Dynamics of Disordered Elastic systems

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MaNEP
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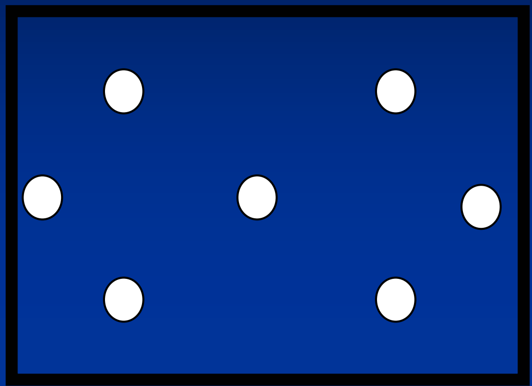
P. Chauve (Orsay/ENS)
P. Le Doussal (ENS)

A. Kolton (Madrid)
A. Rosso (LPTMS)
W. Krauth (ENS)

S. Lemerle (Orsay)
J. Ferré (Orsay)

J.M. Triscone (Geneva)
P. Paruch (Geneva/Cornell)
T. Tybell (Trondheim)

Basic Features



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

Pinning !!

Larkin length R_c :

$u(R_c) \sim r_f$

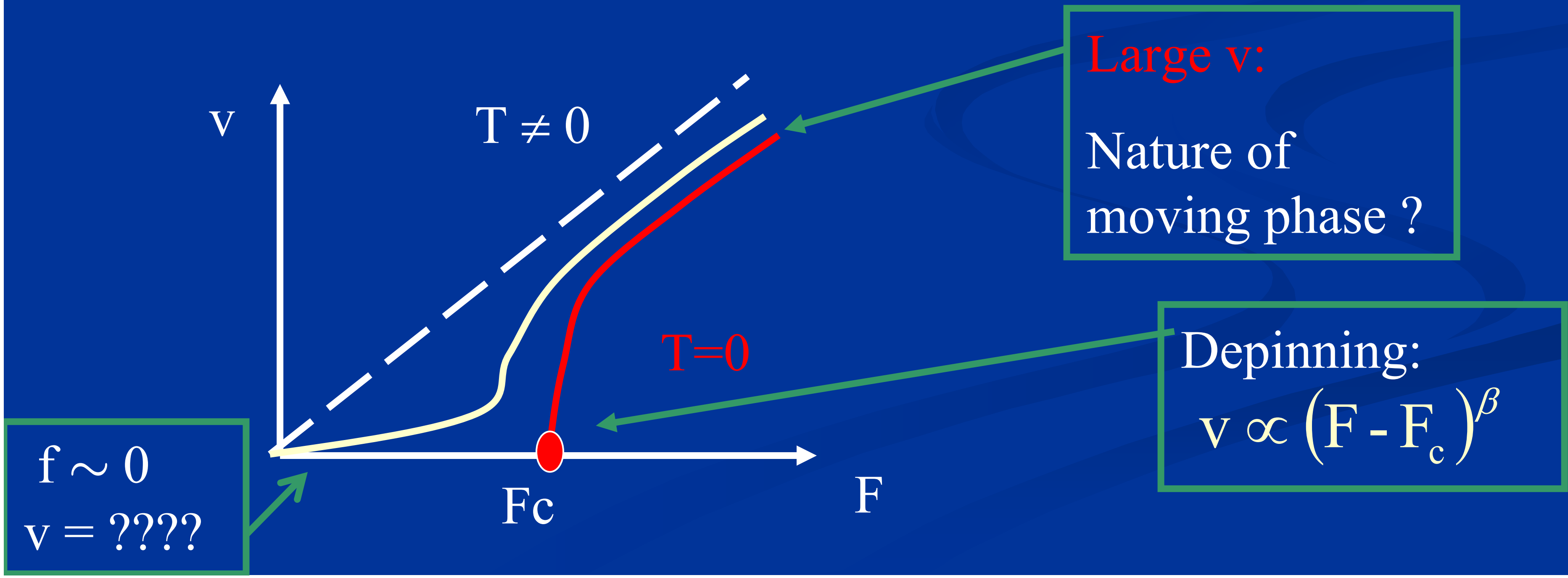
Metastability and pinning !

$$F_c = c\, r_f / R_c^2$$

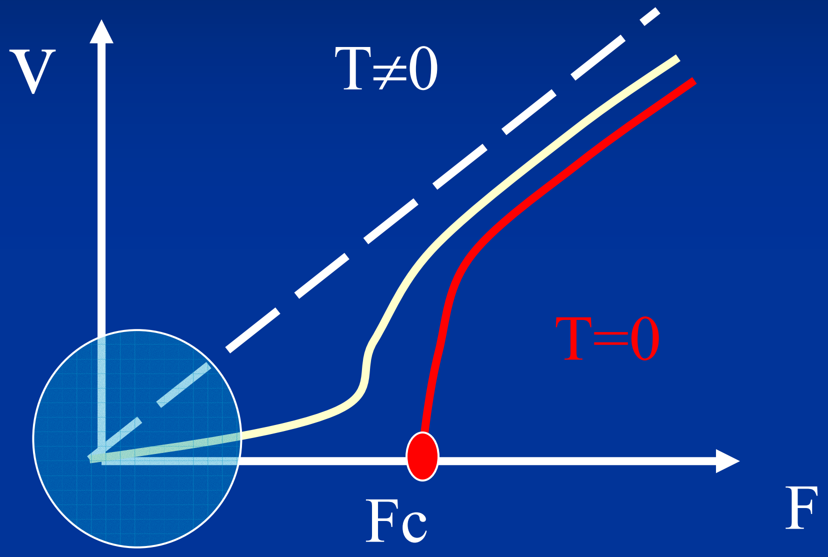
Questions for dynamics

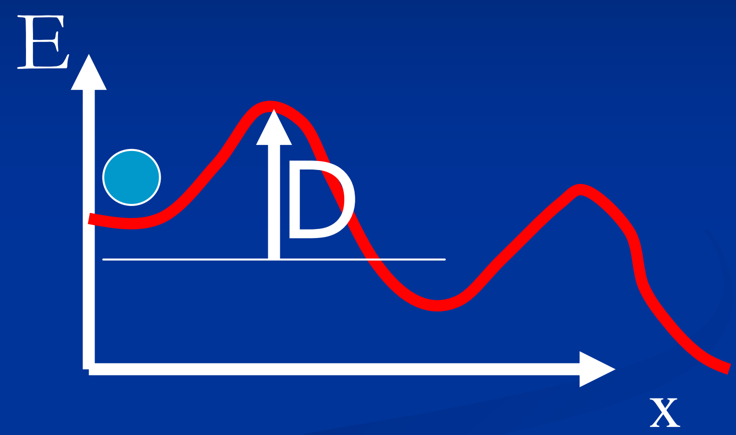
- Response to an external force

- Finite temperature probes barriers



Response to a small force





- TAFF (Anderson+Kim) : typical barrier
- Linear response

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

Glass = infinite barriers

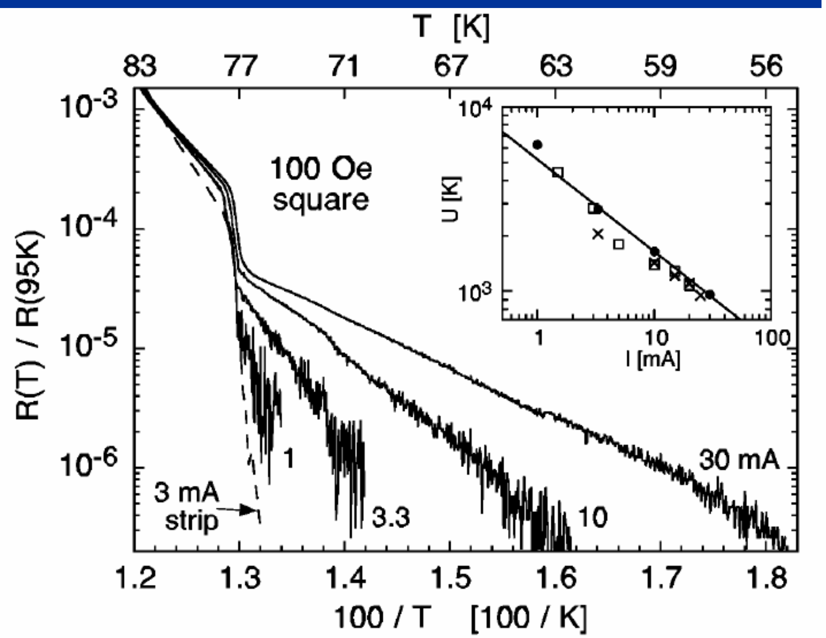
- Creep:

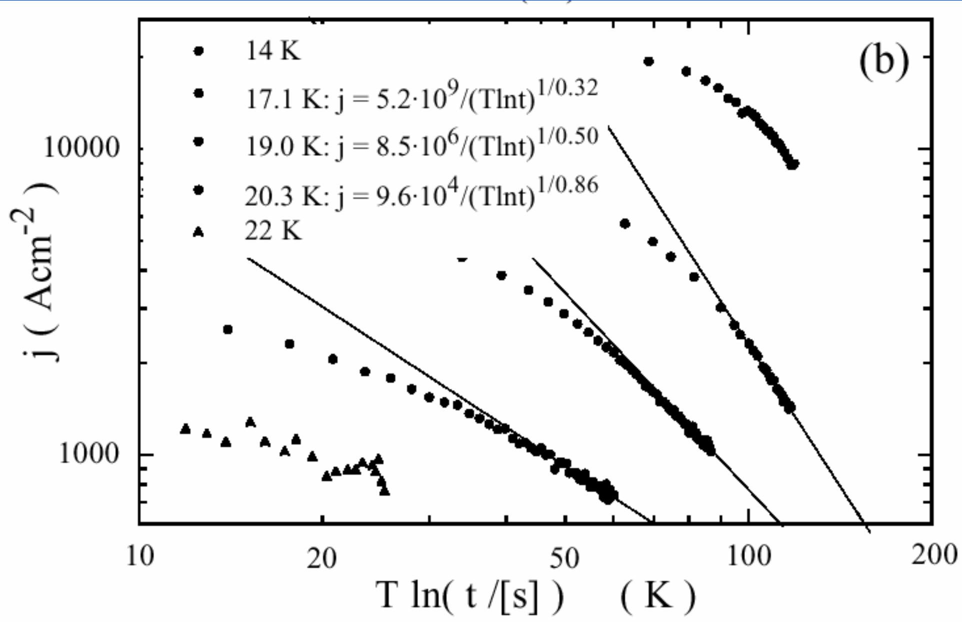
$$v \approx Exp[-\beta U_0 (F_c / F)^{\frac{d+2\varsigma-2}{2-\varsigma}}]$$

Ioffe, Vinokur; Nattermann;
Feigelman,Geshkenbein,Larkin,Vinokur;
Chauve,TG,Le doussal

Vortex Lattice

$$V \propto e^{-\beta(1/J)^{\nu}} \qquad \begin{cases} \nu \approx 0.8 & \text{Random Manifold} \\ \nu = 0.5 & \text{Bragg Glass} \end{cases}$$



