An astrophysicist's approach to epidemiology

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SESE Community Conversation
March 25, 2021

Jan. 26, 2020: A 20-year old male ASU student who visited Wuhan was one of the first 5 reported cases in the US.

Mar. 6, 2020: A woman in her 40s, a healthcare worker in Pinal County, second reported case in Arizona. Probably infected in late-February.

Covid probably had been spreading in Arizona since early February 2020.

My questions at the beginning of the pandemic:

What's going to happen?

How fast and far will this spread?

How many people will die if we do nothing?

What should we do? (wear masks / socially distance / lockdown?)

For how long?

Questions I had at the beginning of the pandemic:

How quickly is this going to spread?

How many people might die if we do nothing?

What's 'herd immunity'?!

The media communicated predictions so badly, I decided to look' under the hood' of the models.

SIR (**S**usceptible – **I**nfectious – **R**ecovered) Model

$$d\mathbf{I} / dt = +\beta (\mathbf{I} / \mathbf{N})\, S - \gamma \mathbf{I}$$

$$d\mathbf{S} / dt = -\beta (\mathbf{I} / \mathbf{N})\, \mathbf{S}$$

$$d\mathbf{R} / dt = +\gamma \mathbf{I}$$

$$\mathbf{I} + \mathbf{S} + \mathbf{R} = \mathbf{N}$$

β = rate at which it spreads from Infectious person to Susceptible person (1/time).

β *changes when behaviors change!*

γ = rate at which Infectious person Recovers (1/time).

SIR (Susceptible – Infectious – Recovered) Model

$d\,[\mathbf{I}/\mathbf{N}]\,/\,dt = +\gamma\,[\,R_0\,(\mathbf{S}/\mathbf{N}) - 1\,]\,[\mathbf{I}/\mathbf{N}]$

$R_0 = \beta\,/\,\gamma$ = how many people one person infects per cycle

Initially $\mathbf{S}/\mathbf{N} \approx 1$, grows exponentially:
$\mathbf{I} = \mathbf{I}(0)\,\exp(+t\,/\,\tau)$,
$\tau = [\,(R_0 - 1)\,\gamma\,]^{-1}$.

Covid growth *initially* +35% day, or τ = 3.33 days
Factor of 10 increase every week.
15 cases → 150 million cases in just 2 months.

Recovery time $\gamma^{-1} \approx 4.7$ days
$R_0 \approx 2.4$

SIR (Susceptible – Infectious – Recovered) Model

$d\,[\mathbf{I}/\mathbf{N}] / dt = +\gamma\,[\,R_0\,(\mathbf{S}/\mathbf{N}) - 1\,]\,[\mathbf{I}/\mathbf{N}]$

Infections stop growing *exponentially* when $S/N < 1 / R_0$

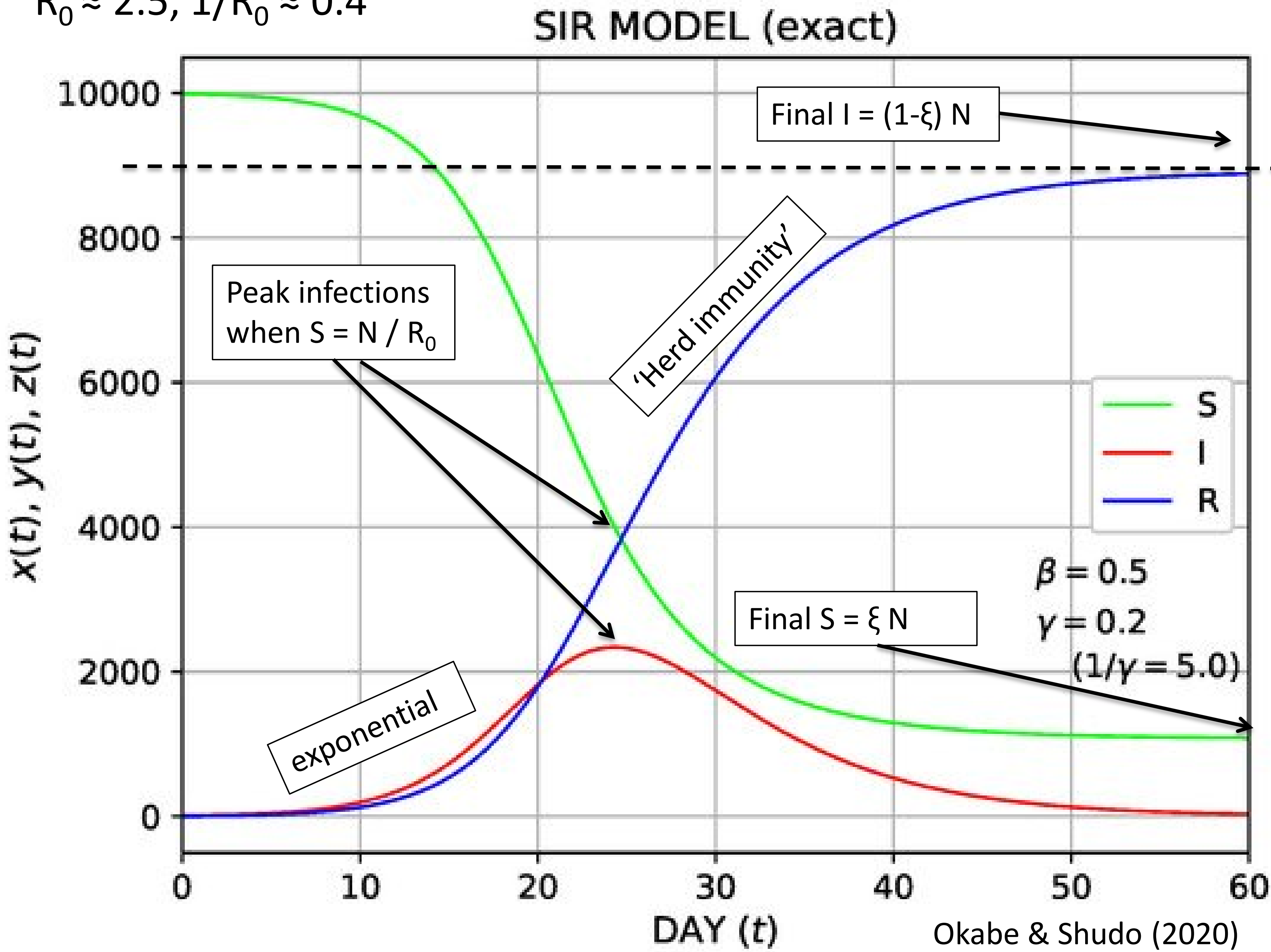
Threshold reached when fraction immune = $\mathbf{(1 - S/N) = 1 - 1/R_0}$
'Herd immunity'. Not a maximum, more like an inflection point.

