High-resolution Contact Networks
PART 1: measurement

Ciro Cattuto
ISI Foundation

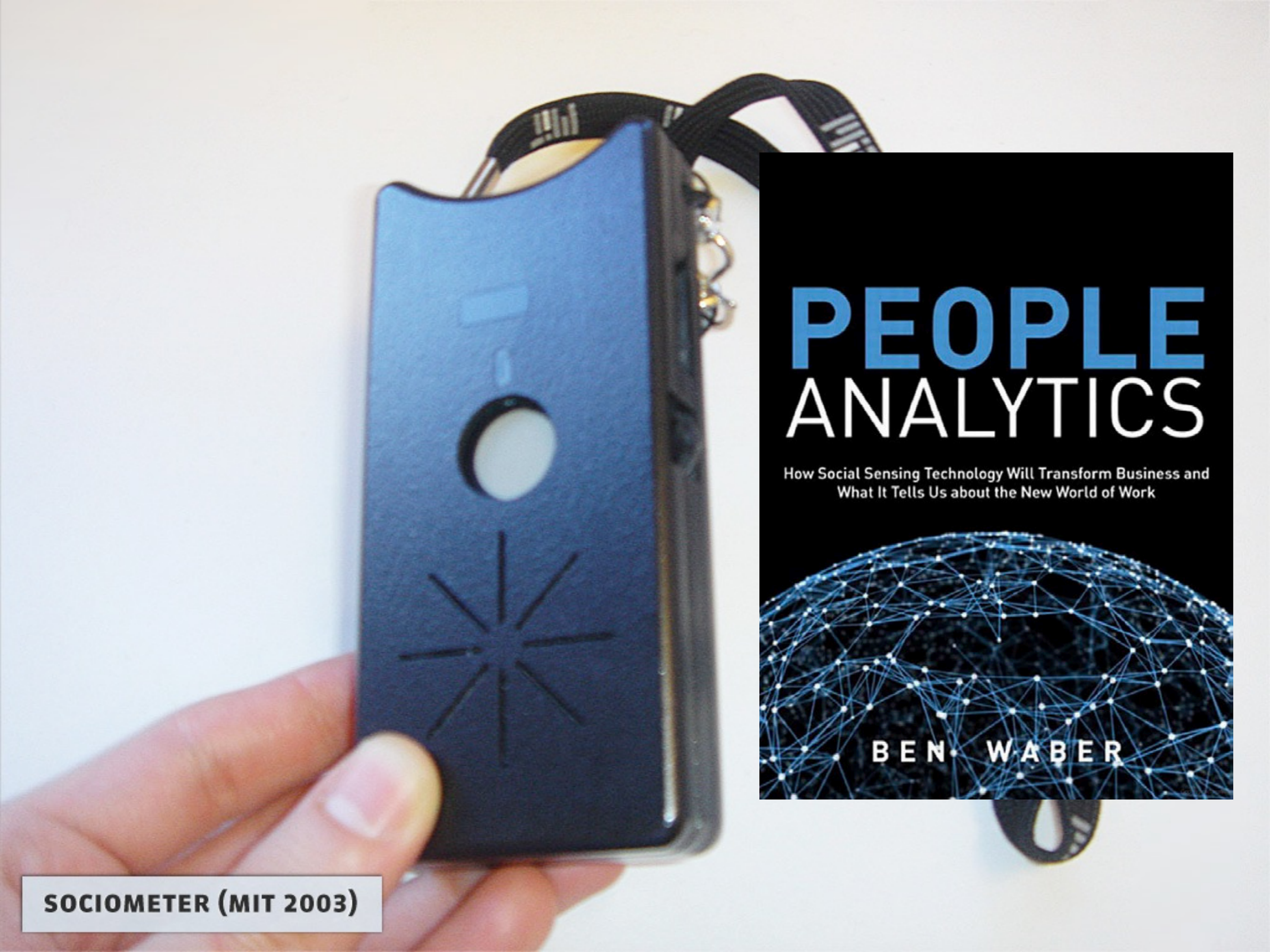
Modeling Infectious Disease Outbreaks Using Genomic Data Workshop

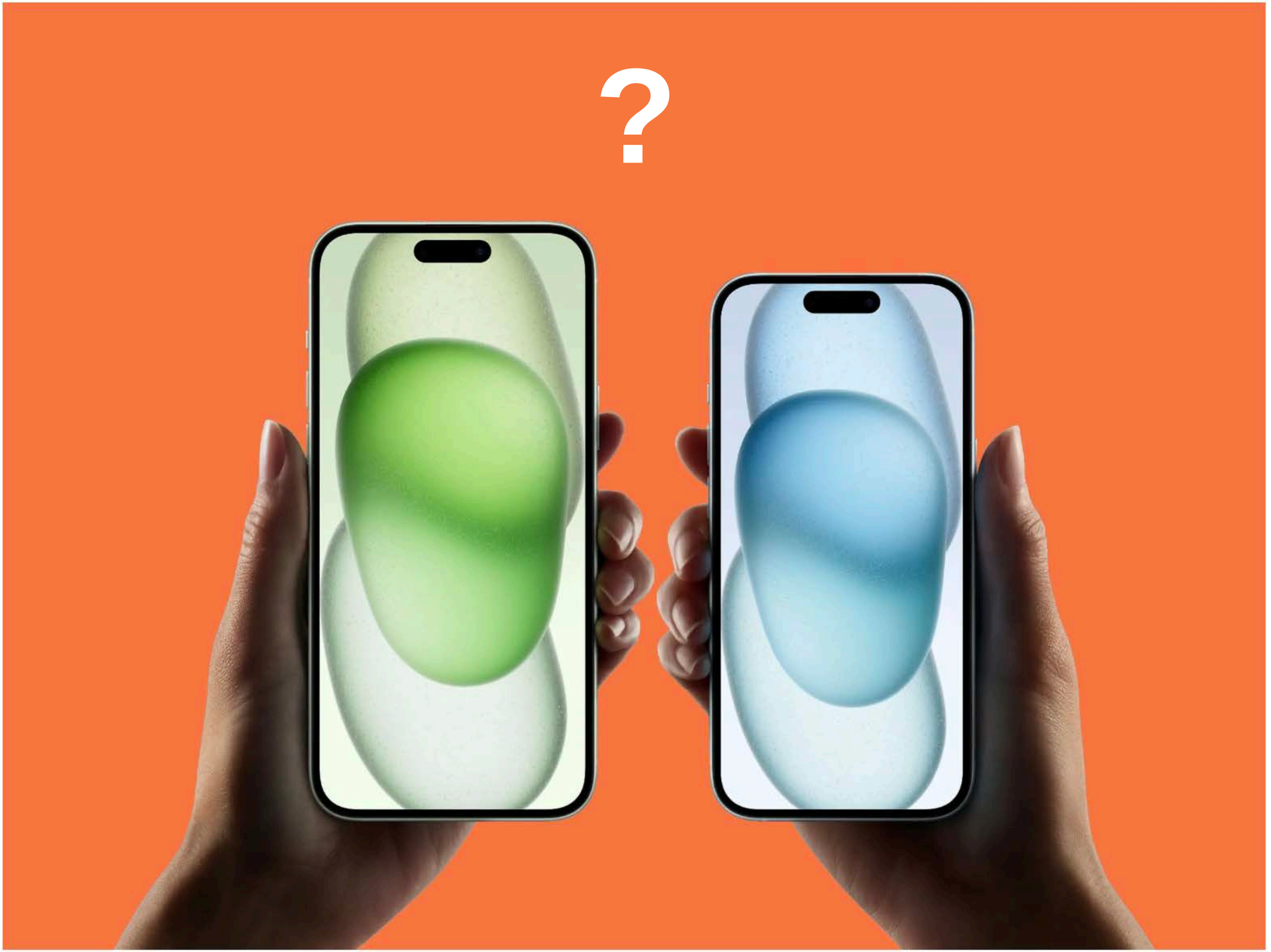
Mahidol University, Bangkok
1 July 2025

ISI Foundation

MEASURING human close-range proximity

ACTIVE BADGE (OLIVETTI/AT&T 1990)


PEOPLE
ANALYTICS
How Social Sensing Technology Will Transform Business and
What It Tells Us about the New World of Work
BEN WABER
SOCIOMETER (MIT 2003)



PHOTOGRAPH: APPLE

scientific data

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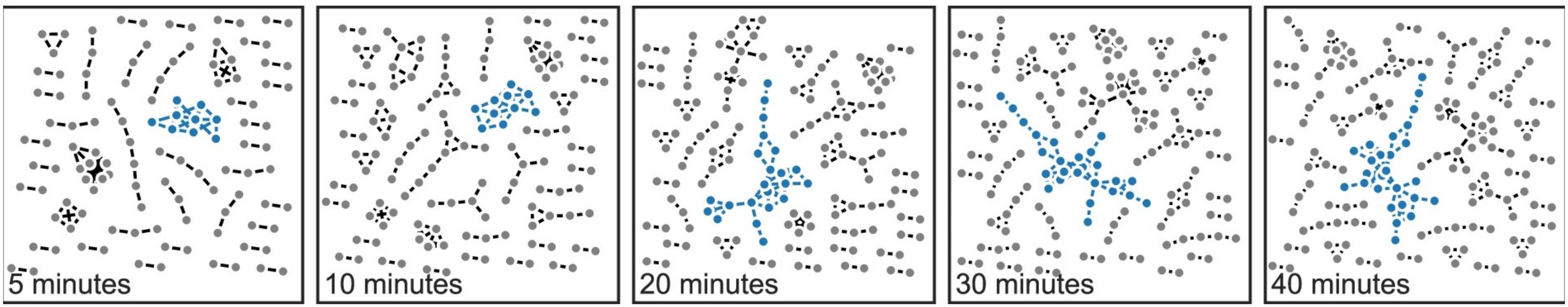
nature › scientific data › data descriptors › article

Data Descriptor | Open Access | Published: 11 December 2019

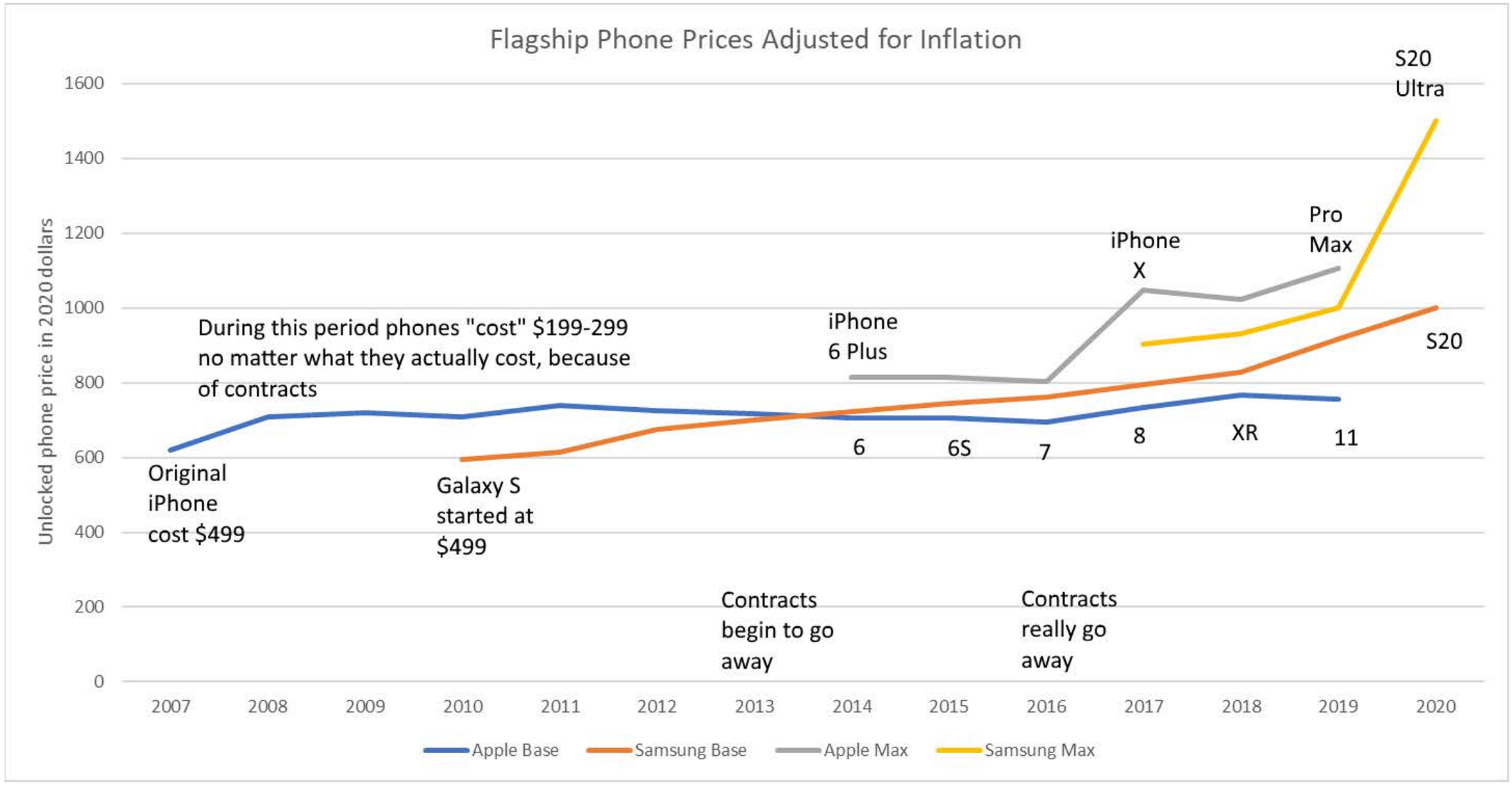
Interaction data from the Copenhagen Networks Study

