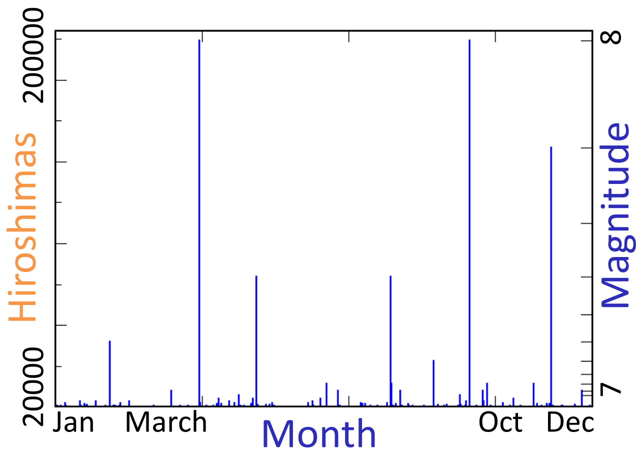
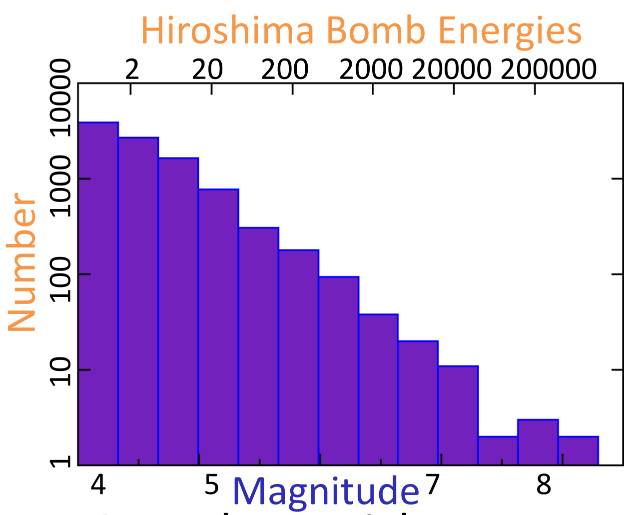
Crackling Noise

JPS, Shekhawat, Papanikolaou, Bierbaum, ..., Dahmen, Myers, Durin, Zapperi



Earthquakes: 1995

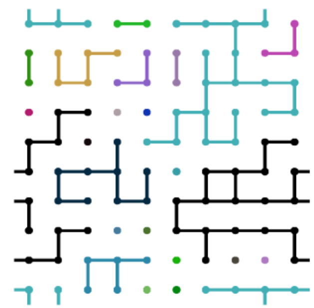
Sharp events of many sizes

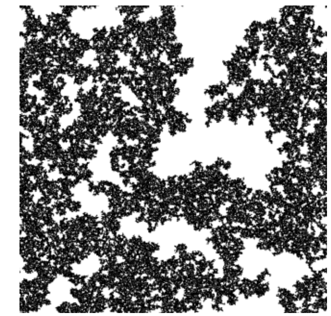


Gutenberg-Richter Law

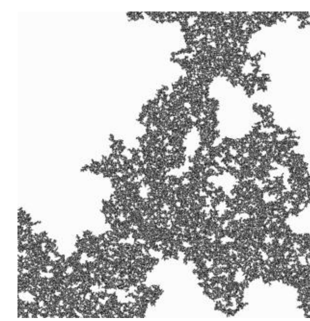
Power laws, critical exponents

Bond vs. Site Percolation



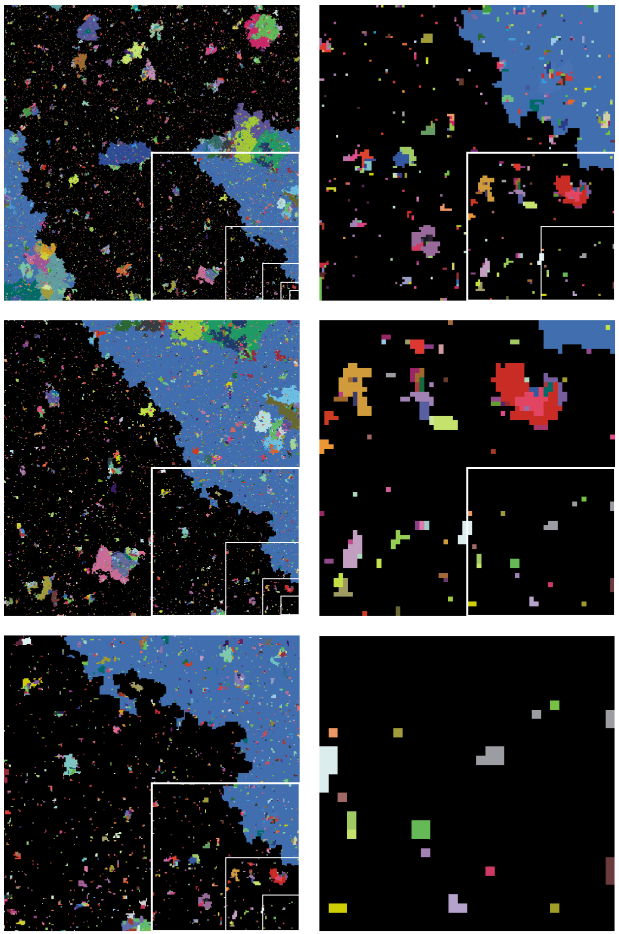


Universality: different systems same behavior. Also allows theory to fit experiment



