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Single crystal study of the Kagomé antiferromagnet $U_3Ru_4Al_{12}$

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Outlines

- Introduction

  $U_3T_4Al_{12}$ family (T = Fe, Co, Ru)

- Single crystalline $U_3Ru_4Al_{12}$

  Magnetism

  Electrical transport

  Specific heat

- Conclusion and perspectives

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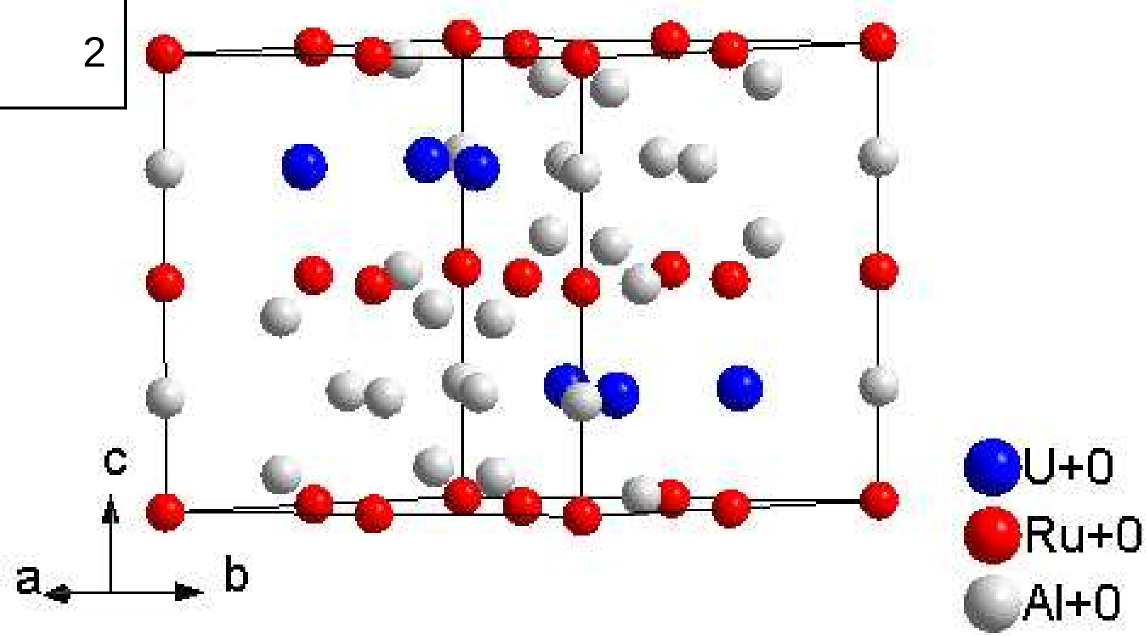
$U_3T_4Al_{12}$ (T = Fe, Co, Ru)

Structure-type	$Gd_3Ru_4Al_{12}$
Space-group	$P6_3/mmc$ (n°194)
Cell parameters (Å)	a =8.8300(1) c =9.4296(2)
V (Å^3)	636.71(2)
Z	2

1 U position (6h)

2 Ru (2a, 6g)

4 Al (2b, 4f, 6h, 12k)



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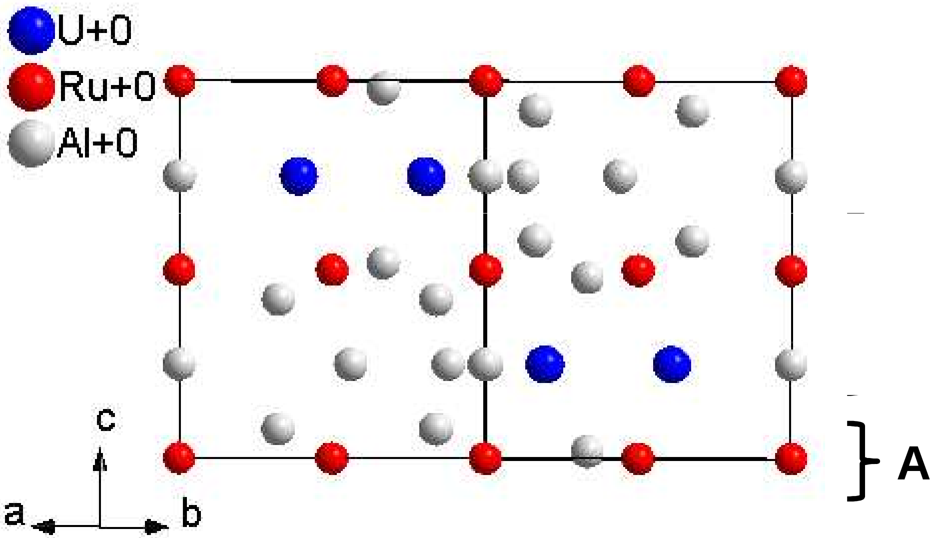