Piotr Sapiezynski, Arkadiusz Stopczynski, David Dreyer Lassen & Sune Lehmann ✉

Scientific Data **6**, Article number: 315 (2019) | Cite this article



the issue with phones



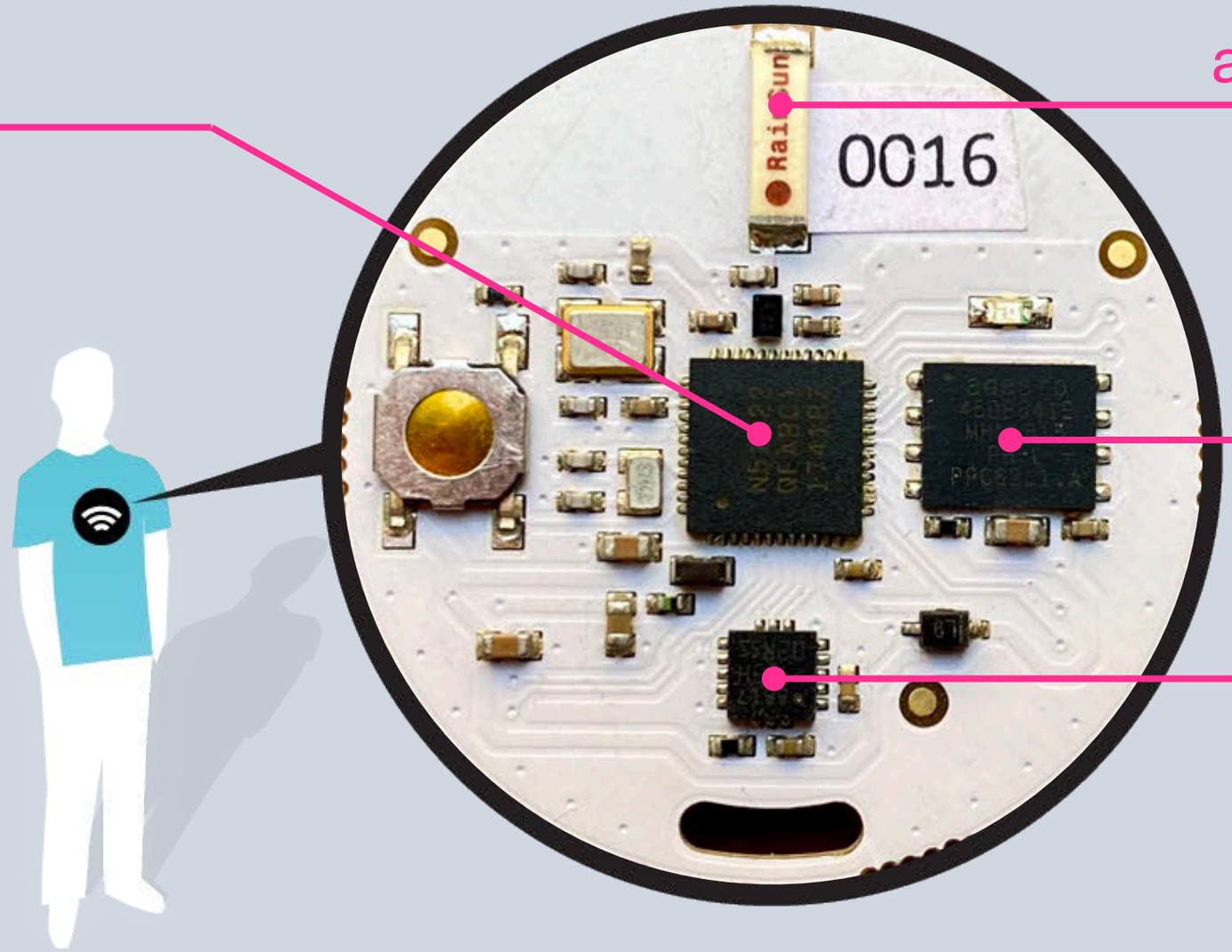
www.pcmag.com/news/why-axis-are-flagship-phones-more-expensive-than-ever

+ walled app ecosystem

(e.g., the digital contact tracing experience)

