Metal insulator transitions

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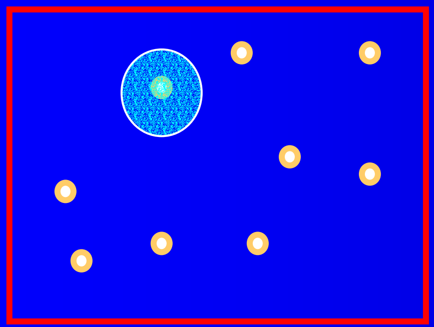
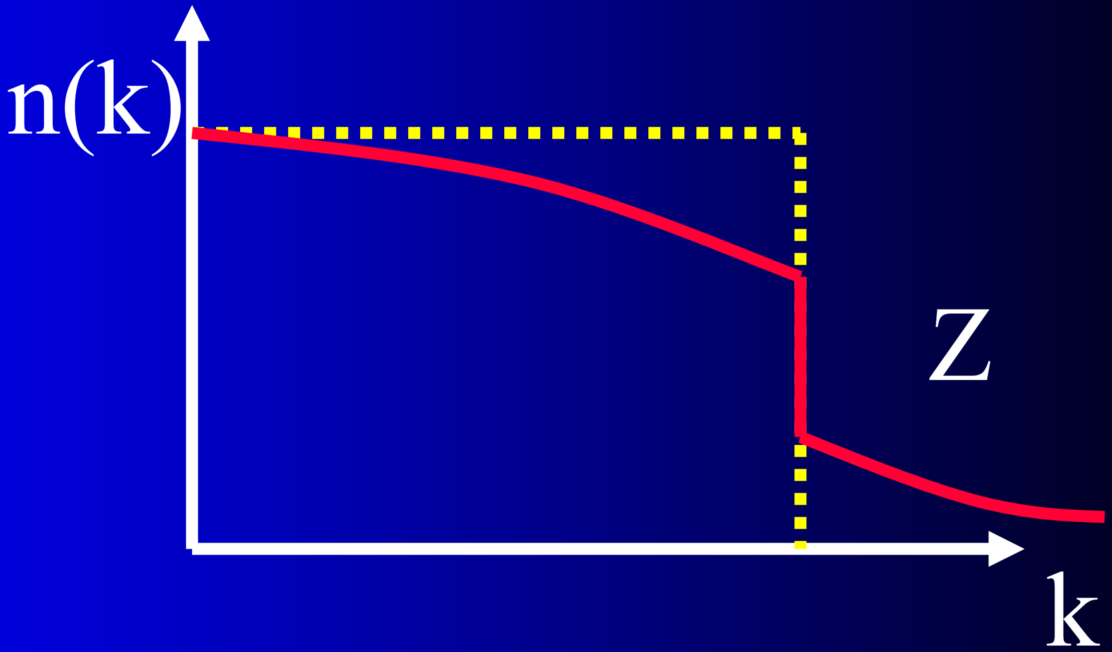
Fermi liquid : crash course

- Individual fermionic excitations exist (as for free electrons)



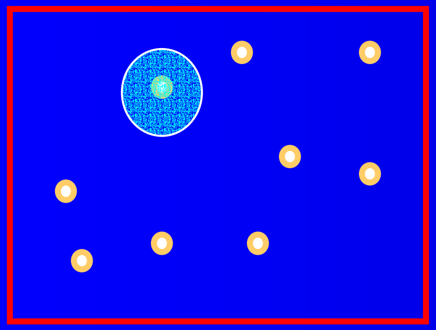


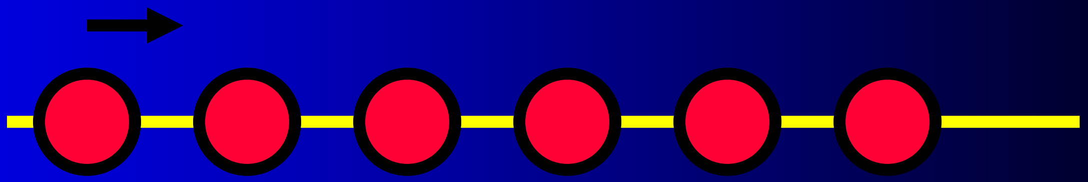
Goal of the game

- Electron + interactions : physical properties ???
- d=3 : Fermi liquid = interactions not really important
- Special cases (d=1, strong interactions, disorder …)

D=1

- No individual excitation can exist (only collective ones)

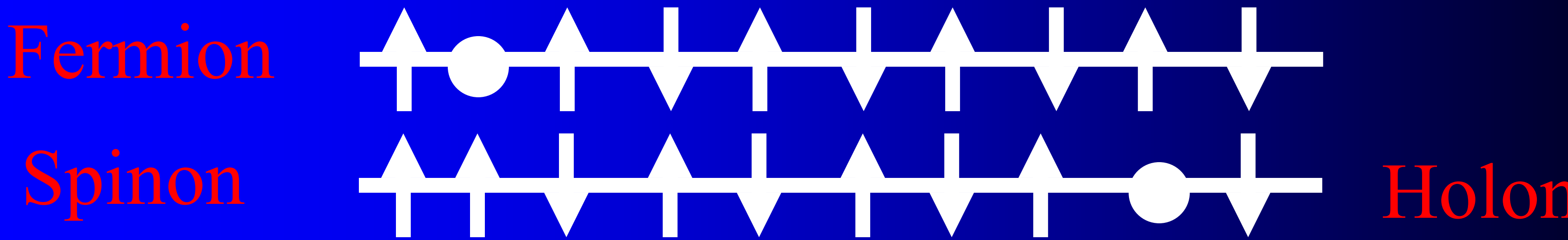




- Strong quantum fluctuations (``no'' ordered state or mean field possible)

