Exotic Superconducting State Coexisting with an Antiferromagnetic Order

---NQR study under pressure in $Ce(Rh_{1-x}Ir_x)In_5$ ---

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Outline

1. Microscopic coexistence of AF order and SC in $CeRhIn_5$ under pressure and in $Ce(Rh_{1-x}Ir_x)In_5$.

2. Gapless superconducting state coexisting with magnetic order.

3. Recent NQR measurements on $Ce(Rh_{1-x}Ir_x)In_5$ under high pressure.

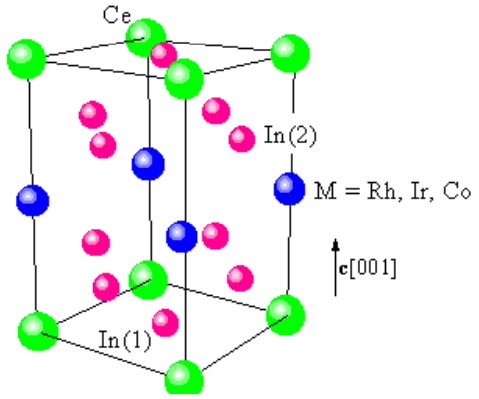
4. Possible exotic superconducting state.

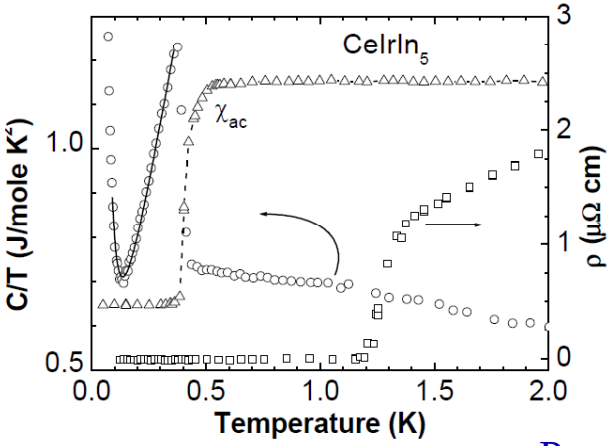
Collaborators

S. Kawasaki, A. Sorime — *Okayama U, Dept. Phys.*

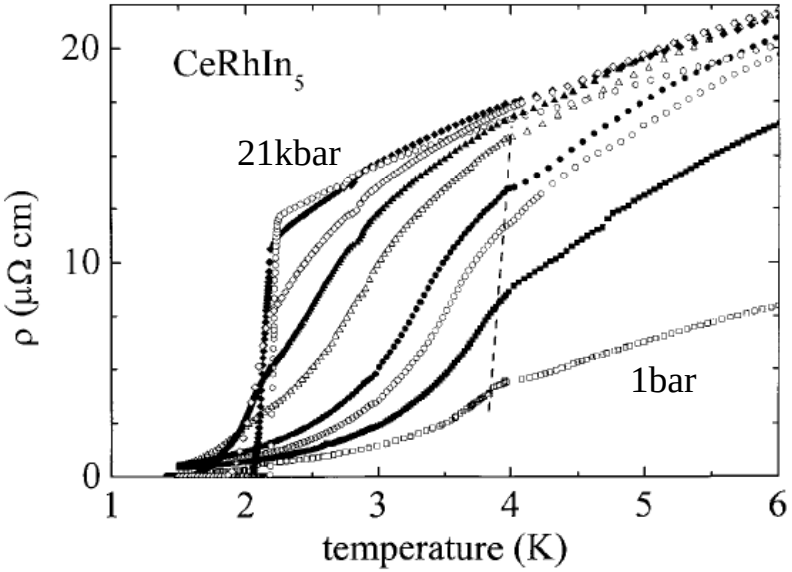
J.L. Sarrao, J.D. Thompson — *Los Alamos Nt'l Lab*

