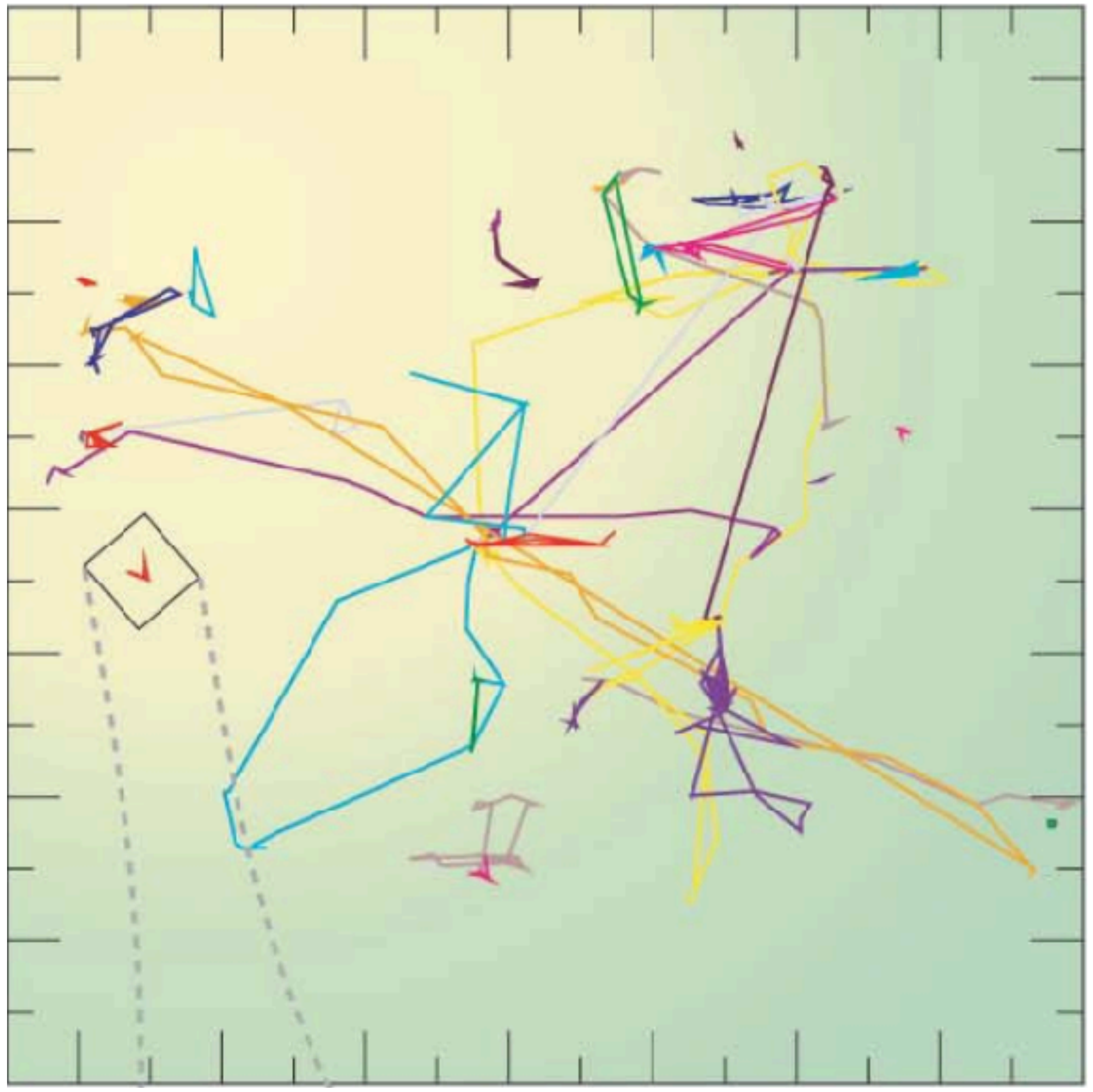
Lecture 11: Individual mobility

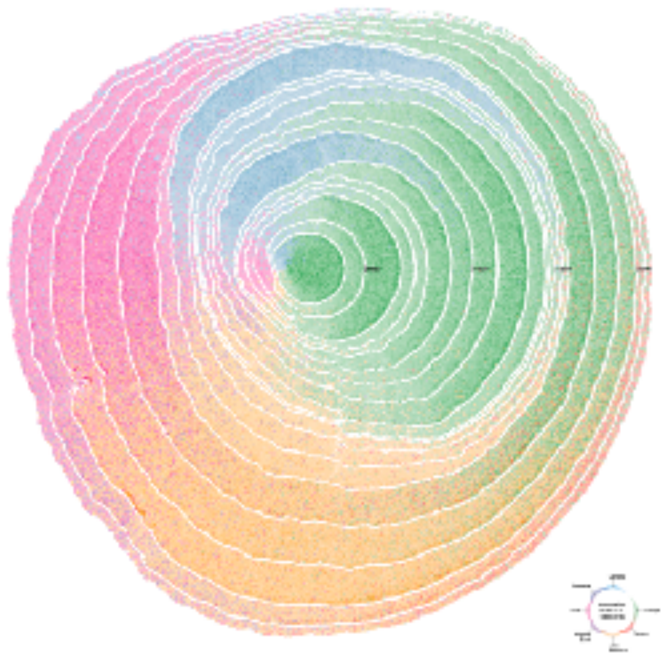
Instructor: Michael Szell

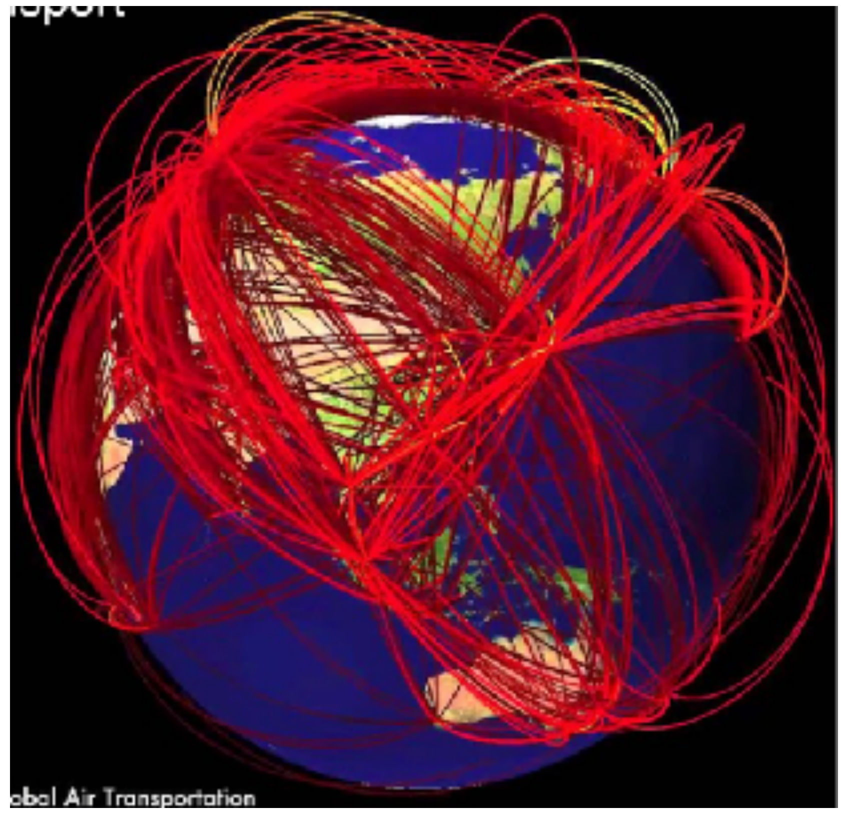
Mar 31, 2022



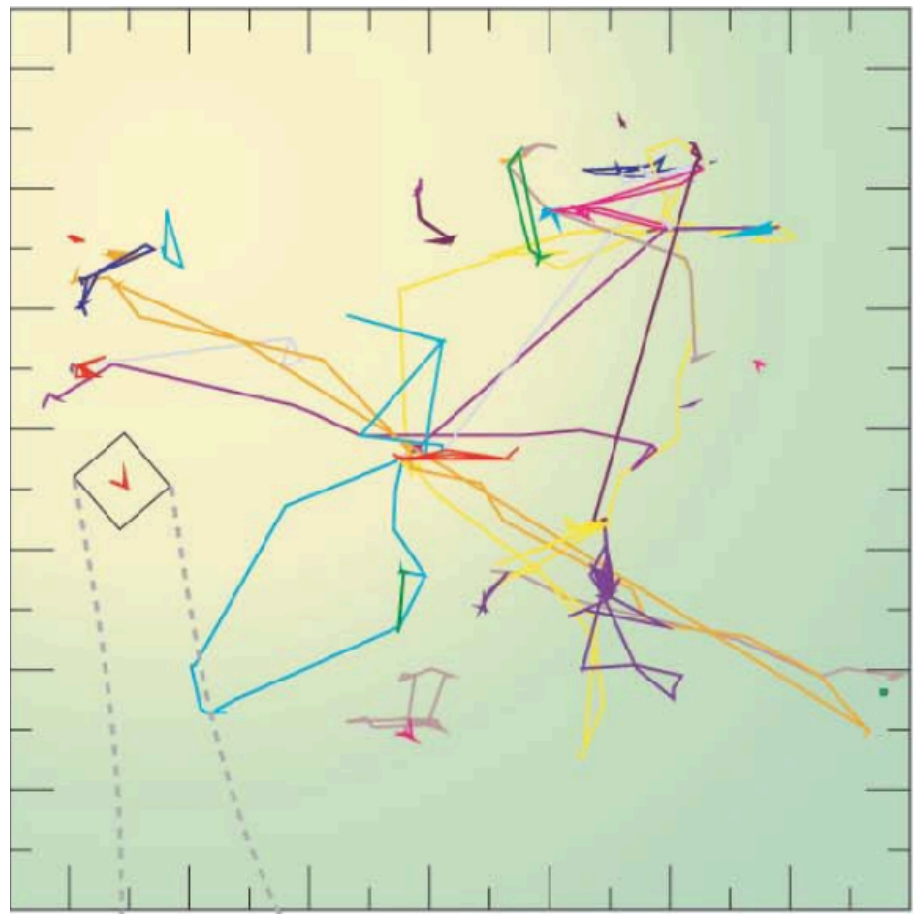
Today you will learn about individual mobility

Overview of mobility approaches

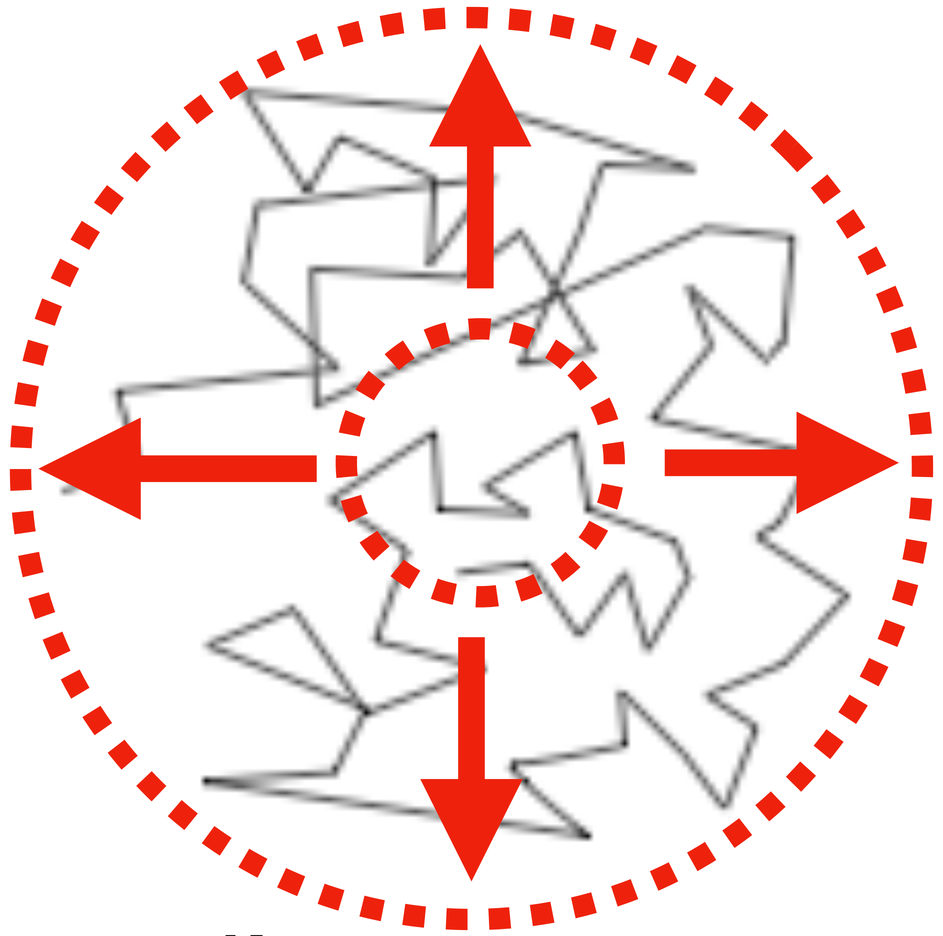




Research on individual trajectories

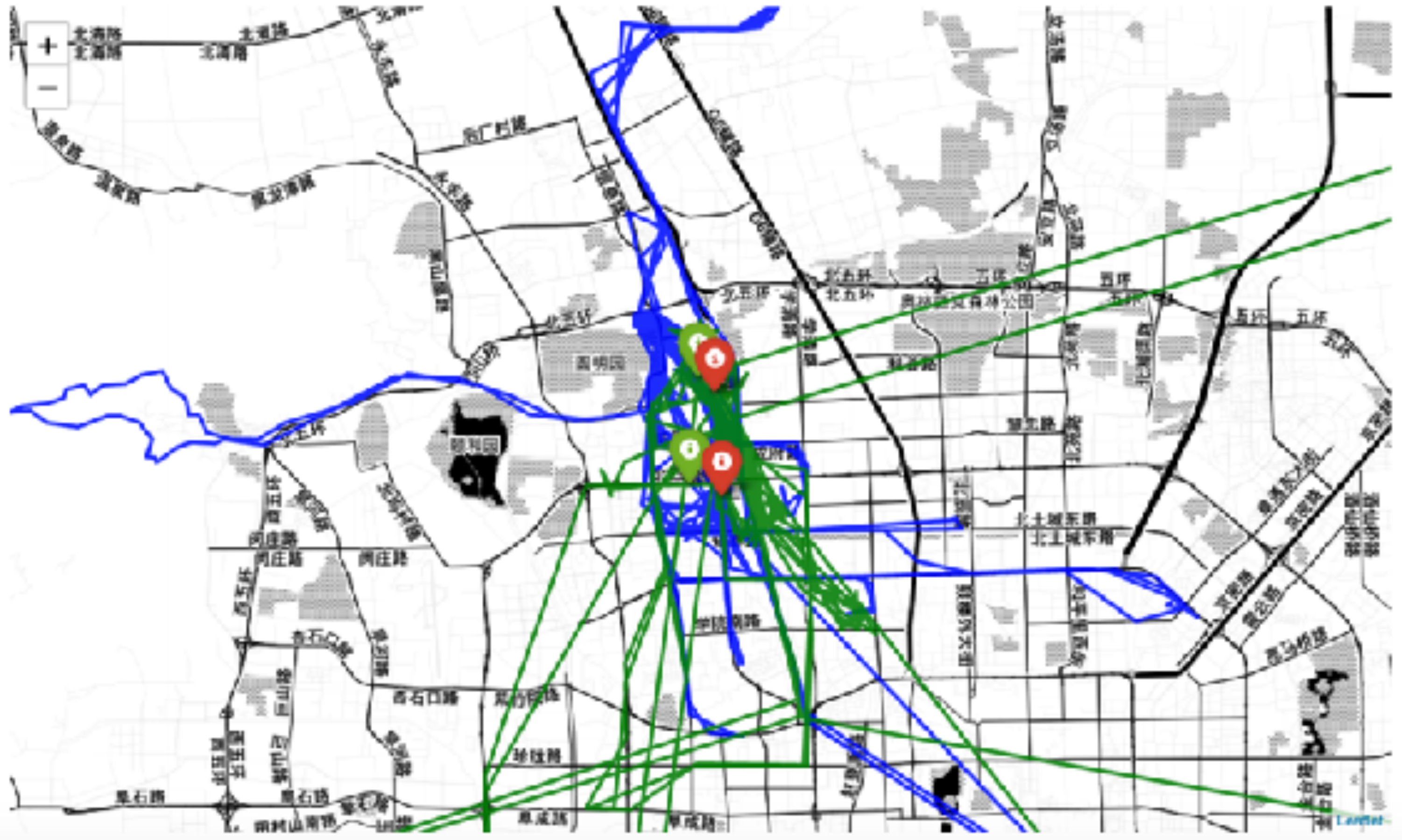


Physics-inspired metrics



$$MSD = \langle r^2(\tau) \rangle = \frac{1}{N} \sum_{n=1}^{N} \left(x_n(\tau) - x_n(0) \right)^2$$

scikit-mobility



You can study mobility=human movements at different scales

Individual

- Single-scale
  - Pedestrian movements
  - Air transport
  - Sea networks
- Multi-scale
  - Intra/Inter-urban mobility
  - Epidemic spreading
- Virtual scale

