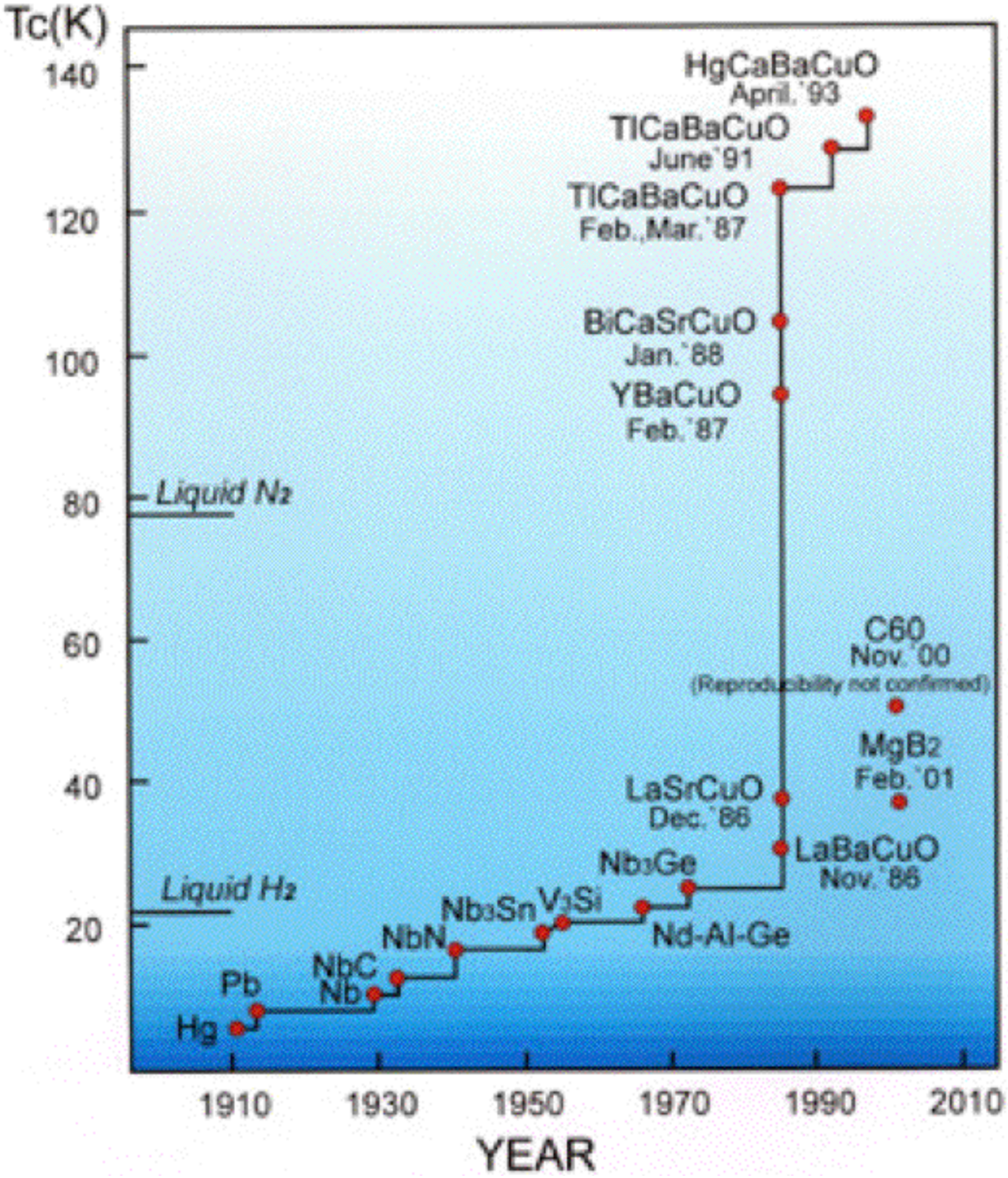
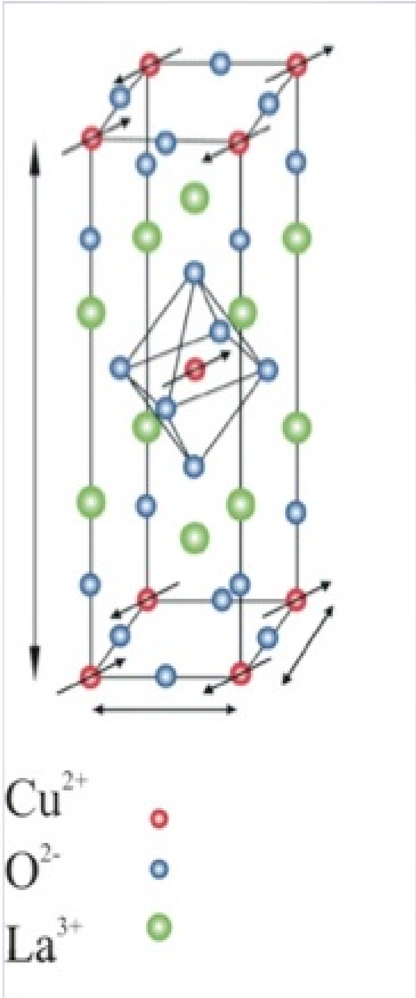
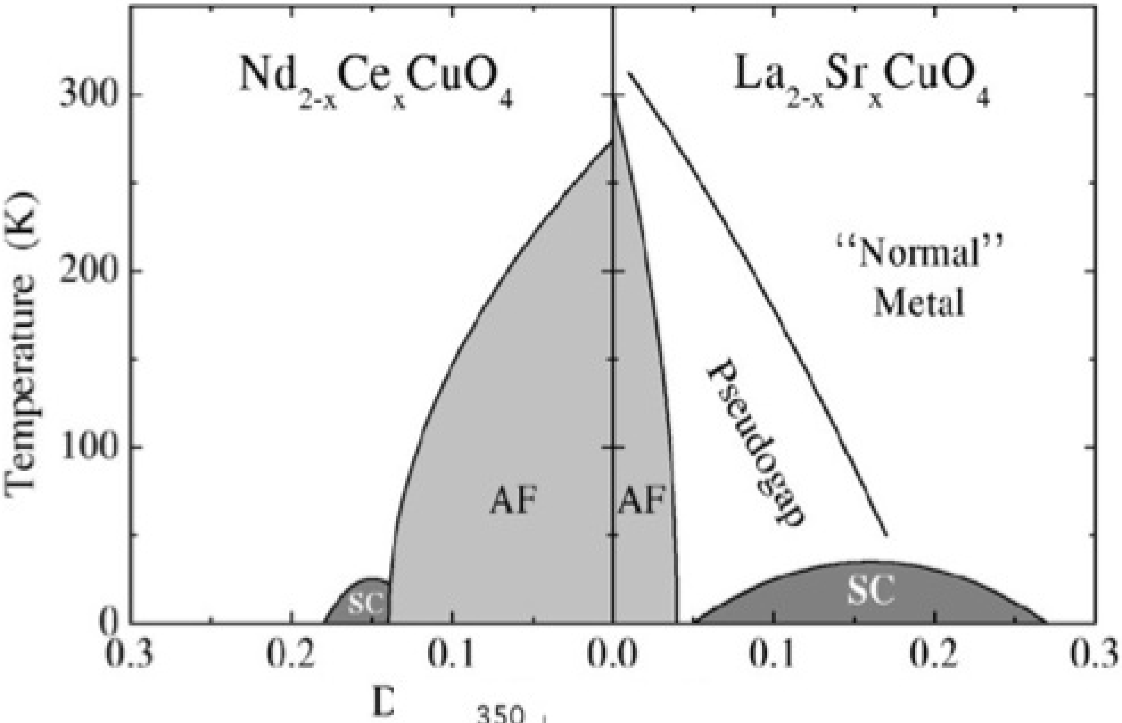
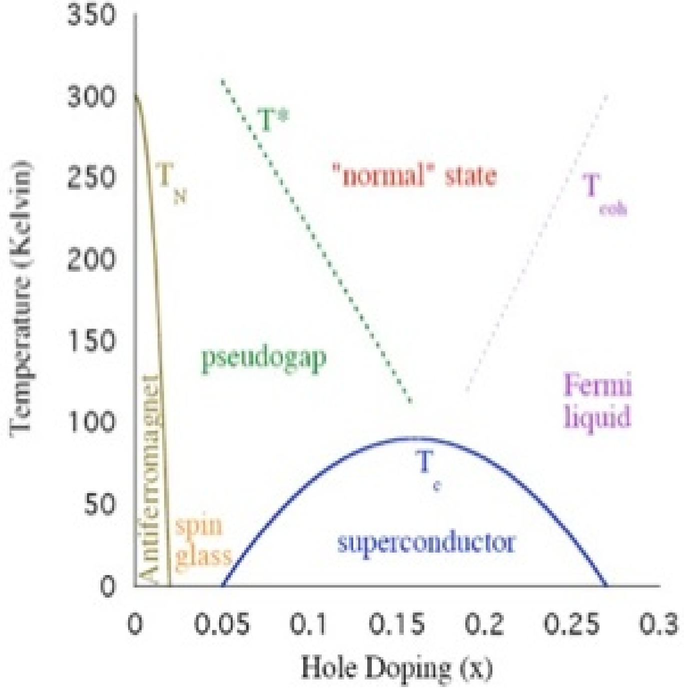
M. Norman, Argonne



