Temporal Networks: Empirics

Stationarity & dynamics

Burstiness

New tools

Air transportation network

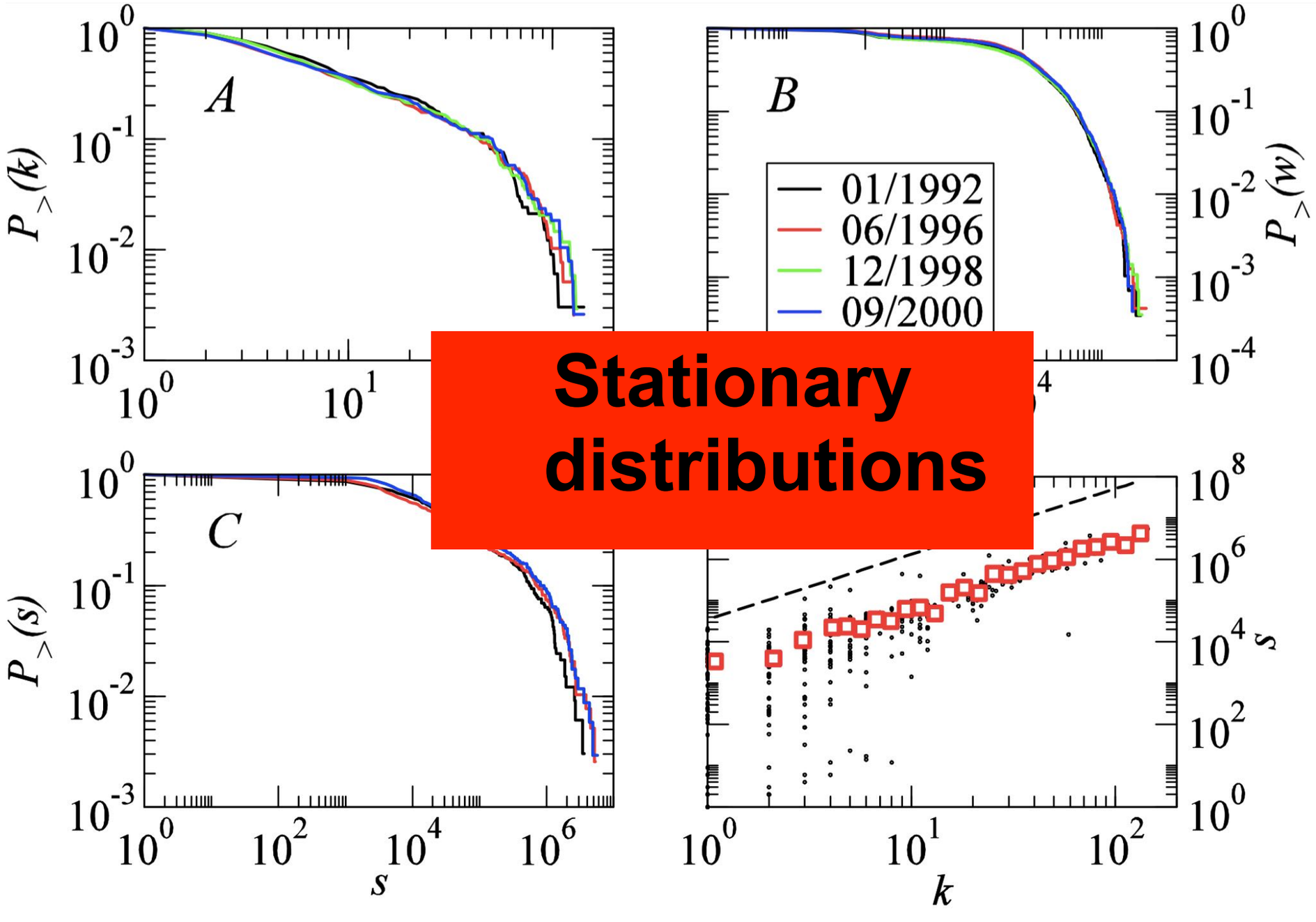
Airport network: dynamically evolving

- Airports opening and closing
- New links appearing
- Links disappearing

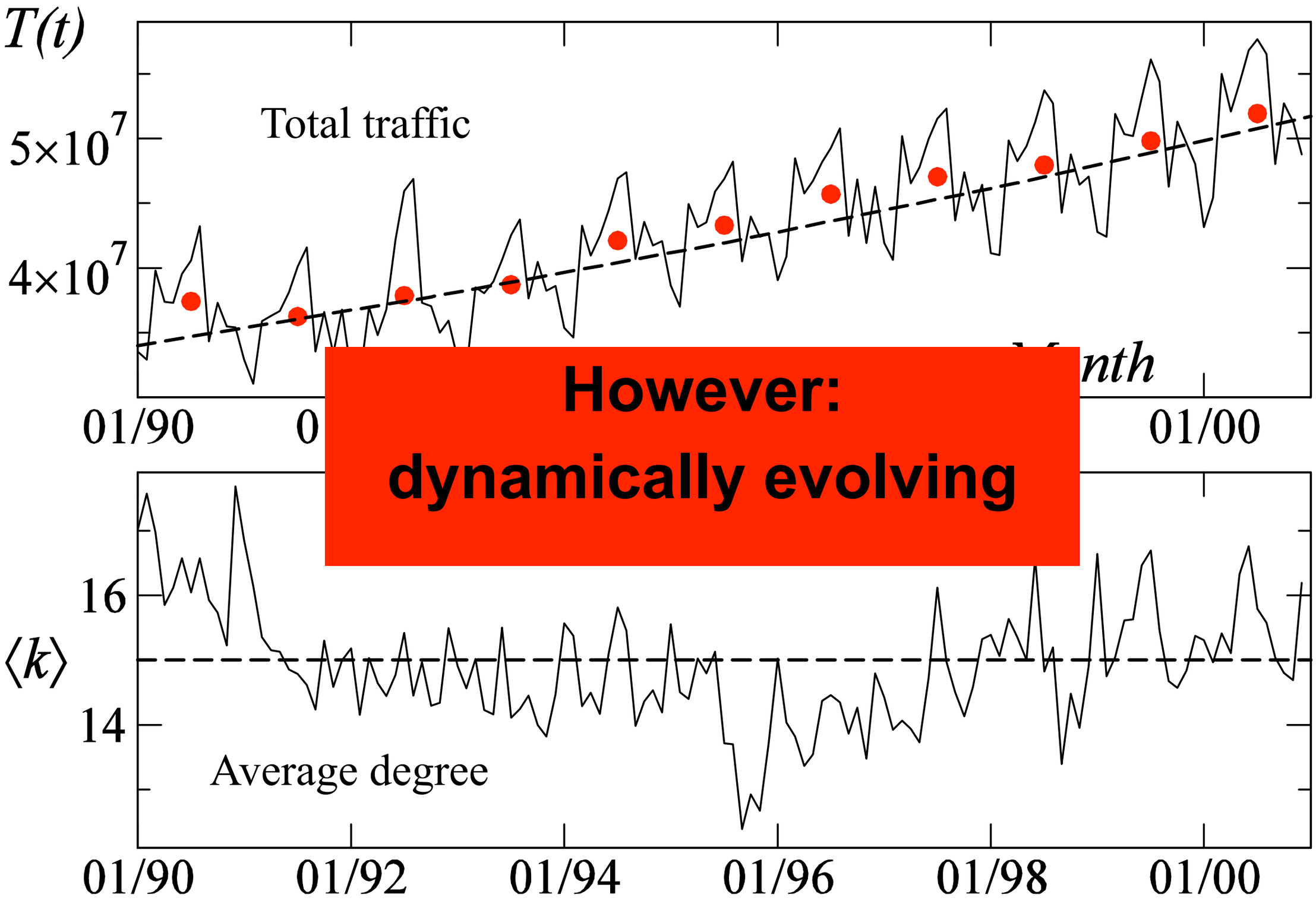
Example: the US airport network, 1990-2001

(Gautreau, Barrat, Barthélemy, PNAS (2009))

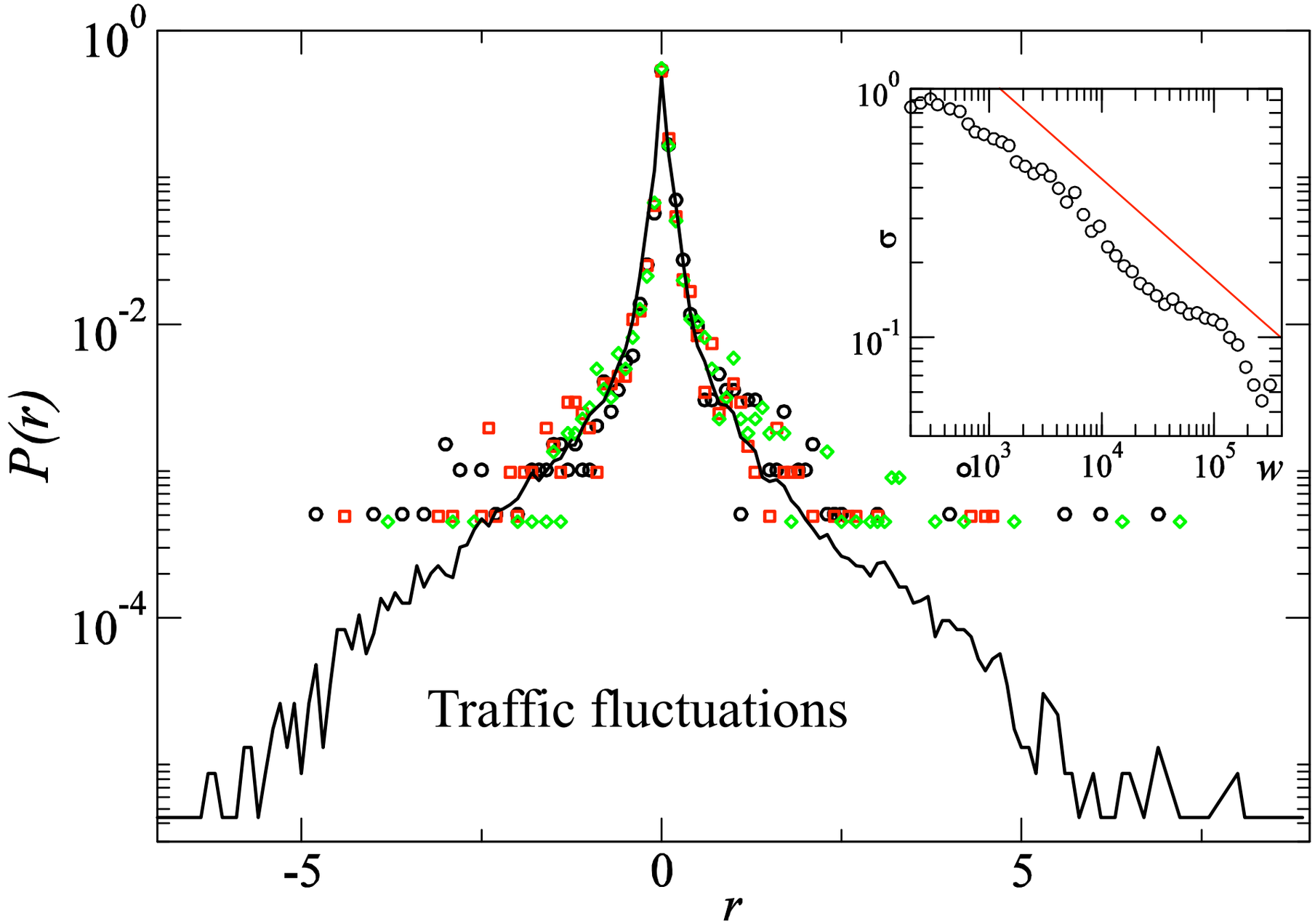
US airport network



US airport network



US airport network



$$r = \ln(w(t+1)/w(t))$$

Dynamical networks of human interactions

Dynamical social networks: communication networks

- Email networks

  (P. Holme, Network reachability of real-world contact sequences, Phys. Rev E (2005))

- MSN

  (J. Leskovec, E. Horwitz,Planetary-scale views on a large instant-messaging network, WWW'08)

- Mobile phones
  - Onnela et al 2007: aggregated networks, community structure
  - Gonzalez et al 2009, Song et al, 2010: Localisation,Mobility patterns
  - Karsai et al 2010: role of temporality

Dynamical social networks: proximity patterns

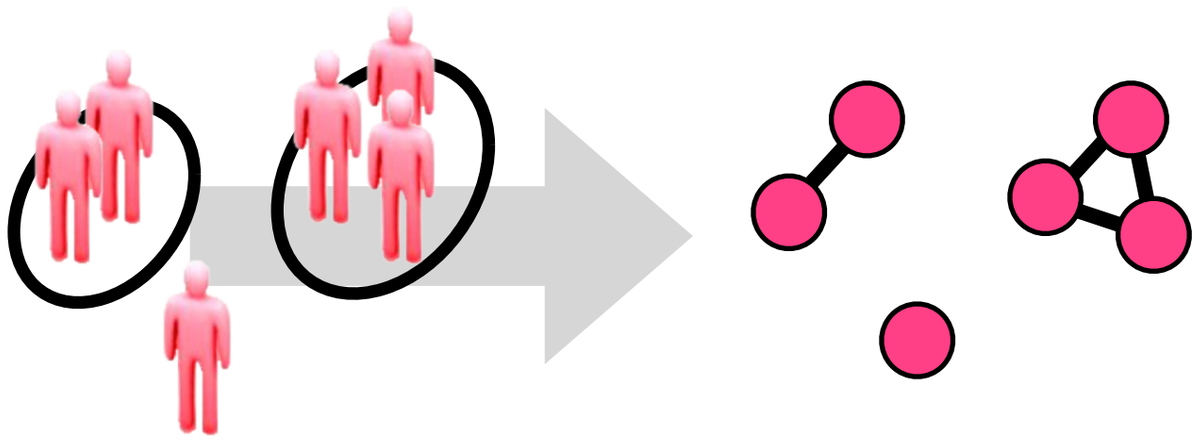
- Bluetooth, wifi (O' Neill et al 2006; Scherrer et al 2008; Eagle, Pentland 2009)
- MIT Reality mining project (sociometric badges)
- MOSAR european project (hospitals)
- Salathé et al. 2010 (school)

LACKING: large-scale time-resolved data on f2f proximity across a variety of contexts

Gathering data:
The SocioPatterns collaboration

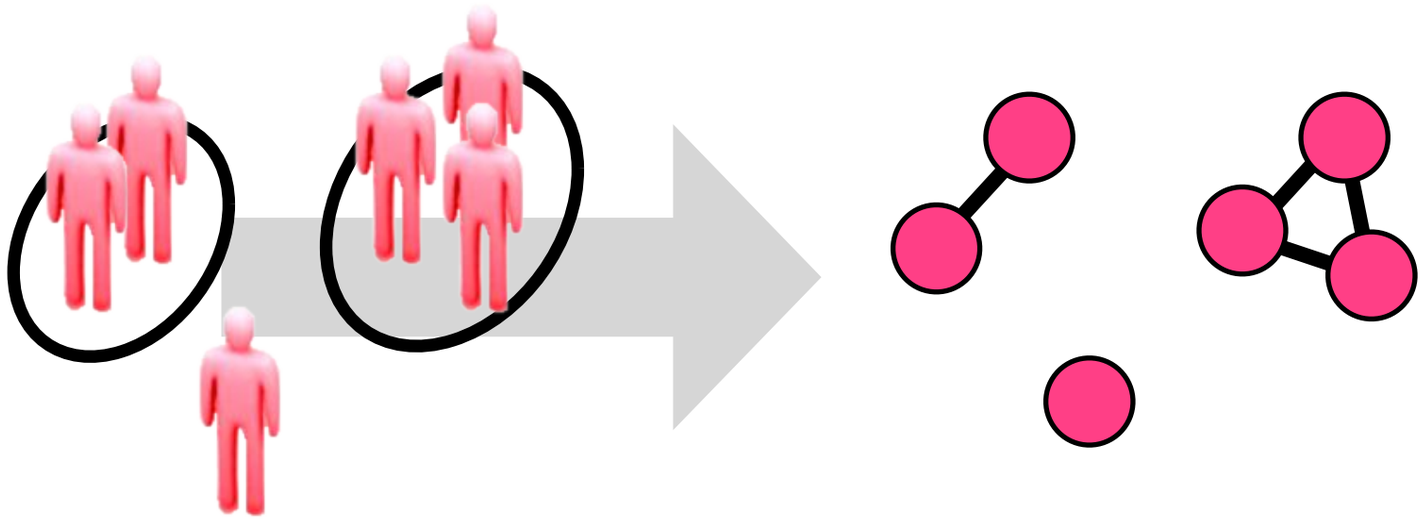
SocioPatterns.org

what are the statistical and dynamical properties of the networks of contact and co-presence of people in social interaction?



fine-grained **spatial** (~ m) and **temporal** (<min) resolution

Motivations

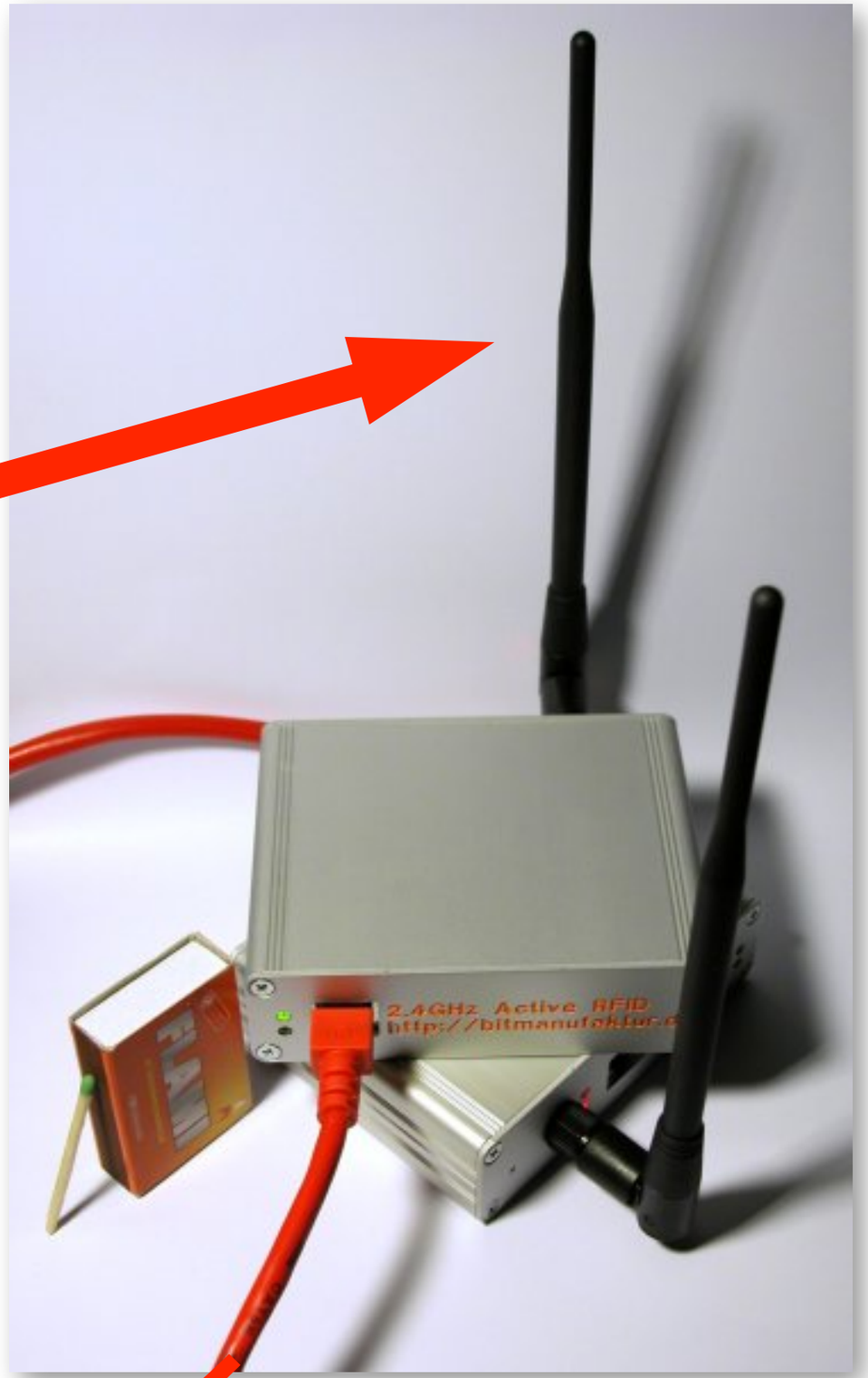


- ★ fundamental knowledge on human contact
- ★ epidemiology
- ★ social sciences
- ★ ad-hoc networks
- ★ integration with on-line information
- ★...

