特定領域 Physics of New Quantum Phases in Superclean Materials　発足研究会

2005. 12.16

Mott transition and spin degrees of freedom in quasi-2D with triangular lattice

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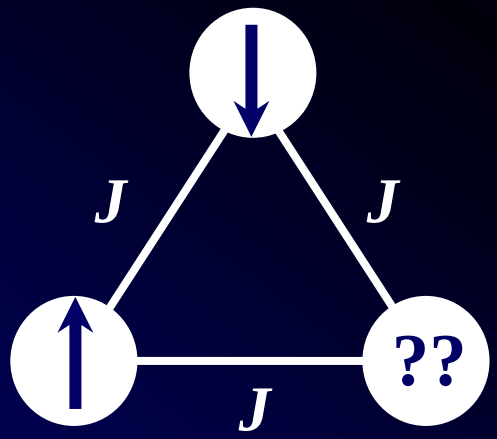
藤山　茂樹　講師

New Quantum Phases
on **Triangular lattice**

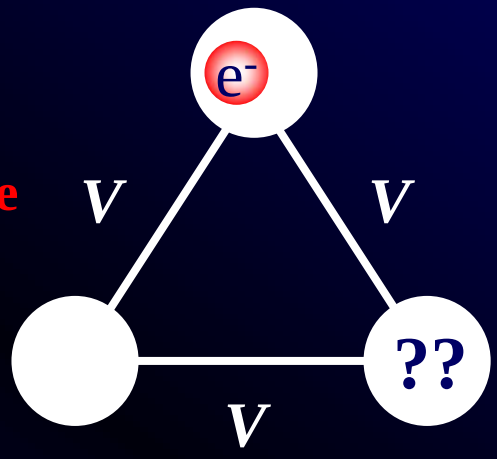
Spin-1/2 on the lattice
(½-filled band)



Antiferromagnetic interaction

frustration
in
spin and **charge**

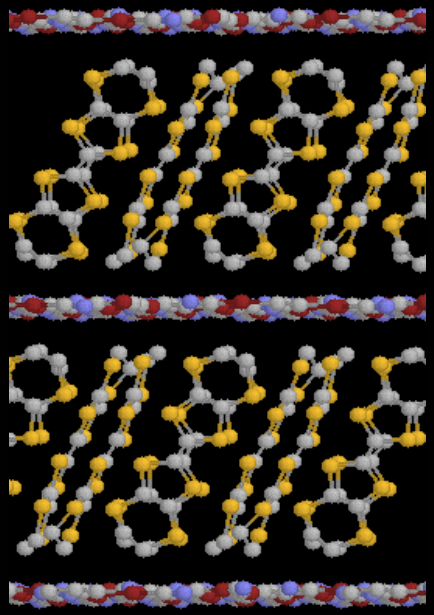
Charge-1/2 on the lattice
(¼-filled band)

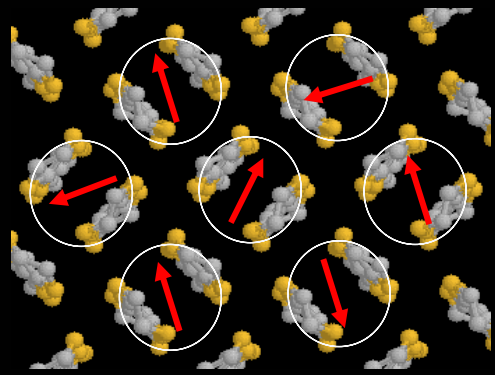


Inter-site Coulomb interaction

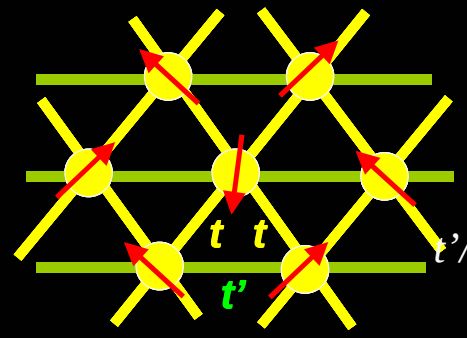
$$\mathcal{H} = \sum_{i,j,\sigma} t_{ij} C^{\dagger}_{i\sigma} C_{j\sigma} + \sum_{i} U n_{i\uparrow} n_{i\downarrow} + \sum_{<ij>} V_{ij} n_i n_j$$

