

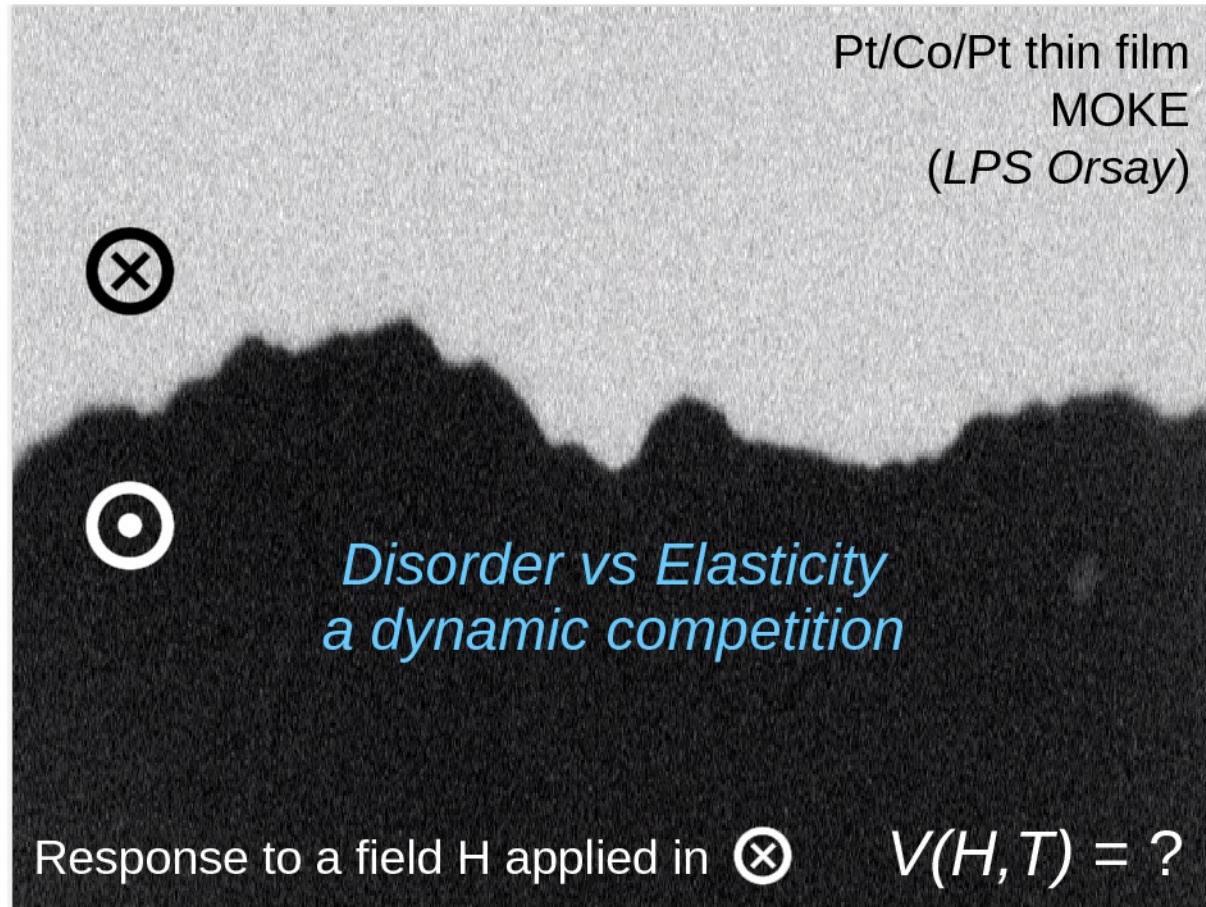
Spatio-temporal patterns in ultra-slow domain wall creep dynamics

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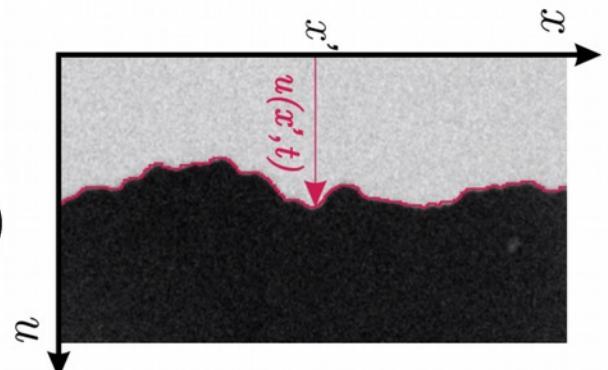
STATPHYS26, Lyon, July 21st 2016

