Disordered 1D quantum systems

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FNSNF

FONDS NATIONAL SUISSE
SCHWEIZERISCHER NATIONALFONDS
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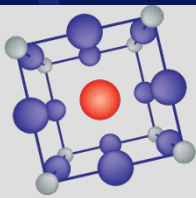
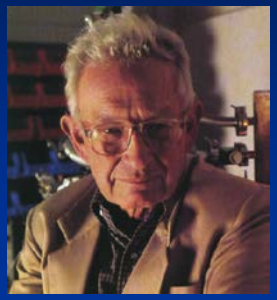


MaNEP
SWITZERLAND

Theory:

H. J. Schulz*
J. Vidal (Jussieu)
D. Mouhanna (Jussieu)
G. Roux (Aachen)
T. Barthel (LPTMS)
I. P. McCulloch (Aachen)
C. Kollath (Polytechnique)
U. Schollwoeck (Aachen)
G. Orso (Orsay)
A. Iucci (La Plata)
M. Cazalilla (DIPC)
Z. Ristivojevic (ENS, Paris)
A. Petkovic (ENS, Paris)
P. Le Doussal (ENS, Paris)
S. Furuya (Geneva)

Anderson Localization



PHYSICAL REVIEW VOLUME 109, NUMBER 5 MARCH 1, 1958

Absence of Diffusion in Certain Random Lattices

P. W. ANDERSON
Bell Telephone Laboratories, Murray Hill, New Jersey

(Received October 10, 1957)

Light, sound, electrons, etc……. waves

www.andersonlocalization.com

What about interactions :

- U>0 Landau Fermi liquid $m \rightarrow m^*$

Non interacting problem?

Disorder and Interactions

- Fermions: reinforcement of interactions by disorder

  perturbative: Altshuler-Aronov-Lee (80)

  RG: Finkelstein (84); TG+Schulz (88)

Localization ? Phases (electron glass) ? Transport ? …..

Disorder and Interactions

- Fermions: reinforcement of interactions by disorder
  perturbative: Altshuler-Aronov-Lee (80)
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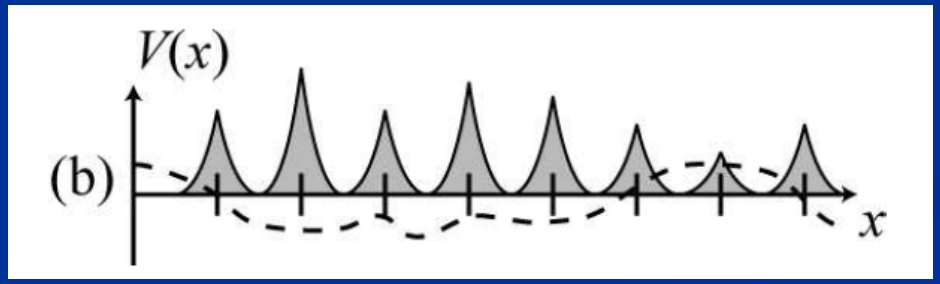
Localization ? Phases (electron glass) ? Transport ? …..

- Bosons: competition between superfluidity/localization

Free Bosons: pathological



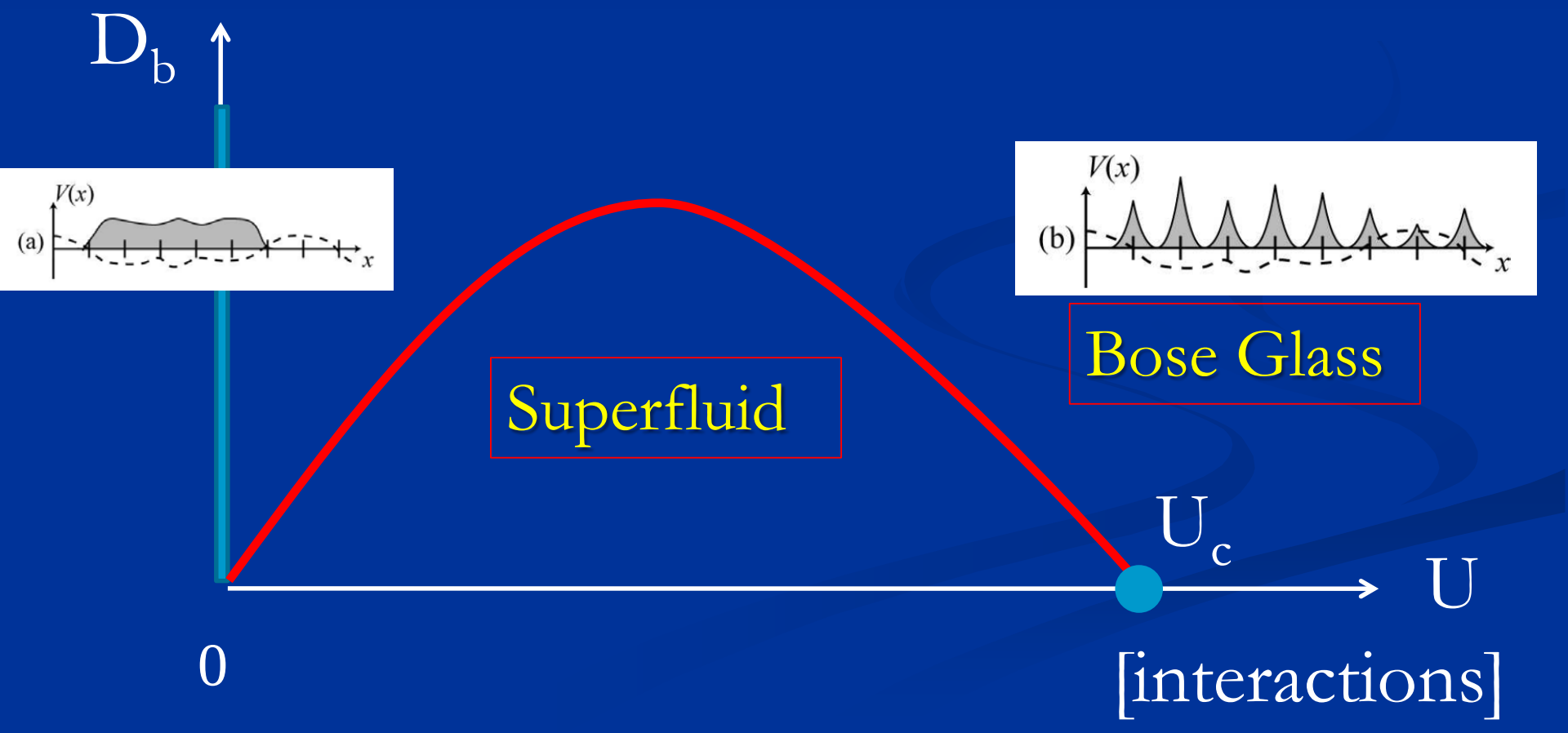
$$H = \frac{1}{2m}\left(\frac{1}{L}\right)^2 - V_0$$

Interactions needed from the start

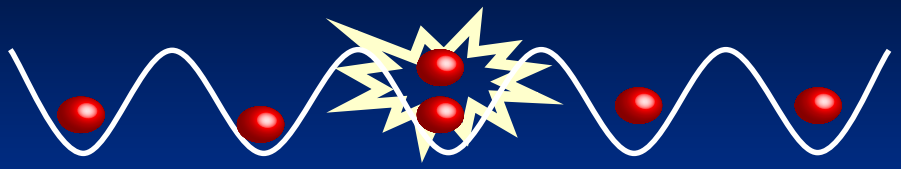
Bose glass phase

TG + H. J. Schulz EPL 3 1287 (87); PRB 37 325 (1988);

M.P.A. Fisher et al. PRB 40 546 (1989)