Q2D organics κ-$(ET)_2X$; spin-1/2 on triangular lattice





Kino & Fukuyama — dimer model

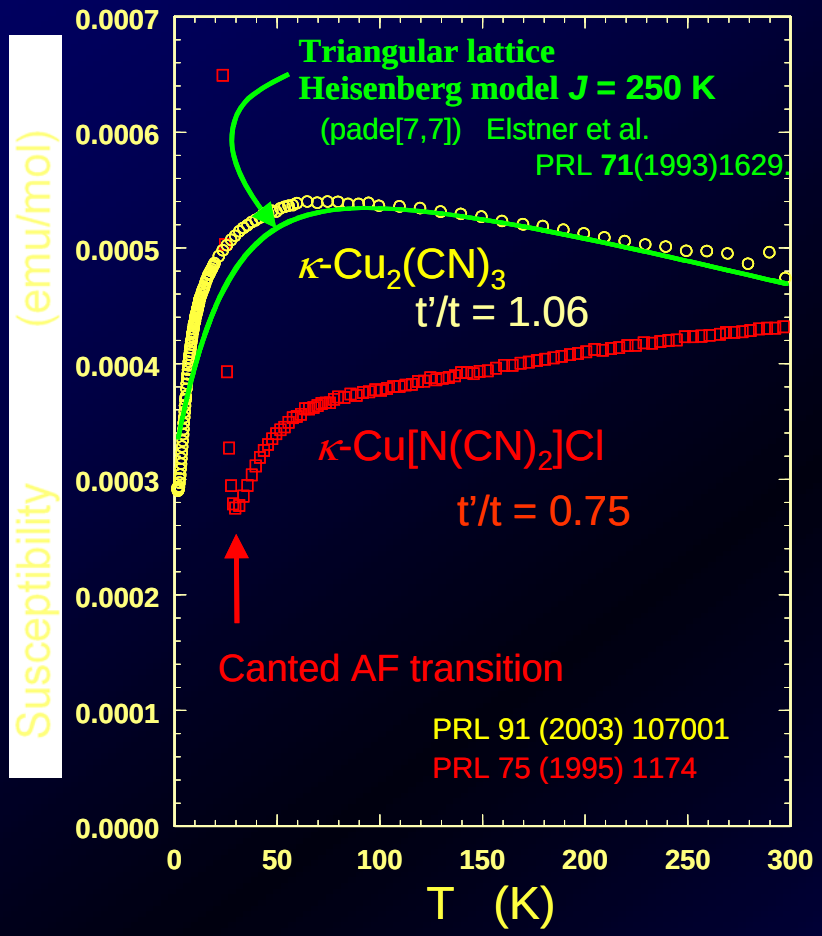


Triangular lattice
Half-filled band

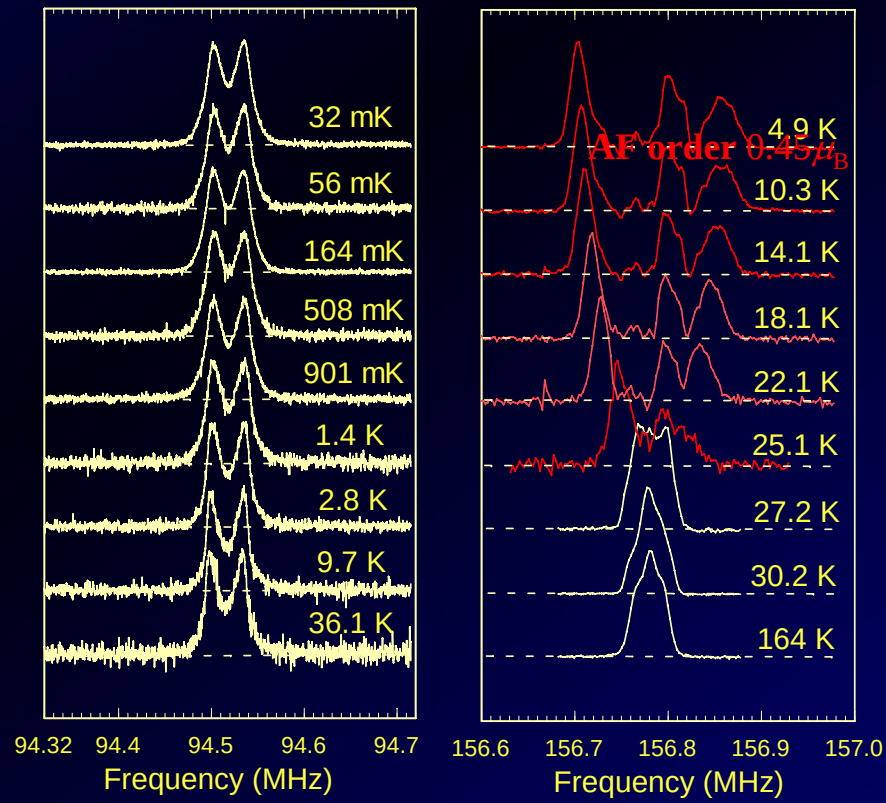
X^-	Ground State	t'/t
$Cu_2(CN)_3$	Mott insulator	1.06
$Cu[N(CN)_2]Cl$	Mott insulator	0.75
$Cu[N(CN)_2]Br$	SC	0.68
$Cu(NCS)_2$	SC	0.84

