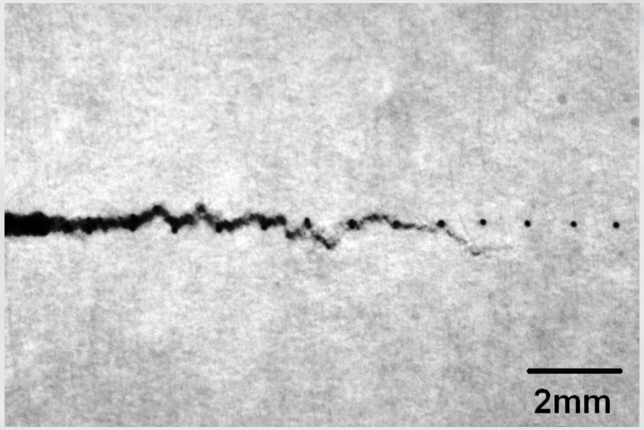
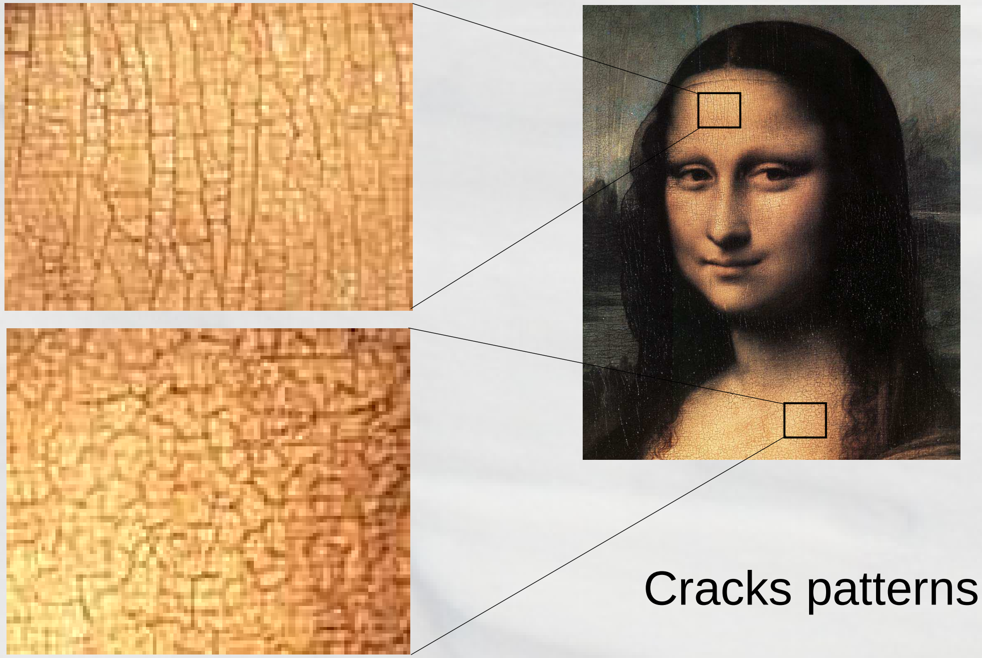
http://www.pmmh.espci.fr/~oramos/

Osvanny Ramos.

Main projects & collaborators



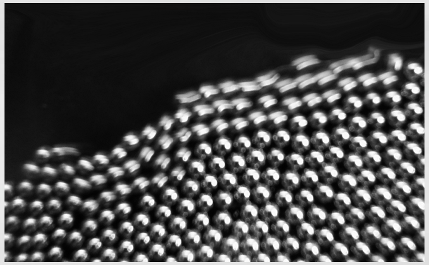
Slow crack propagation



Cracks patterns

L. Vanel, S. Ciliberto, S. Santucci, J-C. Géminard, J. Mathiesen

Criticality in Earthquakes. Good or bad for prediction?



Osvanny Ramos

Universidad de la Habana

E. Altshuler

complex
Universitetet i Oslo

K. J. Måløy

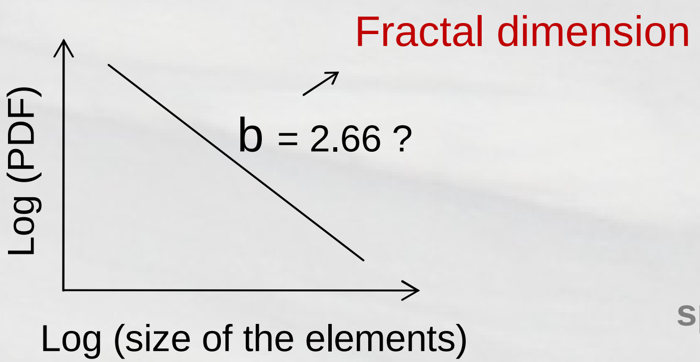
pmmh ESPCI ParisTech

ENS LYON

Scale invariance in Nature

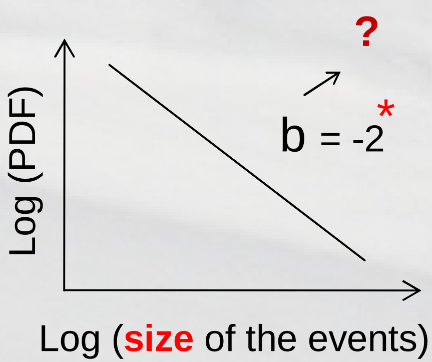
Spatial domain

Fractals



Temporal domain

Catastrophic events distributed following a power-law



The events distribute spatially forming fractals.

Motivation

The magnitude distribution of declustered earthquakes in Southern California

Leon Knopoff*

Department of Physics and Astronomy and Institute of Geophysics and Planetary Physics, University of California, Los Angeles, CA 90095

Contributed by Leon Knopoff, May 22, 2000

PNAS (2000)

Because of its reputation of validity over a wide range of magnitudes, the log-linear Gutenberg–Richter (G-R) frequency-magnitude law of earthquake occurrence (1, 2)

$$\log_{10} N = a - bM \quad [1]$$

has been a simple paradigm for modeling the evolution of earthquake patterns. Eq. **1** is expressed in the power law form

$$N \sim E^{-b/\beta} \quad [2]$$

through the intermediary of either a logarithmic energy-magnitude relation derived originally by Gutenberg (3) or a logarithmic moment-magnitude relation (4, 5); $\beta \approx 3/2$ for both surface wave and local magnitudes in the magnitude range of this paper (3). Because of the presumed universality of local estimates of the exponent $b \approx 1$, and because of the scale independence implicit in Eq. **2**, the model of self-organized criticality (SOC) to understand earthquake occurrence (6–9) has been proposed and discussed abundantly in recent years. The corre-

$N(E) \sim E^{-2/3}$

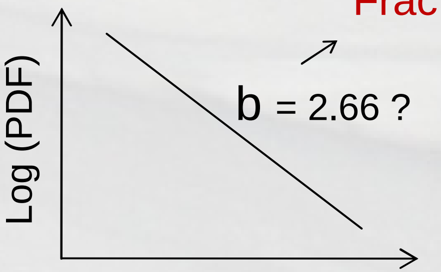
$P(E) \sim E^{-2/3\ -1} = E^{-1.66}$

Scale invariance in Nature

Spatial domain

Fractals

Fractal dimension

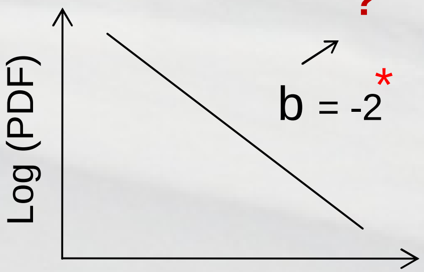


Log (size of the elements)

Temporal domain

Catastrophic events distributed
following a power-law

?



Log (**size** of the events)

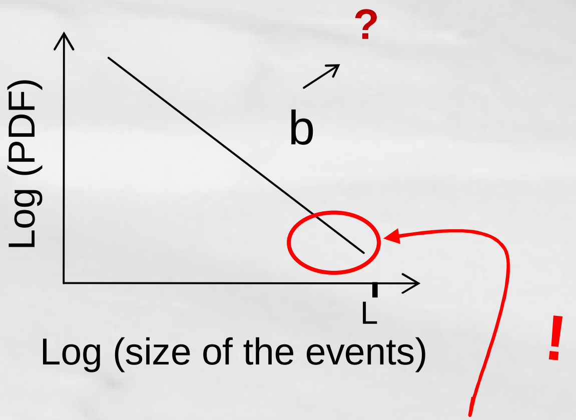
The events distribute spatially forming fractals.

Motivation

Scale invariance in Nature vs. Critical phenomena

Temporal domain

Catastrophic events distributed following a power-law



1 - Events reaching the size of the system. Interpreted as a *divergence of the correlation length.*

2 - The events distribute spatially forming fractals.

At the critical point of a phase transition:

1 - The correlation length diverges.

2 - The system displays a fractal structure.

However,

Critical phenomena need a **tuning!**

Motivation

SELF-ORGANIZED CRITICALITY (SOC)

BTW model (1987)

Cellular Automaton

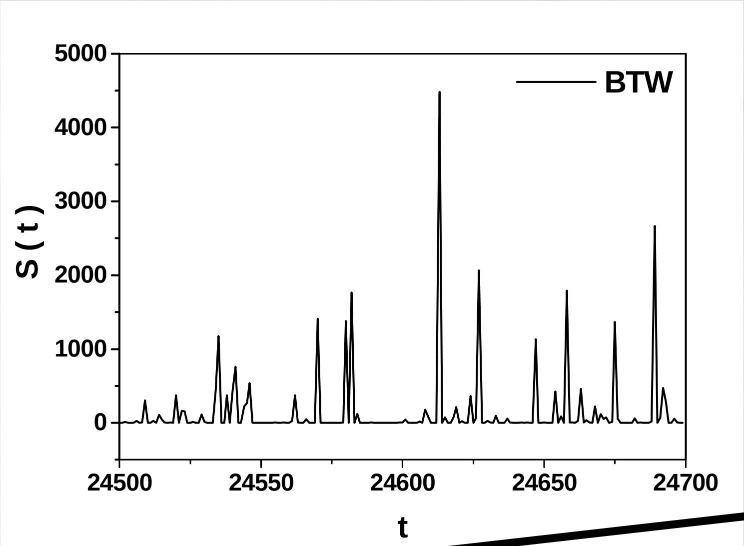
1	2	0
0	3	0
1	3	1

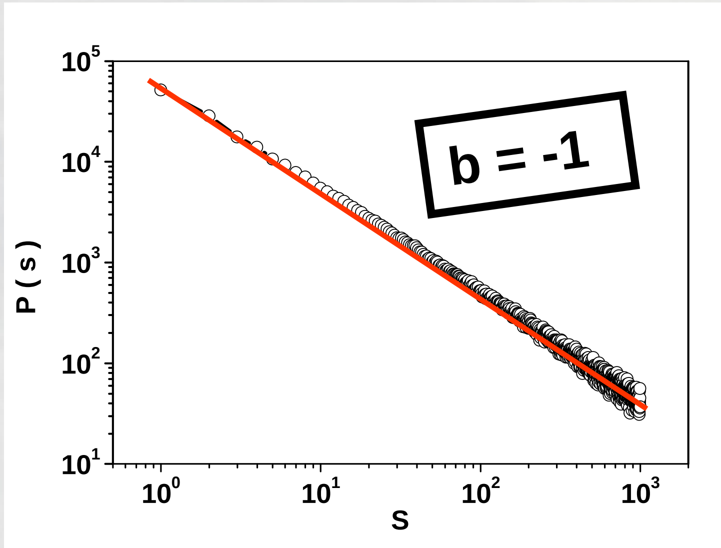
1	2	0
0	**4**	0
1	3	1

1	3	0
1	0	1
1	**4**	1

1	3	0
1	1	1
2	0	2

"time" → ↓ **1**





Uncorrelated avalanches

Sandpiles :

Motivation

Does it really work ? (SOC in real systems ?)

Lab. experiments: sandpiles

→ Quasi-periodic very large avalanches (big piles of sand)

Jaeger *et al* (1989), Held *et al* (1990), Rosendahl *et al* (1993)

→ Power-law distributed avalanches (very disordered piles)

Frette *et al* (1996), Altshuler *et al* (2001)

(**b=-2**) (**b=-1.6**)

Models: Earthquakes (**b=-2**), Solar flares (**b=-1.8**), Superconducting vortices (**b=-1.6**)

Evolution (**b=-1.3**), Stock markets (**b=-1.8**) **…**

Labeling a system as SOC:

► Catastrophic events and more frequent small events are a result of the same dynamics.

► Intrinsic unpredictability **!** as a heritage of critical systems.

Unpredictability of SOC avalanches !

…the consensus of a recent meeting was that the Earth is in a state of self-organized criticality where any small earthquake has some probability of cascading into a large event.

