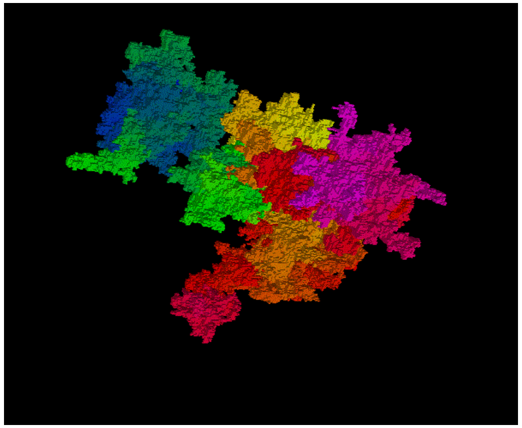
Crackling Noise, Glassiness, and Disorder Induced Critical Scaling In and Out of Equilibrium: Are they the same ???



1. Magnets:

Yang Liu, A. Mehta, J. Carpenter, S. Loverde, R. Vanderveldt, R. White, A. Travesset, *Nir Friedman, Braden Brinkman*

Jim Sethna, M. Kuntz, O.Perkovic (Cornell University), Gary Friedman (Drexel.U.), Alan Middleton (Syr. U.)

Experiments:

A. Berger, O. Hellwig, Nanogune.
Gianfranco Durin (Torino, Italy).
A. Mills, Mike Weissman (UIUC),
Karen Daniels (NCSU),
Robert Behringer (Duke)

2. Plasticity, granular materials, earthquakes:

Y. Ben-Zion, J.T. Uhl,

DD Simulations: **G. Tsekenis,**

PFC: Pak Yuen Chan, Nigel Goldenfeld

superconductors:

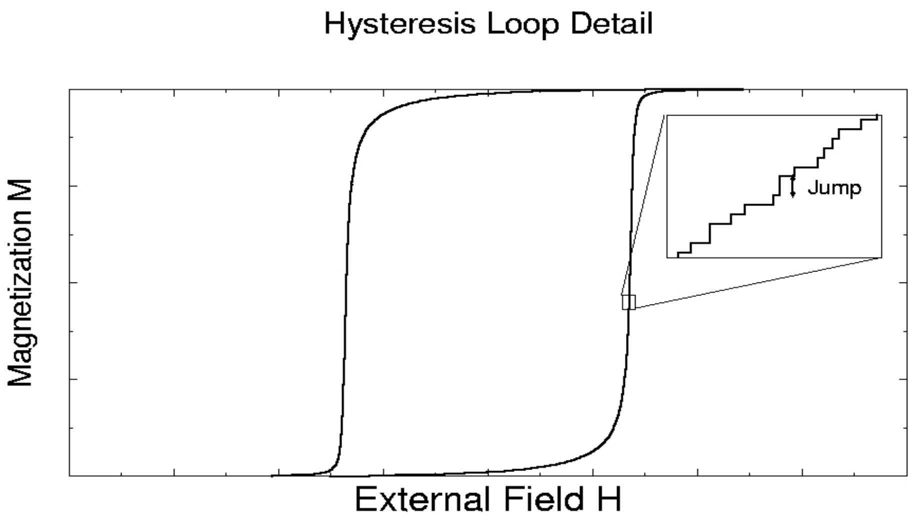
E. Carlson (Perdue), E. Fradkin (UIUC), S. Kivelson (Stanford), D. van Harlingen, M. Weissman (UIUC)

Plastic CDW: C. Marchetti (Syr.)

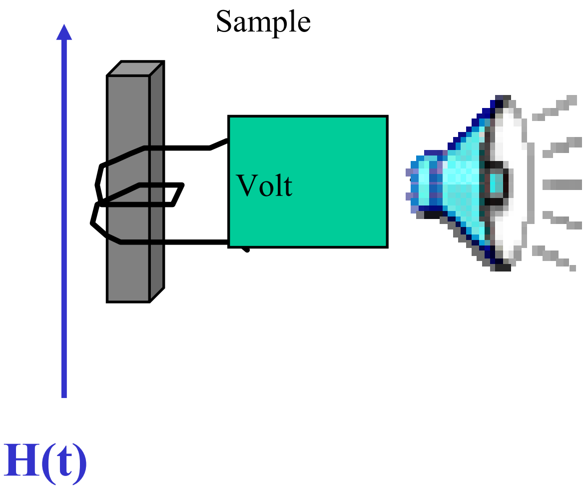
Funding/Equipment:
NSF, MCC, SLOAN, UIUC, IBM, SANDIA

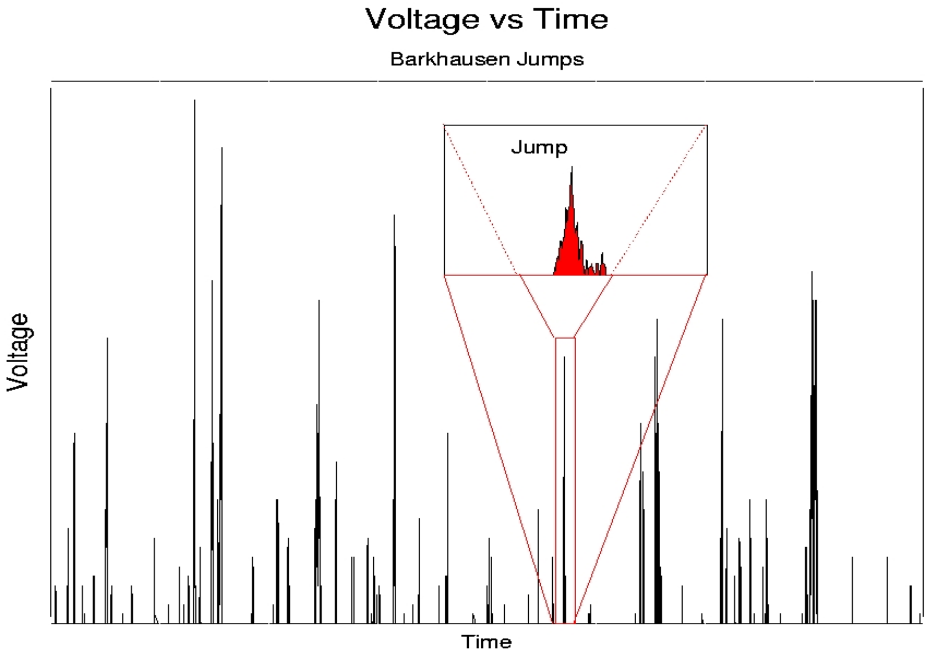
Physics Illinois

Magnets and Barkhausen Noise- or Martensites and acoustic emission


Hysteresis Loop Detail

Crackling noise




Voltage vs Time

Barkhausen Jumps

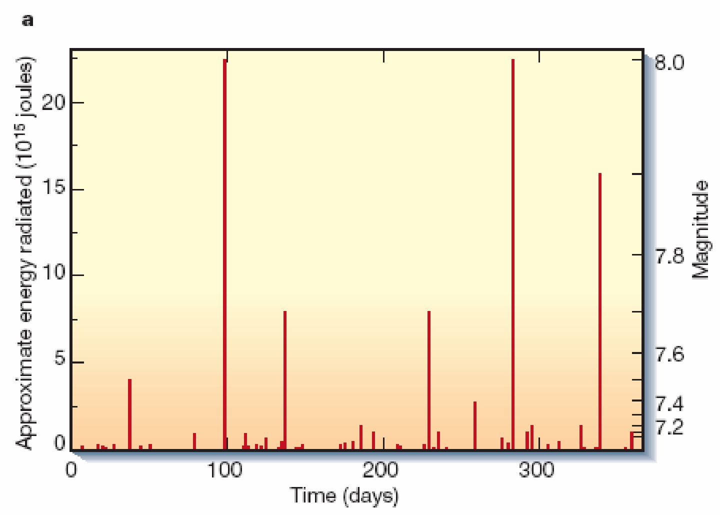
Crackling Noise / Avalanches: Simple Models right!

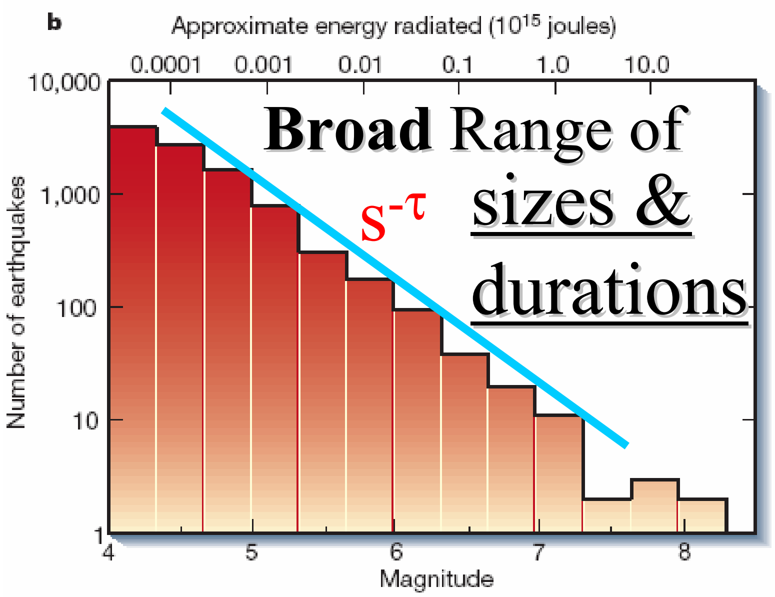
- 1. Barkhausen Noise (magnets) (Bertotti, Durin, Weissman,...)

Acoustic emission (Martensites) (Ortin, Vives,...)

Liquids invading porous materials (Hallock, Lilly,…, Robbins...)

- 2. Dislocation slips/Plasticity (Dimiduk, Weiss, Miguel, Zaiser, Zapperi,…)
- 3. Slips in Granular Materials (Behringer, Daniels,… Uhl)
- 4. Earthquakes (Ben-Zion)





$s^{-\tau}$

Broad Range of sizes & durations

Simple (analytic) models work amazingly well!

Big open questions:

(1) Go beyond universal power laws? Universal scaling ***functions*** ?

Example: average temporal avalanche shape.

(2) What is the extent of the underlying universality classes ???

(3) What is the relation between crackling noise and glassiness?

Glasses: stuck in (thermal) metastable states

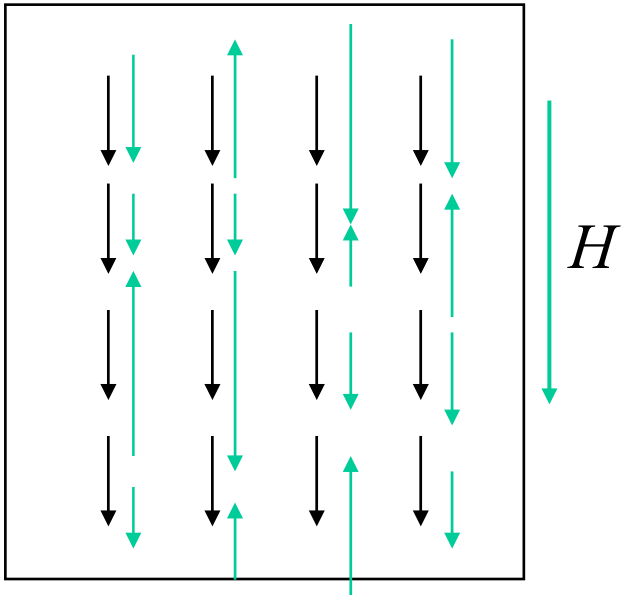
Crackling noise: (driven) transitions between metastable states

SAME?

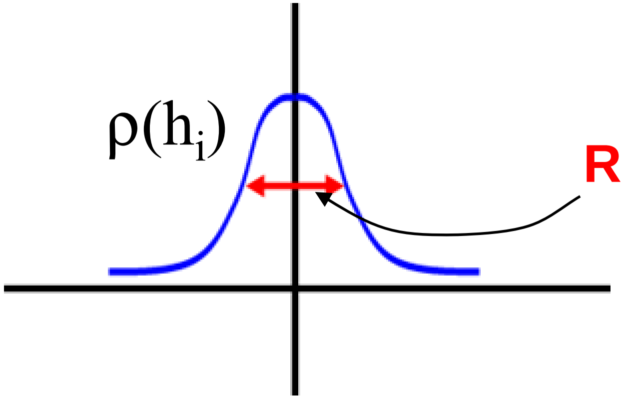
For random-field Ising model: same scaling behavior (universality class)

(4) Experimental tests with disorder as a tuning parameter ?!!!!!

1. MAGNETS: The Zero Temperature Non-equilibrium Random Field Ising Model



Random Field Distribution

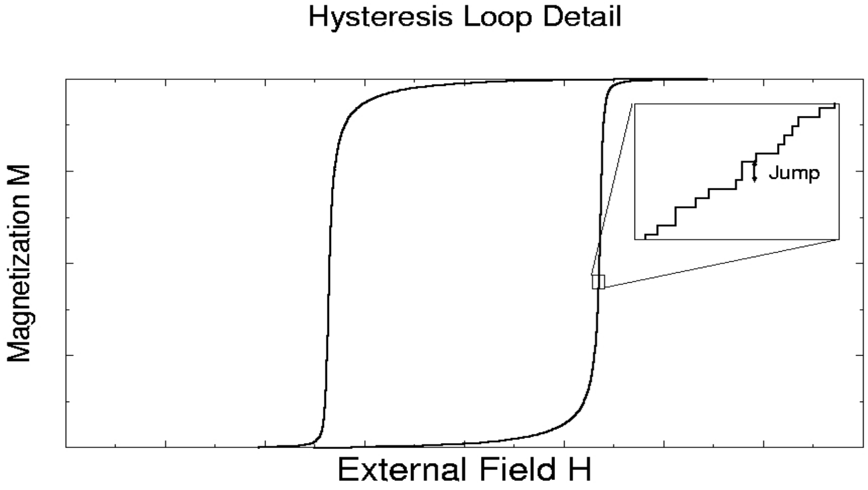


R="strength" of disorder

Each spin is always aligned with the direction of the

$$\text{local "force"} = H(t) + h_i + J \sum_{n.n.} S_j$$

Zero Temperature : (Equilibration time scale) >> (Experimental time scale)

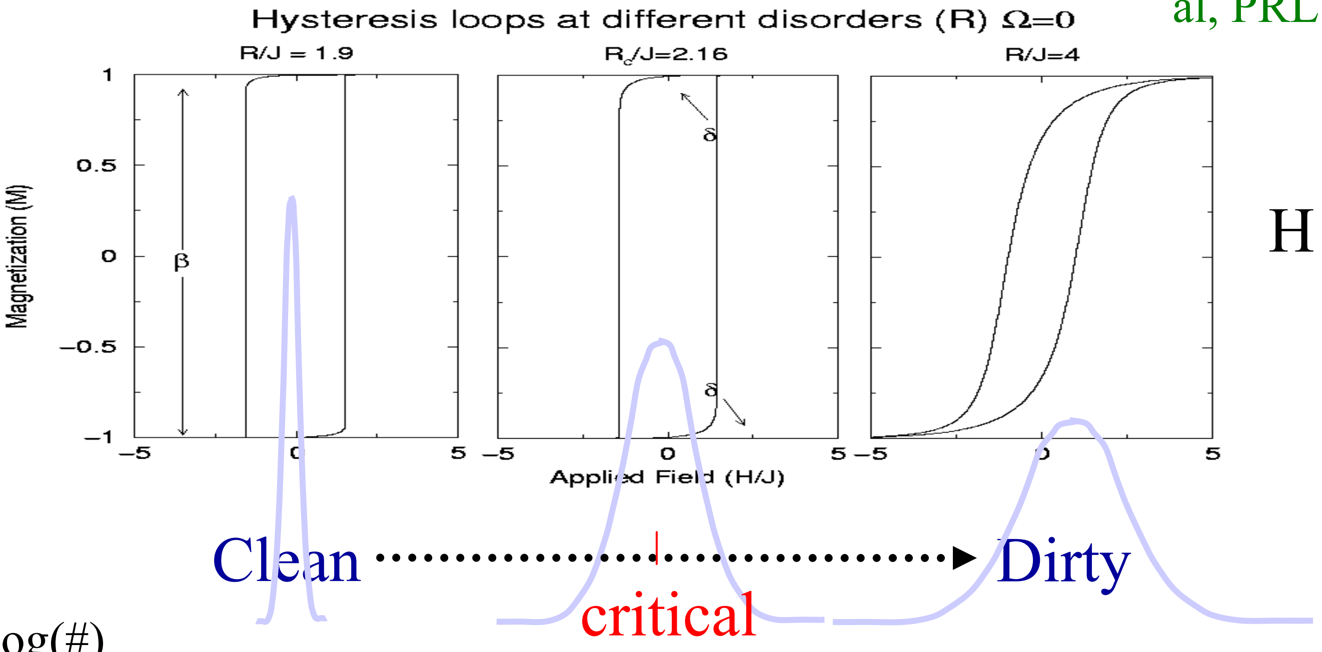


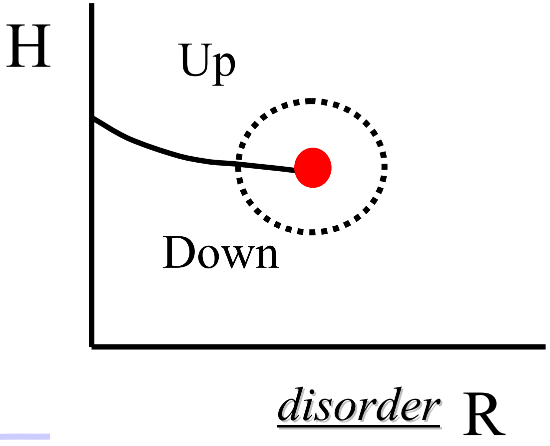
Jumps = Avalanches =

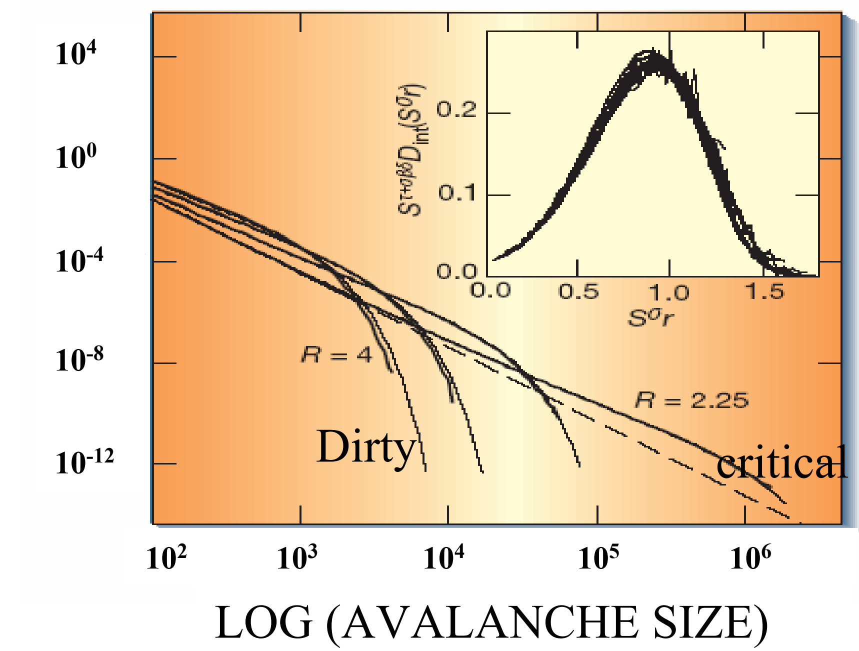
Barkhausen noise

The Disorder Induced Critical Point

Seen also in experiments: Berger et al, PRL 2000, J.Appl.Phys. 2004





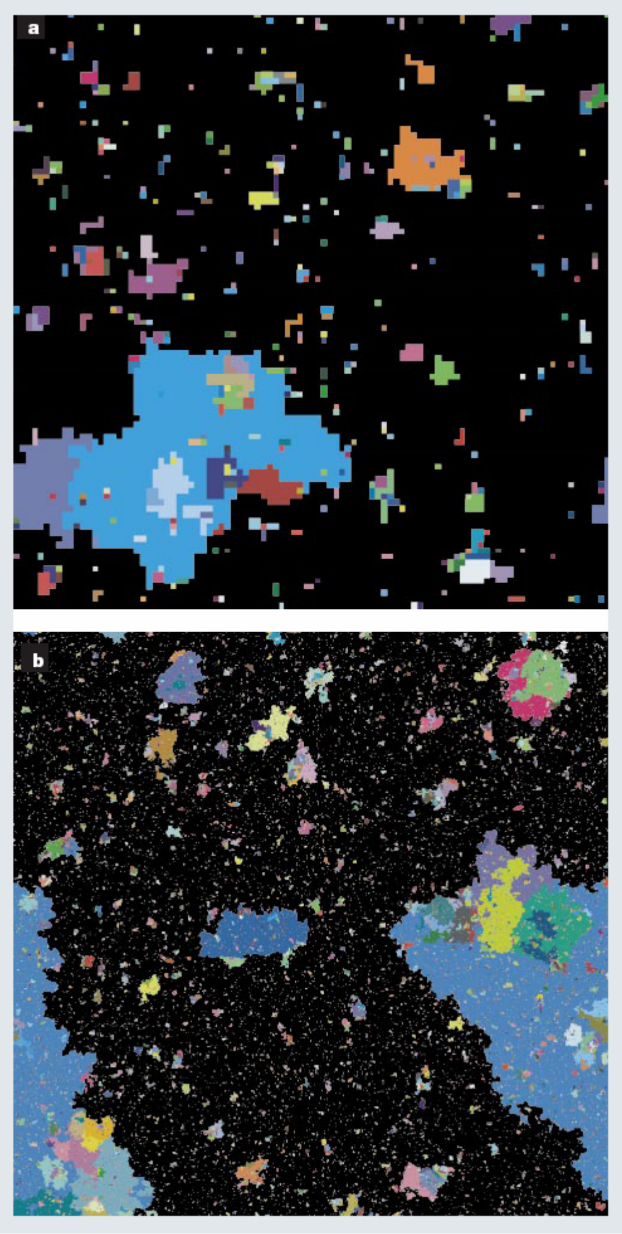


$\tau+\sigma\beta\delta=2.03\pm0.03$, $1/\sigma=4.2\pm0.3$, ...

