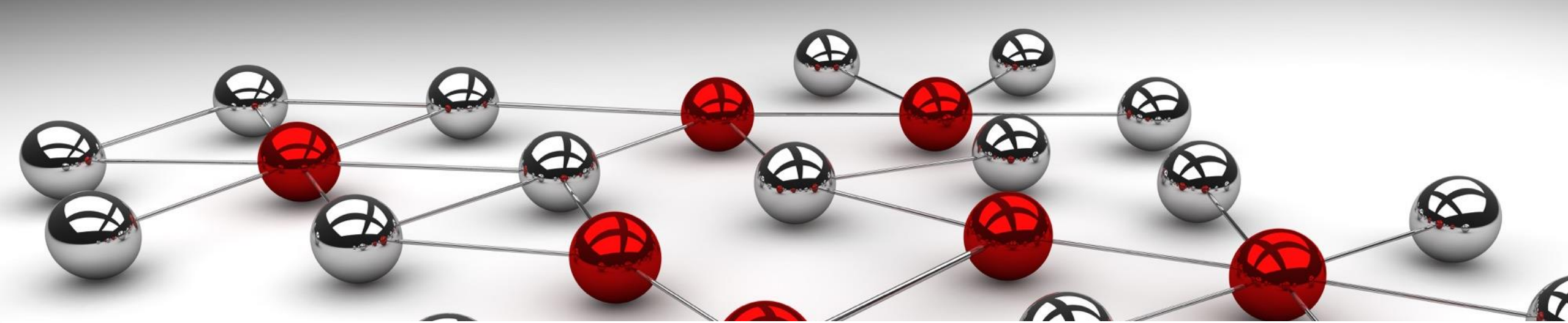


03 Regime Shifts and Tipping Points (Part I)

By NTU Complexity Institute

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Layman Definitions

Tipping point

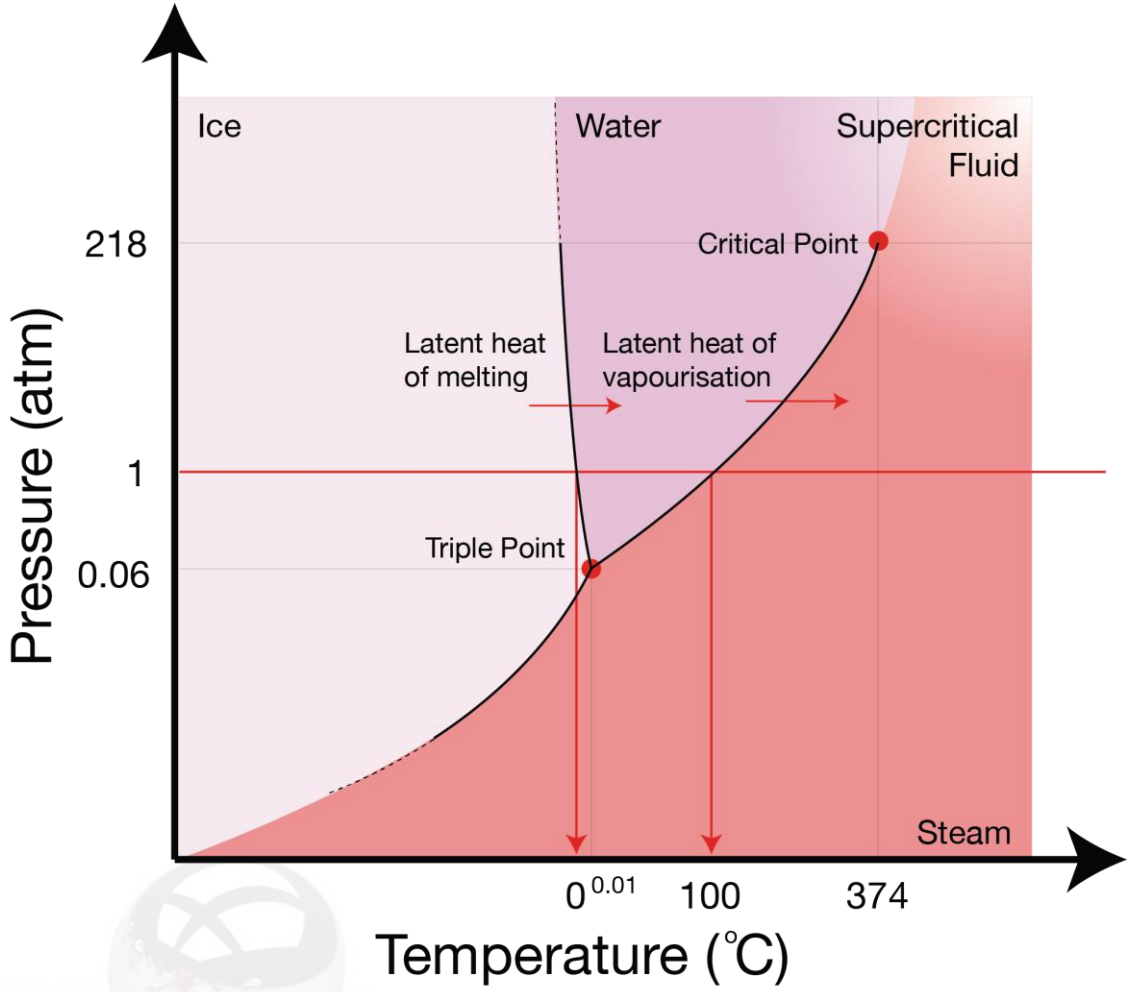
- Dictionary.com
  - the point at which an issue, idea, product, etc., crosses a certain threshold and gains significant momentum, triggered by some minor factor or change
  - the point in a situation at which a minor development precipitates a crisis
- Merriam-Webster
  - the critical point in a situation, process, or system beyond which a significant and often unstoppable effect or change takes place

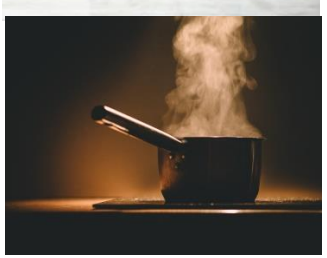
Sudden Change!

Nomenclature

- Physical science
  - Phase transitions
  - Critical transitions
- Ecological science
  - Regime shifts
  - Critical transitions
- Socio-economic science
  - Regime shifts
  - Regime switches

