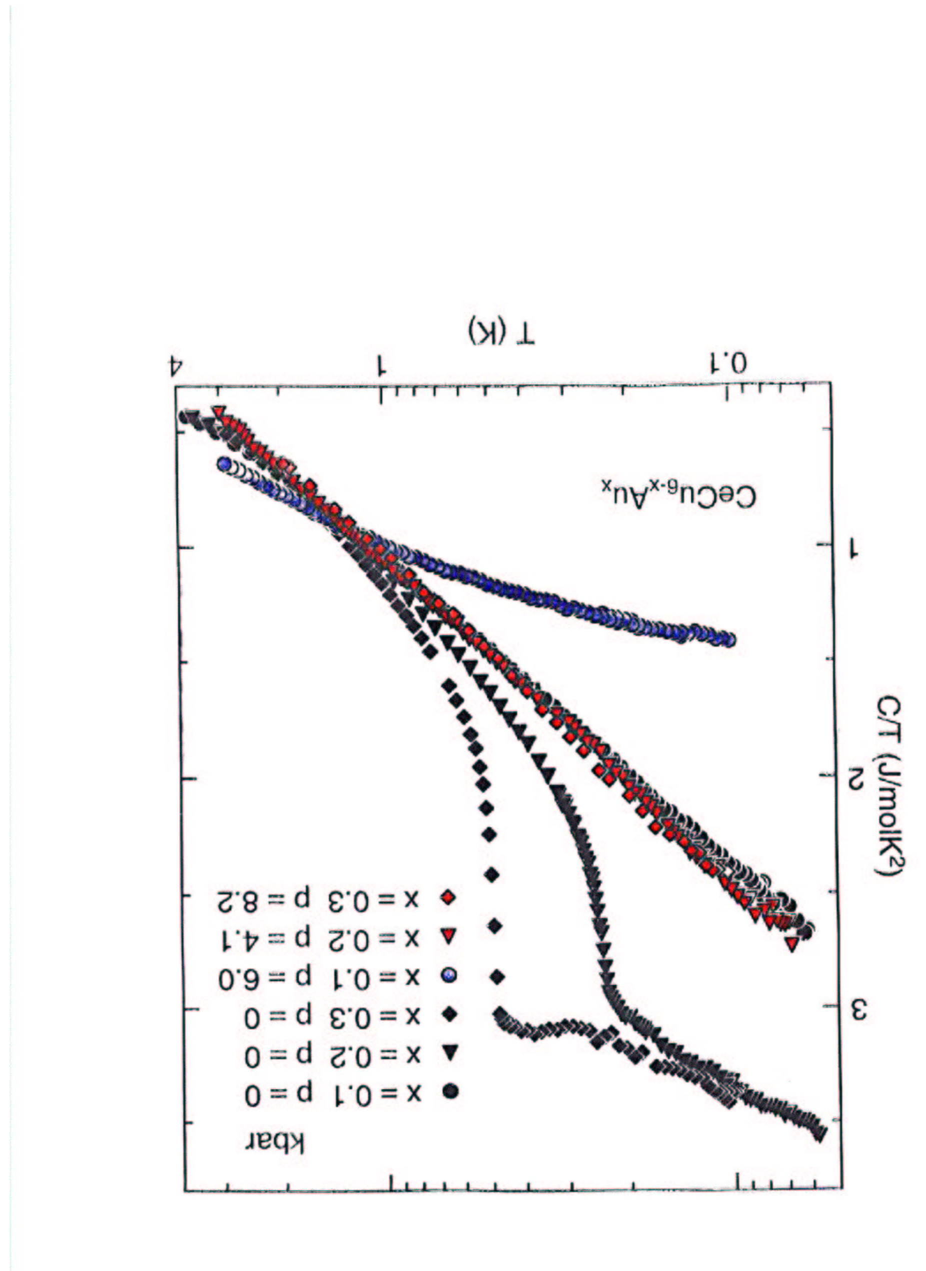
c* component of Q





$T_N(x)$ unaffected by jump of Q!