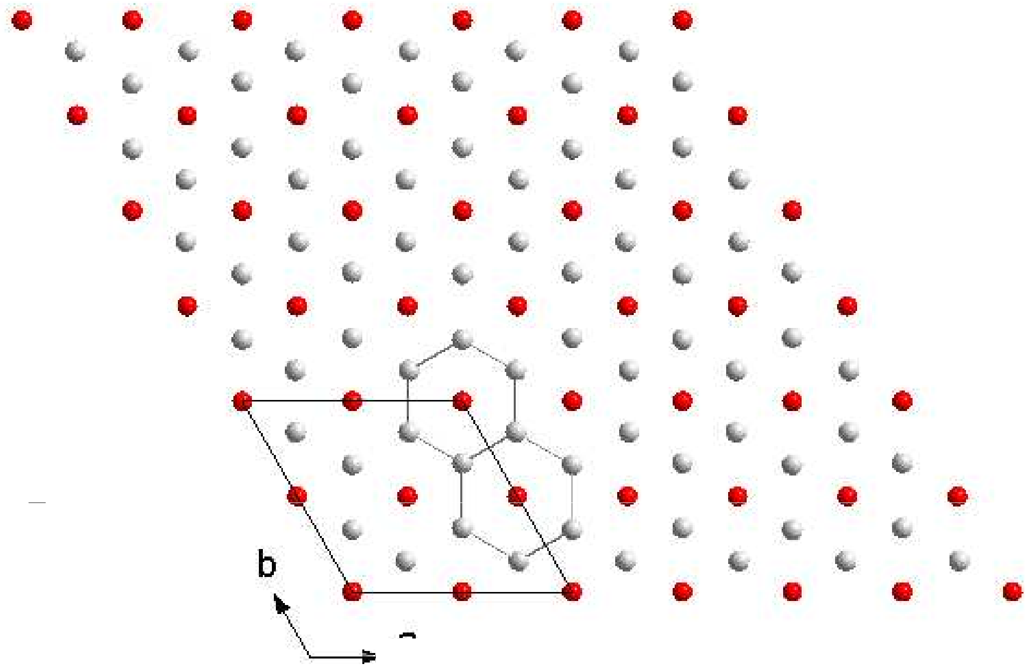

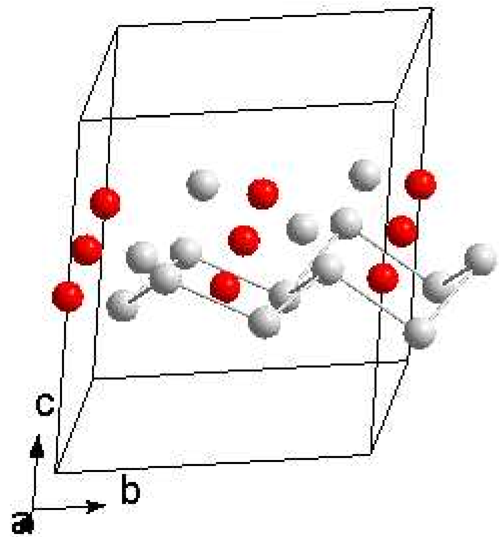

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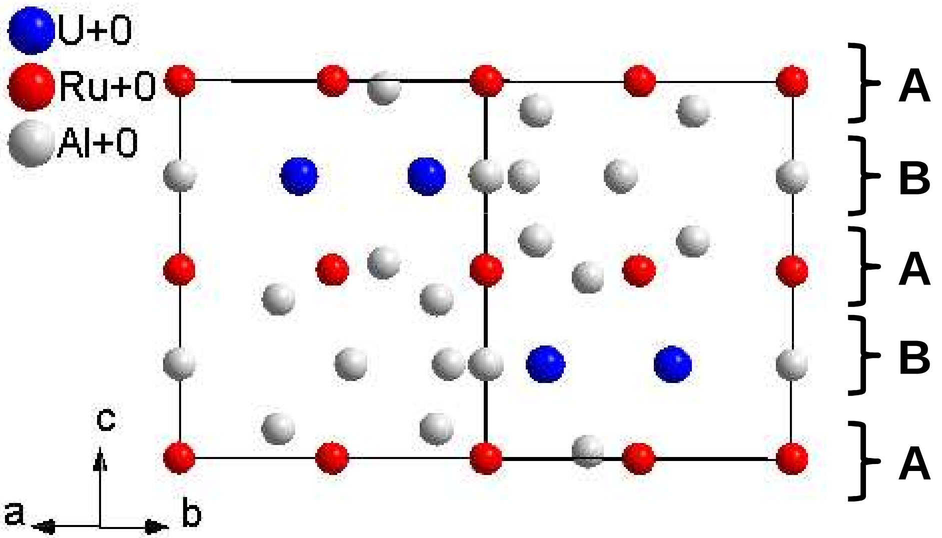
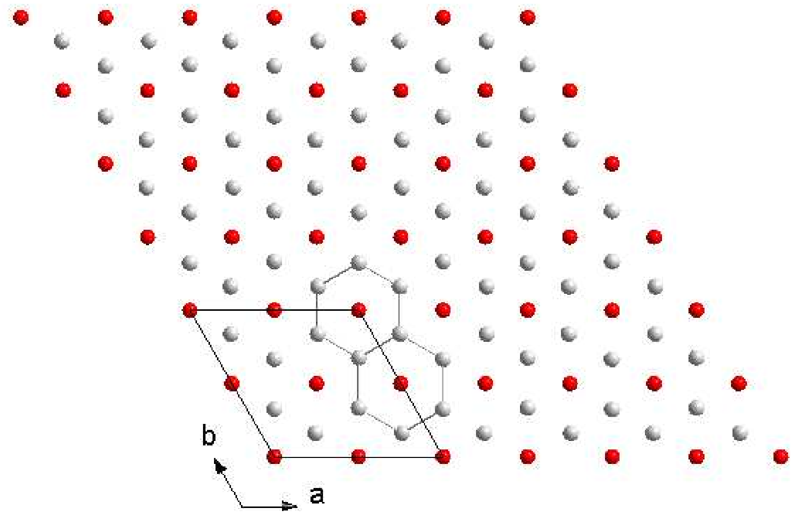
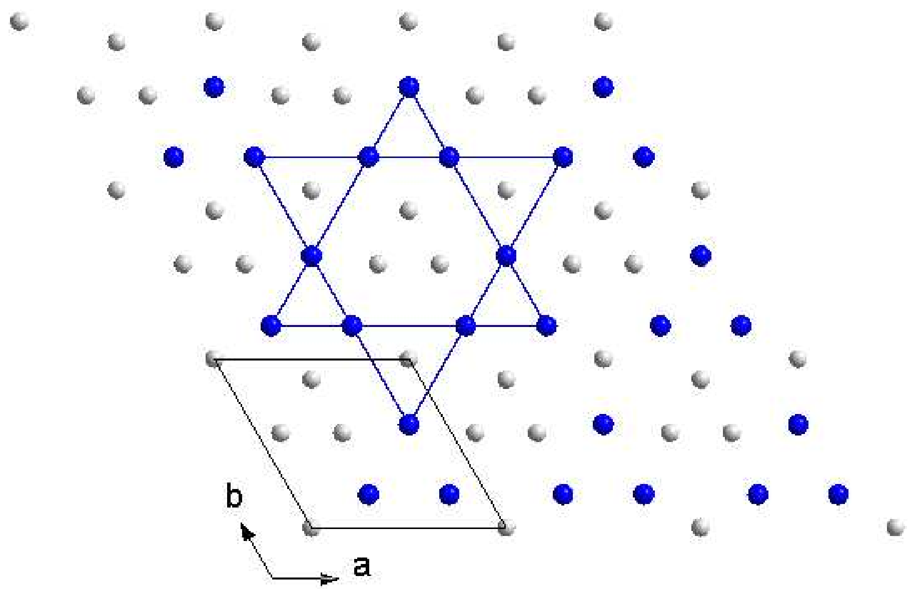




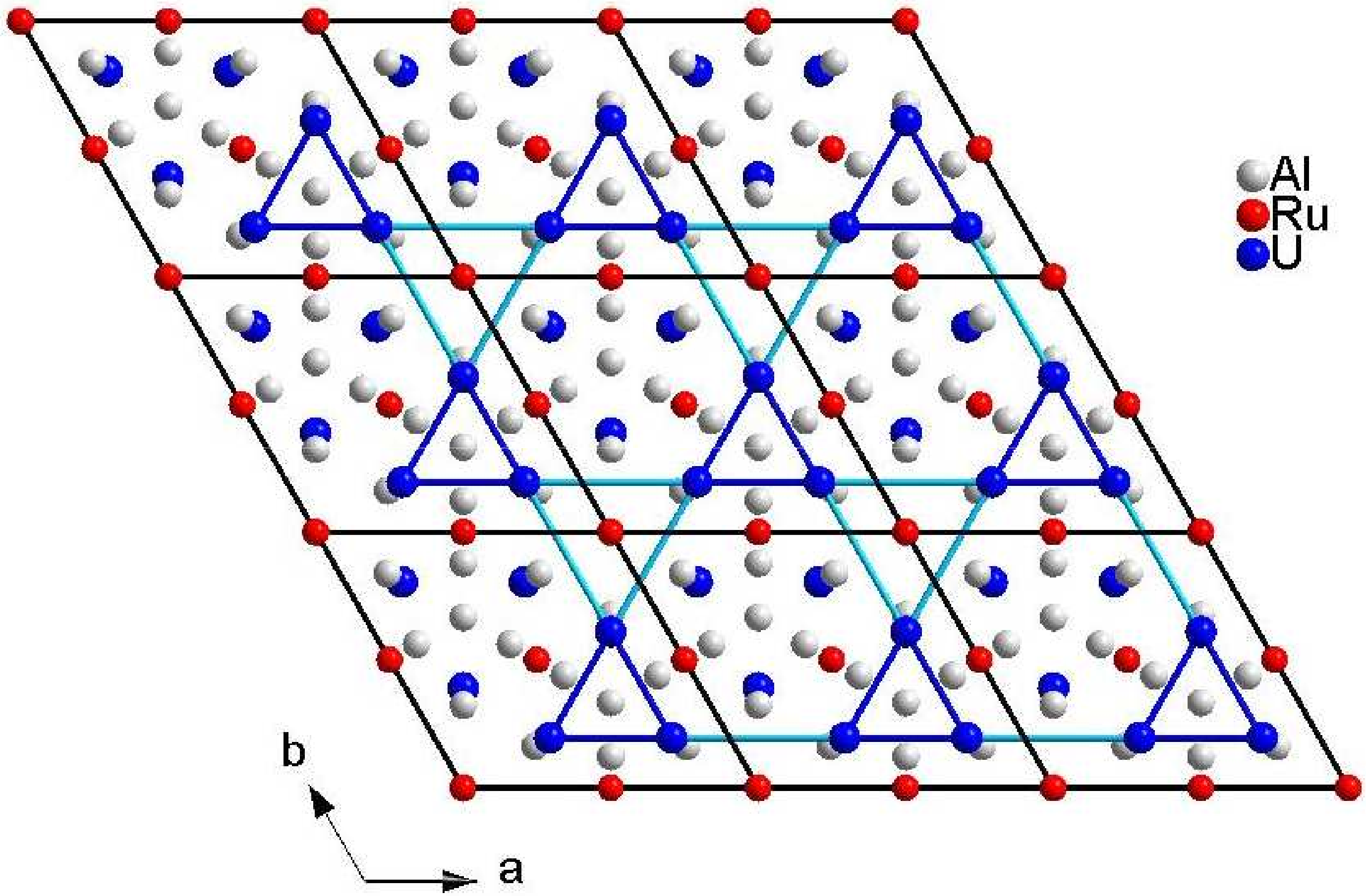


Dans B $d_{U\text{-}U}$ = 3.662 Å
5.168 Å

$d_{B\text{-}B}$ = 4.715 Å

Entre B $d_{U\text{-}U}$ = 5.580 Å

$U_3T_4Al_{12}$ (T = Fe, Co, Ru)



U-atoms distorted Kagomé lattice parallel to the (a,b) plane

⇒ favourable for magnetic frustrations

$U_3T_4Al_{12}$ (T = Fe, Co, Ru)

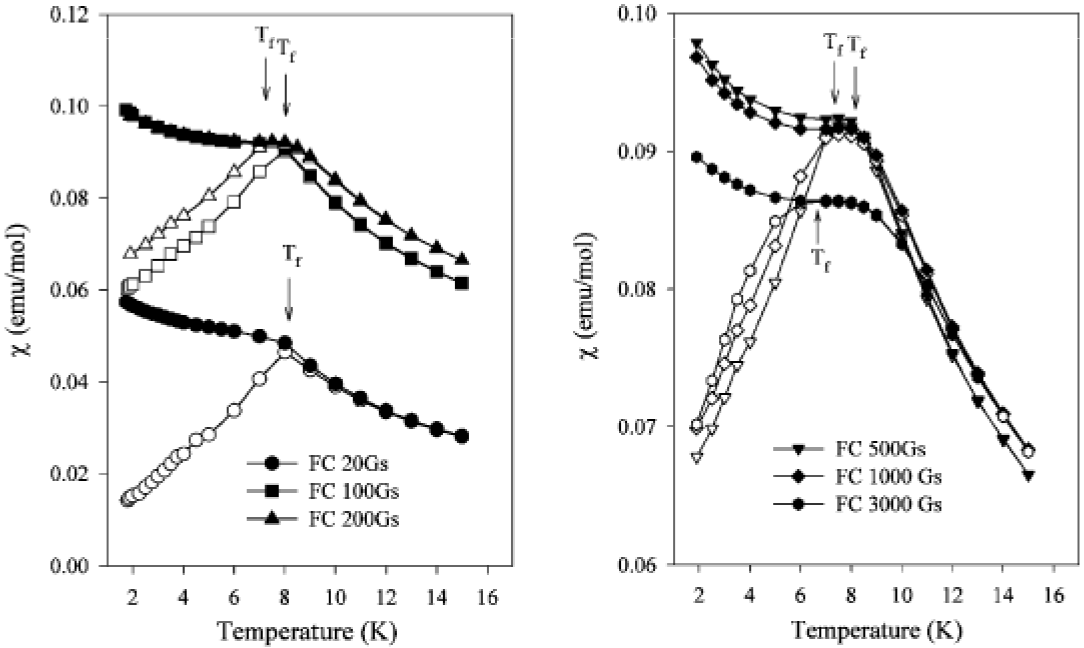
U-atoms distorted Kagomé lattice ⇒ favourable for magnetic frustrations

