Disordered Elastic systems

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T. Tybell (Trondheim)

Some references

- General reviews (and refs therein)
- Refs to some own papers in the field

• Periodic systems (mostly vortices):

G. Blatter et al. Rev. Mod. Phys 66 1125 (1994).
T. Nattermann and S. Scheidl, Adv. Phys. 49, 607 (2000)
TG and S. Bhattacharya, in High Magnetic Fields: Applications in Condensed Matter Physics and Spectroscopy, edited by C. B. et al. (Springer-Verlag, Berlin, 2002), p.314, cond-mat/0111052

• Interfaces:

TG, A. B. Kolton, and A. Rosso, in Jamming, Yielding and Irreversible deformation in condensed matter, edited by M. C. Miguel and J. M. Rubi (Springer-Verlag, Berlin, 2006), p. 91, cond-mat/0503437

• Quantum systems:

TG, in Quantum phenomena in mesoscopic system, edited by S. I. di Fisica (IOS Press, Amsterdam, 2003), cond-mat/0403531
TG, E. Orignac, In ``Theoretical Methods for Strongly Correlated Electrons", CRM Series in Mathematical Physics, Eds. D. Senechal et al., Springer, New York, 2003

and references therein...

• Bragg glass:

TG, P. Le Doussal Phys. Rev. B 52 1242 (1995); PRB 55 6577 (1997).
P. Le Doussal TG Physica C 331 233 (2000).
Review: TG, P. Le Doussal In ``Spin Glasses and Random Fields'', ed. A.P. Young, World Scientific (Singapore) 1998, p. 321, cond-mat/9705096

• Moving glass:

TG, P. Le Doussal Phys. Rev. Lett. 76 3408 (1996).
P. Le Doussal + TG Phys. Rev. B 57 11356 (1998).

• Creep:

P. Chauve, TG, P. Le Doussal Phys. Rev. B 62 624 (2000).
A.B. Kolton, A. Rosso, TG, PRL 94 047002 (2005)

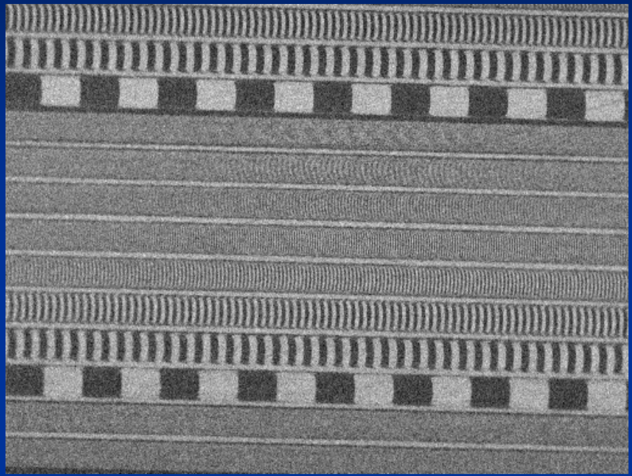
• Aging:

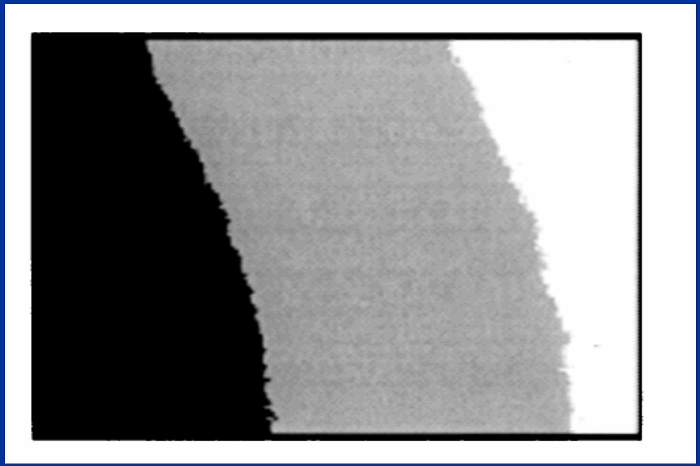
A.B. Kolton, A. Rosso, TG, PRL 95 180604 (2005)
L.F. Cugliandolo, TG, P. Le Doussal, PRL 96, 217203 (2006)

Plan of the lectures

- What are disordered elastic systems ? [1]
- Fundamental concepts for statics [1]
- Fundamental concepts for dynamics [2]
- Depinning of Interfaces [3]

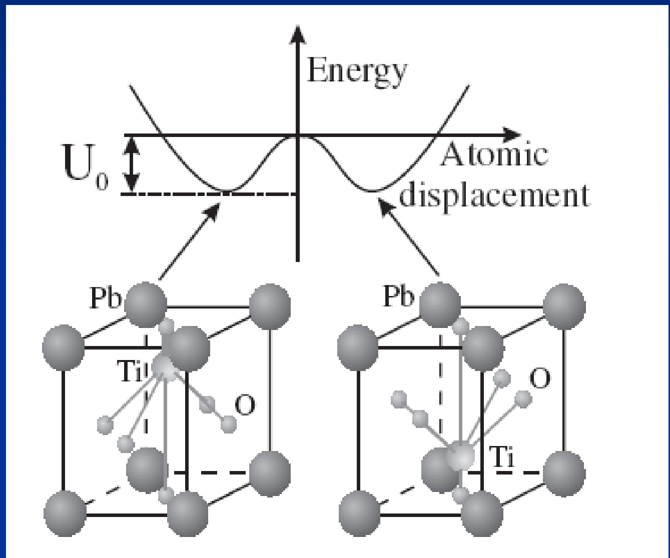
Magnetic domain wall

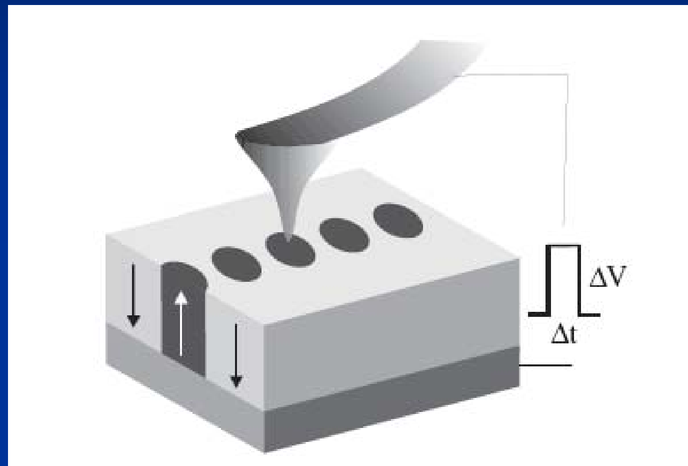


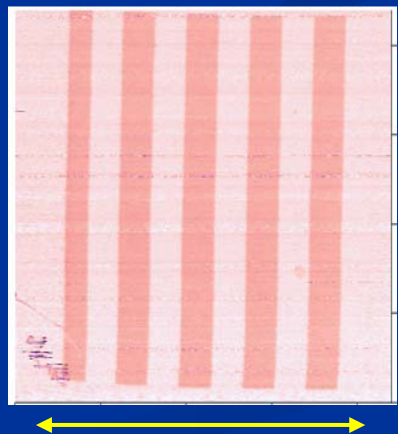


S. Lemerle et al. PRL 80 849 (98)

Ferroelectrics





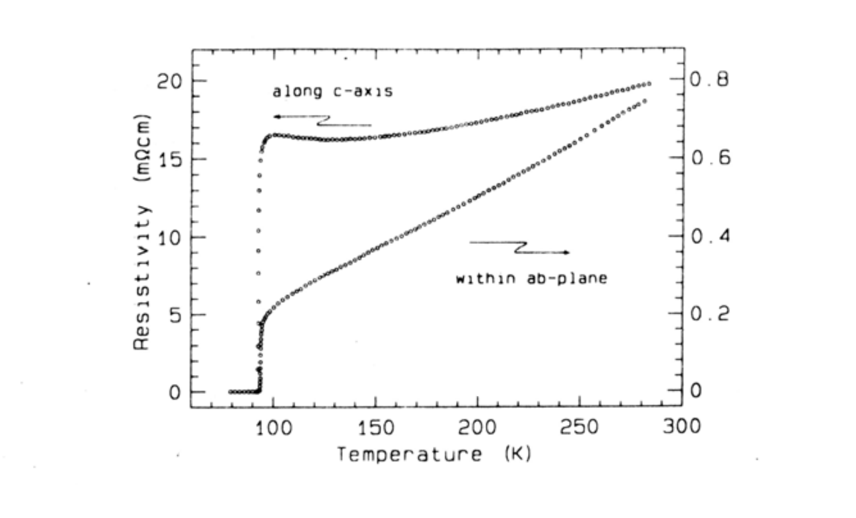

10 µm


500 nm

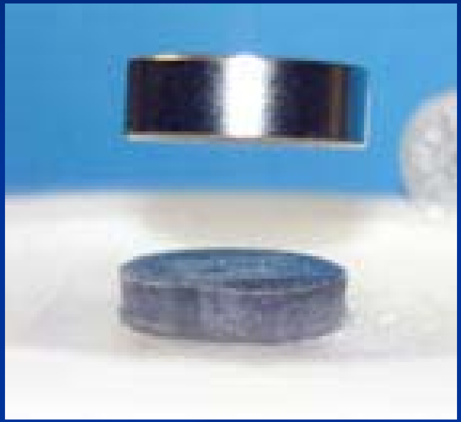
P. Paruch et al.
cond-mat/0411178

Vortices in superconductors

T< T_c: zero resistance



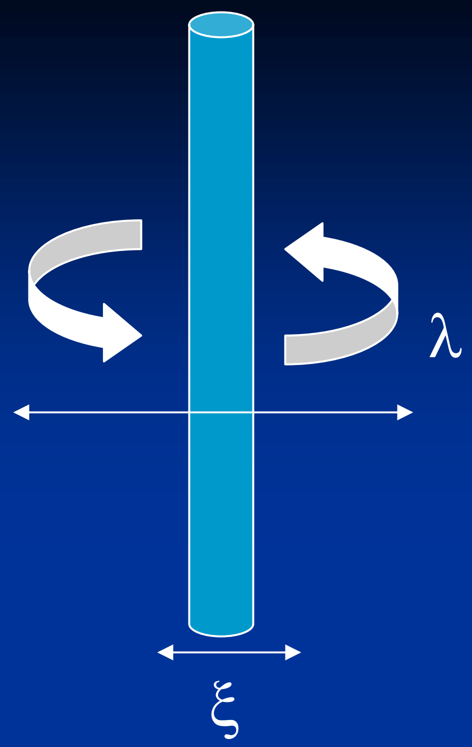
Flux expulsion (Meissner)

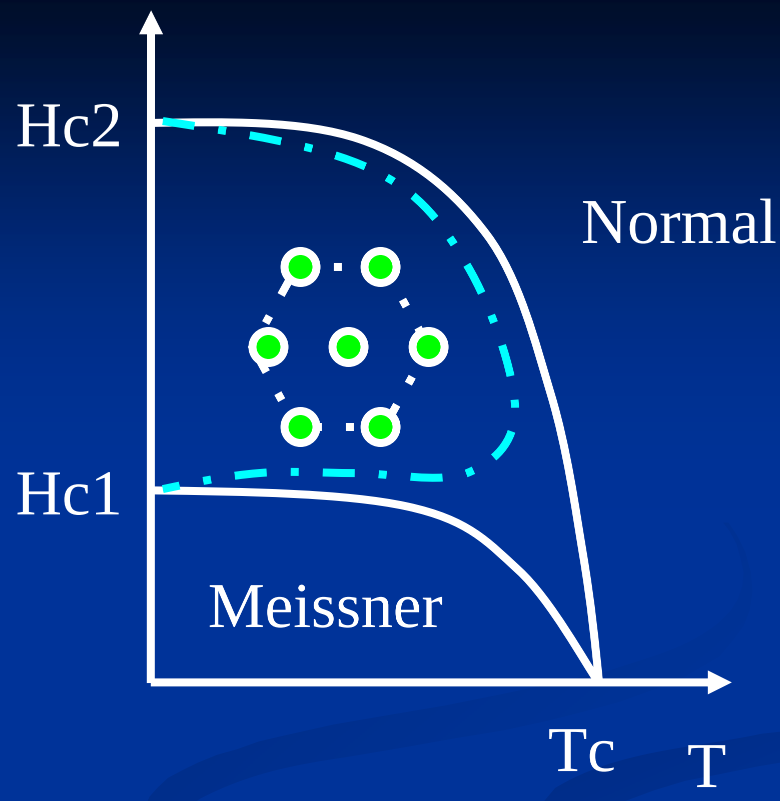


Magnet

YBCO

But ...... Vortices



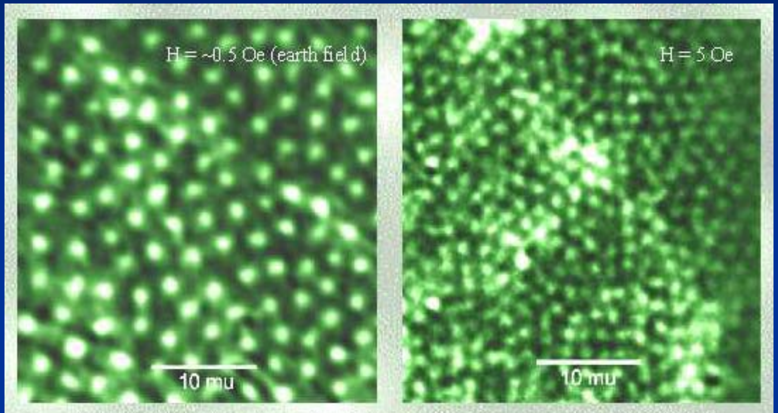


- λ ~ 10000 Å
- ξ ~ 10 Å
- Hc1 ~ 100 G
- Hc2 ~ 300 T

Abrikosov lattice

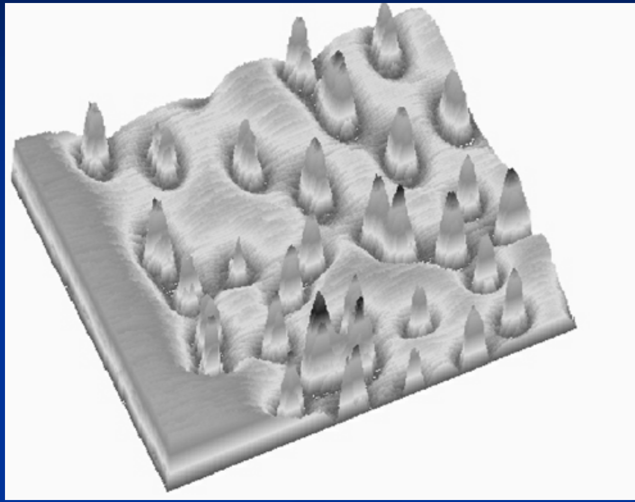
How to see vortices ?

Magneto-optics NbSe$_2$



MO indicator placed on top of bulk sample. T = 4.3 K

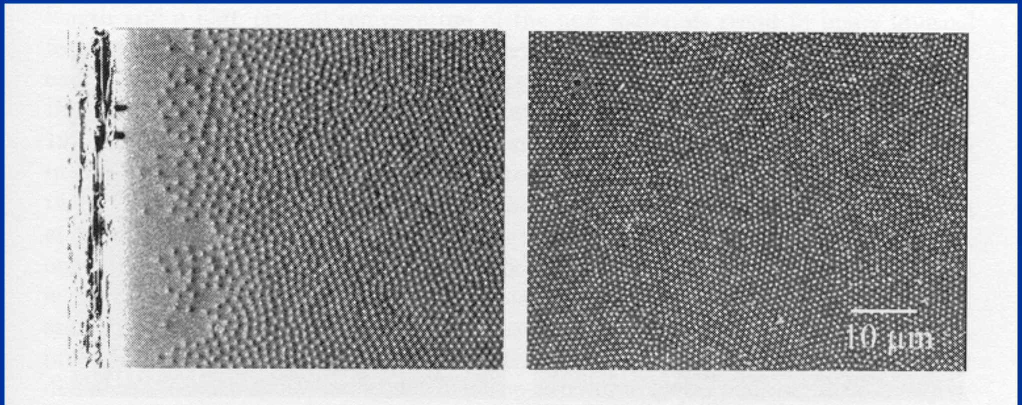
Y. Baselevitch
T. Johansen
Oslo



Scanning SQUID
Nb

C. Veauvy, D. Mailly, & K Hasselbach
CRTBT Grenoble

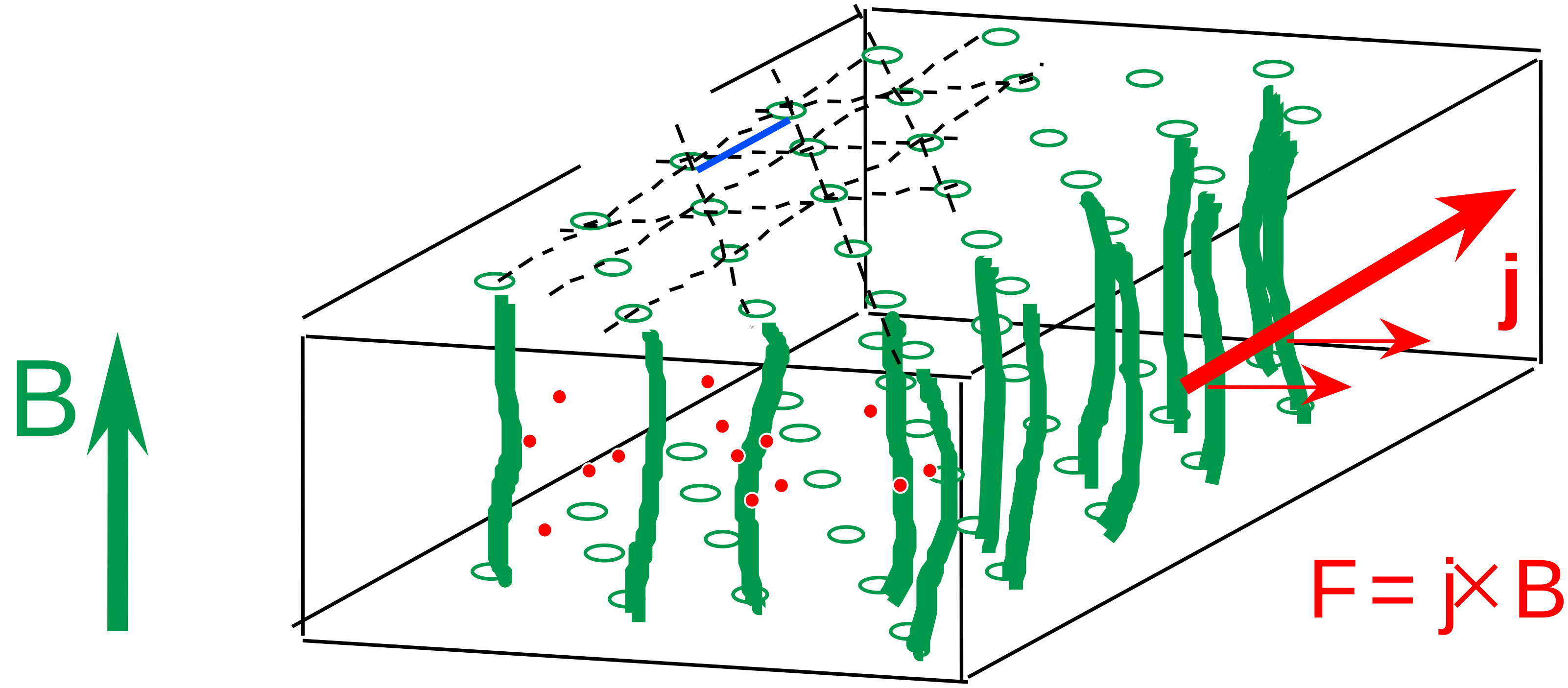
Bitter decoration NbSe$_2$

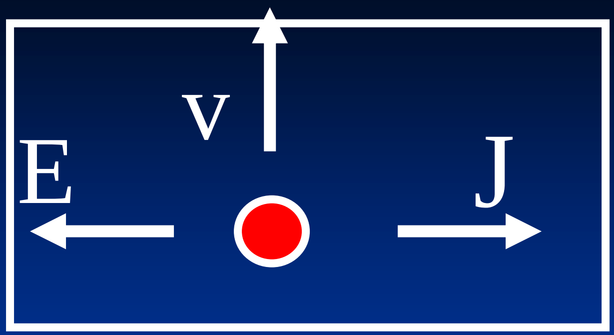


M. Marchevsky, J. Aarts, P.H. Kes
(Kamerlingh Onnes Laboratorium,
Leiden University)

Elastic description of Vortex Lattice

$$a = 1.07\sqrt{\Phi_0 / B}$$

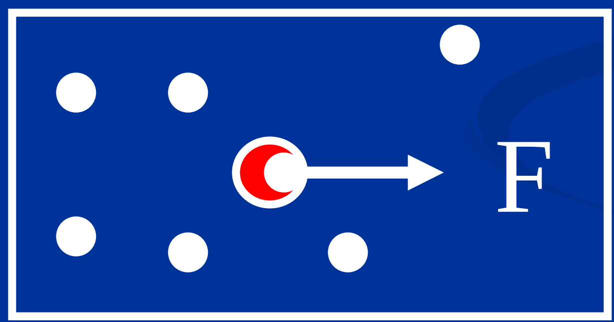




$$\rho \sim \rho_n \left(\frac{H}{H_{c2}} \right)$$

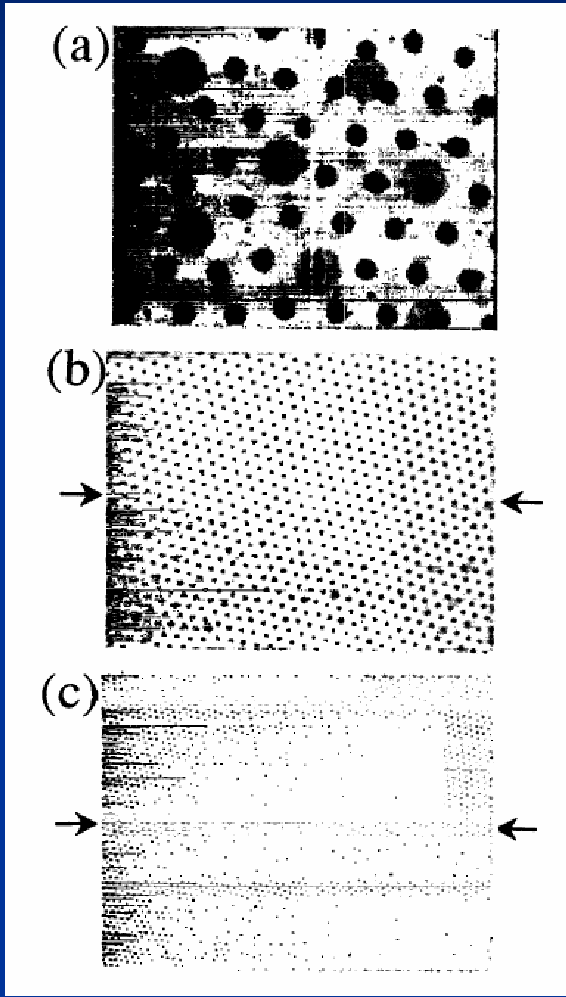
Bad conductor

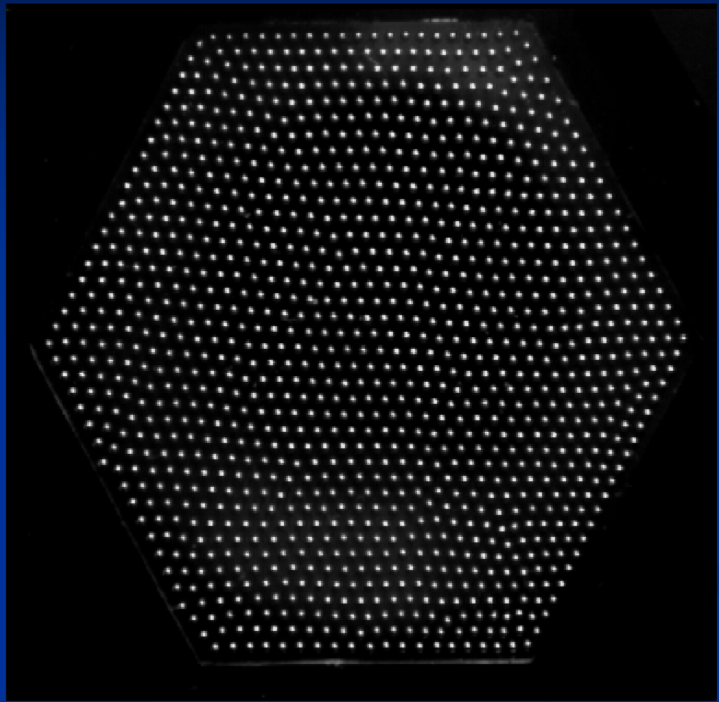
Need to pin the vortices: Disorder



Effect of external disorder on a Solid/Liquid

Classical crystals





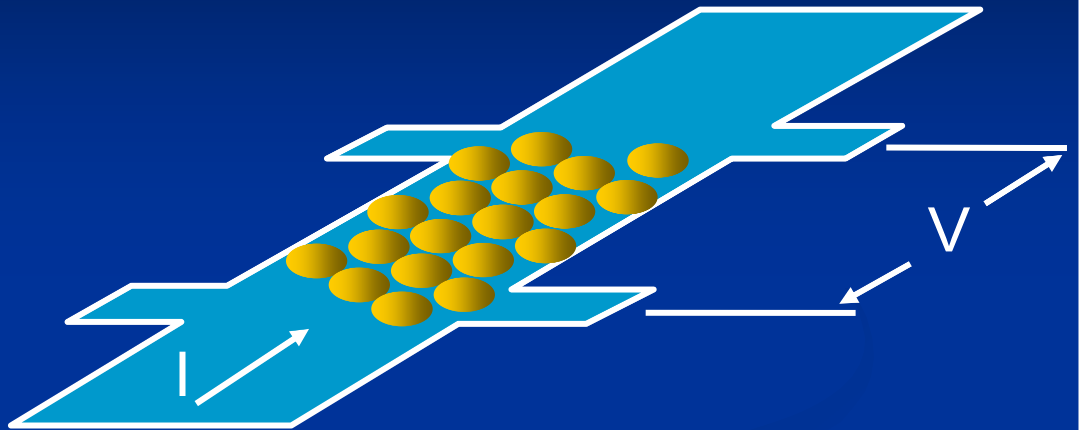
Charged spheres: M. Saint Jean, GPS (Jussieu), 2000

Magnetic Bubbles: R. Seshadri et al.

