Spin Liquids in Triangular Lattice Organic Compounds: a Nodal Fractionalized State?

Tarun Grover, Nandini Trivedi, T. Senthil, Patrick Lee

Basics: Phases of Matter

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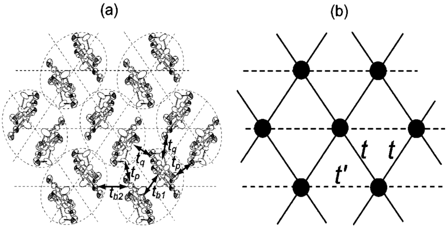

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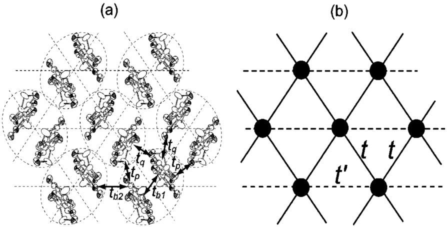

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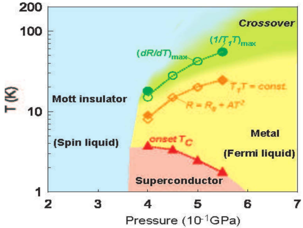

Kurosaki et al
Phys Rev Lett.
(2005)

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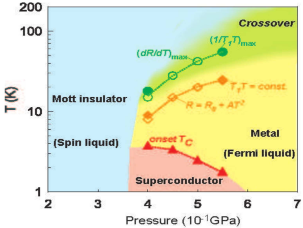

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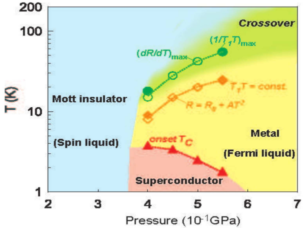

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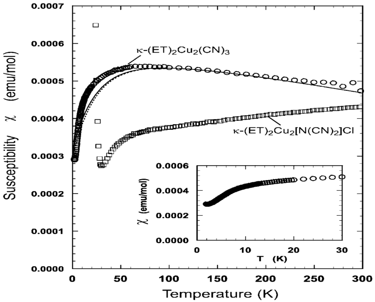

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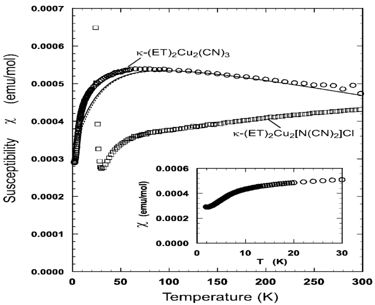

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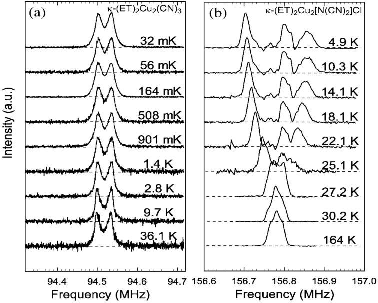
Insulator: NMR spectra



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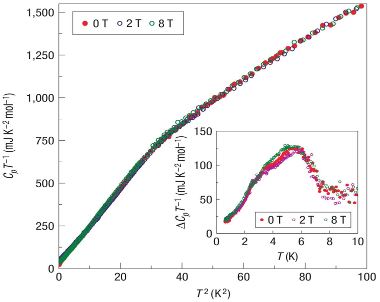
- No appreciable shift ⇒ No local magnetization.

Insulator: Specific Heat



Yamashita et al, Nature Physics, (2008)

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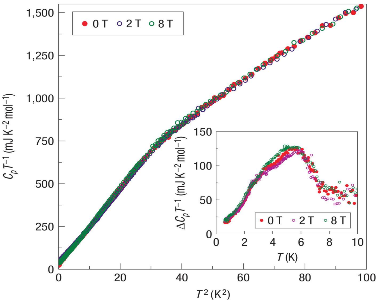

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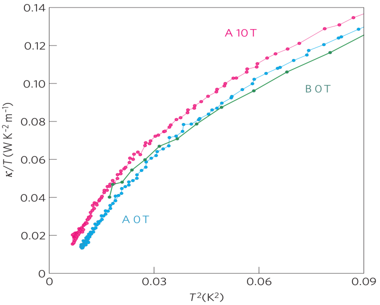

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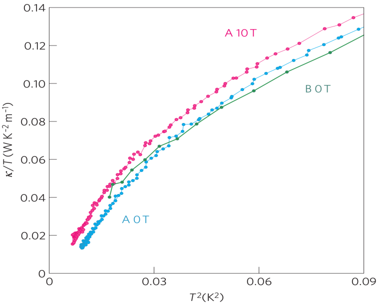