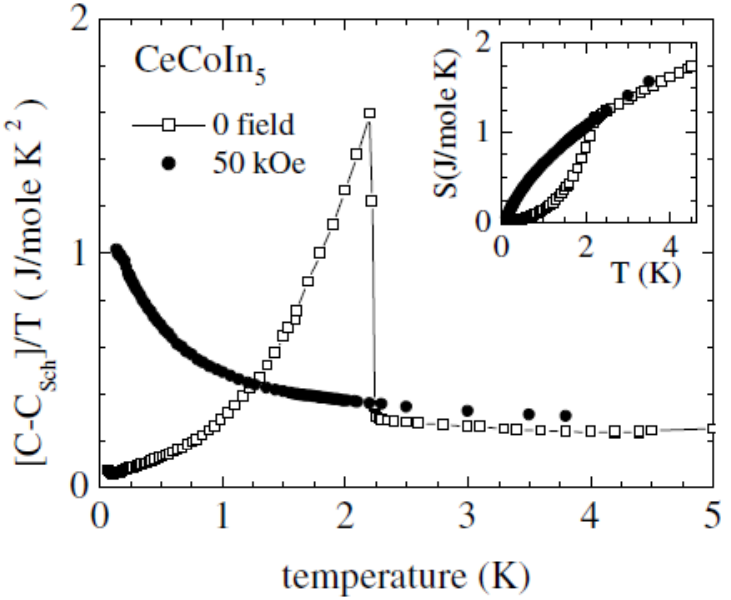
HF superconductors Ce(Rh,Ir,Co)In_5





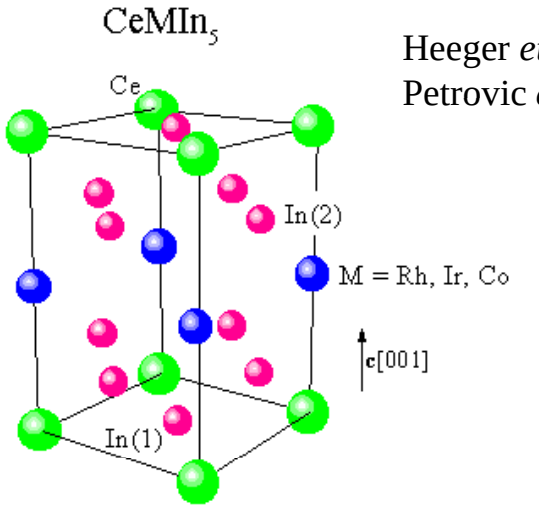
Petrovic *et al*



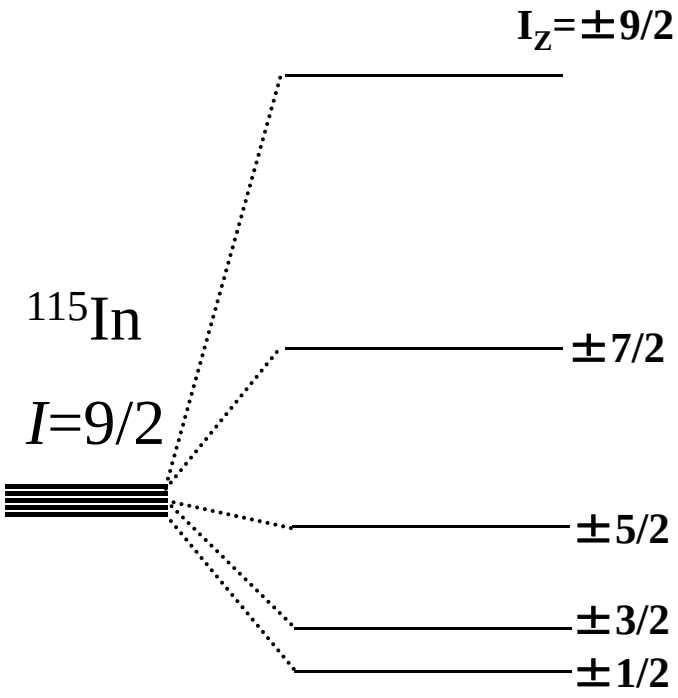


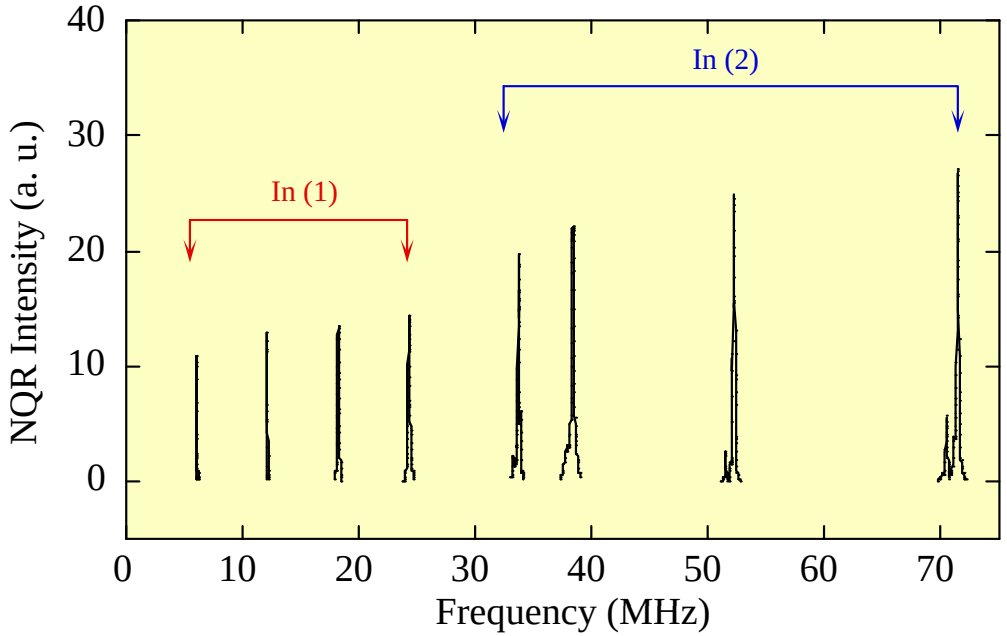
Hegger et al, PRL **84**, 4986

Crystal Structure & ^{115}In NQR spectra

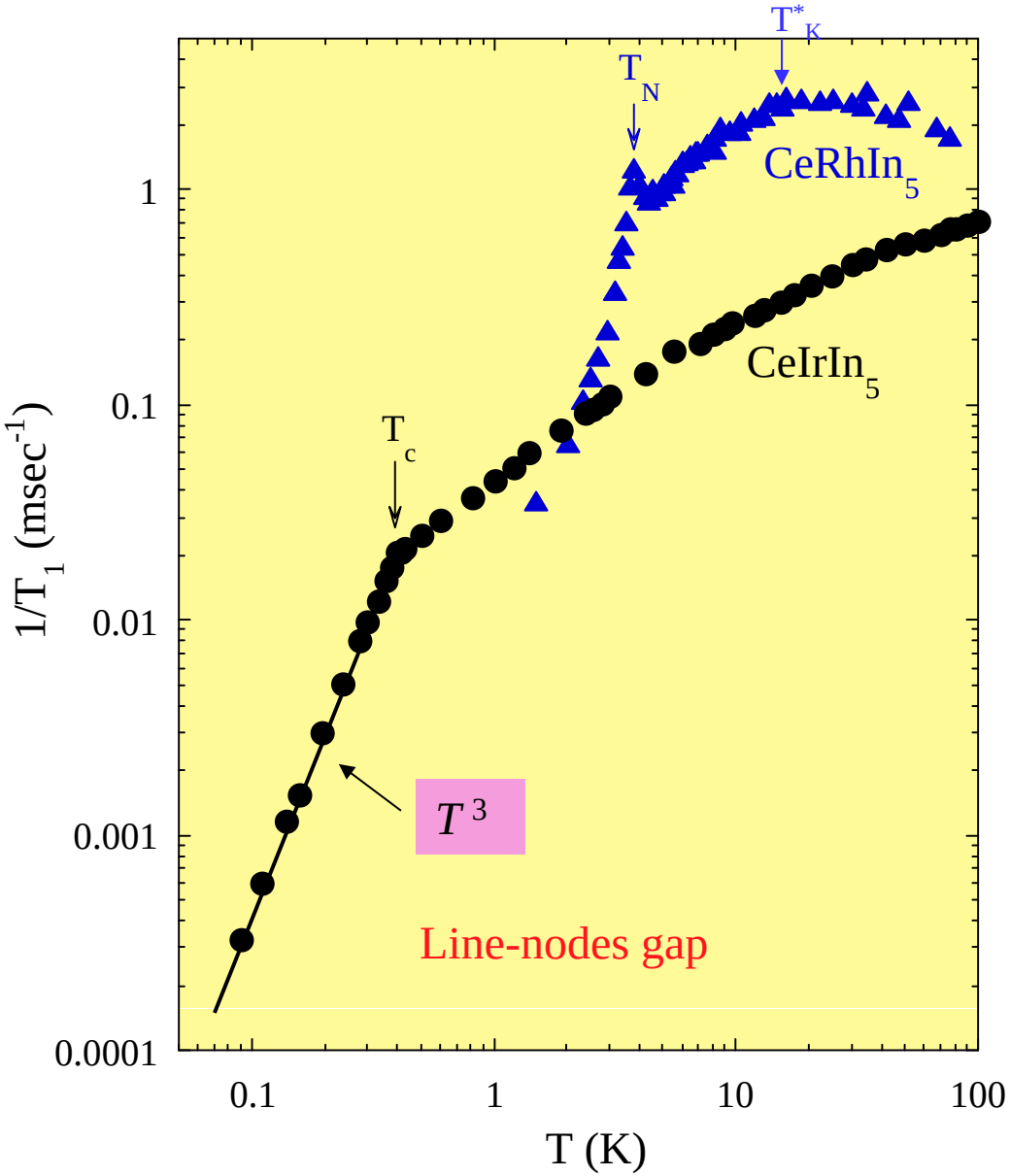


Heeger *et al*
Petrovic *et al*





$Ce(Rh,Ir)In_5$: viewed from NQR



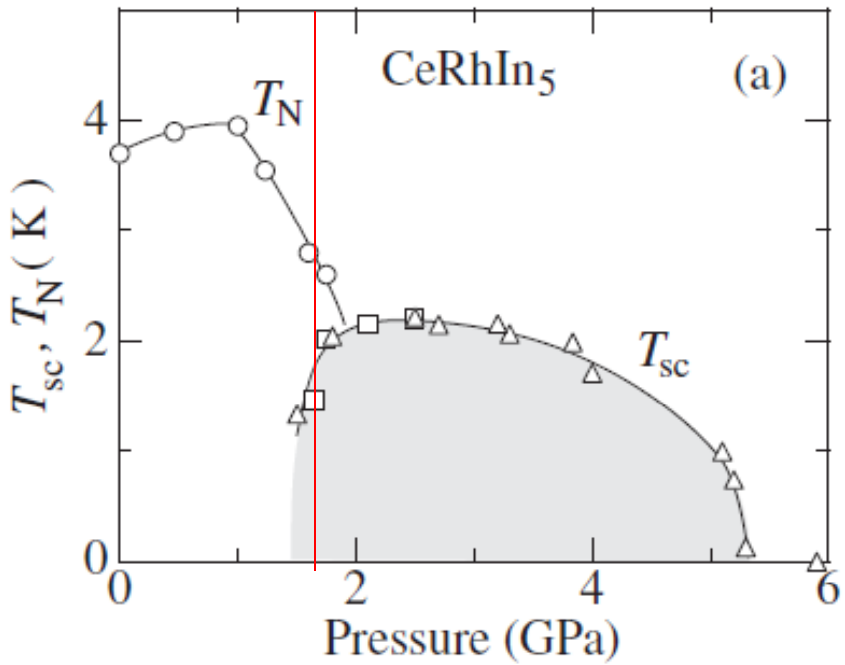
$CeIrIn_5$ is much more itinerant (wider bandwidth) than $CeRhIn_5$

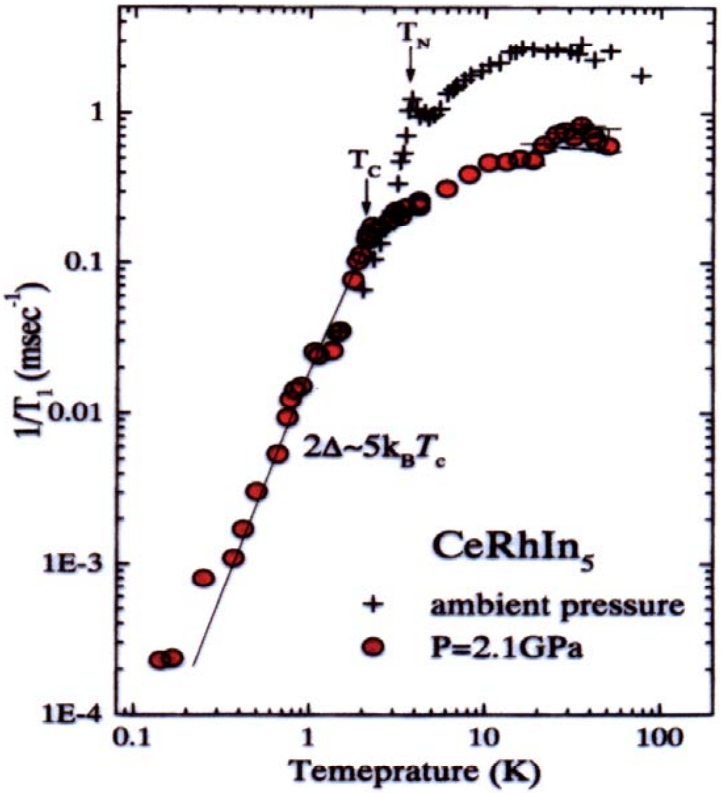
G.-q. Zheng *et al*,

Phys. Rev. Lett. **86**, 4664 (2001)