Other classical systems

- Charge density waves
- Contact line of liquid menisci
- Crack propagation

Quantum systems



• Strong repulsion : Wigner crystal

• Quantum fluctuations instead (in addition to) thermal fluctuations

Wigner Crystal

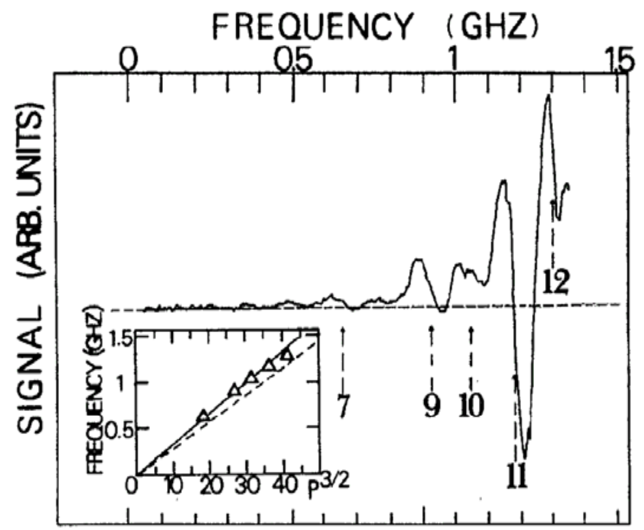


FIG. 1. Absorption spectrum at 28 T and 60 mK for density 0.77×10^{11} cm^{-2} (filling factor $\nu=1/8.7$, reduced temperature $t=0.33$) showing successive resonances and their identification as pth spatial harmonics ($q=pq_0$) of the exciting structure. The values of p are chosen for the best alignment 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.

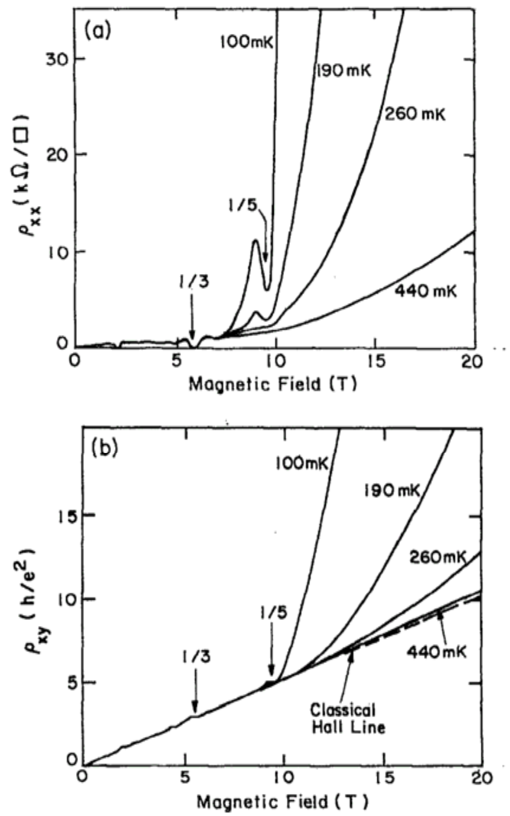


FIG. 1. (a) Diagonal resistivity ρ_{xx} and (b) Hall resistance ρ_{xy} of a low-density ($n=4.8\times10^{10}$ cm^{-2}) high-mobility ($\mu=1.7\times10^6$ cm^2/V sec) two-dimensional electron system at various temperatures.

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

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

Other quantum Crystals

- Spin density waves

- Luttinger liquids (1D interacting electrons)

Some examples of Disordered Elastic Systems

- Interfaces

  (magnetic domain walls, ferroelectrics, growth interfaces,…)

- Periodic systems

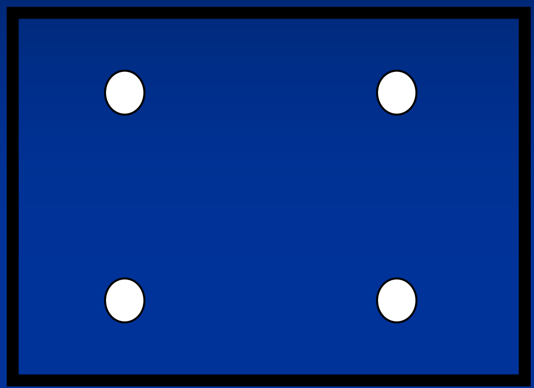
  (vortex lattice,CDW, colloids, magnetic bubbles,..)

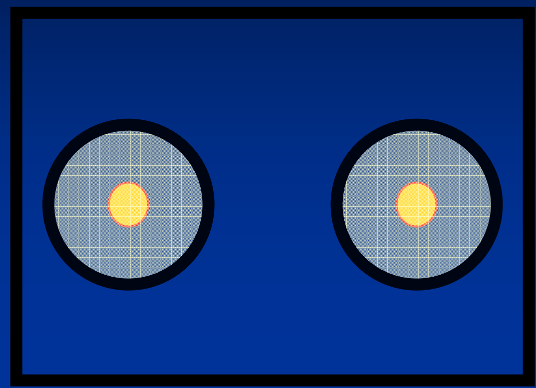
- Quantum systems

  (Luttinger liquids,Wigner crystal,SDW,Stripes,..)

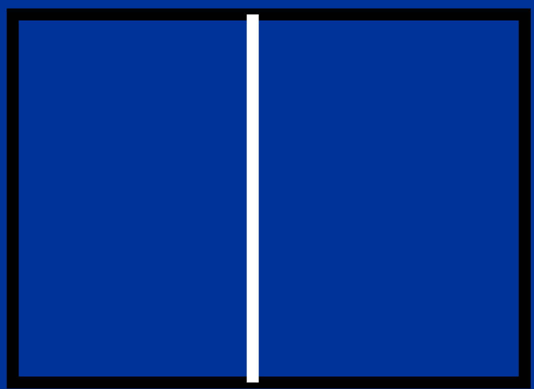
Competition ``Order'' / ``Disorder''

• Basic Features :

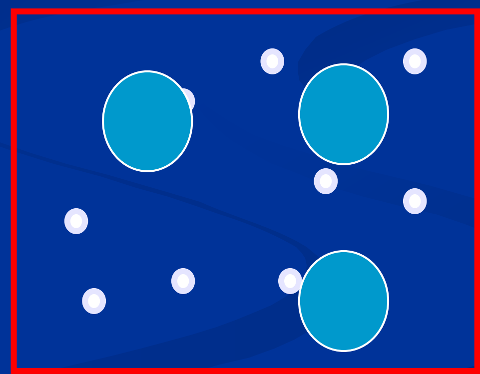




(Thermal, quantum) fluctuations



`Elasticity'



Disorder

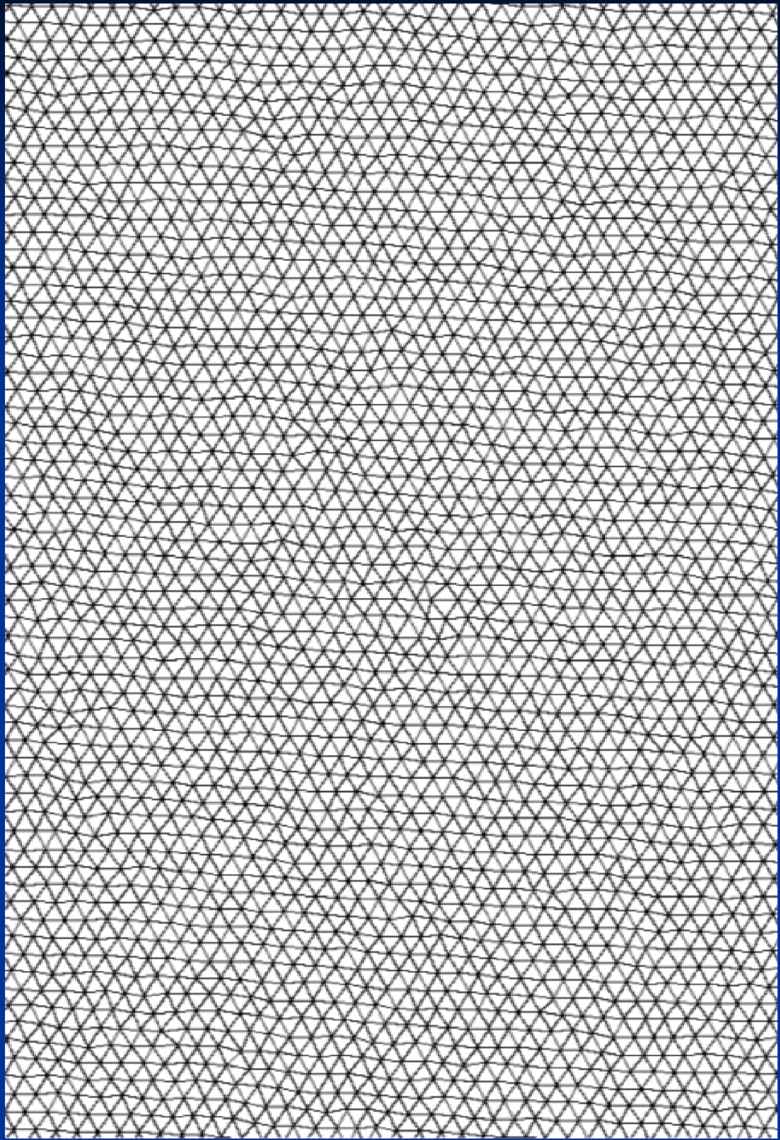
Questions

Competition ``Order'' / ``Disorder''

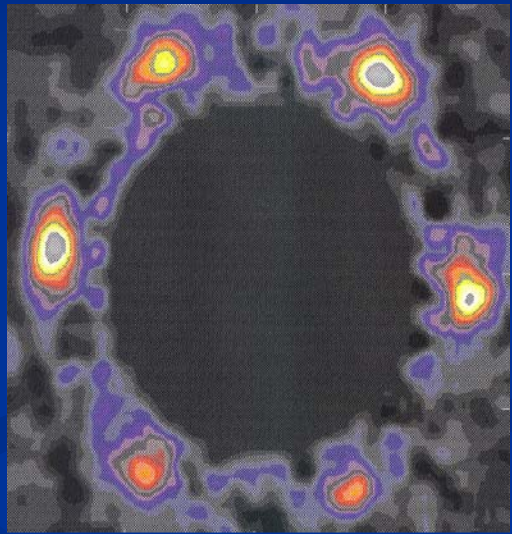
- Melting
- Glassy phases

- Statics
- Dynamics

Statics



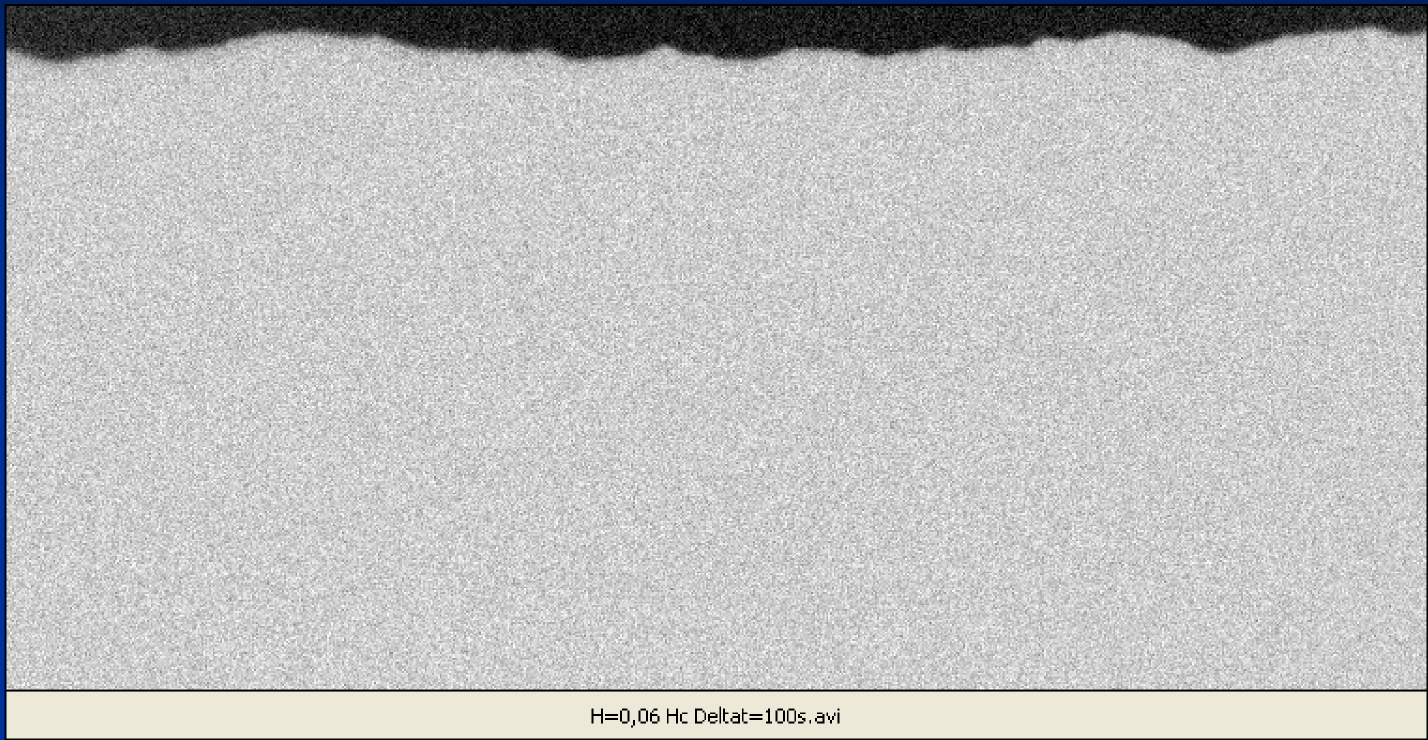
P. Kim PRB 60 R12589 (99)



T. Klein et al. Nature 413, 404 (2001)

Dynamics

+



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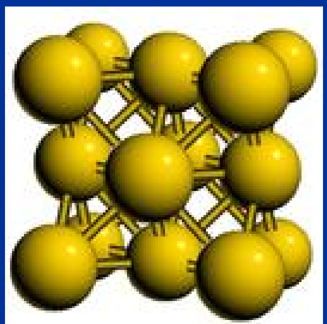
(V. Repain et al. (Orsay))

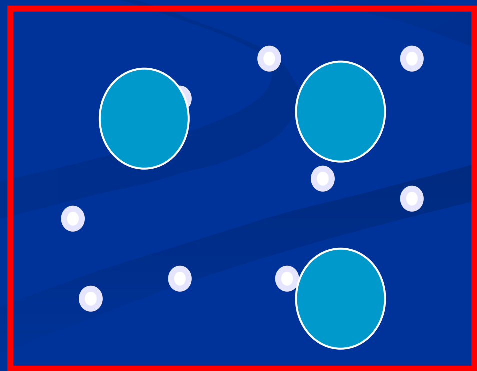
New type of physics

- Very controlled (e.g. magnetic field)

- Can pull on on the system

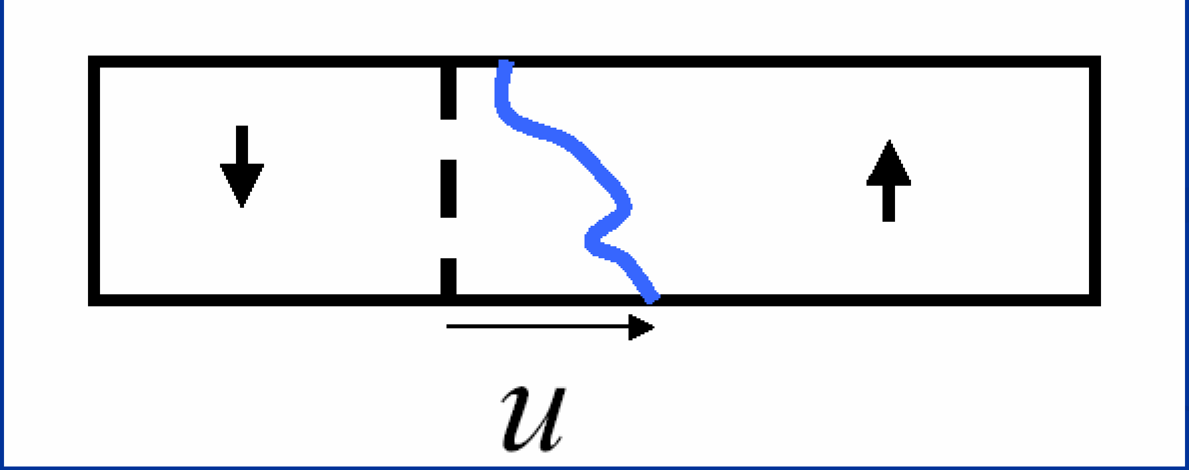
- Plunged in an external disorder





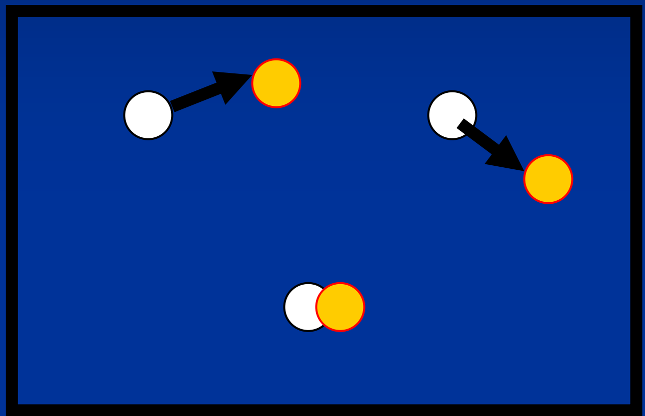
How to model

- Elastic description



$$H = \frac{c}{2}\int dx(\nabla u(x))^2 = \frac{c}{2}\sum_q q^2 u^*(q)u(q)$$

Elastic description of crystals



R^0_i : crystal

u_i : displacements

n=2 d=3 vortices

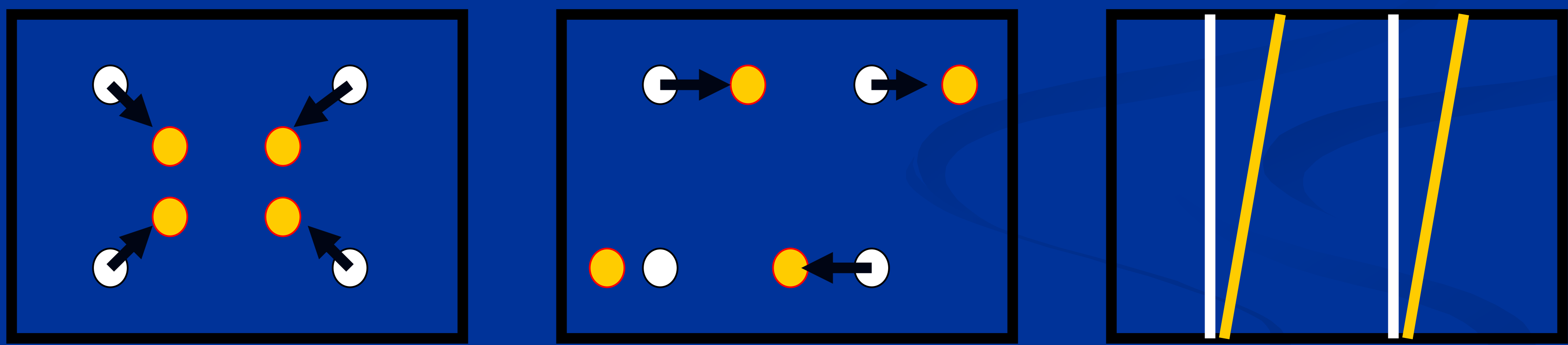
Elastic hamiltonian

$$H = \frac{1}{2}\sum_{\alpha\beta}\int c_{\alpha\beta}(q)u_{\alpha}(q)u_{\beta}(-q)dq$$

Simplest elastic hamiltonian : c(q) = c q^2

$$H = \tfrac{1}{2}\int c(\partial_\alpha u_\beta(x))^2$$

Long range forces ; bulk, shear and tilt

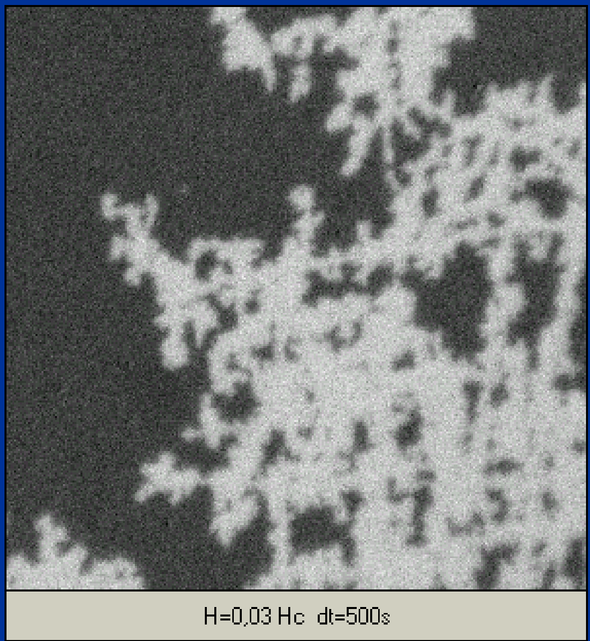


$\partial_\alpha u_\alpha(x,y,z)$ $\partial_y u_x(x,y,z)$ $\partial_z u(x,y,z)$

Limitations

- Interfaces

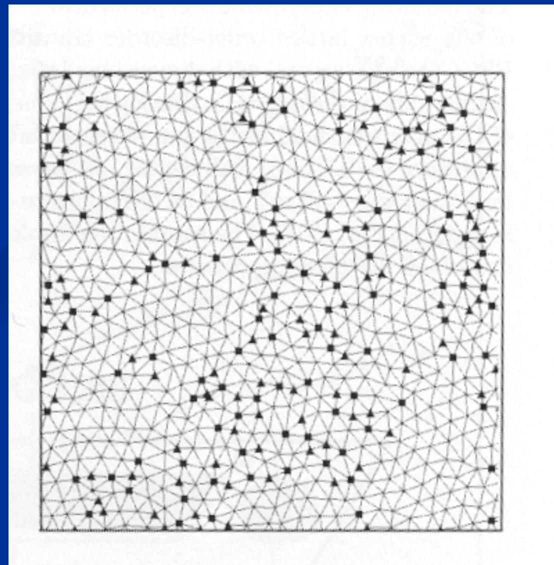
(overhangs, bubbles)



J. P Jamet, V. Repain

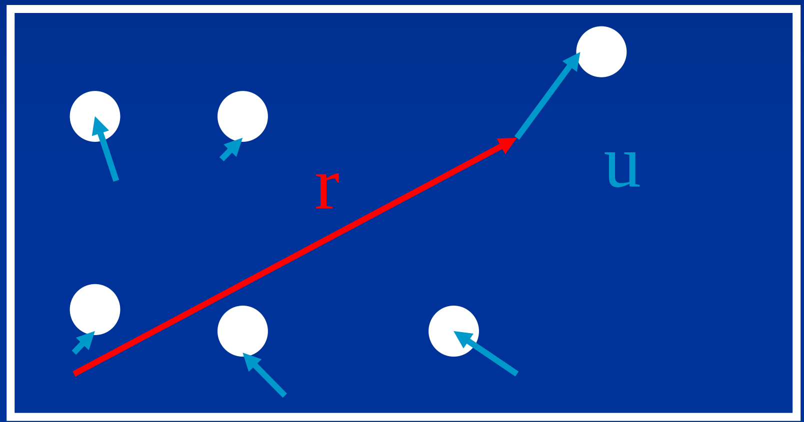
- Periodic

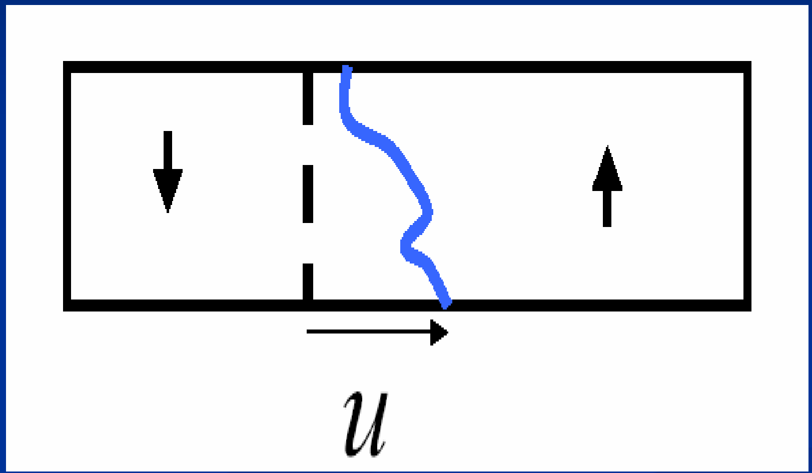
dislocations, etc.



