Superconductivity in doped or pressurized insulators : cuprates and organics

A.-M. Tremblay

G. Sordi, K. Haule, D. Sénéchal, C.-D. Hébert

P. Sémon, B. Kyung, G. Kotliar,

M. Civelli, S. Kancharla,

CIFAR
CANADIAN INSTITUTE for ADVANCED RESEARCH

UNIVERSITÉ DE SHERBROOKE

Caen, 20 March, 2015

VERITATEM IN CHARITATE

UNIVERSITÉ DE SHERBROOKE

Half-filled band is metallic?

Half-filled band: Not always a metal

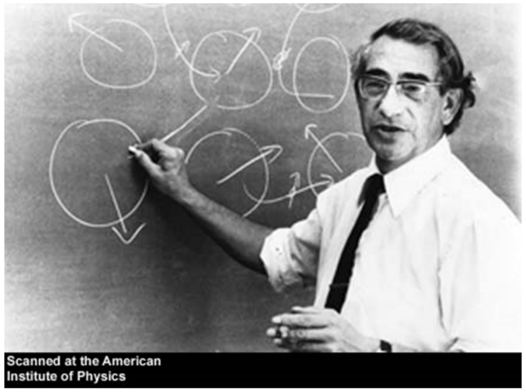
NiO, Boer and Verway

Peierls, 1937

Mott, 1949

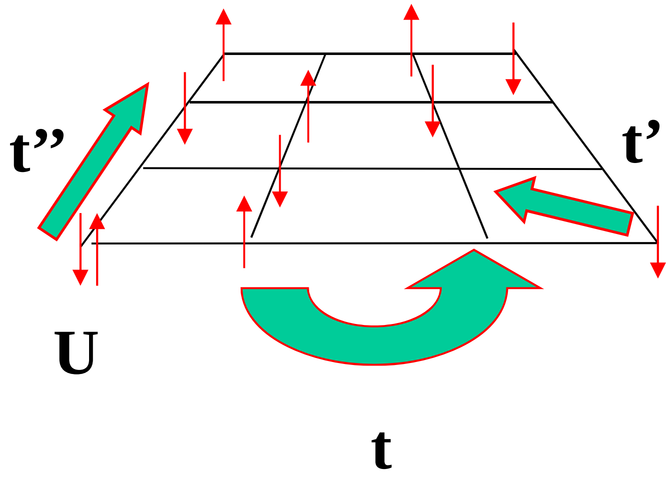
UNIVERSITÉ DE SHERBROOKE

Hubbard model

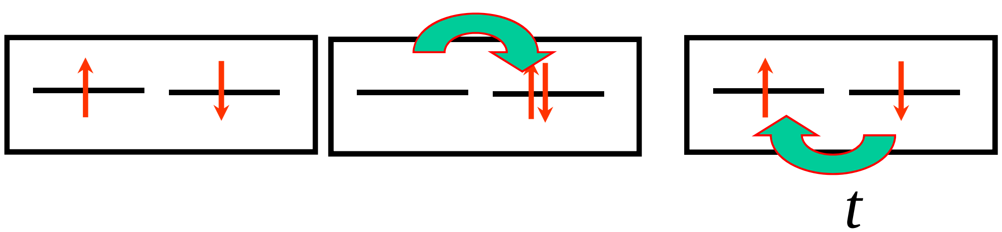


1931-1980

μ



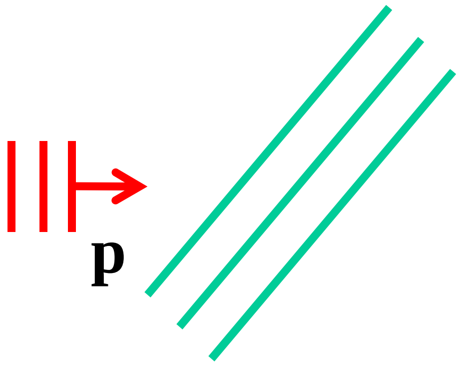
$$H = -\sum_{<ij>\sigma} t_{i,j}\left(c^{\dagger}_{i\sigma}c_{j\sigma} + c^{\dagger}_{j\sigma}c_{i\sigma}\right) + U\sum_{i} n_{i\uparrow}n_{i\downarrow}$$



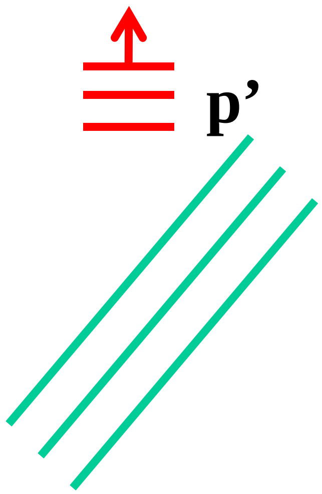
Effective model, Heisenberg: $J = 4t^2/U$

Superconductivity and attraction?

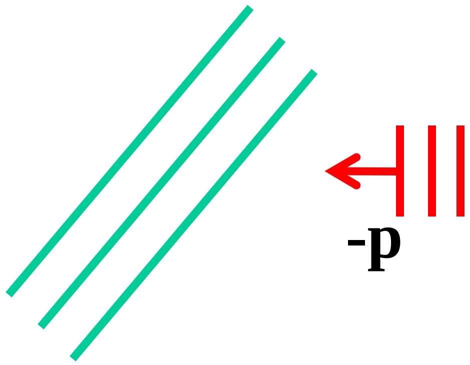
Attraction mechanism in the metallic state



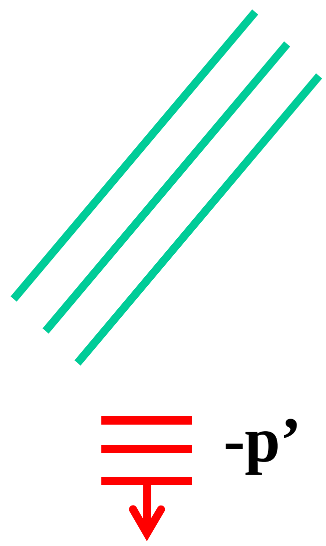
Attraction mechanism in the metallic state



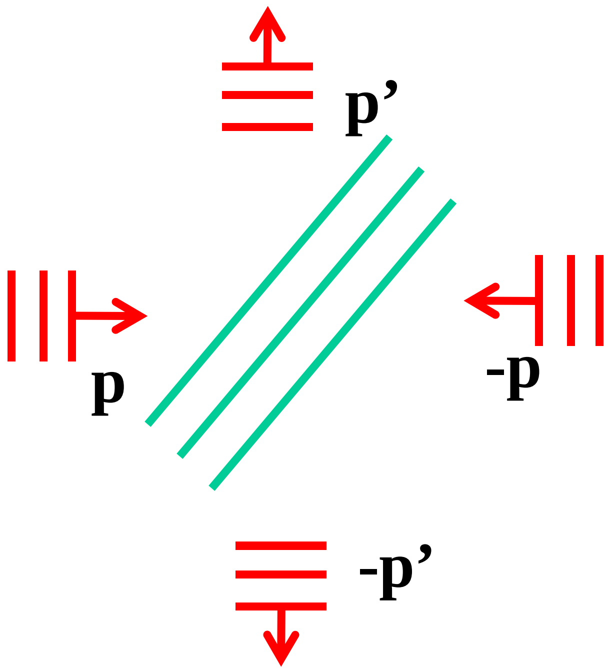
Attraction mechanism in the metallic state



Attraction mechanism in the metallic state



Attraction mechanism in the metallic state



UNIVERSITÉ DE SHERBROOKE

#1 Cooper pair, #2 Phase coherence

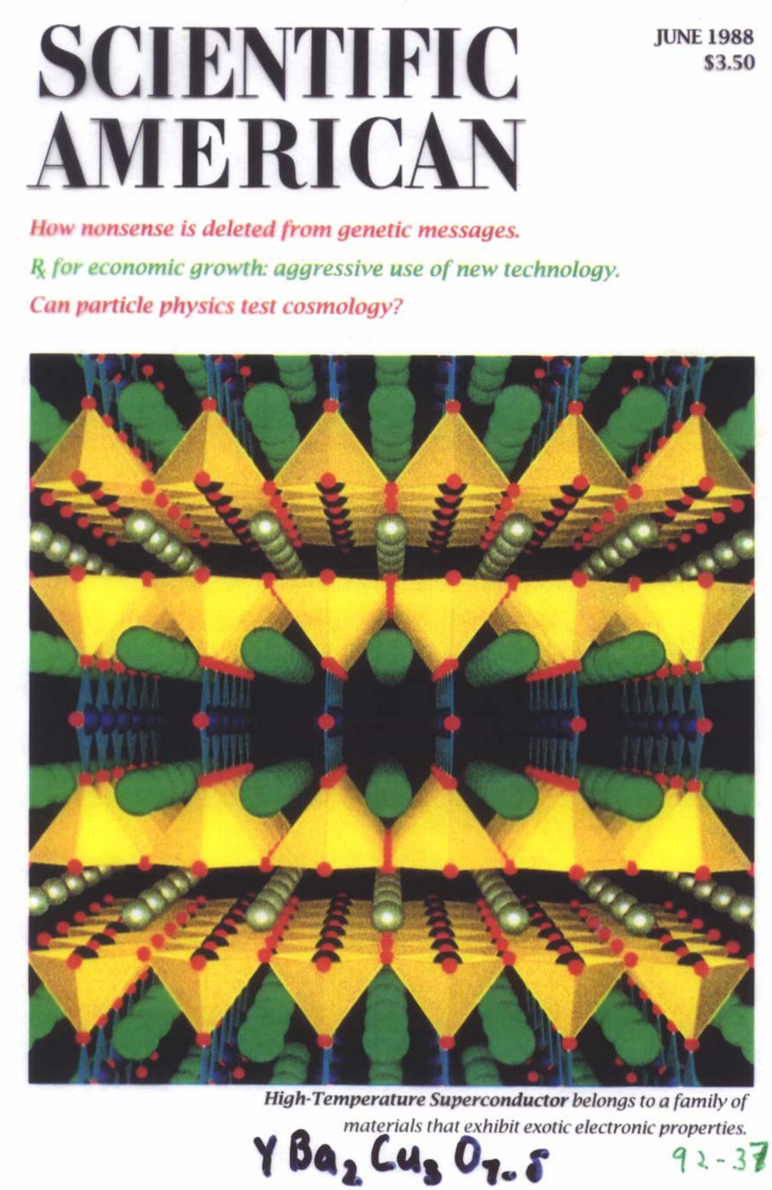
$$E_P = \sum_{\mathbf{p},\mathbf{p}'} U_{\mathbf{p}-\mathbf{p}'} \psi_{\mathbf{p}\uparrow,-\mathbf{p}\downarrow} \psi^*_{\mathbf{p}'\uparrow,-\mathbf{p}'\downarrow}$$

$$E_P = \sum_{\mathbf{p},\mathbf{p}'} U_{\mathbf{p}-\mathbf{p}'} \left(\langle \psi_{\mathbf{p}\uparrow,-\mathbf{p}\downarrow} \rangle \psi^*_{\mathbf{p}'\uparrow,-\mathbf{p}'\downarrow} + \psi_{\mathbf{p}\uparrow,-\mathbf{p}\downarrow} \left\langle \psi^*_{\mathbf{p}'\uparrow,-\mathbf{p}'\downarrow} \right\rangle \right)$$

$$|\mathrm{BCS}(\theta)\rangle = \ldots + e^{iN\theta}|N\rangle + e^{i(N+2)\theta}|N+2\rangle + \ldots.$$

UNIVERSITÉ DE SHERBROOKE

Cuprates


SCIENTIFIC AMERICAN

JUNE 1988
$3.50

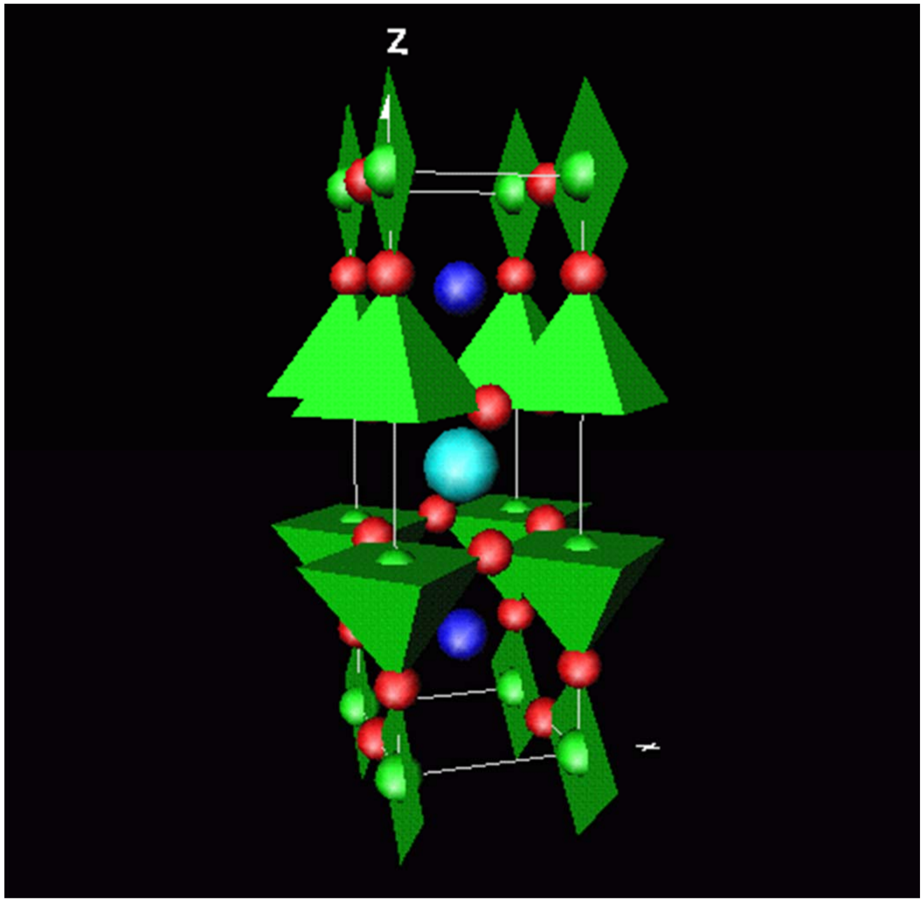
How nonsense is deleted from genetic messages.

℞ for economic growth: aggressive use of new technology.

Can particle physics test cosmology?

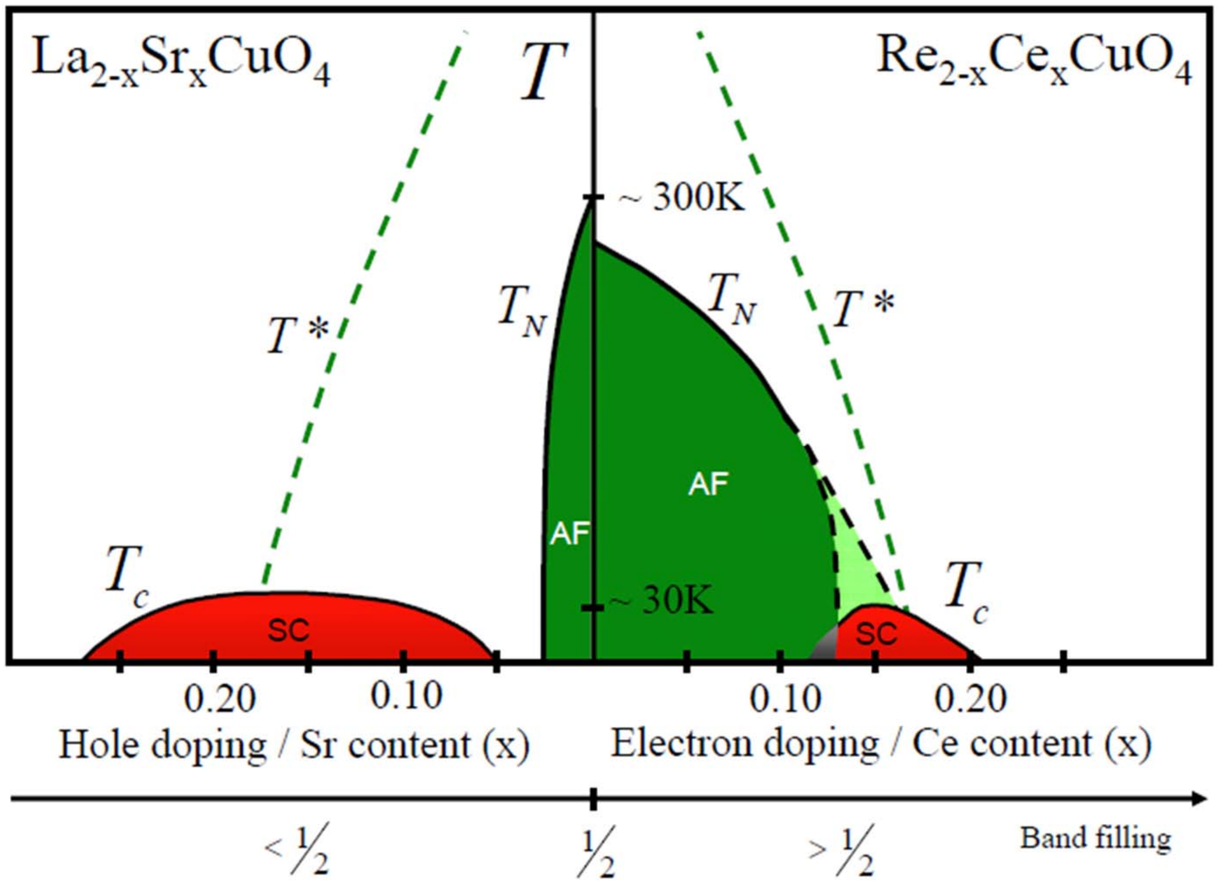
***High-Temperature Superconductor** belongs to a family of materials that exhibit exotic electronic properties.*

$YBa_2Cu_3O_{7-\delta}$ 92-37



High-temperature superconductors

Armitage, Fournier, Greene, RMP (2009)



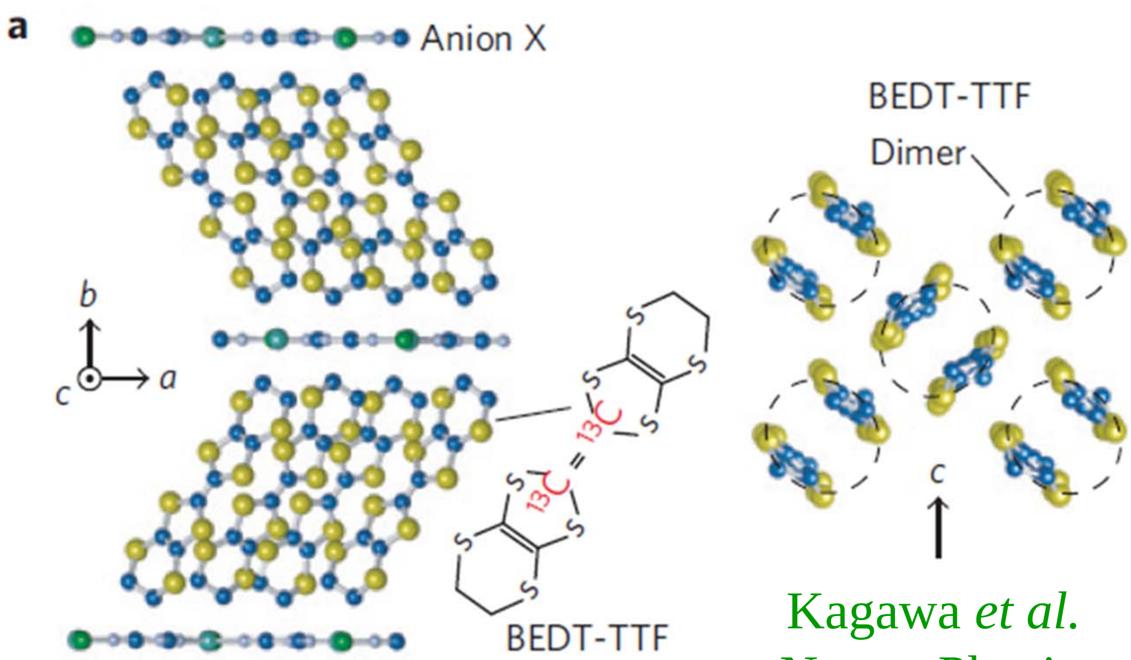
Superconductivity

© Alexis Reymbaut

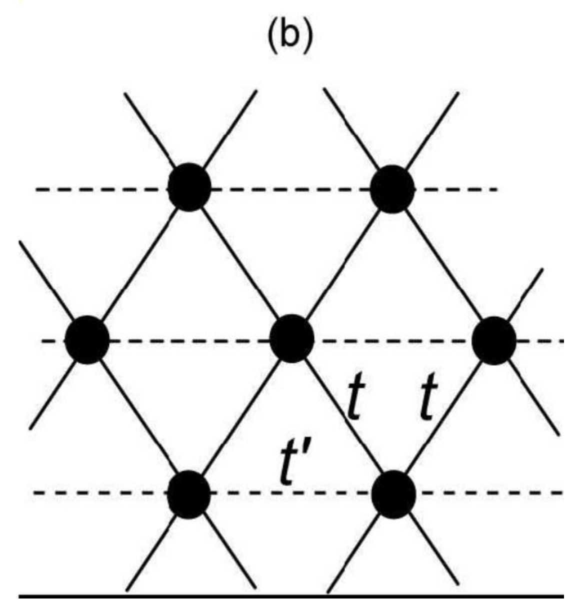
UNIVERSITÉ DE SHERBROOKE

Hubbard on anisotropic triangular lattice

H. Kino + H. Fukuyama, J. Phys. Soc. Jpn **65** 2158 (1996),
R.H. McKenzie, Comments Condens Mat Phys. **18**, 309 (1998)



Kagawa *et al.* Nature Physics **5,** 880 (2009)



n=1, varying *t'/t*

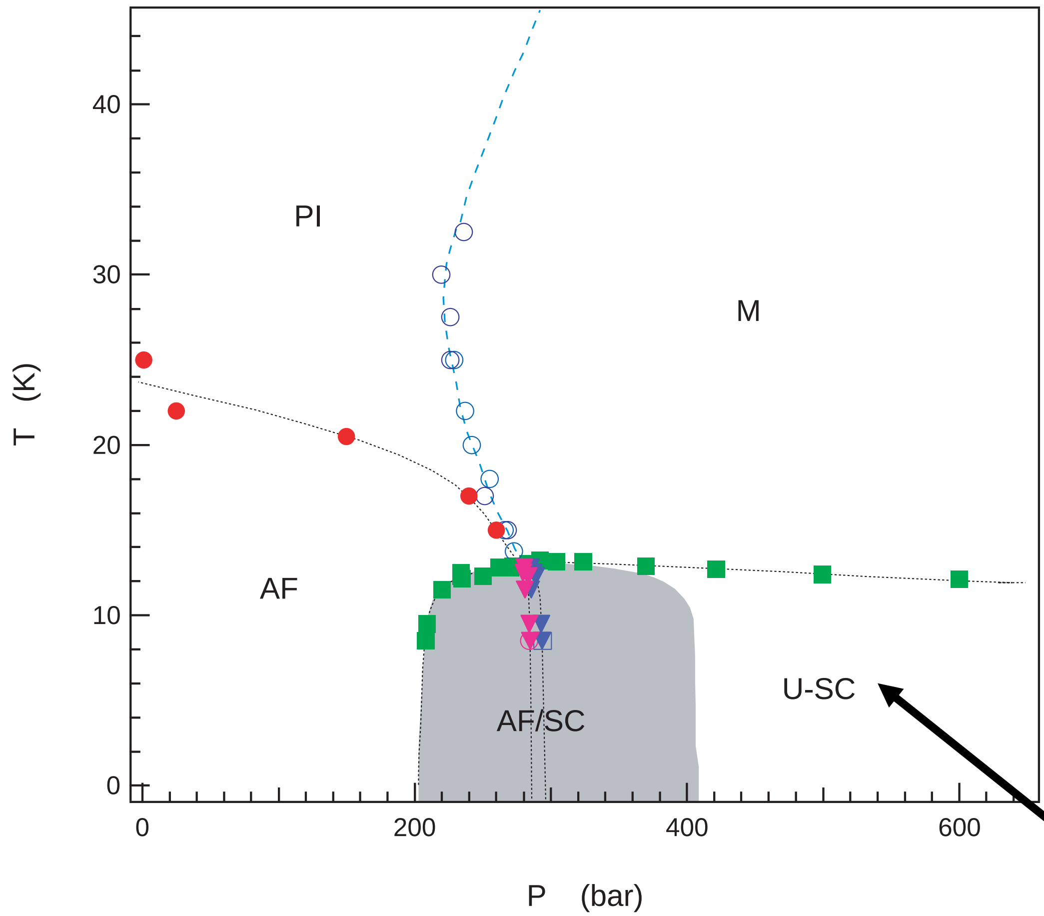
$$H = \sum_{ij\sigma} (t_{ij} - \delta_{ij}\mu) c_{i\sigma}^{\dagger} c_{j\sigma} + U \sum_{i} n_{i\uparrow} n_{i\downarrow}$$

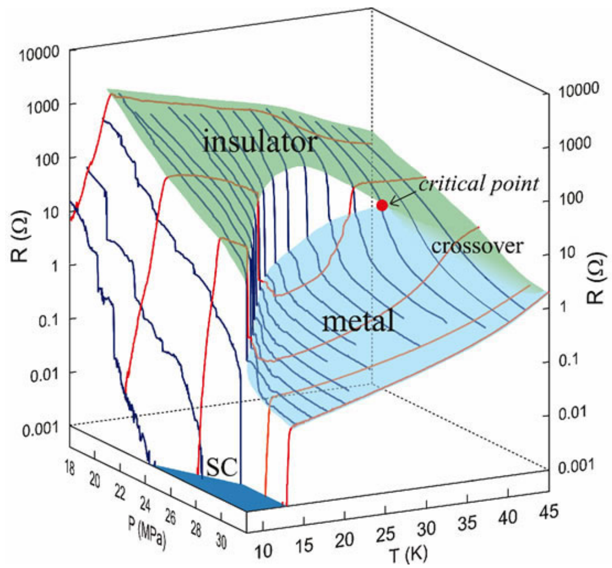
$t \approx 50\,\mathrm{meV}$

$\Rightarrow U \approx 400\,\mathrm{meV}$

t'/t ~ 0.6 - 1.1

Phase diagram for organics





F. Kagawa, K. Miyagawa, + K. Kanoda

PRB **69** (2004) +Nature **436** (2005)

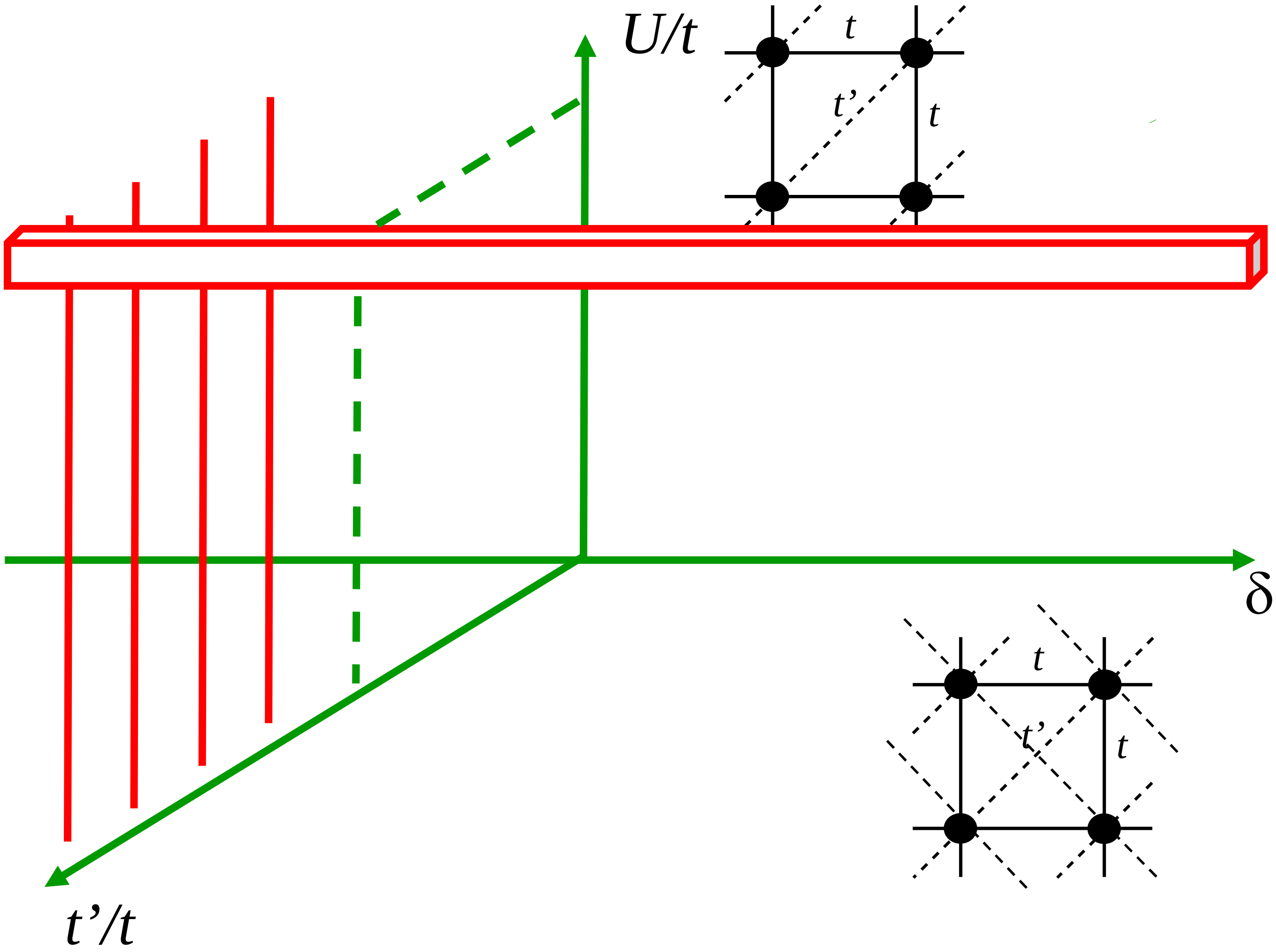
B_g for C_{2h} and B_{2g} for D_{2h}

Powell, McKenzie cond-mat/0607078

Phase diagram (X=Cu[N(CN)$_2$]Cl)

S. Lefebvre et al. PRL **85**, 5420 (2000), P. Limelette, et al. PRL 91 (2003)

Perspective



Outline

- Method
- *T=0* phase diagram
- Finite *T* phase diagram
  - Normal state
    - First order transition
    - Widom line and pseudogap
  - Superconductivity

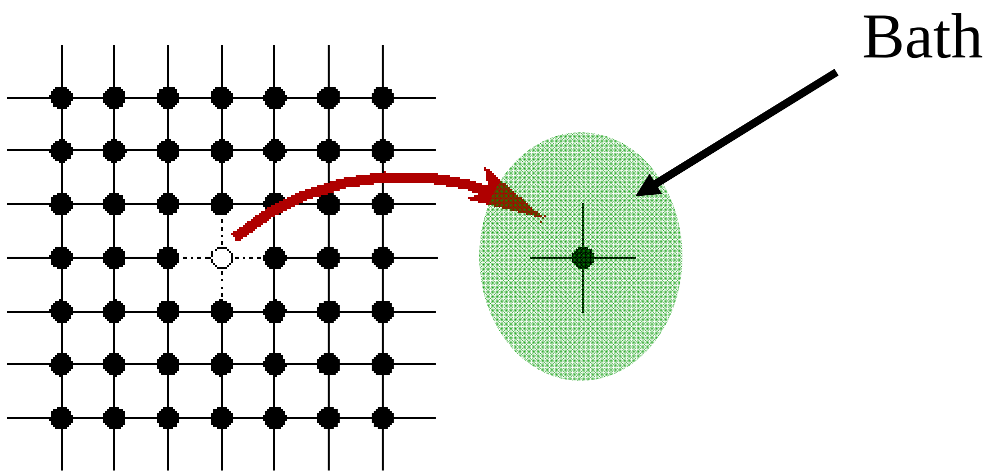
Method

"The effect of concept-driven revolution is to explain old things in new ways. The effect of tool-driven revolution is to discover new things that have to be explained."