Non-Fermi Liquid Effects at Quantum Critical point in CeCu6-xAux
Electrical resistivity
Specific heat


CeCu6-xAux
C/T (J/molK²)
T (K)
kbar

Spin fluctuation scenario of the quantum critical point

Hertz, Millis, Moriya, Lonzarich

$d = 3, z = 3$ FM $C/T \sim \ln(T_0/T)$ $\Delta\rho \sim T^{5/3}$

$d = 3, z = 2$ AF $C/T \sim 1 - \beta\sqrt{T}$ $\Delta\rho \sim T^{3/2}$

$T_N \sim |\delta - \delta_c|^{\mu}$ $\mu = z/(d-2+z) < 1$ for $d = 3$

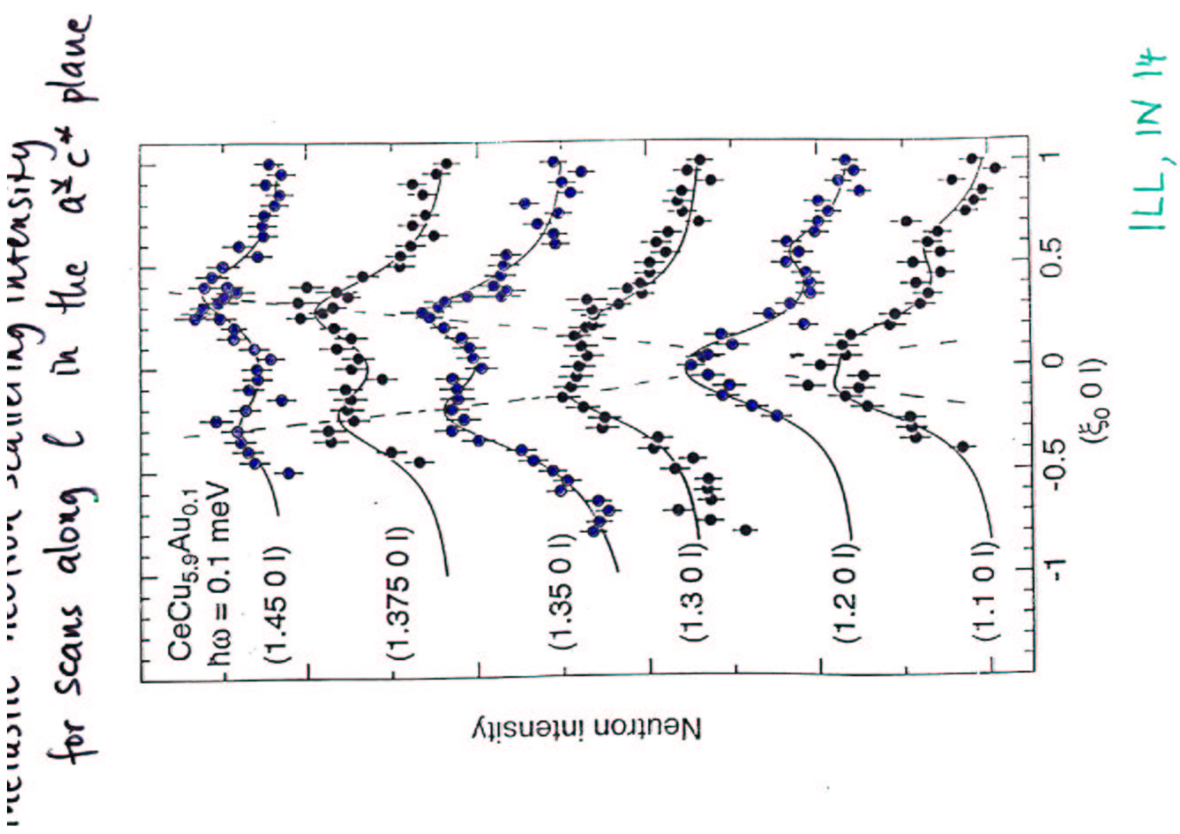
$CeCu_{6-x}Au_x$: AF $C/T \sim \ln(T_0/T)$ $\Delta\rho \sim T$

Determination of spin fluctuations by inelastic neutron scattering:

