Two length scales in finite-temperature creep of an elastic interface

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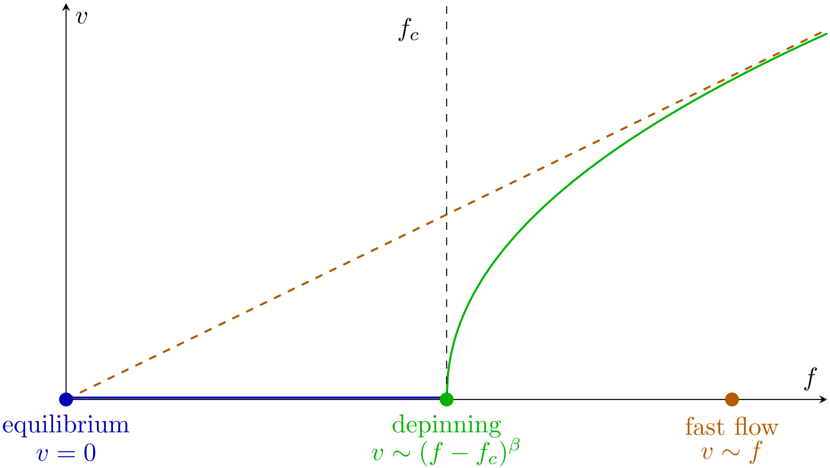
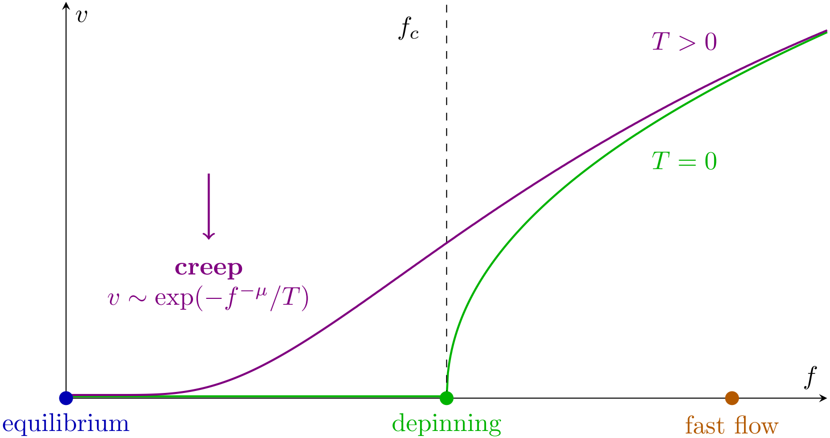
Driven elastic interfaces : from depinning to creep

$$\partial_t u(x,t) = \partial_x^2 u(x,t) - \partial_u V_{\text{dis}}(x,u) + f$$

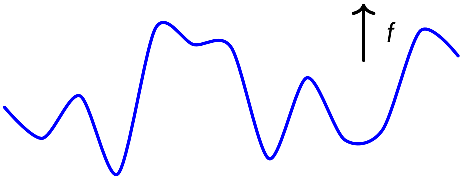


Driven elastic interfaces : from depinning to creep

$$\partial_t u(x,t) = \partial_x^2 u(x,t) - \partial_u V_{\text{dis}}(x,u) + f + \eta(x,t)$$



Creep : activations and avalanches (*Chauve et al., PRB (2000)*)

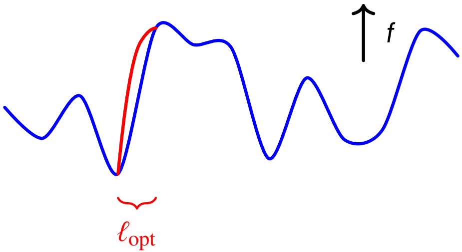


Metastable state

Creep : activations and avalanches (*Chauve et al., PRB (2000)*)

thermal nucleus ℓ_{opt}

$$f \downarrow \quad \Rightarrow \quad \ell_{\text{opt}} \uparrow \quad \Rightarrow \quad U(f) \uparrow \quad \Rightarrow \quad v \downarrow$$



Creep : activations and avalanches (*Chauve et al., PRB (2000)*)

