The complexity of cellular networks

Warning: Statistical physics.
It only works on average.

http://regan.med.harvard.edu/CVBR-course.php

2. Dynamics on Complex Networks

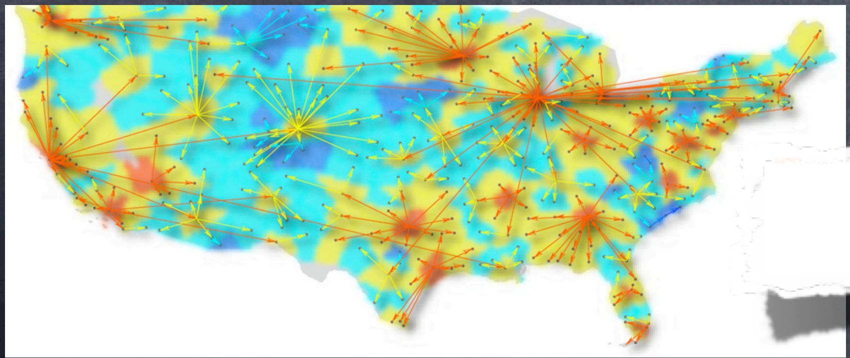
- What do networks do? -

They CONNECT their nodes.

WHY?

Communication

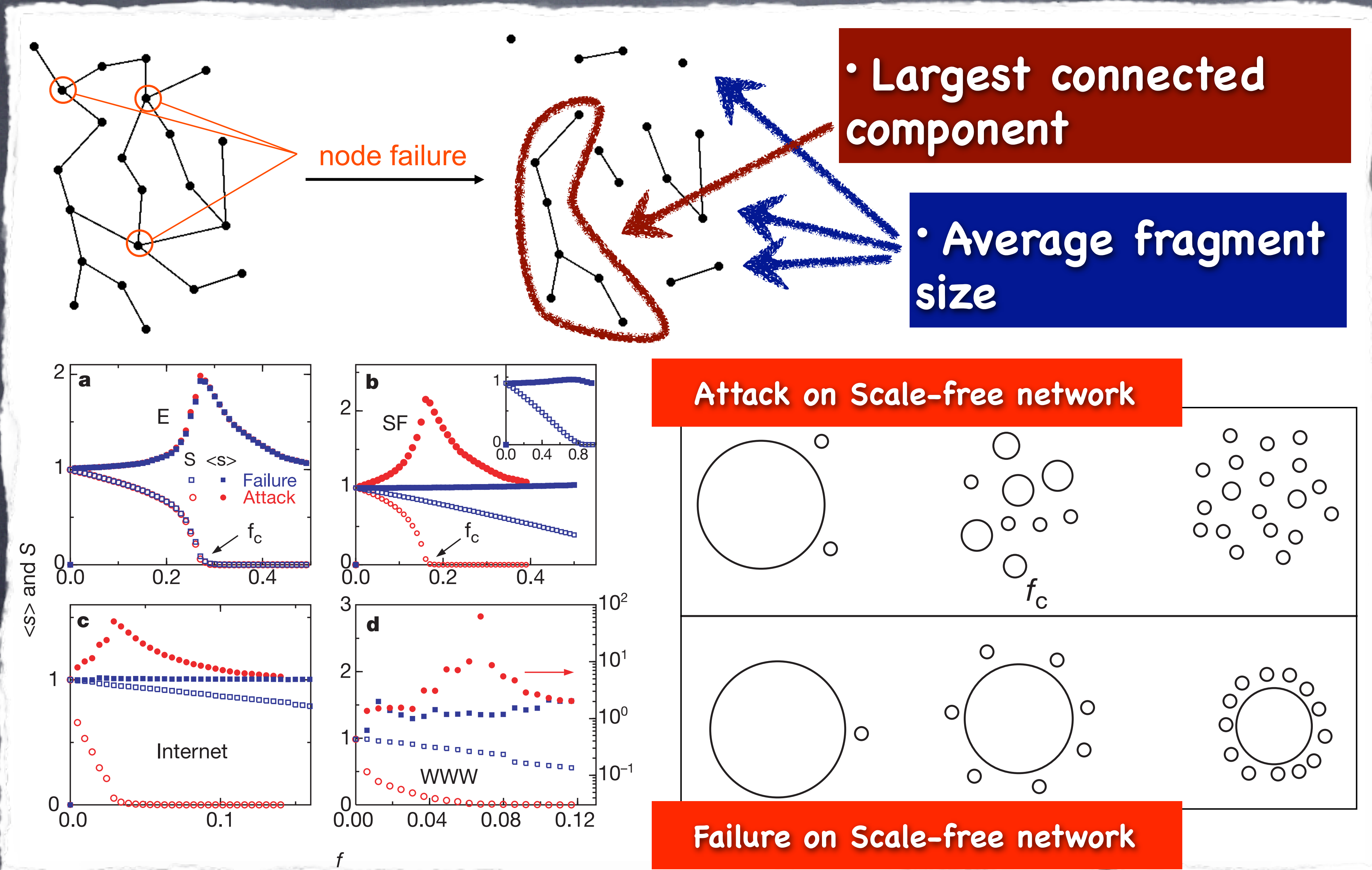
Traffic



Spreading processes

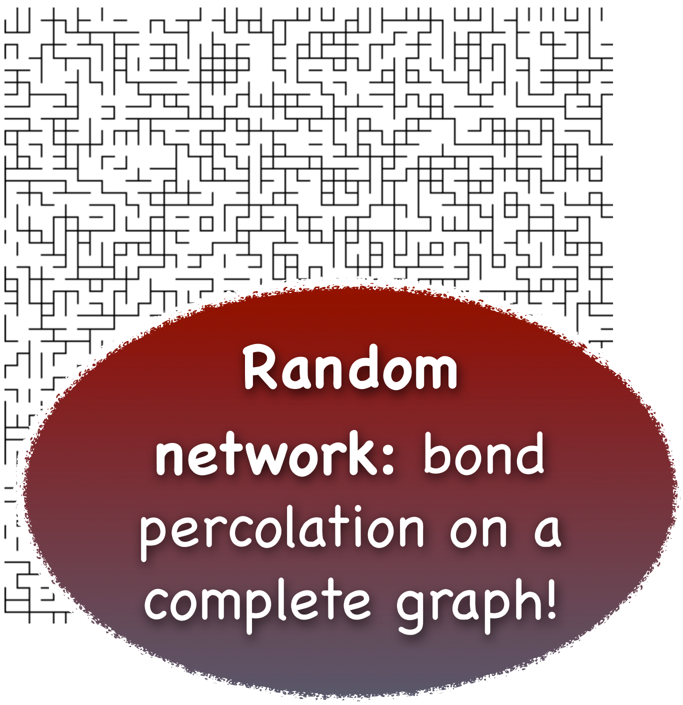
- Robustness and Vulnerability -

