ECONOPHYSICS: PY538

- broadbrush today....details in http://polymer.bu.edu/~hes/
- work by (one could wish no finer collaborators):

Gabaix (Fisher-Black Prize!), Salinger, Pammolli, Riccaboni, Podobnik, Preis, Moat, Vodenska, Buldyrev, Havlin, Mantegna, Gopikrishnan, Plerou (Young Scientist Prize), Petersen, Liu, Cizeau, Fu, D. Wang, H. Wang, F. Wang, Bertella, X. Huang, S. Zhang, G. Li, J. Wu, S. Levy, X. Feng, Yamasaki, Rosenow, Amaral, Ivanov, Matia, W-X Zhou, Z. Q. Jiang, Weber, Chessa, Gou, Lee, Meyer, Y-H Shao, Carbone, Ben-Jacob, Kenett, Fu, Majdanzic, Schneider, Curme, Avakian, Su, Lu, S. Shao, Ling, H. Huang,

&YOU [??]

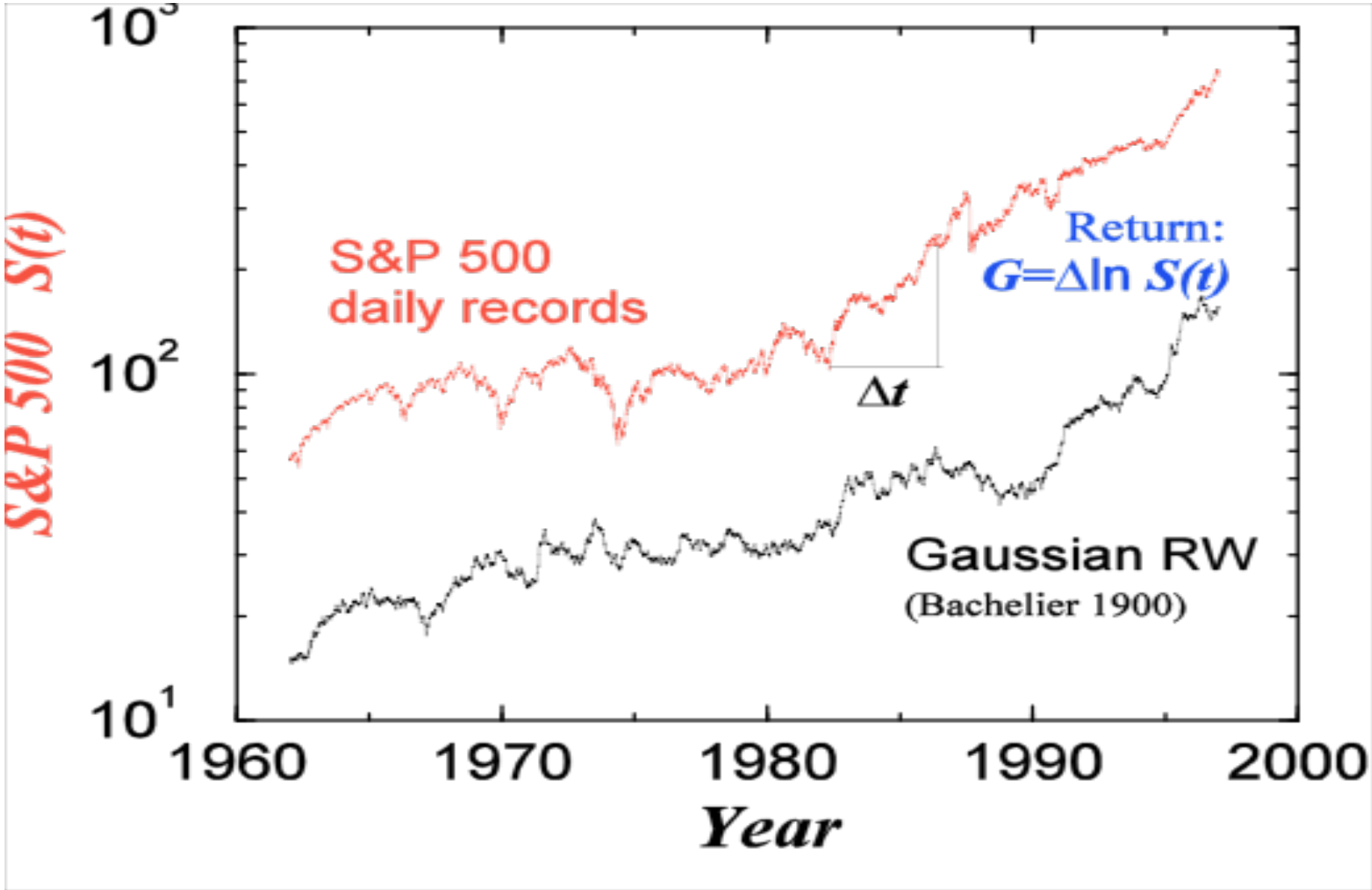
INVITATION: please consider to come to Rm.204.....
i will welcome you at any time!

Can physicists contribute to economics/finance?

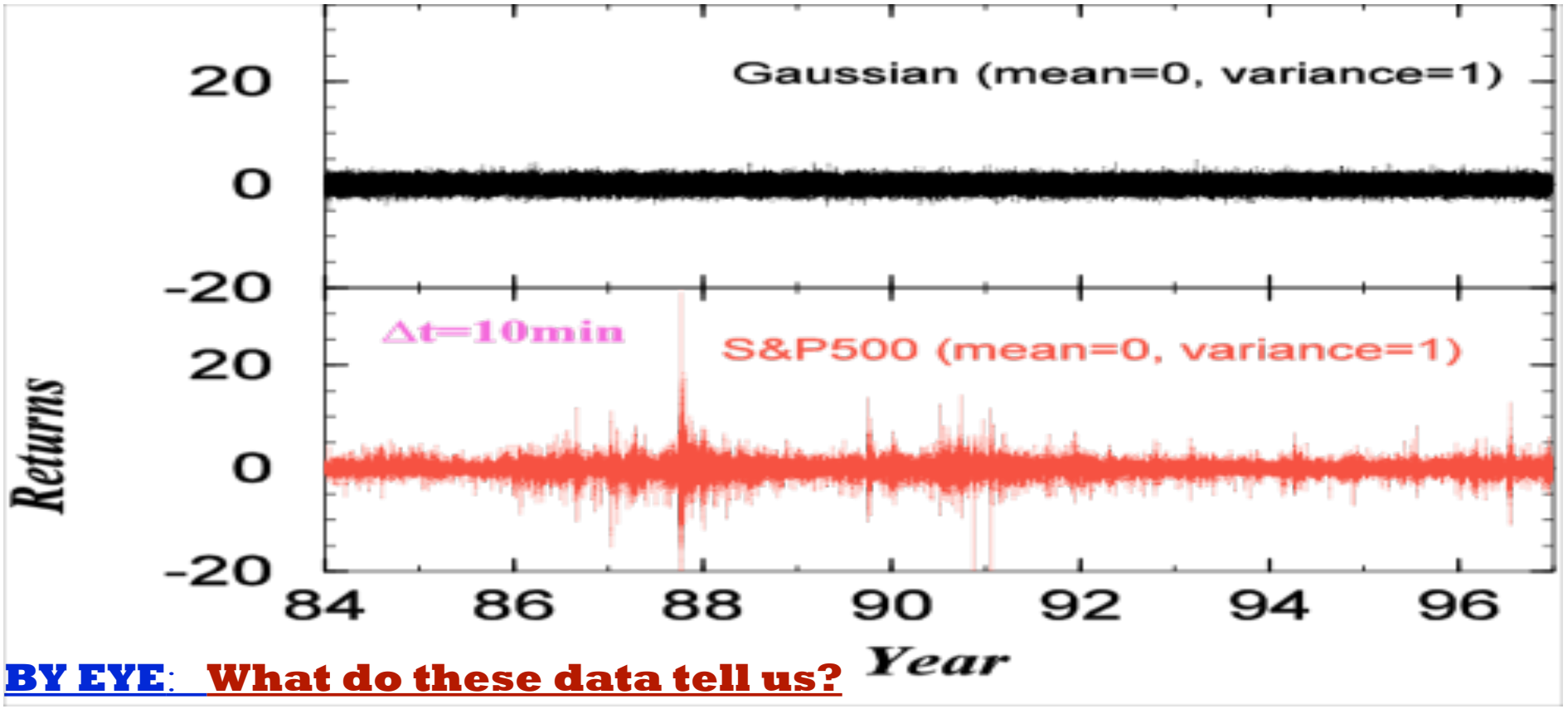
- get an economics partner...& respect him/her!
- get as much data as exists ("big data")
- ask "What are these data telling us?"
- to find out, quantify each finding...
- Do not be too timid: e.g., Aggregate, ...
- try to relate all findings (ex: price, volume, intertrade times, volatility,...)
- Make "model" relating all facts **("cheating"?)**

Dedication: TINBERGEN/EHRENFEST the first econophysicists?[2]

THE PUZZLE: "SWITCHING WITHOUT SWITCHES"



"Big switch" : 19 Oct. 1987 (25% worldwide "earthquake/tsunami")



BY EYE: **What do these data tell us?**

Q: can your **eye** see the power law? that it is inverse cubic?

Returns non-Gaussian (known **qualitatively,** but under-appreciated!)

Large events cluster (like earthquakes) (also known **qualitatively**)

"Aftershocks" Omori-correlated (Palermo 03; BU 07)

"Aftershocks of each aftershock" also Omori-correlated; (BU)

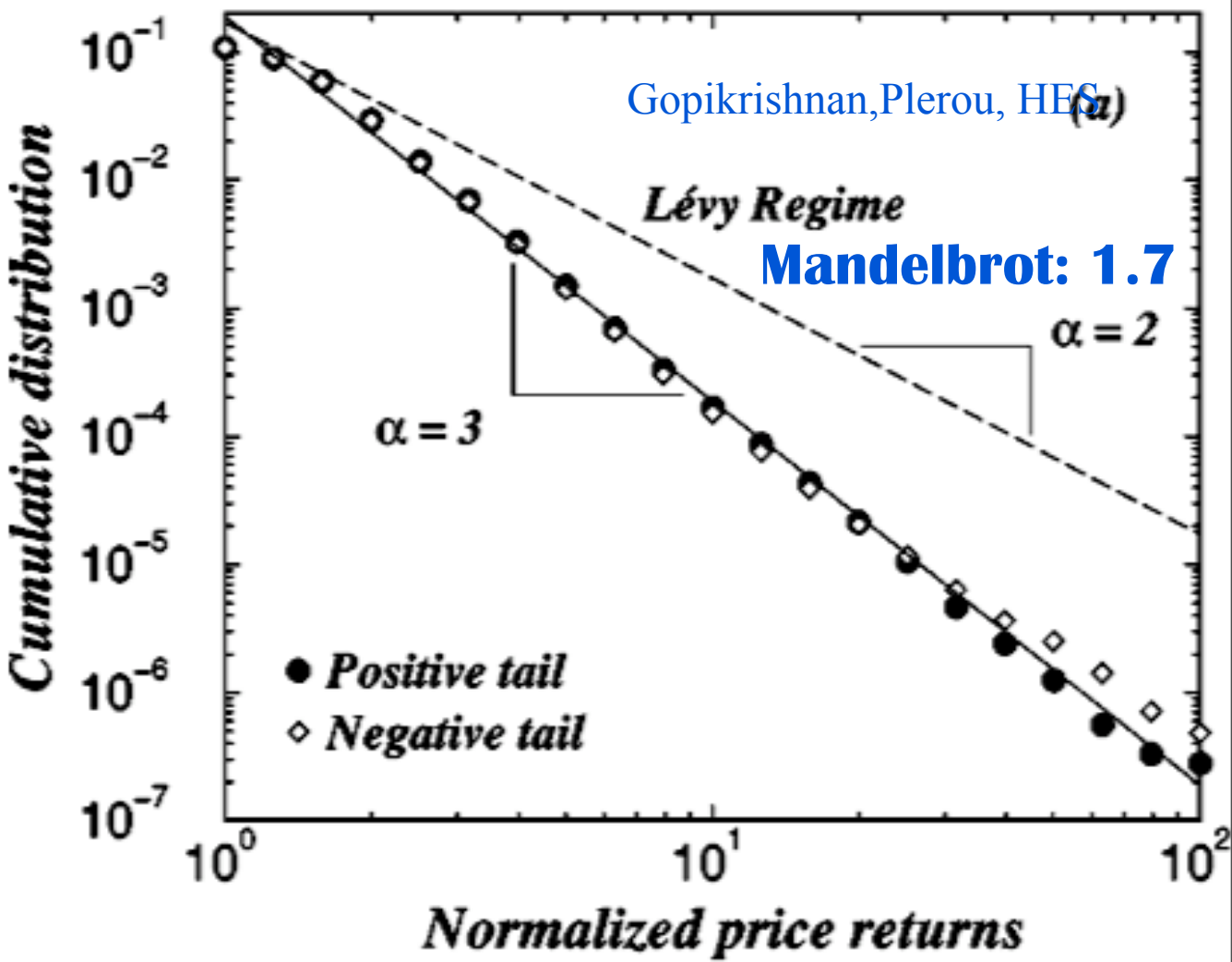
holds over **6** orders of magnitude on y-axis (**8** for pdf: inverse quartic)

200,000 data points per stock **x** 1000 stocks = **200,000,000** data points

events 8 orders of magnitude MORE RARE than everyday values conform to the SAME pdf

Gutenberg-Richter earthquake law:

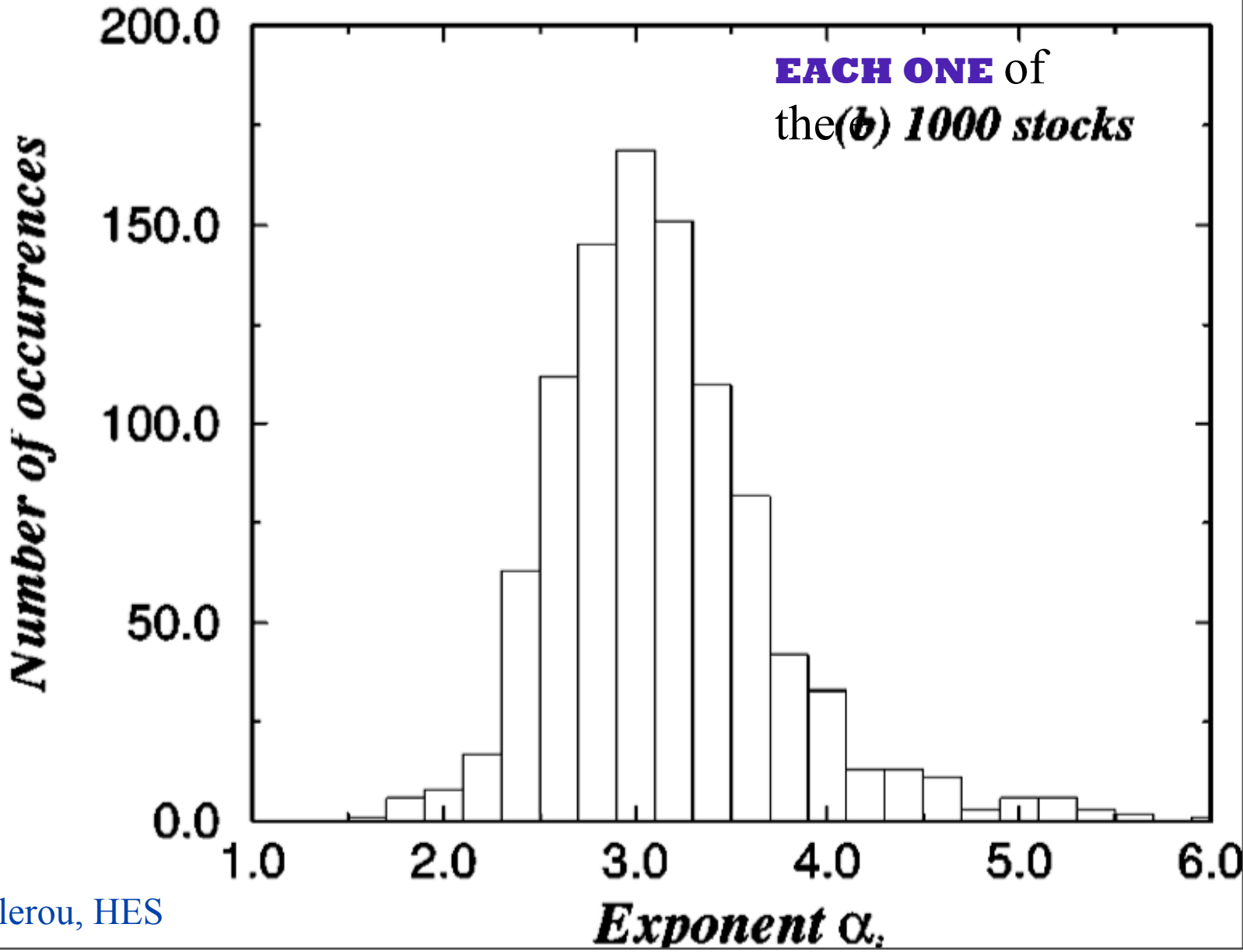
mag = 7 quake **same** law as mag = 1 quake



Note: there is NOT a perfect power law due to corrections at both ends of a power law region, just as for power laws in turbulence.

Aggregating is also "cheating"??