M. Marchevsky, J. Aarts, P.H. Kes

What to measure (statics)



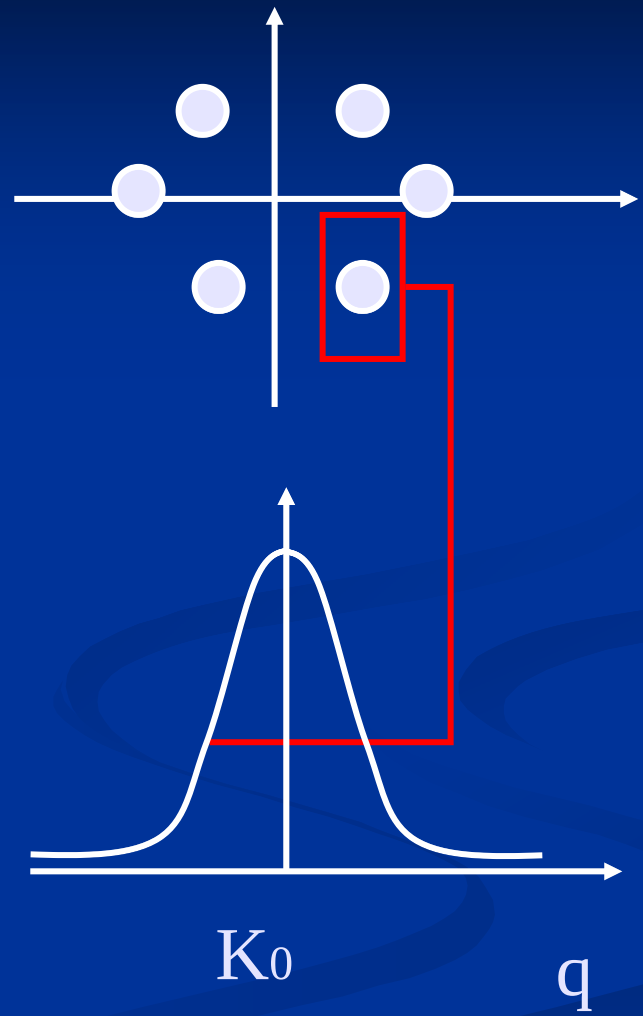


$$B(r) = \overline{\left\langle [u(r) - u(0)]^2 \right\rangle}$$

Positional order

Structure Factor

$$S(q) = \left\langle \rho(q)\rho(-q) \right\rangle$$



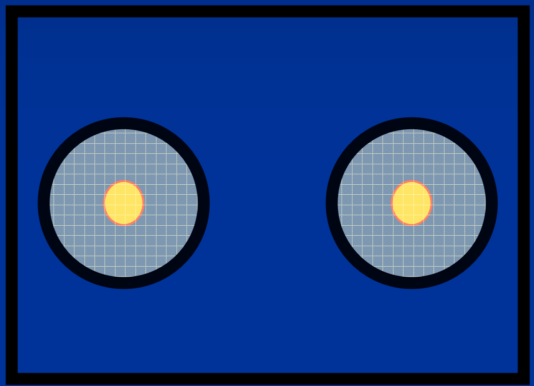
Fourier transform of:

$$C(x) = \overline{\left\langle e^{iK_0 u(r)} e^{-iK_0 u(0)} \right\rangle}$$

Decorations

Neutrons

Thermal fluctuations : Melting

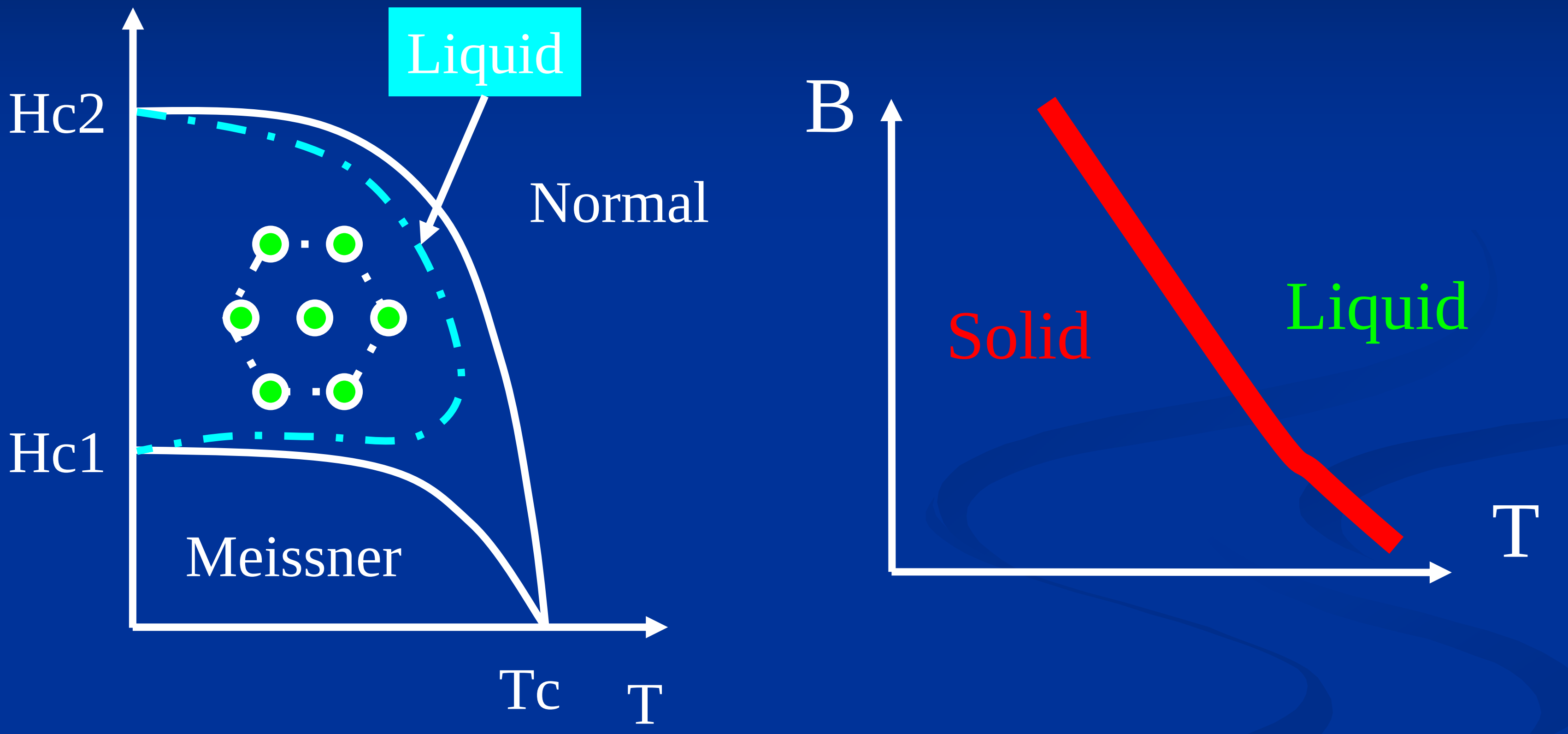


$$\left\langle u^2 \right\rangle = l_T^2 \propto \frac{T}{c}$$

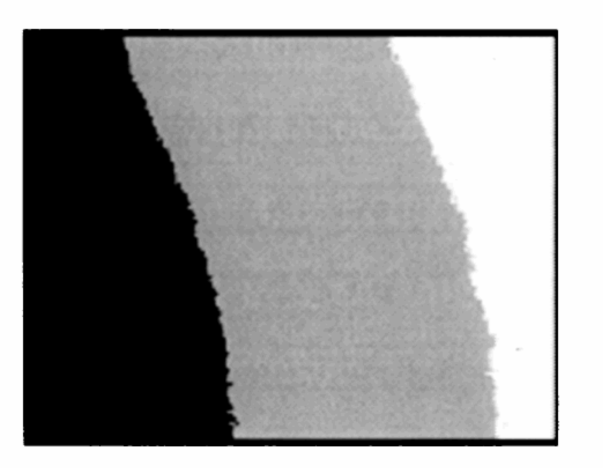
Lindemann criterion of melting :

$$\left\langle u^2 \right\rangle = l_T^2 = C_L^2 a^2 \qquad C_L \approx 0.1 - 0.2$$

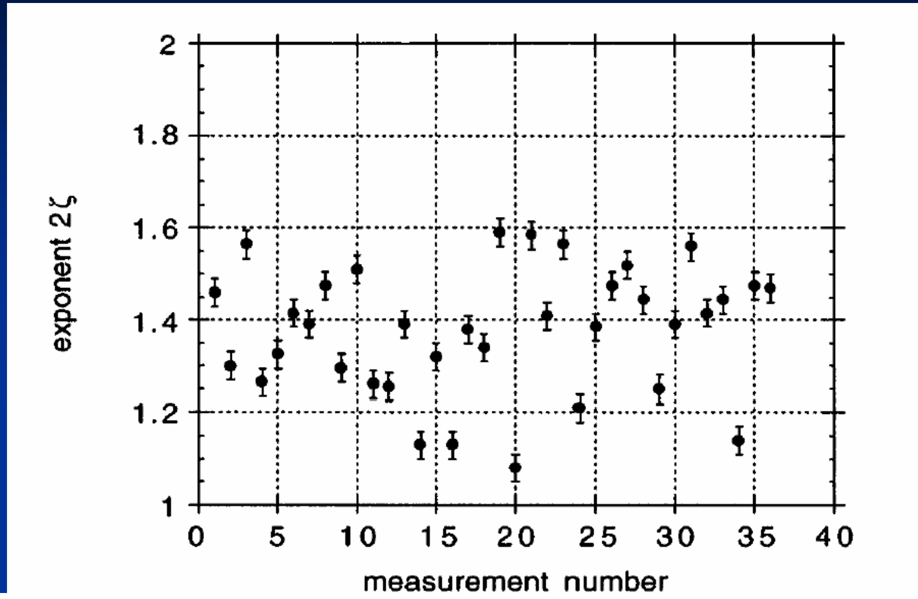
Vortices

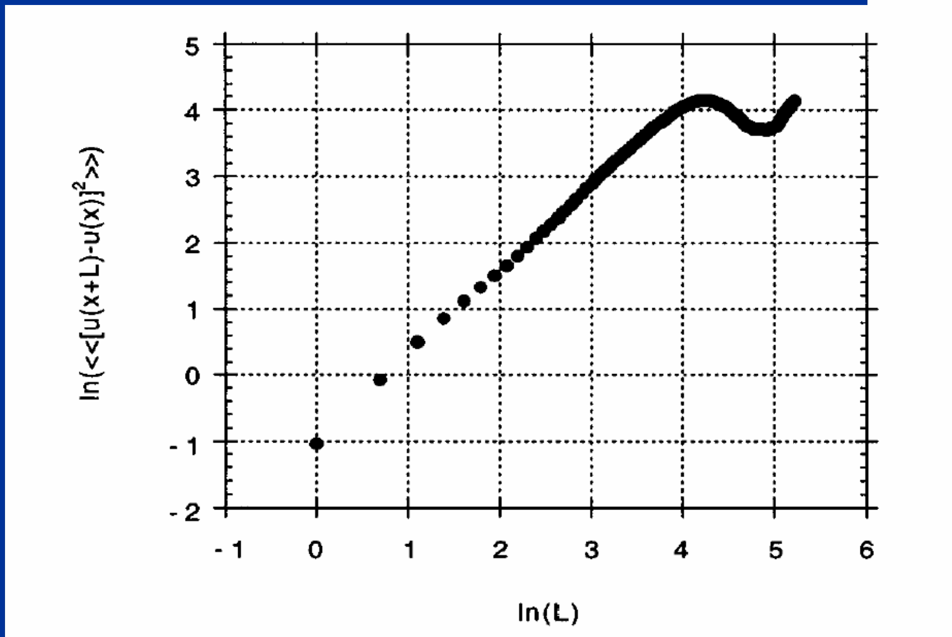


Should we care about disorder?



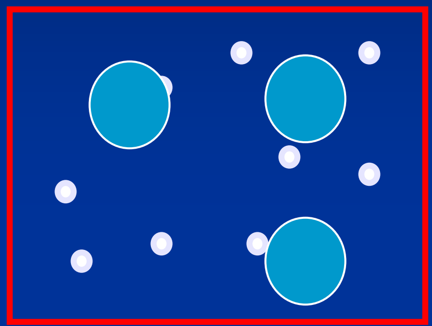
S. Lemerle et al. PRL 80 849 (98)





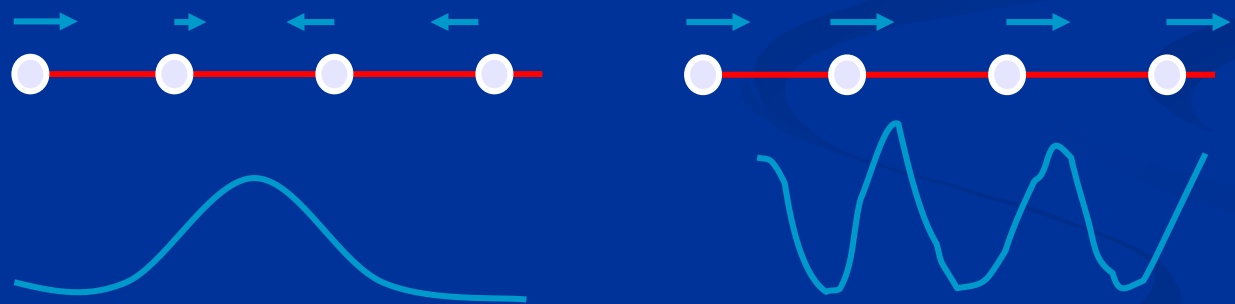
$$u \propto L^{\varsigma}$$

Disorder (point like defects)



$$H = \int V(x)\rho(x)dx$$

$$\rho(x) = \sum_i \delta(x - R_i^0 - u_i)$$



$$\rho(x) = \rho_0 - \rho_0 \nabla u(x) + \rho_0 \sum_K e^{iK(x-u(x))}$$

Loss of translational order (Larkin)

$$u(R_a) \approx a$$

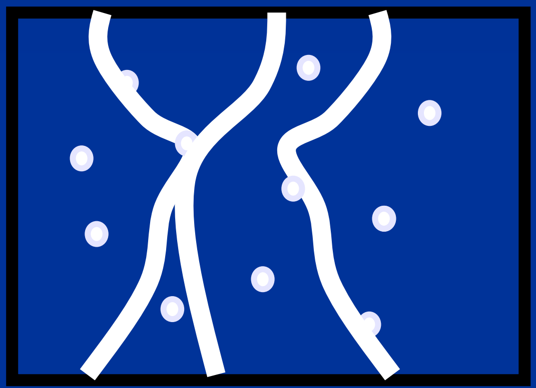
$$H_{el} = \frac{c}{2}\int (\nabla u(r))^2 d^d r \qquad H_{dis} = \int V(r)\rho(r) d^d r$$

$$cR_a^{d-2}a^2 \qquad VR_a^{d/2}\rho_0$$

$$R_a \propto a\left(\frac{c^2 a^d}{V^2 \rho_0^2}\right)^{1/(4-d)}$$

No crystal below four spatial dimensions

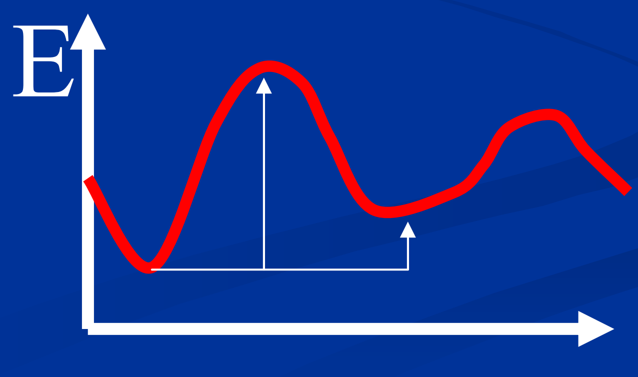
Very difficult stat-mech problem



- Glass

- Optimization :

many solutions



Larkin Model

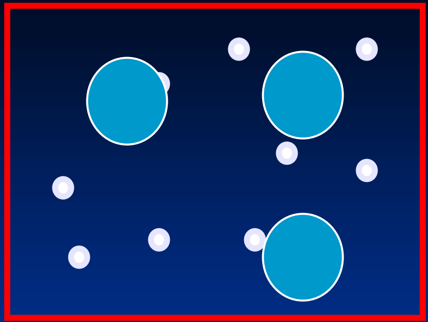
$$H_{el} = \frac{c}{2}\int (\nabla u(r))^2 d^d r \qquad H_{dis} = \int f(r)u(r) d^d r$$

- Exactly solvable

$$B(r) = B_{th} + \frac{\Delta}{c^2} r^{4-d}$$

Exponential loss of translational order $C(r) \approx e^{-r^{4-d}}$

- Not valid at large distance



$$\rho_0 \sum_K e^{iK(x-u(x))} V(x) \approx f(x) u(x)$$

Not valid when : $K_{MAX} u \approx 1$ $u(R_c) \approx \xi$

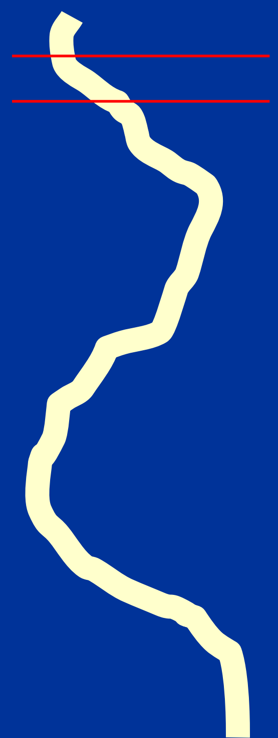
- New length Rc

- Larkin model has no metastable states and pinning

- Rc is related to pinning $J_c \propto \dfrac{c\xi}{R_c^2}$

Interfaces: only one length

- Larkin length $u(R_c) \approx \xi$



$R < R_c$; $u(R) = R^{(4-d)/2}$

$R > R_c$; $u(R) = ?????$

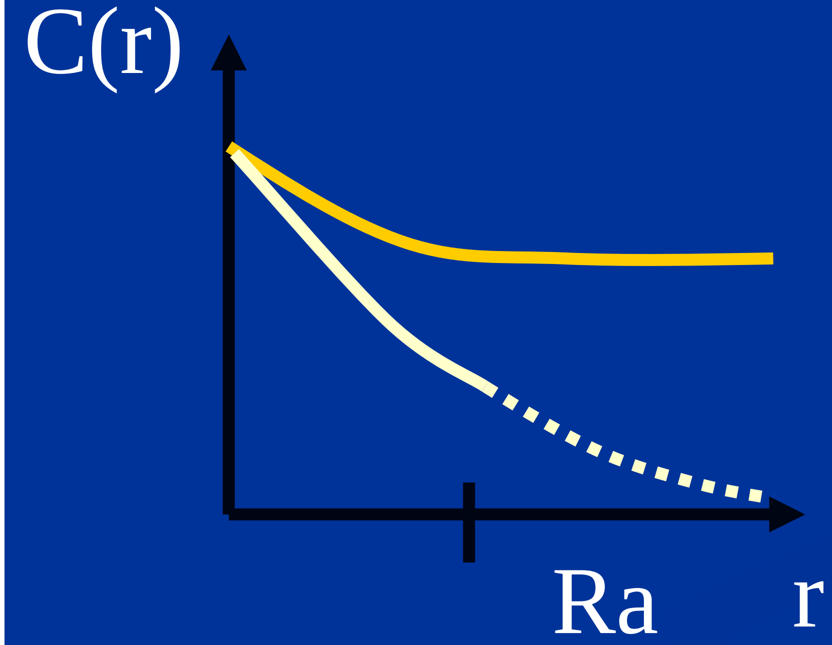
Crystals: Two crucial lengthscales

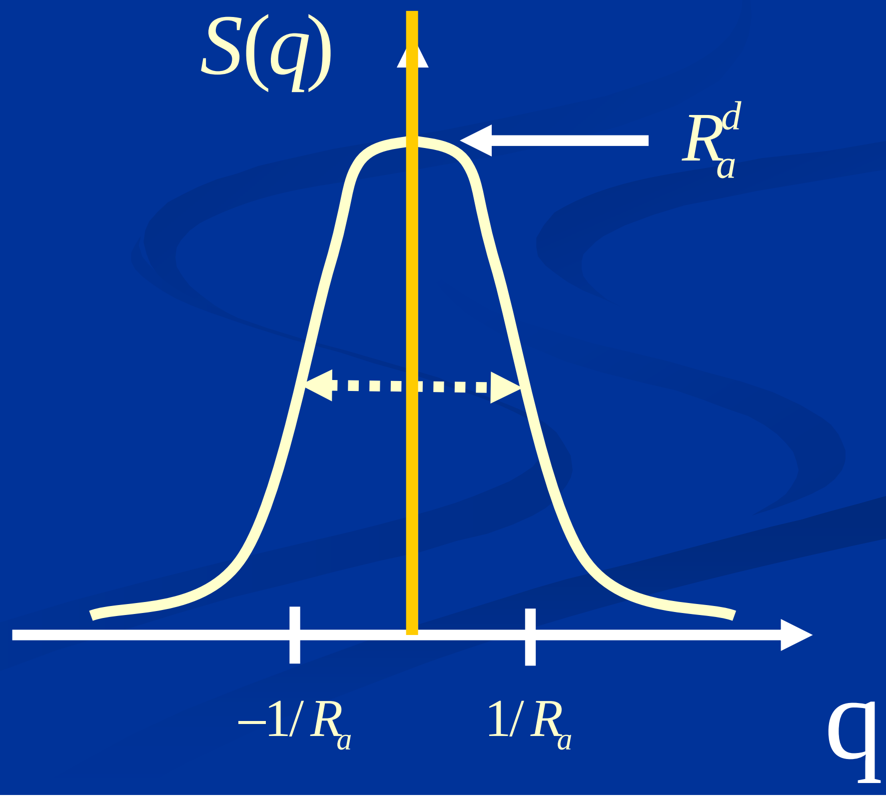
- Positional order

$$u(R_a) \approx a$$

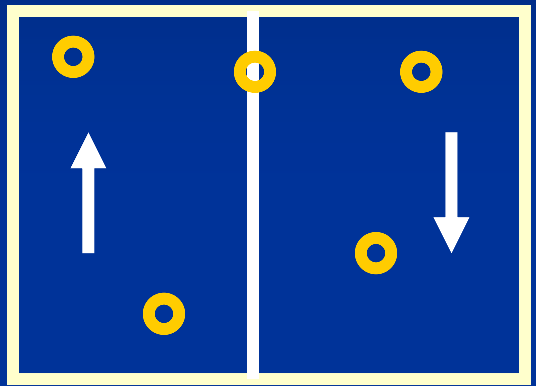
- Larkin length

$$u(R_c) \approx \xi$$



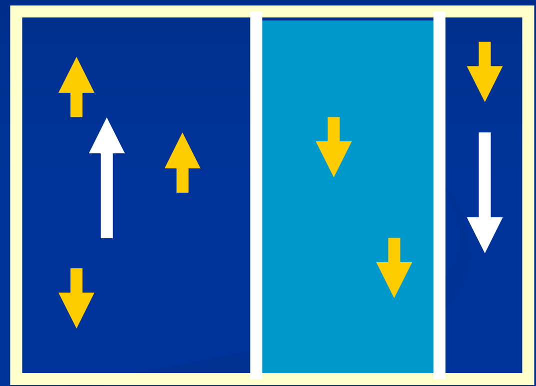


Two types of disorder



Random bond

$$\int dx dz V(x,z)\rho(x,z) = \int dz V(u(z),z)$$



Random field

$$\int dz \int_0^{u(z)} V(x,z)$$

Interfaces

$$H_{el} = \frac{c}{2}\int (\nabla u(r))^2 d^d r \qquad H_{dis} = \int V(r,u(r)) d^d r$$

$$\overline{V(z,x)V(z',x')} = D\delta(x-x')\delta(z-z')$$

$$cu^2 L^{d-2} \qquad D^{1/2} L^{d/2} u^{-m/2}$$

$$u_{RB} \propto L^{\frac{4-d}{4+m}}$$

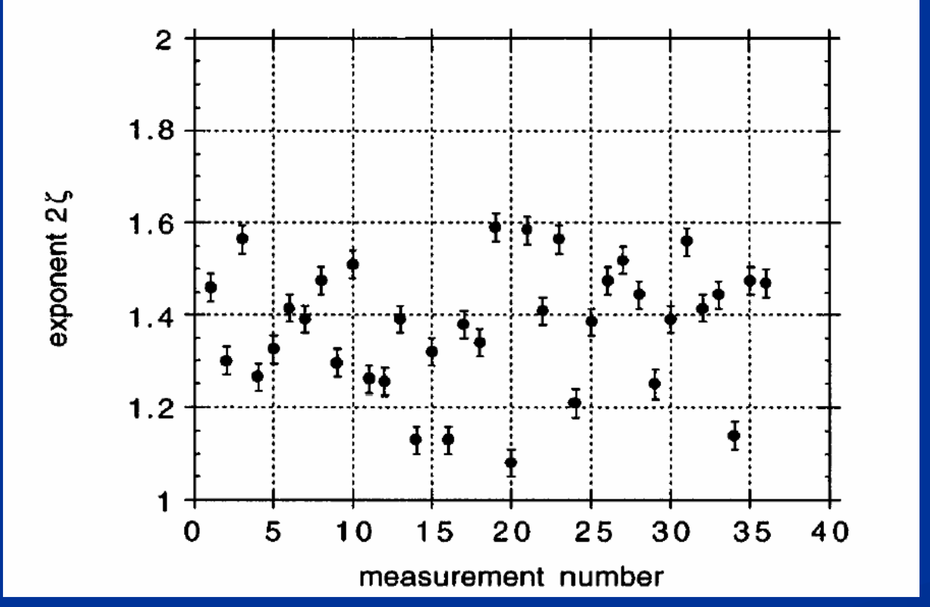
$$u_{RF} \propto L^{\frac{4-d}{4-m}}$$

Flory argument (mean field)

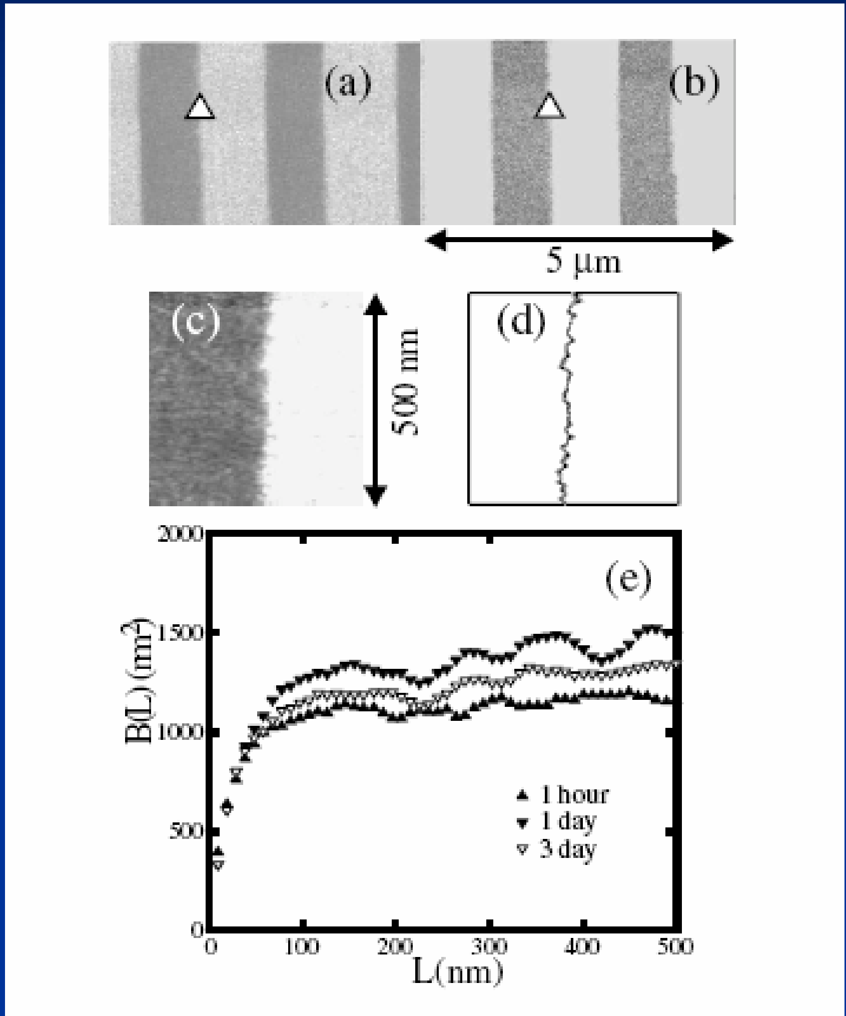
$$u_{RB} \propto L^{\zeta}$$

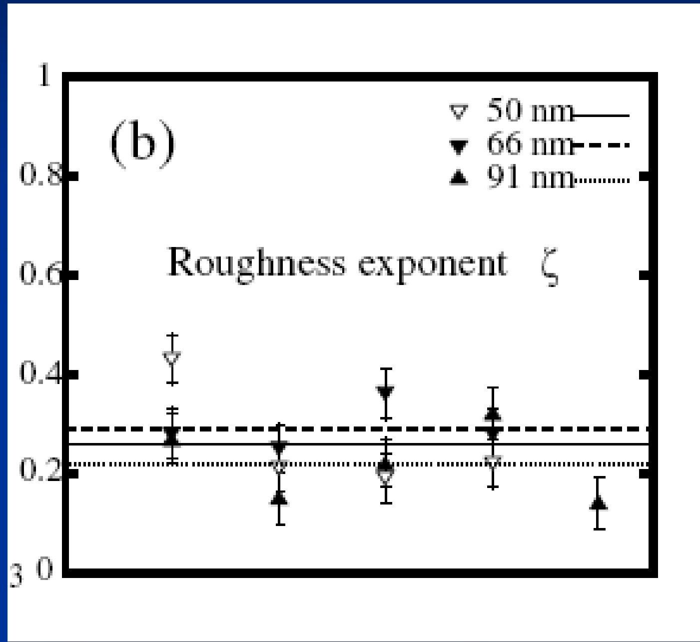
ζ : roughness exponent

d = 1 ; ζ = 2/3 (random bond)



Ferroelectics





P. Paruch et al. PRL 94 194601 (05)

How to solve ?

