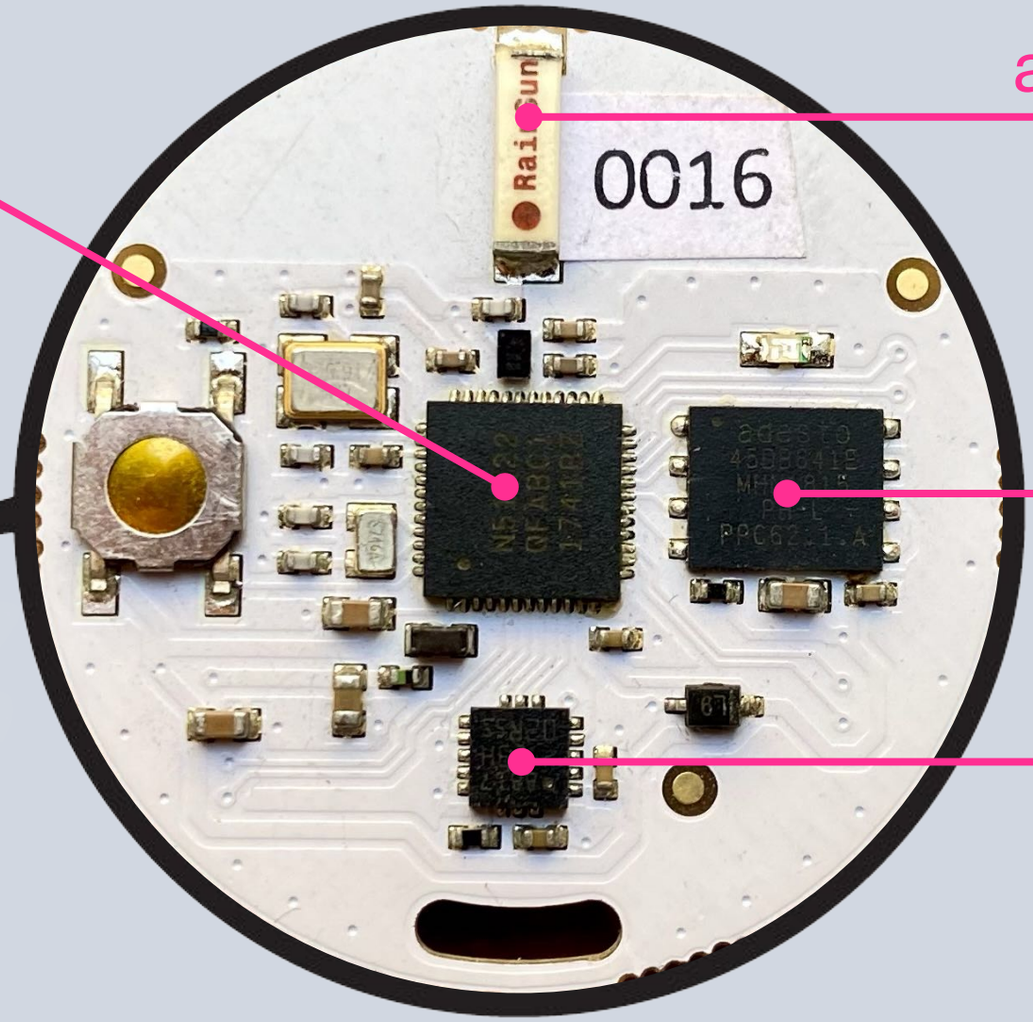
High-resolution human proximity data for epidemic modelling: state of the art and future trends

Ciro Cattuto
ISI Foundation
@ciro

EpiMod Workshop
Girona
19 June 2023

PROXIMITY SENSORS

CPU + 2.4 GHz radio

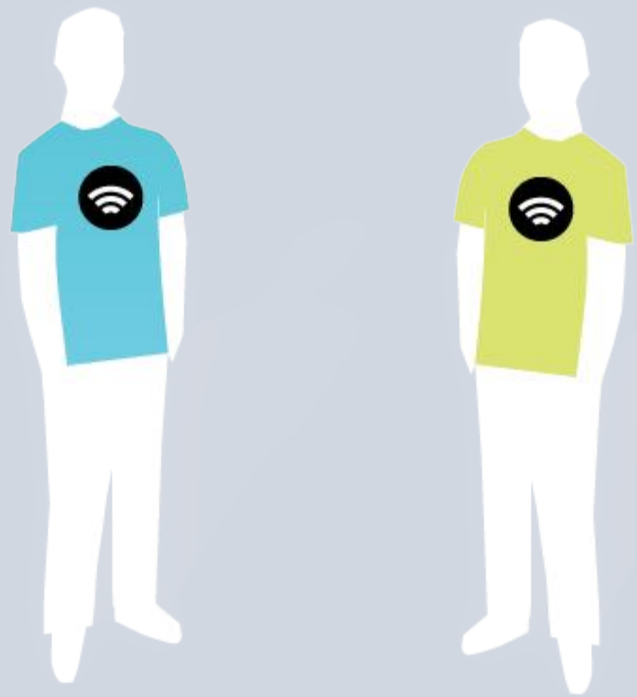


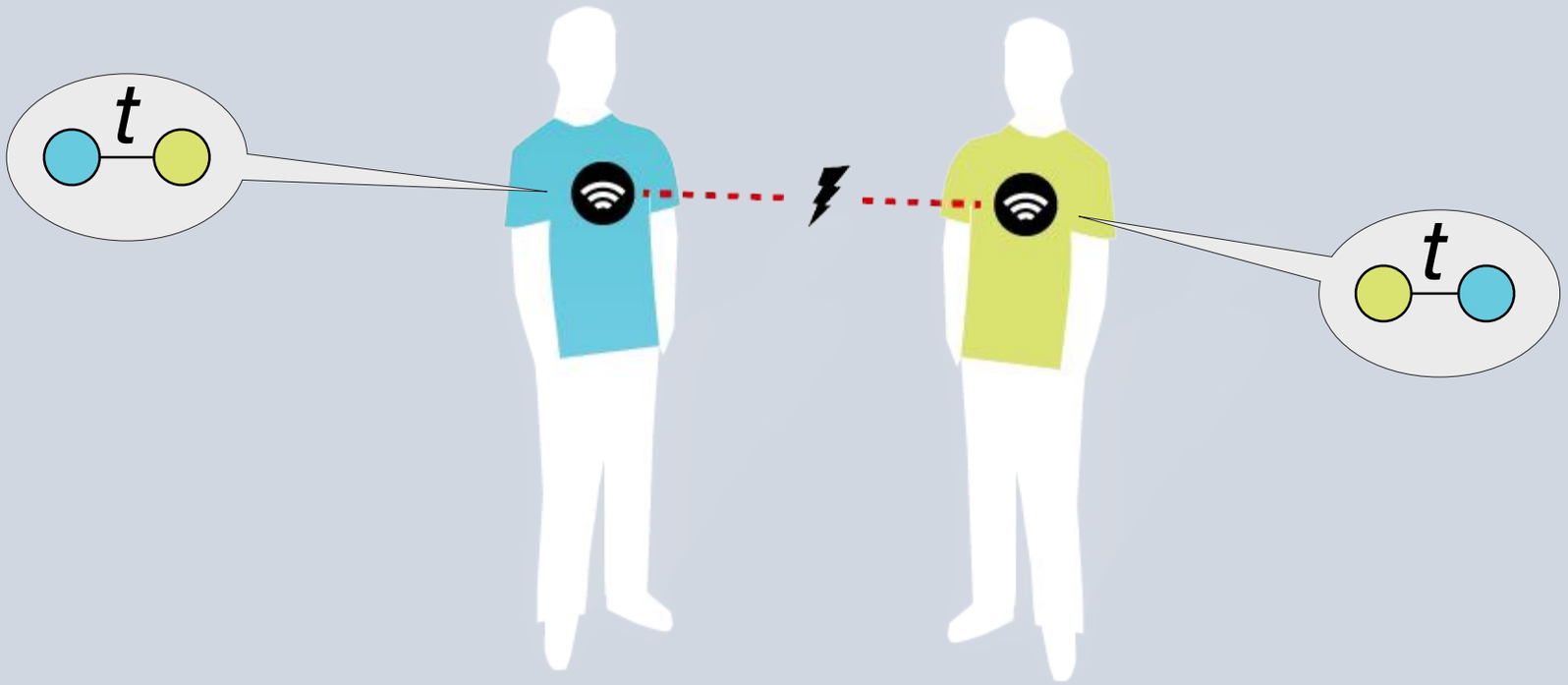
antenna

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)

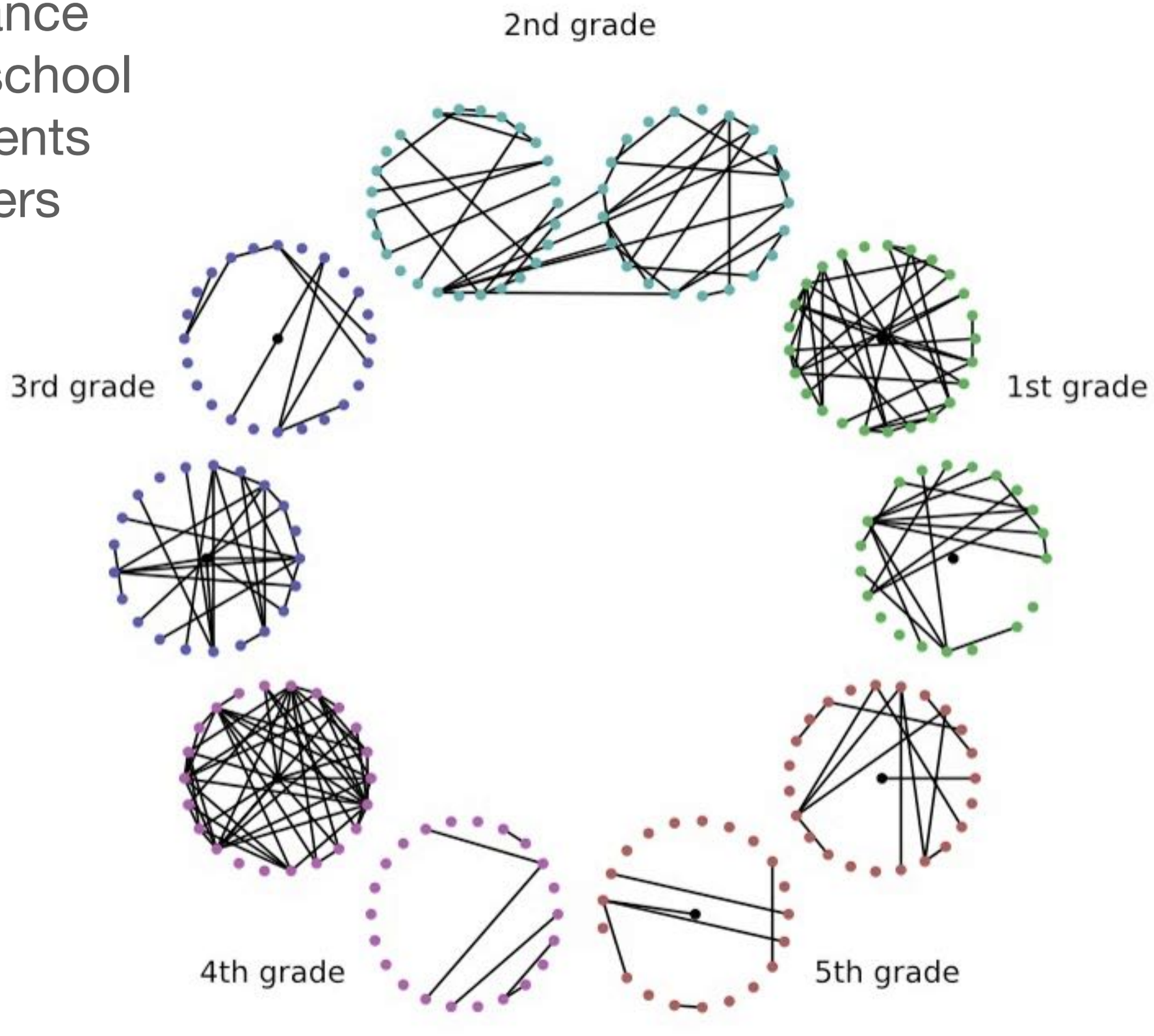
- high school proximity & friendship network
  R. Mastrandrea *et al.*, PLoS ONE 10(9), e0136497 (2015)