Luttinger liquid

- Spin charge separation



- No fermionic quasiparticles
- Power law decay of correlation functions

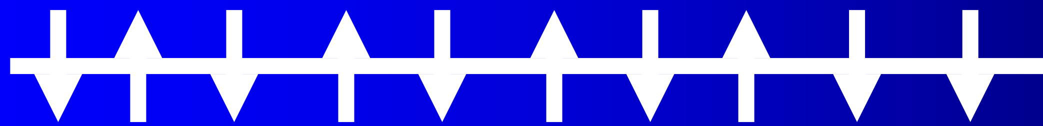
$$\langle S(x)S(0)\rangle = \frac{1}{x^2} + \cos(2k_F x)\left(\frac{1}{x}\right)^{1+K_\rho} + \ldots$$

MI due to interactions

- Commensurability + interactions = Mott transition

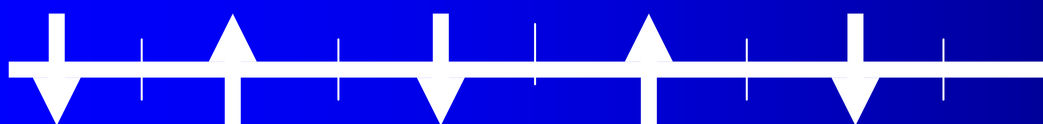
- Commensurability + interactions = Wigner crystallization