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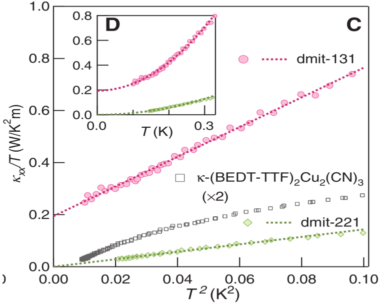
Insulator: Thermal Conductivity for $EtMe_3Sb[Pd(dmit)_2]_2$



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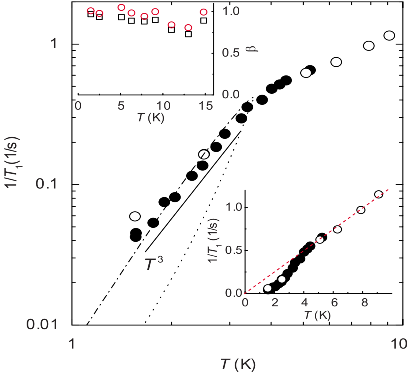
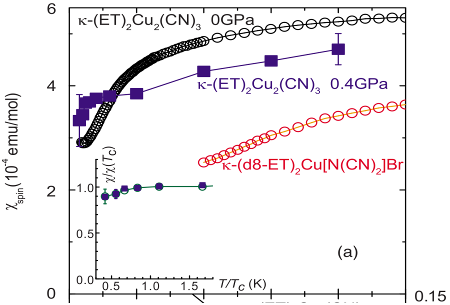
Superconductor: NMR Relaxation



Shimizu et al, PRB (2010).

- $1/T_1 T \to T^2$ for $T \lesssim 3.5$ K.

Superconductor: Suscptibility



Shimizu et al, PRB (2010).

- Almost no change in suscptibility across the Mott transition!

Summary

Insulating Phase

- No magnetic ordering down to 32 mK ($\approx 10^{-4} J$) $\Rightarrow$ Spin-liquid at $T = 0$?
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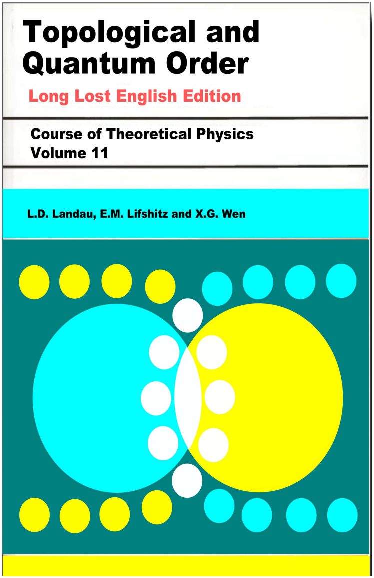
Topological and Quantum Order
Long Lost English Edition
Course of Theoretical Physics
Volume 11
L.D. Landau, E.M. Lifshitz and X.G. Wen

Gapless spin liquids and fractional particles

- κCN as gapless fractionalized Mott insulator.
- Basic idea: electron creation operator $c_\sigma^\dagger = f_\sigma^\dagger b$.
- **Spinon** f_σ carries spin while **chargeon** b carries charge.
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- $\Rightarrow$ Multiple exchange spin-model.

$$H = 2J_2 \sum_{<rr'>} \vec{S}_r . \vec{S}_{r'} + J_4 \sum_{\square} (P_{1234} + h.c) + \ldots \quad (1)$$

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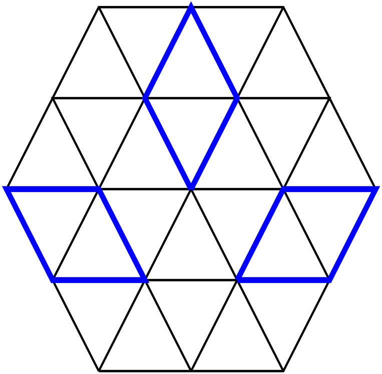
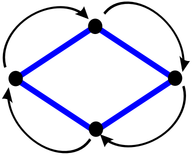
Ring Exchange





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- Insulator → Project out the charges.

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Effective theory of $|PFL\rangle$

- Spinons coupled to $U(1)$ gauge field.

$$S = \sum_{<ij>} \left(f_i^\dagger f_j e^{i a_{ij}} + h.c. \right) + (\nabla \times a)^2 \quad (4)$$

- Renormalized propagator $D(\omega, \vec{k})$ for photon:

$$D(\omega, \vec{k}) = \omega^2 + k^2 + \frac{|\omega|}{k} \quad (5)$$

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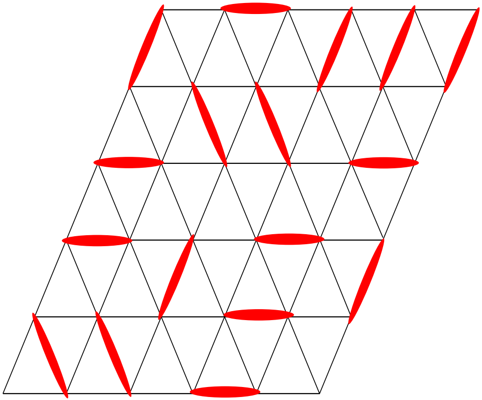

