Classes of materials

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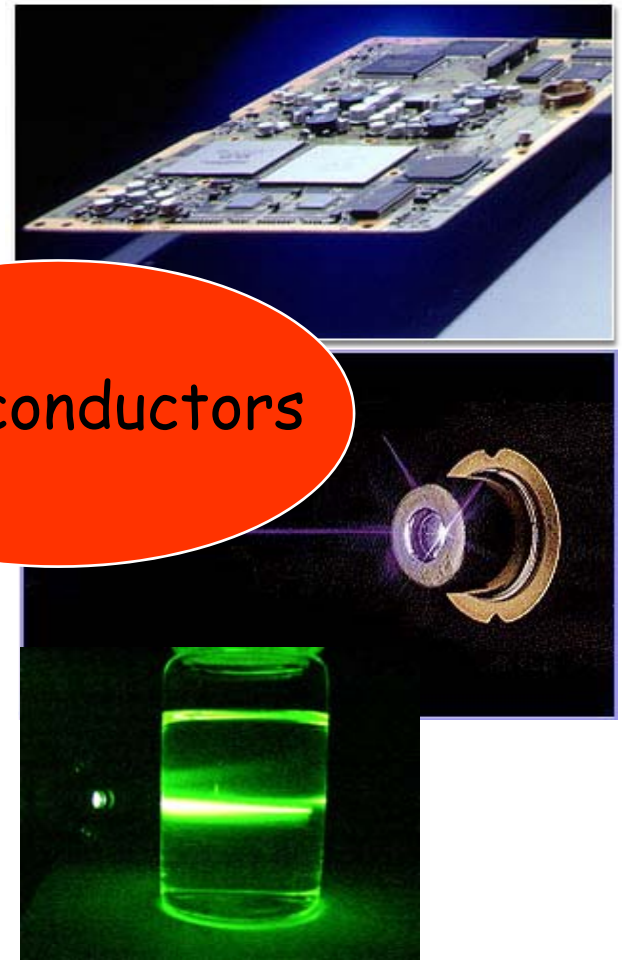
Strong - weak coupling regime

Two material classes

Metals

Semiconductors

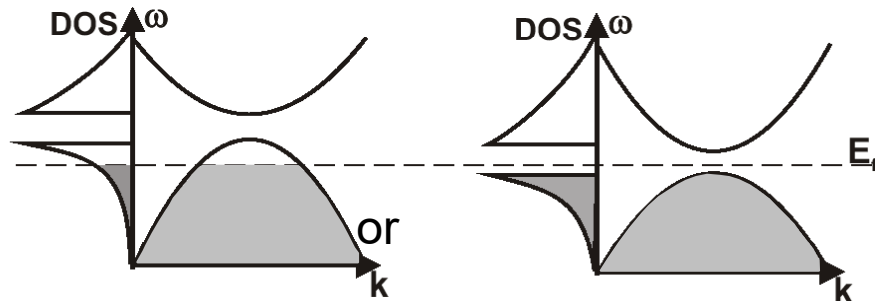


Past and present

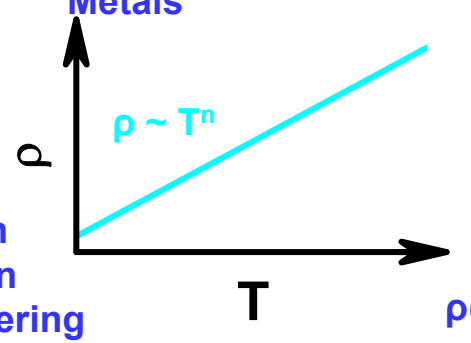
Present

Basic notions:

We understand well the two material classes through electrical transport measurements



Metals



n
1- electron – phonon
2- electron – electron
3- s-d electron scattering
5- electron - phonon

$\rho(T \to 0) \to \rho_0$

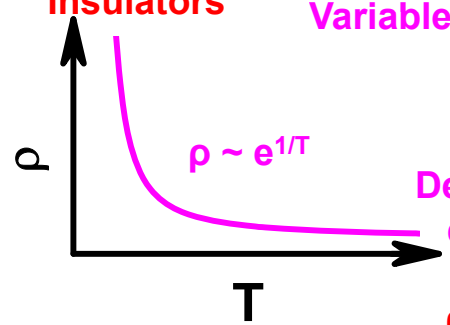
$\rho(300\ K)$ - small

Silver - $1.59 \times 10^{-6}\ \Omega cm$

Cooper - $1.68 \times 10^{-6}\ \Omega cm$

Lead - $2.2 \times 10^{-5}\ \Omega cm$

Insulators



Variable Range Hopping

$$e^{T^{-1/n}}$$

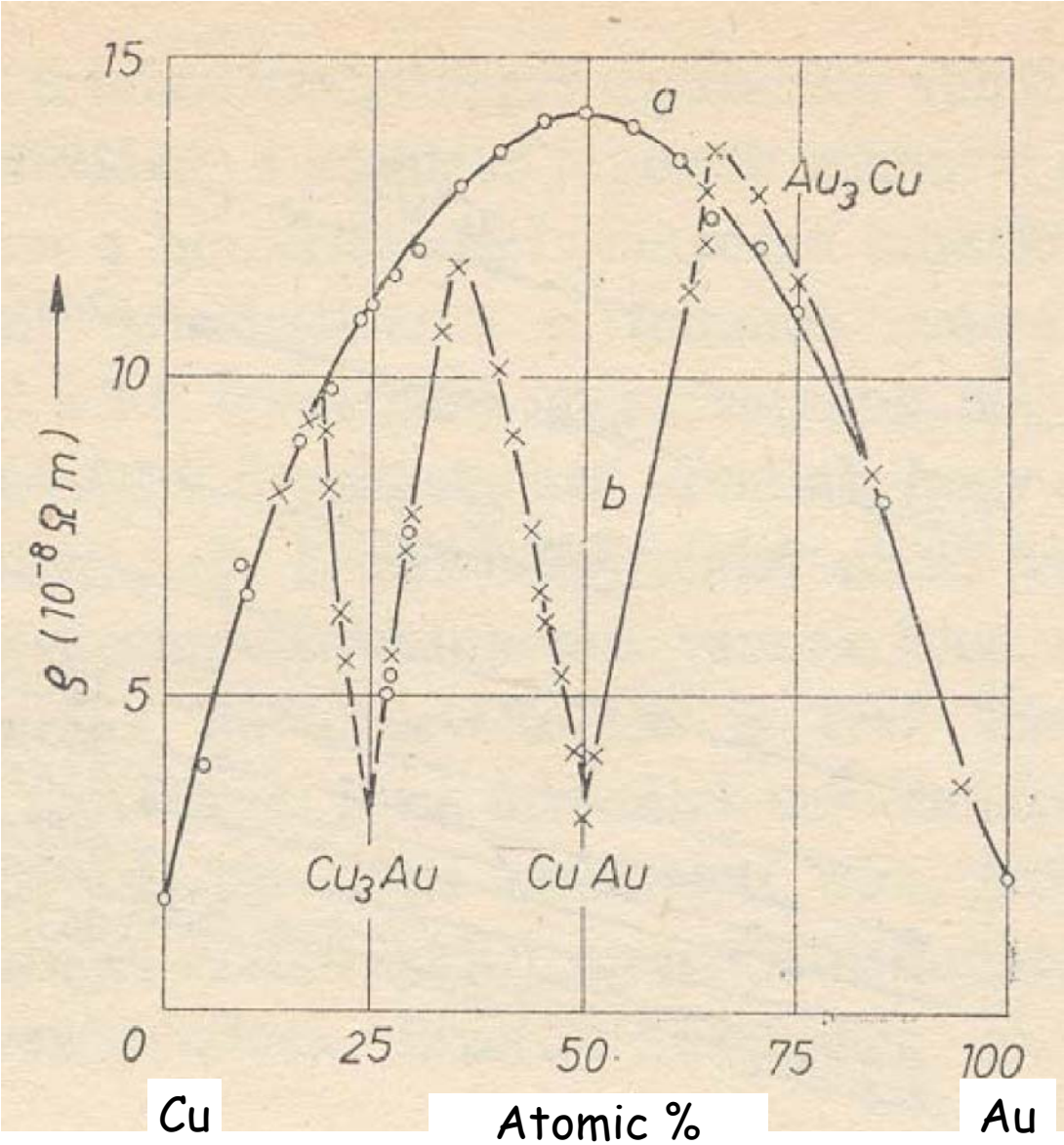
n = 2,3,4
Depending on the dimensionality

$\rho(300\ K)$ -big

Silicon- $6.4 \times 10^{4}\ \Omega cm$

Teflon - $10^{24}\ \Omega cm$

Order-disorder



Metals with strong disorder

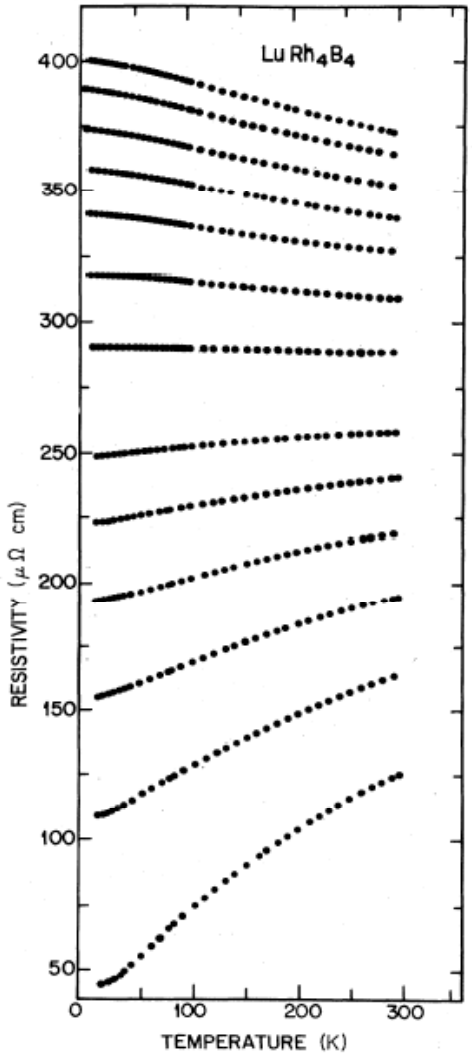


FIG. 20. Resistivity as a function of temperature for $LuRh_4B_4$ at various damage levels. The numbers represent the α-particle dose in units of $10^{16}/cm^2$. From Dynes, Rowell, and Schmidt (1981).

Value of resistivity - very low – metallic
Slope – becomes nonmetallic

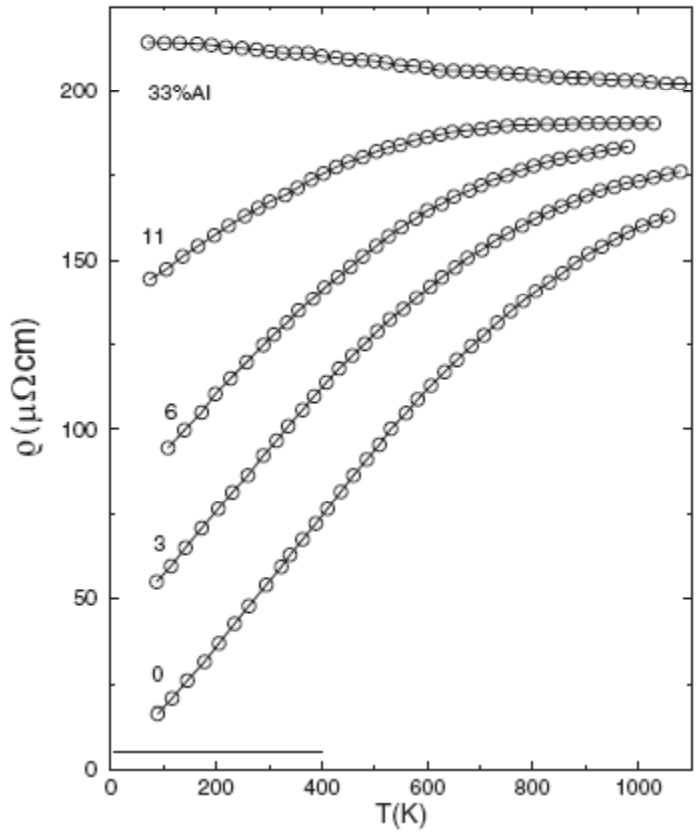
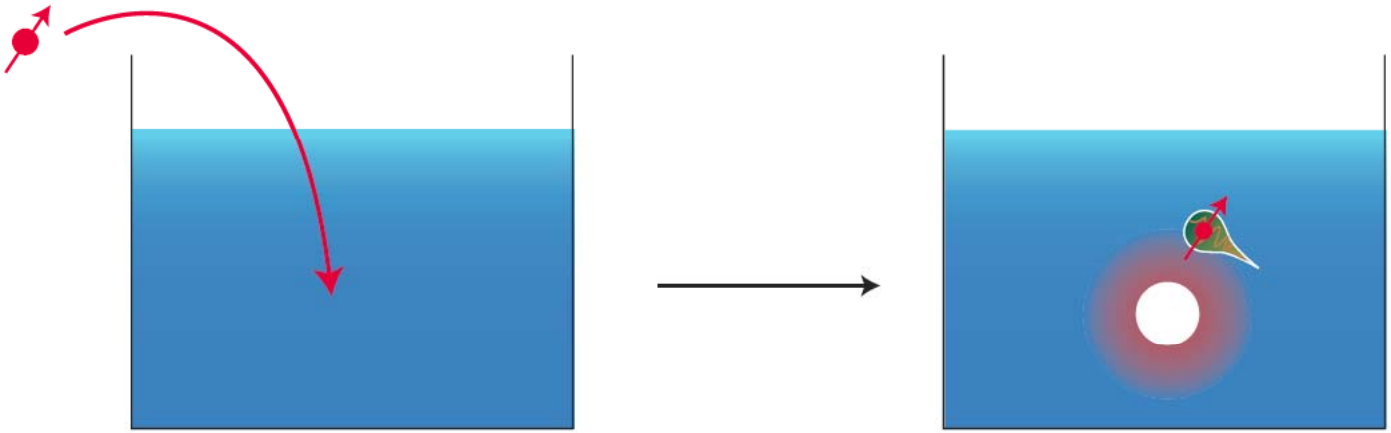


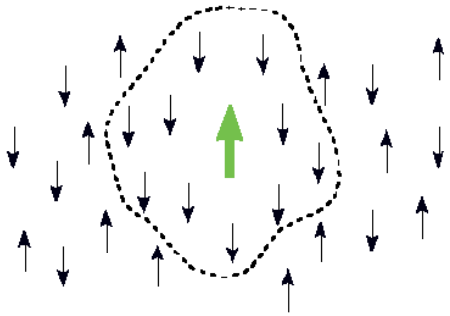
Fig. 2 Resistivity versus temperature for Ti and TiAl alloys containing 0, 3, 6, 11, and 33% Al. Data are from Mooij, Ref. [19]. The solid line represents the temperature range where our theoretical calculation will be compared with the experimental data.

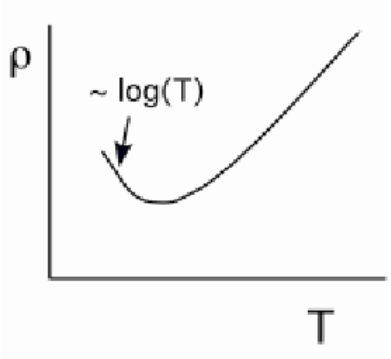
Screening of the magnetic impurity: Kondo-effect



P. Coleman, 2012

$$H_{Kondo} = J \sum_i \vec{S}_i \vec{s}_i$$



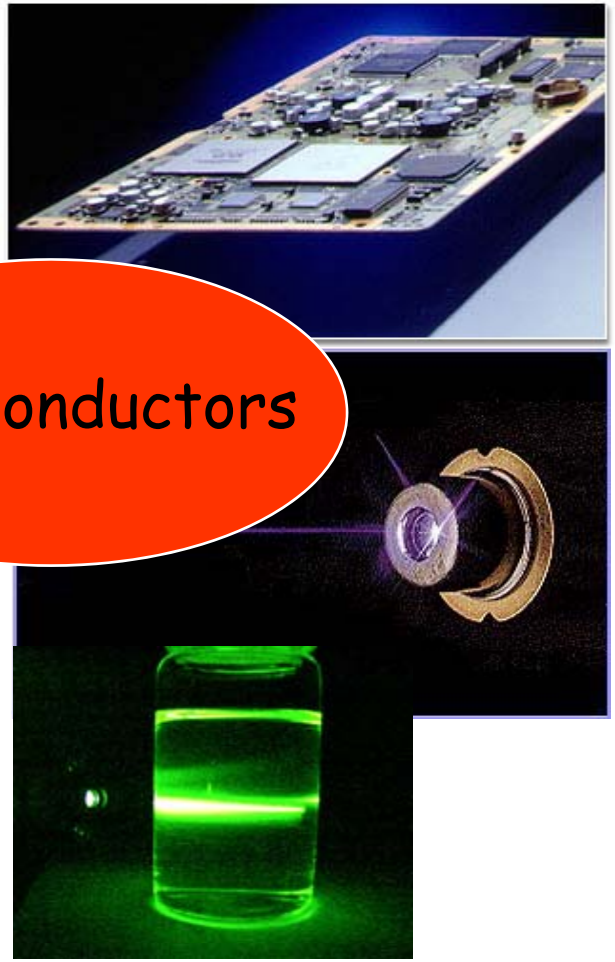


$$\rho = \rho_v + c_m a \ln(\mu/T) + bT^5$$

Where to look for novelities?

How to fill the gap?

10^{-6} Ωcm 10^{4} Ωcm



Metals

Semiconductors

Novel conductors

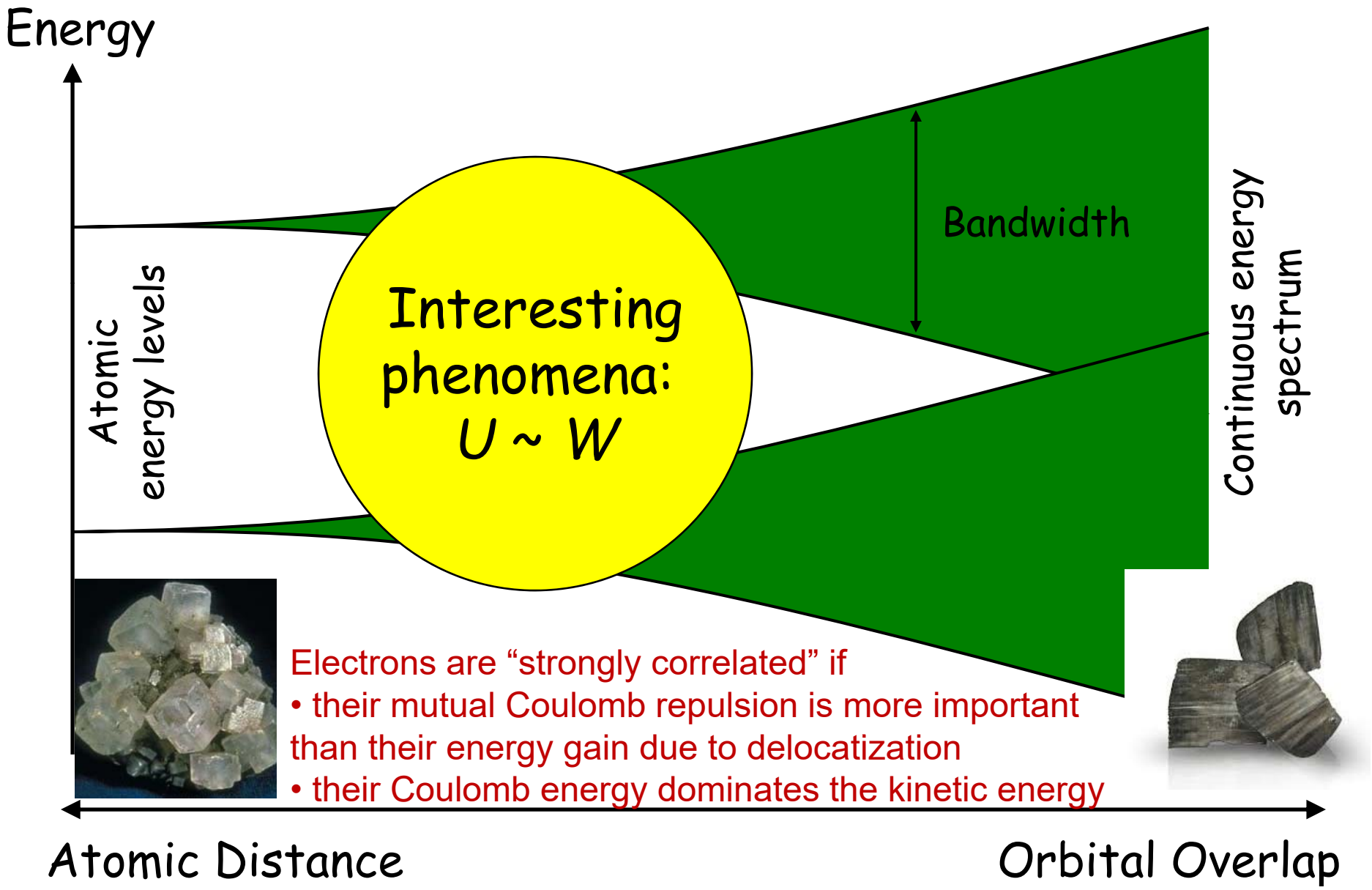
Correlated metals

Past and presence

Presence

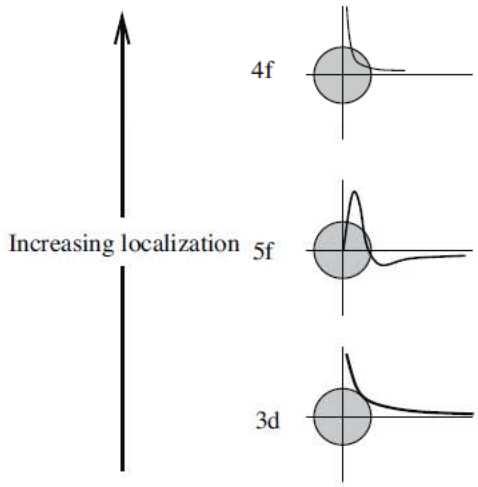
Presence and future

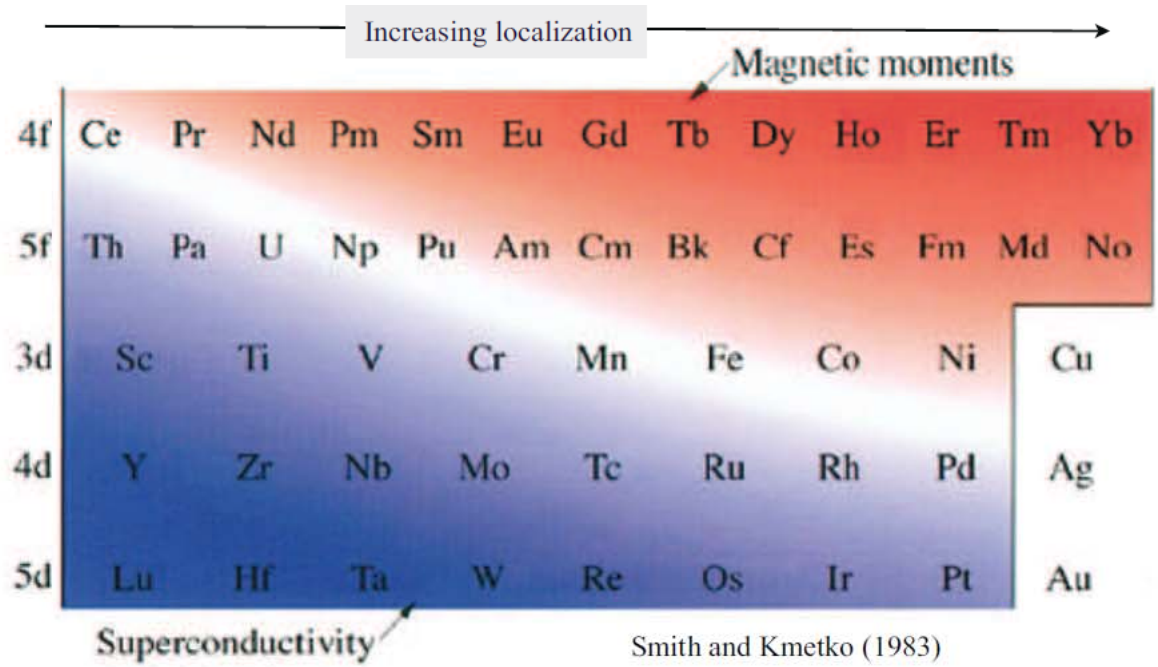
A different look on the same thing



Electrons are “strongly correlated” if
- their mutual Coulomb repulsion is more important than their energy gain due to delocatization
- their Coulomb energy dominates the kinetic energy

Narrow bands compounds





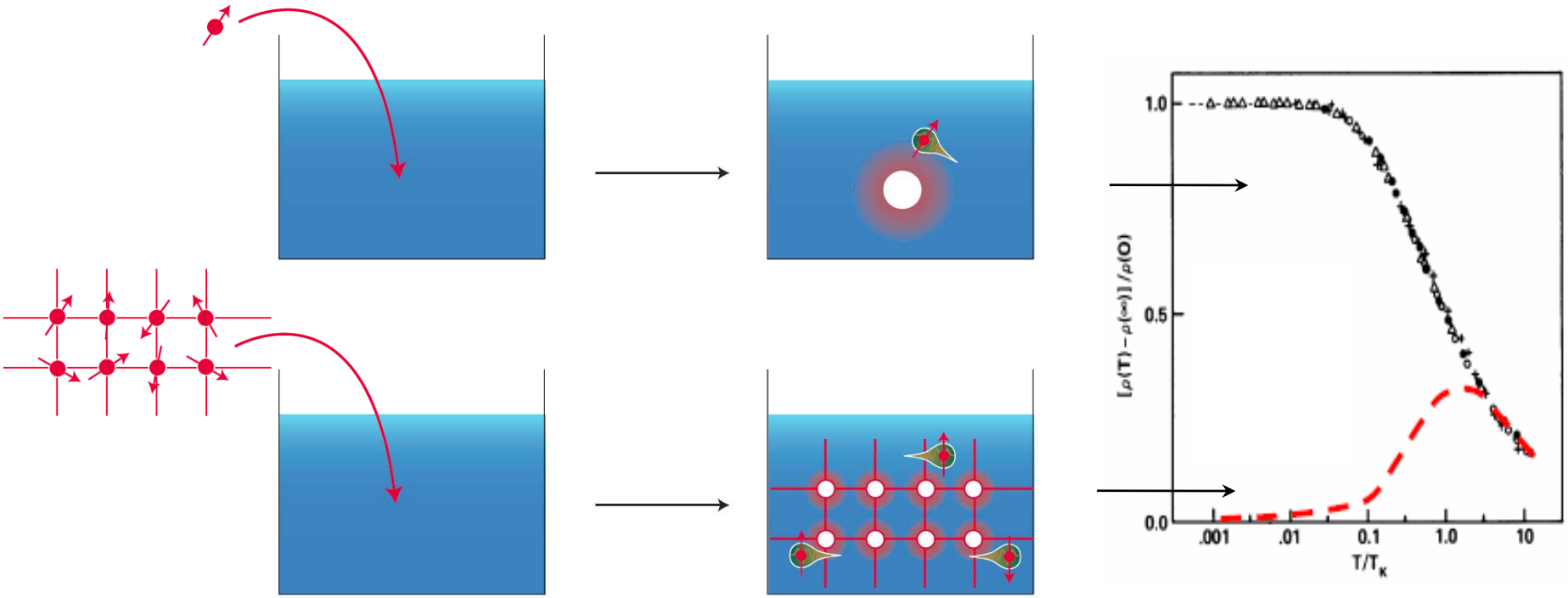
graphic by P. Coleman, after Smith & Kmetko, J. Less-Common Metals **90** (1983) 83

d- & f- electrons are different

strong coupling regime

$$W\ (\sim k_B T) < U$$

A lattice of interacting sites



P. Coleman, 2012

Kondo lattice - development of coherency at low temperature

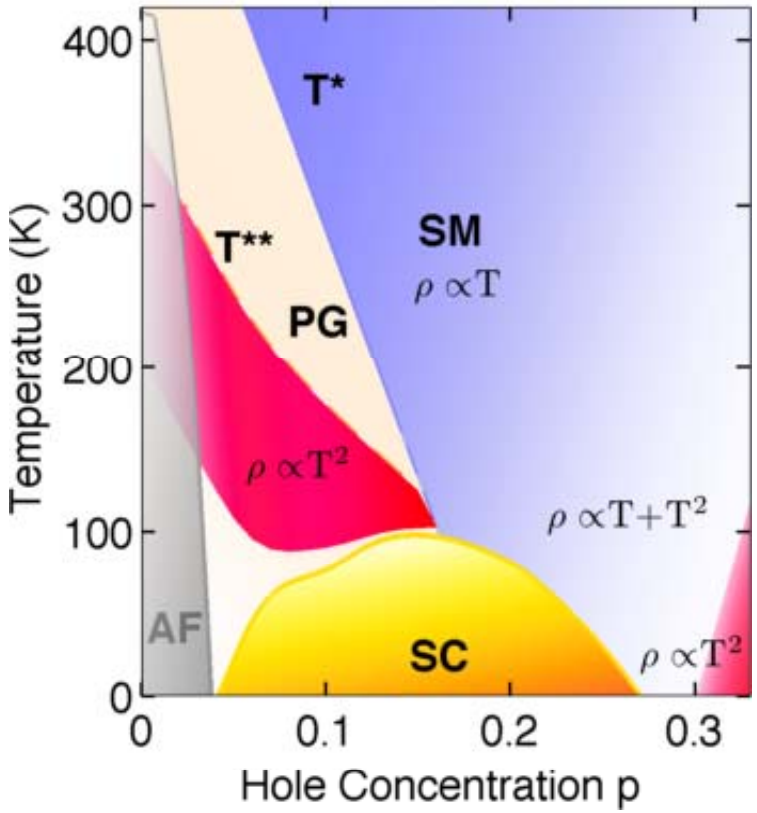
Dissolution of localized, and neutral magnetic f spins into the quantum conduction sea, where they become mobile excitations. Once mobile, these free spins acquire charge and form electrons with a radically enhanced effective mass.

Large W (~ 1eV), but even larger U (~ 10eV)

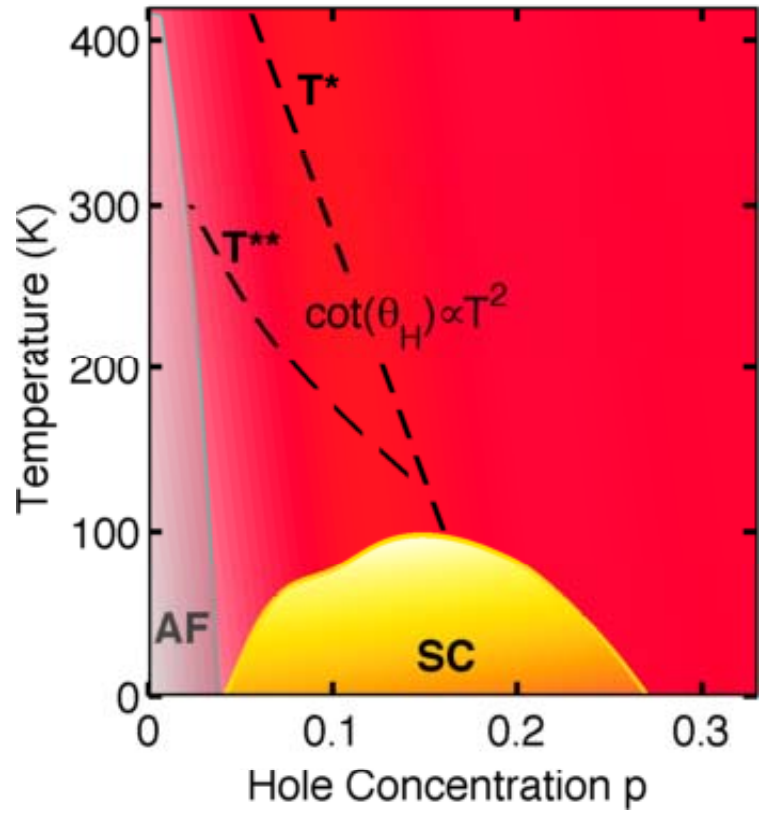
High-T_c cuprate superconductors

Conclusions

Resistivity $\rho = m^*/(p\, e^2 \tau)$



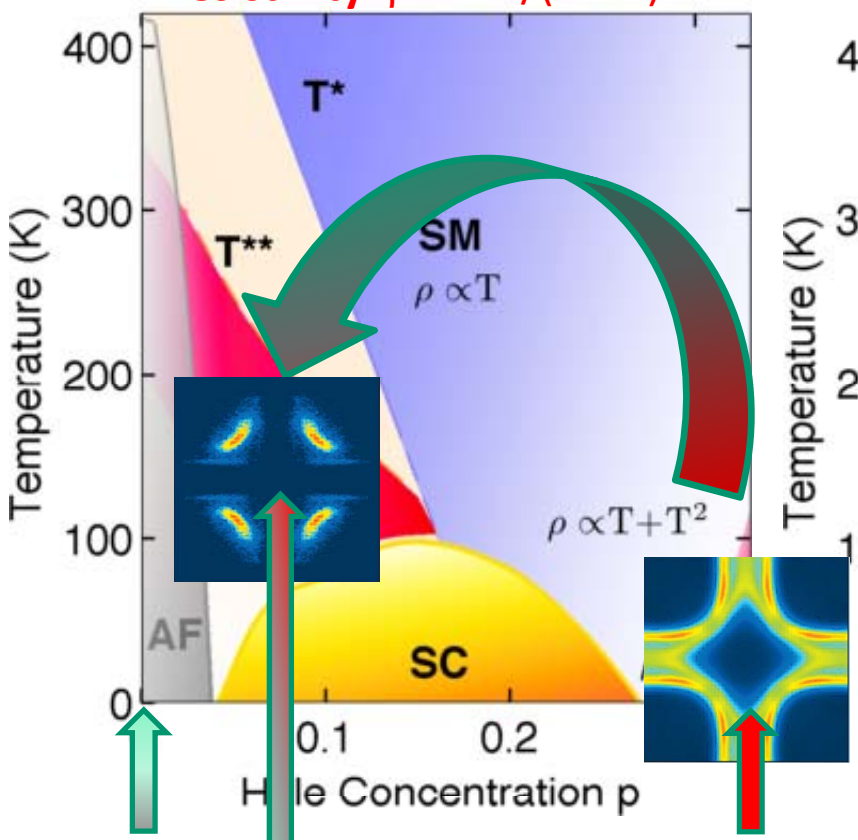
Scattering rate $\cot(\Theta_H) = C_2 T^2 \propto 1/\tau$



N. Barišić *et al.*, *arXiv*:1507.07885 (2015)

Change in paradigm: Novel prospect!

Resistivity $\rho = m^*/(n\,e^2\,\tau)$



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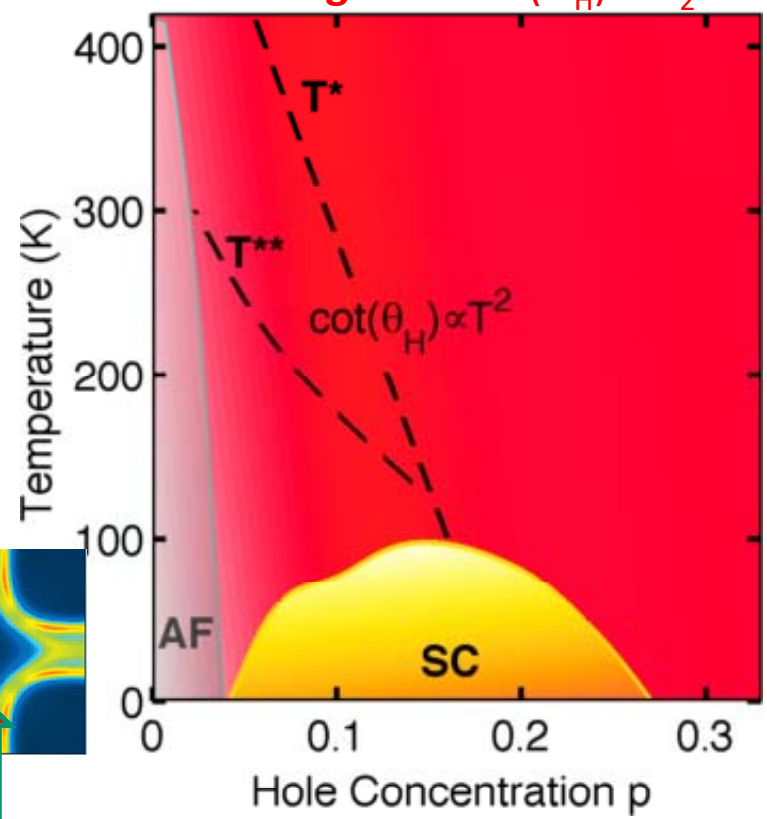


1 - localized hole

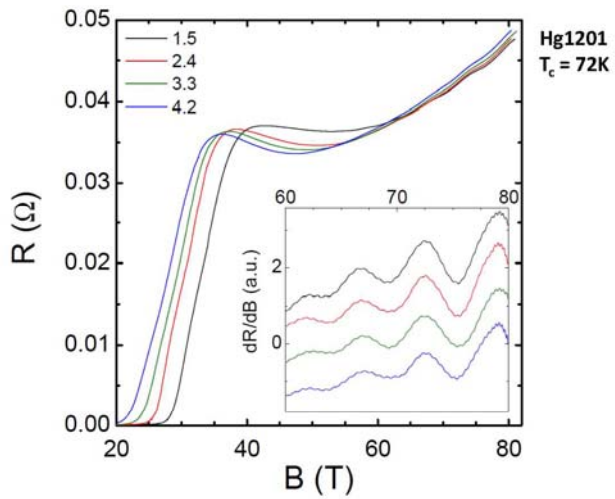
1 + *p* - Fermi liquid holes

1 + *p*
- ***p*** - Fermi liquid holes
- **1** - **localized** hole

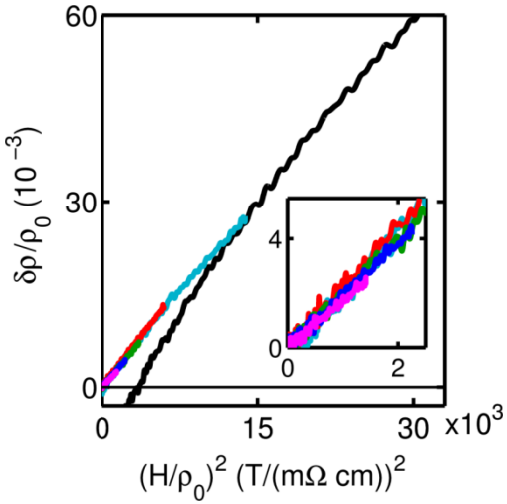
Preprint, submitted to *PRX* 2016

Localization of the ONE

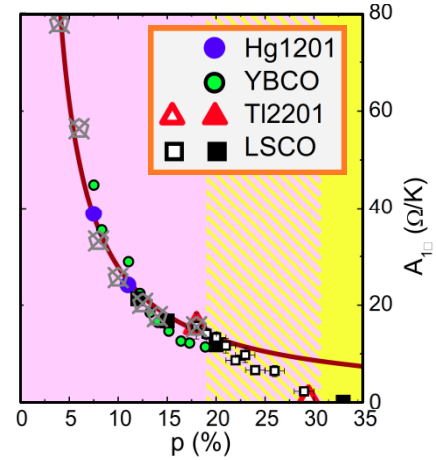
Until now – Universalities only



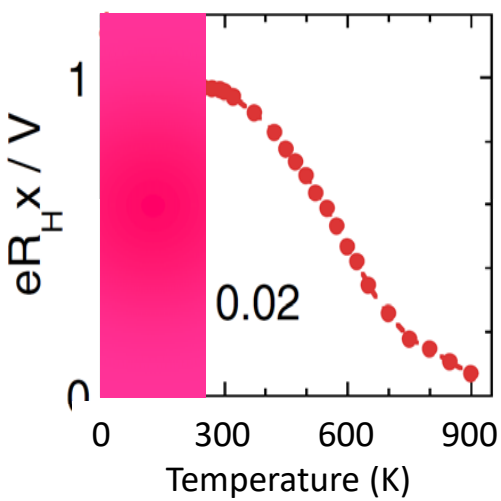
N. Barišić *et al.*,
Nat. Phys. **9**, 761 (2013).



