Human Travel Patterns

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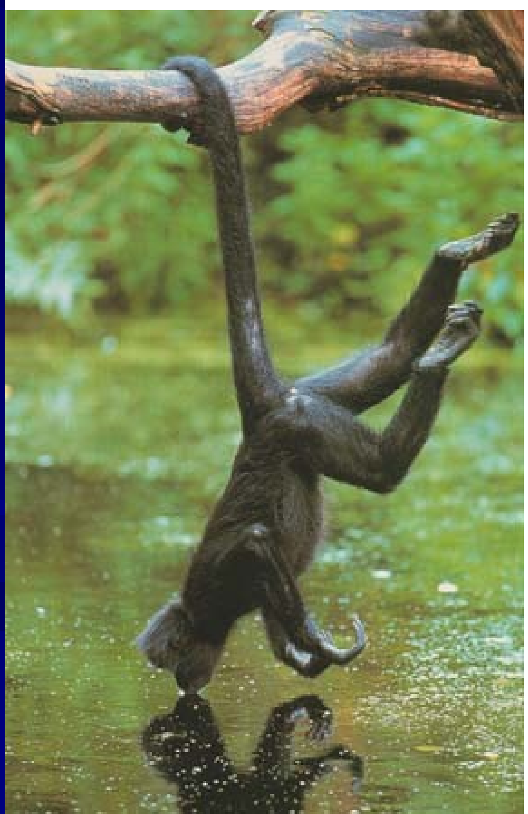
ORIGINAL ARTICLE

Gabriel Ramos-Fernández · José L. Mateos ·
Octavio Miramontes · Germinal Cocho ·
Hernán Larralde · Bárbara Ayala-Orozco

Lévy walk patterns in the foraging movements of spider monkeys (*Ateles geoffroyi*)



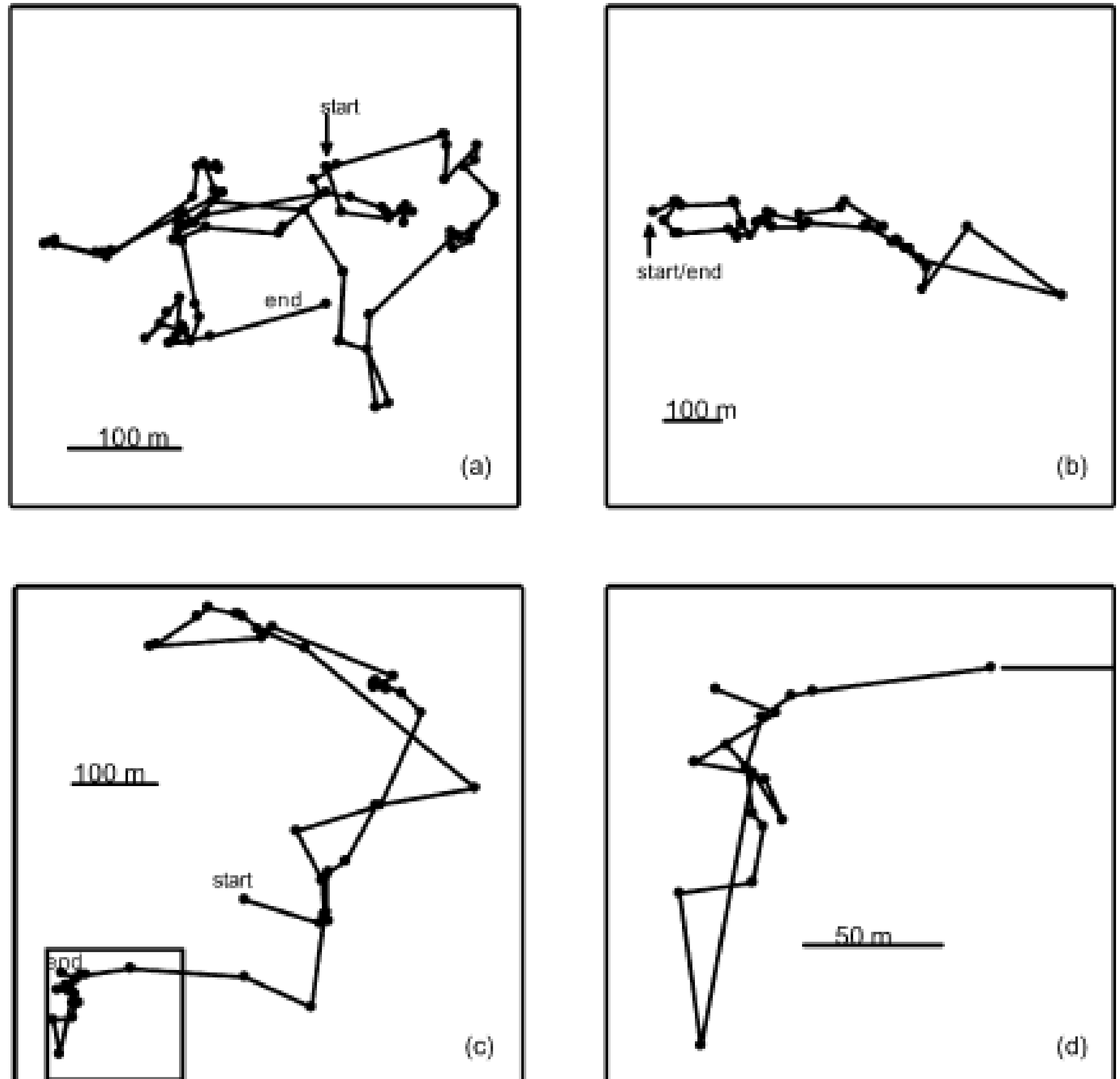
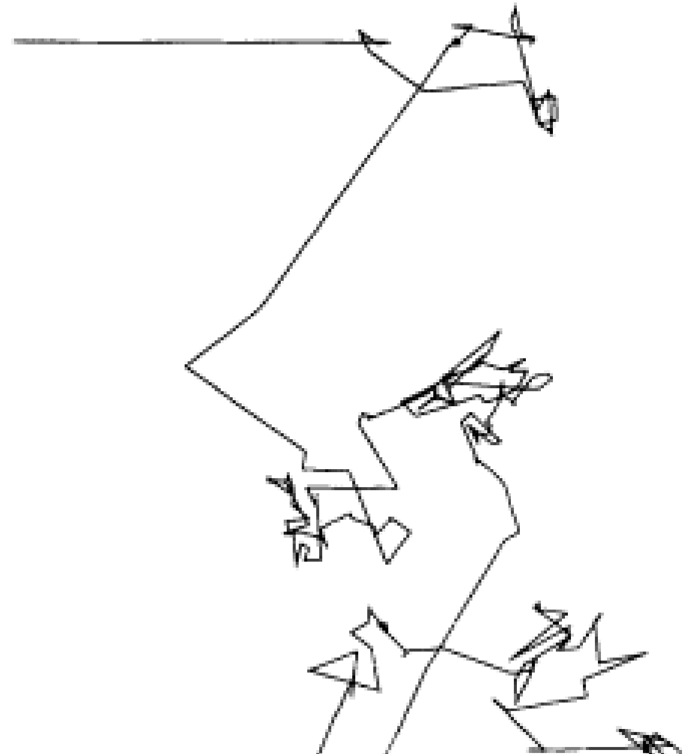


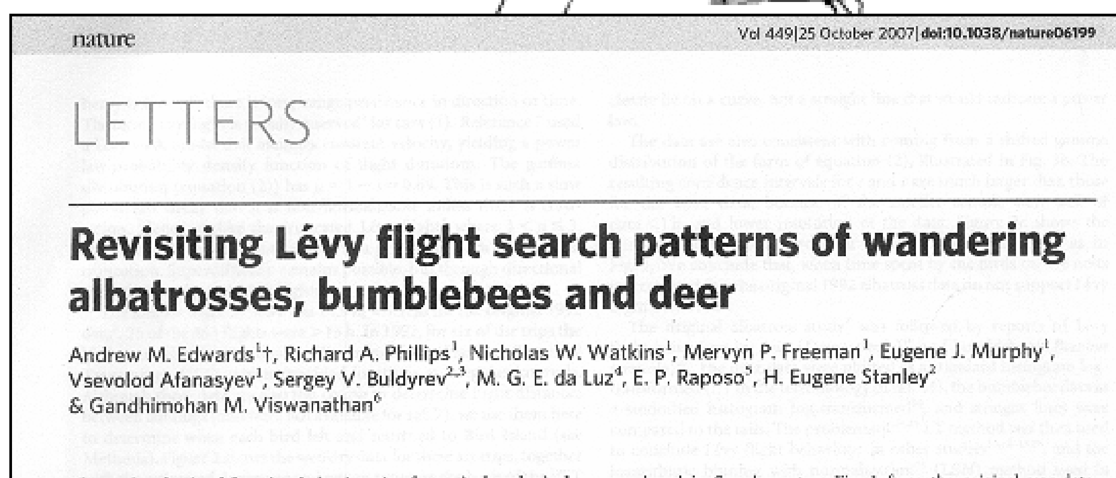
Fig. 1a–d Daily trajectories of spider monkeys. a, b Adult females. c Adult male, with the section of the trajectory within the lower-left square amplified in d. Note that some individuals, like the adult female in b, returned to sleep close to where they started their daily travel

Animal Motion

Wandering Albatross



Vishwanatan *et. al.* Nature (1996);
Nature (1999).



nature Vol 449|25 October 2007|doi:10.1038/nature06199

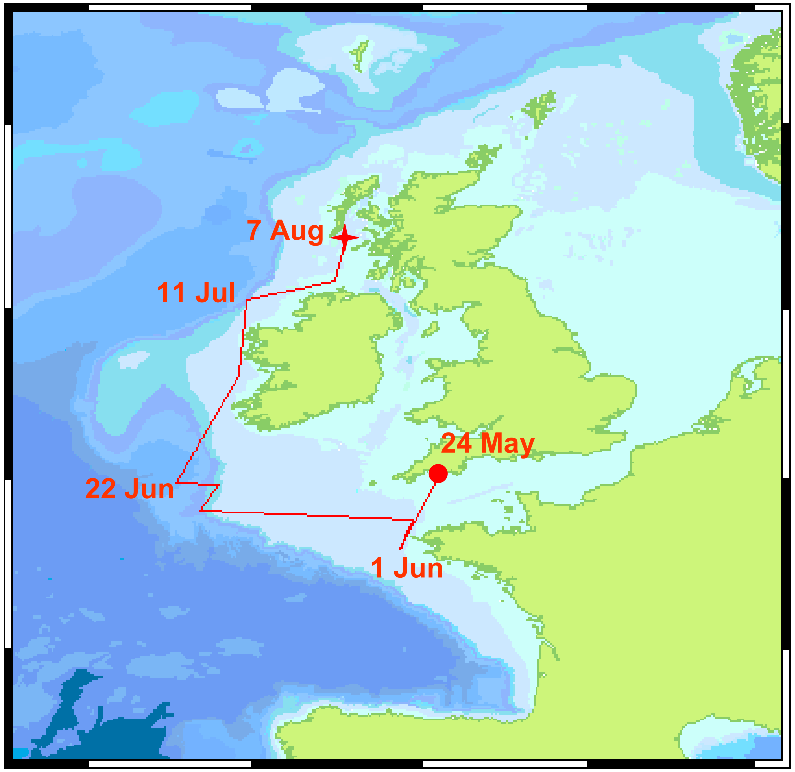
LETTERS

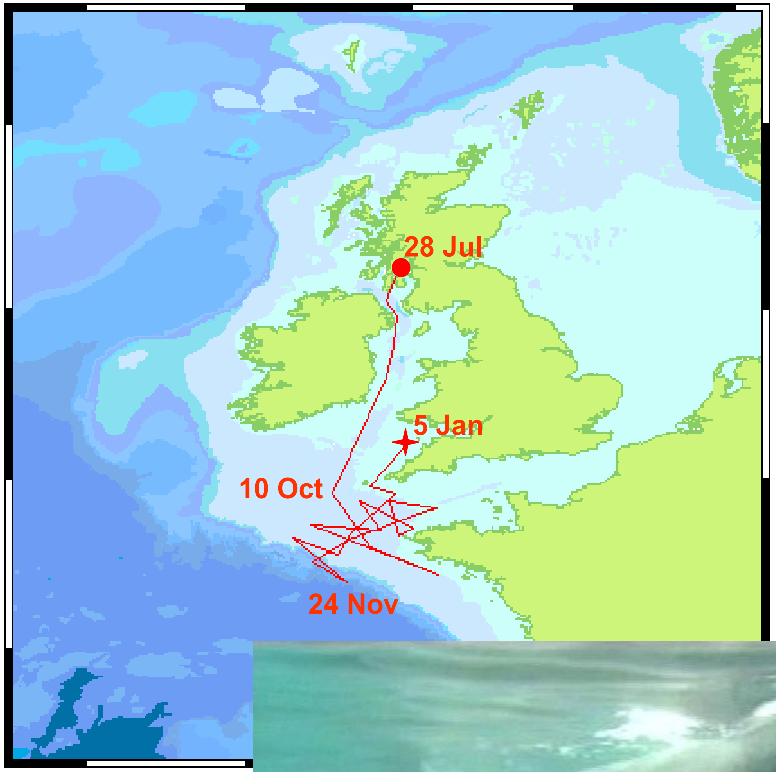
Revisiting Lévy flight search patterns of wandering albatrosses, bumblebees and deer

Andrew M. Edwards[1]†, Richard A. Phillips[1], Nicholas W. Watkins[1], Mervyn P. Freeman[1], Eugene J. Murphy[1], Vsevolod Afanasyev[1], Sergey V. Buldyrev[2,3], M. G. E. da Luz[4], E. P. Raposo[5], H. Eugene Stanley[2] & Gandhimohan M. Viswanathan[6]