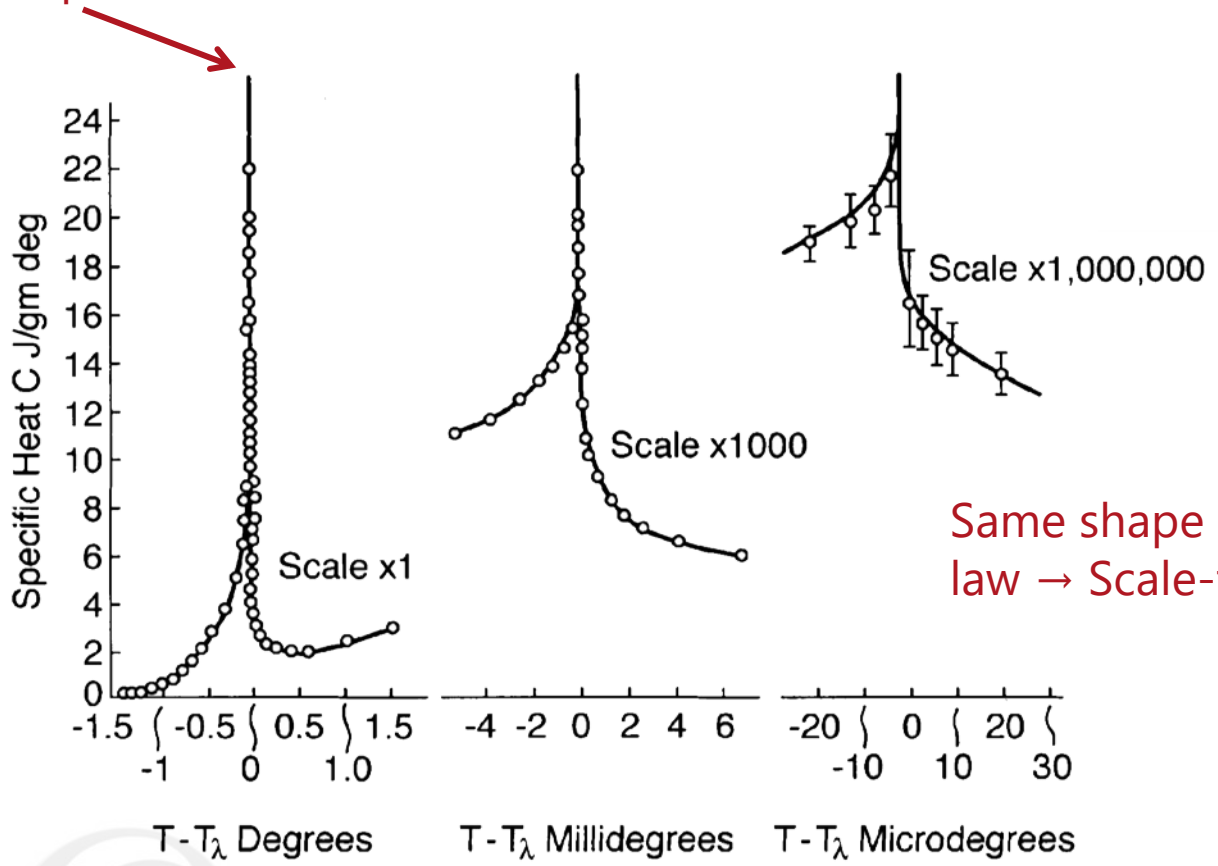
Phase Transitions





Criticality

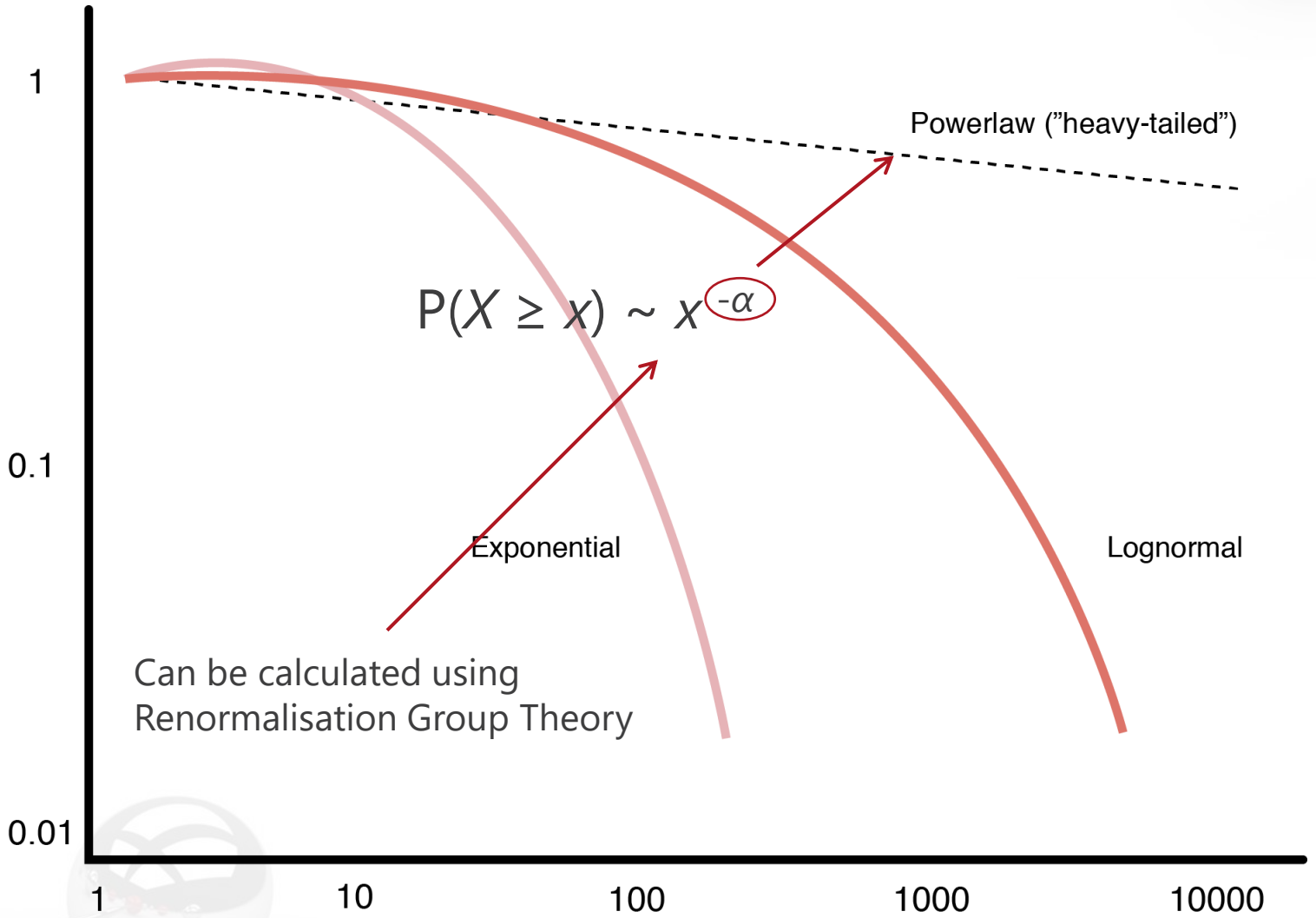
Diverge at critical temperature



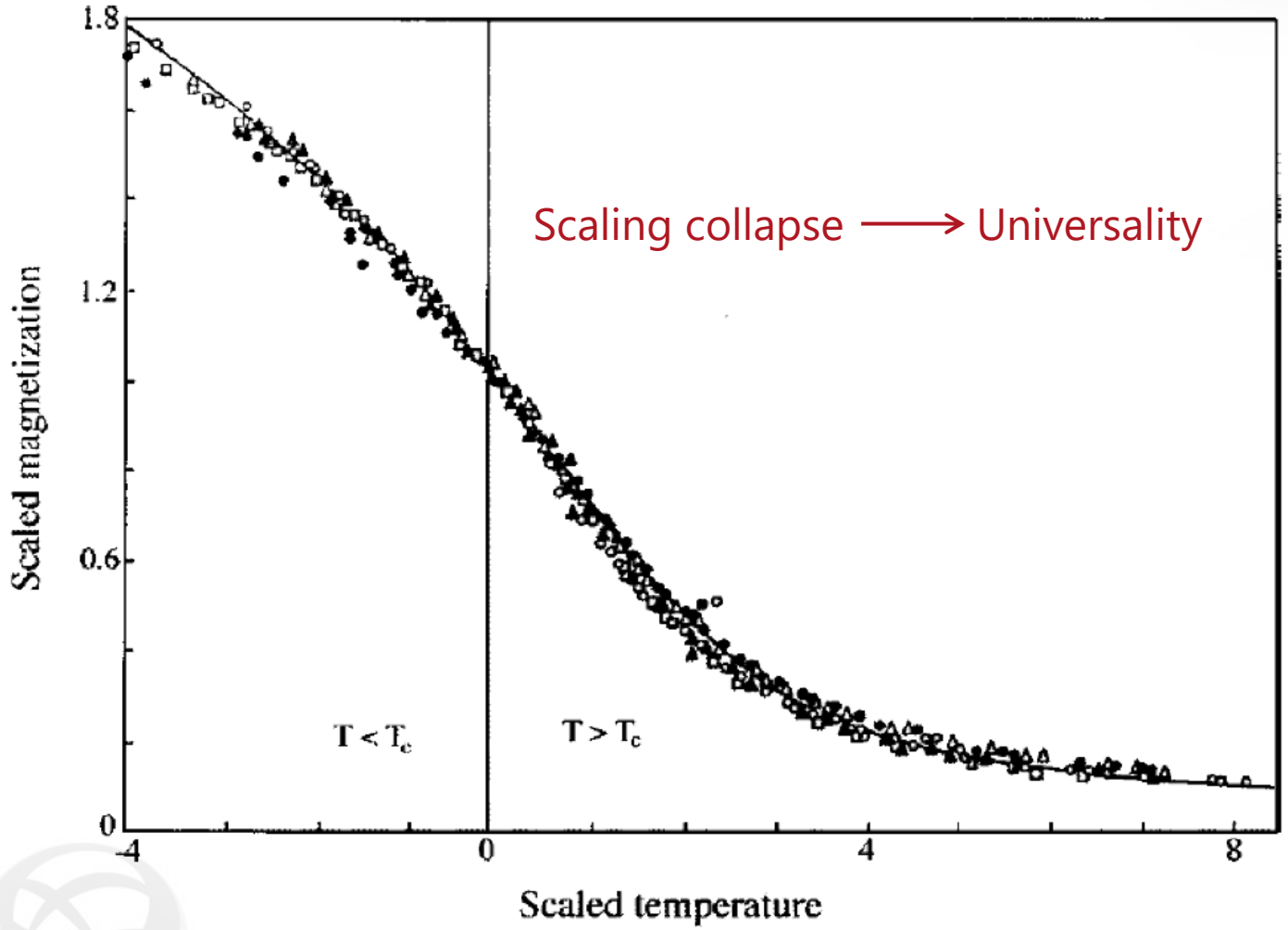
(U.S. Patent No. US 20050229609 A1, 2005)

Same shape at different scale → Power law → Scale-free

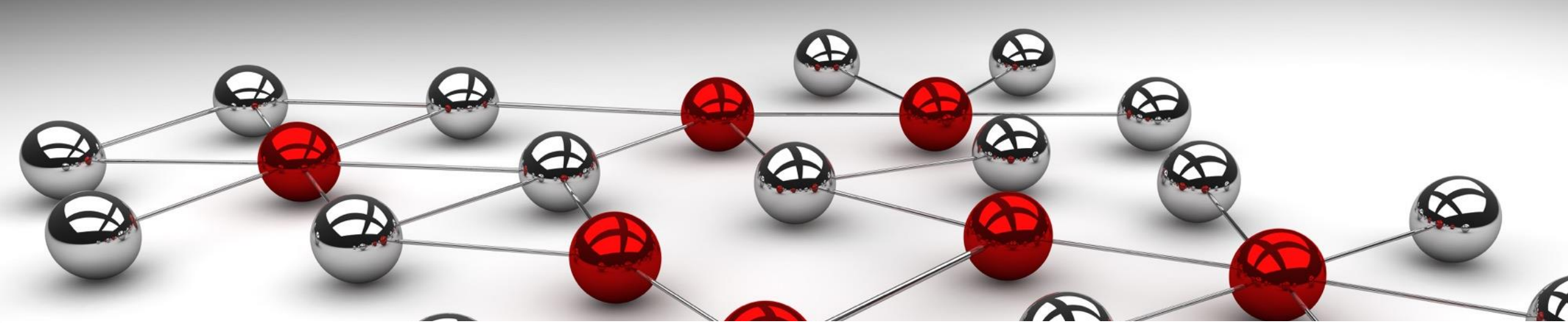
Criticality



Criticality



Retrieved from "Three pillars of modern critical phenomena" (doi:10.1103/RevModPhys.71.S35). Copyright 1999 by The American Physical Society. Reproduced with permission.



03 Regime Shifts and Tipping Points (Part II)

By NTU Complexity Institute

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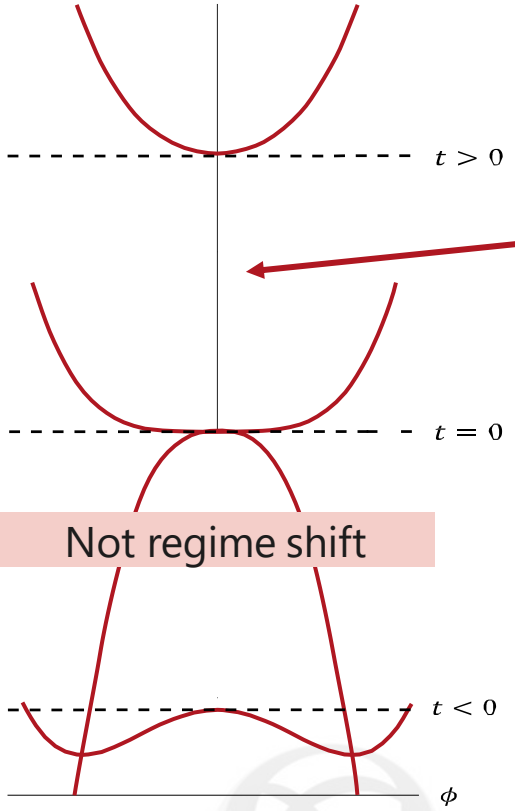
Landau Theory

$$F(\phi) = F_0 + \frac{t}{2!}\phi^2 + \frac{1}{4!}\phi^4$$

Landau free energy

$$F(\phi) = F_0 + h\,\phi + \frac{t}{2!}\phi^2 + \frac{1}{4!}\phi^4$$

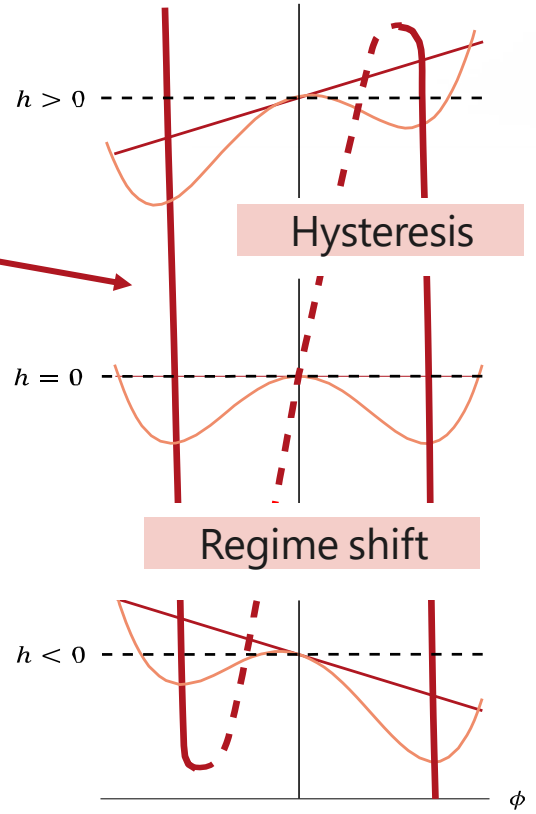


Not regime shift

Second-order phase transition

Fixed points

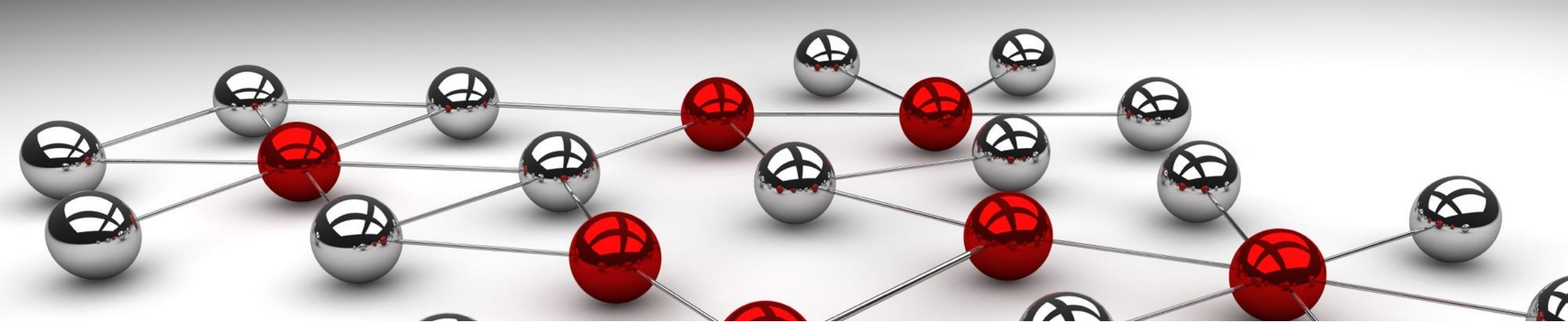
Bifurcation diagram



Hysteresis

Regime shift

First-order phase transition



03 Regime Shifts and Tipping Points (Part III)

By NTU Complexity Institute

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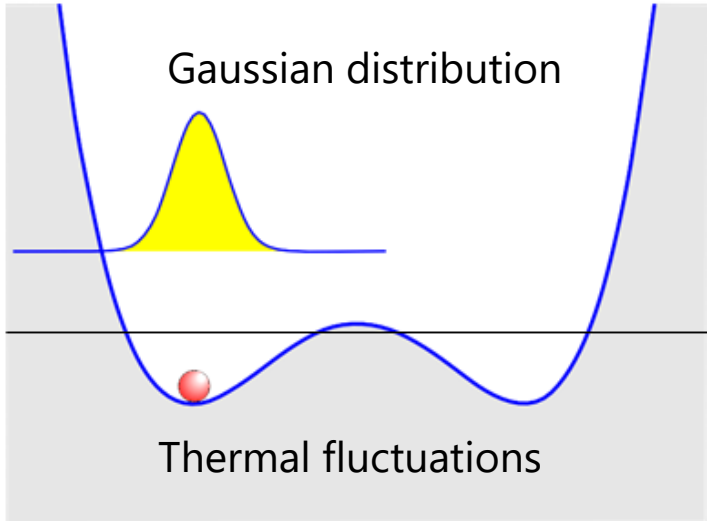
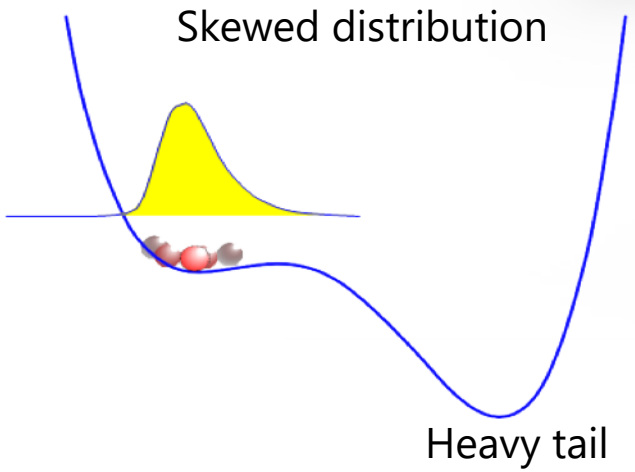
Universal Early Warning



