How will mass-vaccination change COVID-19 lockdown requirements in Australia?

Prof. Mikhail Prokopenko

Centre for Complex Systems, Faculty of Engineering

Marie Bashir Institute for Infectious Diseases and Biosecurity

THE UNIVERSITY OF SYDNEY

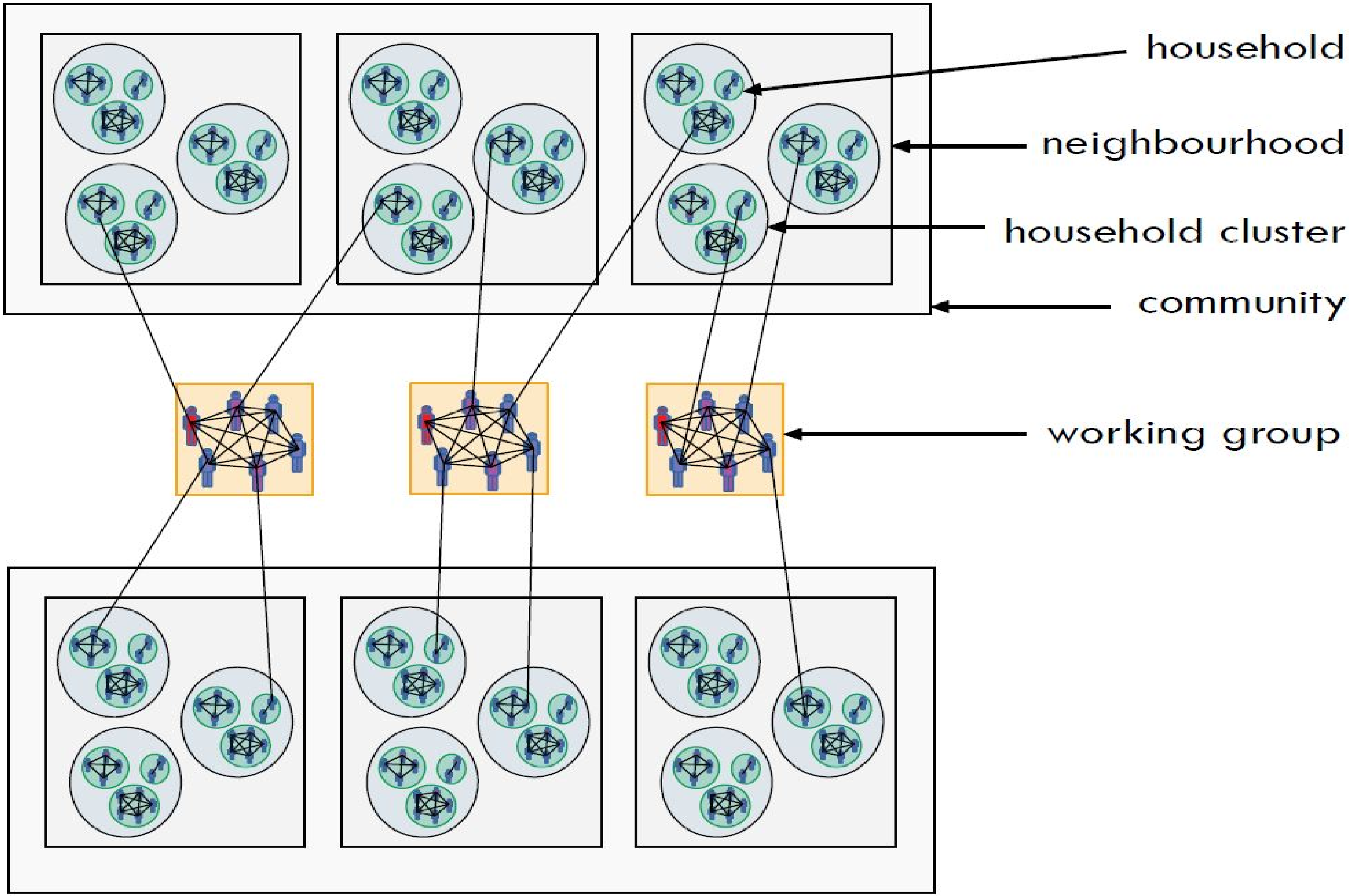
JP Morgan Australia conference
"What will the "New Normal" look like post COVID-19 vaccine rollout?“
June 10, 2021

Pandemic modelling using ABM

- Modelling pandemics with large-scale high-resolution agent-based models
  - *demographics*: from census based data to agents
  - *mobility*: travel patterns including long-distance
  - *infection*: disease transmission and natural history models
  - AMTraC-19 – Agent-based Model of Transmission and Control of the COVID-19 pandemic in Australia (about 24M agents)

- COVID-19 pandemic
  - age-dependent epidemiological characteristics, and calibration
  - pandemic trends (peaks, resurgence), and model validation
  - non-pharmaceutical interventions (NPIs): mitigation, suppression, elimination
  - pharmaceutical interventions: vaccination