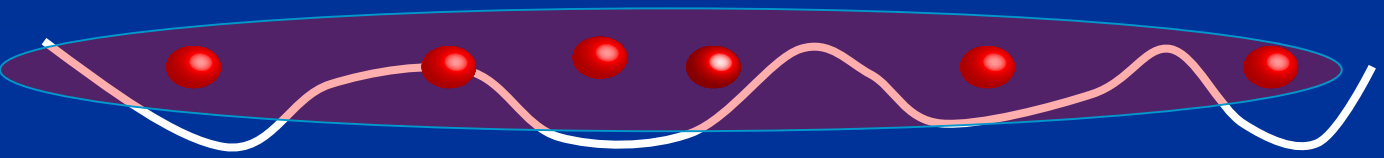


Various phases on a lattice



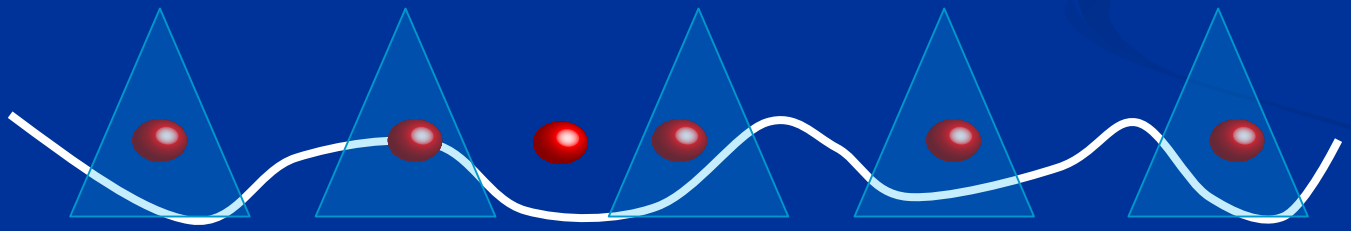
$$\frac{dN}{d\mu} = 0$$

- Mott insulator: incompressible; $\langle \psi \rangle = 0$



$$\frac{dN}{d\mu} \neq 0$$

- Superfluid: compressible; $\langle \psi \rangle \neq 0$

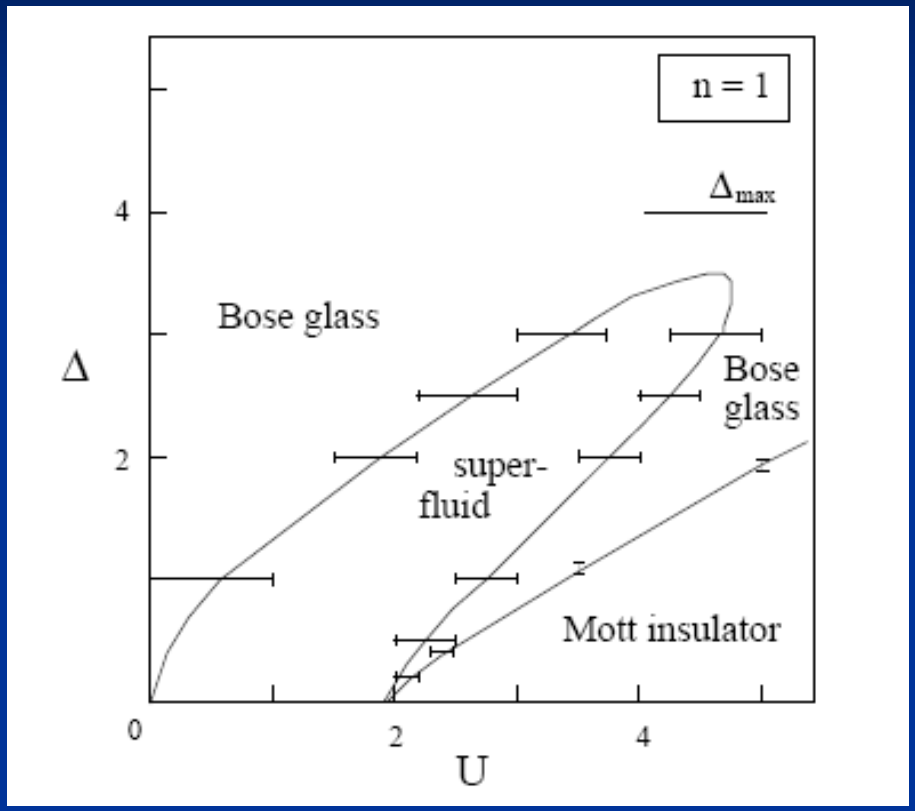


$$\frac{dN}{d\mu} \neq 0$$

- Bose Glass : compressible; $\langle \psi \rangle = 0$

TG, P. le Doussal PRB 53 15206 (96); T. Nattermann et al. PRL 91 056603 (03); E. Altman et al PRB 81 174528 (10),…….

Numerics (disorder)



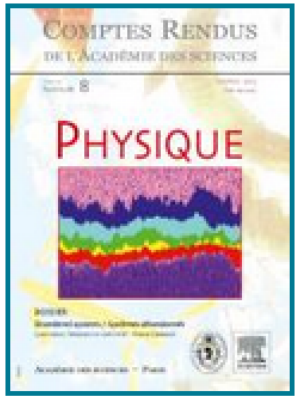
S. Rapsch, U. Schollwoeck, W. Zwerger EPL 46 559 (1999);

G. Batrouni et al. PRL 65 1765 (90);
N. V. Prokof'ev and B. V. Svistunov, PRL 80 4355 (96);
N. Prokofev et al. PRL 92 015703 (04);
O. Nohadani et al. PRL 95, 227201 (05)
K. G. Balabanyan et al. PRL 95, 055701 (05);
L. Pollet et al. PRL 103, 140402 (2009)
…..

Theoretical questions

- Universal exponent at the transition ?

Comptes Rendus AS



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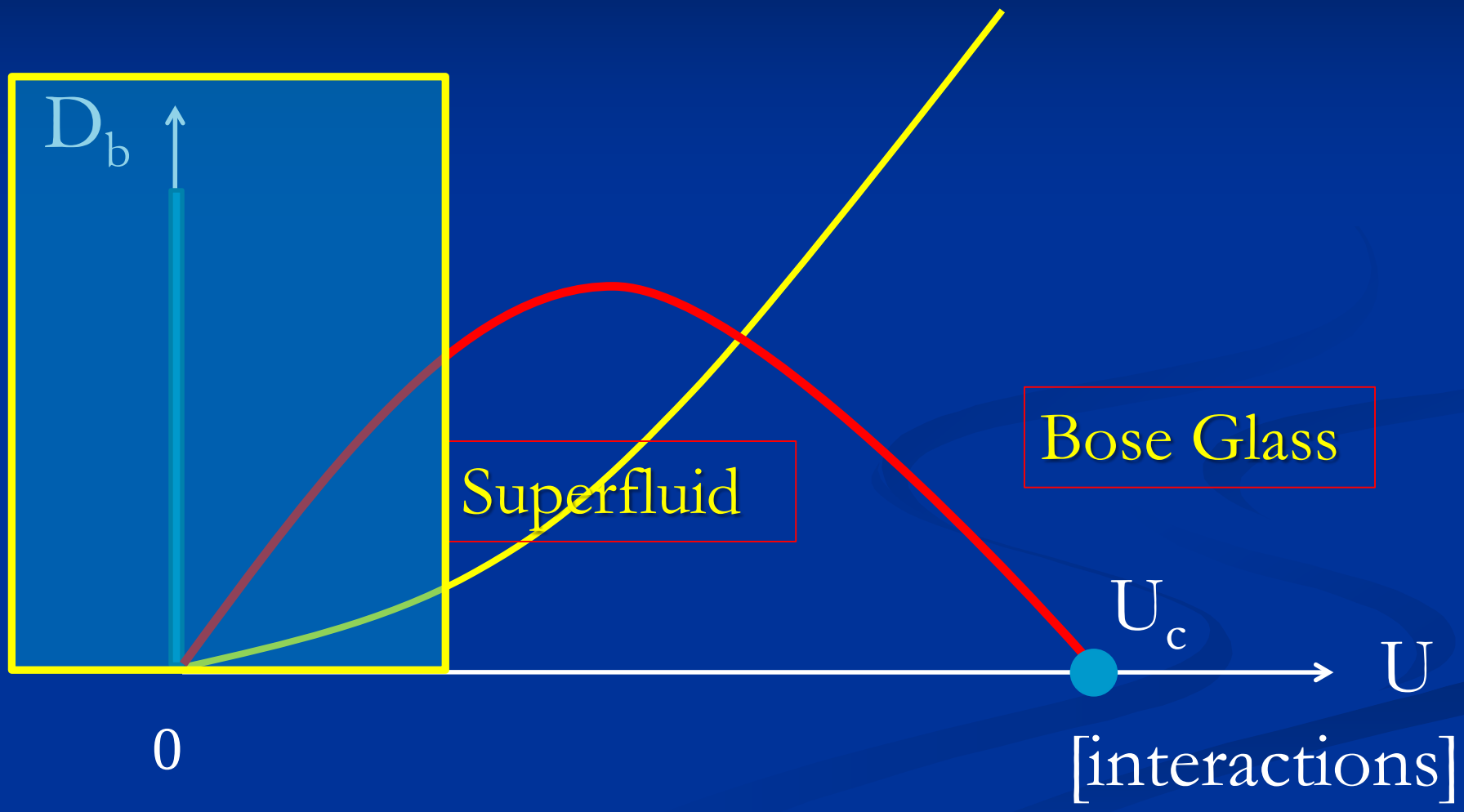
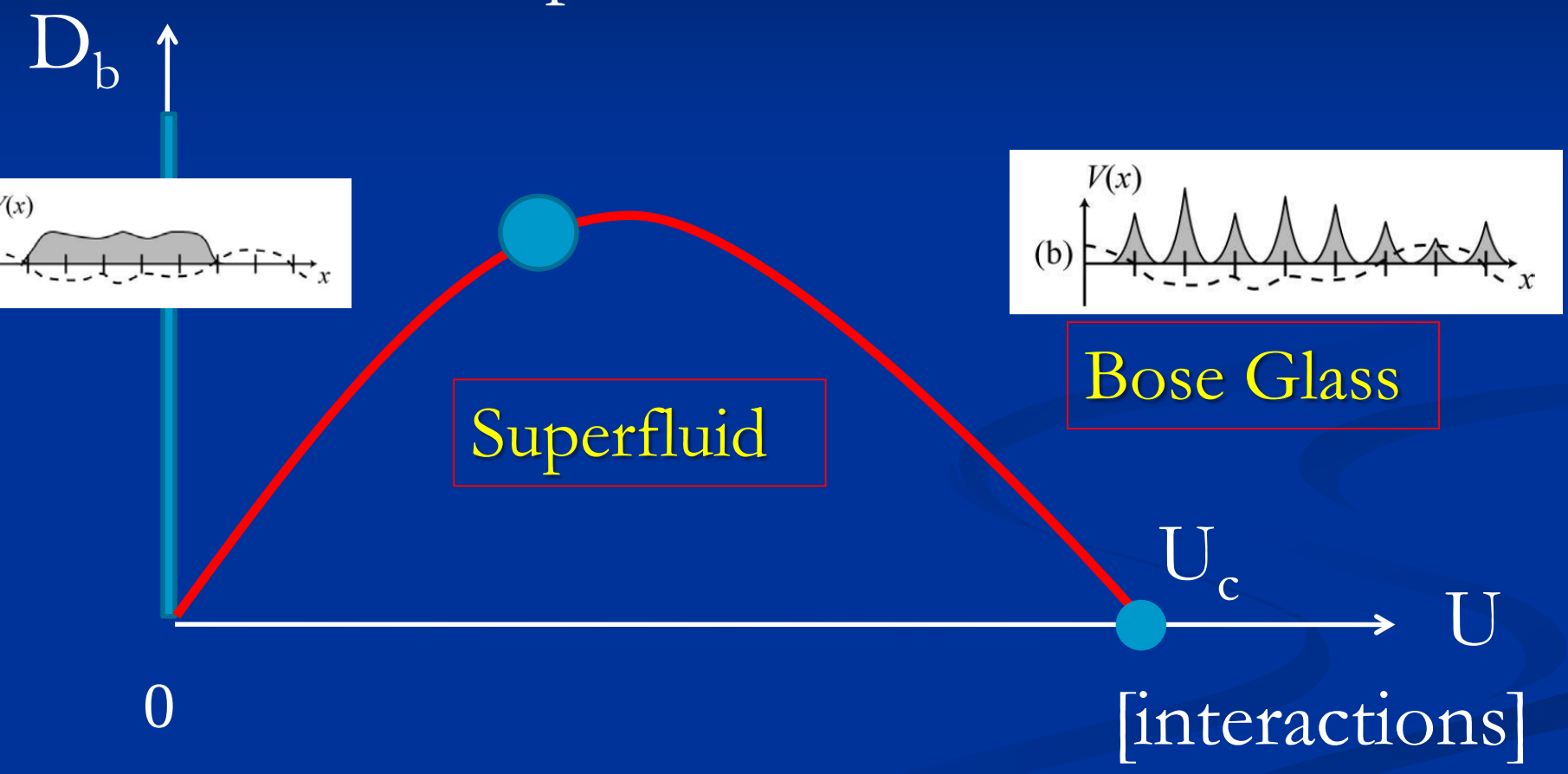
Académie des sciences
Disordered systems / Systèmes désordonnés

