Memory of thermal avalanches in ultra-slow domain wall creep dynamics

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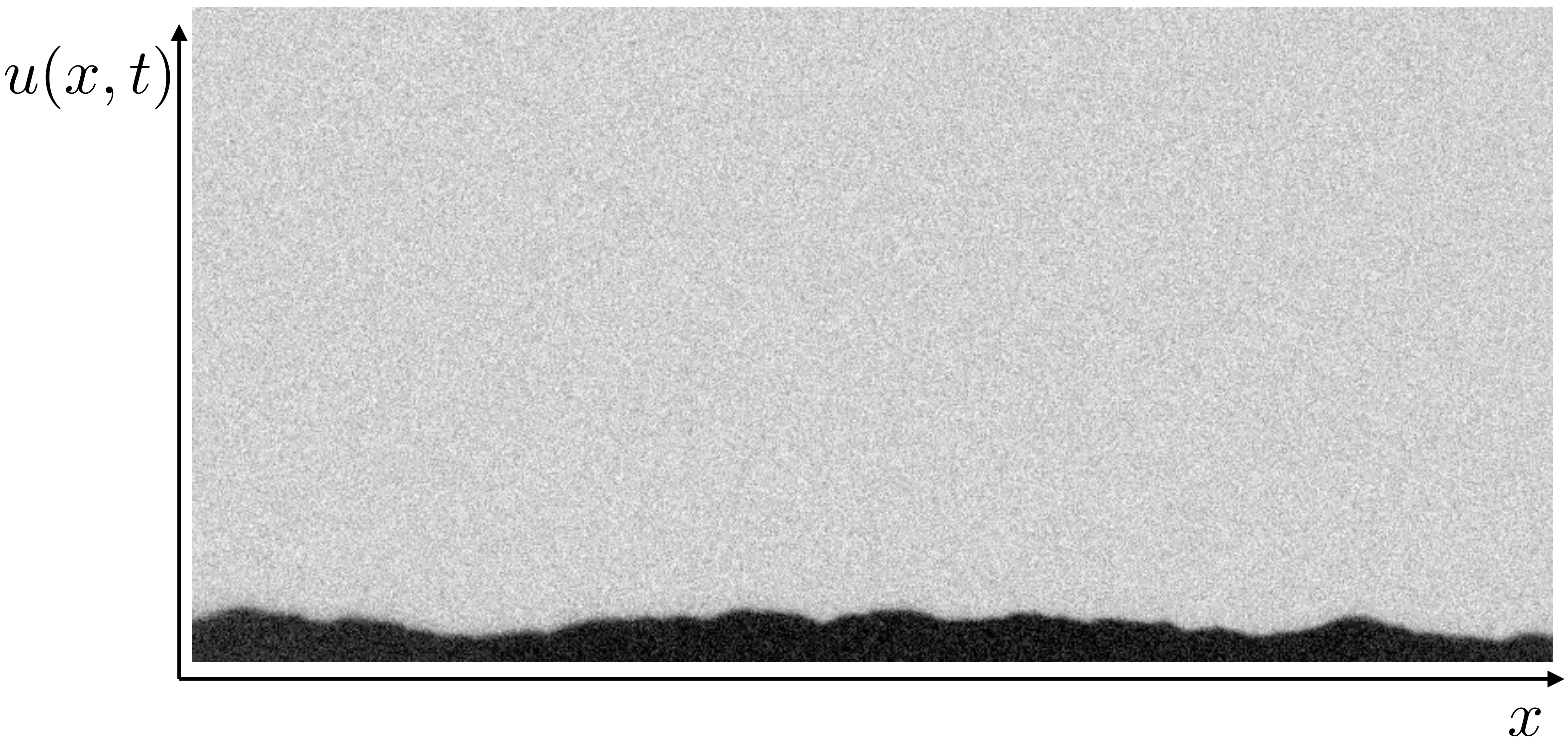
E. Ferrero, L. Foini, T. Giamarchi, A. Kolton, A.Rosso, PRL 2017

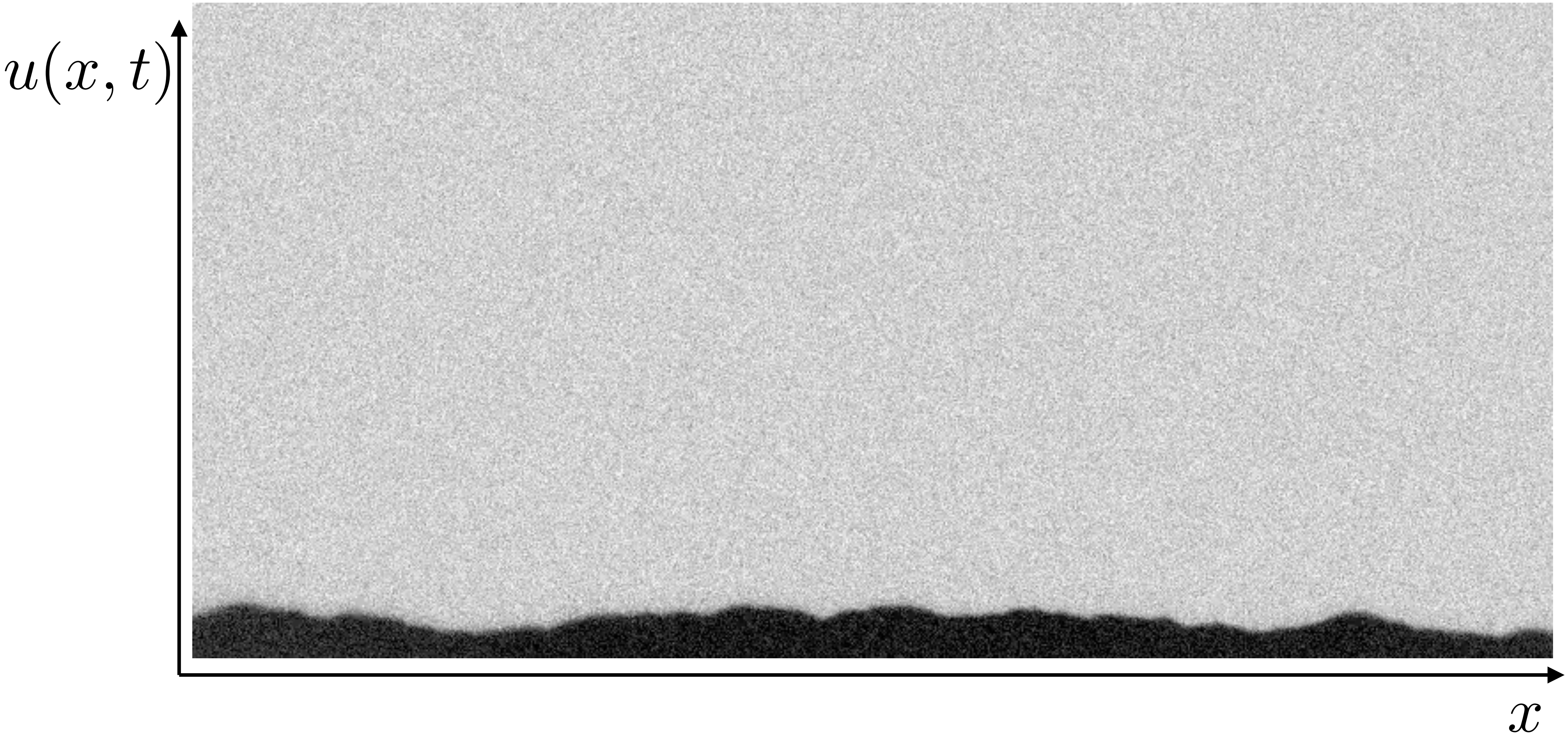
Magnetic domain wall



$$\partial_t u = \partial_x^2 u + f + \eta_{\rm dis}(u,x) + \xi_T(x,t)$$

by Lemerle & Mougin in Paris-Saclay

Magnetic domain wall



$$\partial_t u = \partial_x^2 u + f + \eta_{\rm dis}(u,x) + \xi_T(x,t)$$

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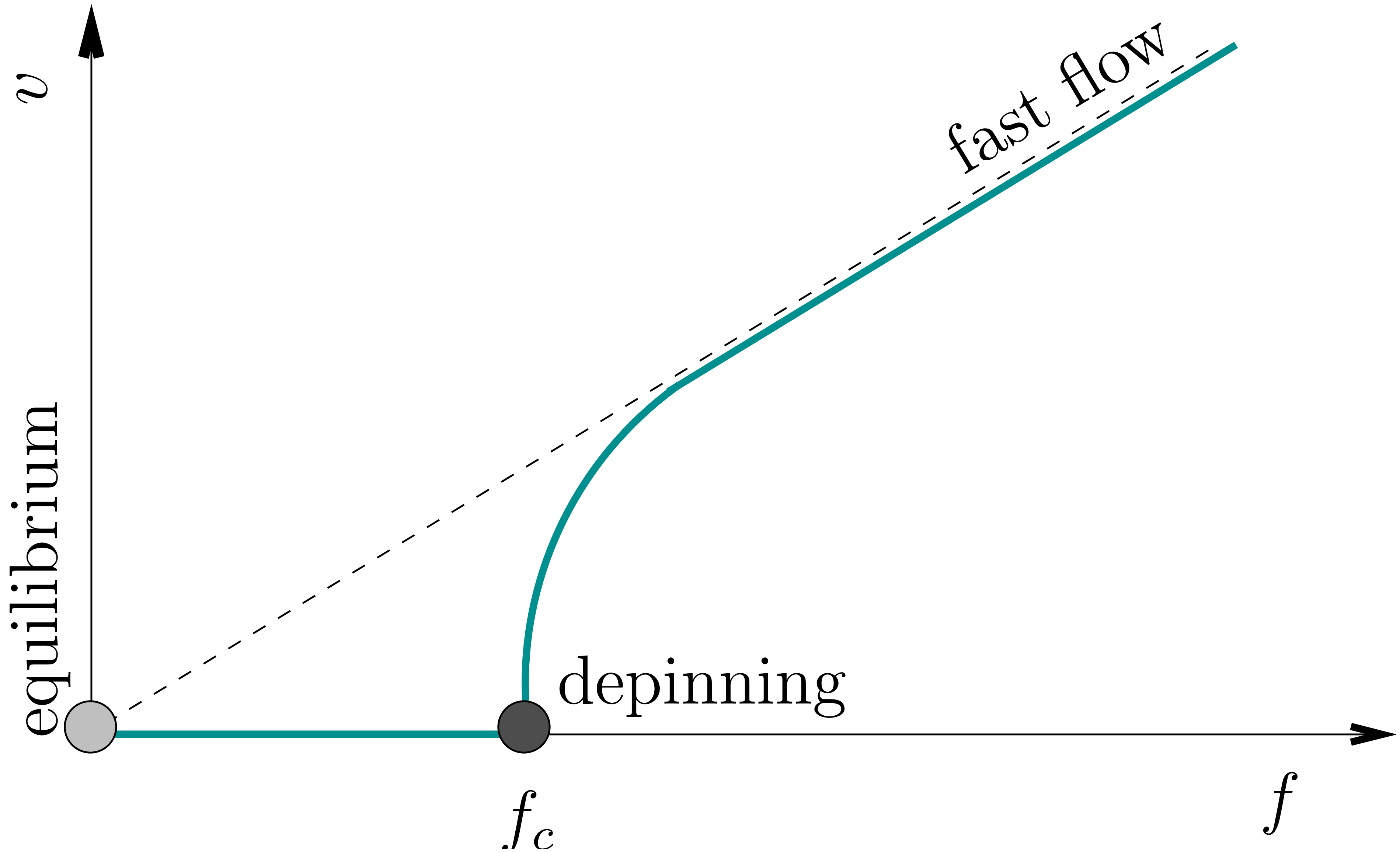
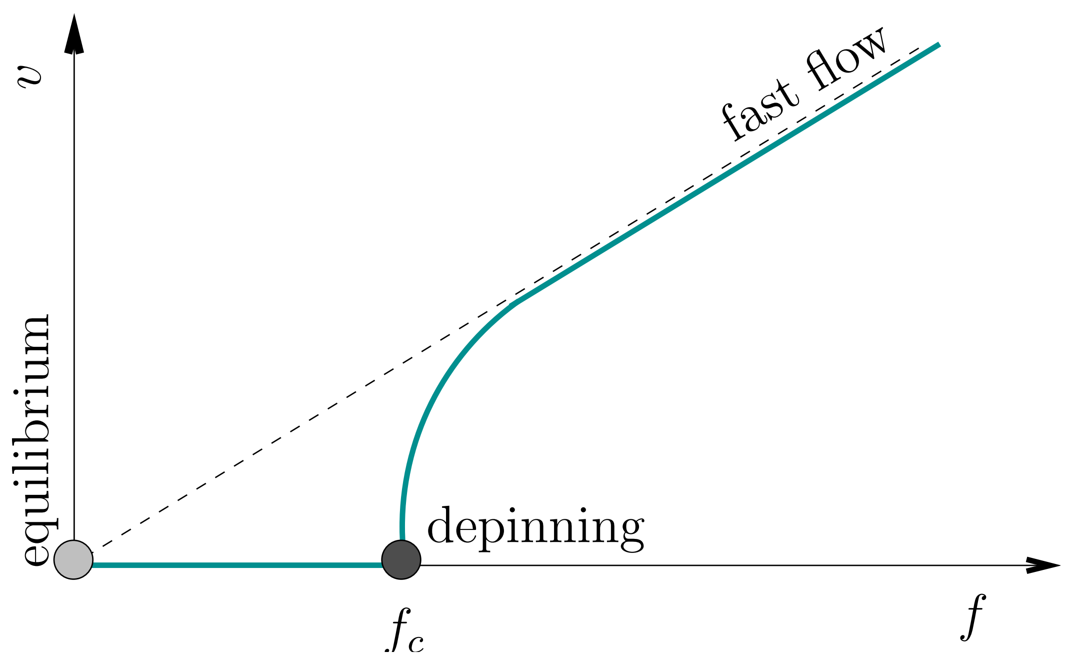
Zero temperature phase diagram