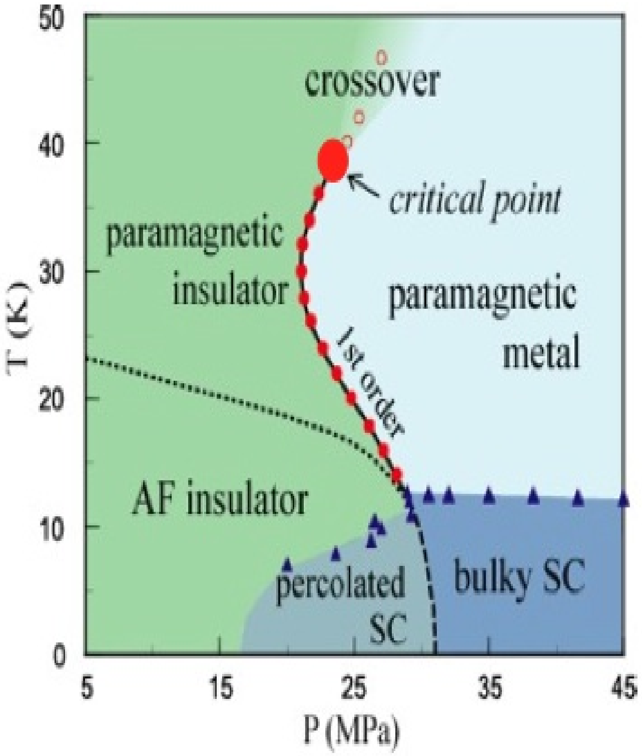






M. Randeria Boulder lectures 2014

Pressure tuned superconductivity in the organics



Pressure decreases U/t.

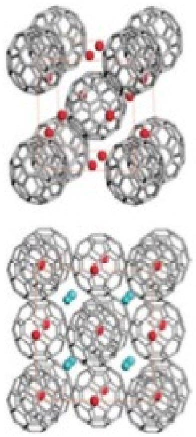
Mott transition is induced by tuning U/t at fixed density of one electron per site.

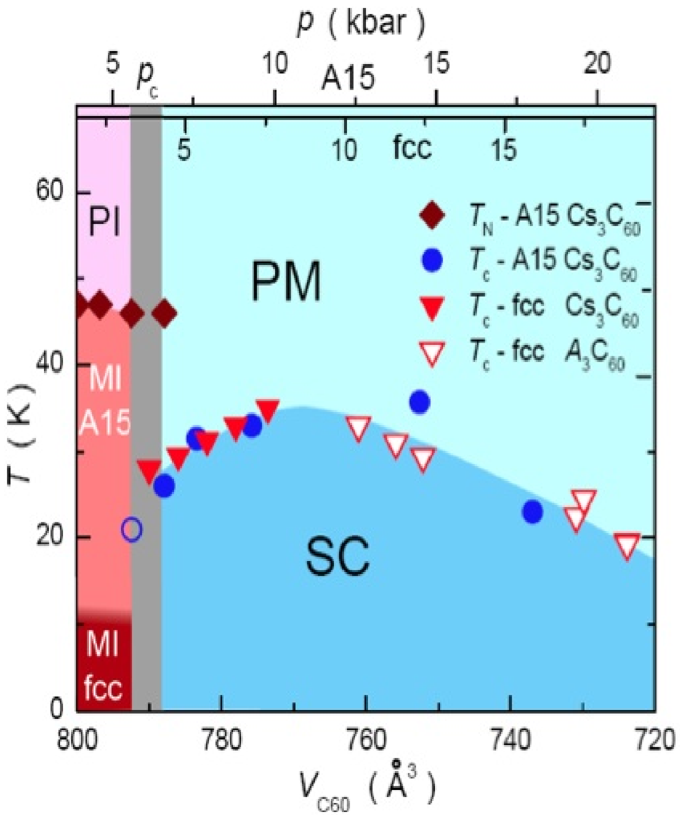
κ-Cu[N(CN)$_2$]Cl

t'/t = 0.75

Senthil, Boulder 2014

Pressure tuned SC in fcc Cs3C60





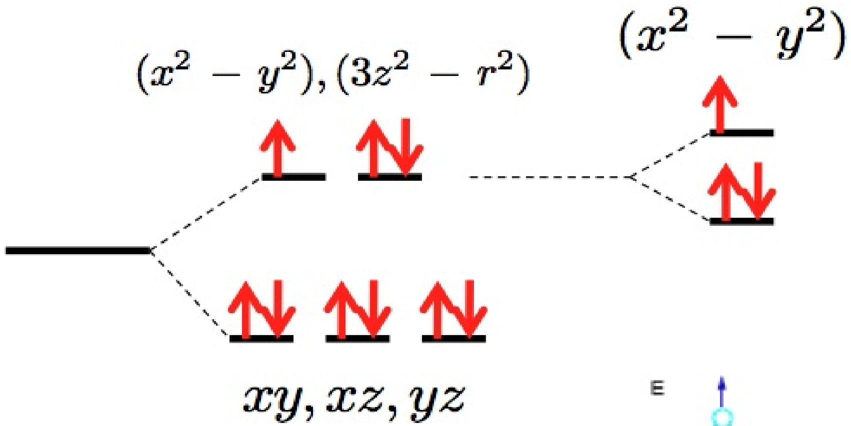
Ganin et al, Nature Materials, 2008, and Nature, 2010.

Ihara, Alloul, et al, PRL 2010.

