Disordered Elastic Systems

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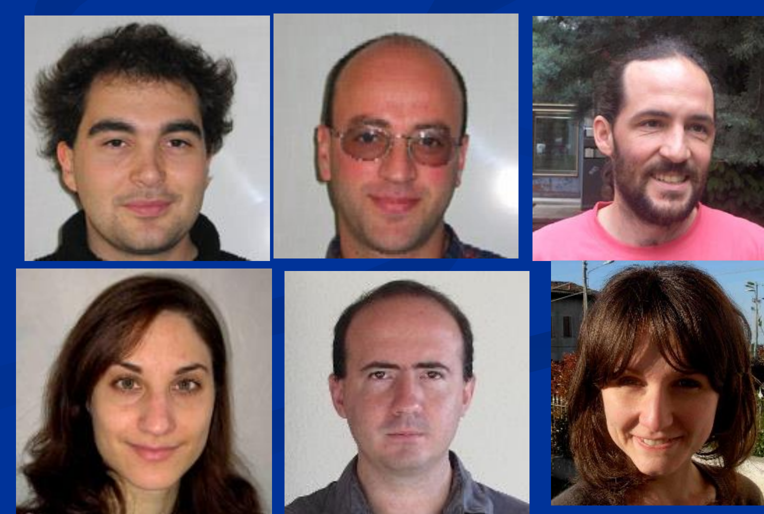


General References

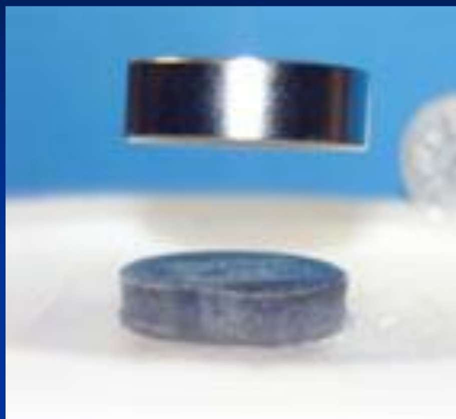
Disordered Elastic Media:
TG, Encyclopedia of Complexity and Systems Science (Springer)

Domain walls:
E. Agoritsas, V. Lecomte, TG,
Arxiv:1111.4899, Physica B 407 1725 (2012)

Vol 14 - N° 8 - octobre 2013
P. 637-756
Académie des sciences
Disordered systems / Systèmes désordonnés

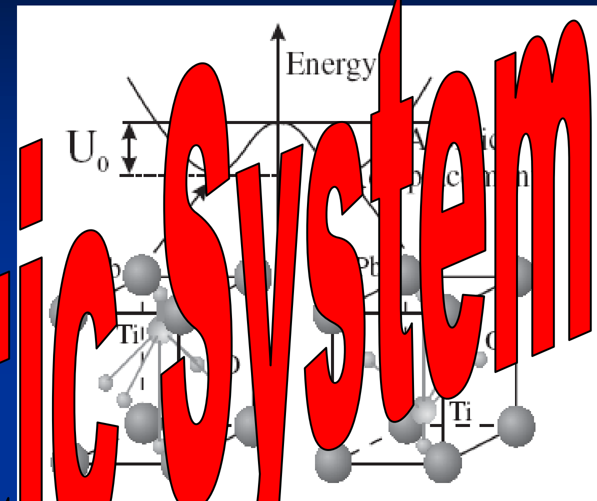
Common denominator of:

Disordered Elastic Systems



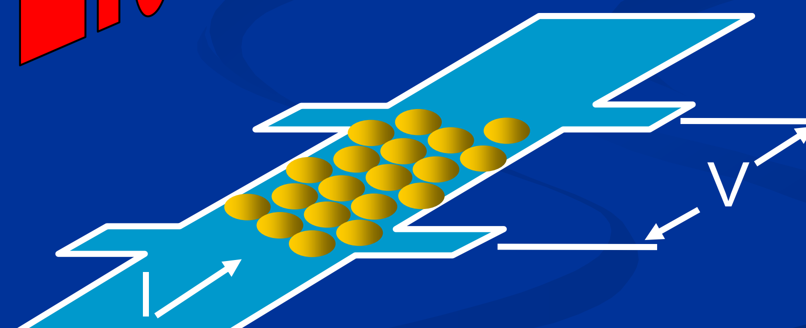
Superconductor

Magnet



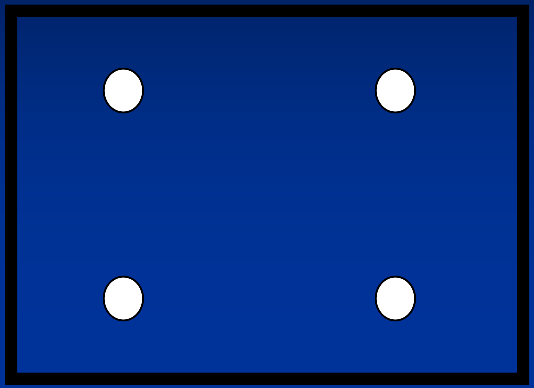
Ferroelectric

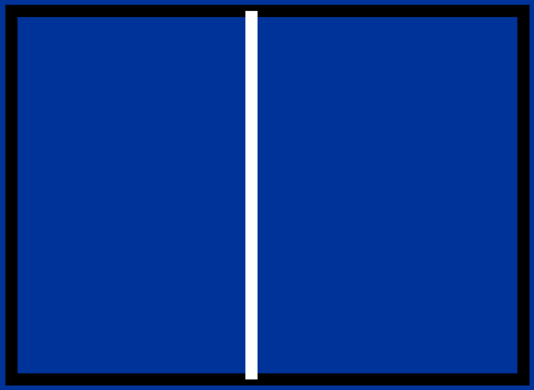
Contact line

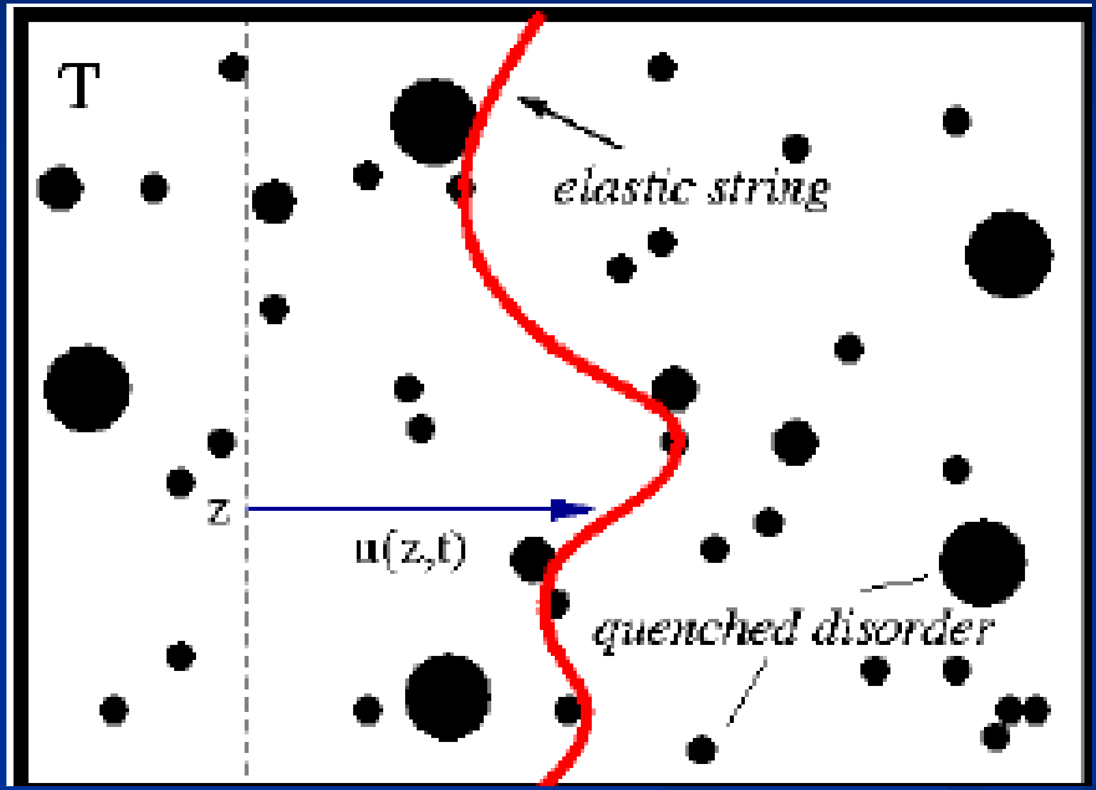


Two dimensional electron gas

Basic Features

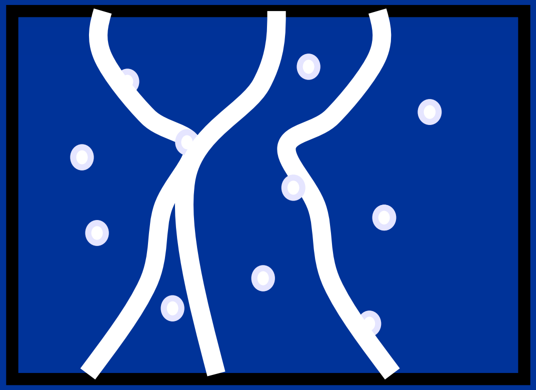






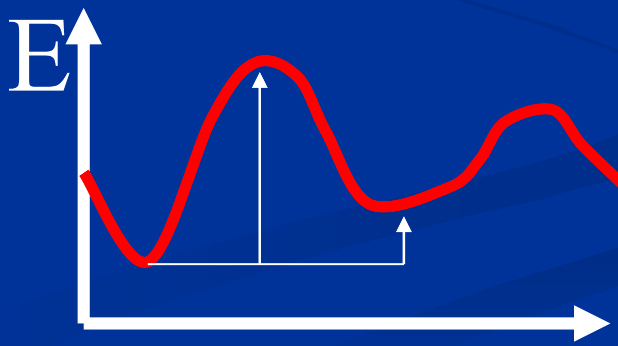
$$H = \frac{c}{2}\int dz(\nabla u(z))^2 + \int dz V(u(z), z)$$

