Highlights, Aspen, Albuquerque

A.-M. Tremblay

http://aspen2016superconductivity.blogspot.ca/

Group meeting, 6 September 2016

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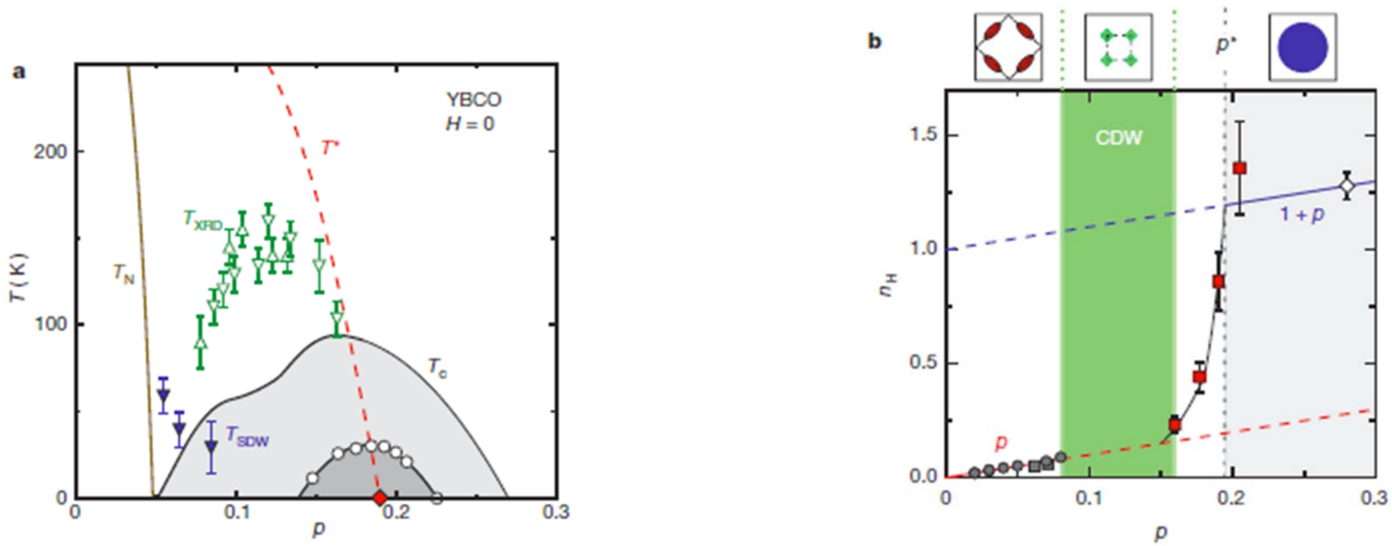
Cuprates: pseudogap

Cuprates : hole-doped pseudogap



doi:10.1038/nature16983

Change of carrier density at the pseudogap critical point of a cuprate superconductor

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Do not forget magnetic field

ARTICLE

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OPEN

Magnetic field controlled charge density wave coupling in underdoped $YBa_2Cu_3O_{6+x}$

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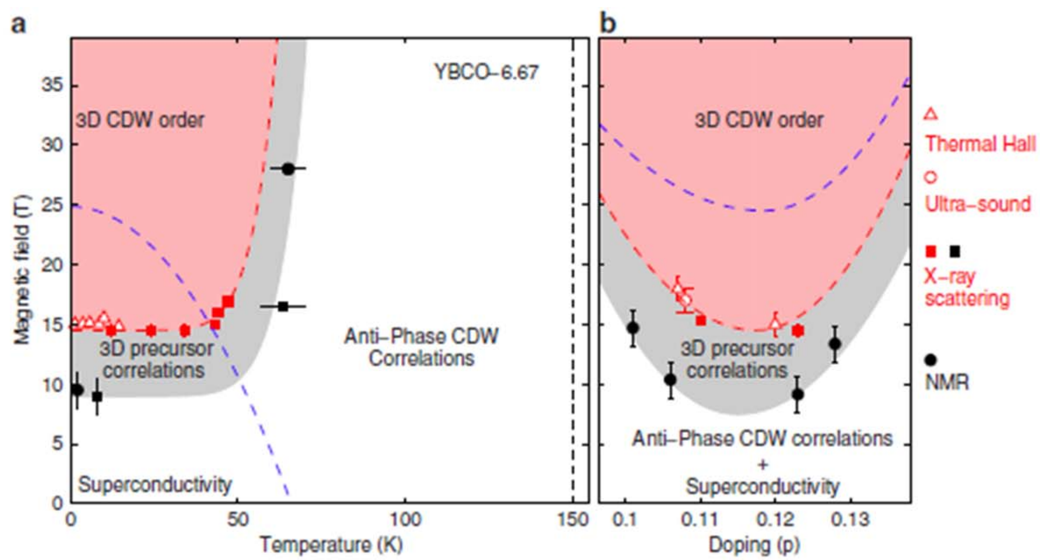