“Same storm, different boats”: Agent-based Modelling



Population partitions: residential areas and destination zones

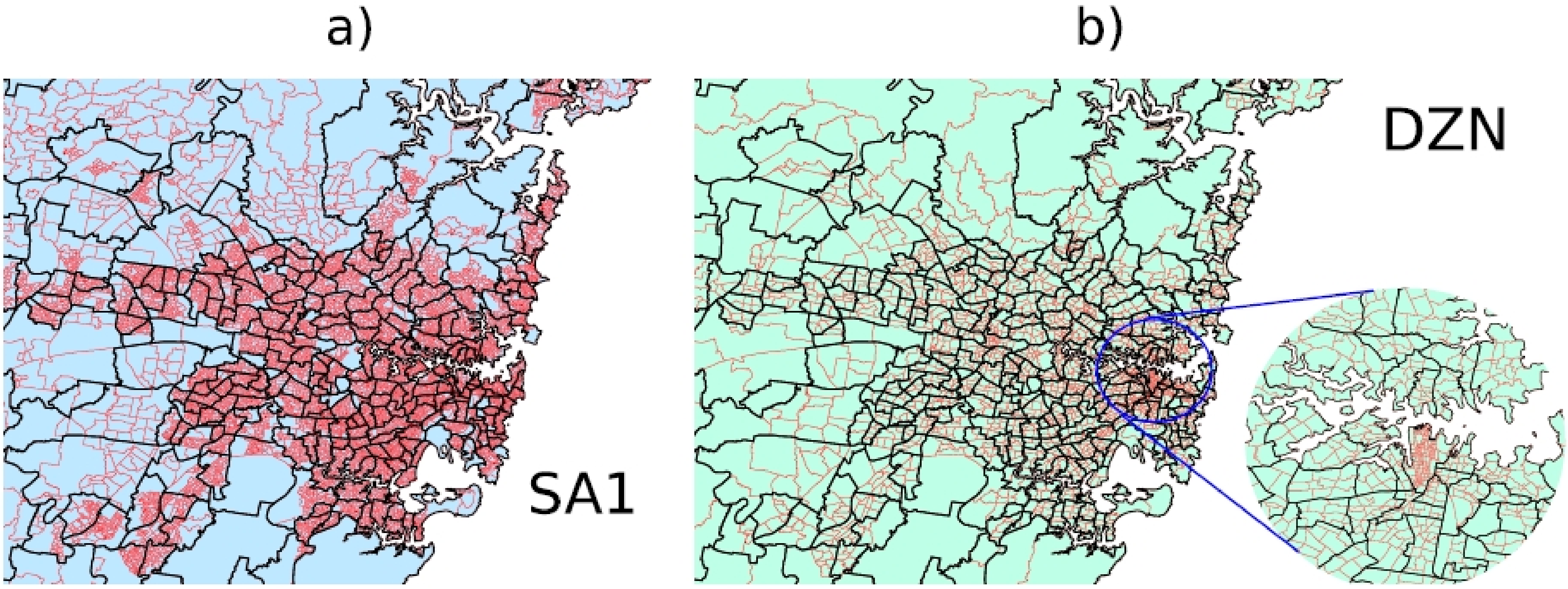


Fig. 1 Maps of the Greater Sydney region illustrating the distribution of population partitions. (**a**) A map of the Greater Sydney region showing SA2 (black) and SA1 (red) population partitions. (**b**) A map of the same area showing SA2 (black) and DZN (red) partitions. The inset in (**b**) zooms in on the Sydney central business district to illustrate the much denser packing of DZN partitions in that area.

K. M. Fair, C. Zachreson, M. Prokopenko, Creating a surrogate commuter network from Australian Bureau of Statistics census data, *Scientific Data*, 6, 150, 2019.

International air traffic

Airport code	State	City	Passengers
SYD	NSW	Sydney	40884
MEL	VIC	Melbourne	25859
BNE	QLD	Brisbane	14250
PER	WA	Perth	11449
OOL	QLD	Gold Coast	3022
ADL	SA	Adelaide	2214
CNS	QLD	Cairns	1874
DRW	NT	Darwin	597
TSV	QLD	Townsville	105

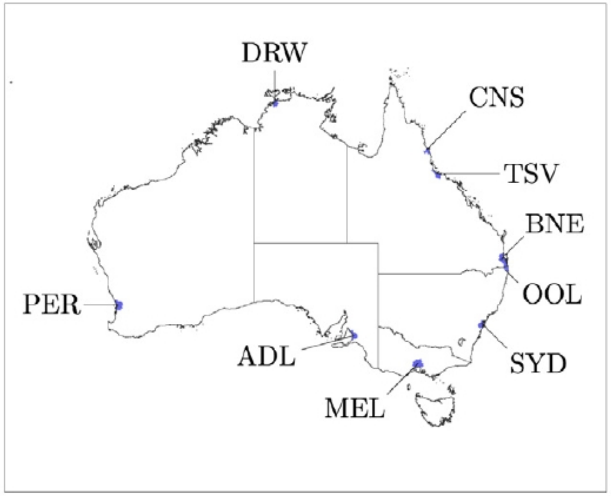
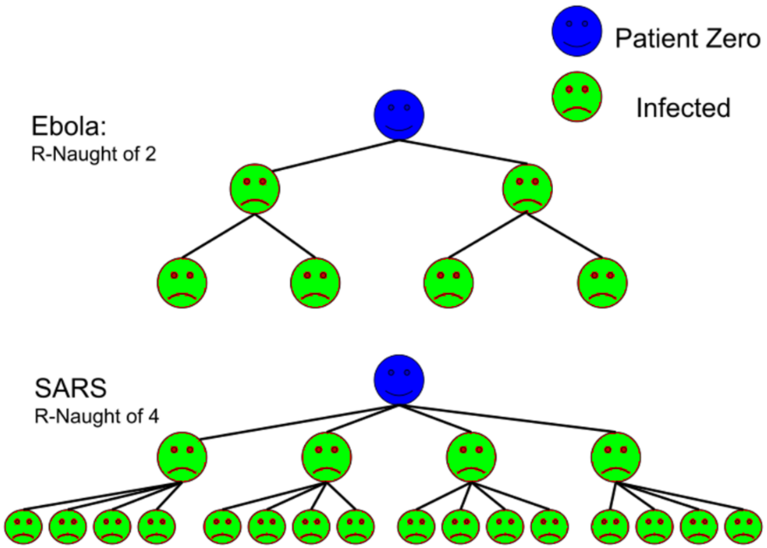
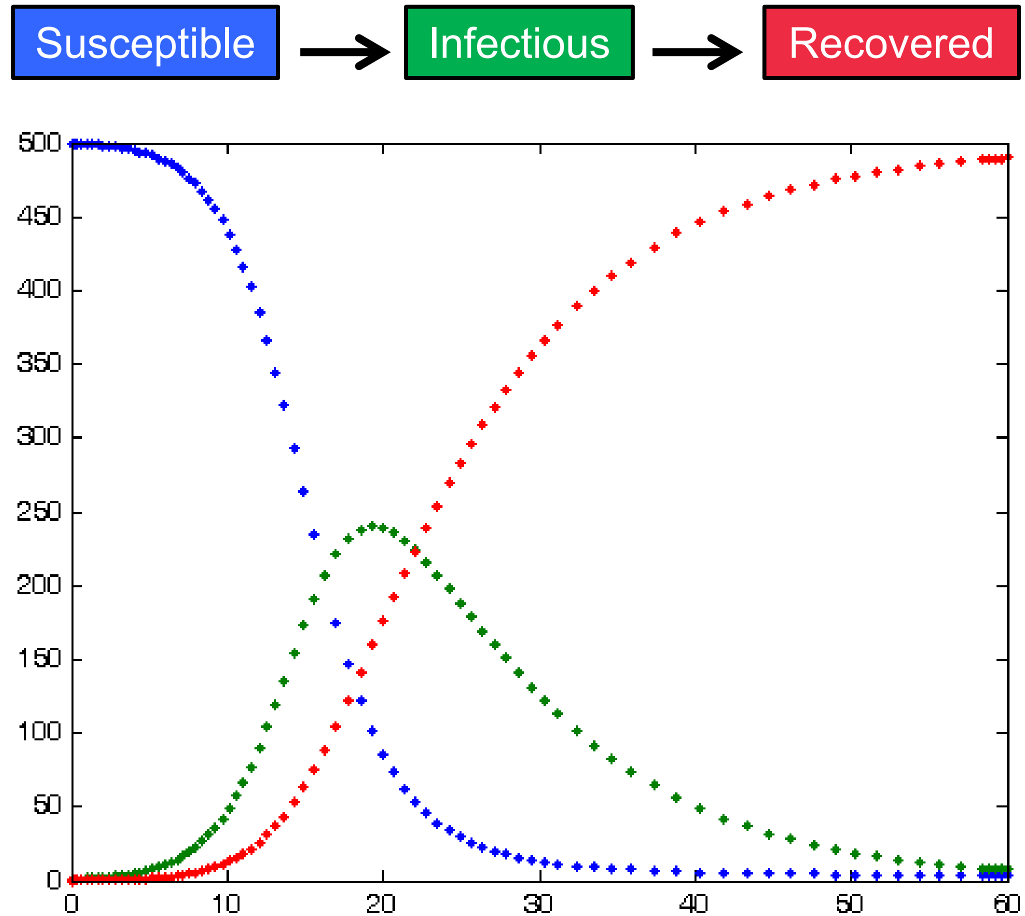


Fig. 3. Daily incoming passengers per Australian international airport obtained from BITRE [30] along with a map detailing the airport locations.