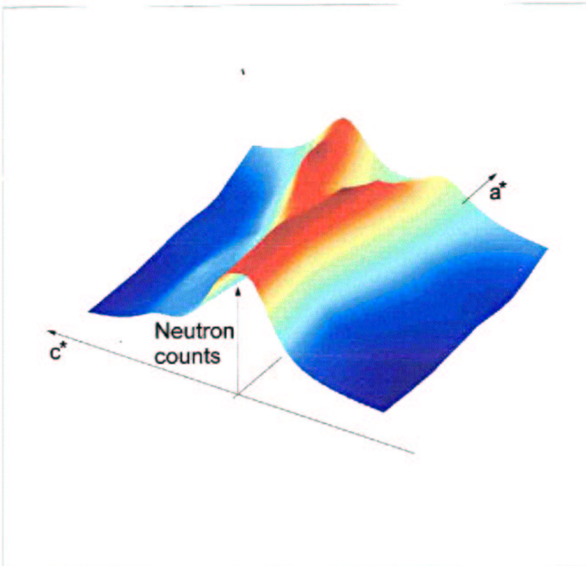
strongly anisotropic fluctuations, effectively $d = 2$

$d = 2, z = 2$ AF $C/T \sim \ln(T_0/T)$ $\Delta\rho \sim T$ *Rosch*

$\mu \approx 1$, $\delta = x, p$



Inelastic Neutron Scattering Intensity for $CeCu_{6-x}Au_x$



energy transfer $\hbar\omega = 0.1$ meV

1D features in k-space

$\hat{=}$ 2D features in real space

$\Rightarrow$ quasi-2D fluctuations

Coupling to 3D quasiparticles

$d = 2,\ z = 2$

$\Rightarrow d_{eff} = d + z = 4$

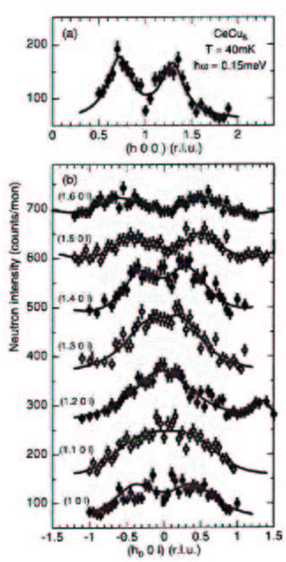
upper critical dimension

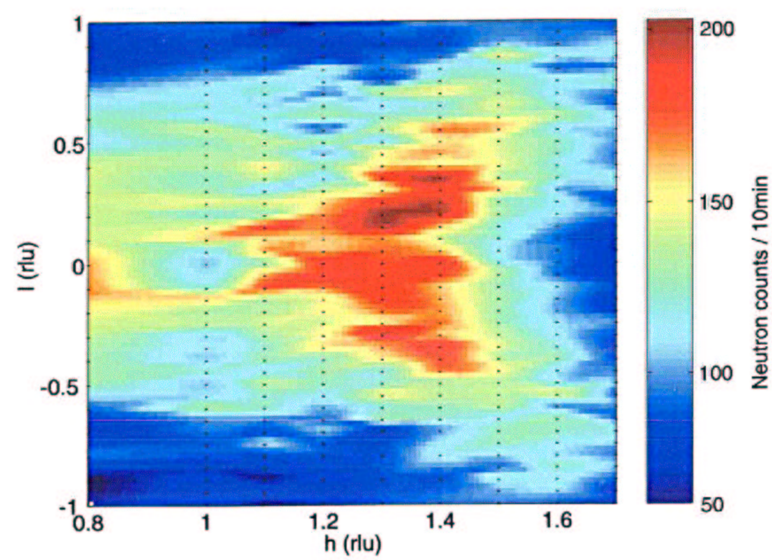
$$\frac{C}{T} = a \ln\left(\frac{T_0}{T}\right), \quad \Delta\rho \sim T$$