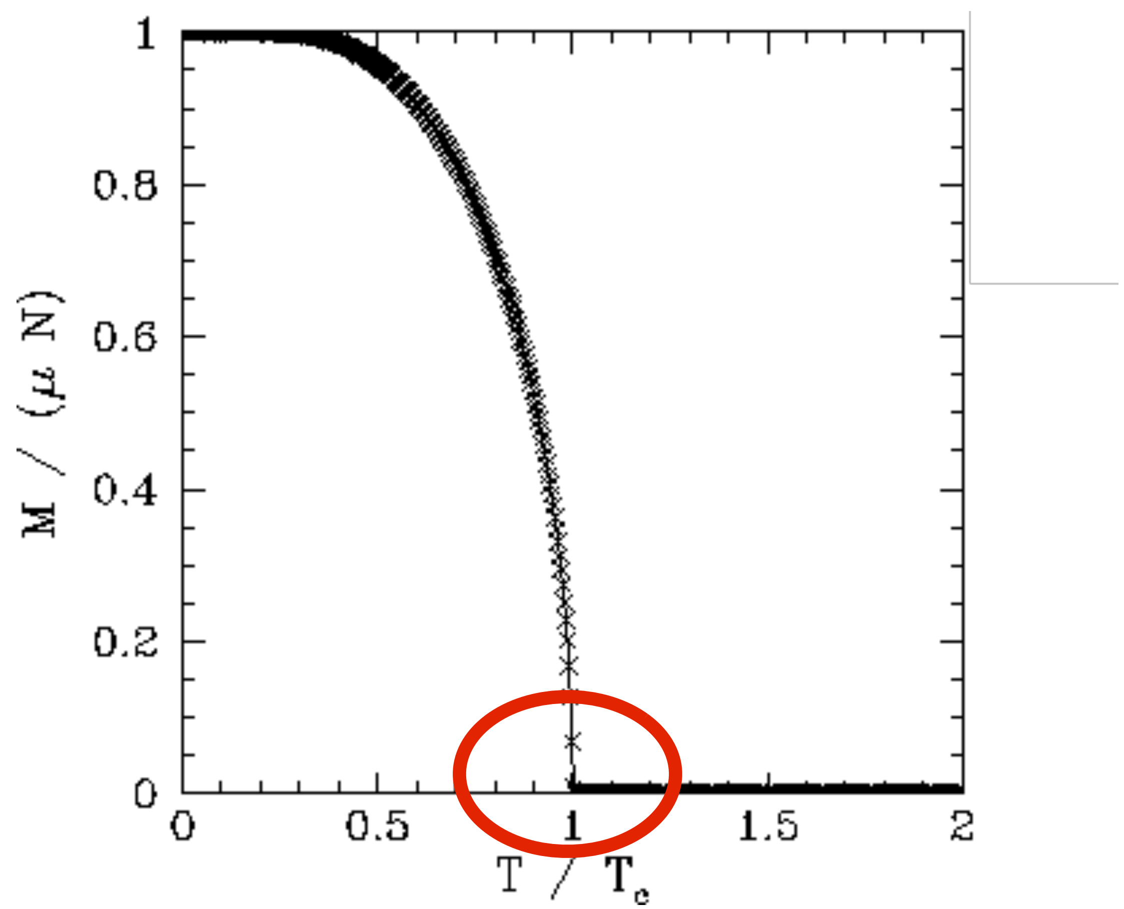


Rugosity: $\langle(u(x) - u(0))^2\rangle] \sim x^{2\zeta}$

Roughness exponent: $\zeta_{\mathrm{eq}} = 2/3$, $\zeta_{\mathrm{dep}} \sim 1.25$, $\zeta_{\mathrm{FF}} = 1/2$

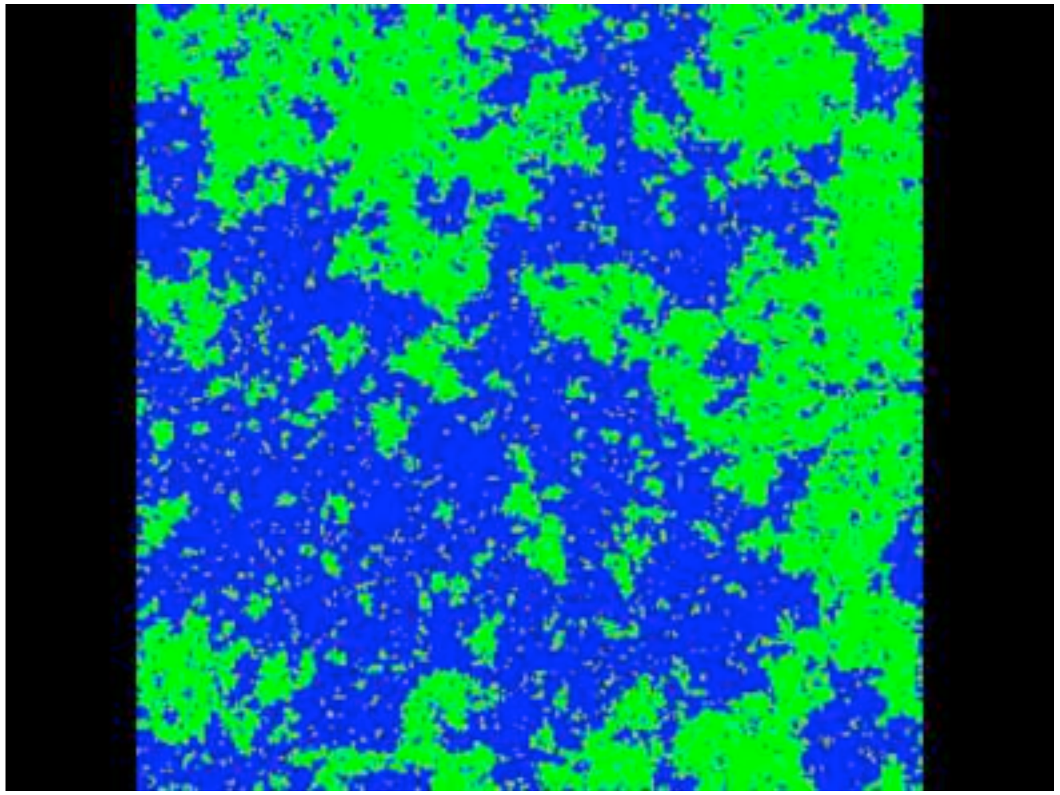
Depinning: analogy with phase transitions



