INVESTIGATION OF THE QUANTUM PHASE TRANSITION IN $CeCu_{6-x}Au_x$*

H. v. Löhneysen[a,b], F. Obermair[a], C. Pfleiderer[a] and O. Stockert[c]

[a]Physikalisches Institut, Universität Karlsruhe
D-76128 Karlsruhe, Germany
[b]Institut für Festkörperphysik, Forschungszentrum Karlsruhe
D-76021 Karlsruhe, Germany
[c]Max-Planck-Institut für Chemische Physik Fester Stoffe
D-01187 Dresden, Germany

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Recent experiments on the quantum phase transition between nonmagnetic ($x \leq x_c$) and magnetically ordered ($x > x_c$) $CeCu_{6-x}Au_x$ alloys, occurring at a critical concentration $x_c \approx 0.1$ are reviewed. In particular, we investigate how the q-dependence of the critical fluctuations observed for $x = 0.1$ by inelastic neutron scattering evolve when moving away from the critical concentration. We also explore the fluctuations when a magnetically ordered alloy ($x = 0.2$) is exposed to a magnetic field suppressing the magnetic order. Finally, we address the question whether at the quantum phase transition the Kondo temperature vanishes, *i.e.* the heavy quasiparticles loose their identity, as proposed by recent theories.

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1. Introduction

$CeCu_{6-x}Au_x$ has become a prototype heavy-fermion system (HFS) where, starting from not magnetically ordered $CeCu_6$ with strongly enhanced Pauli paramagnetism, Au doping introduces long-range incommensurate antiferromagnetism for Au concentration $x > x_c \approx 0.1$ [1]. This transition arises because the strength of the conduction-electron–f-electron exchange interaction J can be tuned by composition, by virtue of the lattice expansion caused by the large Au radius [2]. Indeed, the long-range magnetic order can be suppressed by applying hydrostatic pressure p [2,3]. Hence composition and

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pressure can be employed to tune the delicate balance between dominant Kondo or Ruderman–Kittel–Kasuya–Yosida (RKKY) interactions, which is governed essentially by J [4]. Of course, for an anisotropic system such as $CeCu_{6-x}Au_x$ with the orthorhombic Pnma structure, anisotropy effects in the x or p dependence of the lattice parameters have to be taken into account. In addition, a small monoclinic distortion ($< 1.5°$) occurs for $x < 0.14$ [5]. (For simplicity, we always use the orthorhombic unit cell to denote the crystallographic directions.) However, a detailed study of this transition by means of thermal expansion measurements has shown that it is not related to a magnetic instability [6]. Thus, we are dealing with a *bona fide* magnetic instability, which can ideally be traced to absolute zero temperature, offering the possibility of studying a magnetic quantum phase transition. In the vicinity of this transition, non-Fermi-liquid (NFL) behavior manifests itself as a strong deviation of thermodynamic and transport properties from Fermi-liquid (FL) predictions. The linear specific-heat coefficient $\gamma = C/T$ acquires an unusual temperature dependence, $\gamma \sim -\ln(T/T_0)$, and the T-dependent part of the electrical resistivity $\Delta\rho = \rho - \rho_0$ where ρ_0 is the residual resistivity, varies as $\Delta\rho \sim T^m$ with $m < 2$.

It is generally believed that the NFL behavior observed in HFS at the magnetic-nonmagnetic transition arises from a proliferation of low-energy magnetic excitations [7–9]. This transition, being induced by an external parameter such as concentration or pressure, as mentioned above, may in principle occur at $T = 0$. If the transition is continuous, it is driven by quantum fluctuations instead of thermal fluctuations in finite-T transitions. The critical behavior of such a quantum phase transition (QPT) at $T = 0$ is governed by the dimension d and the dynamical exponent z. In the Hertz–Millis theory [7,8] the effective dimension is given by $d_{\text{eff}} = d + z$. Hence one is in general above the upper critical dimension $d_{\text{eff}} = 4$ except in the marginal case $d = z = 2$.

