Experimental studies of quantum critical phenomena in heavy-electron metals

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1. The exemplary non-Fermi-liquid (NFL) superconductor $CeCu_2Si_2$ shows a quantum phase transition (QPT) of itinerant (SDW) nature.

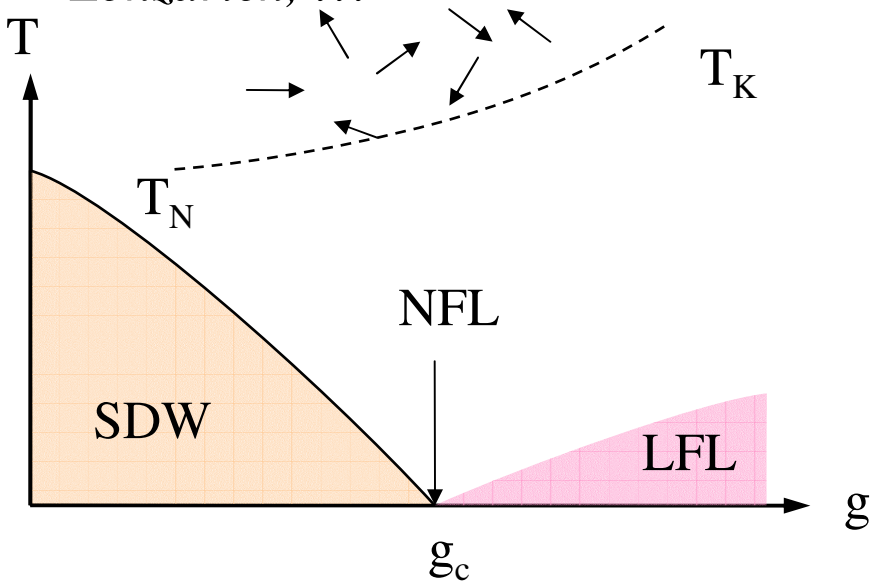
   Conjecture:
   The same holds true for all NFL heavy-electron superconductors.

2. The NFL metal $YbRh_2Si_2$ exhibits a QPT of local (-moment) nature.
   Even single crystals of highest purity are not superconducting.

   Conjecture:
   Local quantum critical fluctuations are unfavorable for superconductivity.

Itinerant vs locally critical scenario

Hertz, Millis, Moriya, Continentino, Lonzarich, …

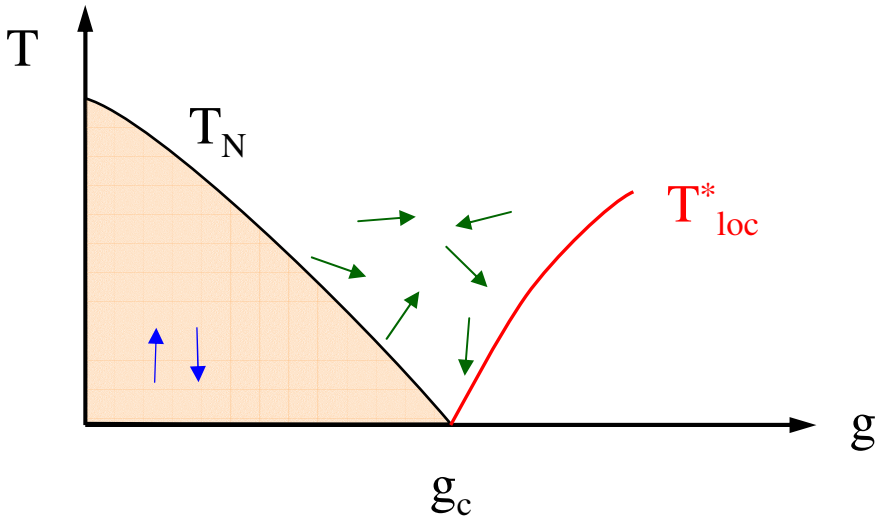


- Heavy QPs considered to be itinerant f-electrons (not part of criticality)
- Scattering of QPs by critical AF-SF

$\tau \sim \xi^z$ (AF: z = 2)

