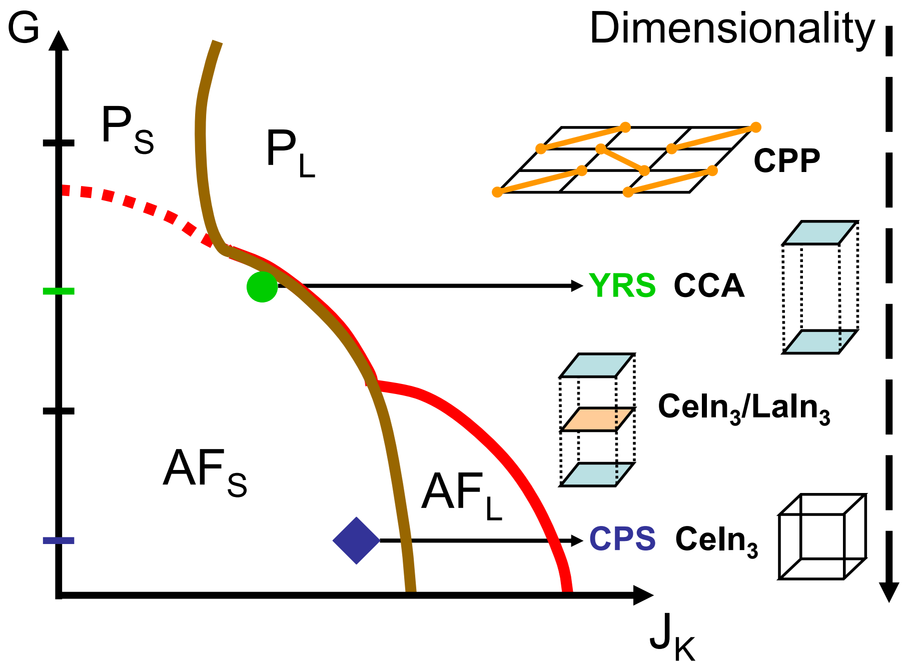
Kondo breakdown in the cubic heavy fermion compound $Ce_3Pd_{20}Si_6$

Silke Paschen

Institute of Solid State Physics, Vienna University of Technology



Kondo breakdown in the cubic heavy fermion compound $Ce_3Pd_{20}Si_6$

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- Heavy fermion quantum criticality
- The case of $YbRh_2Si_2$
- The new *cubic* material $Ce_3Pd_{20}Si_6$
- Materials in the global phase diagram

$Ce_3Pd_{20}Si_6$: J. Custers*, J. Hänel, K.-A. Lorenzer, M. Müller, A. Prokofiev, A. Sidorenko, H. Winkler

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1: ESS, Lund, 2: ILL, Grenoble, 3: ISIS, Oxon, 4: LLB, Saclay

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$YbRh_2Si_2$: S. Friedemann*, P. Gegenwart*, C. Geibel, S. Hartmann*, C. Krellner*, N. Oeschler*, S. Wirth, A. Pikul*, S. Kirchner (& PKS), F. Steglich

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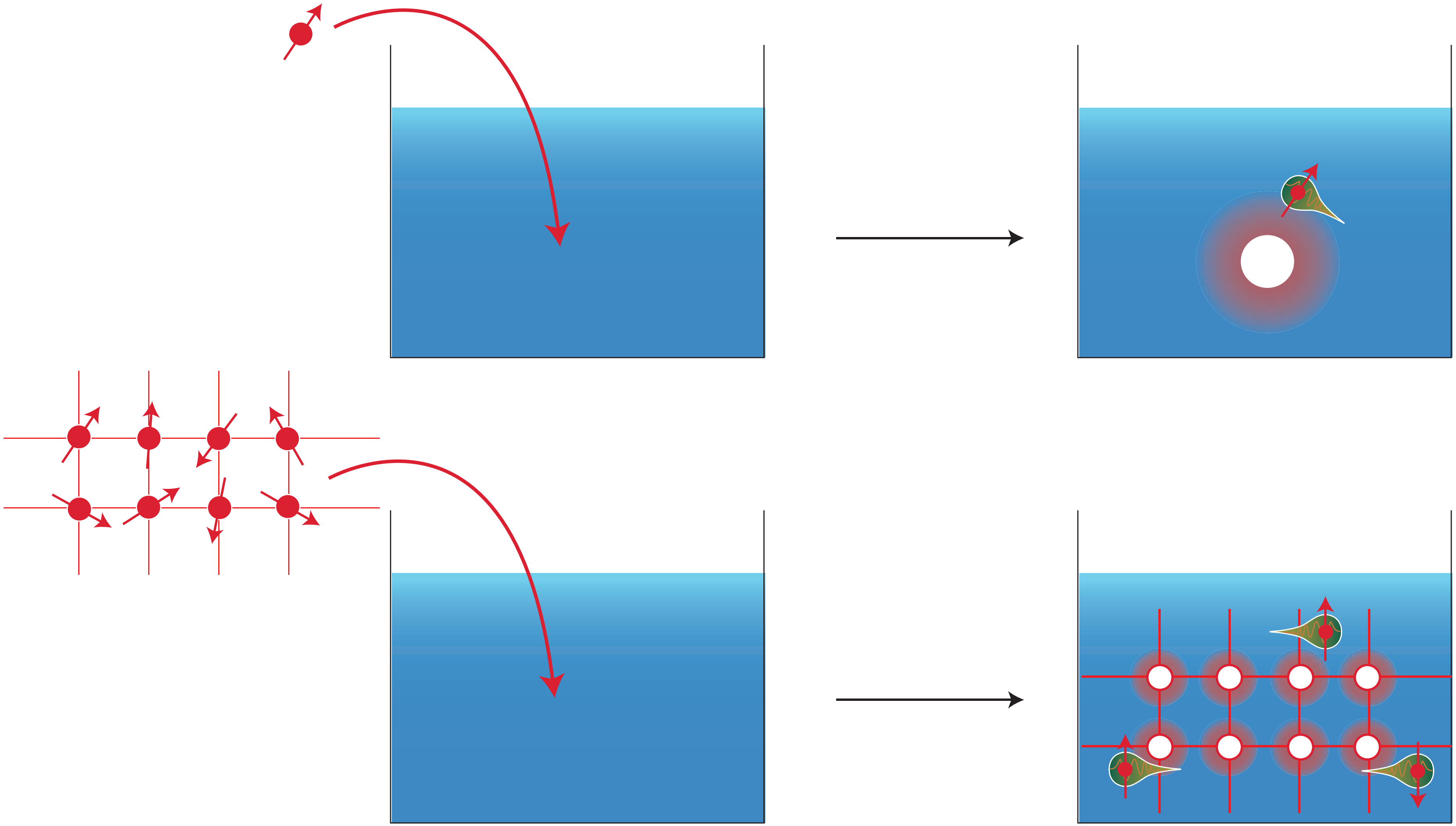
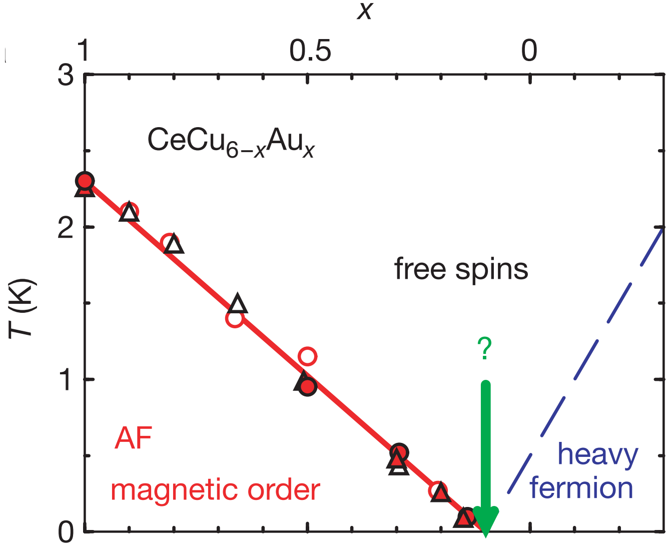
Kondo effect and heavy fermion compounds



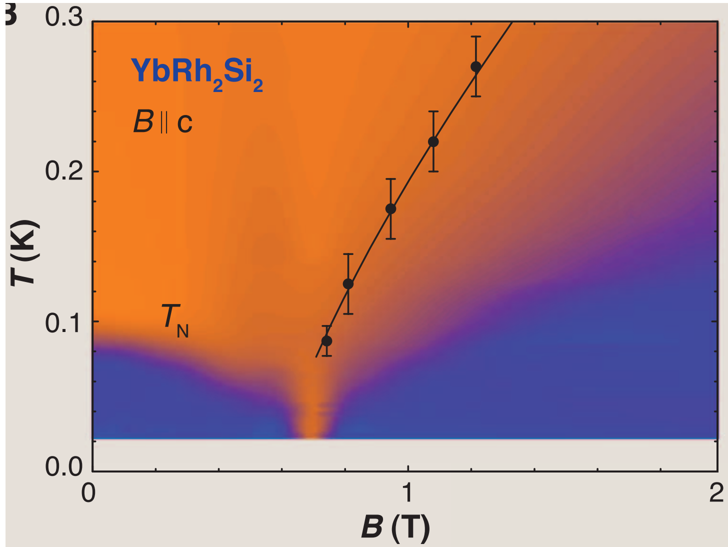
(Coleman, Nature Mater. 11 (2012) 185, news & views)

NFL behaviour at quantum critical points

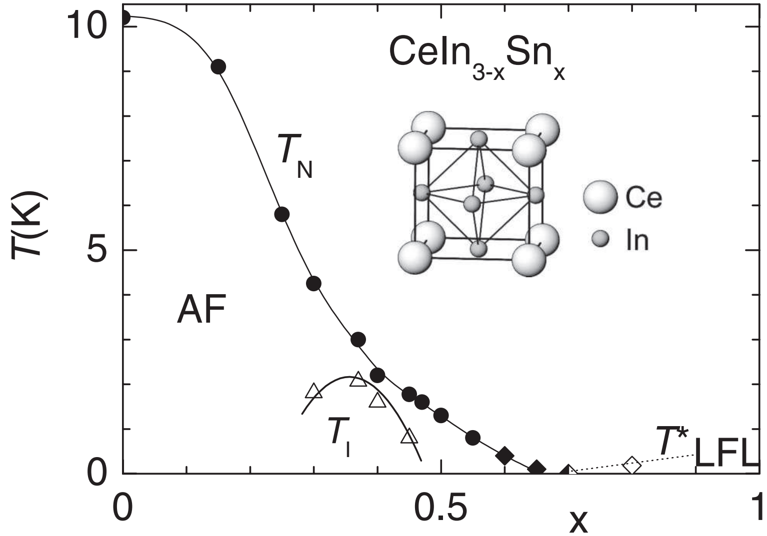
$CeCu_{6-x}Au_x$ (Schröder et al, Nature 2000)



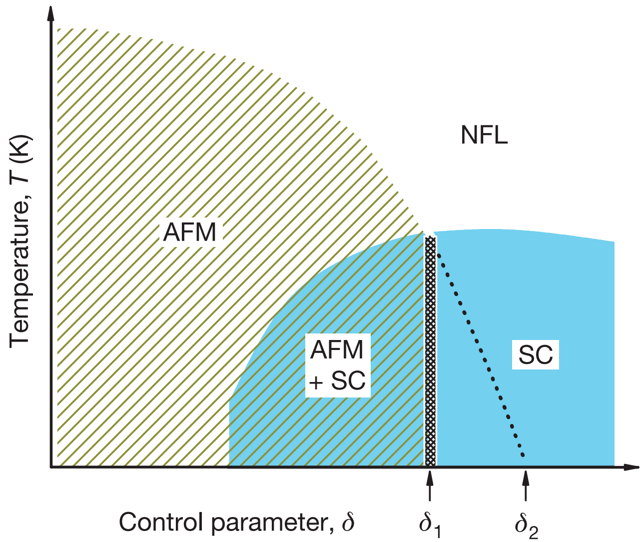
$YbRh_2Si_2$ (Custers et at., Nature 2001)