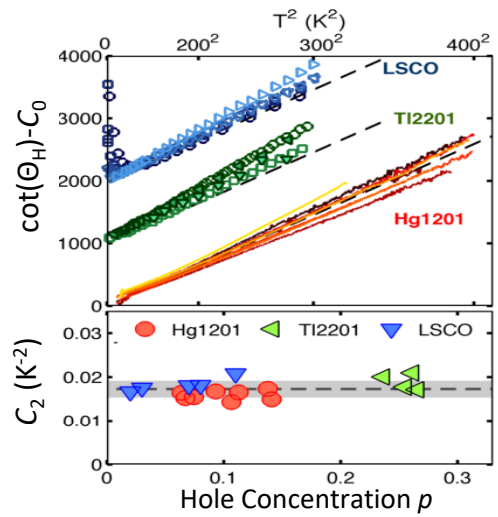
M. K. Chan *et al.*,
Phys. Rev. Lett. **113**, *177005*(2014)



N. Barišić *et al.*,
PNAS **110**, 12235 (2013).



Y. Ando et al.,
Phys. Rev. Lett. **92**,197001 (2004)



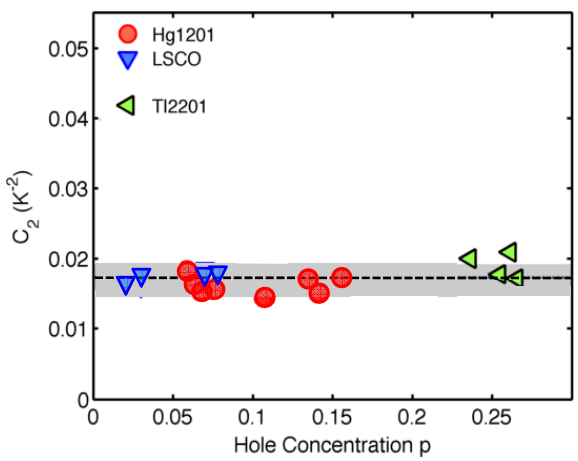
N. Barišić *et al.*,
arXiv:1507.07885 (2015)

- **raw data**
- only **textbook formulas** applied

3rd topic addressed:
Non universal behaviors

Evolution of carrier density near $p^* \approx 0.19$

LSCO



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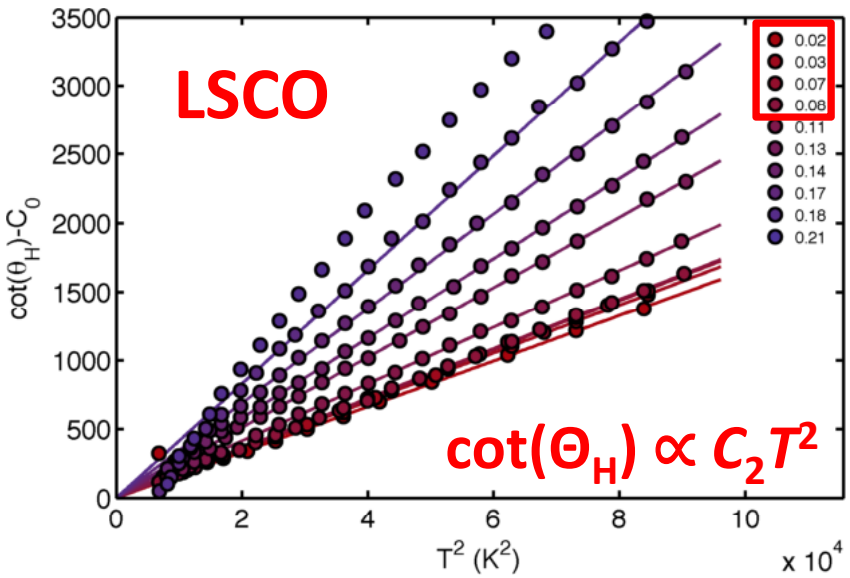
Evolution of carrier density near $p^* \approx 0.19$



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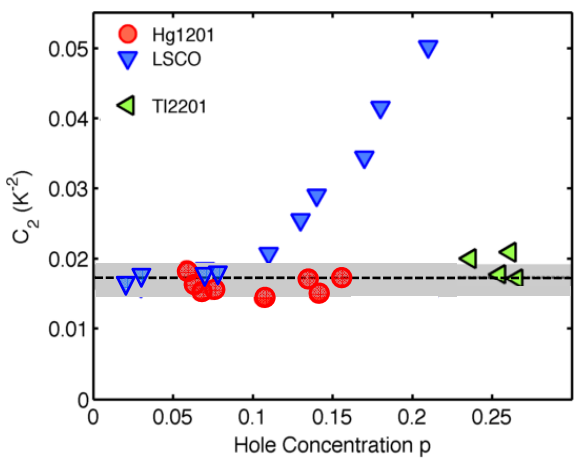

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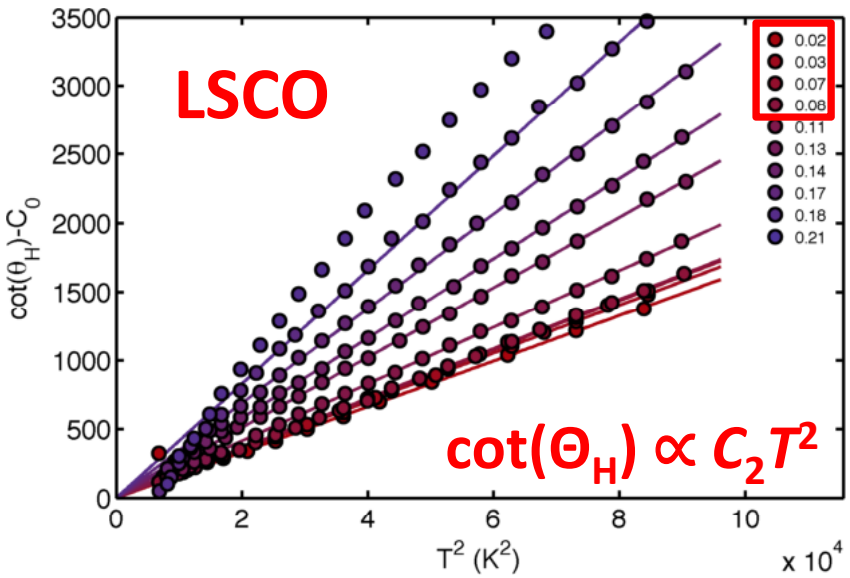

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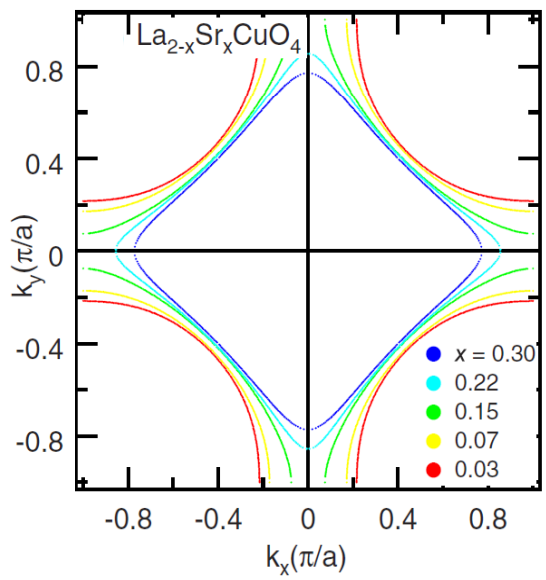

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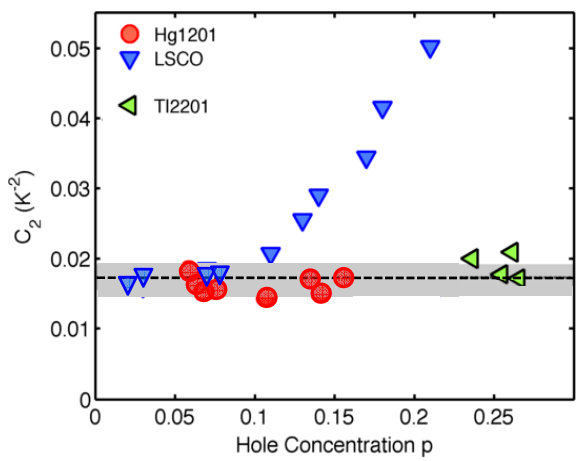

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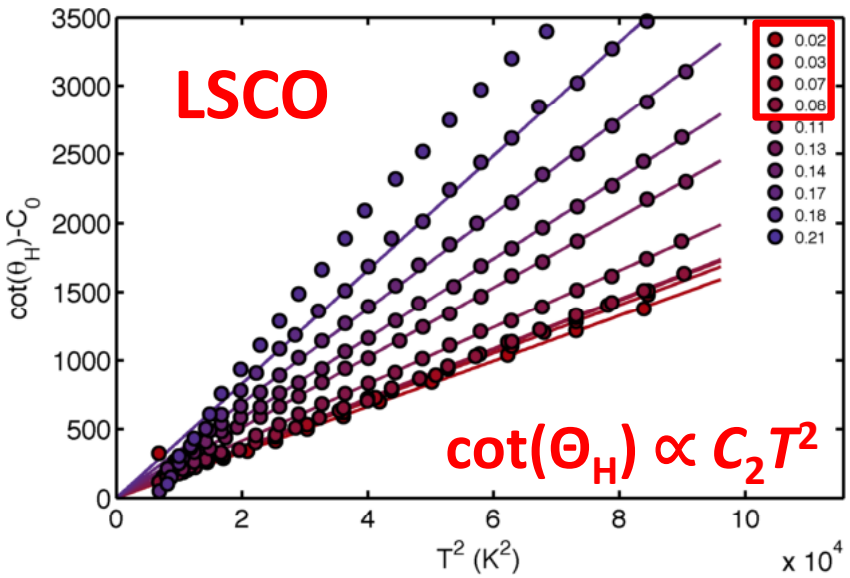

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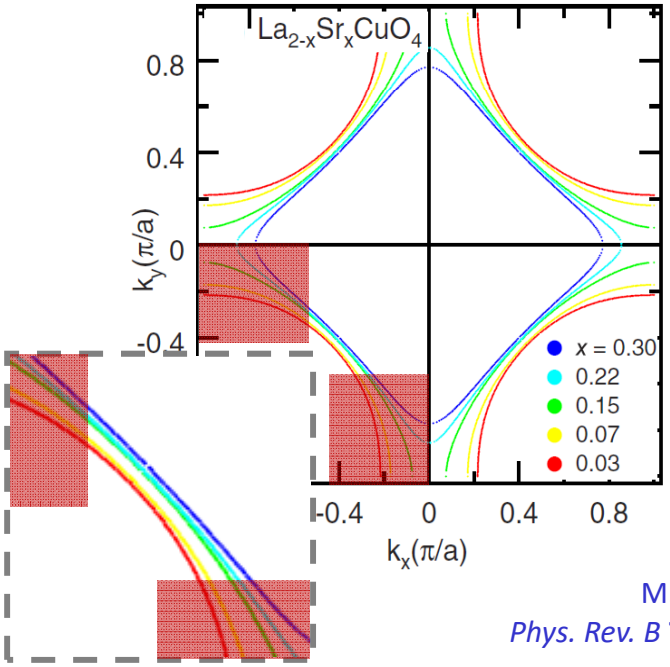

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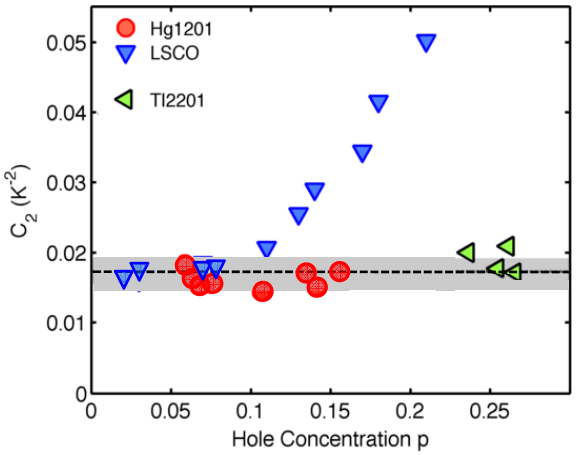

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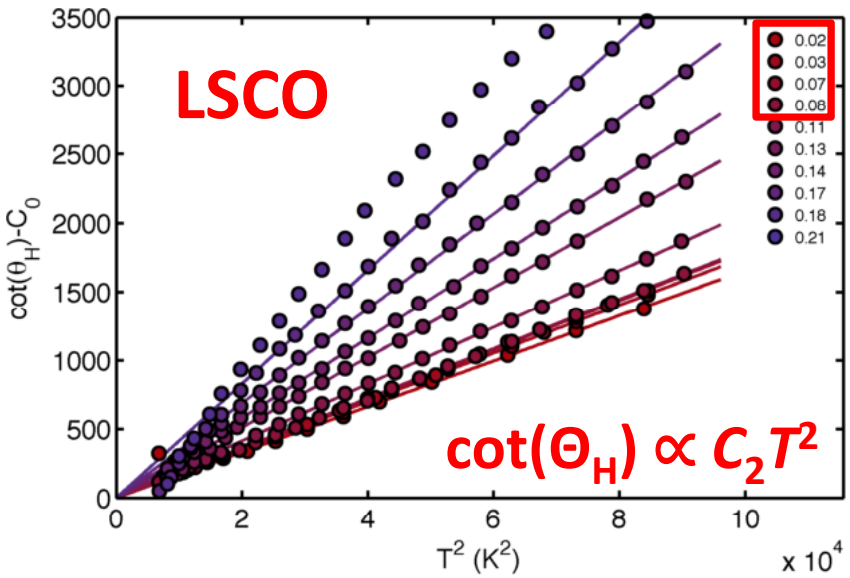

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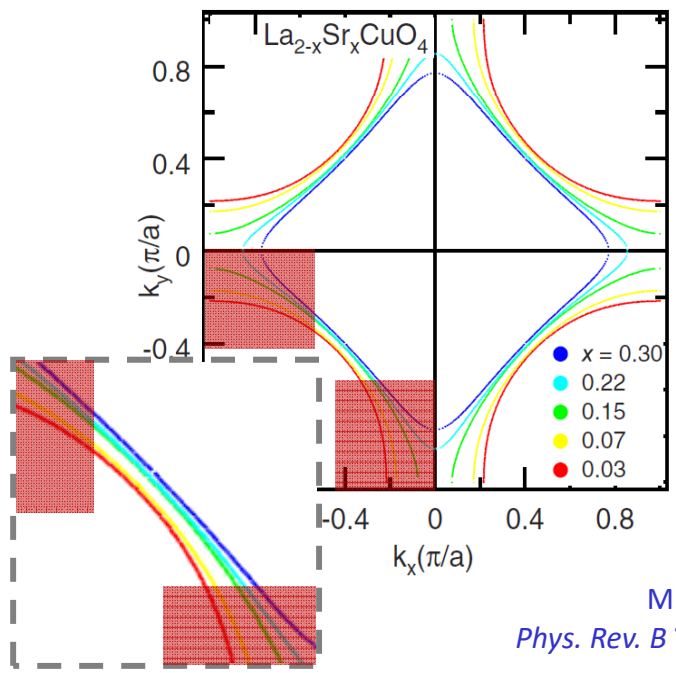

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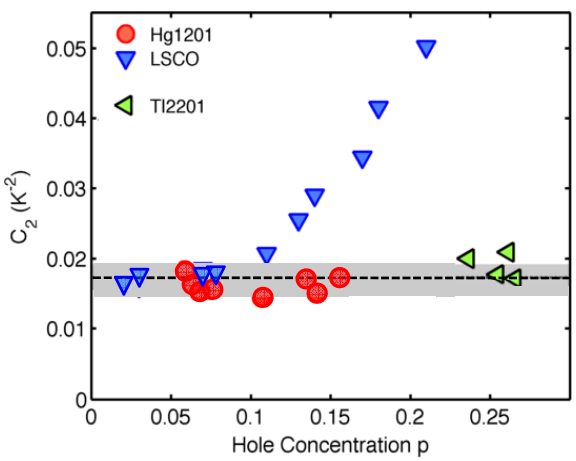


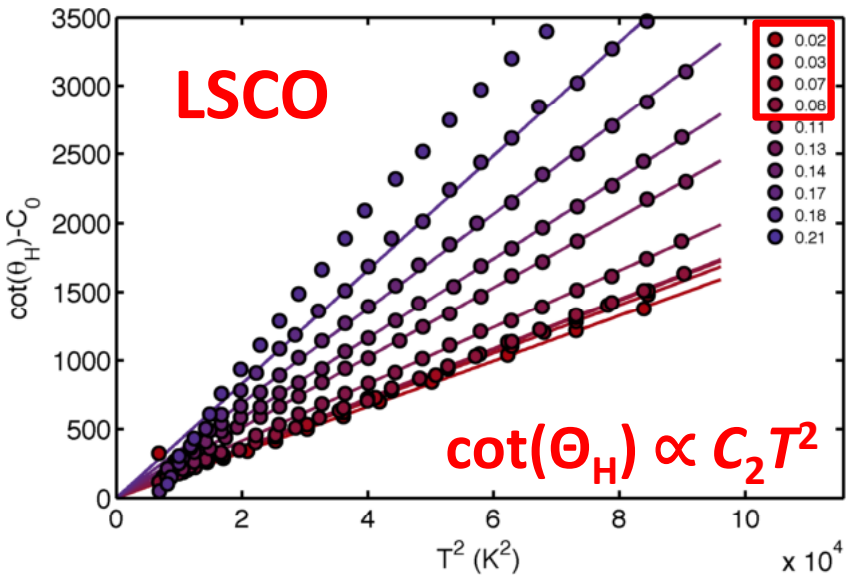
$R_H = \sigma_{xy}/(H\sigma_{xx}\sigma_{yy})$, where σ is the conductivity tensor

$\sigma_{xy} \rightarrow 0 \Rightarrow R_H \rightarrow 0 \Rightarrow C_2 \propto 1/R_H \rightarrow$ diverges

R_H - ceases to be a proper measure of the carrier density!

N. Barišić *et al.*, *arXiv*:1507.07885 (2015)

Evolution of carrier density near $p^* \approx 0.19$



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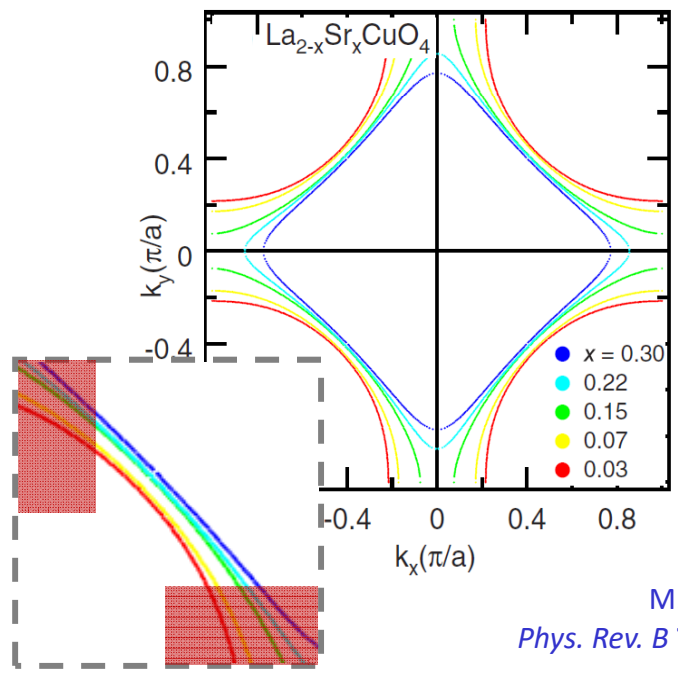

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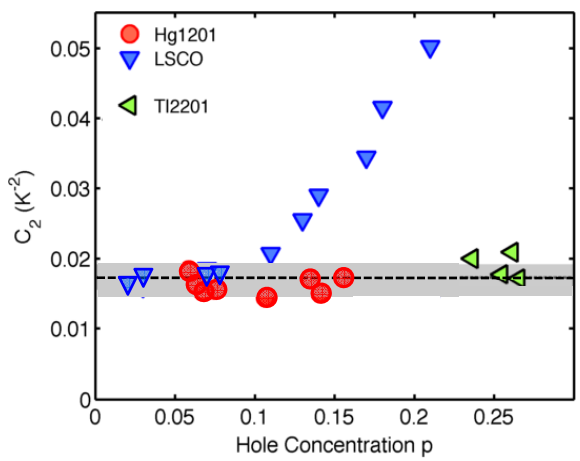
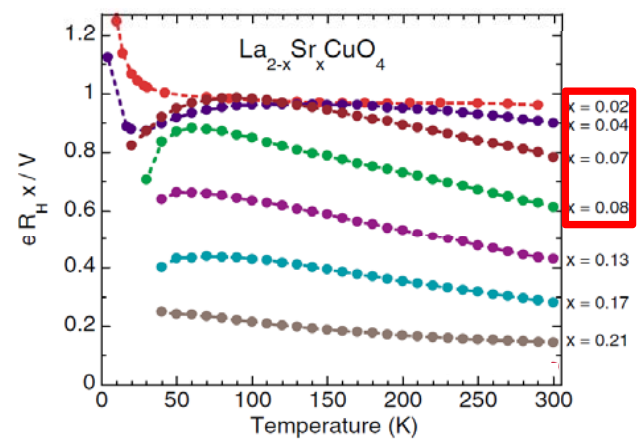


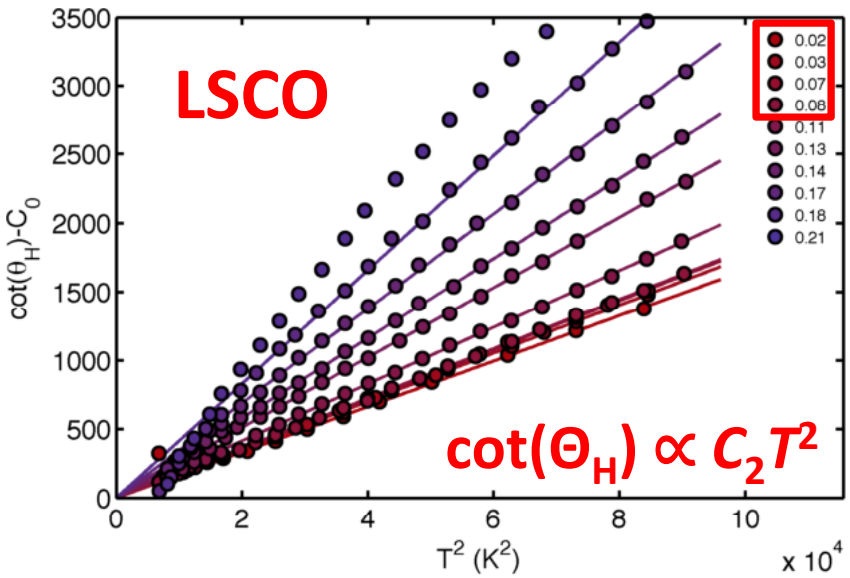
$n_H = 1/(eR_H)$

If $n_H = x/V$

then $eR_Hx/V=1$



Evolution of carrier density near $p^* \approx 0.19$



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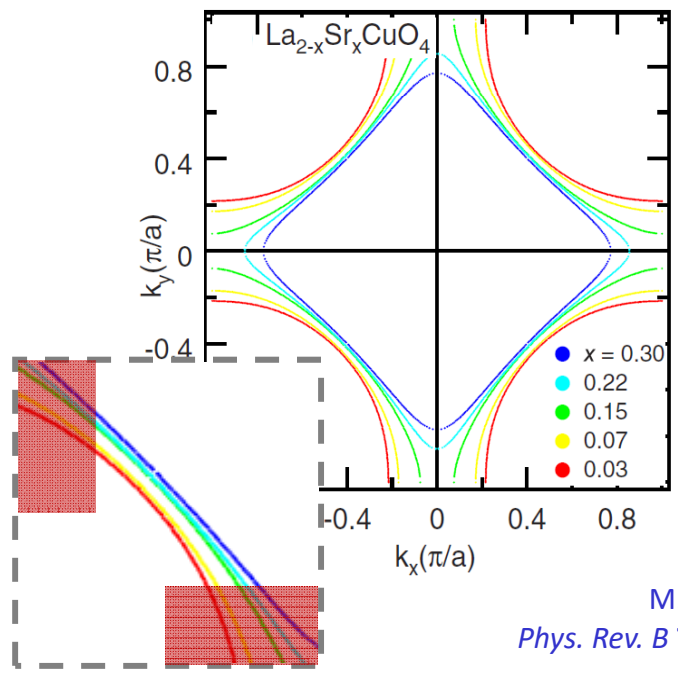

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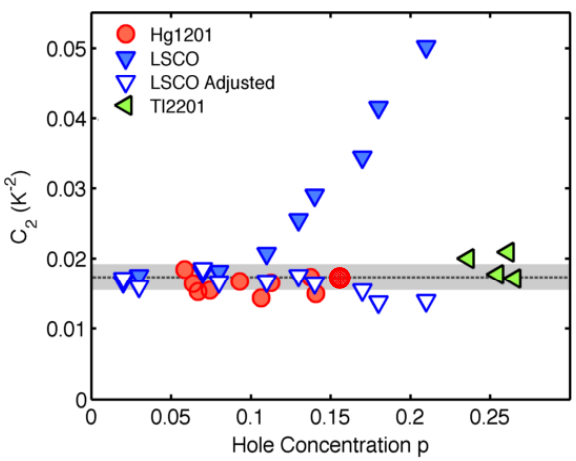

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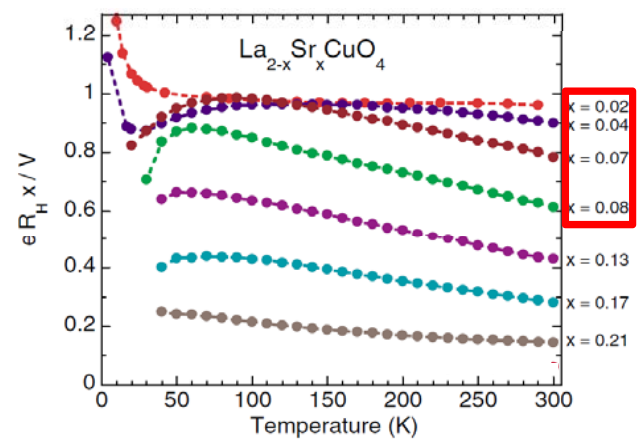
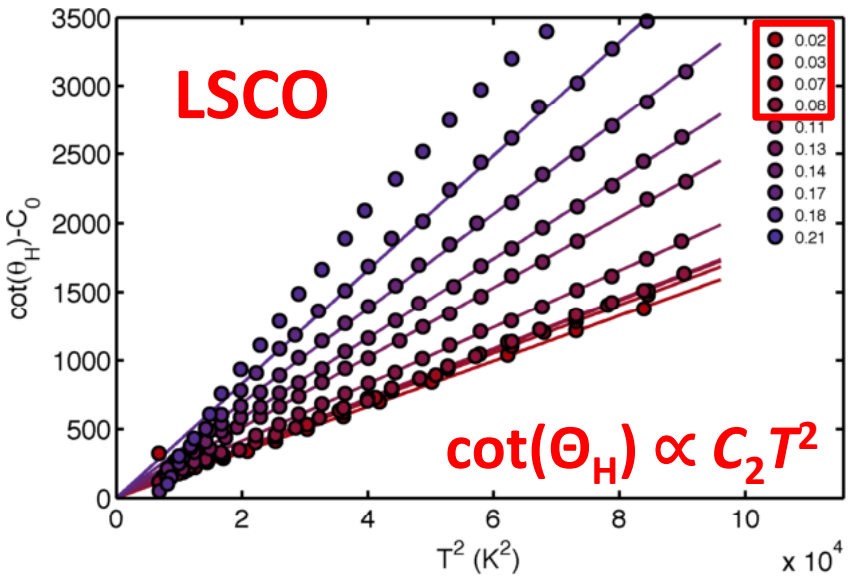


Evolution of carrier density near $p^* \approx 0.19$



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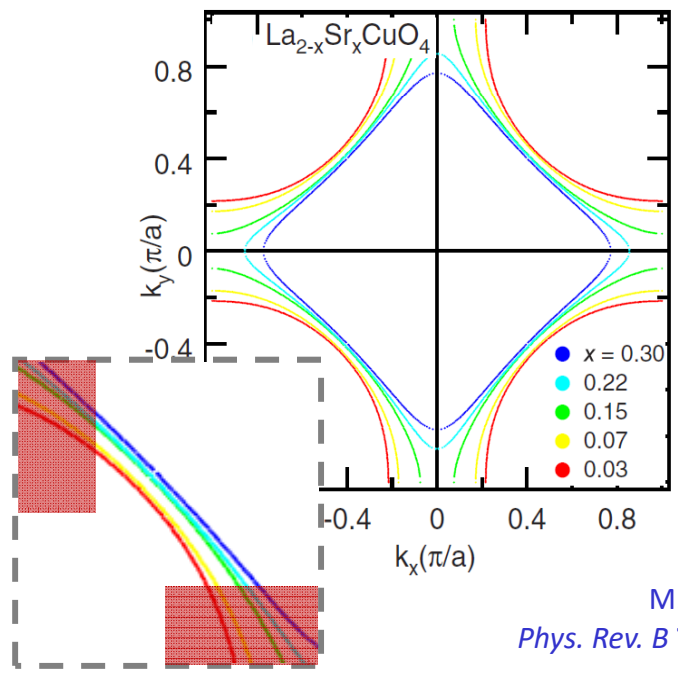

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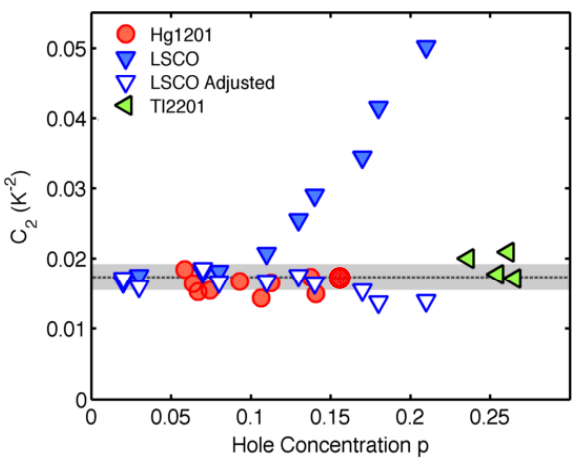


$n_H = 1/(eR_H)$

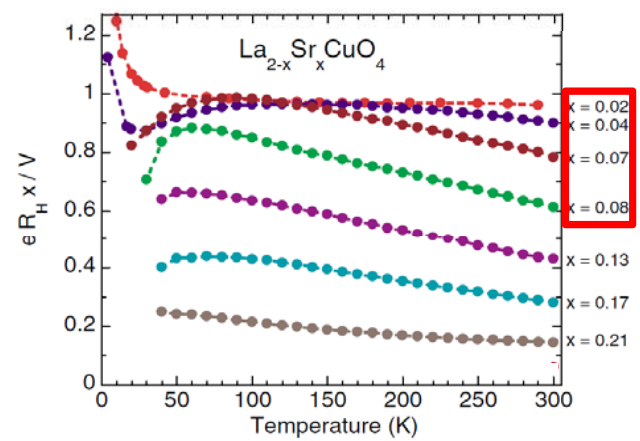
If $n_H = x/V$

then $eR_Hx/V=1$

dc resistivity and optical conductivity

p = x

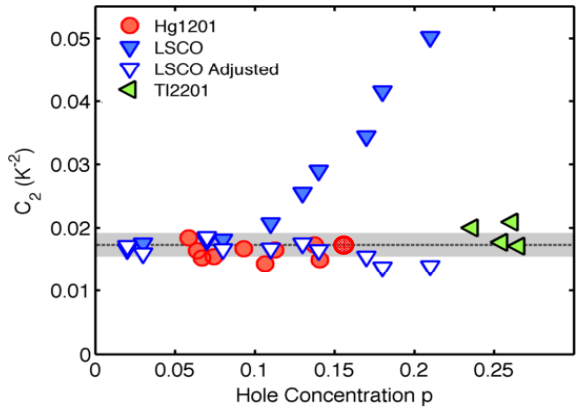
in the PG/FL phase



Evolution of carrier density near $p^* \approx 0.19$

LSCO - Important messages

- R_H - ceases to be a proper measure of the carrier density!
- **Failure of the effective-mass approximation** and **not** of the applicability of the **Fermi Liquid** concept.
- **Resistivity (and optical conductivity) reveals the correct carrier density!**

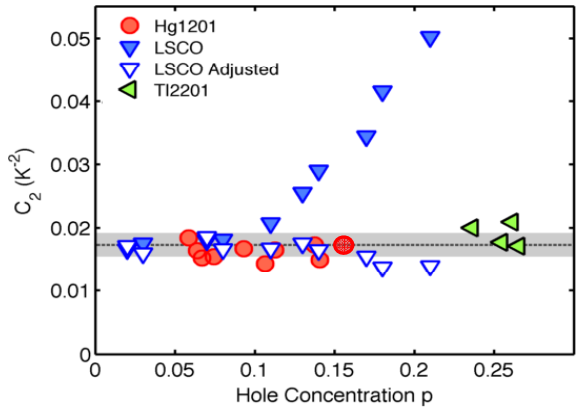


N. Barišić *et al.*, *arXiv*:1507.07885 (2015)

Evolution of carrier density near $p^* \approx 0.19$

LSCO - Important messages

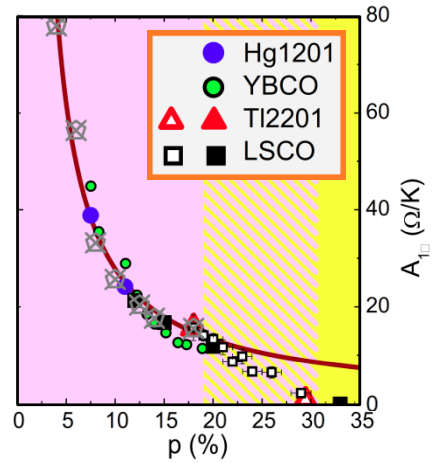
- R_H - ceases to be a proper measure of the carrier density!
- **Failure of the effective-mass approximation** and **not** of the applicability of the **Fermi Liquid** concept.
- **Resistivity (and optical conductivity) reveals the correct carrier density!**



N. Barišić *et al.*, *arXiv*:1507.07885 (2015)

Universal sheet resistance

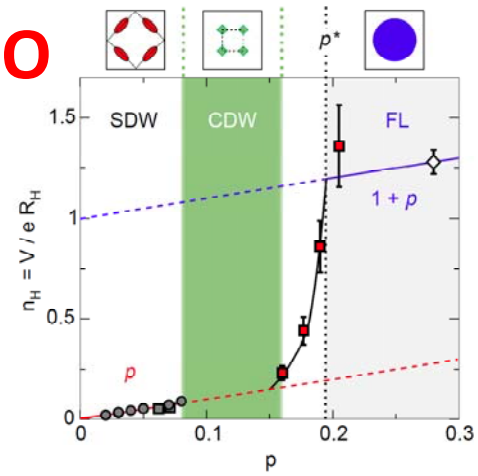
Delocalization of one carrier per planar copper is (not abrupt but) **gradual** (as a function of doping and temperature)



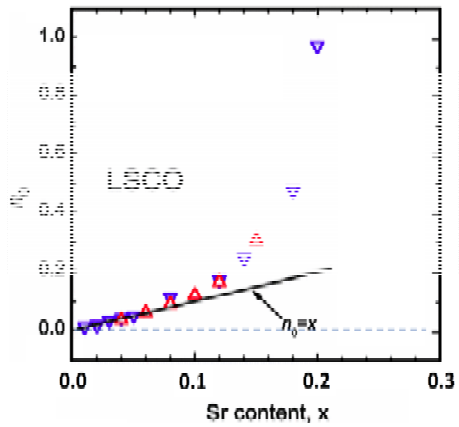
N. Barišić *et al.*, *PNAS* **110**, 12235 (2013)

YBCO & Hall number

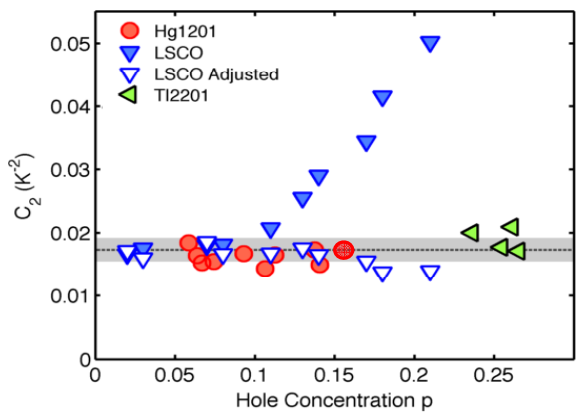
YBCO



S. Badoux *et al.*, arXiv:1511.08162 (2015)
Nature **531**, 210 (2016)



L. P. Gor'kov, G. B. Teitel'baum
Phys. Rev. Lett. **97**, 247003 (2006)



N. Barišić *et al.*,
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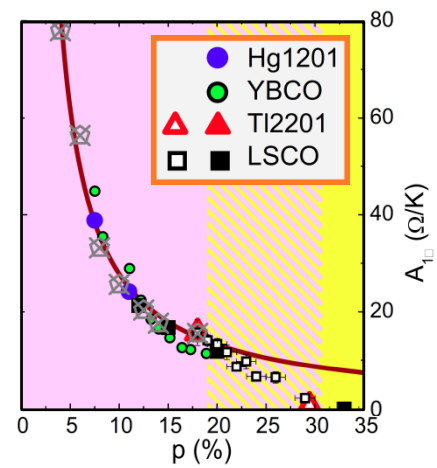

N. Barišić *et al.*,
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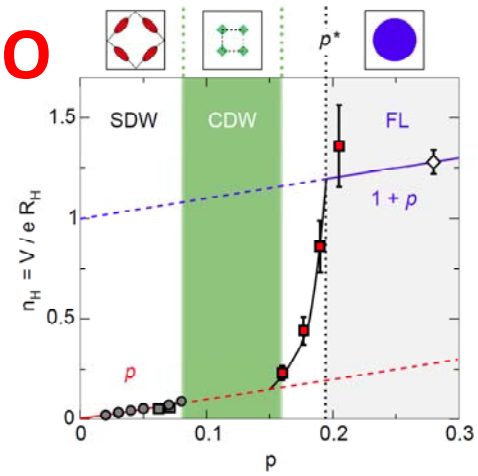
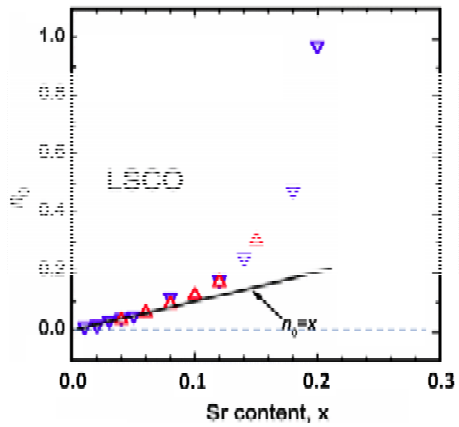


S. Badoux *et al.*, arXiv:1511.08162 (2015)
Nature **531**, 210 (2016)



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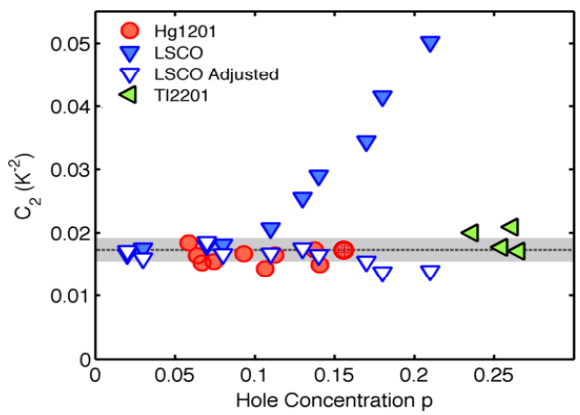

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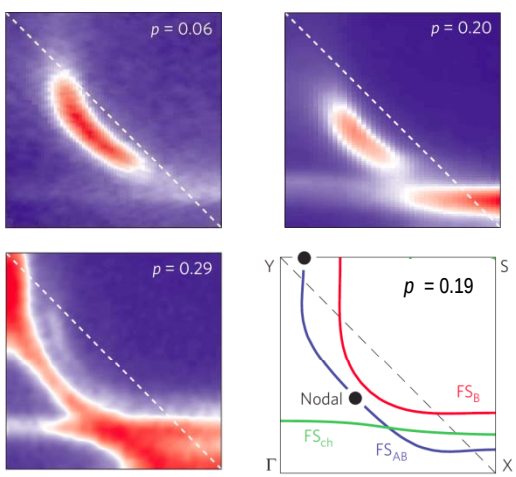
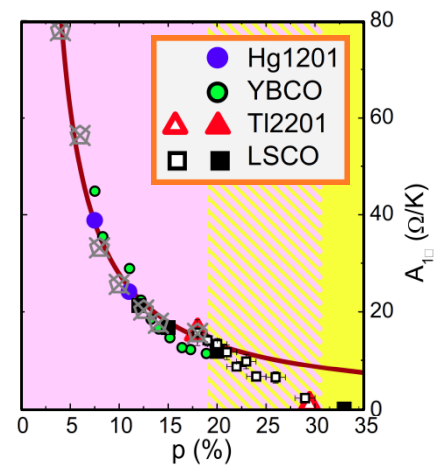


D. Fournier *et al.*, *Nature Phys.* **6**, 905 (2010)



N. Barišić *et al.*,
PNAS **110**, 12235 (2013)

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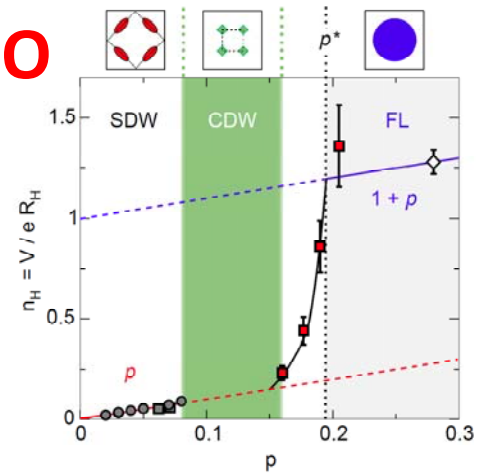
YBCO



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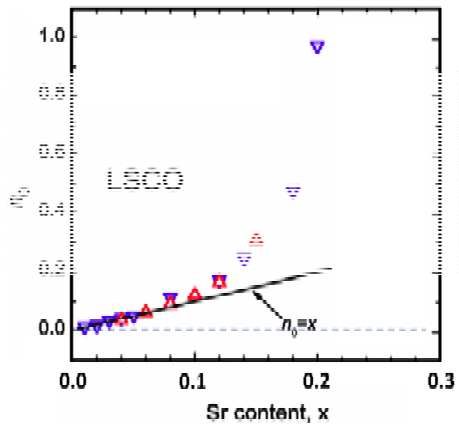

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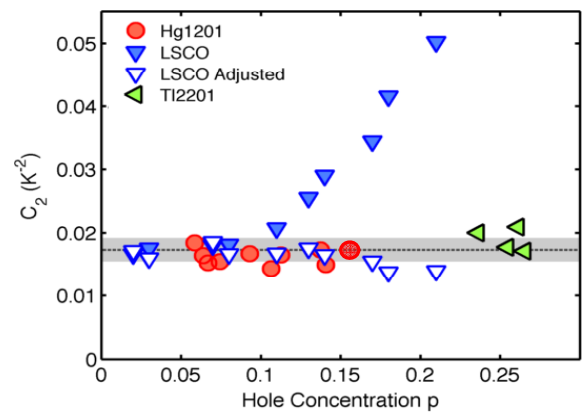
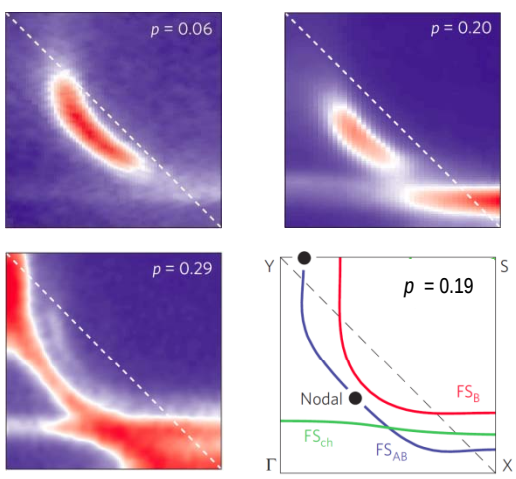


N. Barišić *et al.*,
arXiv:1507.07885 (2015)



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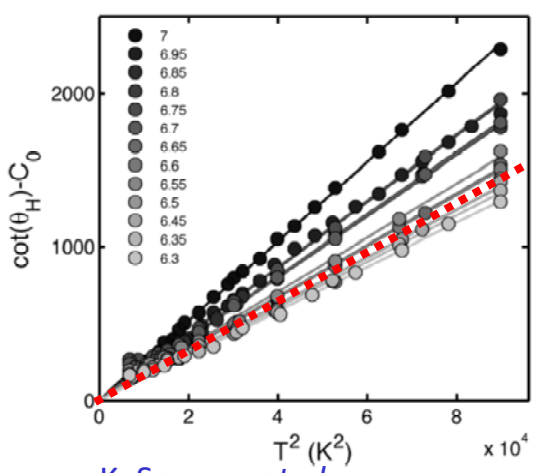
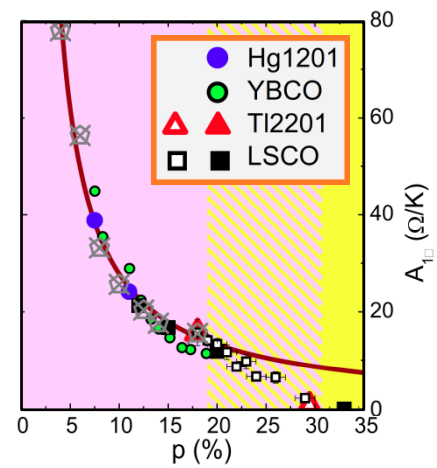


K. Segawa *et al.*,
Phys. Rev. B **69**, 104521 (2004).



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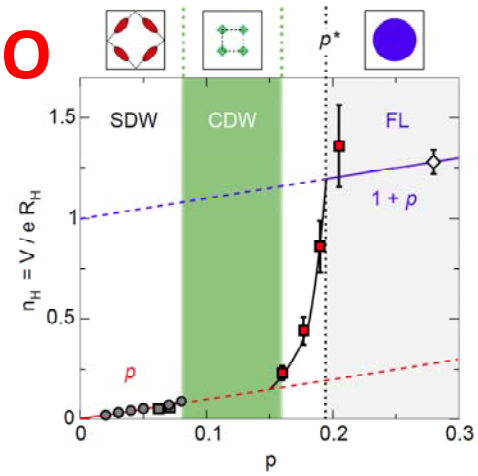

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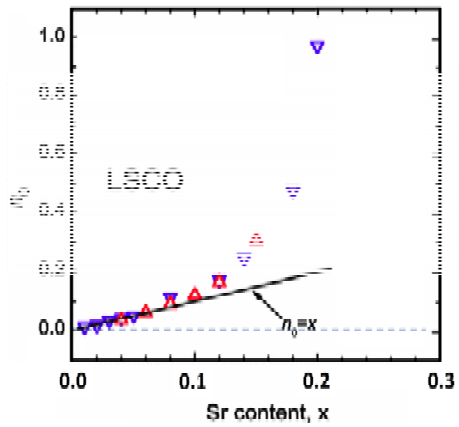
Nature **531**, 210 (2016)