While in three spatial dimensions the renormalization-group treatment by Millis [8] essentially corroborates the previous predictions of the self-consistent renormalization (SCR) theory of spin fluctuations [9], new results are obtained for two-dimensional (2D) systems. The case of 2D fluctuations coupled to itinerant quasiparticles with 3D dynamics has been worked out by Rosch *et al.* [10]. The NFL features observed in $CeCu_{6-x}Au_x$, *i.e.* $C/T \sim -\ln(T/T_0)$ and $\Delta \sim T$, can be nicely explained by this scenario. Indeed, inelastic neutron scattering (INS) experiments performed on a $x = 0.1$ single crystal over a wide range in reciprocal space revealed a strong spatial anisotropy of the critical magnetic fluctuations, thus suggesting the presence of quasi 2D fluctuations [11].

On the other hand, a detailed study of the energy and temperature dependence of the fluctuations carried out by Schröder *et al.* [12,13] demon-

strated convincingly E/T scaling of the dynamic susceptibility, indicating that taking the Hertz–Millis theory at face value, one is in fact below the upper critical dimension. Even more, the E/T scaling comes with an anomalous scaling exponent $\alpha = 0.75$ that is distinctly different from the Lorentzian response ($\alpha = 1$). In addition, this highly unusual E/T scaling (observed earlier — with a different value of α — for another NFL system, *i.e.* $UCu_{5-x}Pd_x$ [14]) appears everywhere in the Brillouin zone, and $\alpha = 0.8$ is even observed for the T dependence of the static uniform susceptibility (*i.e.* $E = 0, \quad q = 0$) [12, 13]. This implies that the dynamics of the critical fluctuations is local, prompting Coleman *et al.* [13, 15] to suggest that one is witnessing a more drastic variant of non-Fermi-liquid behavior than in the Hertz–Millis scenario applied to HFS, where the heavy quasiparticles suffer from singular scattering by magnetic fluctuations at the quantum critical point (QCP). In contrast, the local criticality might signal that the heavy quasiparticles themselves, being composite objects arising from the conduction electron–f-electron interaction, disintegrate [13, 15]. Therefore, one might expect that the Kondo temperature T_K, being a measure of the binding energy of the quasiparticles, goes to zero at the QCP. In a model of a locally critical QPT, a "destruction" of the Kondo resonance has been suggested which leads to critical local-moment fluctuations [16, 17].

As a final, more general point to this introduction we remark that, of course, a quantum phase transition is a delicate phenomenon. On the one hand, disorder may have pronounced effects on the transition. Like in classical phase transitions, inhomogeneities will limit the divergence of the correlation length ξ of the fluctuations. The Harris criterion [18] states that the critical exponent of the specific heat α_c (not to be confused with the scaling parameter α discussed above in conjunction with INS) must be smaller than zero in order to be irrelevant for a classical phase transition. The elucidation of disorder effects on quantum phase transitions requires careful studies of systems where disorder can be introduced in a quantitatively controlled fashion.

On the other hand, any residual interactions might break the delicate balance between quantum liquid (Fermi liquid) and quantum solid (magnetic order) at the QCP. For instance, there is increasing evidence for magnetic ordering in $CeCu_6$ occurring around 2 mK [19]. The presence of a corresponding (very small) energy scale of course renders quantum fluctuations irrelevant below that energy.

In this paper, we will discuss recent experiments on $CeCu_{6-x}Au_x$ which address the following issues: *(i)* exploration of the fluctuations away from the critical concentration $x_c \approx 0.1$, *(ii)* search for fluctuations when field tuning a magnetically ordered system to a magnetic instability, first performed in the related system $CeCu_{6-x}Ag_x$ [20], and *(iii)* search for evidence for a

Kondo energy scale that vanishes at the QCP. These points will be anteceded by a brief introduction to the magnetic instability and NFL behavior of $CeCu_{6-x}Au_x$.

2. Brief review of non-Fermi-liquid features of $CeCu_{6-x}Au_x$

The occurrence of antiferromagnetic order in $CeCu_{6-x}Au_x$ beyond a threshold concentration $x_c \approx 0.1$ was inferred early on from sharp maxima in the specific heat and low-field *dc* magnetization [21,22]. For $x > 0.1$ the Néel temperature T_N varies linearly with x up to $x = 1$ where the stoichiometric compound $CeCu_5Au$ is formed, with the Au atoms completely and exclusively occupying the Cu(2) site of the $CeCu_6$ structure [23] (see Fig. 1).