Self-Similarity: Scale Invariance

Looks the same at different magnifications



Avalanche Model at R_c

Enlarge lower right corner: looks like another snapshot

New scale invariance 'symmetry' near phase transition: same under change of ruler

Renormalization group

Universal power laws

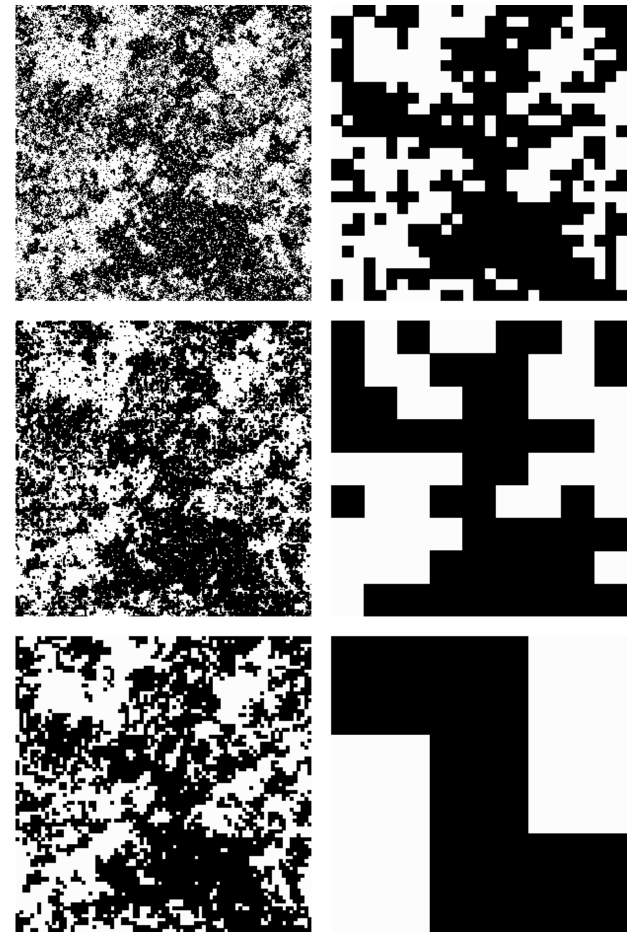
Volume $S \sim L^{d_f}$,

Probability $P(S) \sim S^{-\tau}$

Universal scaling functions

$V(t|S,T) \sim T^{d_f/z-1}\, \mathcal{V}(t/T)$

$P(S|f) \sim S^{-\tau} \mathcal{P}(S/f^{1/\sigma})$



Coarse Graining

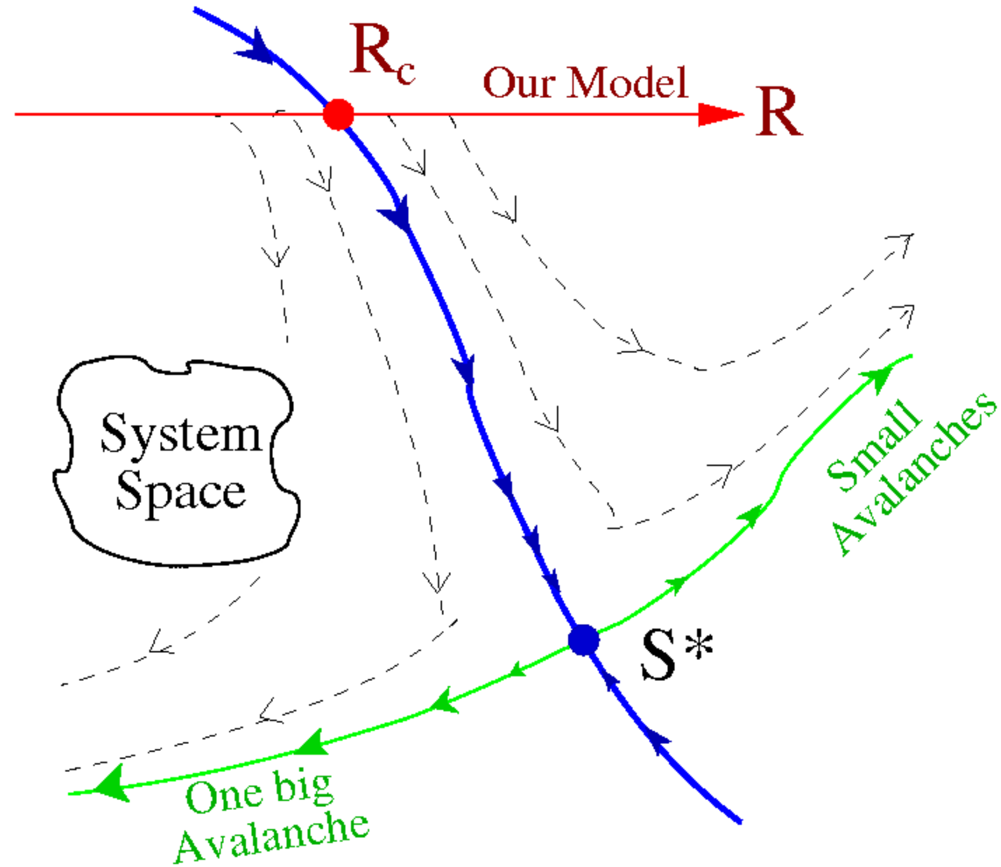
The Renormalization Group

Coarse Graining in the Space of All Systems

Ken Wilson's
amazing abstraction
Space of all possible systems
(experiment or theory)

