Disordered 1D systems

T. Giamarchi

http://dpmc.unige.ch/gr_giamarchi/

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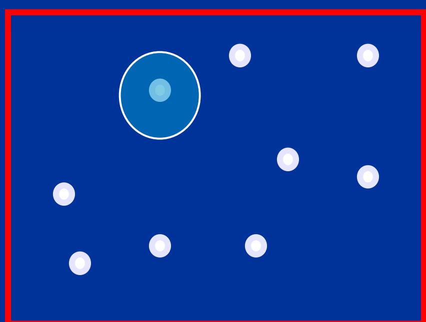
FNSNF
Fonds national suisse
Schweizerischer Nationalfonds
Fondo nazionale svizzero
Swiss National Science Foundation

MaNEP
SWITZERLAND

One dimension is specially interesting

- No individual excitation can exist (only collective ones)

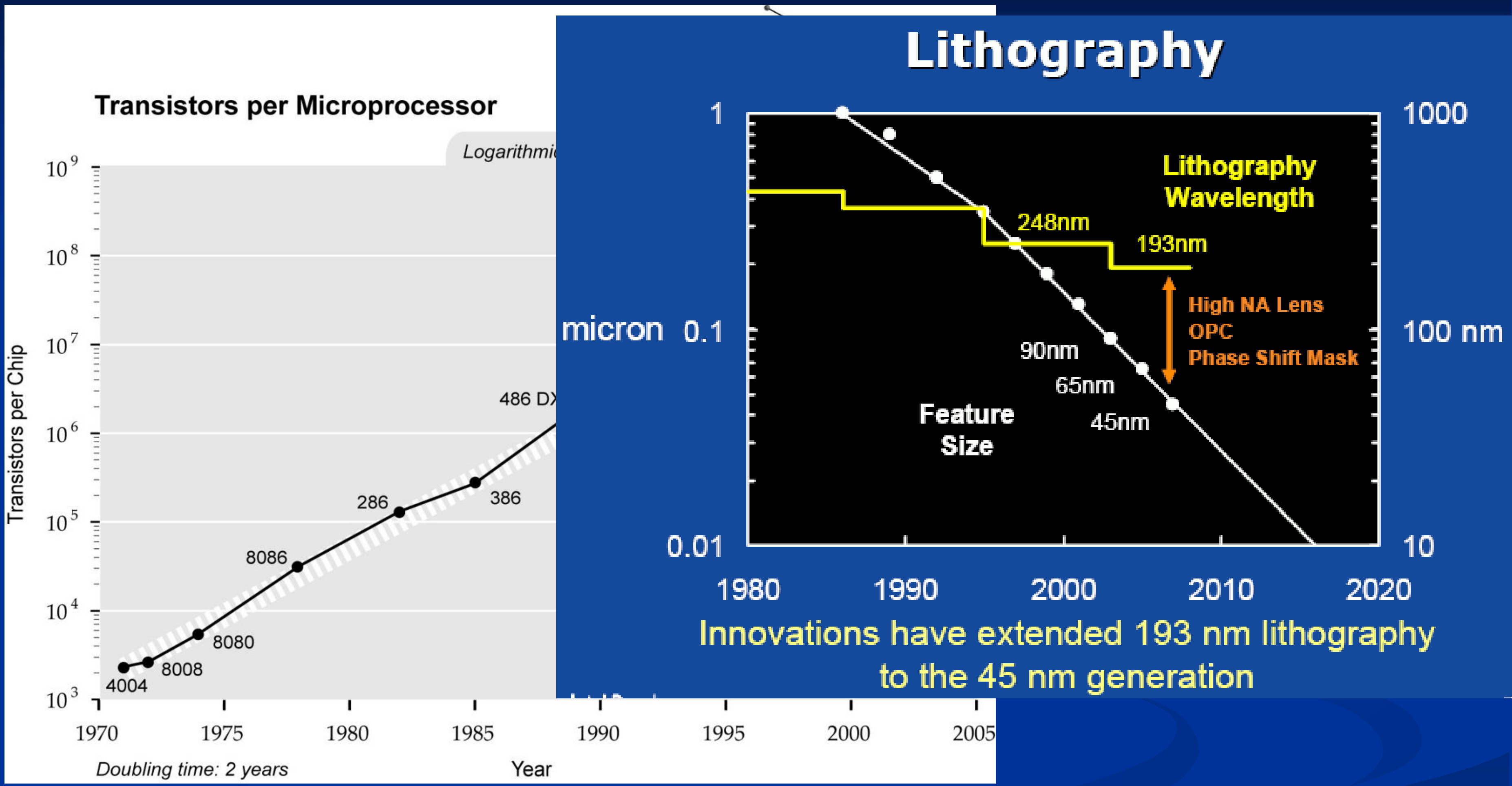


- Strong quantum fluctuations

$$\psi = |\psi| e^{i\theta}$$

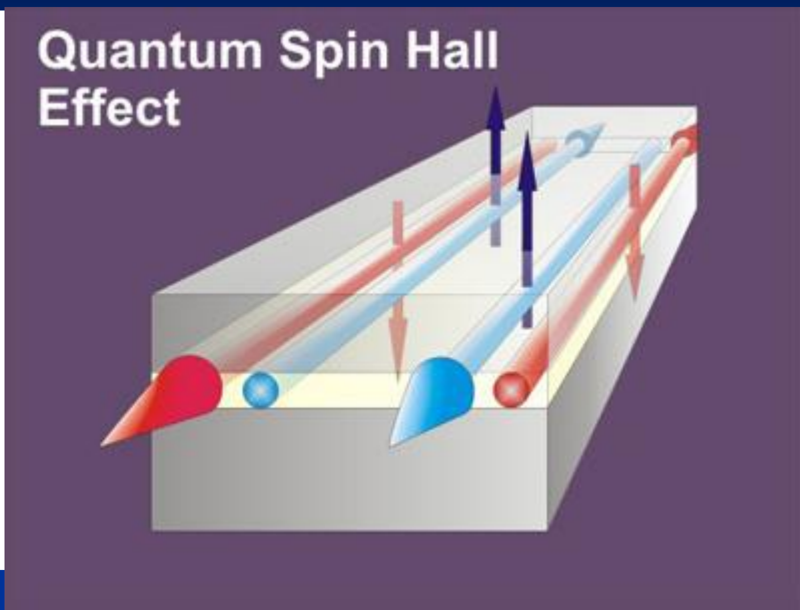
Difficult to order

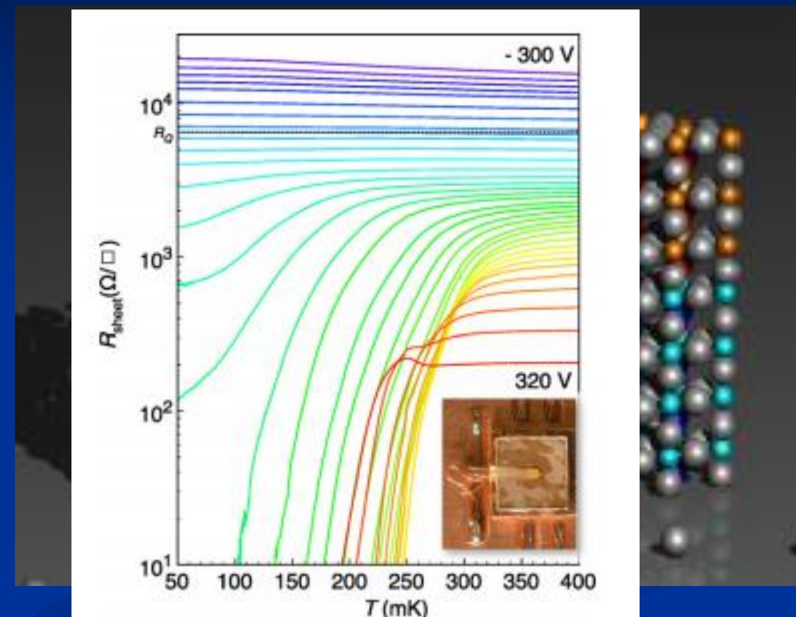
Future electronic



Need to worry about reduced dimensionality

Physics at the edge





Presence of edge
(B. I. Halperin)

LaO/StO interface
(JM Triscone et al.)

Quantum hall effect
Topological insulators….

Superconductivity
between insulators…

A good reason to work on 1D

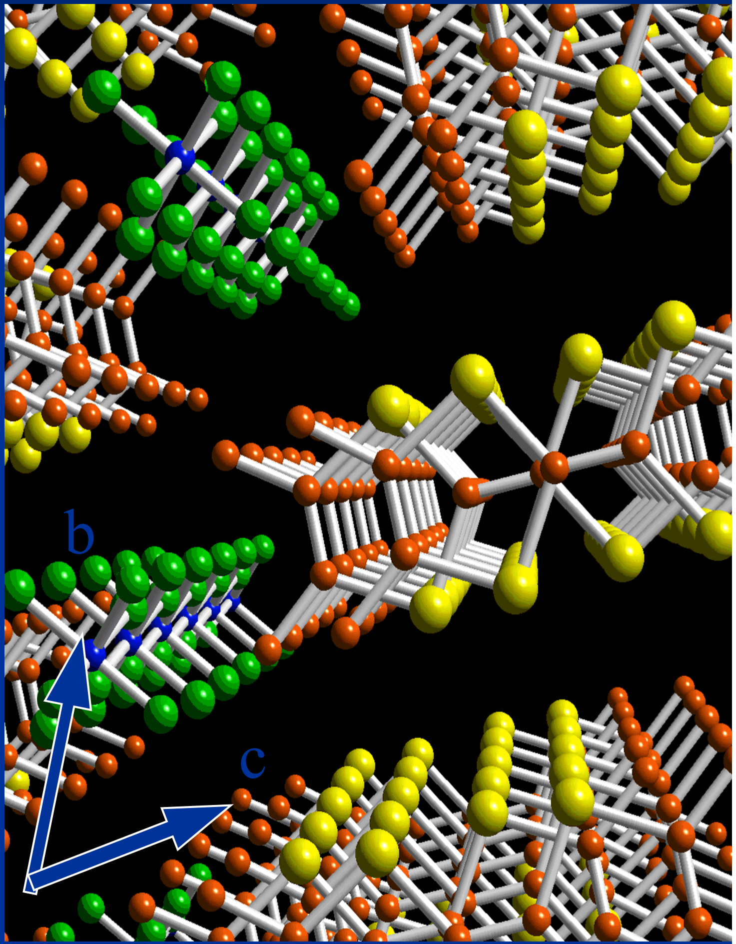
However, my personal reason for working on one-dimensional problems is merely that they are fun. A man grows stale if he works all the time on the insoluble and a trip to the beautiful work of one dimension will refresh his imagination better than a dose of LSD.

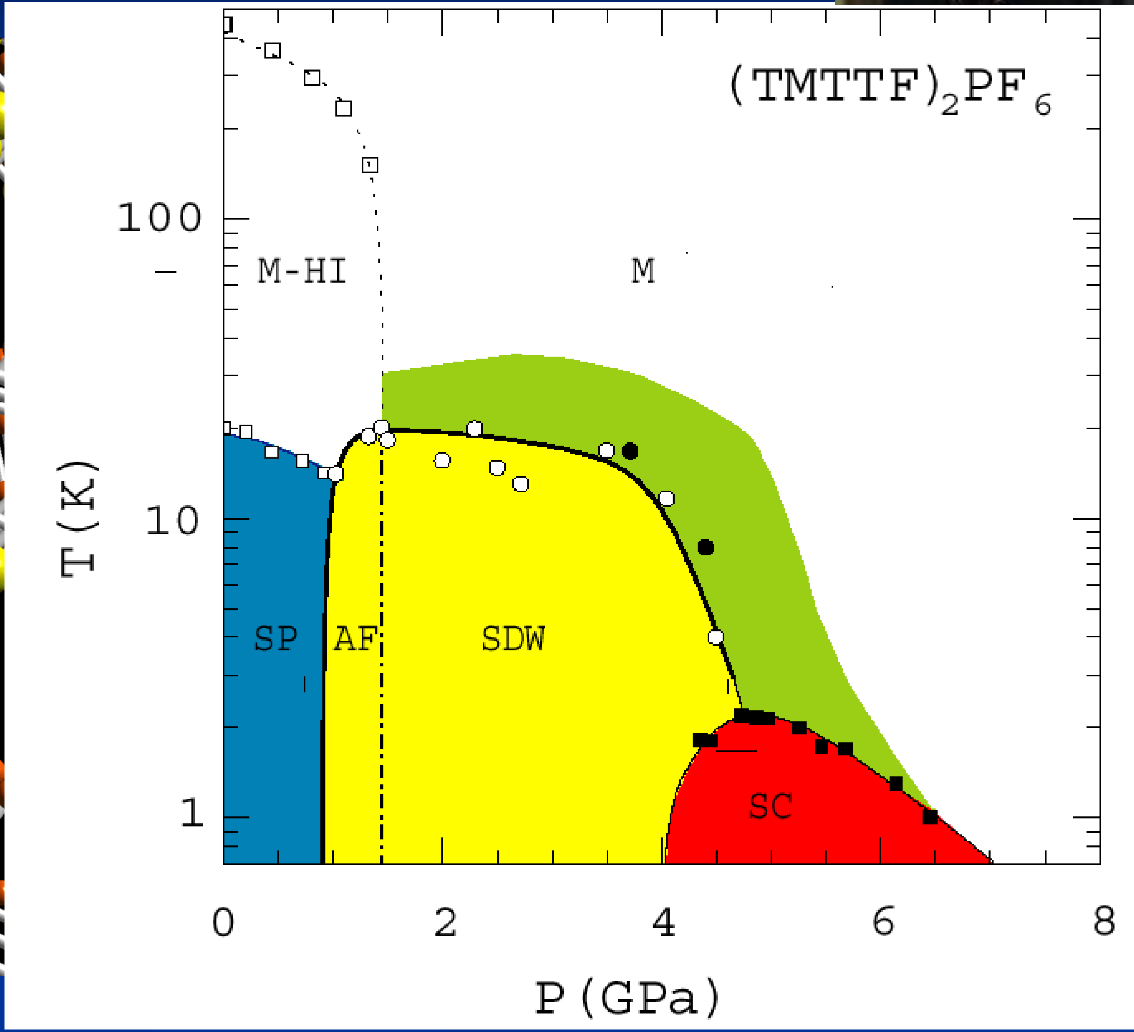
Freeman Dyson (1967)

Interesting…
but…
does it exist ?