No long-range magnetic ordering down to 30 mK

Magnetic susceptibility



^{1}H NMR spectrum



κ-$(ET)_2Cu_2(CN)_3$

$t'/t = 1.06$

Spin liquid

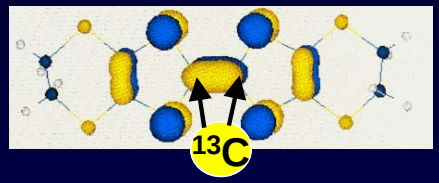
κ-$(ET)_2Cu[N(CN)_2]Cl$

$t'/t = 0.75$

AF ordered

Shimizu et al., PRL 91 (2003) 107001

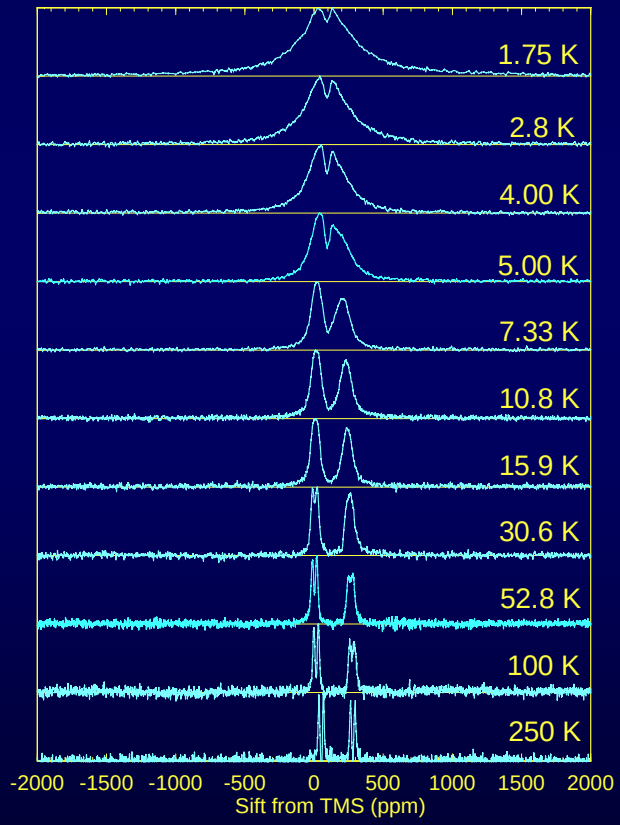
^{13}C NMR

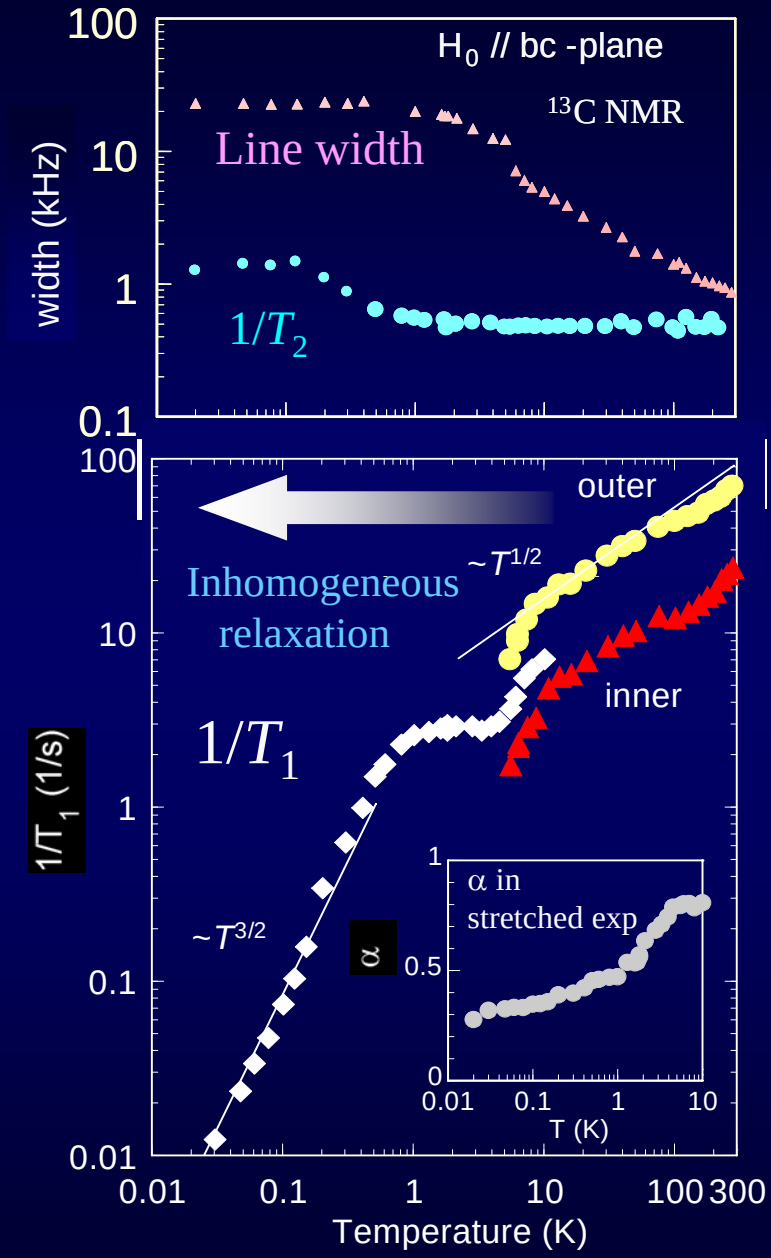


H = 8T ⊥ layer

Line broadening

Spectra



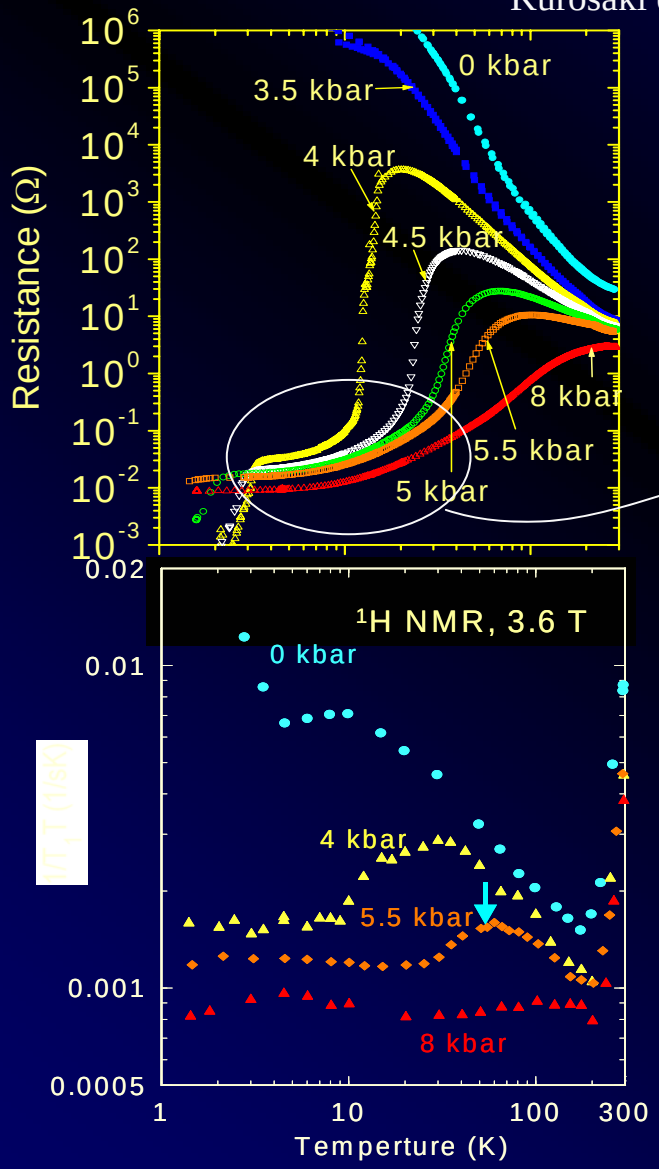


Also, Kawamoto et al., PRB 70 (2004) 060510

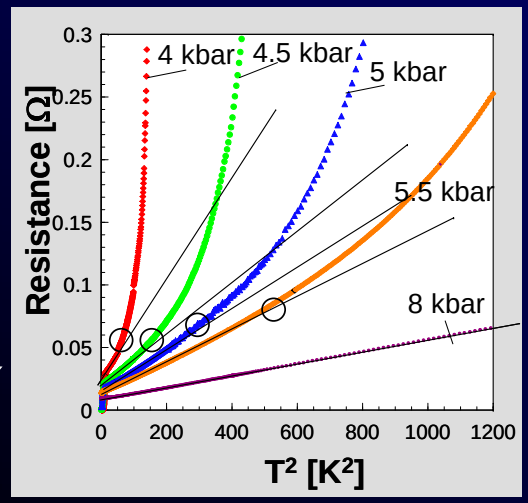
Low-lying spin excitation

Mott transition in κ-$(ET)_2Cu_2(CN)_3$ under pressure

Kurosaki et al.; PRL 95 (2005) 177001 (an earlier work; Komatsu et al. 1996)