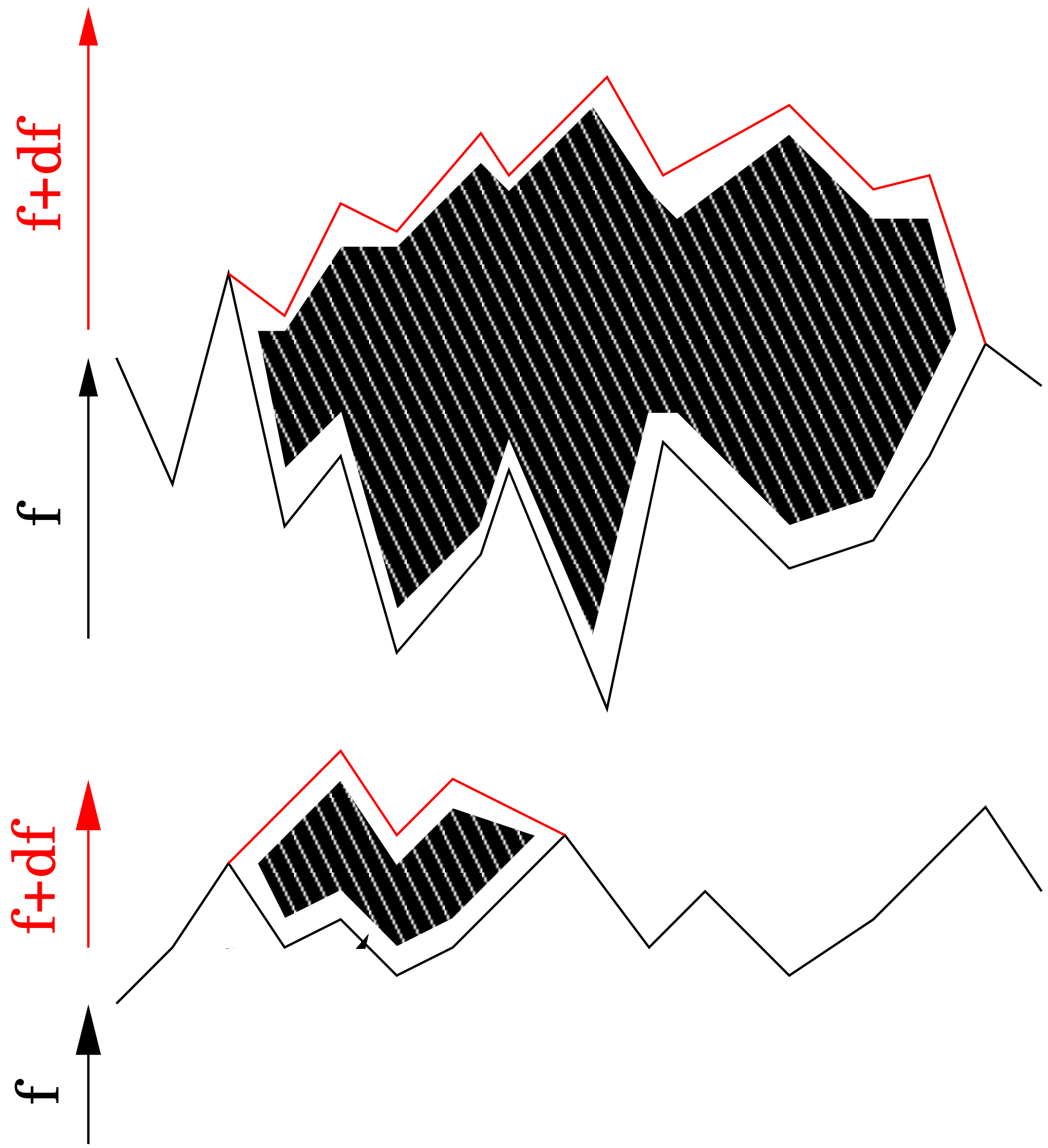


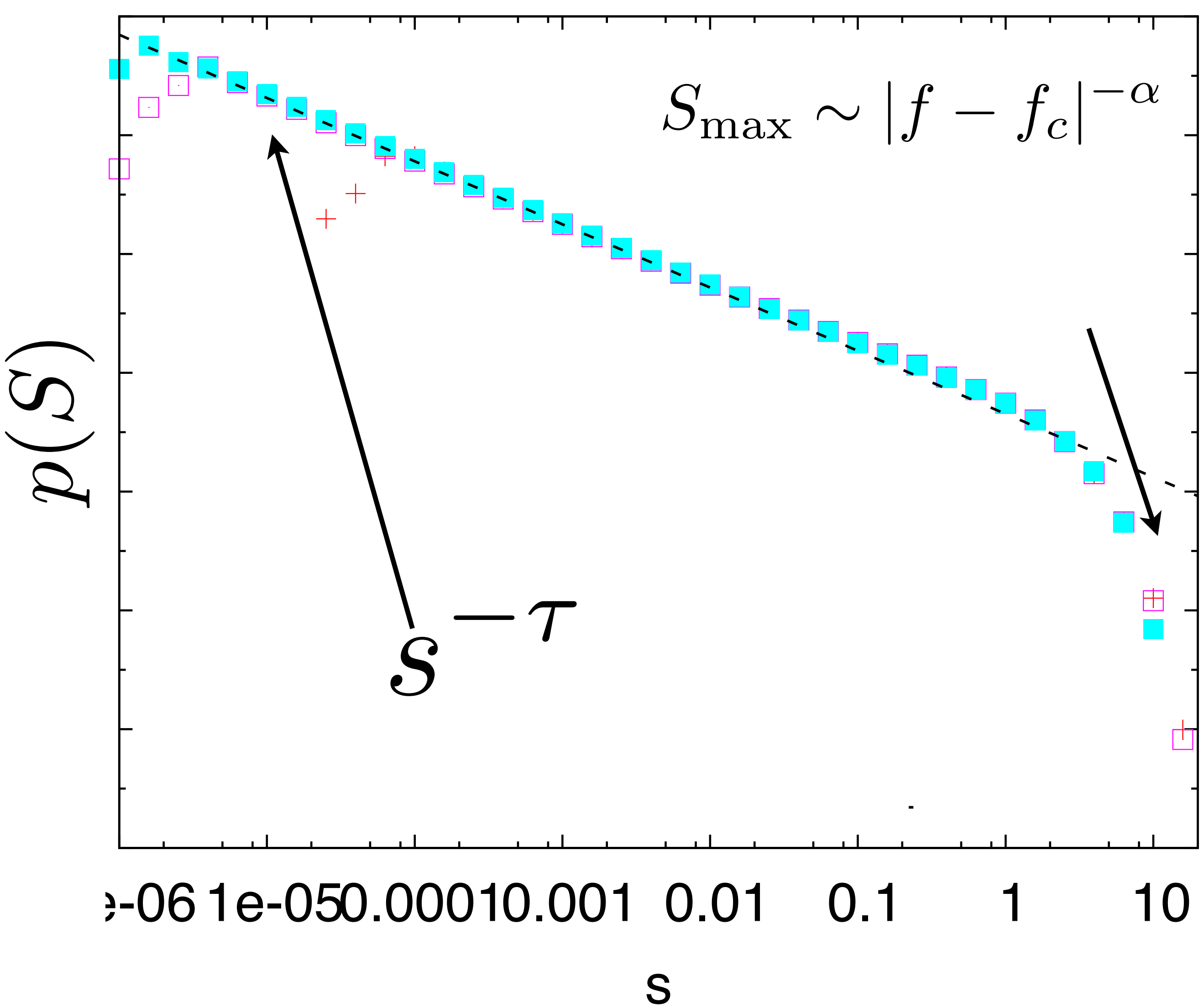
Depinning as a critical phenomenon

- **correlation length**
- **scale invariance**



Scale invariance: avalanches below threshold





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

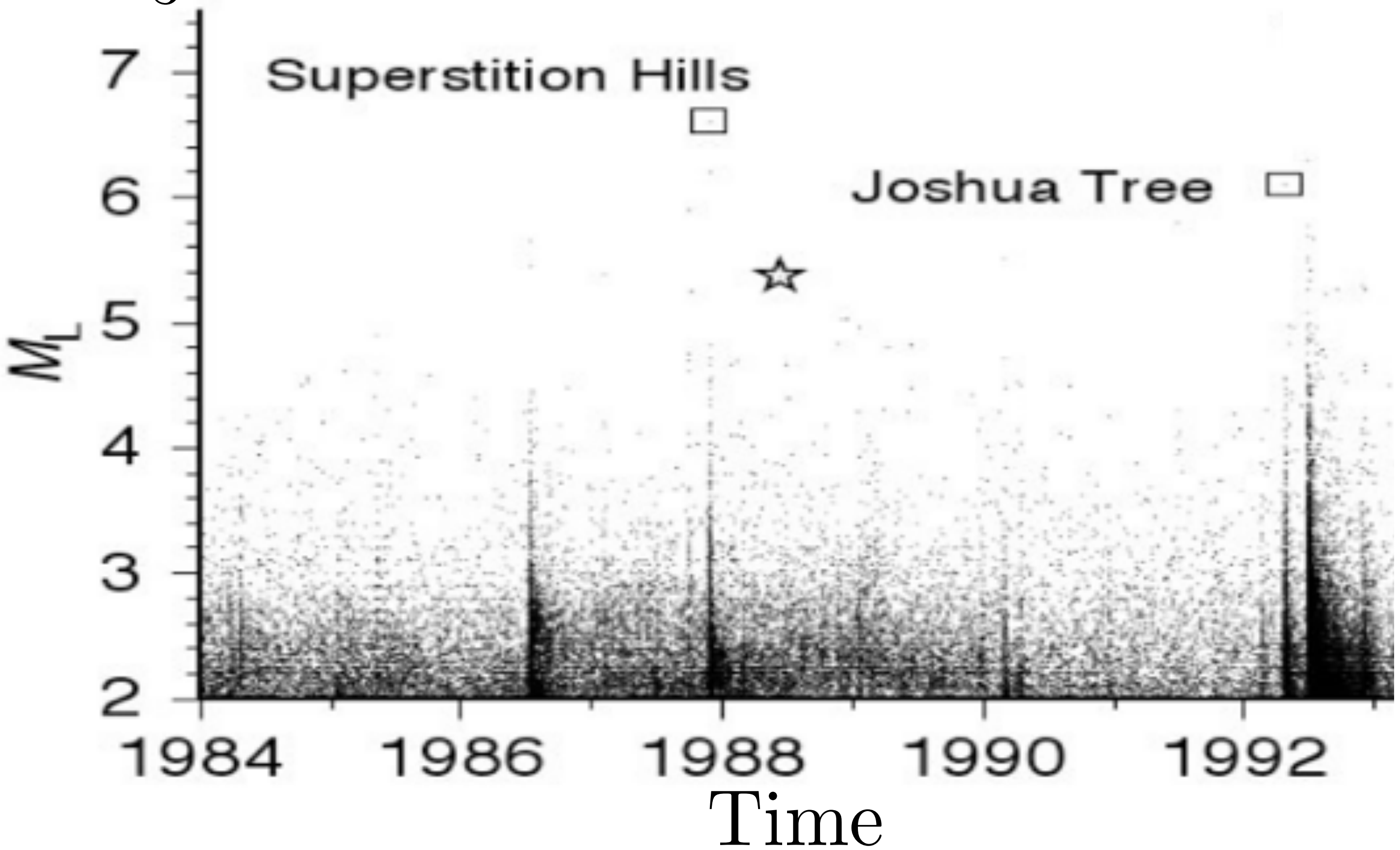
Dahmen, Vandembroucq, Kirsten, Maloney...

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

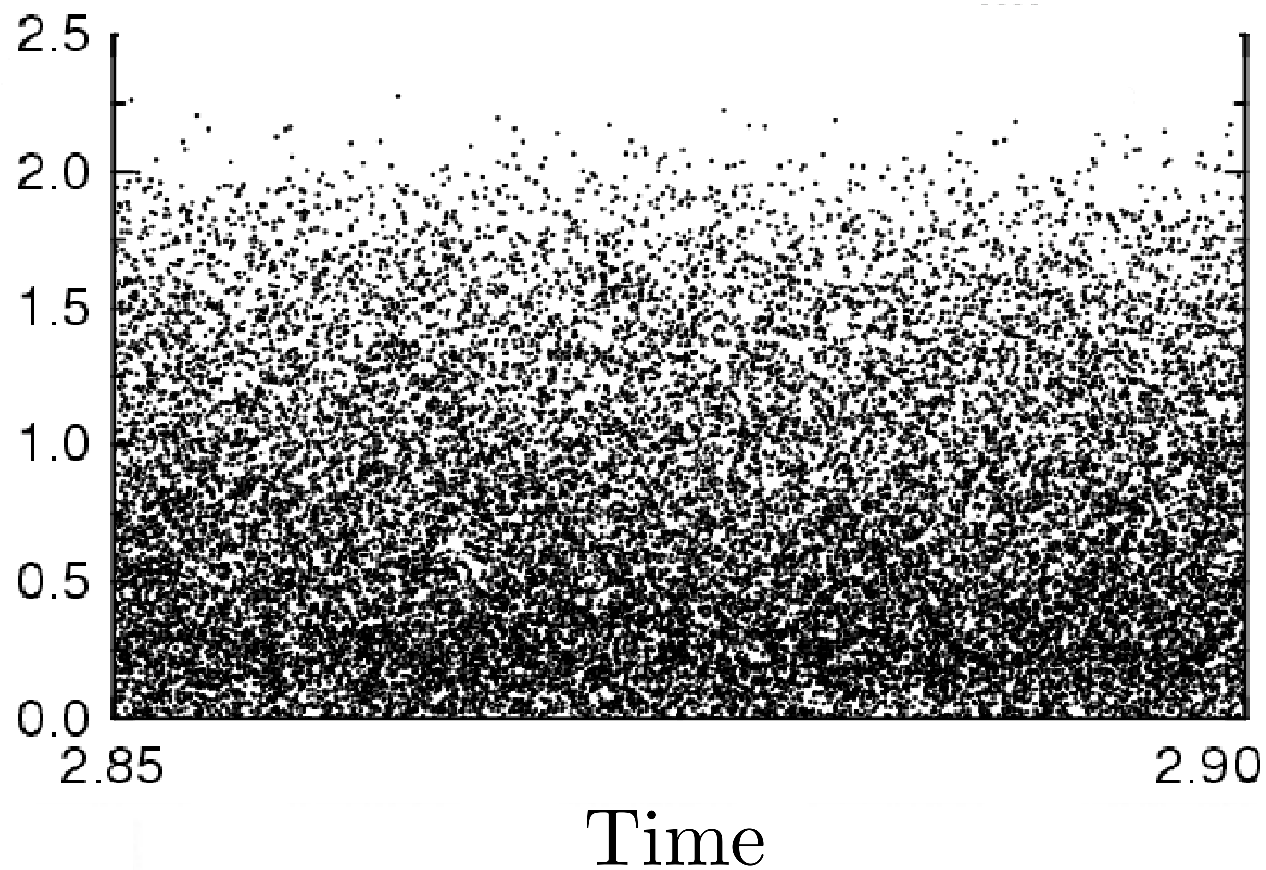
The memory of avalanches

Earthquakes have memory

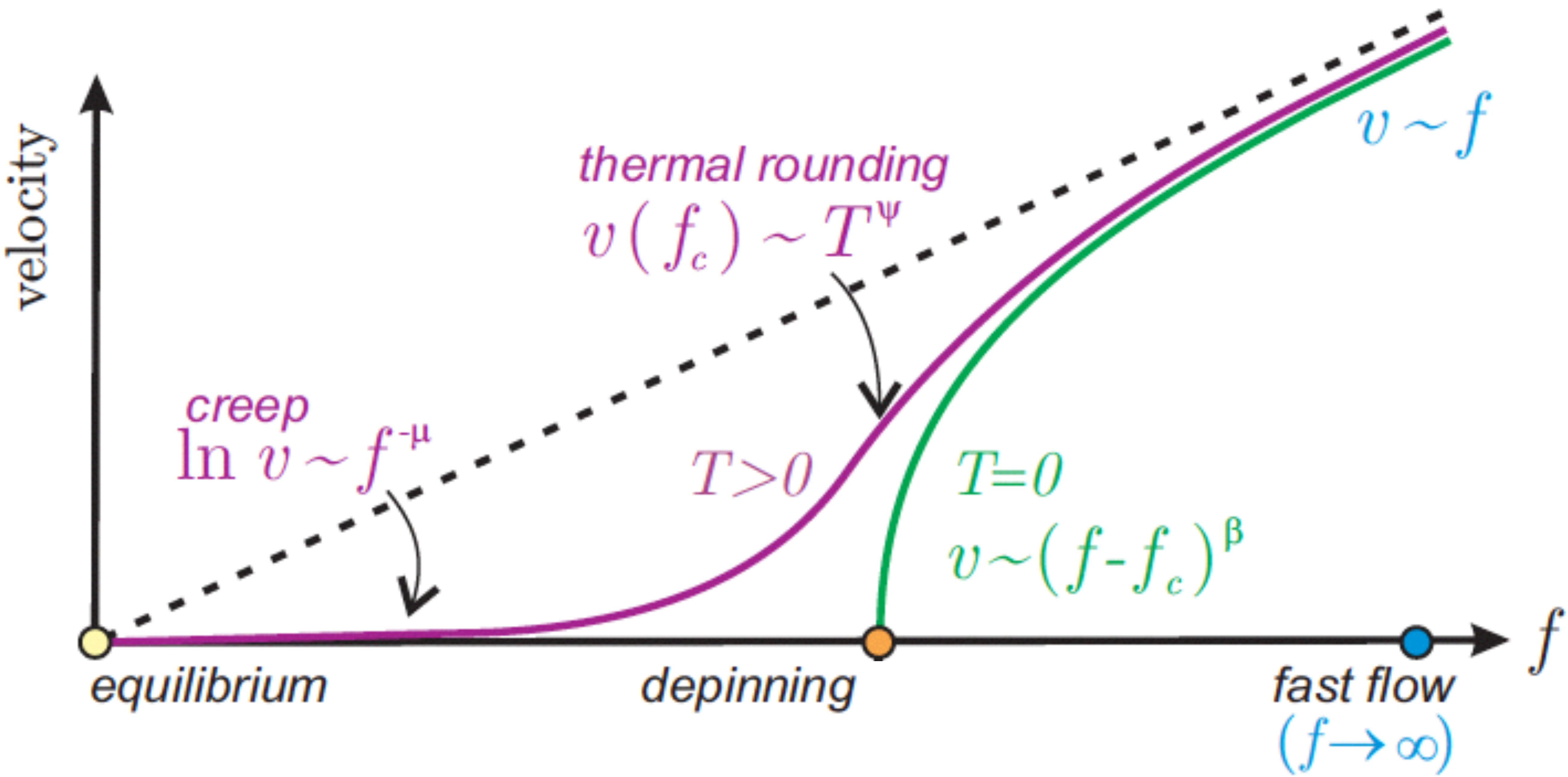
$$M = \frac{2}{3}\log S$$



Depinning



Finite temperature: creep and thermal rounding



Creep: $f \ll f_c$ and $T \to 0^+$

Vinokur & Ioffe 87, Marchetti & Chen 95, Kolton 05, Agoristas & al 16

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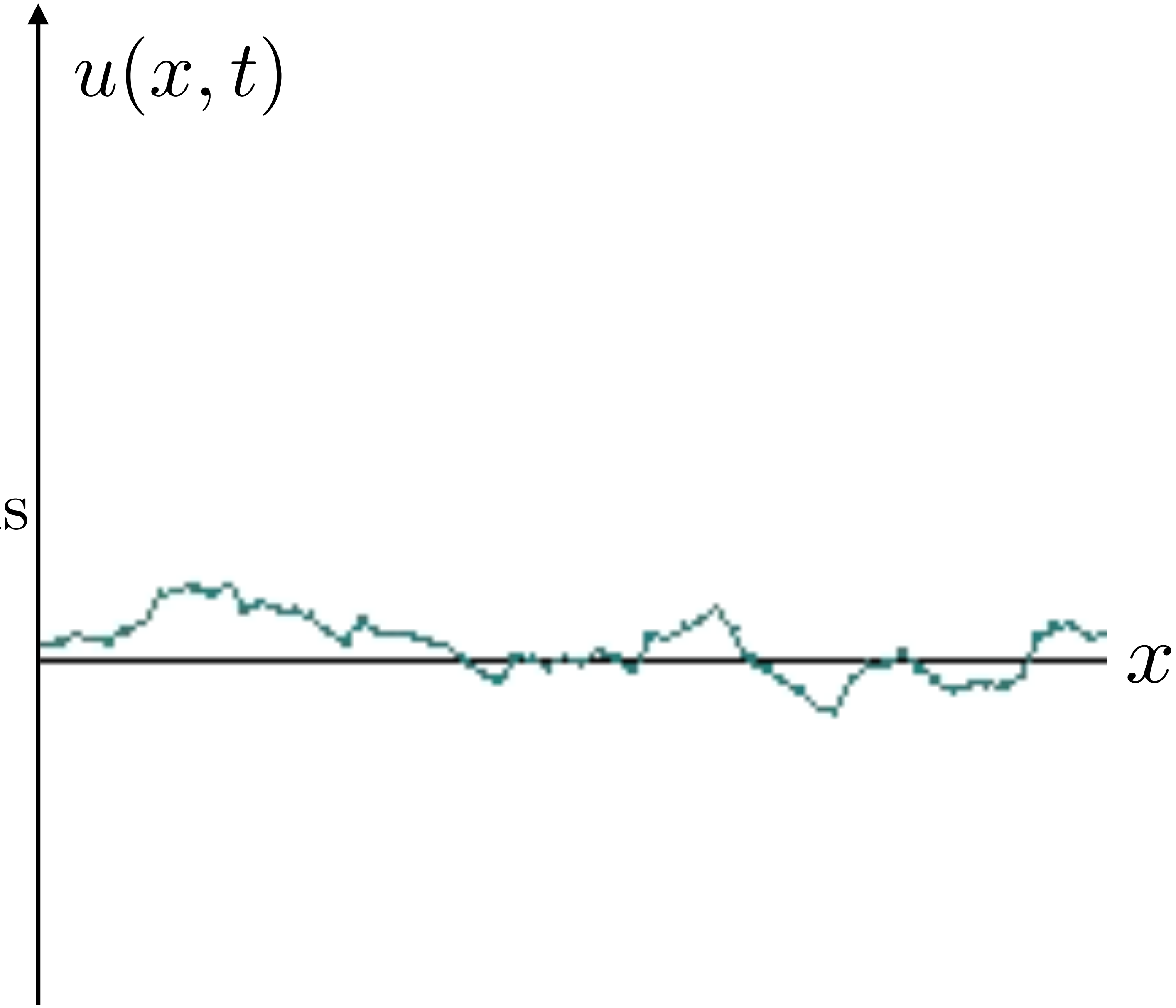

- small scales: thermal fluctuations
- large scales: forward motion

Emergence of collective dynamics?

by Alejandro Kolton (Bariloche)