spin-glass behaviour in $U_3Co_{4+x}Al_{12-x}$ or $U_3Fe_4Al_{12}$

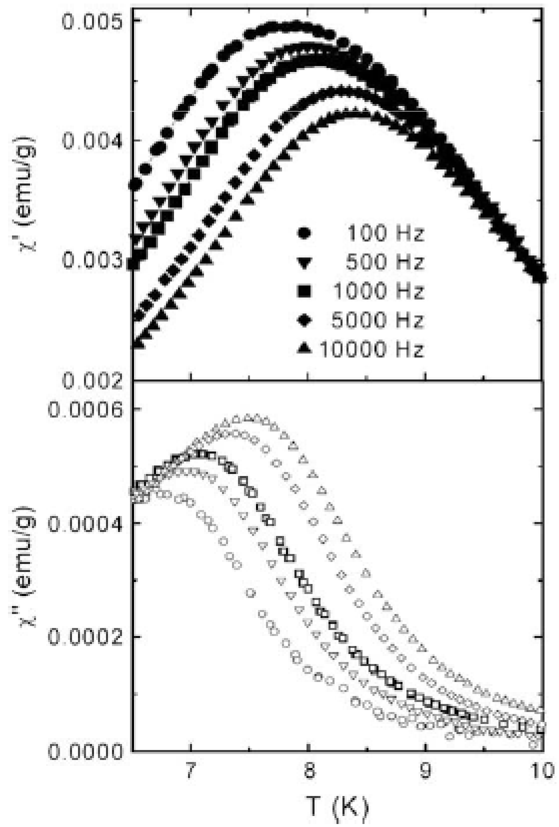
O. Tougait et al., *J. Solid State Chem.*, 177 (2004) 2053.

A.P. Gonçalves et al., *Intermetallics*, 17 (2009) 25.