The study of animal foraging behaviour is of practical ecological

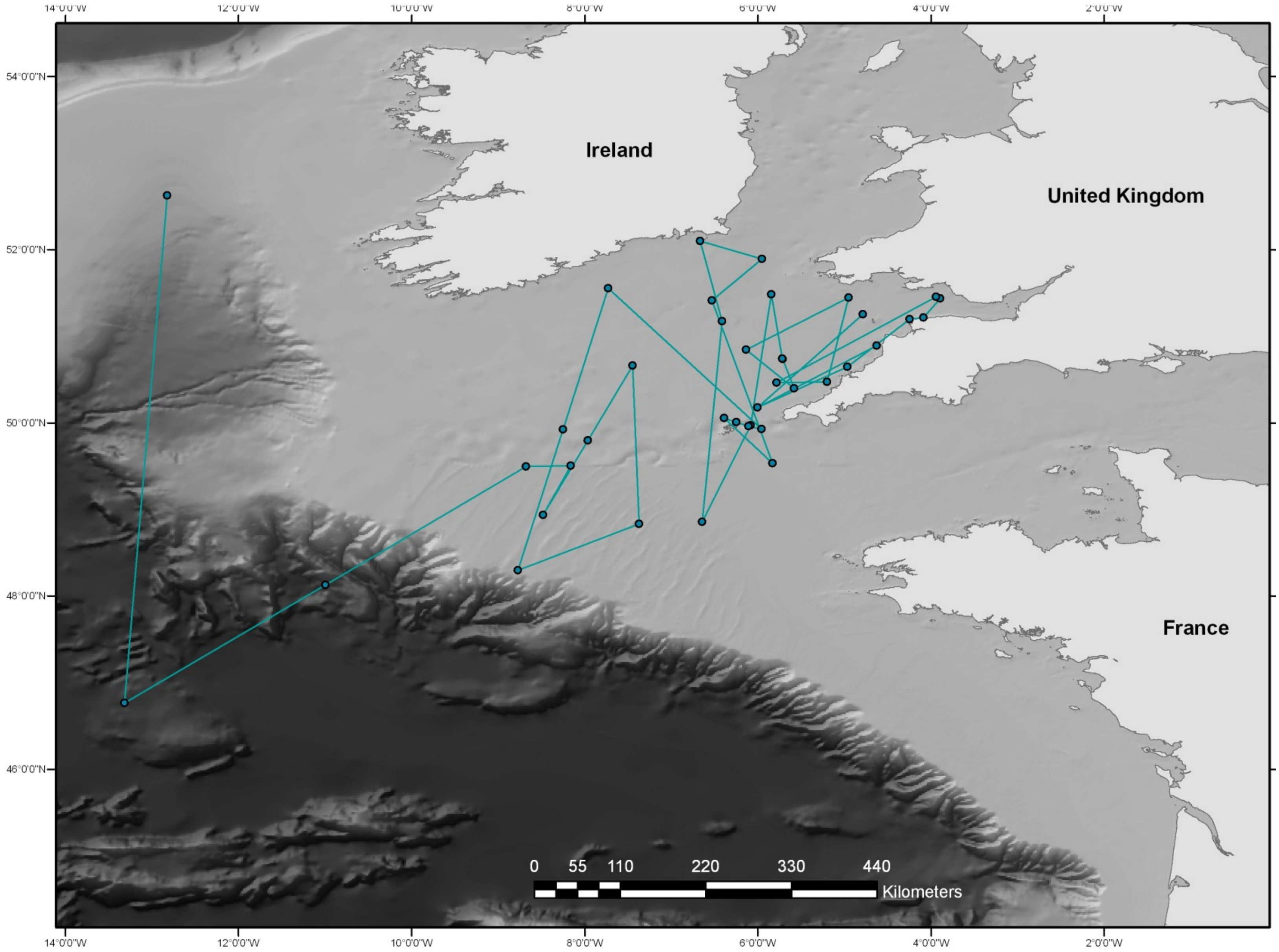
reproduced in Supplementary Fig. 1 from the original raw data.





Basking shark

Sims *et al*. Nature (2008).



Porbeagle shark

Sims *et al*. Nature (2008).

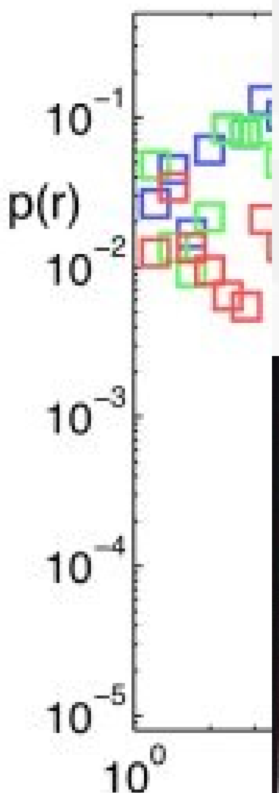
Random Walks

Lévy flights

$$f(\Delta r)=C$$

$$f(\Delta x) \sim \frac{1}{\Delta x^{1+\beta}}$$

Human Motion

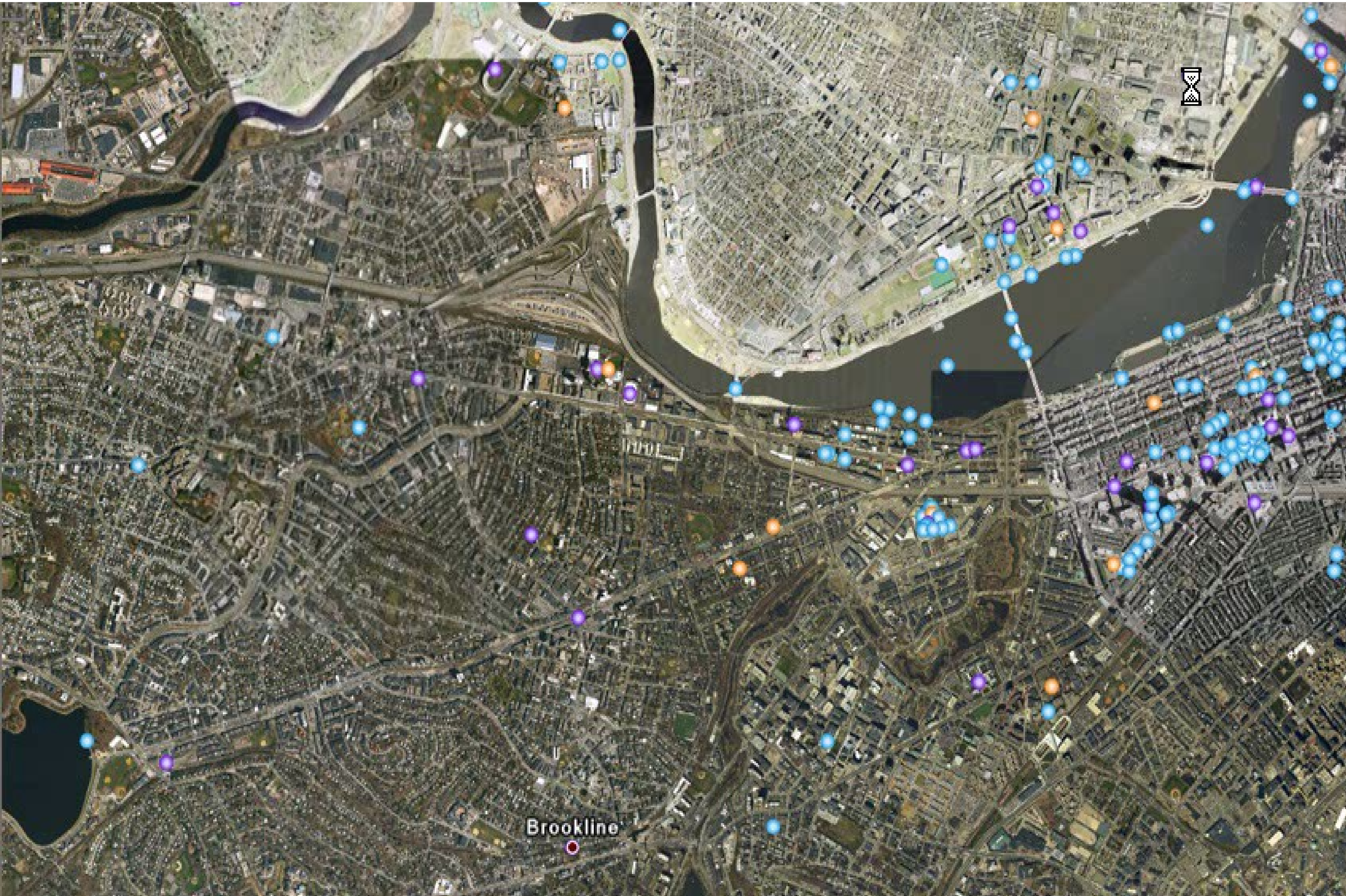


$0 < \alpha < 1.$

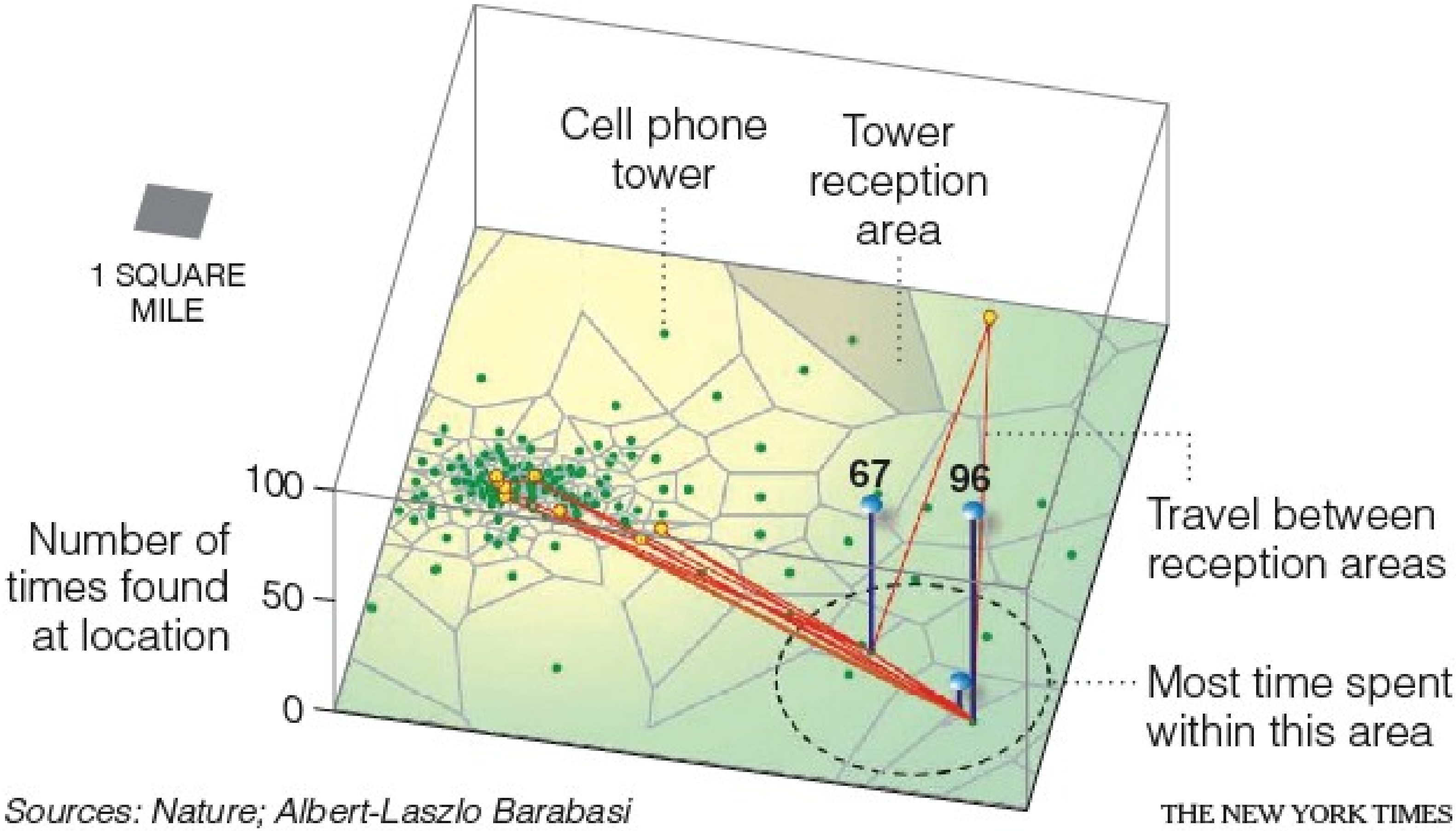
$0 < \beta < 2$

Brockmann *et. al. Nature* (2006)

A real human trajectory



Mobile Phone Users



Data Collection Limitations

We know only the tower the user communicates with, not the real location.

We know the location (tower) only when the user makes a call.

Interevent times are bursty (non-Poisson process— Power law interevent time distribution).