(not your usual) active RFID

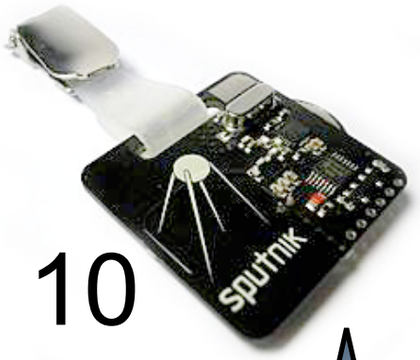
standard active RFID behavior

"I am 42 !"



LAN

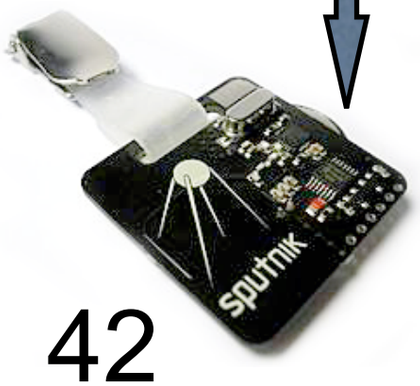
Contact detection



10

Short distance (~1-2m):

Exchange of very low power data packets

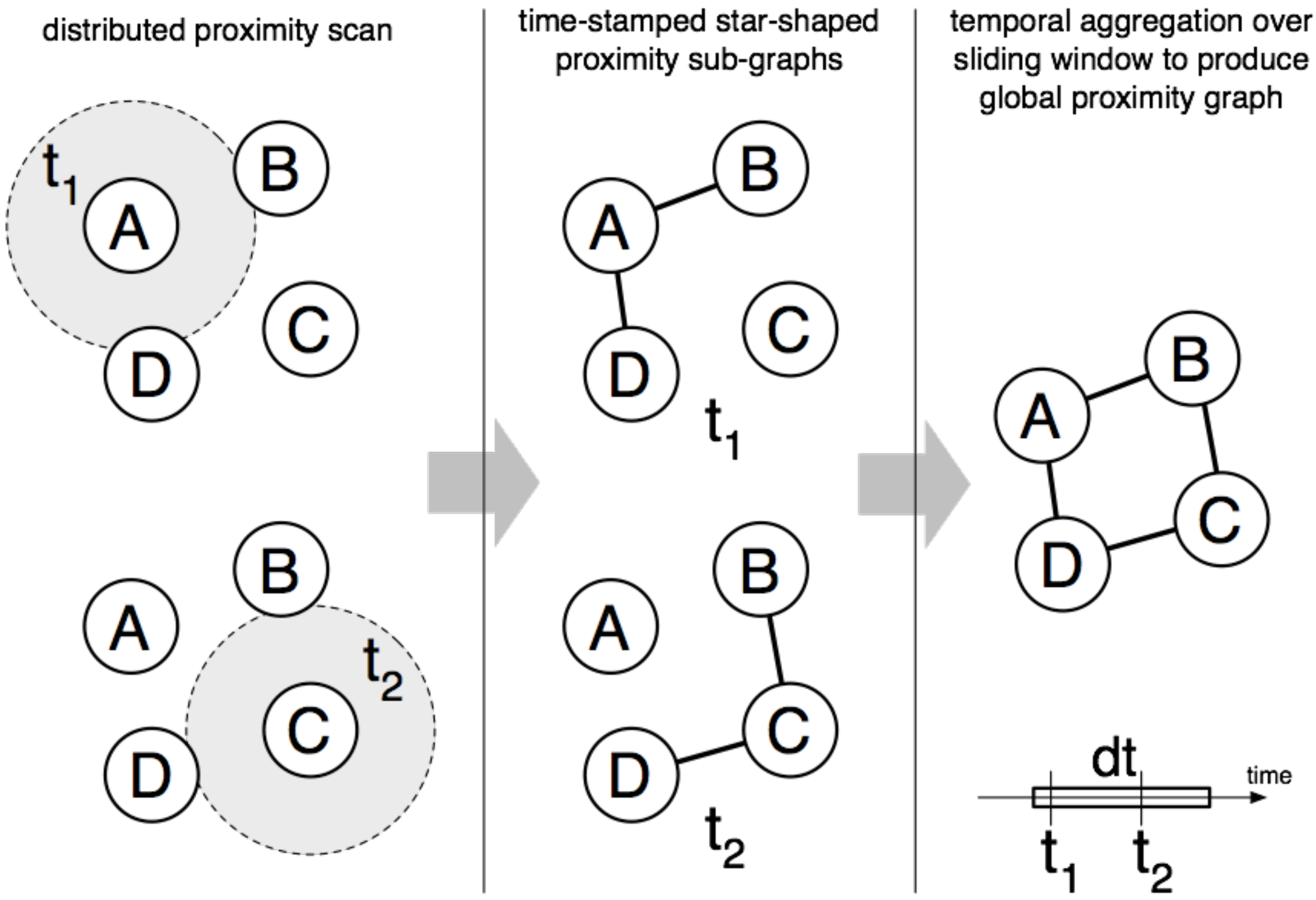


42

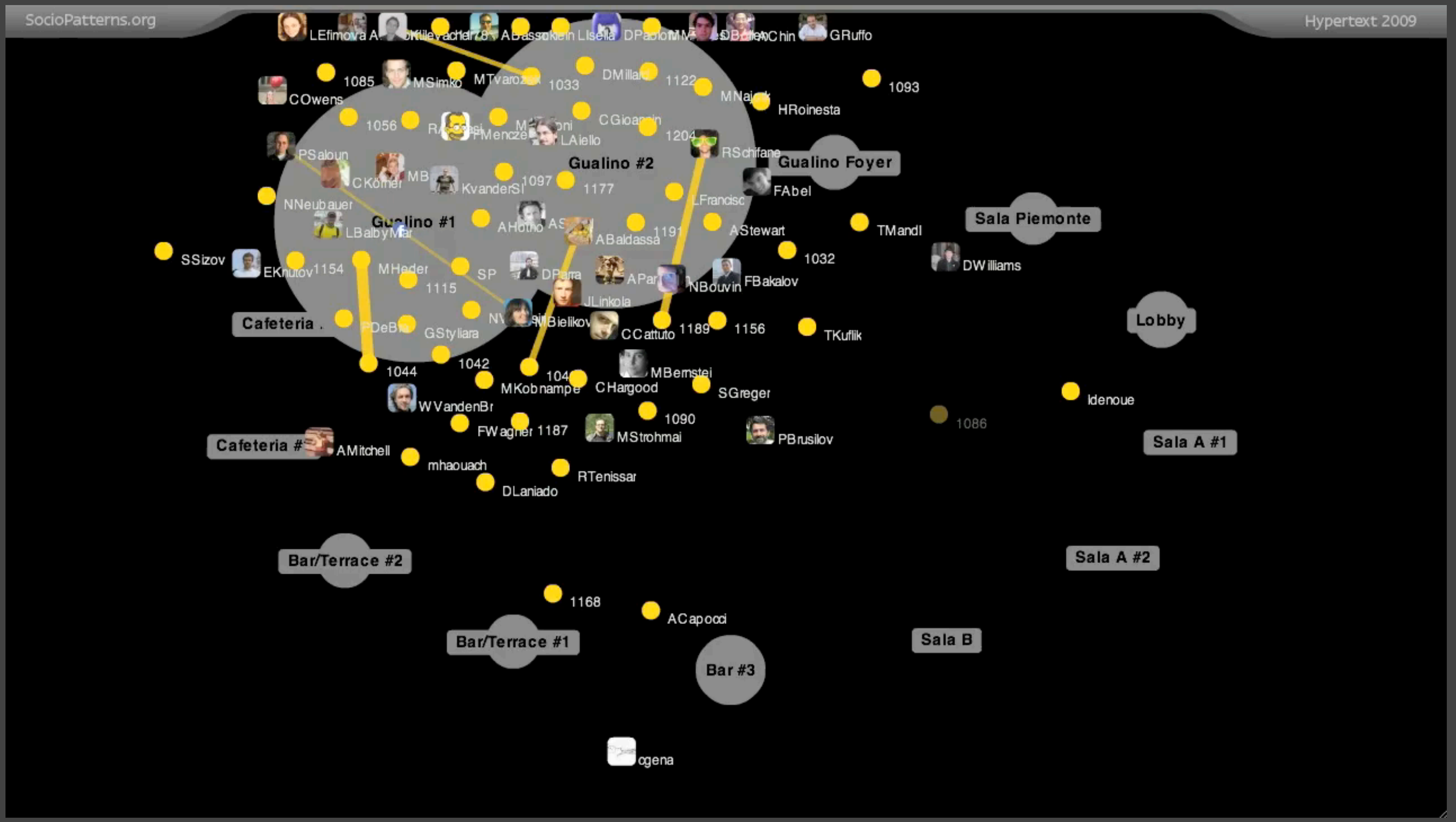
“42 saw 10 at power 0”

- Two power levels => 2 detection ranges
- Face to face situation
- Statistical detection => 20s time resolution
- Small,
- Scalable

From event stream to dynamical network



dynamical network of f2f proximity



http://www.vimeo.com/6590604

sociopatterns.org

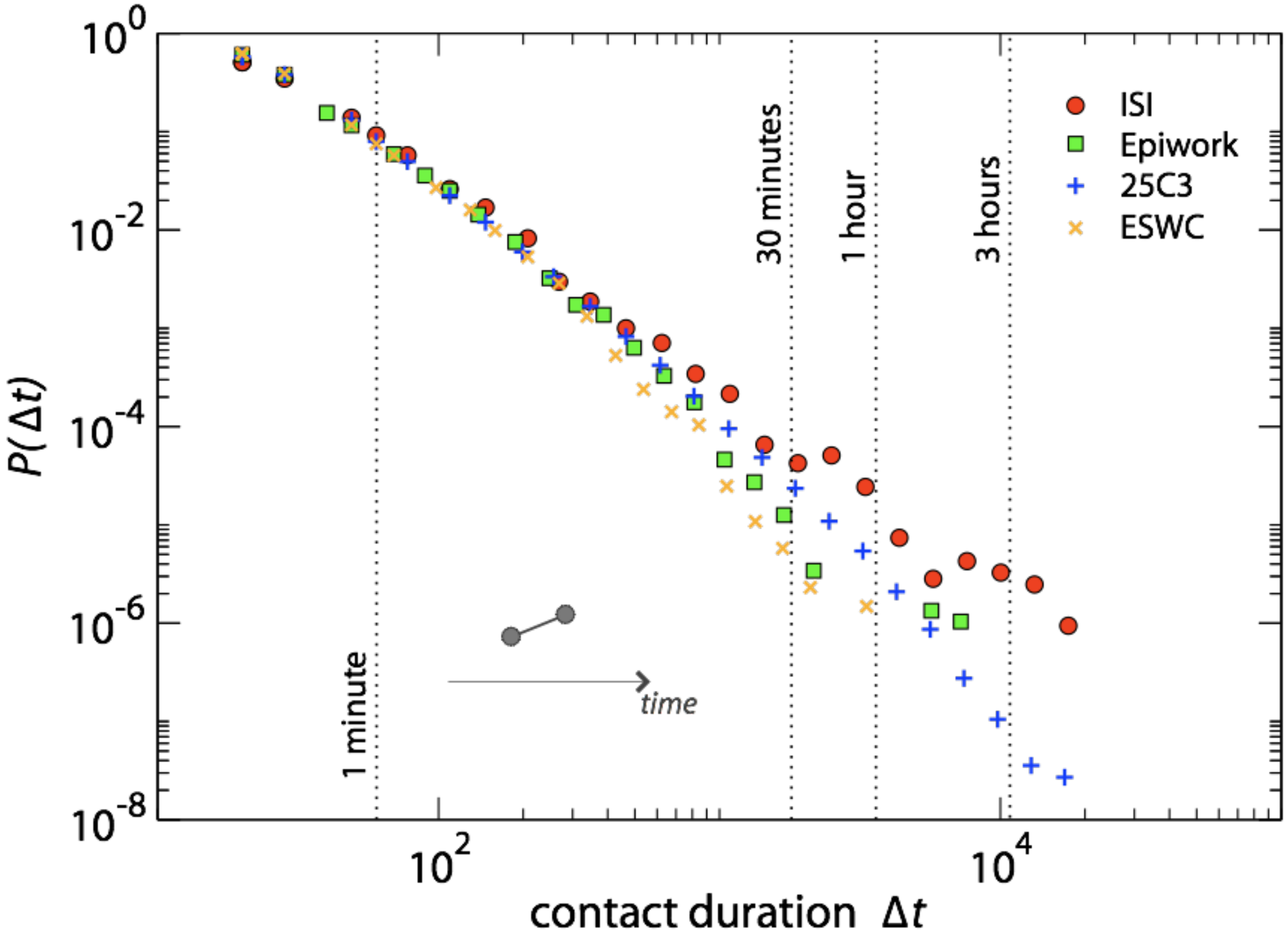
5 years, 20+ deployments, 10 countries, 50,000+ persons

>a glimpse of data

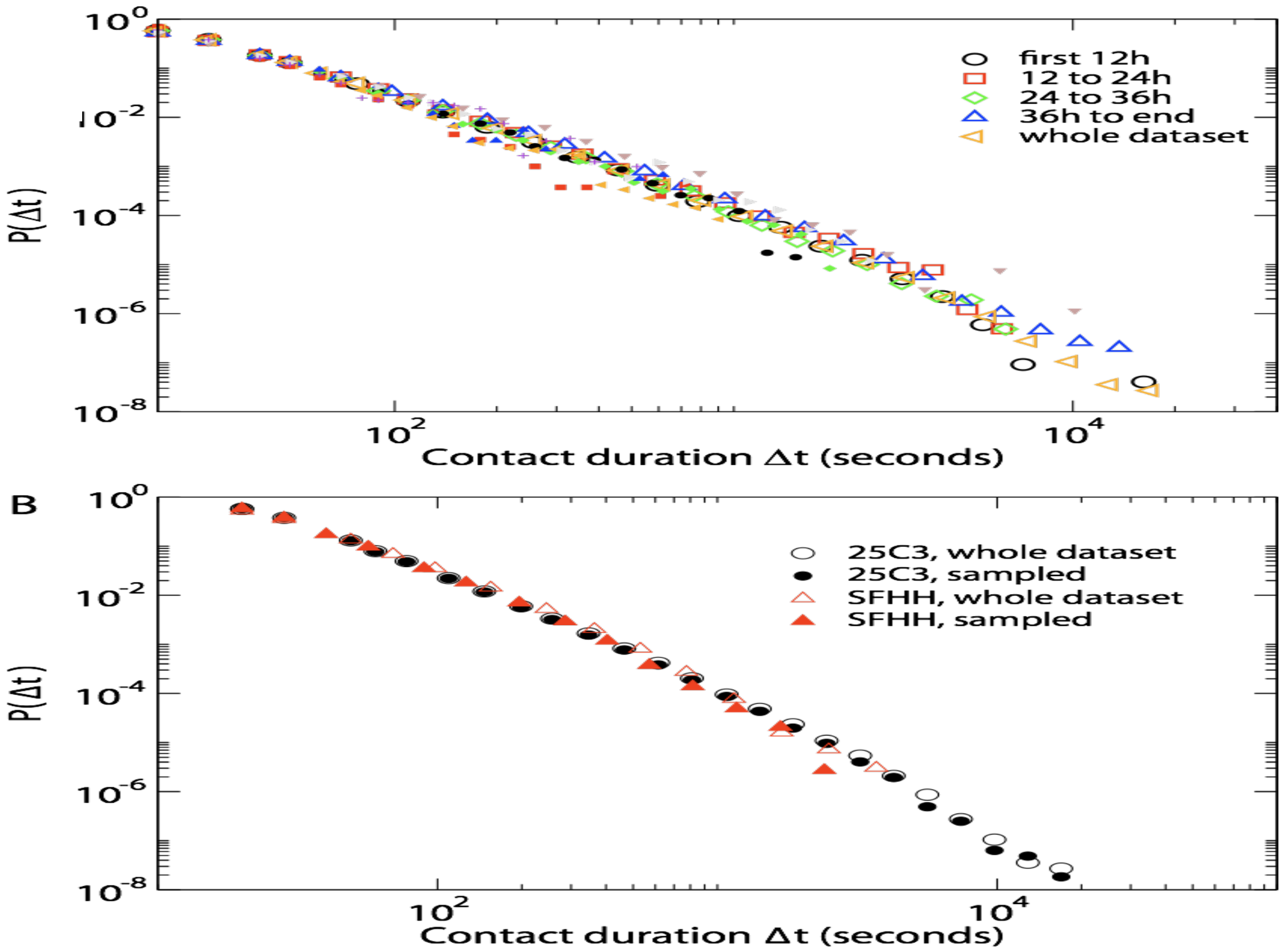
Several data sets available at
www.sociopatterns.org