Figure 5 | Phase diagram of $YBa_2Cu_3O_{6+x}$. The pink shaded areas represent the regions where short-range 3D CDW order exists. Grey bands indicate the regions where growing 3D CDW precursor correlations are observed. (**a**) Temperature-magnetic field phase diagram. (**b**) Doping-magnetic field phase diagram. Solid red square points indicate the onset of a 3D CDW order with $\mathbf{q}_b = (0, \delta_b, 0)$ determined from the variation of the $\xi_{c, \ell=1}$ correlation length and the intensity of the 3D peak (Fig. 4). Triangles are the Fermi surface reconstruction onset determined from thermal Hall coefficient[17]. Solid black squares indicate the onset of growing in-plane CDW correlation lengths (3D precursor correlations) determined from the variation of $\xi_{b, \ell=1}$ (Fig. 4d,e). Dashed blue lines in (**a**,**b**) indicate B_{c2} line[35]. Solid black circles in (**a**,**b**) are derived from NMR[11,15]. The vertical black dashed line is the onset of weakly anti-phase CDW correlations (refs 4, 5 and 8). Red circular and triangular points originate from ultrasound[16] and thermal Hall effect[17] experiments, whereas the red squares are the field onset of $\mathbf{q}_b = (0, \delta_b, 0)$ found by X-ray diffraction.

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Pseudogap and broken symmetry

- Varma:
  - Loop currents
  - Ashkin-Teller, so no TD signature
- Based on analysis of recent ARPES experiments by Zhang Xingjiang

Fluctuation-induced pseudogap

- Catherine Pépin
  - CDW and superconductivity fluctuating together.
- AFM fluctuations in e-doped

$$\xi_{th} \sim \xi_{AFM}$$

SUPERCONDUCTIVITY

Doping-dependent charge order correlations in electron-doped cuprates

10.1126/sciadv.1600782

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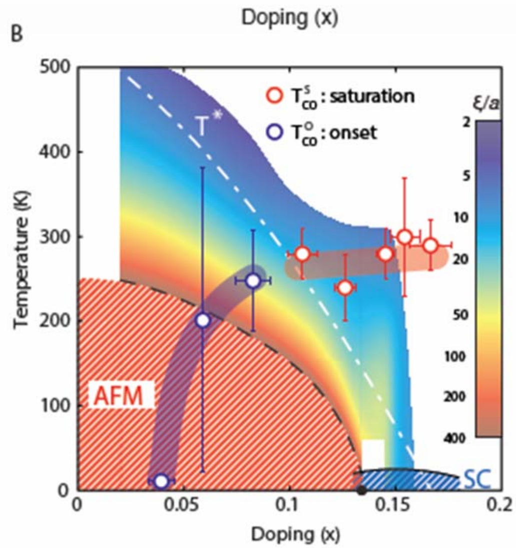

FIG. 3. **Phase diagram of CO in NCCO.** (**A**) Doping dependence of $Q_{CO}(x)$ compared with the separation between the segments of the Fermi surface near $(\pi, 0)$ as determined from ARPES (white arrow in the inset). The inset shows a representative ARPES Fermi surface NCCO for $x = 0.15$ (left) and a schematic of the AFM-folded Fermi surface (right), with electron (blue) and hole (red) pockets. (**B**) Phase diagram of NCCO adapted from [33], including the antiferromagnetism (AFM) and superconductivity (SC) region, the pseudogap temperature (T^*), and the instantaneous AFM correlation length (ξ) (normalized to the tetragonal lattice constant a) determined via inelastic neutron scattering. Superimposed red and blue circles represent T_{CO}^{O}, and T_{CO}^{S}, respectively. Thick semi-transparent blue and red lines are guides to the eye. In (A-B) the horizontal error bars represent the uncertainty in the experimental determination of doping level [29]. The vertical error bars in (B) indicate the uncertainty in locating the temperature where T_{CO}^{O}, and T_{CO}^{S} deviate from their respective high-temperature behaviors [29].