- Finite variance
- Finite relaxation time



- Power-law tail at tipping point
- Variance → ∞

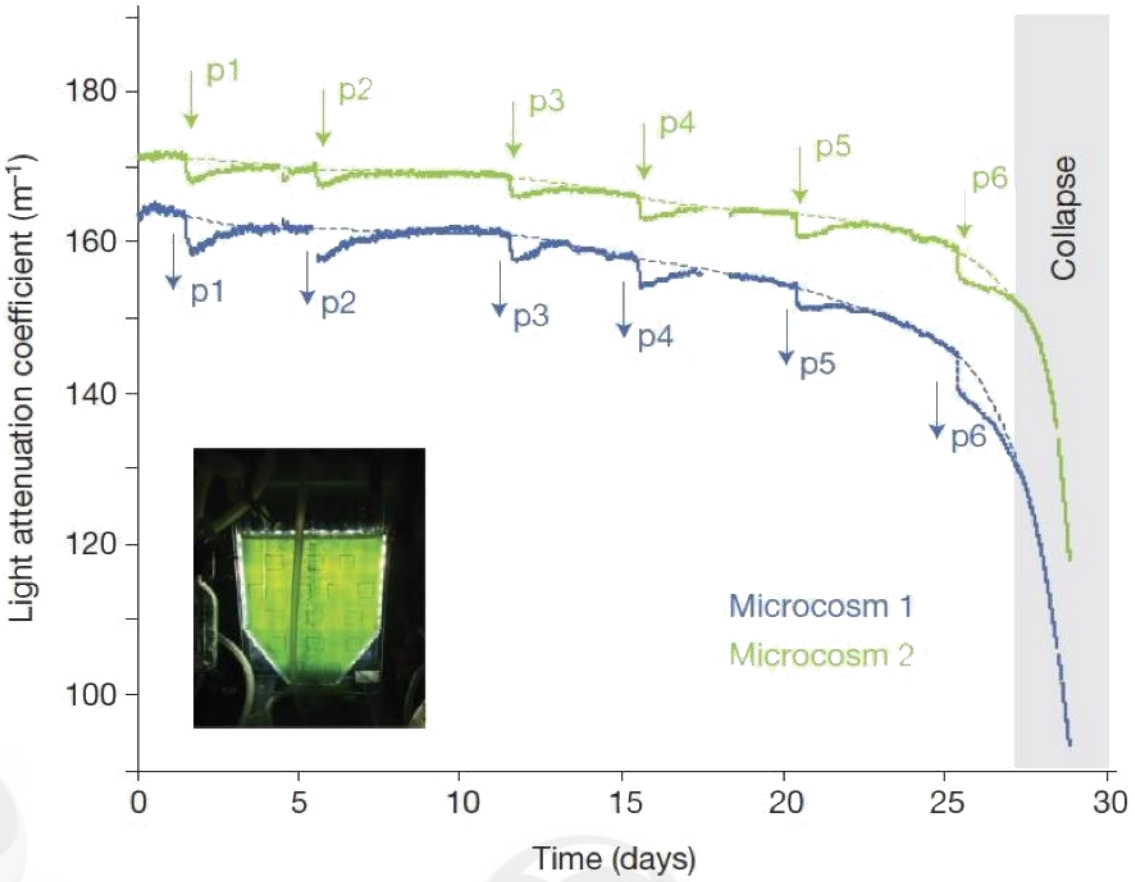
Critical Fluctuations

- Relaxation time → ∞

Critical slowing down

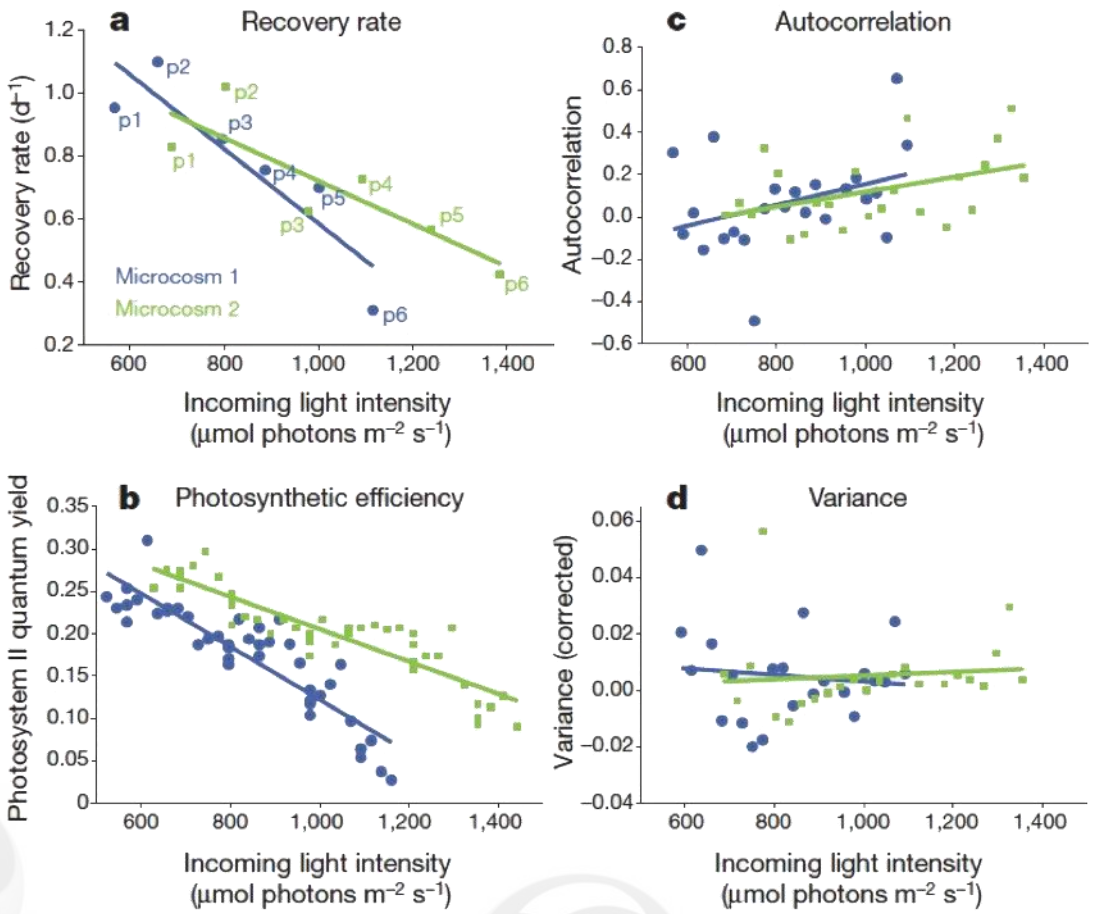
- Growing autocorrelation, spectral reddening

Slow Recovery



- Cyanobacteria in controlled chemostat microcosm
- Light intensity slowly increased until population collapse
- 10% dilution perturbation every four to five days
- Measure recovery rate

Slow Recovery



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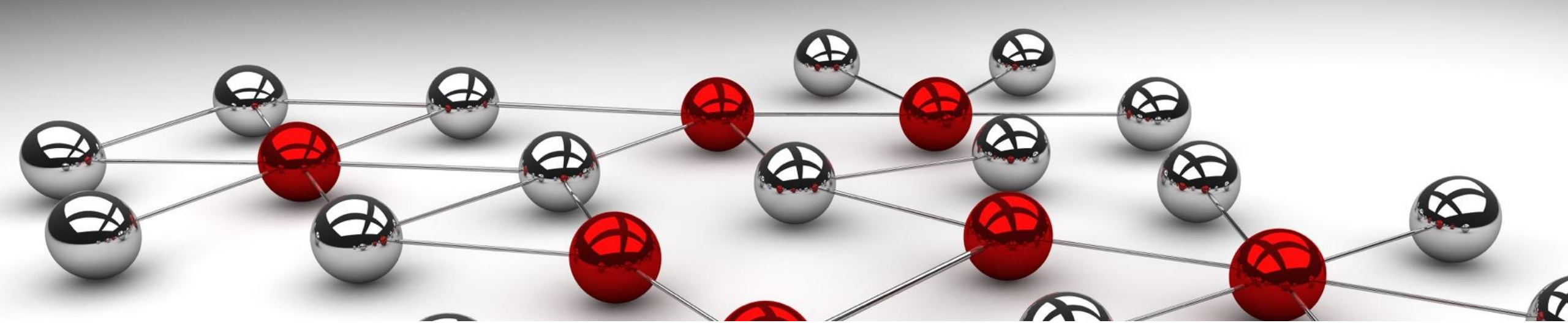
- Measure recovery rate



03 Regime Shifts and Tipping Points (Part IV)

By NTU Complexity Institute

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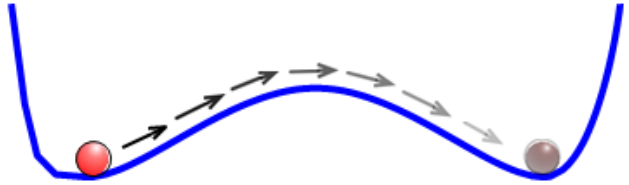
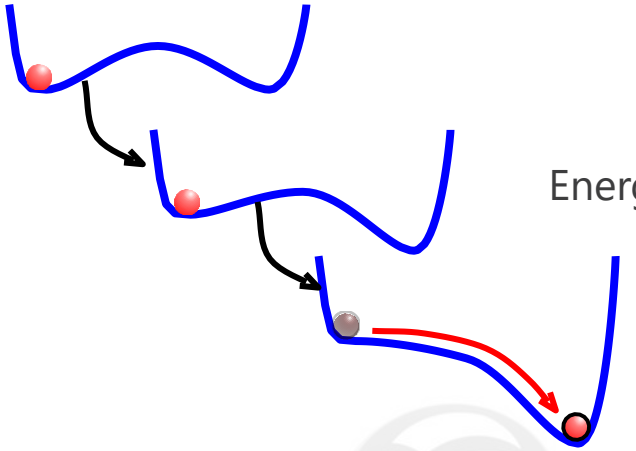
Equilibrium vs Critical Transitions



Equilibrium transition
(noise-driven)

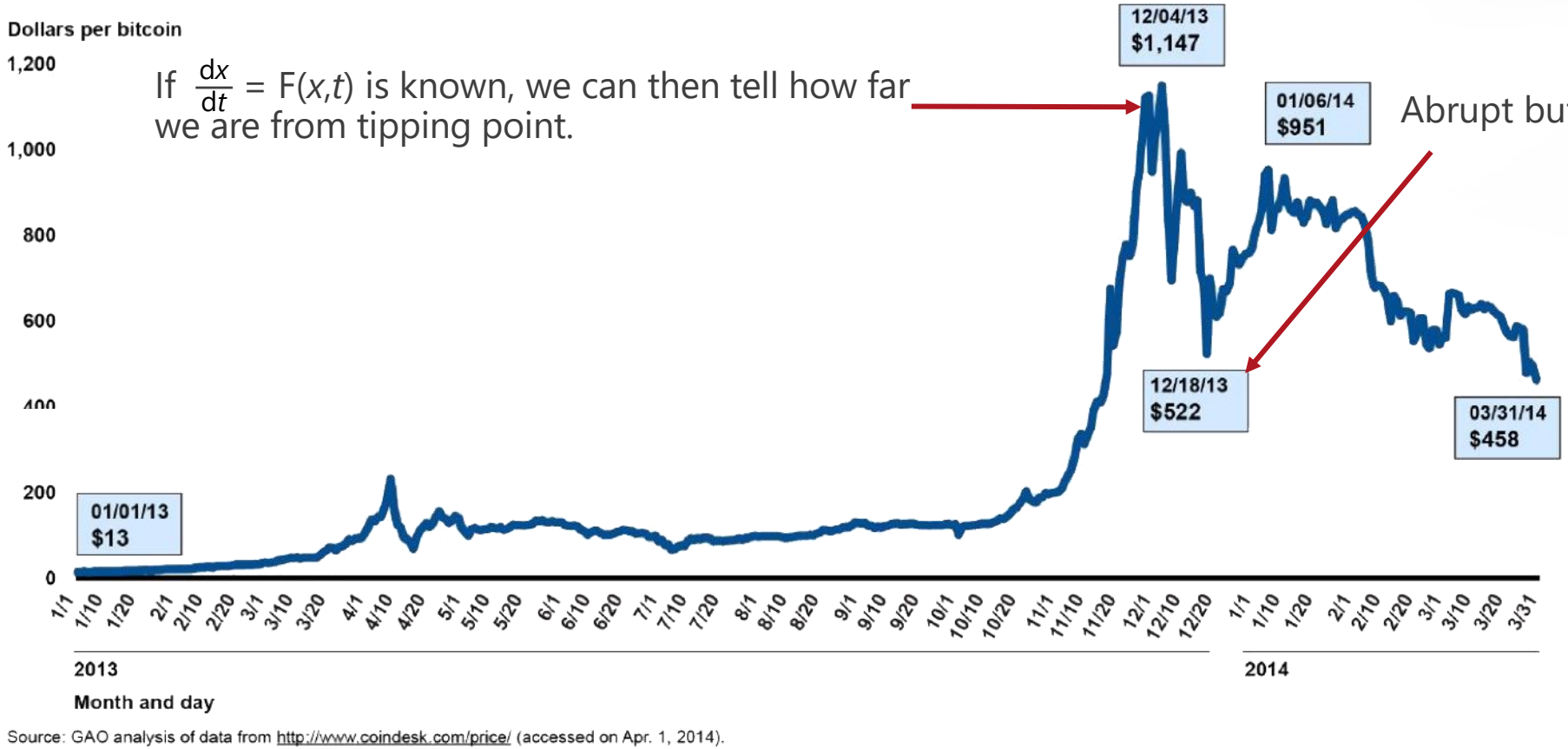


Critical transition (control-parameter-driven)

- Equilibrium transition can occur before tipping point is reached. This can be confusing!

Forecasting Regime Shifts

If $\frac{dx}{dt} = F(x,t)$ is known, we can then tell how far we are from tipping point.