Creep: $f \ll f_c$ and $T \to 0^+$

- small scales: thermal fluctuations
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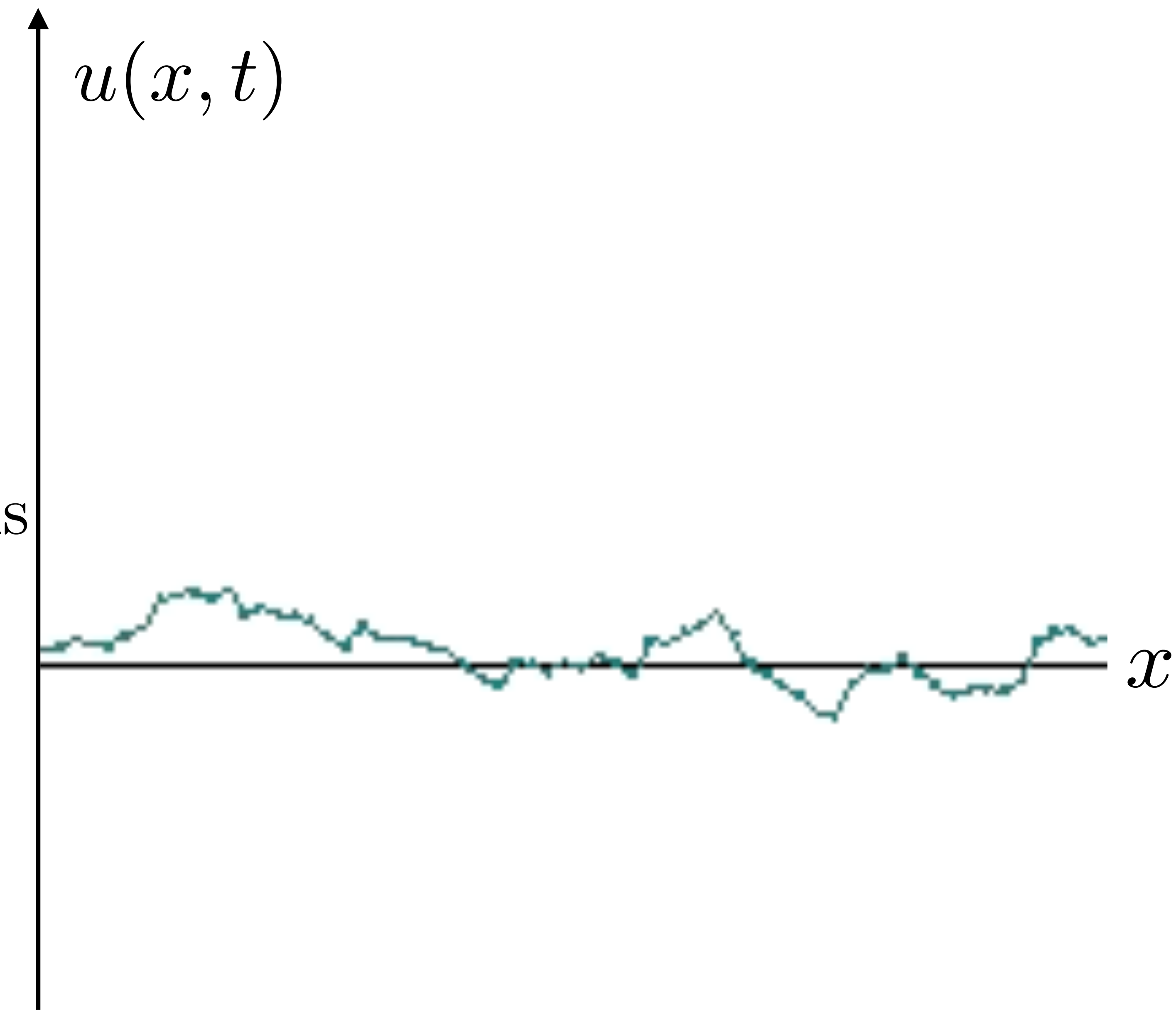

Emergence of collective dynamics?

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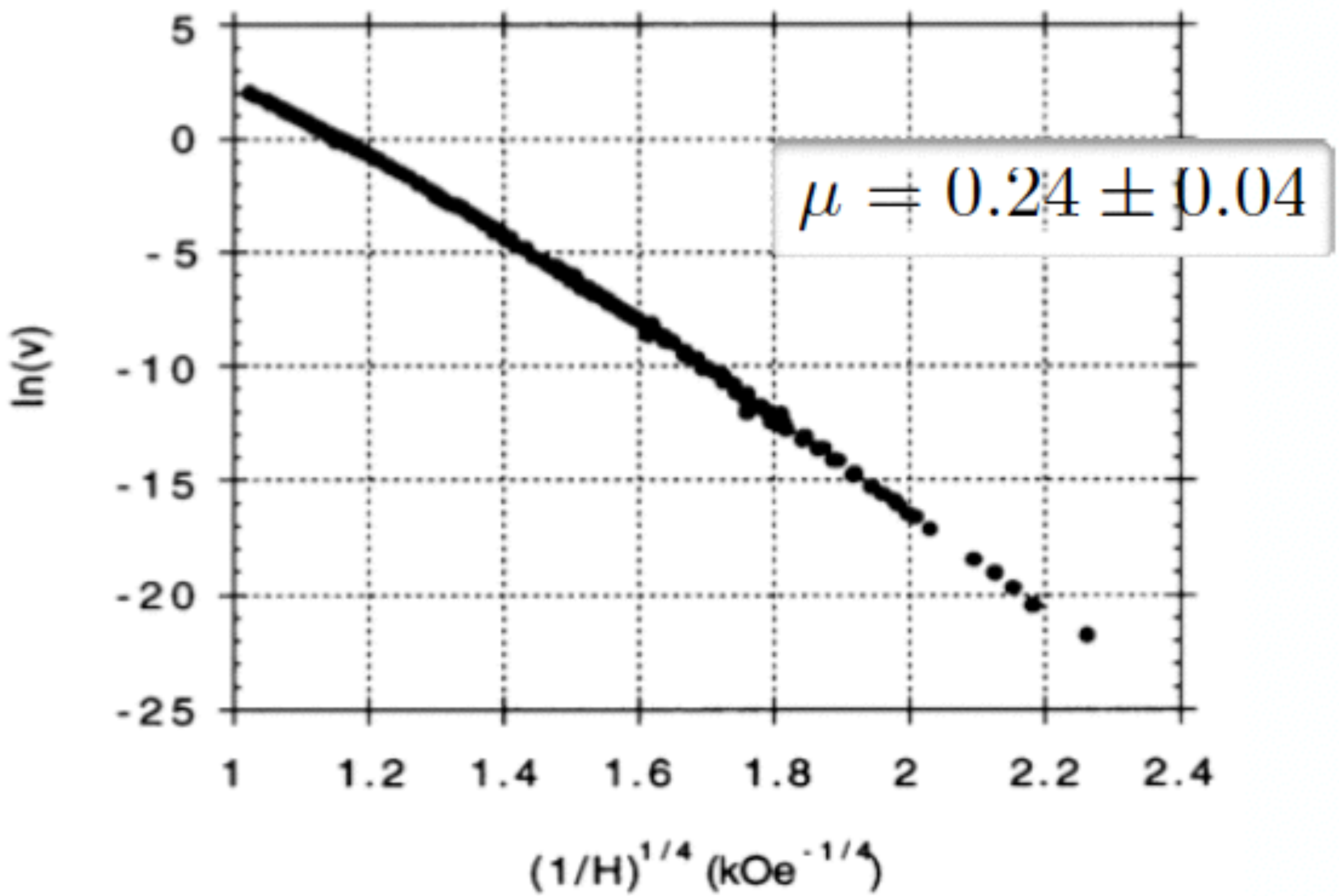
Creep law

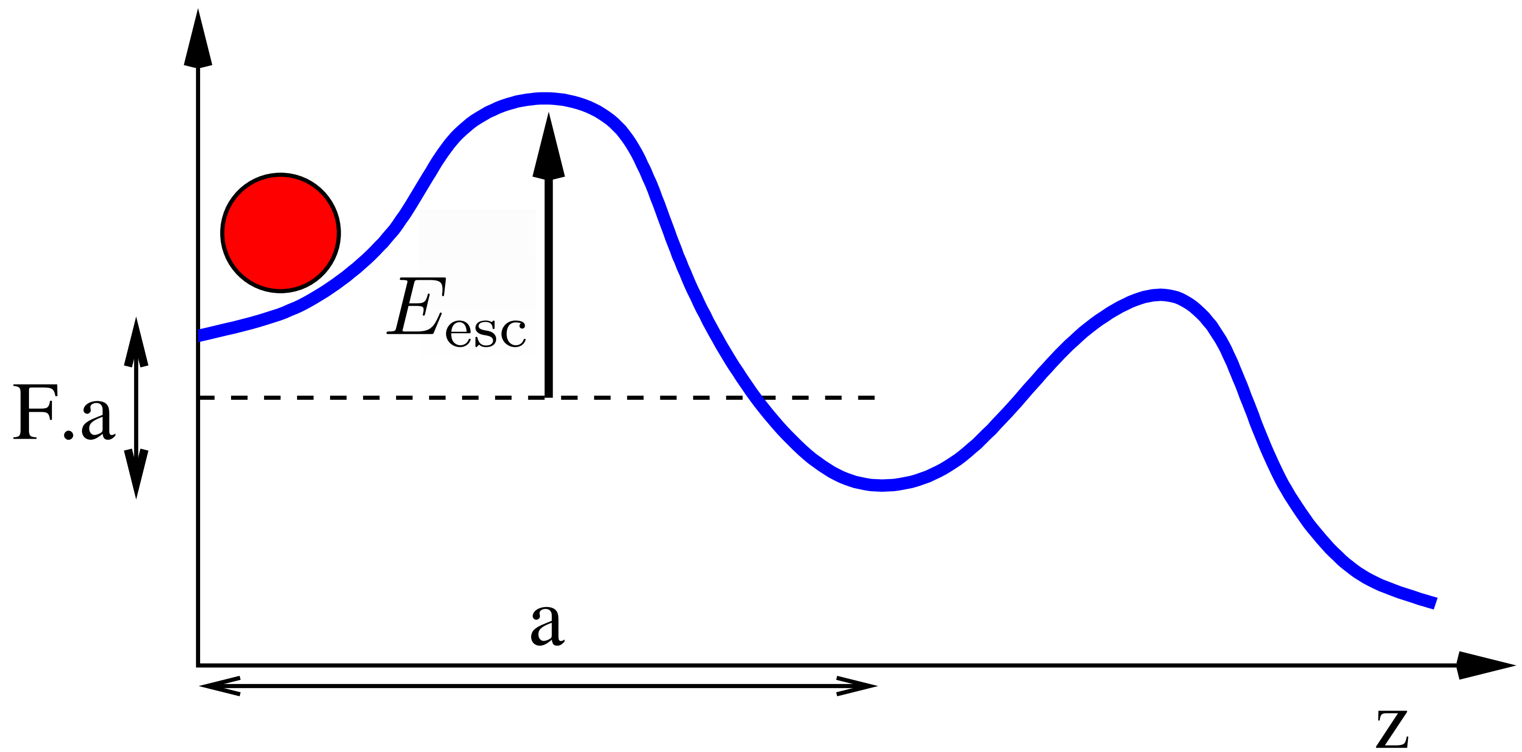
Velocity $\ln v \sim f^{-\mu}$ $\mu(d=1) = \frac{1}{4}$



$\mu = 0.24 \pm 0.04$

Lemerle et al. PRL (1998)

Emergence of collective dynamics?

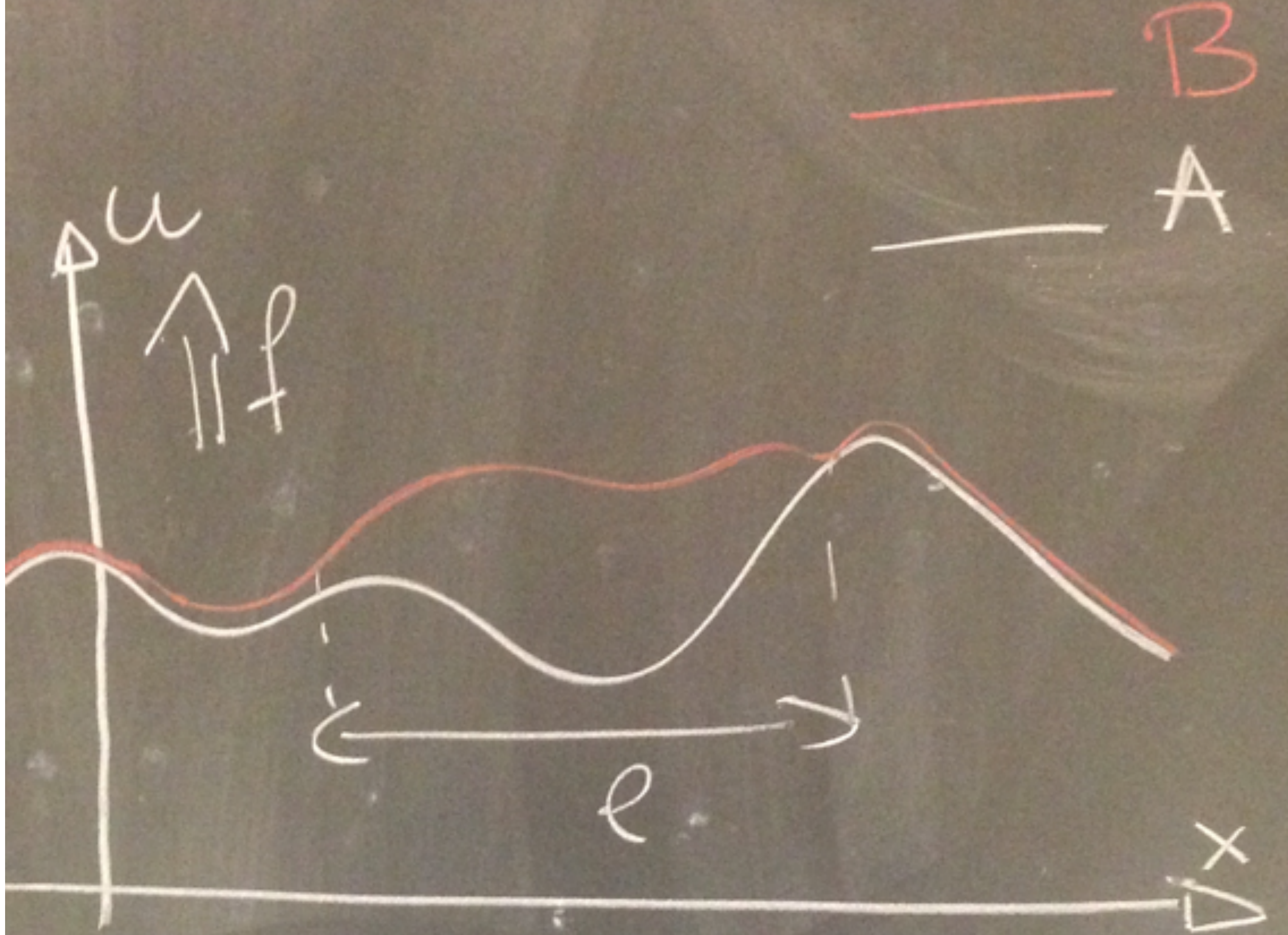


$$v(f) \propto e^{-(E_{\rm esc} - fa/2)/T} - e^{-(E_{\rm esc} + fa/2)/T}$$

$$v(f) \propto e^{-E_{\rm esc}/T} \cdot f$$

Linear response if $E_{\rm esc} \sim$ const.