WEARABLE SENSORS

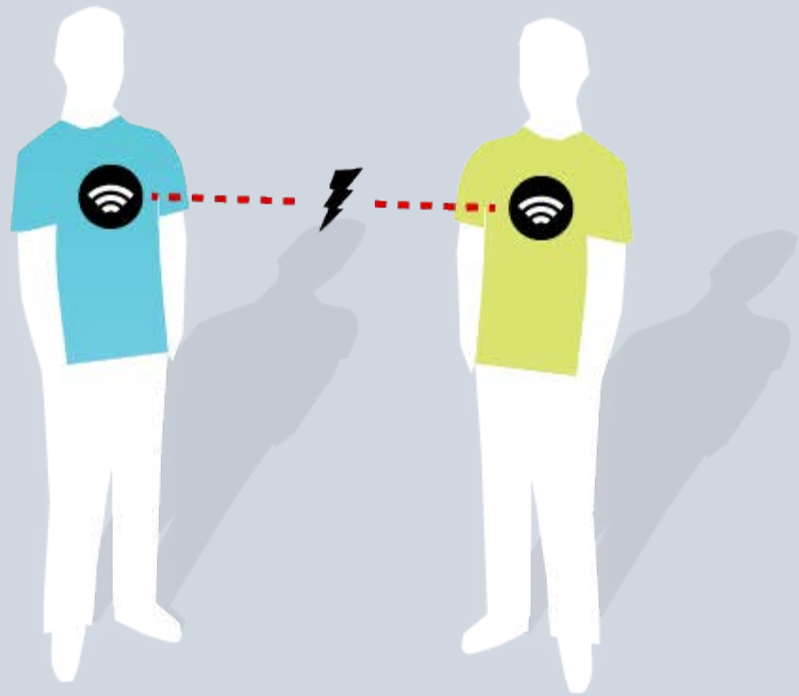
CPU + radio



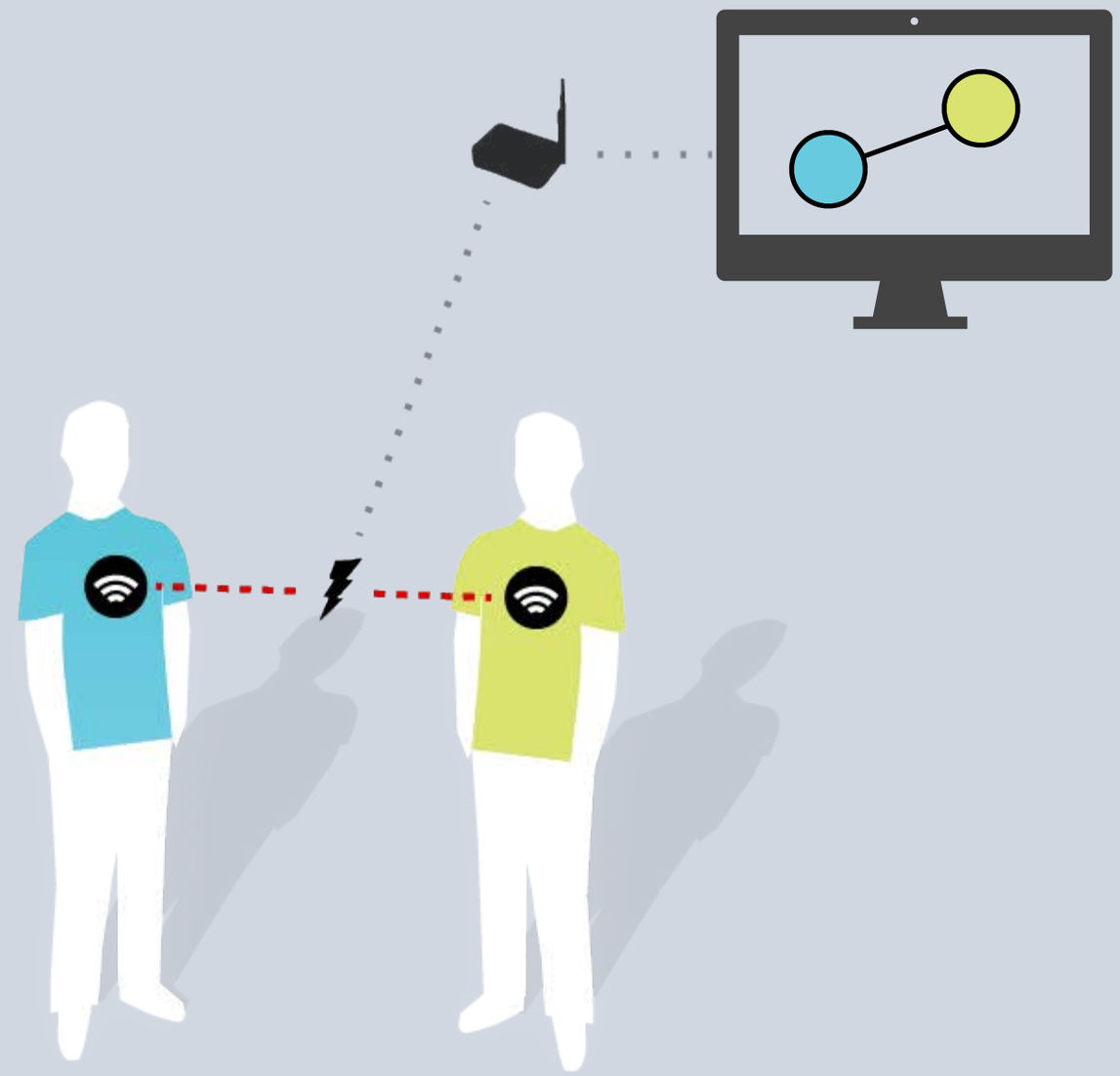
antenna

flash storage

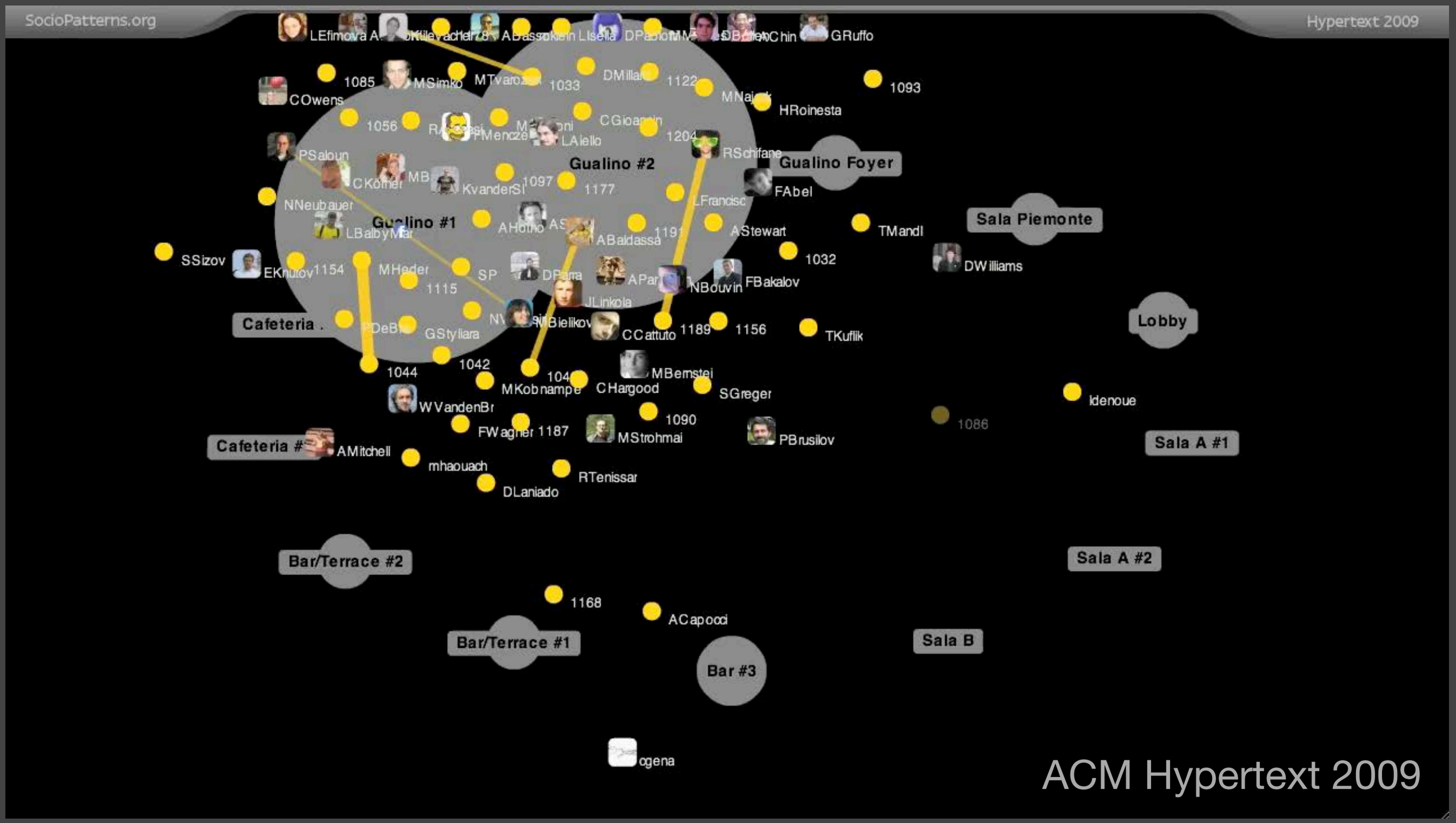
accelerometer



- centralized operation
- instrumented environment



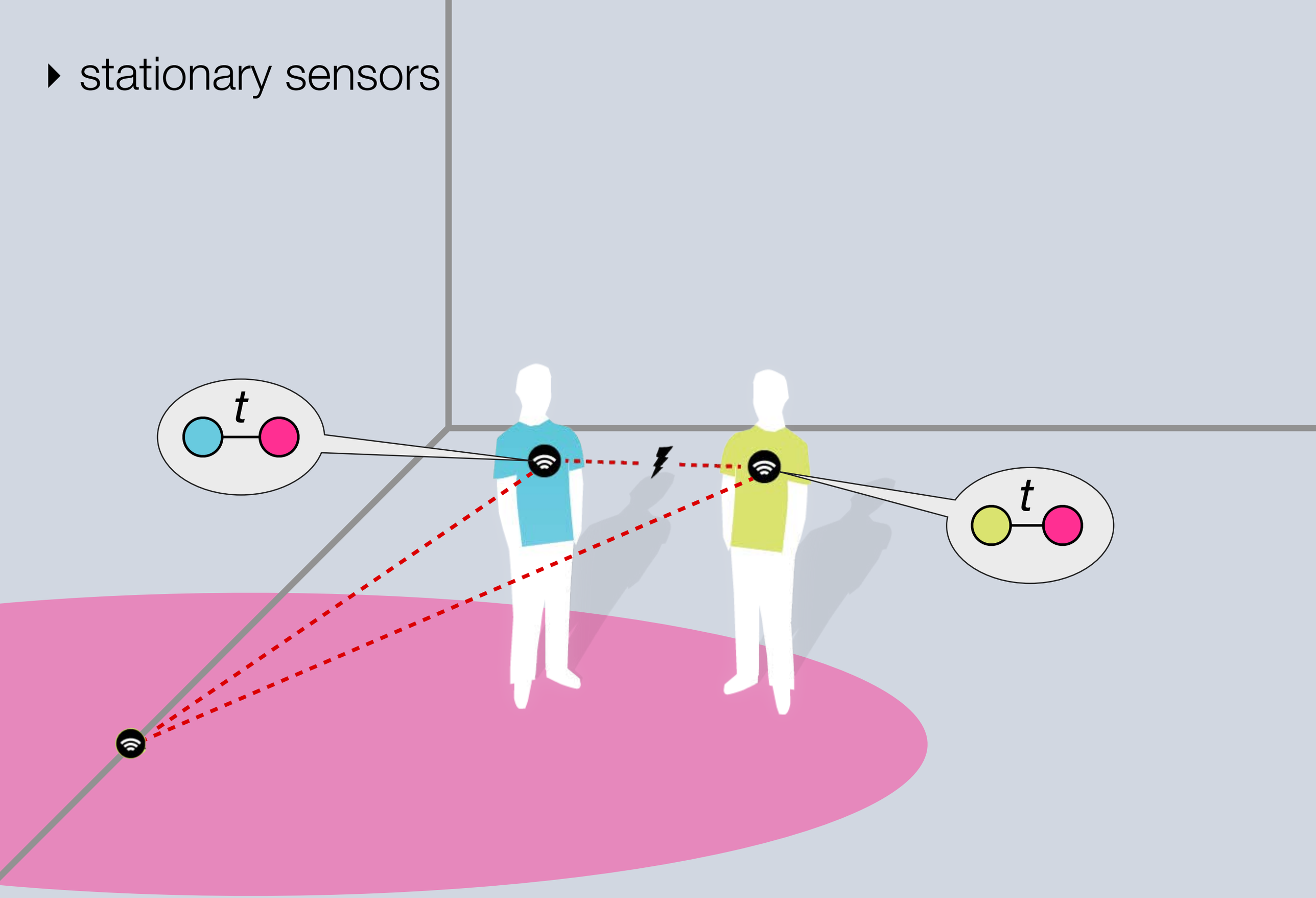
time-resolved proximity network



ACM Hypertext 2009

www.vimeo.com/6590604

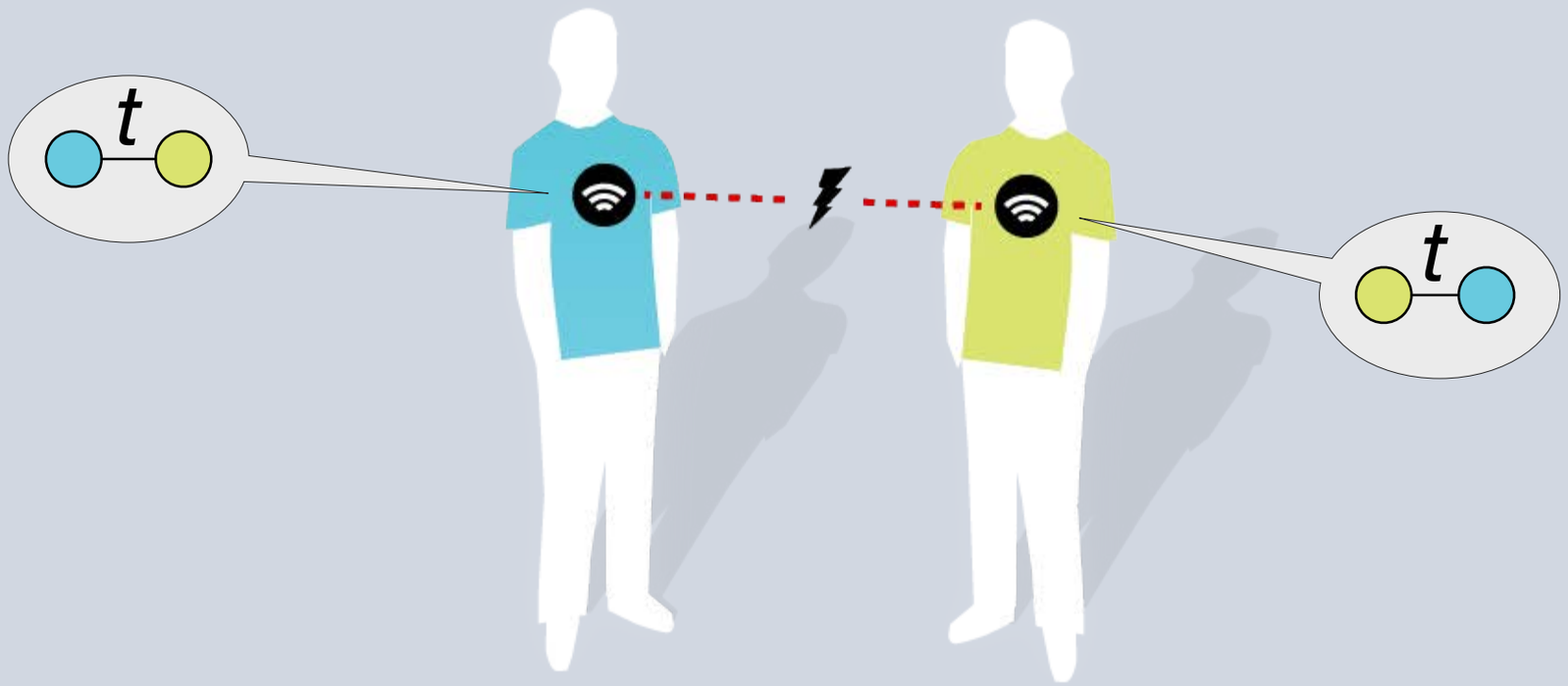
- stationary sensors



hands on!

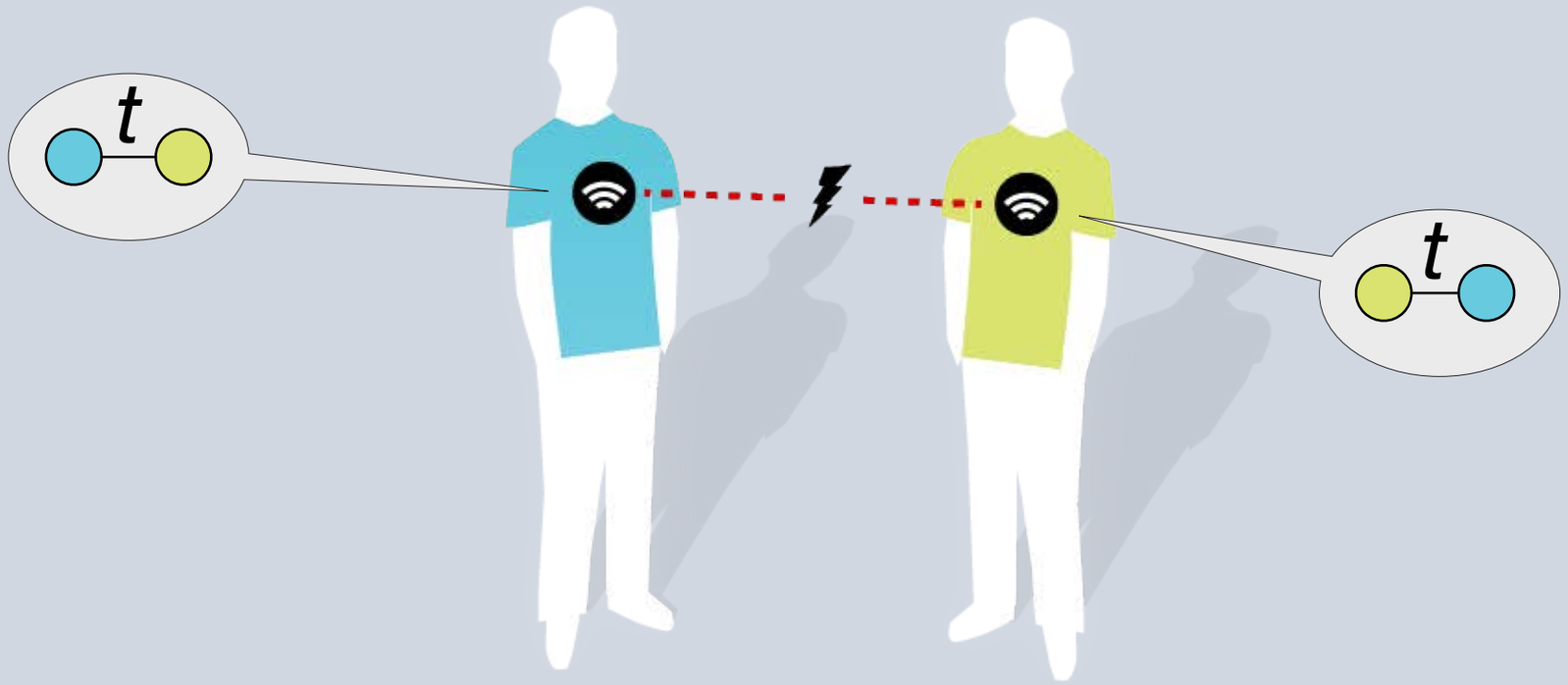
DEPLOY proximity sensors

- decentralized operation
- onboard proximity log



with KEMRI Wellcome Trust

post-processing



- decryption, decompression
- temporal alignment, clock drift compensation
- accelerometer-based data cleaning
- application of contact definition
- metadata fusion