TG, Int J. Mod. Phys. B 26 1244004 (2012)

Organic conductors

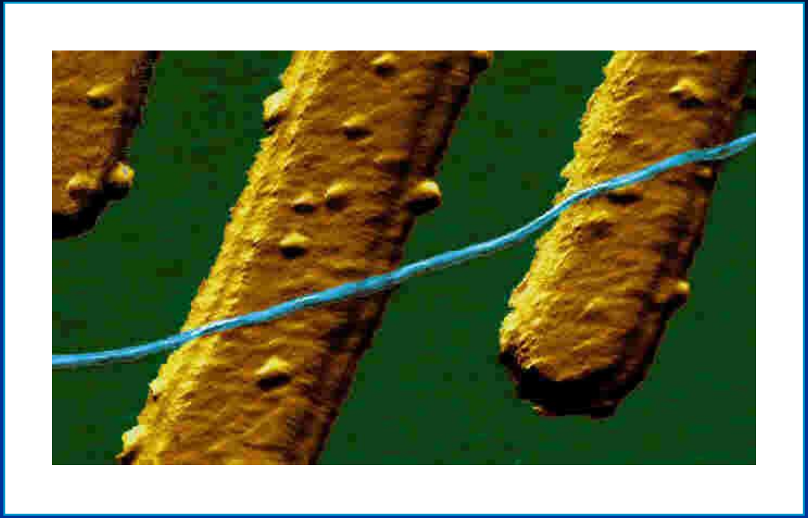


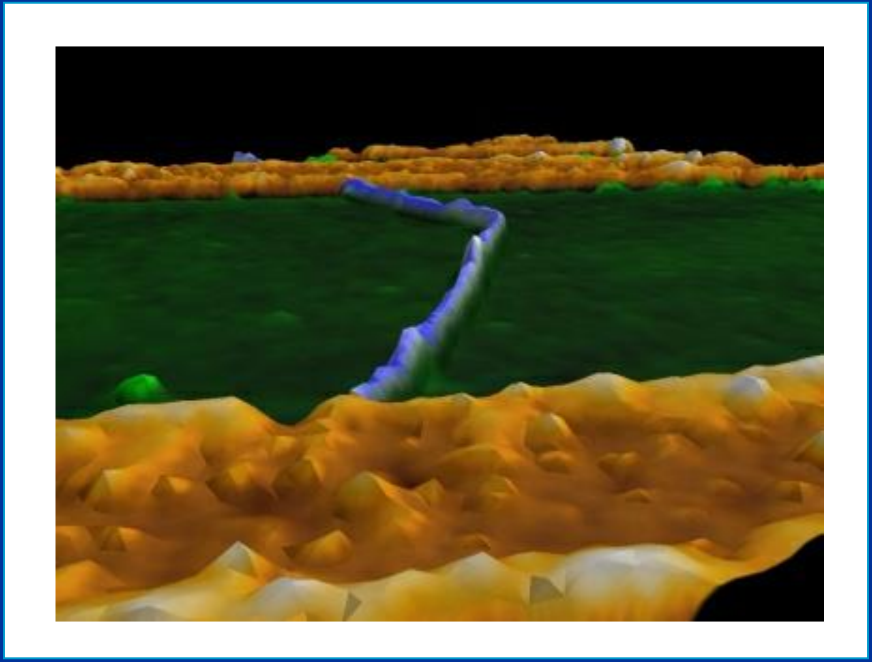


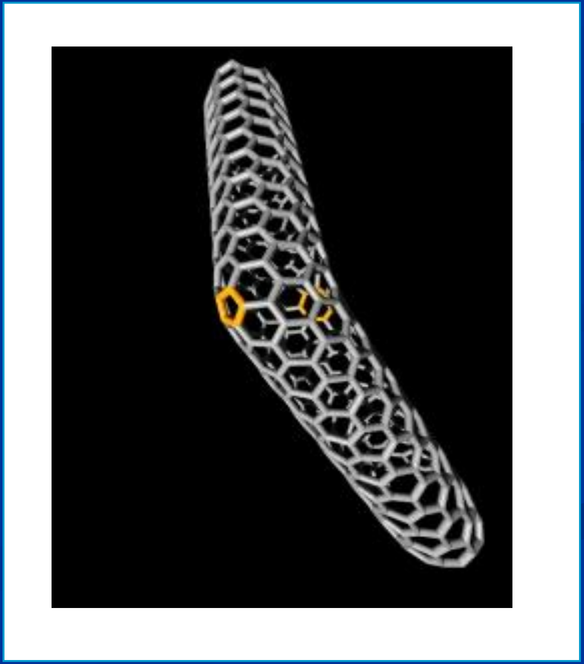
D. Jaccard et al., J. Phys. C, 13 L89 (2001)

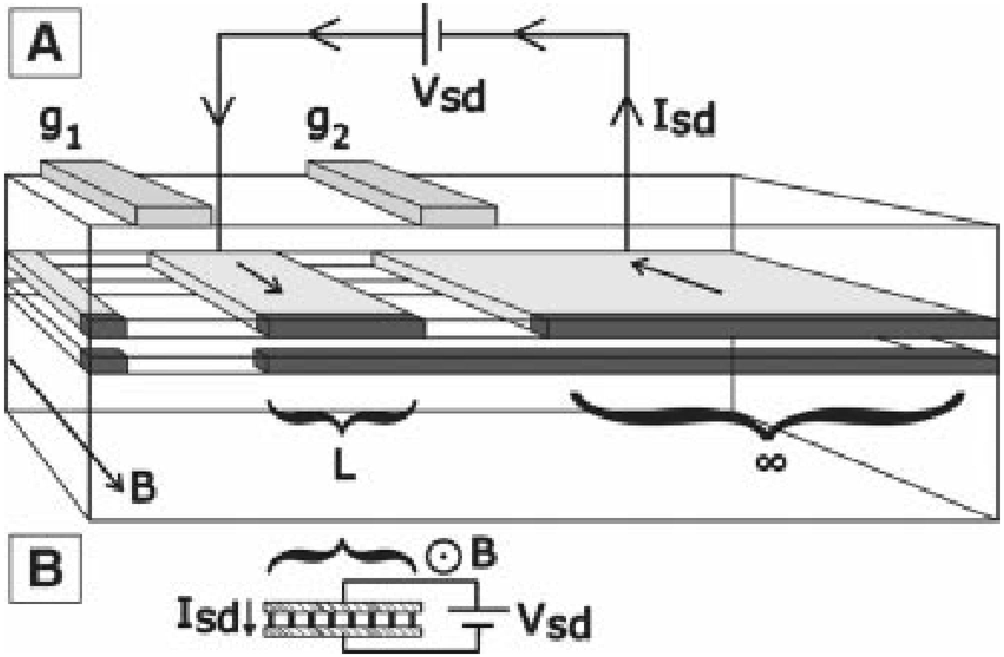
CARBON NANOTUBES

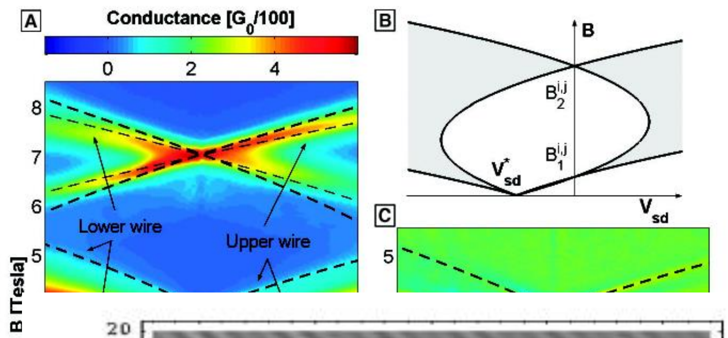
Cees Dekker

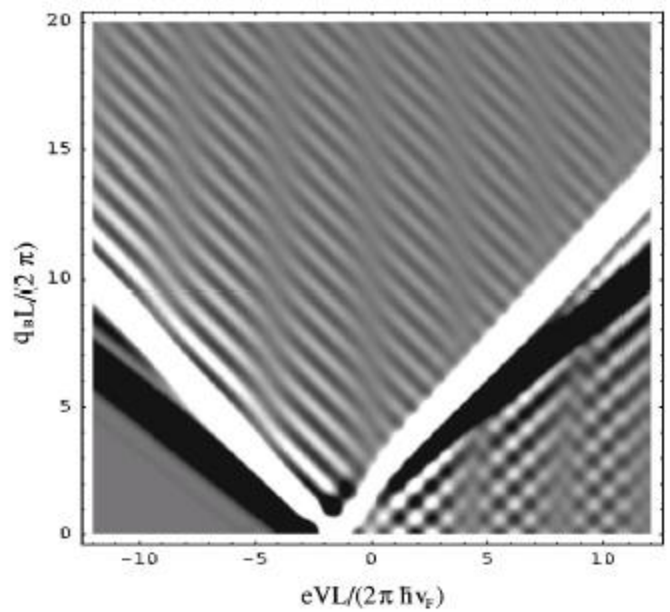












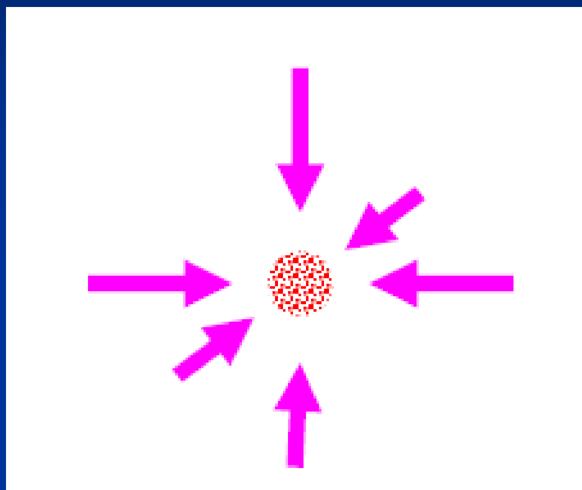
O.M Ausslander et al., Science **298** 1354 (2001)

Y. Tserkovnyak et al., PRL **89** 136805 (2002)

Y. Tserkovnyak et al., PRB **68** 125312 (2003)

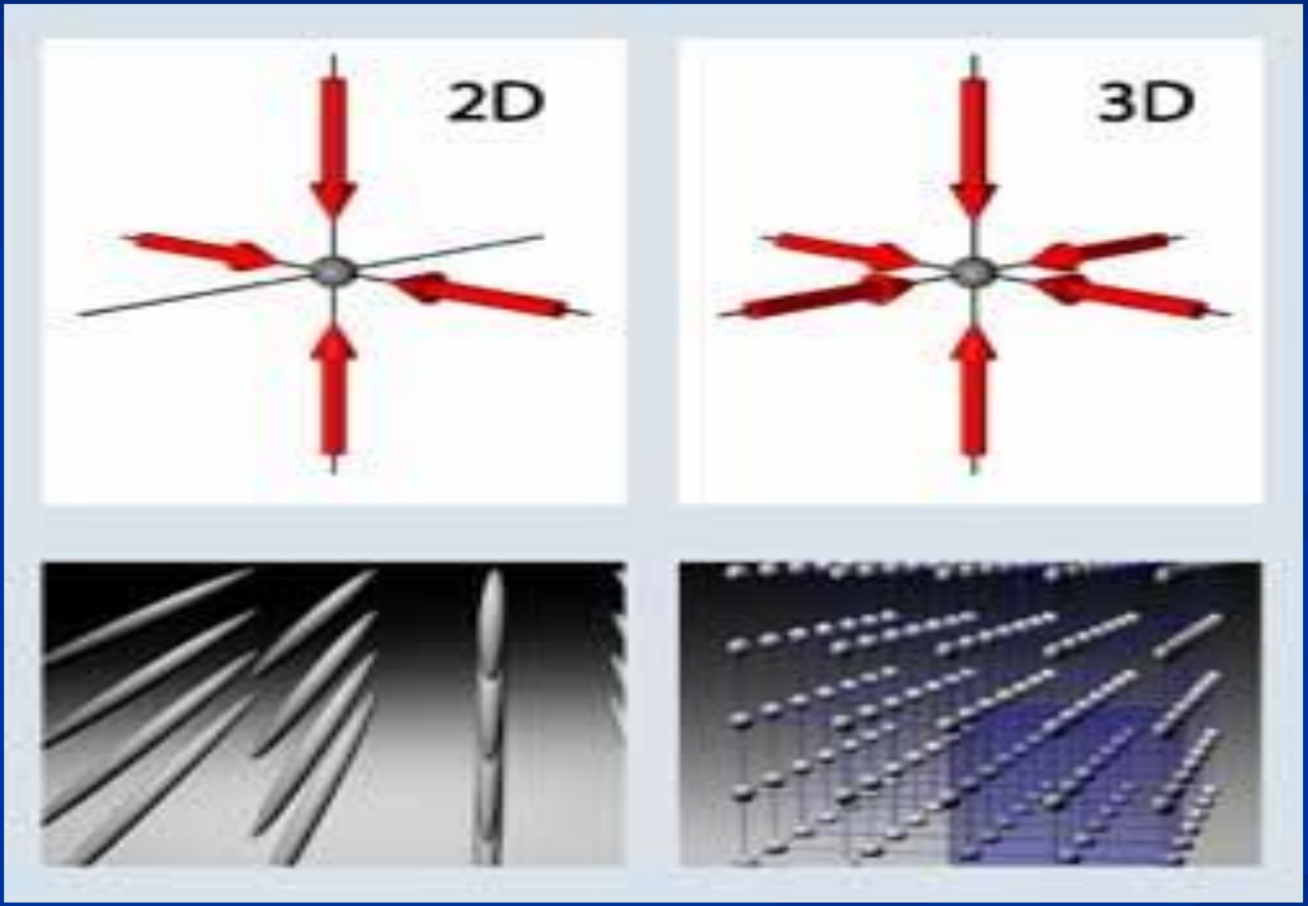
Cold atoms

Atom trapping



- Evaporative cooling

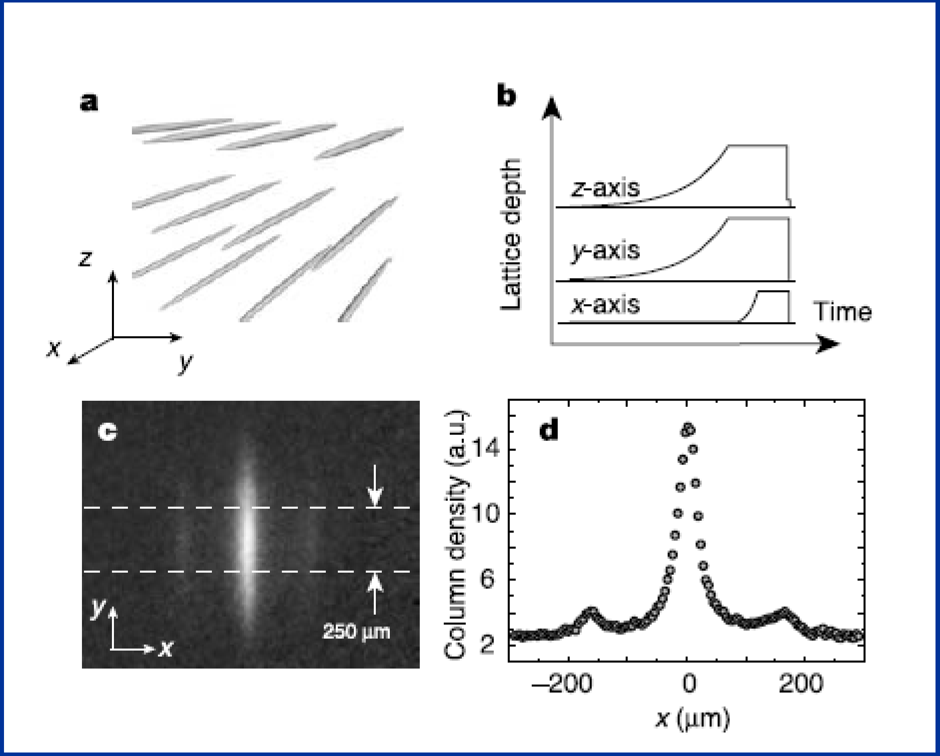
Control on the dimension

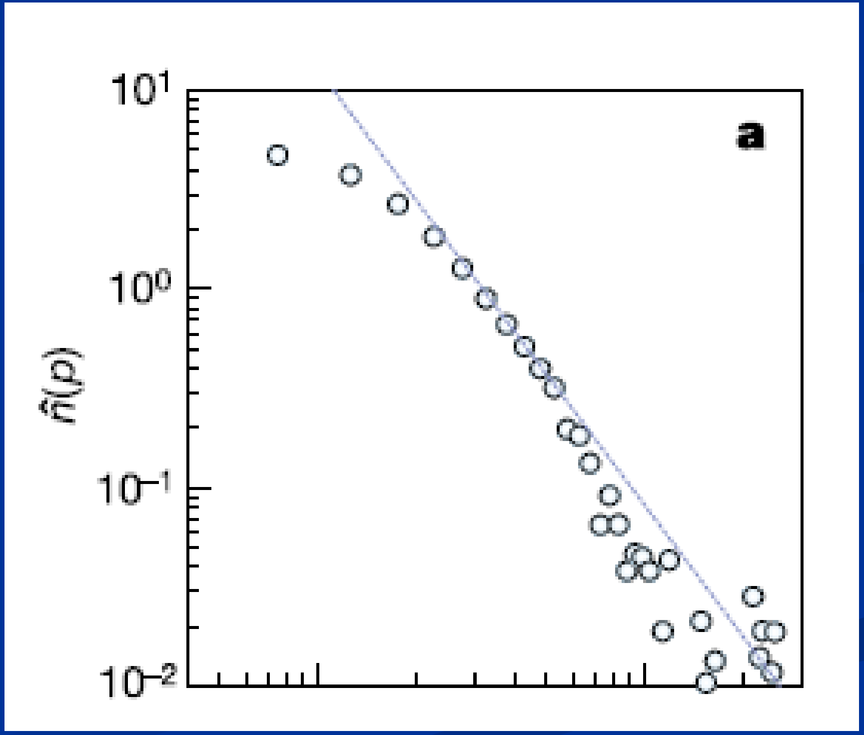


I. Bloch, Nat. Phys 1, 23 (2005)

Cold atoms (Tonks limit)