Very difficult stat-mech problem



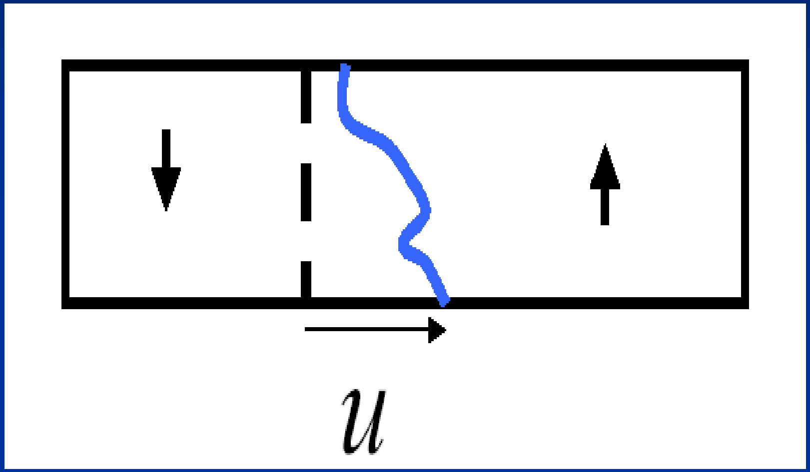
- Optimization :

many solutions



Glass !

What to measure (statics)



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

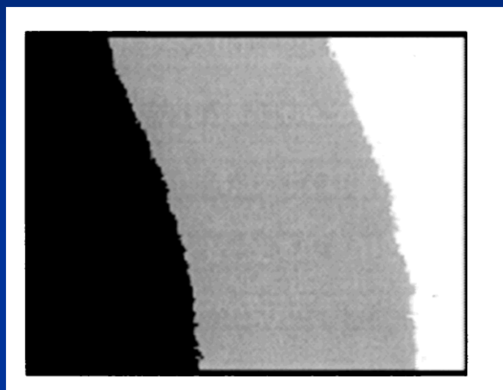
$$B(z) \sim z^{2\zeta}$$

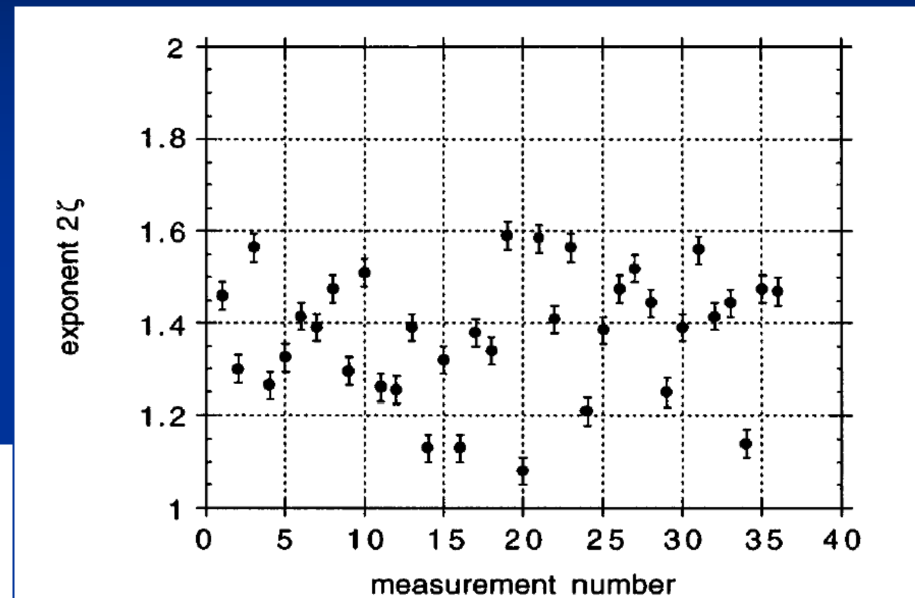
Positional order

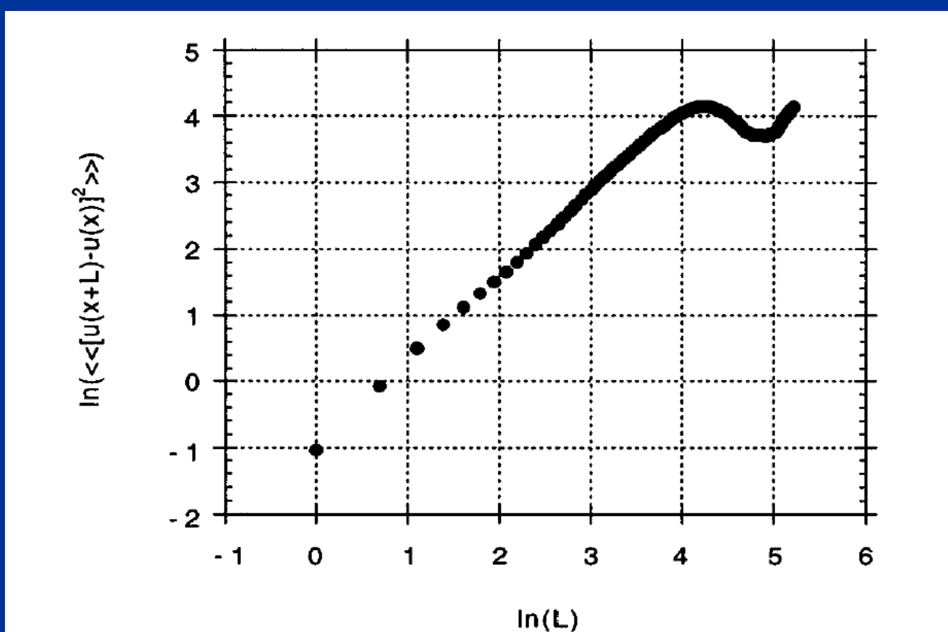
Amplitude: new questions (Calabrese, Le Doussal, Quastel, etc.)

E. Agoritsas et al. PRE 87 042406 (13)

Magnetic systems







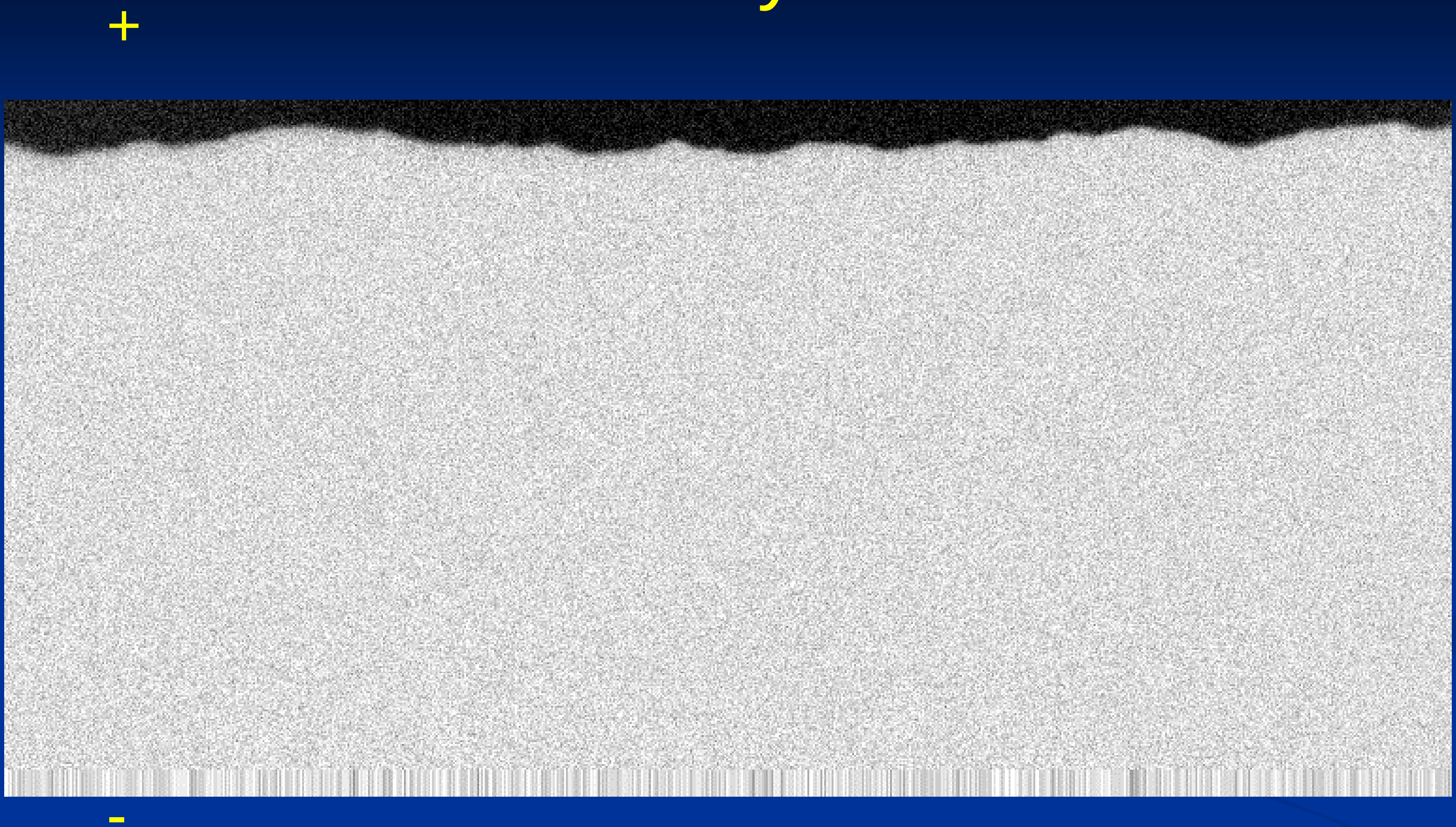
$$u \propto L^{\varsigma}$$

Theory: $\zeta = 2/3$

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

Dynamics

Dynamics



Groupe J. Ferre/J.P. Jamet; Exp: V. Repain

Equation of motion

$$\eta\partial_t u(z,t) = c\nabla_z^2 u(z,t) + F_{pin}[u(z,t)] + F + \zeta(z,t)$$