Albert & Barabási, 2000 : the Achilles Heel of the Internet

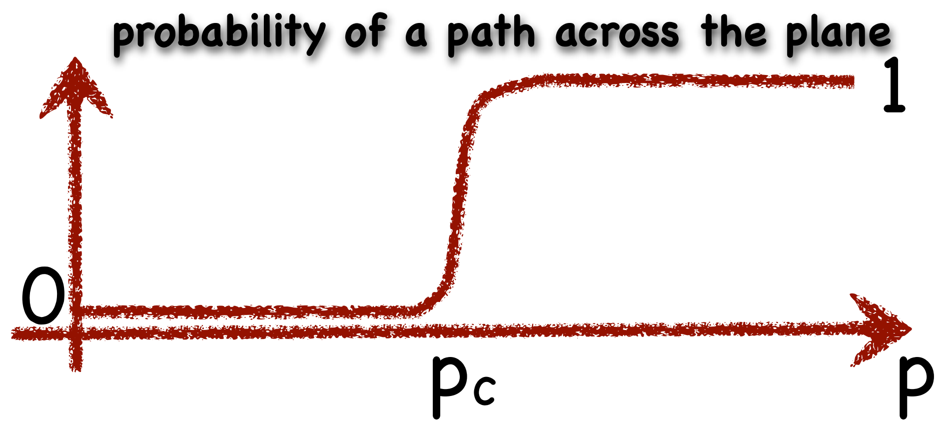


- Statistical physics loves these models! -

- **random failure scenarios map to percolation problems**



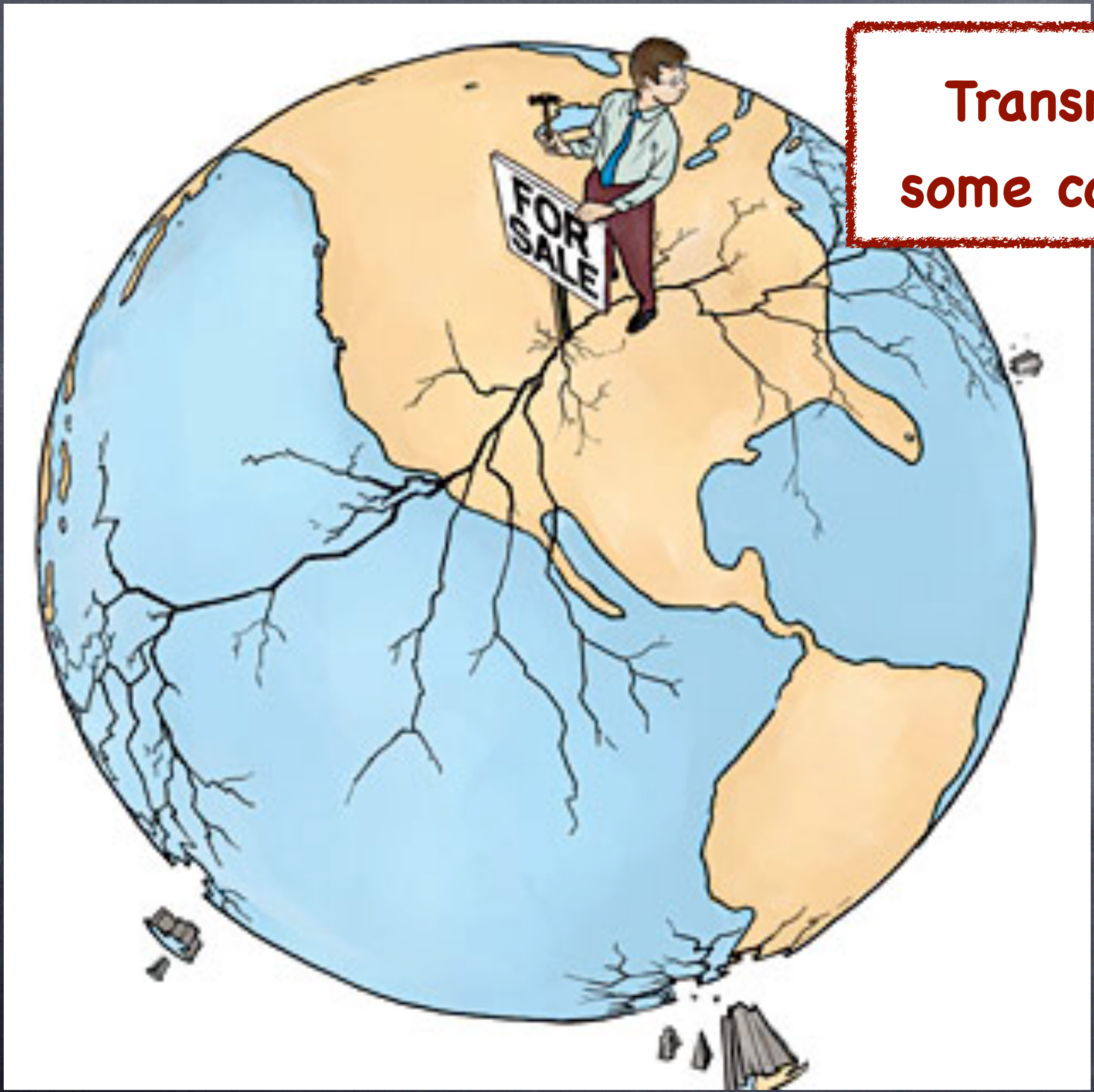
- p - probability of a link (node) being "open"
- phase transition between subcritical and supercritical states



➡percolation threshold in scale-free networks is at $p_c = 0$

- **assortative networks**