Population / Aggregate

- Migration
- Spatial Interaction

You can study mobility=human movements at different scales

Individual

Single-scale

Pedestrian movements
Air transport
Sea networks

Multi-scale

Intra/Inter-urban mobility
Epidemic spreading

Virtual scale

Population / Aggregate

Migration

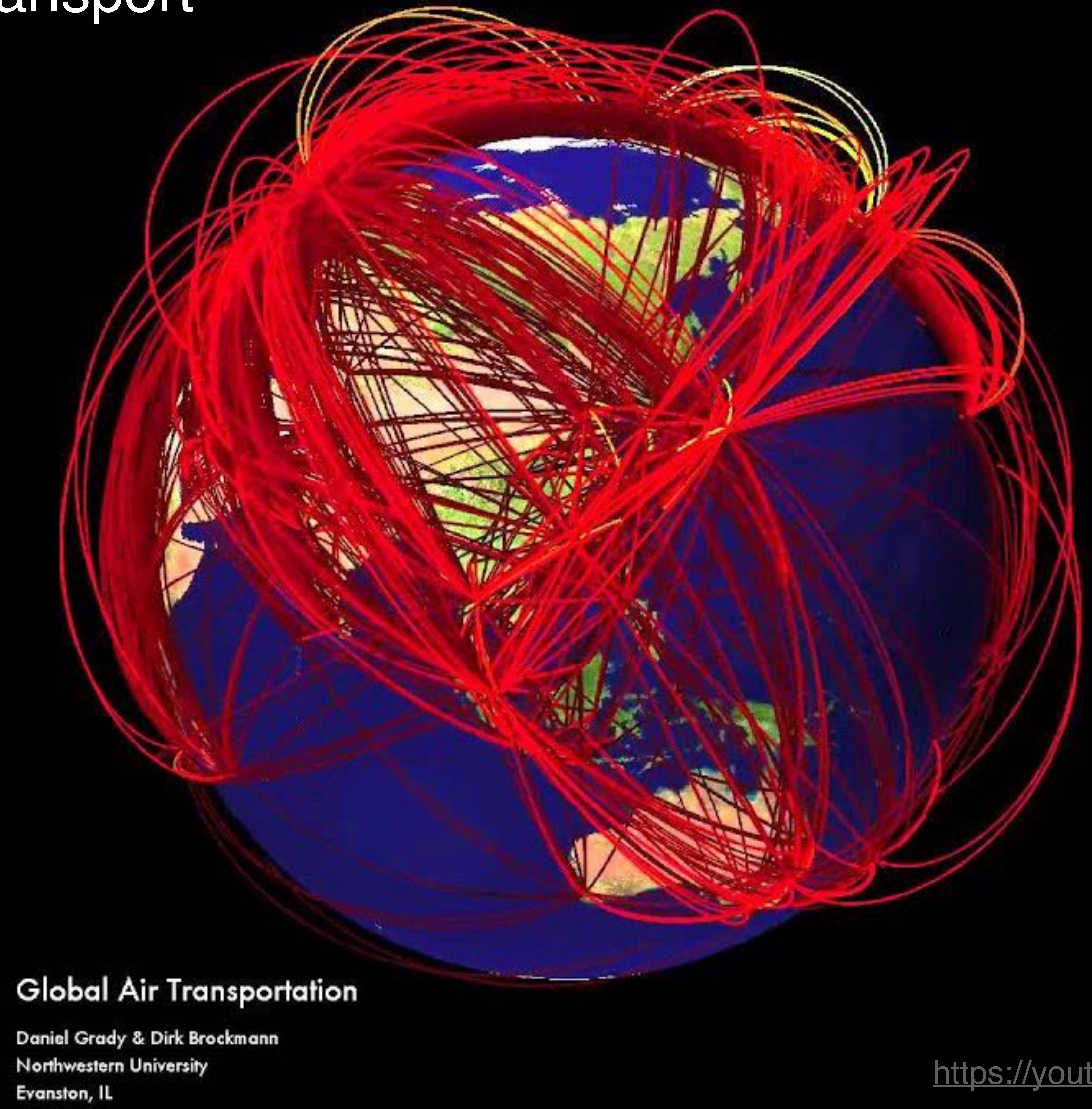
Spatial Interaction

Single scale: Pedestrian movements

Agent-based simulations with the social force model

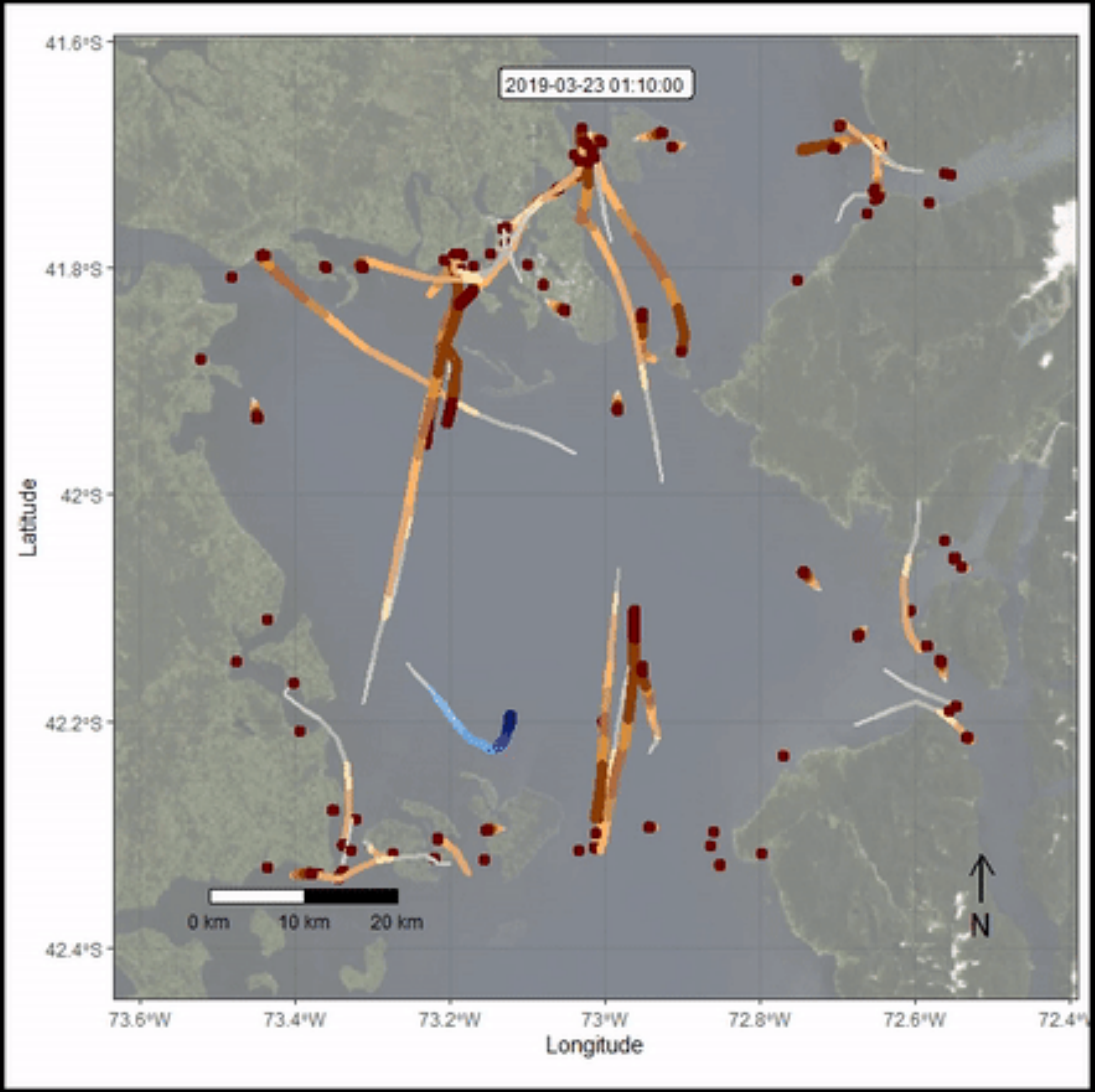
https://youtube.com/watch?v=Xcbc4ff0EY8

Single scale: Air transport



https://youtube.com/watch?v=a6Wh6-6toiQ

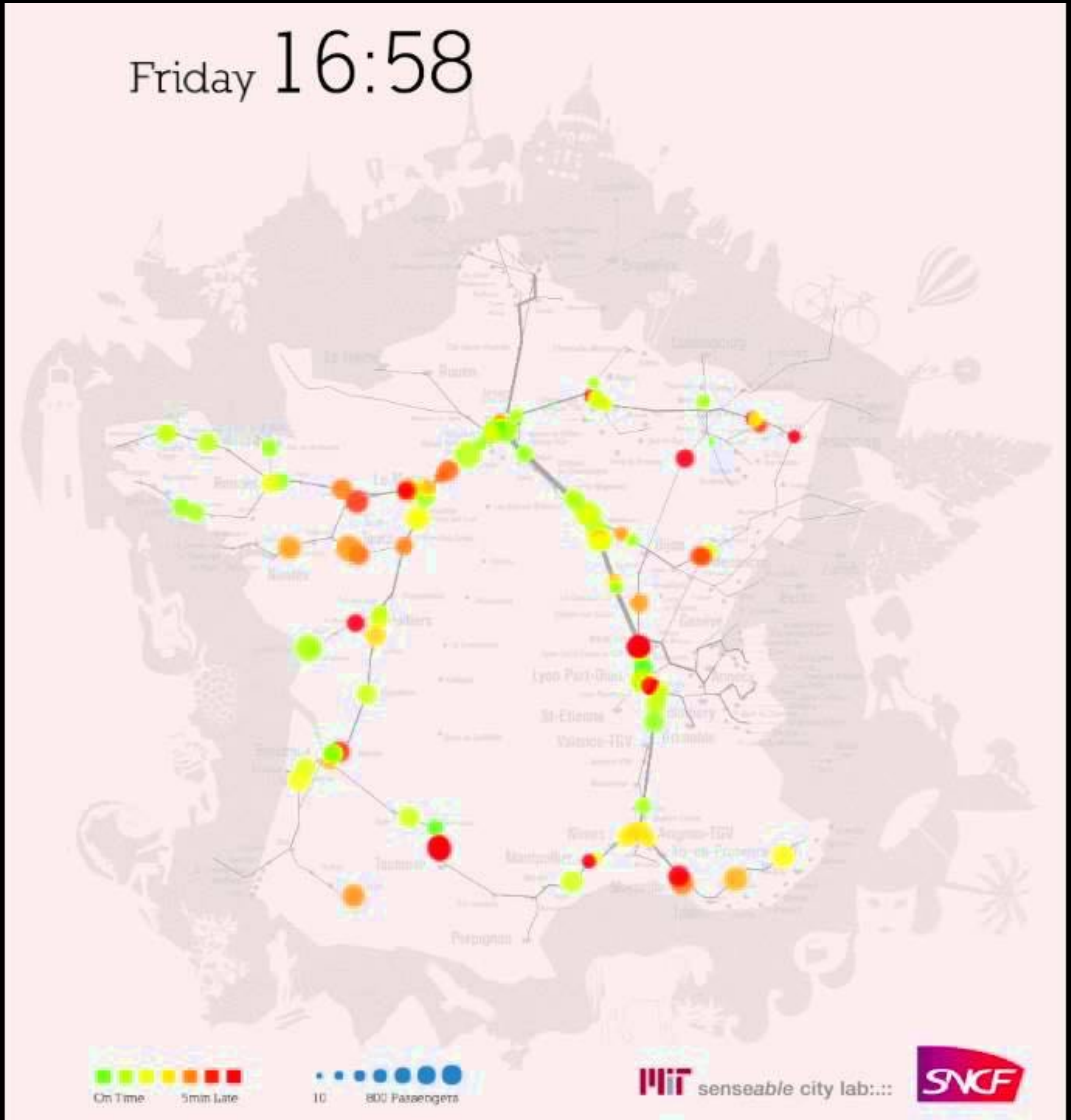
Single scale: Sea transport



Multi-scale: Intra-urban mobility

Multi-scale: Intra-urban mobility

Multi-scale: Inter-urban mobility

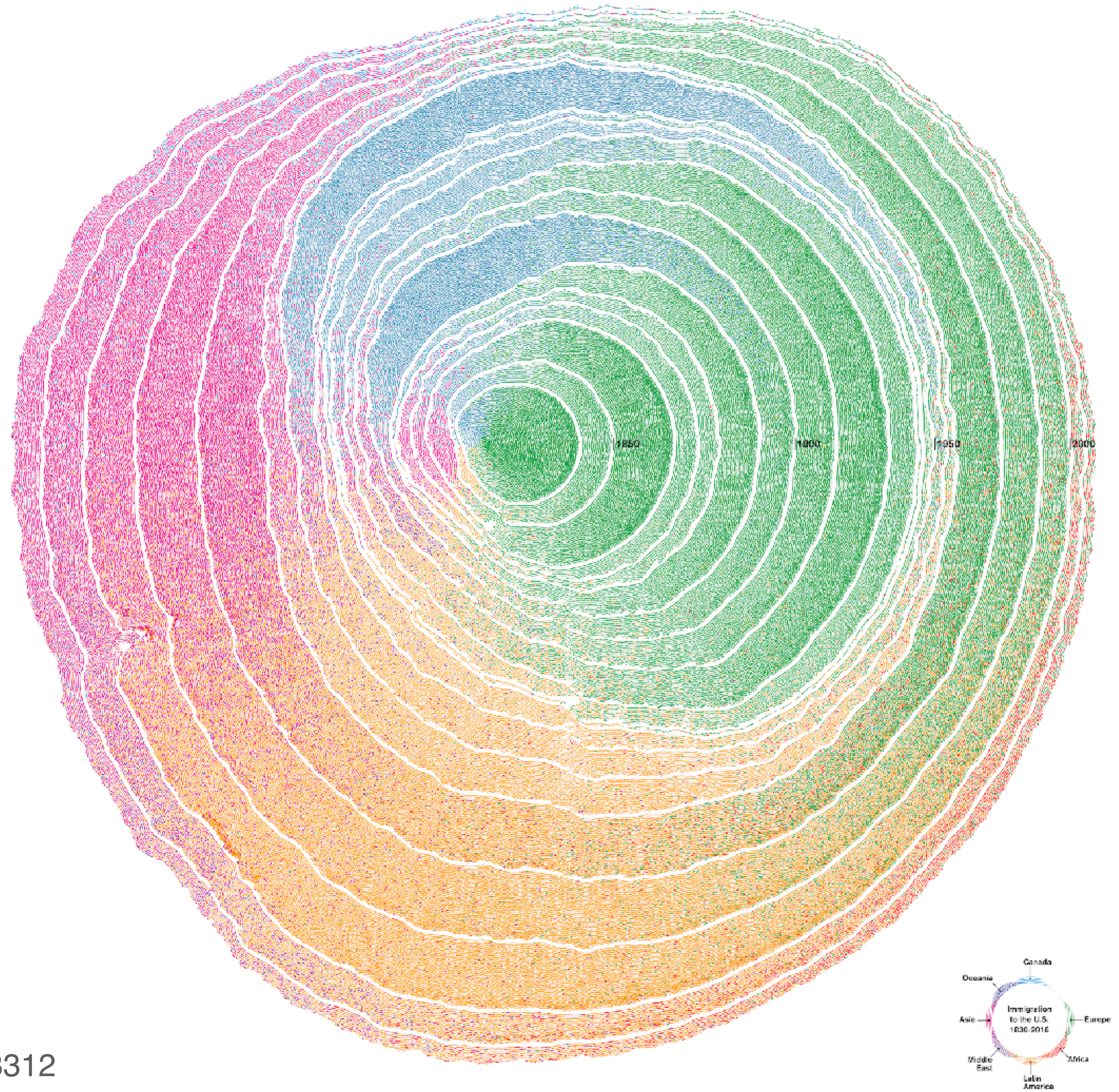


https://youtube.com/watch?v=I17_nuPiJI4

Multi-scale: Epidemic spreading

https://youtube.com/watch?v=YstB9VWDUqE

Population scale: Migration



https://www.informationisbeautifulawards.com/showcase/3312

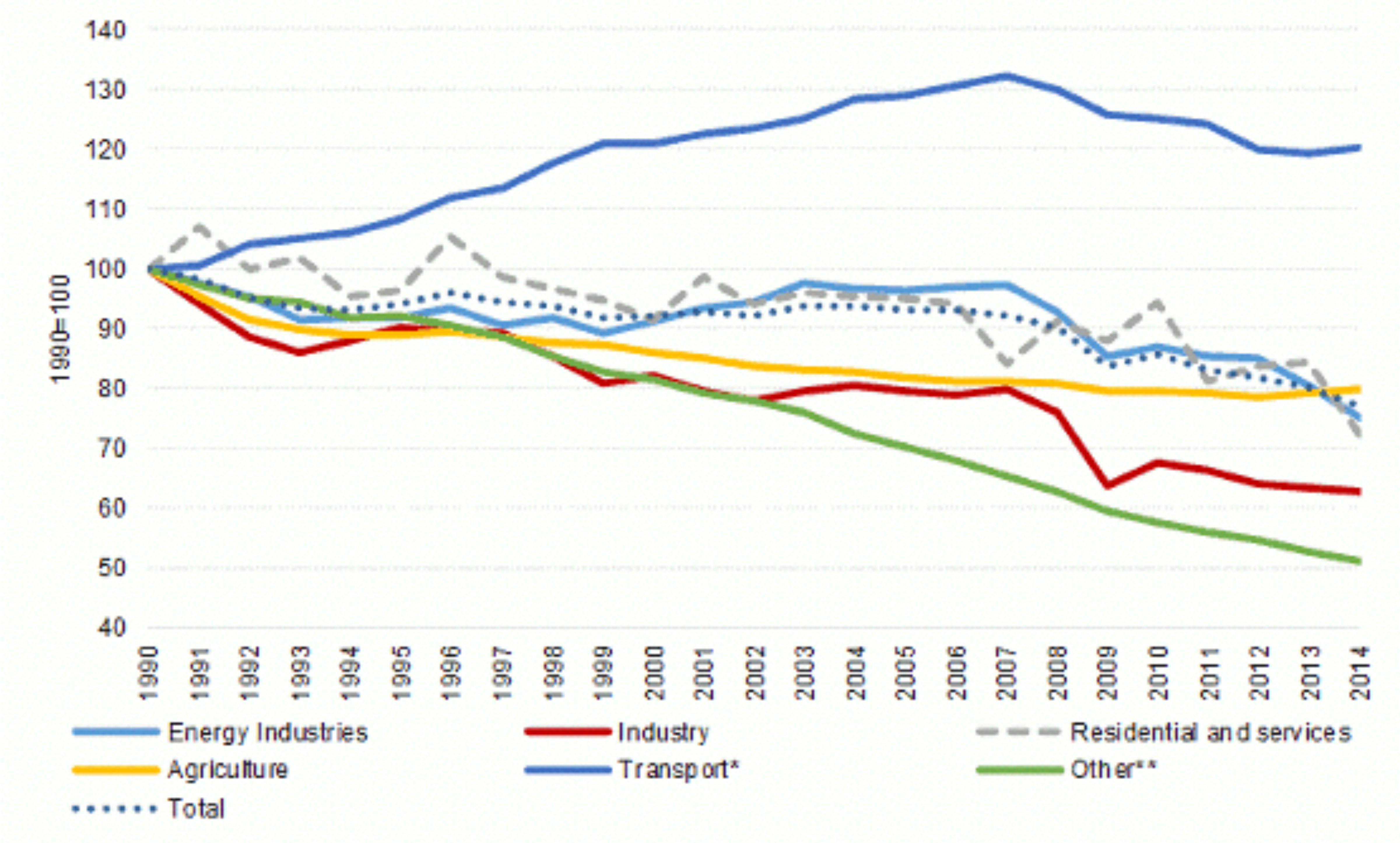
Urban mobility

Mobility takes many resources

Average household spending: ~20%

Mobility takes many resources

Average household spending: ~20%



Transport represents almost a quarter of Europe's greenhouse gas emissions and is the main cause of air pollution in cities.

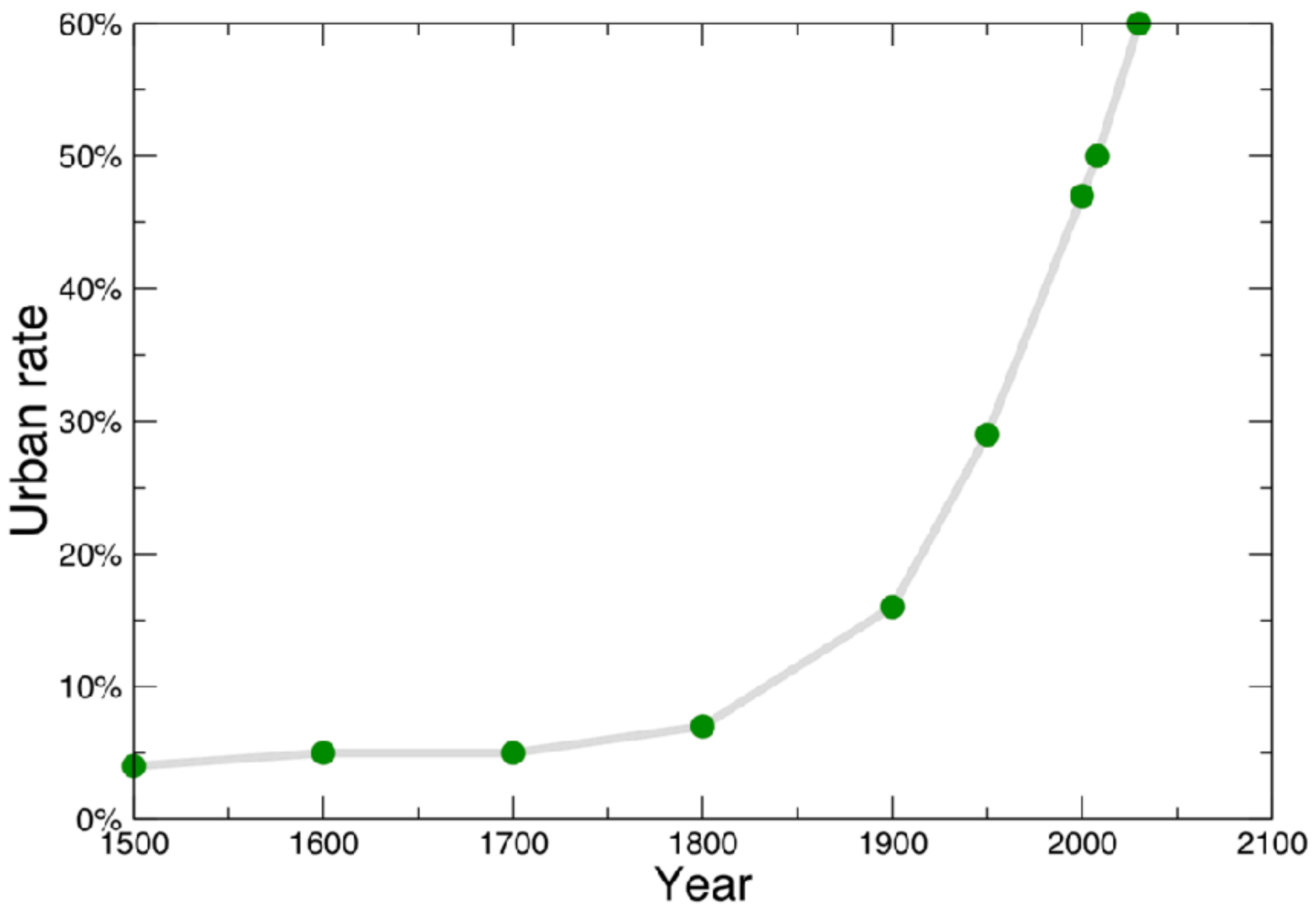
https://ec.europa.eu/clima/policies/transport_en

Mobility is an ever bigger issue in cities

55% of the world's population lives in cities

By 2050, it will be 70%

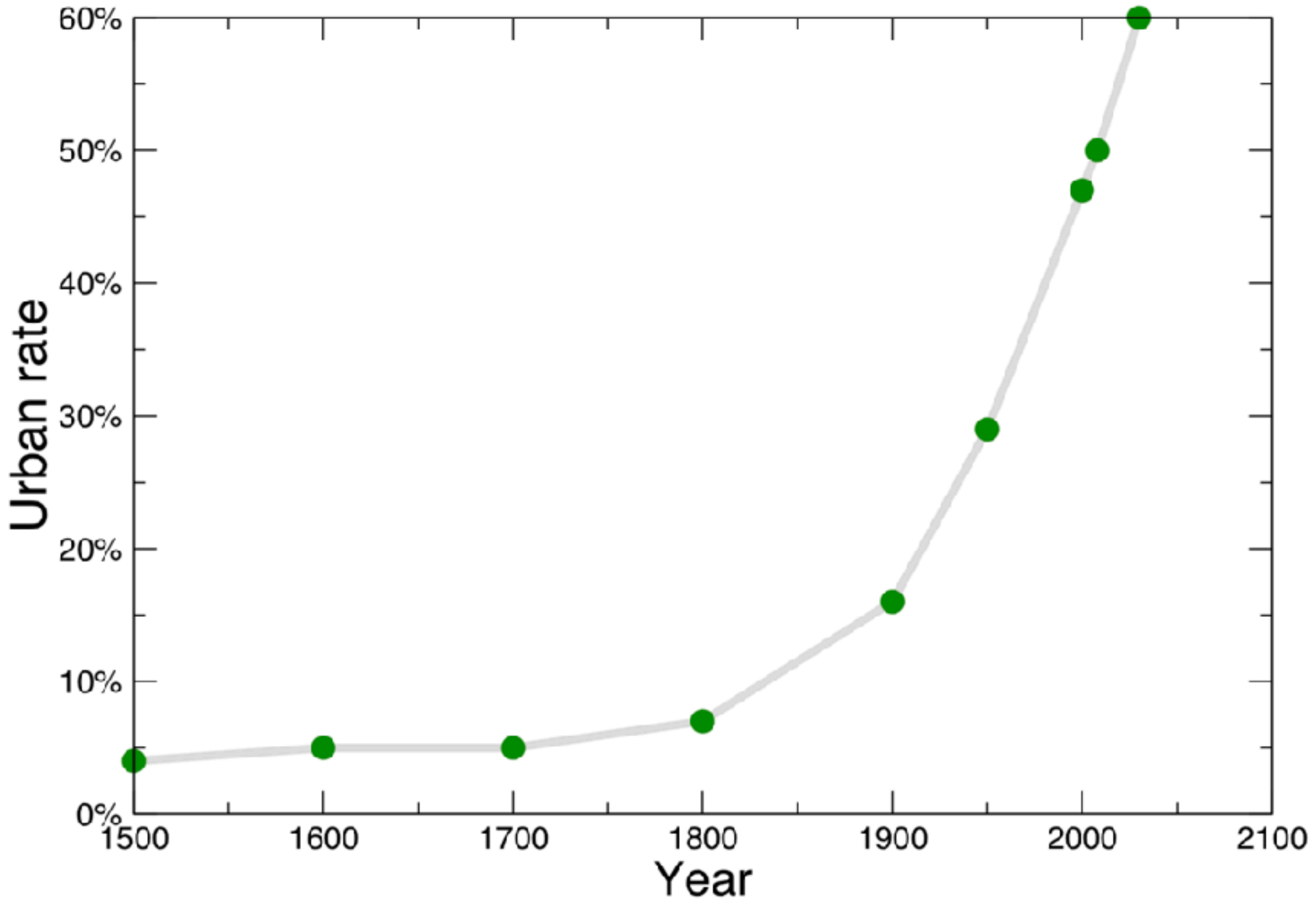
In north america, it is already 82%



https://www.un.org/development/desa/en/news/population/2018-revision-of-world-urbanization-prospects.html

Mobility is an ever bigger issue in cities

Based on satellite images, already 84% of the world's population lives in cities



https://www.reuters.com/article/us-global-cities/everything-weve-heard-about-global-urbanization-turns-out-to-be-wrong-researchers-idUSKBN1K21UU

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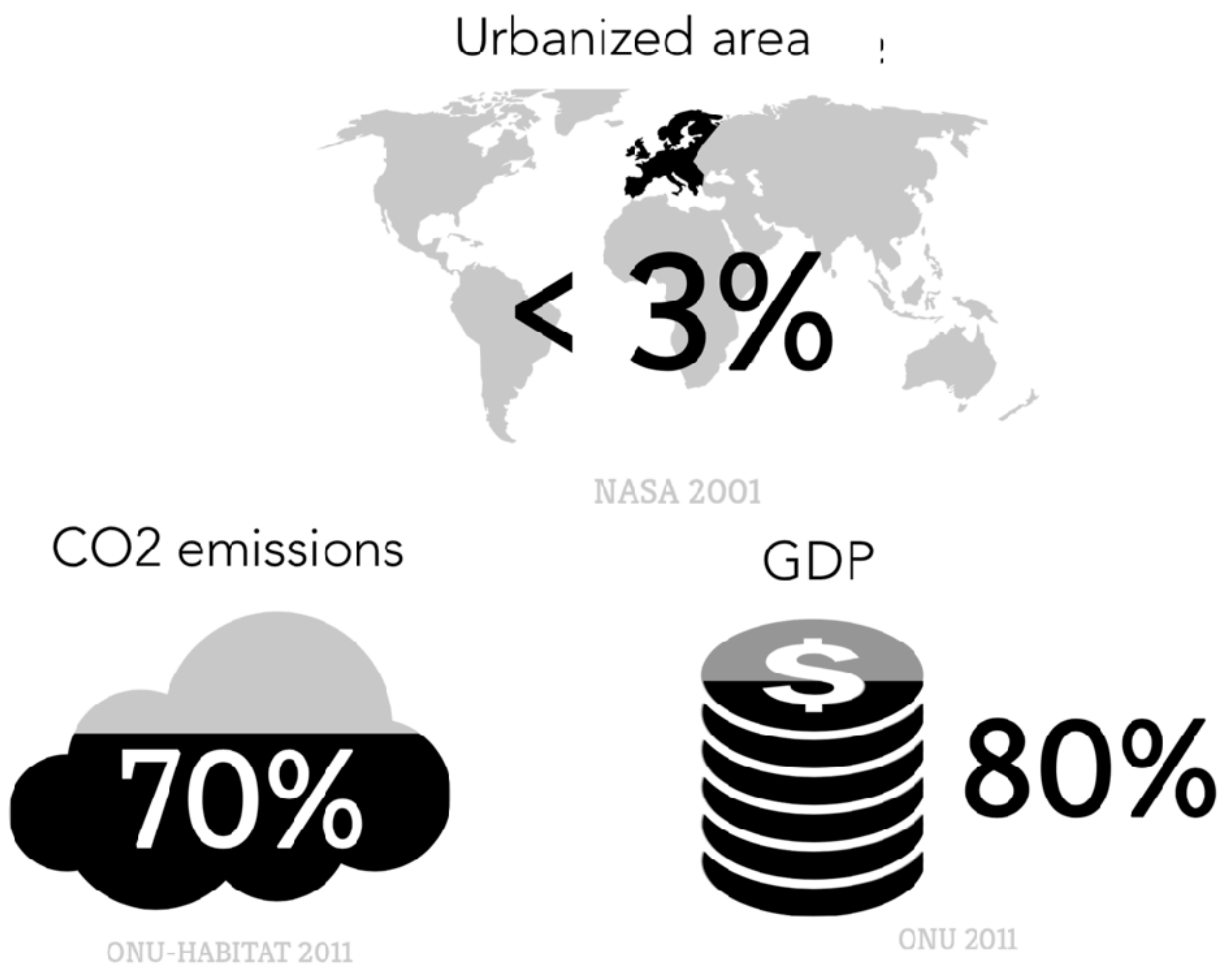
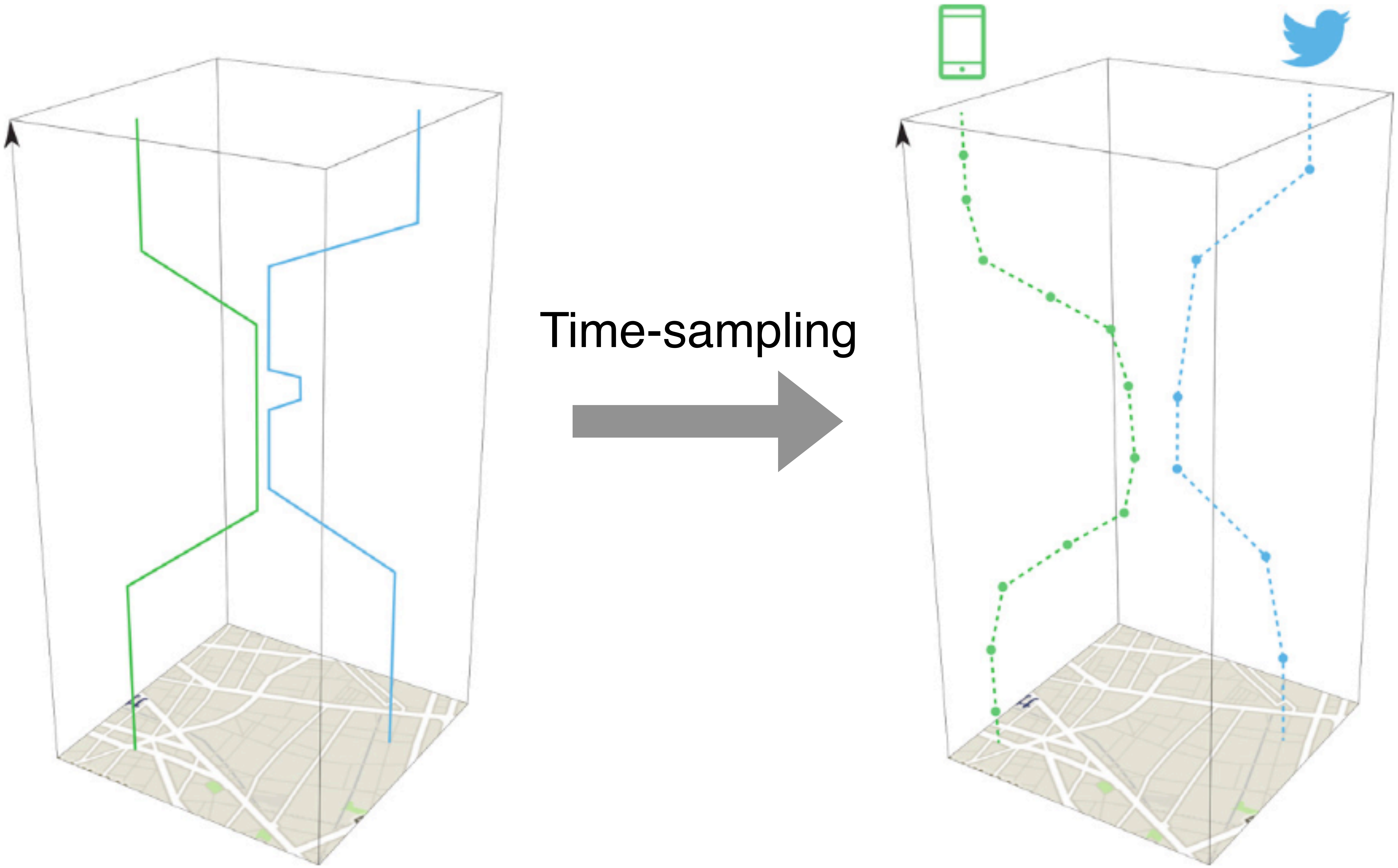


