Crackling Noise: Learning from Magnets about Earthquakes

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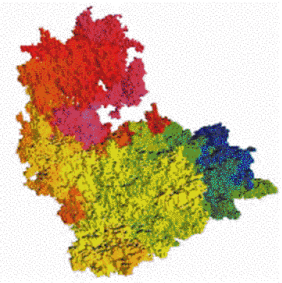
Alex Travesset (now Assis. Prof. Iowa/Ames Lab)
REU's: Ma'ayan Bresler (Princeton), Sharon Loverde (now Northwestern), Riva Vanderveld (now Cornell)



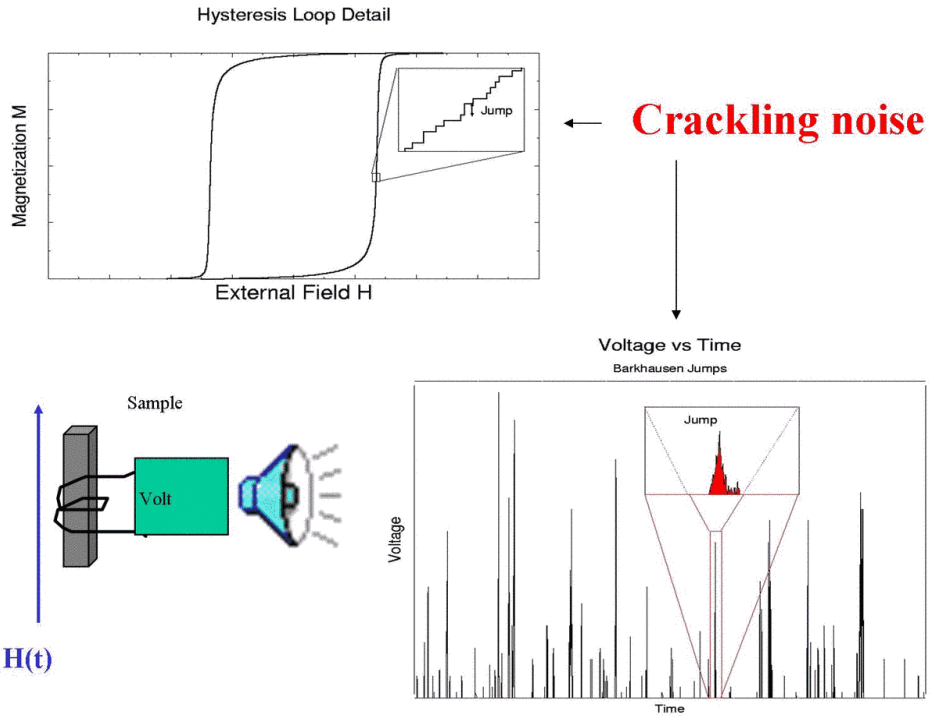
Jim Sethna, M. Kuntz, O. Perkovic (Cornell University) -- theory
Yehuda Ben Zion (USC, Earth and Planetary Sciences), (D.S. Fisher (Harvard)) - earthquakes
A. Berger, O. Hellwig **(IBM/Hitachi)** -- exp.
Gianfranco Durin (Turino, Italy) -- exp.
Andrea Mills, Mike Weissman (UIUC) -- exp.

E. Carlson (Perdue), E. Fradkin (UIUC), S. Kivelson (Stanford), D. VanHarlingen (UIUC), M. Weissman (UIUC), C.Panagopoulos (Cambridge) -- superconductors
C. Marchetti (Syr.)-- plastic CDW
D. Nelson (Harvard) and N. Shnerb (Israel) - spreading Bacteria Colonies

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

Physics Illinois

Magnets and Barkhausen Noise- or Martensites and acc. emission



Crackling Noise / Avalanches:

Barkhausen Noise (magnets)

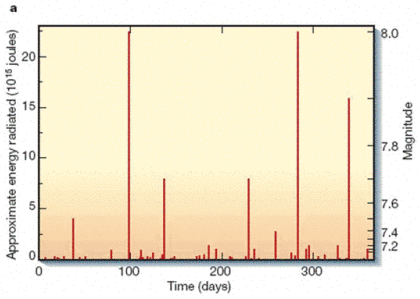
Acoustic emission (Martensites) (Ortin, Vives,...)