  - ➡ more resilient to random failure
  - ➡ more vulnerable to attack

- Cascading failures -



Transmission (flow) of some conserved quantity

(Money)

Electric power

Metabolite mass

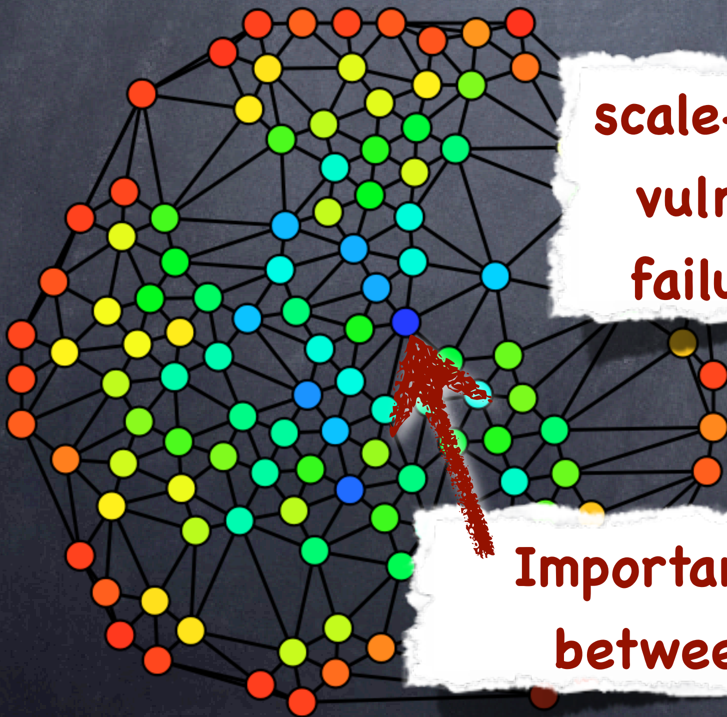
Information packets

- Cascading failures -

Reason: when a node fails, it stops doing its share. Neighbours become overworked.

Motter and Lai, 2002:

- load bearing capacity ~ betweenness
- every pair of nodes exchanges 1 packet / timestep