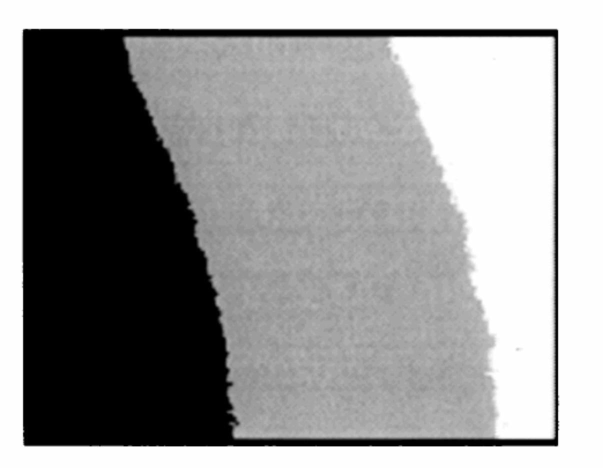


D.T. Fuchs et al. PRL 81 3944 (98)

C. Van der Beek et al. cond-mat 9912282

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

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



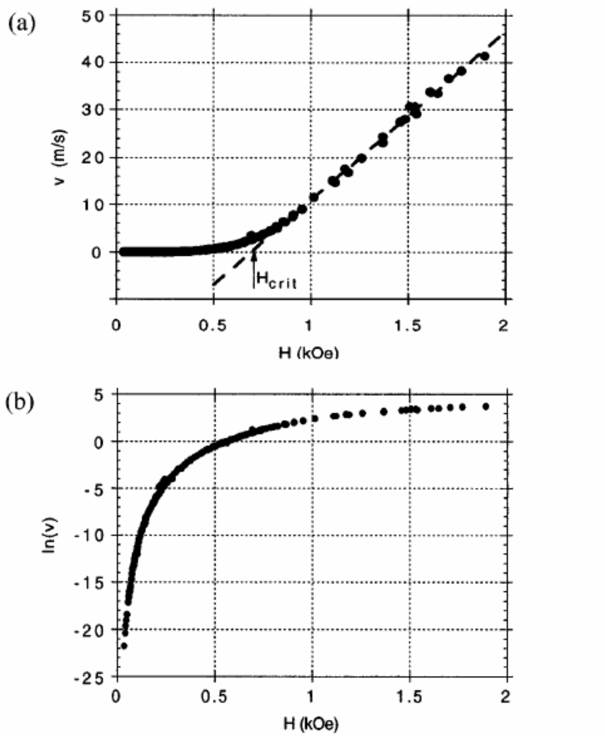
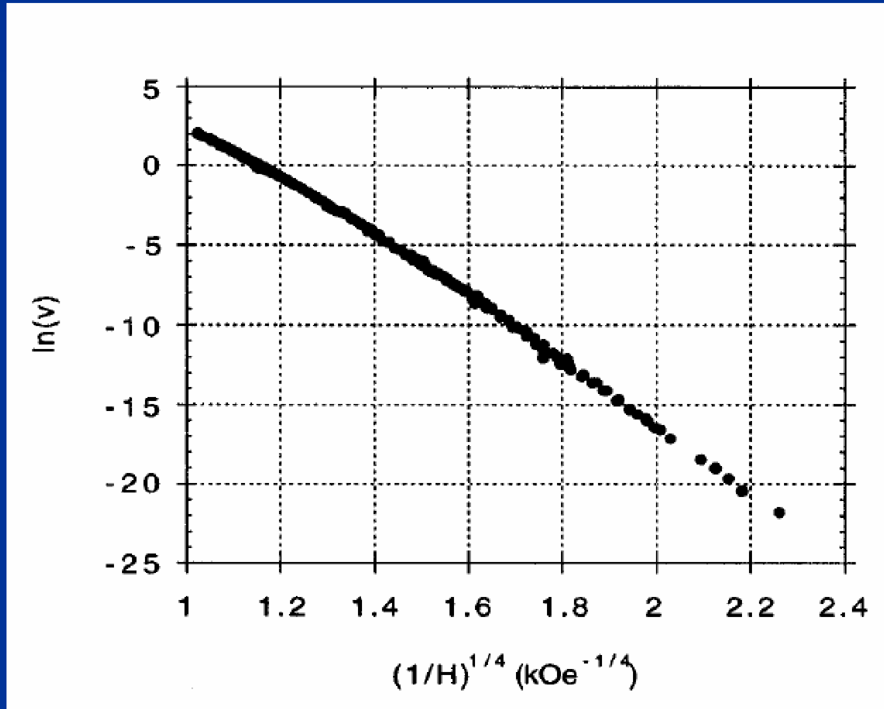
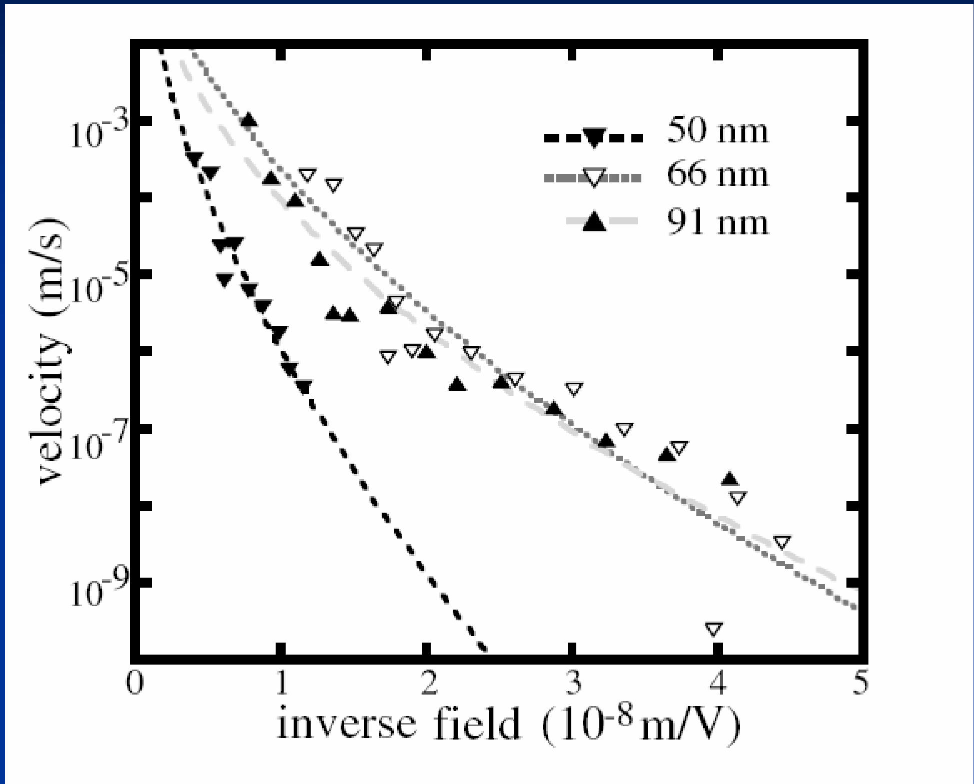


FIG. 2. (a),(b): MDW velocity versus applied magnetic field at room temperature (v in m/s). The dashed line in (a) is the linear fit of the high field part ($H > 0.86$ kOe) and the arrow marks its intersection with the line $v(H) = 0$. This is the definition of H_{crit}.



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

Beyond phenomenology

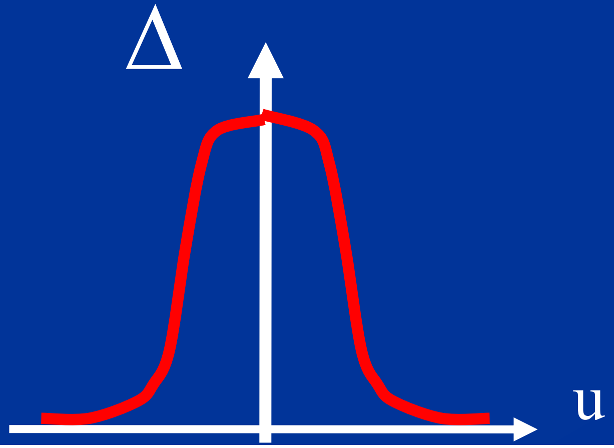
- Barriers scale as minima ?
- Dominated by typical move ?
- Exponents are equilibrium ones ?
- Other physical processes ?

Analytical study: FRG

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

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

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



Correlator of disorder

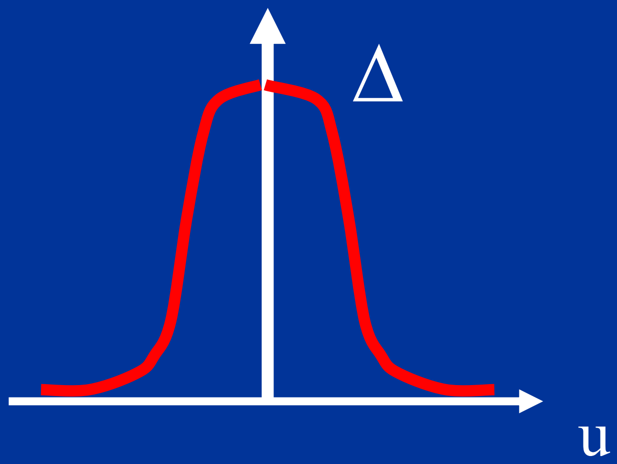
Study by RG

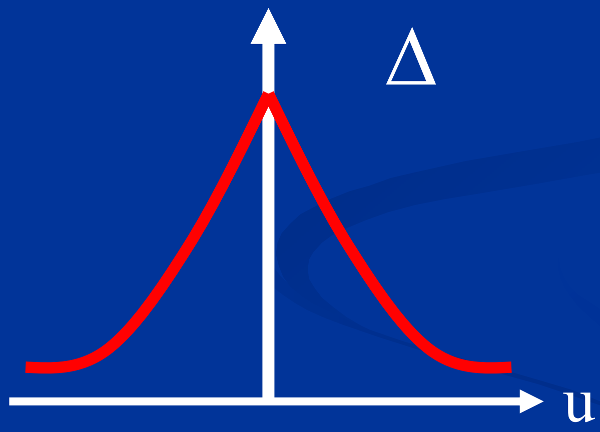
FRG 101

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

All powers are equally important:

Need to renormalize the whole function !