Motivation magnetic domain wall motion



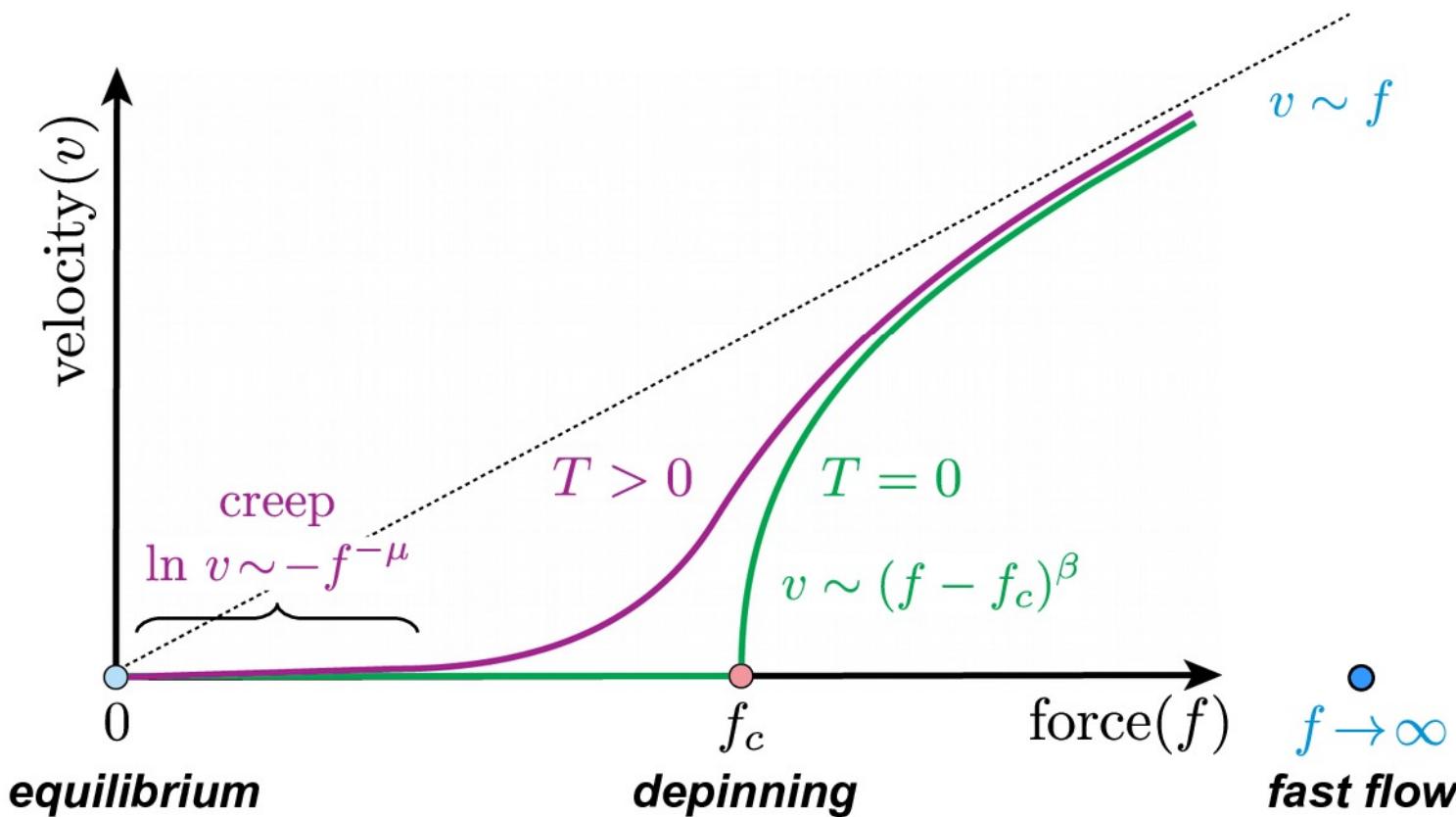
The Quenched-Edwards-Wilkinson elastic line:

$$\gamma \partial_t u(x, t) = c \partial_x^2 u(x, t) + f_{\text{dis}}(u, x) + f + \eta_T(x, t)$$



Phenomenology

velocity-force characteristics - three reference states



At the reference points interface is **rough and self-affine** $w \sim \ell^\zeta$

$$\zeta_{\text{eq}} = 2/3 \quad \zeta_{\text{dep}} = 1.25 \quad \zeta_{\text{ff}} = 1/2$$

Divergent length and **avalanches** at depinning:

$$\ell \sim (f - f_c)^{-\nu}, \quad \nu = \frac{1}{2-\zeta} \quad P(S) \sim S^{-\tau}, \quad \tau = 2 - \frac{2}{d+\zeta}$$