- Average over disorder (replica trick)

- Two main methods :

  Variational approach

  Renormalization (functional RG)

Replicas

$$\overline{\langle O \rangle} = \int \mathcal{D}V p(V) \langle O \rangle_V = \int DV p(V) \frac{\int \mathcal{D}\phi O[\phi] e^{-S_V[\phi]}}{\int D\phi e^{-S_V[\phi]}}$$

$$\int D\phi_1 D\phi_2 \ldots D\phi_n O[\phi_1] e^{-\sum_{i=1}^{n} S_V[\phi_i]} =$$

$$\int D\phi O[\phi] e^{-S_V[\phi]} \left[\int D\phi e^{-S_V[\phi]} \right]^{n-1}$$

Average over disorder

$$H = \frac{c}{2}\int (\nabla u)^2 d^d x + \rho_0 \sum_K \int e^{iK(x-u(x))} V(x)$$

- Classical systems

$$H = \sum_a c\int (\nabla u_a)^2 d^d x - \rho_0 \Delta \sum_{a,b} \sum_K \int \cos(K(u_a(x) - u_b(x))) d^d x$$

- Quantum problem (disorder is time independent)

$$S = \sum_a c\int (\nabla u_a)^2 d^{d+1} x$$

$$- \rho_0 \Delta \sum_{a,b} \sum_K \int \cos(K(u_a(x,\tau) - u_b(x,\tau'))) d^d x d\tau d\tau'$$

Variational Method

Find the best quadratic Hamiltonian

$$H_0 = \sum_{ab} \int G_{ab}^{-1}(q) u_q^a u_{-q}^b d^d q$$

Minimize

G_{ab} is a 0x0 matrix

$$F_{\text{var}} = F_0 + \langle (H - H_0) \rangle_{H_0}$$

$$\frac{dF_{\text{var}}}{dG_{ab}(q)} = 0$$

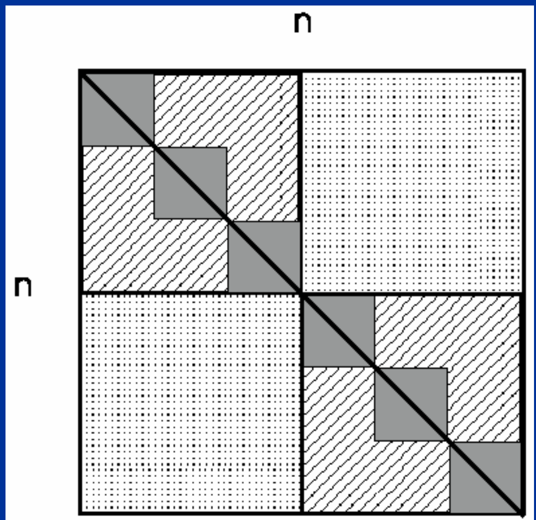
$$G_{ab}^{-1}(q) = q^2 + \int ..e^{\sum \int G_{ab} \cdots\cdot}$$

0x0 limit

- Replica symetric

G_{aa} $\qquad$ $G_{a\neq b}$ $\qquad$ Unstable

- Replica symetry broken solution



Hierarchical structure

a,b continuous in [0,1]

RSB

- Signals metastability and Glassy properties

- Disordered elastic system = glass

- RSB from d=4 to d=2 (or 1+1) above a lengthscale Rc

Functional Renormalization Group

$$\beta H = \sum_a \tfrac{c}{T} \int (\nabla u_a)^2 d^d x$$

$$- \rho_0 \tfrac{\Delta}{T^2} \sum_{a,b} \sum_K \int \cos(K(u_a(x) - u_b(x))) d^d x$$

In usual RG :

$$\Delta(u) \approx a + bu^2 + cu^4 + ...$$

Needs only to keep b and c (higher powers are irrelevant)

Disordered System

$$\sum_a \tfrac{c}{T} \int (\nabla u_a)^2 d^d x$$

$$u \propto L^0$$

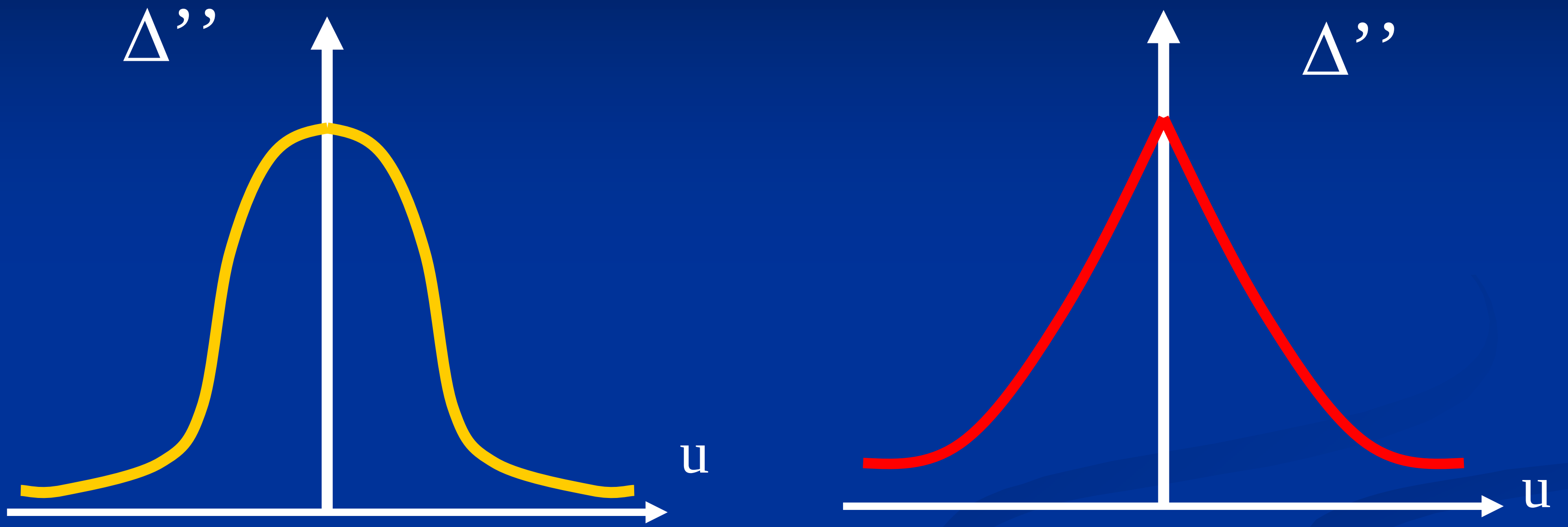
$$T \propto L^{2-d}$$

$$-\tfrac{1}{T^2} \sum_{a,b} \sum_K \int \Delta(K(u_a(x) - u_b(x))) d^d x$$

$$\Delta \propto L^{4-d}$$

Needs to keep the *whole* function

$$\partial\tilde{\Delta}''(0) = \epsilon\tilde{\Delta}''(0) - 3\tilde{\Delta}''(0)^2$$



- Nonanalyticity at a finite lengthscale Rc such that u(Rc) ~lc

(A. Larkin, D. Fisher)

- Cusp signals metastability and glassy states

Interfaces

- Power law growth of the displacements: $u \sim L^{\zeta}$
- $L < L_c$ No metastabiliy (Larkin model): $\zeta = (4\text{-}d)/2$
- $L > L_c$ Metastability, glassy properties
  $\zeta \sim 0.208(4\text{-}d) + ...$ [FRG]
  - $\zeta \sim (4–\delta)/(4+\mu)$ [Flory]

Crystals

- Identical to interfaces ?

$$u \sim L^{\zeta}$$

- Above R_c

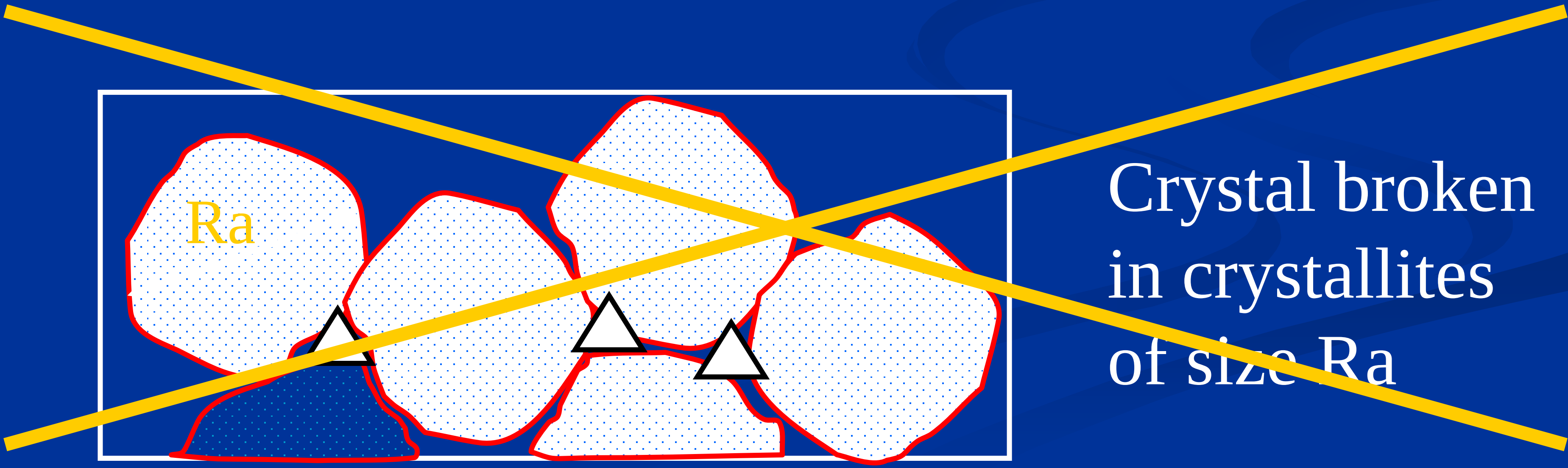
$$C(r) \propto e^{-L^{2\zeta}}$$

- Exponentential loss of positional order ??

Naive vision of a D.E. crystal

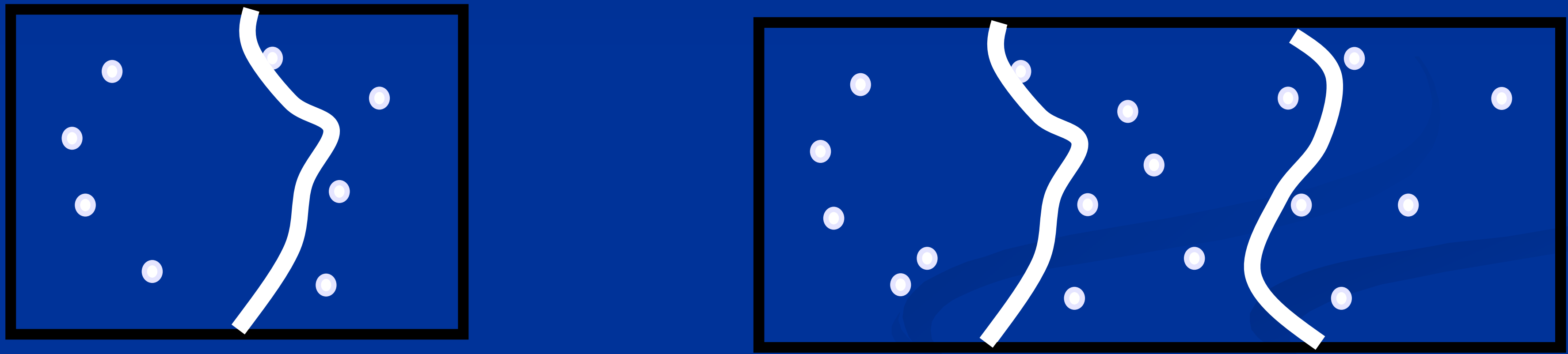
- Loss of translational order beyond Ra

- (Wrong) argument: disorder induces dislocations at Ra



Crystal broken in crystallites of size Ra

Periodic systems: new universality class



$$u \sim L^{\varsigma} \qquad u \sim Log(L)^{1/2}$$

(Nattermann,Korshunov,TG+Le doussal)

Variational and/or FRG

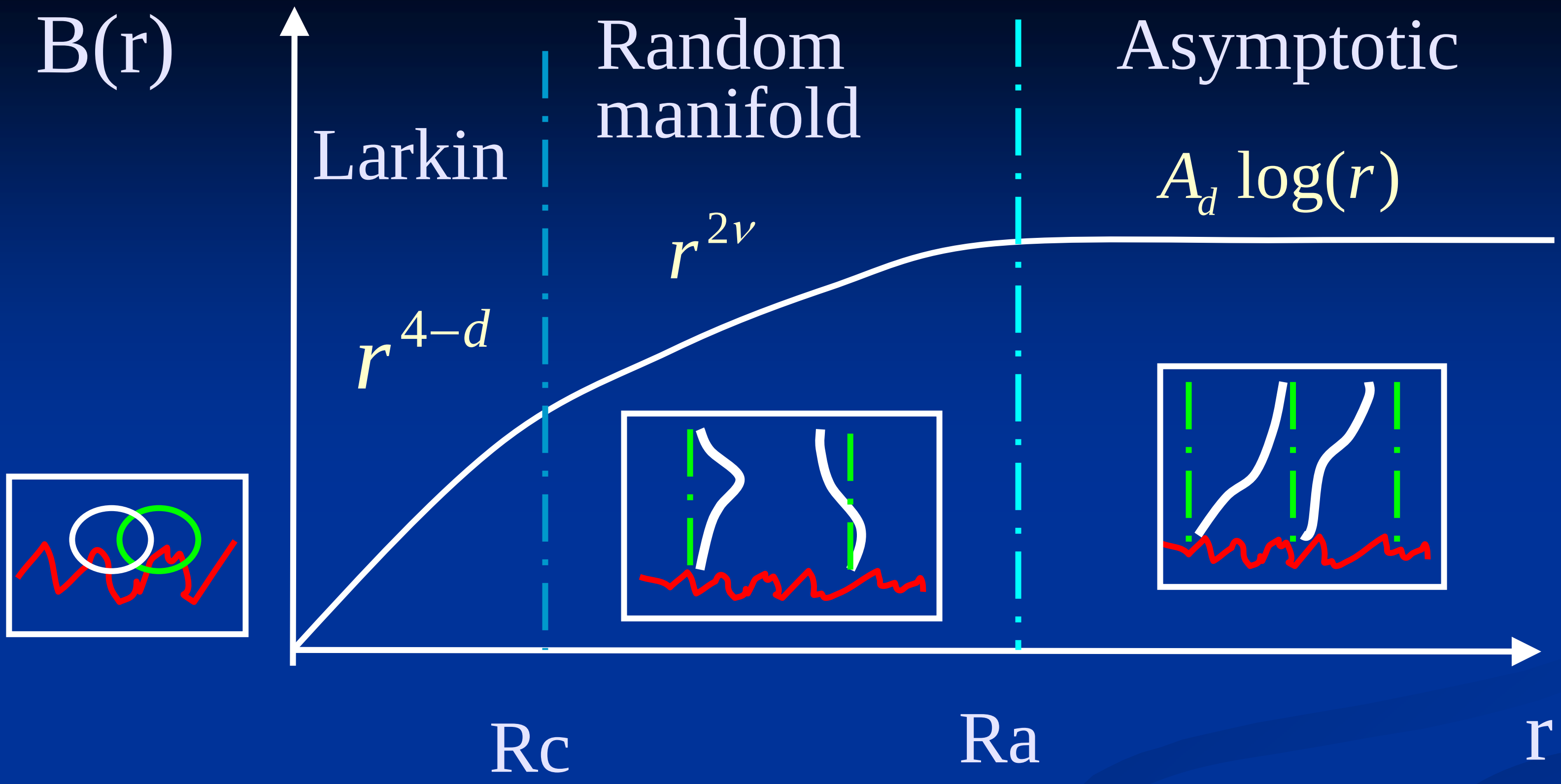
$$\partial\tilde{\Delta}(u)=(\epsilon-2\zeta)\tilde{\Delta}(u)+\zeta u\tilde{\Delta}'(u)+\tilde{T}\tilde{\Delta}''(u)$$
$$+\tilde{\Delta}''(u)[\tilde{\Delta}(0)-\tilde{\Delta}(u)]-\tilde{\Delta}'(u)^2,$$
$$\partial\ln\tilde{T}=\epsilon-2-2\zeta.$$

(TG, P. Le Doussal)

- Periodic system (crystal): $\Delta(u) = A\cos(u)$

- Fixed point: $\zeta = 0$

$$\Delta^*(ax)=\frac{\epsilon a^2}{6}\left(\frac{1}{6}-x(1-x)\right)$$

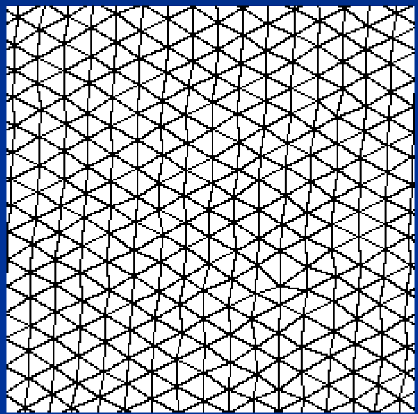


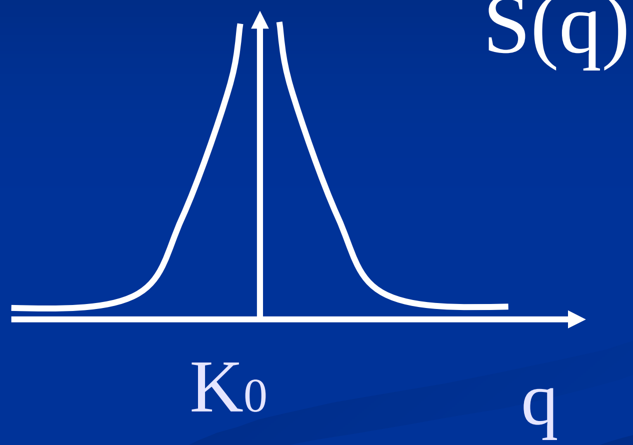
- many metastable states = glass !
- Quasi long range translational order !
- Does disorder generate defects ???

NO!!

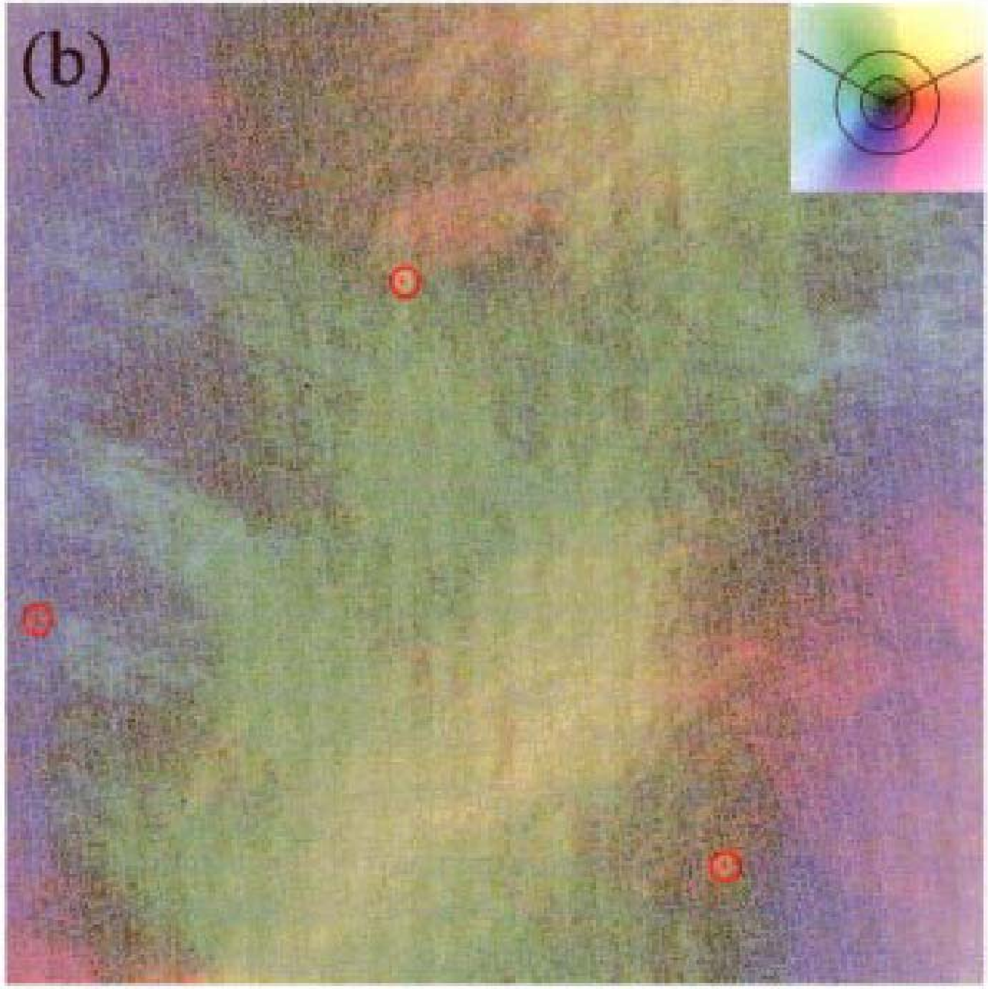
Bragg Glass

(TG, Le Doussal; Nattermann)

