Real-time modelling of the COVID-19 epidemic Perspectives from British Columbia

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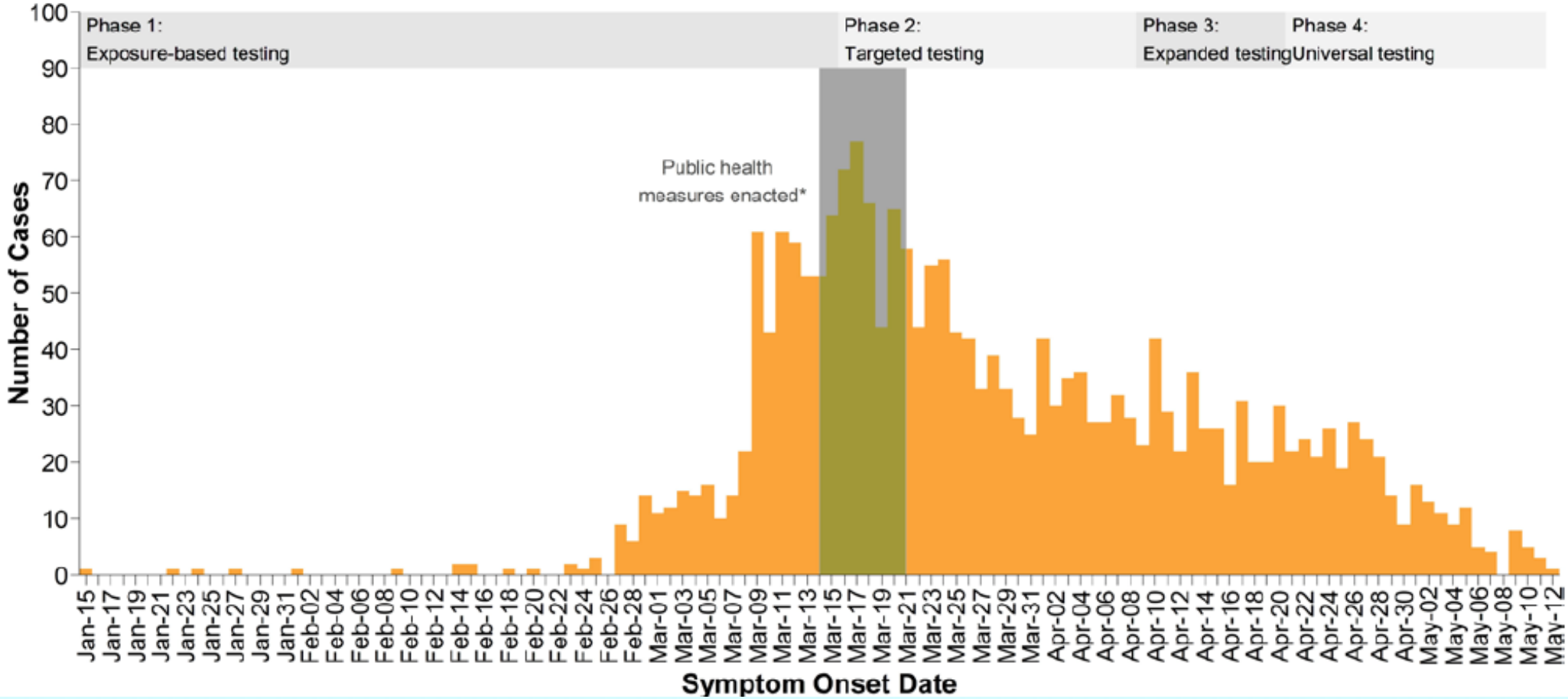
PIMS seminar, May 14, 2020

British Columbia's Epidemic

Figure 2: Epidemic curve, COVID-19 cases in BC by symptom onset date January 15 - May 12, 2020 **(N=2,207†)**



May 13, bccdc.ca

The basic reproductive number R_0

- The *most important* epidemic parameter
  - the *average* number of new infections caused by a single newly infected person *at the beginning of the epidemic*
  - when interventions are in place, becomes R_{eff} or just R.
- $R_0 > 1$: "exponential growth is *possible*"
- $R_0 < 1$: "extinction is *guaranteed*"
  - Pandemic influenza: $R_0 \sim 1.6$
  - SARS $R_0 \sim 2.5$
  - Measles: $R_0 \sim 18$
  - **COVID-19 $R_0 \sim 2 - 4$**

Coming up:

- What comes next?
- Herd immunity and why returning to normality now is a bad idea
- Heterogeneity and an age- and activity- structured model
- Contact tracing and apps
- Predictions, thoughts and scenarios

What comes next?

- In the long term, and unlike SARS, COVID-19 seems unlikely to become extinct

Over the next year, three ways to mitigate the pandemic:

- Vaccination
- Effective treatment
- Herd immunity + social interventions

Where are we going?

- In the long term, and unlike SARS, COVID-19 seems unlikely to become extinct

Over the next year, three ways to mitigate the pandemic:

- Vaccination
- Effective treatment
- Herd immunity + **social interventions**

Herd Immunity

- Breaking R_0 up:
  - average susceptible-infected **contact rate** *c* (per day)
  - average **probability of infection per contact** *p*
  - average ***duration of infectiousness*** *T* (days)

- $R_0 = c\ p\ T$

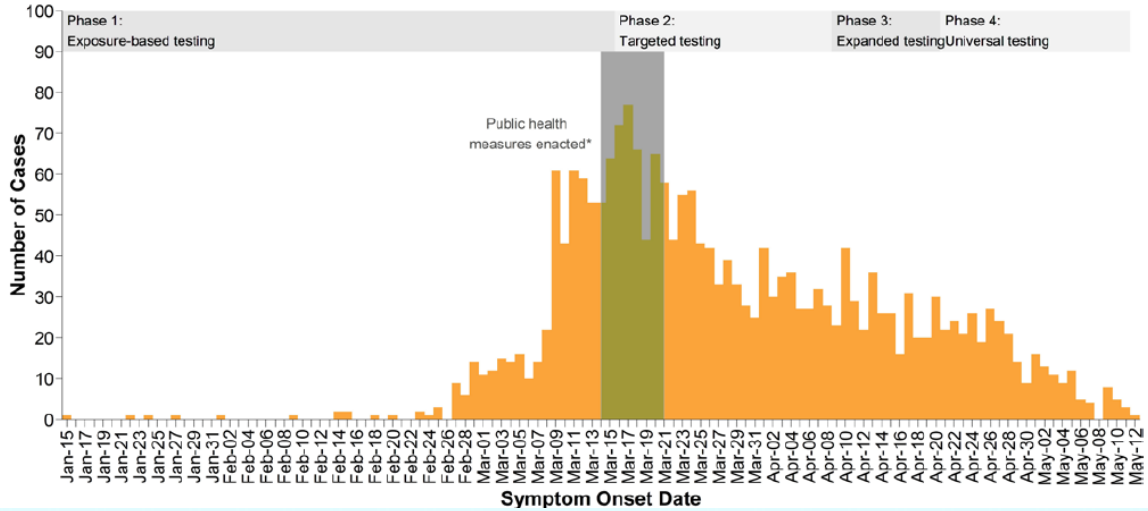
- **Herd immunity / social distancing:**
  - To prevent an epidemic, reduce *c, p* or *T* so $R_0 < 1$.

- Pandemic Influenza: $R_0 \sim 1.6$ so reduce contacts 37%
- Measles: $R_0 \sim 18$ so reduce contacts 94%
- COVID-19: $R_0 \sim 2.5$ so reduce contacts 60%

- Achieve by
  - vaccinating
  - letting the epidemic run its course (bad)
  - social distancing

Do we have herd immunity in BC?