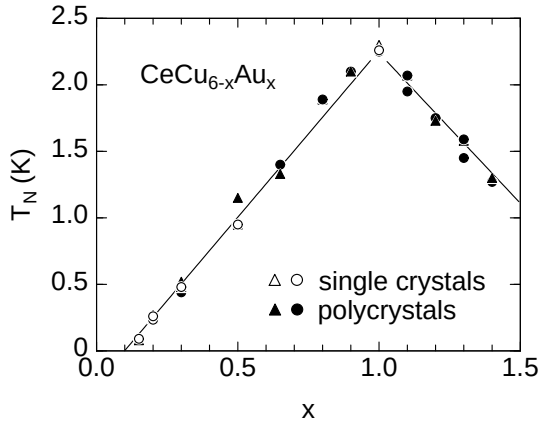

Fig. 1. Dependence of the Néel temperature T_N of $CeCu_{6-x}Au_x$ on Au concentration x. T_N varies linearly between $x = x_c \approx 0.1$ and $x = 1$.

The magnetic structure of $CeCu_{6-x}Au_x$ was determined for various concentrations between $x = 0.15$ and $x = 1$ by elastic neutron scattering [24]. For $x \leq 0.4$, the Q vector of the incommensurate structure lies in the a^*c^* plane, *e.g.* $Q = (0.625\ 0\ 0.275)$ for $x = 0.2$, and hardly depends on x [24,25]. However, for $x \geq 0.5$ incommensurate order is observed along the a^* axis, with $Q = (0.59\ 0\ 0)$ for $x = 0.5$. Assuming a sinusoidal modulation of the magnetic moments, aligned along the easy c axis, we can estimate an average ordered moment μ of 0.1 to 0.15 μ_B/Ce atom for $x = 0.2$, and 0.3 to 0.45 μ_B/Ce atom for $x = 0.3$. For $x = 0.5$ and 1, $\mu \approx 1\mu_B$/Ce atom is estimated. The strong variation of $\mu(x)$ and the change of Q between $x = 0.4$ and 0.5 is contrasted in a remarkable fashion by the simple linear $T_N(x)$ dependence which appears not to be affected by either of these features.

Fig. 2 shows $\rho(T)$ for different $CeCu_{6-x}Au_x$ alloys for current parallel to the orthorhombic a direction. For $x < x_c \approx 0.1$, $\rho(T)$ increases at the lowest

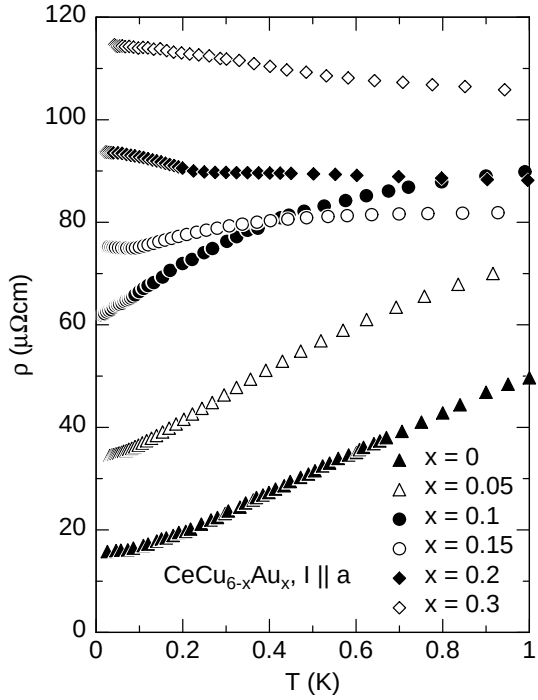

Fig. 2. Electrical resistivity ρ of $CeCu_{6-x}Au_x$ $(0 \leq x \leq 0.3)$ *vs* temperature T.

temperatures as $\rho(T) = \rho_0 + AT^2$ which is expected for a FL with dominant quasiparticle-quasiparticle scattering for $T \to 0$ as has been observed before for $CeCu_6$ [26]. For the magnetically ordered alloys with $0.15 \leq x \leq 0.3$, $\rho_a(T)$ and $\rho_c(T)$ (not shown) exhibit a kink at T_N and an increase with decreasing $T < T_N$. These findings can be qualitatively interpreted [24] in terms of the observed magnetic order, *i.e.* $\rho(T)$ increases below T_N for current directions with a non-zero projection of the magnetic ordering vector Q determined from the elastic neutron-scattering data discussed above.