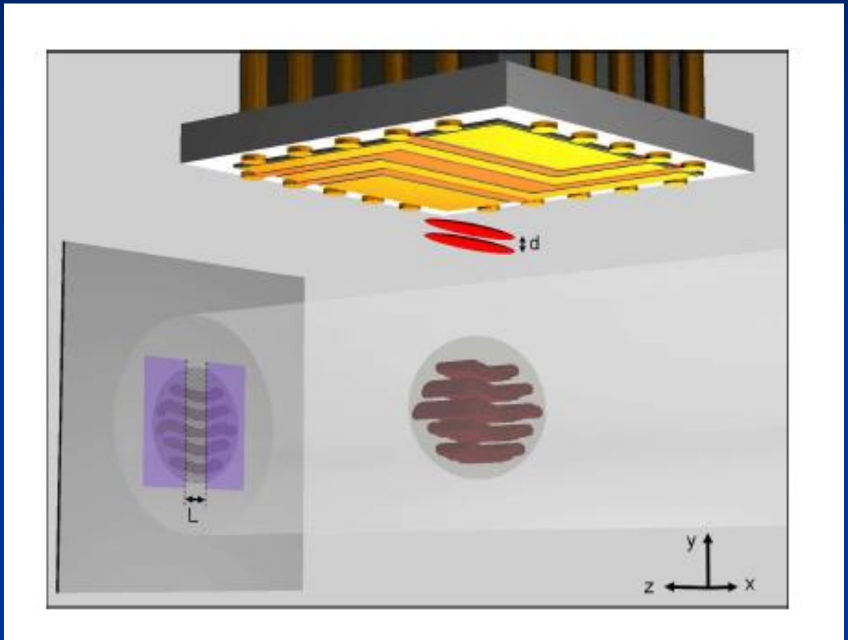
B. Paredes et al., Nature 429 277 (2004)

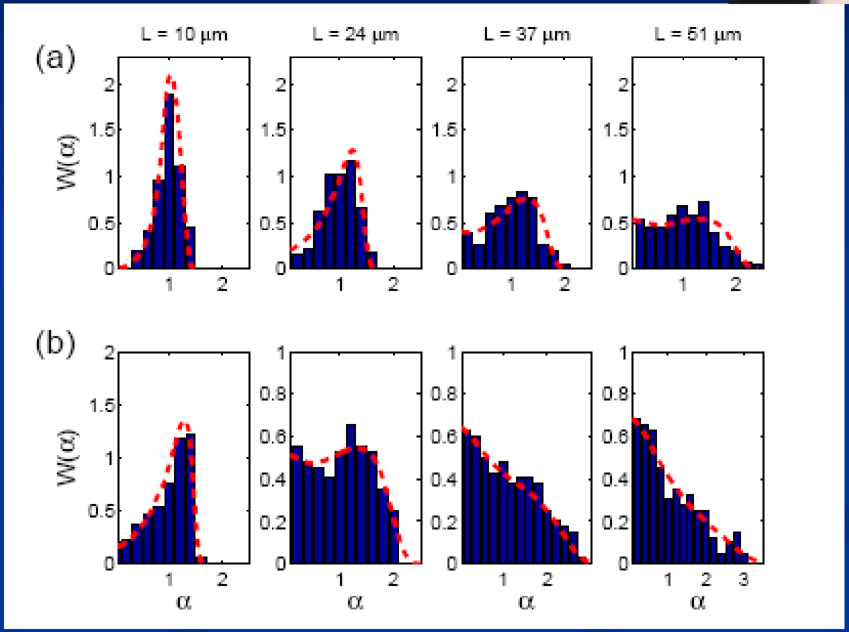




$$n(k) = \int dx e^{ikx} \langle \psi^\dagger(x)\psi(0) \rangle$$

Cold atoms: Interferences





$$\int_0^L dr \langle \psi(r) \psi^\dagger(0) \rangle$$

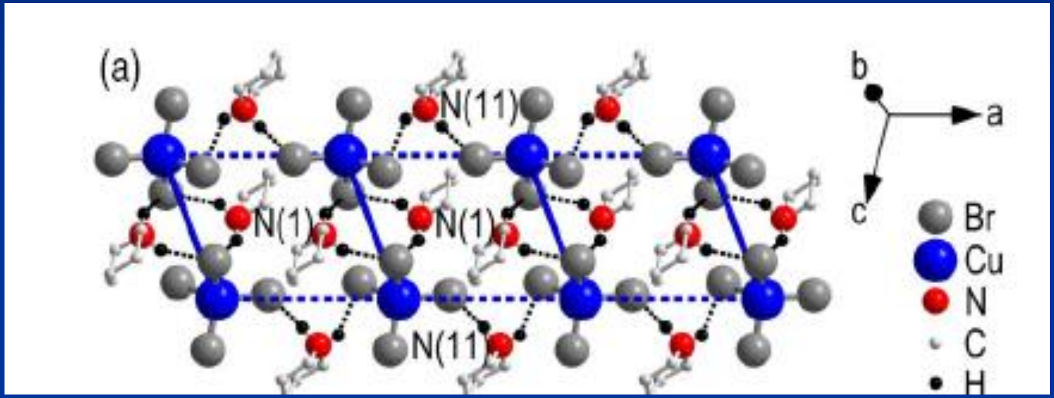
S. Hofferberth et al. Nat. Phys 4 489 (2008)

K large (42)

Magnetic insulators

Spin ladder systems

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

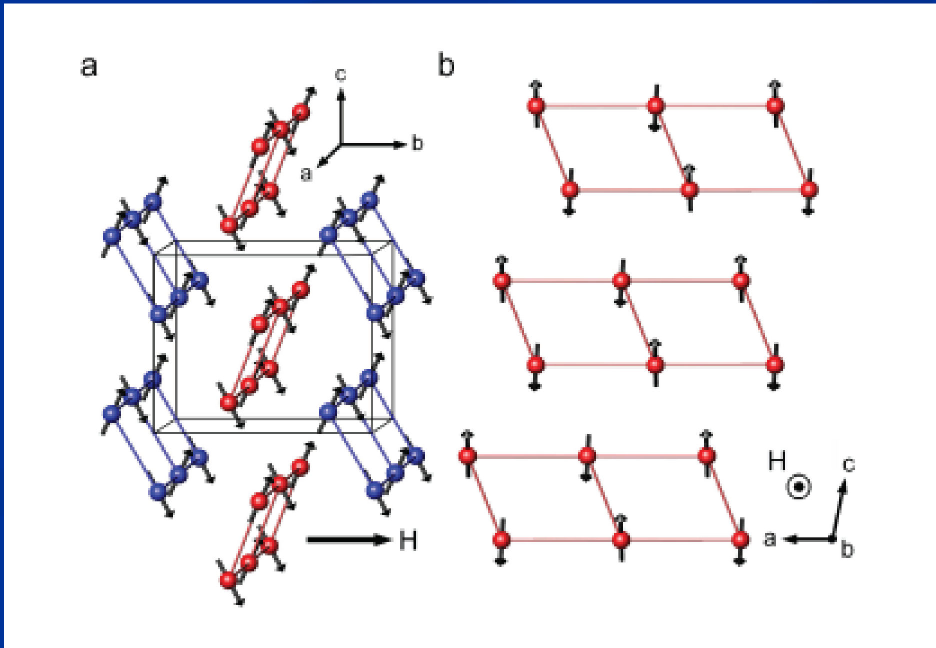


M. Klanjsek et al.,

PRL 101 137207 (2008)

B. Thielemann et al.,

PRB **79**, 020408® 2009

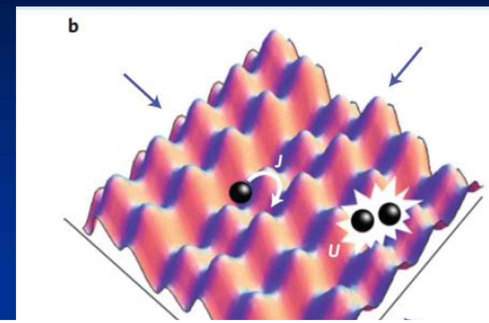


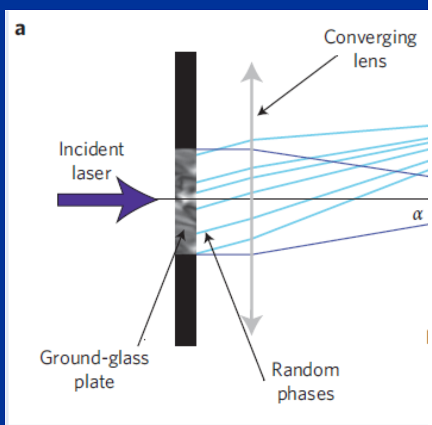
Disorder and interactions

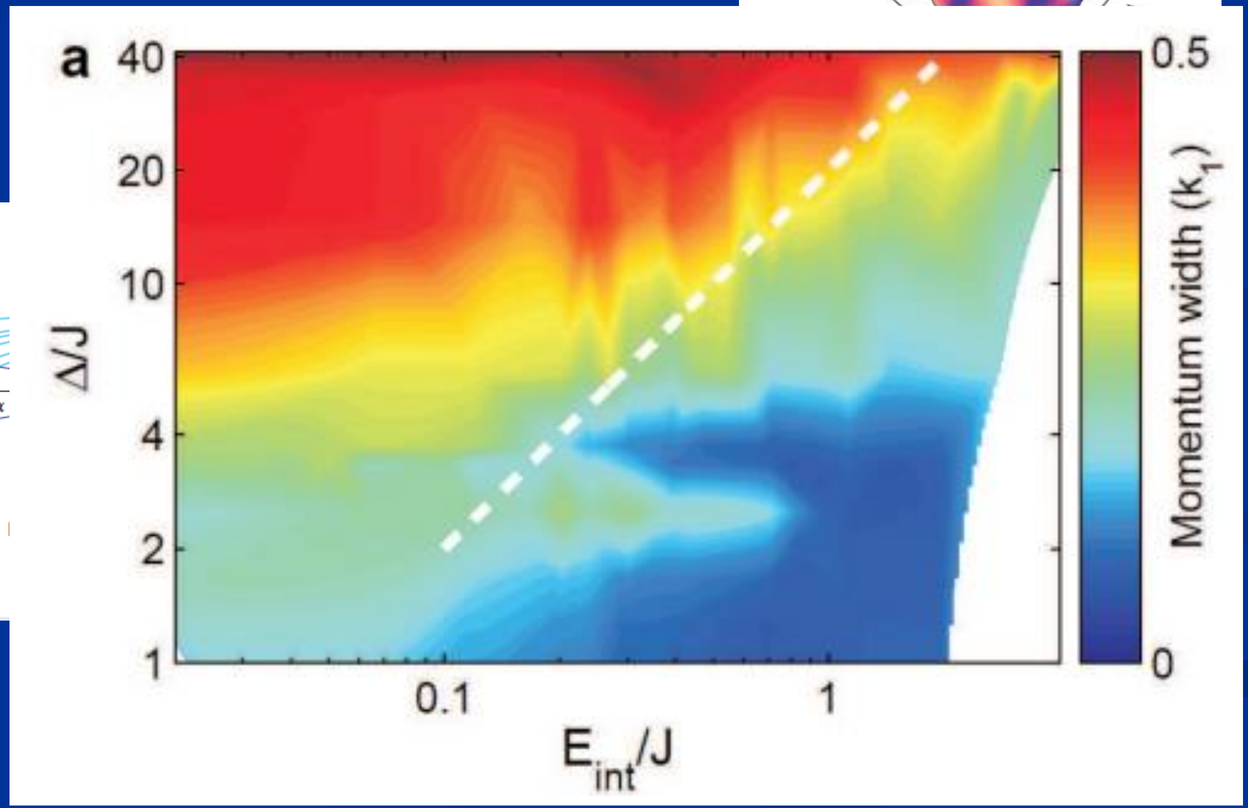

nature physics
PROGRESS ARTICLE
PUBLISHED ONLINE: 1 FEBRUARY 2010 | DOI: 10.1038/NPHYS1507

Disordered quantum gases under control

Laurent Sanchez-Palencia[1]* and Maciej Lewenstein[2]*



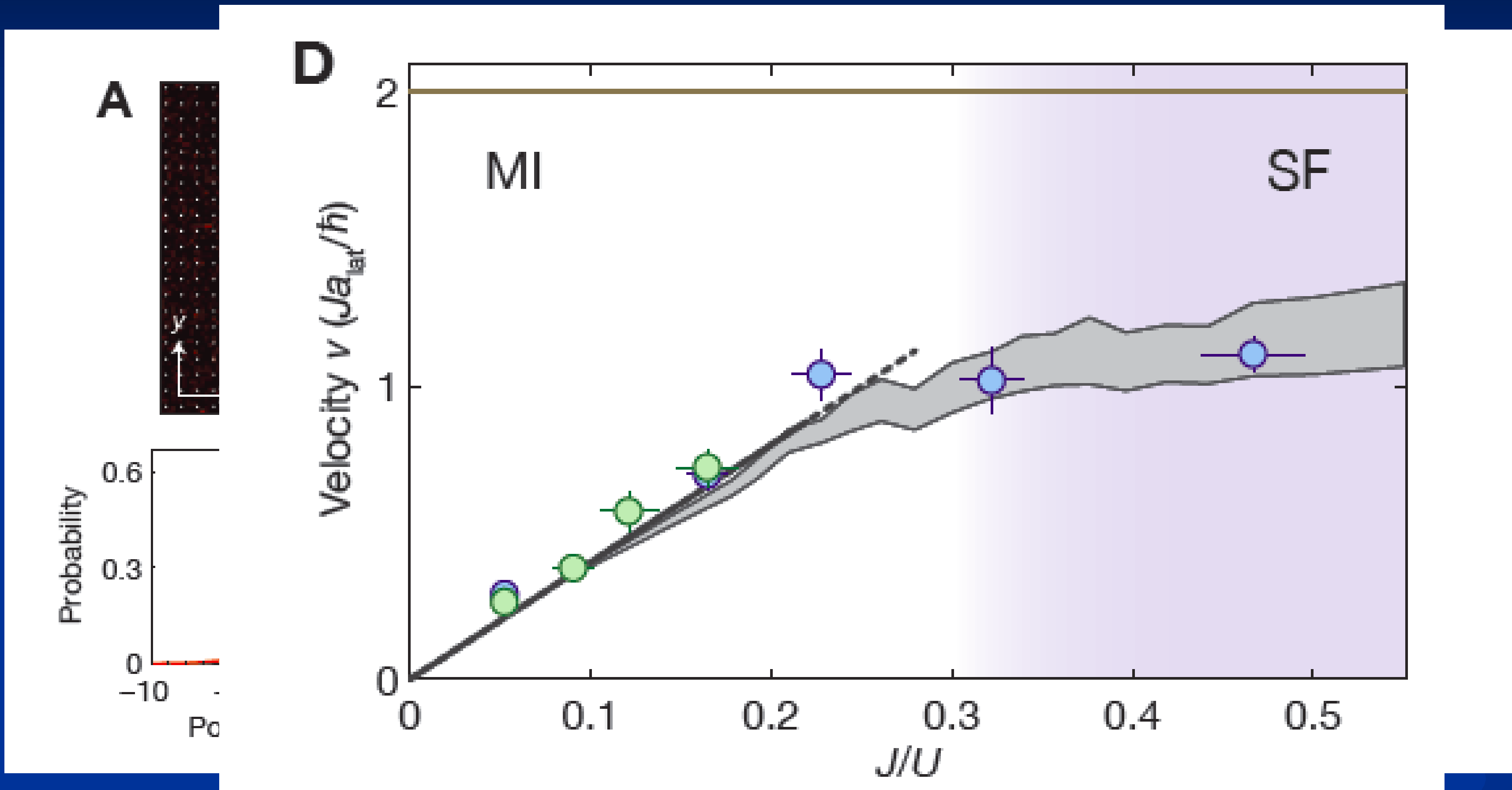




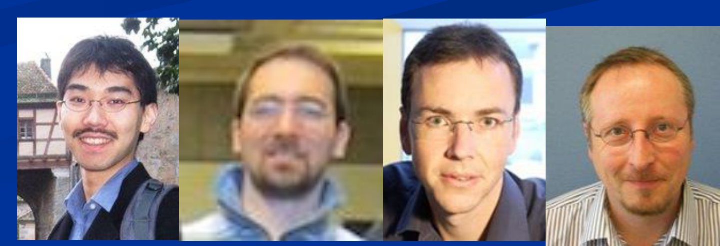
Speckle

G. Modugno, Rep. Prog. Phys. 73, 102401 (2010)

Impurity in a Luttinger liquid



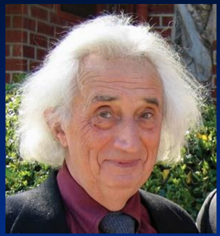
T. Fukuhara et al. **Nat. Phys. (2013)**



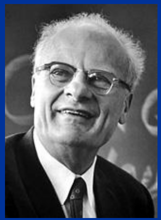
How to treat ?