T. Mito, *et al*,

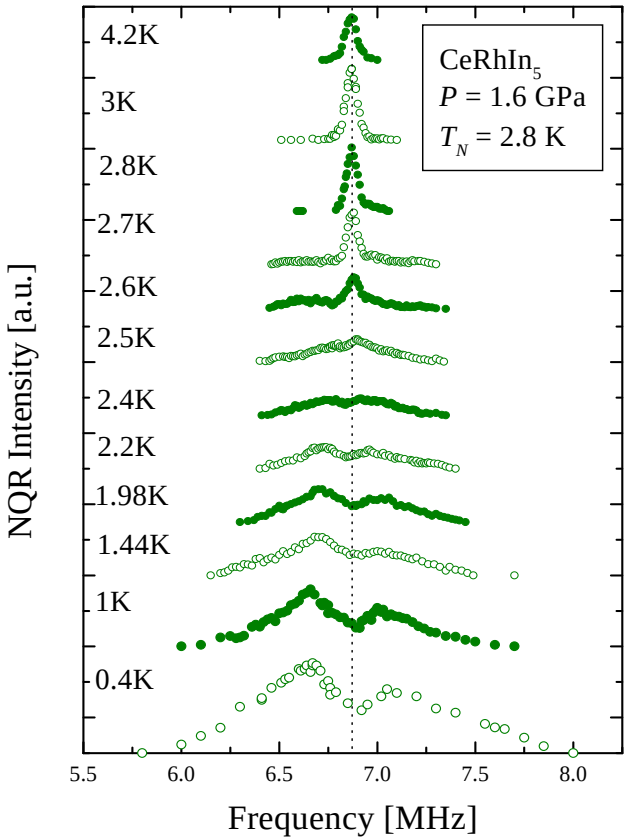
Phys. Rev. **B63**, 220507 (2001)

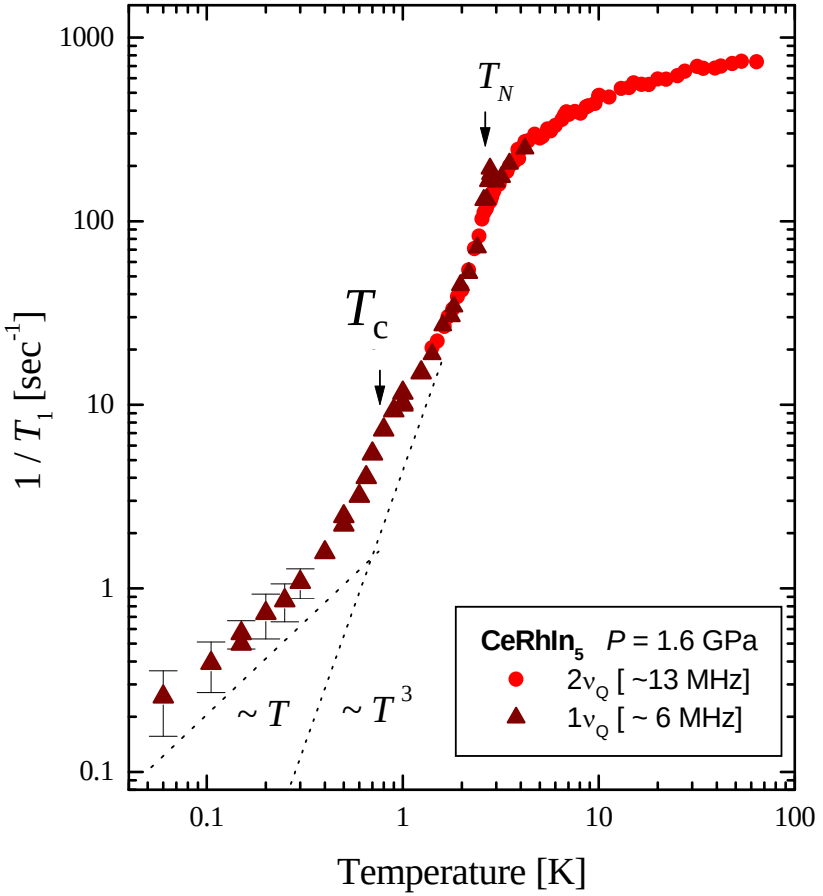

CeRhIn5
(a)
TN
Tsc
Tsc , TN (K)
Pressure (GPa)
0
2
4
6


TN
TC
1/T1 (msec-1)
2Δ~5kBTc
CeRhIn5
ambient pressure
P=2.1GPa
Temeprature (K)
1
0.1
0.01
1E-3
1E-4
0.1
1
10
100

PRB (’01)

Microscopic Coexistence of SC and AFM

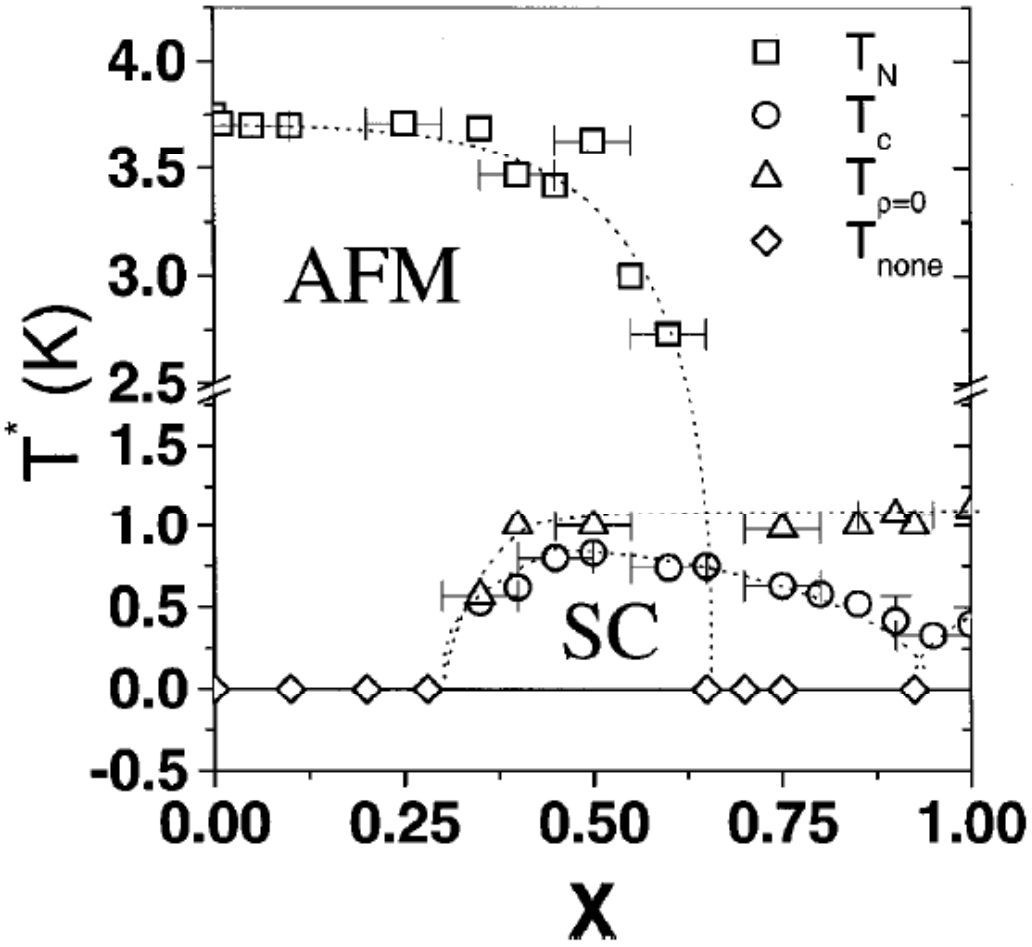




Kawasaki *et al* PRL ('03)