η : friction

ζ : thermal noise

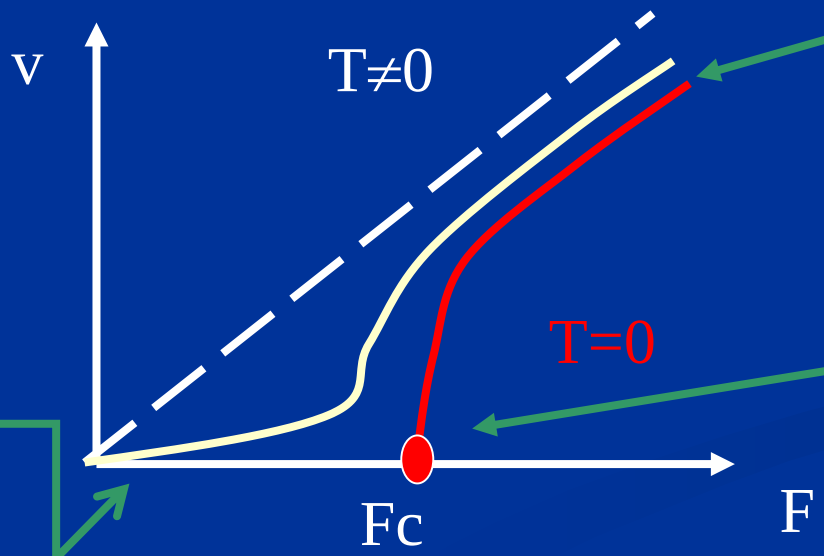
$$F_{\text{pin}} = -\left.\frac{\partial V(x,z)}{\partial x}\right|_{x=u(z,t)}$$

$$\overline{\zeta(z,t)\zeta(z',t')} = \eta T\delta(z-z')\delta(t-t')$$

$$\langle V(\mathrm{x},\mathrm{z})\,\mathrm{V}(\mathrm{x}',\mathrm{z}')\rangle = \mathrm{Df}(\mathrm{x}-\mathrm{x}')\delta(z-\mathrm{z}')$$

Questions for dynamics

- Disorder = pinning
- Finite temperature probes barriers



Large v:

Nature of moving phase ?

Depinning:

$v \propto \left(F\text{-}F_c\right)^{\beta}$

$f \to 0$

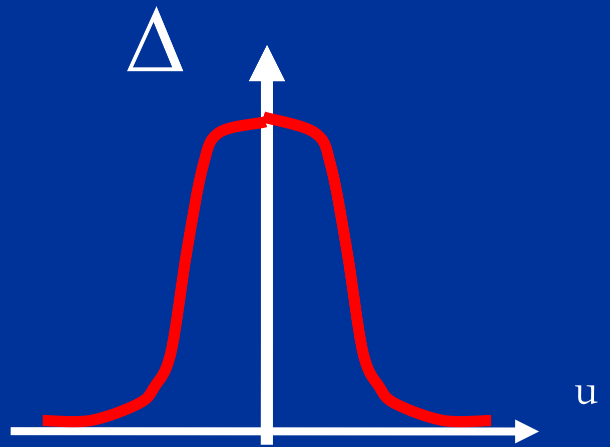
v = ????

How to study microscopically

$$\eta\partial_t u = c\nabla^2 u + F_{pin}[u] + f$$

$$\int DuD\hat{u}e^{i\hat{u}(\partial_t u - c\nabla^2 u - ....)}$$

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



Correlator of disorder

Study by RG

Usual vs Functional RG

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

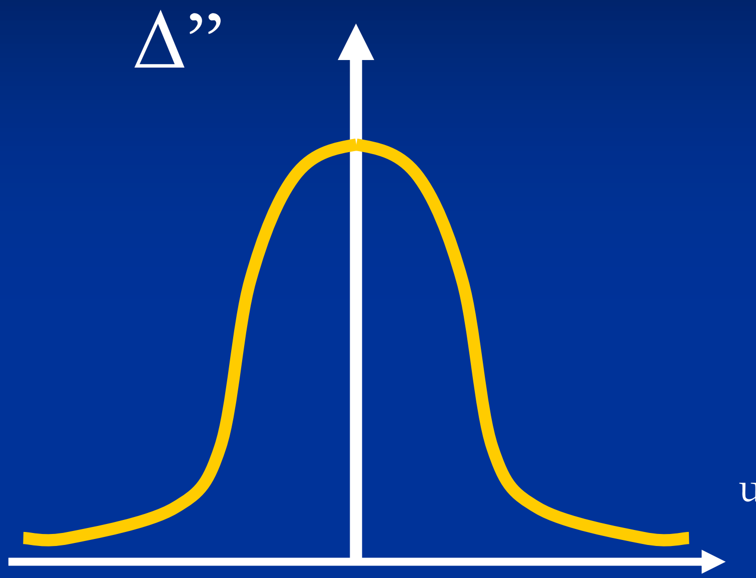
Needs only to keep b and c (higher powers are irrelevant)

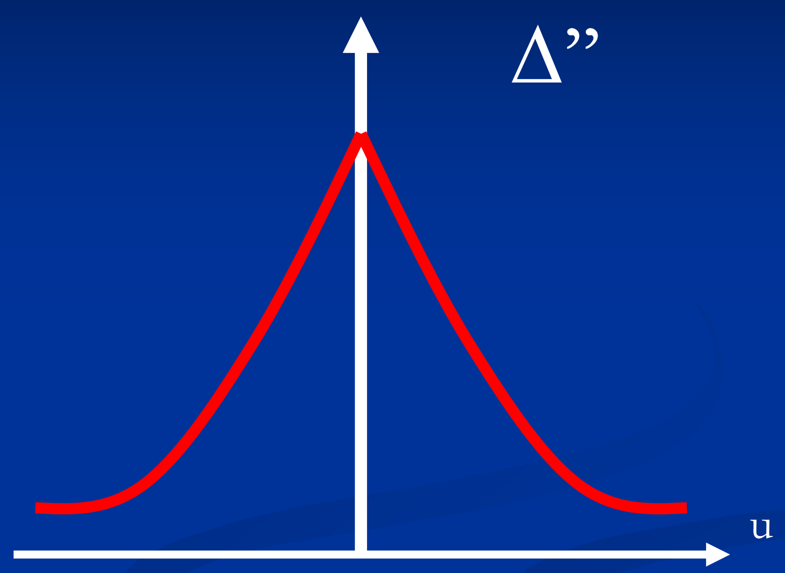
- Disorder: all powers are important

Renormalize the whole function

Review: P. Le Doussal + K. Wiese
arXiv:cond-mat/0611346

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





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

(A. Larkin, D. Fisher)

- Cusp signals metastability and glassy states

Example: static

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

$$\partial\ln\tilde{T}=\epsilon-2-2\zeta.$$

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

- Fixed point: $\zeta = 0$

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

TG + P. Le Doussal, PRB 52 1242 (95)

Dynamics from FRG

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

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

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

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

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

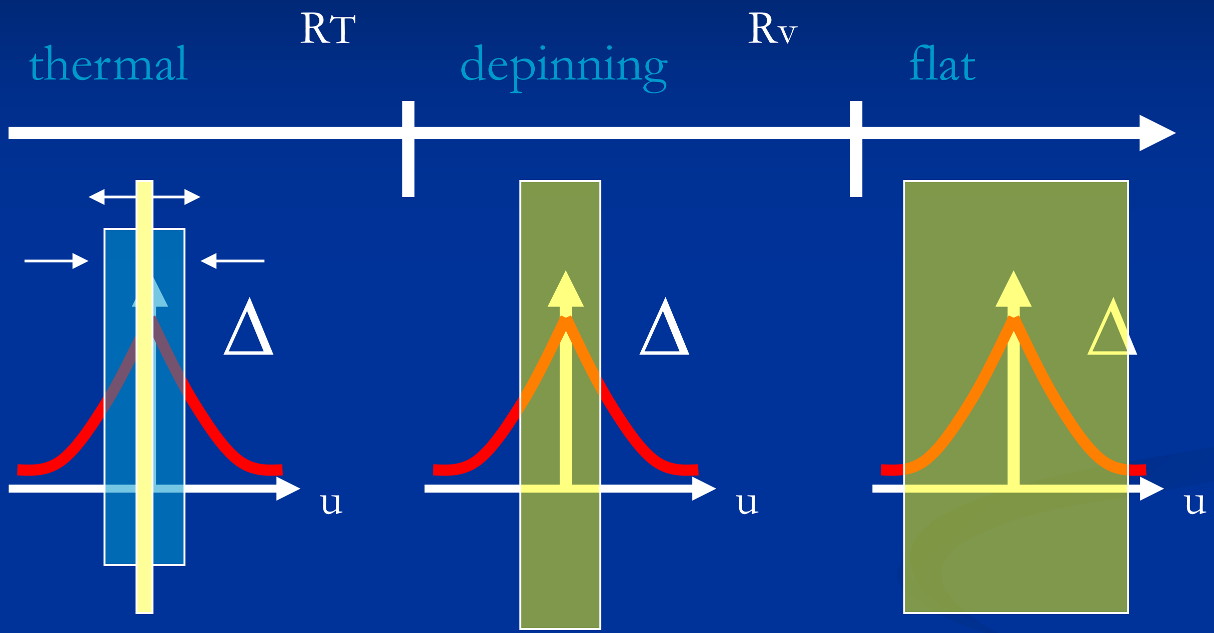
$$\tilde{T}_l=\frac{S_D\Lambda_l^D}{c\Lambda_l^2e^{2\zeta l}}T_l,$$