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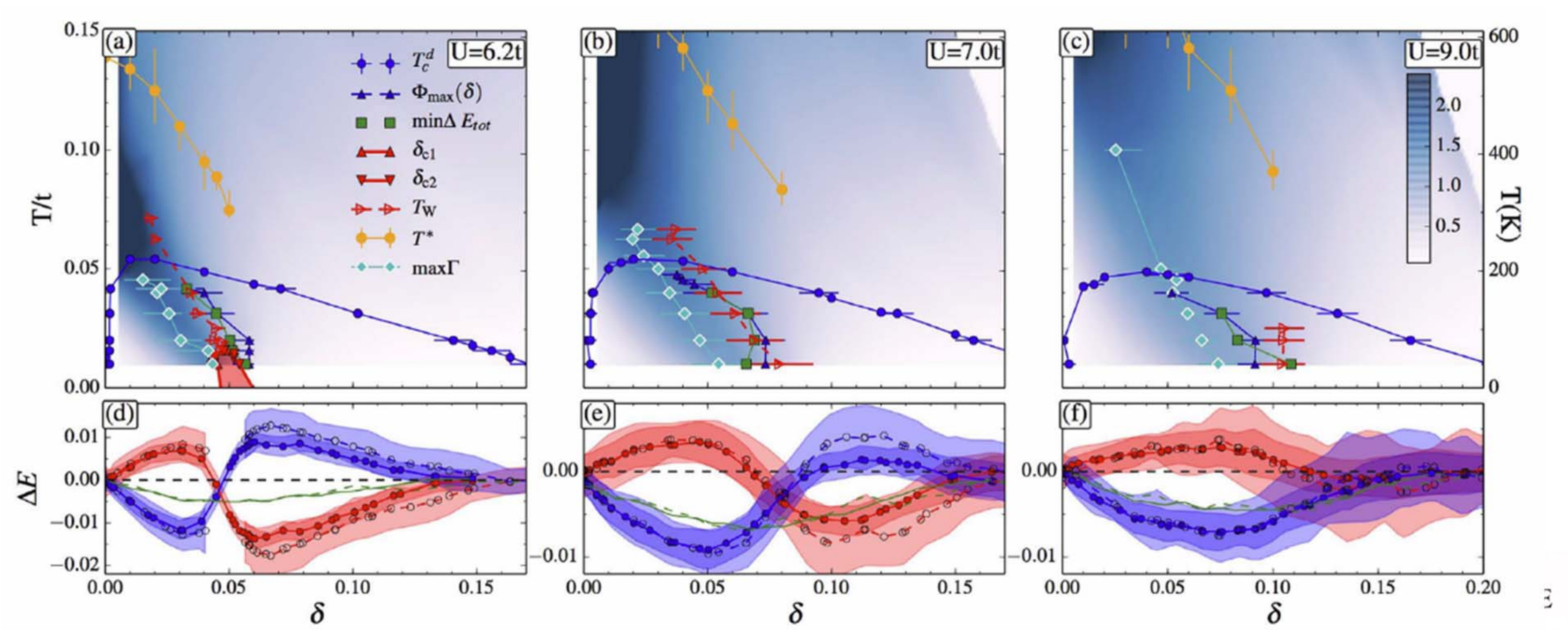
Mott + short-range AFM

