Theoretical Studies of Condensed Matter and Complex Systems

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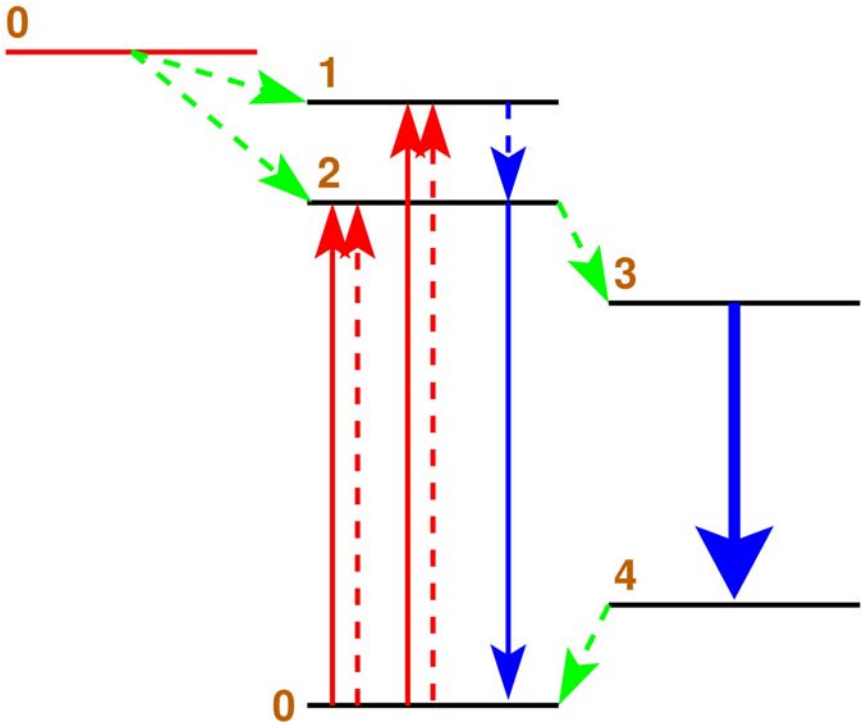
Research Directions

- Data driven, fundamental theory either
  - Too cumbersome for understanding experiments
  - Not available at all
- Effective modeling
  - Progressive refinement of simple models
  - Extraction of effective variables.

Ultrafast Dynamics

- Quantum dots
  - Discrete “atomic” energy levels
  - Photoluminescence or electroluminescence
- Organic light emitters
  - Discrete molecular energy levels
  - Photoluminescence
- HTSC materials
  - Energy band structure
  - Electron-electron and electron-phonon interactions
  - Pump-probe experiments to understand relaxation dynamics

Models and Equations



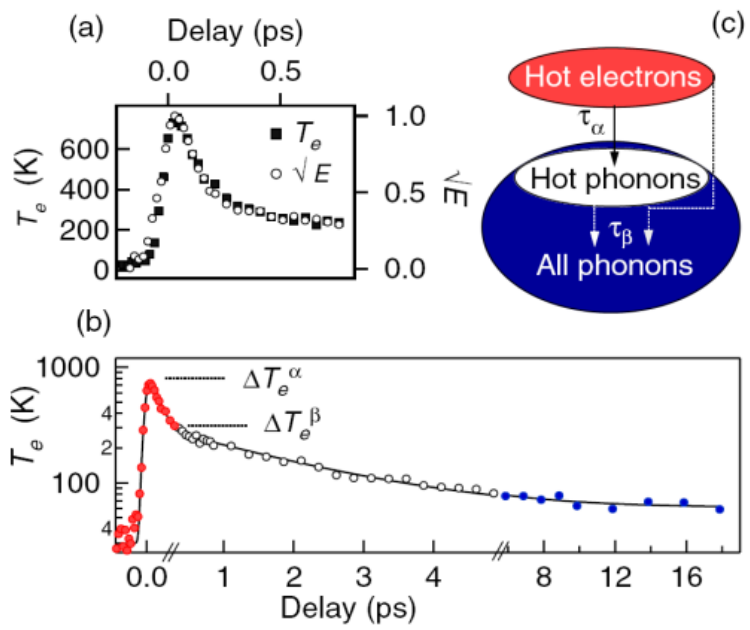
$$\frac{dn_1}{dt} = g_{01}(t) + g_{0'1}(t) - \frac{n_1}{\tau_{12}},$$