Coarse laws give
new point in
system space.
Many coarsenings?
Stops changing at S*

Self-Similarity:
S* similar to itself under
coarsening
Universality:
Many different systems
go to same S*

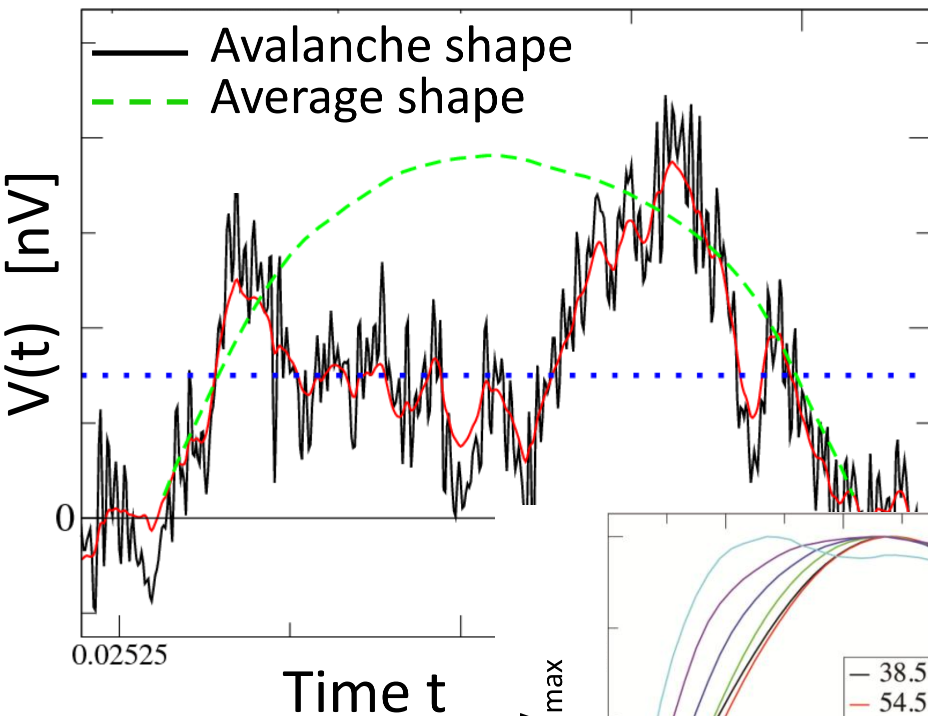


Theory describes experiment if both coarsen to same S.*

Dahmen, Myers

Universal Scaling Functions

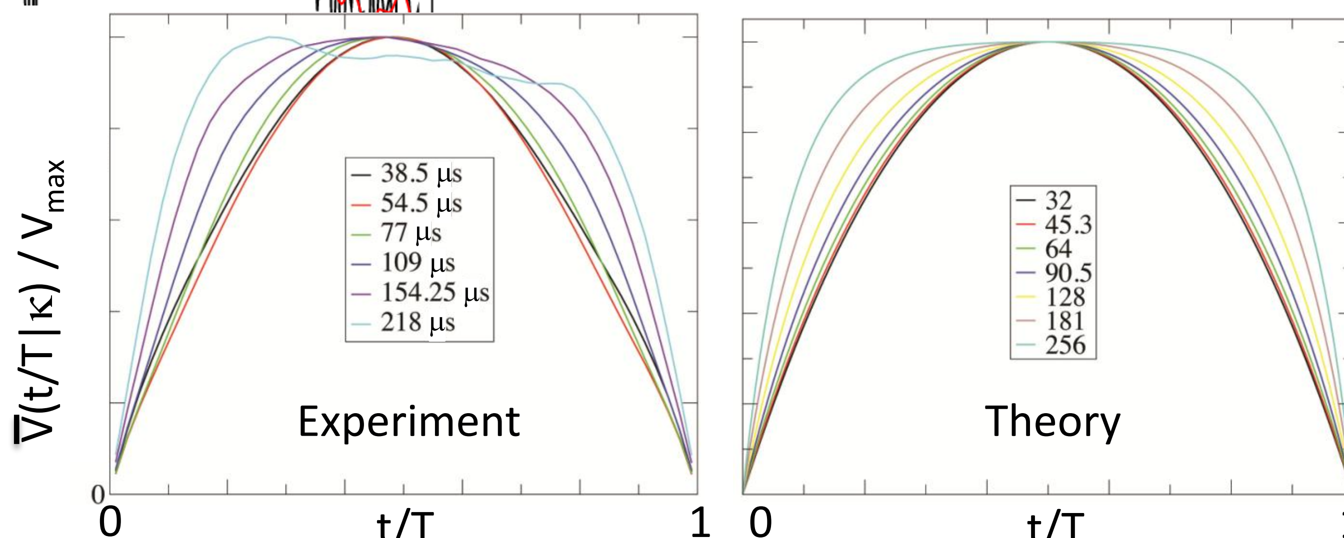
The average shape of avalanches of duration T