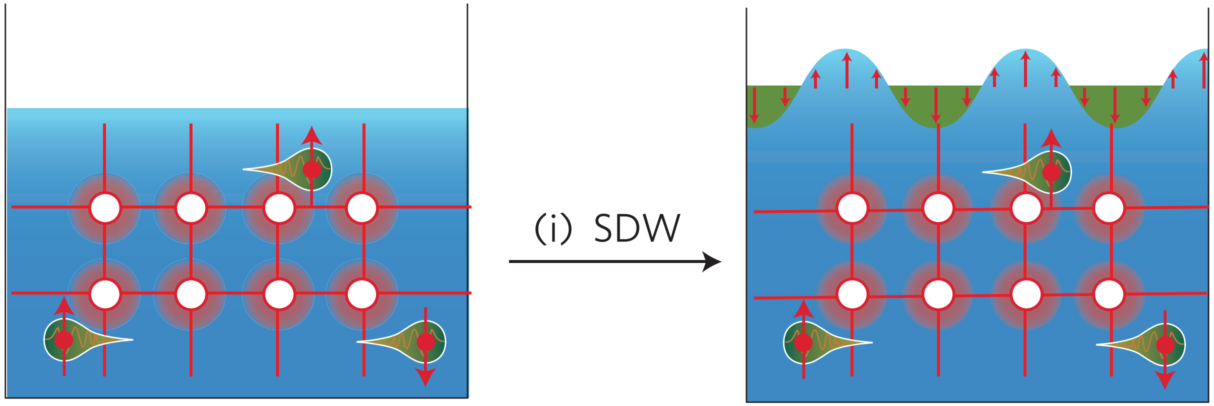
$CeIn_{3-x}Sn_x$ (Küchler et al, PRL 2006)



$CeRhIn_5$ (Park et at., Nature 2006)

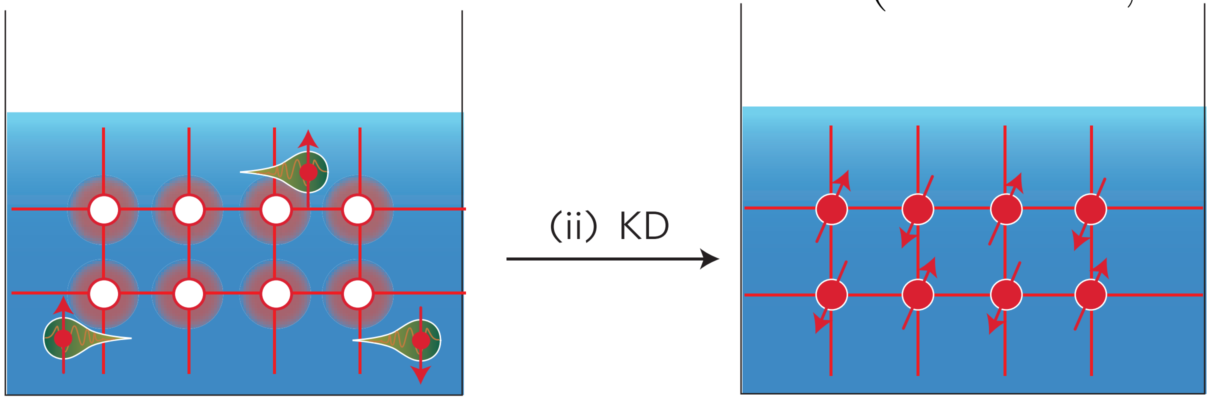


Standard scenario: Spin density wave (SDW) formation



Paramagnet Itinerant antiferromagnet

Alternative scenario in 2D: Kondo breakdown (Coleman, Si, Schröder, ...)

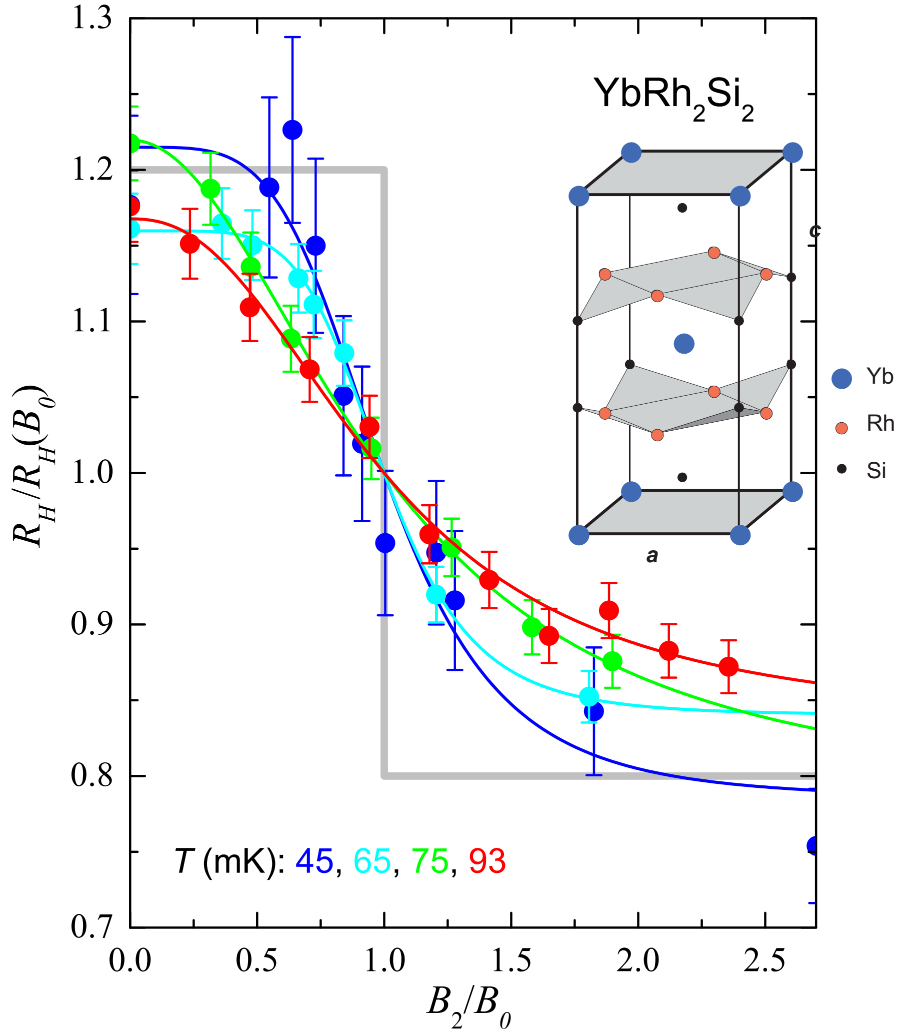


Paramagnet Local moment antiferromagnet

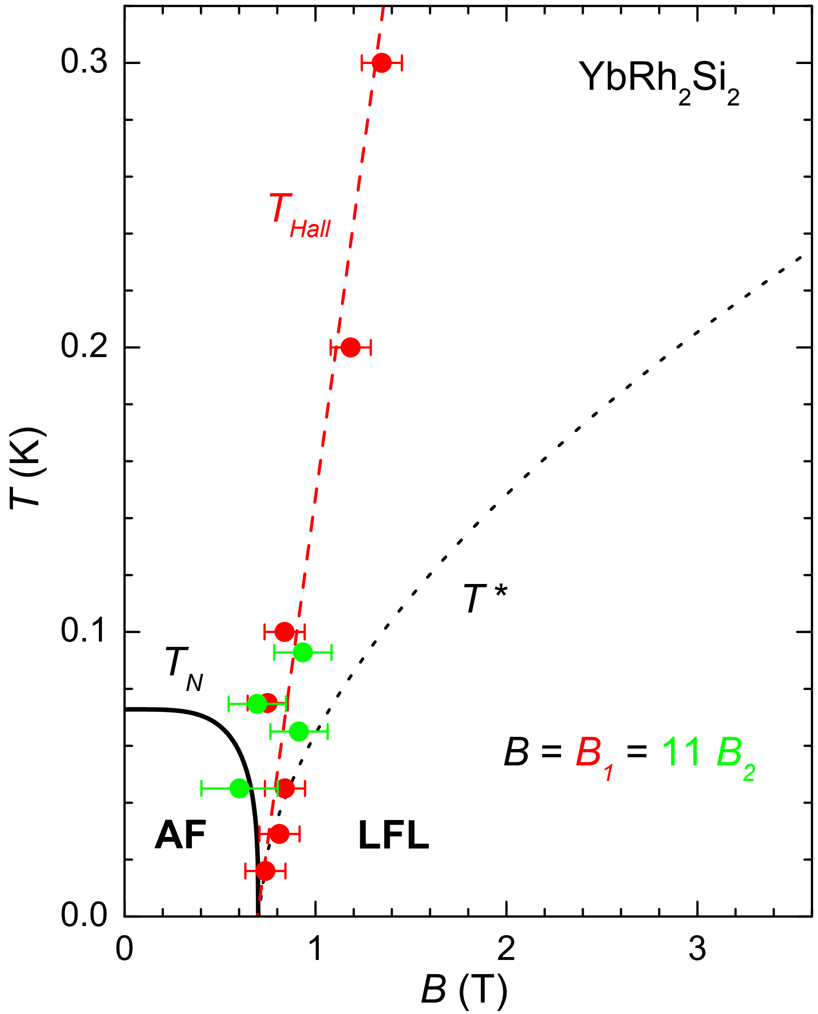
(Coleman, Nature Mater. 11 (2012) 185, news & views)

Hall effect in tetragonal $YbRh_2Si_2$ with 2D spin fluctuations

Hall coefficient vs field



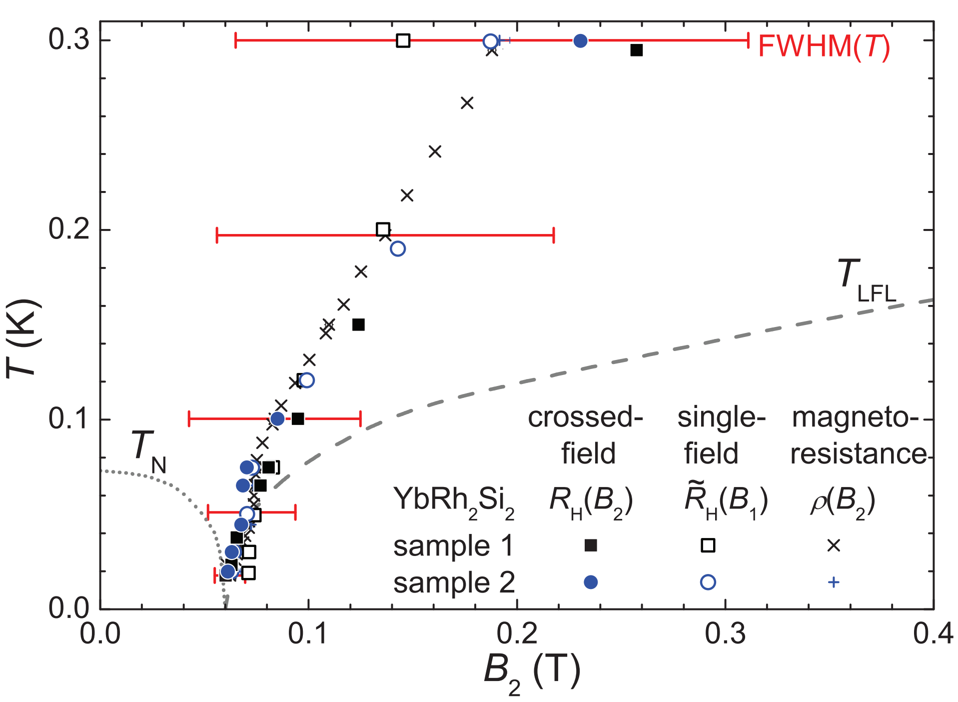
Phase diagram



(SP et al., Nature 432 (2004) 881)