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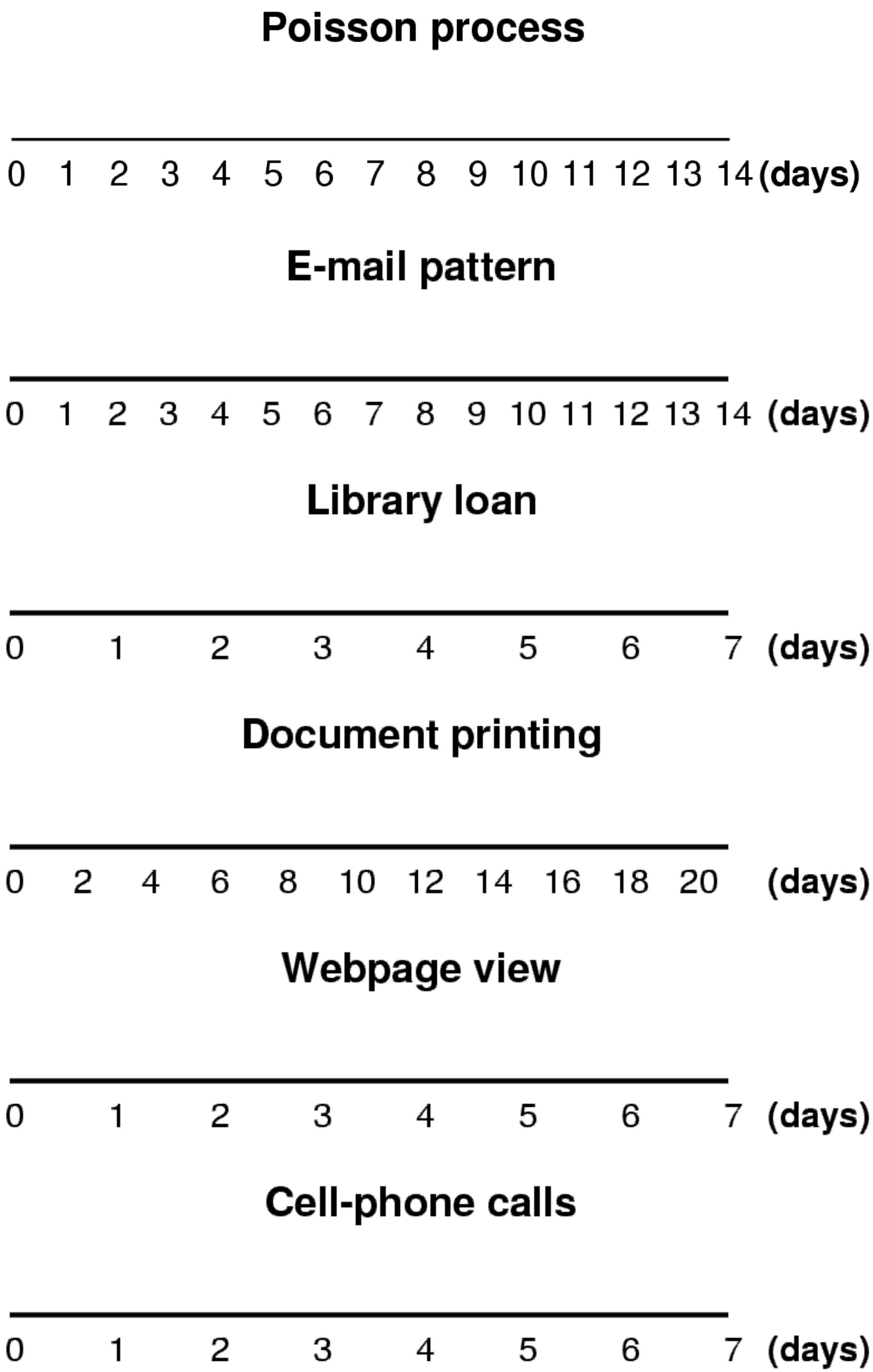
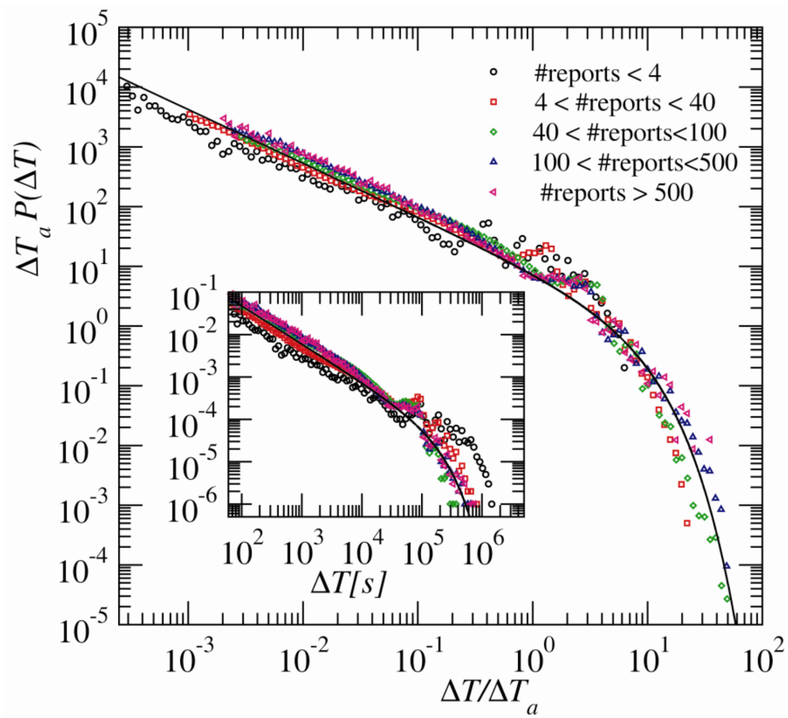
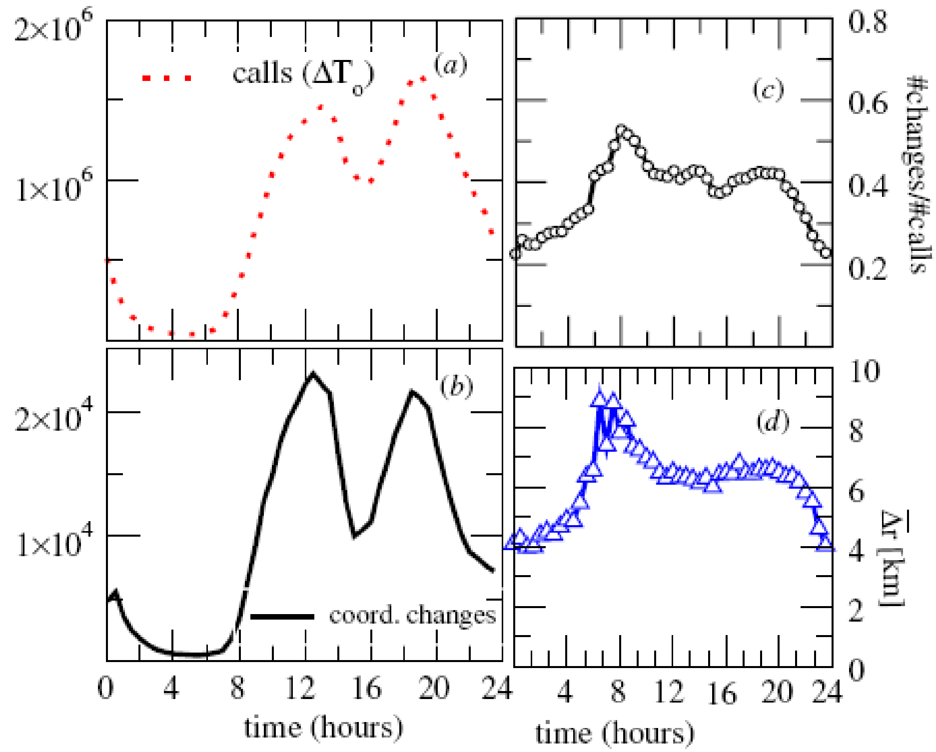


ALB, *Nature* 2005.

Interevent Times





$$P(\Delta T) = 1/\Delta T_a \mathcal{F}(\Delta T/\Delta T_a)$$

$$P(\Delta T) = (\Delta T)^{\alpha} \exp(\Delta T/\tau_c)$$

$\alpha = 0.9 \pm 0.1 \quad \tau_c \approx 48$ days

A-L. B, *Nature* 2005.

J. Candia *et al.*
J. Phys. A: Math. Theor. **41** (2008)

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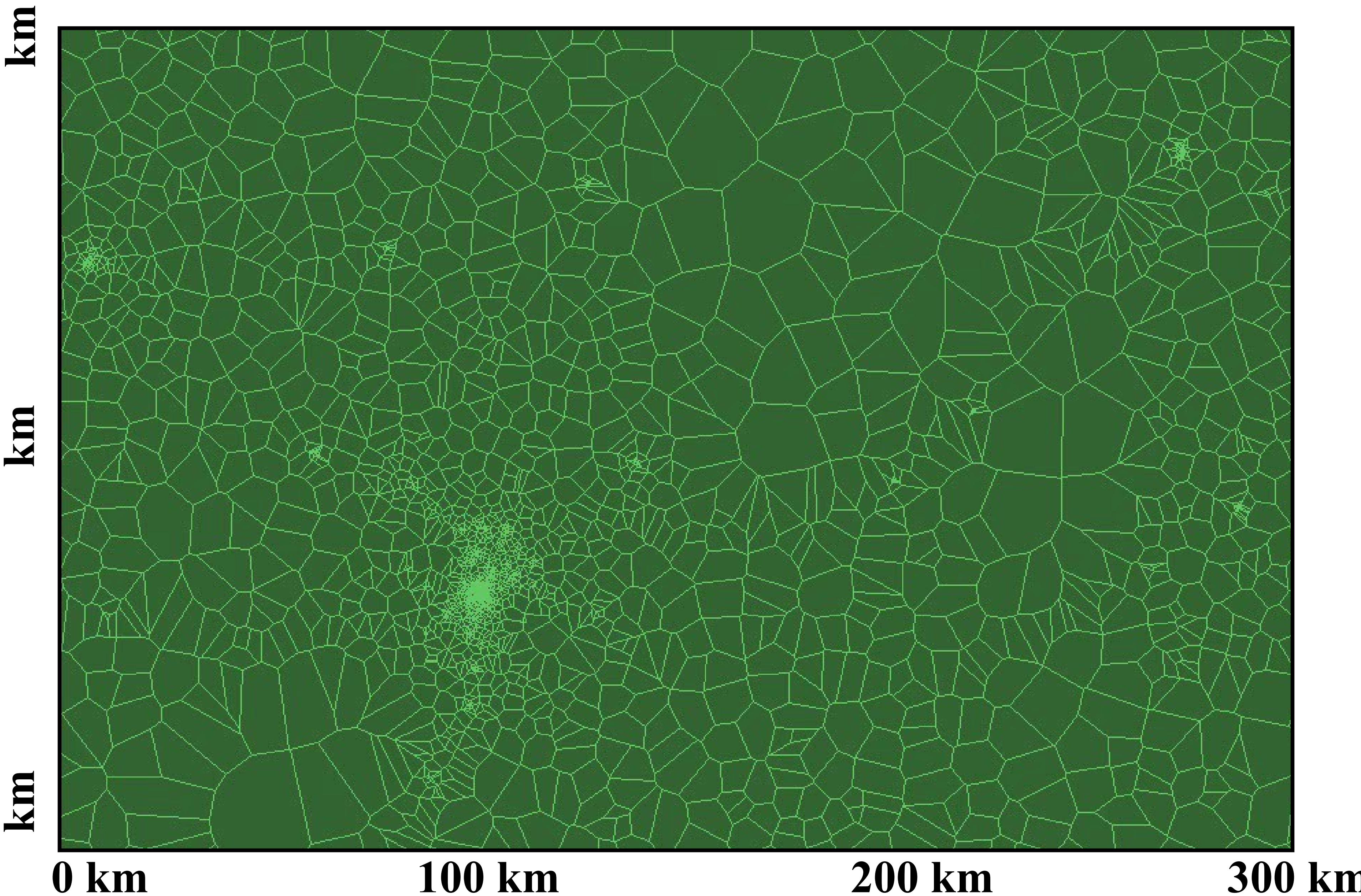
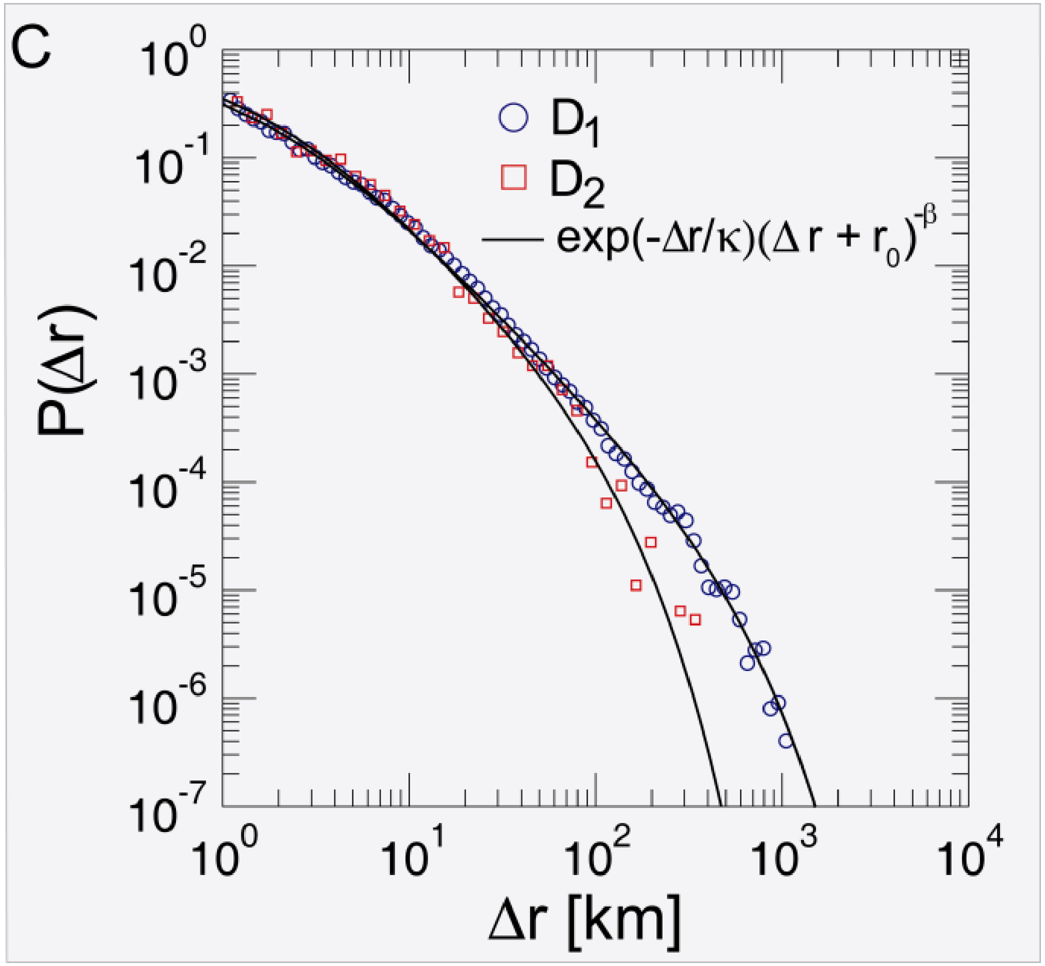
Mobile Phone Users



