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Thermoelectricity across a topological transition in $YbRh_2Si_2$, $CeRu_2Si_2$ ($CeRh_2Si_2$)

A. Pourret*, A. Palacio Morales, M. Boukahil, G. Knebel, D. Aoki, Y. Onuki, J. Flouquet*

GRENOBLE UNIVERSITÉS

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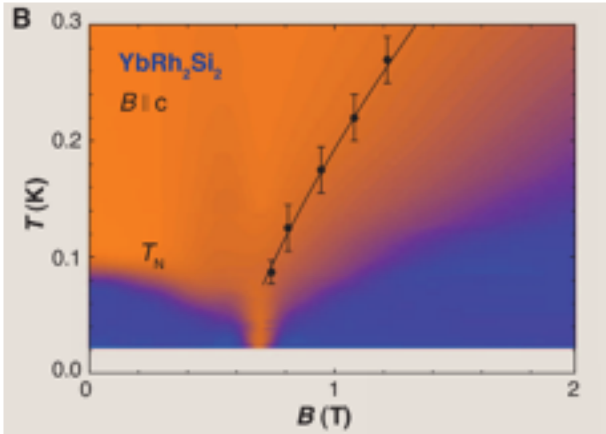
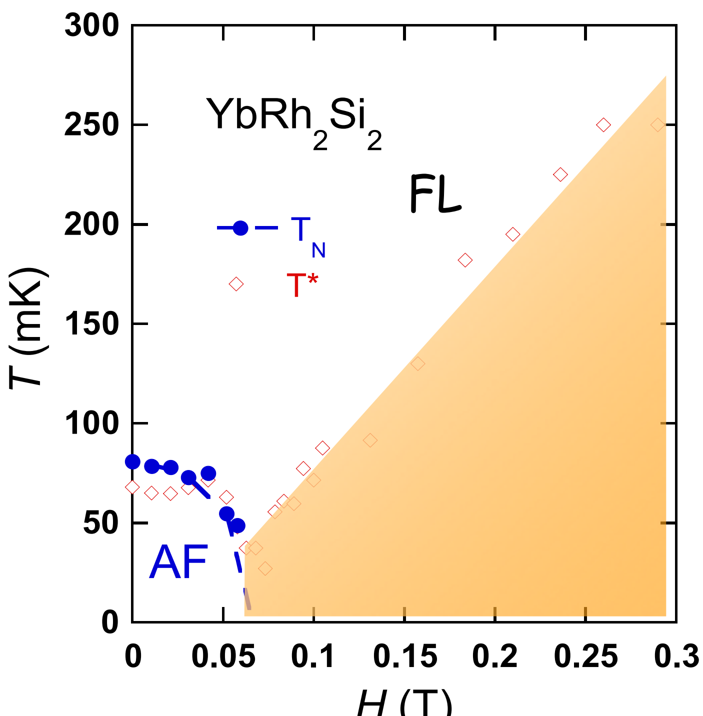
Outline

- Motivation: Well known Lifshitz transition in $YbRh_2Si_2$
- Experimental setup
- TEP results for transverse and longitudinal configuration (B//c) in $CeRu_2Si_2$
- Quantum Oscillations in the TEP $CeRu_2Si_2$ ($CeRh_2Si_2$)
- Conclusion

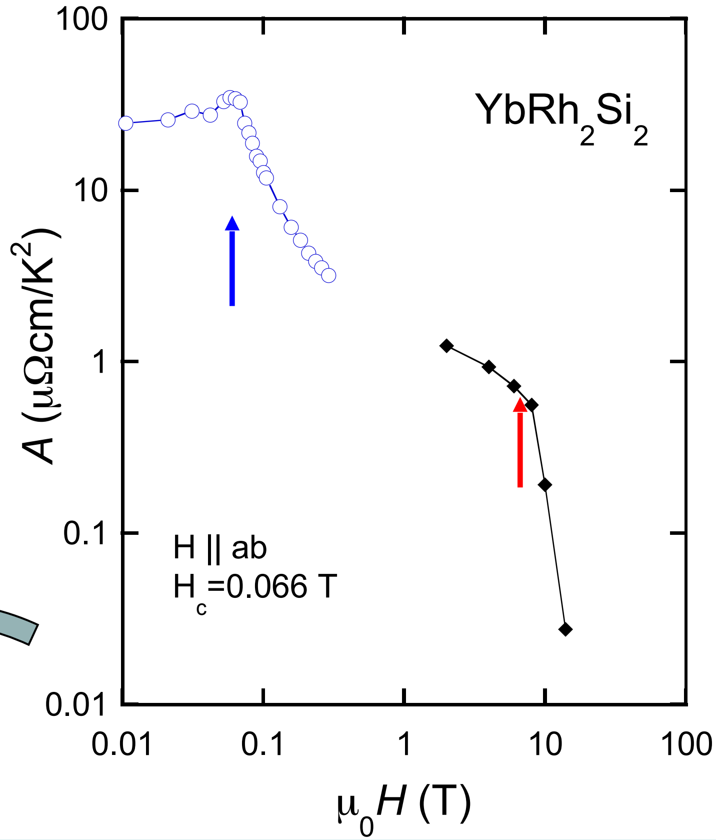
Motivation: $YbRh_2Si_2$

Custers nature 2003





Knebel G. et al. JPSJ 2006

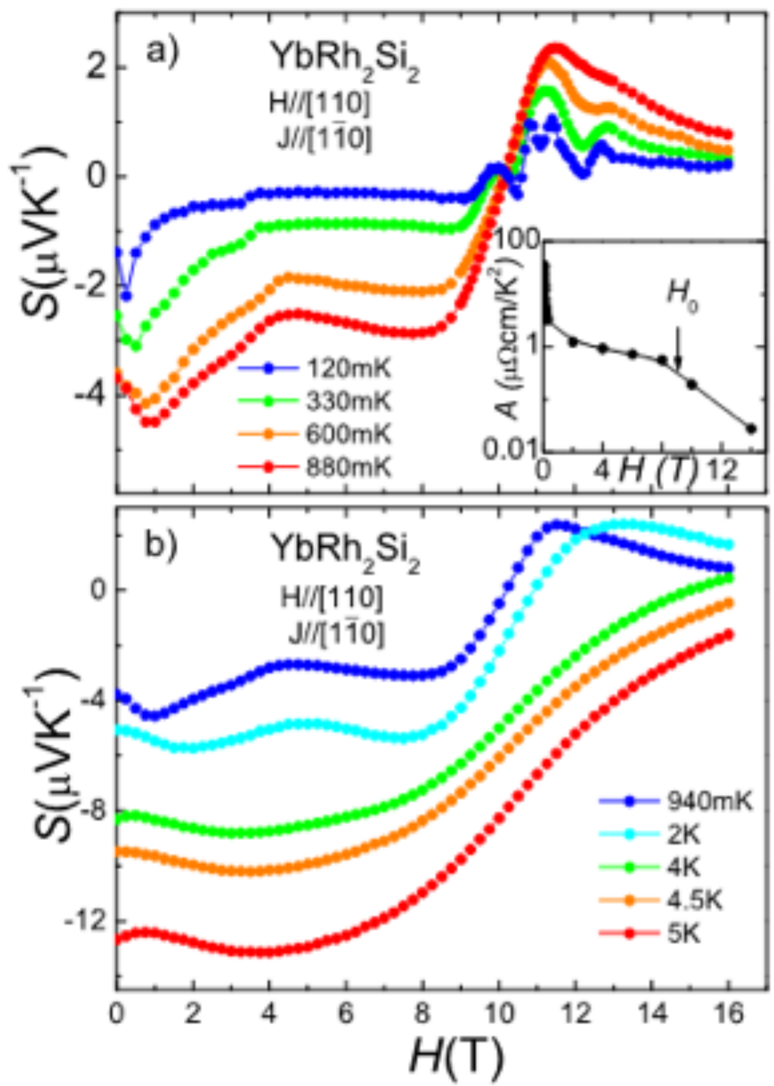


2 characteristic fields !

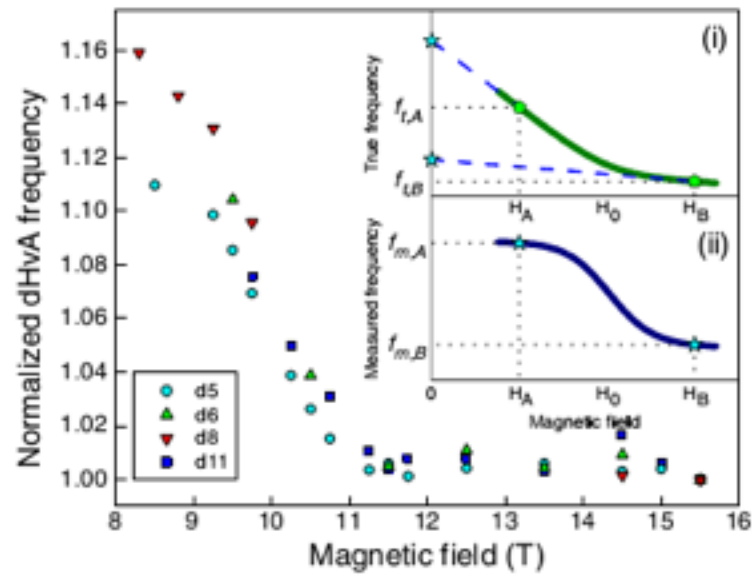
H_c=0.066 T: suppression of AF order

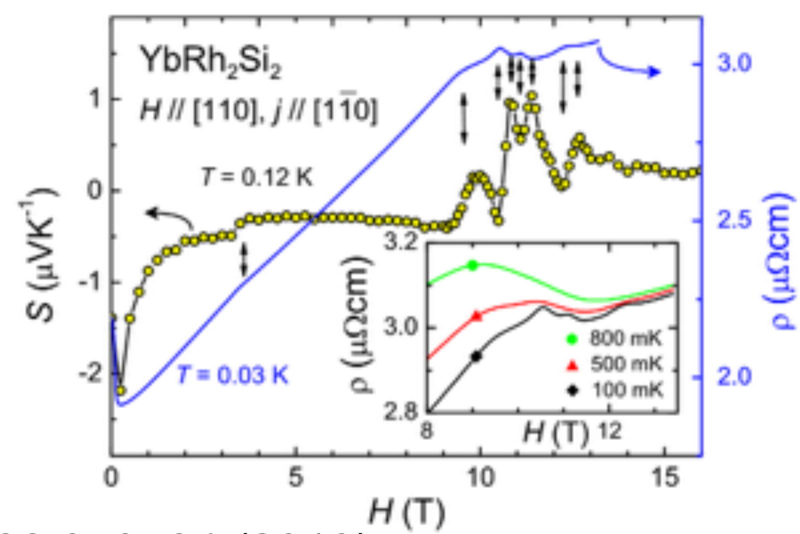
H_K=10 T : suppression of heavy fermion state

TEP across a Lifshitz transition



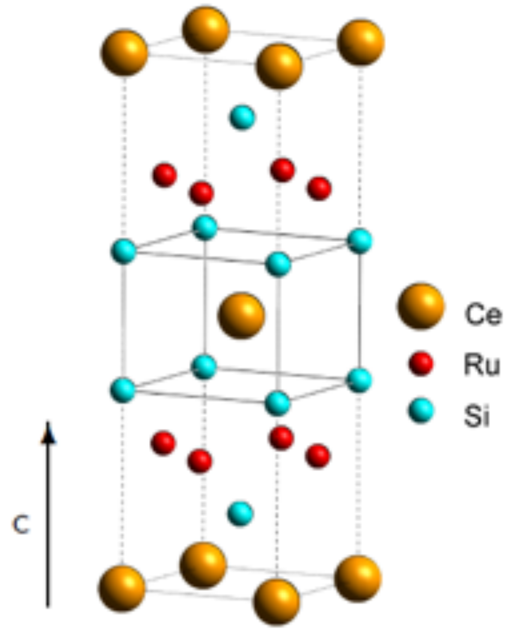
Rourke et al. PRL 2008





A. Pourret, JPSJ ,82,053704 (2013)

The system $CeRu_2Si_2$



Tetragonal cristal structure

Critical end point below T=0K

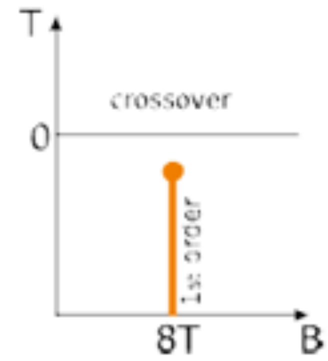
Weickert *et al. PRB* 81,134438 (2010)