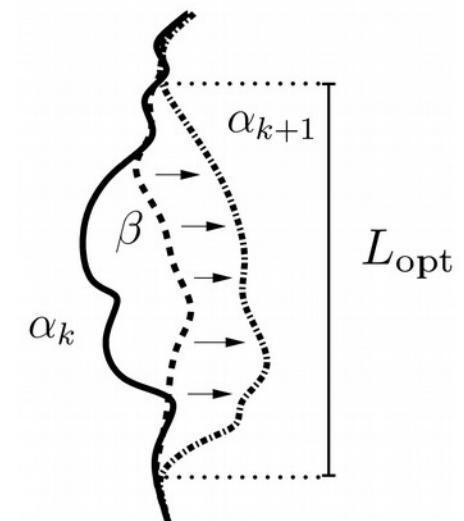
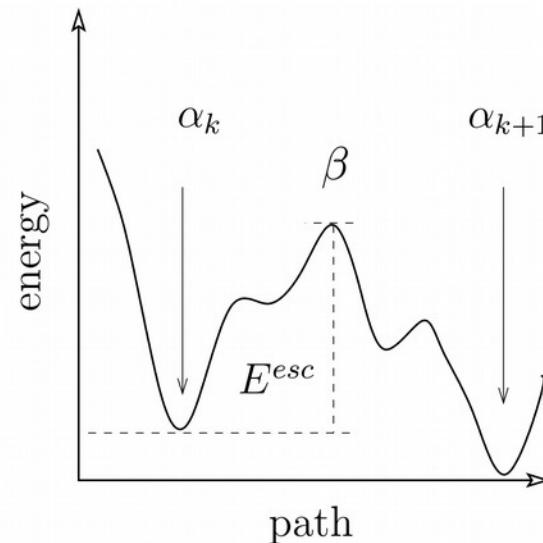
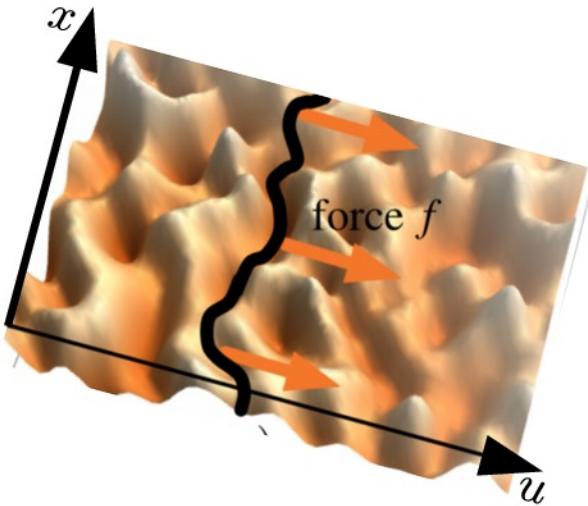
D. Fisher Phys. Reports 1998
M. Kardar Phys. Reports 1998

Creep motion

$$f \ll f_c, T \ll 1$$

→ Ultra-slow dynamics ruled by activation

→ Velocity dominated by collective forward motion



Scaling arguments [Ioffe-Vinokur 1987, Feigel'man 1989, Nattermann 1990]

Required rearrangement for barrier jump

$$L_{\text{opt}} \sim f^{-\nu_{\text{eq}}}, \quad \nu_{\text{eq}} = \frac{1}{2-\zeta_{\text{eq}}}$$

Assumptions

- Static (as-equilibrium) description of the interface at $f > 0$ *. $\theta_{\text{eq}}, \zeta_{\text{eq}}, \nu_{\text{eq}}$
- Forward motion delivered by independent jumps over “typical” barriers.....

Divergent barriers as $f \rightarrow 0$

$$E^{\text{esc}}(L_{\text{opt}}) \sim L_{\text{opt}}^{\theta_{\text{eq}}} \sim f^{-\mu}, \quad \mu = \theta_{\text{eq}} \nu_{\text{eq}}$$