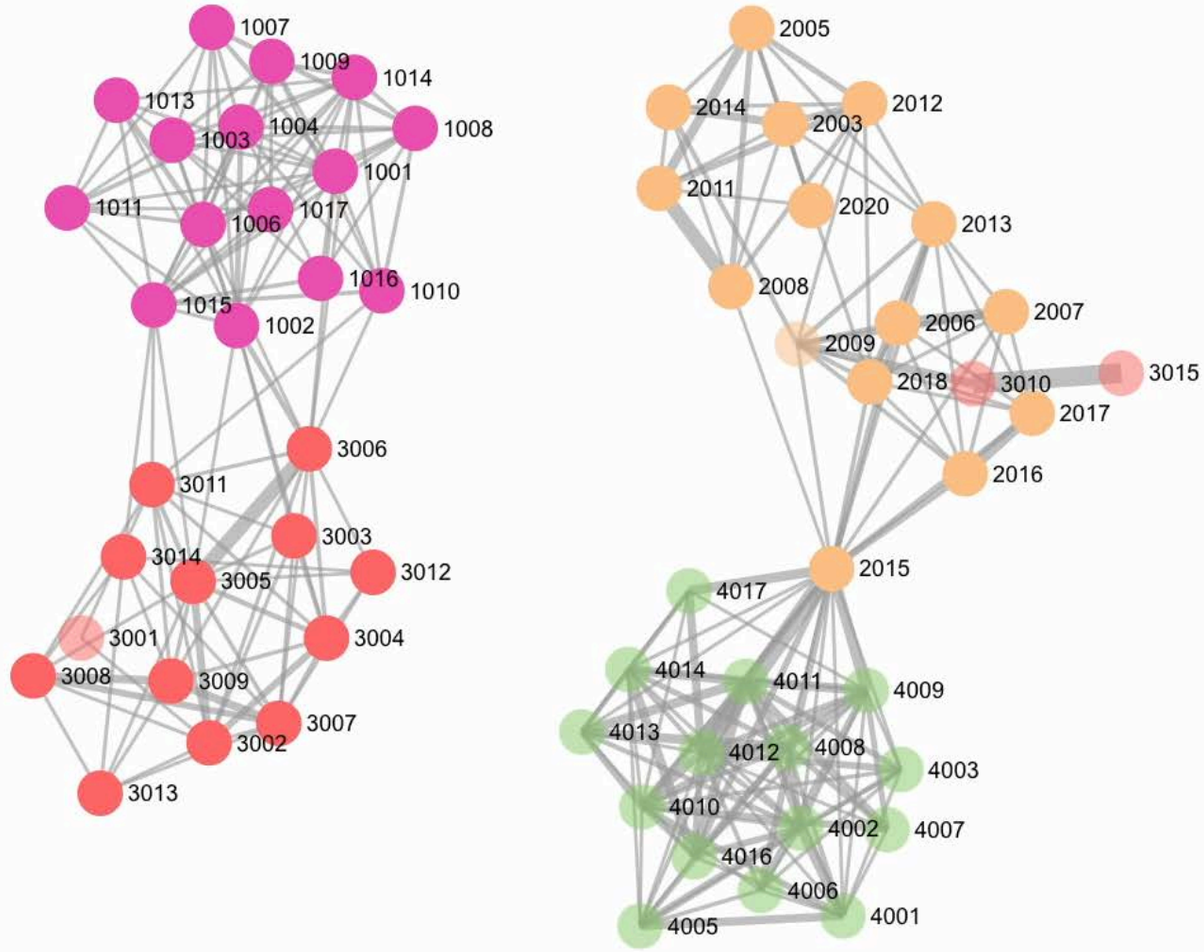
School transmission study, with U Bern

Contact duration filter

Proximity Network

- Time range: **10:00 → 11:30**
- Attenuation range: -50 → -65 dBm
- Showing contacts >= 0 seconds (0 mins)
- Nodes are color-coded by class, transparent nodes are still.

Edge weight ◉ Time in Contact ○ Median Attenuation



hospital in Kenya

Proximity Network

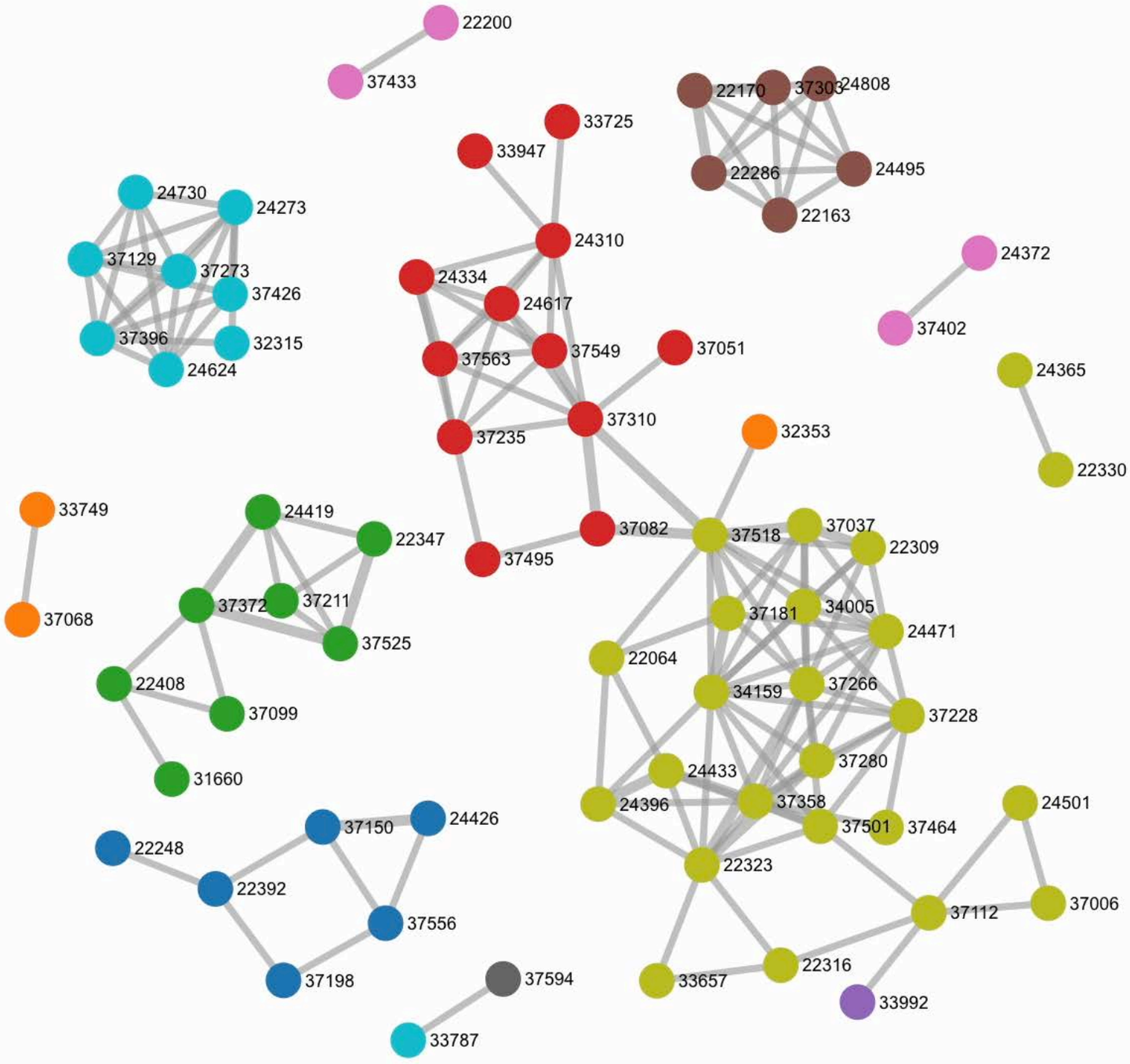
- Time range: **11:15 → 11:45**

Attenuation range: : -50 → **-65 dBm**

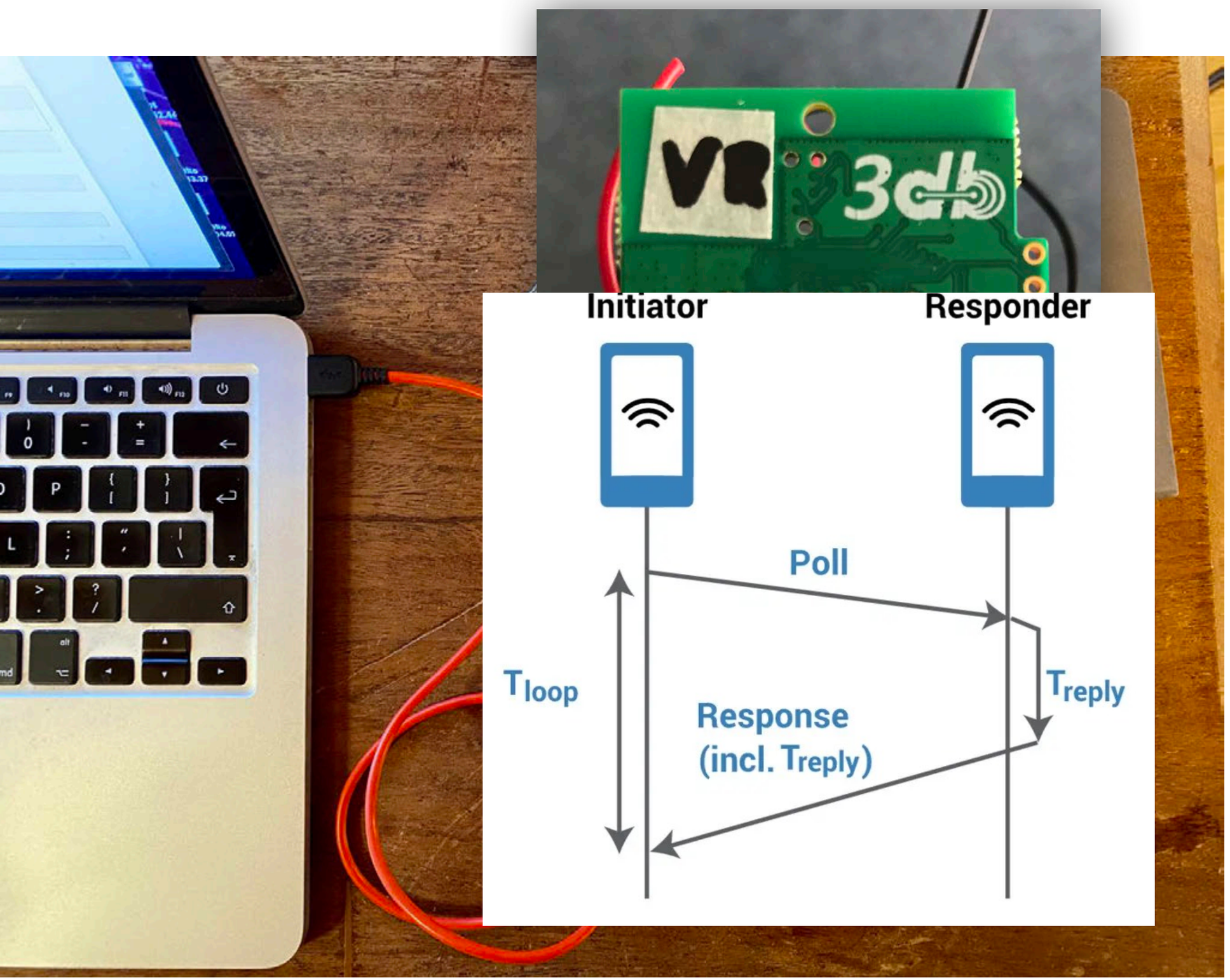
- Nodes are color-coded by **workstation**

Edge weight ◉ Median Distance ○ Time in Contact

Color coding ○ Role ○ Gender ○ Age ◉ Workstation



Ultra-Wideband (UWB) proximity sensors



EPFL

ISI Foundation

ETH zürich

3db

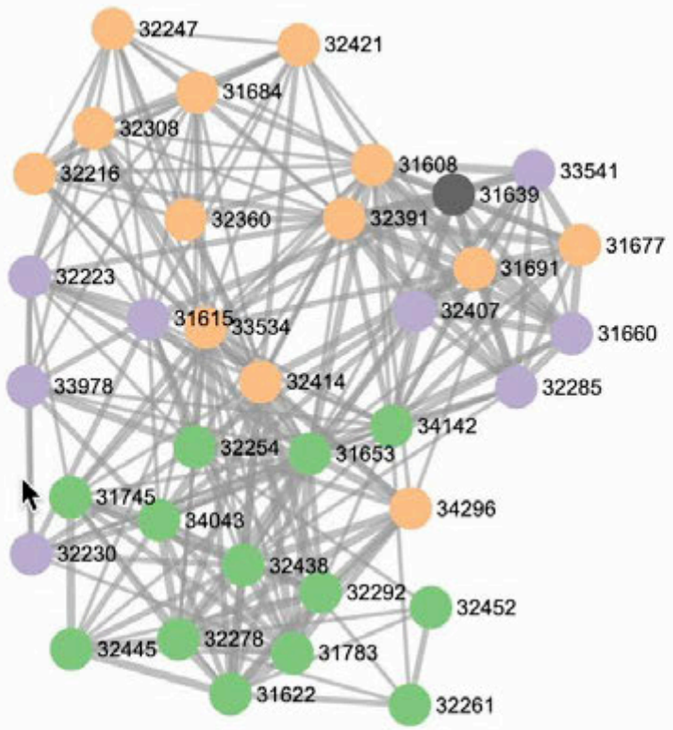
fondation BOTNAR

1 day in a hospital ward (doctors, caregivers, admins)

09:30 - 16:29

1000
900
800
700
600
500
400
300
200
100
0

distance (cm)



a large body of related work

- MIT Reality Mining Project (sociometric badges)
- Bluetooth, Wi-Fi (O' Neill et al. 2006, Scherrer et al. 2008, Eagle and Pentland 2009)
- MOSAR EU project (nosocomial infections)
- P. Polgreen's group
- M. Salathé group (Salathé et al. 2010)
- SMART study in schools (U. of Pittsburgh & CDC)
- S. Lehmann's group at DTU (smartphones)
- N. Osgood's group (U. Saskatoon)
- A. Segre's group at U Iowa (UWB sensors)
- …