- A non analyticity appears at Rc (pinning)

Efetov+Larkin; Villain+Semeria; FRG: D. S. Fisher

FRG and DES

- **Statics:**

  Interface : D. Fisher

  Bragg glass : TG + Le doussal

- **T= 0 Dynamics: (statics ! v=0, T=0)**

  Narayan + Fisher

  Natterman, Stepanow, Tang, Leschhorn

$v \neq 0, T \neq 0$ Dynamics from FRG

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

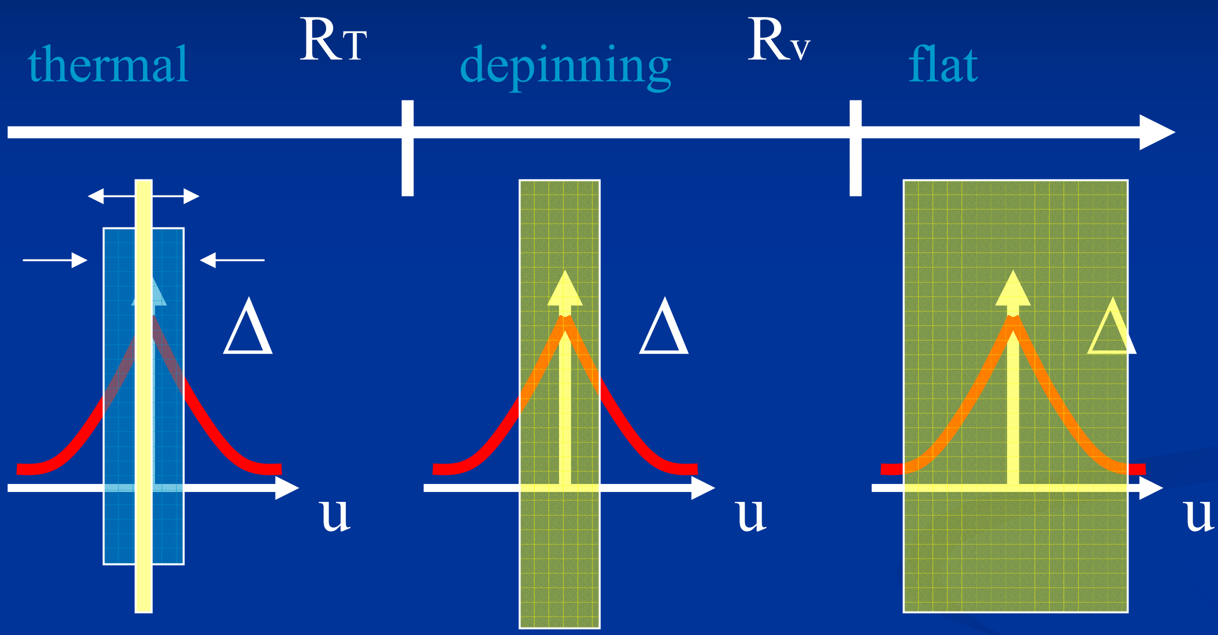
$$\partial \ln\lambda = 2-\zeta-\int_{s>0} e^{-s} s\tilde{\Delta}''(s\lambda),$$

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

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

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

Rounding of cusp



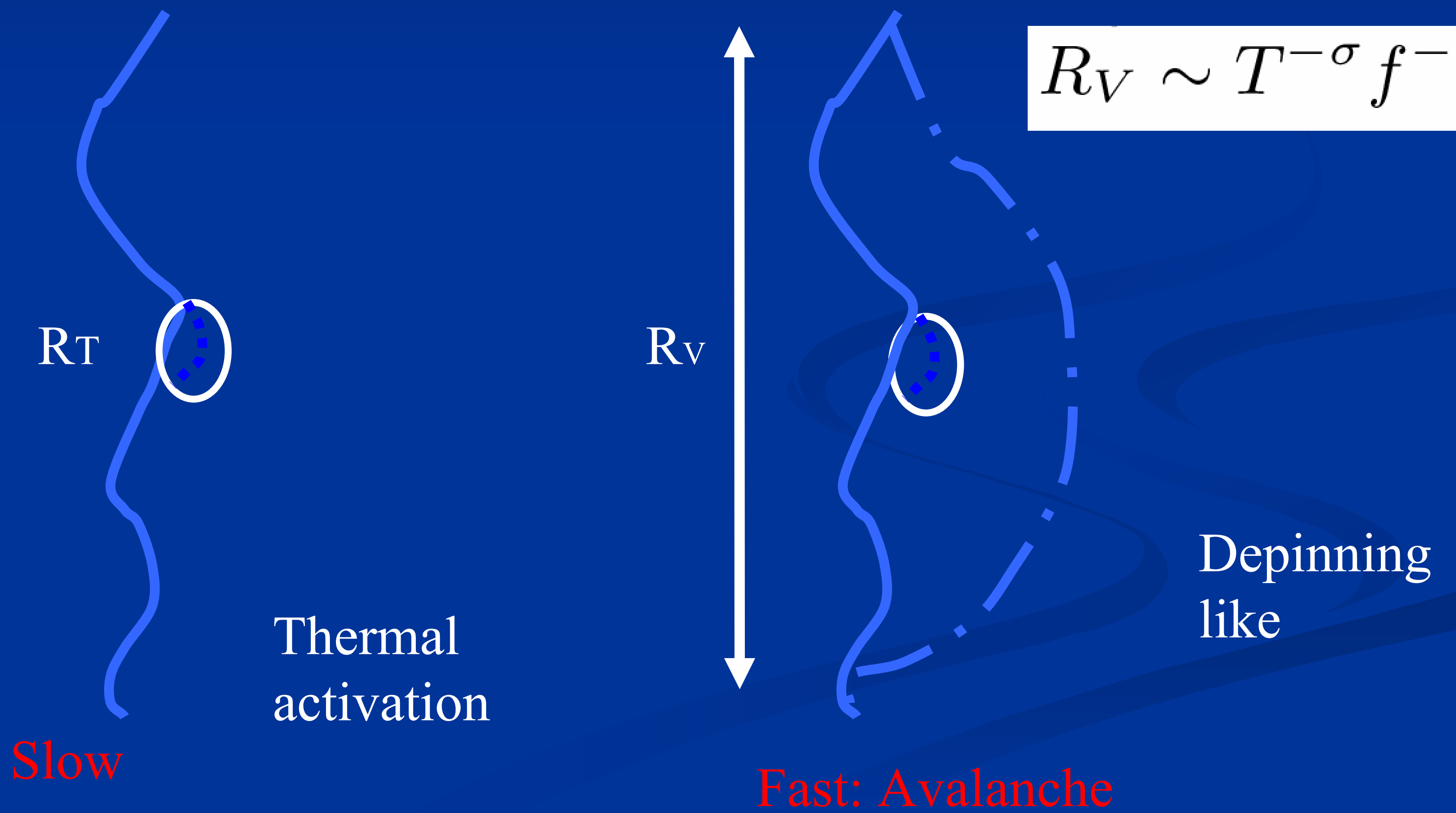
$$\frac{\eta v}{f_c} \approx \exp\left[-\frac{U_c}{T}\left(\frac{f}{f_c}\right)^{-\mu}\right]$$

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

New lengthscale: avalanches

Motion different from phenomenological picture (two regimes)

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



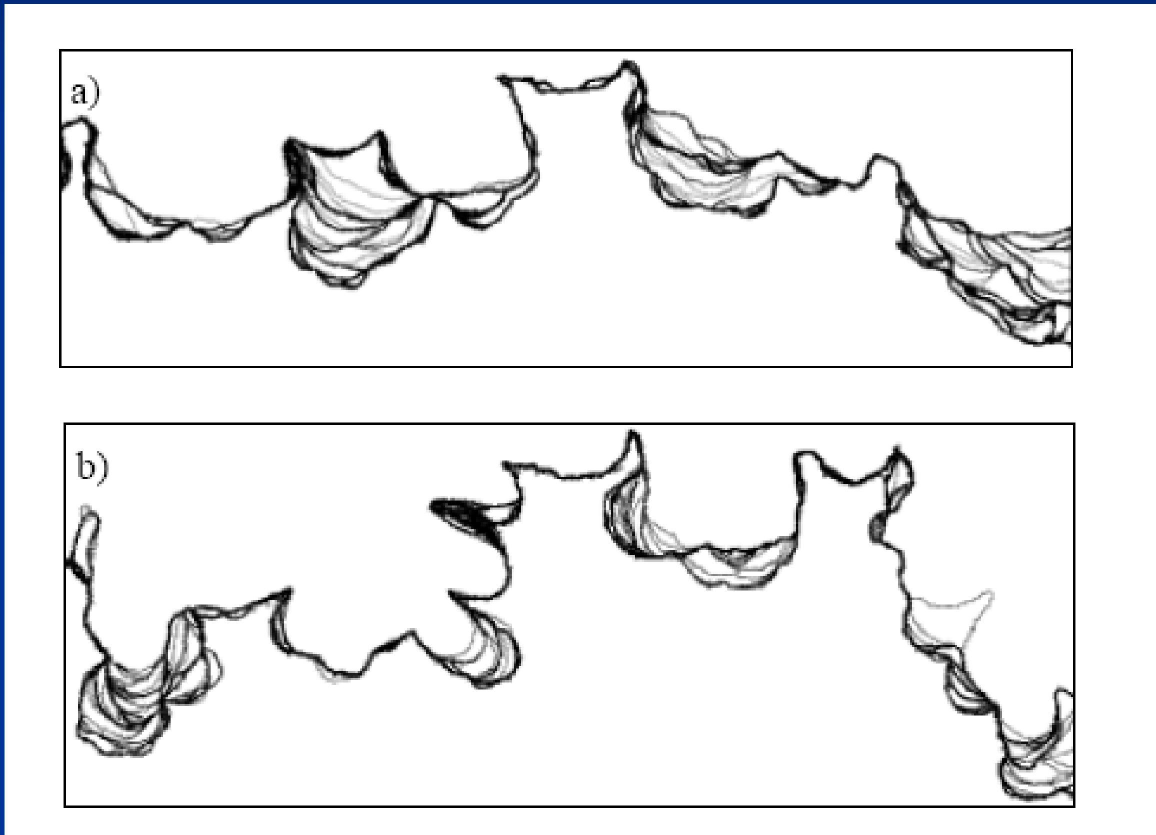
Consequences

- No essential change in the velocity

- Change the roughness of the line

Avalanches = depinning ($\zeta = 1.2..$)

Large avalanches



$L_c = 40$ nm

$L_T = 1\ \mu$ m

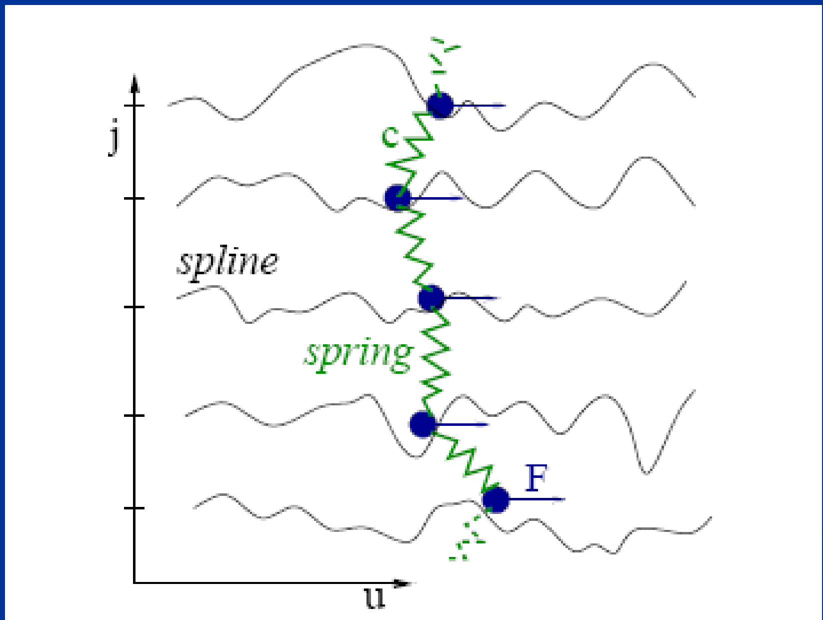
$L_v = 17\ \mu$ m

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

Creep exponents

- Are exponents given by equilibrium ?