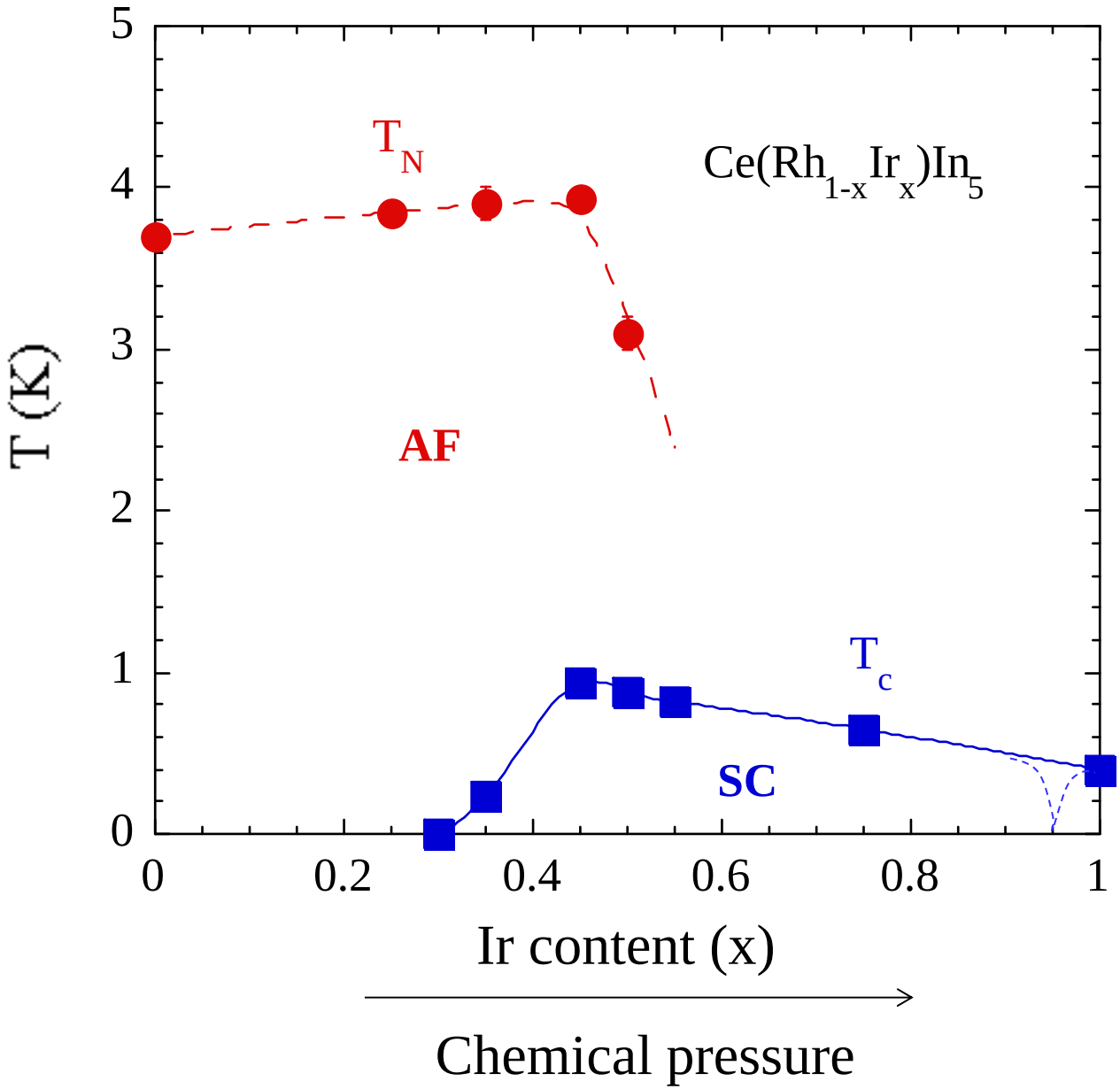
The same electron is responsible for both AFM and SC

$Ce(Rh_{1-x}Ir_x)In_5$

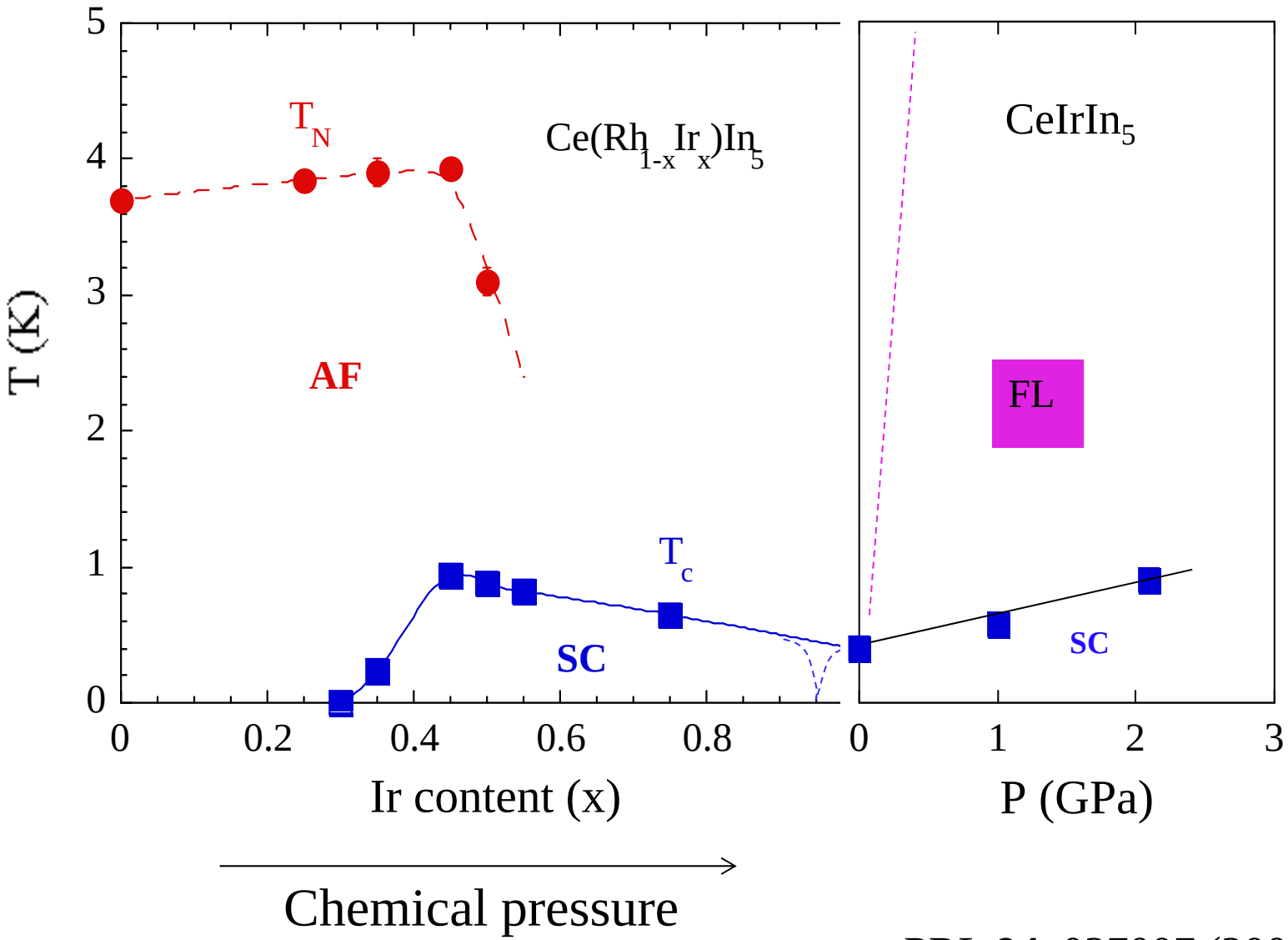


Pagliuso et al, PR **B64**, 100503 (2001)

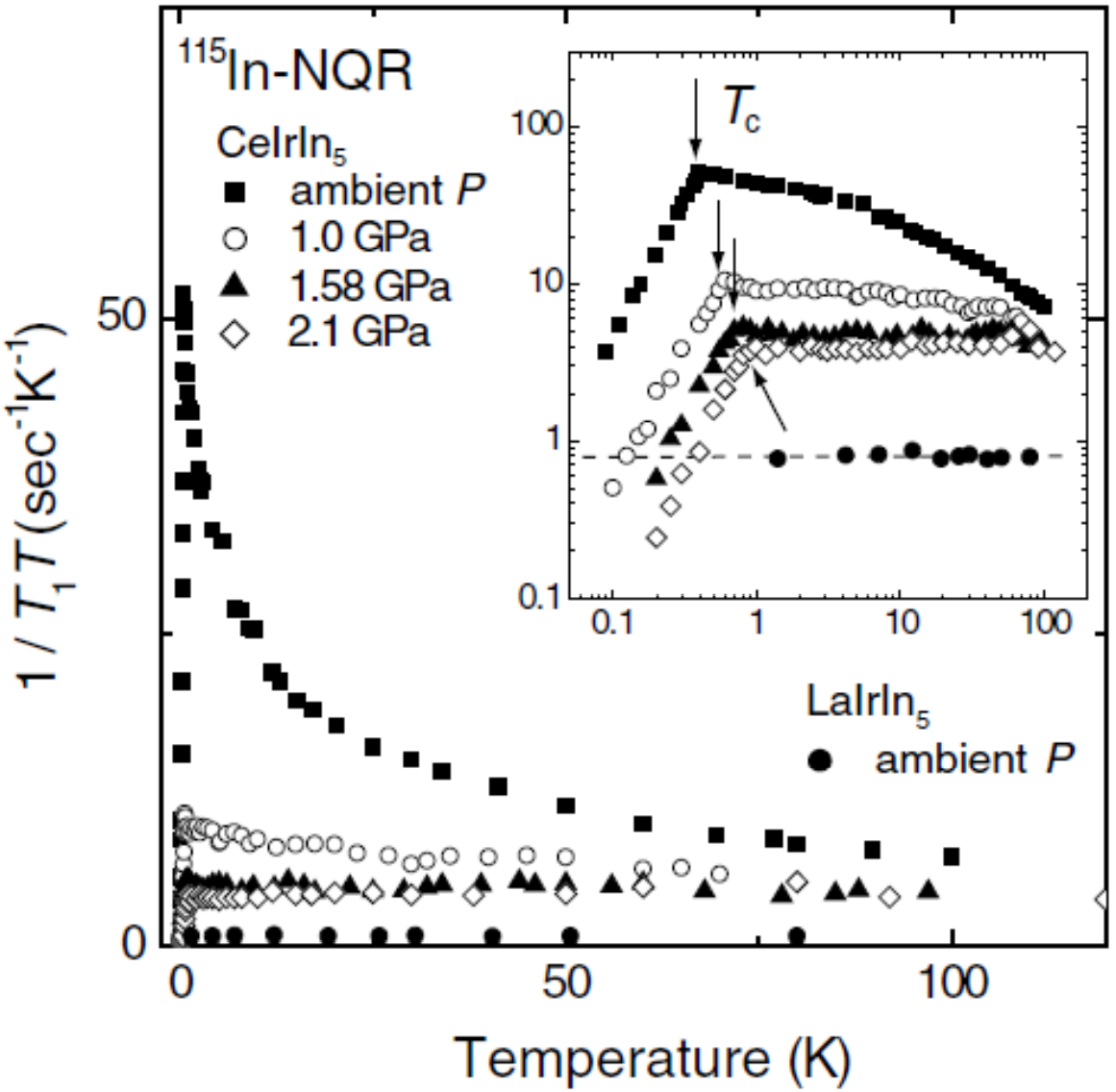
Phase diagram obtained by NQR



Zheng *et al*, PR B **70**, 014511 (2004)