Find that inverse cubic law holds "microscopically" for **each stock**



Gopikrishnan,Plerou, HES

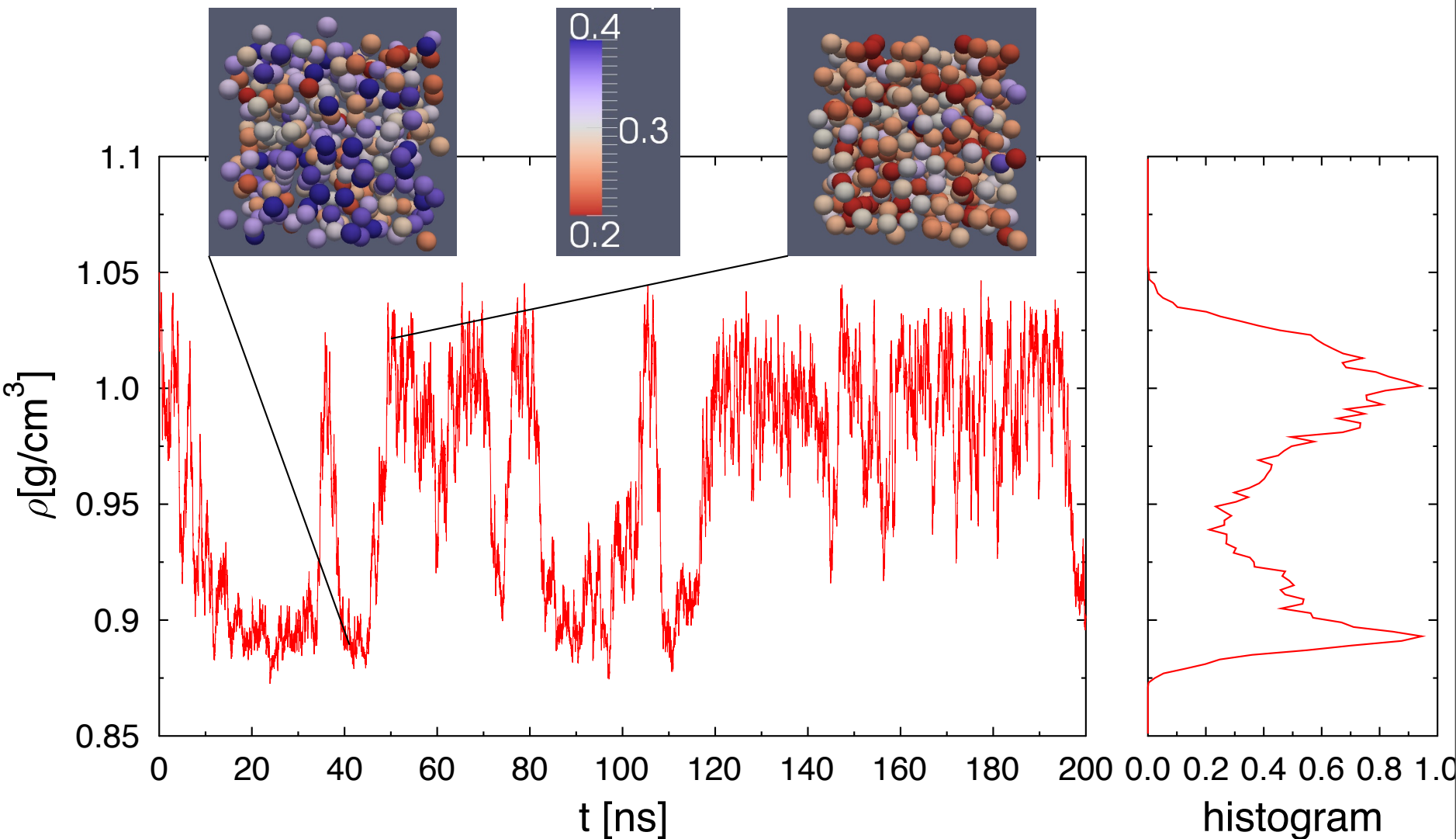
The Economist

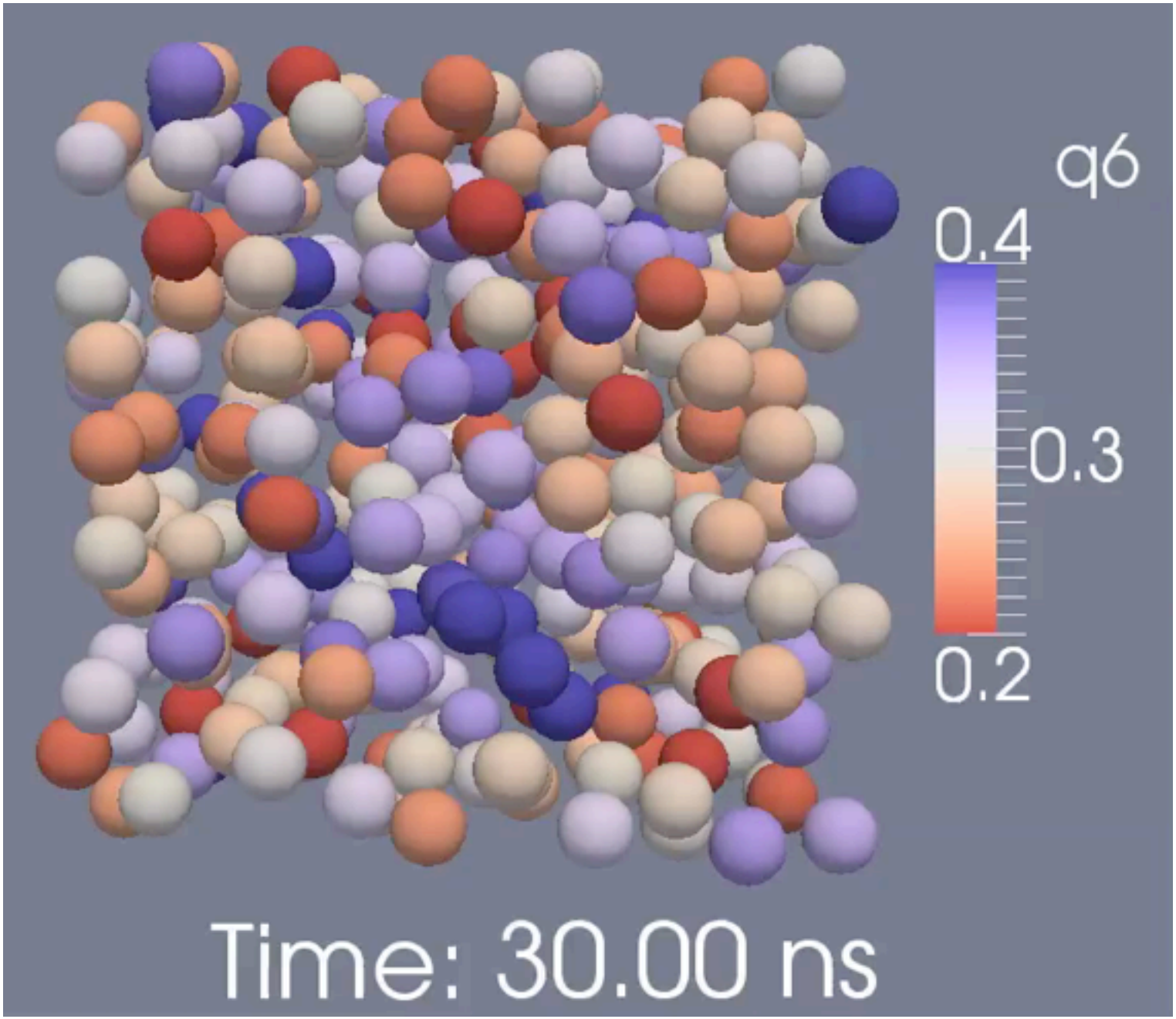
Text

The Economist

Text

water: ***time dep. for 1 state point near ph. trans. line:***




q6
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0.2
Time: 30.00 ns

“How?” “Models?”: Herd vs. News?

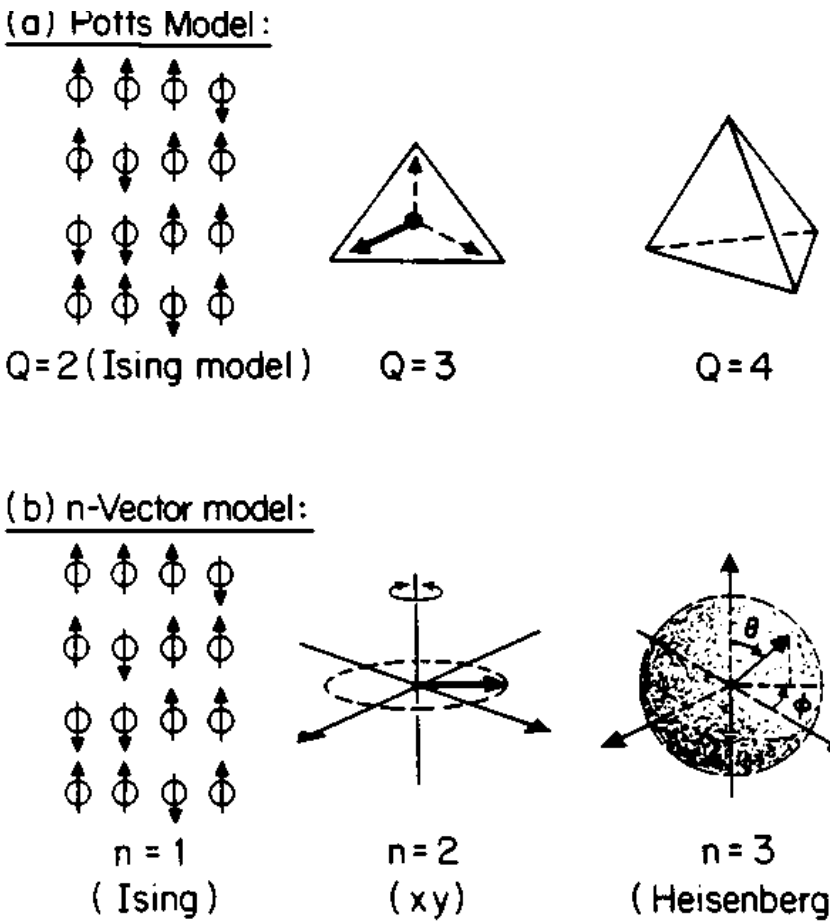
(1) “herd effect” (exchange int. J). (2) news effect (external field H)

Each stock is a unit, interacting with other stocks (units) and bathed in a magnetic field H. J depends on the two stocks, and H depends on the stock. Both can change with time.

Possible models:
(a) Units can be in Q different DISCRETE states: “Potts Model” (Potts 1952).

(b) n-dimensional units. Each can be in a CONTINUUM of states: “n-Vector Model” (HES 1969)

(c) modified Edwards-Anderson “spin glass” (w/ t-dep interactions)

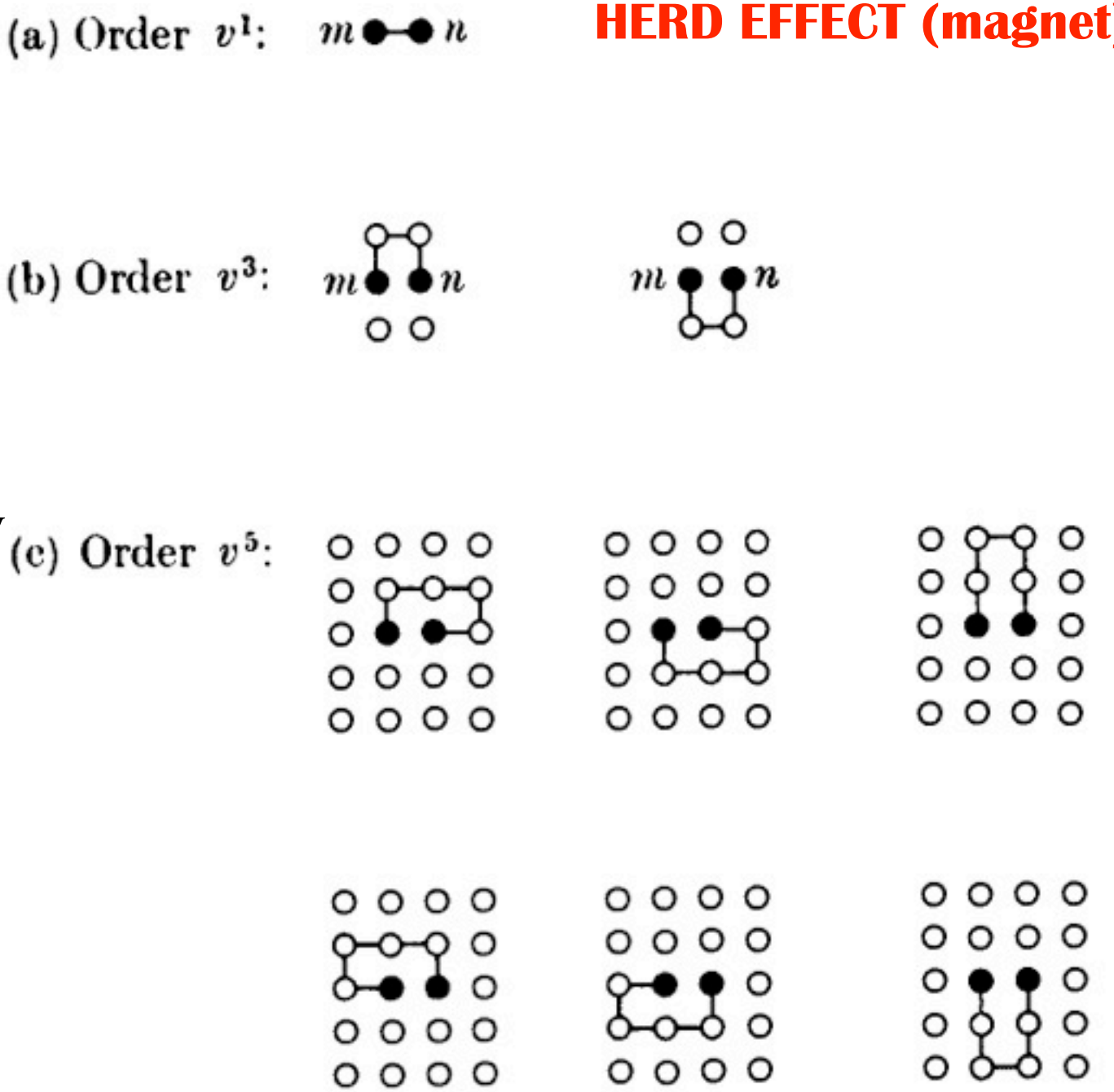


PUZZLE:
How does a paramagnet "know" when to spontaneously order itself?

ANSWER:
When the exponential decay along a 1-d path balances the exponential increase in the number of paths.

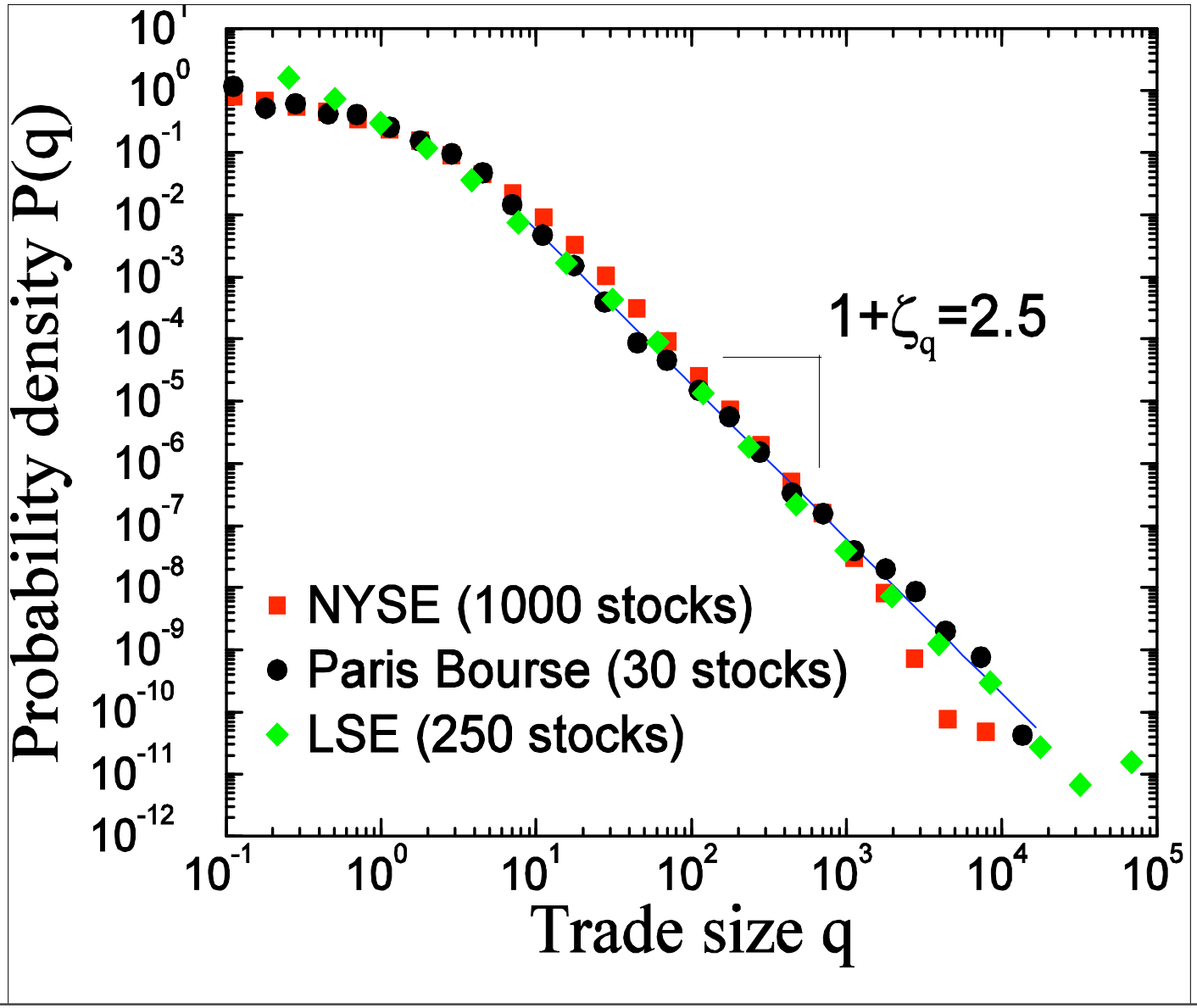
v = J/kT = n.n. coupling strength

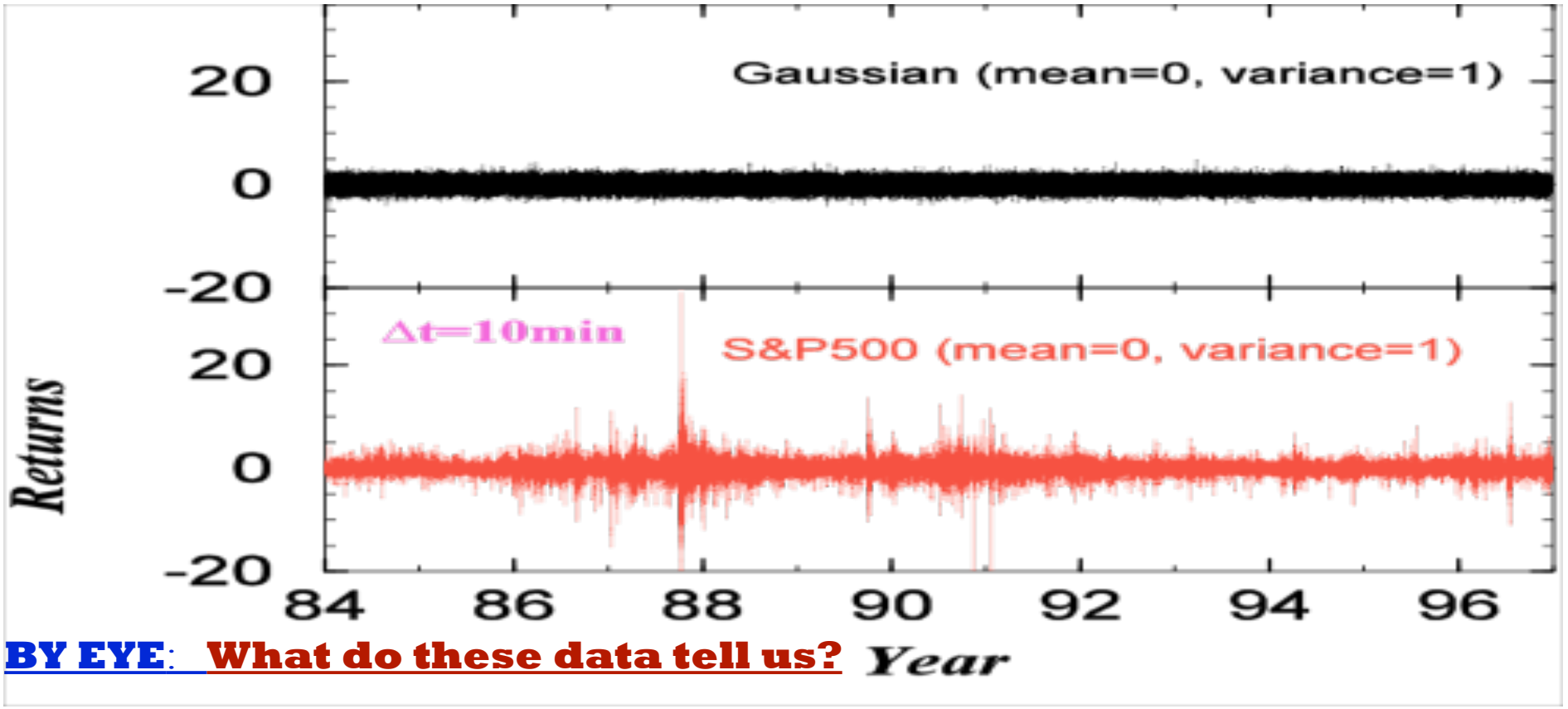
HERD EFFECT (magnet)



TEST #1: if interacting system of subunits, should be "universality"

DATA Show: power-law exponents are Universal (indep of time period, country, volatility (ex 1987,2008,.. same!). implies what??