Coarse grain time -> time/b, V -> V/b^x ;

$$V(t|T,k) = b^{-x} V(t/b|T/b, \kappa b^w)$$
$$= T^{-x} V(t/T|1, \kappa T^w)$$
$$= T^{-x} V(t/T, \kappa T^w)$$

Scaling plot: $T^x V(t)$ vs. t/T



Papanikolaou, Durin, Bohn, Sommer, Zapperi

Entire functional form universal

Universal Multivariable Scaling

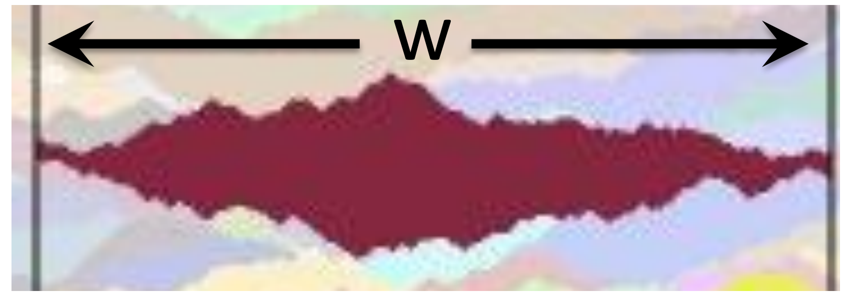
Heights, widths, durations, …

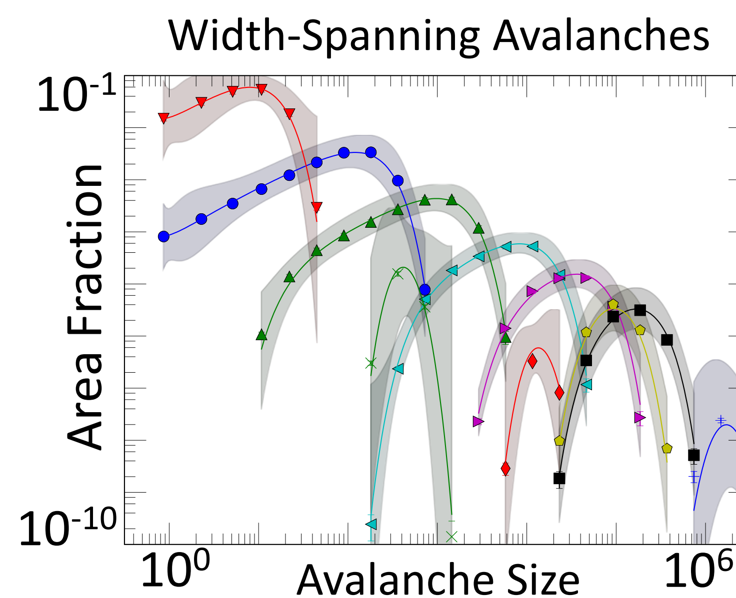
$$A_{wSk}(w, S \mid \xi) = \xi^{(\tau-2)(1+\zeta)} S^{1-\tau-1/(1+\zeta)} A_{wSk}(w/S^{1/(1+\zeta)}, w/\xi)$$

Joint probability that avalanche has size S, width w, height h, duration T …

Scale invariance implies N-variable functions will be a power law times a universal function of N-1 scaling variables

Powerful tool for answering experimentally important questions (avalanches in windows…)