Strong disorder, weak interactions



Phase diagram

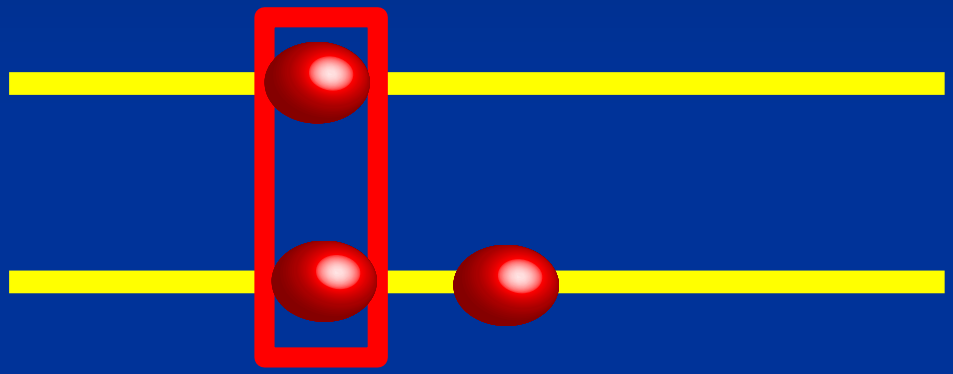
Critical point ?



Many other questions: ``glass properties"

Disordered «ladder»

Z. Ristivojevic, A. Petkovic, P. Le Doussal, TG, PRB 90 125144 (2014)



Two fields («up», «down») : larger density fluctuations

Same disorder on the two legs

Theoretical questions

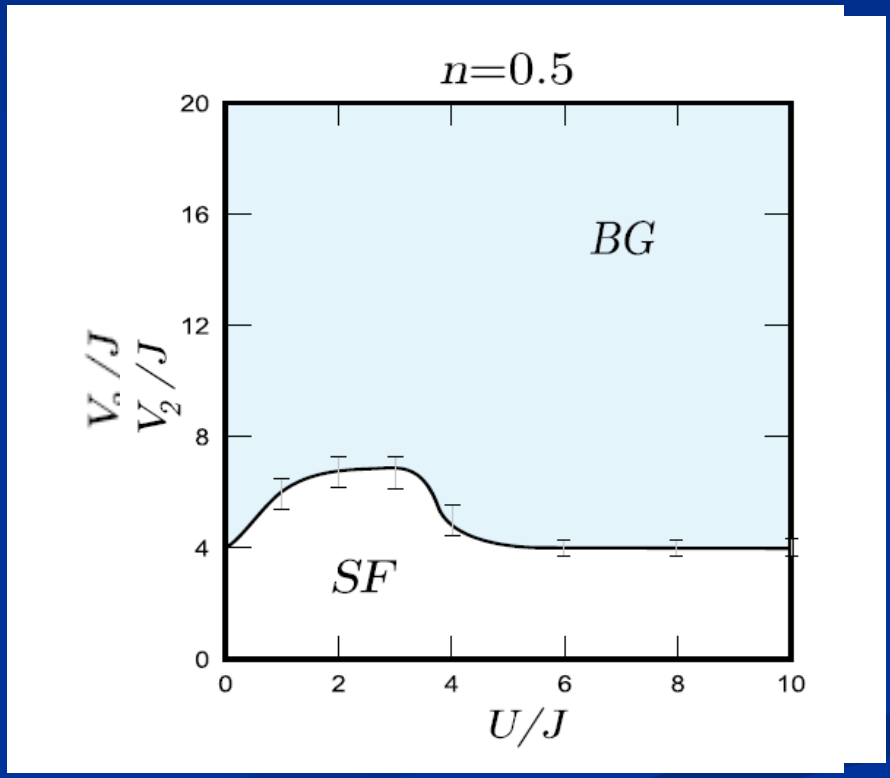
- Universal exponent at the transition ?
- Other forms of ``disorder''

Other potentials: Biperiodics

$$V(x) = V_0 \cos(Q_0 x) + V_1 \cos(Q_1 x)$$

- U= 0
  Aubry-André model
- Localization transition

Effect of interactions?
Same as ``true'' disorder ?



J. Vidal, D. Mouhanna, TG PRL 83 3908 (1999); PRB 65 014201 (2001)

G. Roux et al. PRA 78 023628 (2008); T. Roscilde, Phys. Rev. A 77, 063605 2008; X. Deng et al PRA 78, 013625 (2008);

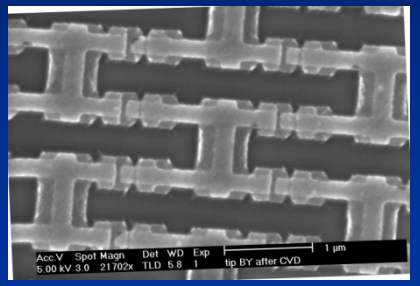
Theoretical questions

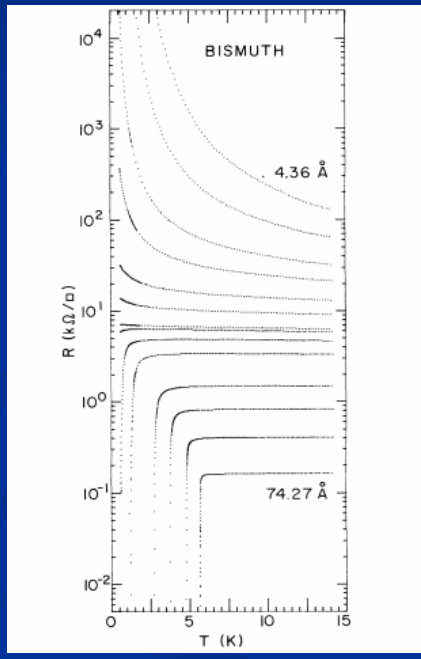
- Universal exponent at the transition ?
- Other forms of ``disorder''
- Connection between LIP and MBL

Hunt for the Bose glass

First generation of experiments

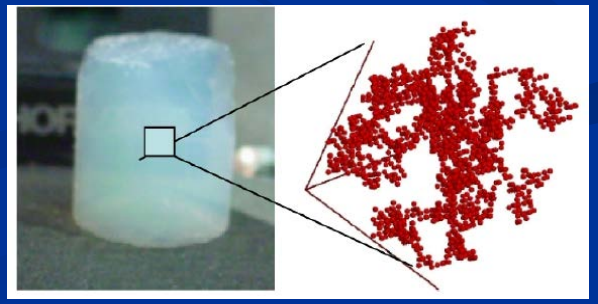
Josephson junction arrays





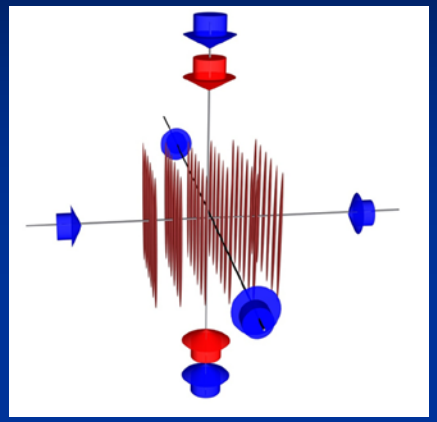
Disordered superconducting films
(D.B. Haviland et al, PRL 62 2180 (89))

Helium in porous media

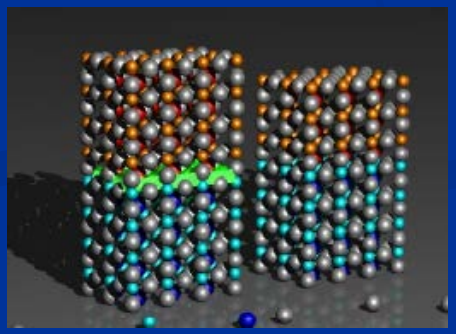


New remarkable systems

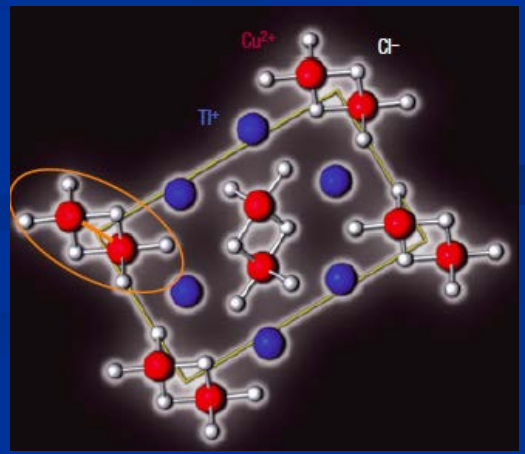
Cold atoms



New superconducting films



Spin dimers



S. Ward et al
J. Phys.: Condens. Matter 25 014004 (2013)

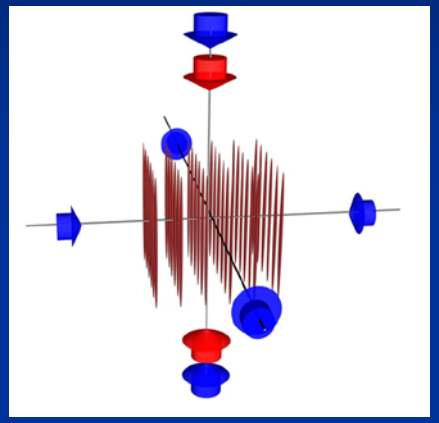
Cold atoms: Control of Interactions and Disorder (quasi-periodic)

Chiara D Errico et al. PRL 113 095301 (2014)