www.sociopatterns.org/datasets

empirical proximity data

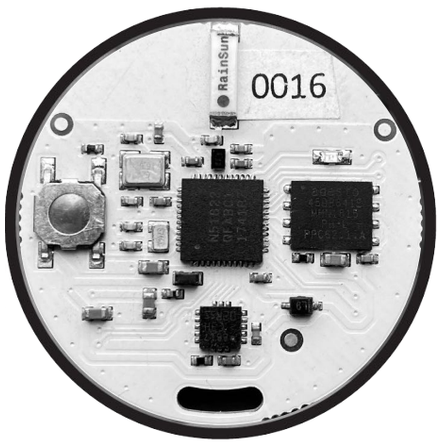
- **network dimension**
  - time-varying topology
  - multi-level community structures
  - assortativity, temporal-structural correlations
  - role structure
- heterogeneity of **weights**
  (e.g., fat-tailed distributions of contact durations)
- **burstiness** of human dynamics, non-Poissonian inter-event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

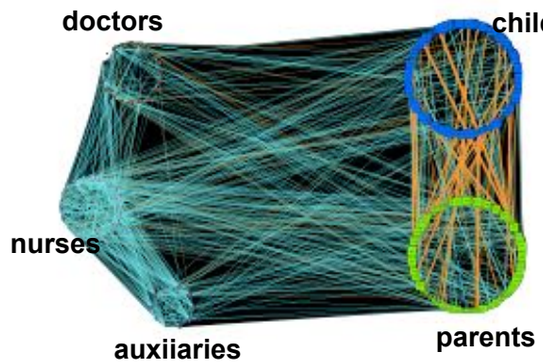
Lyon, France
primary school
231 students
10 teachers



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

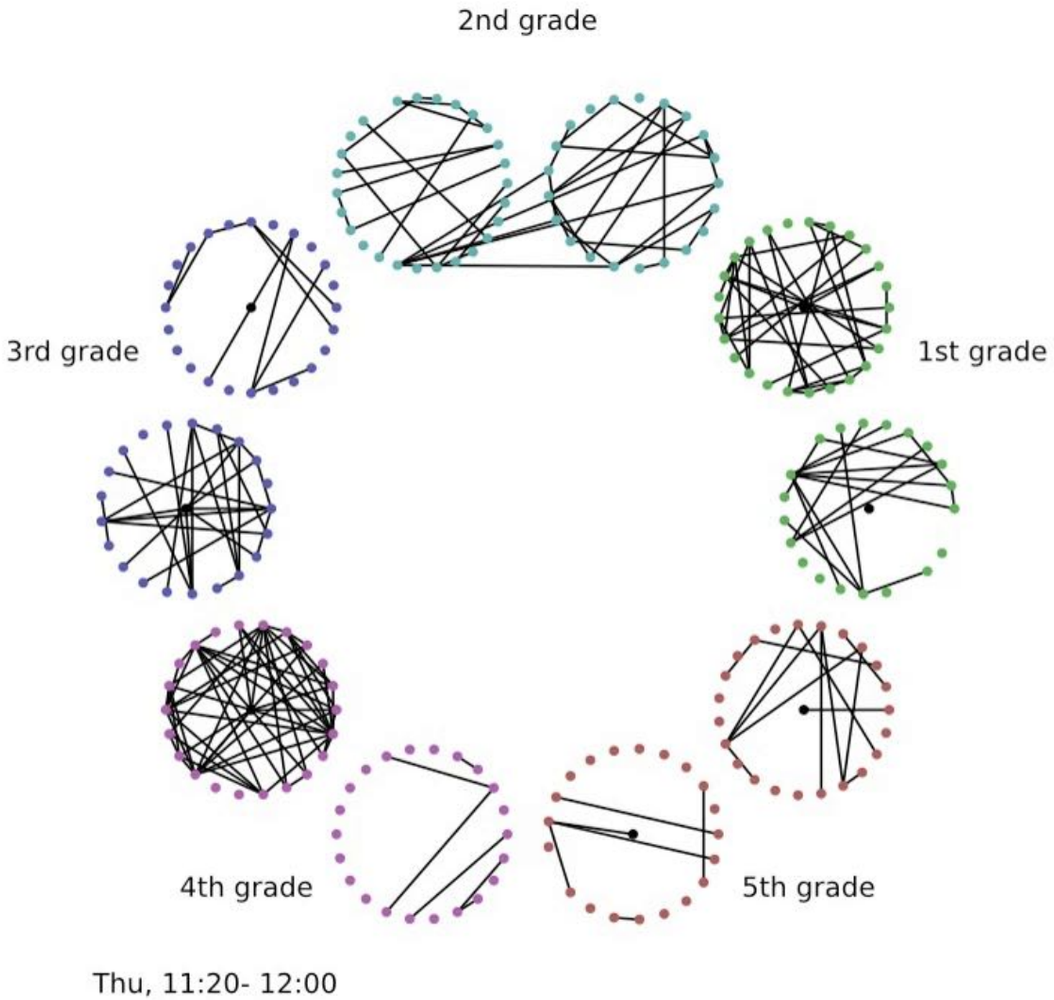
design of targeted interventions

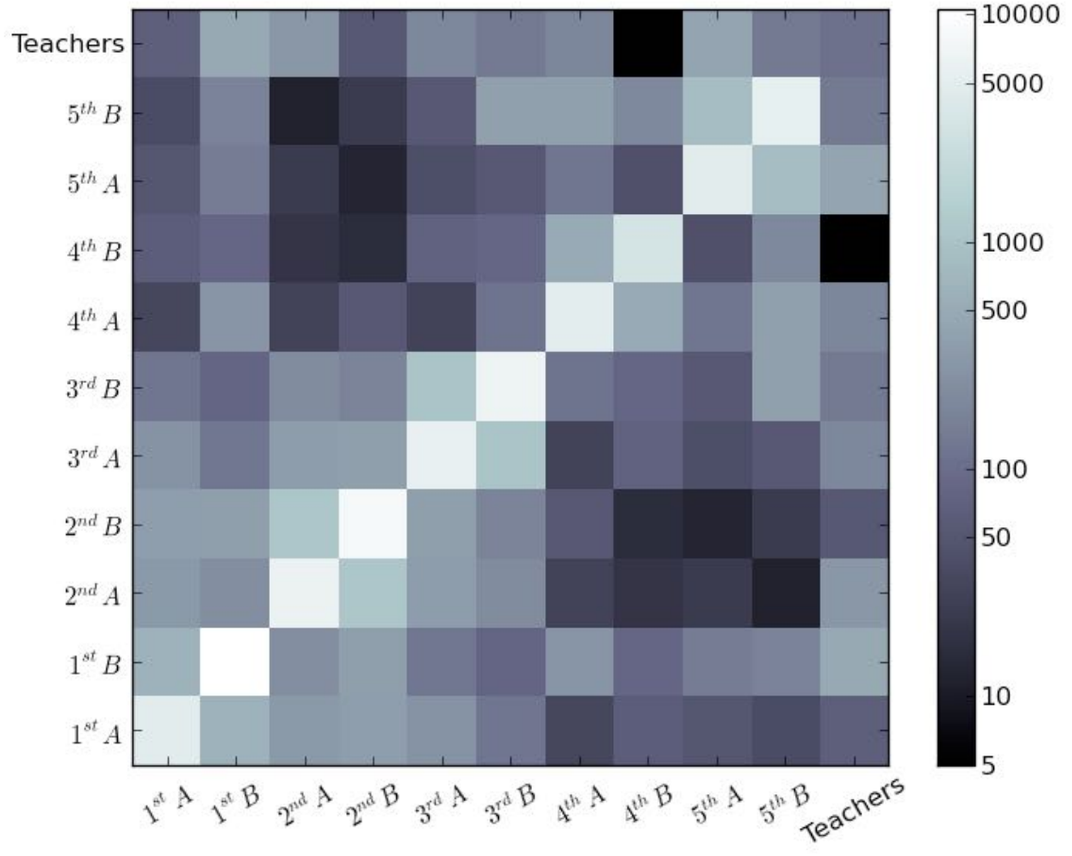




simulation

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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Research Article | Open Access | Published: 31 December 2014

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

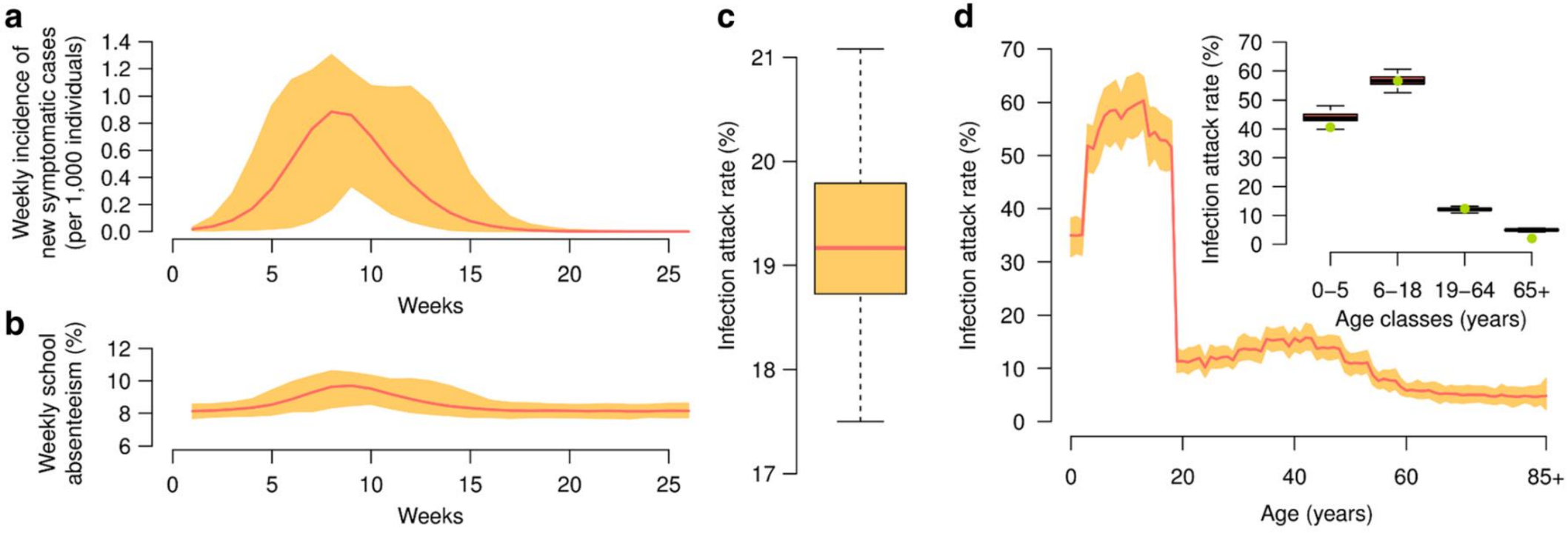
V. Gemmetto *et al.,* BMC Infectious Diseases 14, 695 (2014)