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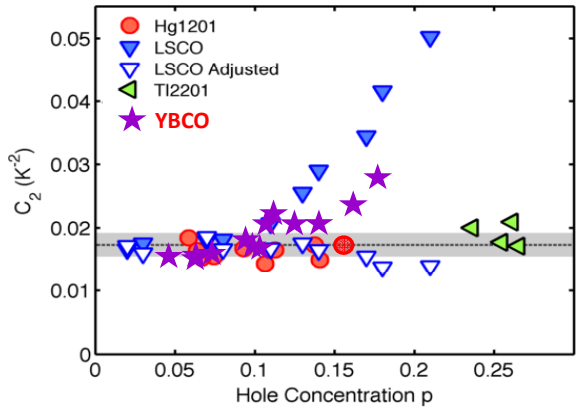
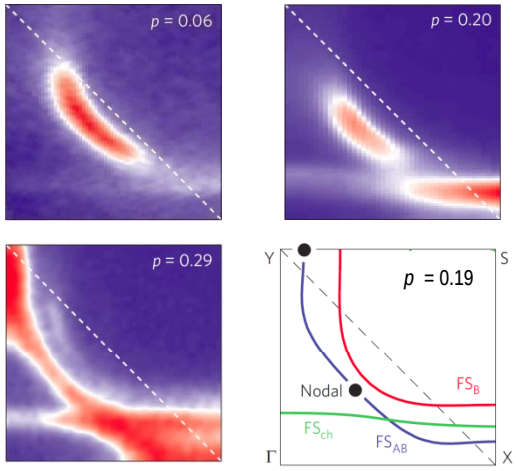


N. Barišić *et al.*,
arXiv:1507.07885 (2015)



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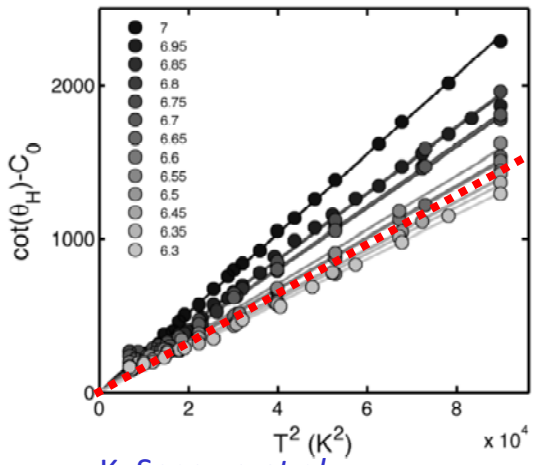

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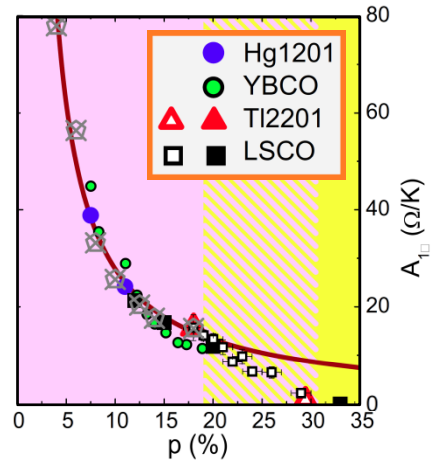
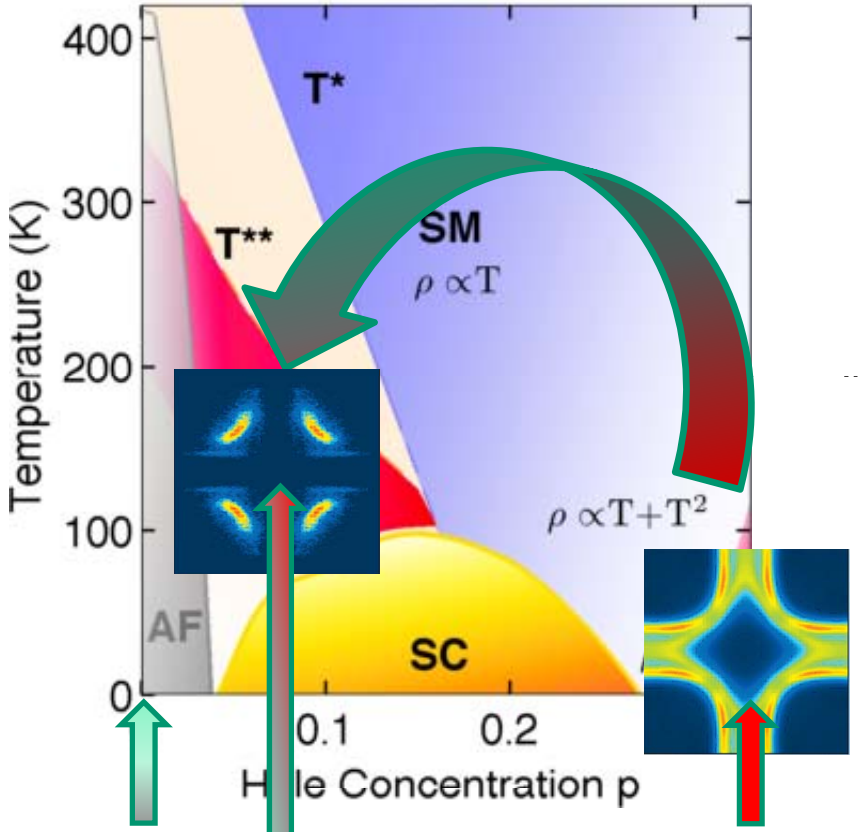


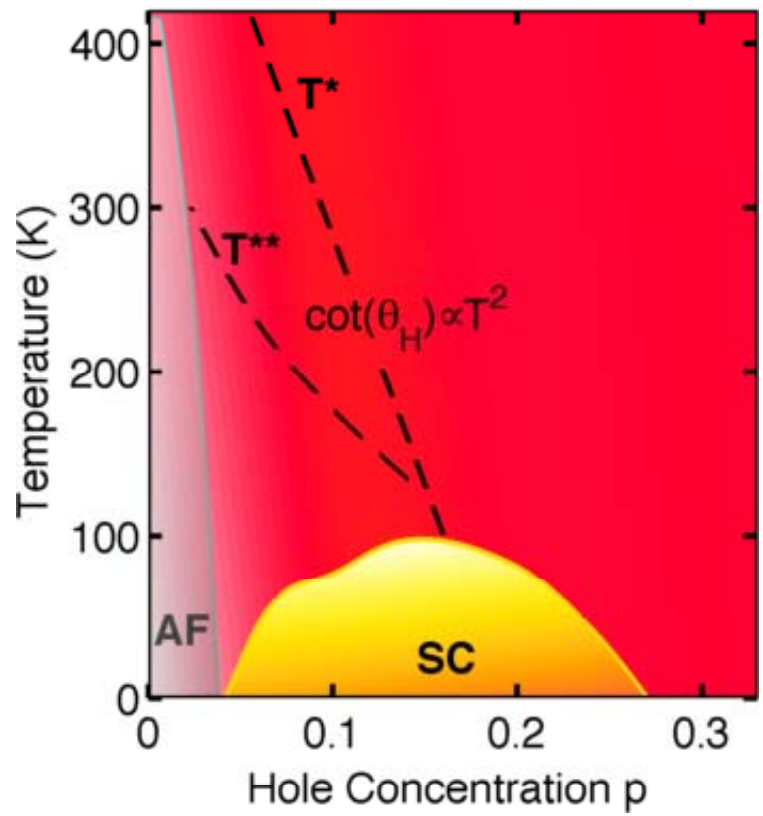
N. Barišić *et al.*,
PNAS **110**, 12235 (2013)

Conclusions

Resistivity $\rho = m^*/(n\, e^2 \tau)$



Scattering rate $\cot(\Theta_H) = C_2 T^2 \propto 1/\tau$



1 - localized hole

1 + *p* - Fermi liquid holes

1 + *p* { ***p*** - Fermi liquid holes; **1** - **localized** hole }

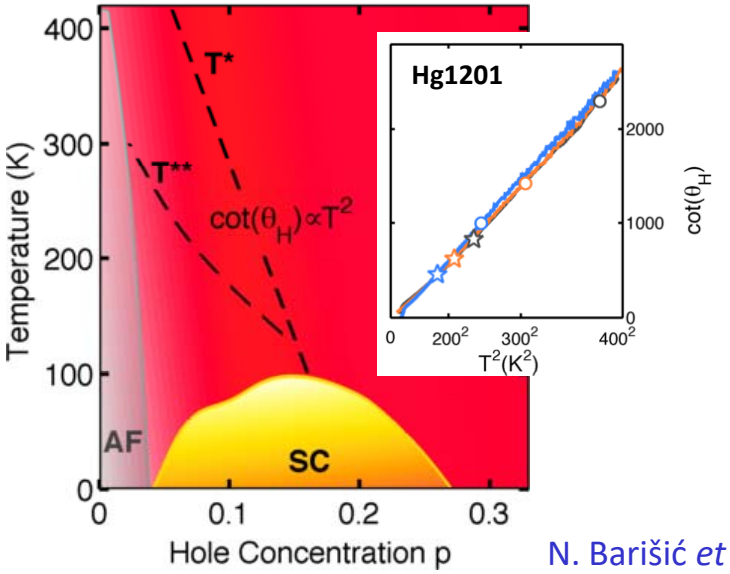
Preprint, submitted to *PRX* 2016

Localization of the ONE – GRADUAL!

4th topic addressed:
Quantum oscillations

Comment on the Quantum oscillations

– universal property of underdoped cuprates



Arcs

-**large** effective E_F

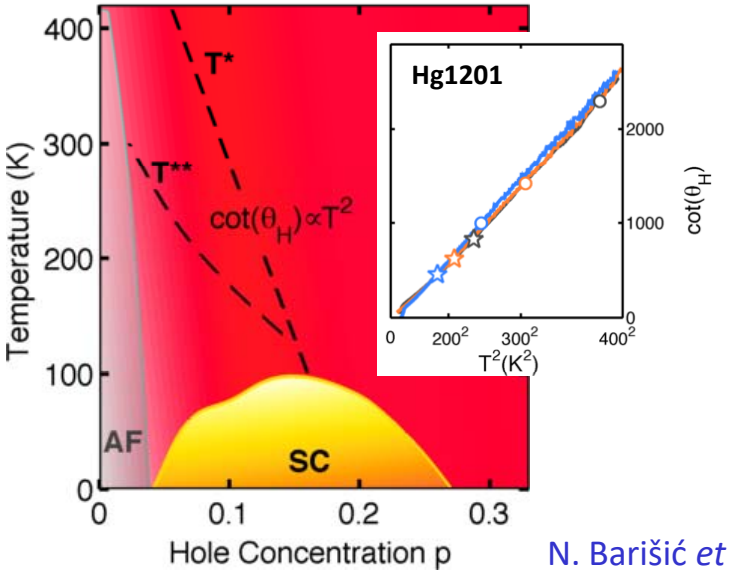
Pockets

-**small** E_F

N. Barišić *et al.*, *arXiv*:1507.07885 (2015)

Comment on the Quantum oscillations

– universal property of underdoped cuprates



N. Barišić *et al.*, *arXiv*:1507.07885 (2015)

Arcs

-**large** effective E_F

- v_F doping and compound independent

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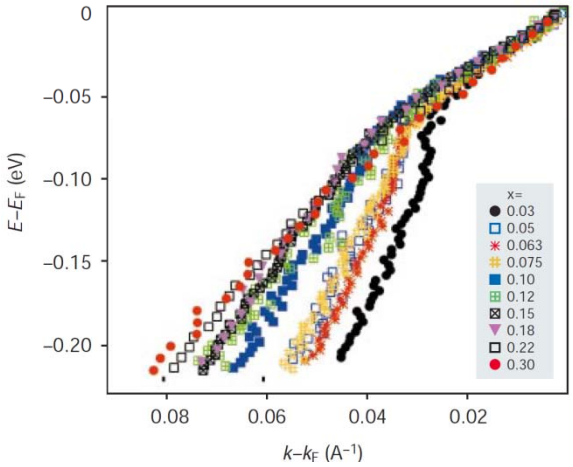
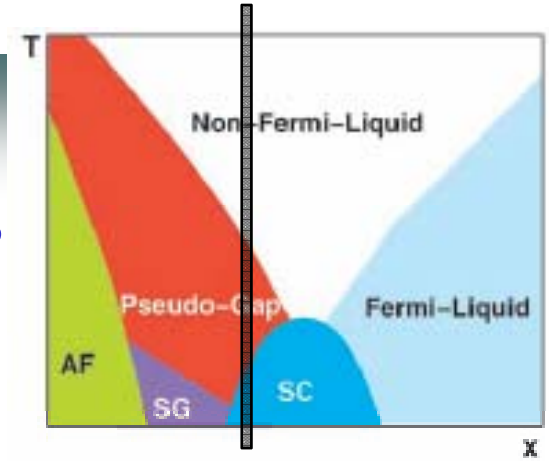
-**small** E_F

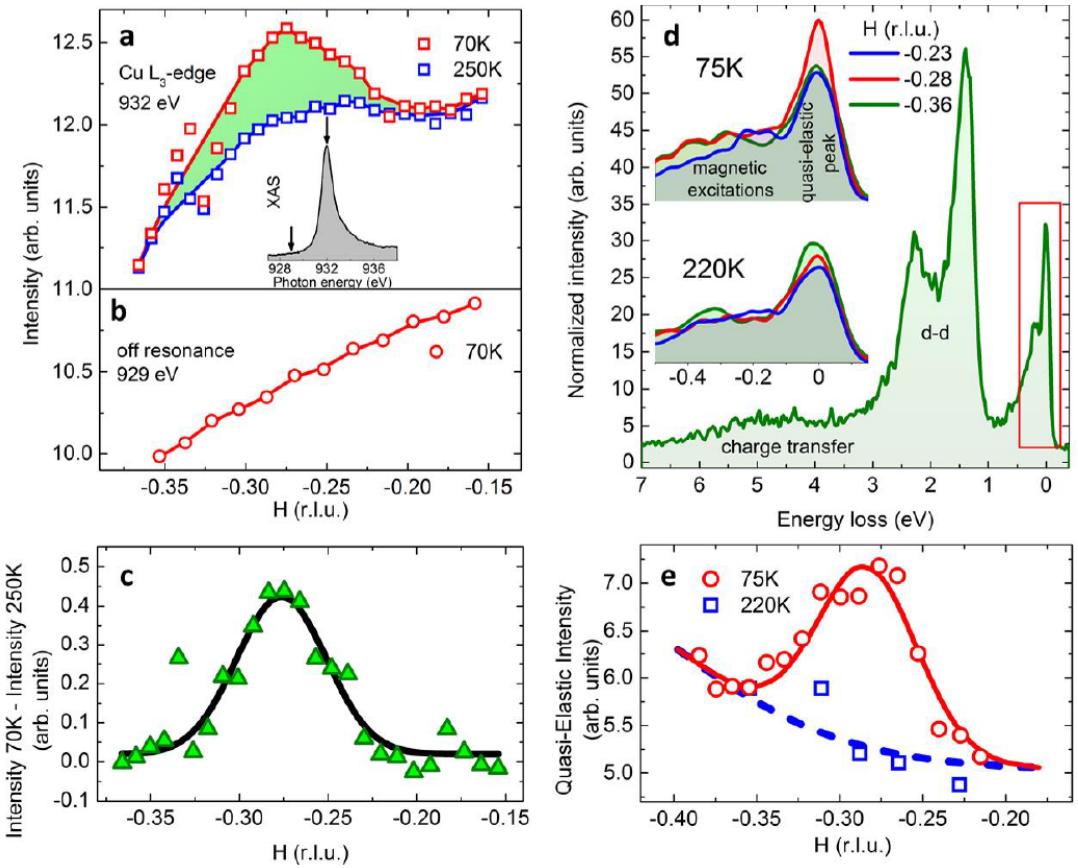


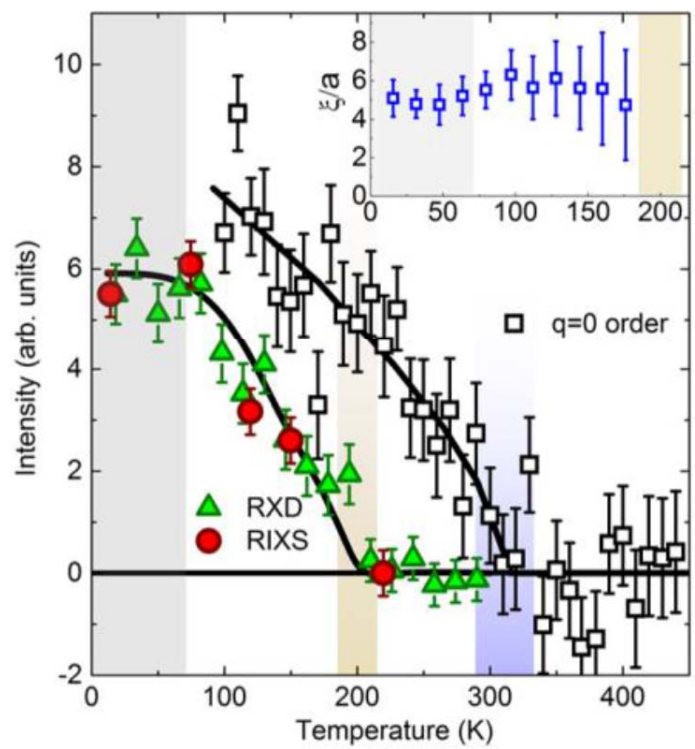
X. J. Zhou *et al.*, *Nature* **423**, 398 (2003)

→ arc to pocket transition expected

Resonant X-ray scattering
-Charge density wave correlations





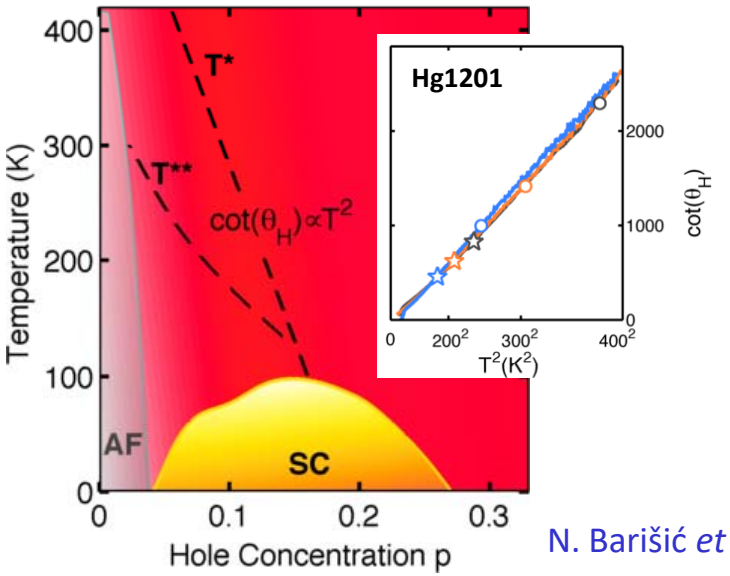


Field induced transition expected

W. Tabis *et al.*, *Nat. Comm.* **5**, 5875 (2014)

Comment on the Quantum oscillations

– universal property of underdoped cuprates



N. Barišić *et al.*, *arXiv*:1507.07885 (2015)

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Pockets

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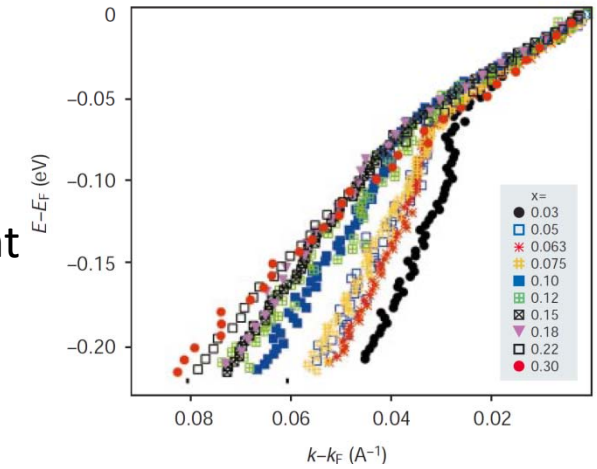
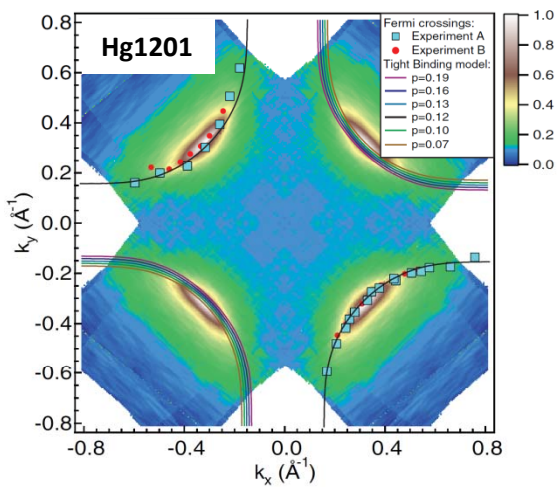


X. J. Zhou *et al.*, *Nature* **423**, 398 (2003)

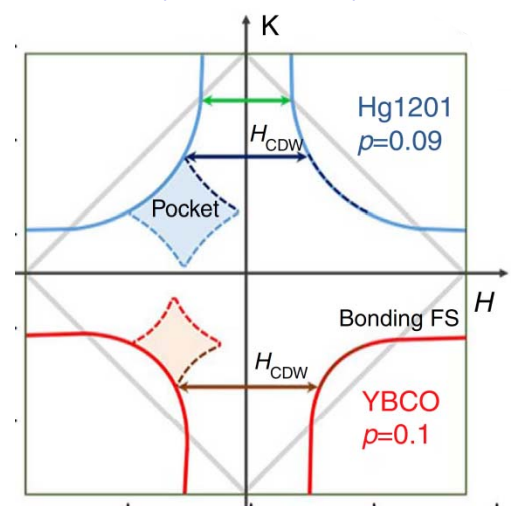


I. M. Vishik *et al.*, *Phys. Rev. B* **89**, 195141 (2014)

H_{CDW}

- Charge Density Wave vector

Single pocket expected



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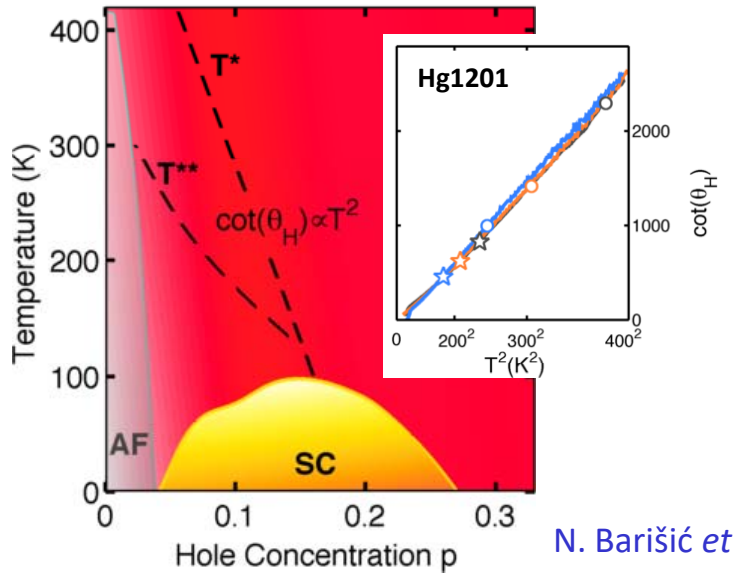
Comment on the Quantum oscillations

– universal property of underdoped cuprates



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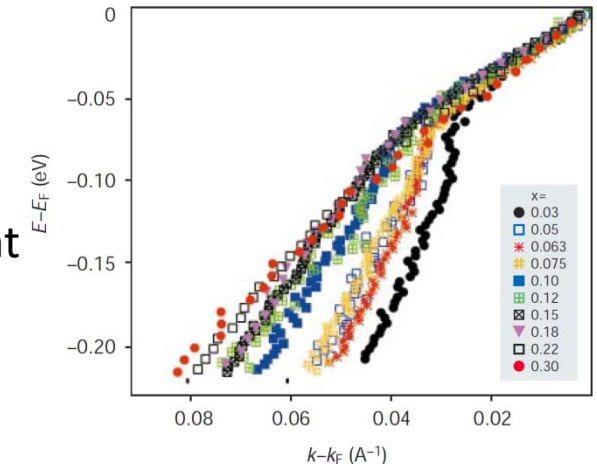

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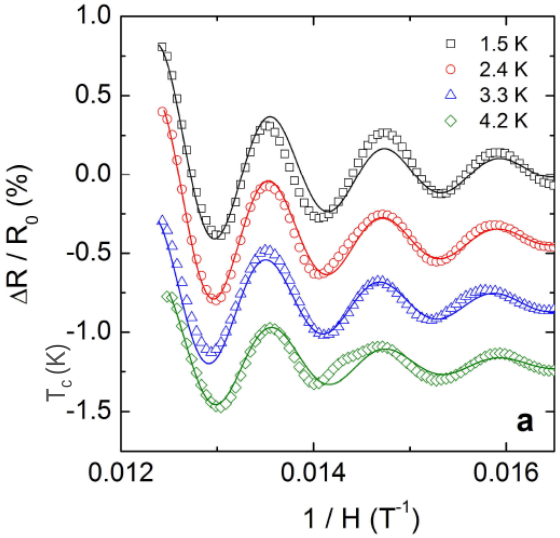
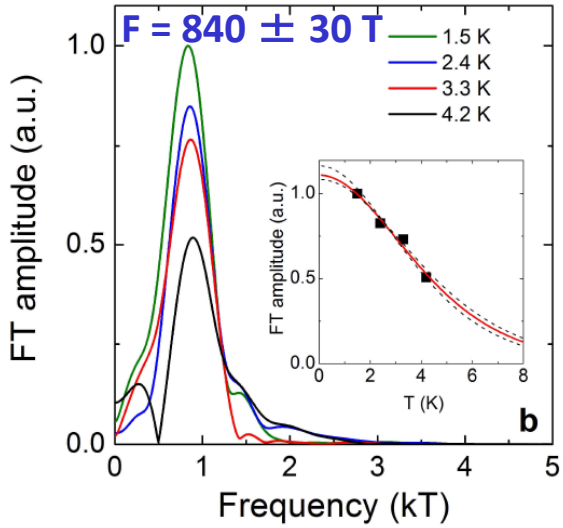




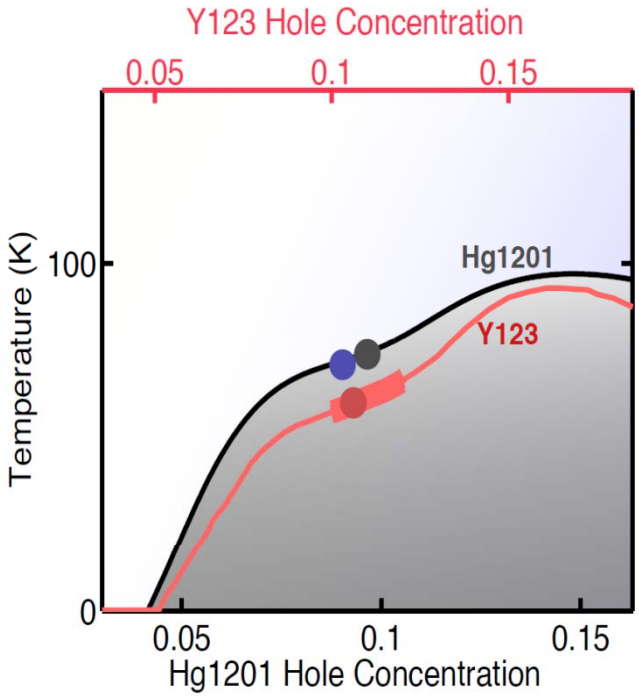
Solid lines correspond to Lifshitz-Kosevich fit.

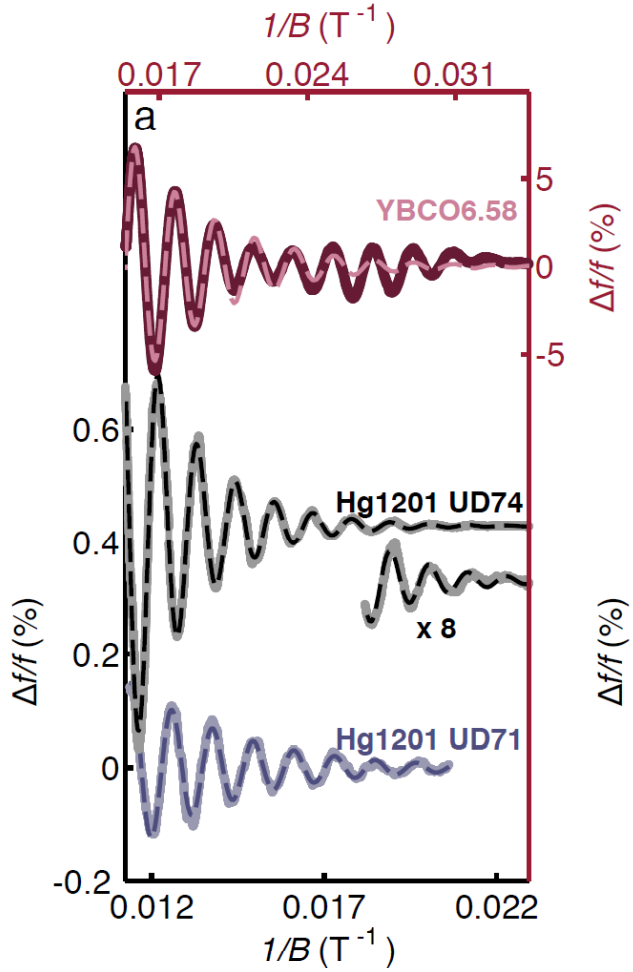
Fourier transform of the oscillatory part - only one peak is observed with temperature independent position.

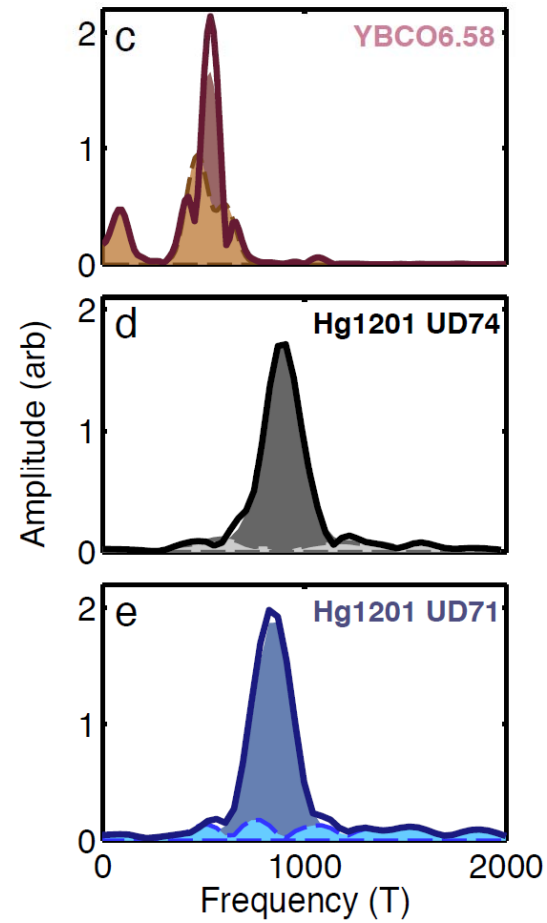
N. Barišić *et al.*, *Nat. Phys.* **9**, 761 (2013)

Comment on the Quantum oscillations

– single frequency





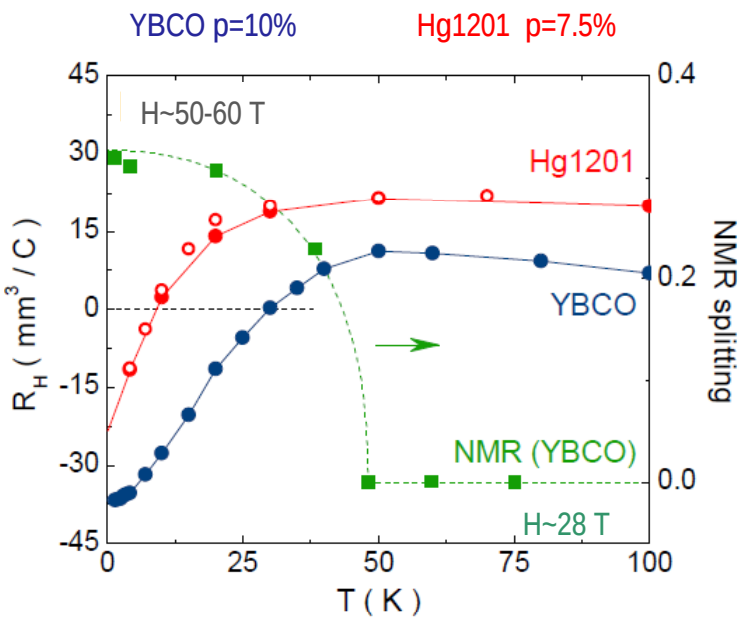


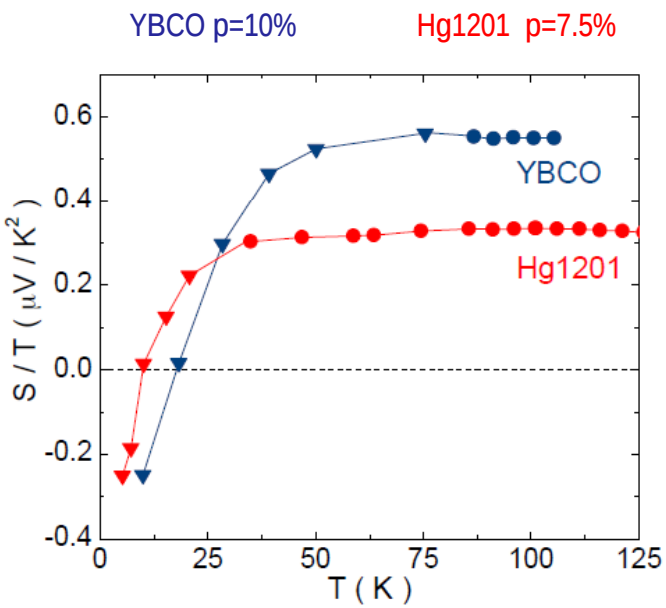
High- resolution measurements

Los Alamos – 100T

M. K. Chan *et al.*, *Nat. Comm.* (2016)

Hall, Seebeck, and Nernst Cofficients
- Fermi-Surface Reconstruction





N. Doiron-Leyraud *et al.*,
Phys. Rev. X **3**, 021019 (2013).

6th topic addressed:
(q=0) Magnetism

Neutron Scattering

- Triple-Axis Spectrometer

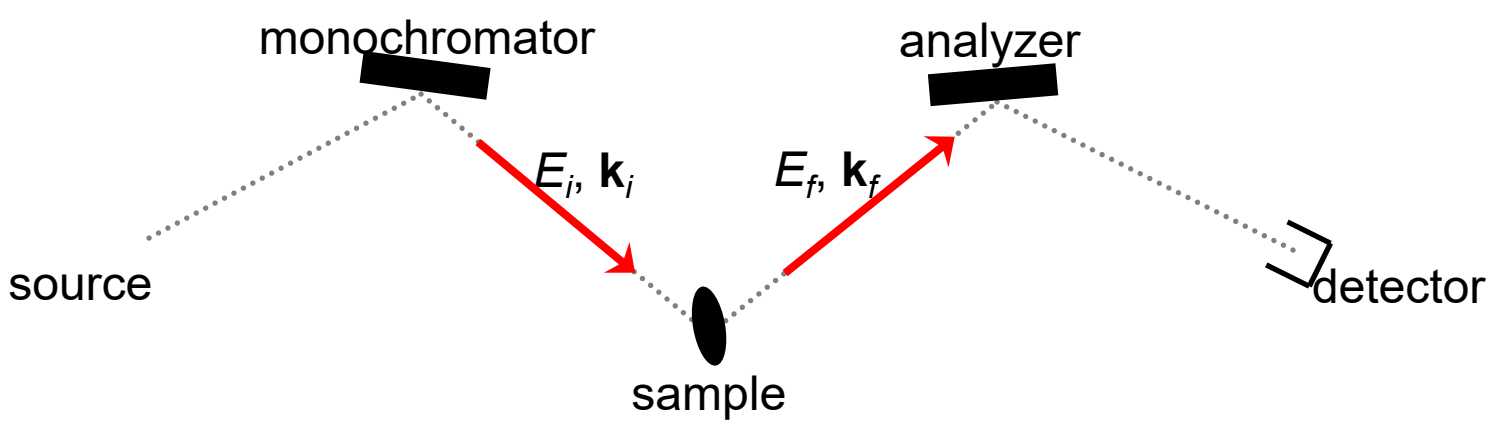
- Cross section proportional to $S(\mathbf{Q},\omega)$, the Fourier transform of the pair correlation function

$$\frac{d^2\sigma}{d\Omega dE_f} \propto S(\mathbf{Q},\omega)$$

Dynamic structure factor

$$S(\mathbf{Q},\omega) \propto \int \langle \rho(\mathbf{r},0)\rho(\mathbf{r}',t)\rangle e^{i(\mathbf{Q}\cdot(\mathbf{r}-\mathbf{r}')-\omega t)}\, d\mathbf{r}d\mathbf{r}'dt$$

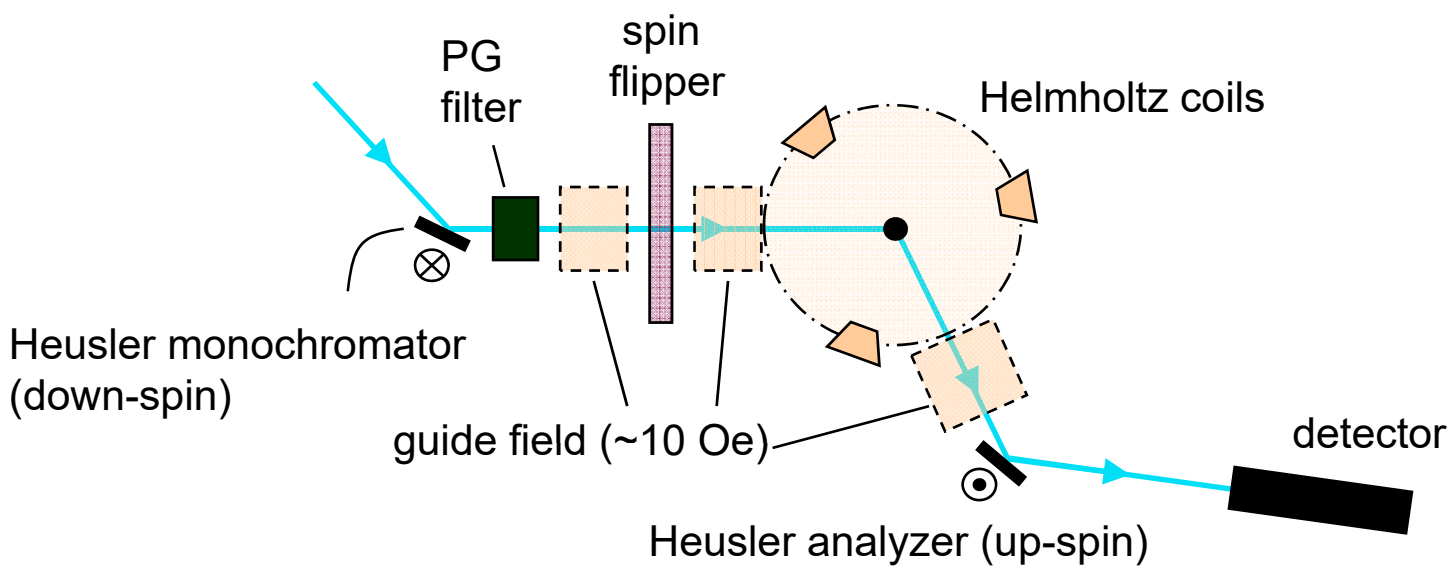
- Momentum transfer $\mathbf{Q} = \mathbf{k}_i - \mathbf{k}_f$ and energy transfer $\hbar\omega = E_i - E_f$
- Geometry for triple-axis neutron scattering:



Neutron Scattering

- Polarized Neutrons

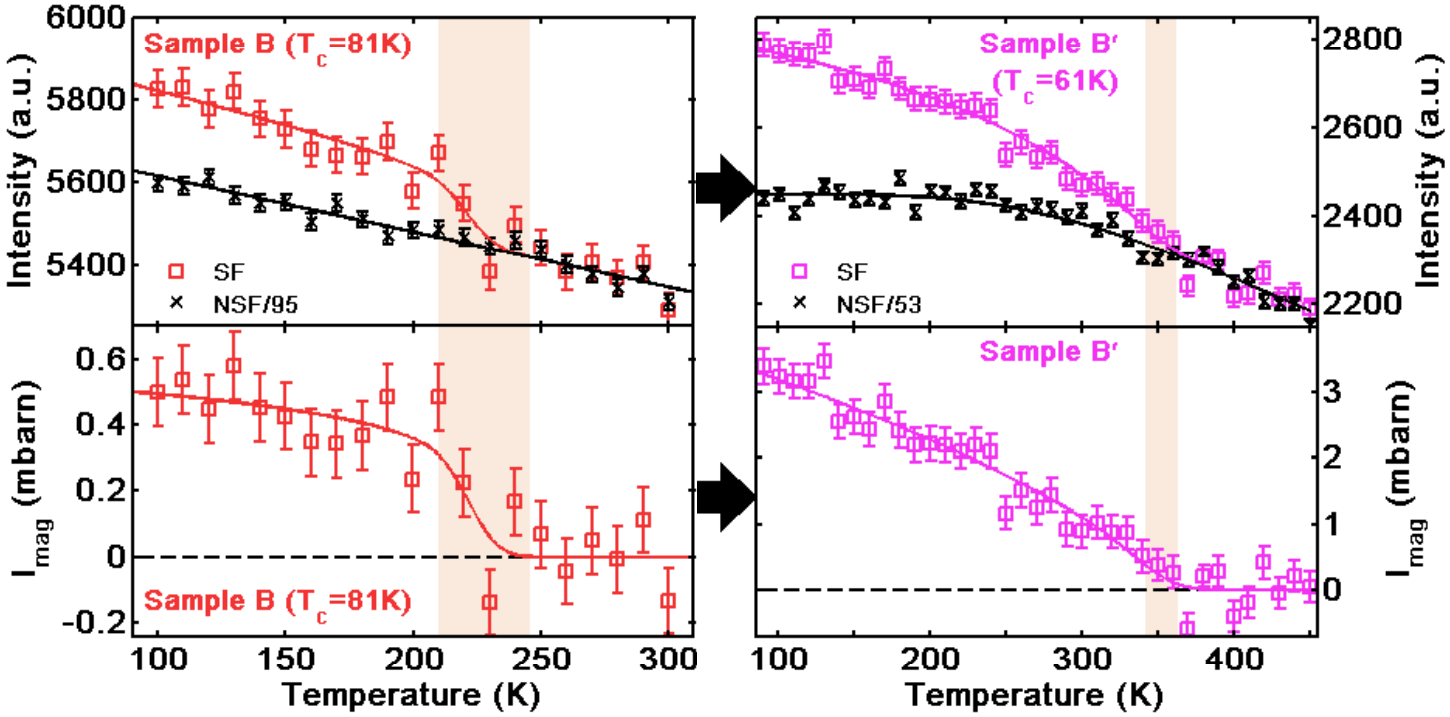
- Polarization analysis: magnetic vs. nuclear scattering
- $\mathbf{Q} = \mathbf{k}_i - \mathbf{k}_f$; $\hbar\omega = E_i - E_f$
- Measure moment component perpendicular to both **Q** and polarization **P**
- For **P** || **Q**, magnetic scattering occurs in spin-flip channel only
- Cold 3-axis instrument (4F1) at LLB used for diffraction (E_i = 14.7 meV):

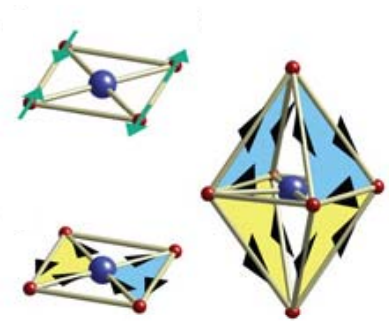


Pseudogap

- “hidden” magnetic order

Nuclear Bragg peak (1 0 1)