50% away from critical amount: still find 2 decades of powerlaw scaling!

… HUGE scaling region!!!

Self-similarity at critical disorder $R_c = 2.16J$



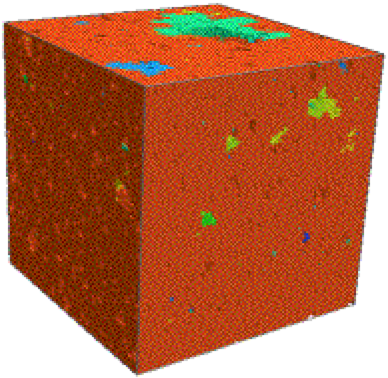
100^3

1000^3

(Cross-sections of avalanches during magnetization)

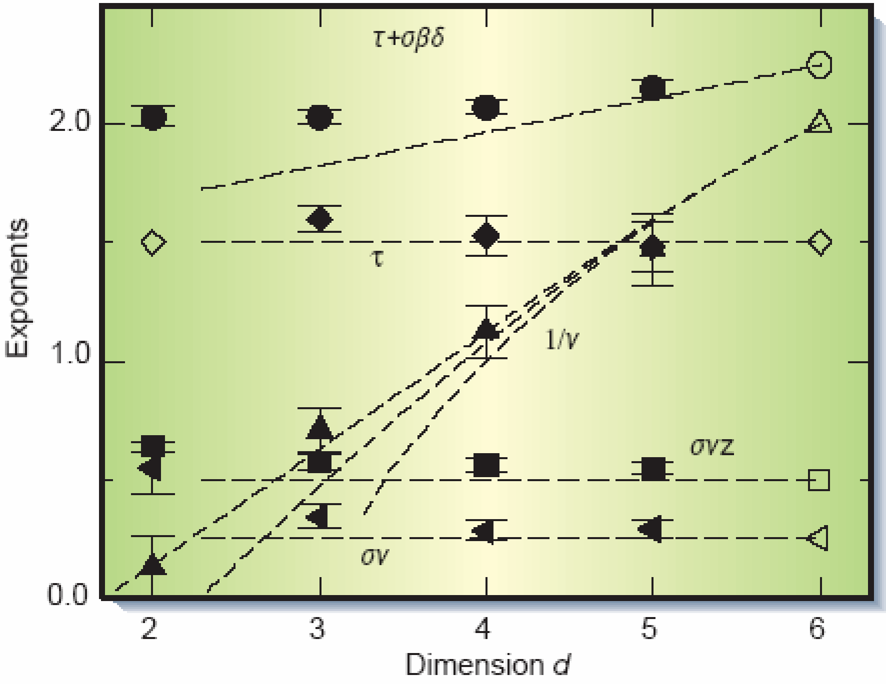
CRITICAL POINT: system is at a fixed point under coarse graining transformation

(Renormalization Group)



http://www.lassp.cornell.edu/sethna/hysteresis/202000_204400_grow_H264.mov

RESULTS



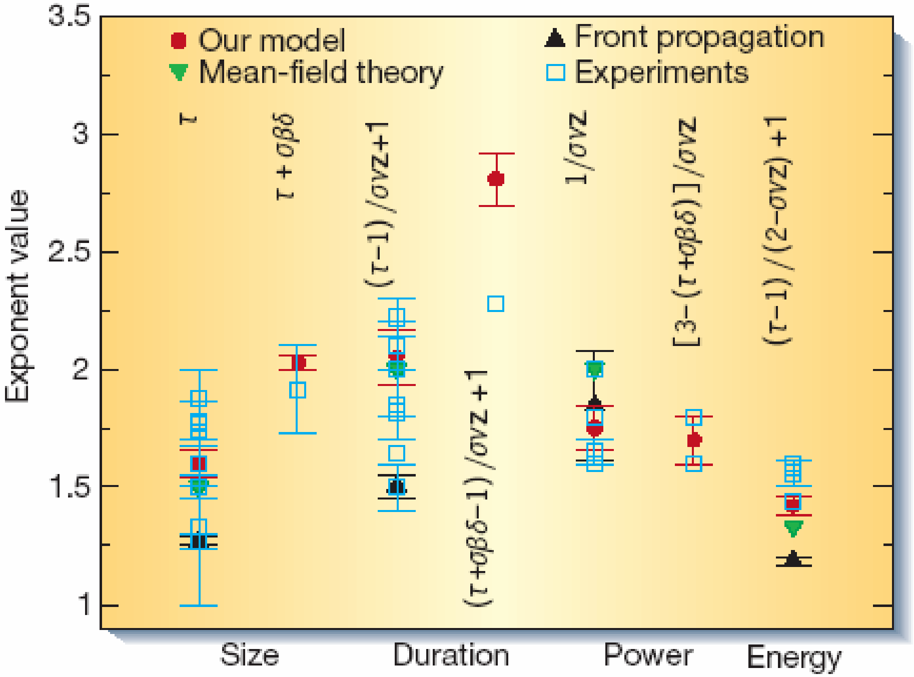
Simulation

6-ε expansion
(Renormalization Group)

$$1/\nu = 2 - \varepsilon/3 - 0.1\varepsilon^2 + 0.1\varepsilon^3 - 0.3\varepsilon^4 + \varepsilon^5 + O(\varepsilon^6)$$

(PRL ‘93,’95, 2003   PRB ‘96, ‘99, 2002 (R))
Nature **410**, 242 (2001)

Experiments and Simulations in 3 dim. (Barkhausen Noise):



Need Noise Experiments Tuning disorder!!!

Big open questions:

(1) Go beyond universal power laws? Universal scaling ***functions*** ?

Example: average temporal avalanche shape.

(2) What is the extent of the underlying universality classes ???

(3) What is the relation between crackling noise and glassiness?

Glasses: stuck in (thermal) metastable states

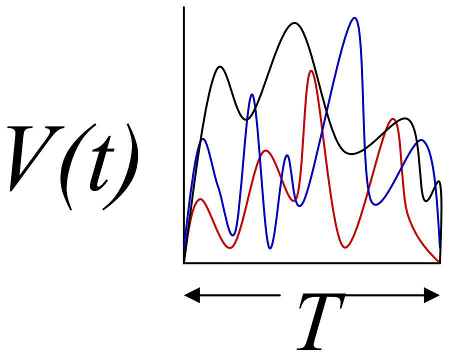
SAME?

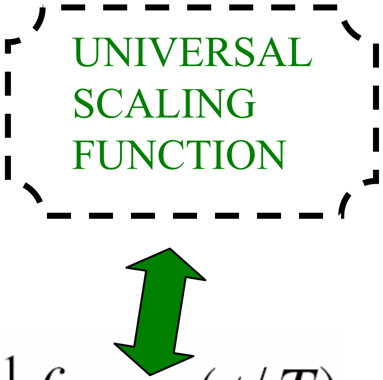
Crackling noise: (driven) transitions between metastable states

For random-field Ising model: same universal fixed point!

(4) Experimental tests with disorder as a tuning parameter ?!!!!!

Universal Scaling ***Functions***:

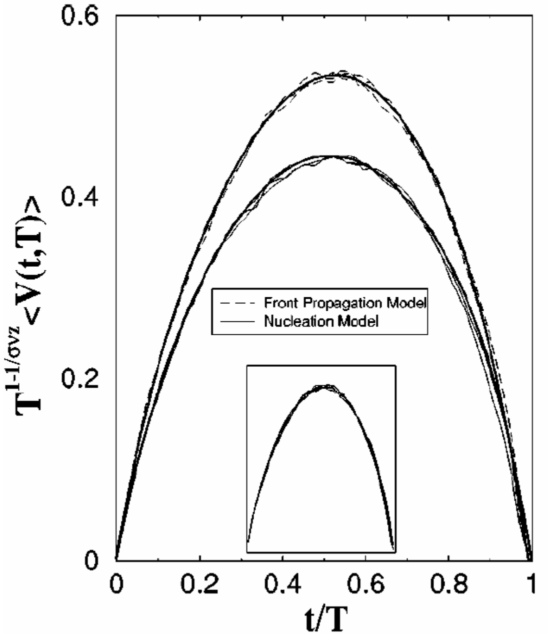




UNIVERSAL
SCALING
FUNCTION

AVERAGE :

$$V(T,t) = T^{1/\sigma\nu z - 1} f_{shape}(t/T)$$

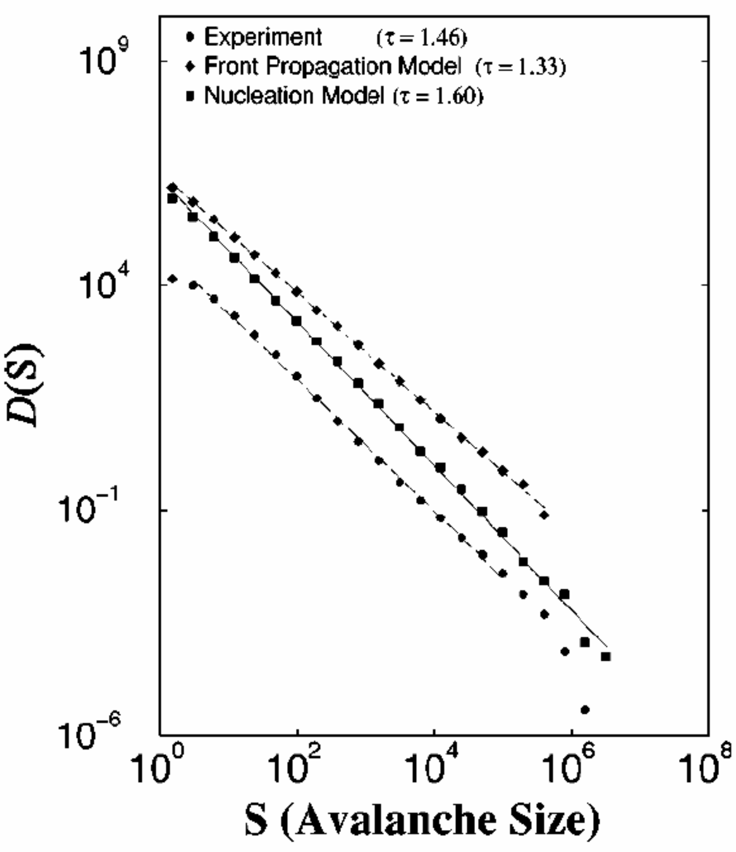


Kuntz
Sethna

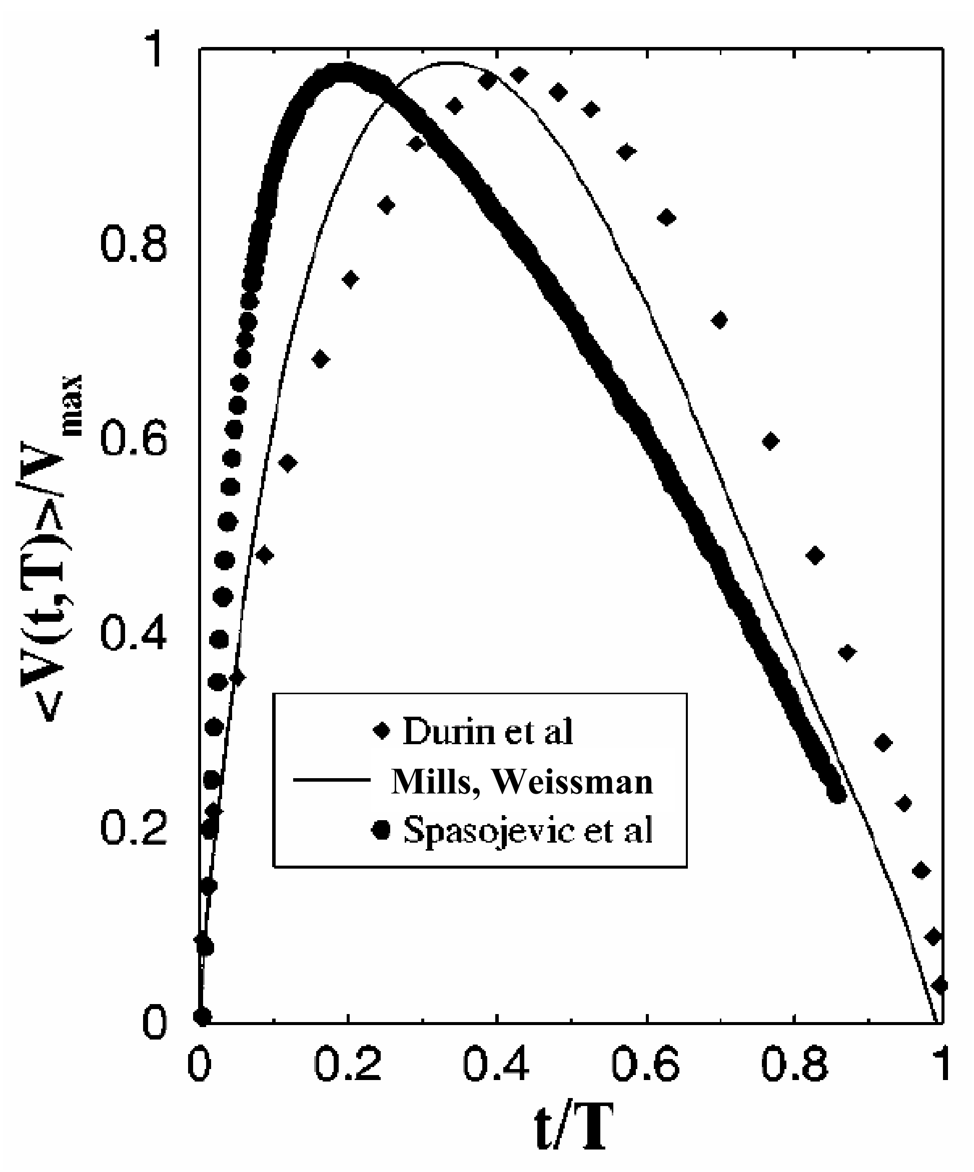
Mehta, KD,
Sethna

AVALANCHE SIZE
DISTRIBUTION:

$$D(S) \sim S^{-\tau} \text{ at criticality}$$



EXPERIMENTAL SCALING FUNCTION



Asymmetric!?!

Eddy currents !

Zapperi, Durin et al.
Nature Physics.
1, 46-49 (2005);
K.D, Nature Physics
1, 13-14 (2005)

Papanikolaou
Bohn, Sommer,
Durin, Zapperi,
Sethna (2009)

Big open questions:

(1) Go beyond universal power laws? Universal scaling ***functions*** ?
Example: average temporal avalanche shape.

(2) What is the extent of the underlying universality class of this simple model ??? (I.e. class of systems with the same exponents)?

(3) What is the relation between crackling noise and glassiness?

Glasses: stuck in (thermal) metastable states

SAME?

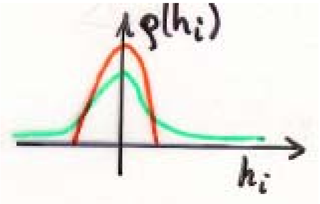
Crackling noise: (driven) transitions between metastable states

For random-field Ising model: same universal fixed point!

(4) Experimental tests with disorder as a tuning parameter ?!!!!!

Huge Universality Class!!! (Details don't matter!)

$$\mathbf{H}_{system} = -J\sum_{n.n.} S_i S_j - \sum_i \left(H(t) + h_i\right) S_i$$



Replace J by random couplings

Use different distribution of h_i or replace h_i by random anisotropies

Magnets (Sethna,KD,Myers, Nature 2001), plastic charge density wave depinning (Marchetti, KD PRB 2002), maybe superconductors(Carlson, KD, Fradkin, Kivelson, 2005), same MFT: *earthquakes (Fisher, KD, Ramanathan, Ben-Zion, 1997, Mehta, BenZion, KD 2005), plasticity (Zaiser 2006, Miguel, Zapperi,07, KD,Ben-Zion,Uhl 09), granular, others ?*

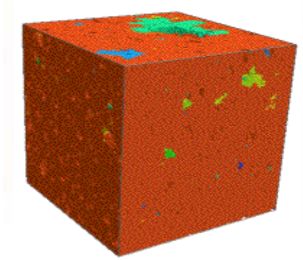
Other Universality classes ?

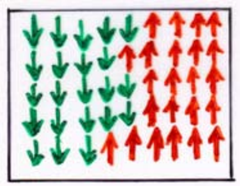
$$\mathbf{H}_{system} = -J\sum_{n.n.} S_i S_j - \sum_i \left(H(t) + h_i\right) S_i$$

+ long range forces

2 Dynamics

With nucleation of new domains





Single domain wall.

Robbins, Ji,…

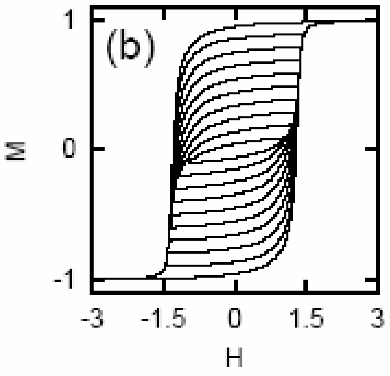
Nattermann, Zapperi, Ciseau, Durin, Stanley, Urbach et al., Narayan, Sethna, ...

Test whether Nucleation or Domain Wall Motion?

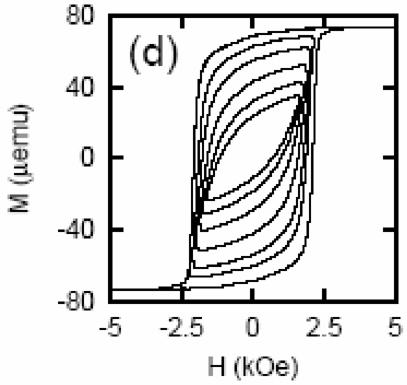
Nucleation: avalanches (cutoff) ***smaller*** for inside loops!

Carpenter,
KD, 2004

Simulation



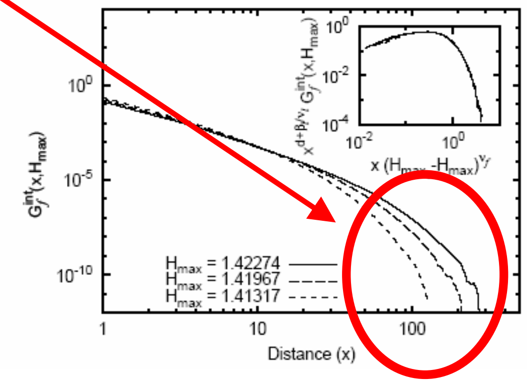
Experiment



Andreas Berger
(NanoGune, Spain)

CoPtCrB

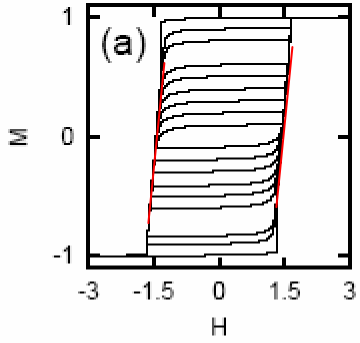
Simulation



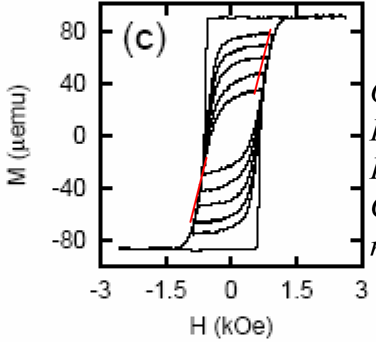
Single domain wall motion: ***same*** cutoff for all loops!