- Yang Zhang Rice



Fratino et al.
Sci. Rep. **6**, 22715

Origins of unconventional superconductivity

Quantum critical point and superconductivity

nature physics

ARTICLES

PUBLISHED ONLINE: 30 MARCH 2014 | DOI: 10.1038/NPHYS2924

Ferroelectric quantum criticality

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Ferroelectric $SrTiO_3$

- QCP under pressure
- SC appears:
  - e-ph
  - Small E_F large ω_D

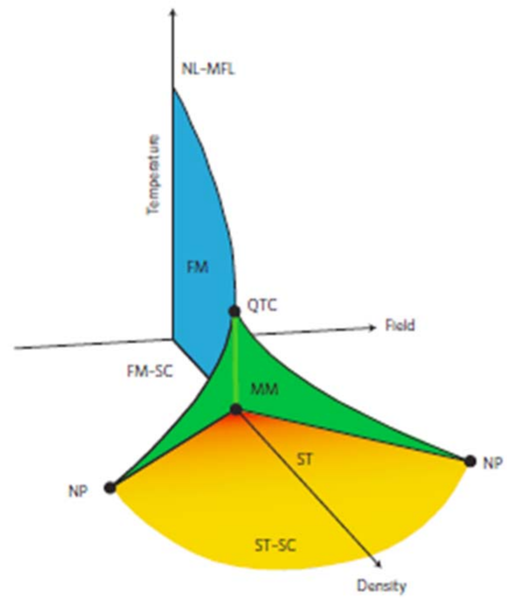
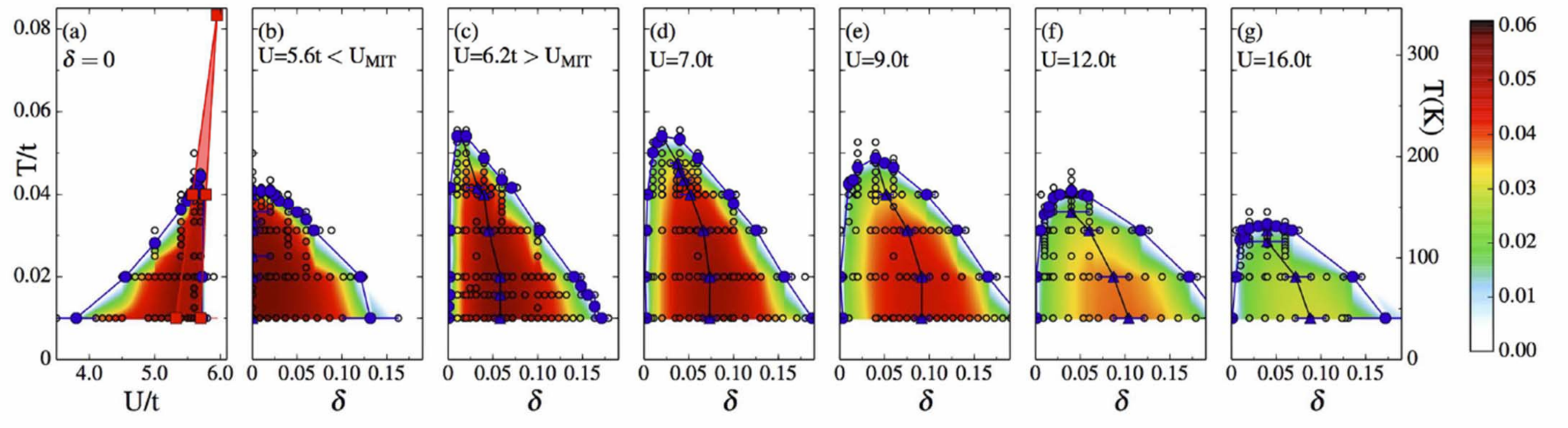


Figure 1 | Temperature–magnetic field–density phase diagram on the border of metallic ferromagnetism. Qualitative form of the phase diagram predicted in a quantum Ginzburg–Landau–Wilson model with an attractive mode–mode coupling term (attractive ϕ^4 term) in the low-temperature limit. With increasing density, or applied pressure, a second-order ferromagnetic transition line bifurcates at a tricritical point into two sheets of first-order metamagnetic transitions. Selected examples of phenomena observed on the border of metallic ferromagnetism (FM) and metamagnetism (MM) are indicated (ref. 6): NL-MFL — non-local marginal Fermi liquid in $ZrZn_2$; FM-SC — ferromagnetism and superconductivity in UGe_2; QTC — quantum tri-criticality in Ni_3Ga; ST — spin texture (skyrmions) in MnSi; ST-SC — spin-triplet superconductivity on the border of ferromagnetism in M_2RuO_4 (M stands for Sr or Ca) and NP — electron nematic phase in $Sr_3Ru_2O_7$.