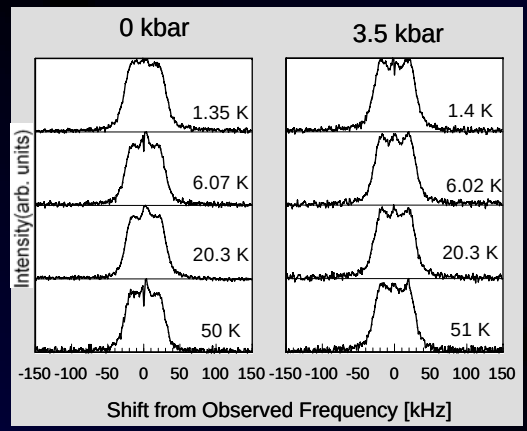


R vs T^2

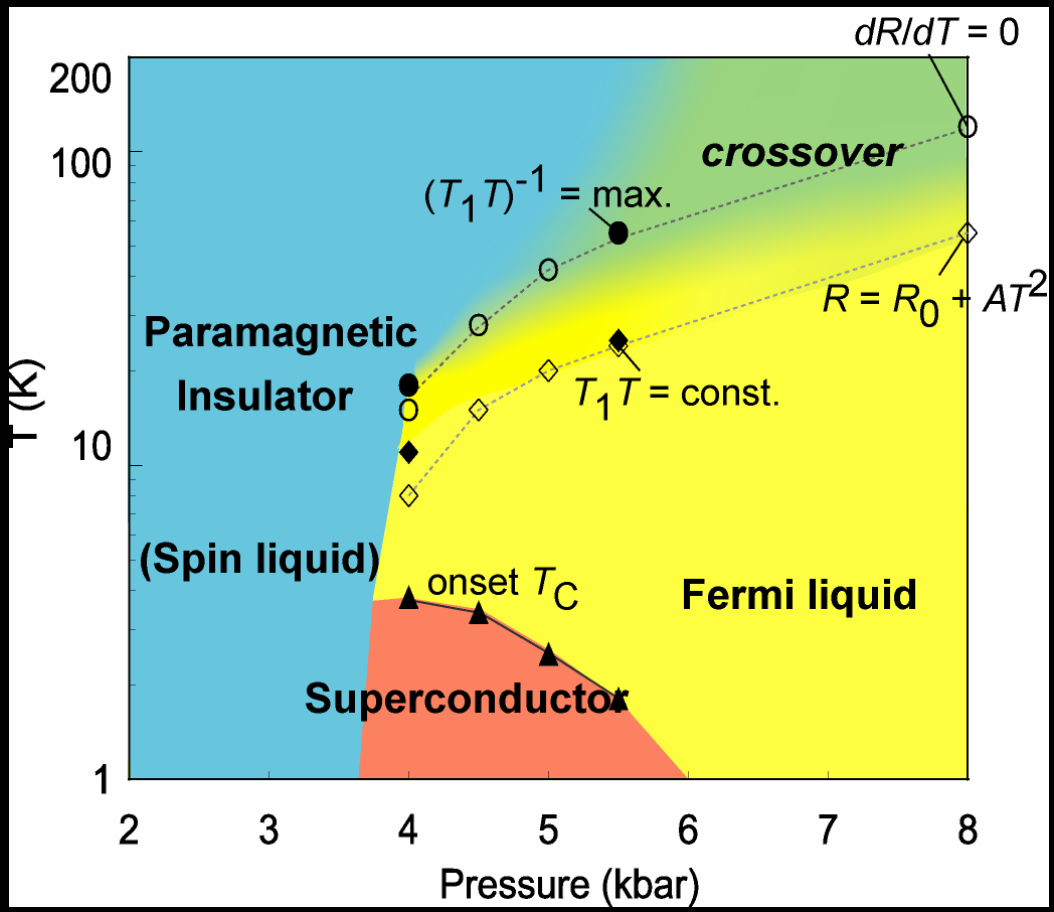


No magnetic ordering under pressure

No change in ^{1}H NMR spectra



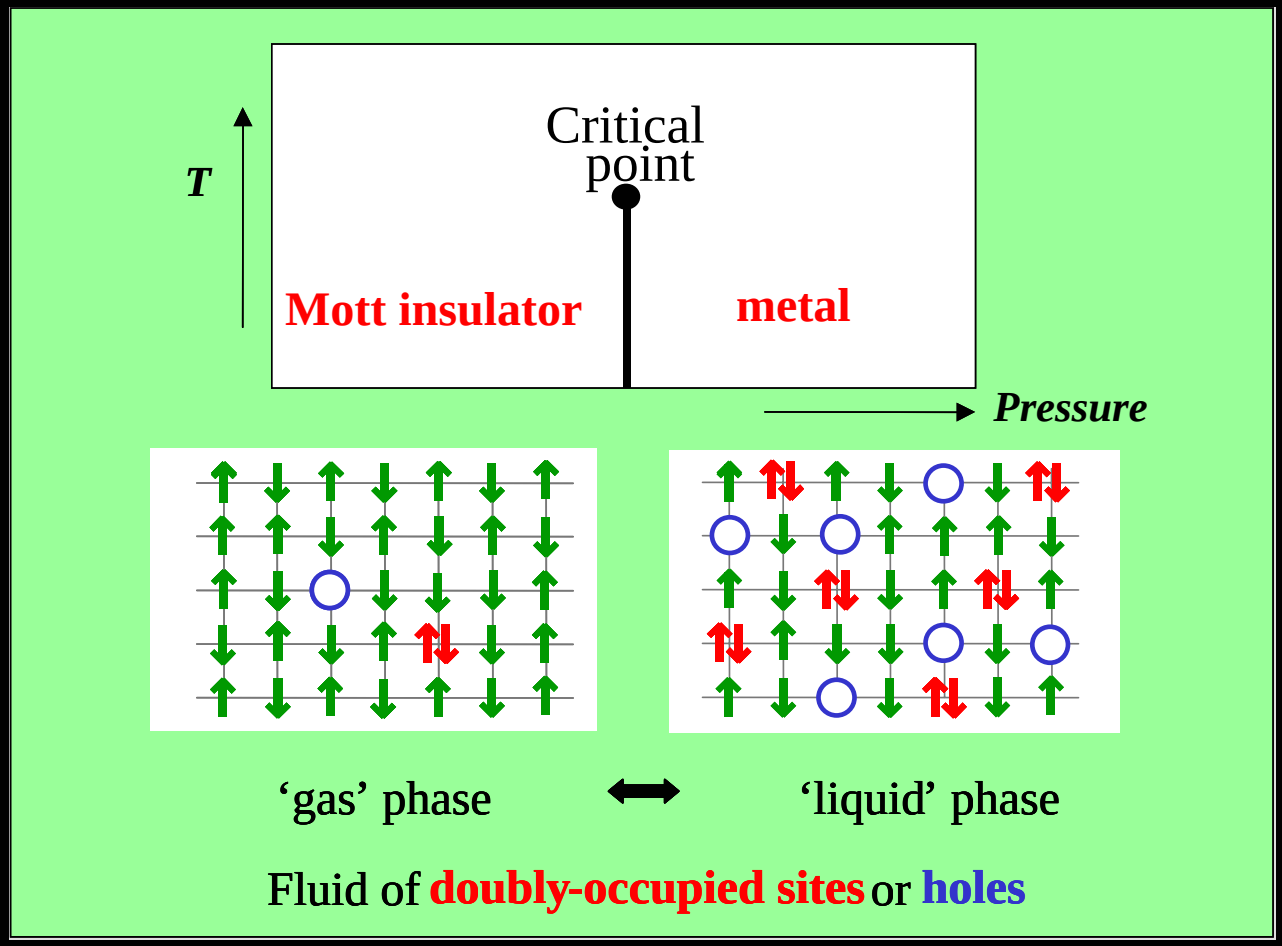
Phase diagram of spin ½ on triangular lattice κ-$(ET)_2Cu_2(CN)_3$



Kurosaki et a., PRL 95 (2005) 177001

Mott transition

Competition between Coulomb energy and kinetic energy

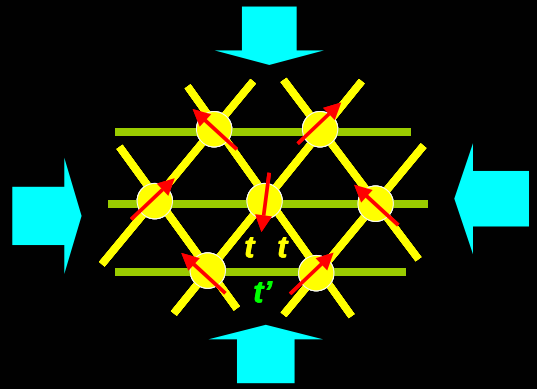


Castellani (1979)

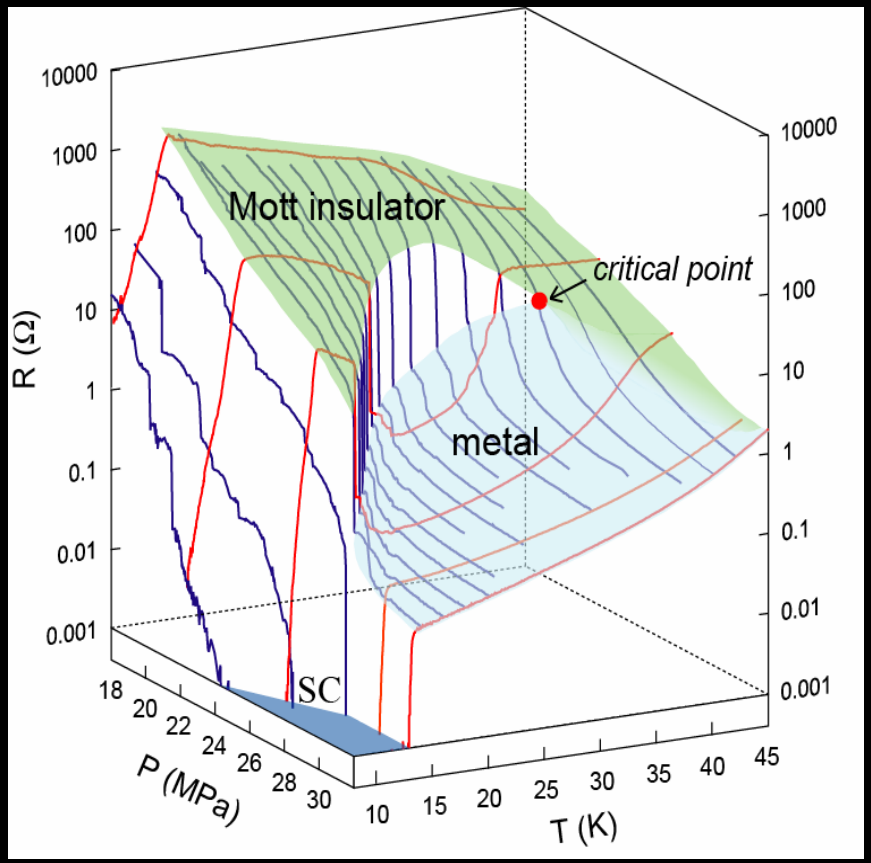
➡ Mott criticality is identical with classical liquid-gas criticality?