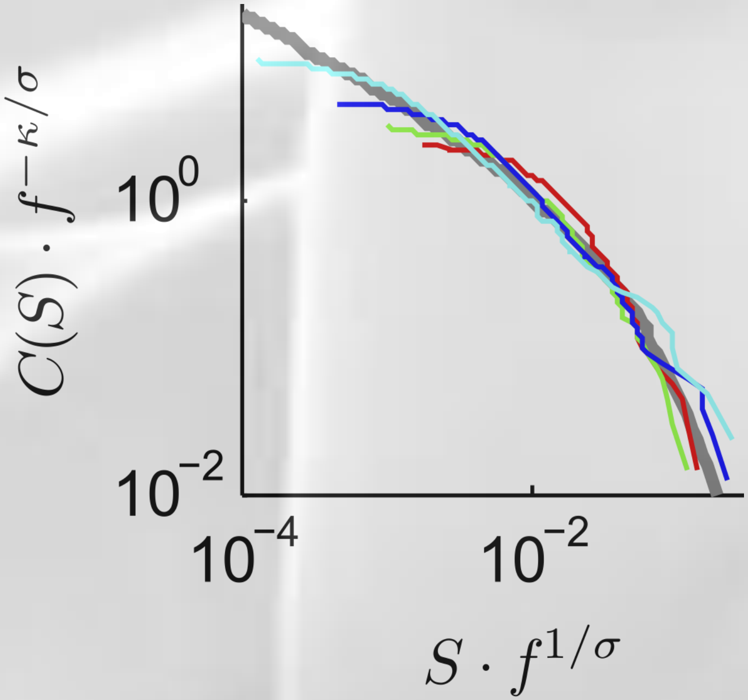




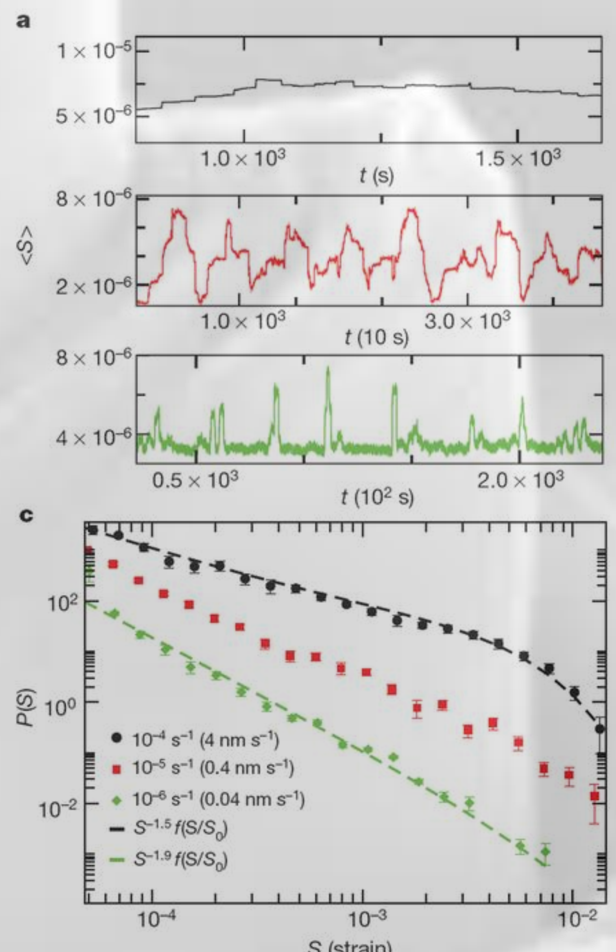
Yanjiun Chen, Papanikolaou, Durin, Zapperi

Crackling Plasticity

Mean-field theory for avalanches



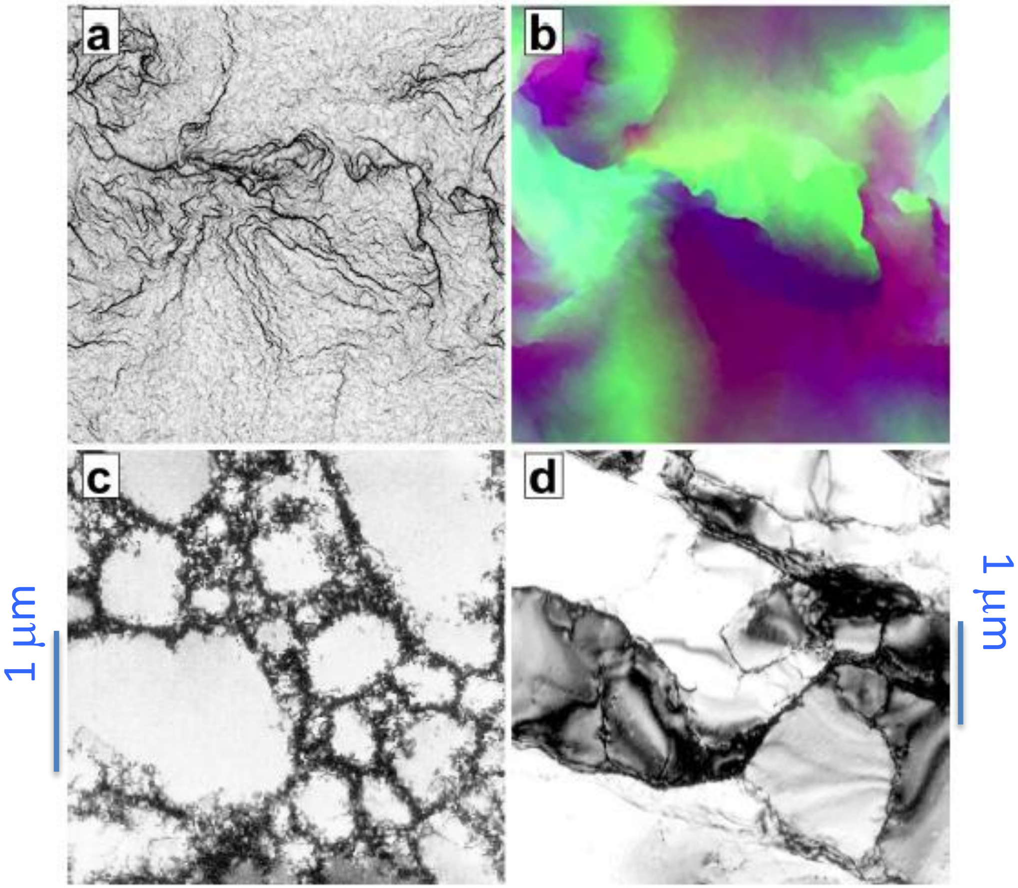
Dahmen, Grier (not me): Yield stress as critical point! Plasticity avalanches = critical fluctuations. Work hardening as self-organization!



