

# Complex Human Mobility Dynamics on a Network

Michael Szell, Giovanni Petri, Roberta Sinatra,  
Vito Latora, Stefan Thurner

Section for Science of Complex Systems  
Medical University of Vienna

[www.complex-systems.meduniwien.ac.at](http://www.complex-systems.meduniwien.ac.at)



# Why study human mobility?

- Spread of epidemics
- Urban planning (railway, underground, airline)
- Crowd dynamics
- Geomarketing
- Spread of computer viruses (WIFI, Bluetooth)

## Statistical physics of social dynamics

Barthelemy, arXiv:1010.0302 (2010)  
Castellano et al, Rev Mod Phys 81, 591-646 (2009)  
Pastor-Satorras and Vespignani, PRL 86, 3200-3203 (2001)  
Wang et al, Science 324, 1071-1075 (2009)  
Helbing et al, PRE 75, 046109 (2007)

# Measuring mobility

Large-scale datasets: mobile phones, dollar bills, subway



- Topology often a spatial network
- Scale-free spatial step distributions
- Scale-free waiting time distributions
- High predictability + anomalous diffusion

**Universal laws? Diffusion model?**

Brockmann et al, Nature 439, 462-465 (2006)  
González et al, Nature 453, 779-782 (2008)  
Roth et al, arXiv:1001.4915 (2010)  
Song et al, Science 327, 1018-1021 (2010)  
Koelbl and Helbing, New J of Phys 5, 48 (2003)

# Establishing a socio-economic laboratory

[www.pardus.at](http://www.pardus.at)

400,000 participants live an alternative life, in an online society interacting with others

- trading
- socializing
- conflicting

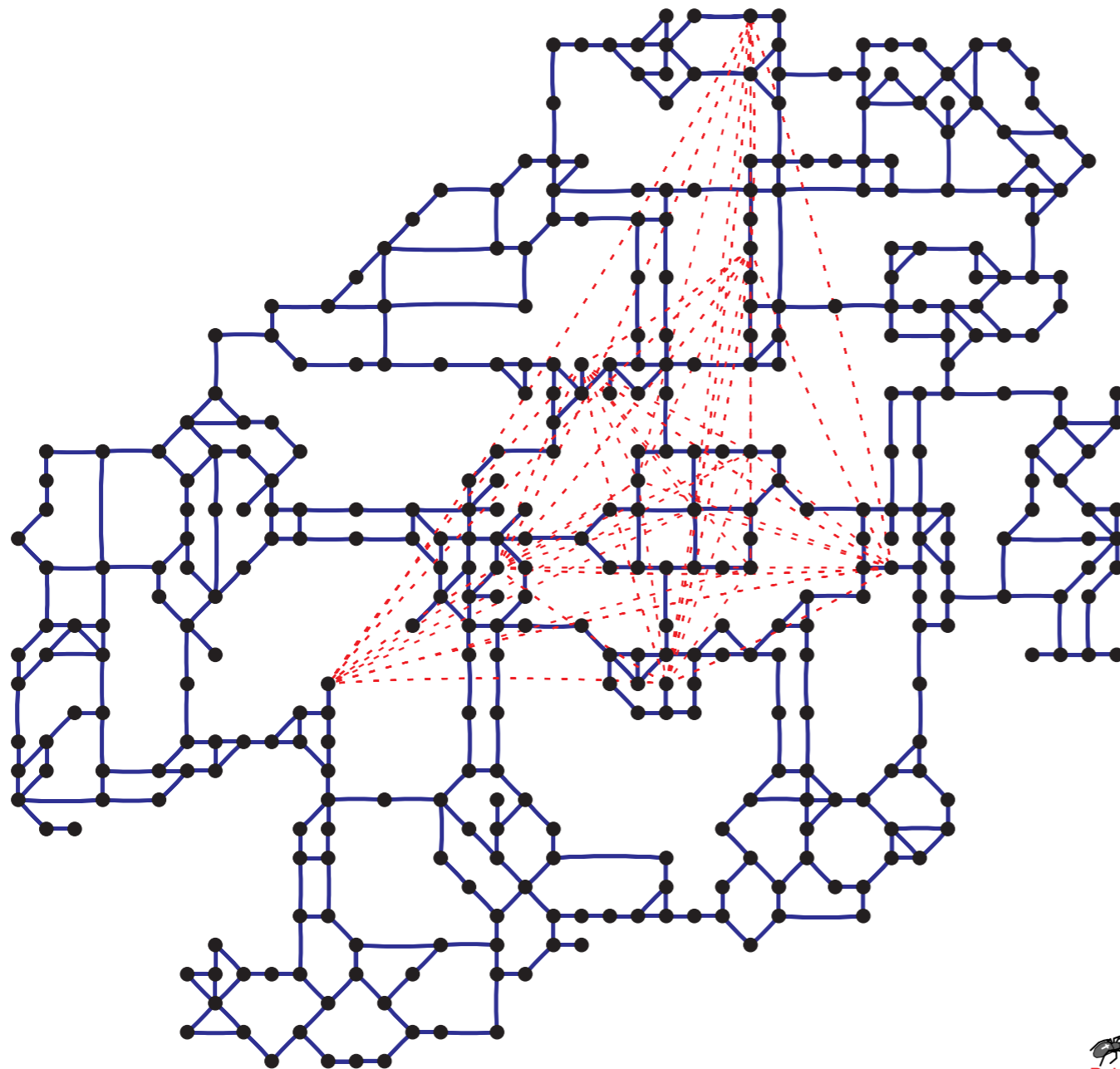


**All data available!**

Bainbridge, Science 317, 472 (2007)  
Szell and Thurner, Social Networks 32, 313-329 (2010)  
Szell et al, PNAS 107, 1363-13641 (2010)