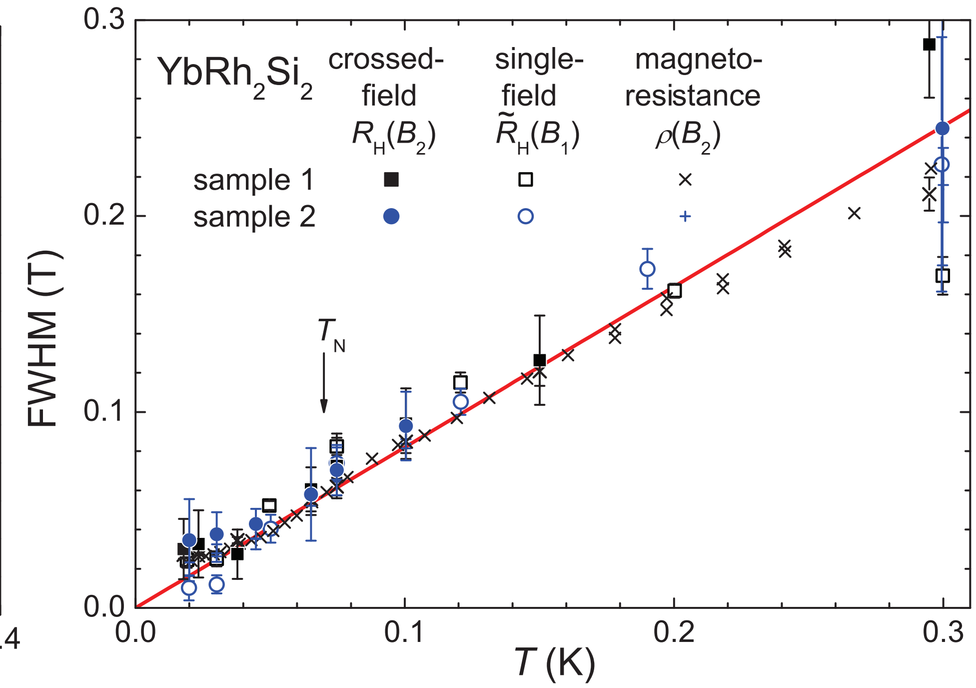
Hall effect in tetragonal $YbRh_2Si_2$ with 2D spin fluctuations:
Experiments on purest samples with enhanced resolution

Phase diagram



(Friedemann et al., PNAS 107 (2010) 14547)

Crossover width



FWHM $\sim T$ (valid up to 1 K)

Suggested scenarios (list incomplete ...):

Kondo breakdown/Orbital selective Mott transition:

Kondo lattice, Kondo-Heisenberg, PAM, Bose-Fermi Kondo models, ...

Coleman, Fabrizio, Kim, Kotliar, Pépin, Senthil, Si, Zaanen, ...

Lifshitz transition/Topological transition:

2D Kondo lattice model, band picture ...

Assaad, Vojta, Watanabe, ...

Valence transition/Valence criticality:

PAM with U_{fc}, band picture ...

Miyake, Norman, Watanabe, ...

Quantum tricritical point:

Self-consistent renormalization theory for spin fluctuations

Imada, Misawa, Yamaji

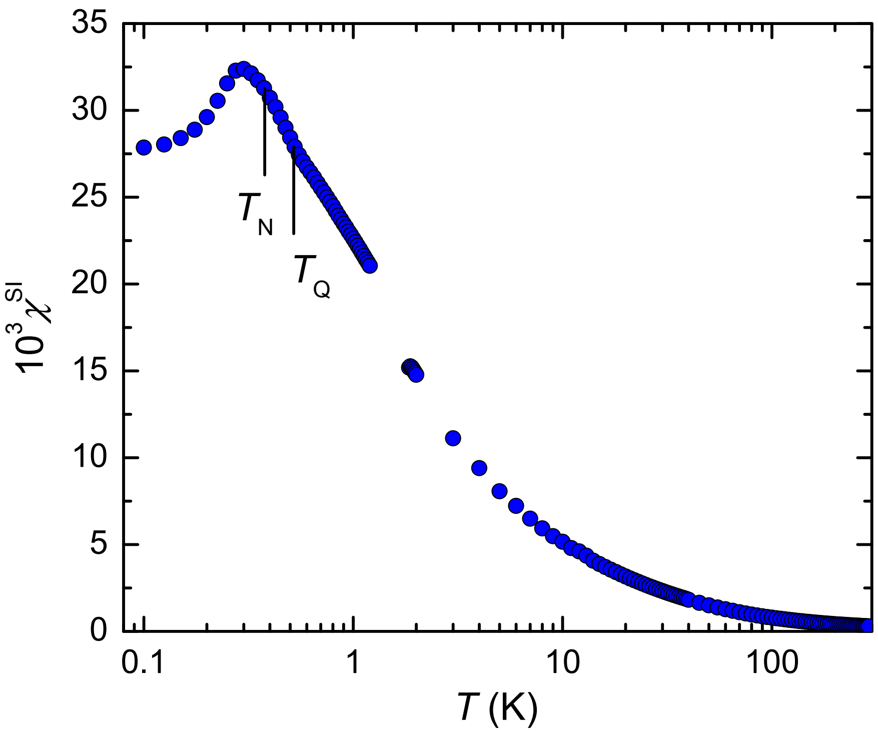
Weak-field breakdown:

Boltzmann transport theory

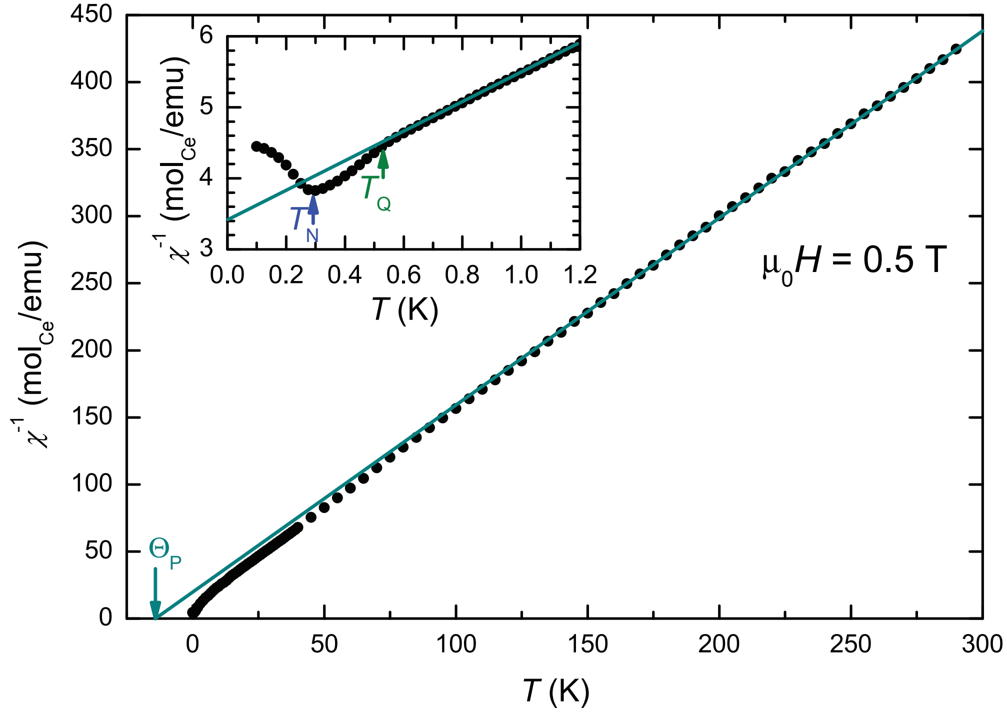
Schofield

A new *cubic* material: $Ce_3Pd_{20}Si_6$

Magnetic susceptibility



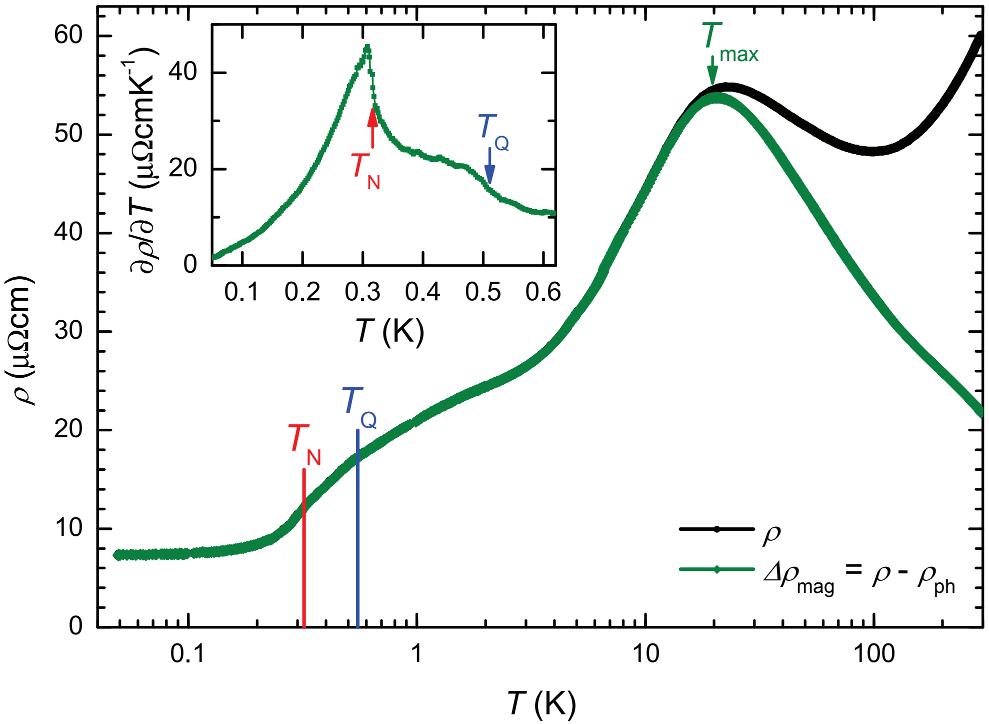
Inverse susceptibility



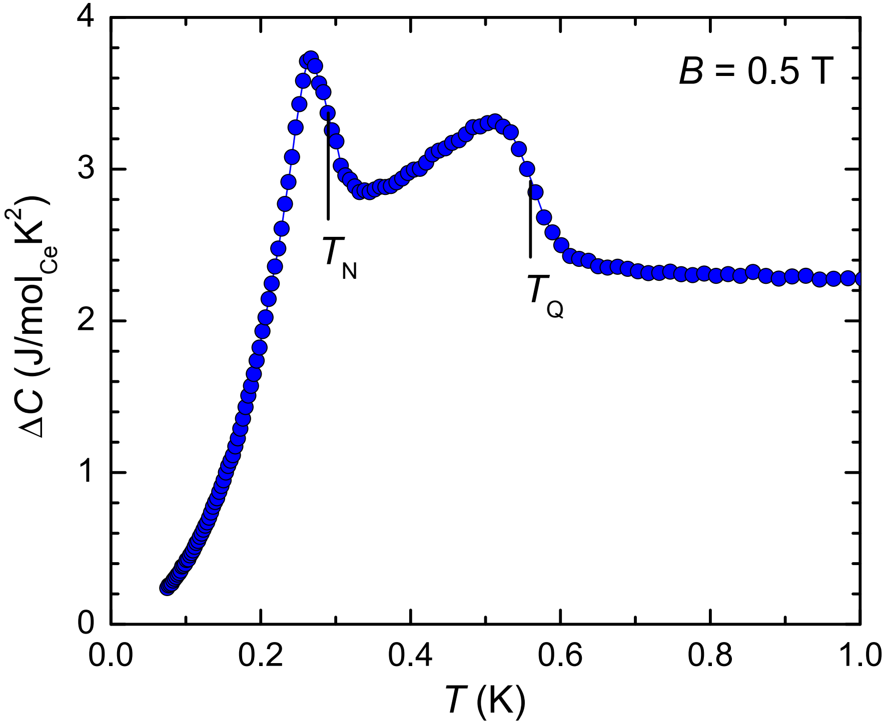
$$\chi_0 = 2.27 \cdot 10^{-6}\ \mathrm{m^3/mol\ Ce}$$