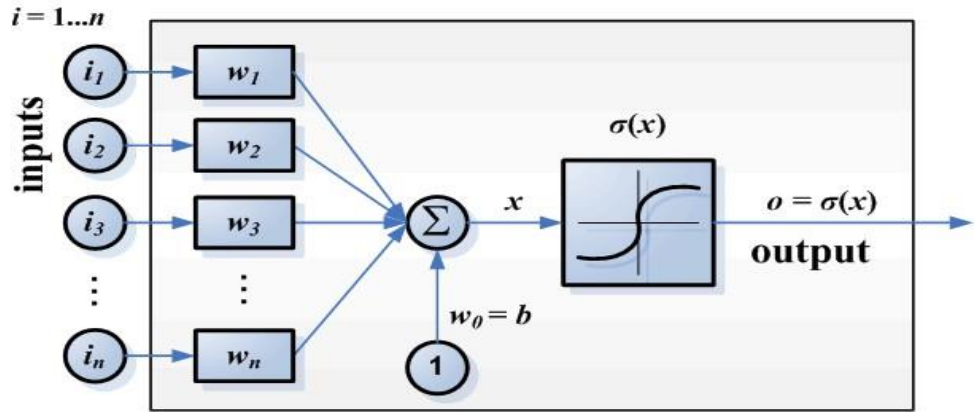
Source: GAO analysis of data from http://www.coindesk.com/price/ (accessed on Apr. 1, 2014).

Abrupt but can be forecasted

AR models $x_{t+1} = \sum_{r=1}^{p} a_r x_{t-r} + \epsilon_t$ Jump diffusion models

Forecasting Regime Shifts

ANN



Not regime-shift-aware!

Technical trading

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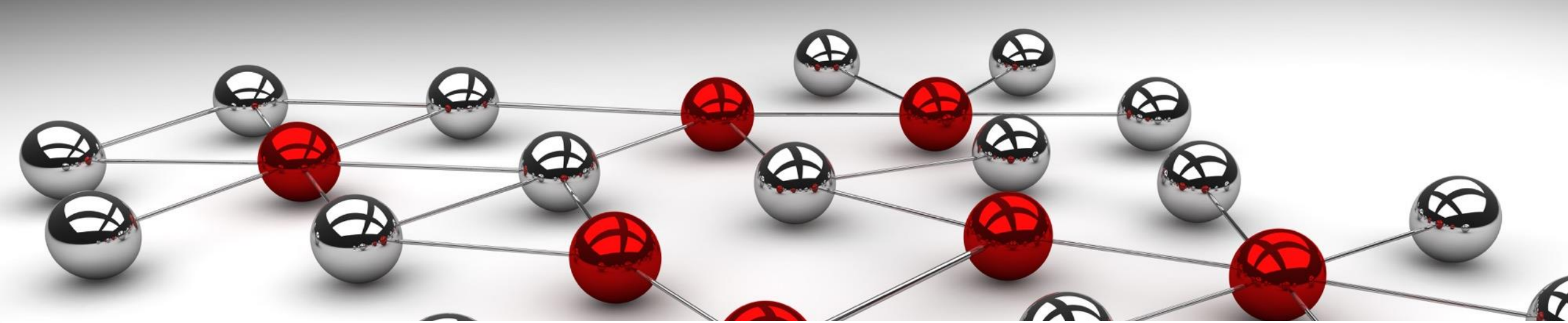


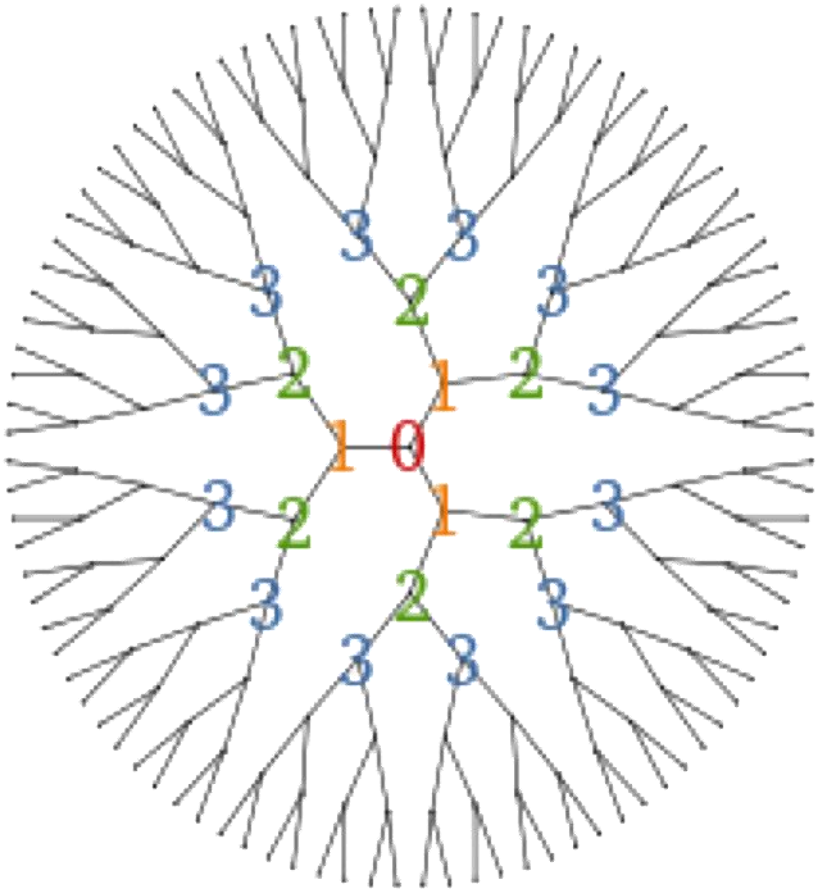
03 Regime Shifts and Tipping Points (Part V)

By NTU Complexity Institute

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

Professor Didier Sornette, ETH Zurich

Log-Periodic Power Law (LPPL)

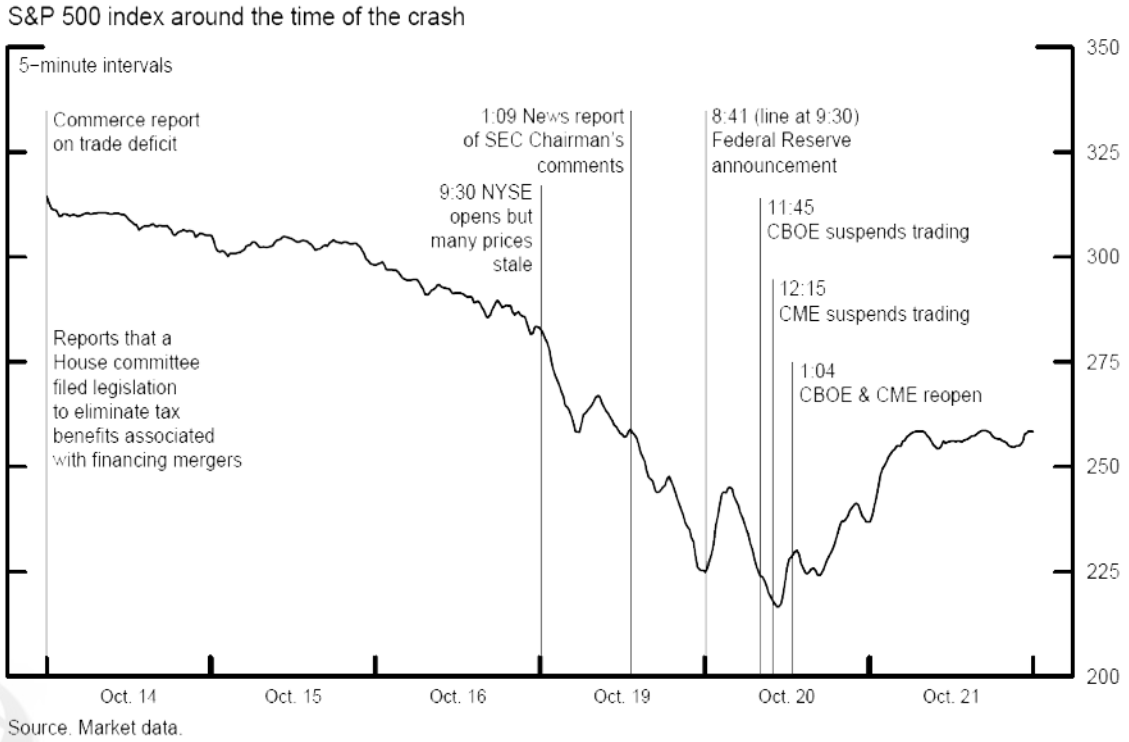


Bethe Lattice

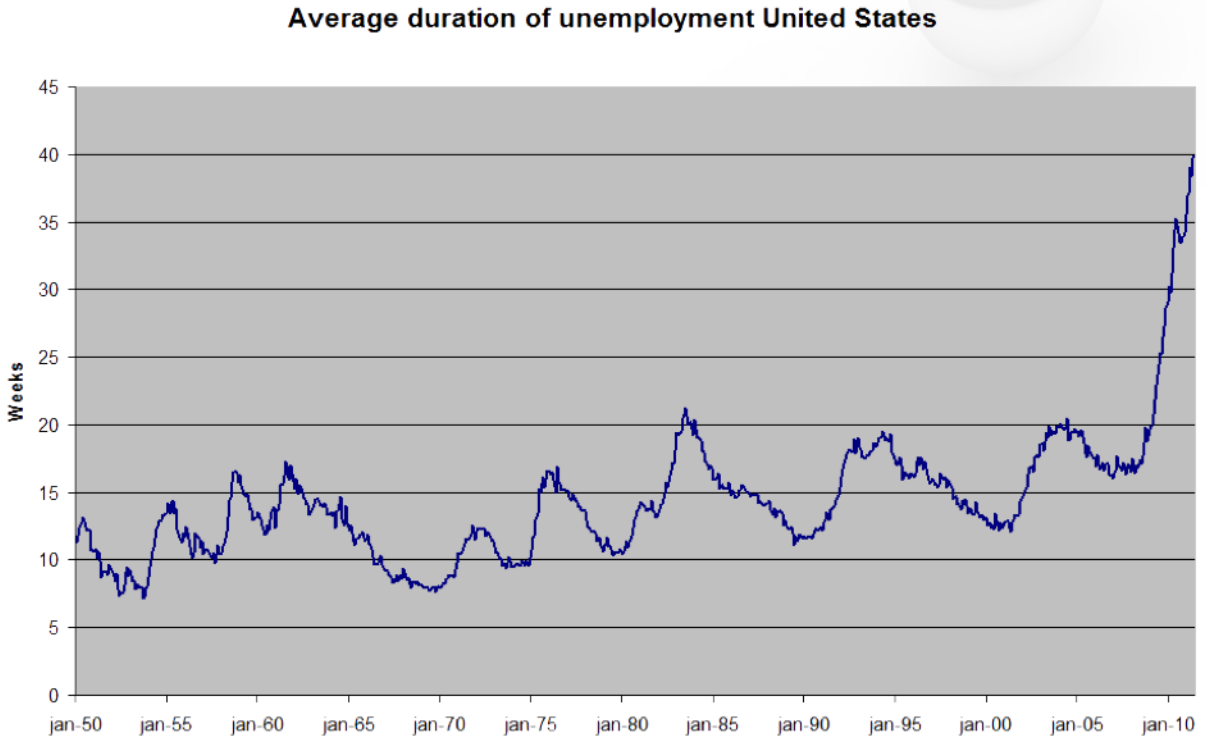
Discrete Scale Invariance

$$I(t) = A + B(t_c - t)^a + C(t_c - t)^a \cos\left[w(t_c - t) + \Phi\right]$$

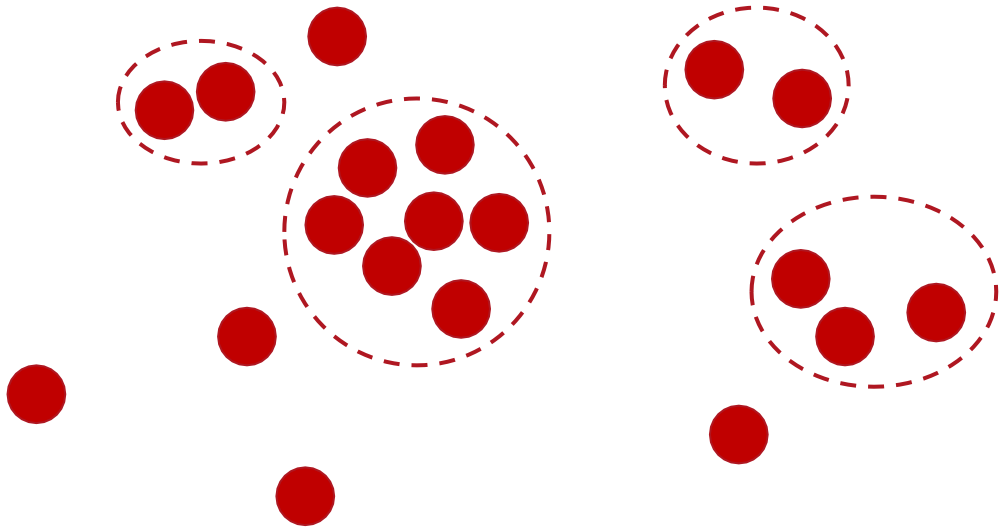
Log-Periodic Power Law (LPPL)