Figure 2: Epidemic curve, COVID-19 cases in BC by symptom onset date January 15 - May 12, 2020 **(N=2,207†)**



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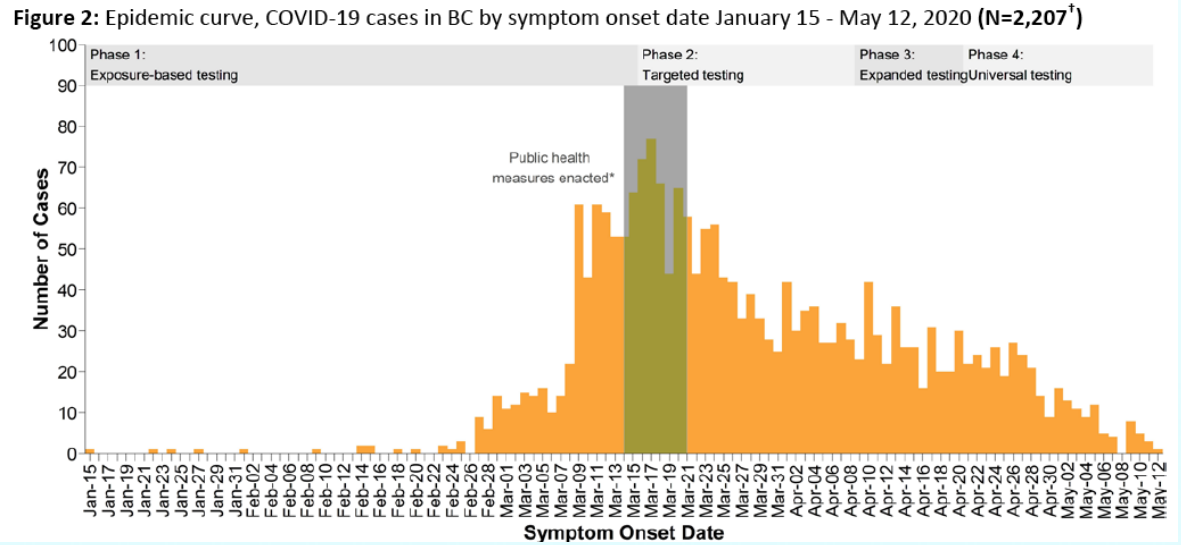
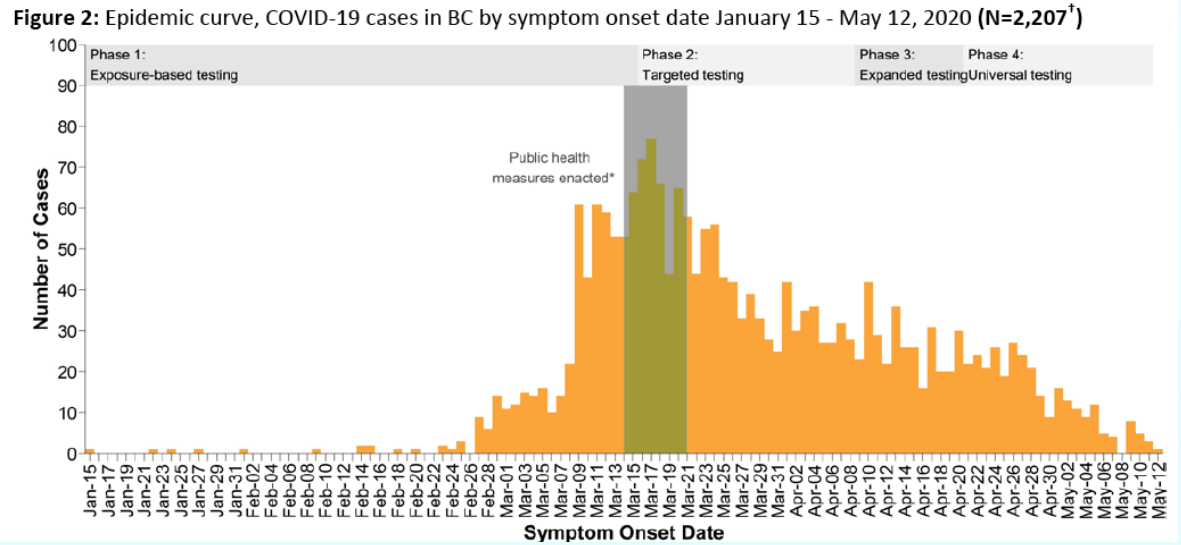


- A poor estimate of the number of undetected infections:

  - Denmark infection fatality rate in adults 18-70 ~0.1%
  - Deaths in BC in adults 18-70 to May 13: 17
  - **Total infections in adults in BC ~ 17,000 (<0.5%)**

  - Under-reporting factor ~ 10x
  - (There's debate, but only on the lower side)

Do we have herd immunity in BC?



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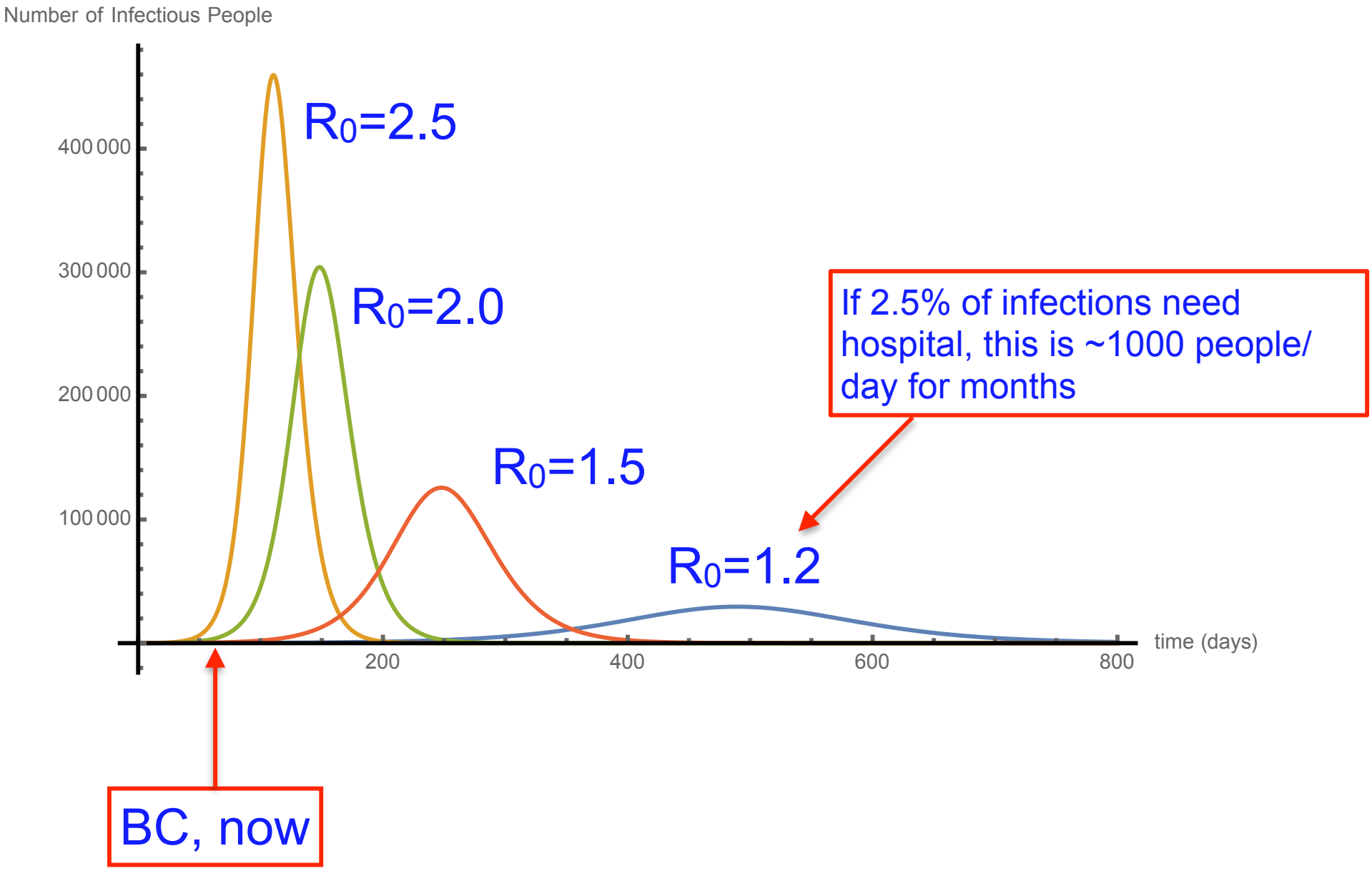
  - Total infections in adults in BC ~ 17,000 (<0.5%)

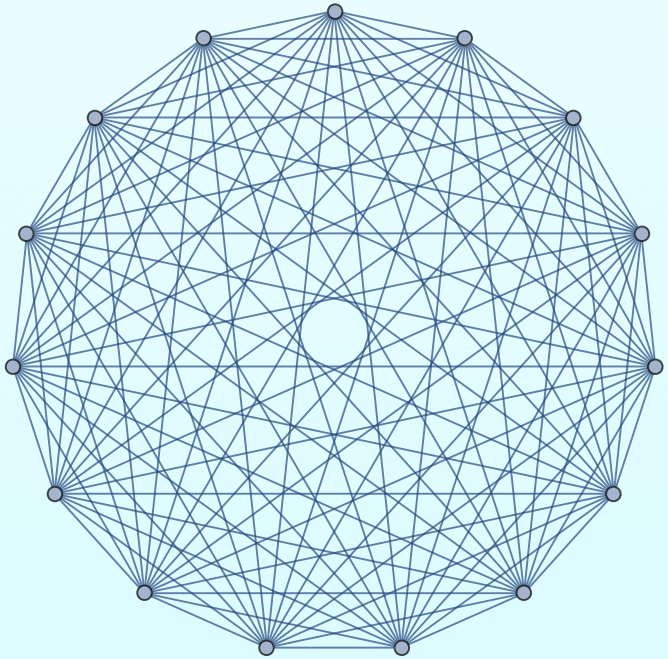
- **Herd immunity in BC is currently minimal**
- Spain May 13 news release indicates <~10%