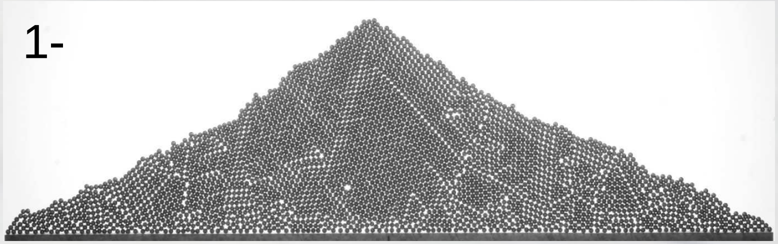
Geller et al, **Science** 275, 1616 (1997)

Thus, any precursor state of a large event is essentially identical to a precursor state of a small event. The earthquake does not "know how large it will become".

Per Bak. in *debates about Earthquake prediction*, **Nature** (1999)

Outline:

1-



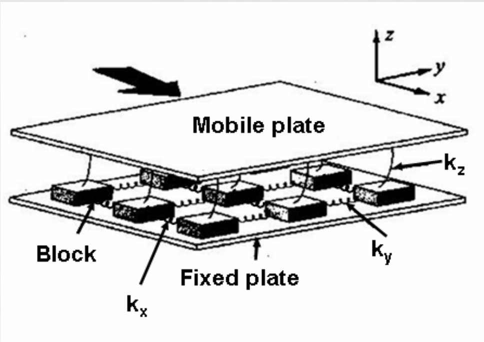
"Avalanche prediction in a self-organized pile of beads"

O. Ramos et al., Phys. Rev. Lett. (2009)

NewScientist

significance

2-

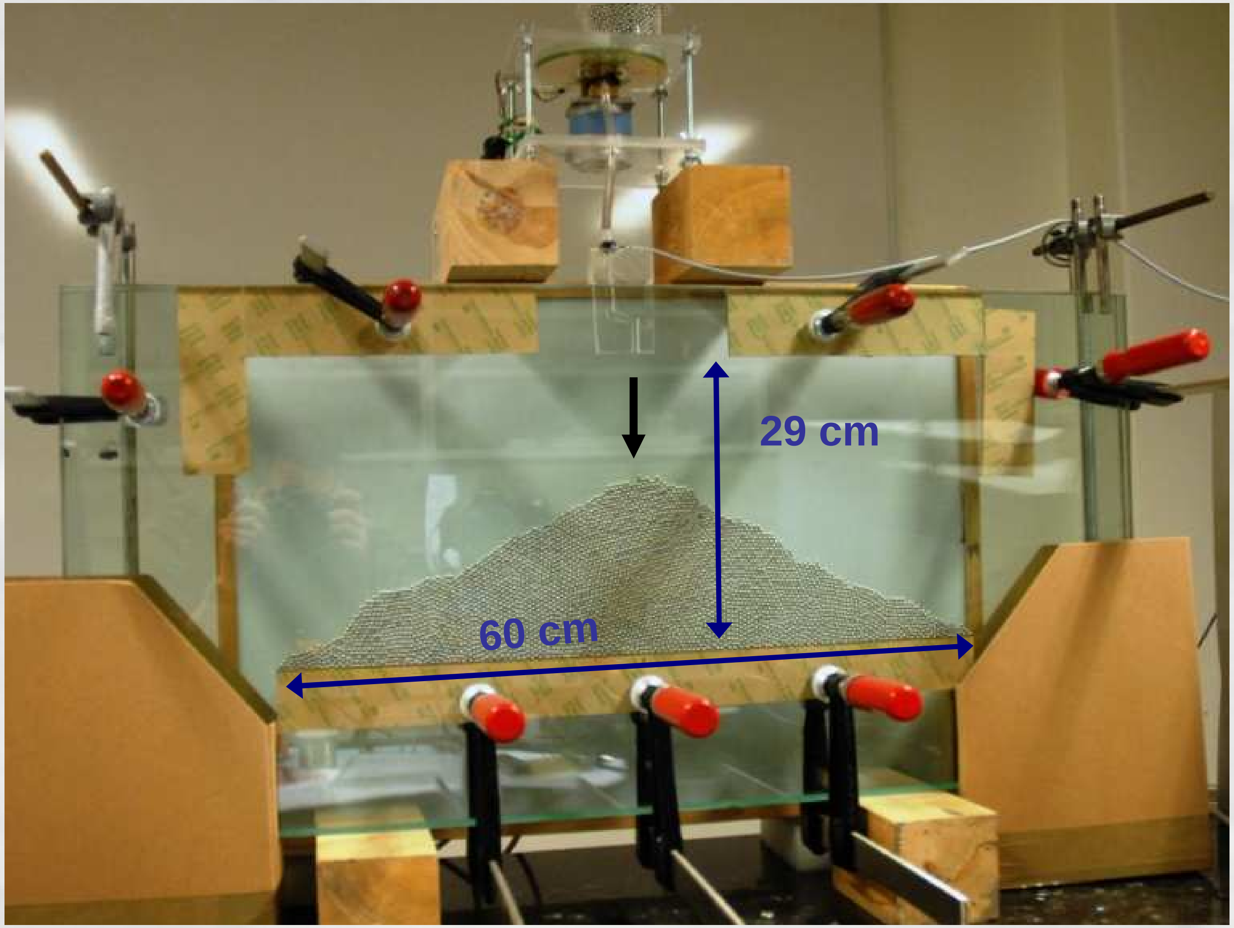


"Criticality in earthquakes. Good or bad for prediction?"

O. Ramos, Tectonophysics. (accepted)

3- Conclusions and open questions

Experimental setup



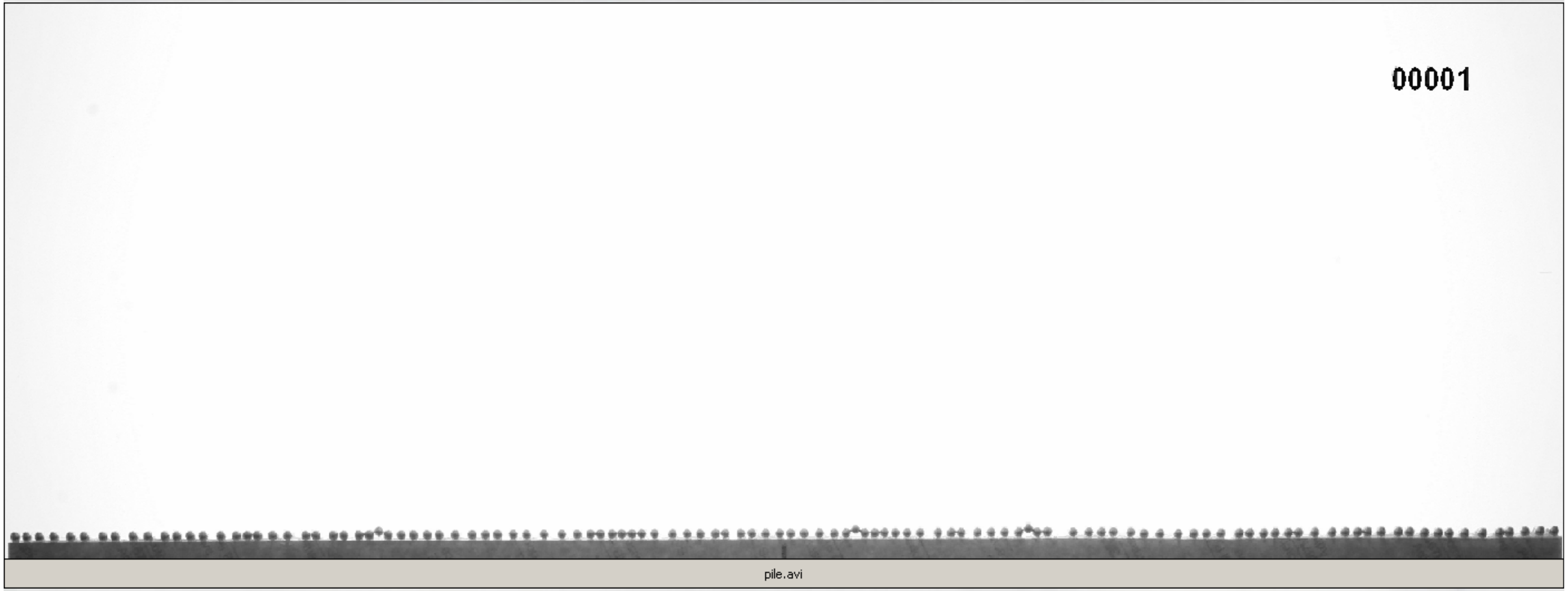
Grains:
4 mm-diameter steel beads.

Spacing between glasses:
4.5 mm.

Base: 60 cm long row of random spaced beads glued to the surface.

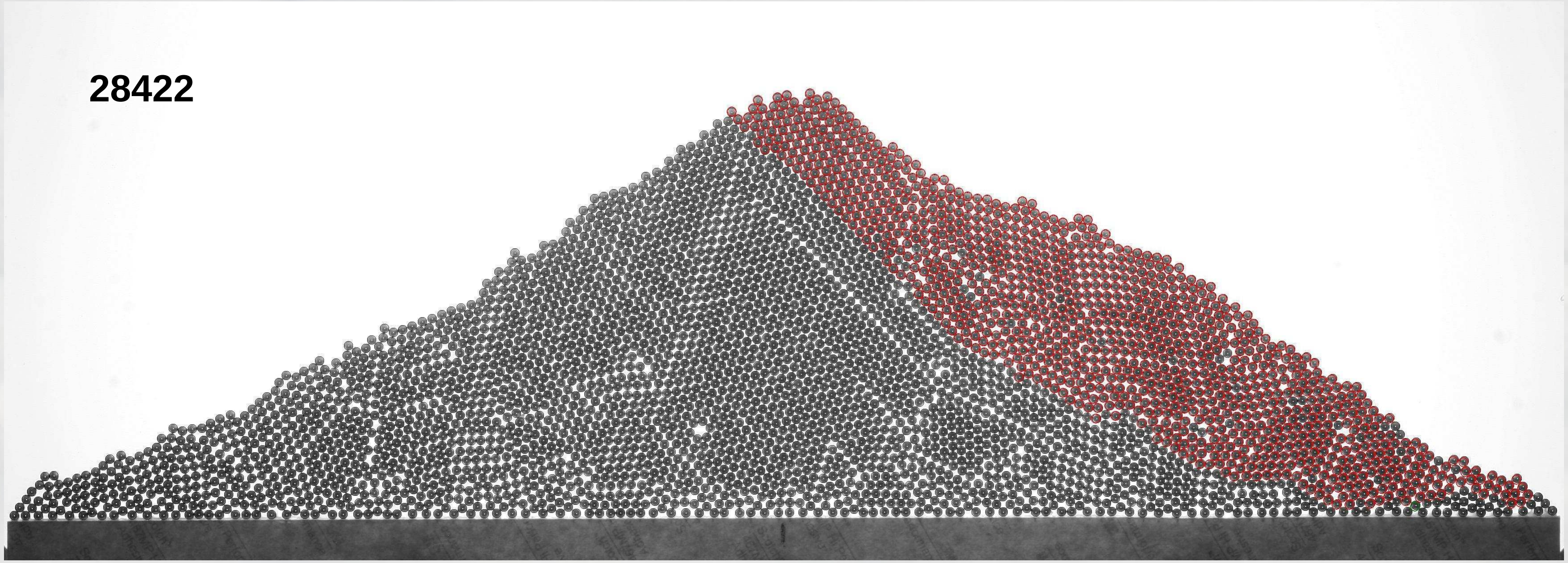
Camera: Canon D20: **resolution:** 20 pixels/bead diameter.

Statistics: 55000 dropping events.



Experiment

Defining avalance size

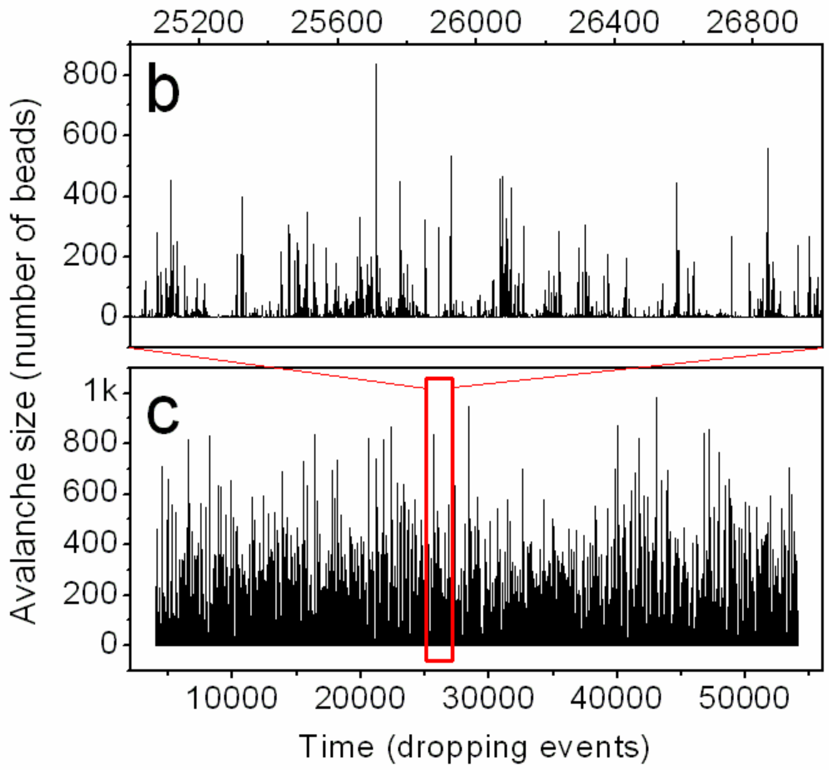


Number of beads that have moved between two consecutive dropping events = Number of beads that don't have any neighbor at a distance ≤ 1/7 diameter in the consecutive image.