Final fraction of people infected = $(1-\xi)\,N$, where $-\ln \xi / (1-\xi) = R_0$

$\mathbf{R_0 = 2.4}$, $1-\xi =$ **0.878**, peak when $(I+R)/N =$ **0.583**
$R_0 = 1.5$, $1-\xi = 0.582$, peak when $(I+R)/N = 0.333$
$\mathbf{R_0 = 1.2}$, $1-\xi =$ **0.313**, peak when $(I+R)/N =$ **0.167**
$R_0 = 1.1$, $1-\xi = 0.177$, peak when $(I+R)/N = 0.091$

Total infected eventually ≈ 1.5 –2.0× total infected at herd immunity threshold.

$R_0 \approx 2.5$, $1/R_0 \approx 0.4$



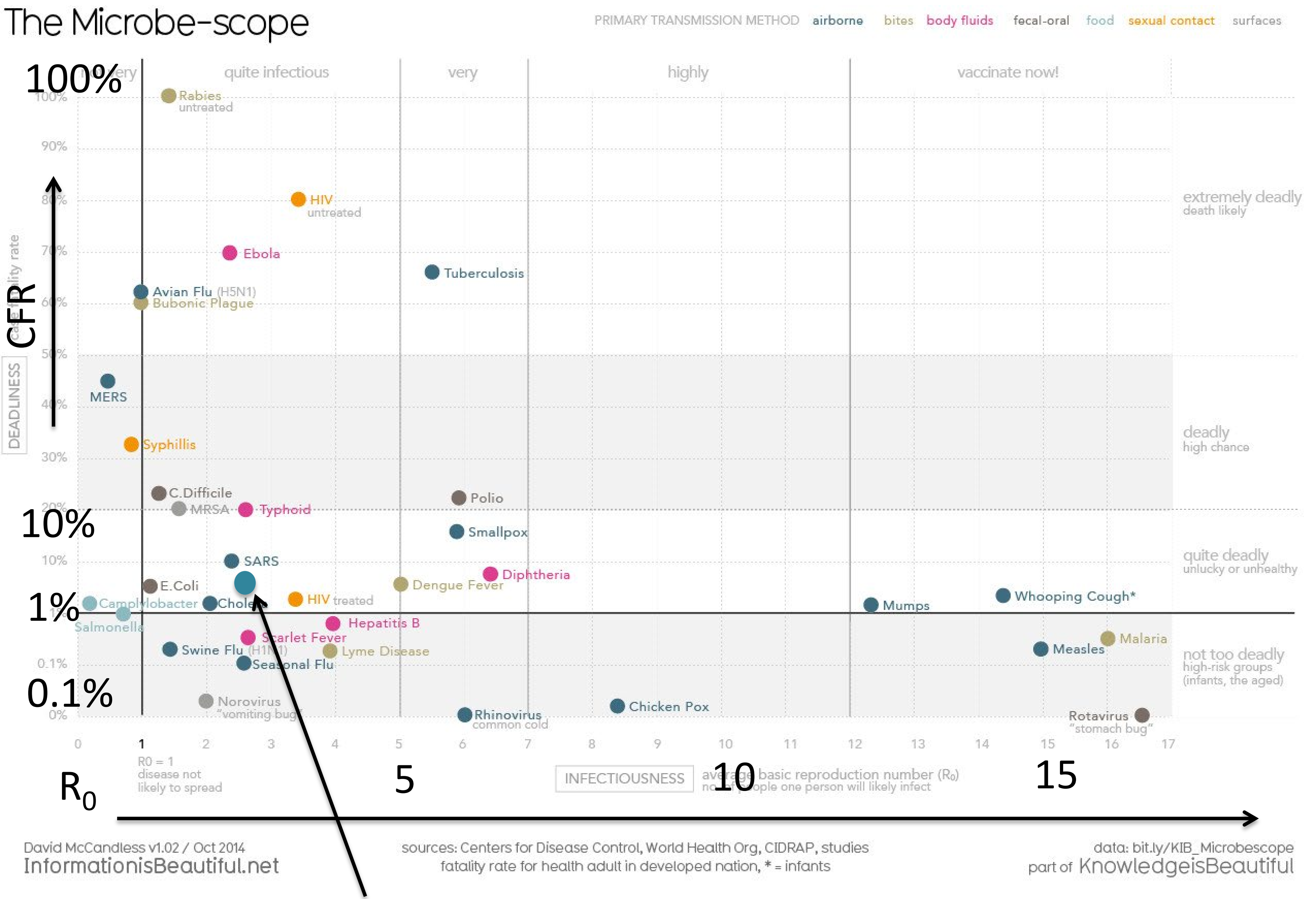
Okabe & Shudo (2020)