Freeman Dyson *Imagined Worlds*

Mott transition and Dynamical Mean-Field Theory. The beginnings in *d = infinity*

- Compute scattering rate (self-energy) of impurity problem.
- Use that self-energy (ω dependent) for lattice.
- Project lattice on single-site and adjust bath so that single-site DOS obtained both ways be equal.

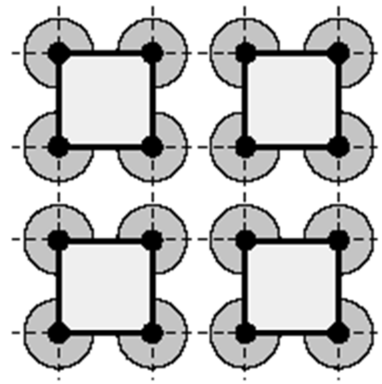


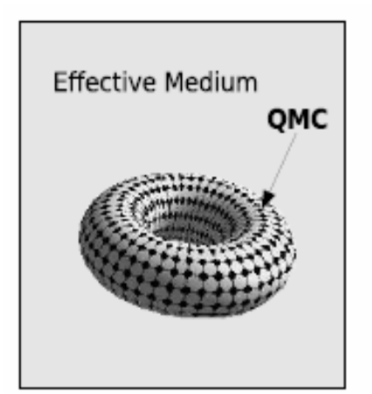
W. Metzner and D. Vollhardt, PRL (1989)
A. Georges and G. Kotliar, PRB (1992)
M. Jarrell PRB (1992)

DMFT, (d = *3)*

2d Hubbard: Quantum cluster method

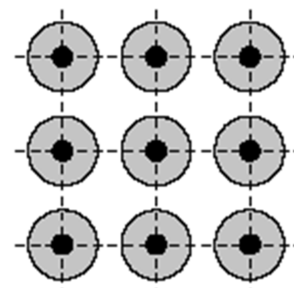
C-DMFT





DCA

DMFT

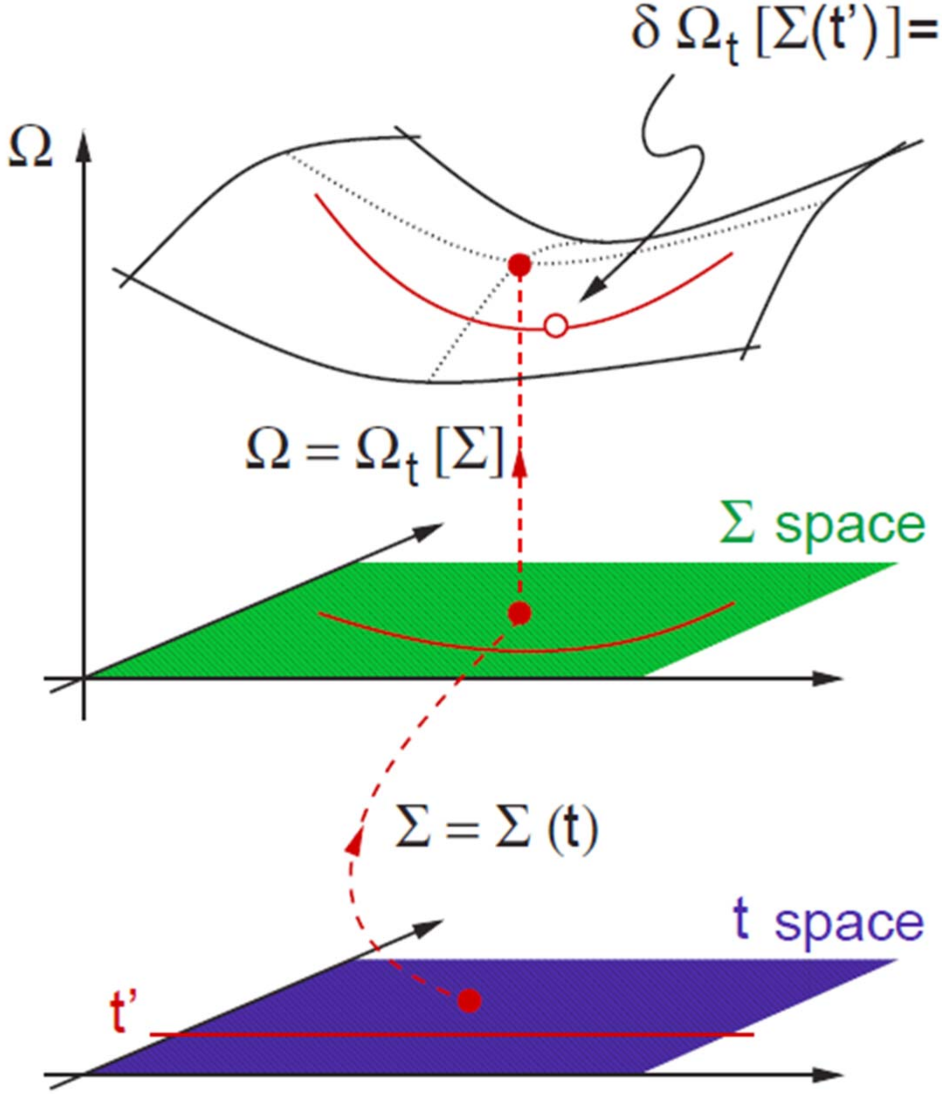


Hettler …Jarrell…Krishnamurty PRB **58** (1998)
Kotliar et al. PRL **87** (2001)
M. Potthoff *et al.* PRL **91,** 206402 (2003).

REVIEWS
Maier, Jarrell et al., RMP. (2005)
Kotliar *et al.* RMP (2006)
AMST *et al.* LTP (2006)

UNIVERSITÉ DE SHERBROOKE

DMFT as a stationnary point



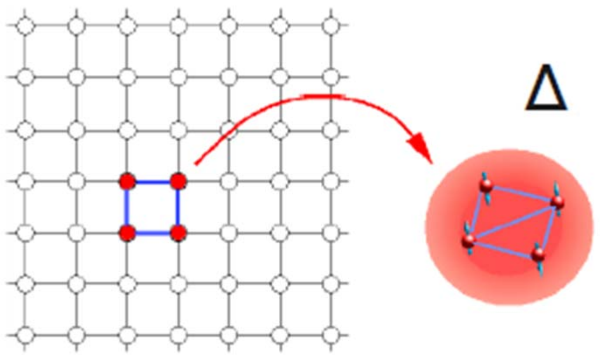
M. Potthoff, Eur. Phys. J. B 32, 429 (2003).

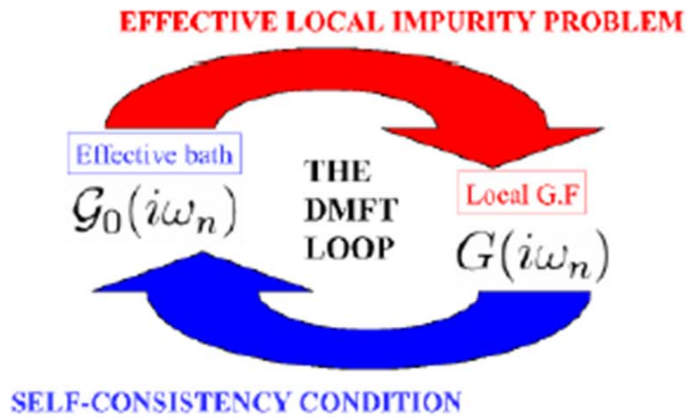
+ and -

- Long range order:
  - Allow symmetry breaking in the bath (mean-field)
- Included:
  - Short-range dynamical and spatial correlations
- Missing:
  - Long wavelength p-h and p-p fluctuations

C-DMFT

$$Z = \int \mathcal{D}[\psi^\dagger, \psi]\, e^{-S_c - \int_0^\beta d\tau \int_0^\beta d\tau' \sum_{\mathbf{K}} \psi^\dagger_{\mathbf{K}}(\tau) \Delta_{\mathbf{K}}(\tau,\tau') \psi_{\mathbf{K}}(\tau')}$$





Mean-field is not a trivial problem! Many impurity solvers.

Here: continuous time QMC

P. Werner, PRL 2006
P. Werner, PRB 2007
K. Haule, PRB 2007

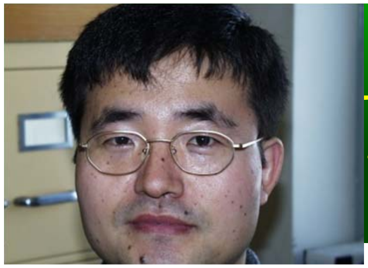
Why important

$$\Delta(i\omega_n) = i\omega_n + \mu - \Sigma_c(i\omega_n) - \left[\sum_{\tilde{k}} \frac{1}{i\omega_n + \mu - t_c(\tilde{k}) - \Sigma_c(i\omega_n)}\right]^{-1}$$

$\boldsymbol{T = 0}$ phase diagram $n = 1$

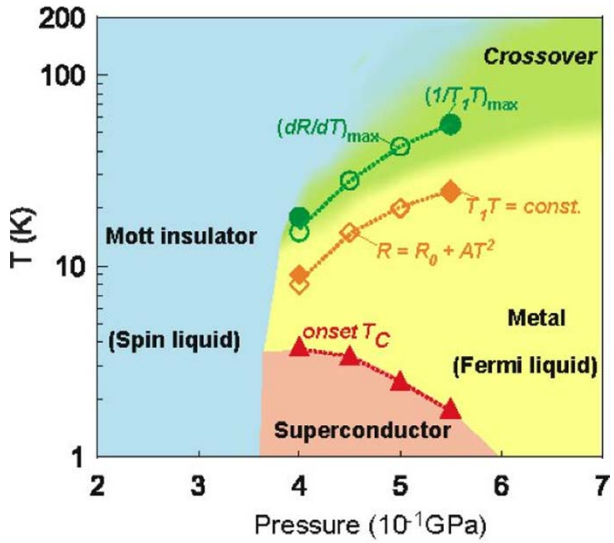
Phase diagram

Exact diagonalization as impurity solver ($T=0$).

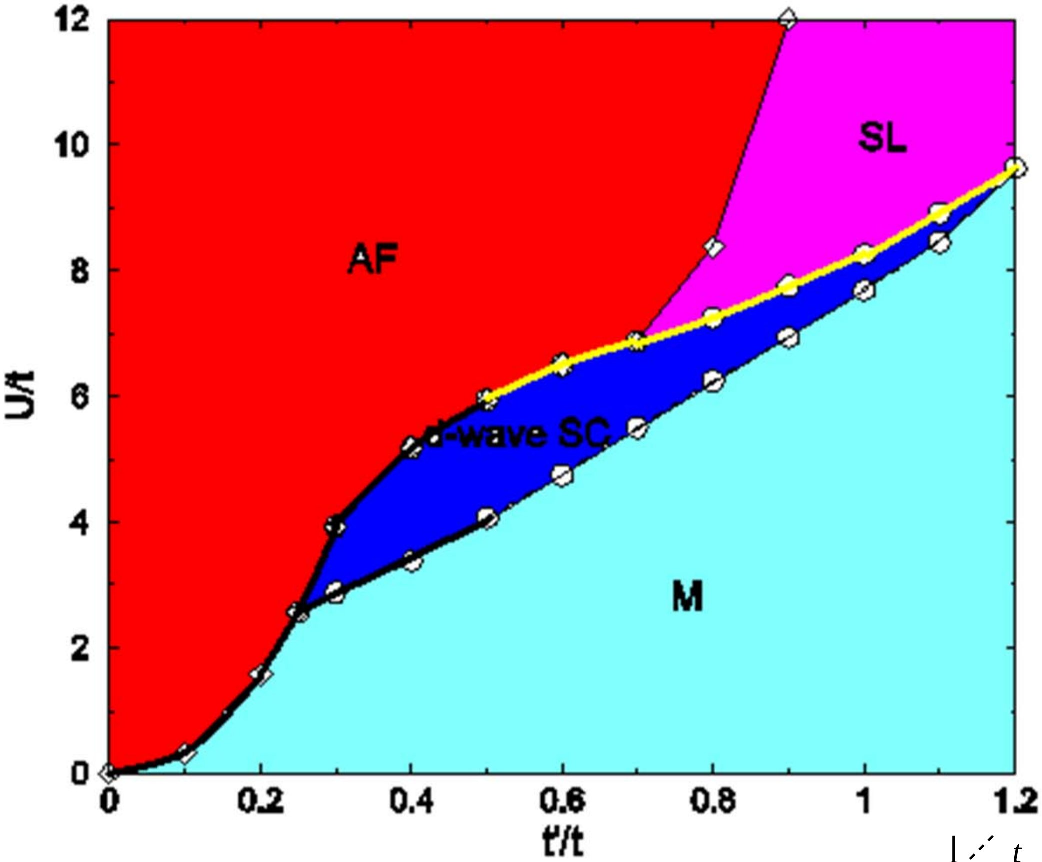


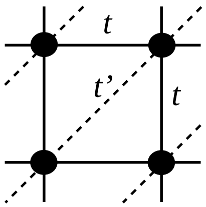
Theoretical phase diagram BEDT

X= $Cu_2(CN)_3$ (t'~ t)



Y. Kurisaki, et al.
Phys. Rev. Lett. **95**, 177001(2005)





Kyung, A.-M.S.T. PRL 97, 046402 (2006)

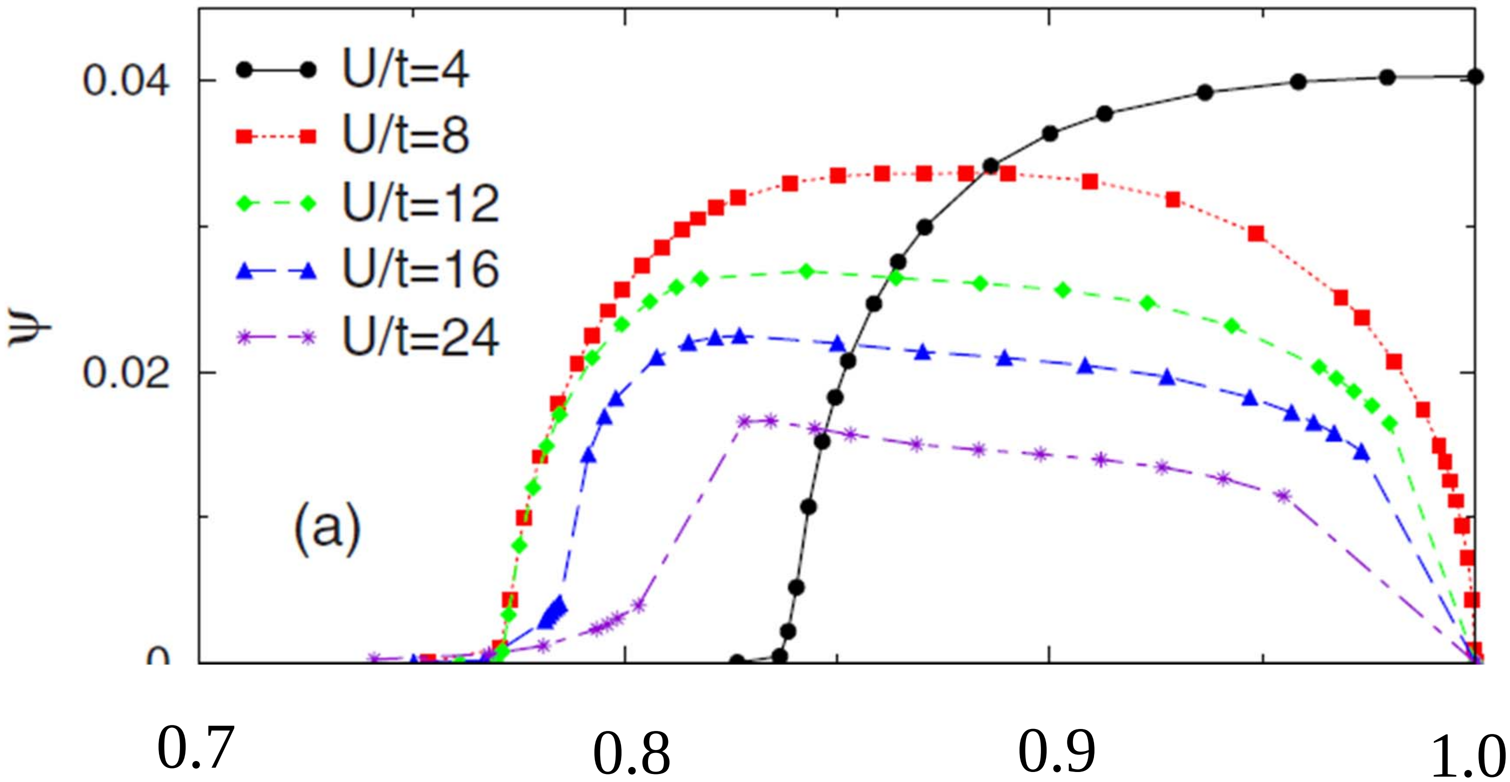
Y. Shimizu, et al. Phys. Rev. Lett. **91**, (2003)

T* = *0 phase diagram: cuprates

Phase diagram

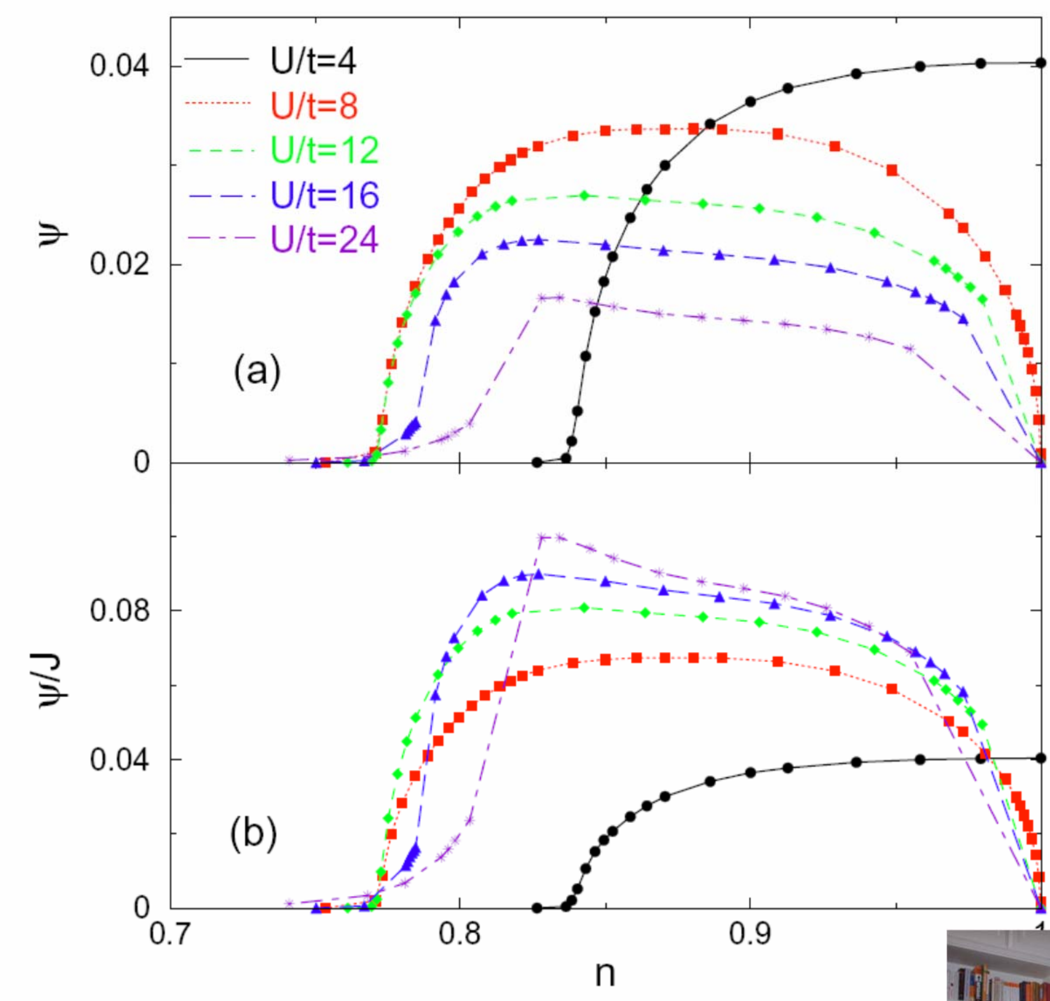
Exact diagonalization as impurity solver (T=0).

Theory: effect of Mott on order parameter

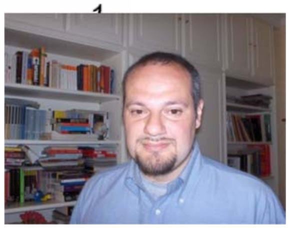


S. Kancharla *et al.* Phys. Rev. B (2008)

Dome vs Mott (CDMFT)

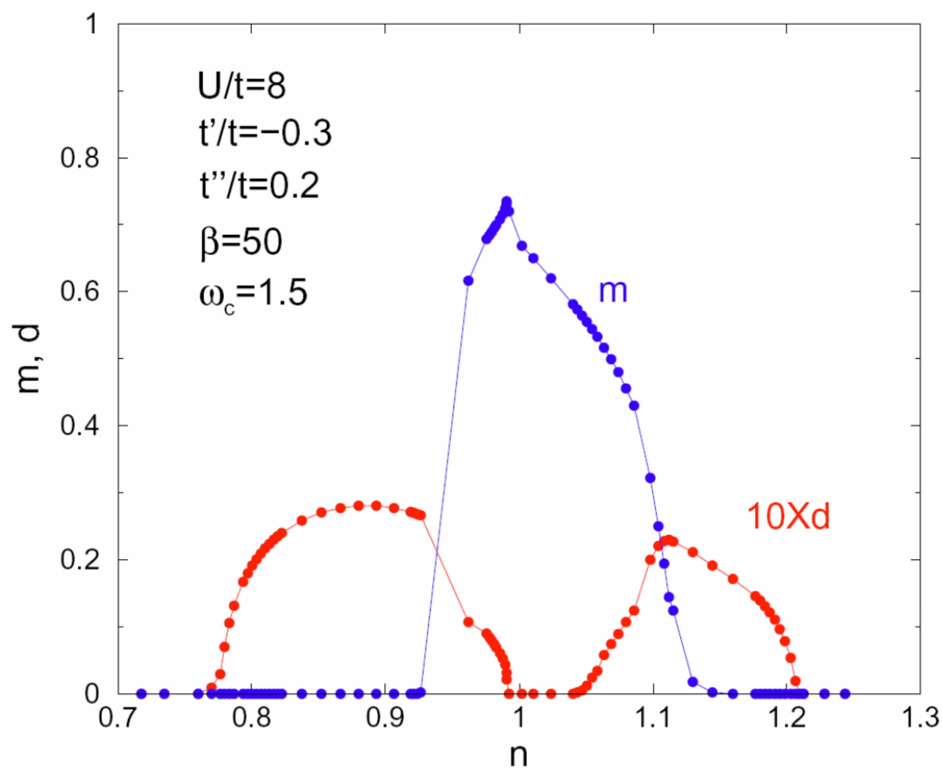


Kancharla, Kyung, Civelli, Sénéchal, Kotliar AMST Phys. Rev. B (2008)

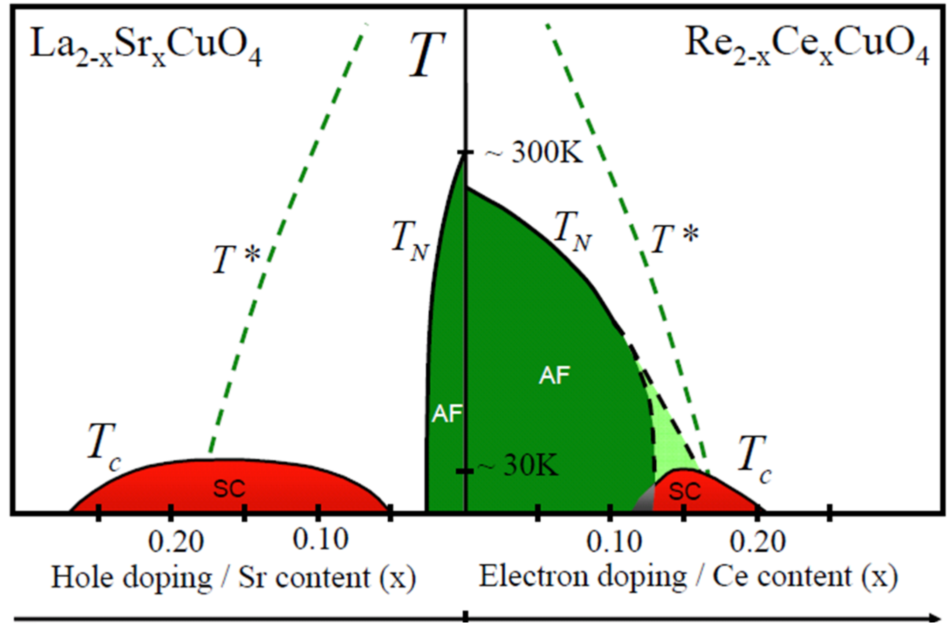


SHERBROOKE

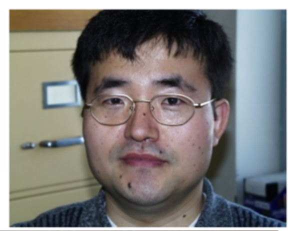
CDMFT global phase diagram

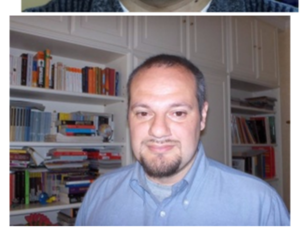


Kancharla, Kyung, Civelli, Sénéchal, Kotliar AMST Phys. Rev. B (2008)
AND Capone, Kotliar PRL (2006)



Armitage, Fournier, Greene, RMP (2009)