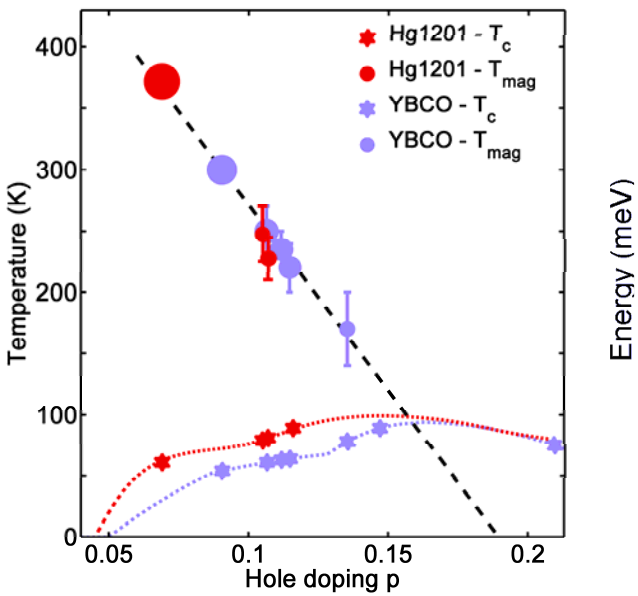


In agreement with previous measurements on YBCO

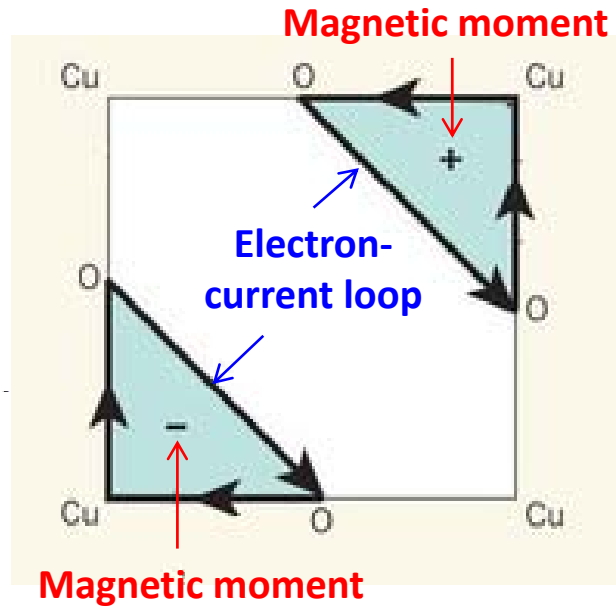
Fauqué *et al*., PRL (2006)

Y. Li, V. Balédent, N. Barišić, et al., Nature (2008)

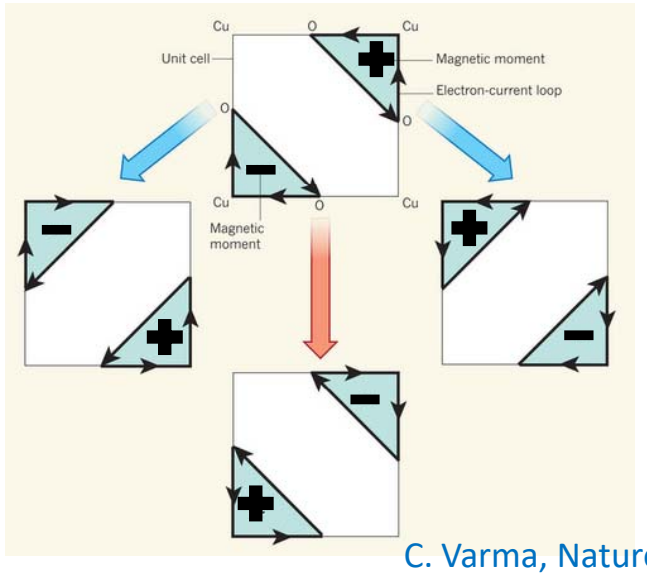
Universal Magnetism in the Pseudogap



Energy (meV)



- Universal magnetic order associated with pseudogap



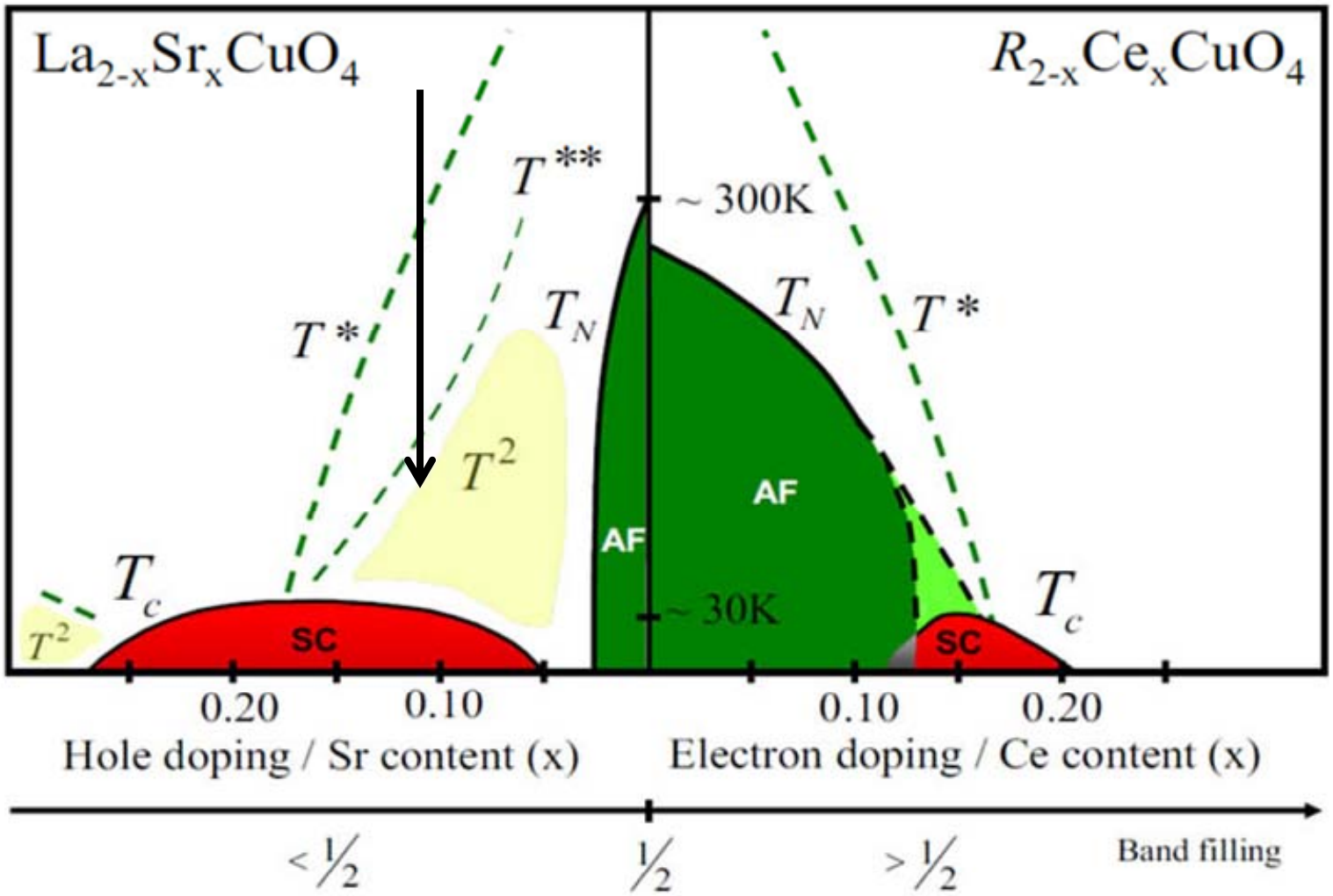
B. Fauque et al., *Phys. Rev. Lett.* **96**, 197001 (2006).

Y. Li , V. Balédent, N. Barišić, et al., *Nature* **455**, 372 (2008)

C. Varma, Nature 468, 184 (2010)

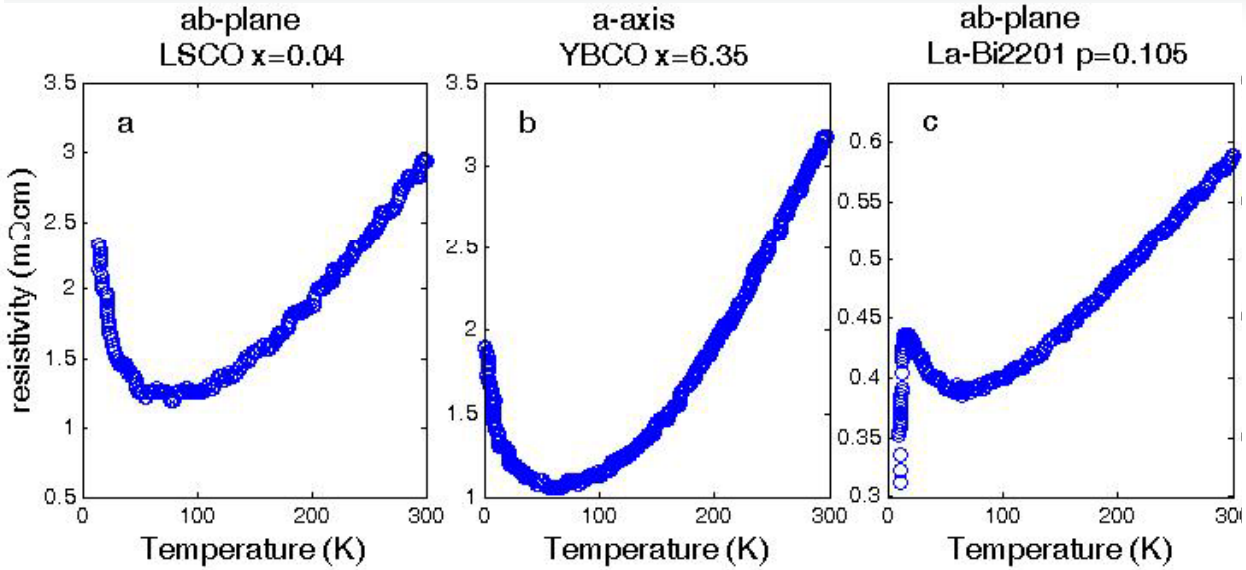
7th topic addressed:
Electron doped cuprates

Phase diagram



Armitage, Fournier and Greene, Rev. Mod. Phys. (2010)

Resistivity: underdoped regime



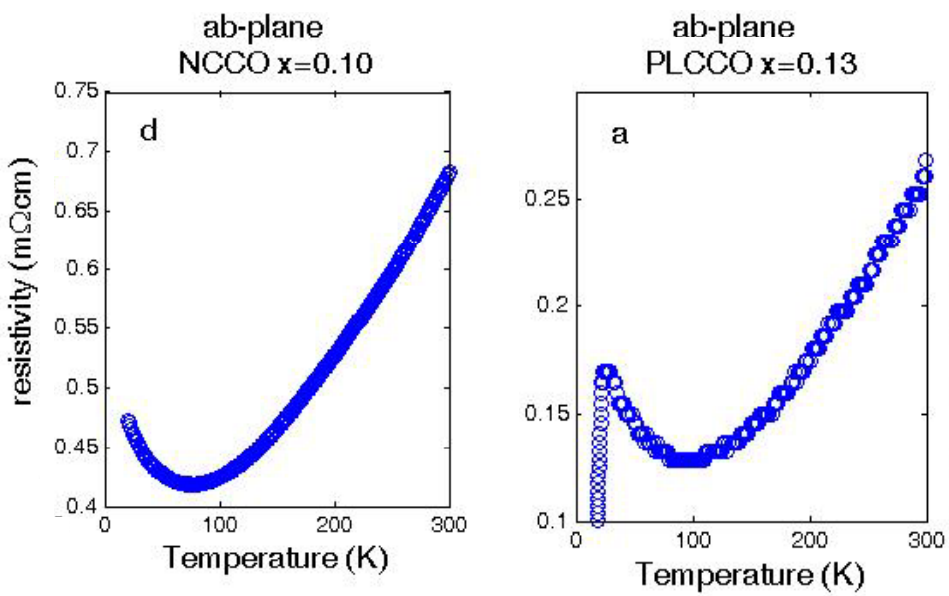
LSCO: $La_{2-x}Sr_xCuO_4$

YBCO: $YBa_2Cu_3O_{6+\delta}$

LYCO : $La_{2-x}Y_xCuO_4$

La-Bi2201 : $Bi_2Sr_{2-x}La_xCuO_{6+\delta}$

Hg1201: $HgBa_2CuO_{4+\delta}$



NCCO: $Nd_{2-x}Ce_xCuO_{4-\delta}$

PCCO: $Pr_{2-x}Ce_xCuO_{4-\delta}$

SCCO: $Sm_{2-x}Ce_xCuO_{4-\delta}$

PLCCO: $Pr_{1.3-x}La_{0.7}Ce_xCuO_{4-\delta}$

Resistivity: upturn

(1) Anderson (strong) localization--disorder

(2) Variable Range Hopping

Mott VRH

Efros-Shklovskii VRH--Coulomb interaction

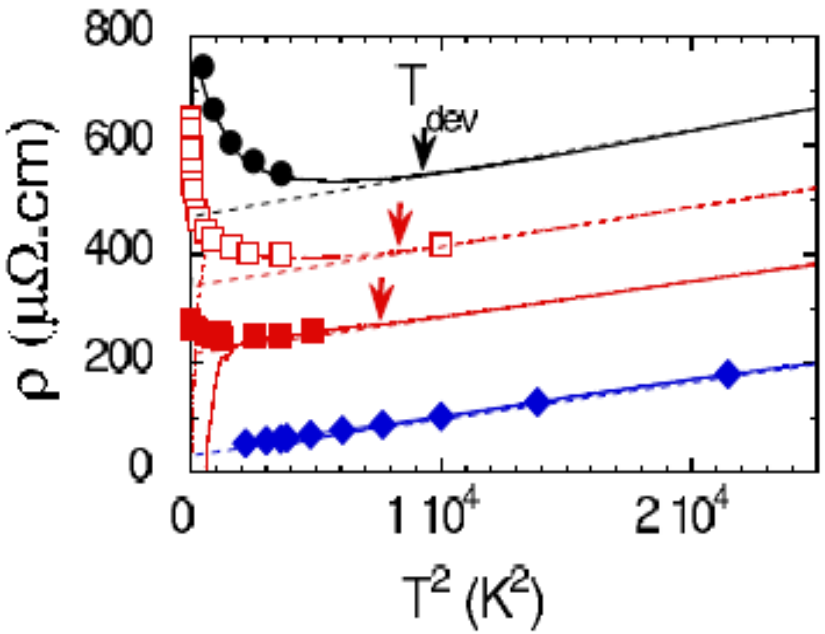
(3) Weak localization--quantum interference

(4) Kondo Effect--magnetic impurities

(5) Scattering with spin/charge order

etc.

Electron irradiation: upturns



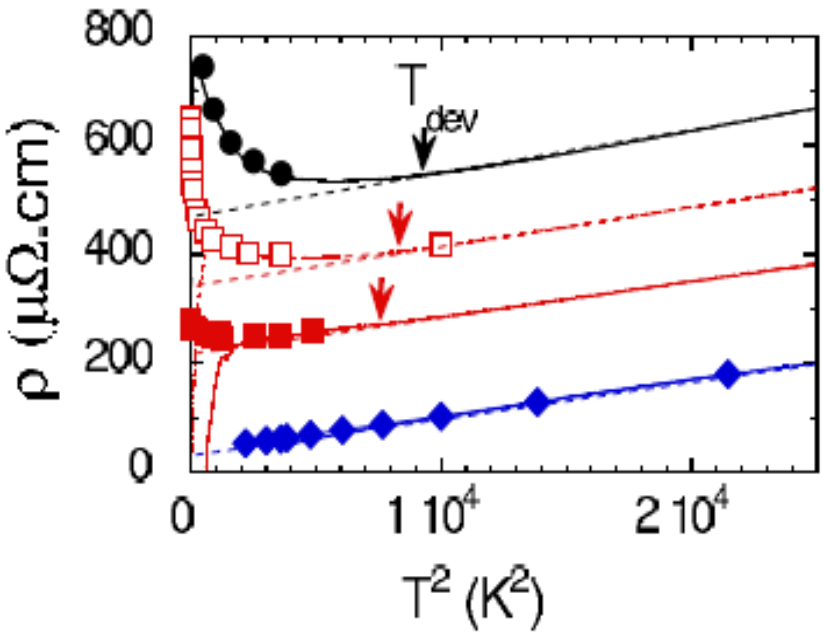
$YBa_2Cu_3O_{6+\delta}$

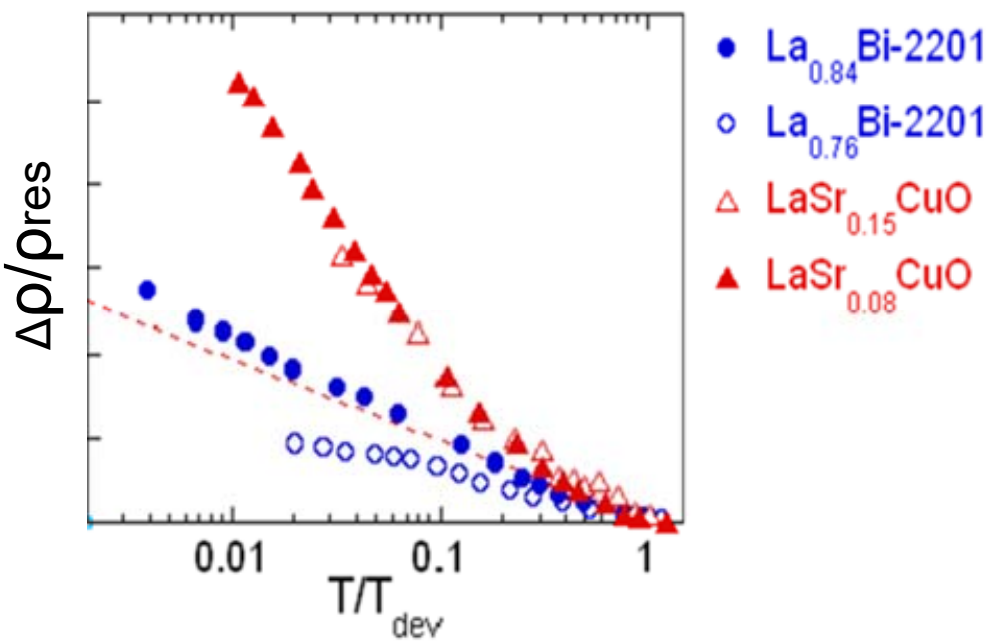
Rullier-Albenque *et al.,* Euro. Phys. Lett. (2008)

Electron irradiation: upturns

$$\rho = \rho_{res} + A_2 T^2 + \Delta\rho$$

$$\Delta\rho \sim -\log(T / T_{\log})$$

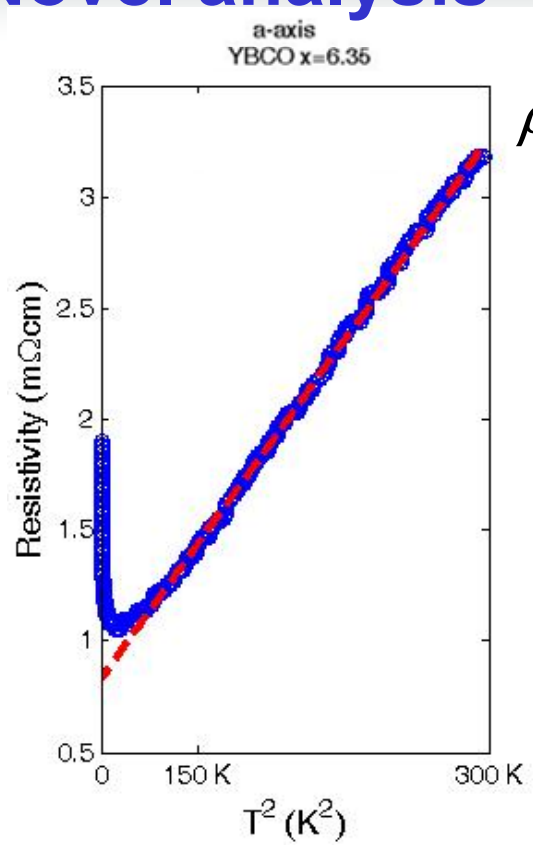




$YBa_2Cu_3O_{6+\delta}$

Rullier-Albenque *et al.,* Euro. Phys. Lett. (2008)

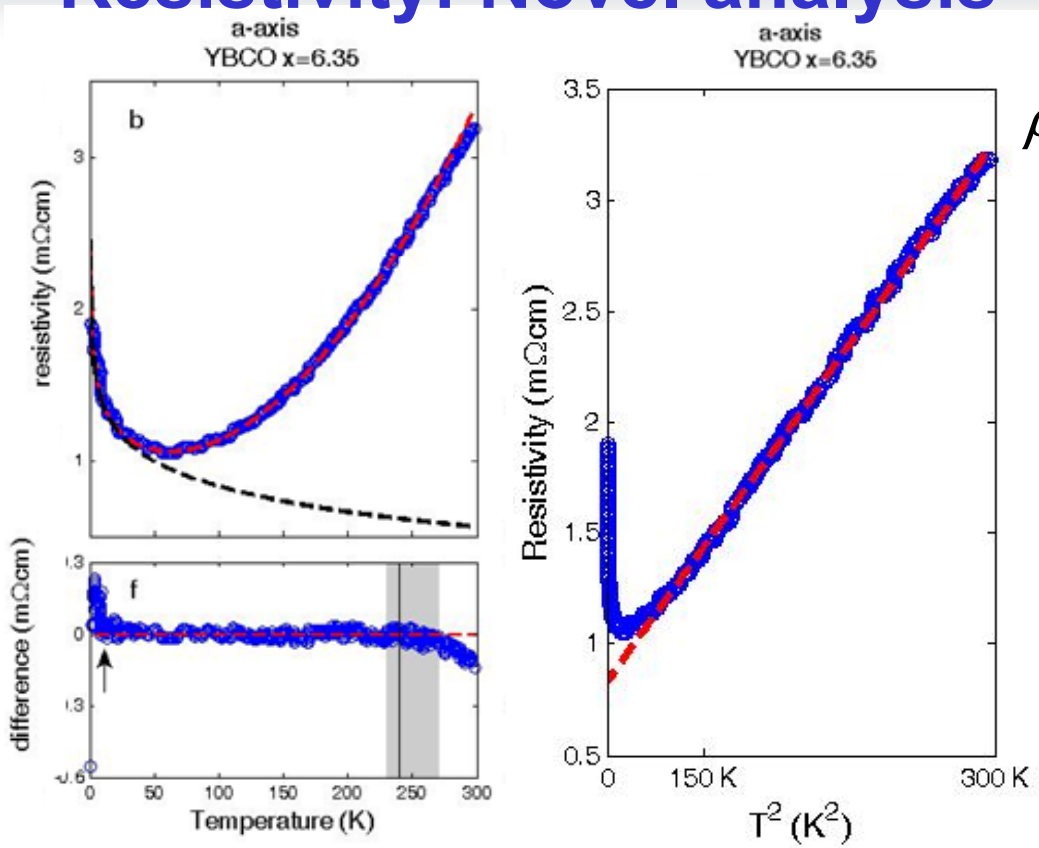
Resistivity: Novel analysis



$$\rho = \rho_{res} + A_2 T^2$$

Y. Li et al., PRL 117, 197001 (2016)

Resistivity: Novel analysis



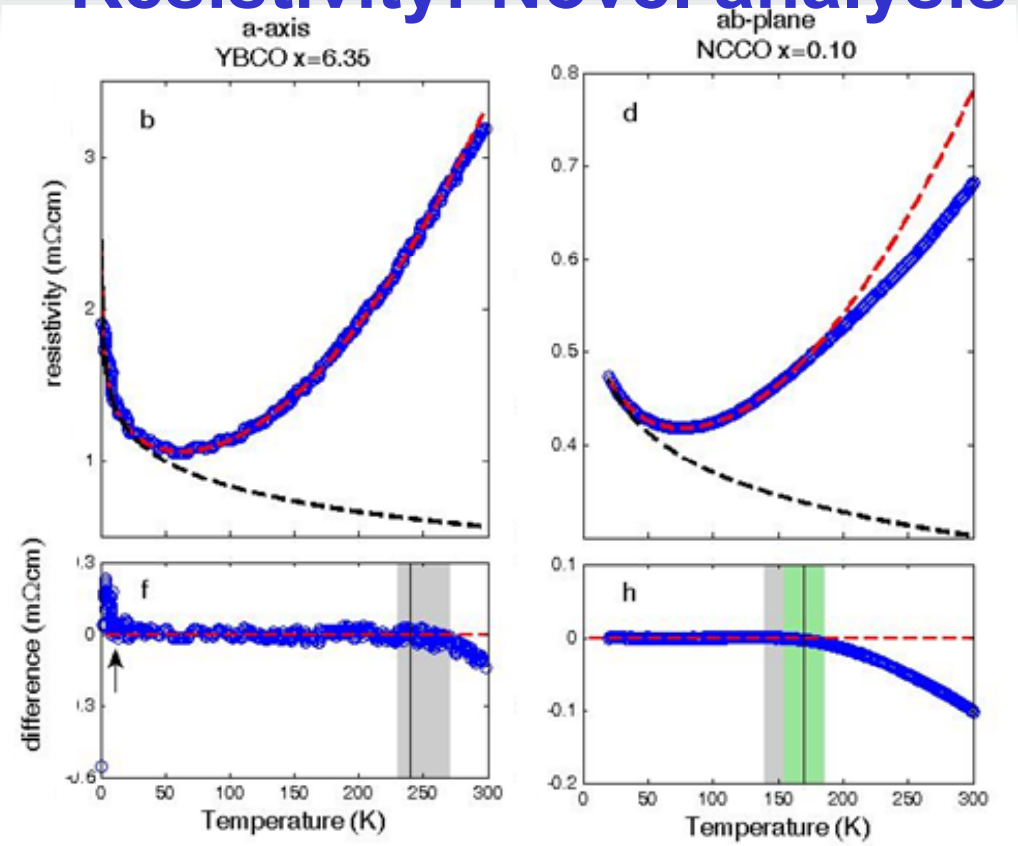
$$\rho = \rho_{res} + A_2 T^2$$

$$\rho = \rho_{res} - A_{\log} \log(T / T_{\log}) + A_2 T^2$$

$$\rho = \rho_{res} + A_{\log} \log(T_{\log} / 1K) - A_{\log} \log(T / 1K) + A_2 T^2$$

$$\rho = A_0 - A_{\log} \log(T / 1K) + A_2 T^2$$

Resistivity: Novel analysis

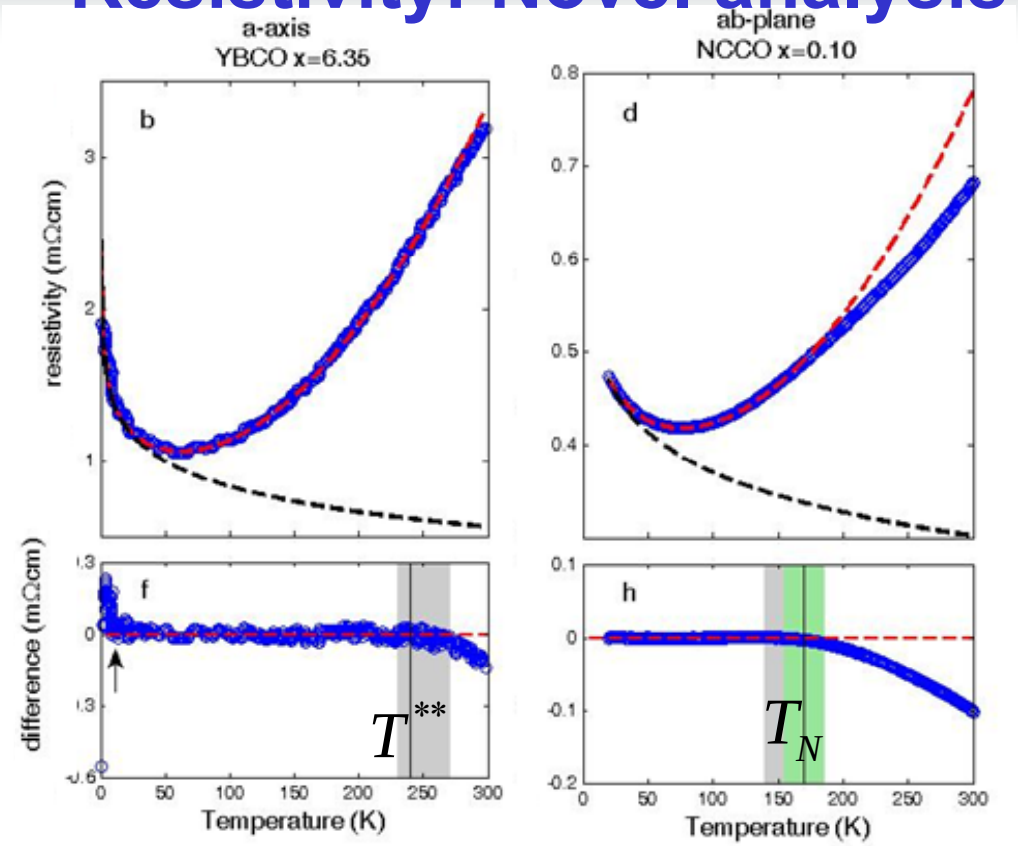


$$\rho = \rho_{res} - A_{\log}\log(T/T_{\log}) + A_2 T^2$$

$$\rho = \rho_{res} + A_{\log}\log(T_{\log}/1K) - A_{\log}\log(T/1K) + A_2 T^2$$

$$\rho = A_0 - A_{\log}\log(T/1K) + A_2 T^2$$

Resistivity: Novel analysis

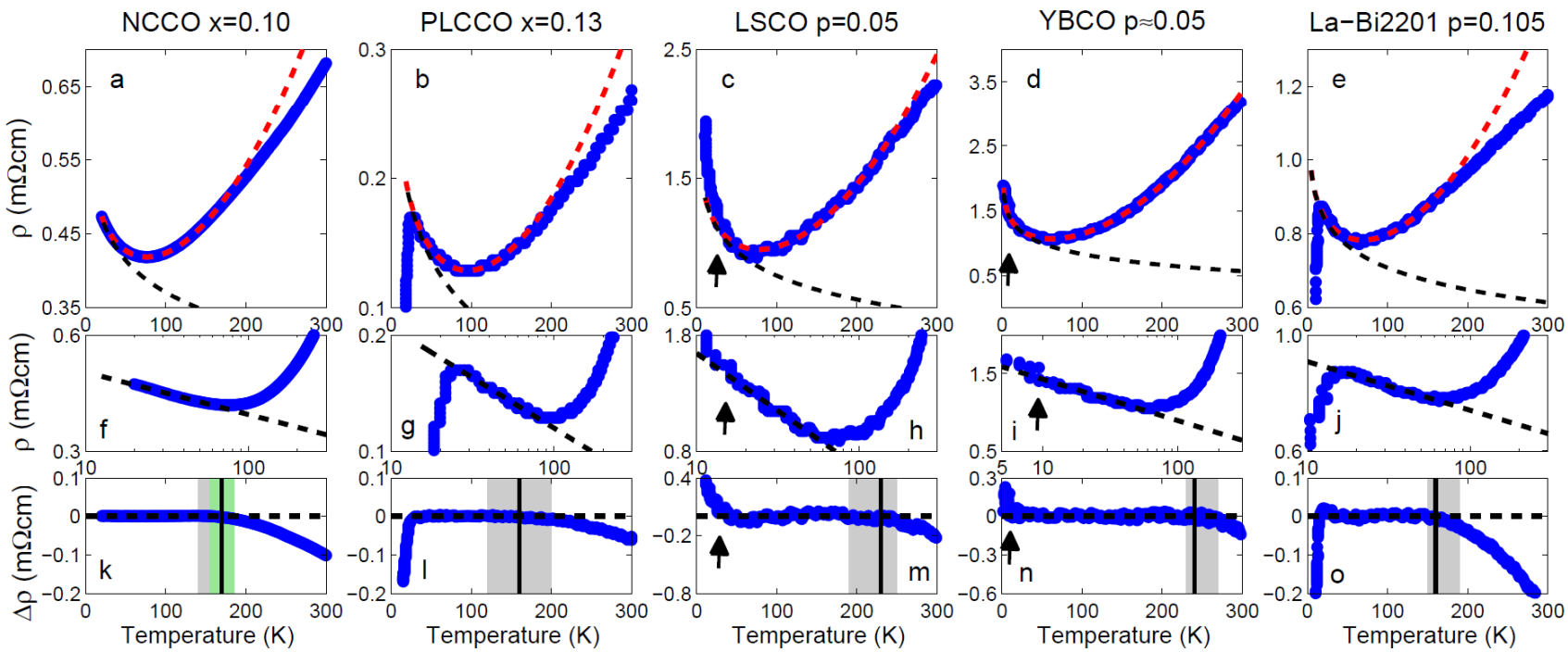


$$\rho = \rho_{res} - A_{\log}\log(T/T_{\log}) + A_2T^2$$

$$\rho = \rho_{res} + A_{\log}\log(T_{\log}/1K) - A_{\log}\log(T/1K) + A_2T^2$$

$$\rho = A_0 - A_{\log}\log(T/1K) + A_2T^2$$

Resistivity: Novel analysis

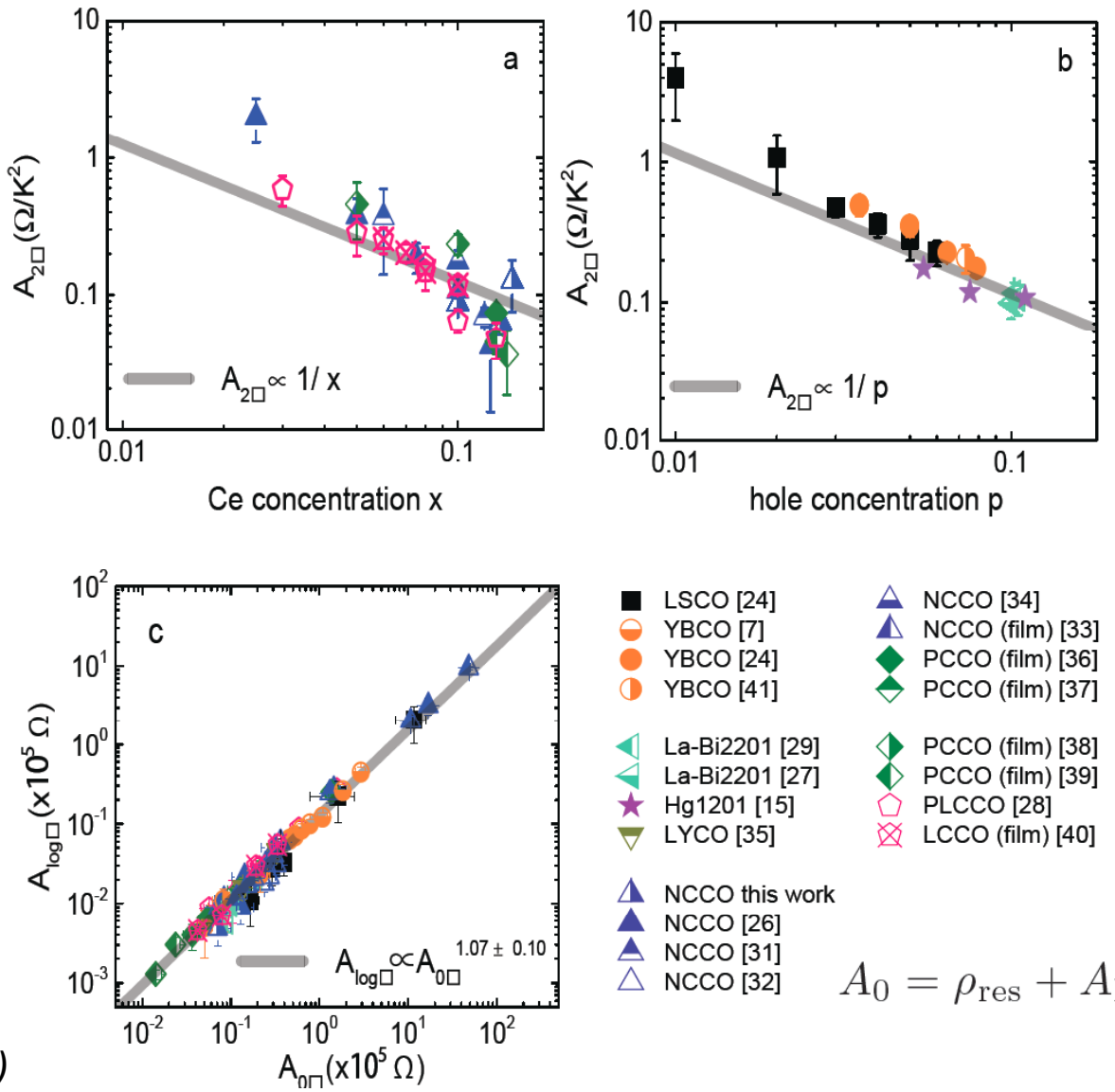


$$\rho = A_0 - A_{\log} \log(T/1\mathrm{K}) + A_2 T^2$$

$A_0 - A_{\log} \log(T/1\mathrm{K})$ - black dashed lines

Y. Li et al., PRL 117, 197001 (2016)

Doping/compound dependecies



$$A_0 = \rho_{\rm res} + A_{\rm log} \log(T_{\rm log}/1{\rm K})$$

Y. Li et al., PRL 117, 197001 (2016)

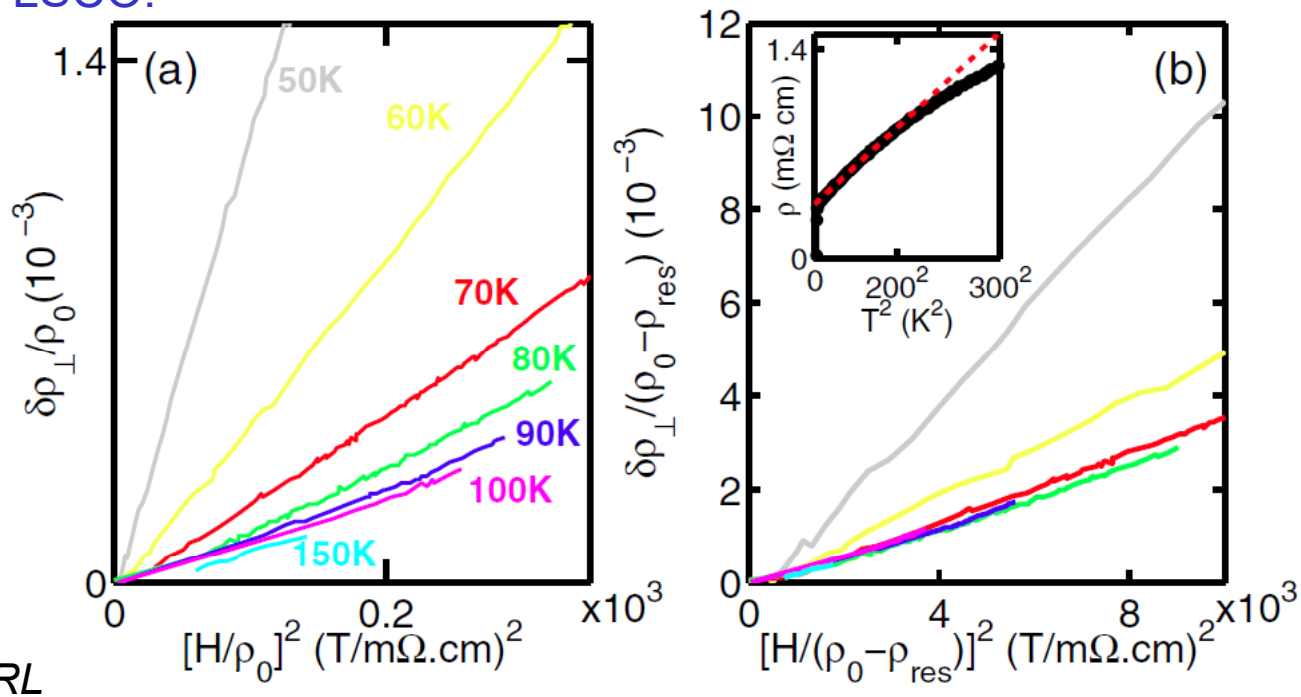
Matthiessen's rule vs. phase separation

$$\rho = A_0 - A_{\log}\log(T/1\mathrm{K}) + A_2 T^2$$

$$1/\tau_{total} = 1/\tau_1 + 1/\tau_2 + ..$$

Matthiessen's rule or serial resistor network?