SIR (Susceptible – Infectious – Recovered) Model

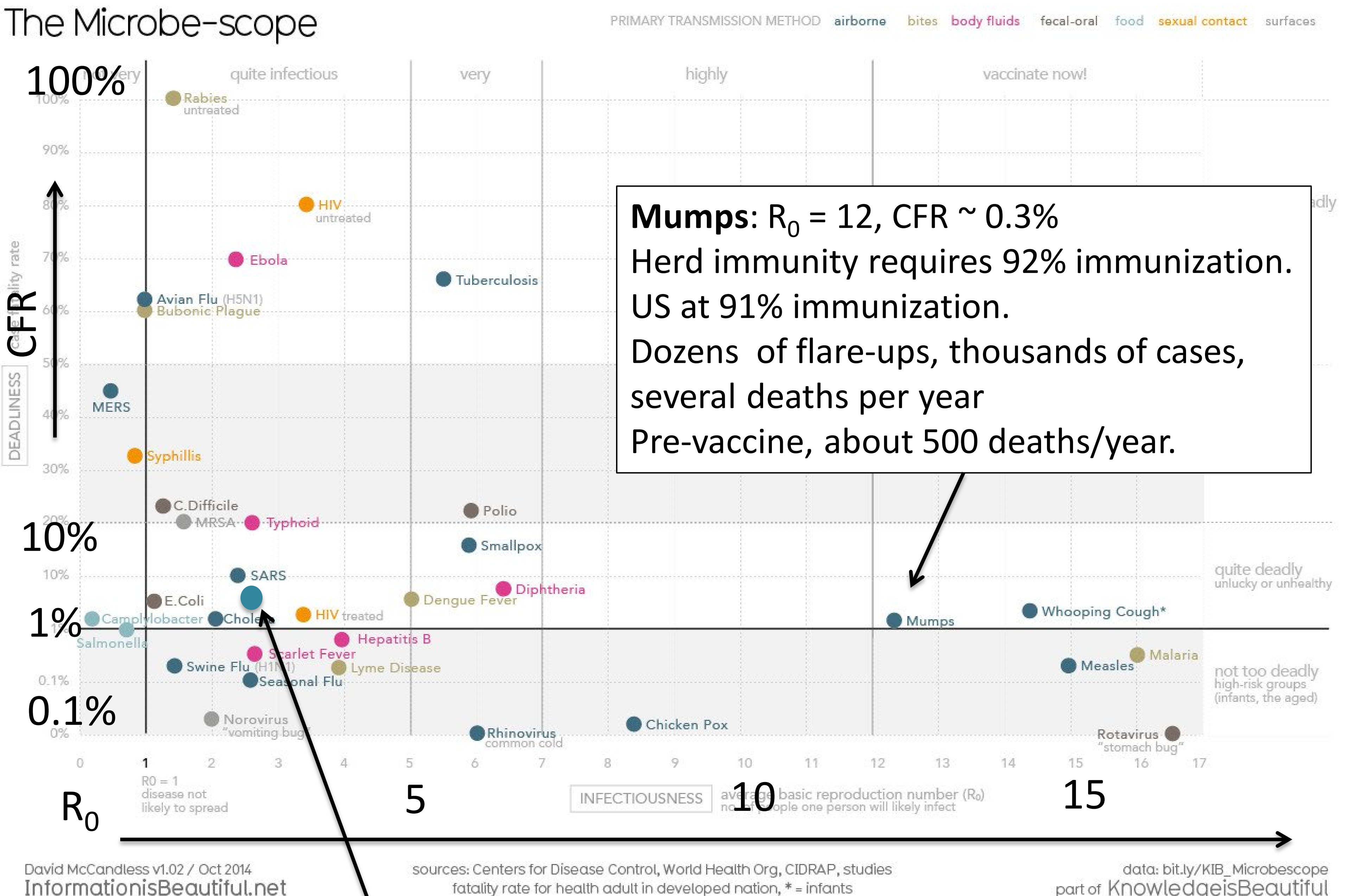
CFR = “case fatality rate” = fraction of those with reported symptoms (cases) who die. Can vary a lot, based on degree of testing, demographics, pressure on medical resources…
CFR ≈ 2% (e.g., 91-divoc.com average)

IFR = “infected fatality rate” = fraction of people ever *infected* who die.
Many cases go unreported, may even be *asymptomatic*.
Much harder to pin down!
IFR ≈ 0.7% (meta-analysis by Meyerowitz-Katz and Merone 2020)

Only about 1/3 of infections ever get reported.