>conference(s)

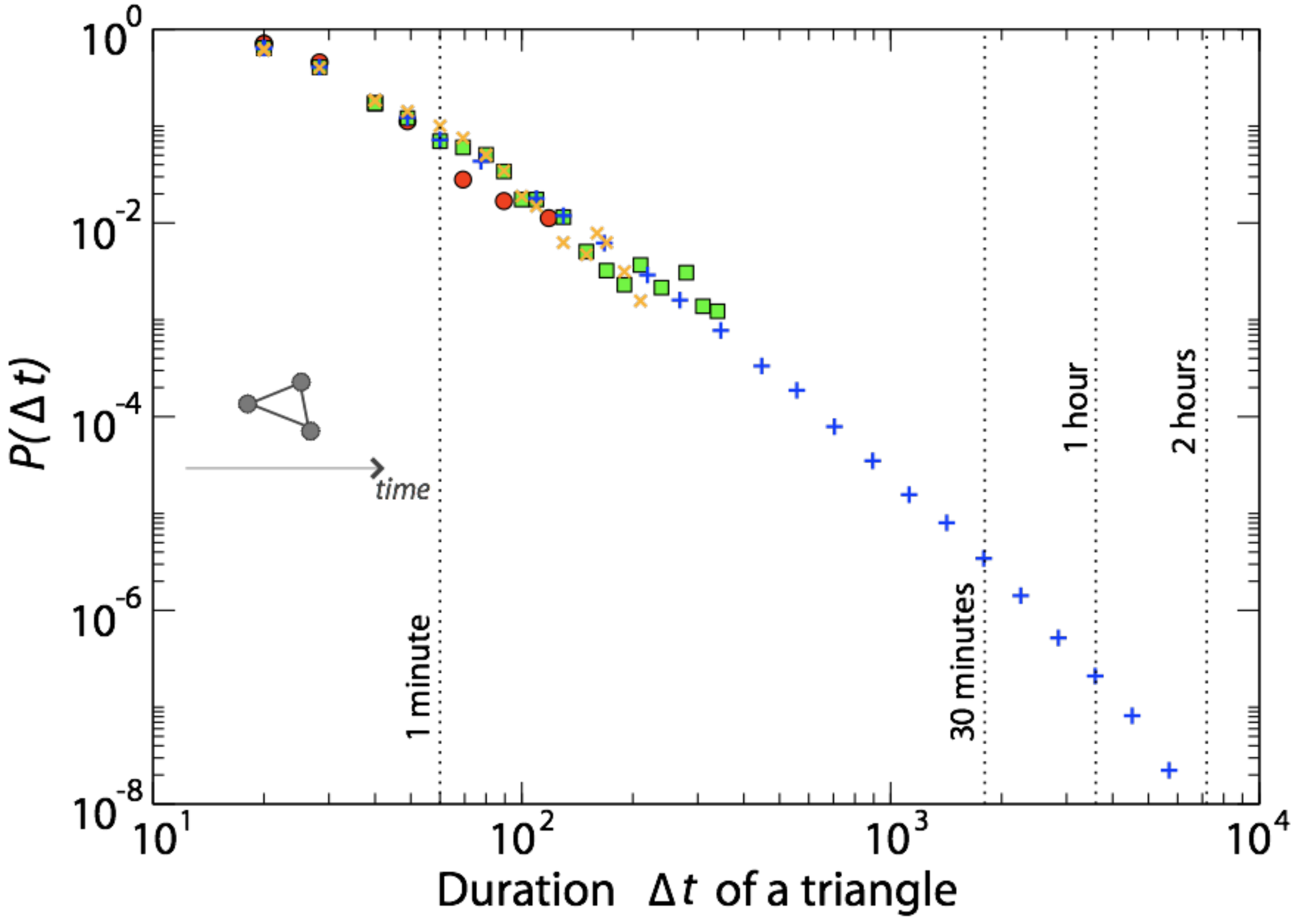
contact duration



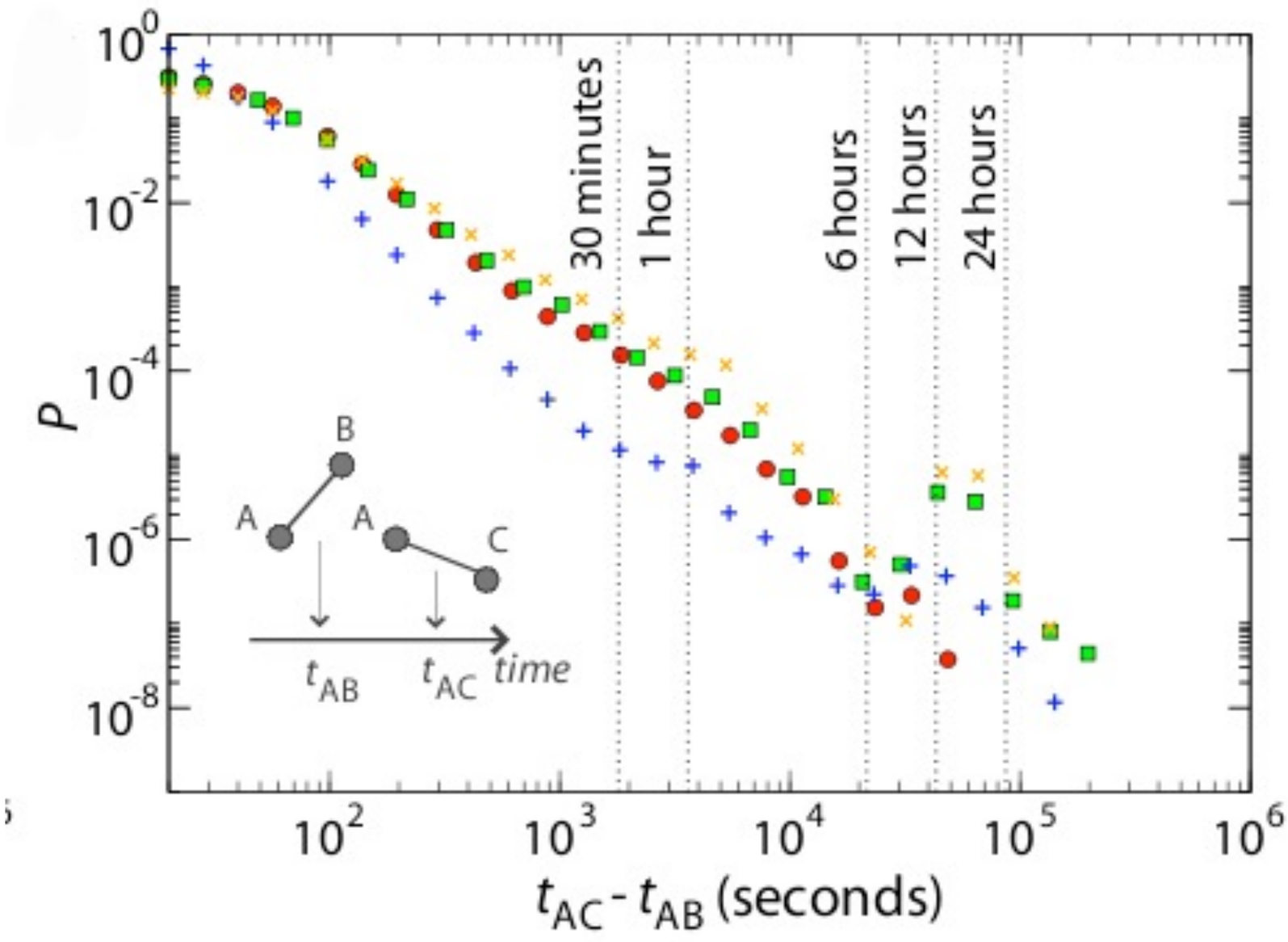
contact duration (2)



lifetime of structures



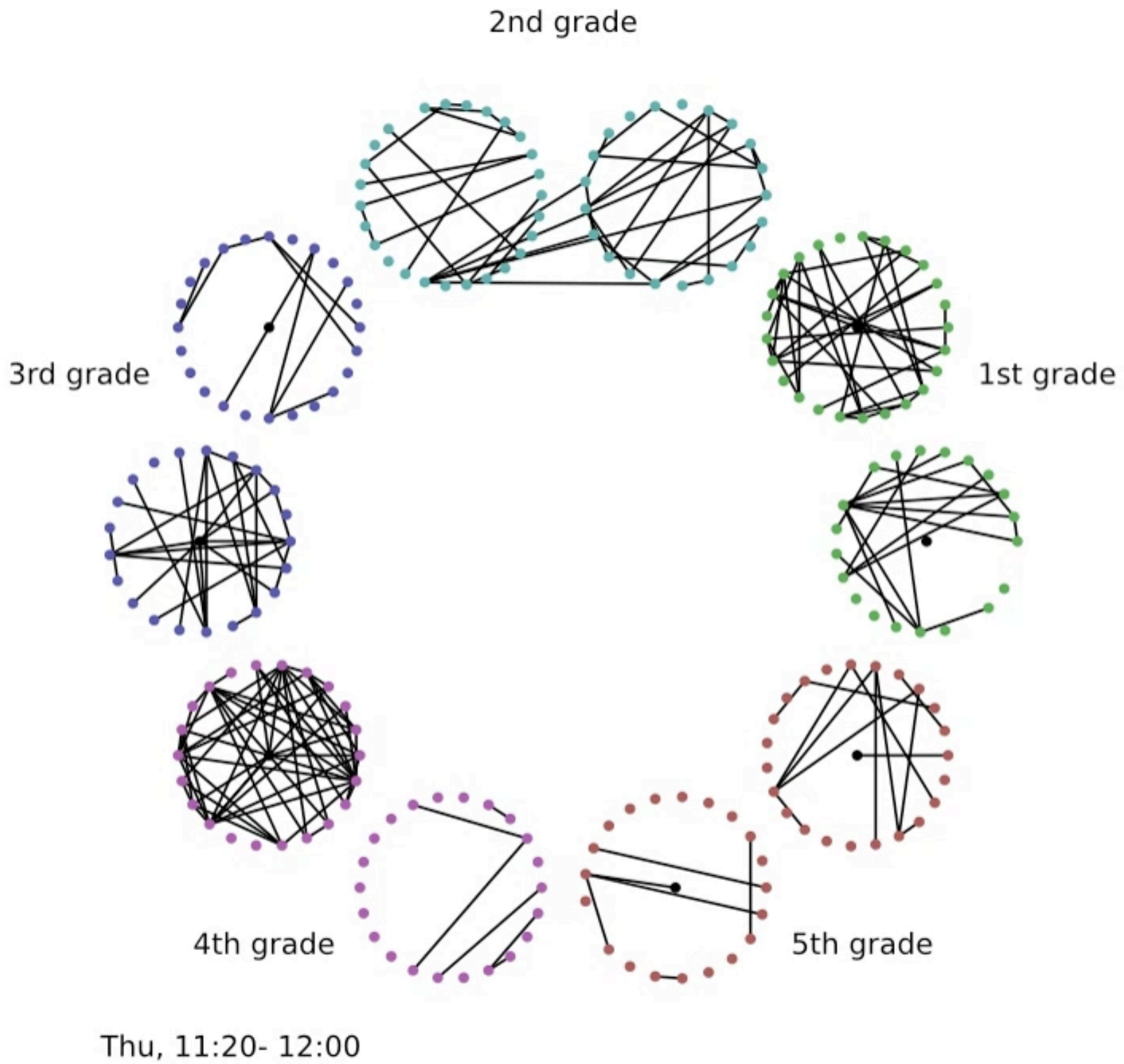
Time between contacts



Burstiness

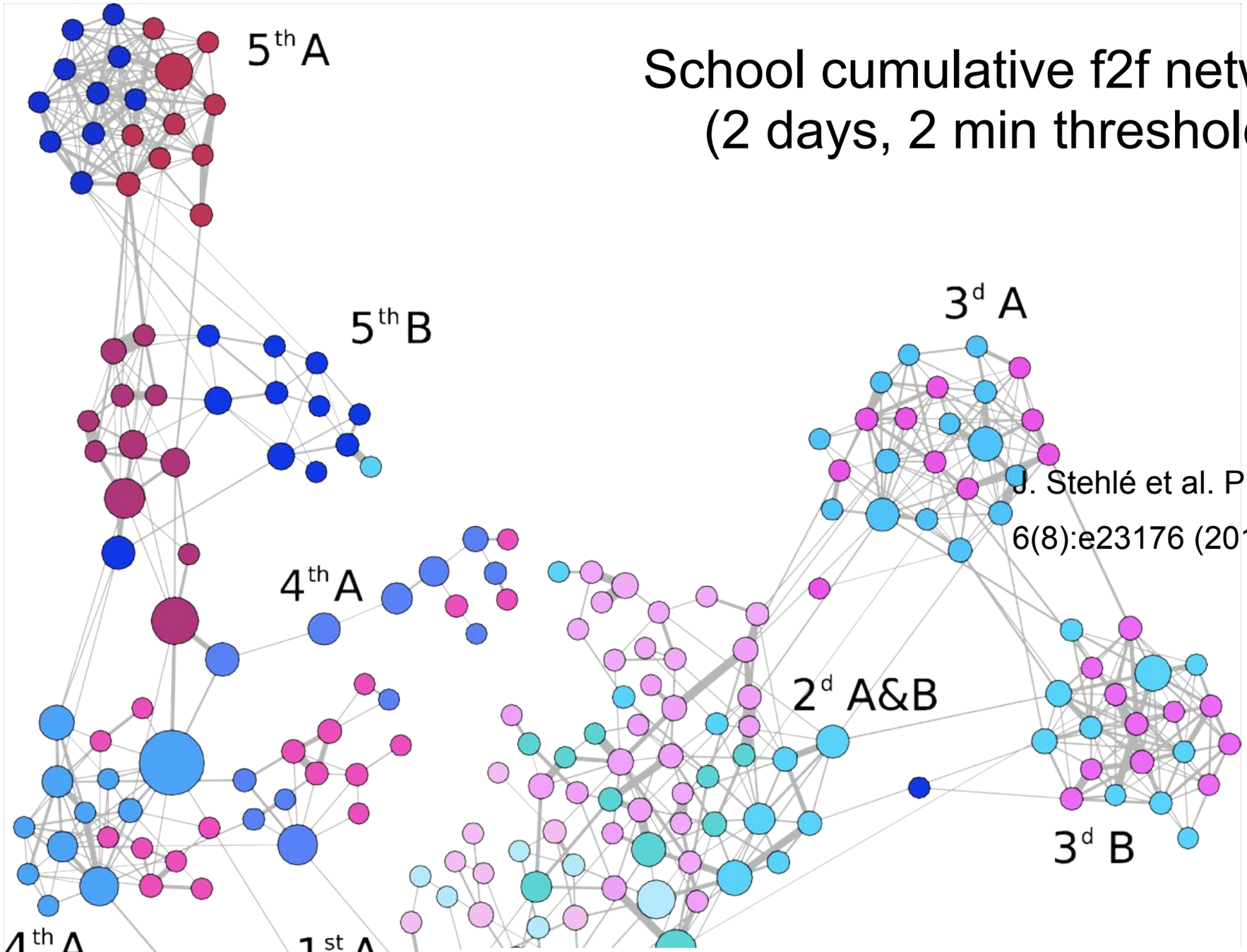
>school

contacts in a primary school



J. Stehle, et al.
High-Resolution Measurements of Face-to-Face Contact Patterns in a Primary School
PLoS ONE 6(8), e23176 (2011)

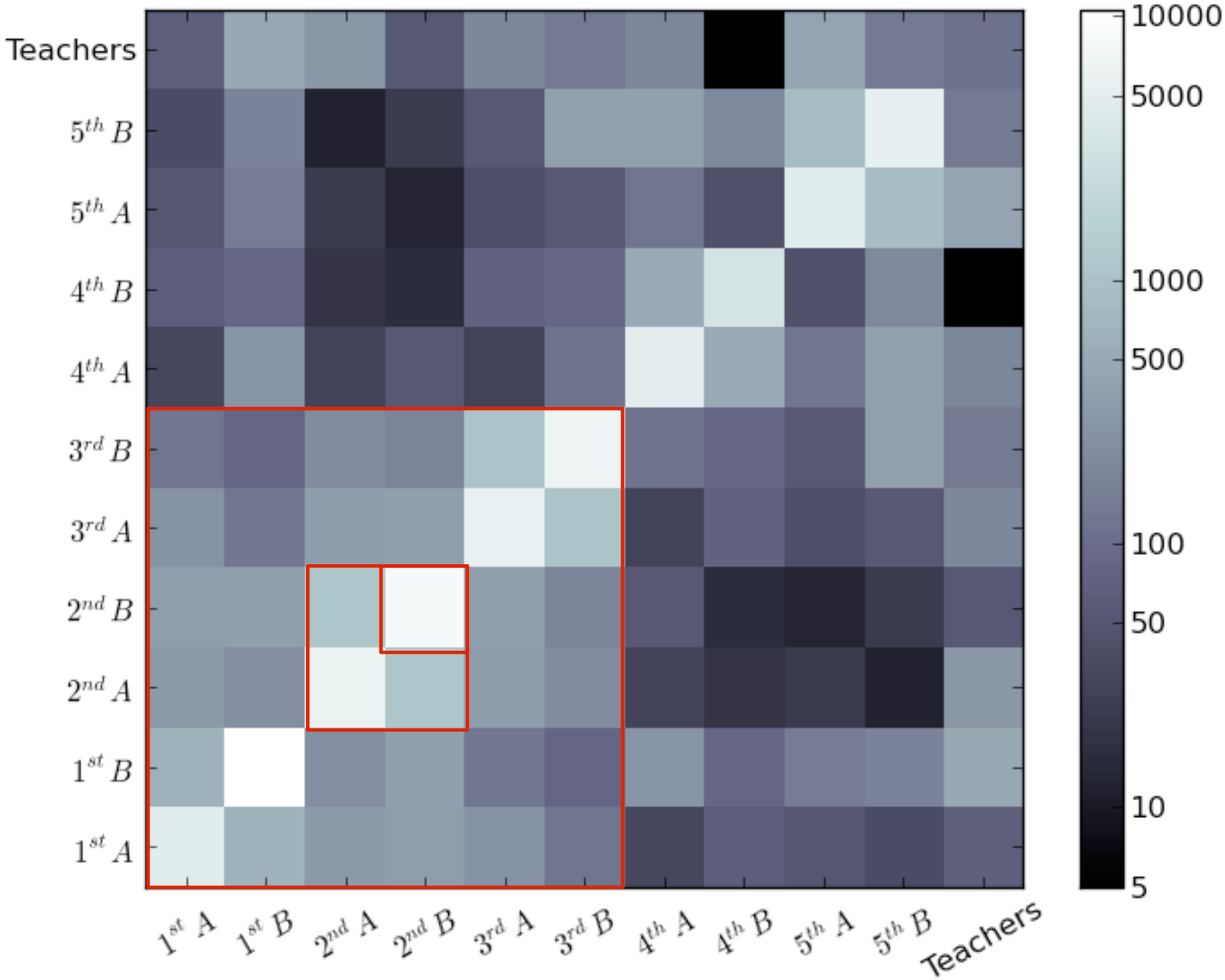
School cumulative f2f network (2 days, 2 min threshold)