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

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

P. Chauve, T. Giamarchi, P. Le Doussal EPL 44 110 (98); PRB 62 6241 (2000)

Small force response



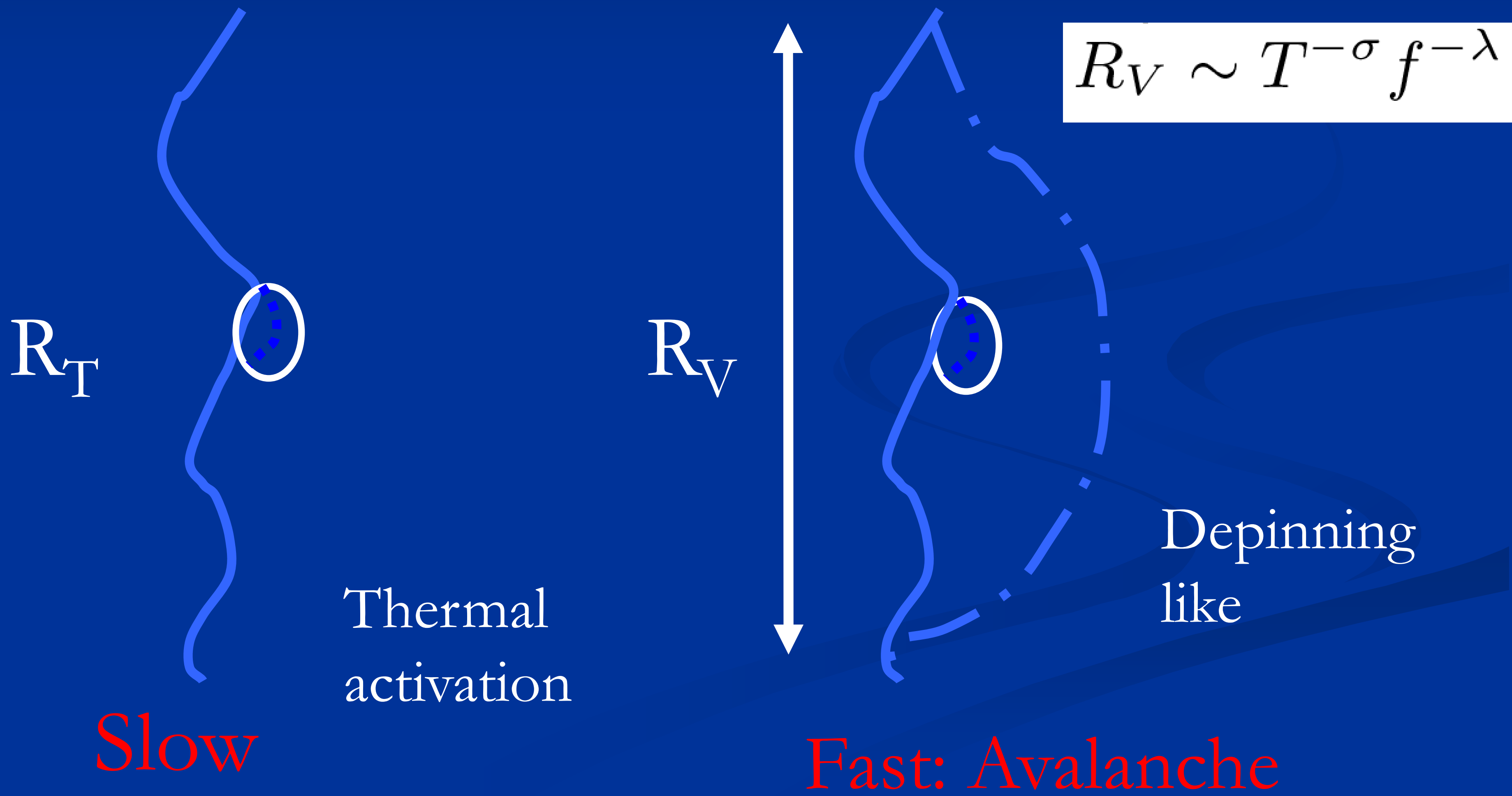
$$\frac{\eta v}{f_c} \approx \exp\left[-\frac{U_c}{T}\left(\frac{f}{f_c}\right)^{-\mu}\right]$$

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

Phenomenological derivation: Ioffe + Vinokur; Nattermann

New lengthscale: avalanches

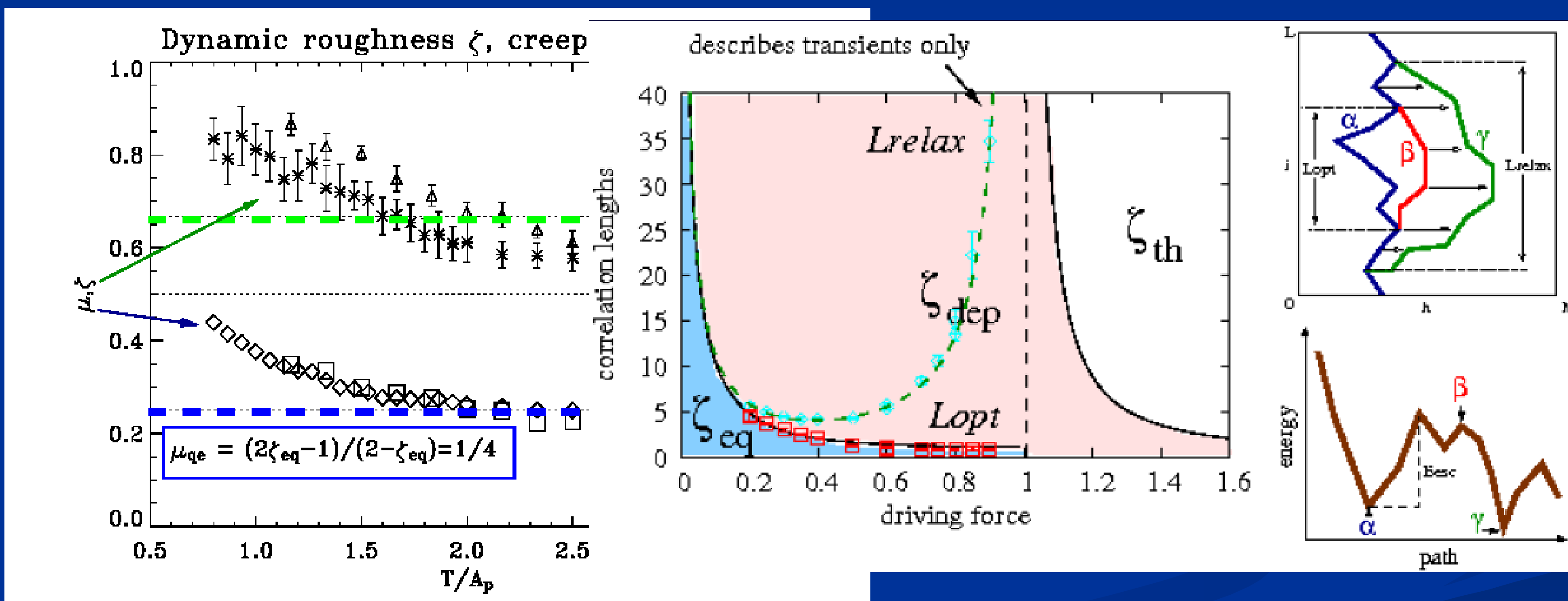
Motion different from phenomenological picture (two regimes)



Tests

Numerical study d=1

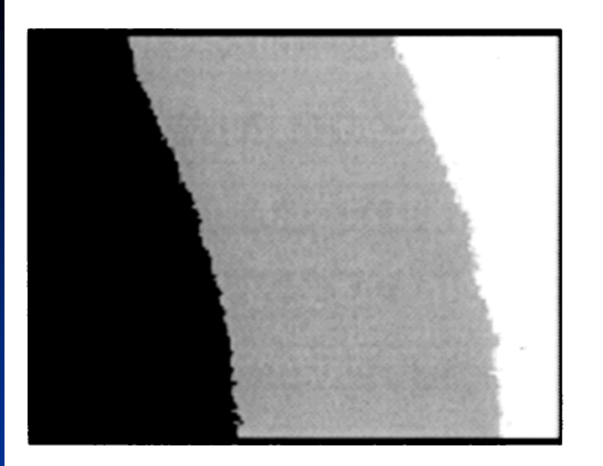
Molecular dynamic simulations:
A. B. Kolton, A. Rosso, TG, PRL 91 056603 (03)