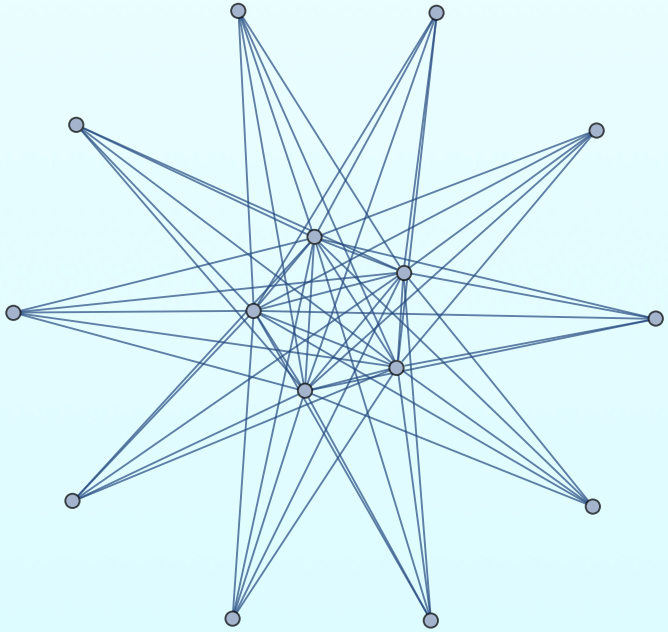
Returning to normal life now is a bad idea



Herd Immunity with Heterogeneity

Variation in susceptibility or contact rate:





- Herd immunity can potentially be achieved with fewer infections
- Accentuated epidemic deceleration
- Smart vaccination policies can be implemented

MGM Gomes, MedR*xiv:*20081893; T Britton *arXiv*:2005.03085

Herd Immunity with Heterogeneity

Variation in susceptibility or contact rate:

Table 1: Disease-induced herd immunity level h_D and classical herd immunity level $h_C = 1-1/R_0$ for different population structures, for $R_0 = 2.0$, 2.5 and 3.0. Numbers correspond to percentages.

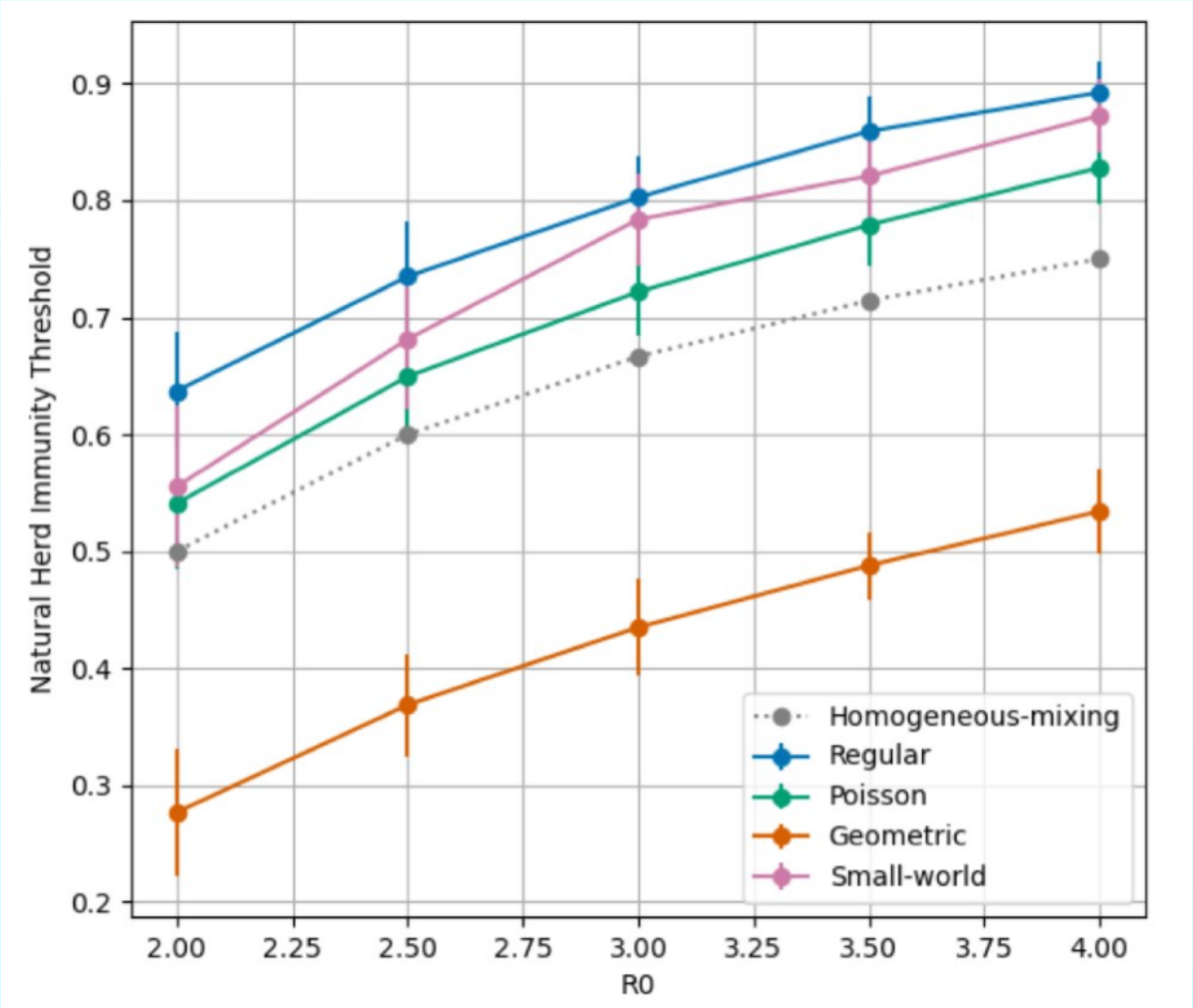
Population structure	h_D	h_C	h_D	h_C	h_D	h_C
Homogeneous	50.0	50.0	60.0	60.0	66.7	66.7
Age structure	46.0	50.0	55.8	60.0	62.5	66.7
Activity structure	37.7	50.0	46.3	60.0	52.5	66.7
Age & Activity structure	34.6	50.0	43.0	60.0	49.1	66.7

- Accumulated prevalence in BC is < 0.5%

T Britton *arXiv*:2005.03085

Herd Immunity with Heterogeneity

Networkologists: Variation in contact rate affects herd immunity threshold in a network-dependent way:



- rapid homogenization of skewed networks during epidemic
- random vaccination of small-world networks better than immunization by natural epidemic spread

Shweta Bansal, Georgetown; M.J. Ferrari et al, *Proc. Roy. Soc. B* (2006)

HOWEVER:

Variation in hospitalization / death rate by age-group

+

Low social activity of elderly people

=

reduced overall morbidity and mortality

leading to ideas for age-dependent social distancing and achieving herd immunity

Chikina and Pegden, arXiv:2004.04144

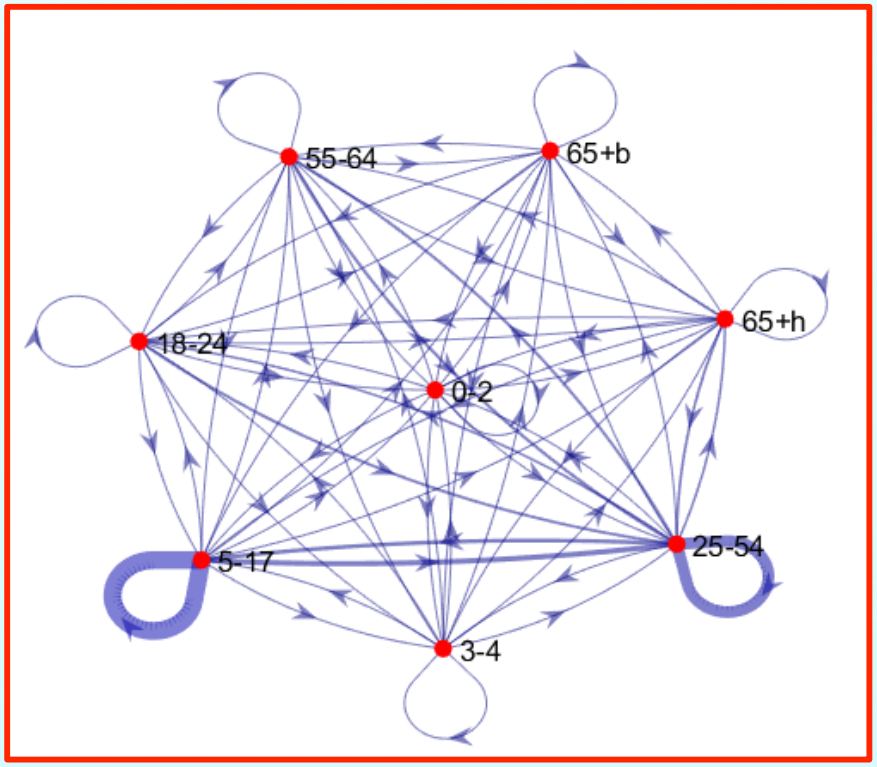
OK, so reaching herd immunity is out. Now what?