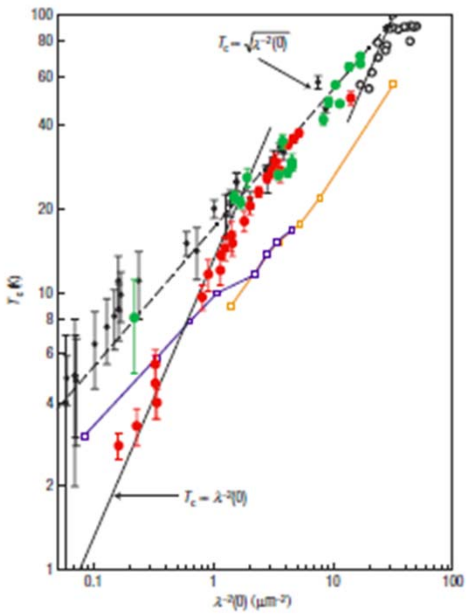
Superconductivity near QCP: Pressure, B field

- Bechgaard salts (Bourbonnais-Jerome)
- many pnictides (not FeSe)
  - Reza vs controversies
- heavy fermions ($CePdSi_2$, $CeCu_2Si_2$)
- MnP
- e-doped cuprates
- H_3S ?

Mott + short-range *J*



Fratino et al.
Sci. Rep. **6**, 22715



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Rice, why so few high-temperature superconductors (M. Rice)?

Cuprates (d^9) vs. Vanadates (d^1) or Nickelates(d^8)

Cuprates described by a ' simple' model – single band Hubbard model on a
2D square lattice

Cuprates are ***highly quantum*** - only a single relevant orbital
Cu^{2+} & Cu^{3+} have same local symmetry no Jahn-Teller

Spins S=1/2 and highly symmetric 2D lattice -> Favors Quantum Domination ?

Contrast with

Vanadates-- d^{1-} oxides (VO_2 - singlet dimer chain 1D lattices)
=> complex structures & site differentiation with V^{4+} & V^{3+} sites when doped

Nickelates - [Jahn-Teller polarons when doped S=1 Ni^{2+} -> S=1/2 Ni^{3+}]
causes doped holes to be self trapped small polarons .

Is strong el. – lattice coupling with strong local distortions the reason why there so few transition metal compounds that superconduct ? and why SC in TMO is rare when compared to Heavy Fermions and Organics ?

Varma

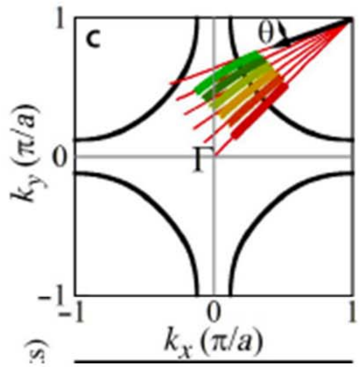
RESEARCH ARTICLE

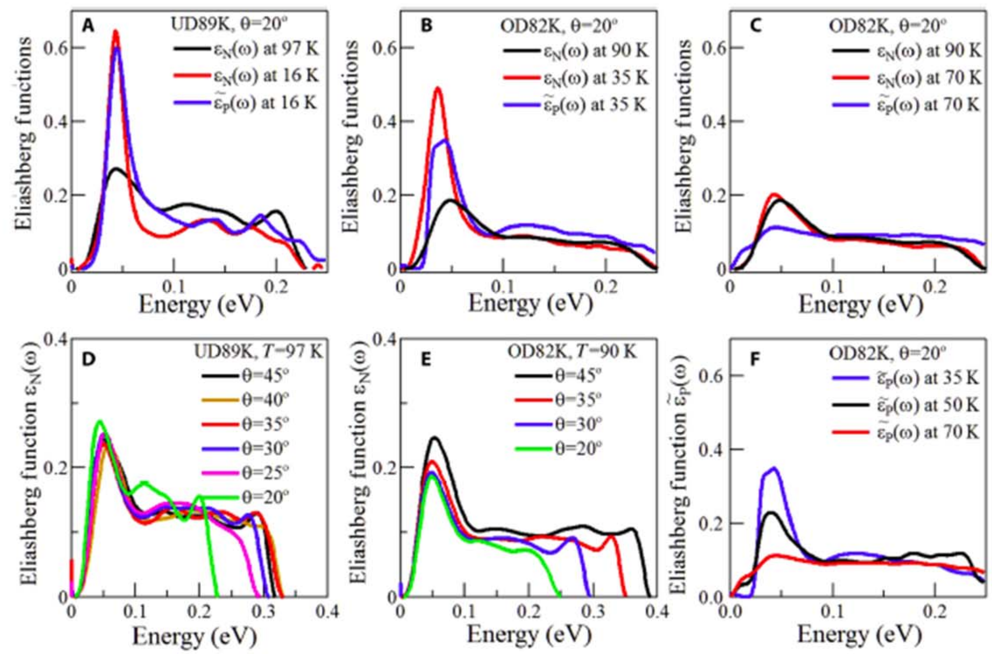
CONDENSED MATTER PHYSICS

10.1126/sciadv.1501329

Quantitative determination of pairing interactions for high-temperature superconductivity in cuprates