$U_3Co_4Al_{12}$

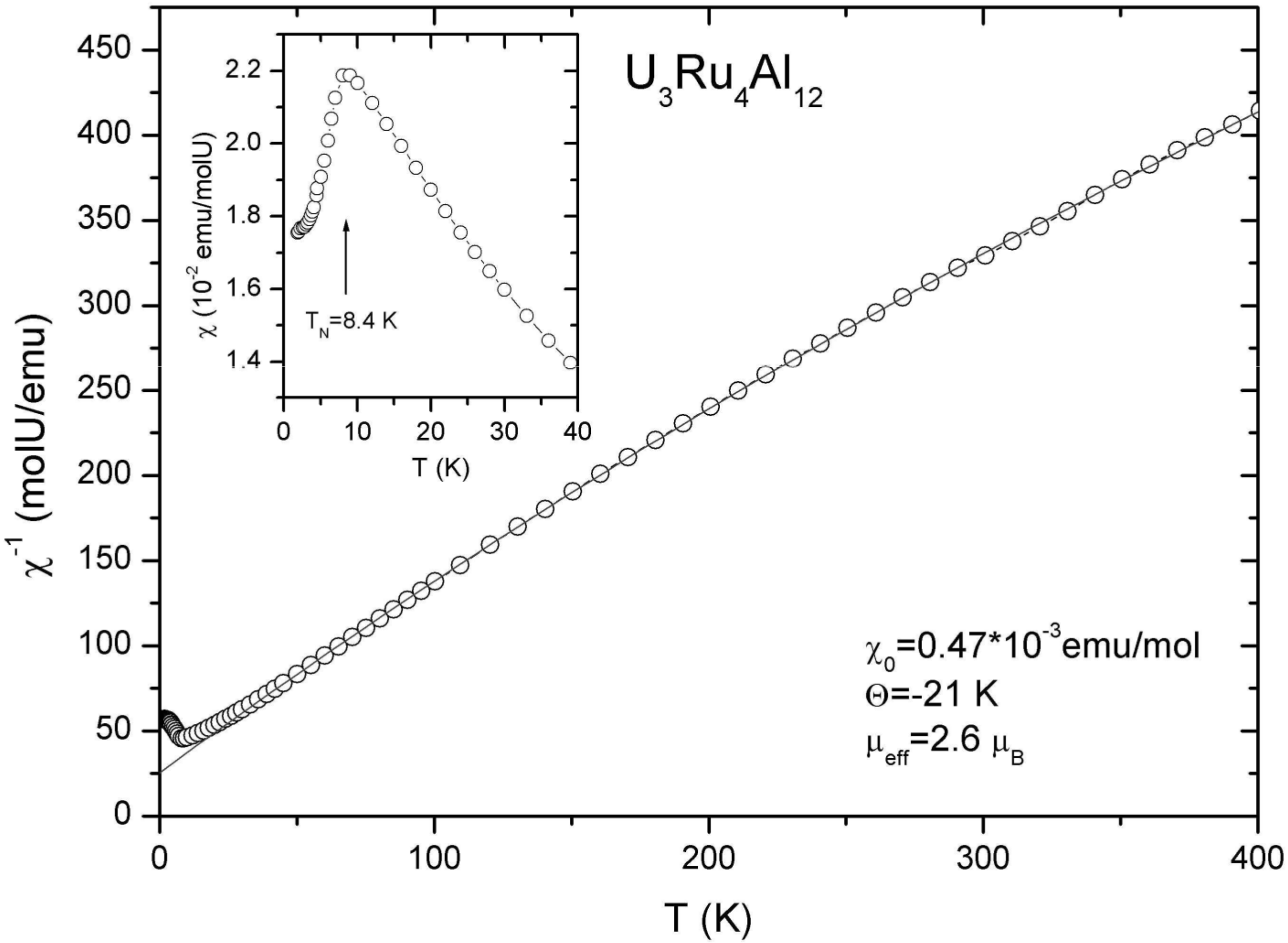


$U_3Fe_4Al_{12}$



Polycrystalline $U_3Ru_4Al_{12}$

Magnetic measurements

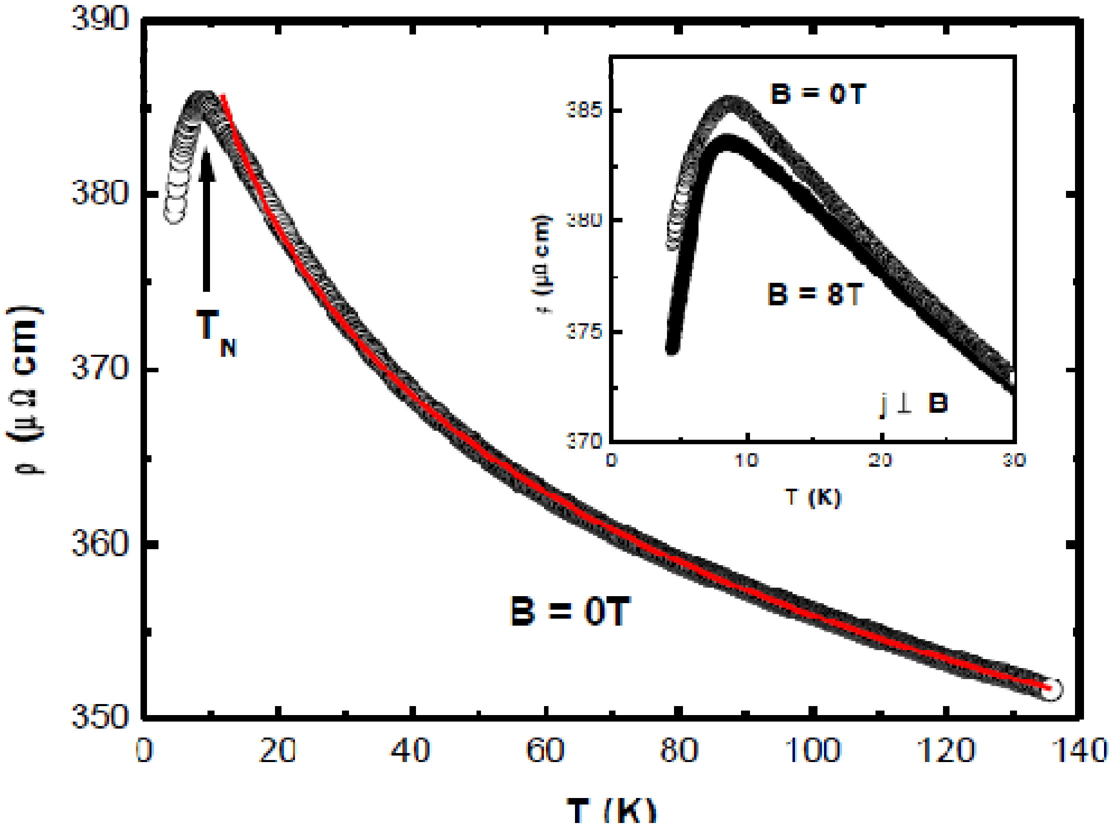


M. Pasturel et al., *J. Phys.:Cond. Matter.*, 21 (2009) 125401.

Antiferromagnetic transition at T_N = 8.4 K

Polycristalline $U_3Ru_4Al_{12}$

Electrical resitivity measurements



$\rho(T) = (\rho_0 + \rho_0^{\infty}) + c_K \ln T$

⇨ **Kondo interactions?**

Kagomé antiferromagnet + Kondo behaviour

$\Rightarrow$ **Stimulating for single crystal study!**

M. Pasturel et al., *J. Phys.:Cond. Matter*., 21 (2009) 125401.

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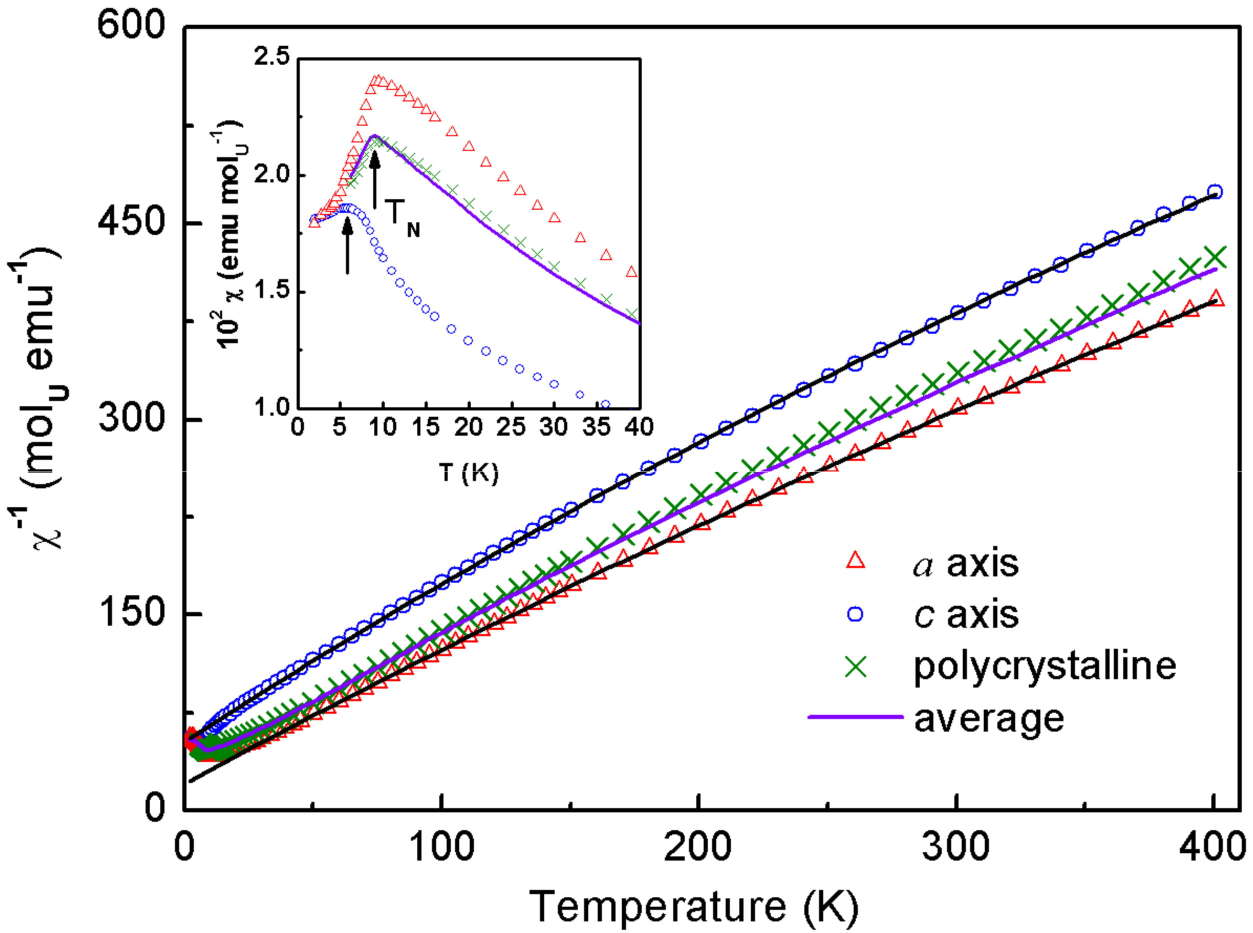
Magnetic properties



Modified Curie-Weiss law

$$\chi_i = C_i/(T - \theta_p^i) + \chi_0^i$$

χ_0^a = 3.60(5) 10^{-4} emu mol^{-1}
μ_{eff}^a = 2.72(5) μ_B
θ_p^a = -19.1(3) K

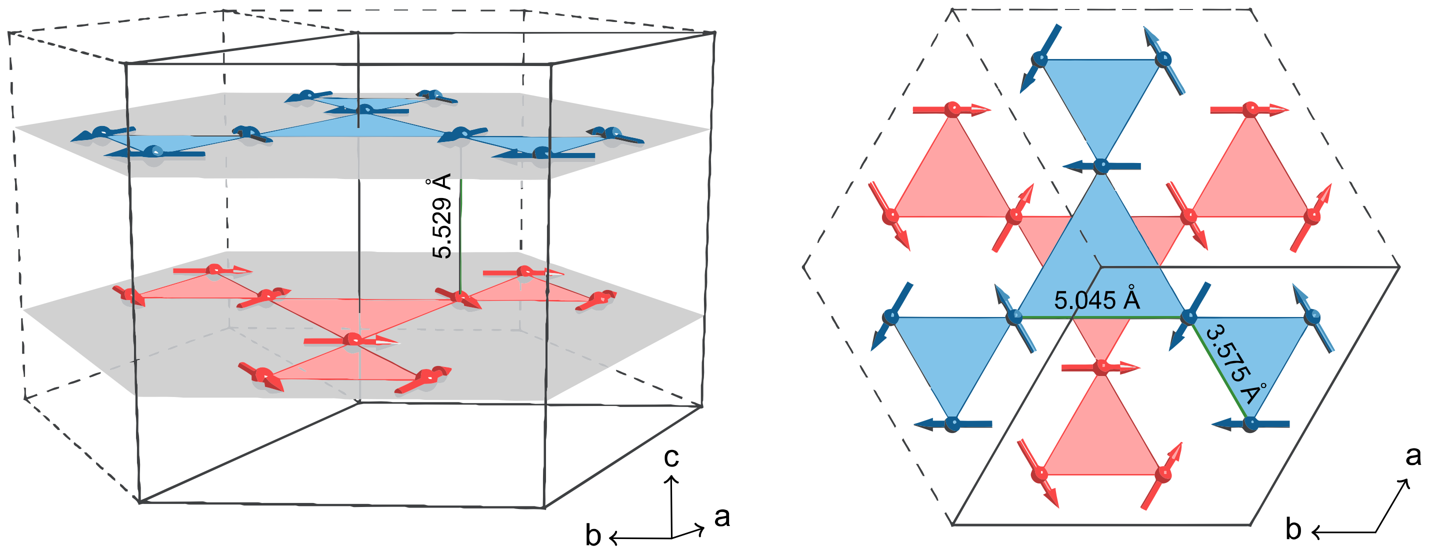
χ_0^c = 4.20(8) 10^{-4} emu mol^{-1}
μ_{eff}^c = 2.45(5) μ_B
θ_p^c = -40.5(3) K

Antiferromagnetic transition at T_N = 9.5(5) K along *a*-axis

Magnetic moments lying in the (a,b) plane?

Magnetic properties

Non polarized single crystal neutron diffraction experiments performed at LLB, Saclay
6C2 spectrometer, T = 10 K and T = 1.6 K, λ = 0.9 Å



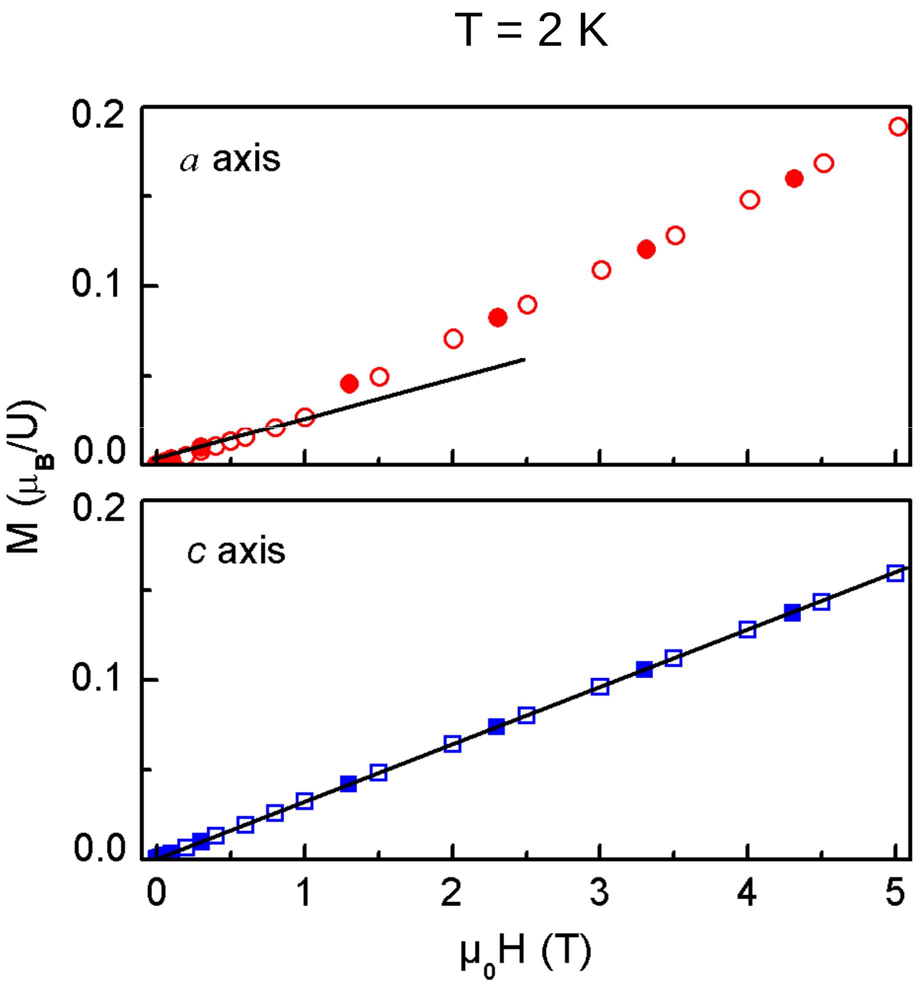
Magnetic moments lying in the (a,b) plane!