Mott Transition

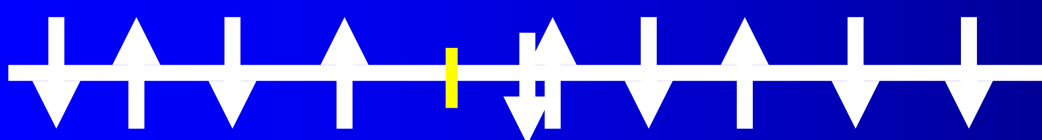


½ filling

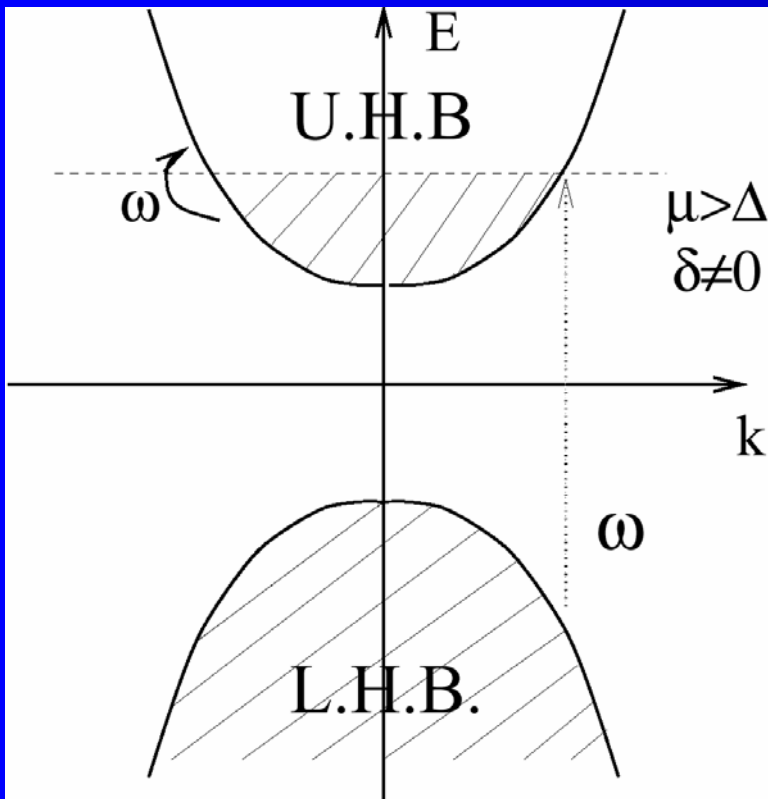
Any commensurate filling works

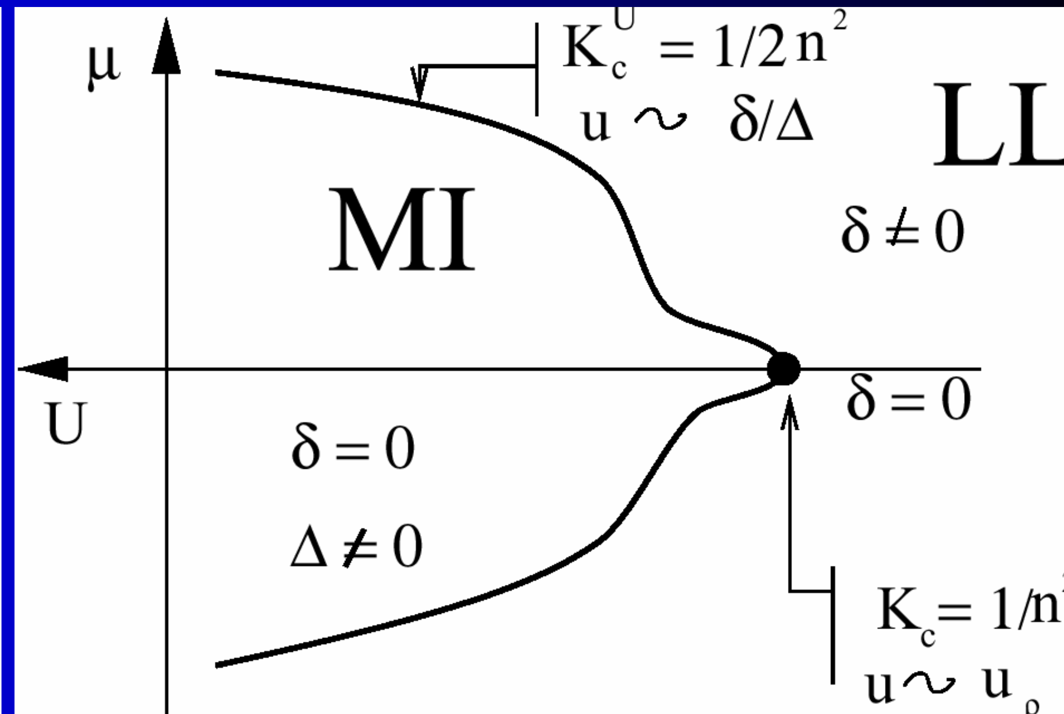


- Charge gap

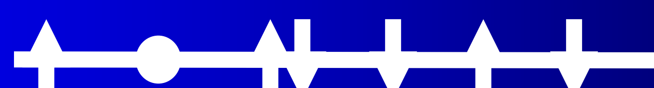


Example: Mott in d=1



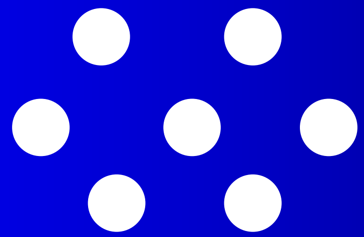


Excitations (solitons of charge) are like fermions



Wigner crystal

- Long range interactions



- Low densities
- Kill kinetic energy with a magnetic field

Effect of disorder

- Anderson localization

- Mott insulator + disorder : Mott glass

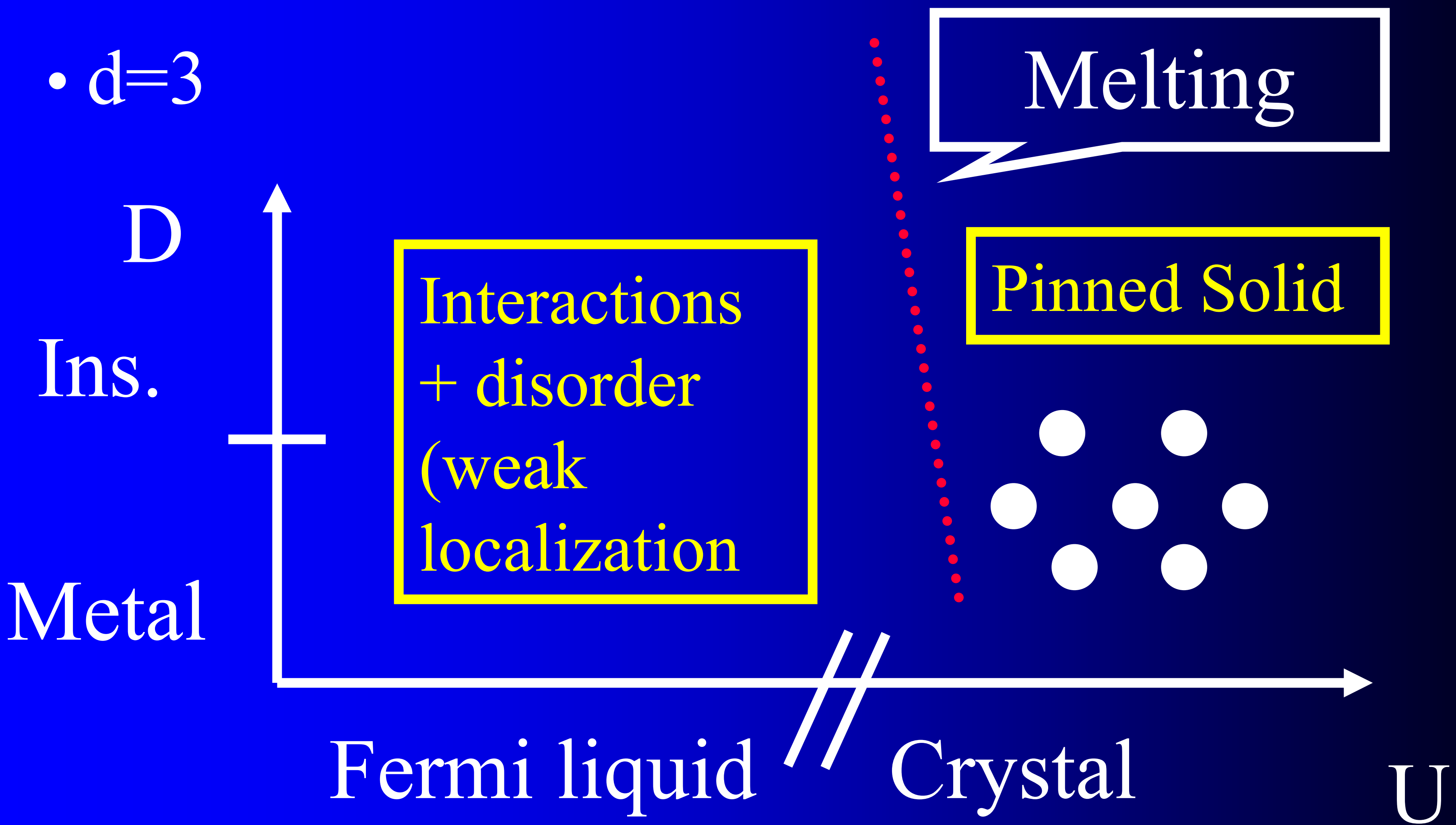
[E. Orignac, TG, P. Le Doussal PRB 64 245119 (2001)]

- Wigner crystal + disorder :

  Quantum crystals

[TG,E. Orignac, cond-mat 0005220; TG cond-mat 0205099]

Disorder and interactions



Wigner Crystal

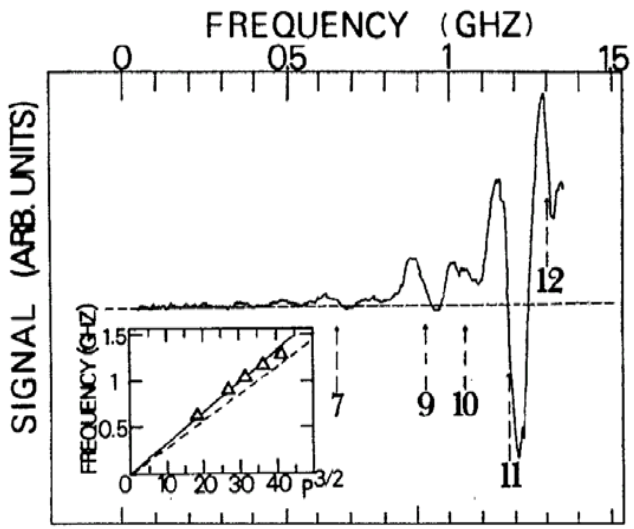


FIG. 1. Absorption spectrum at 28 T and 60 mK for density 0.77×10^{11} cm^{-2} (filling factor $\nu=1/8.7$, reduced temperature $t=0.33$) showing successive resonances and their identification as pth spatial harmonics ($q=pq_0$) of the exciting structure. The values of p are chosen for the best alignment with the origin (full line) on the accompanying plot of f_p vs $p^{3/2}$; the dashed line is the zero-order *a priori* calculation of the frequency of the lower hybrid mode of the solid.