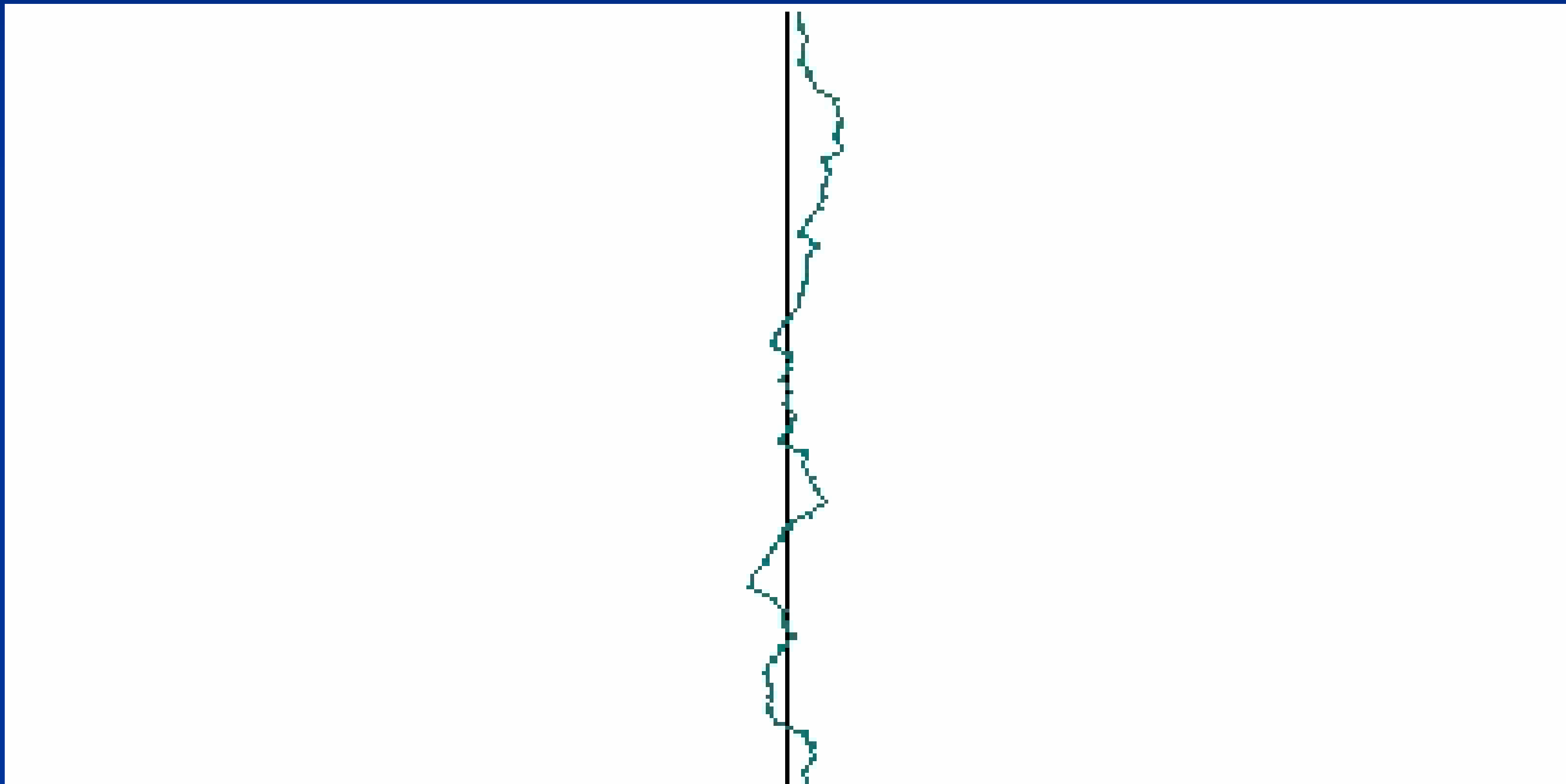
- Molecular dynamics simulations

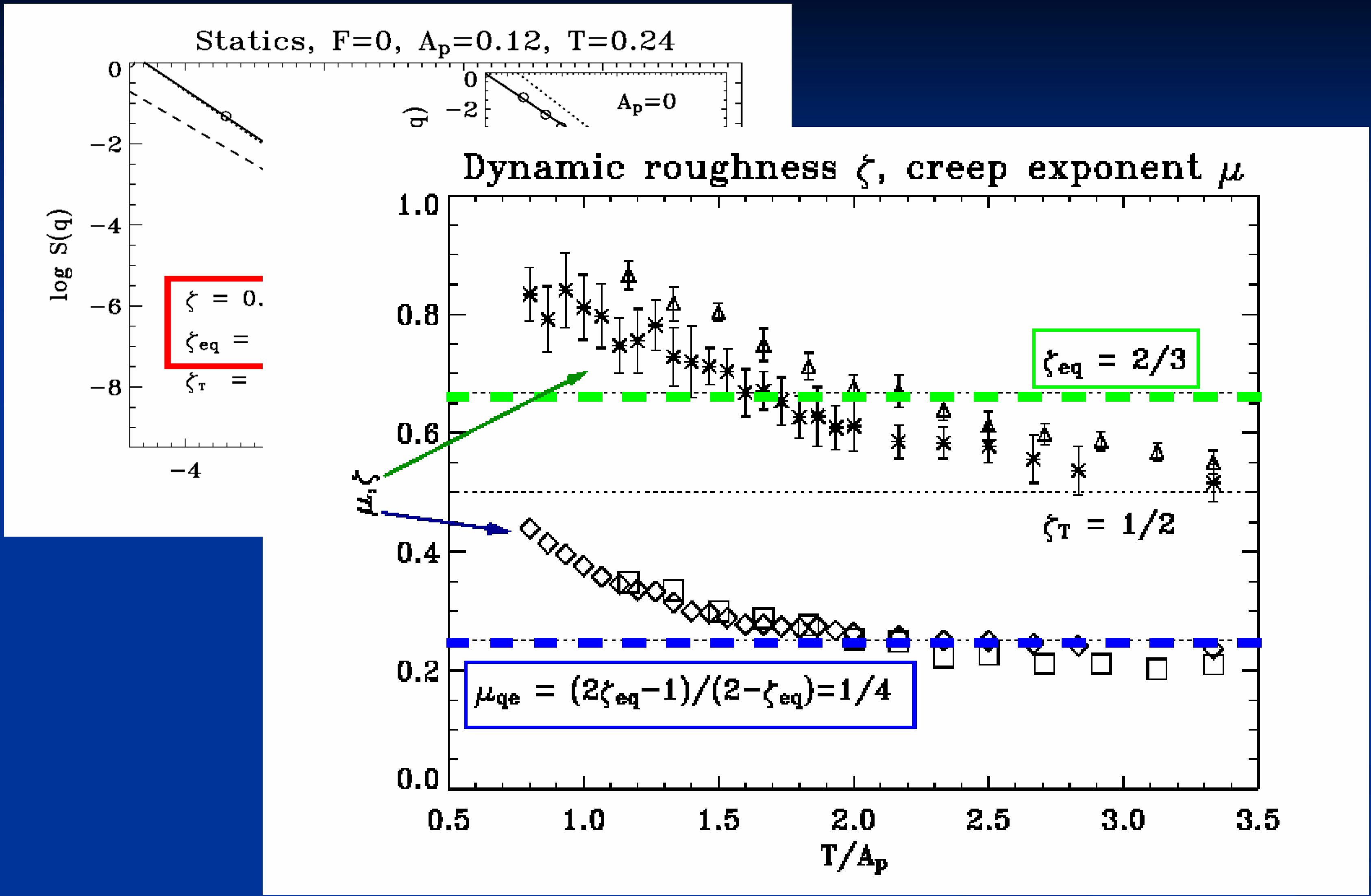


A. B. Kolton, A. Rosso, TG, PRL 91 056603 (03)

A. B. Kolton, A. Rosso, TG, cond-mat/0503437

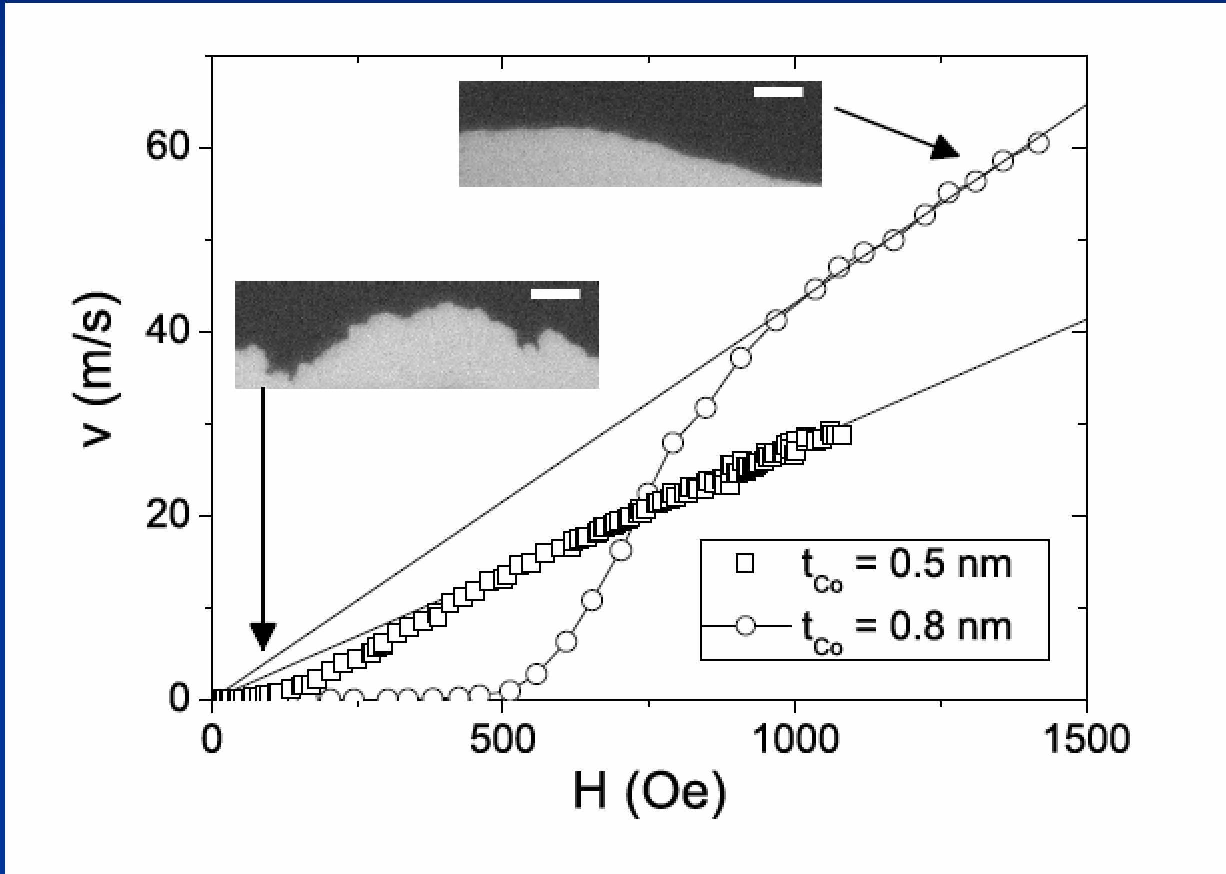
Numerical analysis





Exponents larger than equilibrium value !