Solving problems in cities means solving problems for most of humanity

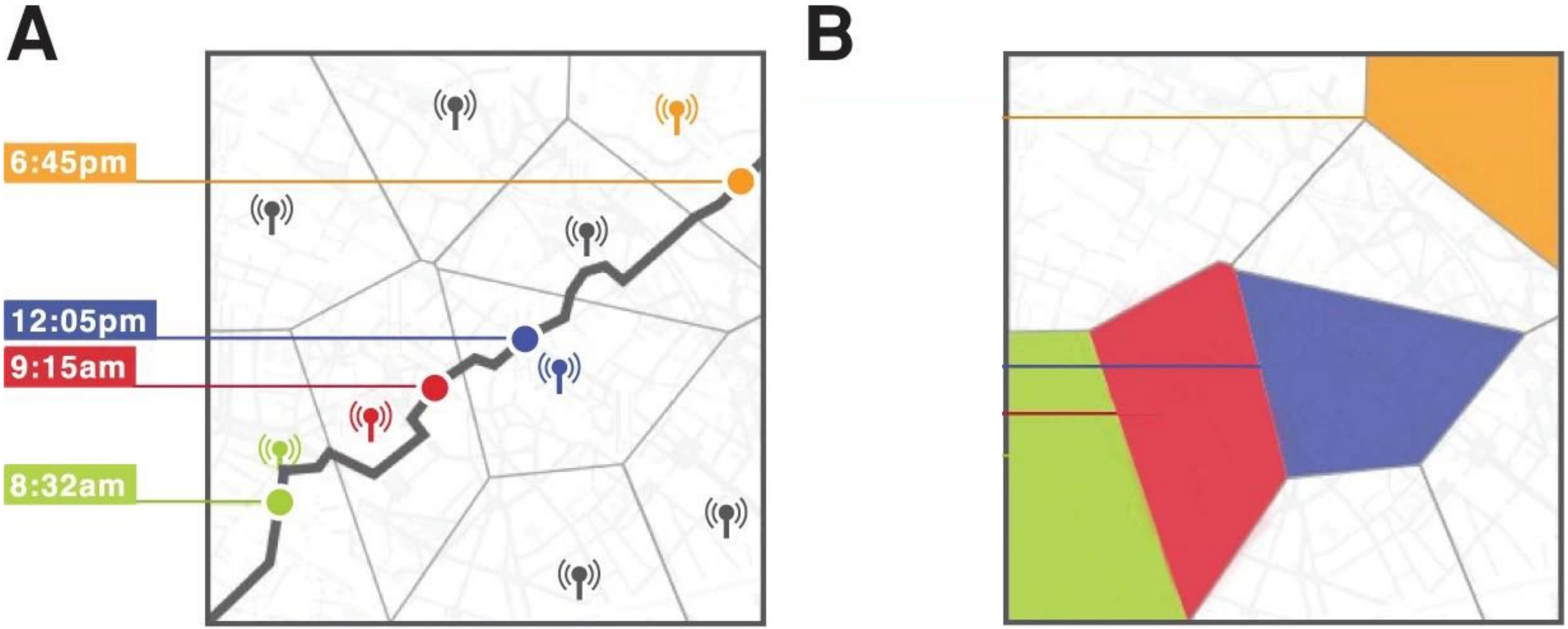
Measuring individual trajectories

The cube of time geography shows mobility in space-time



Hägerstrand (1970)

Call Detail Records (CDR) match location to the nearest tower



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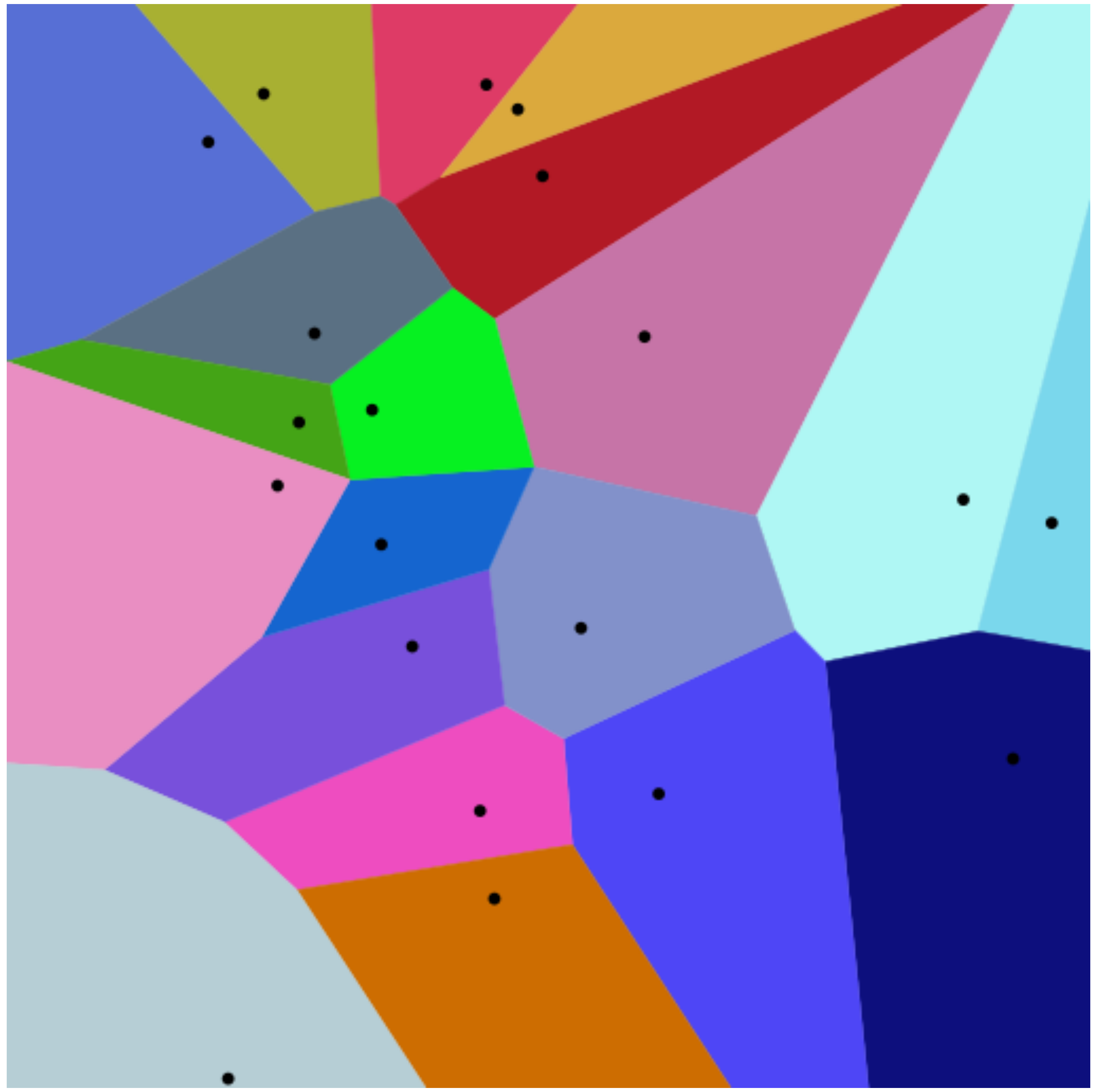
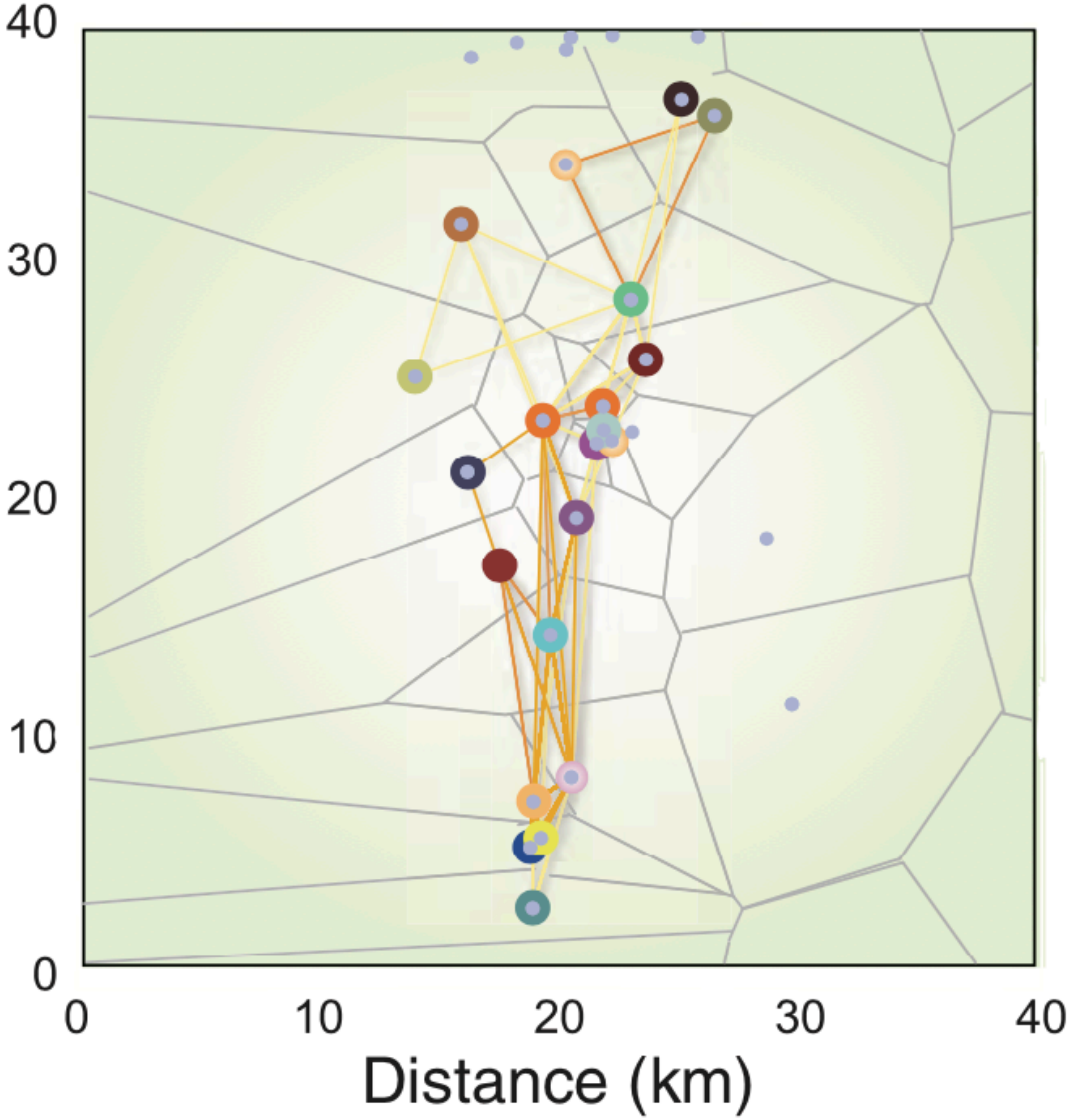
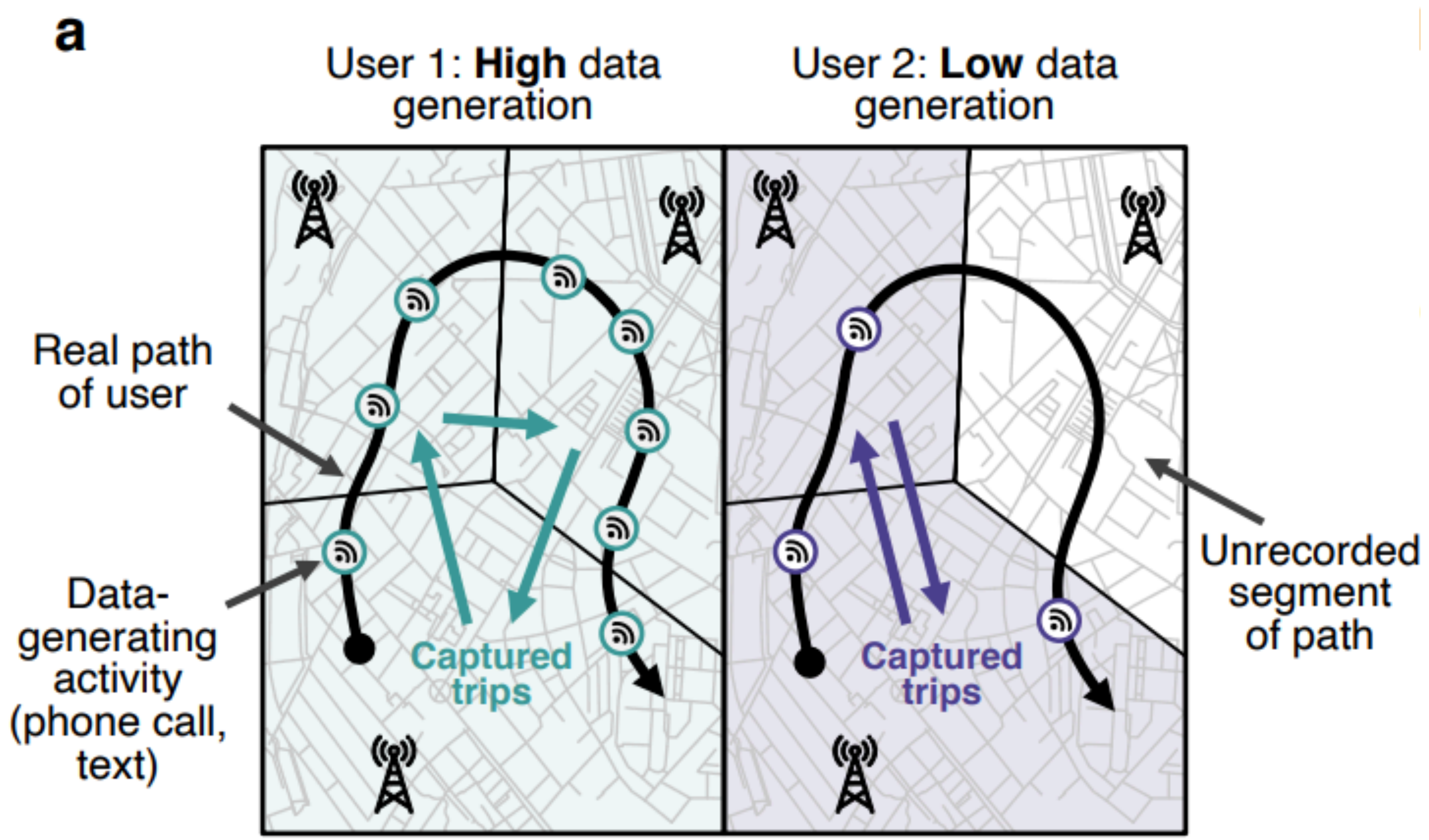




https://en.wikipedia.org/wiki/Voronoi_diagram

Call Detail Records (CDR) have a lot of biases

Sampling bias: record only when making a call or being called



https://arxiv.org/abs/2112.12521

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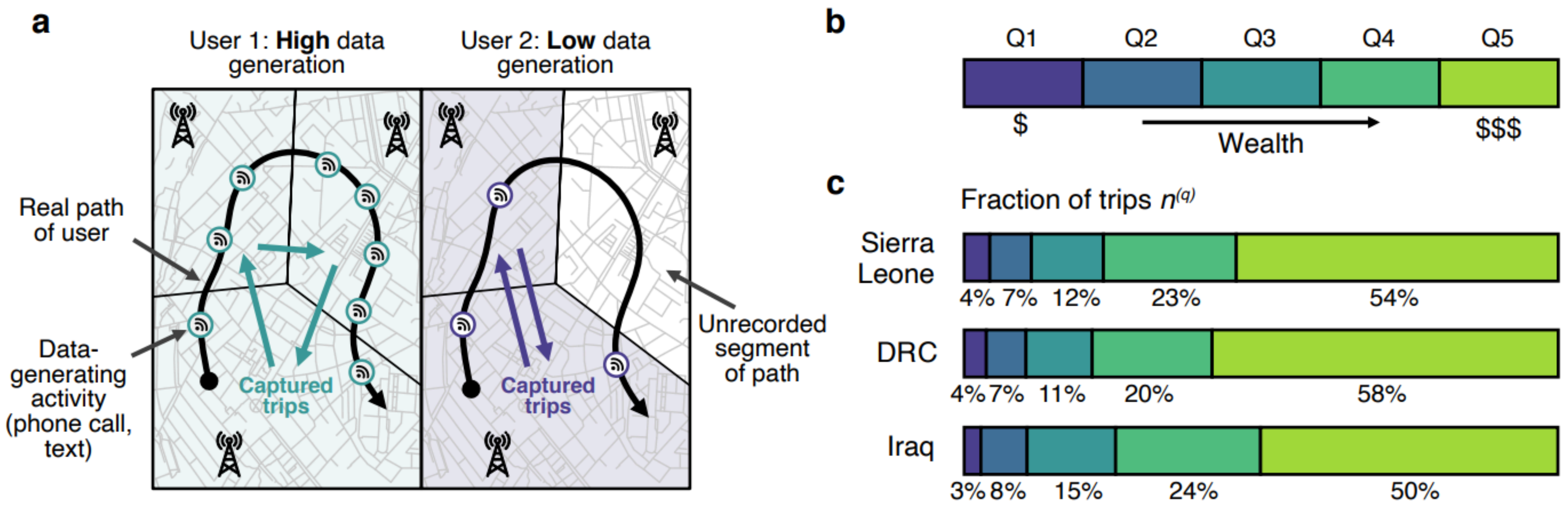
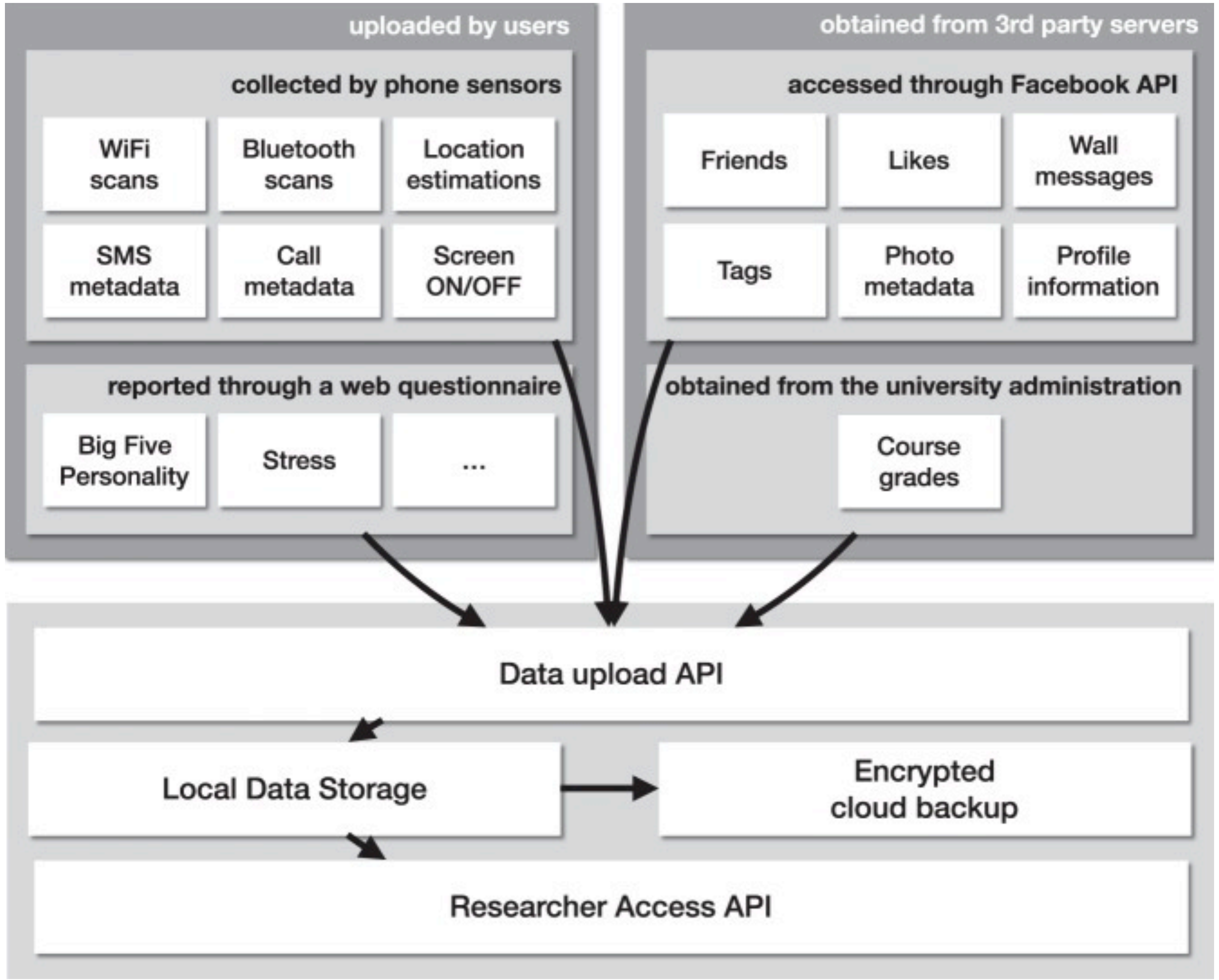


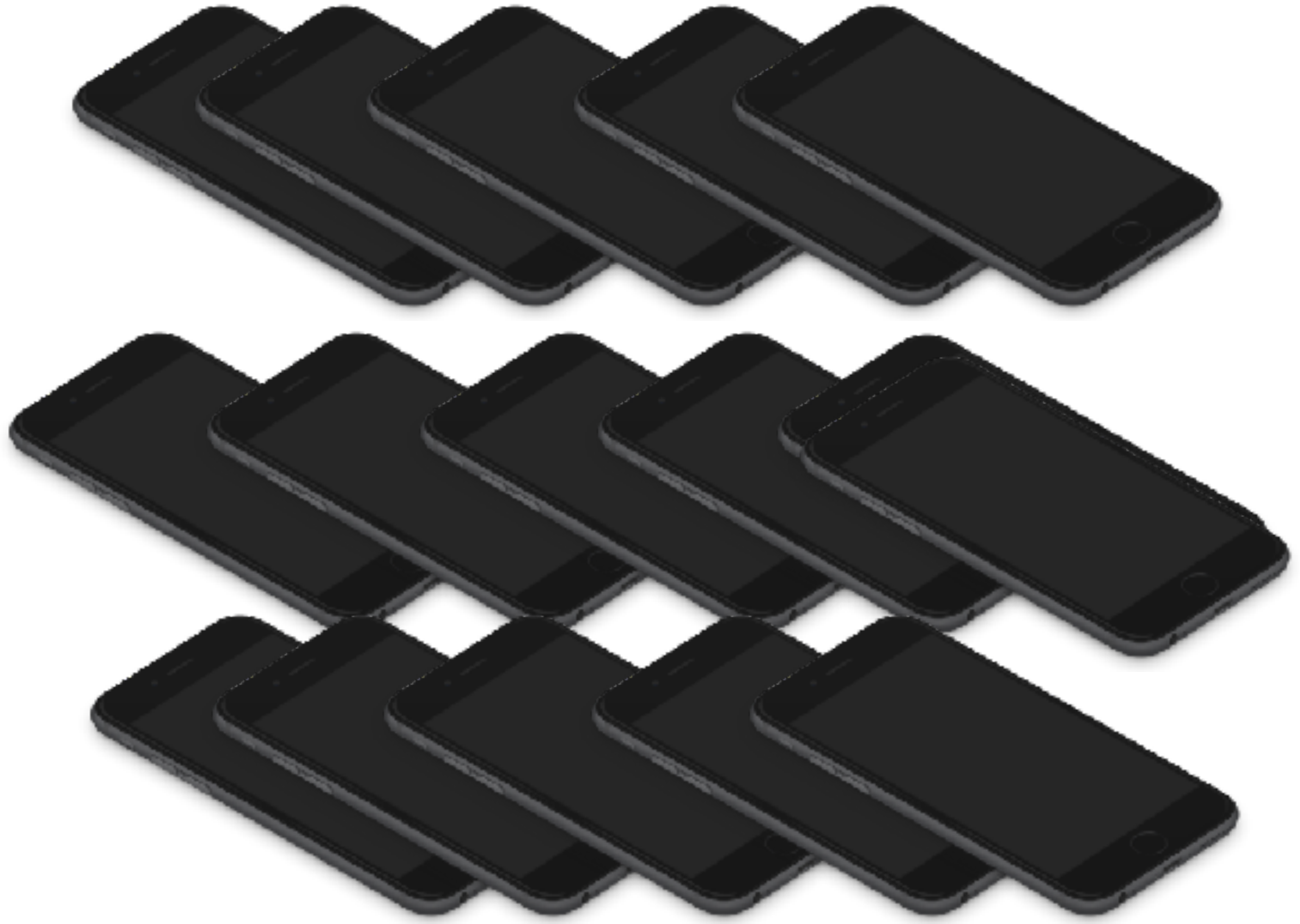
https://arxiv.org/abs/2112.12521

You could track more than just CDR

Activity Data Records (XDR) or deliberate tracking can give more data:
Copenhagen Network Study



1000 x



https://pubmed.ncbi.nlm.nih.gov/31827097/

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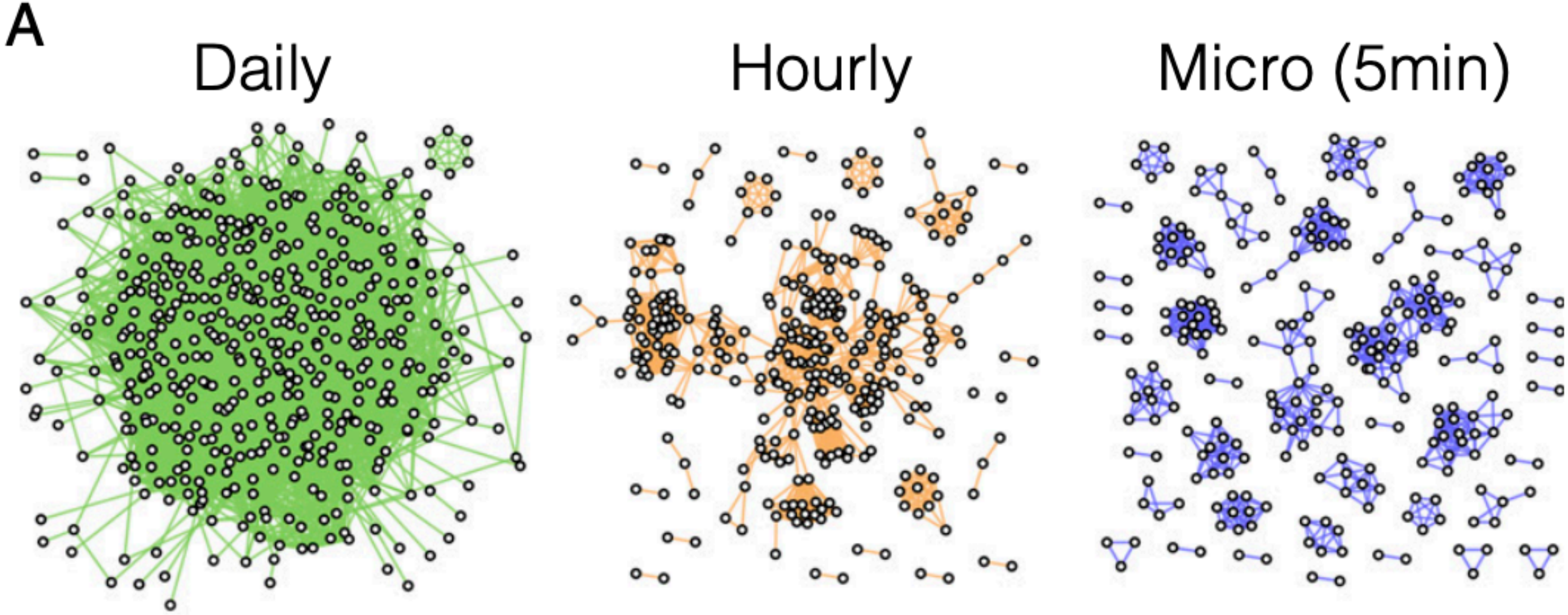


Many other sources or proxies for mobility data exist

Transport

TomTom

Oyster cards

Taxi

Bike sharing

Social media

Foursquare / Facebook check-ins

Geolocated social media posts (Twitter)

Other

Credit card spending

Where's George?

