Physics of Complex Systems,

with Applications to Liquid State Physics, Econophysics, and Failure Cascades in Interdependent Networks

An informal talk based on work by BU students and collaborators, including:
Poole, Sciortino, Sastry, Lascaris, Luo, Strekaleva, Stokely, Su, Araujo, Huber, Glotzer, Barabasi, Larralde, Peng, Makse Amaral, Viswanathan, Zapperi, Sadr, Starr, Dokholyan, Liu, Plerou, Grosse,
Mantegna, Havlin, Buldyrev, Pammolli, Riccaboni, Petersen, Preis, Schneider, Gopikrishnan, Plerou, Liu, Cizeau, Wang, Yamasaki, Rosenow, Amaral, Qian Li, Guanliang Li, Wei Li, Huang, Ivanov, Podobnik, Matia, Weber, Vodenska-Chitkushev, Chessa, Lee, Meyer, Gabaix), Carbone, Ben-Jacob, Kenett, Moat, Fu **& YOU?**

details in a popular article:
http://polymer.bu.edu/hes/press12sciencenews-interdependentnetworks-bigfigs.pdf

Puzzles of water….

**QUESTION 1: What IS the question?
"Understanding" the 64 anomalies of water?
A: One anomaly is easy, and gives clues for many more: Why ice floats...?

**QUESTION 2:
Why care about water?
A1. Practical
A2. Scientific

**QUESTION 3:
What do we actually do?
A: "Liquid-Liquid phase transition hypothesis"

TRUE!

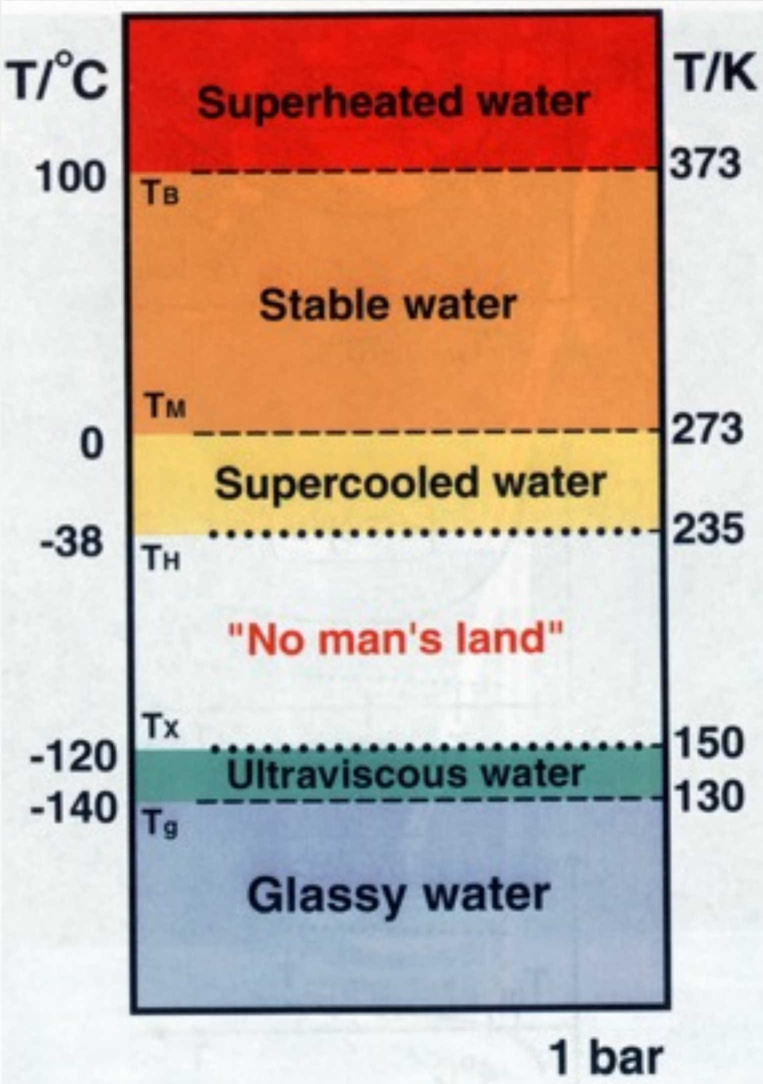


Figure 1: Schematic illustration indicating the various phases of liquid water (color-coded) that are found at atmospheric pressure. Courtesy of Dr. O. Mishima.

Hypothesis (Poole/FS/UE/HES)

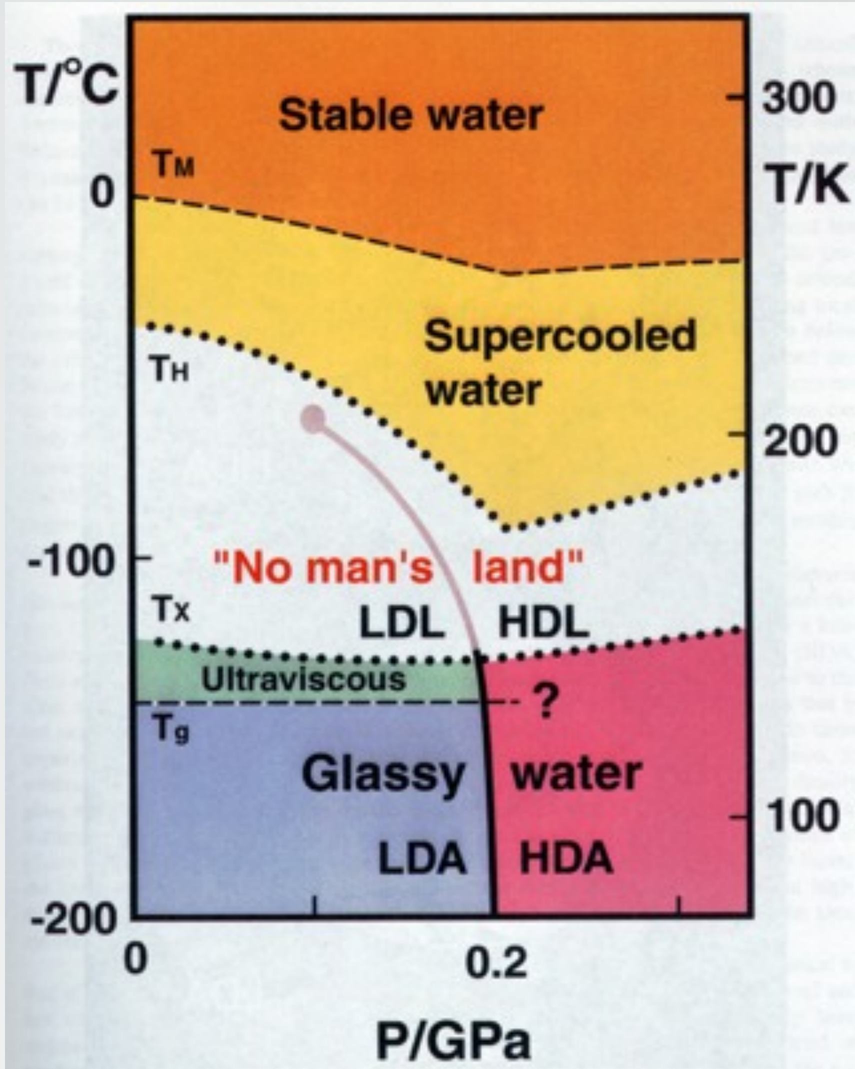
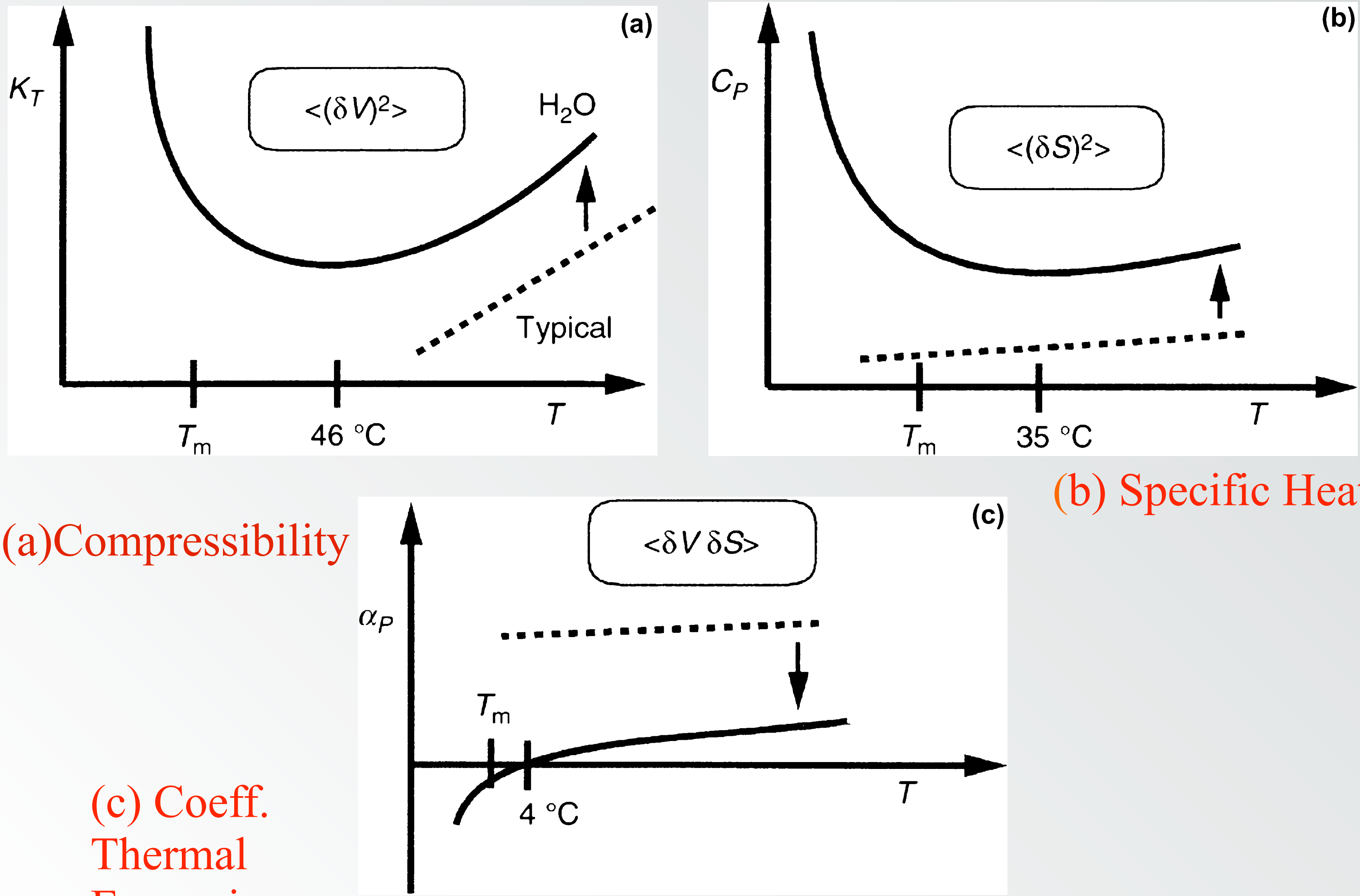