# Mobility on a network

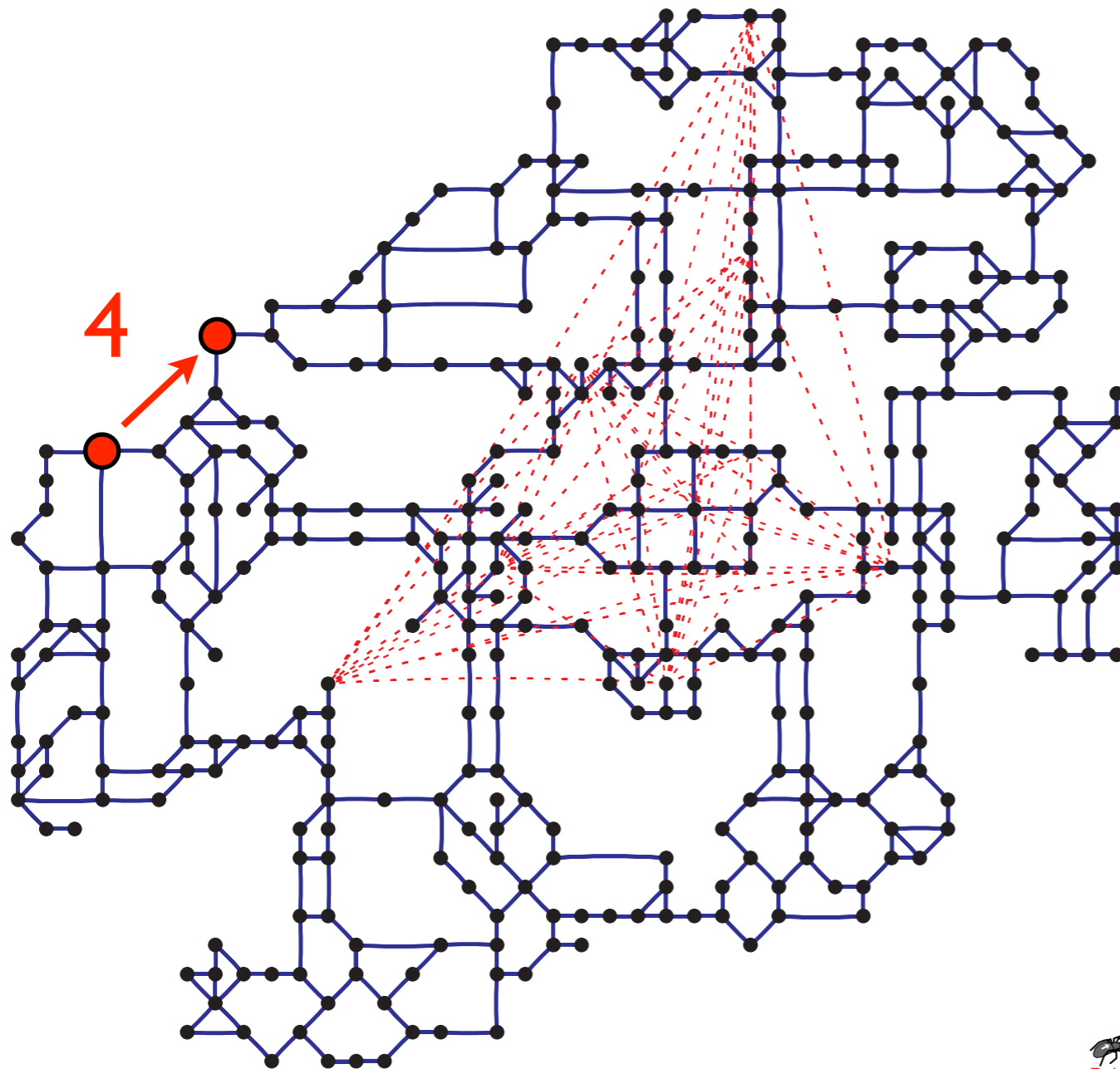
Day-to-day mobility of 2000 participants over 500 days



- 400 Nodes
- Planar
- Diameter 27
- Lattice-like

# Mobility on a network

Metric defined by shortest paths



## Restrictions

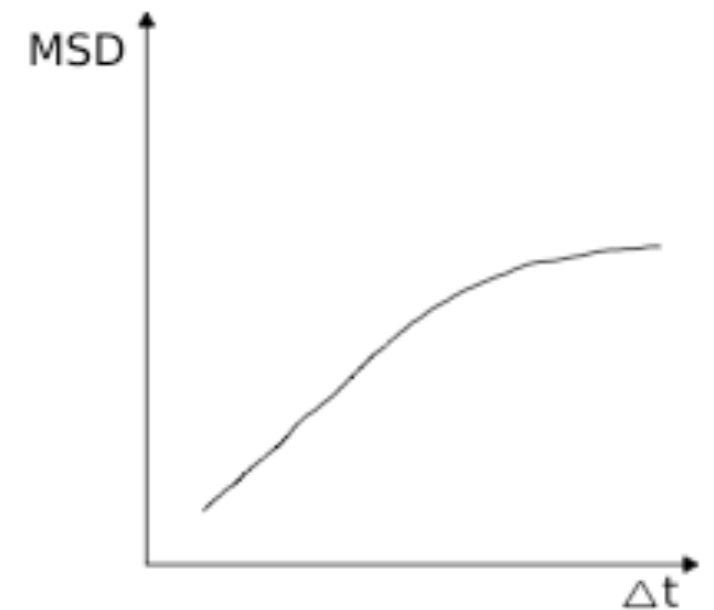
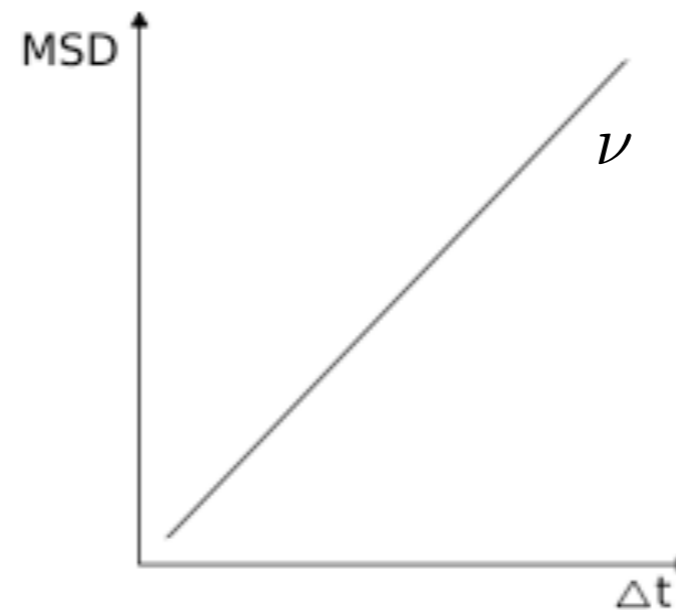
- Number of actions
- Travel cost