Covid-19 at CFR ≈ few %, IFR ≈ 0.7%, R_0 ≈ 2.4



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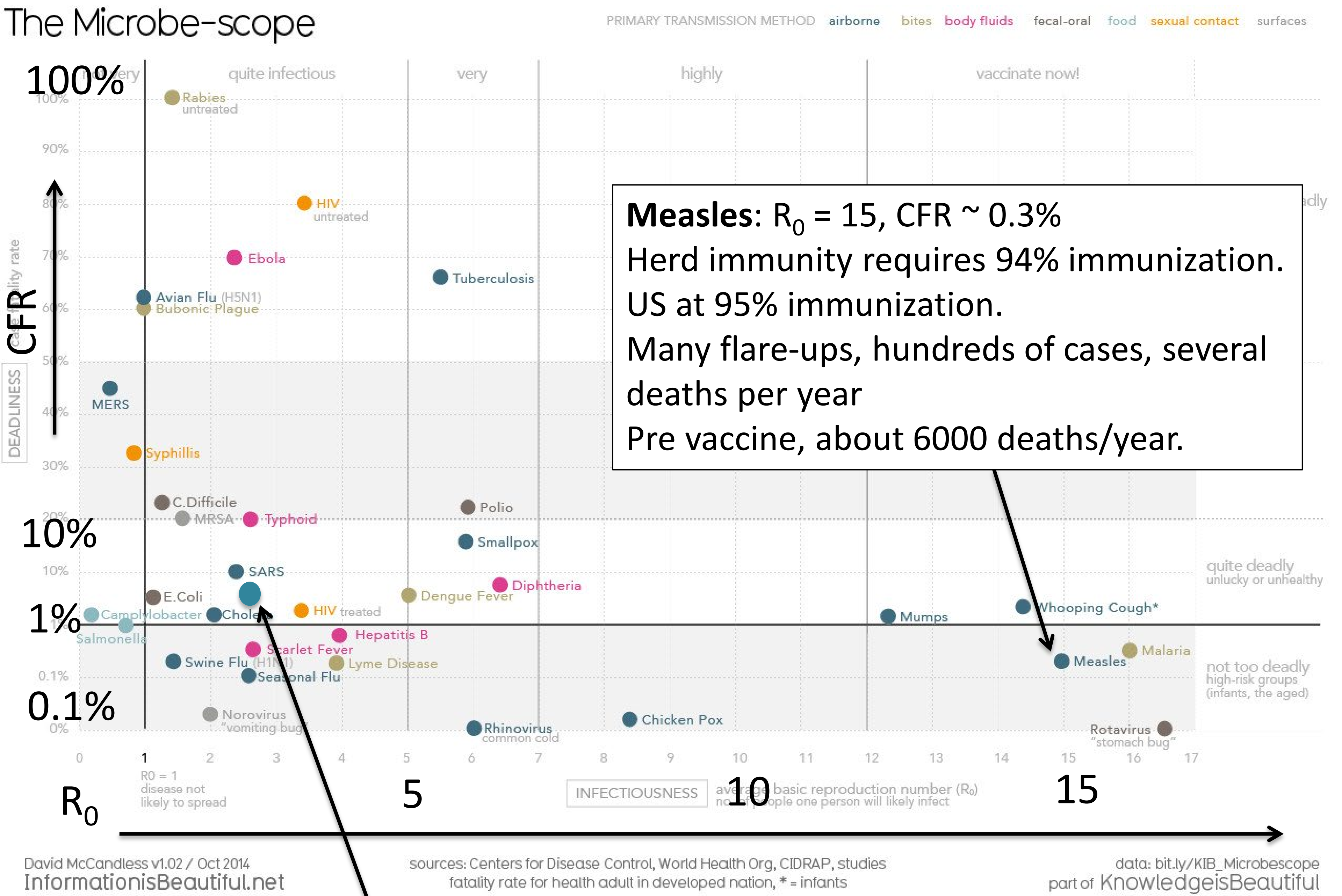


Covid-19 at CFR ≈ few %, IFR ≈ 0.7%, R_0 ≈ 2.4

SIR (Susceptible – Infectious – Recovered) Model

My question last year: How many might die if we do nothing?

Arizona population ≈ 7.3 M

$88\% \times 7.3\text{M} \times 0.7\% \approx 45{,}000$ deaths

US population ≈ 328 M

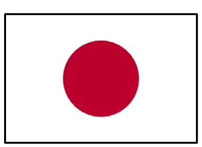
$88\% \times 328\text{M} \times 0.7\% \approx 2.0$ M deaths

World population ≈ 7700 M

$88\% \times 7700\text{M} \times 0.7\% \approx 47$ M deaths

Canada population ≈ 38 M

$88\% \times 38\text{ M} \times 0.7\% \approx 230{,}000$ deaths



Japan population ≈ 126 M

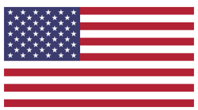
$88\% \times 126\text{ M} \times 0.7\% \approx 780{,}000$ deaths

<u>SIR (Susceptible – Infectious – Recovered) Model</u>

My question this year: Is what we're doing working?

Arizona population ≈ 7.3 M

88% × 7.3M × 0.7% ≈ 45,000 deaths (*now at 17,000, ~37%*)



US population ≈ 328 M

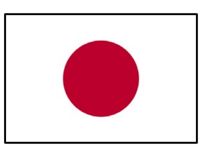
88% × 328M × 0.7% ≈ 2.0 M deaths (*now at 0.54M, ~27%*)

World population ≈ 7700 M

88% × 7700M × 0.7% ≈ 47 M deaths (*now at 2.7M, < 6%*)

Canada population ≈ 38 M

88% × 38 M × 0.7% ≈ 230,000 deaths (*now at 23,000, ~10%*)



Japan population ≈ 126 M

88% × 126 M × 0.7% ≈ 780,000 deaths (*now at 9,000 , ~1%*)

How much do our behaviors change R_0?