Black Monday, 1987



Soup-of-Groups (SOG) Model



ν_{frag} ν_{coal}

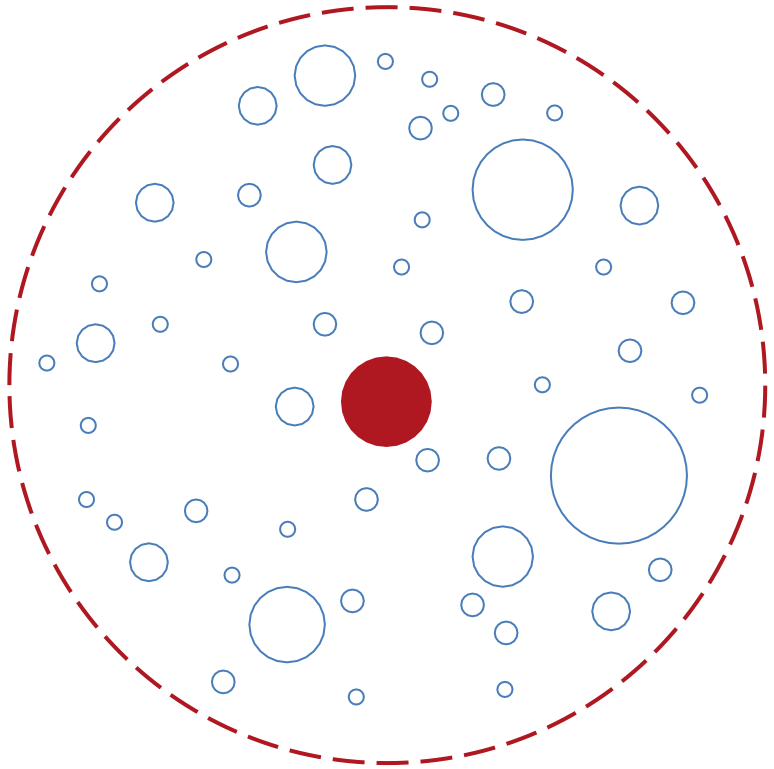
$$\frac{\partial n_s}{\partial t} = \frac{\nu_{\text{coal}}}{N^2}\sum_{k=1}^{s-1} k n_k (s-k) n_{s-k} - \frac{\nu_{\text{frag}} s n_s}{N} - \frac{2\nu_{\text{coal}} s n_s}{N^2}\sum_{k=1}^{\infty} k n_k, \quad s \geq 2,$$

$$\frac{\partial n_1}{\partial t} = \frac{\nu_{\text{frag}}}{N}\sum_{k=2}^{\infty} k^2 n_k - \frac{2\nu_{\text{coal}} n_1}{N^2}\sum_{k=1}^{\infty} k n_k,$$

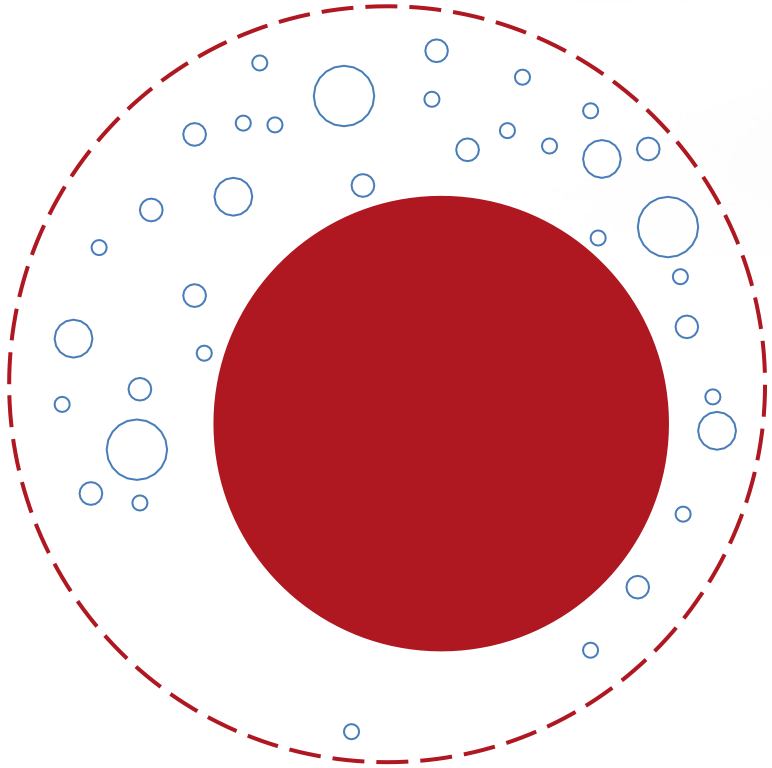
$p(s) \sim s^{-5/2}$ → 2 for $d = 2$ Gutenberg-Richter law!

Bohorquez, Gourley, Dixon, Spagat and Johnson. (2009). *Nature, 462*(911)
Johnson, Ashkenazi, Zhao and Quiroga. (2011). *AIP Advances, 1*(012114)

Growth of Giant Cluster

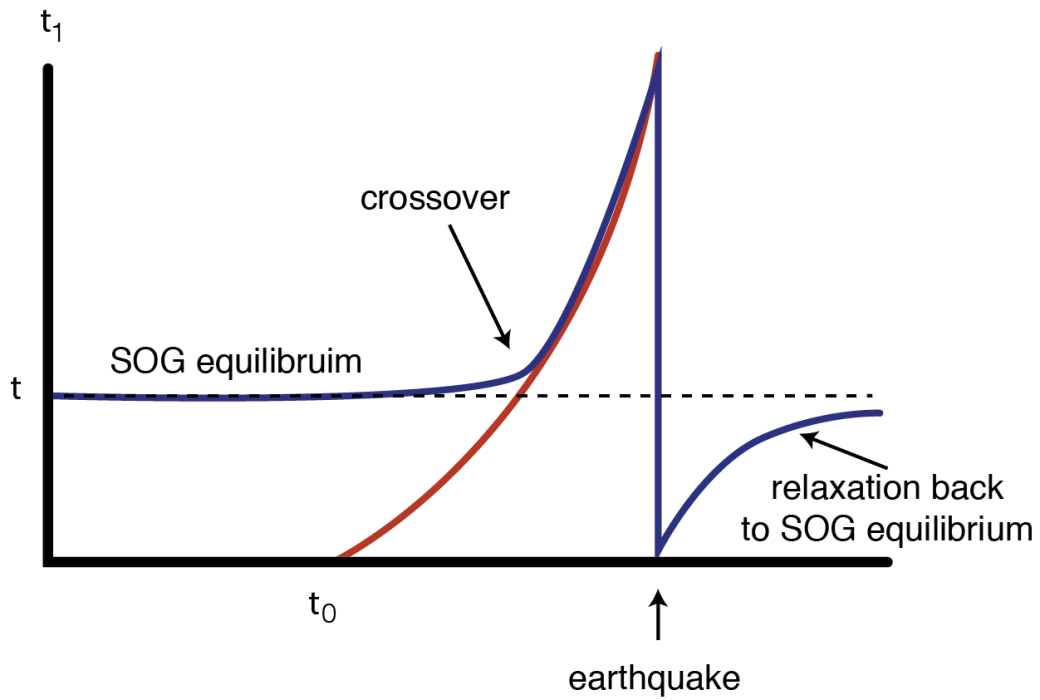


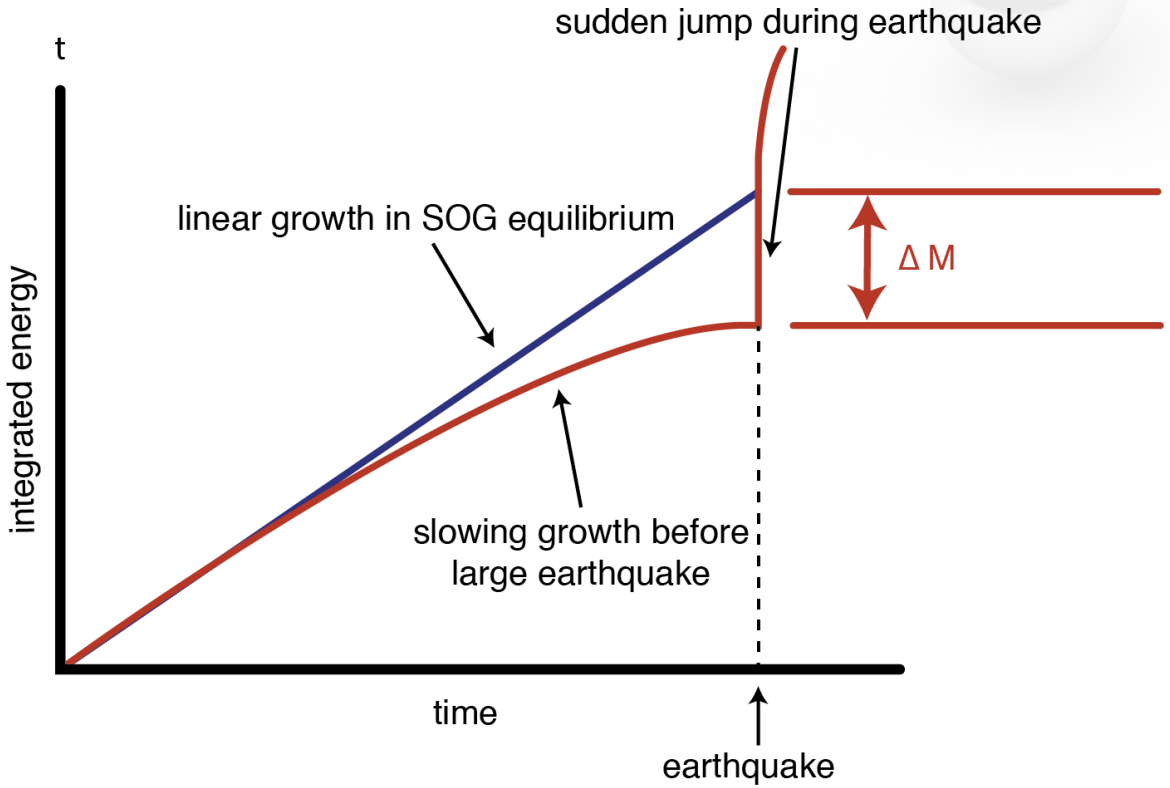
No giant cluster
Equilibrium distribution of cluster sizes
GR law



Giant cluster, resulting in fewer clusters of all sizes
Departure from GR law

Growth of Giant Cluster





Growth of Giant Cluster

Mean Field Theory

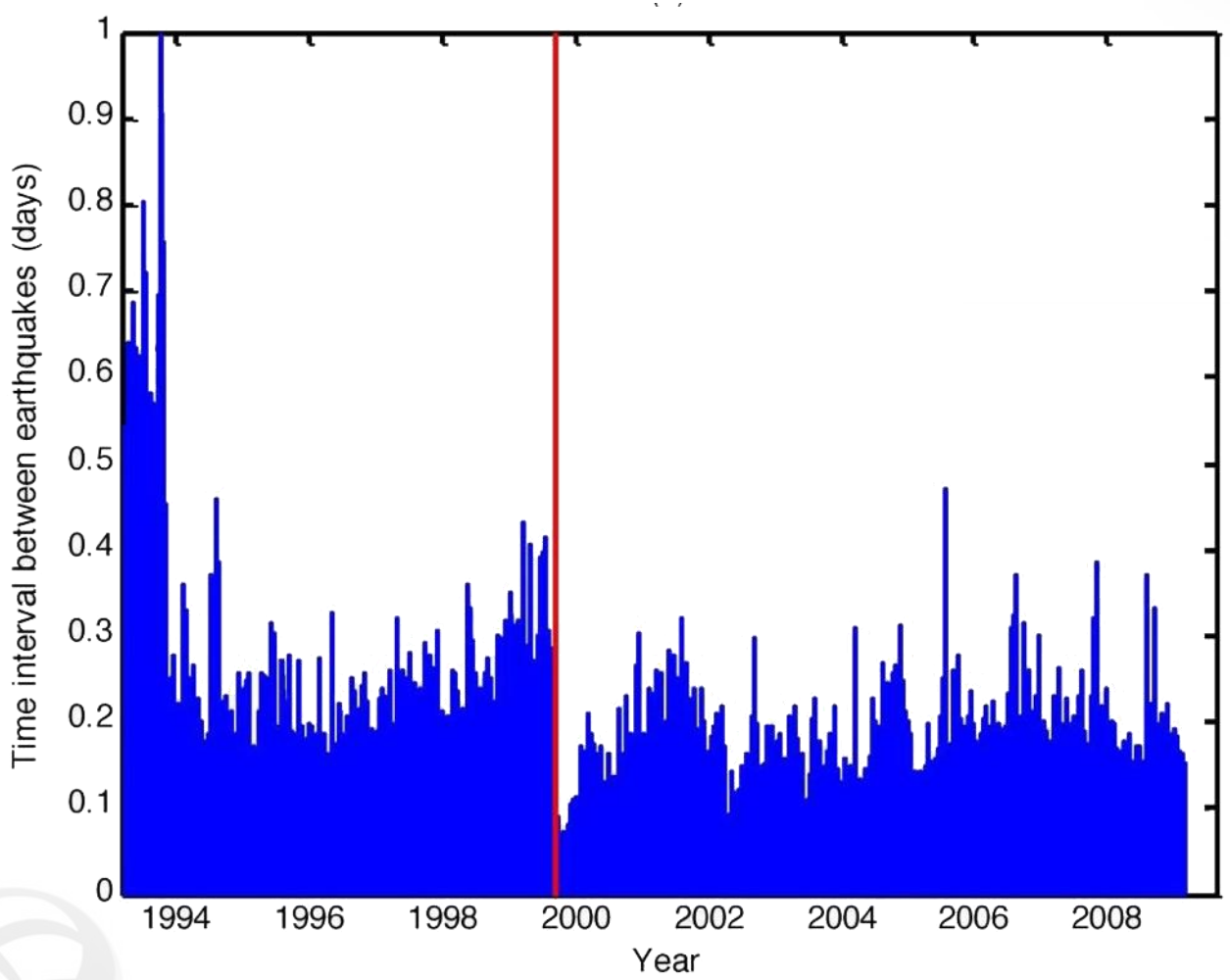
$$E(t) = \int_0^t \int_{m_0}^{\log_{10}(S_0 - \gamma t)} 10^m R(m) dm\, dt'$$