O. M. Cliff, N. Harding, M. Piraveenan, E. Y. Erten, M. Gambhir, M. Prokopenko, Investigating Spatiotemporal Dynamics and Synchrony of Influenza Epidemics in Australia: An Agent-Based Modelling Approach, *Simulation Modelling Practice and Theory*, 87, 412-431, 2018.

Epidemic modelling: reproductive ratio R_0





$$\frac{\mathrm{d}I}{\mathrm{d}t} = \beta IS - \gamma I, \qquad \beta / \gamma = R_0$$

Epidemic modelling: transmission probabilities

Table C2
Daily transmission probabilities $q^g_{j\to i}$ for different contact groups g, obtained by Eq. (4) where $\beta^g_{j\to i}$ are reported by [10].

Contact Group g	Infected Individual j	Susceptible Individual i	Transmission Probability $q^g_{j\to i}$
Household size 2	Any	Child (<19)	0.0933
	Any	Adult (>18)	0.0393
Household size 3	Any	Child (<19)	0.0586
	Any	Adult (>18)	0.0244
Household size 4	Any	Child (<19)	0.0417
	Any	Adult (>18)	0.0173
Household size 5	Any	Child (<19)	0.0321
	Any	Adult (>18)	0.0133
Household size 6	Any	Child (<19)	0.0259
	Any	Adult (>18)	0.0107
School	Child (<19)	Child (<19)	0.000292
Grade	Child (<19)	Child (<19)	0.00158
Class	Child (<19)	Child (<19)	0.035

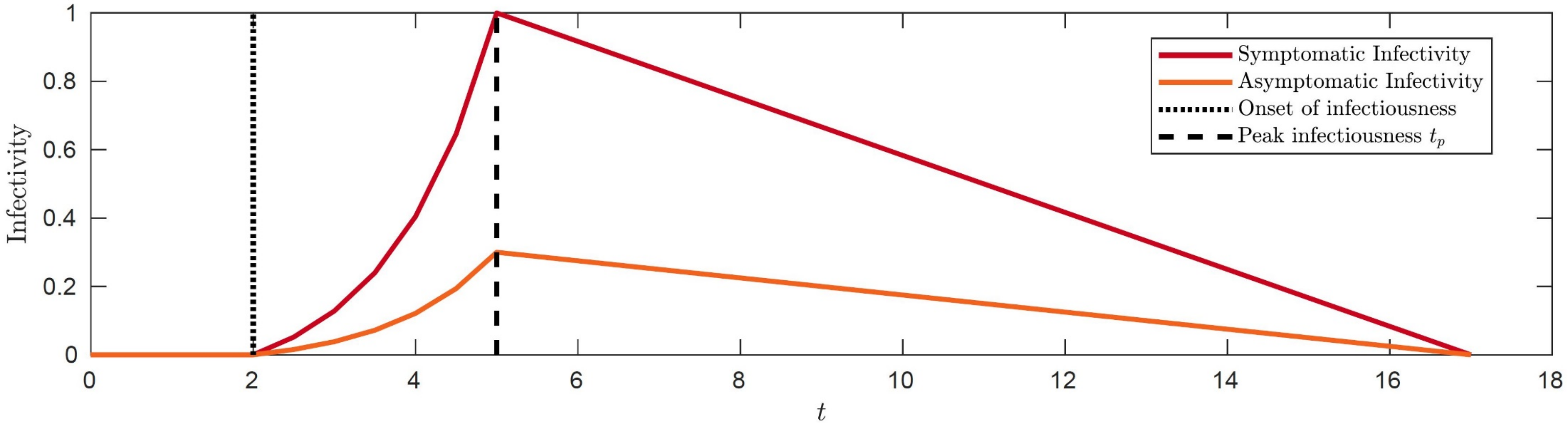
$$p^g_{j\to i}(n) = \kappa\, f(n - n_j \mid j)\, q^g_{j\to i}$$

$$p_i(n) = 1 - \prod_{g\in G_i(n)} \left[\prod_{j\in A_g\setminus i} \left(1 - p^g_{j\to i}(n)\right) \right]$$