# Diffusion and MSD

Mean Squared  
Displacement

$$\text{MSD} = \langle r^2(t) \rangle$$

$$\nu = \lim_{t \rightarrow \infty} \frac{d}{dt} (\text{MSD})$$



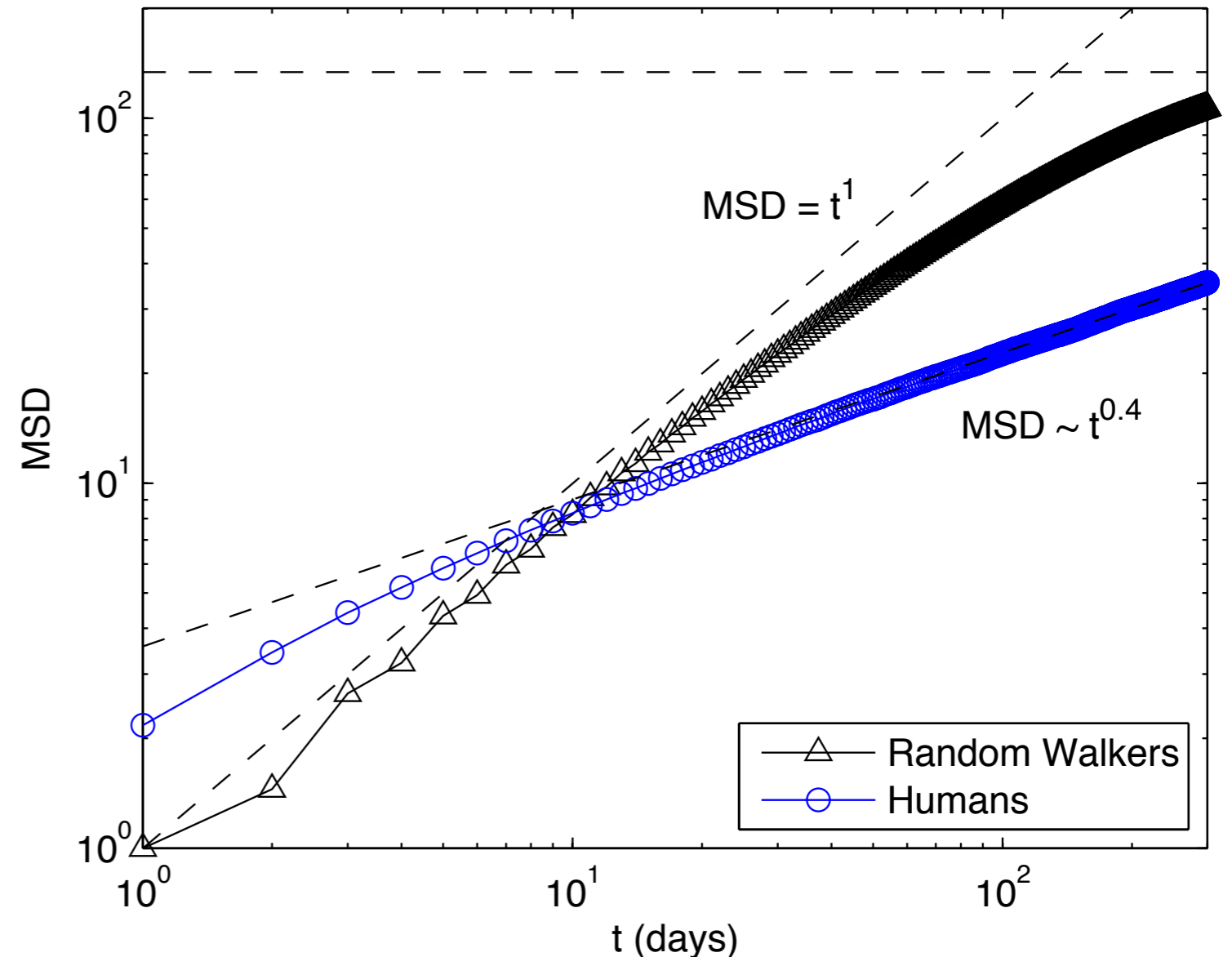
# Human mobility is highly subdiffusive

Mean Squared  
Displacement

$$\text{MSD} = \langle r^2(t) \rangle$$

$$\nu = \lim_{t \rightarrow \infty} \frac{d}{dt} (\text{MSD})$$

$$\nu = 0.4 < 1$$



Similar in mobile phone study

Song et al, Nature Physics 6, 818-823 (2010)