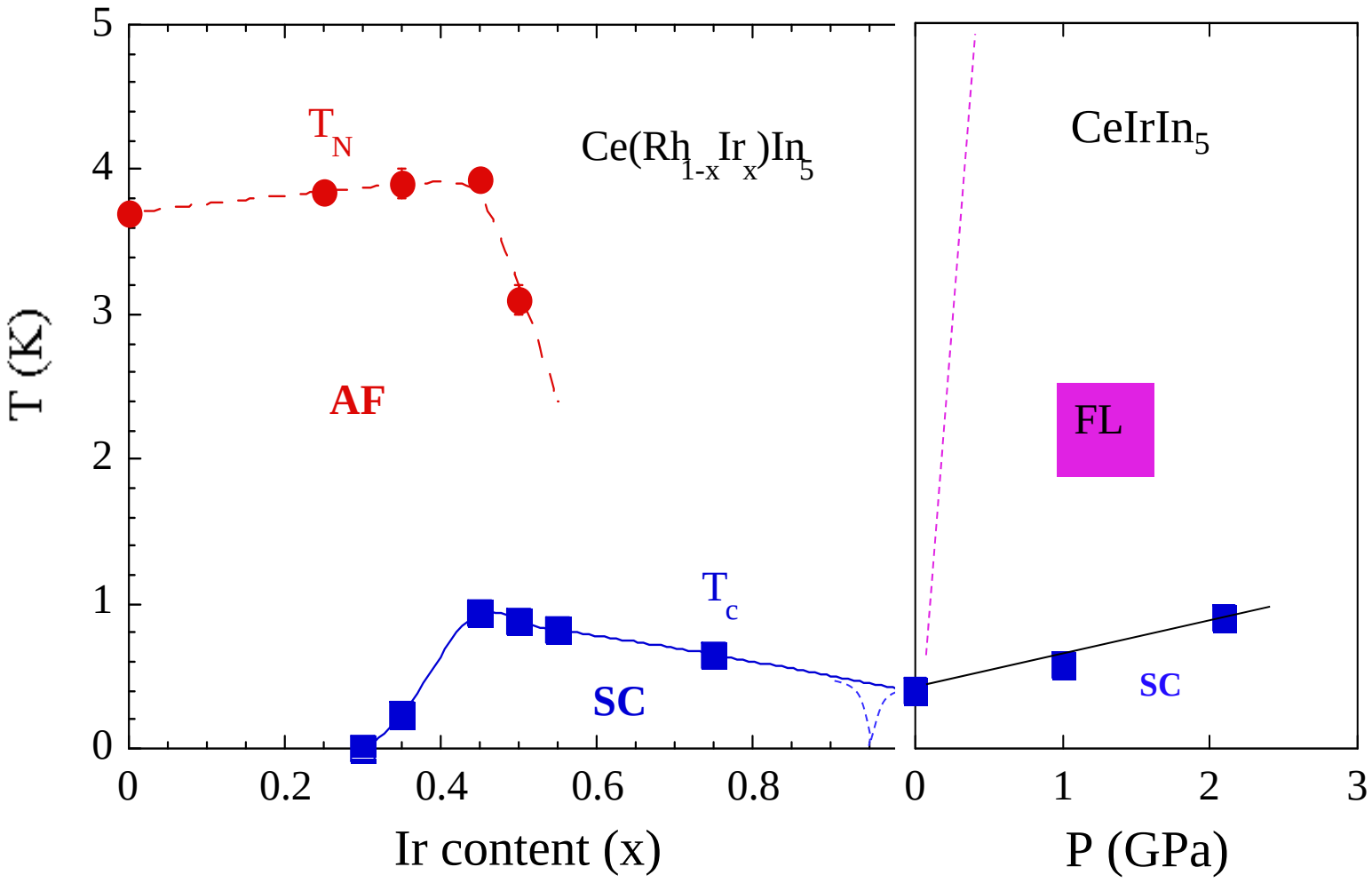


PRL **94,** 037007 (2005)



PRL **94,** 037007 (2005)

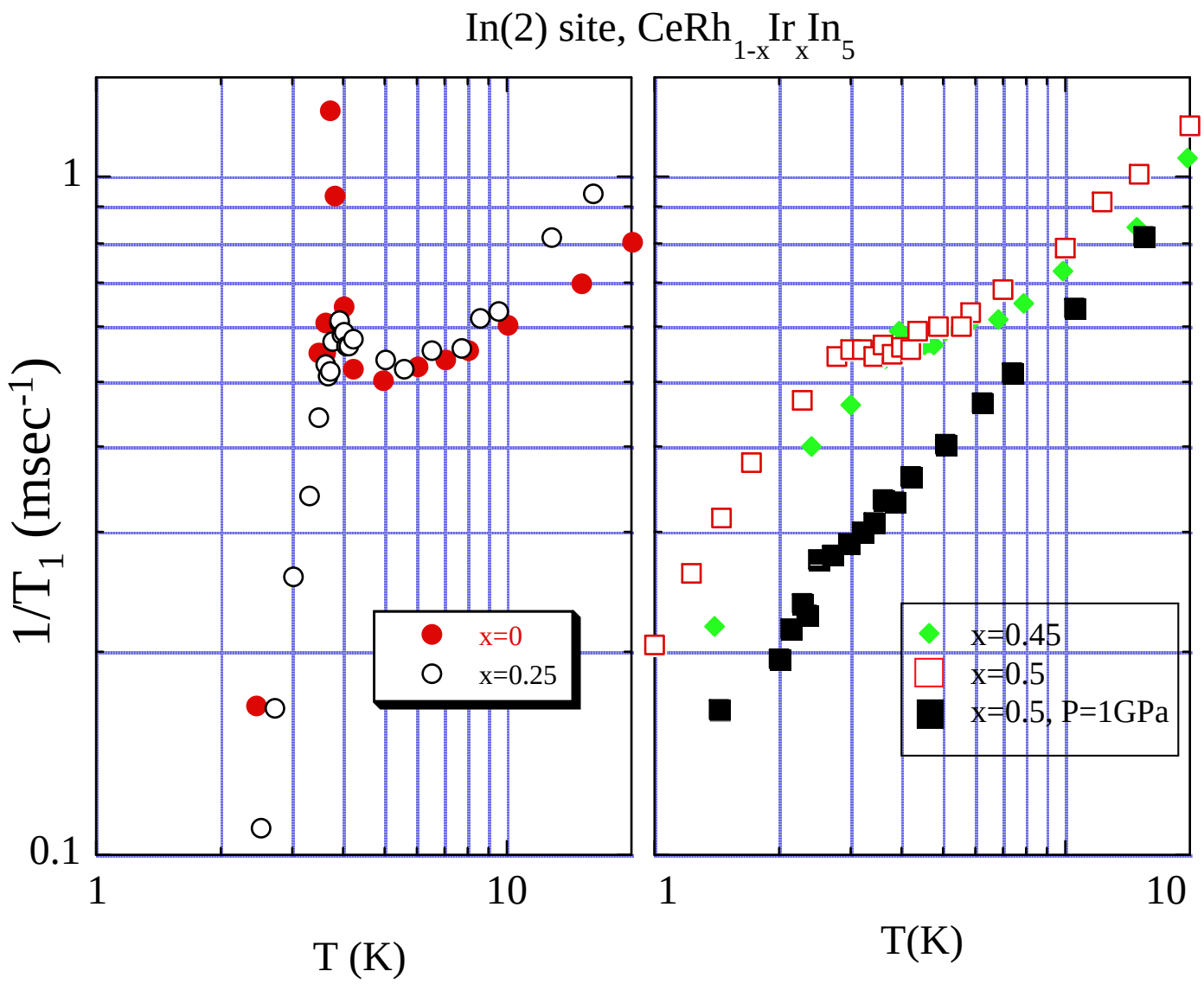
Multiple routes to superconductivity?