Small ferromagnetic moments in each small triangle and (a,b) parallel layer

Layers coupled antiferromagnetically along the *c*-axis.

$\mu = 2.5(2)\ \mu_B$

Magnetic properties

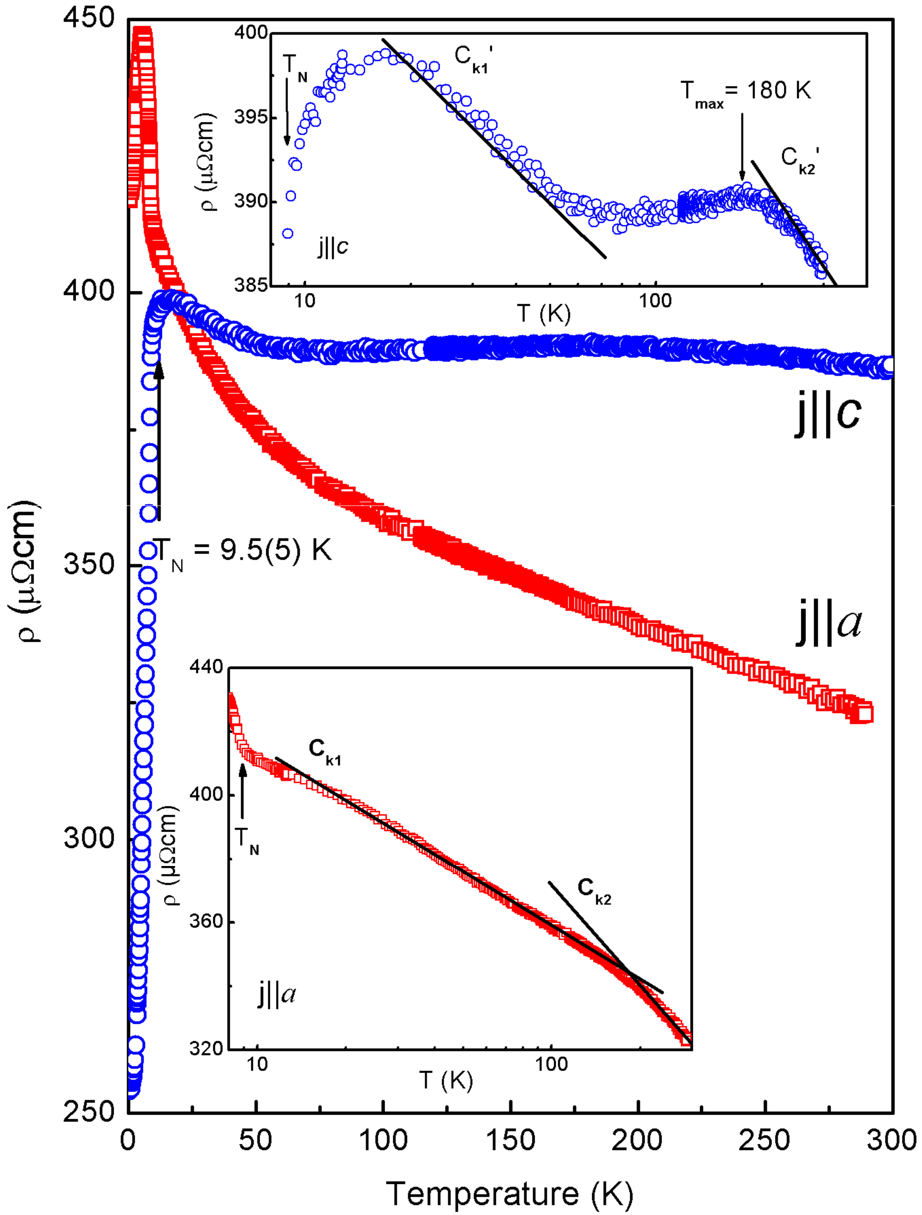


Field induced metamagnetic transition?

Neutron diffraction under applied magnetic field planned!

Full reversibility of M(B) along c-axis compatible with para- or antiferromagnetic state!

Electrical resistivity



Decrease of $\rho_c(T)$ at T_N in agreement with spin ordering

Sharp peak occuring at T_N on $\rho_a(T)$ curve

Opening of a gap at the Fermi surface:
- New BZB in the AF state?
- Spin density Wave (SDW) formation?

Electrical resistivity

UNi_2Ge_2

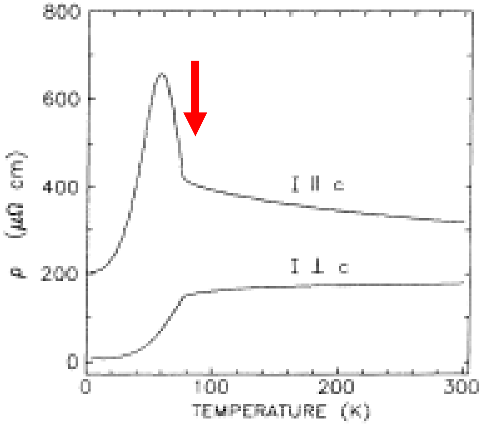


FIG. 3. Temperature dependence of the resistivity of UNi_2Ge_2 with the current parallel and perpendicular to the c axis.

Y. B. Ning et al., *Phys. Rev B.*, 46 (1992) 8201.

UCu_5

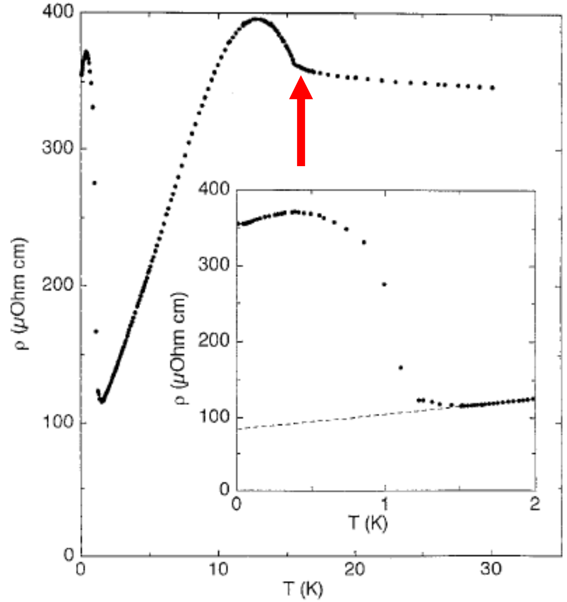
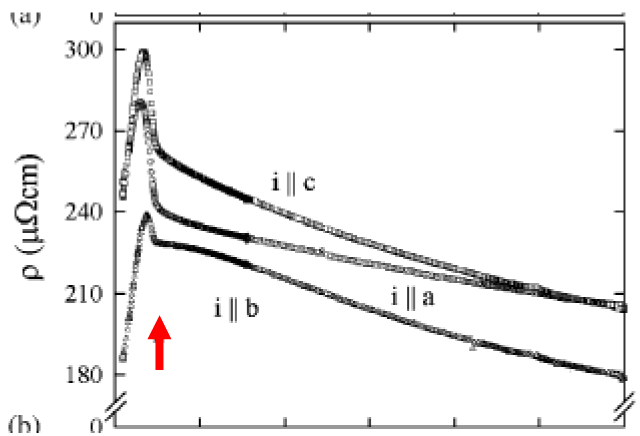


Fig. 1 Electrical resistivity $\rho(T)$ of UCu_5 between 0.02 and 30 K. The inset shows the results for $T < 2$ K on an expanded scale