La_2CuO_4

$2(+3) + Cu + 4(-2) = 0$

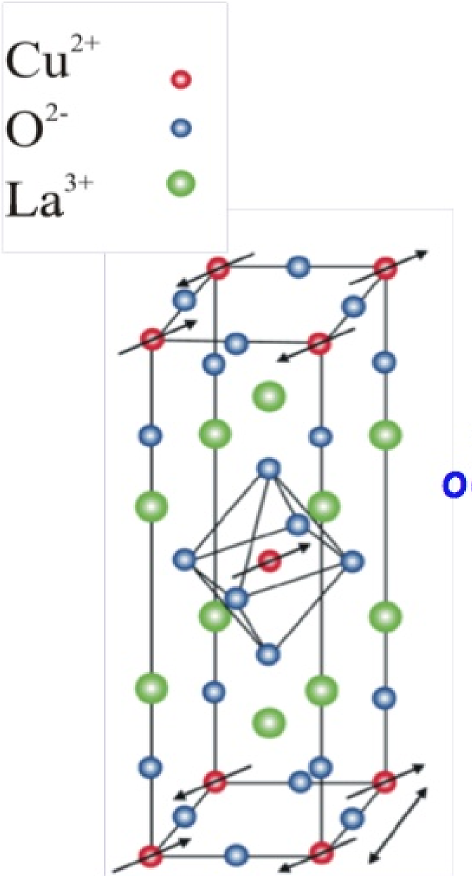
→ Cu 2+ $\Rightarrow 3d^9$



1 elect.
(or 1 hole)
per u.c.
= Spin 1/2

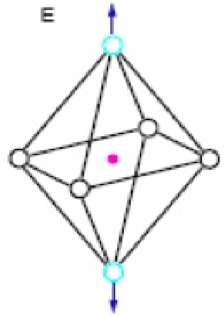
↓

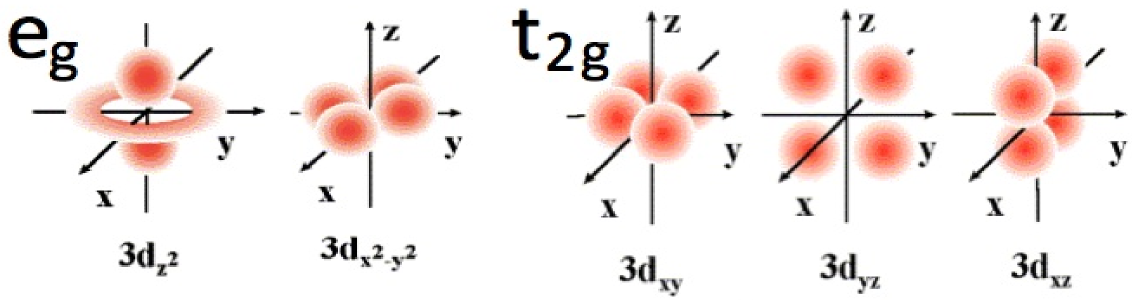
Hybridize
with O
pσ orbitals

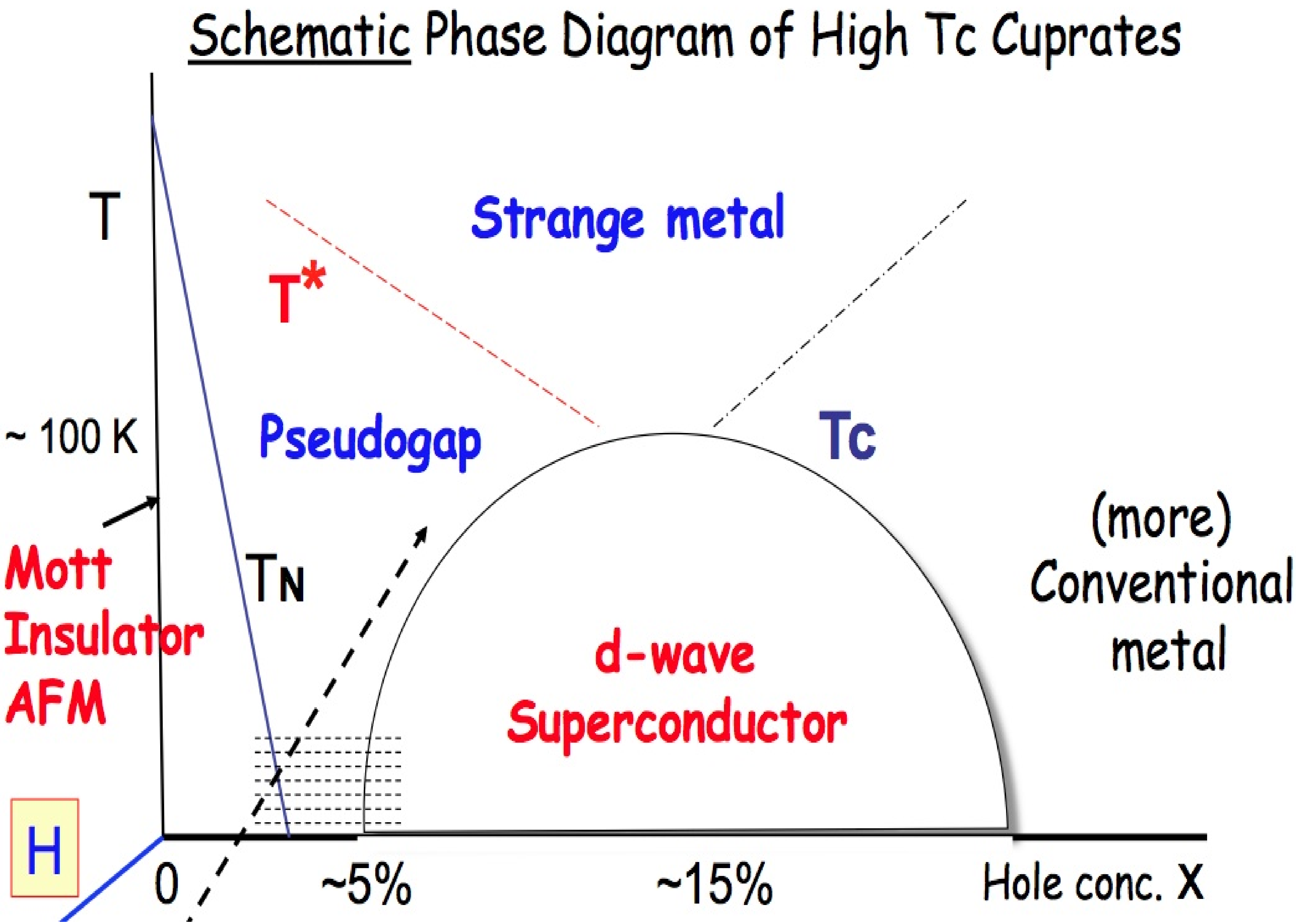


corner sharing octahedra