1. What kinds of relaxation of distancing measures may be possible?
    - estimating the relative contributions of different groups to overall spread
    - children's infections

2. Can we remain in the "maintenance phase" indefinitely?
    - contact tracing
    - apps

Age- and activity-structured model for BC

- ODE-based compartmental model following work from 2006-2010 from BCCDC (Babak Pourbohloul group)
- Detailed contact-based picture of the lower mainland.
- Divide population into 8 age-groups and 5 activity-levels
- 65+ age-group divided into community- and care-home groups

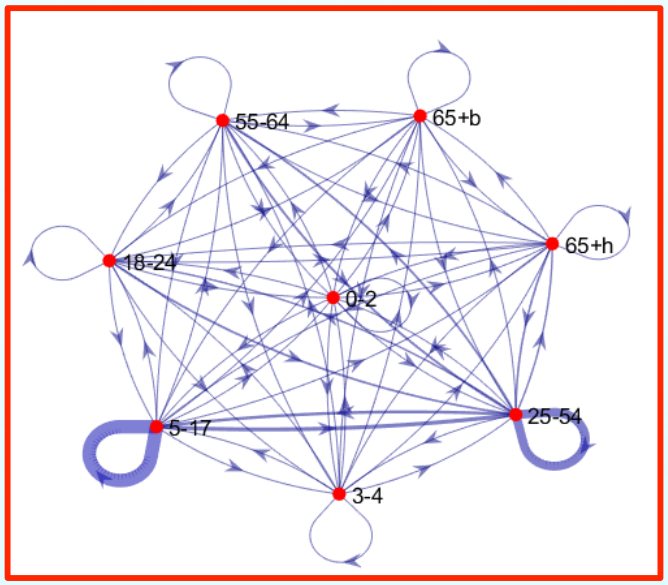


Sarafa Iyaniwura
Rebeca Falcao

Babak Pourbohloul
Jessica Conway

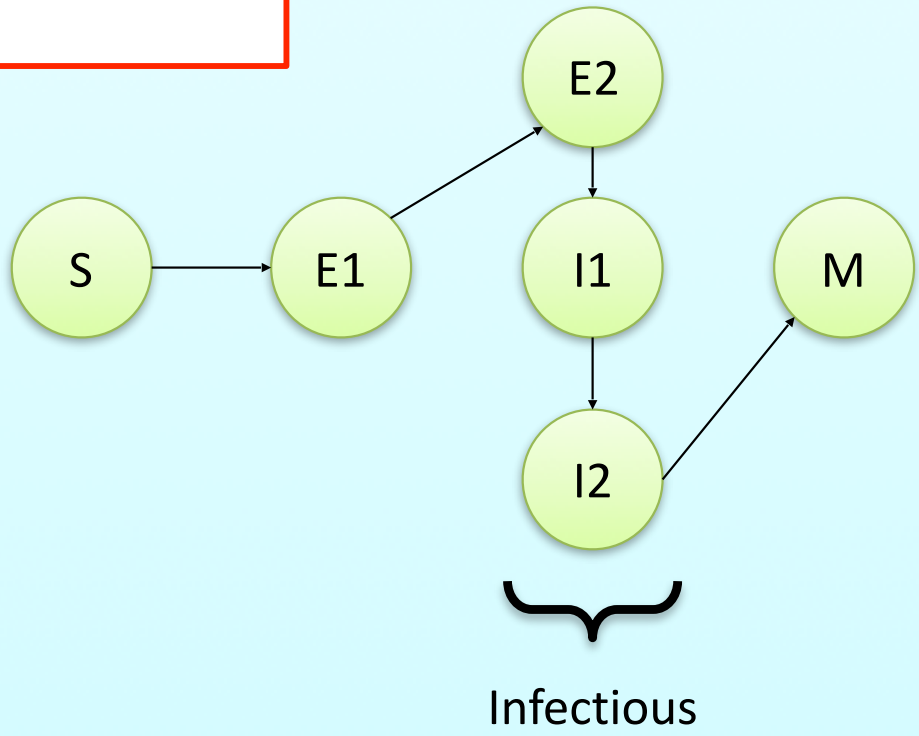
Conway et al, BMC Public Health 11:932 (2011)

Age- and activity-structured model for BC



- Within each age-group, the model follows

  S-E1-E2-I1-I2-R
- Self-isolation occurs (from I1)
- Control measures are implemented as changes to the contact structure and self-isolation parameter



JM Conway et al, BMC Public Health 11:932 (2011)

Calibration to BC Data

- Many possible ways to calibrate this model to BC data

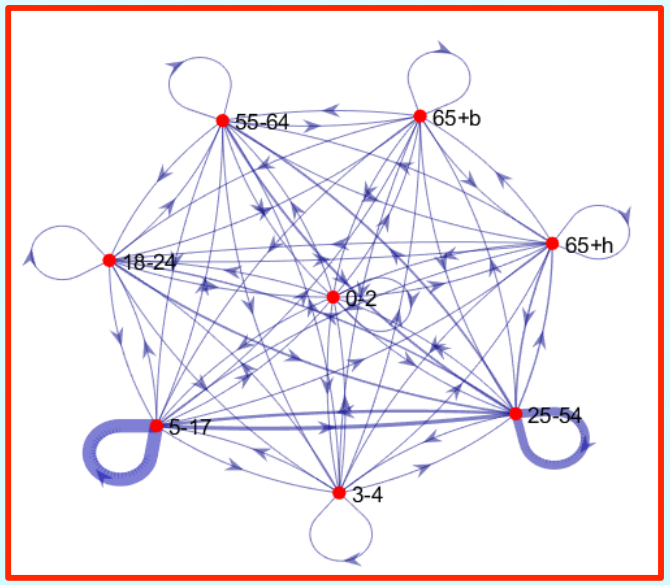
- Simplified method:
  - Estimate an initial R0 from March 1 to 14
  - On March 14th, modify contact structure:
    - Reduce # of contacts
    - Start self-isolation
  - Generate simulation from March 1 – April 30
  - Allowing for a time-lag, correlate age-structured infection to hospitalization/ICU admission

- Similar approach to new study from France
  - H. Salje et al, *Science* eabc3517
  - Estimates based on Diamond Princess passengers

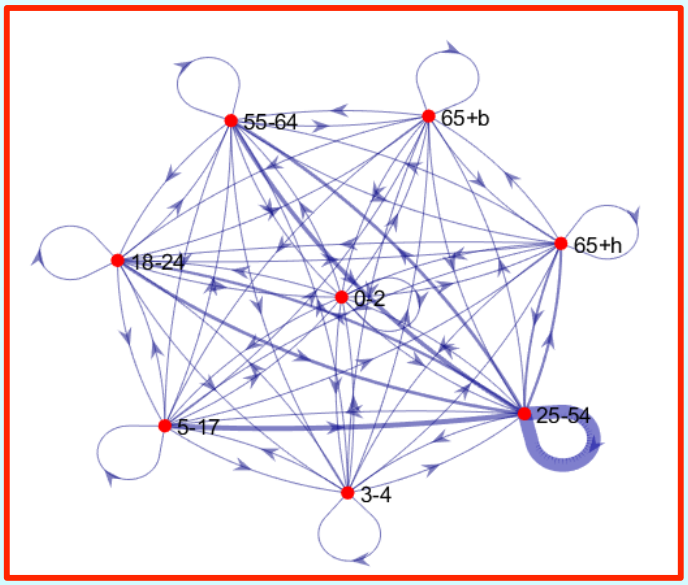
Children

- No consensus on child susceptibility or infectivity.
- In BC scenarios (no herd immunity), it makes no difference to the dynamics whether (i) kids are regularly infected but rarely transmit, or (ii) kids are rarely infected
- Child susceptibility is less important than one might initially think:
  - During calibration, if children are less susceptible, the observed infections must be accounted for by increased adult transmission.
  - As a result, the main effect of lower susceptibility is on the attack rate in kids when restrictions are lifted

100%



5%



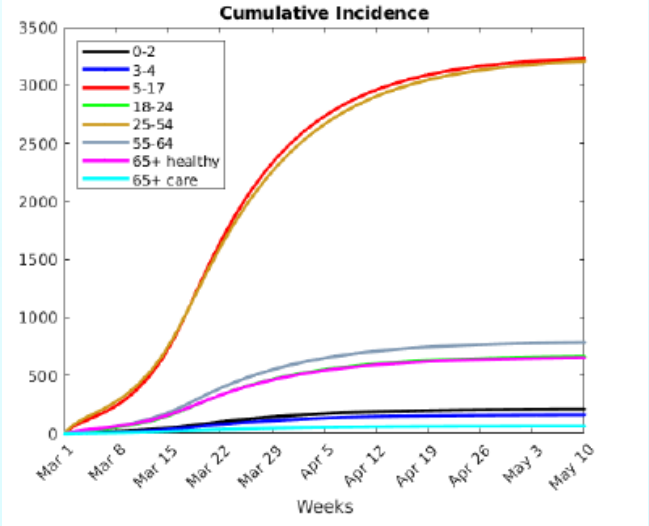
Example Calibration

- Social distancing: reduce contact numbers by 66% on March 14
- 70% self isolation after March 14