Heavy fermion system

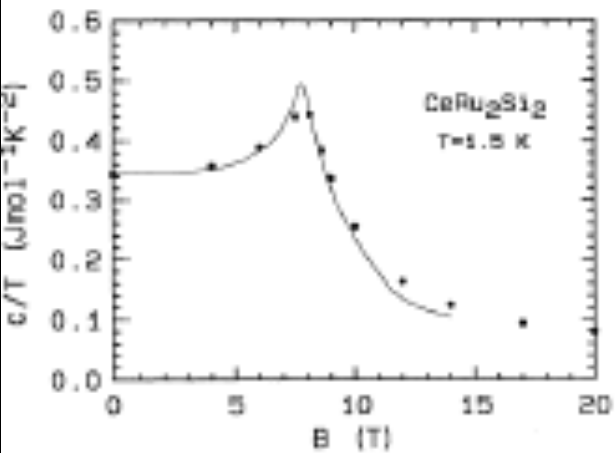
Kondo interaction T_K~ 20K

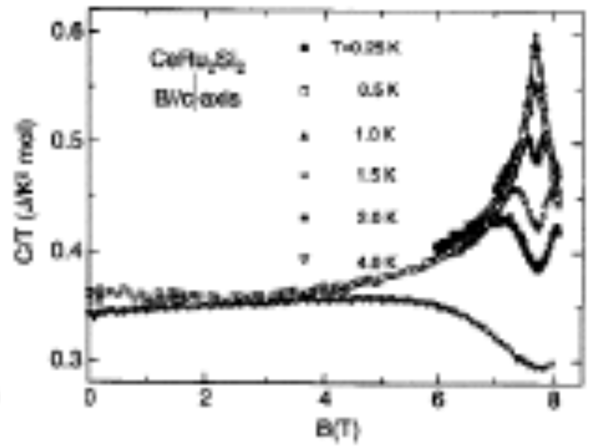
Paramagnetic ground state

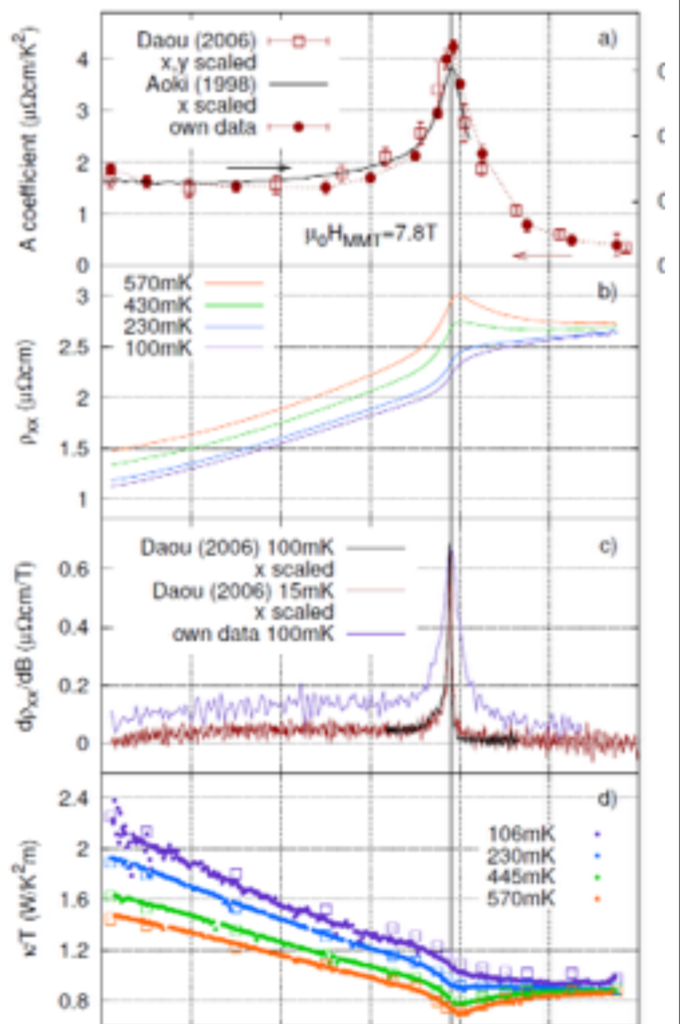
Metamagnetic transition at B=7.8T



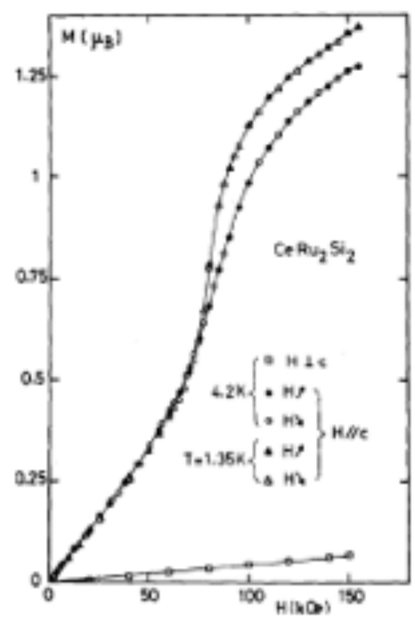
MMT transition in $CeRu_2Si_2$







Magnetisation



Metamagnetic transition at 7.8T

H. P. Van der Meulen *et al . Phys . Rev. B 44, 814 (1994)*
H. Aoki , *.et al. J. Magn. Mater. 177, 271(1998)*
Pfau. H., *et al Phys. Rev. Lett. (2011)*

Lifshitz transition

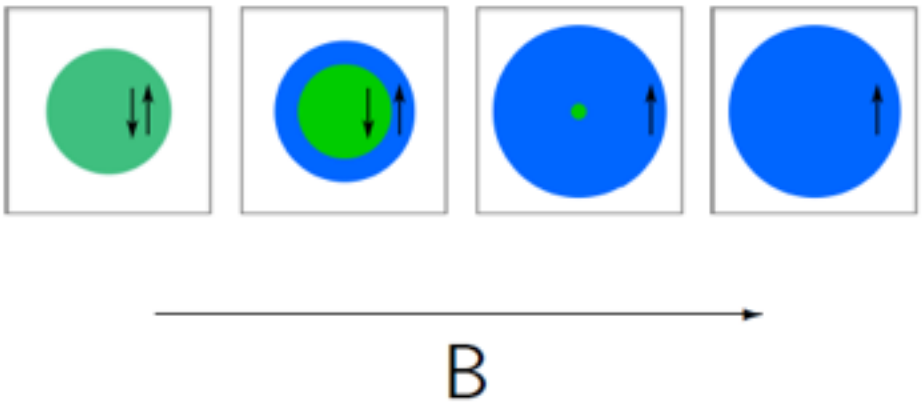
$CeRu_2Si_2$: old idea the metamagnetic transition is accompagned by an abrupt **localization of the f electron ?**

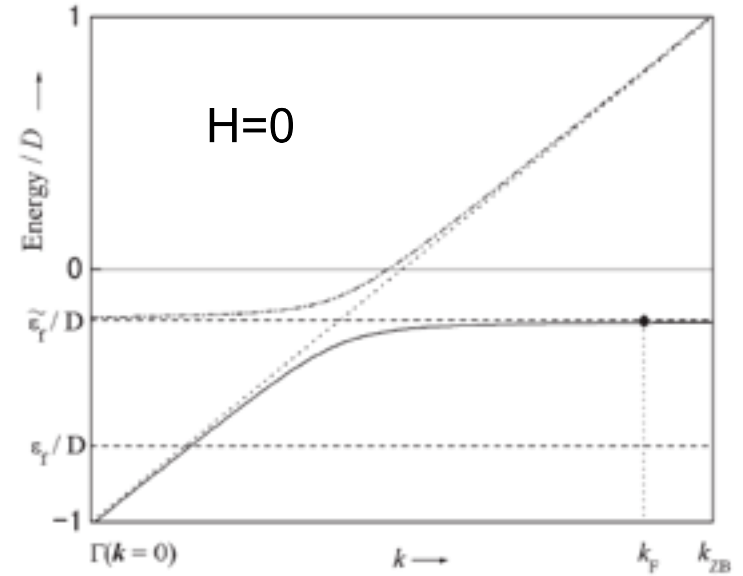
but

- the MMT transition is more a cross over
- above Hm, both magnetization ($0.7\mu_B$) and specific heat (500mJ/K/mol) depart drastically from a local moment scenario
- X ray absorption spectroscopy indicates that a fully localized state is expected only at H~200T
- « large » versus « small » FS maybe not pertinent in spin polarized sytems

⟶ **New interpretation:**
FS volume conserving topology driven transition
$CeRu_2Si_2$ remains a Fermi liquid at all field
Zeeman splitting scenario ($\mu_B B=E_F$)

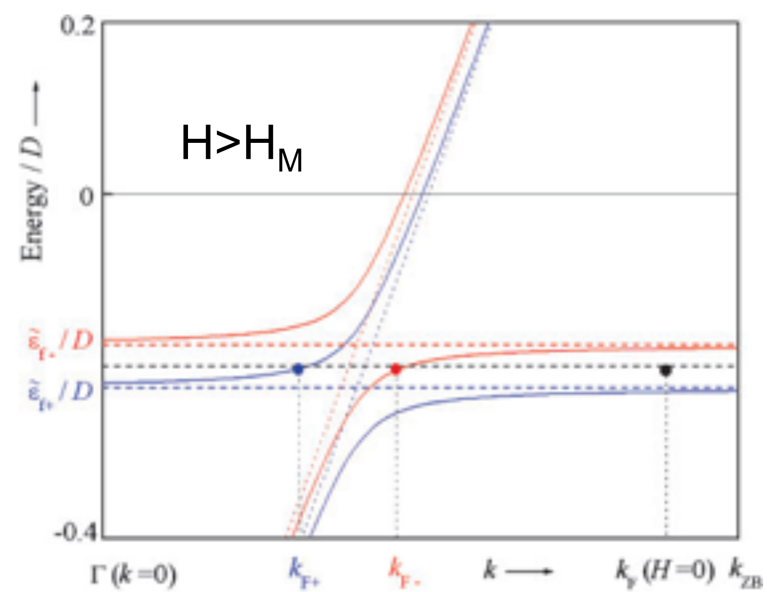
Lifshitz transition





spin split FS undergoes a Lifshitz transition:

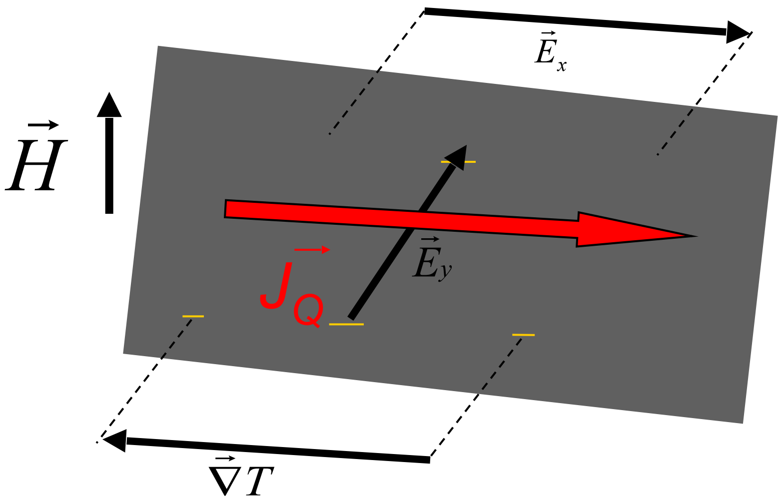
- majority spin branch disappears at H_0
- no localization of f electron
- “large” FS to “small “FS