J. Stehlé et al. PLoS ONE 6(8):e23176 (2011)

- Epidemiology:
  - Information of models
  - Design and efficiency of containment measures
- Social sciences:
  - Gender homophily
  - Age homophily

class contact matrix



J. Stehle, et al.
High-Resolution Measurements of Face-to-Face Contact Patterns in a Primary School
PLoS ONE 6(8), e23176 (2011)

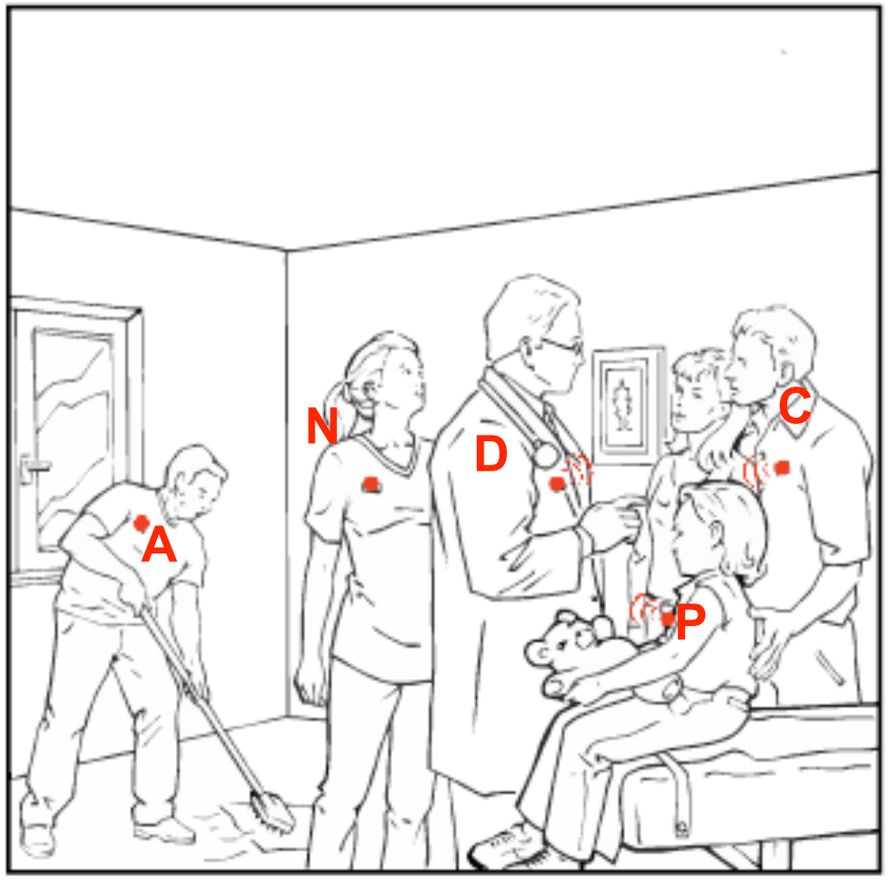
>hospital

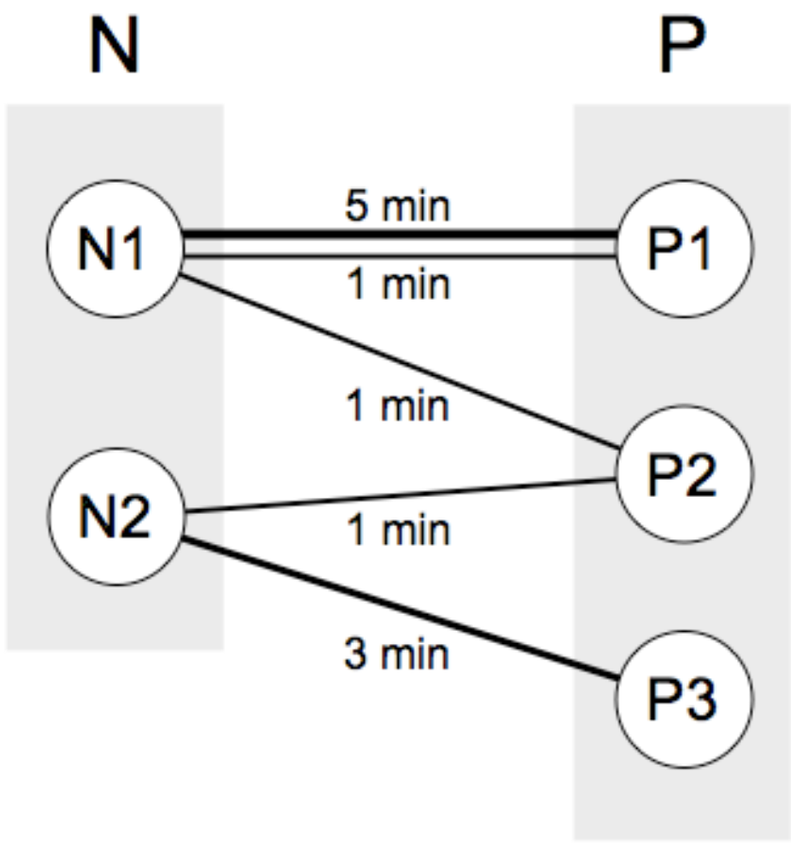
hospital

12 days
~250 persons

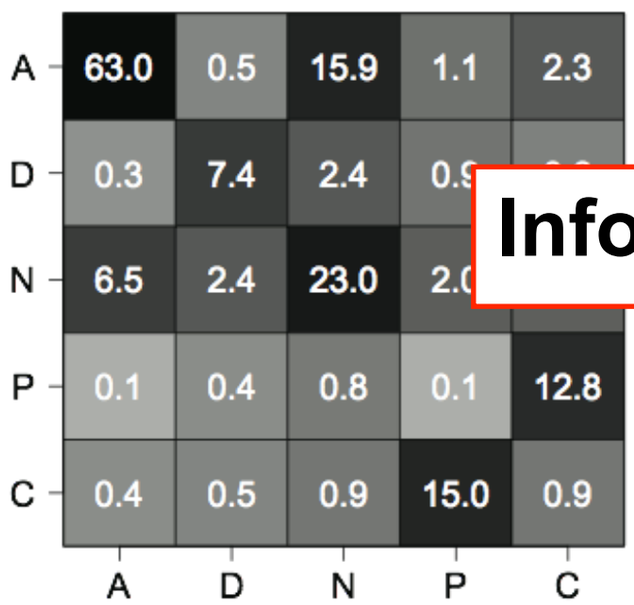
Text

contact matrices

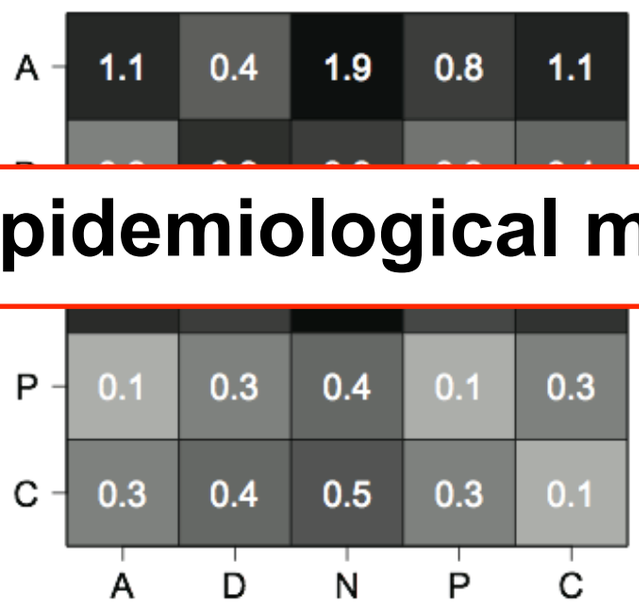




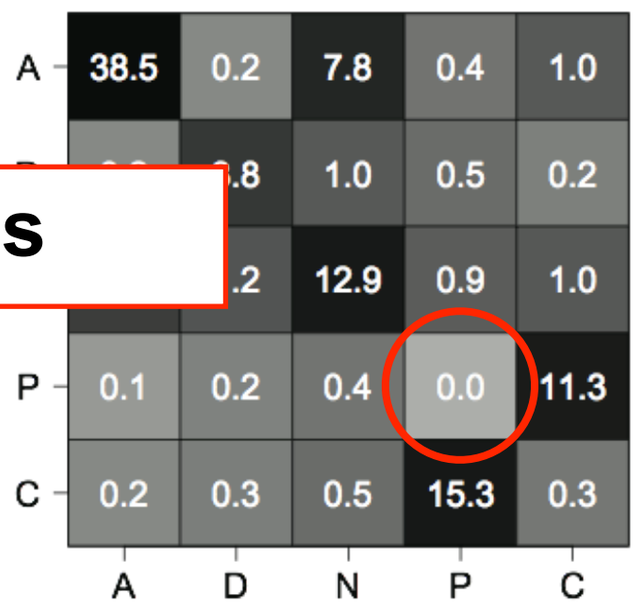
number of contacts s^n

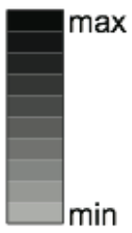


number of distinct contacts s^p



cumulative time in contact s^t (min)



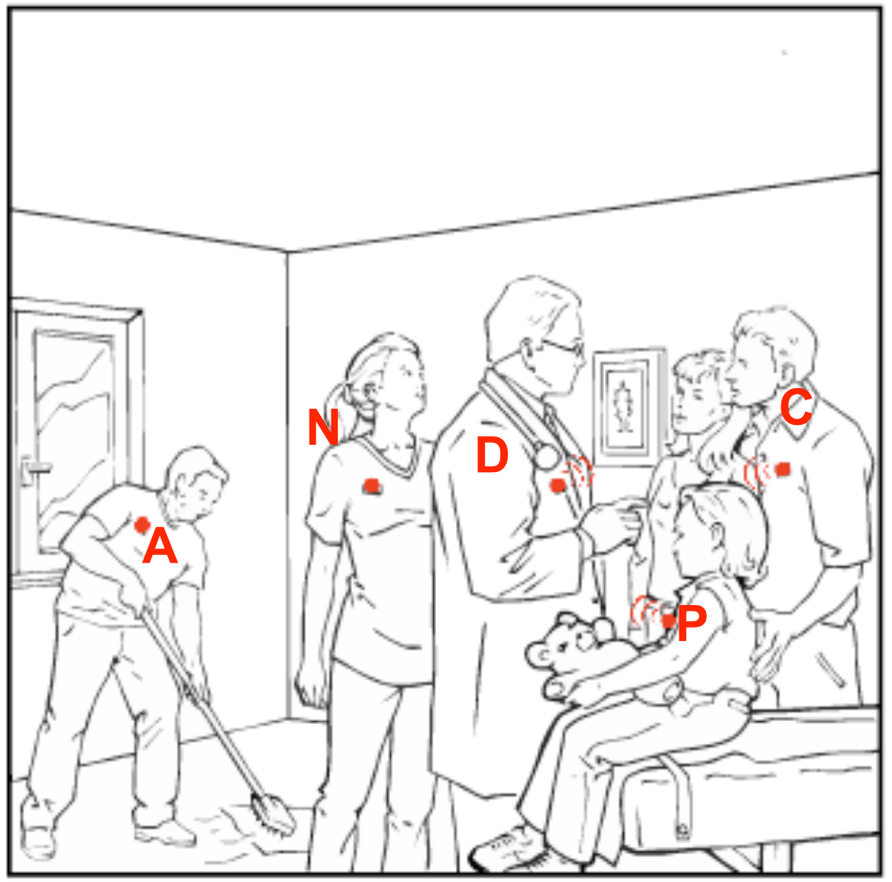


Inform epidemiological models

L. Isella *et al.*, PLoS ONE 6(2), e17144 (2011)

doctors

children



Inform epidemiological models
Go beyond a contact matrix description

nurses

auxiliaries

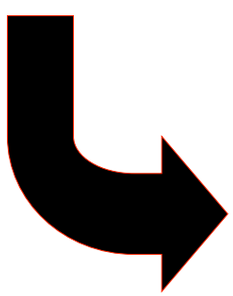
parents

>dealing with data: similarities and differences across contexts

DATE	EVENT	SIZE	DURATION
May 2008	Socio-physics workshop, Torino, IT	~65	3 days
Jun 2008	ISI offices, Torino, IT	~25	3 weeks
Oct 2008	ISI workshop, Torino, IT	~75	3 days
Dec 2008	Chaos Comm. Congress, Berlin, DE	~600	4 days
Apr-Jul 2009	Science Gallery, Dublin, IE	~30,000	3 months
Jun 2009	ESWC09, Crete, GR	~180	4 days
Jun 2009	SFHH, Nice, FR	~400	2 days
Jul 2009	ACM HT2009, Torino, IT	~120	3 days
Oct 2009	Primary school, Lyon, FR	~250	2 days
Nov 2009	Bambino Gesù Hospital, Rome, IT	~250	10 days
Jun 2010	ESWC10, Crete, GR	~200	4 days
Apr 2010	Practice Mapping, Gijon, ES	~100	10 days
Jul 2010	H-Farm, Treviso, IT	~200	6 weeks

Different contexts

- Conference (HT09)
  - Fixed number of attendees
  - Unconstrained mobility
- Museum (SG)
  - Flux of individuals
  - Predefined visiting path
- School

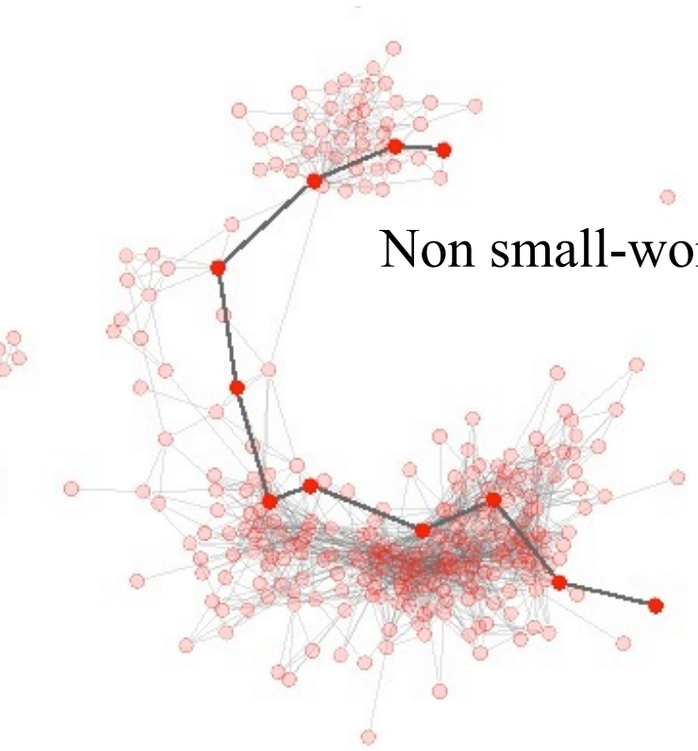


Similarities/differences in the f2f proximity patterns?