$$\frac{dn_2}{dt} = g_{02}(t) + g_{0'2}(t) + \frac{n_1}{\tau_{12}} - \frac{n_2}{\tau_{02}} - \frac{n_2}{\tau_{23}},$$

$$\frac{dn_3}{dt} = \frac{n_2}{\tau_{23}} - \frac{n_3}{\tau_{34}},$$

$$\frac{dn_4}{dt} = \frac{n_3}{\tau_{34}} - \frac{n_4}{\tau_{04}}.$$

Models and Equations



(Taken from Perfetti et al, PRL **99**, 197001 (2007))

$$\frac{dT_{el}}{d\tau} = -\frac{3\lambda\Omega_0^3}{\hbar\pi k_B^2}\frac{n_{el}-n_{ph}}{T_{el}} + \frac{P}{C_{el}},$$

$$\frac{dT_{ph}}{d\tau} = \frac{C_{el}}{C_{ph}}\frac{3\lambda\Omega_0^3}{\hbar\pi k_B^2}\frac{n_{el}-n_{ph}}{T_{el}} - \frac{T_{ph}-T_{latt}}{\tau_\beta},$$

$$\frac{dT}{d\tau} = \frac{C_{ph}}{C_{latt}}\frac{T_{ph}-T_{latt}}{\tau_\beta};$$

$$n_{el} = \frac{1}{e^{\Omega/k_B T_{el}}-1},\ n_{ph} = \frac{1}{e^{\Omega/k_B T_{ph}}-1}.$$

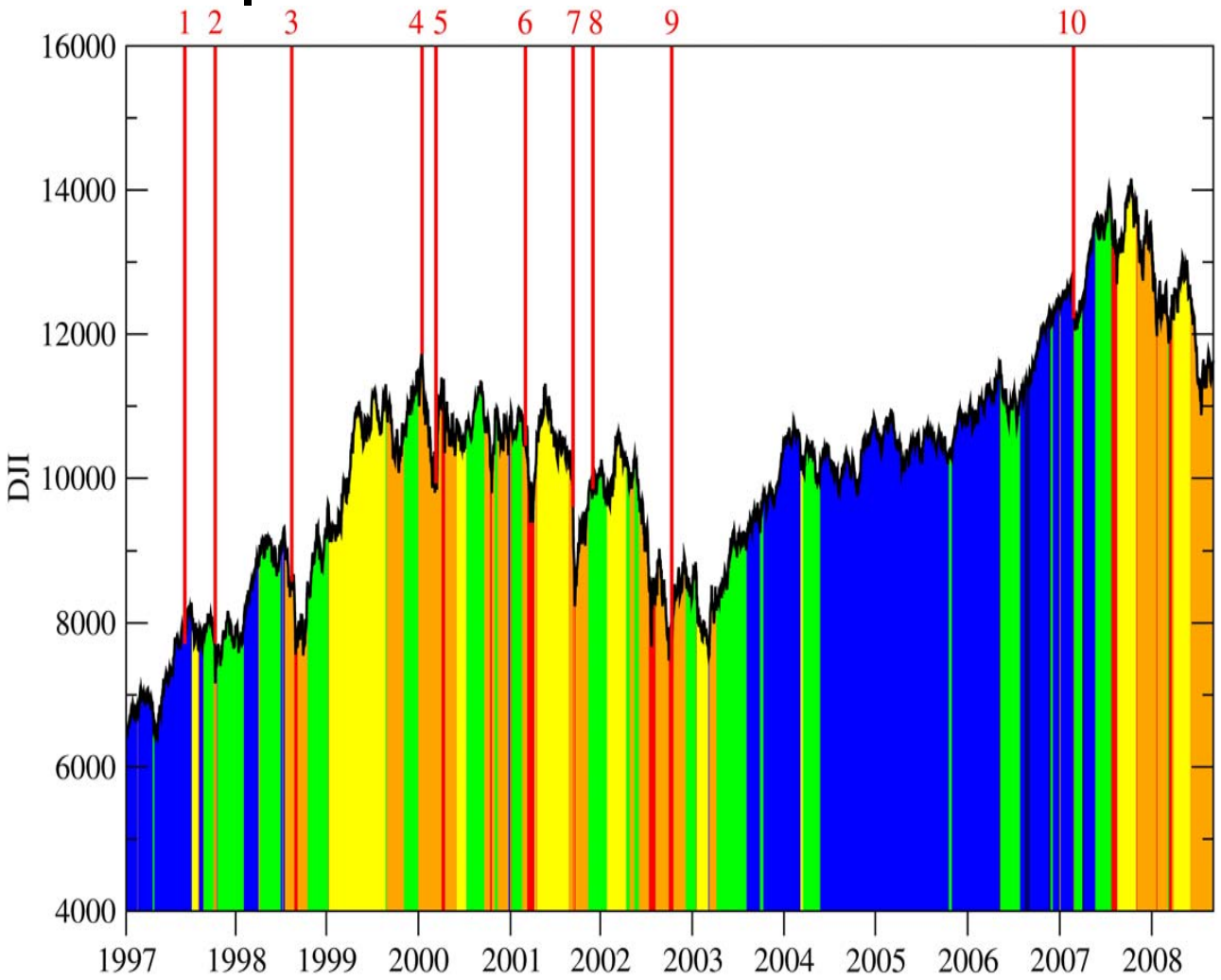
Dynamical Mean Field Theory for Spin Systems