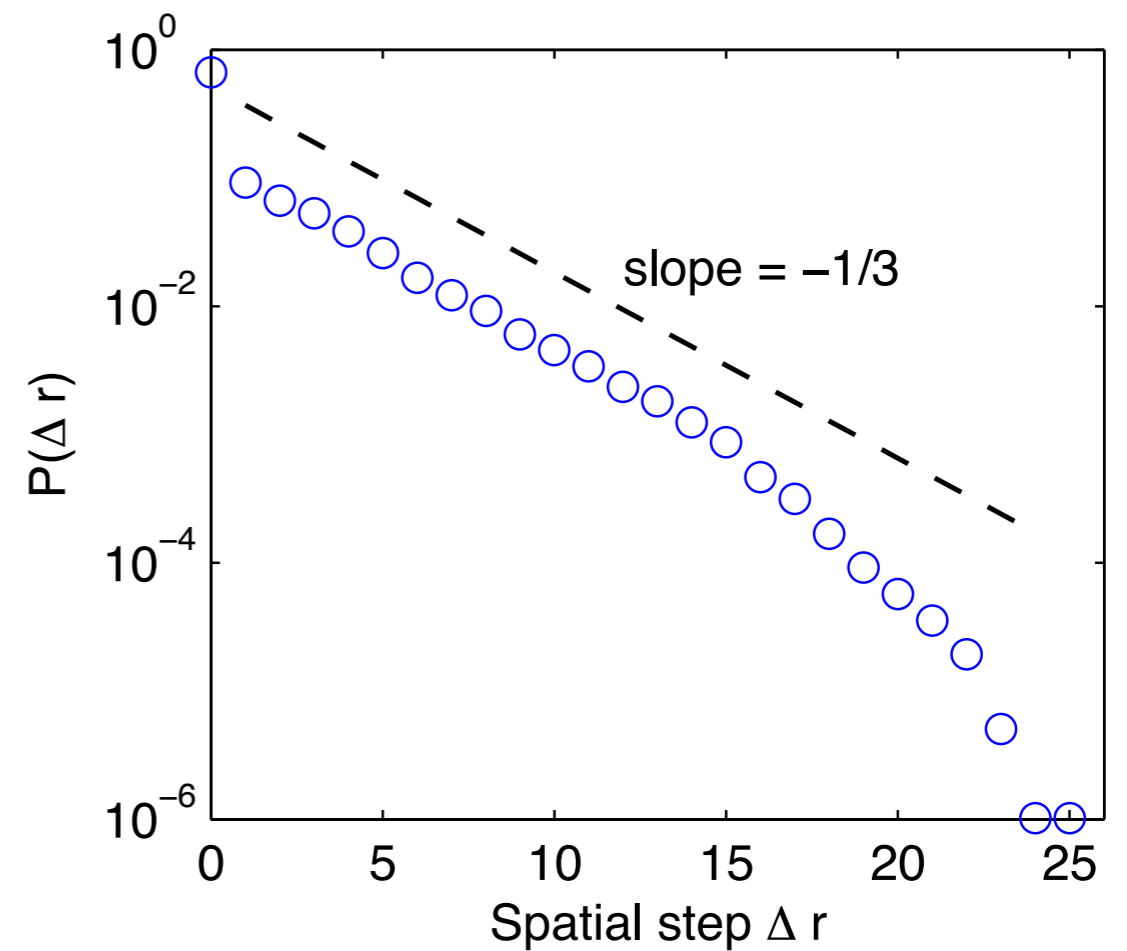
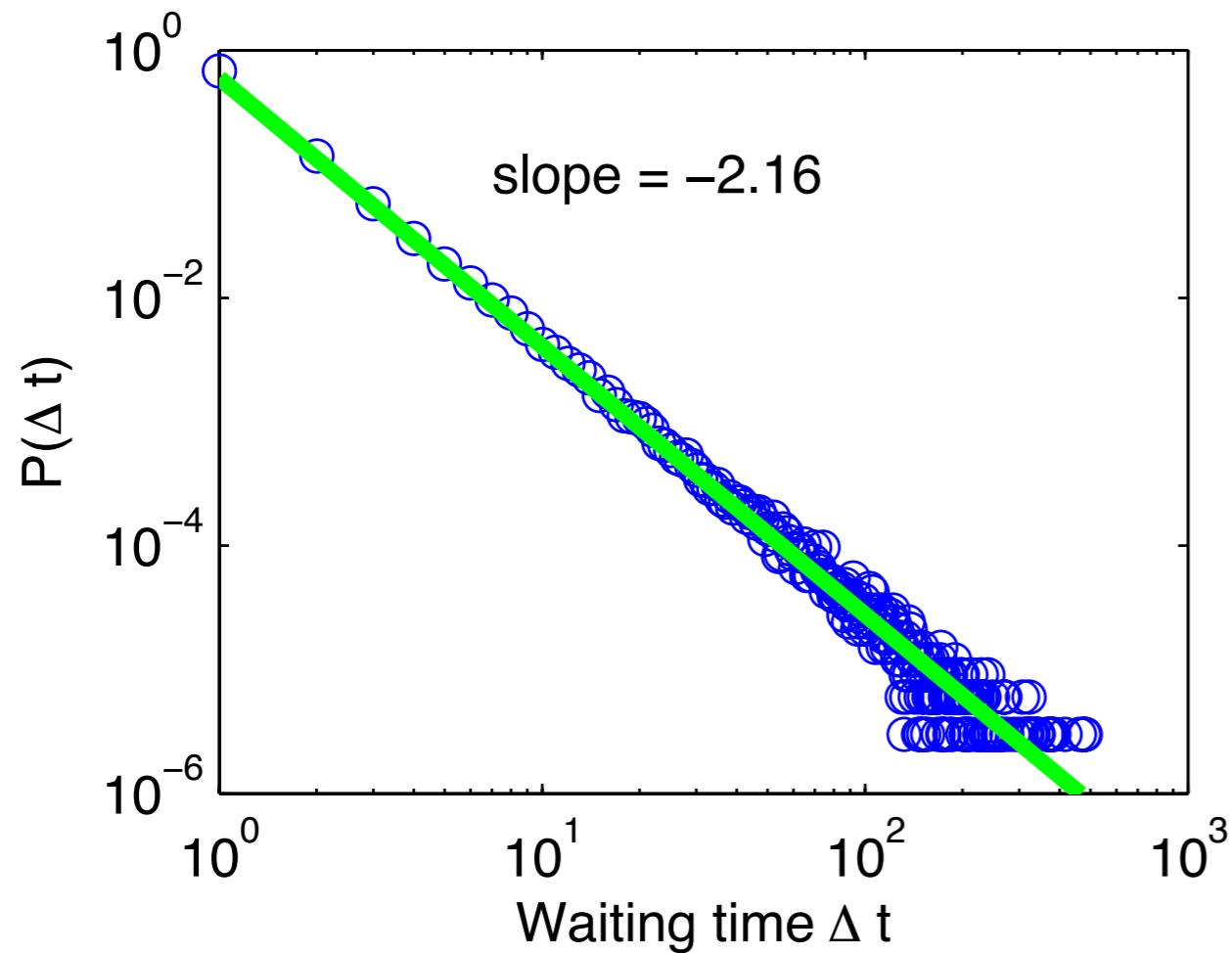