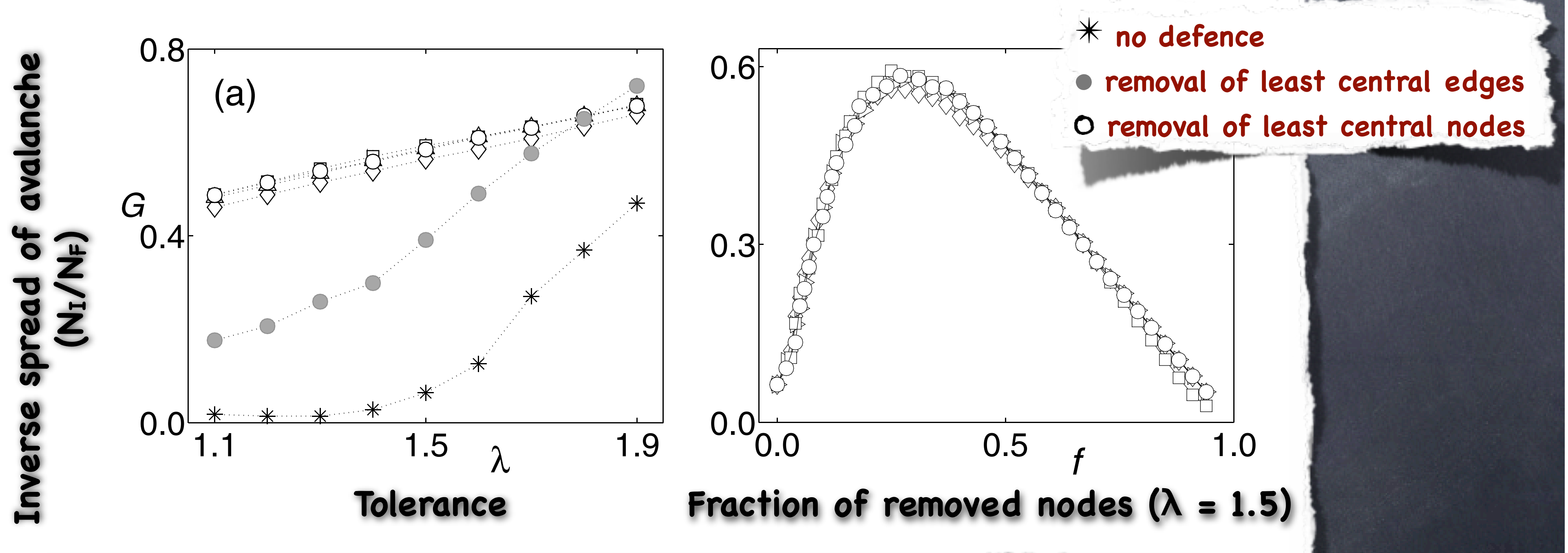
scale-free networks MORE vulnerable to cascading failure of random nodes

Importance of largest betweennes nodes!