Do our actions decrease spread in *infections*?
We don't count infections, we count cases, and they're not the same.

But, Deaths ÷ 0.7% = new infections about 17 days before

As of 3/22/21 in Arizona:

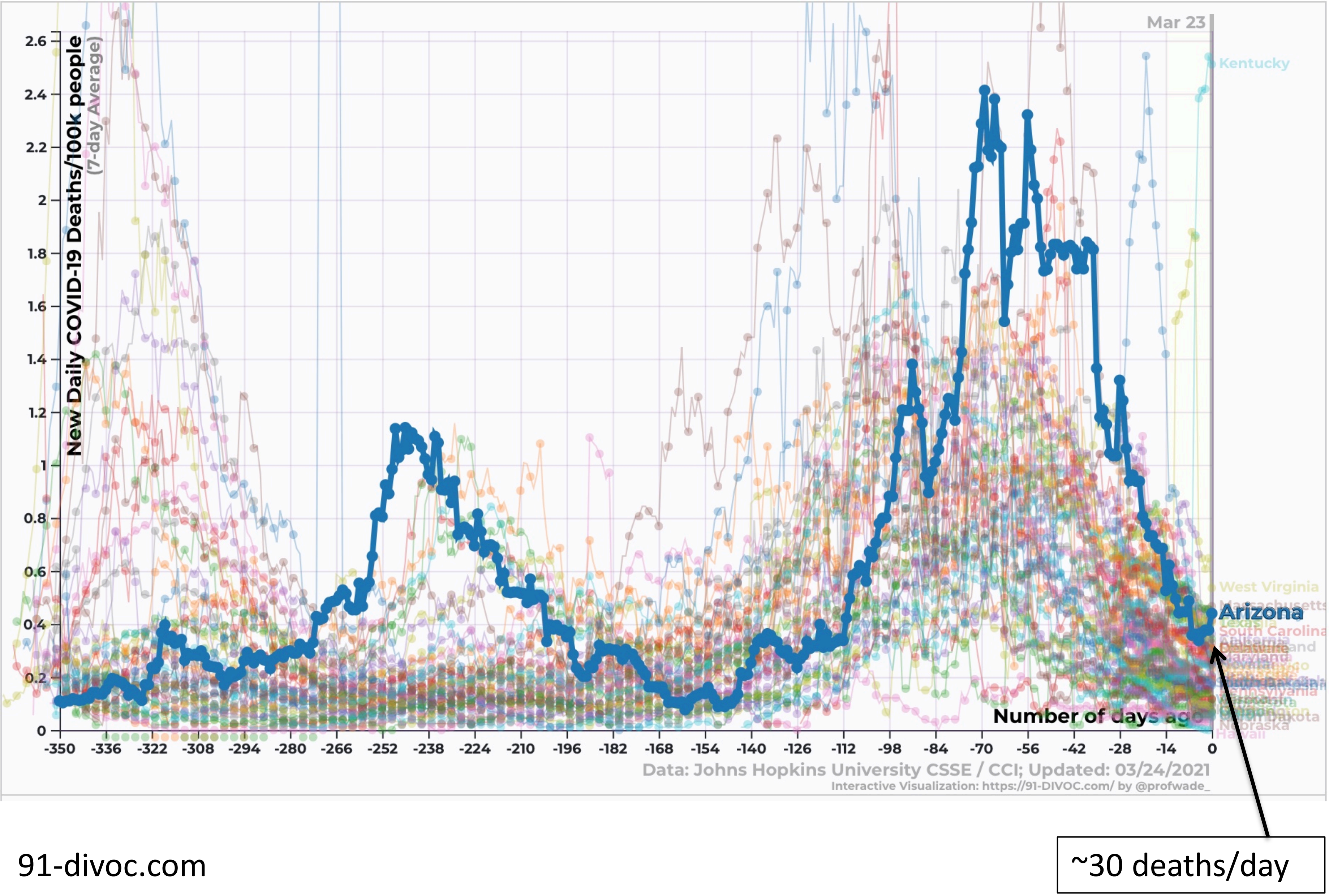
836k reported cases
17k deaths,
implies 2400k infections, about 33% of population
infections ≈ 3× reported cases
presumably 2/3 of cases are "mild" or even asymptomatic