# Waiting times and spatial steps

$$P(\Delta t) \sim \Delta t^{-1-\beta}$$

$$\beta \approx 1.16$$

$$P(\Delta r) \sim e^{-1/3\Delta r} \quad ?$$

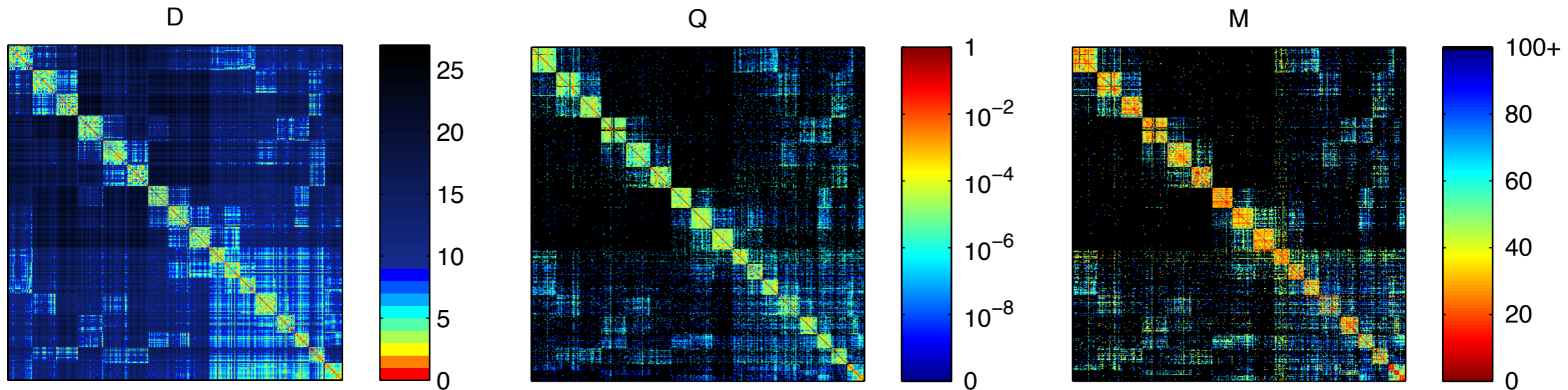


# Transition probabilities and passage times

$D = (d_{ij}) =$  Distance from node  $i$  to node  $j$

$Q = (q_{ij}) =$  Probability to jump from node  $i$  to node  $j$

$M = (m_{ij}) =$  Mean time to walk from node  $i$  to node  $j$



How do they relate?

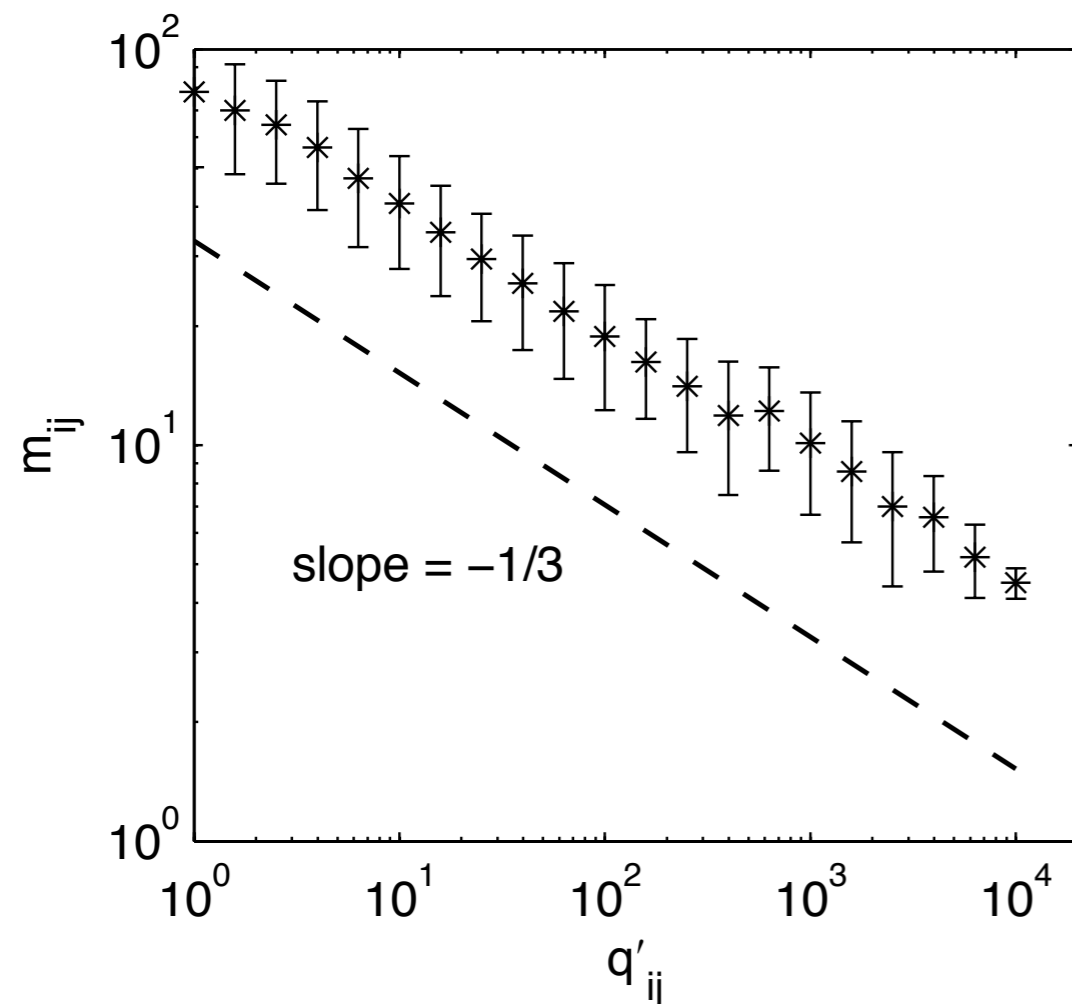
# Transition probabilities and passage times