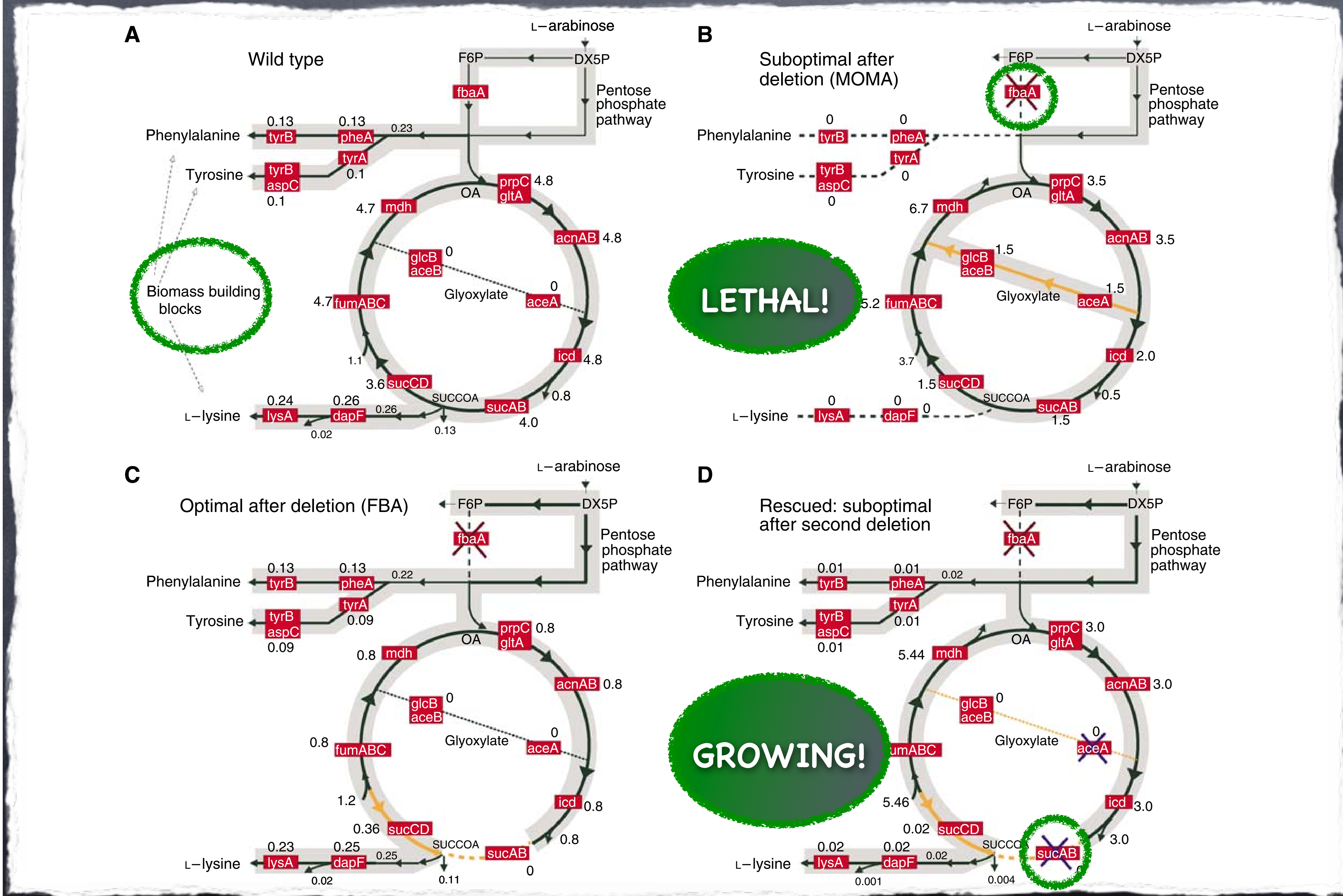
- A surprising quick-fix -

Motter, 2004: **REMOVE / DISCONNECT nodes that carry small amounts of load:**

- **then generate more load than they carry**
- **their paths to the system are large -> burden many intermediary nodes**



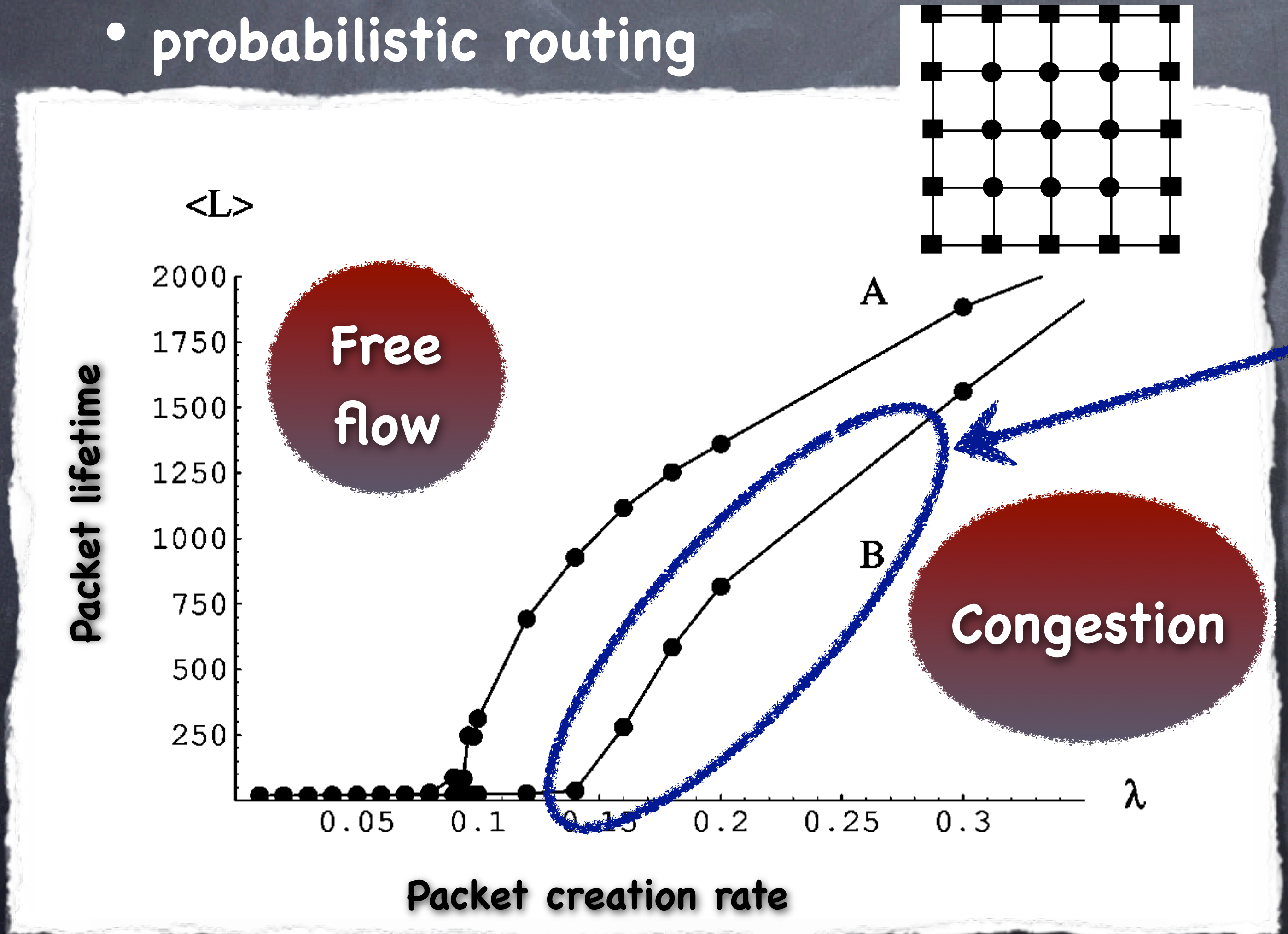
- Predicted to work in E.coli's TCA cycle! -



- Congestion -

Ohira and Sawatari, 1998:

- 2D lattice
- packets (cars) start at boundary
- nodes have unlimited queue (no cascades)
- shortest route
- **probabilistic routing**



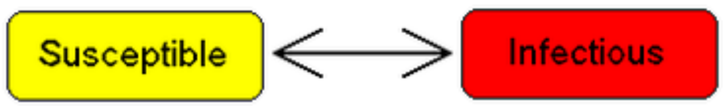
Optimal amount of randomness in choosing alternate, longer routes

- Physicists love these models! -

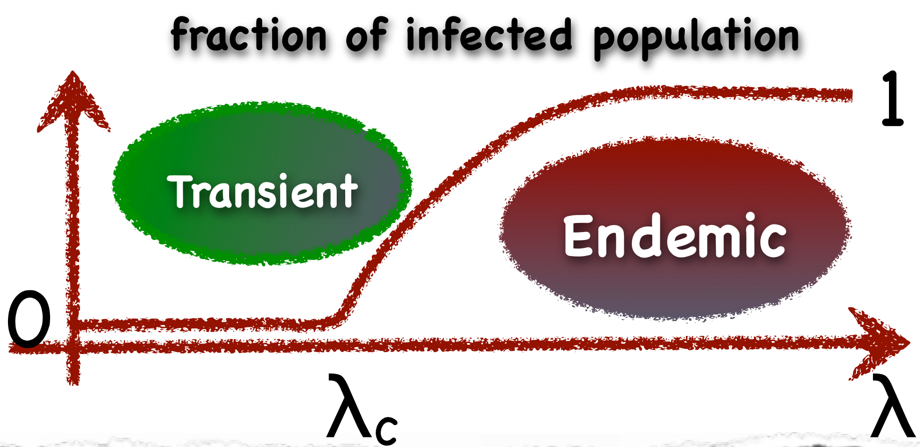
- **Influence of network topology:**
  - ➡ Zhao et al, 2005: random & scale-free networks are less congested than lattices IF processing capacity ~ degree
    - ➡ SAME congestion threshold on all networks if processing capacity ~ **betweenness**
  - ➡ Toroczkai and Bassler, 2004: **gradient aware flow.**
    - ➡ Congestion factor (% of nodes with no incoming trafic) grows with system size in random networks
    - ➡ it is constant in scale-free networks -> scalable!
- **The "Shannon limit" of networks:**
  - ➡ Sreenivasan and Toroczkai, 2007: for every physical network there exists a communication threshold that is entirely structural. No routing protocol can do better.

- Spreading Processes -

SIS model in epidemiology:



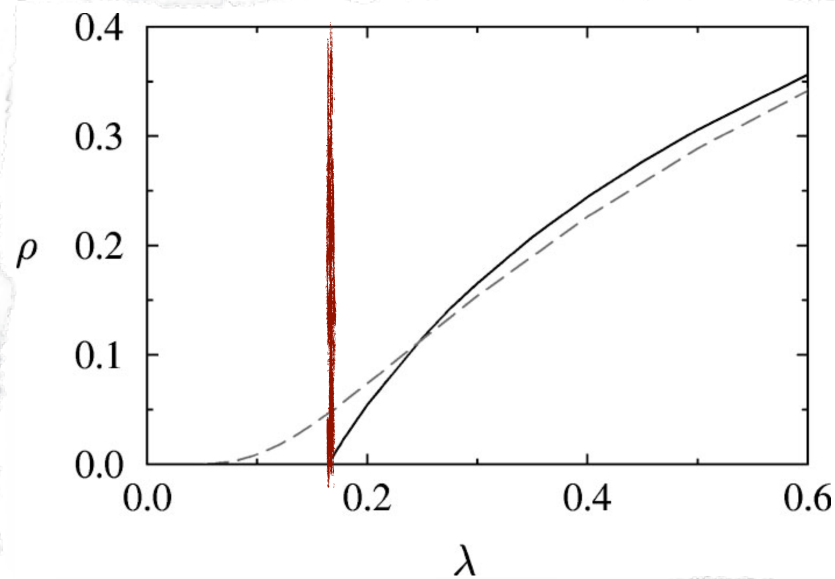
- effective spreading rate λ



Homogeneous mixing

↓

Spreading on networks



Partor-Satorras and Vespignani, 2001

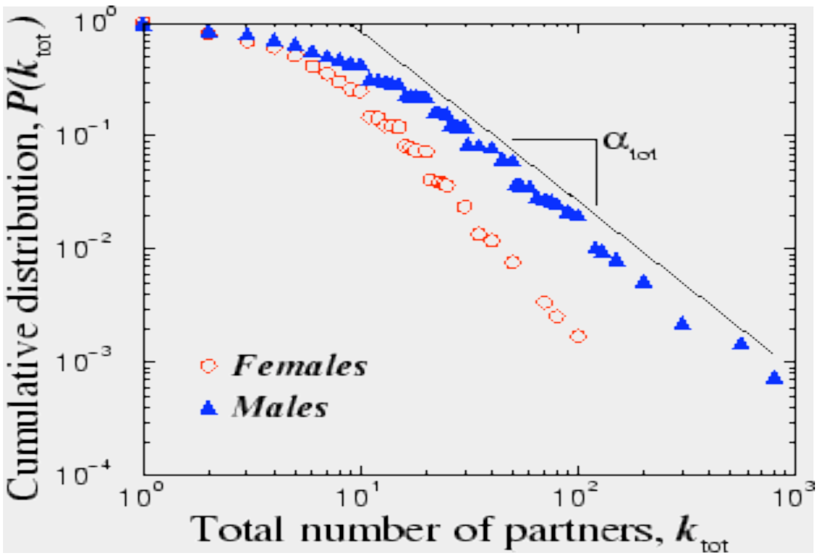
SIR model: SIMILAR RESULT!