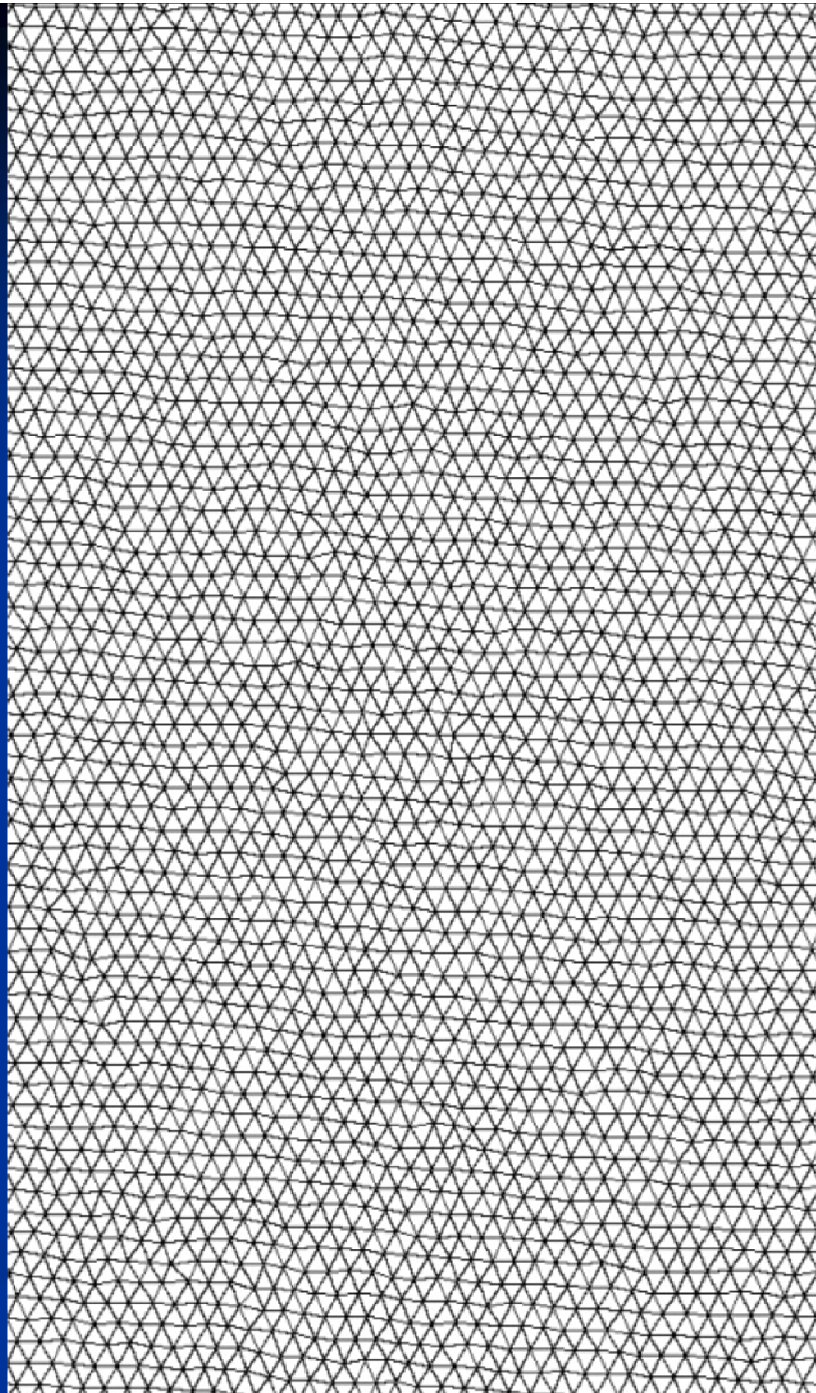




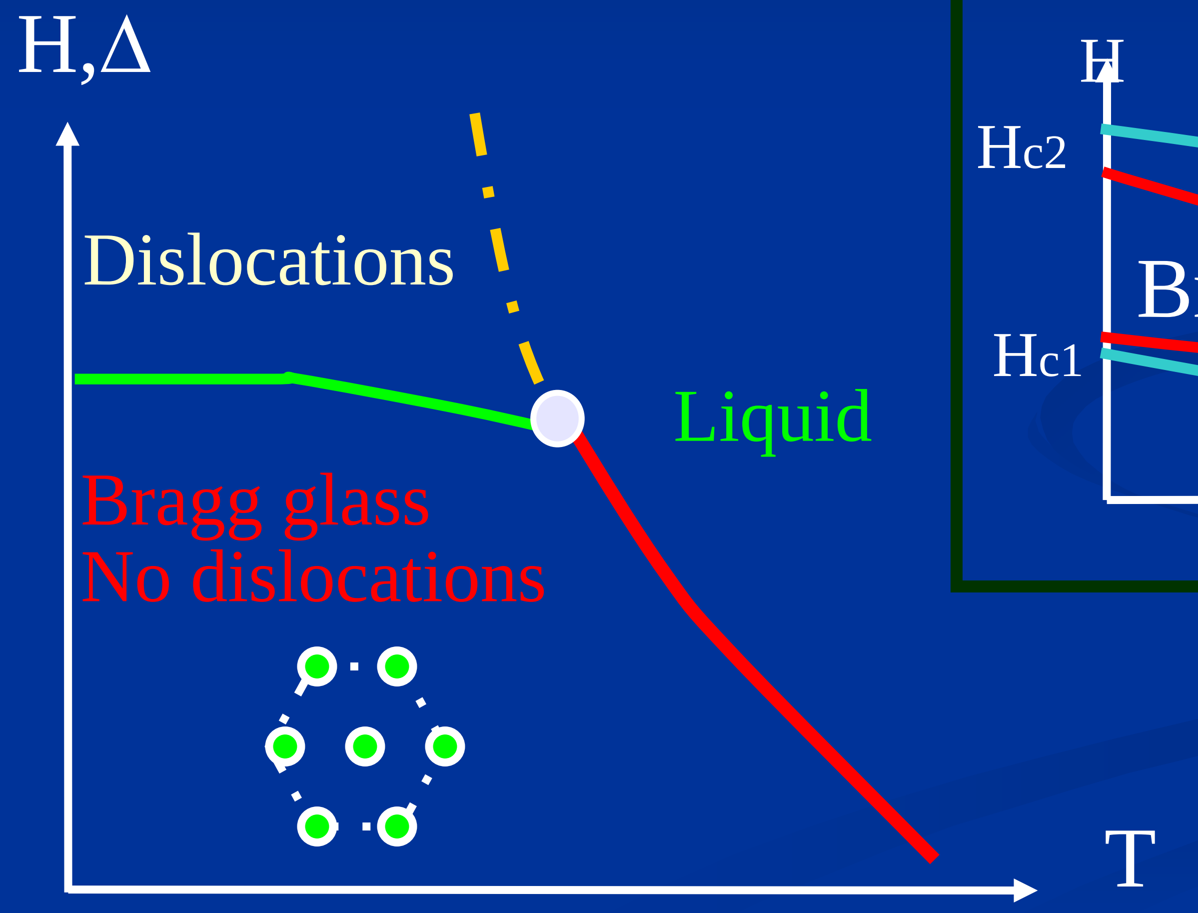
- quasi long range translational order (powerlaw Bragg peaks)
- perfect topological order (no free defects)
- Glassy properties

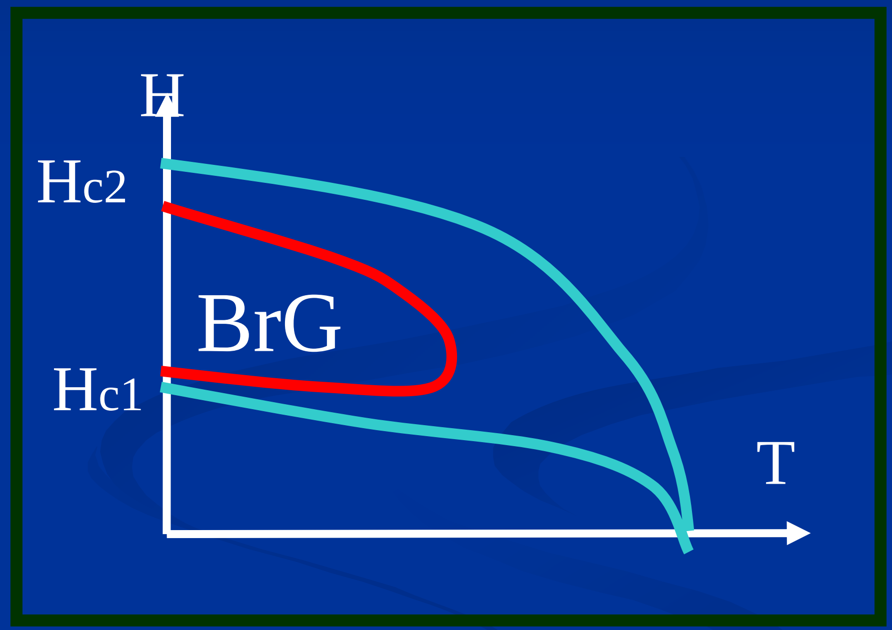


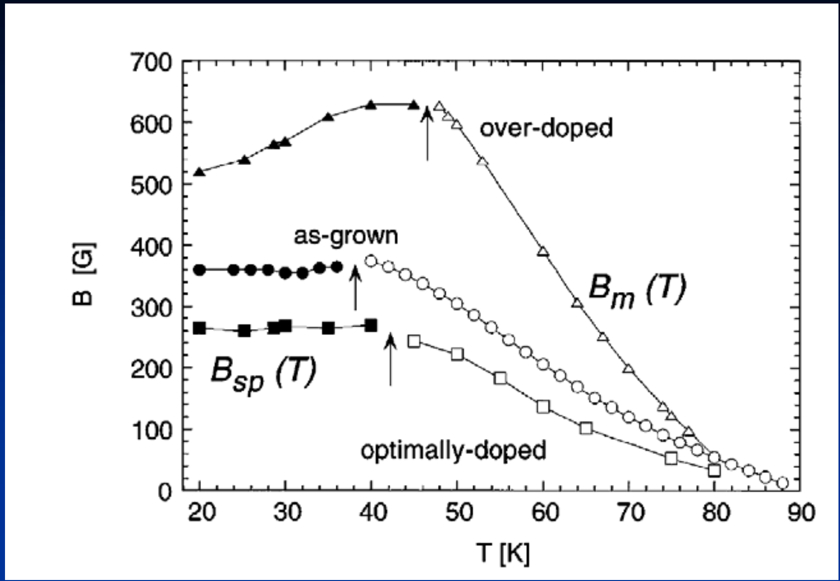
P. Kim PRB 60 R12589 (99)

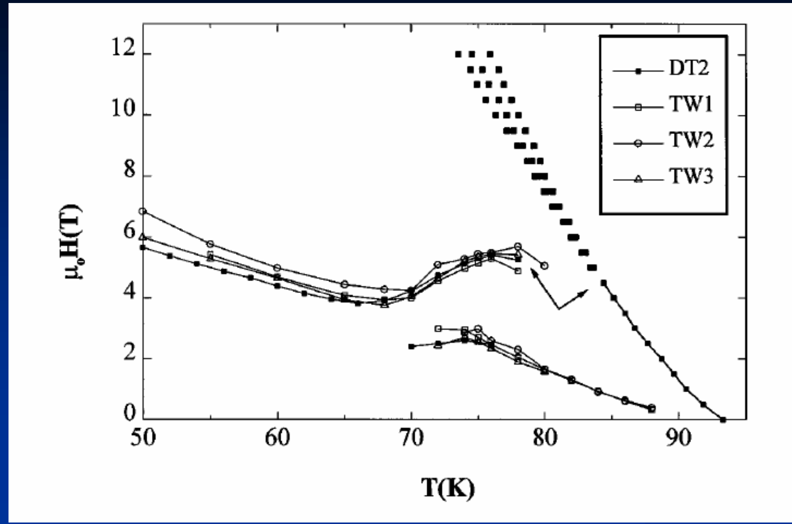


Unified phase diagram

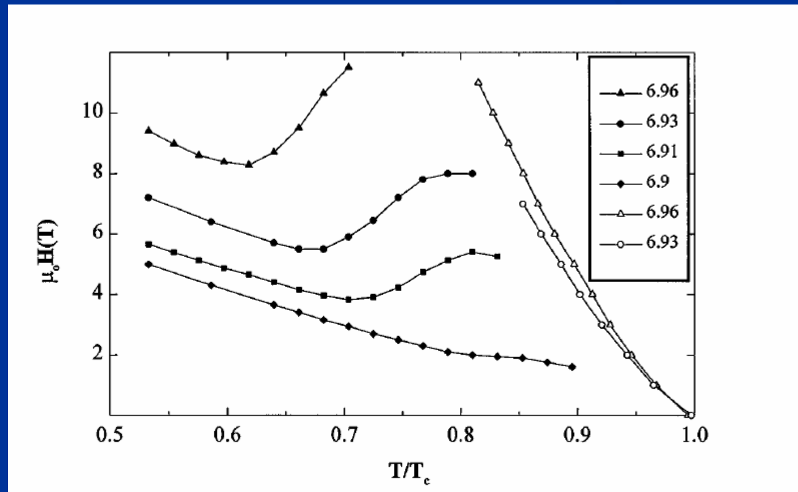


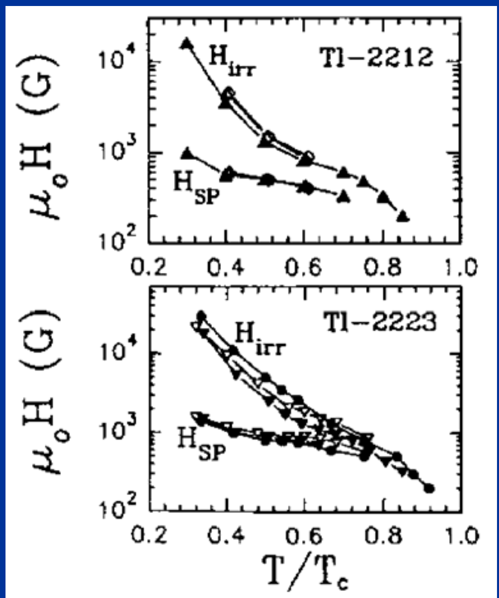






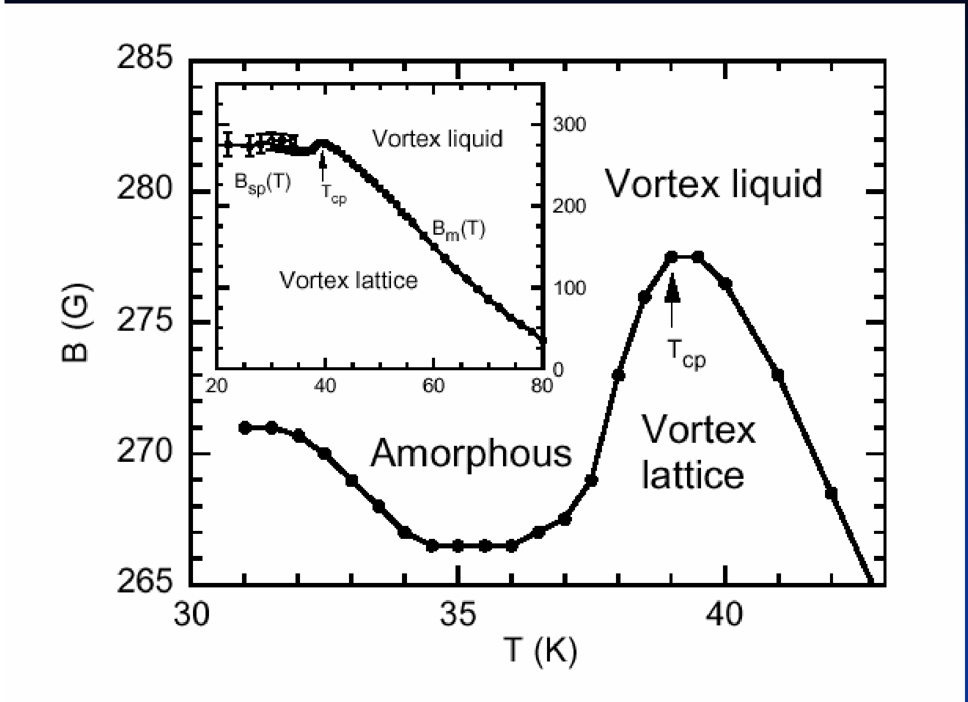
B. Khaykovich et al. PRL 76 2555 (96)

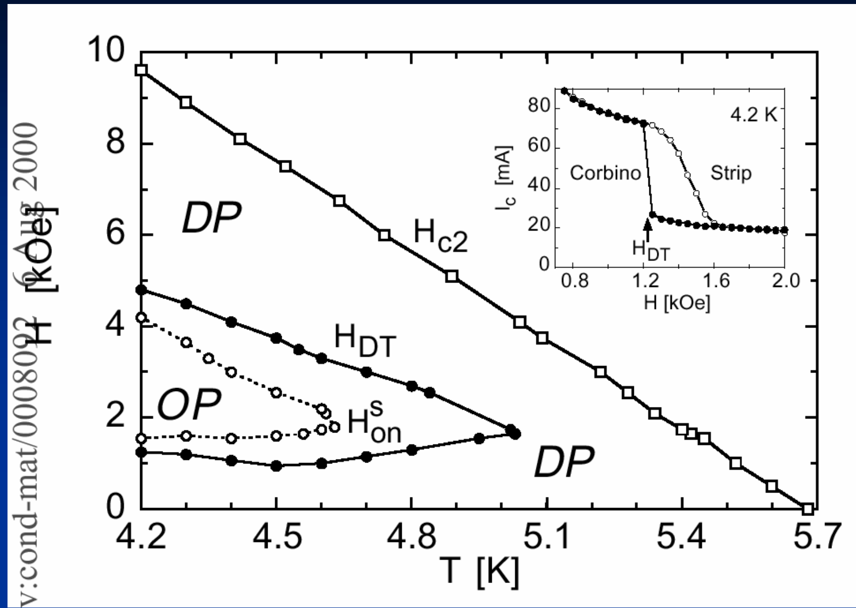




Hardy et al. Physica C 232 347 (94)

K. Deligiannis et al. PRL 79 2121 (97)





N. Avraham et al. Nature 411 451 (2001)

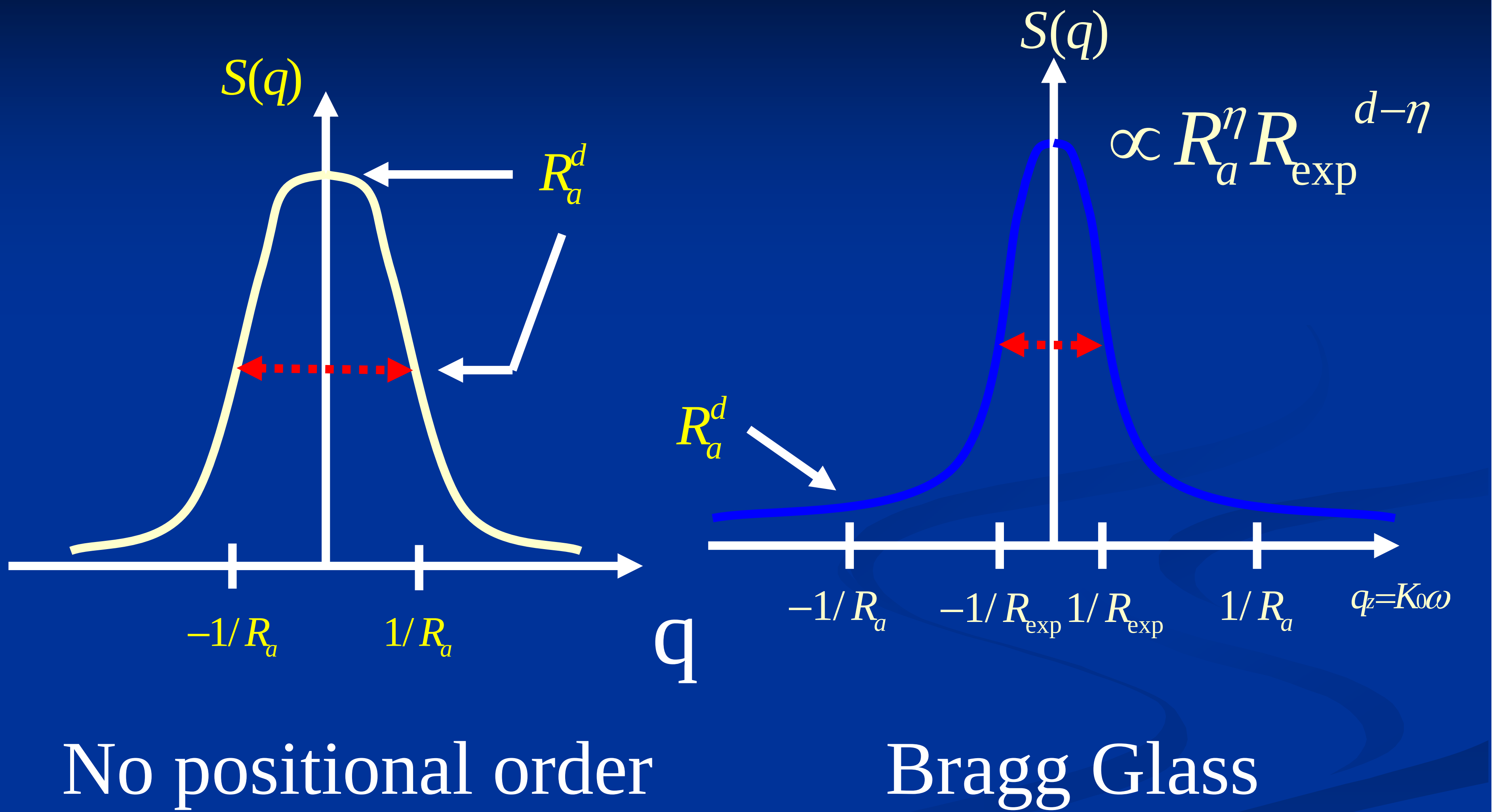
Y. Paltiel et al. PRL 85 3712 (2000)

BSCCO

NBSe2

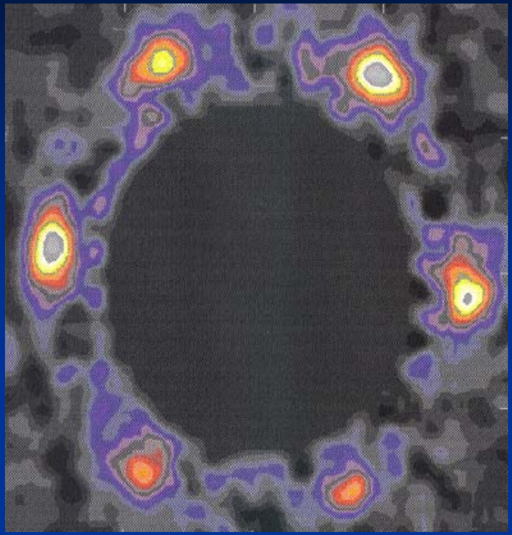
Bragg glass : « melts » like a crystal (first order melting)

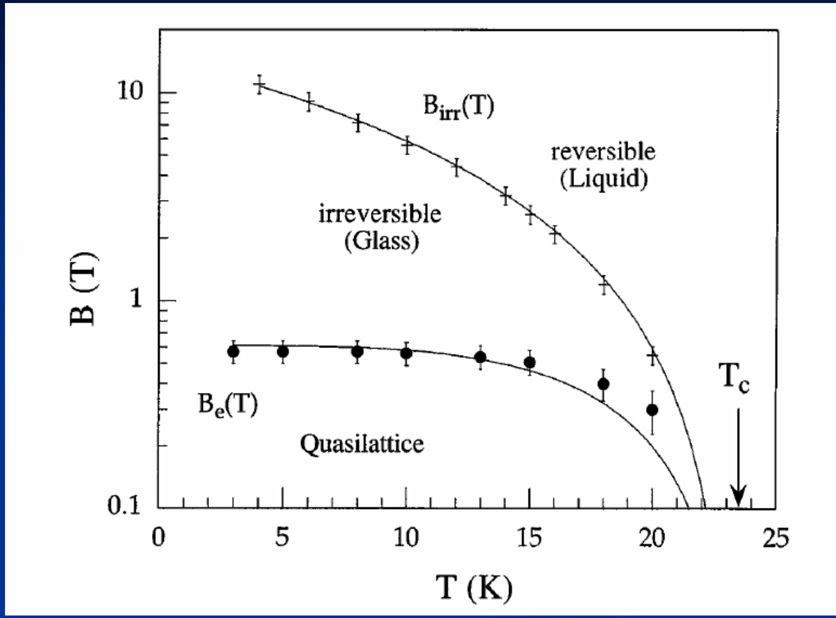
Neutrons

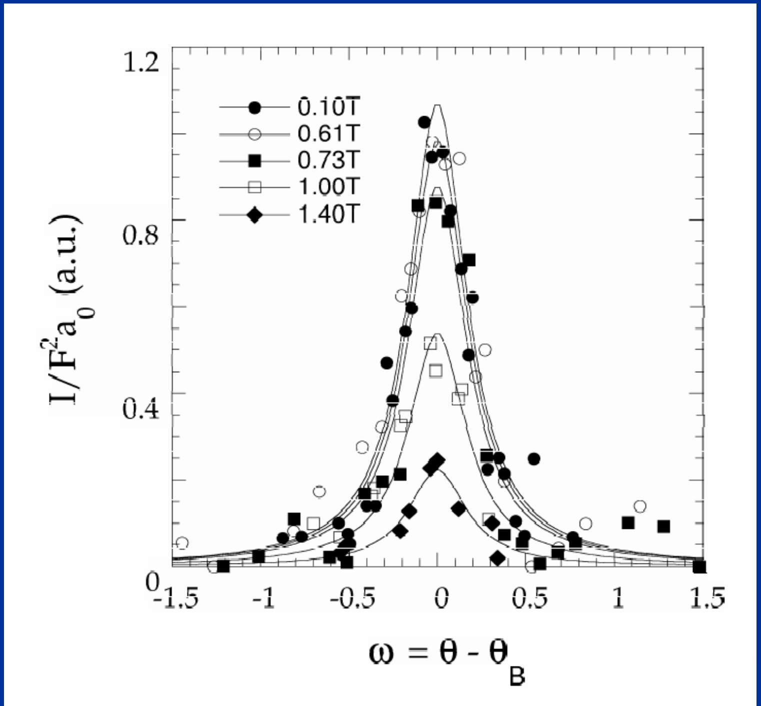


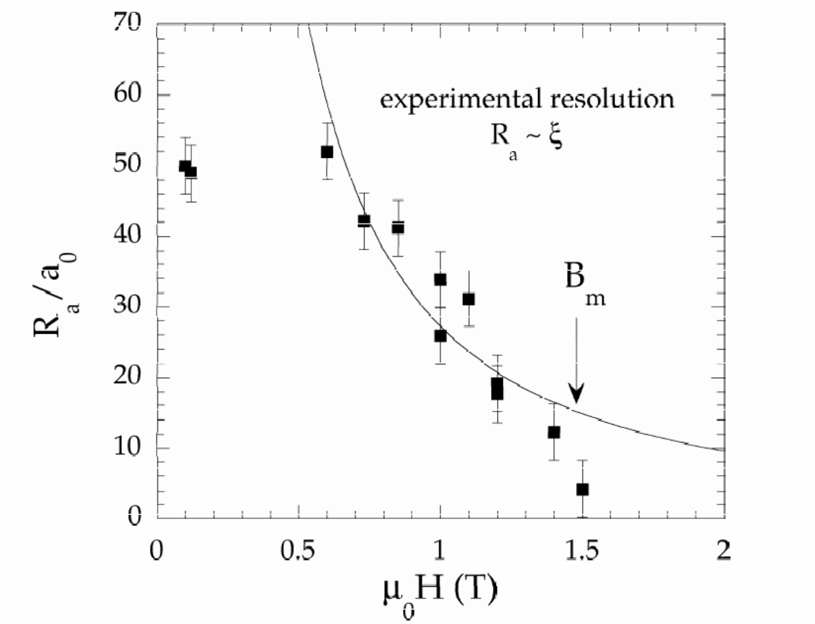
- Collapse of intensity without broadening