$D = (d_{ij}) =$  Distance from node  $i$  to node  $j$

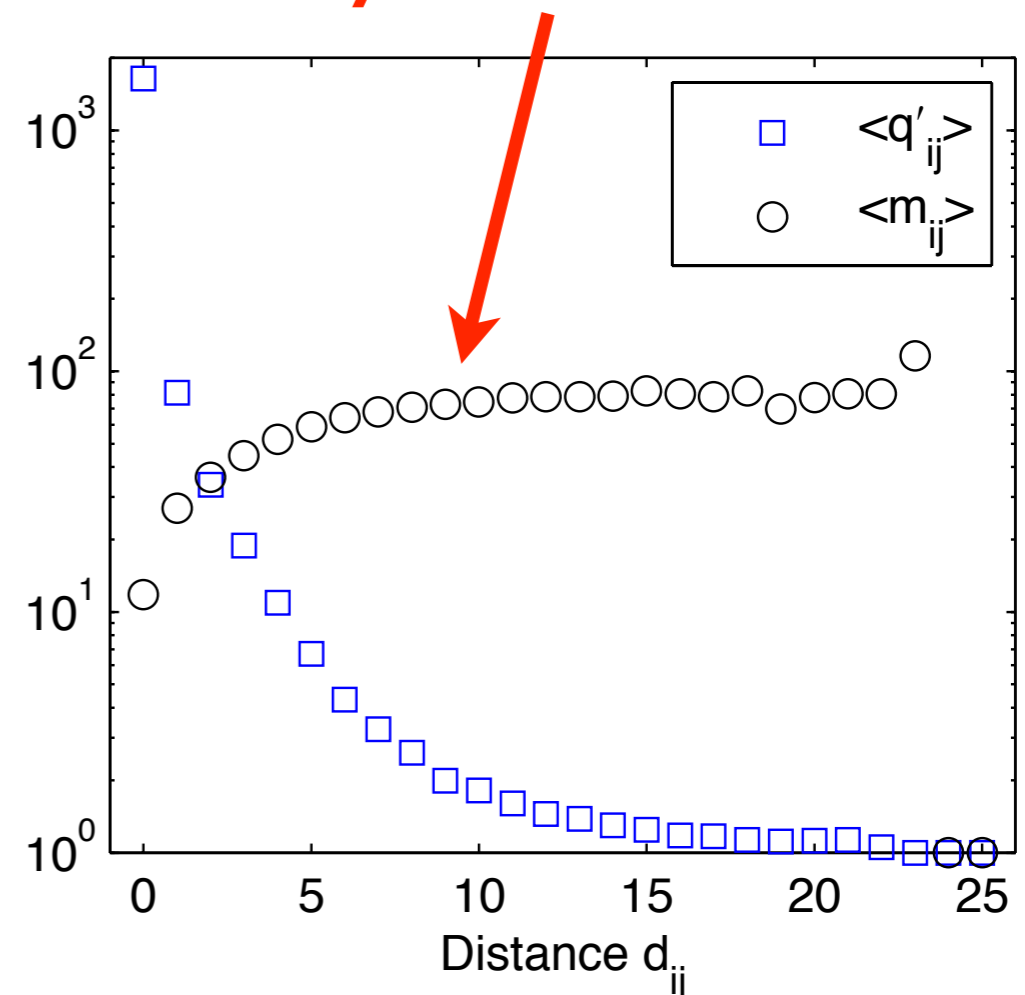
$Q = (q_{ij}) =$  Probability to jump from node  $i$  to node  $j$