- ``Standard" many body theory



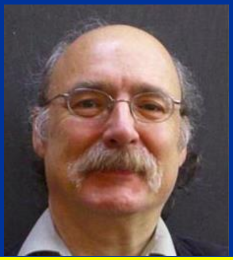




- Exact Solutions (Bethe ansatz)




- Field theories (bosonization, CFT)



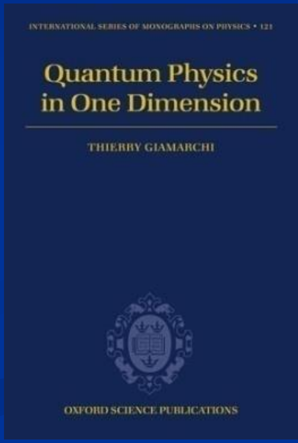


- Numerics (DMRG, MC, etc.)

References

TG, arXiv/0605472 (Salerno lectures)

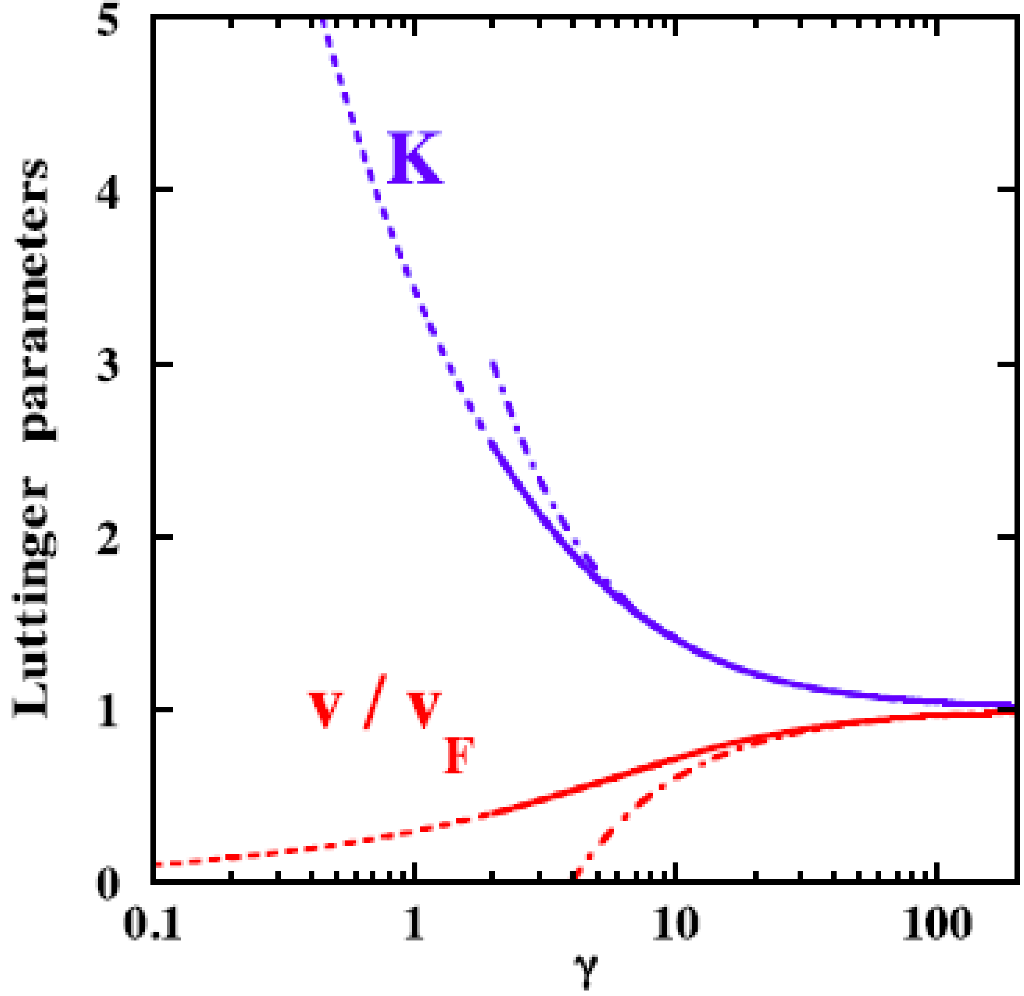
TG, Quantum physics in one dimension, Oxford (2004)



M. Cazalilla et al.,
Rev. Mod. Phys.83 1405 (2011)

TG, Int J. Mod. Phys. B 26 1244004 (2012)

Tomonaga-Luttinger liquid (bosons)



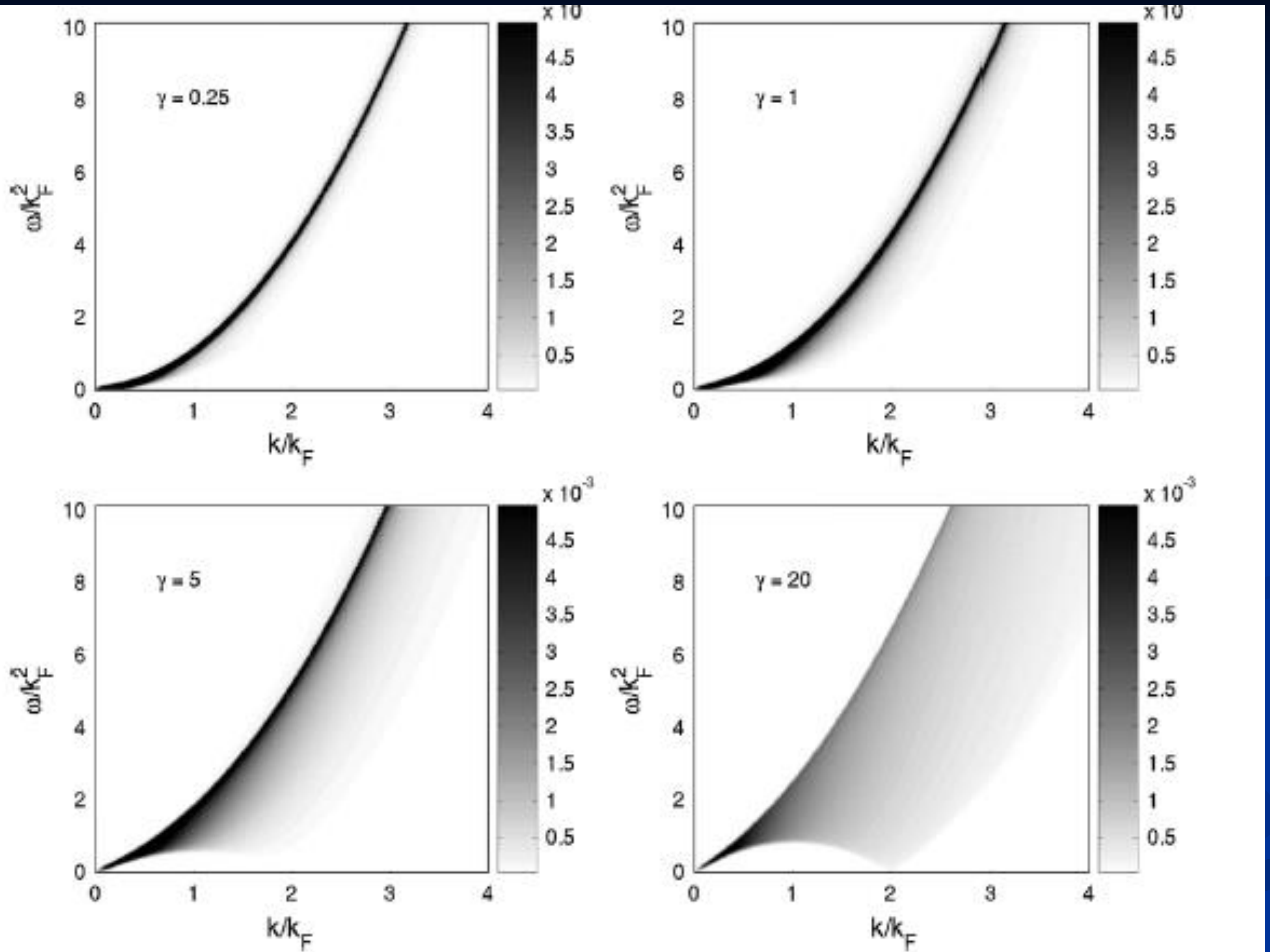


FIG. 3. Intensity plots of the dynamical structure factor [$S(q, \omega)$]. Data obtained from systems of length $L = 100$ at unit density, and $\gamma = 0.25$, 1, 5, and 20. From Caux, and Calabrese, 2006.

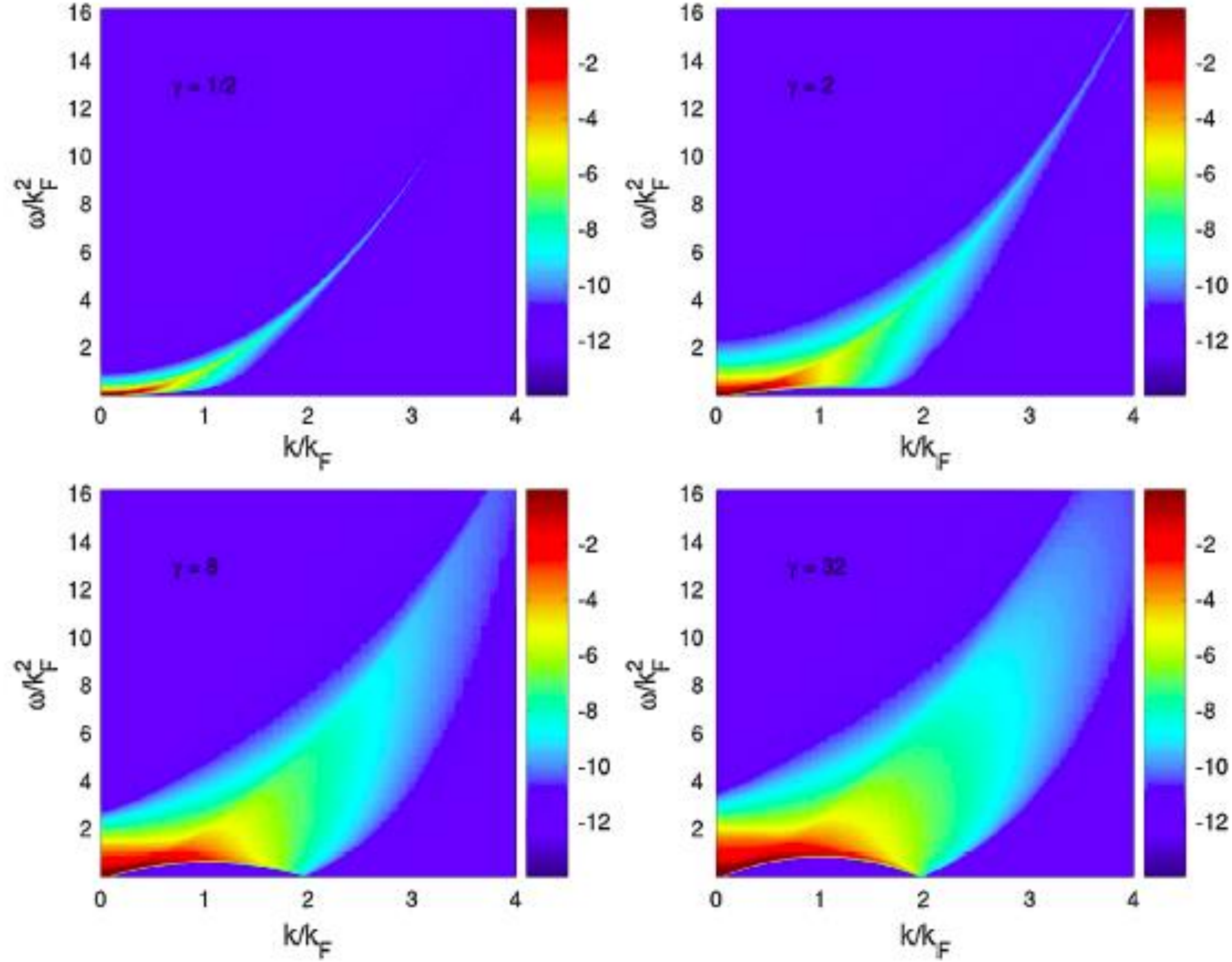
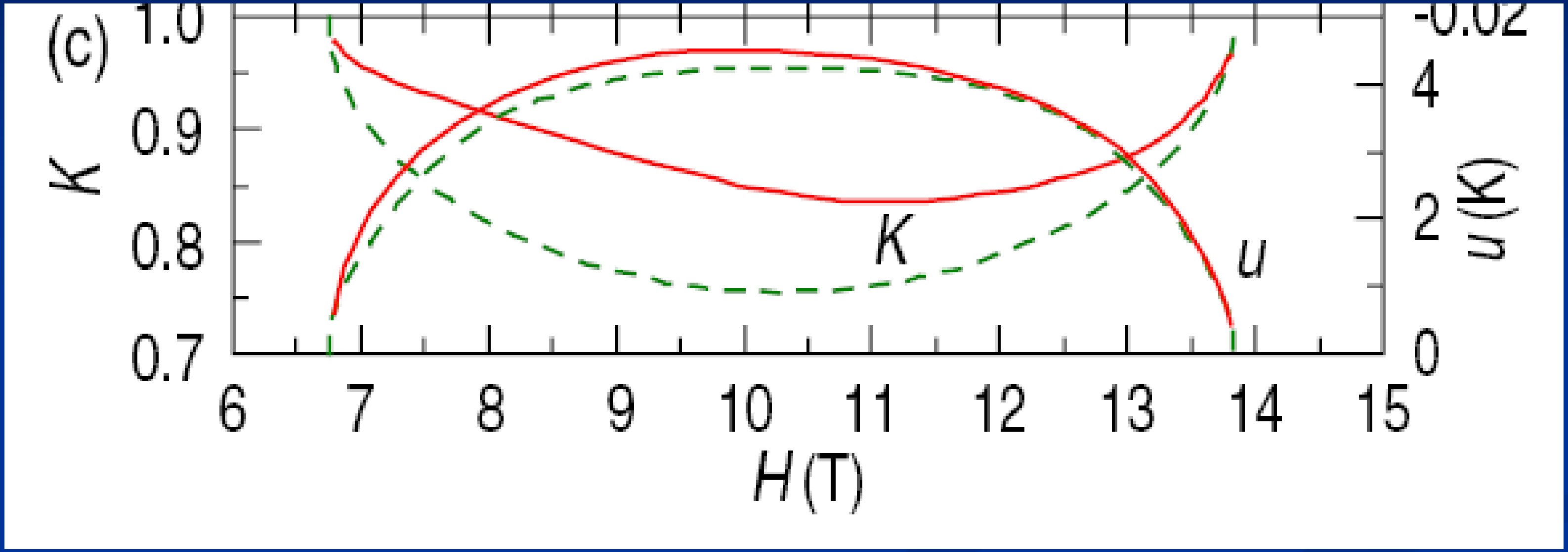


FIG. 4 (color online). Intensity plots of the logarithm of the dynamical one-particle correlation function of the Lieb-Liniger gas. Data obtained from systems of length $L = 150$ at unit density, and $\gamma = 0.5$, 2, 8, and 32. From J.-S. Caux, *et al.* (2007).