linear growth

GR law

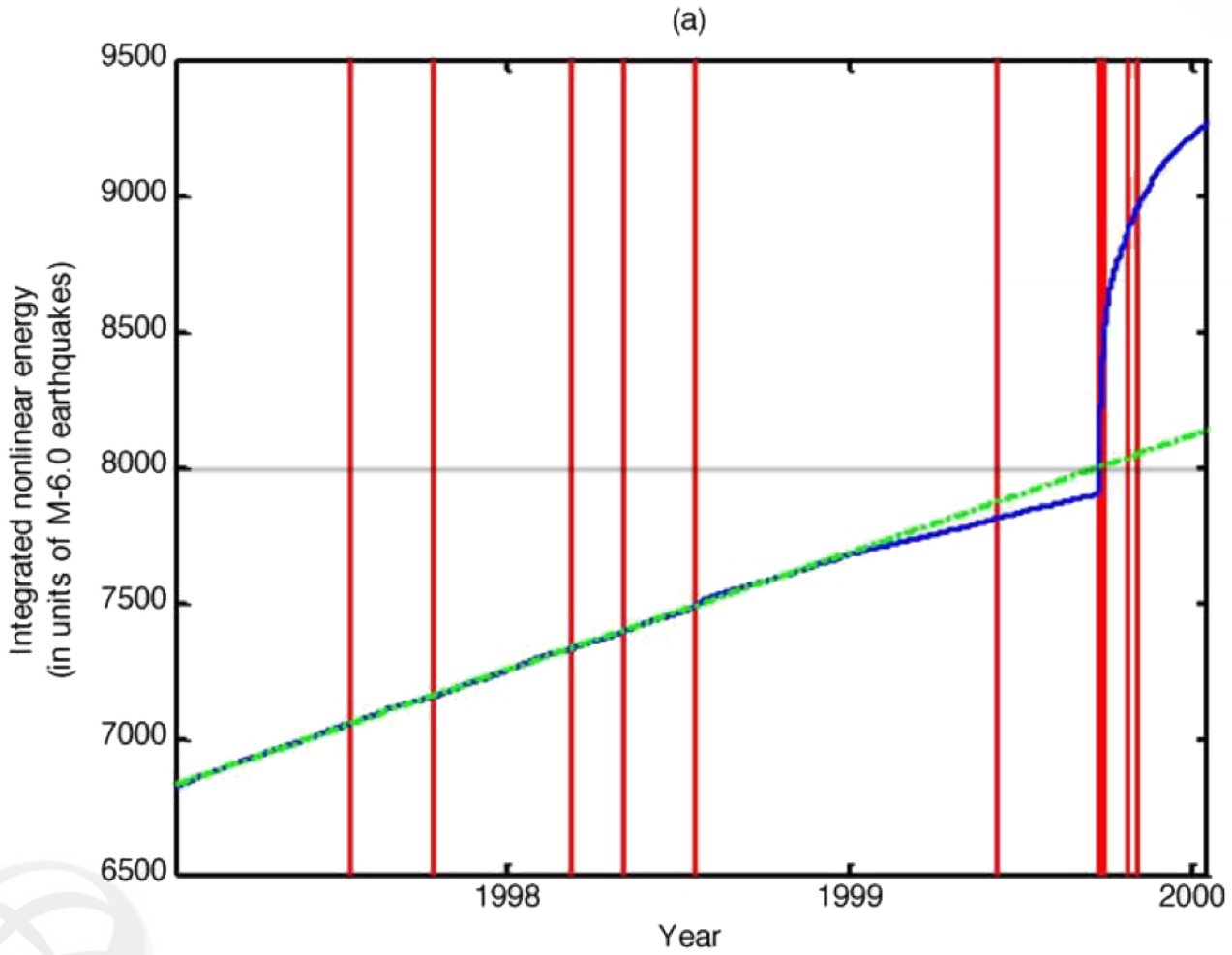
$$= At\left(\log_{10}\frac{S_0 - \gamma t}{s_0} - 1\right) - \frac{AS_0}{\gamma}\log_{10}\frac{S_0 - \gamma t}{S_0}$$

Sep 1999 Chi-Chi Earthquake



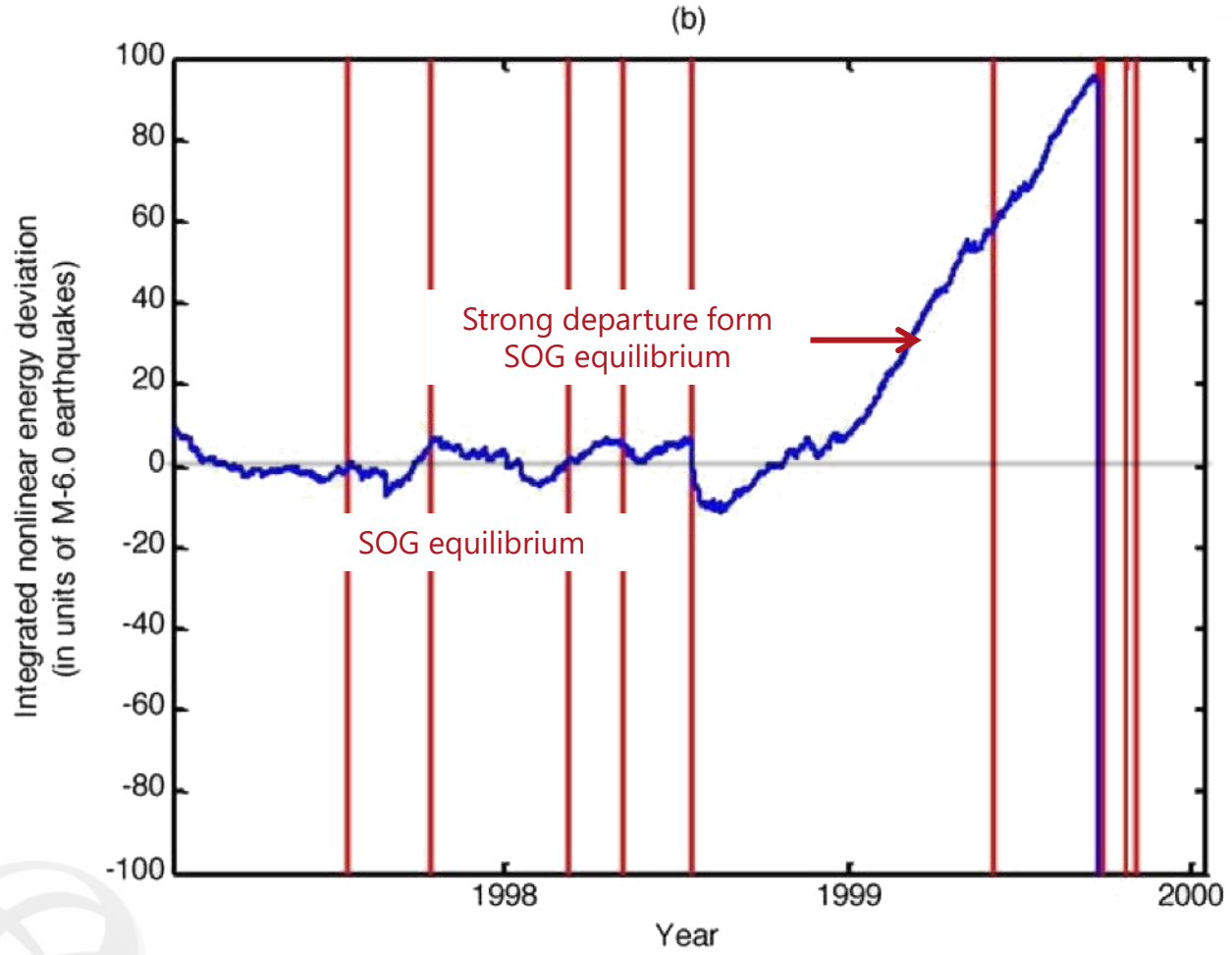
Cheong et al. (2014). *Scientific Reports, 4*, 3624.

Sep 1999 Chi-Chi Earthquake



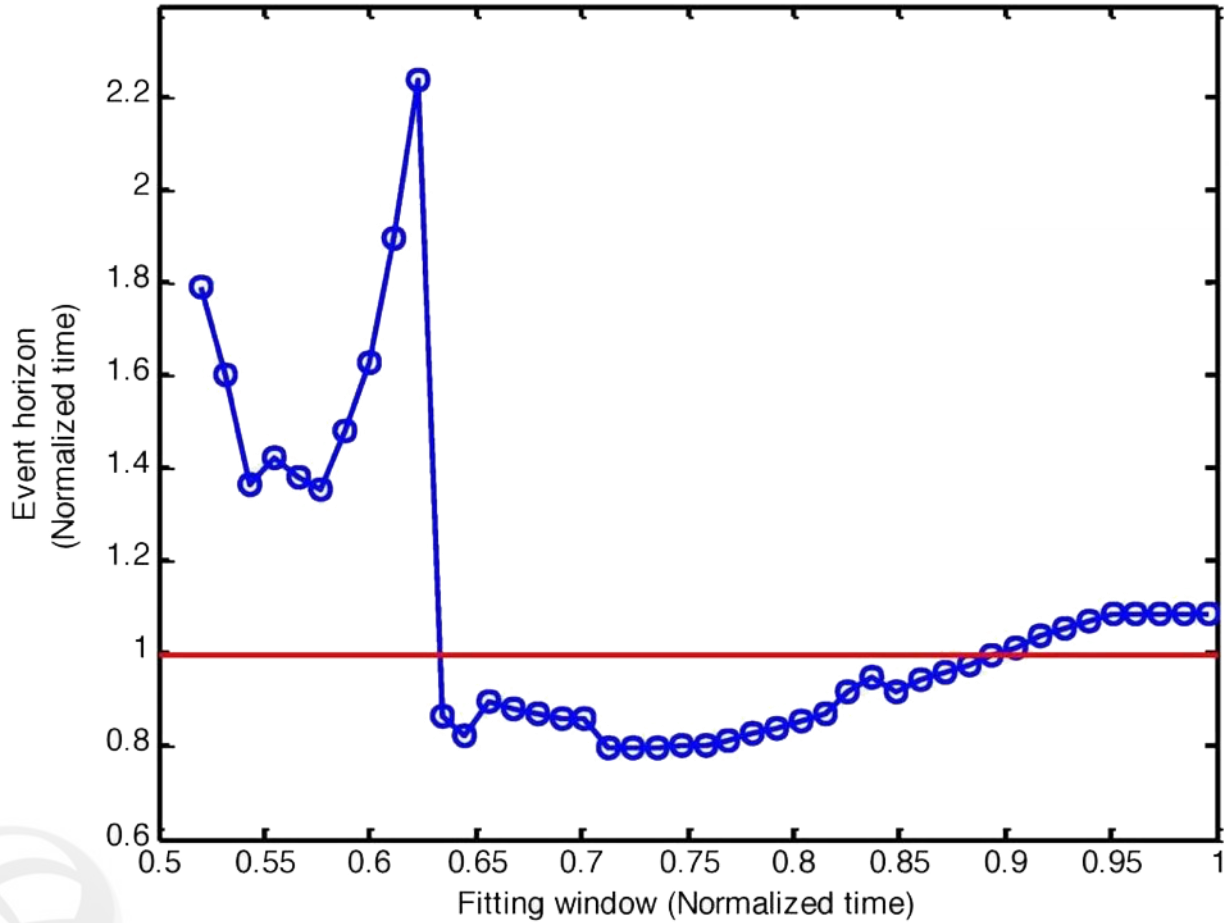
Cheong et al. (2014). *Scientific Reports, 4*, 3624.