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

RESEARCH ARTICLE Open Access

THE LANCET
Infectious Diseases

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

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CrossMark

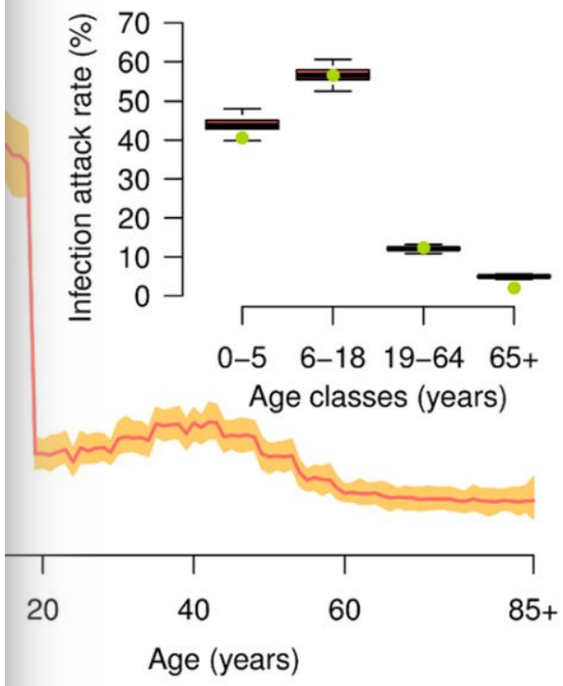
Articles

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

Ajelli[1*]

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]

[a] INSERM, Sorbonne Université, Pierre Louis Institute of Epidemiology and Public Health, Paris, France
[b] Aix-Marseille Univ, Université de Toulon, CNRS, Centre de Physique Théorique, Turing Center for Living Systems, Marseille, France
[c] Mathematical Modelling of Infectious Diseases Unit, Institut Pasteur, UMR2000, CNRS, Paris, France



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

nature communications

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Digital proximity tracing on empirical contact networks for pandemic control

G. Cencetti, G
Lepri ✉

Nature Comm

4385 Access

Abstract

Digital conta
including th
omitted imp
influencing
informed by
contact trac
apps, couple

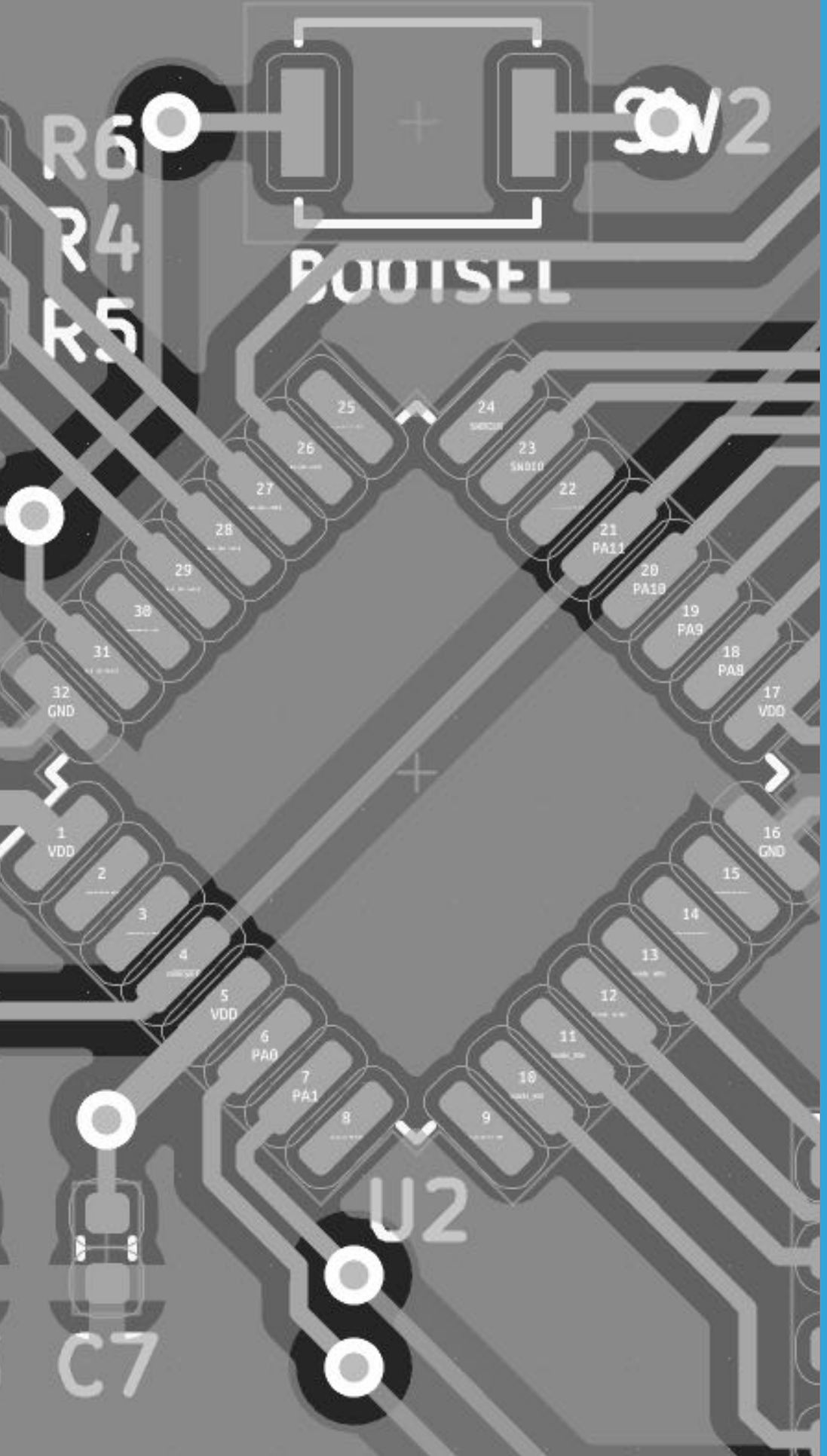
JOURNAL OF THE ROYAL SOCIETY INTERFACE

Research articles

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

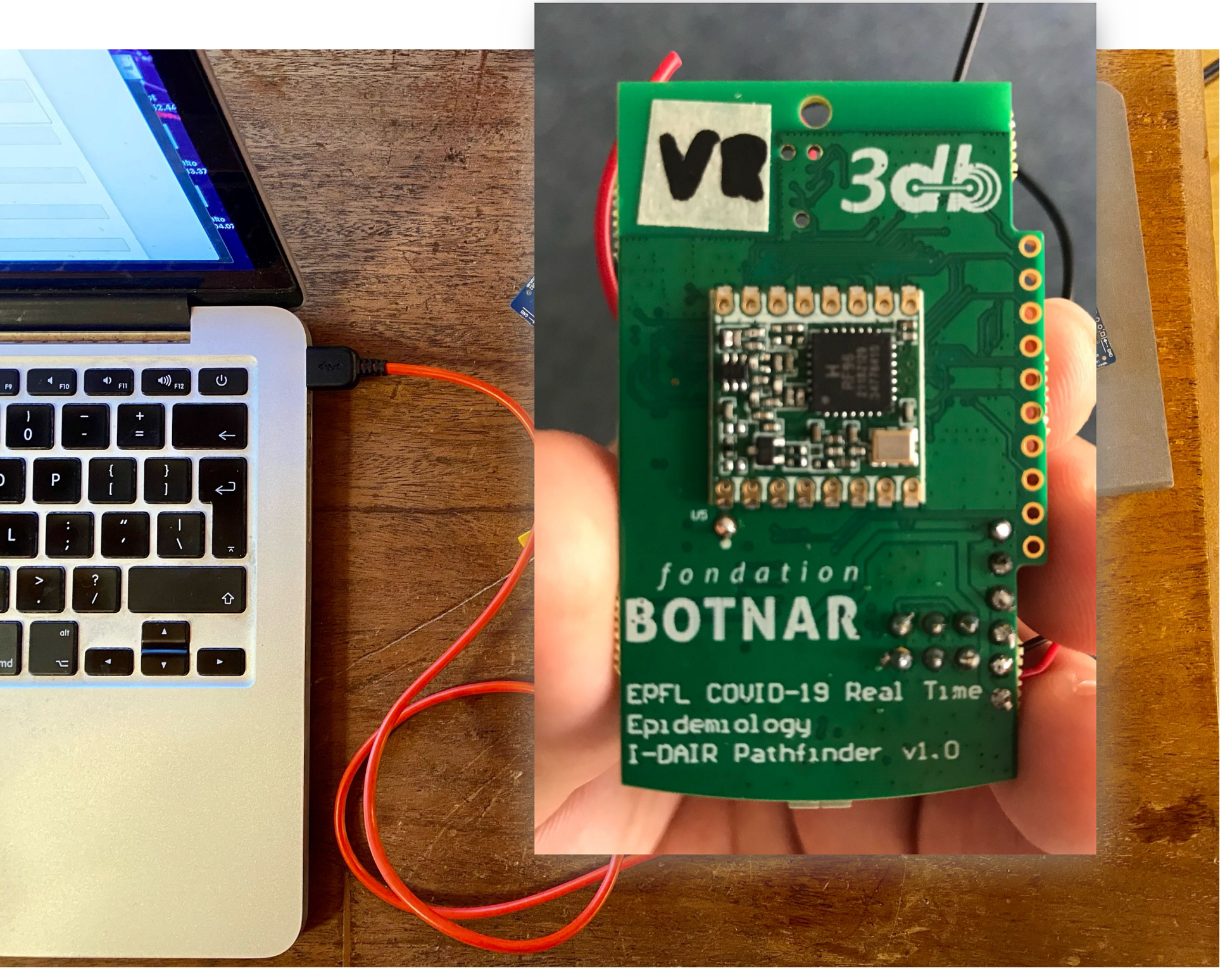
A. Barrat ✉, C. Cattuto, M. Kivelä, S. Lehmann and J. Saramäki