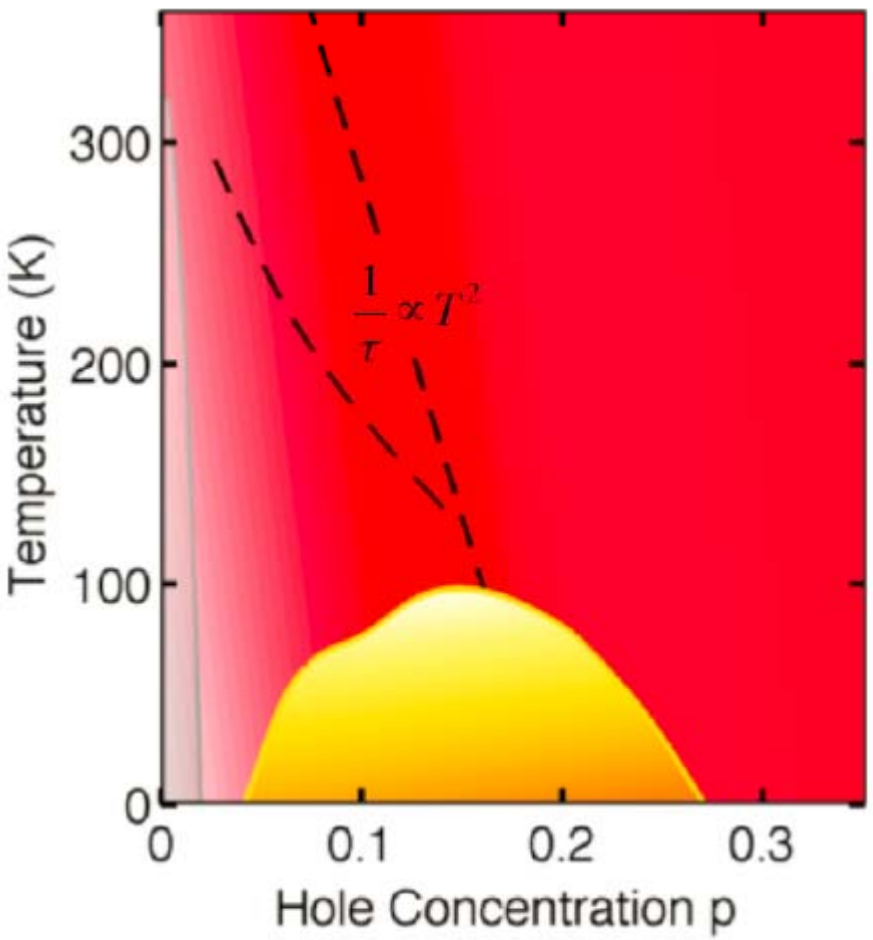
Kohler's rule in LSCO:

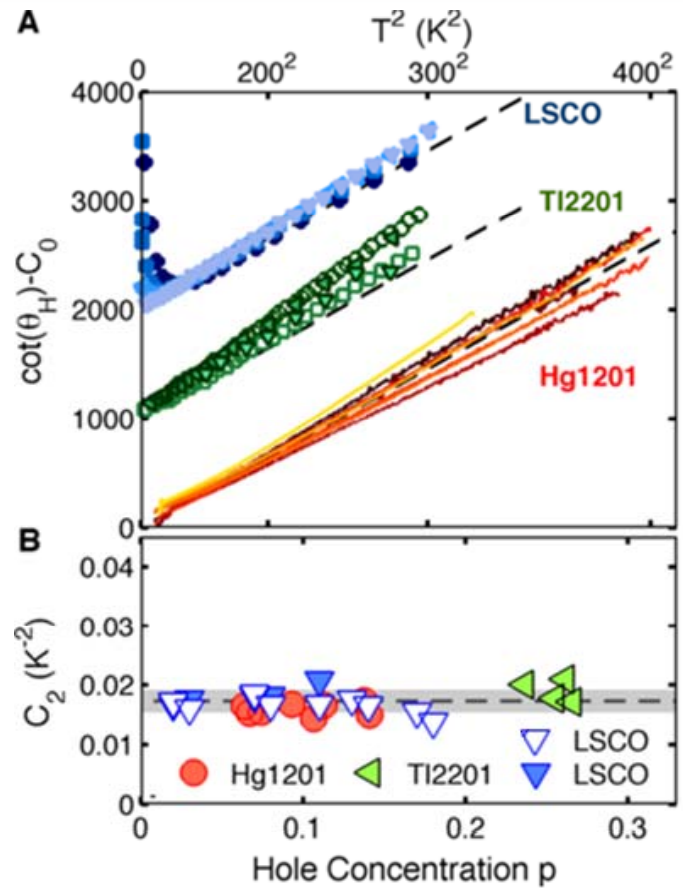


M. K. Chan et al., PRL 113, 177005 (2014)

Hole-doped cuprates

Scattering rate $\cot(\Theta_H) = C_2 T^2 \propto 1/\tau$





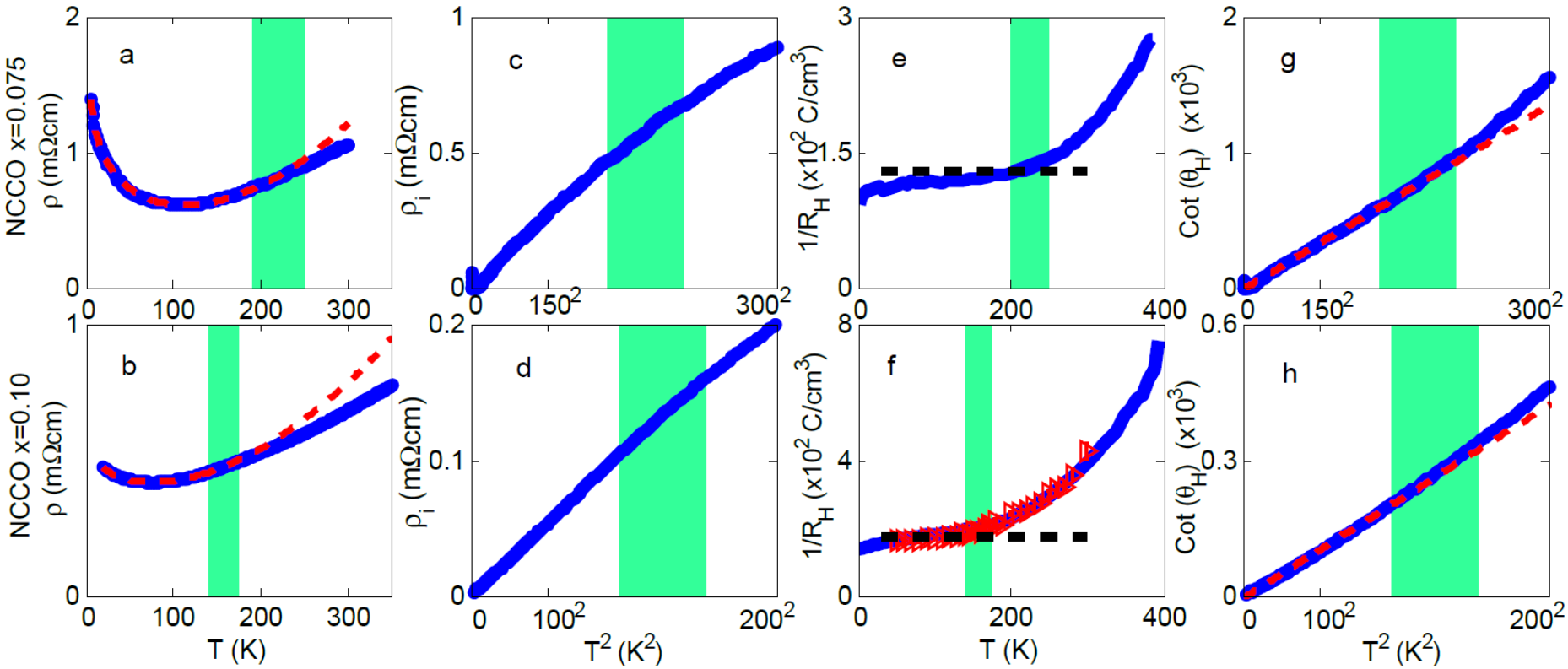
- Fermi-liquid scattering rate across T*
- independent of doping and compound

Barišić et al., arXiv:1507.07885

Electron-doped cuprates

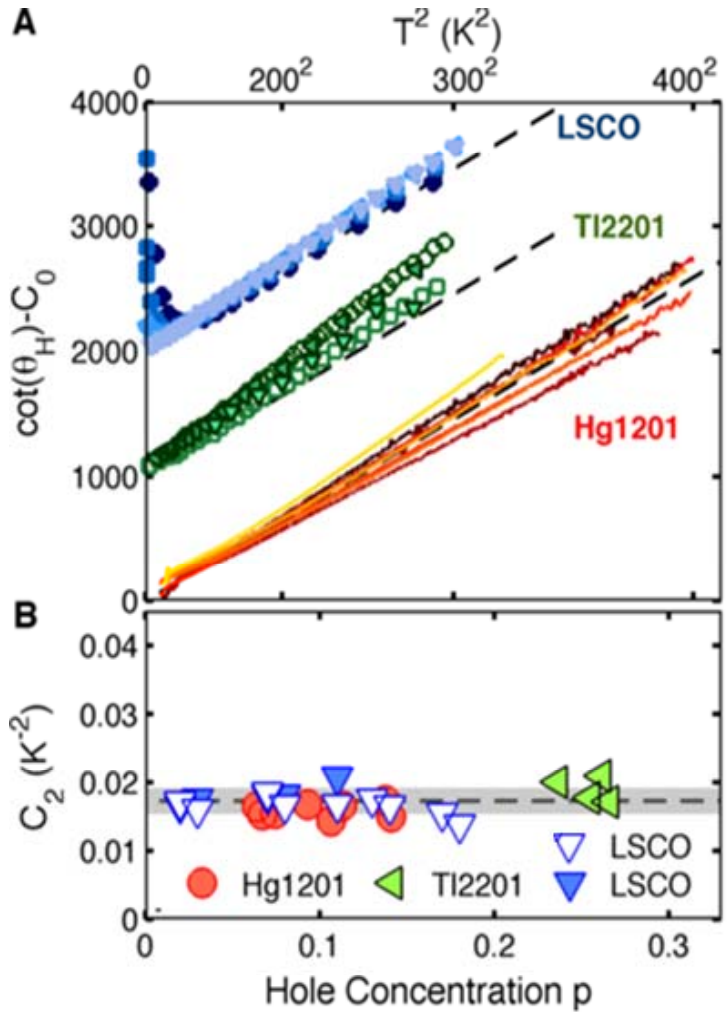
$$\cot\theta_H = \frac{\rho}{BR_H} \propto \frac{m^*}{\tau}$$

$$\rho = A_0 - A_{\log}\log(T/1K) + A_2 T^2$$

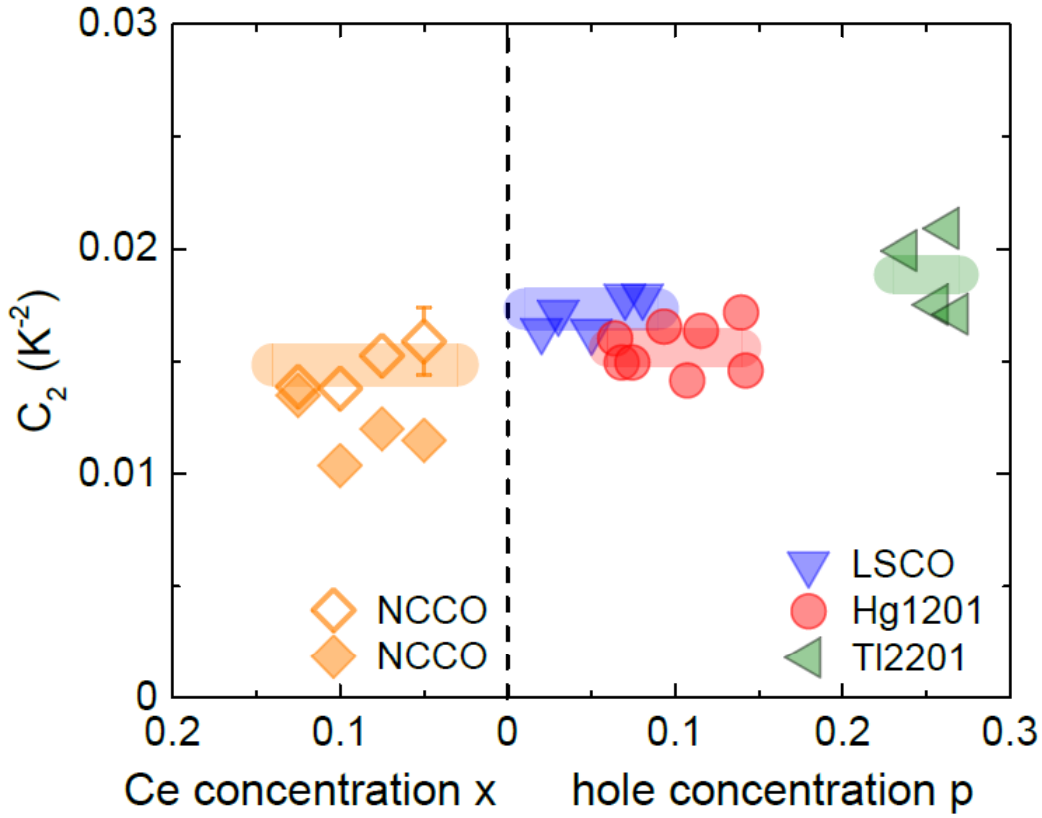


Y. Li et al., PRL 117, 197001 (2016)

Universal planar scattering rate



Scattering rate $\cot(\Theta_H) = C_2 T^2 \propto m^*/\tau$



Y. Li et al., PRL 117, 197001 (2016)

Disclaimer ☺

I do not wish to imply that the cuprates are trivial!

The observation of a protected Fermi-liquid transport scattering rate in an **inherently inhomogeneous** system that exhibits **strong correlations** with a **carrier density that varies with temperature** (localization of one carrier per planar copper) and results in **arcs** remains a challenge to capture theoretically.

Effective Fermi energy is large ($E_F >> k_B T$).

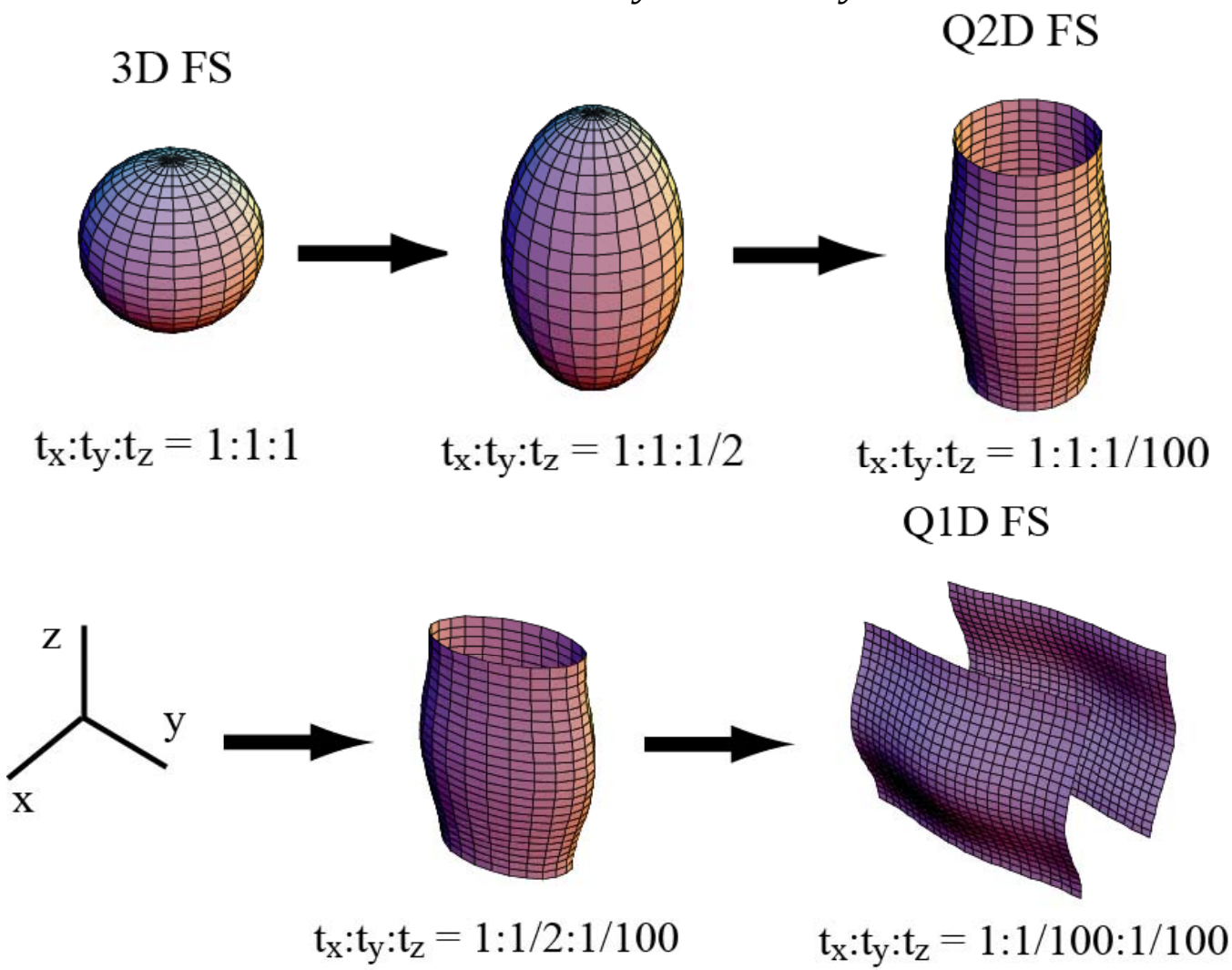
It appears necessary to explicitly include the planar oxygen degrees of freedom.

Large W small U

Dimensionality
(Iron pnictides, $BaVS_3$)

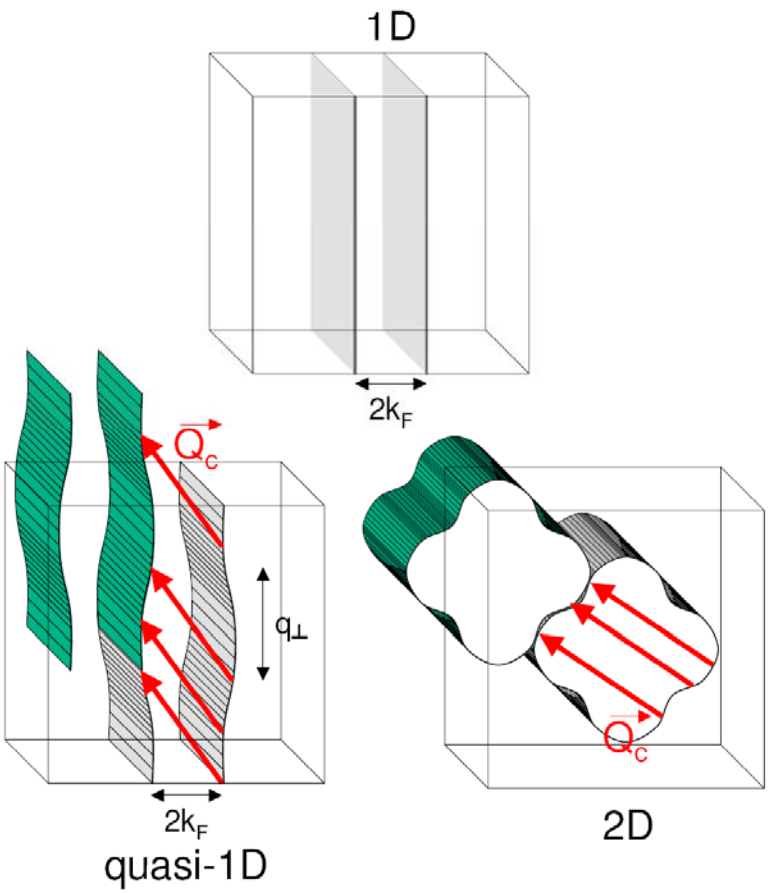
Fermi surface

$$\varepsilon(\vec{k}) = -2t_x \cos(k_x a) - 2t_y \cos(k_y b) - 2t_z \cos(k_z c)$$

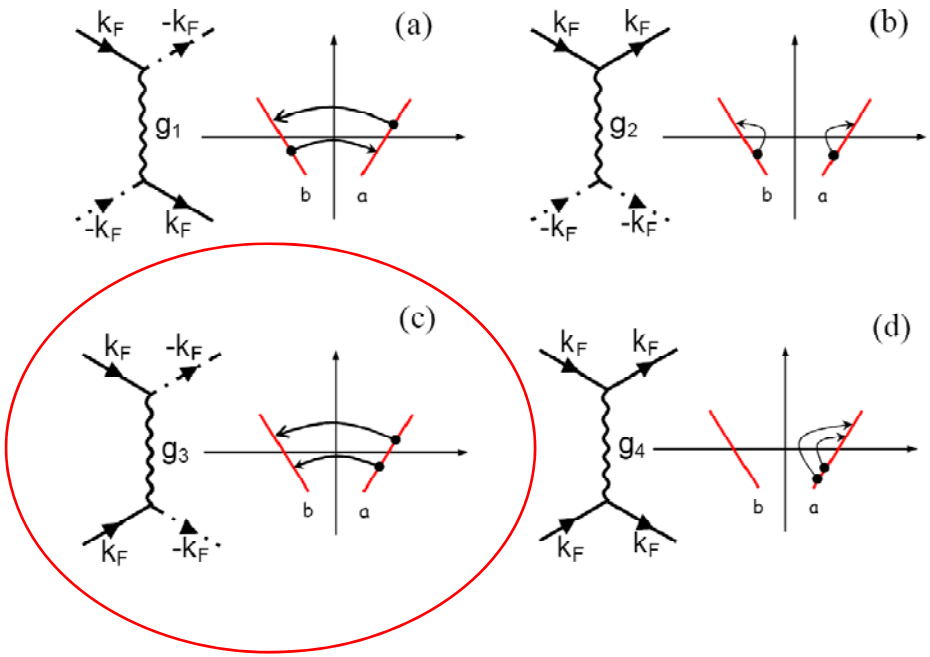


$(TMTSF)_2ClO_4$ $t_x:t_y:t_z$~300:25:2 meV

Nesting



electron-electron (phonon mediated) scatterings



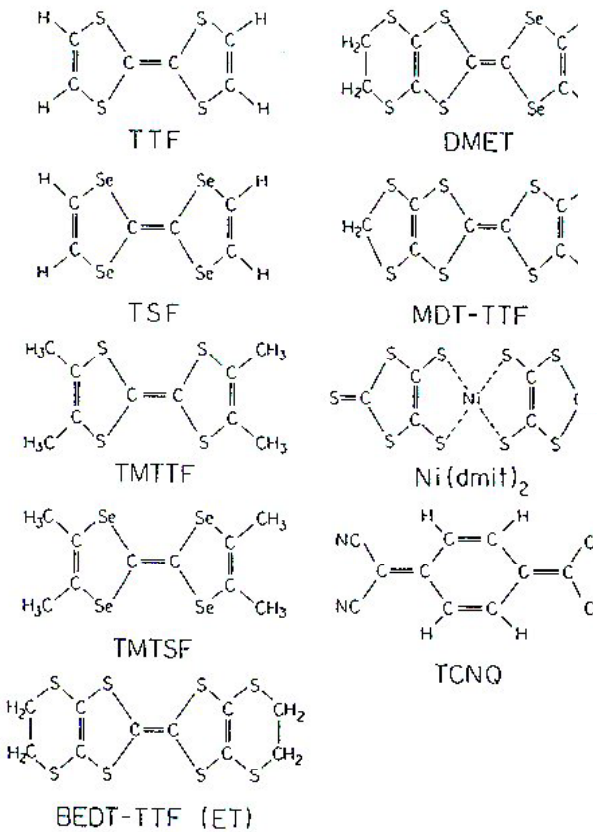
Backward scattering

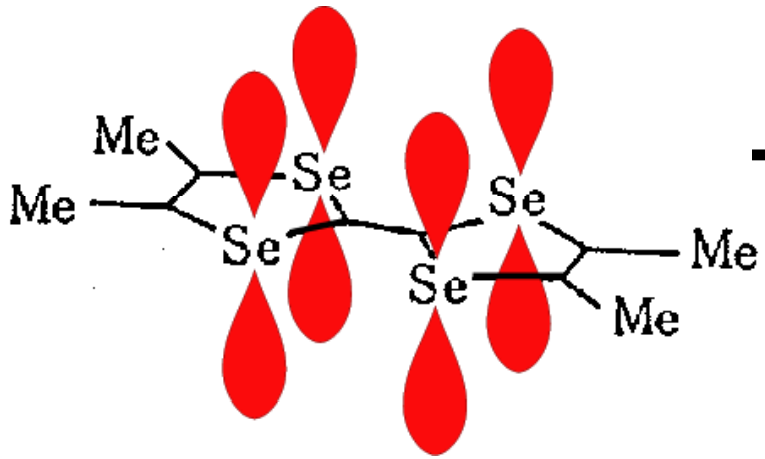
Forward scattering

Umklapp scattering-commensurability

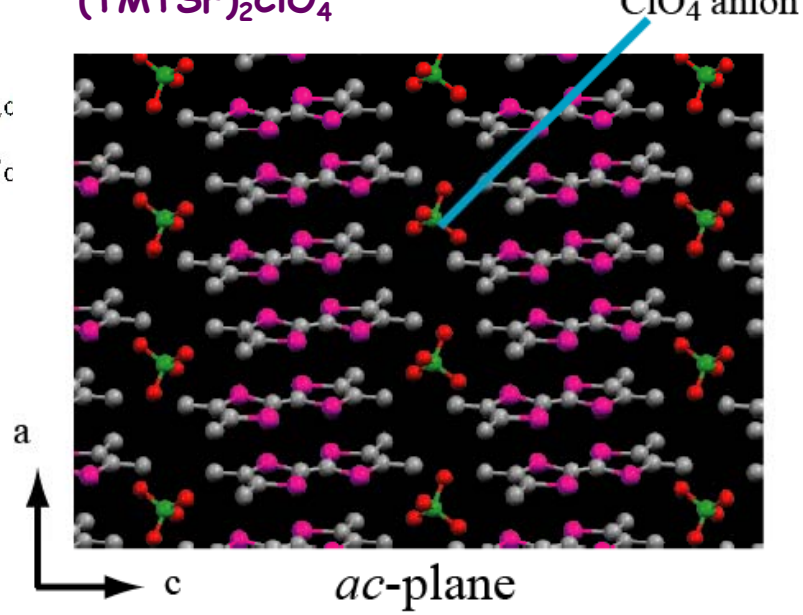
Another forward scattering

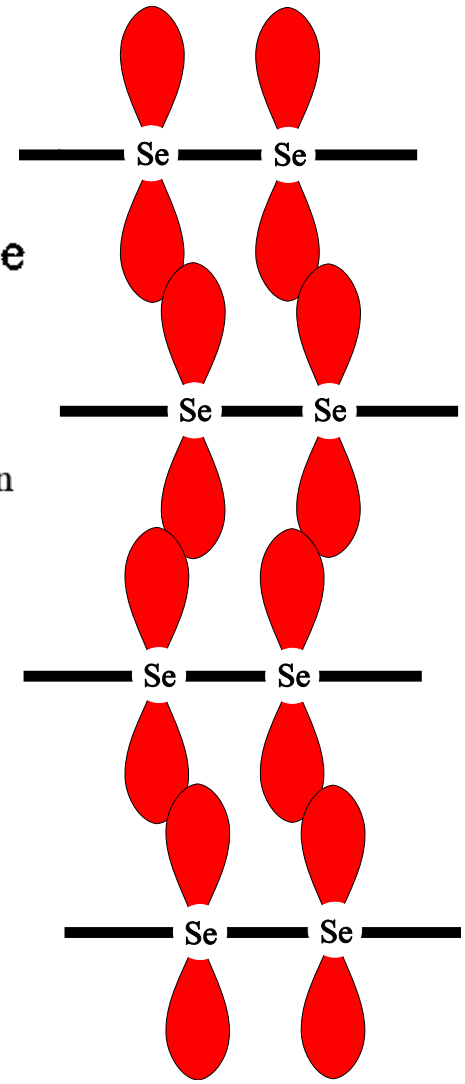
Quasi 1d - Organic conductors



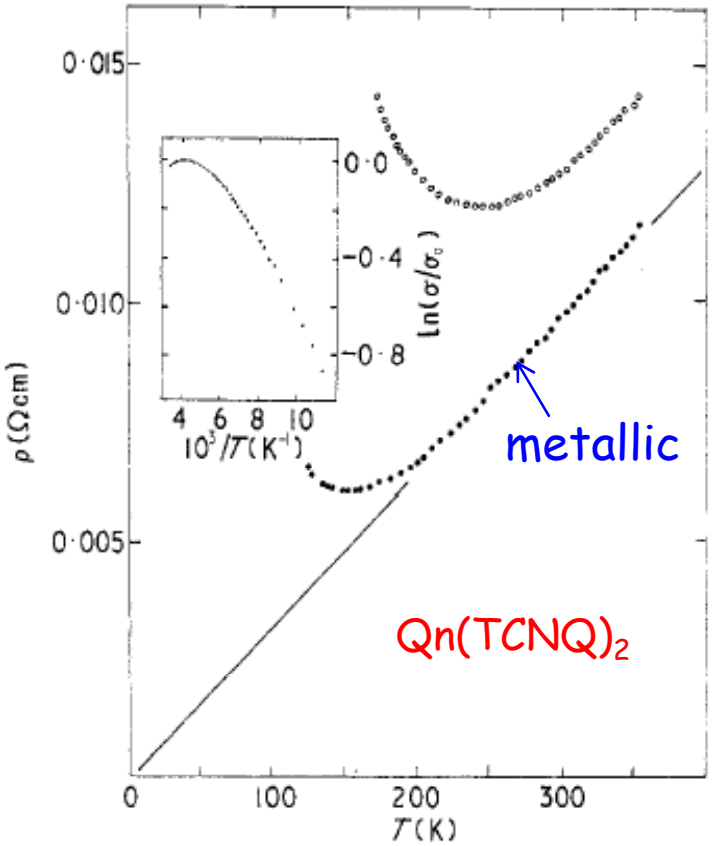


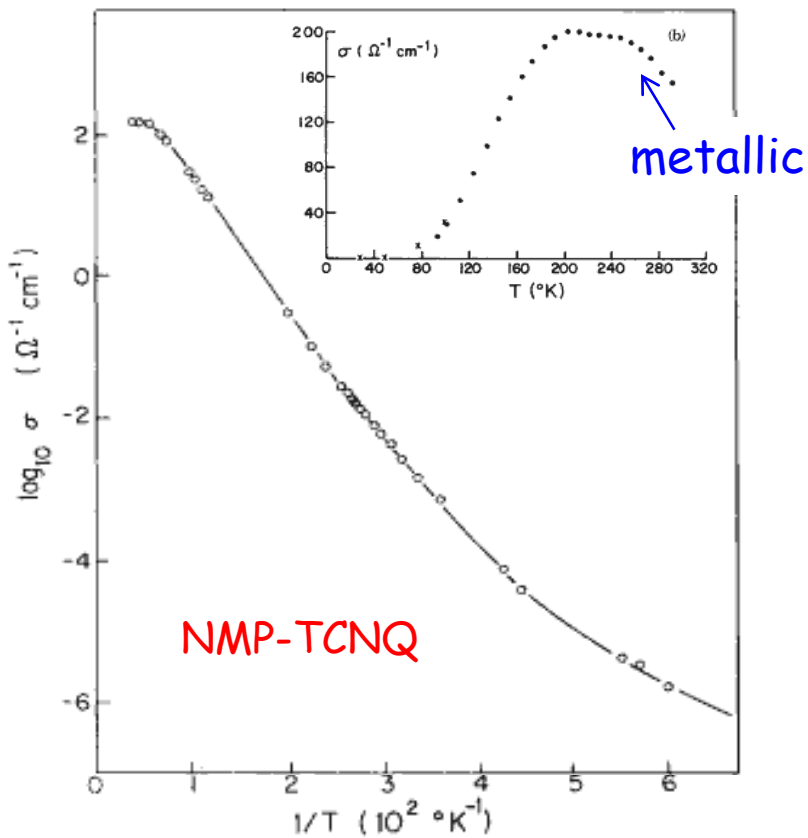
$(TMTSF)_2ClO_4$





First organic metals



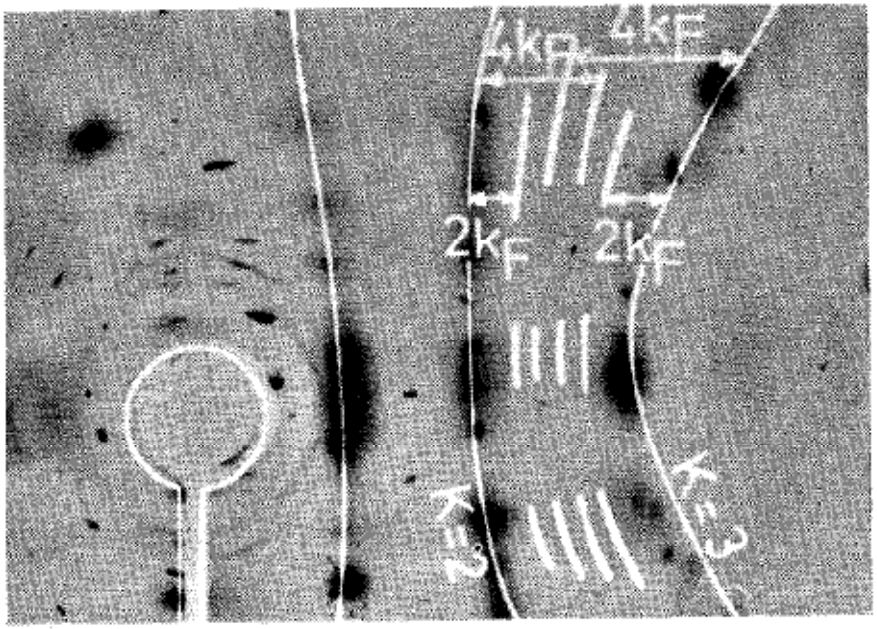


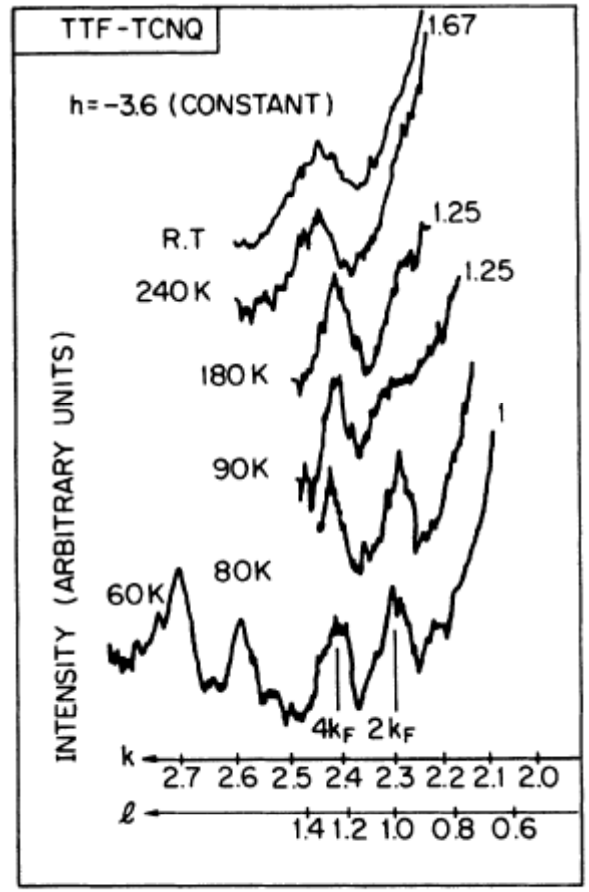
Shchegolev I F 1972
Phys. Stat. ***Solidi A*** **12** 9-45

Epstein AJ, et al., Phys.
Rev. B 5, 952–977 (1972)

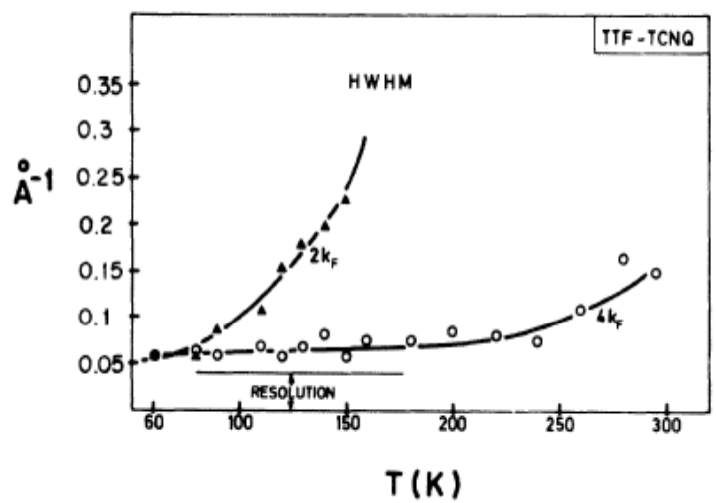
Peierls taransition, CDW
Q-1D fluctuations

(a



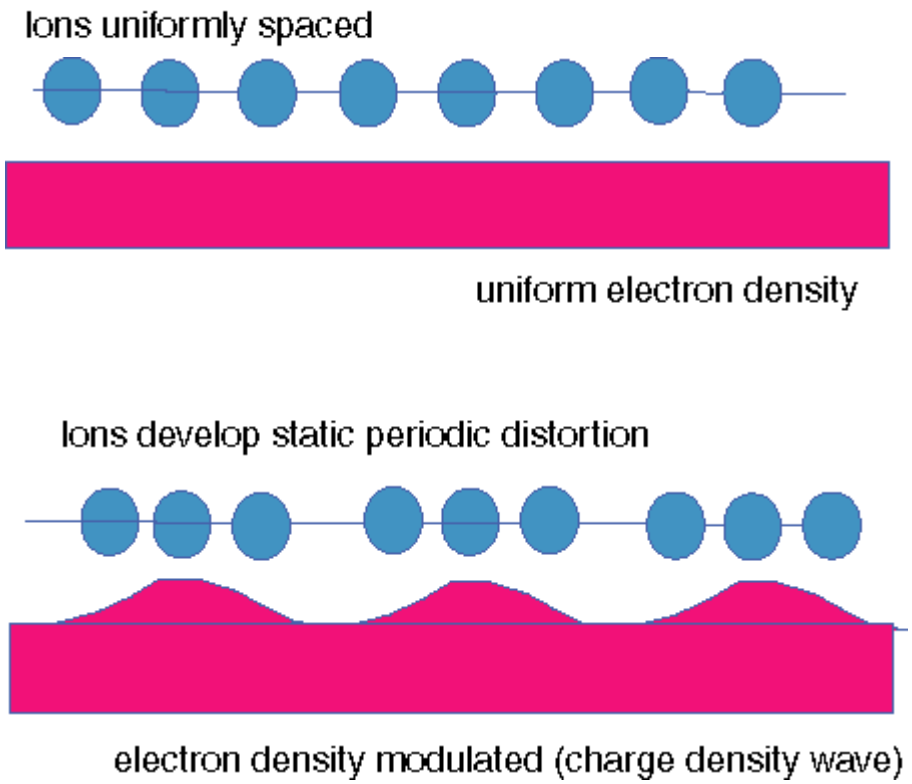


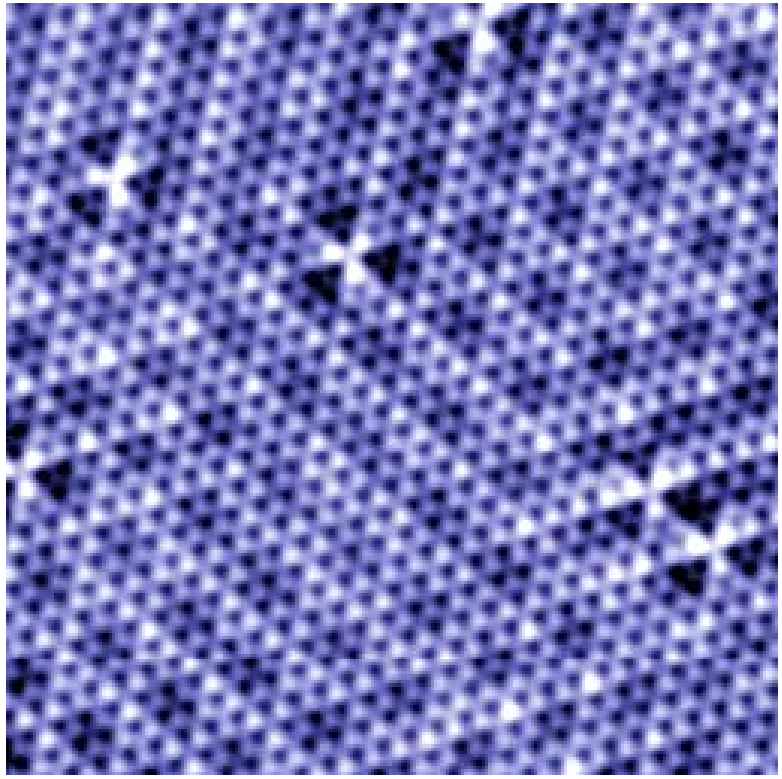
TTF-TCNQ



Pouget JP. Et al., Phys. Rev. Latt. 37, 437 (1976)
Khanna, SK et al., Phys. RevB 16, 1468 (1977)

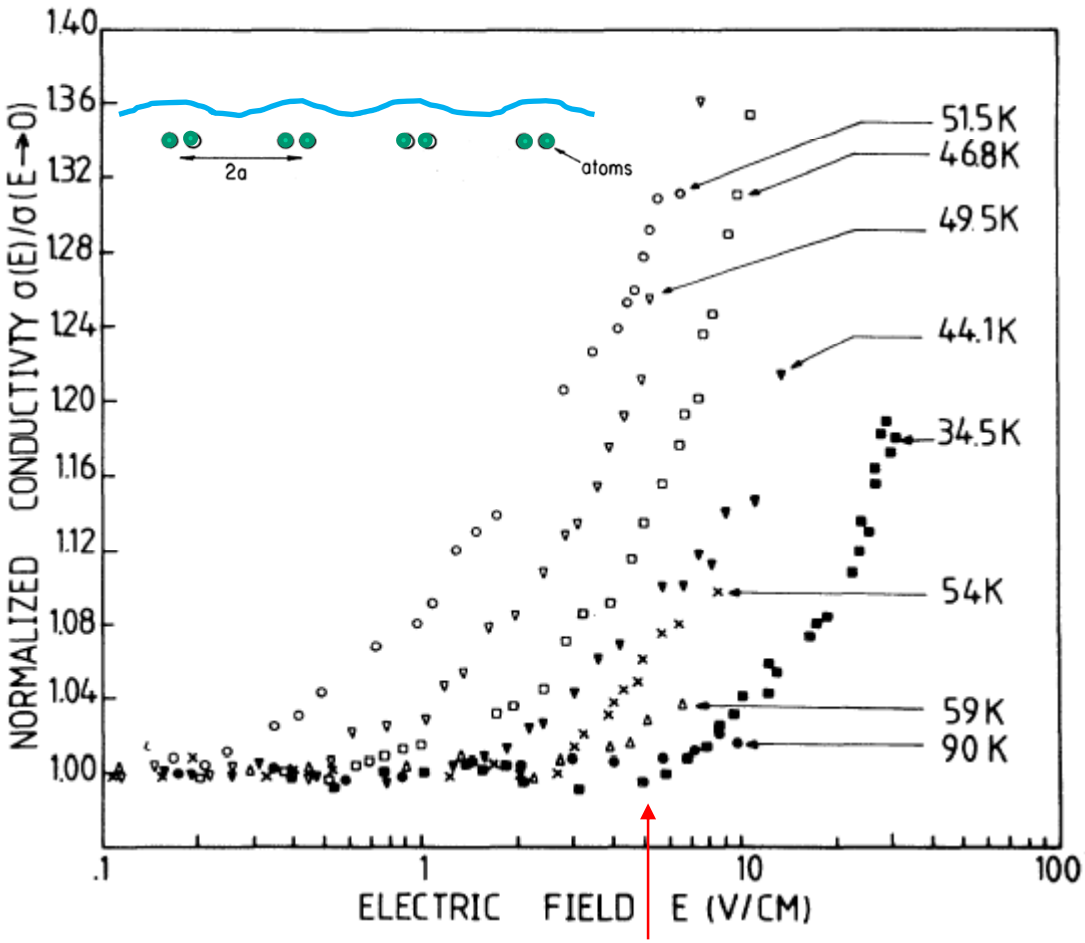
Strong interaction of electrons with the ions (lattice) leads to charge density waves



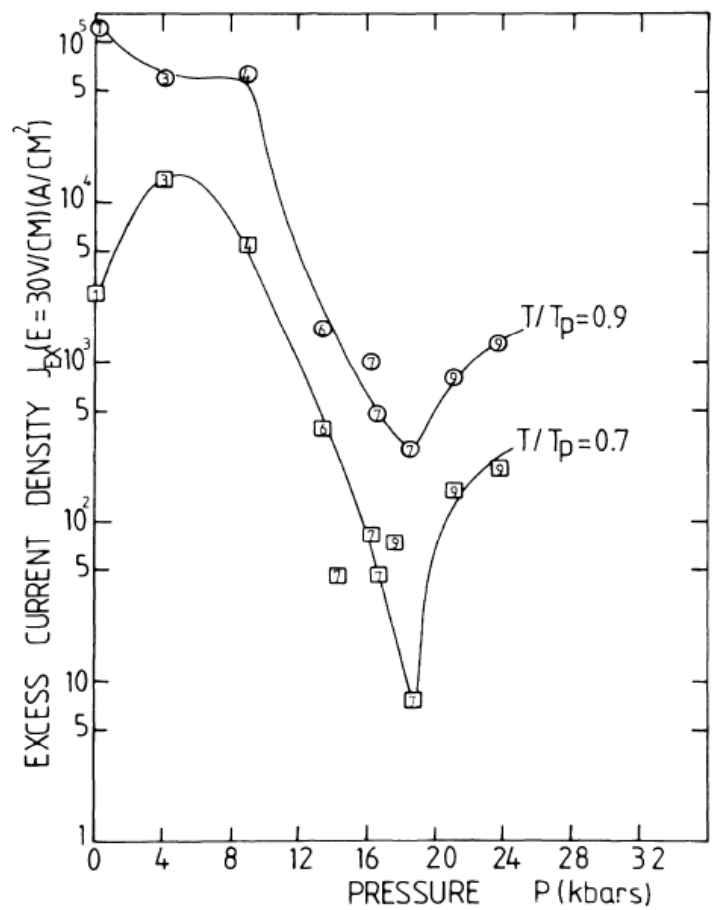


STM image of individual atoms on the $NbSe_2$ surface 96Å x 96Å. The additional 3x3 triangular structure is a collective electronic state known as a charge density wave.