A new *cubic* material: $Ce_3Pd_{20}Si_6$

Electrical resistivity



Electronic specific heat

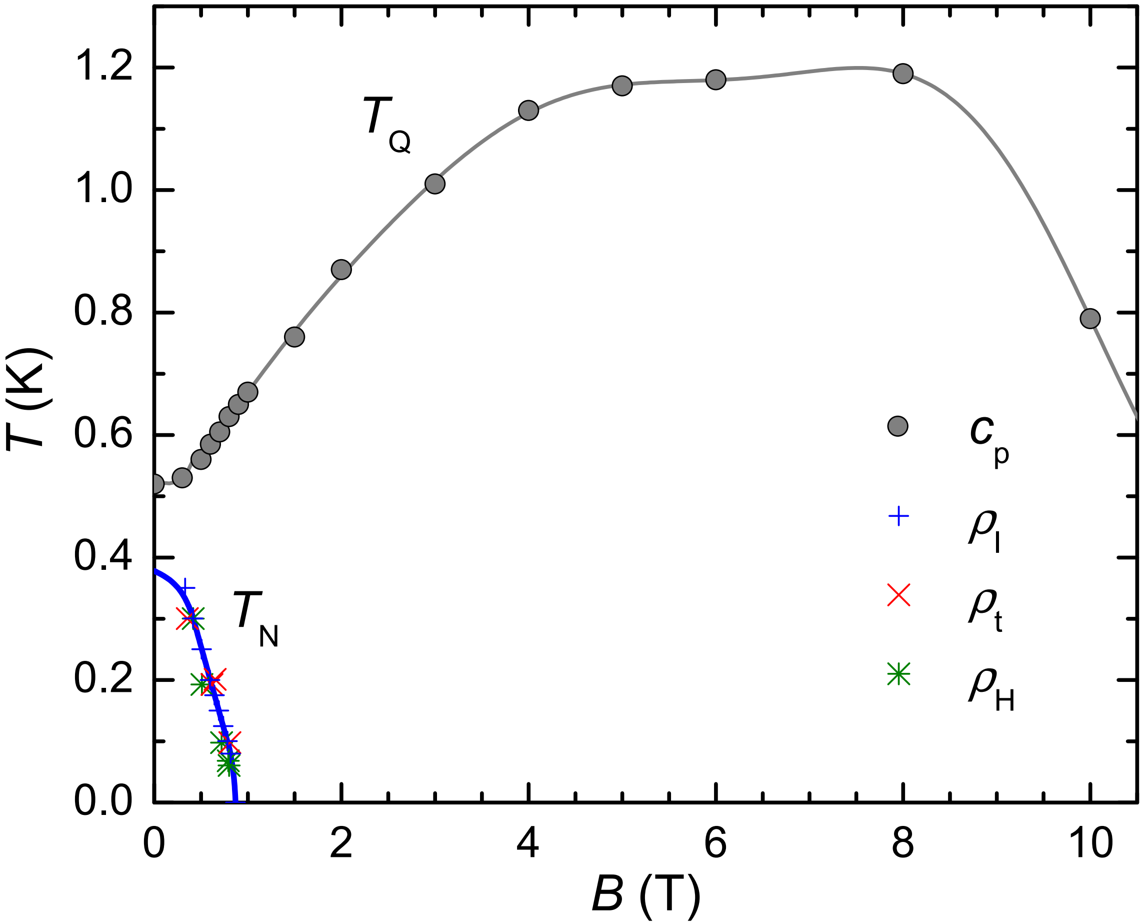


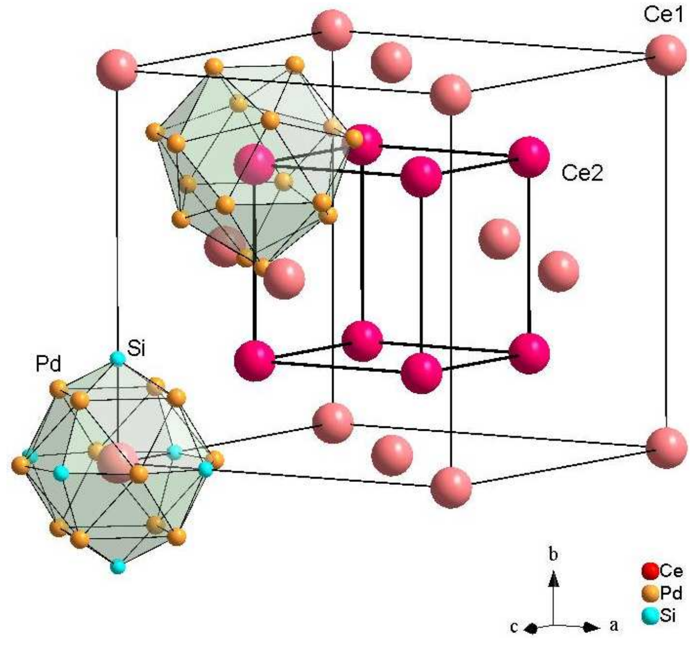
$\rho = \rho_0 + AT^2$, $A = 14.9\ \mu\Omega\text{cm}/\text{K}^2$ $\qquad \Delta C/T = \gamma + DT^3$, $\gamma = 1.5\ \text{J}/\text{molK}^2$

$$\text{KWR} = A/\gamma^2 = 6.7\ (\mu\Omega\text{cm}/\text{K}^2)/(\text{J}/\text{molK}^2)^2,\ \text{SWR} = 1.9$$

A new *cubic* material: $Ce_3Pd_{20}Si_6$

Temperature-field phase diagram





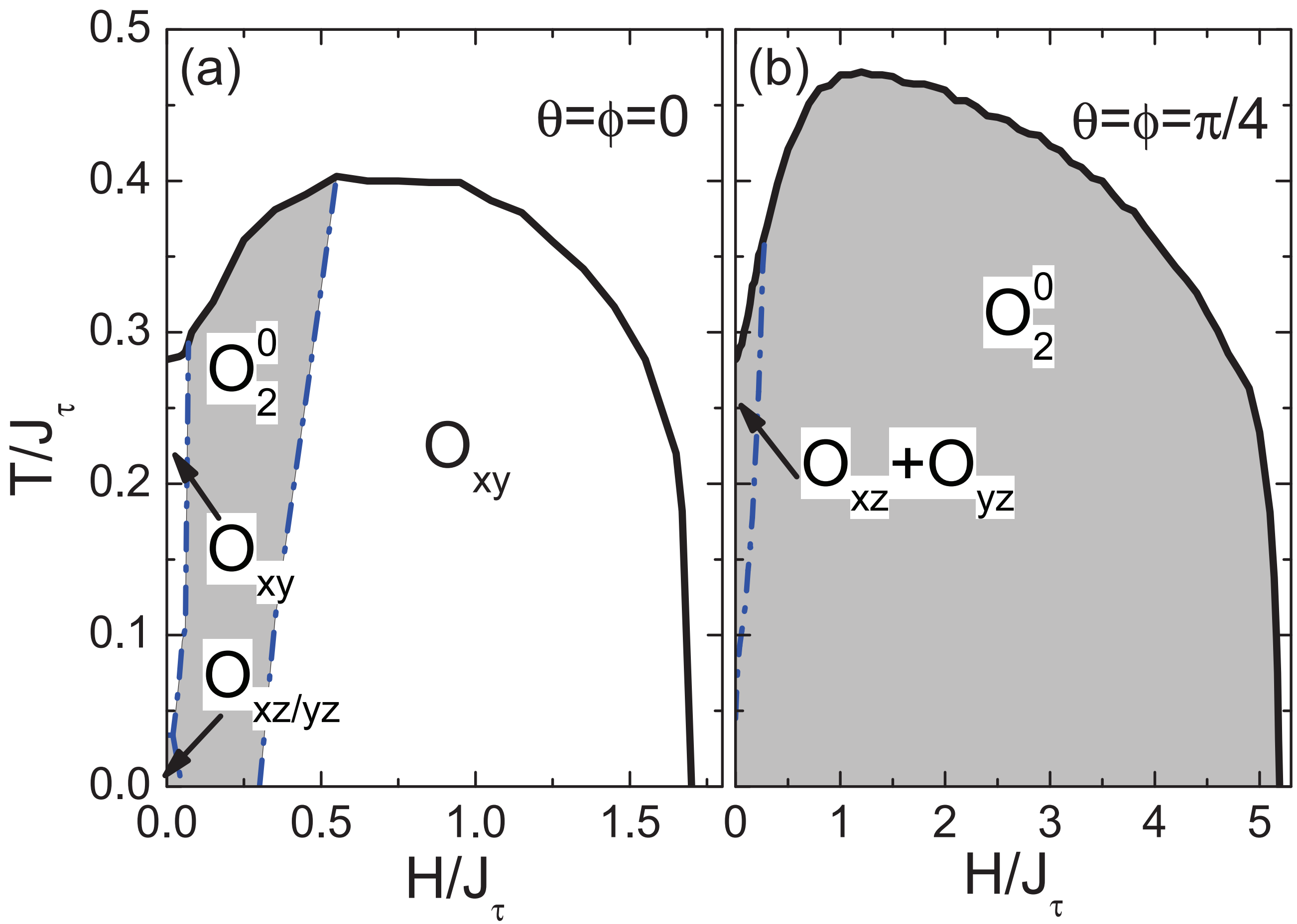
Cubic, $Fm\bar{3}m$

Ce1: fcc, 4a

Ce2: sc, 8c

Ordered phases in $Ce_3Pd_{20}Si_6$: Below T_Q

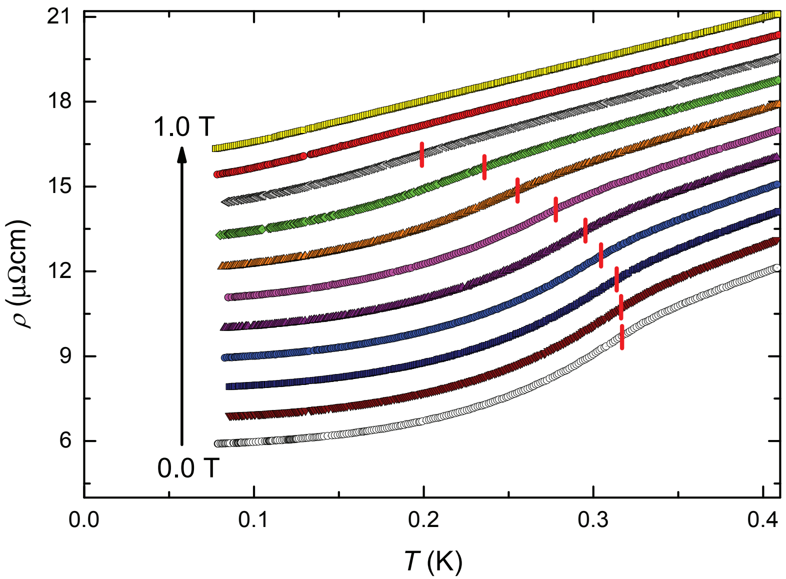
Mean field solution of effective pseudospin model (Γ_8, sc)