$d_{eff} = d + z$

Schröder, Coleman, Pépin, Si



- $T^*_{loc} \rightarrow 0$ at QCP

$\Rightarrow$ Kondo- resonance not fully developed at QCP

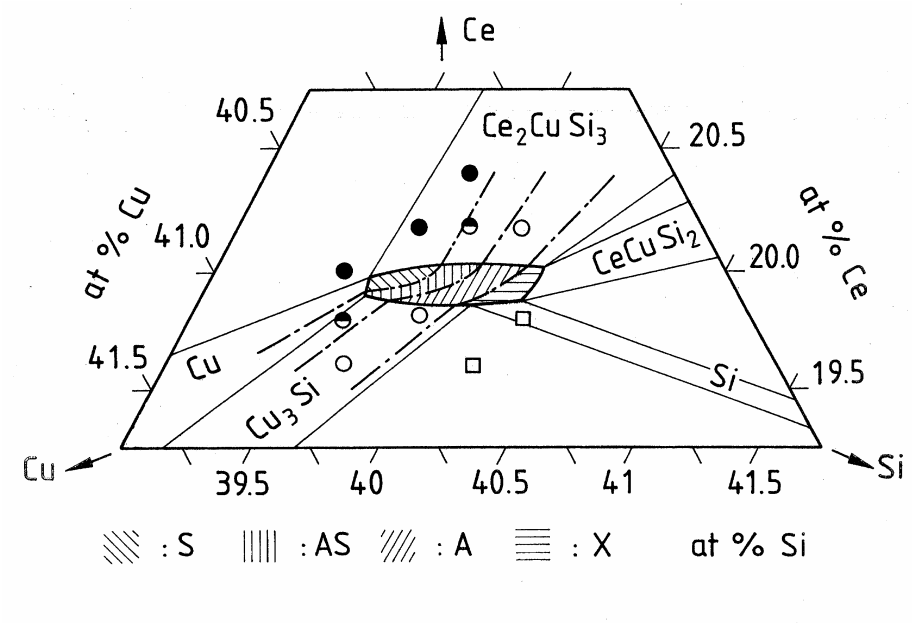
2 different QCPs coinciding:

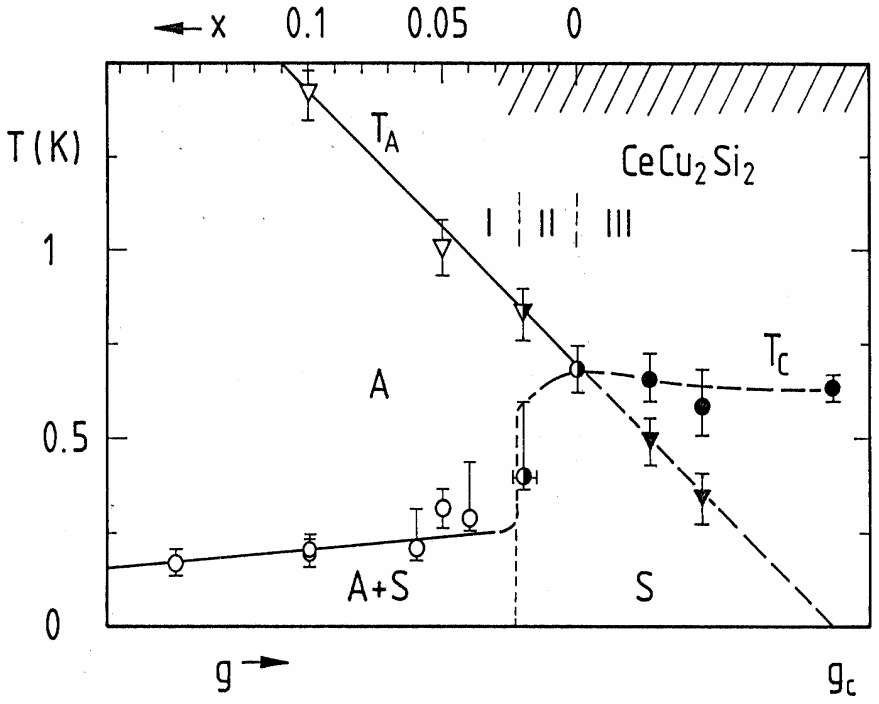
(i) AFM $\leftrightarrow$ PM

(ii) LFL $\leftrightarrow$ NFL

$CeCu_2Si_2$: Phase diagrams

chemical (C. Geibel et al., 1995)