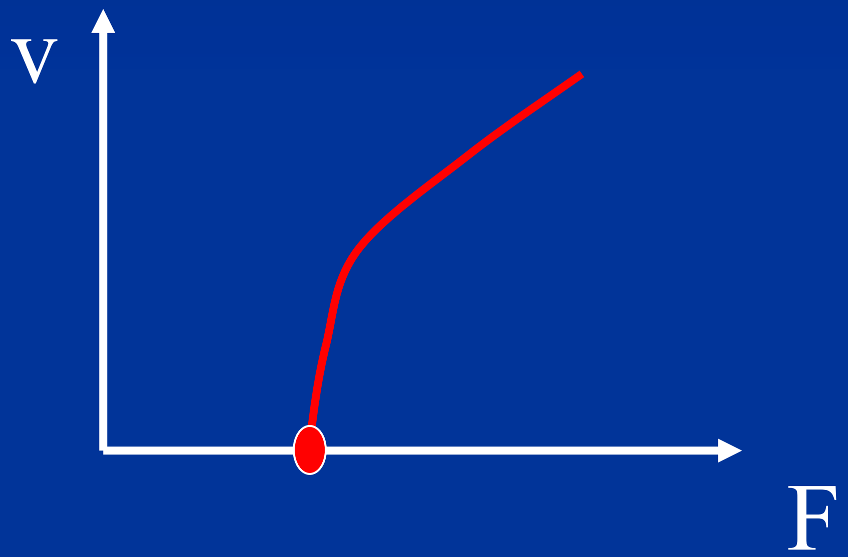
Consequences/study of depinning



C. J. Metaxas et al. cond-mat/0702654

Depinning as a critical phenomena ?

(D.S. Fisher)



Depinning	Crit. phen.
F	T
v	magn.

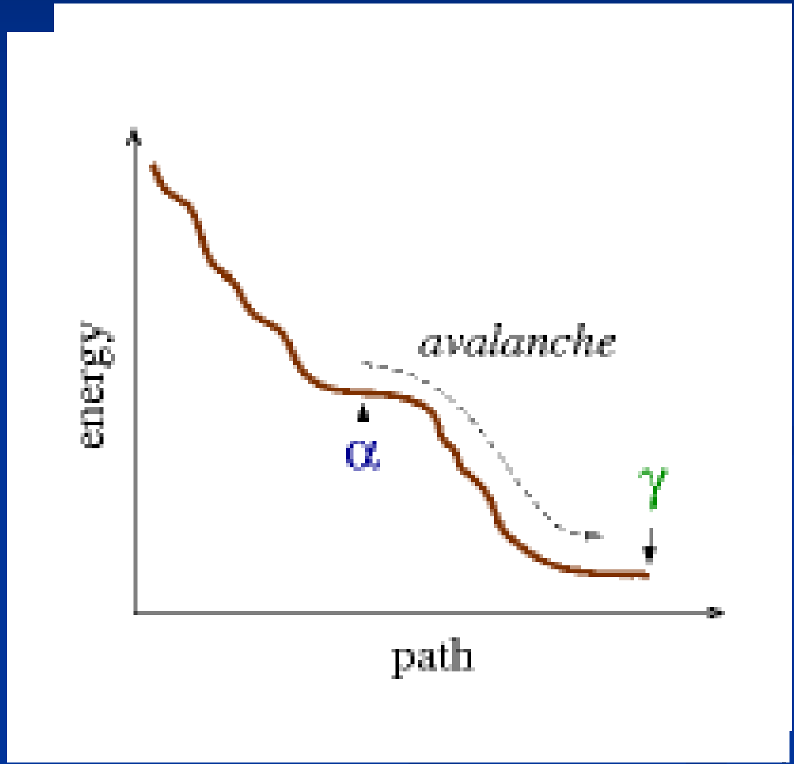
Suggests : critical exponents for $F \sim F_c$

Exponents and divergent lengthscales

Order parameter: $v \sim (F-F_c)^{\beta}$

Divergent length: $\xi \sim (F-F_c)^{-\nu}$

Divergent time: $t \sim \xi^{z}$



Scaling relations:

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

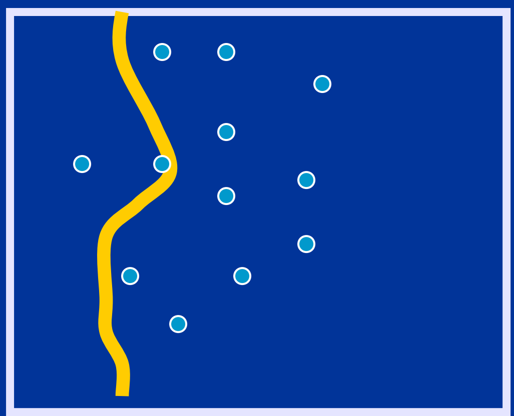
Roughness of line

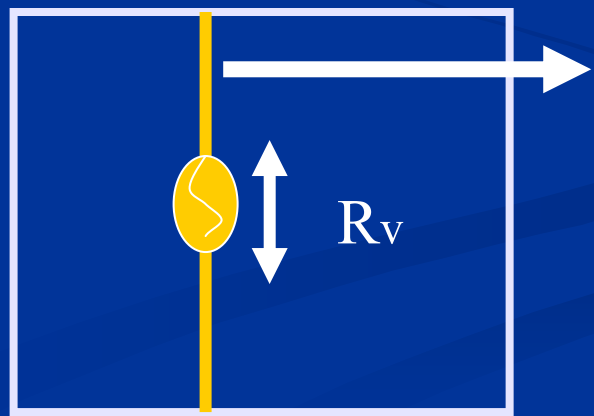
- $F = F_c$

Line is rough but with $\zeta = \zeta_{dep}$

$\zeta_{dep} \sim 1.2..$

- Large lengthscales $v \neq 0$

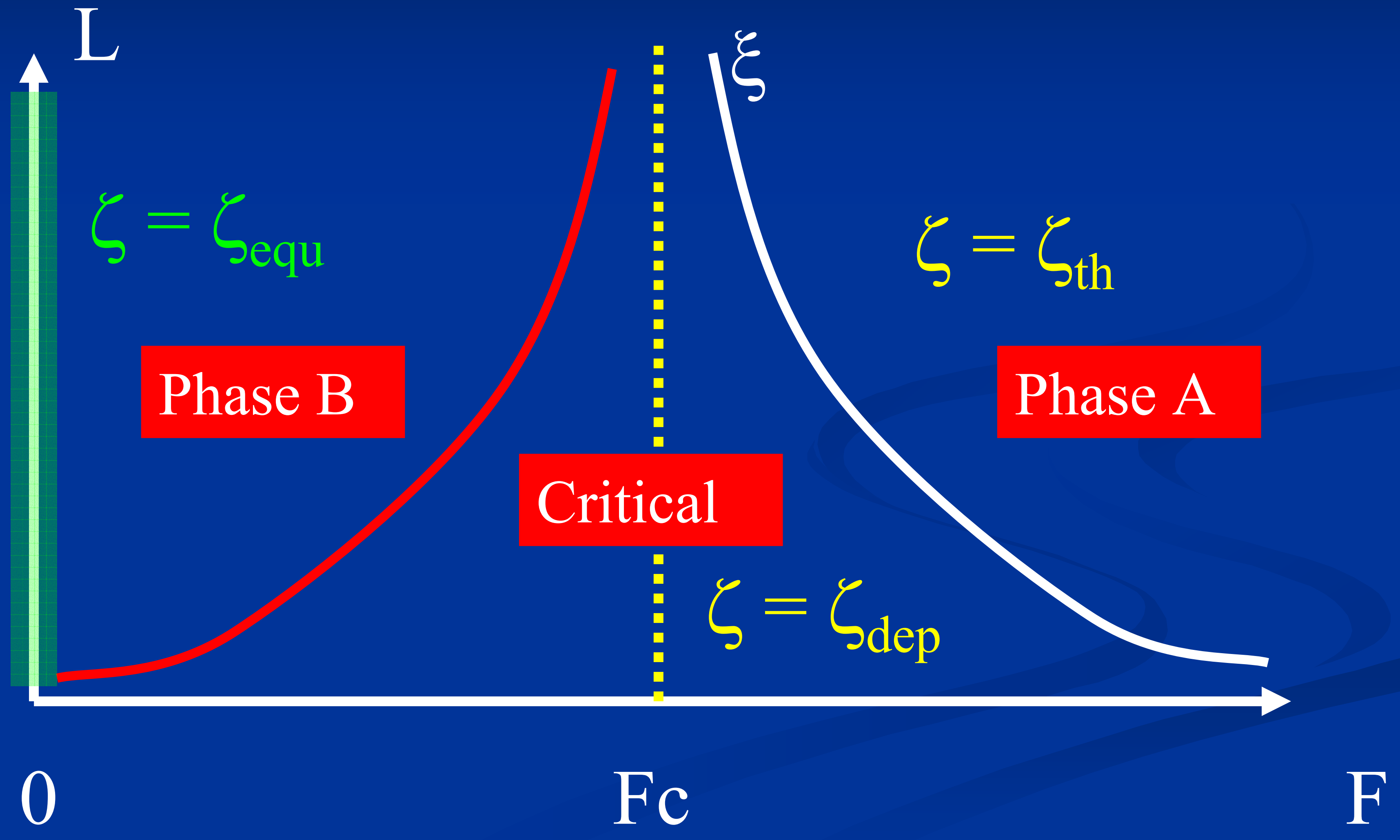




$\zeta = \zeta_{th}$

$\zeta_{th} \sim 0.5$

Consequence for aspect of line at $T=0^+$



How to study

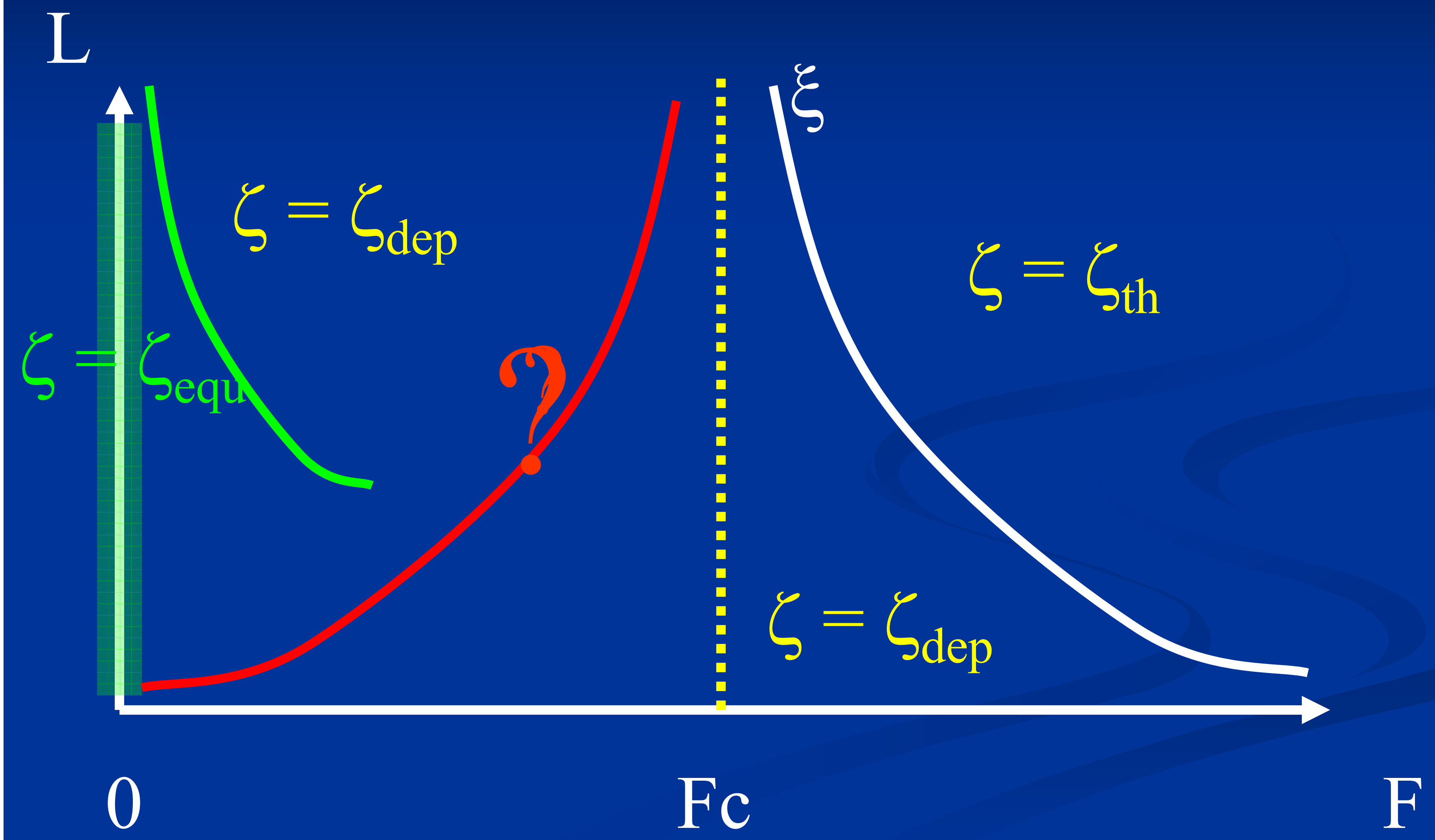
- T = 0

Only transient dynamics

Divergent lengthscale in transient
(Middleton, Fisher, Narayan, Chen, Marchetti)

- Very serious problem with FRG analysis of F → 0 (creep)

Consequence for aspect of line



Need to study T $\neq$ 0 steady state motion

- Analytic

FRG Difficult ! and 4-d

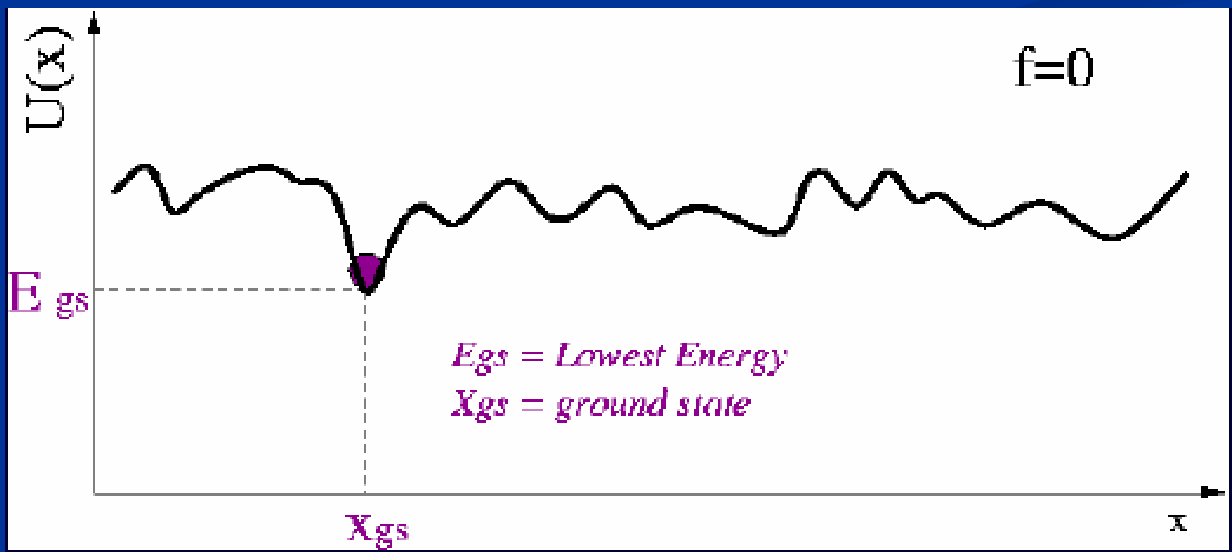
- Numerics

Molecular dynamics Extremely slow: inefficient

Novel Algorithm

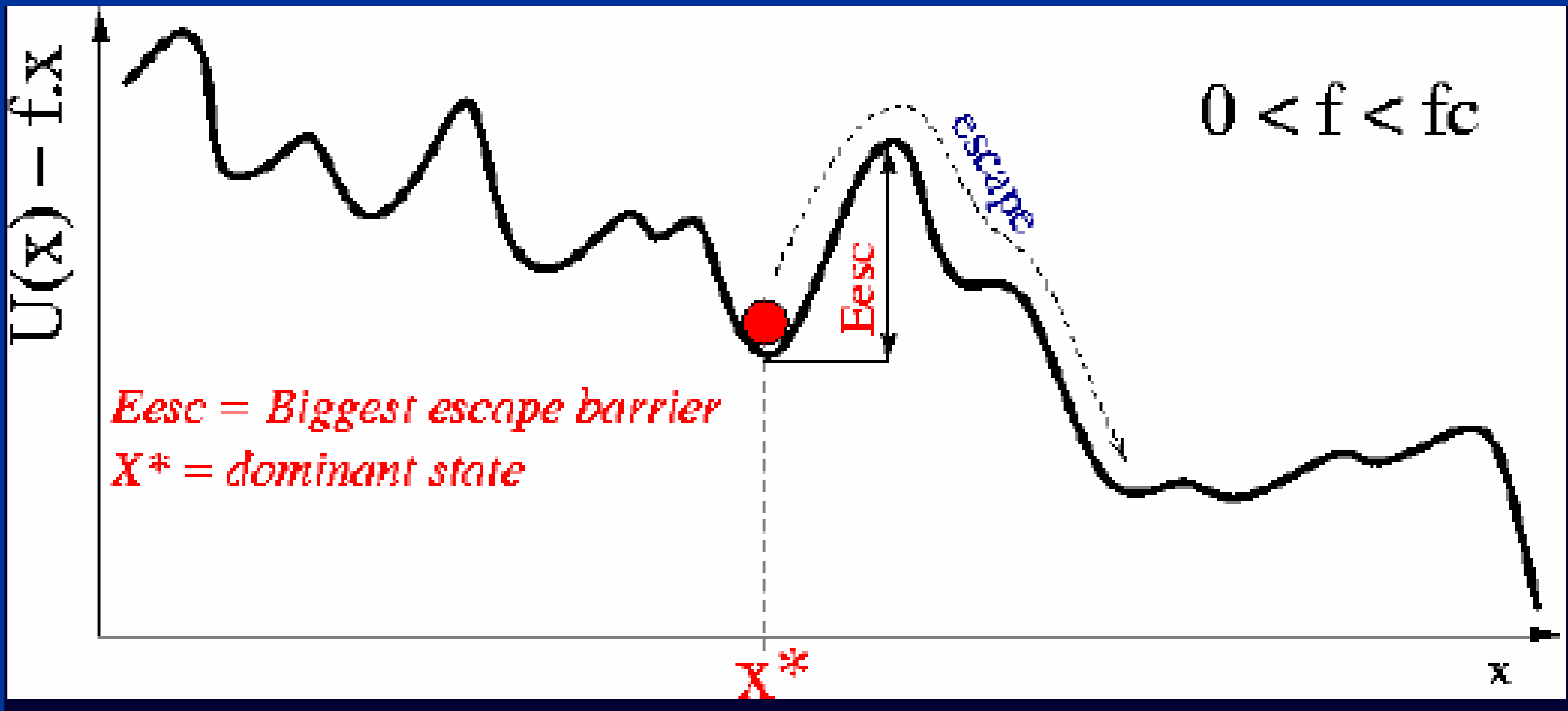
A.B. Kolton, A. Rosso, TG, W. Krauth PRL 97 057001 (06)