Mott transition in by pressure

κ-$(ET)_2Cu[N(CN)_2]Cl$
(t'/t =0.75)

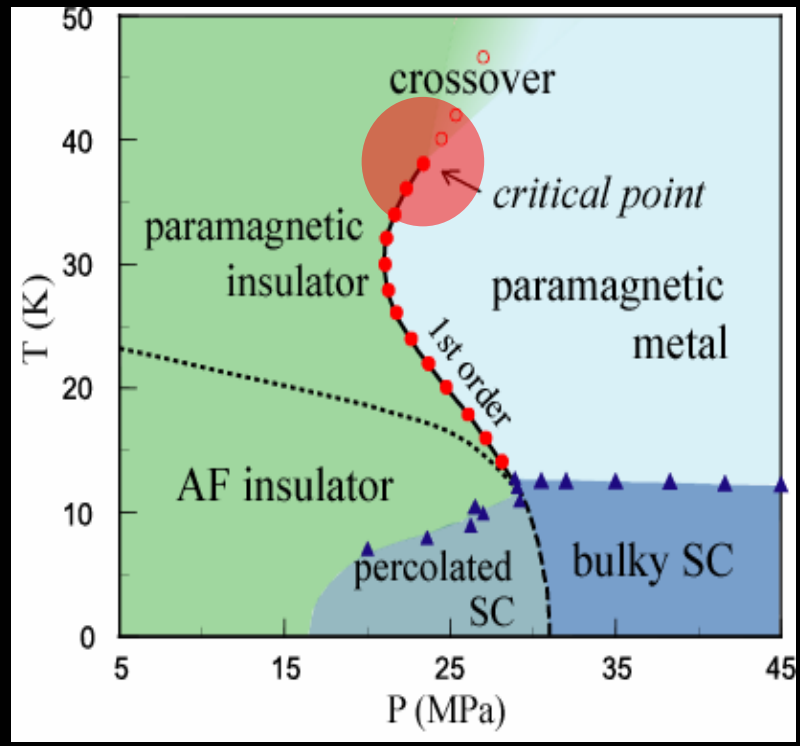


Resistance on (T,P) plane



Kagawa *et al.*, PRB 69 (2004) 064511

Mott phase diagram



Kagawa *et al.*, PRL 93 (2004) 127001

Mott Criticality and Mott scaling

Unconventional critical exponents $(\delta, \beta, \gamma) \sim (2, 1, 1)$

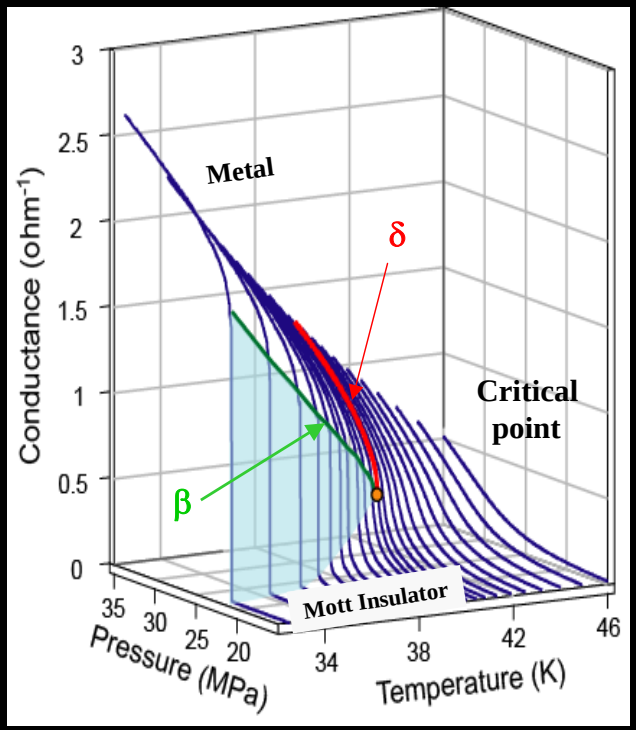
Imada, PRB72 (2005)075113
JPSJ64(1995)2954

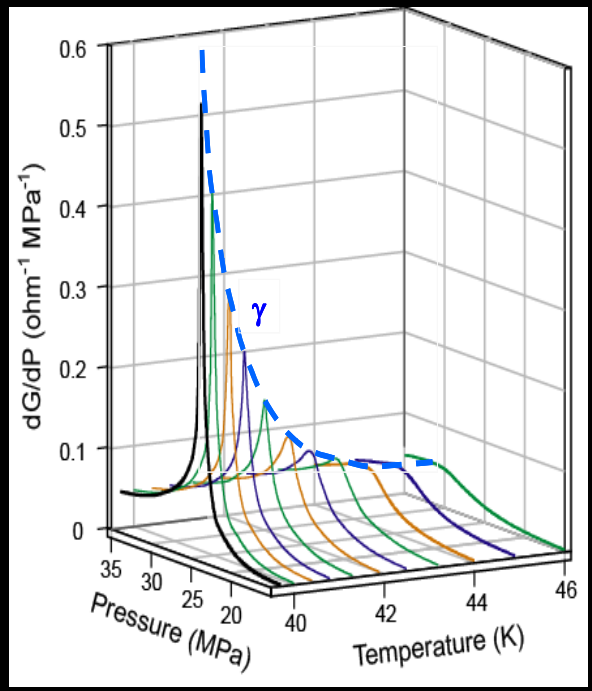
Scaling relation is fulfilled

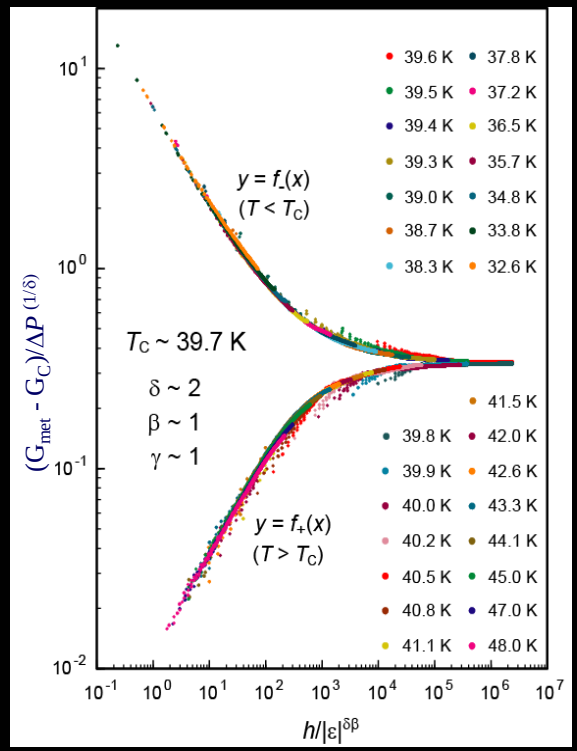
$$\delta = 1 + (\gamma / \beta)$$

Scaling function

$$G_{\mathrm{met}}(P, T) - G_{\mathrm{C}} = (\Delta P)^{1/\delta} f_{\pm}\left(\frac{\Delta P}{|\Delta T|^{\beta\gamma}}\right)$$