Papanikolaou, Zapperi, …: Creep leads to *avalanche oscillator*, periodic approaches to criticality, 'integrated' exponents

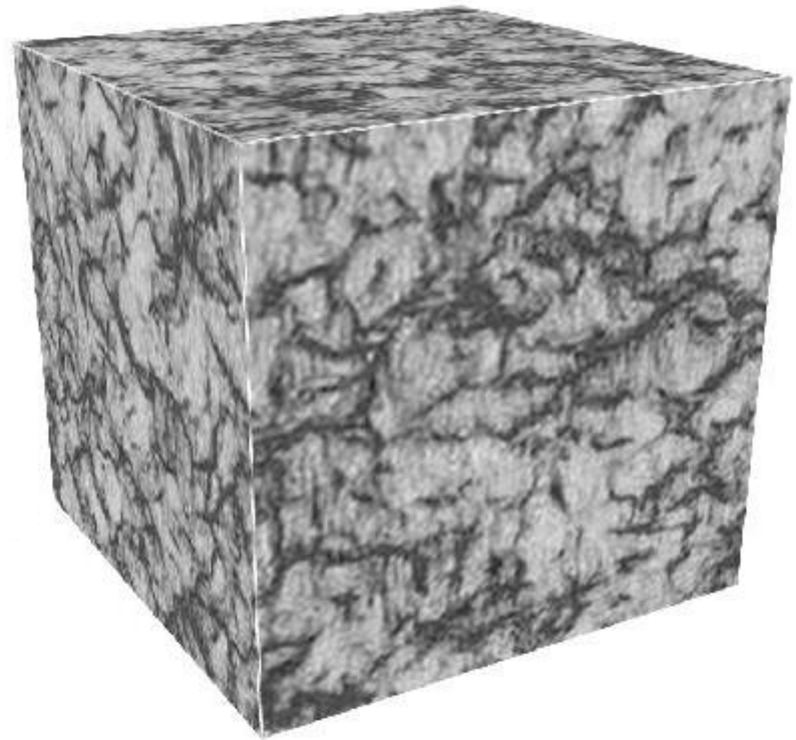
Morphology of Plasticity

Dislocations organize into cellular structures



Copper

Aluminum



Our models yields self-similar, fractal cell structures

Are the fractal dynamics related to the fractal structures?

Bierbaum, Papanikolaou, …

Ramified Mean-Field theories

Spatial dynamics *must* depend on system

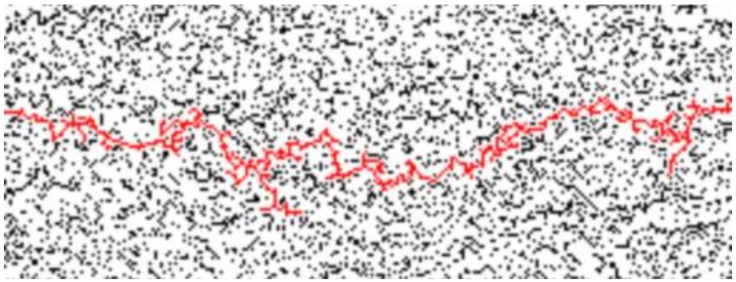
Mean field theories describe:

- Short range models in high dimensions
  (connected, fractal avalanches)
- Models with power-law interactions
  (disconnected avalanches dispersed throughout system)
  elastic dipole, magnetic dipole, …
- Front propagation models
  (anisotropic, self-affine fronts and avalanches)
- All the plasticity models and most experiments
  (avalanche sizes & durations likely independent of morphology)

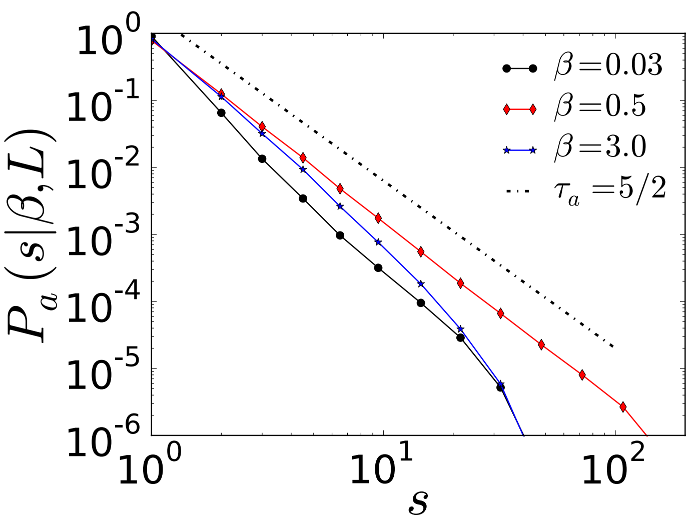
Can we understand the dependence of the spatial morphology on the anisotropy of the long-range interaction?