OUR GOAL: high-coverage, time-resolved proximity networks across a variety of real-world settings

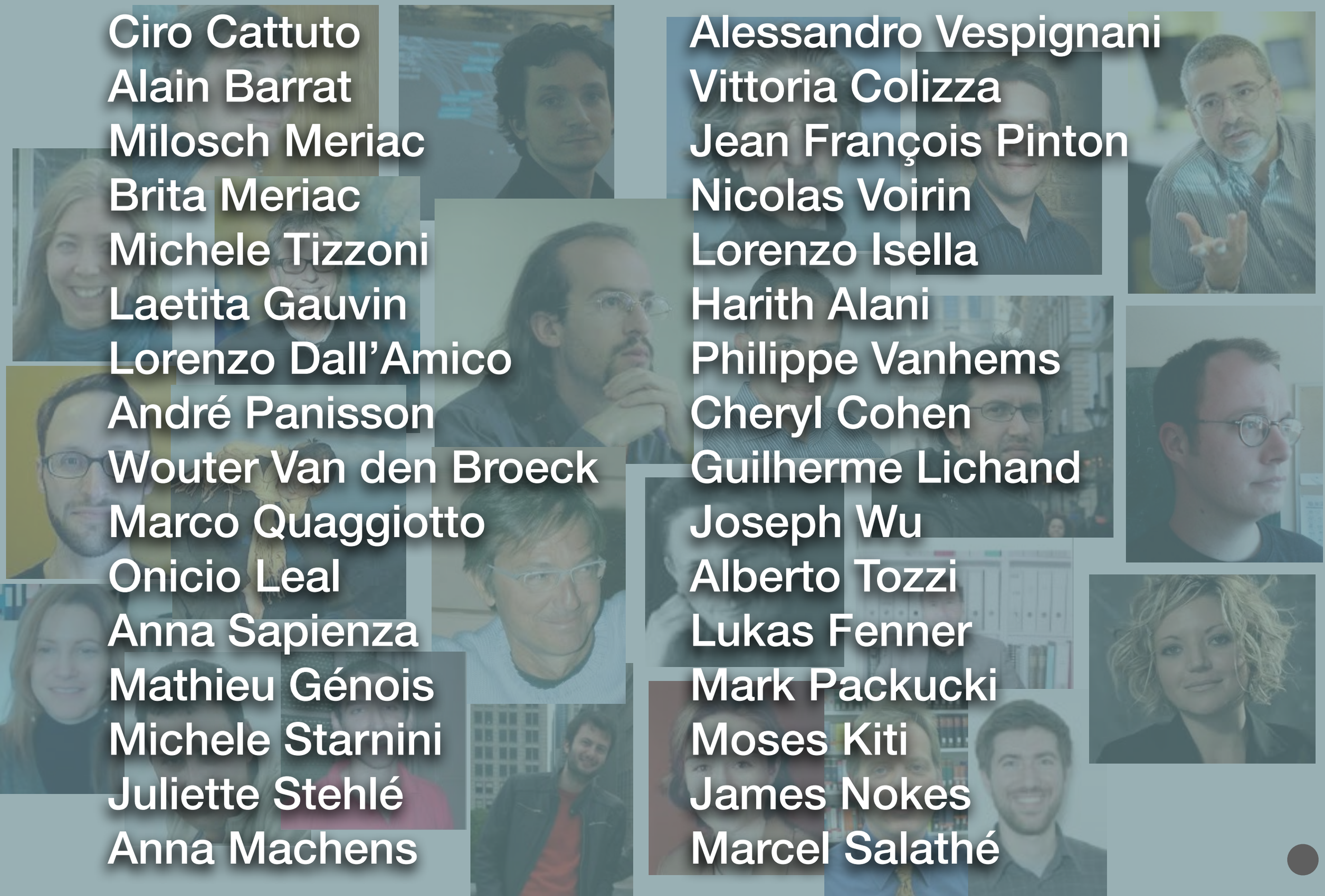
SocioPatterns.org

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

collaboration network



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Harith Alani
Philippe Vanhems
Cheryl Cohen
Guilherme Lichand
Joseph Wu
Alberto Tozzi
Lukas Fenner
Mark Packucki
Moses Kiti
James Nokes
Marcel Salathé

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

High-resolution Contact Networks
PART 2: empirical data

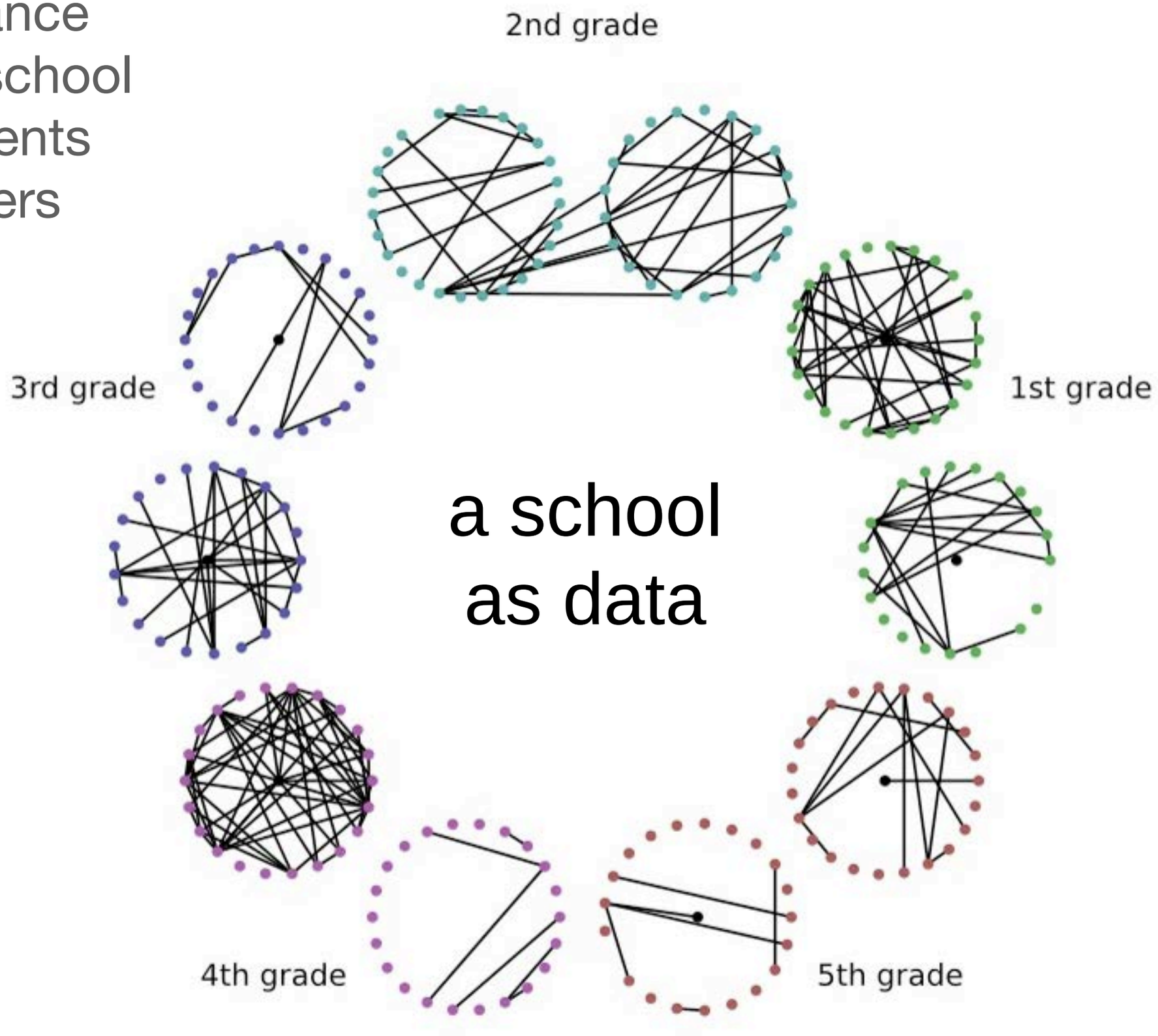
Ciro Cattuto
ISI Foundation

Modeling Infectious Disease Outbreaks
Using Genomic Data Workshop

Mahidol University, Bangkok
1 July 2025

ISI
Foundation

Lyon, France
primary school
231 students
10 teachers



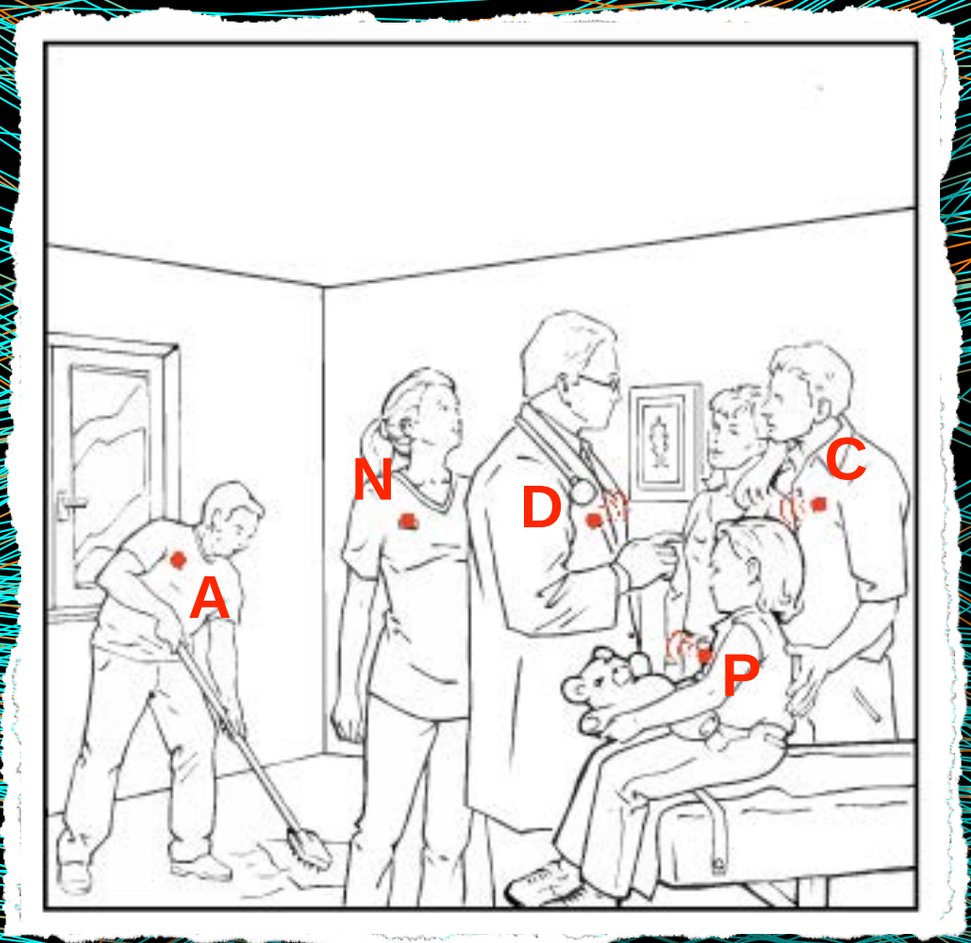
a school as data

Thu, 11:20- 12:00

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

doctors

children



nurses

auxiliaries

parents

PLoS ONE 6(2), e17144 (2011)