Sep 1999 Chi-Chi Earthquake



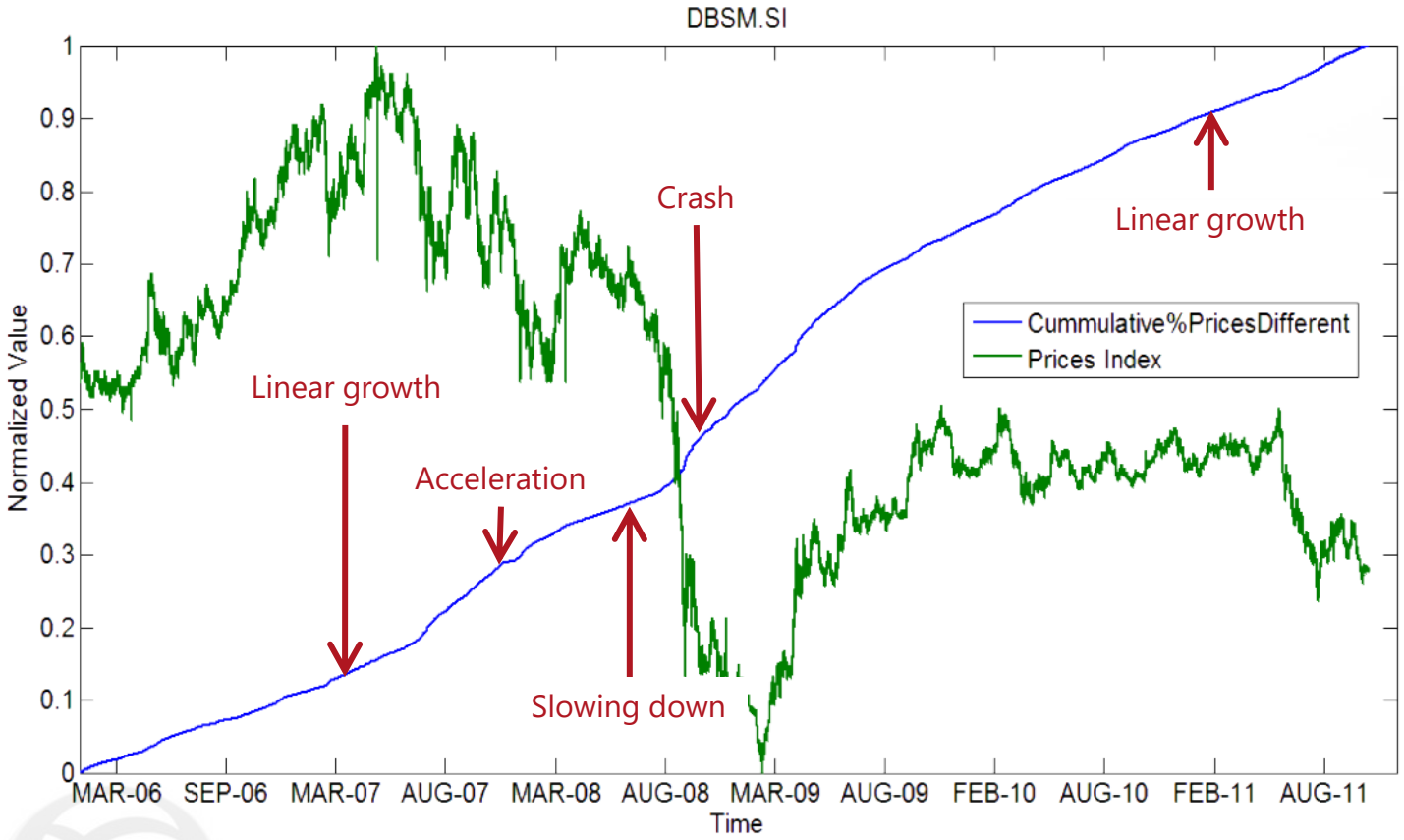
Cheong et al. (2014). *Scientific Reports, 4*, 3624.

Sep 1999 Chi-Chi Earthquake

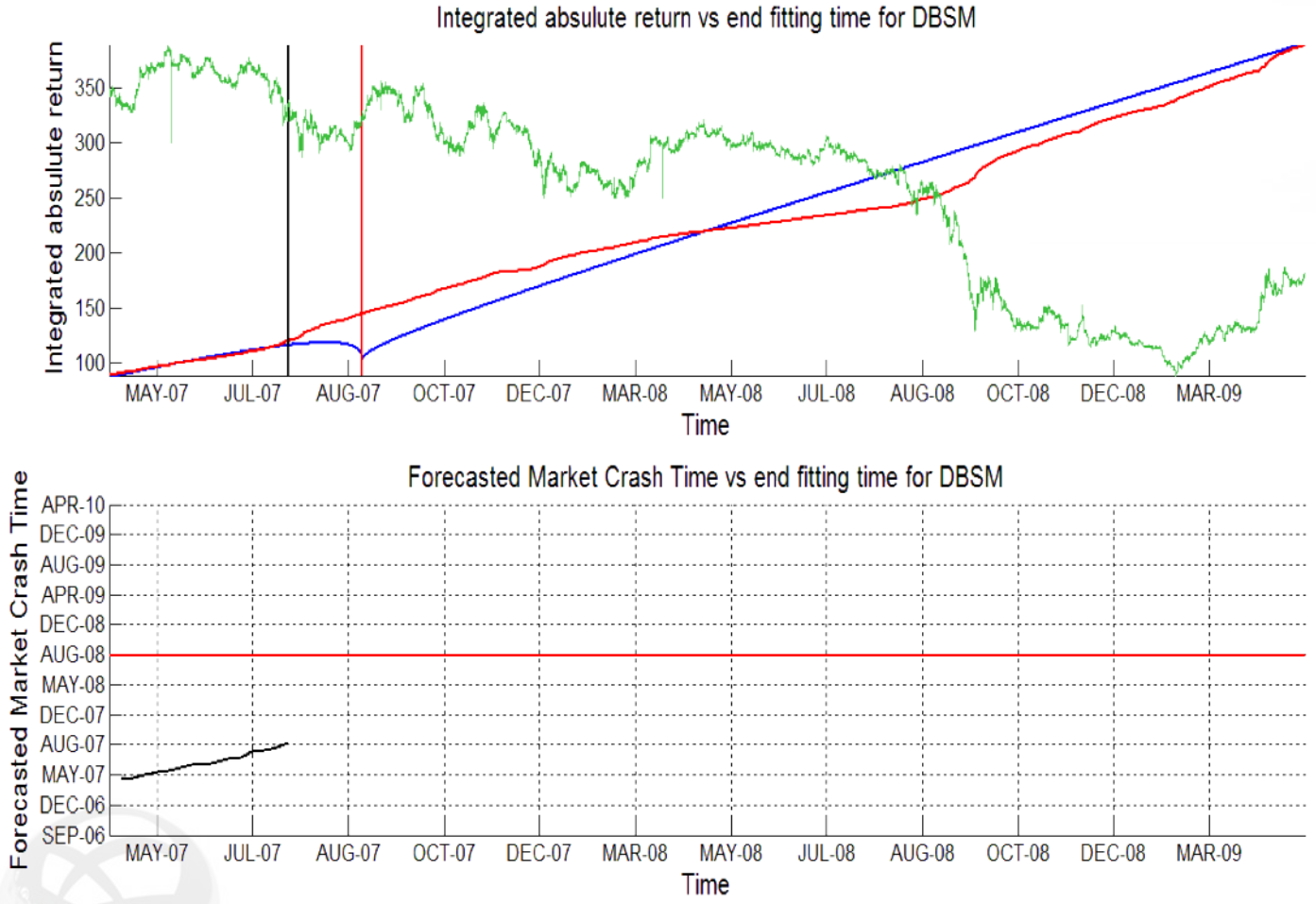


Cheong et al. (2014). *Scientific Reports, 4*, 3624.

Oct 2008 SGX Crash: Precursors

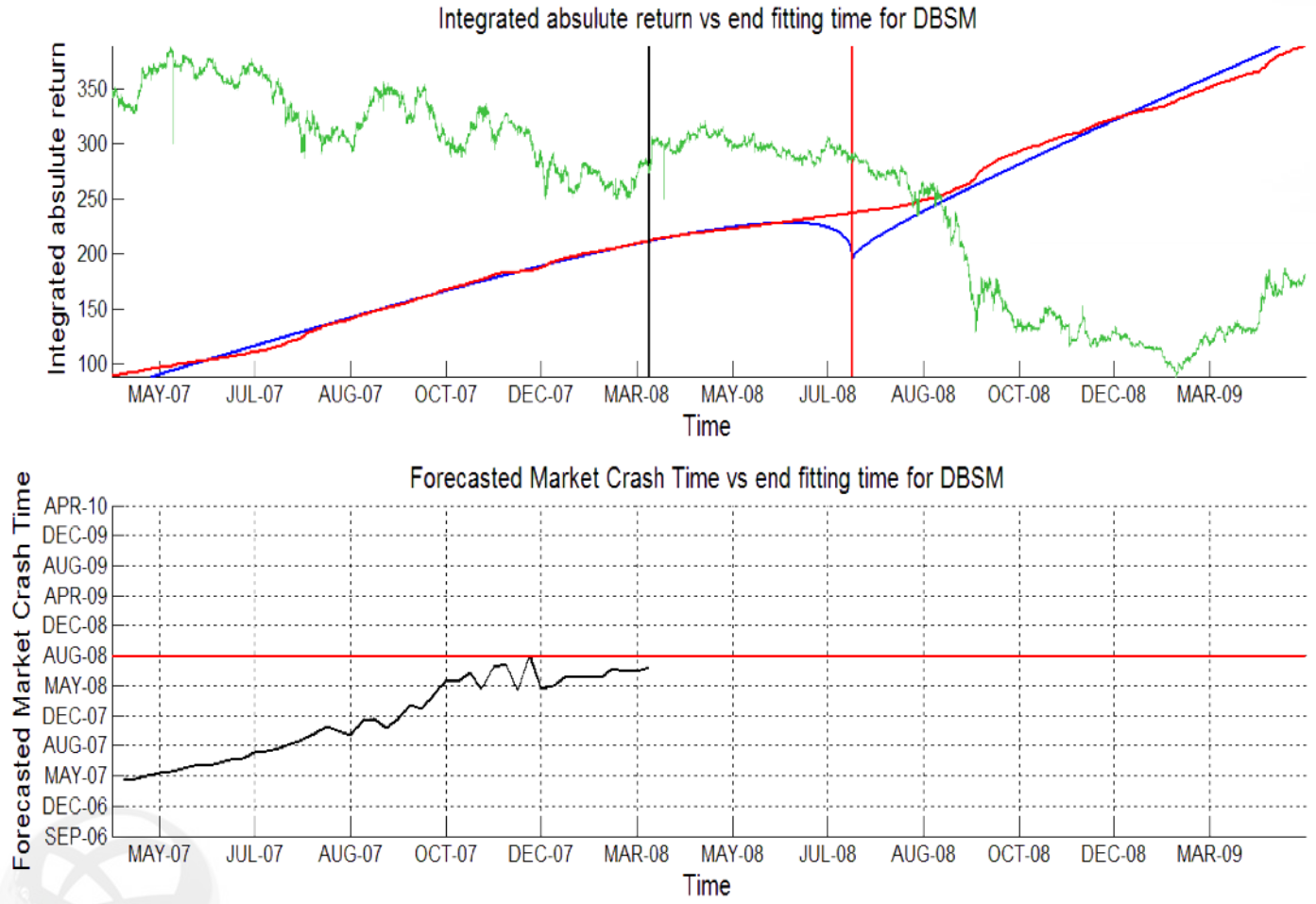


Oct 2008 SGX Crash: Prediction



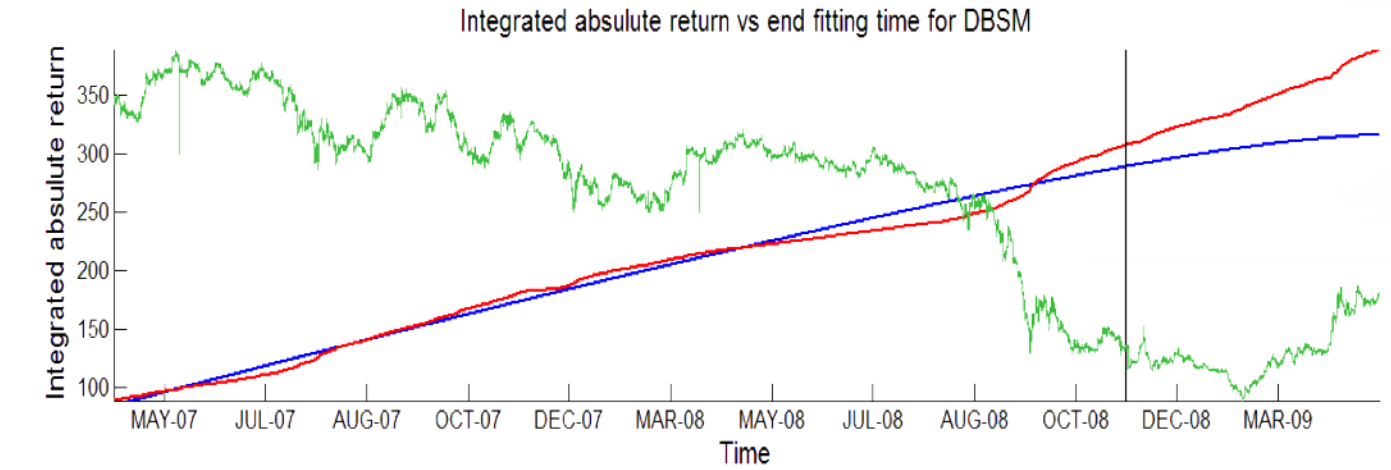
Adapted from Teh and Cheong. (2016). *PLoS ONE 11*(10), e0163842.

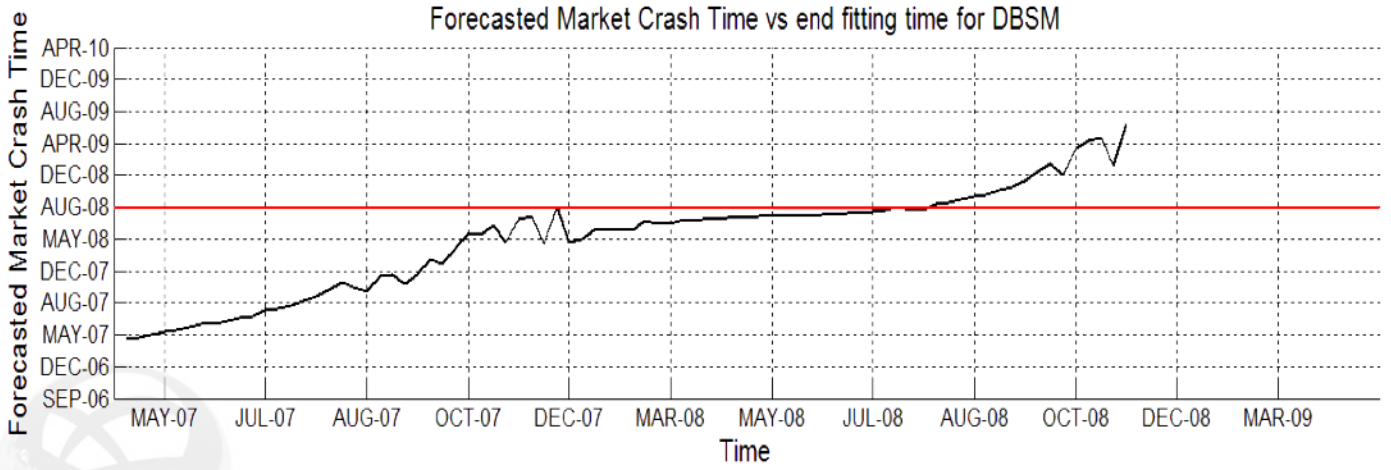
Oct 2008 SGX Crash: Prediction



Adapted from Teh and Cheong. (2016). *PLoS ONE 11*(10), e0163842.