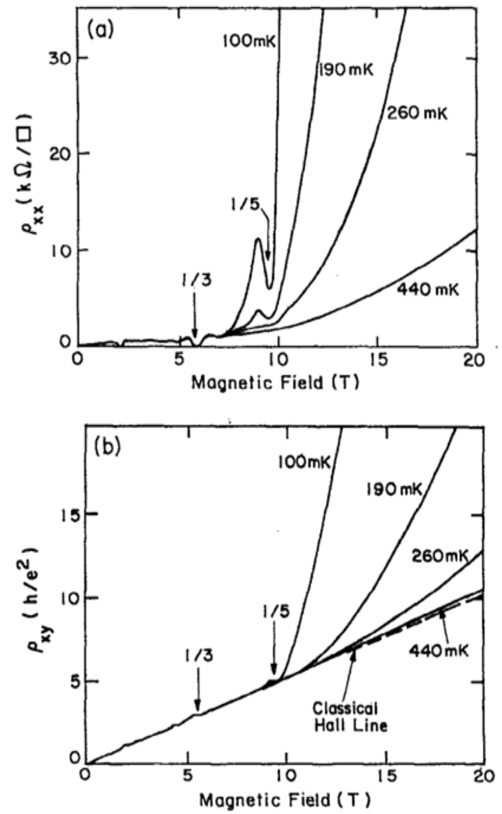
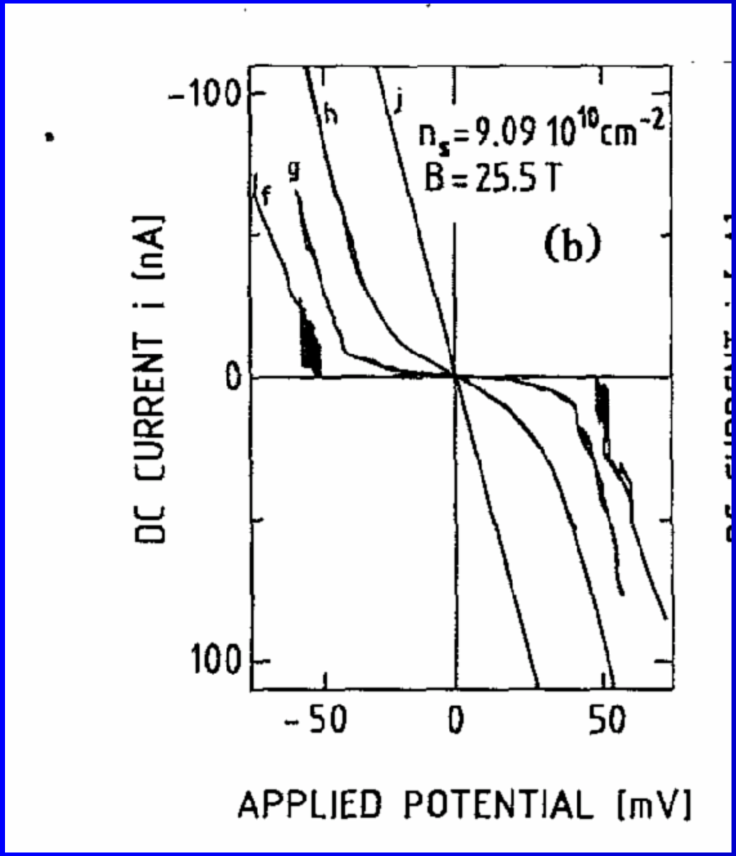
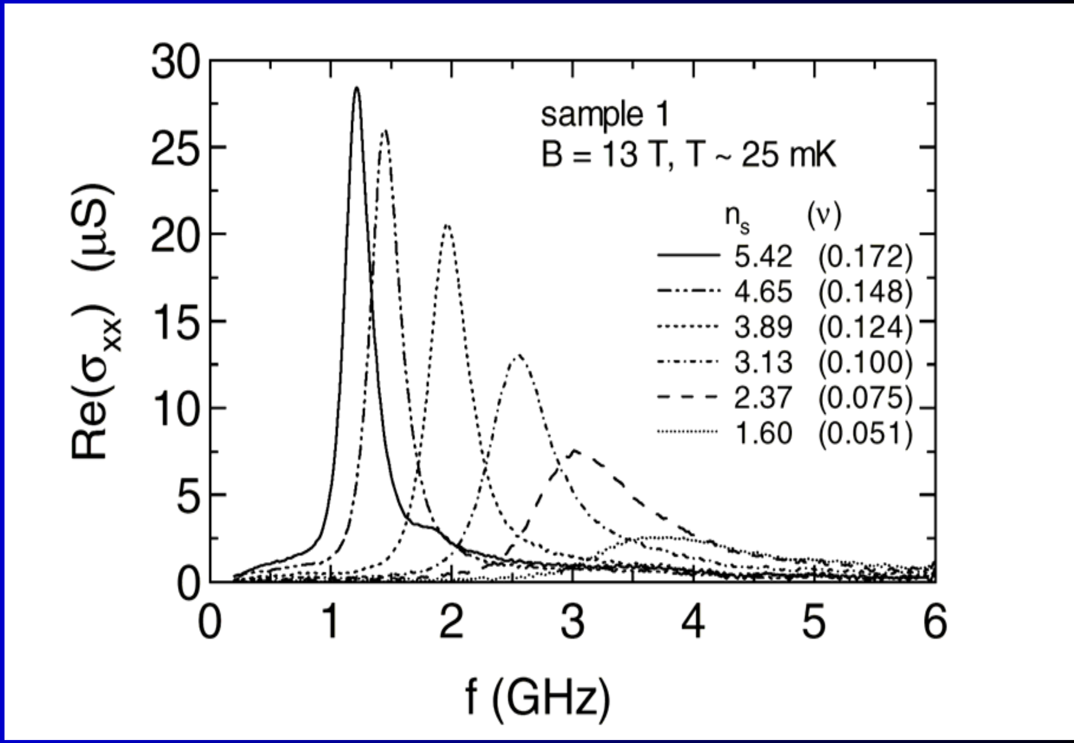


FIG. 1. (a) Diagonal resistivity ρ_{xx} and (b) Hall resistance ρ_{xy} of a low-density ($n=4.8\times10^{10}$ cm^{-2}) high-mobility ($\mu=1.7\times10^{6}$ cm^2/V sec) two-dimensional electron system at various temperatures.