Luttinger parameters



M. Klanjsek et al., PRL 101 137207 (2008)

Red : Ladder (DMRG)

Green: Strong coupling ($J_r \to \infty$) (BA)

Correlation functions

M. Klanjsek et al., PRL 101 137207 (2008)

R. Chitra, TG PRB 55 5816 (97); TG, AM Tsvelik PRB 59 11398 (99)

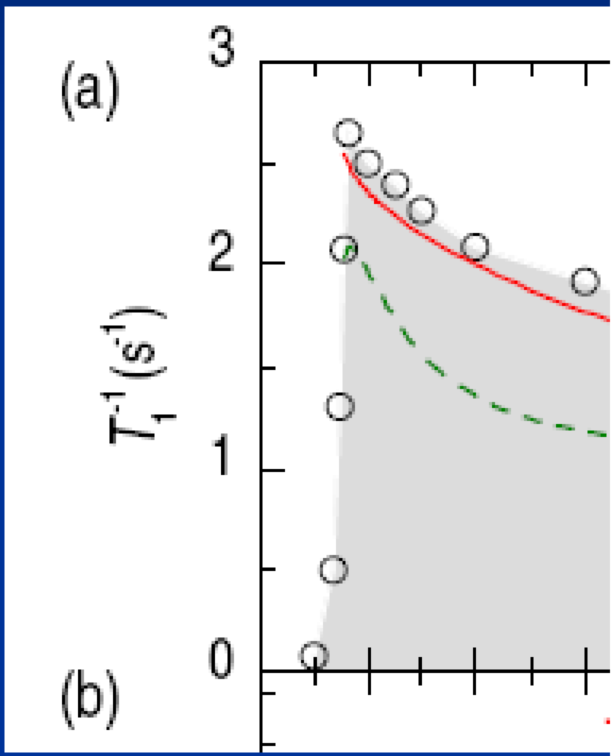
- NMR relaxation rate:

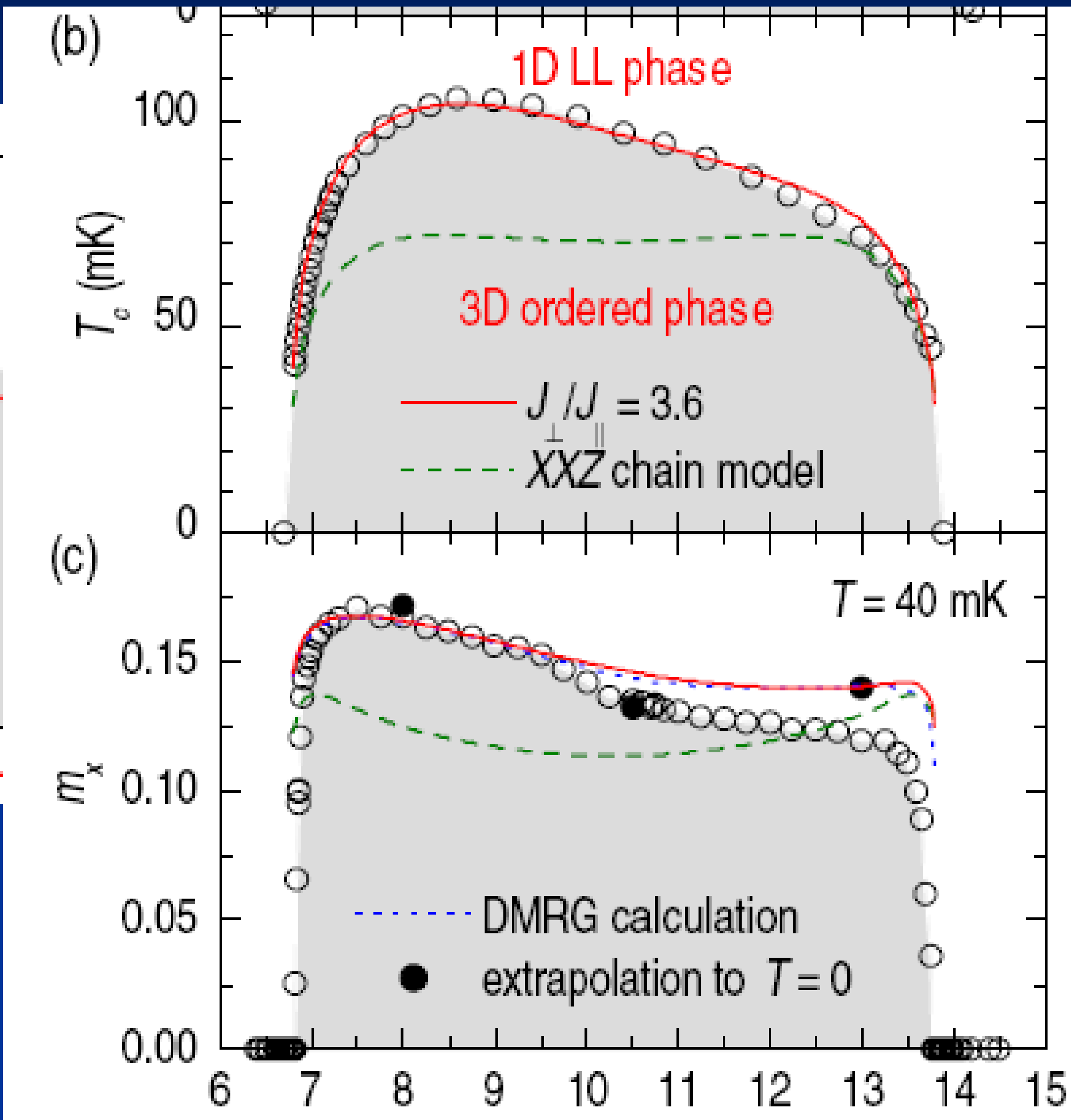
$$T_1^{-1} = \frac{\hbar\gamma^2 A_\perp^2 A_0^x}{k_B u} \cos\left(\frac{\pi}{4K}\right) B\left(\frac{1}{4K}, 1 - \frac{1}{2K}\right)\left(\frac{2\pi T}{u}\right)^{(1/2K)-1},$$

- Tc to ordered phase: $1/J' = \chi_{1D}(Tc)$

$$T_c = \frac{u}{2\pi}\left[\sin\left(\frac{\pi}{4K}\right) B^2\left(\frac{1}{8K}, 1 - \frac{1}{4K}\right)\frac{zJ' A_0^x}{2u}\right]^{2K/(4K-1)}.$$


NMR

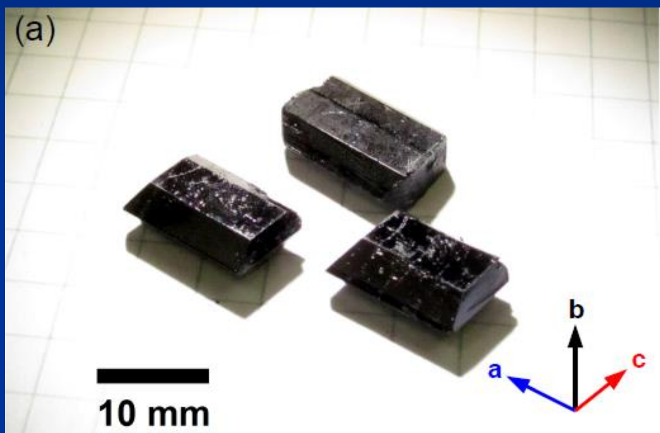


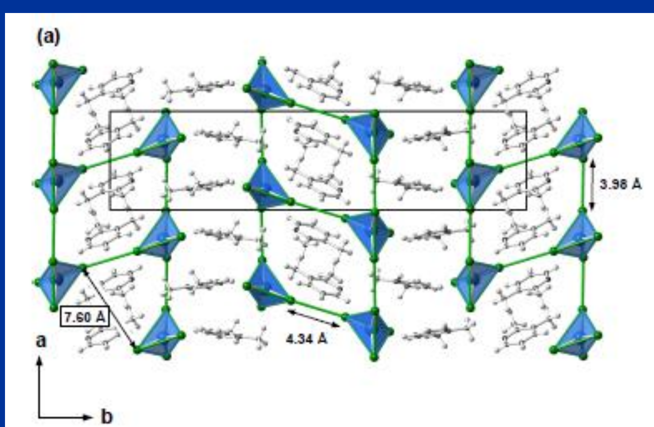
M. Klanjsek et al.,

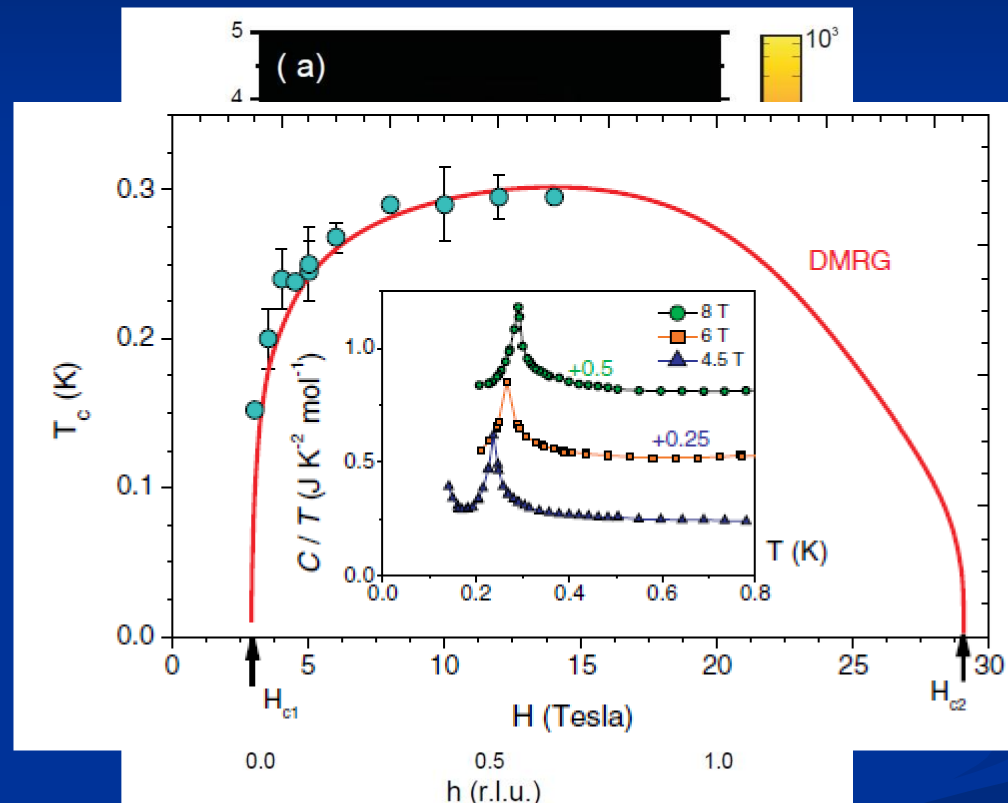
PRL 101 137207 (2008)

Ab initio reconstruction

D. Schmidiger et al. PRL 108 167201 (2012)







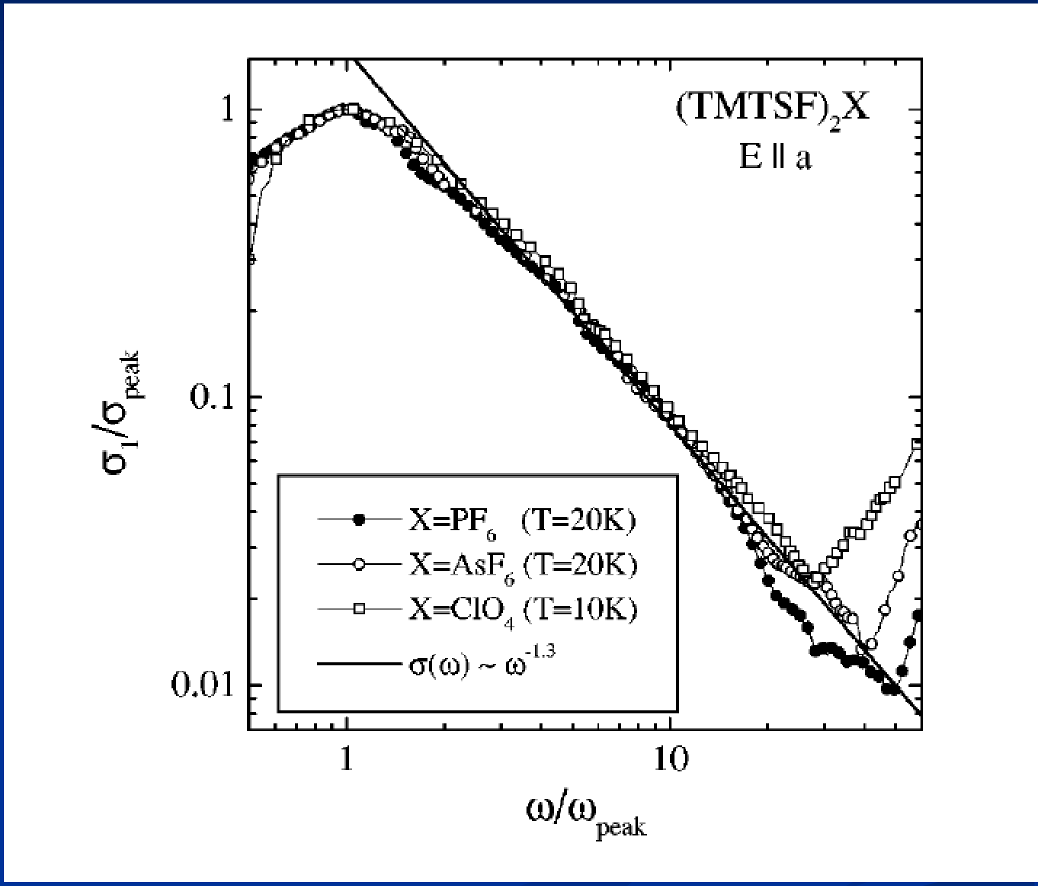
$$\mathcal{H} = J_{\rm leg}\sum_{l,j} S_{l,j}\cdot S_{l+1,j} + J_{\rm rung}\sum_{l} S_{l,1}\cdot S_{l,2} - g\mu_B H \sum_{l,j} S^z_{l,j}.$$

Optical conductivity

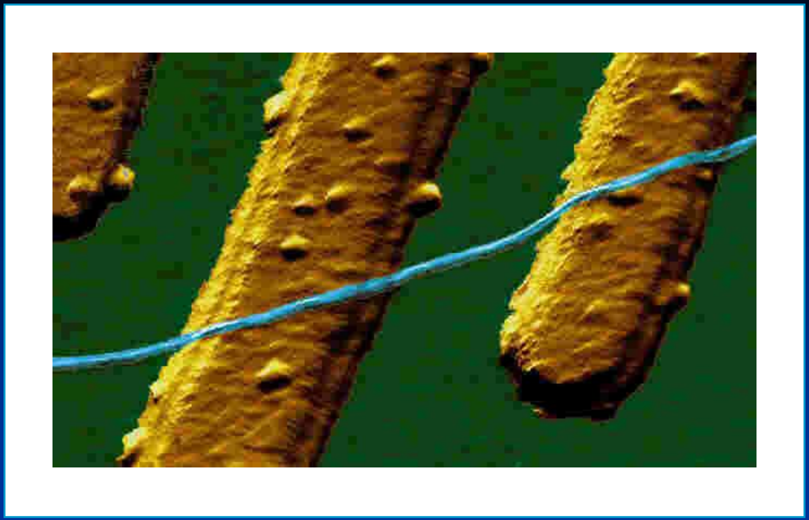
$$\sigma(\omega) \propto \omega^{\nu}$$

TG PRB (91) :
Physica B 230 (1996)