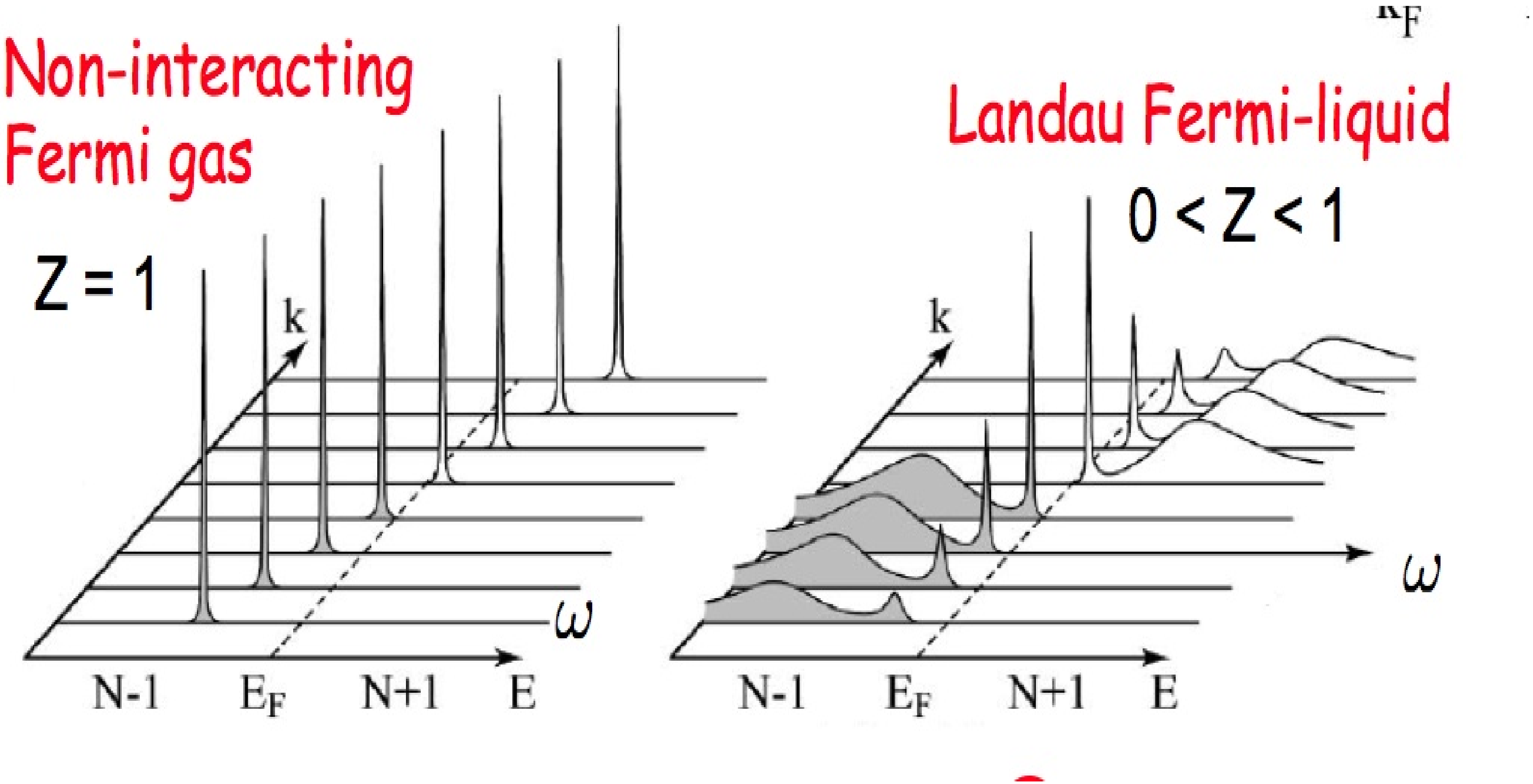
Octahedral/
Cubic crystal
field





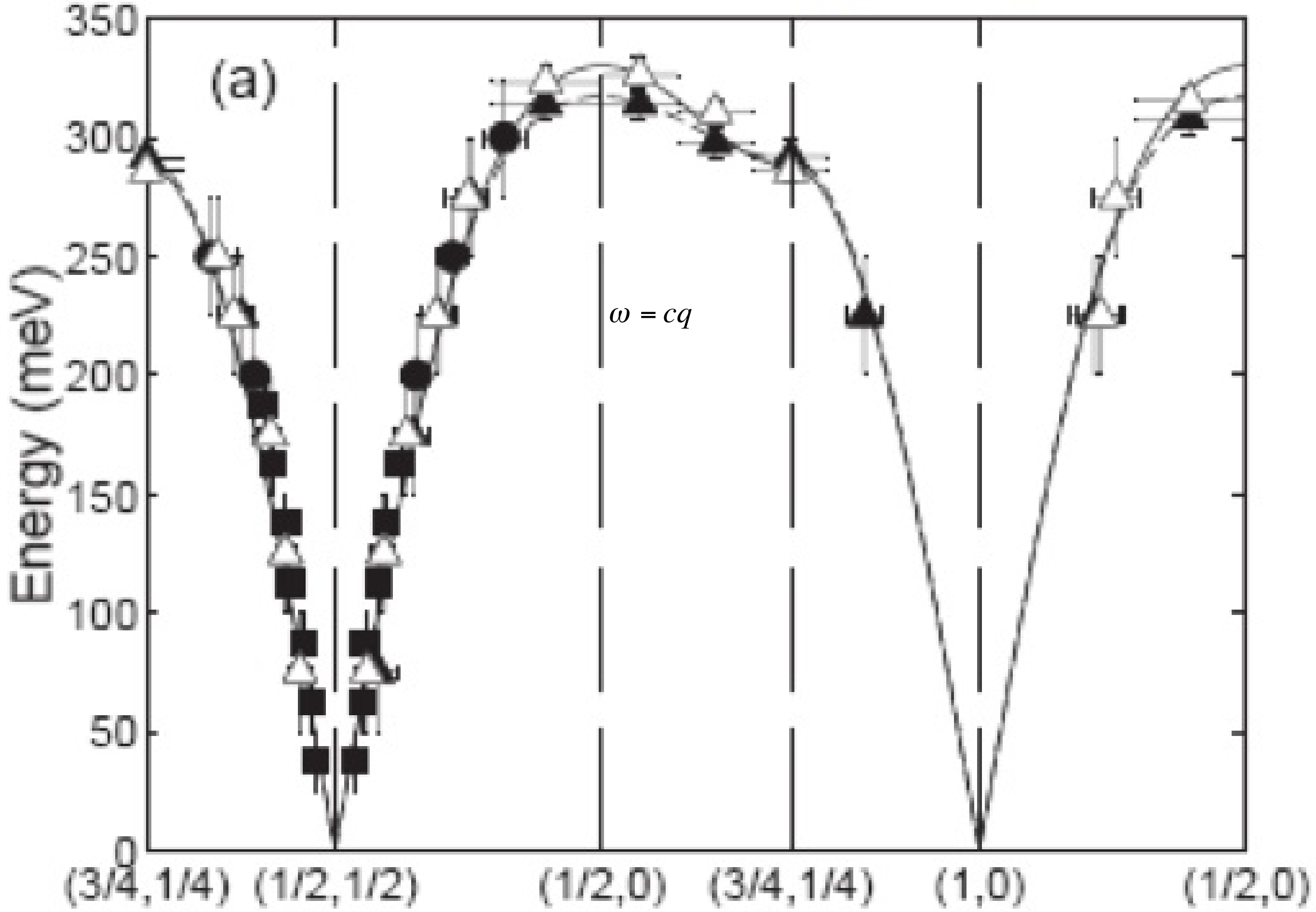


M. Randeria Boulder lectures 2014


Non-interacting
Fermi gas
Z = 1
k
ω
N-1
E_F
N+1
E
Landau Fermi-liquid
0 < Z < 1
k
ω
N-1
E_F
N+1
E

Neutron inelastic scattering: gapless magnetic excitations w=c q
in antiferromagnetic phase (Goldstone modes)