For $CeCu_{6-x}Au_x$ near the critical concentration $x = 0.1$ for the onset of magnetic order, an unusual T dependence of thermodynamic and magnetic properties has been observed in addition to the T-linear resistivity shown above [27]. Fig. 3 shows C/T *vs* $\log T$ for various x. The kinks or maxima for $x \geq 0.15$ signal the onset of magnetic order. For $x = 0.1$ the linear specific-heat coefficient depends logarithmically on T, $C/T = a\ln(T_0/T)$, between 0.06 and 2.5 K, with $a = 0.58\,\mathrm{J/molK^2}$ and $T_0 = 6.2\,\mathrm{K}$, the latter corresponding to the Kondo temperature T_K of pure $CeCu_6$ [26]. The magnetic susceptibility χ for $x = 0.1$ was found to vary approximately as $\chi \approx M/B \sim 1 - a'\sqrt{T}$ between 0.08 and 3 K. Here M is the *dc* magnetization

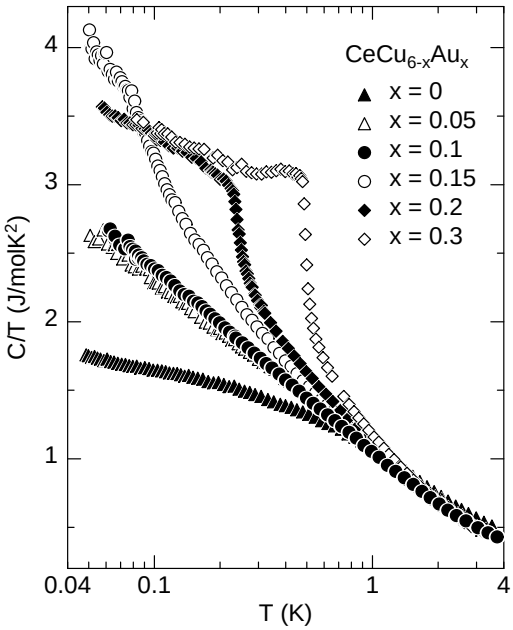

Fig. 3. Specific heat C of $CeCu_{6-x}Au_x$ ($0 \leq x \leq 0.3$) divided by temperature T, plotted *vs* T on a logarithmic scale.

measured in a magnetic field $B \approx 0.1\,\mathrm{T}$ [26]. As already mentioned above, Schröder *et al.* showed that the $\chi(T)$ data can be described very well by a different functional dependence, *i.e.* $\chi(T)^{-1} - \chi(0)^{-1} = a''T^{\alpha}$ with $\alpha = 0.8$ [12]. This fit extends to 7 K, *i.e.* to well above T_{K}. This is surprising because the FL regime in $CeCu_6$ is observed only well below T_{K}.

The abundance of low-energy magnetic excitations when T_{N} is just tuned to zero, has been suggested early on to cause the NFL behavior at the magnetic instability [26]. However, the $-\ln T$ dependence of C/T and the linear T dependence of ρ in $CeCu_{6-x}Au_x$ at the magnetic instability have constituted a major puzzle ever since they were first reported because spin-fluctuation theories for 3D itinerant fermion systems predict [8,9] $C/T = \gamma_0 - \beta\sqrt{T}$ and $\Delta\rho \sim T^{3/2}$ for antiferromagnets ($z = 2$) in the limit $T \to 0$. In addition, T_{N} should depend on the control parameter $\delta_x = x - x_{\mathrm{c}}$ or $\delta_p = p - p_{\mathrm{c}}$ as $T \sim \mid \delta \mid^{\zeta}$ with $\zeta = z/(d + z - 2) = z/(z + 1)$ for $d = 3$ [8], while for $CeCu_{6-x}Au_x$ $\zeta \approx 1$ for both δ_x [26] and δ_p [3] is found. However, 2D critical fluctuations coupled to quasiparticles with 3D dynamics do indeed lead to the observed behavior $C/T \sim -\ln T$, $\Delta\rho \sim T$ and $T_{\mathrm{N}} \sim \mid \delta \mid$, *i.e.* $\zeta = 1$ as pointed out by Rosch *et al.* [10].