Exact enumeration algorithm: A.B. Kolton, A. Rosso, TG, W. Krauth PRL 97 057001 (06); PRB 79 184207 (09)

Experiments

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



$$v \propto e^{-\beta (1/B)^{\mu}}$$

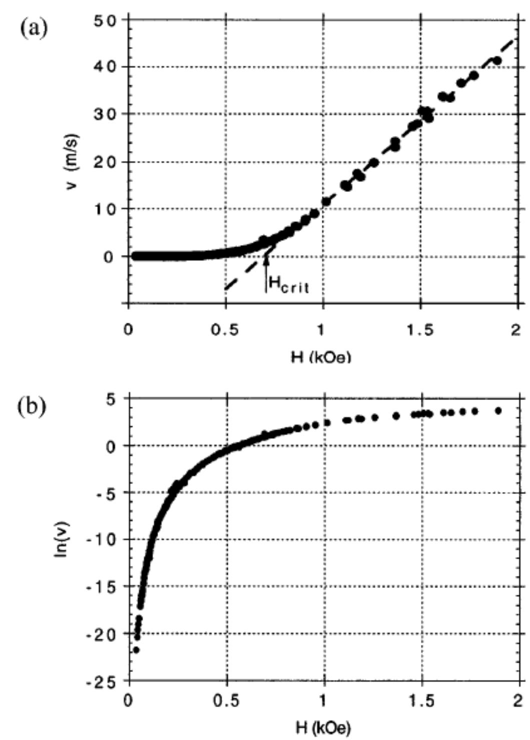
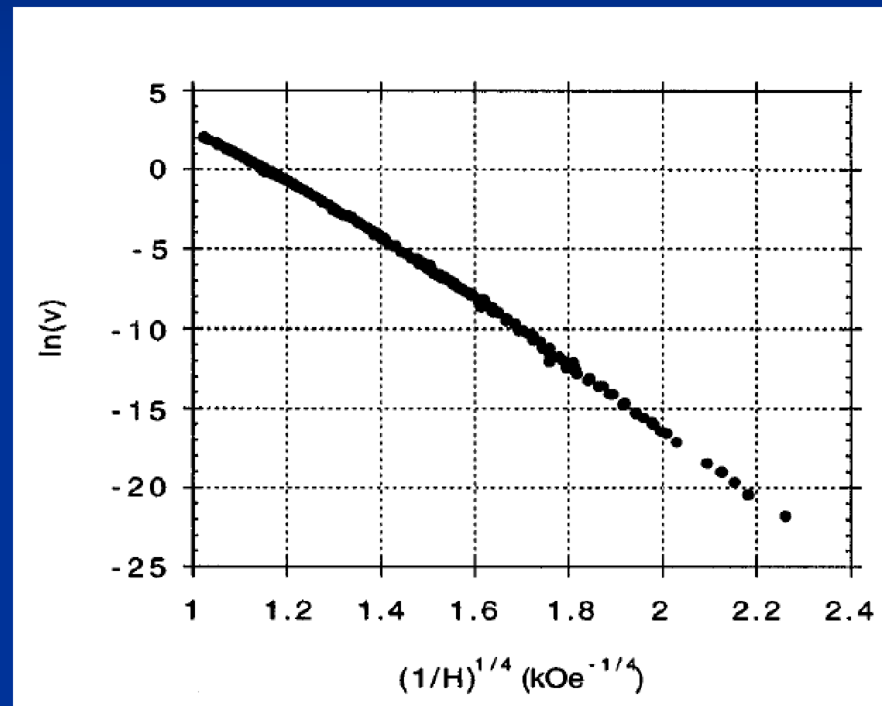
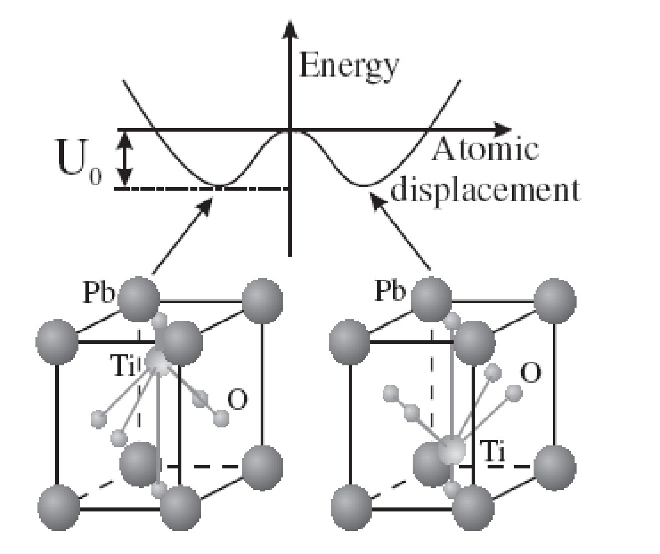


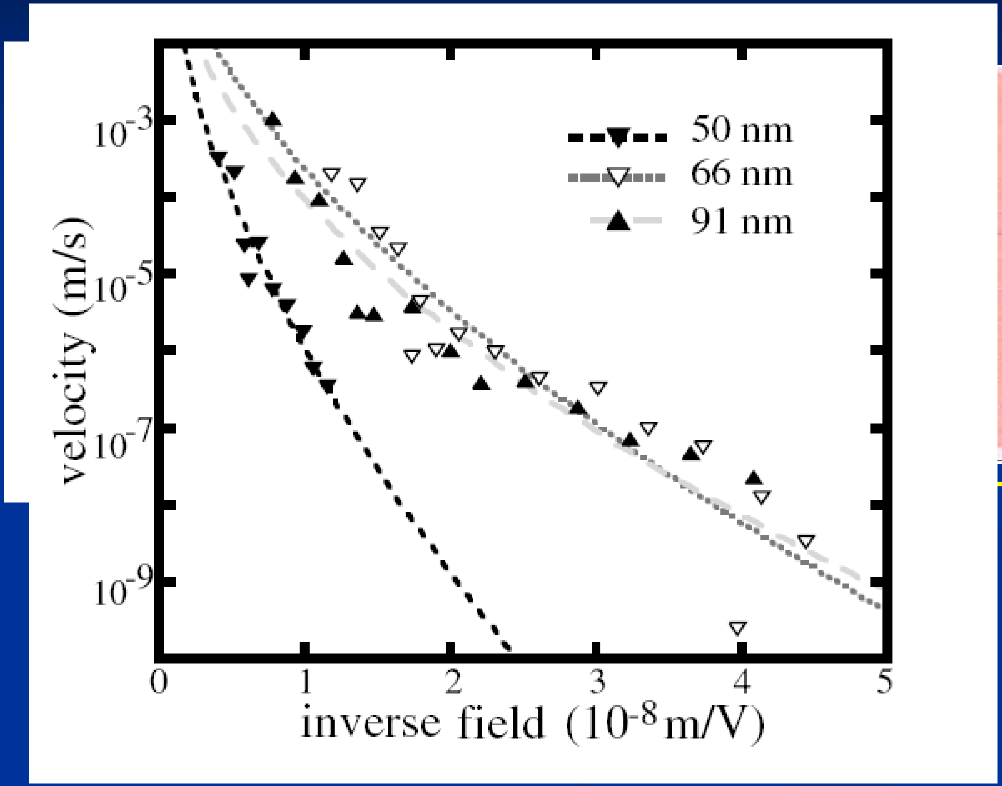
FIG. 2. (a),(b): MDW velocity versus applied magnetic field at room temperature (v in m/s). The dashed line in (a) is the linear fit of the high field part ($H > 0.86$ kOe) and the arrow marks its intersection with the line $v(H) = 0$. This is the definition of H_{crit}.



$$\zeta = 2/3 \qquad \mu = \frac{d-2+2\zeta}{2-\zeta} = 1/4$$

Ferroelectrics





P. Paruch et al.
cond-mat/0411178

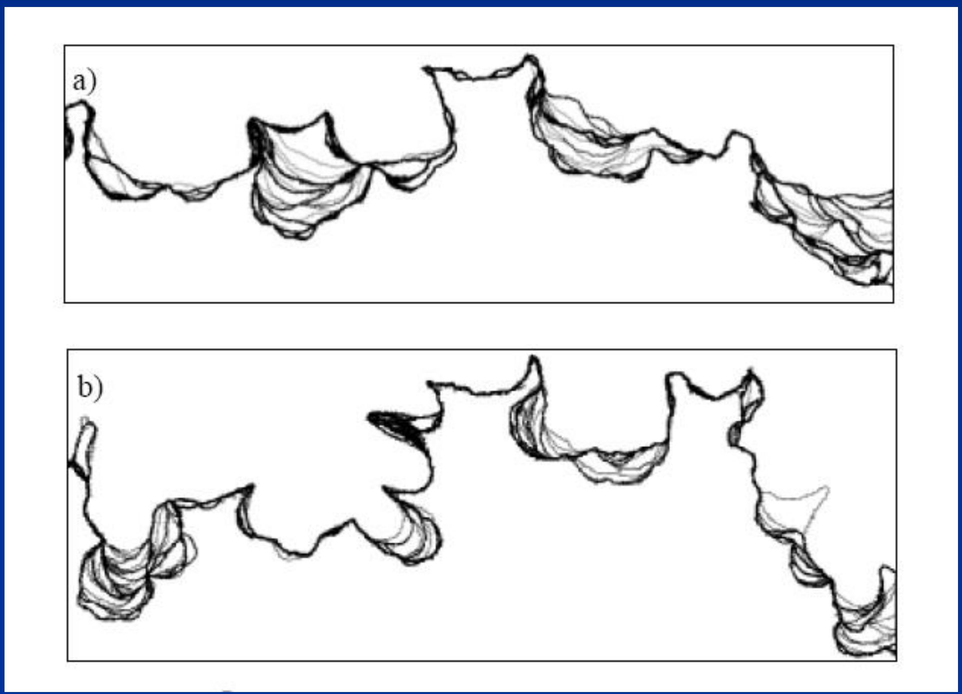
T. Tybell et al. PRL 89 097601 (02)