- Dynamical mean field theory (DMFT)
  - powerful numerical method for study of strongly correlated materials
  - Single out a single electron, and approximate the influence of other electrons by time-dependent potential
  - Solve effective Schrödinger equation self-consistently
- DMFT for spin systems?

Complex System Dynamics

- Biological, economical, financial, and sociological systems.
- Macroscopic Phases
  - Statistical segmentation and clustering of index time series
  - Causal link analyses
- Effective Variables
  - Whole-market correlational analysis
  - Understand nature of market crashes

Macroeconomic Phases

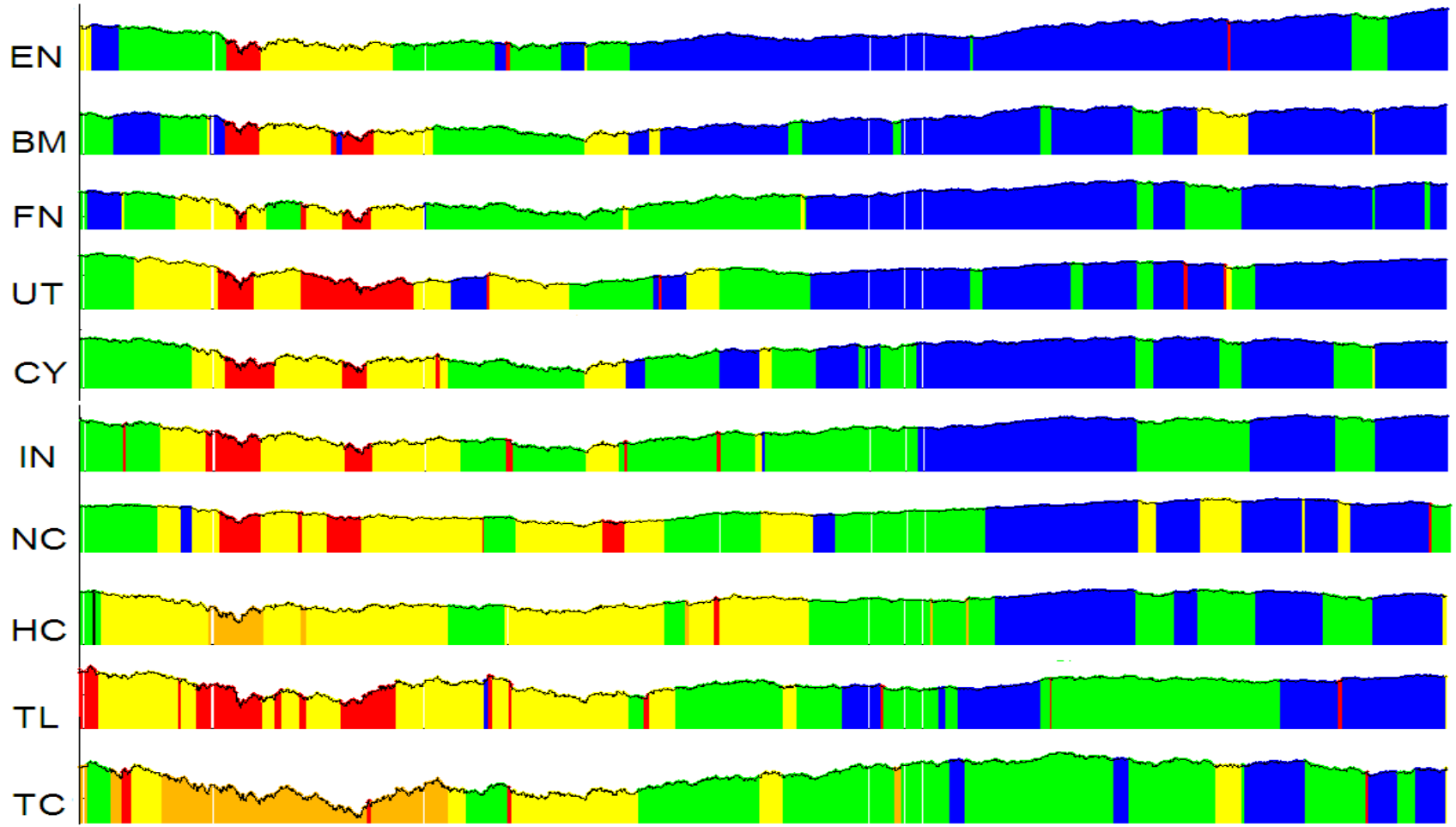


	Date	Event
1	July 1997	Asian Financial Crisis
2	Oct 1997	US Market Mini Crash
3	Aug 1998	Russian Financial Crisis
4	Jan 2000	DJI 2000 High
5	Mar 2000	NASDAQ Crash
6	Mar 2001	Start of recession
7	Sep 2001	Sep 11 Attack
8	Nov 2001	End of recession
9	Oct 2002	DJI 2002 Low
10	Feb 2007	Chinese Correction