Figure 2: Generalization of Fig. 1 to incorporate a second control parameter, the pressure. The colors are the same as used in Fig. 1. Courtesy of Dr. O. Mishima.

***TEST # 2: Thermodynamic response functions quantify fluctuations



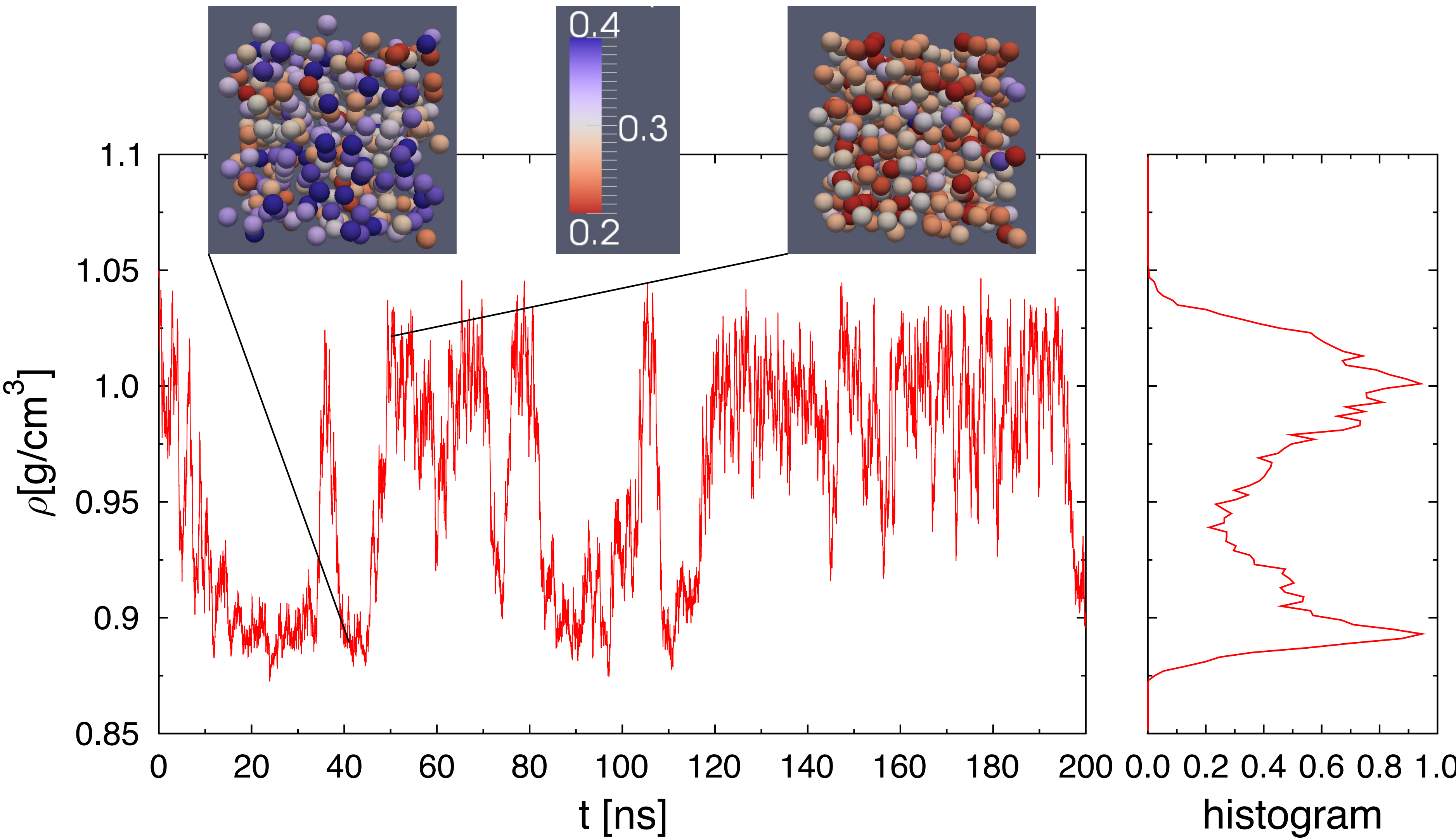
(a)Compressibility

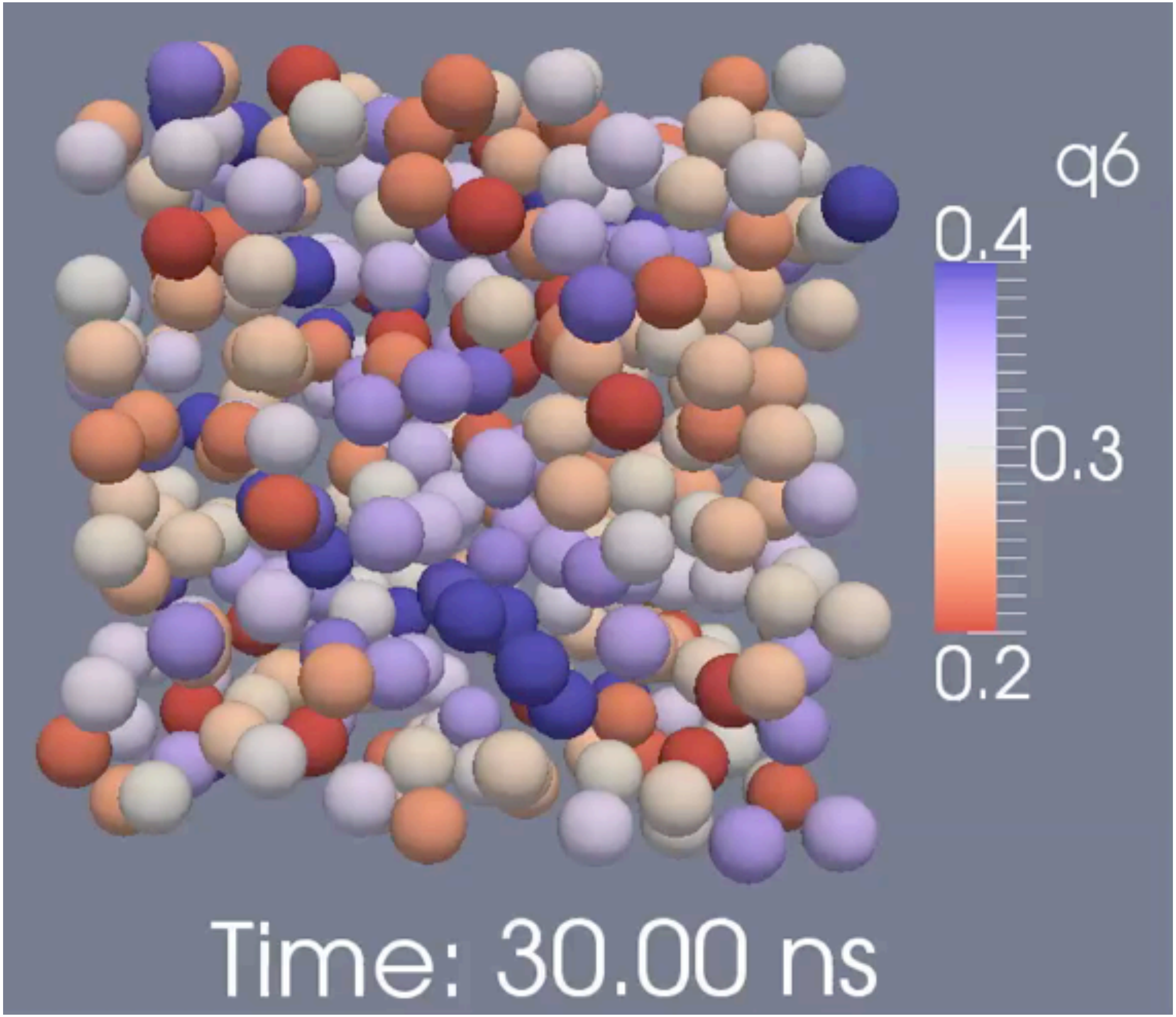