UNIVERSITÉ DE SHERBROOKE

Outline

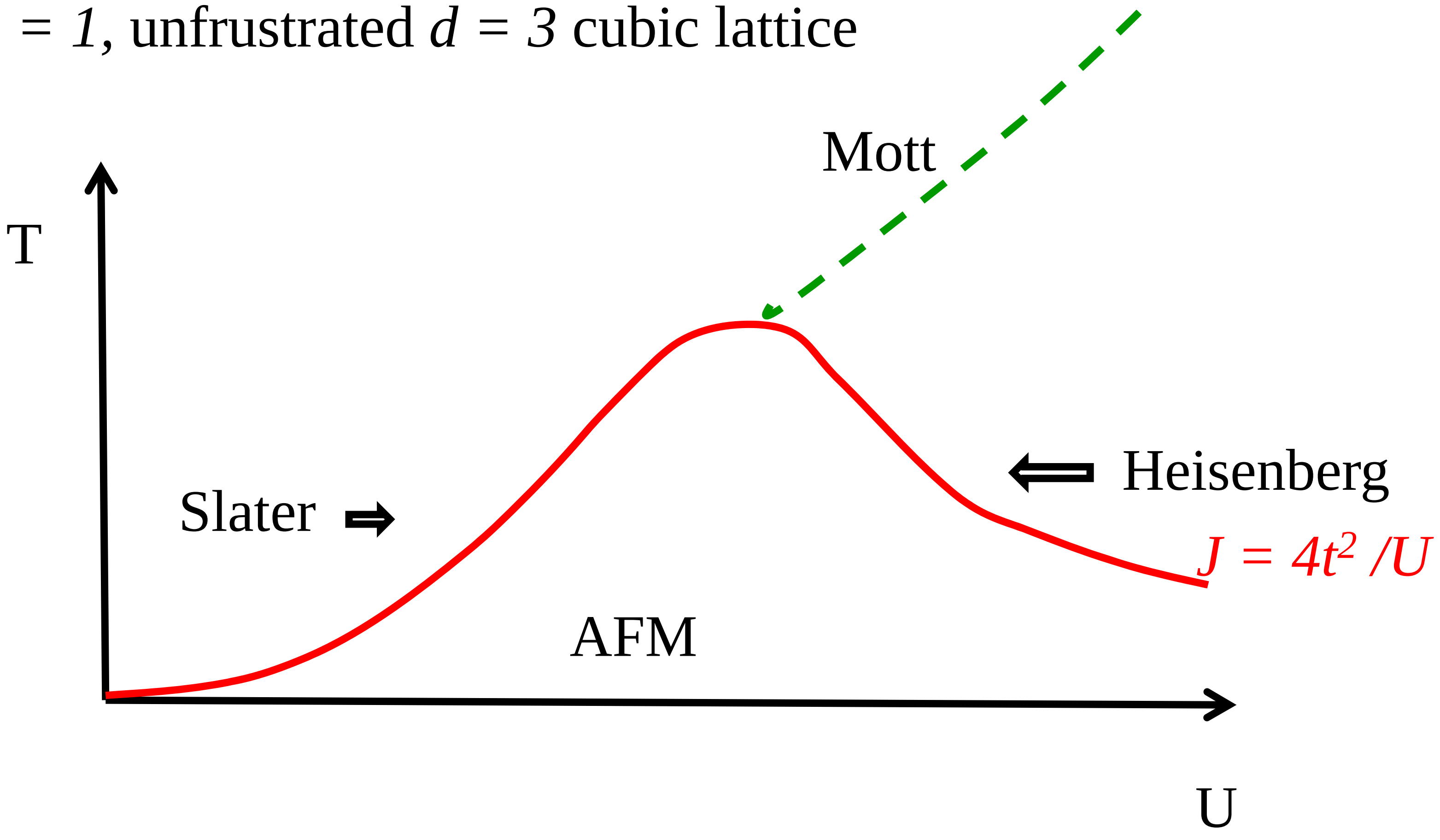
- Method
- *T=0* phase diagram
- Finite *T* phase diagram
  - Normal state
    - First order transition
    - Widom line and pseudogap
  - Superconductivity

Finite *T* phase diagram

Normal state of the cuprates

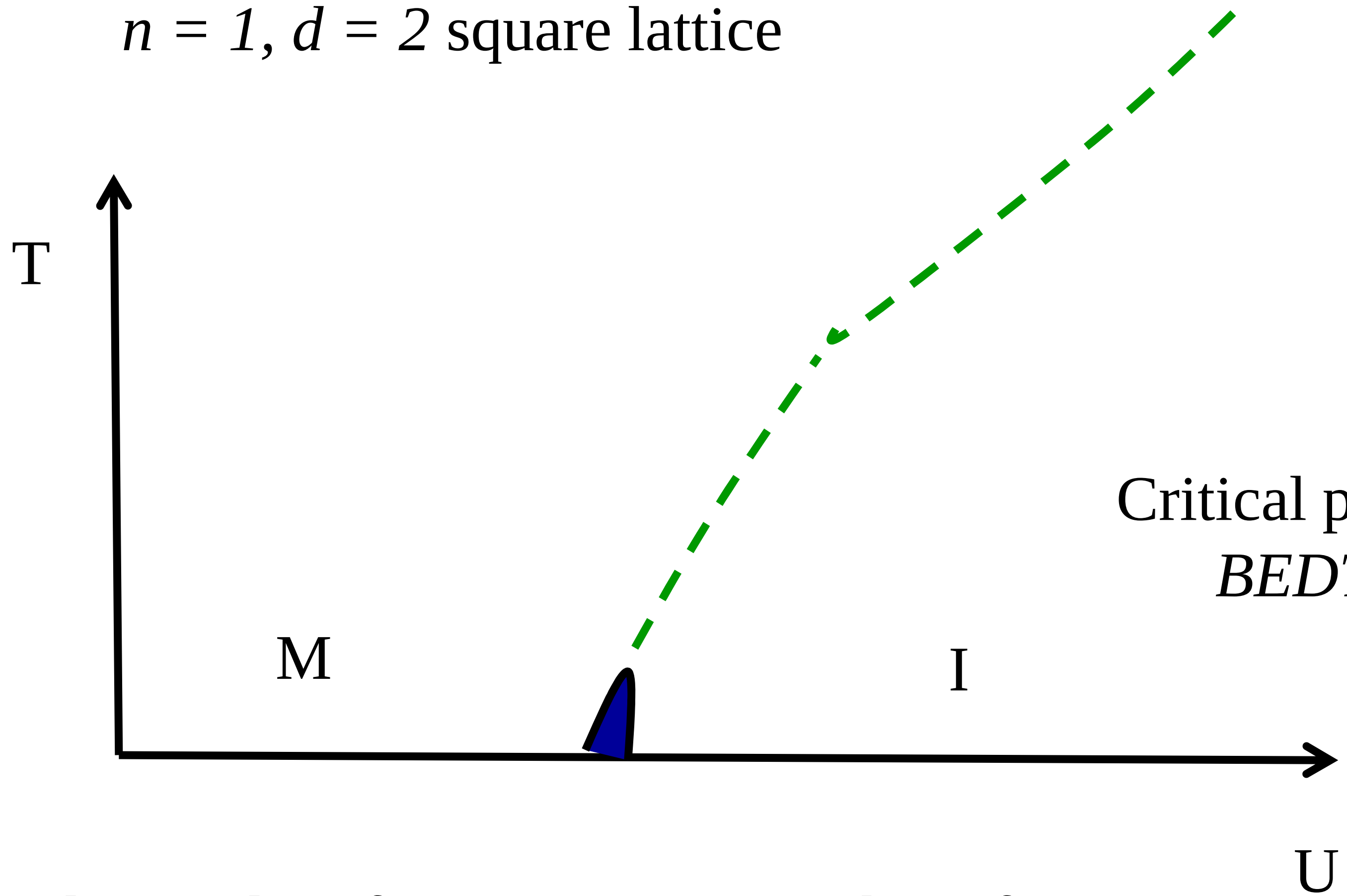
Preliminary: Weak vs Strong correlations

n = 1, unfrustrated *d = 3* cubic lattice



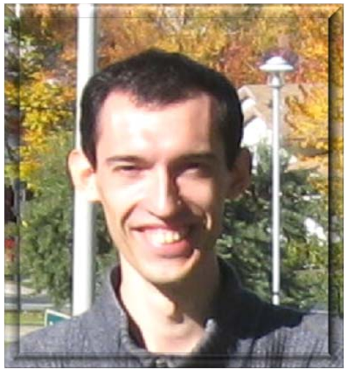
Local moment and Mott transition

n = 1, *d = 2* square lattice



Critical point visible in
BEDT organics

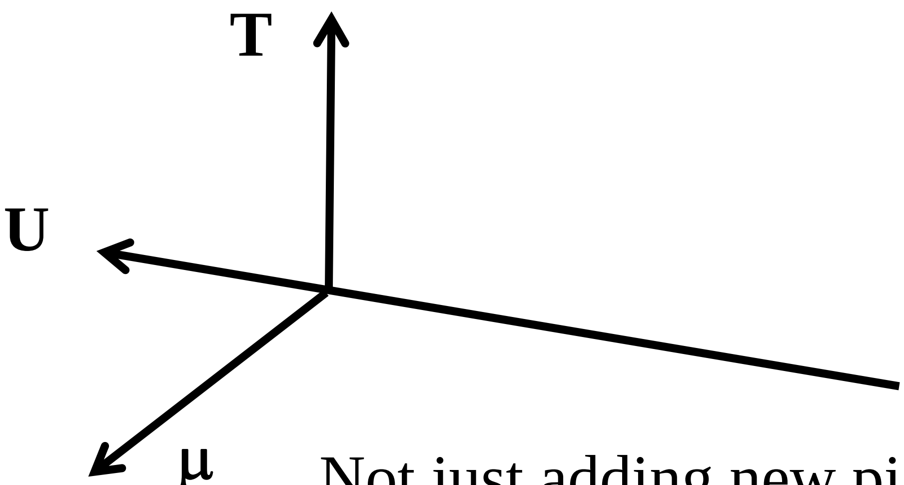
Understanding finite temperature phase from a *mean-field theory* down to $T = 0$



Giovanni Sordi

G. Sordi, K. Haule, A.-M.S.T
PRL, **104**, 226402 (2010)
and
Phys. Rev. B. **84**, 075161 (2011)

Doping-induced Mott transition (*t'=0*)

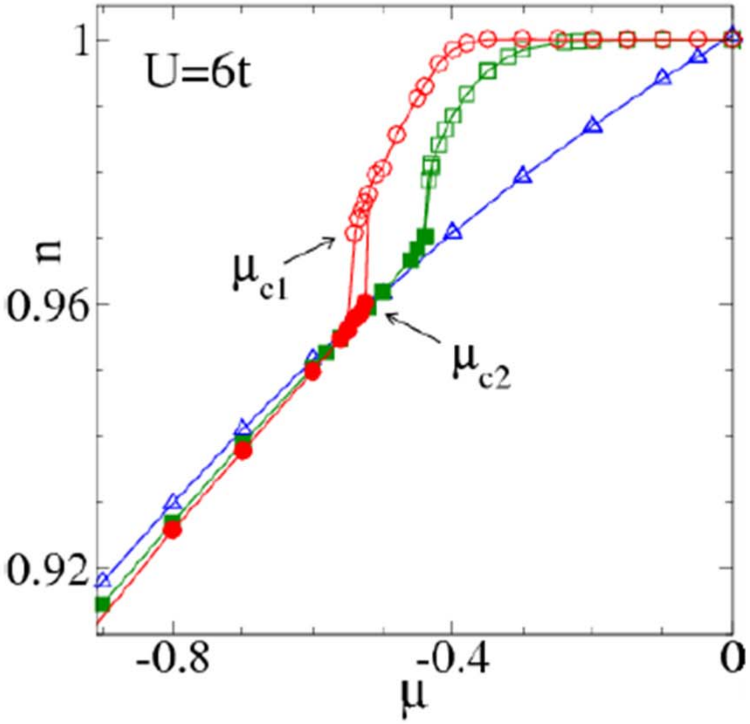


Kristjan Haule

Not just adding new piece:
Lesson from DMFT, first order transition + critical point governs phase diagram

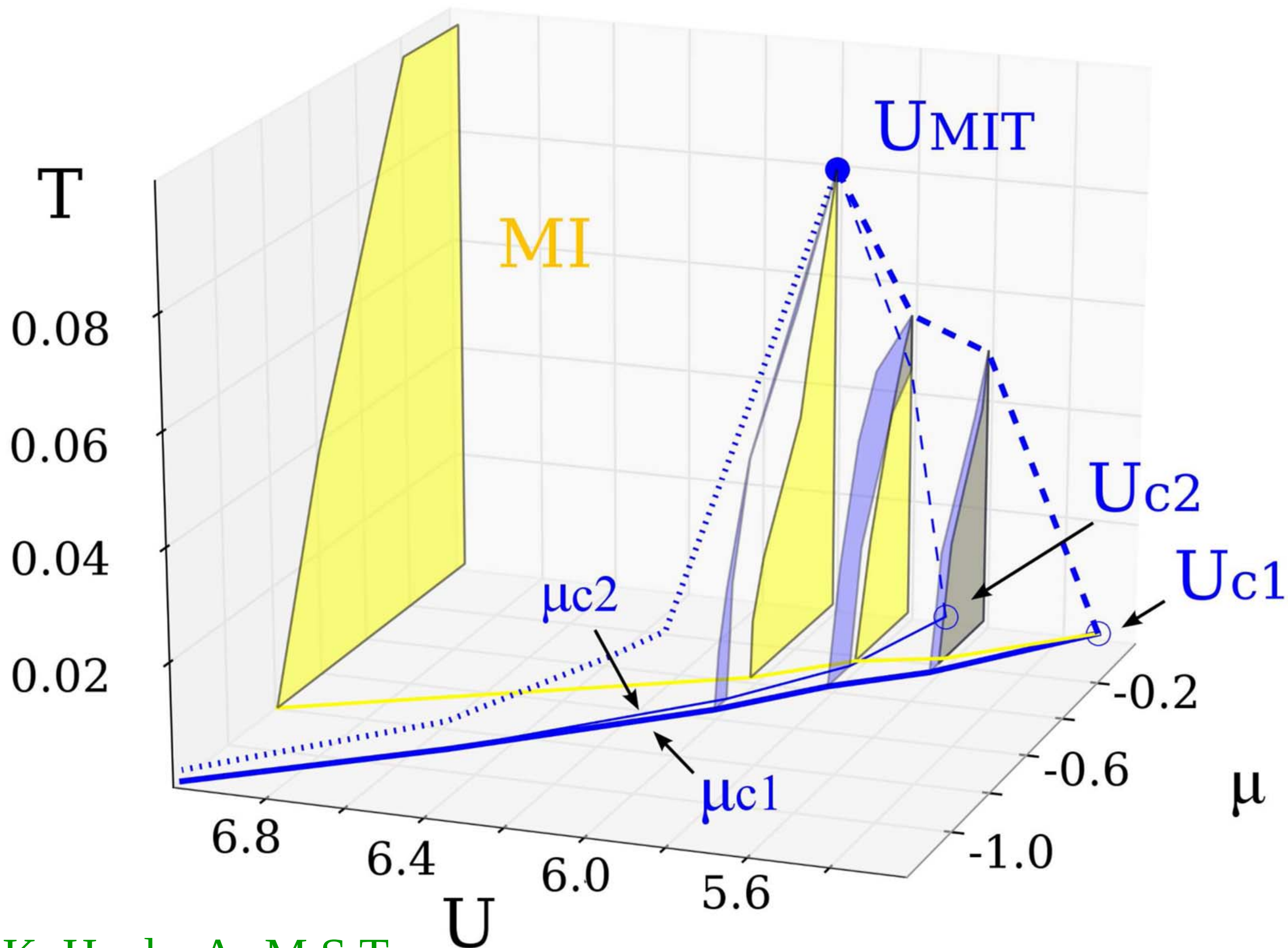
UNIVERSITÉ DE SHERBROOKE

First order transition at finite doping



$n(\mu)$ for several temperatures:
$T/t =$1/10, 1/25, 1/50

Normal state phase diagram



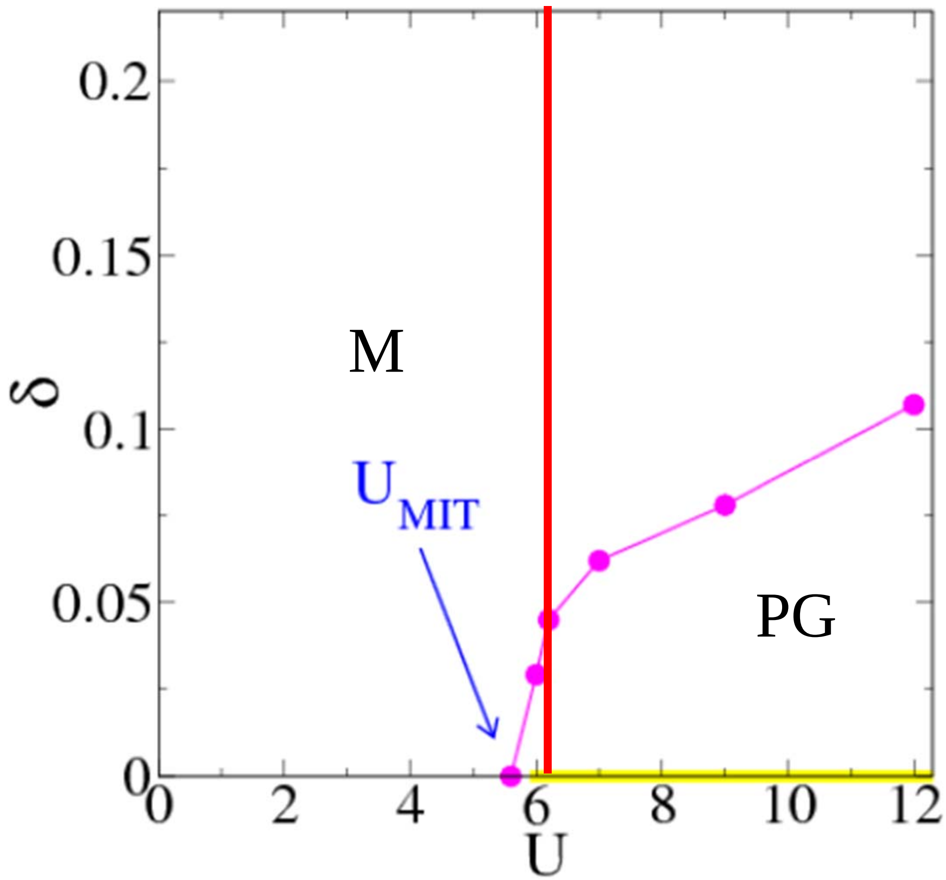
G. Sordi, K. Haule, A.-M.S.T
PRL, **104**, 226402 (2010)

μ = 0, H. Park, K. Haule, and G. Kotliar,
Phys. Rev. Lett. 101, 186403 (2008).

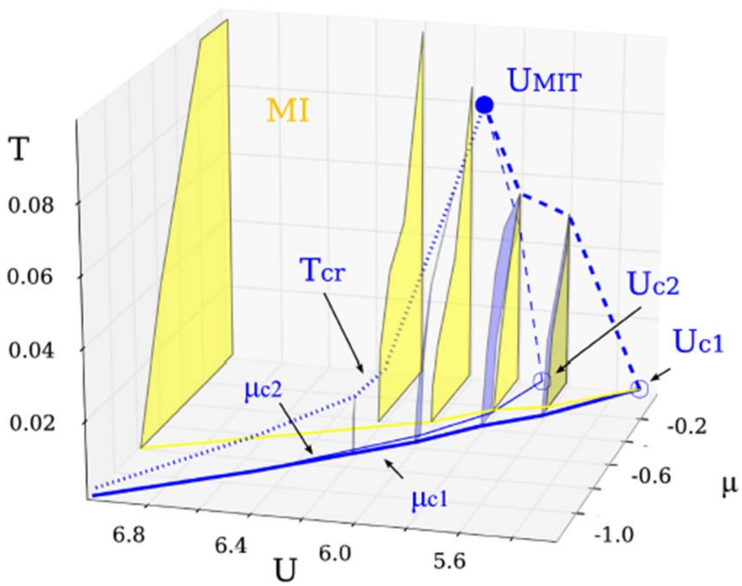
UNIVERSITÉ DE SHERBROOKE

Link to Mott transition up to optimal doping

Doping dependence of critical point as a function of *U*

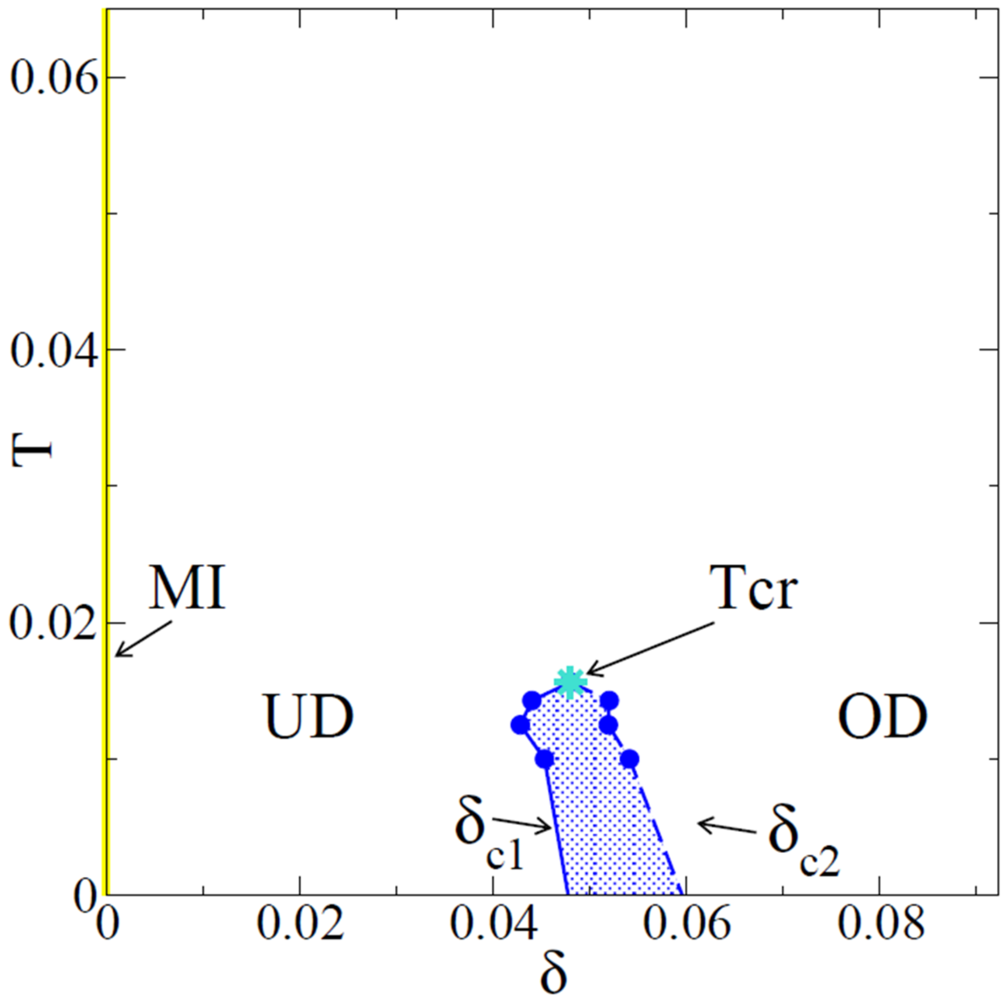


Smaller *D* and *S*



UNIVERSITÉ DE SHERBROOKE

Characterisation of the phases (U=6.2t)



$U > U_{\mathrm{MIT}}$:

1. Mott insulator (MI)
2. Underdoped phase (UD): $\delta < \delta_c$
3. Overdoped phase (OD): $\delta > \delta_c$
4. Coexistence/forbidden region

Here "optimal doping" $\delta_c =$ doping at which the 1st order transition occurs

How does the UD phase differ from the OD phase?

Giovanni Sordi

Patrick Sémon

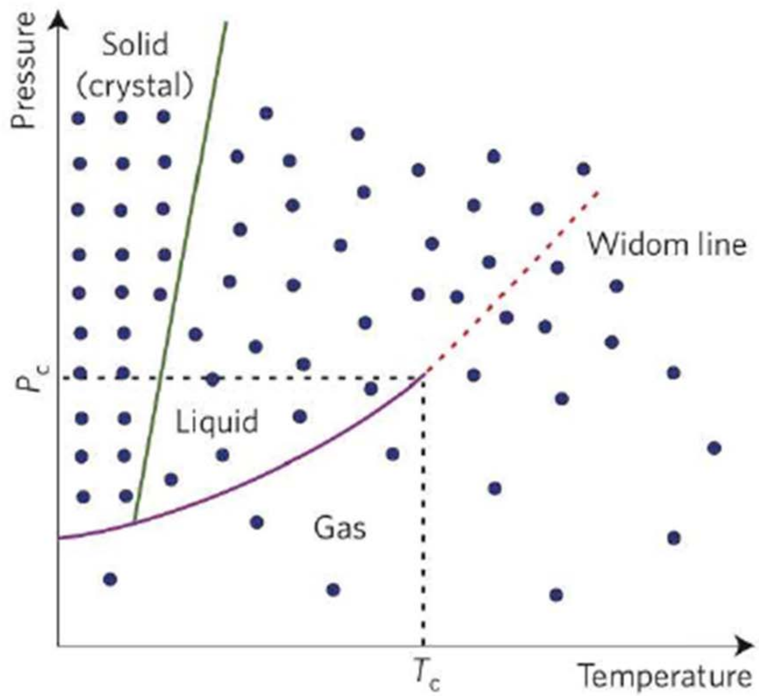
Kristjan Haul

Widom line *(t' = 0)*

Pseudogap in the normal state and the Widom line

UNIVERSITÉ DE SHERBROOKE

What is the Widom line?

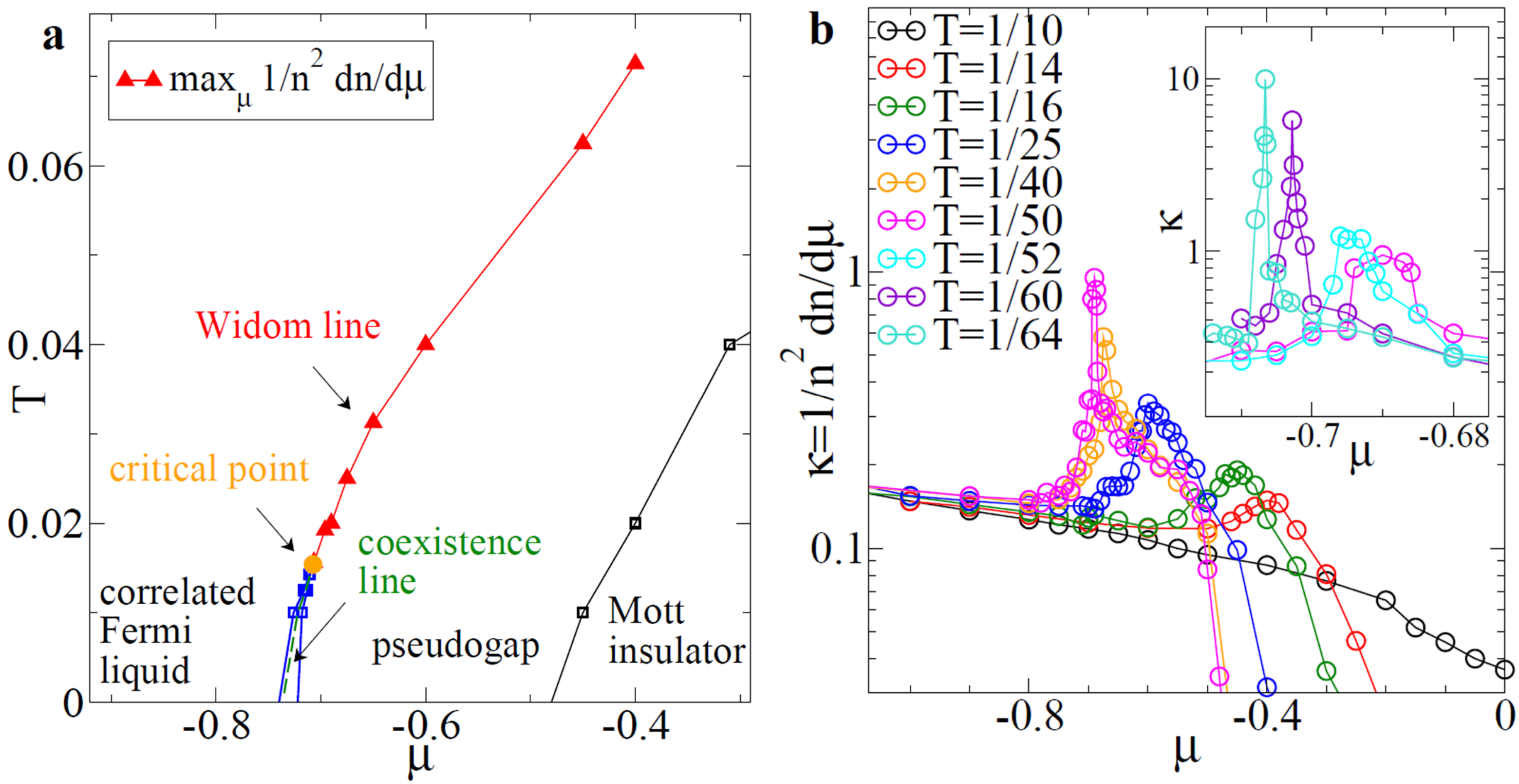


McMillan and Stanley, Nat Phys 2010

- it is the continuation of the coexistence line in the supercritical region
- line where the maxima of different response functions touch each other asymptotically as $T \to T_p$
- liquid-gas transition in water: max in isobaric heat capacity C_p, isothermal compressibility, isobaric heat expansion, etc
- DYNAMIC crossover arises from crossing the Widom line!
  water: Xu et al, PNAS 2005, Simeoni et al Nat Phys 2010