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$\Downarrow$

depinning-like avalanche ℓ_{av}

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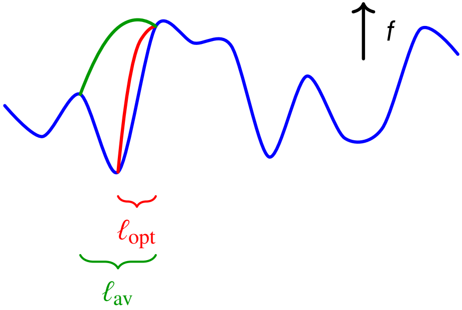
$$\boxed{\ell_{\mathrm{av}} \gg \ell_{\mathrm{opt}}}$$



Creep : activations and avalanches (*Chauve et al., PRB (2000)*)

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depinning-like avalanche $\ell_{\rm av}$

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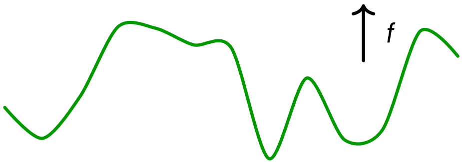


Metastable state

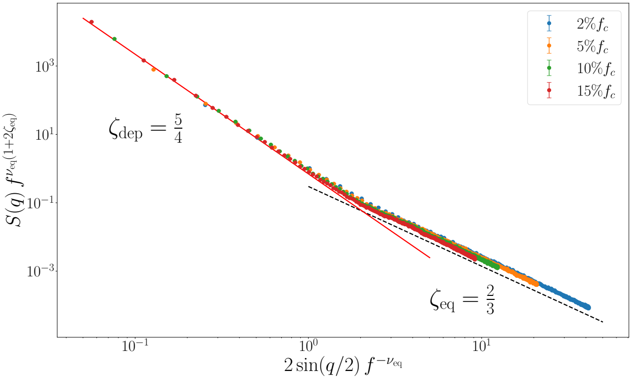
The $T \to 0^+$ limit : ℓ_{opt} selection (*Ferrero et al., Annu. Rev. CMP (2021)*)

The dynamics selects the minimal activated rearrangement lowering the energy

$$\ell_{opt}(f) \sim f^{-\nu_{eq}}$$

$$\zeta_{eq} = \frac{2}{3} \longrightarrow \zeta_{dep} = \frac{5}{4}$$

$$\nu_{eq} = \frac{1}{2 - \zeta_{eq}} = \frac{3}{4}$$



Open question : what cuts off thermal avalanches ?

At fixed drive, define the finite-temperature avalanche scale :

$$\ell_{\rm av}(f, T) \sim T^{-\sigma}$$

Several scenarios predict different values of σ

FRG

$$\sigma = \frac{\nu_{\rm dep}}{\beta} \approx 5.46$$

depinning-like regime
cut by finite velocity

Chauve et al., PRB (2000)

EPM

$$\sigma = \frac{1}{d} = 1$$

cutoff induced by dimensionality

Tahaei et al., PRX (2023)

Cellular Automata

$$\sigma = \nu_{\rm dep} = \frac{4}{3}$$

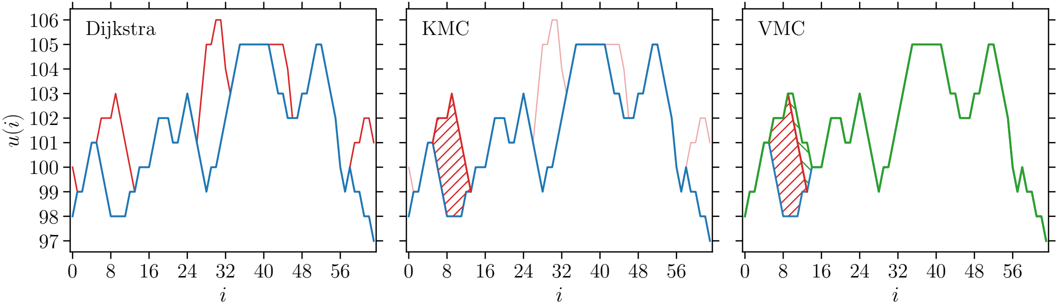
depinning-like regime

de Geus et al., PRE (2025)

A finite-temperature effective dynamics

Starting from a metastable state :

1. find all forward energy-lowering rearrangements using **Dijkstra**'s algorithm, assigning barriers $U(\ell) \sim \ell^{1/3}$;
2. assign Arrhenius rates $r_i \sim \exp\left[-\frac{U(\ell_i)}{T}\right]$ and select one event by **KMC** ;
3. relax deterministically via **VMC**