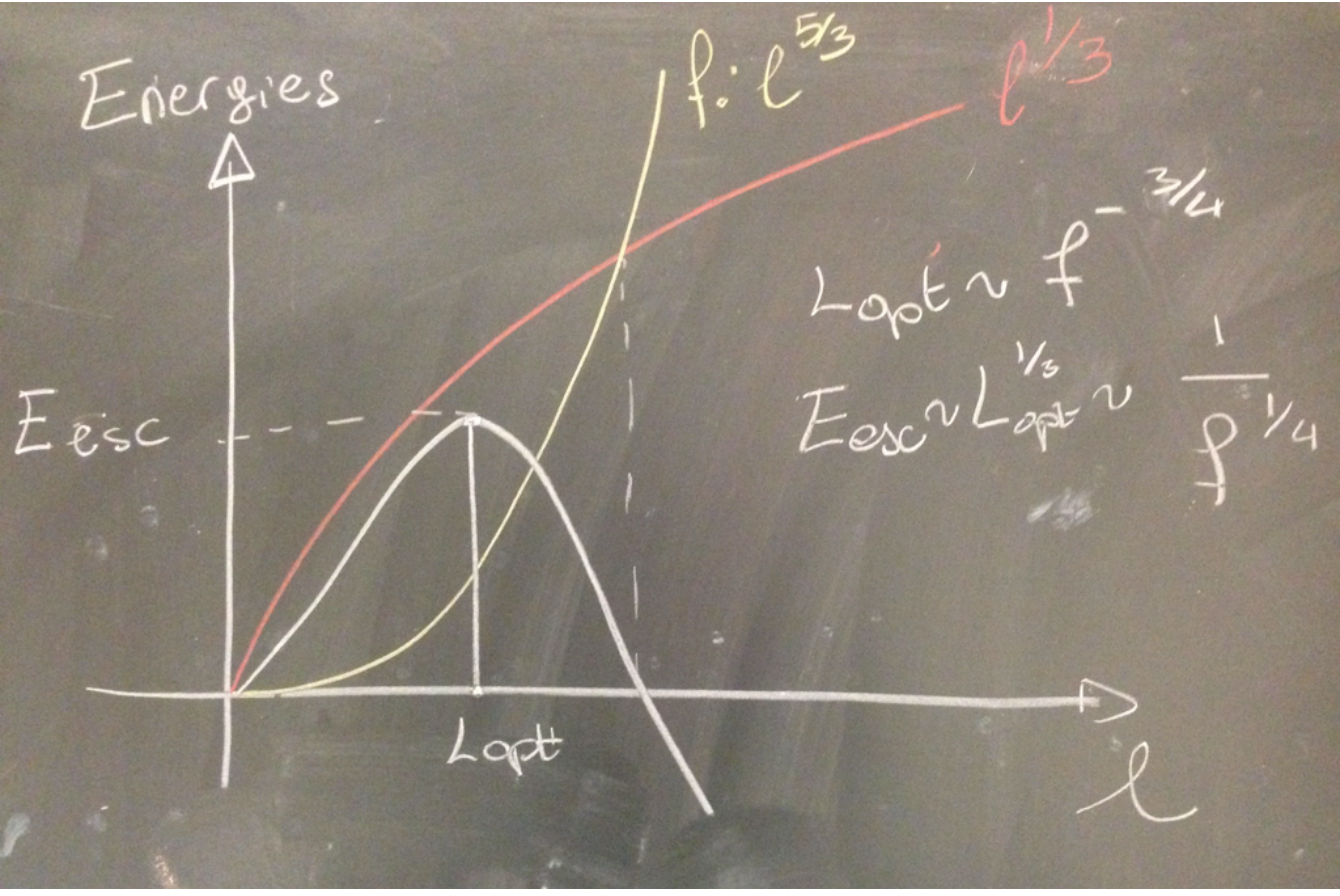
Creep response if $E_{\rm esc}(f) \sim f^{-\mu}$



$A \to B$

$$E_{Barrier}(\ell) \propto \ell^{1/3}$$

$$E_f(\ell) = - f\,\ell^{5/3}$$

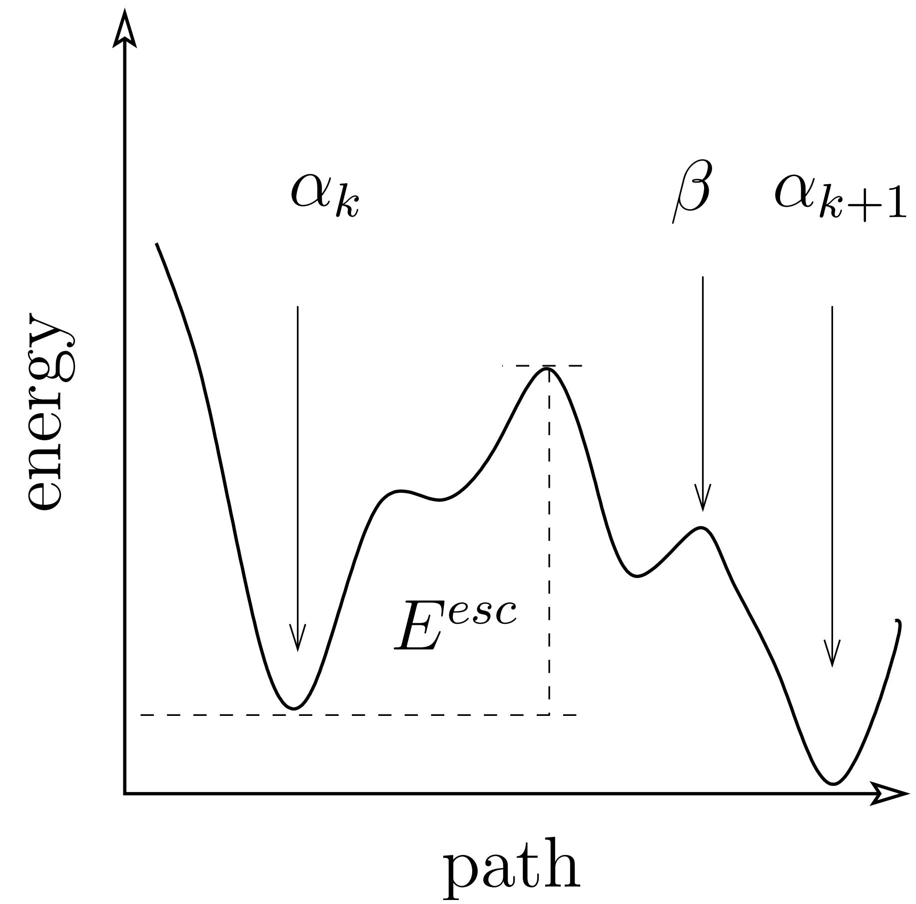


Vinokur & Ioffe 87, Agoristas & al 16

Algorithm to unveil creep

Molecular dynamics
huge problems of futility

Coarse grained dynamics
sequence of metastable states
$\alpha_1 \to \alpha_2 \to \ldots \to \alpha_t$



Decreasing energy:

$$E(\alpha_1) > E(\alpha_2) > \ldots$$

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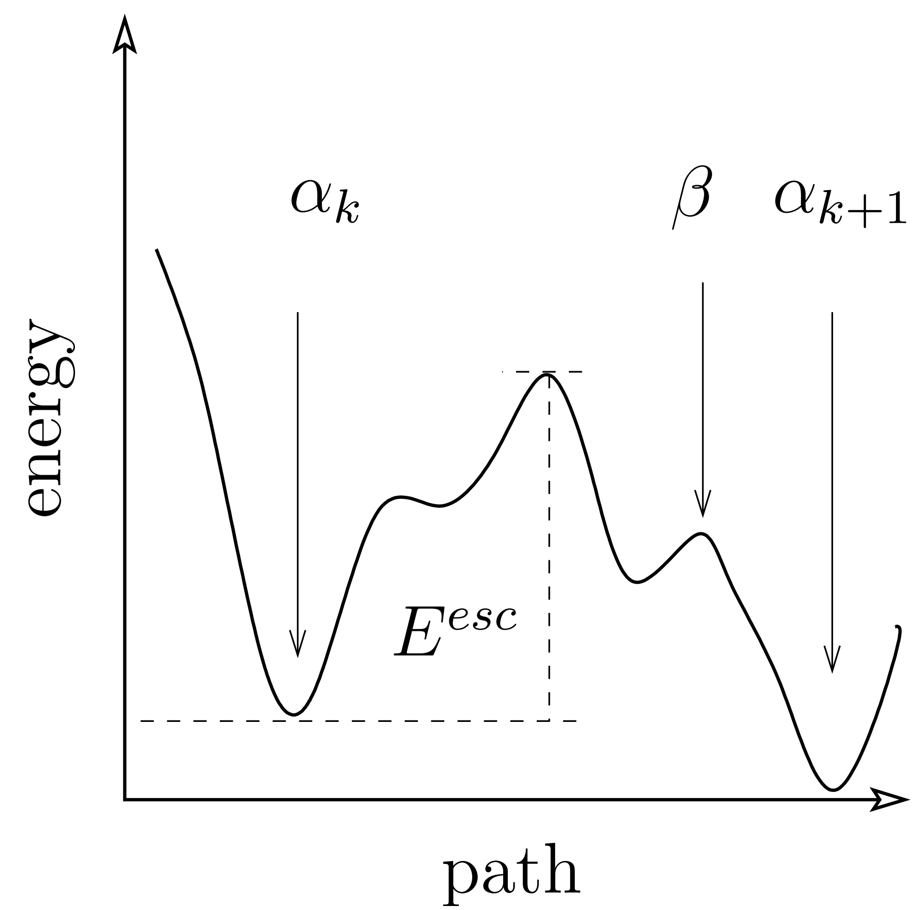

Decreasing energy:

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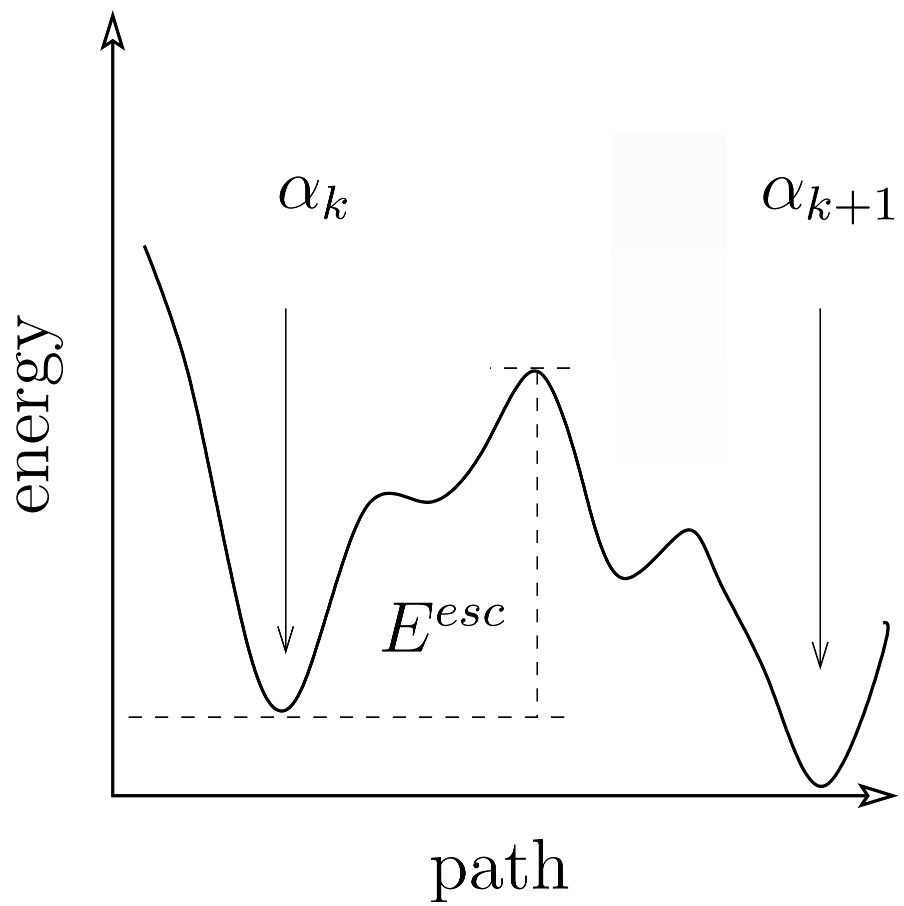
Criterium for the next metastable state