L. Isella *et al.*, Journal of Theoretical Biology 271, 166 (2011)

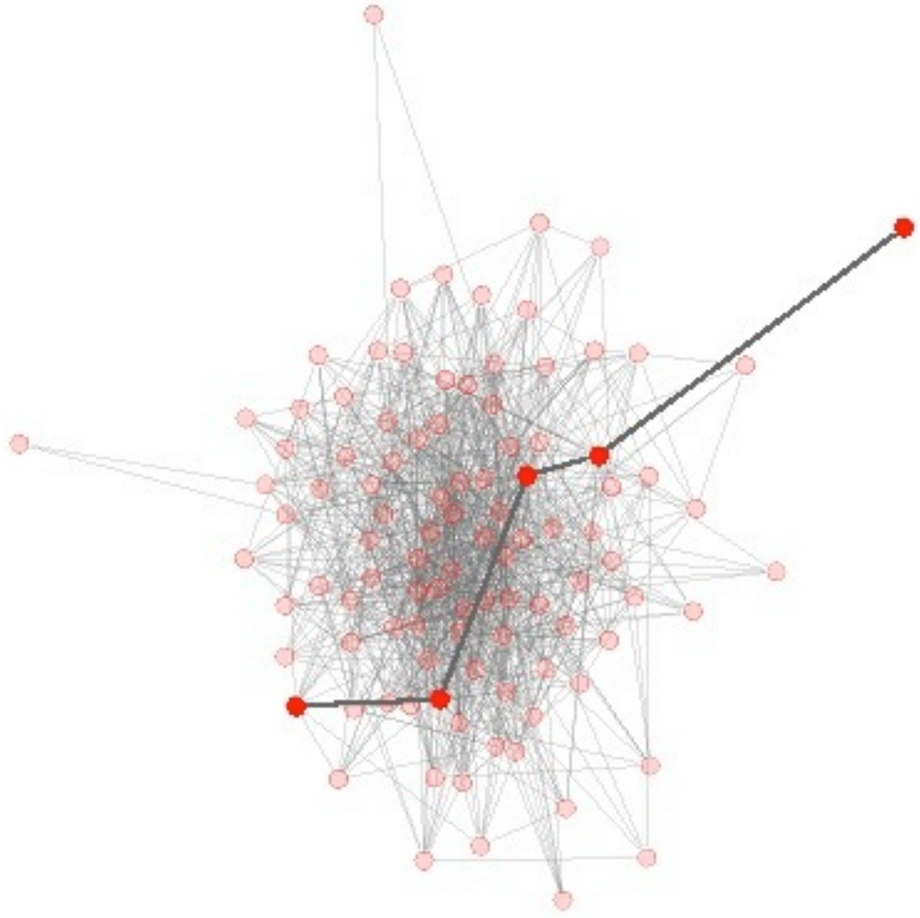
Daily cumulated networks

Museum



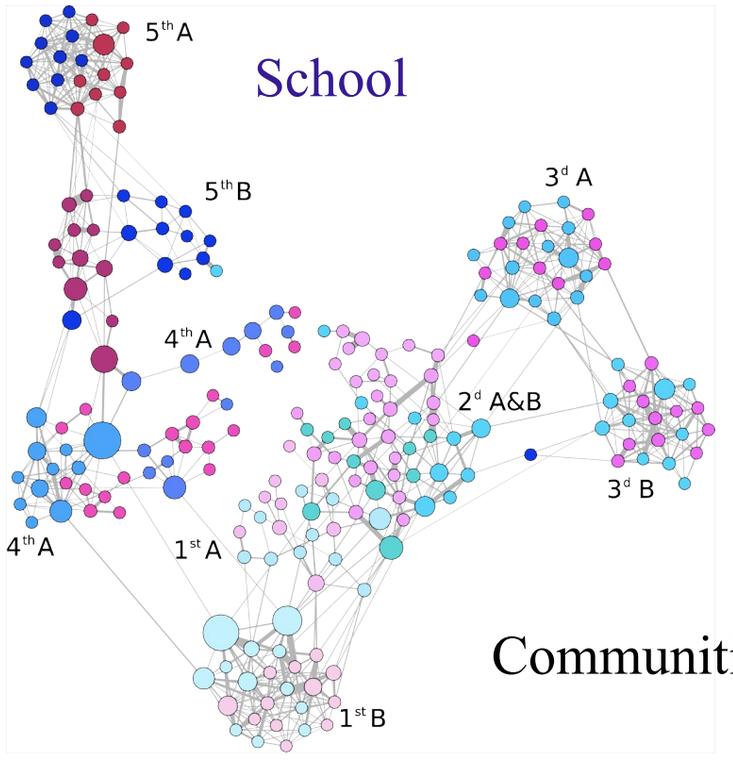
Non small-world

Conference



Small-world

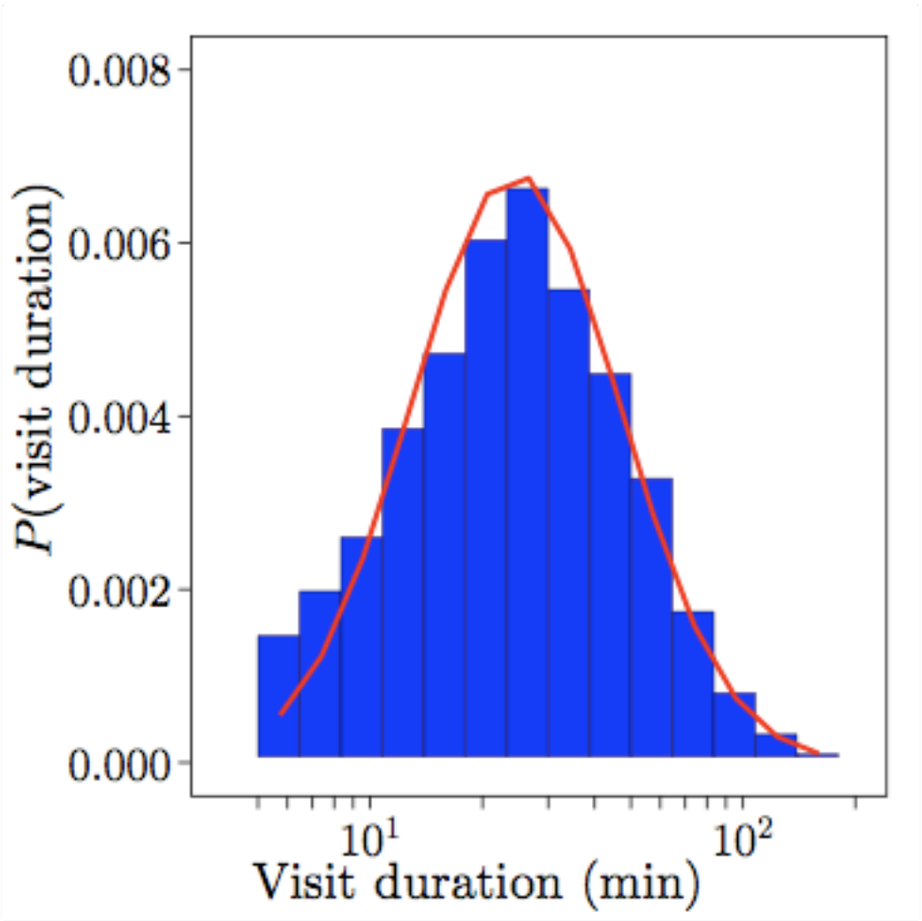
School

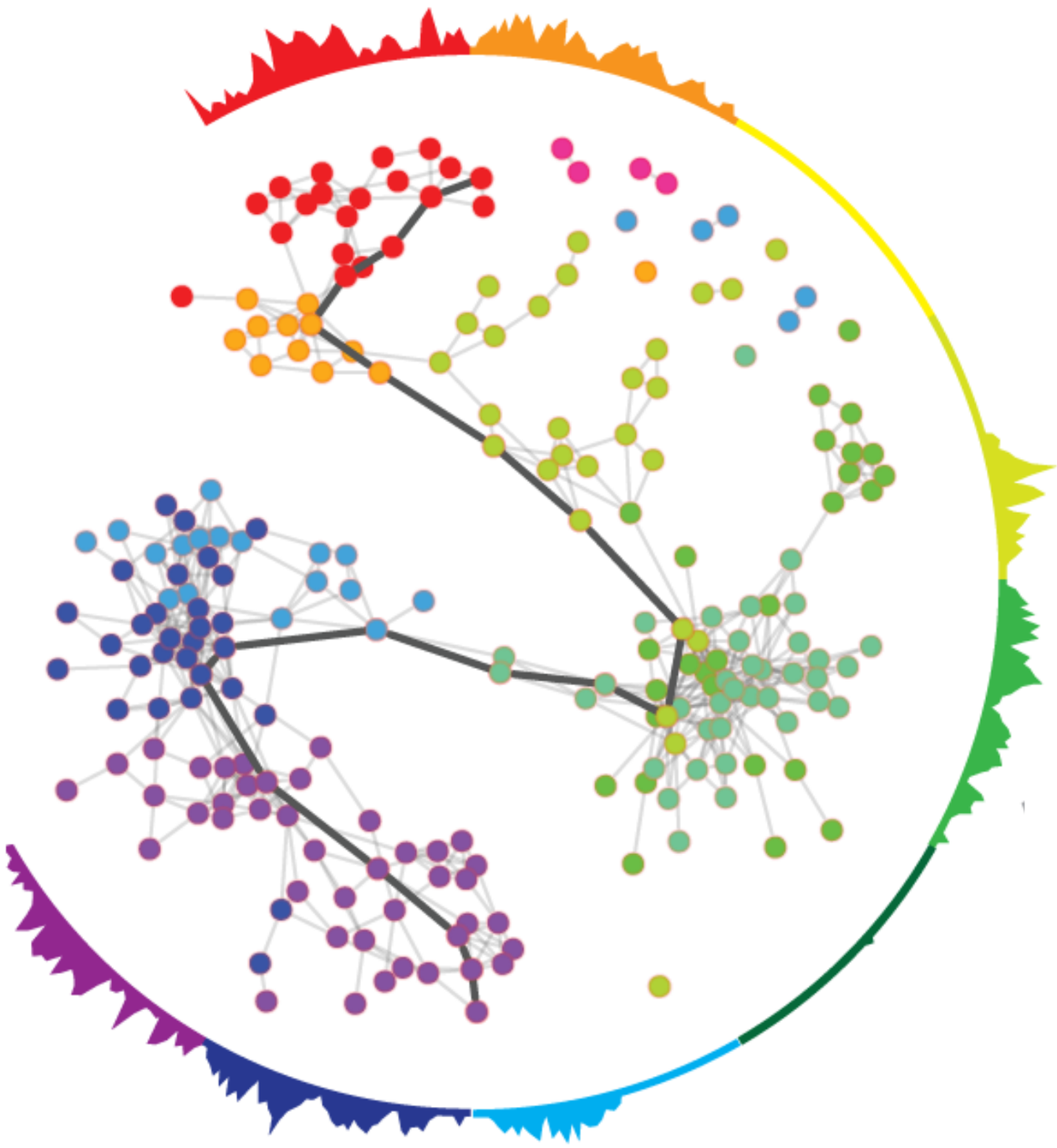


Communities

cumulative contact networks

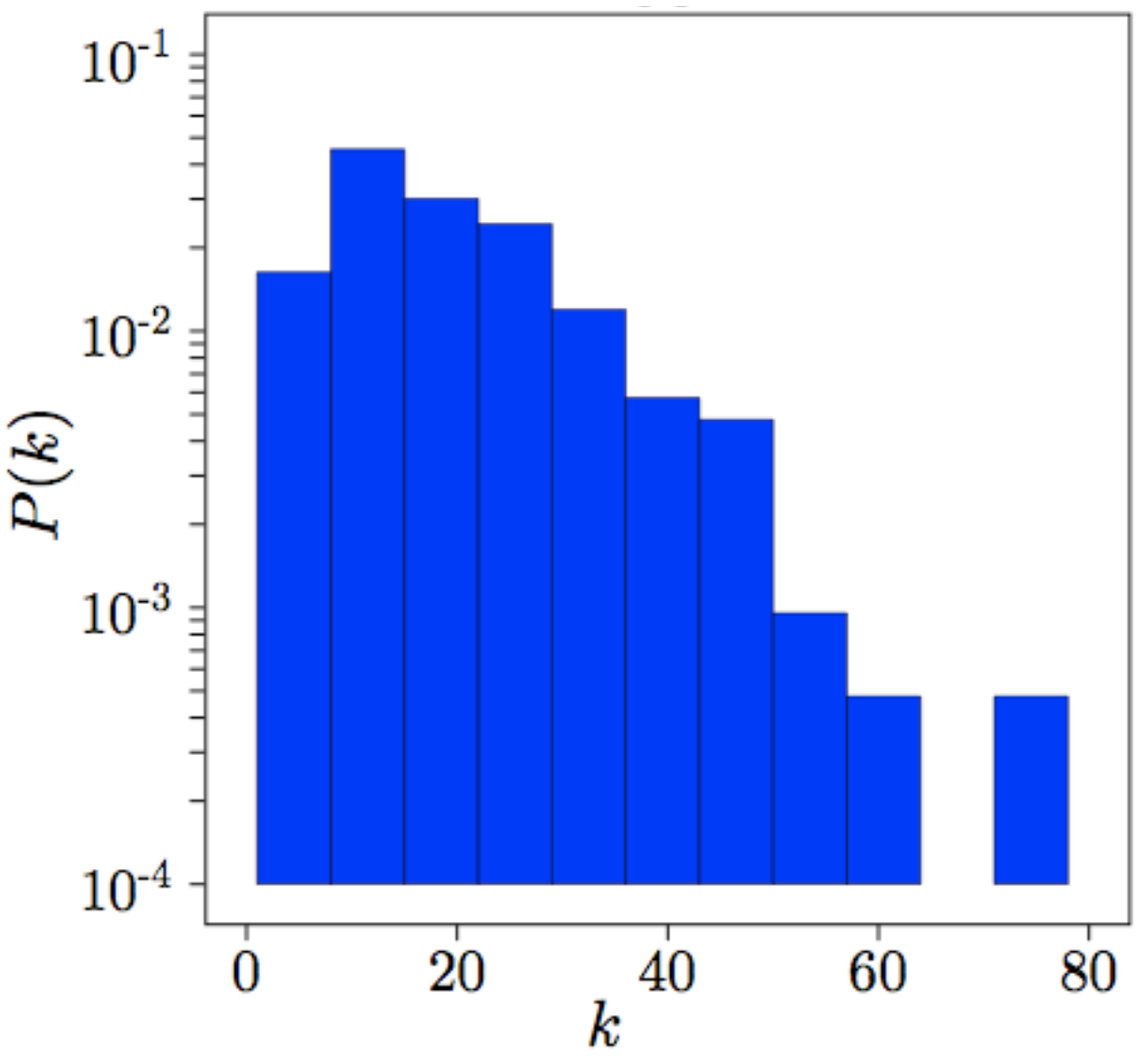
- color encodes the time of day
- node are colored by arrival time
- several groups (guided tours)