global scalar

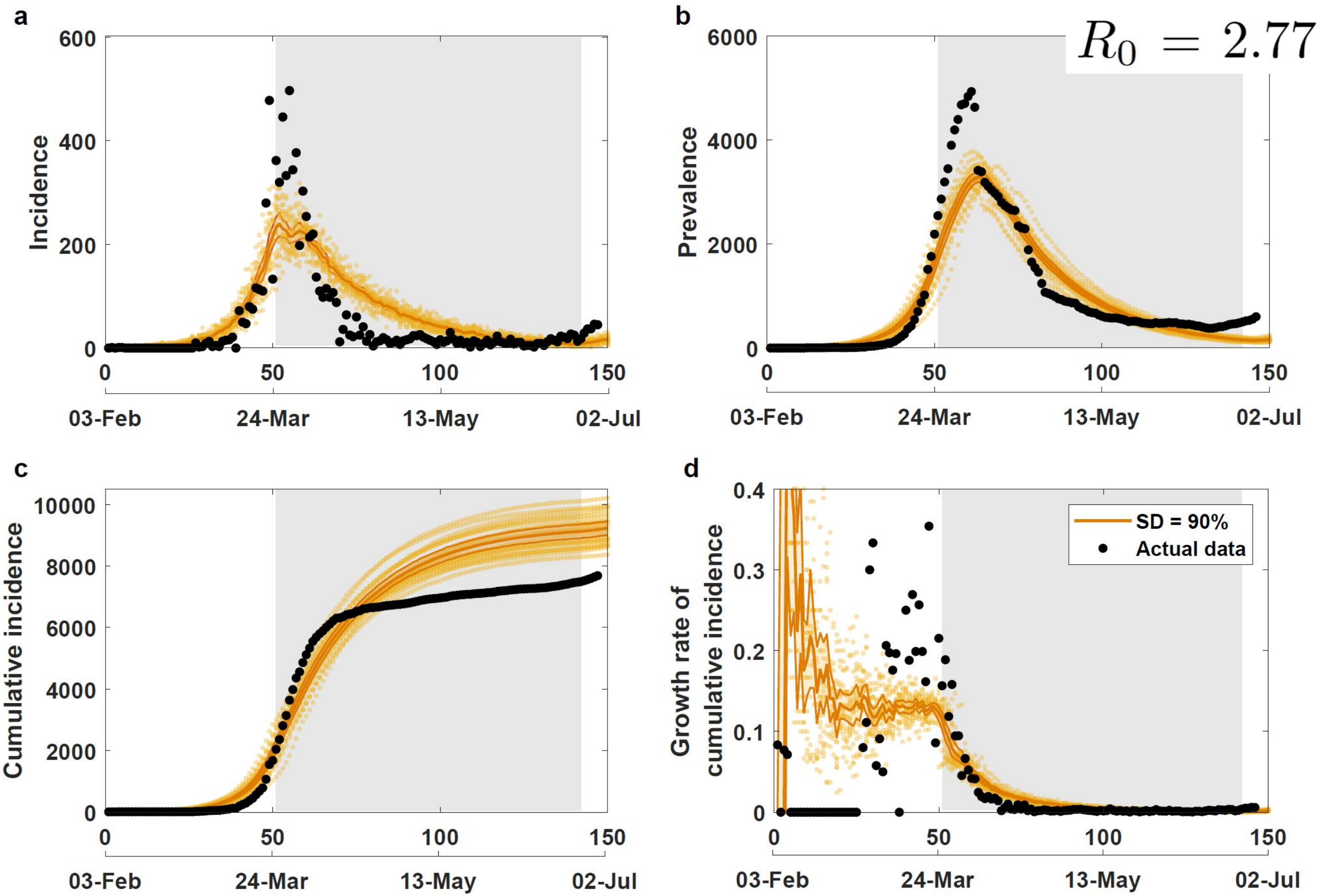
$$\beta / \gamma = R_0$$

Epidemic modelling: natural history of the disease (our 2020 model: AMTraC-19 version 6.1)

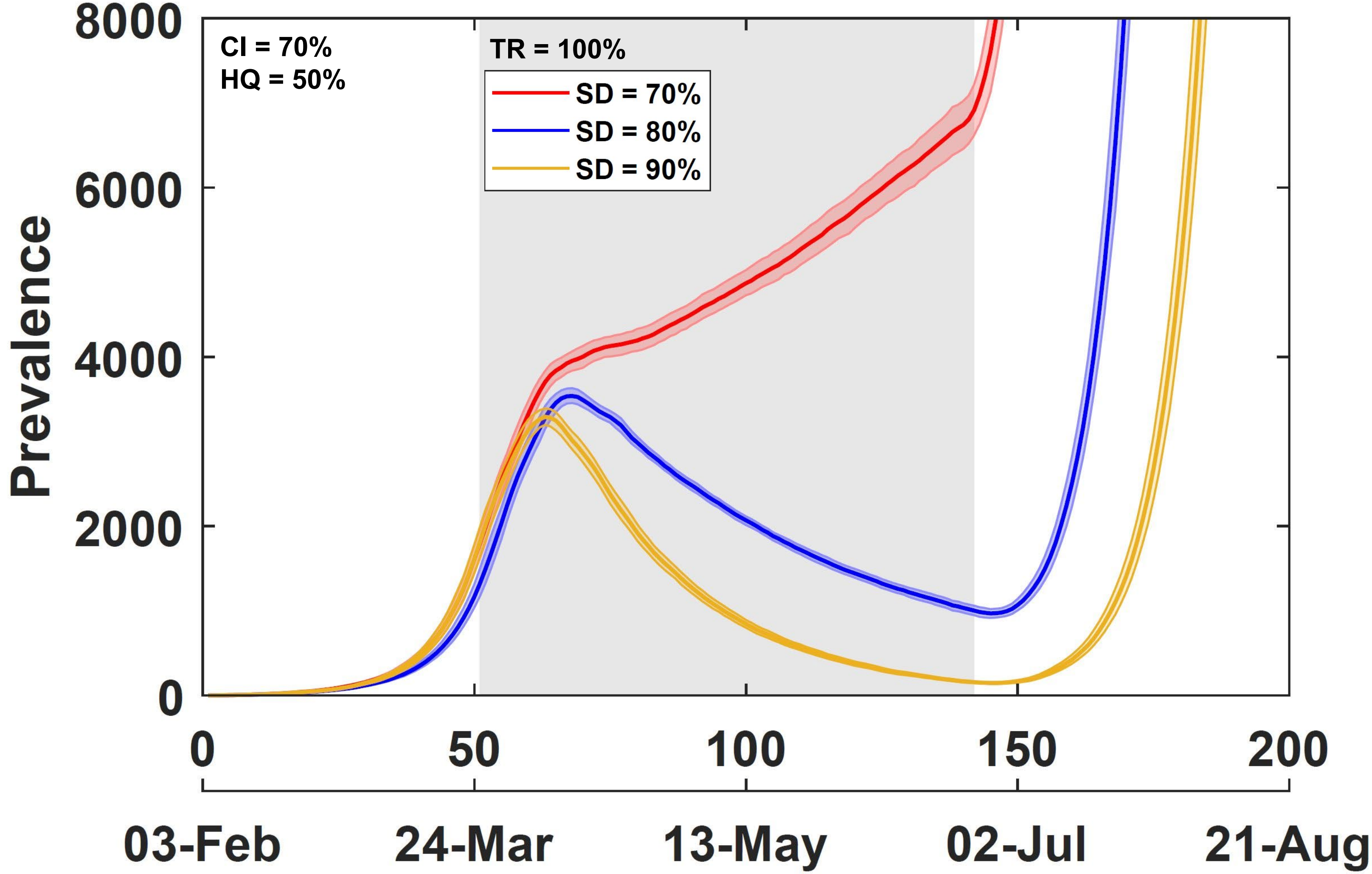


S. L. Chang, N. Harding, C. Zachreson, O. M. Cliff, M. Prokopenko, Modelling transmission and control of the COVID-19 pandemic in Australia, *Nature Communications*, 11, 5710, 2020.