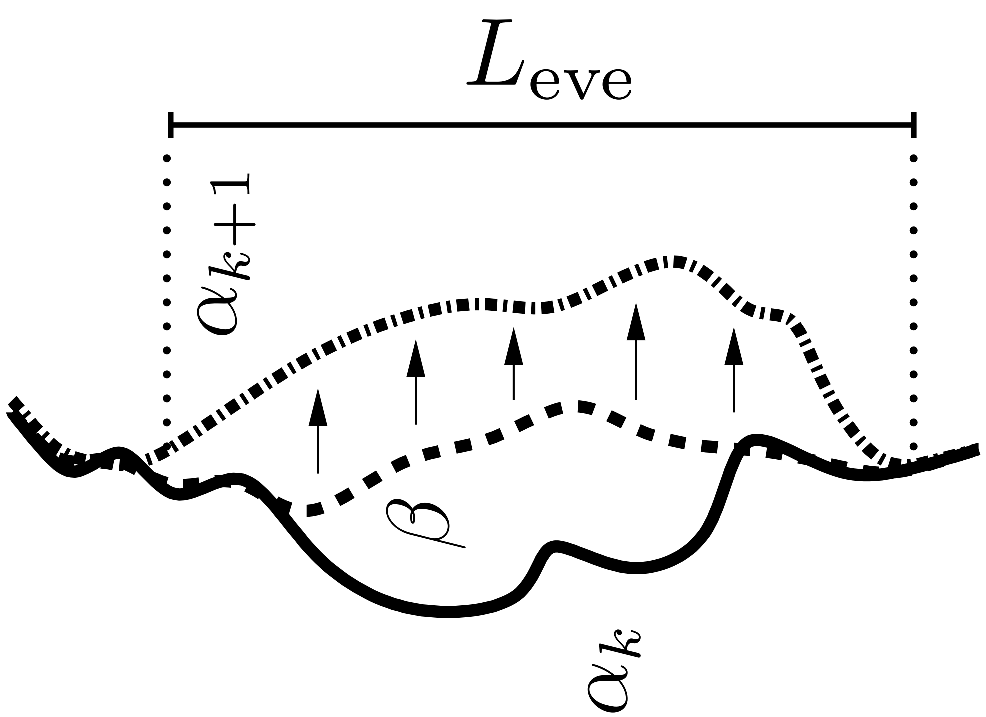


Minimal Barrier E_{esc}

Exponential cost in L_{opt}

Performance: $f \approx 0.5 f_c$

$L \approx 64$



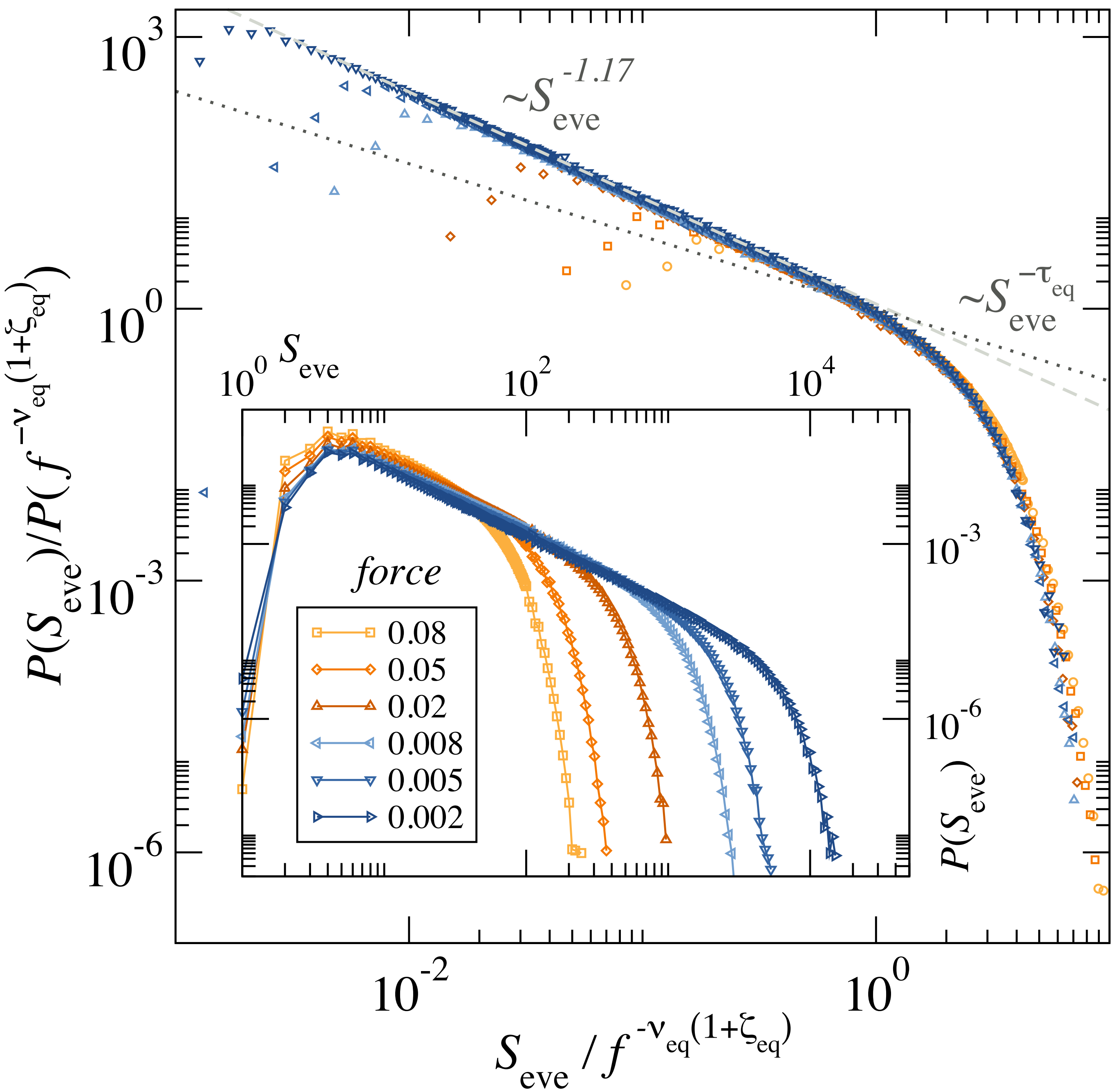
Minimal rearrangement

Polynomial cost (Dijkstra algorithm)

Performance: f up to $0.002 f_c$

$L \approx 4000$

Creep : events statistics

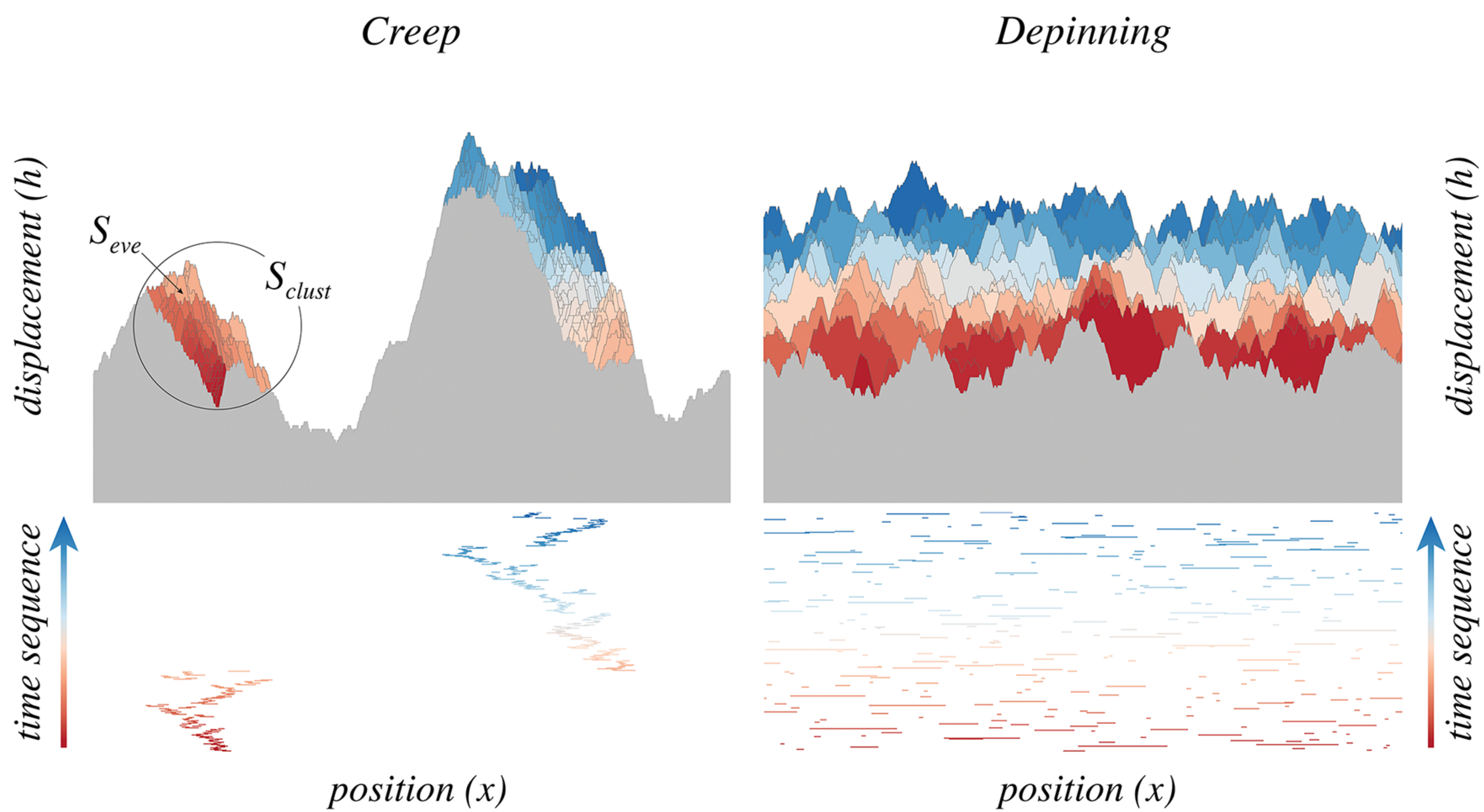


- Scale free when $f \to 0$
- Collapse of $S_{\max} \sim L_{\mathrm{opt}}^{1+\zeta_{\mathrm{eq}}}$
- Anomalous $\tau > \tau_{\mathrm{eq}}$

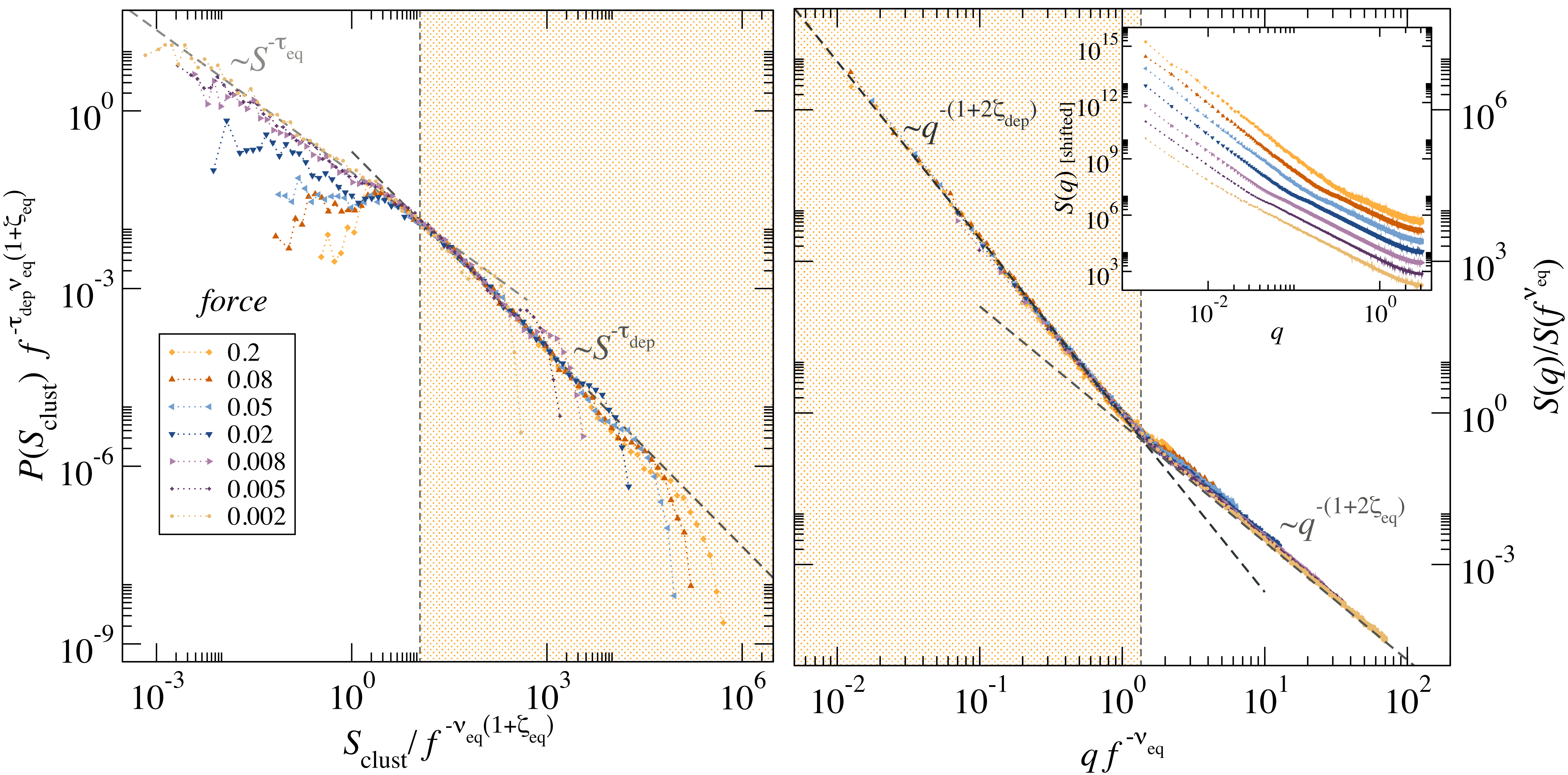
$$\tau_{\mathrm{eq}} = 2 - \frac{2}{d + \zeta_{\mathrm{eq}}}$$