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



PROXIMITY-SENSING TECHNOLOGY

next generation UWB sensors



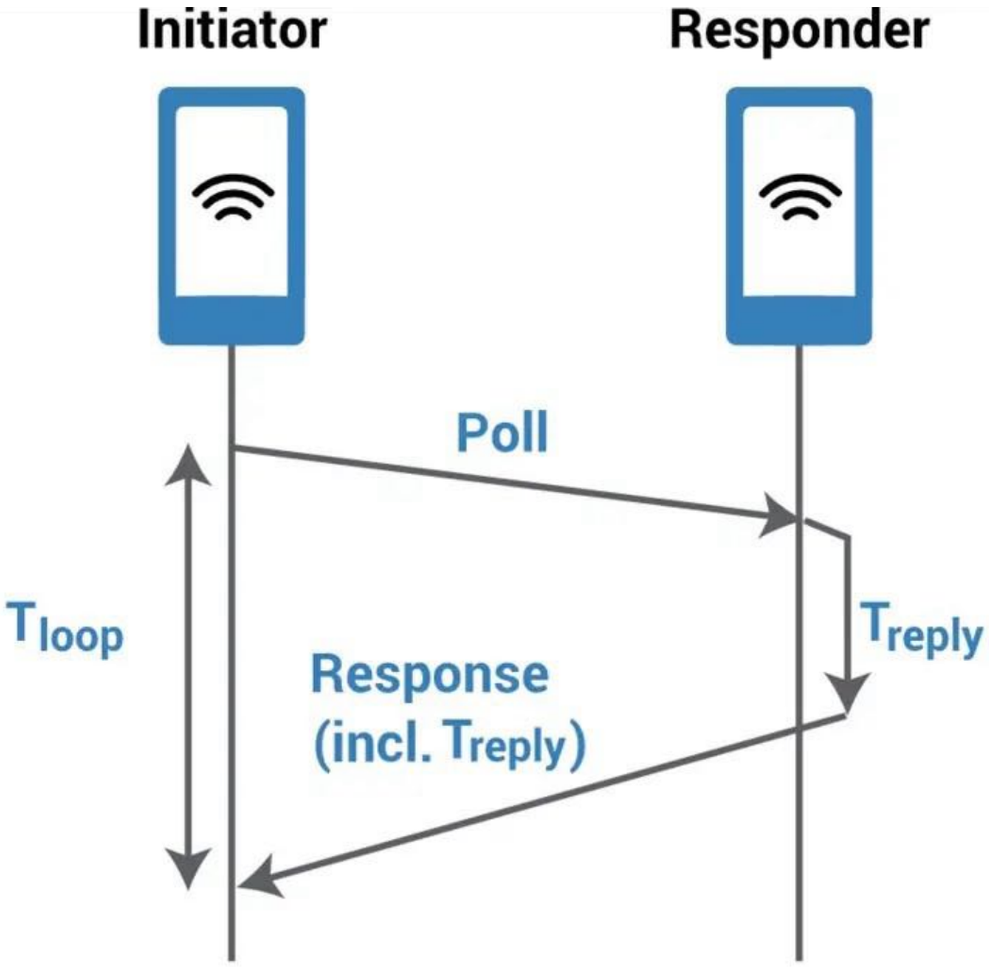
UWB

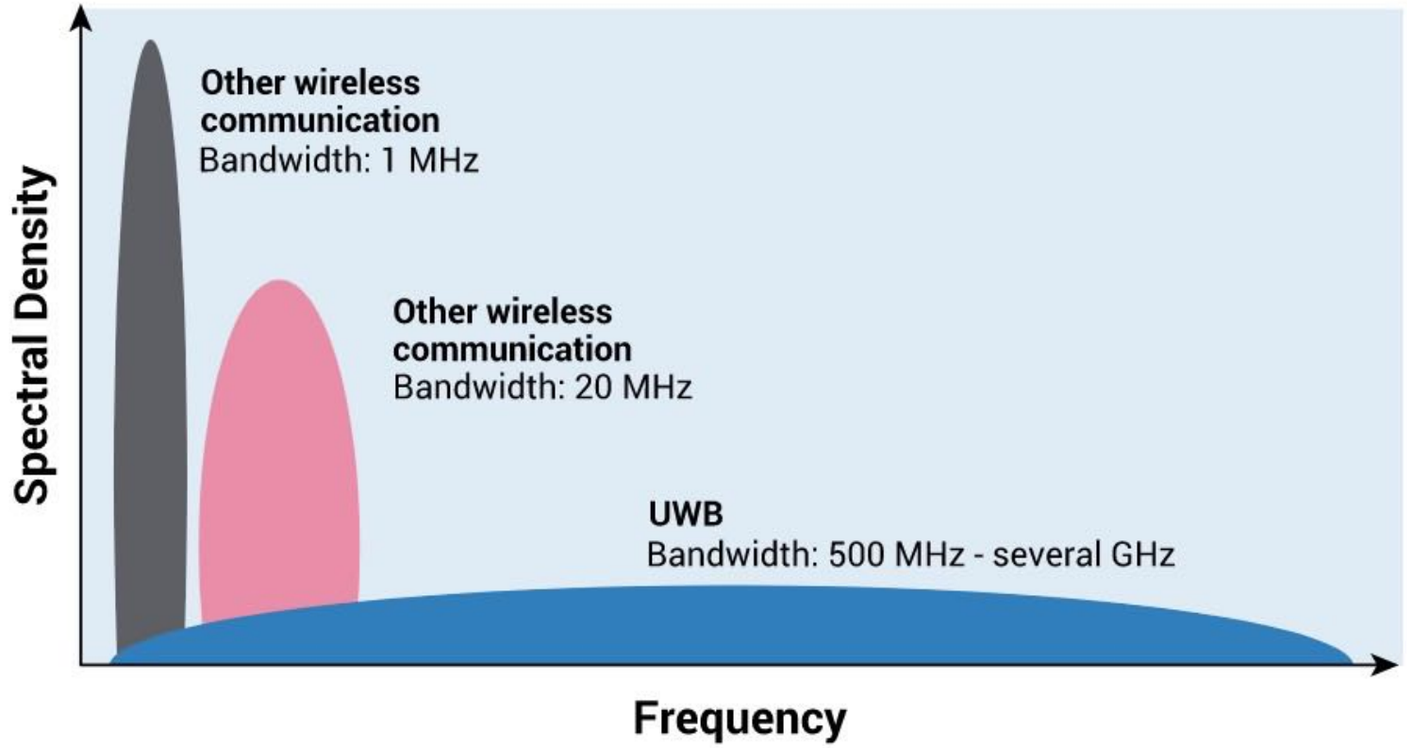
3db

I-DAIR

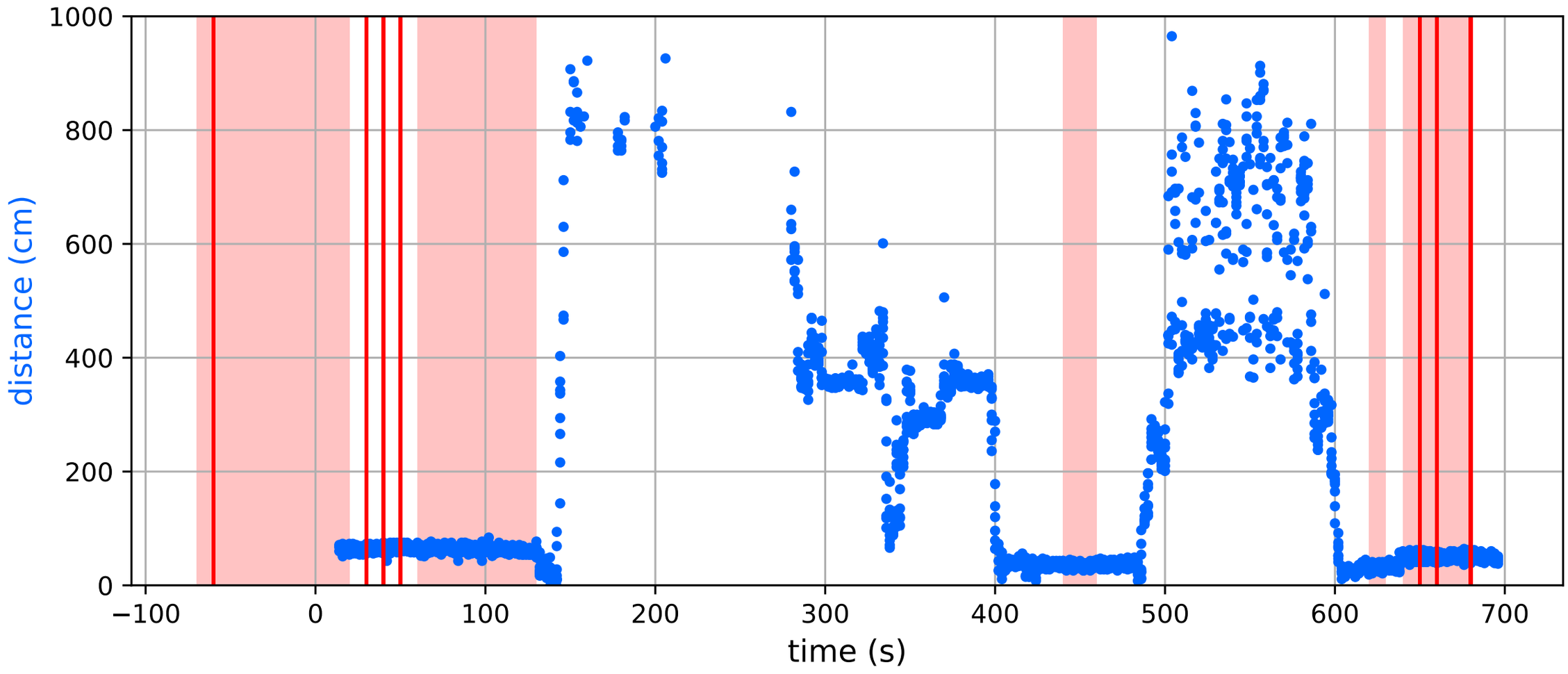
fondation
BOTNAR

next generation UWB sensors





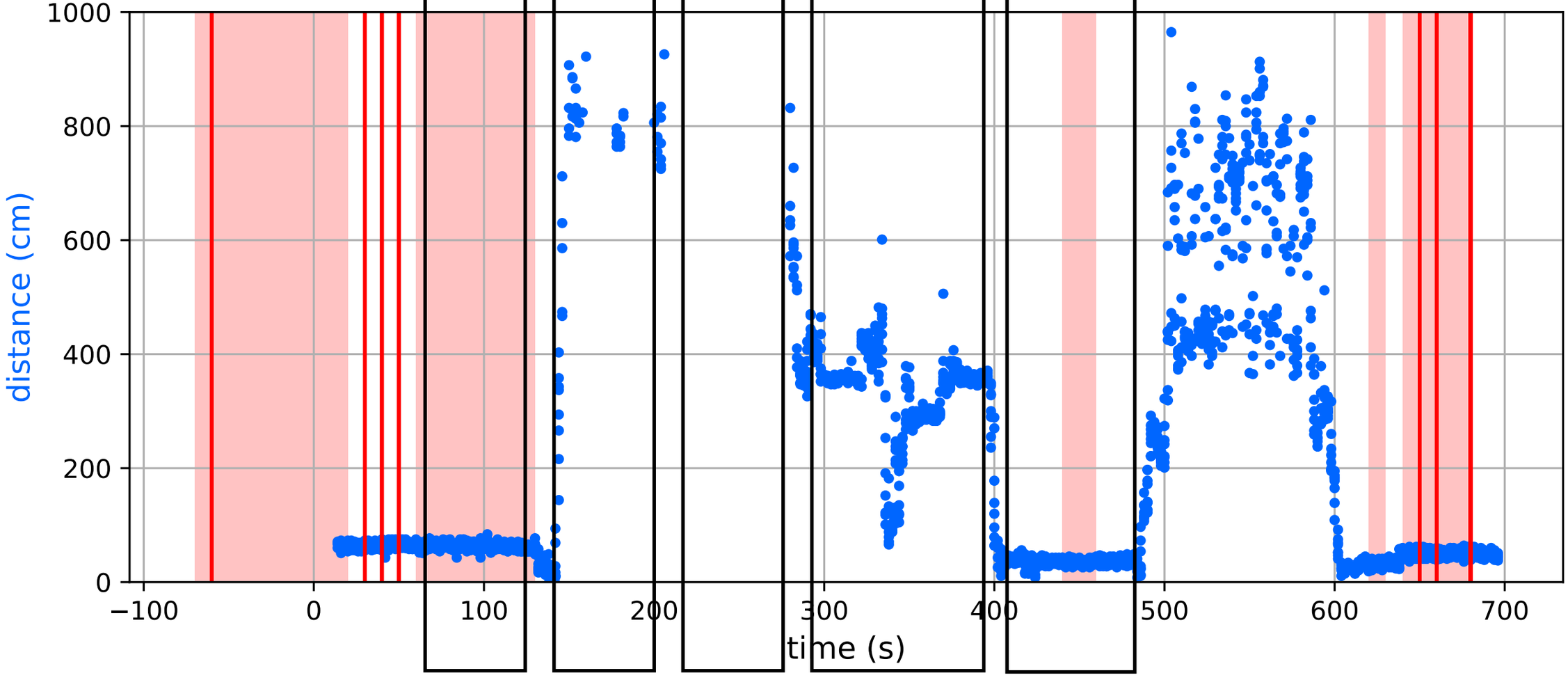