Article | Open Access | Published: 12 April 2022

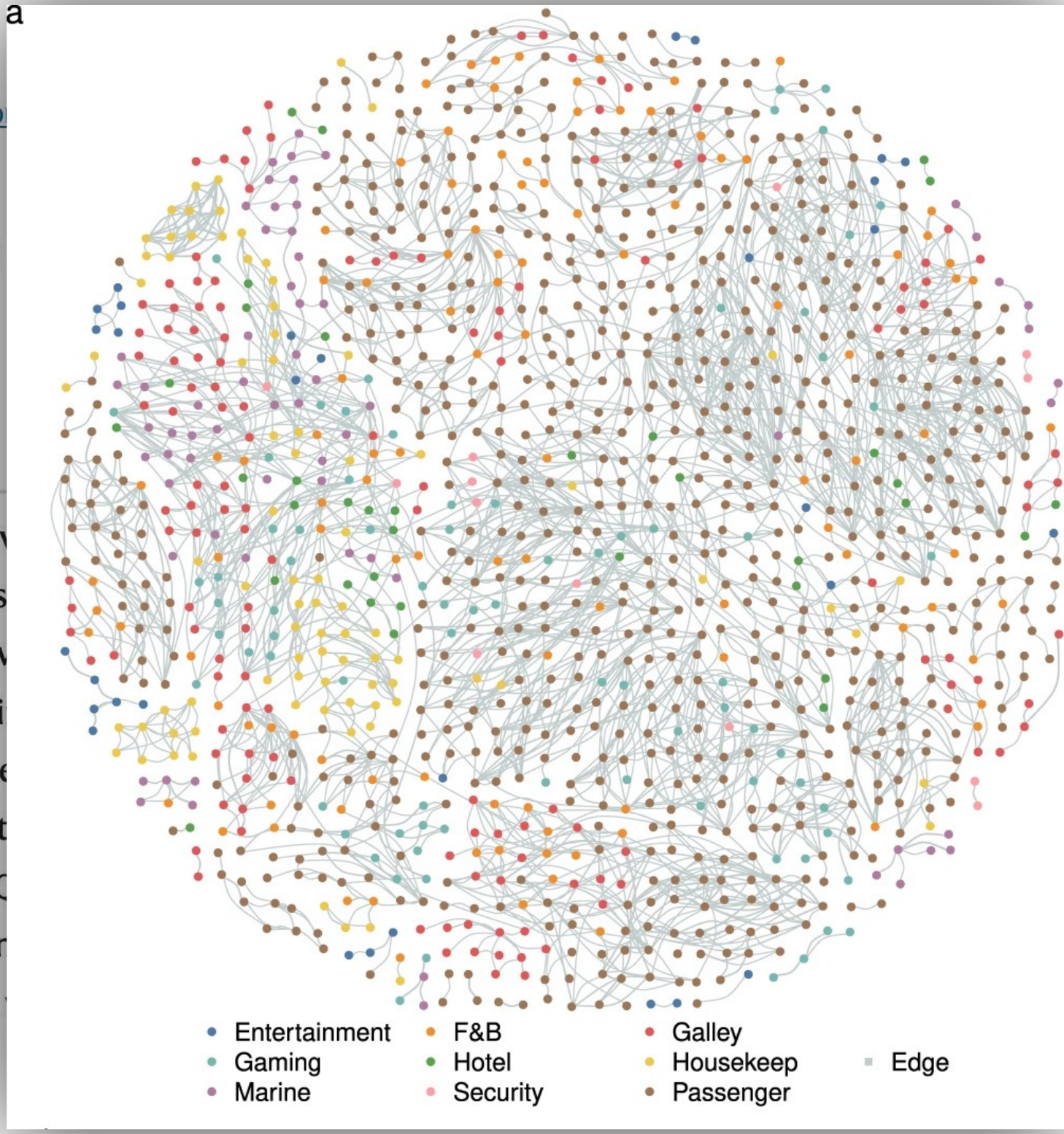
Using high-resolution contact networks to evaluate SARS-CoV-2 transmission and control in large-scale multi-day events

Rachael Pung ✉, Josh A. Firth, Lewis G. Spurgin, Singapo
19 working group, Vernon J. Lee & Adam J. Kucharski

Nature Communications **13**, Article number: 1956 (2022)

Abstract

The emergence of highly transmissible SARS-CoV-2 v
risk posed by increasing social contacts as countries
particularly in the context of resuming large-scale ev
social contacts formed in different activity settings i
control Delta variant outbreaks, we collected high-re
passengers and crew on cruise ships and combined t
models. We found passengers had a median of 20 (IC
and over 60% of their contact episodes were made in
wearing is typically limited. In simulated outbreaks,



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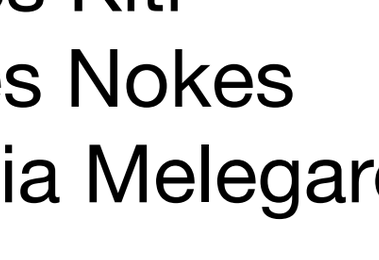
- Moses Kiti
- James Nokes
- Alessia Melegaro
- Laura Ozella
- Michele Tizzoni

Kenya

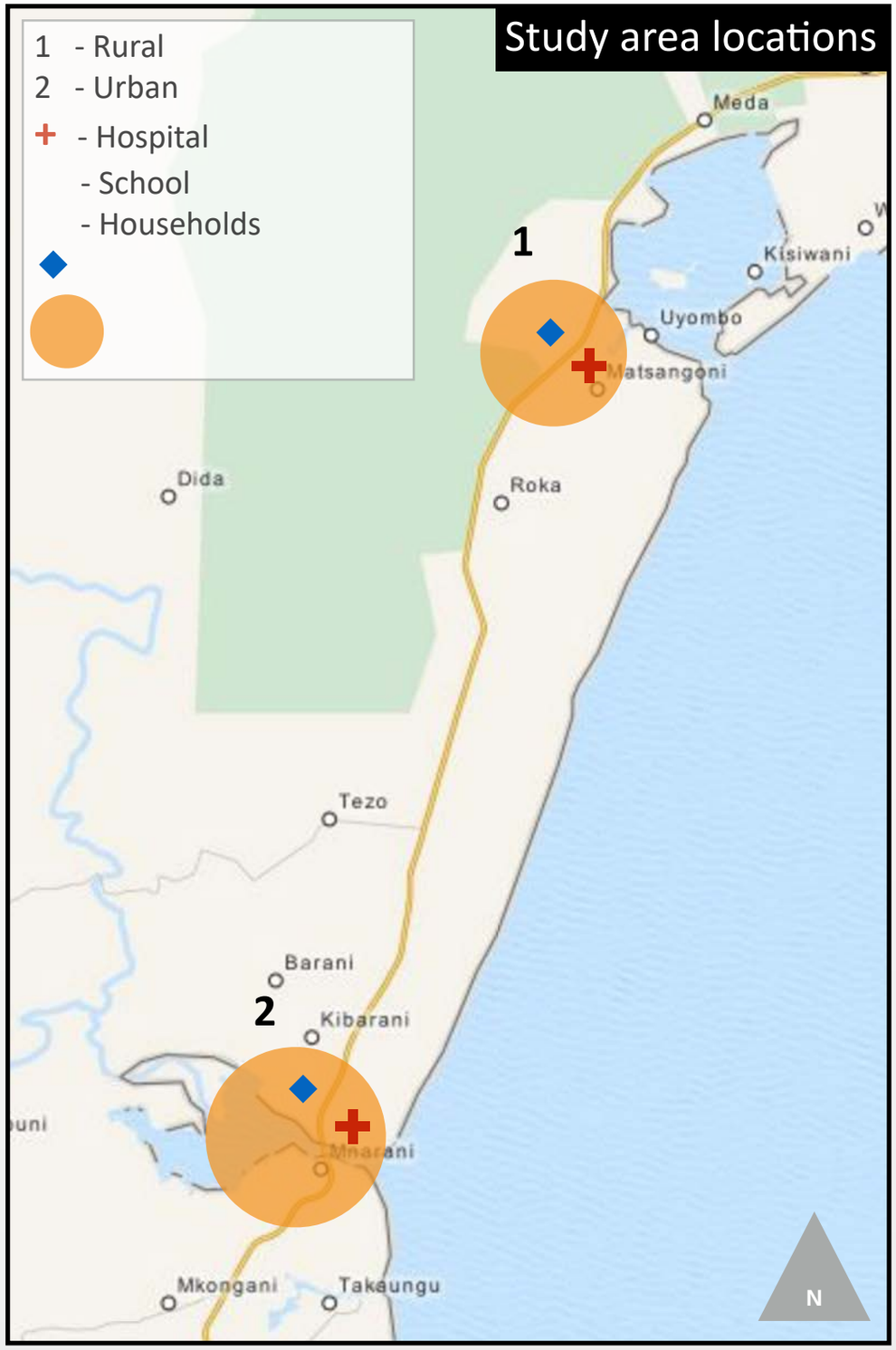
Social contacts in **households** and **schools**, transmission of **respiratory diseases** in two sites of coastal region



community engagement

M. Kiti *et al.*, EPJ Data Science 5:21 (2016)

urban vs rural settings in Kenya

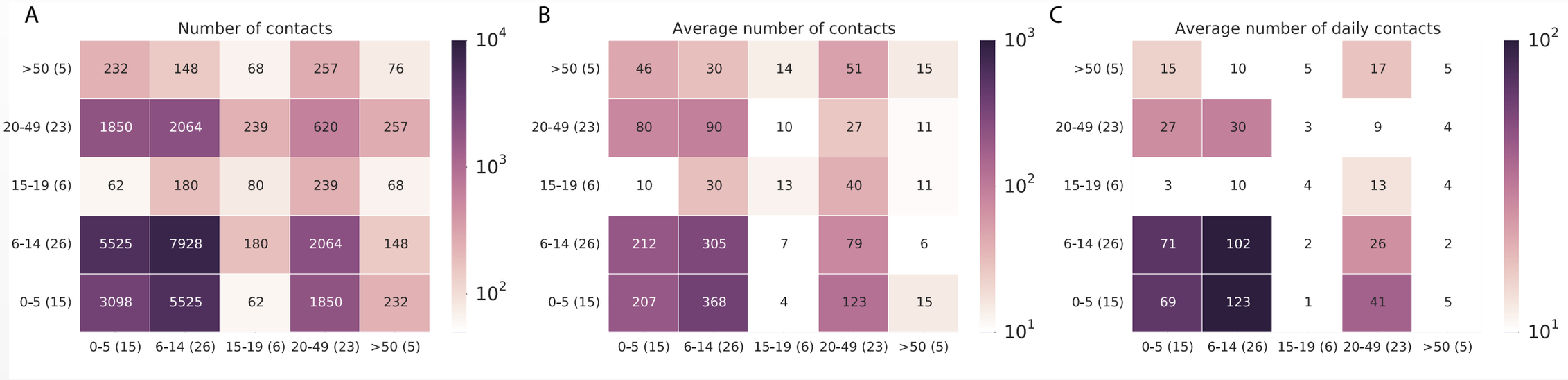


- contact networks in 2 schools
- contacts in households linked to schools by index students
- ~1,000 tracked individuals

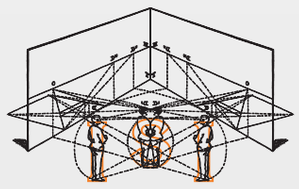
	Kilifi township	**Matsangoni**
Demographics	Pop size = 50,775 (Jan 2017); Avg age = 23.4 y	Pop size = 15,372 (Oct 2016); Avg age = 21.8 y
Social structure	Nuclear families esp in town area (1 generation households). Living in personal/ rented houses	Extended families (>1 generation). Living in homesteads. Stronger family ties
Economy	Small scale businesses, Formal employment	Farming, Fishing