Avalanche size (28422) = 984

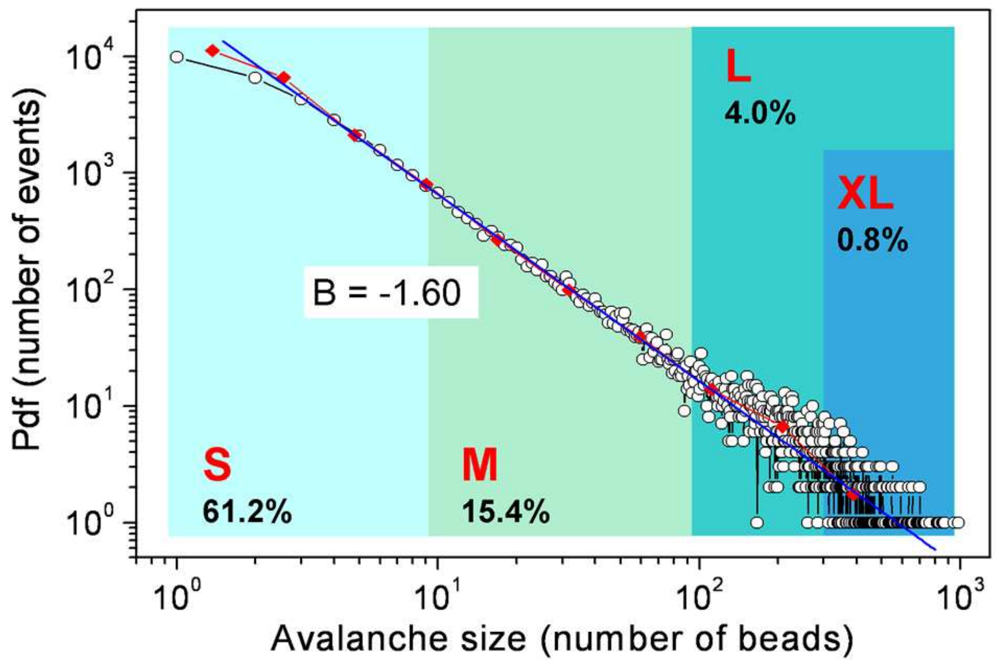
Experiment

Avalanche distributions



Avalanche time series

Avalanche size distribution

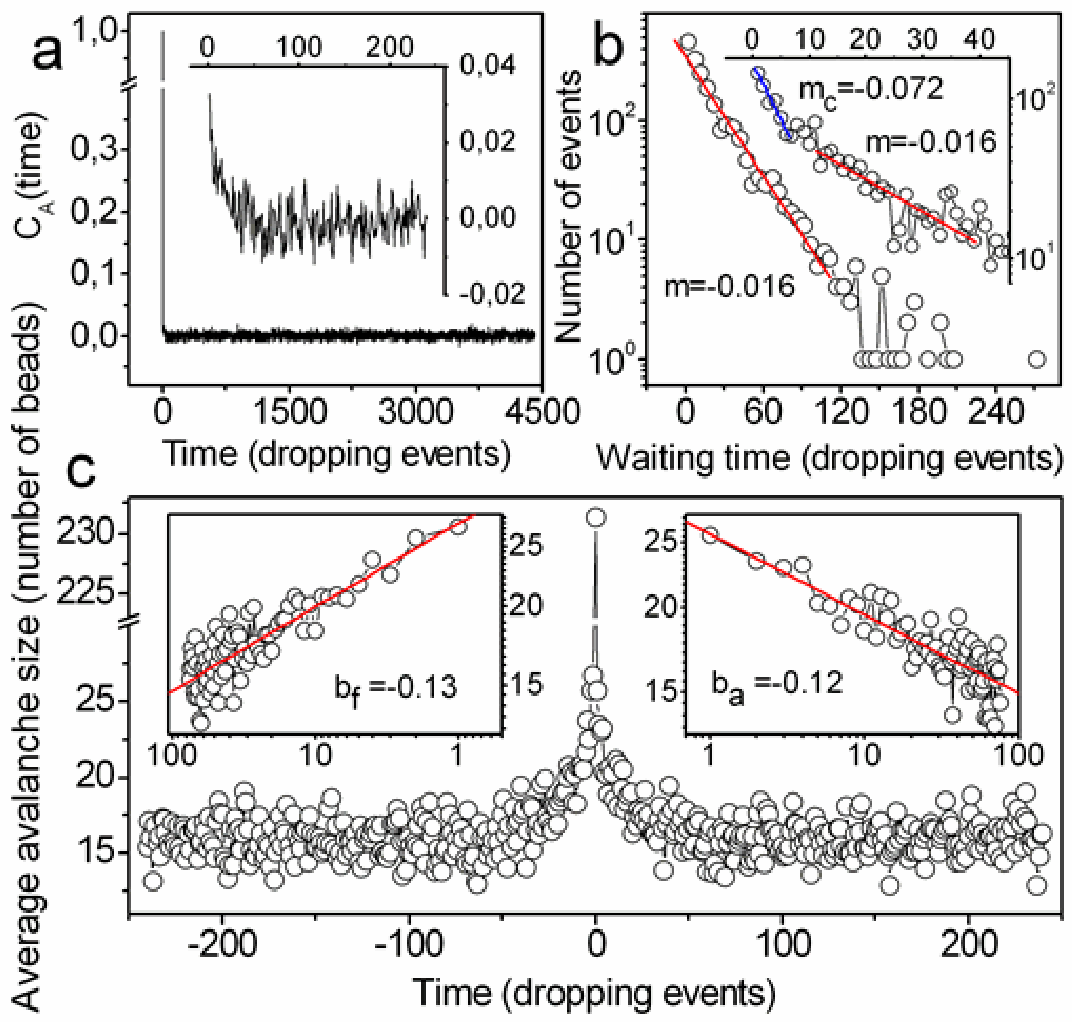


Experiment

Analysis of the avalanche time series

$$C_A(t) = \frac{\sum[s(\tau)s(\tau+t)] - \langle s(\tau)\rangle^2}{\sum[s(\tau) - \langle s(\tau)\rangle]^2}$$

s(t)=1   if size(avalanche)=L
s(t)=0   if size(avalanche)=S, M



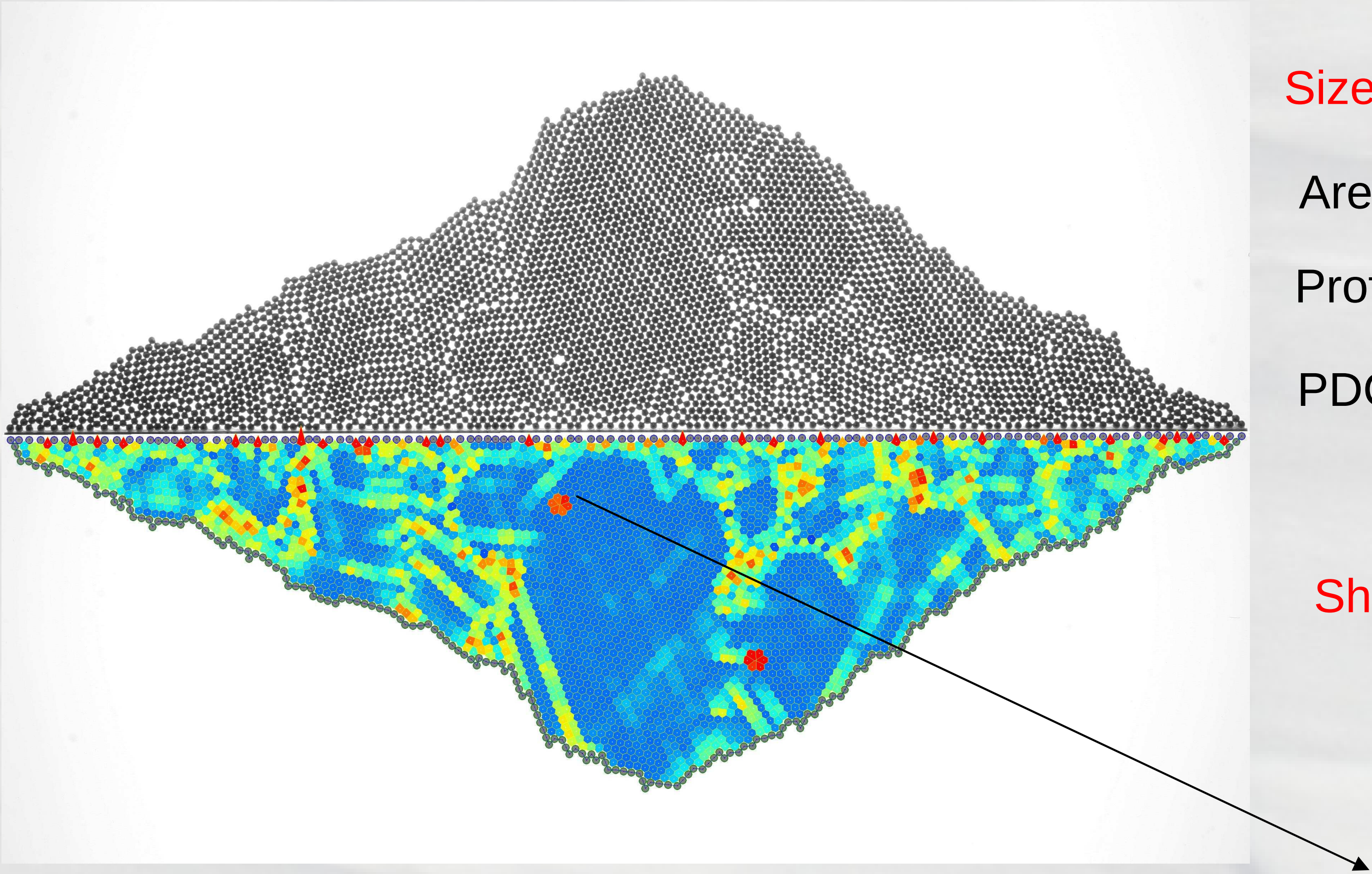
- Uncorrelated L events.

- Exponential decay of the waiting times between L events.

- Signs of foreshocks and aftershocks, but too weak in order to work as precursors of L events

Experiment

Internal structure



Size **= number of beads**

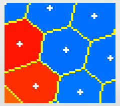
Area of the pile

Profile perimeter

PDC= profile disorder coefficient

Shape factor **ζ**

$$\zeta = \frac{C^2}{4\pi \cdot S}$$



Voronoi cells

Circle ζ = 1

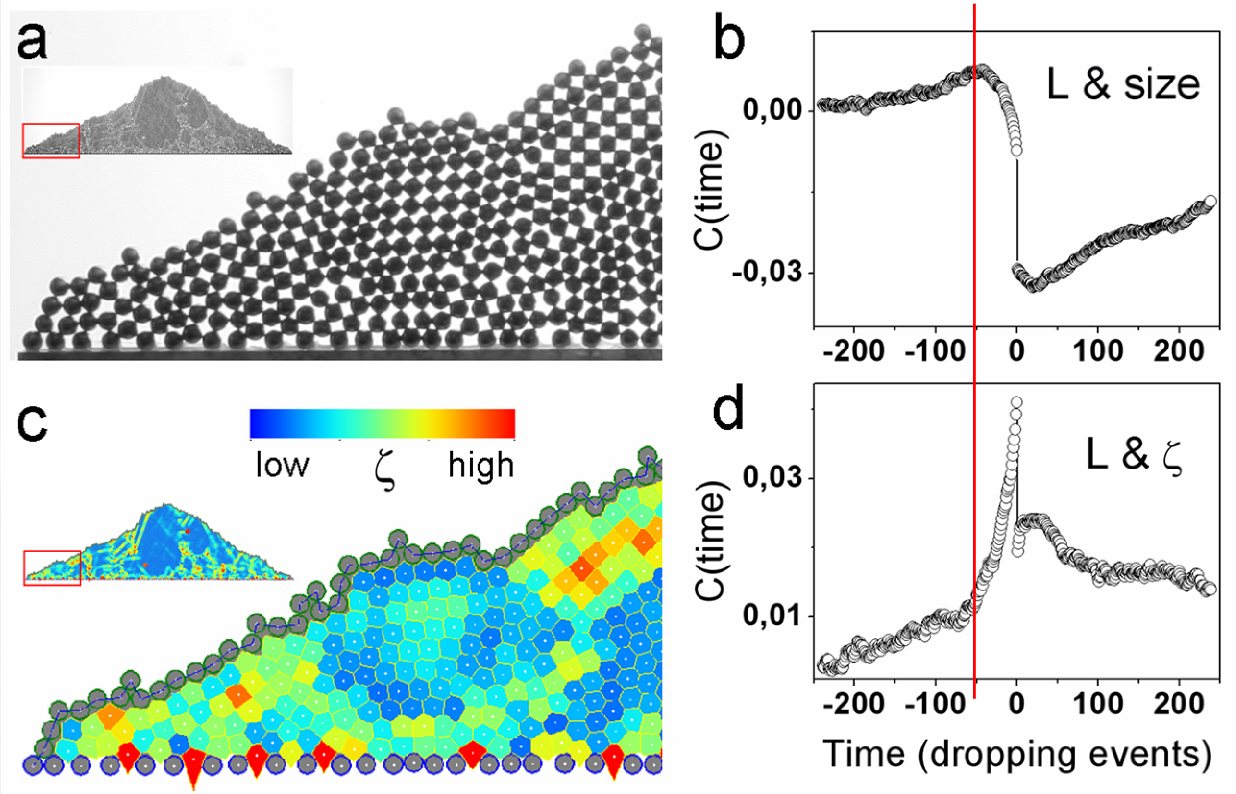
Regular hexagon ζ = 1.103

square ζ = 1.273

Experiment

correlation between structure & L avalanches

$$C(t) = \frac{\sum \big(s(\tau)\,x(\tau+t)\big) - \langle s(\tau)\rangle \langle x(\tau)\rangle}{\sqrt{\sum \big(s(\tau) - \langle s(\tau)\rangle\big)^2 \sum \big(x(\tau) - \langle x(\tau)\rangle\big)^2}}$$