Crackling Fracture

Power-law fracture precursors



Fuse model for fracture



Microfractures happen in bone, seashells: toughens

(Black) clusters of weak bonds break early, with a power law size distribution.

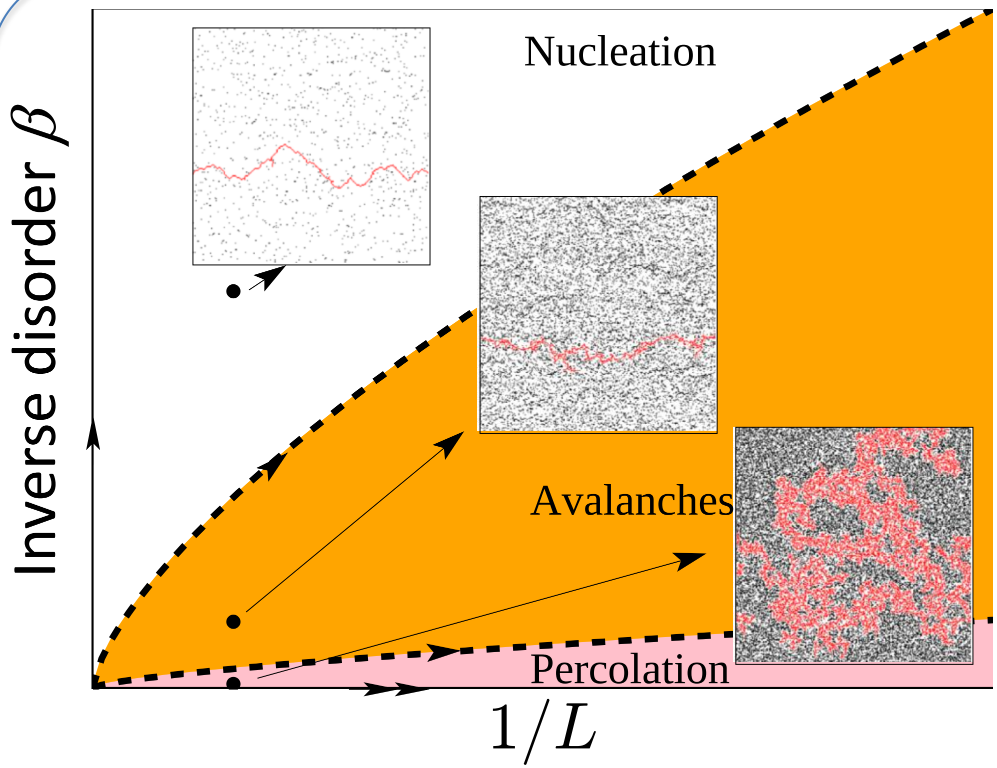
But *larger is weaker:* for infinite system, fracture stress goes to zero, so no precursors!

Precursors are a finite size effect: *finite size criticality*

Shekhawat, Zapperi

Crackling Fracture

Shekhawat: Power-law fracture precursors



Large disorder: 'avalanches' sizes S=1

Small disorder: one big avalanche

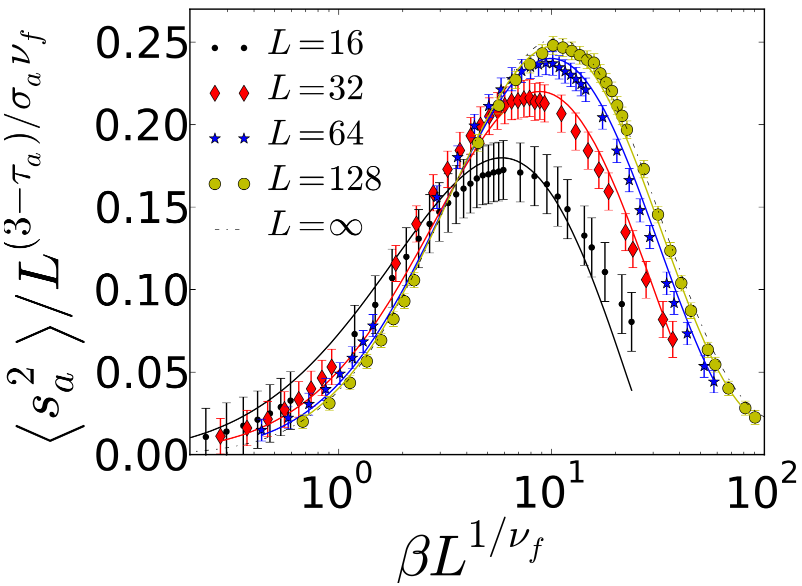
Universal crossover

$P(S) \sim S^{-\tau} F(\beta L^{-1/\nu}, S L^{-1/\sigma\nu}, U L^{-\Delta/\nu})$

Percolation controls scaling

New relevant perturbation β

Second moment of avalanche sizes



Note: Analysis includes first correction to scaling *U*, with universal exponent *Δ*

Shekhawat, Zapperi

Conclusions

Remarkable emergent symmetry: *scale invariance*. Assuming quantities rescale by factors of b^x:

Functions of one variable take on power law forms with universal critical exponents.