Jin Mo Bok,[1,2] Jong Ju Bae,[1] Han-Yong Choi,[1,3]* Chandra M. Varma,[4]* Wentao Zhang,[2,5] Junfeng He,[2] Yuxiao Zhang,[2] Li Yu,[2] X. J. Zhou[2,6]*





- Scattering near $(\pi,0)$ inelastic or not?
- Alexis

Bad metal

T linear resistivity > Mott-Ioffe Regel

Similarity of Scattering Rates in Metals Showing *T*-Linear Resistivity

J. A. N. Bruin,[1] H. Sakai,[1] R. S. Perry,[2] A. P. Mackenzie[1]

Many exotic compounds, such as cuprate superconductors and heavy fermion materials, exhibit a linear in temperature (*T*) resistivity, the origin of which is not well understood. We found that the resistivity of the quantum critical metal $Sr_3Ru_2O_7$ is also *T*-linear at the critical magnetic field of 7.9 T. Using the precise existing data for the Fermi surface topography and quasiparticle velocities of $Sr_3Ru_2O_7$, we show that in the region of the *T*-linear resistivity, the scattering rate per kelvin is well approximated by the ratio of the Boltzmann constant to the Planck constant divided by 2π. Extending the analysis to a number of other materials reveals similar results in the *T*-linear region, in spite of large differences in the microscopic origins of the scattering.

804 15 FEBRUARY 2013 VOL 339 SCIENCE

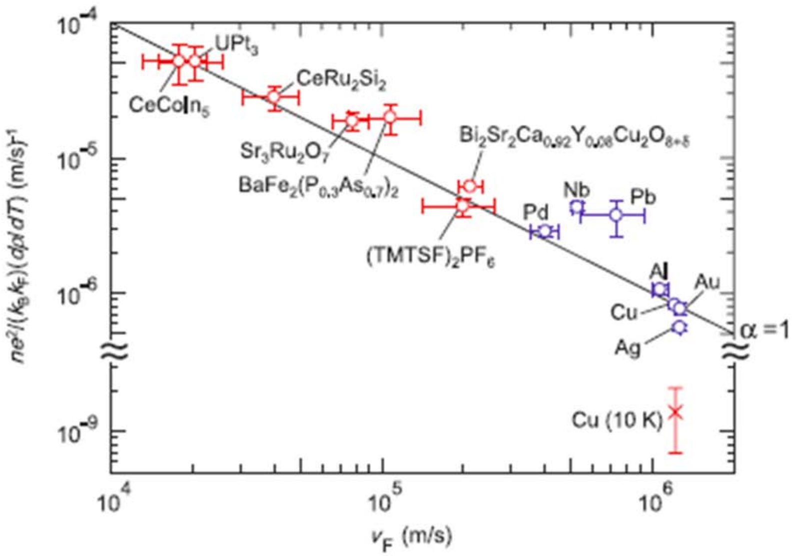


Fig. 2. In spite of two orders of magnitude variations in their Fermi velocities (v_F), a wide range of metals in which the resistivity varies linearly with temperature have similar scattering rates per kelvin. These include heavy fermion, oxide, pnictide, and organic metals for which *T*-linear resistivity can be seen down to low temperatures with appropriate tuning by magnetic field, chemical composition, or hydrostatic pressure, and more conventional metals for which *T*-linear resistivity is seen at high temperatures (blue symbols). At low temperatures, the scattering rate per kelvin of a conventional metal is orders of magnitude lower, as illustrated for the case of Cu at 10 K, shown in the lower right hand corner (*11*). On the graph, the line marked $\alpha = 1$ corresponds to $(\tau T)^{-1} = k_B/\hbar$. The near-universality of the scattering rates is observed in spite of the fact that the scattering mechanisms vary across the range of materials. The point for $Bi_2Sr_2Ca_{0.92}Y_{0.08}Cu_2O_{8+\delta}$ is based on the value $\alpha = 1.3$, which is determined from optical conductivity (*21*), combined with the measured value of v_F for this material (*44*). For all others, the analysis is based on resistivity data combined with knowledge of the Fermi volume and average Fermi velocity. Full details of the determination of the parameters in the axis labels are given in (*11*).