AMTraC-19 validation (version 6.1)

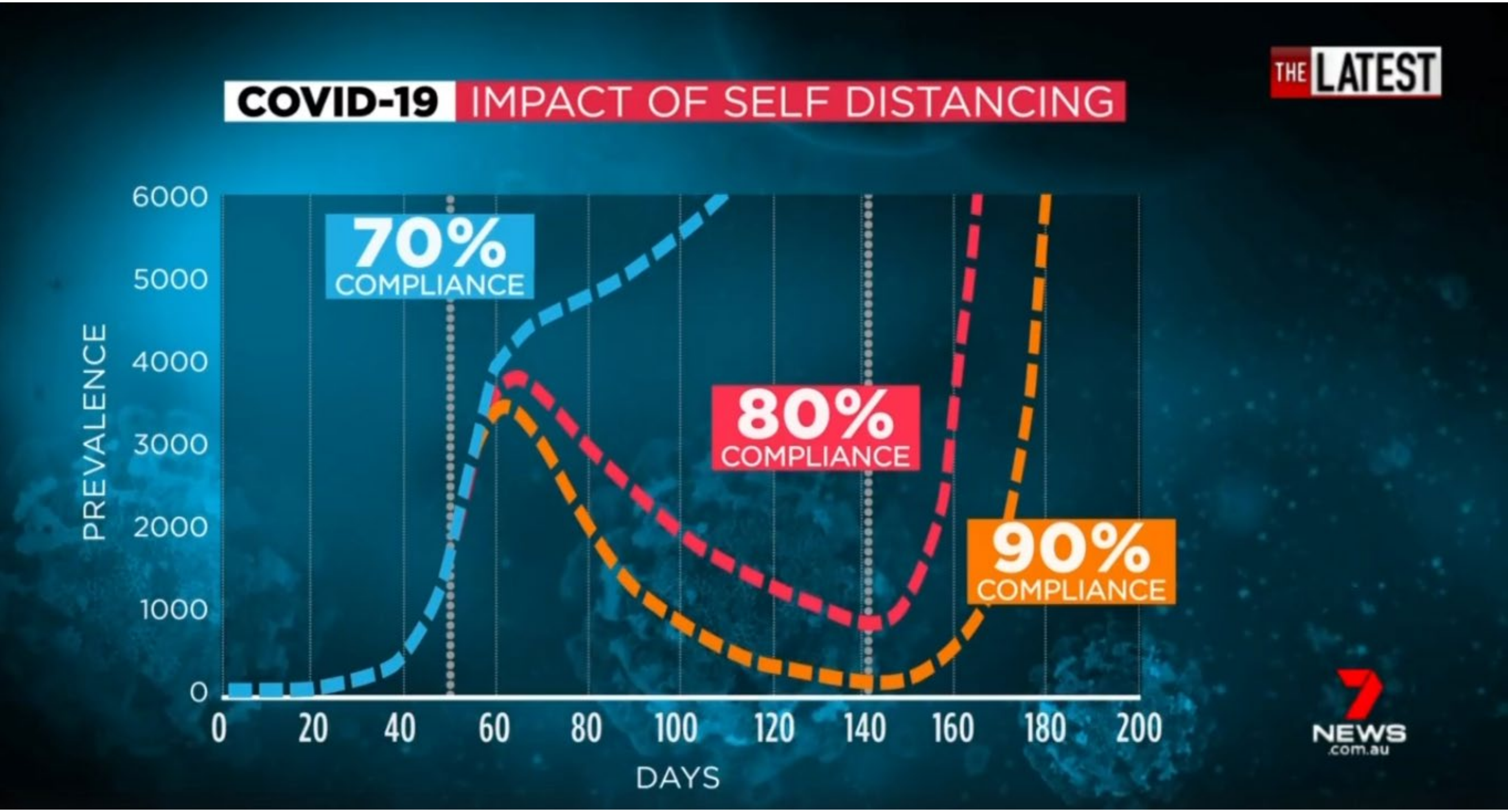


2020 model: a tipping point in social distancing



S. L. Chang, N. Harding, C. Zachreson, O. M. Cliff, M. Prokopenko, Modelling transmission and control of the COVID-19 pandemic in Australia, *Nature Communications,* 11, 5710, 2020.

Media coverage (April 2020)



Epidemic modelling: natural history of the disease (our 2021 model: AMTraC-19 version 7.6)

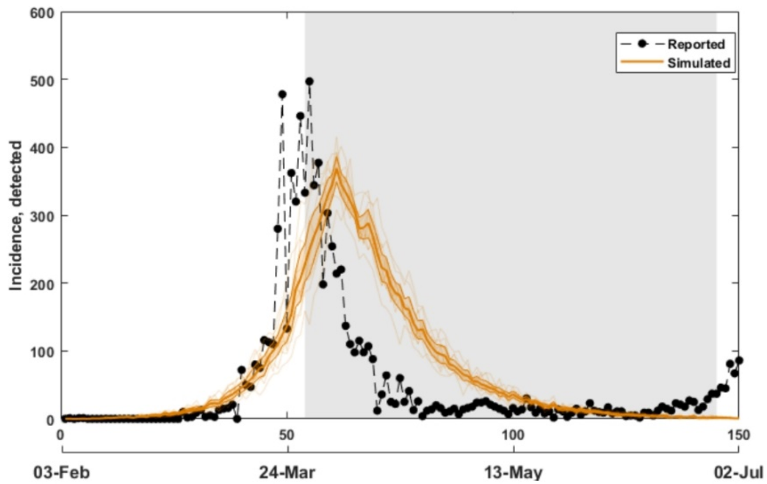
- infectious incubation period is log-normally distributed with mean 5.5 days
- infectious asymptomatic or symptomatic period, following incubation, lasts between 7 and 14 days (uniformly distributed with mean 10.5 days)
- differentiation between:
  - "asymptomatic infectivity" (factor of 0.5) and
  - "pre-symptomatic infectivity" (factor of 1.0)
- detection probabilities:
  - symptomatic (detection per day is 0.23)
  - pre-symptomatic and asymptomatic (detection per day is 0.01)

C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *arXiv*:2103.07061, 2021.

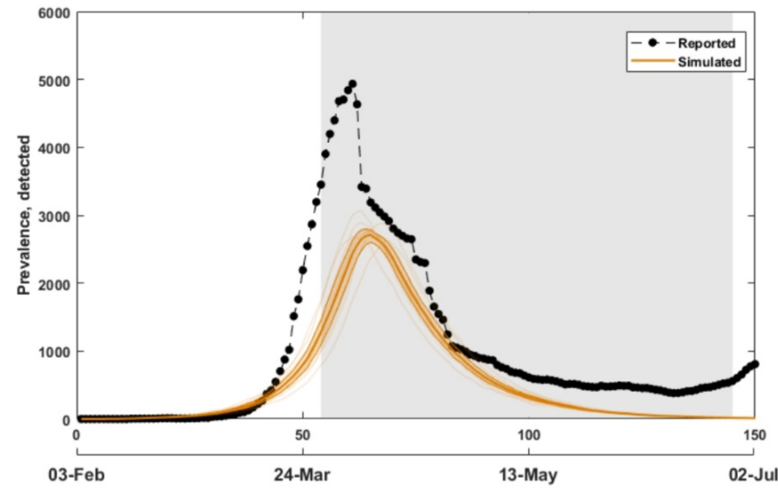
AMTraC-19 validation (version 7.6): 1st wave