- So... how do we immunize? -

Dezső and Barabási; Satorras and Vespignani, 2001

- **Scale-free networks DO NOT respond to random immunization!**
  - ➡ random immunization does not restore the threshold
    - ➡ need to target the hubs

Similar to failure (random event) vs. attack!



4781 Swedes; 18-74;
59% response rate.

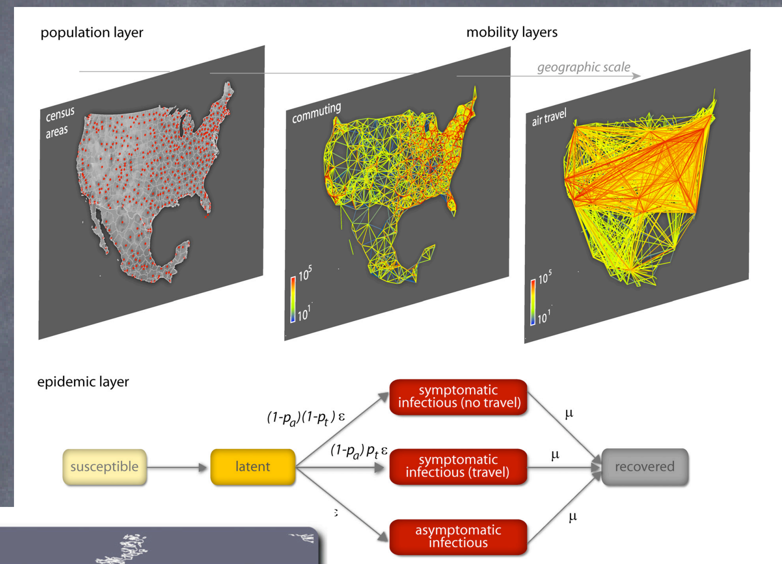
- **possible policy:** choose random individual, ask them to name a friend!