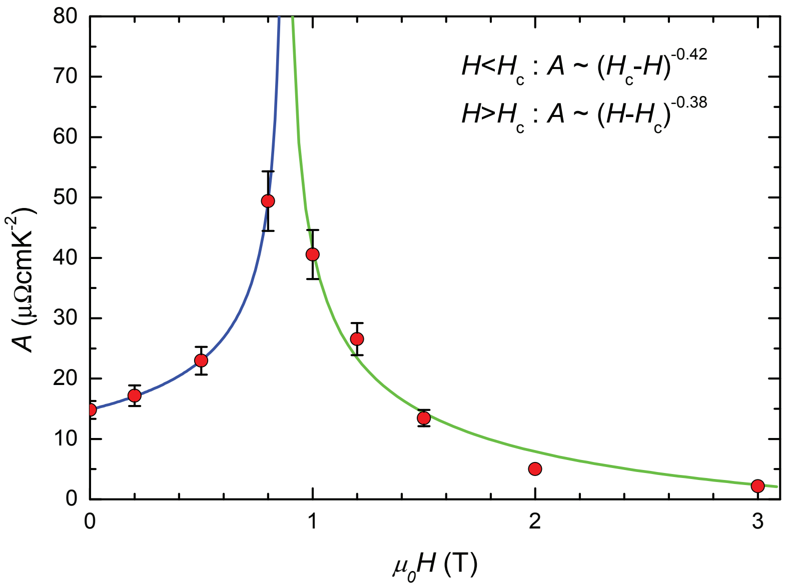


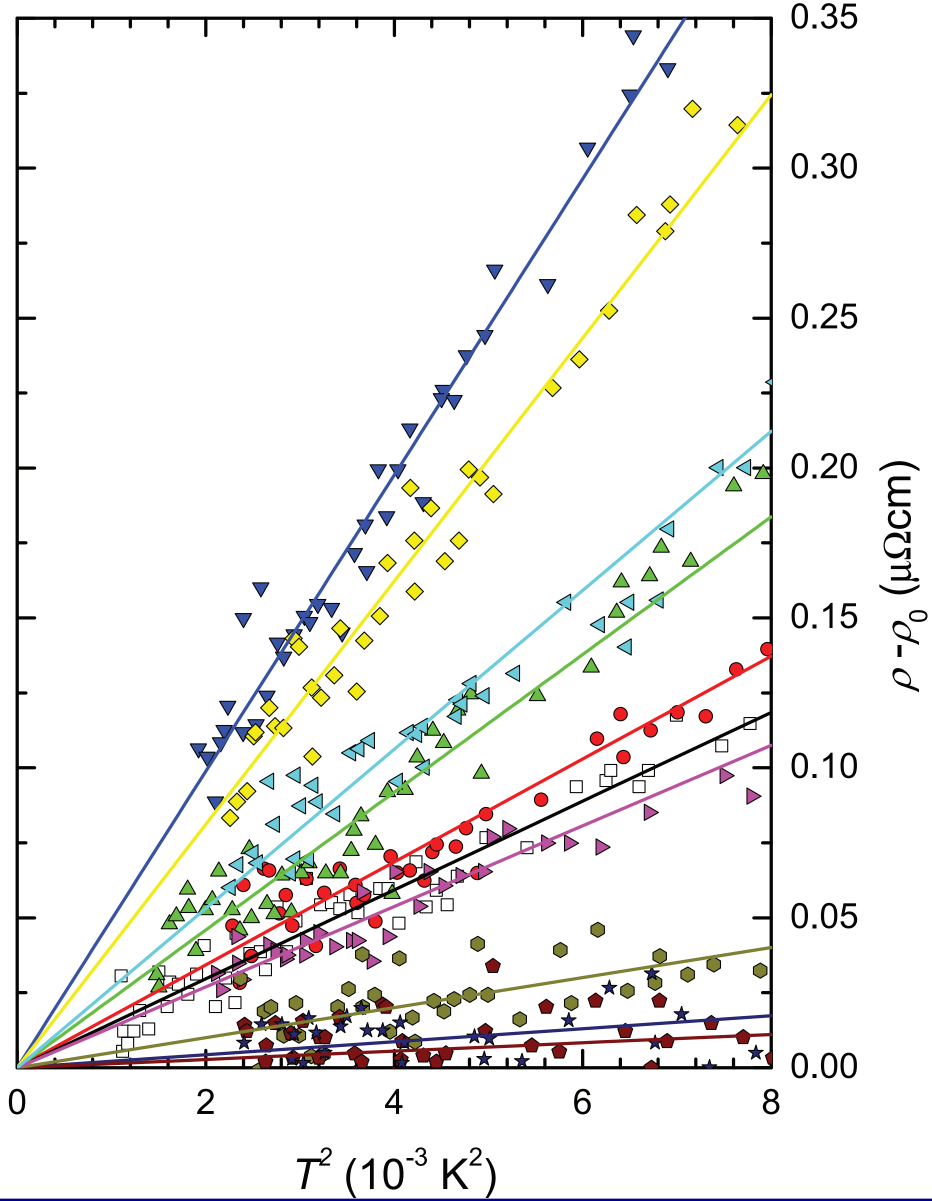
J_τ: quadrupole-quadrupole coupling strength

(SI of Custers et al., Nature Mater. 11 (2012) 189)