- Equilibrium: One dominant configuration when $T \rightarrow 0$



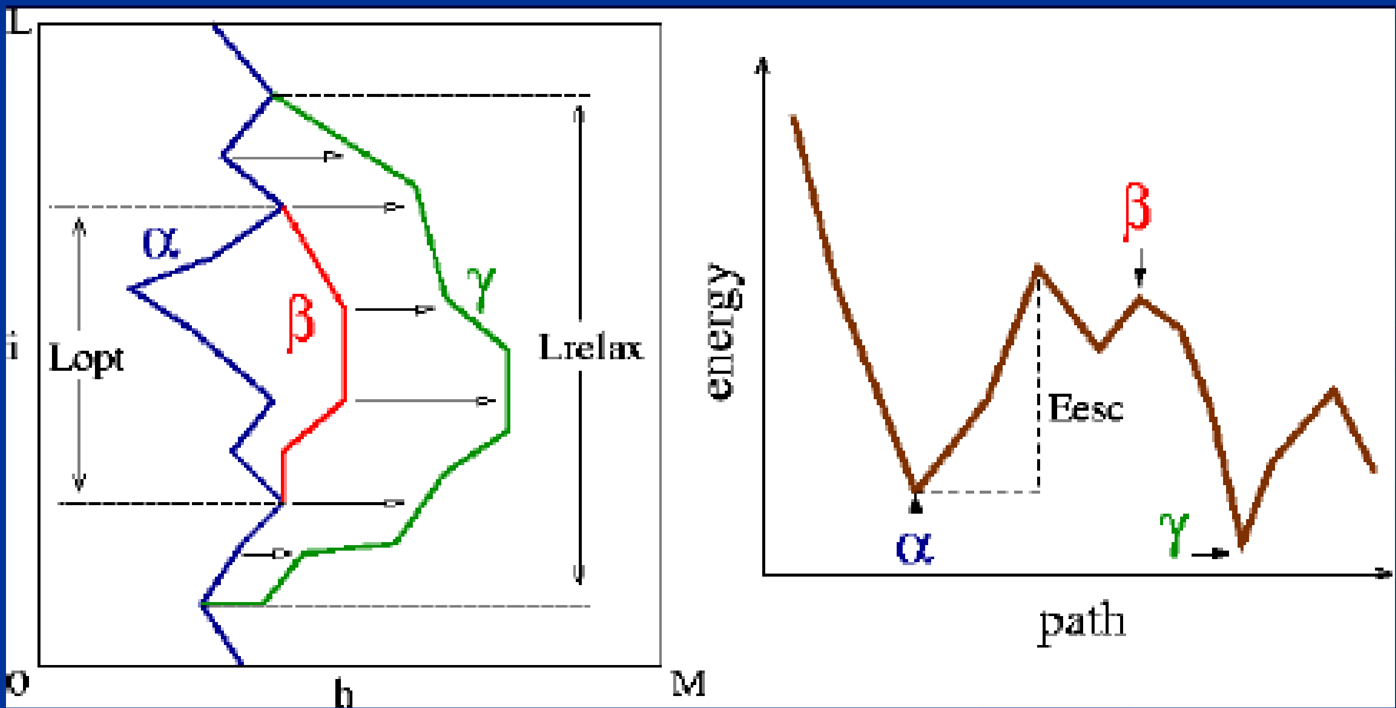
Dynamics for T→ 0^+

Also one dominant configuration



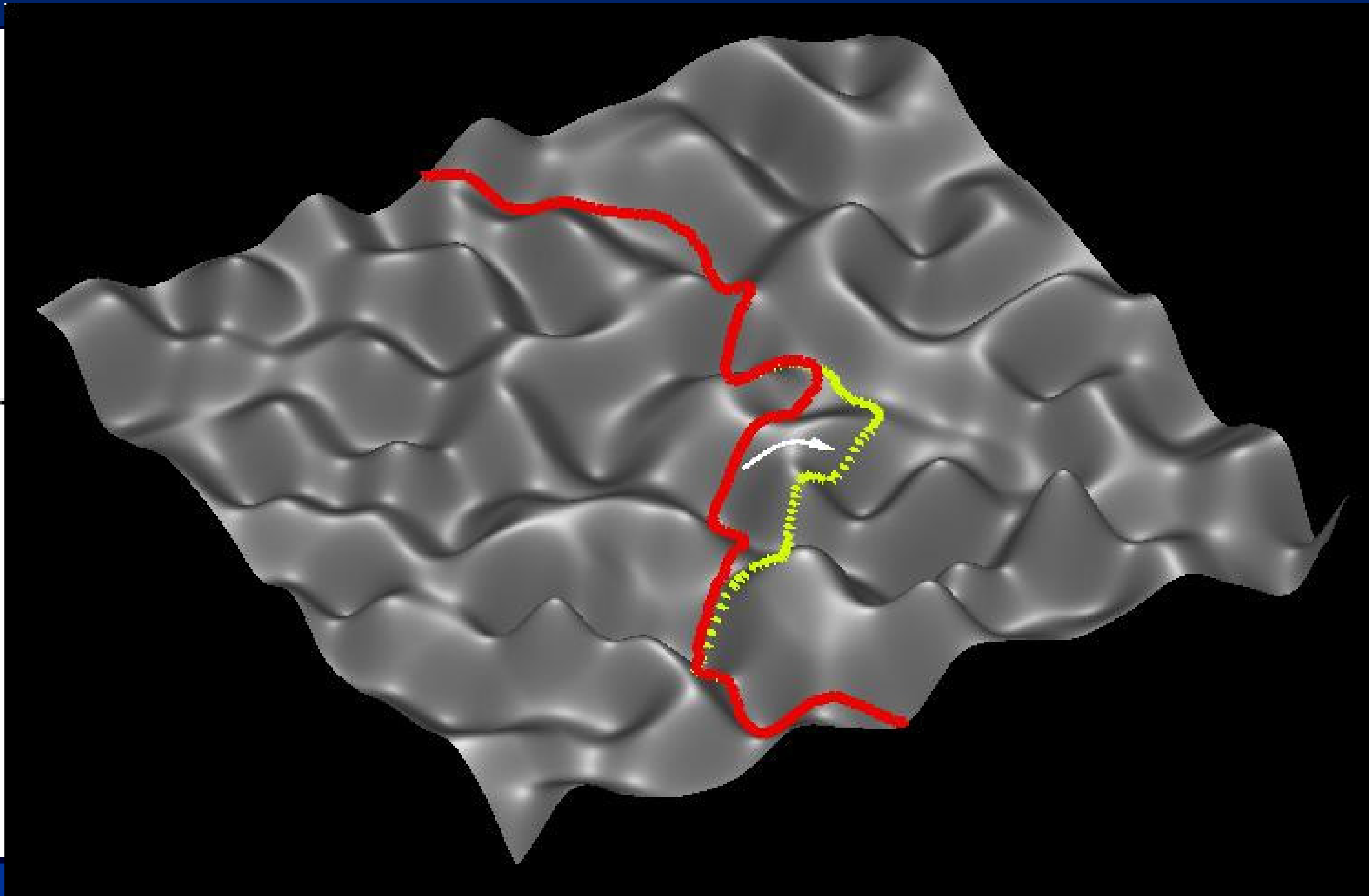
How to find it ?

Enumeration of all « good » moves

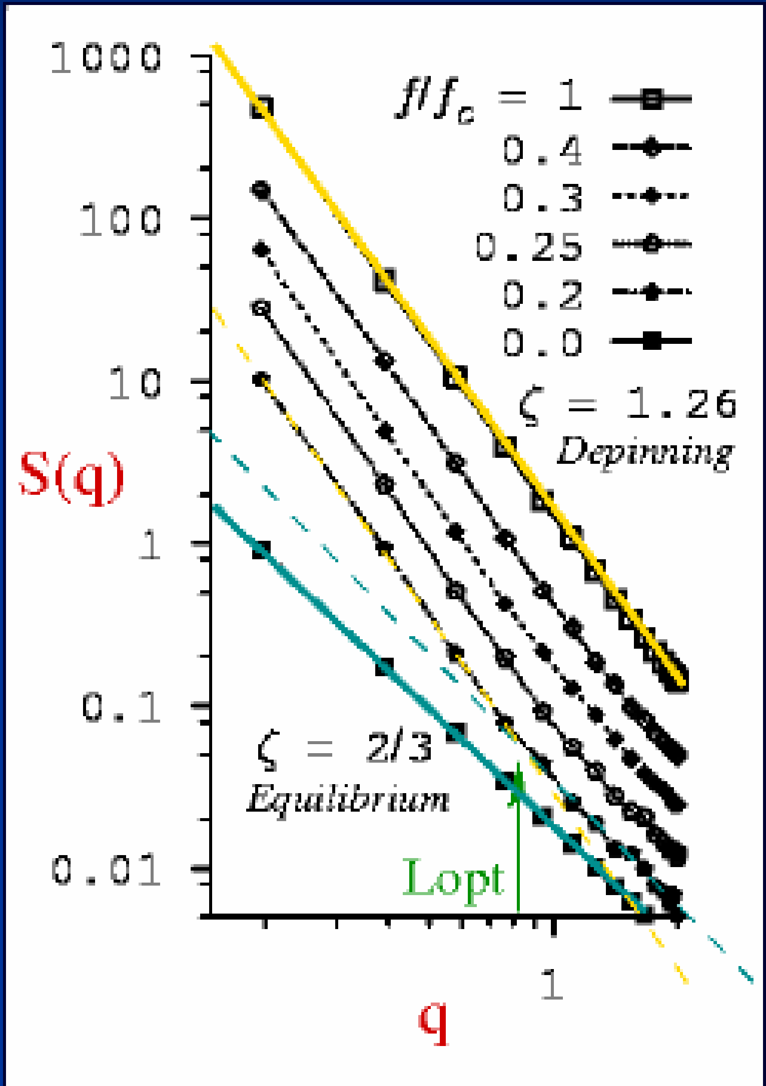


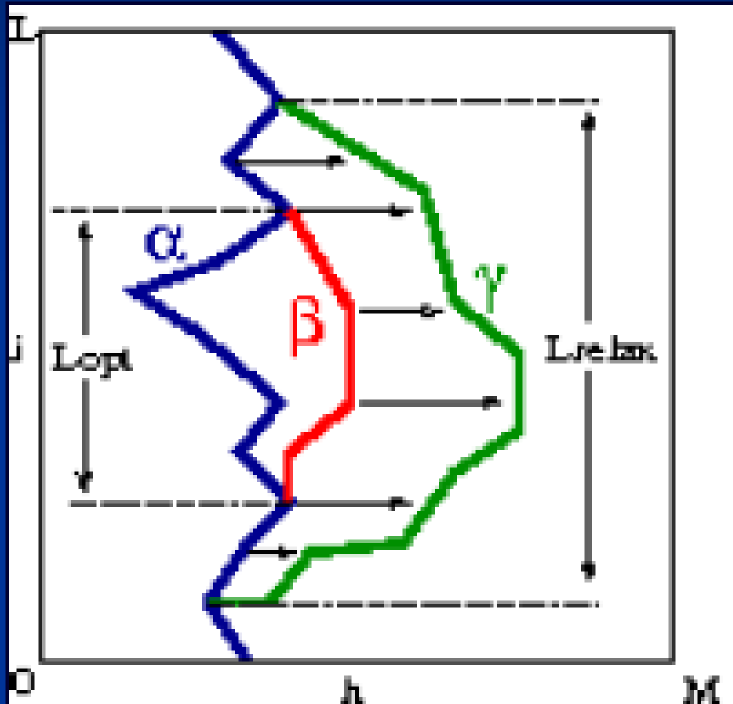
Works well when nucleus size not too big (F ~ Fc)