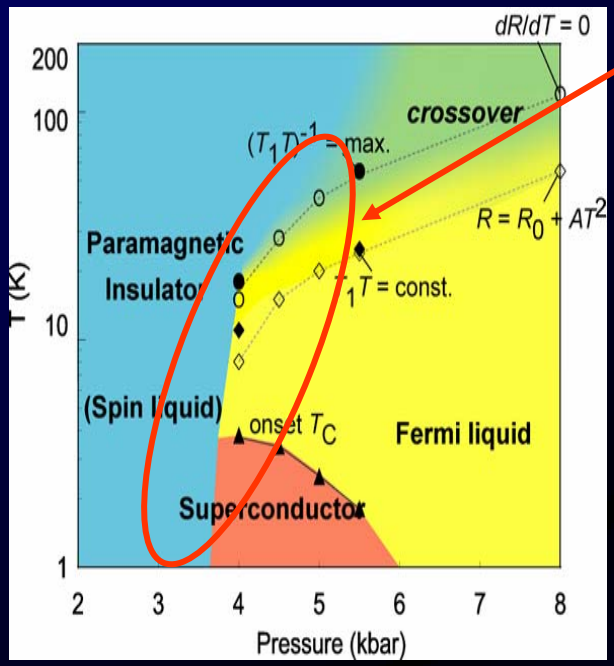




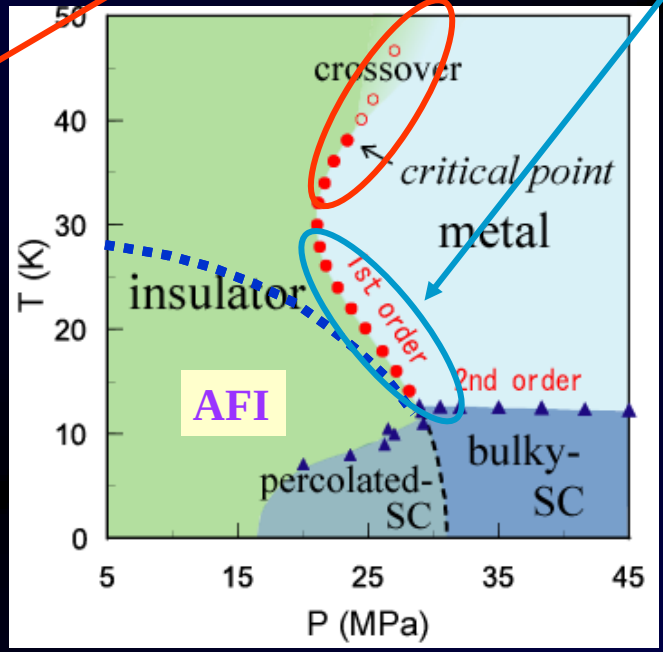
Kagawa *et al.*, Nature 436 (2005) 534

Role of spin degrees of freedom in phase diagram

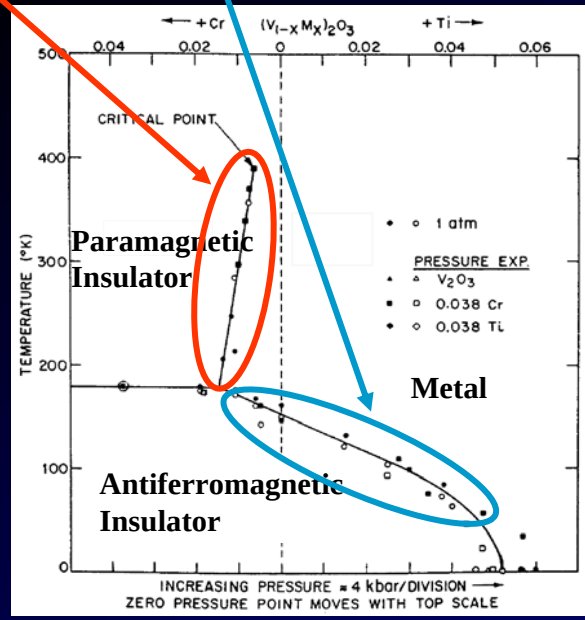
Clausius Clapeyron $dT/dP = \Delta V/\Delta S$ > 0 < 0



Q2D spin liquid
κ-$Cu_2(CN)_3$



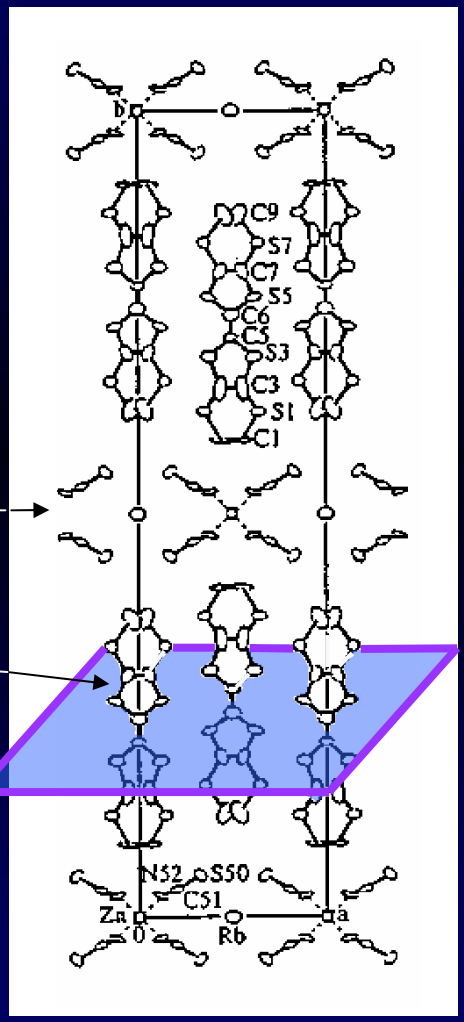
Q2D antiferromagnet
κ-$Cu[N(CN)_2]Cl$



3D antiferromagnet
V_2O_3

Entropy of the spin liquid
is larger than that of Fermi liquid !

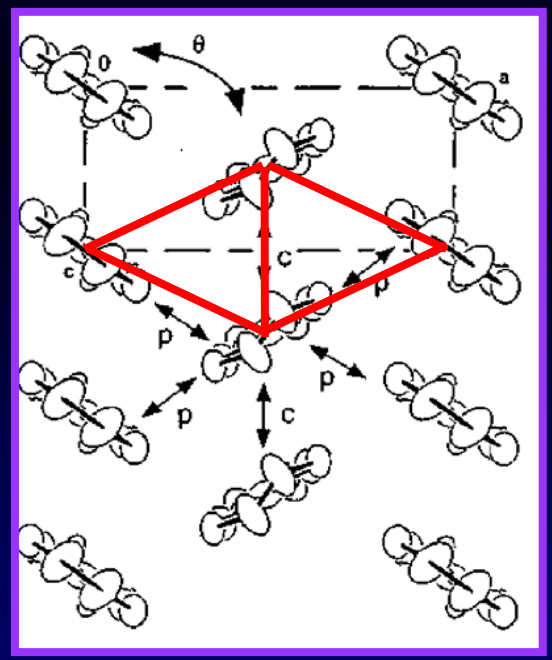
θ–$(ET)_2X$; charge-1/2 on triangular lattice