$$T_N \sim |\delta - \delta_C|, \quad \delta = p,x$$

A. Rosch

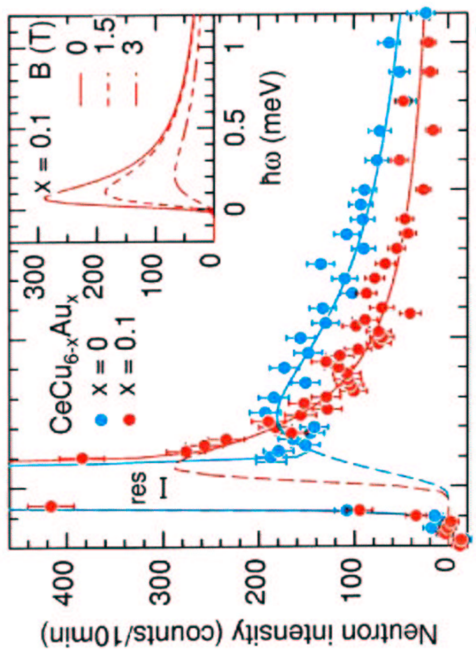
Magnetic fluctuations in $CeCu_6$





Neutron inelastic scattering at $Q = (1.2\ 0\ 0)$

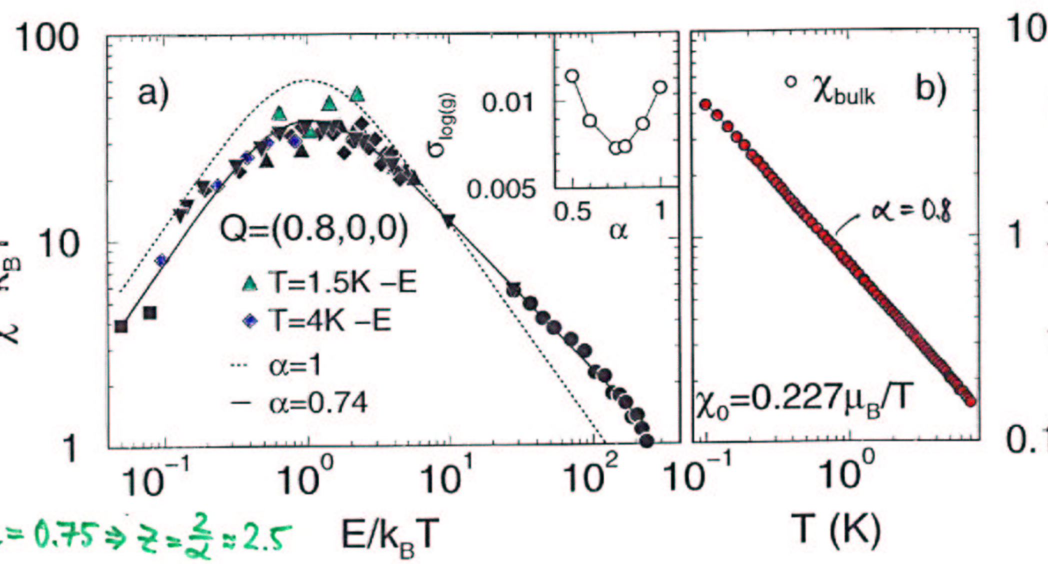
energy dependence



Dynamical scaling of magnetic fluctuations in $CeCu_{5.9}Au_{0.1}$

$$\chi''(E,T) = T^{-\alpha} g\left(\frac{E}{k_B T}\right)$$

A. Schröder, G. Aeppli, ...



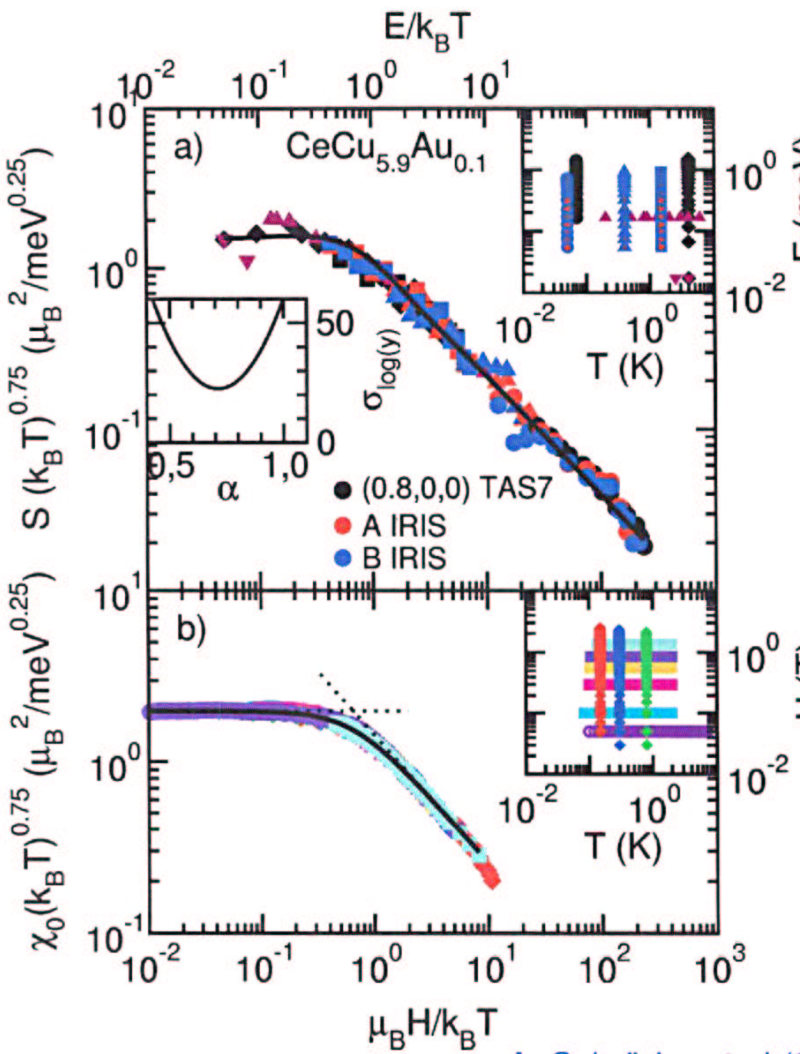
$\alpha = 0.75 \Rightarrow z = \frac{2}{\alpha} = 2.5$