(b) Specific Heat

(c) Coeff. Thermal Expansion

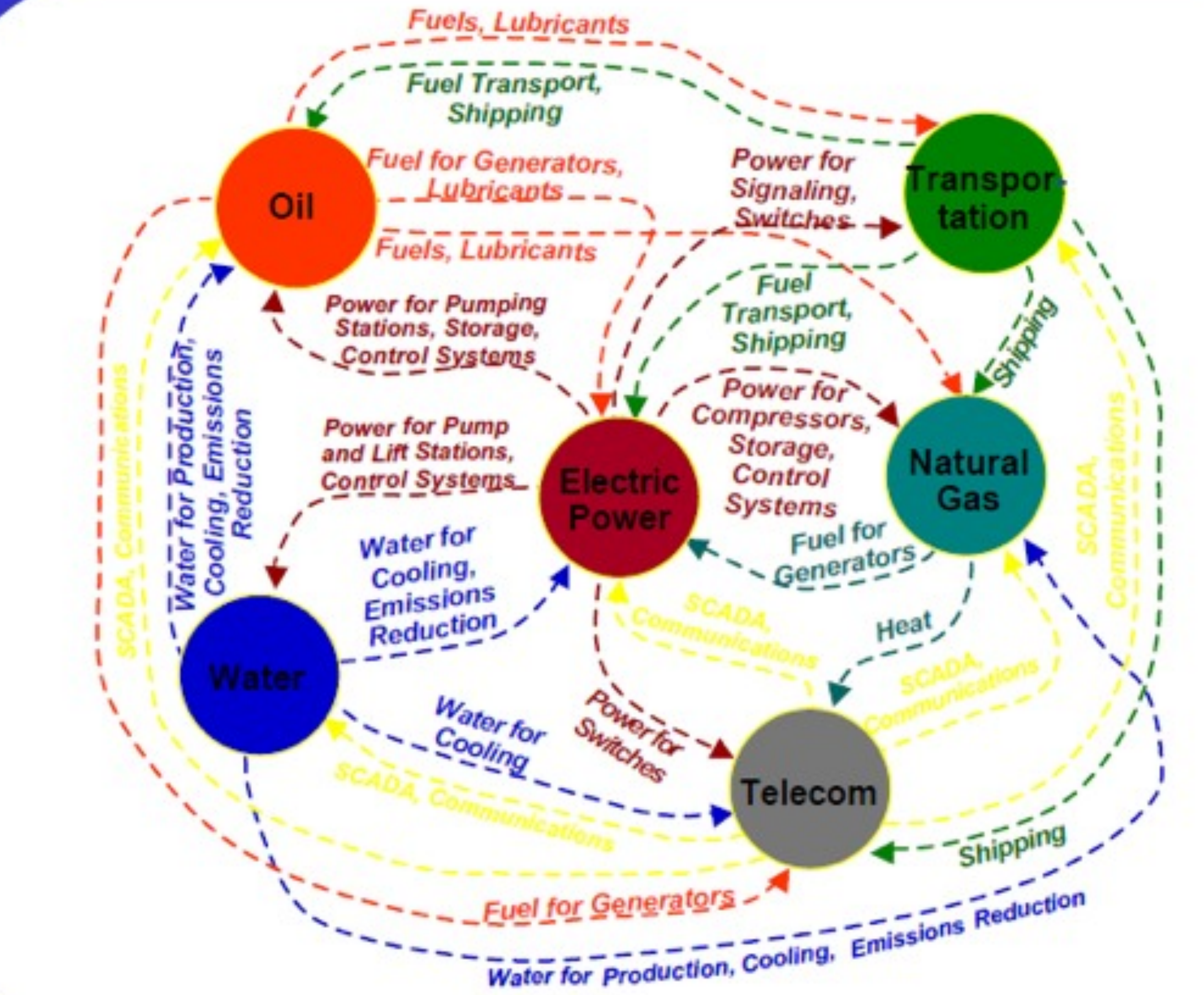
QUESTION: Why apparent singularity about -50 C ??

Test 18: time dependence for state point near ph.tr. line:




q6
0.4
0.3
0.2
Time: 30.00 ns

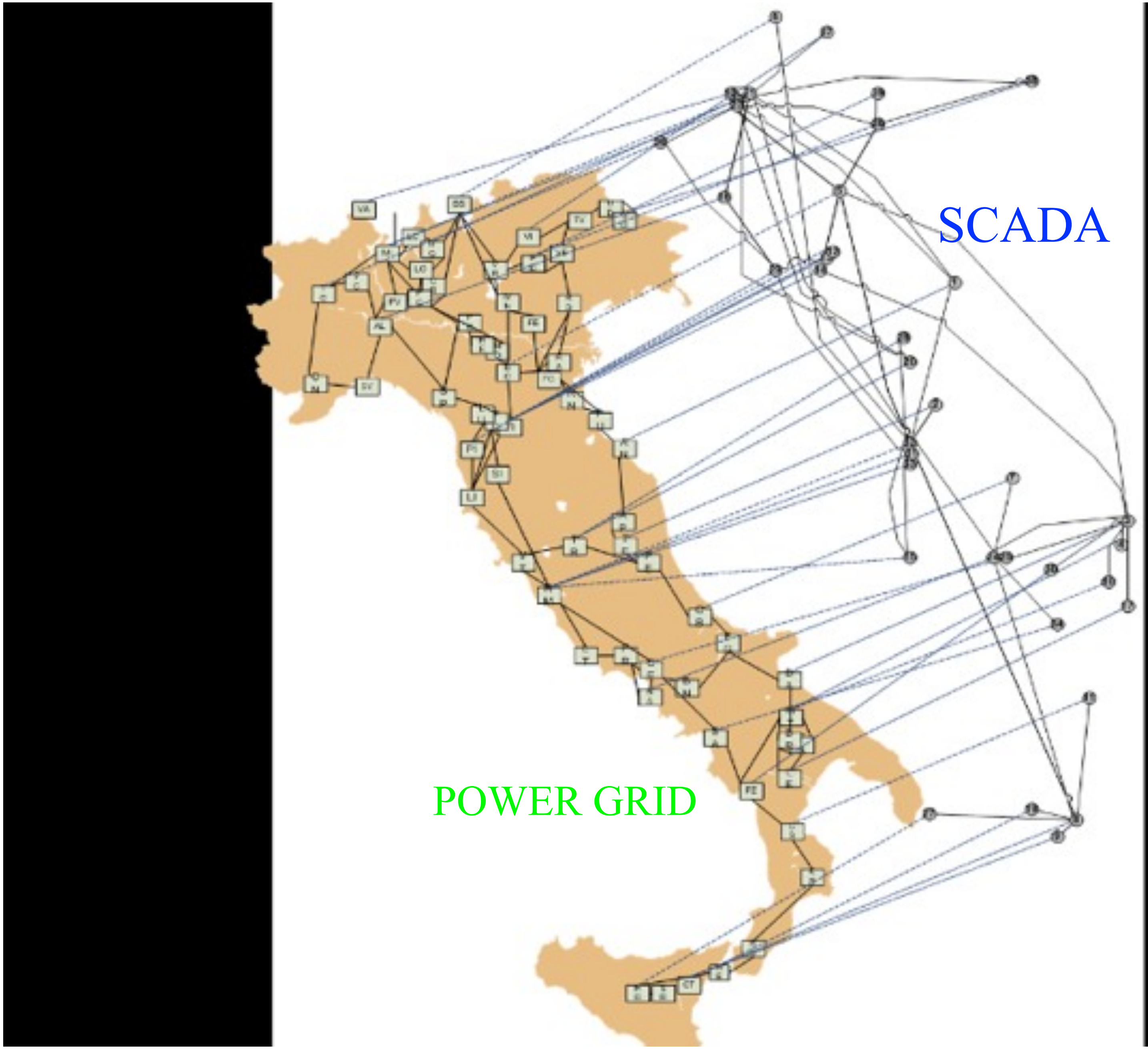
How interdependent are infrastructures?