Global Analysis

Alarms:

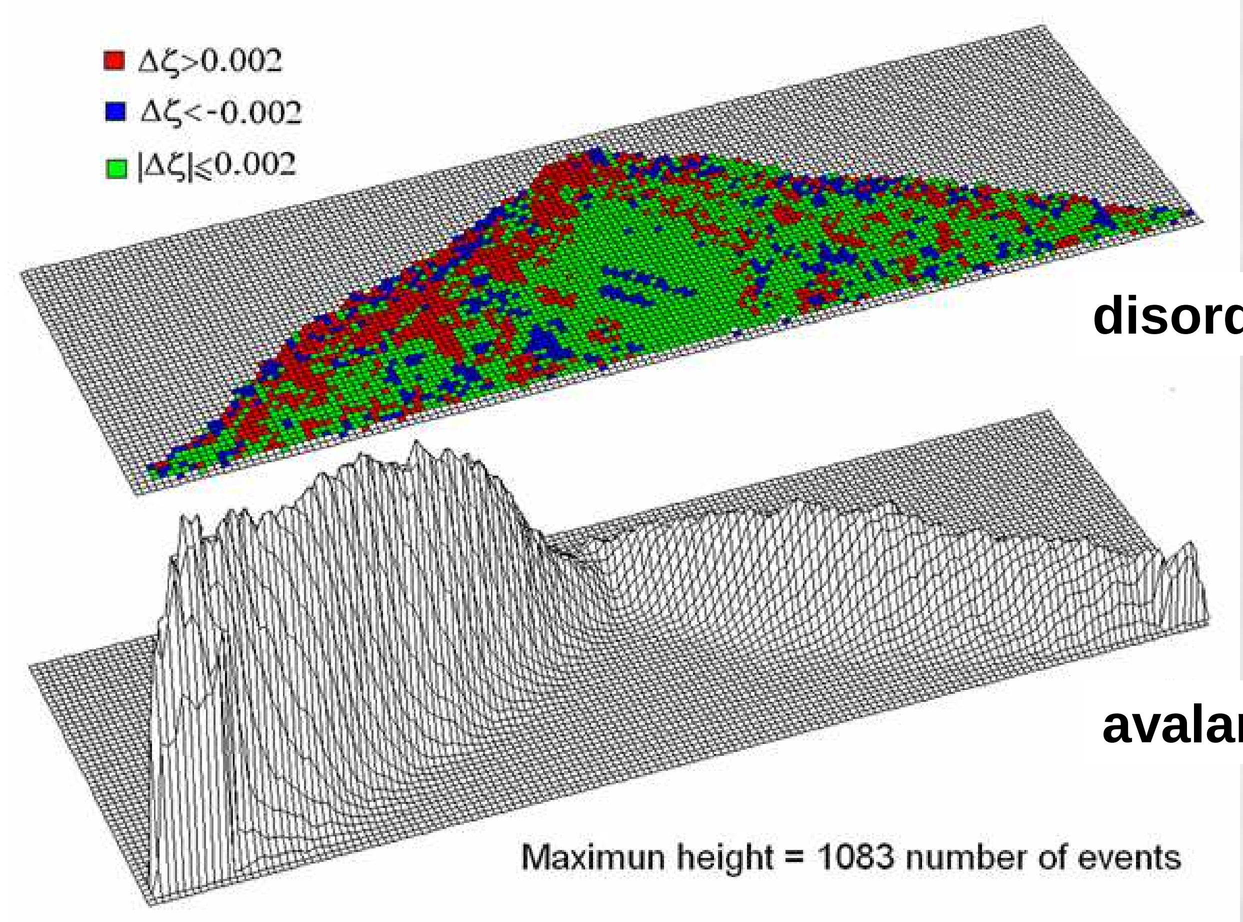
Contidions		Alarm *ON*	Success
If ζ(t) > ζ(t-50)	(L)	51 ± 3%	62 ± 4%
	(XL)	51 ± 3%	64 ± 7%
considering aftershocks:	(L)	50.0 ± 0.1%	65 ± 4%

short-term prediction !

Experiment

correlation between structure & avalanches

Local Analysis



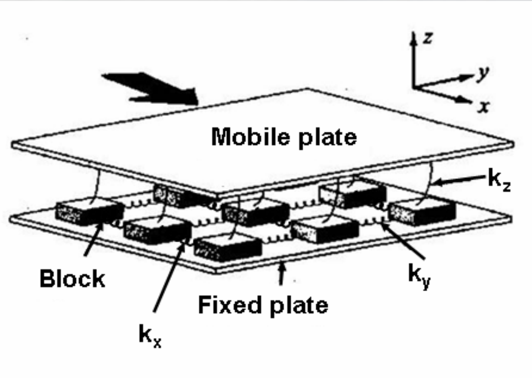
disorder

avalanches

Experiment

Simulations in an earthquake model

Burridge - Knopoff



O.F.C. → **Cellular Automaton**

Phys. Rev. Lett. (1992)

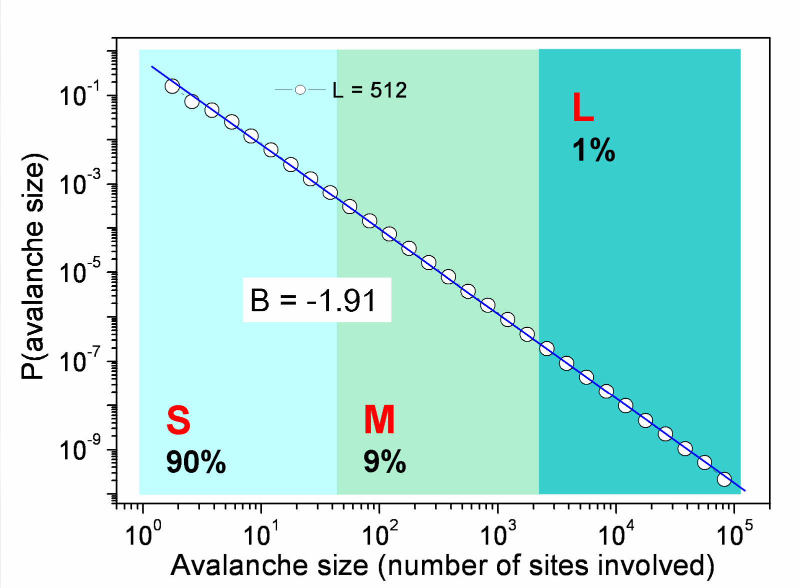
-The Force is applied to every site at the same time.

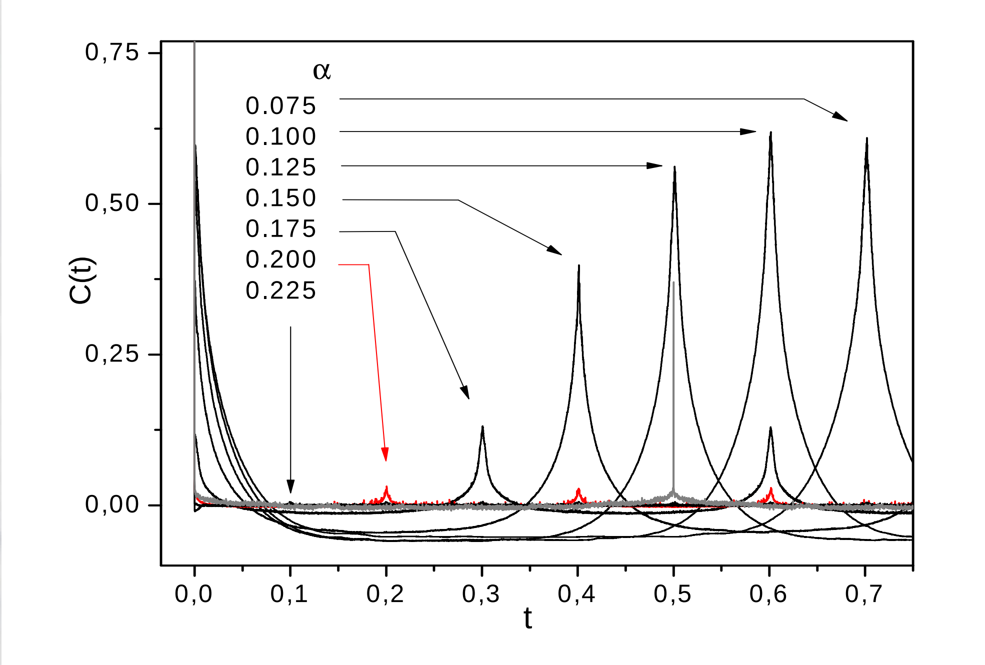
-When a site reaches the threshold Its force goes to zero and a fraction 4*α of it is redistributed equally between its nearest neighbors.

	OFC	**Ours**
Source of randomness	Block thresholds have a single value. At t=0 random forces are imposed.	Thresholds distributed randomly following a Gaussian distribution with an standard deviation σ . When a block slips a new threshold is imposed.
Excitation	Force added ”ad hoc” to excite the site closest to the threshold (speed→0) . Infinitely accurate tuning.	A quantum of force is added in each step (speed = constant).

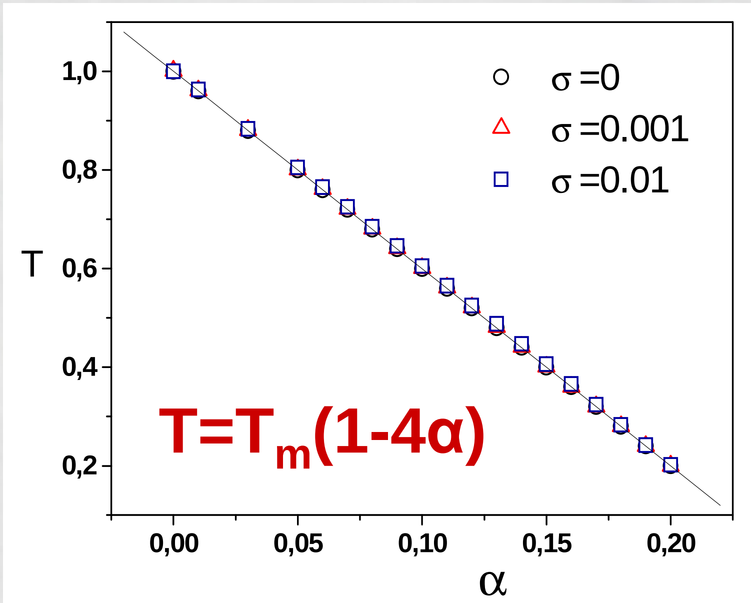
O. Ramos et al., *Phys. Rev.Lett.* (2006)

Quasi-periodicity in the avalanches





α = 0.2 **σ = 0.001**



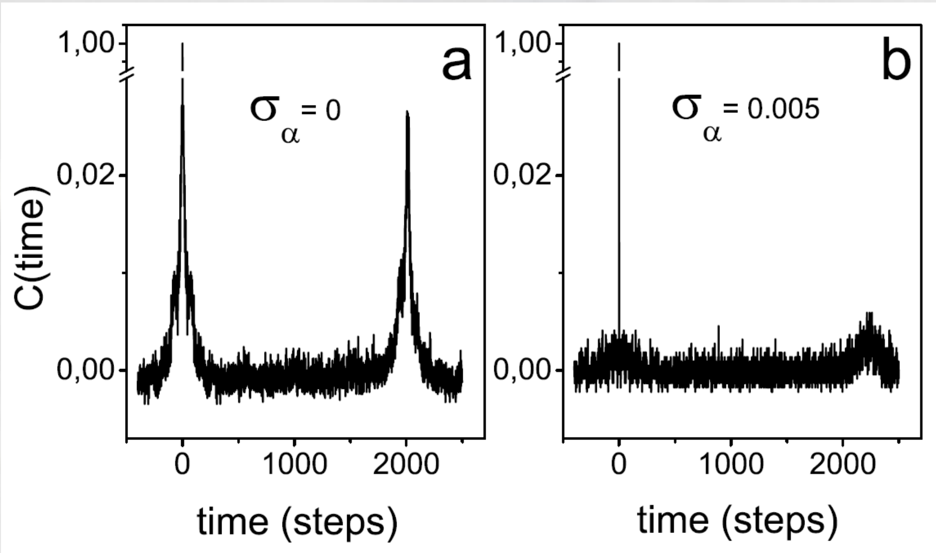
Quasi-periodic behavior as “natural” state in earthquakes?