E.Y. Andrei, et al PRL 60 2765 (1988)

R.L. Willett, et al. PRB 38 R7881 (1989)

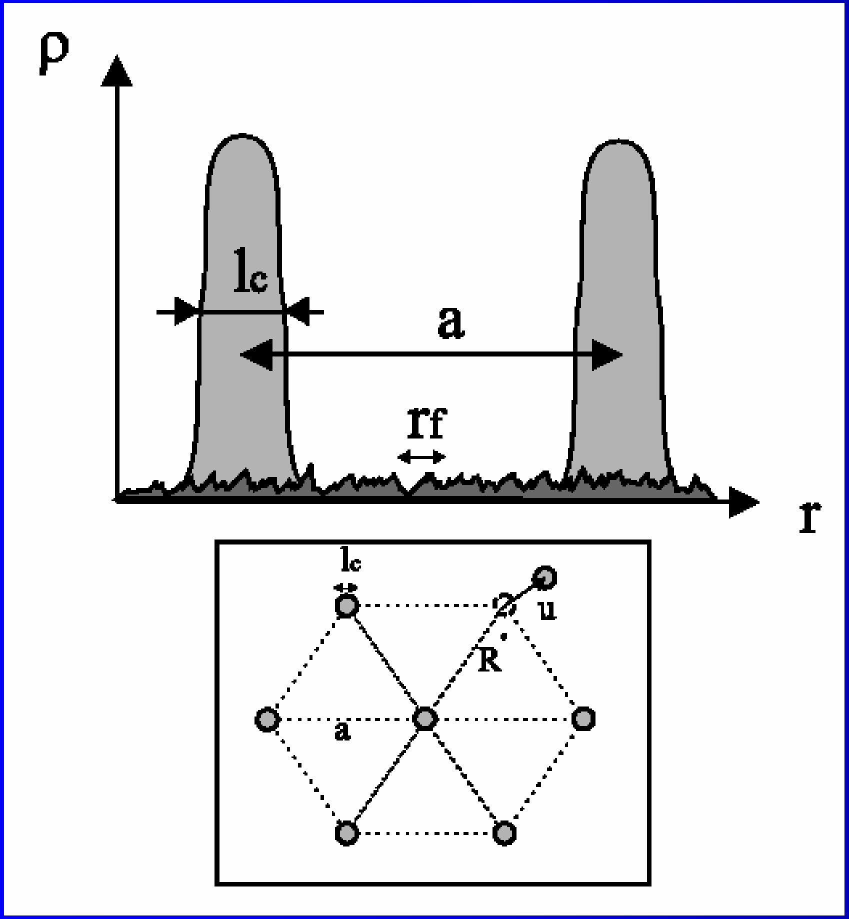




F.I.B. Williams et *al.*
PRL 66 3285 (1991)

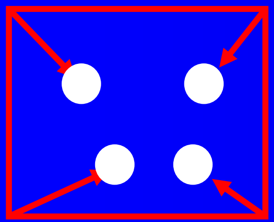
C.-C. Li, et al. PRB 61
10905 (2000)

Model for quantum solids

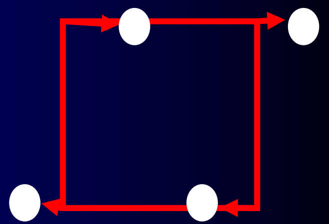


- Forget exchange (valid inside crystal phase)
- Model by a quantum crystal
- Elastic description