$R_0 = 2.75$

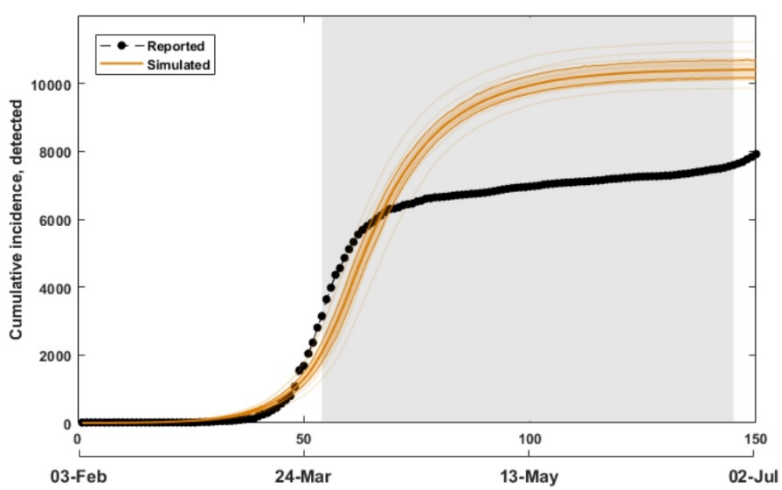
a)



b)

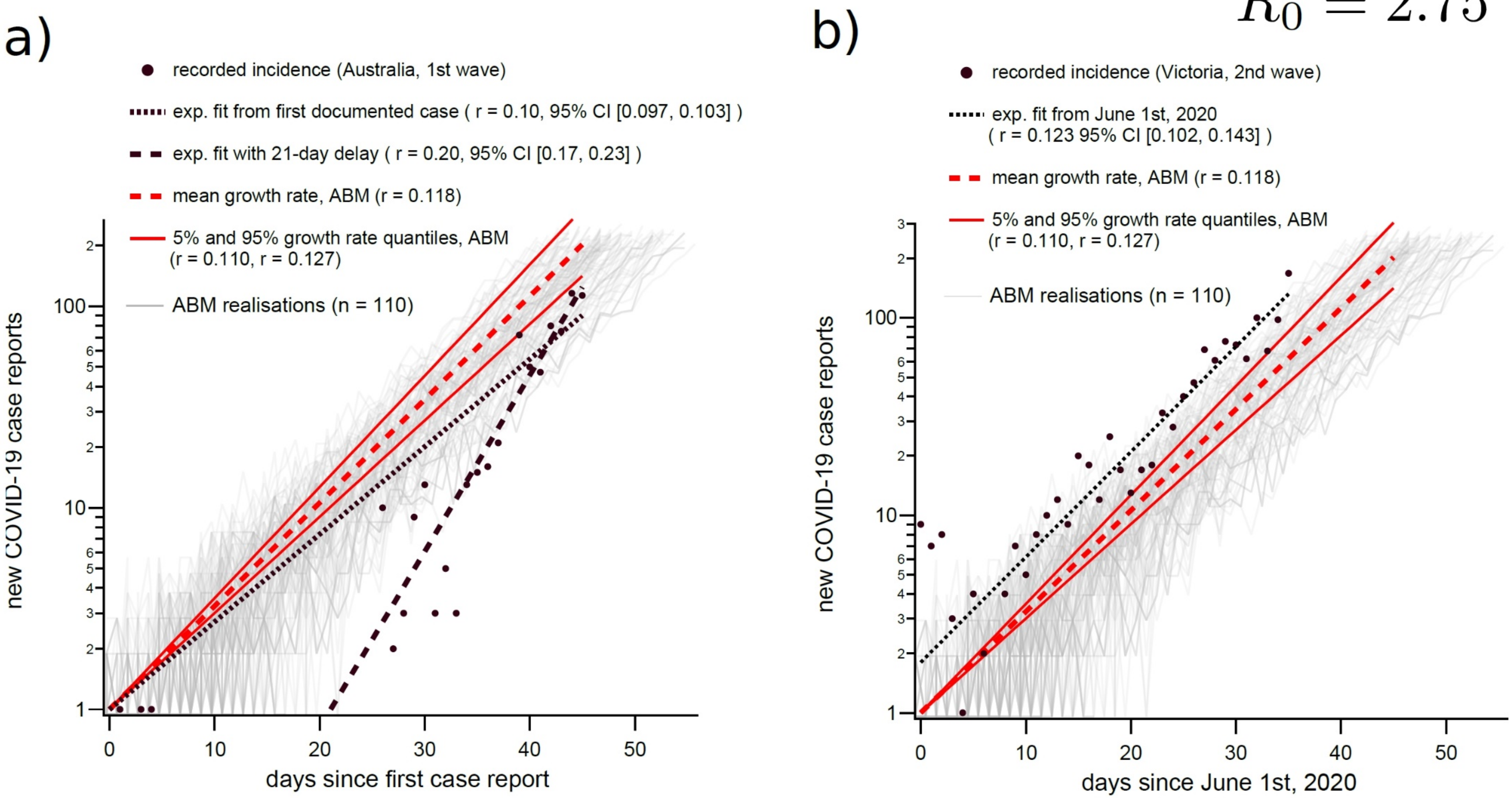


c)



AMTraC-19 validation (v7.6): 1st and 2nd waves

$$R_0 = 2.75$$



C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *arXiv*:2103.07061, 2021.

THE UNIVERSITY OF SYDNEY

Vaccine efficacy and herd immunity (…textbook)

Vaccine efficacy: VE = 1 – risk

where risk is relative risk for developing a condition in vaccinated people compared to unvaccinated people

Herd immunity threshold:

$$\frac{1 - 1/R_0}{VE}$$

$R_0 = 2.75$ and $VE = 0.9$:

$$\frac{1 - 1/2.75}{0.9} = 0.707$$

$R_0 = 5.5$ and $VE = 0.8$:

$$\frac{1 - 1/5.5}{0.8} = 1.023$$

Modelling vaccination rollout (our 2021 model: AMTraC-19 version 7.6)

- Efficacy for susceptibility (VEs): impacts immunity in those susceptible to the virus (reduces the probability of becoming infected if exposed)

- Efficacy for disease (VEd): impacts the expression of illness in those who are vaccinated and subsequently become infected (reduces the probability of expressing symptoms if infected)