Analyzing tracked dollar bills as proxy for travel

wheresgeorge.com

Humans carry banknotes, so they are a proxy for travel

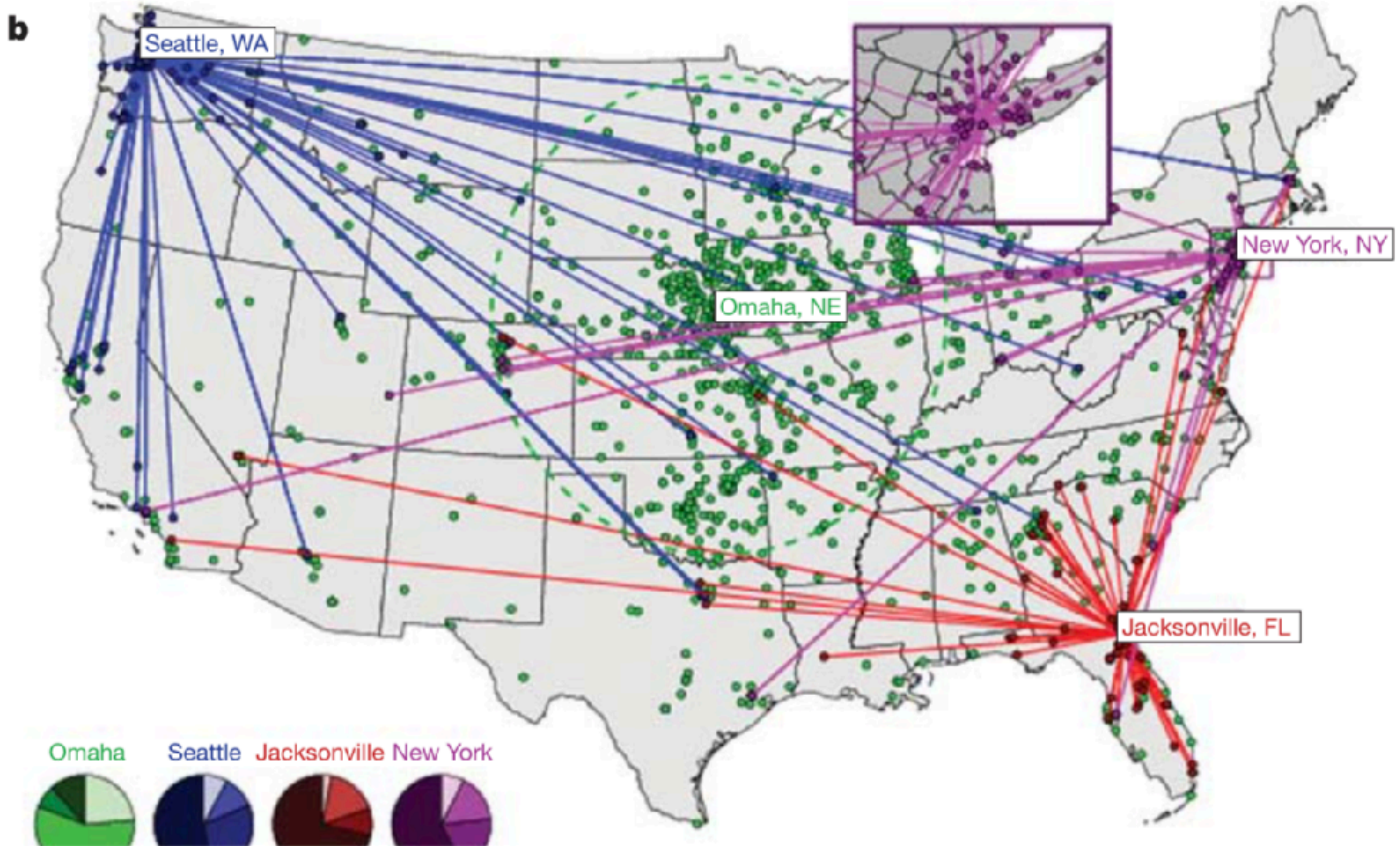
Analyzing tracked dollar bills as proxy for travel

nature

LETTERS

The scaling laws of human travel

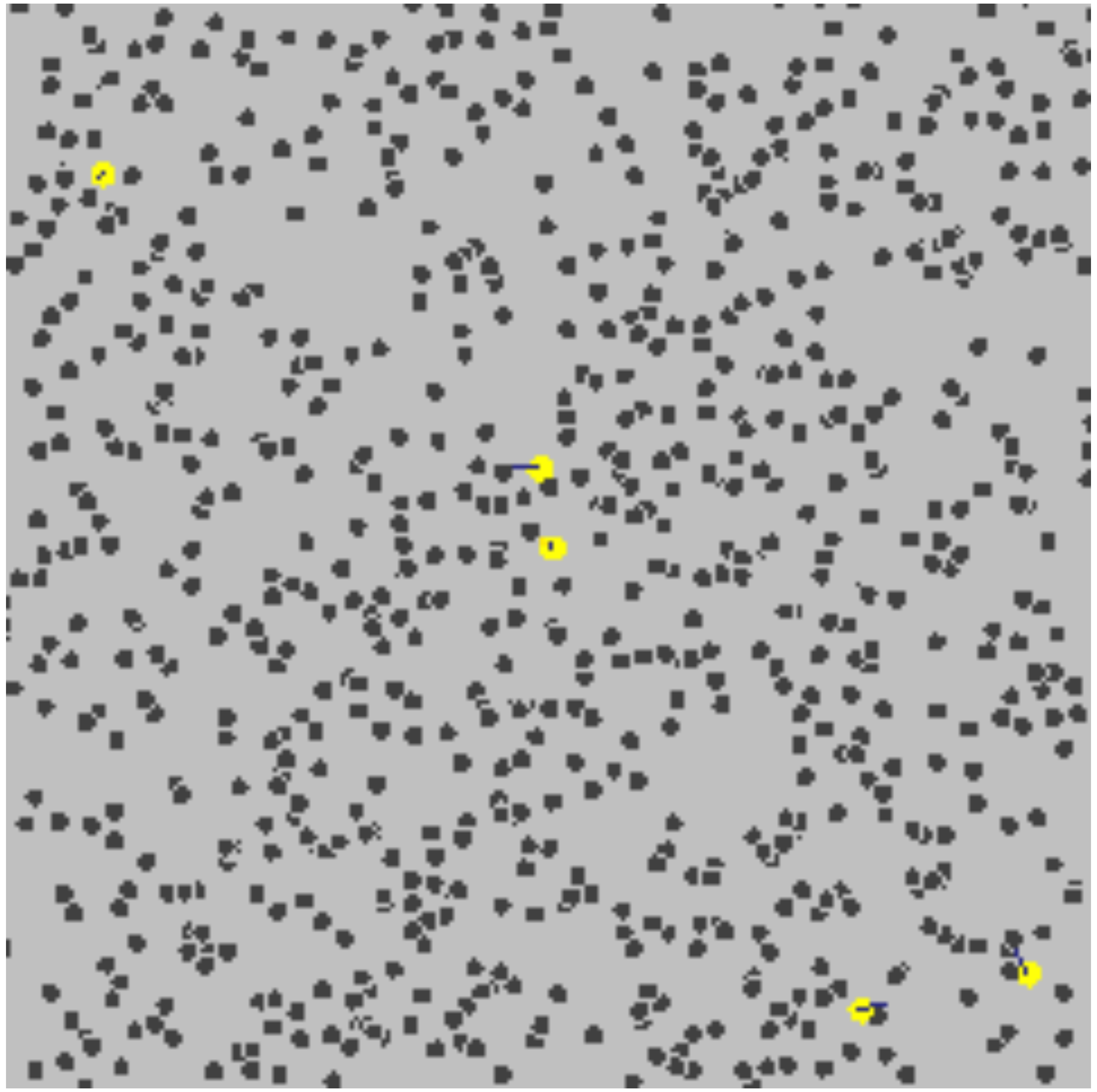
D. Brockmann[1,2], L. Hufnagel[3] & T. Geisel[1,2,4]



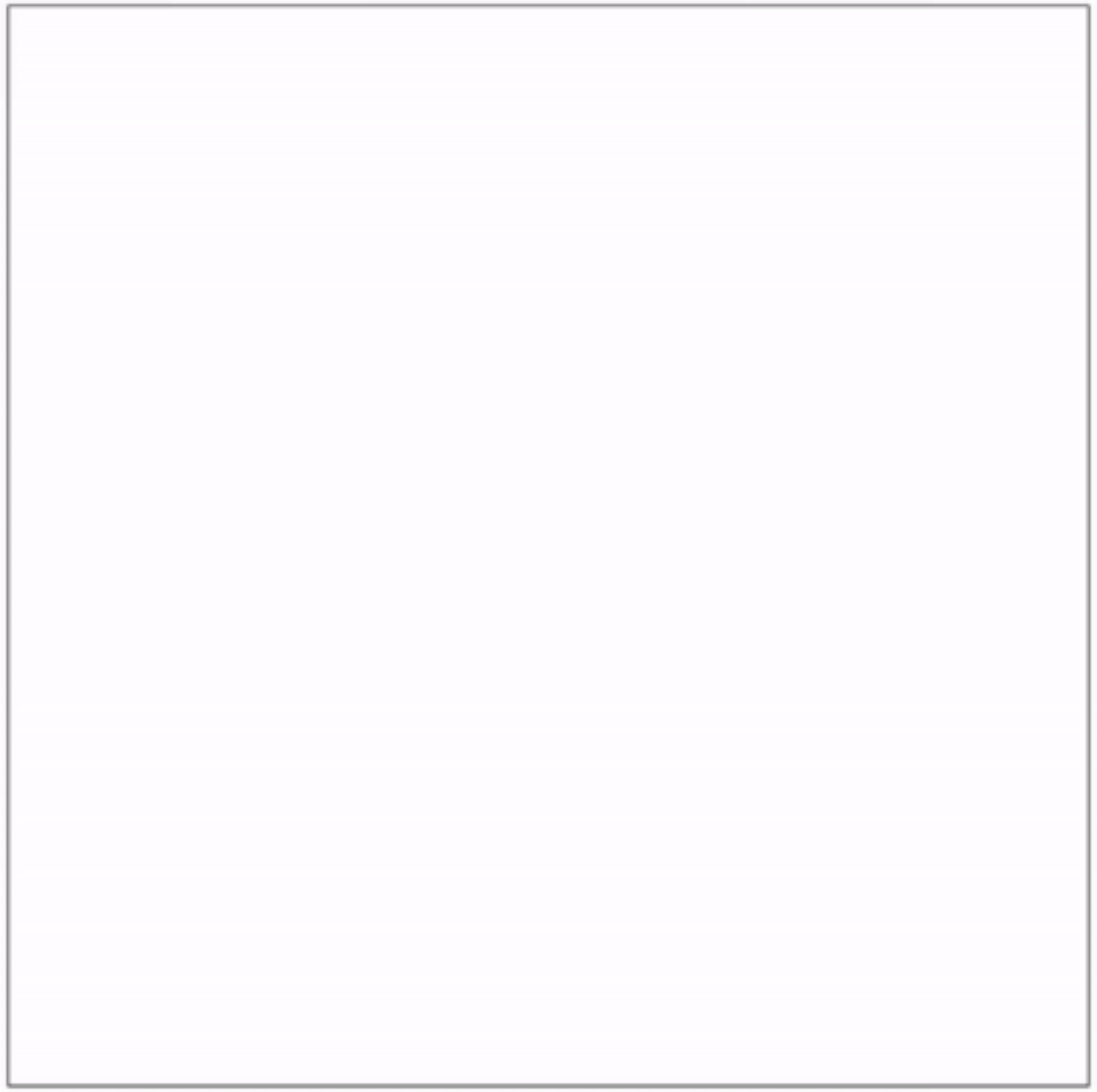
Brockmann, 2006: Are there statistical laws? Is it a random walk?

A physics approach to human mobility

In the simplest mobility model, a random walker moves a fixed distance every fixed time step into a random direction (random walk)



https://en.wikipedia.org/wiki/Brownian_motion



https://en.wikipedia.org/wiki/Random_walk

A physics approach to human mobility

This is a jump process: Discrete movements (jumps) rather than continuous movement

Here the displacement Δr is constant

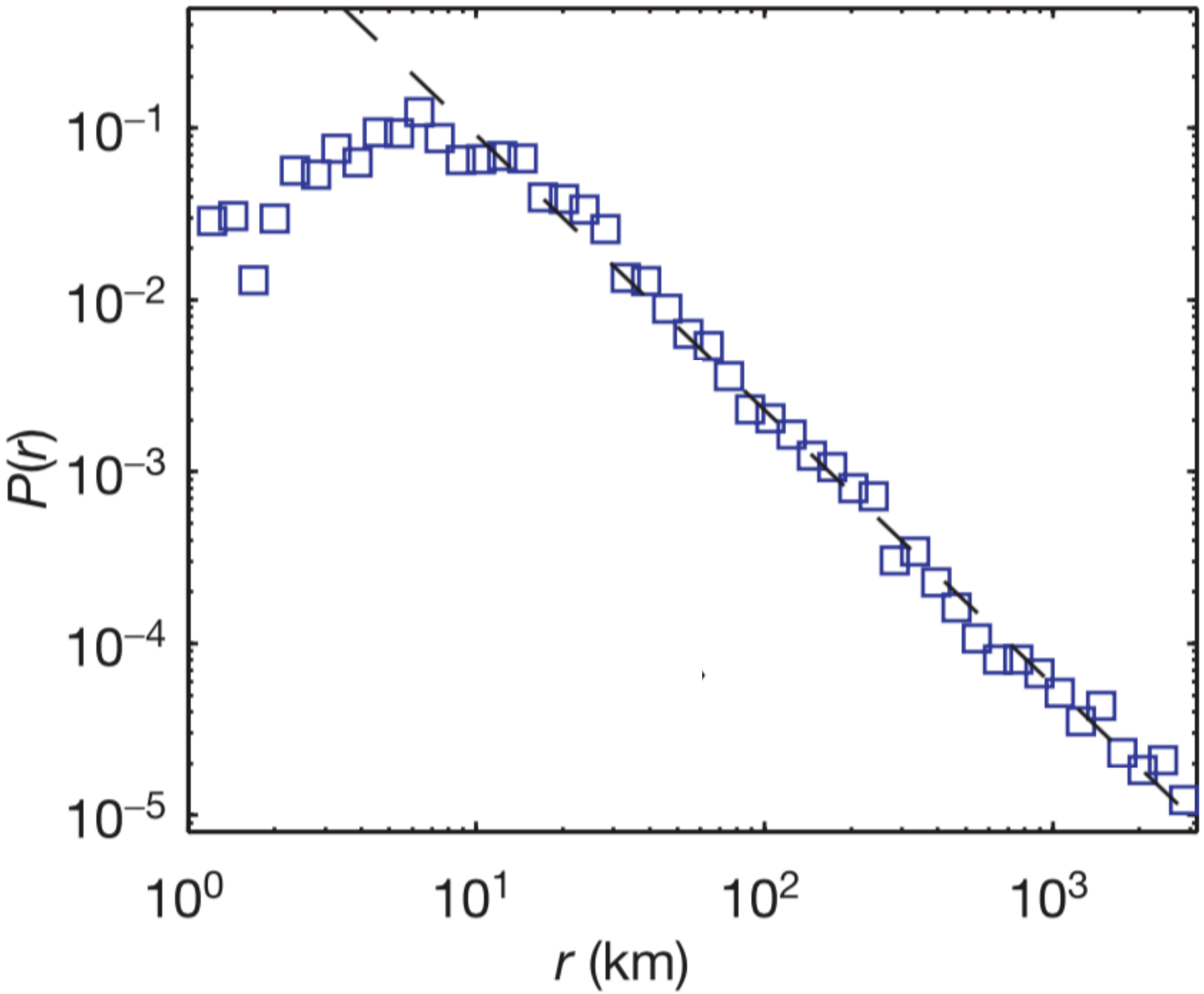
Here the waiting time Δt is constant

How is it for Where's George?

https://en.wikipedia.org/wiki/Random_walk

Discplacement distribution of banknotes is heavy-tailed

Probability that a banknote travels distance r in less than 4 days

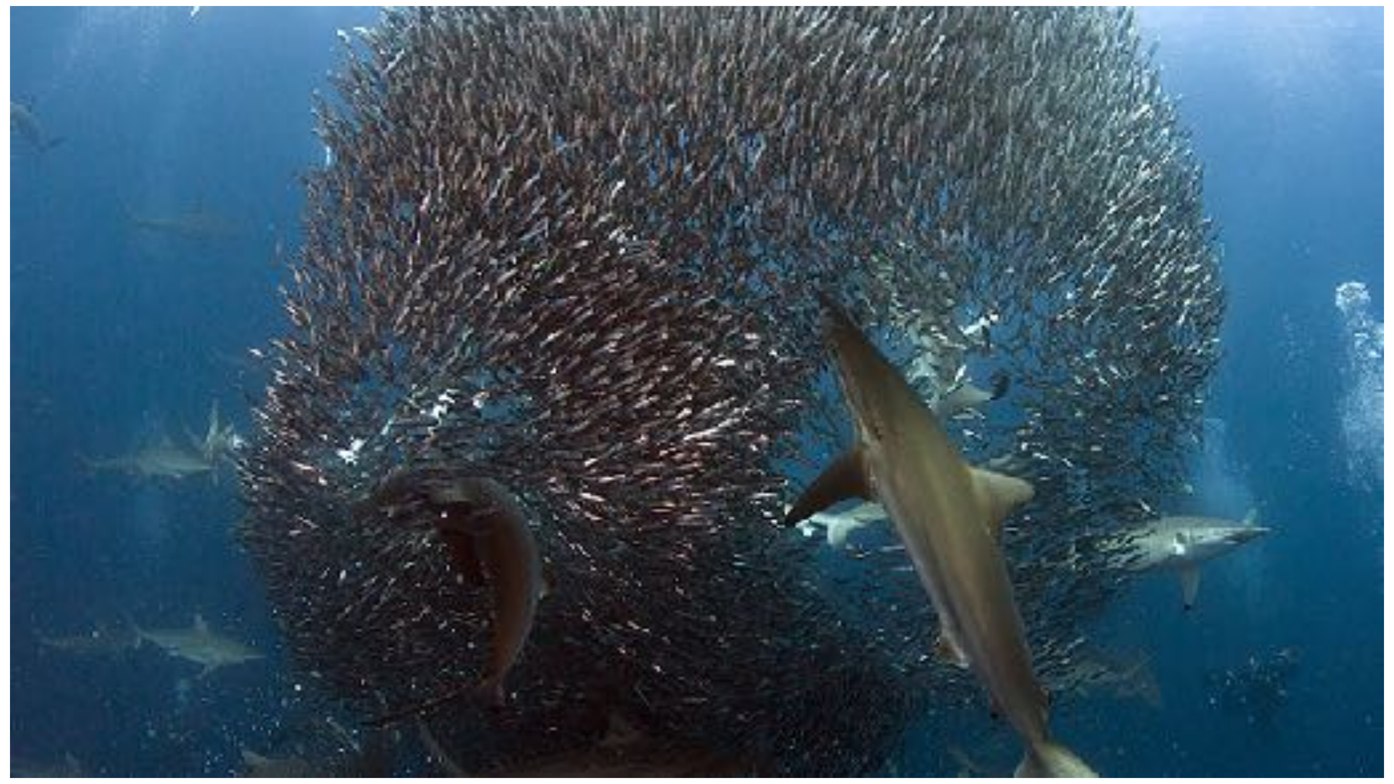


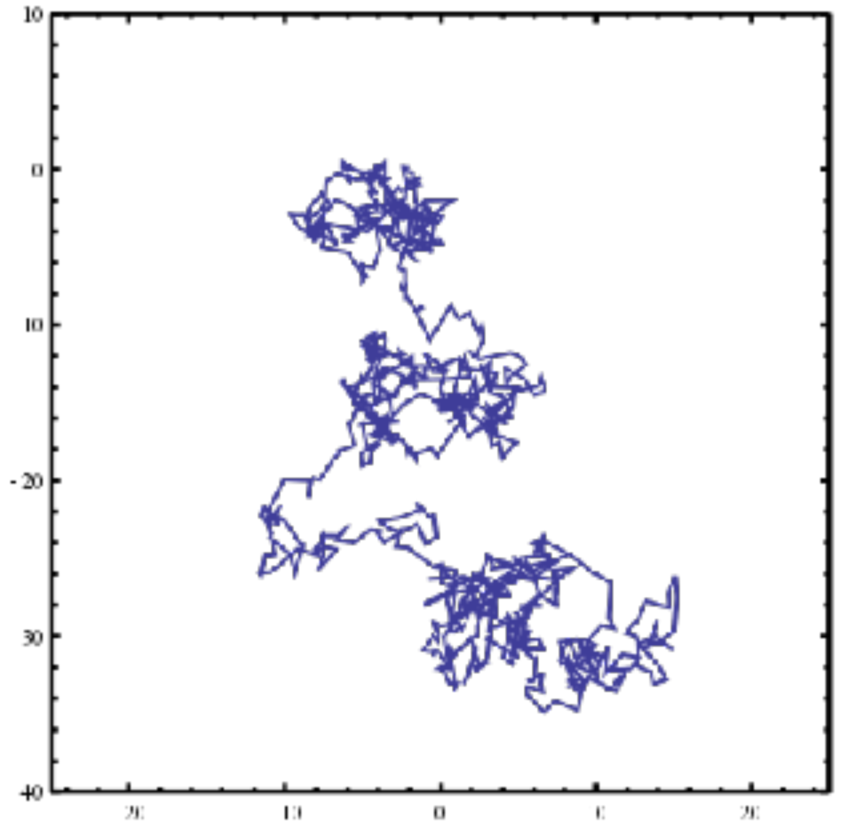
This is called a Lévy-flight

A Lévy flight has huge jumps sometimes

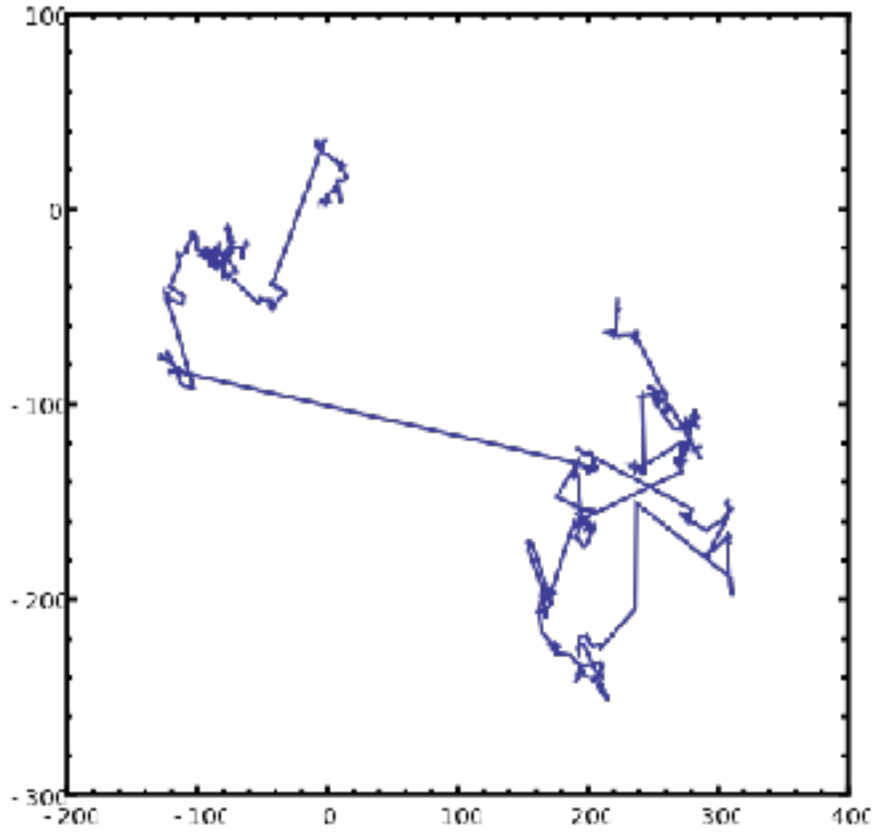
Biology: Levy flight foraging hypothesis

If there is enough food around, use brownian motion (small steps)