Experiment

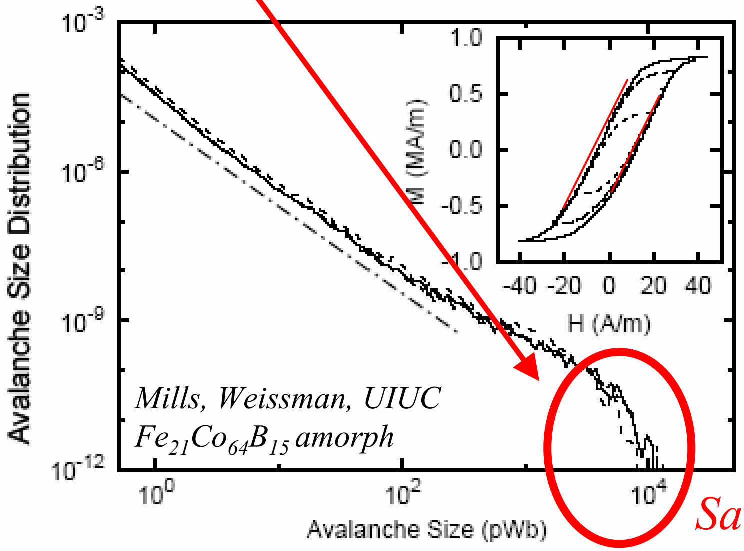
Simulation



Experiment



Olav
Hellwig,
Hitachi
Co/Pt
multilayer



Mills, Weissman, UIUC
$Fe_{21}Co_{64}B_{15}$ amorph

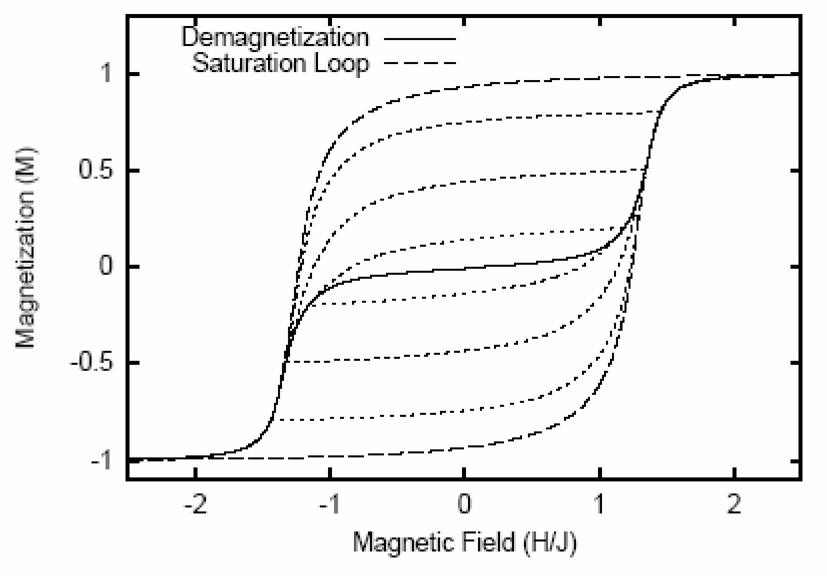
Same
Cutoff

Demagnetizing curves in the T=0 Random Field Ising Model:

also SAME scaling behavior!

John Carpenter, KD, PRB 2003 (R)

Zapperi et al., PRB 2004

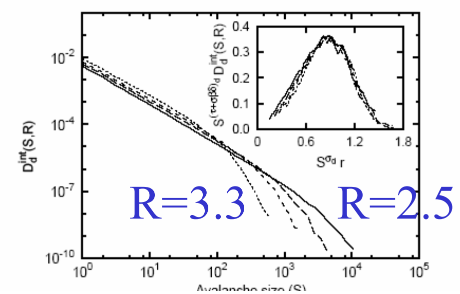


Same disorder induced critical point as saturation loop:

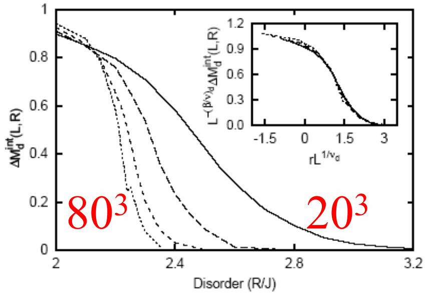
Exponent	Demagnetization	Saturation[a]
$\tau + \sigma\beta\delta$	2.10 ± 0.05	2.03 ± 0.03
$1/\sigma$	3.9 ± 0.4	4.2 ± 0.3
$d + \beta/\nu$	3.1 ± 0.2	3.07 ± 0.30
$1/\nu$	0.71 ± 0.10	0.71 ± 0.09
θ	0.01 ± 0.01	0.015 ± 0.015
β/ν	0.03 ± 0.02	0.025 ± 0.020

Need: Experiments on Barkhausen Noise (for various disorders) ???

Avalanche Size Distribution



ΔM vs R



Big open questions:

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Example: average temporal avalanche shape.

(2) What is the extent of the underlying universality classes ???

(3) What is the relation between crackling noise and glassiness?

$$\left.\begin{array}{l}\text{Glasses: stuck in (thermal) metastable states}\\[2ex]\text{Crackling noise: (driven) transitions between metastable states}\end{array}\right\}\text{SAME?}$$

For random-field Ising model: same universal fixed point!

(4) Experimental tests with disorder as a tuning parameter ?!!!!!

EQUILIBRIUM and NONEQUILIBRIUM RFIM:

same scaling behavior !!

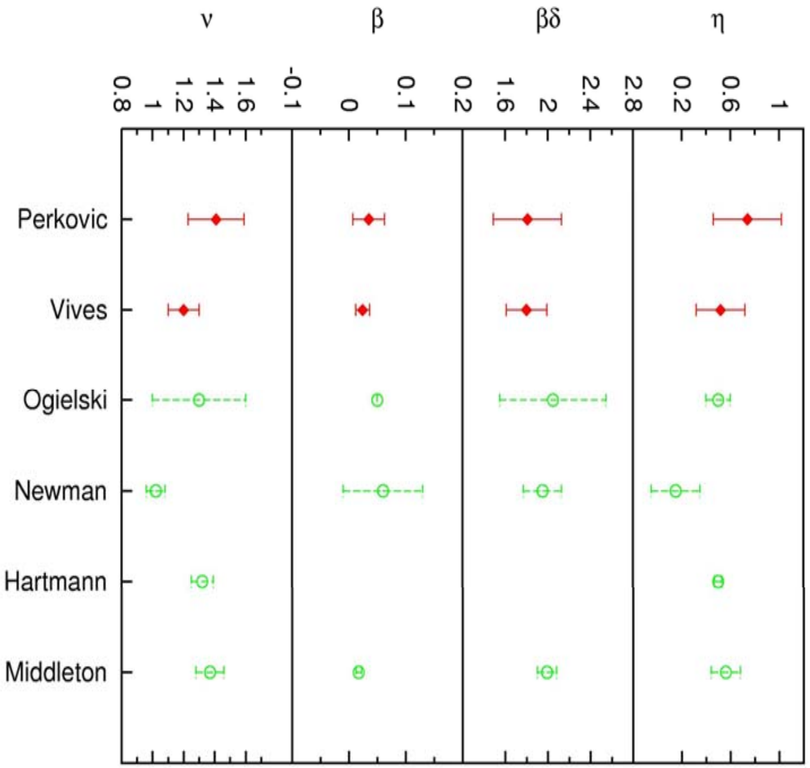
(Maritan, Banavar, and Vives,Ortin,Perez Reche et al., and YANG LIU, KD):

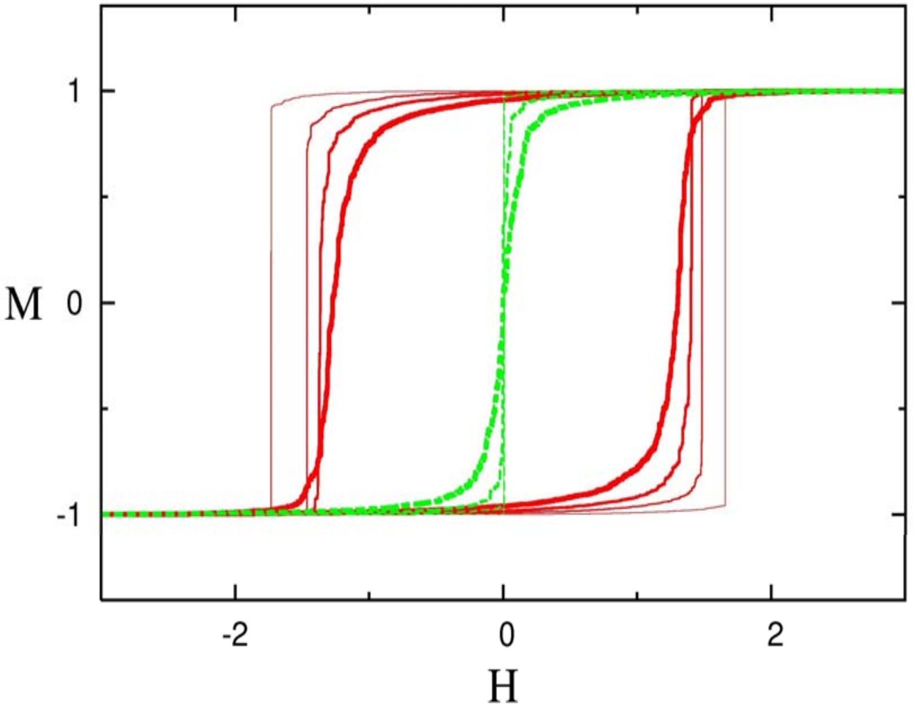
1. *SAME MEAN FIELD EXPONENTS (β=1/2, ν=1/2, δ=3) τ =3/2 and σ =1/2 (Liu, KD)*

2. *ABOUT SAME SIMULATION EXPONENTS in 3D and even in 4D*

3. *6- ε expansion of noneq. mapped to all orders in ε to eq. expansion (KD, Sethna)*

spin can’t flip back with increasing field. (Liu, KD)



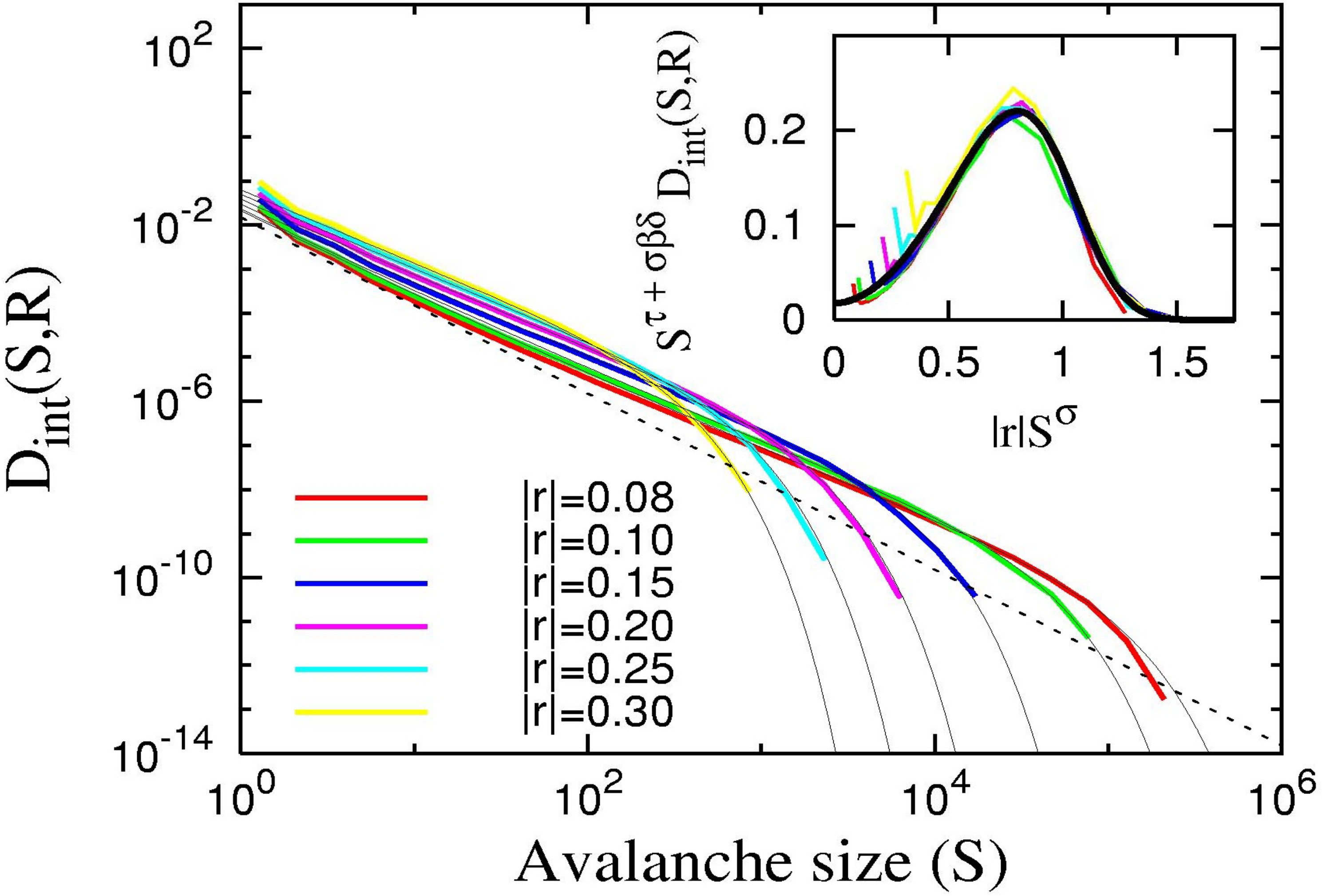


Surprizing Result: same Avalanche Exponents and Scaling Function

In Equilibrium (no hysteresis) and Nonequilibrium (hysteresis):

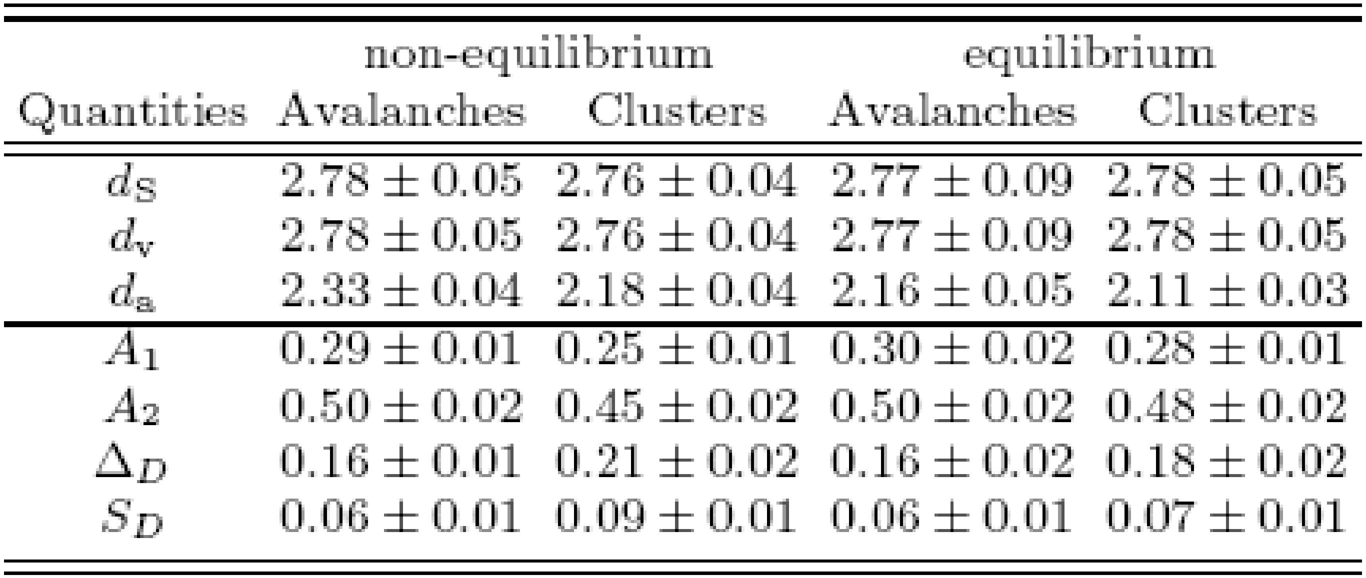
Ground state "Avalanches":

$$D_{\text{int}}(S,R) \sim S^{-(\tau+\sigma\beta\delta)}\ \bar{\mathcal{D}}^{\text{int}}_{\pm}(S^{\sigma}|r|)$$



Liu, KD
2009

•Many other quantities: equilibrium and nonequilibrium



	non-equilibrium		equilibrium	
Quantities	Avalanches	Clusters	Avalanches	Clusters
d_S	2.78 ± 0.05	2.76 ± 0.04	2.77 ± 0.09	2.78 ± 0.05
d_v	2.78 ± 0.05	2.76 ± 0.04	2.77 ± 0.09	2.78 ± 0.05
d_a	2.33 ± 0.04	2.18 ± 0.04	2.16 ± 0.05	2.11 ± 0.03
A_1	0.29 ± 0.01	0.25 ± 0.01	0.30 ± 0.02	0.28 ± 0.01
A_2	0.50 ± 0.02	0.45 ± 0.02	0.50 ± 0.02	0.48 ± 0.02
Δ_D	0.16 ± 0.01	0.21 ± 0.02	0.16 ± 0.02	0.18 ± 0.02
S_D	0.06 ± 0.01	0.09 ± 0.01	0.06 ± 0.01	0.07 ± 0.01

Avalanche distributions and spatial structures (fractal dimensions and anisotropy measures), etc. all scale the same !!

=> **equilibrium** and **non-equilibrium** transitions of T=0 RFIM: **same universality class**… !!!???