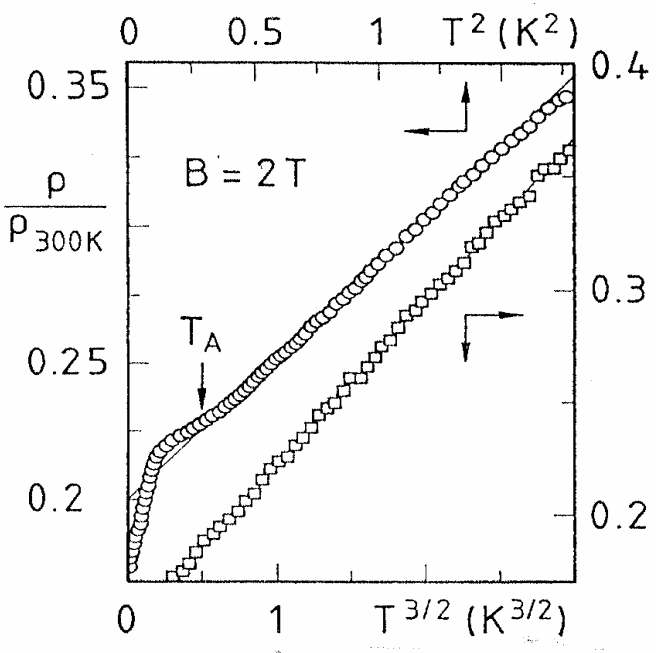




physical (P. Gegenwart et al., 1998)

$CeCu_2Si_2$: "A-S" transition at p < 0.7 GPa

[G. Sparn et al., Rev. High Press. Sci. Technol. **7**, 431 (1998)]

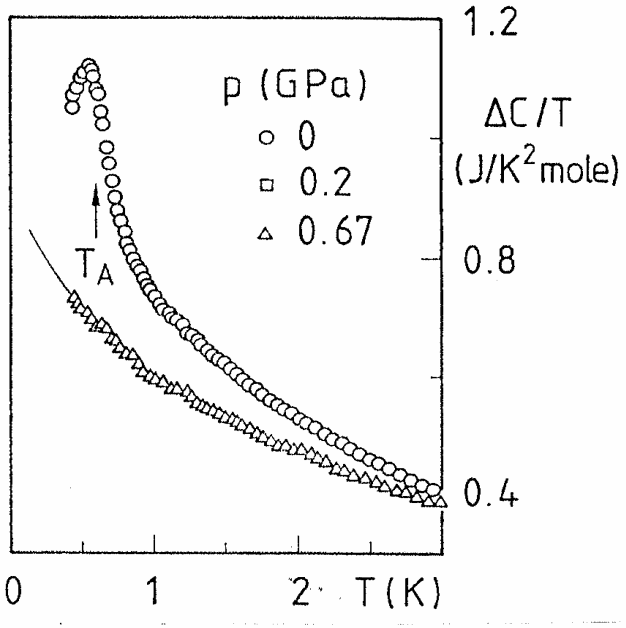


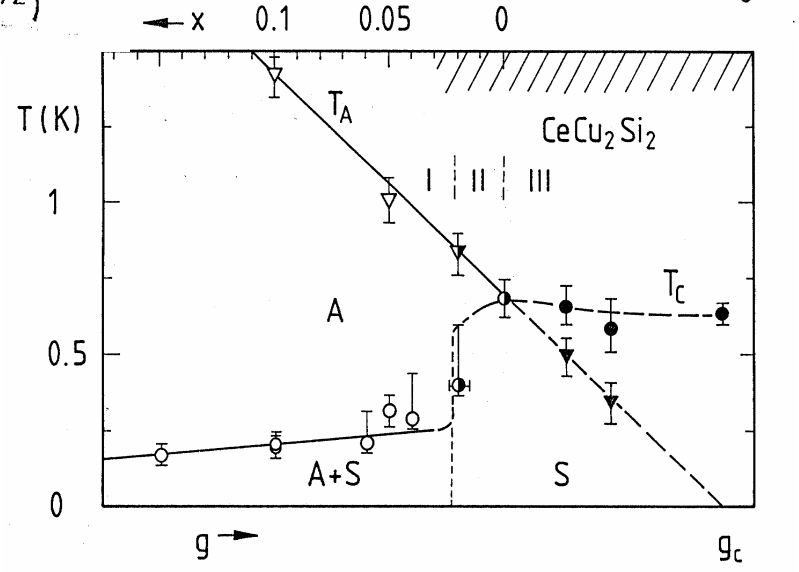
$p > p_c$:

$\Delta\rho = \alpha T^{1.5}$

$\gamma = \gamma_0 - \beta T^{0.5}$

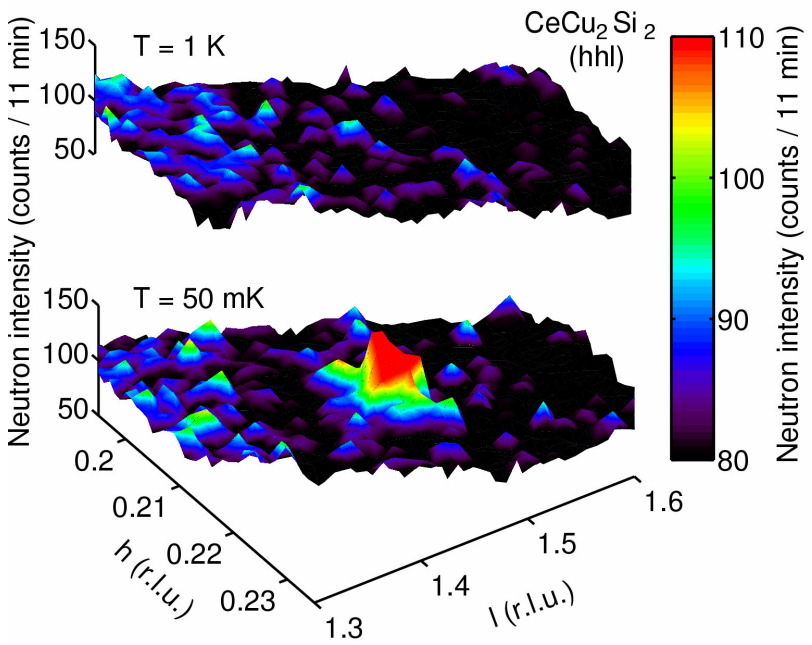
(3D-SDW scenario)



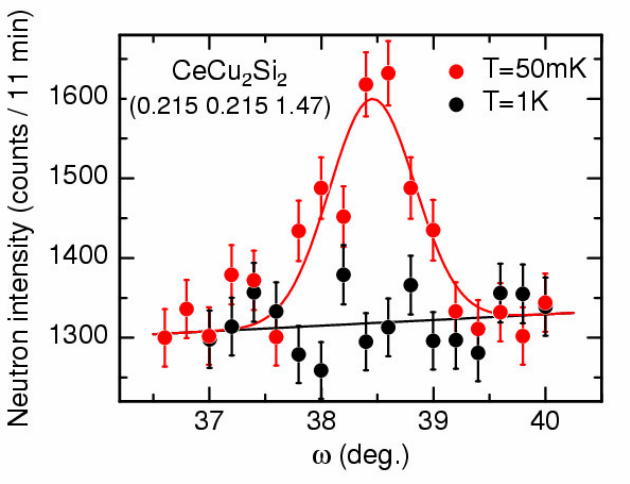


Nature of the magnetic A phase in $CeCu_2Si_2$

[O. Stockert et al., Phys. Rev. Lett. **92**, 136401 (2004)]