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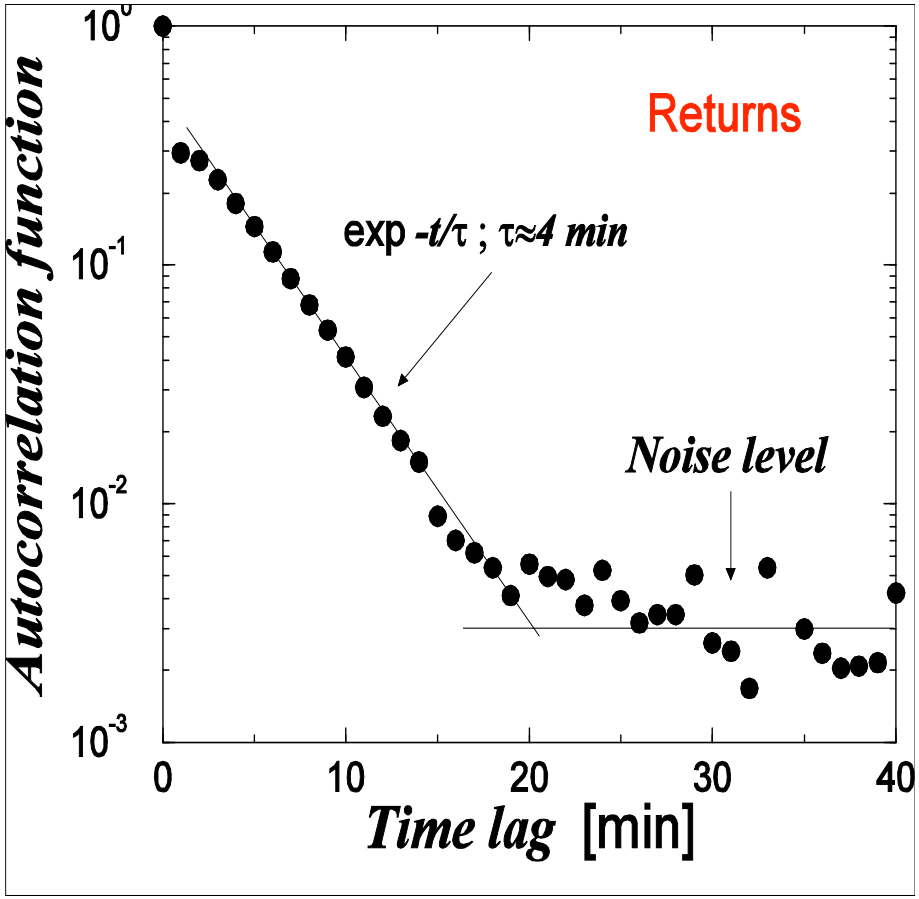
"Aftershocks" Omori-correlated (Palermo 03; BU 07)

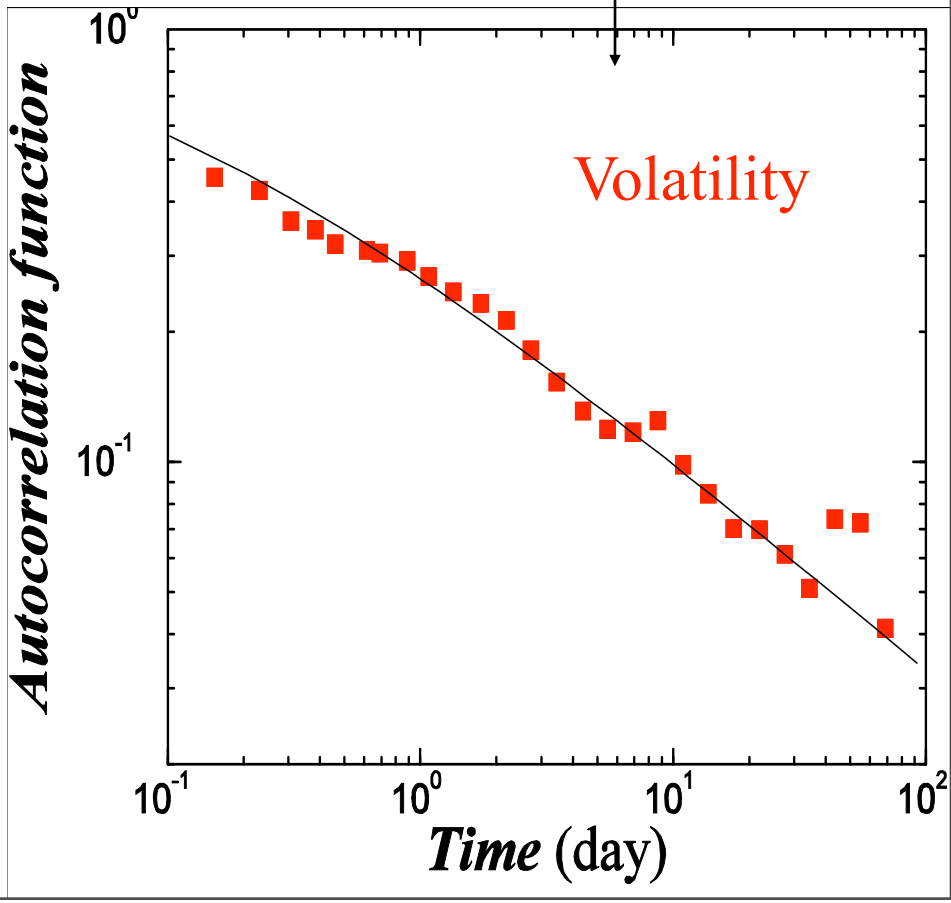
"Aftershocks of each aftershock" also Omori-correlated: (BU)

QUASI-TEST 2: Are there time Correlations?

((economists knew these results, qualitatively, as volatility clustering....so calculate autocorrelation function and get a "law"))

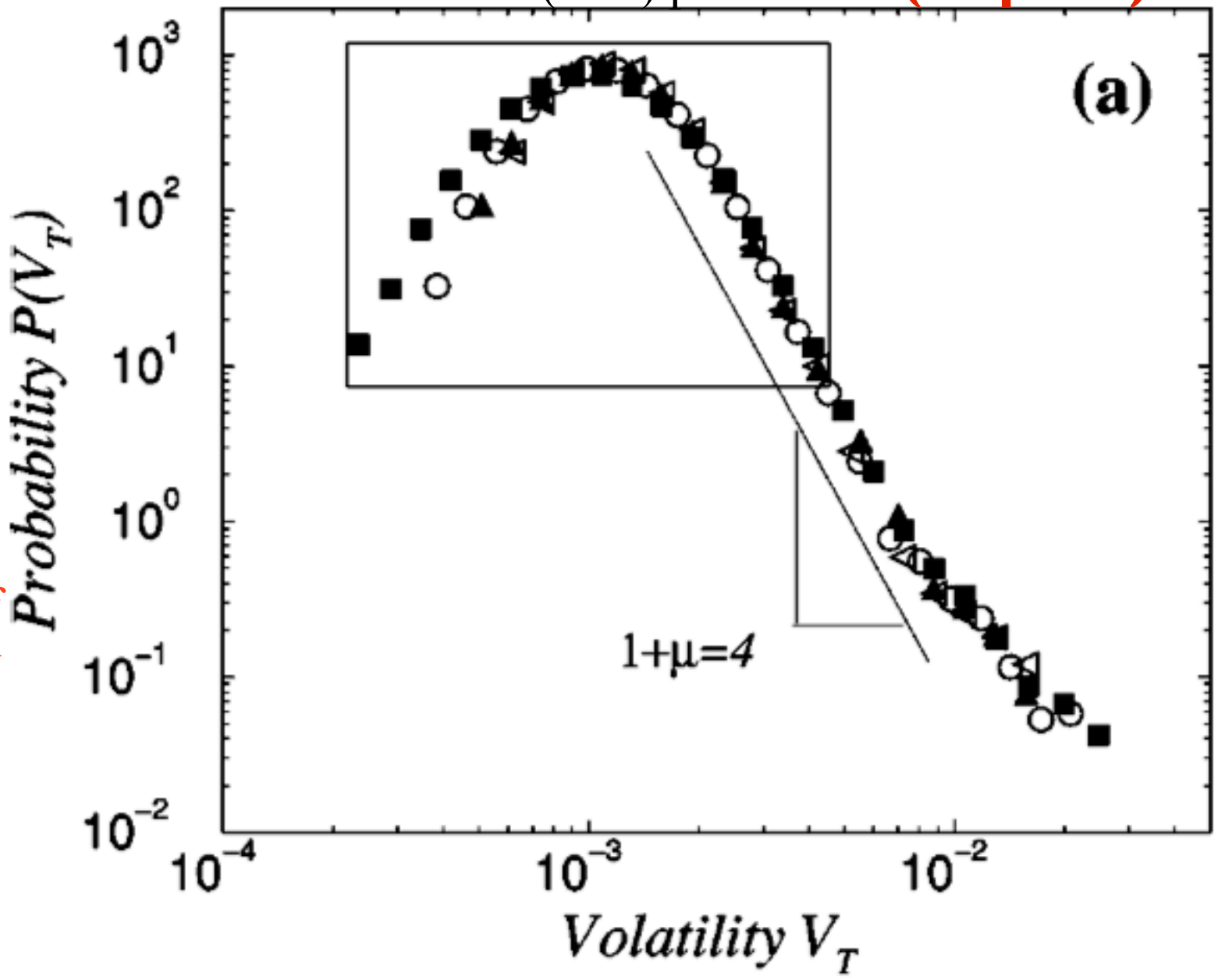


$R_t = \mathrm{sgn}(R_t) \quad |R_t|$



- Returns are UN-correlated after 4 min
- Absolute value of returns (volatility) is long range correlated, so returns CAN NOT BE serially independent.

QUASI-TEST 3: Crossover in Volatility pdf from (known) log-normal to (new) power law **(Surprise!)**



Liu,Cizeau, Meyer.``The Statistical Properties of the Volatility of Price Flucts" Phys. Rev. E 60, 1390.

Can a law describe bubbles and crashes in financial markets?

Goal: every trade---msec level...

Tobias Preis [1,2] and H. Eugene Stanley [1]

Physics World, May 2011

DETAILS IN:

T. Preis, J. Schneider, HES``Switching Processes in Financial Markets," PNAS 108, 7674 (2011).

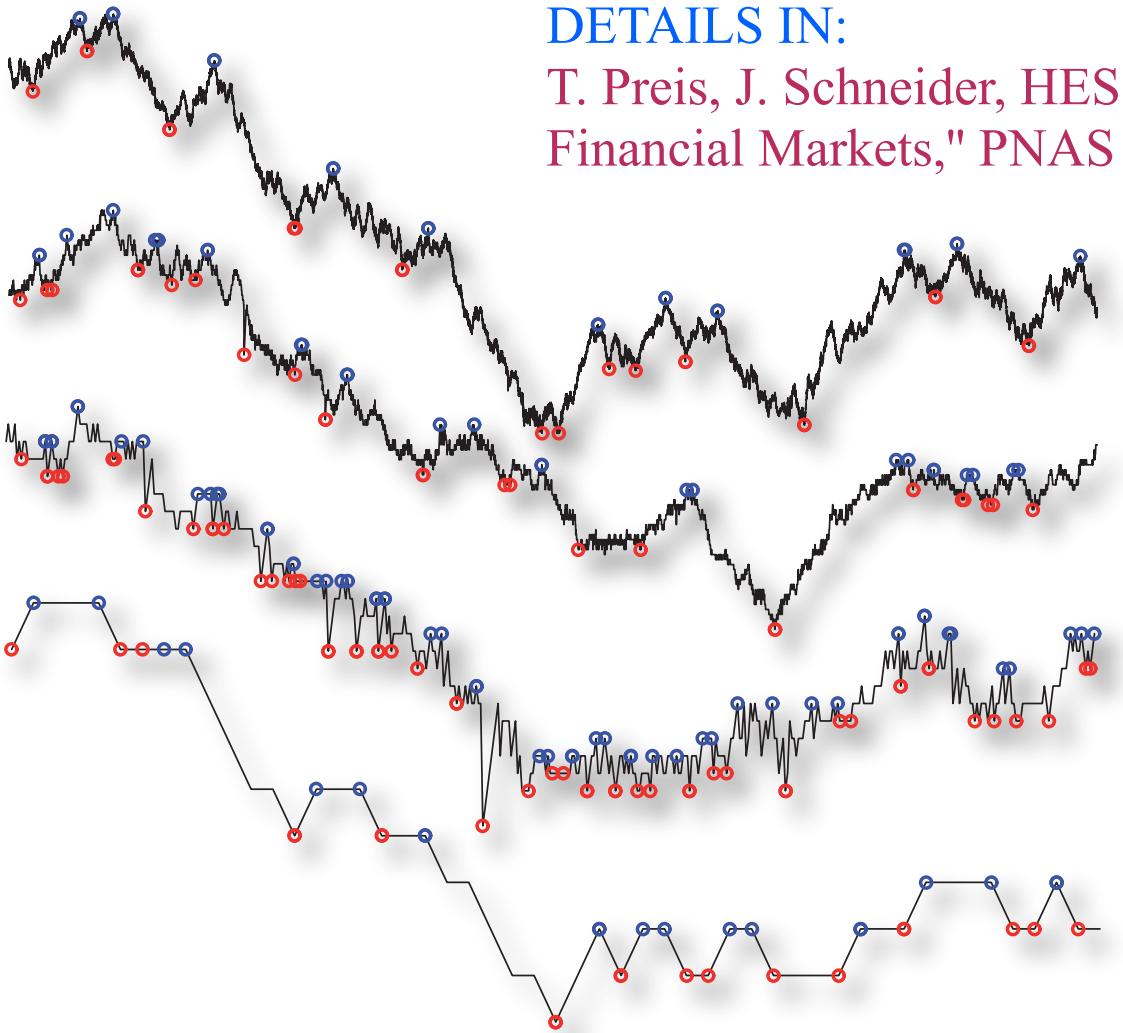
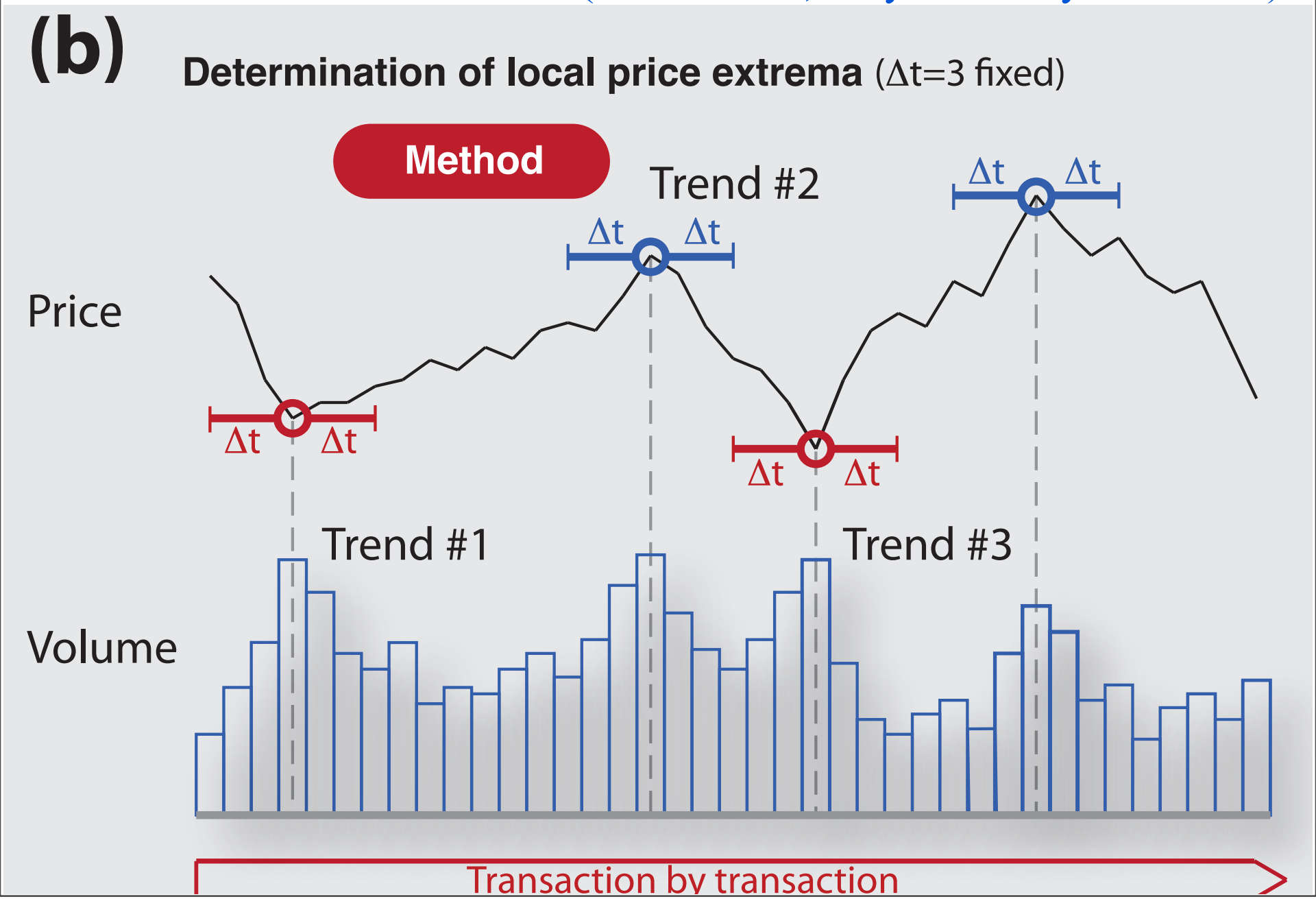


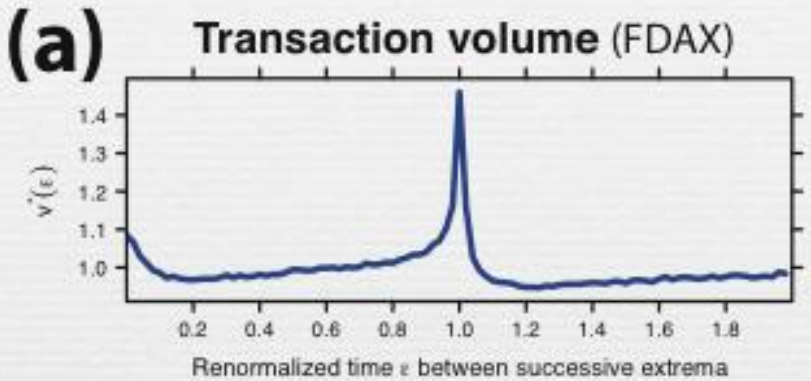
Figure 1 | Scale-free behavior of financial market fluctuations. Financial market time series feature identical properties on very different time scales. All four curves are subsets of a 14 million transactions dataset taken from a German DAX future time series. The price curves cover time periods of roughly 1 day (top curve), 1 hour, 10 minutes, and 1 minute (bottom curve). Local maximum and minimum values are marked as blue and red circles.

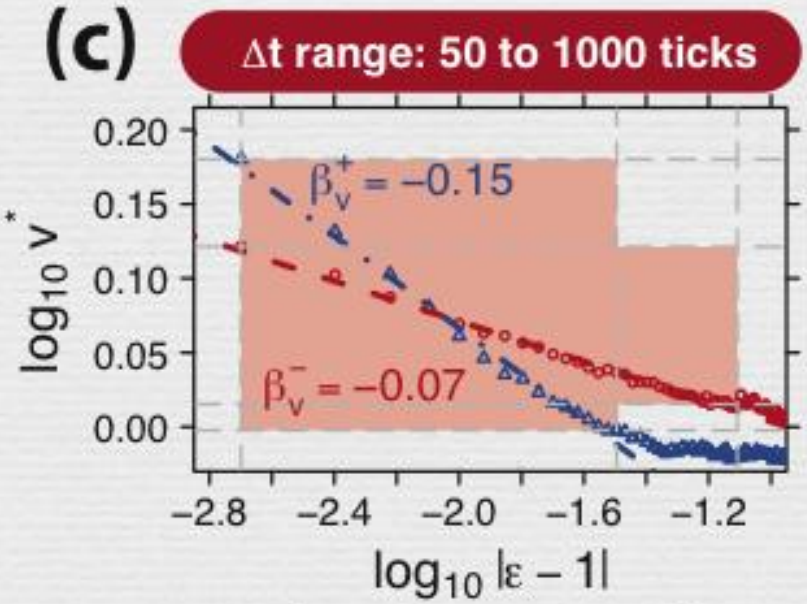
BIG QUESTION: How to quantify/analyze?????