3 lengthscales: lc, a, rf



$$\vec{u}(q) = \hat{q} u_L(q) + \hat{q} \wedge \hat{z} u_T(q)$$

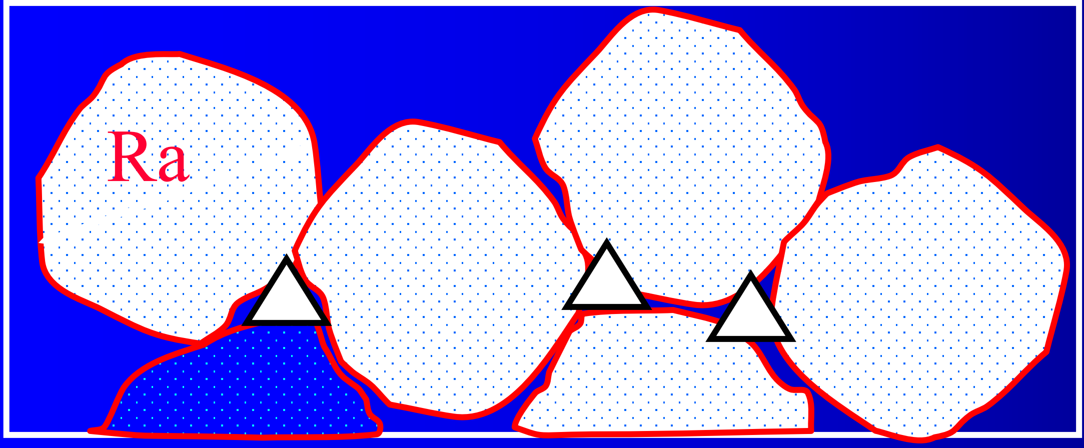


Quantum effects, Coulomb, Lorentz

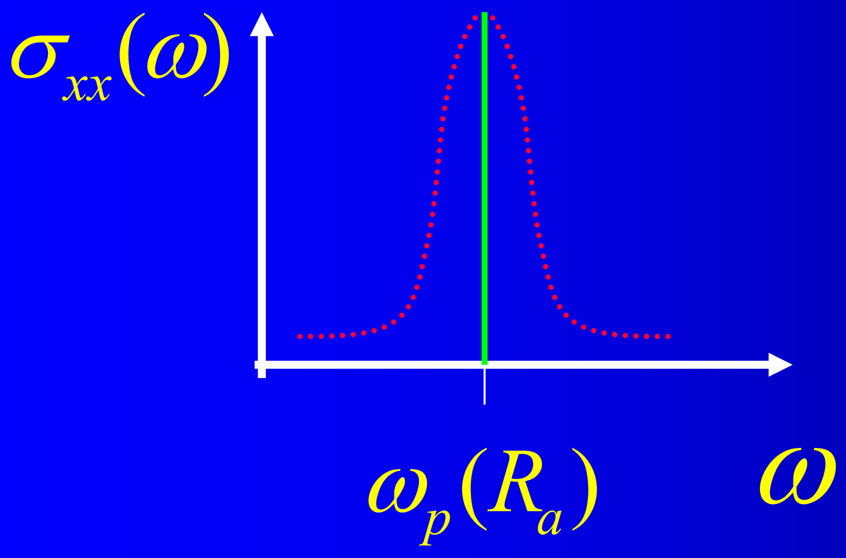
$$S[u] \quad = \quad \int \sum_n \left[u^L_{q,\omega_n} (\rho_m \omega_n^2 + c q^2 + d q) u^L_{-q,-\omega_n} \right]$$
$$+ \left[u^T_{q,\omega_n} (\rho_m \omega_n^2 + c q^2) u^T_{-q,-\omega_n} \right]$$
$$+ \rho_m \omega_c \omega_n \left[u^L_{q,\omega_n} u^T_{-q,-\omega_n} - u^L_{-q,-\omega_n} u^T_{q,\omega_n} \right]$$

+ disorder

Conventional Wisdom



Each block is pinned individually



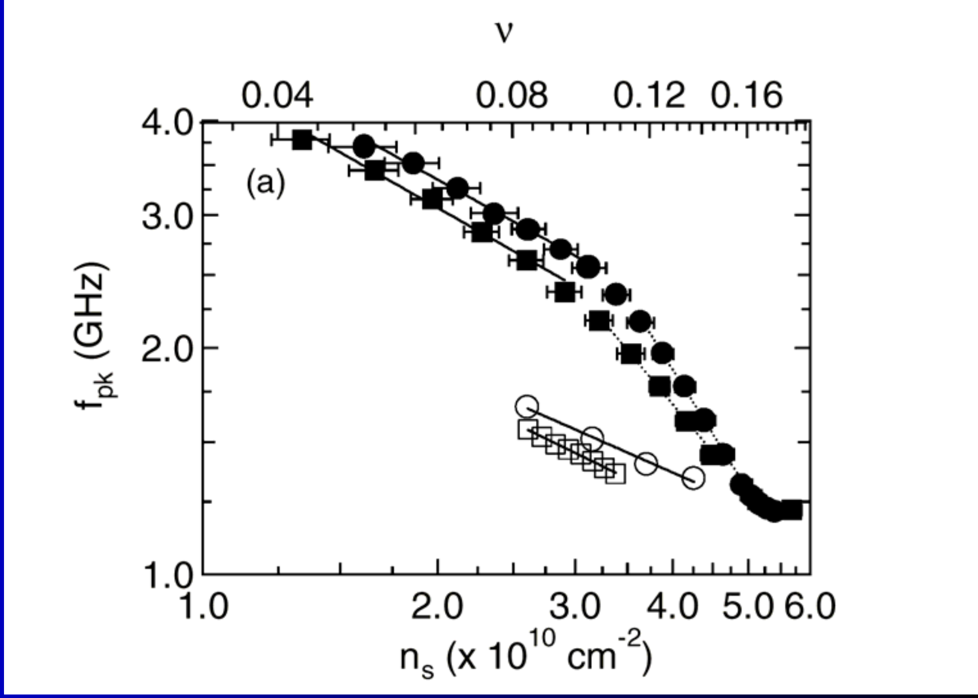
- pinning at Ra
- Broadening ? (lorentzian)

Does it work ?