If there is not enough food around, use Levy flight (add big jumps)



https://en.wikipedia.org/wiki/L%C3%A9vy_flight

A Lévy flight has huge jumps sometimes

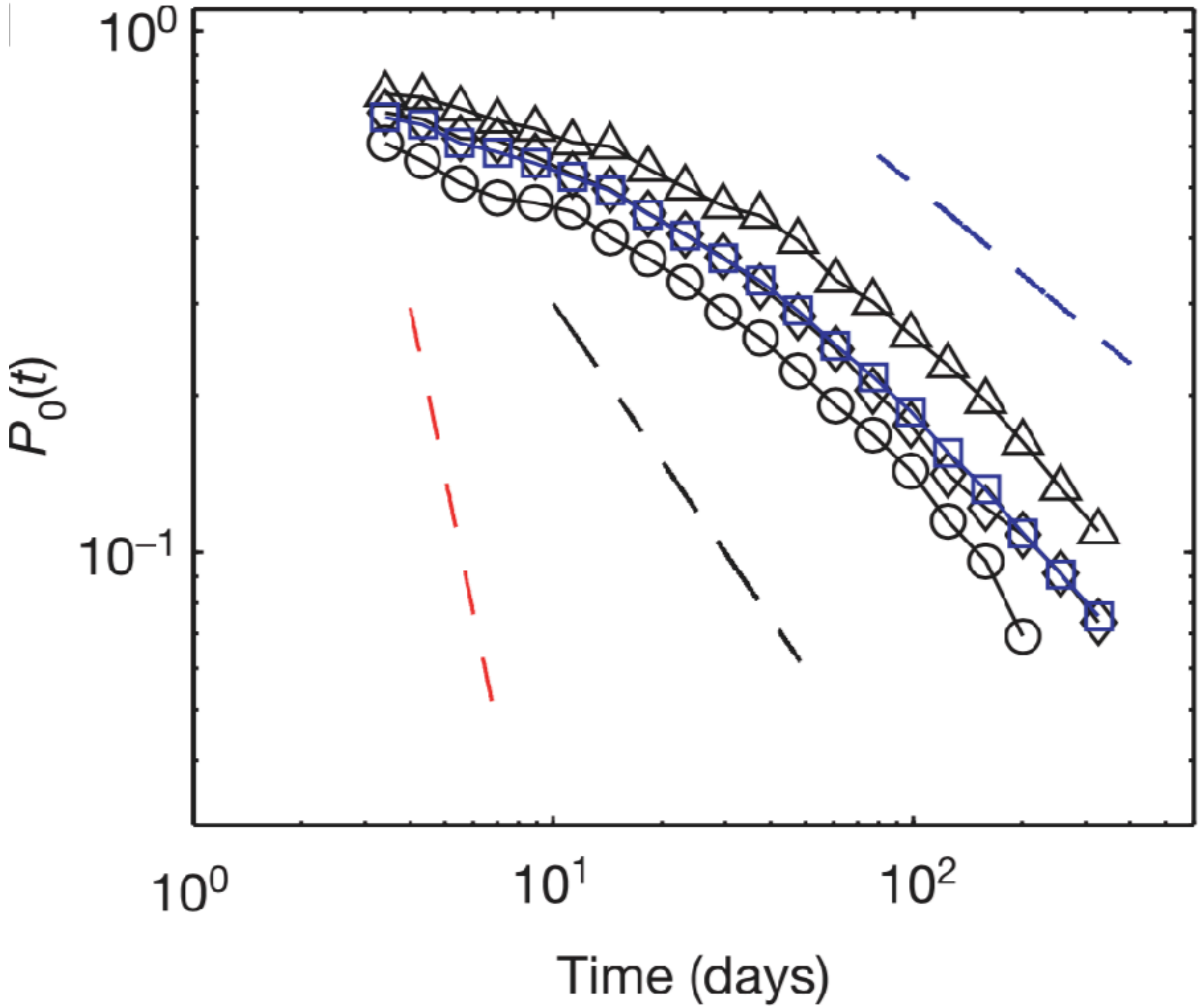
Finance: Black Swans and big jumps in stock market movements

A physics approach to human mobility

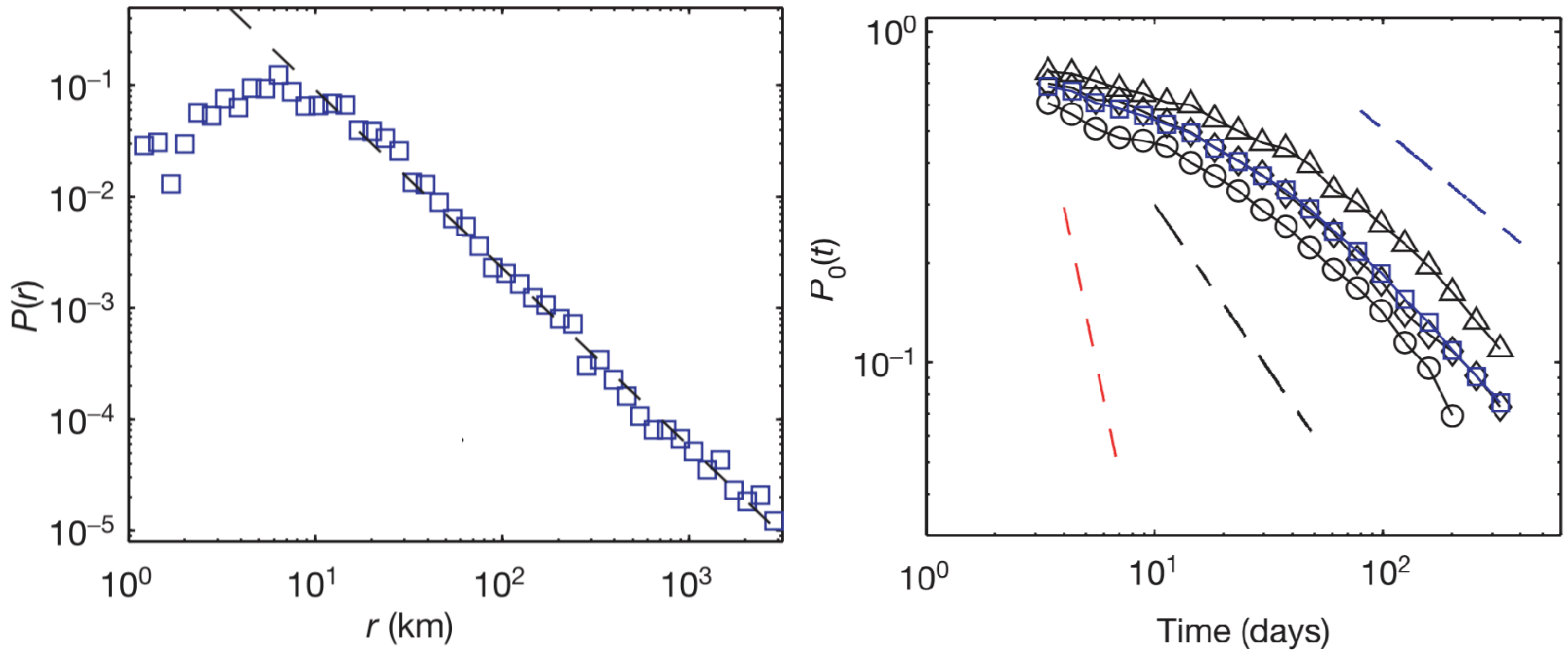
A continuous-time random walk (CTRW) is a generalized random walk with random waiting times between jumps

Waiting time distribution of banknotes is also heavy-tailed

Probability that a banknote does not travel for t days
(waiting time distribution) is also heavy-tailed

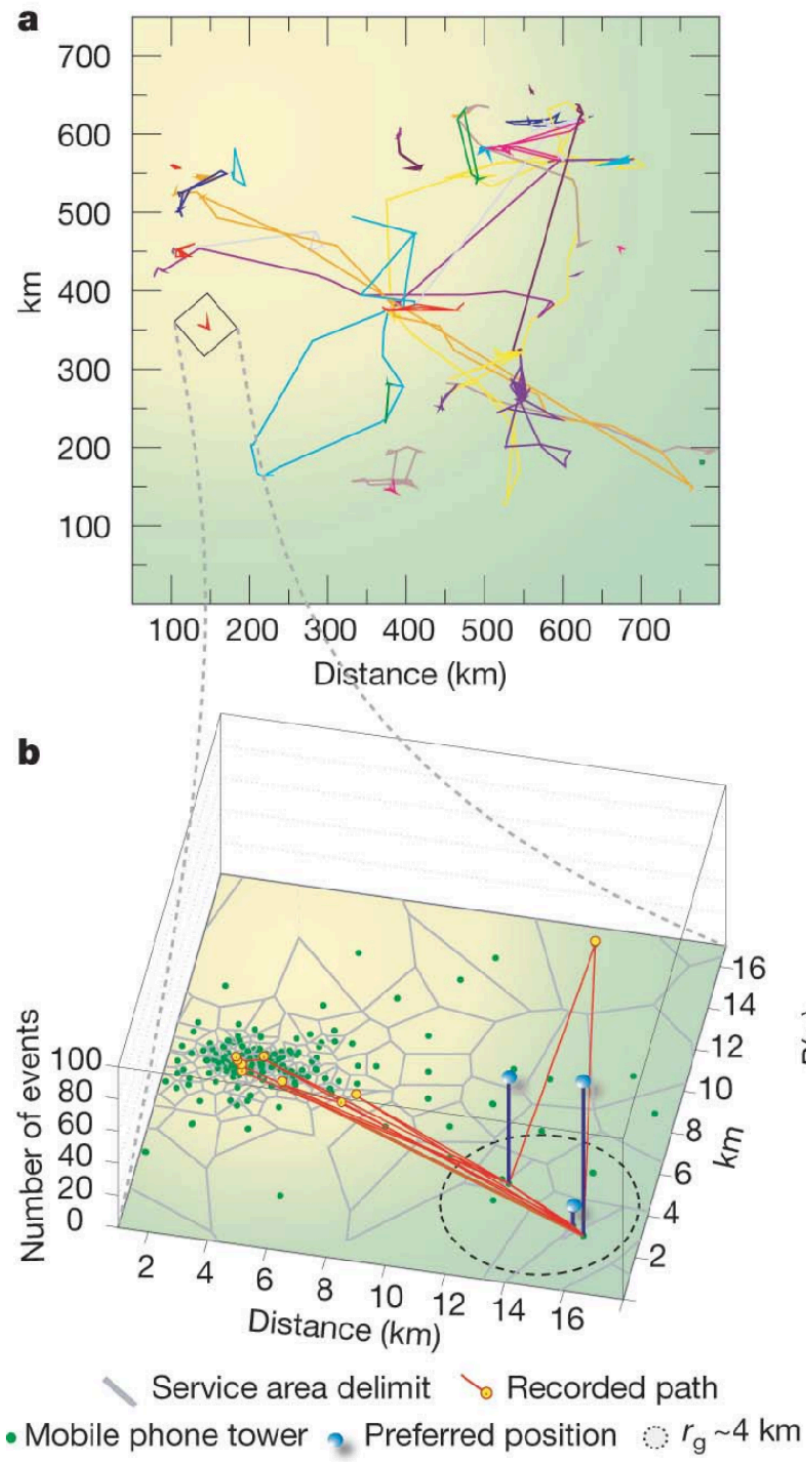


These two properties suggest "superdiffusive" mobility



Important for modeling spread of diseases!

With mobile phone data researchers revisited WheresGeorge



Vol 453 | 5 June 2008 | doi:10.1038/nature06958 nature

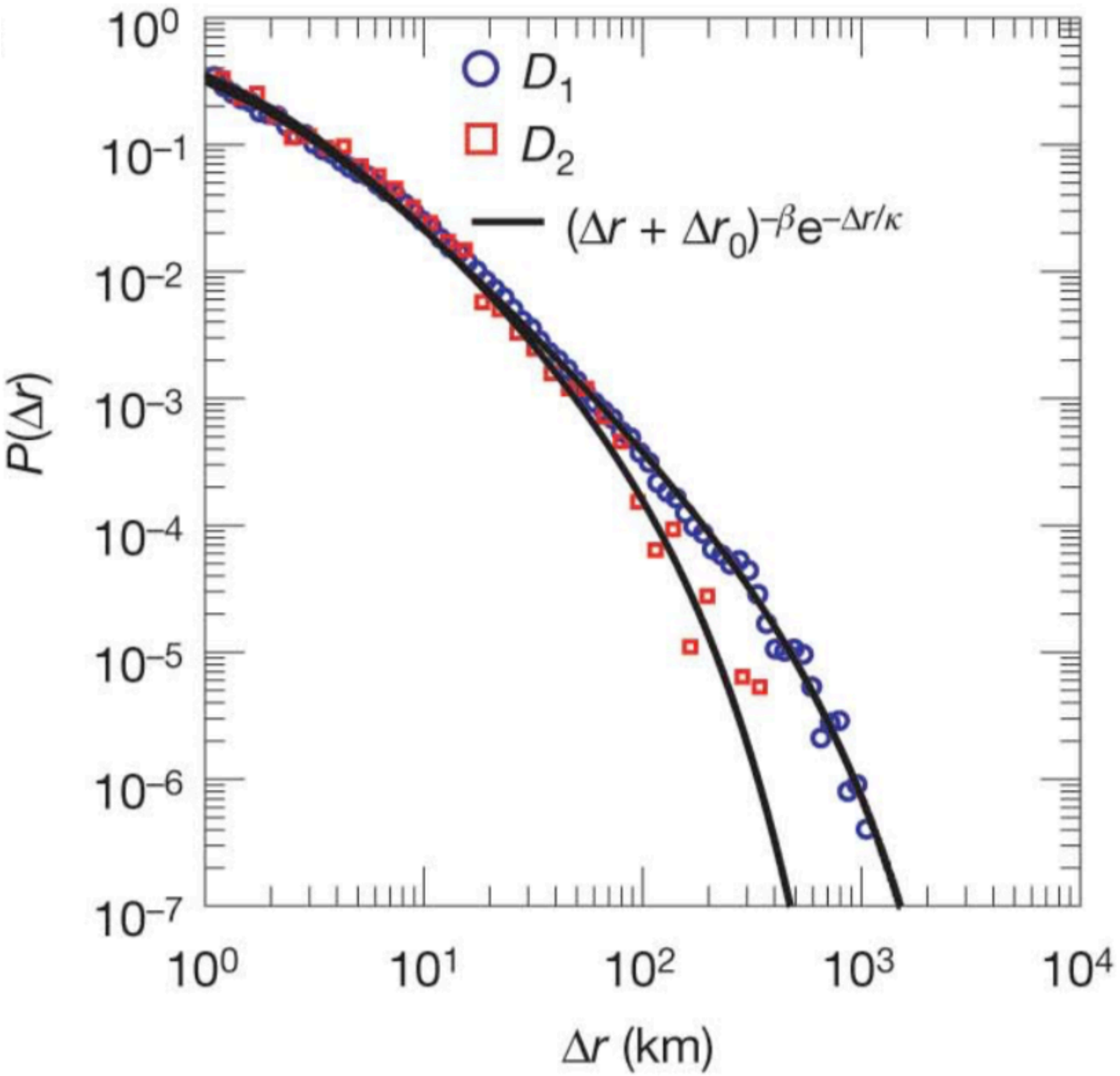
LETTERS

Understanding individual human mobility patterns

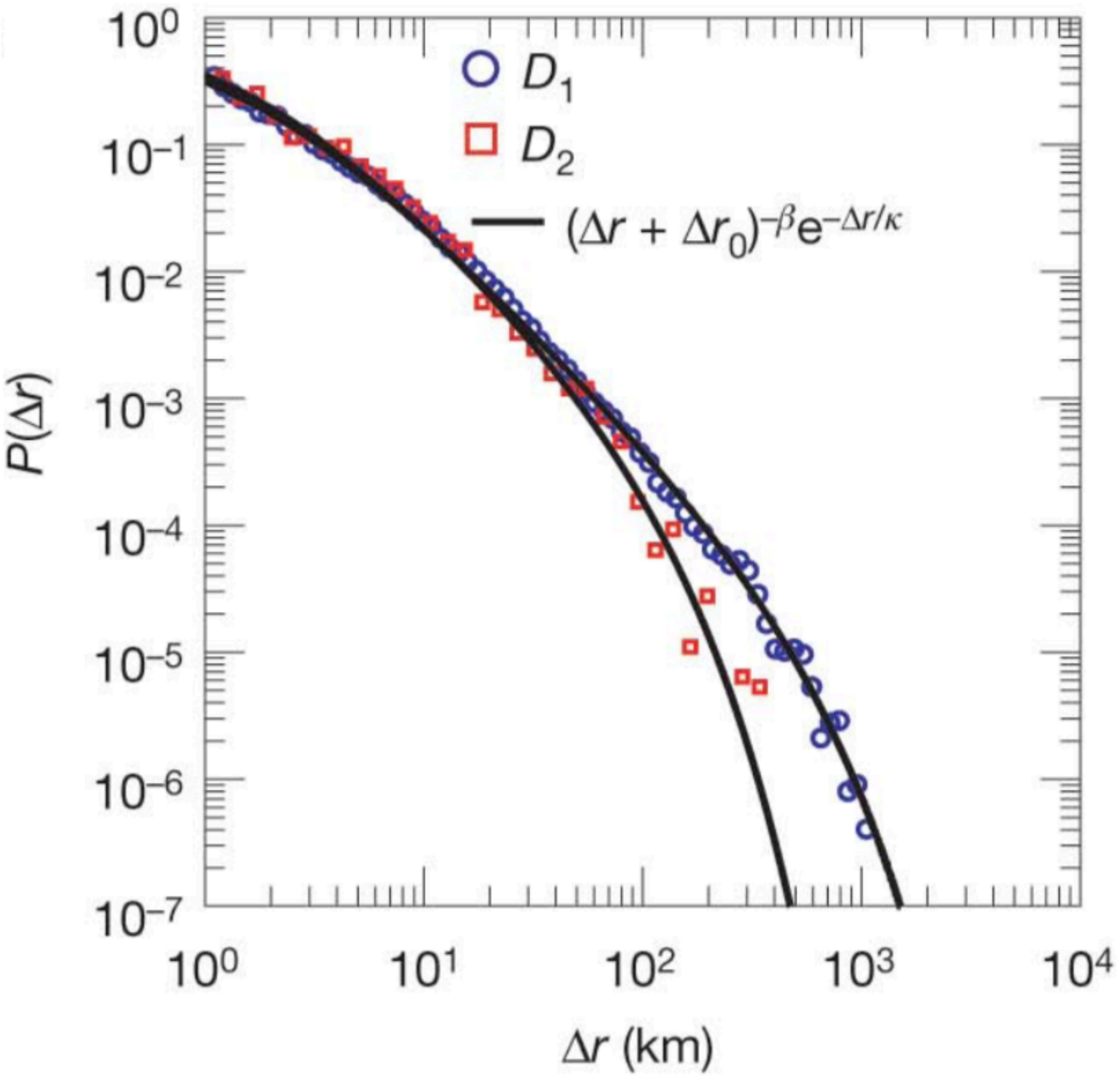
Marta C. González[1], César A. Hidalgo[1,2] & Albert-László Barabási[1,2,3]

Now the data is better: We can follow individuals!

Again the displacement distribution is heavy-tailed



With individual trajectories, we can test 3 hypotheses



A) All same Levy flight:

Each individual follows the same Levy flight process

B) Different mobility, but no Levy flights:

The distribution results from individuals moving differently

C) Different Levy flights:

Individuals follows different Levy flight processes

With individual trajectories, we can test 3 hypotheses

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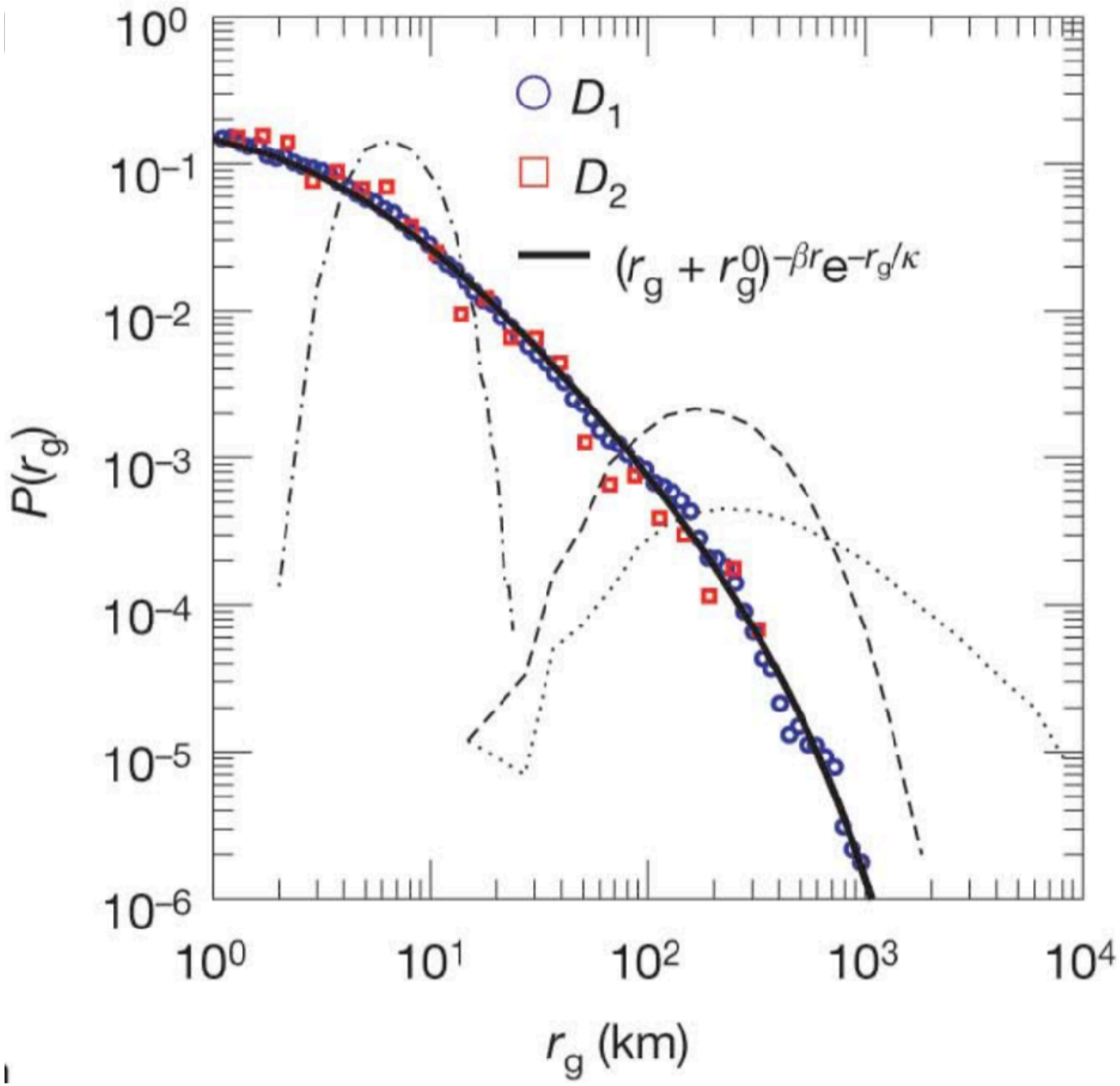
The radius of gyration r_g is the typical distance travelled by an individual over a fixed timespan

$$r_g = \sqrt{\frac{1}{n}\sum_{i=1}^{n} |r_i - r_{\mathrm{cm}}|^2}$$

With individual trajectories, we can test 3 hypotheses



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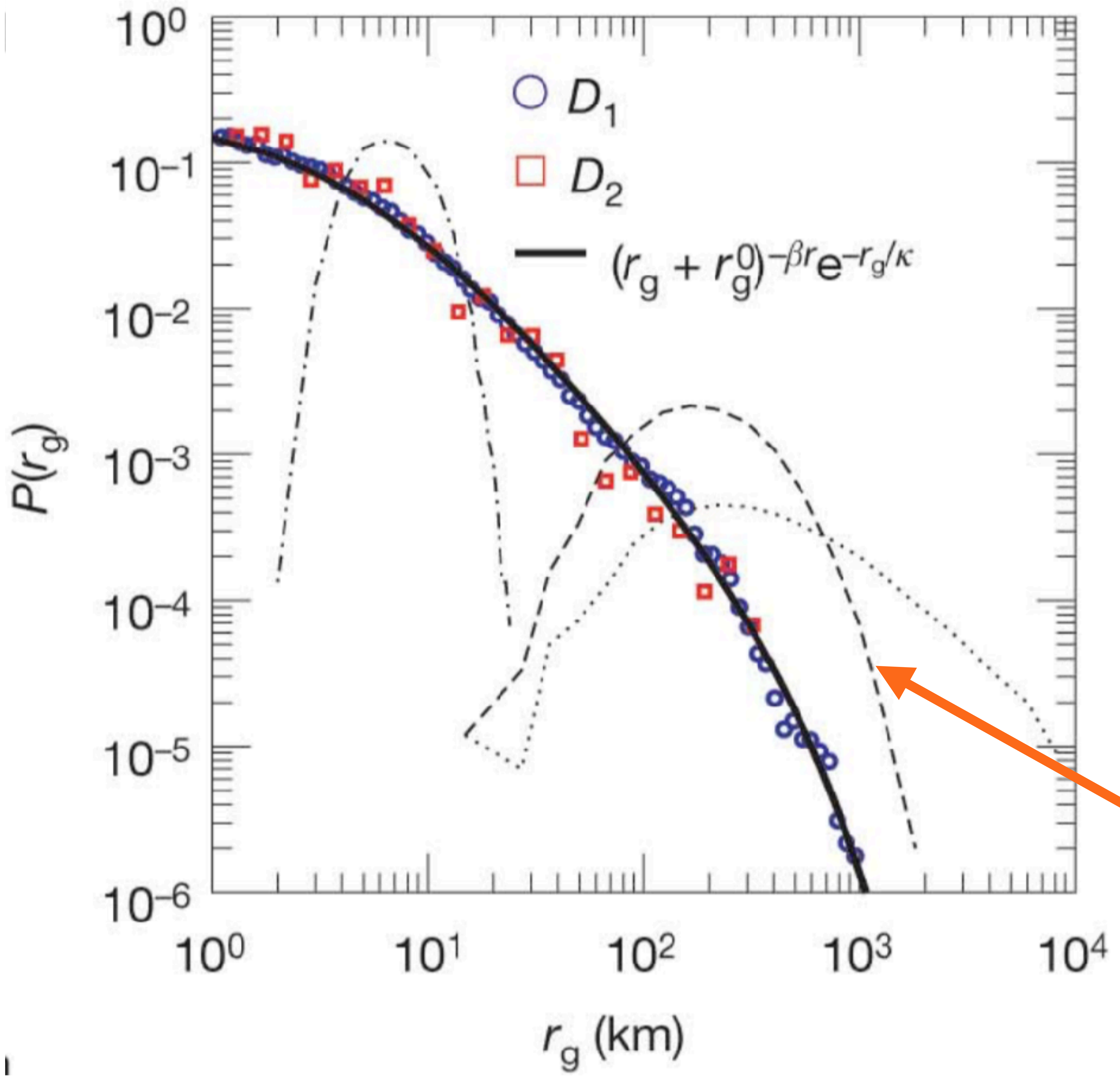

~~A) All same Levy flight?~~

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The radius of gyration r_g is the typical distance travelled by an individual over a fixed timespan

$$r_g = \sqrt{\frac{1}{n}\sum_{i=1}^{n} |r_i - r_{\mathrm{cm}}|^2}$$

People have different mobility behaviors.