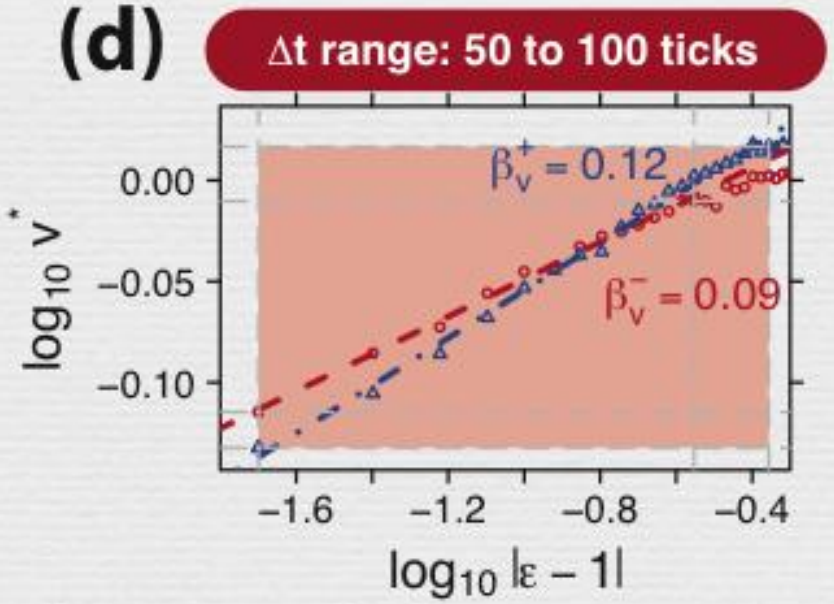
ANS: :: Preis/HES/Schneider (2011 PNAS; May 2011 Physics World)



Quantities With Scale-Free Behavior





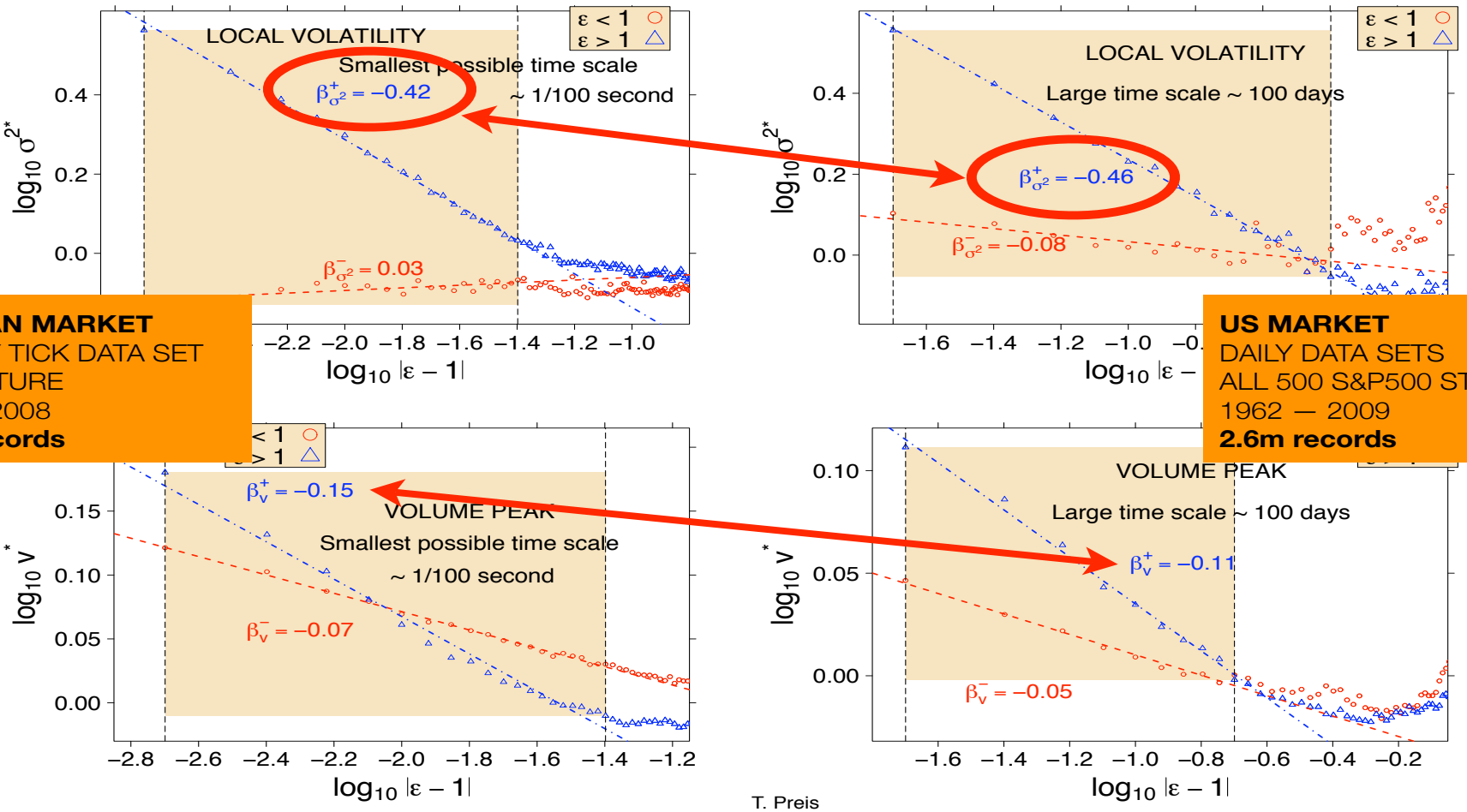


- Randomly reshuffling confirms our findings.

Preis/HES/Schneider (2011 PNAS; May 2011 Physics World)

FROM THE VERY SMALL TO THE VERY LARGE

~1/100 SECOND → ~100 DAYS



GERMAN MARKET
TICK BY TICK DATA SET
DAX FUTURE
2007—2008
14m records

US MARKET
DAILY DATA SETS
ALL 500 S&P500 STOCK
1962 — 2009
2.6m records

T. Preis

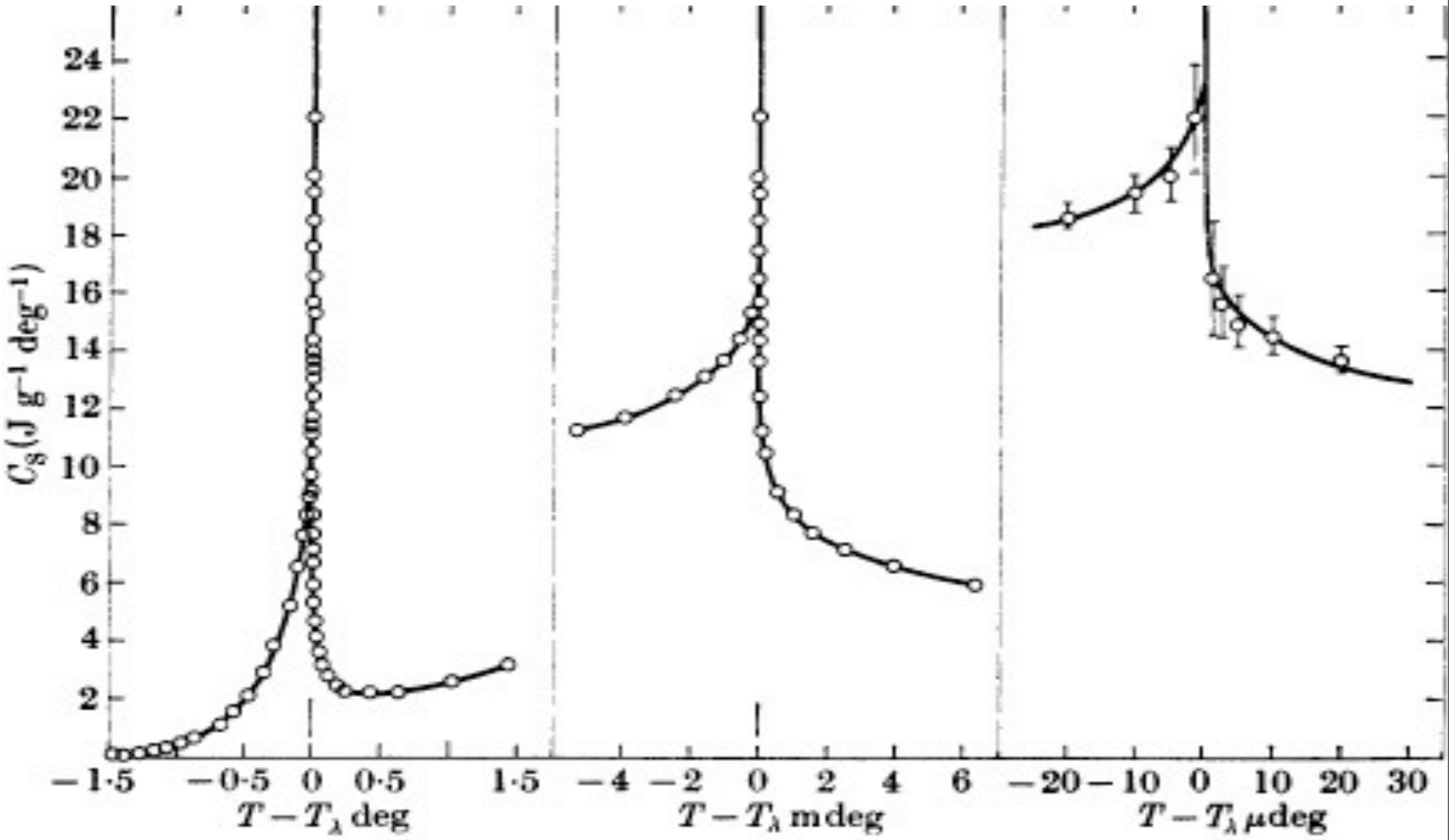
100x60x60x24x100 = 1,000,000,000....9 orders of magnitude !

19

Preis/HES/Schneider (2011 PNAS, May 2011 Physics World)

SCALE FREE SPECIFIC HEAT NEAR HELIUM SWITCH POINT

Note: Same FUNCTION for 3 different scales: 6 orders of magnitude!!!



The Economist

Text

The Economist

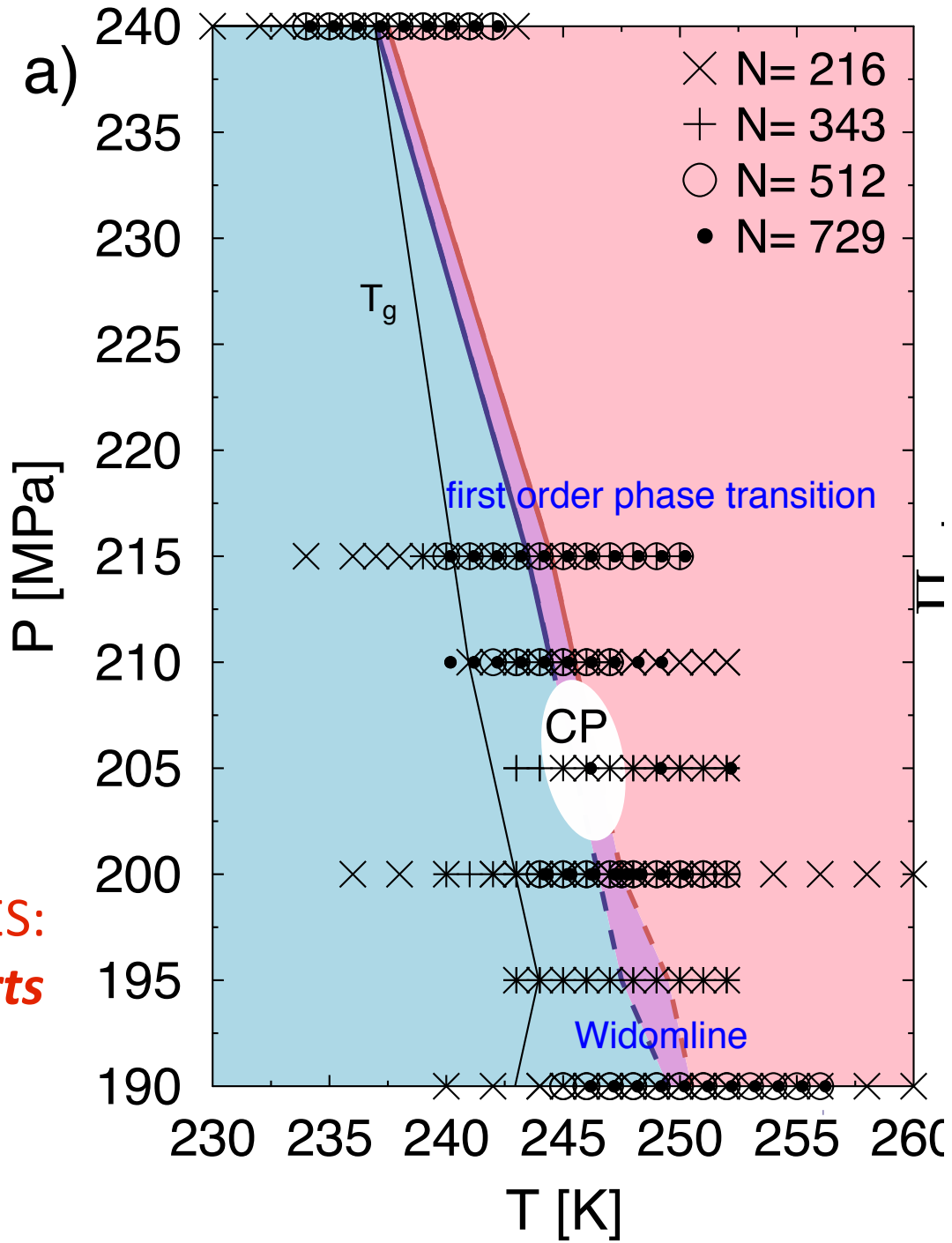
Text

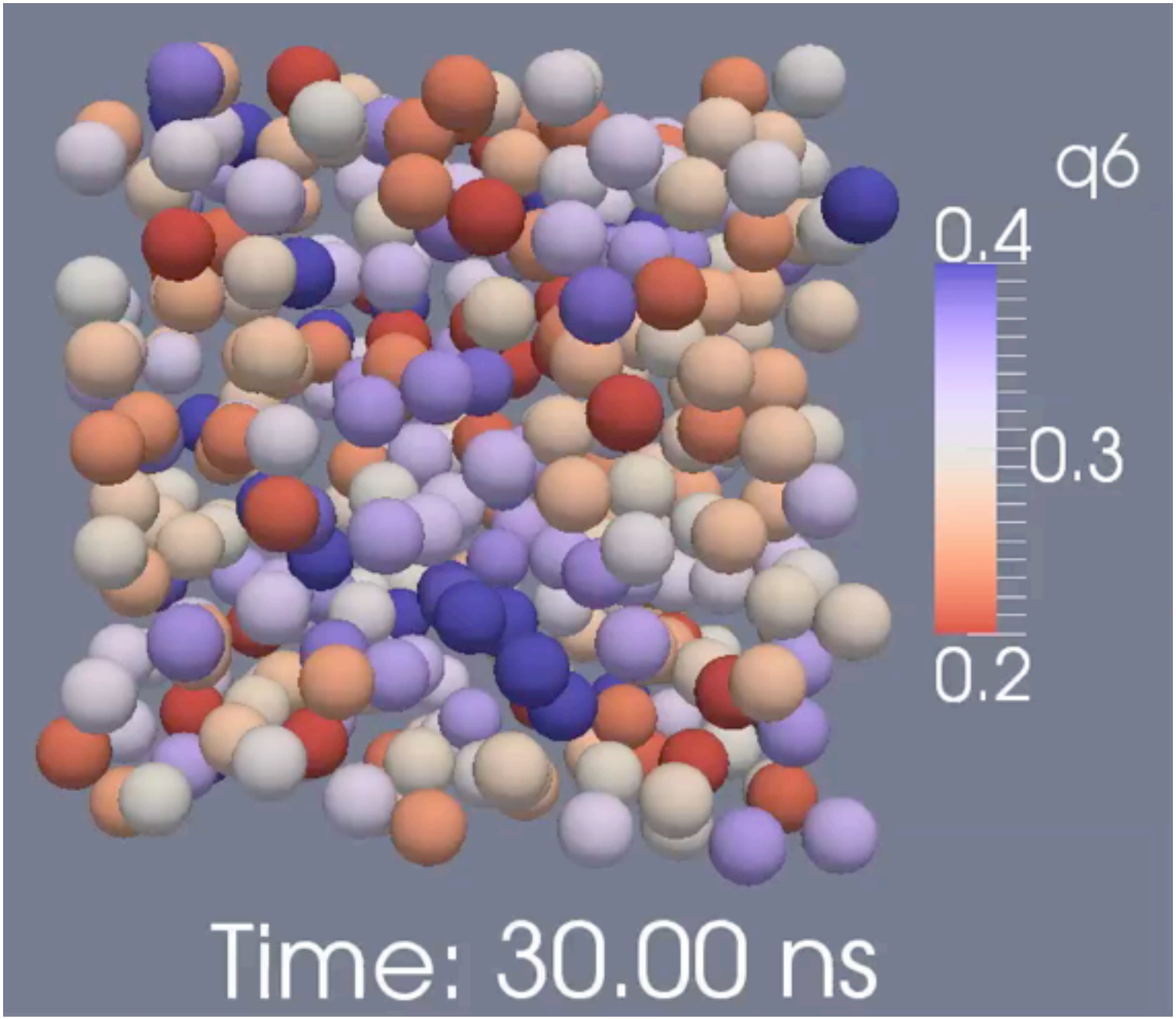
350 State Points analyzed
4 system sizes

both sides of Widom line

both sides of LLPT line

Kesselring, Franzese, Buldyrev, Herrmann,HES: ***Nature Scientific Reports*** 2012; ***J. Chem. Phys.*** 2013




q6
0.4
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0.2
Time: 30.00 ns

CNN News today:
A “failure cascade” affecting many infrastructure networks:
power, internet, ...

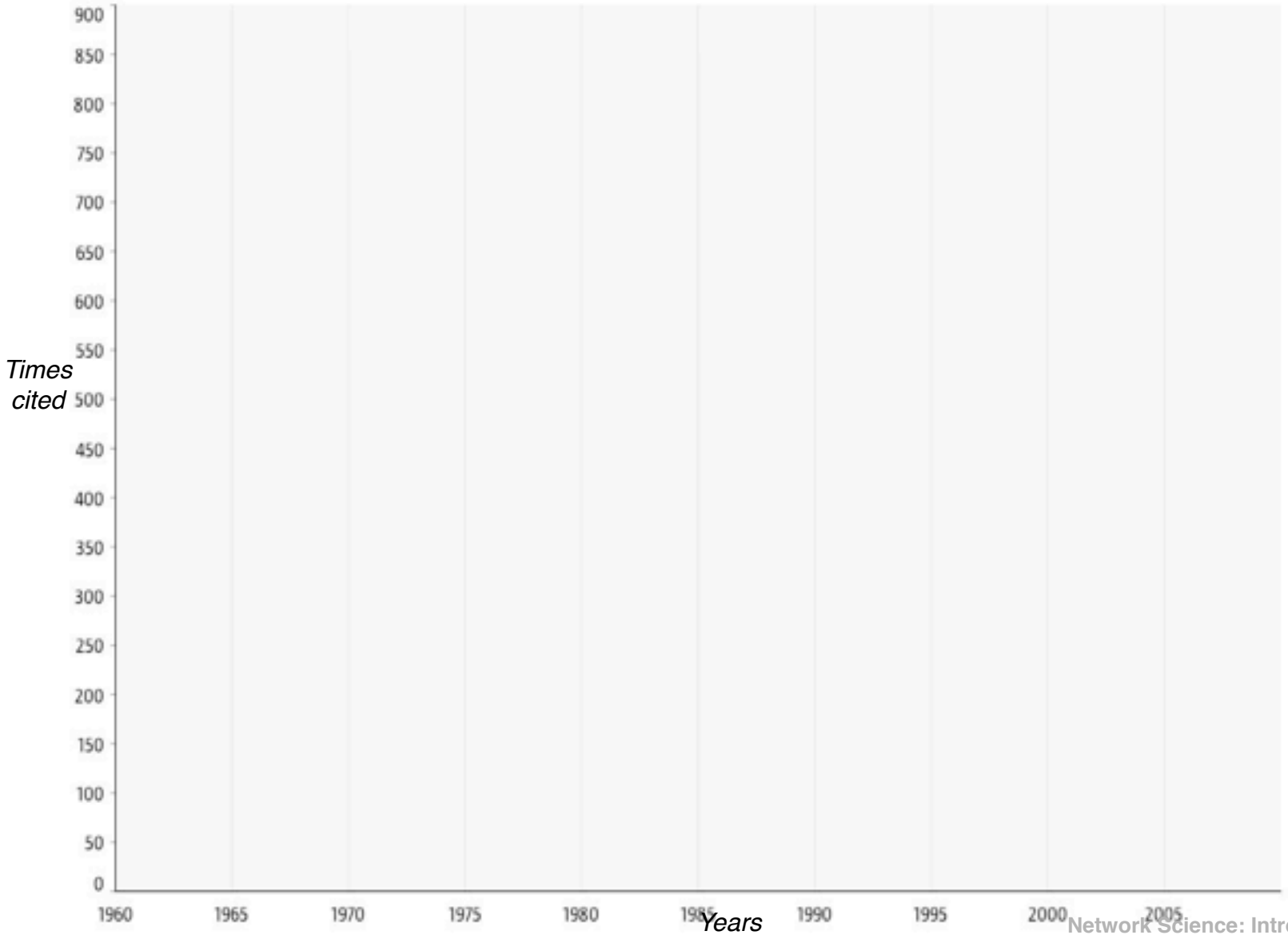
TWO MINUTES OF TODAY’S CNN NEWS BROADCAST