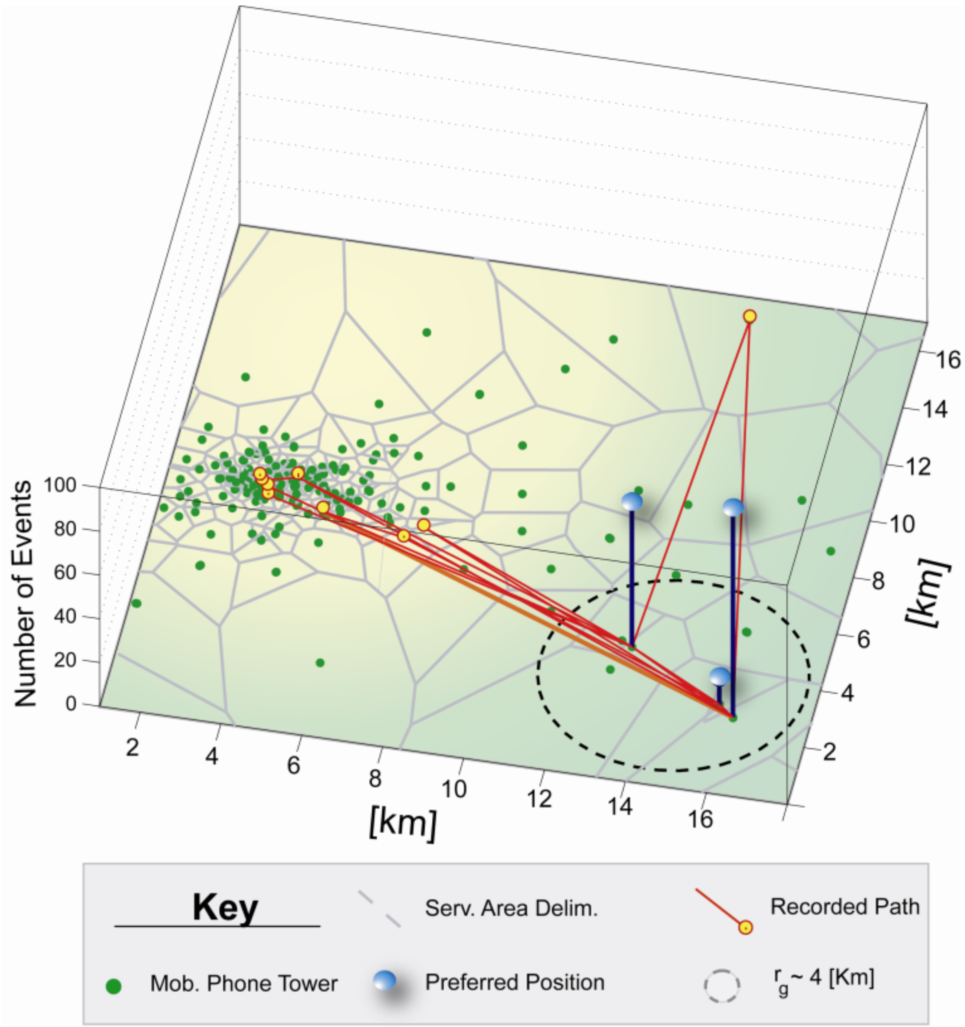


β=1.75±0.15

<u>**Two possible explanations**</u>

1. **Each users follows a Lévy flight**
2. **The difference between individuals follows a power law**

Understanding human trajectories



Center of Mass:

$$\vec{r}_{cm} = \frac{1}{n_p} \sum_{i=1}^{n_p} \vec{r}_i .$$

Radius of Gyration:

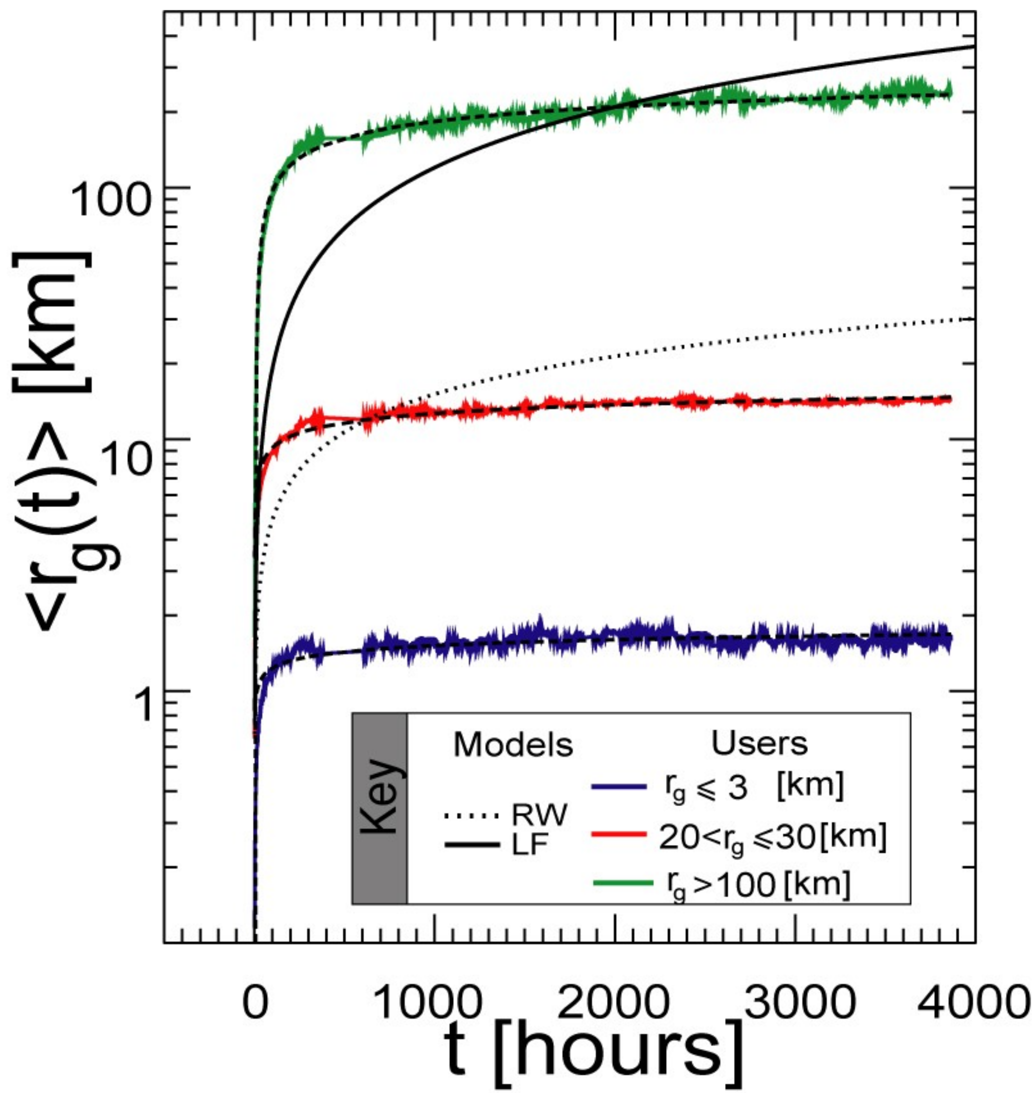
$$r_g^a(t) = \sqrt{\frac{1}{n_c^a(t)} \sum_{i=1}^{n_c^a} (\vec{r_i^a} - \vec{r}_{cm}^a)^2}$$

Characterizing human trajectories

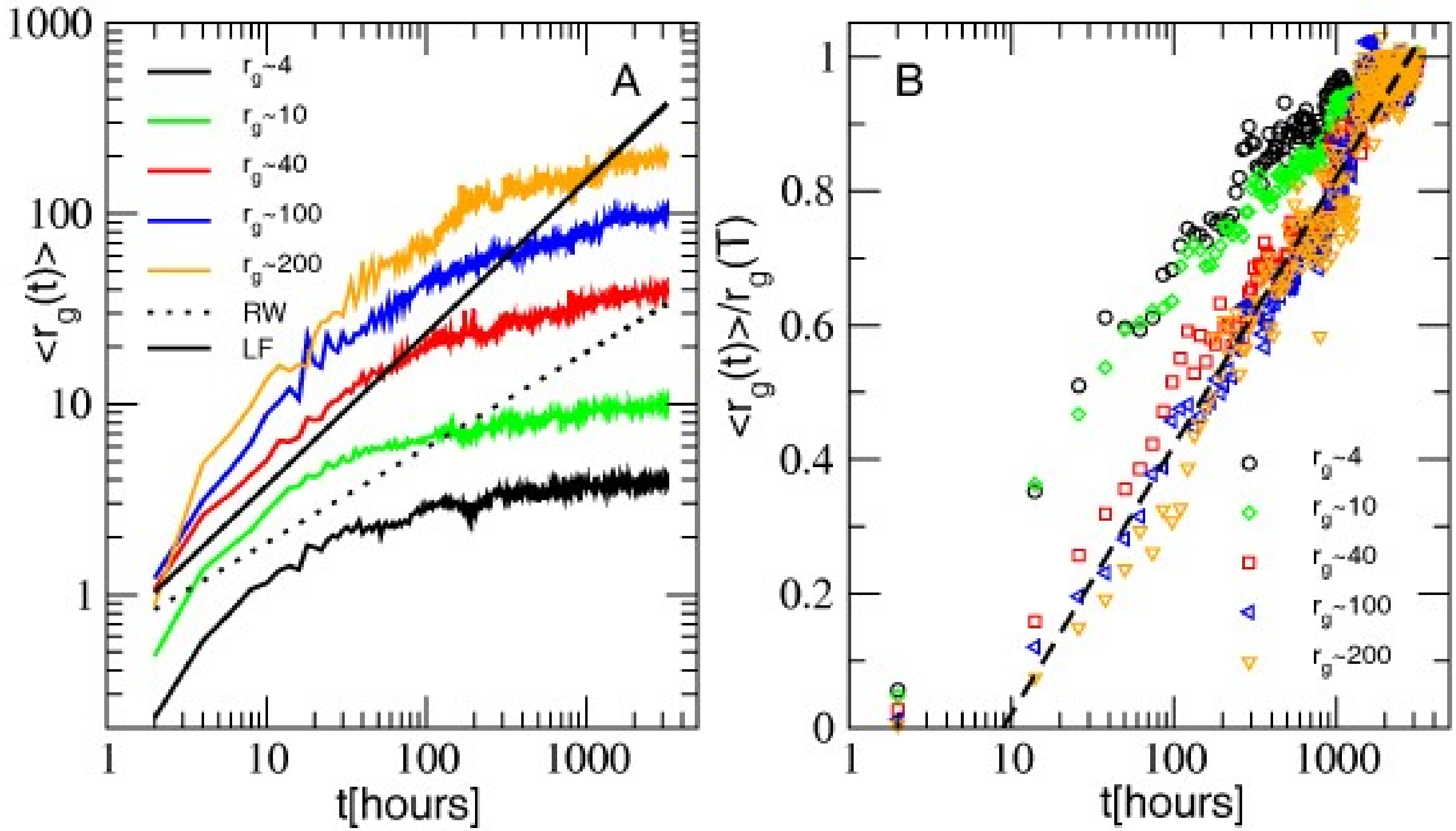
Radius of Gyration:

$$r_g^a(t) = \sqrt{\frac{1}{n_c^a(t)} \sum_{i=1}^{n_c^a} (\vec{r_i^a} - \vec{r}_{cm}^a)^2}$$

$$\vec{r}_{cm} = \frac{1}{n_p} \sum_{i=1}^{n_p} \vec{r_i}.$$



Characterizing human trajectories

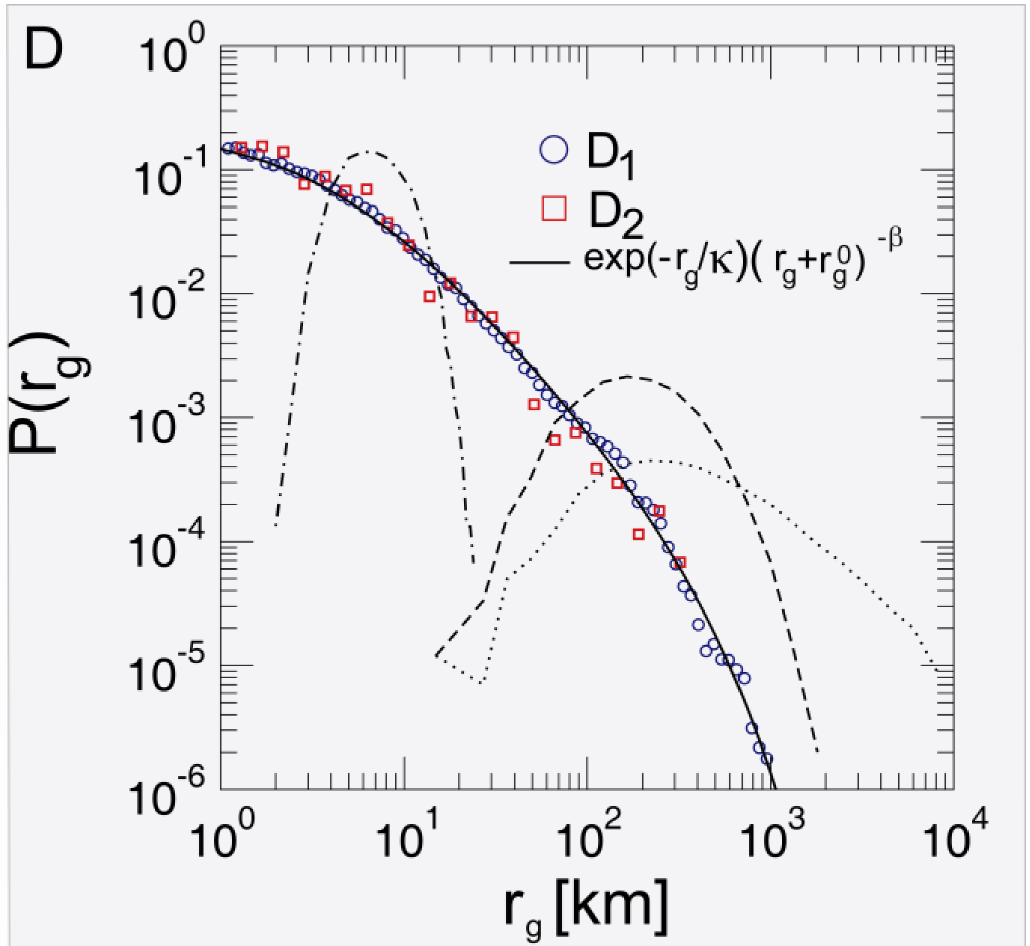


Radius of Gyration:

$$r_g^a(t) = \sqrt{\frac{1}{n_c^a(t)} \sum_{i=1}^{n_c^a} (\vec{r_i^a} - \vec{r}_{cm}^a)^2}$$