Liljeros et al. Nature 2001

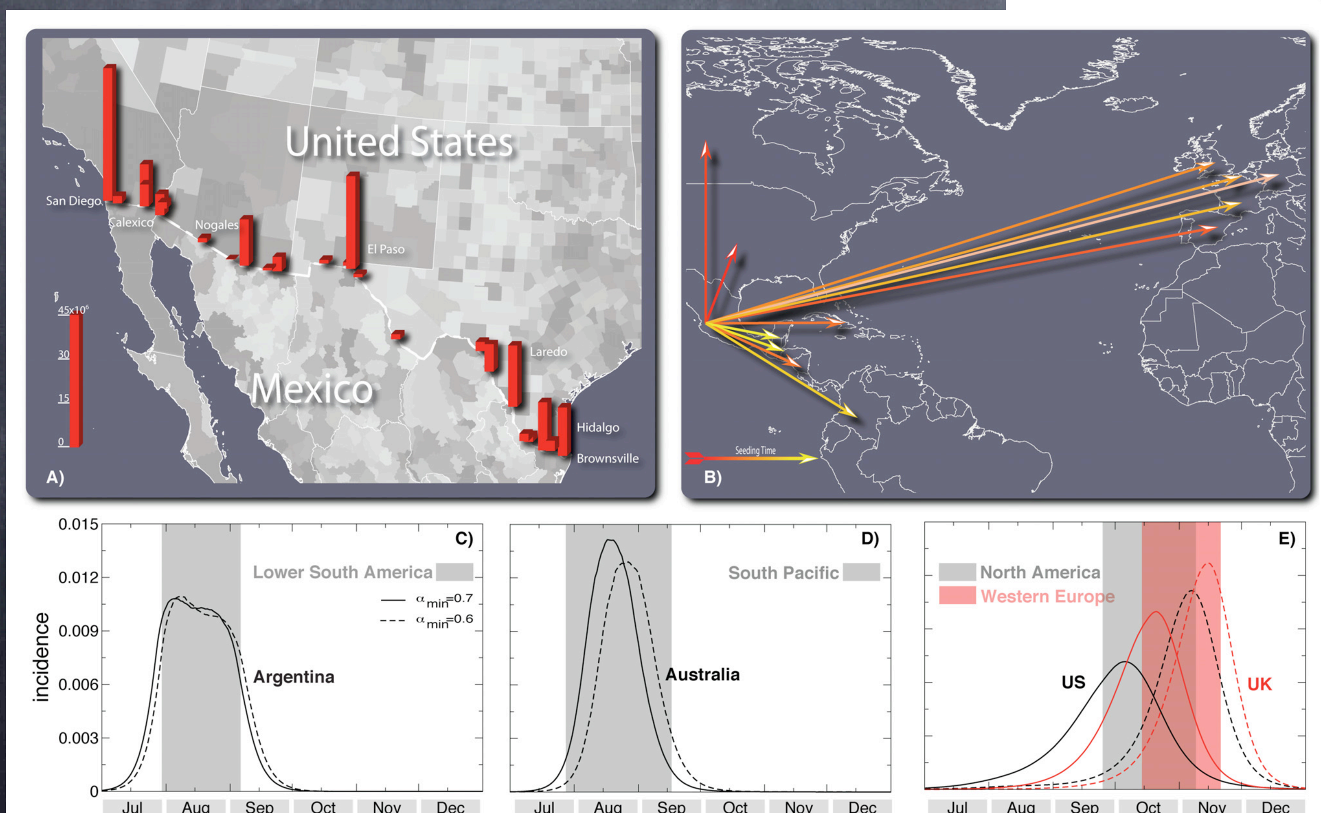
- Would you like it more realistic? -

Vespignani and Colizza, July 2009

GLobal Epidemic and Mobility (GLEaM) model

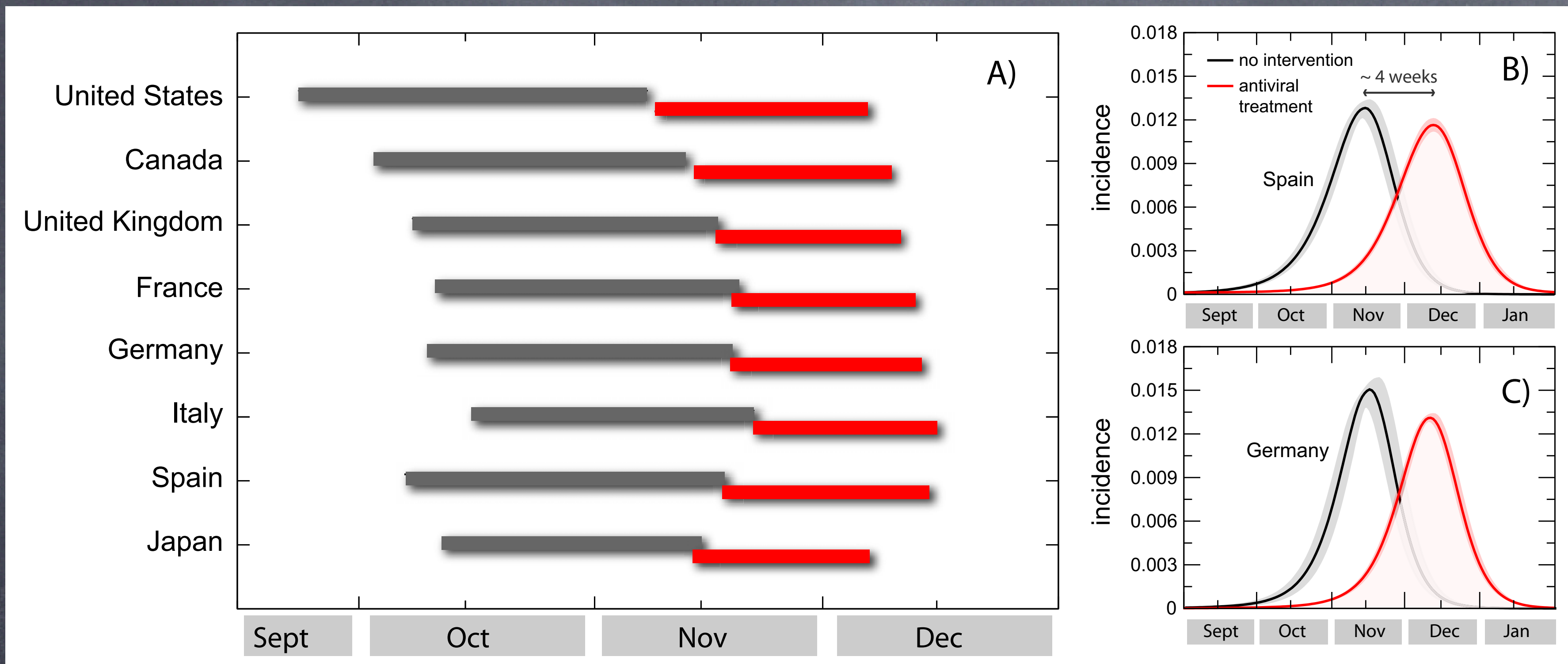


N1H1 predictions



outbreak near La Gloria in Mexico, Feb. 18, 2009

Effects of systematic antiviral treatment



Buys time for mass vaccinations

- More topics you can read up on -

- **Pick your favourite model in classical statistical mechanics**
- **Synchronization phenomena**
- **Walking and searching on networks**
- **Social networks**
  - ➡ rumor and news spreading phenomena
  - ➡ voter models, coalition formation
  - ➡ economic models on networks
- **Biological networks**

The rest of the course...

Slides and organized citations: on line by evening of lecture.

3. Modeling transcriptional regulation, one promoter at a time

April 27

12 PM