Gap theory?

Simulations

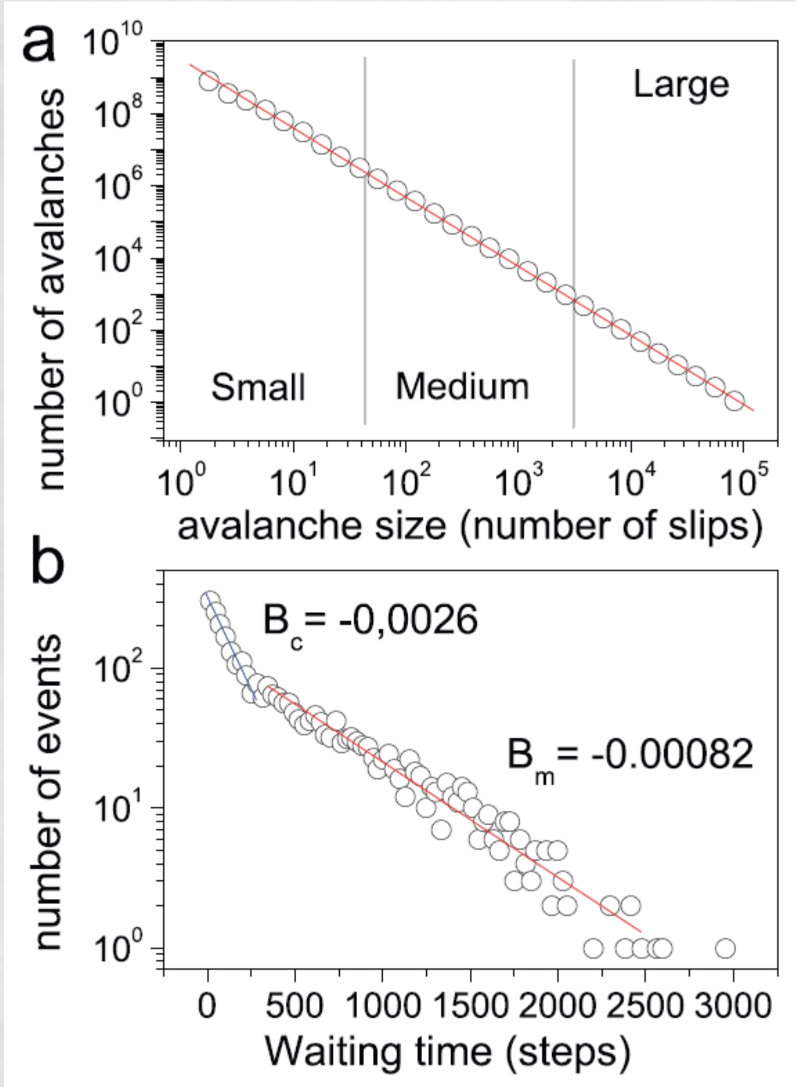
However, real earthquakes are not qusi-periodic!

By adding disorder.



α = 0.2 **σα = 0.005** (dissipation)

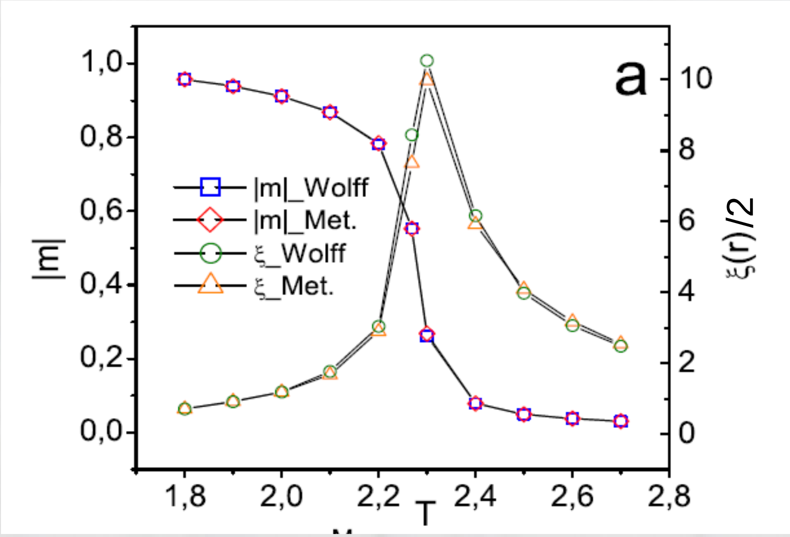
σ = 0.001 (friction thresholds)



A more realistic situatuion

Simulations

Classical critical phenomena

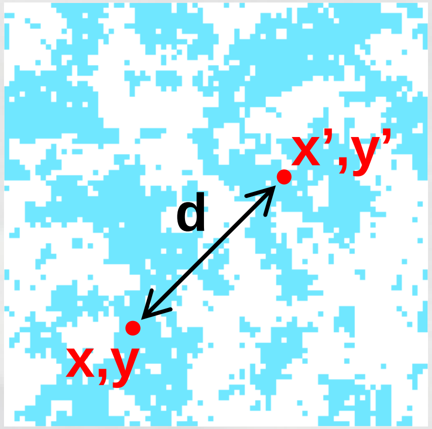


1- *Divergence of the correlation length* (*ξ*):

$$\langle C_A s(d,t)\rangle_t = \left\langle \frac{\sum (f(x,y)f(x',y')) - < f(x,y) >^2}{\sum (f(x,y) - < f(x,y) >)^2} \right\rangle_t$$

$$C_A s(d) \sim \exp(d/\xi) \quad (\forall\ T \neq Tc)$$

Ising Model



t_i

$$\xi = |t|^{-\nu} \qquad t = (T - Tc)/Tc$$

Some basics

Classical critical phenomena

*1- Divergence of the correlation length (**ξ**):*

$$\langle C_A s(d,t)\rangle_t = \left\langle \frac{\sum (f(x,y)f(x',y')) - < f(x,y) >^2}{\sum (f(x,y) - < f(x,y) >)^2} \right\rangle_t$$

$$C_A s(d) \sim \exp(d/\xi)$$

$$(\forall\ T \neq Tc)$$

2- Divergence of the correlation time (τ): **Critical slowing down**

$$C_A t(t) = \frac{\sum (f(t_i)f(t_i + t)) - < f(t_i) >^2}{\sum (f(t_i) - < f(t_i) >)^2}$$

$$C_A t(t) \sim \exp(t/\tau)$$

$$\xi = |t|^{-\nu}$$

$$\tau = |t|^{-z\nu}$$

$$t = (T - Tc)/Tc$$

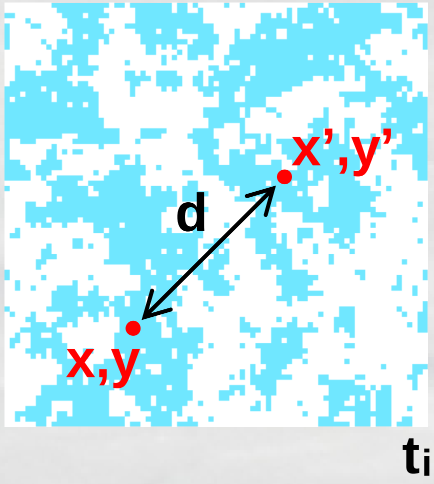
$$\tau = \xi^z$$

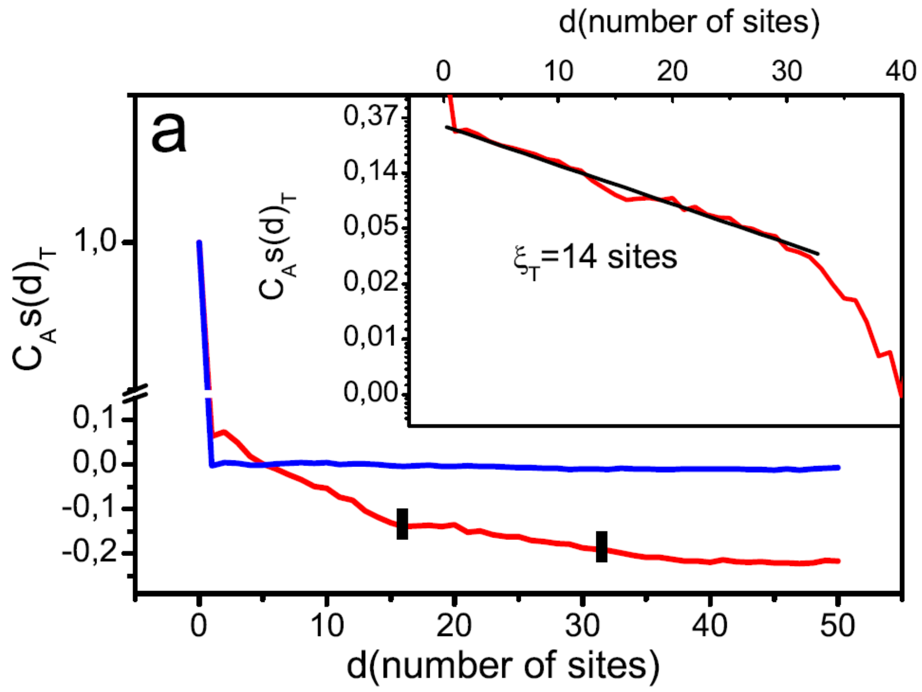
3- As the size of the system increases, the transition between the two states becomes sharper, and it is infinitely sharp in an infinite system.

Some basics

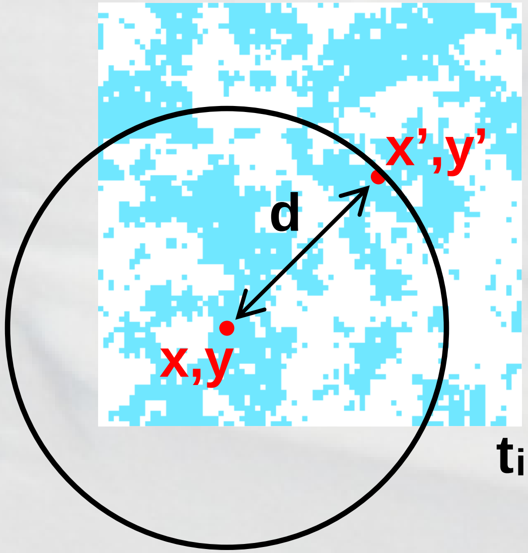
Spatial autocorrelation function & correlation length

$$\langle C_A s(d,t)\rangle_t = \left\langle \frac{\sum (f(x,y)f(x',y')) - < f(x,y) >^2}{\sum (f(x,y) - < f(x,y) >)^2} \right\rangle_t$$