A detailed investigation right at the critical concentration $x = 0.1$ by Stockert *et al.* [11] showed that the critical fluctuations as measured with

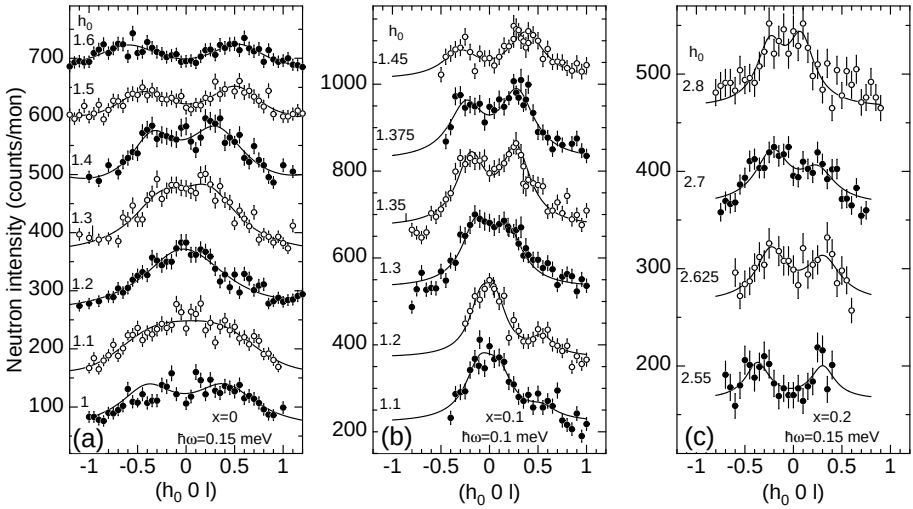

Fig. 4. Inelastic neutron scattering scans in the reciprocal a^*c^*plane of $CeCu_{6-x}Au_x$ for (a) $x = 0$ with an energy transfer $\hbar\omega = 0.15\,\mathrm{meV}$, (b) $x = 0.1$, $\hbar\omega = 0.10\,\mathrm{meV}$, and (c) $x = 0.2$, $\hbar\omega = 0.15\,\mathrm{meV}$. Data were taken at the triple axis spectrometers IN 12 ($x = 0$) and IN 14 ($x = 0.1; 0.2$) at the ILL Grenoble. The individual scans are shifted by 100 counts ($x = 0; 0.2$) or 150 counts ($x = 0.1$) with respect to each other. Scans along $(2.8 - \xi\ 0\ l)$ for $x = 0.2$ are symmetry equivalent to $(1.2\xi\ 0\ l)$ scans ($x = 0; 0.1$).

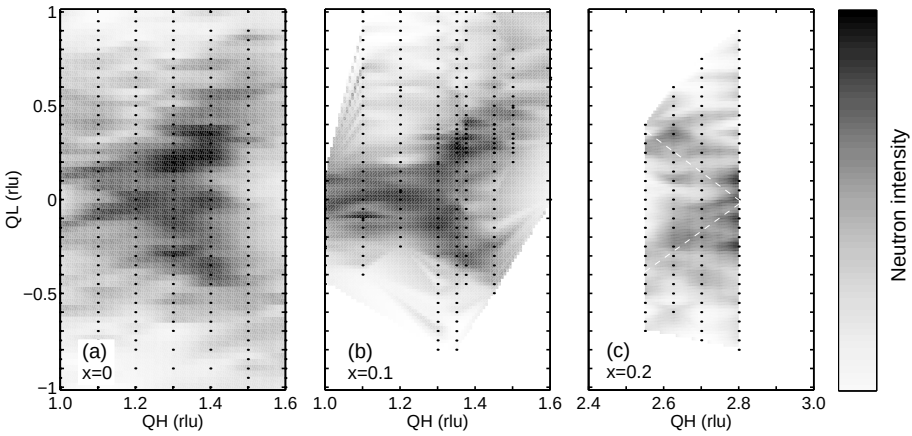

Fig. 5. Gray-scale contours of inelastic neutron scattering intensity in the a^*c^* plane for the data of Fig. 4(a)–(c). The dashed lines in (c) indicate the direction into which the dynamic correlations extend in the a^*c^* plane.

an energy transfer of 0.10 meV by INS lie in the a^*c^* plane. This is inferred from a large number of scans in the a^*c^* plane, some of which are shown in Fig. 4(b). Hence the dynamical structure factor $S(q, \hbar\omega = 0.10\,\mathrm{meV})$ has the form of rods as indicated by the bright regions in the false color plots of Fig. 5(b). The 3D ordering Bragg peaks for $x = 0.15, 0.2$ and 0.3 fall on the rods for $x = 0.1$ [24] which therefore can be viewed as precursors of 3D ordering.