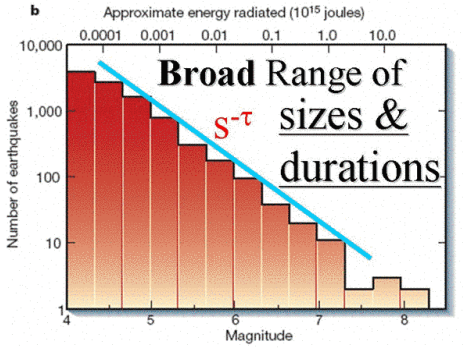
Superconductors (P.Adams; Field,Witt,Nori,...)

Liquid He invading Nuclepore (Hallock, Lilly,Wooters...)

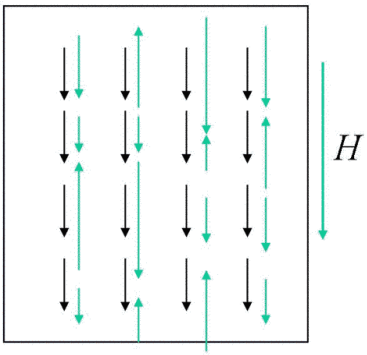
Rupture of fibrous Materials

Earthquakes

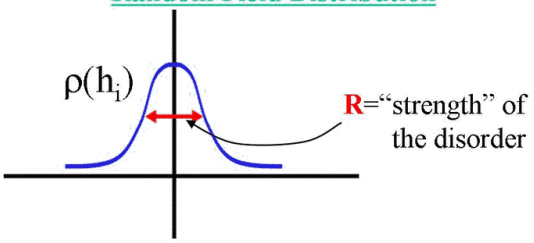




The Zero Temperature Non-equilibrium Random Field Ising Model



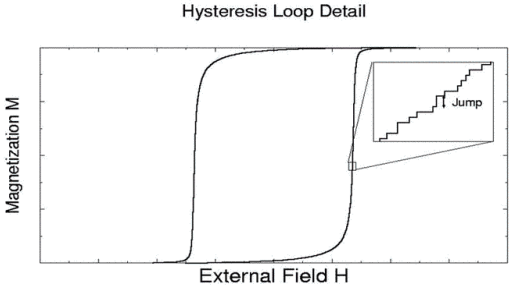
Random Field Distribution



Each spin is always aligned with the direction of the

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

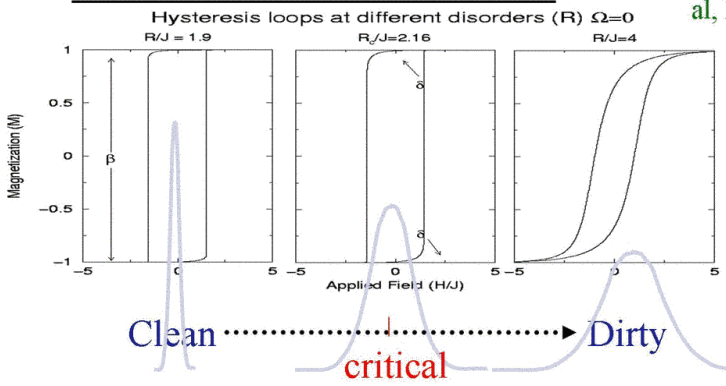
Zero Temperature : (Equilibration time scale) >> (Experimental time scale)