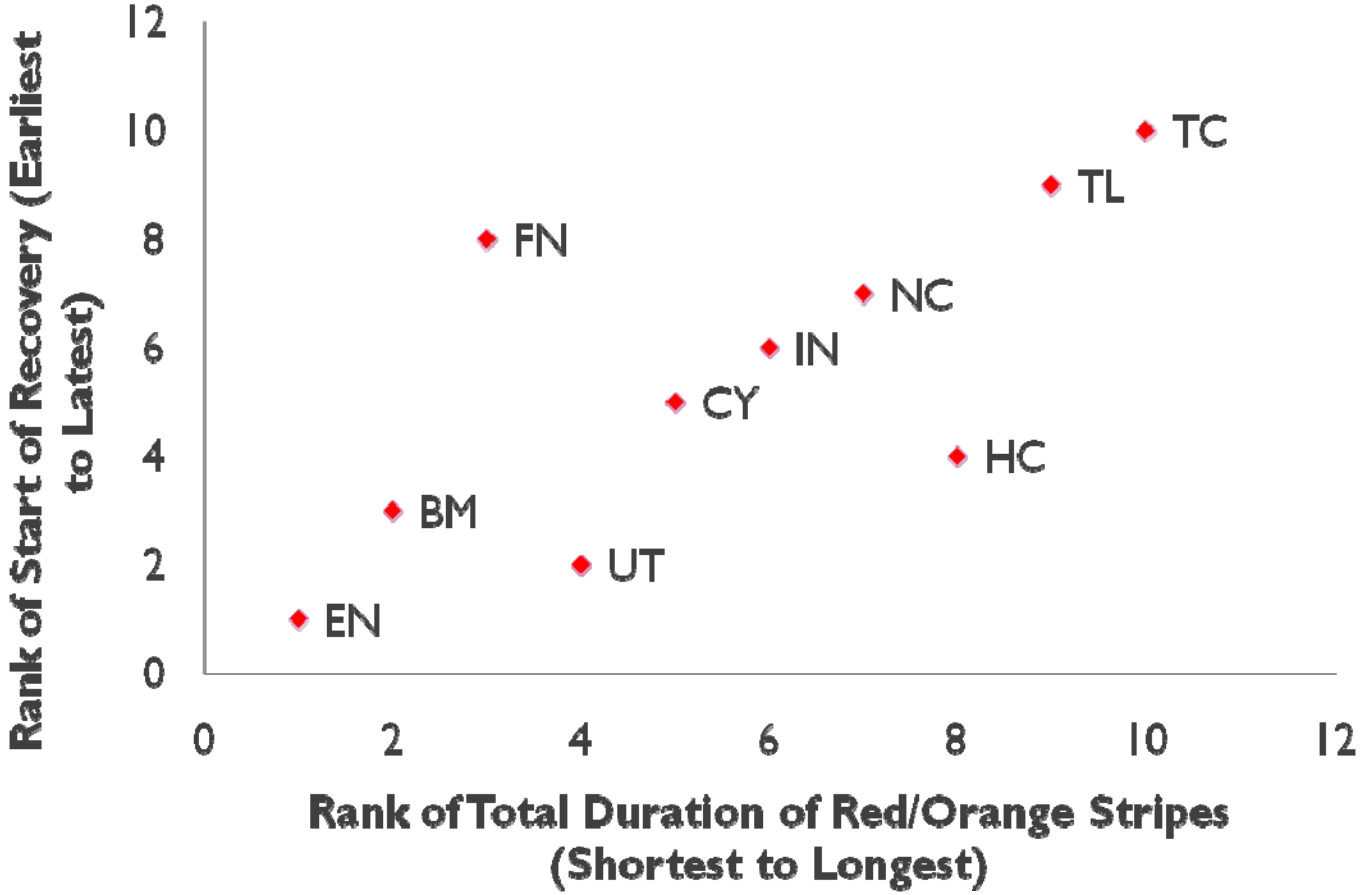
Causal Link Analysis

- Working Hypothesis
  - Closer causal relationship
    - Shorter delays between onsets of shocks
    - Similar patterns of shocks
  - Leading sector
    - More shocks
    - Stronger shocks
    - Shocks last longer

Recovery from Previous Financial Crisis