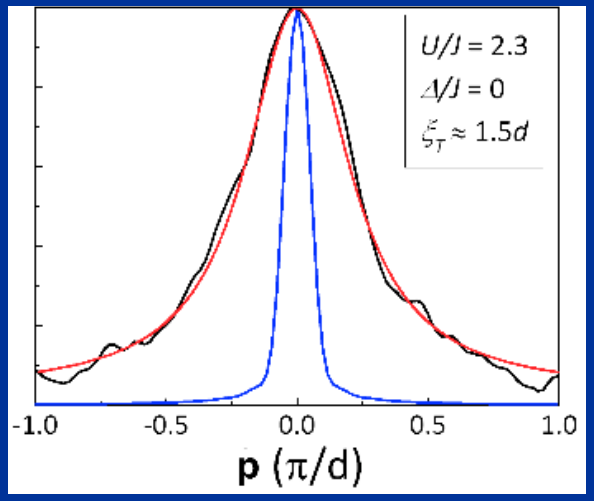
Theory: G. Roux (LPTMS, France)
I. McCulloch (Queensland U)


Exp. : Florence group
(C. D Errico, E. Lucioni, L. Tanzi, L. Gori, M. Inguscio, G. Modugno)

Bosons in bichromatic lattice

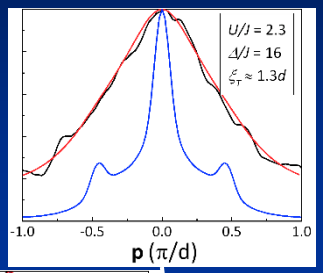


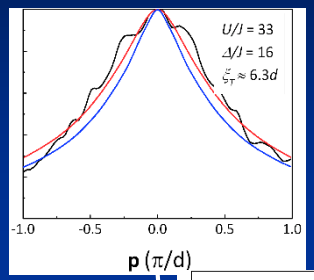
39K atoms
Bichromatic r = 1.243
J = 110 Hz
U can be varied at will

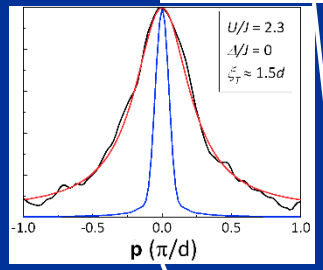


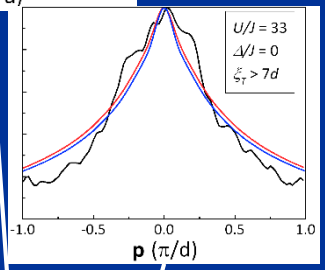
Measure of n(k) (TOF)
Comparison with LL and DMRG calculations