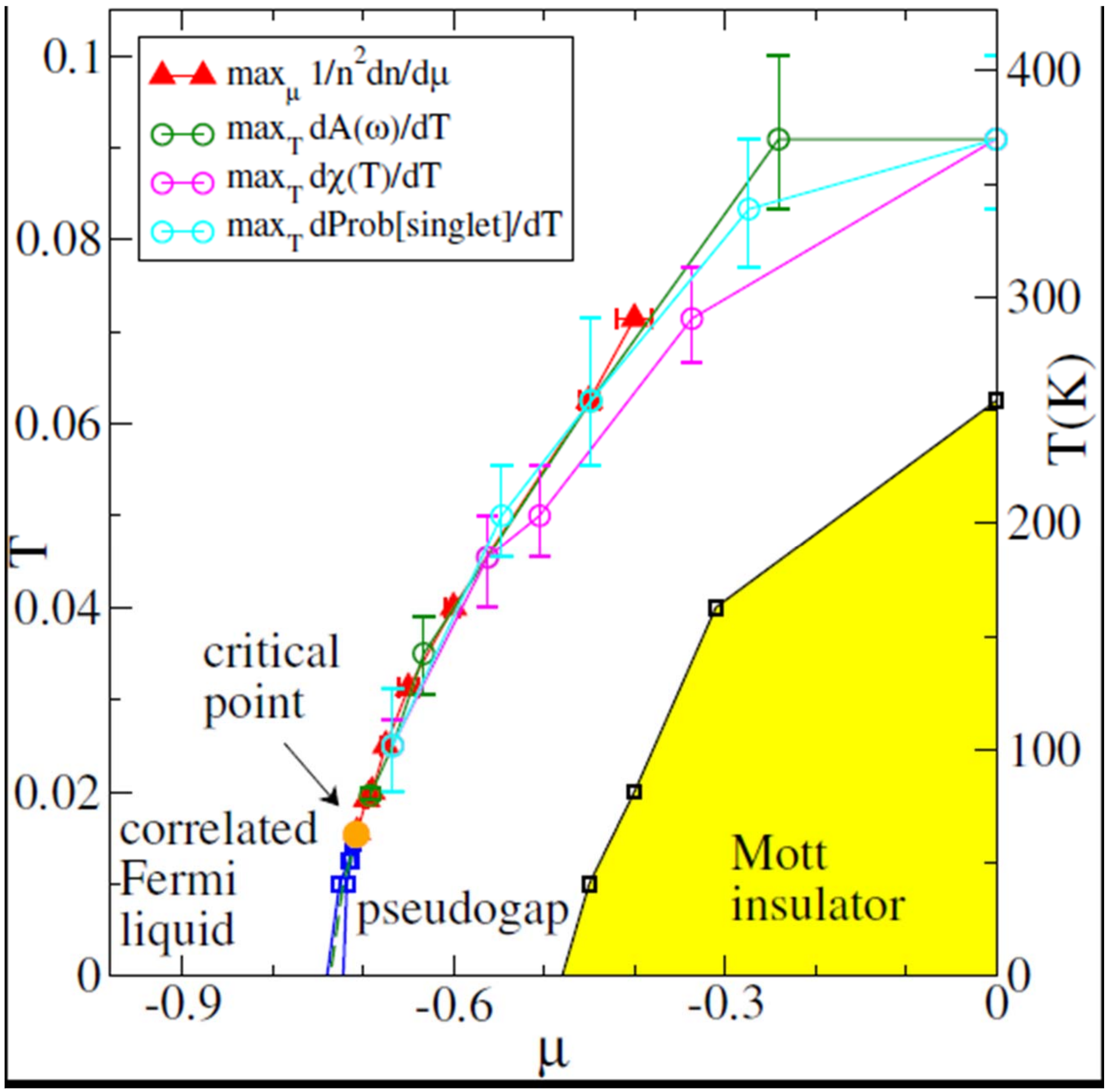
UNIVERSITÉ DE SHERBROOKE

The Widom line

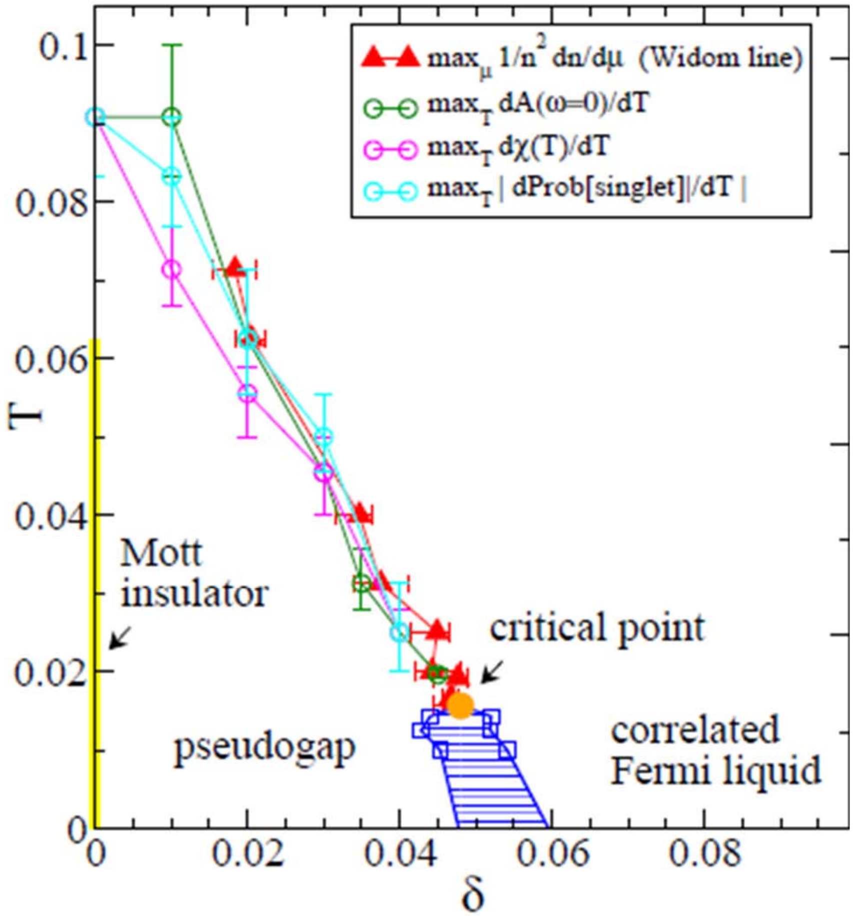


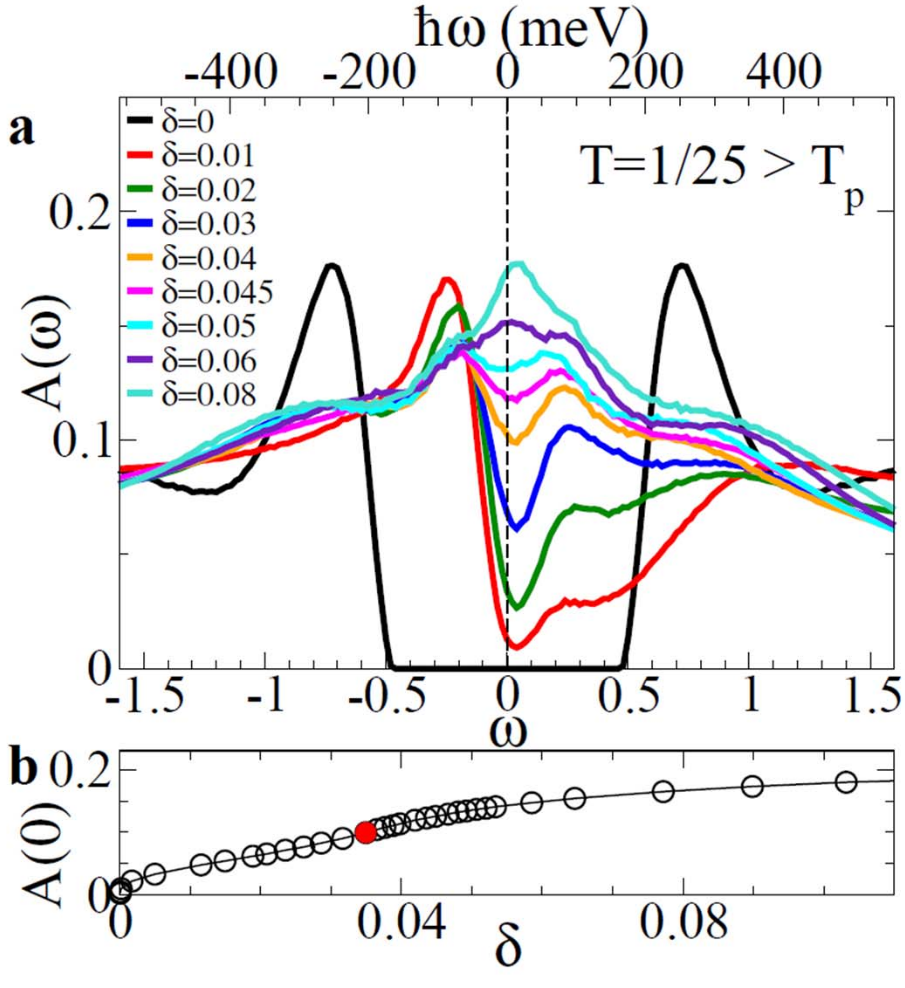
UNIVERSITÉ DE SHERBROOKE

Rapid change also in dynamical quantities

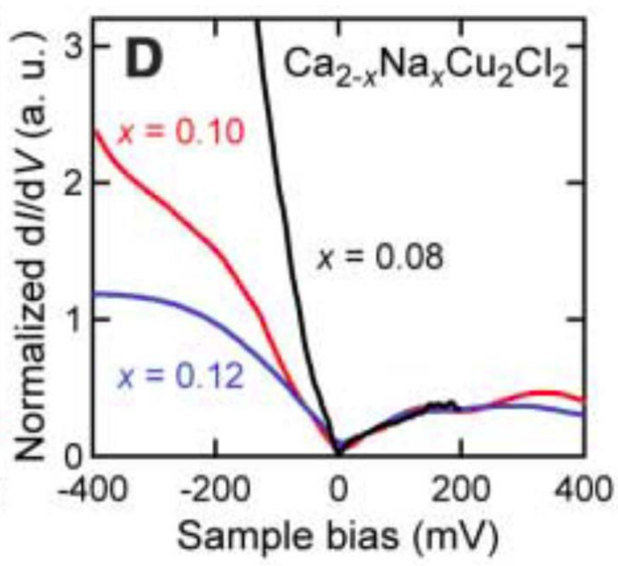


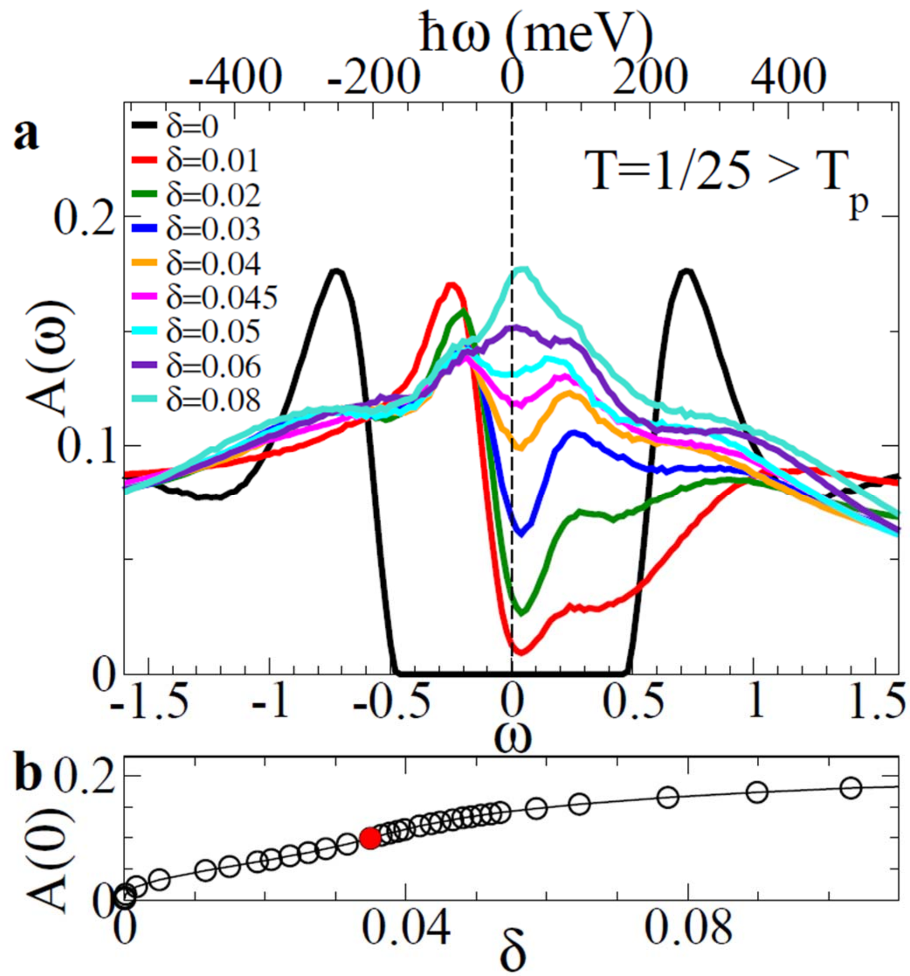
Density of states





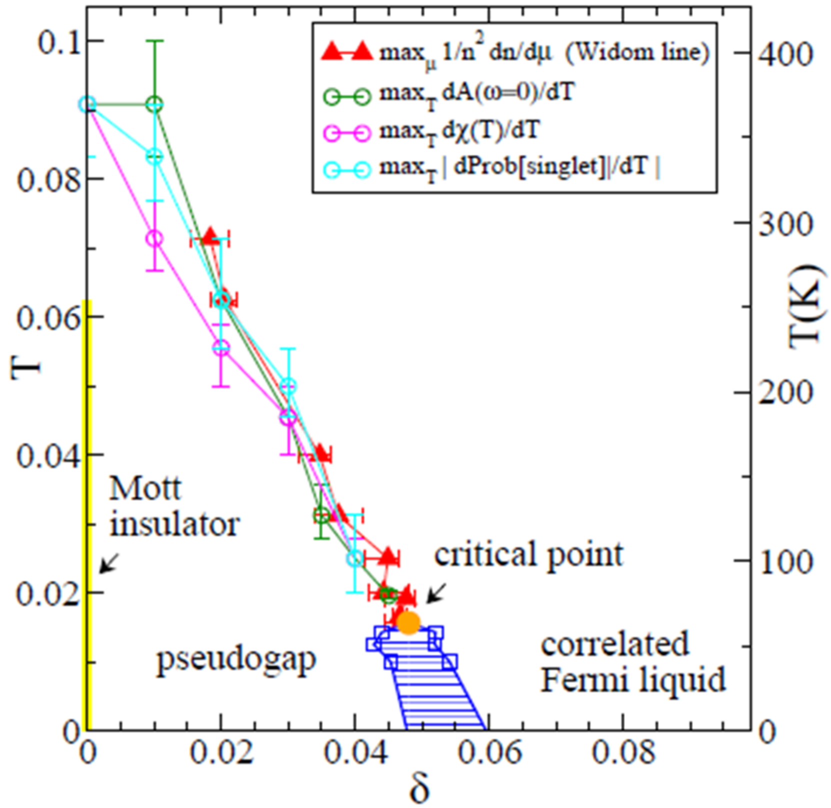
Density of states

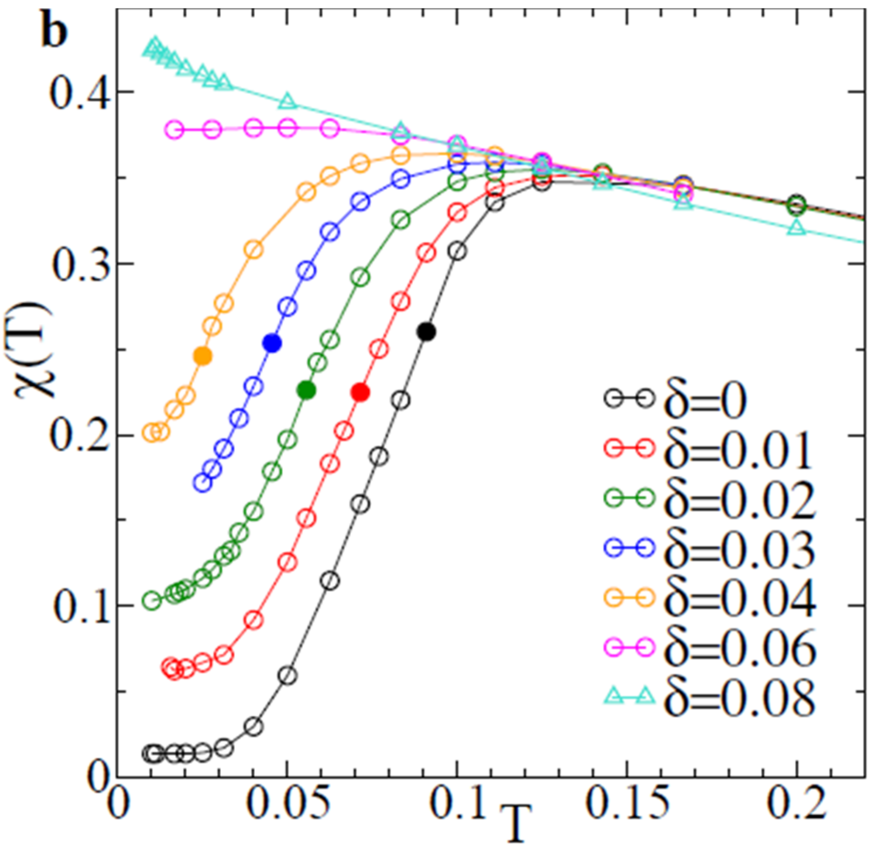




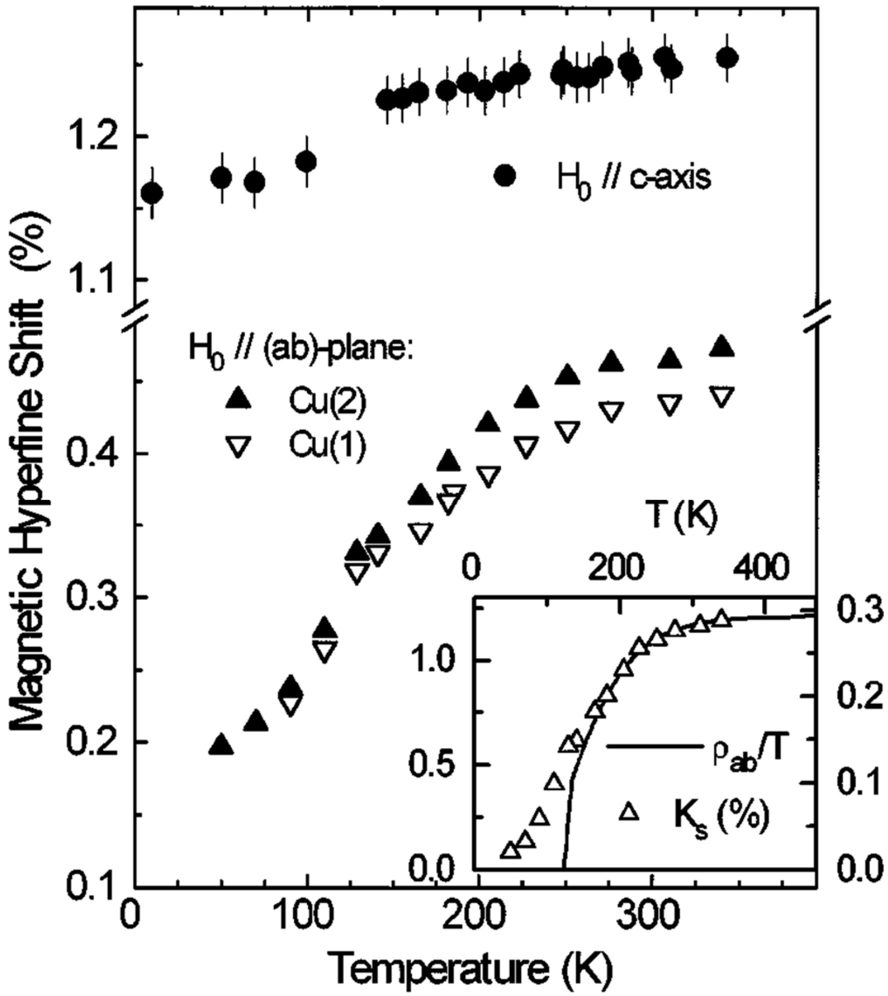
Khosaka et al. *Science* **315**, 1380 (2007);

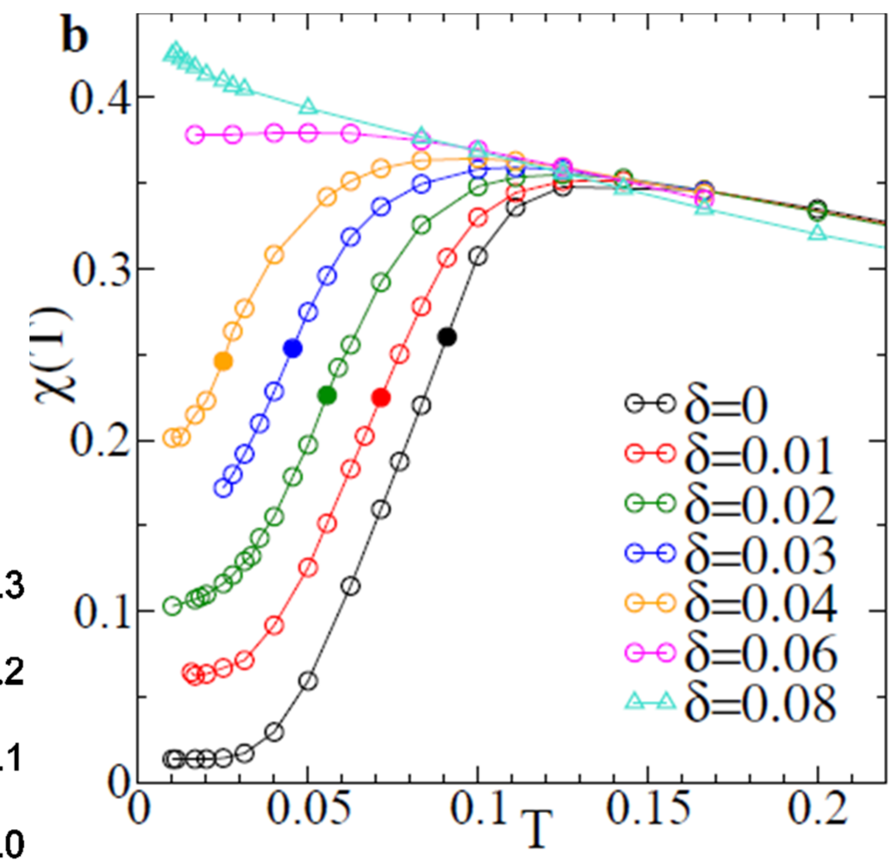
Spin susceptibility





Spin susceptibility





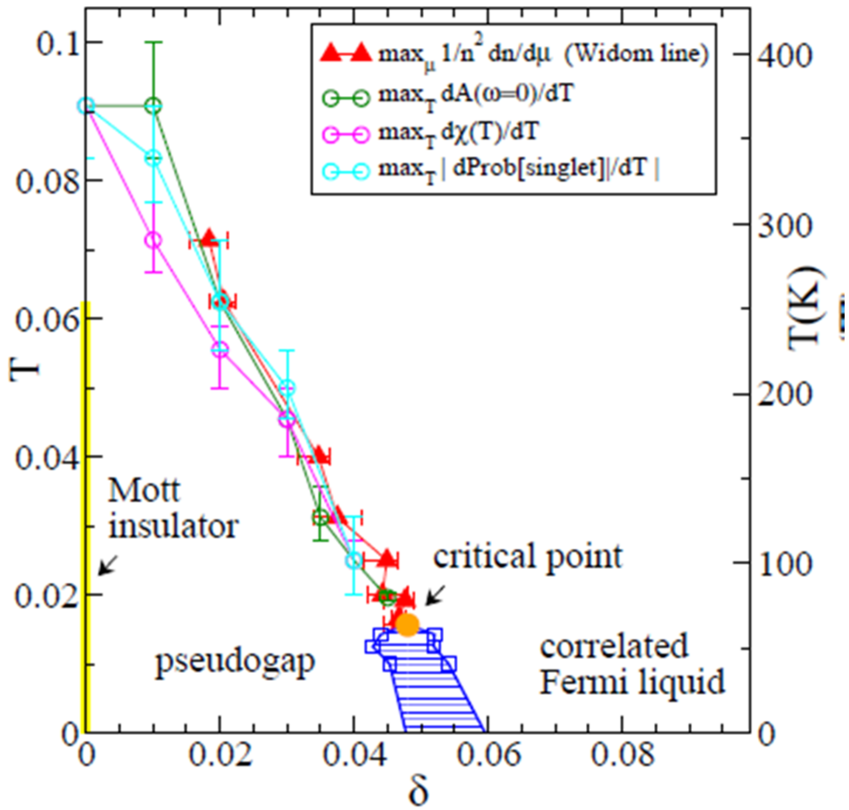
Underdoped Hg1223

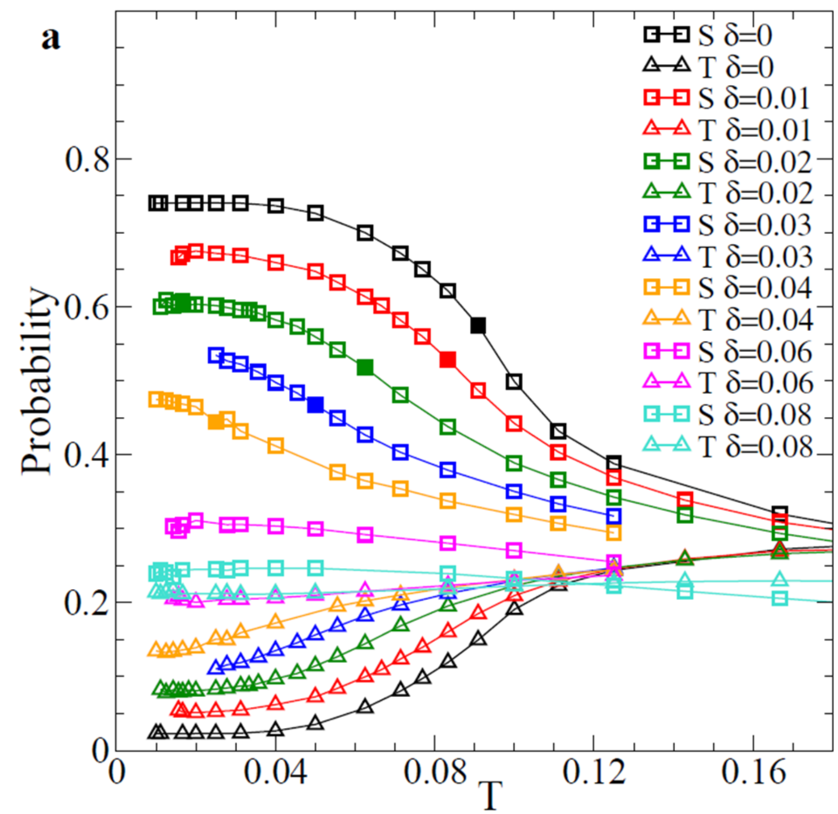
Julien et al. PRL **76,** 4238 (1996)

Physics

UNIVERSITÉ DE SHERBROOKE

Plaquette eigenstates



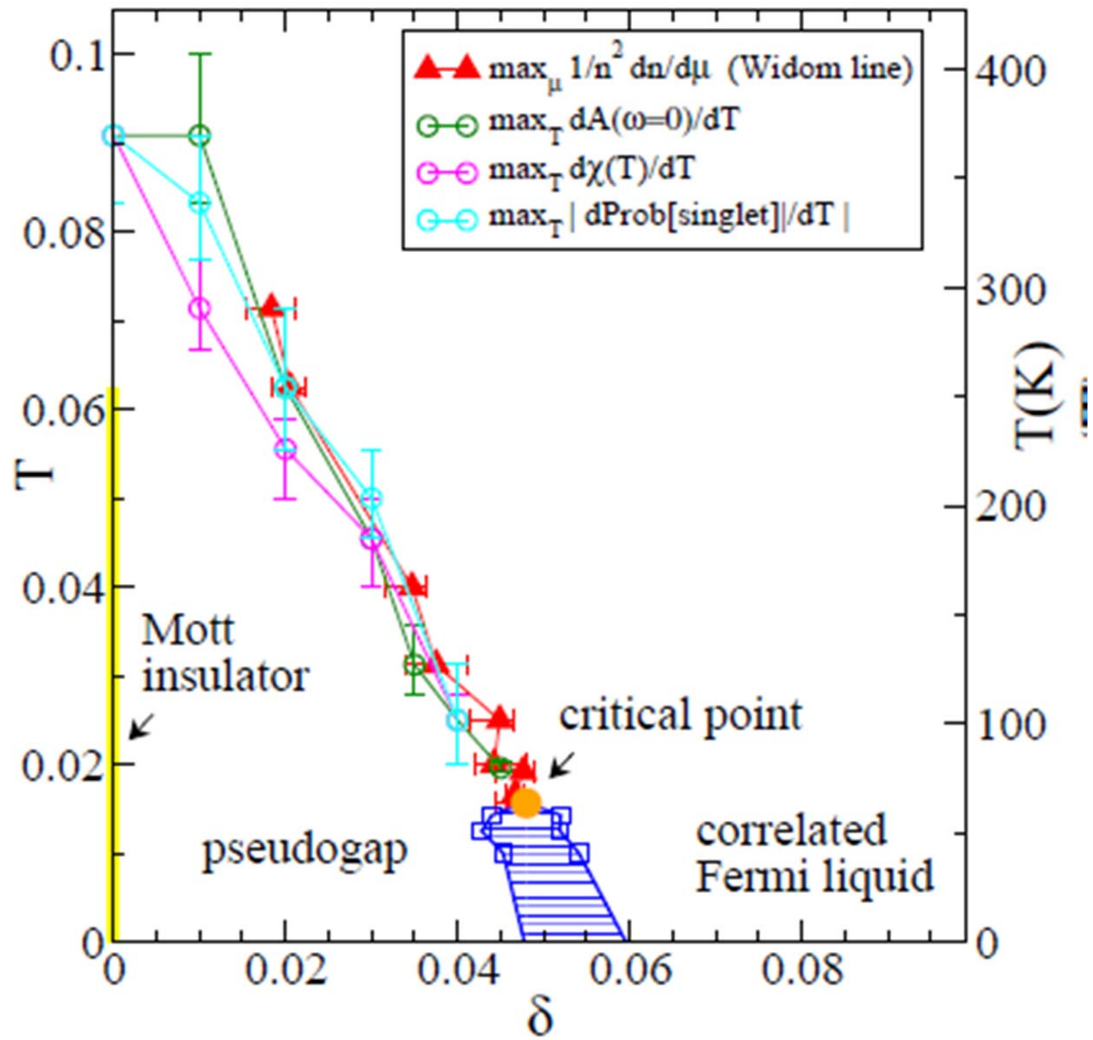


See also:

Michel Ferrero, P. S. Cornaglia, L. De Leo, O. Parcollet, G. Kotliar, A. Georges
PRB **80**, 064501 (2009)

UNIVERSITÉ DE SHERBROOKE

Pseudogap along the Widom line T_W



What is the minimal model?