R. Coldea et al, PRL (2001)



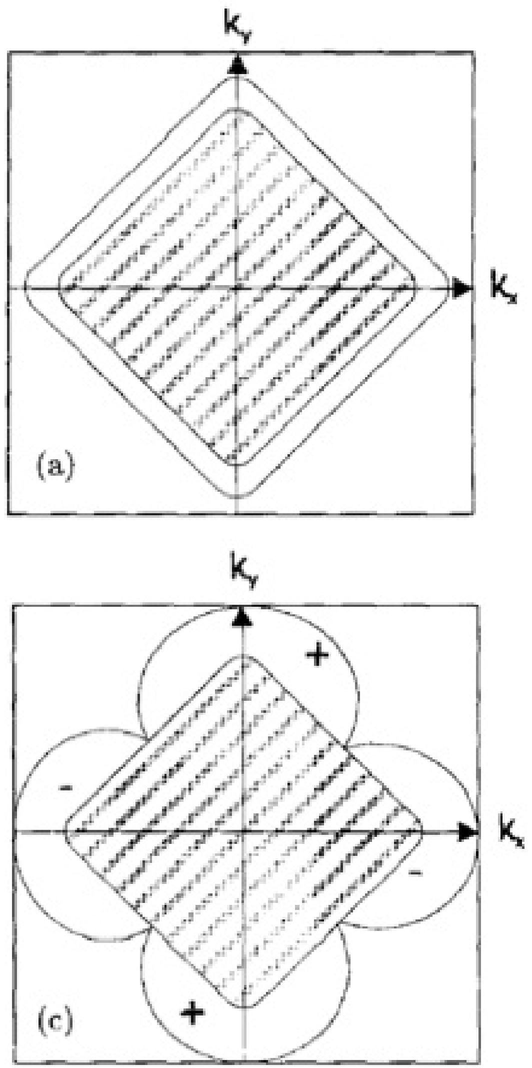
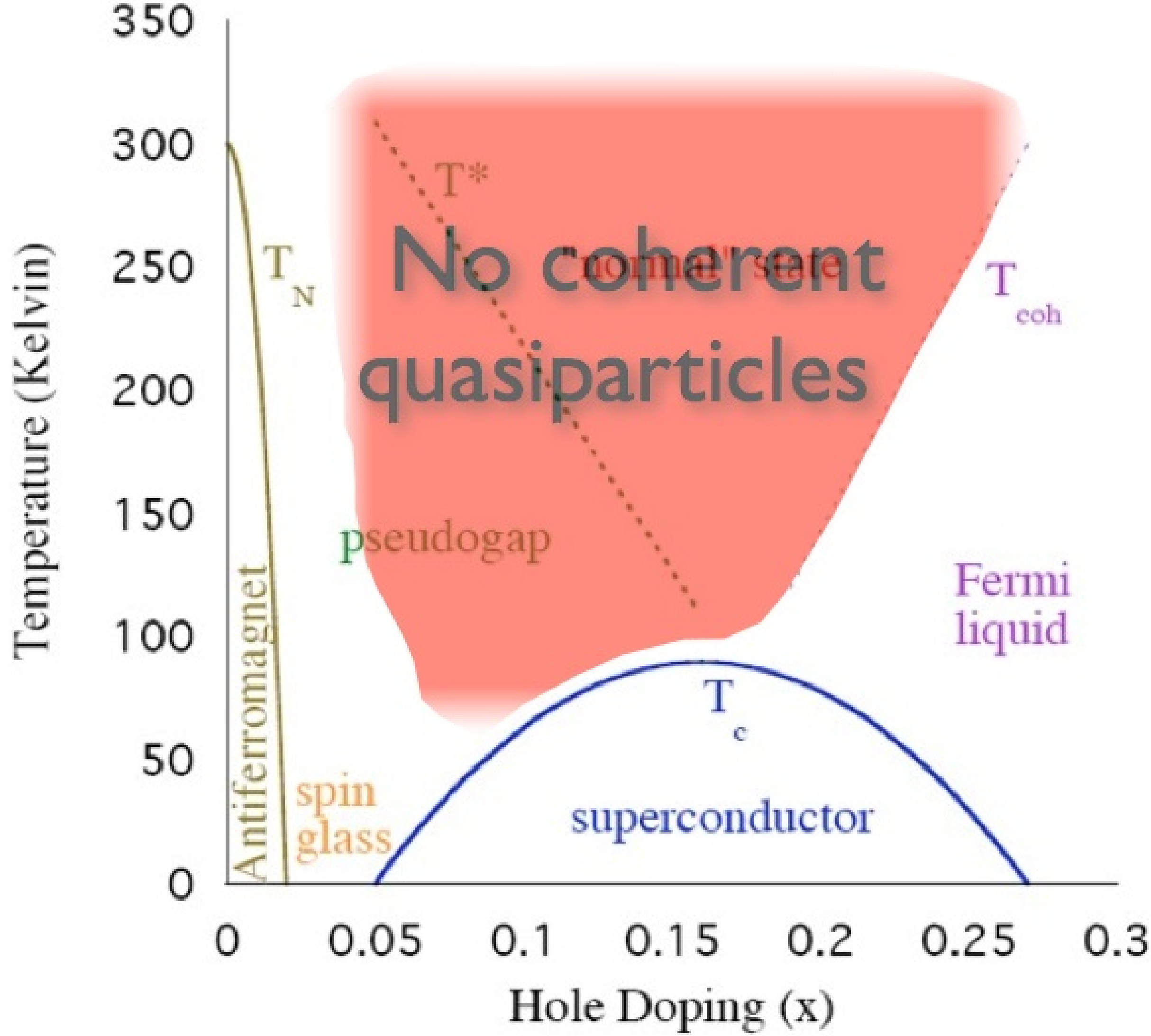


Fig. 5. Schematic plots of (a) an extended s-wave gap, (b) an anisotropic s-wave gap, (c) a $d_{x^2-y^2}$ gap, and (d) an extended s^*-wave gap for a Fermi surface of a system with a second near-neighbor hopping t'. The boundary of the shaded region is the normal state Fermi surface and the size of the gap Δ_k at the momentum k on the Fermi surface is indicated by the solid curve surrounding the Fermi surface. The gap in (a) and (b) has the same phase for all k, while the $d_{x^2-y^2}$ gap shown in (c) and the extended s^*-wave gap shown for the t' altered Fermi surface in (d) change sign as indicated.

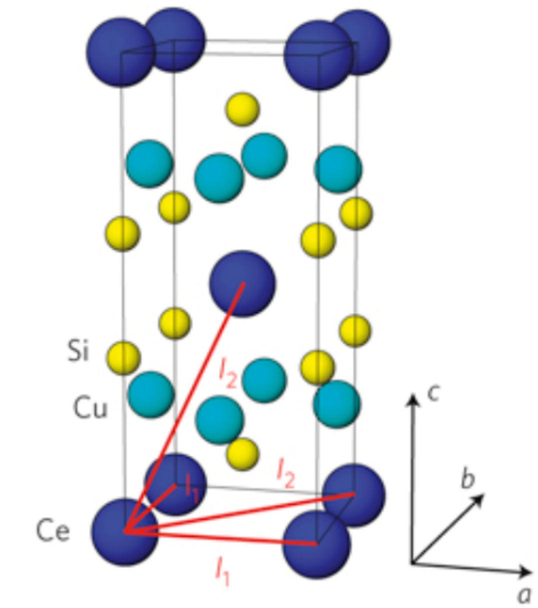
D. Scalapino, Phys. Rep

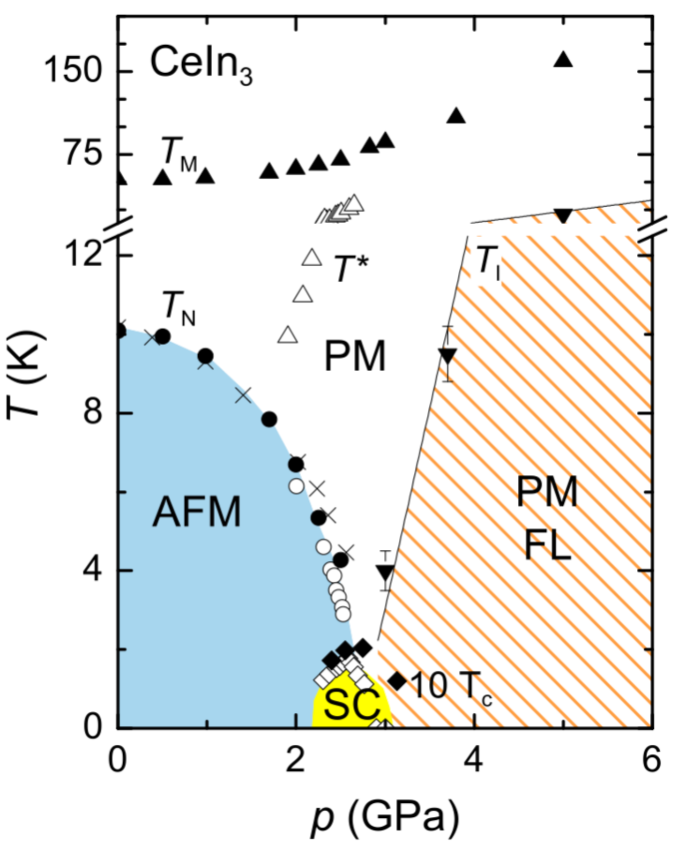


Senthil, Boulder 2014

Superconductivity in heavy fermion compounds (HFC)

- Lanthanide (eg. Ce) or actinide (eg. U) based compounds with **huge effective masses** as big as 1000 times the bare electron mass.
- Strongly correlated *f*-electrons behave like **local magnetic moments** interacting with weakly correlated *s* and *p* conduction electrons.