Observation of AF satellite peaks in (hhl) scattering plane



Long-range AF order with propagation vector

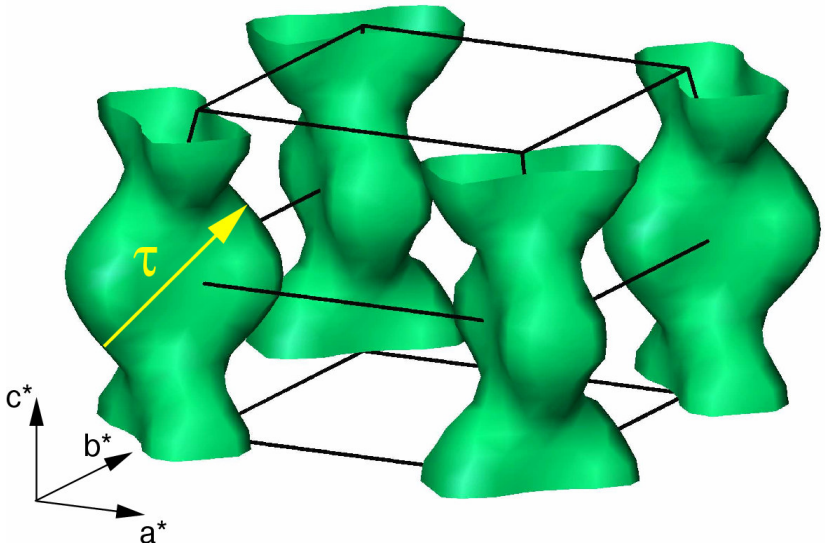
$\tau = (0.215\ 0.215\ 0.530)$ at T = 50 mK

$T_N \approx 0.8$ K

$m_0 \sim 0.1\ \mu_B$

Nesting properties of Fermi surface in $CeCu_2Si_2$

[G. Zwicknagl]

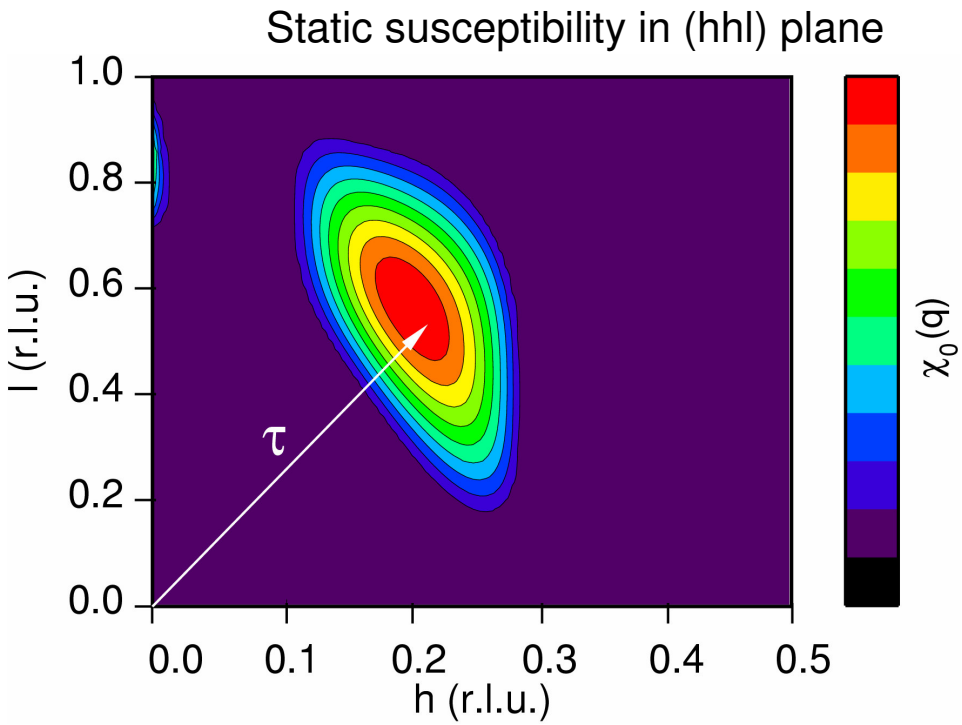


Fermi surface of heavy quasiparticles calculated with renormalized band method,
$m^* \approx 500\ m_e$