The science of the 21st century

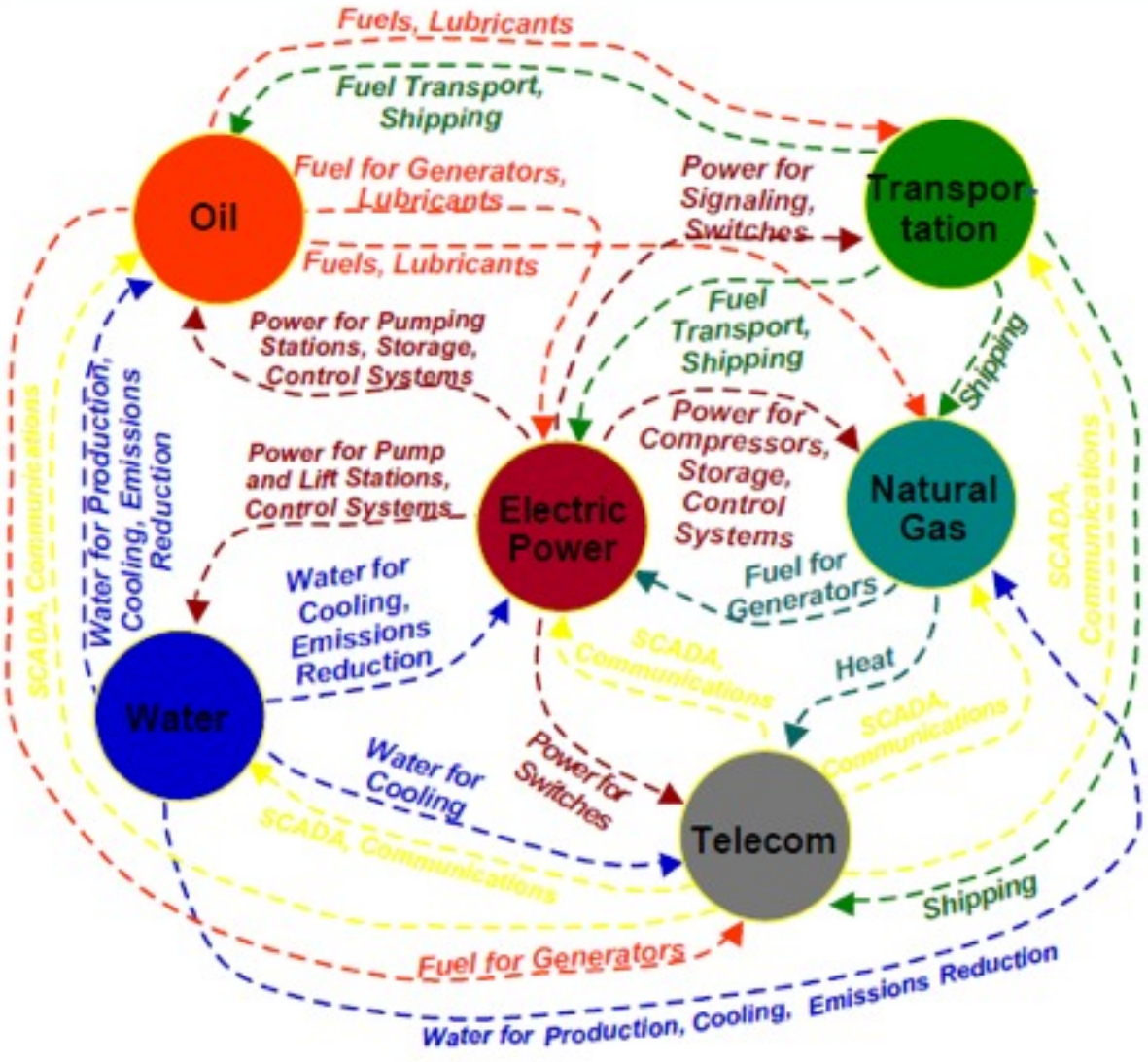
Times cited

Years

The science of the 21st century



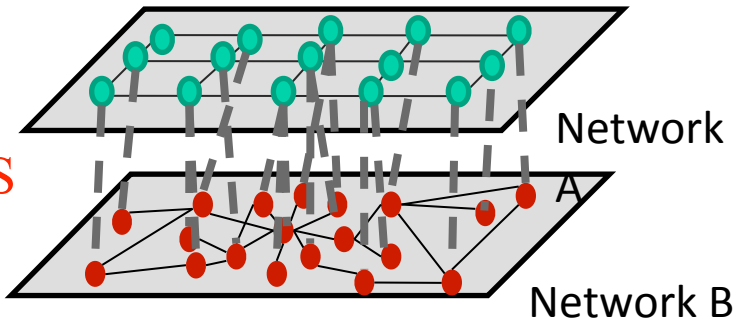
How interdependent are infrastructures?



Peerenboom, Fisher, and Whitfield, 2001

Critical Breakdown Threshold for 2 Interdependent Networks

Failure in network A
causes failure in network B
causes further failure in network A …..CASCADES



What are the critical breakdown thresholds for such interdependent networks?
What is size of cascade failures?

FURTHER EXAMPLES OF INTERDEPENDENT NETWORKS:

- *Economy*: Networks of banks, insurance companies, and firms which interact and depend on each other.

- *Physiology*: The human body is composed of inter-dependent networks (hip!)

- *Biology*: A specific cellular function is performed by a network of interacting proteins, which depend on other networks

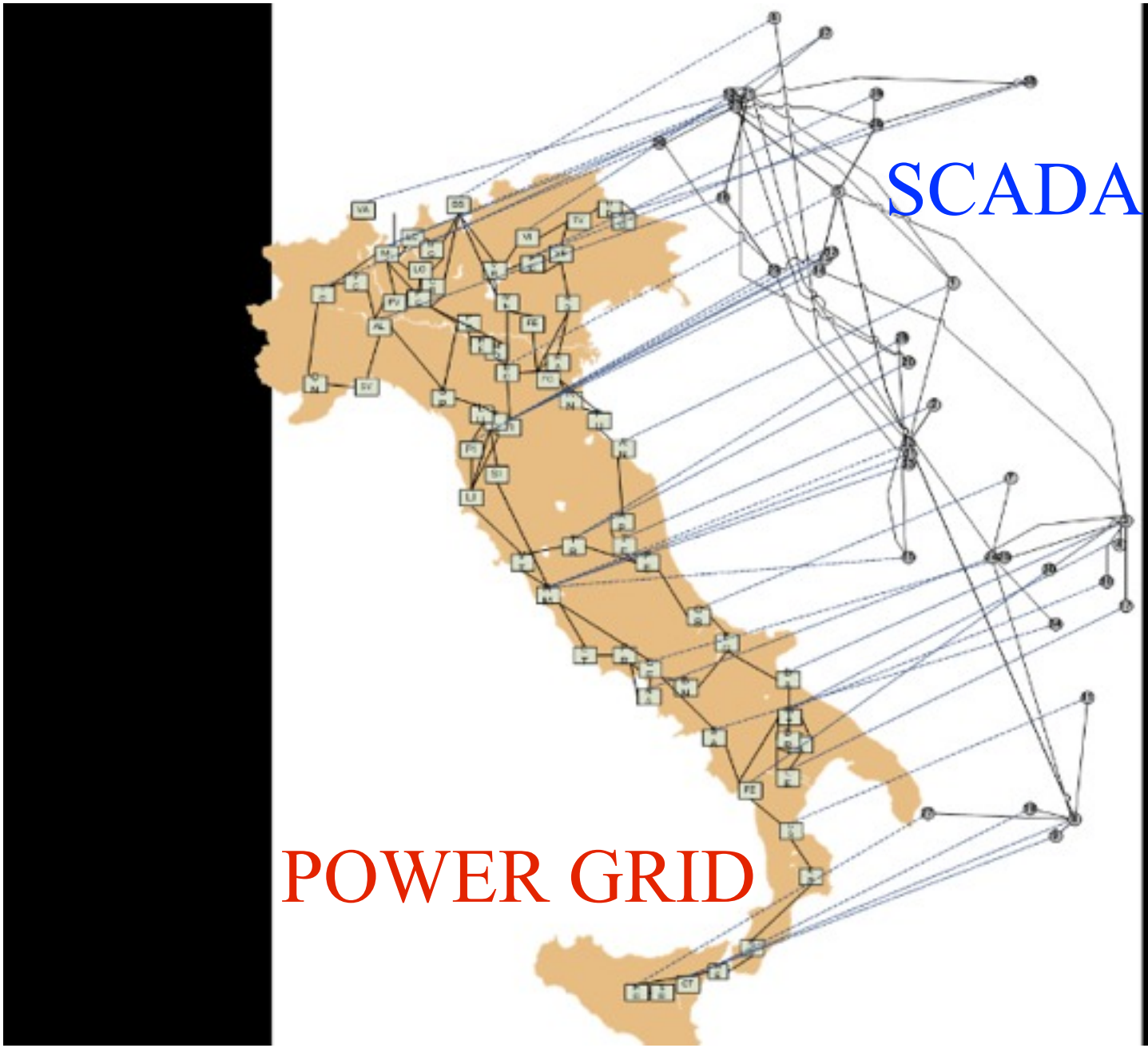
Buldyrev, Parshani, Paul, Stanley, Havlin, Nature, **464**, 1025 (2010)

NATIONWIDE BLACKOUT(28 Sept. 2003)

Thank: Nature referee

27 Sept 2003:
1 DAY
BEFORE THE
CASCADE OF
FAILURES

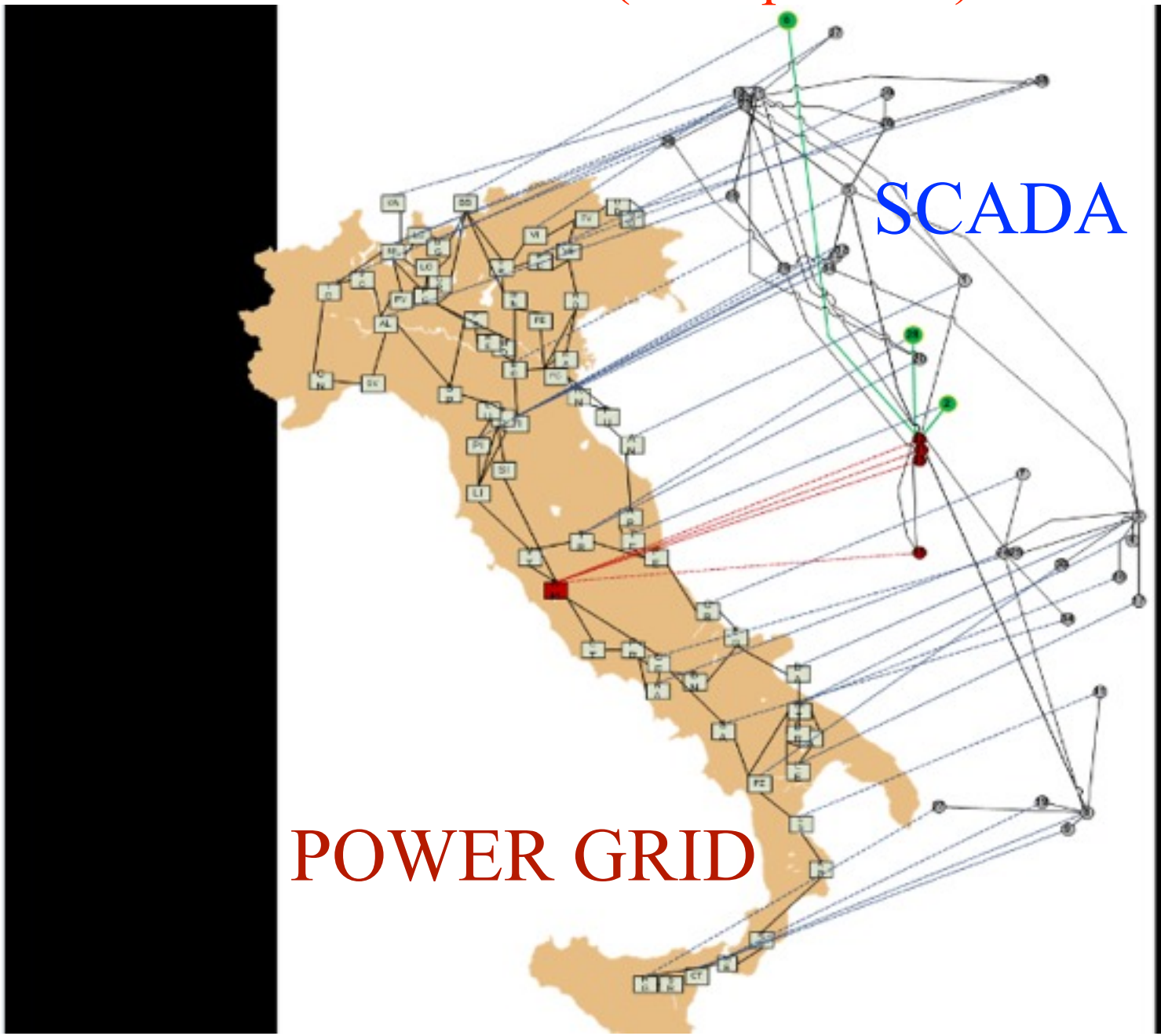
SCADA =
Supervisory
Control And Data
Acquisition



Stage 1: NATIONWIDE BLACKOUT (28 Sept. 2003)

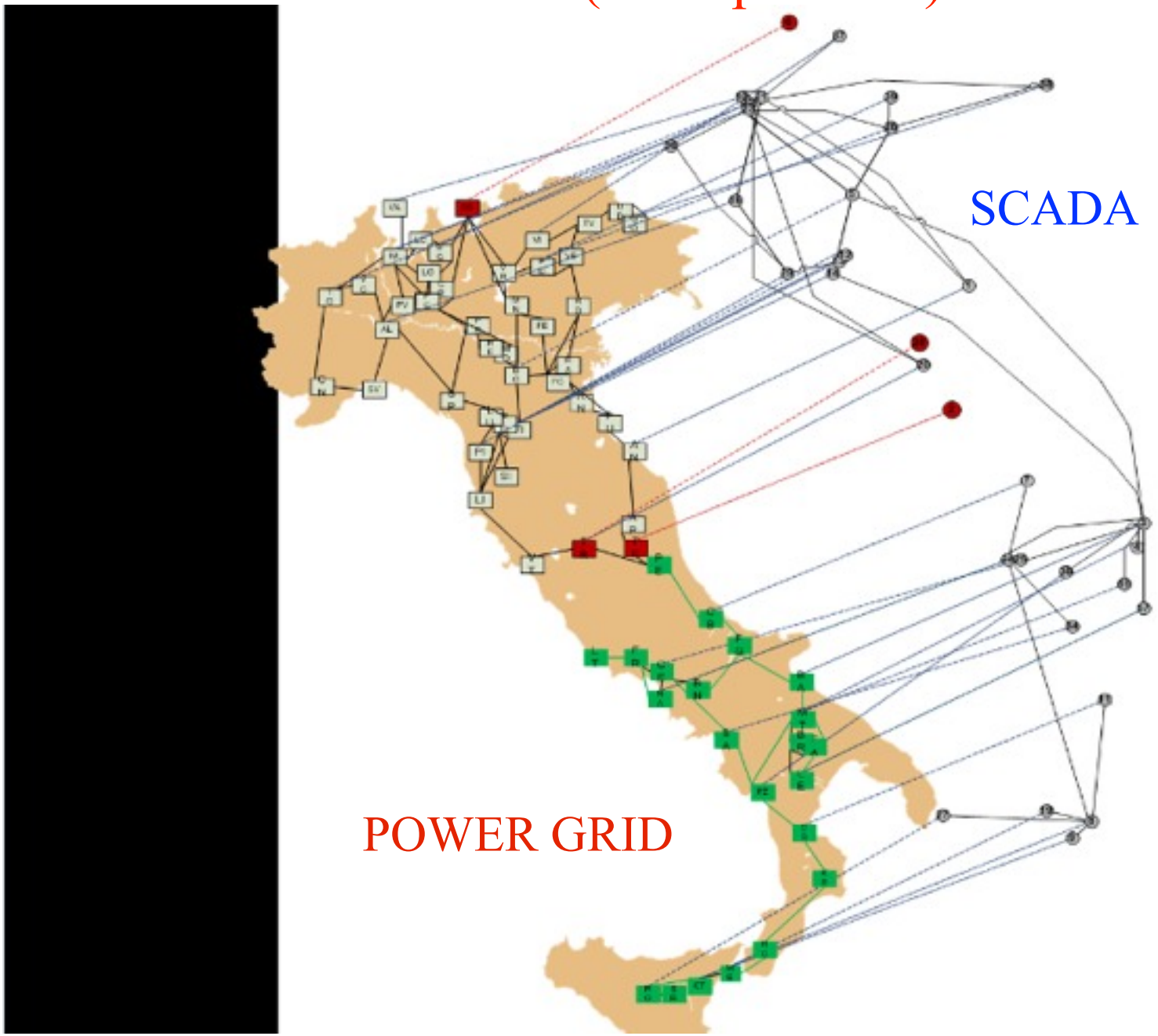
The first second: ABOVE the critical breakdown threshold [only Rome power is out]

SCADA = Supervisory Control AND Data Acquisition



Stage 2: NATIONWIDE BLACKOUT(28 Sept. 2003)

A few seconds later: STILL ABOVE the critical breakdown threshold

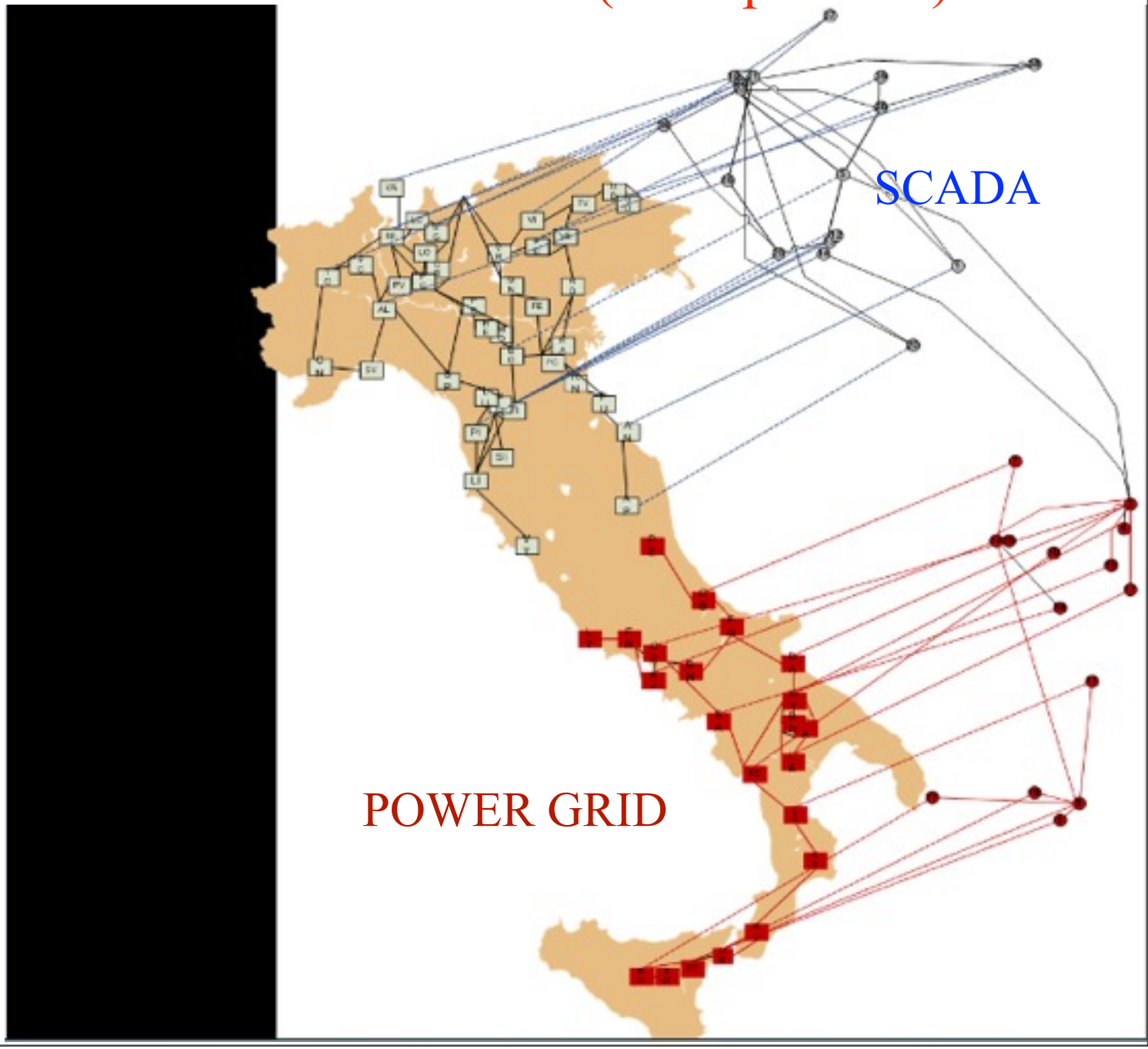


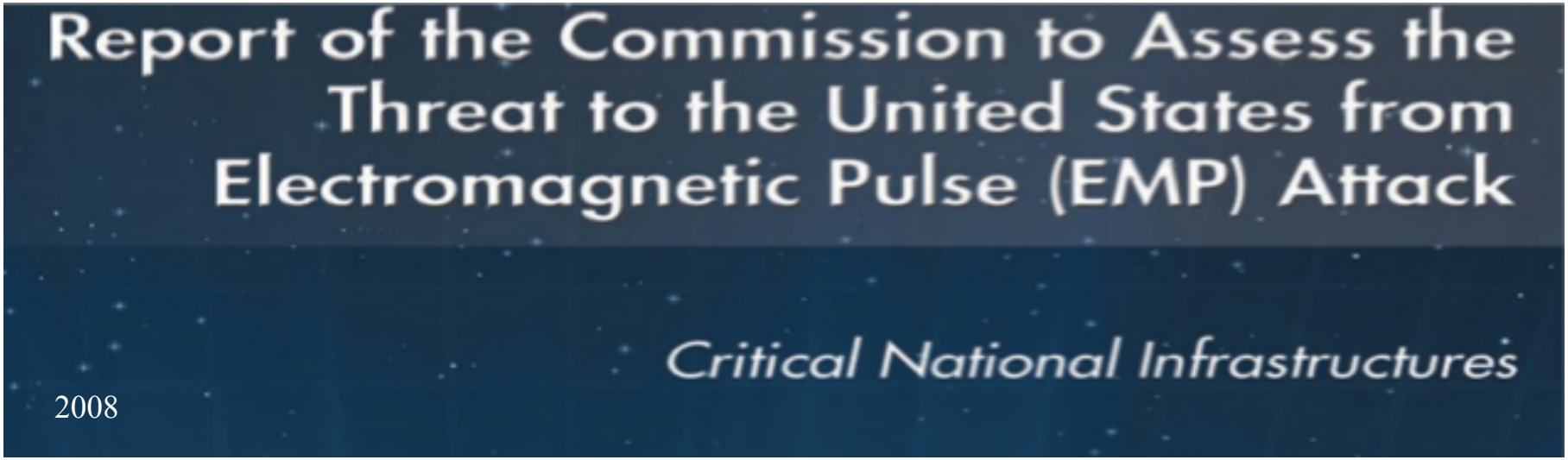
SCADA=Supervisory Control And Data Acquisition

Stage 3: NATIONWIDE BLACKOUT (28 Sept. 2003)

A few seconds later still: Now BELOW the critical breakdown threshold !!!