- creep law is saved
- Gutenberg Richter anomaly *(by F. Landes, E. Jagla)*

Creep (events and clusters) versus depinning avalanches

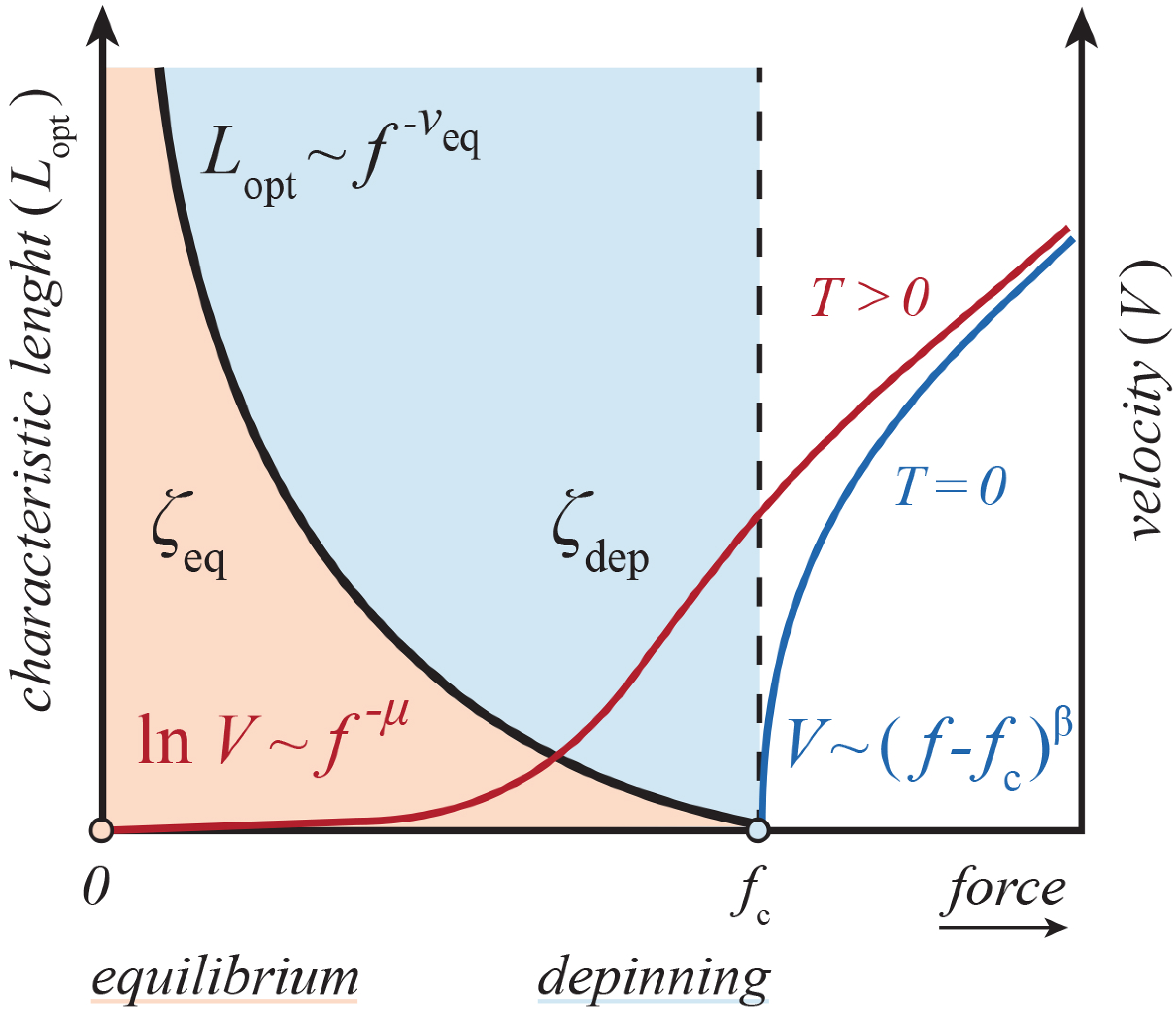


clusters independent and depinning like!



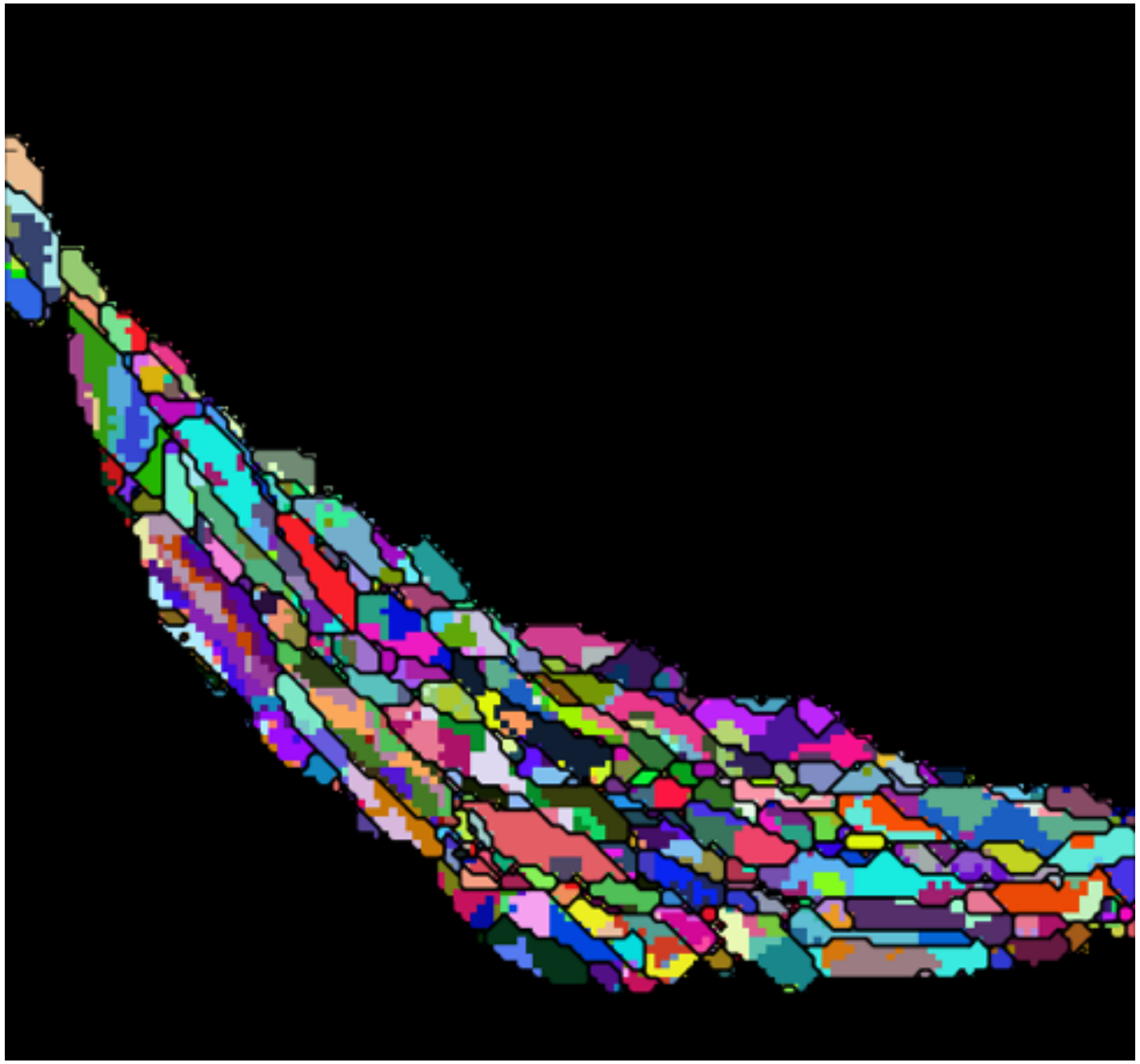
System size cut off: below fc every thing is critical
large scale roughness is depinning like

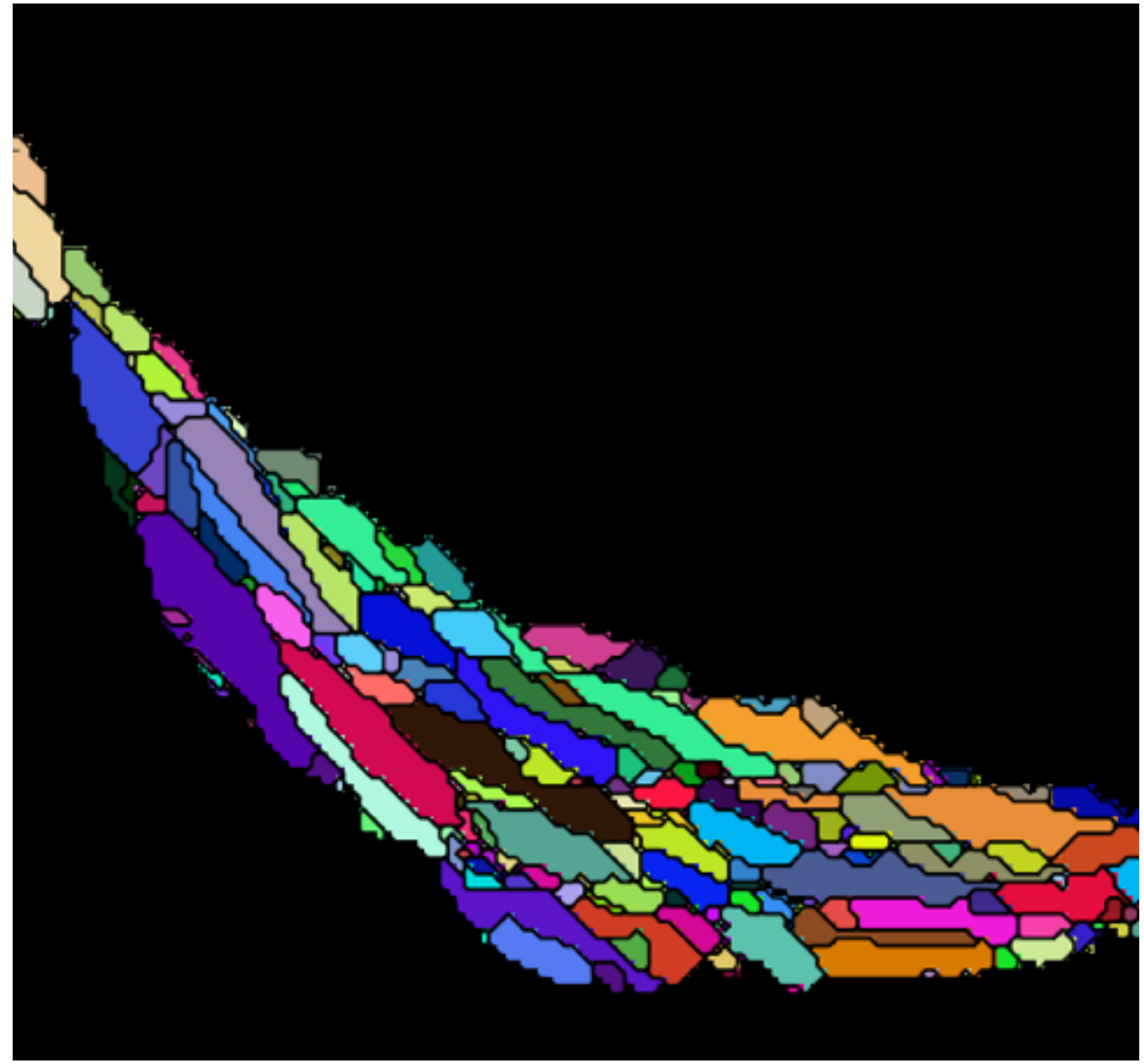
Proposed phase diagram



agreement with FRG calculations Chauve et al 2000

Ongoing experiments





$f = 0.02 f_c$ Room temperature

Gianfranco Durin's group (Turin, Italy)

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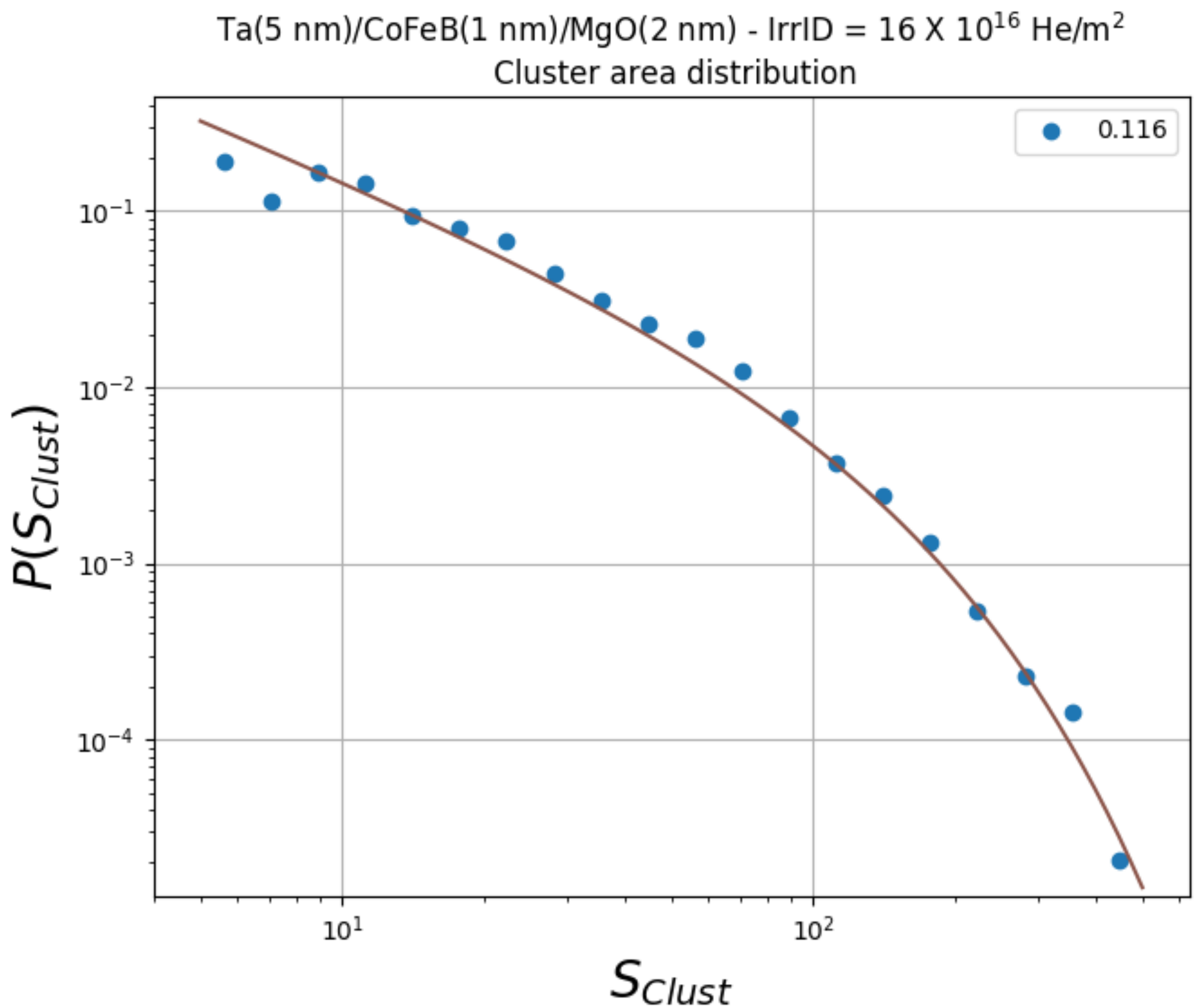