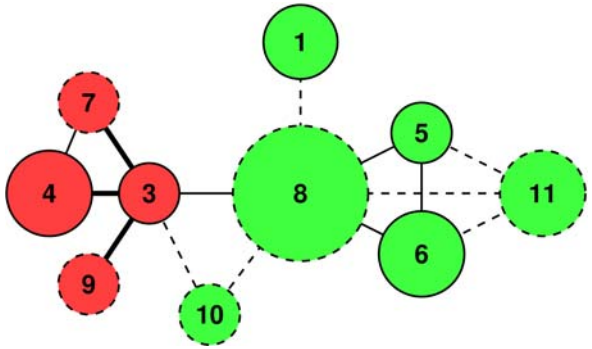
Sequence of Recovery

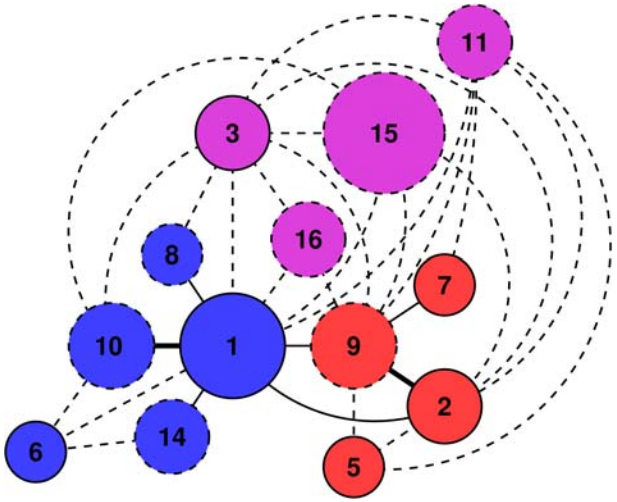


Onset of Current Financial Crisis

- Sequence:
  - (NC, UT)→(HC,IN,TL)→FN→TC→BM→CY
- Interest rate cuts
  - First 2-3 effective
  - Next 2-3 counter-effective
  - Subsequent ones ineffective