If hypothesis A were true, we would see this.

We can now rule out hypothesis A.

With individual trajectories, we can test 3 hypotheses

~~A) All same Levy flight?~~

~~Each individual follows the same Levy flight process~~

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The distribution results from individuals moving differently

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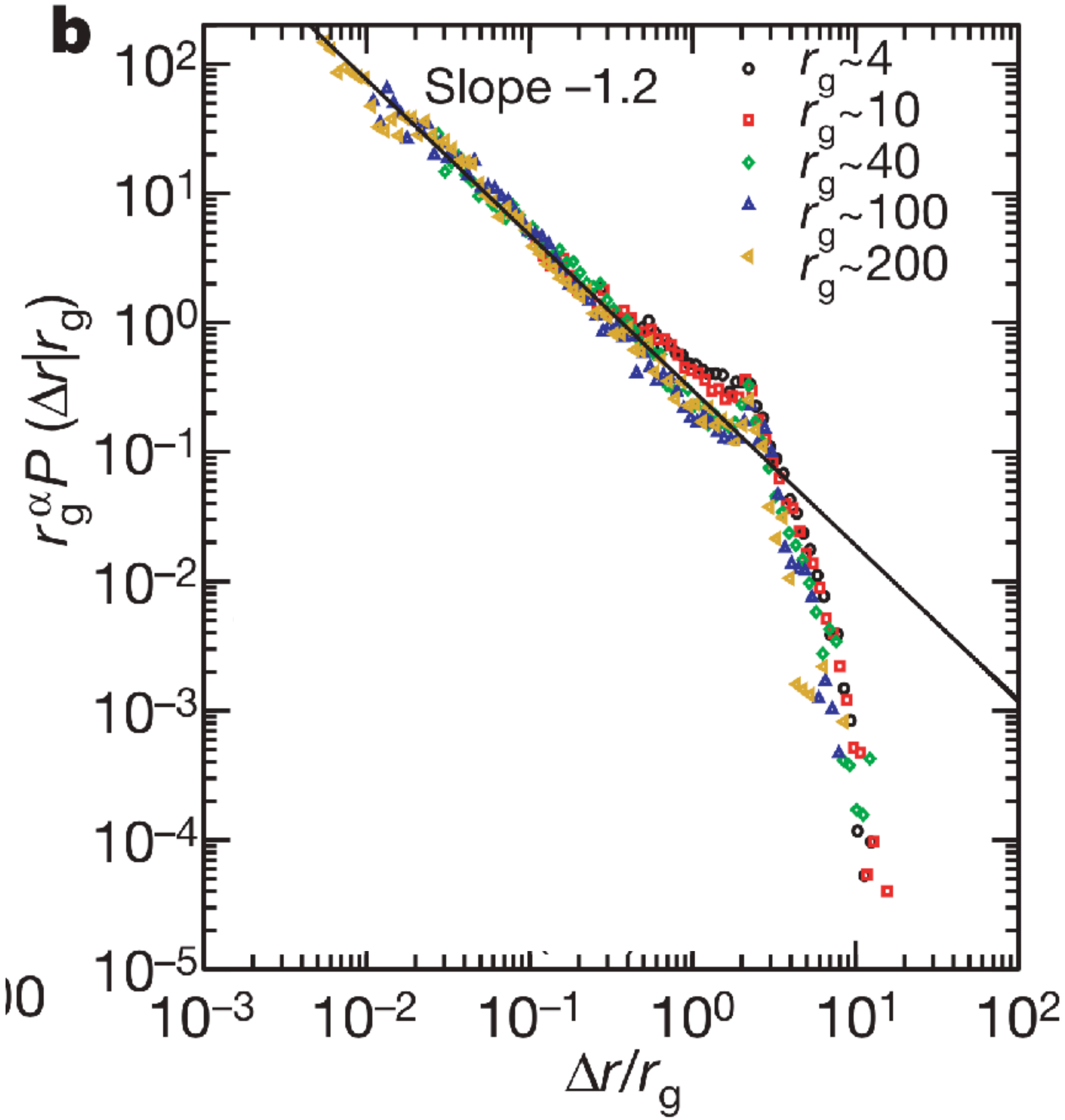

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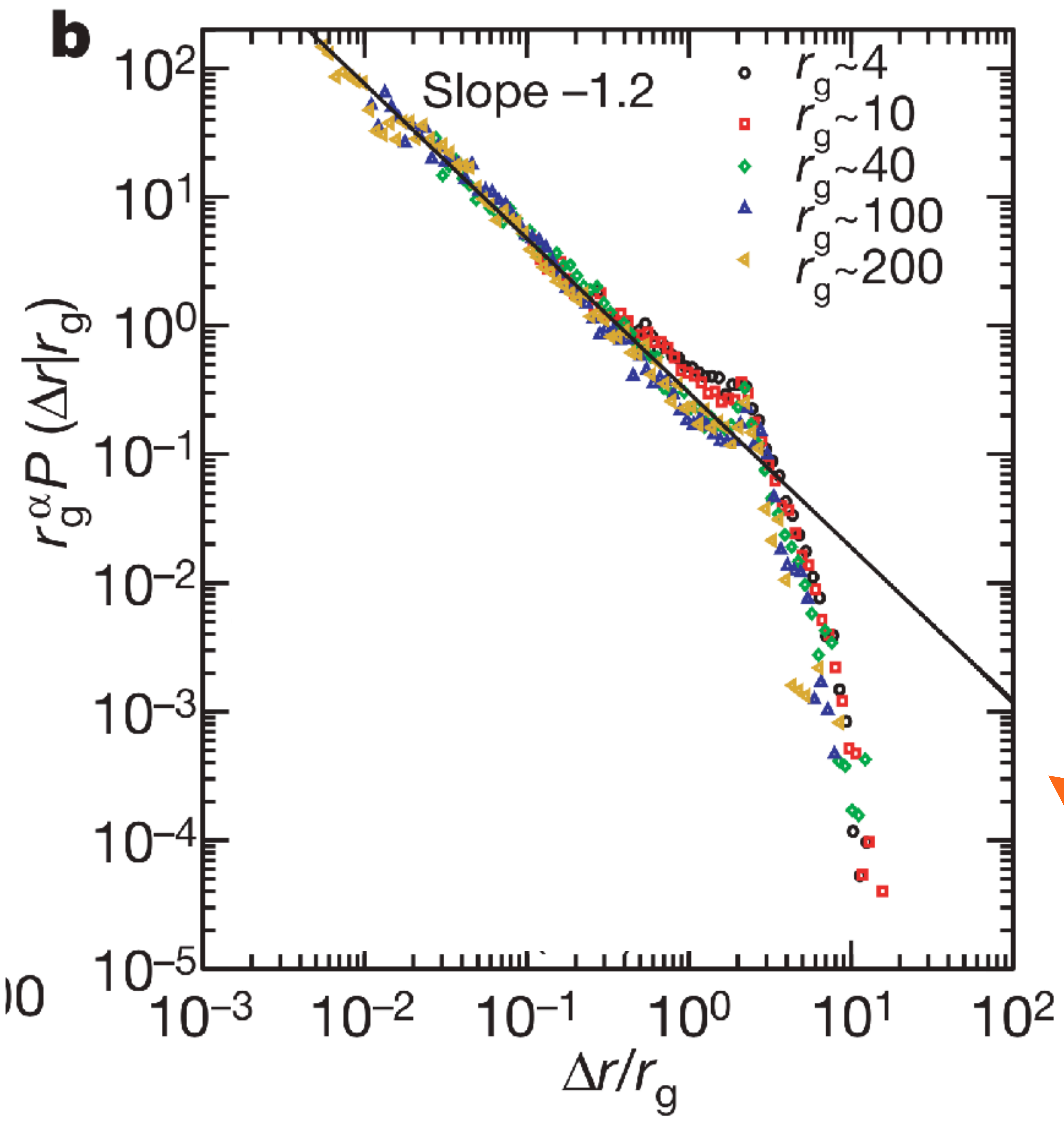
With individual trajectories, we can test 3 hypotheses



~~A) All same Levy flight?~~

~~Each individual follows the same Levy flight process~~

B) Different mobility, but no Levy flights:

The distribution results from individuals moving differently

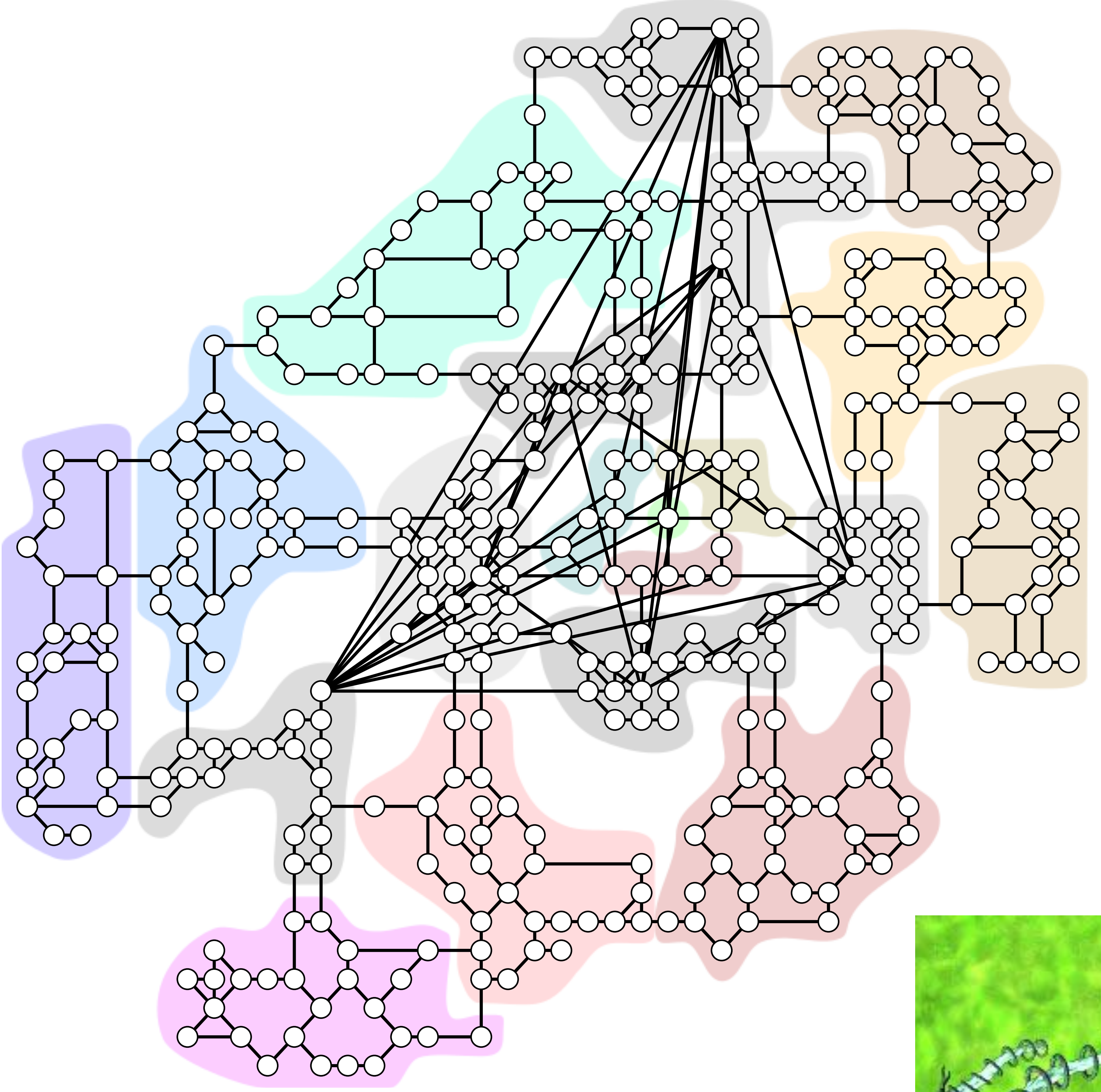
C) Different Levy flights:

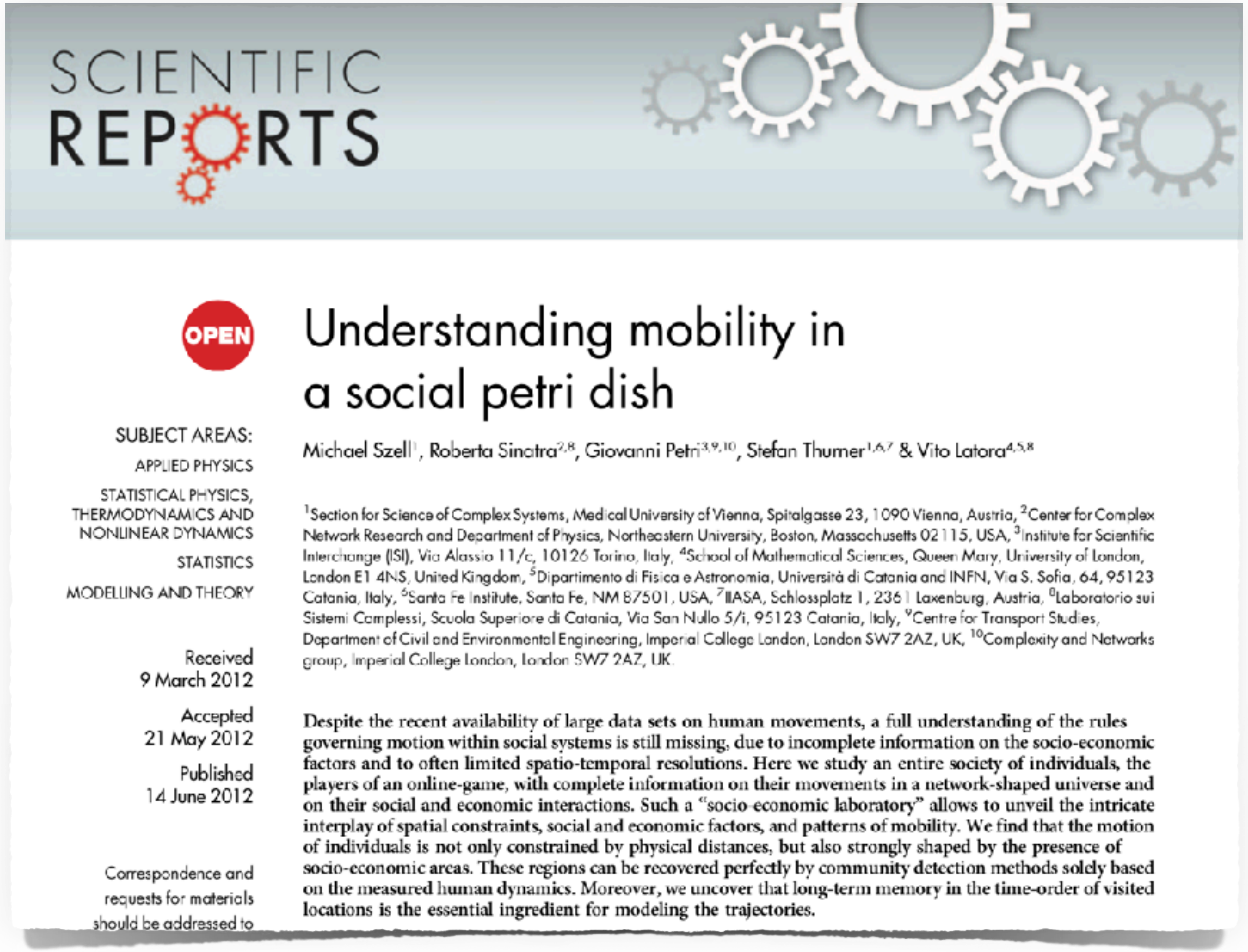
Individuals follows different Levy flight processes

People with different r_g have different mobility behavior, but they can be rescaled on one curve

Consistent with hypothesis C.

Mobility in a virtual world





SCIENTIFIC REPORTS

OPEN

Understanding mobility in a social petri dish

SUBJECT AREAS:
APPLIED PHYSICS
STATISTICAL PHYSICS, THERMODYNAMICS AND NONLINEAR DYNAMICS
STATISTICS
MODELLING AND THEORY

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Correspondence and requests for materials should be addressed to

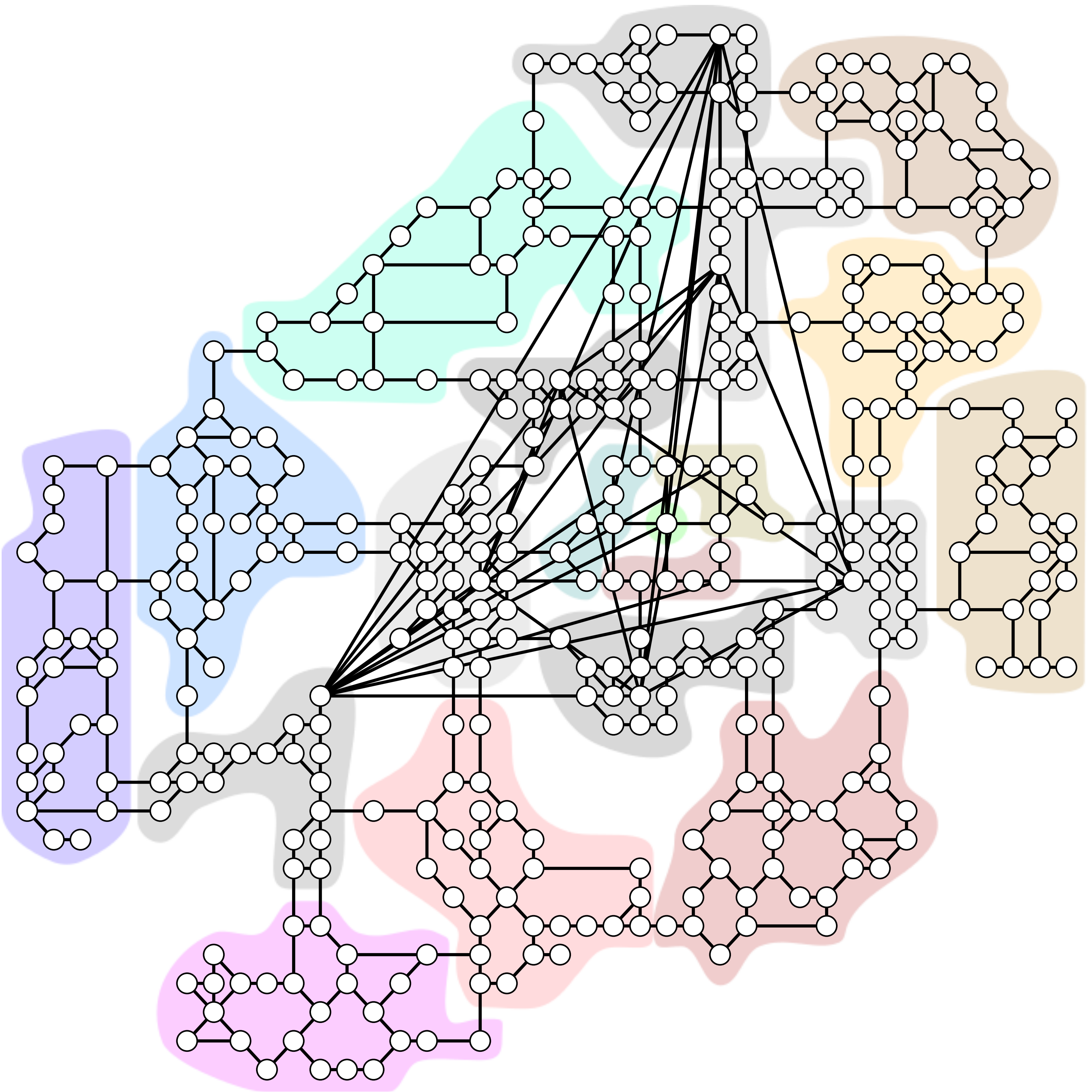
Michael Szell[1], Roberta Sinatra[2,8], Giovanni Petri[3,9,10], Stefan Thurner[1,6,7] & Vito Latora[4,5,8]

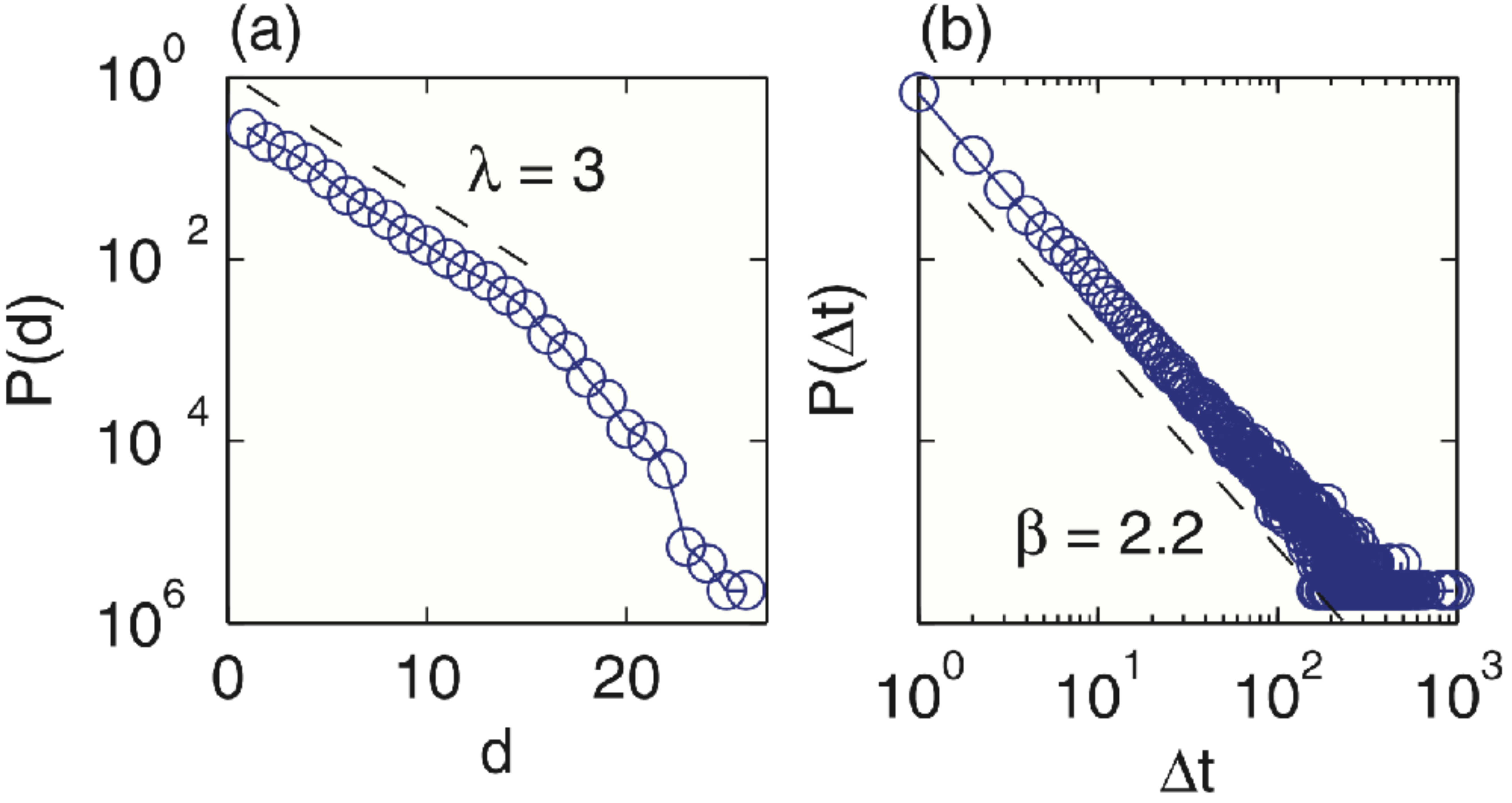
[1]Section for Science of Complex Systems, Medical University of Vienna, Spitalgasse 23, 1090 Vienna, Austria, [2]Center for Complex Network Research and Department of Physics, Northeastern University, Boston, Massachusetts 02115, USA, [3]Institute for Scientific Interchange (ISI), Via Alassio 11/c, 10126 Torino, Italy, [4]School of Mathematical Sciences, Queen Mary, University of London, London E1 4NS, United Kingdom, [5]Dipartimento di Fisica e Astronomia, Università di Catania and INFN, Via S. Sofia, 64, 95123 Catania, Italy, [6]Santa Fe Institute, Santa Fe, NM 87501, USA, [7]IIASA, Schlossplatz 1, 2361 Laxenburg, Austria, [8]Laboratorio sui Sistemi Complessi, Scuola Superiore di Catania, Via San Nullo 5/i, 95123 Catania, Italy, [9]Centre for Transport Studies, Department of Civil and Environmental Engineering, Imperial College London, London SW7 2AZ, UK, [10]Complexity and Networks group, Imperial College London, London SW7 2AZ, UK.