UWB sensors vs Bluetooth



A and B
sitting nearby

A moves
to far room

A back
near B

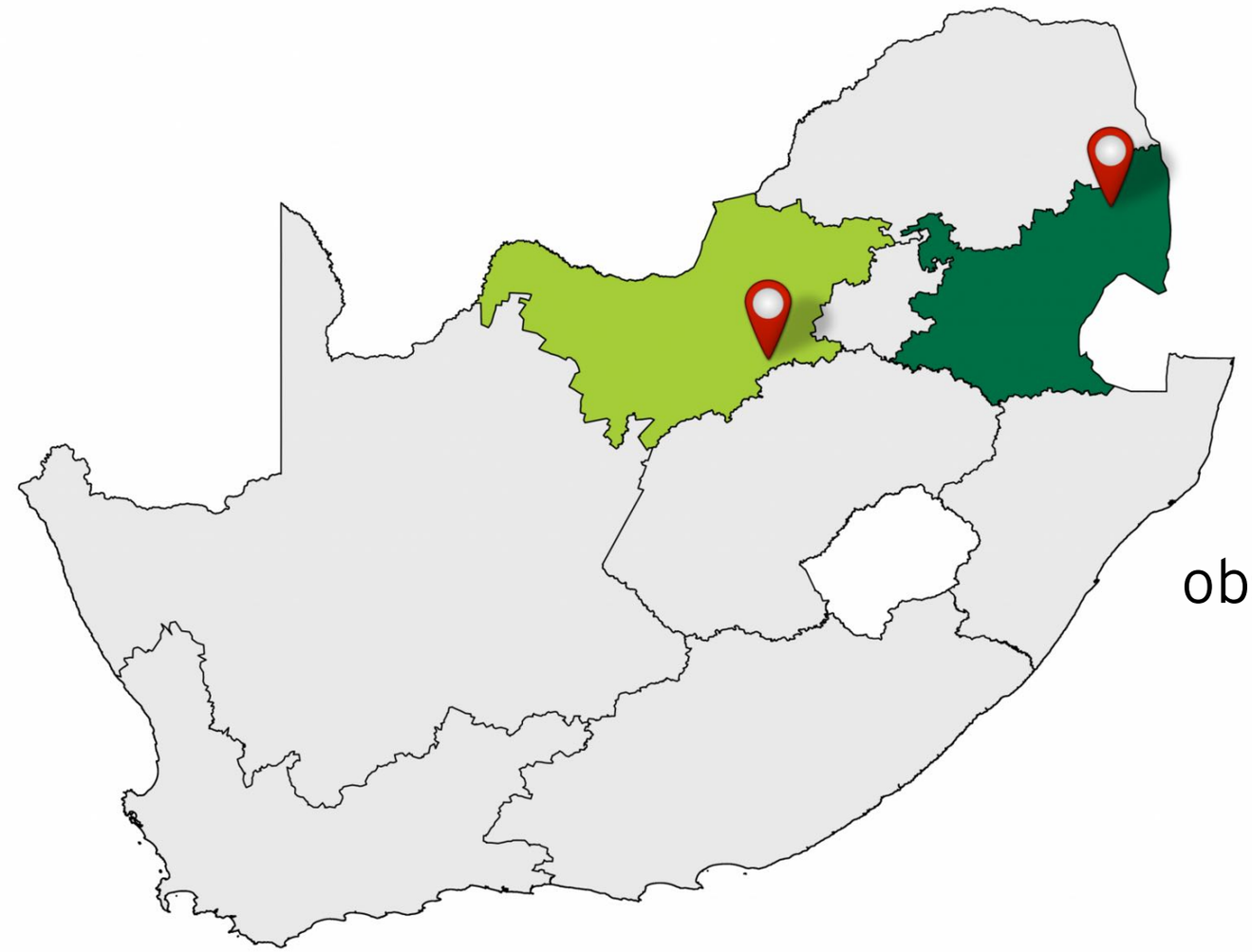


A moves
to nearby room

A moves back
to same room as B

SENSOR DEPLOYMENT PROTOCOL DESIGN

South Africa (rural + urban)

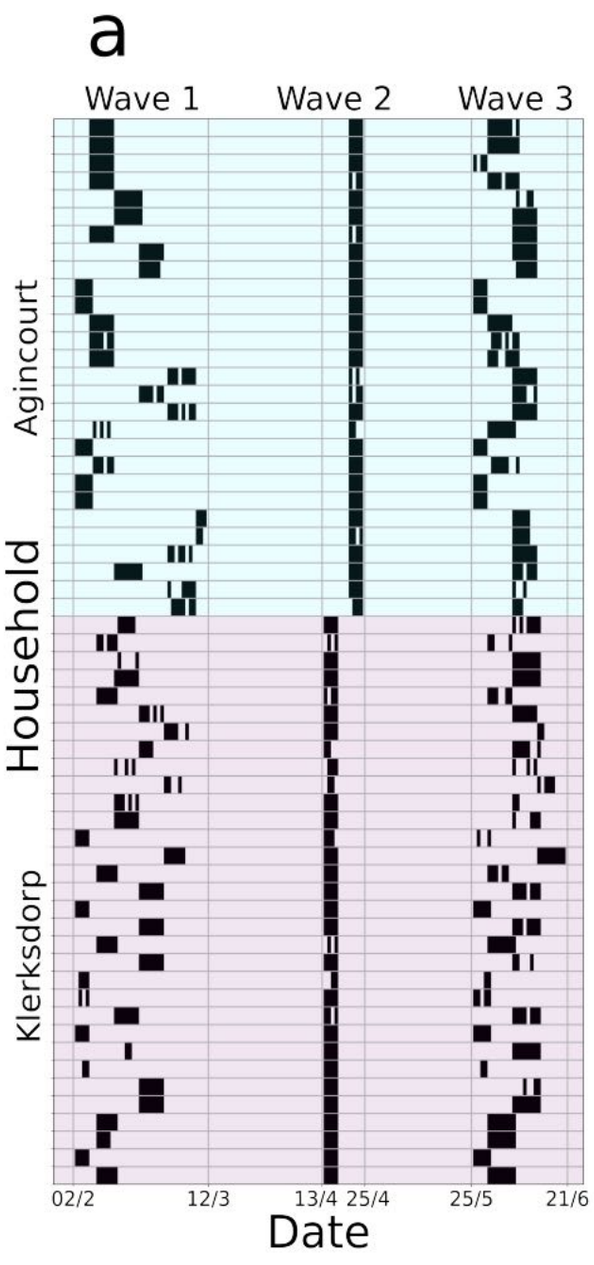


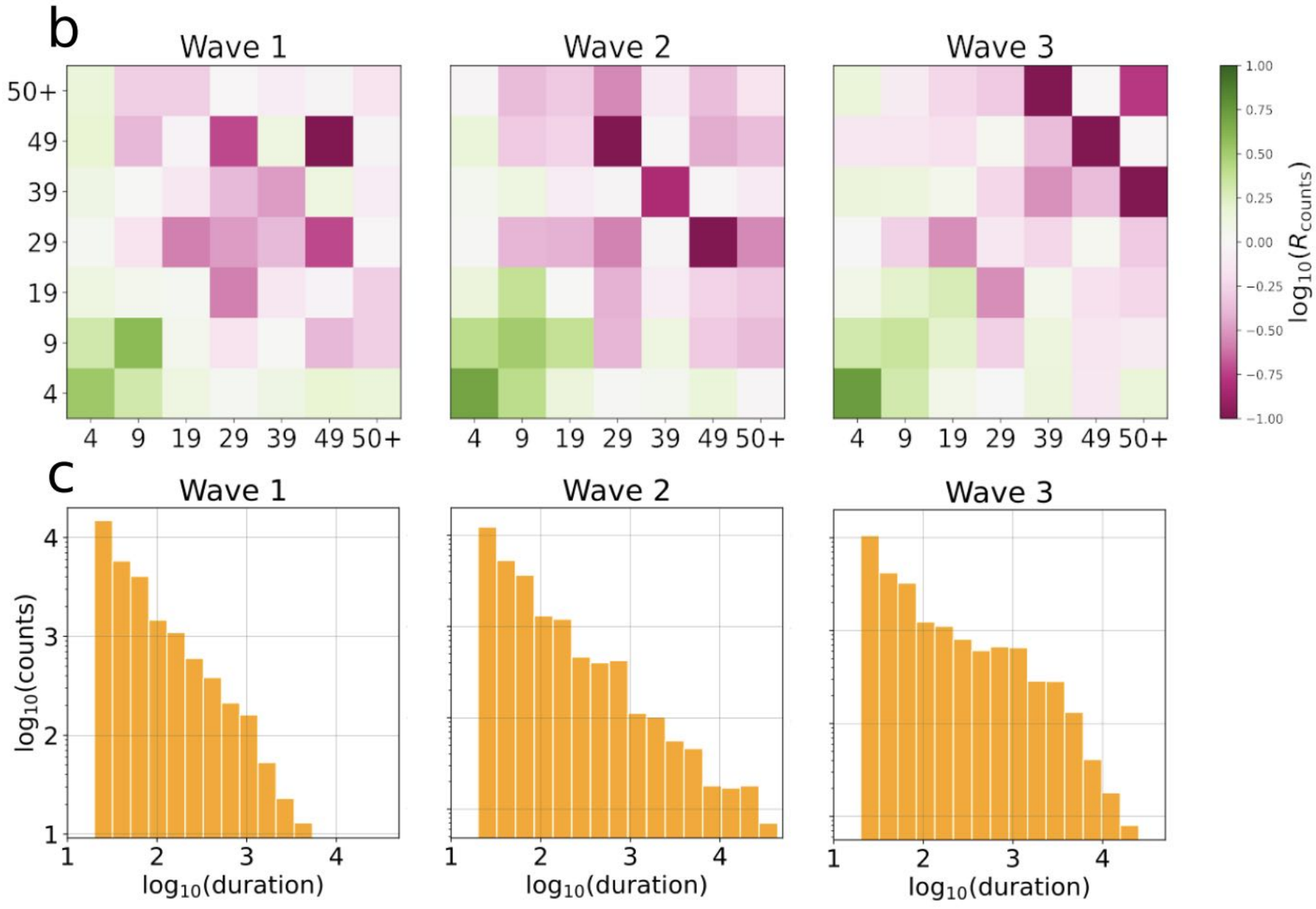
PHIRST (2018)