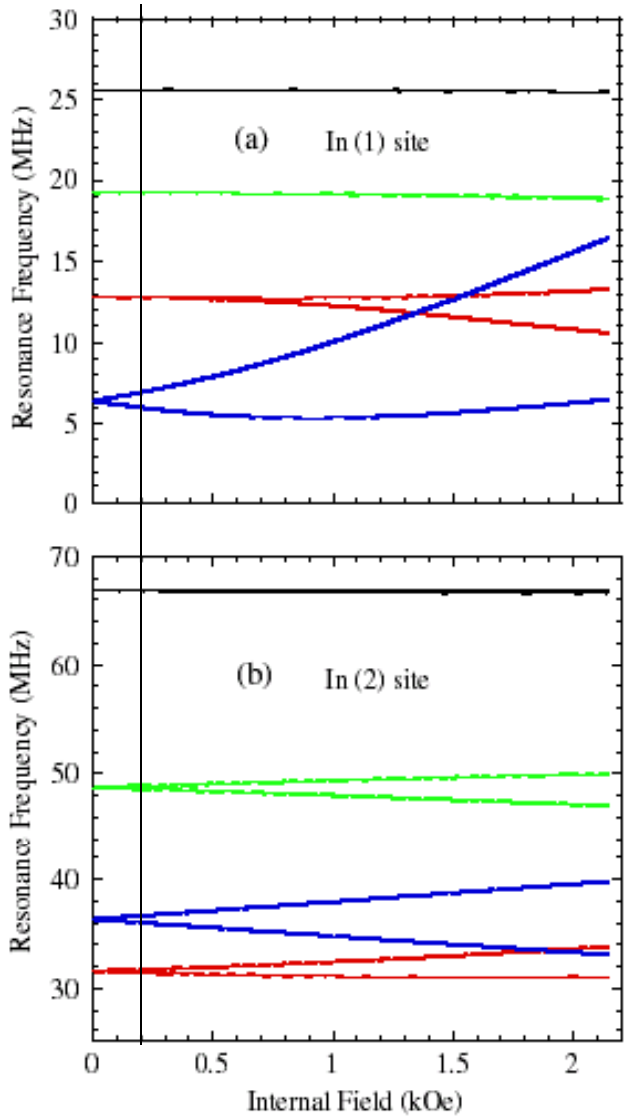
Chemical pressure

PRL **94,** 037007 (2005)

T_N changes with Ir content and pressure



Estimate of internal field



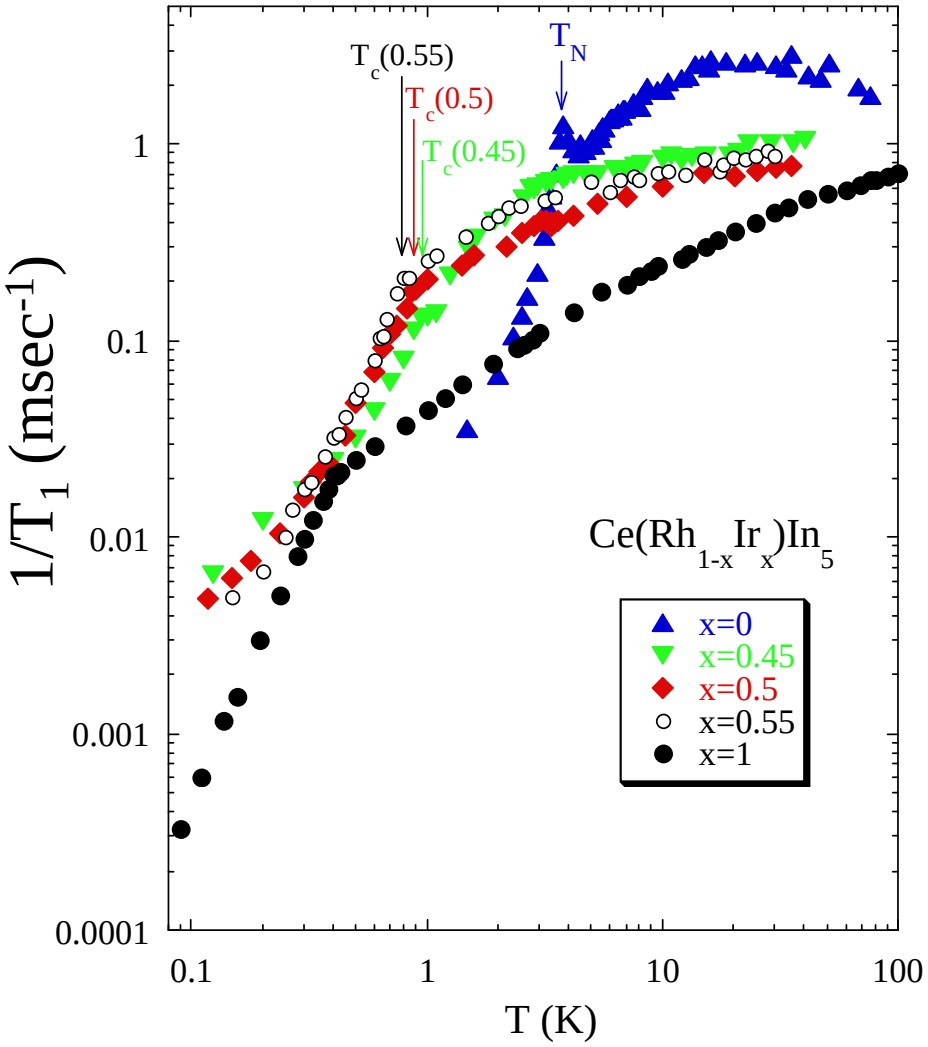
Linewidth=0.26MHz

H_{int}<200 Oe

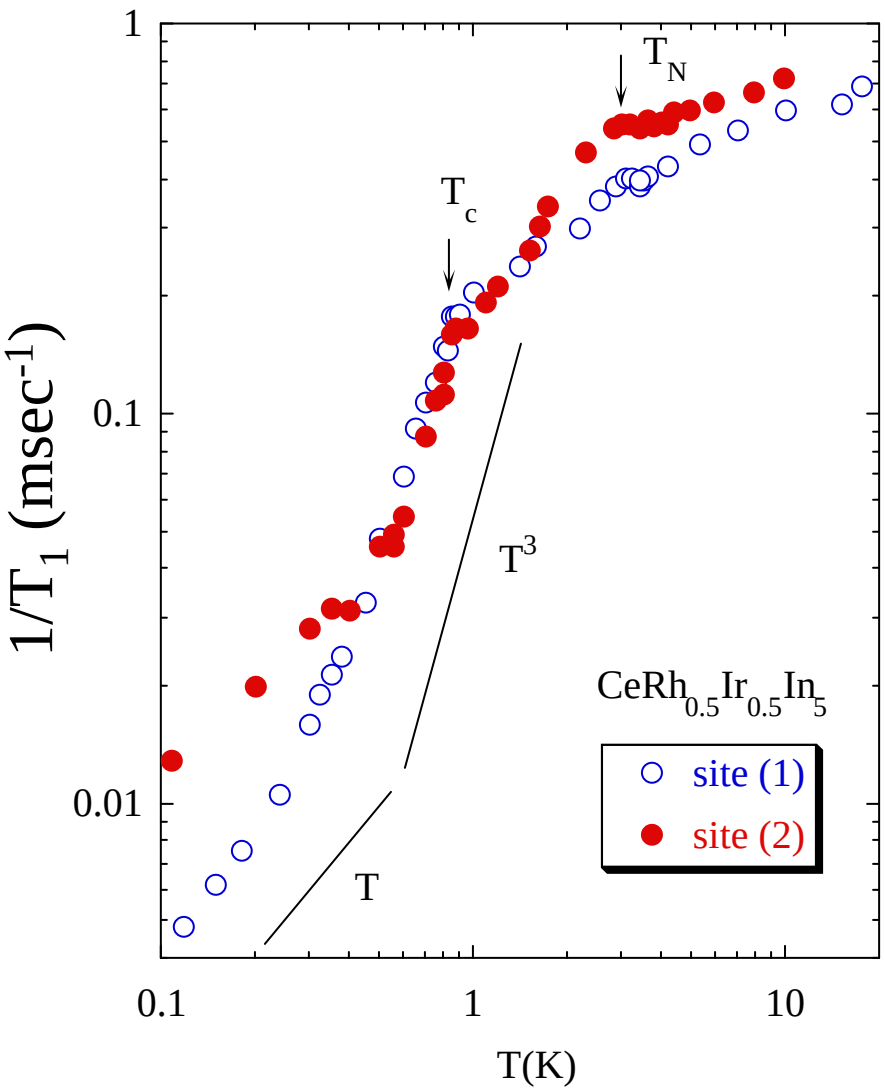
c.f. : H_{int}=2000 Oe in $CeRhIn_5$

Reduction of ordered moment
(1/4? See Llobet's talk)
Reduction of hyperfine coupling
($A_{CeCoIn5}$=1/3 $A_{CeRhIn5}$)