K. Miyake, JPSJ, 75, 033704, 2006

Thermoelectric coefficients

1) Thermoelectric power $S = \frac{-E_x}{\nabla_x T}$



$$S = -\frac{\pi^2 k_B^2 T}{3e}\left(\frac{\partial \ln \sigma(\epsilon)}{\partial \epsilon}\right)_{\varepsilon=\epsilon_F}$$

$$S = -\frac{\pi^2 k_B^2 T}{3e}\left(\frac{\partial \ln \tau(\epsilon)}{\partial \epsilon} + \frac{\partial \ln N(\epsilon)}{\partial \epsilon}\right)$$

multiband system : $S = \sum_i \frac{\sigma_i}{\sigma} S_i$

Miyake, Kohno 2004

free electron gas $S = -\frac{\pi^2}{3}\frac{k_B^2}{e}\frac{T}{\epsilon_F}\left(\frac{3}{2}+\zeta\right)$

$\tau = \varepsilon^{\zeta}$ $\zeta=0$

The universal ratio is inversely proportional to the numbers of heat carriers :

$q = \frac{S}{T}\frac{N_{Av}e}{\gamma}$ Behnia 2004

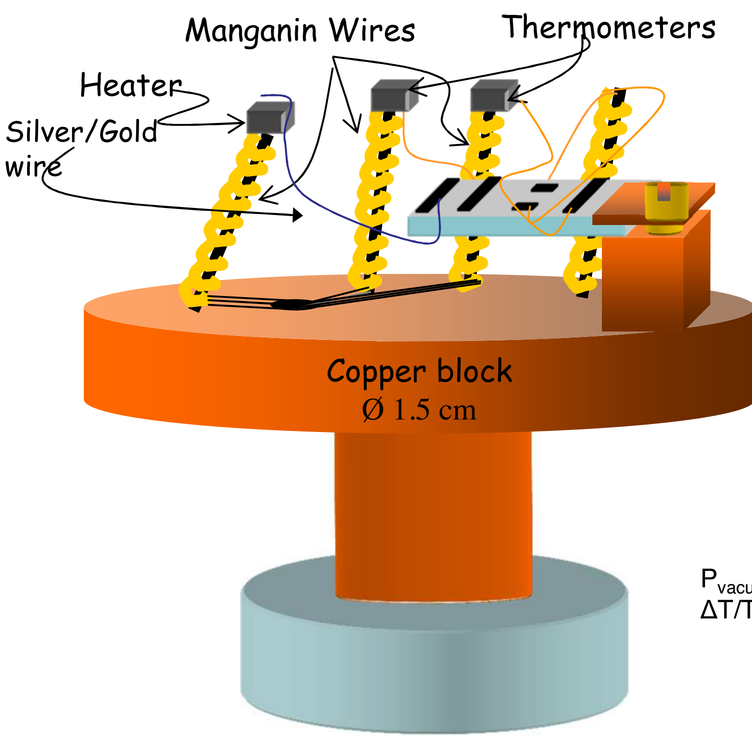
The Seebeck coefficient can probe: any Fermi Surface change, reconstruction;
carrier sign ; effective mass (Quantum oscillations)

Width 0.5mm, length 4mm

Thermoeletric set up

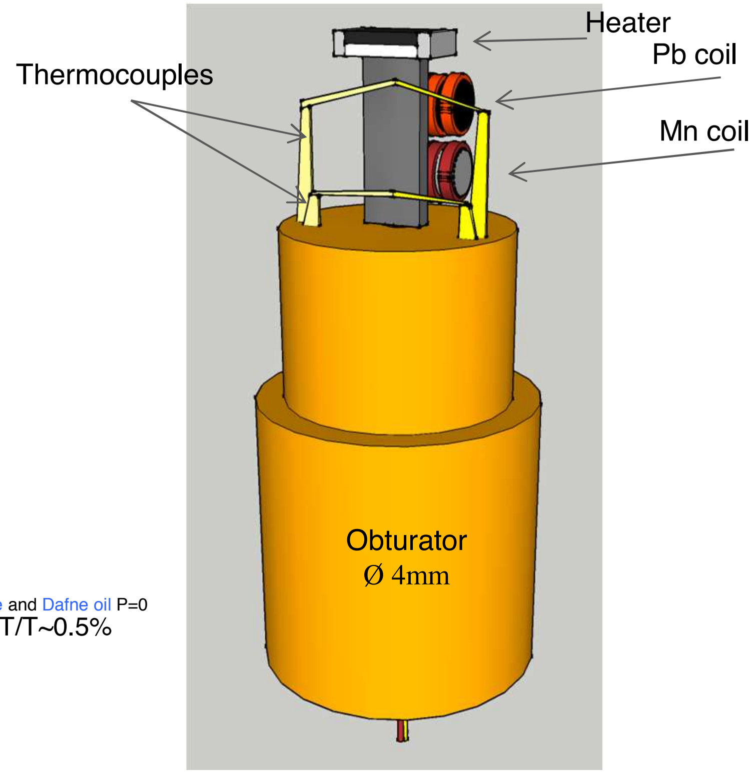
Vacuum setup

« One heater-two thermometers »



Pressure setup

« Thermocouples »



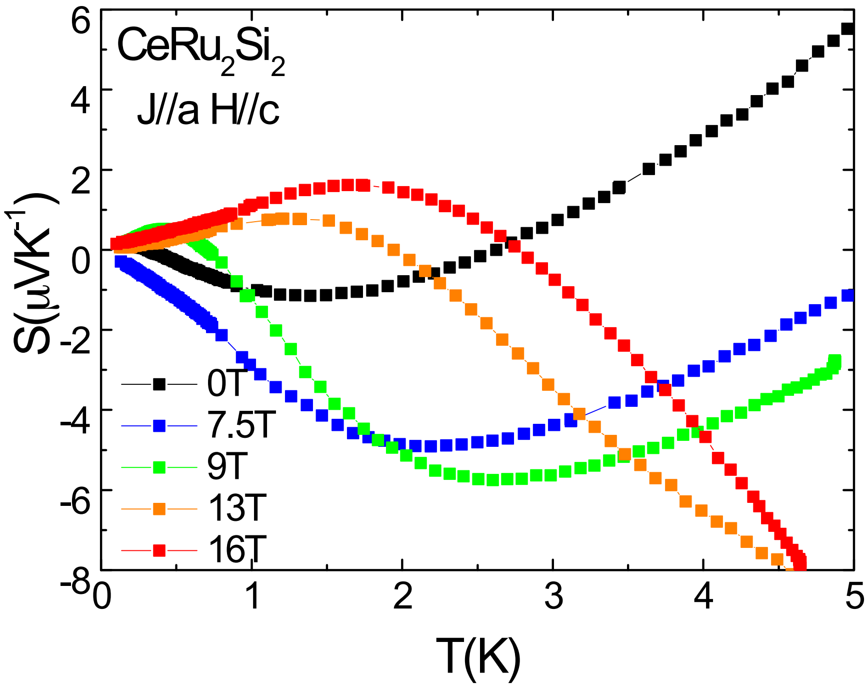
$P_{vacuum}/10$ = $P_{^4He}$ and Dafne oil P=0

ΔT/T~3% ΔT/T~0.5%

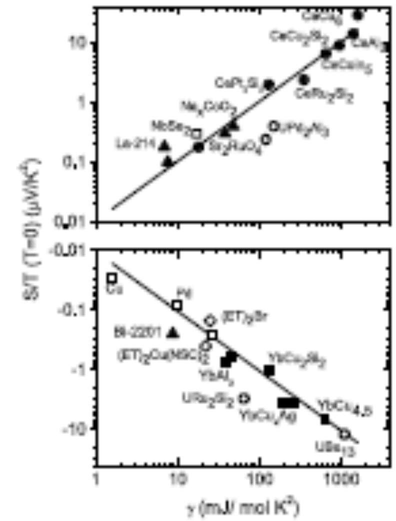
Seebeck coefficient: $S = \frac{-E_x}{\nabla_x T}$

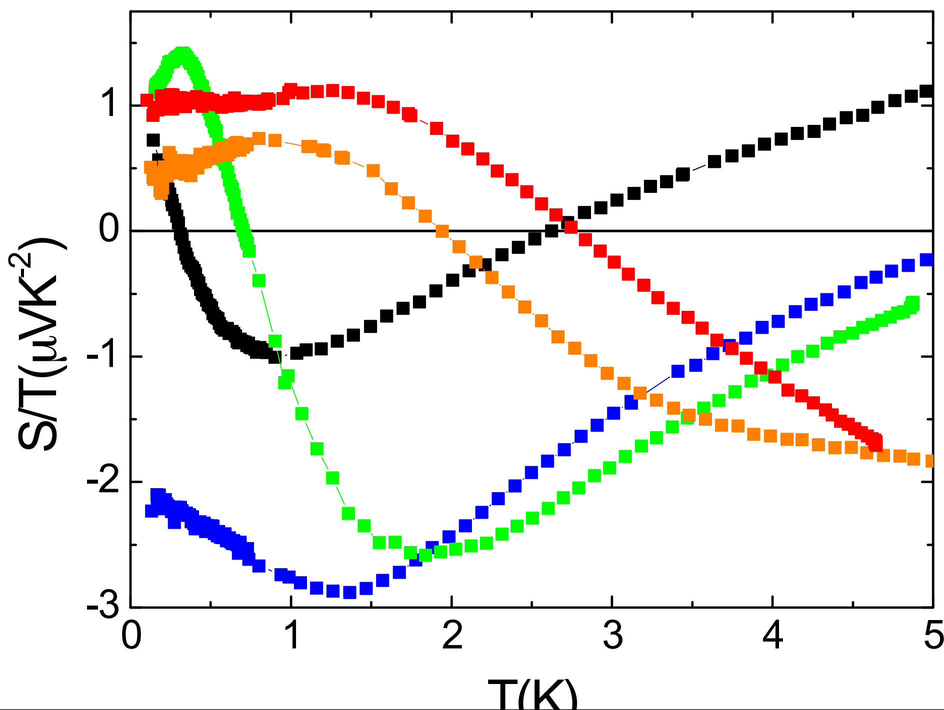
Nernst coefficient: $N = \frac{-E_y}{\nabla_x T}$