Q2D conducting ET plane

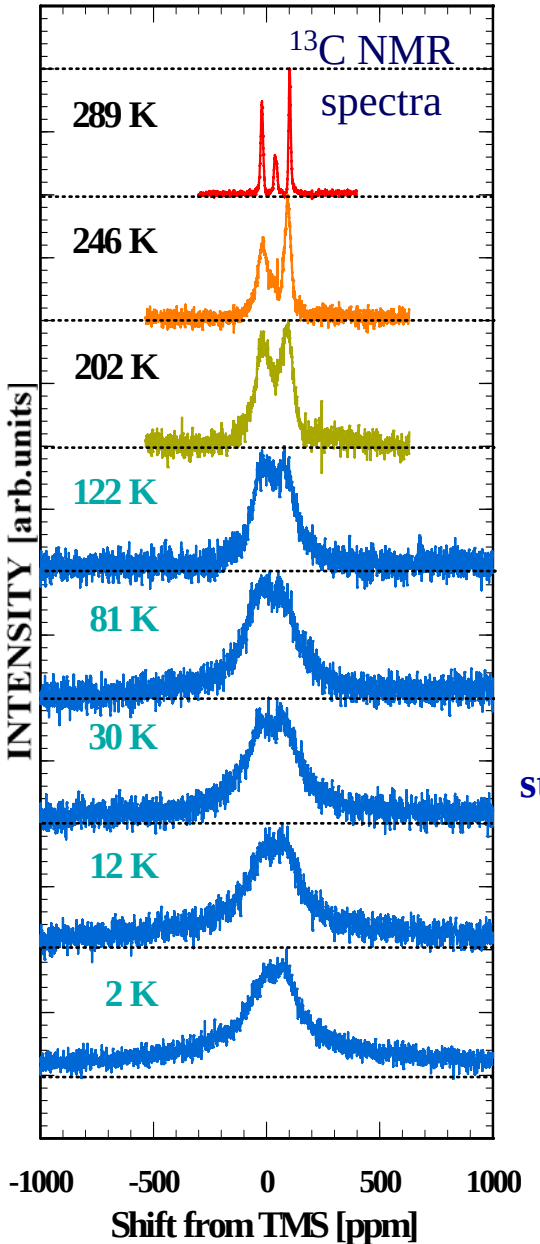
- a quarter-filled hole band
- isosceles triangular lattice ($t_p > t_c$)

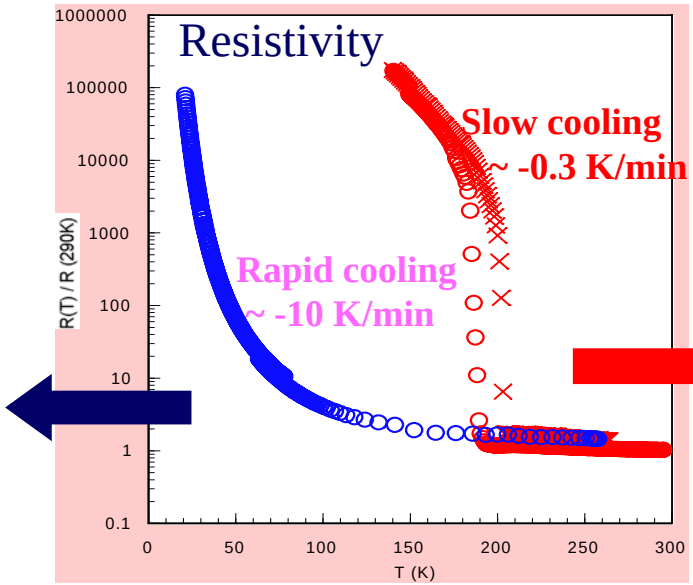
in-plane structure



H. Mori *et.al*
PRB (1998)

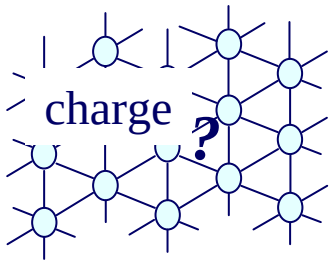
Electron crystalization vs glass in θ-$(ET)_2RbZn(SCN)_4$