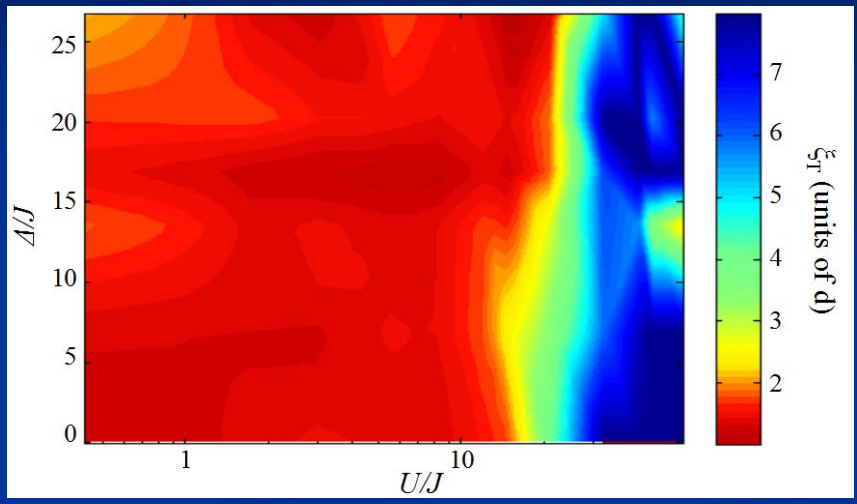
Fitted thermal length

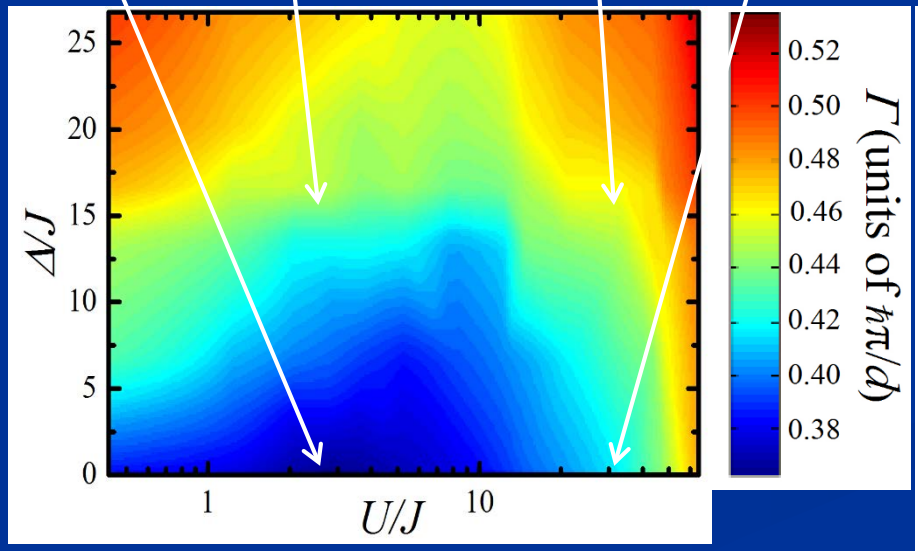


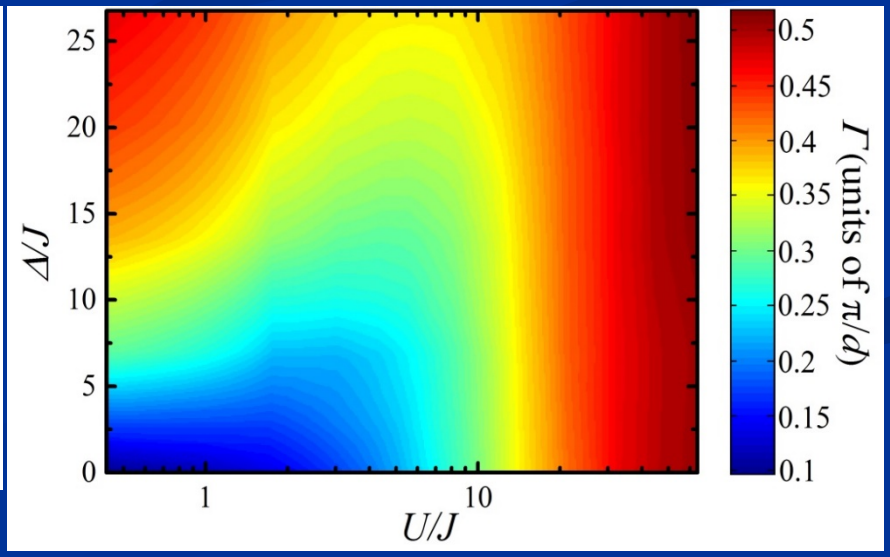




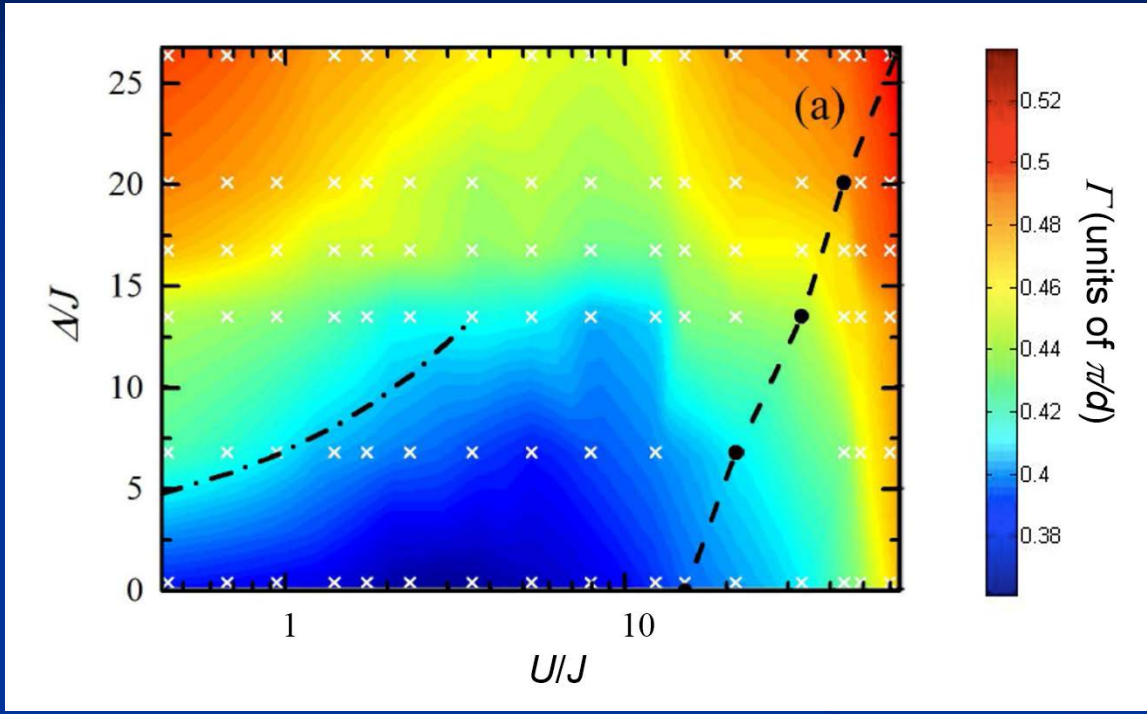


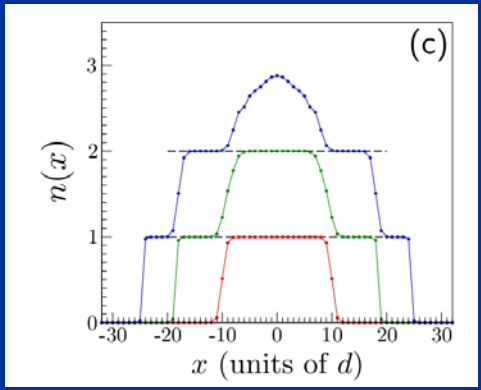






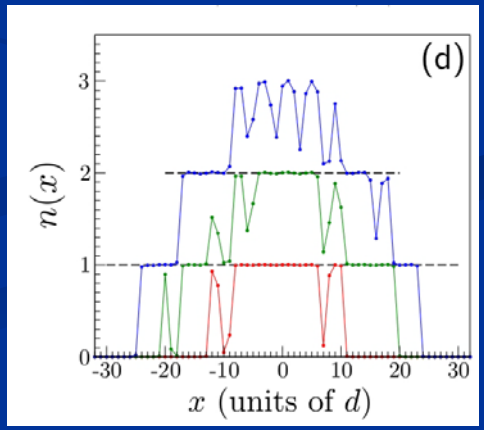
Loss of coherence



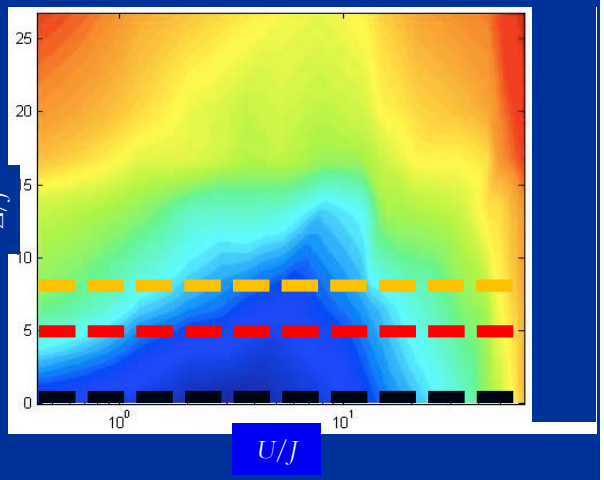


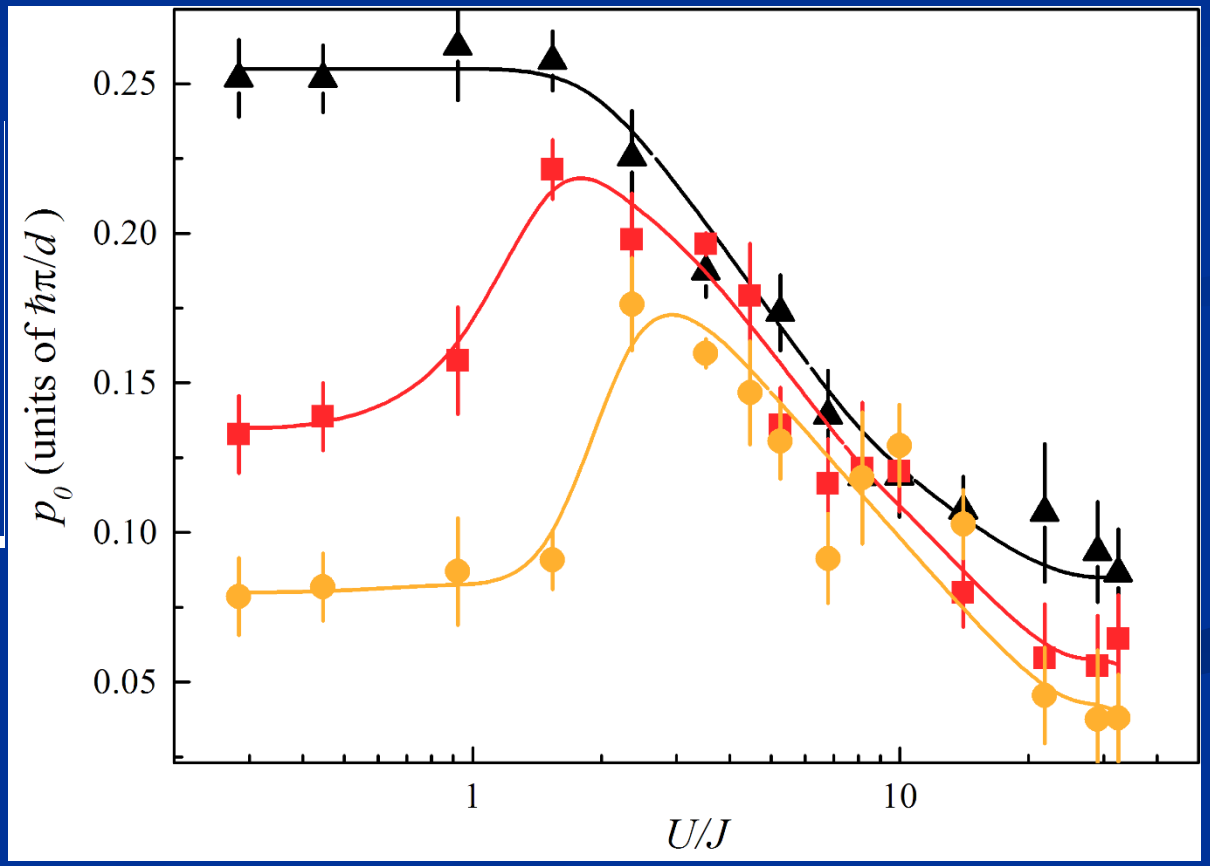
$\Delta = 0$

$\Delta = 6.5$ J



Insulating phase(s)

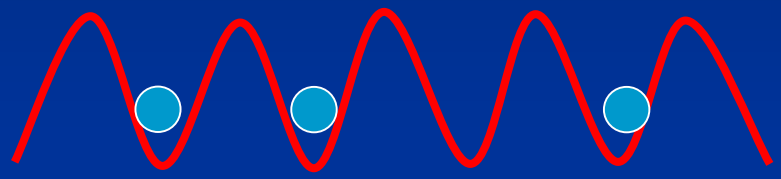




Incoherent regimes are also insulating

Shaking of the lattice

G. Orso, A. Iucci, M. Cazalilla, TG PRA 80 033625 (2009)



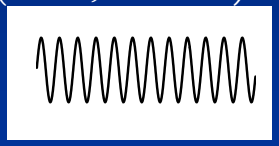
- Modulate amplitude of optical lattice at frequency ω
- Mesure the absorbed energy