Temperature dependence for the transverse configuration



0T: change of sign at 300 mK

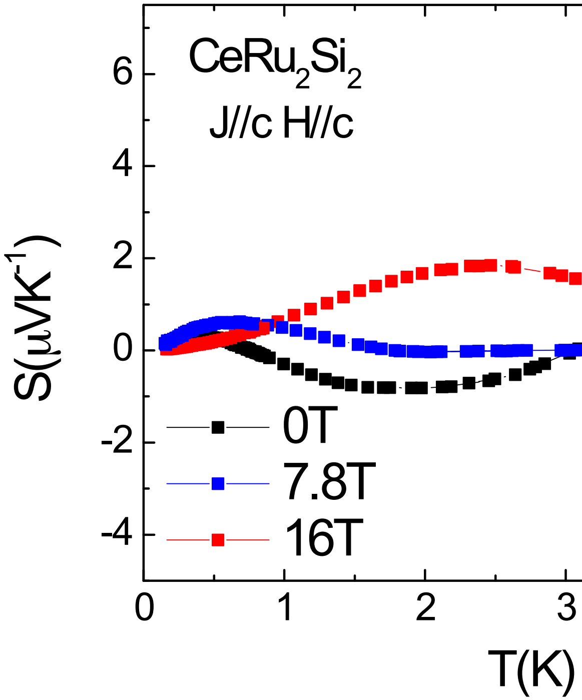


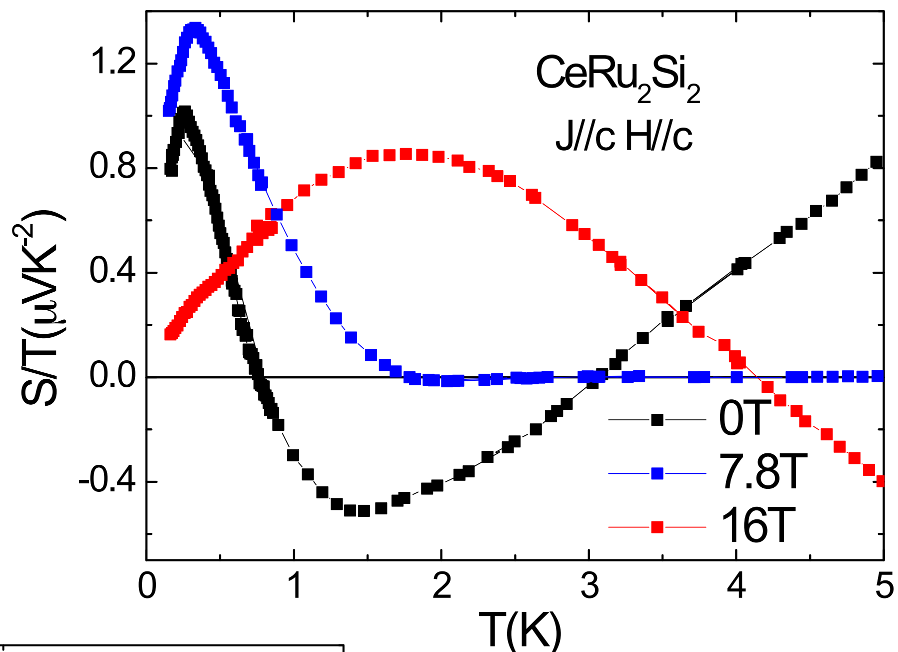


S/T at 0T continues to increase at low temperature

S/T at 16T is constant

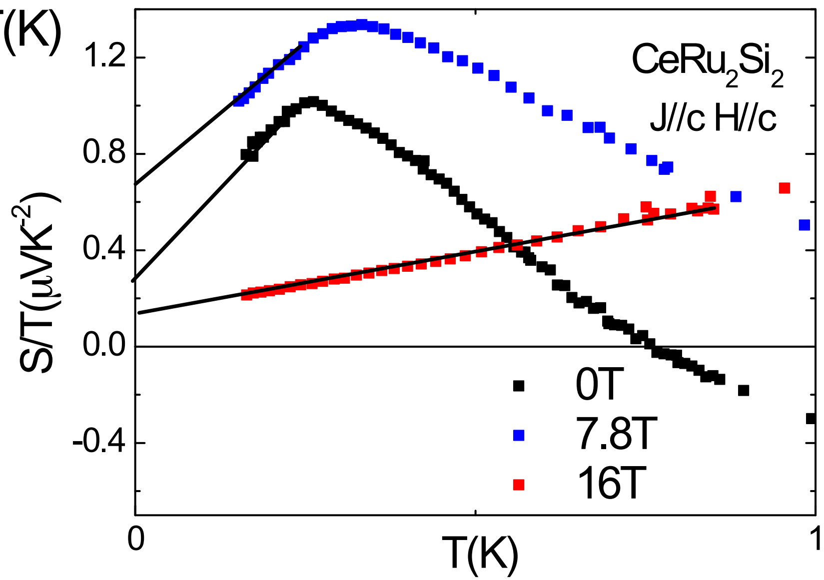
Temperature dependence for the longitudinal configuration





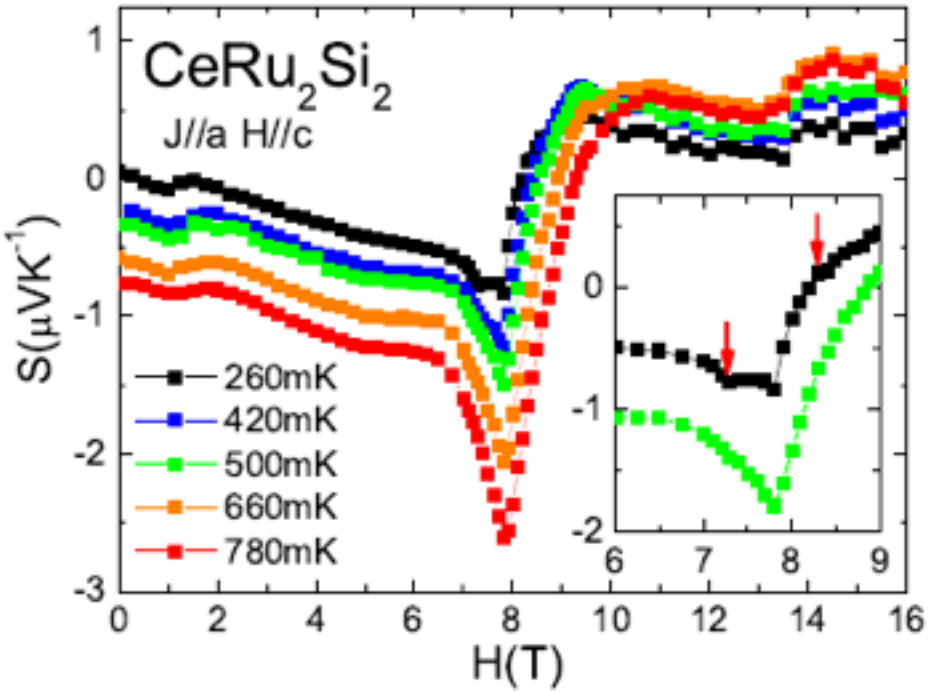
0T: the change of sign occurs at 760mK

q=0.0 8!!!

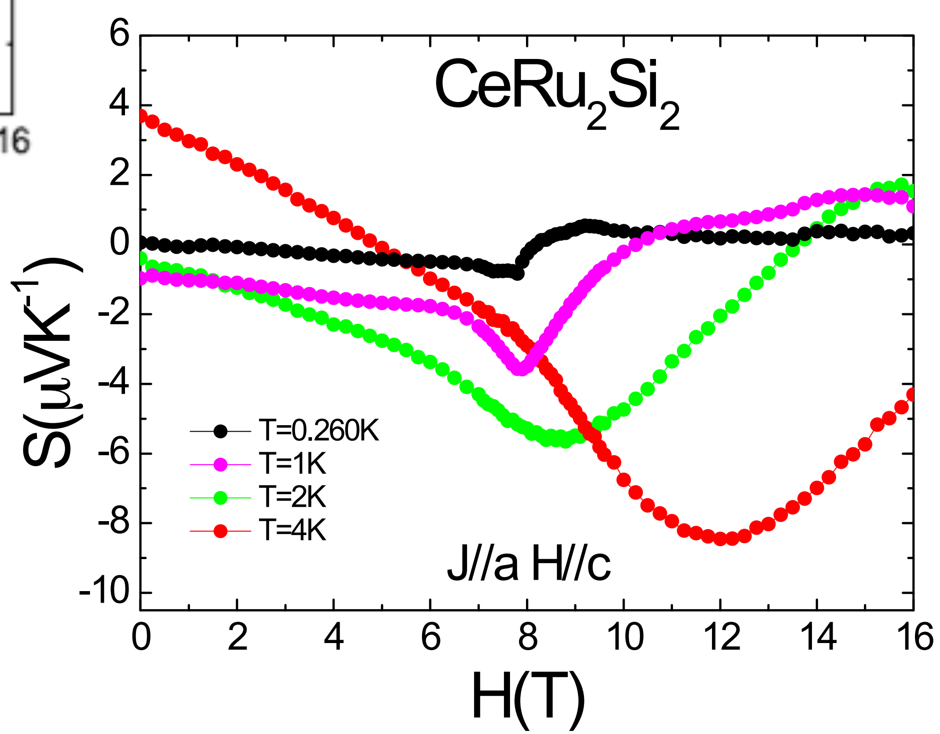


S/T at 0T is similar to 16T

Metamagnetic transition: transverse configuration



At low temperature H_m =7.8T
New anomaly at 13.5 T

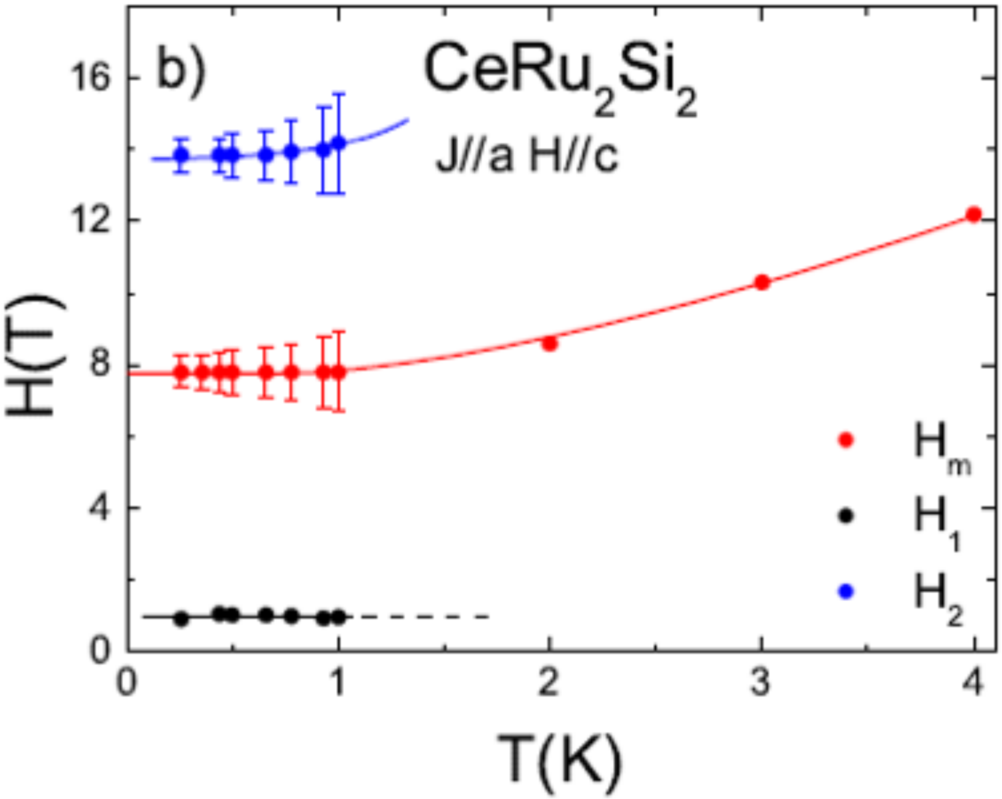


At high temperature, H_m evolves rapidly

Anomaly at 1T: magnetic fluctuation

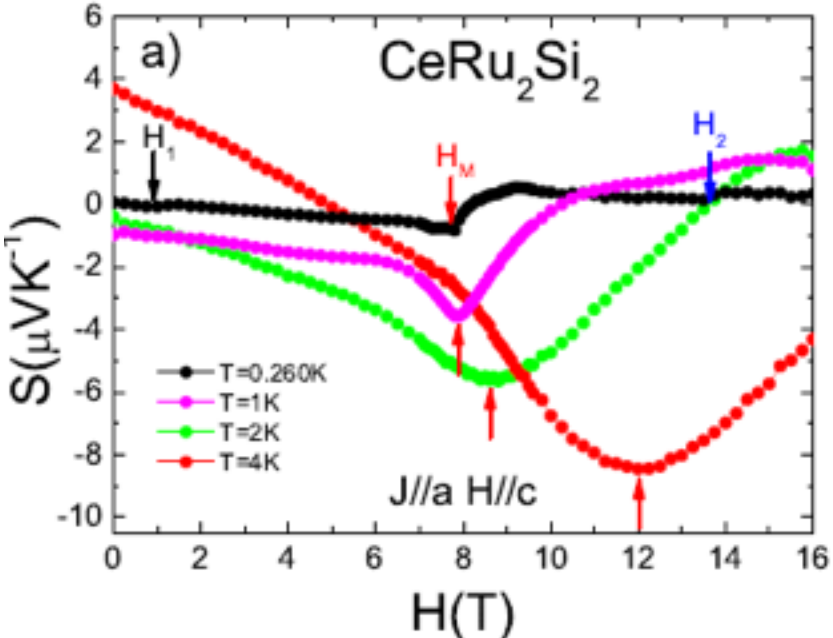
Mignot. J. M Physica B (1990)