$M = (m_{ij}) =$  Mean time to walk from node  $i$  to node  $j$

**Mobility law**  $m \sim q^{-\frac{1}{3}}$  ?

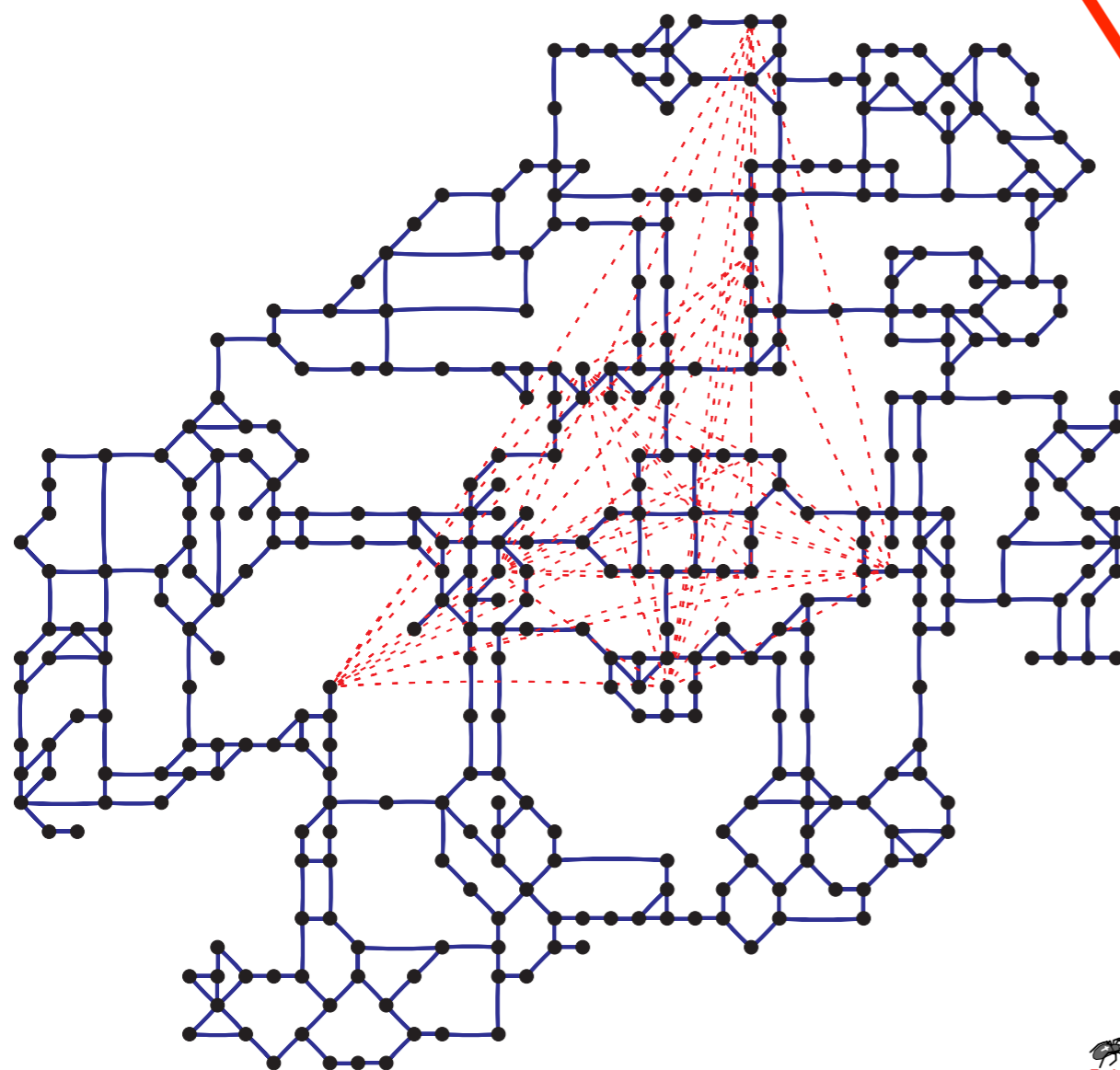


**Why saturation?**

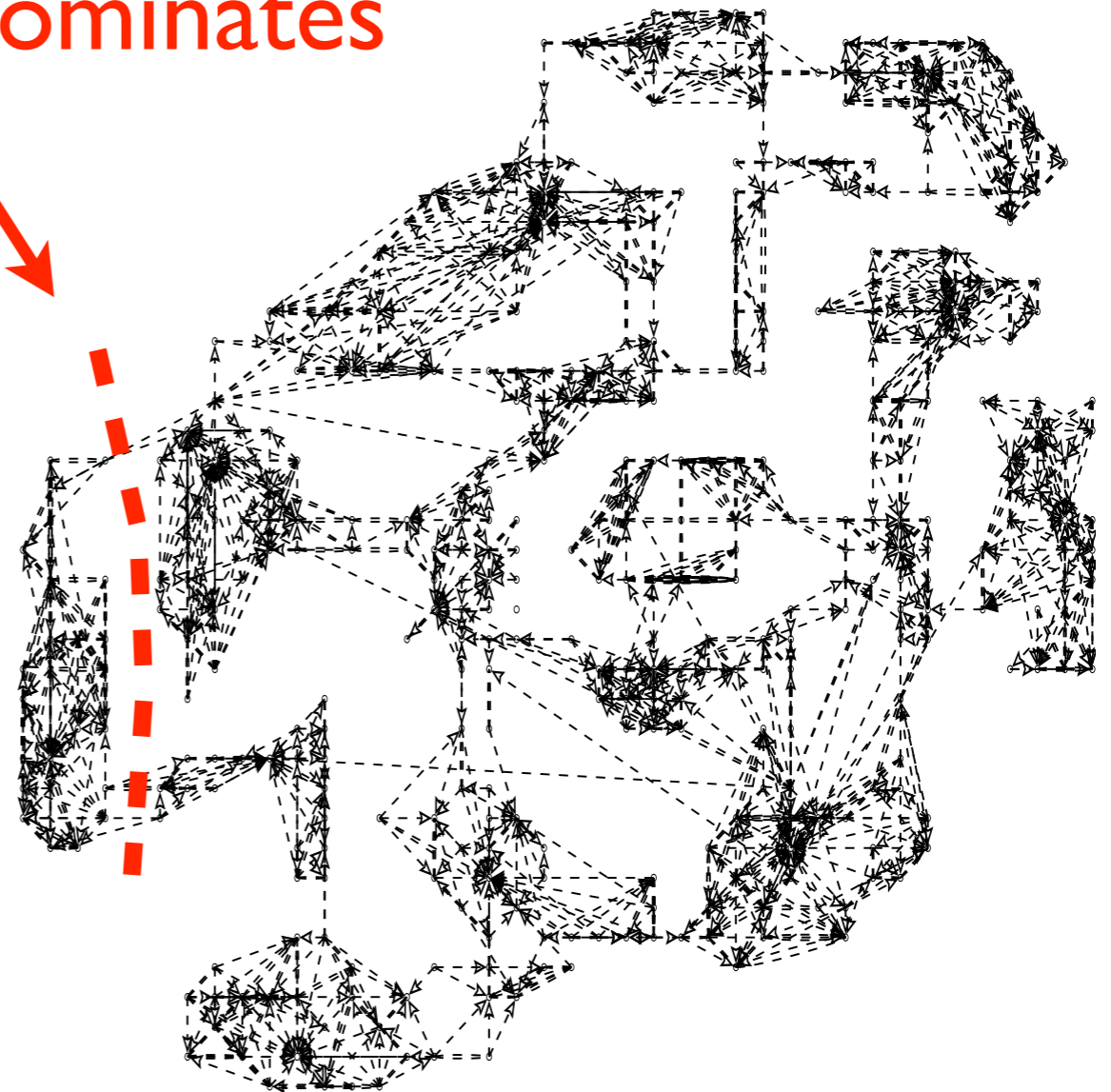


# Two scales of mobility

- 1) **Intra-cluster mobility**: daily routine, home  $\leftrightarrow$  work
- 2) **Inter-cluster mobility**: extraordinary events, war