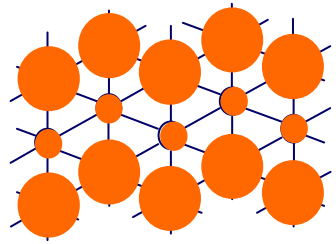
Rapid Cool

Absence of structural transition

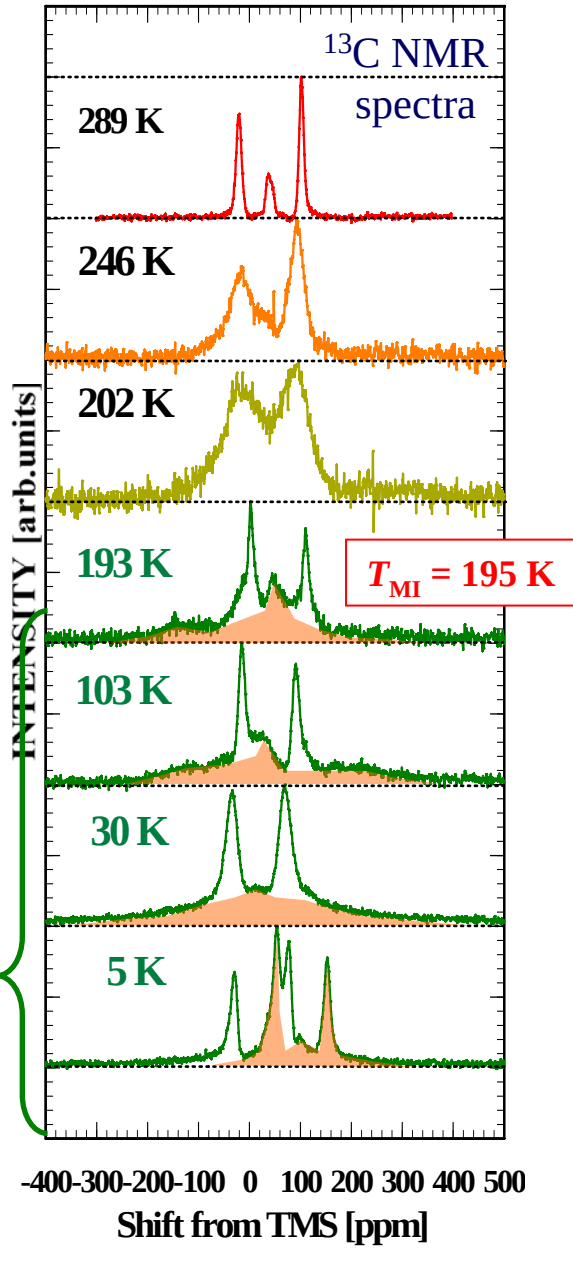


Slow Cool

Structural transition + Charge order



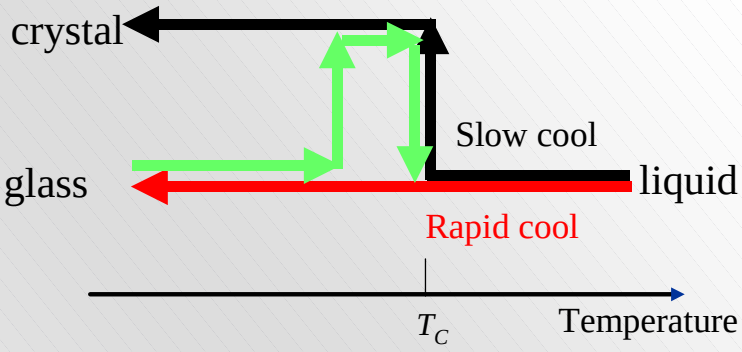
NMR, XRD, Raman, IR, Theoretical

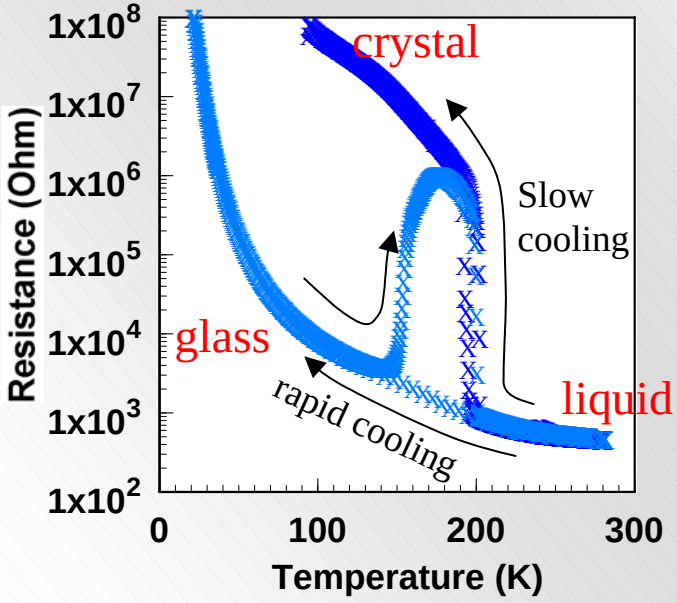


Transport properties of electronic glass

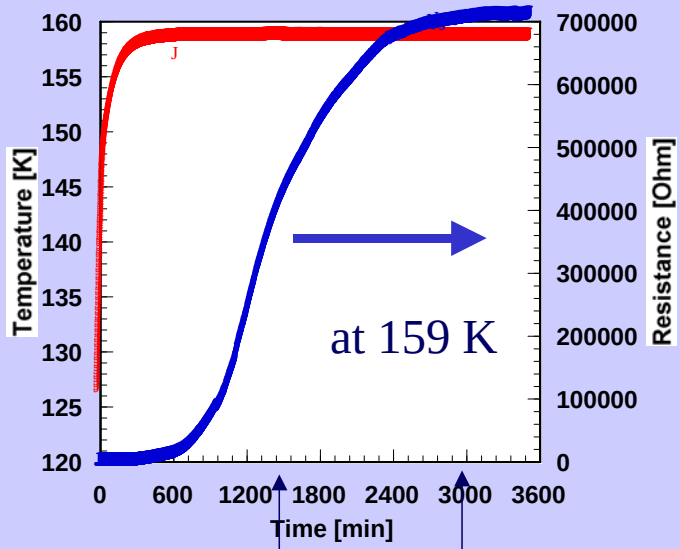
θ-RbZn

Thermal cycle





Relaxation from glass to crystal



Kodama

Spin ½ on triangular lattice

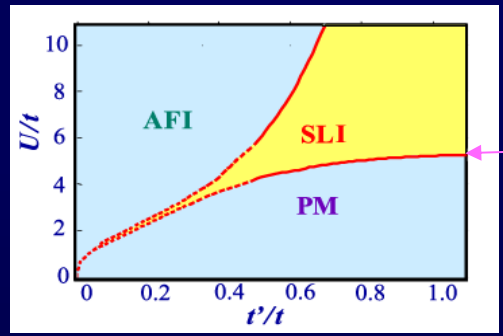
Spin liquid ⟷ Spin order

Theoretical

Imada-Watanabe, Sorella, P.A. Lee
Mismuich et al., Motrunich, M.P.A.Fischer
McKenzie, Schmalian,
Watanabe-Yokoyama-Tanaka, ……

The vicinity of Mott transition is the key.

Imada

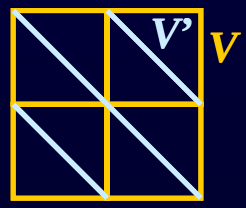


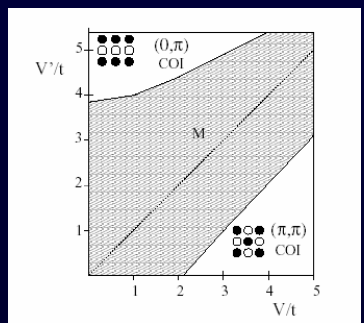
Charge ½ on triangular lattice

Charge glass ⟷ Charge order

el-lattice coupling

Frustration-induced quantum melting



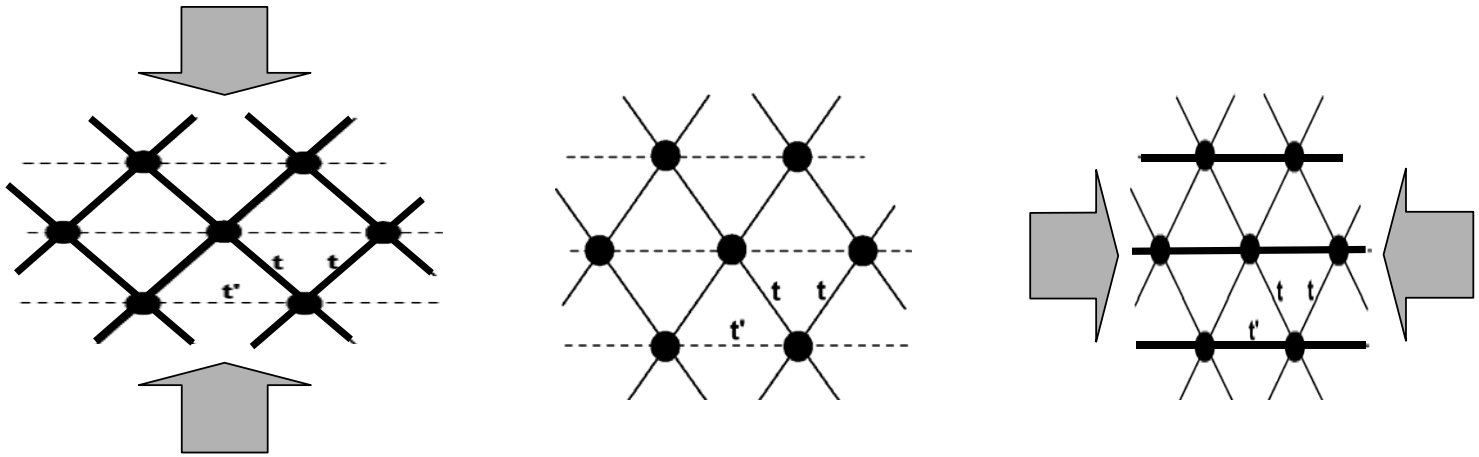


Merino, Seo and Ogata (2004)

In this project,

Anitotropic pressure & doping

2D Square ⟵ 2D triangule ⟶ 1D chains



Spin liq.

Charge liq.

Spin order

superconductivity

Charge order

Spin glass

Charge glass