# Complexity: crackling nosie, avalanches and hysteresis.

Jakub Tworzydło

Institute of Theoretical Physicis
phone: (22)5532919, room 5.19
Jakub.Tworzydlo@fuw.edu.pl

8/03/2022 Pasteura 5, Warszawa

# Plan

# Plan

# Plan

# Earning credits

- lecture contains inroduction to the lab
- during the lab you can earn 1.0 point; one week later 0.8 points
- extra take-home task (0.2 bonus points)
- one short (5min) presentation; final presentations last week
- written exam/test 3.2 points (on 8.06 and 9.06)

# References


1. M. C. Kuntz, O. Perlovic, K. A. Dahmen, J. P. Sethna, and C. R. Myers, “Hysteresis, Avalanches, and Noise”, arXiv:cond-mat/9809122.
2. J. P. Sethna, K. A. Dahmen, and C. R. Myers, “Crackling noise”, Nature **410**, 242 (2001).
3. M. E. J. Newman, “Power laws, Pareto distributions and Zipf’s law” https://arxiv.org/abs/cond-mat/0412004

# Plan

# Physics of crackling

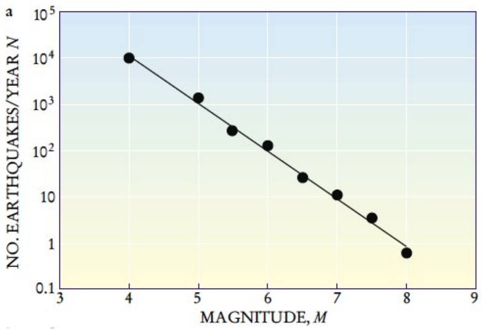
- system responds through discrete, impulsive events
- events span huge range of sizes
- unimportant microscopic details $\Rightarrow$ simple models, universality

# Different systems

- fireplace
- earthquakes
- crampled paper
- magnetic material in an external field

# Gutenberg-Richter law '50

- relation: frequency versus magnitude $N \propto 10^{-\alpha M} \propto E^{-2\alpha/3}$
- power laws are associated with scale invariance
- scale invariance: phenomena that span overy many length scales



# Avalanches and SOC

- Bak's explanation: systems end up naturally at the critical point
- the process is named "self organized criticality" (SOC)
- *however: sandpile models don't crackle*

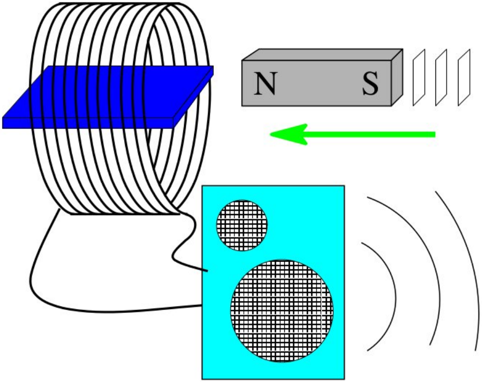
# Recent developments

Physics of crackling studied for

- fluids invading porous materials
- fracture in disordered materials
- fluctuations in the stock markets
- bubbles in foams
- cascading failures in power grids

# Plan

# Barkhausen noise experiment




- magnetic domains flip over in an external $H(t)$
- mag. field jumps are turned into electric signal

# Random field Ising model

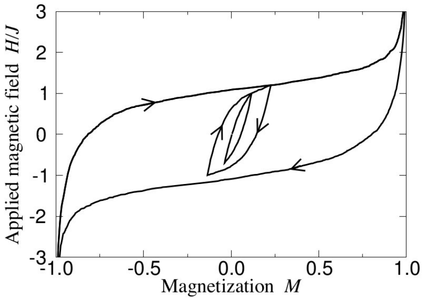
The energy function is

$$\mathcal{H} = -J \sum_{<i,j>} s_i s_j - \sum_i (H(t) + h_i) s_i$$

- local, Gaussian distributed $h_i$, with standard deviation $R$
- all spins pointing down initially (no thermal noise) $s_i = -1$
- slowly increasing $H(t)$
- spin flips over – only to decrease energy

# Hysteresis

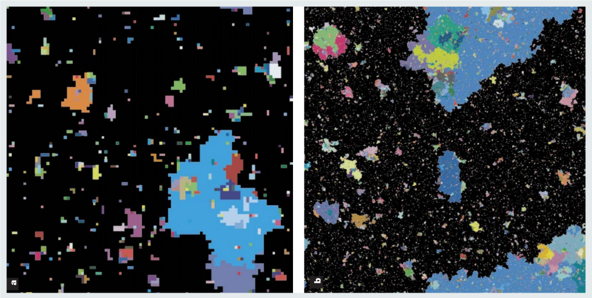
$\longrightarrow$ magnetizations lags behind the field




$\longrightarrow$ growing in a series of sharp jumps

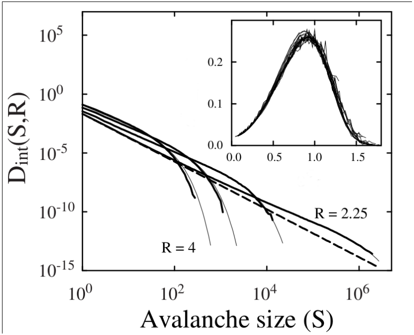
# Plan

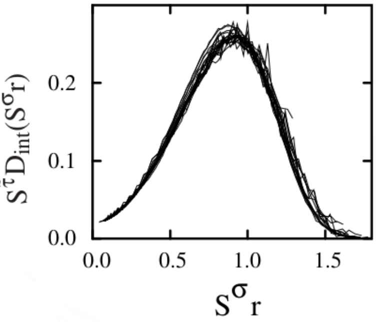
# Self-similarity




- cross-section of 3D simulation for $100^3$ and $1000^3$ spins at $R_c$
- black background is the avalanche spanning over whole system
- at criticallity system looks similar on all scales

# Scaling laws




- number of avalanches *D* of a given size follow a power law
- stright line only at criticality ($R_c = 2.16$)
- *universality:* rescaled plots follow a common curve (different *R*)