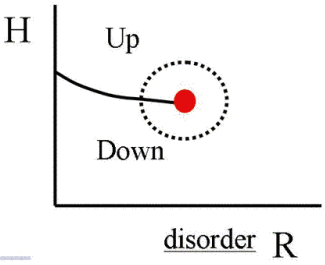


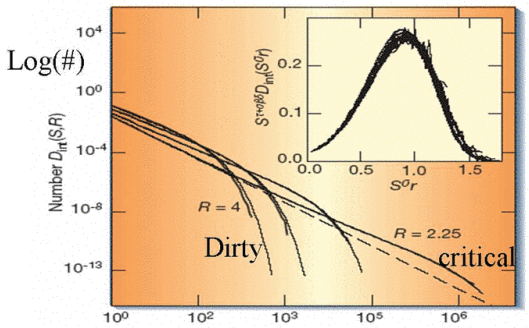
Jumps = Avalanches = Barkhausen noise

The Disorder Induced Critical Point

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



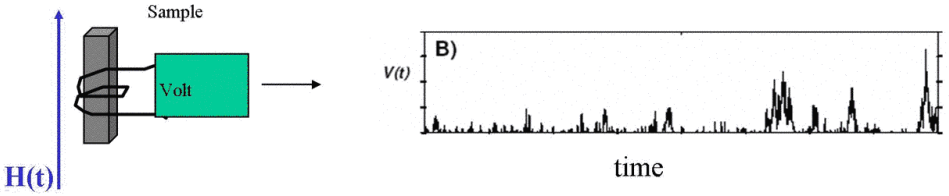




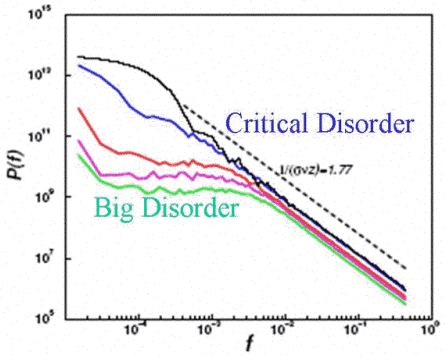
$\tau+\sigma\beta\delta=2.03\pm0.03$, $1/\sigma=4.2\pm0.3$, ...

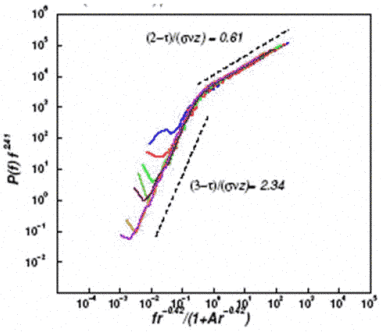
Vary Disorder by 50% of critical amount: still find 2 decades of powerlaw scaling!

… HUGE scaling region!!!



Powerspectra of Avalanche Noise:

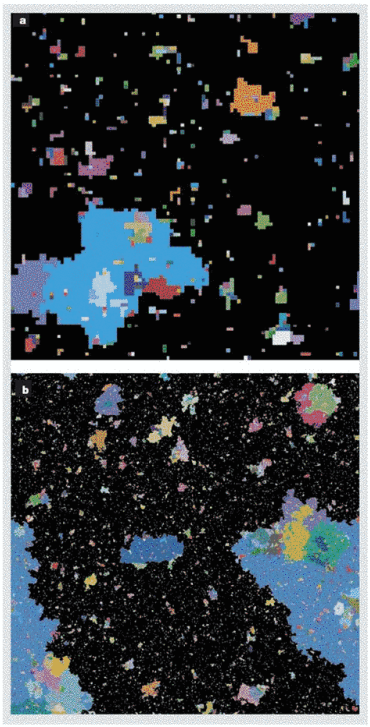




Travesset, White, KD, Phys. Rev. B 2001

Also: Second Spectra and other higher order Spectra in model and experiment, *(Mehta, Mills, Weissman, KD (cond-mat/2005))*

Self-similarity at critical disorder R_c=2.16J



100^3

1000^3

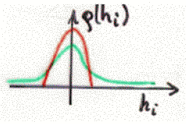
(Cross-sections of avalanches during magnetization)

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

(Renormalization Group)

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

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



Replace J by random couplings

Use different distribution of h_i or replace h_i by random anisotropies

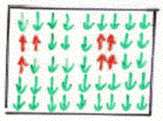
Magnets, plastic charge density wave depinning (Marchetti, KD PRB 2002), earthquakes (Mehta, BenZion, KD 2005), maybe superconductors… (with Carlson, Fradkin, Kivelson, 2005), …others?

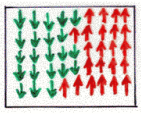
Other Universality classes ?

$$\mathbf{H}_{system} = -J\sum_{n.n.} S_i S_j - \sum_i (H(t)+h_i)S_i + \text{long range forces}$$

2 Dynamics

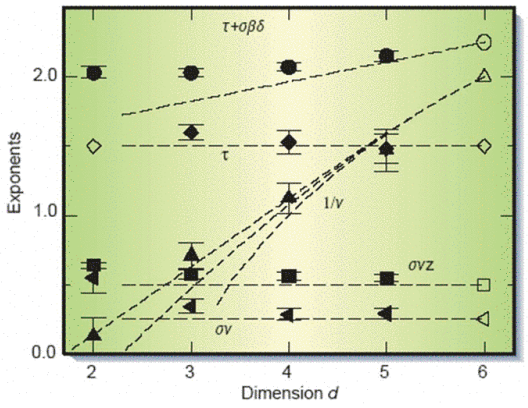
With nucleation of new domains





Single domain wall; Nattermann, Robbins, Ji, Zapperi, Ciseau, Durin, Stanley, Urbach et al., Narayan, Sethna, ...