$$g(y) = c \sin(\alpha\, tg^{-1} y)/(y^2+1)^{\alpha/2}$$

$E = 0$,

$$(\chi'(Q,T)^{-1} - \chi'(Q,0)^{-1})^{-1} \sim T^{-\alpha}$$

Scaling at the quantum phase transition in $CeCu_{5.9}Au_{0.1}$



A. Schröder et al (2000)

Breakdown of Fermi liquid in $CeCu_{6-x}Au_x$?

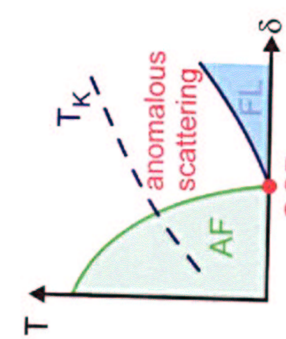
Scaling: $\chi^{-1}(q,E,T) \sim \chi_0^{-1}(E,T) + (\Theta(q))^{\alpha}$

$\chi_0^{-1}(E,T)$: E/T scaling with anomalous $\alpha \approx 0.75$

independent of q: local effect — *Schröder et al.*

What happens to the Fermi surface?

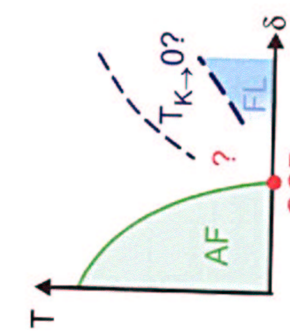
Two scenarios



magnetic instability

quasiparticles and spin fluctuations

Hertz, Millis, Moriya et al.