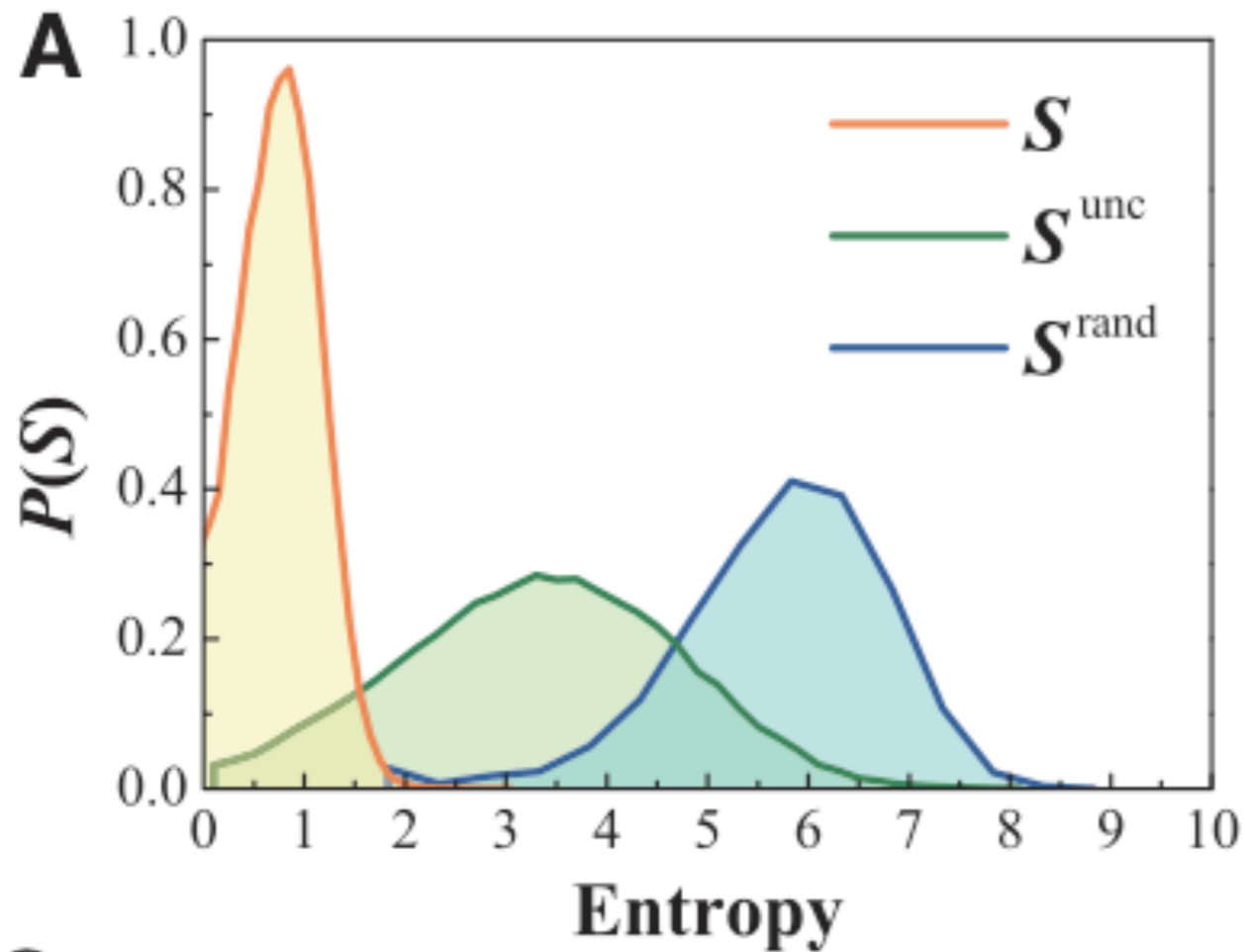


dominates

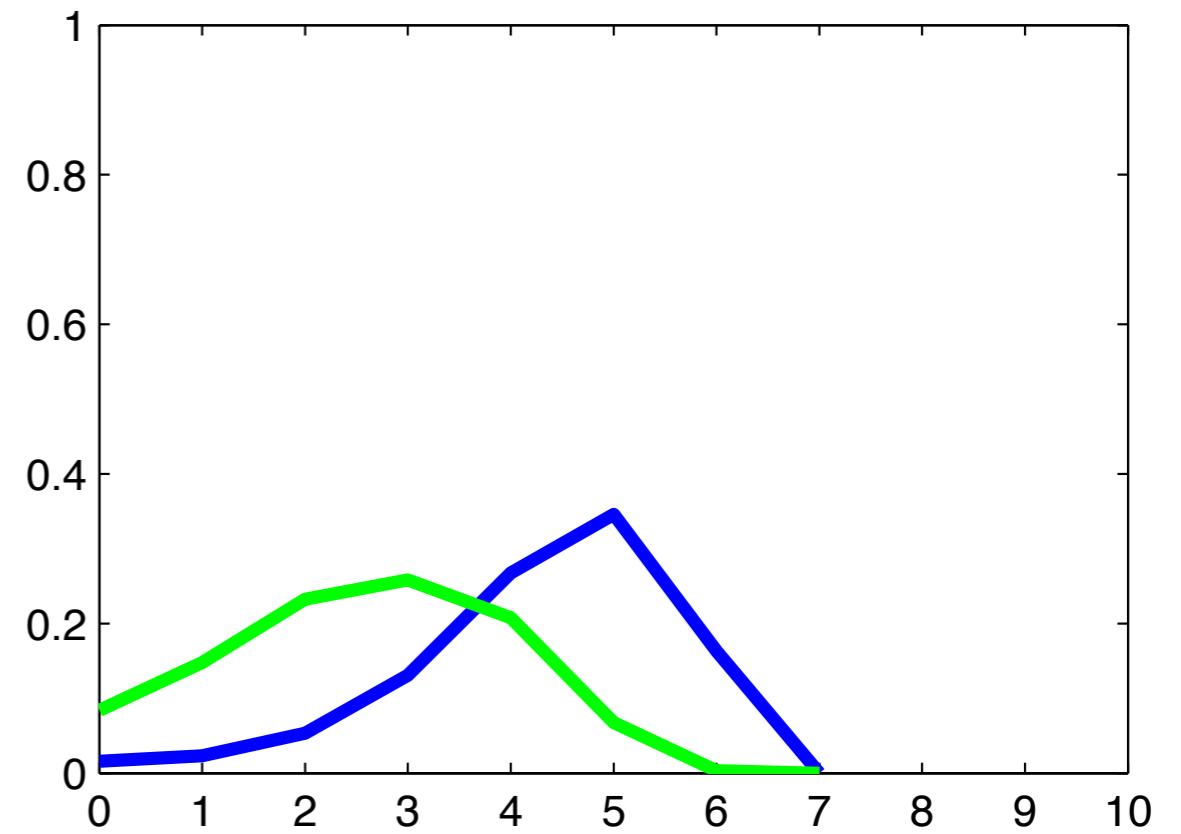


# Comparison with mobile phone study

Mobile phone users



Pardus users



$$S^{\text{rand}} = \log_2 U$$

$$S^{\text{unc}} = - \sum_{i=1}^{400} p_i \log_2 p_i$$

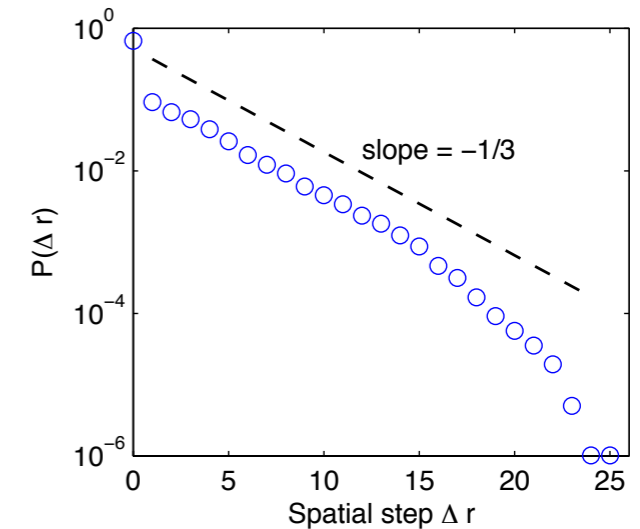
Song et al, Science 327, 1018-1021 (2010)

# Model: Return to previous node

$1 - q$  Draw spatial step from exponential, random-walk until distance reached

$q$  Return to previous node

(where  $0 \leq q < 1$ )



Reproduces properties best (so far)

# Summary

- Establish a **socio-economic laboratory**
- **Subdiffusive mobility** of humans, as in phone study
- Mobility **laws**
- **Two scales**: daily routine versus events

[michael.szell@meduniwien.ac.at](mailto:michael.szell@meduniwien.ac.at)