warped columns along tetragonal axis

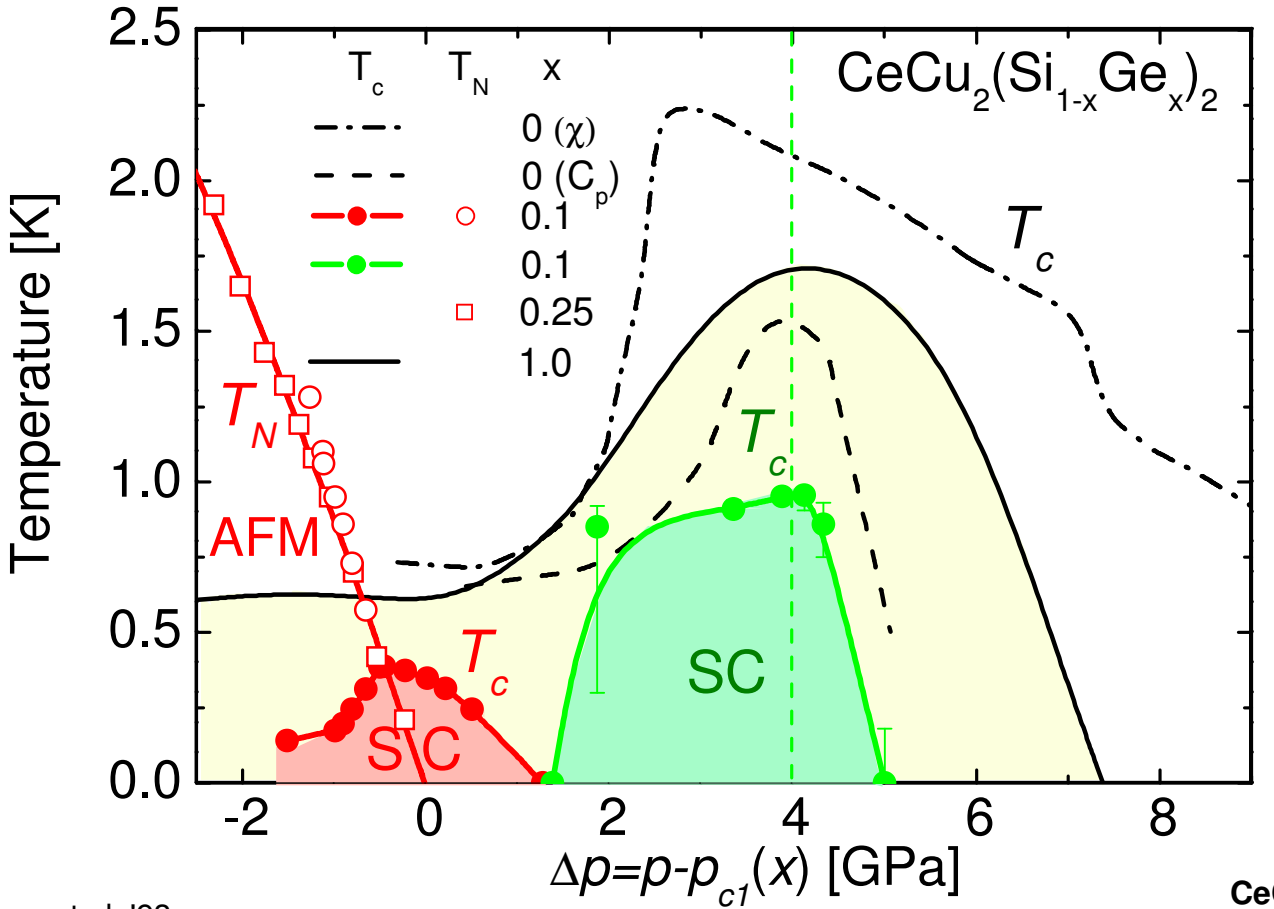
Nesting for incommensurate wave vector
$q \approx (0.21\ 0.21\ 0.55)$

Fermi surface unstable with respect to formation of spin-density wave



Observation of two distinct superconducting phases in $CeCu_2Si_2$

[H. Q. Yuan et al., Science **302**, 2104 (2003)]



$CeCu_2Si_2$
- . - . - F. Thomas et al. '93
- - - - A. T. Holmes et al. '03

$CeCu_2Ge_2$
——— D. Jaccard et al. '99

Summary: $CeCu_2Si_2$

- SC likely to be mediated by coupling of heavy qps to spin (low-p) and charge (high-p) degrees of freedom

- But, open questions concerning

  - NFL phenomena at p = 0:
    γ(T) upturn ⇝ phase separation?