Landau Fermi liquid properties of $Ce_3Pd_{20}Si_6$: $\rho(T, B)$

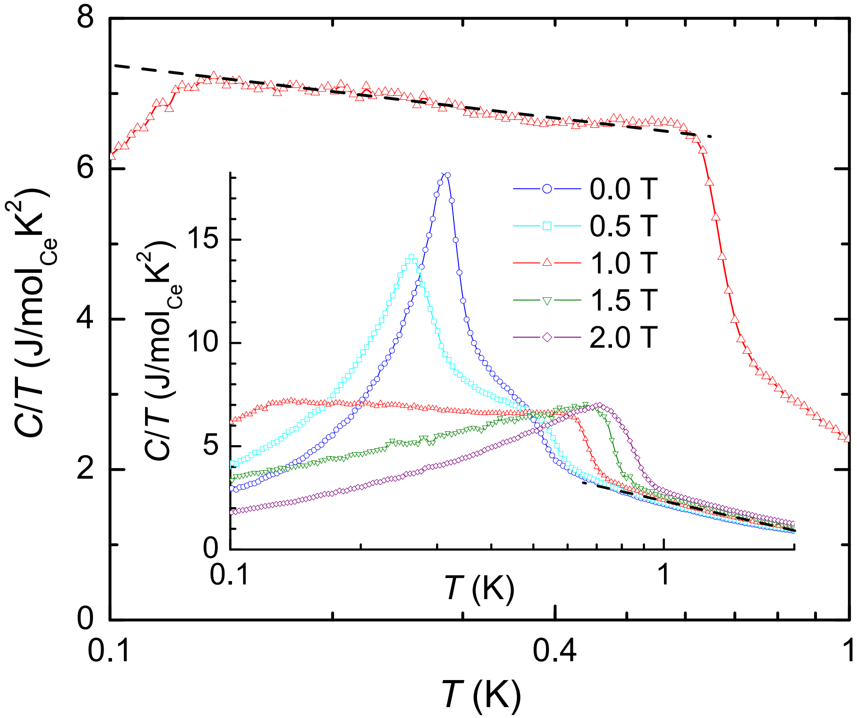






Non-Fermi liquid properties of $Ce_3Pd_{20}Si_6$

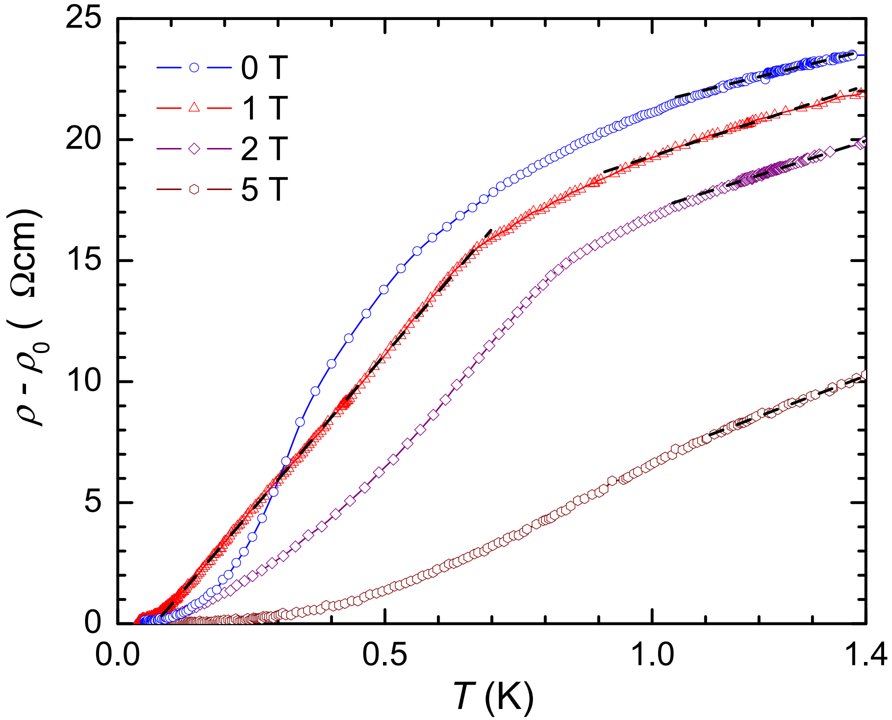
Specific heat



$\Delta C/T \propto -\ln T$

SDW (AFM, $d=3$):
$\Delta C/T = \gamma - b\sqrt{T}$

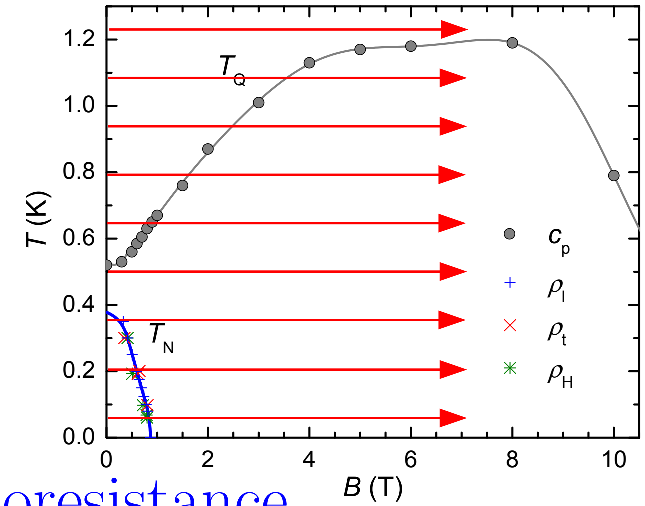
Electrical resistivity



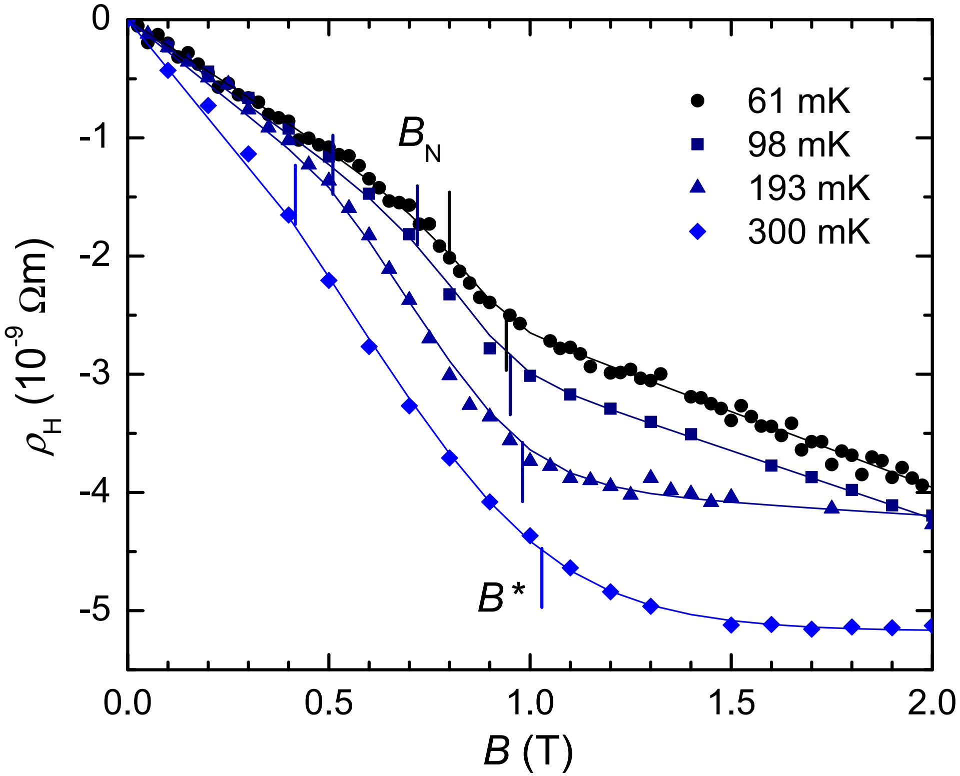
$\Delta\rho \sim T$

SDW (AFM, $d=3$): $\Delta\rho \sim T^{3/2}$

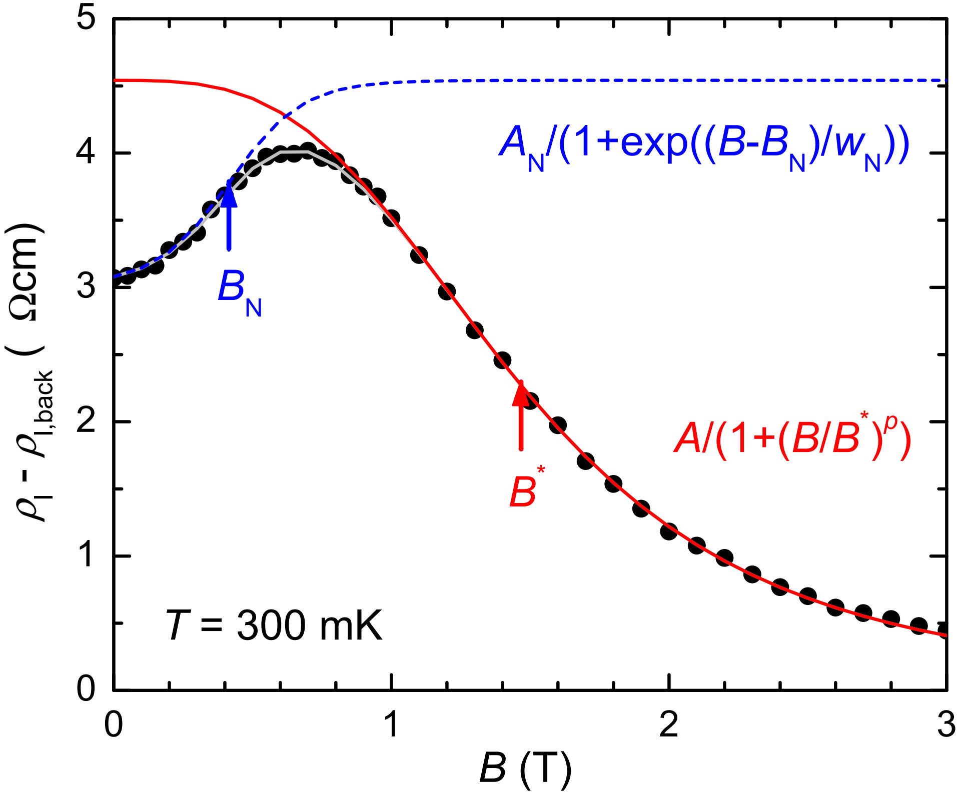
Isotherms crossing phase diagram



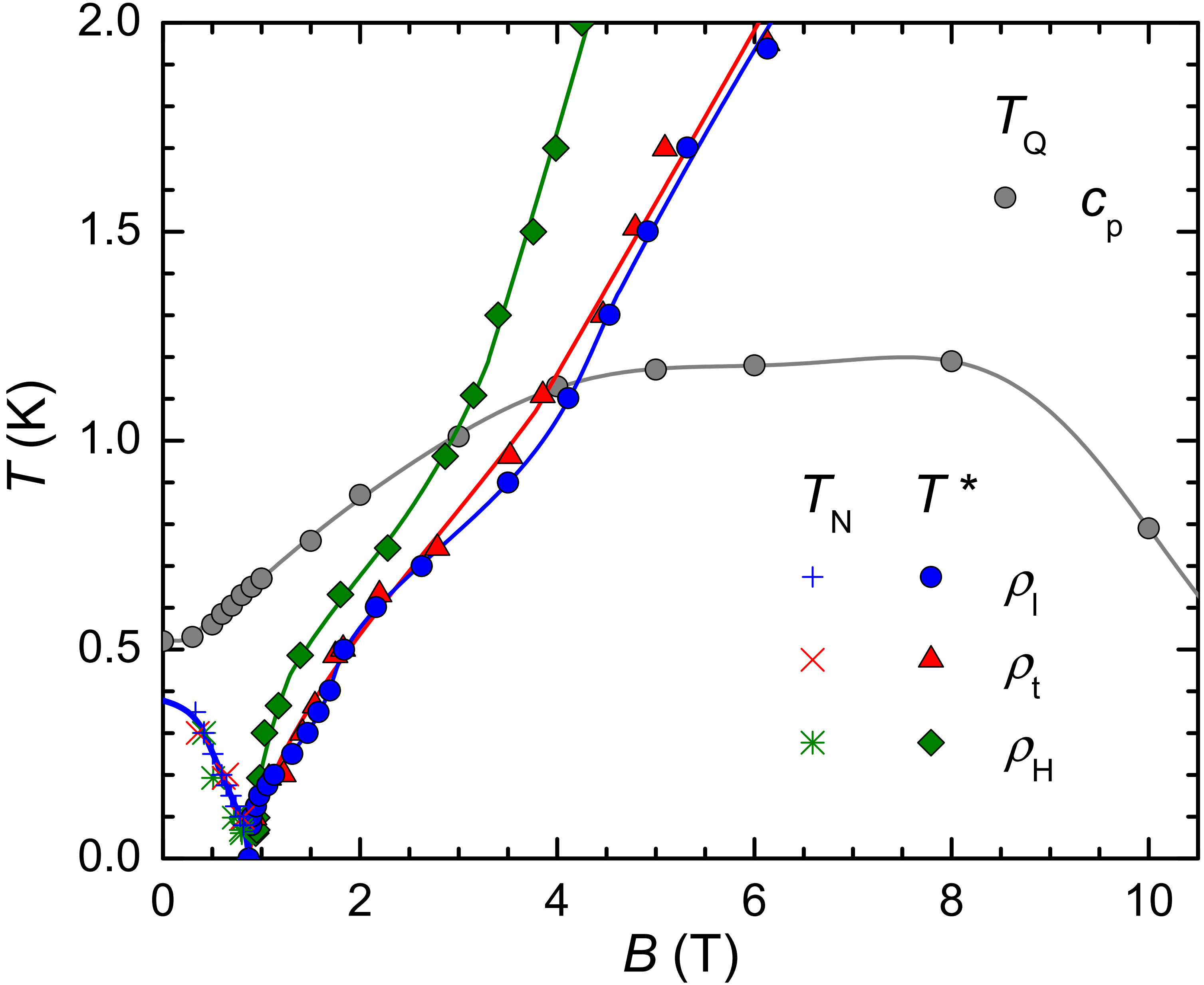
Hall effect



Magnetoresistance

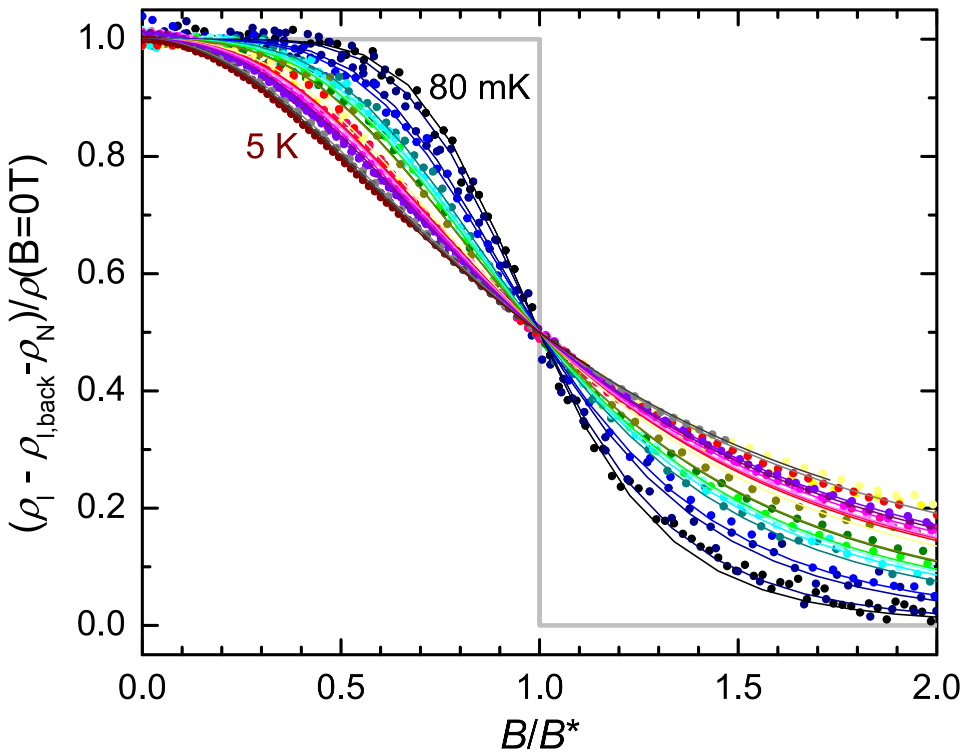


Phase diagram of $Ce_3Pd_{20}Si_6$ with T^* scale

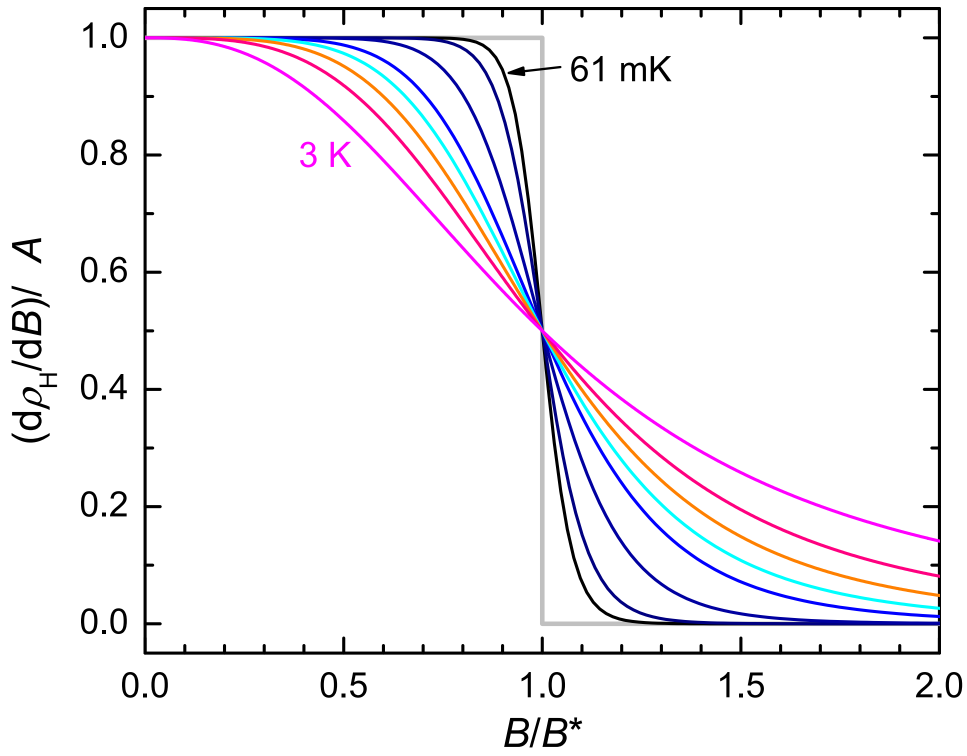