Dominant configuration F<Fc



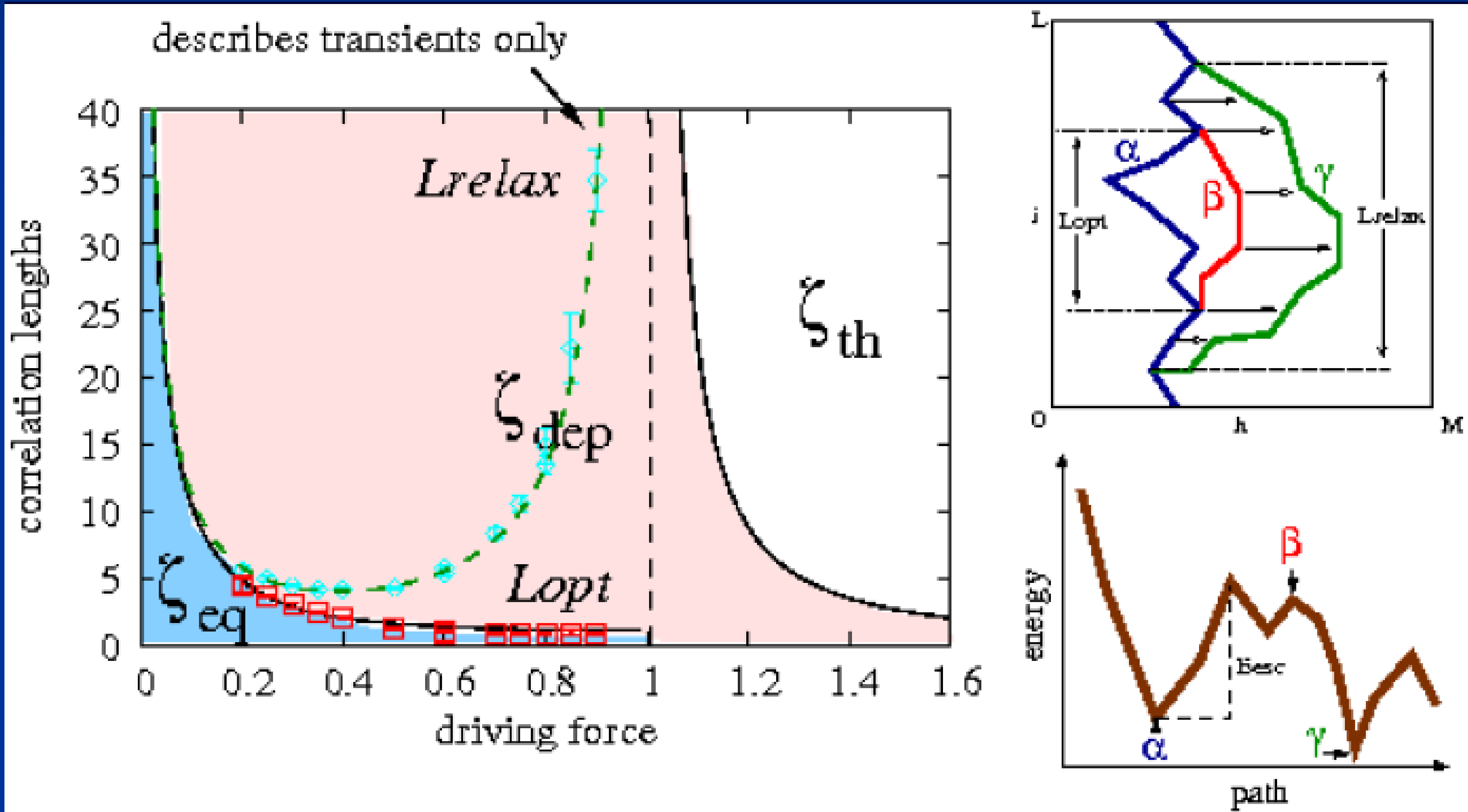
Geometry





ζ_{eq} at **small** scales

Dynamical phase diagram

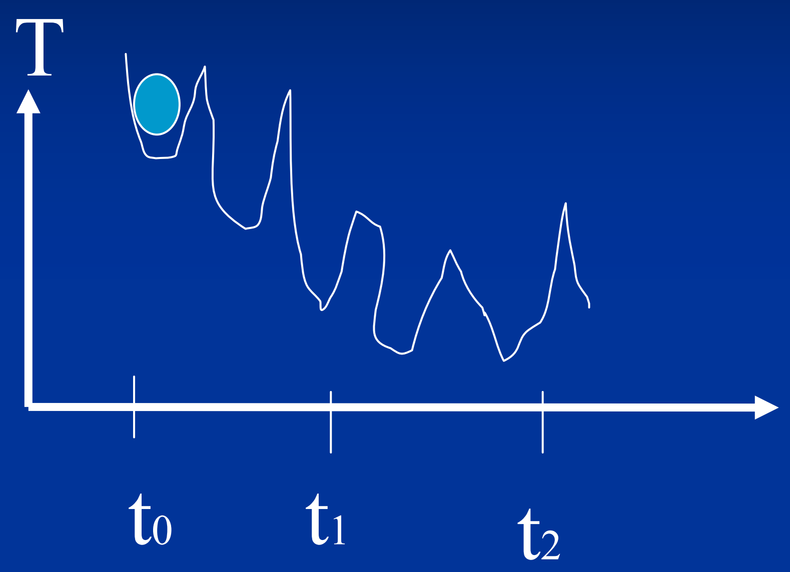


Conclusions

- Creep generic in DES
- v-F well confirmed by FRG
- New lengthscale (avalanches)
- Consequences for roughness
- Depinning not a « standard » critical phenomenon

Other consequences of creep: Aging

Glasses : Aging

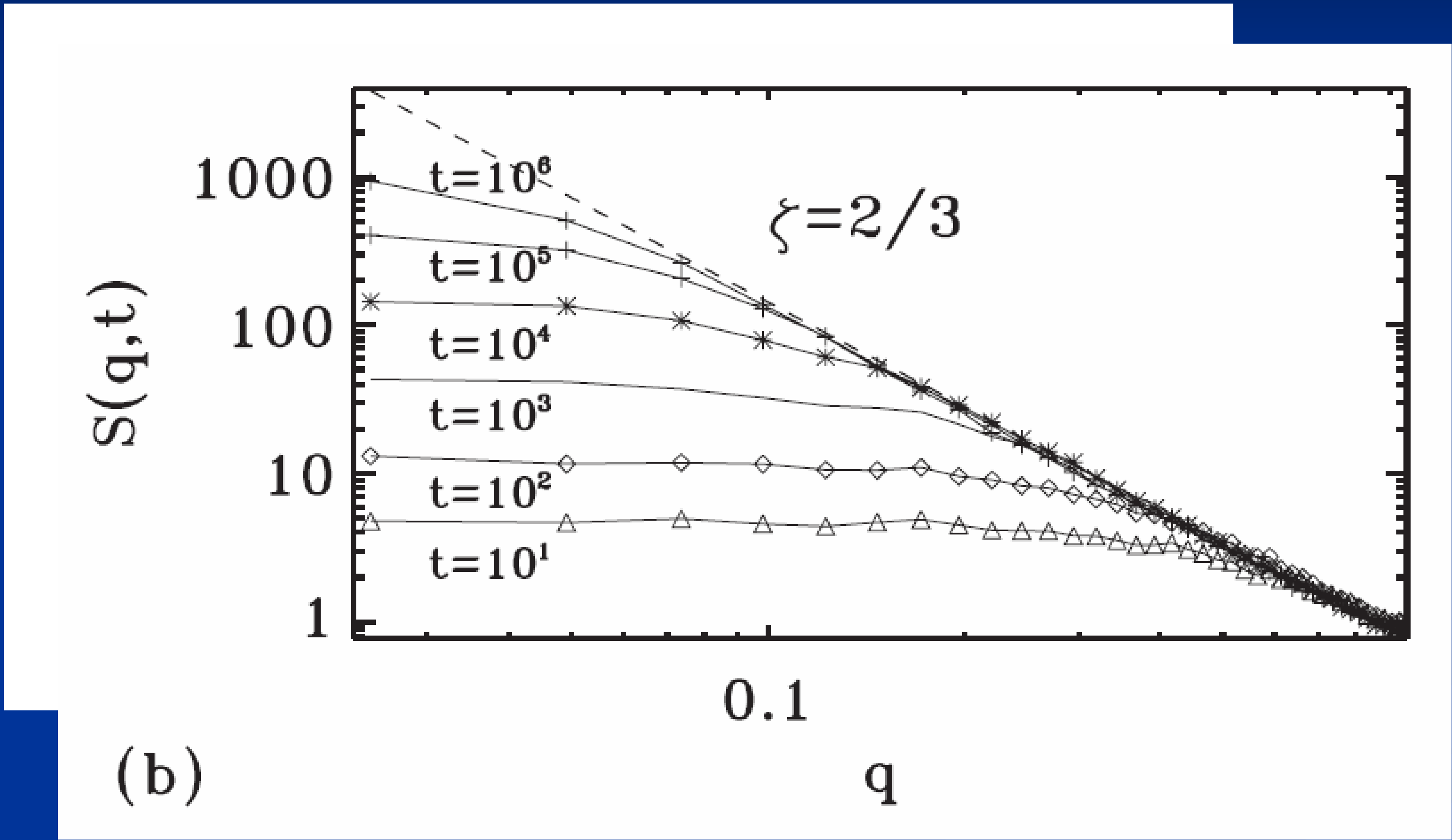


f(t1,t2)

f : Depends on both times

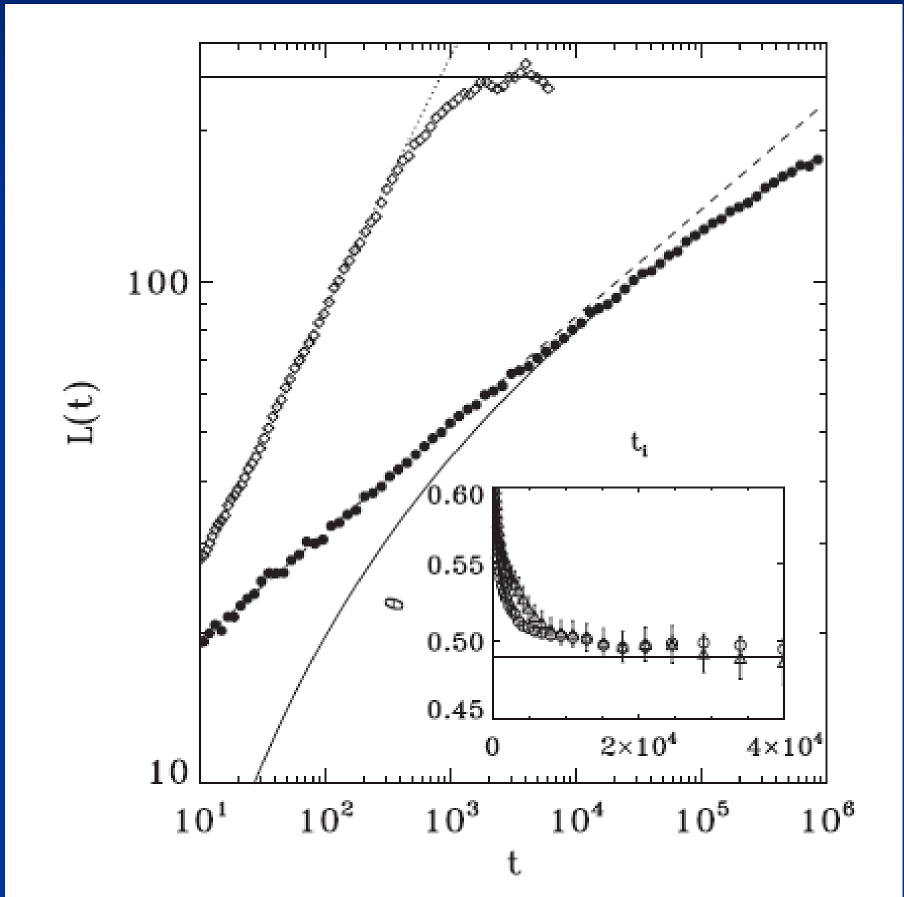
Aging of the Bragg glass or the interfaces ?

Aging in interfaces



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

Creep: $\tau \sim \mathrm{Exp}[-\beta L^{\theta}]$



$\theta = 0.49$

$\theta_{eq} = 1/3$