RESULTS



Simulation

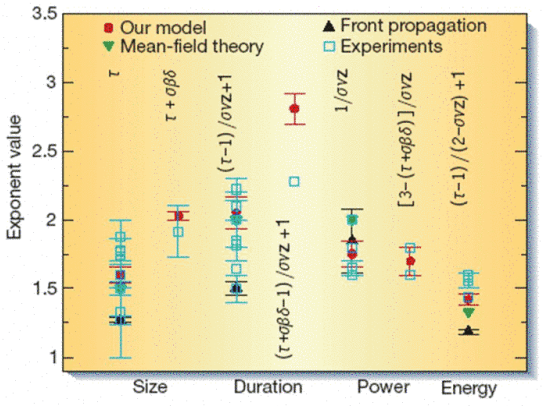
6-ε expansion
(Renormalization Group)

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

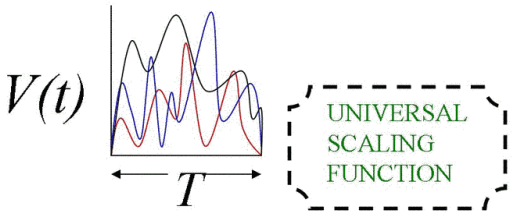
(PRL '93,'95, 2003 PRB '96, '99, 2002 (R))
Nature **410**, 242 (2001)

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

Need Noise Exp. Tuning disorder!!!



Universal Scaling Functions:

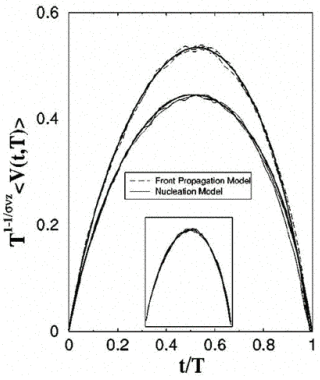


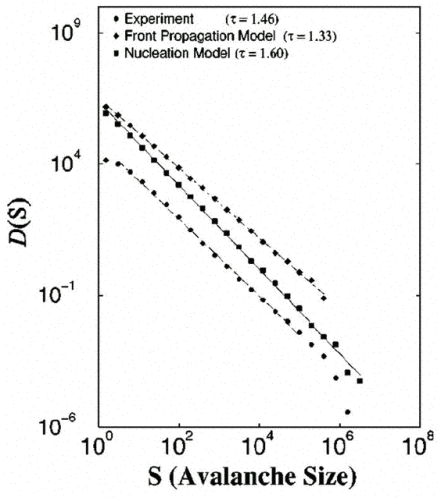
AVALANCHE SIZE DISTRIBUTION:

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

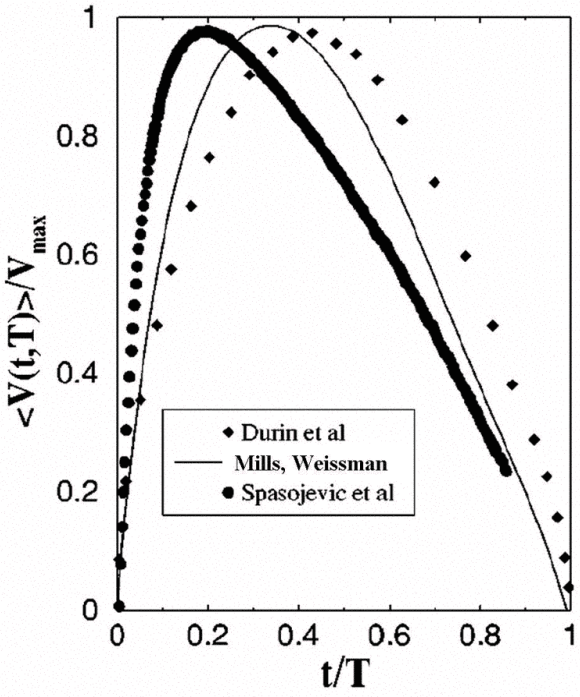
AVERAGE :