Model

Data

100%



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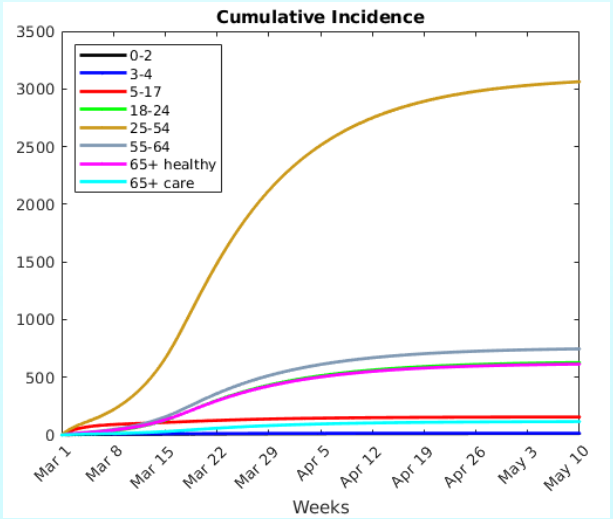
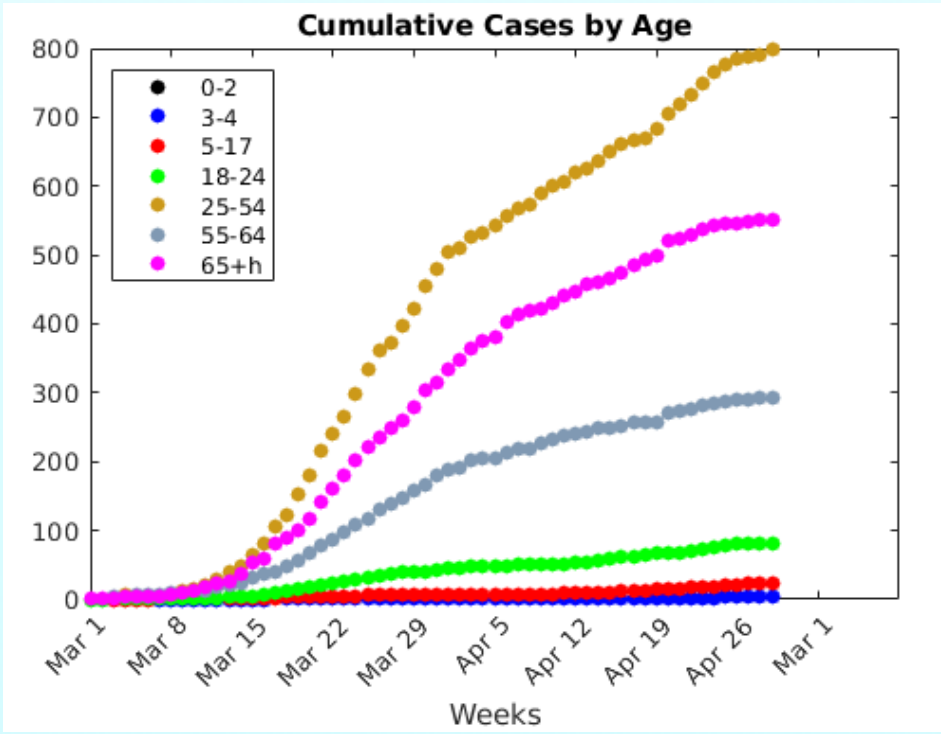


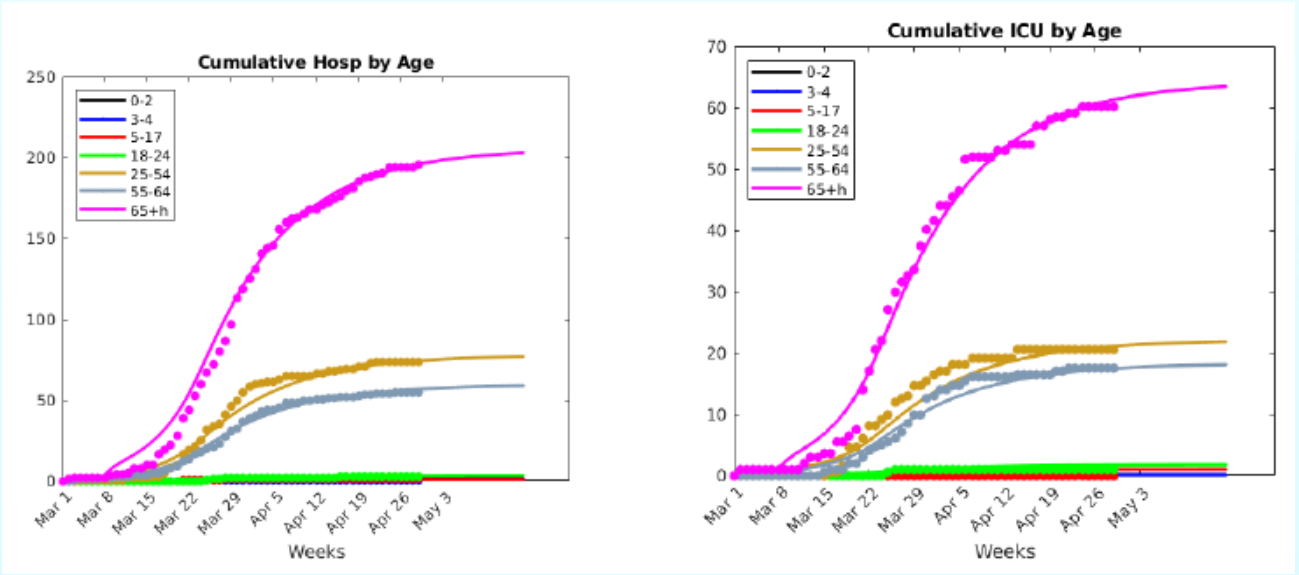


Example Calibration

Hospitalization

ICU

100%



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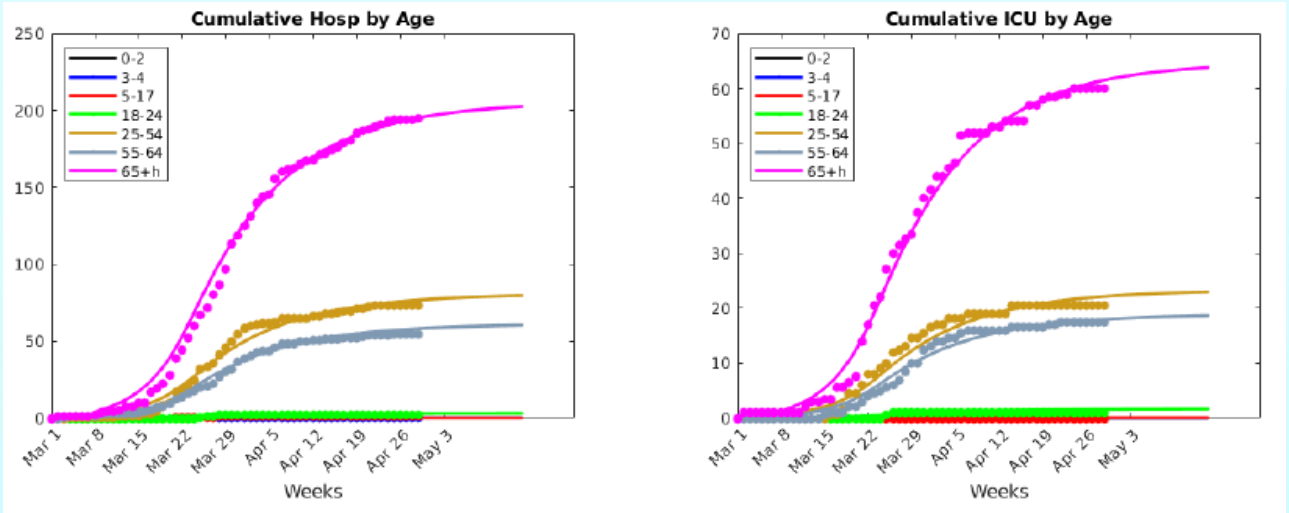