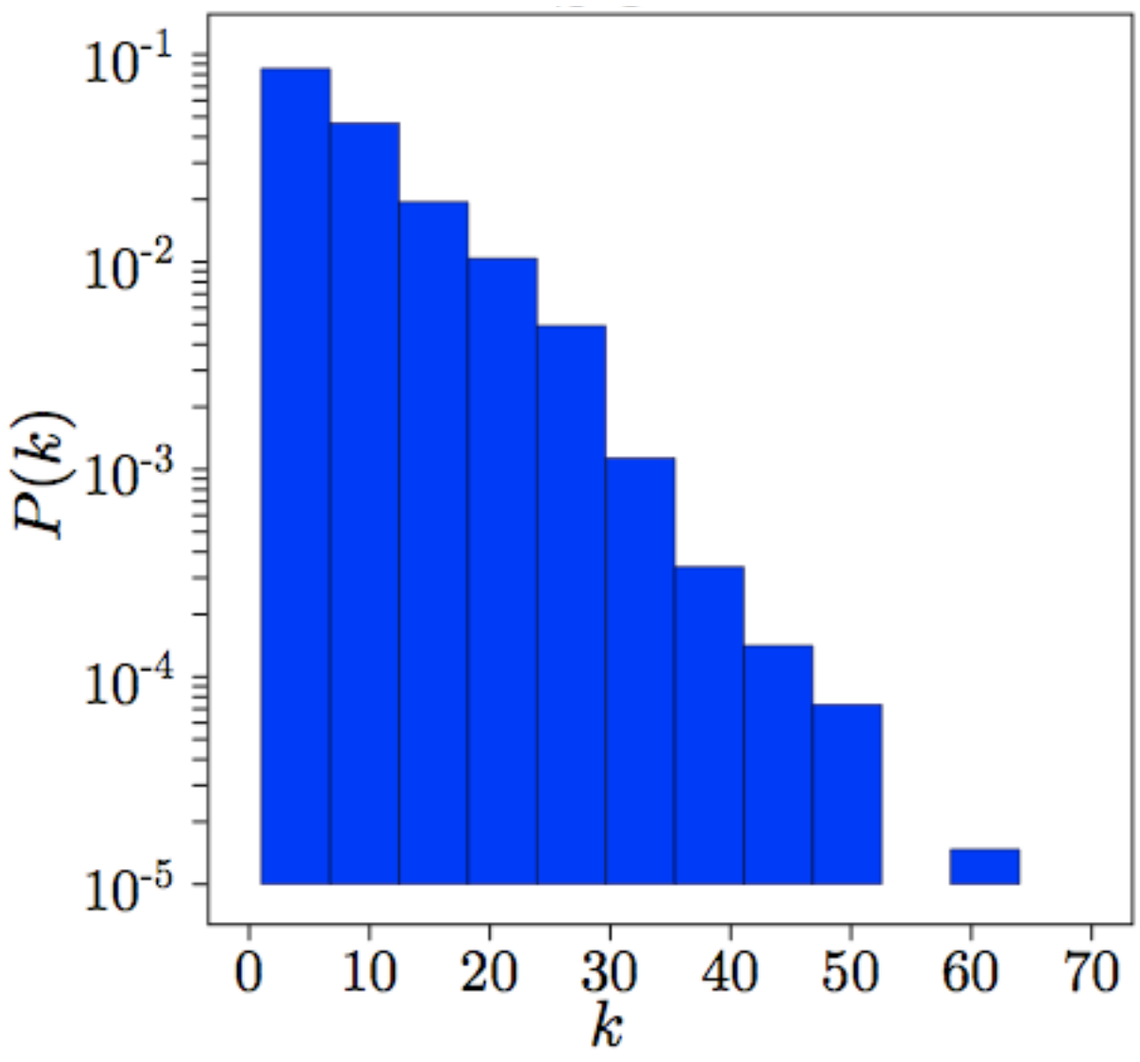
Exp. degree distributions

Conference



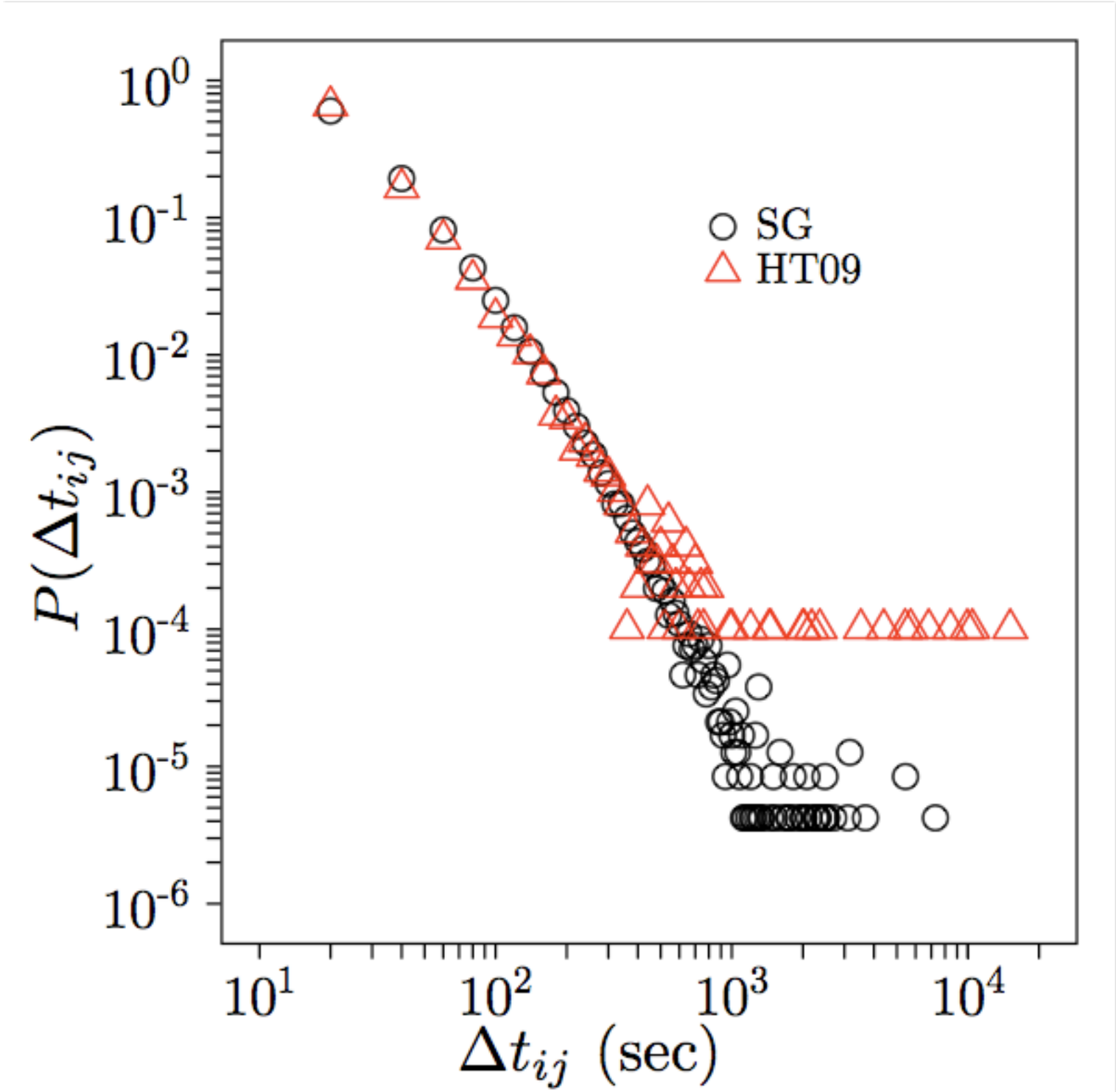
$< k > \simeq 20$

Museum

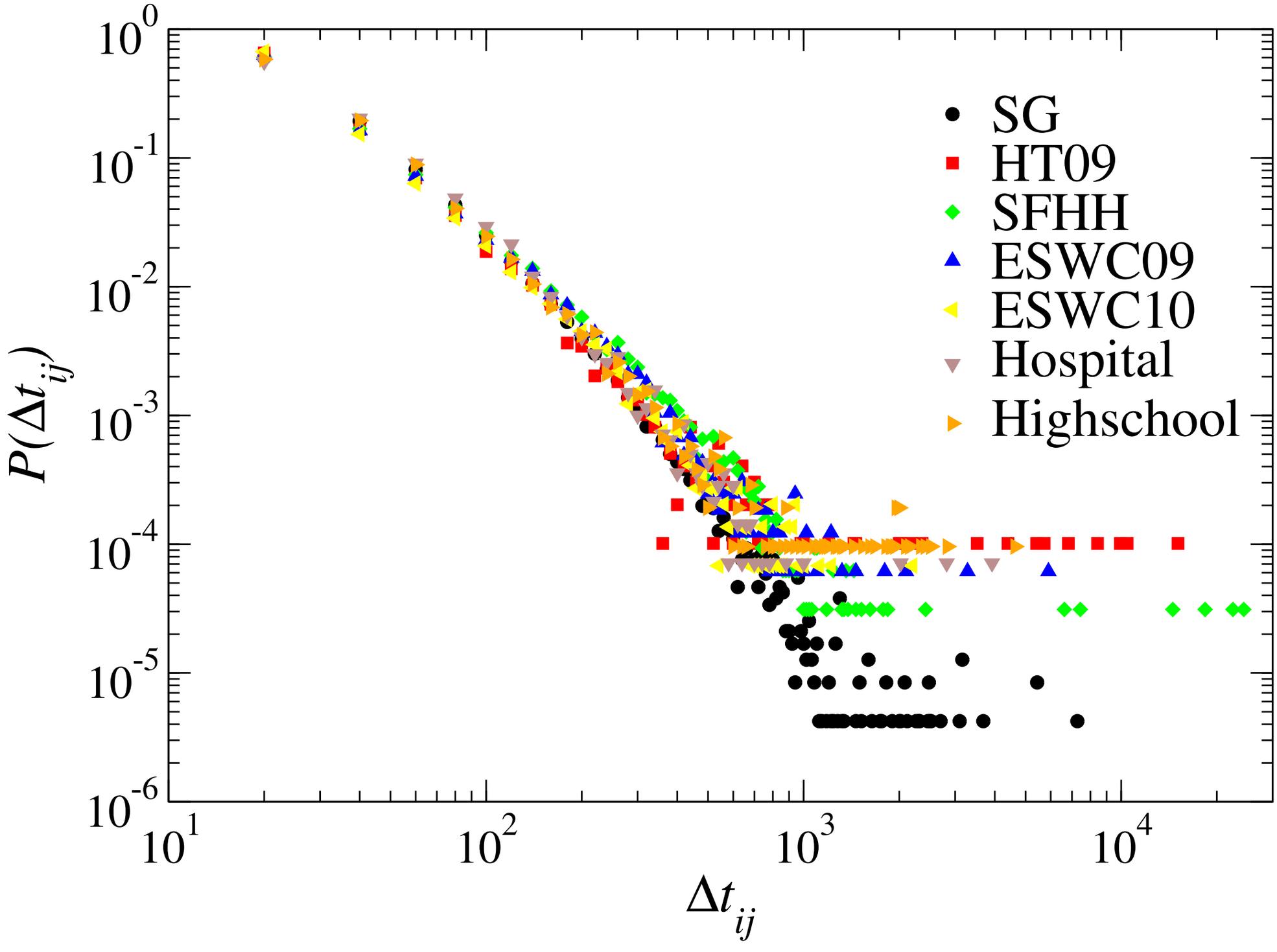


$< k > \simeq 8$

Similar contact durations distributions

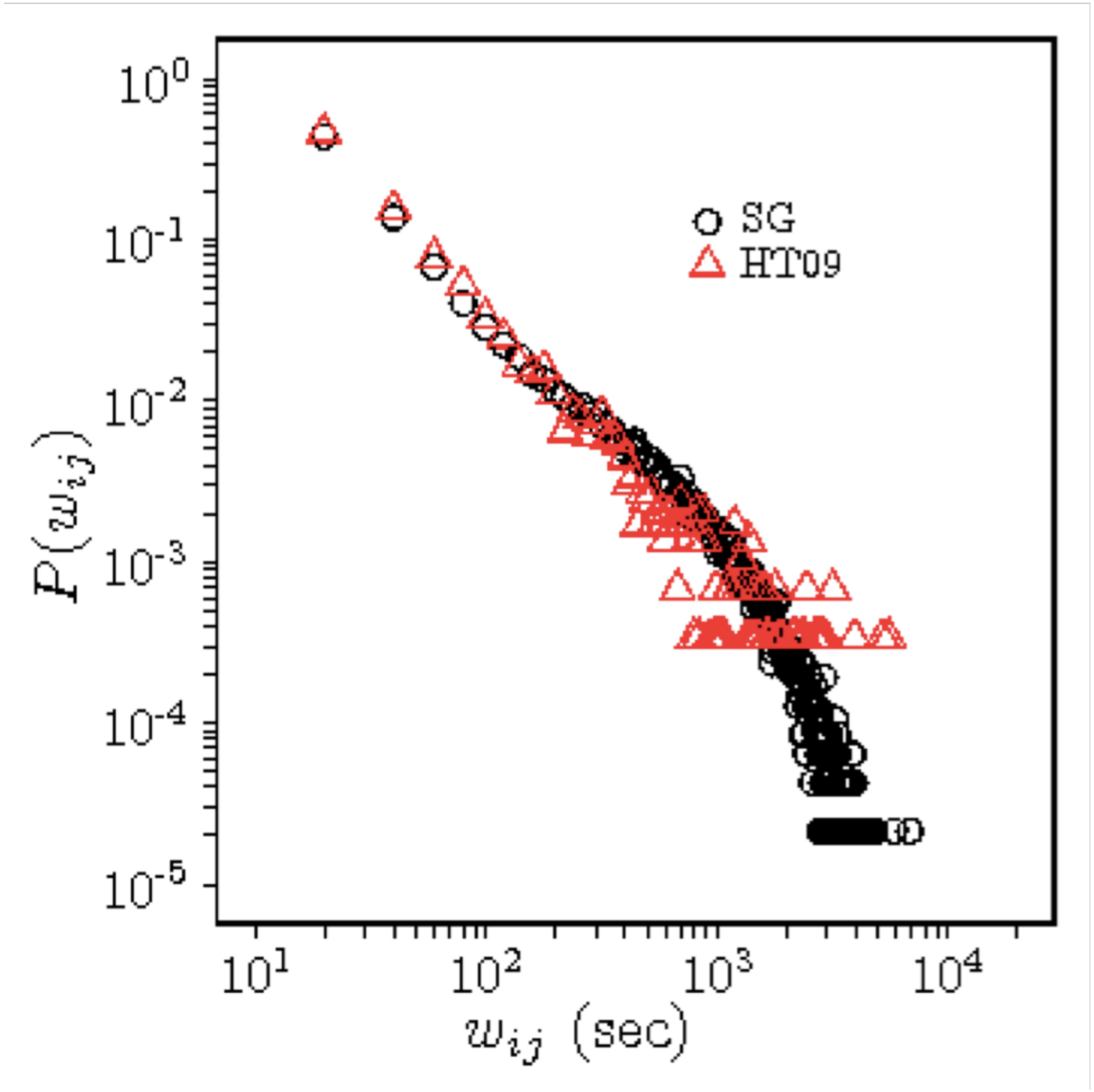


Similar contact durations distributions



Contact duration

Weight (cumulative contact time) distributions



- Similarities in statistical behavior of
  - number of contacts
  - durations of contacts
  - cumulated durations of contacts

- Differences:
  - statistics of inter-event times
  - aggregated network structure
  - correlations between weights (durations of contacts) and topology (number of contacts)
  - propagation phenomena

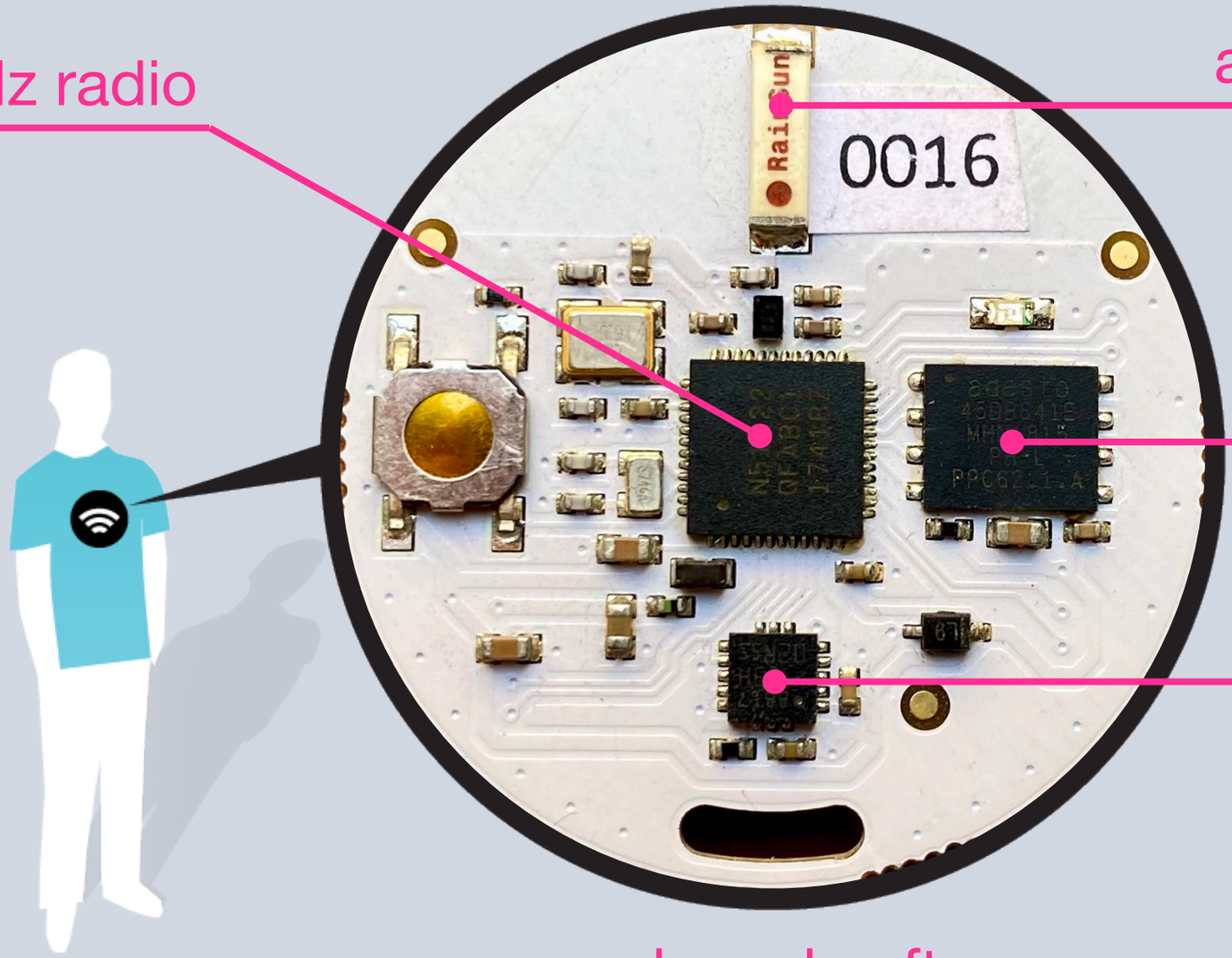
PROXIMITY SENSORS

CPU + 2.4 GHz radio

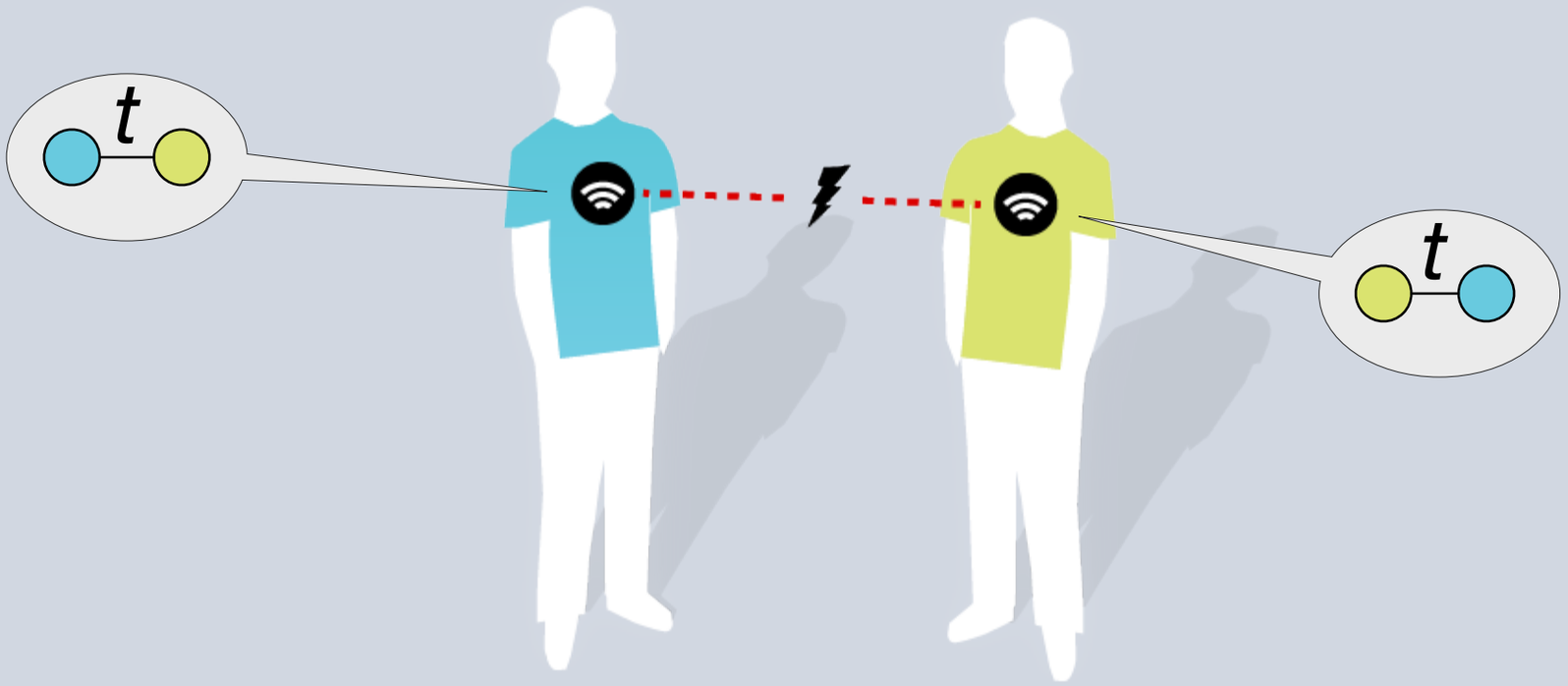
antenna

flash storage

accelerometer



+ on-board software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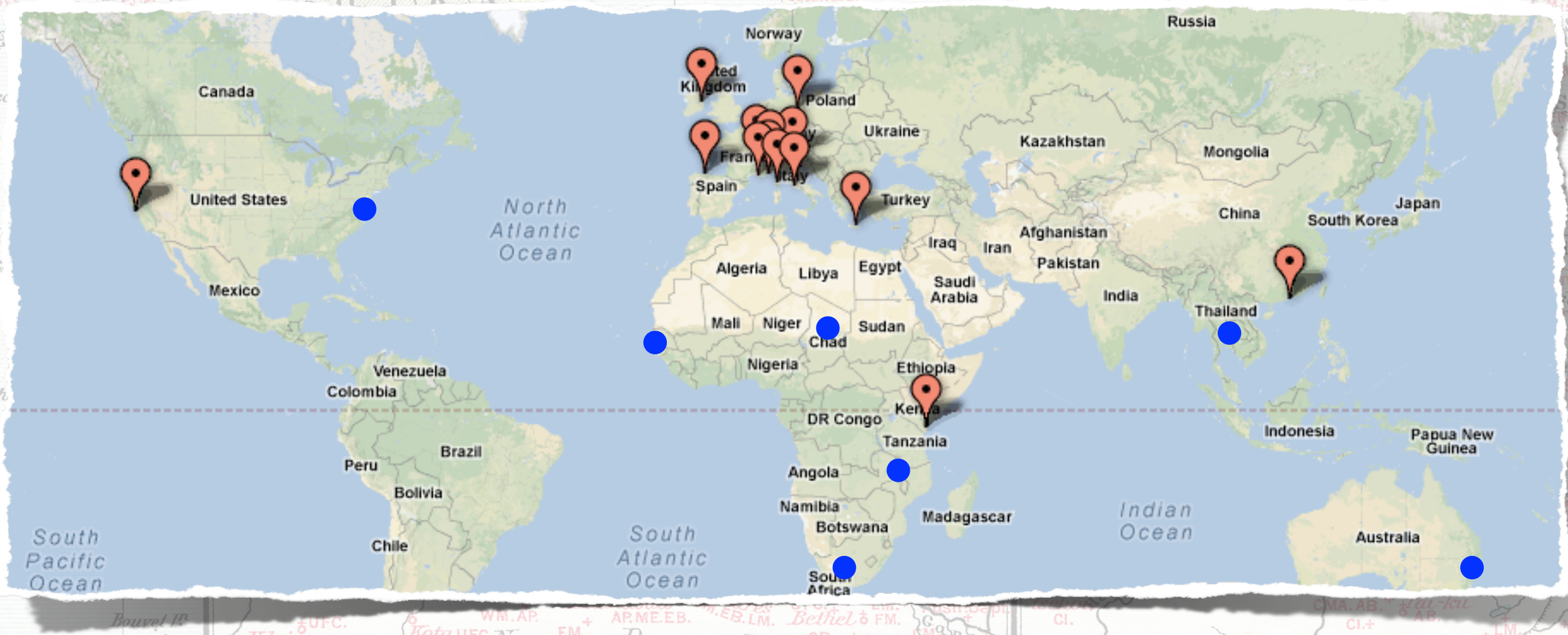
SocioPatterns.org