- Efficacy for infectiousness (VEi): impacts the potential for vaccinated individuals to transmit the virus if infected (reduces the force of infection produced by infected individuals who are vaccinated)

$$VE = VEd + VEs - VEs \times VEd \qquad VEi = \sim 0.5$$

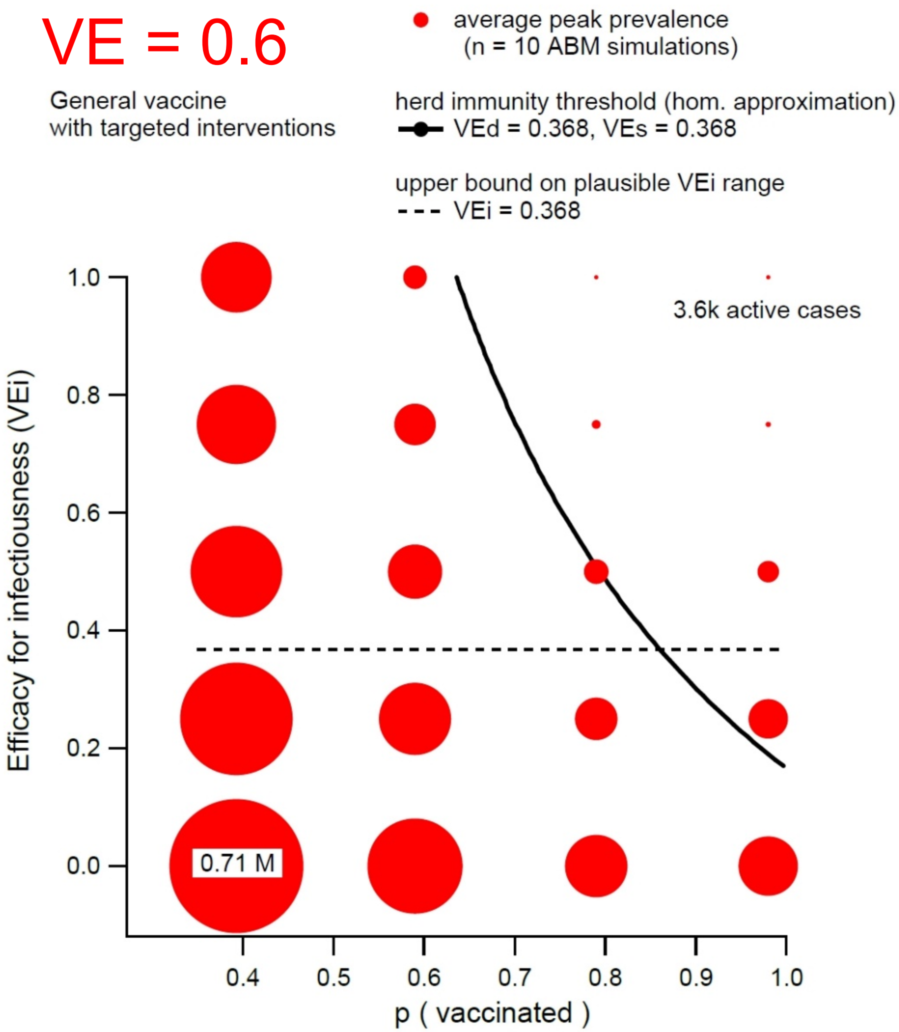
for example:

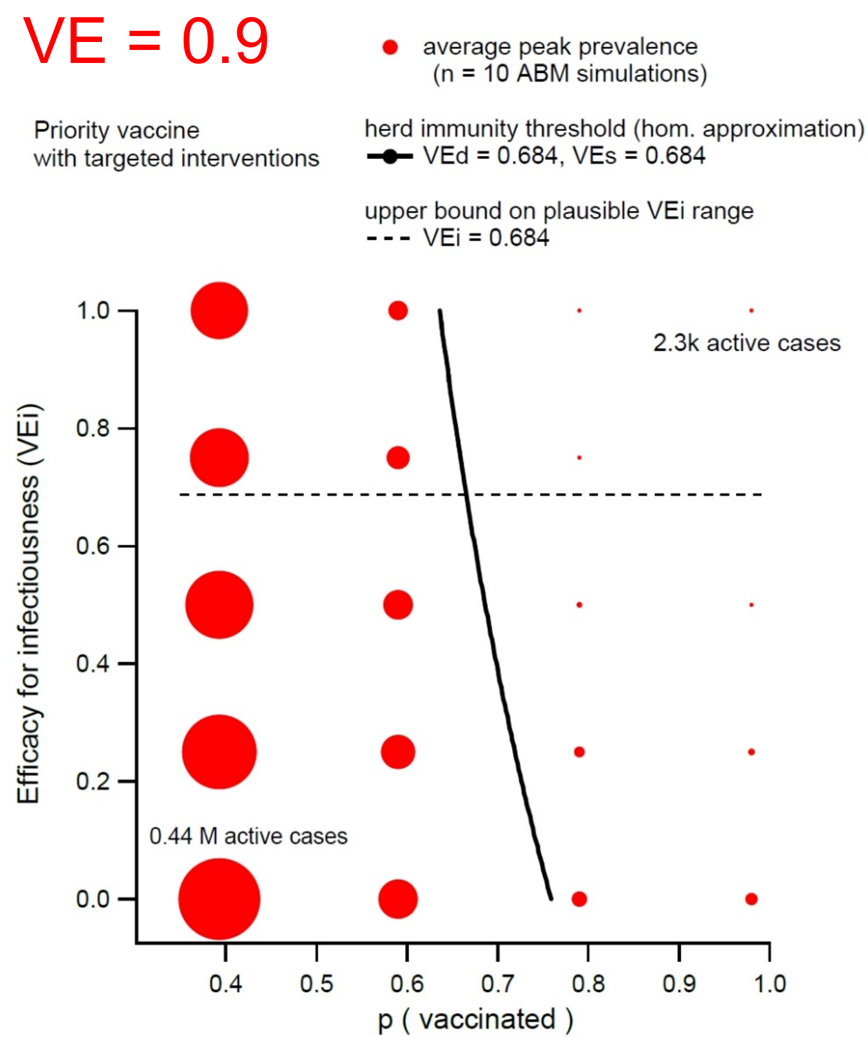
$$0.91 = 0.7 + 0.7 - 0.7 \times 0.7$$
$$0.92 = 0.8 + 0.6 - 0.8 \times 0.6$$

$$0.75 = 0.5 + 0.5 - 0.5 \times 0.5$$
$$0.65 = 0.5 + 0.3 - 0.5 \times 0.3$$

C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *arXiv*:2103.07061, 2021.

Will there be herd immunity?