L=128



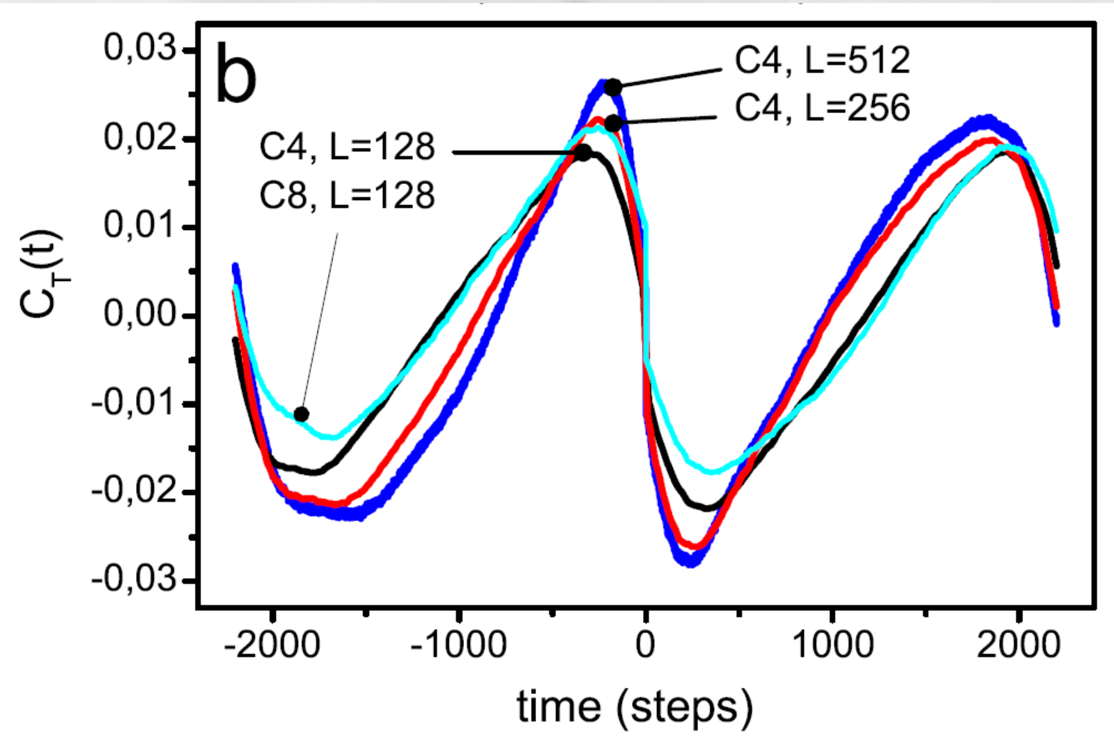
d=L/4, d=L/8

Simulations

Temporal corr (spatial autocorrelation function & Large avalanches)

$$Ct(t) = \frac{\sum (La(t_i)Cx(t_i + t)) - < La(t_i) >< Cx(t_i) >}{\sqrt{\sum (La(t_i) - < La(t_i) >)^2 \sum (Cx(t_i) - < Cx(t_i) >)^2}}$$

La(t)=1 if size(avalanche)=L
La(t)=0 if size(avalanche)=S, M
Cx(t)= C4(t), C8(t)



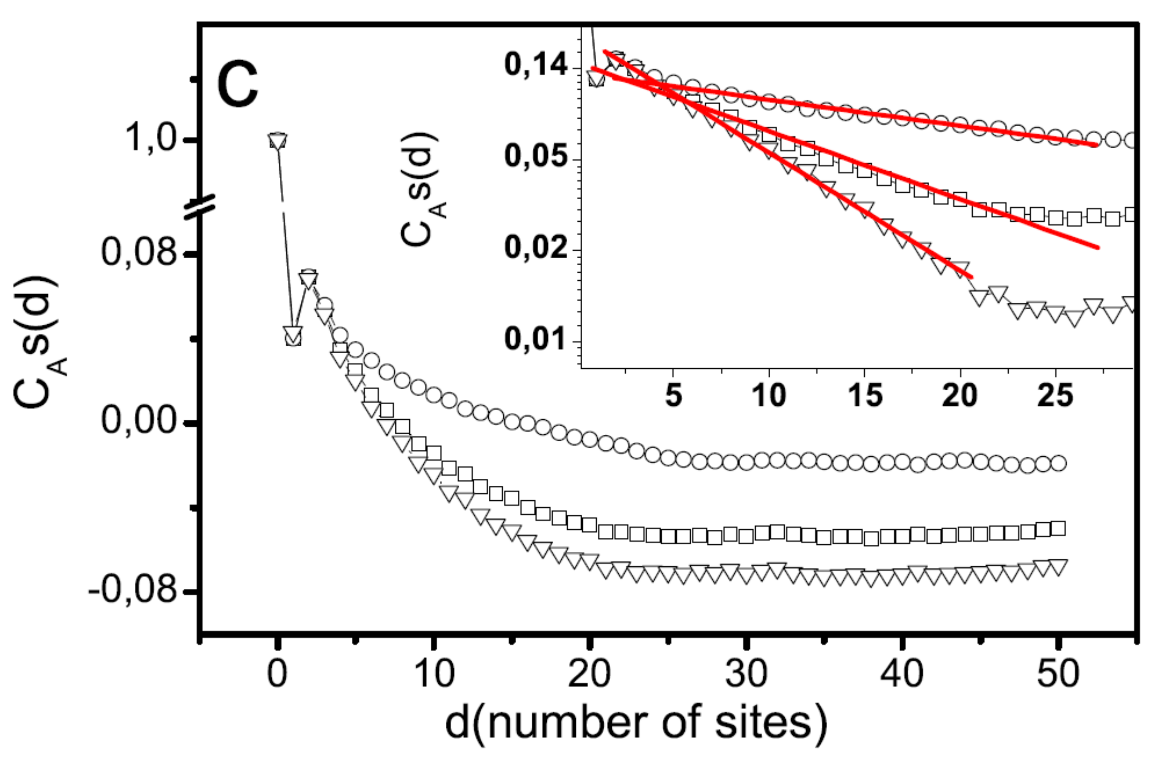
Structure still shows Quasi-periodicity.

Large oscillations of Cx(t) around L events.

Criticality ?

Simulations

Spatial autocorrelation function & correlation length ξ



max. ξ = 36 sites

average ξ = 12 sites

min. ξ = 7 sites

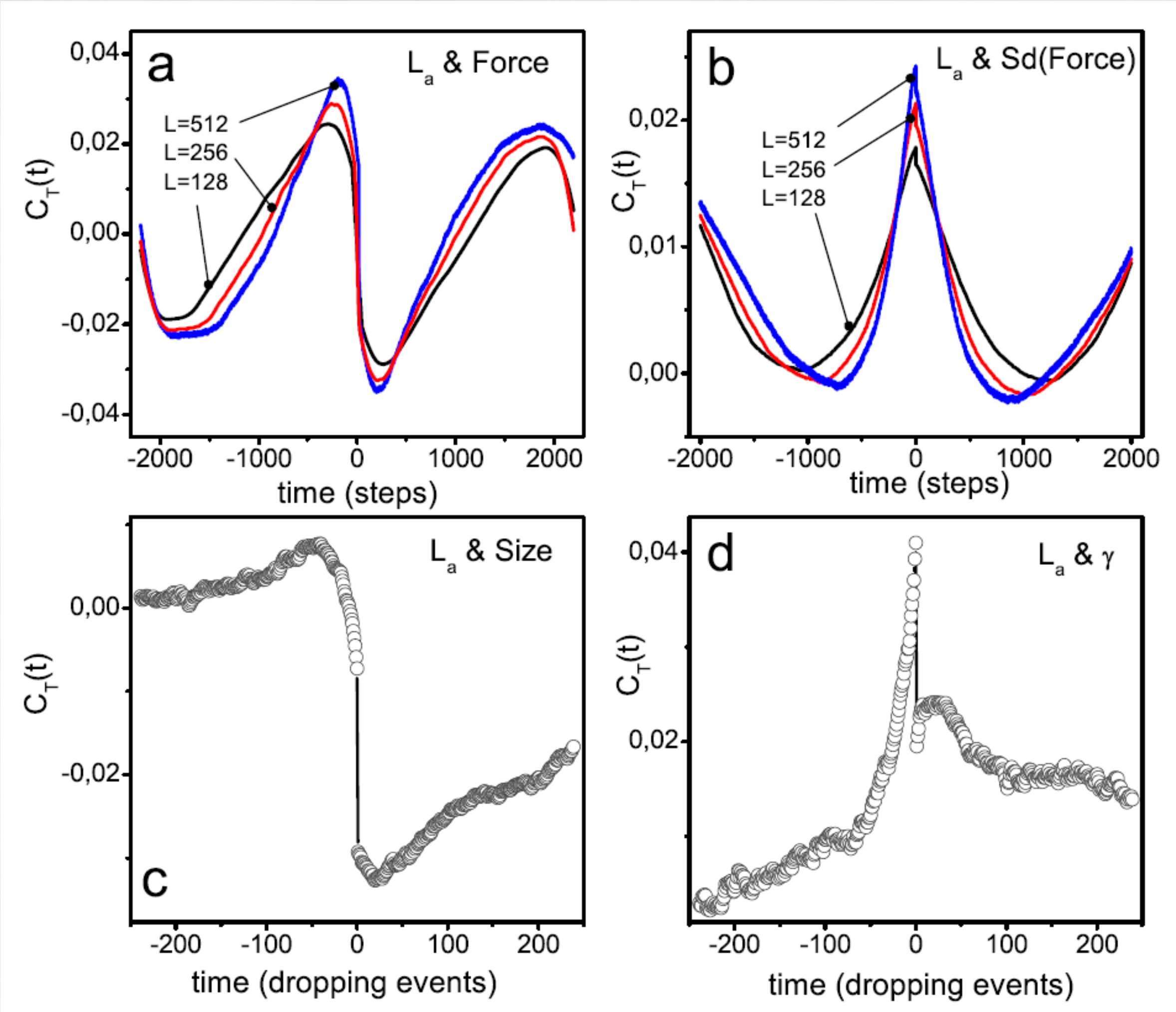
- In average the system is not critical (the correlation length is small).

⇩

In principle, prediction is possible

Simulations

Temporal correlation between structure & avalanches



Simulations

Experiments

Energy accumulation **Disorder accumulation**

Simulations

Can be "criticality" good for prediction?

Vol 461|3 September 2009|doi:10.1038/nature08227 nature

REVIEWS

Early-warning signals for critical transitions

Marten Scheffer[1], Jordi Bascompte[2], William A. Brock[3], Victor Brovkin[5], Stephen R. Carpenter[4], Vasilis Dakos[1], Hermann Held[6], Egbert H. van Nes[1], Max Rietkerk[7] & George Sugihara[8]

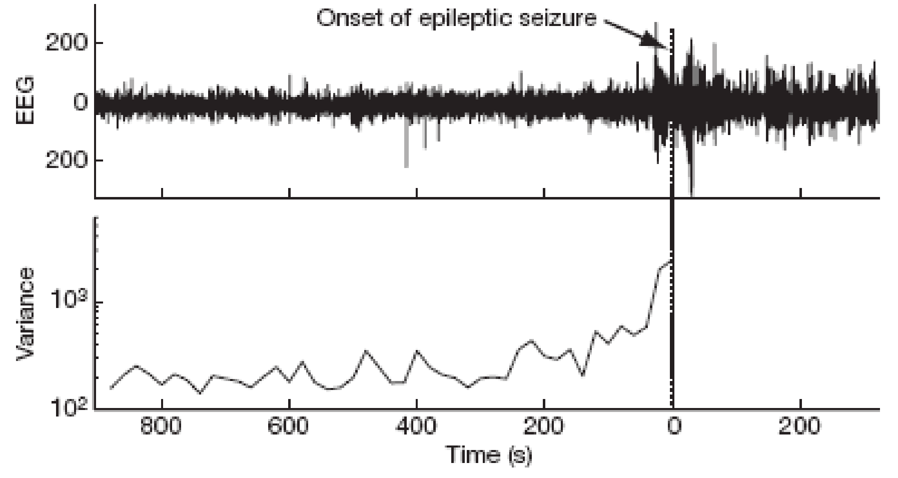


Figure 5 | Subtle changes in brain activity before an epileptic seizure may be used as an early warning signal. The epileptic seizure clinically detected at time 0 is announced minutes earlier in an electroencephalography (EEG) time series by an increase in variance. Adapted by permission from Macmillan Publishers Ltd: Nature Medicine (ref. 3), copyright 2003.

Critical slowing down

Discussions

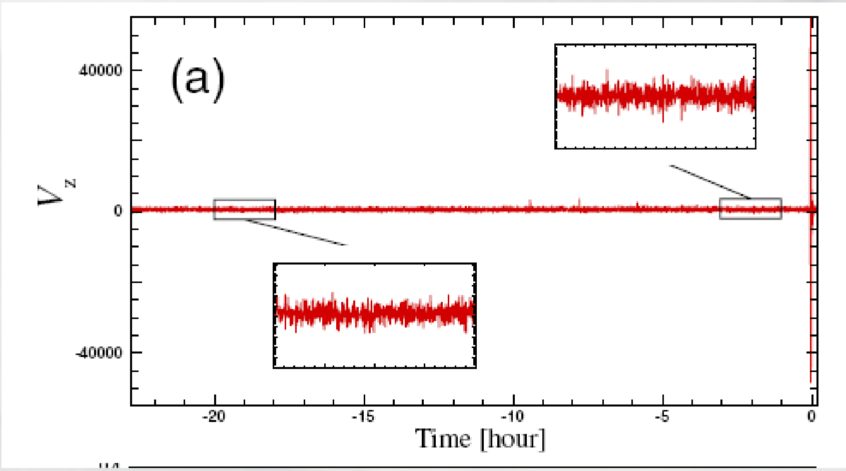
Can be ”criticality” good for prediction?