Phase diagramm



H_m changes above 1K

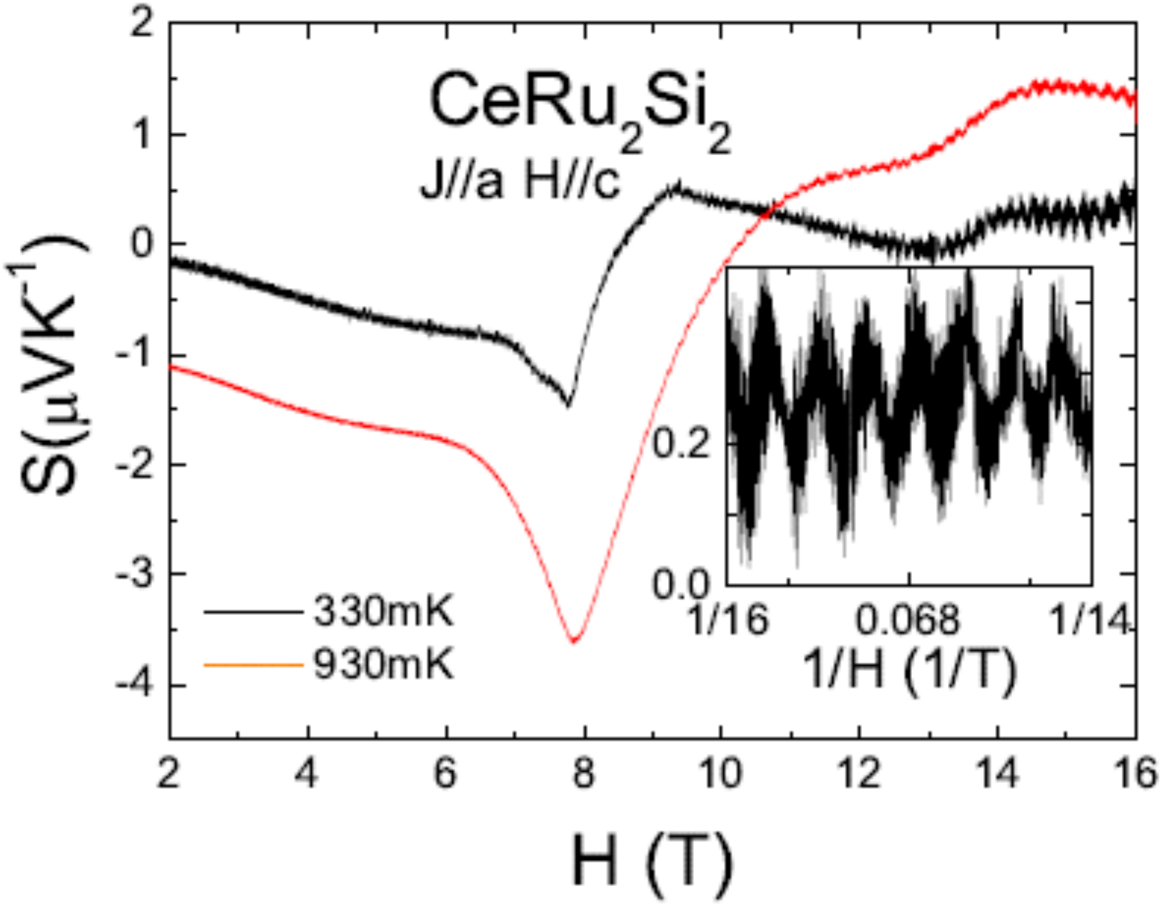
The width of the transition increases drasticaly above 1K

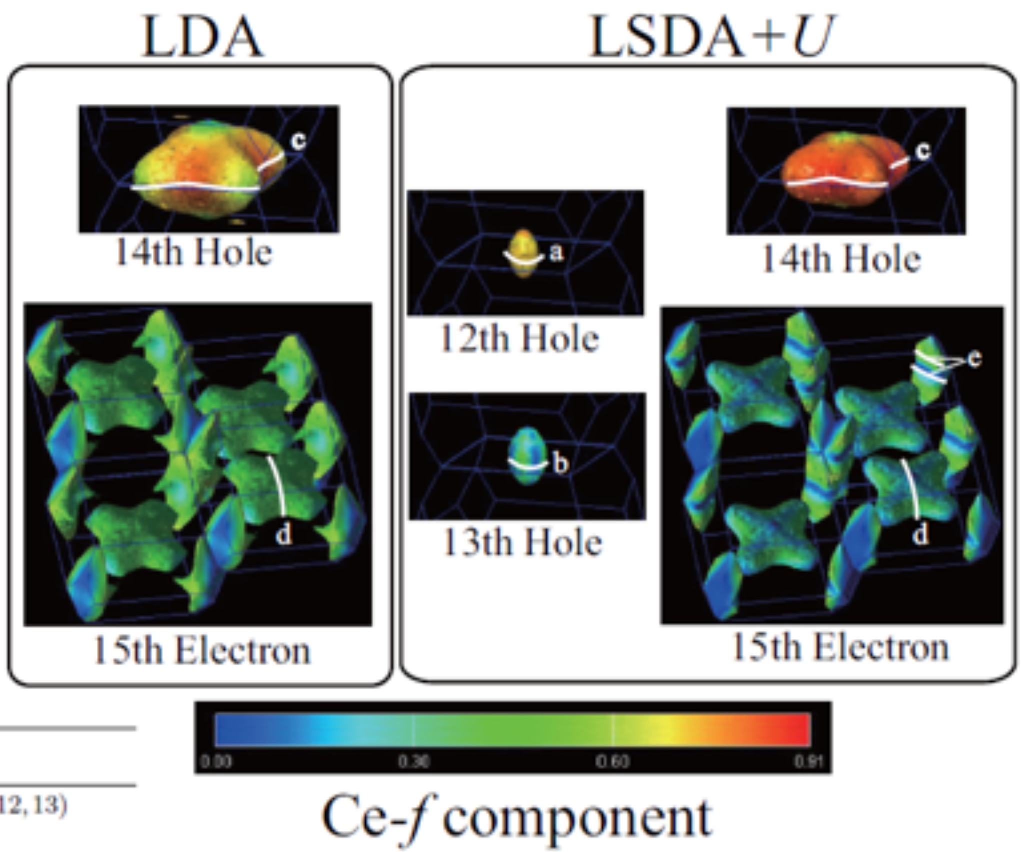


Needs very low temperature…..

Quantum oscillations

Quantum oscillations below and above the metamagnetic transition even inside the transition

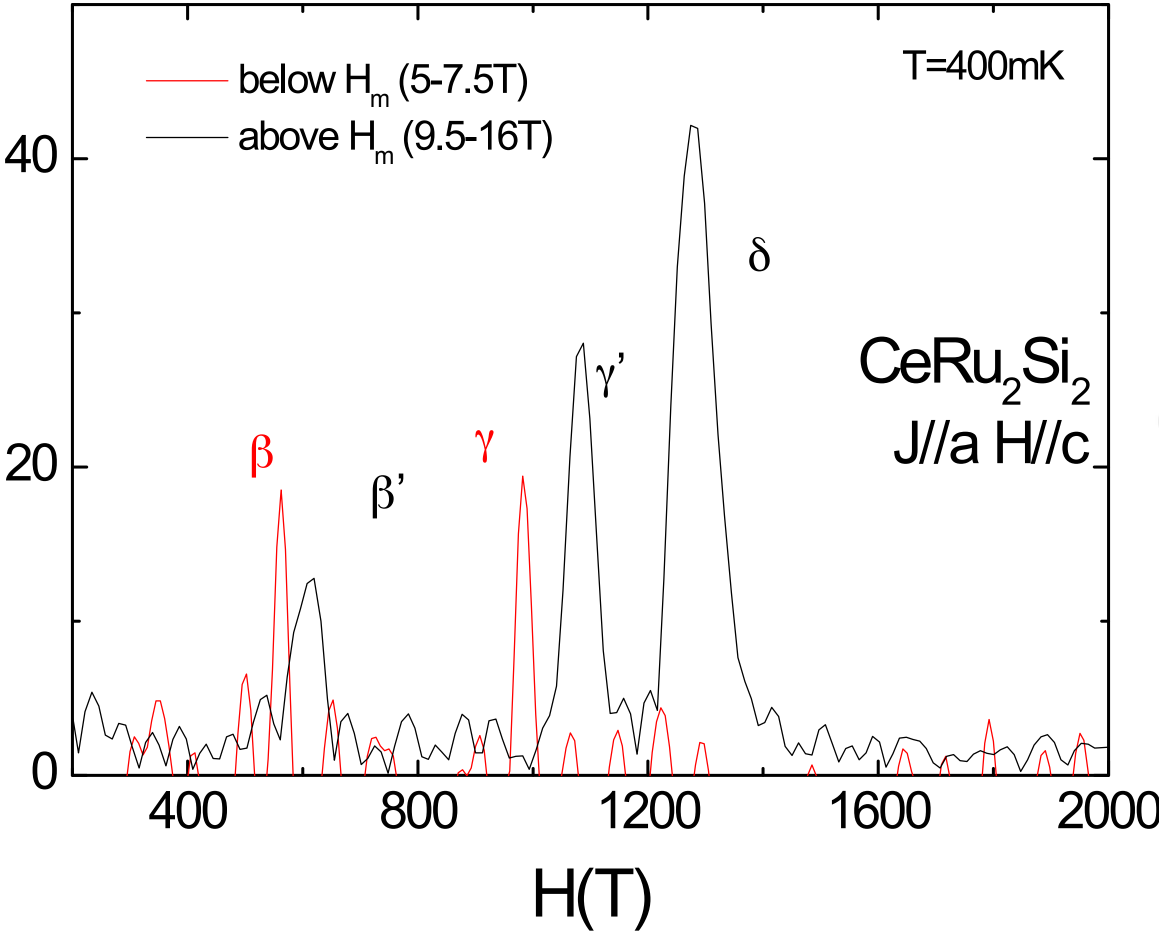


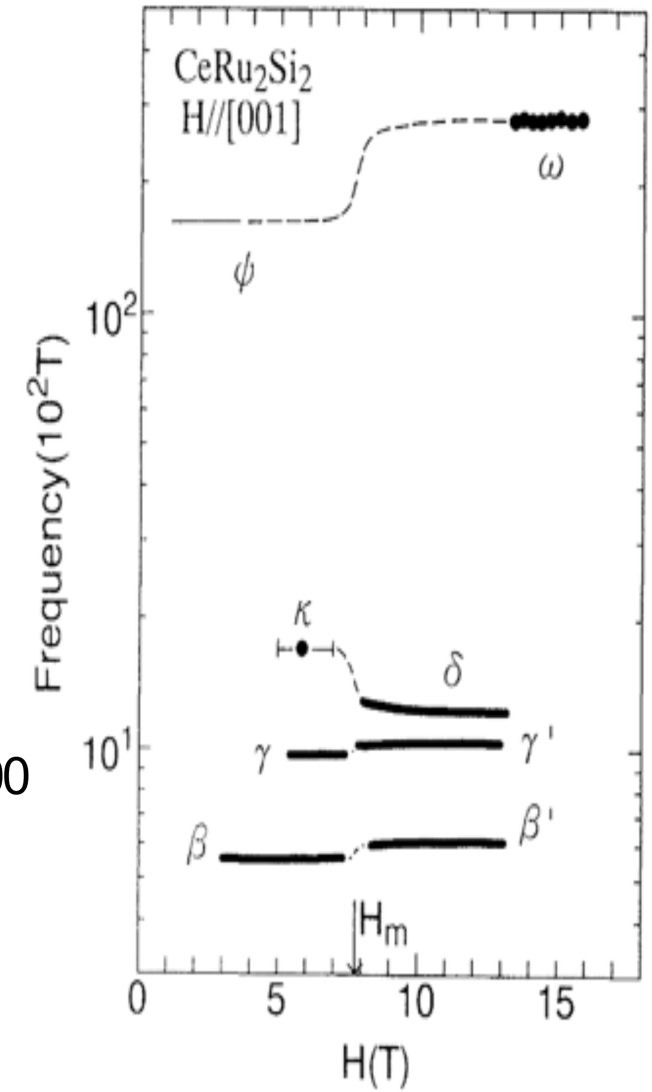


Paramagnetic $CeRu_2Si_2$					
	LSDA+U		Exp.$(H < H_m)$[12,13]		
	$F[\times 10^7 Oe]$	m_c/m_0		$F[\times 10^7 Oe]$	m_c/m_0
a [001]	0.59	0.71	β[001]	0.54	1.5
b [001]	0.98	0.47	γ[001]	0.98	1.6
c [100]	4.45	4.90	ψ[100]	5.36	120
	4.41	3.71			
e [001]	2.19	1.98	κ[001]	1.70	20
	1.59	1.70			