Evolution of the sc state with Ir doping



Onset of SC in the AF state



AF and SC are due to the same electronic state

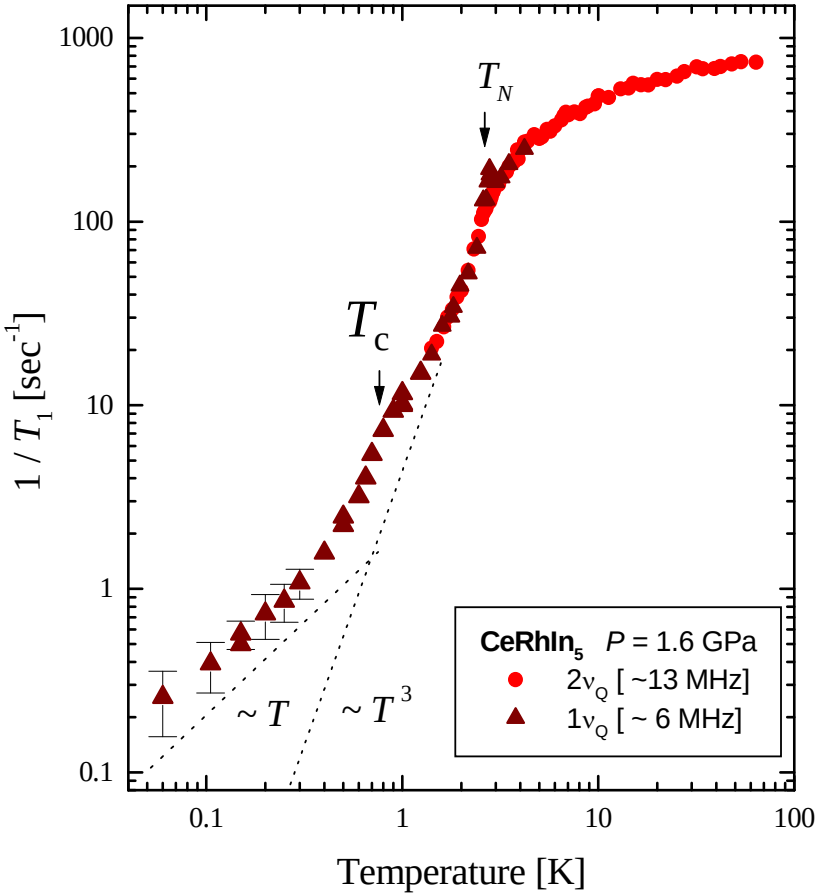
Just above T_C, $1/T_1 \propto T$:

Finite DOS(N_{res}) at E_F

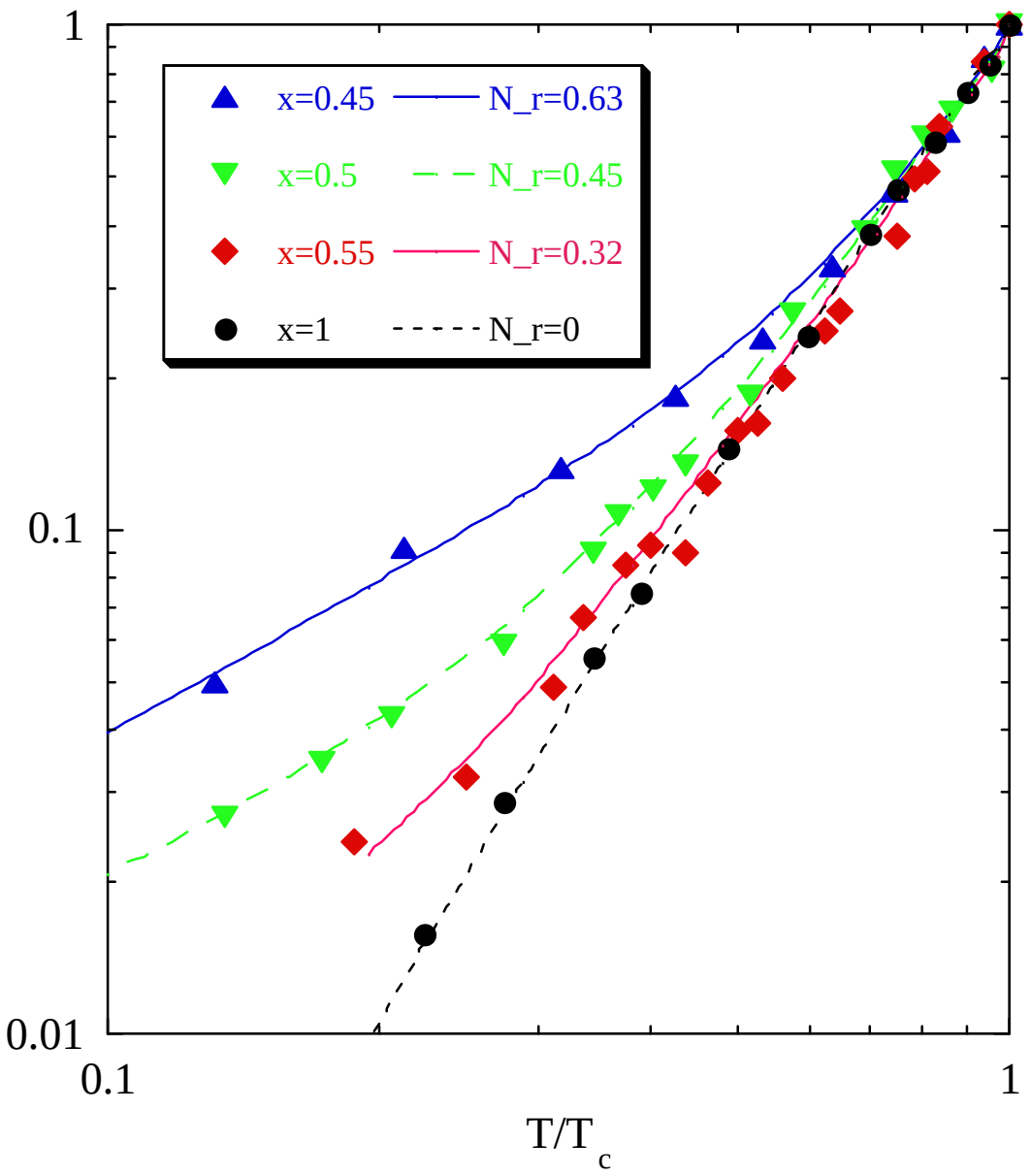
Incomplete gap due to AF order

Coexistence taking place in the *k*-space

Gapless state due to coexisting AF order?



Similar behavior in $CeRh_{1-x}Ir_xIn_5$



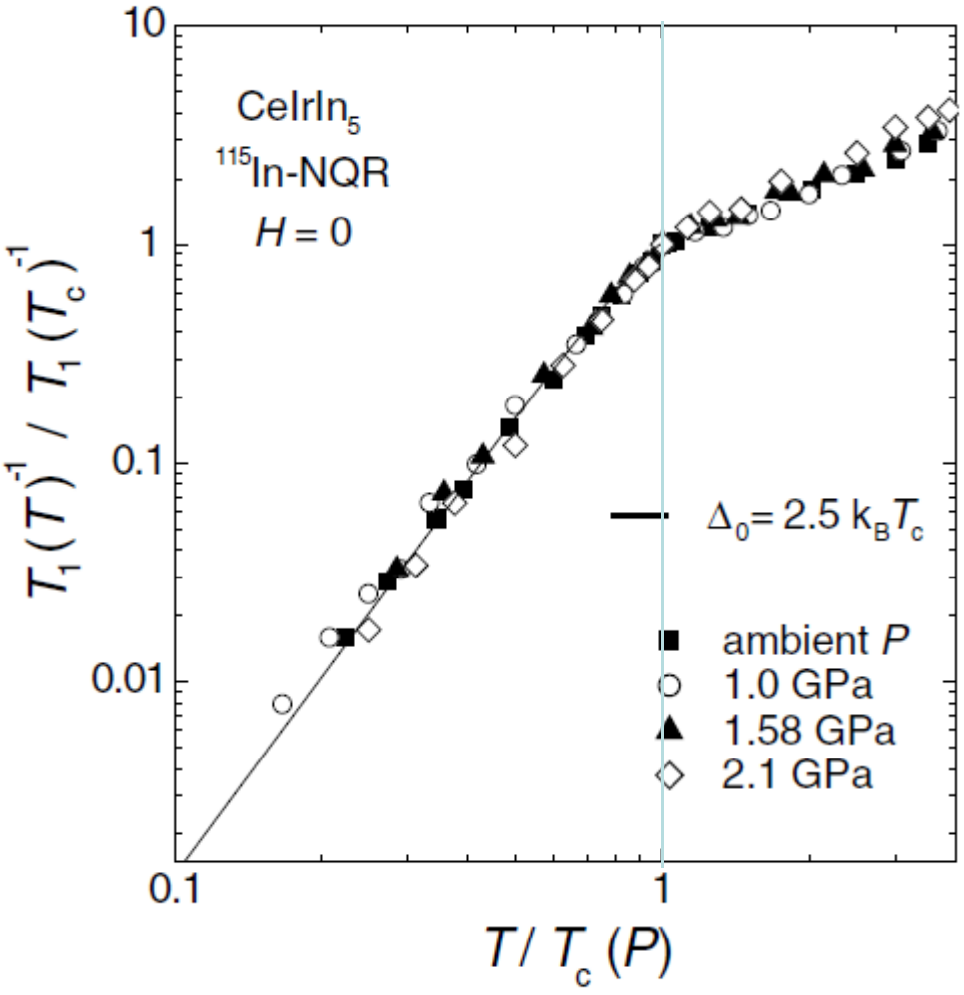
$N\_r=N_{res}/N_0$

N_r (x=0.45)>> N_r (x=0.55)

Cannot be attributed to disorder alone

Due to excitation associated with coexisting magnetism which is more developed at lower x

CeIrIn5 under pressure



PRL **94,** 037007 (2005)

Possible origin:

odd frequency superconducting state

Odd-frequency SC, for example *p*-wave spin singlet (*p*SS), has no gap in the quasiparticle spectrum everywhere on the Fermi surface due to its odd frequency.