Creep law

Arrhenius argument for the activation time

$$t_{\alpha_\kappa \rightarrow \alpha_\kappa + 1} \approx e^{E^{\text{esc}}/T}$$

Creep formula

$$v \sim \exp \left[-\frac{U_0}{k_B T} \left(\frac{f_0}{f} \right)^\mu \right]$$

Creep exponent

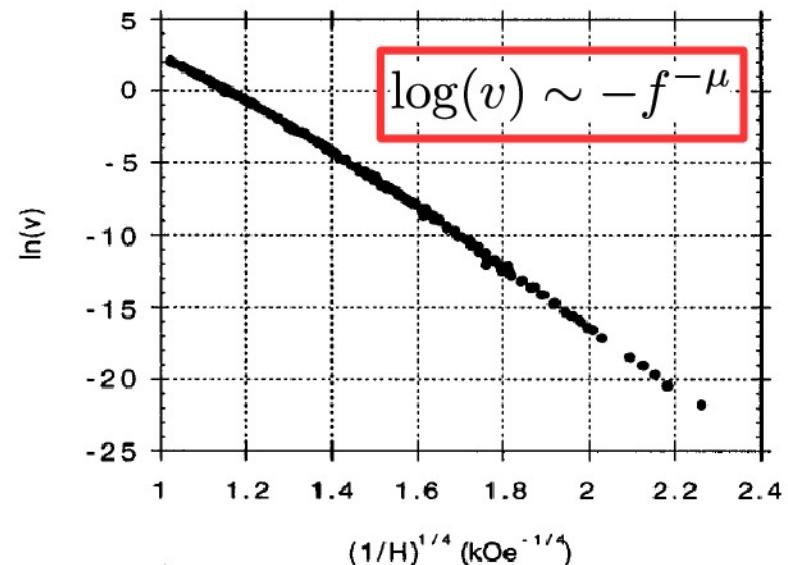
$$\mu = \theta_{\text{eq}} \nu_{\text{eq}} = \frac{d - 2 + 2\zeta_{\text{eq}}}{2 - \zeta_{\text{eq}}}$$

$$d = 1, \quad \zeta_{\text{eq}}^{\text{RB}} = 2/3$$

$$\mu = 1/4$$

[Huse-Henley (1985)]

Experimental success!



[Lemerle et al. PRL 1998]

and elsewhere...

[K.-J. Kim et al Nature 2009]

[J. Gorchon et al. PRL 2014]

[V. Jeudy et al. PRL 2016]

- Are there “typical” creep events?
- What is the actual role of $L_{\text{opt}} \simeq f^{-\nu_{\text{eq}}}$ in the dynamics?
- Do we see avalanche dynamics and universality when $f \rightarrow 0$?

Modeling

- Traditional “MD” approaches fail at very low forces

Transition pathways algorithm for T=0⁺

Exact algorithm: sequence of metastable states connected by minimal barriers E^{esc} [Kolton et al. PRL 2006, PRB 2009]

$$\alpha_1 \rightarrow \alpha_2 \rightarrow \dots \rightarrow \alpha_t$$

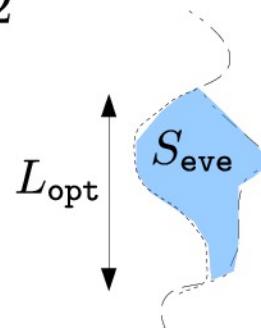
$$E(\alpha_1) \geq E(\alpha_2) \geq \dots \geq E(\alpha_t)$$

- Exponential cost in $L_{\text{opt}}(f)$
- Limited to $L = 32, f \approx 0.2$

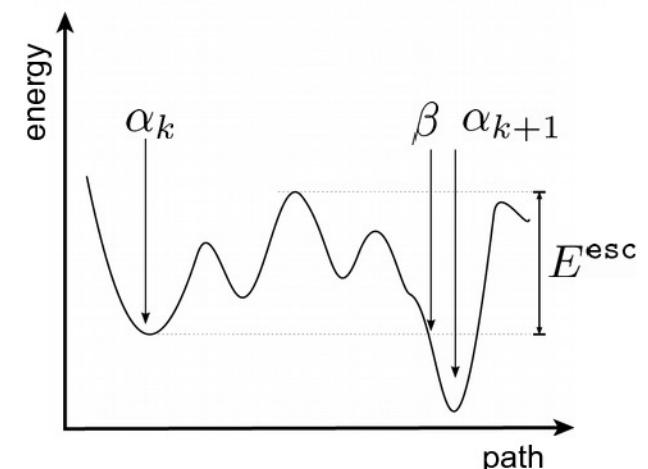
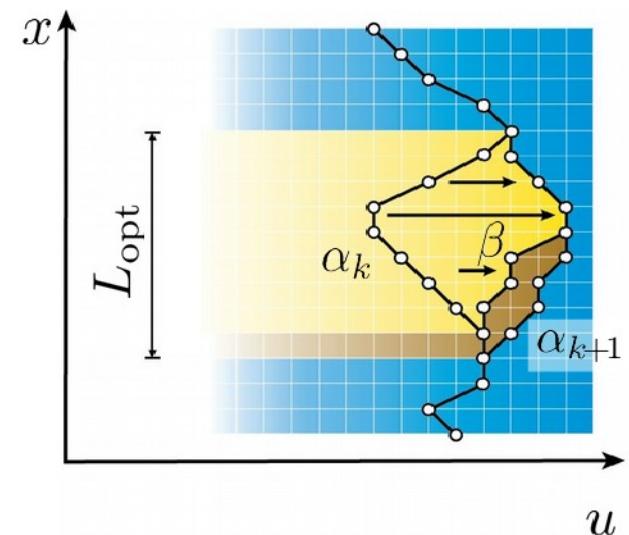
Our approximation: assume $E^{\text{esc}} \sim L_{\text{opt}}^\theta$ and find instead the **smallest favorable move** in length.