Peerenboom, Fisher, and Whitfield, 2001

NATIONWIDE BLACKOUT(28 Sept. 2003)

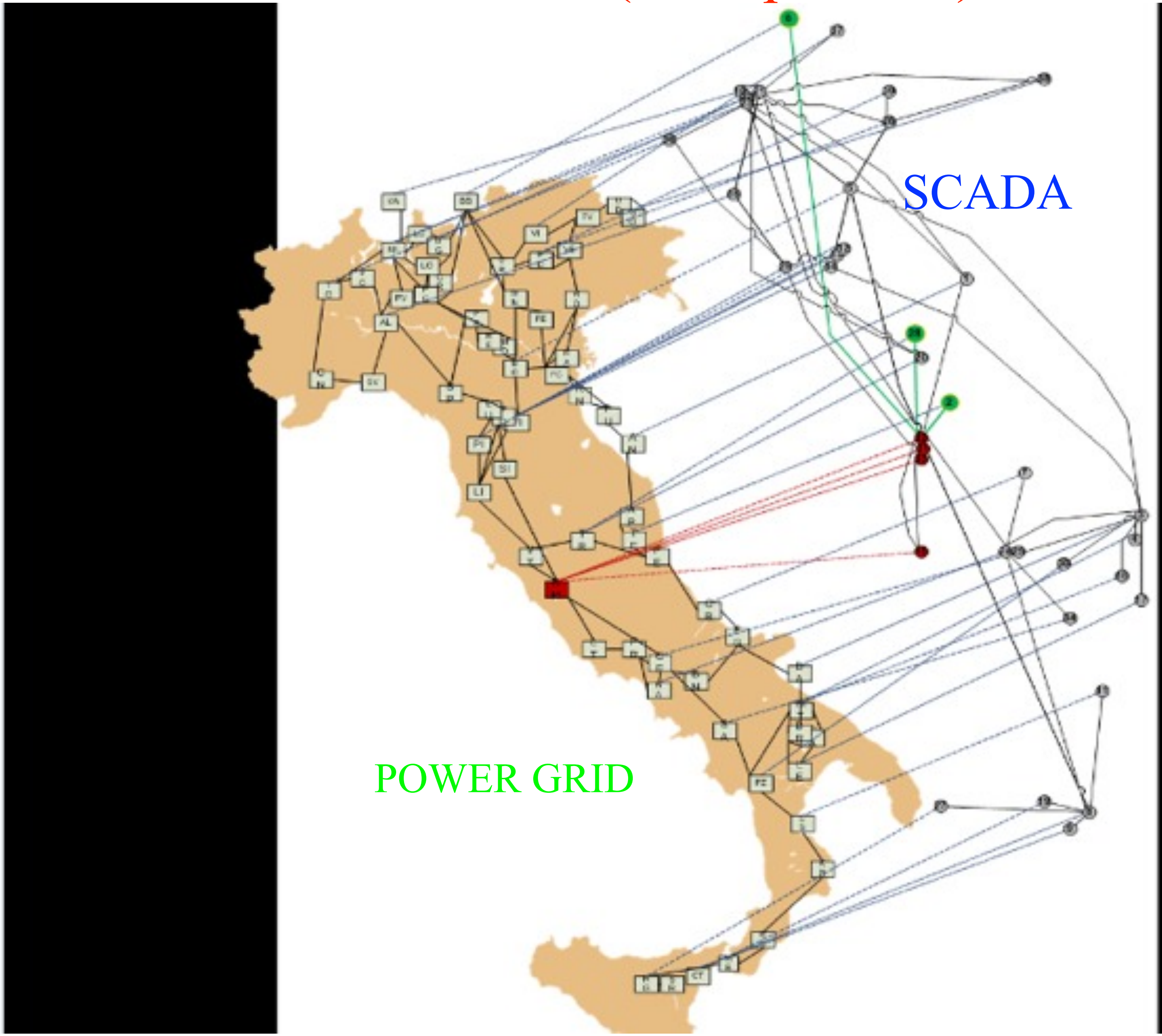
27 Sept 2003:
1 DAY
BEFORE THE
CASCADE OF
FAILURES



SCADA = Supervisory Control And Data Acquisition

Stage 1: NATIONWIDE BLACKOUT (28 Sept. 2003)

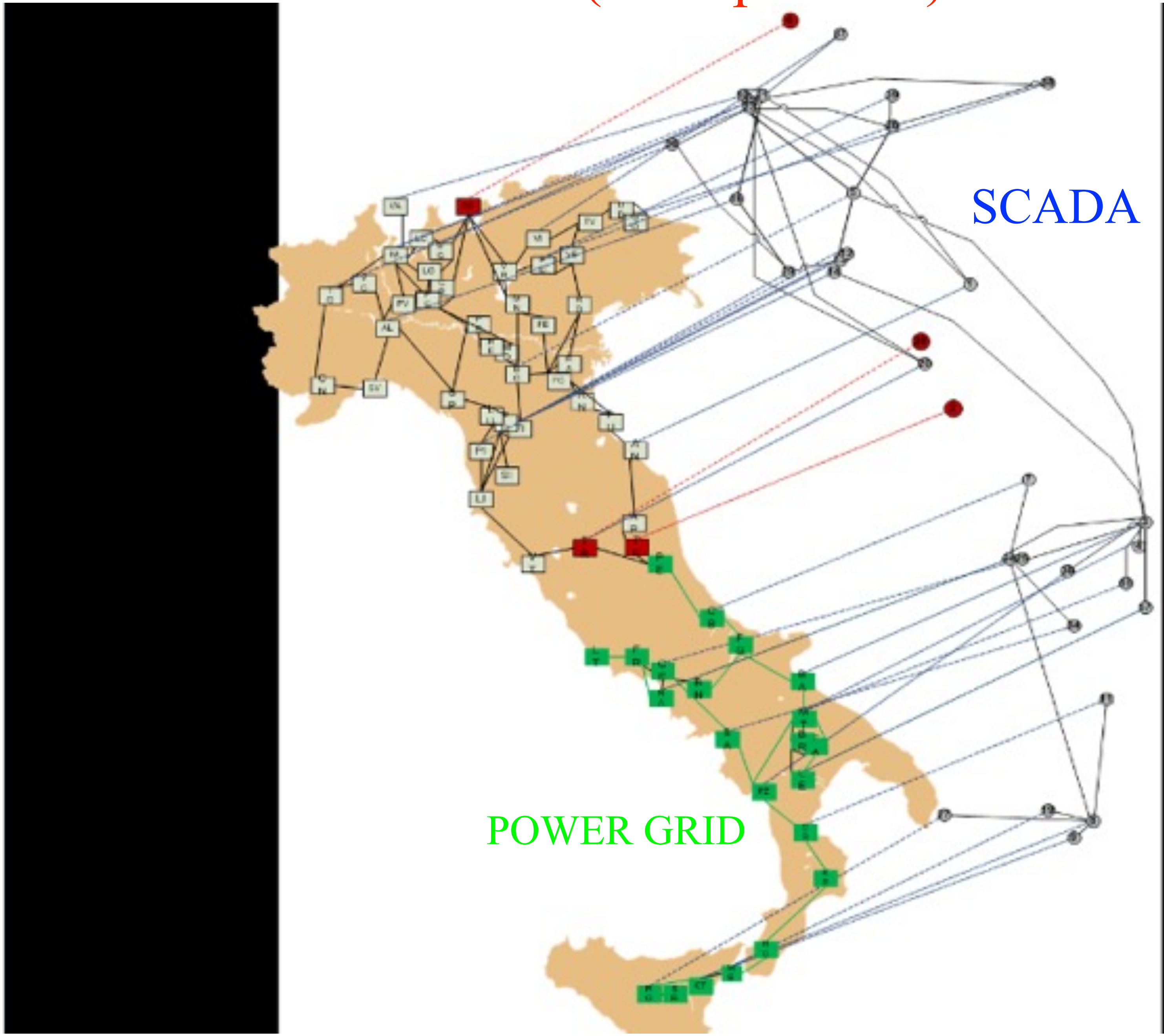
The first second: ABOVE the critical breakdown threshold [only Rome power is out]



SCADA = Supervisory Control And Data Acquisition

Stage 2: NATIONWIDE BLACKOUT(28 Sept. 2003)

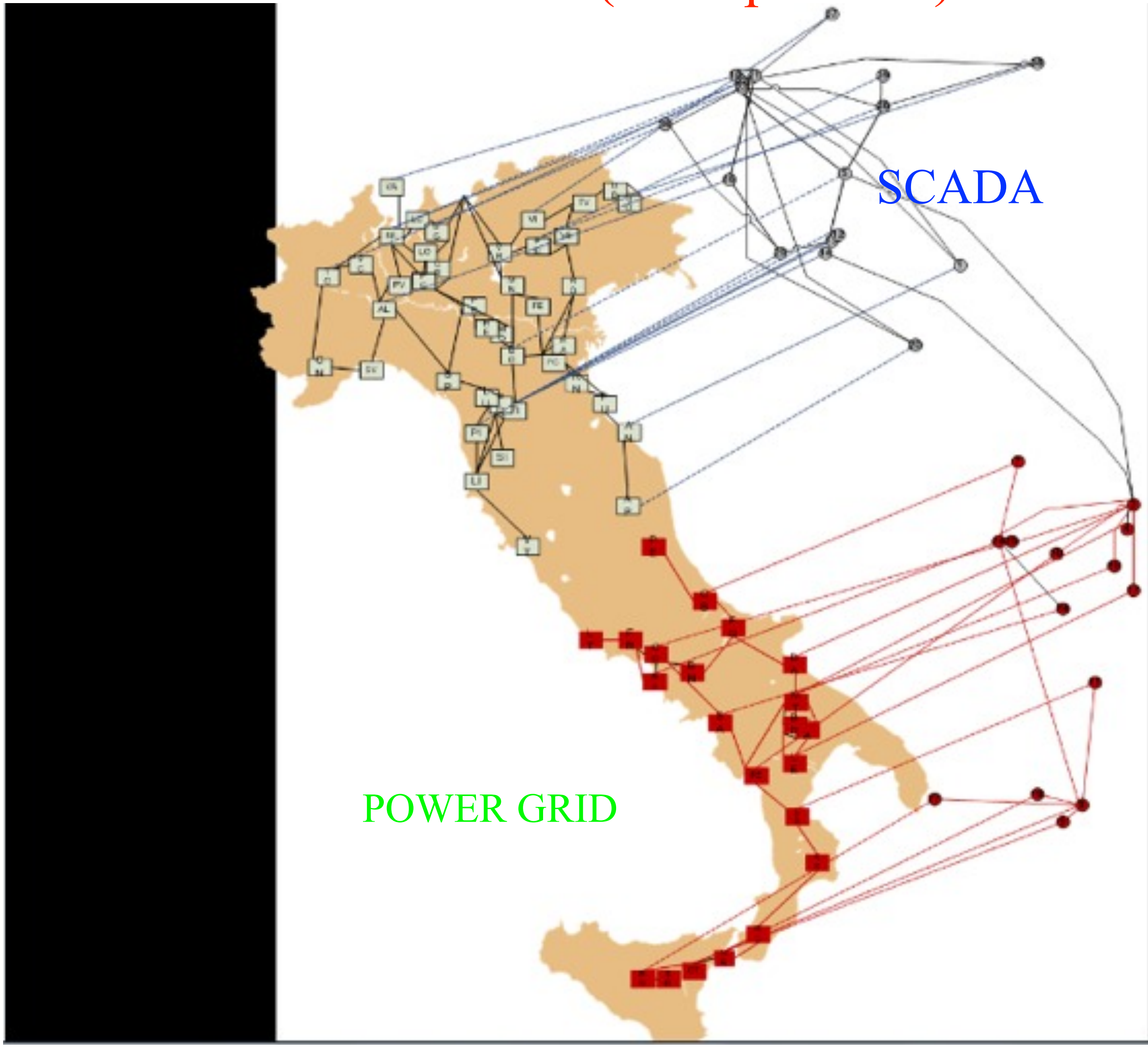
A few seconds later: STILL ABOVE the critical breakdown threshold