Despite the recent availability of large data sets on human movements, a full understanding of the rules governing motion within social systems is still missing, due to incomplete information on the socio-economic factors and to often limited spatio-temporal resolutions. Here we study an entire society of individuals, the players of an online-game, with complete information on their movements in a network-shaped universe and on their social and economic interactions. Such a "socio-economic laboratory" allows to unveil the intricate interplay of spatial constraints, social and economic factors, and patterns of mobility. We find that the motion of individuals is not only constrained by physical distances, but also strongly shaped by the presence of socio-economic areas. These regions can be recovered perfectly by community detection methods solely based on the measured human dynamics. Moreover, we uncover that long-term memory in the time-order of visited locations is the essential ingredient for modeling the trajectories.

www.pardus.at

Mobility in a virtual world

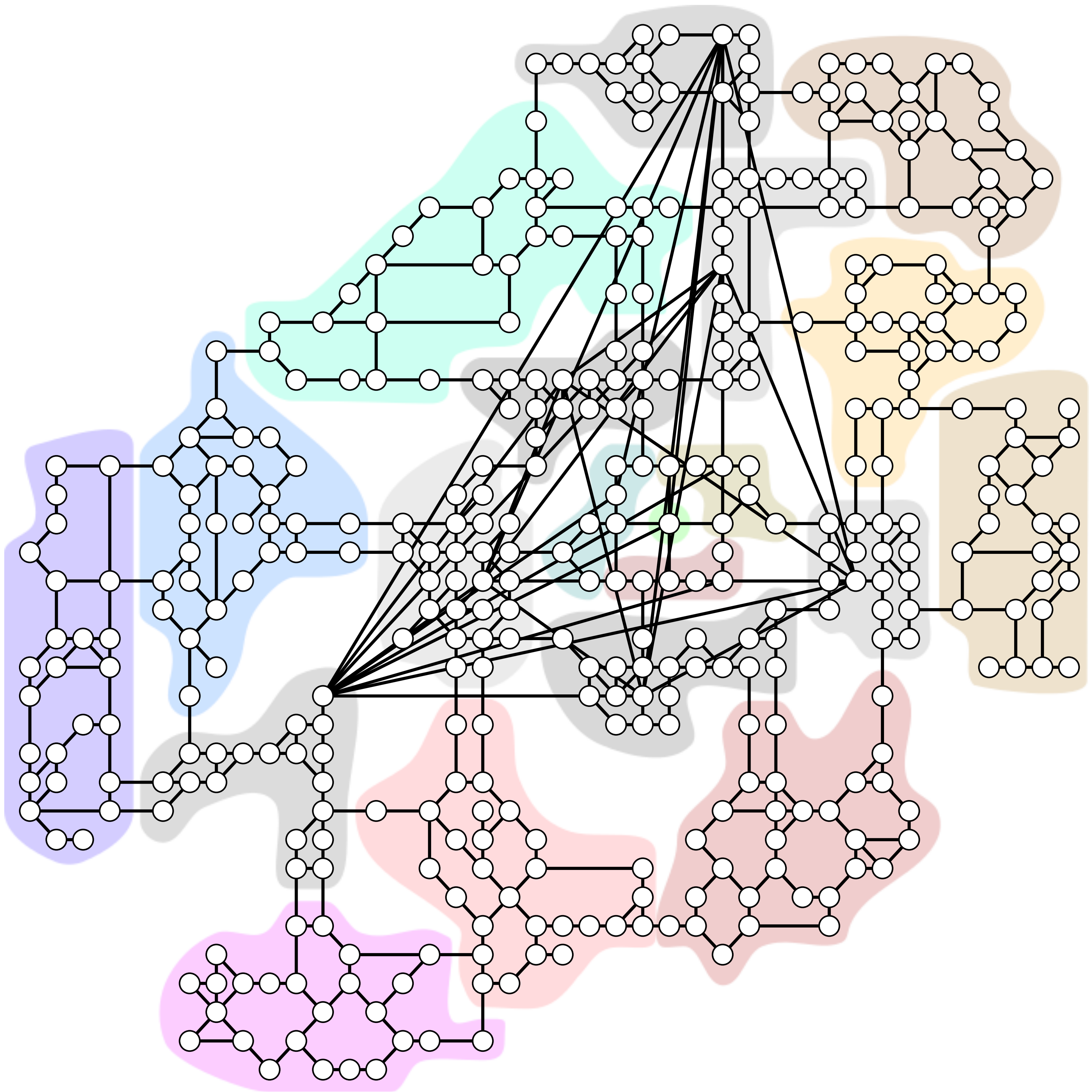




Jump distances
are exponential

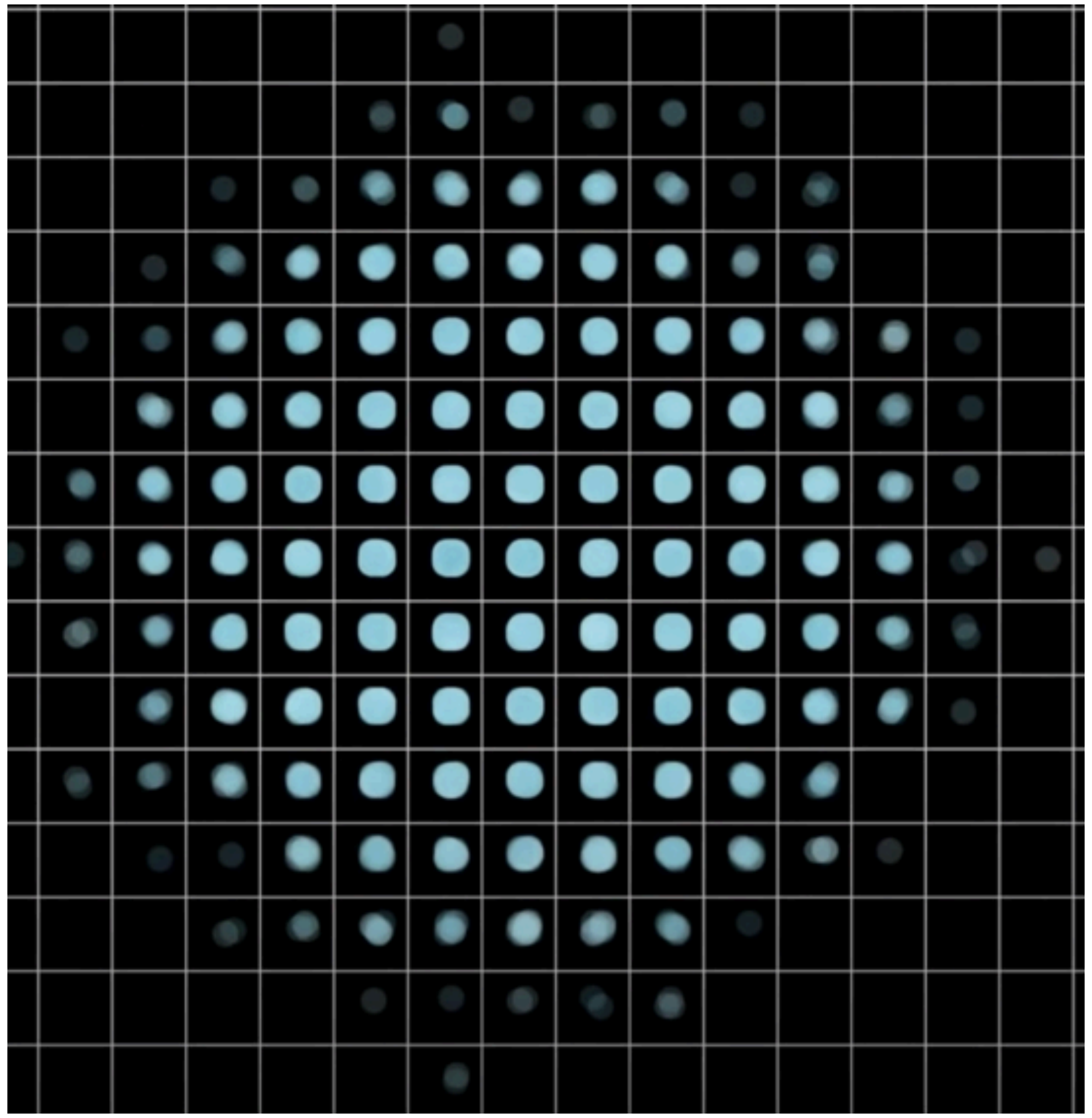
Waiting times
are heavy-tailed

The MSD measures deviation from an initial position



The mean squared displacement characterizes diffusion

$$MSD = \langle r^2(\tau) \rangle = \frac{1}{N} \sum_{n=1}^{N} \left(x_n(\tau) - x_n(0) \right)^2$$



https://youtu.be/a3V0BJLIo_c?t=196

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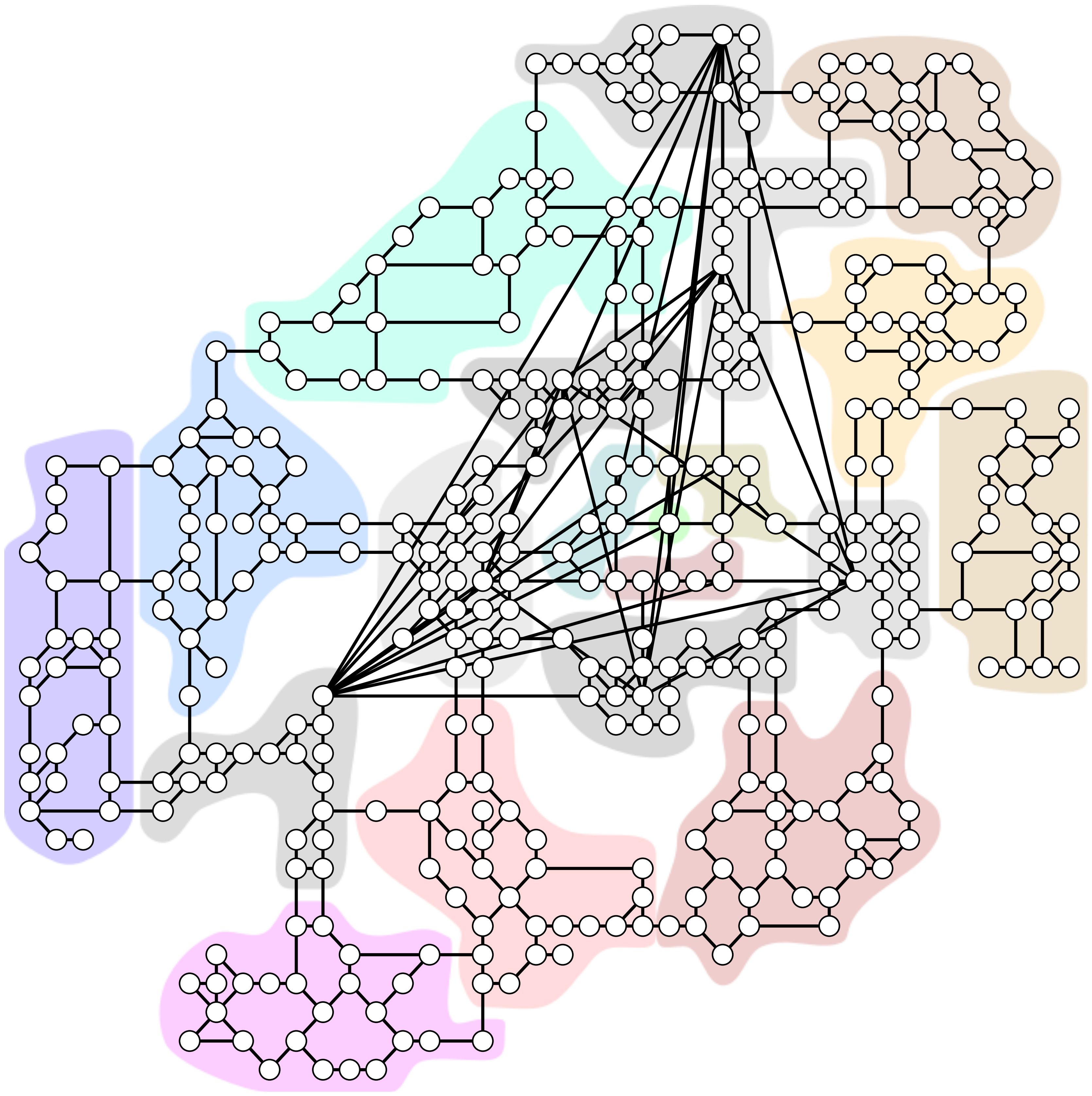

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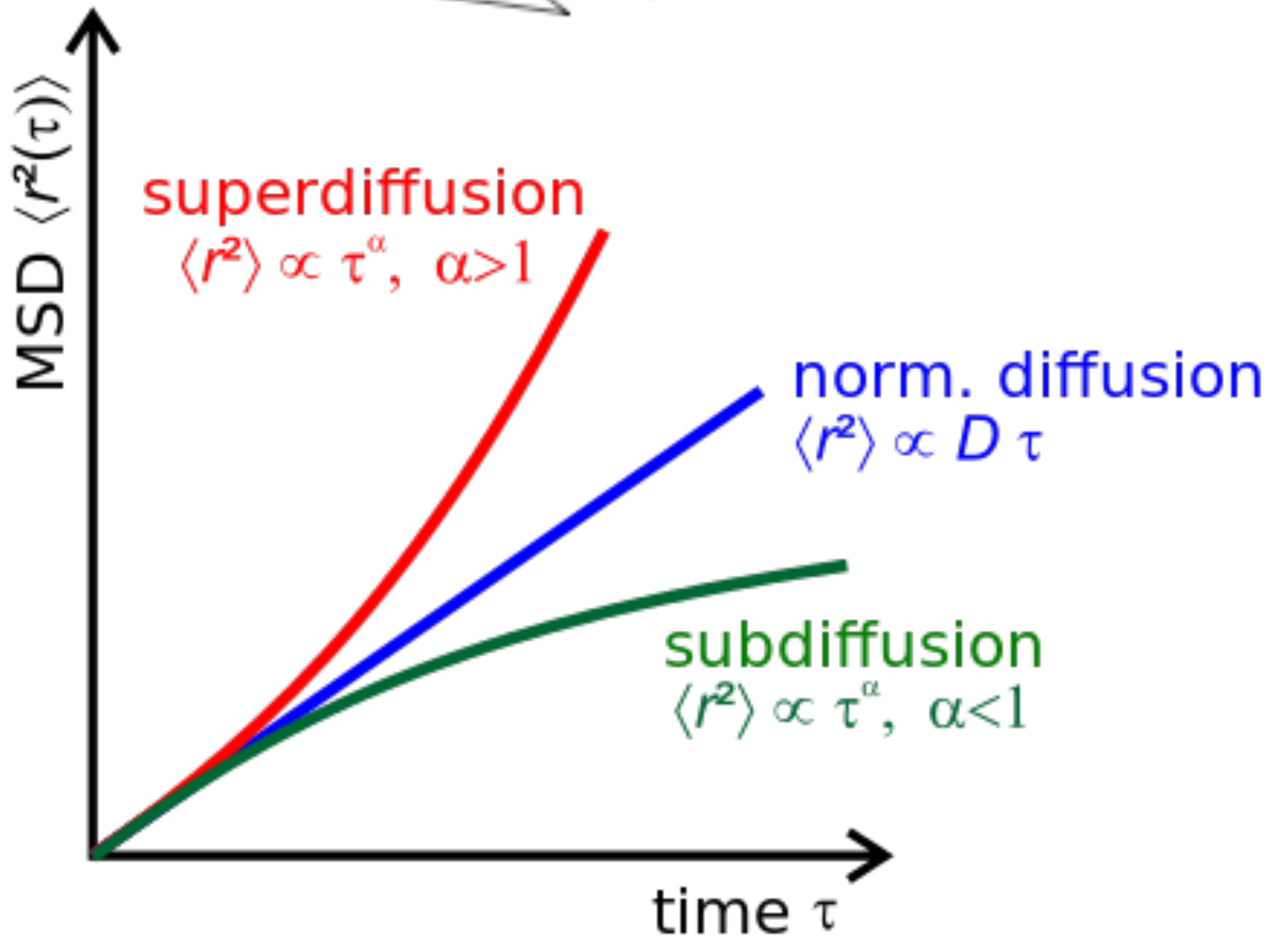
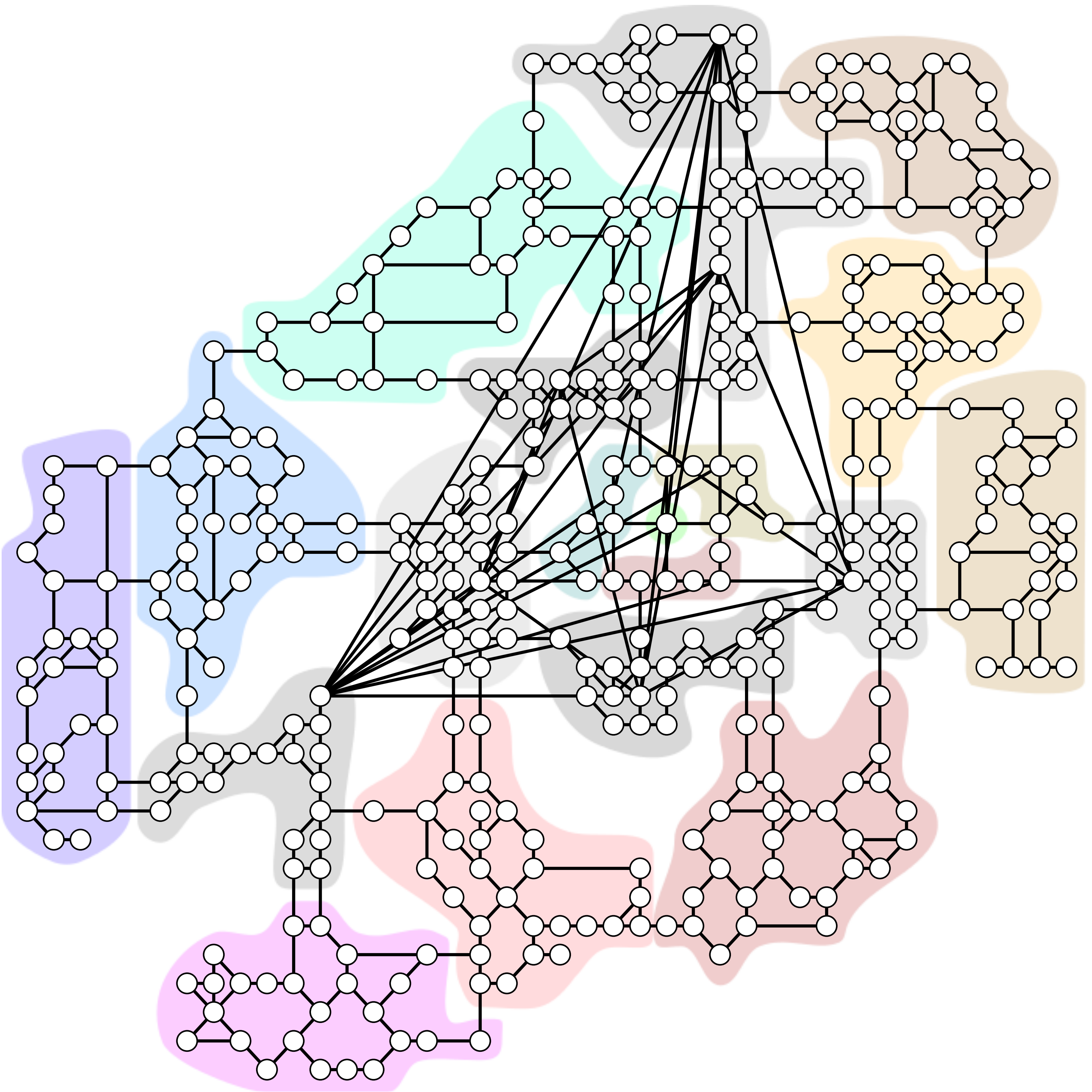


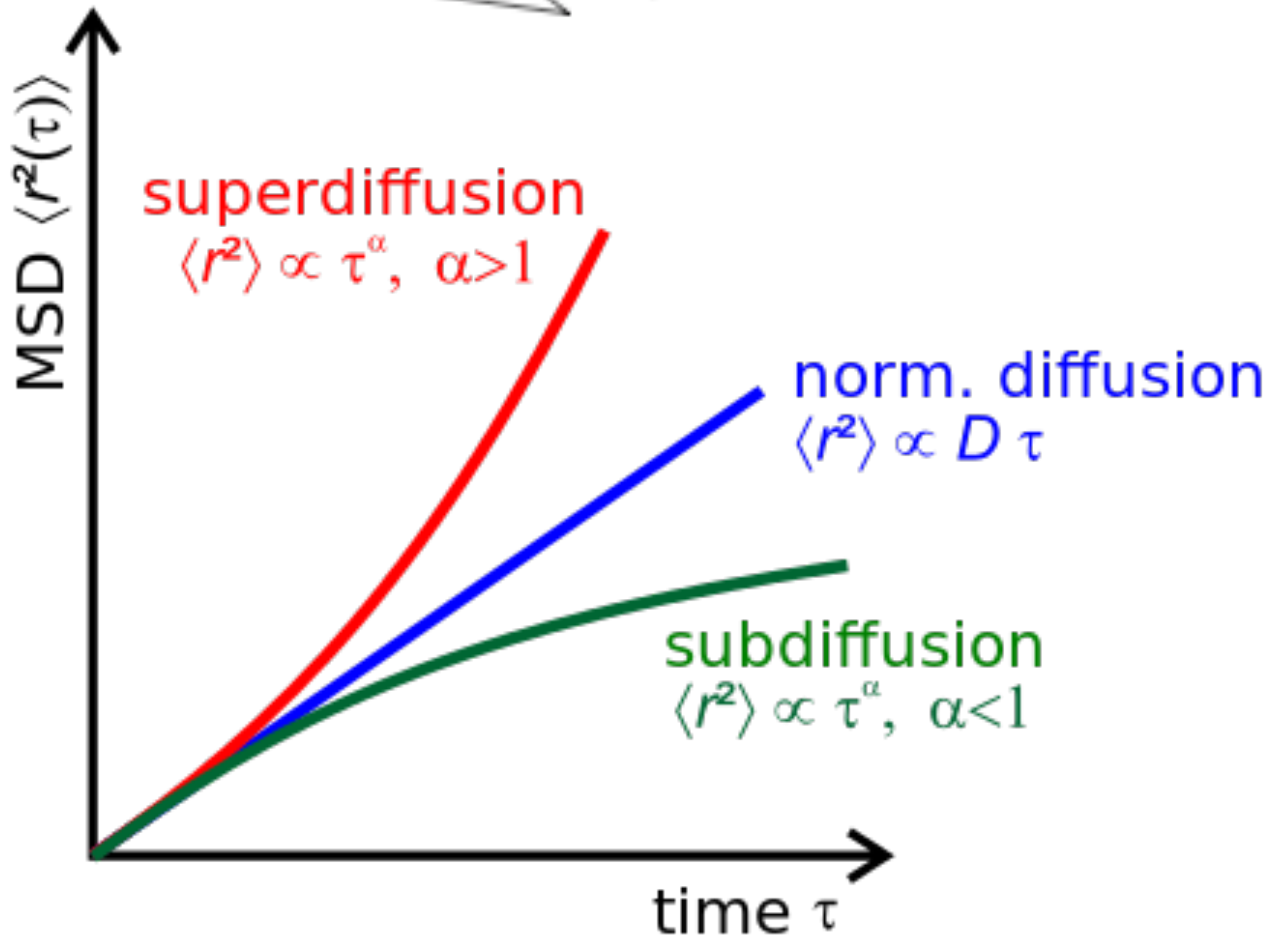
https://en.wikipedia.org/wiki/Anomalous_diffusion

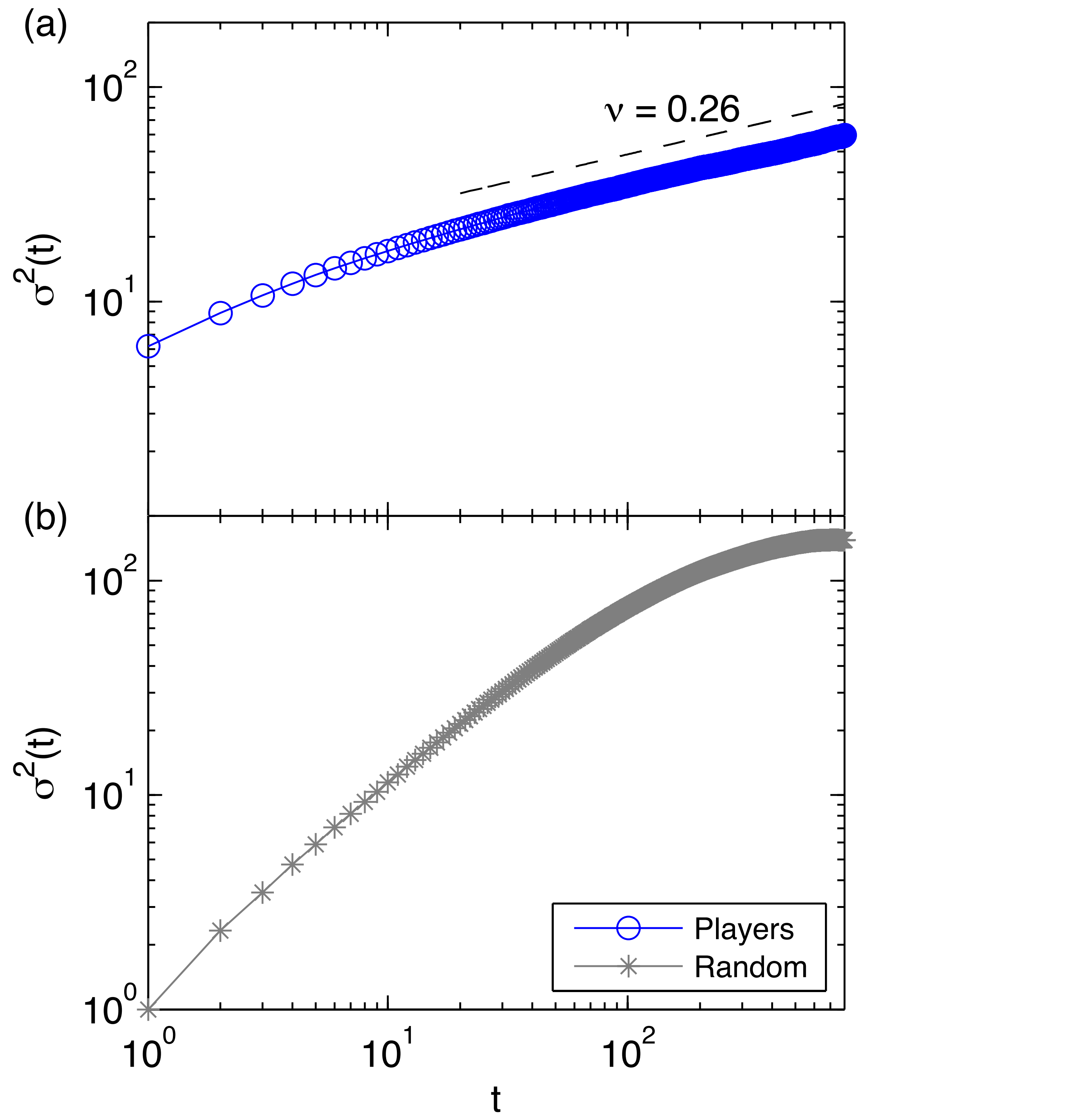
The MSD measures deviation from an initial position



The mean squared displacement characterizes diffusion

$$MSD = \langle r^2(\tau) \rangle = \frac{1}{N} \sum_{n=1}^{N} \left(x_n(\tau) - x_n(0) \right)^2$$