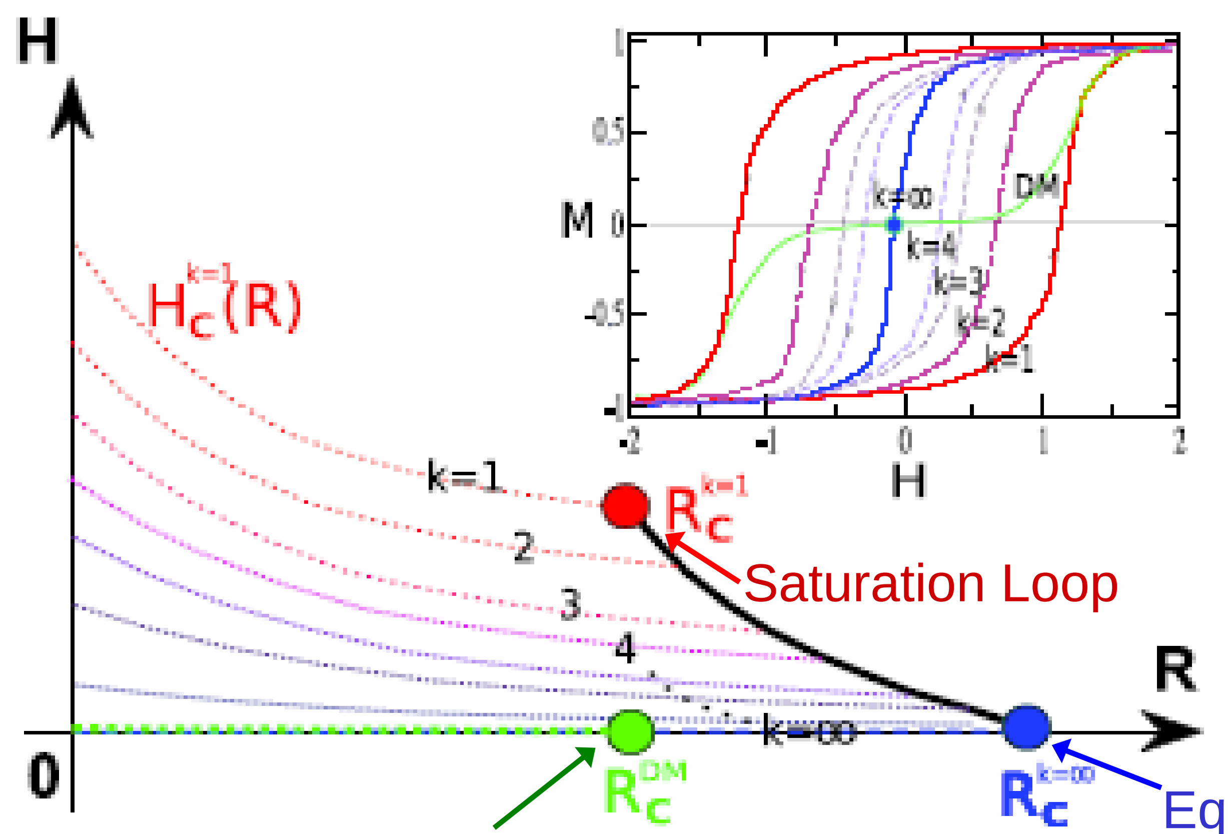
•Thanks to A. A. Middleton and J.P. Sethna

(Yang Liu, KD,
PRE 2009,EPL 2009)

Magnets: RG and simulation, 3 equivalent critical points

Equilibrium, Saturation Loop, Demagnetization curve

(k-spin flip dynamics may connect nonequilibrium and equilibrium critical points?)
(Vives, Stein, Liu,…)



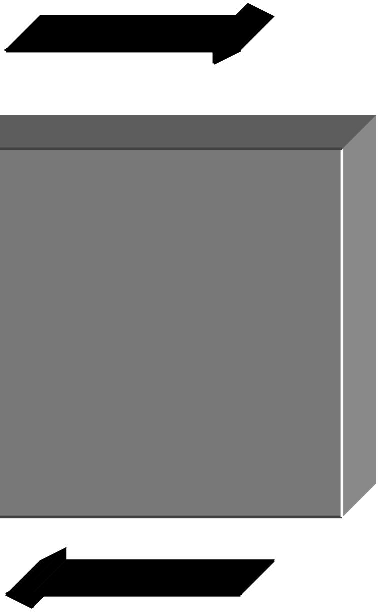
Saturation Loop

Equilibrium

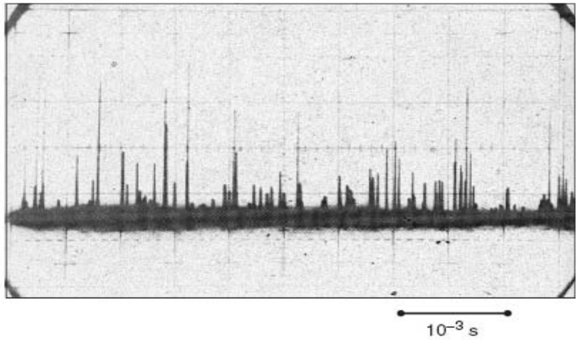
Demagnetization curve

Vives, Rosinberg, Tarjus 2005, Carpenter, KD 2003, Zapperi 2004, Yang Liu, KD, 2009

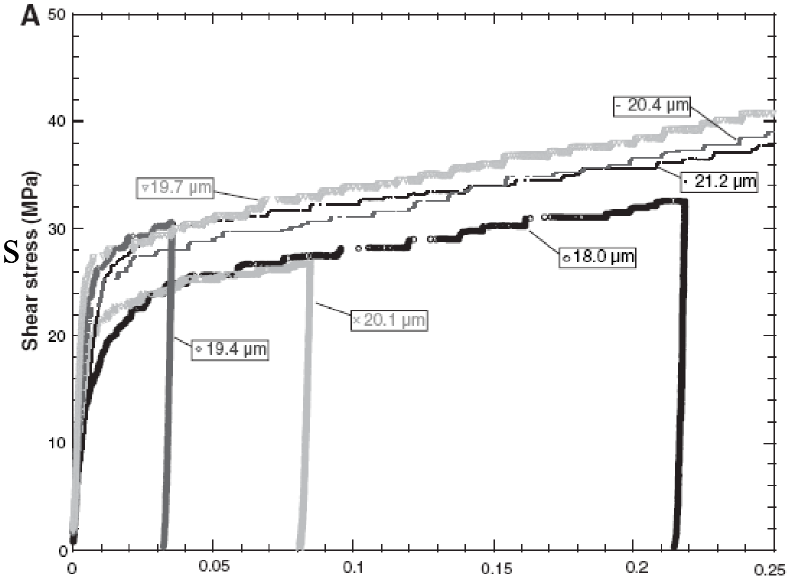
2. Slowly sheared metals: plastic response with discrete jumps !



Acoustic emission



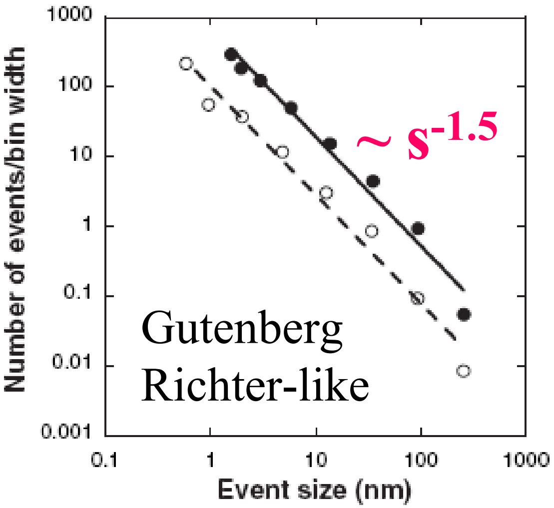
Imanaka et al.



stress

strain

jump size distribution



~ $s^{-1.5}$

Gutenberg
Richter-like

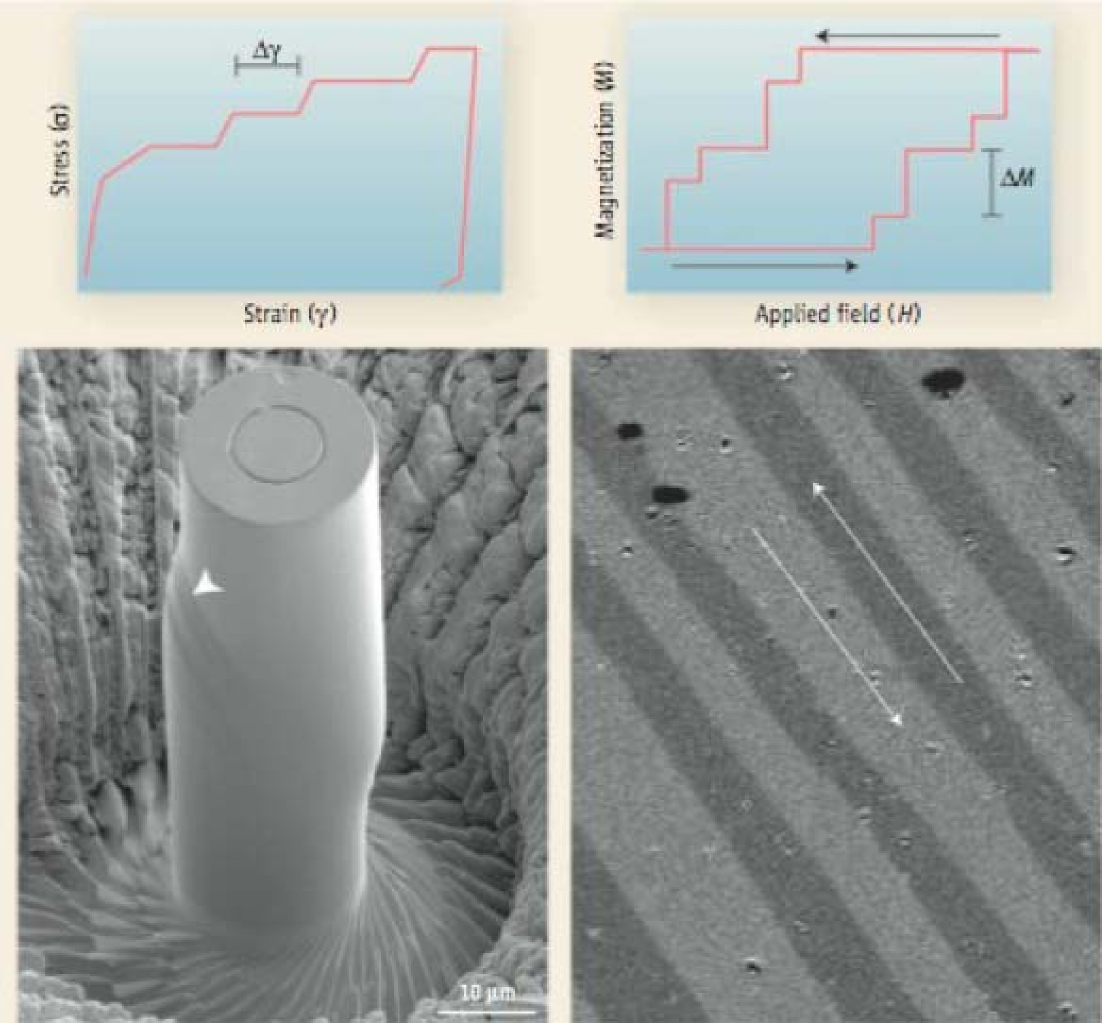
s

Universal!

(Dimiduk, et al
Science 2006)

Resemblance to Barkhausen Noise:

Stress-Strain Magnetization M(H)



Miguel and Zapperi Science **312** (1151-2) 2006

(Dimiduk, et al Science 2006)

Simulations of slip avalanches in sheared crystals:

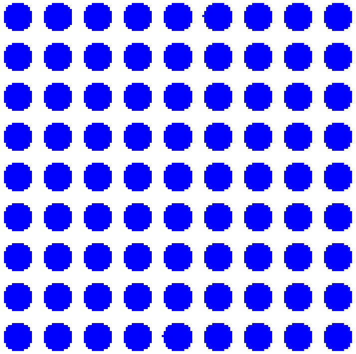
Dislocation Dynamics: Miguel et al Nature 410 (667-671) 2001, Csikor et al. Science (2007)

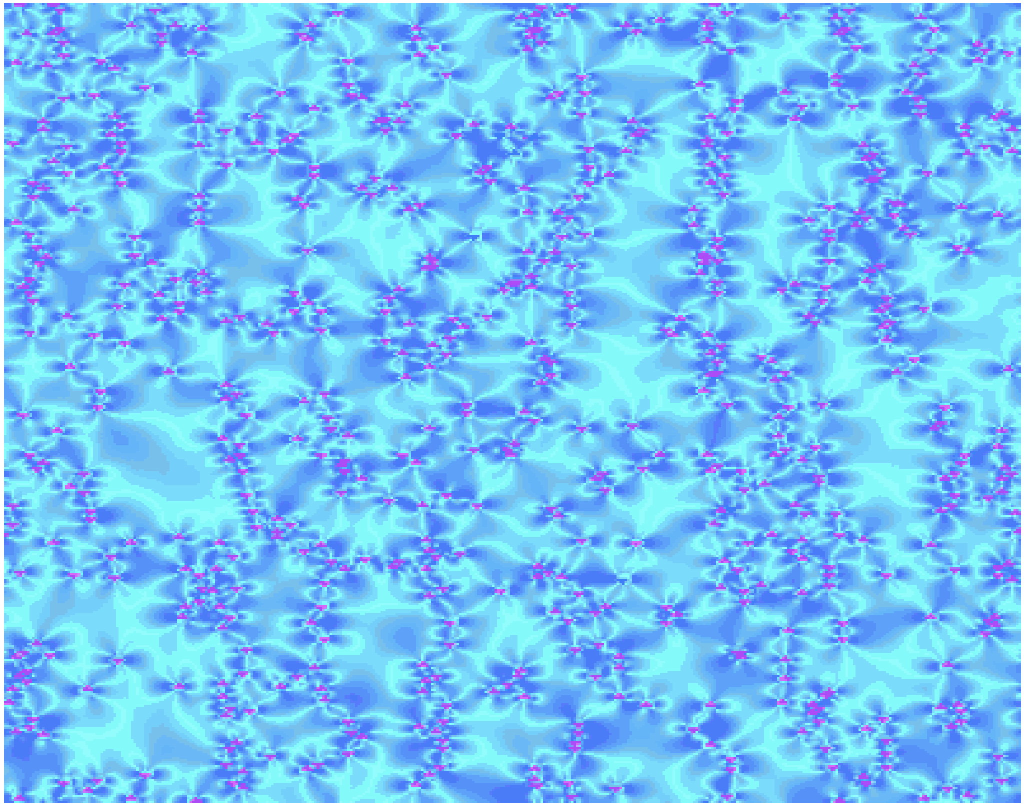
Georgios Tsekenis 2010;

Phase Field Crystal Models: Pak Yuen Chan, Georgios Tsekenis, J. Dantzig, KD, N. Goldenfeld (PRL 2010);

phase field models: M. Koslowski, …

Crystal with many edge dislocations under shear (Miguel et al. Nature 2001)



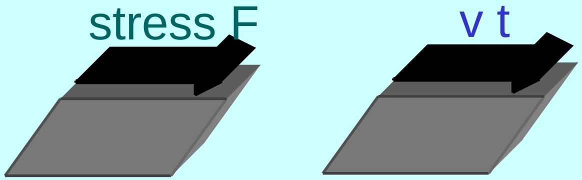


hhttp://www.tf.uni-kiel.de/matwis/amat/def_en/kap_5/illustr/a5_1_1.html

Simple *Analytic* Model for deformation under shear:

- Simple discrete model (KD, Y. Ben-Zion, J.T. Uhl, PRL 2009)
- with only 1 tuning parameter (weakening ε) –
- yields *exact analytical* scaling predictions
- for 2 different boundary conditions:

fixed applied stress OR fixed boundary velocity



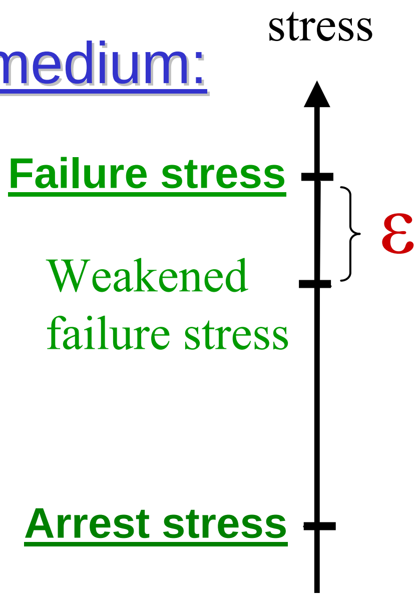
•Results:

- *same* scaling exponents/functions as magnet model,

(because *same* mean field theory).

- *same* mean field theory as for earthquakes

Dynamic equation for slip evolution in heterogeneous medium:

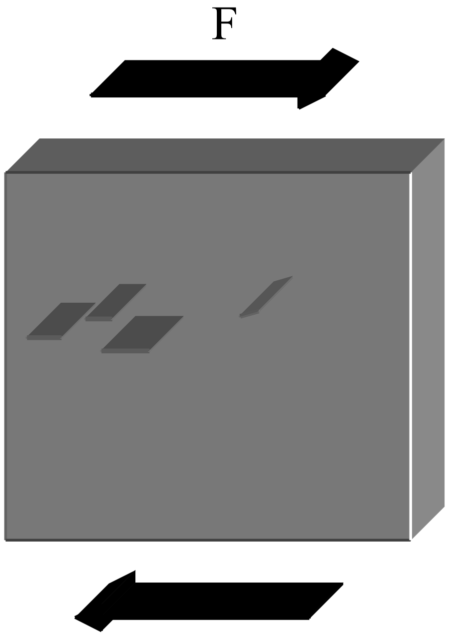


$$\eta\, \partial u(\mathbf{r},\mathbf{t})/\partial t = F + \sigma_{int}(\mathbf{r},t) - f_R[u, r, \text{history}]$$

Slip velocity ~ stress + interaction + Pinning due to heterogeneities

interaction:

$$\sigma_{int}(\mathbf{r},t) = \int_{-\infty}^{t} dt' \int d^d r' \; J(\mathbf{r}-\mathbf{r}', t-t') \times [u(\mathbf{r}',t') - u(\mathbf{r},t)]$$



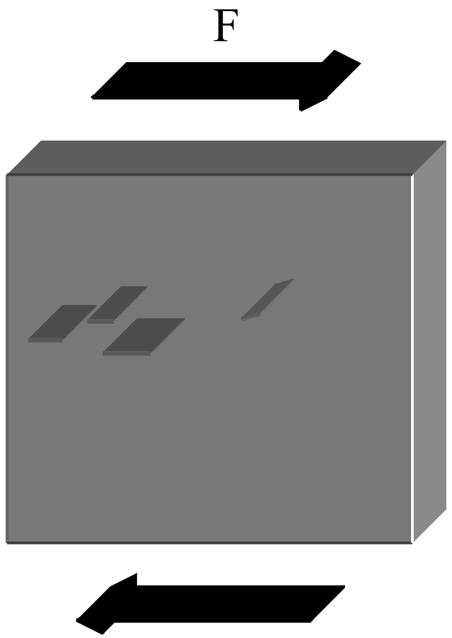
Renormalization Group:

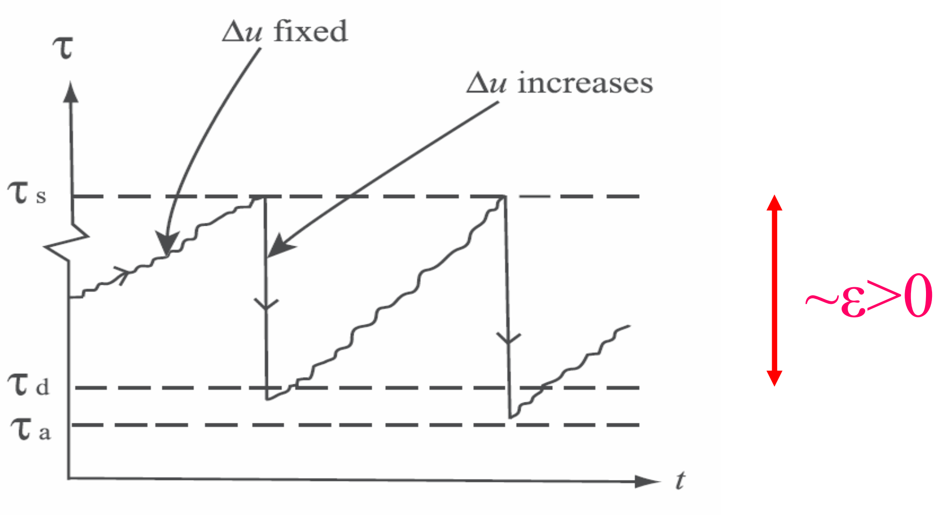
Interaction sufficiently long range $\int dt\; J(\mathbf{r}, t) \sim r^{-2}$

SO THAT **MEAN FIELD THEORY** IS EXPECTED TO GIVE **EXACT RESULTS** !!!

Related models: Chen, Bak, Obukhov (PRA 1991), Zaiser, Adv. of Phys, **55**, 185-245 (2006).