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Conclusion and perspectives

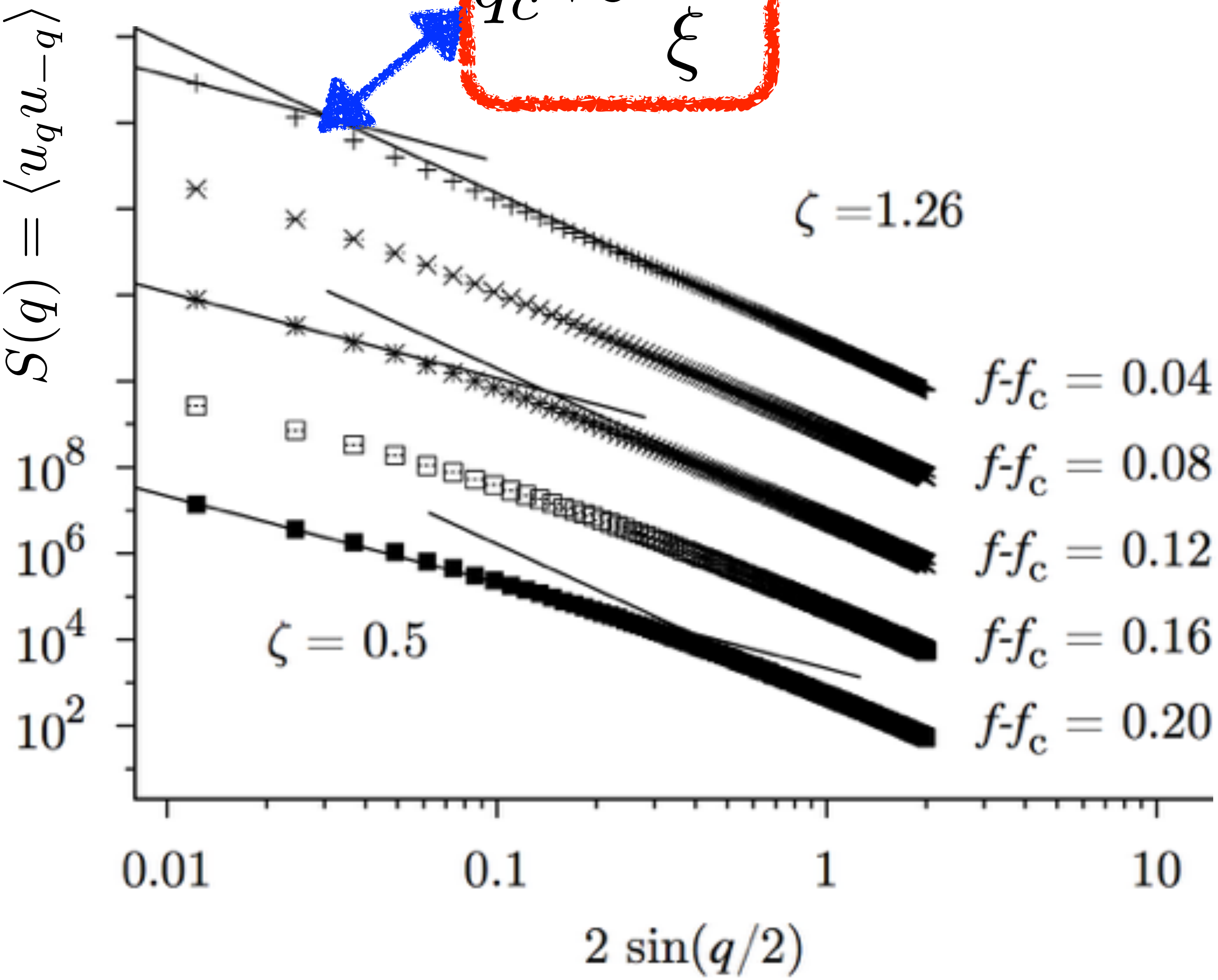
- We introduce an efficient algorithm to study creep dynamics
- Events statistics is similar to earthquakes where main shocks trigger a cascade of aftershocks
- Cluster behaves like depinning avalanches right at the critical point
- We believe that our scenario is very general (long range elasticity, d>1…)
- We hope can be observed experimentally

[redacted]

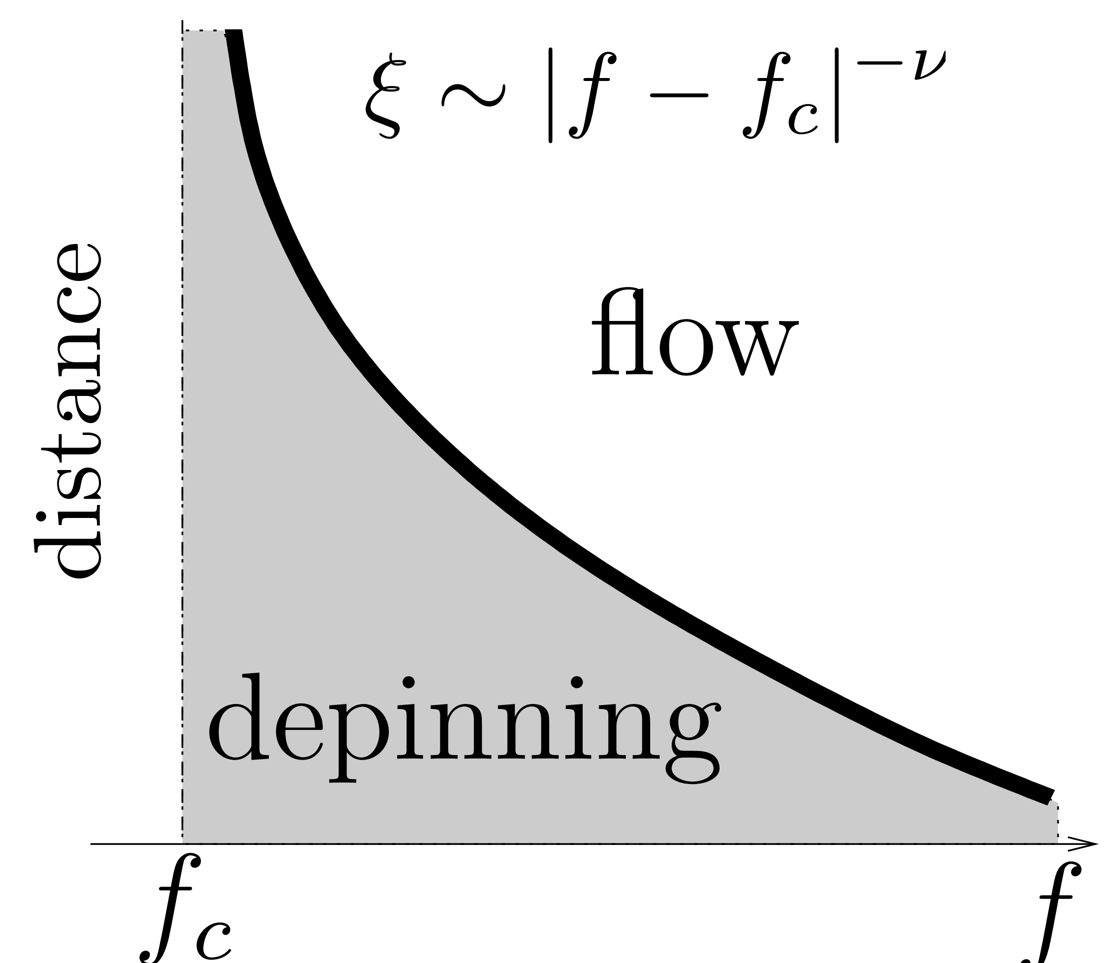
[redacted]

Correlation length: geometry above threshold

$$\boxed{q_c \approx \frac{1}{\xi}}$$

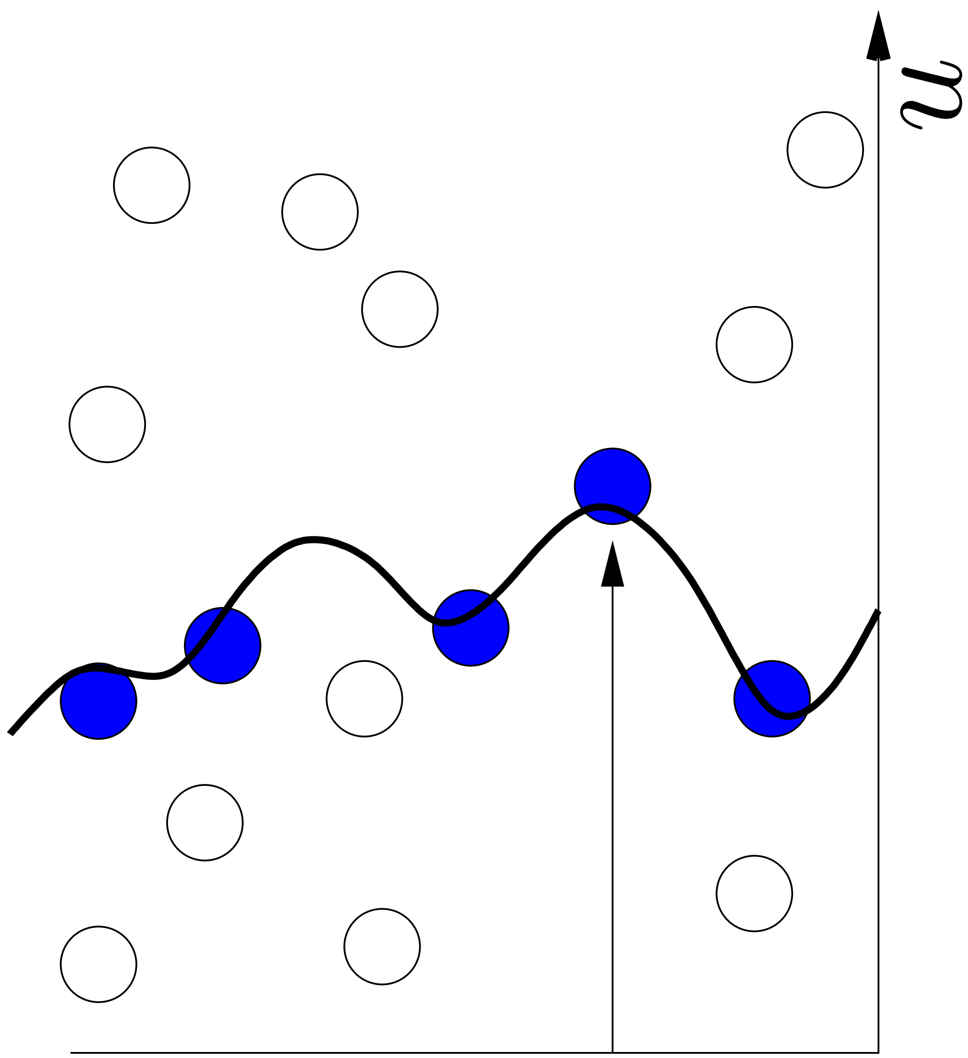


$$S(q) \sim \frac{1}{q^{1+\zeta}}$$

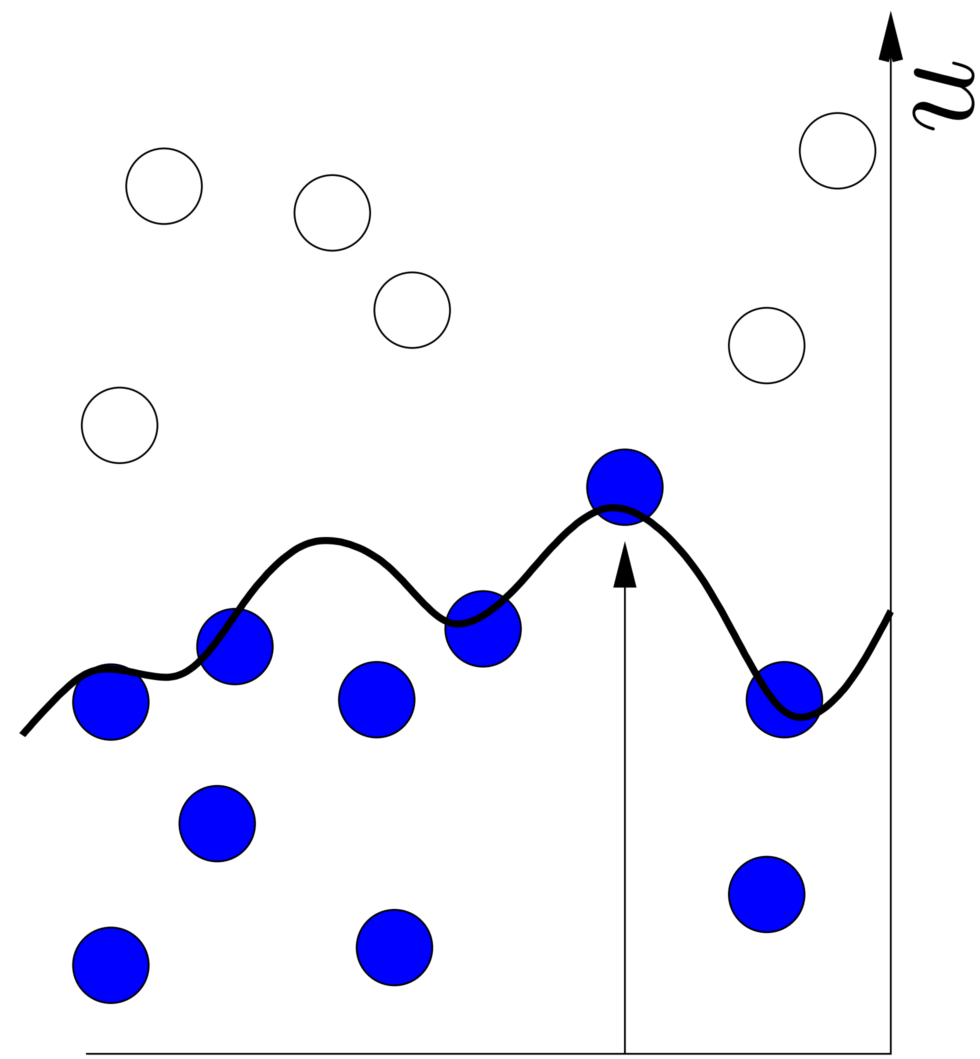


Simulation:
Duemmer and Krauth 2005

RF versus RB disorder



random bond:
disorder energy is withe noise



random field:
disorder energy is Brownian

same depinning universality class
different equilibrium universality class

Confirmation of phase diagram for RF disorder