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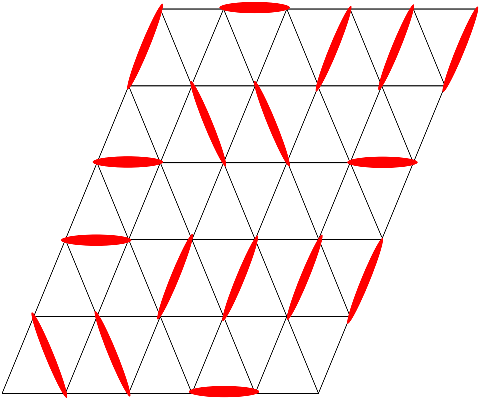

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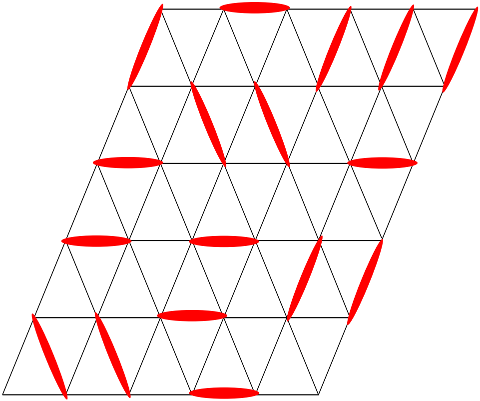

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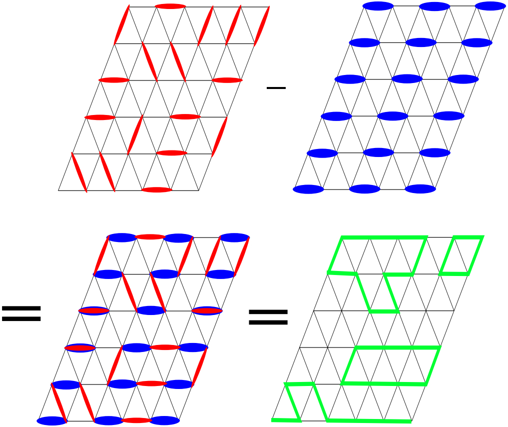

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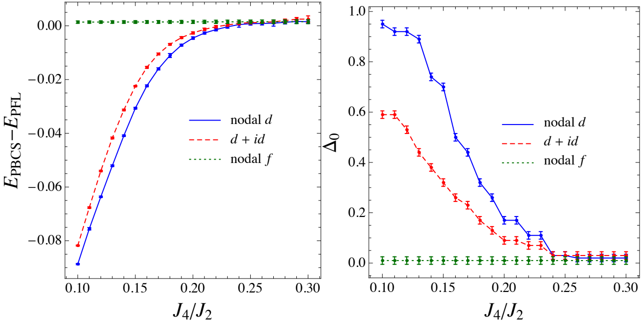
Variational 'Answer' for Isotropic Triangular

Projected nodal $d_{x^2-y^2}$ has the lowest energy!



Why projected nodal *d*-wave is the best state?

- Ring-exchange (J_4) tends to delocalize the spinons.
- Heisenberg (J_2) drives BCS instability.
- For $J_4/J_2 \gg 1$, mean-field gives projected Fermi liquid. (Motrunich 2005)
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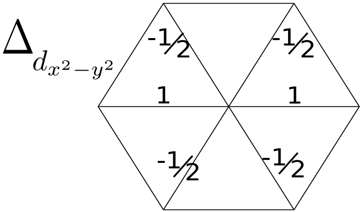
Basic Properties of the $d_{x^2-y^2}$ spin-liquid



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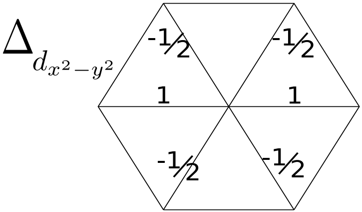
$$S = \sum_{<ij>} \sigma_{ij} \left(f_i^\dagger f_j + \Delta_{ij} f_i f_j + h.c. \right) + \prod_{\square} \sigma_{ij}\sigma_{jk}\sigma_{kl}\sigma_{li} \qquad (8)$$

- Spinons gapless at nodes.
- Breaks lattice orientational symmetry ⇒ 'Nematic spin-liquid'.