Crossovers in magnetotransport of $Ce_3Pd_{20}Si_6$ at B^*

Longitudinal magnetoresistance

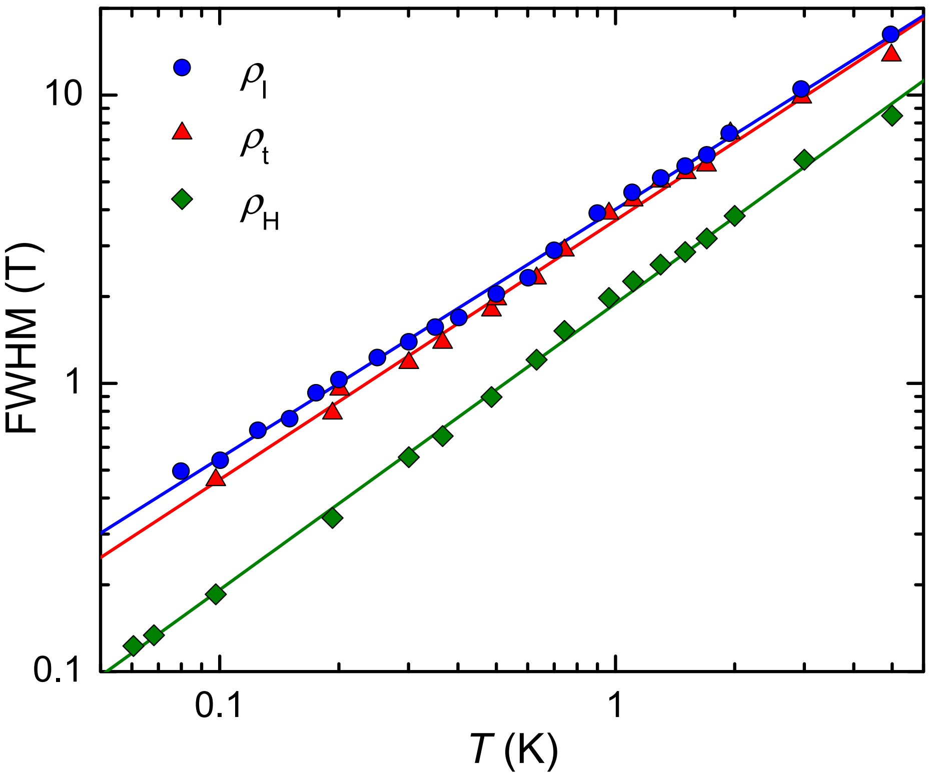


Differential Hall coefficient

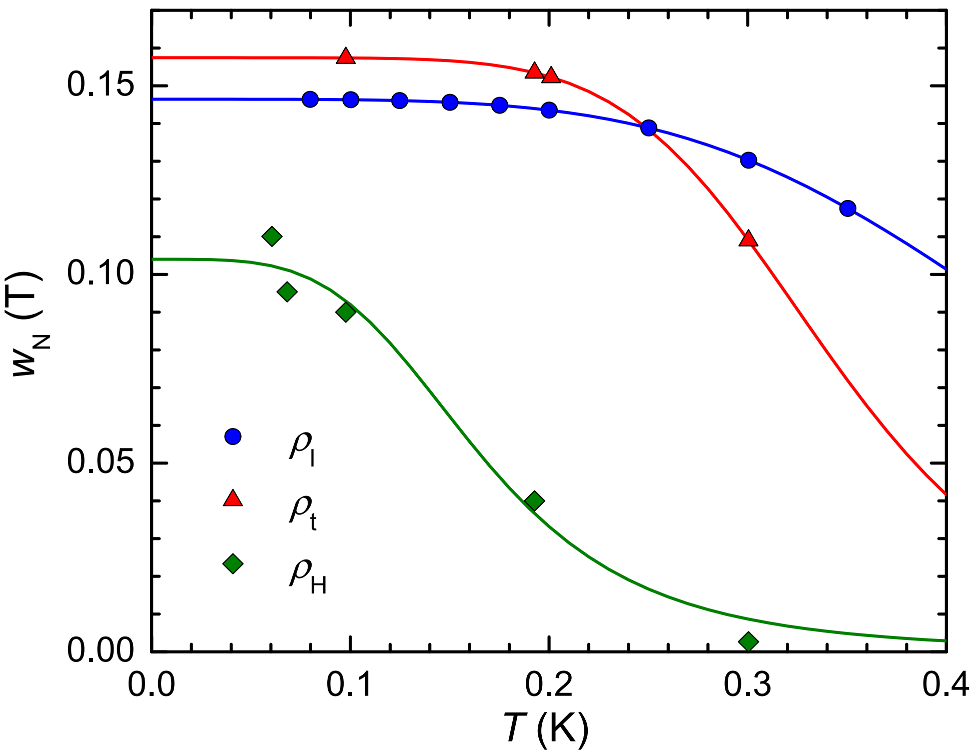


Crossovers at B^* vs transition at B_N

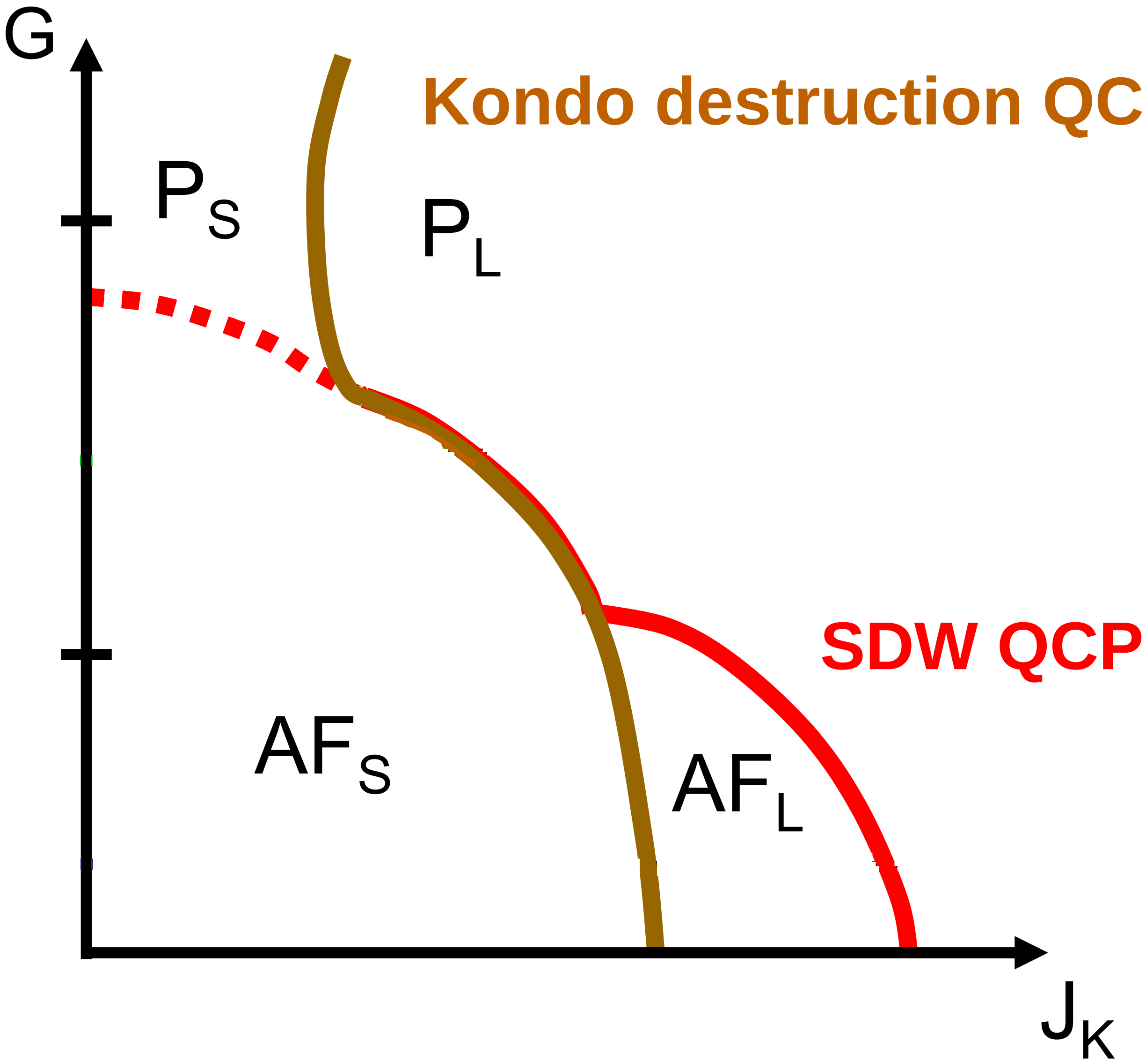
Width of crossover at B^*



Width of transition at B_N

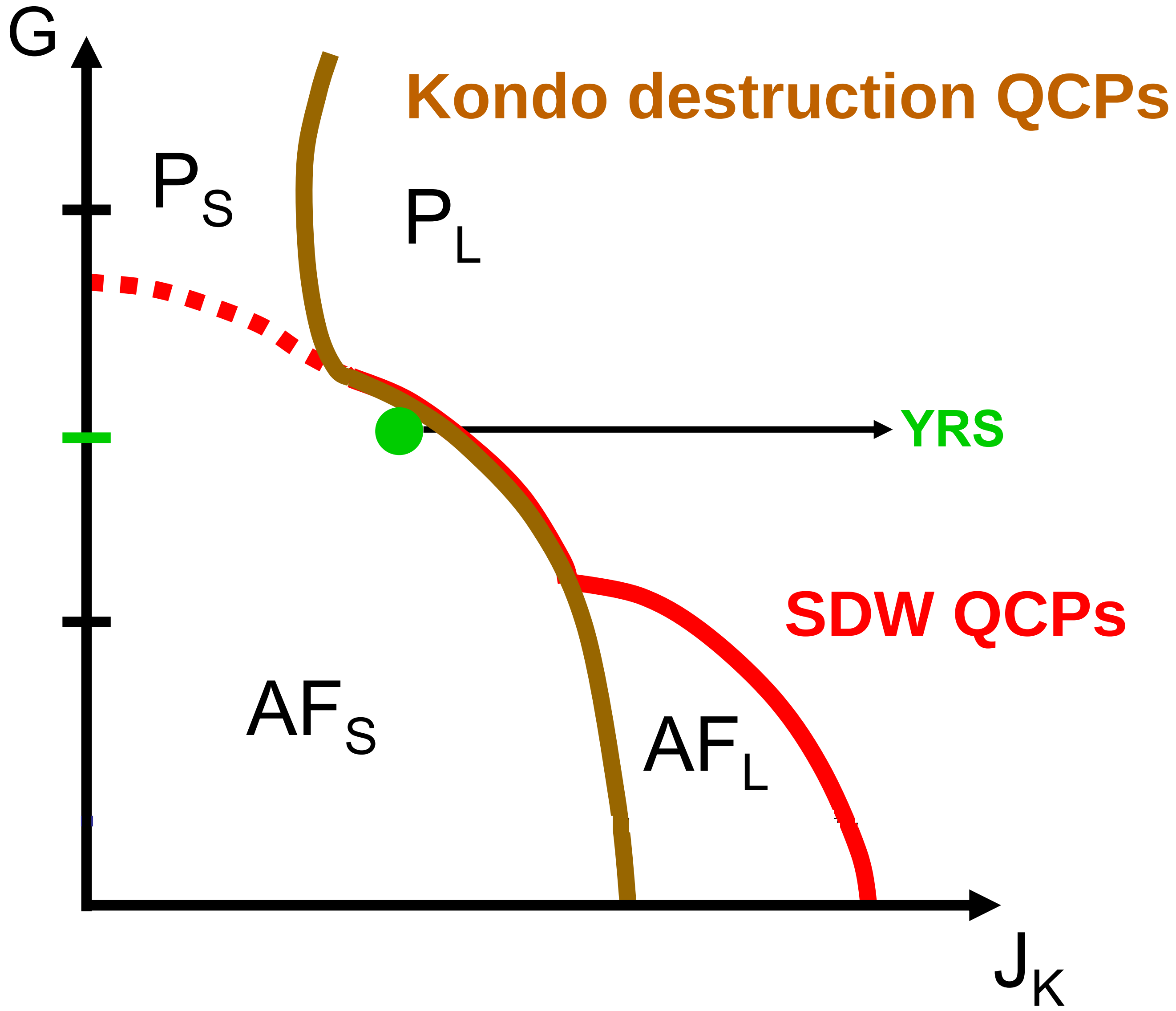


Suggested theoretical phase diagram at $T = 0$



(Si, Physica B 378-380 (2006) 23; Phys. Stat. Sol. 247 (2010) 476; also: Coleman et al.)

Suggested theoretical phase diagram at $T = 0$



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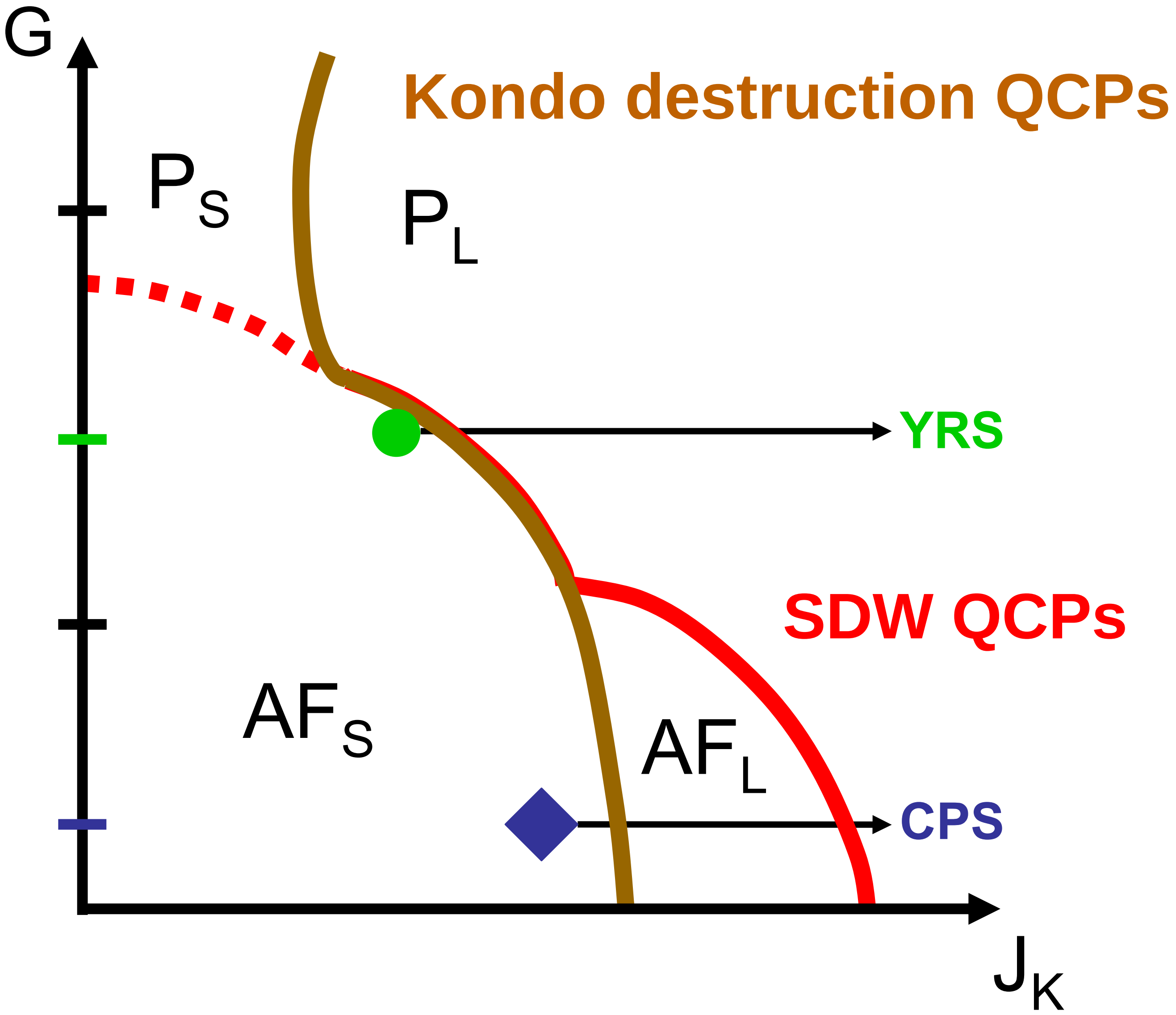
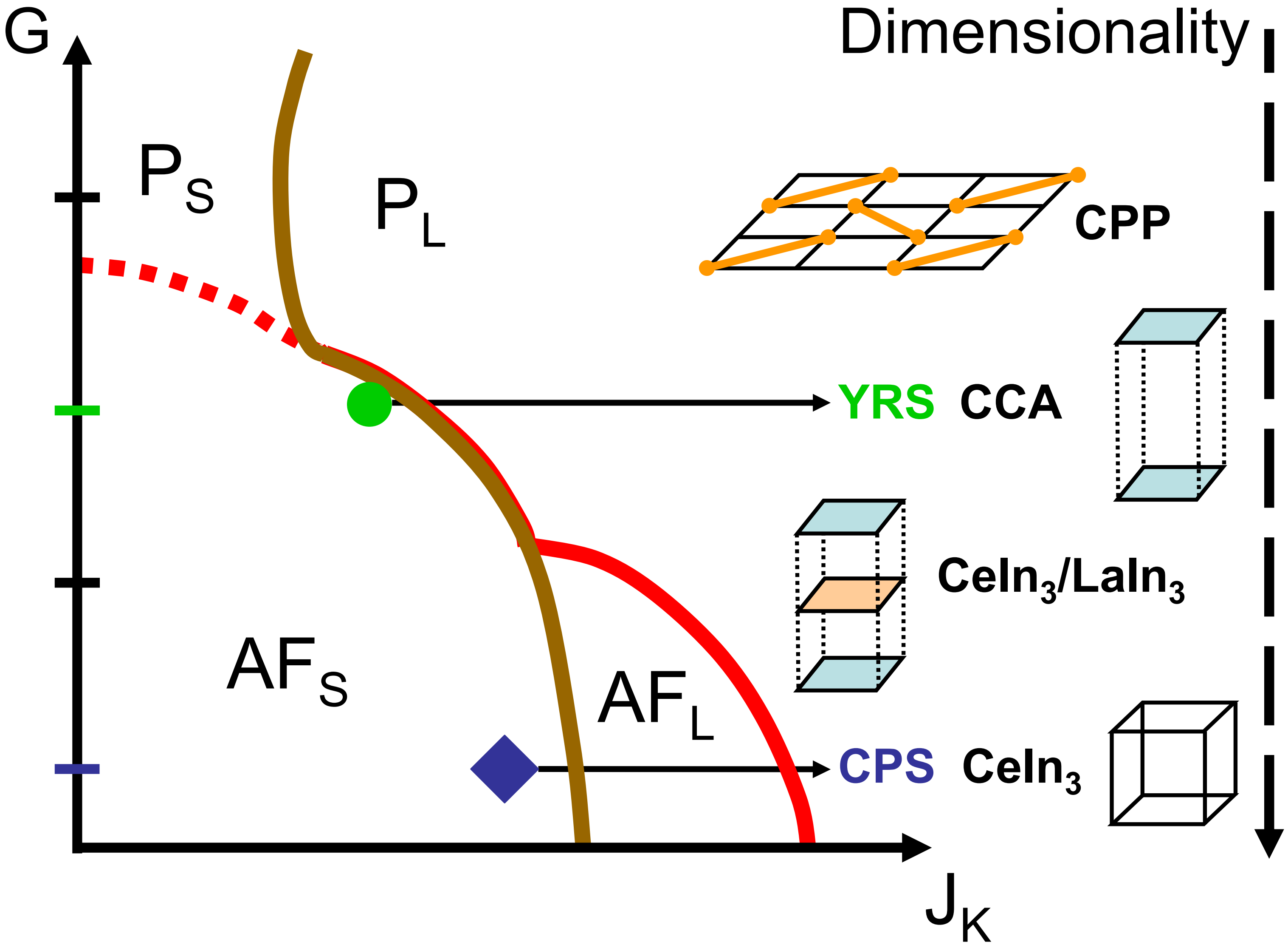
Suggested theoretical phase diagram at $T = 0$



(Si, Physica B 378-380 (2006) 23; Phys. Status Solidi 247 (2010) 476)

Materials-based global phase diagram



(Custers et al., Nature Mater. 11 (2012) 189)

Summary & Outlook

- $Ce_3Pd_{20}Si_6$: New *cubic* quantum critical heavy fermion compound
- Crossover in magnetotransport with similar characteristics as in $YbRh_2Si_2$, at $T \longrightarrow 0$:
  - Crossover position coincides with B_c
  - Crossover width extrapolates to zero
- Important difference: QCP within other ordered phase!
  - Nature of this phase?
  - Nature of transition leaving this phase?
  - Can in Kondo breakdown scenario be related to higher dimensionality (lower G)
  - Other theoretical scenarios?
  - Extensions of theories to 3D?