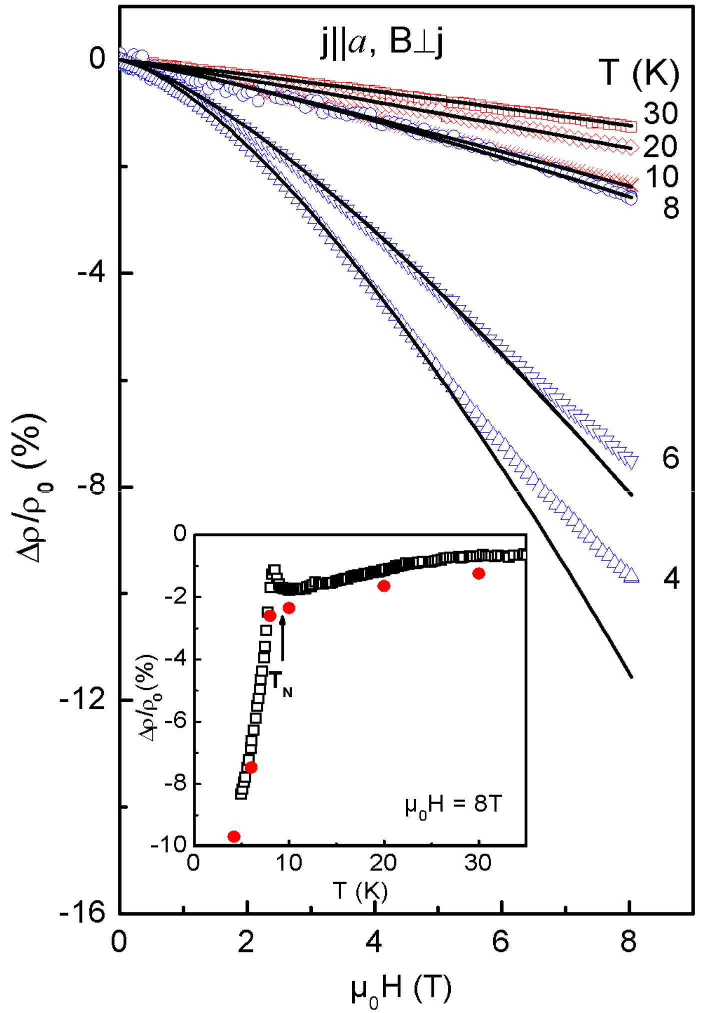
A. Bernasconi et al., *Z. Phys. B.*, 94 (1994) 423.

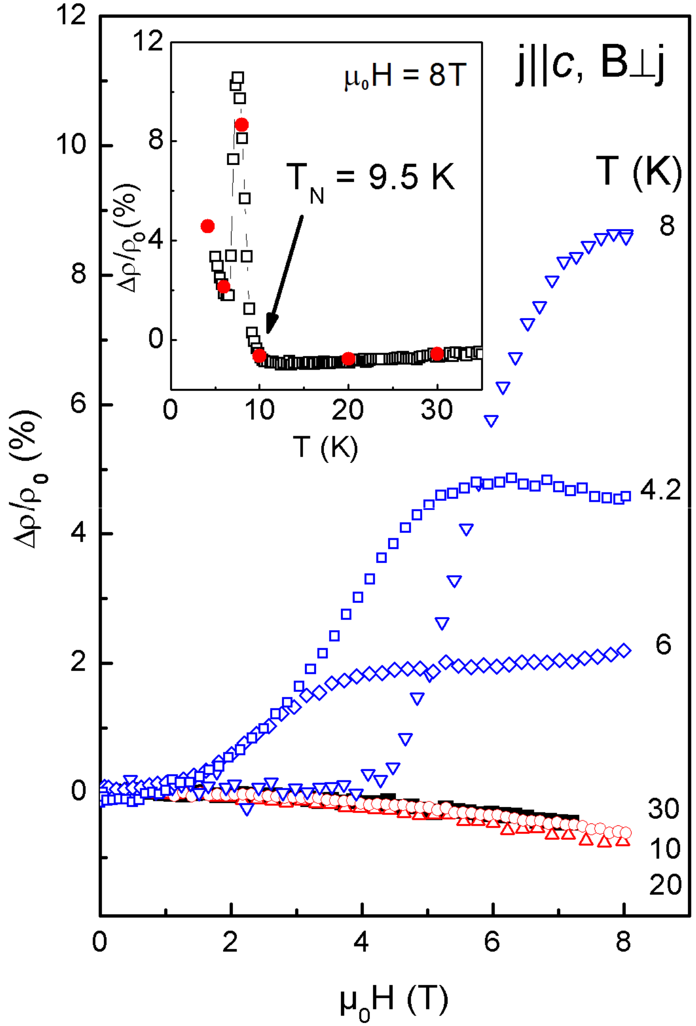
UCu_5In



D. Kaczorowski et al., *Physica B.*, 312-313 (2002) 300.

Magnetoresistivity

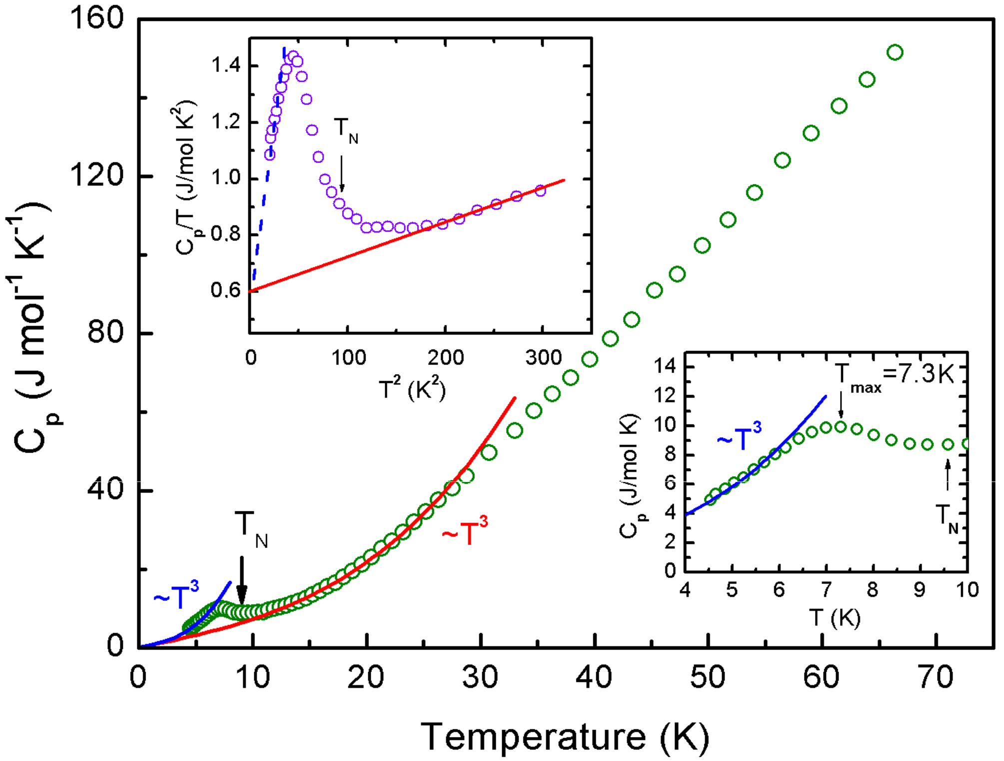




The gap survives an applied magnetic field of 8 T?

Propagation of the gap along c-axis with magnetic field?

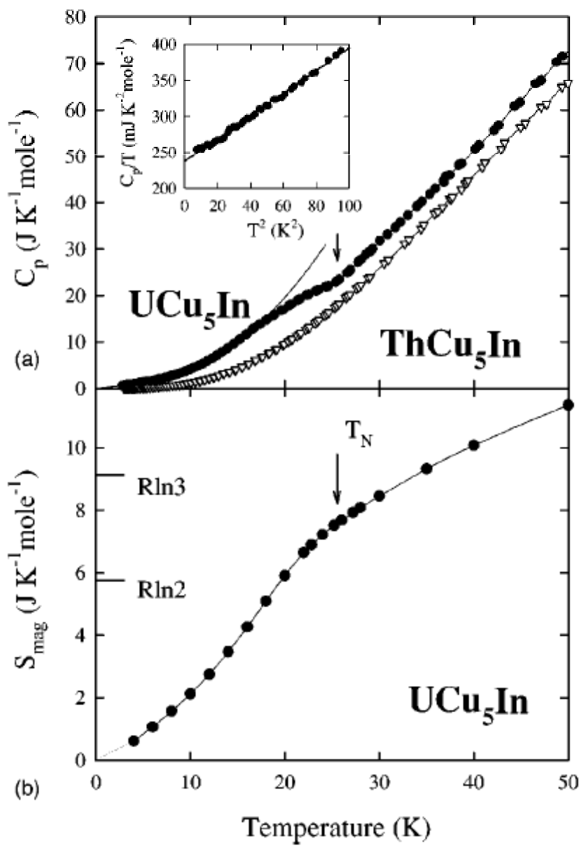
Specific heat (polycrystal)