Fröhlich conductivity and p-dependence



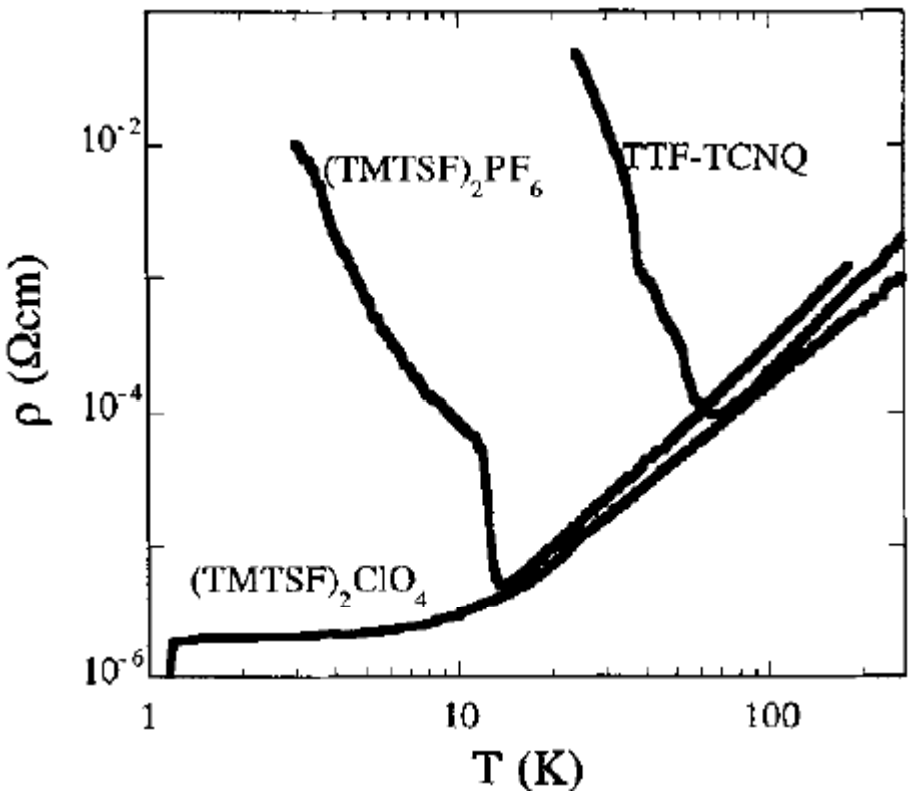
E_T



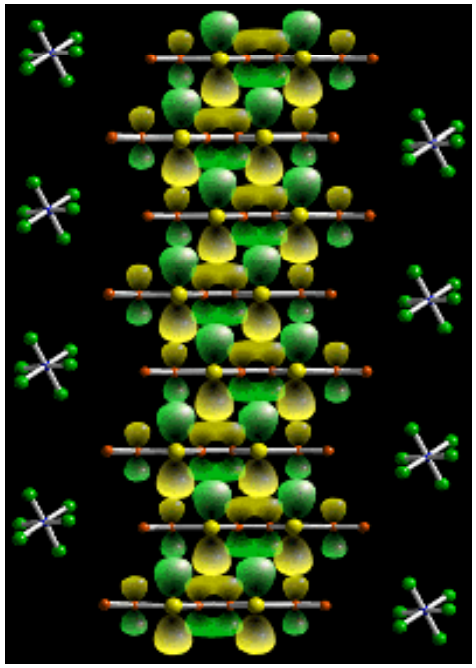
R. Lacoe, et al., Phys. Rev. Lett. 55, 3451 (1985)
R. Lacoe, JR Cooper et al., Phys. Rev. Lett. 58, 262-265 (1987)

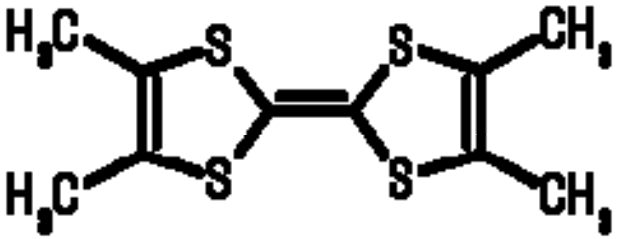
SDW and Superconductivity (1979)

(TMTSF)2X



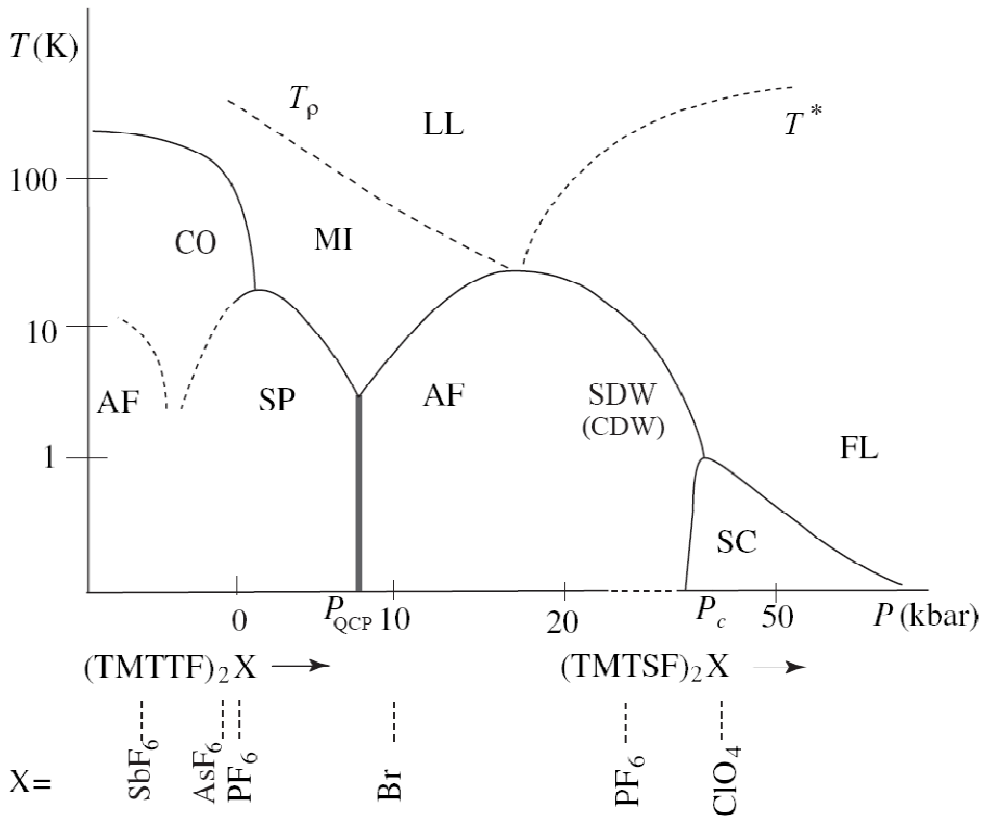
After Cooper J R and Korin-Hamzic B 1992





TMTSF

Phase diagram: Classical 1d conductors

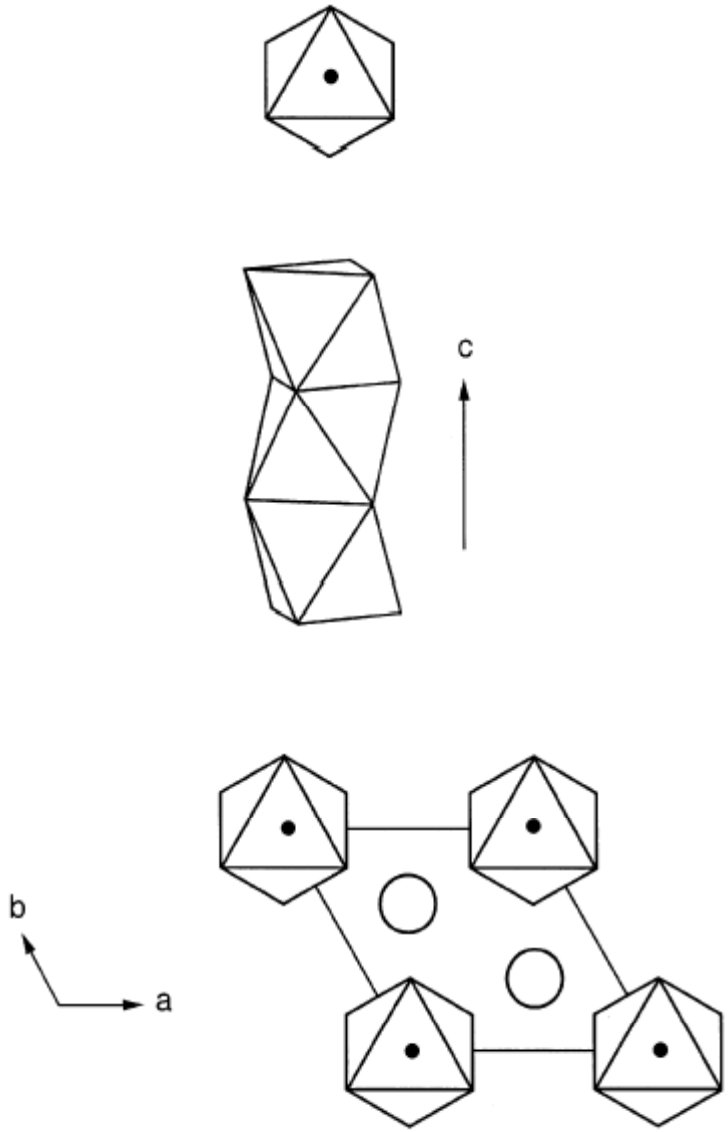


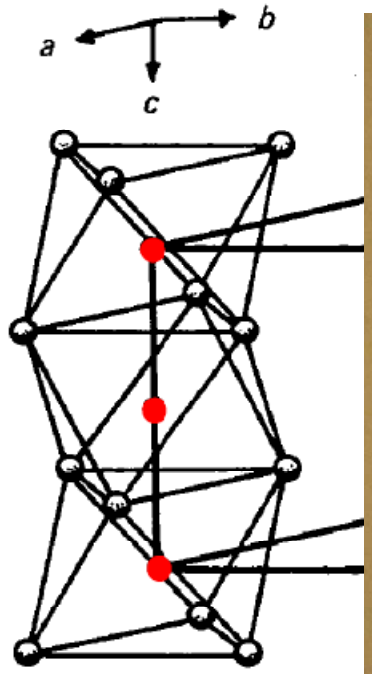
Is that it?

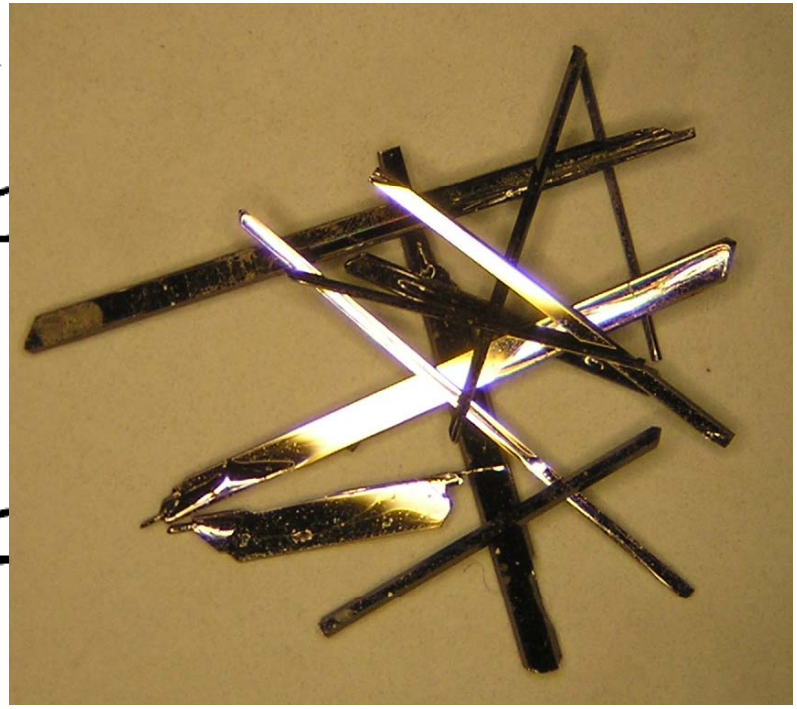
Logical extension of physics related to the Q1D band is by introducing a narrow partially filled band.

Case of: $BaVS_3$.

1D - Crystal structure







Ba V S

T > 240 K
hexagonal

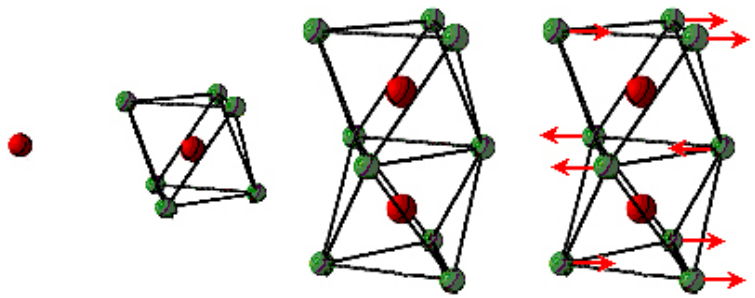
l_{inter} = 6.73 Å
l_{intra} = 2.81 Å

Crystal field splitting

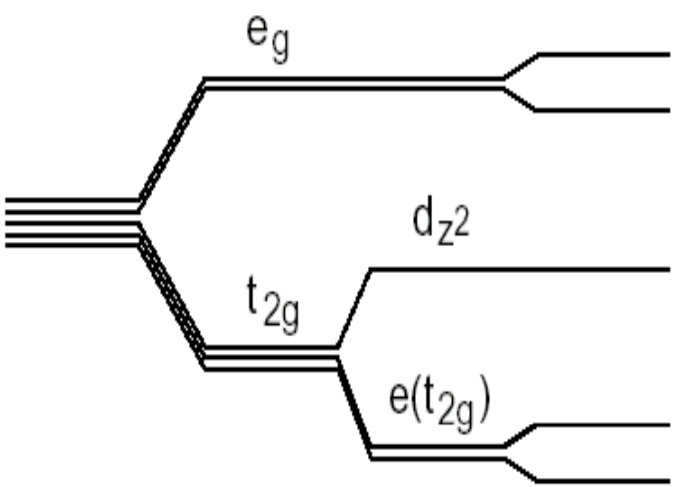
$BaVS_3 \rightarrow Ba^{2+}V^{4+}S^{2-}{}_3$

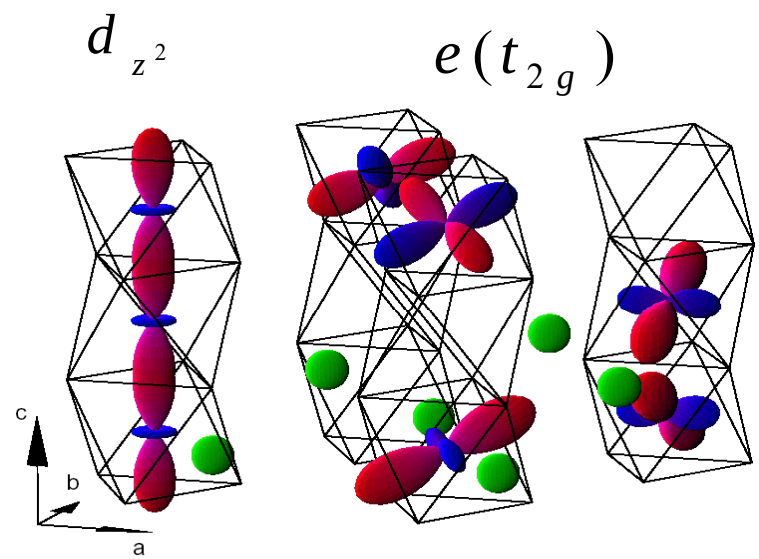
$V^{4+} \rightarrow 3d^1$

Symmetries:



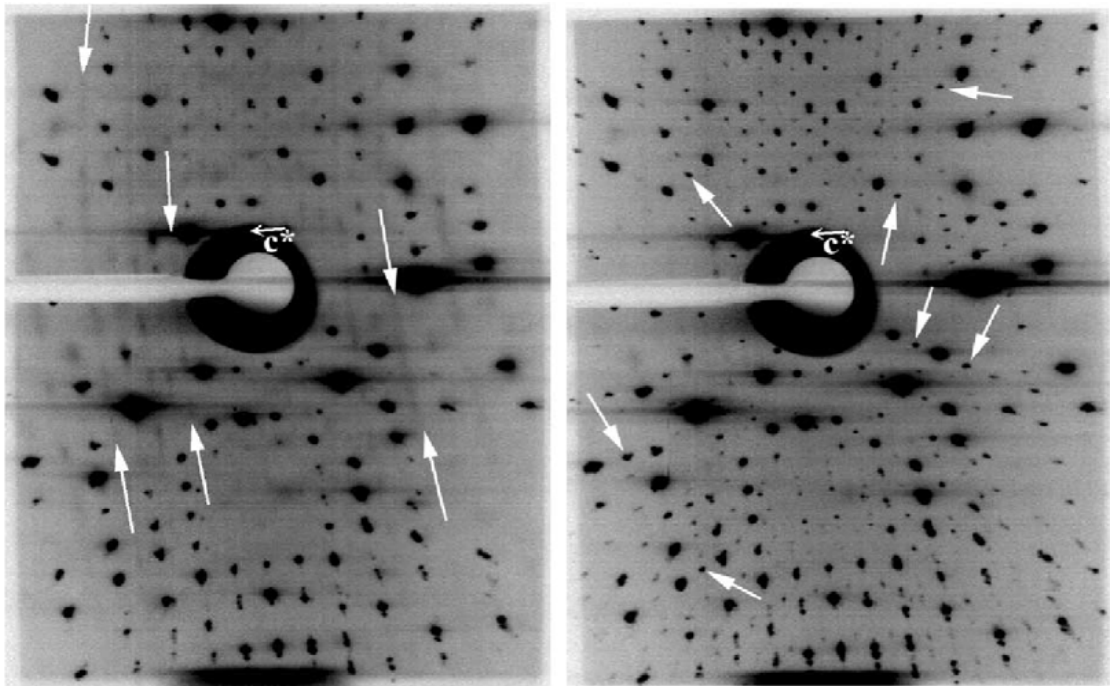
Isotropic → Octahedral → Trigonal → Orthorombic





doubling of the unit cell-screw axis conserved

1D band - 1D fluctuation



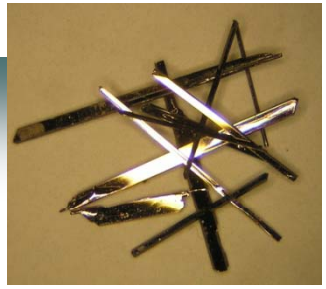
80 K
$T > T_{MI}$

25 K
$T < T_{MI}$

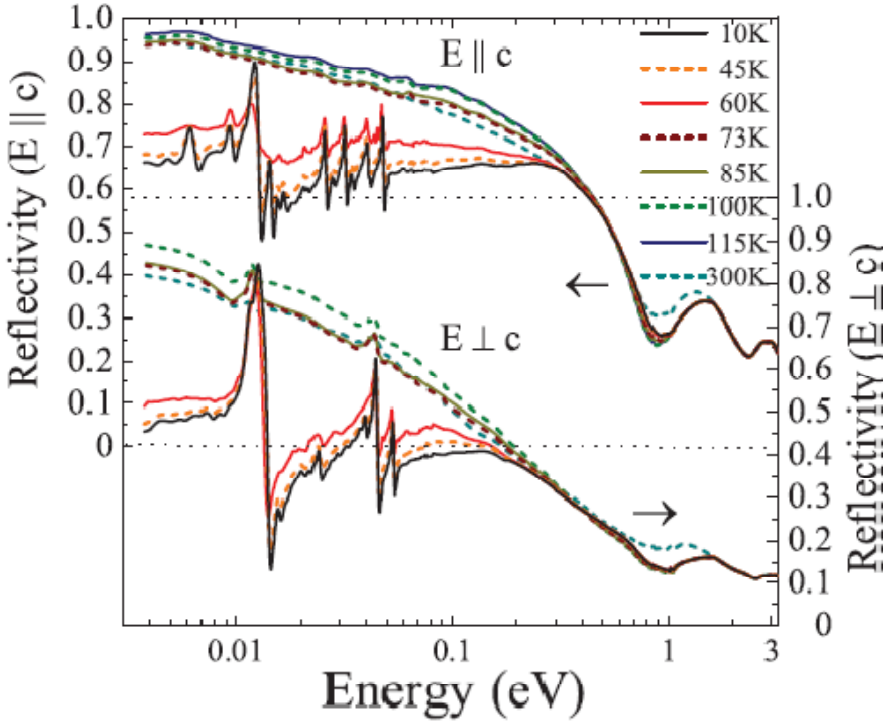
$q_c = 0.5\ c^*$

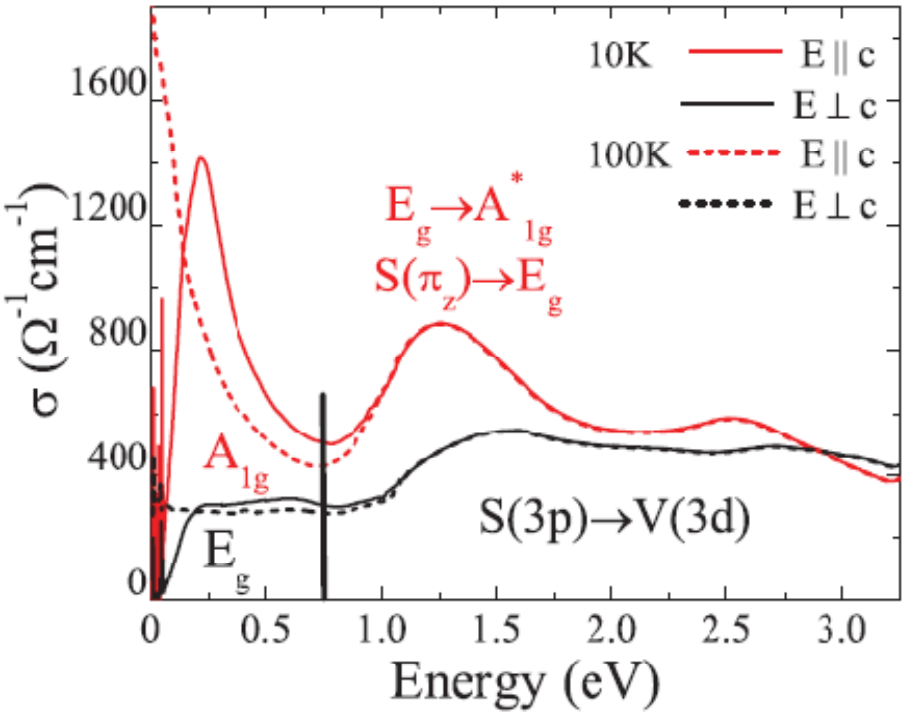
S. Fagot, P. Foury-Leylekian, S. Ravy, J. P. Pouget and H. Berger. 2003. Phys. Rev. Lett., **90**(19), 196401.

Optical conductivity in the infrared range



Polarized light , mosaic sample (phonons)

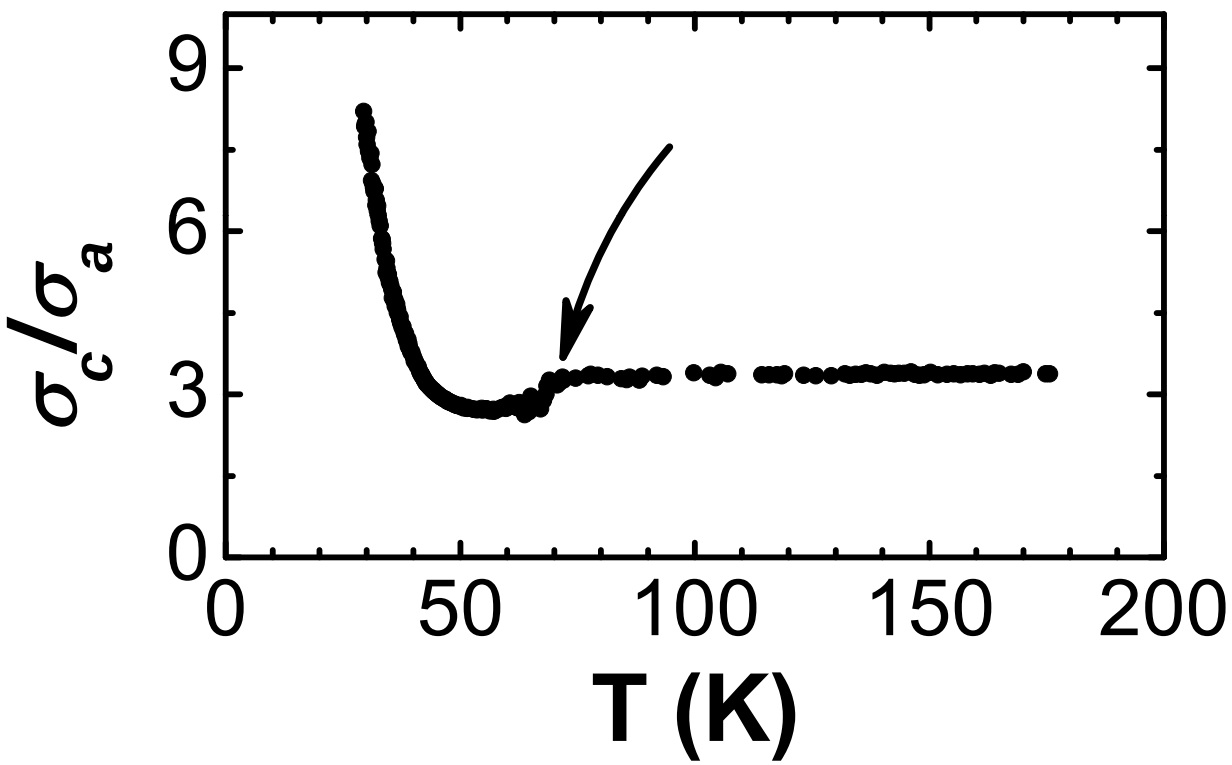




Results in polarized light reveal the anisotropy in the optical response.

Kézsmárki I. , G. Mihály, R. Gaál, N. Barišić, A. Akrap, H. Berger, L. Forró, C. C. Homes, and L. Mihály. *Phys. Rev. Lett.* **96**, 186402 (2006)

Resistivity - 2nd set of electrons

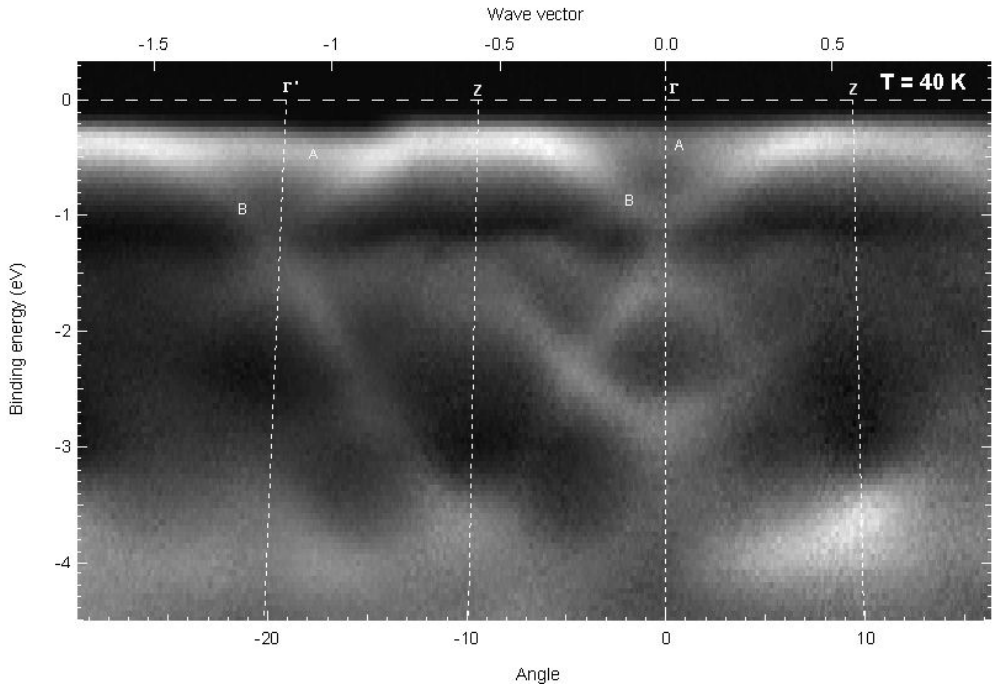


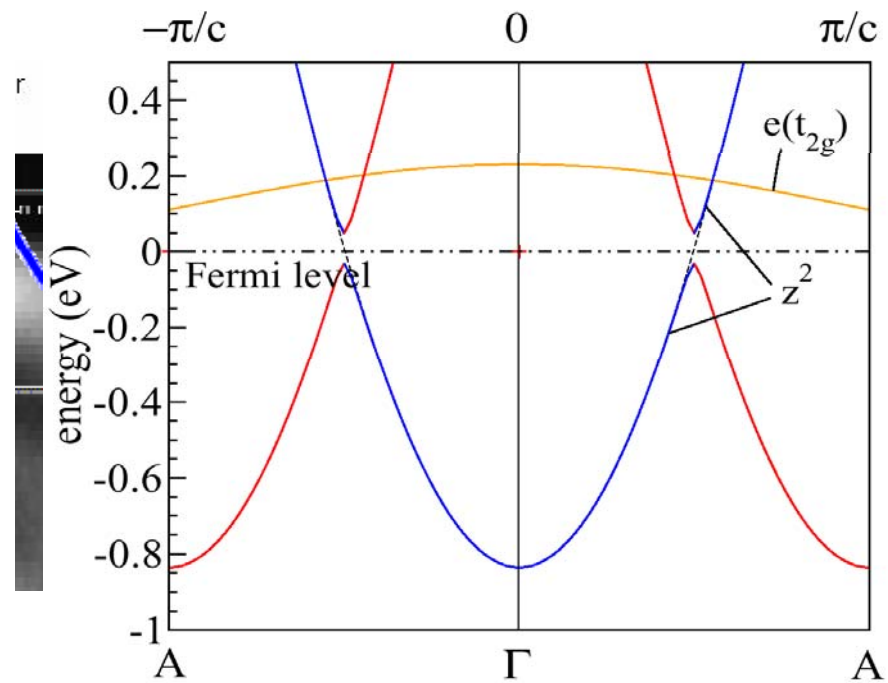
G. Mihàly, I. Kèzsmàrki, F. Zámborszky, M. Miljak, K. Penc, P. Fazekas, H. Berger, and L. Forró. 2000. *Phys. Rev B*, **61**(12), R7831.

ARPES - 2nd set of electrons

Band structure calculations

Commensurable diffusive lines → tetramerization → 1D d_{z^2} band $\frac{1}{4}$ field





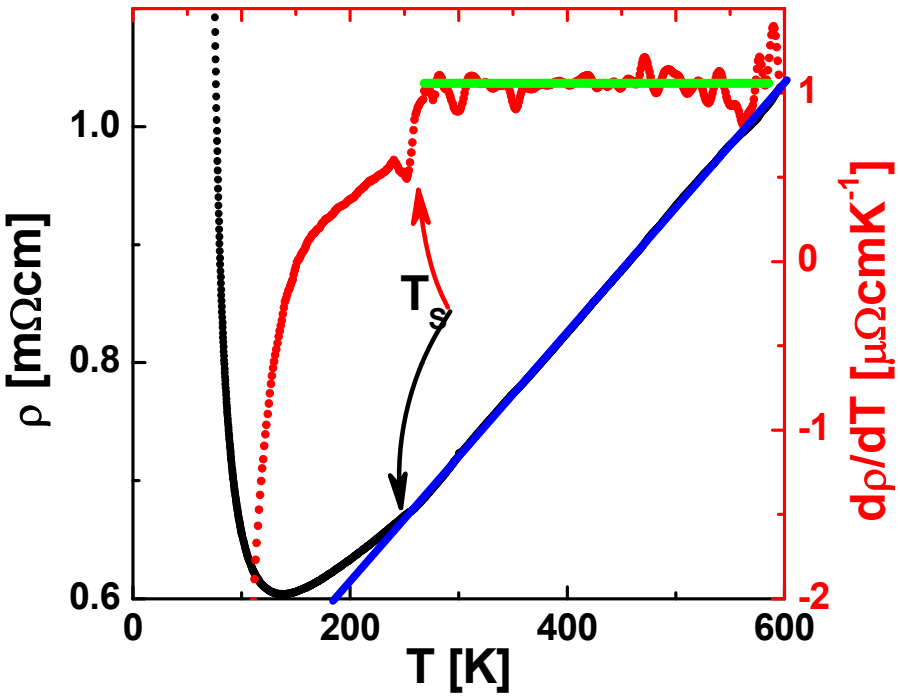
e_g-d_{z^2} hybridizaition → isotropic conductivity

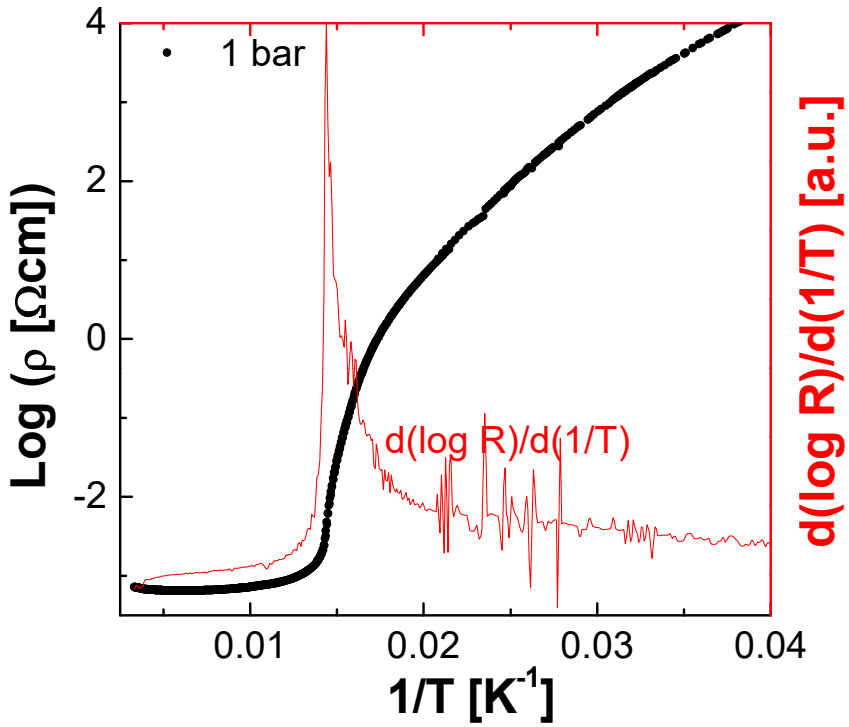
Hidden nesting → CDW and/or SDW instability

S. Mitrovic *et al.*, Phys. Rev. B 75, 153103 (2007)

I. Kupcic et al., *in preparation*.

Phase transitions - Resistivity





T_S = 240 K

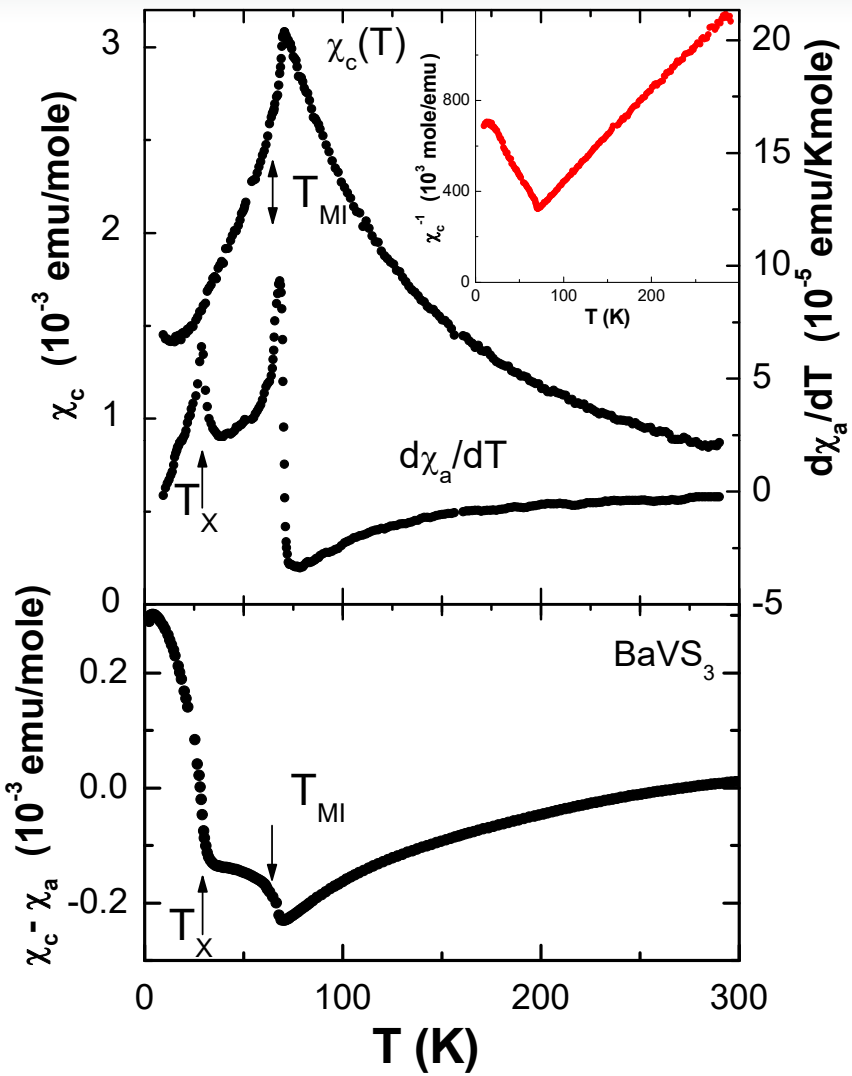
Precursor region

$2\Delta_{ch}$ = 600 K

T_{MI} =69 K

G. Mihàly, I. Kèzsmàrki, F. Zámborszky, M. Miljak, K. Penc, P. Fazekas, H. Berger, and L. Forró. 2000. *Phys. Rev B*, **61**(12), R7831.

Phase transitions - Susceptibility



Metallic phase:
Curie susceptibility

aFM (0.226, 0.226, 0)

G. Mihàly, I. Kèzsmàrki, F. Zámborszky, M. Miljak, K. Penc, P. Fazekas, H. Berger, and L. Forró. 2000. *Phys. Rev B*, **61**(12), R7831.

Nakamura H., T. Yamasaki, S. Giri, H. Imai, M. Shiga, K. Kojima, M. Nishi, K. Kakurai and N.Metoki. 2000. *J. Phys. Soc. Jpn.*, **69**(9), 2763-2766.

Phase transitions Commensurate compounds

Second order:

T_S = 240 K — a-b inequivalence

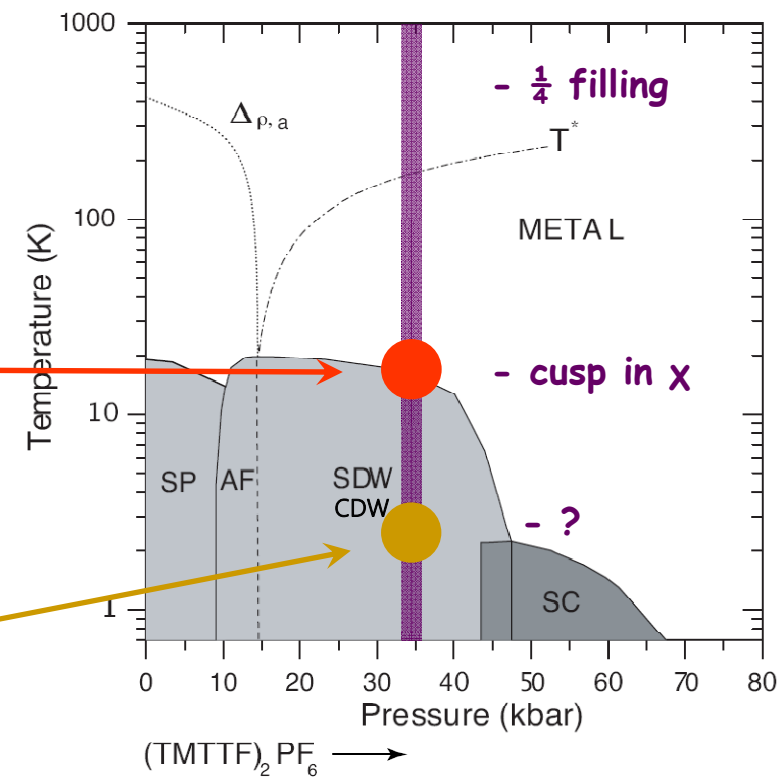
240 K > T > 70 K
orthorhombic

T_{MI} = 70 K — tetramerization of the unit cell along c direction

T_X = 30 K — magnetic transition

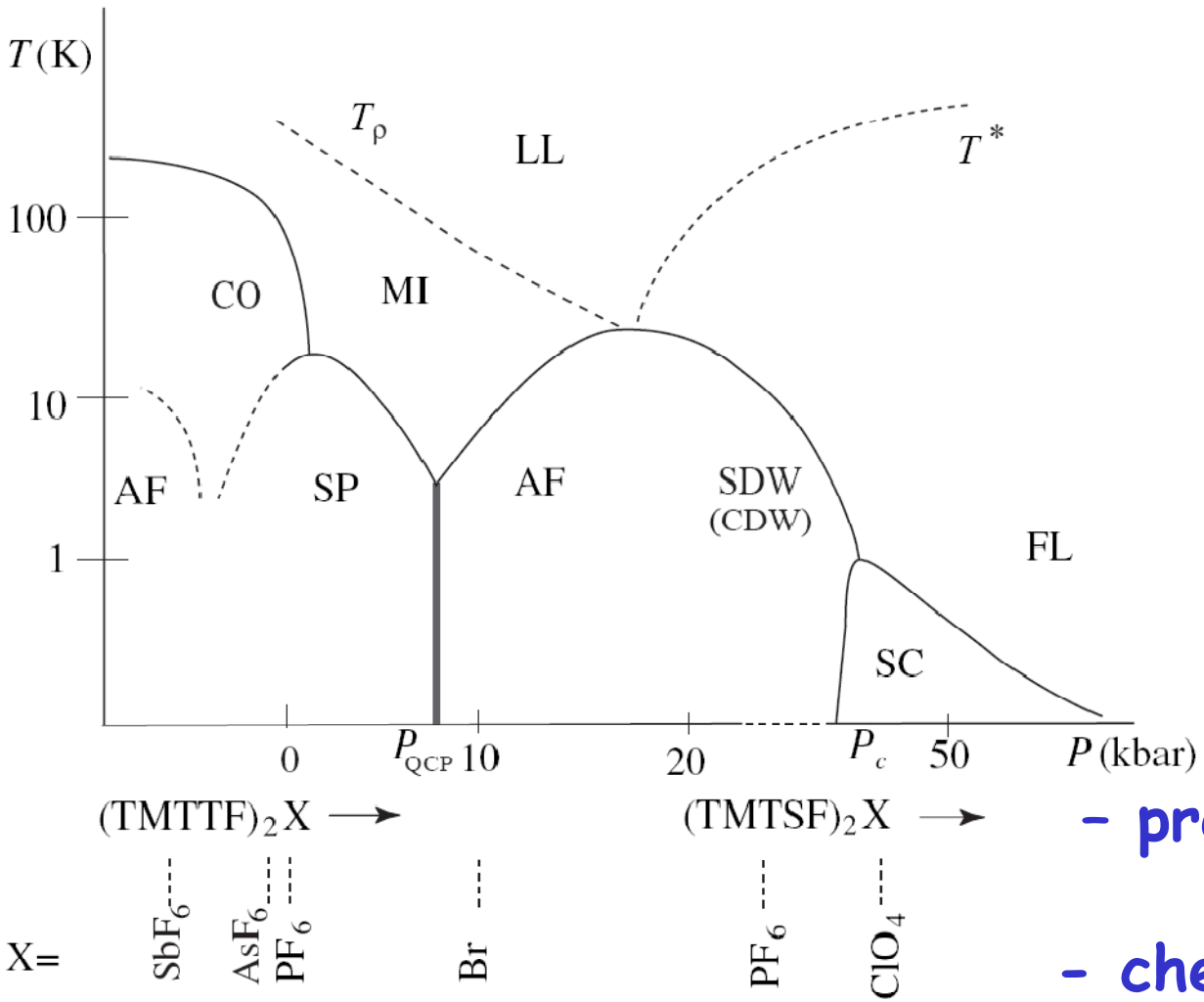
$BaVS_3$

d_{z^2}- e_g INTERPLAY



- $\frac{1}{4}$ filling
- cusp in χ
- ?