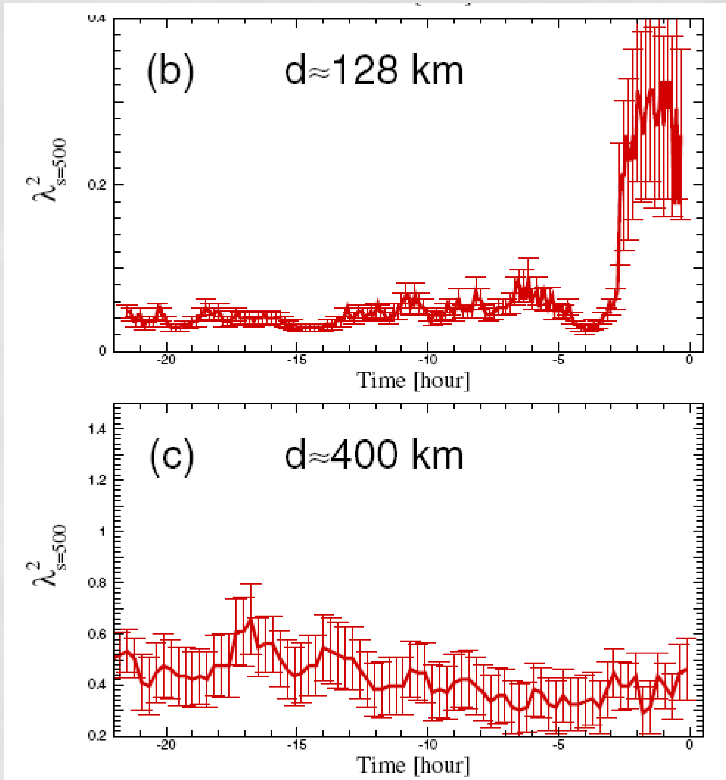
PRL **102,** 014101 (2009) PHYSICAL REVIEW LETTERS week ending 9 JANUARY 2009

Turbulencelike Behavior of Seismic Time Series

P. Manshour,[1] S. Saberi,[1] Muhammad Sahimi,[2] J. Peinke,[3] Amalio F. Pacheco,[4] and M. Reza Rahimi Tabar[1,3,5]

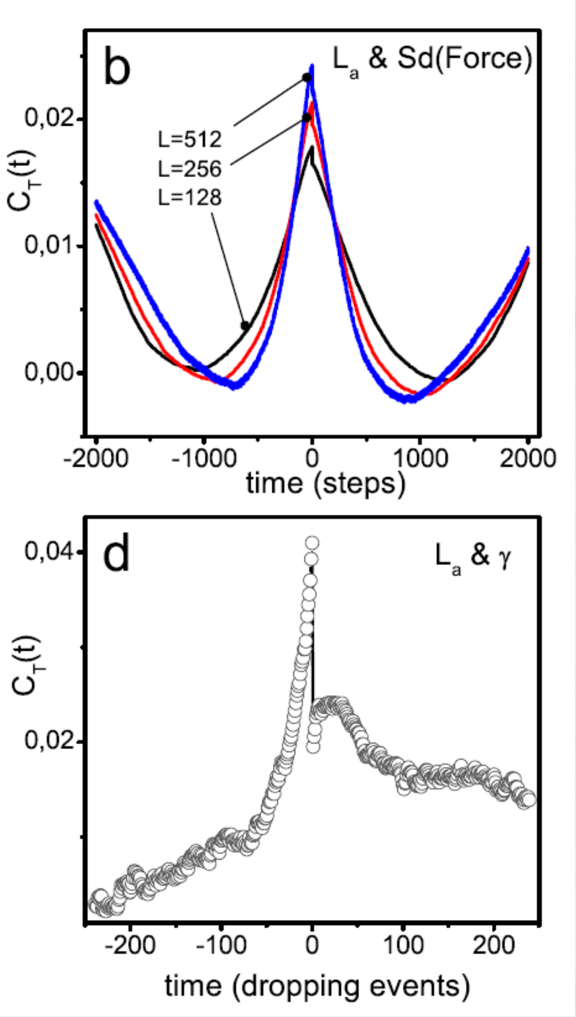
[1]*Department of Physics, Sharif University of Technology, Tehran 11155-9161, Iran*
[2]*Mork Family Department of Chemical Engineering & Materials Science, University of Southern California, Los Angeles, California 90089-1211, USA*
[3]*Institute of Physics, Carl von Ossietzky University, D-26111 Oldenburg, Germany*
[4]*Department of Theoretical Physics, University of Zaragoza, Pedro Cerbuna 12, 50009 Zaragoza, Spain*
[5]*CNRS UMR 6202, Observatoire de la Côte d'Azur, BP 4229, 06304 Nice Cedex 4, France*
(Received 22 February 2008; published 5 January 2009)





Critical slowing down ?

Can be ”criticality” good for prediction?



Simulations

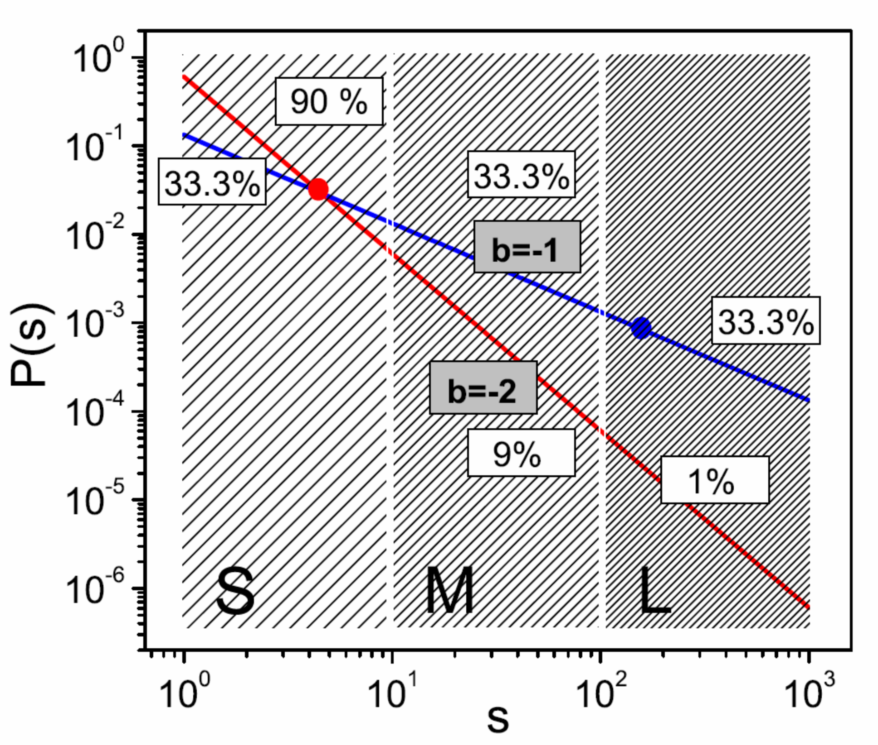
Critical slowing down ?

Experiments

Disorder accumulation

In general

Classifying catastrophic events in power-law distributed avalanches



"Many very small events and a few very large ones". !

Energy balance:

$$\forall t \quad E_{max} >> \langle E_{input} \rangle = \langle E_{dissip} \rangle = \langle E_{bulk} \rangle + \langle E_{boundaries} \rangle$$

αS_{max} $\qquad$ $\alpha < s >$

- Large b values are forbidden in <u>dissipative slowly-driven systems</u>!

- For small b values the system is not critical

In general

PHYSICAL REVIEW E **79**, 051106 (2009)

Size distributions of shocks and static avalanches from the functional renormalization group

Pierre Le Doussal and Kay Jörg Wiese

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Interfaces pinned by quenched disorder are often used to model jerky self-organized critical motion. We study static avalanches, or shocks, defined here as jumps between distinct global minima upon changing an external field. We show how the full statistics of these jumps is encoded in the functional-renormalization-group fixed-point functions. This allows us to obtain the size distribution $P(S)$ of static avalanches in an expansion in the internal dimension d of the interface. Near and above $d=4$ this yields the mean-field distribution $P(S)\sim S^{-3/2}e^{-S/4S_m}$, where S_m is a large-scale cutoff, in some cases calculable. Resumming all one-loop contributions, we find $P(S)\sim S^{-\tau}\exp(C(S/S_m)^{1/2}-\frac{B}{4}(S/S_m)^{\delta})$, where B, C, δ, and τ are obtained to first order in $\epsilon=4-d$. Our result is consistent to $O(\epsilon)$ with the relation $\tau=\tau_\zeta:=2-\frac{2}{d+\zeta}$, where ζ is the static roughness exponent, often conjectured to hold at depinning. Our calculation applies to all static universality classes, including random-bond, random-field, and random-periodic disorders. Extended to long-range elastic systems, it yields a different size distribution for the case of contact-line elasticity, with an exponent compatible with $\tau=2-\frac{1}{d+\zeta}$ to $O(\epsilon=2-d)$. We discuss consequences for avalanches at depinning and for sandpile models, relations to Burgers turbulence and the possibility that the relation $\tau=\tau_\zeta$ be violated to higher loop order. Finally, we show that the avalanche-size distribution on a hyperplane of codimension one is in mean field (valid close to and above $d=4$) given by $P(S)\sim K_{1/3}(S)/S$, where K is the Bessel-K function, thus $\tau_{\text{hyper plane}}=\frac{4}{3}$.

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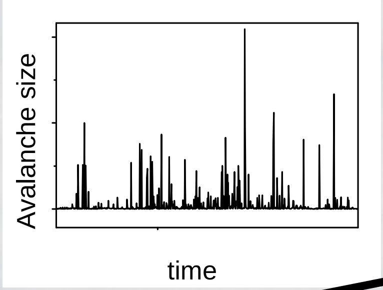
Predicting catastrophic events in power-law distributed avalanches

1 - Temporal autocorrelation



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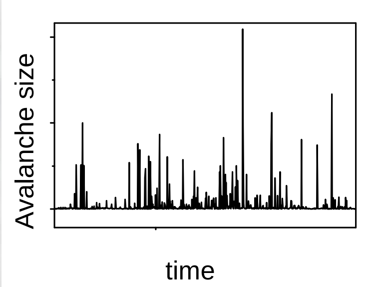
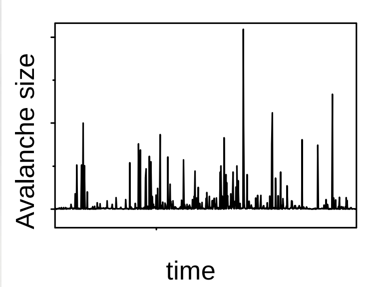


"Spiky" functions

2 - Temporal correlation
between
avalanches & structure



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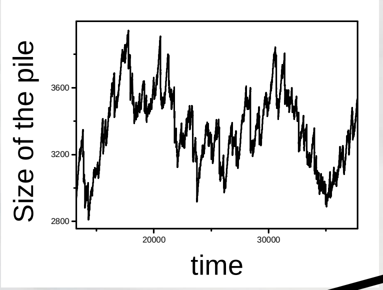


continuous function

In general

Conclusions:

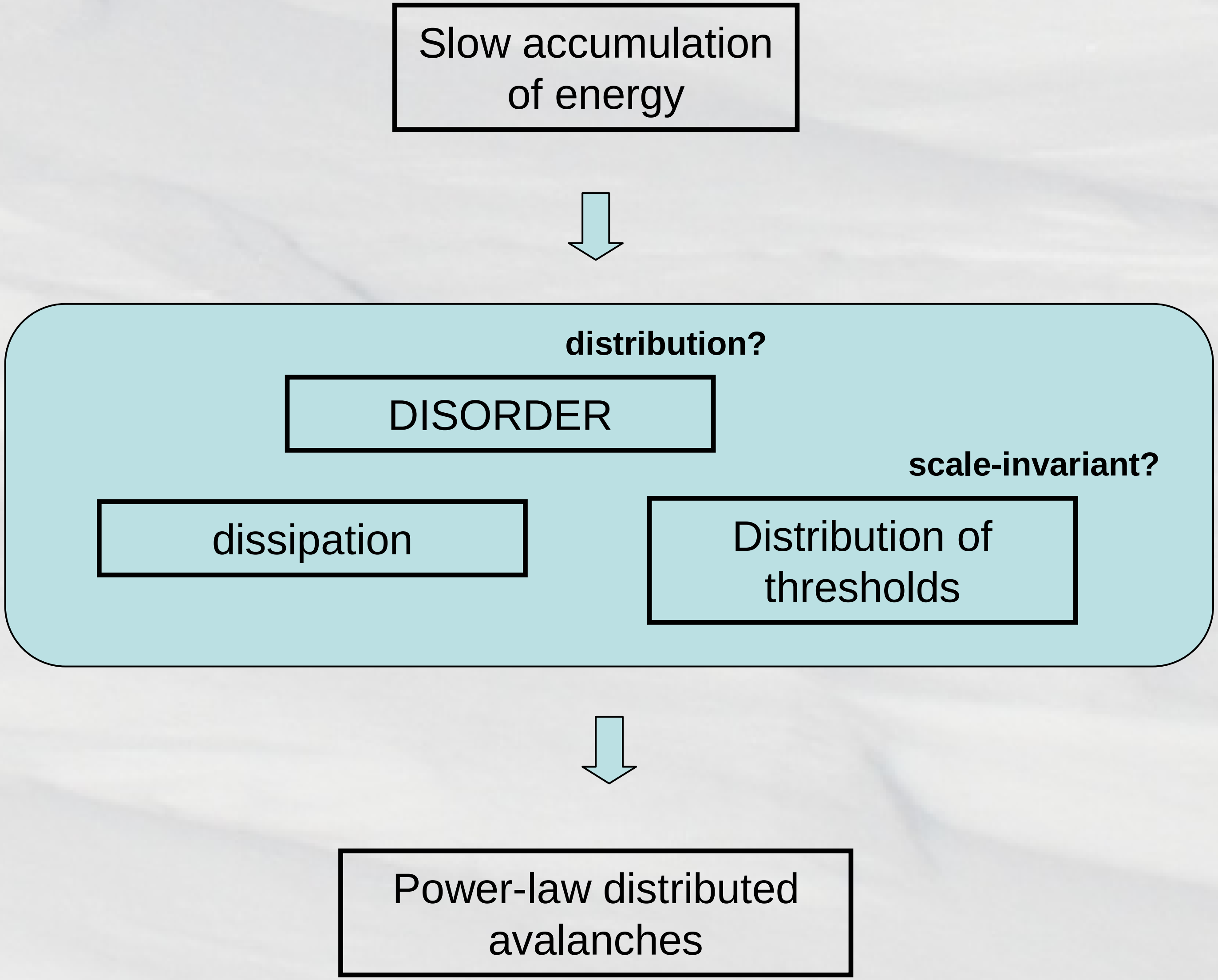
- Power law distributed avalanches do not imply necessarily that the correlation length diverge and the system is all the time in the verge of a catastrophic event.