Sommerfeld coefficient

γ = 200 mJ K^{-2} mol$_U^{-1}$

⇒ **« Moderate heavy fermion »**



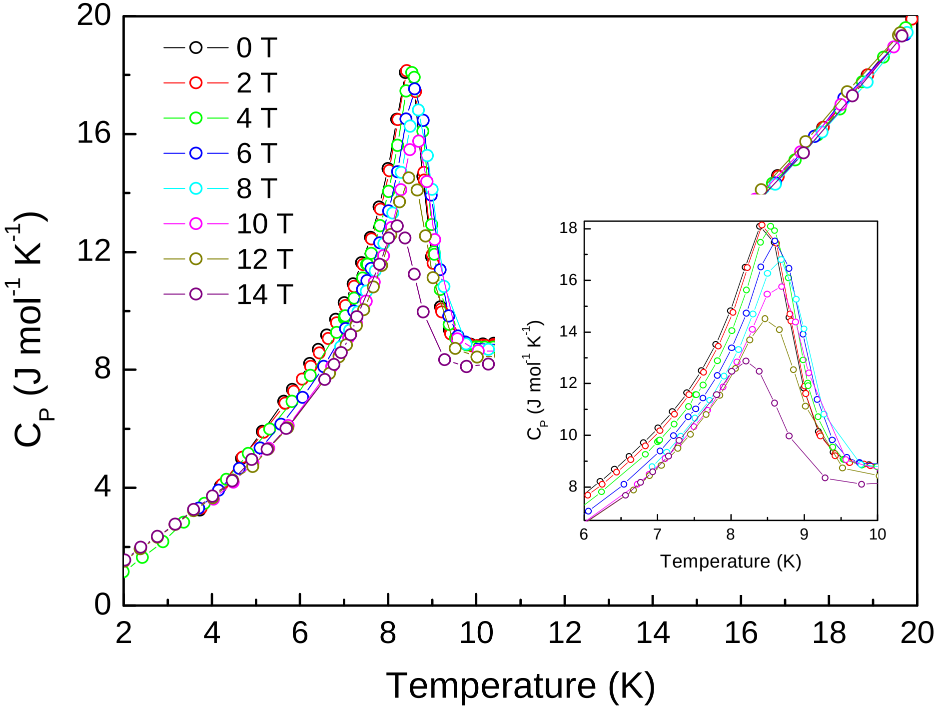
D. Kaczorowski et al., *Phys. Rev. B.*, 63 (2001) 144401.

No sharp λ-type anomaly!

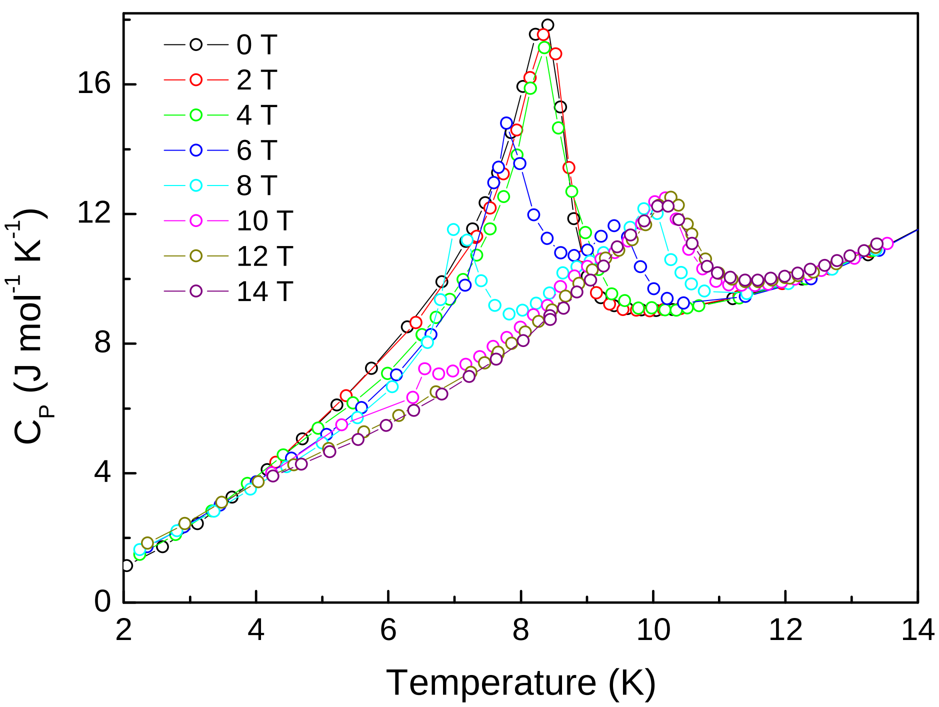
Similar to UCu_5In which is a SDW compound

Specific heat (single crystal)

Magnetic field perpendicular to the *c*-axis



Magnetic field perpendicular to the *a*-axis



AF ordering almost **not affected** by an external **magnetic field** ***//* to the (a,b) plane**

AF ordering **strongly affected** by an external **magnetic field** **⊥ to the *a*-axis**

Above 6 T:
1 AF + 1 Ferro component s?

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Conclusions

- An unique antiferromagnetic structure of $U_3Ru_4Al_{12}$ has been determined by neutron diffraction, showing moments lying inside the Kagomé lattice.
- Geometric frustrations are not the only reason of spin-glass behaviour of $U_3T_4Al_{12}$ (T = Fe, Co).
- Electrical transport properties are dominated by the opening of a gap in the Fermi surface at T_N.
- Complex (B,T) phase diagram to be further investigated.

Perspectives

- Influence of high magnetic field on the magnetic ordering

- Influence of applied pressure

Cr

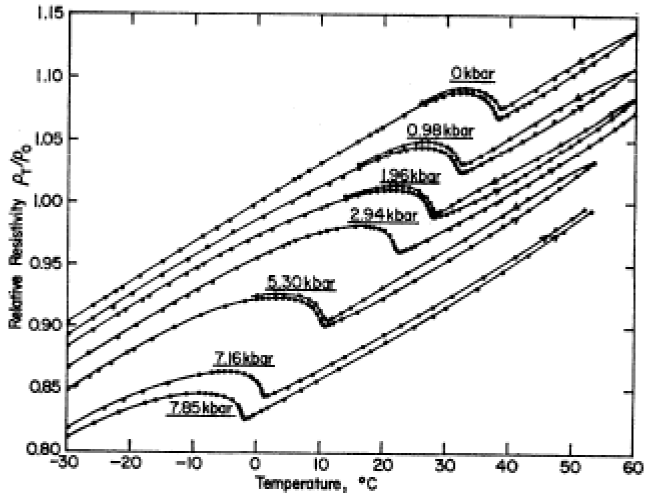
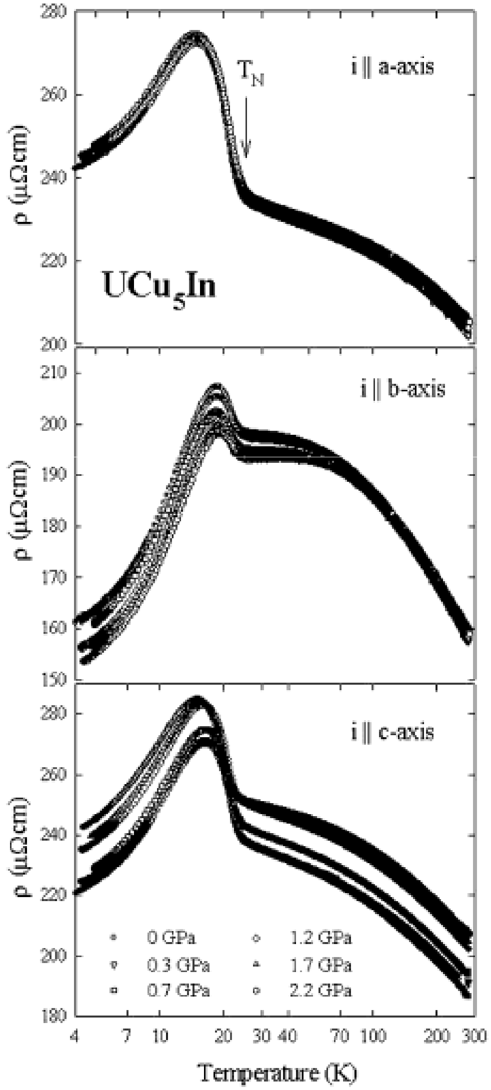


FIG. 1. The relative electric resistivity of chromium as a function of temperature and pressure. ρ_0 at 0°C and atmospheric pressure was found to be 1.27×10^{-5} Ω cm.

T. Mitsui et al., *Phys. Rev.*, 137 (1965) A564.

SDW are usually pressure resistant!

UCu_5In



D. Kaczorowski et al., *Solid State Commun.*, 122 (2002) 527.

- **Any other idea or collaboration are welcome!**

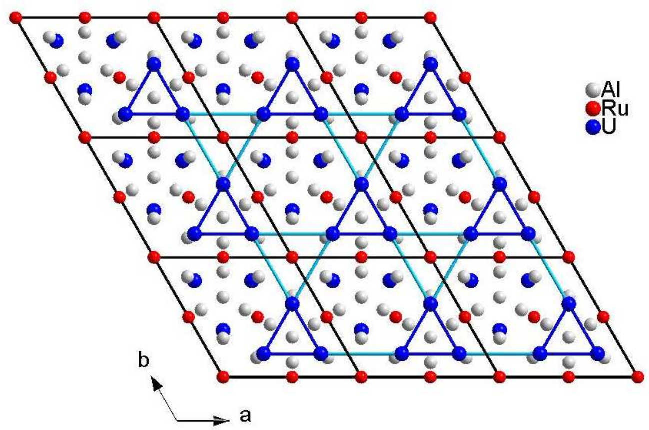
Aknowledgements

- Prof. Komatsubara for useful advices in SC growth

- A. Hackemer, R. Wawryk, R. Gorzelniak and D. Badurski for their assistance in thermal and transport measurements.