$$\frac{dE}{dt} \propto \langle [H_K(t), H_K(0)] \rangle$$

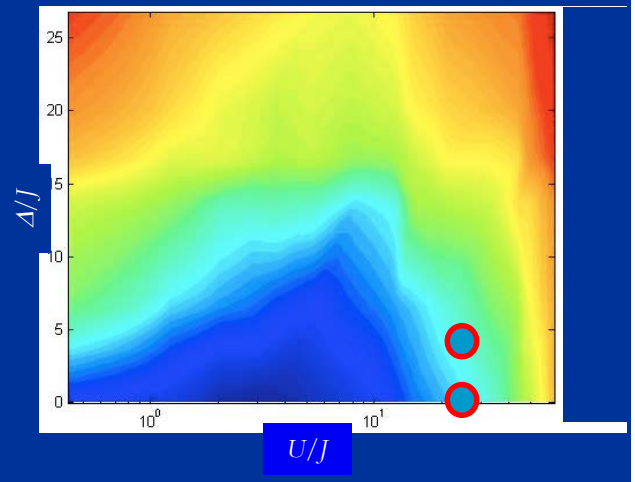
Experiment

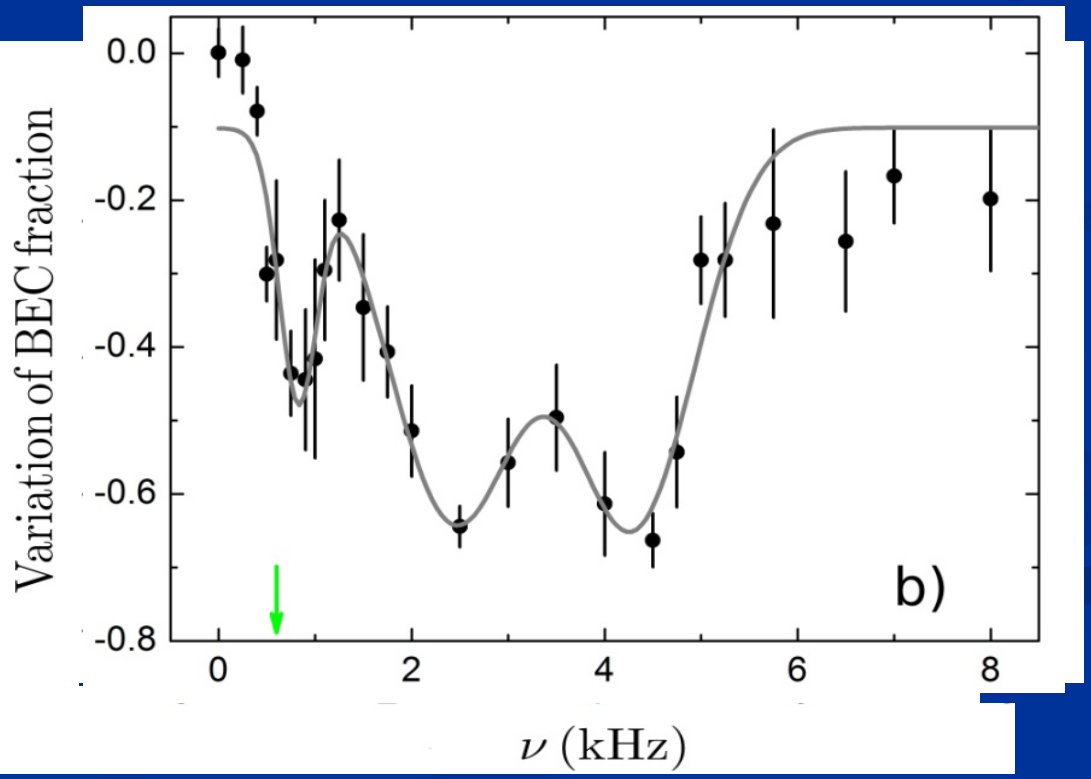
prepare in equilibrium

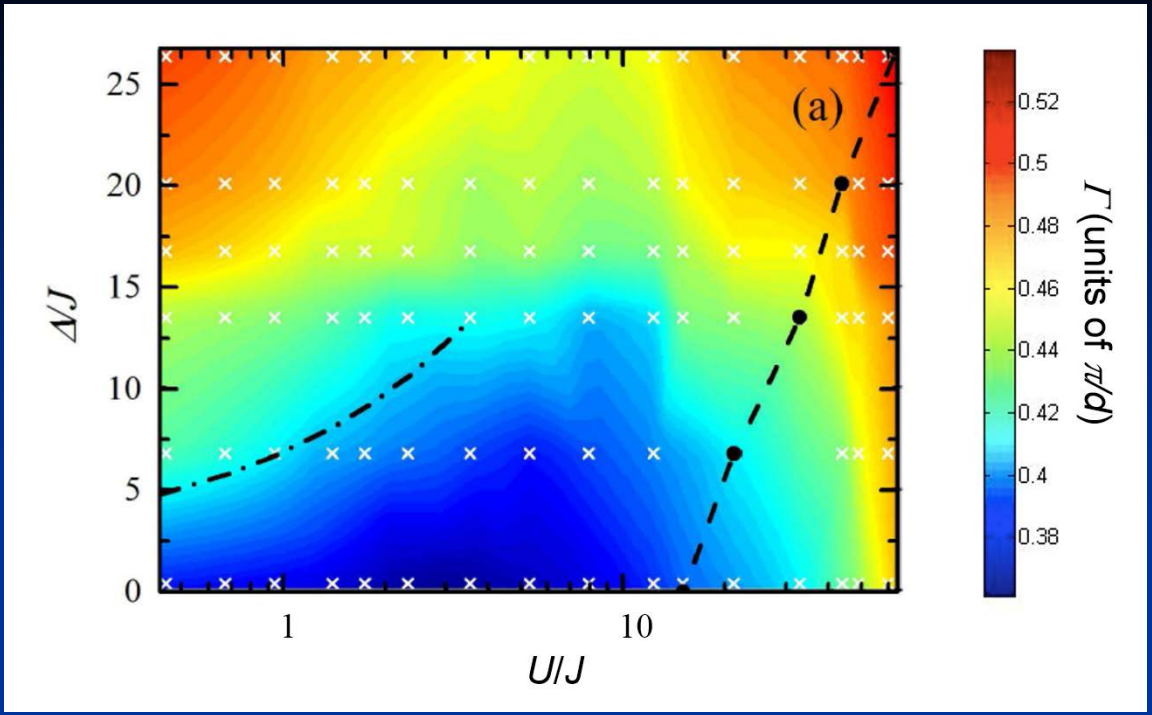
main lattice modulation
(15%, 200ms)



"energy" measurement







- Reentrant phase diagram (consistent with theory)
- Disordered insulator (``Bose glass")

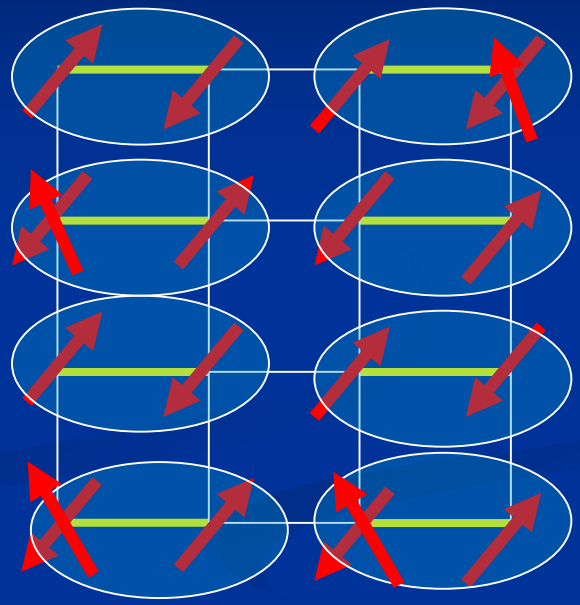
- But one can improve on : temperature, Mott insulator, trap

Quantum spins: Control of particle density

Spin Dimers: QS for bosons

TG and A. M. Tsvelik PRB 59 11398 (1999)

$J_r \gg J$

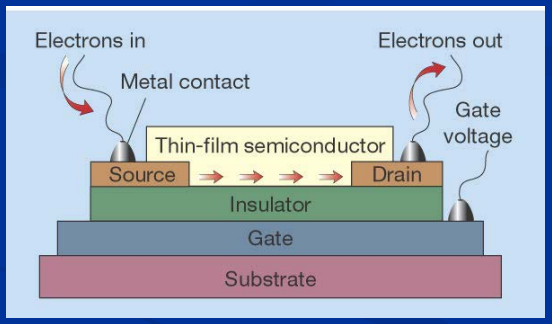


$|S\rangle \rightarrow |0\rangle, |T_+\rangle \rightarrow |1\rangle$

Hard core bosons on a lattice

$$H = -\frac{J_{xy}}{2}\sum_{ij}[b_i^\dagger b_j + \mathrm{hc}] + J_z \sum_{ij}(n_z - \frac{1}{2})(n_j - \frac{1}{2})$$

- Magnetic field : chemical potential (gate voltage) for the bosons



Nature **428**, 269 (2004)

- In 3D !

- Go from 0 bosons/site to 1 boson/site

Probes

- Magnetization – number of bosons

$$m_z = \langle S_z \rangle$$

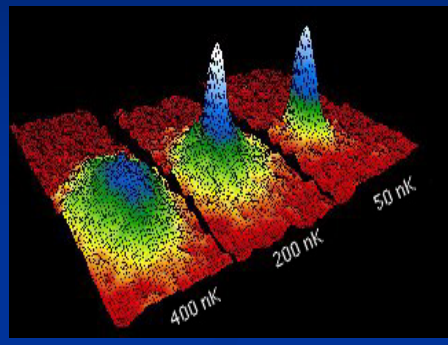
- Neutrons/NMR : dynamical correlations

$$\langle S_z(r,t) S_z(0,0) \rangle_{q,\omega} \rightarrow \langle \rho_z(r,t) \rho_z(0,0) \rangle$$

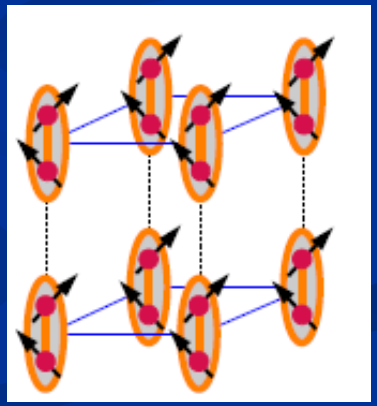
$$\langle S^-(r,t) S^+(0,0) \rangle_{q,\omega} \rightarrow \langle \psi(r,t) \psi^\dagger(0,0) \rangle$$

Complementary systems

- Cold atoms:
  - control of lattice and parameters
  - short range interactions
  - inhomogeneous systems
  - probes



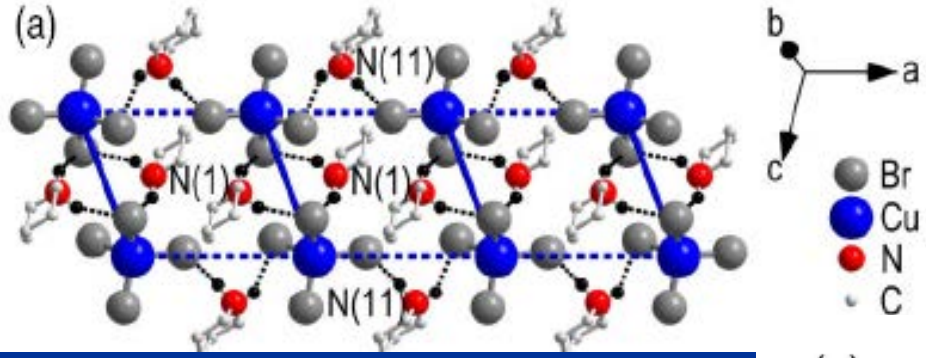
- BEC dimers/spins:
  - homogeneous, density control
  - probes
  - lattice fixed by chemistry



TG, Ch. Rüegg, O. Tchernyshyov, Nat. Phys. 4 198 (08)