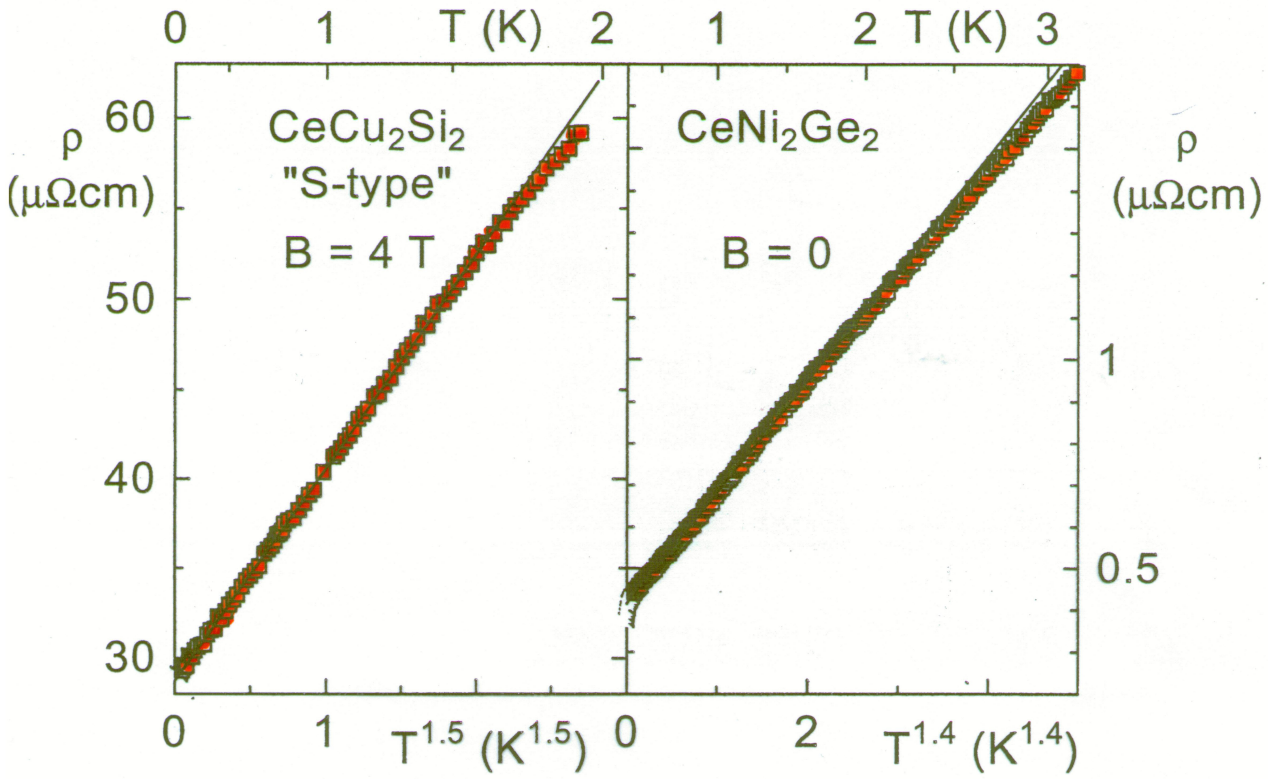
  - A-phase properties:
    disparity $\mu_S \approx 0.1\ \mu_B \leftrightarrow$ 40 % FS gapping ⇝ hidden order?

  - Role of lattice degrees of freedom p = 0:
    A-phase transition anomalies are big in elastic constants and thermal expansion, but tiny in magnetization
    high p:
    maximum T_c coincides with jump in Ce valence

normal-state resistivity, $\rho = \rho_0 + \beta T^{\varepsilon}$

$T > 10$ mK, more than 2 decades

P. Gegenwart '98



cf. SF theory by

A. Rosch, Phys. Rev. Lett. **82**, 4280 (1999).