Threshold pinning ($f_R[u, r, \text{history}]$)





$$\varepsilon = (\tau_s - \tau_d)/\tau_s = \text{dynamic weakening}$$

weakening (ε>0)

during failure avalanche:

failed regions get weakened by O(ε)

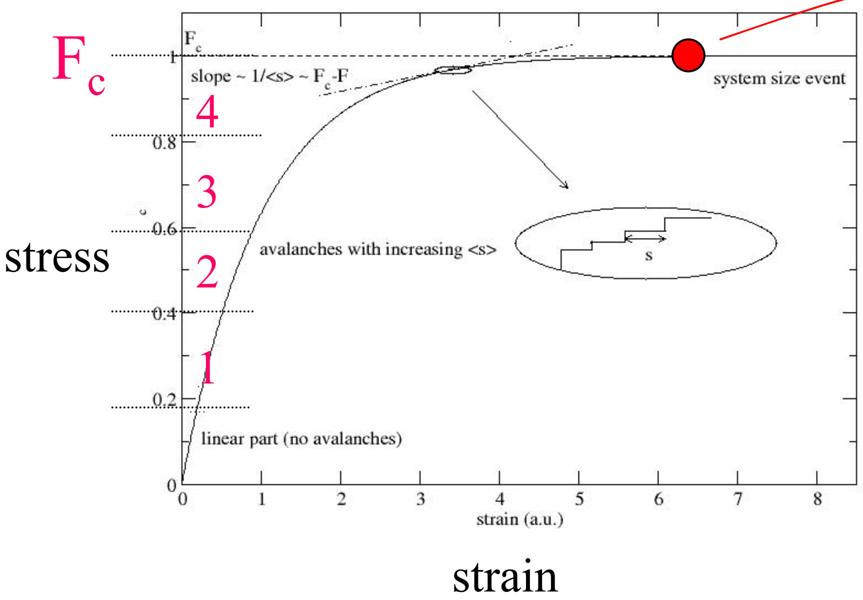
reheal to old strength after avalanche

hardening (ε<0)

each failure event raises failure threshold everywhere by ~|ε/N|.
used to model aftershocks
(Mehta, KD, Ben-Zion, PRE 2006)

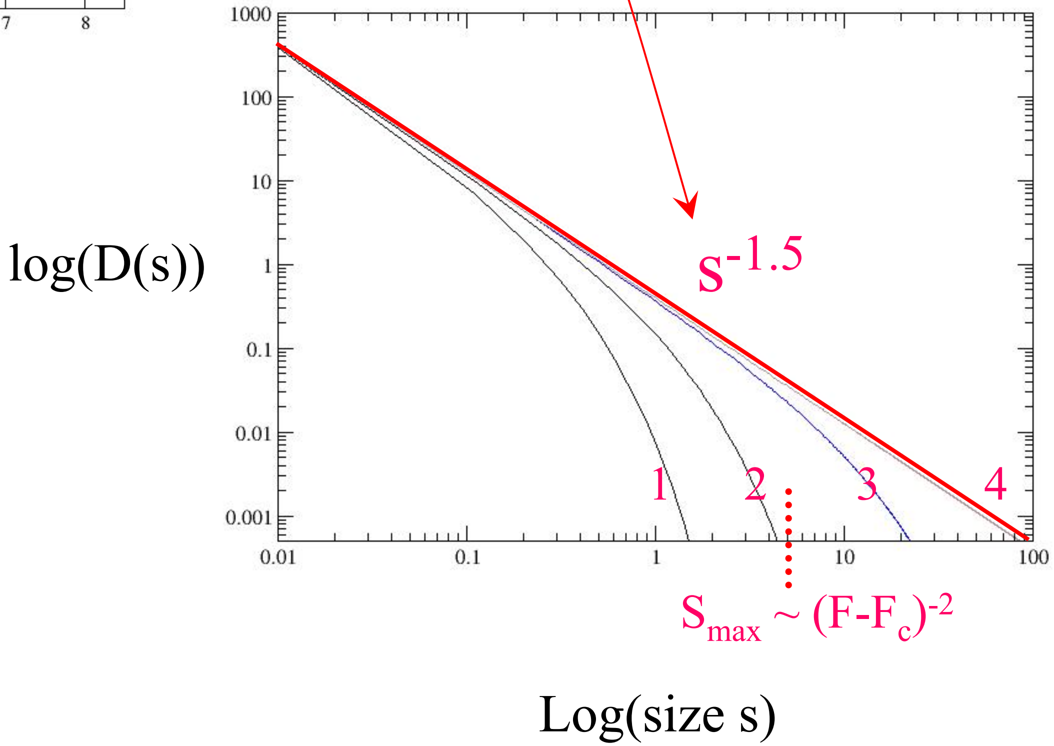
Fixed stress boundary condition: Results for ε=0:

Stress strain curve (ductile)

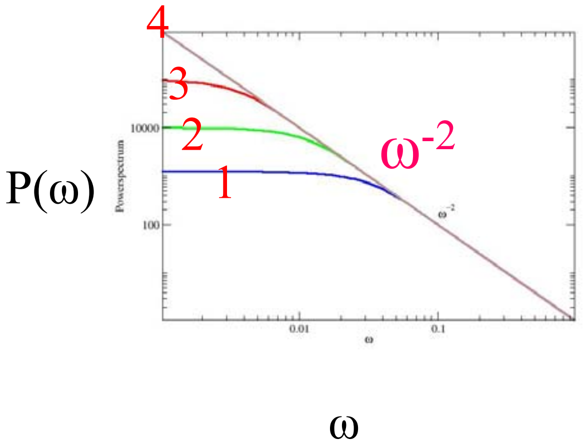


critical point

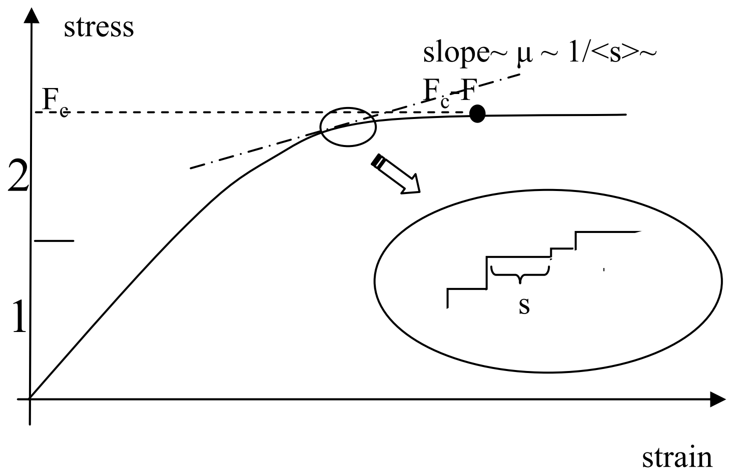
Avalanche size distribution:



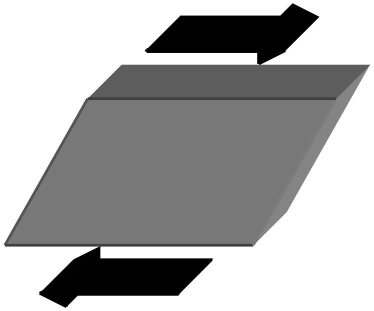
Power spectrum



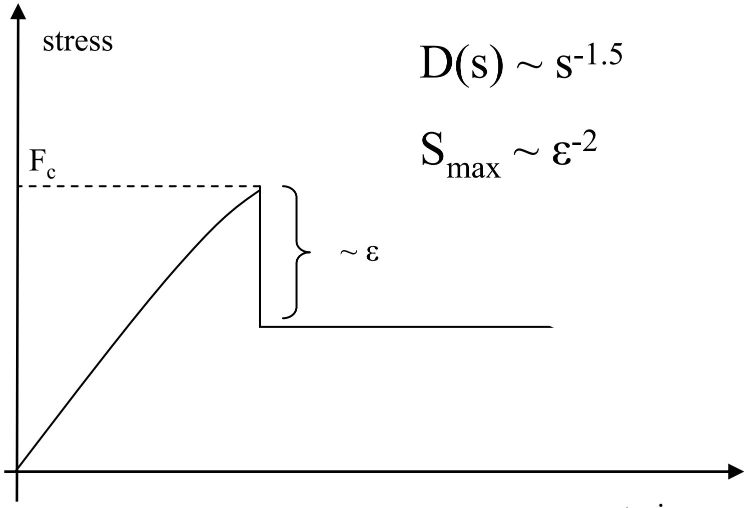
Without weakening ("ductile"): ($\varepsilon=0$):



cont. depinning transition
and distributed slip



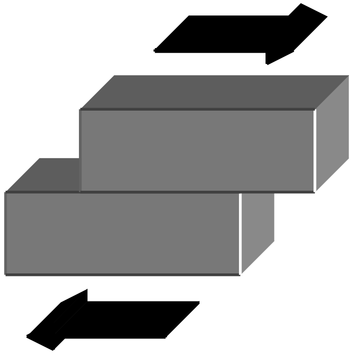
With weakening ("brittle"): ($\varepsilon>0$):



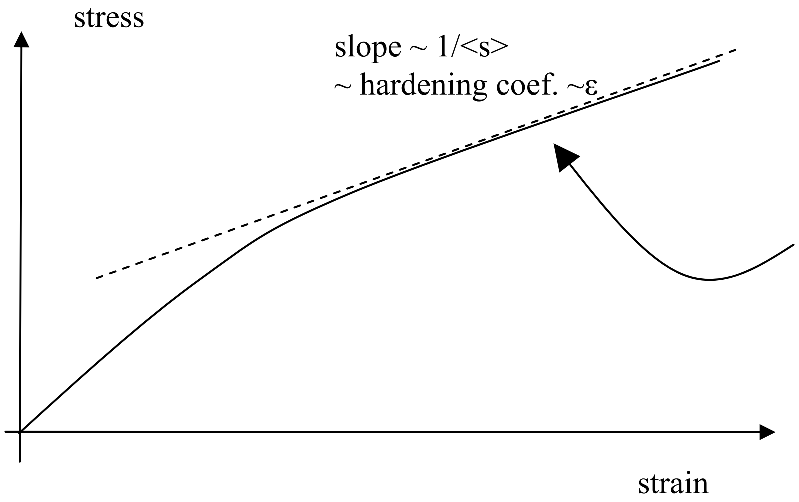
$$D(s) \sim s^{-1.5}$$

$$S_{max} \sim \varepsilon^{-2}$$

first order depinning transition
and slip localization



Stress Strain Curve in the presence of hardening (“ductile”): $(\epsilon < 0)$

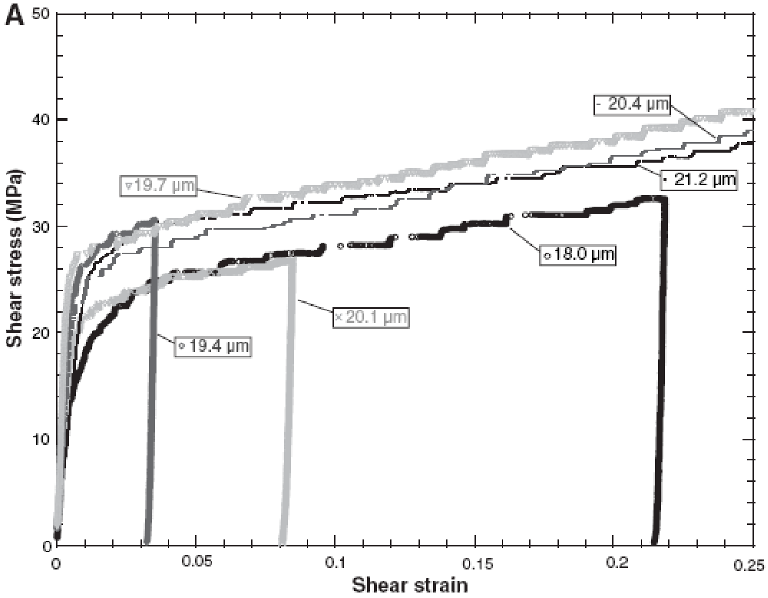


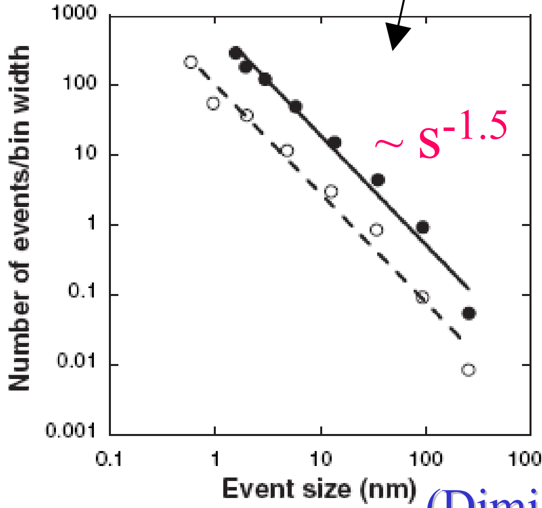
$D(s) \sim s^{-1.5}$
$P(\omega) \sim \omega^{-2}$
$D(T) \sim T^{-2}$

etc.

distributed deformation

Agrees with experiment



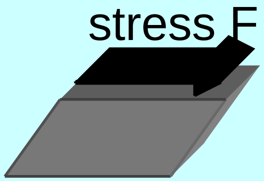


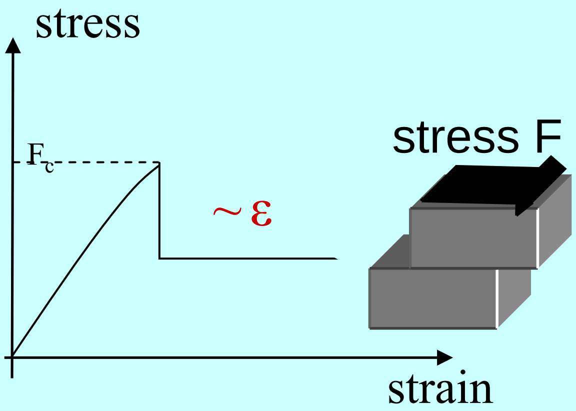
(Dimiduk, et al Science 2006)

Simple *Analytic* Model for deformation under shear:

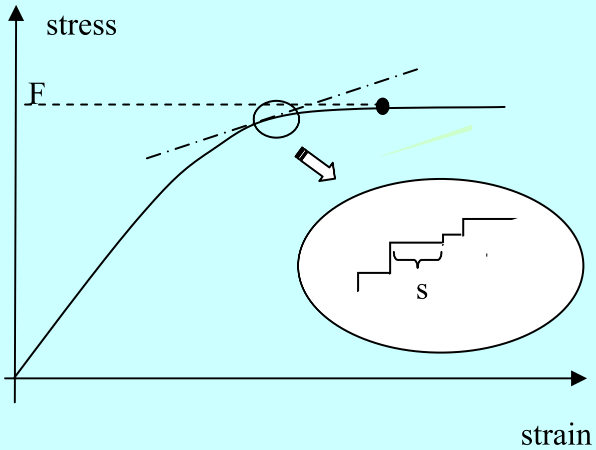
Main Results: (KD, Ben-Zion, Uhl, PRL 2009)

- For slowly increasing stress boundary condition:

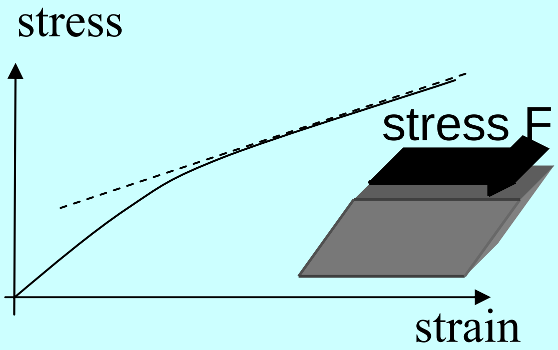




Brittle $(\varepsilon>0)$



Plastic $(\varepsilon=0)$

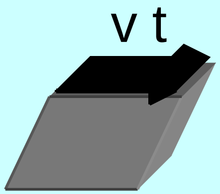


Hardening $(\varepsilon<0)$

Avalanche-size distributions (power laws with stress dependent cutoff)

Power spectra, Scaling Functions !! Scaling behavior agrees with experiments!

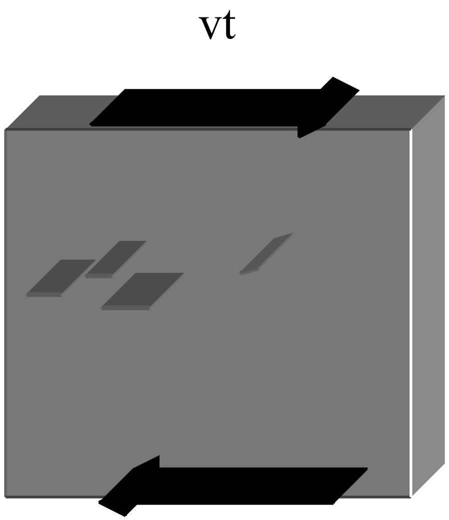
- For slow tangential velocity boundary condition:



same scaling behavior and phase diagram as Ben-Zion and Rice single earthquake fault zone model

For slowly moving boundary cond.: Same phase diagram and scaling as Ben-Zion and Rice single fault zone eq. model:

Ben-Zion and Rice, 1993, 1995; Ben-Zion, 1996; Fisher et al., 1997; KD et al., 1998; Mehta et al., 06; Zöller et al., 05, 07; KD and Ben-Zion, 08; Bailey and Ben-Zion, 08)

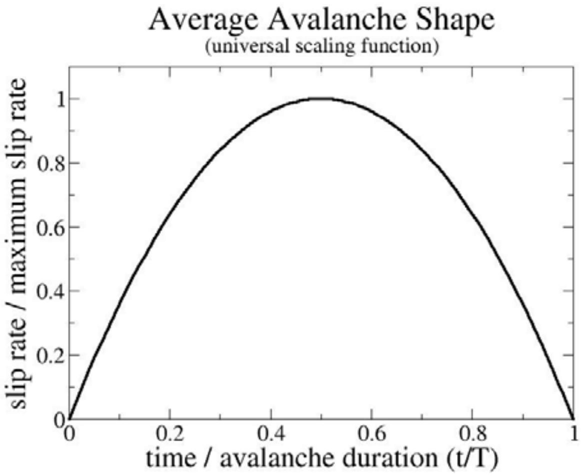


weakening ($\varepsilon>0$): Char.Eq.Distr. + mode switching

$\varepsilon=0$: Gutenberg Richter

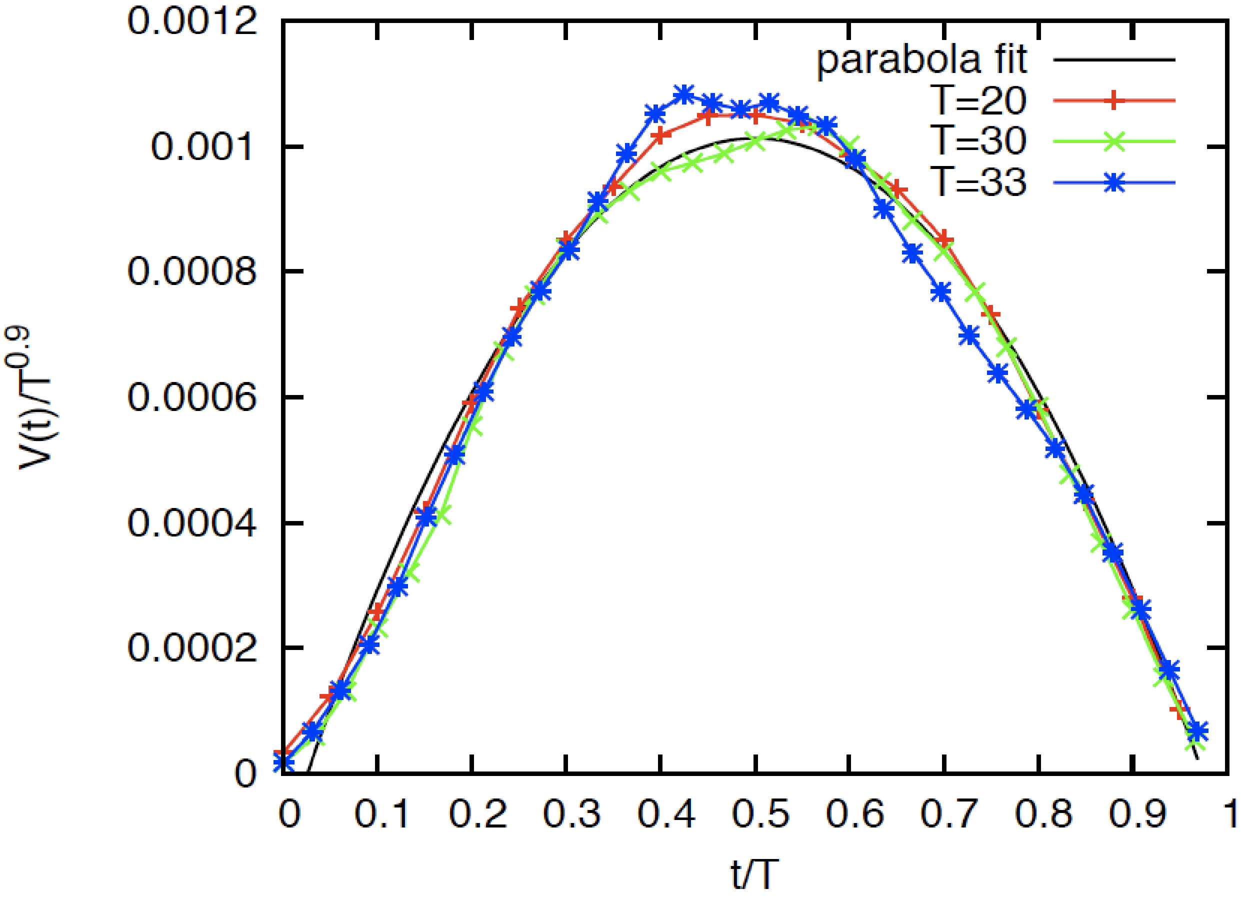
hardening ($\varepsilon<0$): Gutenberg Richter (with Aftershocks)

There are more predictions for universal exponents, scaling functions, etc…



Georgios Tsekenis: Simulation of slip avalanche profiles

Exponents and Scaling function match Mean Field Theory Predictions!