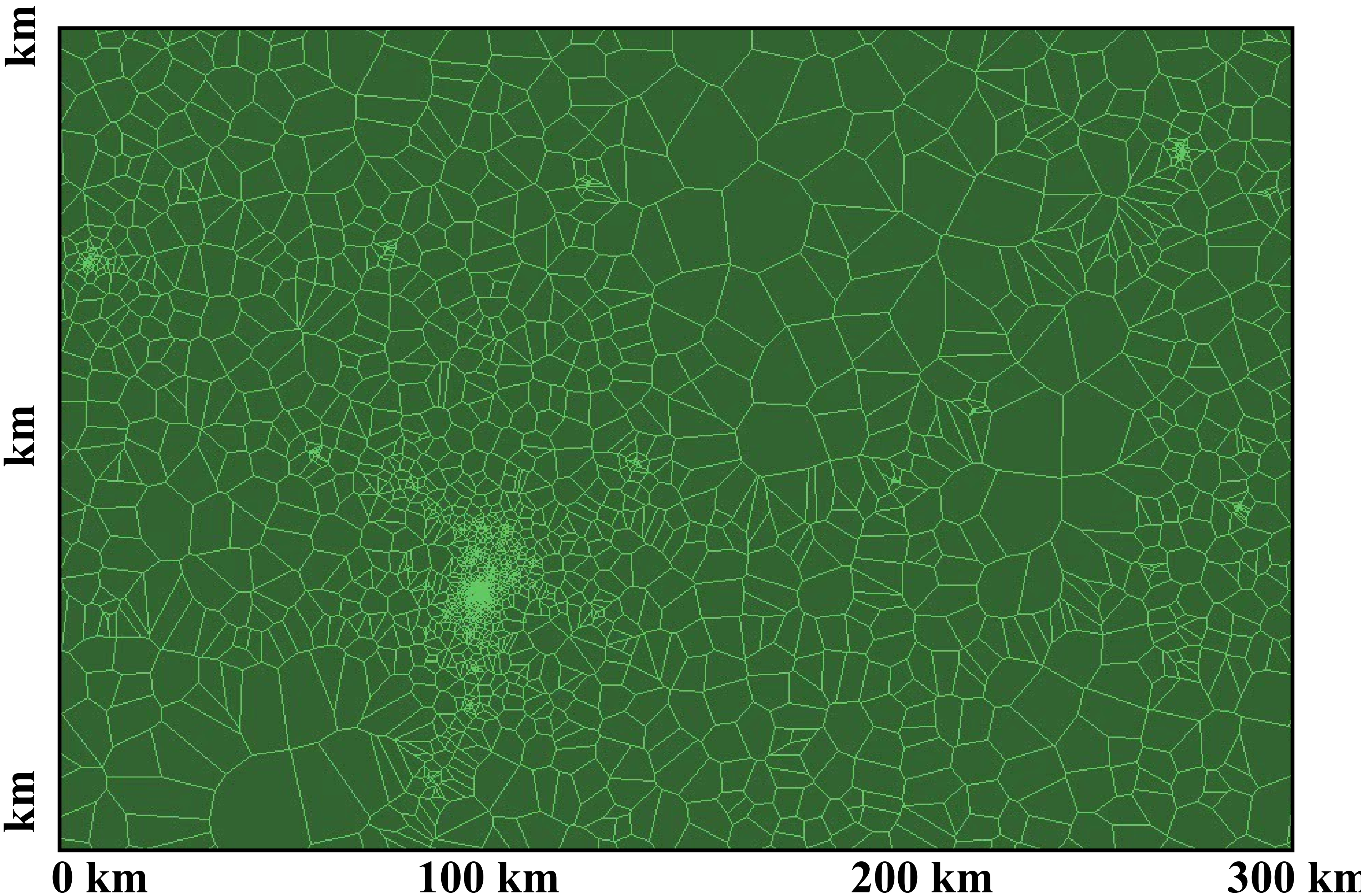
CCNR

Scaling in human trajectories

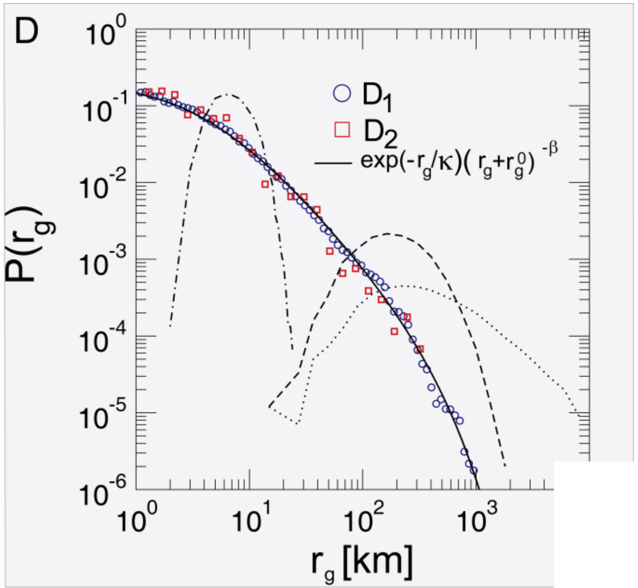


β_r=1.65±0.15

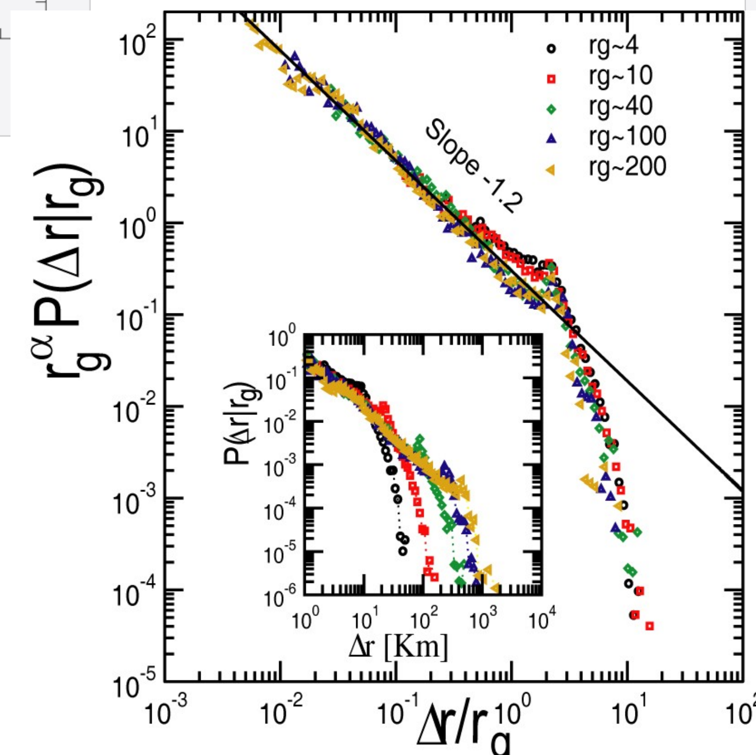
Mobile Phone Users

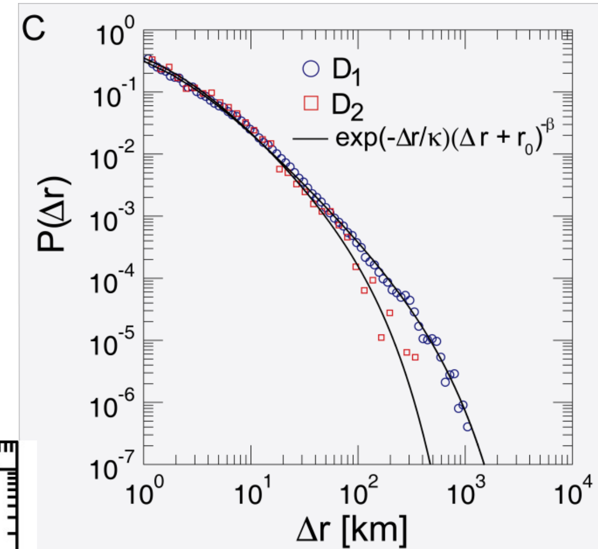


Scaling in human trajectories



β_r=1.65±0.15





β=1.75±0.15

α=1.2

Relationship between exponents

$$P(\Delta r) = \int_0^\infty P(\Delta r | r_g) P(r_g) dr_g$$

$$P(\Delta r) = \int_0^\infty r_g^{-\alpha} F(\frac{\Delta r}{r_g})(r_g + r_g^0) e^{-r_g/\kappa} dr_g$$

$$P(\Delta r) \approx \Delta r^{-\alpha-\beta_r+1} \int_0^\infty x^{-\alpha} F(\frac{1}{x}) e^{x\Delta r/\kappa} dx$$

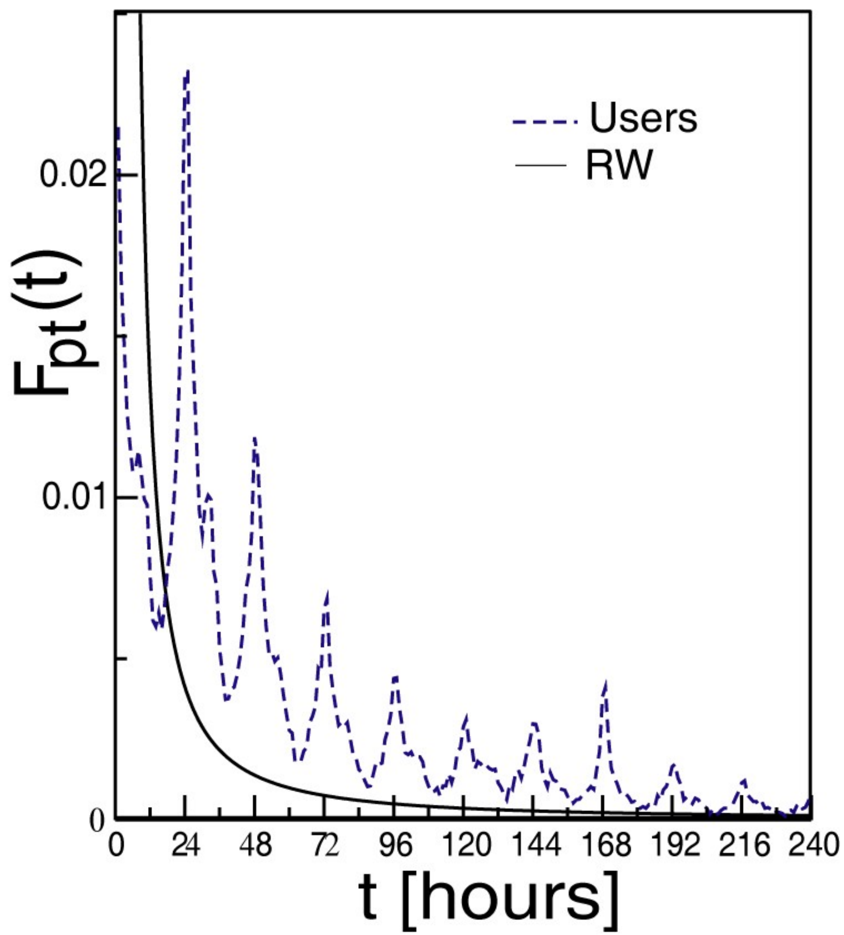
$$\beta = \alpha + \beta_r - 1$$

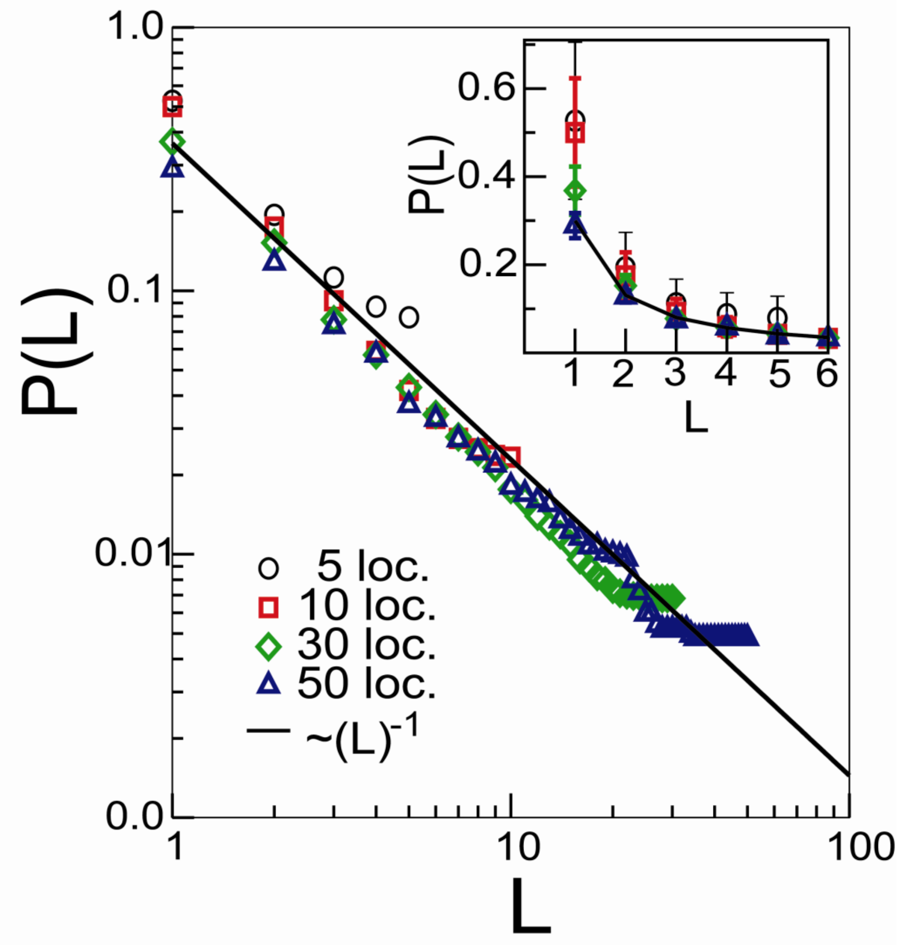
<u>Jump size distribution $P(\Delta r) \sim (\Delta r)^{-\beta}$ represents a convolution between</u>