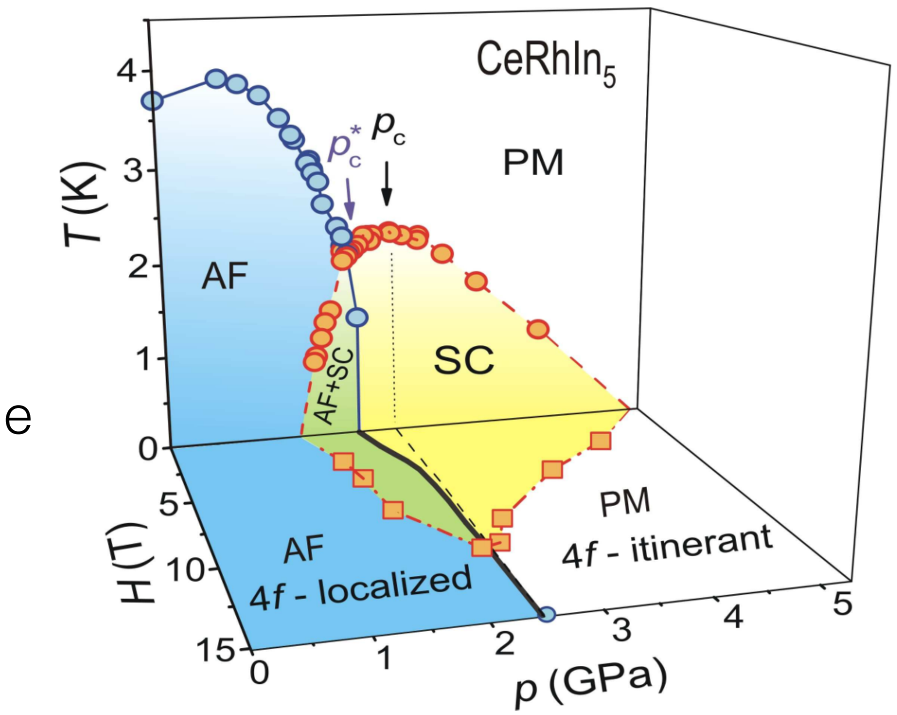
- A rich and complex phase diagram including (non-)Fermi liquid, itinerant and local magnetism (AFM and F), …, and superconductivity (SC).
- The discovery of **superconductivity in HFC was first dismissed** because of the dense presence of Cooper pair breaking magnetic centres.
- The proximity of SC with magnetism, in particular ferromagnetism, hints towards a **magnetic mechanism for pairing**.

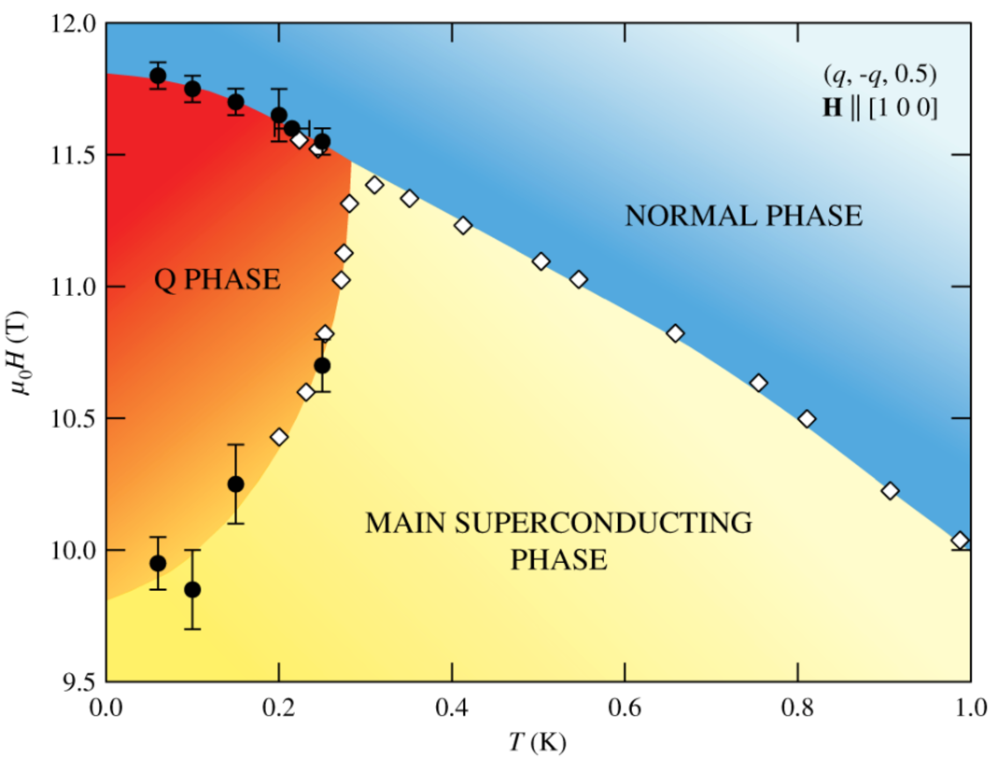
- HFC are the first exemple of **high-T_c superconductivity** since $T_c/T_F \sim 0.2 - 0.05$ although $T_c \sim 2$ K only. Compare with $T_c/T_F \sim 10^{-2}$ for the Cuprates and $T_c/T_F \sim 10^{-3}$ for conventional superconductors.
- The exact symmetry of the Cooper pairs in HFC has not yet been unambiguously determined but spin singlet and triplet pairings are realised.

The intriguing case of the 115 family

- The family of HFC $CeMIn_5$ (M = Rh, Ir, Co) exhibits **unconventional gap function with nodal structure** (Eg.: power-law T-dependence of the specific heat instead of the standard exponential dependence)

  - Superconductivity in $CeRhIn_5$ appears only under an applied magnetic field and/or pressure.
  - **Re-entrance of AFM inside the SC phase** with increasing magnetic field for $p < p_c$.
  - Small specific heat jump at T_c for $p < p_c^*$ and large one for $p > p_c^*$.





- Superconductivity in $CeCoIn_5$ is present at ambient pressure and is **Pauli-limited.**
- Existence of **a modulated phase** in the high field - low T region of the (H-T) phase diagram:
  - FFLO phase ?
  - Co-existing field-induced SDW magnetic phase ?

The precise nature of the pairing glue is still elusive !

History

After cuprates: Other perovskite structure superconducting?