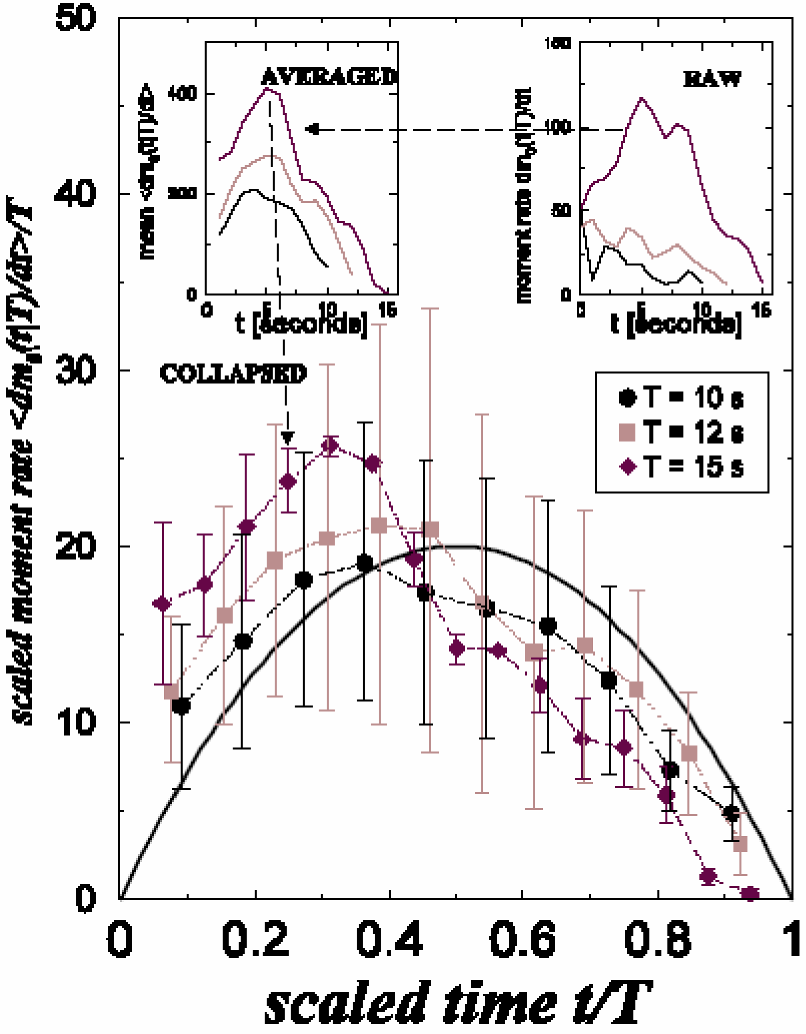


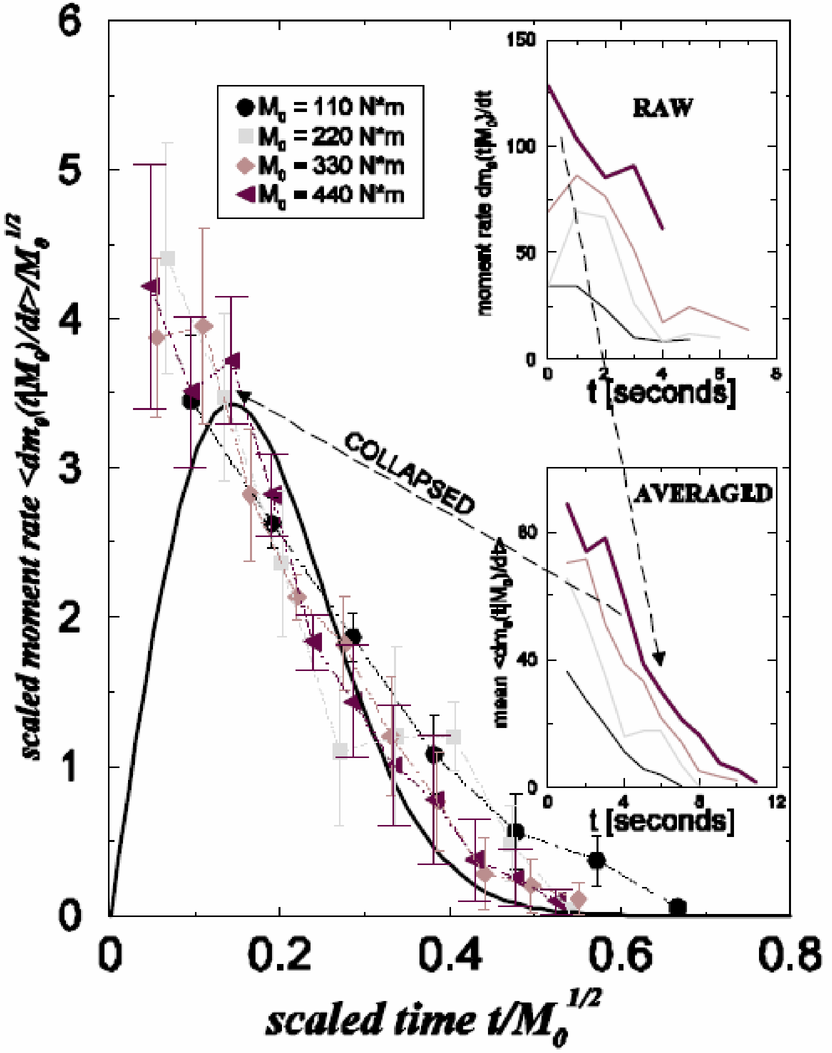
(Prediction of MFT parabola: Kuntz, Panagopoulos, Sethna)

Earthquakes: Universal Scaling Functions:

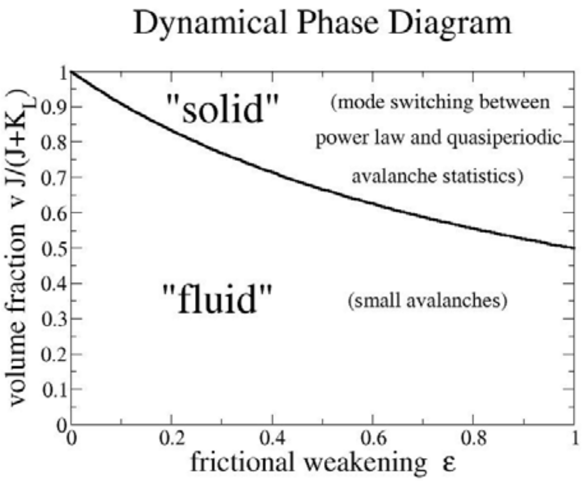
Data from Susan Bilek, see

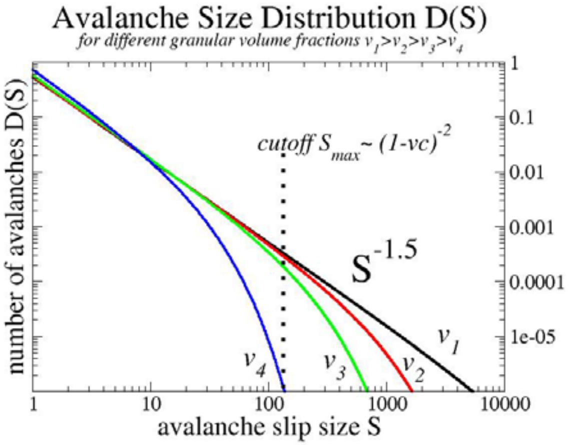
Mehta, KD, Ben-Zion, 2005

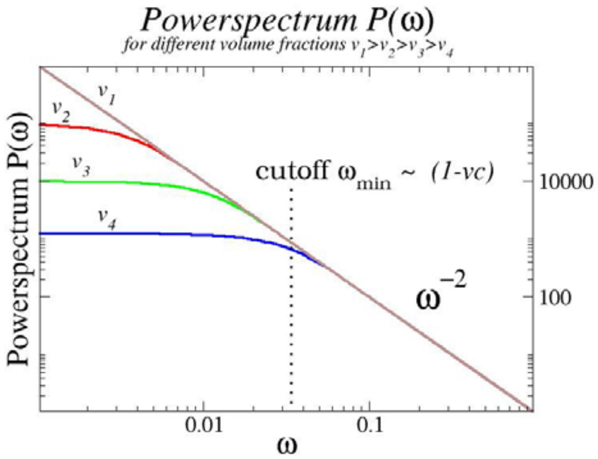




Similar SIMPLE model for avalanches in sheared granular materials:

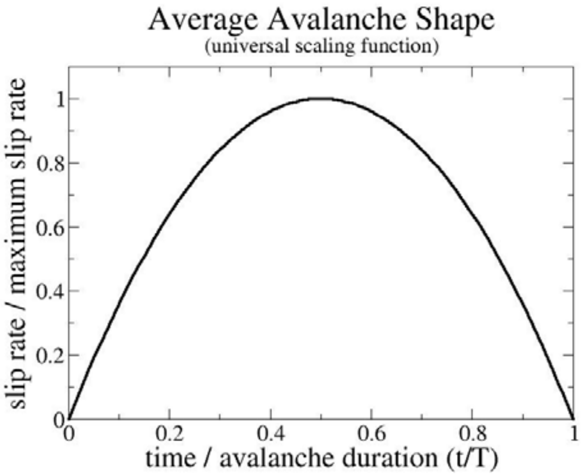

Dynamical Phase Diagram


Avalanche Size Distribution D(S)
for different granular volume fractions $v_1>v_2>v_3>v_4$

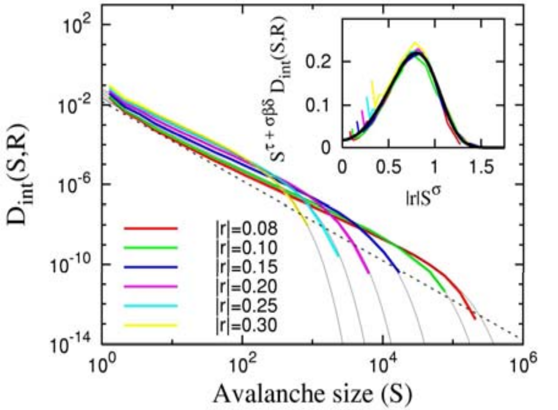

Powerspectrum P(ω)
for different volume fractions $v_1>v_2>v_3>v_4$

Experiments: APS talk by Karen Daniels

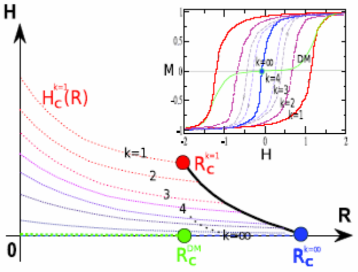
Exponent or other universal quantity	**Mean Field Theory**	**granular experiment [6,8-10,20-21]**	**granular simulations [2-4]**
κ (size distribution)	1.5	1.5	?
1/ρυz (power spectrum)	2 if v ≈ 1; 0 if v <<1	1.8-2.5, 2	2 in solid regime 0 in fluid regime
α (duration distribution) (^)	2	2 or exponential ?	?
Source time function averaged over all avalanches of same duration T.	Symmetric (parabola)	?	Symmetric: fit by sine function (?)
Quasiperiodic event statistics	Yes, if ε>0 and v>v*	some-times	during mode switching
Mode switching (between powerlaw and quasiperiodic)	Yes, if ε>0 and v>v*	?	Yes, in solid regime

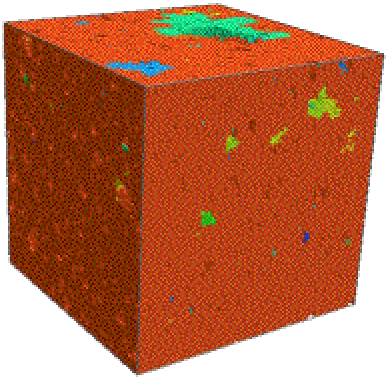

Average Avalanche Shape
(universal scaling function)

SUMMARY

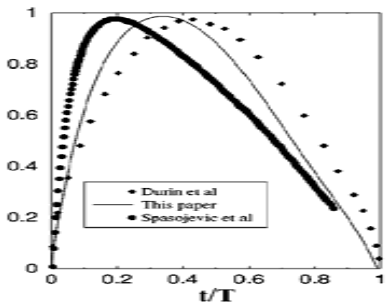


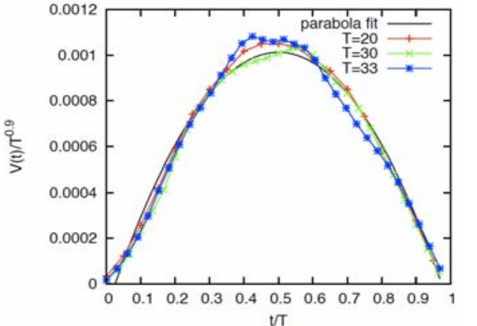
- **HUGE nucleation universality class include:**
  - ✓ hard magnets
  - ✓ equilibrium and nonequilibrium
  - ✓ plastic charge density wave depinning
  - ✓ high Tc superconductors(?)…





- **Domain wall mean field theories exact & same scaling results for:**
  - ✓ magnetic domain wall motion
  - ✓ plasticity
  - ✓ granular materials
  - ✓ Earthquakes

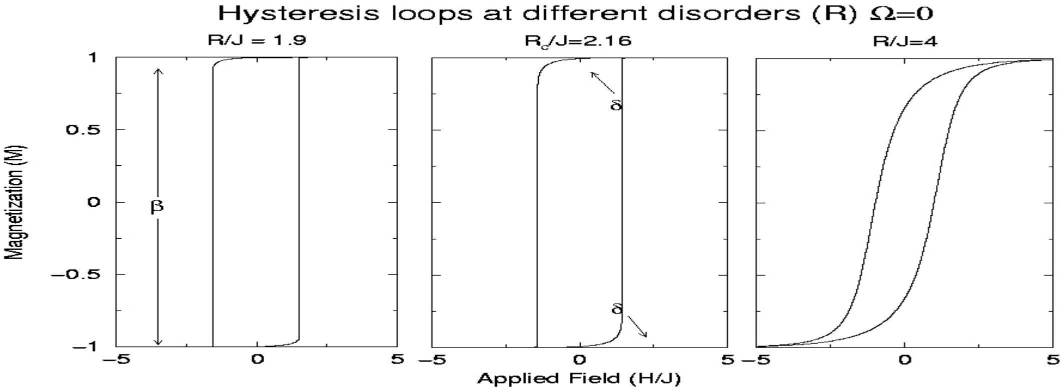




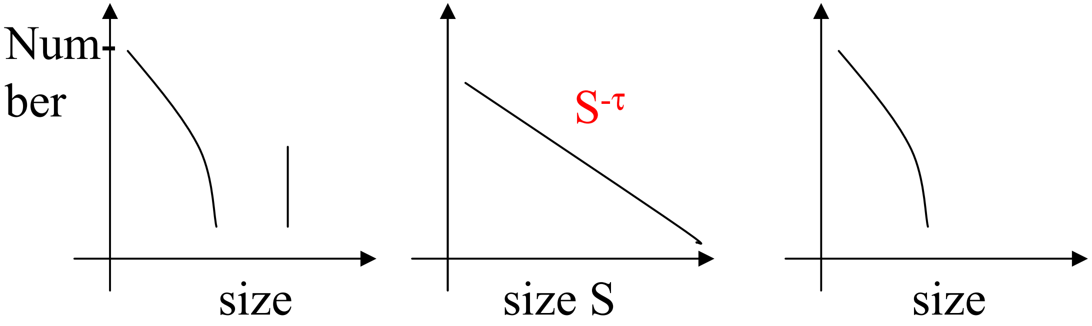
- **Experimental tests ?!** Got DATA ?

Discussion Slides:

Summary on simple magnet model & further results:



clean ⋯⋯⋯⋯⋯⋯⋯⋯⋯→ disordered



EXPERIMENTS ???!!!

Renormalization group (**huge universality class**)

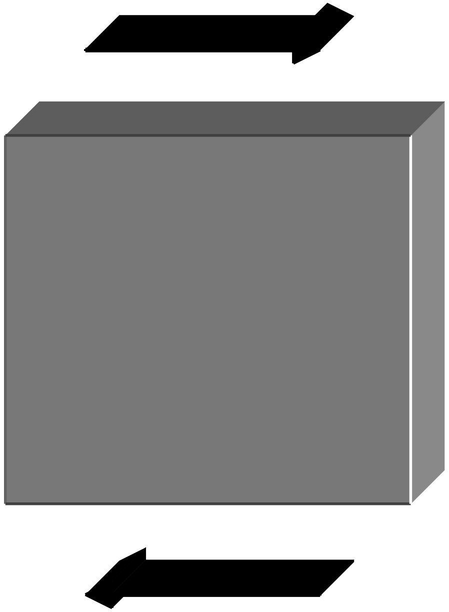
equilibrium and **nonequilibrium** critical behavior the same !!

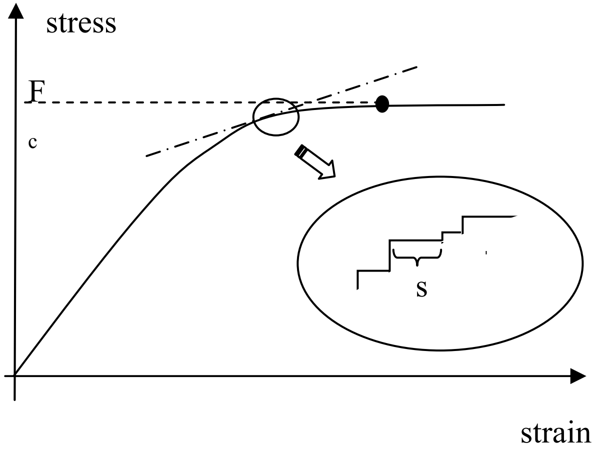
- finite sweep rate effects (model indep. theory)
- Second Spectra (mean field theory), universal scaling functions, return point memory,
- Temperature effects...

Next:
*Plasticity,
*Granular materials,
*Earthquakes….

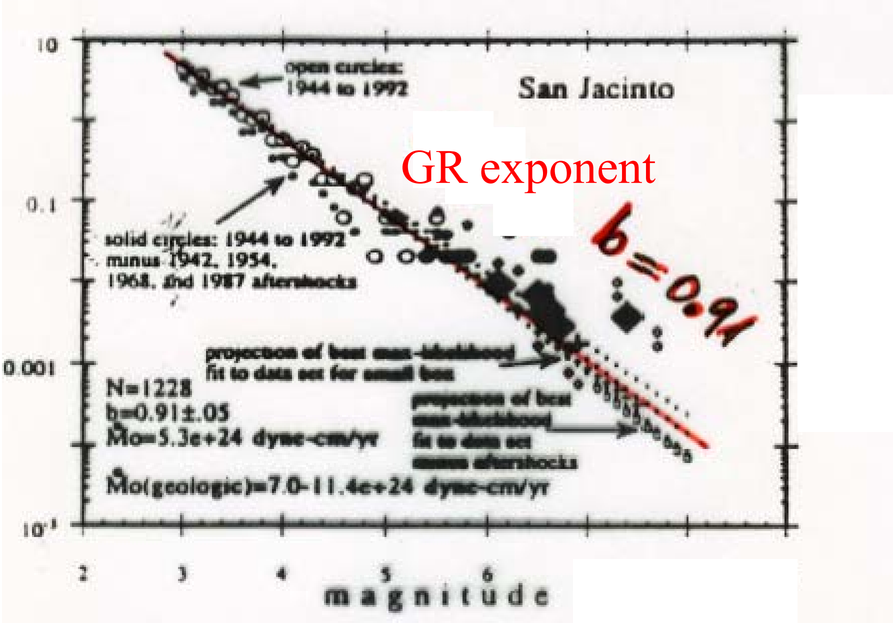
Plastic deformation and crackling noise: Learning from Dislocations and granular materials about Earthquakes ???