Basic Properties of the $d_{x^2-y^2}$ spin-liquid



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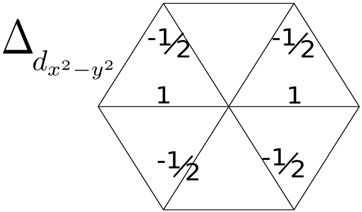

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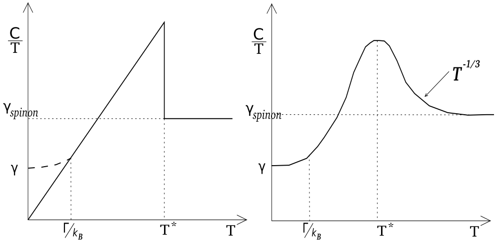
Nematic Spin Liquid: Specific heat and Spin Susceptibility



- No impurities $\Rightarrow C(T) \sim T^2$ at low T.
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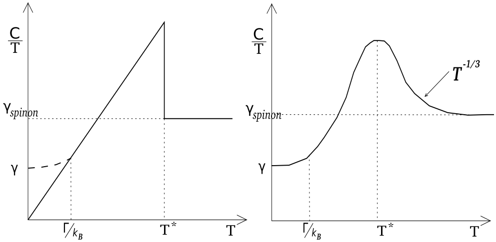

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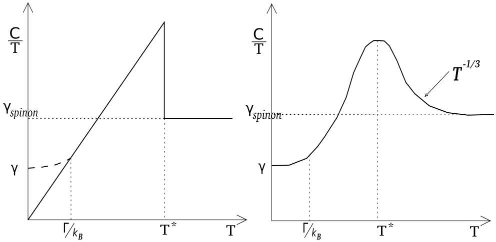

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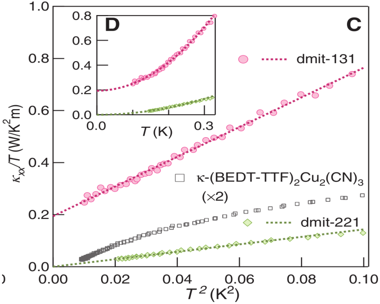
Nematic Spin Liquid: Thermal Conductivity

- Universal thermal conductivity $\kappa \sim T$



Yamashita et al, Science 2010.

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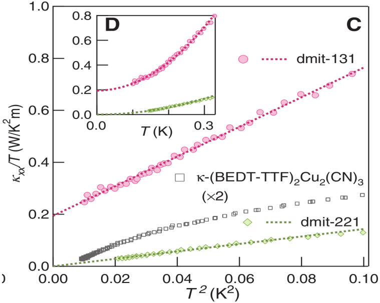

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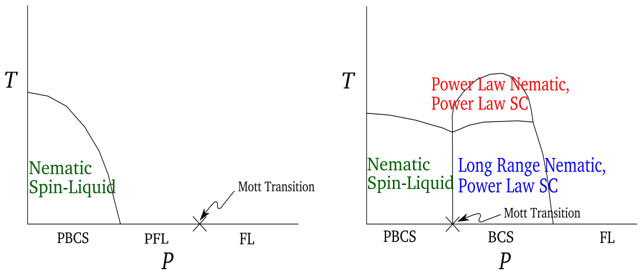
Pressure-Temperature Phase Diagram



(a) Mott Transition After Pair-Breaking (b) Mott Transition Before Pair-Breaking

- Case *a* and *b* relevant for two different materials.
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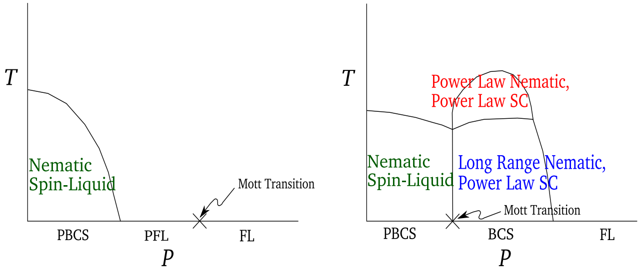

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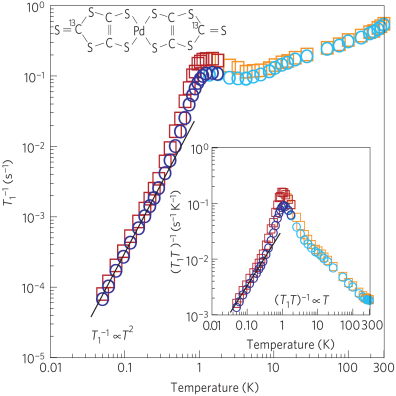
Phase transition/cross-over in dmit-331?



T. Itou et al, Nature Physics 6, 2010.

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Questions:

- Experimental detection of the Z_2 topological order and/or spinon Fermi surface?
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Acknowledgements

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THANK YOU!