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



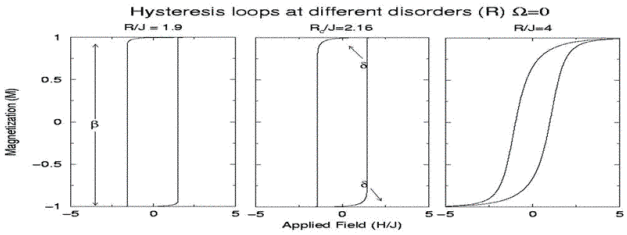


EXPERIMENTAL SCALING FUNCTION

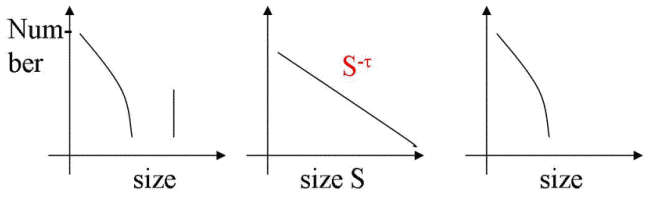


Asymmetric!?!

Summary on magnets and further results:



clean ····· disordered



Renormalization group (huge universality class)

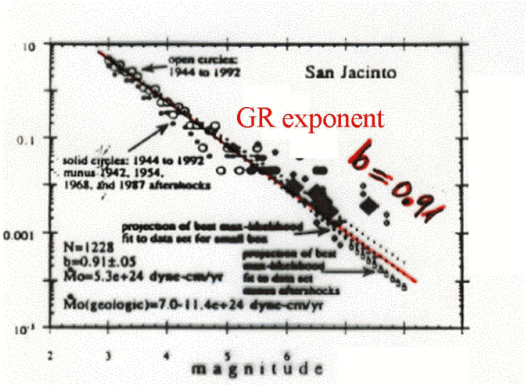
finite sweep rate effects (model indep. theory)

history induced critical behavior

Second Spectra (mean field theory), universal scaling functions, return point memory, temperature effects...

Earthquakes,...

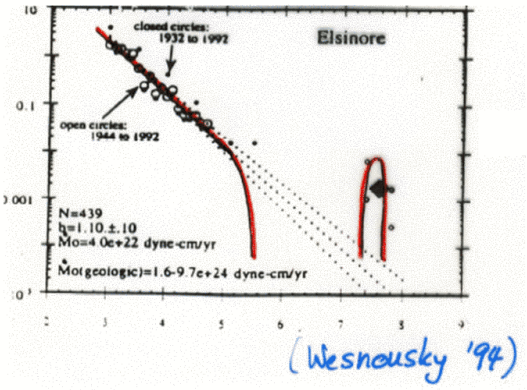
EXPERIMENTS ???!!!



Universal
Gutenberg Richter
Scaling behavior

OR

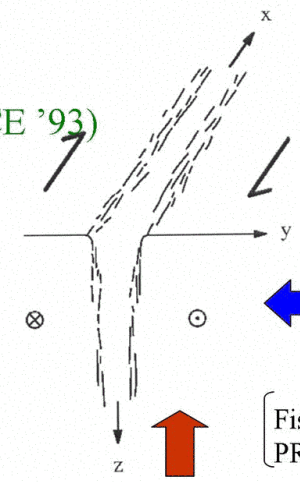
Magnitude = 2/3 Log(total displacement)



Characteristic
Earthquake
distribution ?

MODEL

(BEN-ZION & RICE '93)

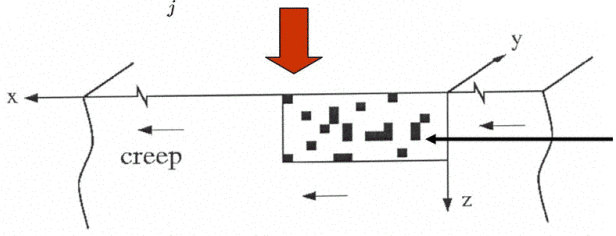


3D FAULT ZONE

Fisher, KD, Ben-Zion, et al.
PRL **78** (1997)