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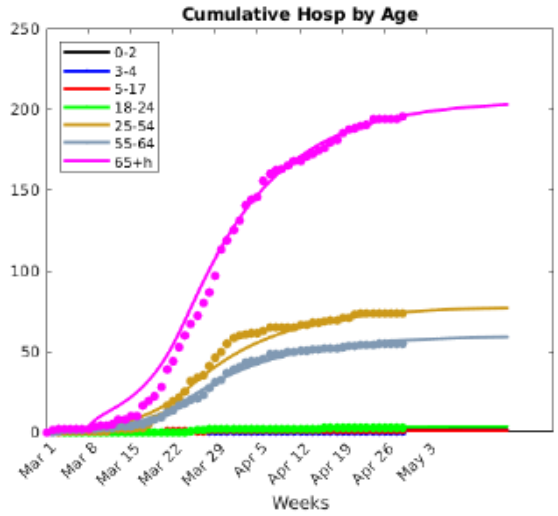
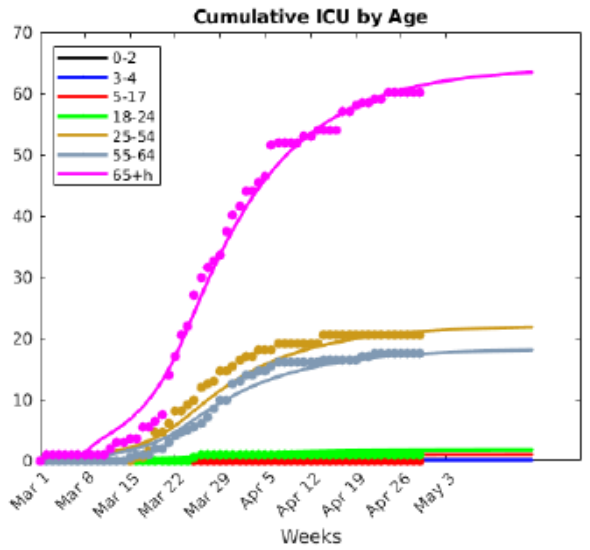
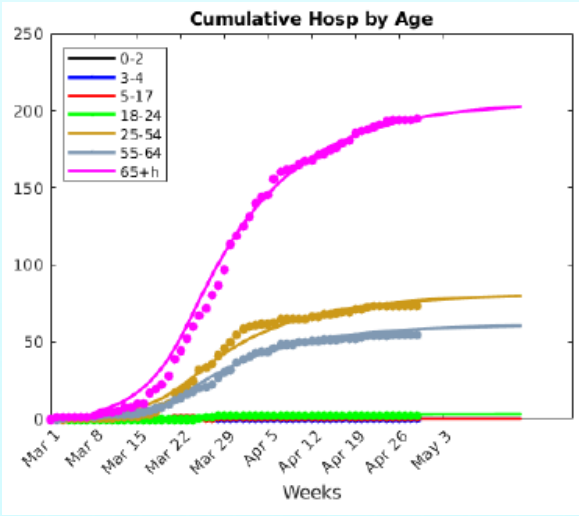


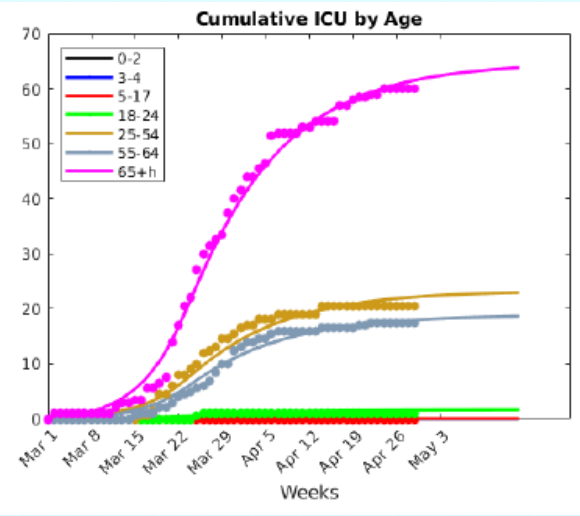


BC

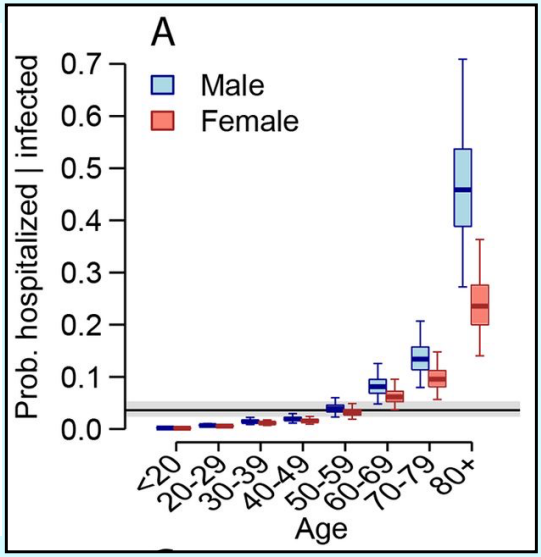
Age groups	Hospitalization (%)
0 - 2	0.67
3 - 4	0.67
5 - 17	0.03
18 - 24	0.50
25 - 54	2.60
55 - 64	8.10
65+ health	33.00

5%





France



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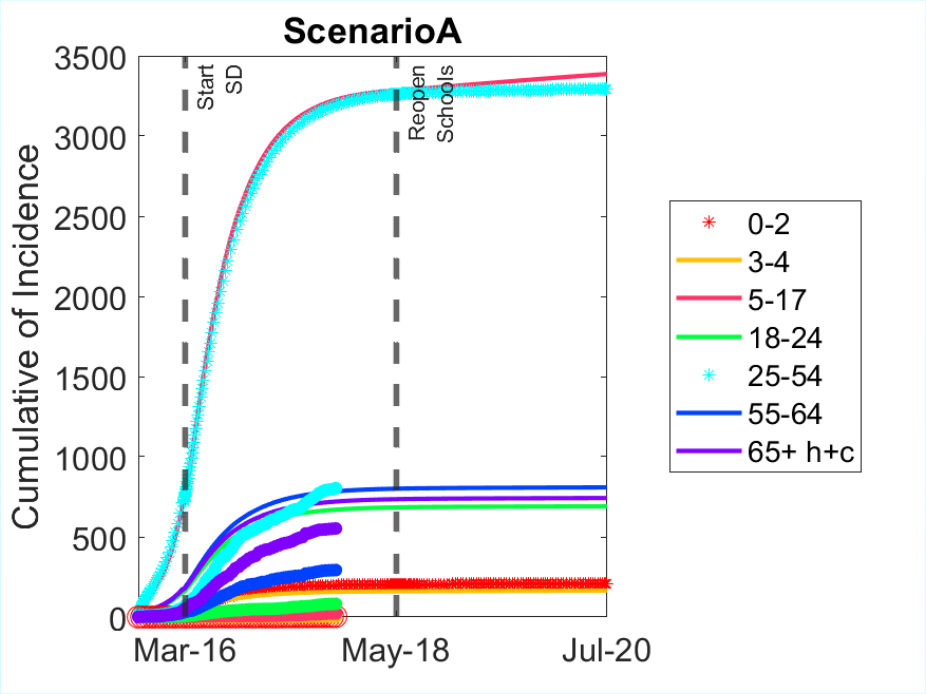
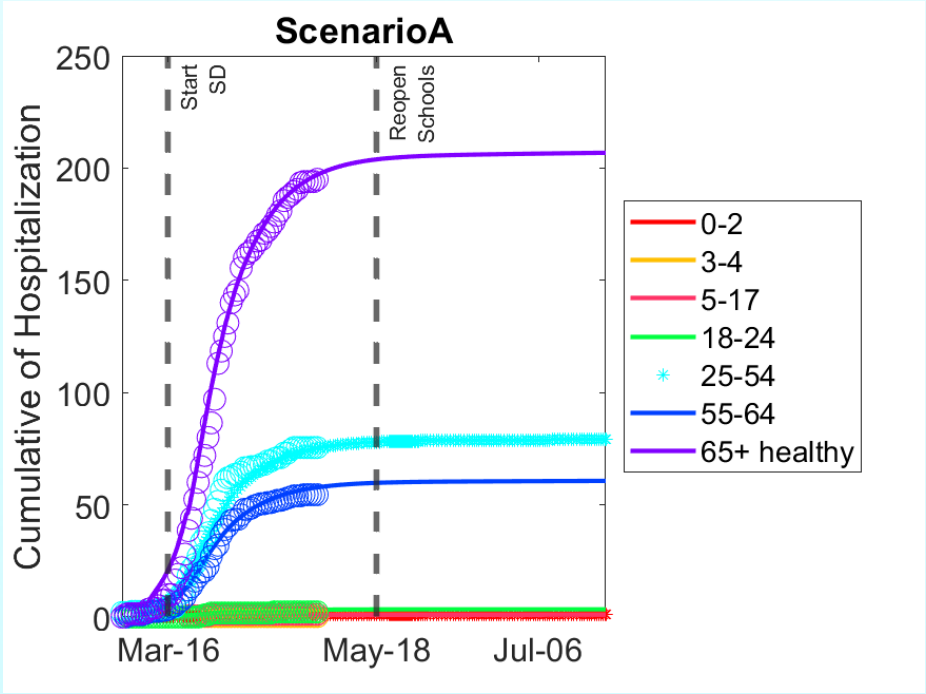
Relaxation Scenarios