3. Magnetic fluctuations away from the critical concentration

What happens to the critical fluctuations if one moves away from the critical concentration x_c? The investigation of magnetic fluctuations in $CeCu_6$, *i.e.* not too far from the QCP, has in fact a long history [28, 29]. Fig. 4 shows scans along the c direction in the reciprocal a^*c^* plane for $x = 0$, and 0.2, together with the previous data for $x = 0.1$ for comparison. The fluctuations as measured with an energy transfer of 0.15 meV persist on both sides of the QCP, albeit much broader in q space, as might be expected. Overall, they look rather "symmetric" about the QCP. This might be compared with the specific heat (Fig. 3) where the data for $x = 0.05$, just below x_c, are almost undistinguishable from those for $x = 0.1$ while the data for $x = 0.15$, just above x_c, clearly show the magnetic transition at 0.08 K, with precursor effects being visible already at 0.5 K as an upward deviation from the $C/T \sim \ln(T_0/T)$ behavior. Moving further away from $x = 0.1$, viz. $x = 0$ and 0.2, the data look nearly "symmetric" with respect to $x = 0.1$: the upward deviation of the $x = 0.2$ data from the $\ln(T_0/T)$ curve above T_N corresponds to the downward deviation of the $x = 0$ data, in qualitative agreement with the neutron data.

An important observation is that the peculiar q dependence of the fluctuations, nicknamed "rods" [11] or "butterfly" [13] persists to $x = 0.2$ as well as to $x = 0$ (see Fig. 5). We note that the present data for $CeCu_6$ have been taken with much higher resolution than the previous data [28,29]. However, all data are compatible with each other, taking the difference in resolution into account. The fact that the "rod/butterfly" structure of critical fluctuations in $CeCu_{5.9}Au_{0.1}$ is present in pure $CeCu_6$ as well, rules out disorder as an origin of this remarkable feature of the quantum phase transition in $CeCu_{6-x}Au_x$. That disorder does not qualitatively affect the QPT has already been inferred from the fact that pressure tuning the Néel temperature to zero for $x = 0.2$ and 0.3 leads to the same specific-heat behavior $C/T = a\ln(T_0/T)$ at the critical pressure p_c of about 4 and 8 kbar, respectively, with identical (within the accuracy of measurement) coefficients a and T_0 [1].

4. Magnetic fluctuations at the field-tuned transition for $x = 0.2$

As just mentioned, tuning a magnetically ordered $CeCu_{6-x}Au_x$ alloy to the QCP by hydrostatic pressure yields the same behavior for the specific heat at p_c as for an alloy with the critical Au concentration $x = 0.1$ at ambient pressure. Likewise, the electrical resistivity for $x = 0.2$ exhibits a linear T dependence at the critical pressure [30]. This strongly suggests that the magnetic fluctuation spectrum under pressure may be similar to that of $x = 0.1$ at ambient pressure. However, when applying a magnetic field to suppress the incommensurate antiferromagnetism for $x = 0.2$, specific heat and resistivity can be described quite accurately [30] by the standard 3D SCR theory [9] when the field reaches the critical field $B_c = 0.42\,\mathrm{T}$, *i.e.* $C/T = \gamma_0 - \beta T^{0.5}$ and $\Delta\rho \sim T^{1.5}$. Here B_c was determined unambiguously by the vanishing of the intensity of the magnetic reflections [30].