RG: MEAN FIELD THEORY EXACT IN THE PHYSICAL DIMENSION

$$\tau_i = J/N \sum_j (u_j - u_i) + K_L(vt - u_i)$$



BRITTLE PATCHES

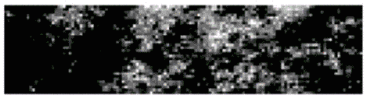
Phase Diagram

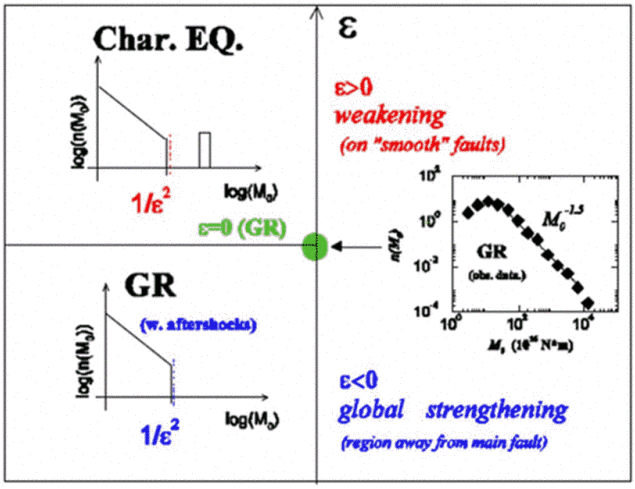
Mean field exponent: b=0.75

for Frequency~ 10^{-bM}

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

small events scale as
moment~area



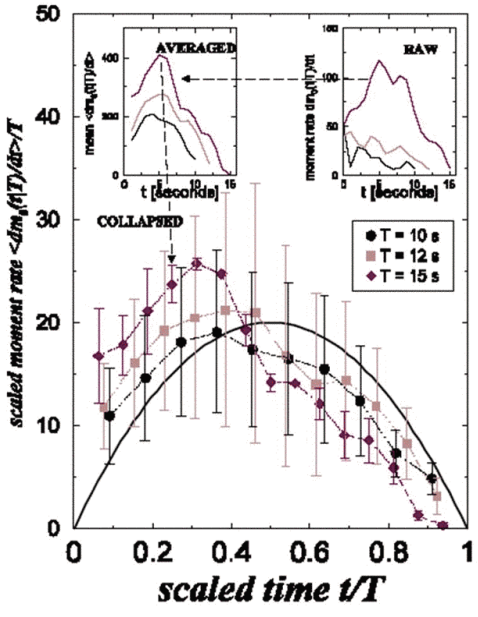


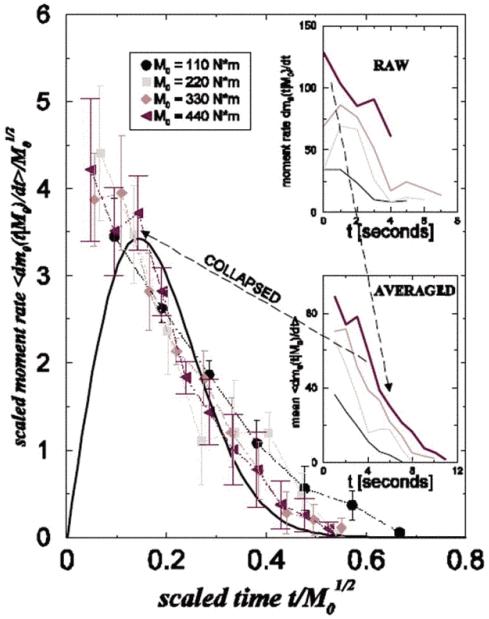
Mehta, KD, Ben-Zion, 2005

Universal Scaling Functions:

Data from Susan Bilek, see

Mehta, KD, Ben-Zion, 2005





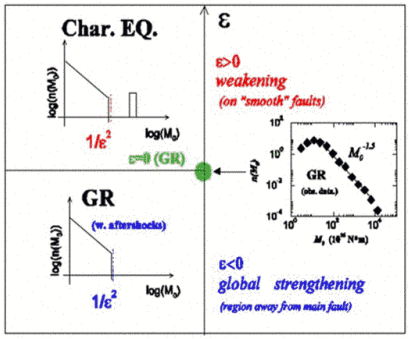
Conclusions and Outlook:

-"Disorder" effects similar in Magnets and Earthquakes!

- Renormalization Group for universal predictions (for eq: mean field theory exact in the physical dimension)

- Exponents the same, universal scaling functions seem similar

- Similar phase diagrams (disorder in magnets same role as dynamic weakening/strengthening in Ben-Zion-Rice earthquake model)



NEED:

- improved models (geometry, correlations in disorder, fault network, friction laws, seismic emission,...)

- more time resolved data for small earthquakes, (moment rates), time vs. diameter, slip vs. M, regularity, parameters for $M_{runaway}$,...