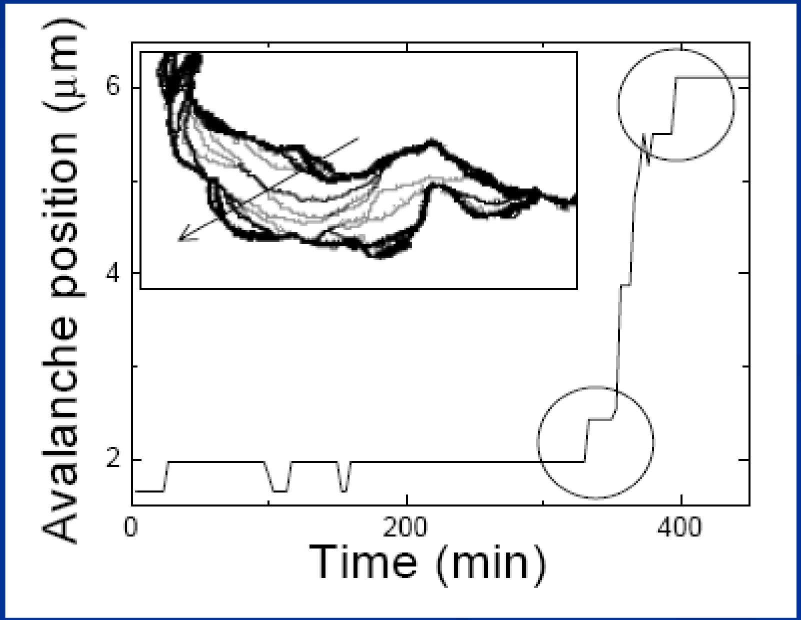
P. Paruch et al. PRL 94 197601 (05)

Lenthscales

Probing R_T and R_v

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





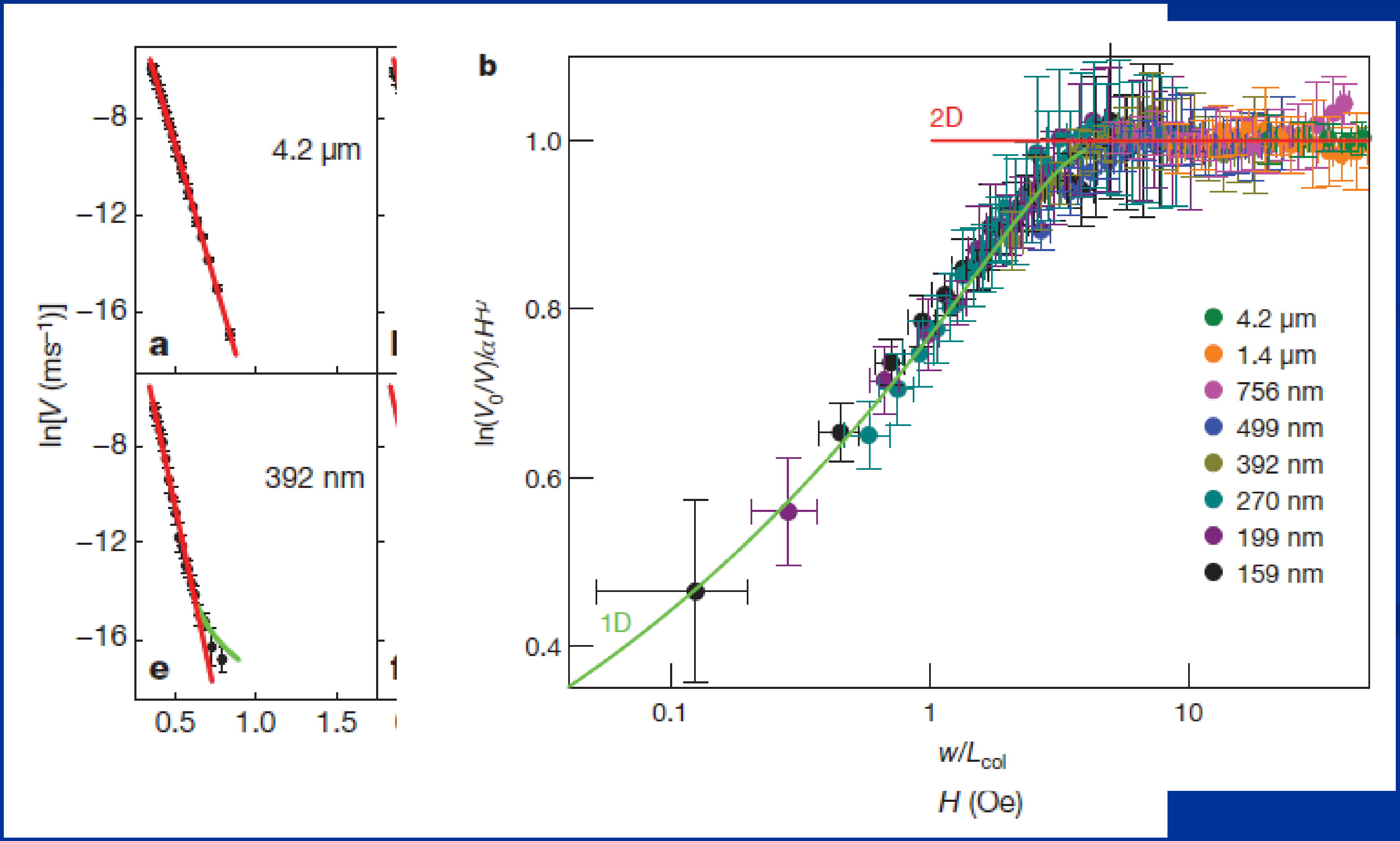
$H = 159\,\mathrm{A\,m^{-1}}$ and $L_C = 40\,\mathrm{nm}.$

R_T » 1 µ m

R_v » 17 µ m

Probe the lengthscale R_T

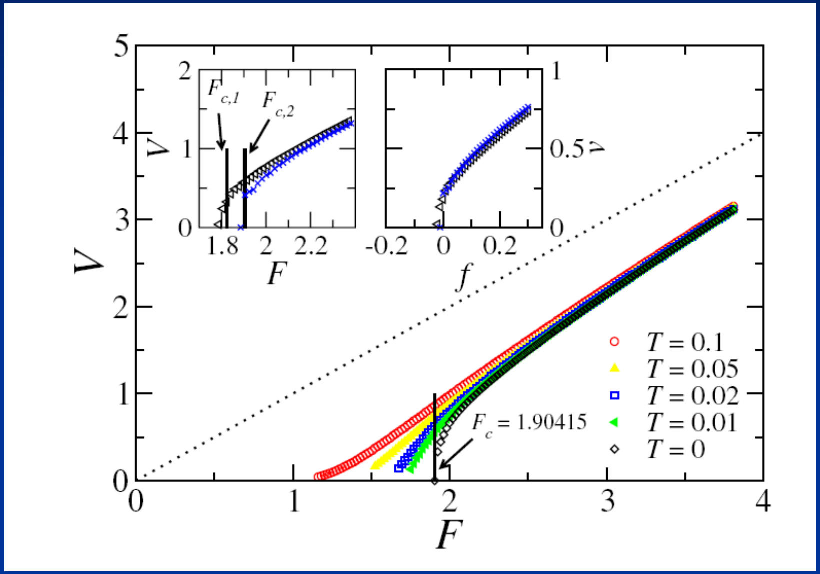
K.J. Kim et al. Nature 458 540 (09)

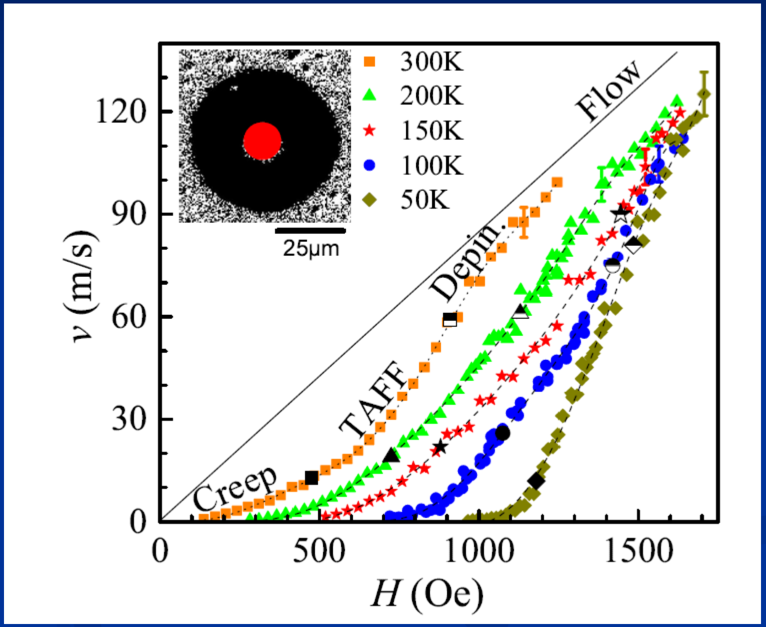


Open challenges

- Thermal rounding; Depinning
- Out of equilibrium issues (aging)
- Defects (overhangs, bubbles)
- Internal degrees of freedom (spintronic etc.)
- Quantum systems (bosons, magnets etc.)