This matters because 33% of population is now immune, S/N = 0.67

$R_t = 0.67\ R_0$

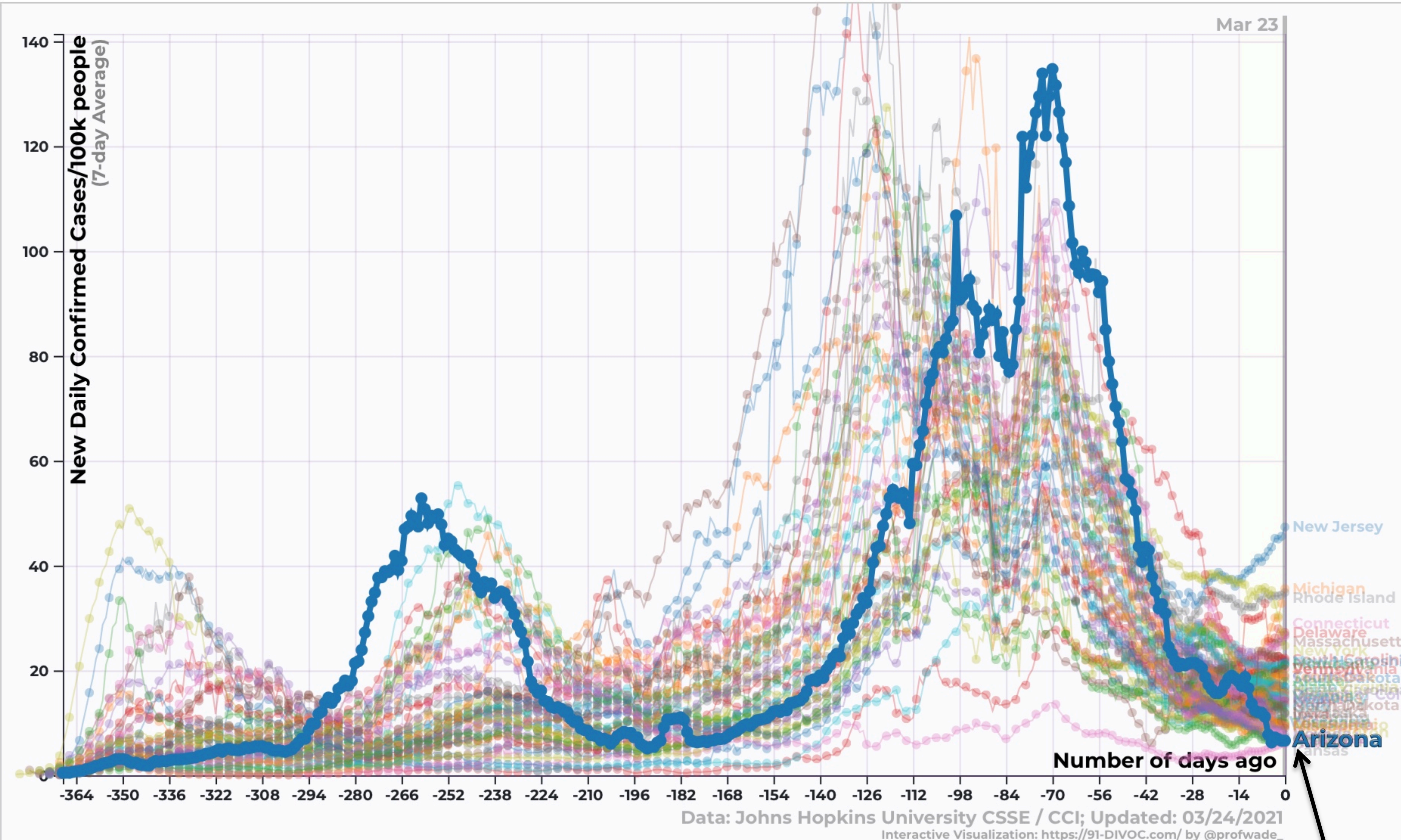
This can flip R_0 from >1 to < 1.