Structure factor : two geometric crossovers

$$S(q) = \overline{|u(q)|^2} \sim q^{-(1+2\zeta)}$$

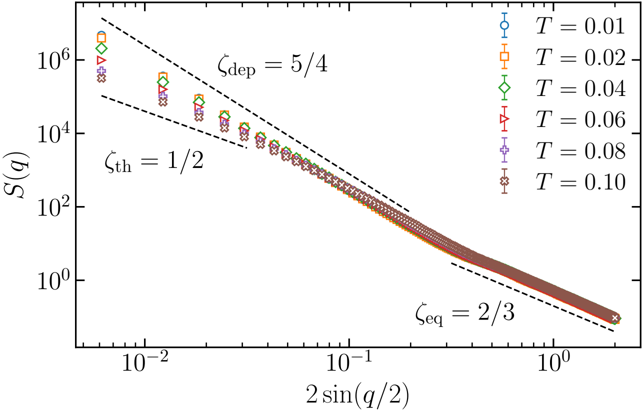
Three roughness regimes :

$$\zeta_{\mathrm{eq}} = \frac{2}{3} \qquad \zeta_{\mathrm{dep}} = \frac{5}{4} \qquad \zeta_{\mathrm{th}} = \frac{1}{2}$$

At fixed $f/f_c = 0.1$:

ℓ_{opt} is T-independent

ℓ_{av} is T-dependent

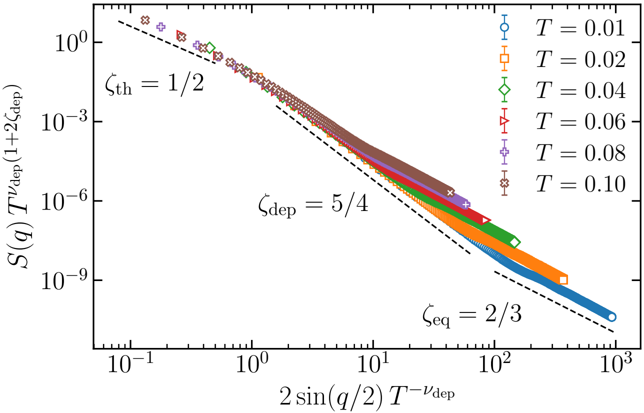


Avalanche scale from roughness collapse

Collapse with the depinning exponent :

$$\nu_{\text{dep}} = \frac{1}{2 - \zeta_{\text{dep}}} = \frac{4}{3}$$

$$\ell_{\text{av}}(T) \sim T^{-\nu_{\text{dep}}}$$



Persistence : a dynamical probe of creep

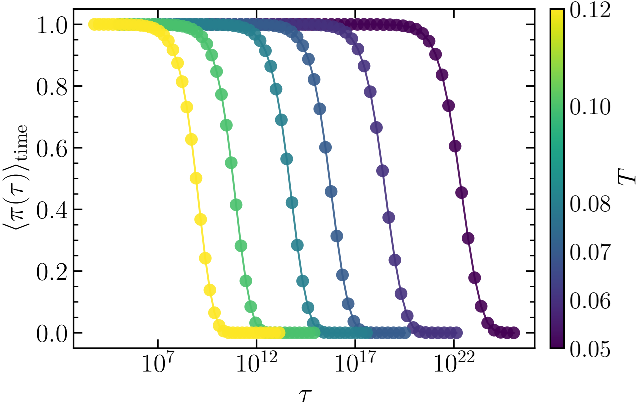
Persistence field over a time window τ :

$$p_i(\tau) = \begin{cases} 1, & \text{if site } i \text{ does not move,} \\ 0, & \text{otherwise} \end{cases}$$

$$\pi(\tau) = \frac{1}{L}\sum_i p_i(\tau)$$

As T decreases :

$\langle \pi(\tau) \rangle_{\text{time}}$ decays more slowly



Activation still controls time

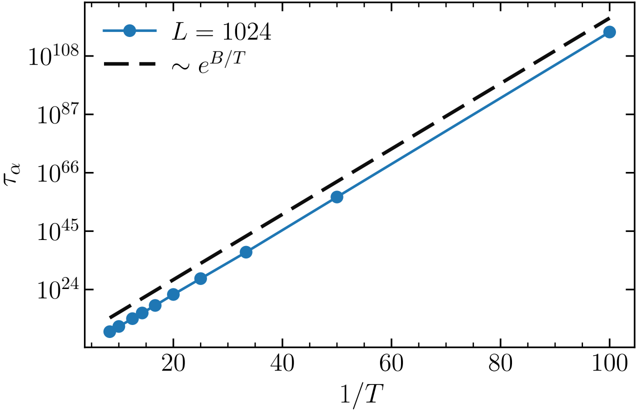
Relaxation time :

$$\langle \pi(\tau_\alpha) \rangle_{\text{time}} = 0.5$$

Arrhenius growth :

$$\tau_\alpha \sim \exp\left(\frac{B}{T}\right) \qquad B \simeq \text{constant}$$