15 years, 45+ deployments, 14 countries, 50,000+ subjects,
>2,000 papers using our datasets

time-resolved proximity networks across
a variety of real-world settings

www.sociopatterns.org/publications

open data

- primary school aggregated contact network
  J. Stehlé *et al.*, PLoS ONE 6(8), e23176 (2011)

- ACM HT2009 conference temporal network
  L. Isella *et al.*, J. of Theoretical Biology 271, 166 (2011)

- INFECTIOUS exhibition temporal network
  L. Isella *et al.*, J. of Theoretical Biology 271, 166 (2011)

- hospital ward temporal network
  P. Vanhems *et al.*, PLoS ONE 8(9), e73970 (2013)

- high school temporal network
  J. Fournet *et al.*, PLoS ONE 9(9), e107878 (2014)

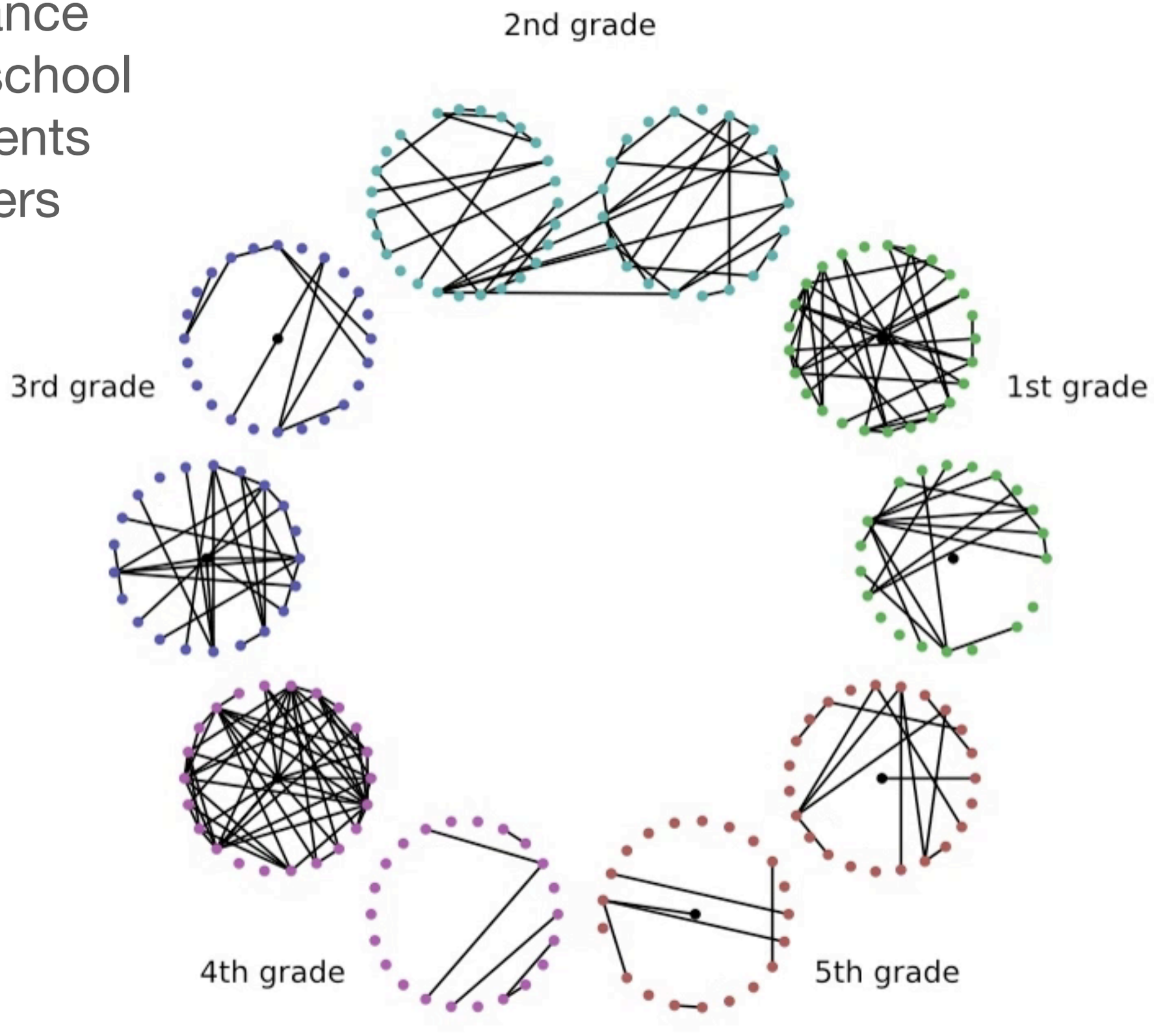
- high school proximity & friendship network
  R. Mastrandrea *et al.*, PLoS ONE 10(9), e0136497 (2015)

www.sociopatterns.org/datasets

empirical proximity data

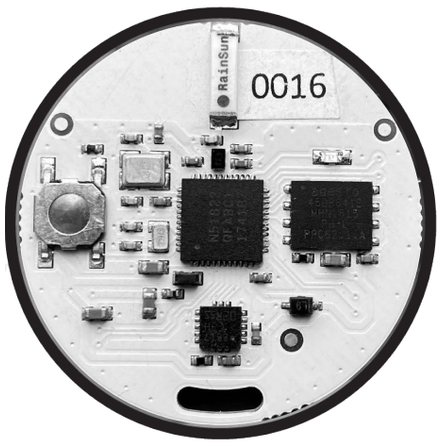
- **network dimension**
  - time-varying topology
  - multi-level community structures
  - assortativity, temporal-structural correlations
  - role structure
- heterogeneity of **weights**
  (e.g., fat-tailed distributions of contact durations)
- **burstiness** of human dynamics, non-Poissonian inter-event distributions, fat-tailed temporal correlations
- daily, weekly, seasonal, organizational **periodicities**
- **spatial** and physical constraints

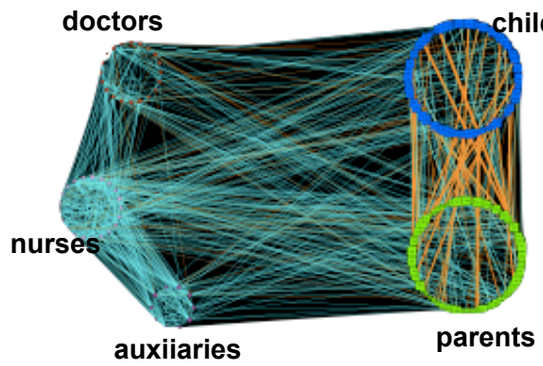
Lyon, France
primary school
231 students
10 teachers

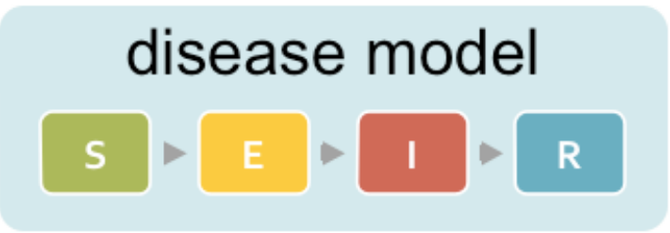


J. Stehlé *et al.*,
PLoS ONE 6(8), e23176 (2011)

design of targeted interventions

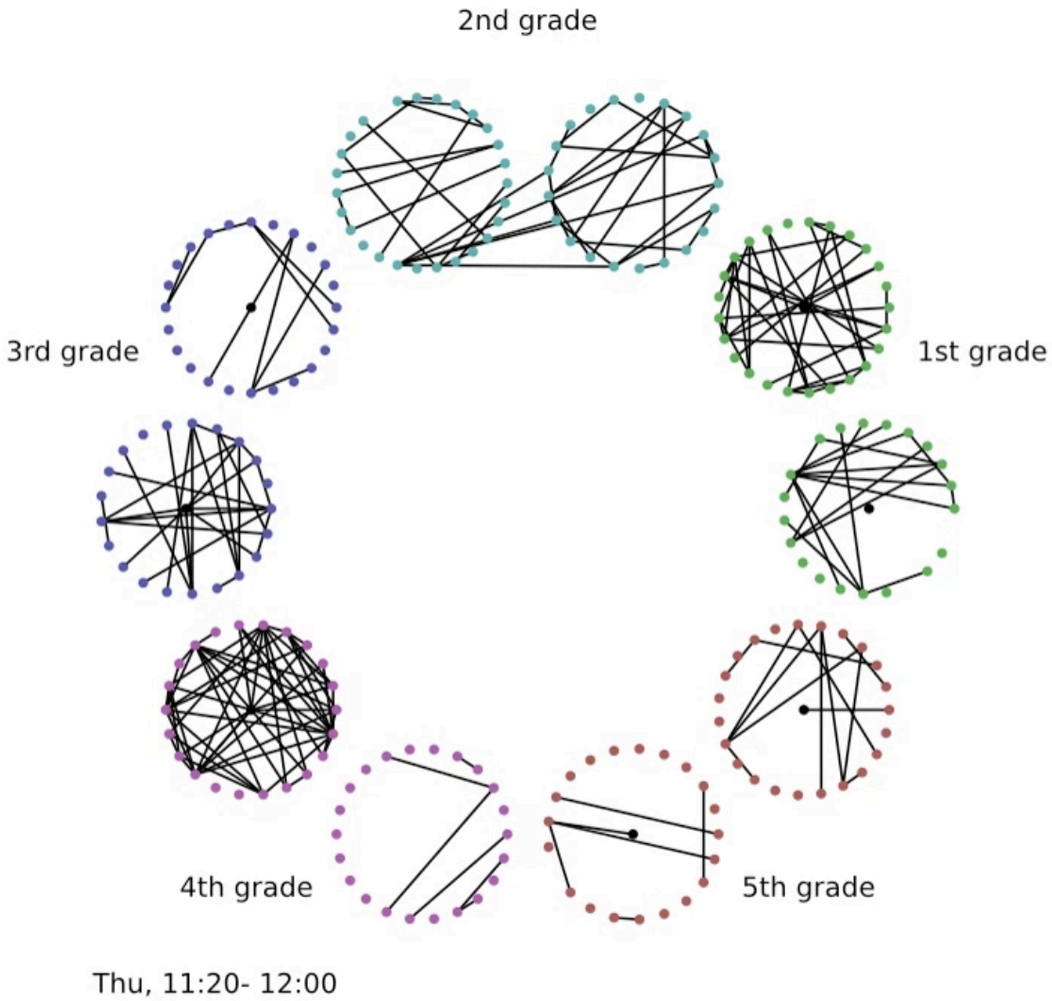


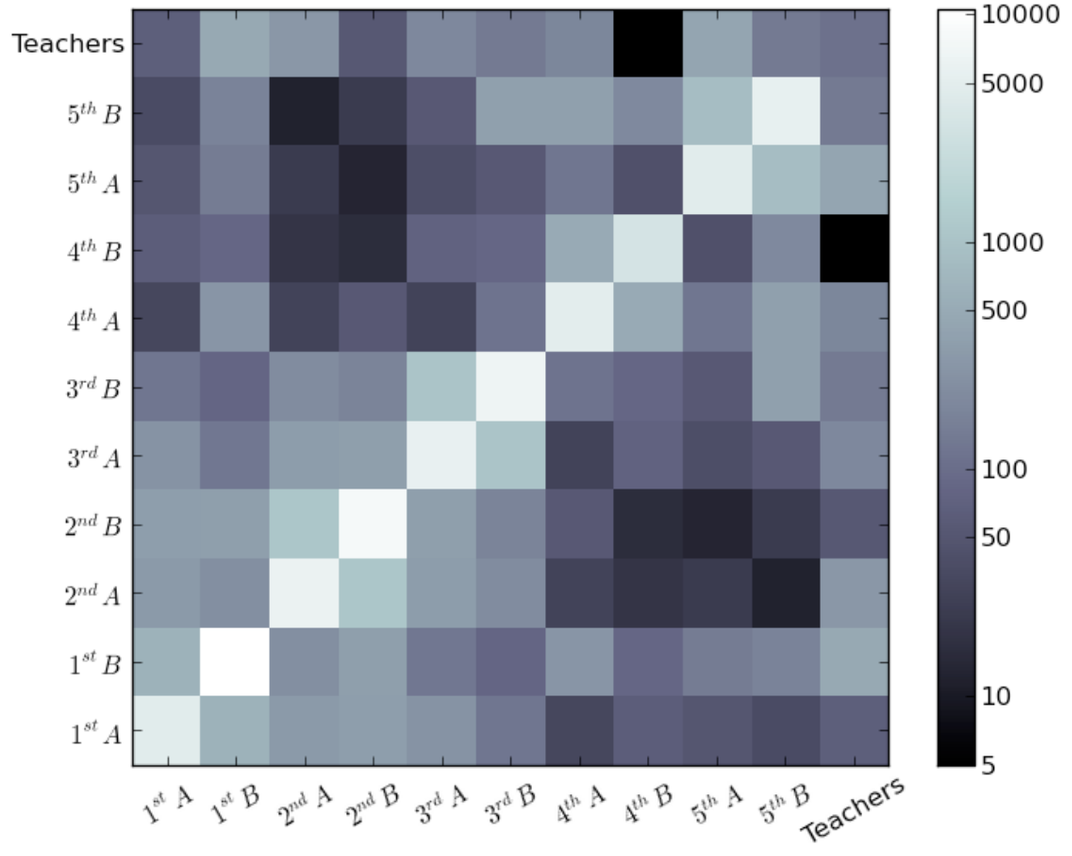




simulation

design of targeted interventions





epidemic model simulated using high-res social network

[unavailable in general]

interventions based on observed cases + class structure

[readily available]

design of targeted interventions

BMC Infectious Diseases

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Mitigation of infectious disease at school: targeted class closure vs school closure

Valerio Gemmetto, Alain Barrat & Ciro Cattuto

BMC Infectious Diseases **14**, Article number: 695 (2014) | Cite this article

9824 Accesses | **119** Citations | **54** Altmetric | Metrics

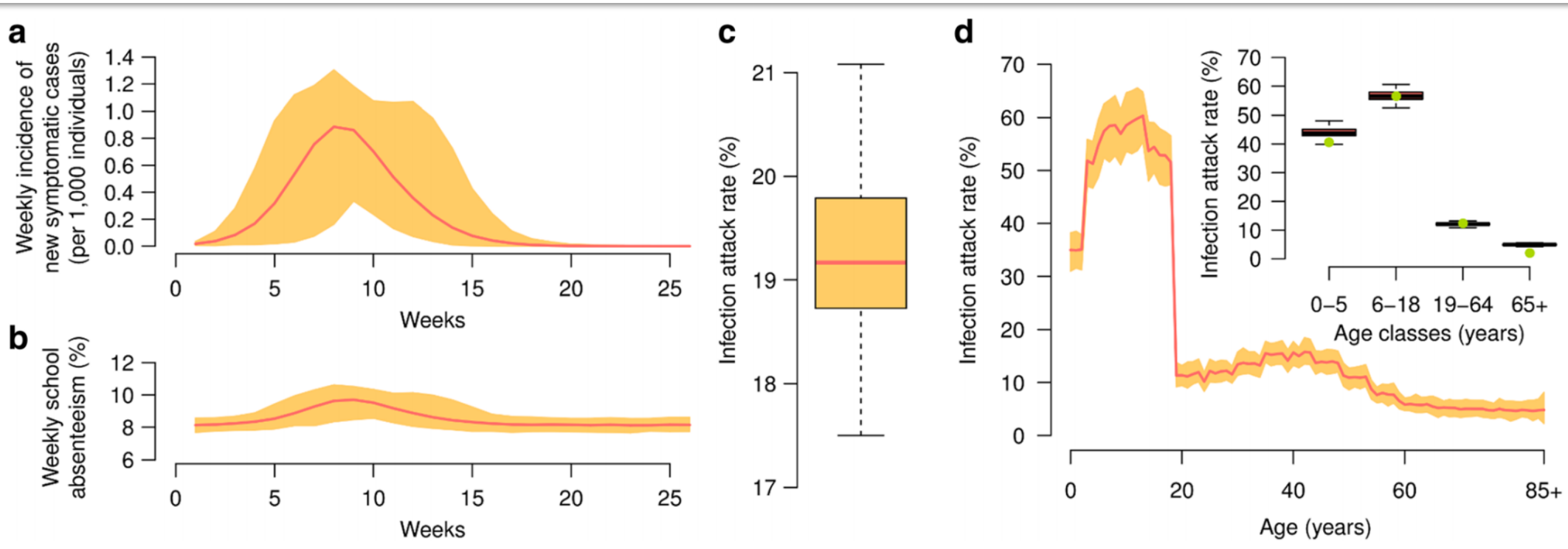
V. Gemmetto *et al.,* BMC Infectious Diseases 14, 695 (2014)

design of targeted interventions

RESEARCH ARTICLE Open Access

School closure policies at municipality level for mitigating influenza spread: a model-based evaluation