T. Klein et al. Nature 413 404 (2001)







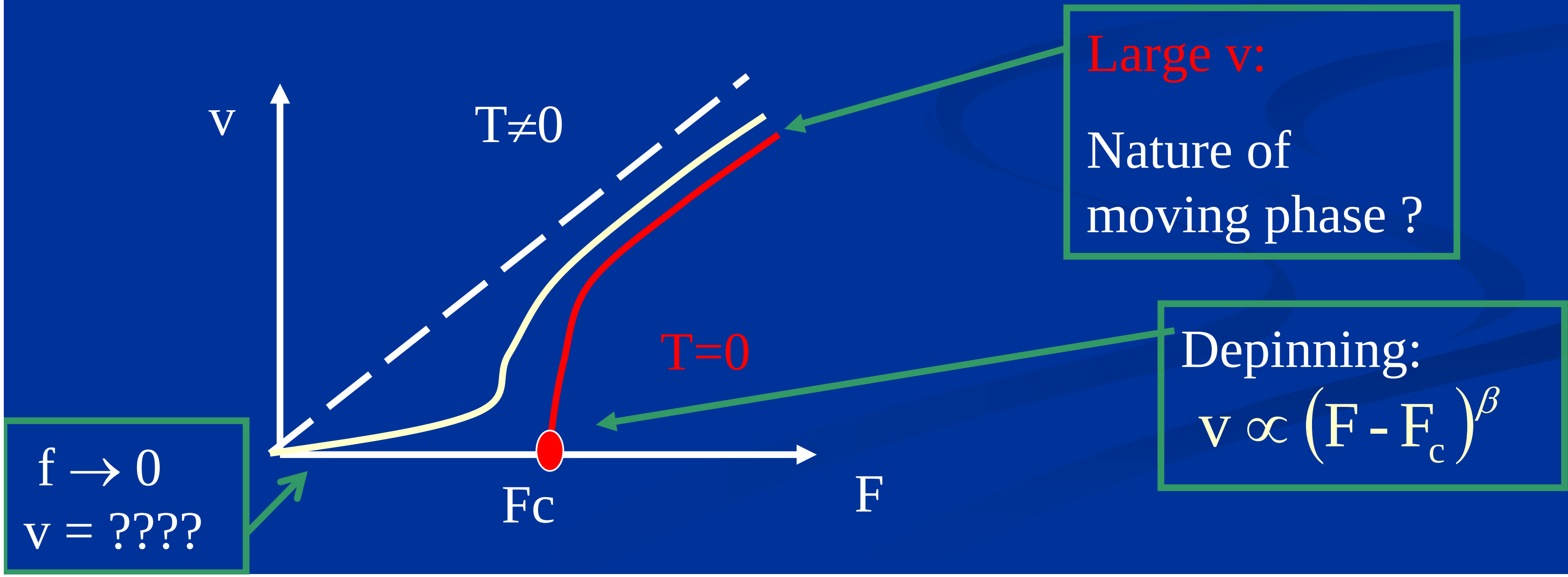


Dynamics

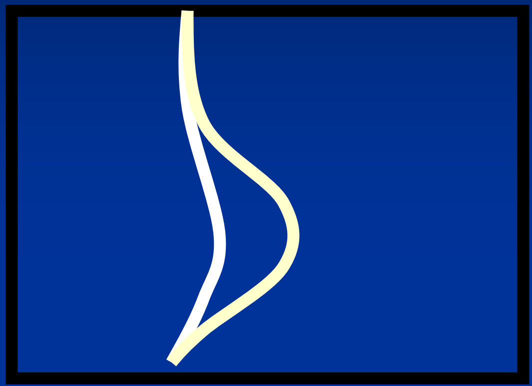
Questions for dynamics

- Competition between disorder and elasticity:
  glassy properties

- Dynamics ?



Pinning (Fc) and Larkin length (Rc)



$$F_c = \frac{c\xi}{R_c^2}$$

$$H_{el} = \frac{c}{2}\int (\nabla u(r))^2 d^d r \qquad H_{el} = \int F u(r) d^d r$$

$$cR_c^{d-2}\xi^2 \qquad FR_c^d\xi$$

Depinning (T=0)

$$\overline{(u_{r,t}-u_{0,0})^2}=r^{2\zeta}\mathcal{C}(t/r^z),$$

ζ for F ~ F_c differs from ζ for F=0

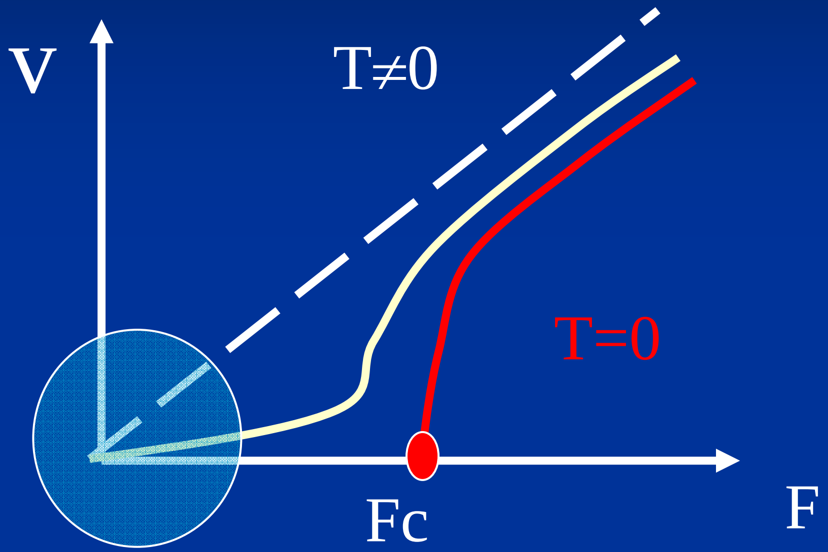
$$v\sim(f-f_c)^{\beta},$$

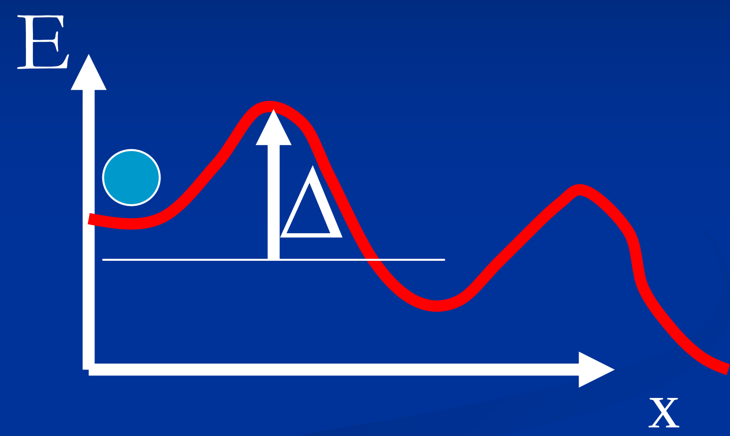
$$\xi\sim(f-f_c)^{-\nu}.$$

$$\nu=\frac{1}{2-\zeta}=\frac{\beta}{(z-\zeta)}.$$

Only RF universality class

Response to a small force





- TAFF : typical barrier
- Linear response

$$v \propto e^{-\beta\Delta} F$$

Creep

- Glassy system: no typical barrier

(Ioffe + Vinokur; Nattermann)

$$H_{el} = \frac{c}{2}\int (\nabla u(r))^2 d^d r$$

$$H_{el} = \int F u(r) d^d r$$

$$cR^{d-2+2\varsigma}$$

$$FR^{d+\zeta}$$

$$L_{opt} \approx F^{\varsigma-2}$$

$$U(L_{opt}) \approx F^{\frac{d+2\varsigma-2}{\varsigma-2}}$$

$$v \propto e^{-\beta U_c (F_c/F)^{\frac{d-2+2\zeta}{2-\zeta}}}$$

Strong assumptions

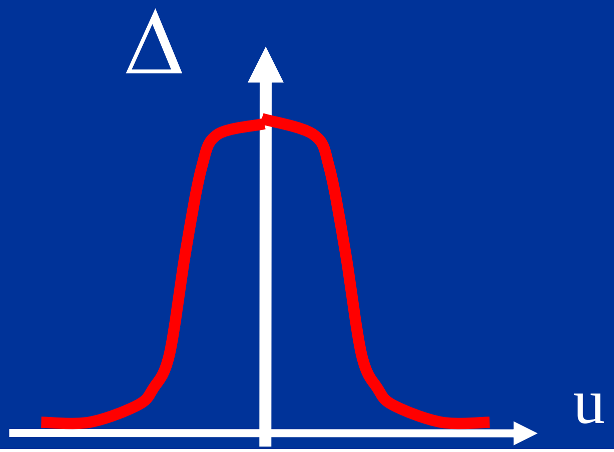
- Motion so slow that static properties can be used
- Scaling of barriers is identical to the one of metastable states
- Dominated by typical barriers

Microscopic calculation ??

How to study

$$\eta \partial_t u = c \nabla^2 u + F_{pin}[u] + f + \zeta \qquad \int DuD\hat{u} e^{i\hat{u}(\partial_t u - c\nabla^2 u - ....)}$$

$$\begin{aligned} S_{\rm uns}(u,\hat{u}) = \int_{rt} i\hat{u}_{rt}(\eta\partial_t - c\nabla^2)u_{rt} - \eta T \int_{rt} i\hat{u}_{rt} i\hat{u}_{rt} \\ -f \int_{rt} i\hat{u}_{rt} \qquad\qquad (4.1) \\ -\frac{1}{2}\int_{rtt'} i\hat{u}_{rt} i\hat{u}_{rt'} \Delta(u_{rt} - u_{rt'}) \end{aligned}$$



Martin-Siggia-Rose, Keldysh

Correlator of disorder

Creep from FRG

$$\partial\tilde{\Delta}(u) = (\epsilon - 2\zeta)\tilde{\Delta}(u) + \zeta u \tilde{\Delta}'(u) + \tilde{T}\tilde{\Delta}''(u)$$
$$+ \int_{s>0,s'>0} e^{-s-s'} (\tilde{\Delta}''(u)\{\tilde{\Delta}[(s'-s)\lambda]$$
$$- \tilde{\Delta}[u+(s'-s)\lambda]\} - \tilde{\Delta}'(u-s'\lambda)\tilde{\Delta}'(u+s\lambda)$$
$$+ \tilde{\Delta}'[(s'+s)\lambda][\tilde{\Delta}'(u-s'\lambda) - \tilde{\Delta}'(u+s\lambda)]), \quad (4.11)$$

$$\partial \ln \lambda = 2 - \zeta - \int_{s>0} e^{-s} s \tilde{\Delta}''(s\lambda),$$

$$\partial \ln \tilde{T} = \epsilon - 2 - 2\zeta + \int_{s>0} e^{-s} s\lambda \tilde{\Delta}'''(s\lambda),$$

$$\partial \tilde{f} = e^{-(2-\zeta)l} c \Lambda_0^2 \int_{s>0} e^{-s} \tilde{\Delta}'(s\lambda),$$

$$\tilde{\Delta}_l(u) = \frac{S_D \Lambda_l^D}{(c\Lambda_l^2 e^{\zeta l})^2} \Delta_l(u e^{\zeta l}),$$

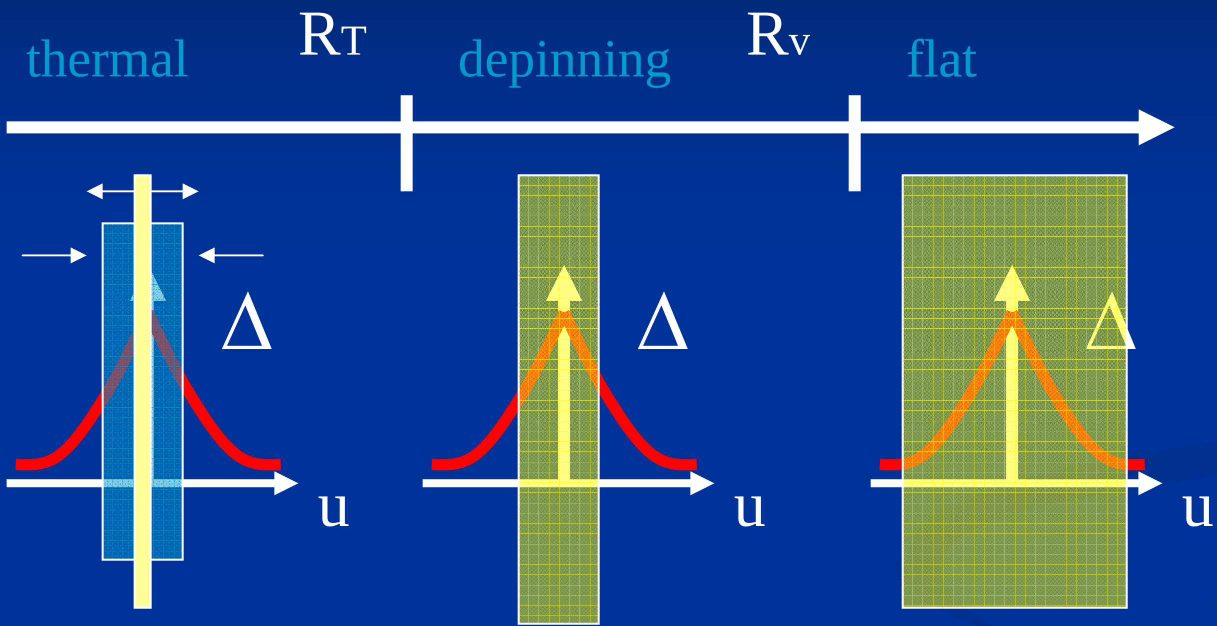
$$\tilde{T}_l = \frac{S_D \Lambda_l^D}{c\Lambda_l^2 e^{2\zeta l}} T_l,$$

$$\lambda_l = \frac{\eta_l v}{c\Lambda_l^2 e^{\zeta l}},$$

$$\tilde{f}_0 = f - \eta_0 v,$$

(Chauve, TG, Le doussal)

Dynamics: rounding of cusp



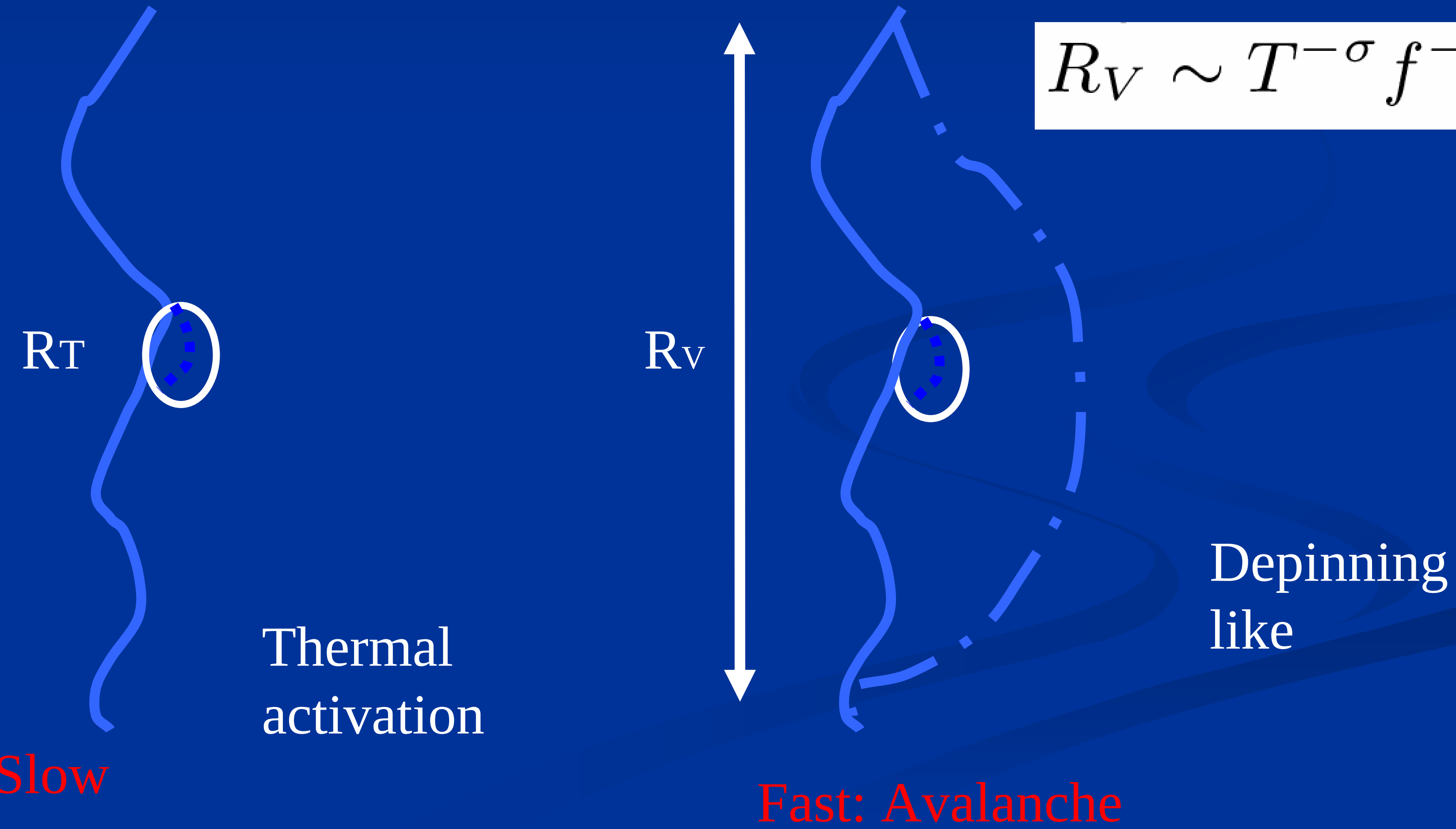
$$\frac{\eta v}{f_c} \approx \exp\left[-\frac{U_c}{T}\left(\frac{f}{f_c}\right)^{-\mu}\right]$$

$$\mu = \frac{D-2+2\zeta_{\rm eq}}{2-\zeta_{\rm eq}}$$

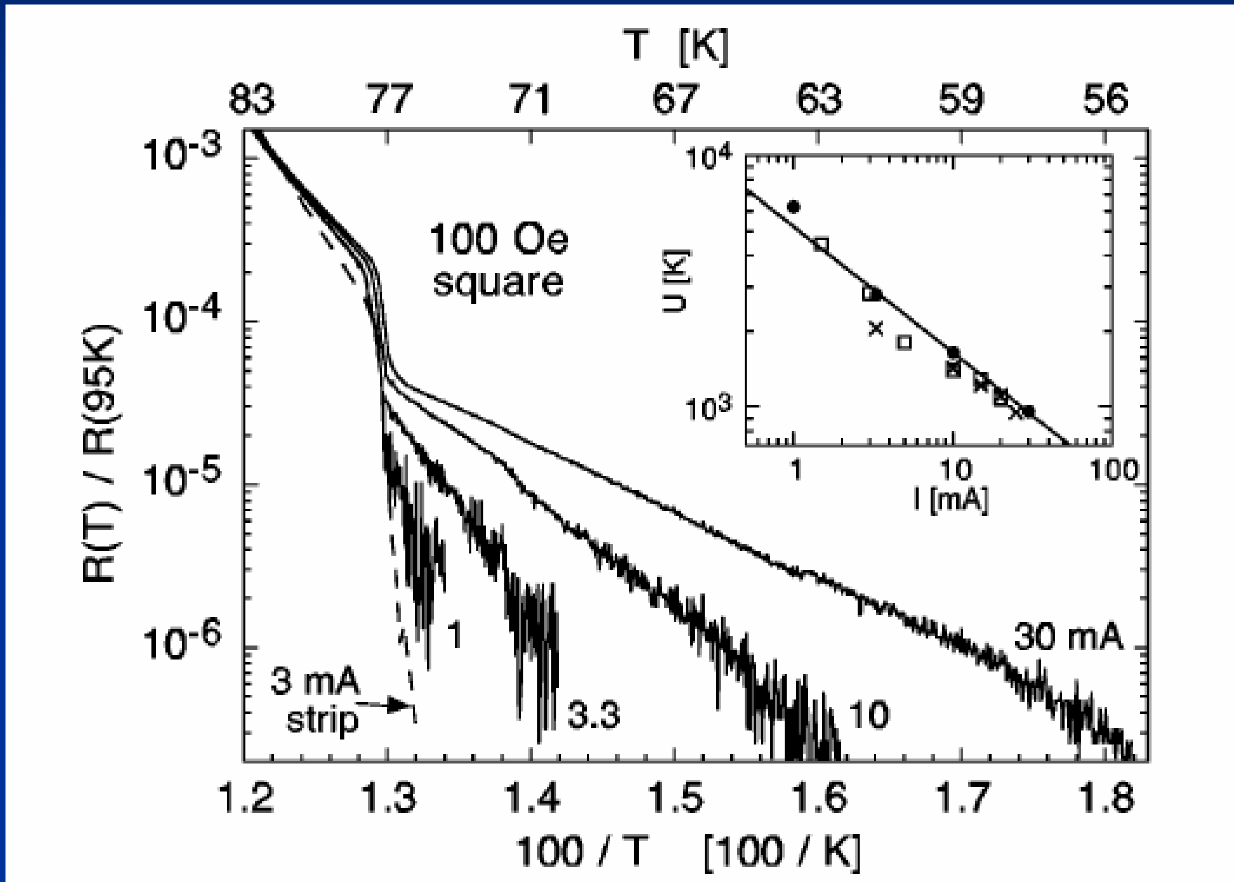
New lengthscale: avalanches

Motion quite different from phenomenological picture (two regimes)

$$R_V \sim T^{-\sigma} f^{-\lambda}$$



Vortices

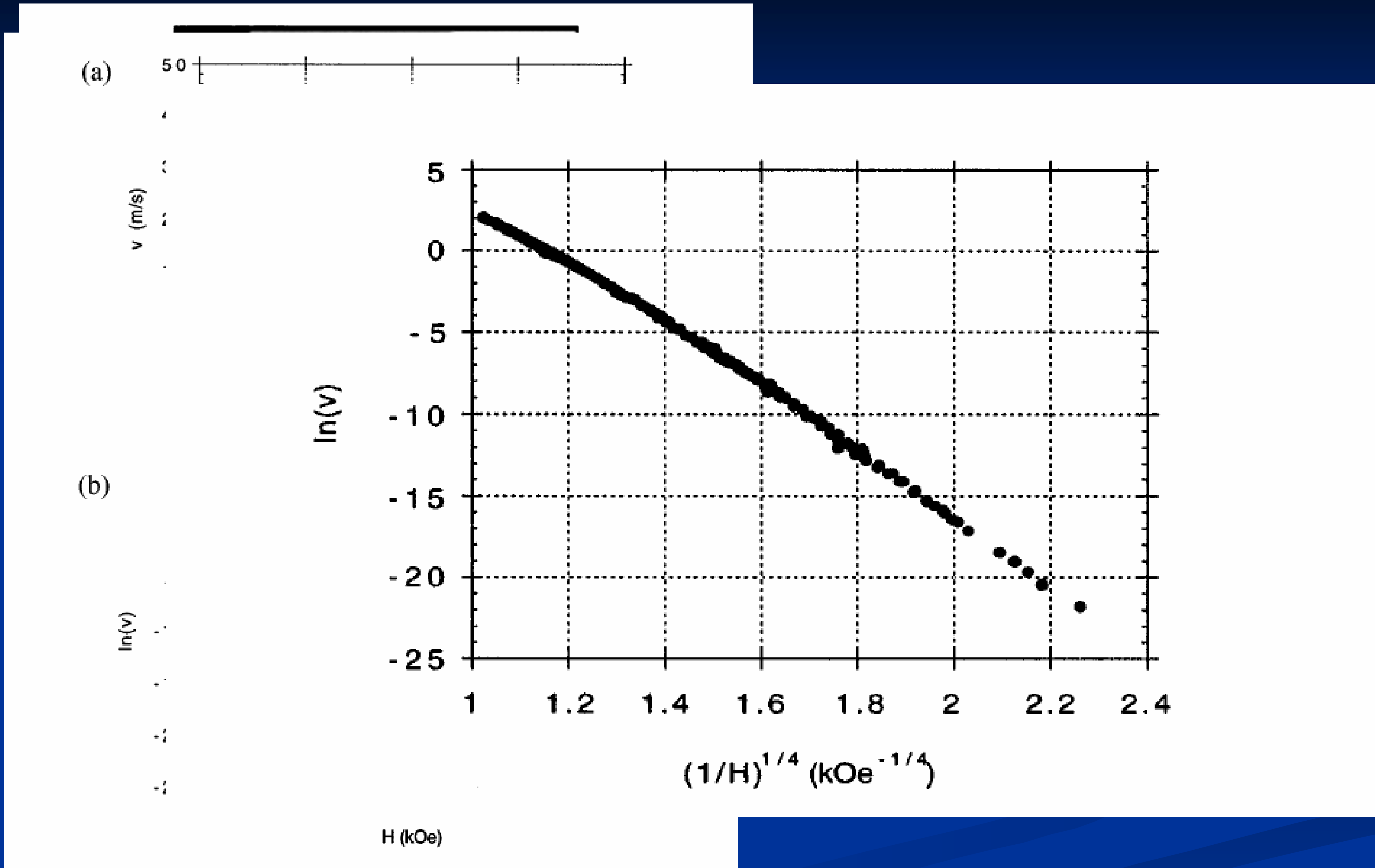


Bragg glass

$\zeta = 0$, d=3

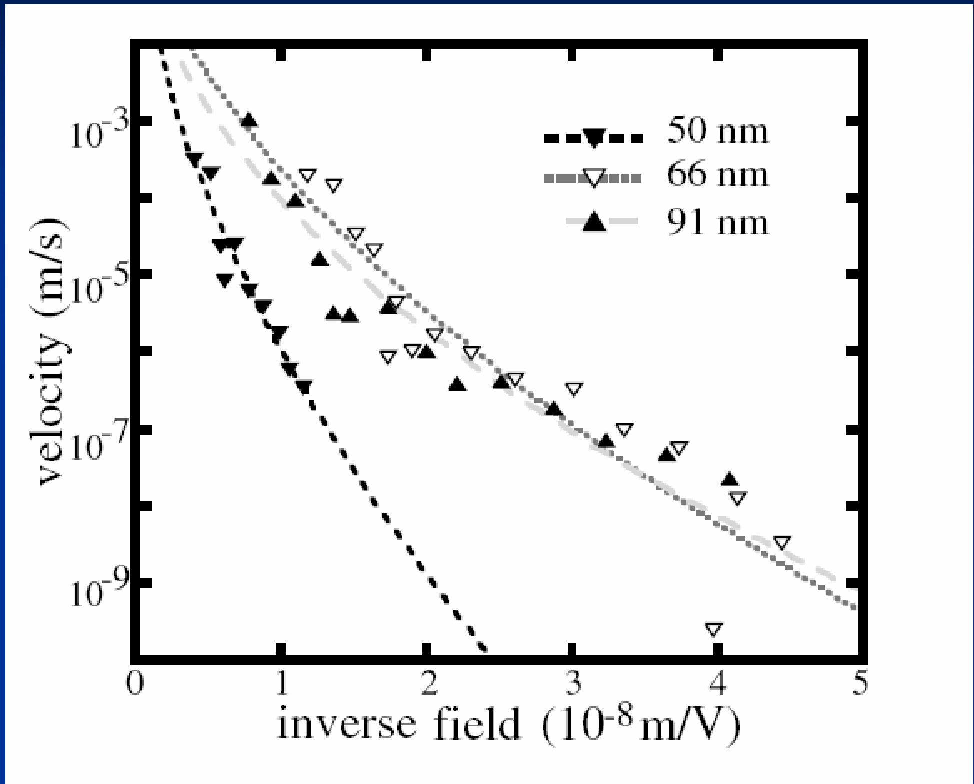
$\mu = 0.5$

D.T. Fuchs et al. PRL 81 3944 (98)