$$\frac{\hbar}{\tau} = k_B T$$

$$(T\tau)^{-1} = \alpha k_B/\hbar$$

$$\ln\left(\frac{ne^2}{k_B k_F}\frac{\partial \rho}{\partial T}\right) = -\ln v_F + \ln\alpha$$

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Bad metal behavior : (linear in *T* resistivity)

- Anisotropic MFL (McKenzie) in *overdoped*

$$\Sigma''(\omega,T) = 1.6\frac{T_c(p)}{T_0^{\max}}\cos^2(2\phi)\max(\pi T,\omega)\frac{\pi}{2}$$

  – No vertex corrections

Dobrosavljevic

- From DMFT

PRL **114**, 246402 (2015)
T scale too large?

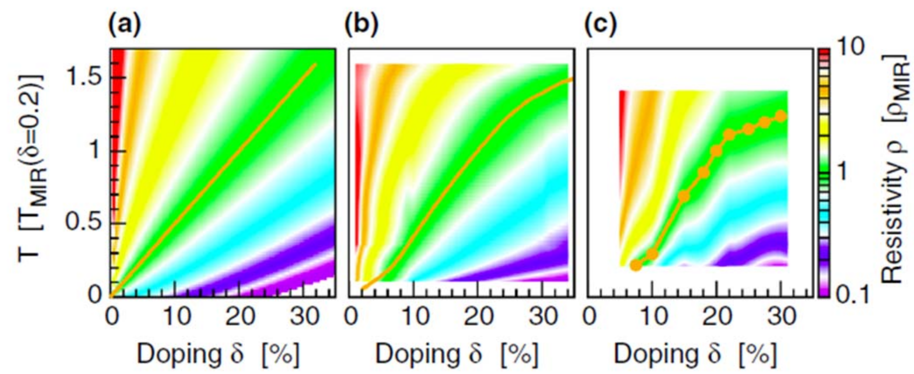
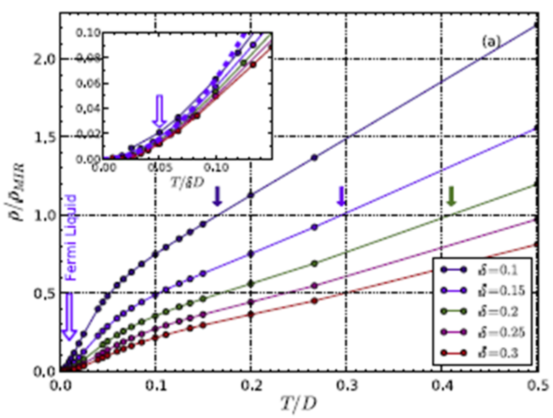
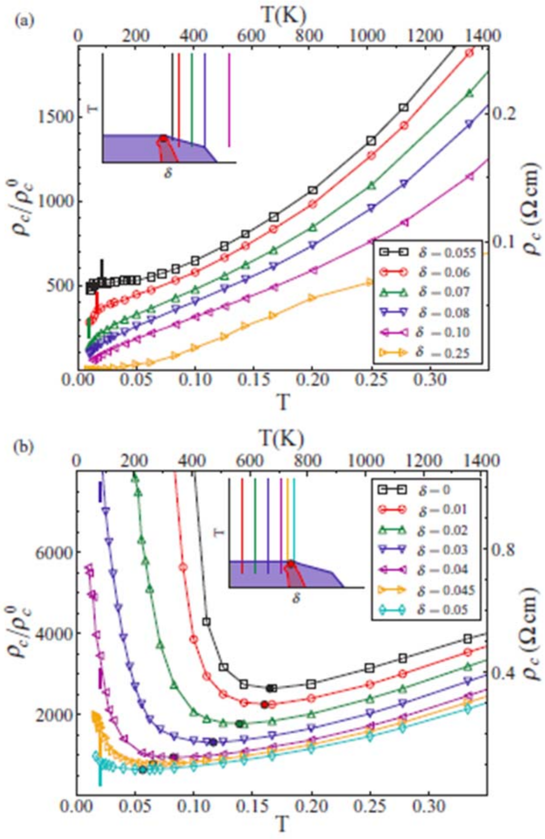


FIG. 4 (color online). Resistivity given by (a) the semianalytical formula obtained from the scaling hypothesis, (b) DMFT result, and (c) the experimental result on cuprate $La_{2-x}Sr_xCuO_4$ samples from Ref. [8].