H. Alloul arXiv:1302.3473
C.R. Académie des Sciences, (2014)

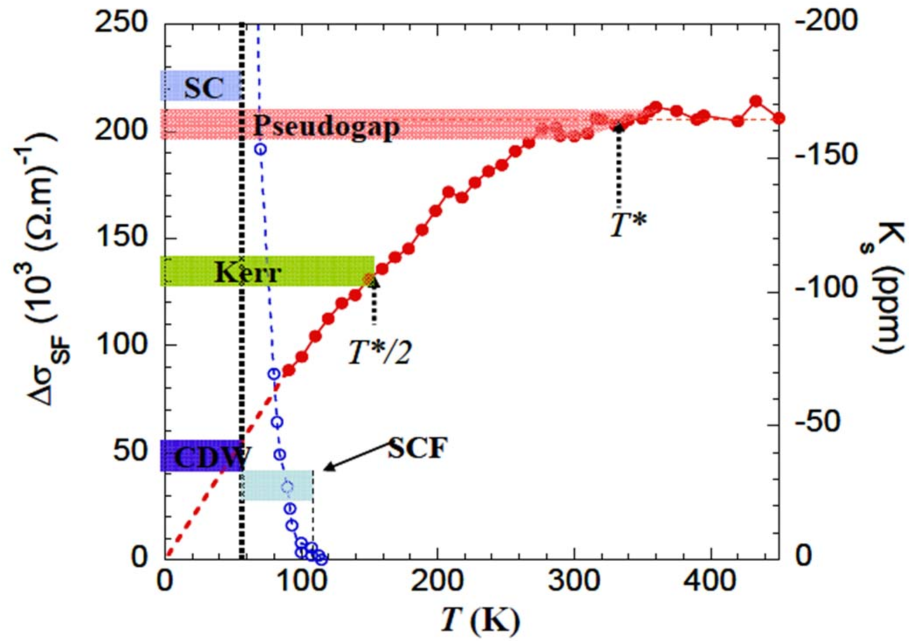


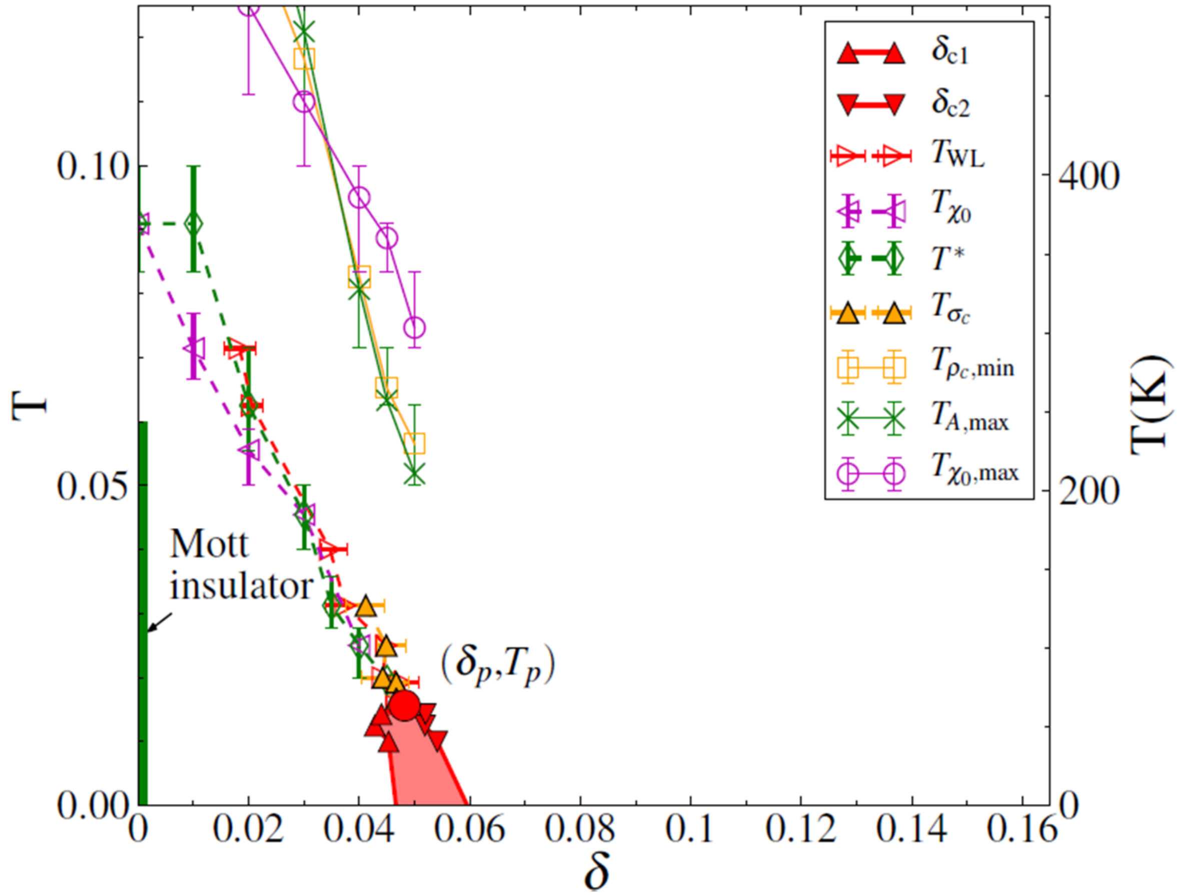
Fig 1 Spin contribution K_s to the ^{89}Y NMR Knight shift [11] for $YBCO_{6.6}$ permit to define the PG onset T^*. Here K_s is reduced by a factor two at $T \sim T^*/2$. The sharp drop of the SC fluctuation conductivity (SCF) is illustrated (left scale) [23]. We report as well the range over which a Kerr signal is detected [28], and that for which a CDW is evidenced in high fields from NMR quadrupole effects [33] and ultrasound velocity data [30]. (See text).

UNIVERSITÉ DE SHERBROOKE

Two crossover lines

Giovanni Sordi

Patrick Sémon

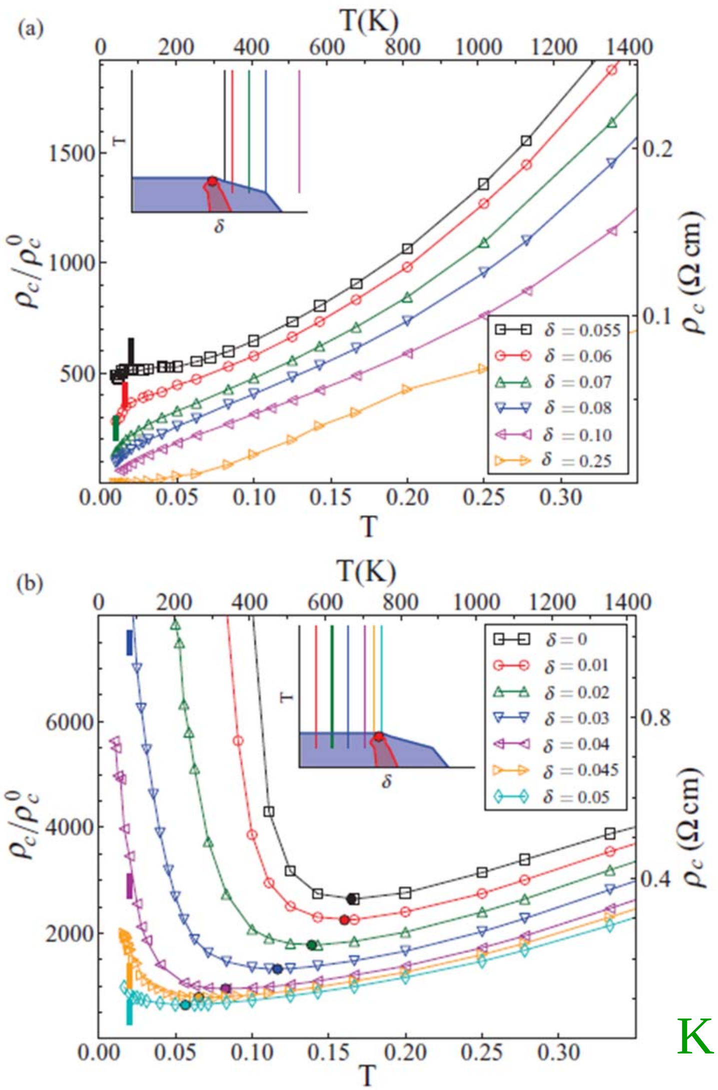


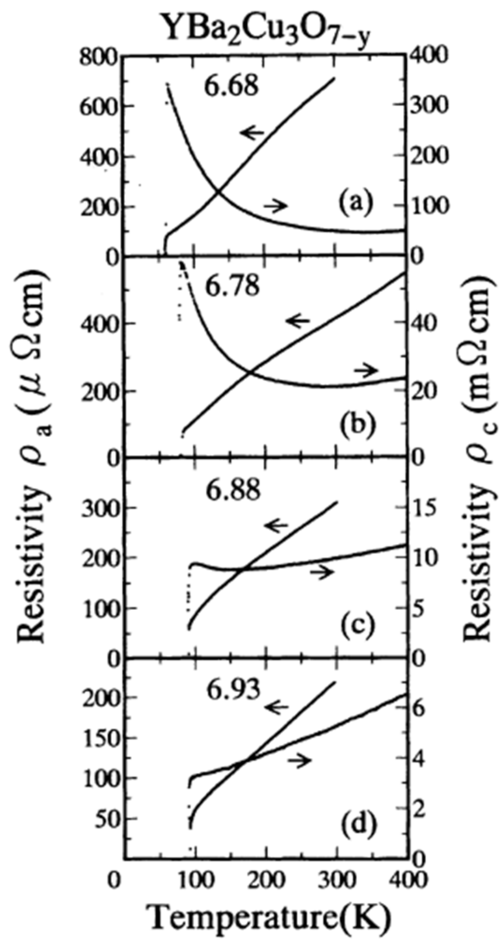
G. Sordi et al. Phys. Rev. Lett. 108, 216401/1-6 (2012)

P. Sémon, G. Sordi, A.-M.S.T., Phys. Rev. B **89**, 165113/1-6 (2014)

UNIVERSITÉ DE SHERBROOKE

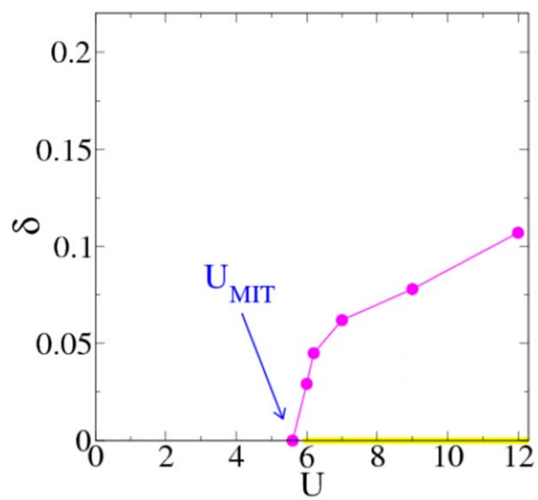
C-axis resistivity

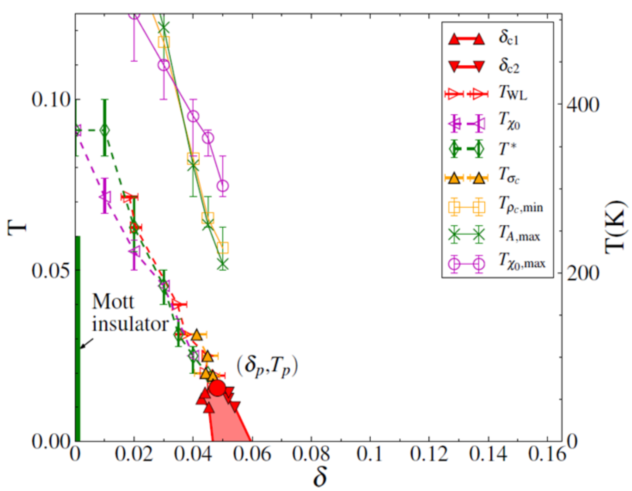




K. Takenaka, K. Mizuhashi, H. Takagi, and S. Uchida, Phys. Rev.B 50, 6534 (1994).

Summary: normal state



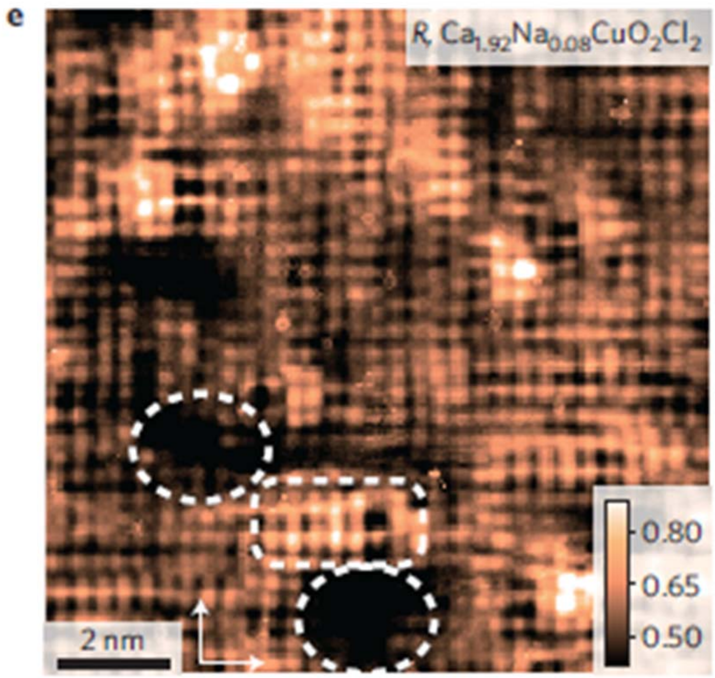


- Signatures of Mott physics extend way beyond half-filling
- Pseudogap is a phase
- Pseudogap *T** controlled by a Widom line and its precursor
- High compressibility (stripes?)

Charge Density Wave
Back to experiment

h-doped

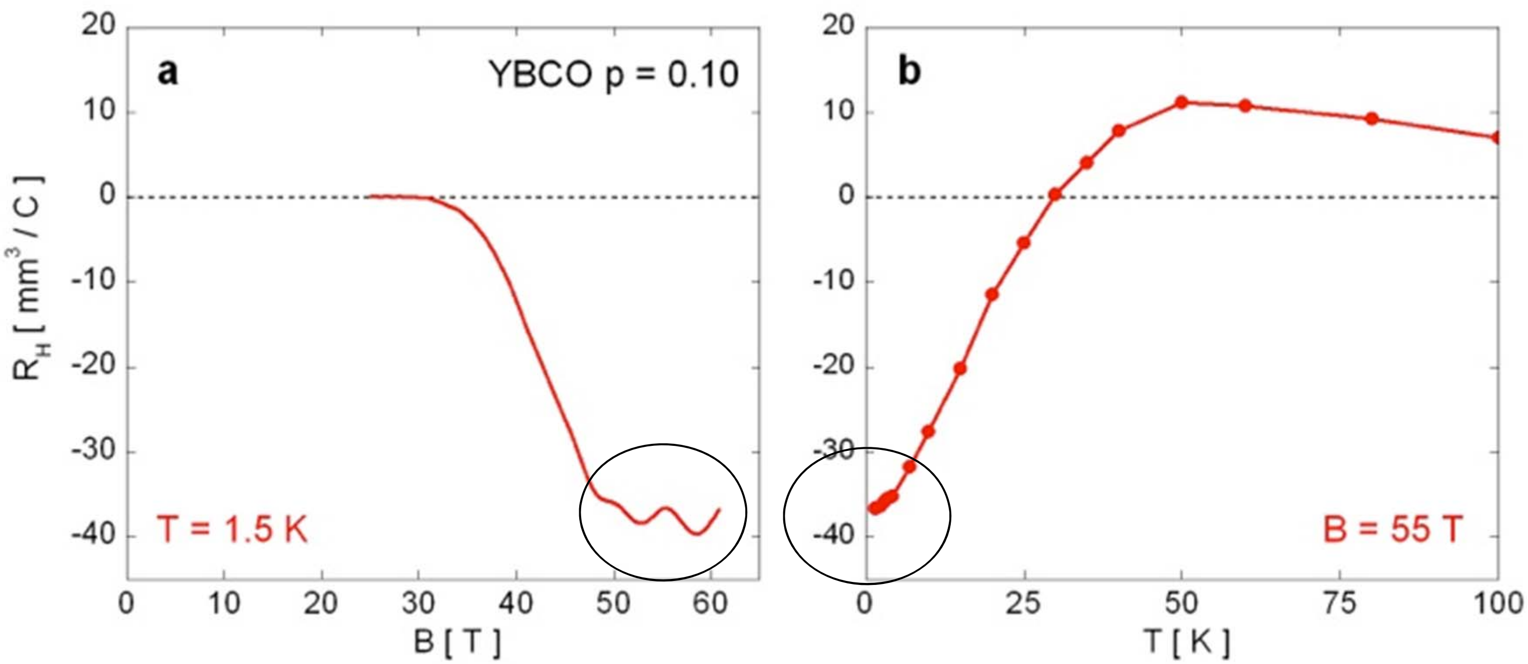
Intra-unit cell nematic order: STM

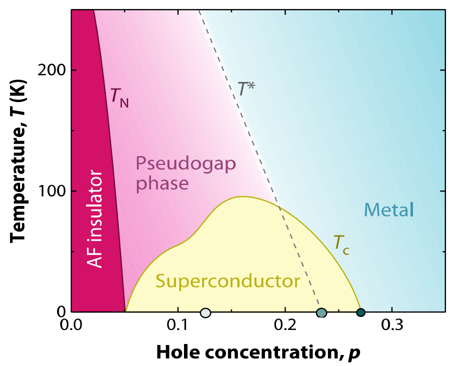


Kohsaka et al. Nature Physics 2012

Quantum oscillations in cuprates: 2007

N. Doiron-Leyraud et al., Nature 2007 *D. LeBoeuf et al., Nature 2007*



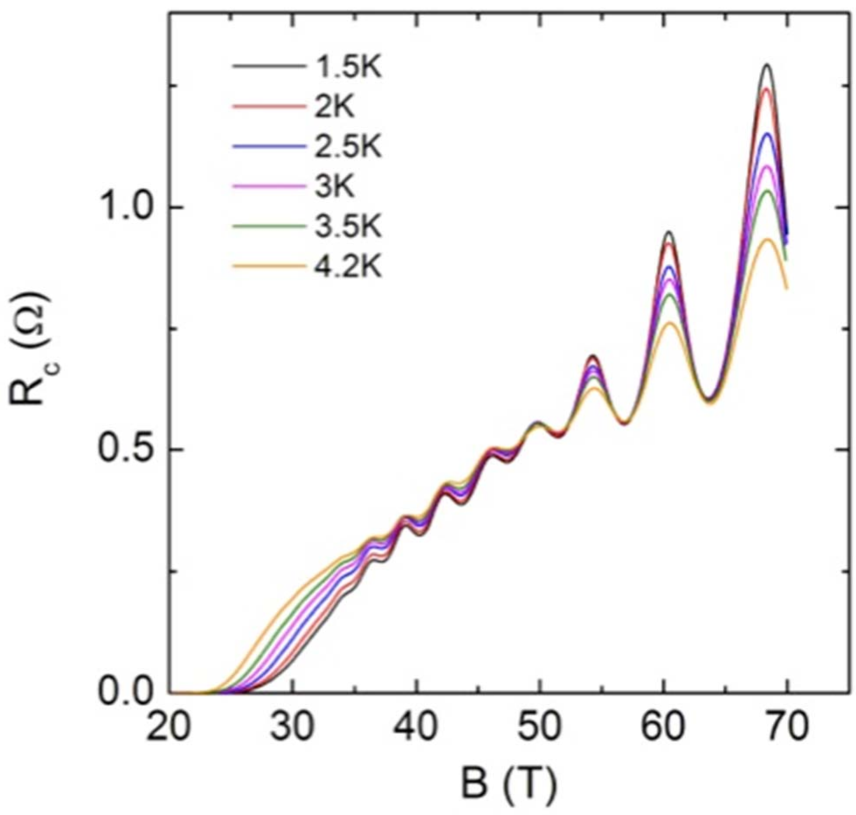


Quantum oscillations ***$R_H < 0$***

Fermi surface includes a small *electron* pocket !

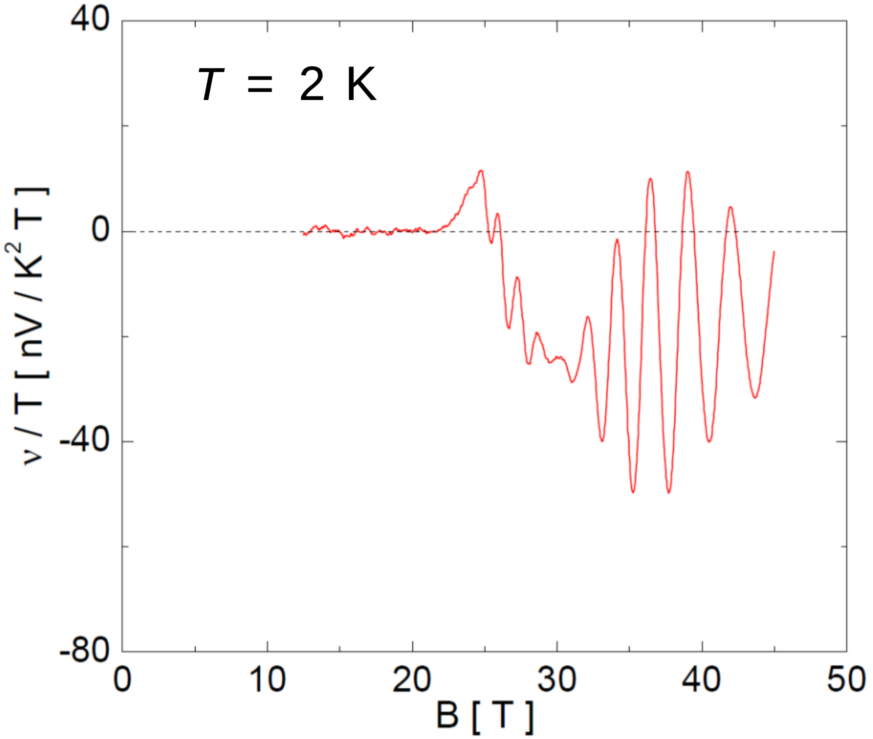
Quantum oscillations in cuprates: 2013

Resistance



LNCMI, Toulouse

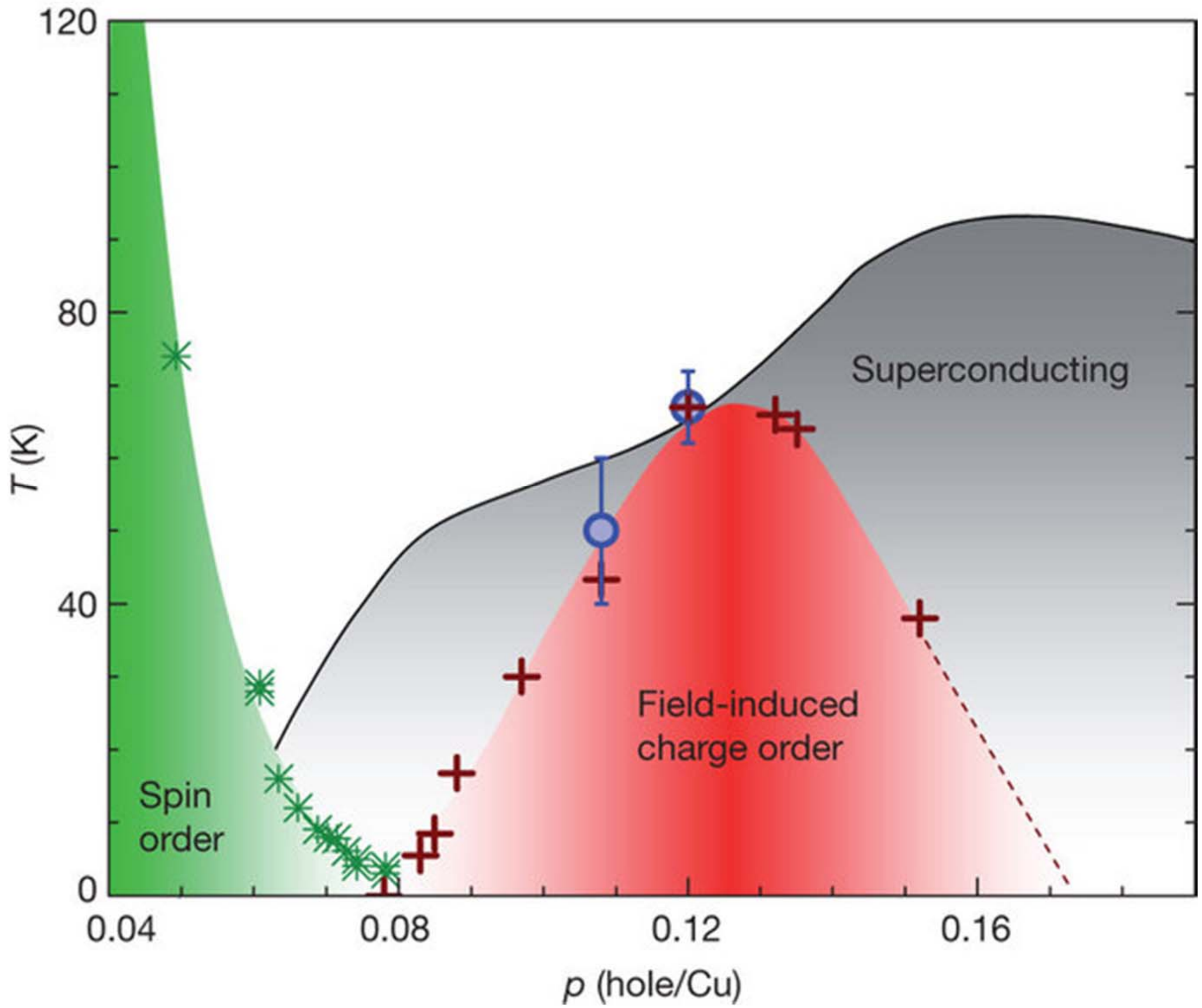
Nernst



NHMFL, Tallahassee

UNIVERSITÉ DE SHERBROOKE

Stripes and reconstructed Fermi surface



Wu et al. Julien, Nature **477**, 191–194 (2011)

Competing CDW order

- Wise, W. D. et al. Charge-density-wave origin of cuprate checkerboard visualized by scanning tunnelling microscopy. Nature Phys. 4, 696699 (2008).
- Lawler, M. J. et al. Intra-unit-cell electronic nematicity of the high-Tc copper-oxide pseudogap states. Nature 466, 347351 (2010).
- Parker, C. V. et al. Fluctuating stripes at the onset of the pseudogap in the high-Tc superconductor B2Sr2CaCu2O8Cx. Nature 468, 677680 (2010).
- Chang, J. et al. Direct observation of competition between superconductivity and charge density wave order in YBa2Cu3O6:67. Nature Phys. 8, 871876 (2012).
- Ghiringhelli, G. et al. Long-range incommensurate charge fluctuations in (Y;Nd)Ba2Cu3O6Cx. Science 337, 821825 (2012).
- Achkar, A. J. et al. Distinct charge orders in the planes and chains of ortho-III-ordered YBa2Cu3O6C superconductors identified by resonant elastic X-ray scattering. Phys. Rev. Lett. 109, 167001 (2012).
- Wu, T. et al. Magnetic-field-induced charge-stripe order in the high-temperature superconductor YBa2Cu3Oy. Nature 477, 192194 (2011).
- LeBoeuf, D. et al. Thermodynamic phase diagram of static charge order in underdoped YBa2Cu3Oy. Nature Phys. 9, 7983 (2013).