SCADA=Supervisory Control And Data Acquisition

Stage 3: NATIONWIDE BLACKOUT (28 Sept. 2003)

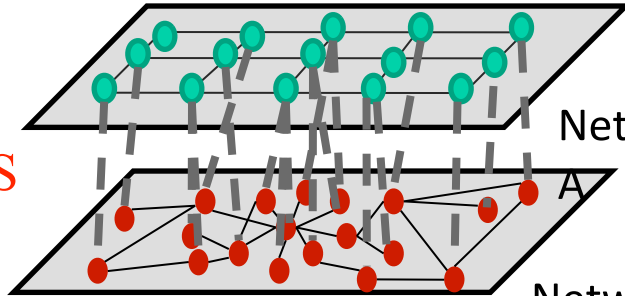
A few seconds later still: Now BELOW the critical breakdown threshold !!!



SCADA= Supervisory Control And Data Acquisition

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 firms, insurance companies, and banks 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)

2 INTERDEPENDENT NETWORKS (summary):

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

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

- Isolated systems rarely occur in nature nor in technology [non-interacting molecules rarely occur--otherwise liquids could not exist!].

- Take home message: Results for interacting "interdependent" networks are strikingly different from those of single networks.

Can a law describe bubbles and crashes in financial markets?

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).

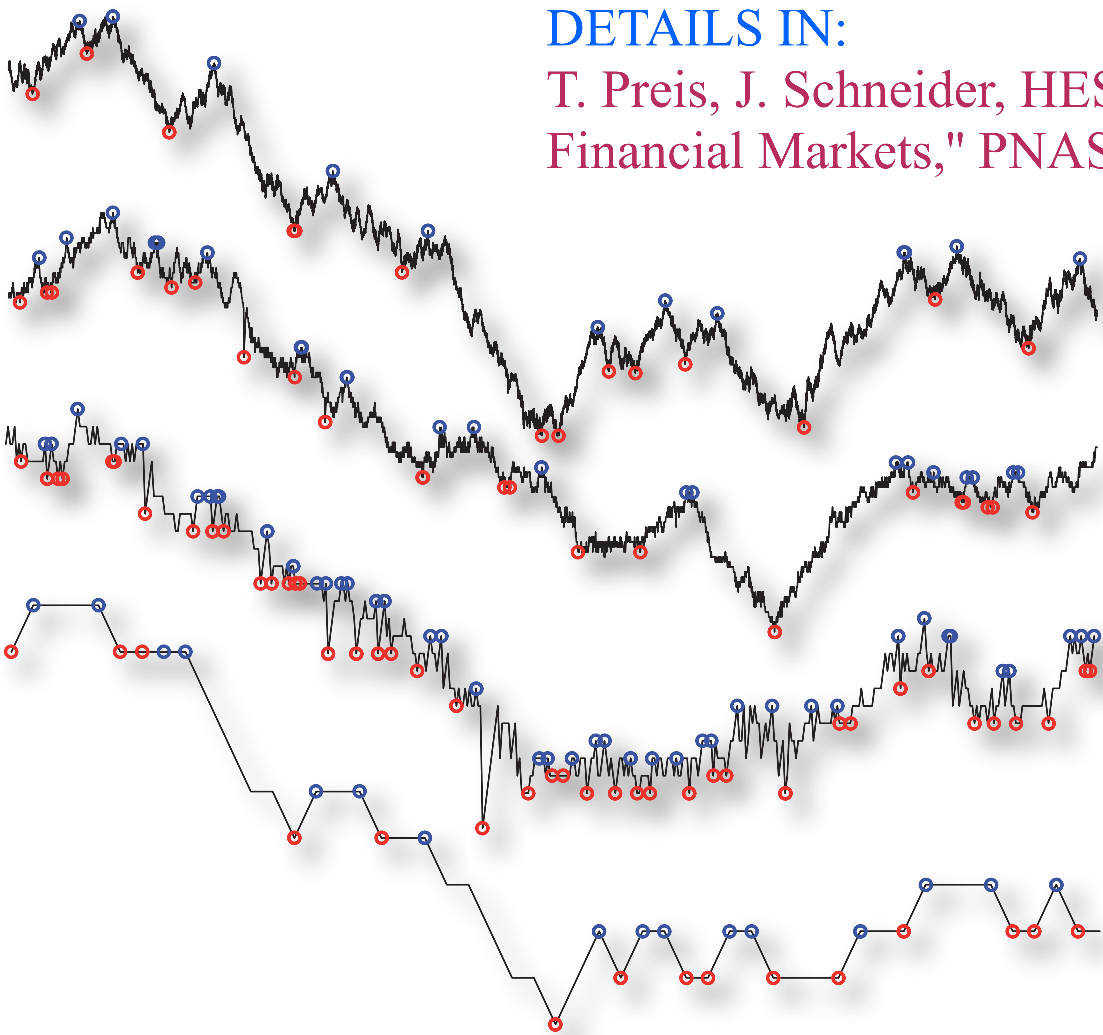
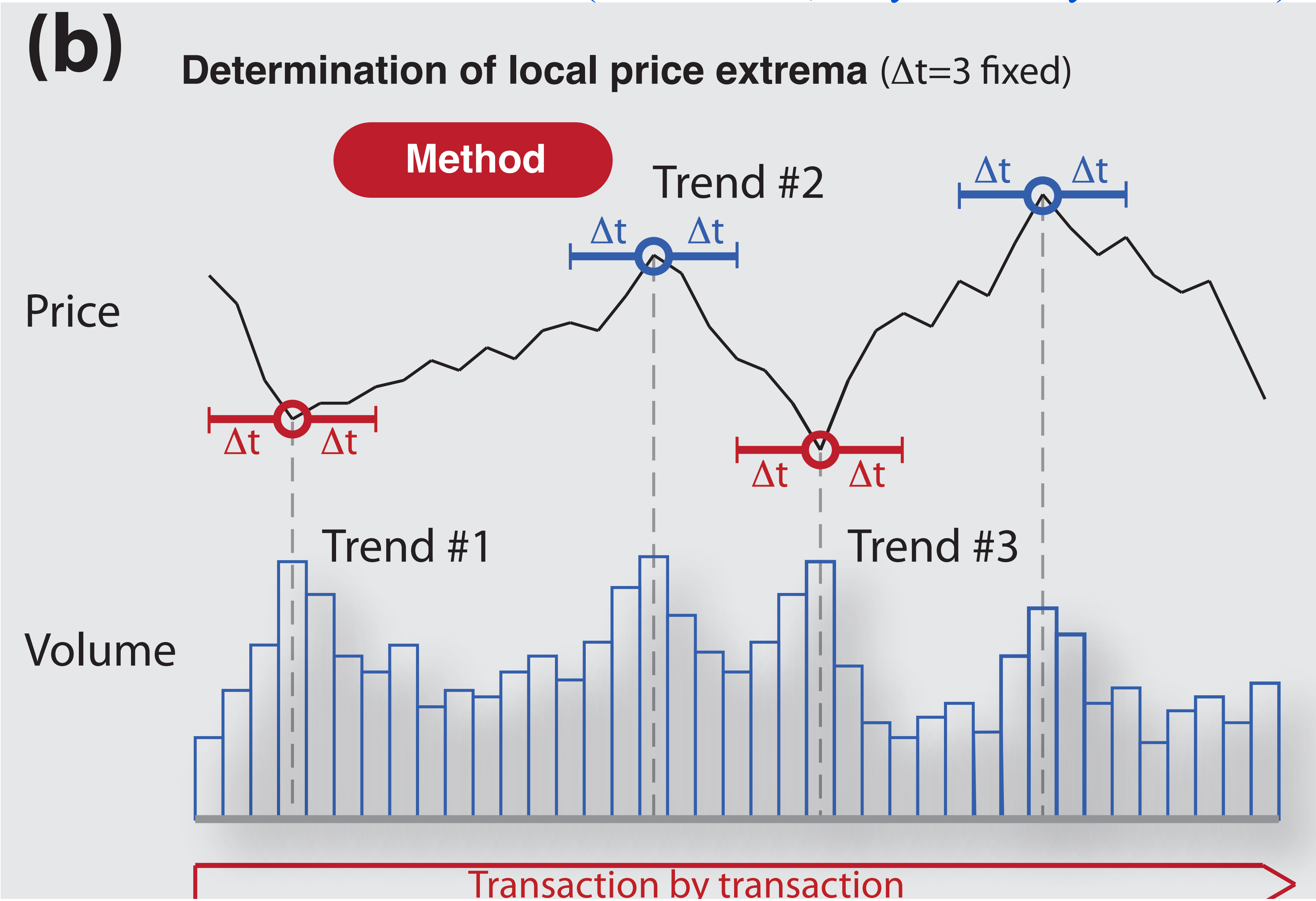


Figure 1 | Scale-free behavior of financial market fluctuations. Financial market time series feature identical properties on very different time scales. All four curves are subsets of a 14 million transactions dataset taken from a German DAX future time series. The price curves cover time periods of 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)



The Economist

"How?" "Models?": Herd vs. News?