SCADA= Supervisory Control And Data Acquisition





"The physical & social fabric of civilized countries is sustained by a system of systems; a complex and dynamic network of interlocking and interdependent infrastructures (critical national infrastructures) whose harmonious functioning enables the myriad actions, transactions, and information flow that undergird the orderly conduct of civil society in this country. . . ."

". . .the vulnerability of the whole — of all the highly interlocked critical infrastructures — may be greater than the sum of the vulnerability of its parts. . ."

"No currently available modeling and simulation tools exist that can adequately address the consequences of disruptions and failures occurring simultaneously in different critical infrastructures that are dynamically interdependent."

2 INTERDEPENDENT NETWORKS:

- Until 2010***, scientists focused on the case of a single network which is isolated AND is not influenced by other networks.

*** Buldyrev et al, Nature, **464**, 1025 (2010); Leicht et al cond-mat)

- Isolated systems rarely occur in nature nor in technology [ex: non-interacting molecules NEVER occur--otherwise liquids could not exist!].

- Take home message: Results for interacting "interdependent" networks strikingly different from single networks..& different from "chaos theory"

What today's "catastrophic failure" is NOT:

Chaos theory & systemic breakdown: 700 year old paradigm (ancestor of "Beijing butterfly" paradigm)

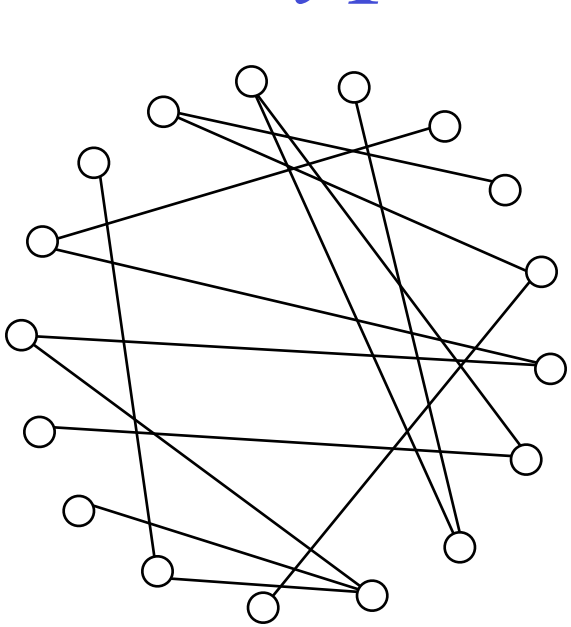
For Want of a Nail

For want of a nail the shoe was lost.
For want of a shoe the horse was lost.
For want of a horse the rider was lost.
For want of a rider the battle was lost.
For want of a battle the kingdom was lost.
And all for the want of a horseshoe nail.

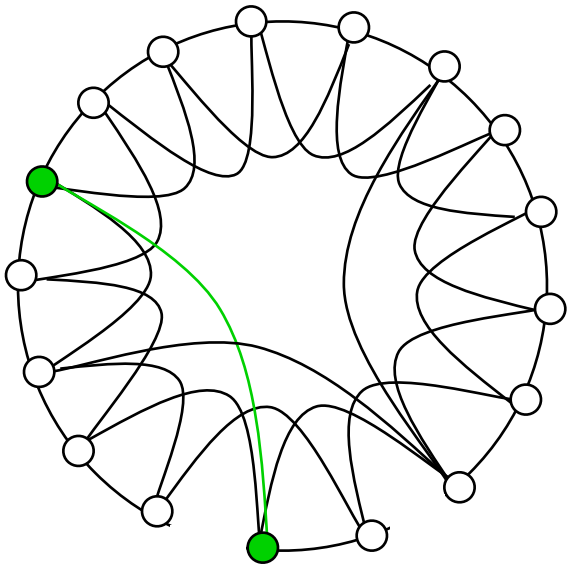
PROBLEM:

p x p x p x p x p = 1/1,000,000,000,000,000(very tiny)

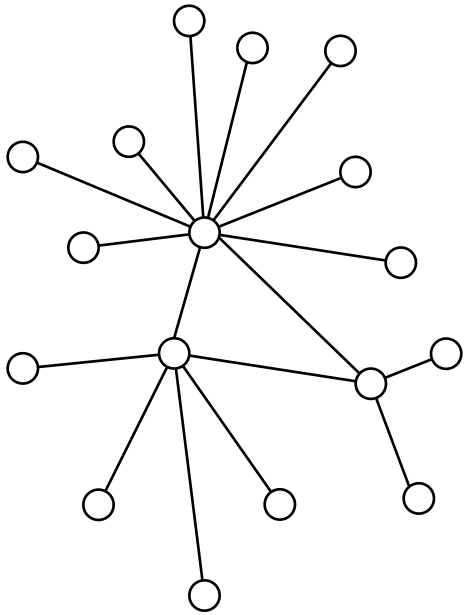
3 types of networks...



Erdös-Rényi
(Exponential tail)
Adv: solvable
Disadv: not realistic

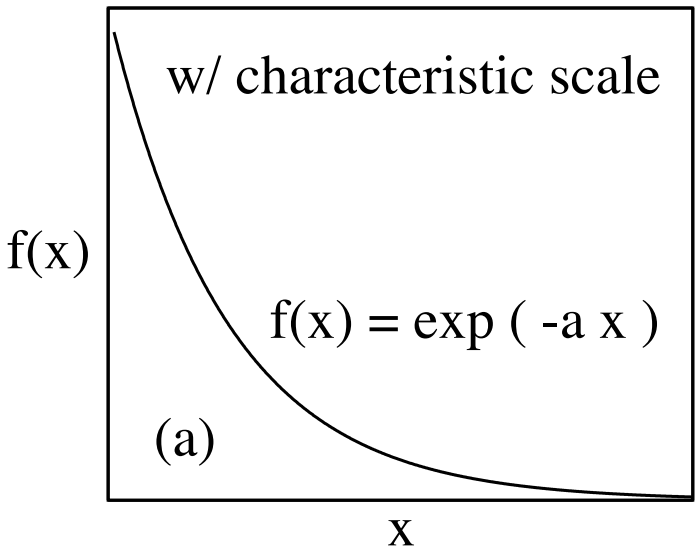


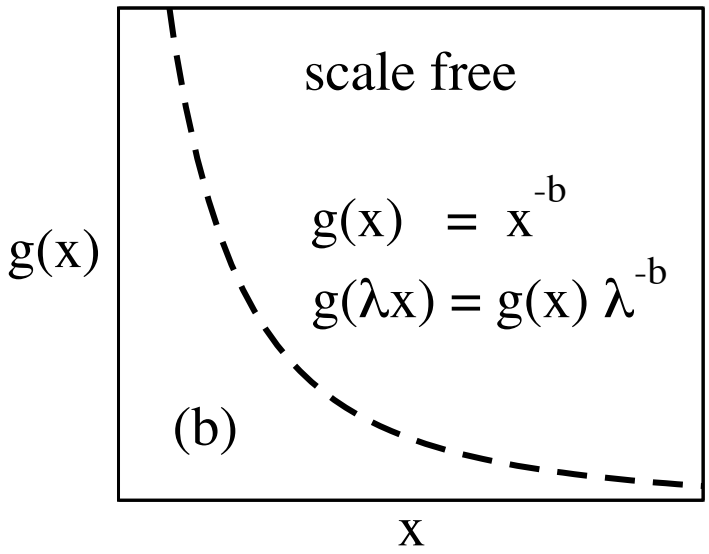
Watts-Strogatz
("re-wire")
Adv: Small world
Disadv: not realistic

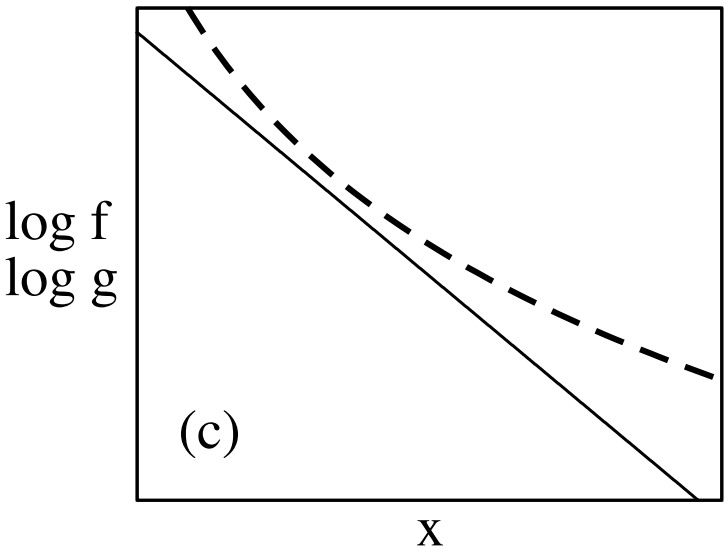


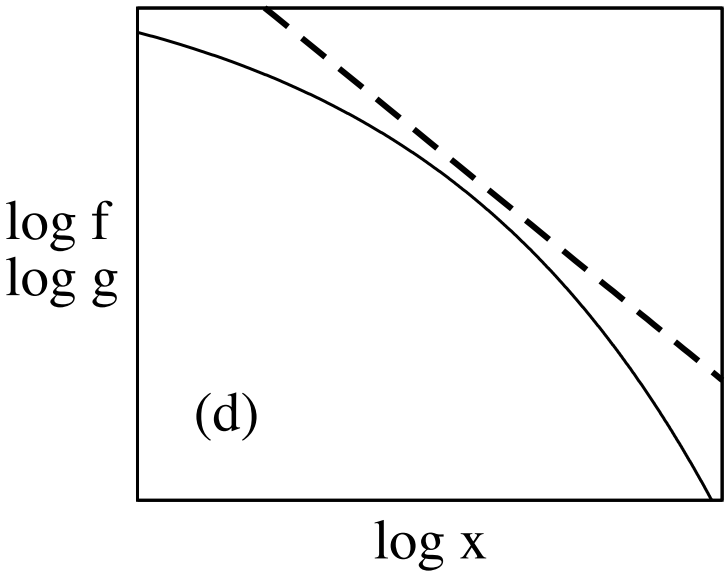
Scale-free
(Power law tail)
Adv: more realistic
Disadv: not solvable

"Dummies Guide" to Discovering if a network is scale free:





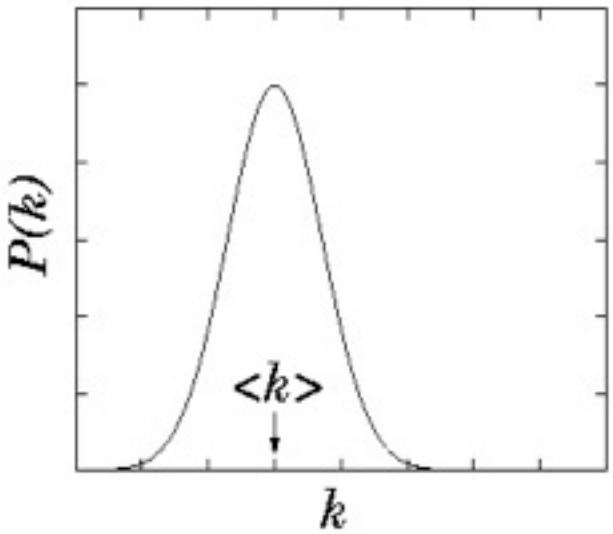




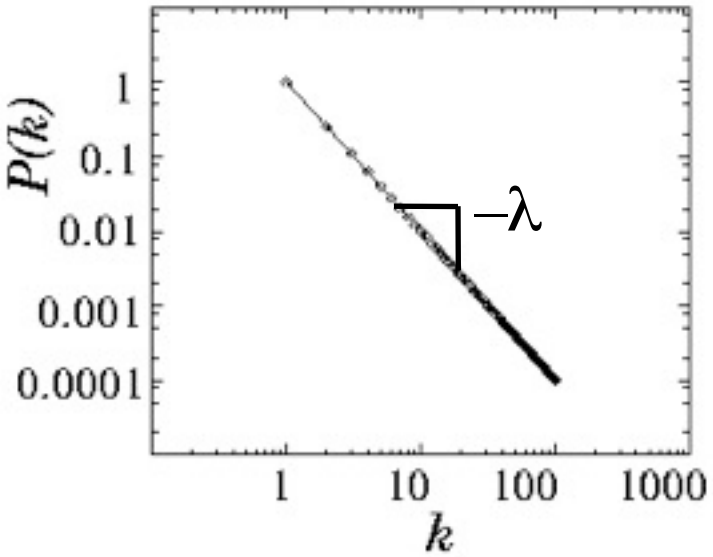
How to quantify? Number of nodes of degree *k [new]*

Courtesy: Barabasi 1999 plane

Erdos-Renyi distribution (exponential tail)



Scale-free distribution (power law tail)



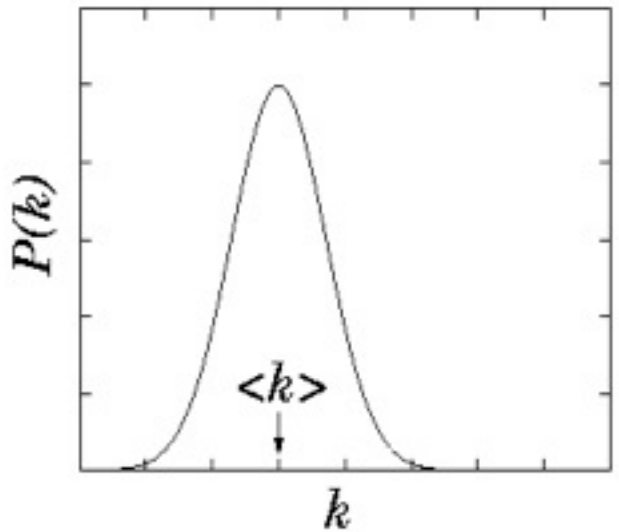
Exponential Tail

Power Law Tail

How to quantify? Number of nodes of degree *k [new]*

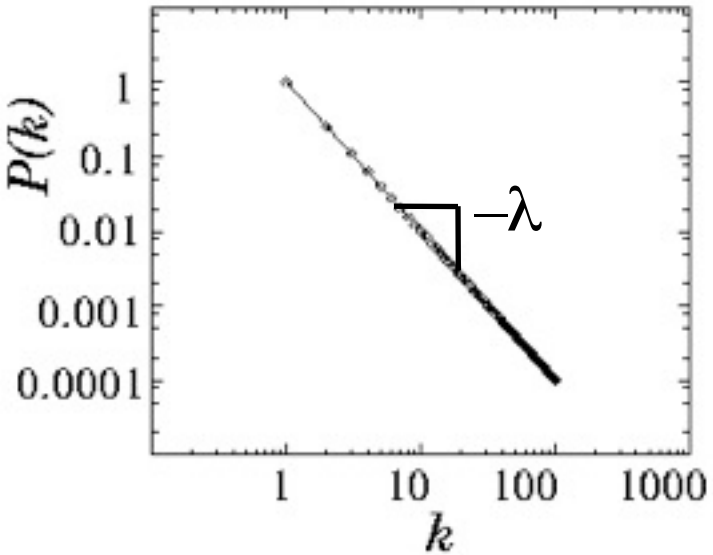
Courtesy: Barabasi 1999 plane

Erdos-Renyi distribution (exponential tail)



Exponential Tail

Scale-free distribution (power law tail)

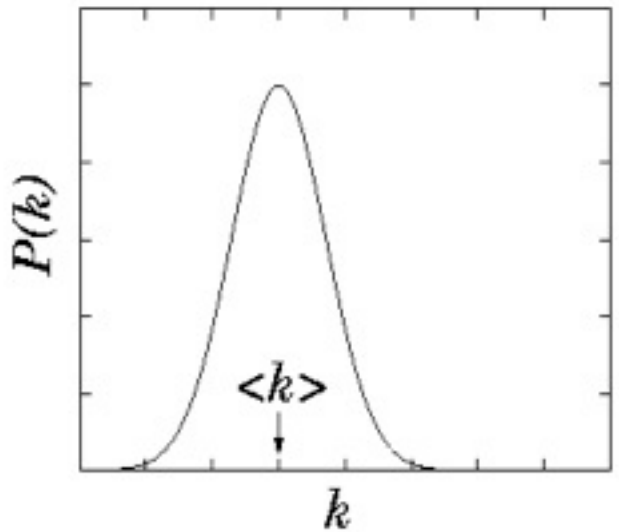


Power Law Tail

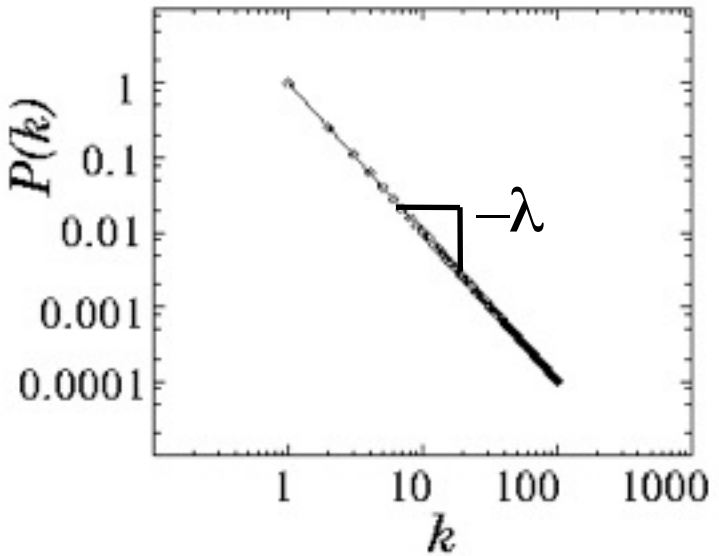
How to quantify? Number of nodes of degree *k [new]*

Courtesy: Barabasi 1999 plane

Erdos-Renyi distribution (exponential tail)



Scale-free distribution (power law tail)