UNIVERSITÉ DE SHERBROOKE

nature physics
LETTERS
PUBLISHED ONLINE: 14 OCTOBER 2012 | DOI:10.1038/NPHYS2456

Direct observation of competition between superconductivity and charge density wave order in $YBa_2Cu_3O_{6.67}$

J. Chang[1,2★], E. Blackburn[3], A. T. Holmes[3], N. B. Christensen[4], J. Larsen[4,5], J. Mesot[1,2], Ruixing Liang[6,7], D. A. Bonn[6,7], W. N. Hardy[6,7], A. Watenphul[8], M. v. Zimmermann[8], E. M. Forgan[3] and S. M. Hayden[9]

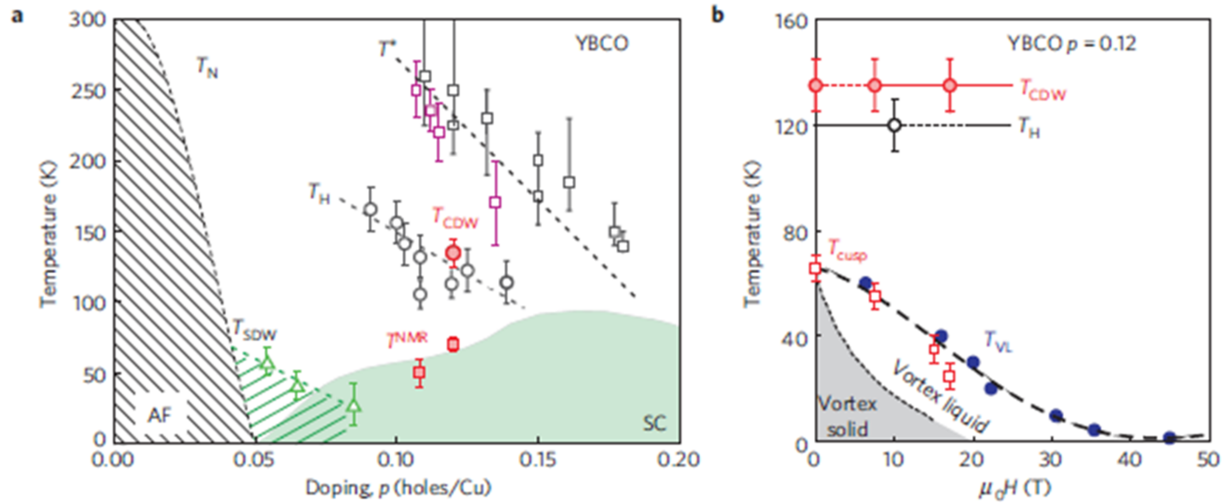
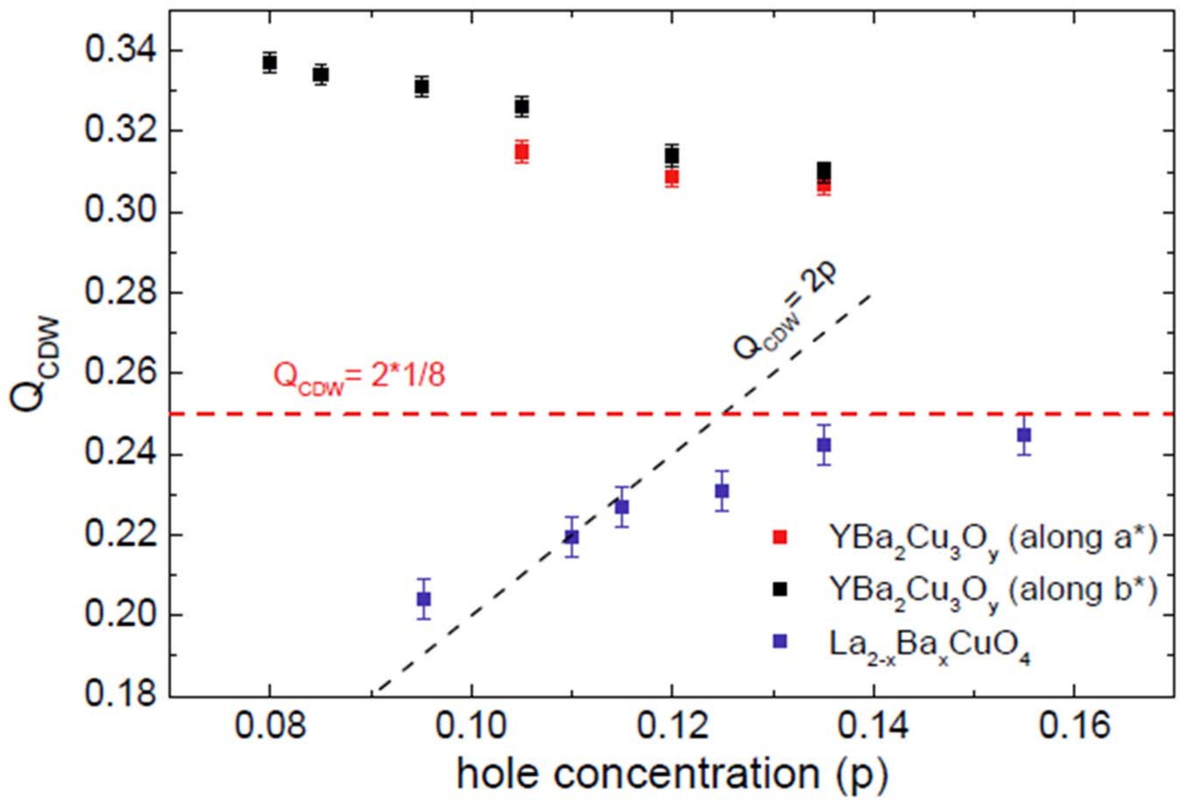


Figure 4 | Phase diagram of $YBa_2Cu_3O_{7-x}$. a, Doping dependence of the antiferromagnetic ordering temperature T_N, the incommensurate spin-density wave order T_{SDW} (green triangles; ref. 21), the superconducting temperature T_c and the pseudogap temperature T^* as determined from the Nernst effect[30] (black squares) and neutron diffraction[29] (purple squares). Notice that the Nernst effect[30] indicates a broken rotational symmetry inside the pseudogap region, whereas a translational symmetry preserving magnetic order is found by neutron scattering[29]. Below temperature scale T_H (black circles), a larger and negative Hall coefficient was observed[26] and interpreted in terms of a Fermi surface reconstruction. Our X-ray diffraction experiments show that in YBCO $p = 0.12$ incommensurate CDW order spontaneously breaks the crystal translational symmetry at a temperature T_{CDW} that is twice as large as T_c. T_{CDW} is also much larger than T^{NMR} (red squares), the temperature scale below which NMR observes field-induced charge order[13]. **b**, Field dependence of T_{CDW} (filled red circles) and T_{cusp} (open squares), the temperature below which the CDW is suppressed by superconductivity, compared with T_H (open black circle) and T_{VL} (filled blue circles), the temperature where the vortex liquid state forms[26]. Error bars on T_{SDW}, T_H, T_{NMR}, and T^* are explained in refs 21,26,30,33. The error bars on T_{CDW} and T_{cusp} reflect the uncertainty in determining the onset and suppression temperature of CDW order from Fig. 2.

KE

Wave vector



Keimer, Julich summer school 2013

Theories

S. Sachdev and R. La Placa Phys. Rev. Lett. **111**, 027202 (2013)
D. Chowdhury, S. Sachdev arxiv. 1501.00002

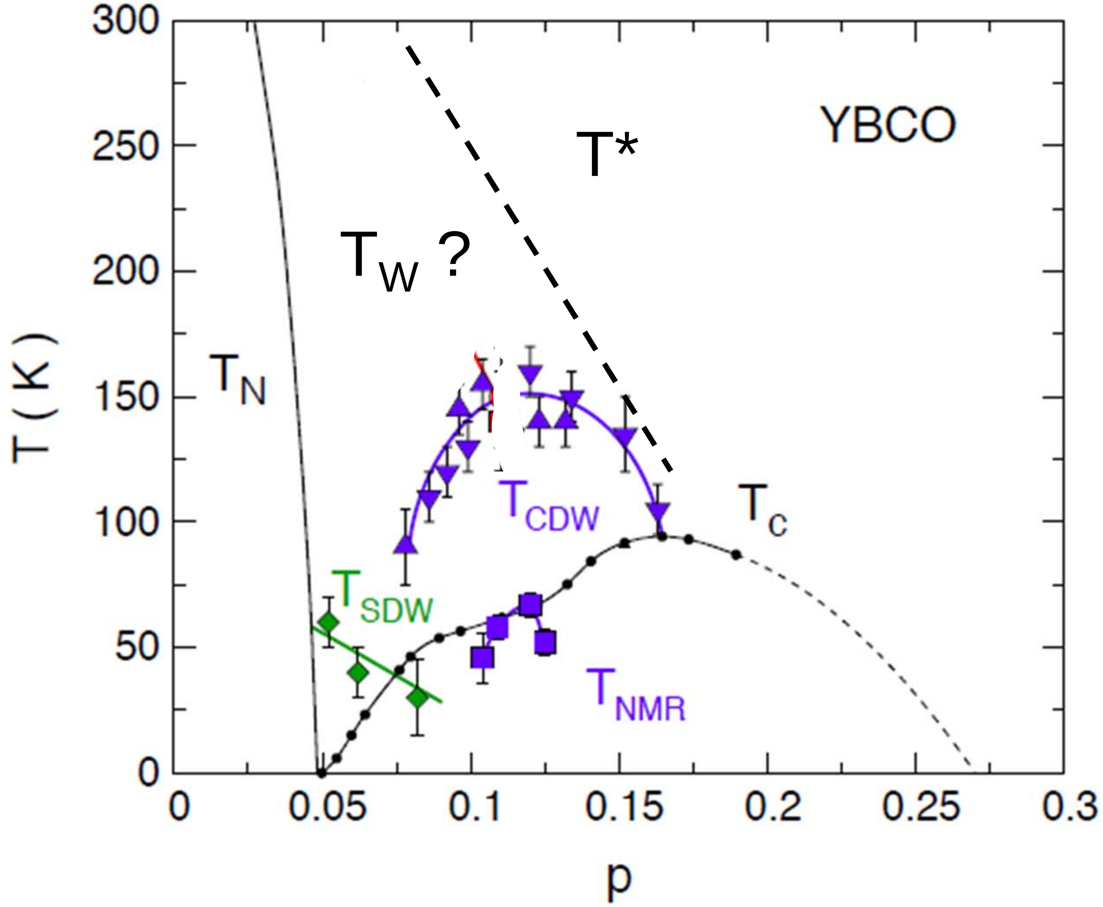
K. B. Efetov, H. Meier, and C. Pepin, Nat Phys **9**, 442 (2013).

Y. Wang and A. Chubukov, Phys. Rev. B 90, 035149 (2014).

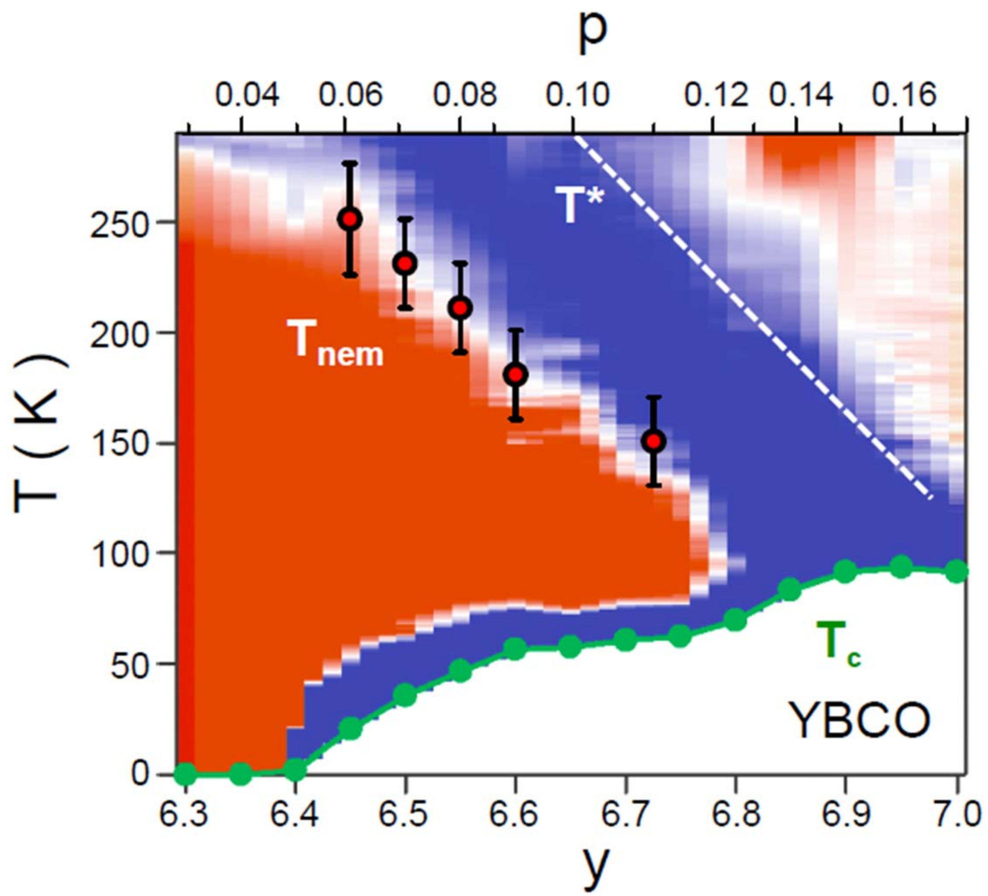
…

UNIVERSITÉ DE SHERBROOKE

Phase diagram for hole-doped cuprates



Resistivity anisotropy and curvature map



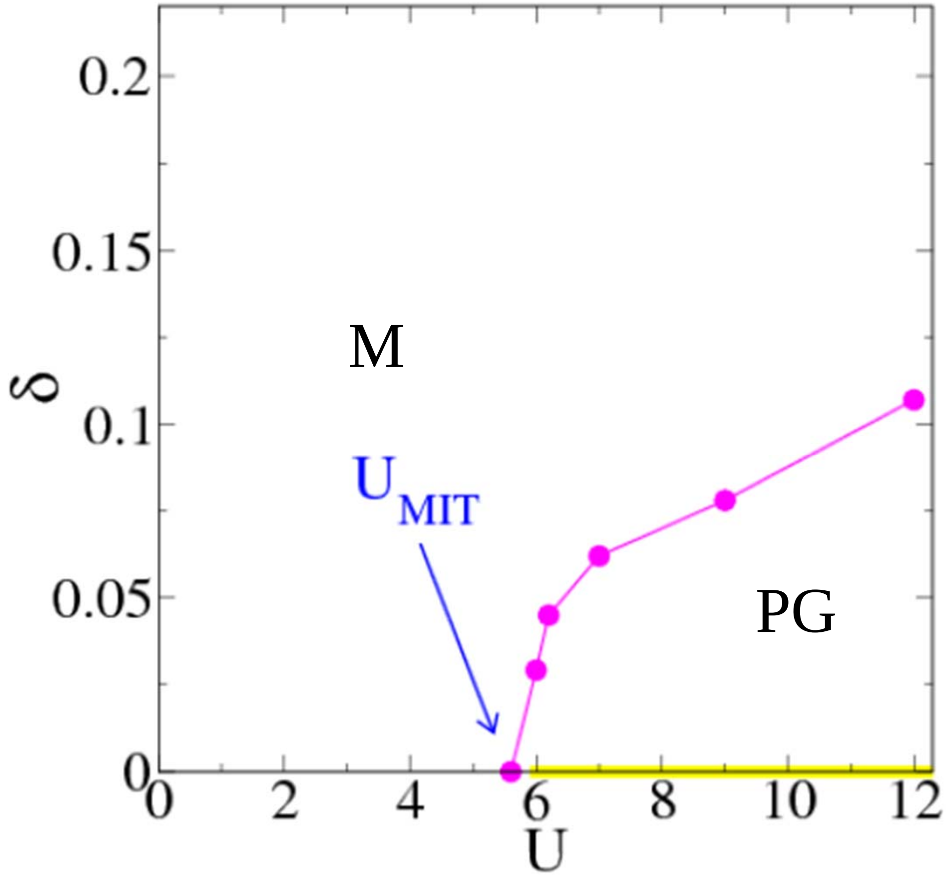
Y. Ando *et al.*, *Phys. Rev. Lett.* **93**, 267001 (2004).

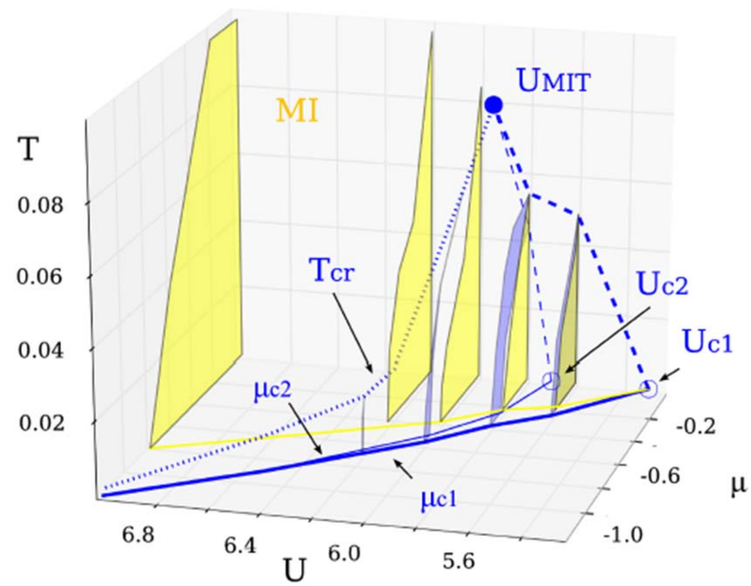
$T = 0$ phase diagram

Normal state and large anisotropy

Recall phase diagram

Doping dependence of critical point as a function of U





Underdoped metal very sensitive to anisotropy

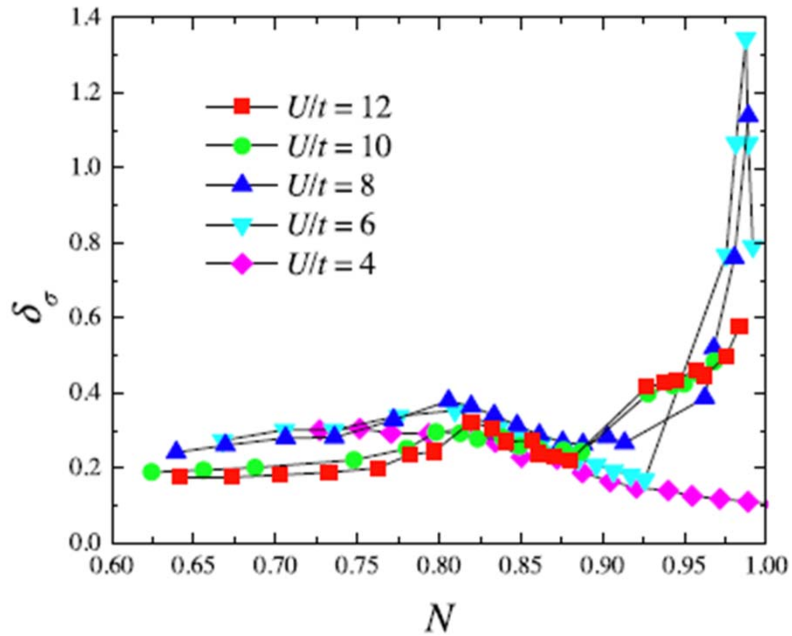
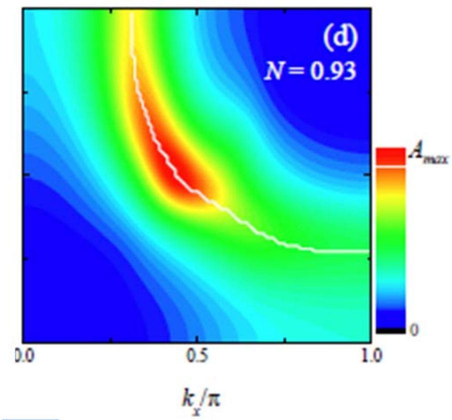
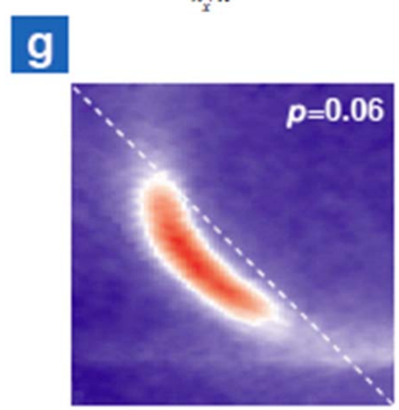


FIG. 3: (Color online) Anisotropy in the CDMFT conductivity $\delta_\sigma = 2\left[\sigma_x(0) - \sigma_y(0)\right] / \left[\sigma_x(0) + \sigma_y(0)\right]$ as a function of filling N for various values of U and $\eta = 0.1$, $\delta_0 = 0.04$.

Okamoto, Sénéchal, Civelli, AMST
Phys. Rev. B **82**, 180511R 2010



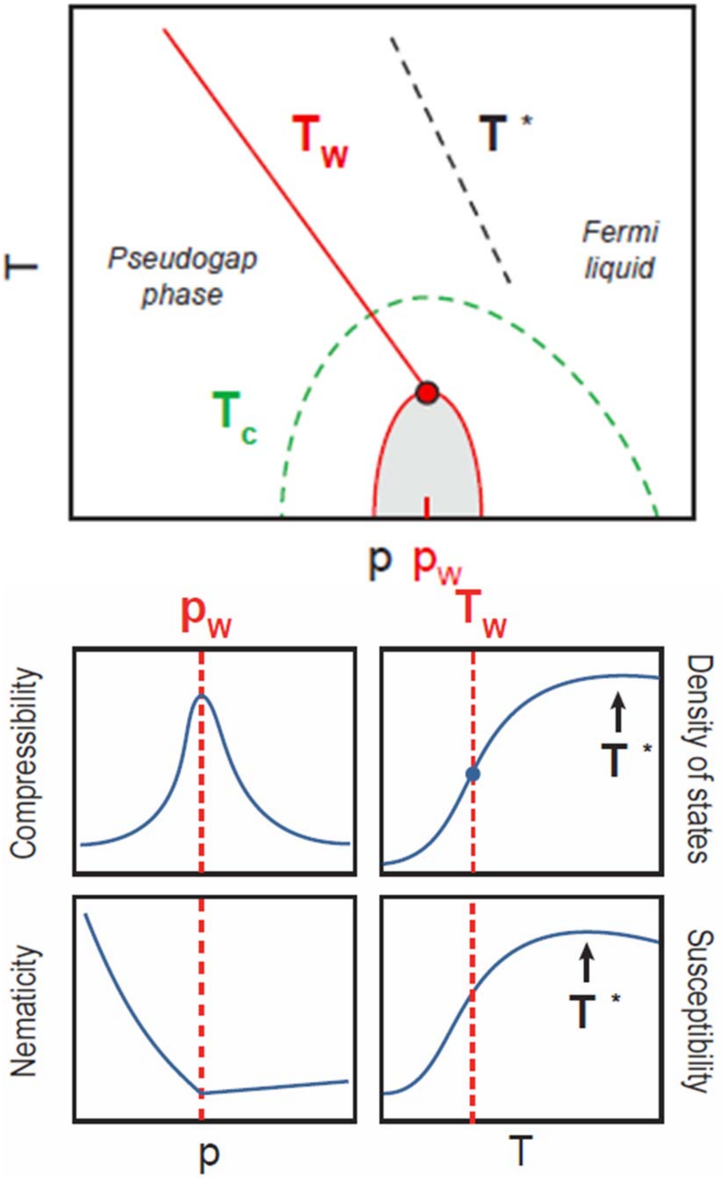


Satoshi Okamoto

David Sénéchal

D. Fournier *et al.* Nature Physics (Marcello Civelli

Summary



T
T_W
T^*
Pseudogap phase
Fermi liquid
T_c
p
p_W
p_W
T_W
Compressibility
Density of states
T^*
Nematicity
Susceptibility
T^*
p
T

Giovanni Sordi

Patrick Sémon

Kristjan Haul

Finite *T* phase diagram

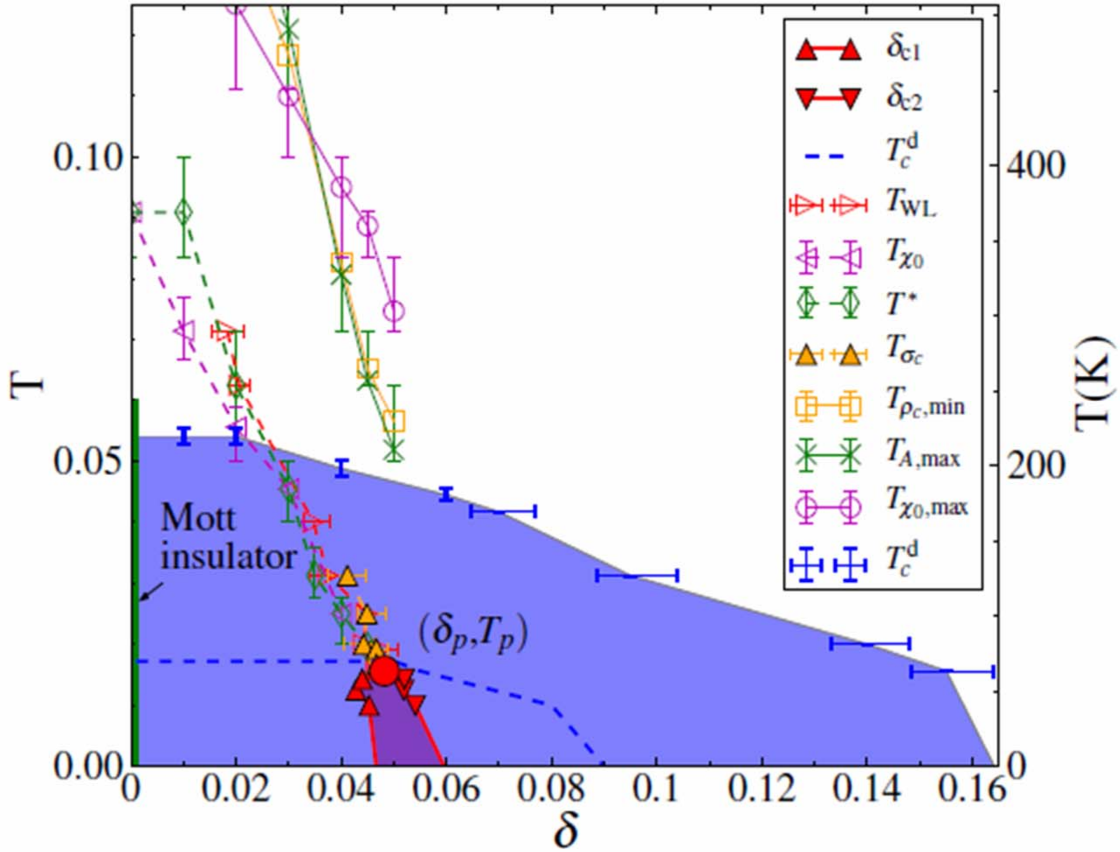
Superconductivity

G. Sordi et al. Phys. Rev. Lett. 108, 216401/1-6 (2012)
P. Sémon, G. Sordi, A.-M.S.T., Phys. Rev. B **89**, 165113/1-6 (2014)

Dôme?