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

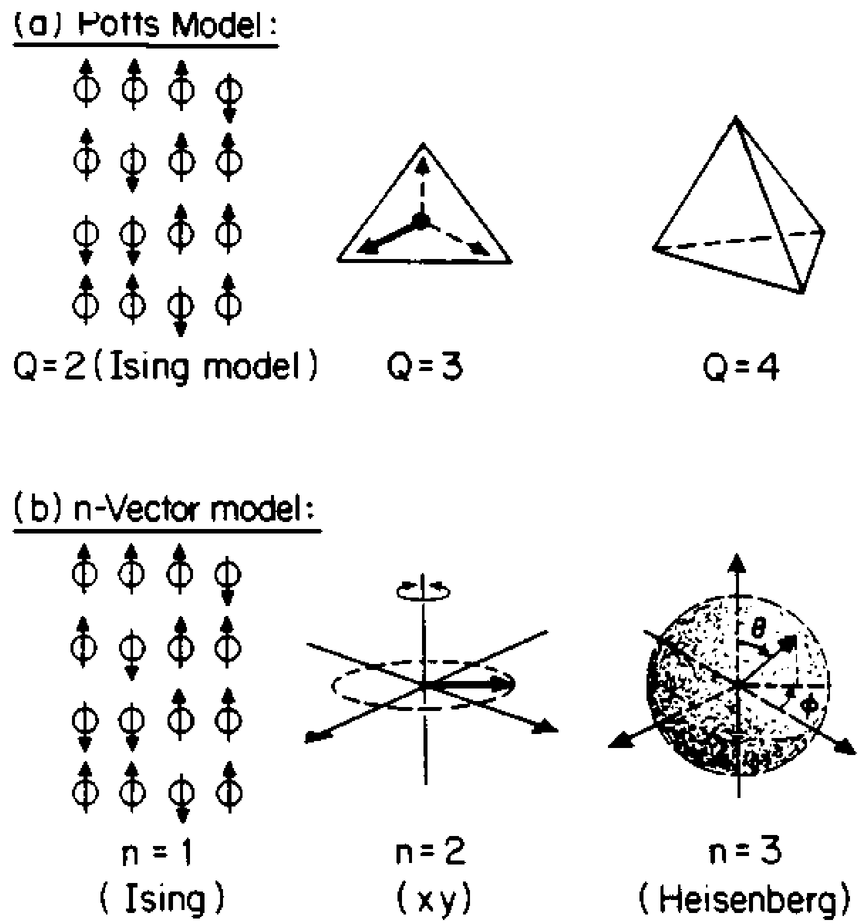
Each stock is a unit, interacting with other stocks (units) and bathed in a magnetic field H. J depends on the two stocks, and H depends on the stock. Both can change with time.

Possible models:

(a) Units can be in Q different DISCRETE states: "Potts Model" (Potts 1952).

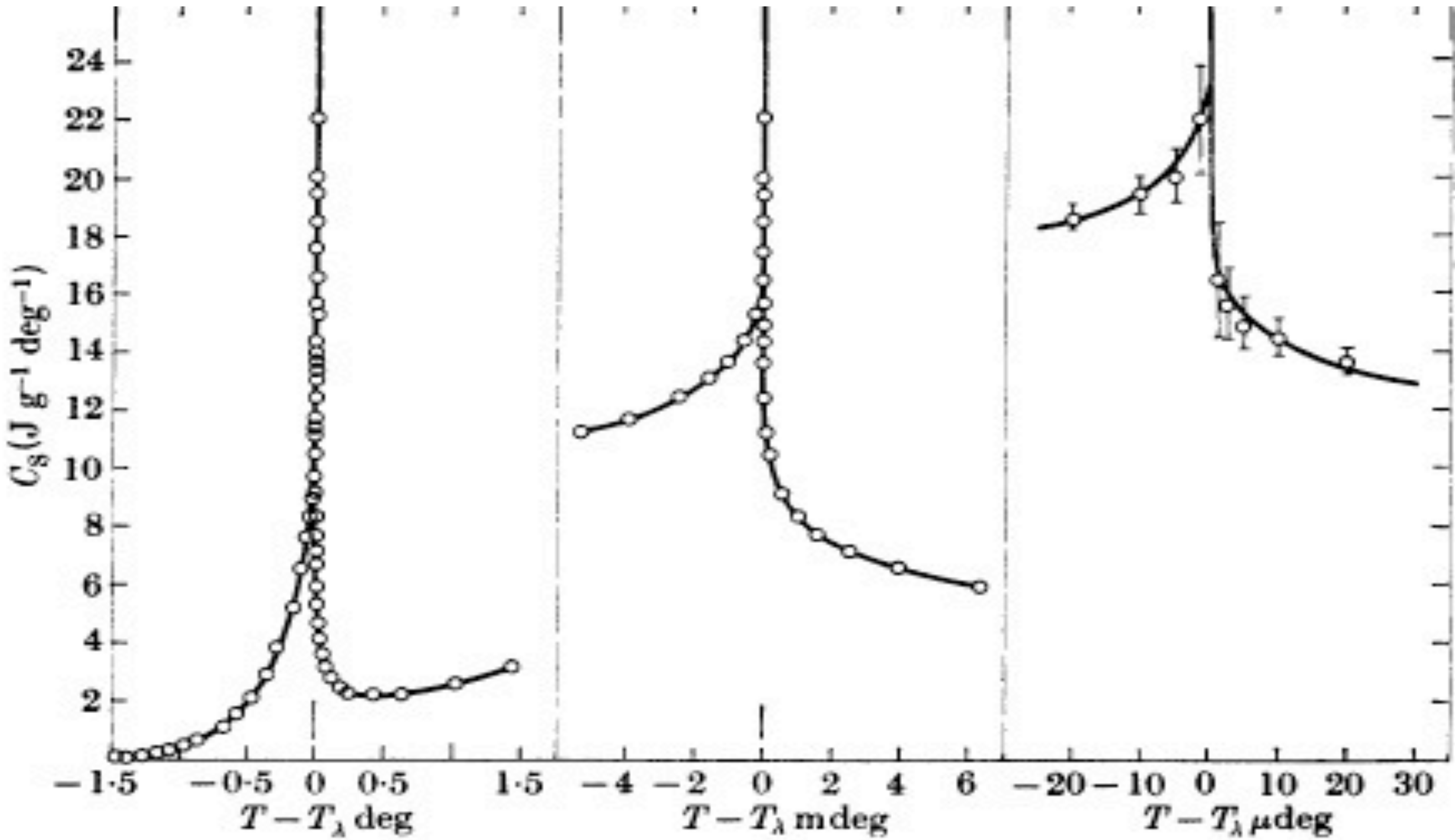
(b) n-dimensional units. Each can be in a CONTINUUM of states: "n-Vector Model" (HES 1969)