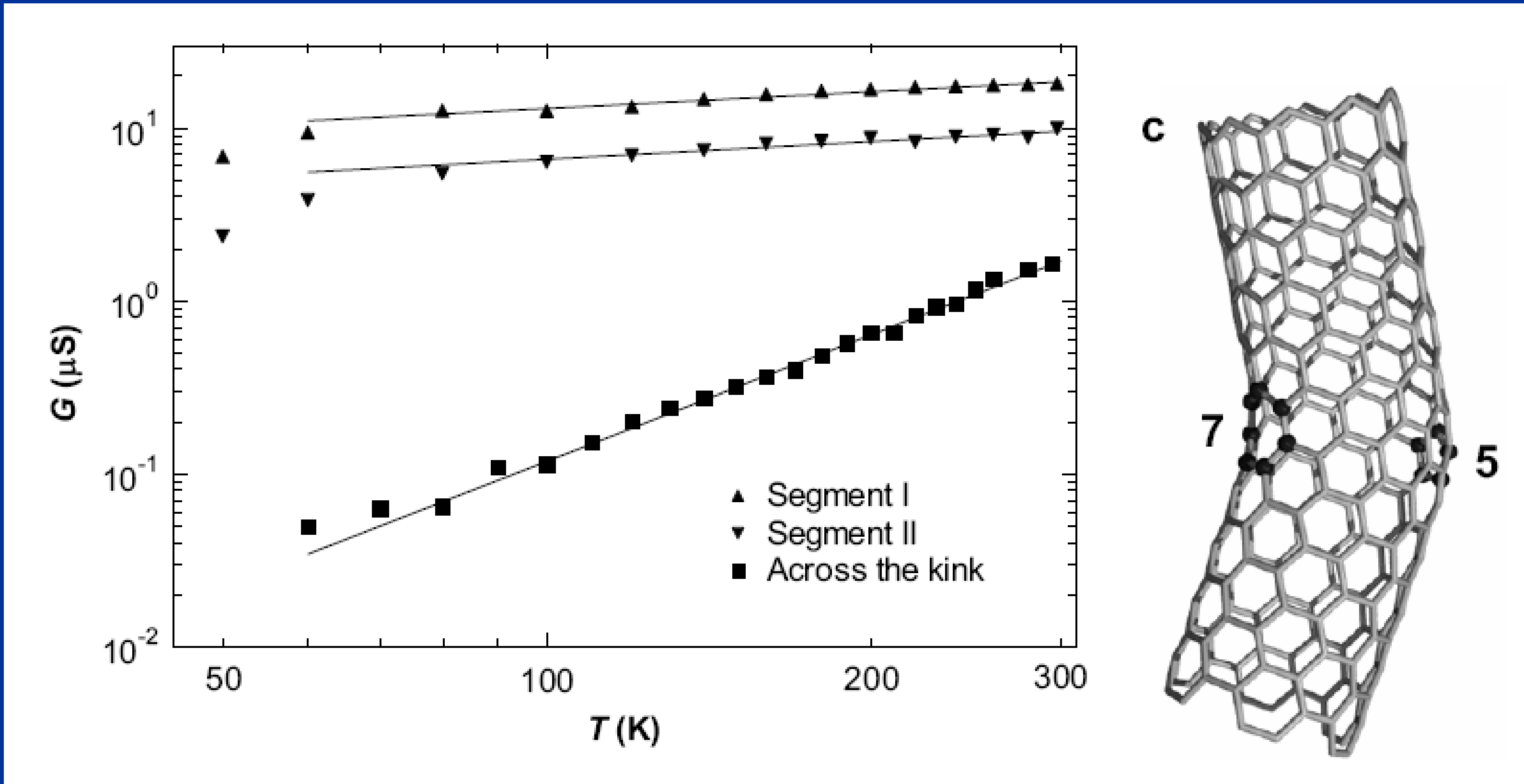
First observation of LL !!



A. Schwartz et al. PRB 58 1261 (1998)

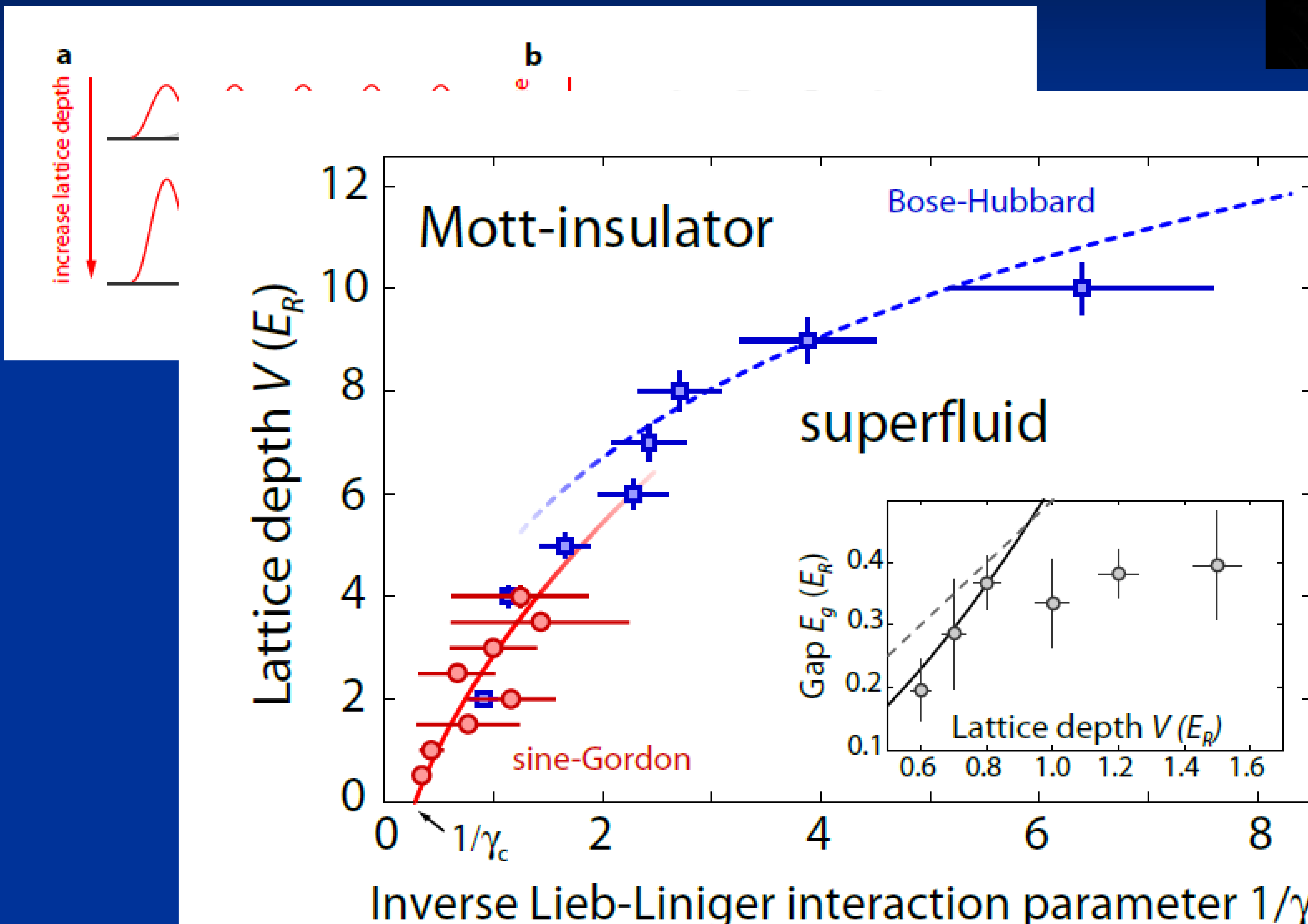


Z. Yao et al. Nature 402 273 (1999)



External potentials

E. Haller et al. Nature 466 597 (2010)



Disorder

Bose glass phase

1D : TG + H. J. Schulz PRB 37 325 (1988)

Superfluid – Localized (Bose glass) transition for $K < 3/2$

BKT like transition

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

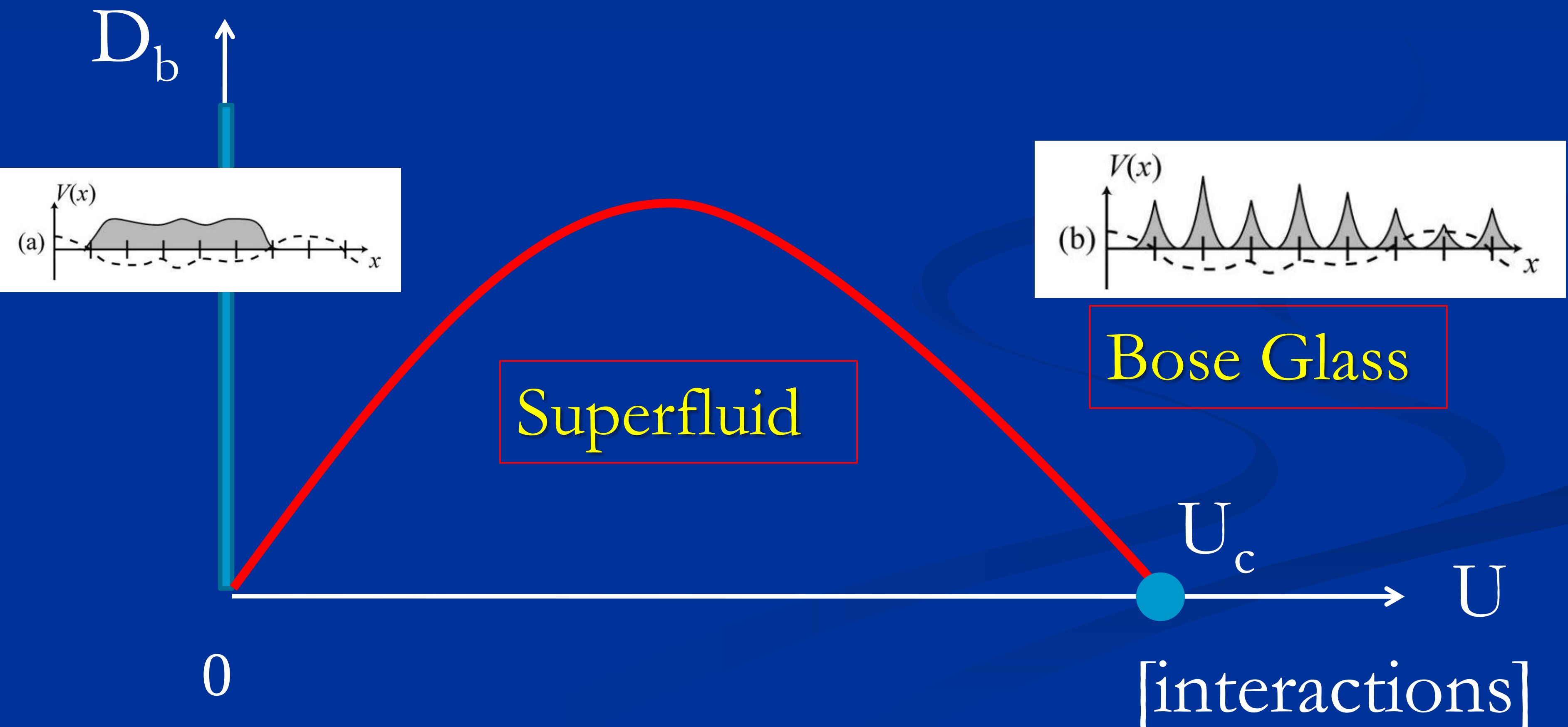
Bose glass also exists (scaling theory)

continuous transition

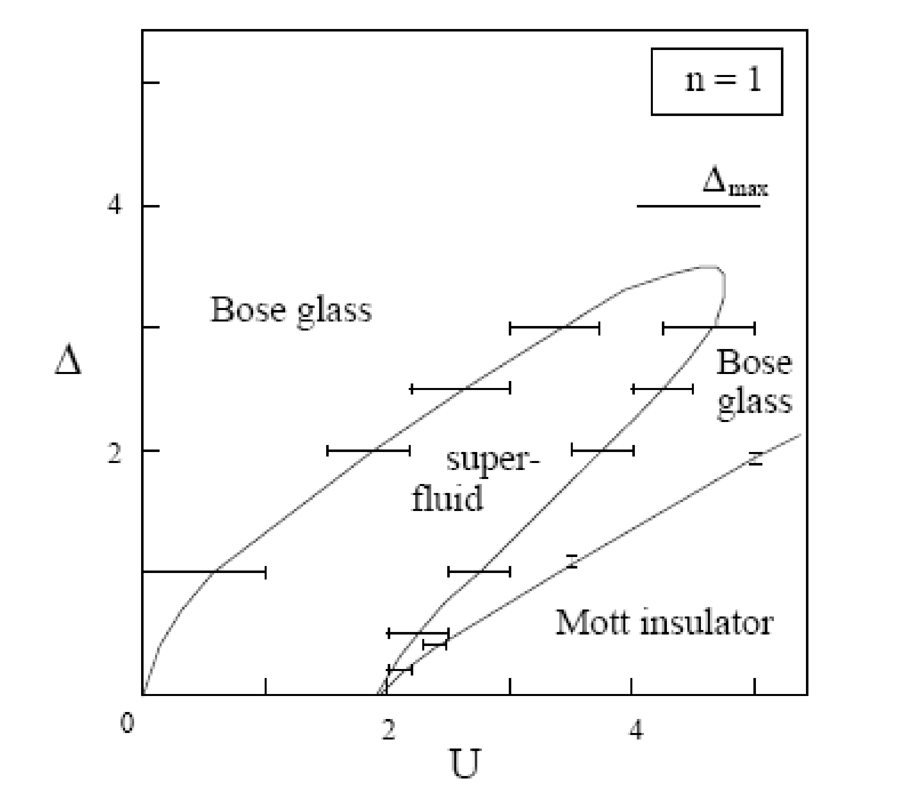
Bose glass phase

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

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



Numerics



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

G. Batrouni et al. PRL 65 1765 (90);
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)
…..

Strong disorder, weak interactions

PHYSICAL REVIEW B **81**, 174528 (2010)