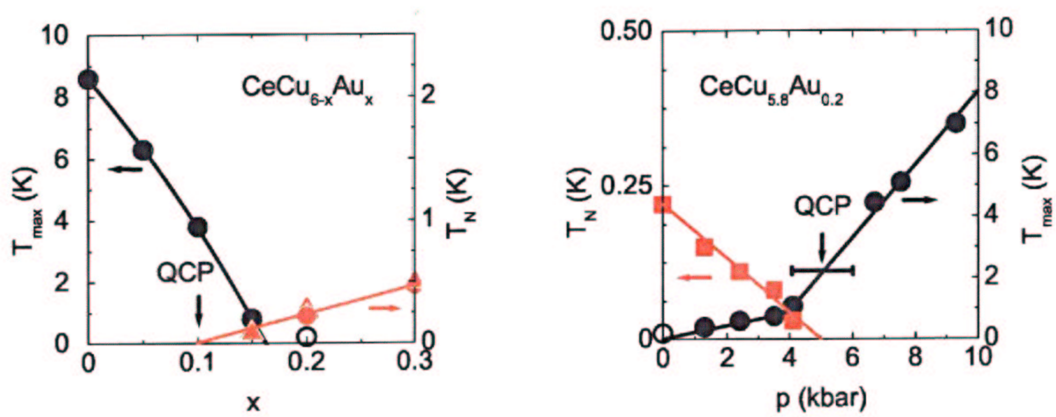
breakdown of Fermi liquid

local instability

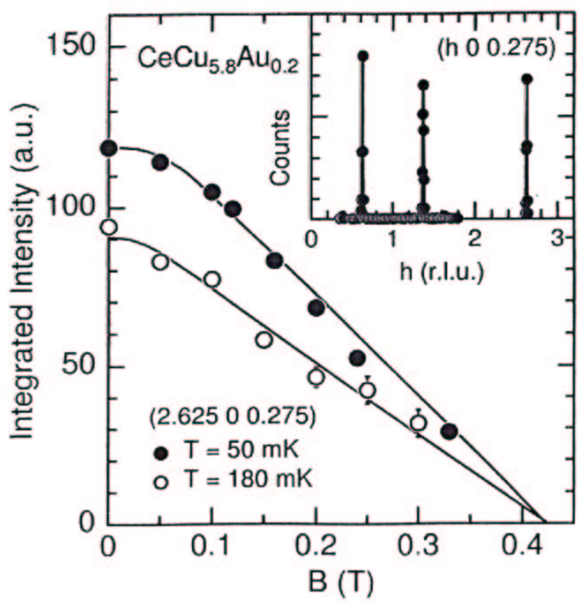
Coleman, Si et al.

Break–up of heavy fermions at the QCP?

If $T_K \to 0$ at the QCP and local moments appear,
then also $T_{max} \to 0$ is expected at the QCP.



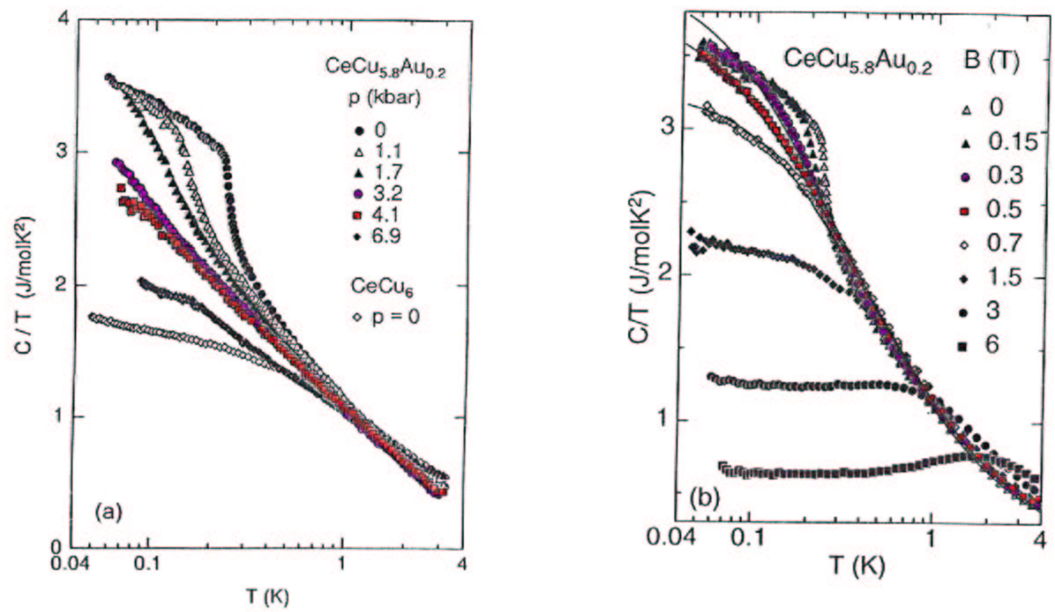
What is the local energy scale?



Tuning the magnetic instability of $CeCu_{1-x}Au_x$ ($x = 0.2$) by pressure or magnetic field: Specific heat

at p_c: $C/T \backsim \ln(T_0/T)$
$2d$ fluctuations (?)

at B_c: $C/T \backsim \gamma_0 - a'\sqrt{T}$
standard $3d$ fluctuations - SRC (?)



The puzzles of $CeCu_{6-x}Au_x$

Jump in c* component of Q not reflected in $T_N(x)$

Origin of low-dimensional fluctuations
(required also in local criticality scenario)?

Local criticality: breakdown of Fermi liquid?

How can one determine breakdown of quasiparticles at QCP?

Different pressure vs. field critical behavior

Other systems? Low-T upturn of C/T as in $YbRh_2Si_2$?