Discovered 1994 by Maeno et al. in Japan

Transition first seen by a first-year graduate student

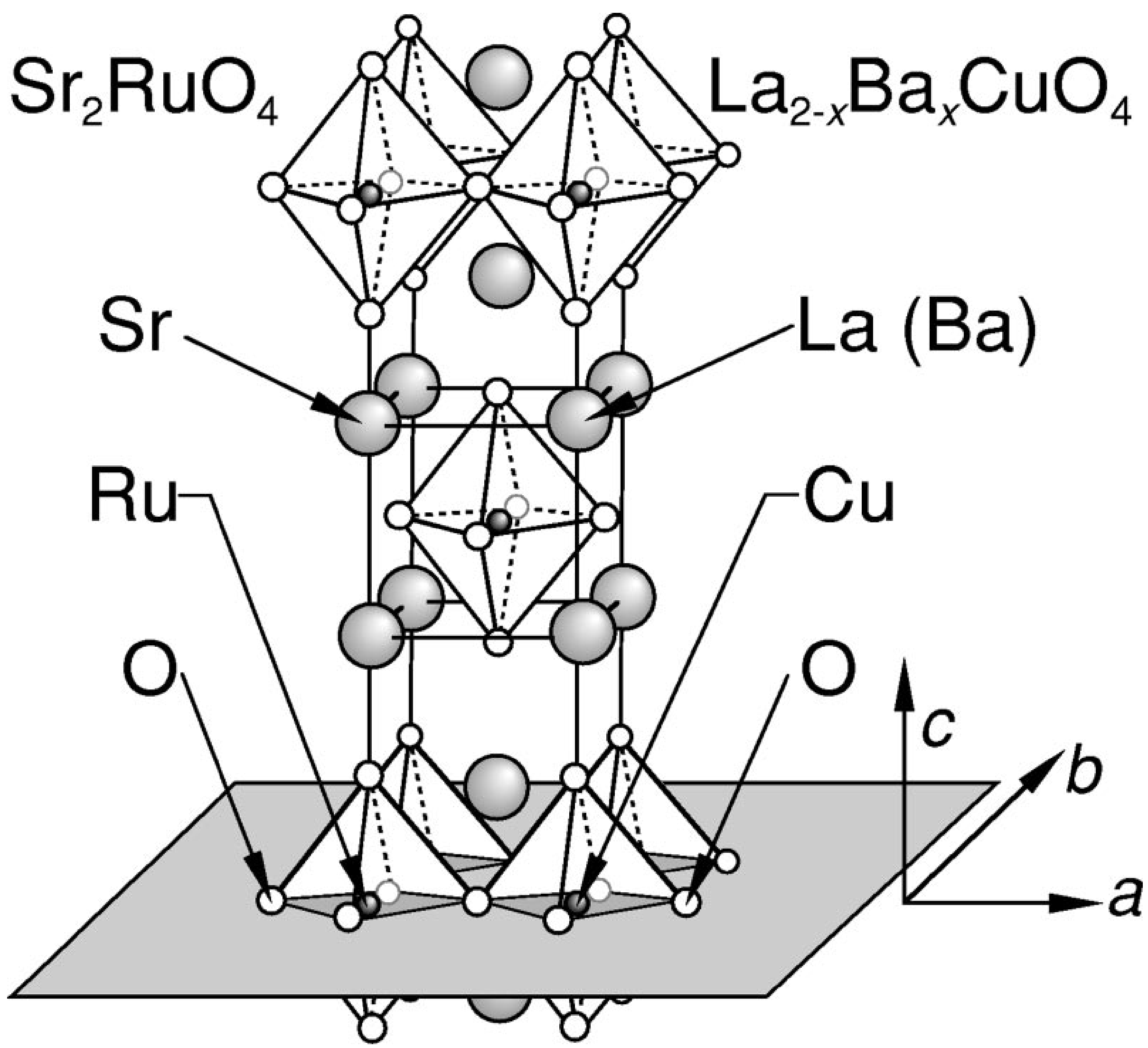
De Haas van Alphen and bulk magnetic and transport measurements show Fermi liquid state with similarity of Landau parameters to ^3He

Strongly correlated quasi 2D Fermi liquid

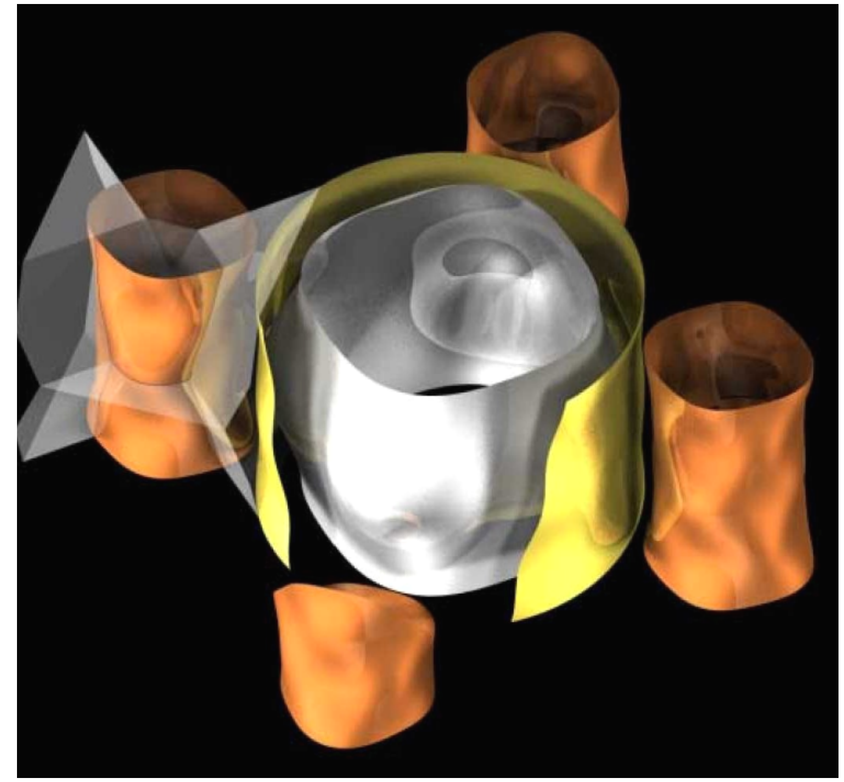
T_c=1.5 K

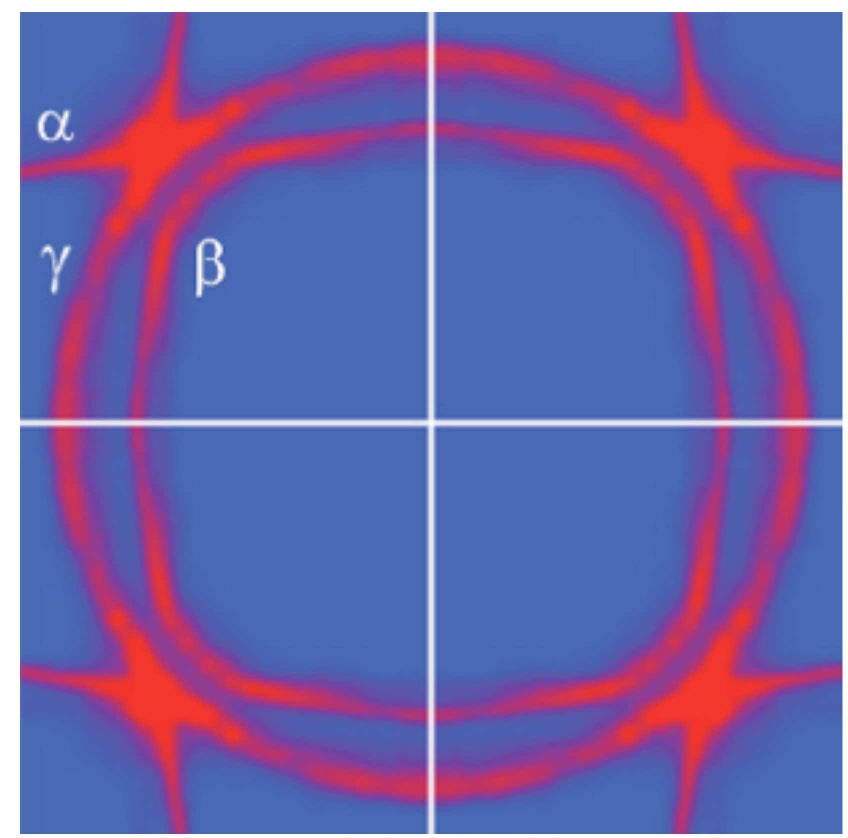
Spin triplet pairing suggested by Rice and Sigrist in 1995, and independently by Baskaran in 1996