Timescale controlled by activation



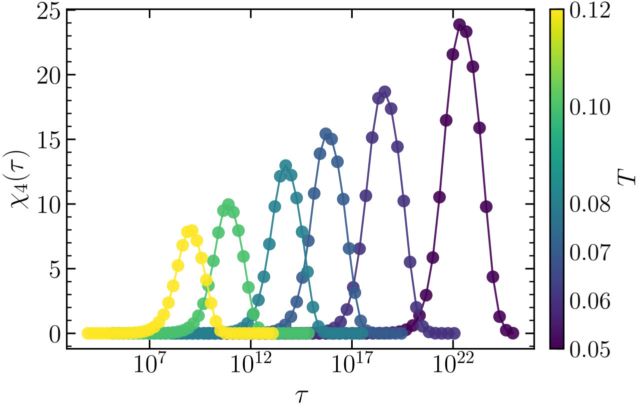
Four-point susceptibility : dynamical correlations

Variance of persistence :

$$\chi_4(\tau) = L\left[\langle \pi^2(\tau)\rangle_{\text{time}} - \langle \pi(\tau)\rangle^2_{\text{time}}\right]$$

The peak grows as T decreases :

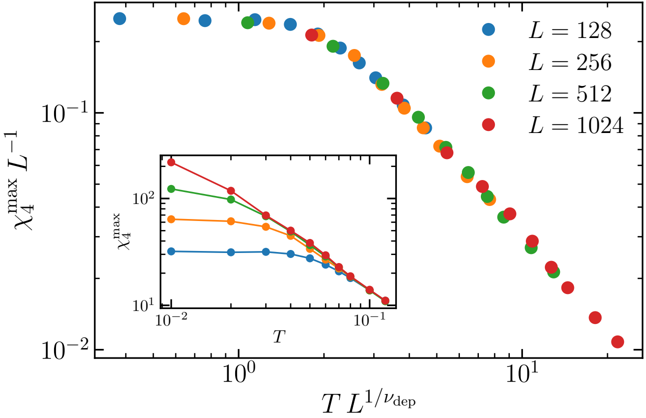
$$\chi_4^{\max}(T) \sim \ell_{\text{av}}(T)$$



Finite-size scaling :

$$\chi_4^{\max} L^{-1} = \mathcal{F}\left(T L^{1/\nu_{\mathrm{dep}}}\right)$$

$$\chi_4^{\max} \sim \ell_{\mathrm{av}}(T) \sim T^{-\nu_{\mathrm{dep}}}$$



Conclusion

Finite-temperature creep is governed by two length scales

Activation

$$\ell_{\rm opt}(f) \sim f^{-\nu_{\rm eq}}$$

$$\nu_{\rm eq} = \frac{3}{4}$$

controls time

Avalanches

$$\ell_{\rm av}(f, T) \sim T^{-\nu_{\rm dep}}$$

$$\nu_{\rm dep} = \frac{4}{3}$$

controls space

Outlook : creep in amorphous solids

Elastic interfaces :

f_c depinning threshold

Amorphous solids :

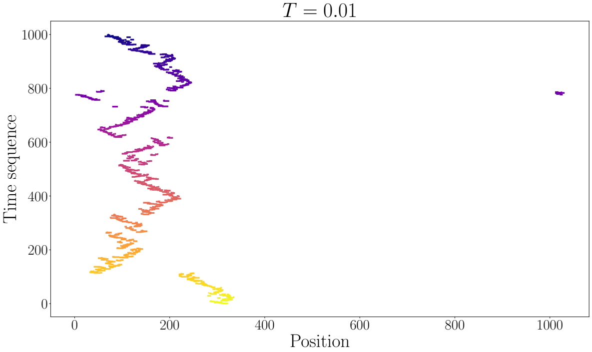
Σ_Y yielding threshold

Below threshold and at finite temperature :

thermal activation + collective avalanches

Do thermally activated avalanches control amorphous creep ?

Activity Maps for $L = 1024$, $f/f_c = 0.1$



Activity Maps for $L = 1024$, $f/f_c = 0.1$