Exponential Tail

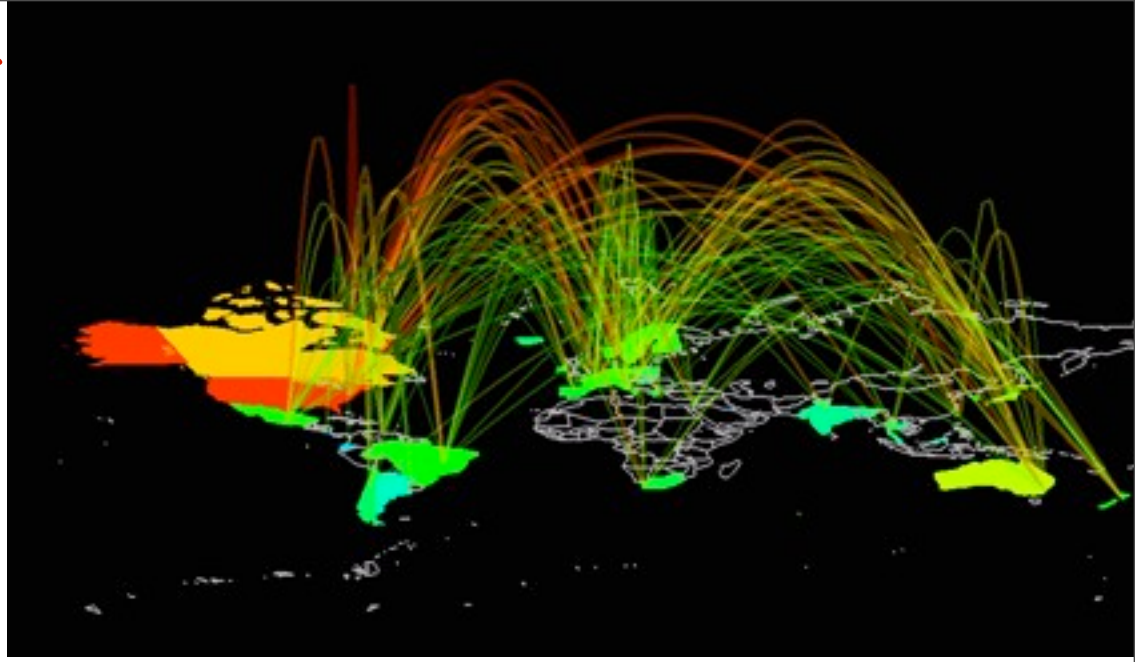
Power Law Tail

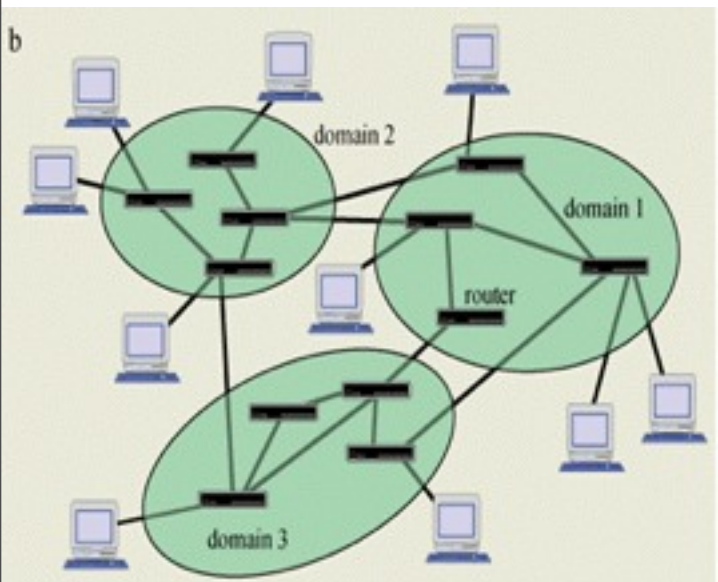
Question:

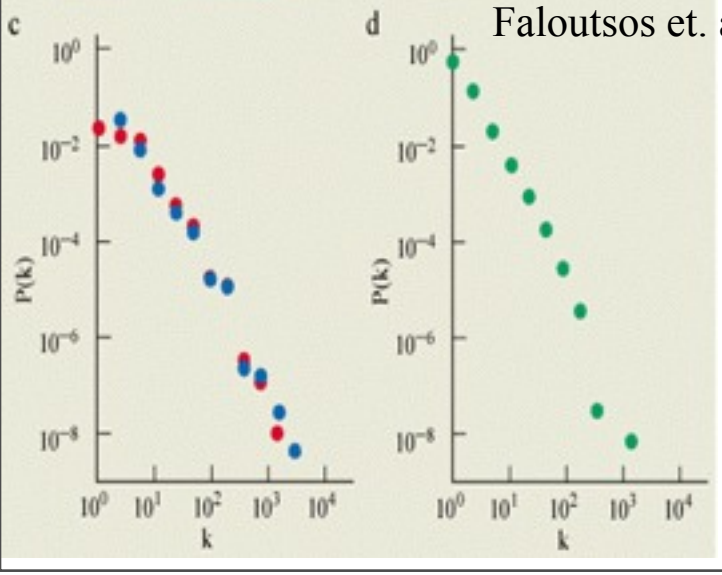
To which class belongs the airline network?

(CLUE: Hubs & Spokes)

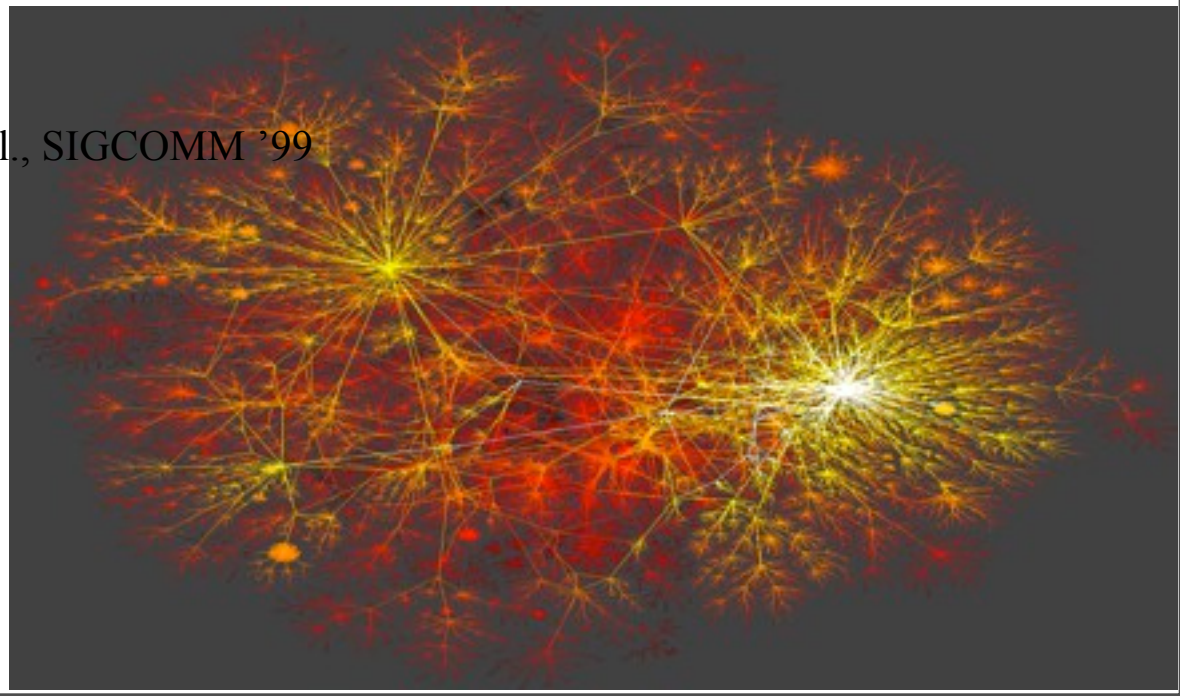
Real world example of scale-free networks: Internet







Faloutsos et. al., SIGCOMM '99



F. Liljeros, C. R. Edling, L. A. N. Amaral, H. E. Stanley, and Y. Aberg,

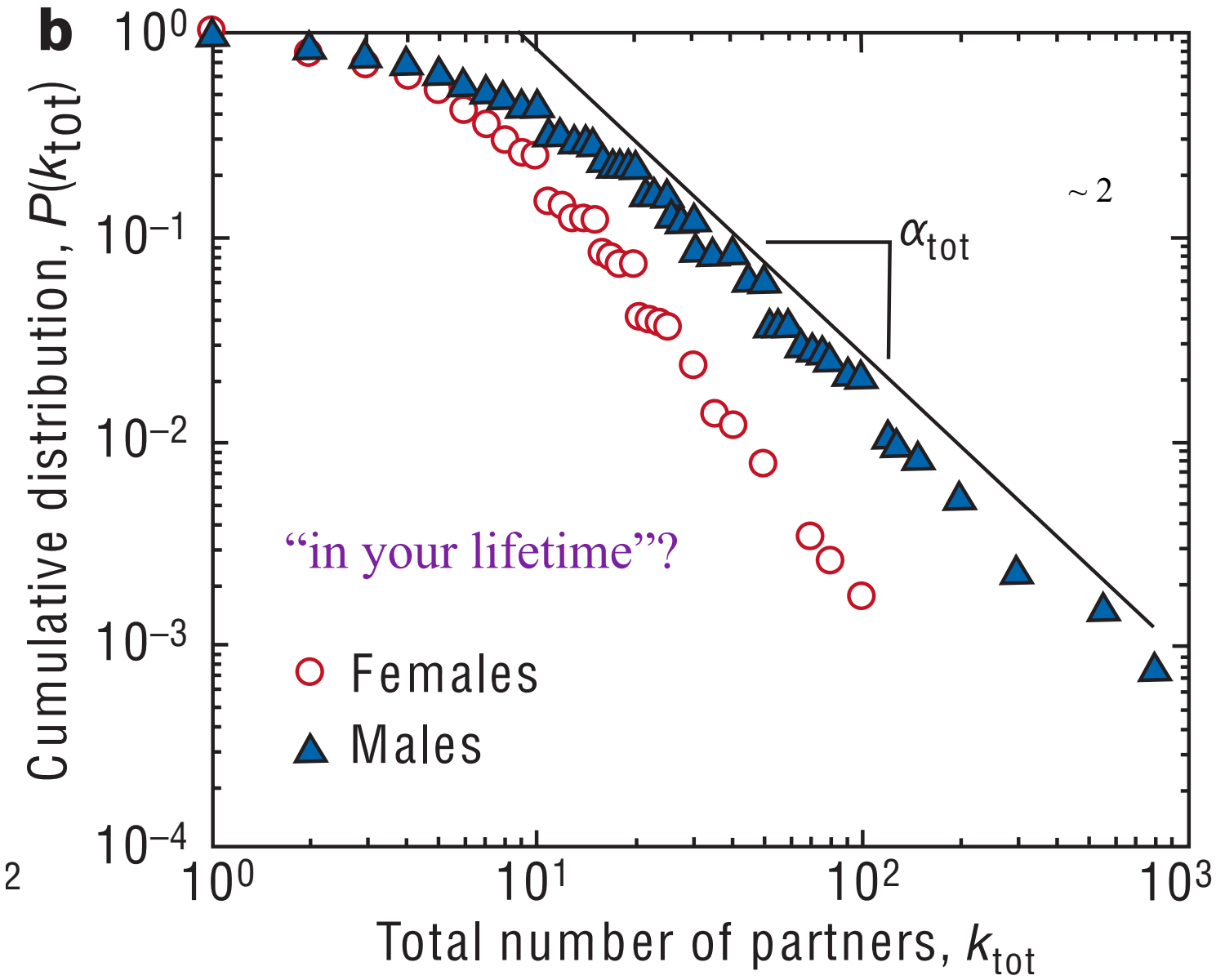
"The Web of Human Sexual Contacts," Nature **411**, 907-908 (2001).

[Citations: 851]

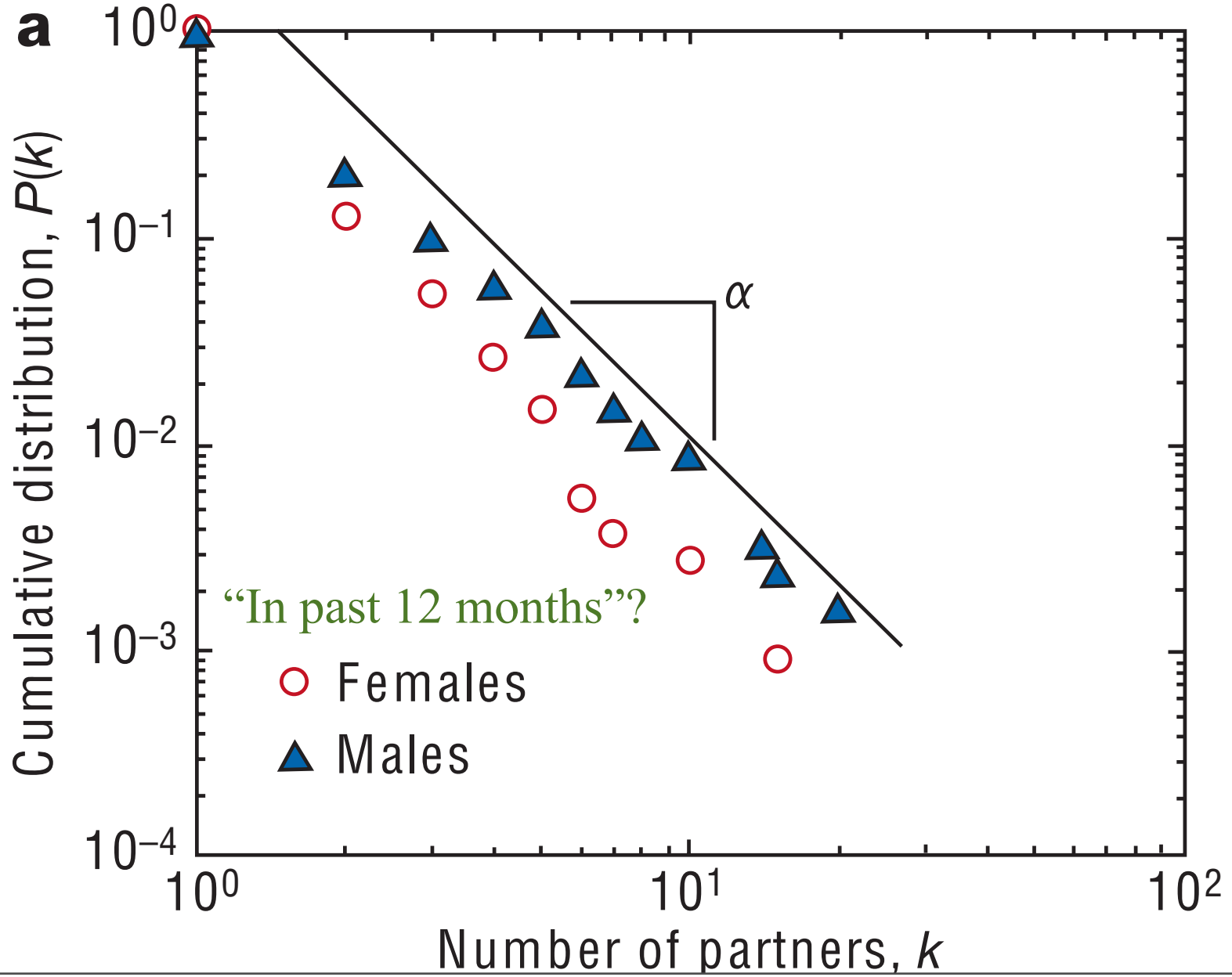
Unlike clearly defined 'real-world' networks[1], social networks tend to be subjective to some extent[2,3] because the perception of what constitutes a social link may differ between individuals. One unambiguous type of connection, however, is sexual contact, and here we analyse the sexual behaviour of a random sample of individuals[4] to reveal the mathematical features of a sexual-contact network. We find that the cumulative distribution of the number of different sexual partners in one year decays as a scale-free power law that has a similar exponent for males and females. The scale-free nature of the web of human sexual contacts indicates that strategic safe-sex campaigns are likely to be the most efficient way to prevent the spread of sexually transmitted diseases.

Q1: A "LAW" OF HUMAN BEHAVIOR? Q2: WHY CARE?

F. Liljeros, C. R. Edling, L. A. N. Amaral, H. E. Stanley, and Y. Aberg, Nature **411** (2001).



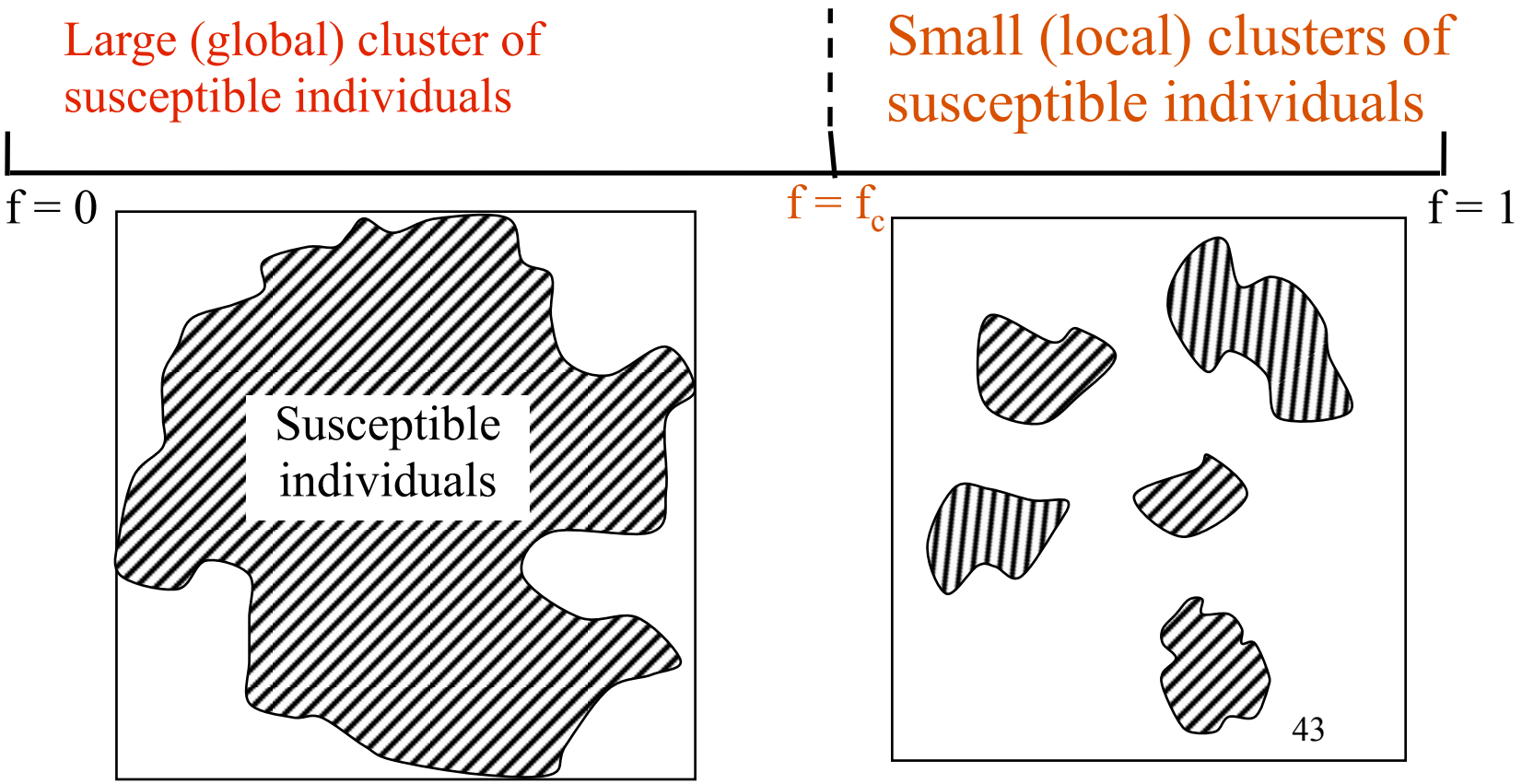
Worry: Artifact of "scale-free imagination"???



EXAMPLE: Network Immunization Strategies

REQUIREMENTS of an efficient immunization strategy:

- Immunize at least a critical fraction f_c ("Immunization threshold") of the number of individuals so that only isolated clusters of susceptible individuals remain.
- Effective without detailed knowledge of the network.

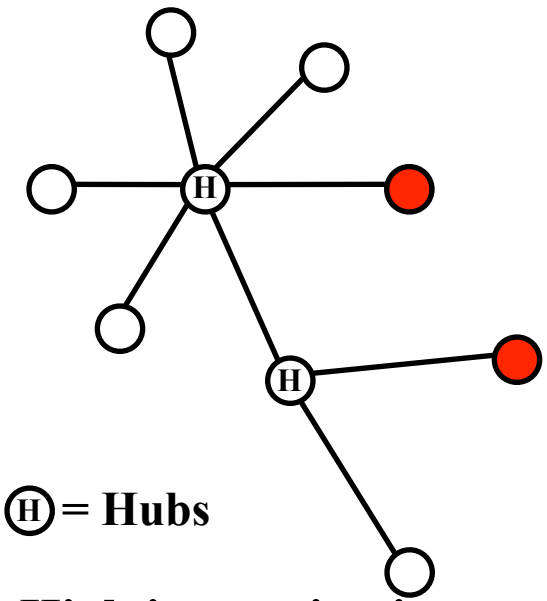


Three immunization strategies

Example: Immunize 2 of the 9 nodes in a scale-free network
Question: What is chance to stop the spread?