Giovanni Sordi

Patrick Sémon

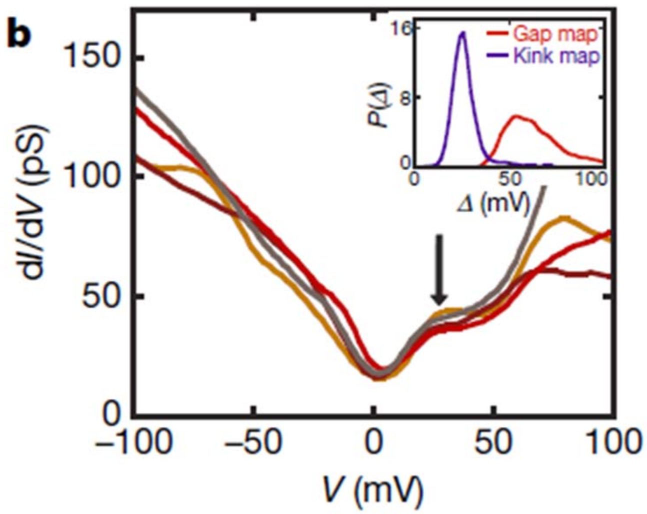


G. Sordi et al. Phys. Rev. Lett. 108, 216401/1-6 (2012)

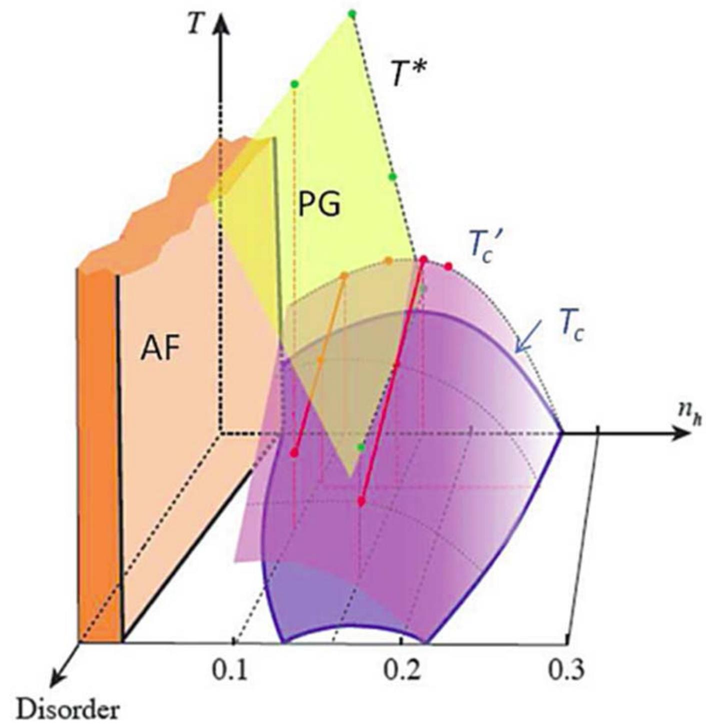
P. Sémon, G. Sordi, A.-M.S.T., Phys. Rev. B **89**, 165113/1-6 (2014)

Meaning of T_c^d

- Local pair formation

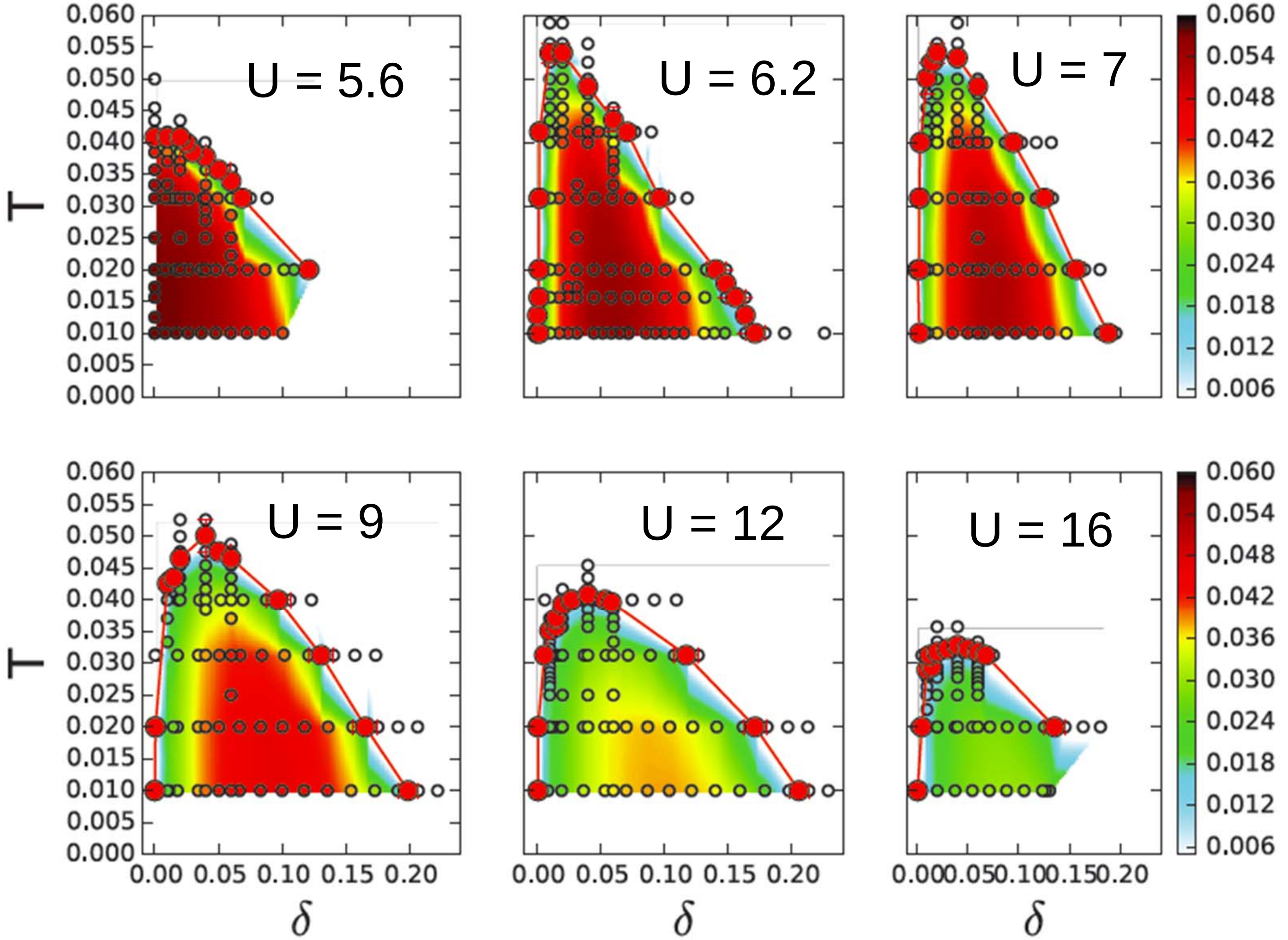


K. K. Gomes, A. N. Pasupathy, A. Pushp, S. Ono, Y. Ando, and A. Yazdani, Nature **447**, 569 (2007)



F. Rullier-Albenque, H. Alloul, and G.Rikken, Phys. Rev. B **84**, 014522 (2011).

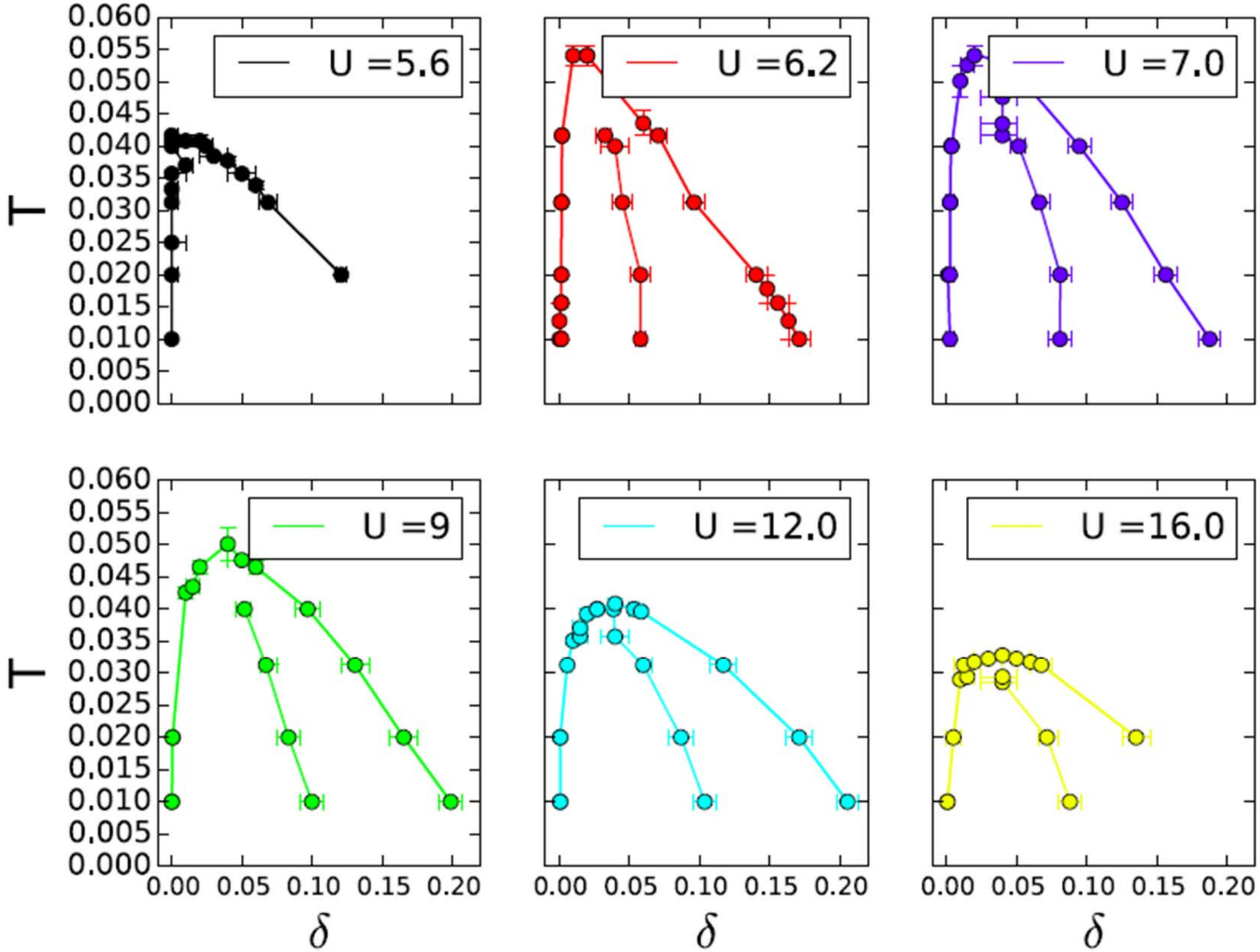
Order parameter (color) and T_c



L. Fratini, G. Sordi (unpublished)

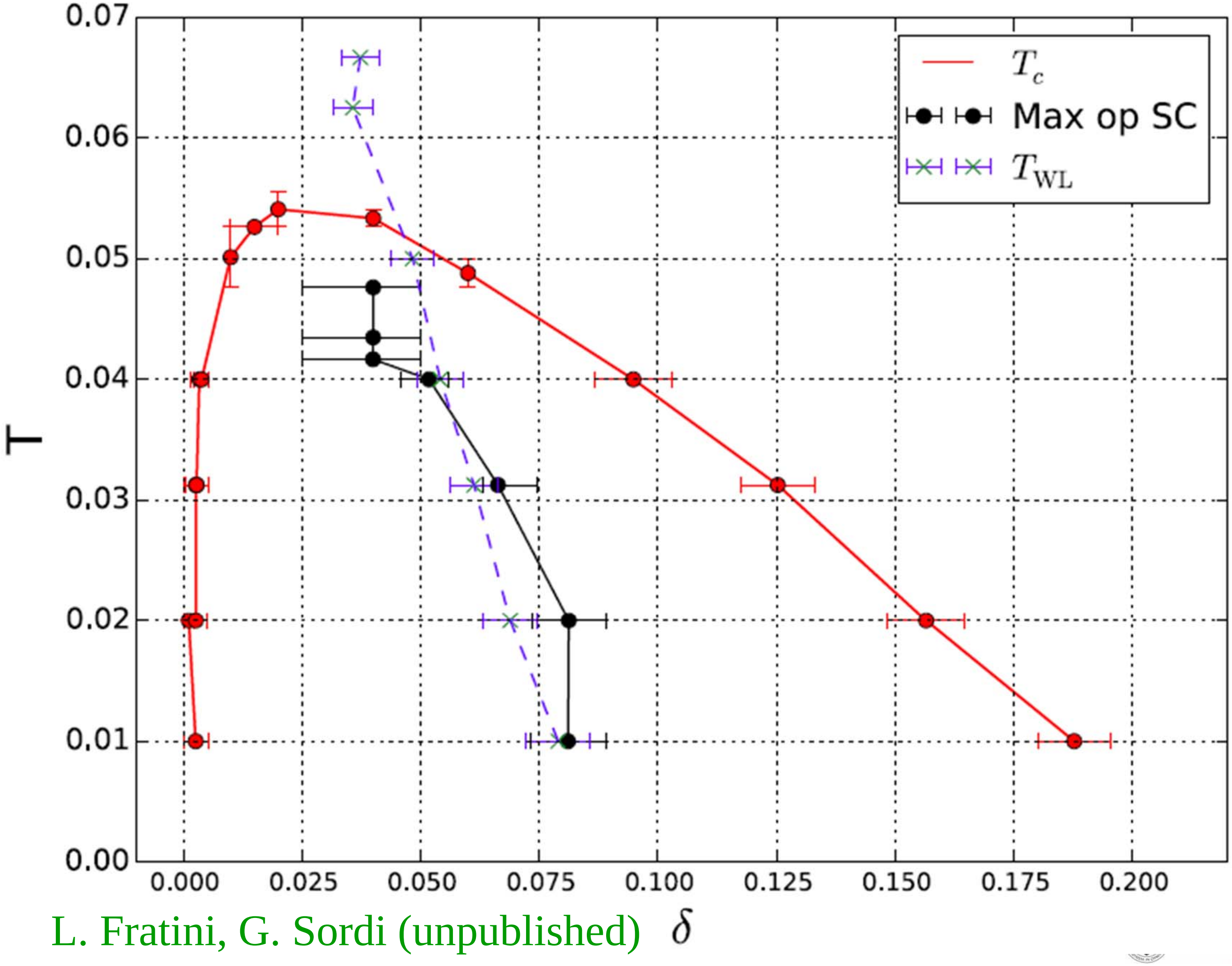
UNIVERSITÉ DE SHERBROOKE

T_c vs $T_{max\ order\ parameter}$



L. Fratini, G. Sordi (unpublished)

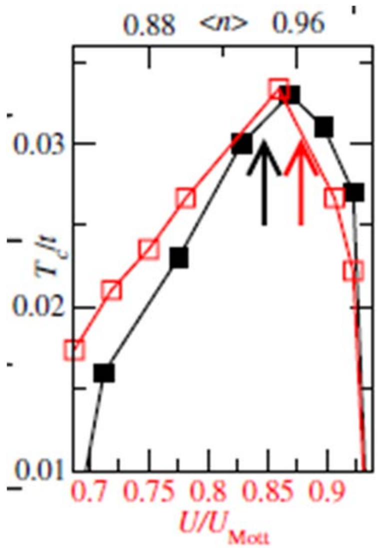
U=7, T_W vs T_c vs $T_{\text{max order parameter}}$



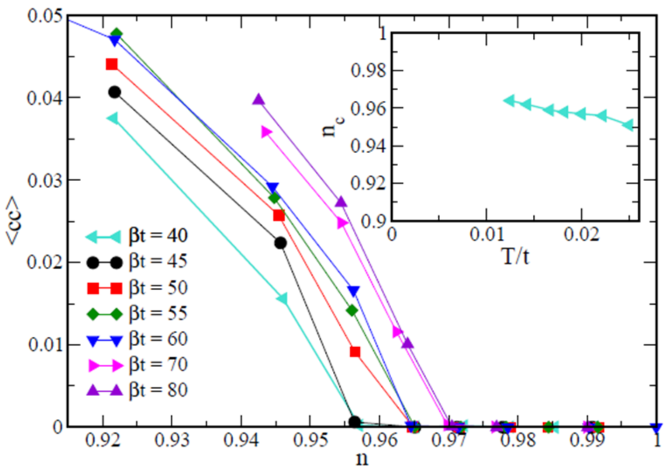
L. Fratini, G. Sordi (unpublished)

Larger clusters

- In 2x2 T_c vanishes extremely close to half-filling. In larger cluster, earlier.
- Local pairs in underdoped (2x2)



8 site DCA, *U=6t*



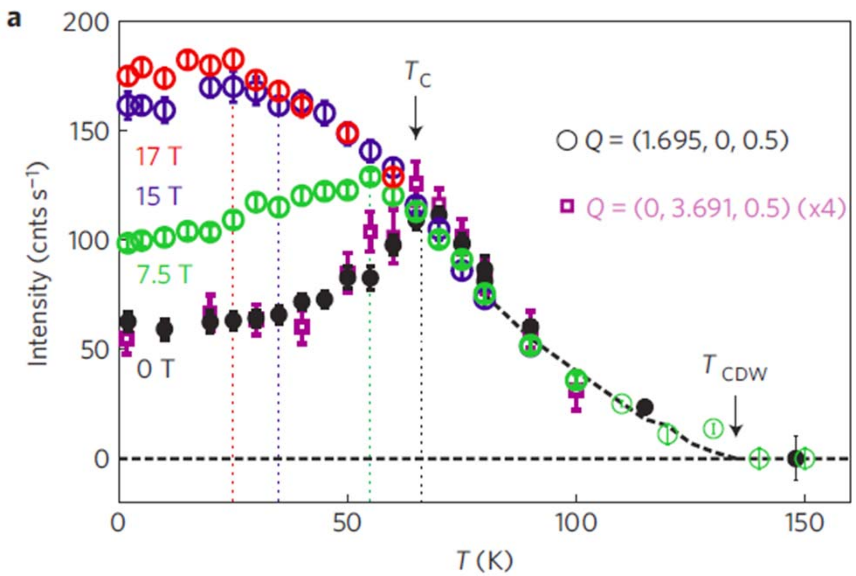
8 site DCA, *U=6.5t*

Gull Parcollet Millis,
PRL **110**, 216405 (2013)

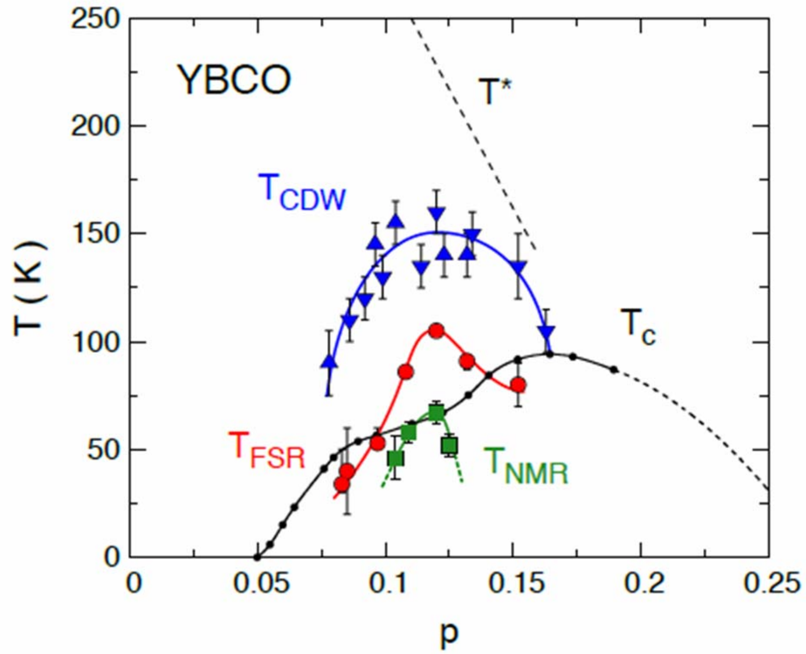
UNIVERSITÉ DE SHERBROOKE

Back to experiment: CDW vs SC

Competition between CDW and SC

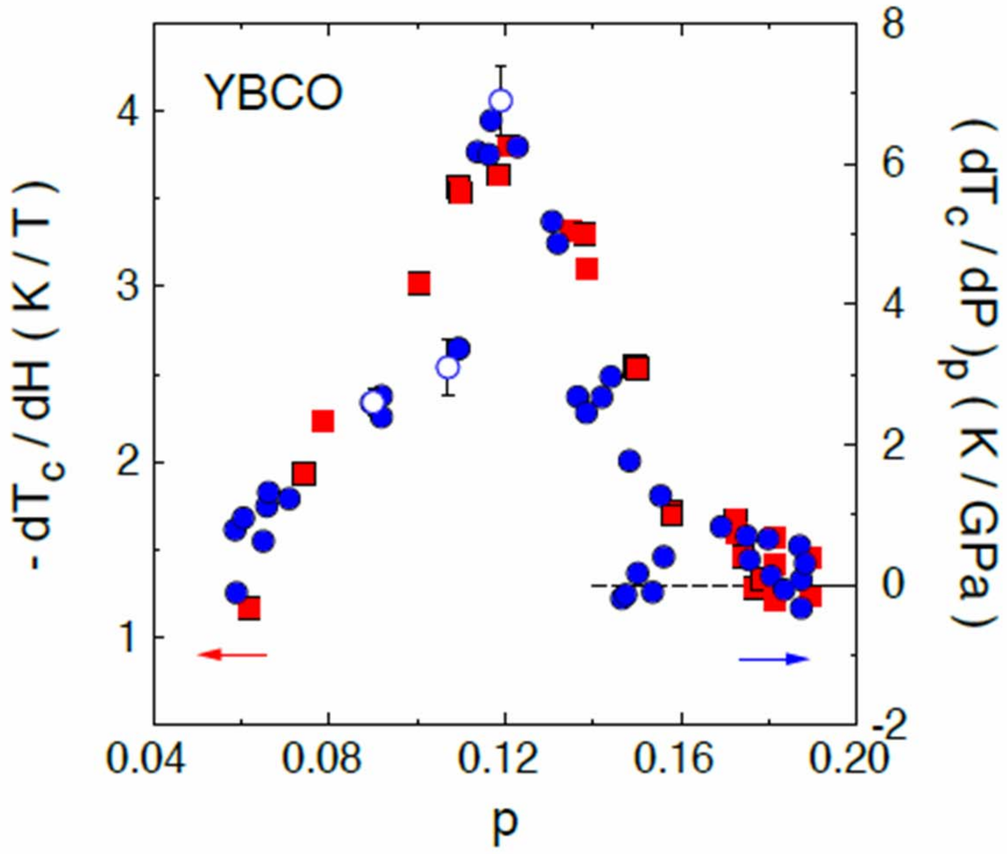


J. Chang *et al.*, *Nat. Phys.* **8**, 871-876 (2012).



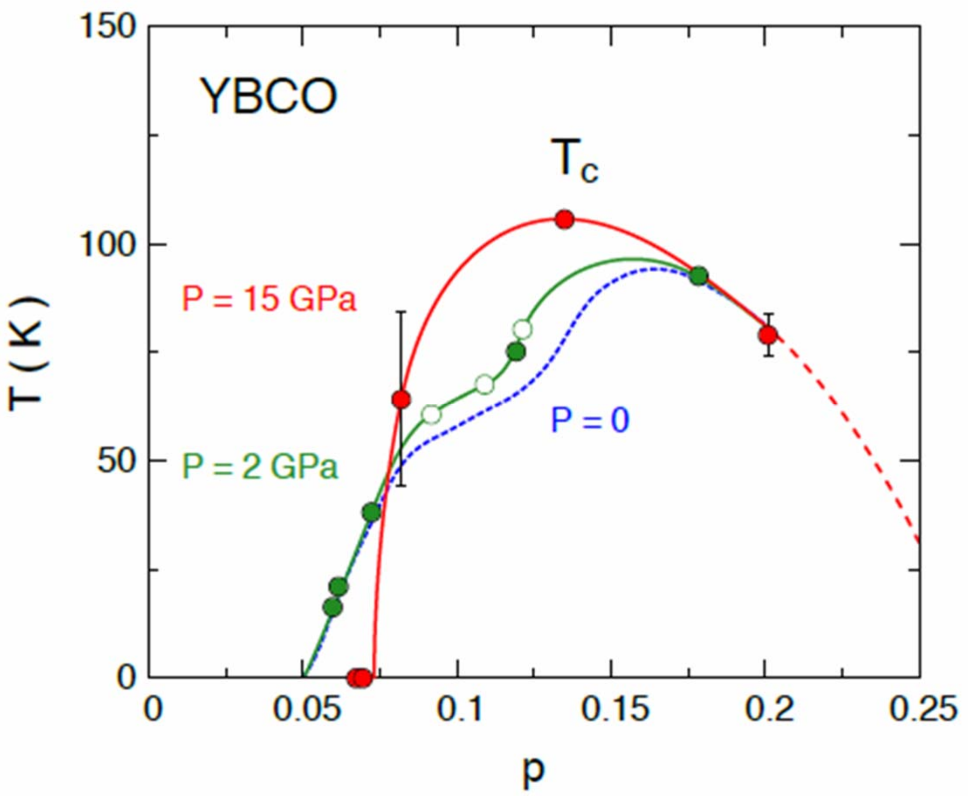
Cyr-Choinière et al, arxiv1503.02033

Tuning SC and CDW



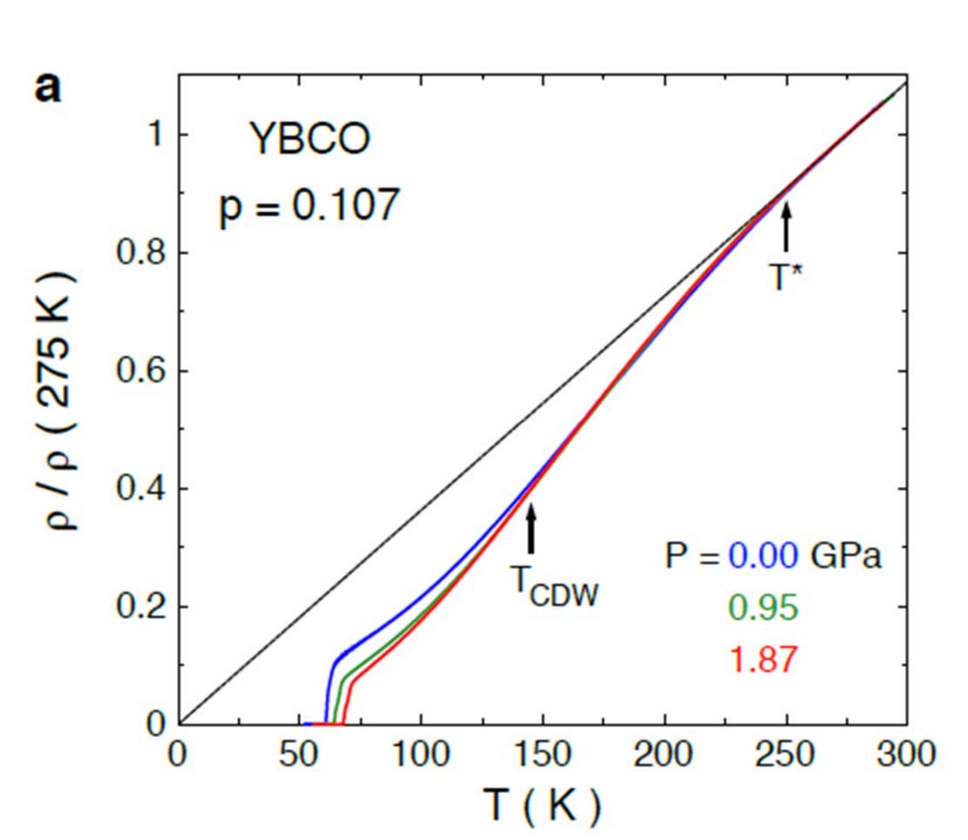
Cyr-Choinière et al, arxiv1503.02033

Getting rid of the CDW



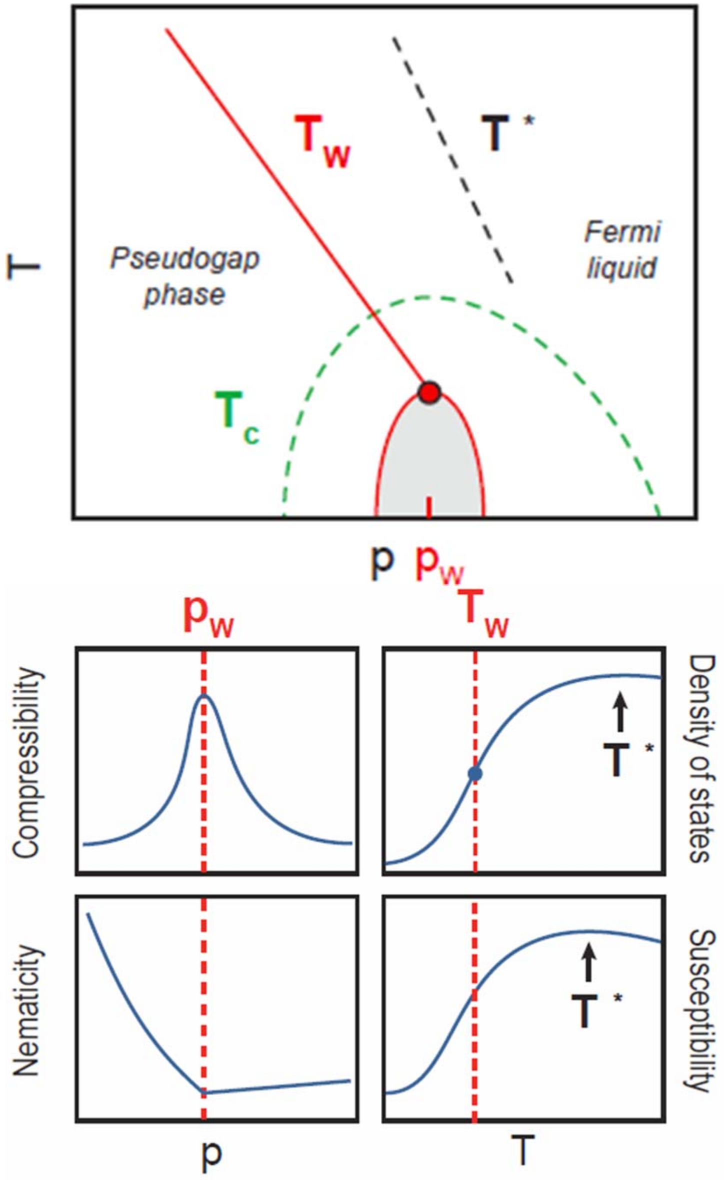
Cyr-Choinière et al, arxiv1503.02033

T* not affected



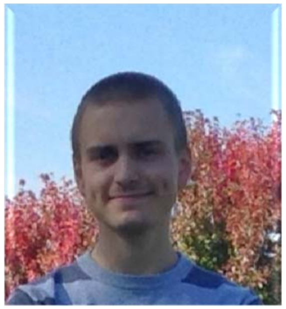
Cyr-Choinière et al, arxiv1503.02033

An alternate point of view



- - Is the pseudogap (PG) a crossover or a phase transition ?
- - Relation between CDW and the PG ?
- - Why CDW peaked at 12% doping ?
- - Origin of nematicity ?
- - Why superconducting ?
- - Why a dome of SC ?
- - Does a one-band model capture the key physics ?
- AFM QCP important?
- Lessons from other SC?