M. Kiti *et al.*, EPJ Data Science 5:21 (2016)

households in rural Kenya



M. Kiti *et al.*, EPJ Data Science 5:21 (2016)



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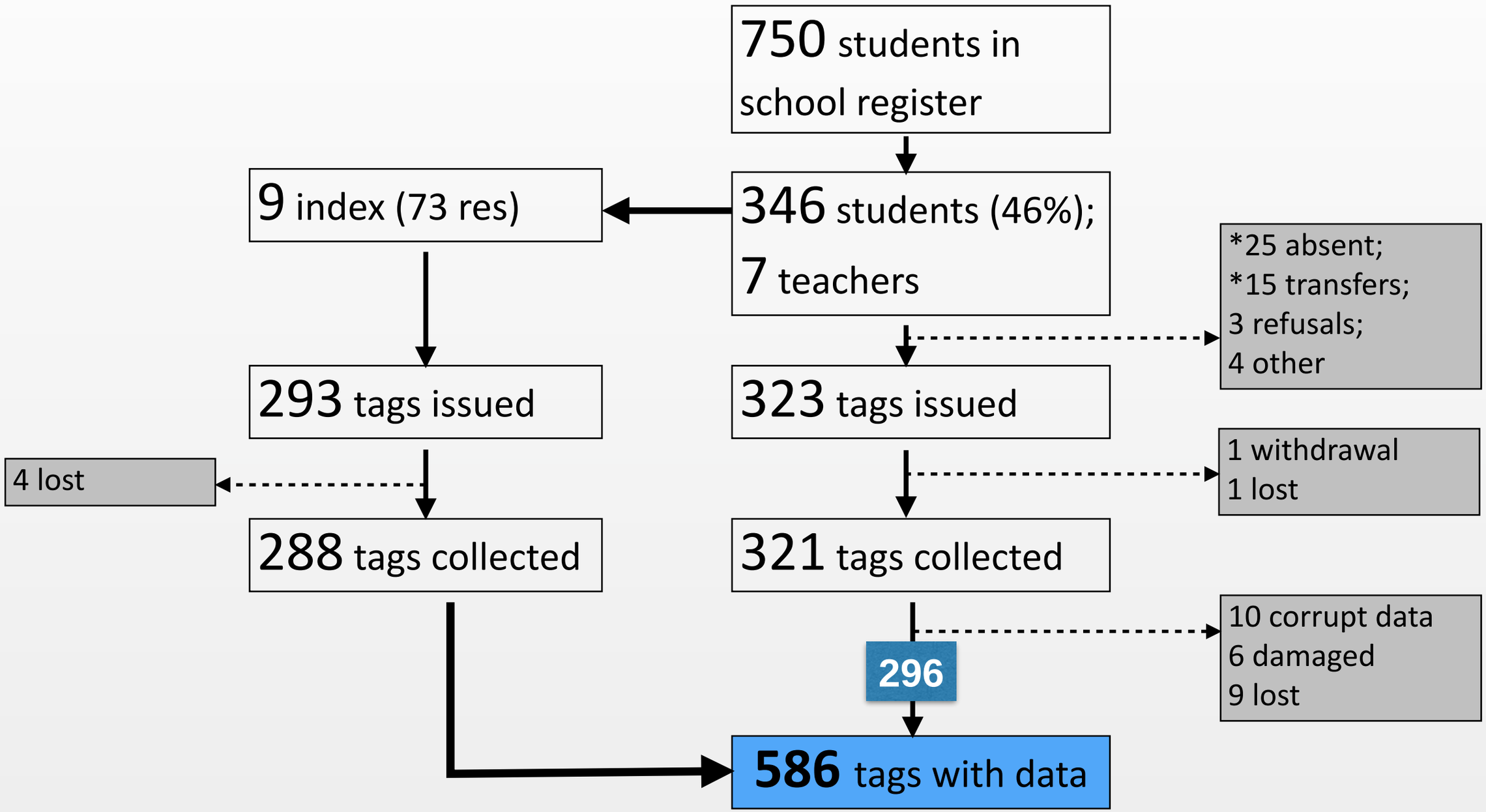
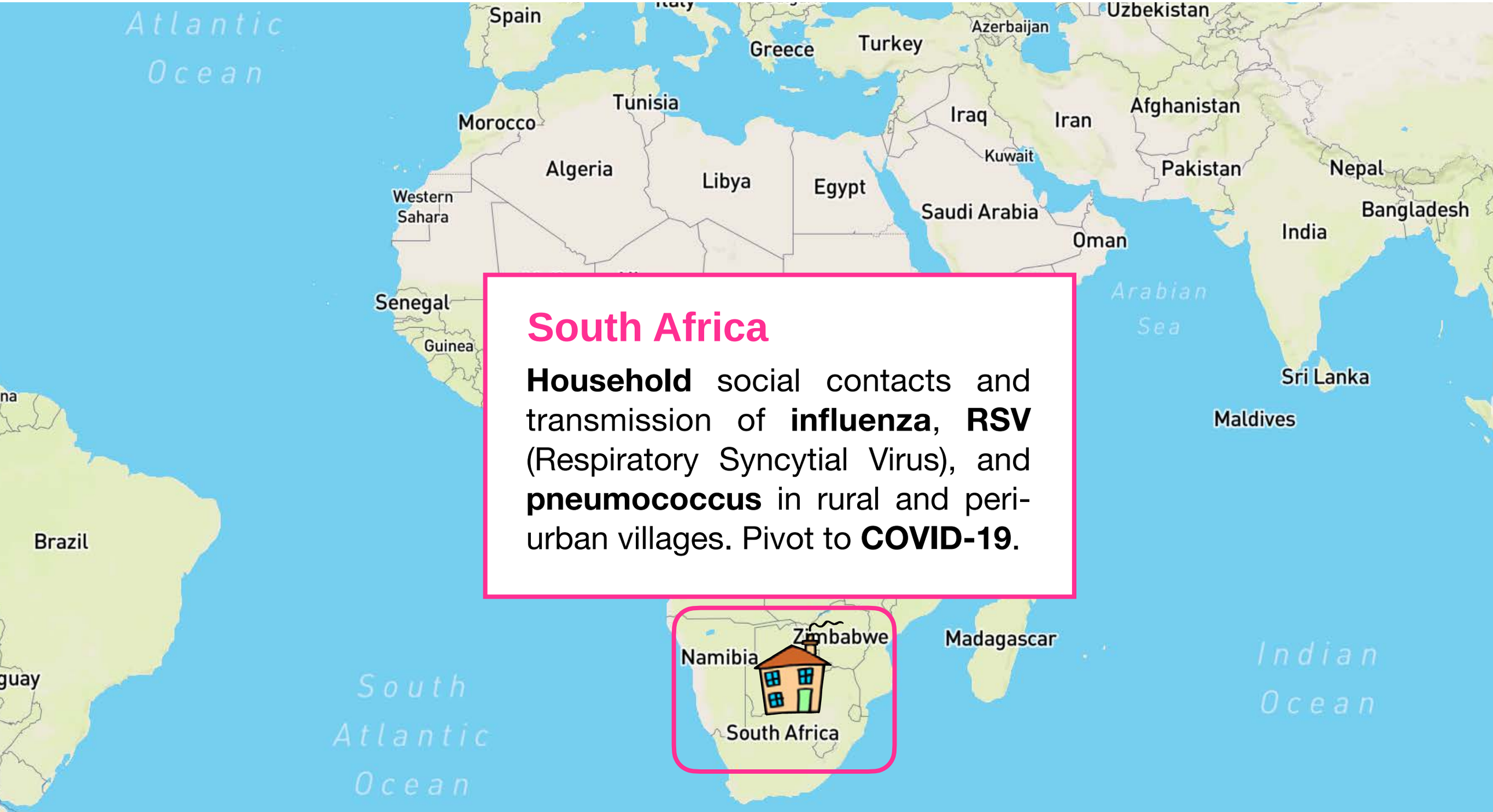
sensor deployment logistics



NATIONAL INSTITUTE FOR COMMUNICABLE DISEASES

ISI Foundation

- Jackie Kleynhans
- Cheryl Cohen
- Stefano Tempia
- Mvuyo Makhasi
- Laura Ozella
- Laetitia Gauvin
- Michele Tizzoni
- J. P. Rodriguez
- L. Dall'Amico



South Africa

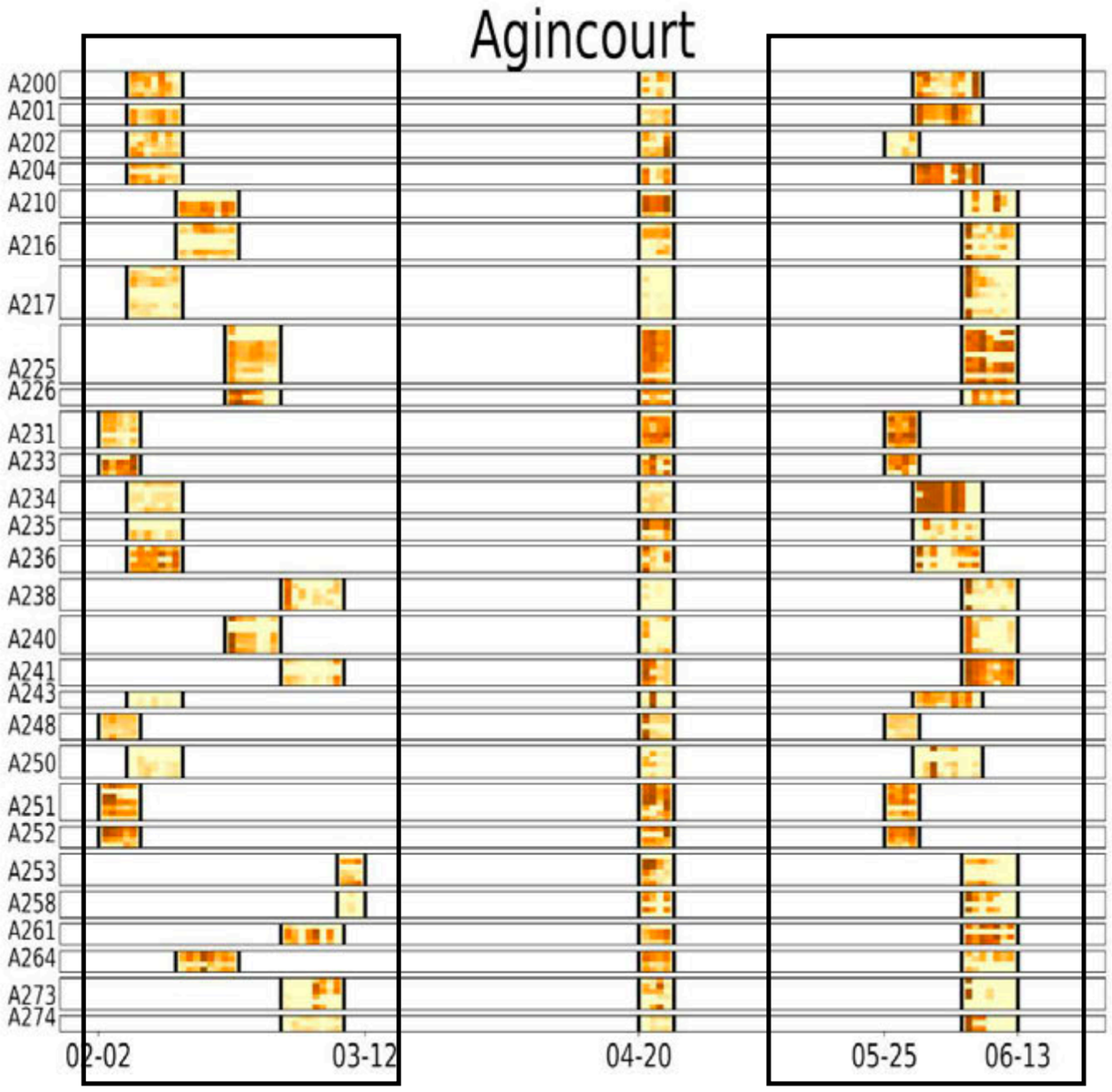
Household social contacts and transmission of **influenza**, **RSV** (Respiratory Syncytial Virus), and **pneumococcus** in rural and peri-urban villages. Pivot to **COVID-19**.

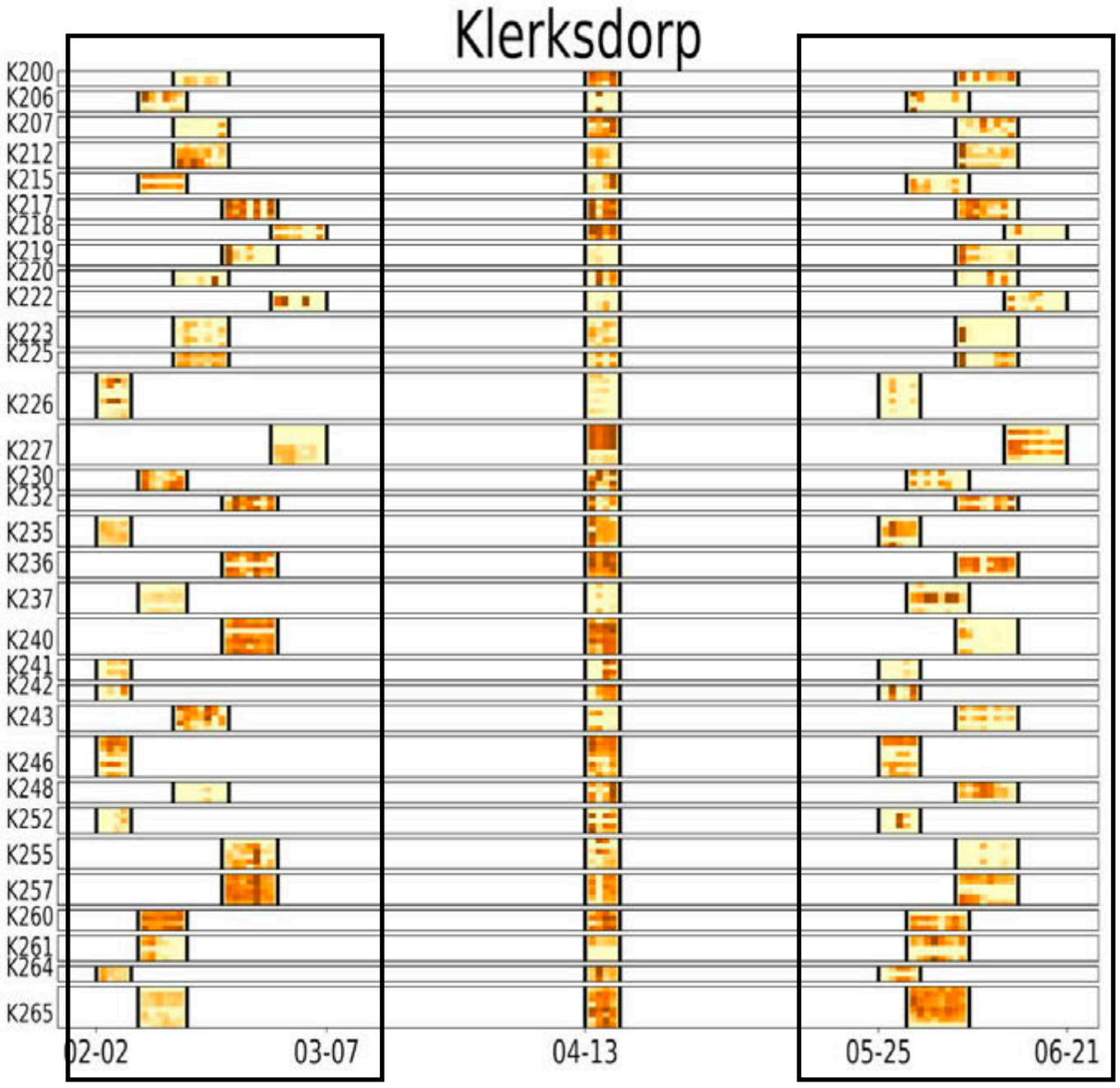
households in rural South Africa

- **contact patterns between household members**, two different communities
- **main study**:
  - 56 households Agincourt (rural settings)
  - 61 households in Klerksdorp (semi-urban settings)
- **~600 participants** in ~**120 households**