Yehuda Ben-Zion, Jonathan T. Uhl, Georgios Tsekenis, Pak Yuen Chan, Nigel Goldenfeld, Jonathan Dantzig, KD



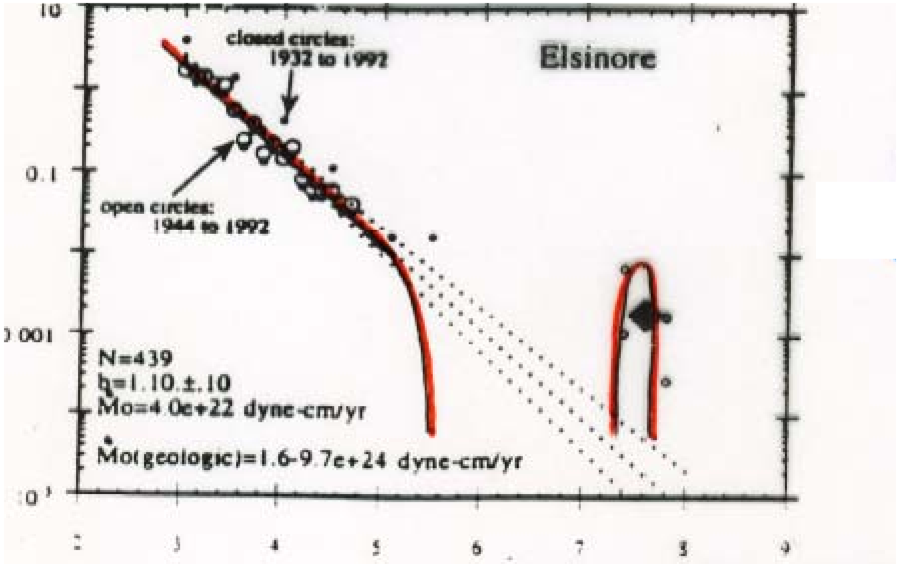


Universal
Gutenberg Richter
Scaling behavior



Magnitude ~ 2/3 Log(total displacement)

OR



(Wesnousky '94)

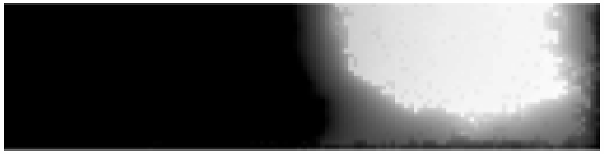
Characteristic
Earthquake
distribution ?

Phase Diagram

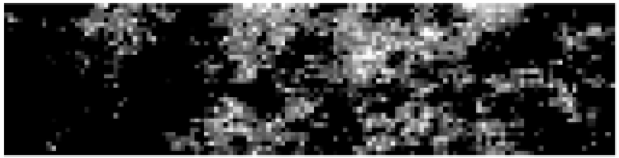
Mean field exponent: $b=0.75$

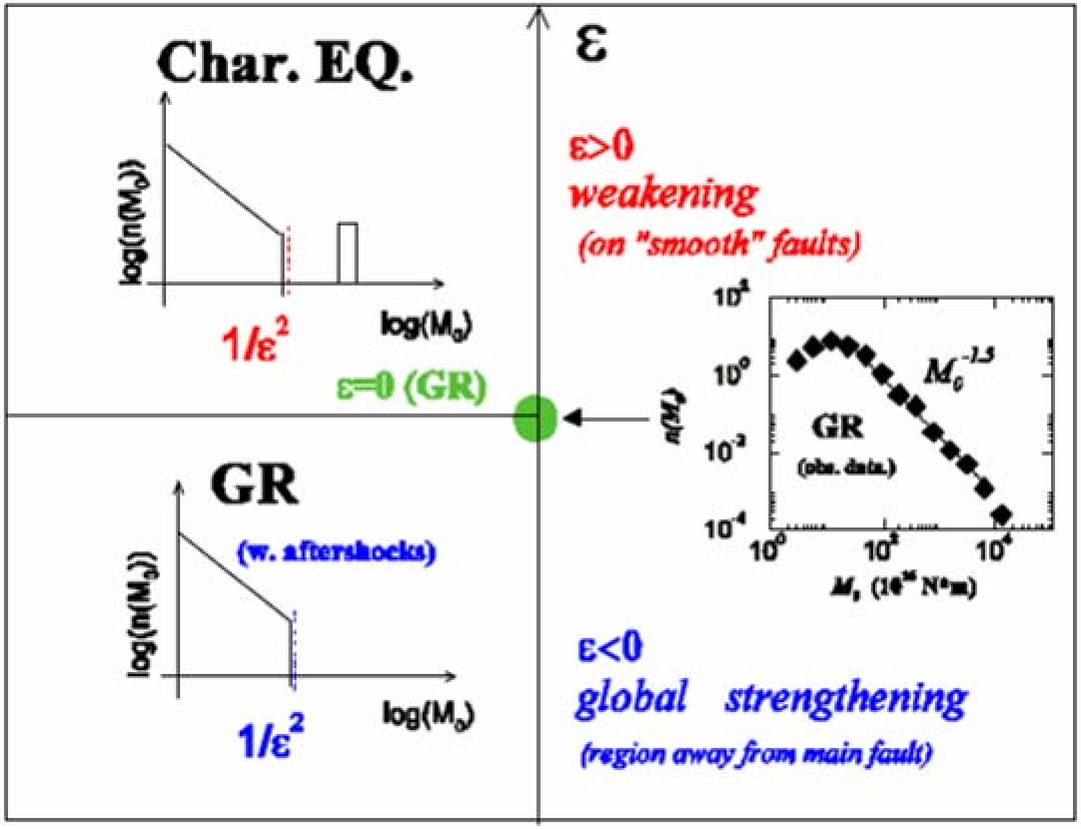
for Frequency~10^{-bM}

cracklike large events:
moment~area$^{3/2}$



small events scale as
moment~area

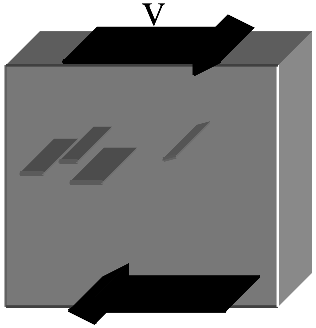


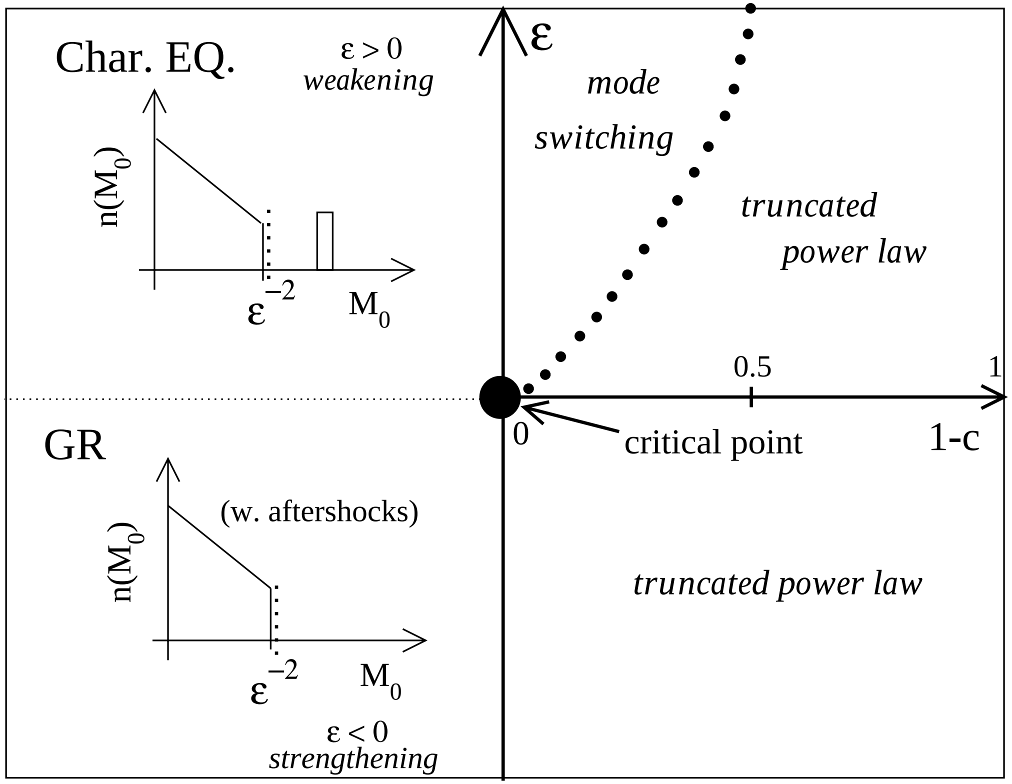


Mehta, KD, Ben-Zion, PRE 2005

For fixed velocity boundary conditions:

Scales like Ben-Zion and Rice earthquake model

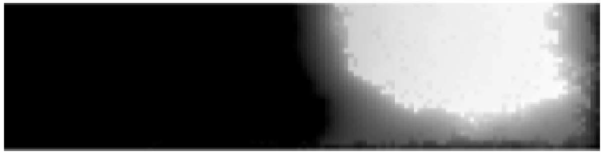




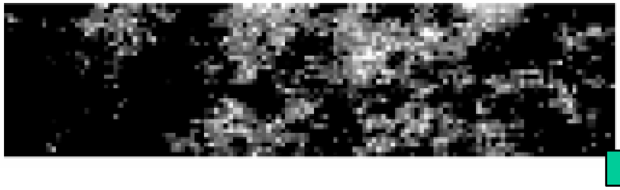
Mean field exponent: $b=0.75$

for Frequency~ 10^{-bM}

cracklike large events:
moment~area$^{3/2}$



small events scale as
moment~area

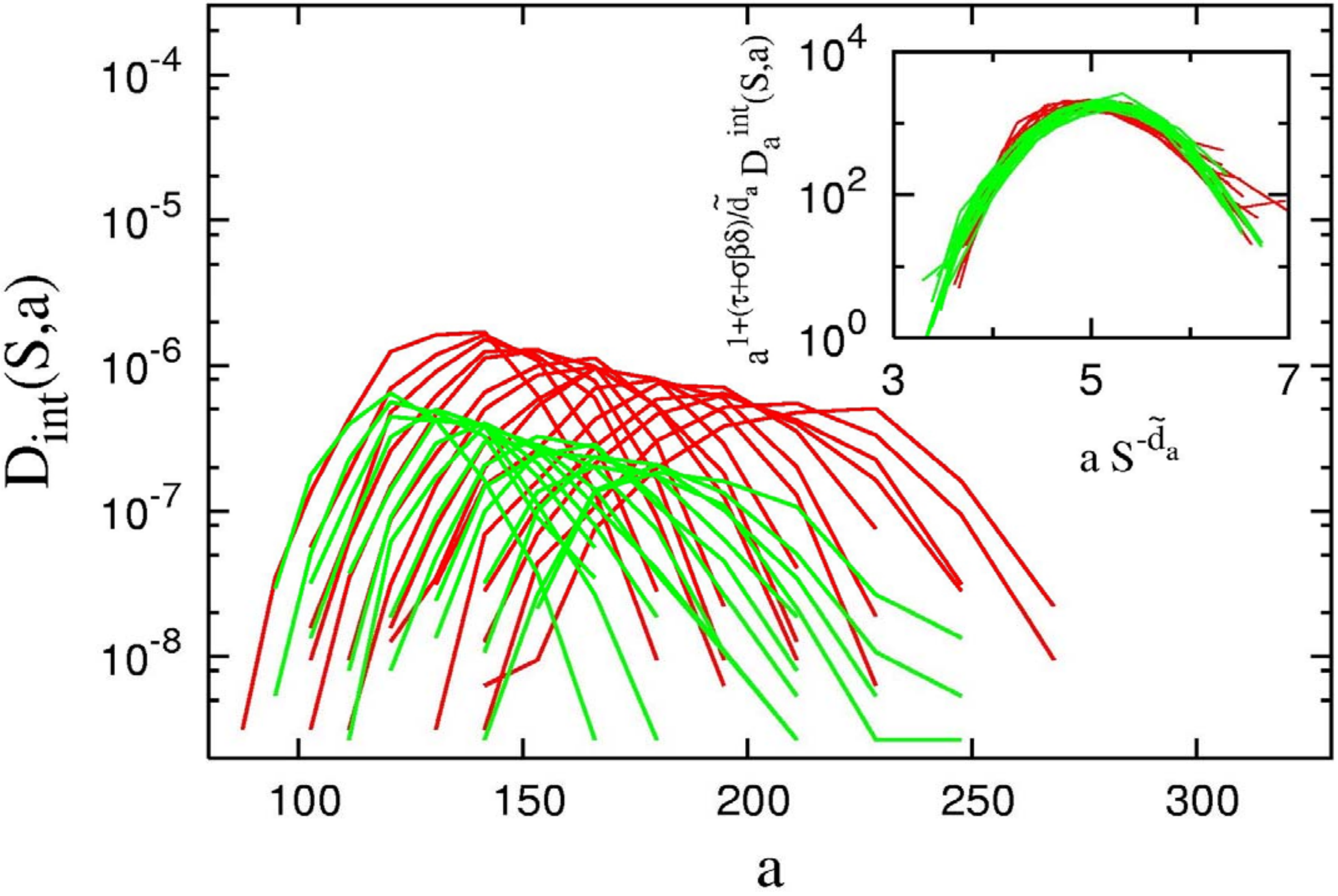


KD, Ben Zion (2008)

•Result: ~Same scaling of Avalanche Surface Area Distribution

Integrated avalanche surface distribution for avalanche size S

$$D_{\mathrm{a}}^{(\mathrm{int})}(S,a) \sim a^{-(\tau+\sigma\beta\delta+\tilde{d}_{\mathrm{a}})/\tilde{d}_{\mathrm{a}}}\ \mathcal{D}_{\mathrm{a}}^{(\mathrm{int})}(a/S^{\tilde{d}_{\mathrm{a}}})$$

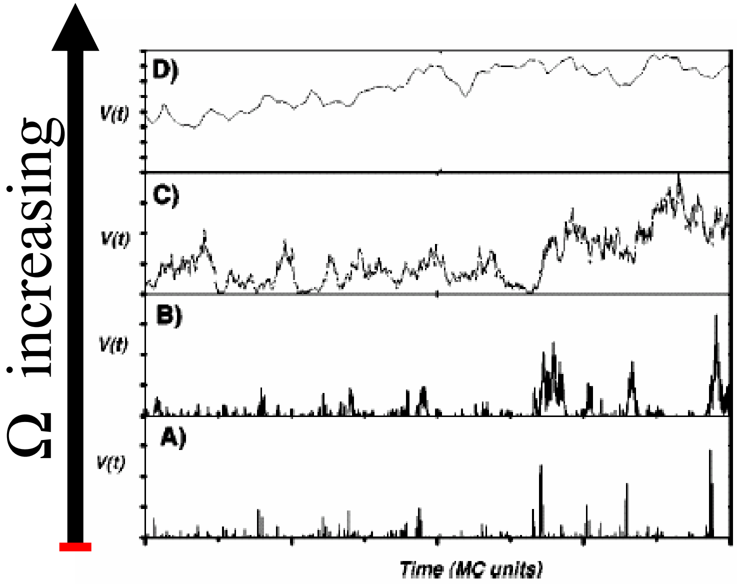


Liu, KD, 2009

$$\Omega > 0$$

Sweep Rate Regimes of Barkhausen Noise

White,KD
PRL2003



Region III ("fast")

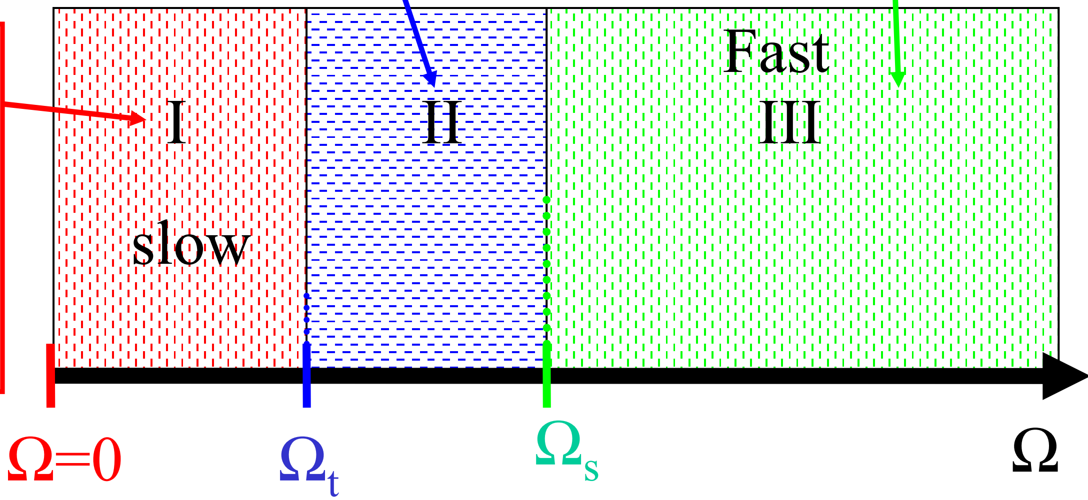
- Low Freq. PS changed due to spatial overlap

Region II (intermediate)

- Power spectra unchanged.
- Only temporal overlap

Region I ("slow")

- power spectra unchanged
- Pulse statistics are affected in general



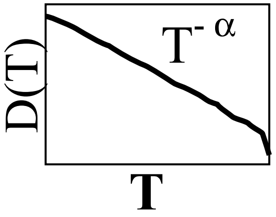
No pulse statistics for $\Omega>\Omega_t$

How are finite sweeprate effects to be understood?(White, KD PRL 2003)

(MODEL “INDEPENDENT” THEORY):

Superposition of power law distributed avalanches

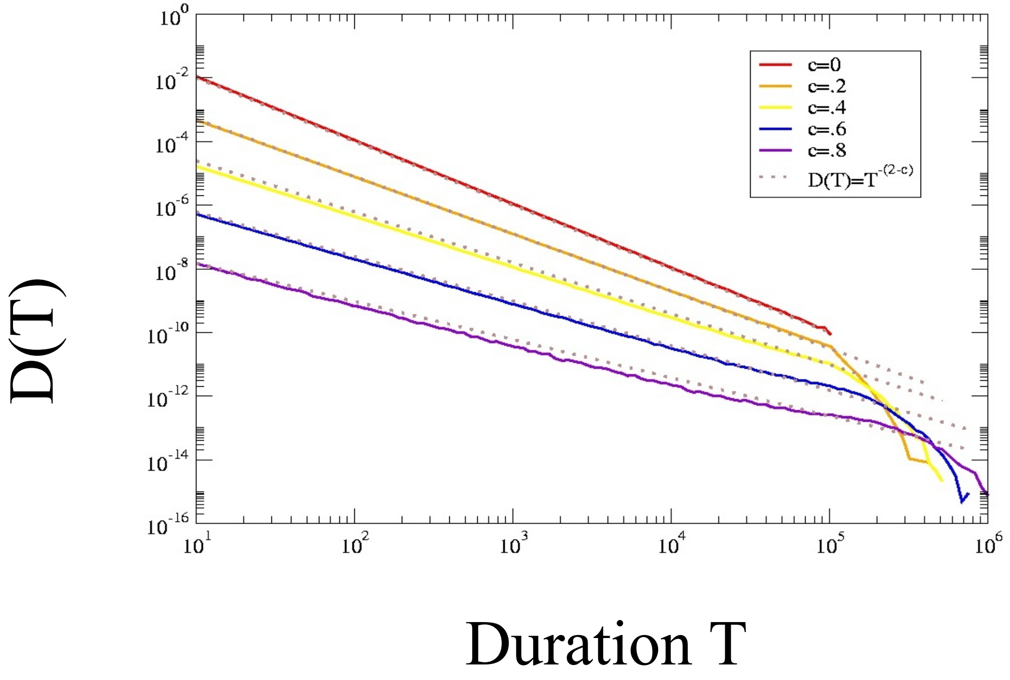
In slow regime dependence of pulse exponents on sweep rate explained by temporal overlap of pulses



$\Omega=0$	$\Omega>0$	
$\alpha_o < 2$	α unchanged	Durin, Zapperi
$\alpha_o = 2$	$\alpha(\Omega) = \alpha_o - c\Omega$	ABBM,Durin
$\alpha_o > 2$	α unchanged for large durations	???