New Deaths from COVID-19 per Day by States/Territories, normalized by population



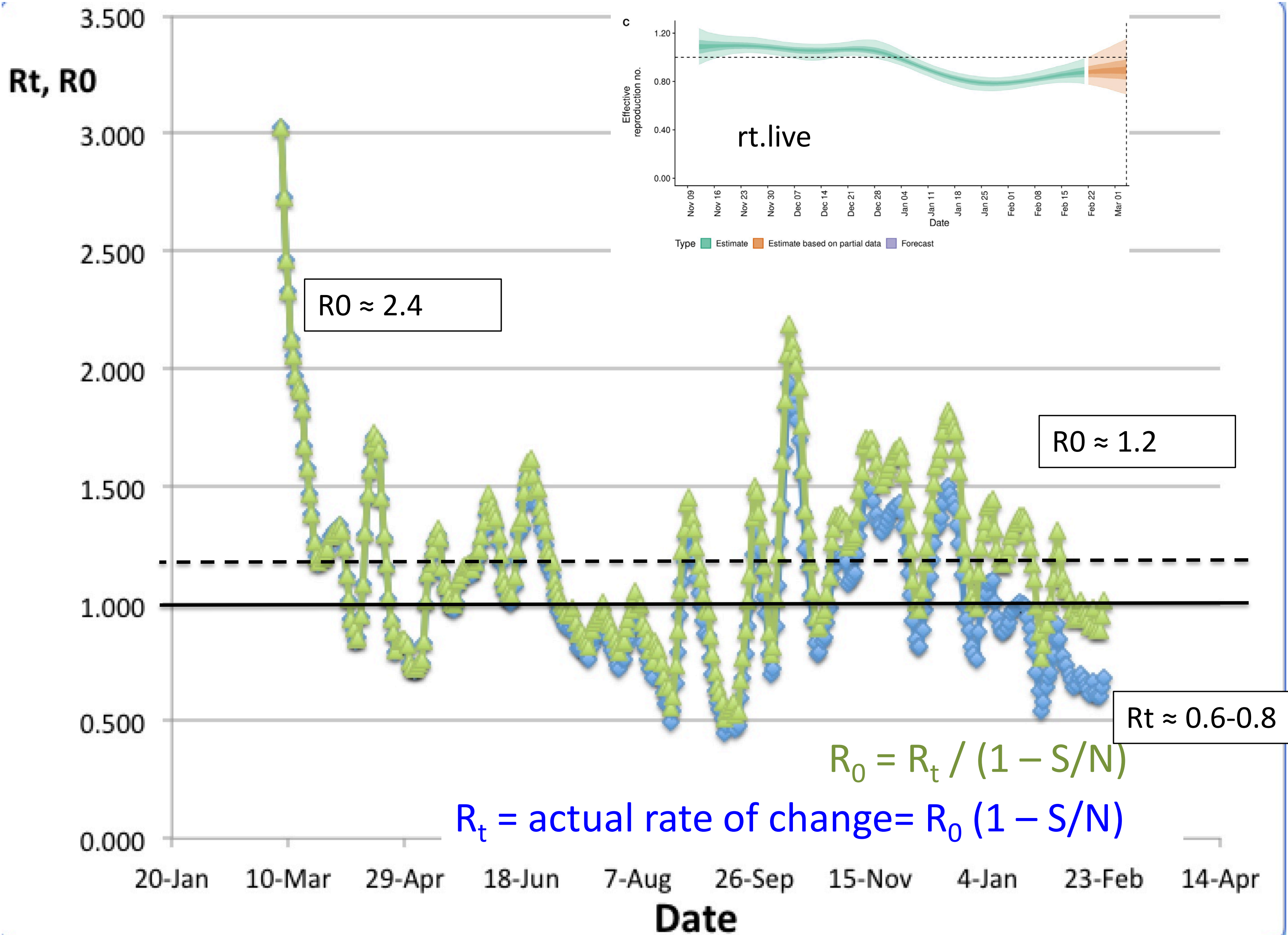
91-divoc.com

New Confirmed COVID-19 Cases per Day by States/Territories, normalized by population