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

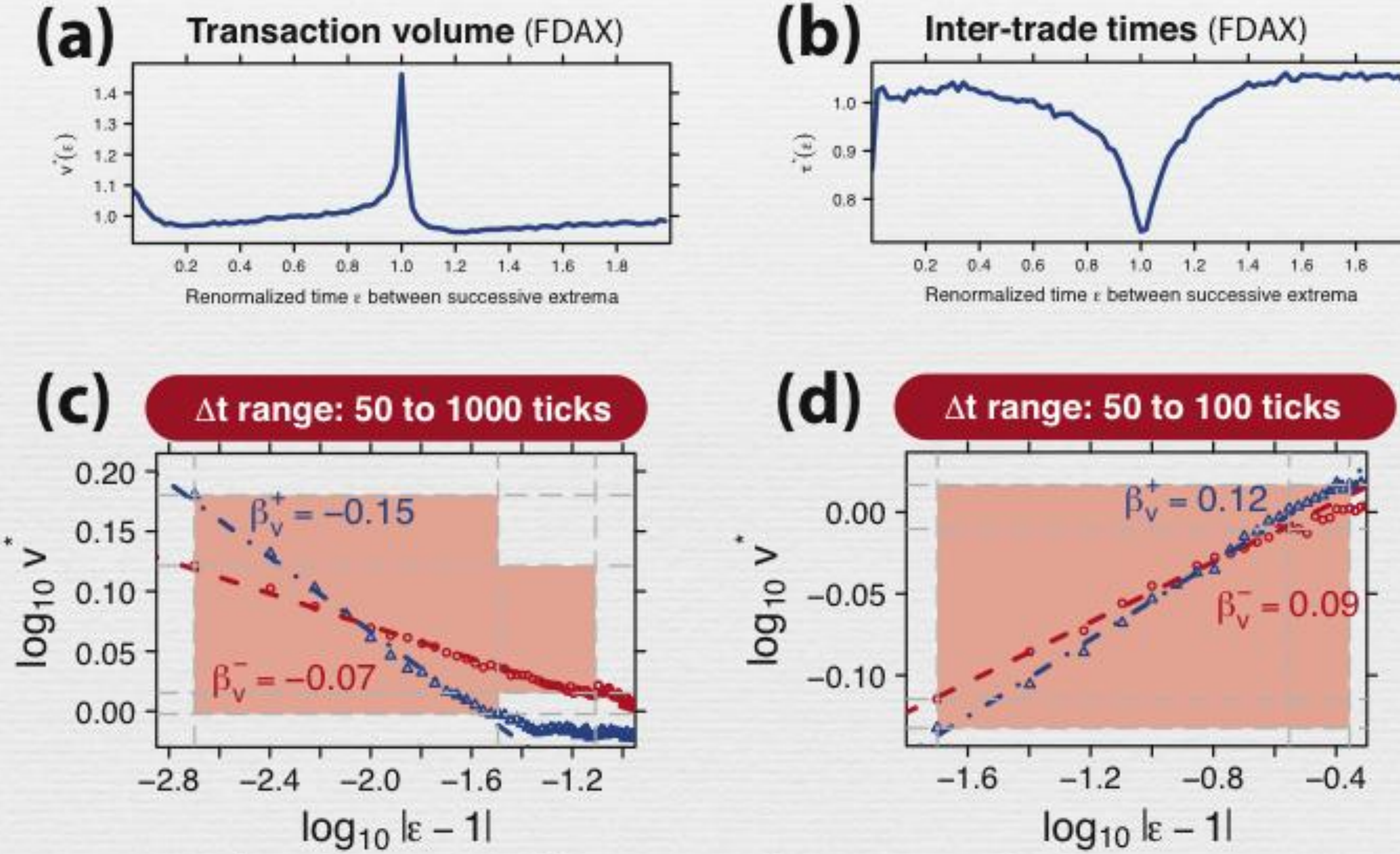


SCALE FREE SPECIFIC HEAT NEAR HELIUM SWITCH POINT

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



Quantities With Scale-Free Behavior

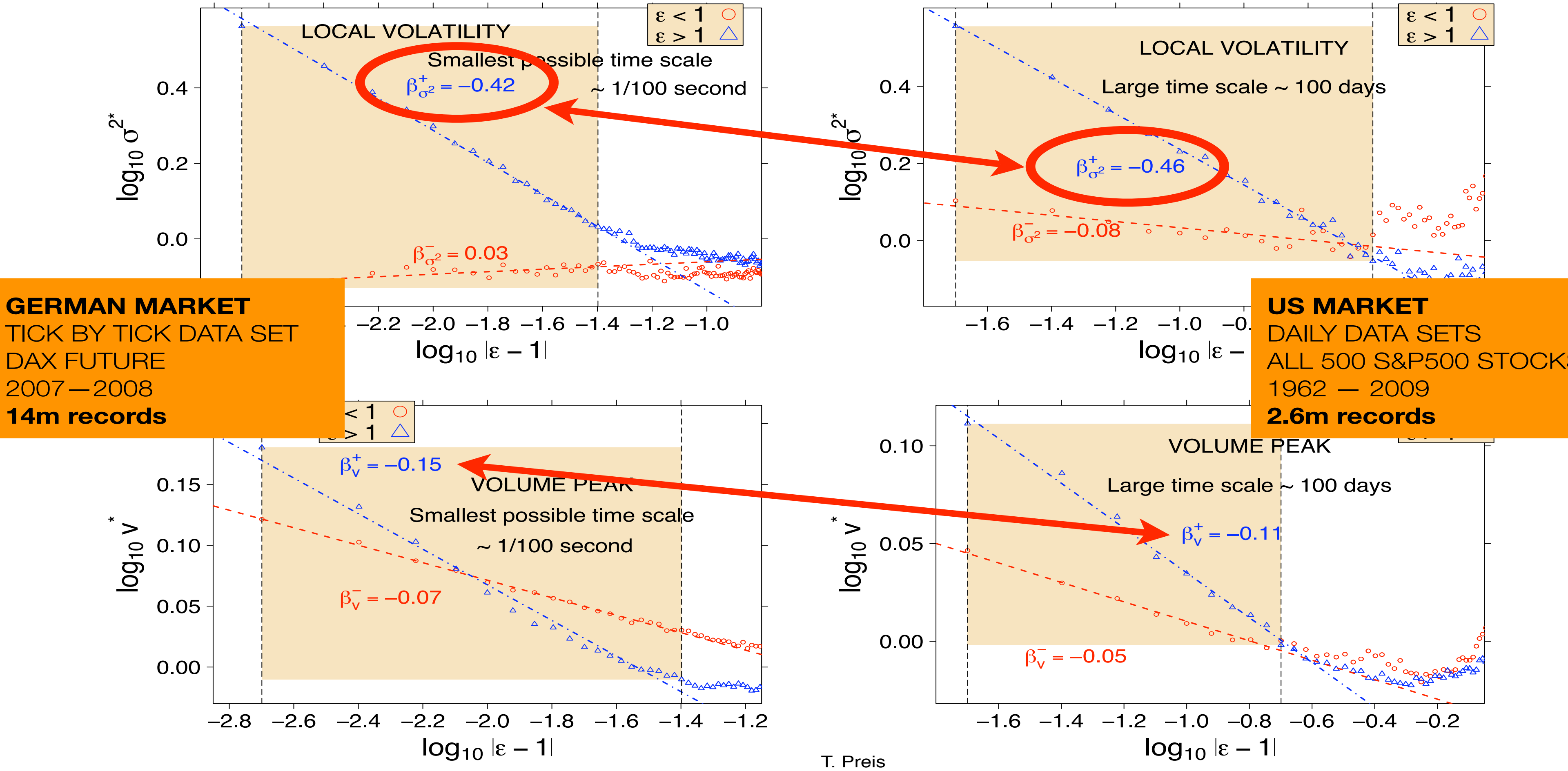


- Randomly reshuffling confirms our findings.

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

FROM THE VERY SMALL TO THE VERY LARGE

~1/100 SECOND → ~100 DAYS



T. Preis

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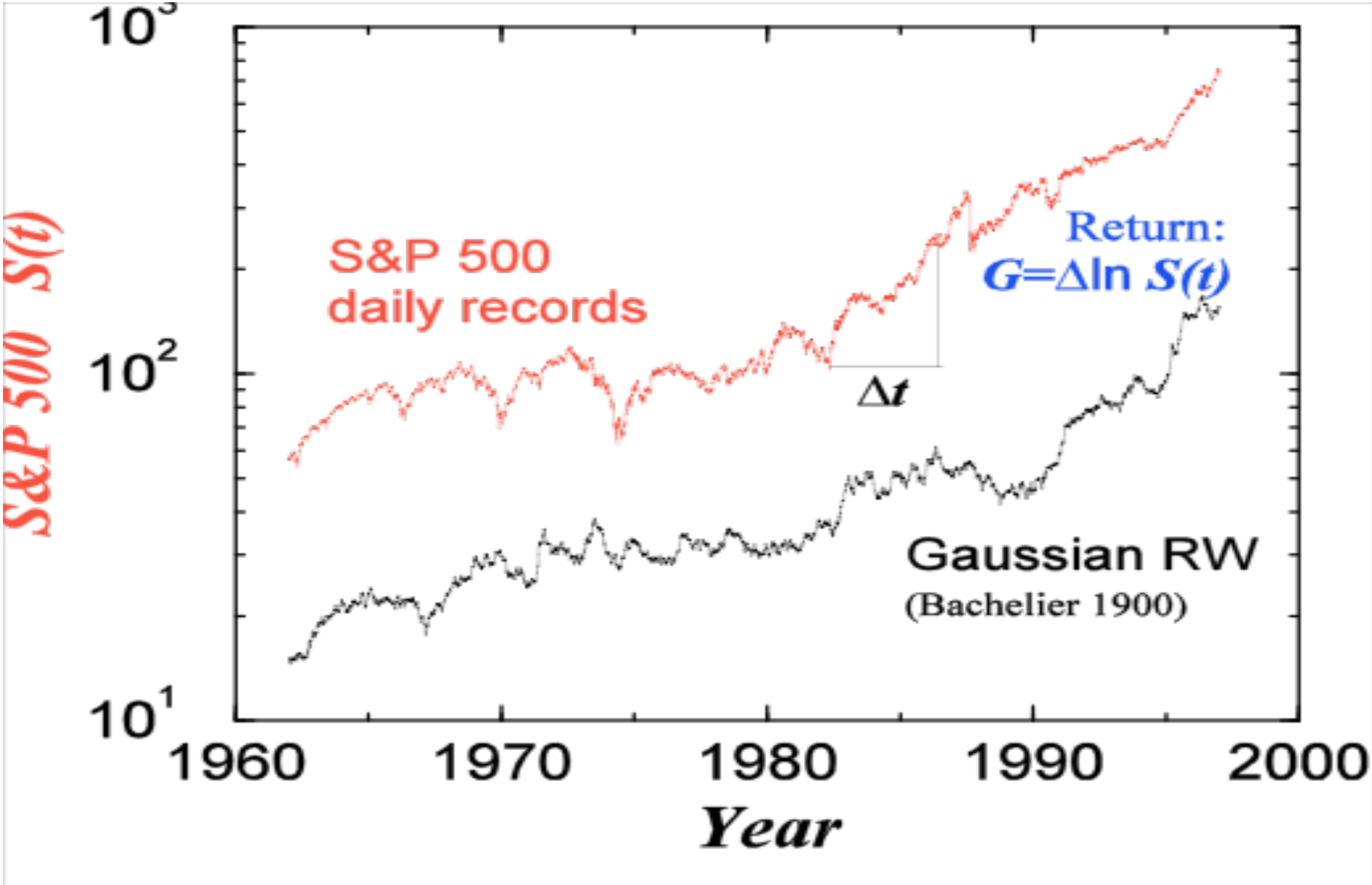
Preis/HES/Schneider (2011 PNAS, May 2011 Physics World)