Theory : $\omega_p \propto n^{+1/2}$

Measured $\omega_p \propto n^{-1/2}$

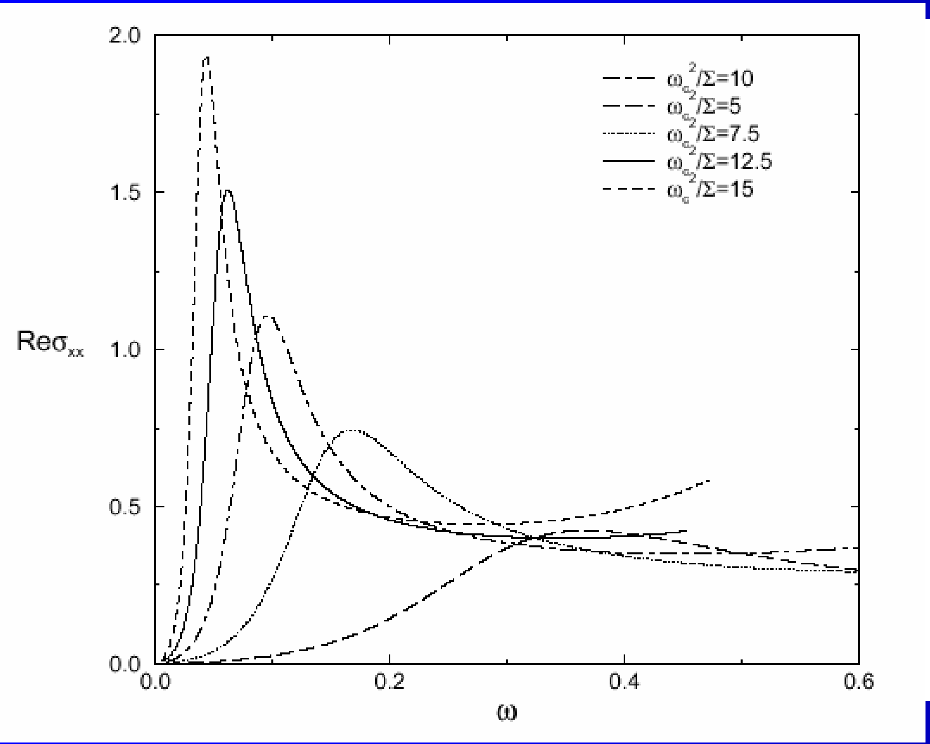
$\omega_p \propto n^{-3/2}$

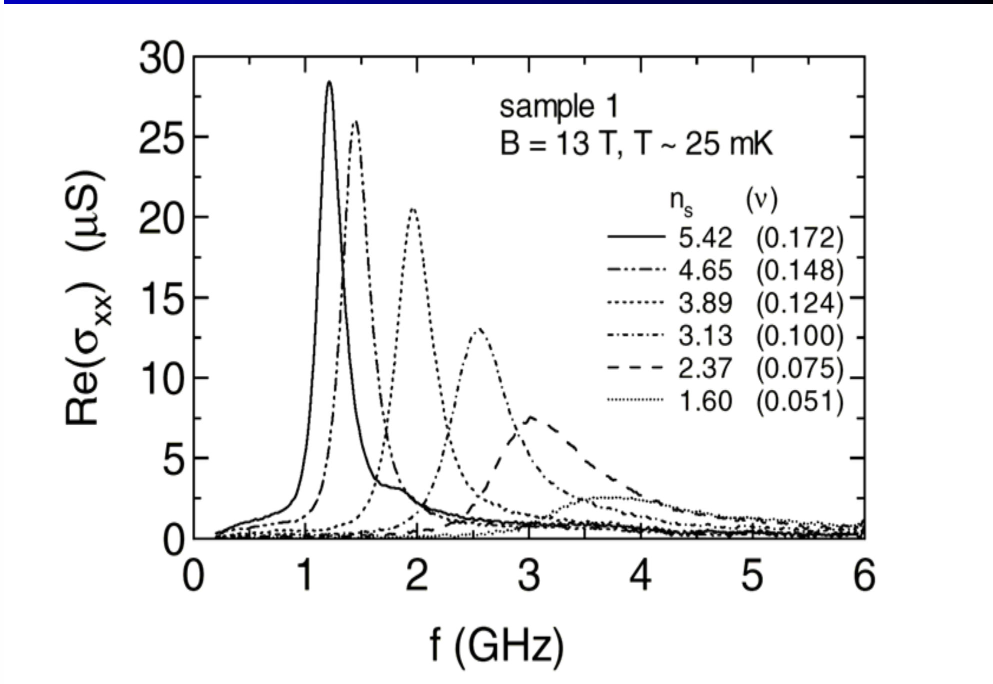


Theory : $\omega_p = Cste / \omega_c$

Measured : ω_p increases with B

Conductivity

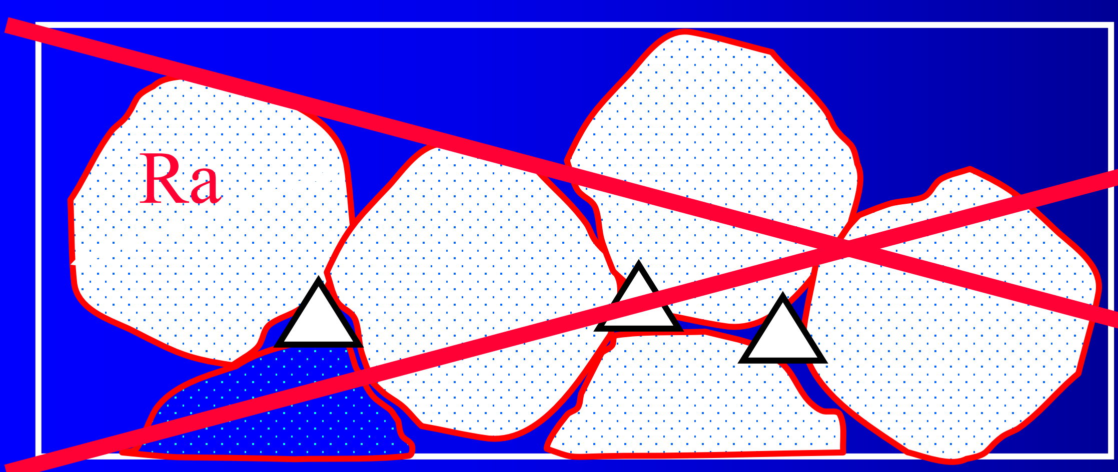




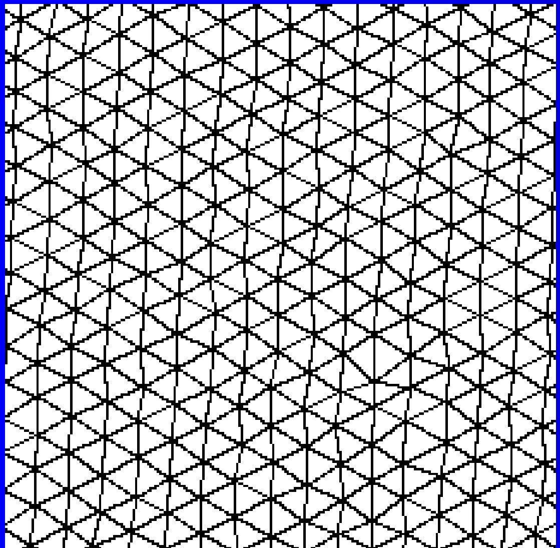
- Glassy properties (RSB)
- ω_p fixed by Rc not Ra : $\omega_p \uparrow$ with B
- $\omega_p \propto n^{-3/2}$