UNIVERSITÉ DE SHERBROOKE

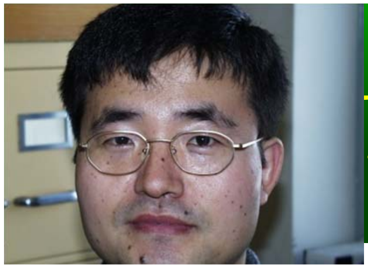


Charles-David Hébert

Patrick Sémon

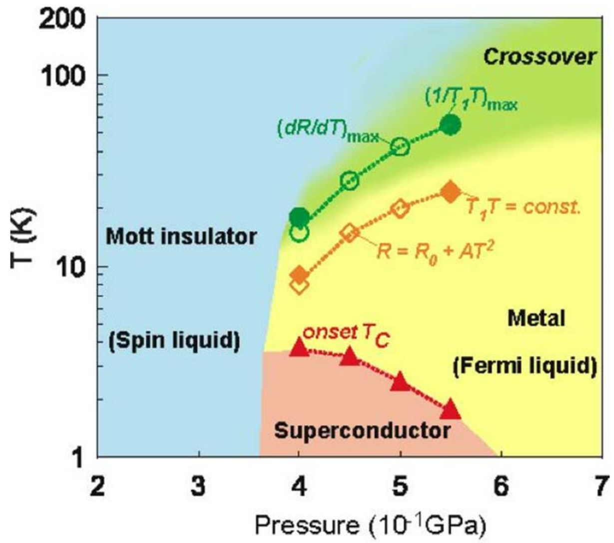
Bandwidth control and doping control of the Mott transition in organics

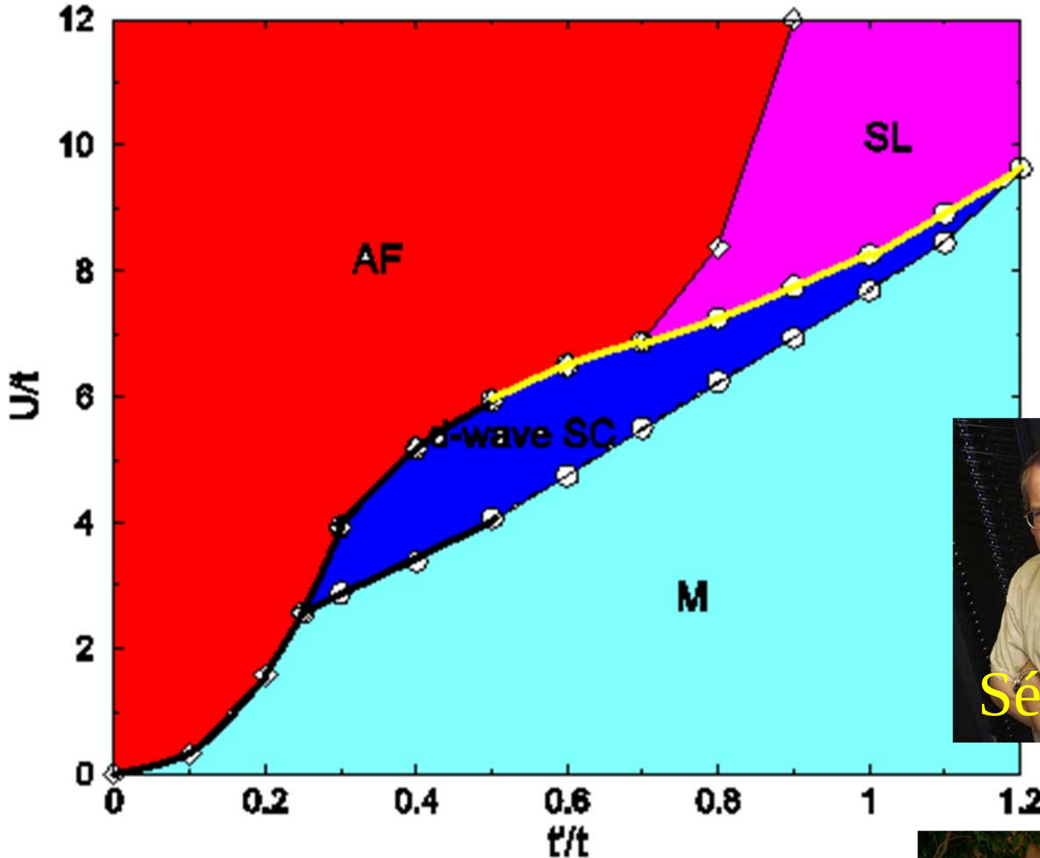
UNIVERSITÉ DE SHERBROOKE

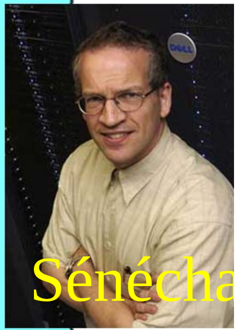


Theoretical phase diagram BEDT

X= $Cu_2(CN)_3$ (t'~ t)





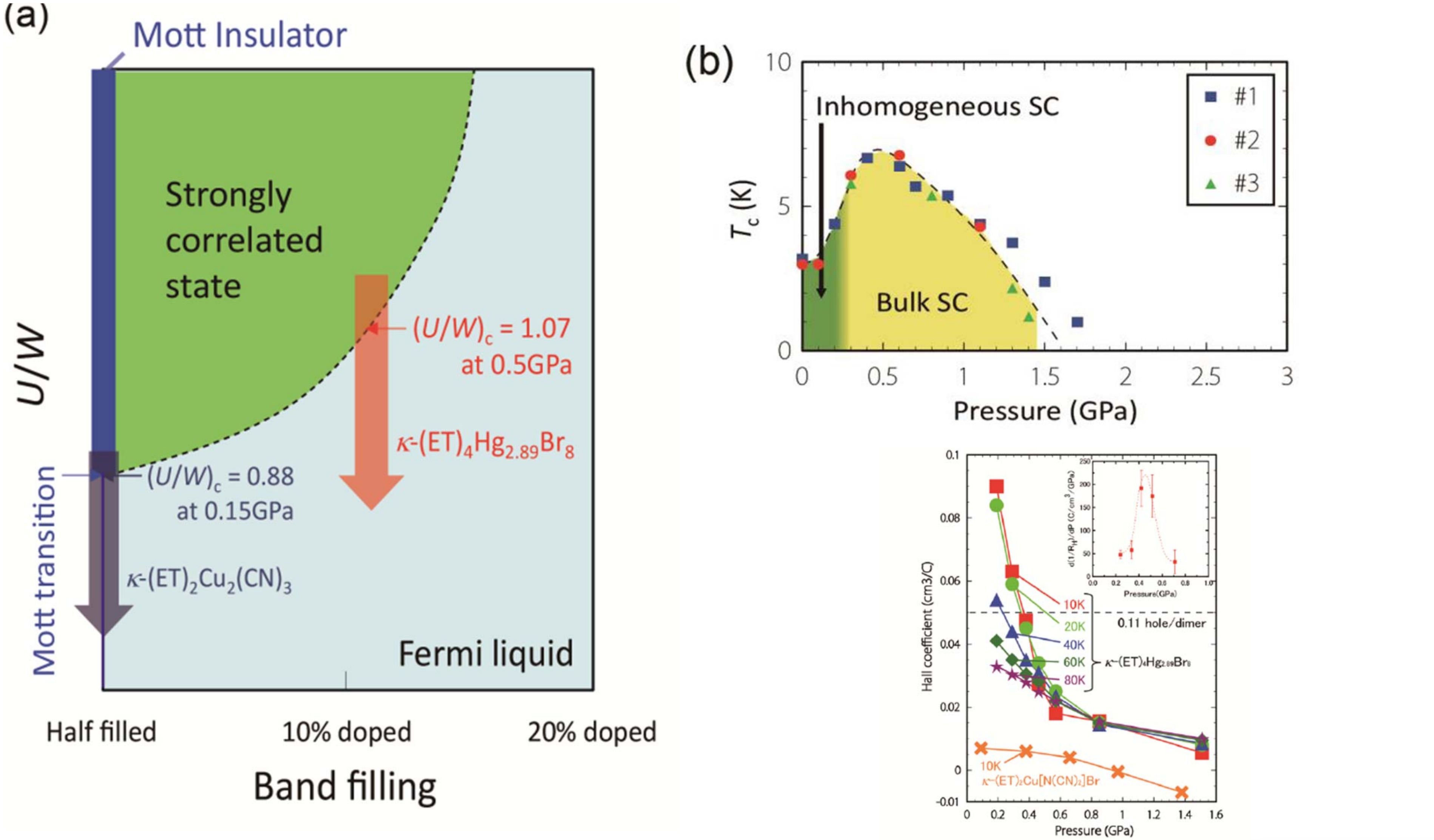


Kyung, A.-M.S.T. PRL 97, 046402 (2006)

Sénéchal, Sahebsara, Phys. Rev. Lett. **97**, 257004

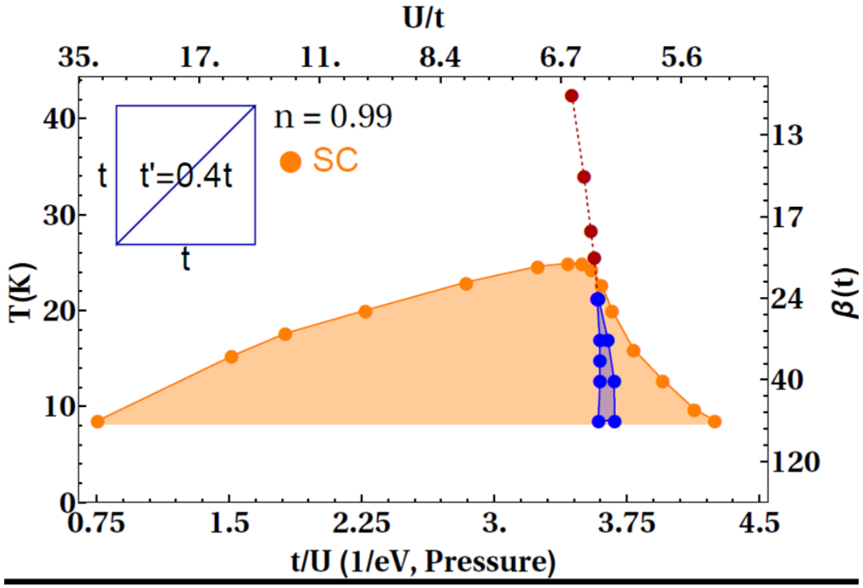
Y. Kurisaki, et al.
Phys. Rev. Lett. **95**, 177001(2005) Y. Shimizu, et al. Phys. Rev. Lett. **91**, (2003)

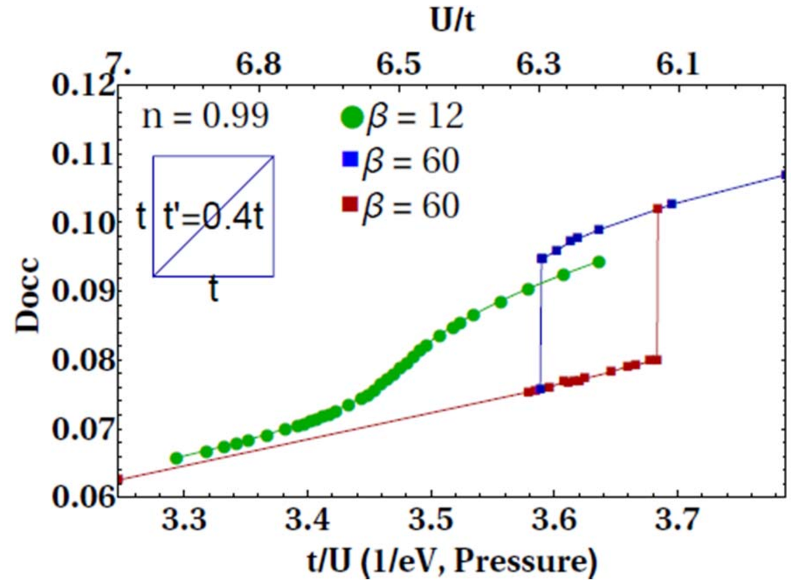
Doped BEDT

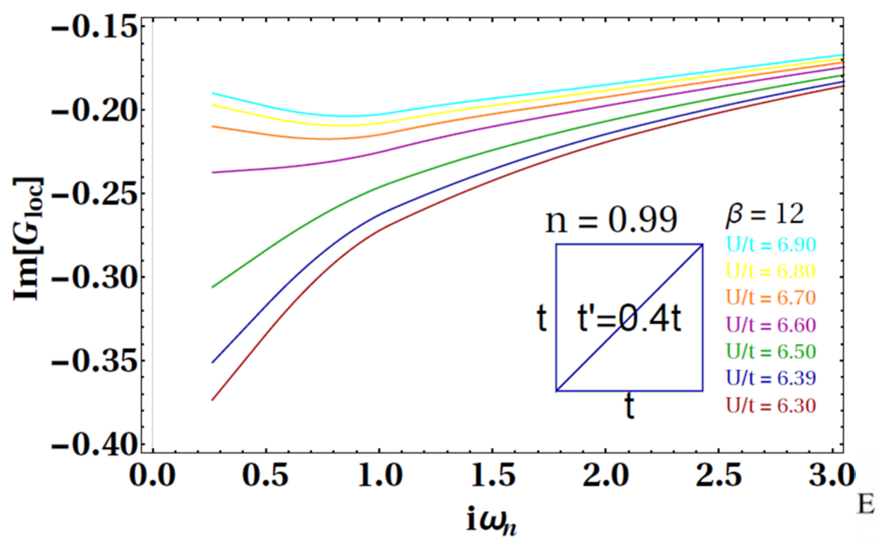


H. Oike, K. Miyagawa, H. Taniguchi, K. Kanoda PRL **114**, 067002 (2015)

Widom line in organics

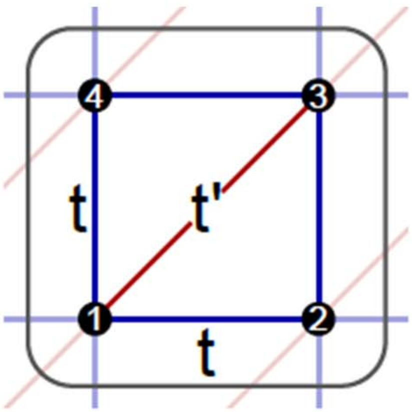




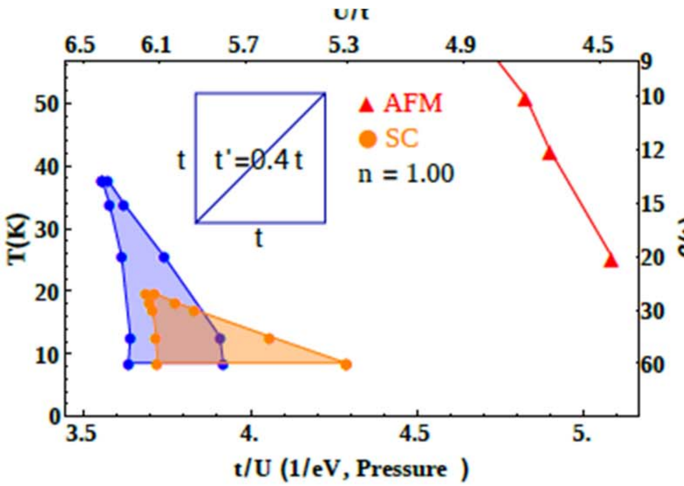


Charles-David Hébert, Patrick Sémon , AMT

t'=0.4t

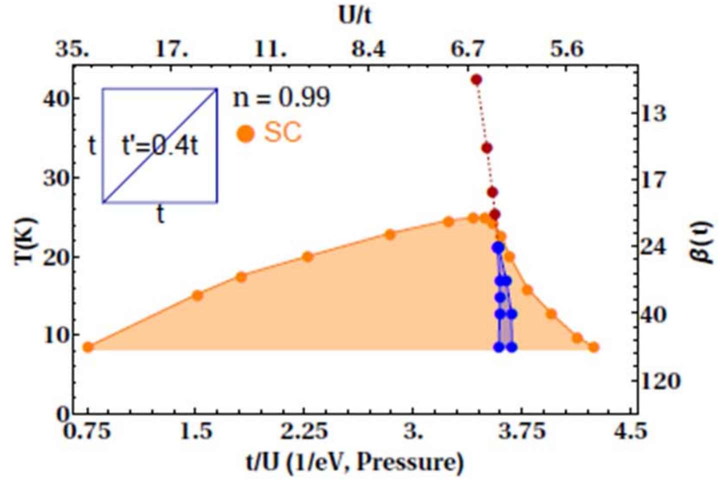


t
t'
t
1
2
3
4



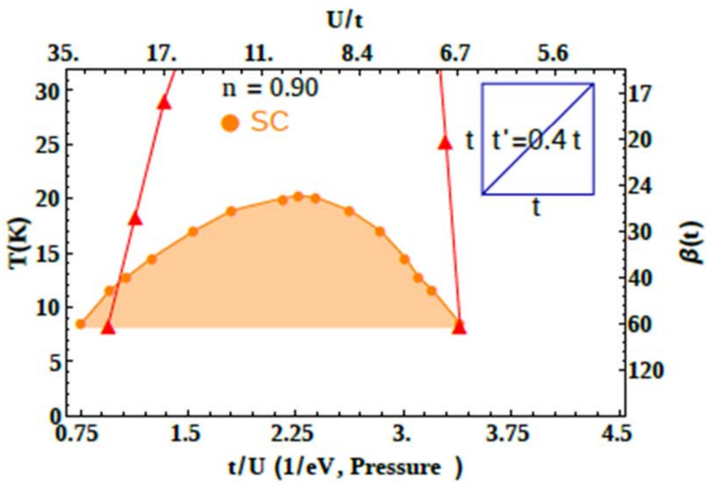
U/t
AFM
SC
n = 1.00
t'=0.4 t
T(K)
β(t)
t/U (1/eV, Pressure)

(a)

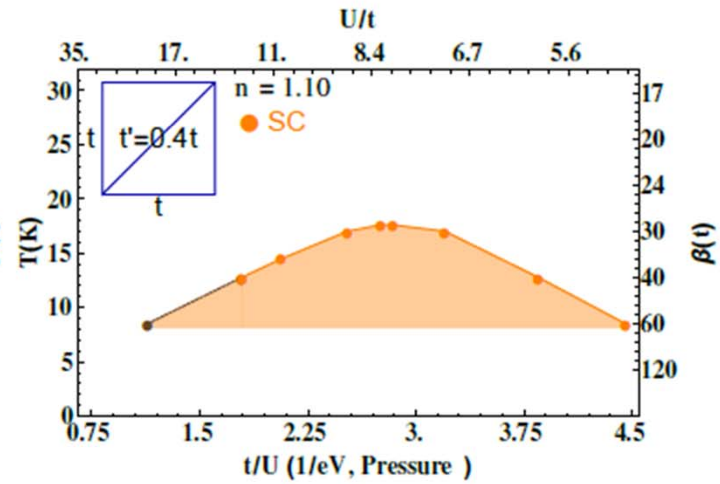


U/t
n = 0.99
SC
t'=0.4t
T(K)
β(t)
t/U (1/eV, Pressure)

(b)

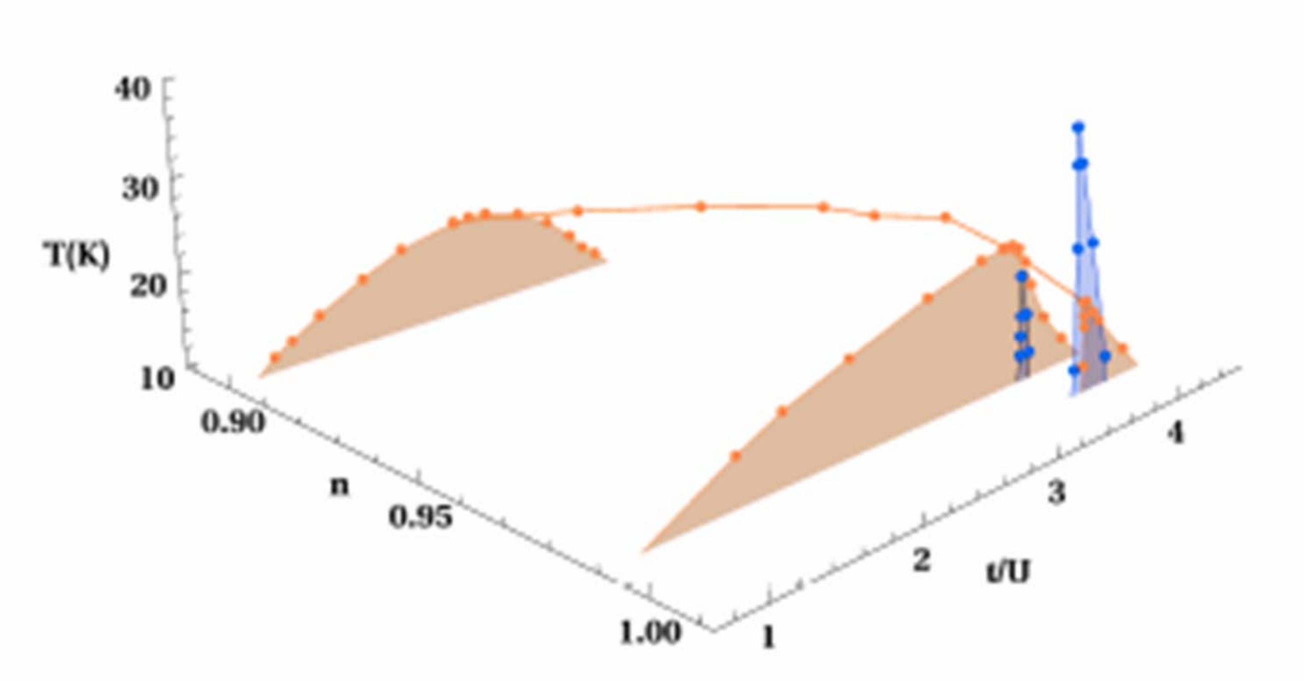


U/t
n = 0.90
SC
t'=0.4 t
T(K)
β(t)
t/U (1/eV, Pressure)

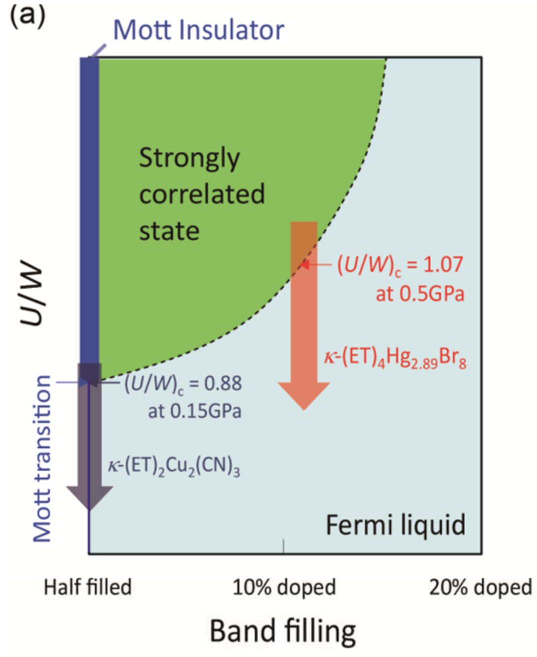


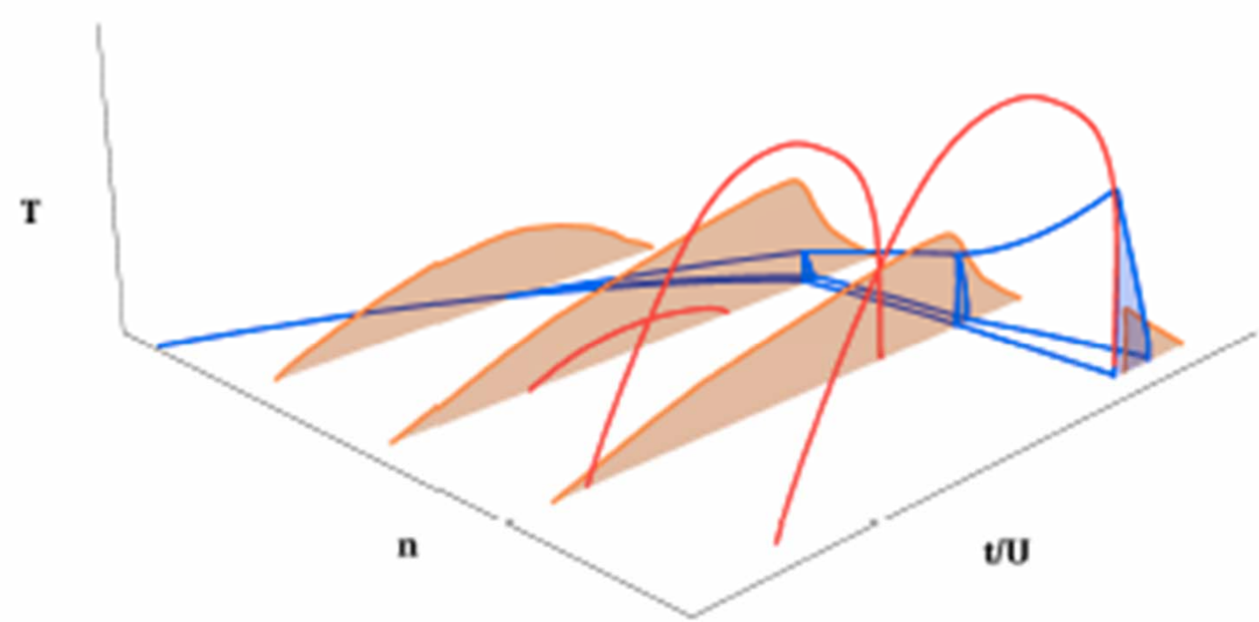
U/t
n = 1.10
SC
t'=0.4t
T(K)
β(t)
t/U (1/eV, Pressure)

t' = 0.4t overview



Generic case





Summary : organics

- Agreement with experiment
  - SC: larger T_c and broader P range if doped
  - Larger frustration: Decrease T_N and T_c
  - Normal state metal to pseudogap crossover
- Predictions
  - First order transition at low T in normal state (or remnants in SC state)
- Physics
  - SC dome without a AFM-QCP. Follows first-order.
  - SC from short range J.
  - T_c decreases at Widom line

UNIVERSITÉ DE SHERBROOKE

Main collaborators

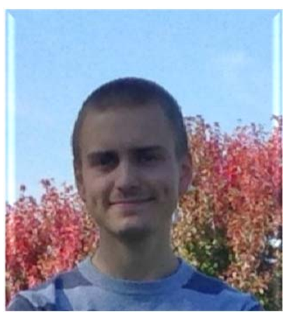
Giovanni Sordi

Kristjan Haule

David Sénéchal

Bumsoo Kyung

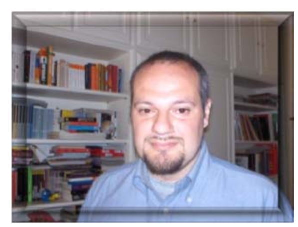
Patrick Sémon



Charles-David Hébert

Sarma Kancharla

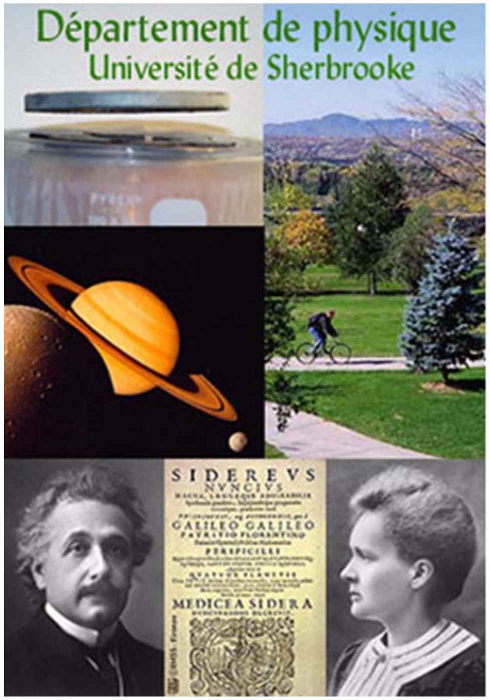
Marcello Civelli



Massimo Capone

Gabriel Kotliar

UNIVERSITÉ DE SHERBROOKE



André-Marie Tremblay

CANADA RESEARCH CHAIRS
CHAIRES DE RECHERCHE DU CANADA

RQMP
Le regroupement québécois sur les matériaux de pointe

UNIVERSITÉ DE SHERBROOKE

CIAR The Canadian Institute for Advanced Research

Sponsors:

CRSNG NSERC

Fonds FCAR

RQCHP

Fondation canadienne pour l'innovation

UNIVERSITÉ DE SHERBROOKE

Mammouth

Éducation, Loisir et Sport Québec

Canada Foundation for Innovation
Fondation canadienne pour l'innovation

compute • calcul CANADA

High Performance Computing
CREATING KNOWLEDGE
DRIVING INNOVATION
BUILDING THE DIGITAL ECONOMY

Le calcul de haute performance
CRÉER LE SAVOIR
ALIMENTER L'INNOVATION
BÂTIR L'ÉCONOMIE NUMÉRIQUE

Calcul Québec

UNIVERSITÉ DE SHERBROOKE

Review: A.-M.S.T. arXiv: 1310.1481

Merci

Thank you

A.-M.S. Tremblay

"Strongly correlated superconductivity"

Chapt. 10 : *Emergent Phenomena in Correlated Matter Modeling and Simulation, Vol. 3*, E. Pavarini, E. Koch, and U. Schollwöck (eds.)

Verlag des Forschungszentrum Jülich, 2013