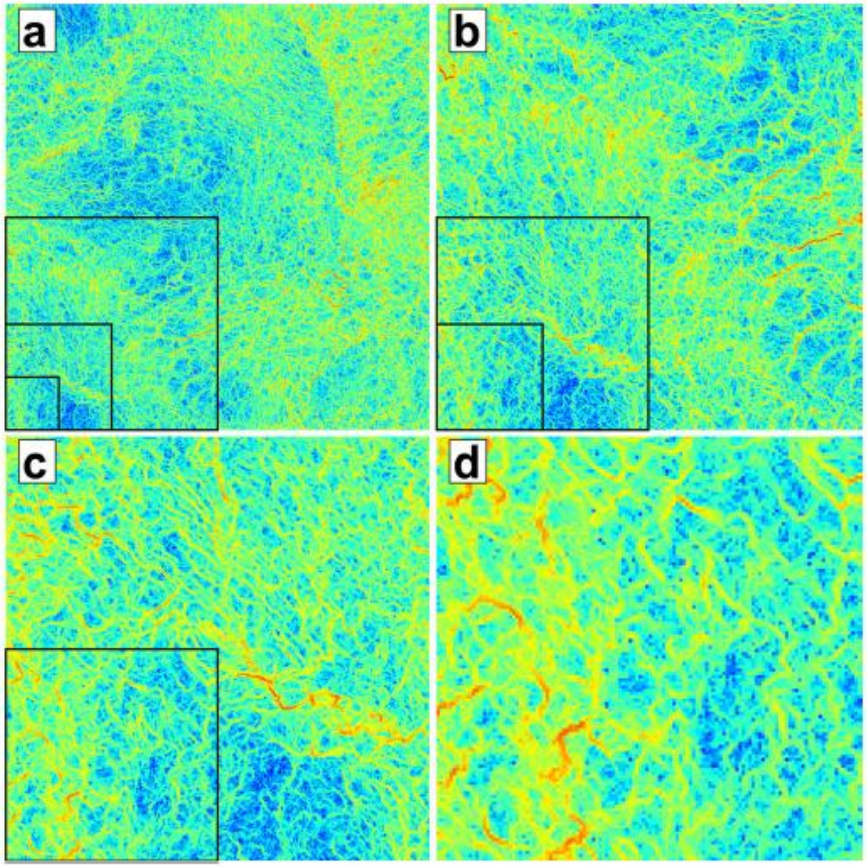
Full strength comes with several variables: size ***S***, duration ***T***, temporal shape ***V*(*t*)**, height ***H***, width ***W***, spectra ***P*(ω)**, correlation function ***C*(*r*)**, demagnetizing field κ, system size ***L***, inverse disorder β, leading irrelevant field ***U***, analytic corrections, crossovers… These give universal scaling *functions.*

Predictive far beyond critical exponents.

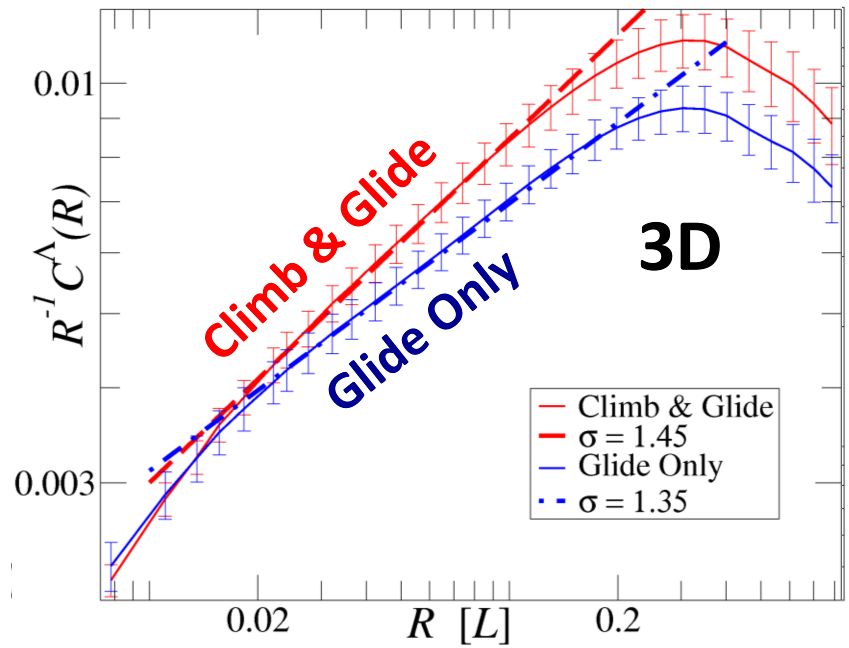
Grappling with universal scaling functions is intellectually challenging and rewarding, while physically intuitive and insightful, even without ε-expansions and field theories.

Emergent scale invariance

Self-similar in space; correlation functions



Real-space rescaling



Power law dependence of mean misorientations

DOE BES

Scaling theory!