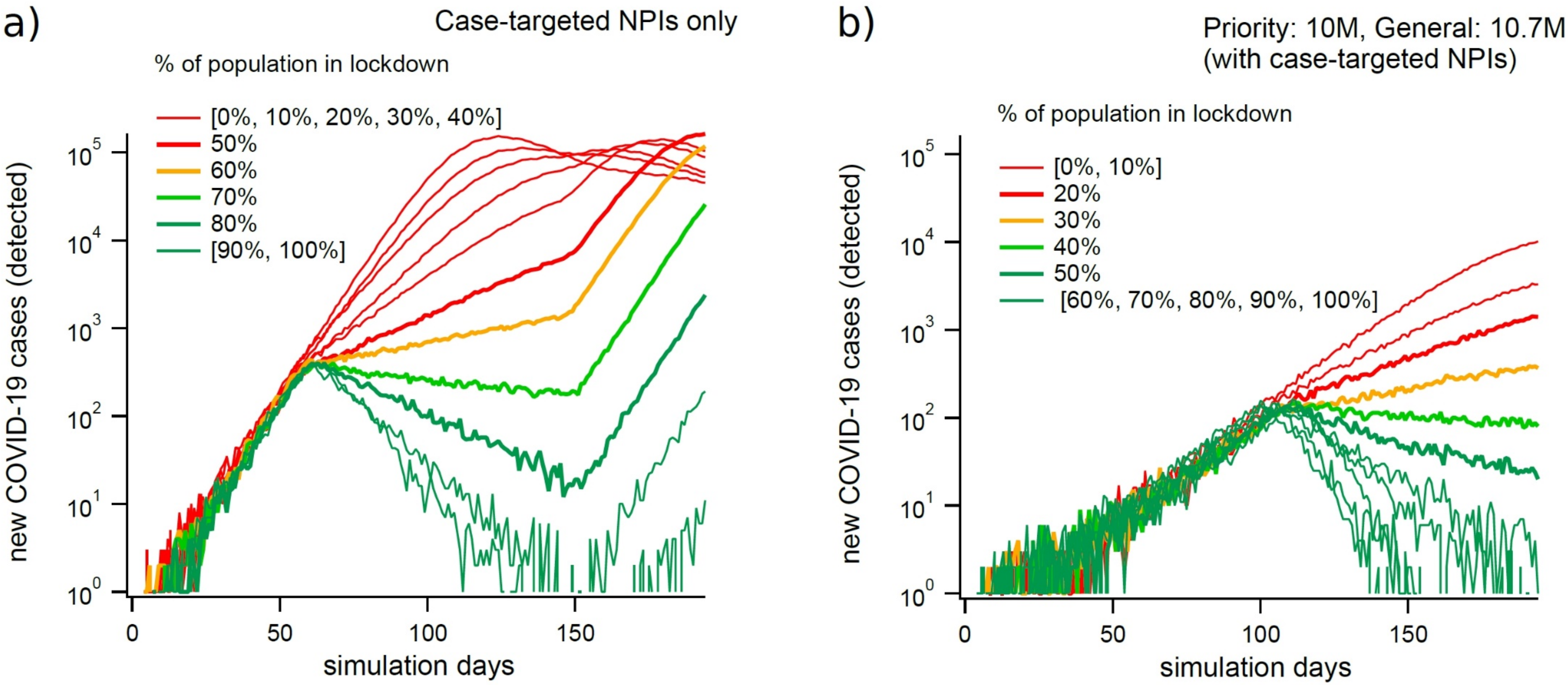
C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *arXiv*:2103.07061, 2021.

Feasible rollout scenarios

scenario	targeted NPIs	priority immunisations	general immunisations
no intervention	nil	nil	nil
targeted NPIs only	TR, CI, HQ*	nil	nil
priority vaccine (5M)	”	5×10^6	nil
general vaccine (11.5M)	”	nil	11.5×10^6
priority vaccine (10M)	”	10^7	nil
priority 10M, general 2.5M	”	10^7	2.5×10^6
priority 10M, general 6.1M	”	10^7	6.1×10^6
priority 10M, general 10.7M	”	10^7	10.7×10^6

C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *arXiv*:2103.07061, 2021.

How much social distancing will be required?



C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *arXiv*:2103.07061, 2021.

THE UNIVERSITY OF SYDNEY

Implications…

- targeted interventions (CI, HQ) would continue to be required in near future
- a hybrid rollout (using both priority and general vaccine), even with 80-90% of coverage, will not reach herd immunity:
  - partial restrictions will be needed during outbreaks (~40% SD: working from home, reduced contacts, school closures, …);
  - otherwise, rapid sizeable outbreaks with thousands of new cases per day are likely
- border closures (TR) would be required until at least 70% of the population is vaccinated with a high-efficacy vaccine (VE > 0.9), assuming $R_0 < 3$
- mass-vaccination with current vaccines needs to be completed before the booster(s) for new variants become available, and before the first vaccinated cohorts lose immunity
- if efficacy remains high (VE > 0.9) against new variants ($R_0 > 5$), then vaccinating 90% of the population would be required before returning to "new normal" (small isolated outbreaks)
- potential risks:
  - convergence to a super-bug (say, $R_0 > 10$)
  - increased symptoms in children
  - immune escape (e.g., efficacy of AZ is 10.4% against the variant found in S. Africa)
  - lasting immunity gets shorter than 9-12 months
- potential solutions:
  - wide-spread adoption of mRNA vaccines and boosters (e.g., Pfizer, Moderna)
  - new anti-viral drugs and treatments (beyond Regeneron "antibody cocktail")

THE UNIVERSITY OF SYDNEY

References

- O. M. Cliff, N. Harding, M. Piraveenan, E. Erten, M. Gambhir, M. Prokopenko, Investigating spatiotemporal dynamics and synchrony of infuenza epidemics in Australia: An agent-based modelling approach, *Simulation Modelling Practice and Theory*, 87, 412-431, 2018.
- K. M. Fair, C. Zachreson, M. Prokopenko, Creating a surrogate commuter network from Australian Bureau of Statistics census data, *Scientific data*, 6, 150, 2019.
- C. Zachreson, K. M. Fair, N. Harding, M. Prokopenko, Interfering with influenza: nonlinear coupling of reactive and static mitigation strategies, *Journal of Royal Society Interface*, 17(165): 20190728, 2020.
- S. L. Chang, N. Harding, C. Zachreson, O. M. Cliff, M. Prokopenko, Modelling transmission and control of the COVID-19 pandemic in Australia, *Nature Communications,* 11, 5710, 2020.
- O. Dyer, Covid-19: Countries are learning what others paid for vaccines, *BMJ*, 372: n281, 2021.
- S. A. Madhi et al., Efficacy of the ChAdOx1 nCoV-19 Covid-19 Vaccine against the B.1.351 Variant, *The New England Journal of Medicine*, DOI: 10.1056/NEJMoa2102214, 2021.
- Europe secures 55,000 doses of Roche-Regeneron COVID drug hope, *Reuters*, 4 June 2021, https://www.reuters.com/business/healthcare-pharmaceuticals/europe-secures-55000-doses-roche-regeneron-covid-drug-hope-2021-06-03/
- Here's what we know about the Indian Delta COVID-19 variant detected in Victoria's outbreak, *ABC News*, 5 June 2021, https://www.abc.net.au/news/2021-06-04/what-do-we-know-about-delta-kappa-covid-variants/100190414
- C. Zachreson, S. L. Chang, O. M. Cliff, M. Prokopenko, How will mass-vaccination change COVID-19 lockdown requirements in Australia? *arXiv*:2103.07061, 2021.