Organic ladder

B. C. Watson et al., PRL 86 5168 (2001)

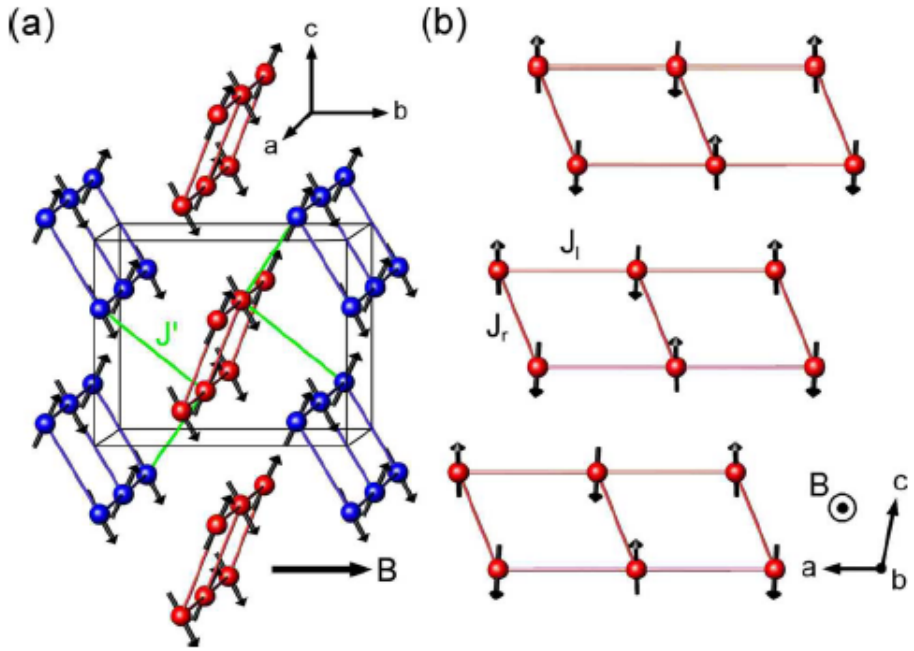


M. Klanjsek et al.,

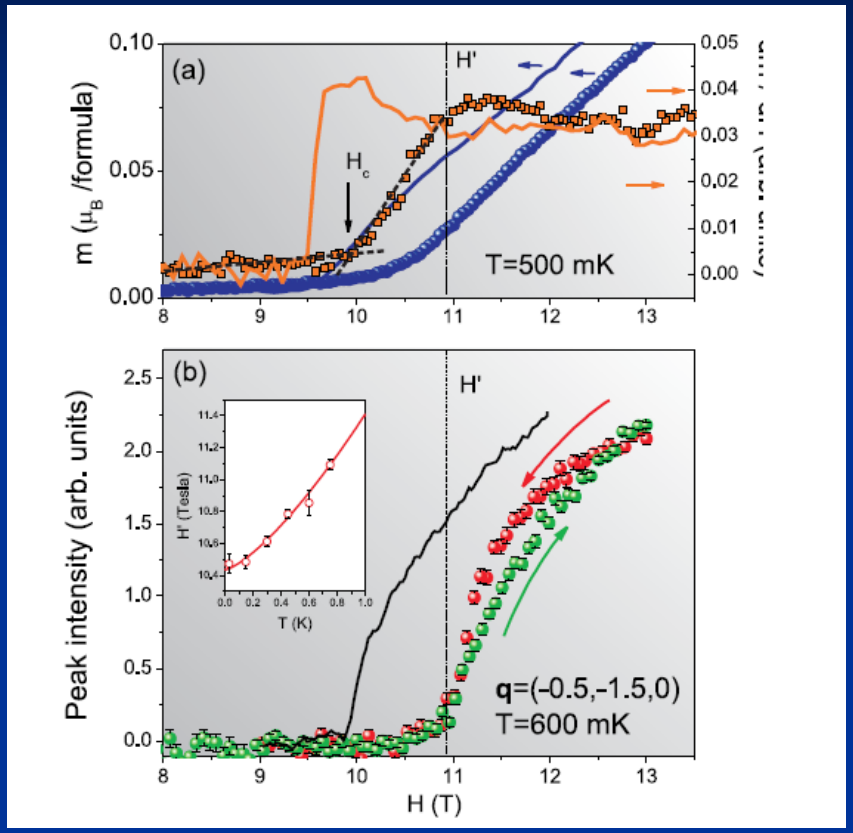
PRL 101 137207 (2008)

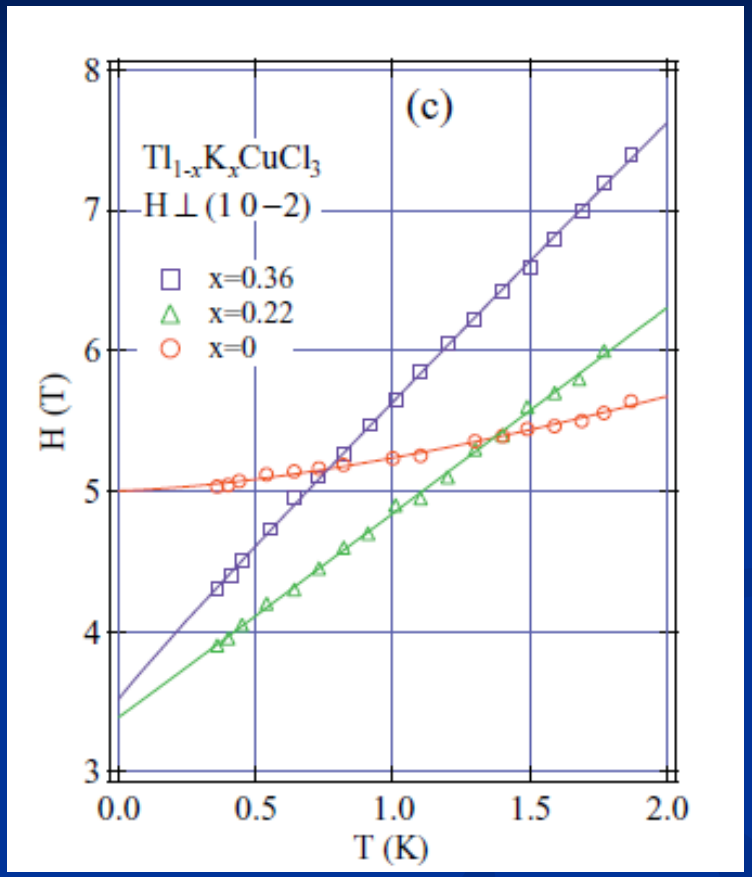
B. Thielemann et al.,

PRB 79, 020408(R) (2009)



Bose glass in dimer systems





$IPA\text{-}Cu(Cl_{0.95}Br_{0.05})_3$

T. Hong et al.

Phys. Rev. B **81**, 060410 (2010)

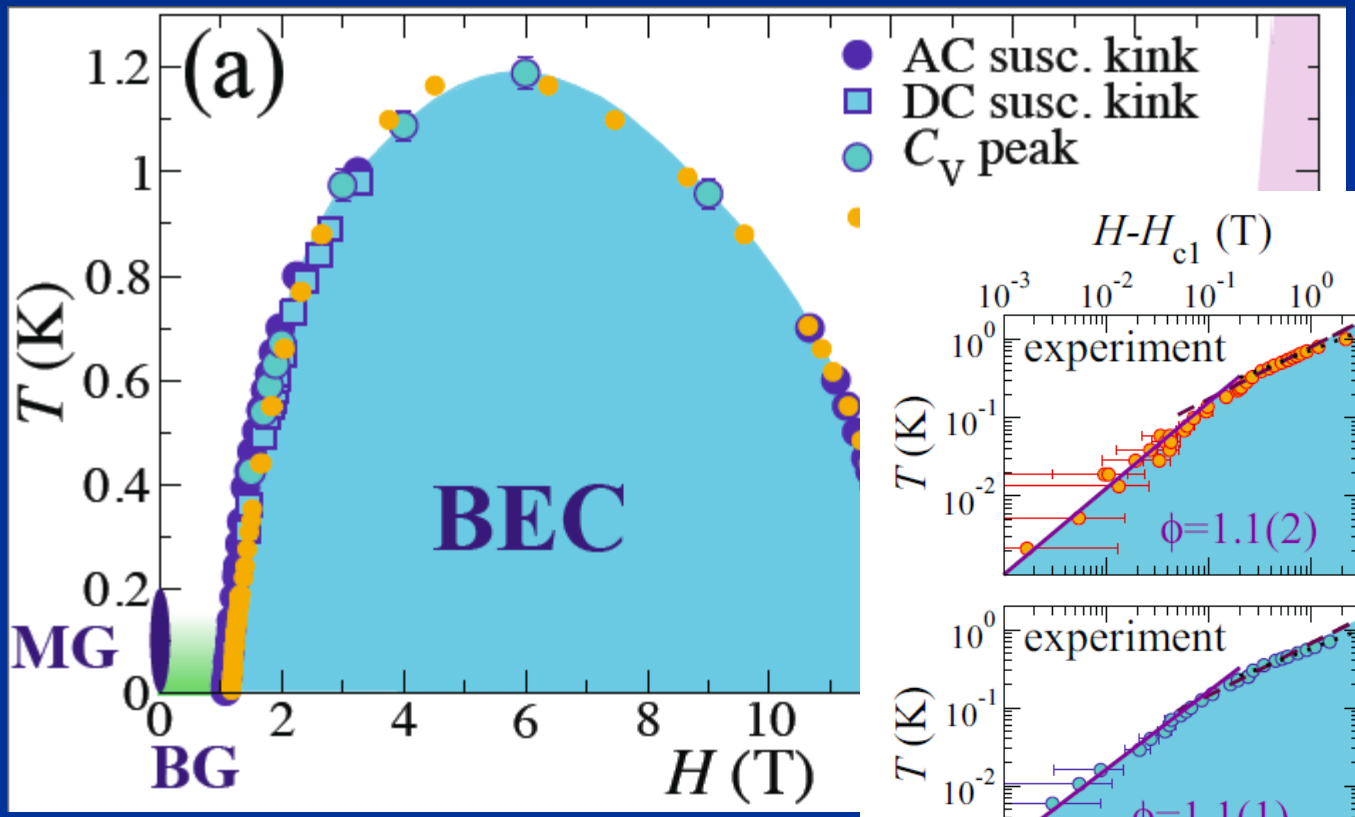
$Tl1\text{-}xKxCuCl_3$

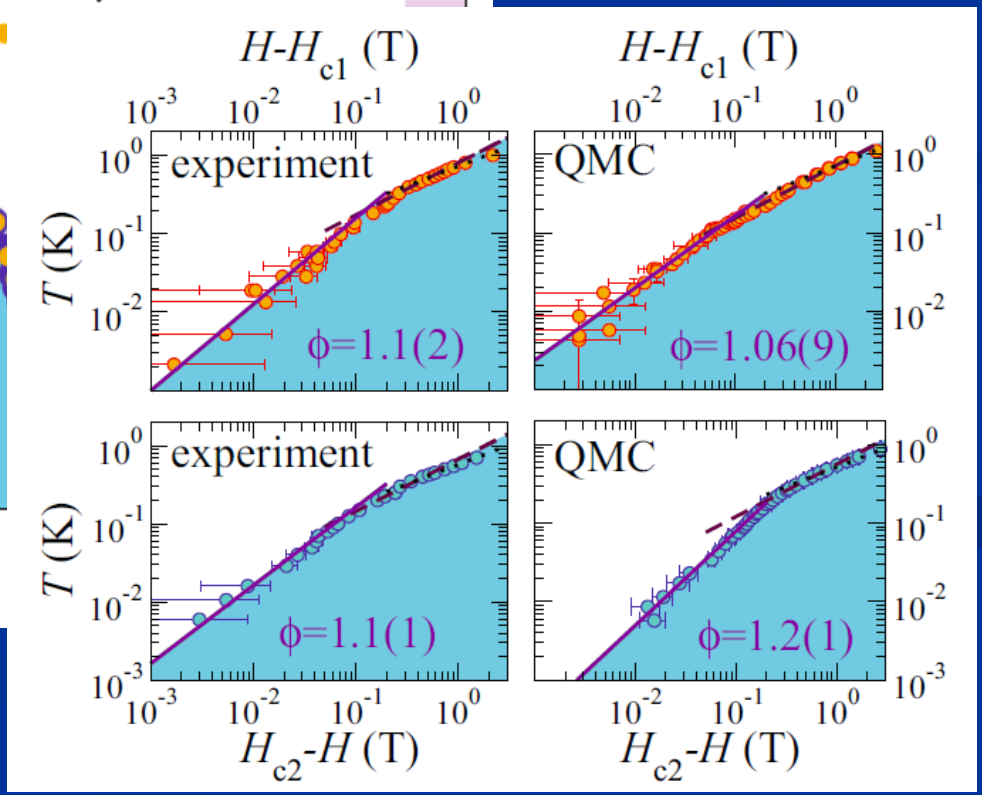
F. Yamada et al.