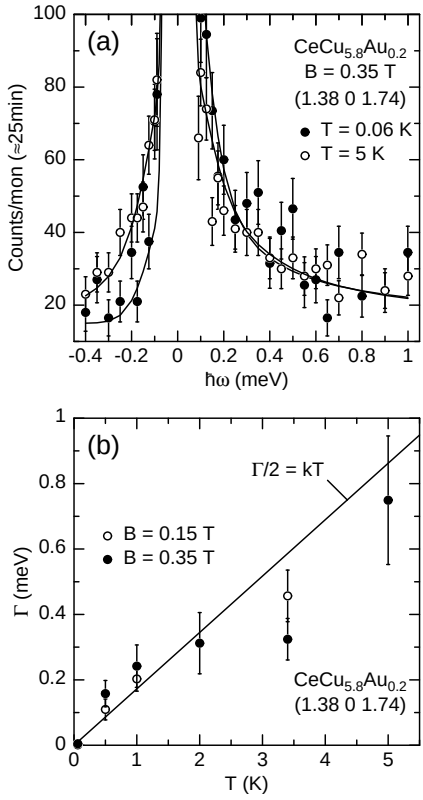

Fig. 6. (a) Neutron scattering function $S(q, \hbar\omega)$ of $CeCu_{0.8}Au_{0.2}$, in an applied magnetic field $B = 0.35$ at $q = (0.138\ 0\ 1.74)$ for two temperatures. (b) Line width Γ (FWHM) as a function of T for two fields $B = 0.35$ and $0.15\,\mathrm{T}$. Fits are Lorentzians, corresponding to $\alpha = 1$.

Shown in Fig. 6(a) is $S(q,\hbar\omega)$ at $q = (0.138\ 0\ 1.74)$ for two different temperatures. The applied field was 0.35 T, *i.e.* close to B_c. The fits correspond to Lorentzians convoluted with the Gaussian shaped energy resolution of the triple-axis spectrometer IN 12 at the ILL Grenoble, where the data were taken. The data are clearly compatible with a Lorentzian lineshape which would correspond to $\alpha = 1$ in the dynamical susceptibility. Hence these data support our previous interpretation [30], based on macroscopic thermodynamic and transport measurements, that a magnetic-field induced instability in the incommensurate antiferromagnet $CeCu_{5.8}Au_{0.2}$ leads to fluctuations that are well accounted for by the standard Hertz–Millis–Moriya model [7–9]. Fig. 6(b) shows the linewidth Γ(FWHM) as derived from $S(q,\hbar\omega)$, as a function of T for two fields $B = 0.35$ T and 0.15 T. Γ scales with T, supporting that T is the only relevant energy scale and hence that one is indeed dealing with a quantum phase transition. It is interesting to note that even far away from B_c, Γ has not changed within the (rather large) error bars. Only below 0.15 T does the linewidth increase considerably. Unfortunately, because of the required scattering geometry, with the scattering vector in the a^*c^* plane and the field applied along the (easy) c direction, the use of a horizontal magnet was necessary which eliminated the possibility to investigate the q dependence of $S(q,\hbar\omega)$.

5. Tuning of the Kondo temperature in $CeCu_{6-x}Au_x$

The Kondo temperature T_K is well defined for a single isolated magnetic impurity in a metallic host only. It is well known that in a HFS such as $CeCu_6$ which can in certain aspects be viewed as a Kondo lattice, T_K will be renormalized because of the interactions between Kondo "impurities". Here we adopt the pragmatic point of view that T_K in a HFS presents the mean binding energy of the heavy quasiparticles. Well below T_K, in a lattice with translational symmetry, these quasiparticles will be eigenstates of the periodic potential, strongly modified by electron-electron interactions. This gives rise to a maximum ρ_{max} of the resistivity $\rho(T)$ in many HFS, signaling the onset of lattice coherence of the quasiparticles. The temperature of this coherence maximum is therefore usually called coherence temperature T_{coh}.

Again, $CeCu_6$ presents a textbook example of a HFS derived from Kondo physics. First, the specific heat of $La_{1-y}Ce_yCu_6$ scales with the Ce concentration y, indicating that the large linear specific heat coefficient $\gamma = C/T \approx 1.6\,\mathrm{J/moleK^2}$ can be viewed as a simple superposition of individual Kondo impurity contributions [32], although one has to bear in mind that there are numerous counter examples where such a scaling does not hold. Second, T_K can be tuned by hydrostatic pressure because it depends sensitively on J, $T_K \sim \exp(-1/N(E_F)J)$ where $N(E_F)$ is the (unrenormalized) conduction

electron density of states at the Fermi level. For $CeCu_6$, the electrical resistivity, normalized to its value $\rho_{\max}$ under pressure, scales reasonably well with $T/T_{\rm coh}$ over a wide range of T and p [32], implying the presence of an intimate relation between $T_{\rm coh}$ and $T_{\rm K}$.

Because $T_{\rm K}$ is not well defined for a HFS and, in addition, is not easy to determine unambiguously, we adopt the view that the very presence of a coherence maximum in $CeCu_{6-x}Au_6$ implies the existence of a finite Kondo energy. This qualitative assessment is independent of exactly how the Kondo temperature depends on x or p and therefore much more robust than an attempt to quantitively evaluate $T_{\rm K}$.