Deng, Georges, Kotliar
PRL **110**, 086401 (2013)

CDMFT



Sordi *et al.*

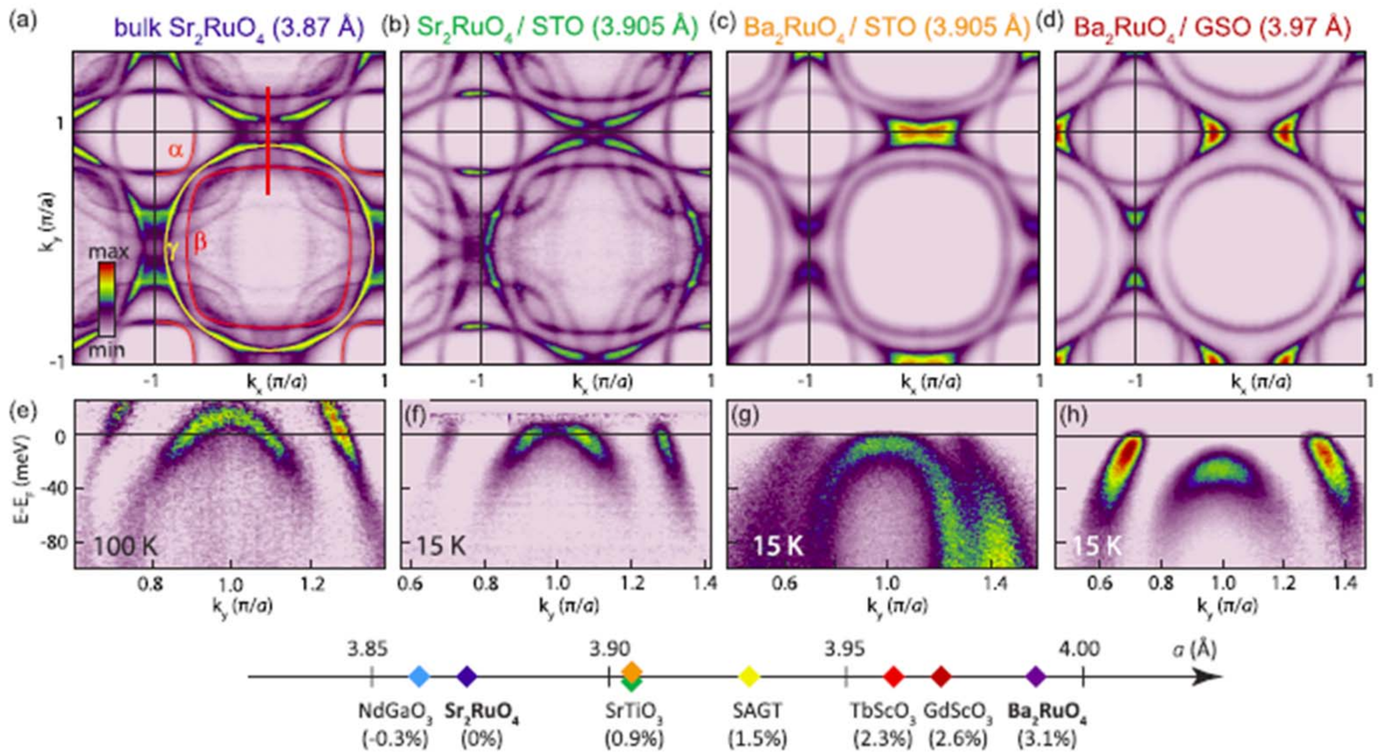
PRB **87**, 041101(R) (2013)

Topological superconductivity

Sr_2RuO_4

PRL **116**, 197003 (2016) PHYSICAL REVIEW LETTERS week ending 13 MAY 2016

Strain Control of Fermiology and Many-Body Interactions in Two-Dimensional Ruthenates



Why interesting

- p_x+ip_y superconductors can carry Majorana edge modes.
- 4/3 filled with electron-hole transformation. Near 30% doping close to van Hove singularity. Stoner-like ferro instability towards ferromagnetism.
- SrRuO_4 can be large Chern number chiral p_x+ip_y (no-nodes)
  - (Scaffidi, sin 3kx is dominant)
- Or *d*-wave with nodes (Louis) (Breaks TR through interband *d+id*)

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