***population heterogeneity $P(r_g) \sim r_g^{-\beta r}$**

***Levy flight with exponent α truncated by r_g**

Return time distributions





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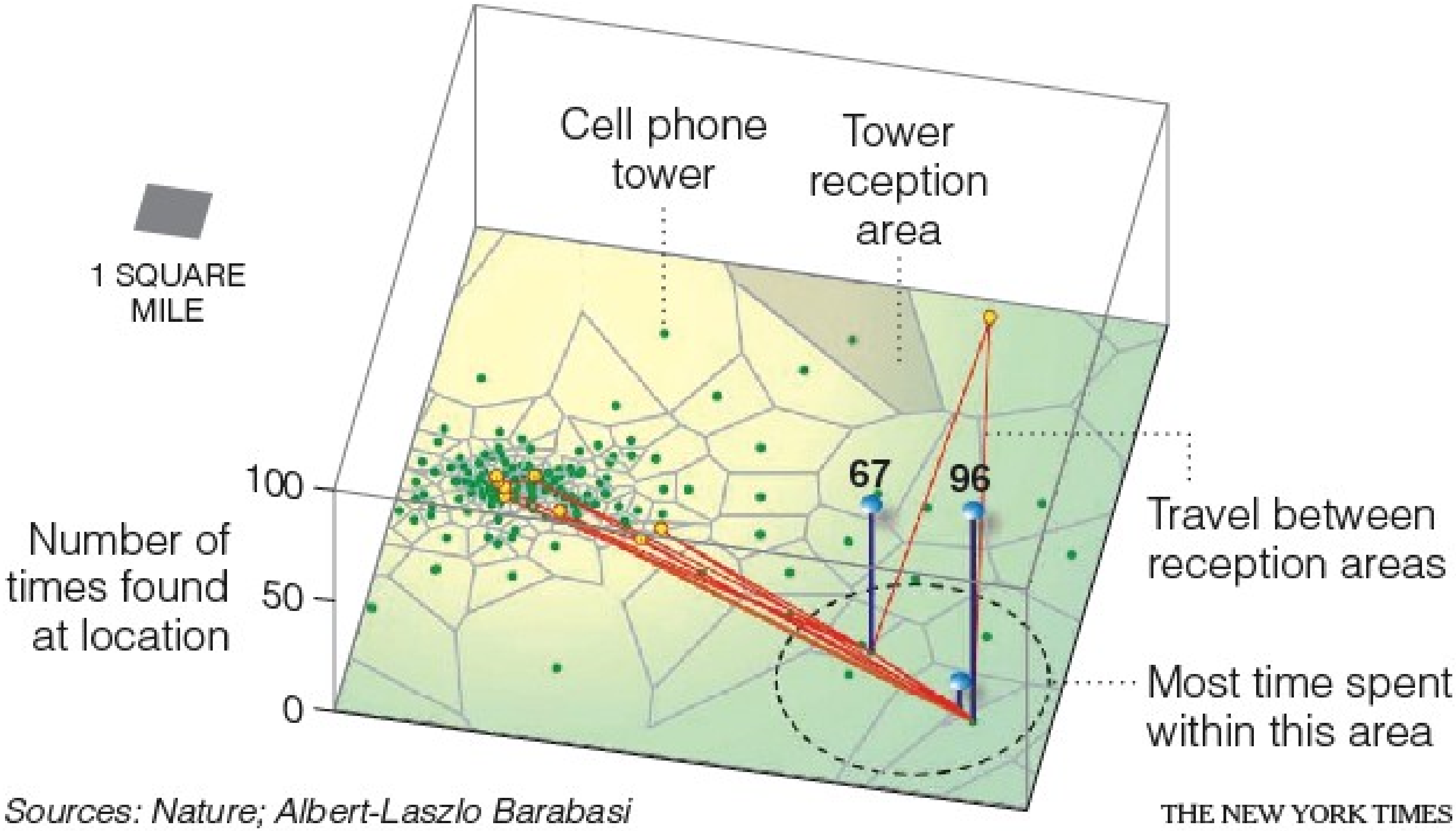
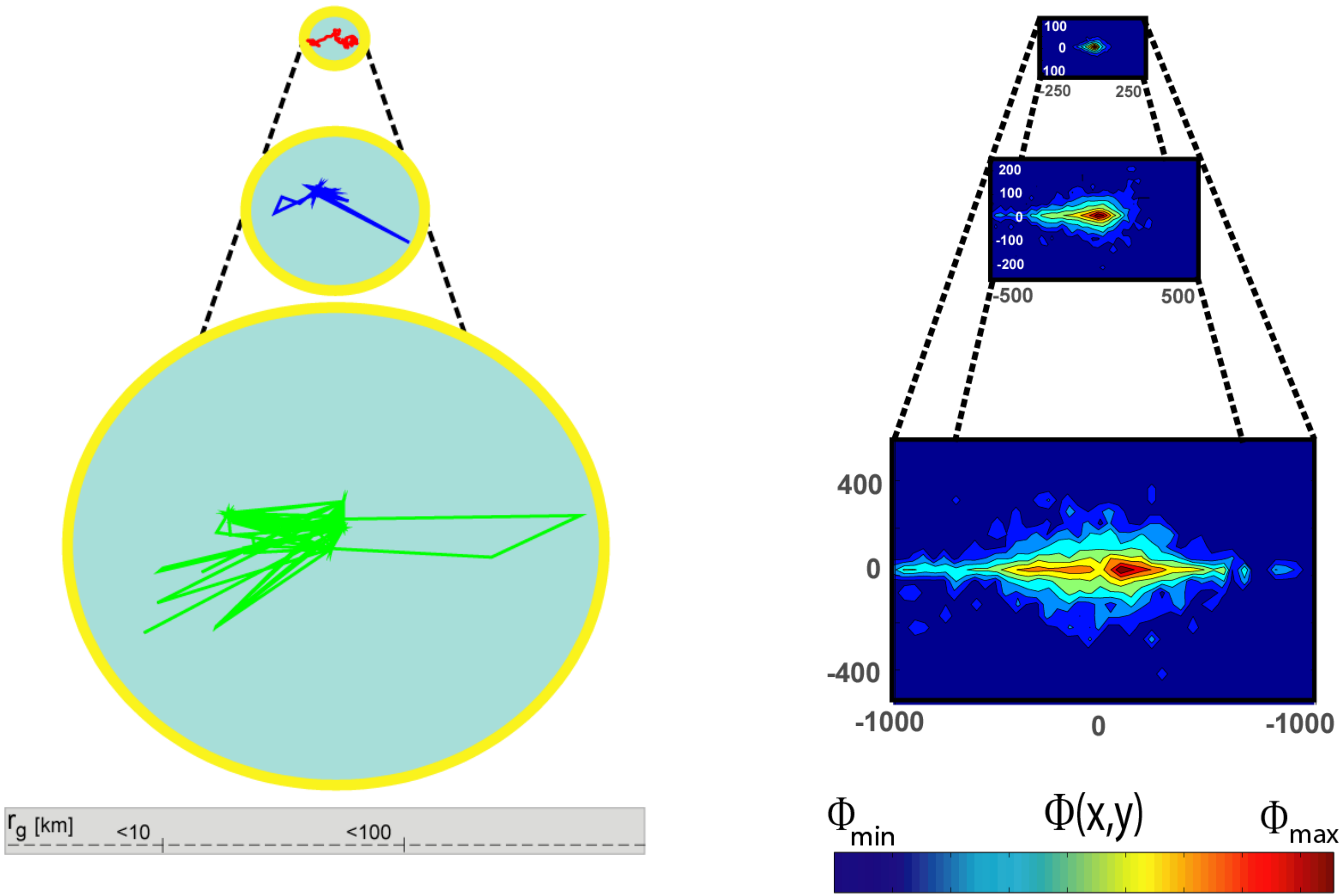
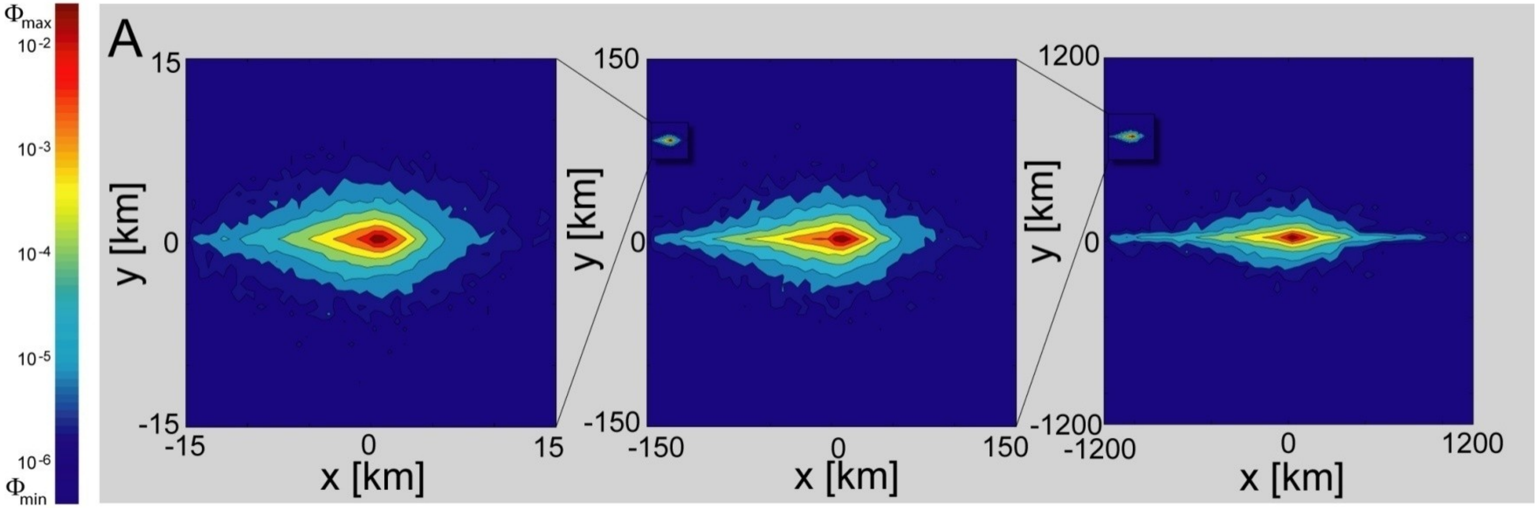
Mobile Phone Users

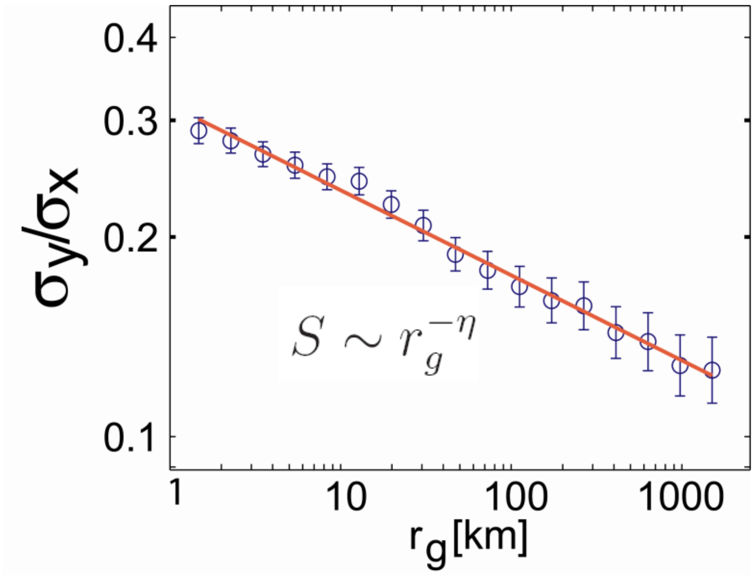




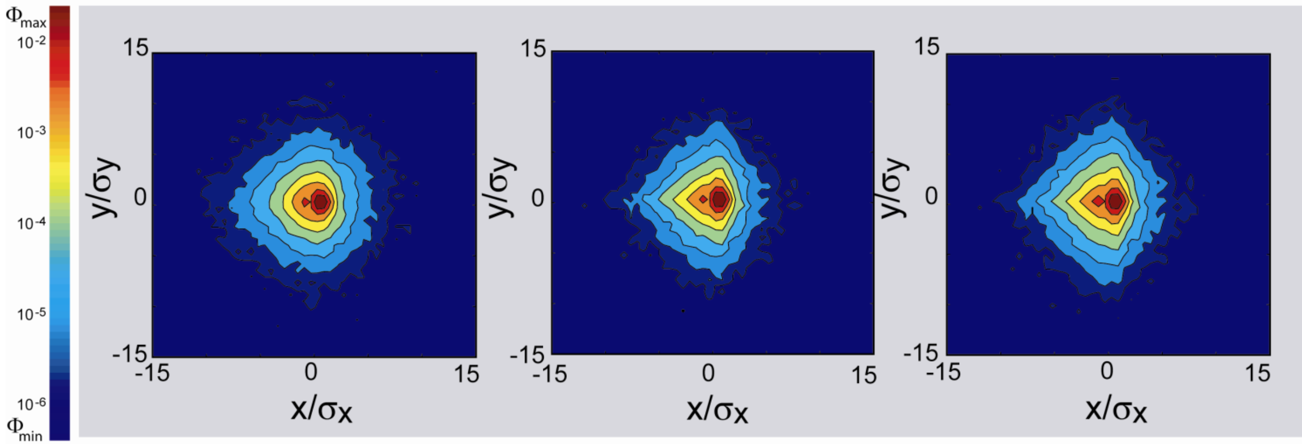
100
0
100
-250
250
200
100
0
-100
-200
-500
500
400
0
-400
-1000
0
-1000
r_g [km]
<10
<100
Φ_{min}
$\Phi(x,y)$
Φ_{max}