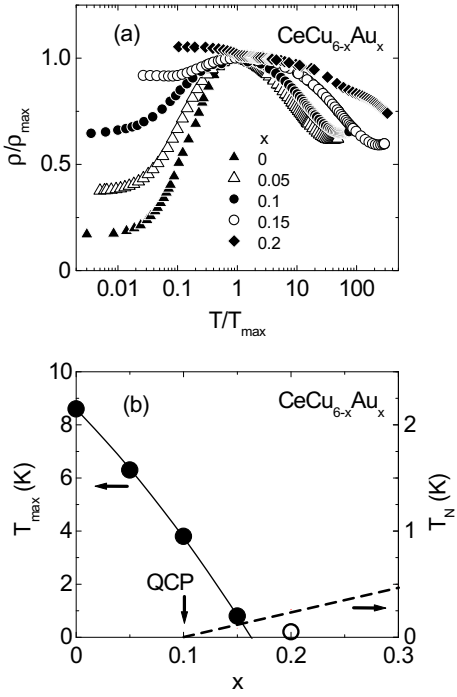

Fig. 7. (a) Electrical resistivity $\rho/\rho_{\max}$ of $CeCu_{6-x}Au_x$ *vs* $T/T_{\max}$. $\rho_{\max}$ and $T_{\max}$ denote the $\rho(T)$ maximum. (b) $T_{\max}$ (left scale) and $T_{\rm N}$ (right scale) *vs* x. Open circle denotes upper limit of $T_{\max}$ for $x = 0.2$.

Shown in Fig. 7(a) is the resistivity $\rho(T/T_{\max})/\rho_{\max}$ for different x. Here $T_{\max}$ is the temperature where the maximum $\rho_{\max}$ occurs. For $0 \leq x \leq 0.15$ a resistance maximum is clearly resolved. The resistivity maximum presents a crossover which, when considering different alloys, is also affected by the magnitude of the residual resistivity ρ_0 and disorder scattering, which of course strongly depends on x. It is thus denoted by $T_{\max}$ and not by $T_{\rm coh}$. We therefore do not expect a scaling of $\rho(T/T_{\max})\rho_{\max}$ as seen in $CeCu_6$

under pressure. In addition, the onset of magnetic order, with its pronounced effect on transport [24], precludes the observation of a maximum for $x > 0.2$. For $x = 0.2$, an upper bound can be given by $T_{\max} < T_K$, leading to the position of the $x = 0.2$ data as indicated in Fig. 7(a). $T_{\max}$ *vs* x is shown in Fig. 7(b). The main point to note is the smooth, nearly linear decrease of $T_{\max}$ which appears to vanish at $x \approx 0.16$. In particular, no anomaly of $T_{\max}(x)$ occurs in the vicinity of the QCP at $x = 0.1$. We conclude that because $T_{\max}$ remains finite, *a fortiori* T_K must remain finite as well, whatever the exact relation between $T_{\max}$ and the binding energy of quasiparticles may be. Hence it appears that the local energy scale which has been suggested to vanish in recently proposed scenarios [13, 15] of the QPT in $CeCu_{6-x}Au_x$, is not directly related to T_K. Work on pressure tuning the coherence temperature of an initially magnetically ordered $CeCu_{5.8}Au_{0.2}$ alloy is in progress.

6. Conclusion

Although $CeCu_{6-x}Au_x$ has been studied for a number of years, new features evolve continuously as this prototype NFL system is probed in depth. The existence of the complex q dependence of the magnetic fluctuations finds its expression in precursor effects with the same q dependence in pure $CeCu_6$, showing that disorder is not relevant for this feature. On the other hand, the observed switching of the temporal response of the fluctuations to a more conventional behavior at the field-tuned QCP, compared to anomalous scaling at the QCP in zero magnetic field, calls for an explanation. Likewise, the search for a relevant local low-energy scale that vanishes at the QCP must be continued. Finally, an all-important issue is whether the physics of $CeCu_{6-x}Au_x$ presents a singular case, or whether it is a respresentative of a more general behavior akin to strongly correlated electron systems at a QCP, as suggested, *e.g.* by thermodynamic and transport measurements on $YbRh_2Si_2$ [33]. Therefore, the search for new systems and their thorough investigations, is a challenging task for the future.

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