M Suzuki and H Harima

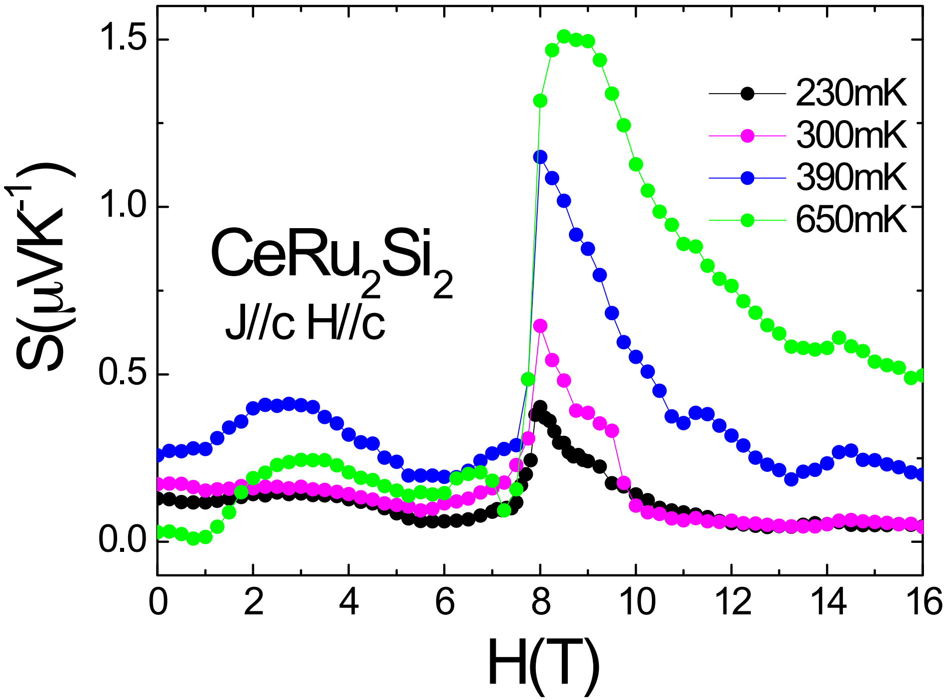
Quantum oscillations



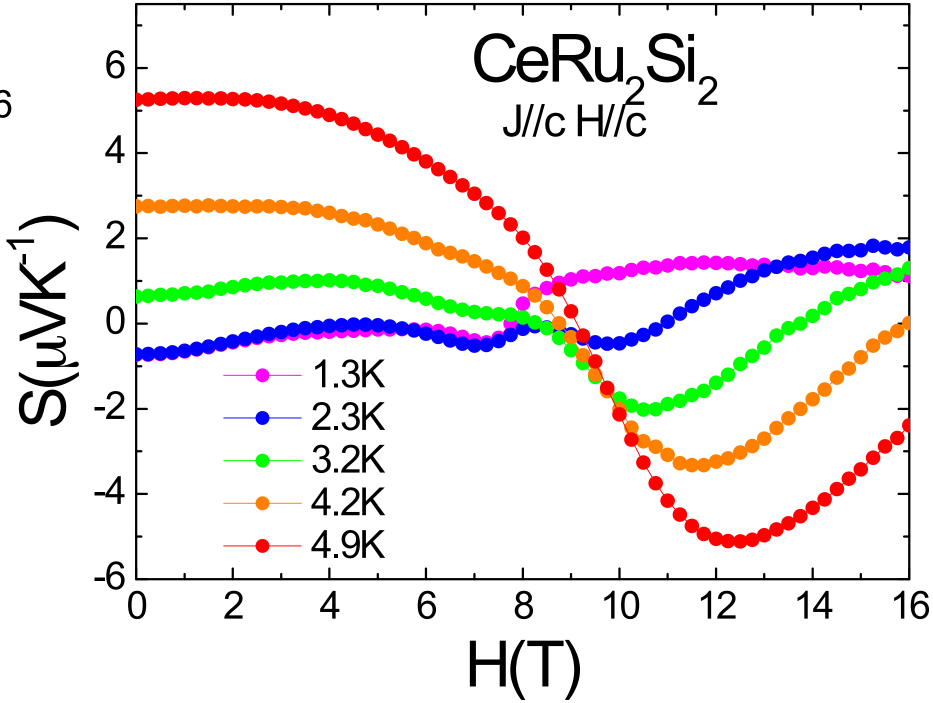


Aoki H. *et al.* Phys. Rev. Lett. (1993)

Longitudinal configuration

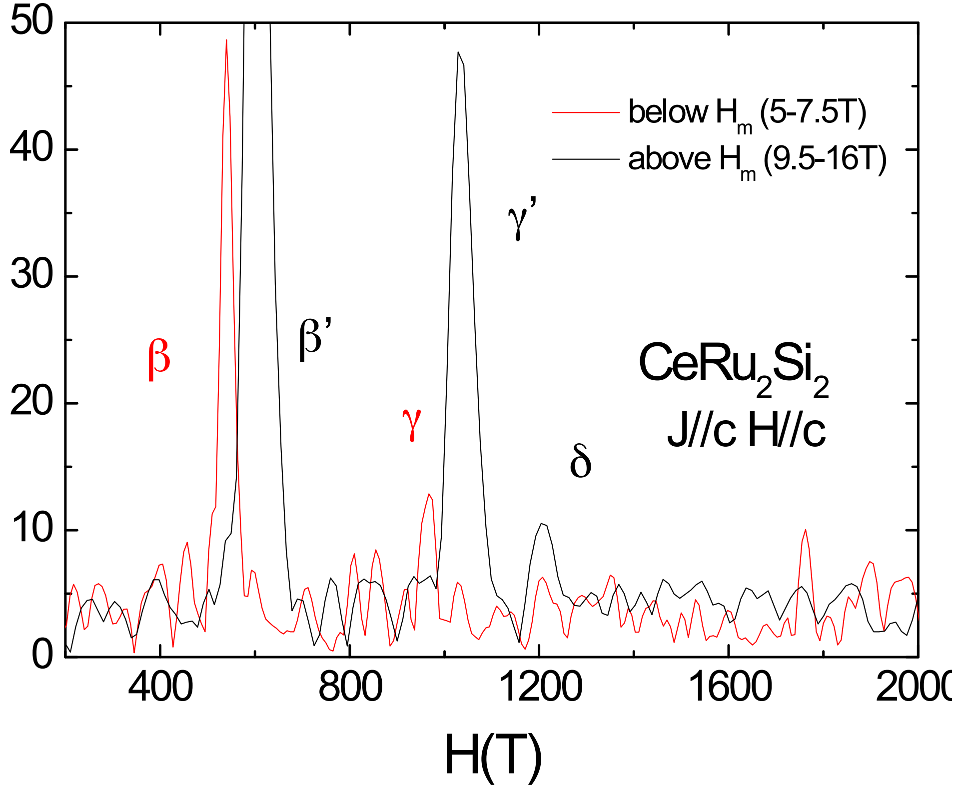


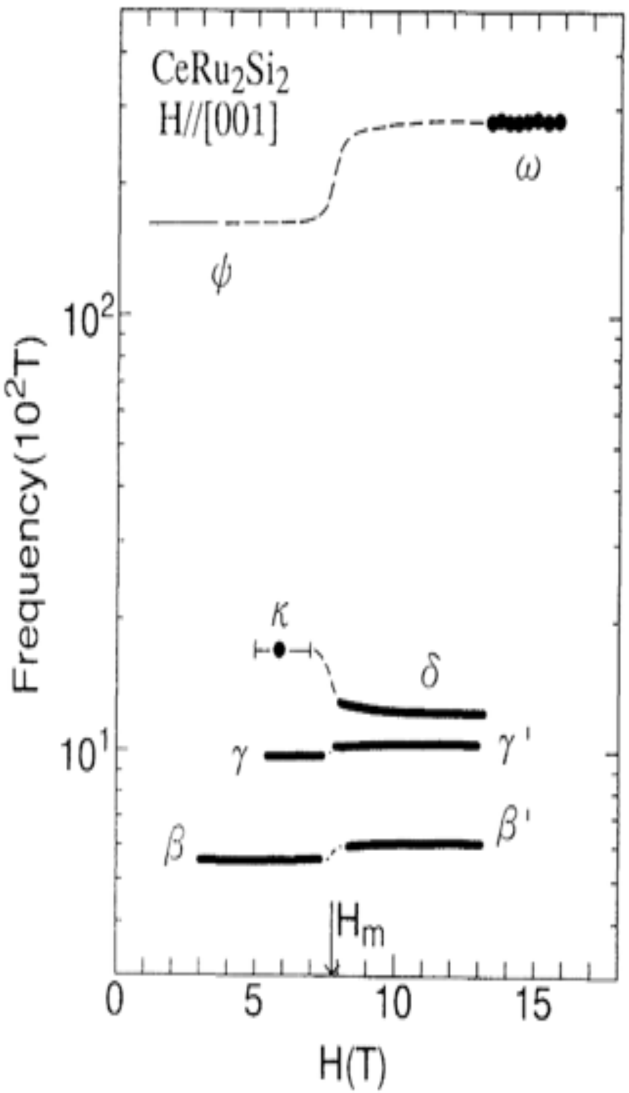
Contrary to the transversal case, the transition is positive



At high temperature the dependence in field is more complicated

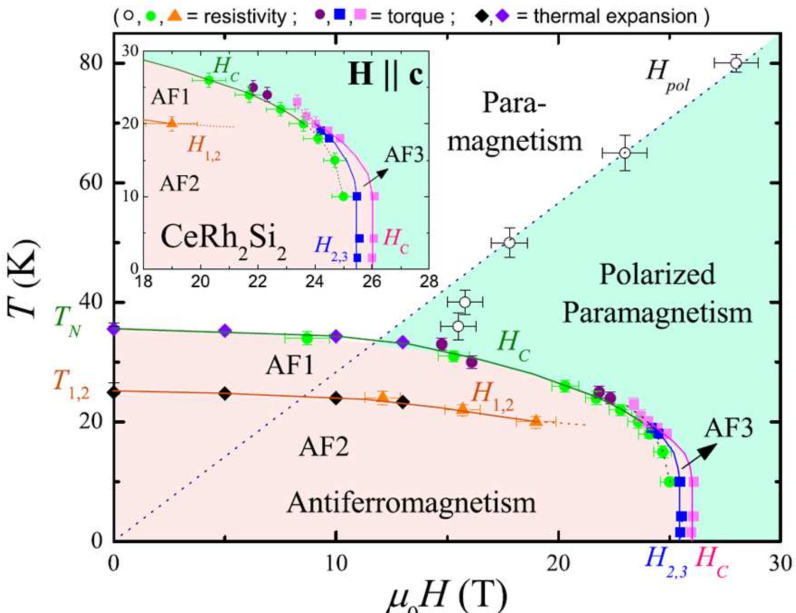
Quantum oscillations





Aoki H. *et al.* Phys. Rev. Lett. (1993)