The Prospective Household observational cohort study of Influenza, Respiratory Syncytial virus

- 735 people in 146 households and two villages
- 3 deplyoments of 7 days each
- two visits to the household per week

South Africa (rural + urban)

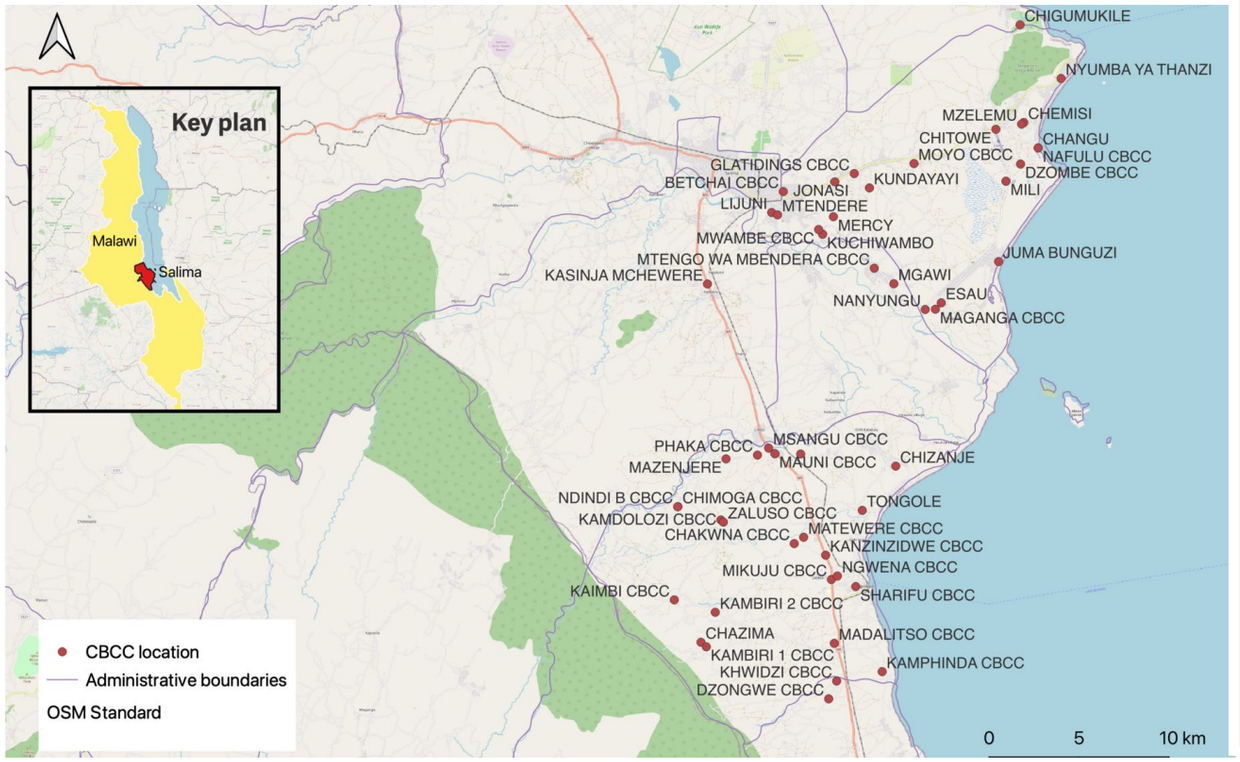




Malawi

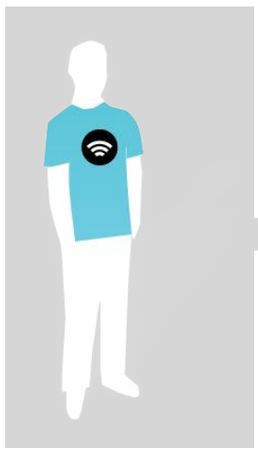
CCWD (2022)

Study on childhood developement

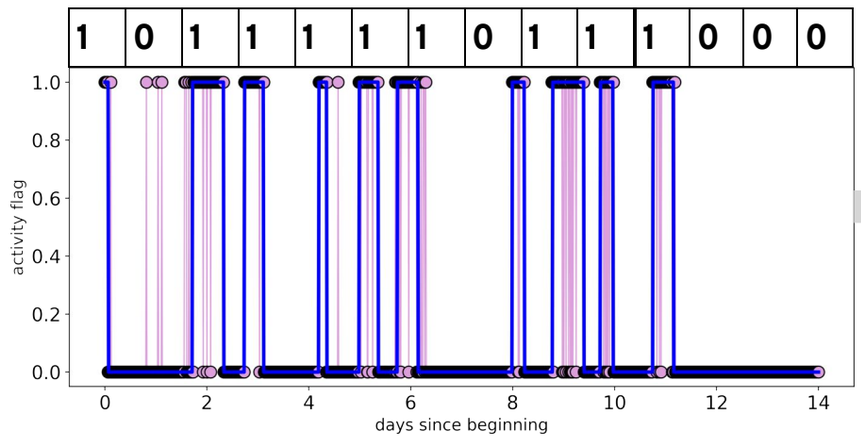


- 300 households in Salima district, rural Malawi
- 15 days of measurement
- 59 Community Based Childcare Centers (CBCCs)
- Two children (aged typically between 3 and 6) and one guardian
- Two groups: one performing also EEG and ECG

wearing protocol compliance



compliance timeline



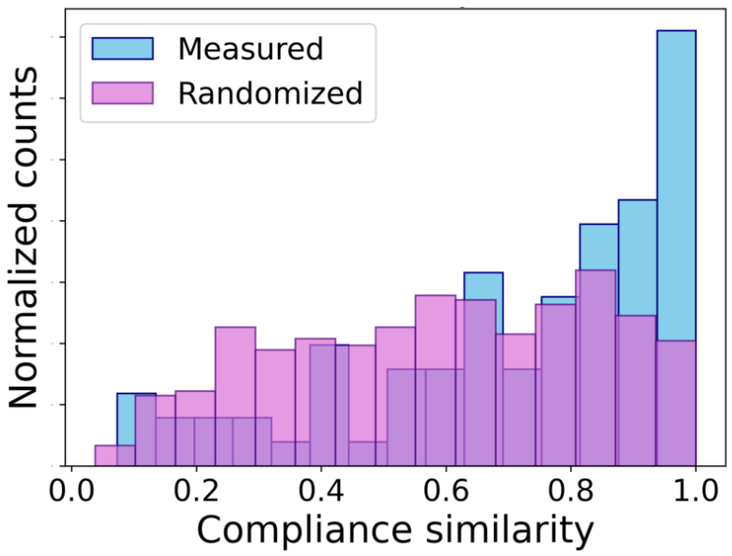
compliance similarity score

$$S_{ij} = \frac{N_{ij}^{(\mathrm{cc})}}{\sqrt{N_i^{(\mathrm{c})} N_j^{(\mathrm{c})}}}$$

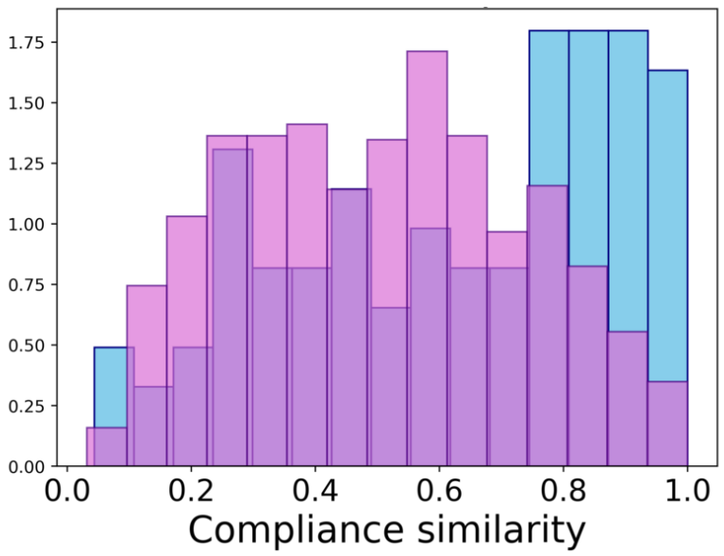
$N_{ij}^{(\mathrm{cc})}$ = days of common compliance

$N_i^{(\mathrm{c})}$ = days of compliance of i

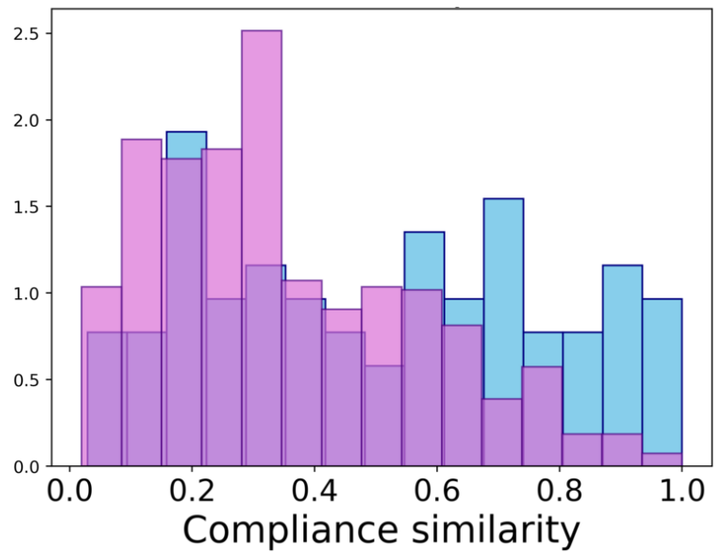
wave #1



wave #2



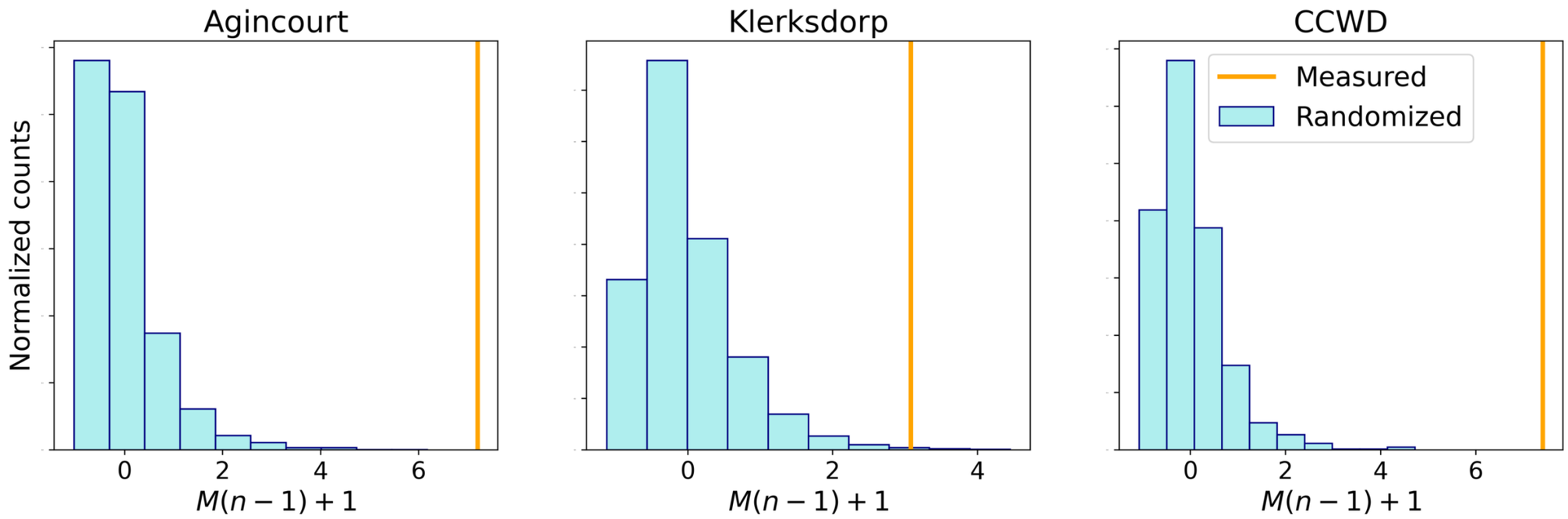
wave #3



L. Dall'Amico *& CC*, *"A comparative study of compliance in large-scale sociometric studies in sub-Saharan countries"* (2023), under review