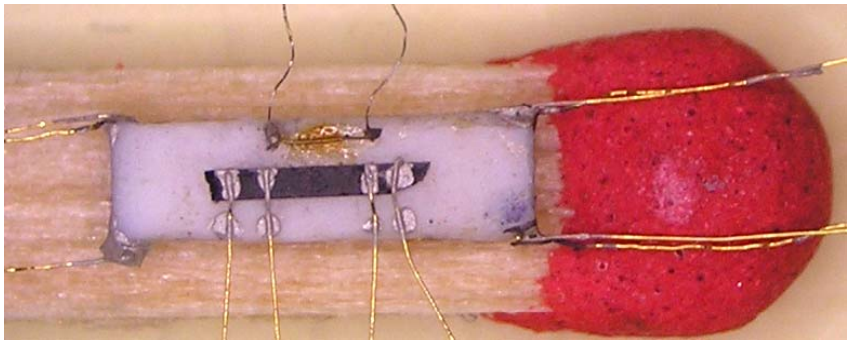
What to do next?

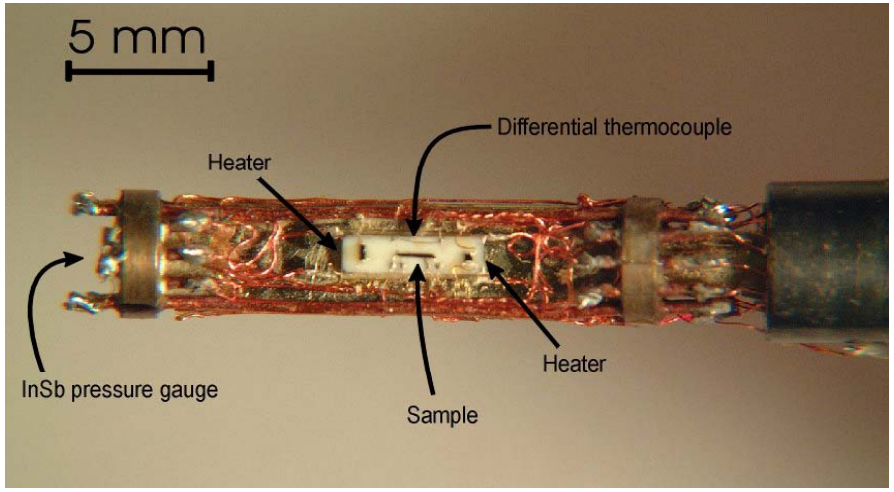


- pressure

- chemical pressure

High-pressure setup



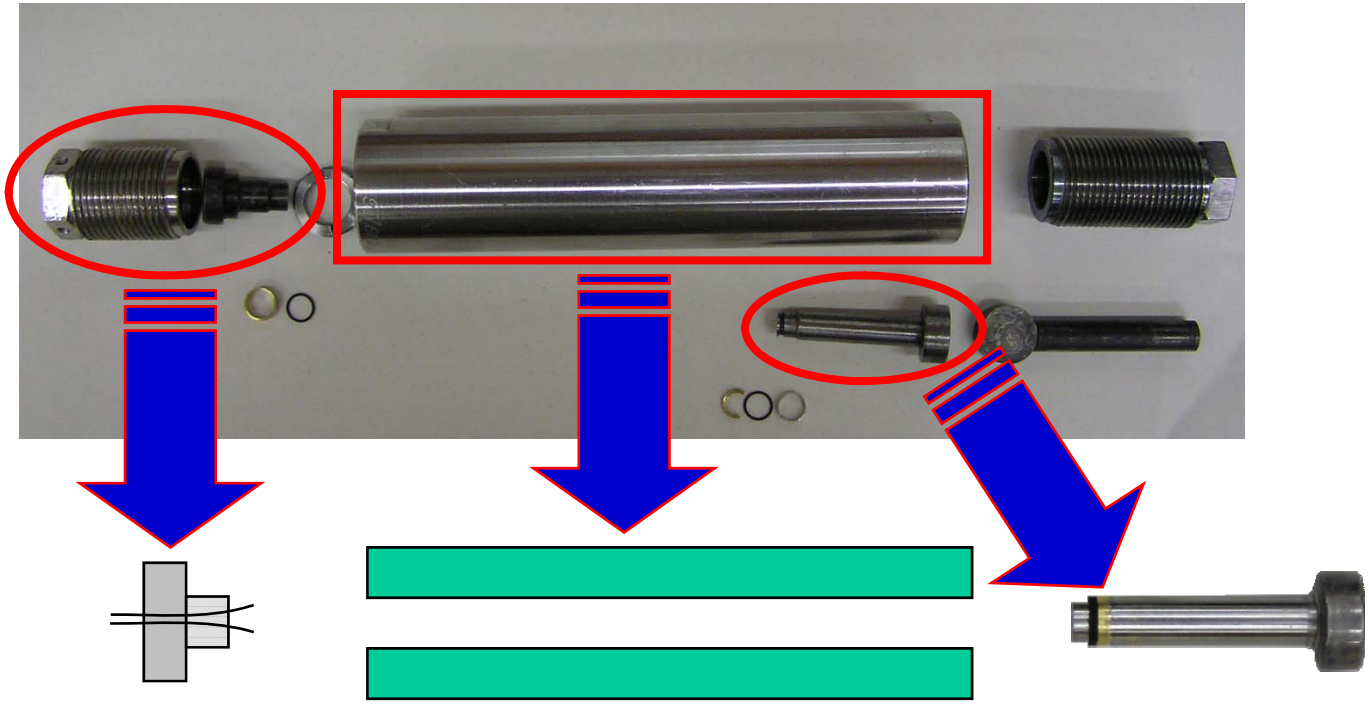


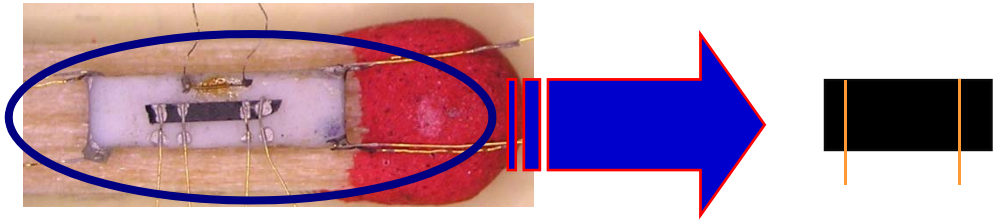
Pressure range: 1bar - 3 GPa

Temperature range: 1.5 – 300 K

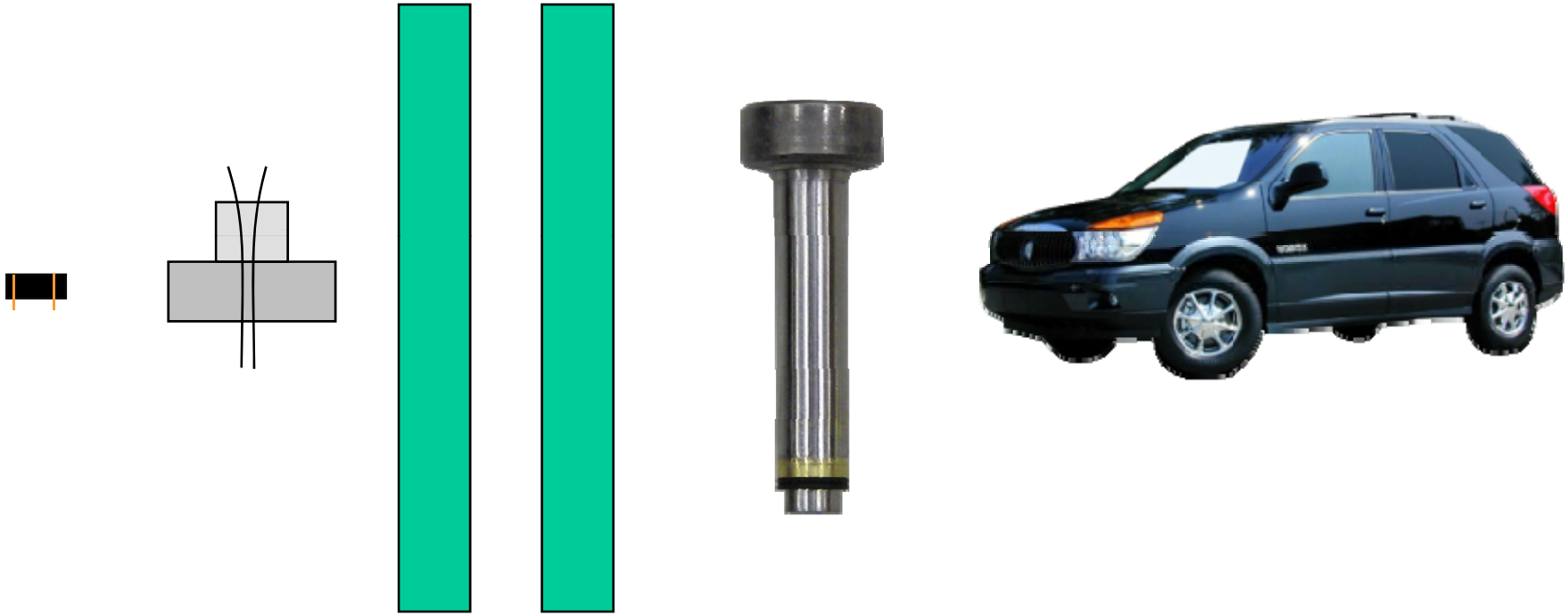
Magnetic fields: 0 – 12.7 T

High-pressure setup



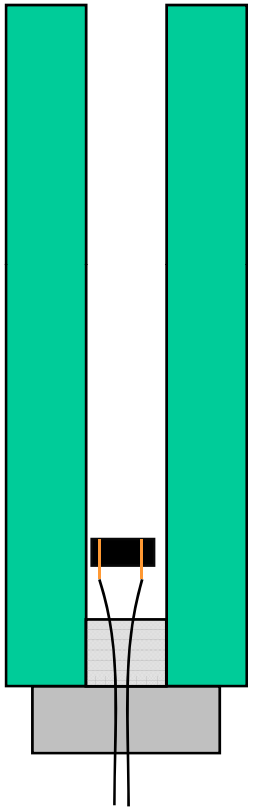


High-pressure setup

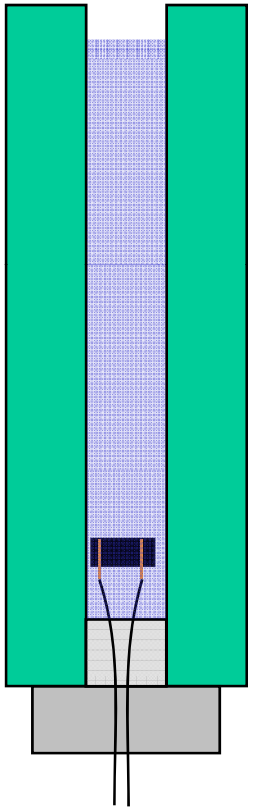


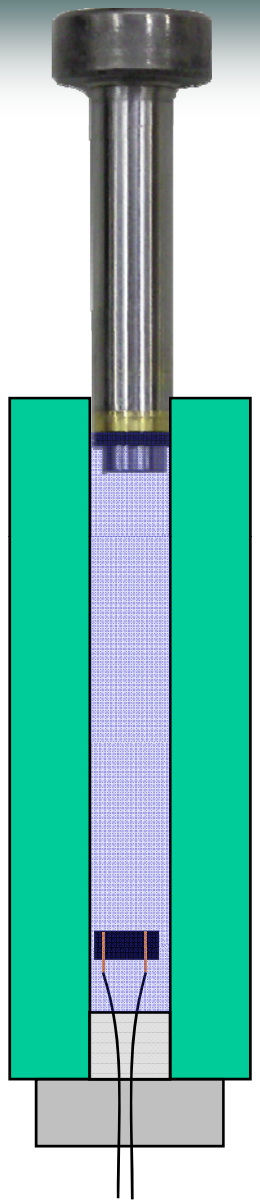
High-pressure setup

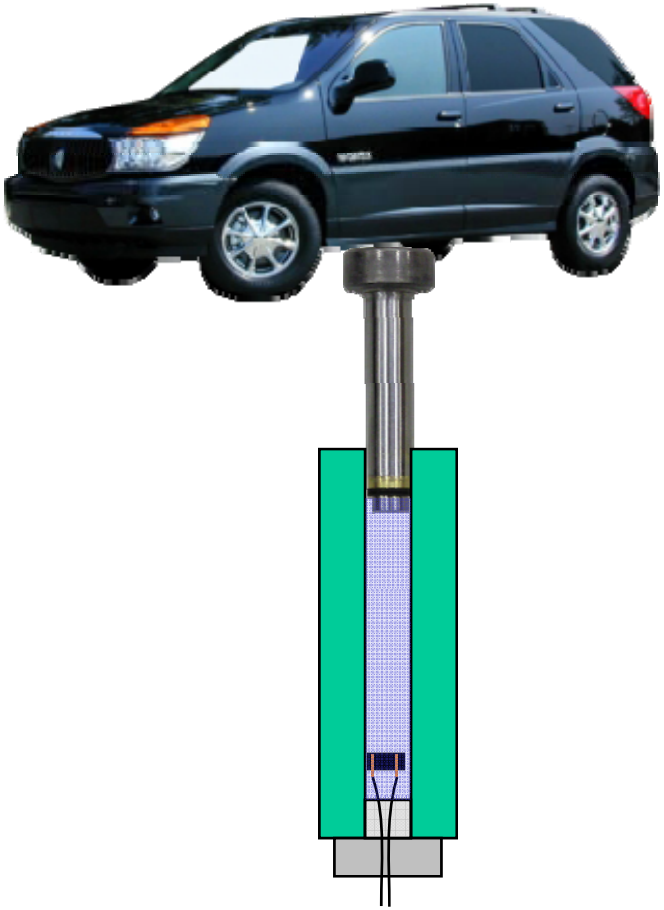
High-pressure setup



High-pressure setup







1500 kg ~ 2 kBar

$$p = \frac{F}{S} = \frac{mg}{r^2 \pi}$$

2 kbar = 2 10^8 Pa

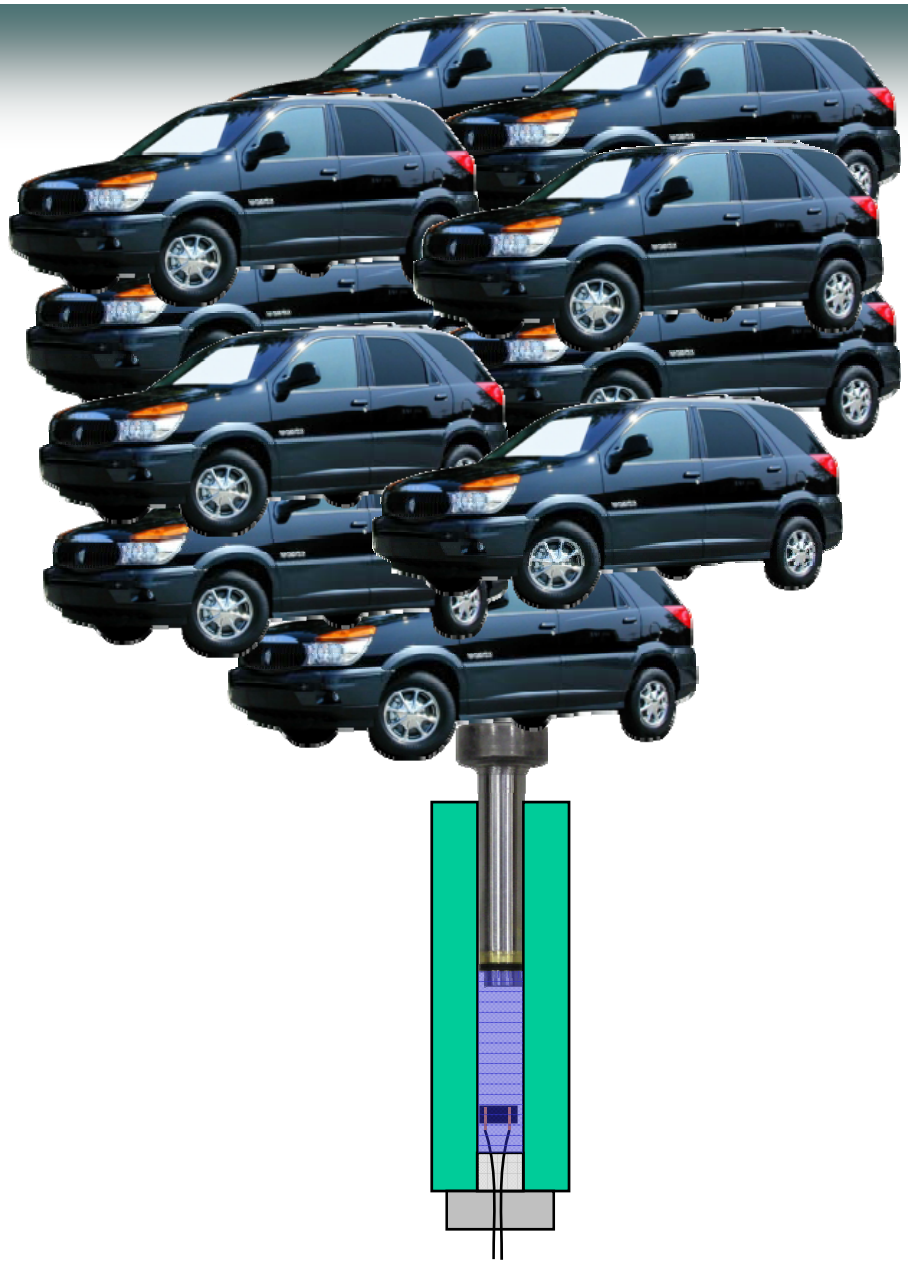
g ~ 10 m/s^2

r = 3.5 mm = 3.5 10^{-3} m

r^2 ~ 10^{-5} m^2

$$2\ 10^8 = \frac{10\ m}{10^{-5}\pi} = \frac{m}{\pi} 10^6$$

m ~ 1500 kg



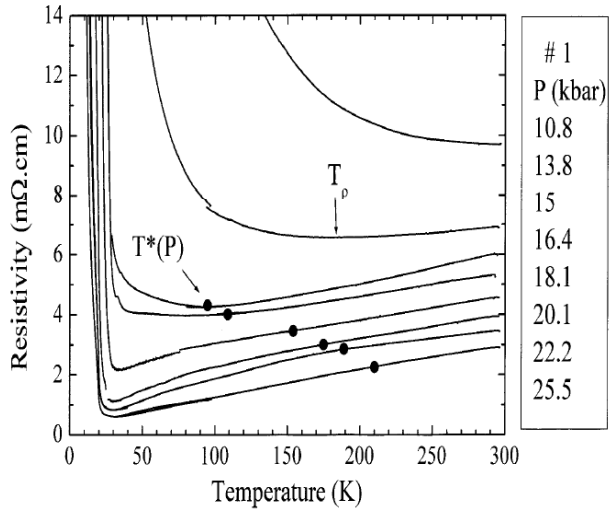
10*

1500 kg ~ 2 kBar

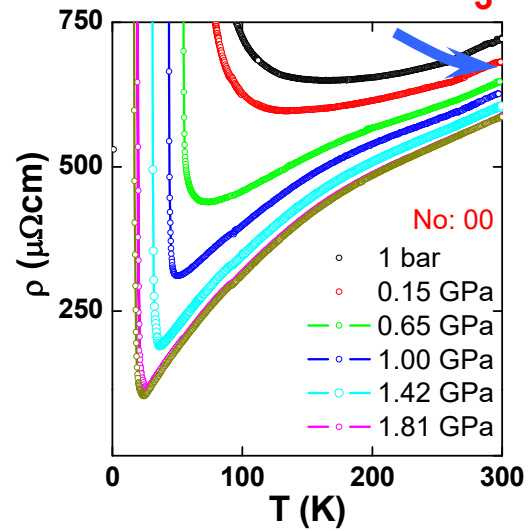
= 20 kBar

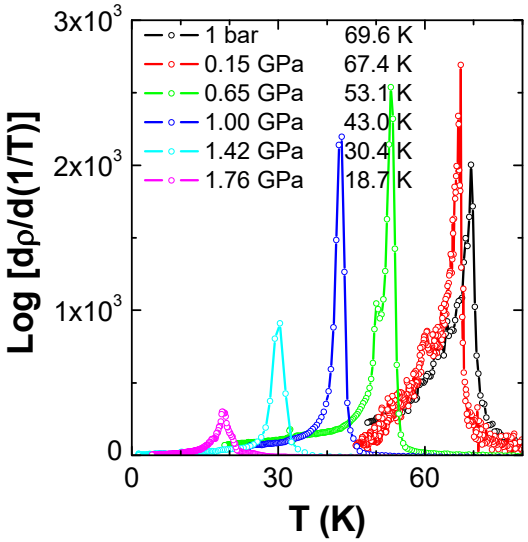
Following the T_{MI} by: pressure

$(TMTTF)_2PF_6$



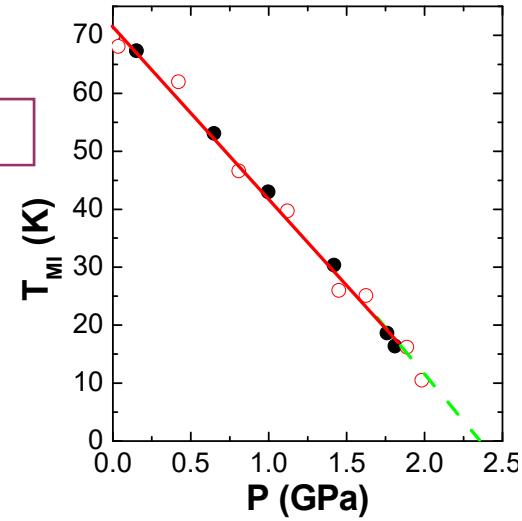
$BaVS_3$





T_{MI} = 70K - 29.15K/GPa p

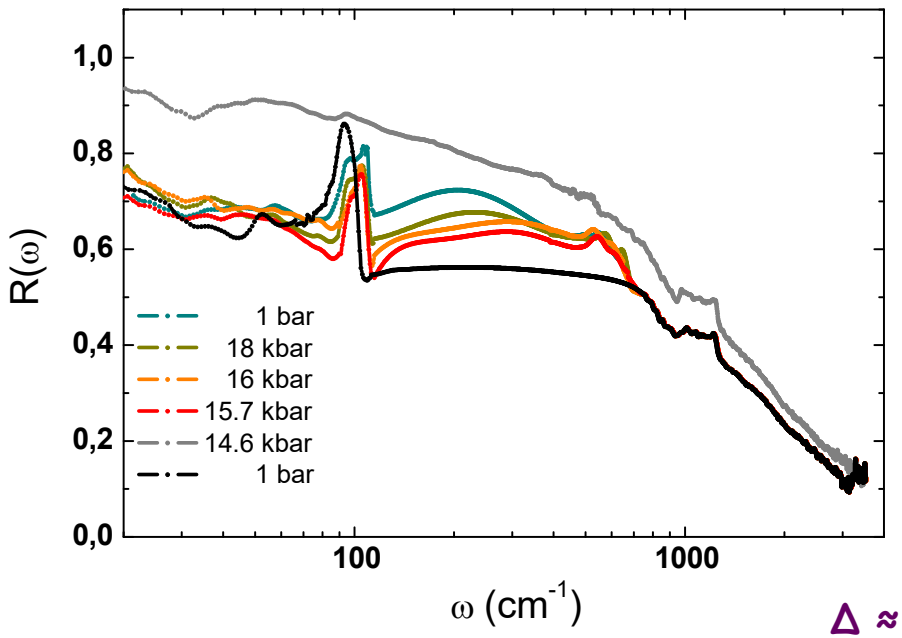
At p ~ 2.4 GPa T_{MI} extrapolates to 0 K.

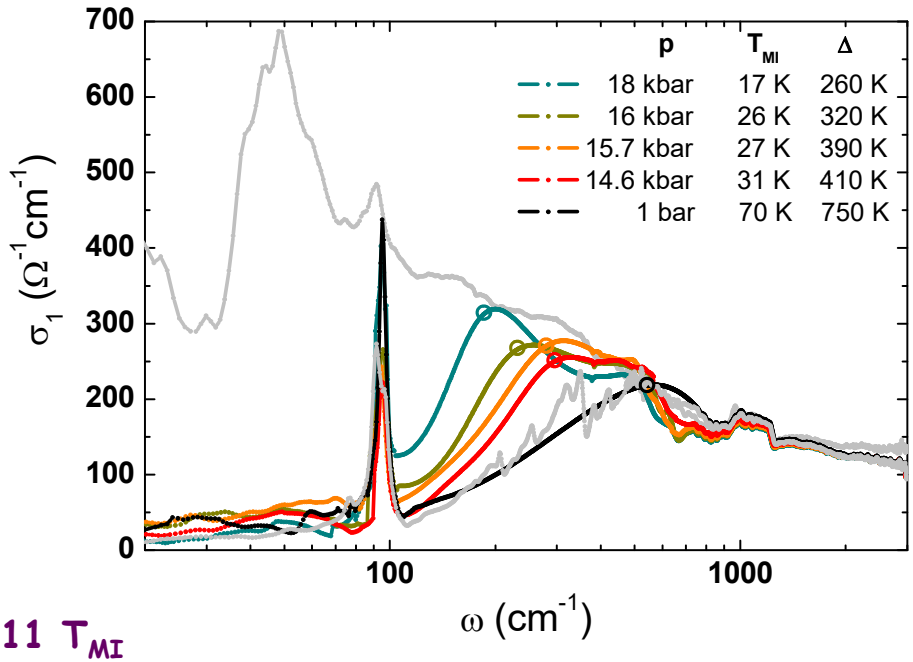


Auban P., D. Jérome, C. Carcel, and J. Fabre.
J. Phys. IV (France) **114**, 41 (2004)

L. Forró, R. Gaàl, H. Berger, P. Fazekas, K. Penc, I. Kèzsmàrki and G. Mihàly. 2000. *Phys. Rev Lett.*, **85**(9), 1938.

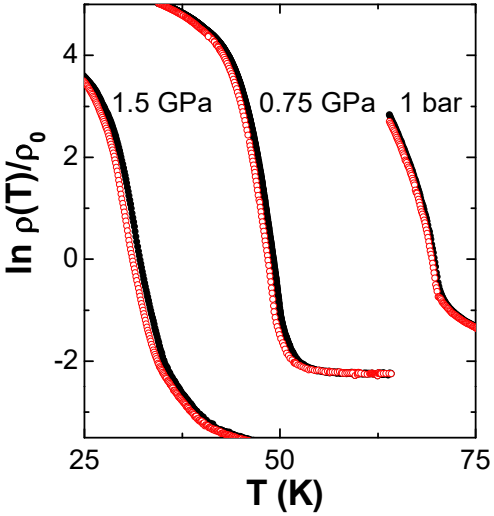
Pressure dependence:
of optical conductivity in the infrared rang

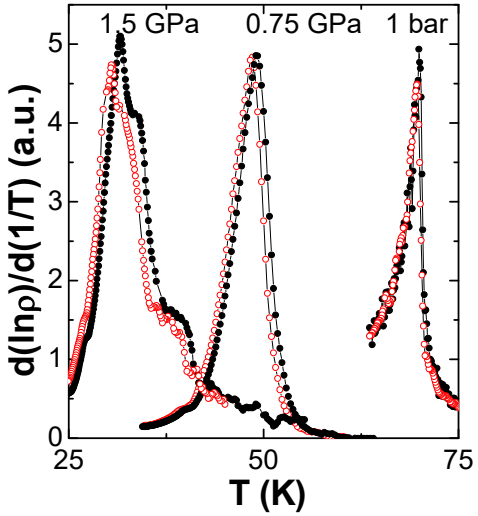


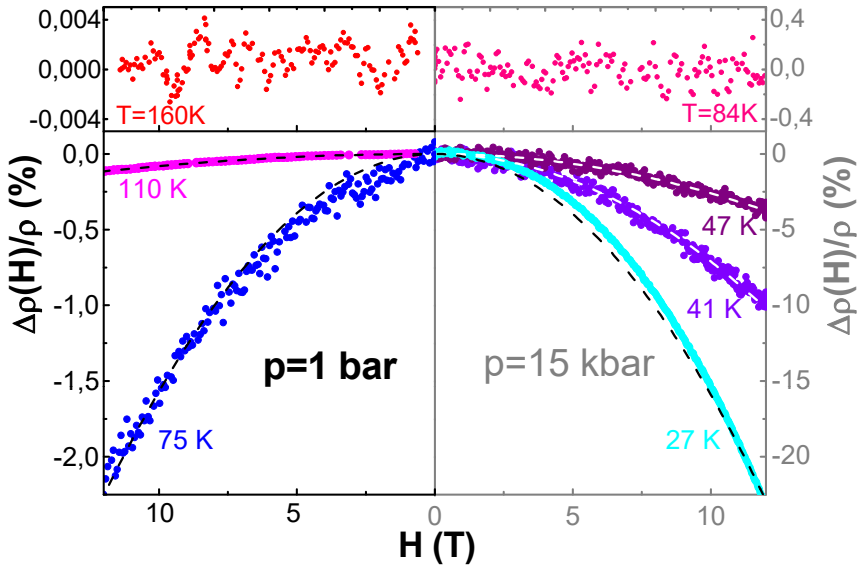


$\Delta \approx 11\ T_{MI}$

Magnetoresistance







Shift of the transition temperature:

$$\frac{\Delta T_{MI}(H,p_0)}{T_{MI}(p_0)} = -\gamma\left(\frac{gS\mu_B H}{k_B \cdot T_{MI}(p_0)}\right)^2$$

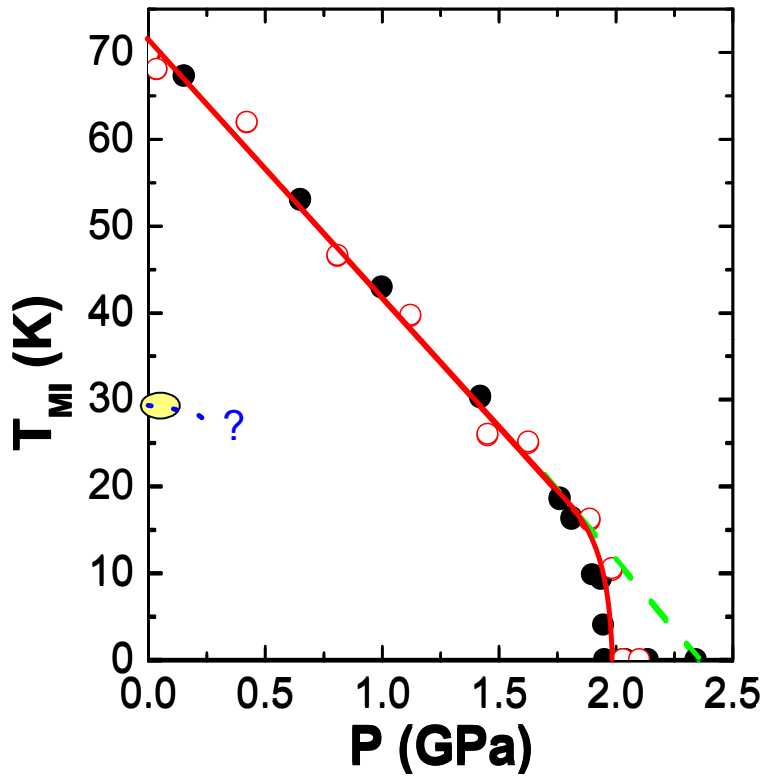
γ = 0.45 is

- **pressure independent**
- **same value as in spin-Peierls systems**

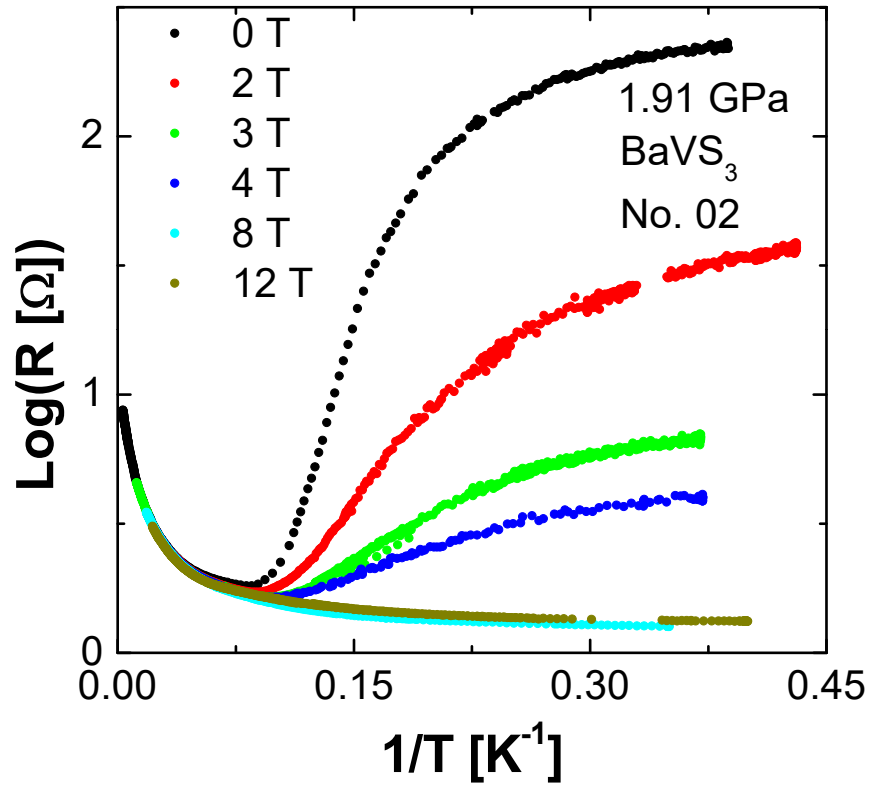
C. H. Booth, E. Figueroa, J. M. Lawrence, M. F. Hundley, and J. D. Thompson. 1999. *Phys. Rev. B*, **60**(21), 14852.

Kézsmarki, S. Csonka, H. Berger, L. Forro, P. Fazekas and G. Mihaly. 2001. *Phys. Rev. B*, **63**(8), 081106.

Following the T_{MI} by: pressure



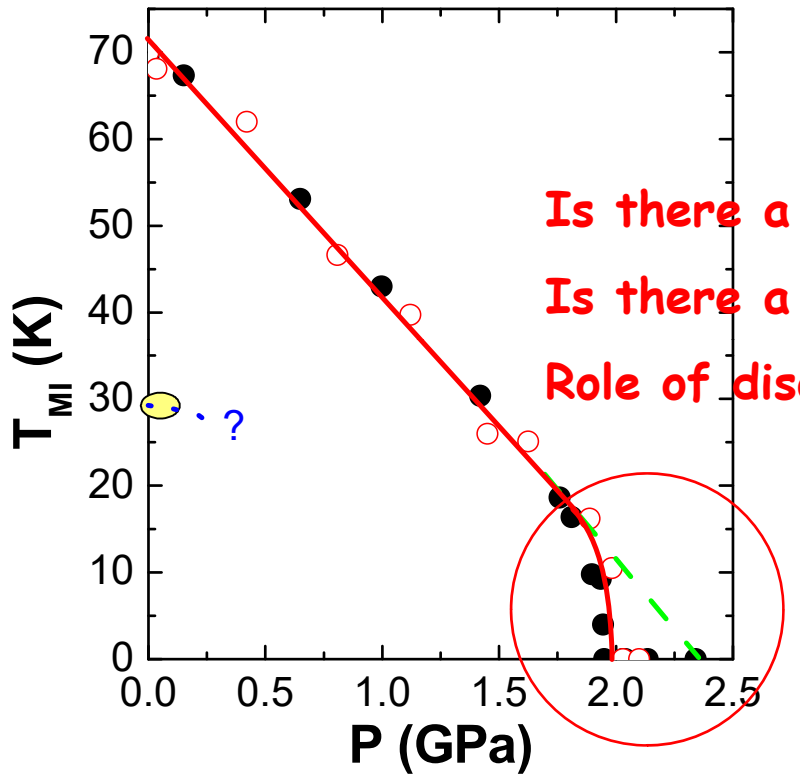
Collapse of the insulating phase T_{MI} extrapolates to 0 K at p_c ~ 1.9 GPa and T_{MI} ~ 15 K



Collapse of the insulating phase by increase of the magnetic field.

L. Forró, R. Gaàl, H. Berger, P. Fazekas, K. Penc, I. Kèzsmàrki and G. Mihàly. 2000. *Phys. Rev Lett.*, **85**(9), 1938.

Following the T_{MI} by: pressure



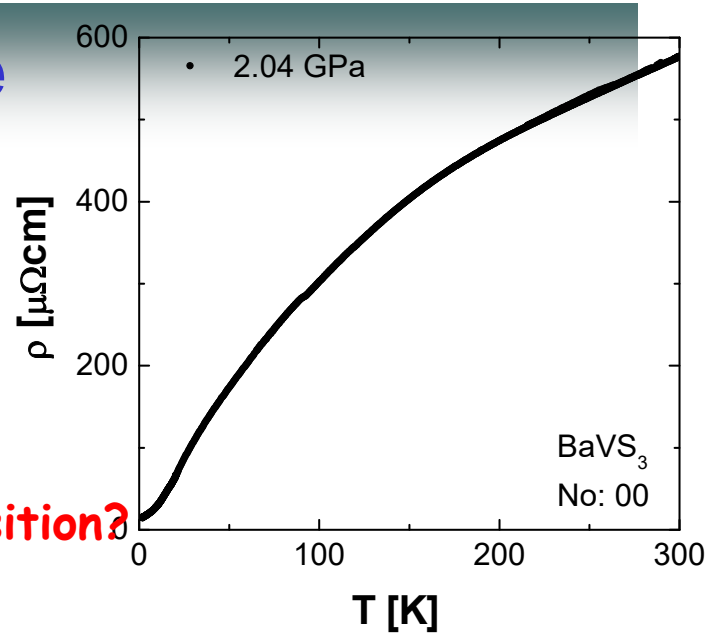
Is there a QCP?

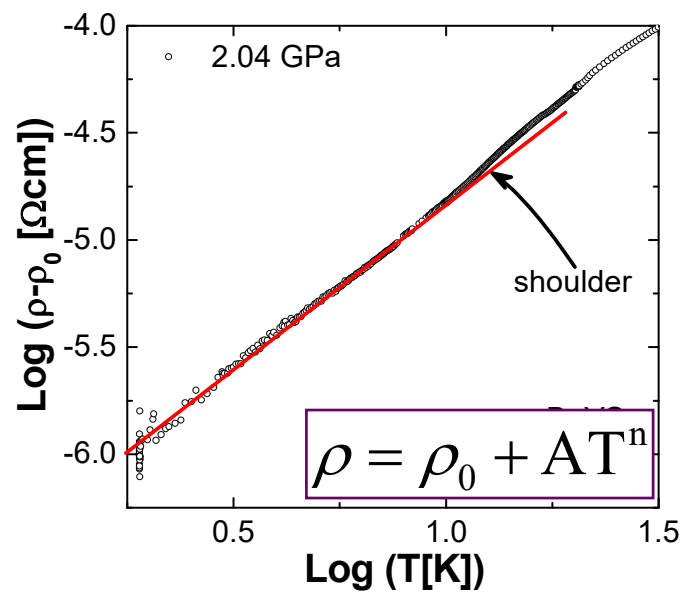
Is there a NFL-FL transition?

Role of disorder?

Collapse of the insulating phase

p ~ 1.7 GPa and T_{MI} ~ 15 K

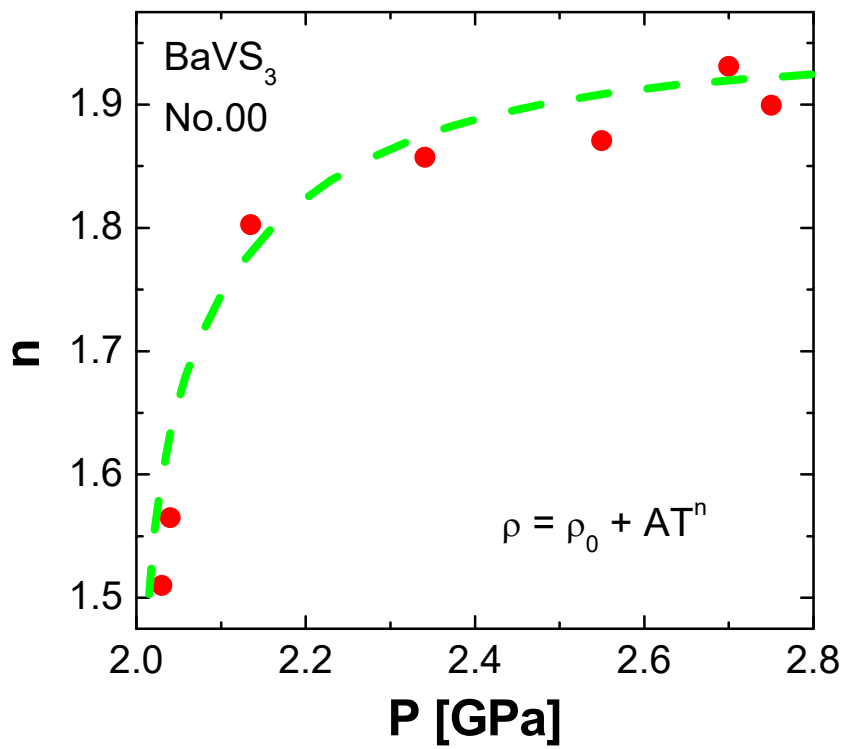


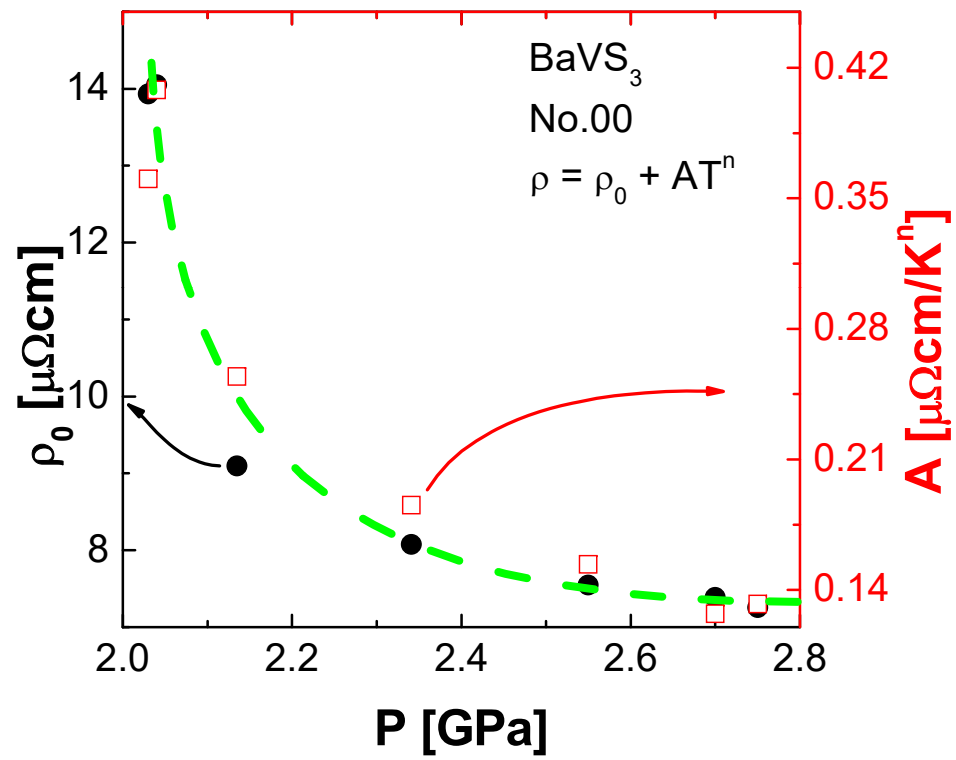


L. Forró, R. Gaàl, H. Berger, P. Fazekas, K. Penc, I. Kèzsmàrki and G. Mihàly. 2000. *Phys. Rev Lett.*, **85**(9), 1938.

Crossover from Non-Fermi Liquid to Fermi Liquid

$$\rho = \rho_0 + AT^n$$



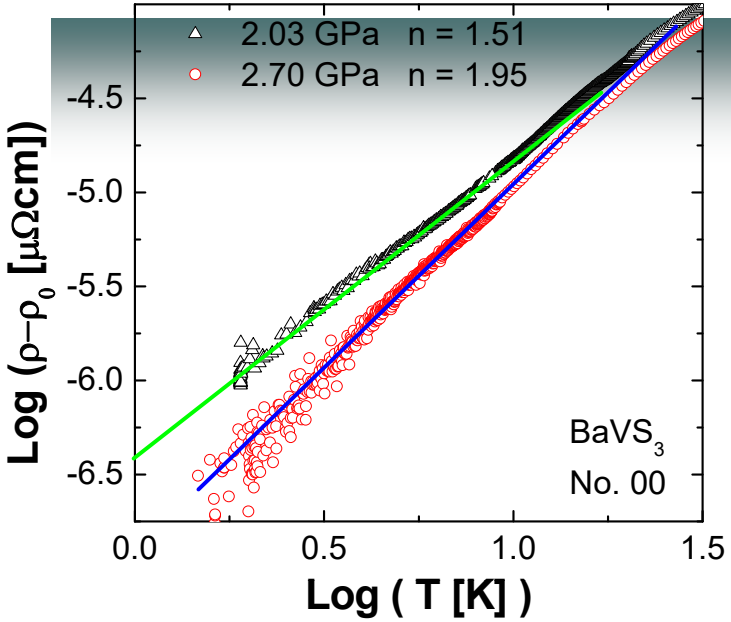


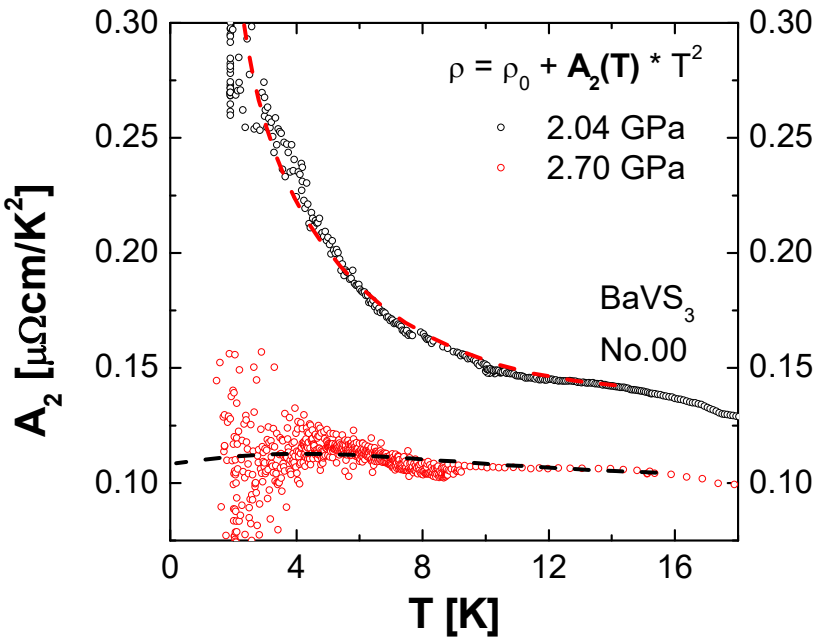
ρ_0 - by its definition describes the behavior of the system at the temperature of absolute zero.