- Polynomial cost in $L_{\text{opt}}(f)$ + parallel implementation
- We can reach $L = 3360, f \approx 0.002$

We collect S_{eve} for several events

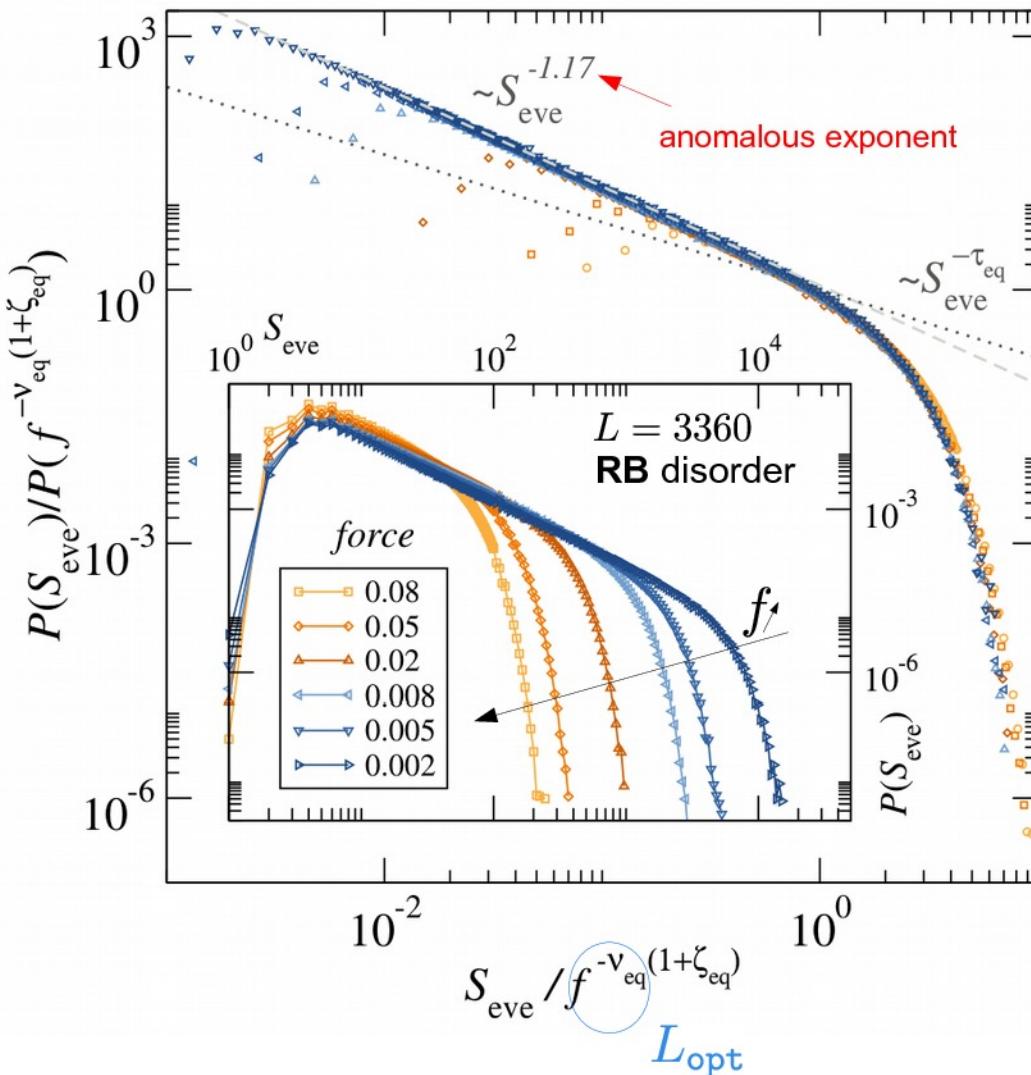


Discrete polymer of size L in a grid
Two-steps algorithm



Results

Creep events size distribution



- Power-law distributed when $f \rightarrow 0$
Event sizes are not distributed around a “typical” value
- Collapse with $S_c^{\text{eve}} \sim (L_{\text{opt}}(f))^{1+\zeta_{\text{eq}}}$
Creep law is safe! :^)
- Anomalous $\tau > \tau_{\text{eq}}$