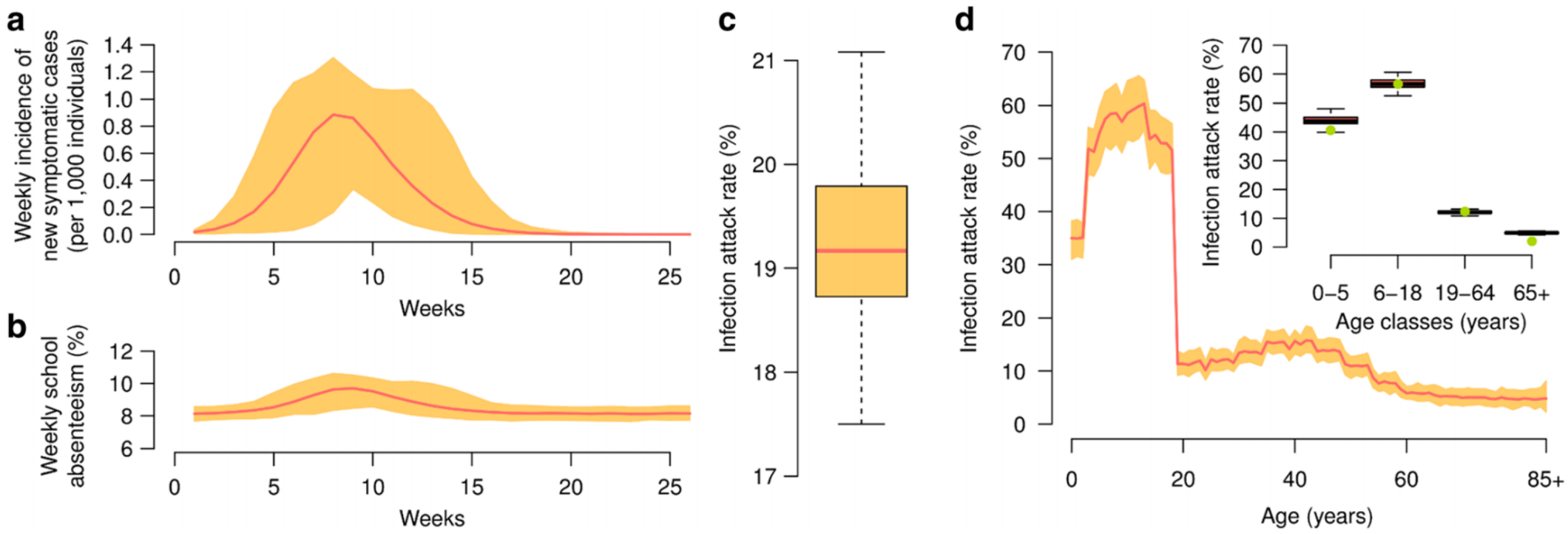
Constanze Ciavarella[1], Laura Fumanelli[1], Stefano Merler[1], Ciro Cattuto[2] and Marco Ajelli[1*]



C. Ciavarella *et al.*, BMC Infectious Diseases 16, 576 (2016)

design of targeted interventions

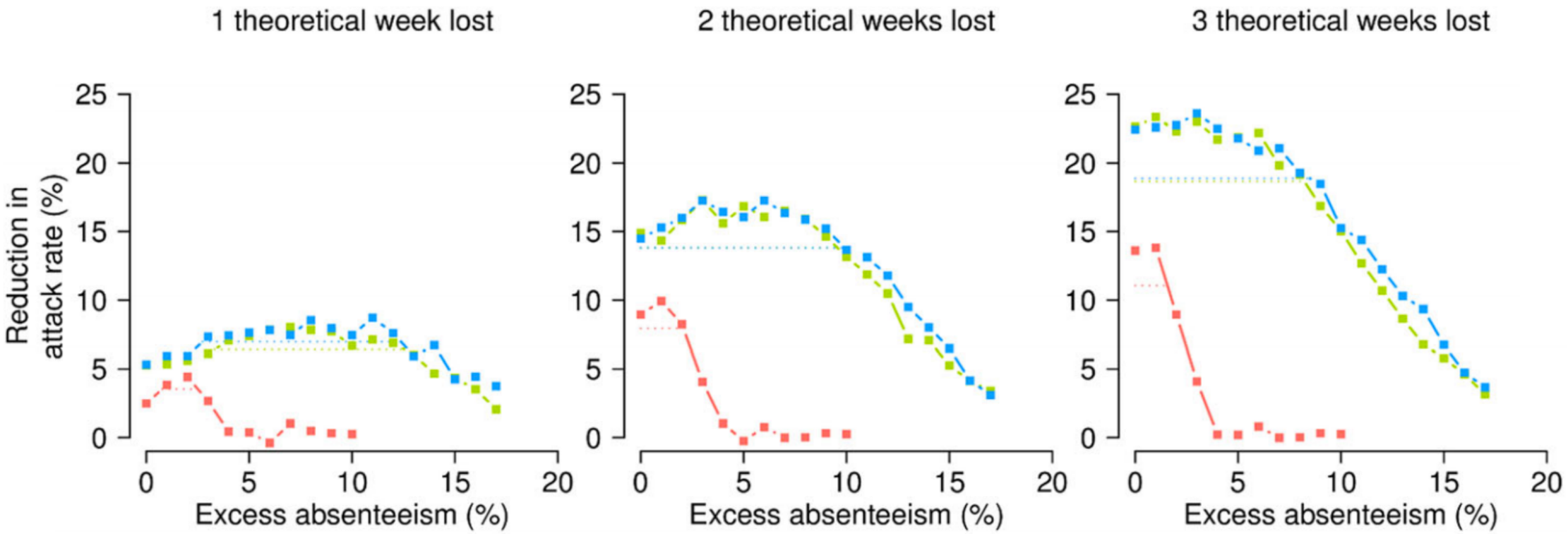
- individual-based model of influenza transmission
- municipality level, ~100,000 simulated individuals
- sociodemographic data + time-use survey data +
  + face-to-face contact matrix from sensor data
- 2009 H1N1 pandemic influenza reference scenario,
  SLAIR model, R_e=1.4, generation time ~ 2.7 days



C. Ciavarella *et al.,* BMC Infectious Diseases 16, 576 (2016)

design of targeted interventions

entire school vs class-school vs class-grade-school



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design of targeted interventions

RESEARCH ARTICLE Open Access

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Ajelli[1*]

THE LANCET
Infectious Diseases

Volume 22, Issue 7, July 2022, Pages 977-989

Articles

Screening and vaccination against COVID-19 to minimise school closure: a modelling study

Elisabetta Colosi MSc [a], Giulia Bassignana PhD [a], Diego Andrés Contreras PhD [b], Canelle Poirier PhD [a], Prof Pierre-Yves Boëlle PhD [a], Simon Cauchemez PhD [c], Prof Yazdan Yazdanpanah PhD [d e], Prof Bruno Lina PhD [f g], Prof Arnaud Fontanet PhD [h i], Alain Barrat PhD [b j], Vittoria Colizza PhD [a j]

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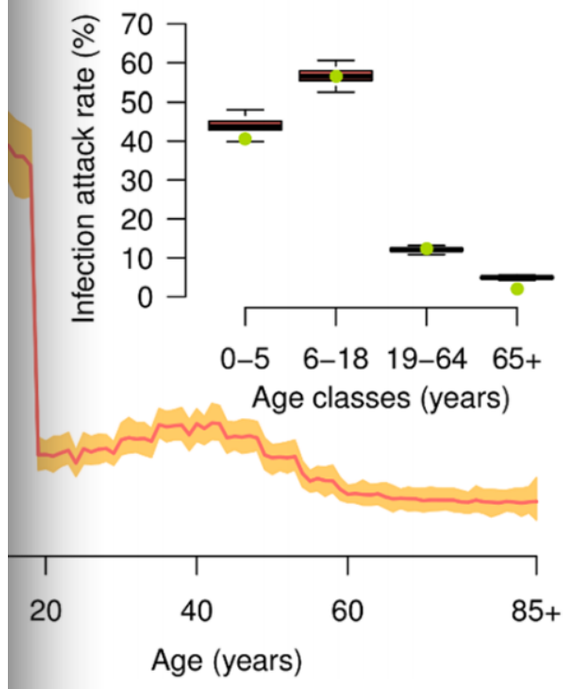
[c] Mathematical Modelling of Infectious Diseases Unit, Institut Pasteur, UMR2000, CNRS, Paris, France



C. Ciavarella *et al.*, BMC Infectious Diseases 16, 576 (2016)

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Article | Open Access | Published: 12 March 2021

Digital proximity tracing on empirical contact networks for pandemic control

G. Cencetti, G
Lepri ✉

Nature Comm

4385 Access

Abstract

Digital conta
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informed by
contact trac
apps, couple

JOURNAL OF THE ROYAL SOCIETY INTERFACE

Research articles

Effect of manual and digital contact tracing on COVID-19 outbreaks: a study on empirical contact data

A. Barrat ✉, C. Cattuto, M. Kivelä, S. Lehmann and J. Saramäki

Published: 05 May 2021 | https://doi.org/10.1098/rsif.2020.1000

PROXIMITY DATA

+

BIOLOGICAL DATA

influenza in acute care geriatric unit

- proof-of-concept observational study
- 37 patients, 32 nurses, 15 doctors
- 12 days of high-res contact data
- nasopharyngeal swabs
- PCR-confirmed influenza A & B infections
- culture-based subtyping and phylogenetics

Work or hospitalization period

Contagious period

Cumulative contacts duration < 60s

Cumulative contacts duration ≥ 60s and < 120s

Cumulative contacts duration ≥ 120s

• Symptoms onset

\+ Influenza positive swab

\- Influenza negative swab

Culture result	RFID tag number (group)	D1**	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	Comments
nd	602 (PAT)		+						+					Asymptomatic
neg	633 (MED)	+											-	Symptoms onset February 26
pos †	640 (MED)	+•												Symptoms onset February 27
neg	647 (PAT)	+		+										Symptoms onset February 26
nd	609 (PAT)		+							+				Symptoms onset February 24 + isolation
nd	626 (NUR)		+								+			Back from sick leave February 28 after a previous ILI episode
nd	663 (NUR)				+								-	Back from sick leave March 1 after a previous ILI episode
neg	657 (PAT) *				-	+•			+					Symptoms onset March 2
pos †	612 (PAT) *		-			+•			+					Symptoms onset March 2
nd	675 (PAT)						•		+				+	Symptoms onset March 3 (reported by the patient)
neg	677 (PAT)						•		+			+		Symptoms onset March 3 (reported by the patient)
neg	678 (PAT)					•			+				-	Symptoms onset March 2 (reported by the patient) + isolation
neg	600 (PAT) *	-					-•		+					Symptoms onset March 3
nd	683 (PAT)									•	+		+	Symptoms onset March 6 (reported by the patient) + isolation
pos †	644 (NUR) *	-									•	+		Symptoms onset March 7

N. Voirin *et al.,* Infection Control and Hospital Epidemiology 36, 254 (2015)

pathogen carriage & microbiome
vs
social networks

with Norwegian Institute of Public Health
& Fit Futures team

ELSEVIER

International Journal of Infectious Diseases

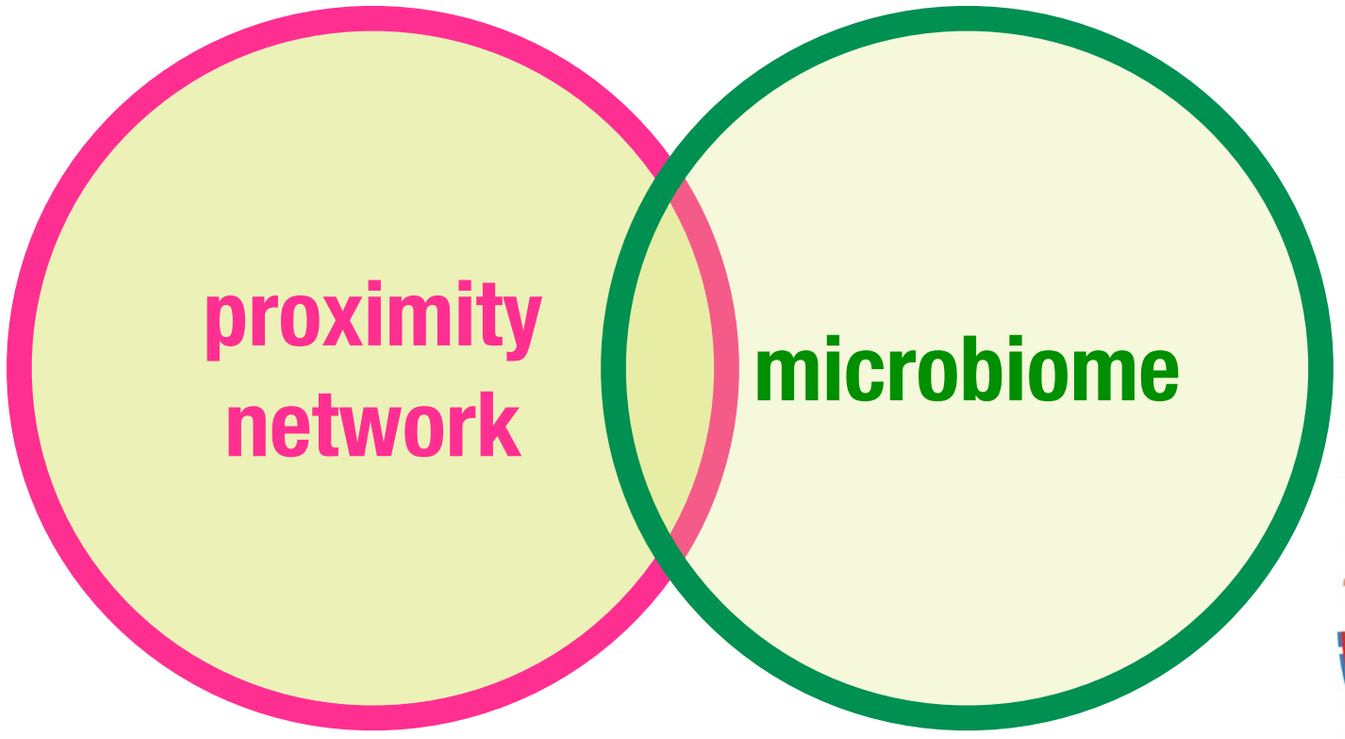
Volume 123, October 2022, Pages 200-209

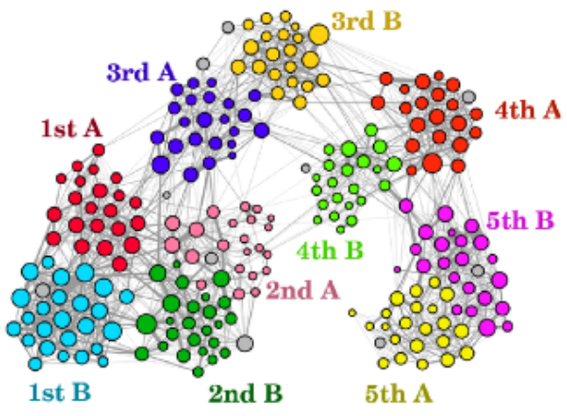
Social network analysis of *Staphylococcus aureus* carriage in a general youth population

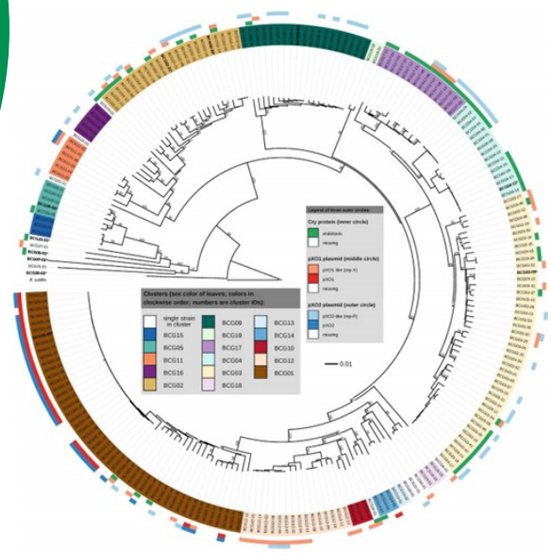
Dina B. Stensen [1, 2, #], Rafael A. Nozal Cañadas [3, #], Lars Småbrekke [4], Karina
Sivert Nielsen [6, 7], Kristian Svendsen [4], Anne Merethe Hanssen [8], Johanna U. Erics
Simonsen [5, 8], Lars Ailo Bongo [3], Anne-Sofie Furberg [5, 9]

social network vs oral microbiome

- pilot study: completed
- primary school, 50 students, opt-in, 96% compliance
- 4 months, 1 measurement wave / month, ~2 weeks each







- proximity sensors
- continuously worn for 2 weeks

- saliva samples
- 1 sample / week
- 16S rRNA sequencing

CHALLENGES FOR COLLECTING & SHARING DATA ?

challenges

- **logistics:** sensor preparation / distribution / retrieval, dealing with lost / damaged / replaced sensors, recording participant consent
- **engagement** of participants, obtaining consent, compliance with wearing protocol
- **metadata** collection and linking
- **data quality** & data cleaning
- **hardware** is a moving target, software forced to track hardware evolution, development never ends
- **data protection** and **ethics**
- **lack of proper academic recognition** of data collection work for young researchers