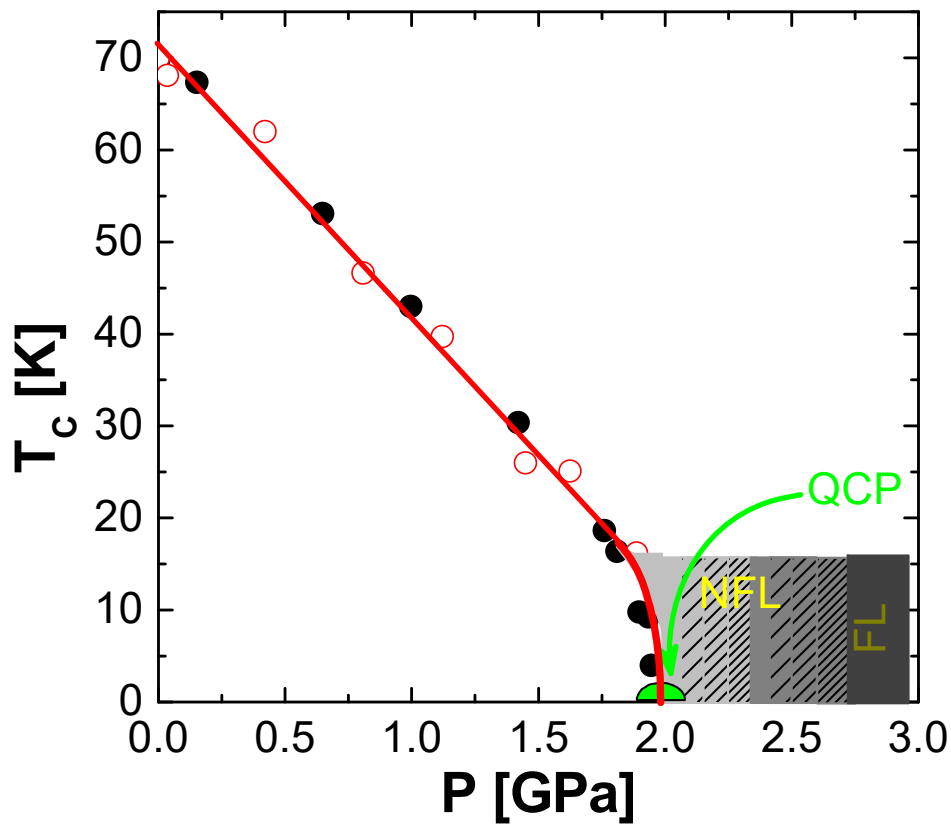
Pressure dependence of the low temperature resistivity coefficients n, A, ρ_0 strongly suggests that at 2 GPa system is in the proximity of a QCP.

NFL - FL

p = 2.04 GPa - 2.7 Gpa







$m^* \propto A_2^{\frac{1}{2}}$

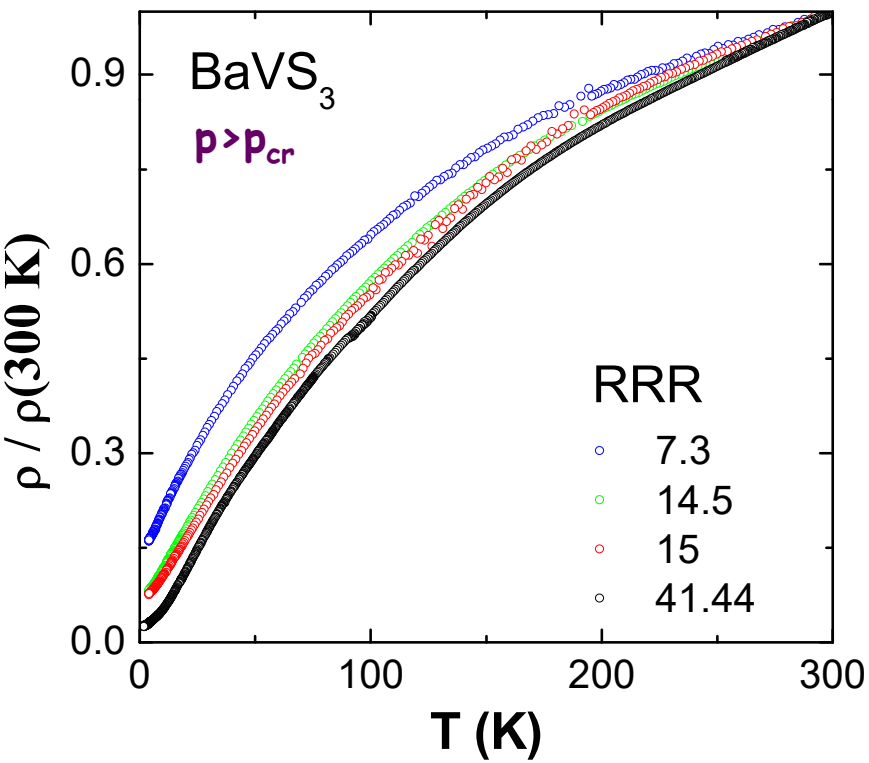
Disorder and NFL behavior ($p>p_{cr}$)

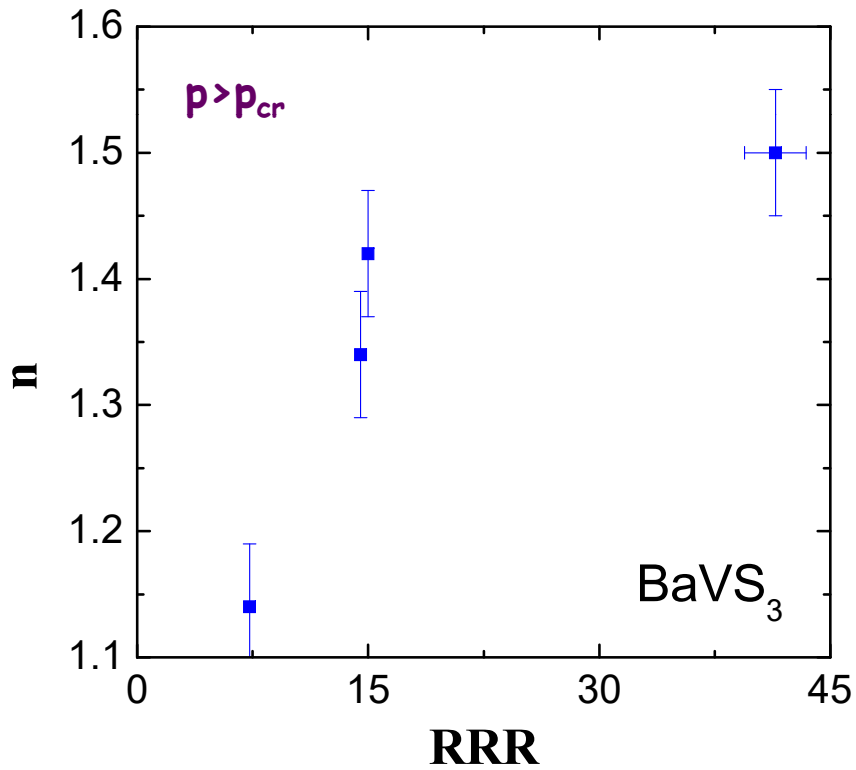
-Imperfections in the crystal structure
-Sulfur deficiency

-Isovalent substitution

Theoretical prediction for n(c)

RRR ratio ~ 10 – low quality samples
~ 100 – high quality samples





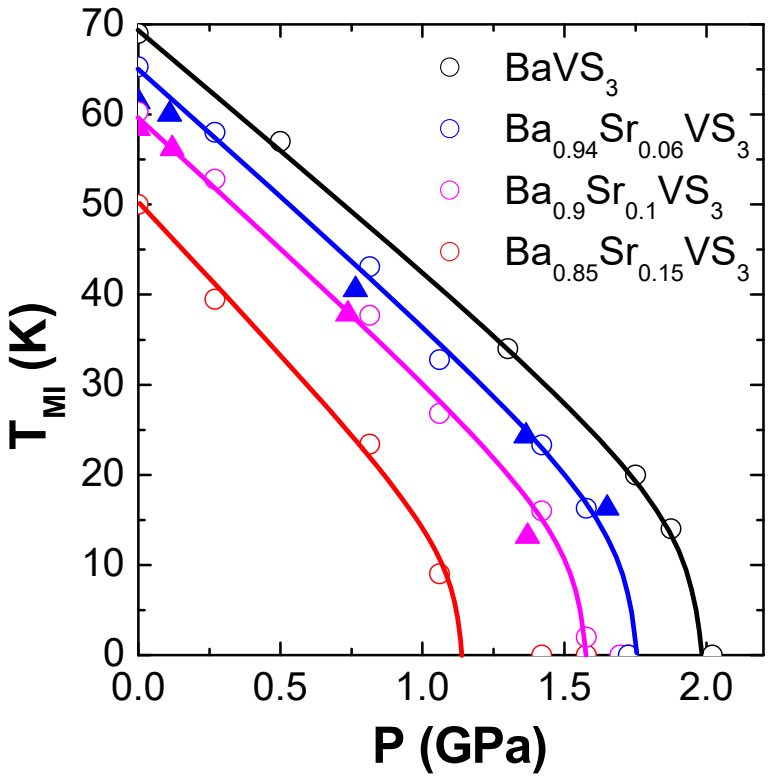
n(c) 1.5 → 1

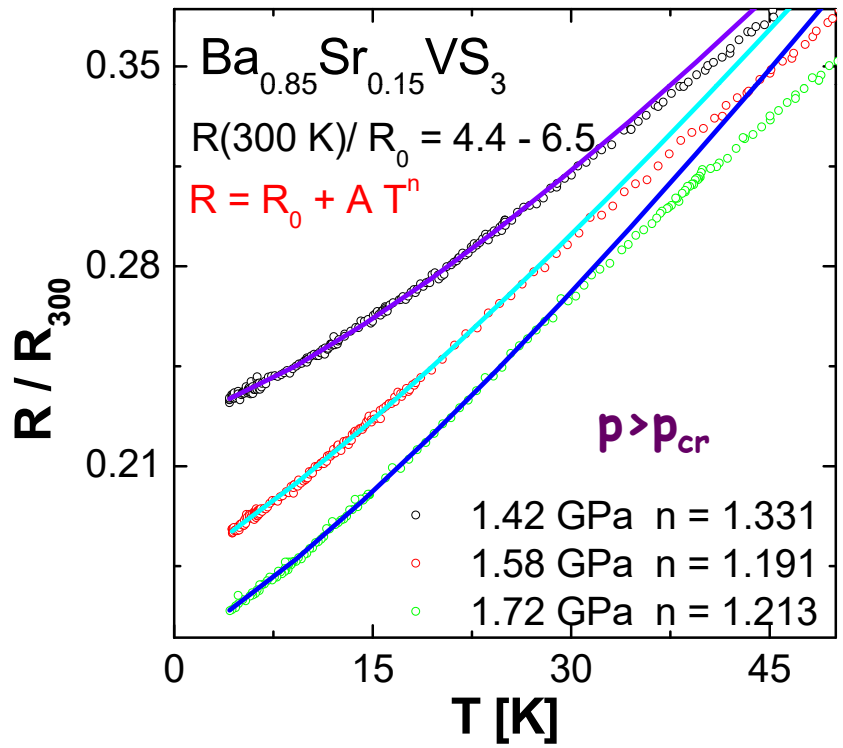
Disorder and NFL ($p>p_{cr}$)

Theoretical prediction for n(c)

RRR ratio ~ 10 – low quality samples
~ 100 – high quality samples

-Isovalent substitution

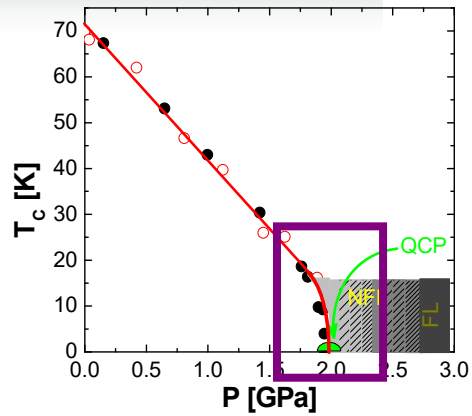


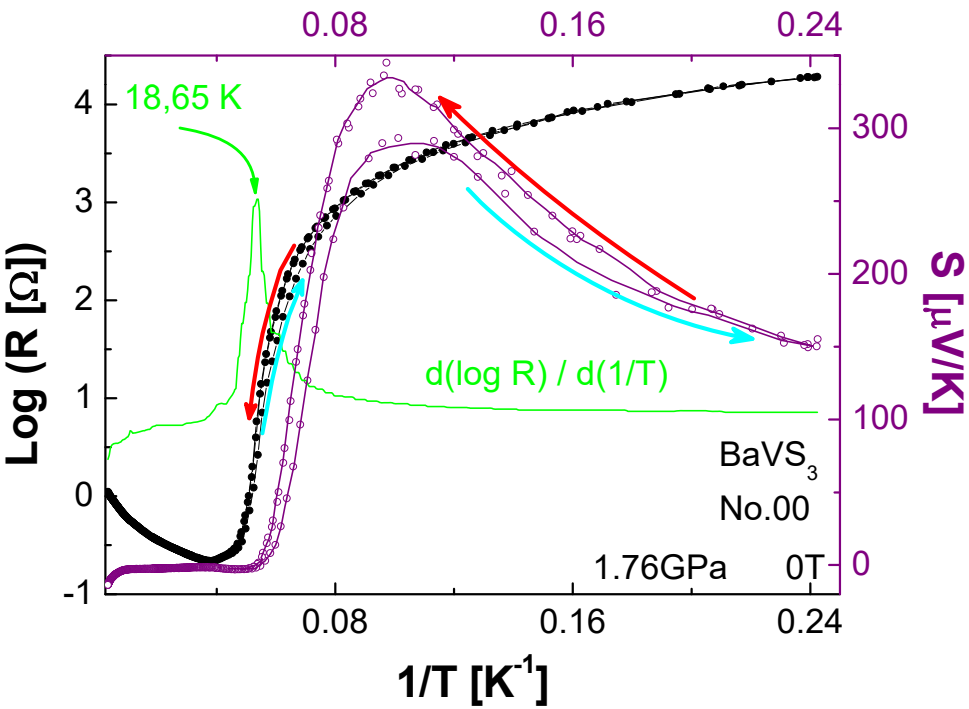


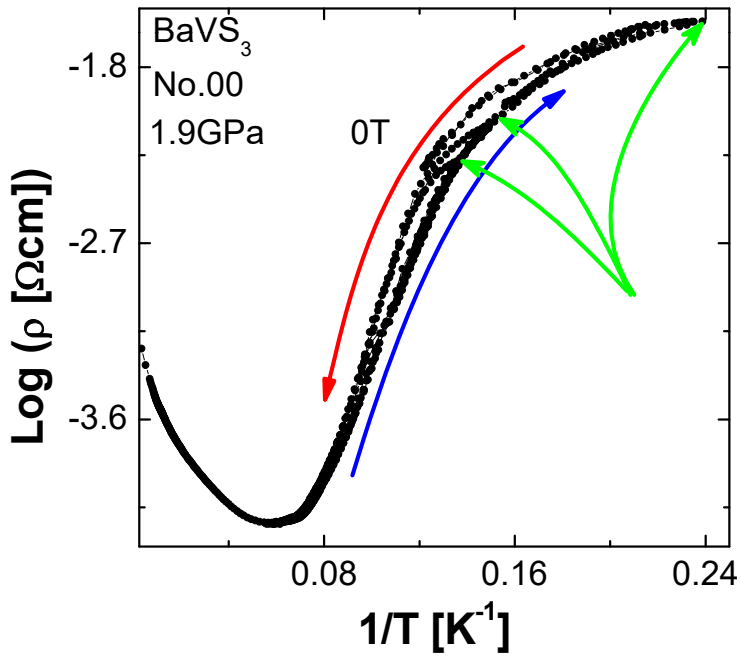
A. Gauzzi, F. Licci, N. Barisic, G. L. Calestani, F. Bolzoni, E. Gilioli, M. Marezio, A. Sanna, C. Franchini and L. Forro. 2003. Int. J. Mod. Phys. B, 17(18-20), 3503-08

n(c): $1.5 \rightarrow 1$

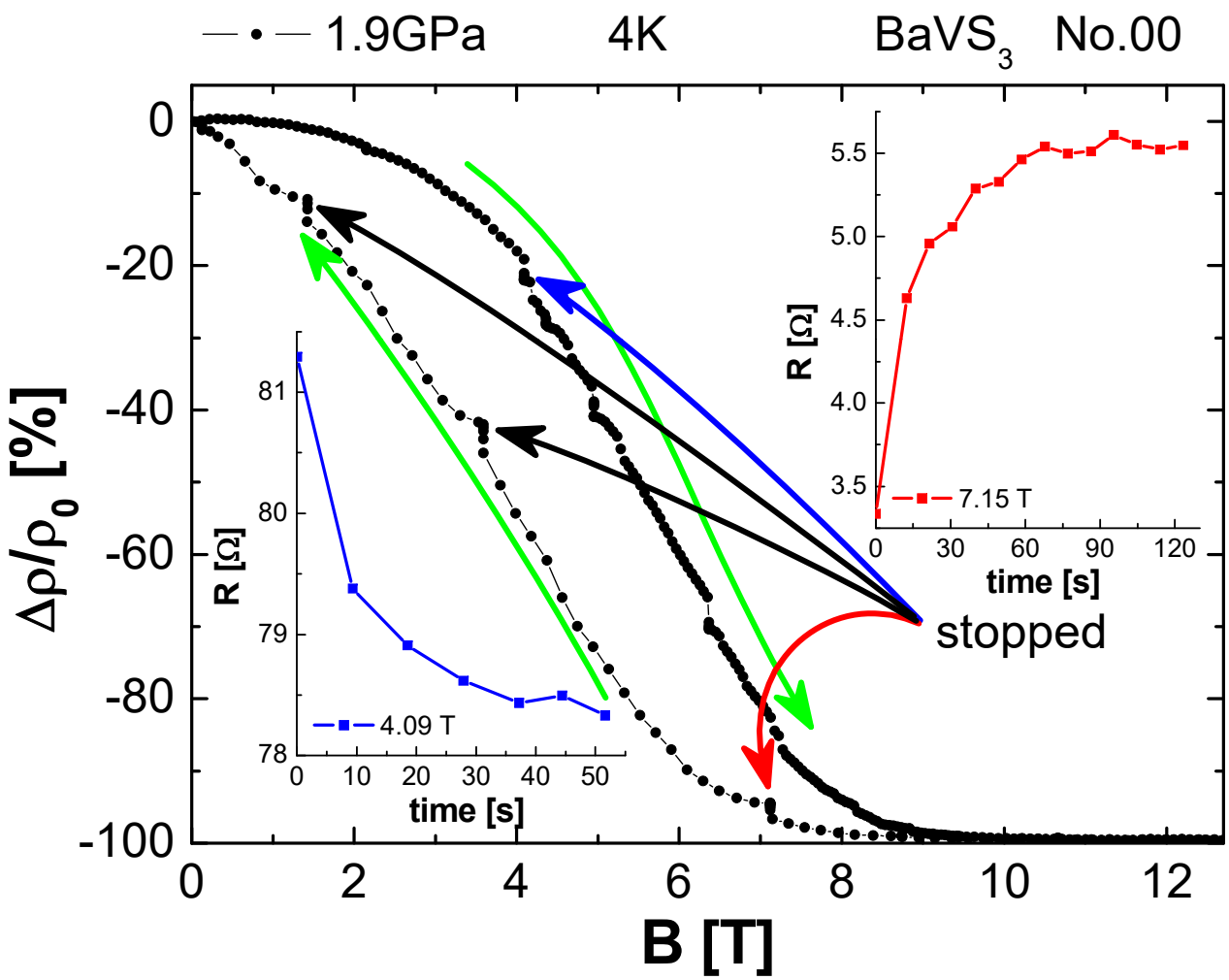
New features in pure samples – Hysterisis in T





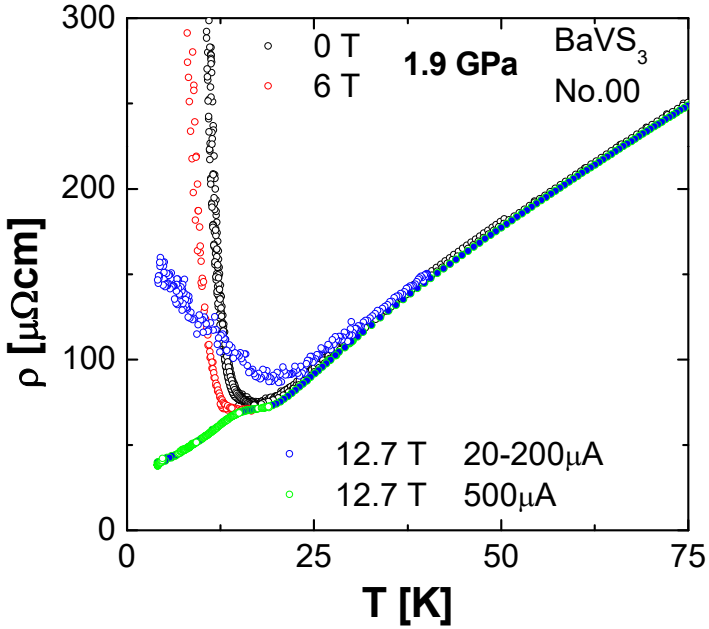


New features in pure samples – Hysterisis in B



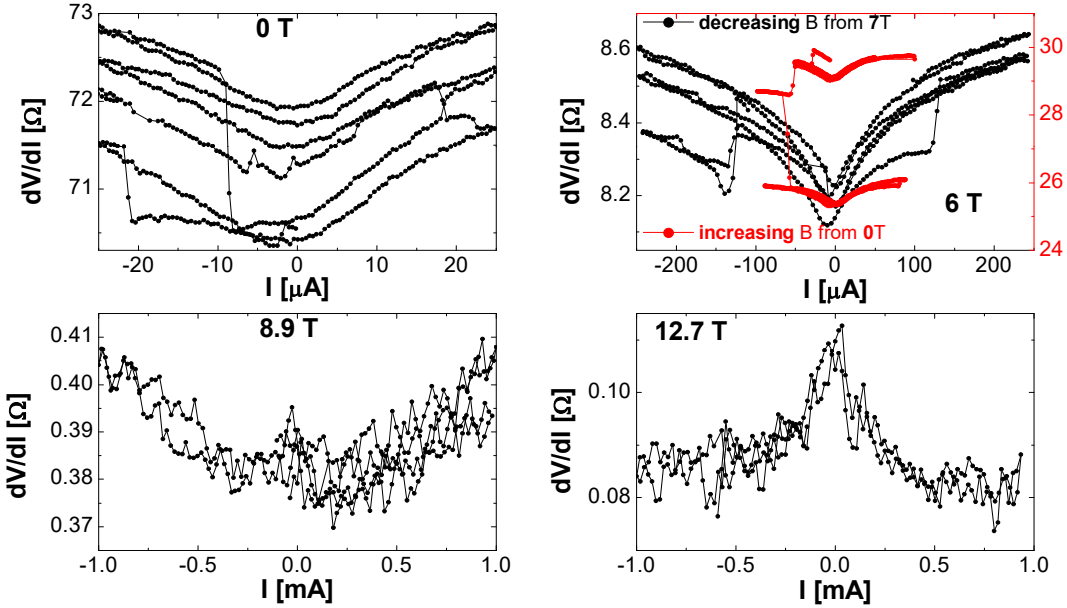
Nonlinear behaviour in I

d.c. current



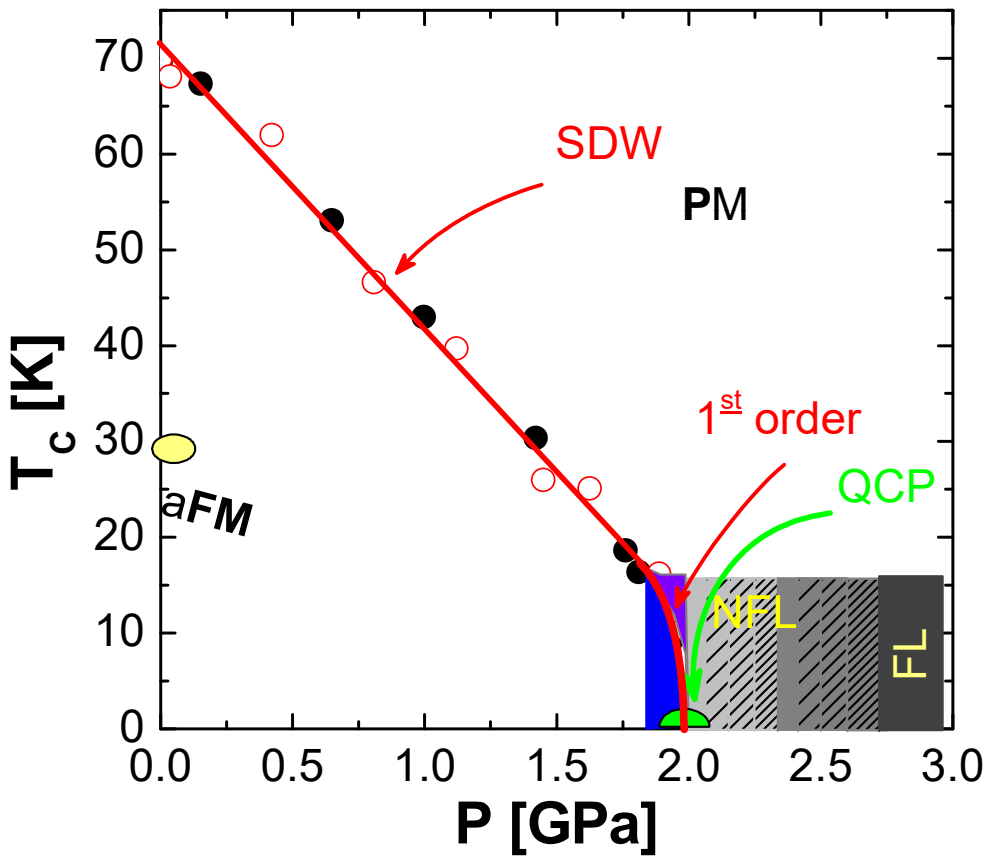
a.c. current

4 K



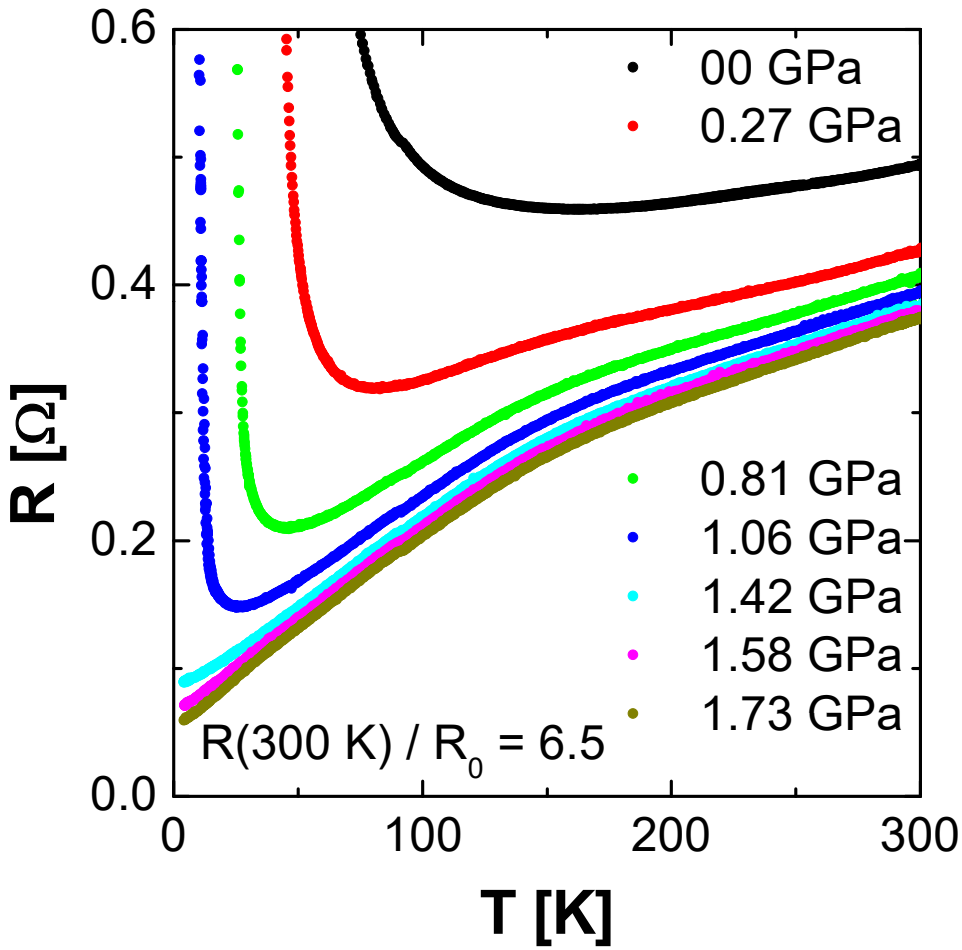
Phase diagram for pure $BaVS_3$

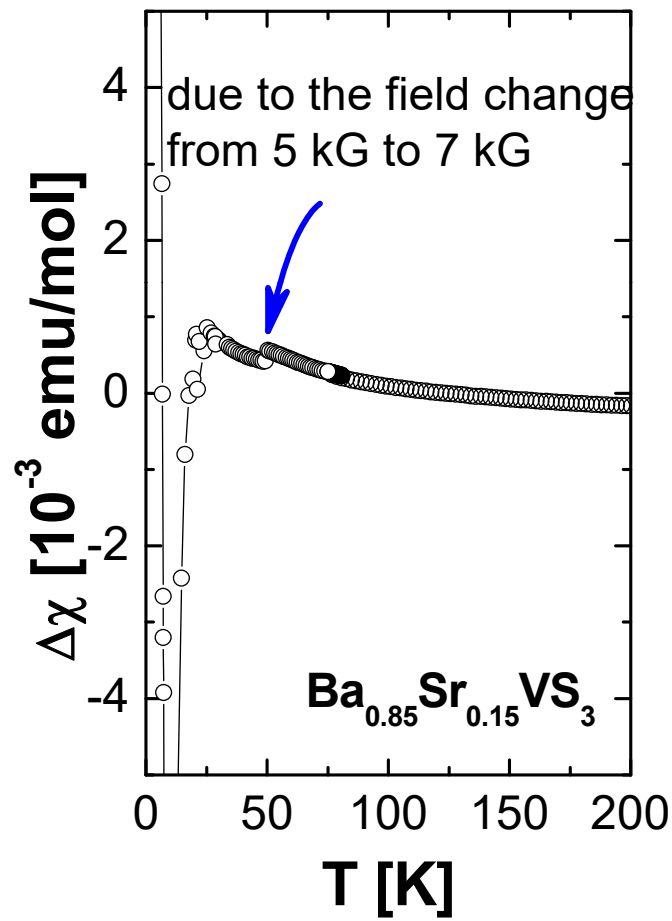
RRR ratio ~ 60 – high quality samples



Disorder effects on T_{MI} and T_X

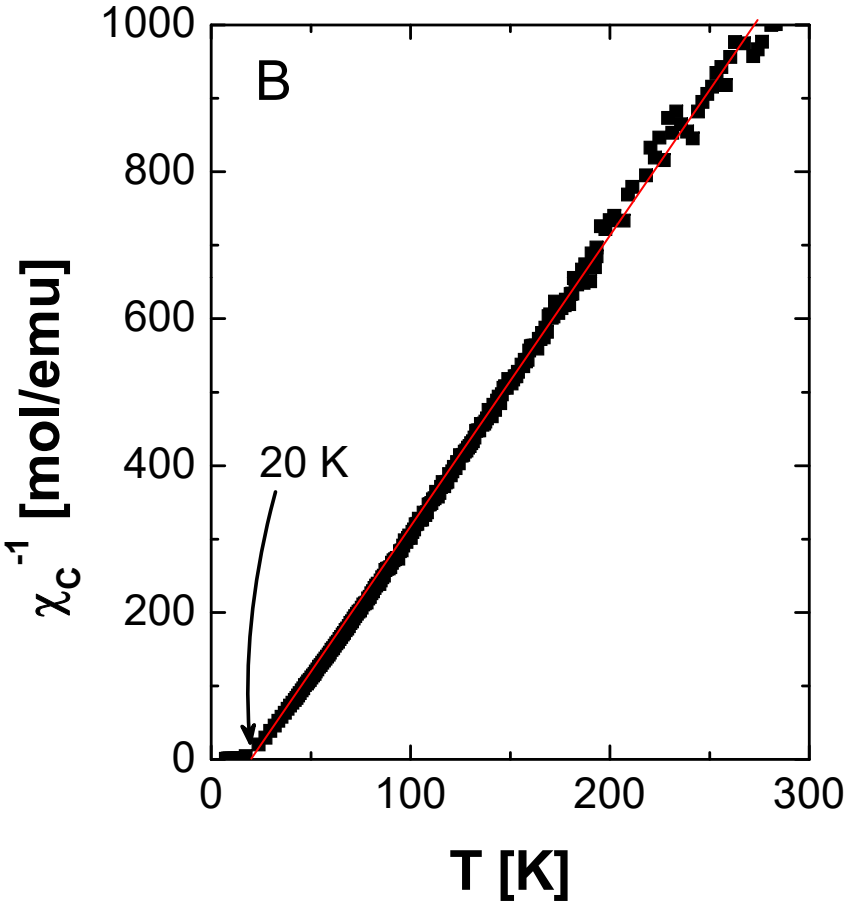
Isovalent substitution

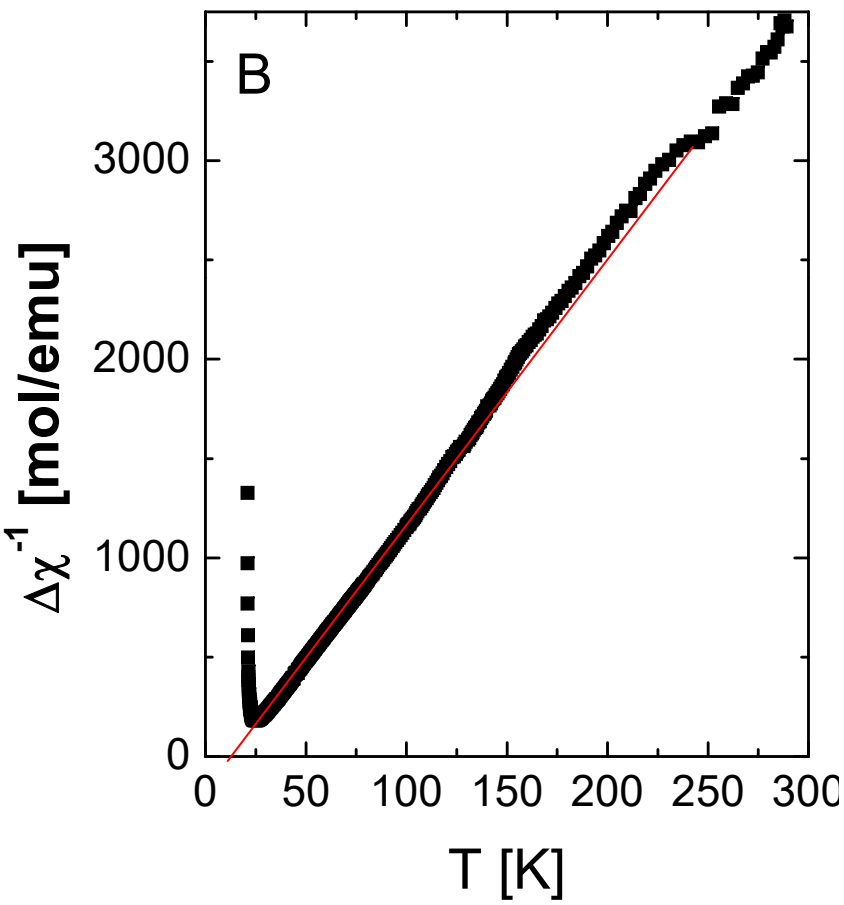




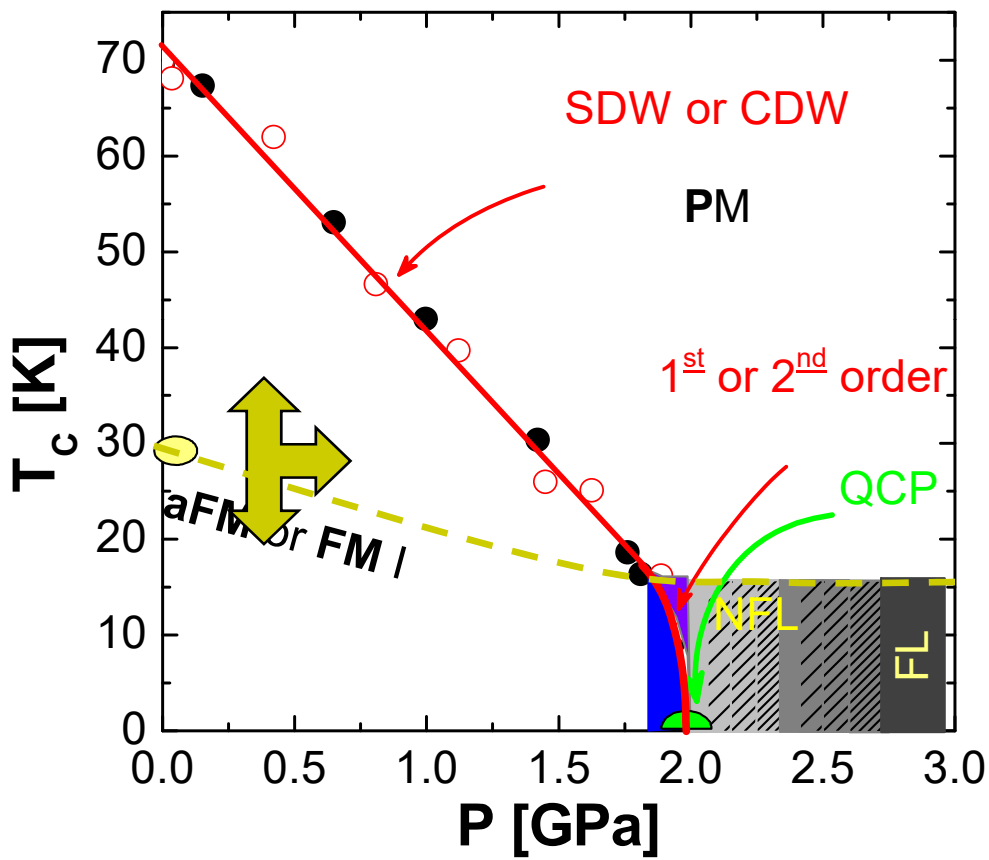
Disorder effects on T_{MI} and T_X

-Imperfections in the crystal structure
-Sulfur deficiency





Phase diagram for $BaVS_3$



T_X as a function of pressure?

$BaVS_3$

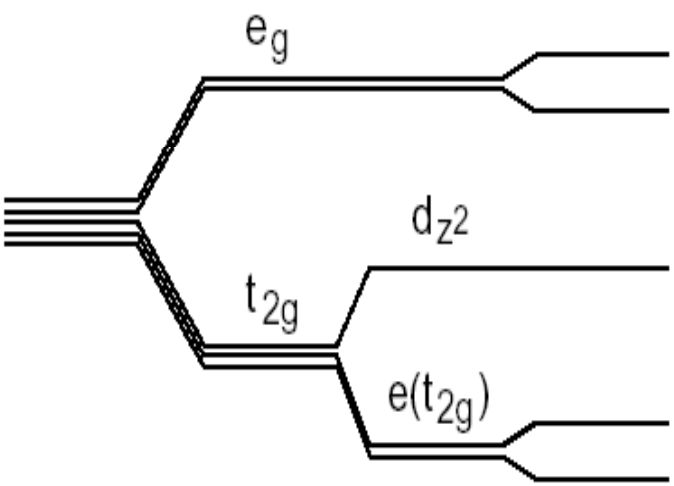
Brings together all three discussed material classes:

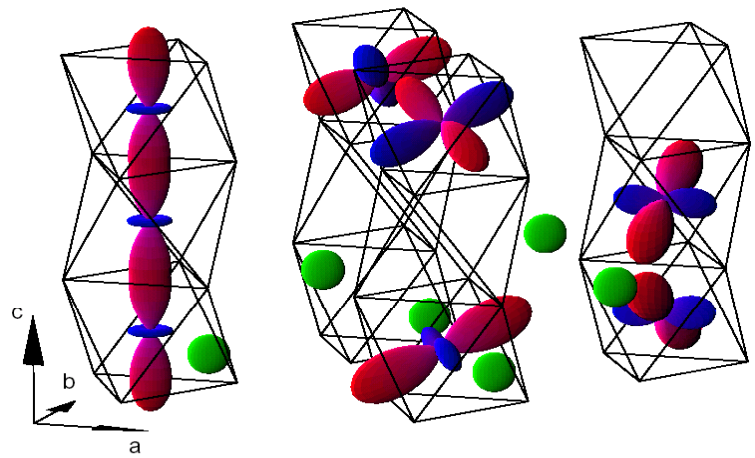
Quasi 1d conductors (quasi 1d band)

Heavy Fermions (narrow band + broad band)

Cuprates (d-orbital of V in the center of S octahedron)

Frustrations – triangular lattice





Acknowledgements

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FWF
Der Wissenschaftsfonds.

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