S. Lemerle et al. PRL 80 849 (98) $\zeta = 2/3$; $\mu = 1/4$

Ferroelectics



T. Tybell et al. PRL 89 097601 (02)

P. Paruch et al. PRL 94 197601 (05)

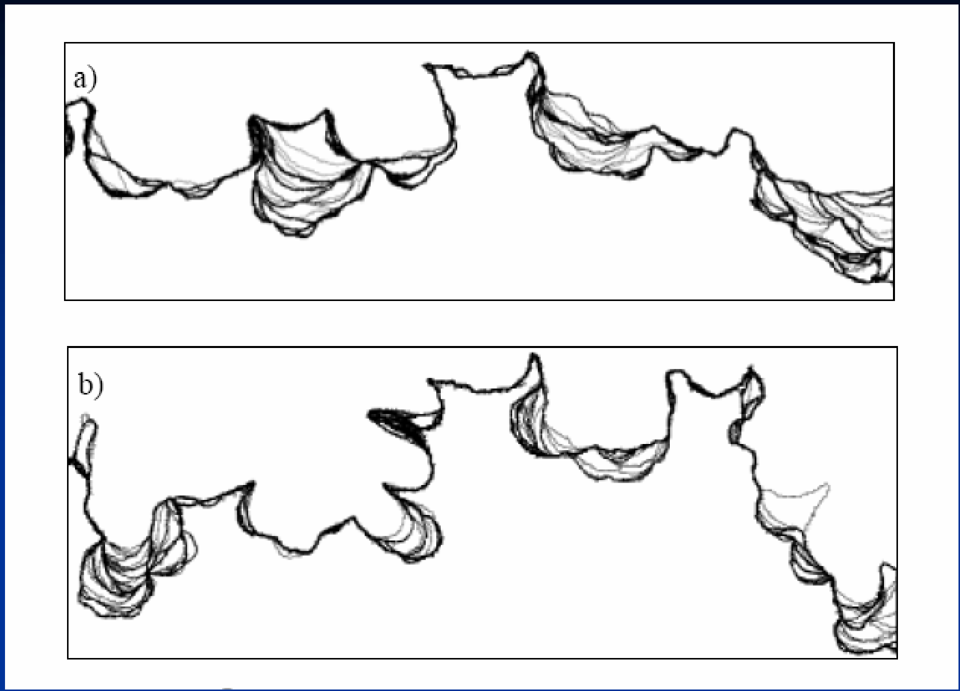
$\mu \sim 0.58$

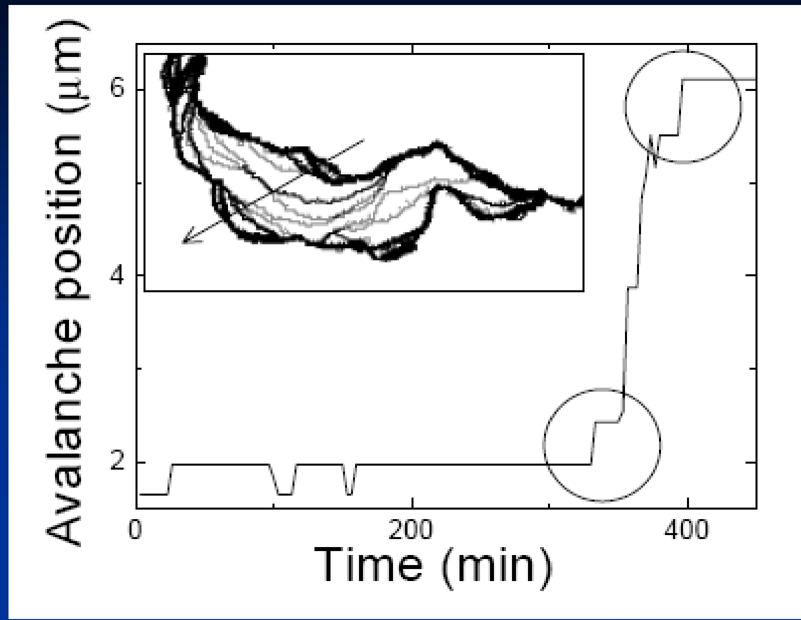
$\zeta \sim 0.26$

$$\mu = \frac{d - 2 + 2\zeta}{2 - \zeta}$$

d ~ 2.49

Compatible with d=2 + dipolar interactions





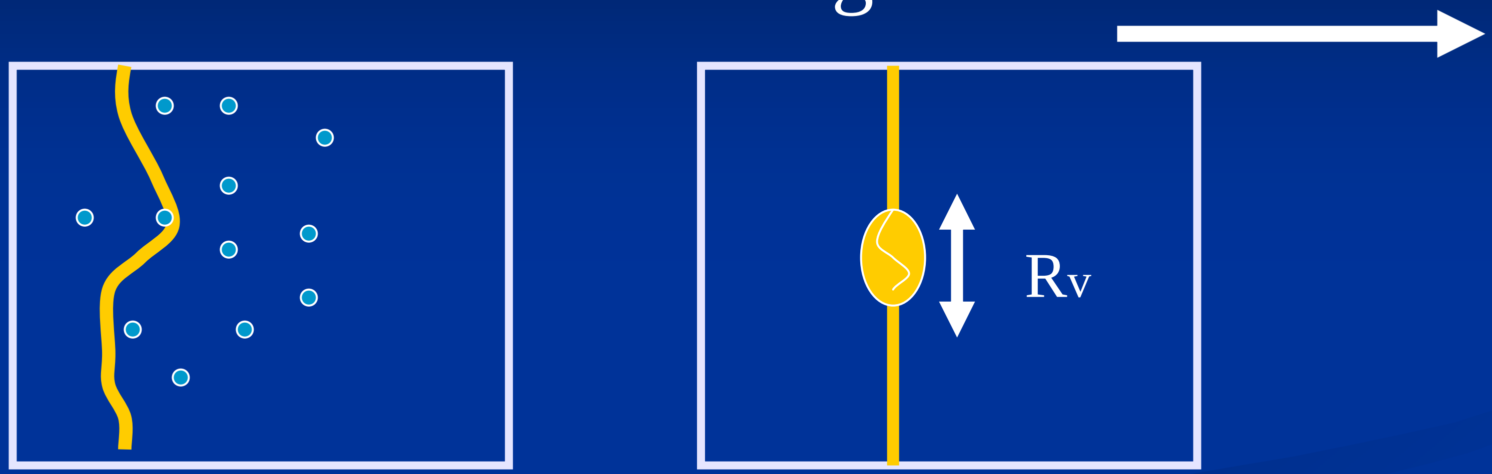
$H = 159\,\mathrm{A\,m^{-1}}$ and $L_C = 40\,\mathrm{nm}$.

$R_T \sim 1\ \mu\mathrm{m}$

V. Repain et al. EPL 68 460 (04)

Large V

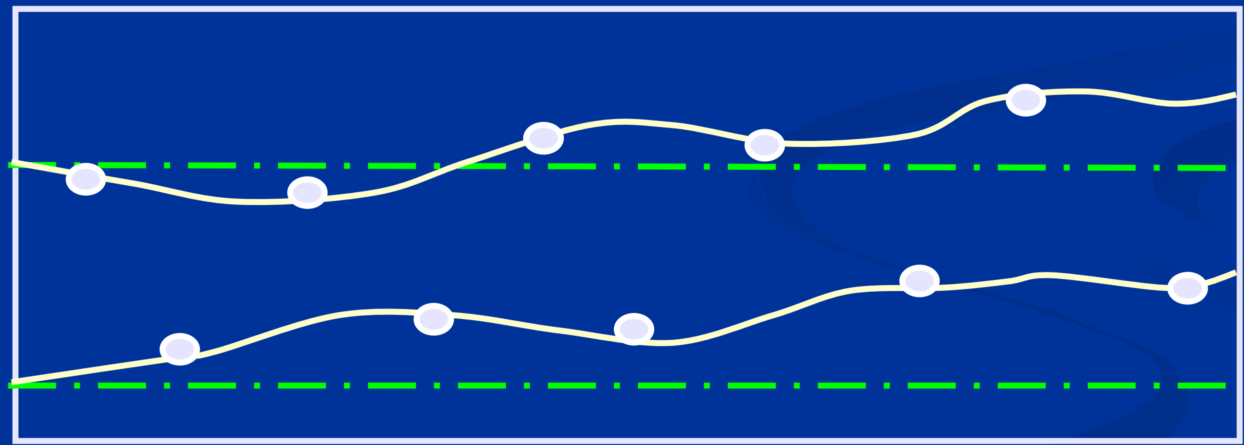
Interfaces reorder at large V



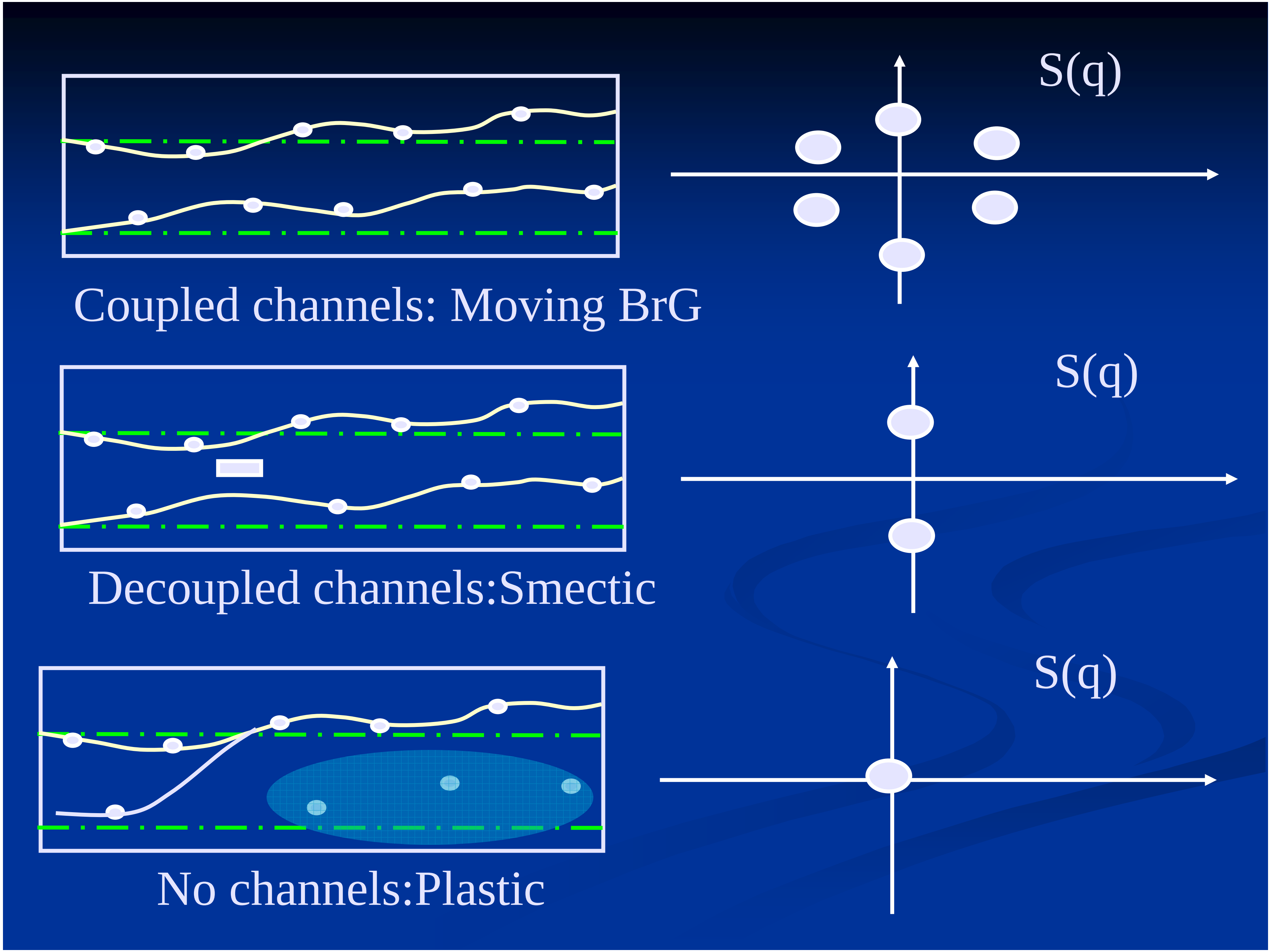
Thermal Roughening for R > R_v

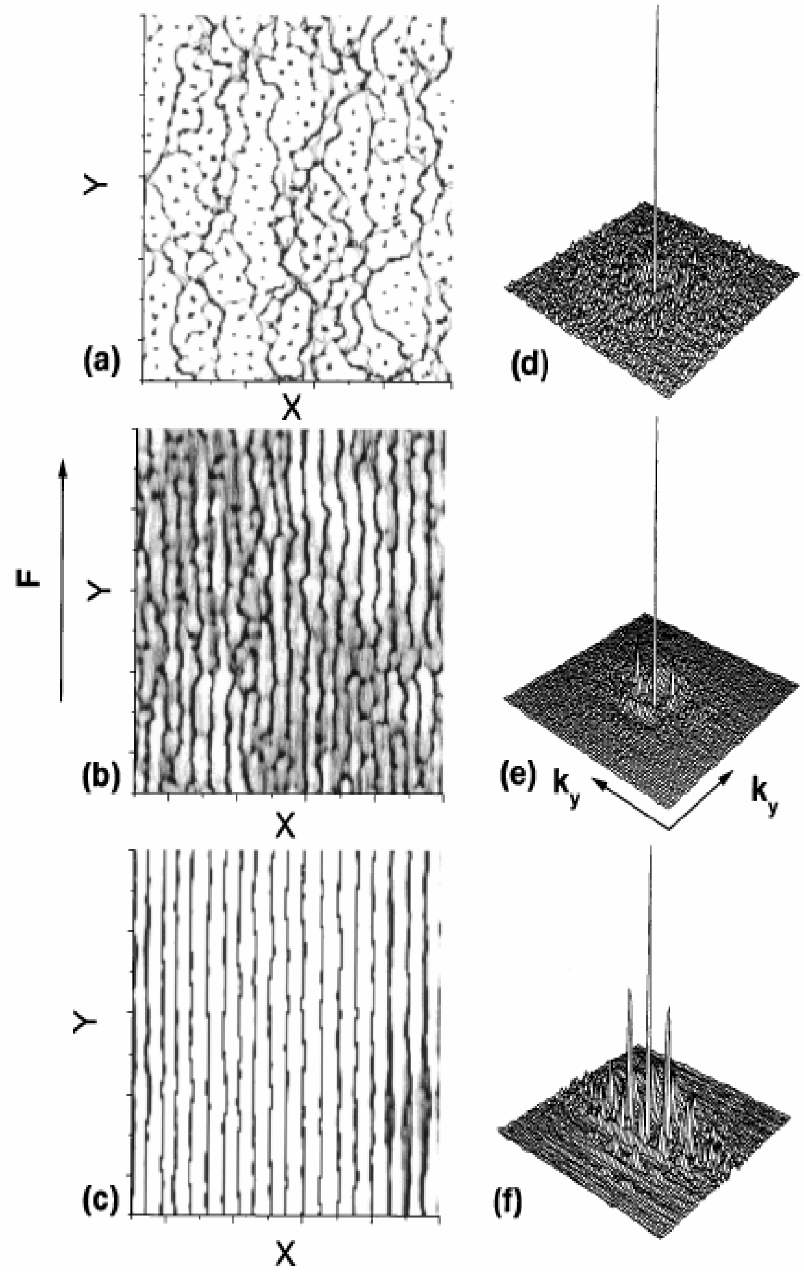
Crystal vs Interfaces

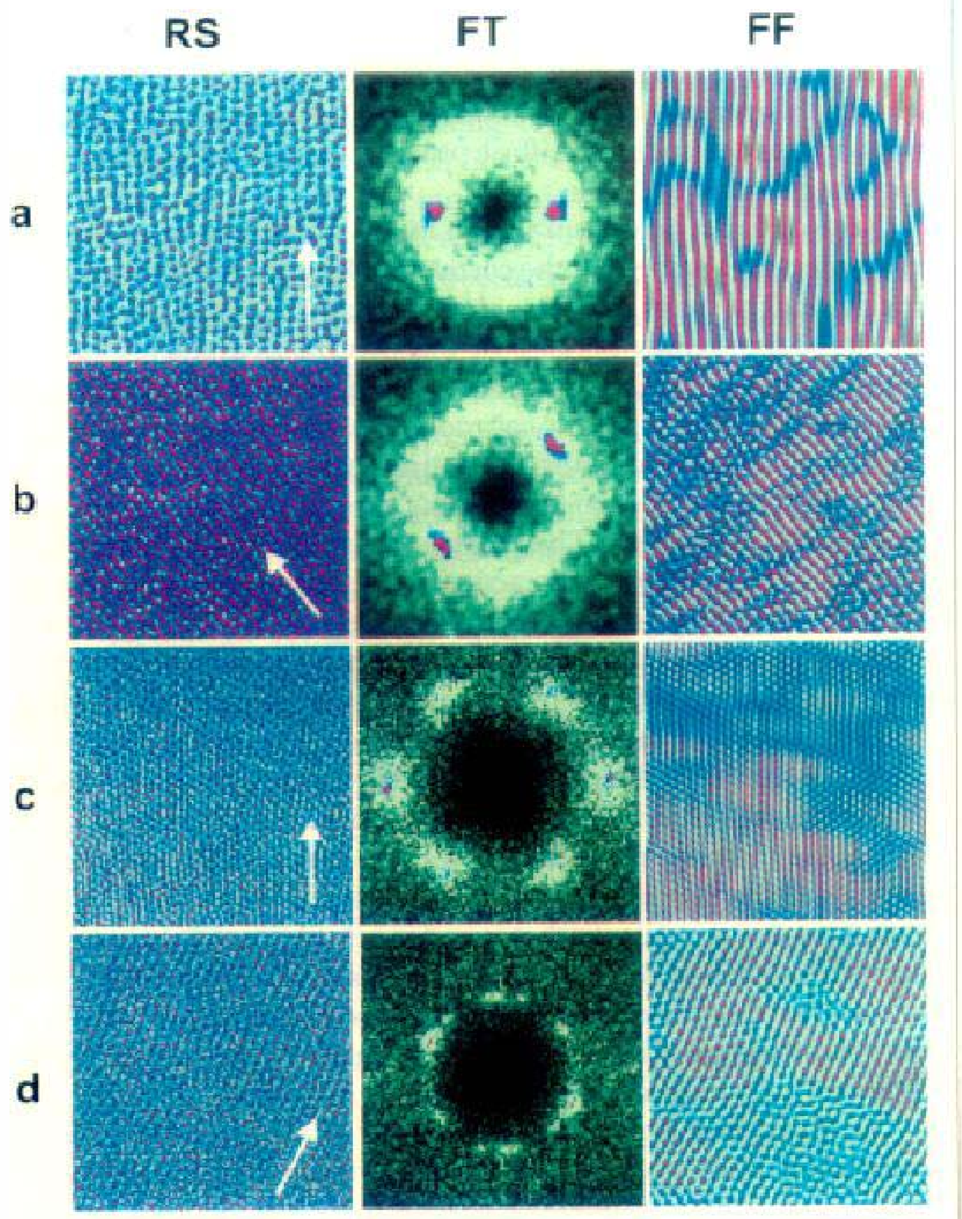
- Disorder remains in perp. direction
- Motion via static channels



- Moving glass (TG, P. Le Doussal)


S(q)
Coupled channels: Moving BrG
S(q)
Decoupled channels:Smectic
S(q)
No channels:Plastic

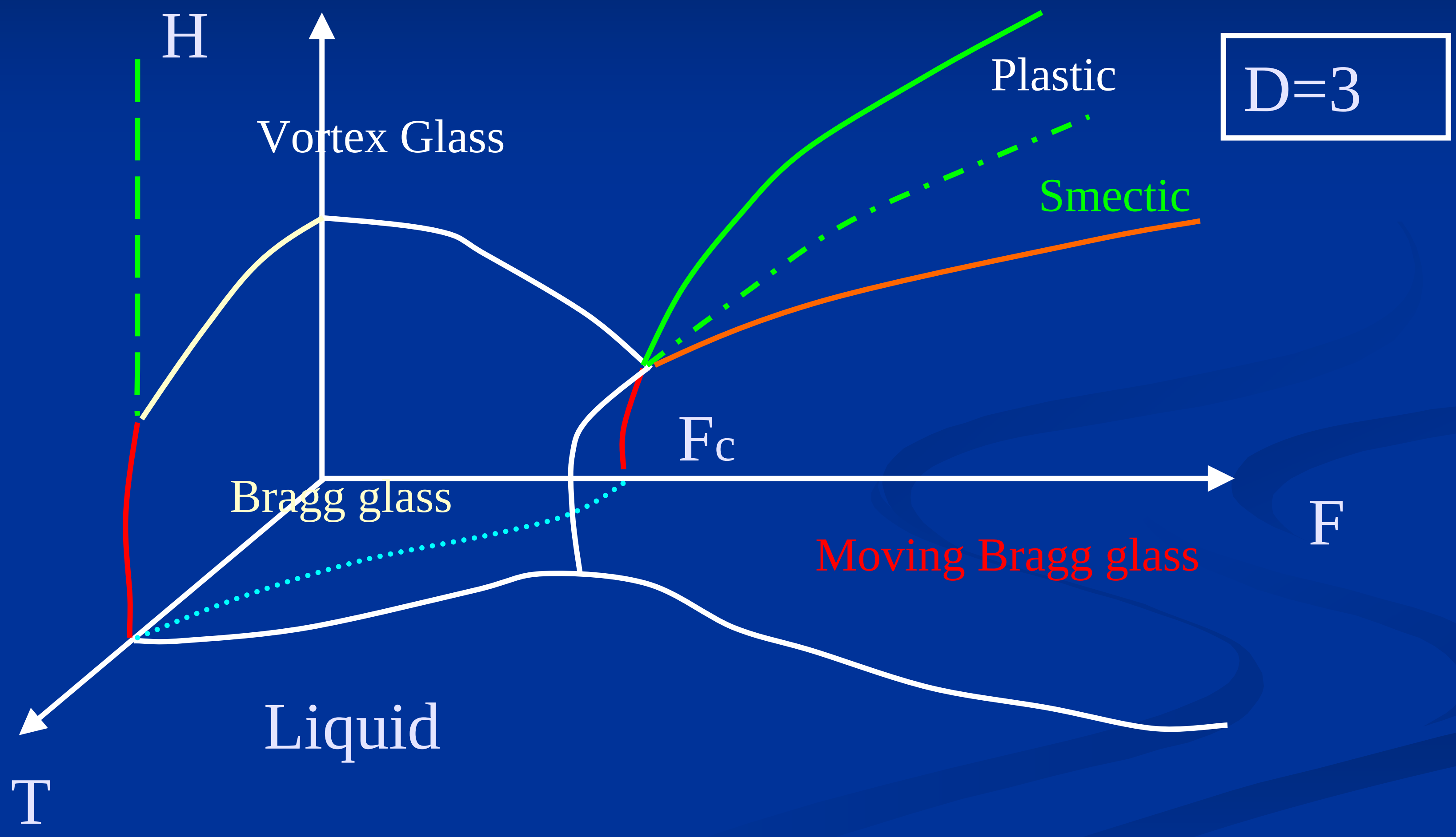




A. Kolton et al PRL 83 3061 (1999)

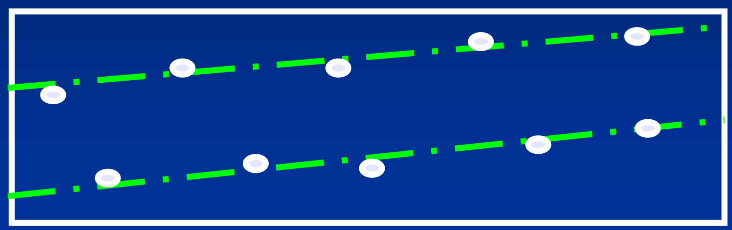
F. Pardo et al. Nature, 396 348 (1998)