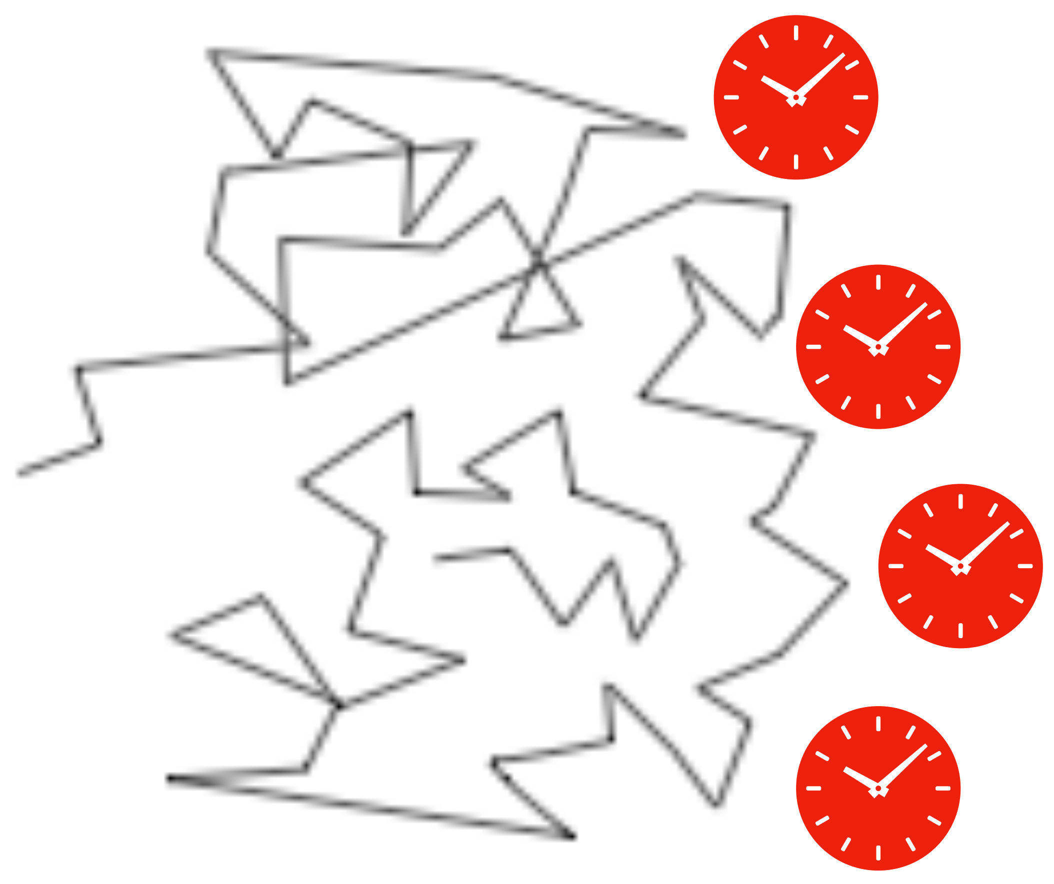
We found $\alpha = 0.26$:
Players explore *much* less than a random walker

https://en.wikipedia.org/wiki/Anomalous_diffusion

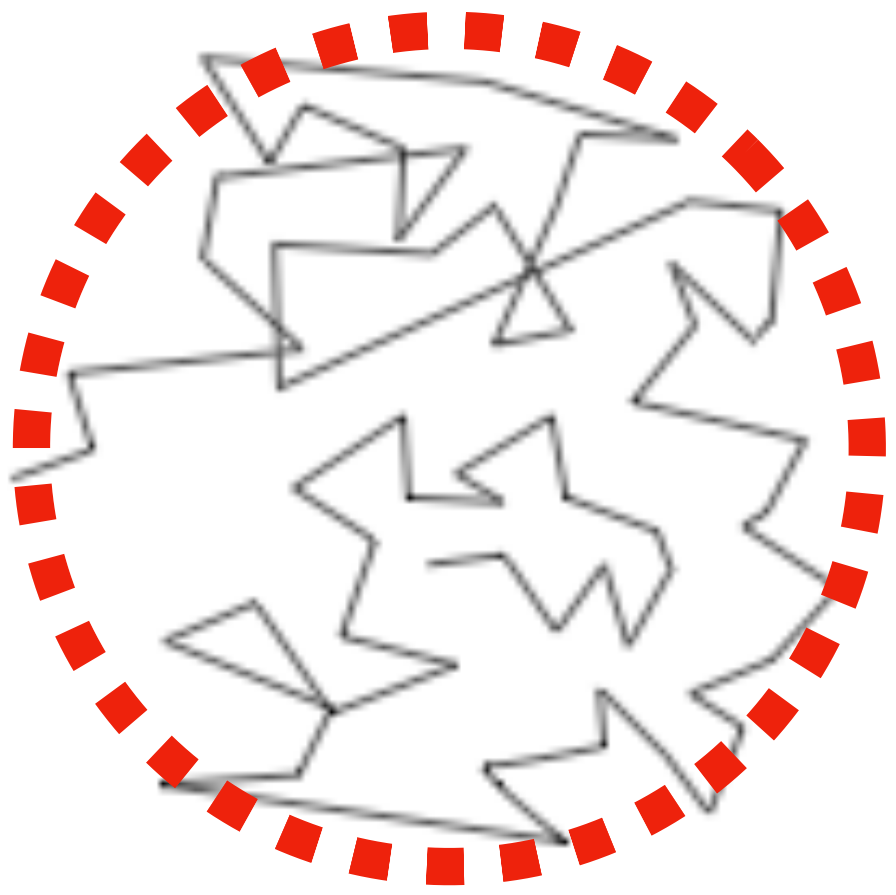
Summary of physics-inspired mobility measures

Jump distribution

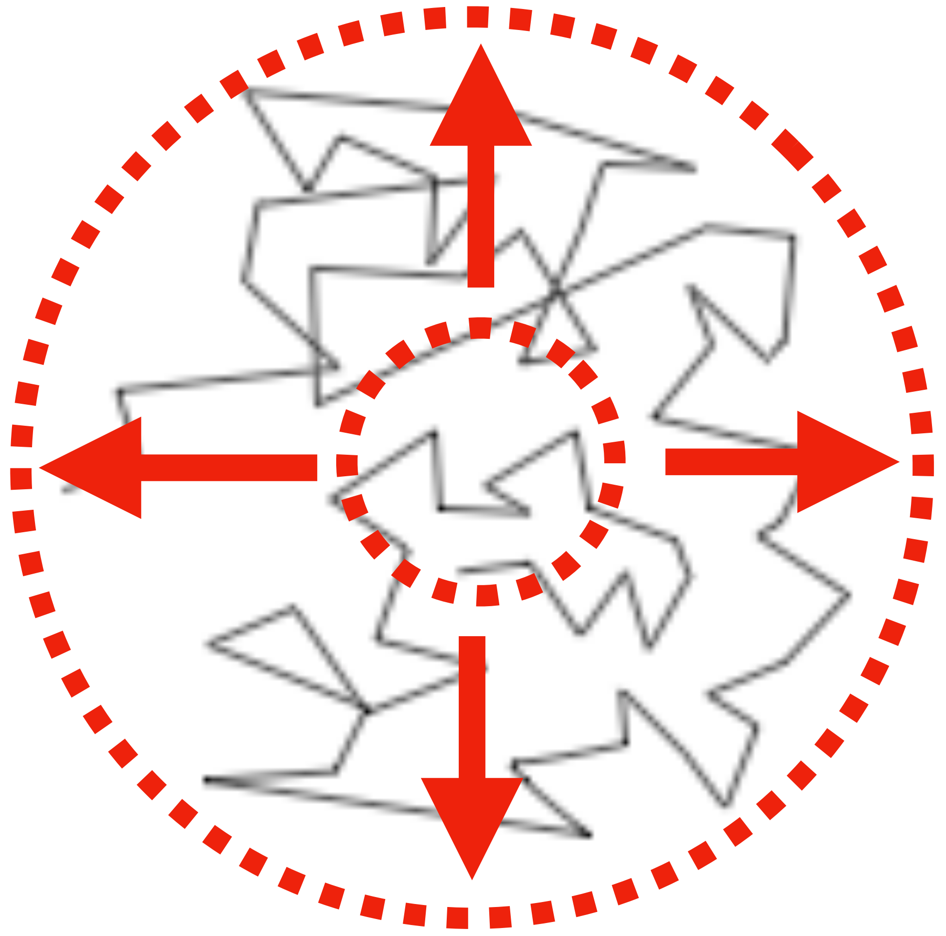
Waiting time distribution



Radius of gyration

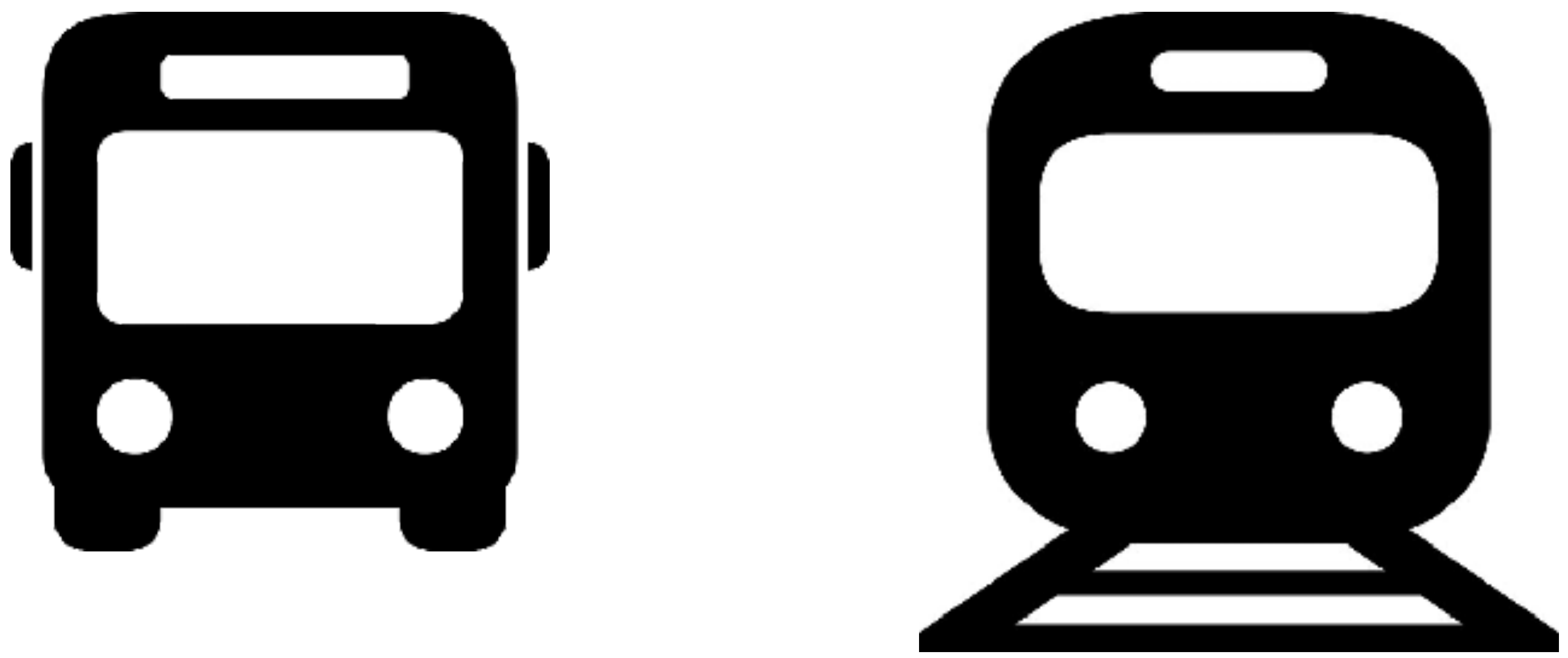


Mean squared displacement



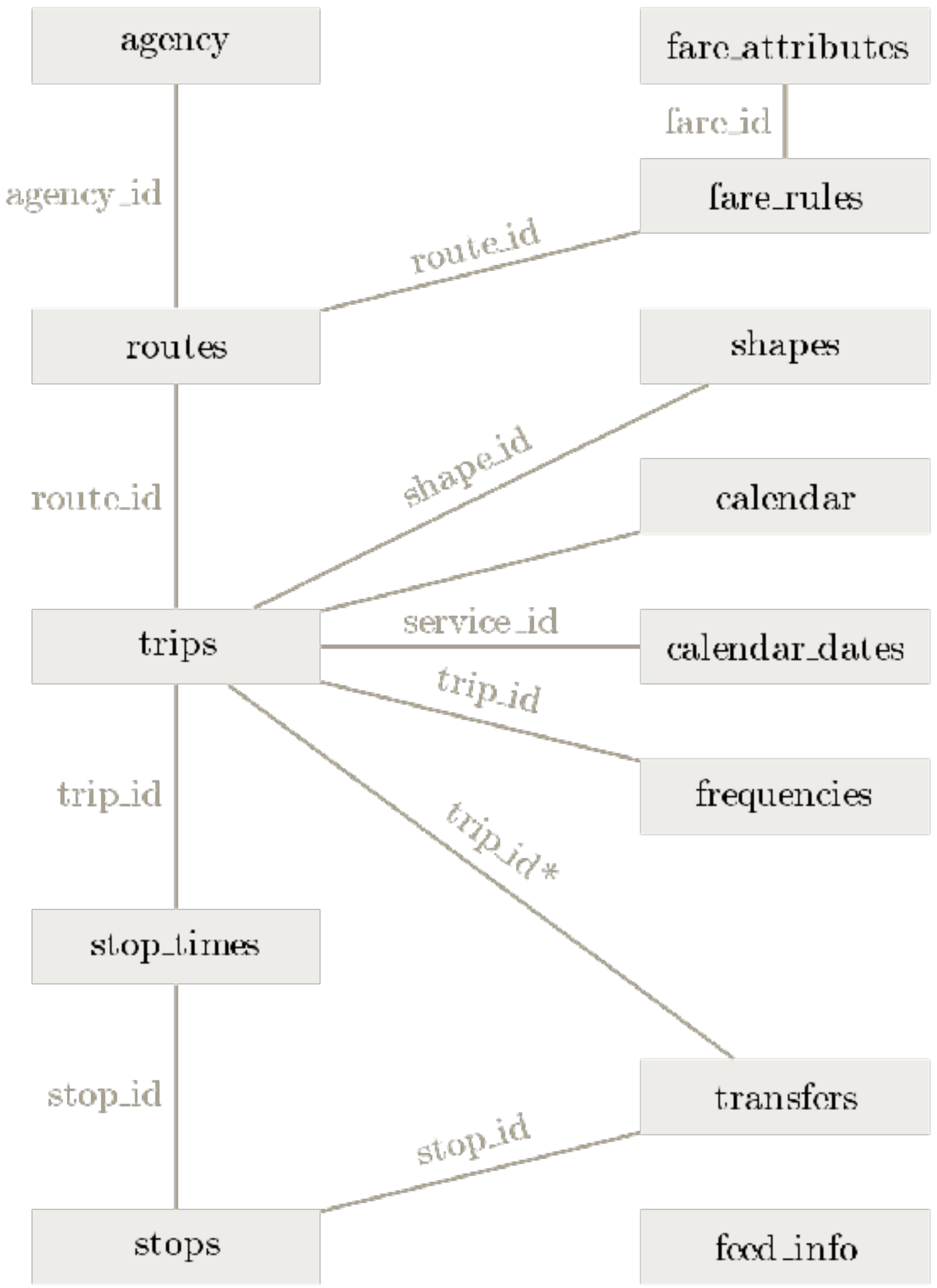
GTFS defines a format for public transportation schedules

General Transit Feed Specification



Denmark data:

https://transitfeeds.com/p/rejseplanen/705



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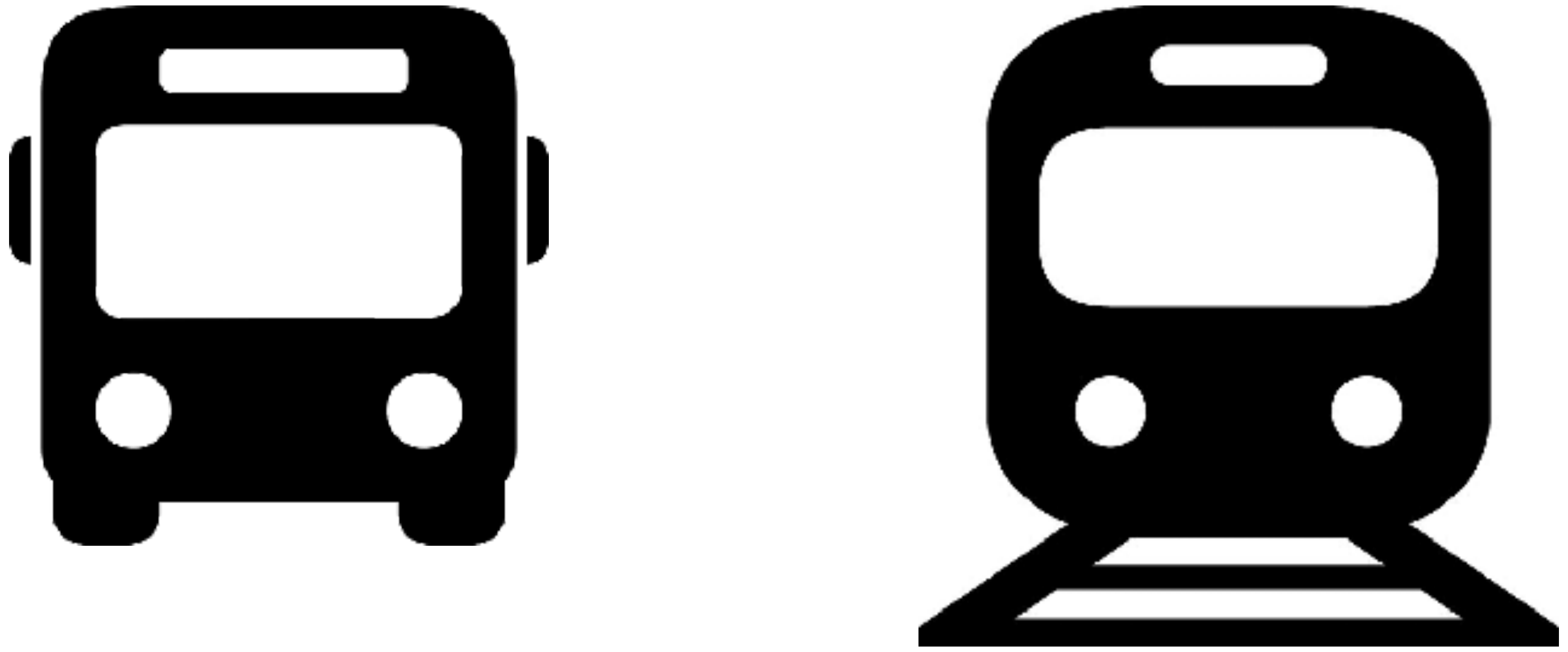
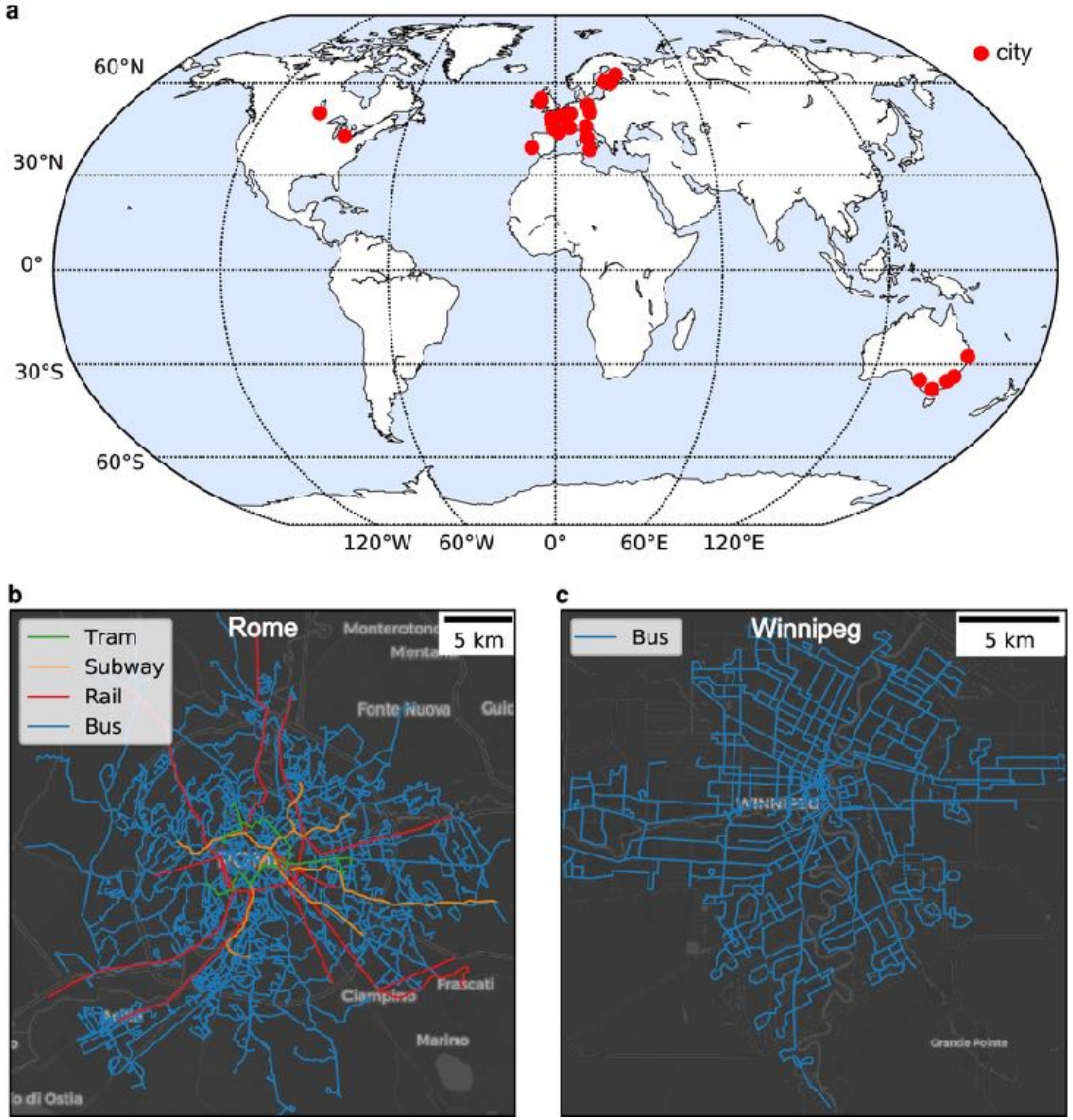


Open, curated data set of 25 cities:



https://www.nature.com/articles/sdata201889

Python packages to study human mobility

scikit mobility

movingpandas

Physics-based metrics and models

GIS exploration and visualization

https://scikit-mobility.github.io/scikit-mobility/

https://anitagraser.github.io/movingpandas/

From individual trajectories to OD matrices and flow maps

Individual trajectories are aggregated spatially in a tesselation = tiling of the plane without gaps. These tiles are called origins and destinations.

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3	T_{31}			
Z	T_{Z1}			T_{ZZ}

The OD-Matrix (Origin-Destination), or trip table, trip matrix, gives the number of trips going from each origin to each destination.

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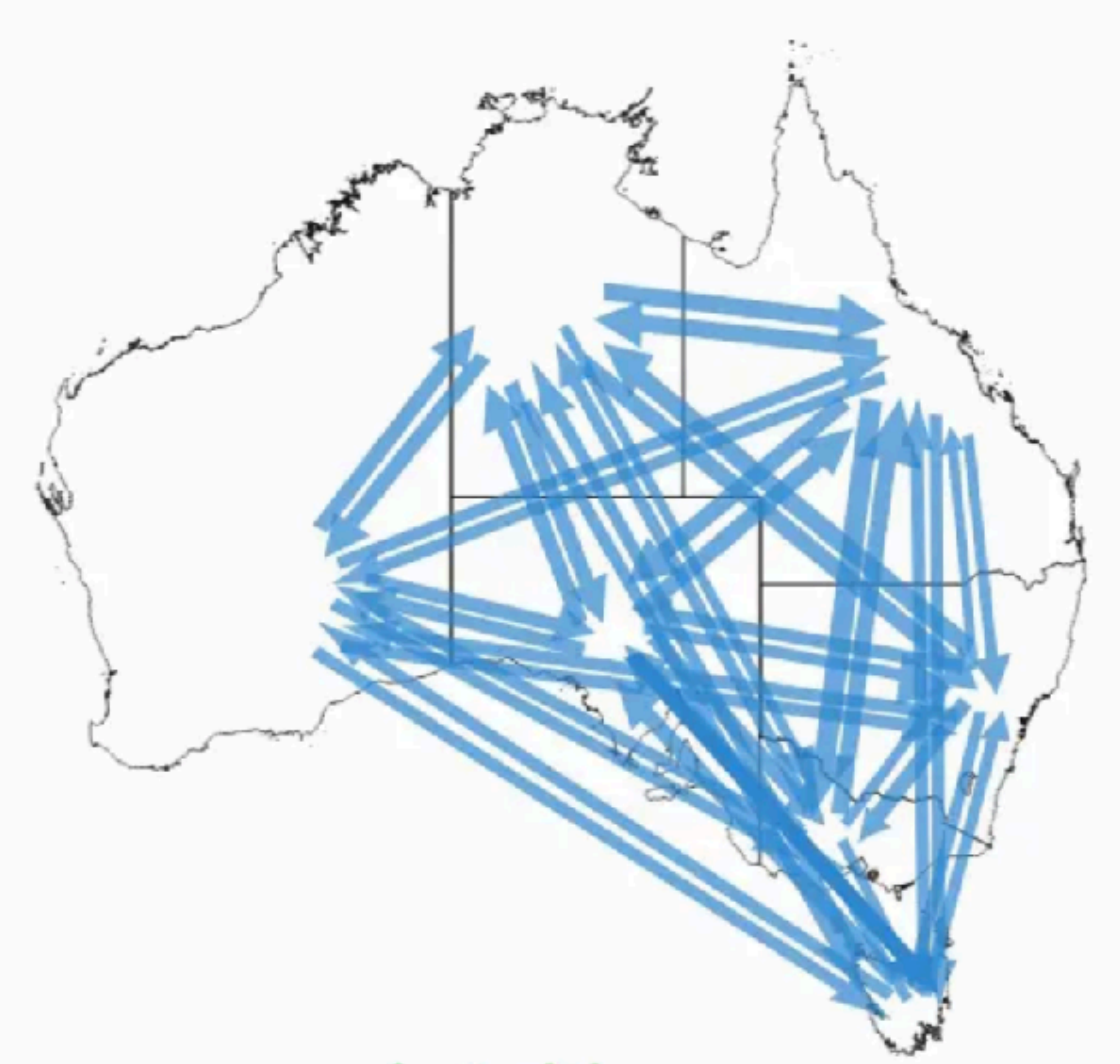
This is visualized in the flow map:



Jupyter