- If the correlation length (averaged over the entire experience) does not diverge, prediction is in principle possible. Prediction of power law distributed events has been reached experimentally.

-The increase of the disorder of the structure and others signs of *critical slowing down* seems to be related with the occurrence of large events.

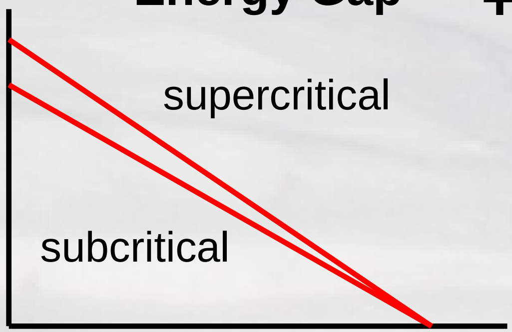
- (*trivial, but important*) In general, the analysis of functions which evolve continuously with time bring more useful information than the functions of “spikes”. So, collecting and analyzing this kind of data can be relevant in order to achieve prediction.

Open questions:



Quasi-periodicity as an "ideal" state that is perturbed by instabilities

Energy Gap **+** **little inertia**
little disorder
large friction



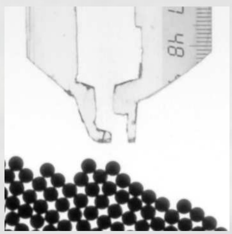
Quasi-periodic large events

Held *et al* (1990),
Rosendahl *et al* (1993)

add disorder

Power-law dist. events

Fretté *et al* (1994),
Altshuler *et al* (2001)



dissipation,
noise vs. stability

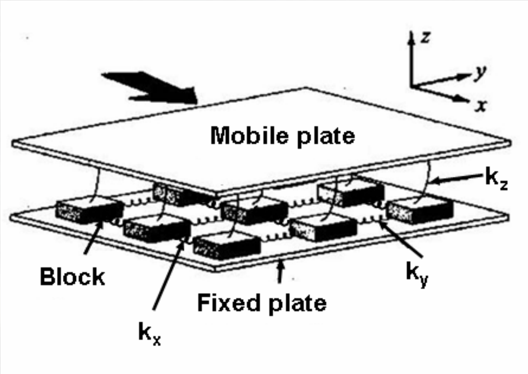
exponent b

Ramos *et al* (to be pub.)

Open questions

Quasi-periodicity as an "ideal" state that is perturbed by instabilities

Earthquake **simulations**



O. Ramos *et al, PRL (2006)*

Basic state: No interaction between blocks or identical initial conditions to all: **Trivial periodic behavior**

Interactions (dissipation) +
different friction thresholds (Gaussian)

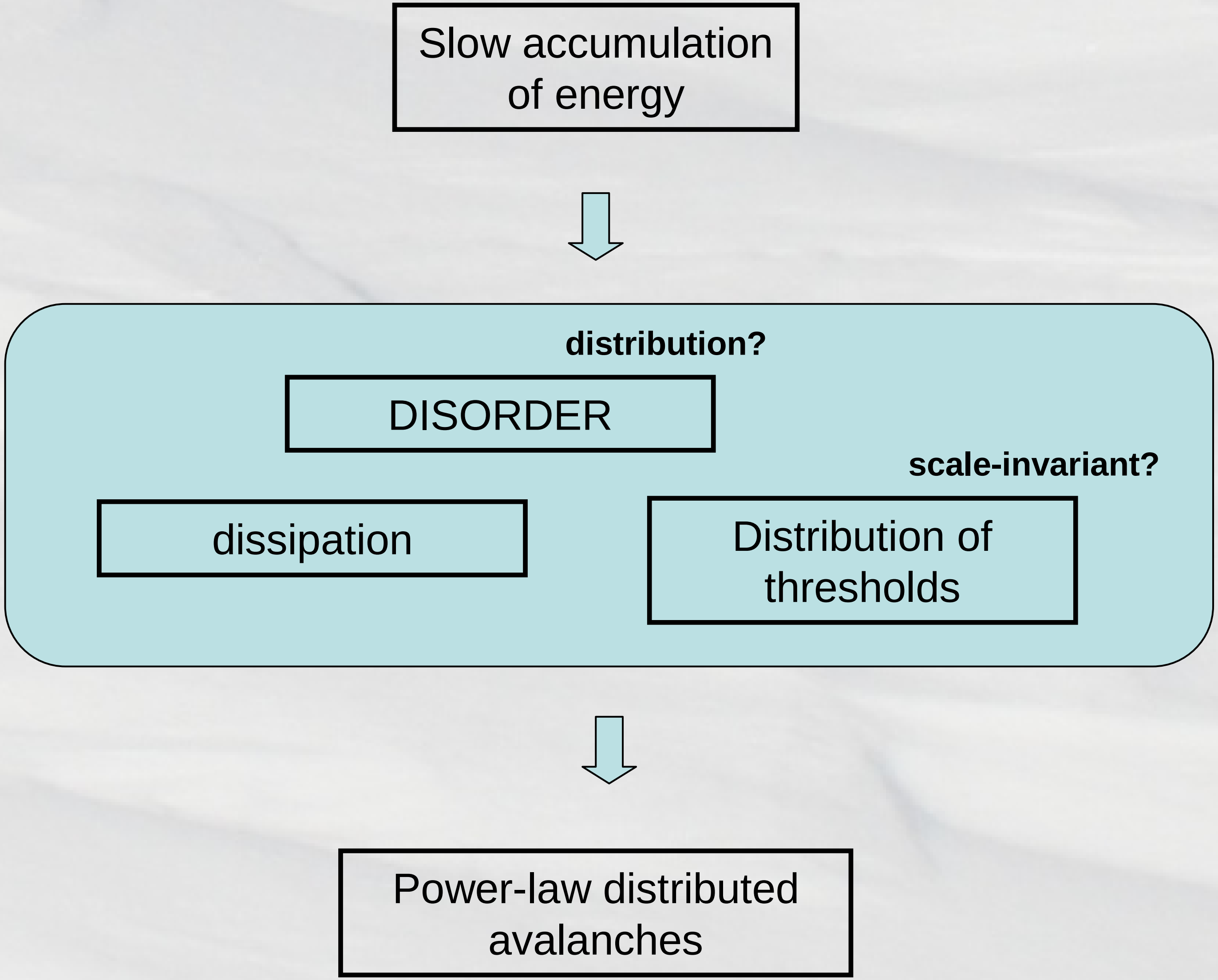
Non trivial quasi-periodic behavior proportional to the degree of dissipation as a "natural" state. (coexisting with a power-law distribution of events)

Addition of disorder (Gaussian) to the values of the dissipation

The quasi-periodicity is broken (the power-law distribution of events remains). More realistic situation

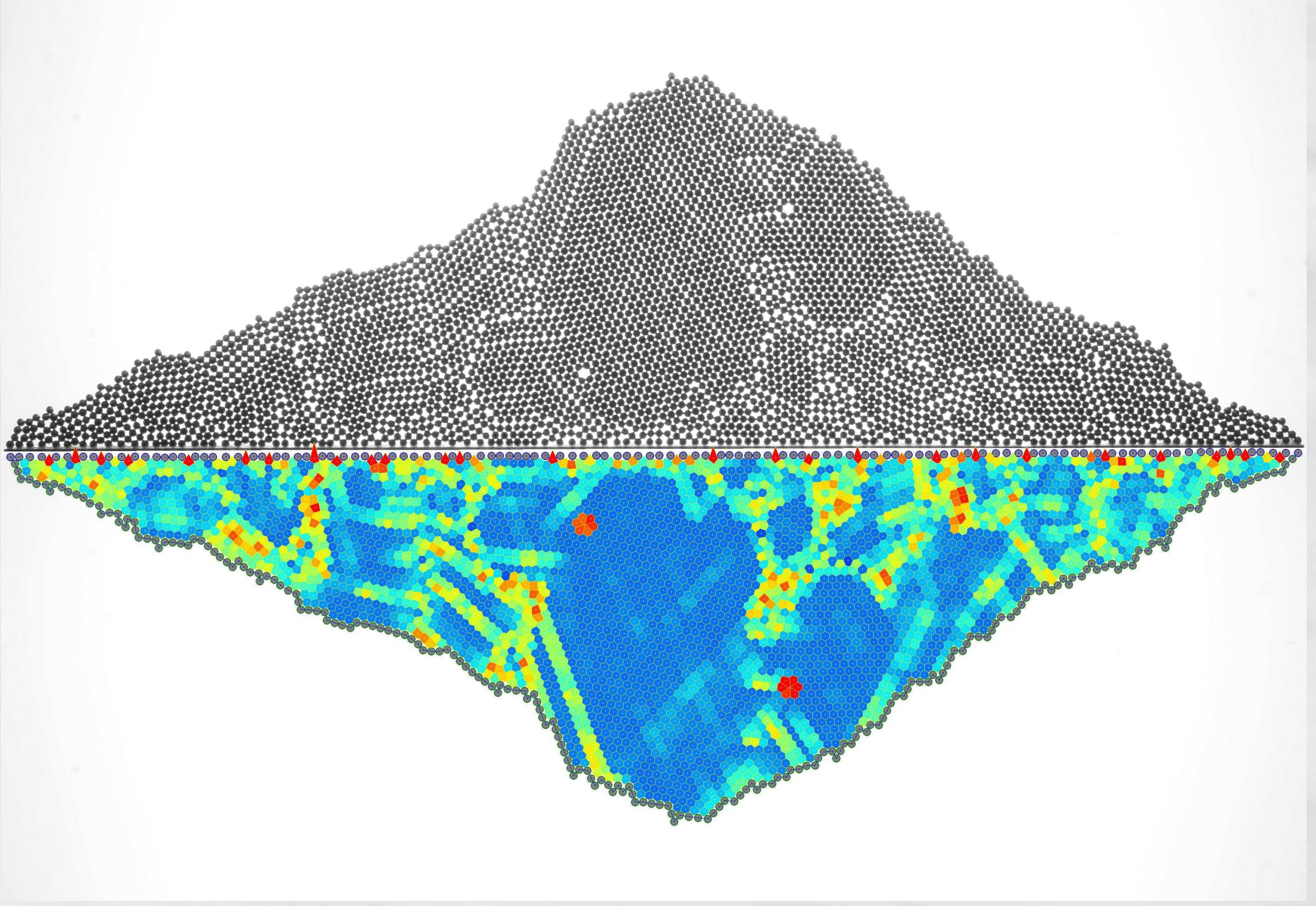
Open questions

Open questions:



Merci beaucoup!

http://www.pmmh.espci.fr/~oramos



Gutenberg – Richter law: **Log [N (x)] ~ bM**

where:

N (x): cumulative number of earthquakes. (earthquakes with a magnitude larger than M)

M ~ Log E : magnitude (damage)

b ~ -1

then

Log [N (E)] ~ - Log E

N (E) ~ E $^{-1}$

P(x) : distribution of avalanches
N(x) : cumulative number of avalanches

$$P(x) = N(x) - N(x + \Delta x)$$

$$\frac{P(x)}{\Delta x} = -\left[\frac{N(x+\Delta x) - N(x)}{\Delta x}\right]$$

$$P(x) \sim -N'(x)$$

$$N(x) \sim -\int P(x)dx$$

If N (x) = **x $^{-1}$**

$$P(x) \sim -\left(x^{-1}\right)' = -\left(-x^{-2}\right) = x^{-2}$$

back