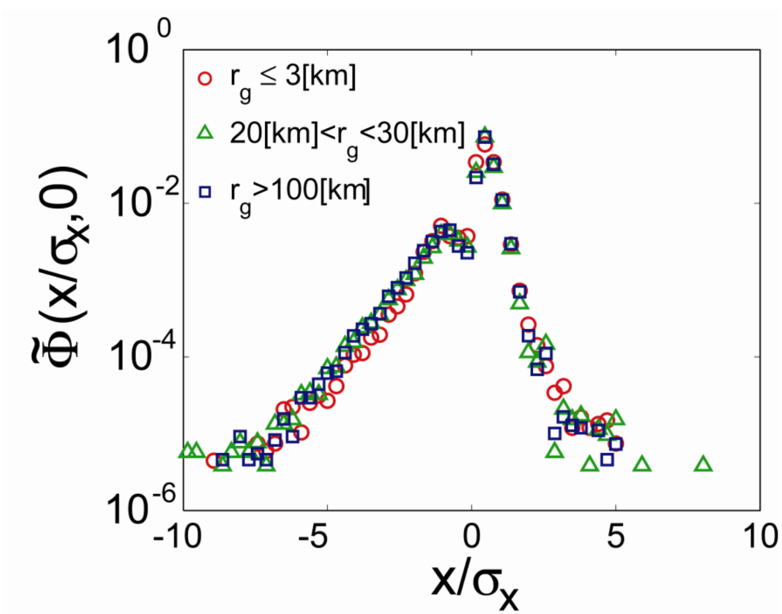
The shape of human trajectories





The shape of human trajectories



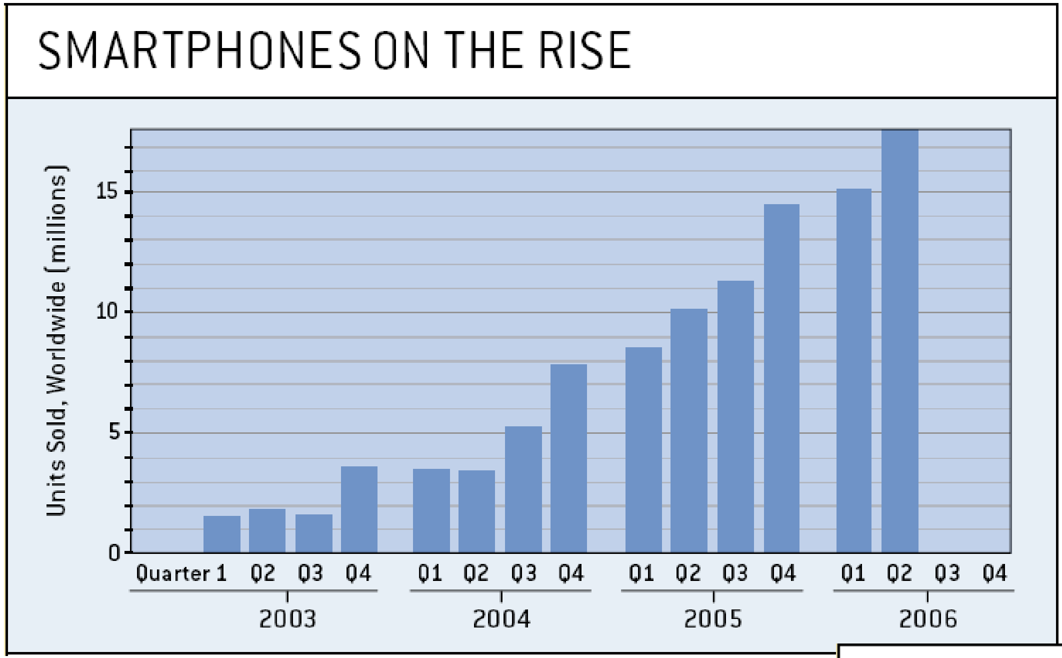


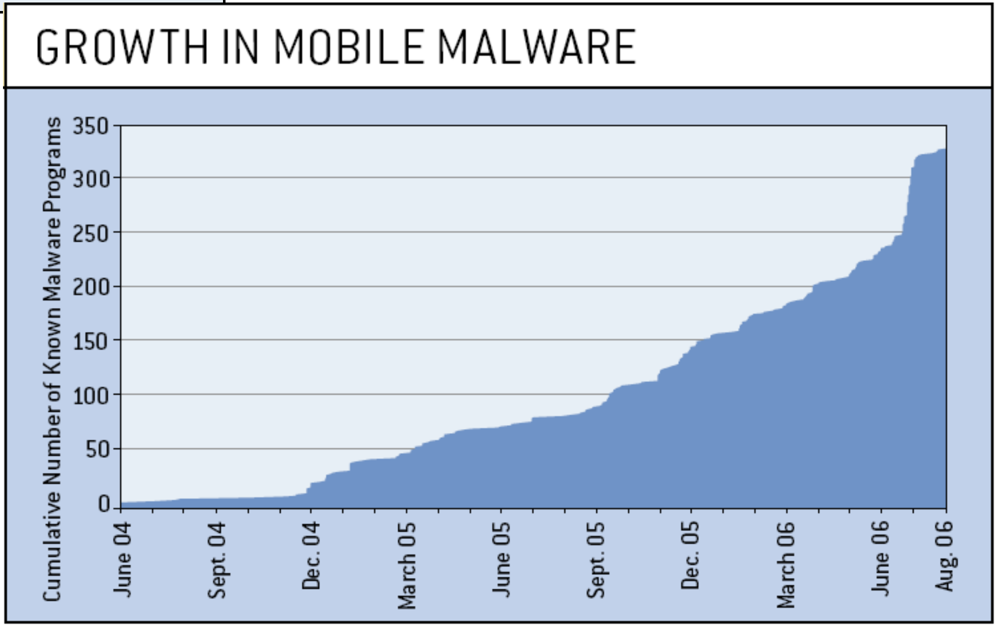
$$\sigma_x^a = \sqrt{\frac{1}{n_c^a}\sum_{i=1}^{n_c^a}(x_i^a - x_{cm}^a)^2}$$

$$\sigma_y^a = \sqrt{\frac{1}{n_c^a}\sum_{i=1}^{n_c^a}(y_i^a - y_{cm}^a)^2}$$

CCNR

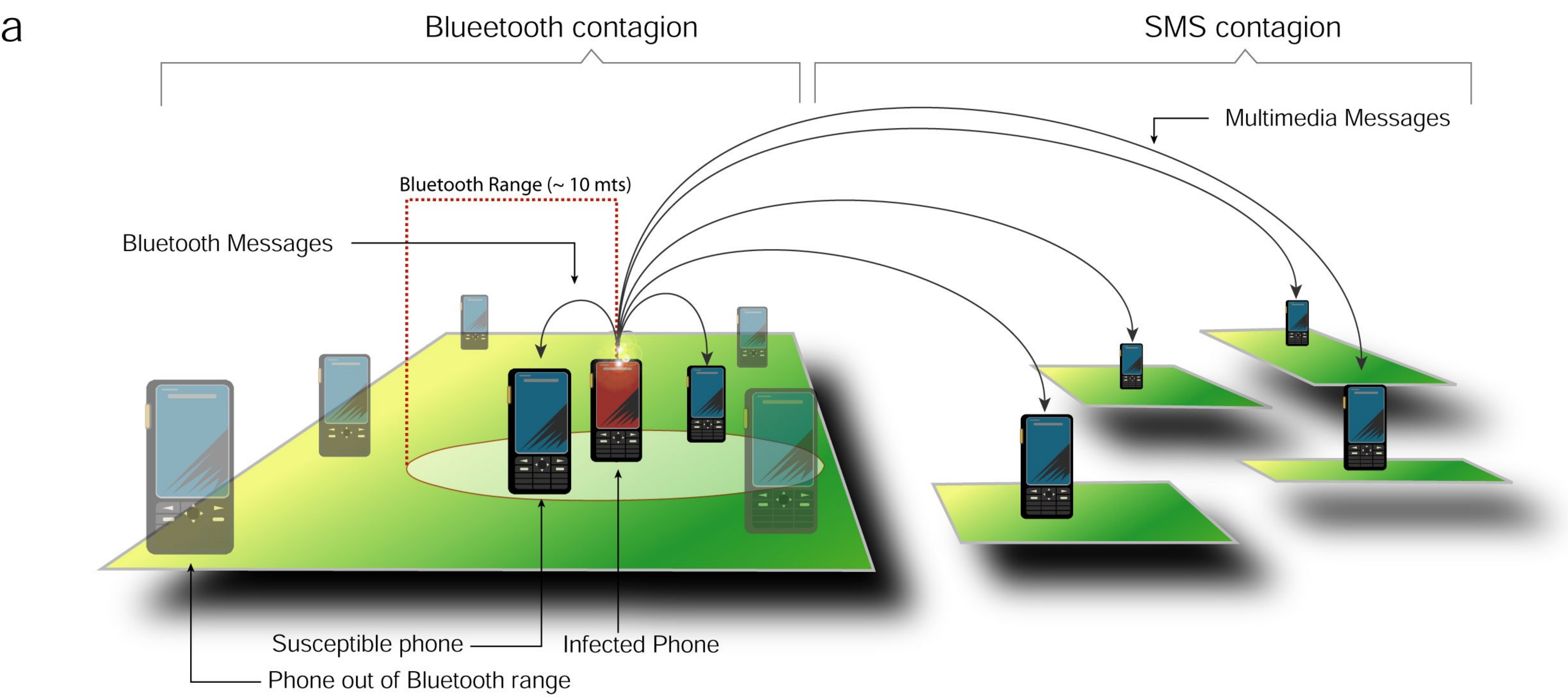
Mobile Phone Viruses





Hypponen M. *Scientific American* Nov. 70-77 (2006).

Spreading mechanism for cell phone viruses



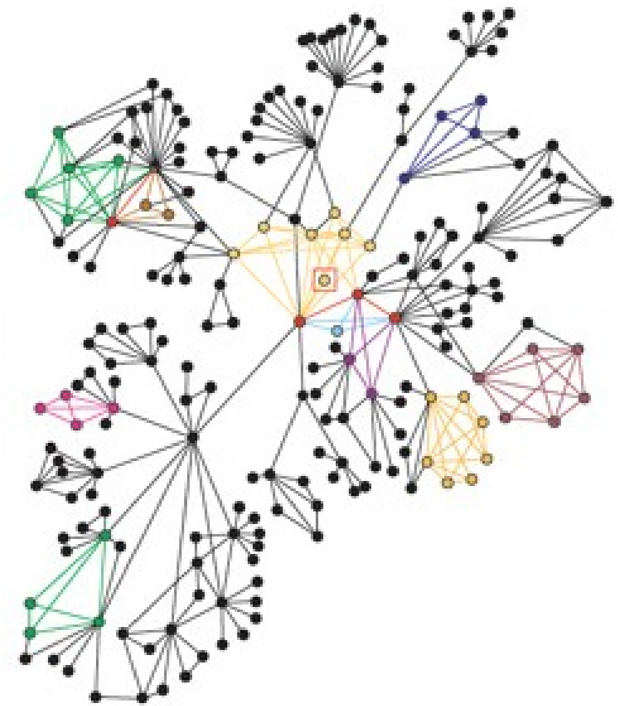
Short range infection process

(similar to biological viruses, like influenza or SARS)

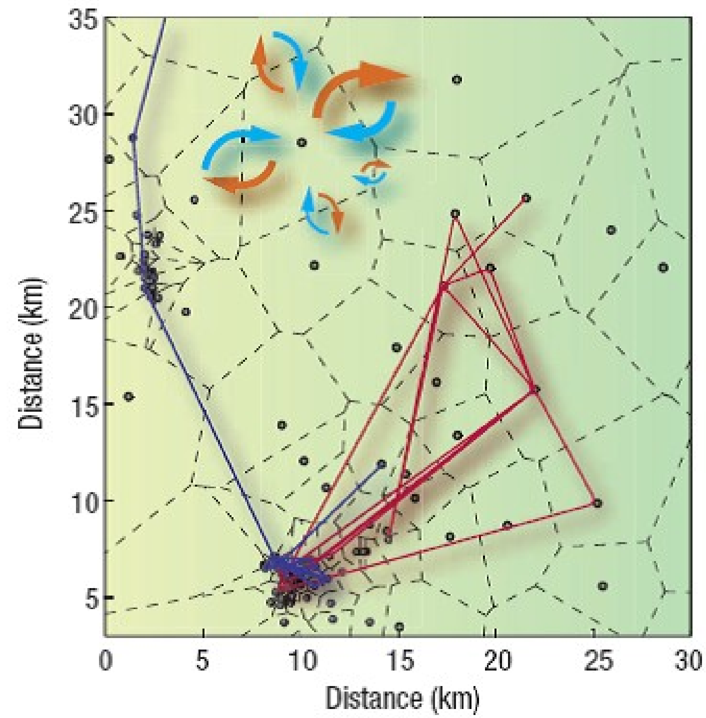
Long range infection process

(similar to computer viruses)

MMS and Bluetooth Viruses



Social Network
(MMS virus)

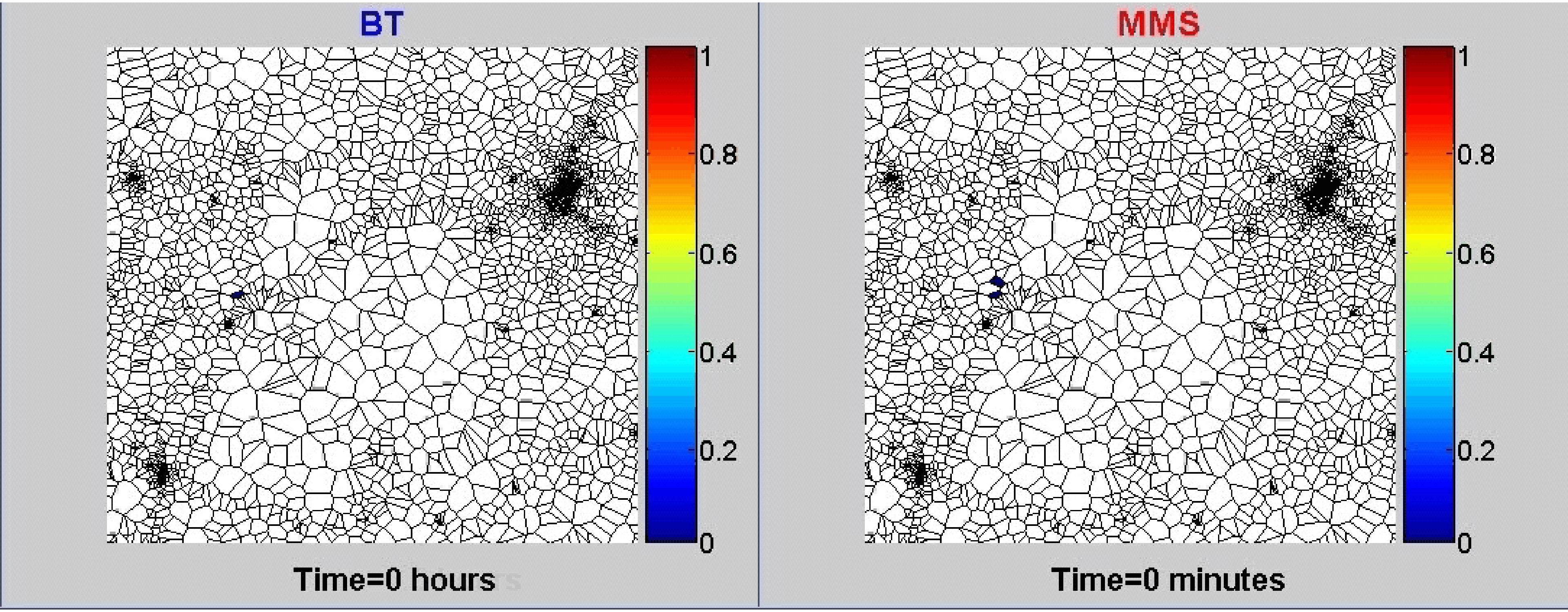


Human Motion
(Bluetooth virus)