- "Reopening schools and daycares alone"
  - Return all kids (0-18) contacts to initial levels on May 15
  - Adult contacts remain low
  - Self-isolation remains at 70%
- Kids 100% susceptible





Relaxation Scenarios

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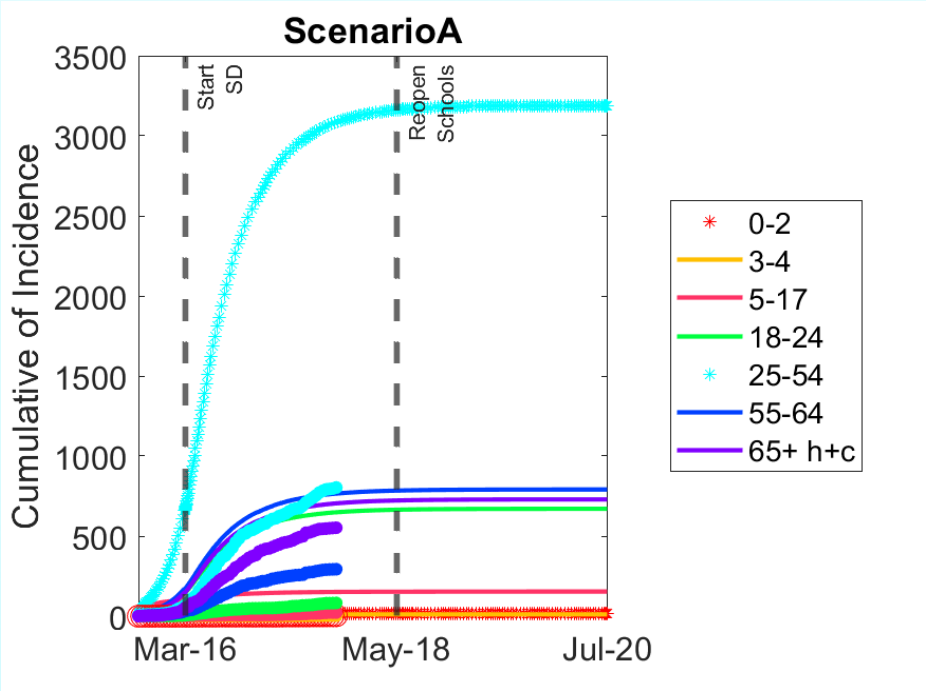
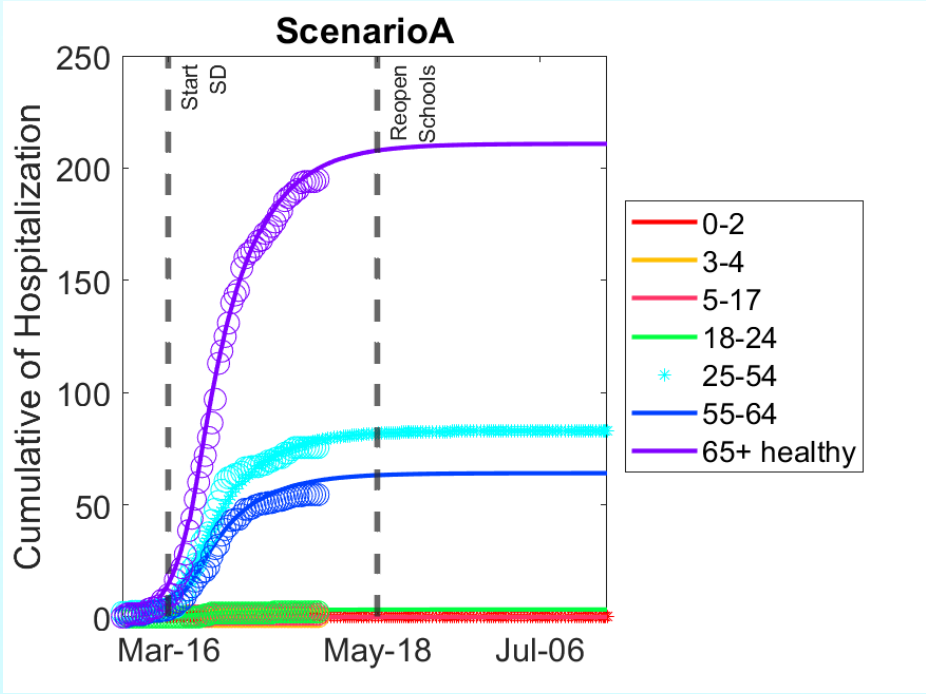
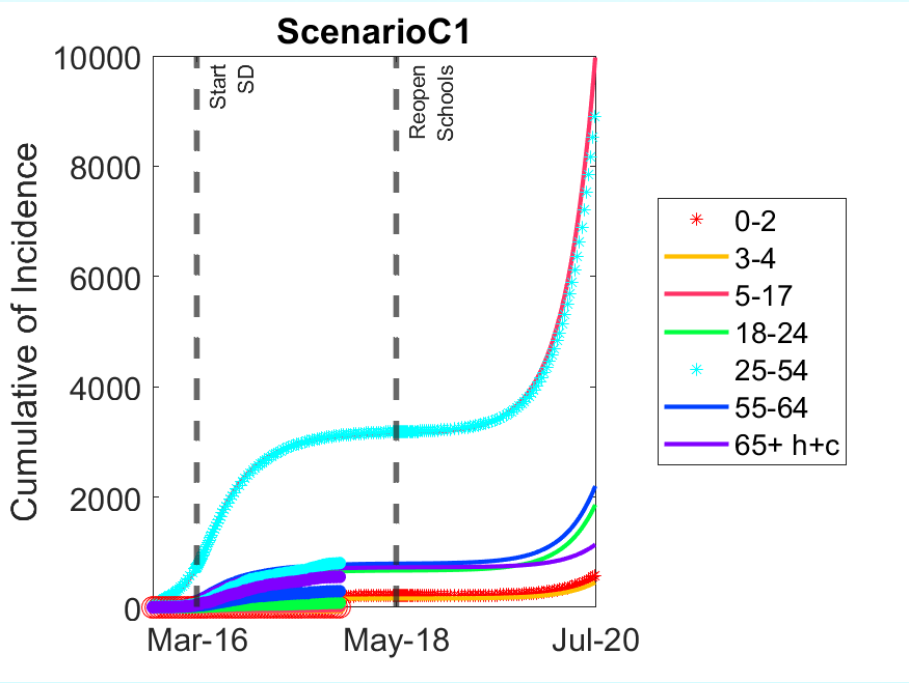
- Kids 5% susceptible

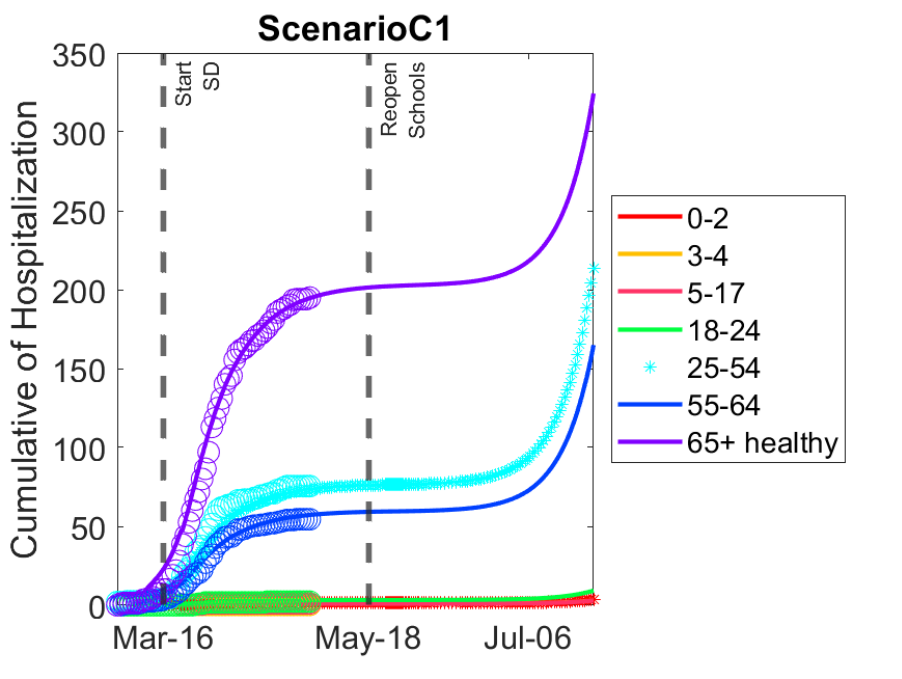




Relaxation Scenarios

- "Focus on elderly people only"
  - All kids and adults (0-65) contacts return to initial levels on May 15
  - Elderly people contacts remain low
  - Self-isolation drops to 20%
- Kids 100% susceptible