Superfluid-insulator transition of disordered bosons in one dimension

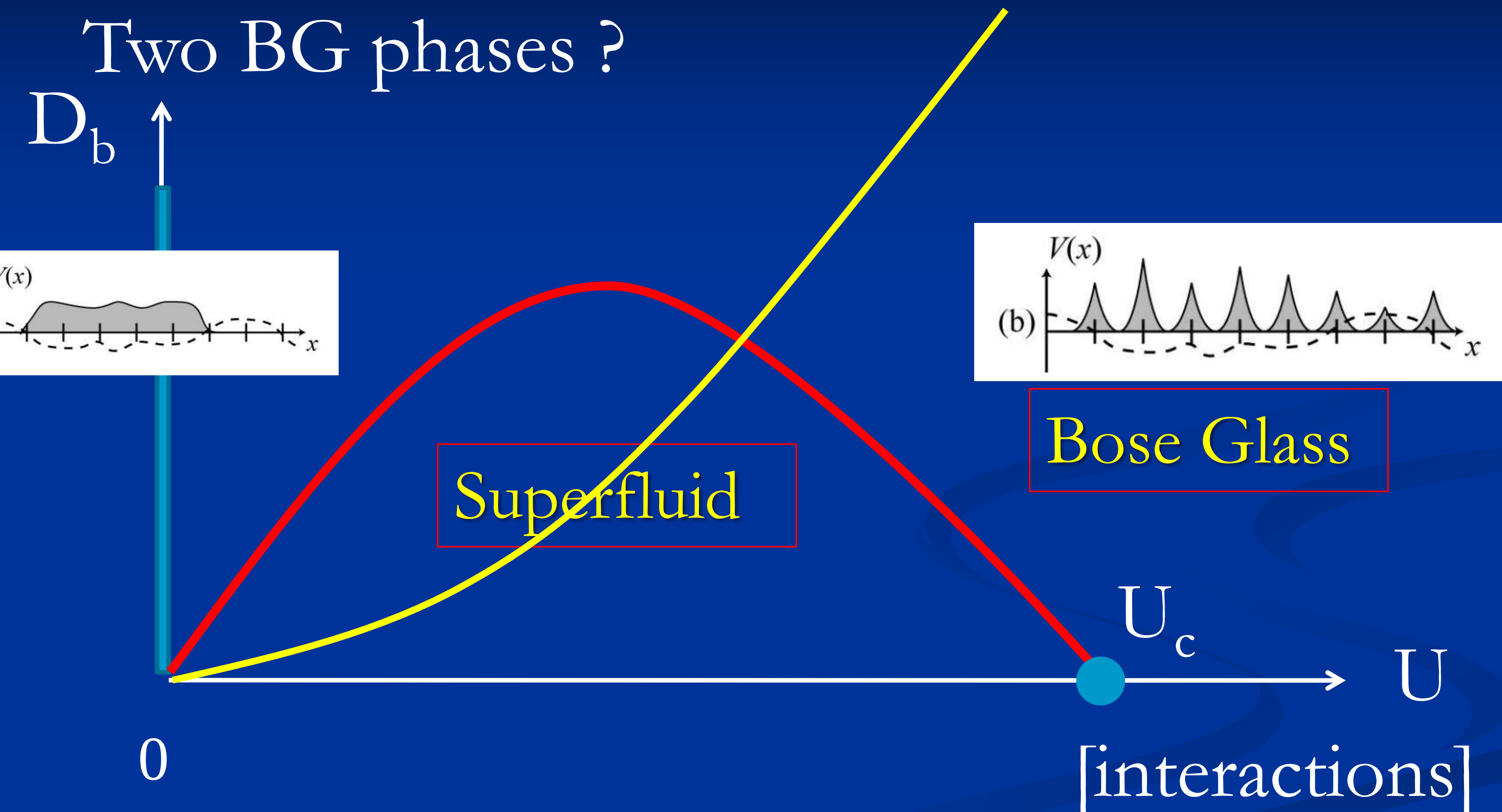
Ehud Altman,[1] Yariv Kafri,[2] Anatoli Polkovnikov,[3] and Gil Refael[4]

phase diagram. We show that the superfluid-insulator transition is always Kosterlitz-Thouless like in the way that length and time scales diverge at the critical point. Interestingly however, we find that the transition at strong disorder occurs at a nonuniversal value of the Luttinger parameter, which depends on the disorder strength. This result places the transition in a universality class different from the weak disorder transition first analyzed by Giamarchi and Schulz [Europhys. Lett. **3**, 1287 (1987)]. While the details of the disorder potential

How to connect the two results ?

Phase diagram

Two BG phases ?



Order parameter ? Moments of distribution ?

Experiments

Cold atomic gases

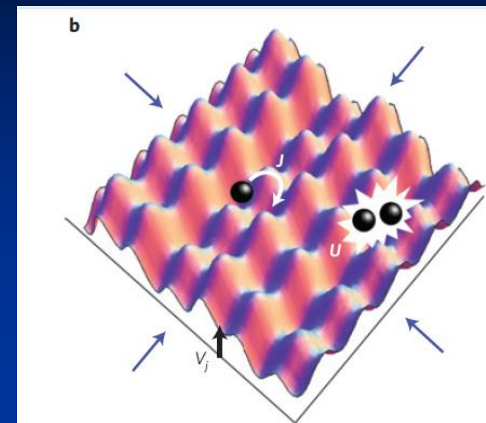
nature physics

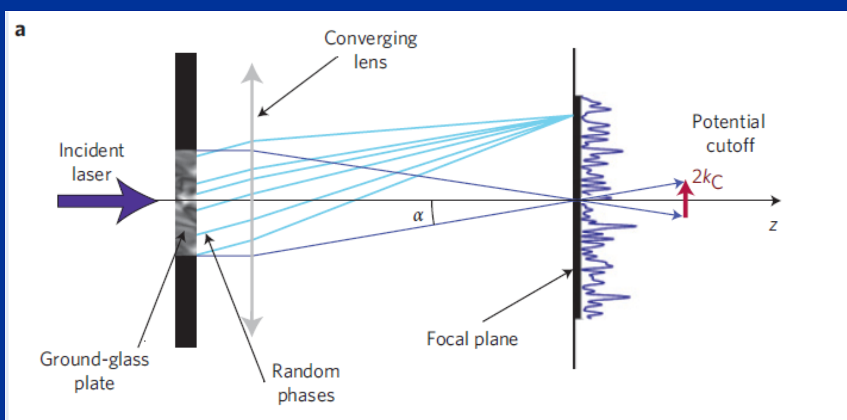
PROGRESS ARTICLE

PUBLISHED ONLINE: 1 FEBRUARY 2010 | DOI: 10.1038/NPHYS1507

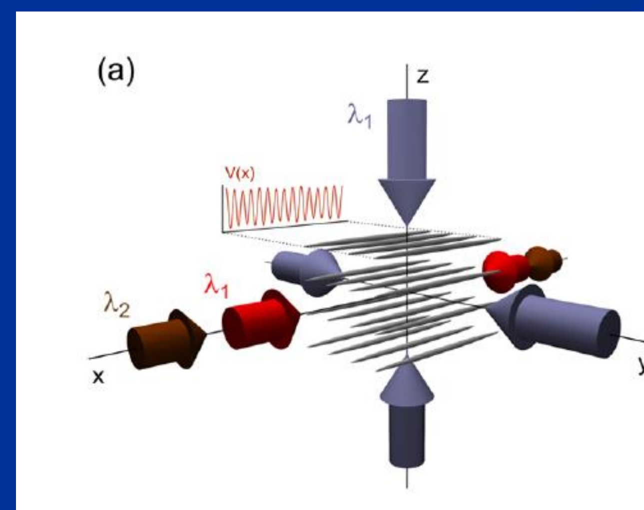
Disordered quantum gases under control

Laurent Sanchez-Palencia[1]★ and Maciej Lewenstein[2]★





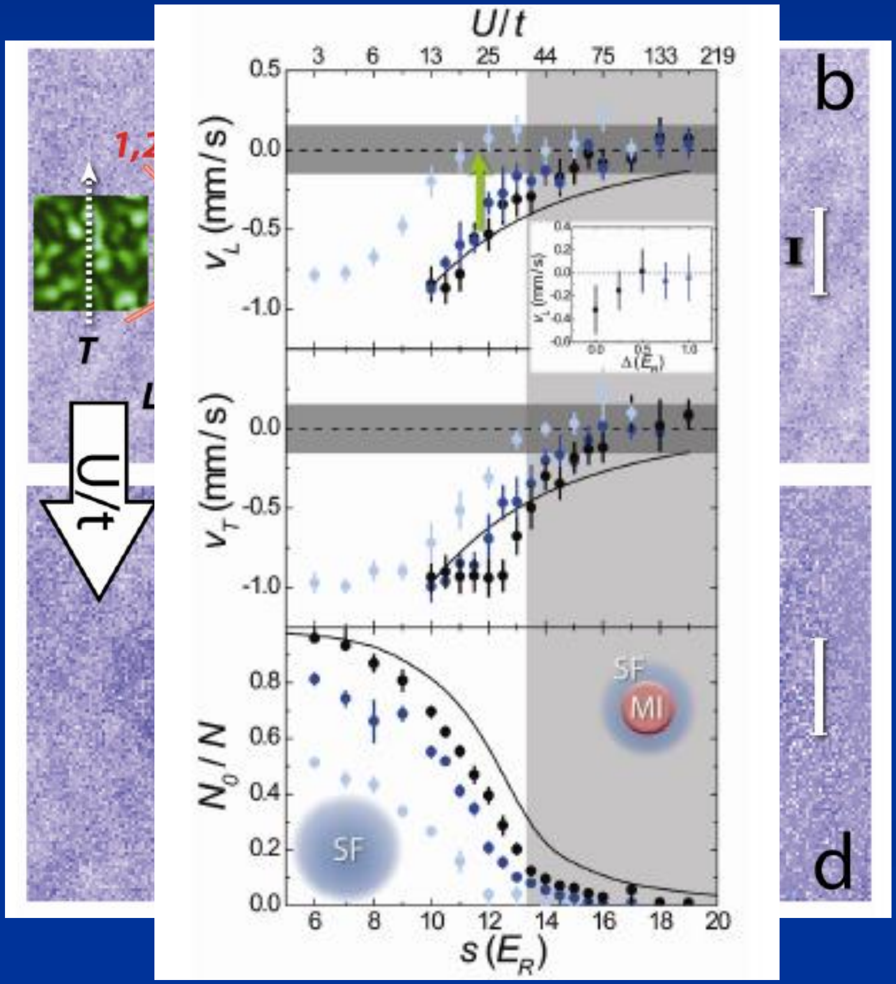
Speckle

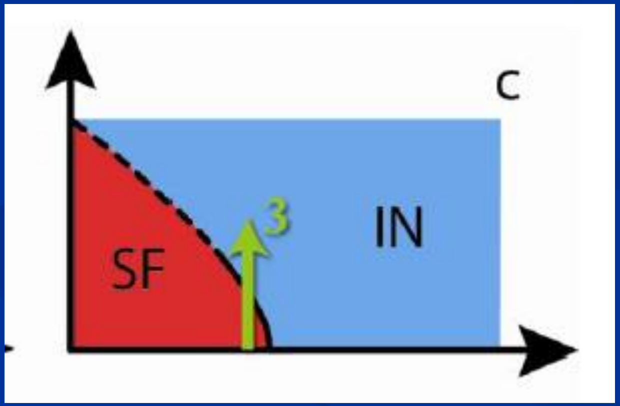


Biperiodic lattices

Speckle

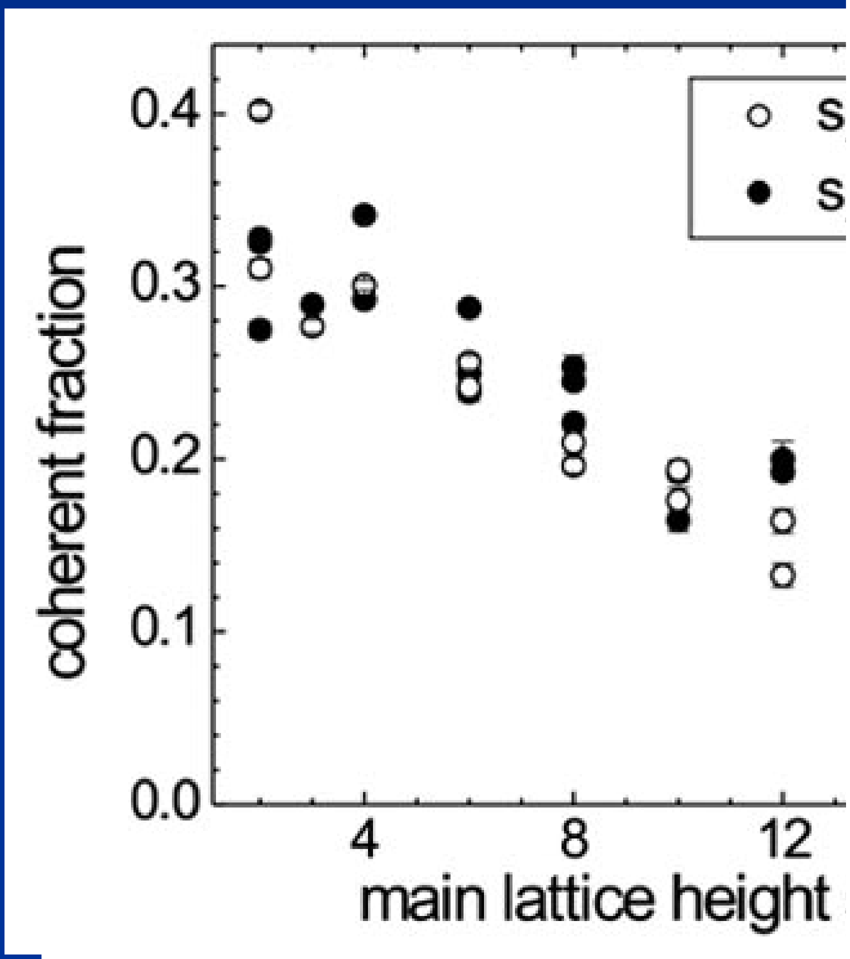
Pasienski et al. Nat. Phys 6 677 (2010)

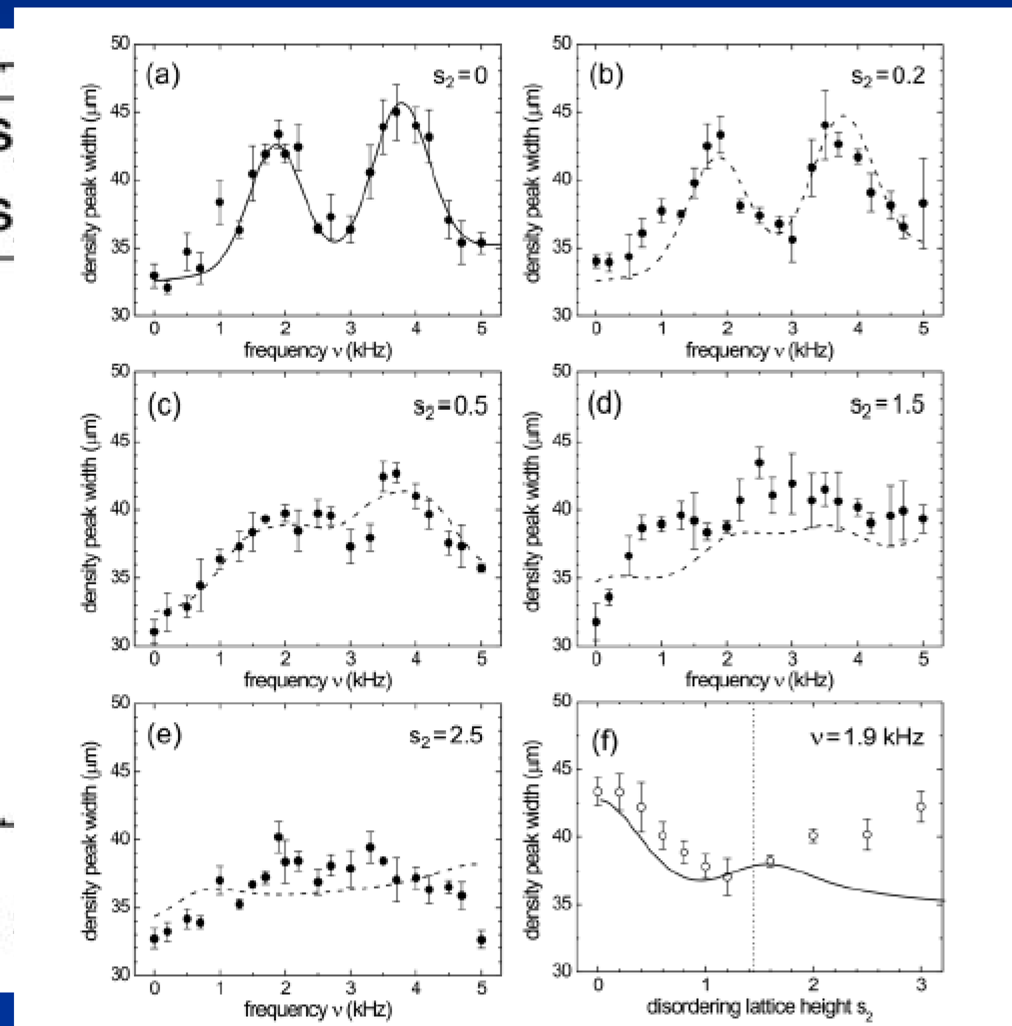




Quasi-periodic

Quasiperiodic (1D):





Same as true disorder ?