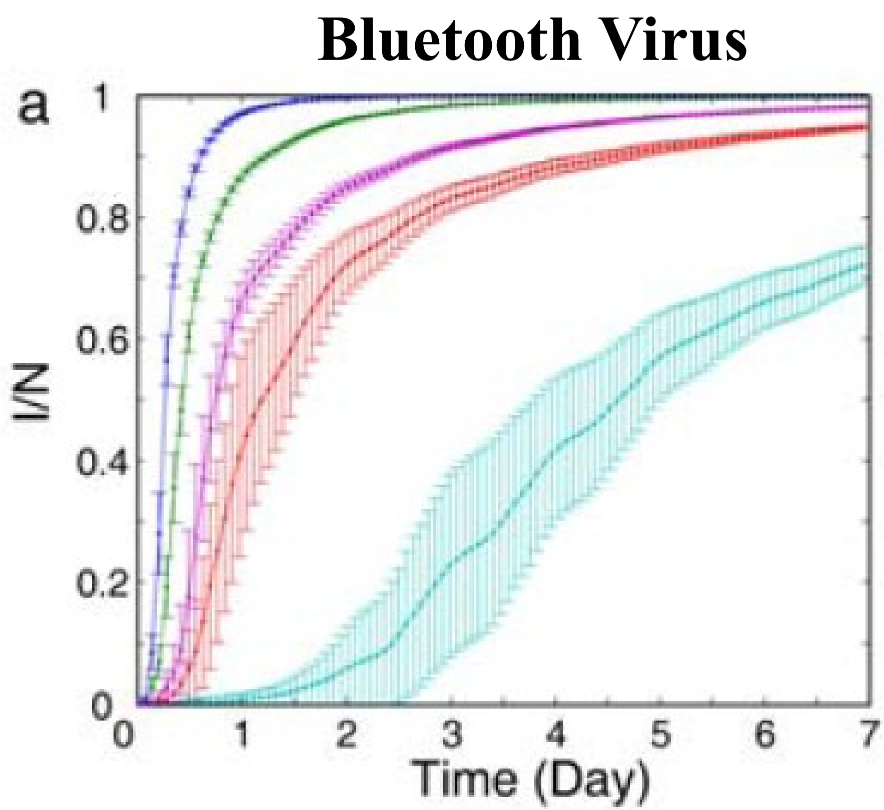
Palla, A.-L. B & Vicsek (2007).
Onella et al, PNAS (2007)

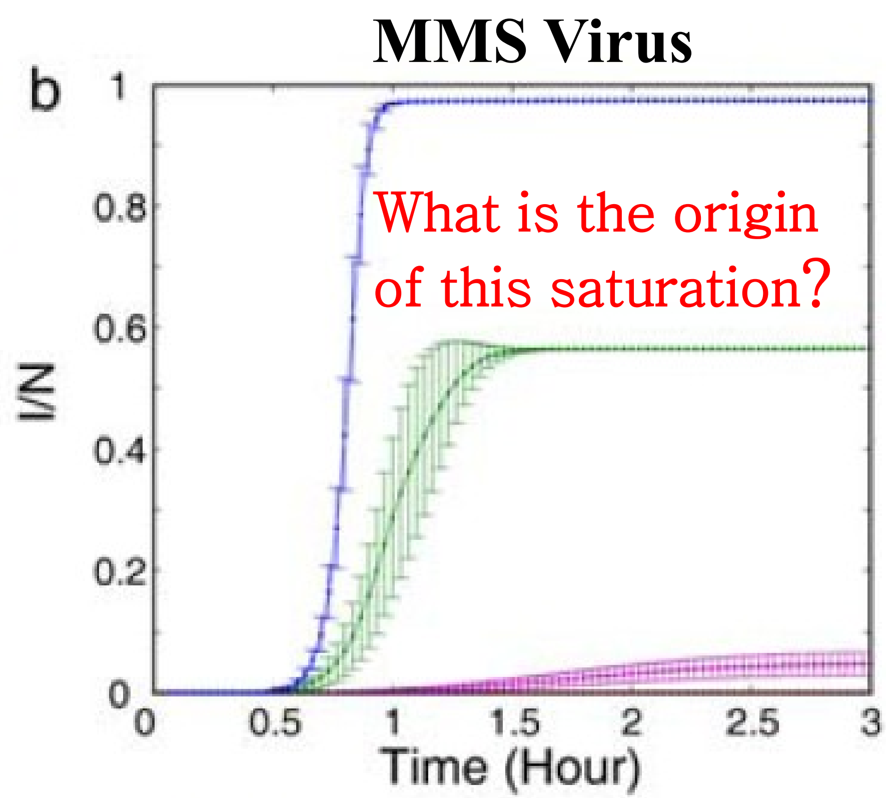
González, Hidalgo and A-L.B.,
Nature 453*, 779* (2008)

Spatial Spreading Patterns of Bluetooth and MMS virus



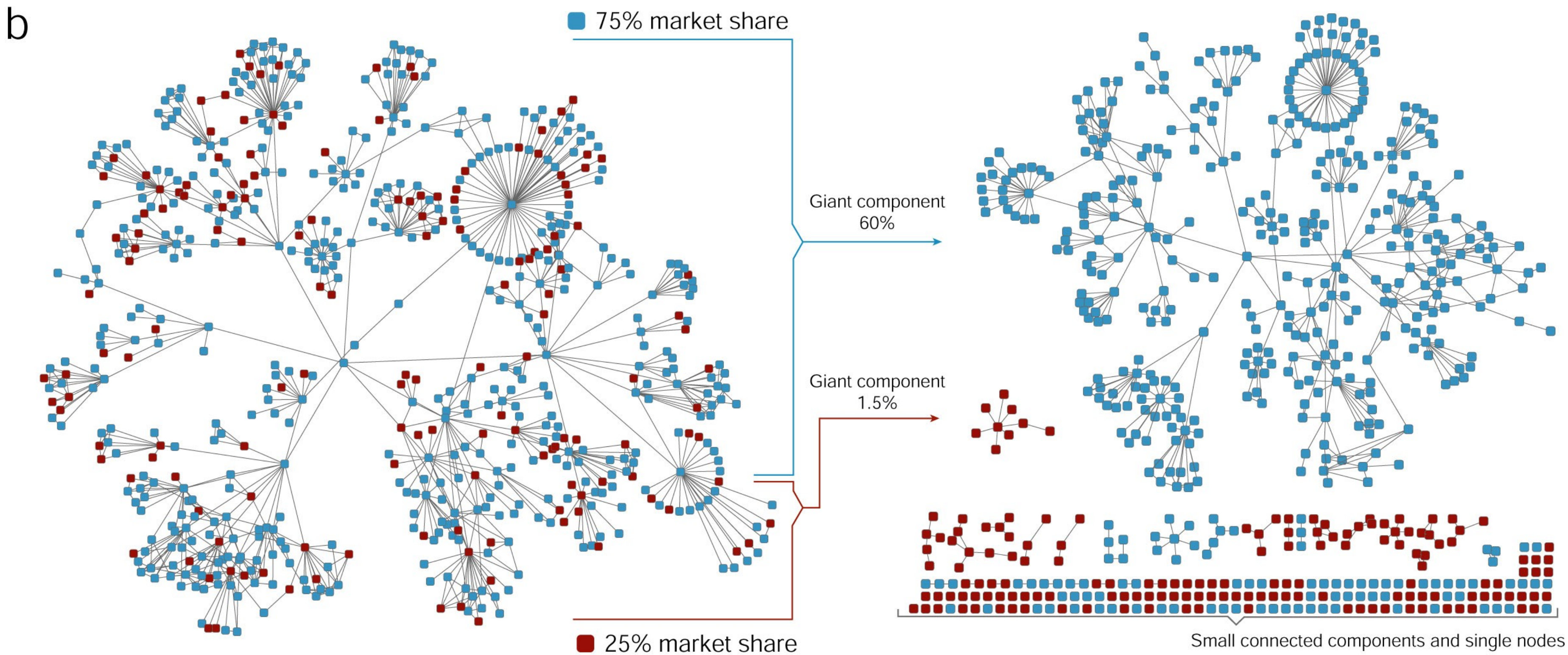
Spatial Spreading patterns of Bluetooth and MMS viruses

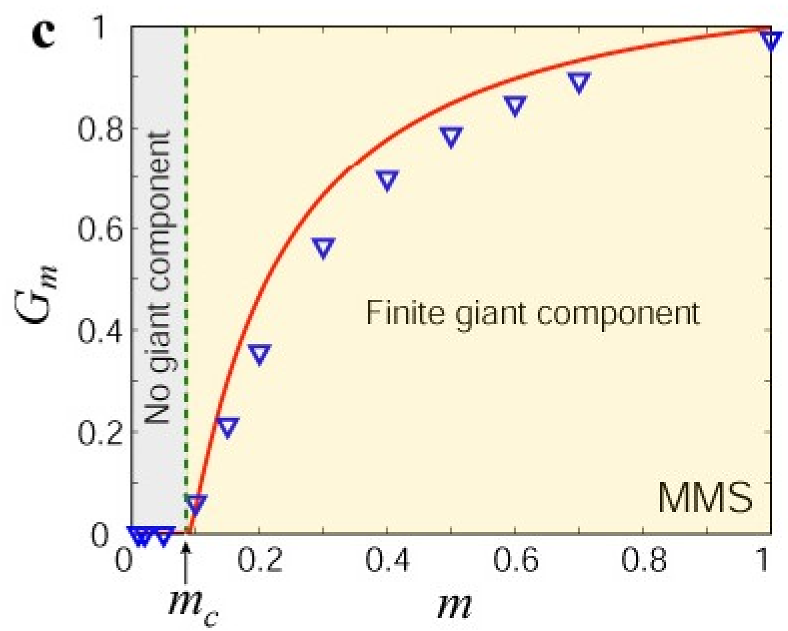




Driven by Human Mobility:
Slow, but can reach all users with time.

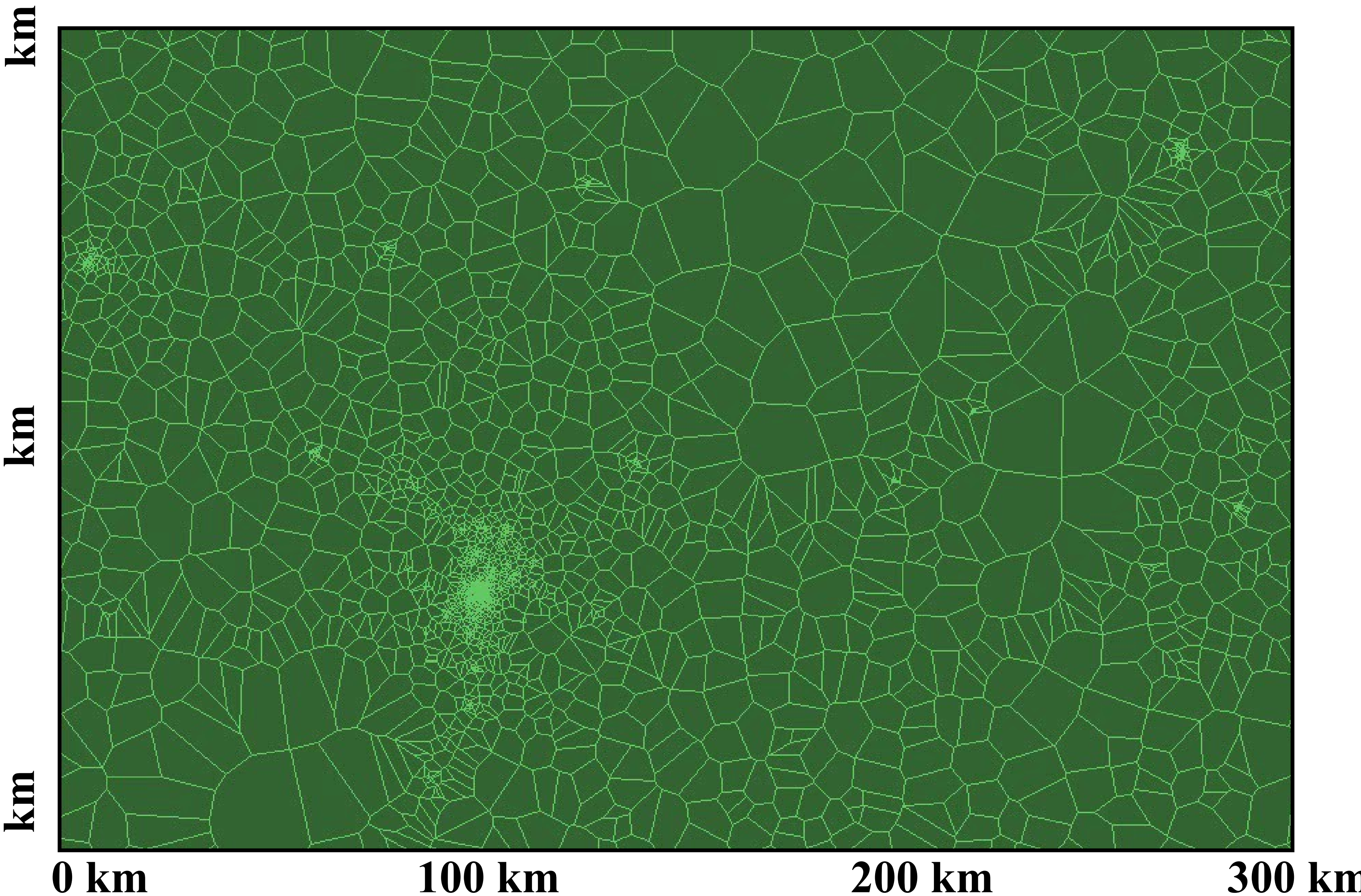
Driven by the Social Network:
Fast, but can reach only a finite fraction of users (the giant component).





If the market share of an Operating System is under m_c~10%, MMS viruses cannot spread.

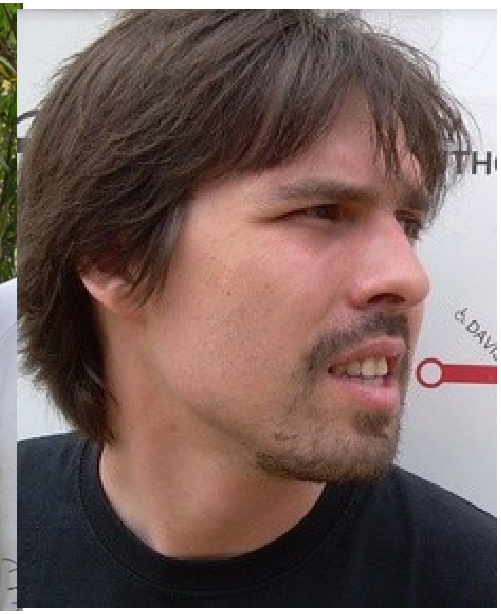
Mobile Phone Users



Collaborators

Pu Wang

Marta Gonzalez



Cesar Hidalgo

www.BarabasiLab.com