Phys. Rev. B **83**, 020409 (2011)

DTN Br

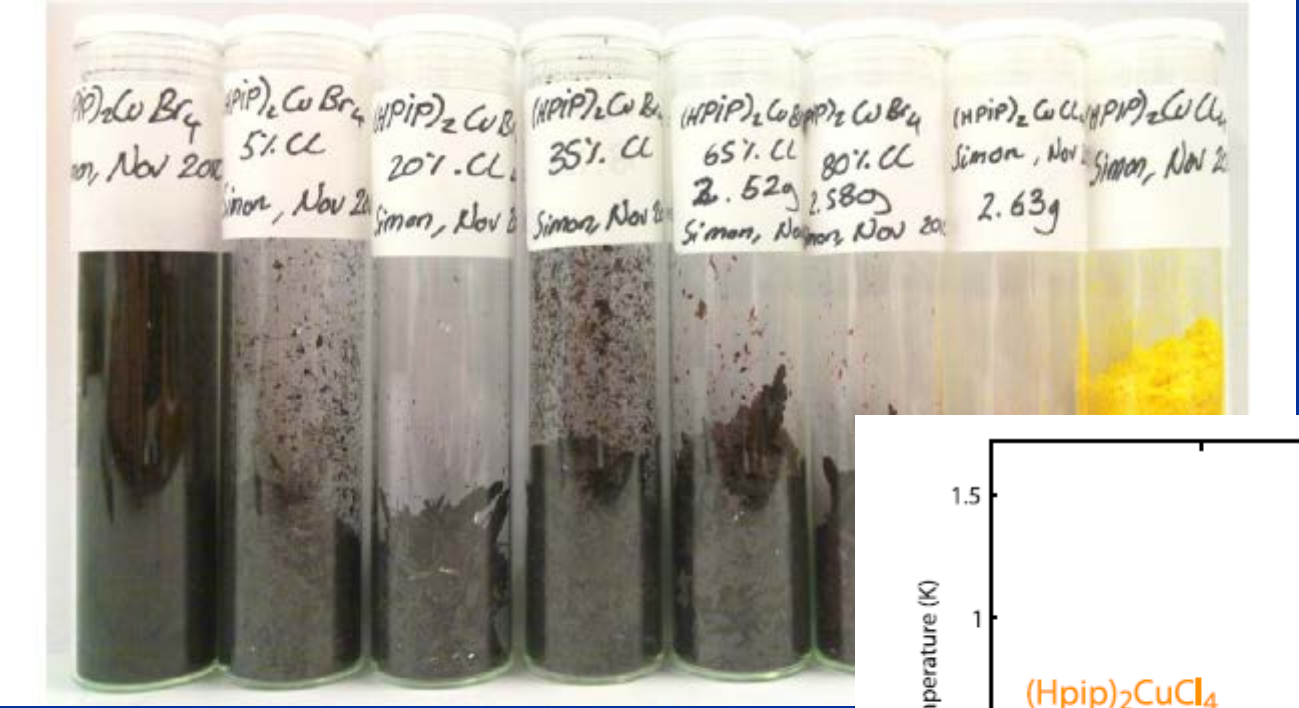
Rong Yu et al. Nature 489 379 (2013)

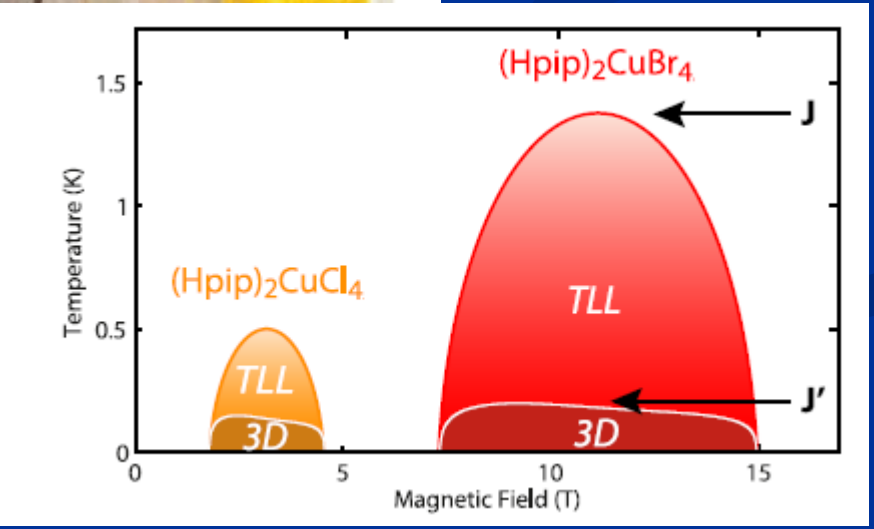




HPIP Cl-Br

S. Ward et al. J. Phys C 25 014004 (2013)





Disordered HPIP

Theory: S. Furuya (Geneva)
C. Kollath (Bonn U)

Exp. : PSI group
S. Ward, C. Ruegg

Neutron scattering in gapped phase

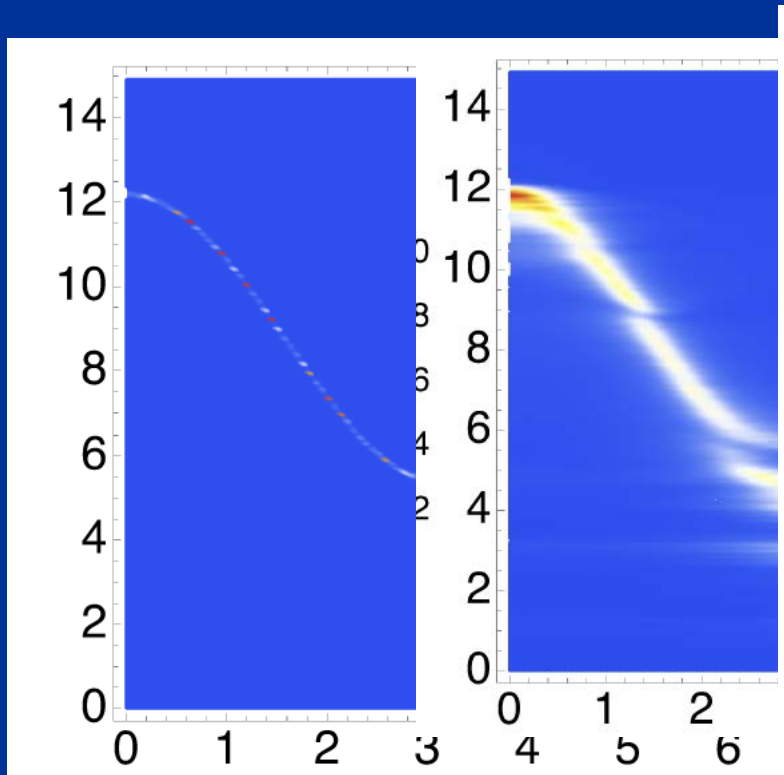
- One single triplon: non-interacting Anderson localization

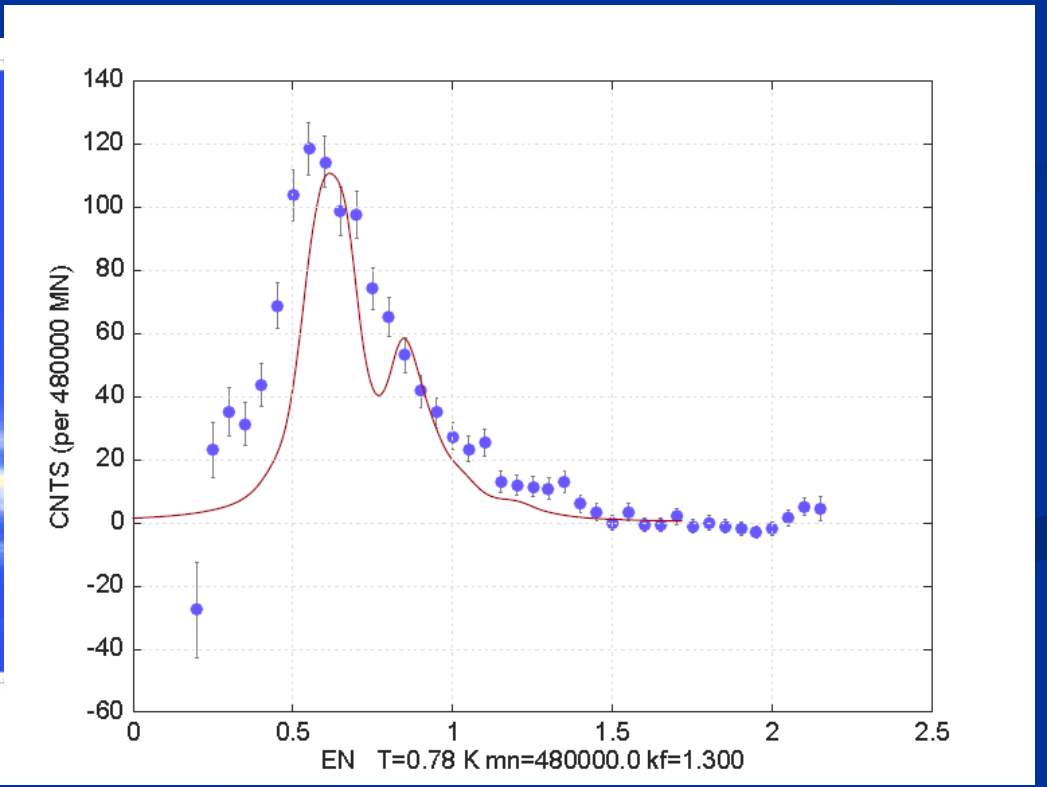
- Neutrons probe single particle Green's function for the boson

$$\langle b(x,t)b^{\dagger}(0,0)\rangle$$

Disordered HPIP

S. Ward, S. Furuya





Conclusions ?

Disorder and interactions is alive and kicking

I am certainly looking forward to discussions and interactions with Boris on this for the next 60 years !!!


Happy birthday Boris !