Renormalization treatment

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

$$\frac{dK}{dl} = -K^2 \Xi(l),$$

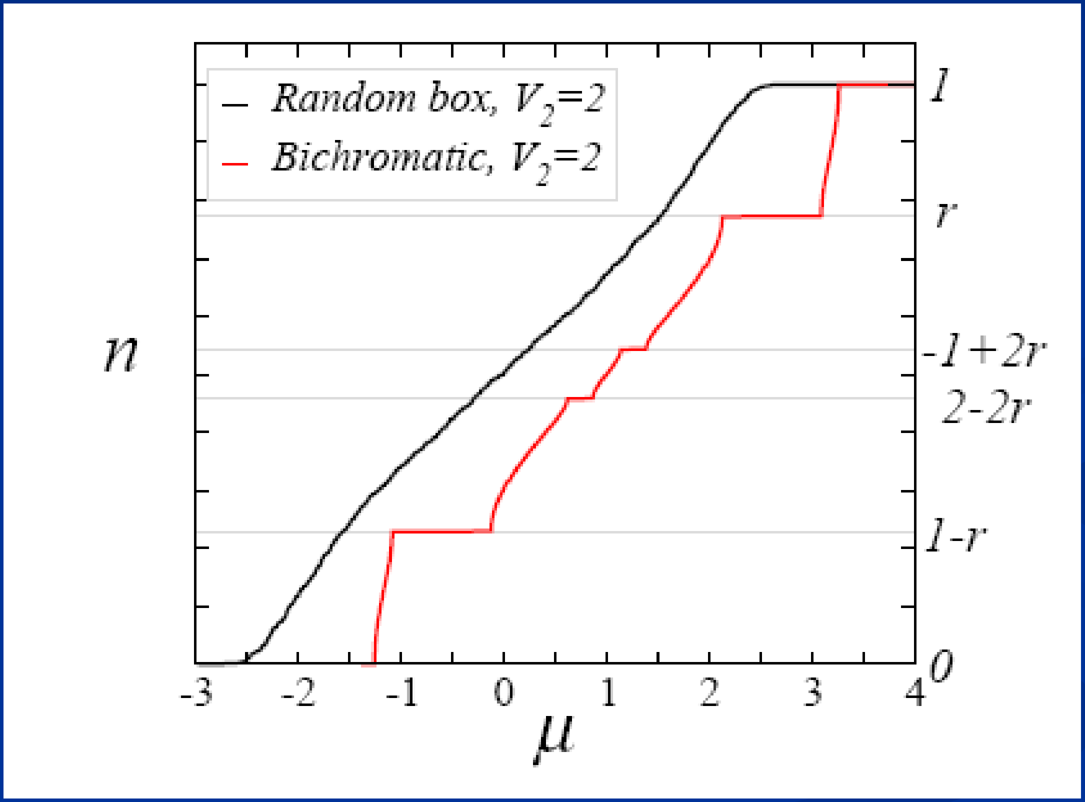
$$\frac{dy_Q}{dl} = (2-K) y_Q,$$

y_Q : Fourier components of potential

$$\Xi(l) = \frac{1}{2} \sum_Q y_Q^2 [\mathrm{J}(Q^+ \alpha(l)) + \mathrm{J}(Q^- \alpha(l))],$$

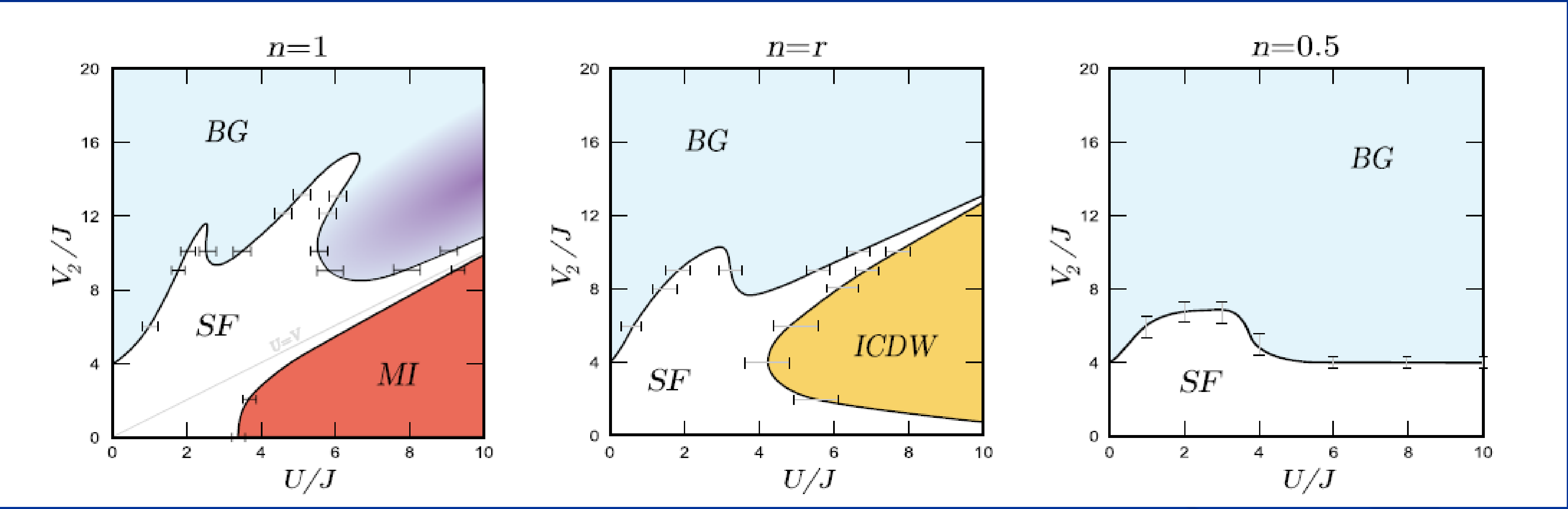
Numerics: DMRG

G. Roux et al. PRA 78 023628 (2008)

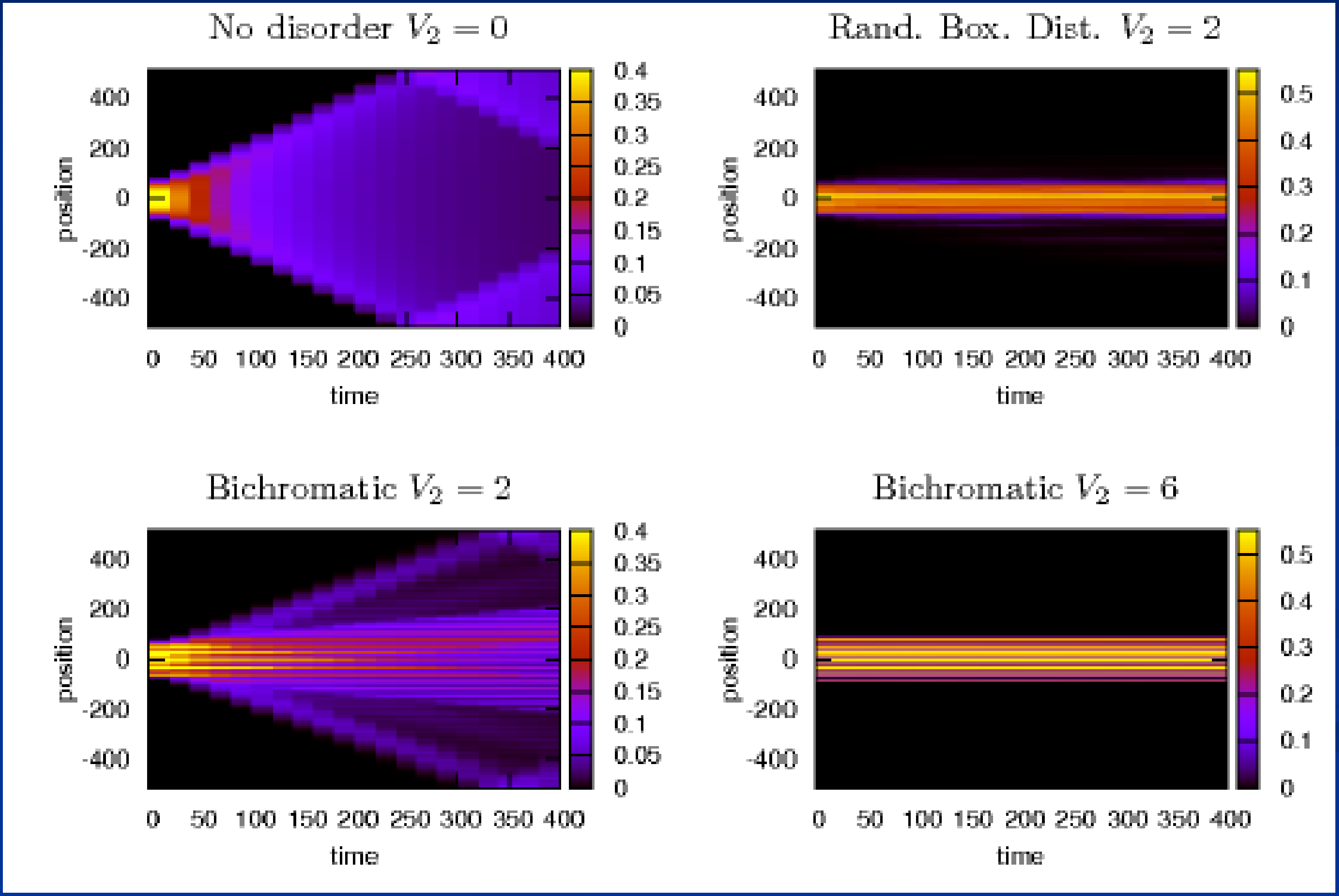


Related works: T. Roscilde, Phys. Rev. A 77, 063605 2008; X. Deng et al PRA 78, 013625 (2008)

Phase diagram

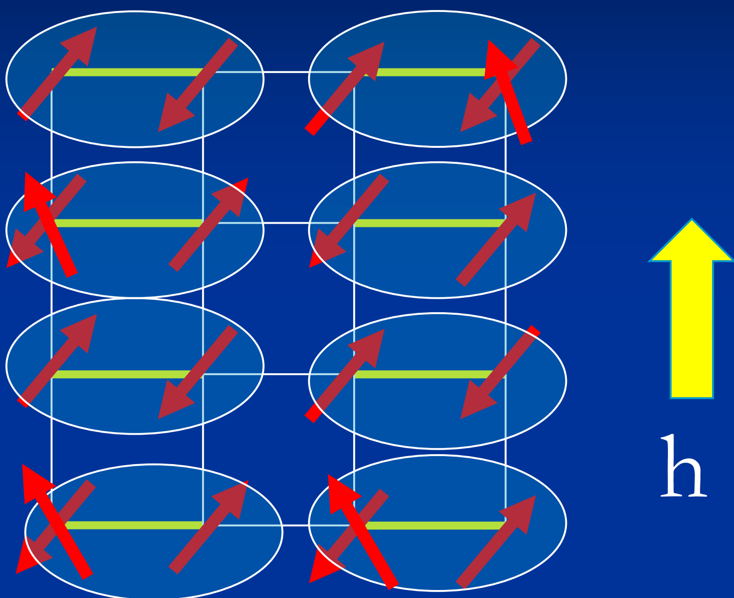


Expansion



No disorder $V_2 = 0$
Rand. Box. Dist. $V_2 = 2$
Bichromatic $V_2 = 2$
Bichromatic $V_2 = 6$
position
time
400
200
0
-200
-400
0 50 100 150 200 250 300 350 400
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.5
0.4
0.3
0.2
0.1
0

Disordered spin dimers



$|S\rangle, |T\rangle \rightarrow |0\rangle, b^{\dagger}|0\rangle$

$\langle S_x \rangle = \langle \tilde{A} \rangle$ superfluid order parameter

d m/d h = compressibility

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

RAPID COMMUNICATIONS

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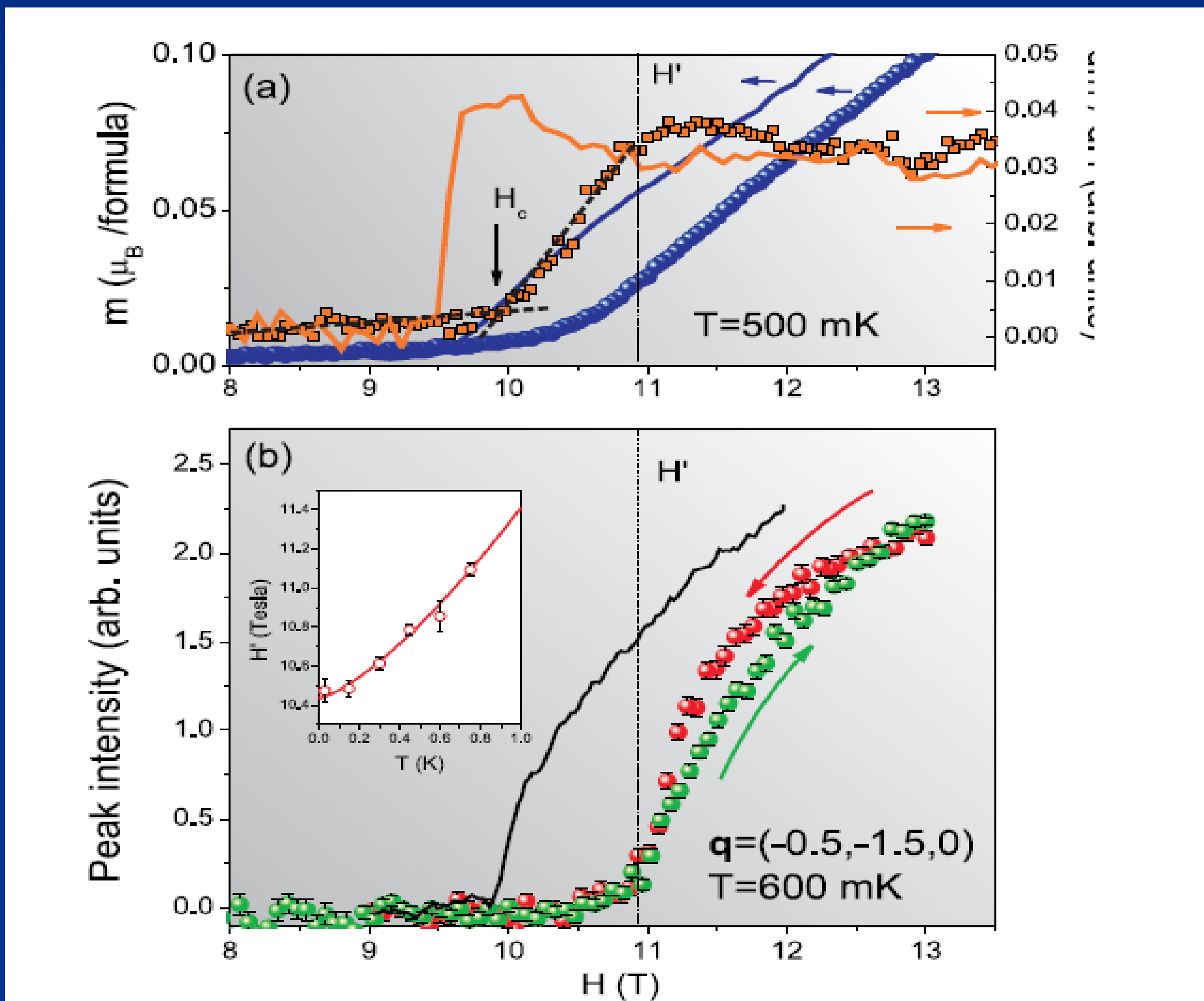
Evidence of a magnetic Bose glass in $(CH_3)_2CHNH_3Cu(Cl_{\{0.95\}}Br_{\{0.05\}})_3$ from neutron diffraction

Tao Hong,[1] A. Zheludev,[2,3,*] H. Manaka,[4] and L.-P. Regnault[5]



$$\frac{dm}{dh} \neq 0$$

$$\langle \psi \rangle = 0$$

Bose Glass phase

DTN

Bose glass and Mott glass of quasiparticles in a doped quantum magnet

Rong Yu,[1] Liang Yin,[2] Neil S. Sullivan,[2] J. S. Xia,[2] Chao Huan,[2] Armando Paduan-Filho,[3] Nei F. Oliveira Jr.,[3] Stephan Haas,[4] Alexander Steppke,[5] Corneliu F. Miclea,[6] Franziska Weickert,[6] Roman Movshovich,[6] Eun-Deok Mun,[6] Vivien S. Zapf,[6] and Tommaso Roscilde[7]

arXiv:1109.4403v2