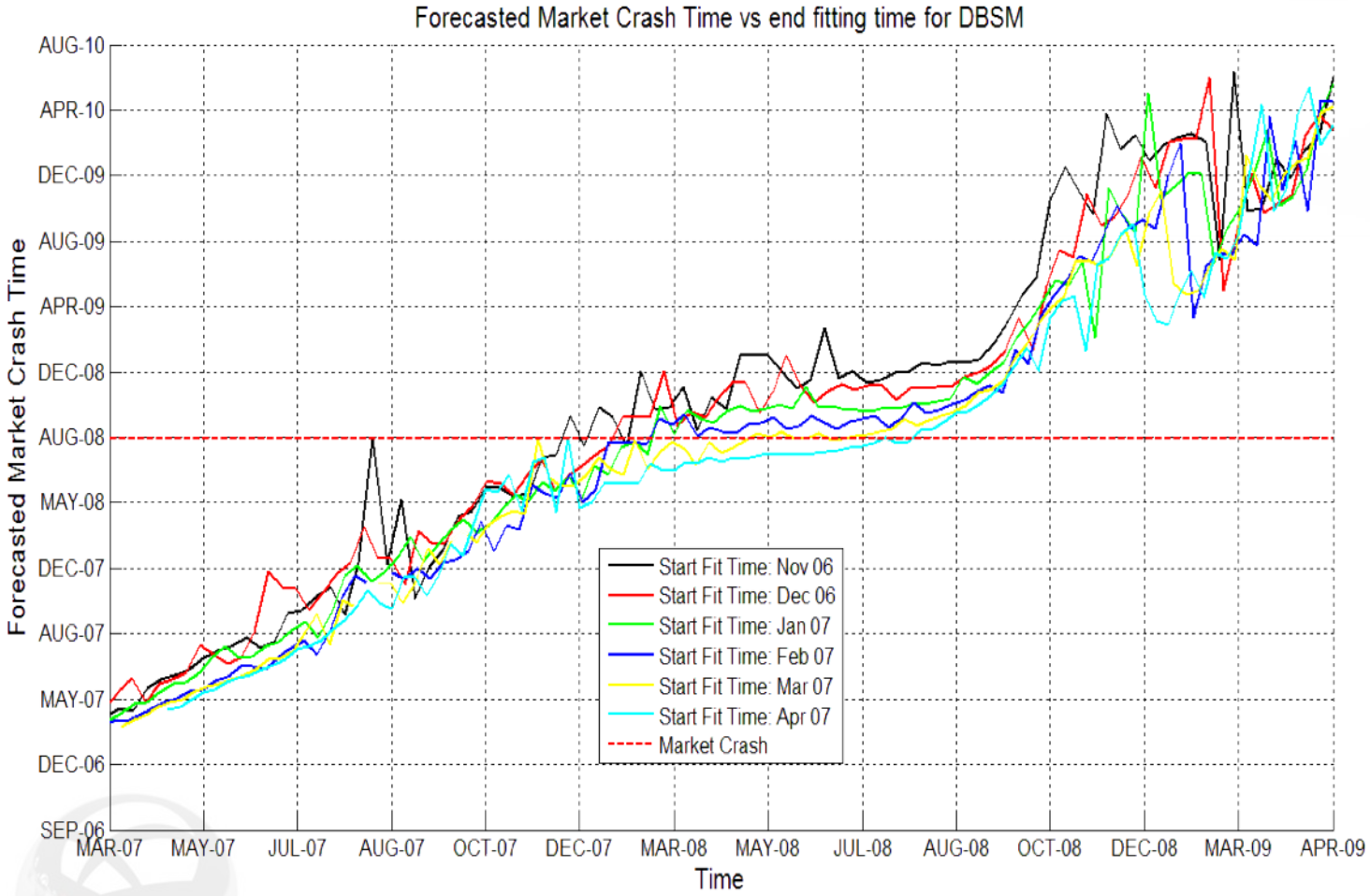
Oct 2008 SGX Crash: Prediction





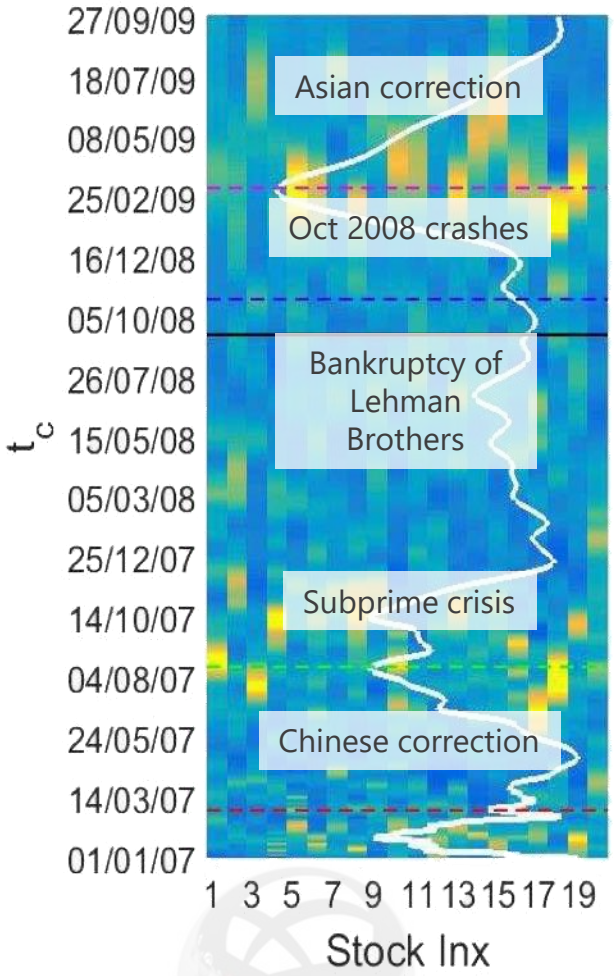
Adapted from Teh and Cheong. (2016). *PLoS ONE 11*(10), e0163842.

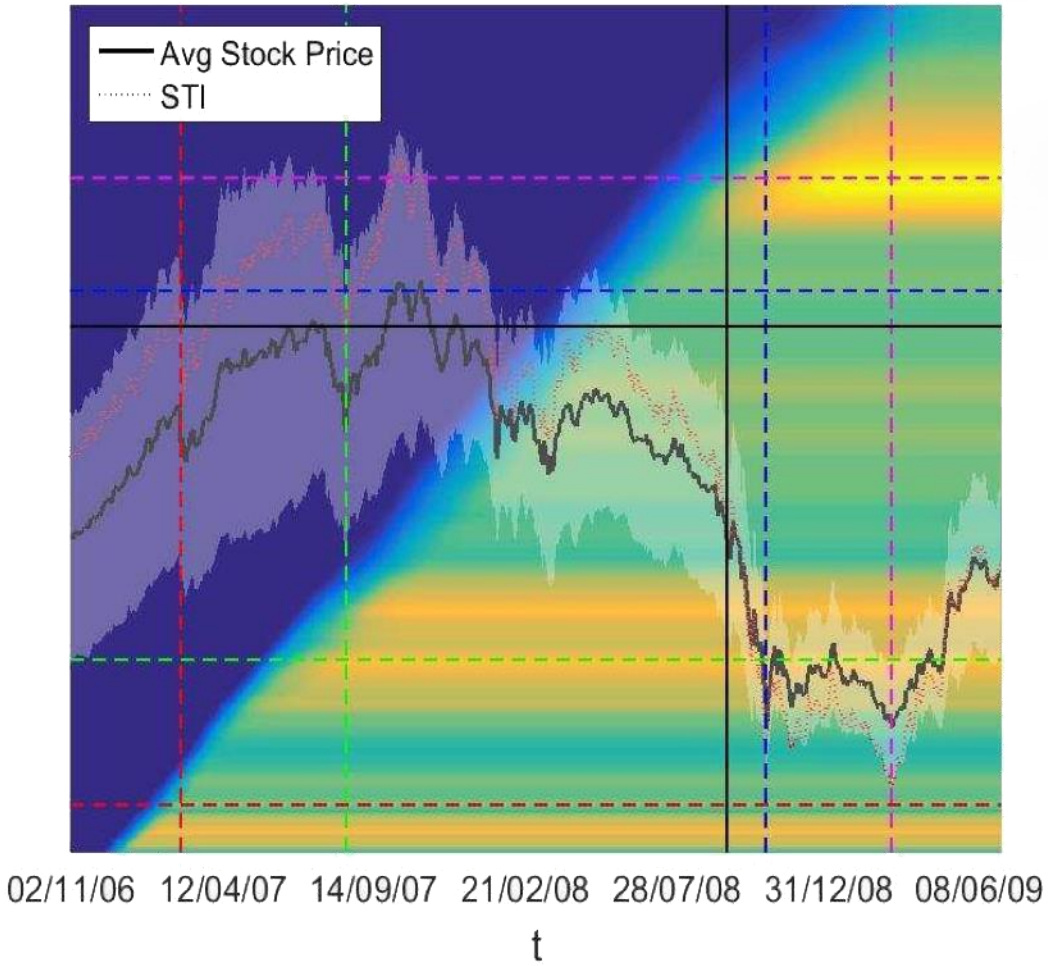
Oct 2008 SGX Crash: Prediction



Adapted from Teh and Cheong. (2016). *PLoS ONE 11*(10), e0163842.

Oct 2008 SGX Crash: Prediction





Teh and Cheong. (2016). *PLoS ONE 11*(10), e0163842.

Summary

- Regime and regime shifts
  - Universal phenomenology
  - Landau theory
- Early warnings
  - Critical fluctuation
  - Critical slowing down
- Quantitative forecasting
  - Log-Periodic Power Law
  - SOG forecasting

Acknowledgements

- Slide 4: Photo of ice cubes, extracted from Pixabay: https://pixabay.com/en/ice-cubes-cold-water-melt-drink-1224804/ by ColiN00B: https://pixabay.com/en/users/ColiN00B-346653/ (Public Domain)
- Slide 4: Photo of water glass, extracted from Pixabay: https://pixabay.com/en/water-freeze-photography-glass-1263493/ by Aman21: https://pixabay.com/en/users/Aman21-2237083/ (Public Domain)
- Slide 4: Photo of steaming pot, extracted from Pixabay: https://pixabay.com/en/pot-steaming-hot-cooking-kitchen-820012/ by Republica: https://pixabay.com/en/users/Republica-24347/ (Public Domain)
- Slide 5: Kirichek, O. & Kouzmenko, G. (2005). *U.S. Patent No. US 20050229609 A1*. Washington, DC: Google Patents.
- Slide 6: Chris Anderson. (2006). Lognormal distribution [Graph]. *The Long Tail*. Retrieved May 9, 2017, from http://www.longtail.com/the_long_tail/2006/08/a_billion_dolla.html.
- Slide 7: Stanley, H. Eugene. (1999). Scaling, universality, and renormalization: Three pillars of modern critical phenomena. *Reviews of Modern Physics, 71*(2), S358-S366. doi:10.1103/RevModPhys.71.S358
- Slides 12-13: Veraart, A.J., Faassen, E.J., Dakos, V., van Nes, E.H., Lürling, M. and Scheffer, M. (2012). Recovery rates reflect distance to a tipping point in a living system. *Nature, 481*(7381), 357-359. doi:10.1038/nature10723
- Slide 16: Graph showing GAO analysis of data, extracted from Wikimedia Commons: https://commons.wikimedia.org/wiki/File:Bitcoin_Price_Index_in_U.S._Dollars,_January_1,_2013_through_March_31,_2014.jpg by U.S. Government Accountability Office: (https://www.flickr.com/photos/usgao/14534919596/ (Public Domain)
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- Slide 21: Graph showing United State's unemployment rate, extracted from Wikimedia Commons: https://en.wikipedia.org/wiki/File:US_average_duration_of_unemployment.png by MartinD: https://commons.wikimedia.org/wiki/User:MartinD under CC BY-SA 3.0: https://creativecommons.org/licenses/by-sa/3.0/deed.en

- Slides 26-29: Cheong, S. A., Tan, T. L., Chen, C.-C., Chang, W.-L., Liu, Z., Chew, L. Y., … Johnson, N. F. (2014). Short-Term Forecasting of Taiwanese Earthquakes Using a Universal Model of Fusion-Fission Processes. *Scientific Reports, 4*, 3624. http://doi.org/10.1038/srep03624
- Slides 31-35: Teh, B.K. and Cheong, S.A. (2016) The Asian Correction Can Be Quantitatively Forecasted Using a Statistical Model of Fusion-Fission Processes. *PLoS ONE 11*(10), e0163842. doi: https://doi.org/10.1371/journal.pone.0163842 (Licensed under CC BY 4.0: https://creativecommons.org/licenses/by/4.0/)