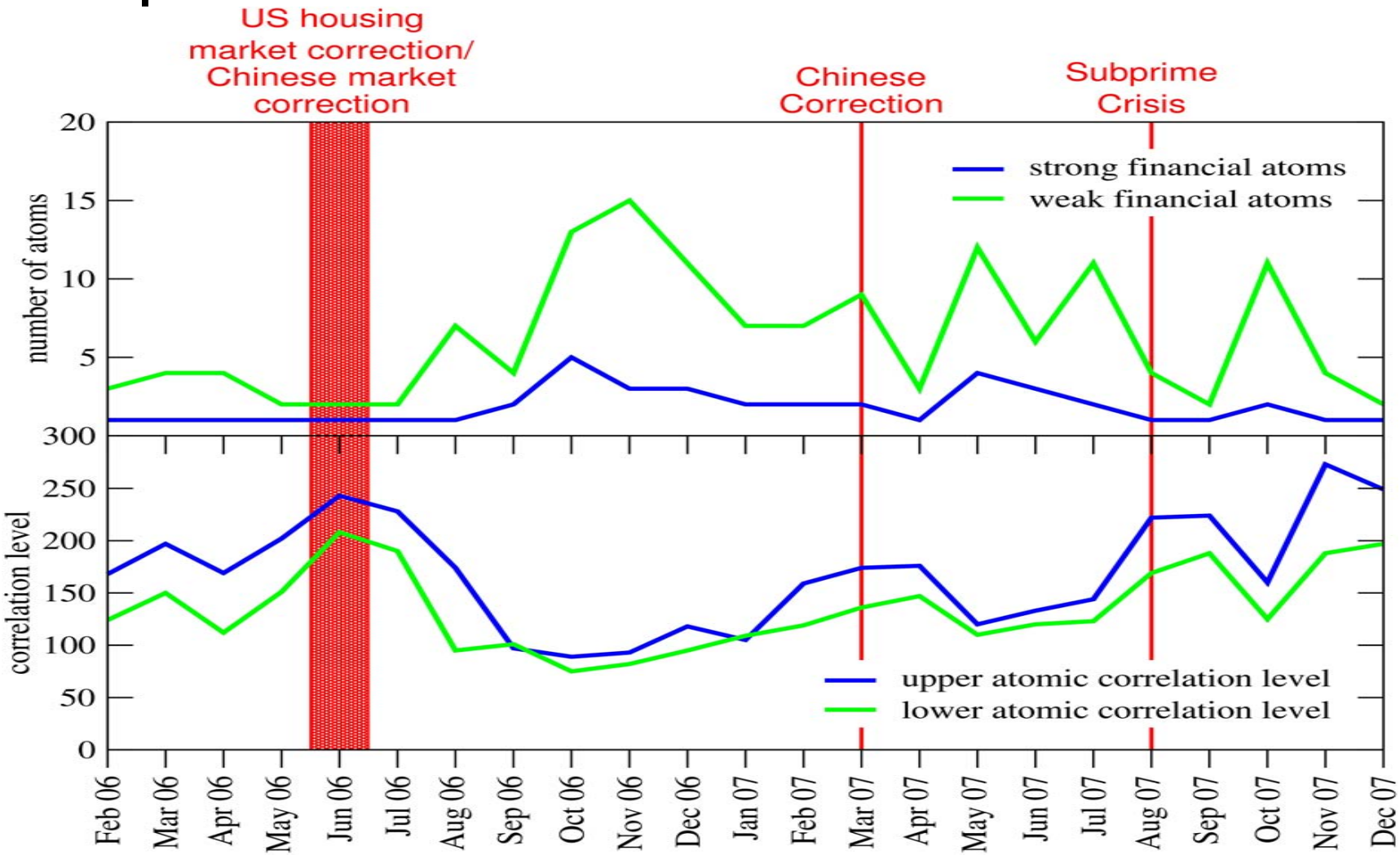
Financial Atoms and Molecules



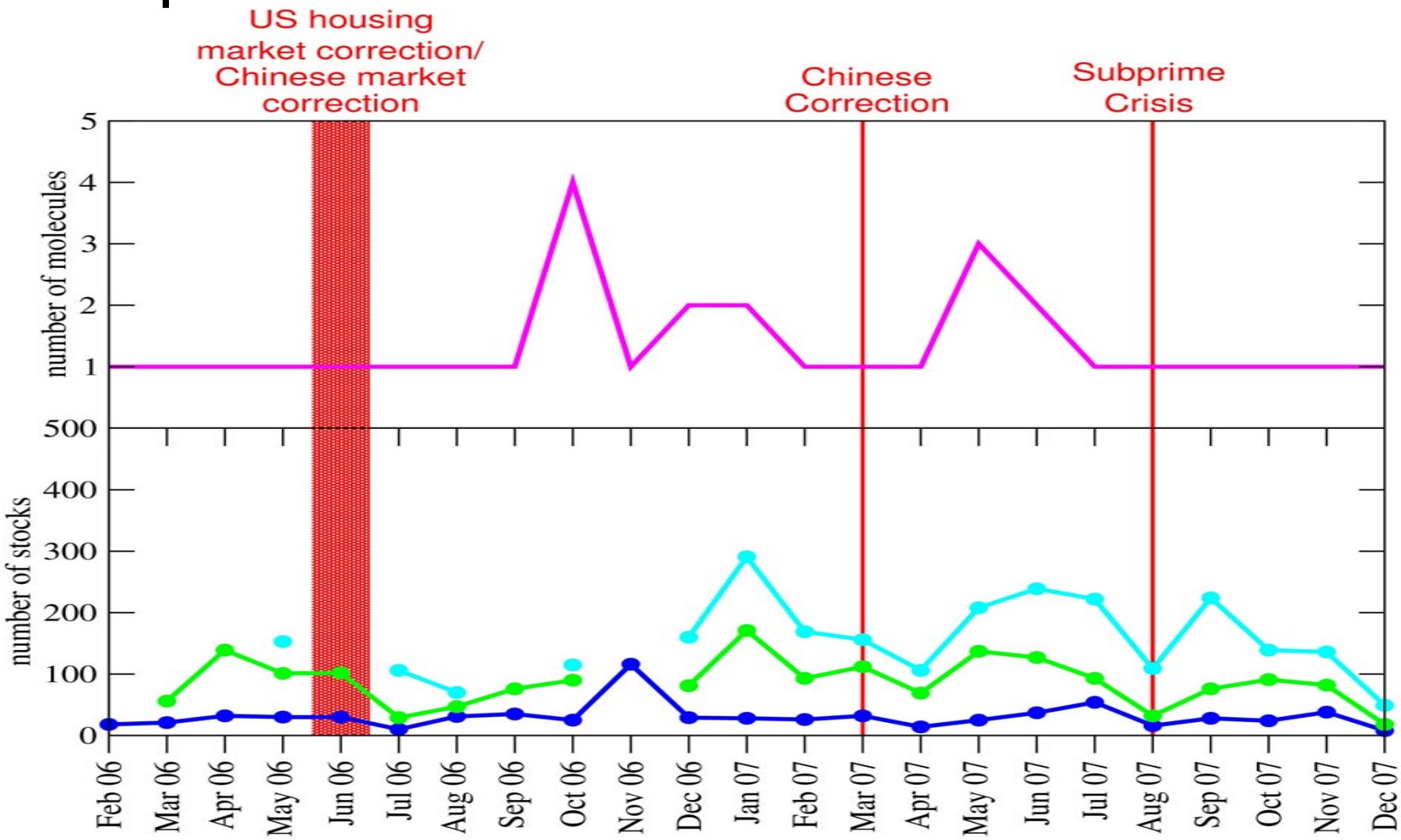


- Whole-market correlational analysis
  - Daily price movements for 2006 & 2007
  - NYSE, LSE, TSE, HKSE & SGX
- Hierarchical organization of effective variables
  - Financial atoms
  - Financial molecules
- One financial molecule each in HKSE & SGX
  - Half local stocks, half Chinese stocks
  - No apparent reason apart from Chinese Correction

Understanding the Feb 2007 Chinese Correction



Understanding the Feb 2007 Chinese Correction



Collaborations

- Ultrafast phenomena
  - Interplay between experimentation and modeling
- Complex system dynamics
  - Extract effective variables from
    - Protein dynamics simulations
    - Earthquake time series
    - Large-scale high-throughput transcriptome experiments