R. Chitra, TG, P. Le Doussal PRL 80 3827 (1998);
PRB 65 035312 (2001)

Defects in crystal



Crystal broken in crystallites of size Ra



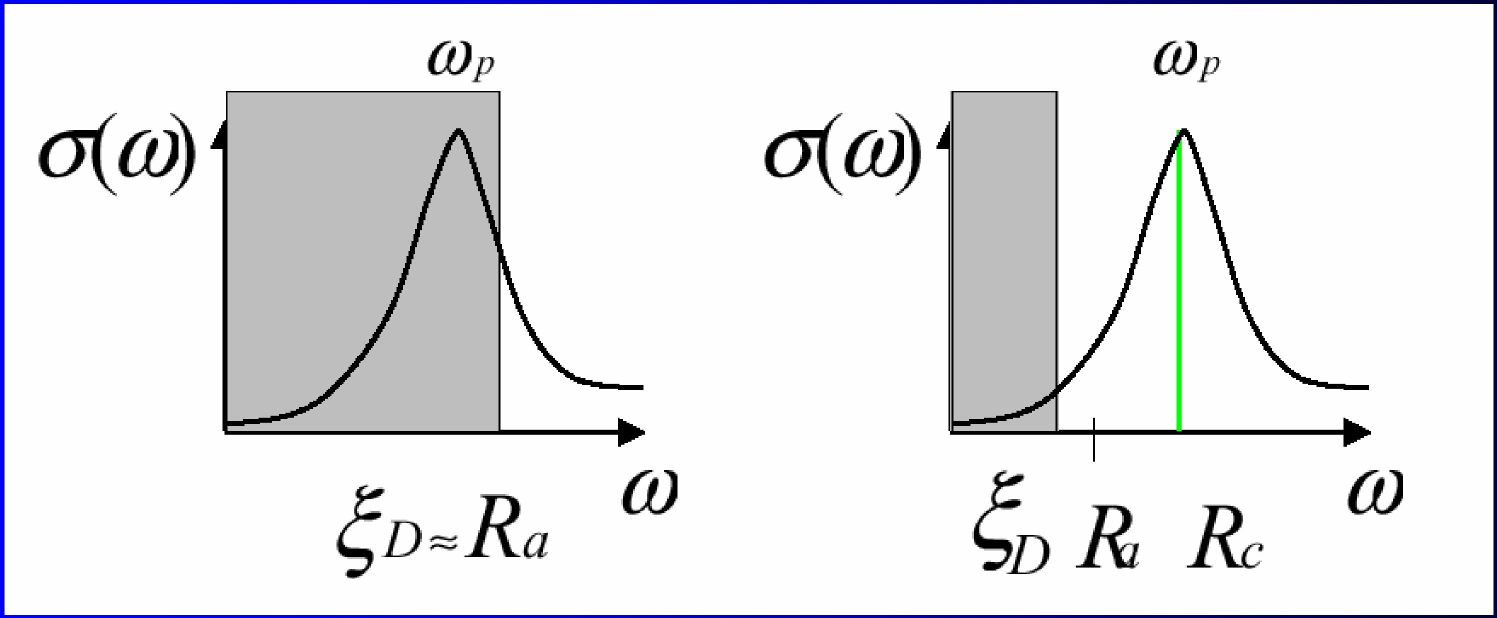
D=3

Bragg glass

D=2

$$\xi_d = R_a e^{c\sqrt{\log(R_a/a)}}$$

• Bragg glass at intermediate distances



Elastic theory does give the ac transport correctly even in d=2

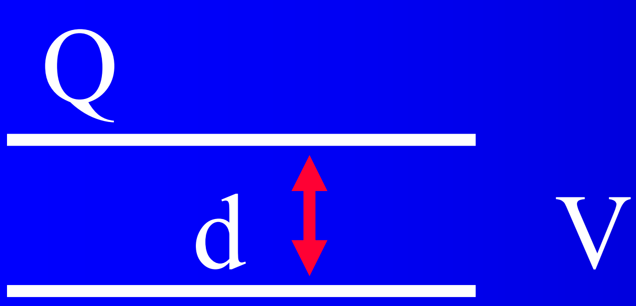
Defects crucial for dc transport

Compressibility

- Standard (density-density correlation)

$$\kappa(\omega_n = 0) = 0$$

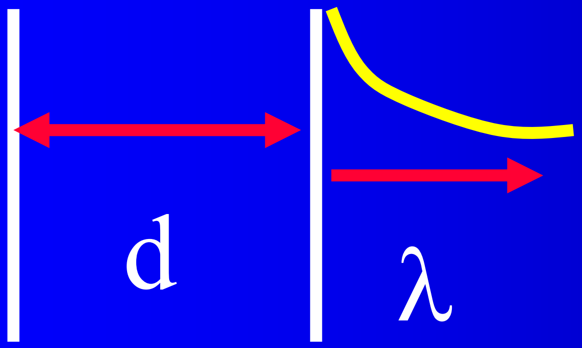
- Capacitance measurement :



$$1/C = 1/C_{geom} + 1/C_{el}$$

$$1/C_{geom} = d$$

- Normal metal :



$$1/C_{el} = 2\lambda$$

Coincides with compressibility

- Wigner crystal :

$$1/C_{el} < 0$$

Overscreening

Not changed by disorder

Puzzles

- Broadening in B dependence
- Hall resisitivity $\rho_{xy}(\omega) \rightarrow B/\rho_c$
- Compressibility

$\kappa(\omega_n = 0) = \kappa_0$ $\kappa(\omega \rightarrow 0) \rightarrow 0$

Correlation (Coulomb) gap ?

Experiments for B=0

- Optical conductivity; density dependence of ω_p

- ω_p versus threshold field

- Hall resistivity versus longitudinal current (transverse critical force)

Conclusions

- Strong interplay between disorder and interactions
- Importance of quantum crystals
- Good tools for statics and ac transport
- Glassy behavior of pinned crystal

Pandora Box

- Dislocations

  3D: lucky (Bragg glass)

  2D: dislocations control dc transport

  Melting

- Non linear transport in quantum case
- Aging and other glassy goodies