households in rural South Africa

~600 participants in **~120 households**





wave 1 wave 2 wave 3

time

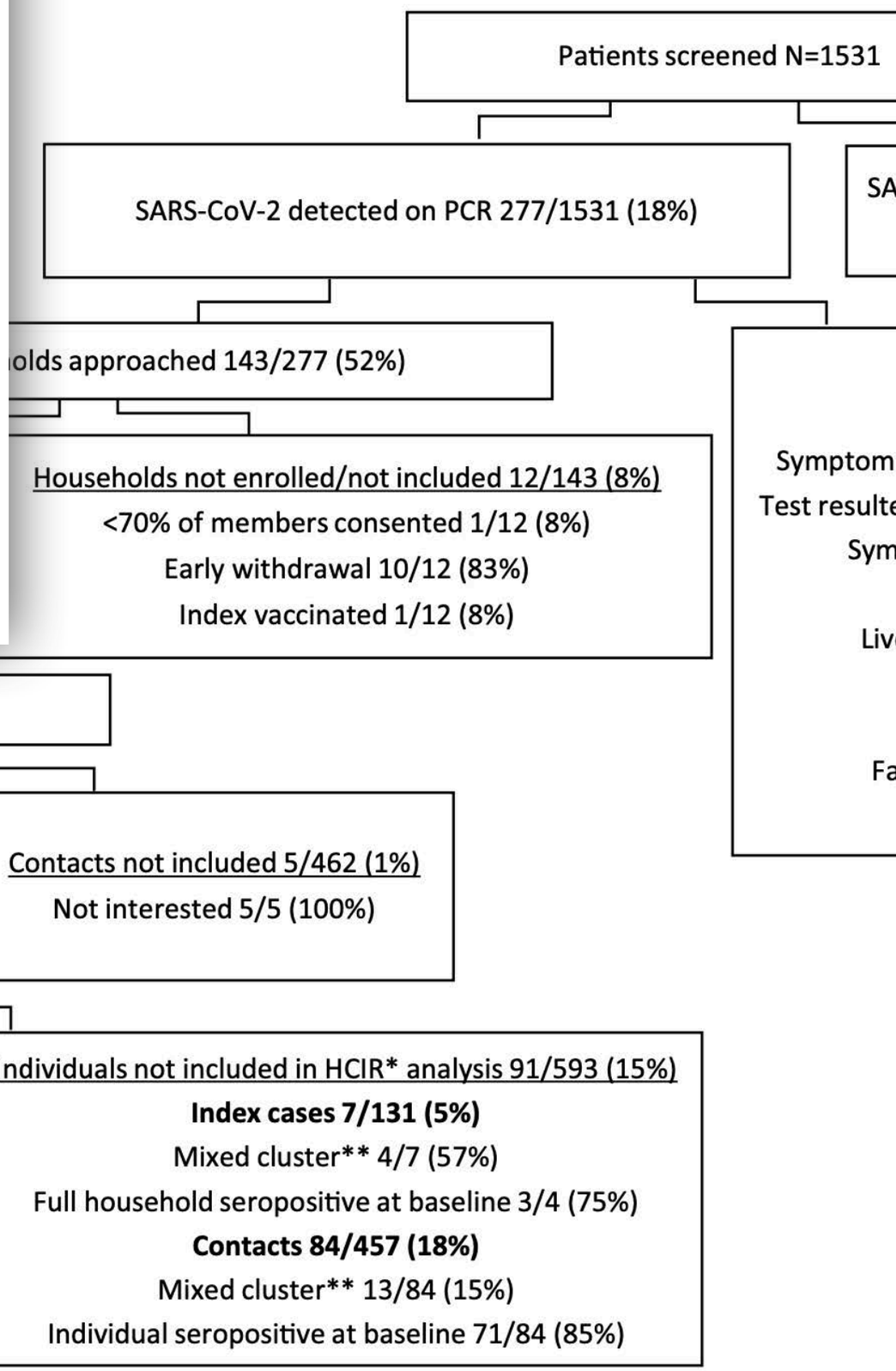
wave 1 wave 2 wave 3

time

Association of close-range contact patterns with SARS-CoV-2: a household transmission study

Jackie Kleynhans[1,2]*, Lorenzo Dall'Amico[3], Laetitia Gauvin[3,4], Michele Tizzoni[3,5], Lucia Maloma[6], Sibongile Walaza[1,2], Neil A Martinson[6,7], Anne von Gottberg[1,8], Nicole Wolter[1,8], Mvuyo Makhasi[1,2], Cheryl Cohen[1,2], Ciro Cattuto[3,9], Stefano Tempia[1,2], SA-S-HTS Group

[1]Centre for Respiratory Diseases and Meningitis, National Institute for Communicable Diseases of the National Health Laboratory Service, Johannesburg, South Africa; [2]School of Public Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa; [3]ISI Foundation, Turin, Italy; [4]Institute for Research on Sustainable Development, Aubervilliers, France; [5]Department of Sociology and Social Research, University of Trento, Trento, Italy; [6]Perinatal HIV Research Unit, University of the Witwatersrand, Johannesburg, South Africa; [7]Johns Hopkins University Center for TB Research, Baltimore, United States; [8]School of Pathology, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa; [9]Department of Informatics, University of Turin, Turin, Italy



J. Kleynhans *et al.*, eLife 12, e84753 (2023)


Concordia Station
Concordia Station, Ant...
75.10°S, 123.35°E
New Zealand
Madagascar
Concordia Station
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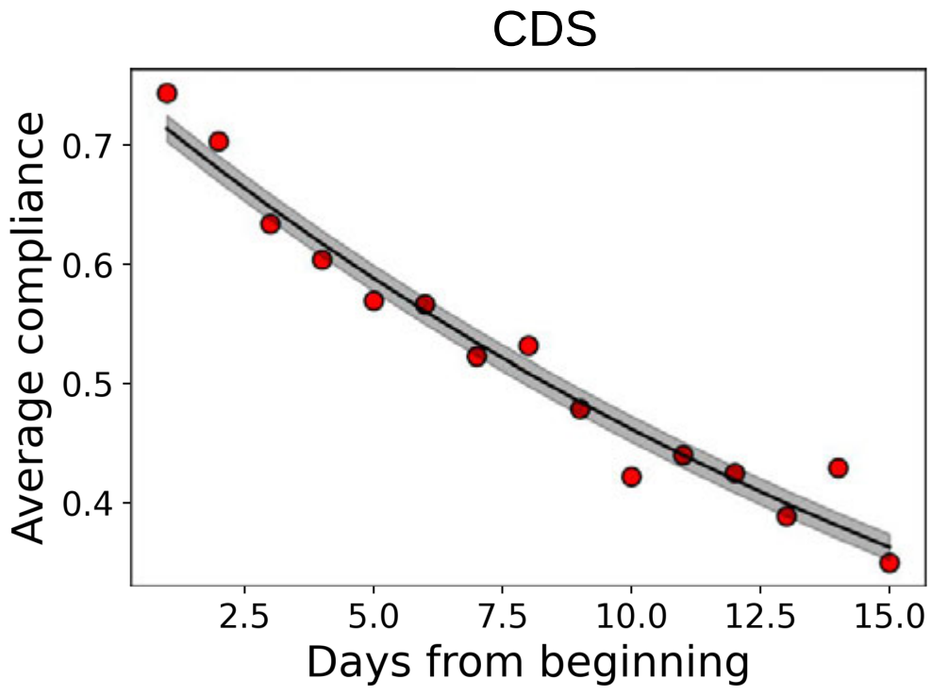
3D

data collection challenges

- **logistics:** sensor distribution / retrieval, dealing with lost / damaged / replaced sensors
- **engagement** of participants, recording 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**
- **insufficient academic recognition** of data collection work for young researchers

compliance & fatigue

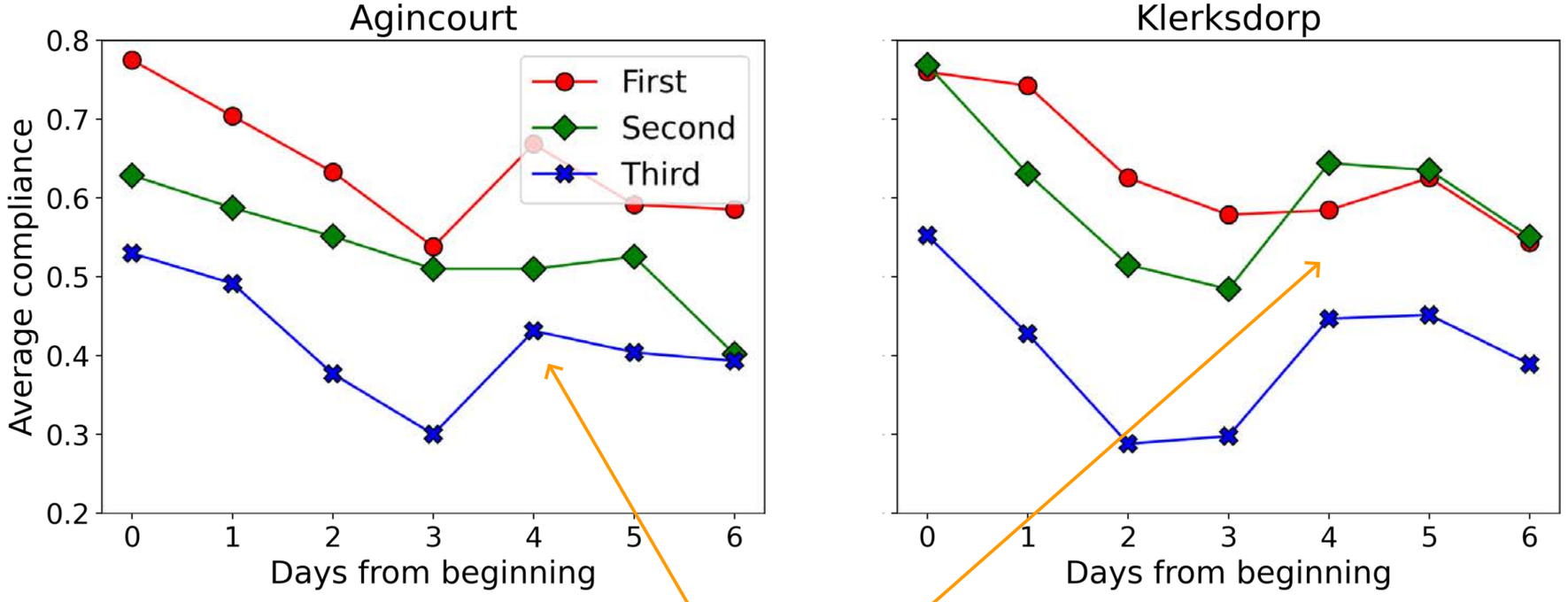
Malawi



~300 households

2 weeks

South Africa



L. Dall'Amico *et al.*, *"A comparative study of compliance in large-scale sociometric studies in sub-Saharan countries"* (2023), in preparation

data collection challenges

- **logistics:** sensor distribution / retrieval, dealing with lost / damaged / replaced sensors
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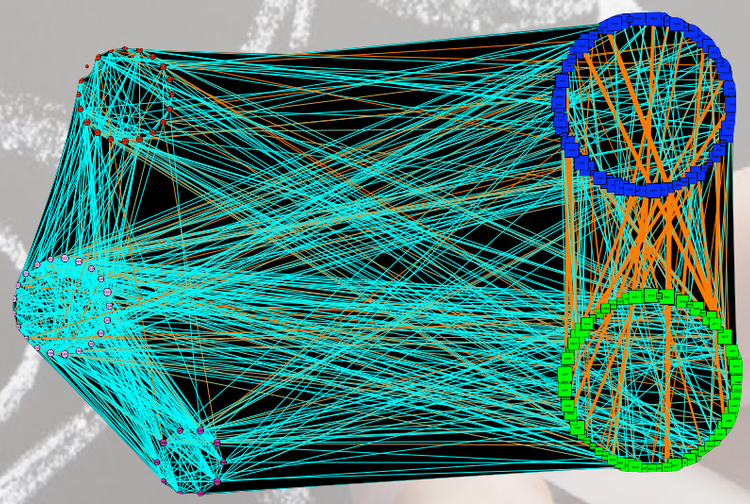
comparison with other data sources ?



proximity sensors vs contact diaries

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Probability that a sensed contact was reported in diary:

- 72% for <5 min contact duration
- 86% for 5-15 min
- 89% for 15-60 min
- 94% for >60 min

Contact diaries versus wearable proximity sensors in measuring contact patterns at a conference: method comparison and participants' attitudes

Timo Smieszek[†], Stefanie Castell[†] ✉, Alain Barrat, Ciro Cattuto, Peter J. White and Gérard Krause

[†] Contributed equally

BMC Infectious Diseases BMC series – open, inclusive and trusted 2016 16:341 | DOI: 10.1186/s12879-016-1676-y

Received: 5 October 2015 | Accepted: 10 June 2016 | Published: 22 July 2016

Open Peer Review reports

hands on!

VISUALIZE a contact network from sensors

👉 `gephi.org/gephi-lite`

⬇️ `tinyurl.com/sp-school-day01`

⬇️ `tinyurl.com/sp-school-day02`