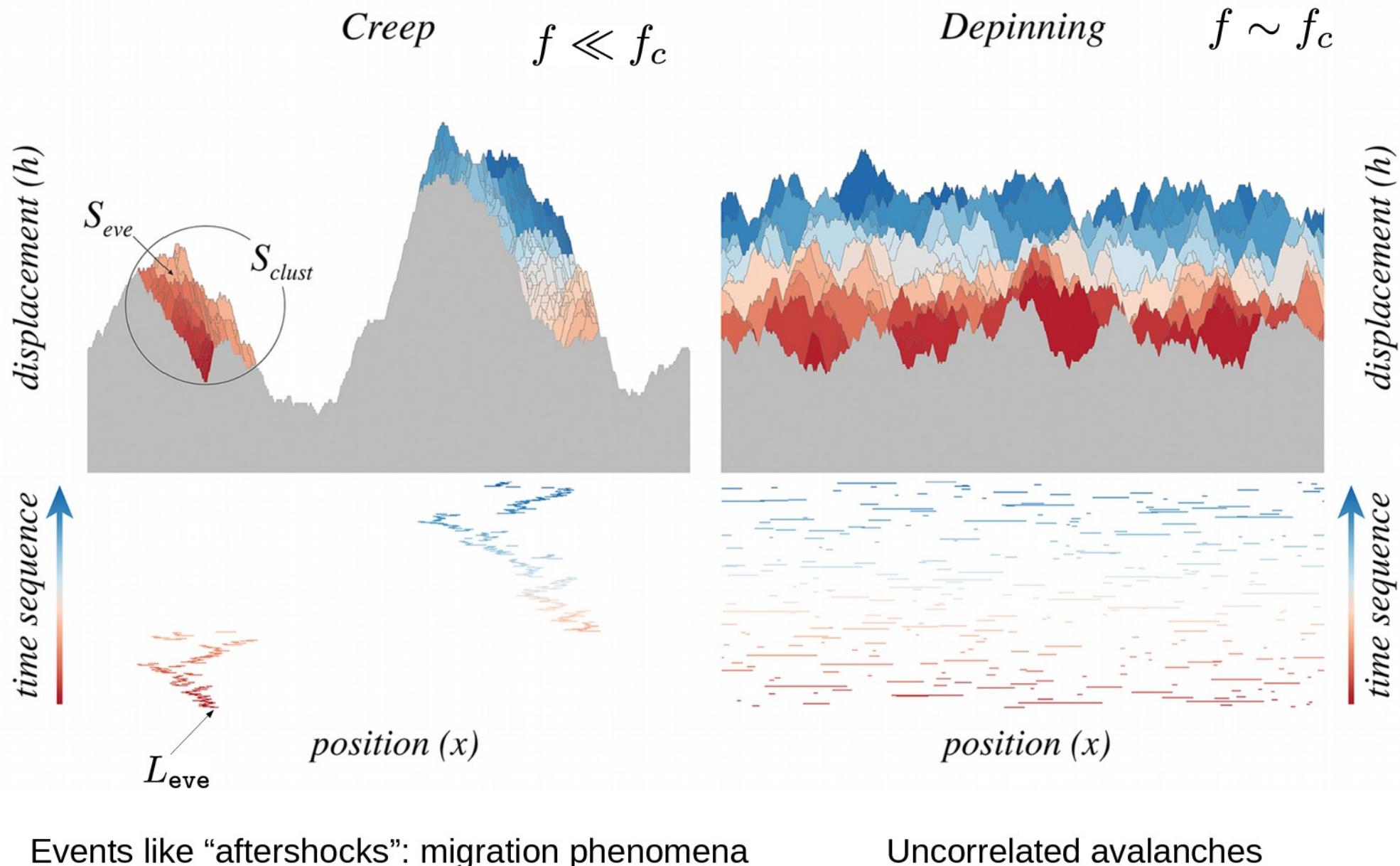
$$\tau_{\text{eq}} = 2 - \frac{2}{d + \zeta_{\text{eq}}} = 4/5 \quad (\text{for } d=1)$$

Reason? events are not independent!