$CeRh_2Si_2$



W. Knafo *et al., Phys. Rev. Lett.* **81** 094403 (2010)

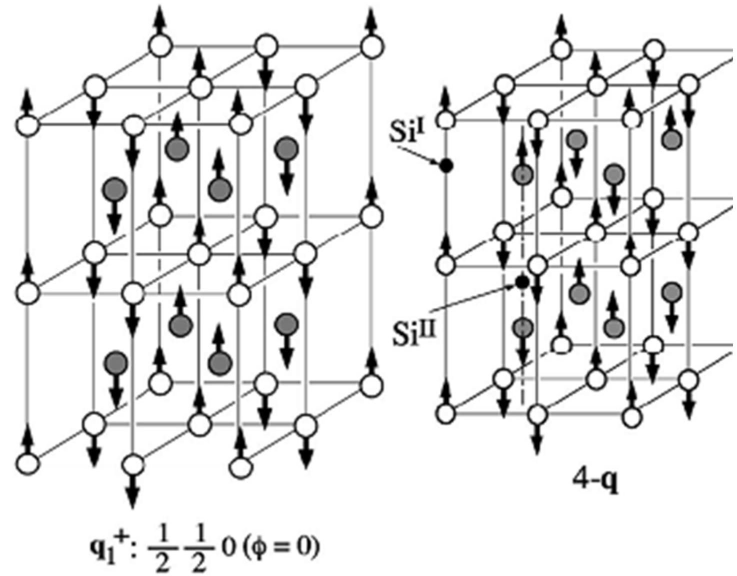
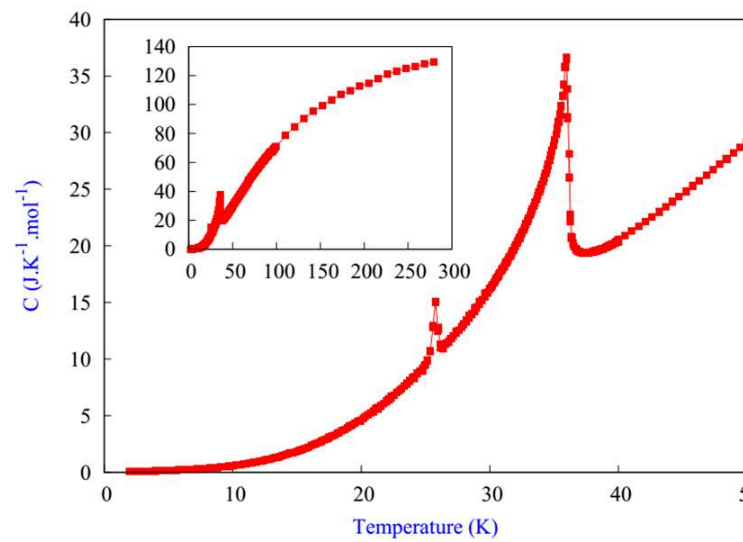
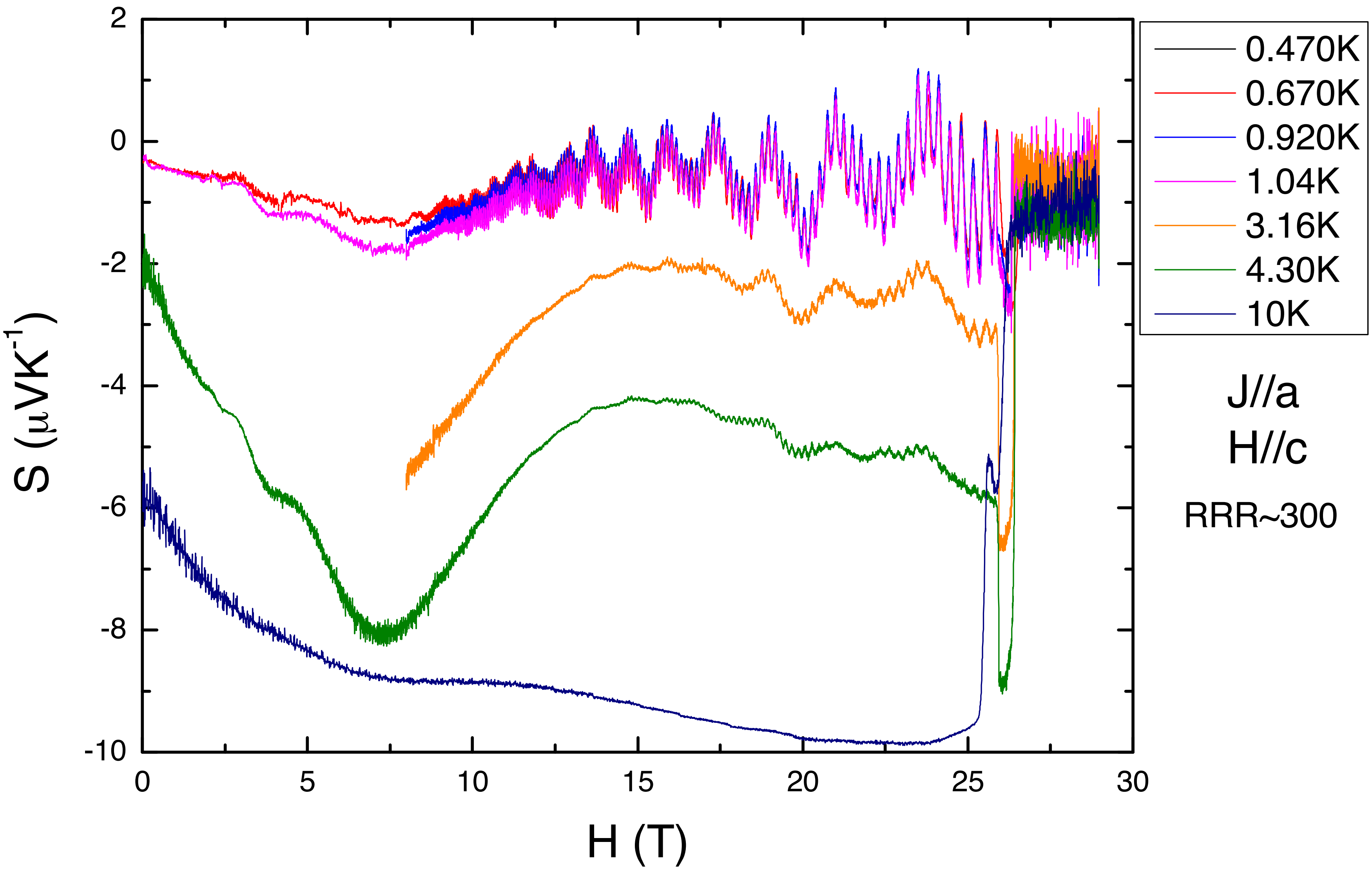


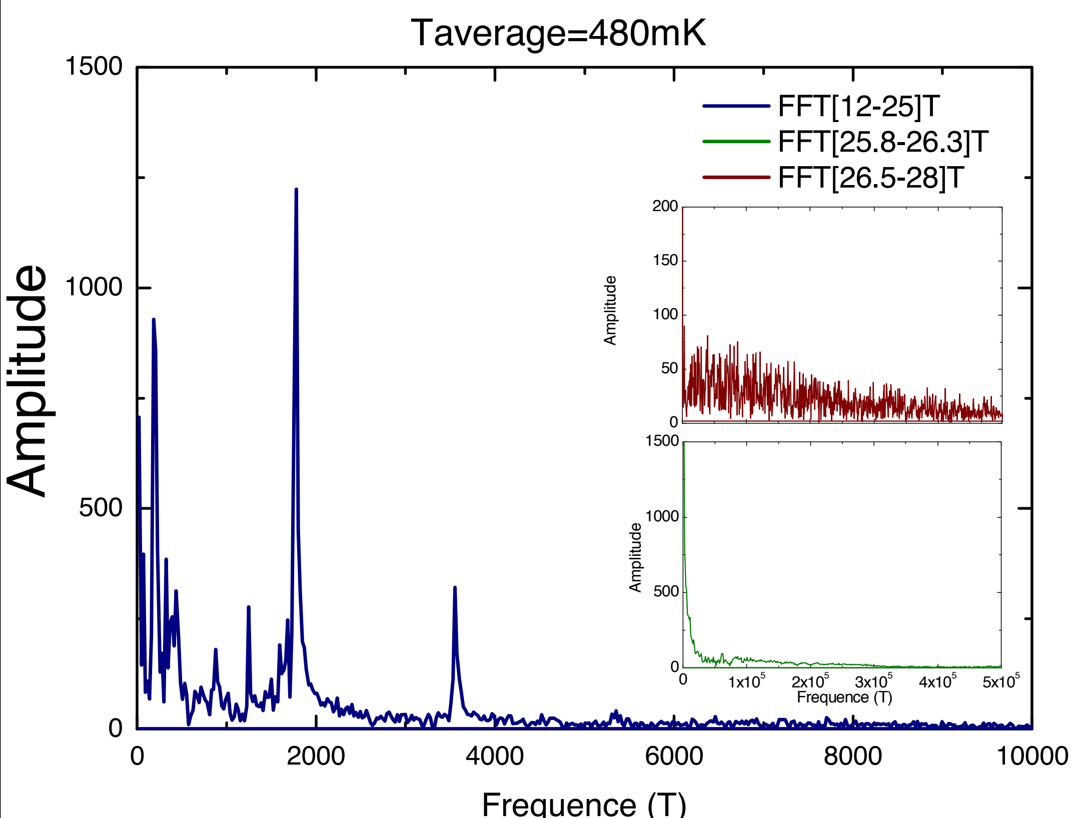
FIG. 4.1 – *Structure magnétique de $CeRh_2Si_2$ entre T_{N1} et T_{N2} (gauche)*

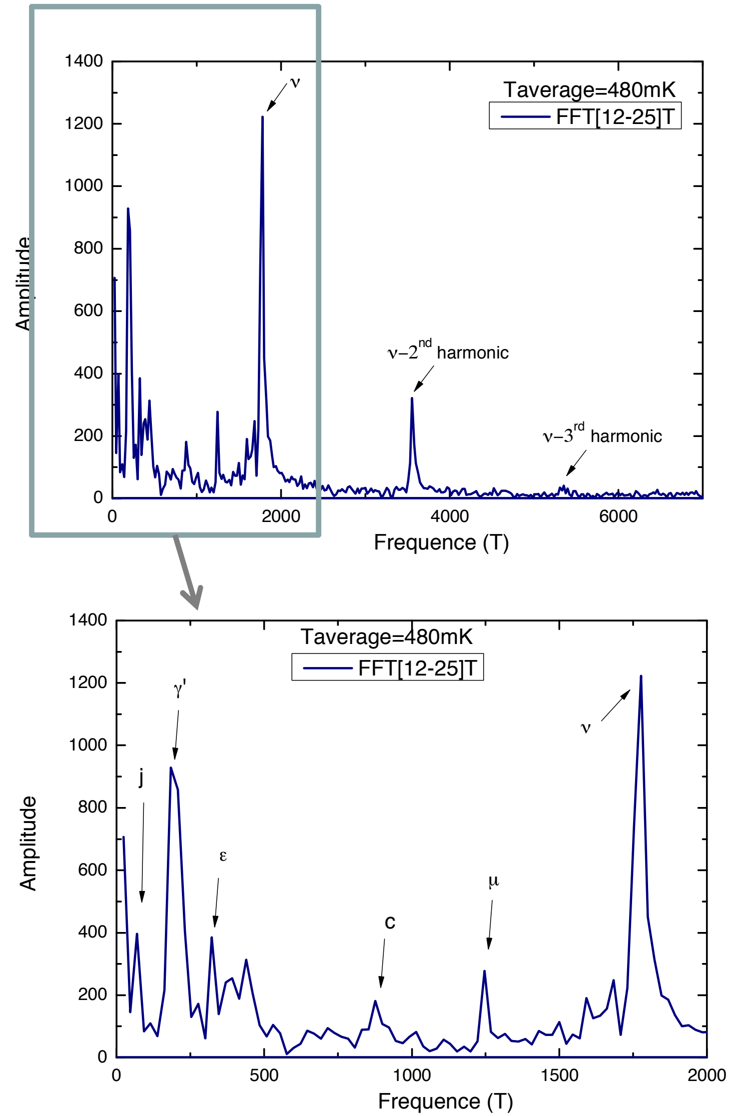


$CeRh_2Si_2$



Frequency Spectrum of Thermopower Quantum Oscillations: Transversal Configuration