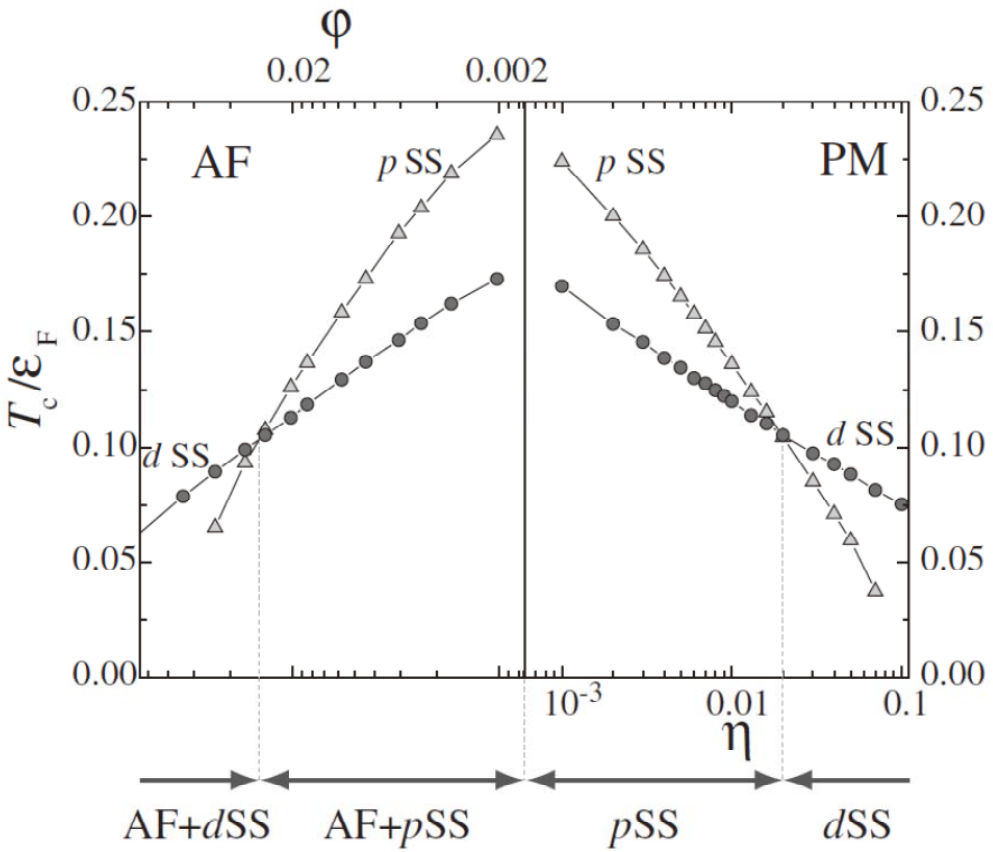
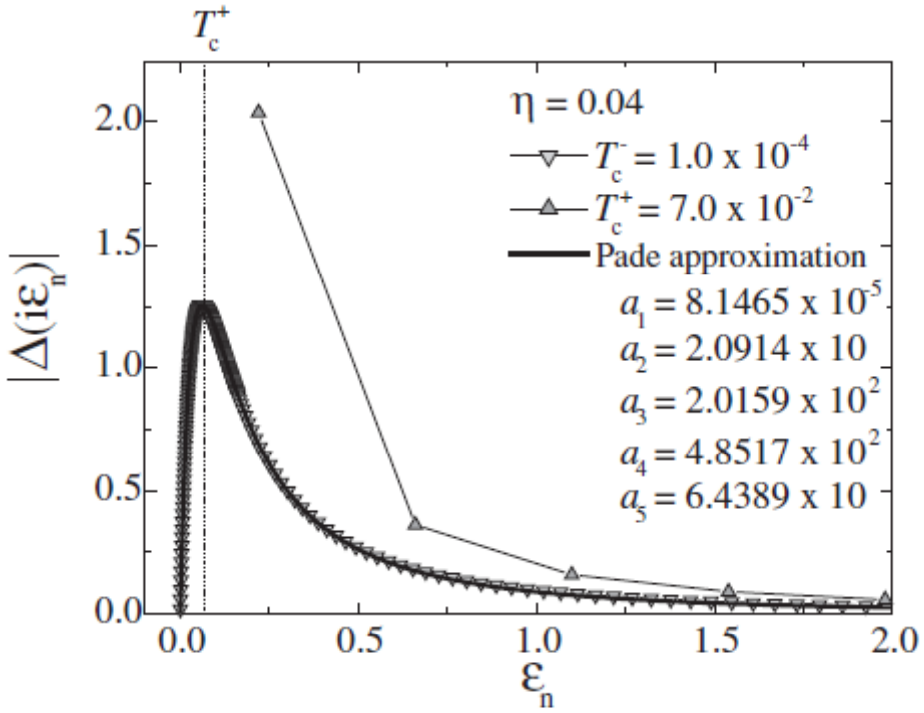


Fig. 13. Superconducting transition temperature near the QCP.

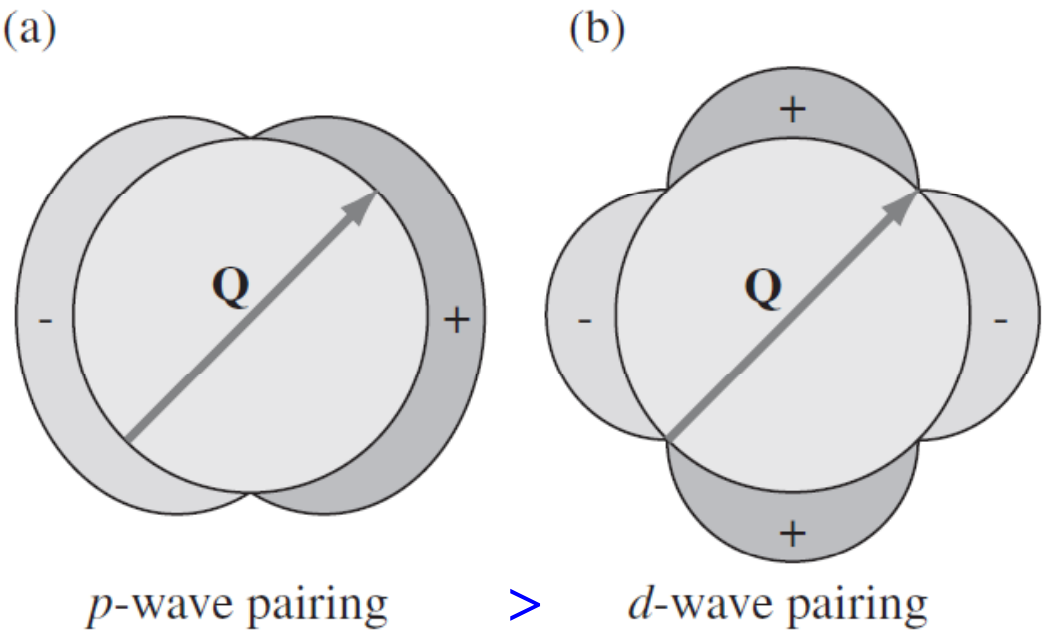
$CeRhIn_5$

Y. Fuseya, H. Kohno and K. Miyake, JPSJ 72, (2003) 2914

Gapless sc state due to odd frequency



Y. Fuseya, H. Kohno and K. Miyake, JPSJ 72, (2003) 2914



p-wave pairing > *d*-wave pairing

The dominant pair scattering process is weakened by the nodes for *d*-wave singlet, so *p*-wave singlet prevails

Y. Fuseya, H. Kohno and K. Miyake, JPSJ 72, (2003) 2914

Summary and outlook

1) In the superconducting state coexisting with AF order, a gapless state is observed.

2) Such gapless state is possibly due to odd-frequency superconducting state that prevails over even-frequency *d*-wave state due to the coexisting magnetism.

3) Continue measurements in the pure superconducting state using an Indenter-type pressure cell.

PHYSICAL REVIEW B 78, 064510 (2008)

^{123}Sb-NQR study of unconventional superconductivity in the filled skutterudite heavy-fermion compound $PrOs_4Sb_{12}$ under high pressure up to 3.82 GPa

S. Kawasaki,[1,*] K. Katayama,[1] H. Sugawara,[2] D. Kikuchi,[3] H. Sato,[3] and Guo-qing Zheng[1]