Structure and Fermi surface



cover of Physics Today





ARPES

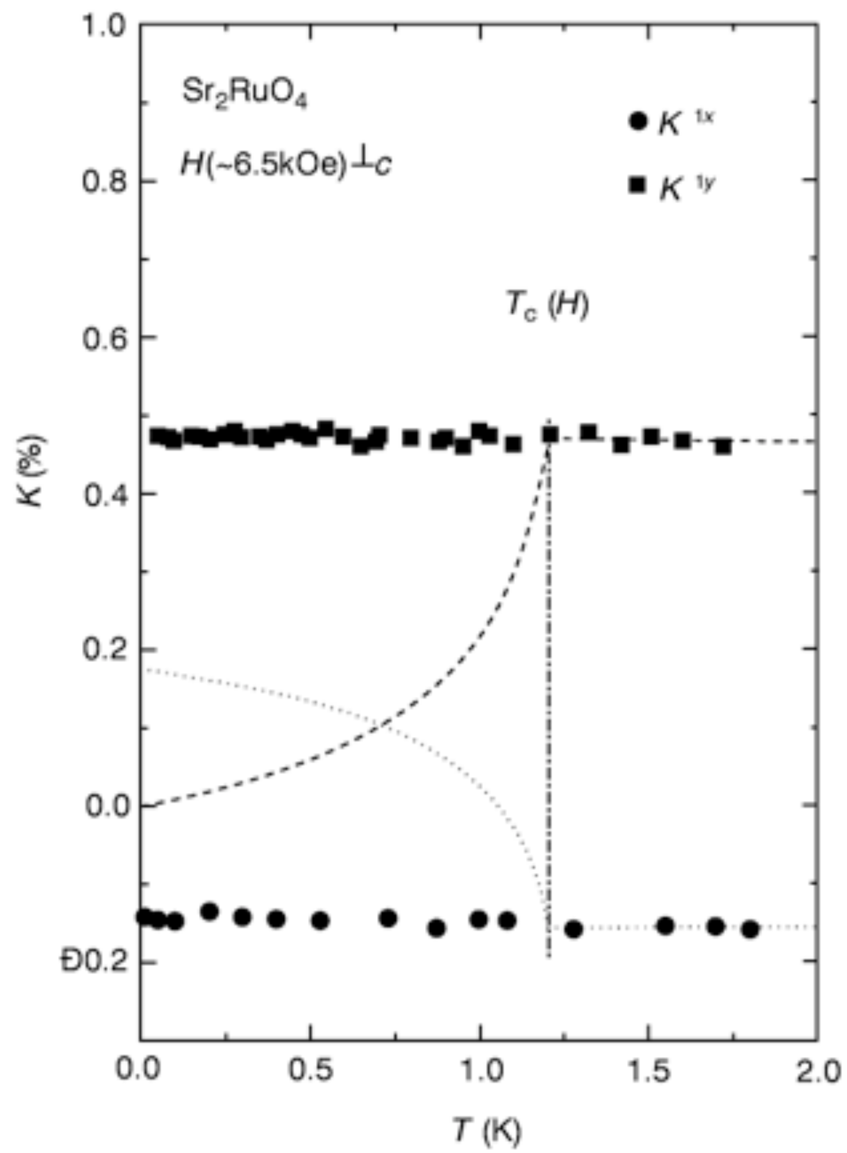
from Kallin review

Spin triplet

$(S,S_z)=(1,0)$ with in-plane equal-spin pairing

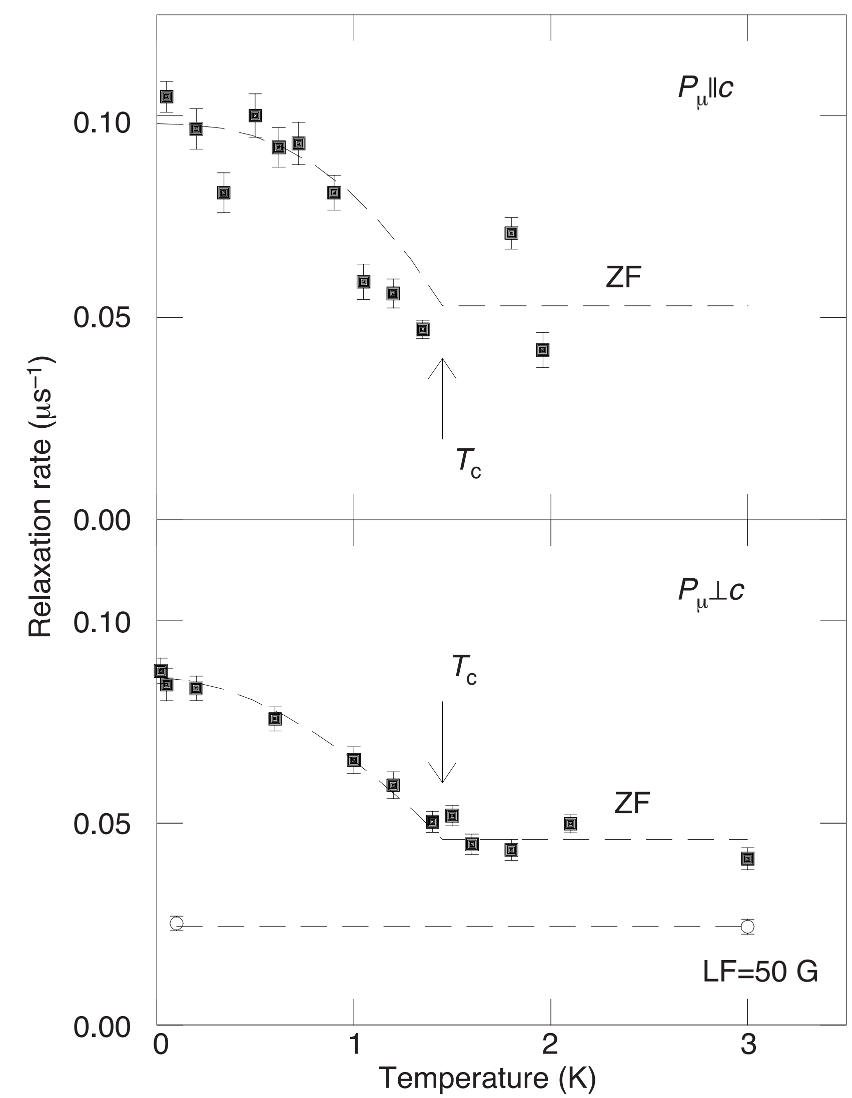
$L_z=\pm 1$, chiral degeneracy 2

chiral p-wave: $\vec{d}(\vec{k}) = \Delta\hat{z}(k_x \pm ik_y)$? controversy...



Knight shift

from Ishida et al., Nature 396, 658-660 (1998)



μSR

from Luke et al., Nature 394, 558-561 (1998)

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The superconductivity of Sr2RuO4 and the physics of spin-triplet pairing
by A. Mackenzie and Y. Maeno, Rev. Mod. Phys. 75, 657 (2003)

Evaluation of Spin-Triplet Superconductivity in Sr2RuO4
by Y. Maeno et al., J. Phys. Soc. Jpn. 81, 011009 (2012)

Chiral p-wave order in Sr2RuO4
by C. Kallin, Rep. Prog. Phys. 75 042501(2012)

very simple overview:

The intriguing Superconductivity of Strontium Ruthenate
by Y. Maeno, T.M. Rice and M. Sigrist, Physics Today, 54:42–47 (2001)