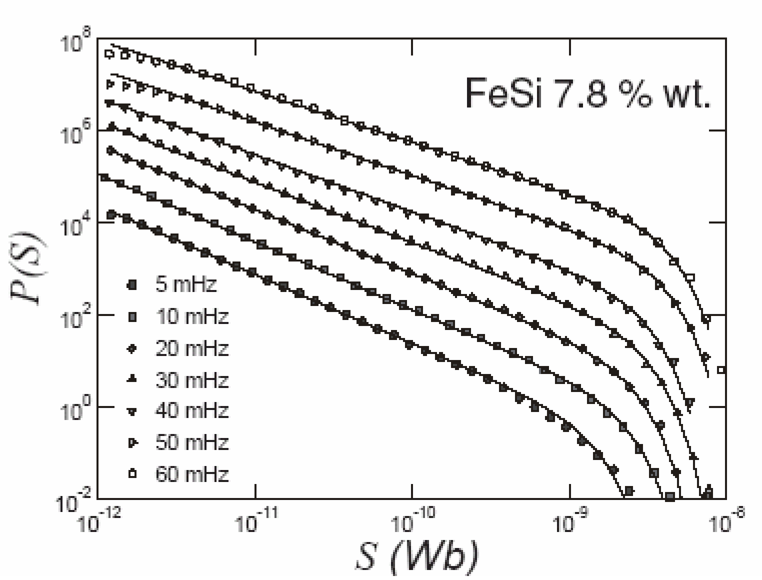
Results for $\alpha(\Omega = 0) = 2$

Linear change in exponent $\alpha(\Omega) = \alpha_o - c\Omega$



Agrees with Experiment:
Plot from Durin and Zapperi
Cond-mat/0404512v1

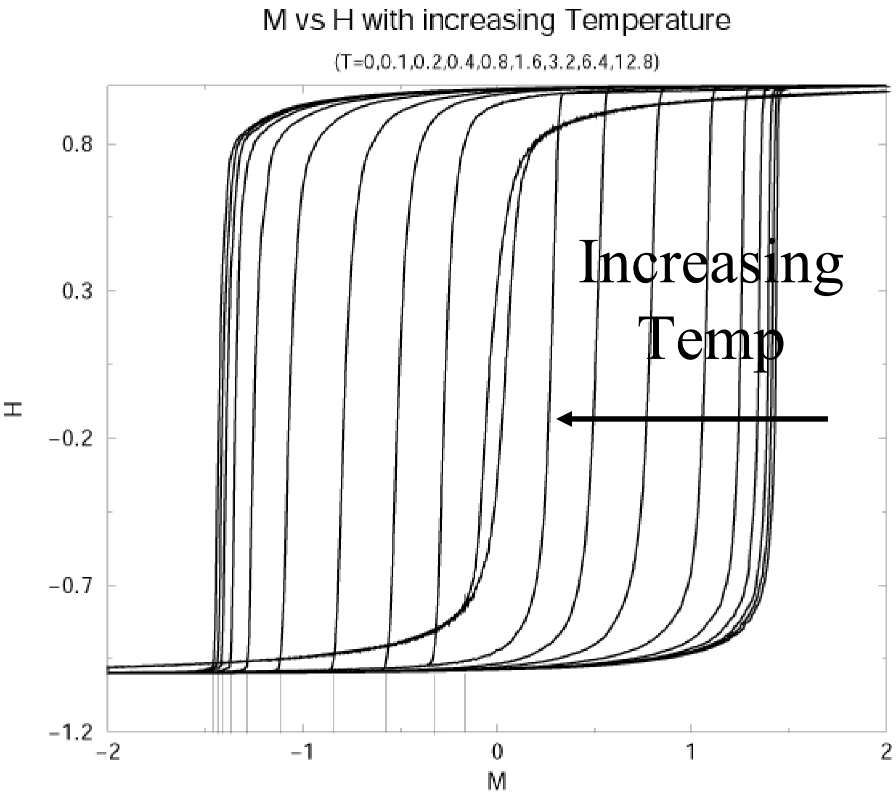
$\tau(\Omega) = 1.5 - c\Omega/2$



Temperature > 0

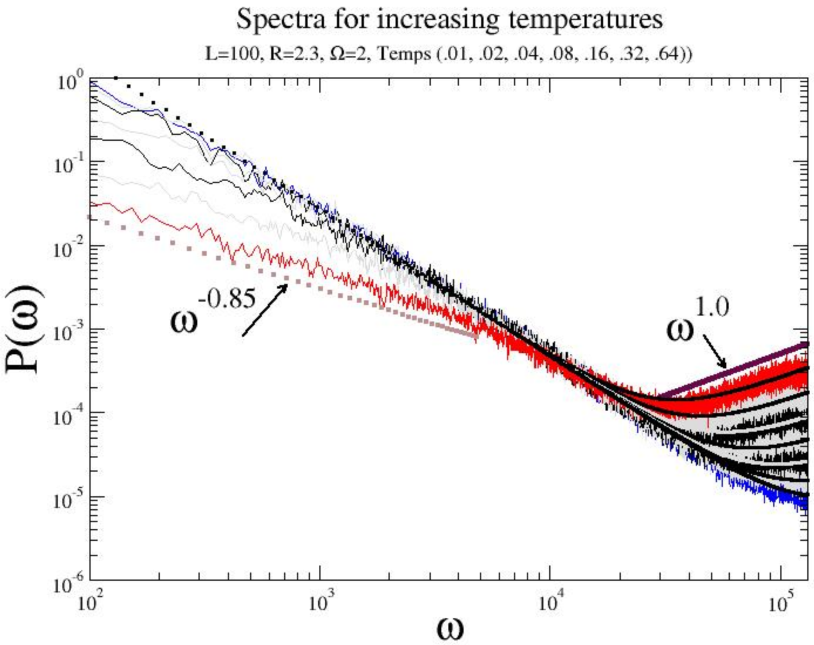
Scaling Theory and
Simulations using the random field Ising model near the
zero temperature far from eq. critical regime (in progress)

Robert White, Alex Travesset, Yang Liu, KD, EPL 2009,


M vs H with increasing Temperature

(T=0,0.1,0.2,0.4,0.8,1.6,3.2,6.4,12.8)

Increasing Temp


Spectra for increasing temperatures

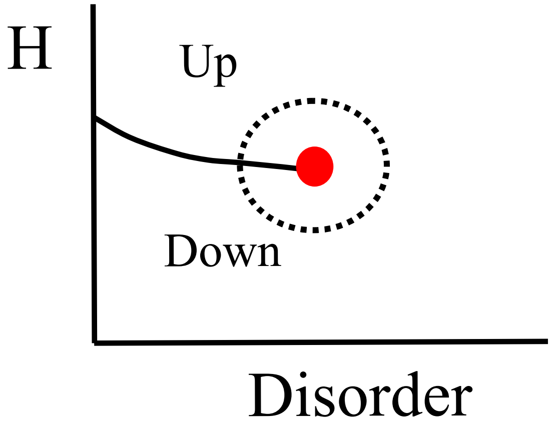
L=100, R=2.3, Ω=2, Temps (.01, .02, .04, .08, .16, .32, .64))

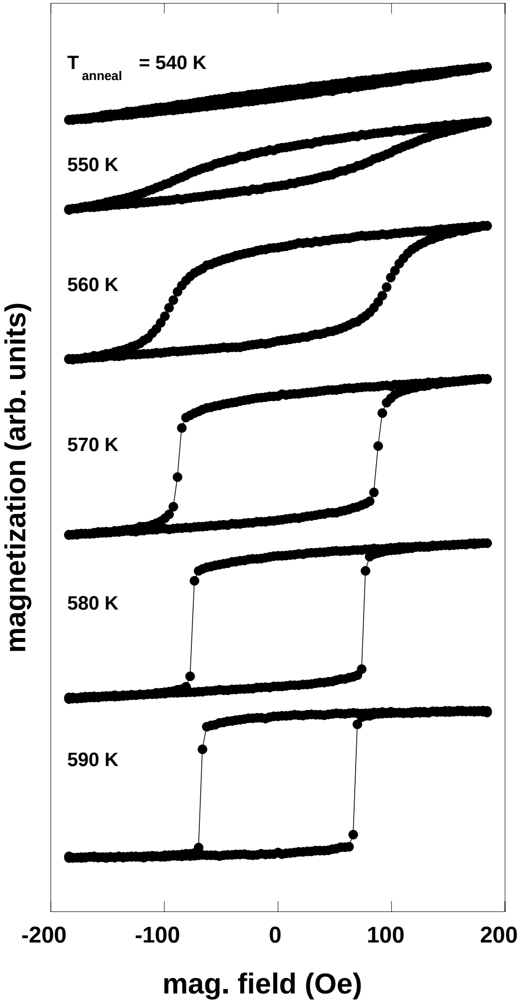
Experiments-

Phase transition?

Disorder is important!

Noise experiments?





“Dirty”

“Clean”

A.Berger et.al. PRL 85 4176(2000)

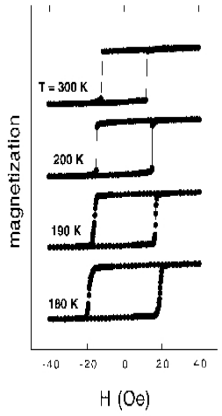
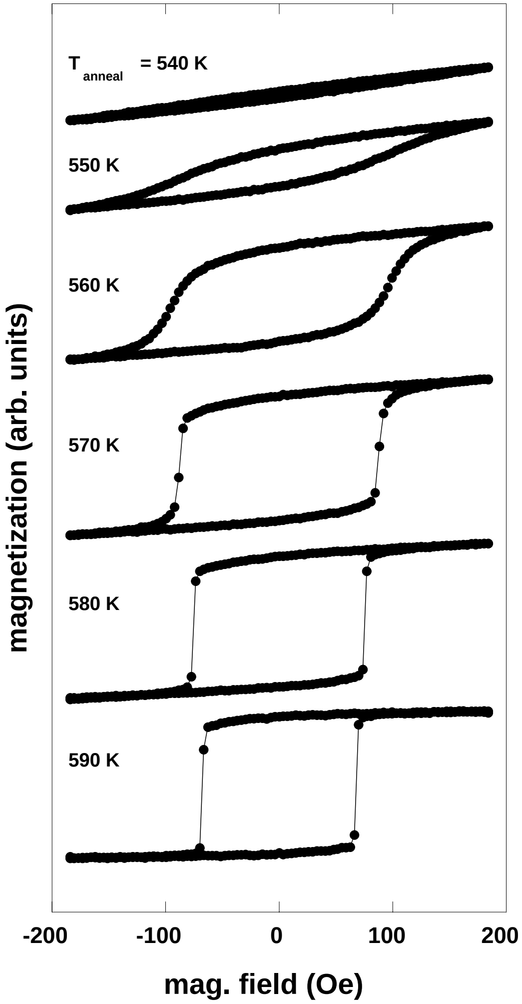


FIG. 1. $M(H)$ loops measured on a Co/CoO-bilayer structure for the temperatures indicated. The thin lines are guides to the eye.

Gd(0001)/W(110)-films

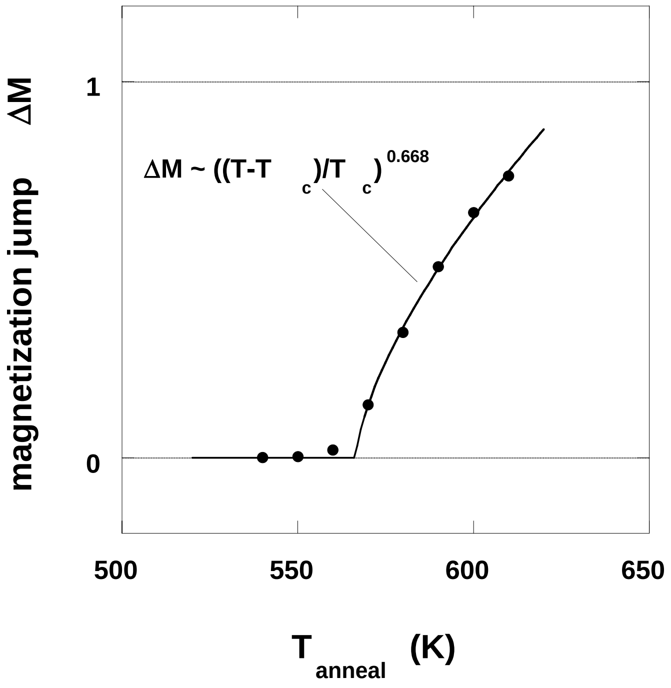
annealing study



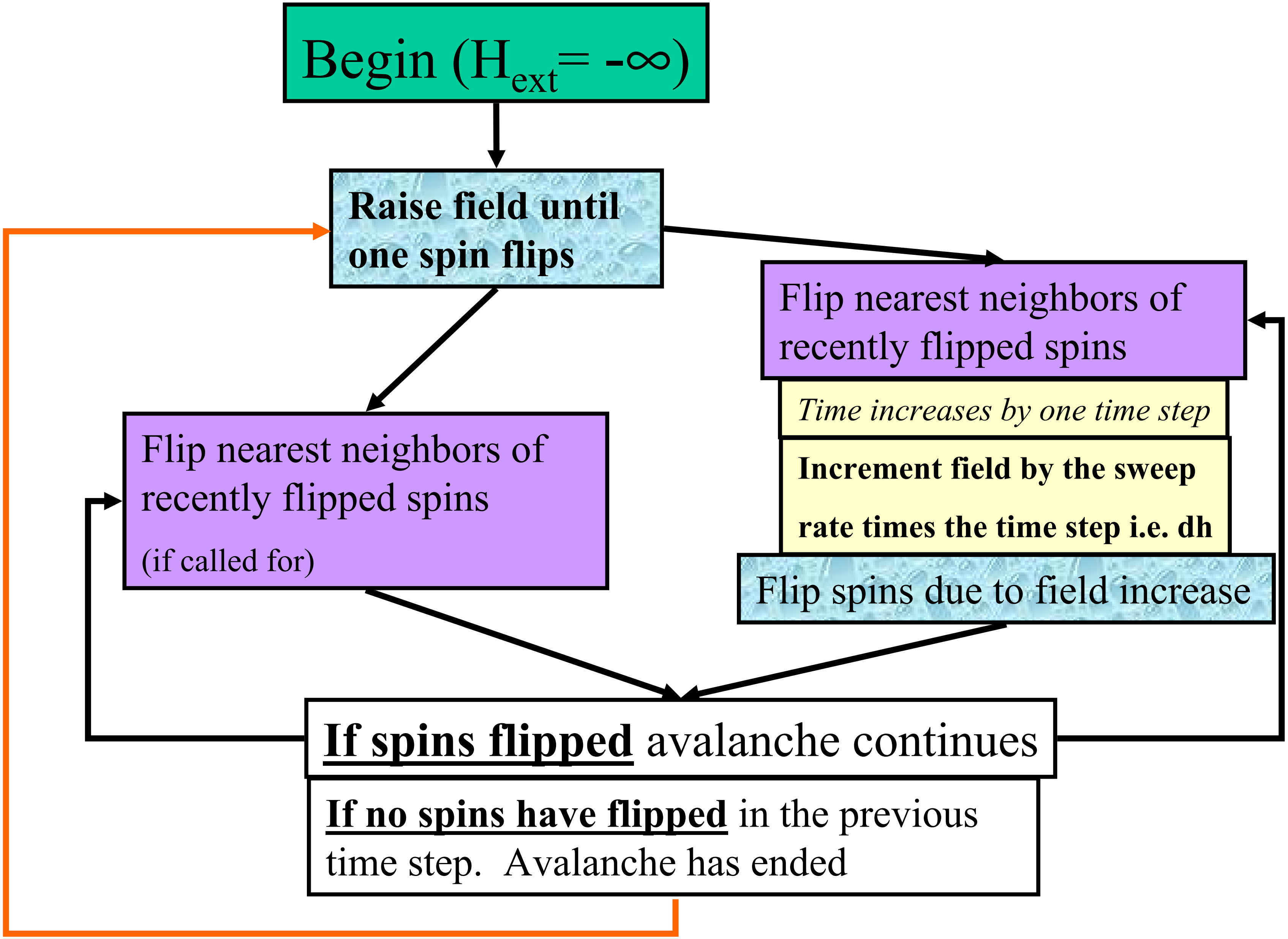
data analysis

fit of experimental data to:

$$M(H) = \Delta M \cdot tan^{-1}\left(\frac{H - H_C}{\delta_1}\right) + A_2 \cdot tan^{-1}\left(\frac{H - H_C}{\delta_2}\right)$$



The Algorithm- (adiabatic…. Finite sweep rate)



Begin (H_{ext}= -∞)

Raise field until one spin flips

Flip nearest neighbors of recently flipped spins

(if called for)

Flip nearest neighbors of recently flipped spins

Time increases by one time step

Increment field by the sweep rate times the time step i.e. dh

Flip spins due to field increase

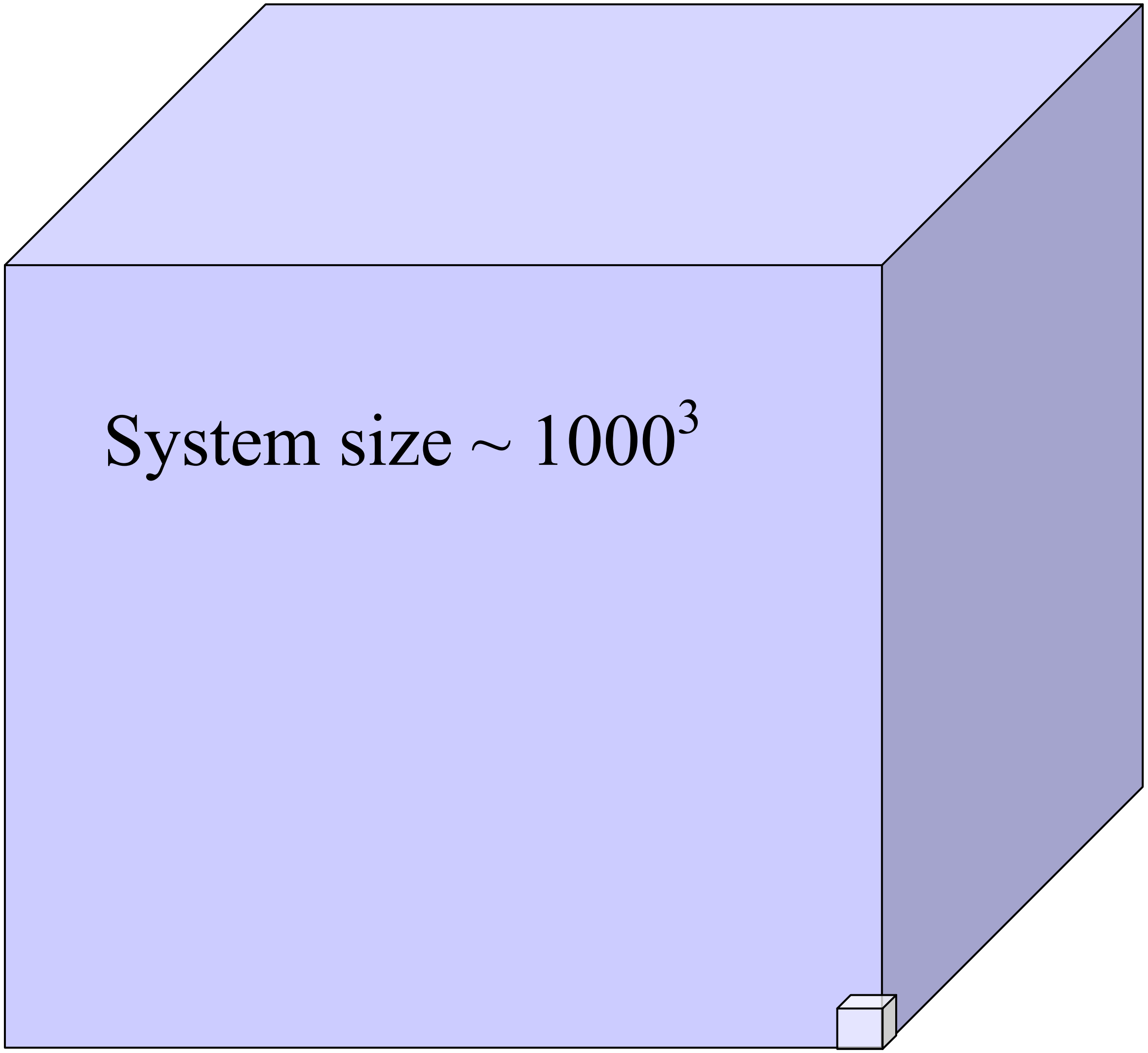
<u>If spins flipped</u> avalanche continues

<u>If no spins have flipped</u> in the previous time step. Avalanche has ended

Simulation Overview-

Run Time Scaling
O(NlogN)

Memory Scaling
O(N)



System size ~ 1000^3

Equilibrium RFIM
MC methods size ~ 25^3

M. Kuntz, et al.. Computing in Science and Engineering 1, 73 (1999). pdf