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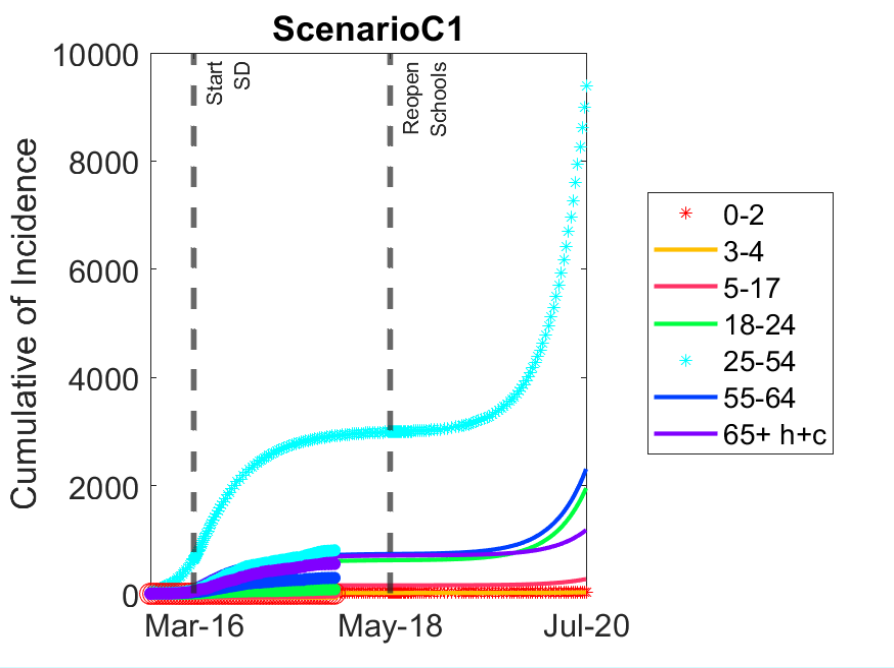
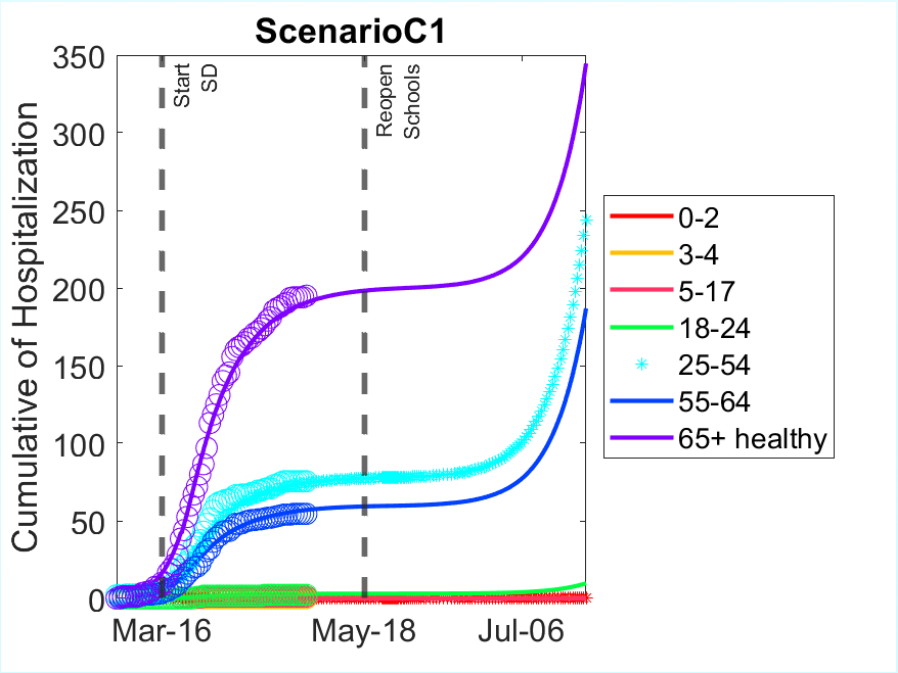




- Essentially, we just need to:
  - Calibrate (somehow)
  - Calculate leading eigenvalue (+ eigenvector)
- More nuanced outputs:
  - Time dynamics
  - Numbers of hospitalization/ICU per age group
- Future work:
  - Improve calibration (!)
  - More realistic scenarios:
    - Region-specific “metapopulation” models
    - Coupling to economic/business data
    - Exploiting activity structure

OK, so reaching herd immunity is out. Now what?

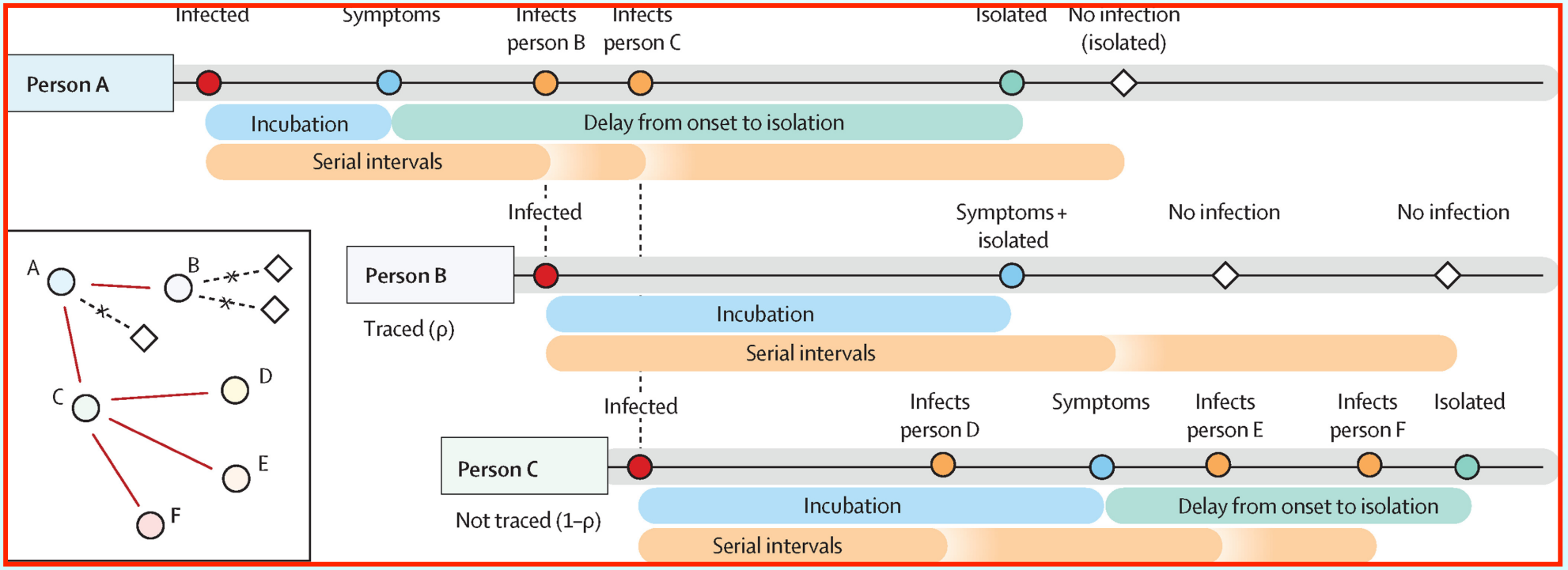
1. What kinds of relaxation of distancing measures may be possible?
    - estimating the relative contributions of different groups to overall spread

2. Can we remain in the "maintenance phase" indefinitely?
    - **contact tracing**
    - **apps**

Contact Tracing + Apps

- Current low prevalence in BC suggests a trace + test strategy coupled with ongoing self-isolation and social distancing may be effective

- Model: contact tracing stochastic with explicit time delays
  - new chains could be imported or sporadic local



J. Hellewell et al, Lancet Global Health, 2020

App-based rapid contact tracing

Well-mixed math:

- 70% of population has a capable phone
- 70% of those people will use the app reliably
- so 49% community penetration
- probability of detecting a contact ~25%
- elderly people and marginalized groups

- An amazing source of data for modelling
- Potential for certain populations (high-school, university)
- Areas with low public health capacity

- Performance vs self-isolation + regular tracing?
- Setting alert thresholds in low-prevalence setting?

- Projections from models will be important here

Christophe Fraser (Oxford Big Data) https://045.medsci.ox.ac.uk
Gorgi et al, *medRxiv* 20045237 (2020)

Final thoughts:

- As we countenance de-escalation, new challenges:

- Models to obtain deeper understanding of surveillance data
    - localized facility outbreaks vs community spread
    - specific surveillance activities
    - estimating imported infections
    - links to human activity and transportation data streams

- Estimating potential effects of de-escalation:
    - economic sectors / businesses
    - schools, colleges, universities
    - understanding transmission networks pre/post

- Vaccination modelling
    - extensive experience from influenza

- Multiple epidemics in the fall/winter of 2020-21
- Small behavioural changes may be very important in the aggregate
    - let's keep it up!

De-escalation by Reversing the Escalation with a Stronger Synergistic Package of Contact Tracing, Quarantine, Isolation and Personal Protection……. Tang et al, MDPI Biology, 2020