Conclusion

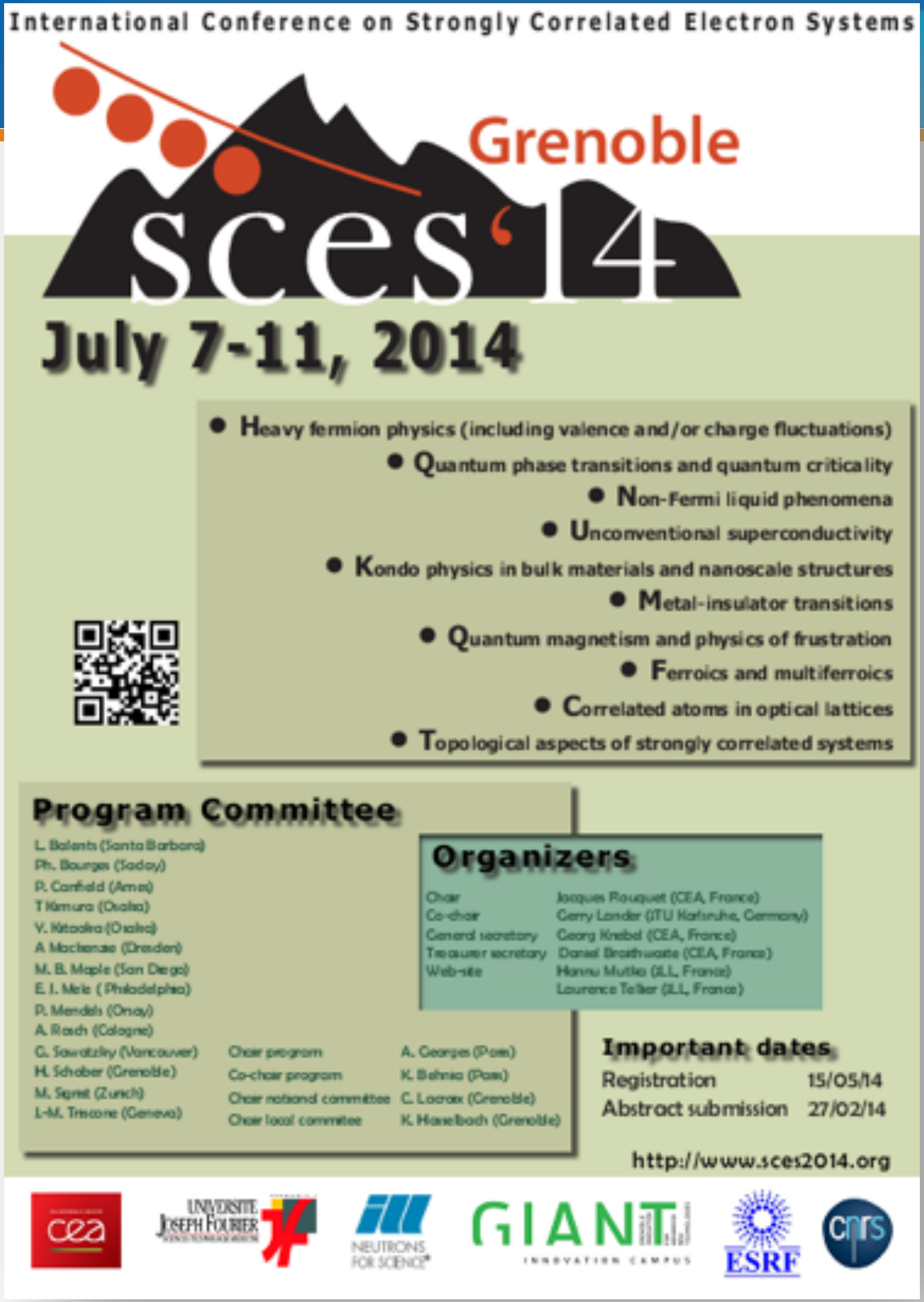
Thermopower favours a Lifshitz scenario for metamagnetic transition in $CeRu_2Si_2$

Thermopower shows additional peak at 13.5T.

Probably additionnal anomalies inside the metamagnetic transition: Lifshitz transition induces cascade of transitions like in $YbRh_2Si_2$

Thermopower shows quantum oscillations in good agreement with dHVA experiment ($CeRh_2Si_2$, $CeRu_2Si_2$)

→ New approach of FS change under pressure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Grenoble
sces'14
July 7-11, 2014
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• Quantum phase transitions and quantum criticality
• Non-Fermi liquid phenomena
• Unconventional superconductivity
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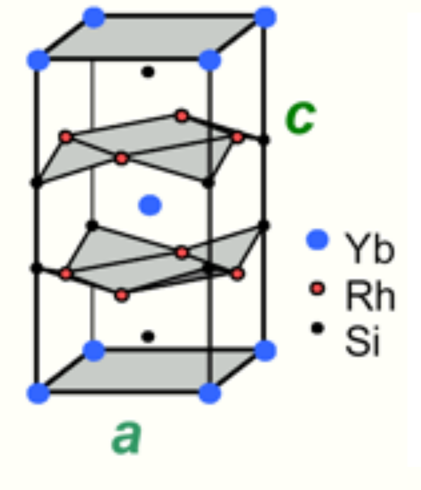
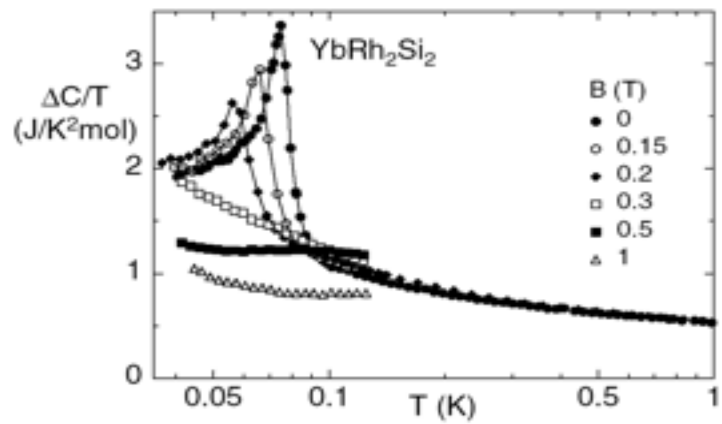
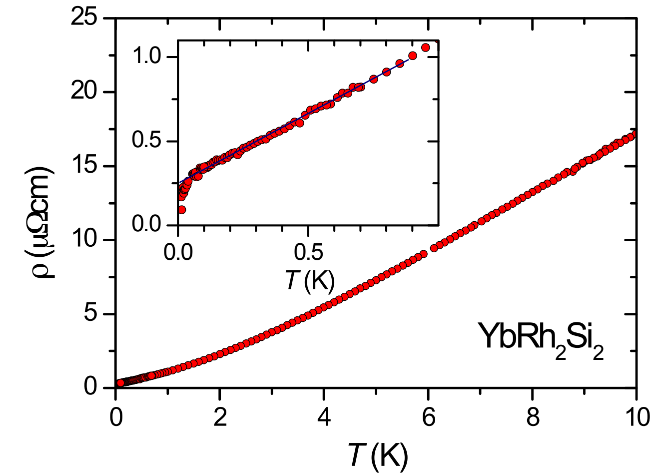
Unconventional metallic state in $YbRh_2Si_2$



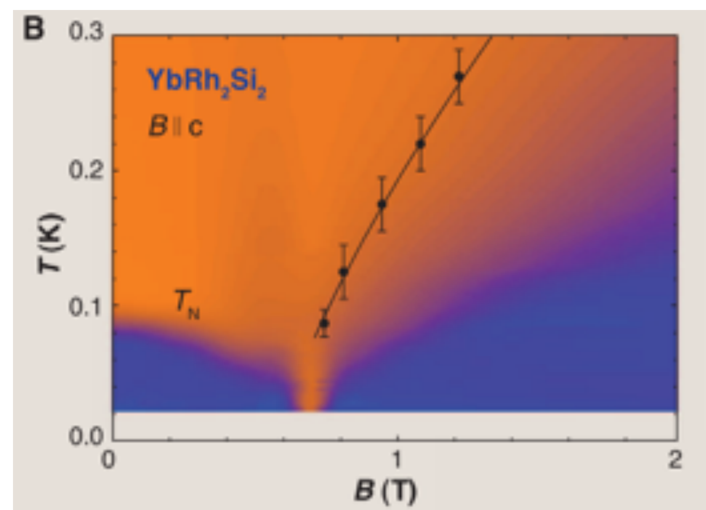




- Yb based heavy fermion system with very low magnetic order
  - T_K = 25 K, T_N ~ 70mK
  - Δ_{CF}= 200, 290, 500 K
  - m~ 0.02 μ_B

- field induced QCP
  - local criticality
  - ESR signal of Yb^{3+}
- above H_c, strong FM fluctuations

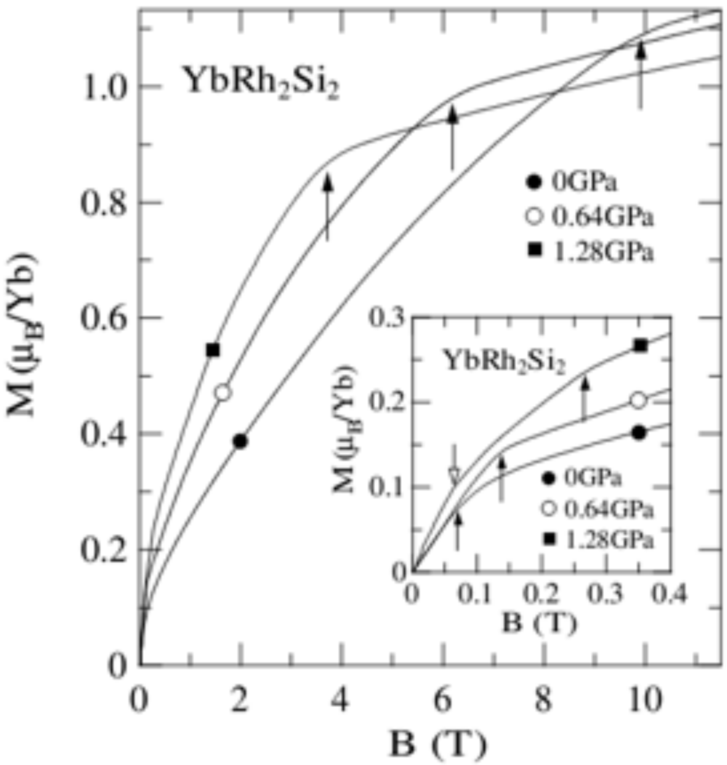
Ishida et al, PRL 89, 107202 (2002)
Gegenwart et al. PRL 94, 076402 (2005)

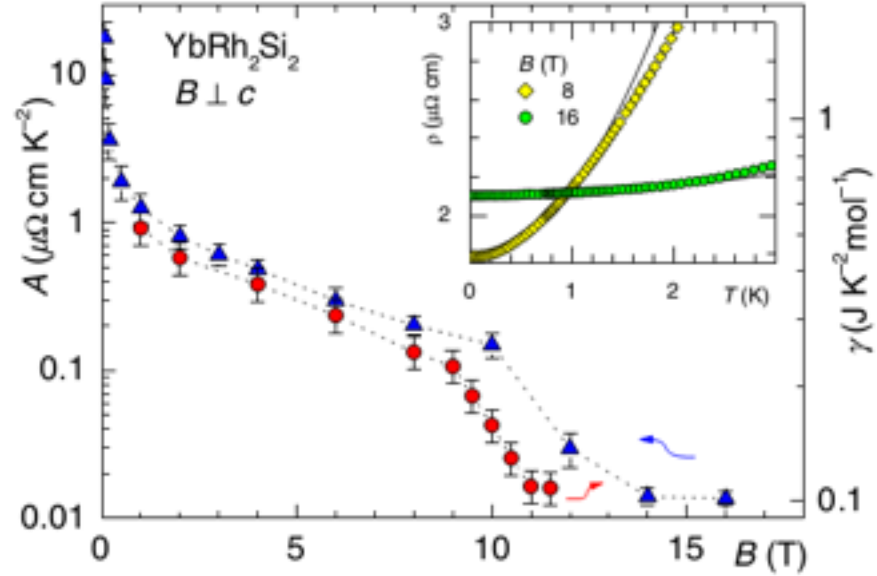


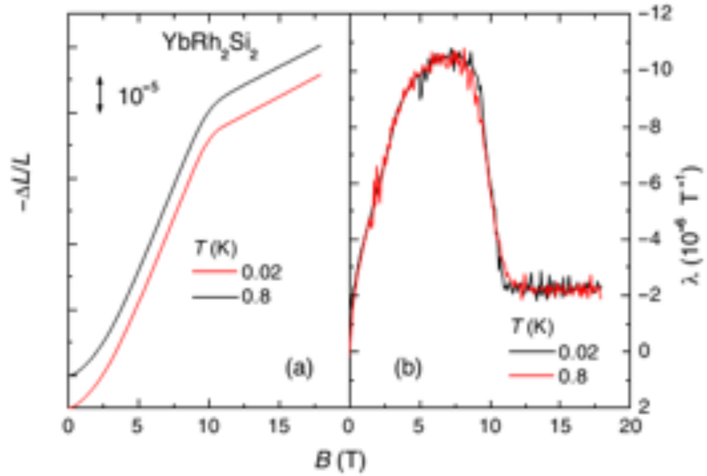
Trovarelli et al. PRL 85, 626 (2000)
Gegenwart et al. PRL 89, 056402 (2002)
Custers et al. nature 2003

High field properties : $T_K \sim T_{zeeman}$

Interpretation 2006: destruction of the Kondo effect







Tokiwa PRL 2005

Gegenwart NJP 2006