Example: S&P 500 index



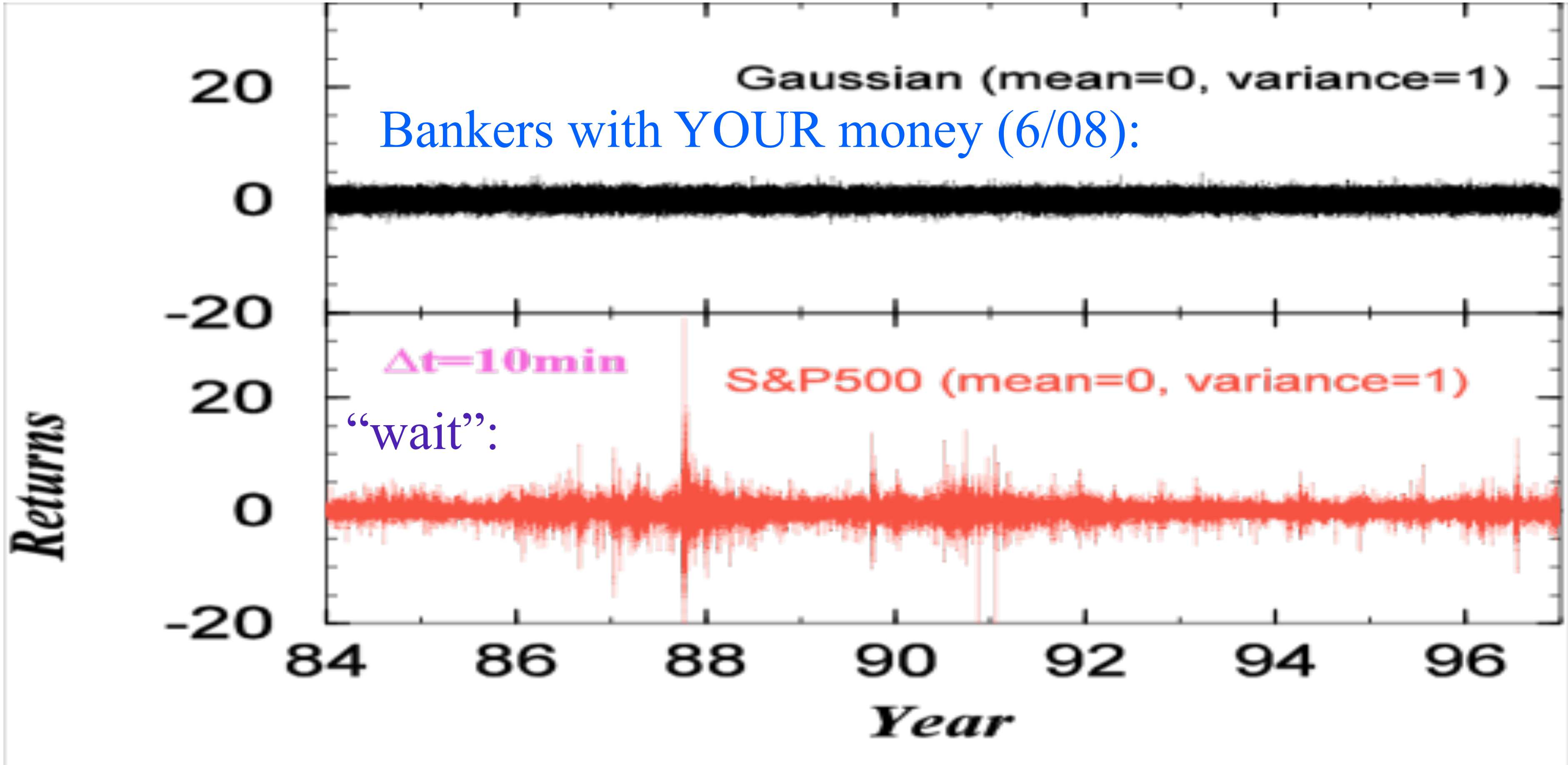
"Big switch" (???): 19 Oct. 1987 (25% worldwide "earthquake/tsunami")

BY EYE:

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

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

"Aftershocks" Omori-correlated (Lillo/Mantegna 03; Weber/Wang/Petersen/Havlin/HES 07)

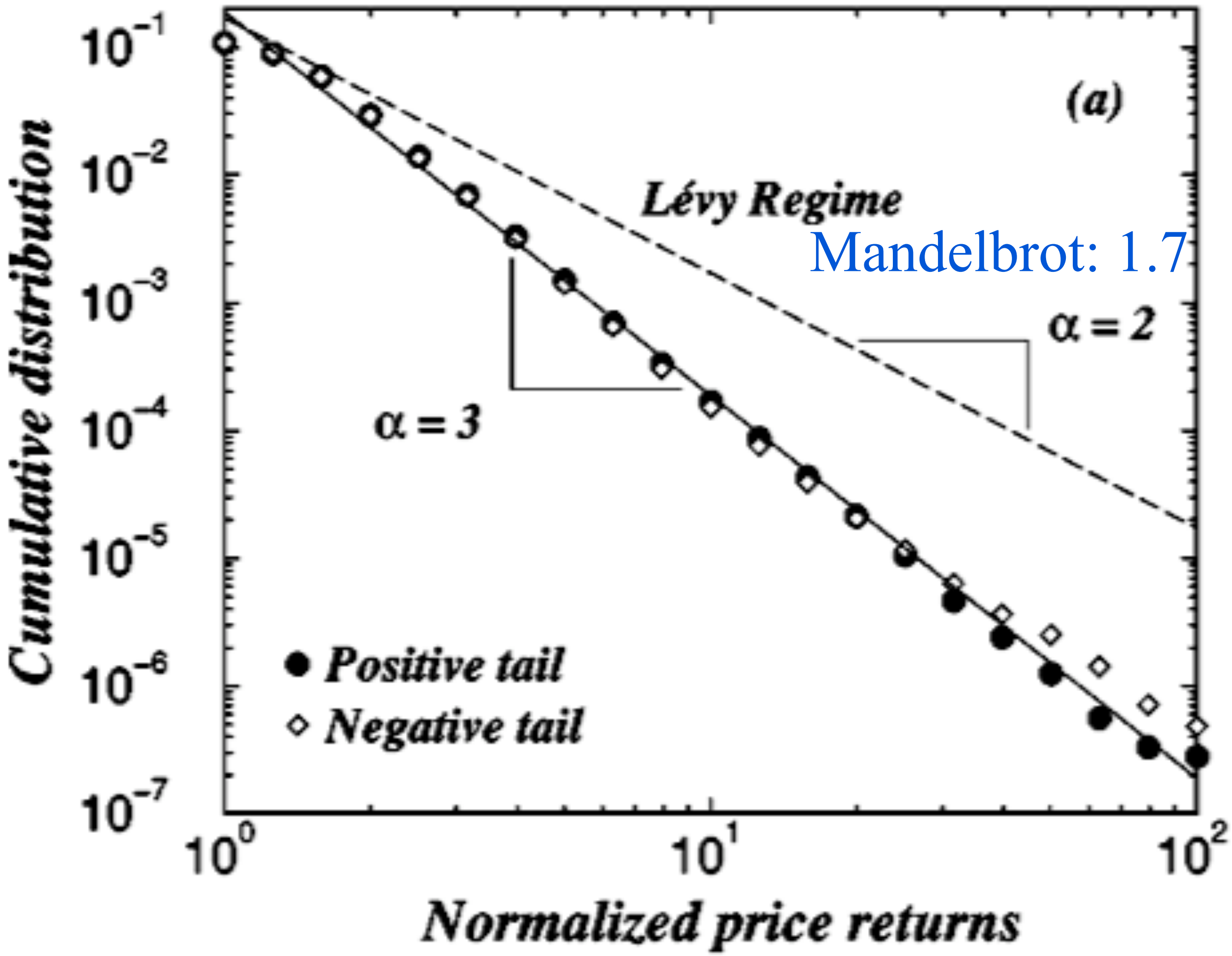


QUESTION: can your eye see the power law? that it is inverse cubic?

“Inverse cubic law” holds over 6 orders of magnitude on y-axis (8 for pdf: inverse quartic)

Gopikrishnan, Plerou, HES

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



Gutenberg-Richter earthquake law:
mag = 7 quake obeys same law as mag = 1 quake

200,000 data points per stock, 1000 stocks
Hence total of 200,000,000 data points

THANK YOU....

- broadbrush today....details in http://polymer.bu.edu/~hes/
- for details, google Gene Stanley....all papers are a 1-click pdf download