Similar to Gutenberg-Richter exponent anomaly in earthquakes models*

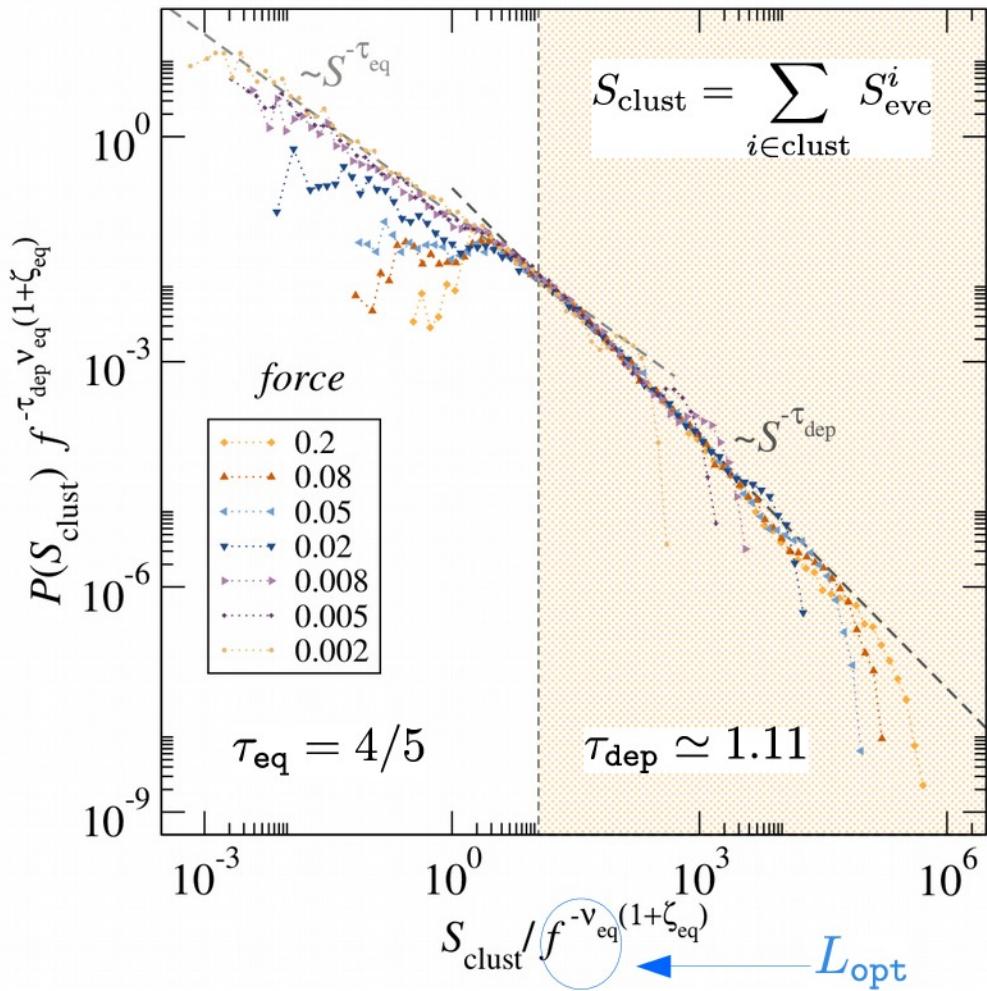
Results

Event patterns and activity maps



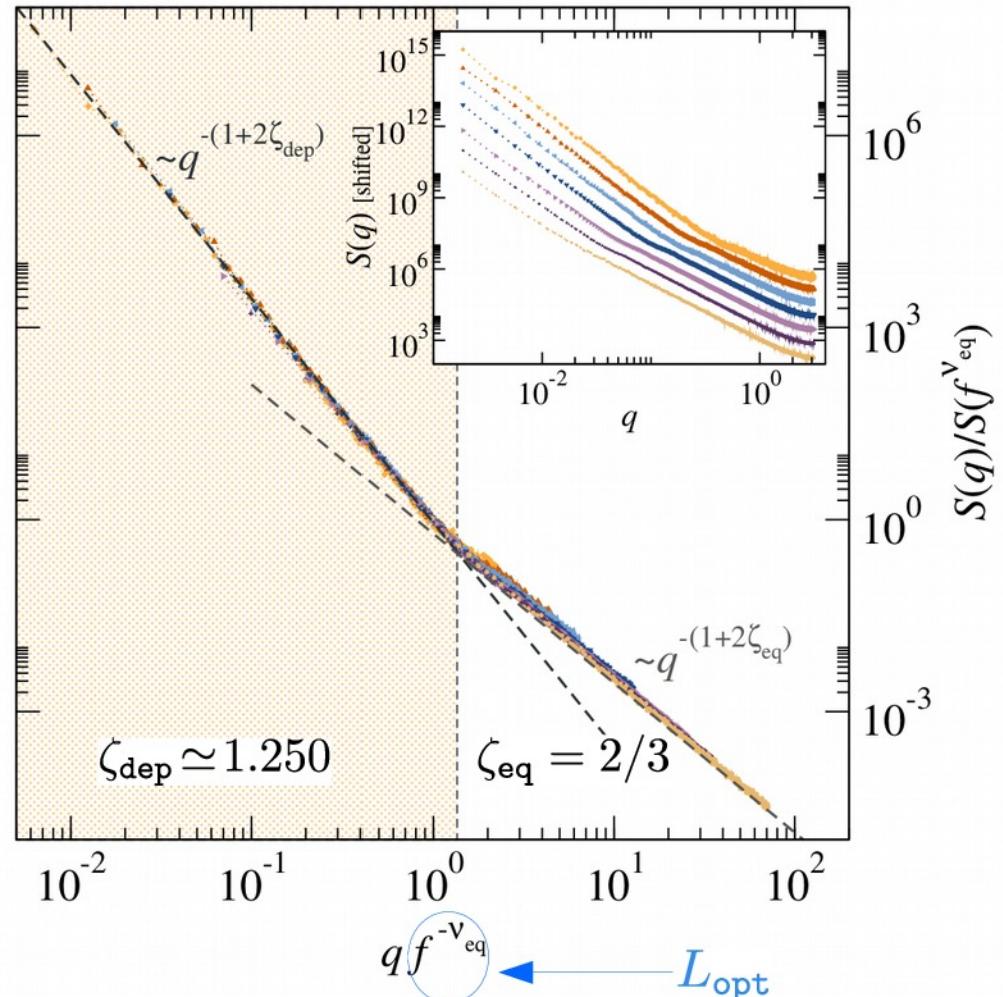
Results

Clusters size distribution



Small size → **equilibrium-distribution**
 Large size → **depinning-distribution**
 → **Upper cutoff controlled by system size.**

Structure factor $S(q) = \langle u_q u_{-q} \rangle$



NF conjecture holds

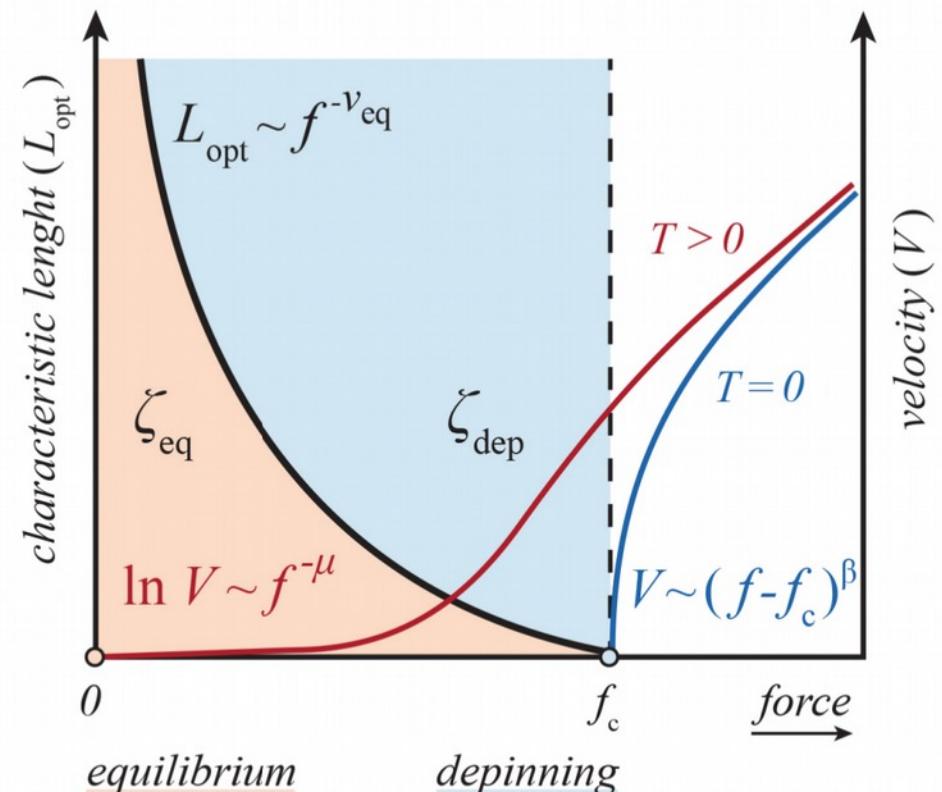
$$\tau = 2 - \frac{2}{d + \zeta}$$

ζ_{eq} **at short length-scales**
 ζ_{dep} **at large length-scales**

Conclusions

- Distribution of creep events is power-law with cutoff characterized by $L_{\text{opt}} \sim f^{-\nu_{\text{eq}}}$
- Creep events are correlated in space and time sequence.
- Large clusters of events behave like depinning avalanches at the far away critical point.
- We believe that our scenario is able of being measured and is general ($d > 1$, long-range elasticity,....).

Phase diagram*



My institution:



Spatio-temporal patterns in ultra slow domain wall creep dynamics
E.E.Ferrero, L. Foini, T. Giamarchi, A.B. Kolton, A. Rosso
arXiv:1604.03726

Thanks !

www.ezequielferrero.com

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Computing resources:

Froggy hybrid cluster

CIMENT - UGA