spatial autocorrelation of compliance

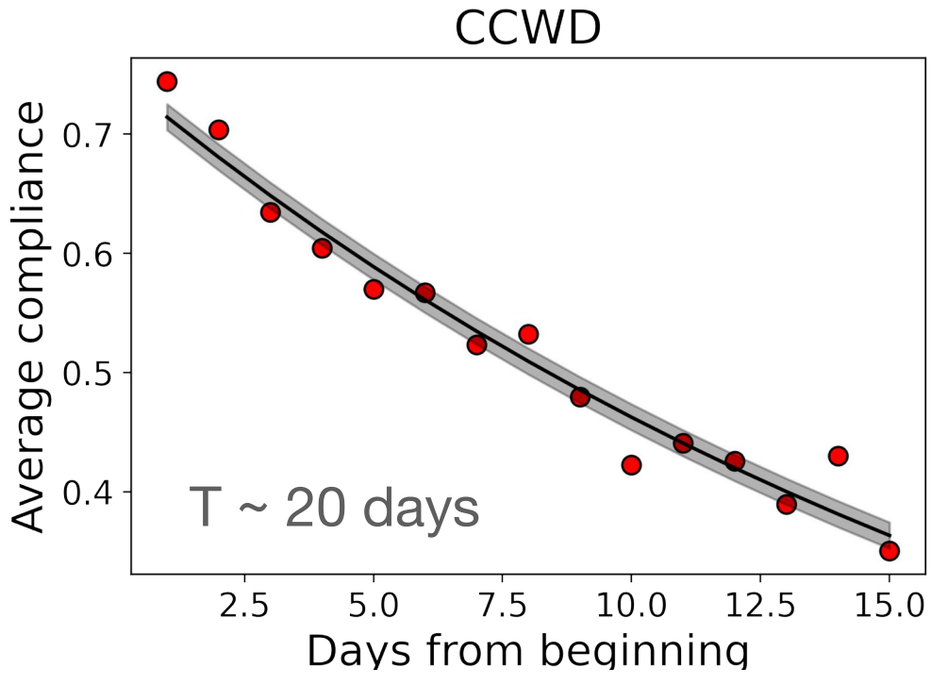
- HH distance based on known GPS coordinates of HHs
- spatial auto-correlation of compliance quantified via Moran's I
- compare w/ null model that randomizes HH-GPS association

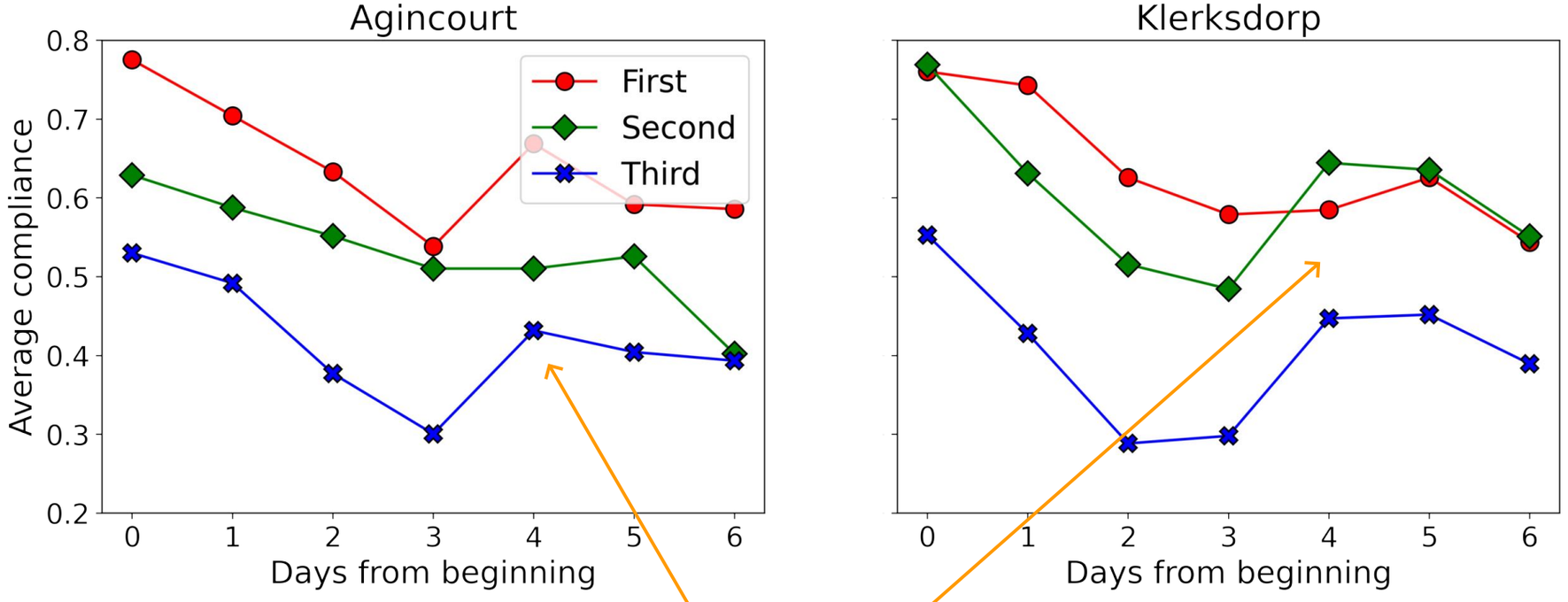


Moran's I coefficient (rescaled so that exp. value = 0)

L. Dall'Amico *& CC*, *"A comparative study of compliance in large-scale sociometric studies in sub-Saharan countries"* (2023), under review

compliance & fatigue





L. Dall'Amico *& CC*, *"A comparative study of compliance in large-scale sociometric studies in sub-Saharan countries"* (2023), under review

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

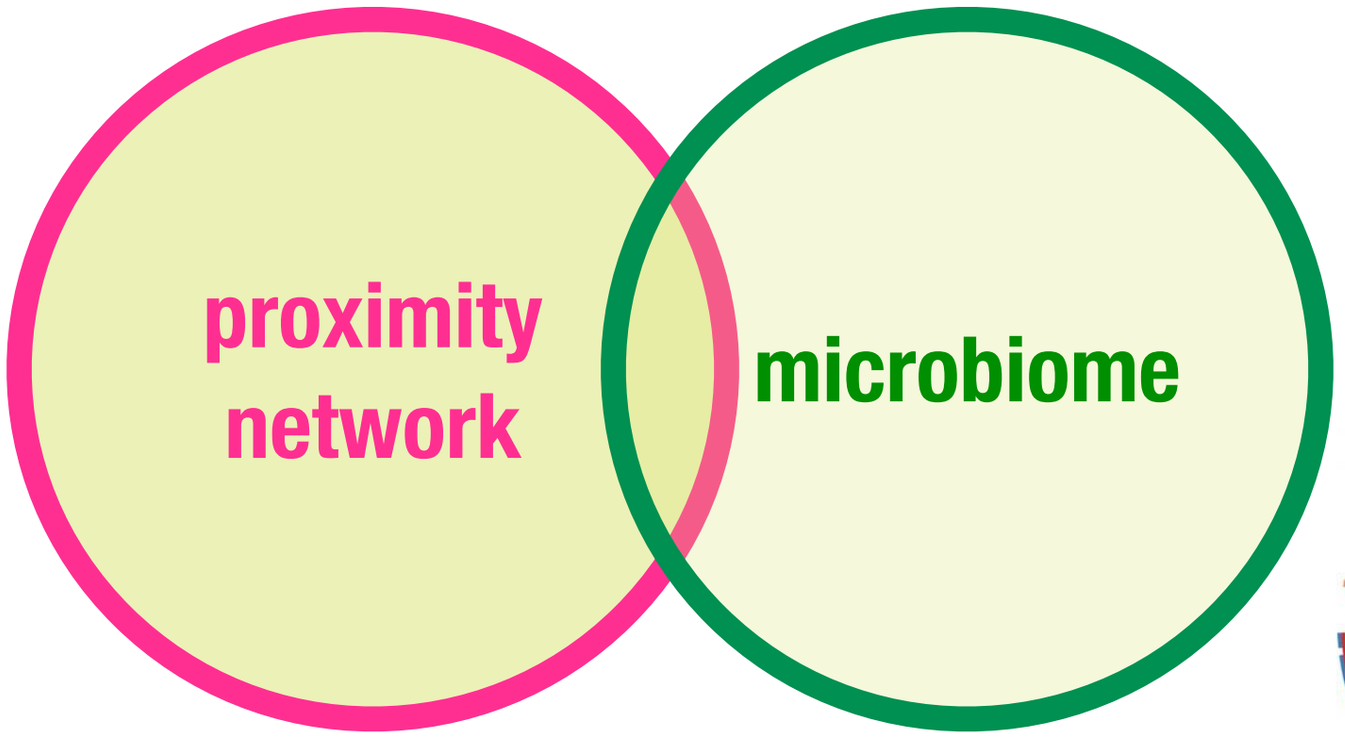
Volume 123, October 2022, Pages 200-209

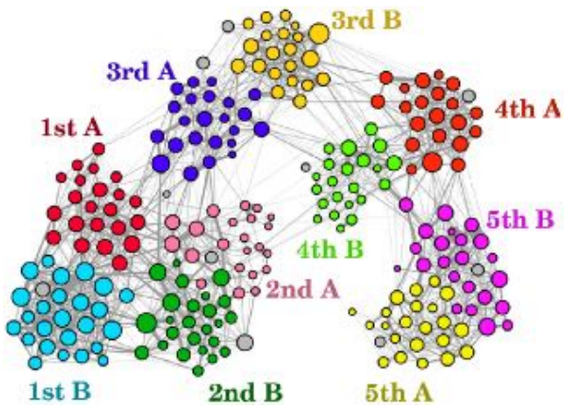
Social network analysis of *Staphylococcus aureus* carriage in a general youth population