Thermal rounding; Depinning





S. Bustingorry, A. B. Kolton, TG, EPL 81 26005 (2008)

J. Gorchon et al. PRL (14)

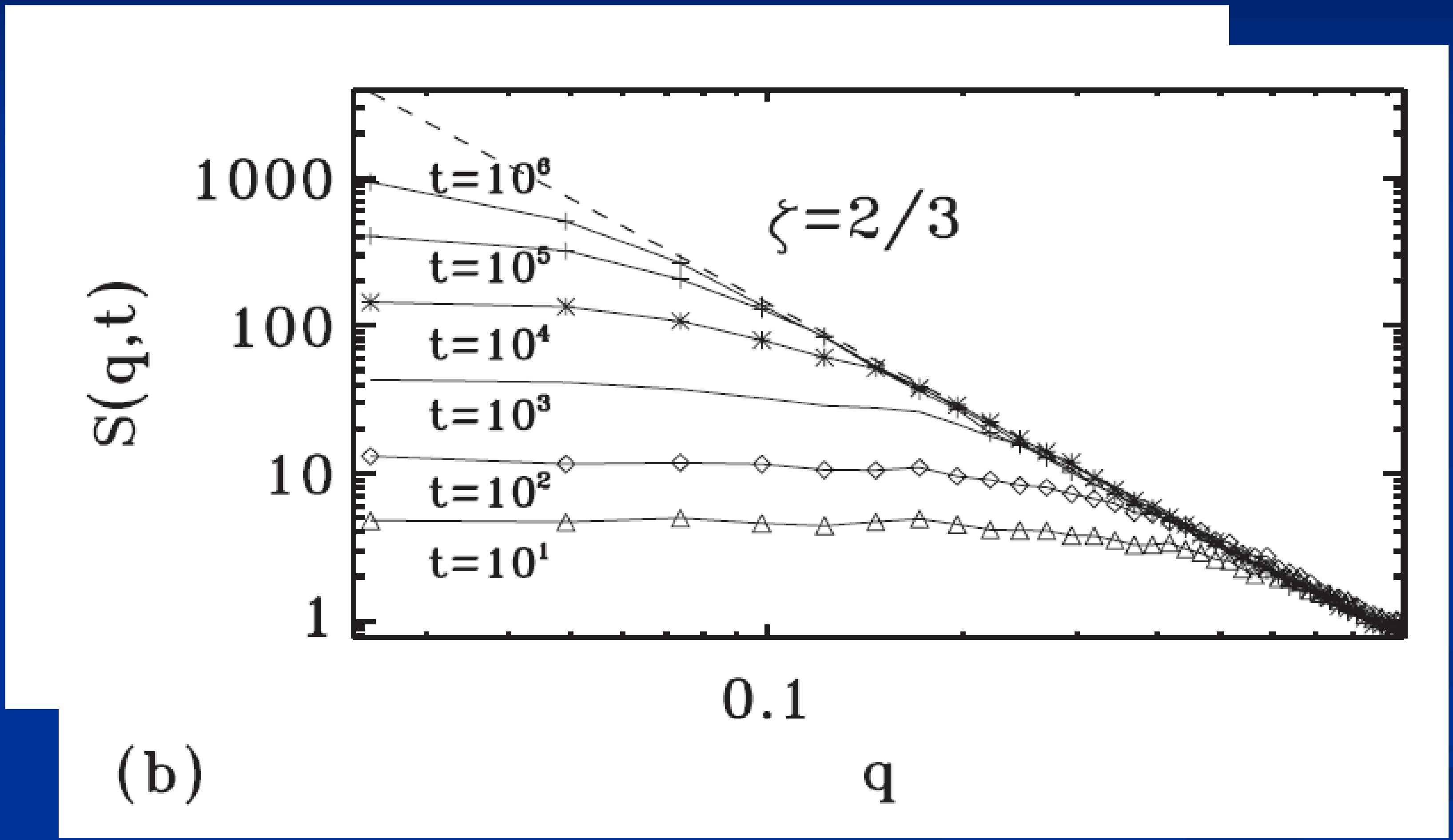
$$v(F_c) \propto T^{\psi}$$

$$\psi = 0.15 \pm 0.01$$

Not understood yet !!

Aging

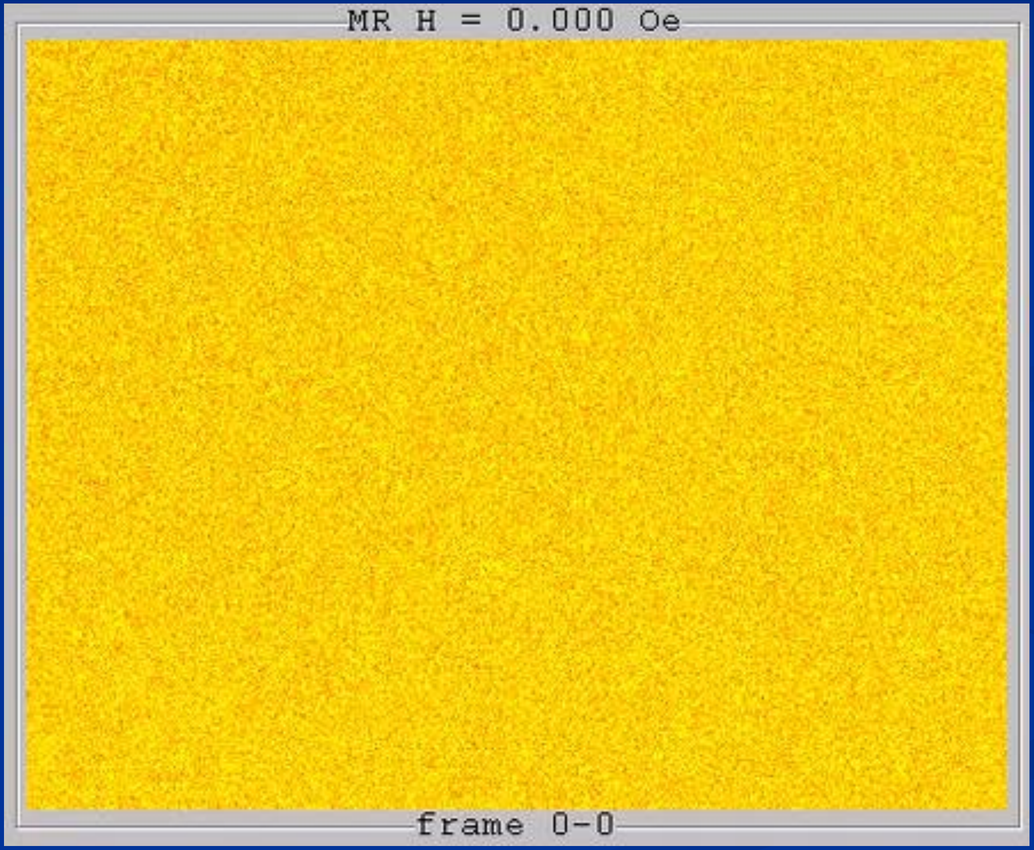
Out of equilibrium



A. B. Kolton, A. Rosso, TG, PRL 95 180604 (05)

Defects

(V. Repain et al. (Orsay))



210 μm

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

Internal degrees of freedom

Wall with internal degree of freedom

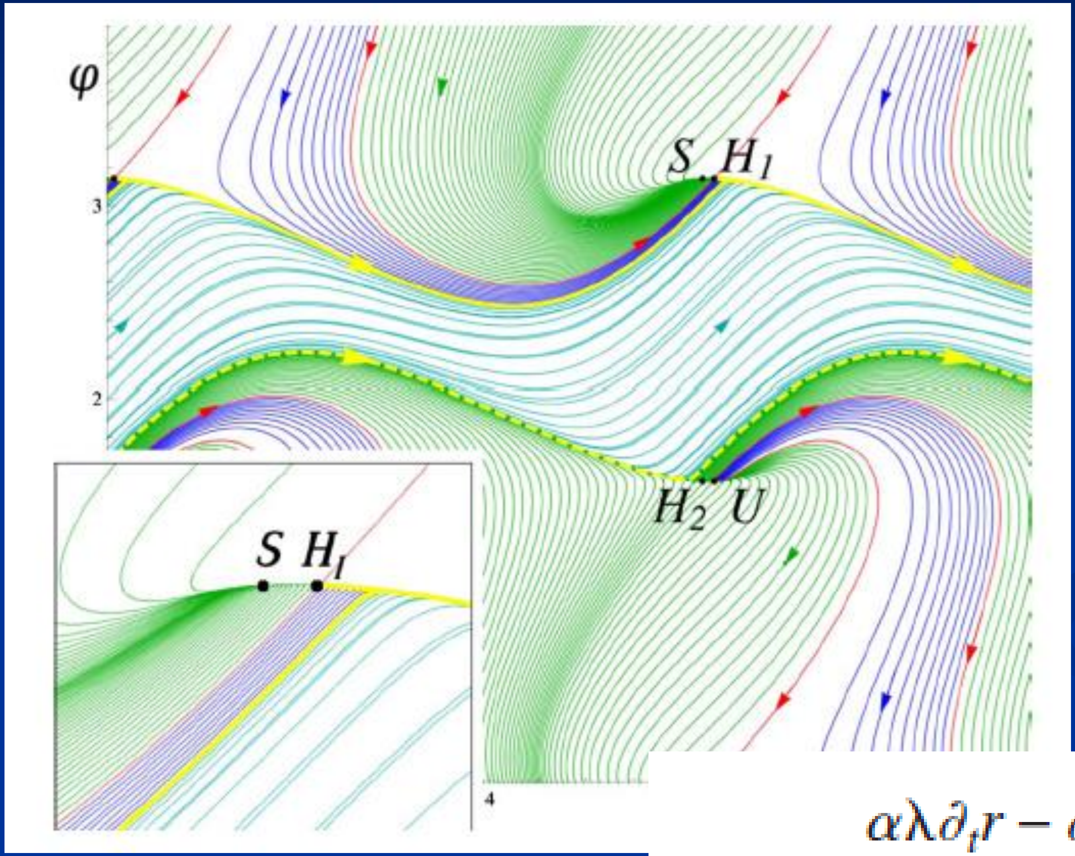
V. Lecomte, S. Barnes, J.P. Eckmann, TG PRB 80 054413 (09)
Nonlinearity 25 1427 (12)