Random:

2/9

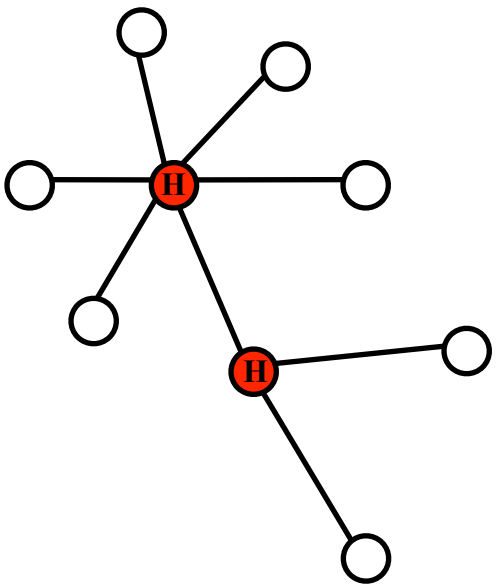


Ⓗ = Hubs

- **High immunization threshold**
- **No prior network information needed**

Targeted:

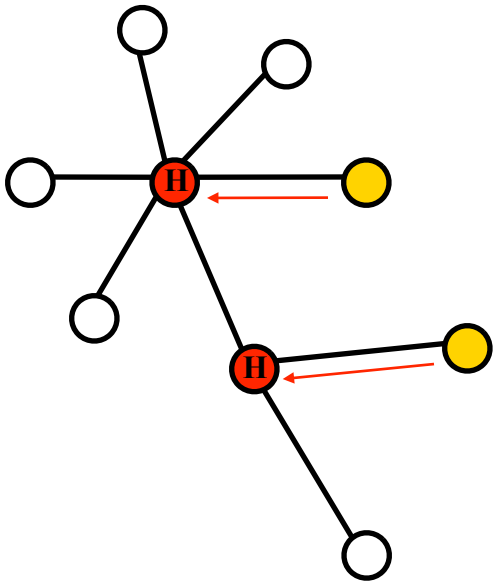
1



- **Low immunization threshold**
- **Need to know hubs (highly connected individuals)**

Acquaintance:

7/9



- **Low immunization threshold**
- **No prior network information needed**

44

Real world example: Stopping spread of heresy in Middle Ages
Ormerod/Roach -- The medieval inquisition: scale-free networks & the suppression of heresy

Real world example: Stopping spread of heresy in Middle Ages Ormerod/Roach -- "The medieval inquisition: scale-free networks & the suppression of heresy"

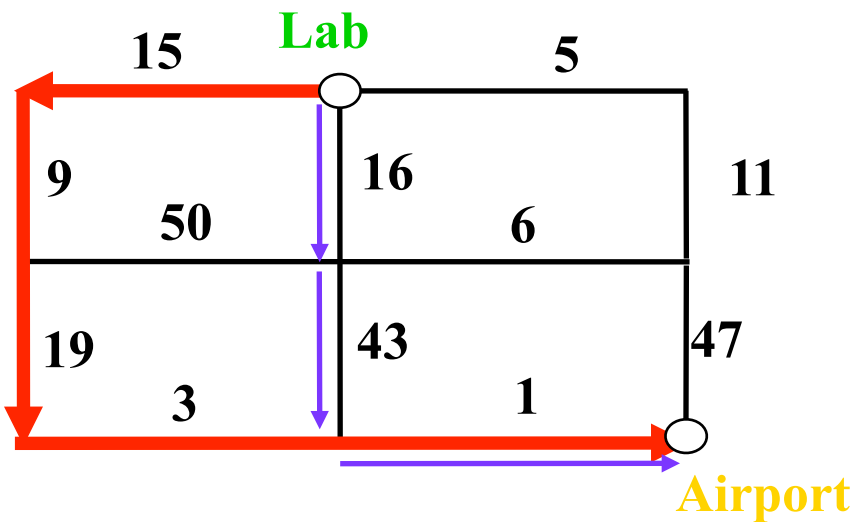
Knowing from the confessions of these Catholics that they were mixed up with heretics, [the crusaders] said to the abbot. 'What shall we do, lord? We cannot tell the good from the bad. The abbot, ……is said to have said: "Kill them. For God knows who are his." Thus innumerable persons were killed in that city.

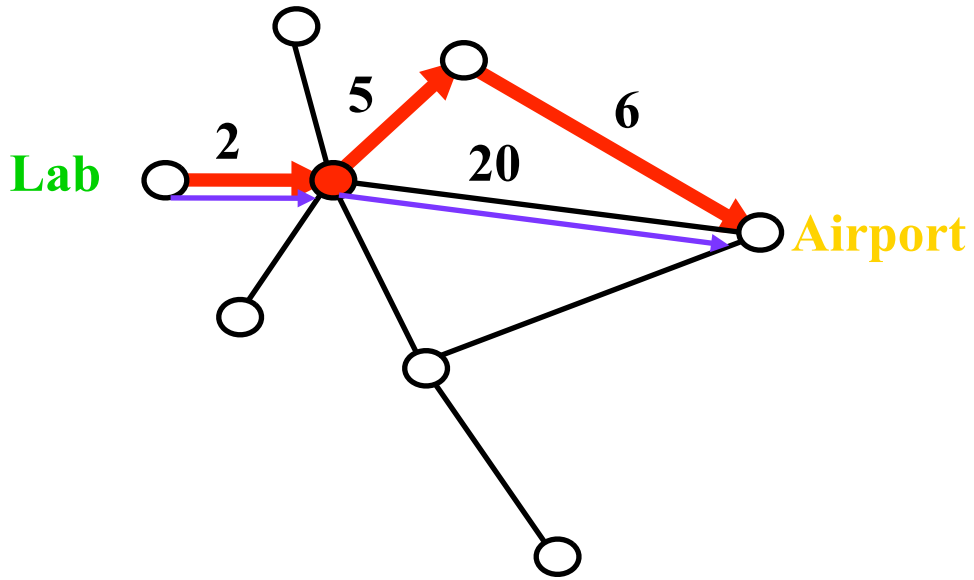
This singling out of guides and messengers, the contacts of the key heretics, rather than the heretics (*perfecti*) themselves is now known as 'acquaintance immunisation.' It is usually more efficient to inoculate one of the contacts of a node rather than the node itself [17].

R. Cohen et al. "Efficient Immunization Strategies for Computer Networks and Populations," Phys. Rev. Lett. **91**, 247901 (2003).

Optimal Path: Minimize total "cost"

L. A. Braunstein, S. V. Buldyrev, R. Cohen, S. Havlin, and H. E. Stanley,
``Optimal Paths in Disordered Complex Networks" Phys. Rev. Lett. {\bf 91}, 168701.





For this example:

Shortest path: 3 (cost = 60)

Optimal path: 5 (cost = 47)

Shortest path: 2 (cost = 22)

Optimal path: 3 (cost = 13)

Generally:

Shortest path = $N^{0.50}$

Optimal path = $N^{0.61}$

$N^{0.50} < N^{0.61}$

ex: $(10^6)^{0.50} < (10^6)^{0.61}$

Shortest path = Log N

Optimal path = $N^{1/3}$

$\log N << N^{1/3}$

ex: $N=10^6$, $\log 10^6 << (10^6)^{1/3}$

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The Boston Globe

MONDAY, MARCH 14, 2011

A NEW WEAK

TODAY: *Partly sunny and colder. Hi 37-42. Low 27-32.*
TOMORROW: *Mostly sunny, milde High 42-47. Low 32-37.*
HIGH TIDE: *6:42 a.m., 7:25 p.m.*
SUNRISE: *6:59* SUNSET: *6:49*
FULL REPORT: PAGE B13

Cascading disaster in Japan

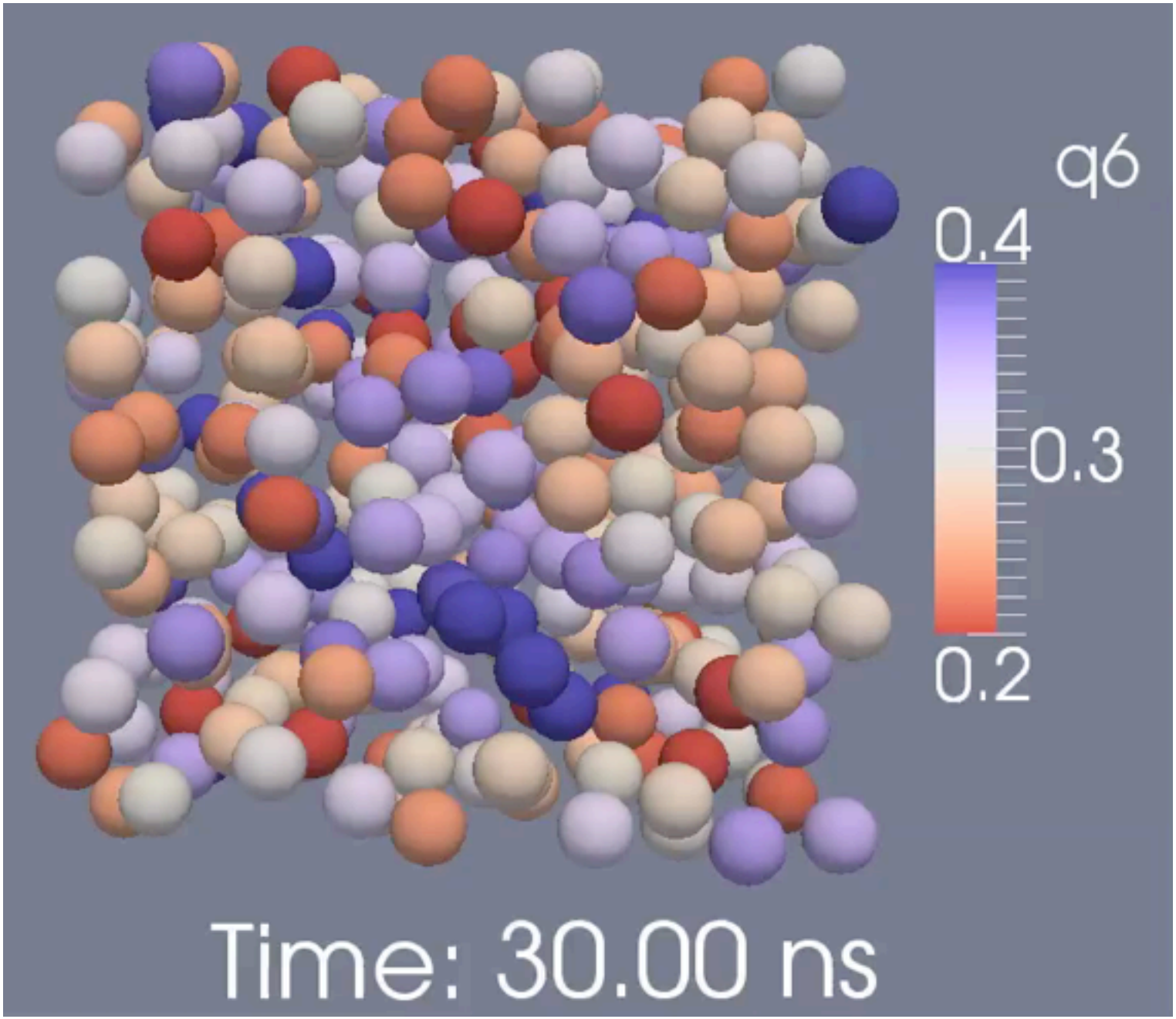
Blast shakes a second reactor death toll soar

By Martin Fackler and Mark McDonald
NEW YORK TIMES

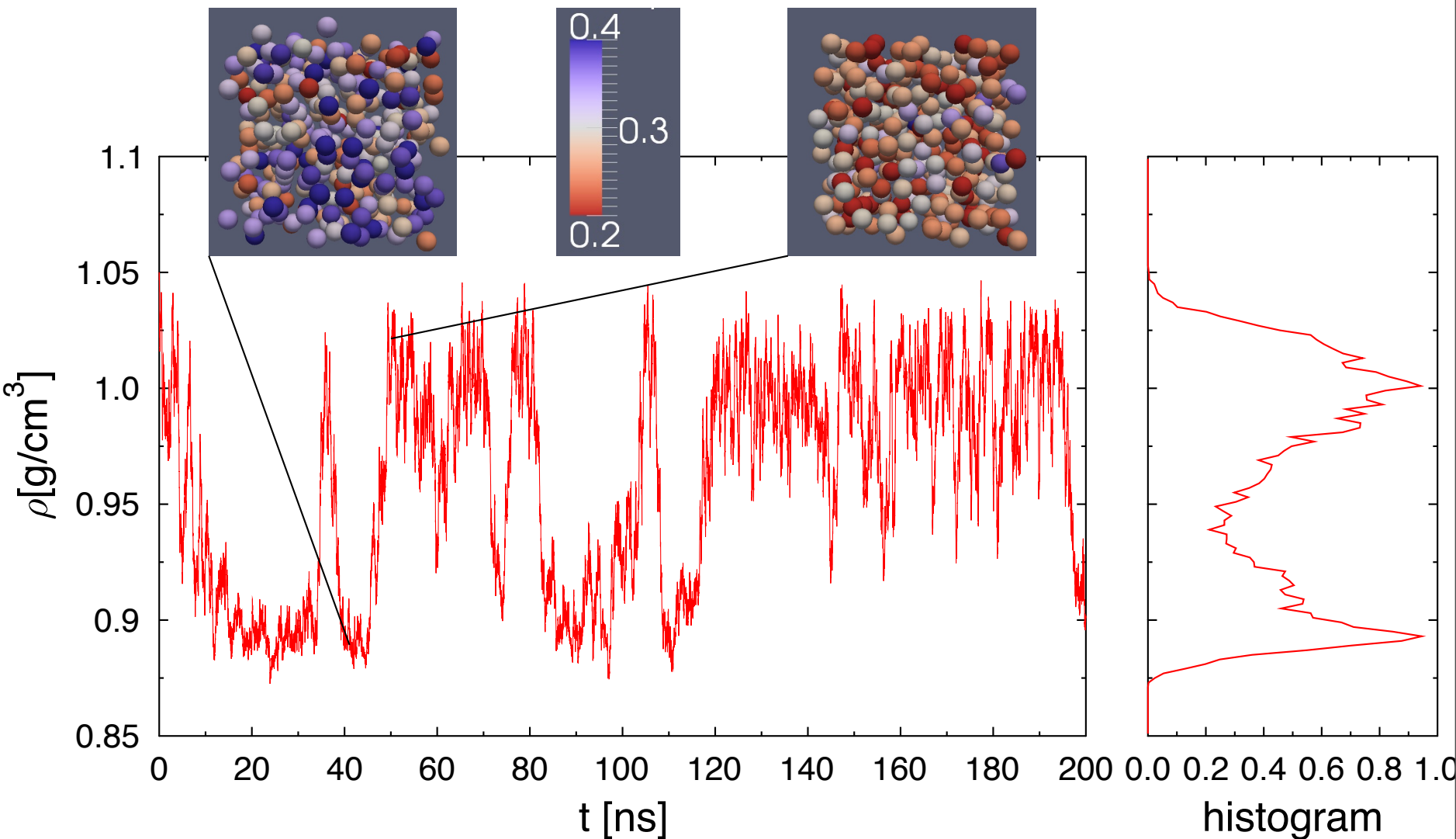
SENDAI, Japan — Japan reel from a rapidly unfolding disaster epic scale yesterday, pummeled by t death toll, destruction, and homele ness caused by the earthquake a tsunami and new hazards from da aged nuclear reactors. The prime m ister called it Japan's worst crisis sin World War II.

Japan's $5 trillion economy, t world's third largest, was threaten with severe disruptions and partial p ralysis as many industries shut do temporarily. The armed forces and v unteers mobilized for the far more gent crisis of finding survivors, eva ating residents near the strick power plants and caring for the v tims of the record 8.9 magnitu quake that struck on Friday.

The disaster has left more th 10,000 dead, many thousands hom less, and millions without water, po er, heat, or transportation.


q6
0.4
0.3
0.2
Time: 30.00 ns

water: ***time dep. for 1 state point near ph. trans. line:***



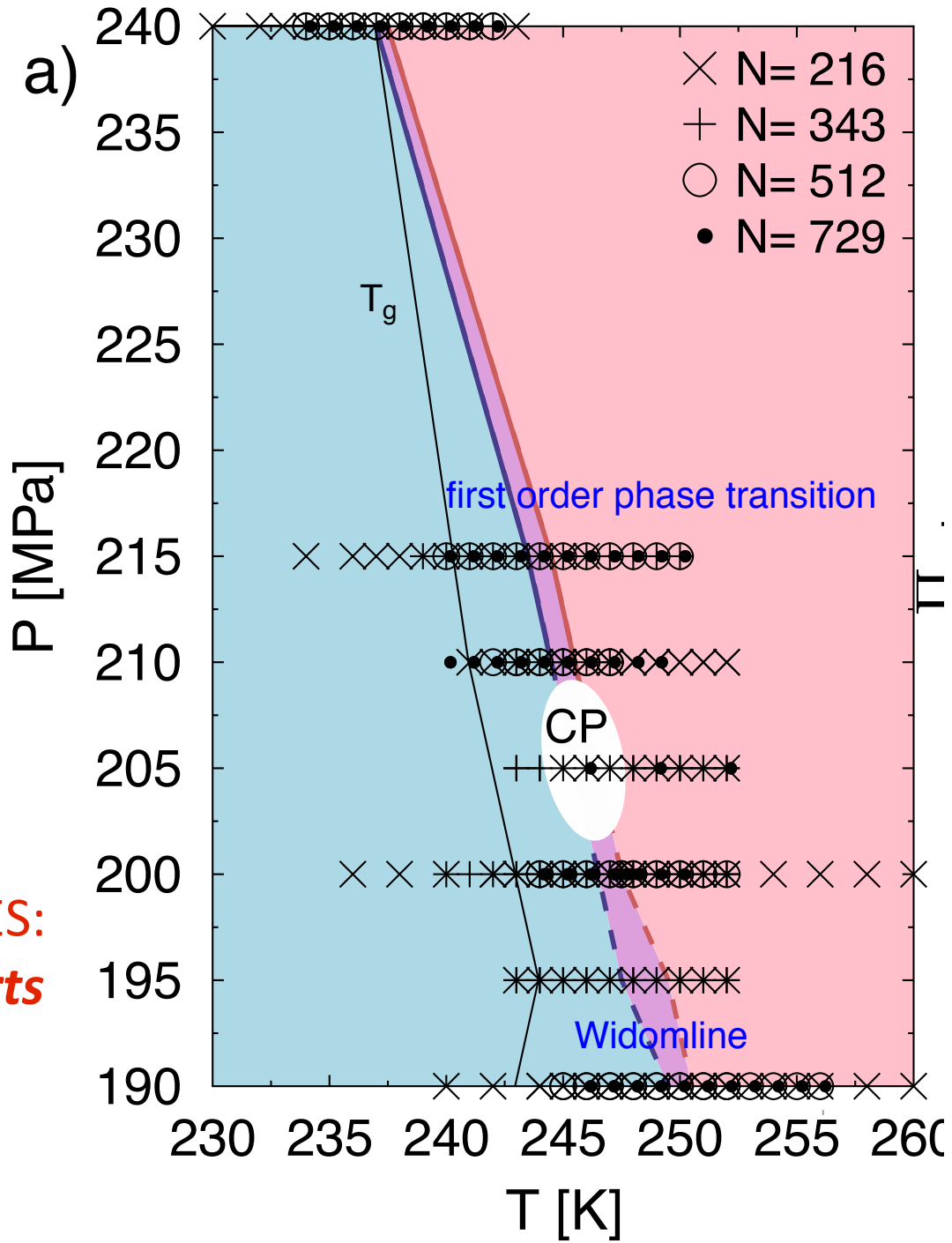
+

350 State Points
analyzed
4 system sizes

both sides of Widom line

both sides of LLPT line

Kesselring, Franzese, Buldyrev, Herrmann,HES: ***Nature Scientific Reports*** 2012; ditto + Lascaris, ***J. Chem. Phys.*** 2013



Did Ehrenfest contribute to economics?

YES, says Jan Tinbergen!

Between 1921 and 1925, Tinbergen studied mathematics and physics at the University of Leiden under Paul Ehrenfest. During those years at Leiden he had numerous discussions with Ehrenfest, Kamerlingh Onnes, Hendrik Lorentz, Pieter Zeeman, and Albert Einstein.

In 1929 he defended his PhD thesis titled "Minimumproblemen in de natuurkunde en de economie" (Minimisation problems in Physics and Economics). This topic was suggested by Ehrenfest and allowed Tinbergen to combine his interests in mathematics, physics, economics and politics. Diego Garlaschelli biosketch