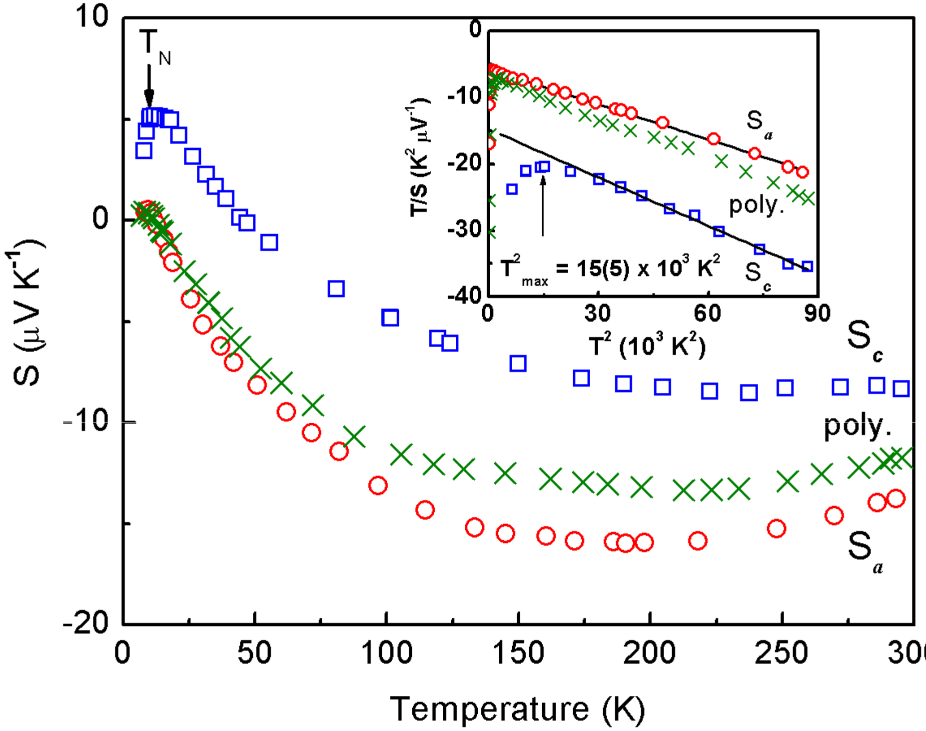
- PHC Polonium and PAN-CNRS funding bilateral exchanges

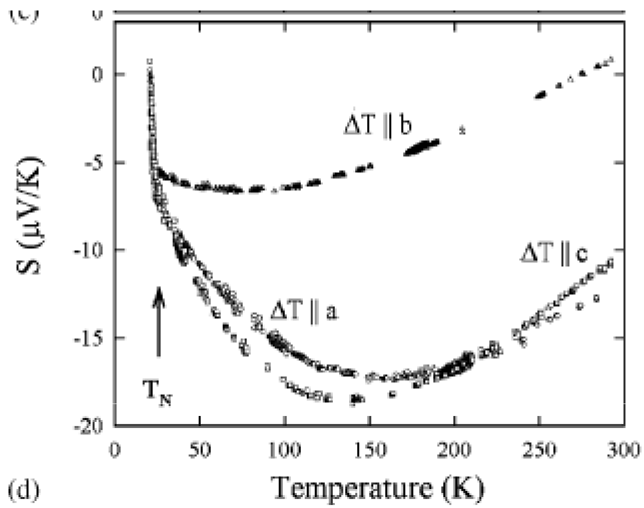
- Thank you for your attention.



Thermopower

and





D. Kaczorowski et al., *Physica B*., 312-313 (2002) 300.

Single Lorentzian band model:

$$S(T) = \frac{AT}{B^2 + T^2} \qquad A = \frac{2\Delta}{|e|} \qquad B^2 = \frac{3(\Delta^2 + \Gamma^2)}{(\pi k_B)^2}$$

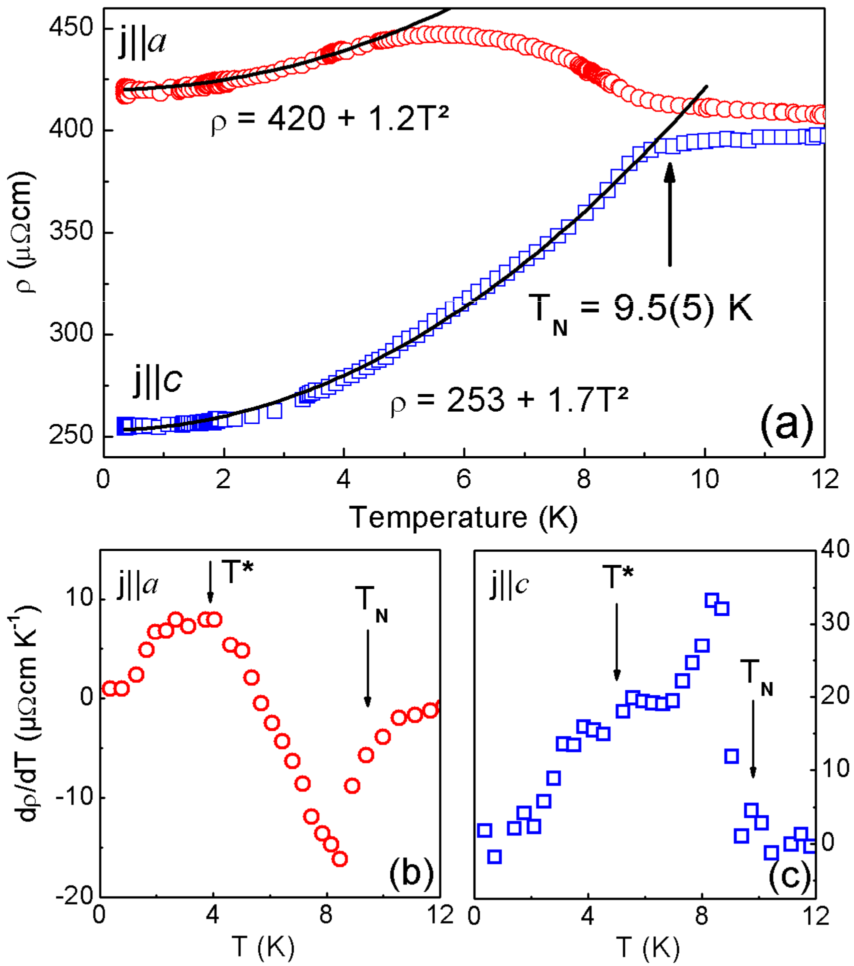
where $\Delta_\iota = \varepsilon_{5f} - \varepsilon_F$ is a measure of the position of the 5*f*- DOS of a peak ε_{5f} with respect to the Fermi level ε_F, and Γ_ι is the width of the Lorentzian shaped 5*f* band.

Γ_a = 27.9 meV and Δ_a = -2.82 meV
Γ_c = 38.4 meV and Δ_c = -2.06 meV

Values comparable to those observed for different aluminides like $CeAl_2$ or UAl_2 being moderate heavy fermions.

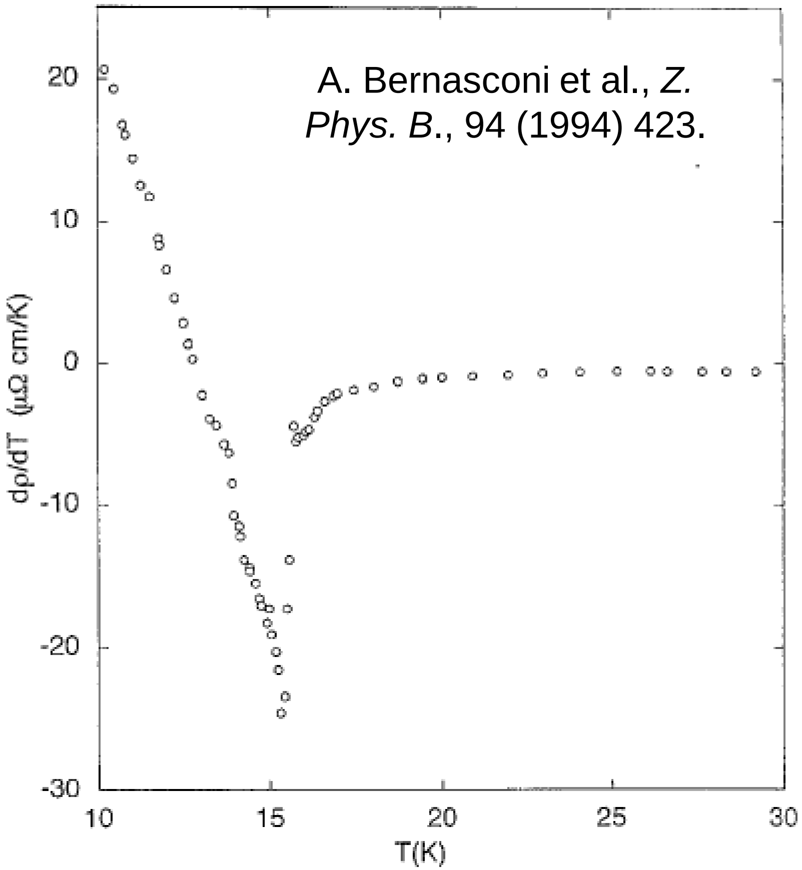
Electrical resistivity

$U_3Ru_4Al_{12}$



Other example

UCu_5



A. Bernasconi et al., *Z. Phys. B.*, 94 (1994) 423.