$$E = \frac{1}{2}\int d^3x\{J[(\nabla\theta)^2 + \sin^2\theta(\nabla\varphi)^2] + K\sin^2\theta + K_\perp \sin^2\theta\cos^2\varphi\}.$$

$$\alpha\lambda\partial_t r - \partial_t\varphi - \beta_s v_s = f_{ext}(r) + \eta_1,$$

$$\alpha\partial_t\varphi + \lambda\partial_t r - v_s = -\frac{1}{2}K_\perp \sin 2\varphi + \eta_2.$$

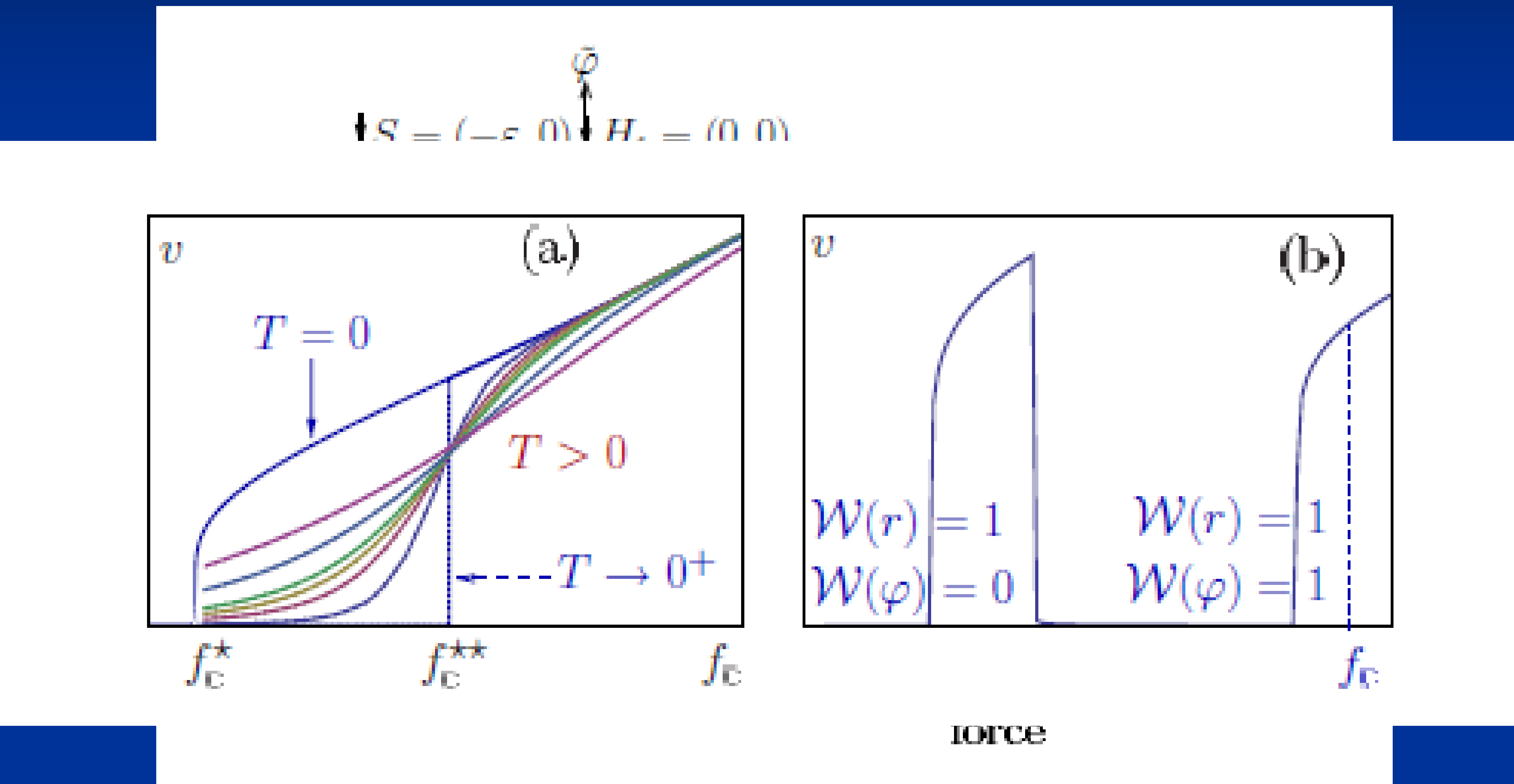
Rigid wall approximation



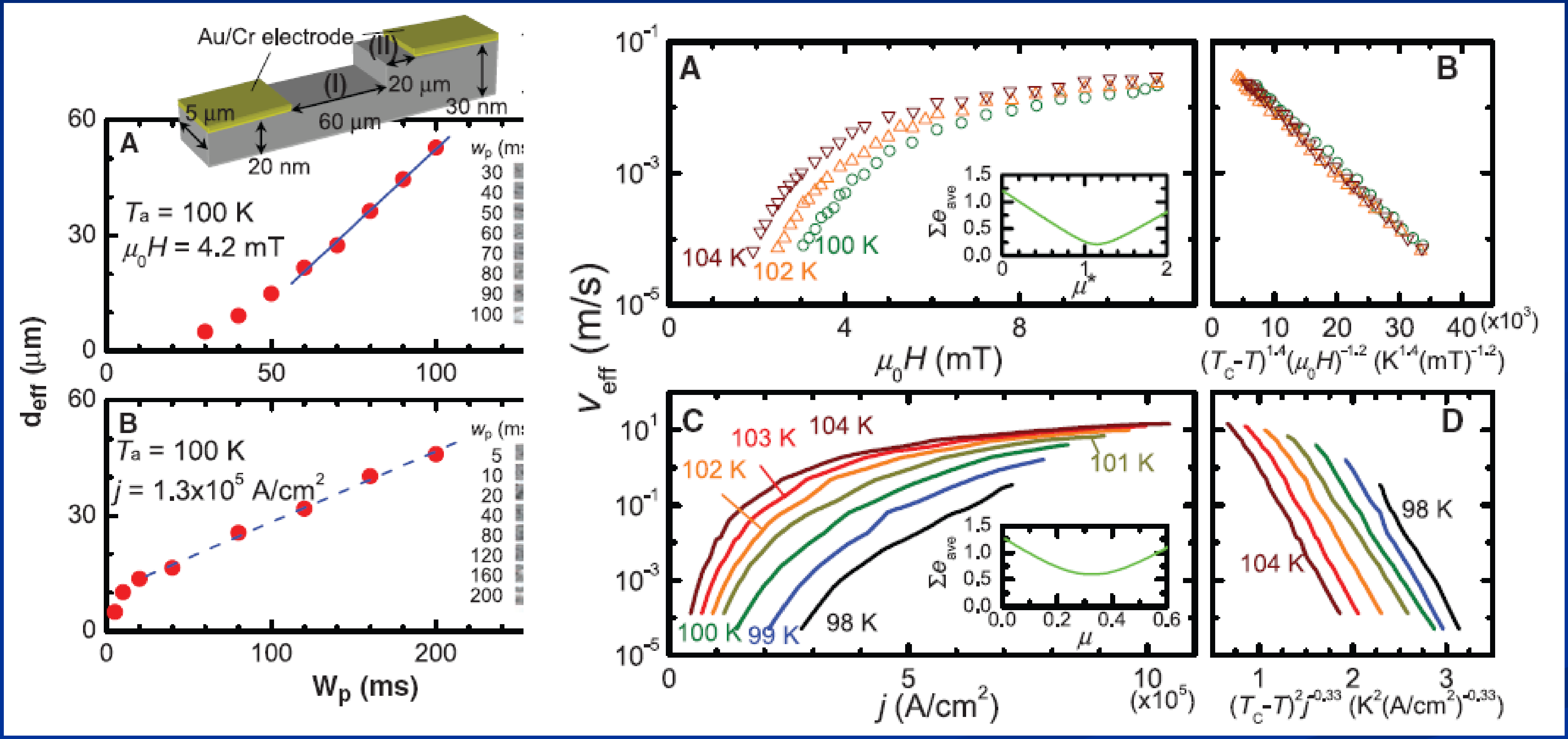
$$\alpha\lambda\partial_t r - \partial_t\varphi - \beta_s v_s = f_{ext}(r) + \eta_1,$$

$$\alpha\partial_t\varphi + \lambda\partial_t r - v_s = -\frac{1}{2}K_\perp \sin 2\varphi + \eta_2.$$

Different from standard depinning



Drive with magnetic field or current



Yamanouchi et al. Science 317 1726 (2007); H. Ohno Nature Materials 9 952 (2010)