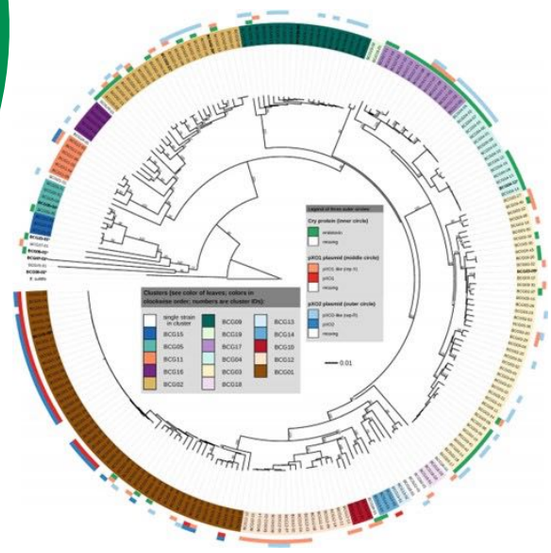
Dina B. Stensen [1, 2, #], Rafael A. Nozal Cañadas [3, #], Lars Småbrekke [4], Karina
Sivert Nielsen [6, 7], Kristian Svendsen [4], Anne Merethe Hanssen [8], Johanna U. Erics
Simonsen [5, 8], Lars Ailo Bongo [3], Anne-Sofie Furberg [5, 9]

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





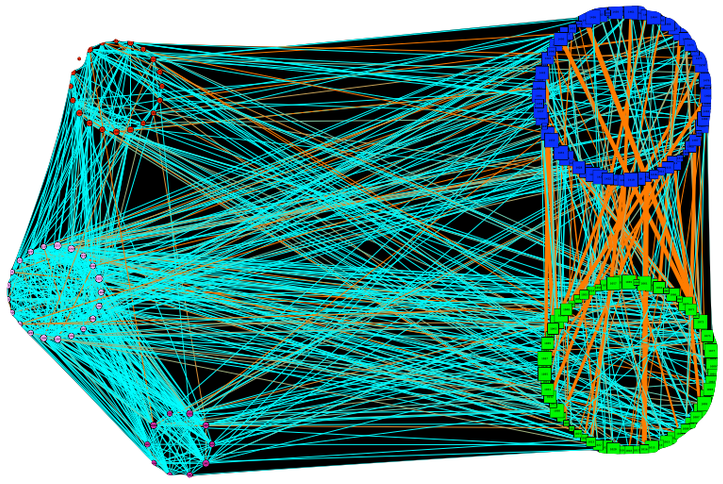


- proximity sensors
- continuously worn for 2 weeks

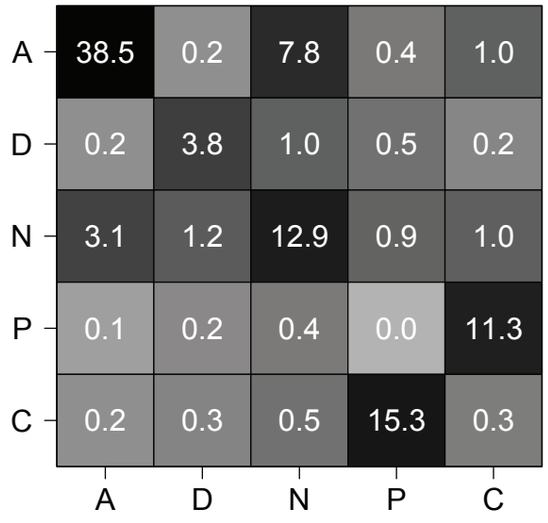
- saliva samples
- 1 sample / week
- 16S rRNA sequencing

LOW-DIMENSIONAL REPRESENTATIONS OF PROXIMITY DATA

how much detail ?



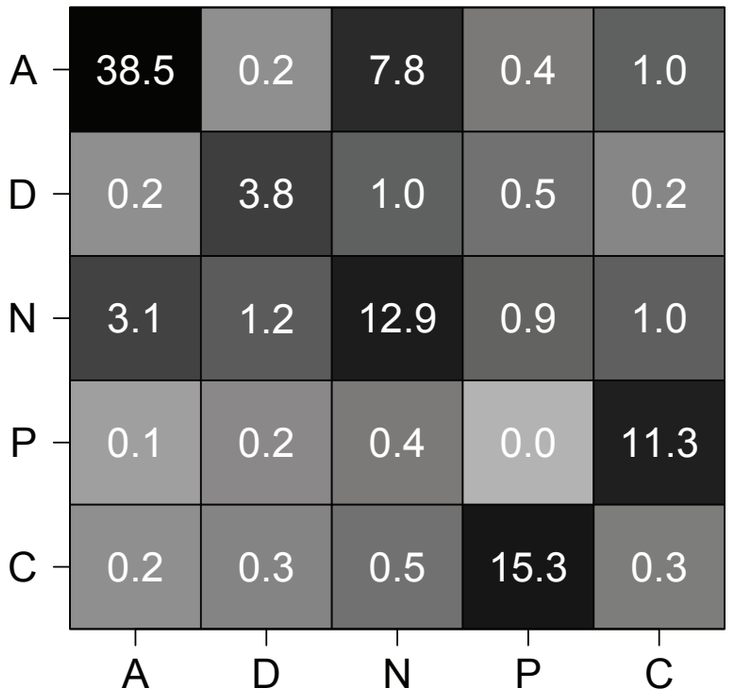
more detailed,
less generalizable



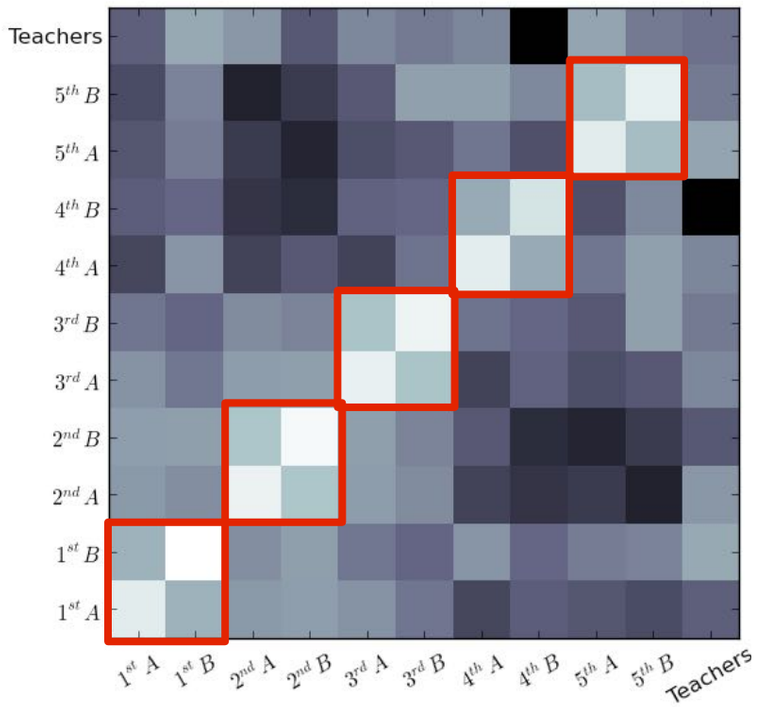
less detailed,
more generalizable

how much detail ?

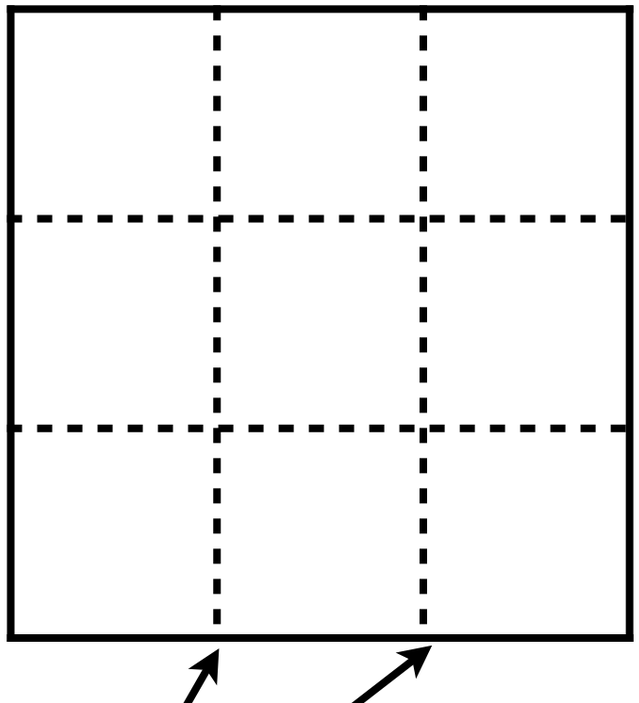
hospital

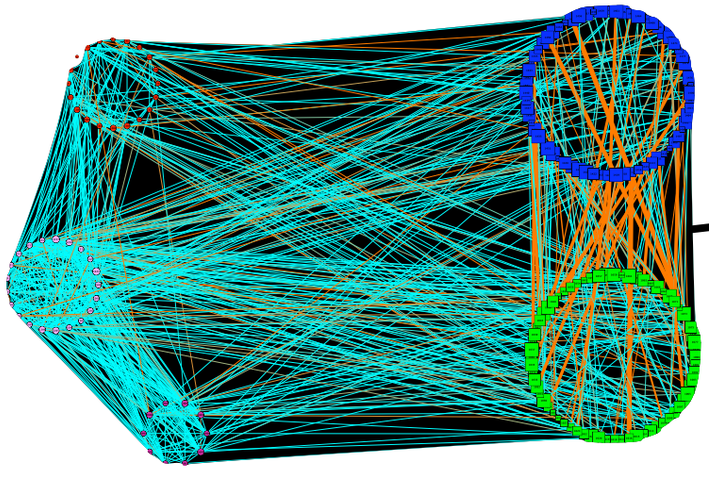


school



general case





learning

?

CAN WE *NOT* MEASURE ?

Estimating household contact matrices structure from easily collectable metadata

Lorenzo Dall'Amico[1,*], Jackie Kleynhans[2,3], Laetitia Gauvin[1], Michele Tizzoni[1,4]
Laura Ozella[1], Mvuyo Makhasi[2], Nicole Wolter[2,5], Brigitte Language[6], Ryan G. Wagner[7]
Cheryl Cohen[2,3], Stefano Tempia[2,3], Ciro Cattuto[1,8]

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[2]National Institute for Communicable Diseases of the National Health Laboratory Service, Johannesburg, South Africa
[3]School of Public Health, Faculty of Health Sciences, University of the Witwatersrand, Johannesburg, South Africa
[4]Department of Sociology and Social Research, University of Trento, Trento, Italy
[5]School of Pathology, University of the Witwatersrand, Johannesburg, South Africa
[6]Unit for Environmental Science and Management, Climatology Research Group,
North-West University, Potchefstroom, South Africa
[7]MRC/Wits Rural Public Health and Health Transitions Research Unit (Agincourt)
[8]University of Turin, Department of Informatics, Turin, 10124, Italy
[*]Corresponding to: lorenzo.dallamico@isi.it

November 17, 2022

Abstract

The ability of developing accurate models plays a pivotal role in understanding infectious diseases dynamics and designing effective measures for epidemic mitigation. Contact matrices are of crucial importance to quantify the interaction between age groups, but their estimation is a rather time and effort consuming task. In this article we show that they can reliably be estimated combining a context-independent model with easily collectable data, such as co-presence and an age activity parameter. The proposed model is tested on high resolution proximity data collected in a rural and an urban village in South Africa. Given its simplicity and interpretability, we expect our method to be easily applied to other contexts as well and we identify relevant questions that need to be addressed during the data collection procedure.

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

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