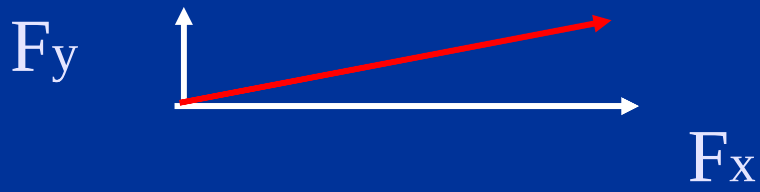
Dynamical Phase Diagram

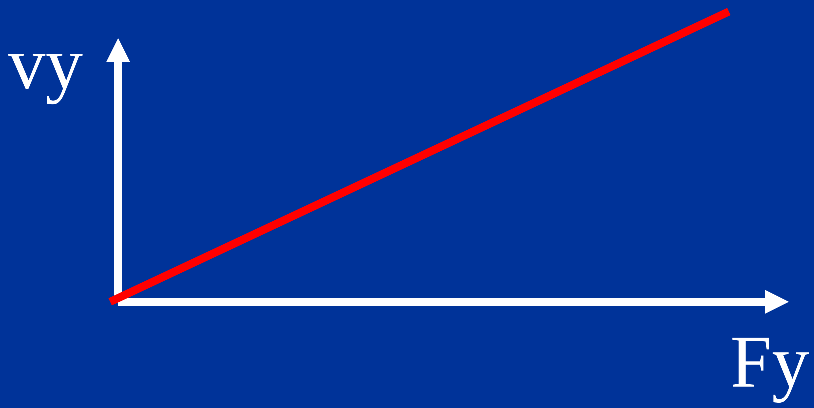


Transverse critical force

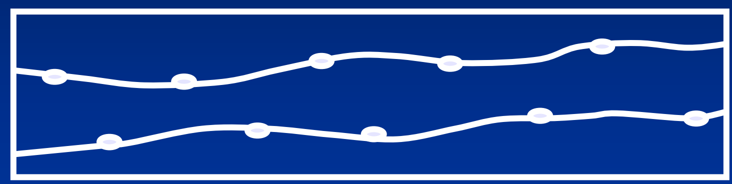
Crystal without disorder

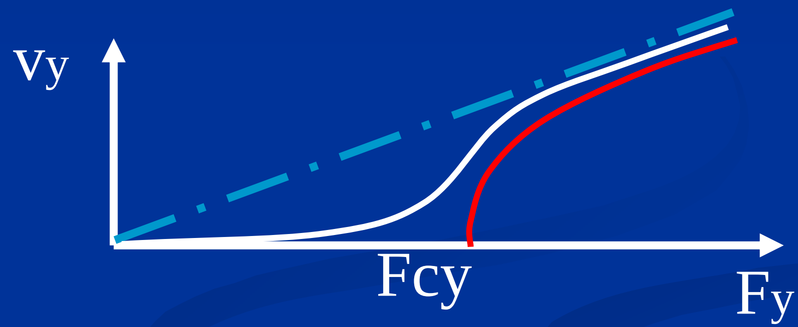


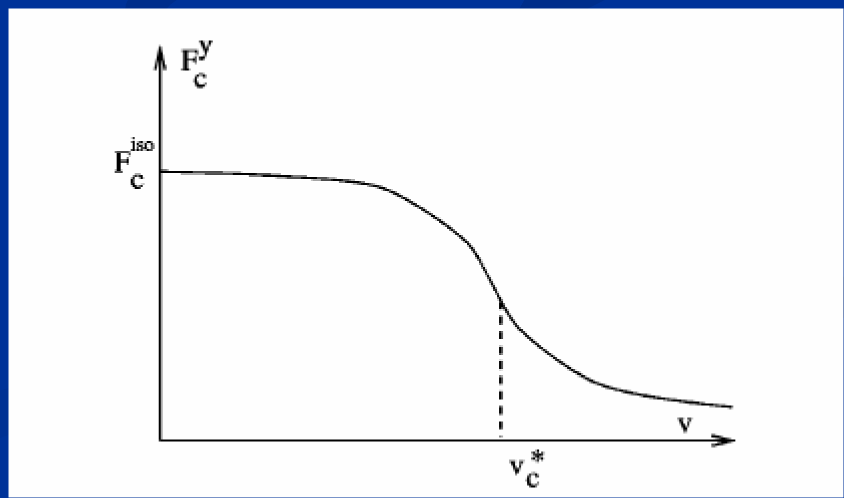




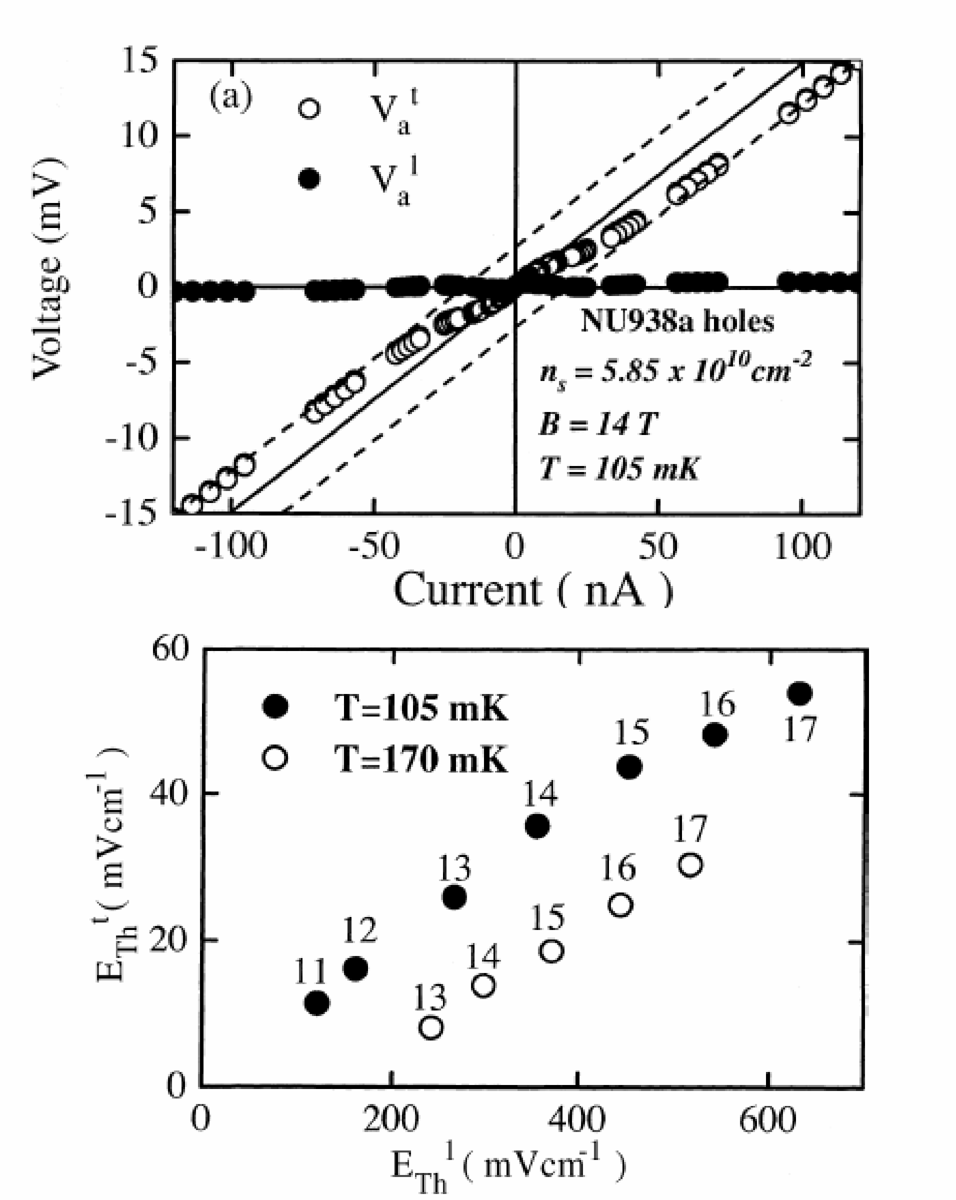
Moving glass







Absence of Hall voltage



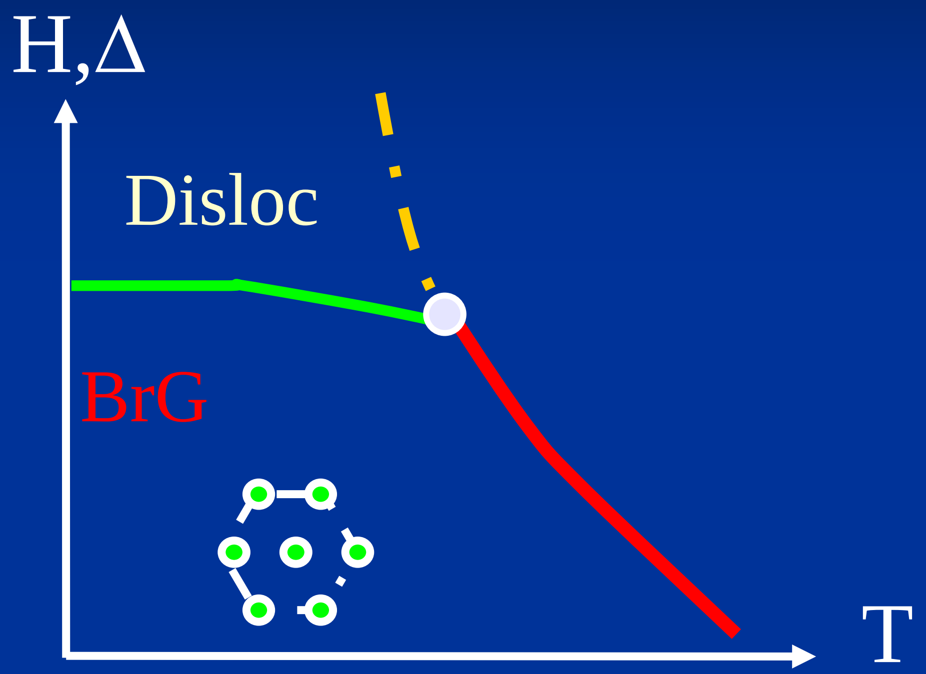
- $F_{lor} < F_{tran}$: no hall voltage
- Compatible with the existence of a transverse threshold

F. Perruchot et al. Physica B 256 587 (1998)

Not the end of the story

? Defects ?

Defects !

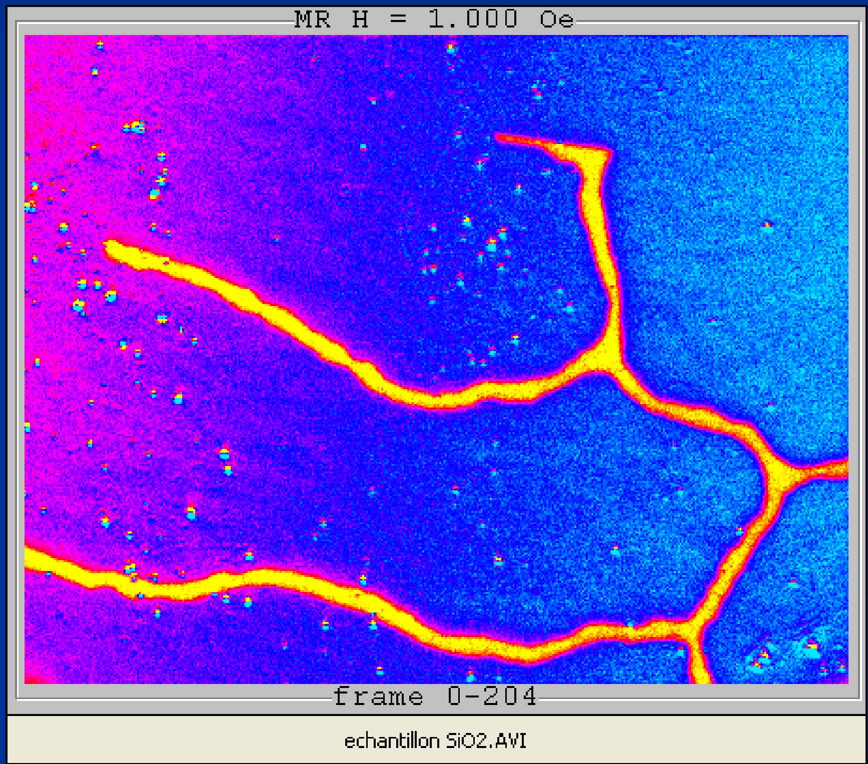


Nature of high field phase ?

Influence on dynamics ?

Roughness of the irradiated layer :

(V. Repain et al. (Orsay))

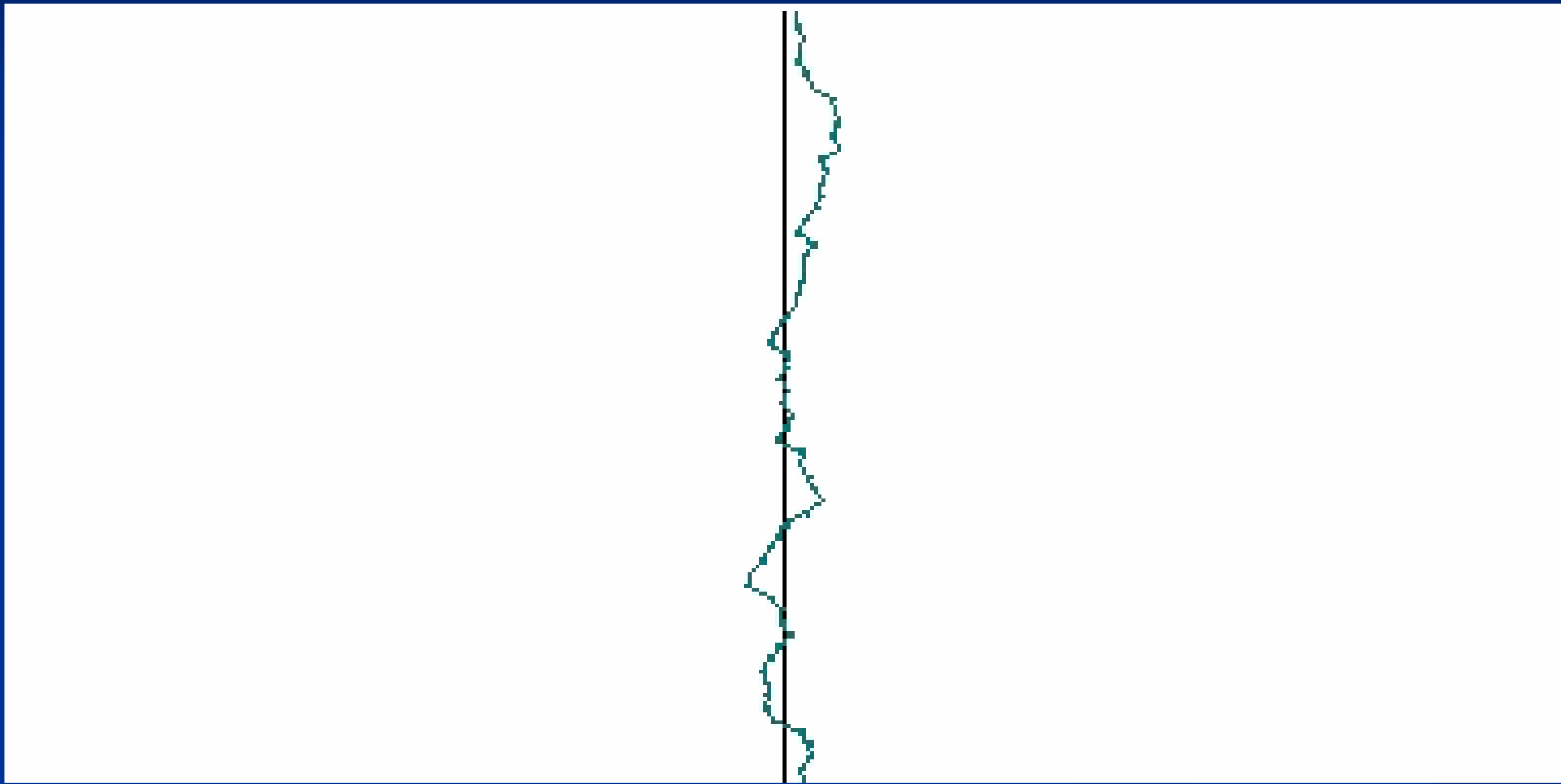


210 μm

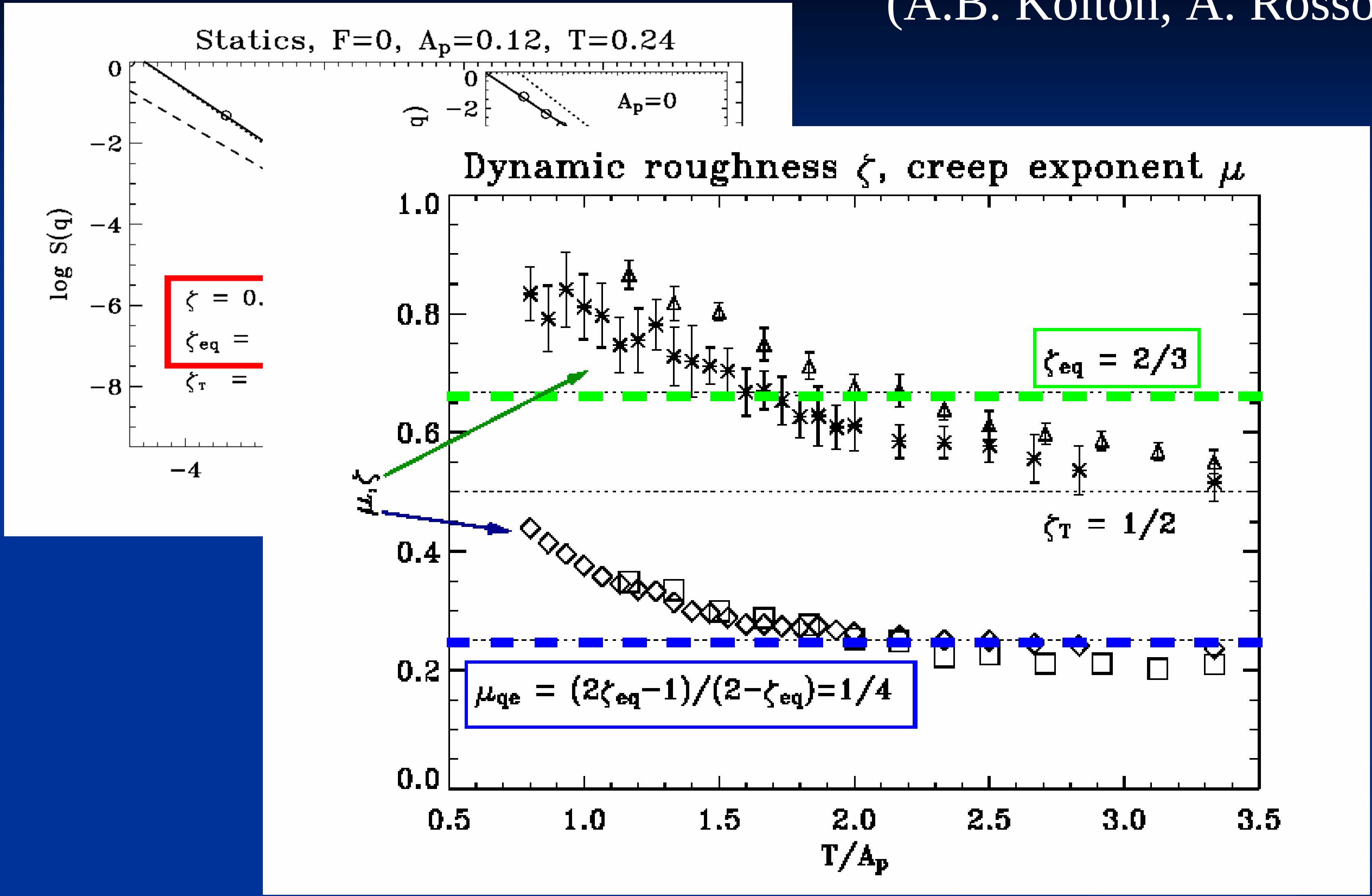
Pt/Co(0,5 nm)/Pt/SiO_2

Out of equilibrium

Creep: Molecular dynamics

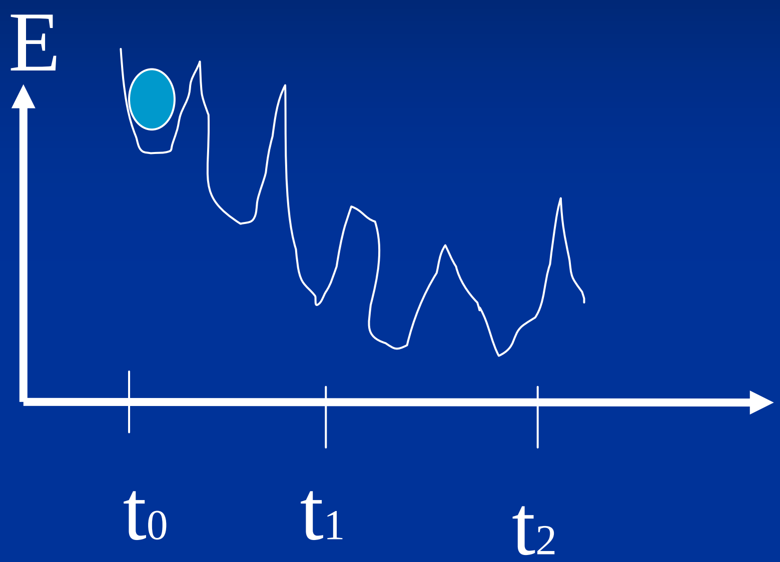


(A.B. Kolton, A. Rosso, TG)



Exponents larger than equilibrium value !

Glasses : Aging

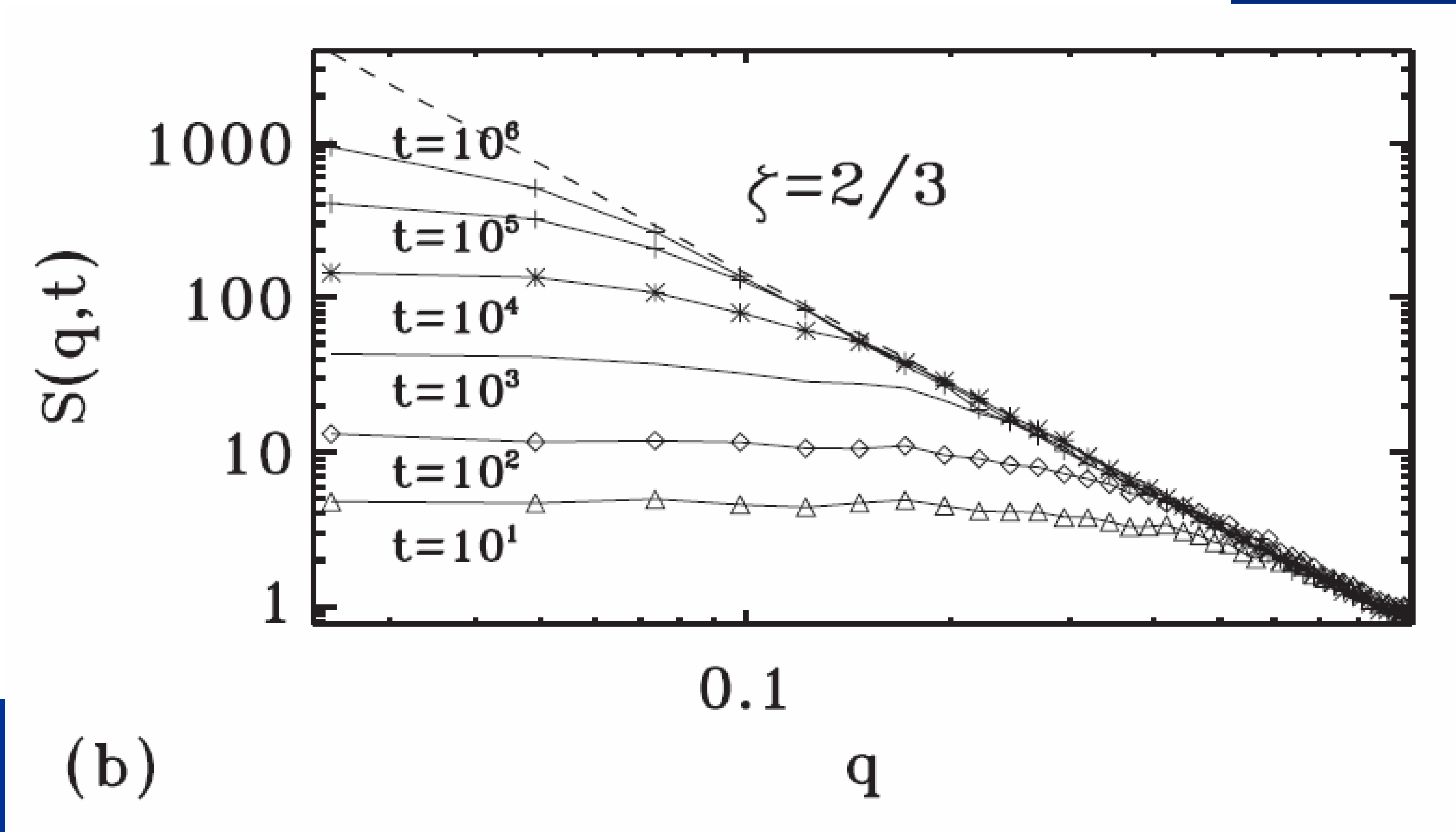


f(t1,t2)

f : Depends on both times

Aging of the Bragg glass or the interfaces ?

Aging in interfaces



(A. B. Kolton, A. Rosso, TG)

Conclusions ?

… It is a magical world

… Let’s go exploring !