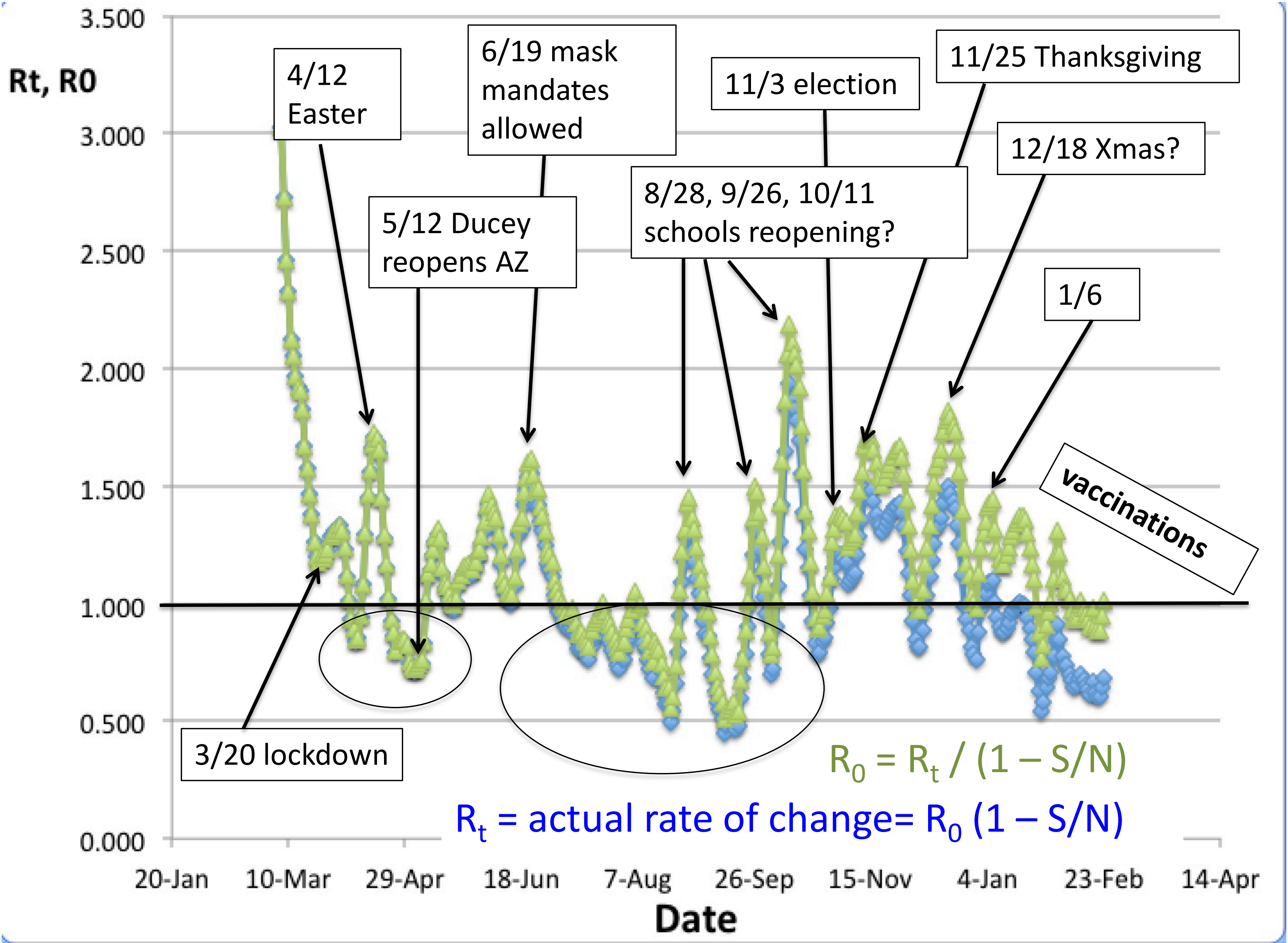


91-divoc.com

480 cases/day ~ 1400 infections/day



Rt, R0
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
20-Jan
10-Mar
29-Apr
18-Jun
7-Aug
26-Sep
15-Nov
4-Jan
23-Feb
14-Apr
Date
R0 ≈ 2.4
R0 ≈ 1.2
Rt ≈ 0.6-0.8
$R_0 = R_t / (1 – S/N)$
R_t = actual rate of change= $R_0 (1 – S/N)$
c
Effective reproduction no.
1.20
0.80
0.40
0.00
rt.live
Nov 09
Nov 16
Nov 23
Nov 30
Dec 07
Dec 14
Dec 21
Dec 28
Jan 04
Jan 11
Jan 18
Jan 25
Feb 01
Feb 08
Feb 15
Feb 22
Mar 01
Date
Type
Estimate
Estimate based on partial data
Forecast



Rt, R0
3.500
3.000
2.500
2.000
1.500
1.000
0.500
0.000
4/12 Easter
6/19 mask mandates allowed
11/3 election
11/25 Thanksgiving
12/18 Xmas?
5/12 Ducey reopens AZ
8/28, 9/26, 10/11 schools reopening?
1/6
vaccinations
3/20 lockdown
$R_0 = R_t / (1 – S/N)$
R_t = actual rate of change= R_0 (1 – S/N)
20-Jan
10-Mar
29-Apr
18-Jun
7-Aug
26-Sep
15-Nov
4-Jan
23-Feb
14-Apr
Date

My questions now, same as last year: What comes next?

As of 3/24 in Arizona, 3.0 M doses given, ~1.5 M people vaccinated, 21% of state (~26% with 1 dose, ~16% with both). Plus 33% of state has had covid.

Immunity probably at ≈47%.

R_0 = 1.2 (rough average with masks+social distancing) reduced to 1.2×(1-0.47) = 0.64. Drop to < 2 cases/day *by end of April*.

R_0 = 2.0 (masks+social distancing, but B.1429 variant 1.7× as contagious) reduced only to 2.0×(1-0.47) = 1.1. Cases will plateau..

R_0 = 4.1 (**no** masks+social distancing, and variant 1.7× as contagious) becomes 4.1×(1-0.47) = 2.2. Cases would explode as in March 2020.

What comes next?

BUT we can expect another 2 million people vaccinated by end of April, 48% of state. Immunity would be 65%

R_0 = 2.0 (masks+social distancing, and variant 1.7× as contagious) reduced to 2.0×(1-0.65) = 0.70. Drop to < 15 cases/day *by end of May*.

R_0 = 4.1 (**no** masks+social distancing, and variant 1.7× as contagious) becomes 4.1×(1-0.65) = 1.4. Cases would continue growing like the December surge.

What comes next?

Probably *another* 2.5 million people vaccinated by end of May, 82% of state. Immunity would be 88%.

R_0 = 2.0 (masks+social distancing, but variant 1.7× as contagious) reduced to 2.0×(1-0.88) = 0.24. Drop to << 1 cases/day *by end of June*.

R_0 = 4.1 (**no** masks+social distancing, and variant 1.7× as contagious) becomes 4.1×(1-0.88) = 0.50. Drop to <1 cases/day *by end of June*.

Conclusions

"All models are wrong, but some are useful."
"The purpose of computing isn't numbers, it's insight."

Keys to developing models: a little bit of math, a lot of logic, and an ability to do interdisciplinary research online i.e., a Ph.D. in SESE!

Behaviors (masks, social distancing) *matter*. Cases *dropped* here last August! Even in Arizona (which has done a manifestly bad job of handling covid) these actions have likely saved ~30,000 lives.

We're in a race to see which wins first: the variants and lockdown fatigue, or the vaccines. Variants will fight back this month, but vaccines should win by June, or sooner if we don't give up.

'New normal' starting this summer will include covid. It won't go away soon. But, we can hope to make it as *managed* as mumps and measles.

SESE Community Conversation: 25 March 2021

COVID-19 Vaccines

- As of yesterday, COVID-19 vaccines are available to all Arizona residents 16 or older, at state-operated vaccination sites in Maricopa, Pima, and Yuma counties
- No official ASU communication on this to students as yet, but at this stage any ASU personnel who want a vaccine are eligible to register.
- Not known if vaccines will be required for students.
- Please check this website for Vaccine updates and FAQs:

https://eoss.asu.edu/health/announcements/coronavirus/vaccine-faqs

On Campus Presence

- ASU's safety protocols and policies with regard to masks and social distancing will remain in place at least till the end of the Spring semester, despite relaxation of guidelines by CDC for fully vaccinated individuals. Please uphold all Community of Care practices!
- Expect to have information regarding the Spring graduation soon.
- Most summer camps, activities, and programs are still expected to be remote, unless permission is given by Provost to hold in-person.

Travel

- Travel (local, domestic, international) insured or paid for by ASU still requires Provost's approval.
- Almost no international travel is being approved.
- Research-related travel, especially if associated with federal research awards, is being approved with relatively short turnaround.
- For field work, especially involving students, there is greater scrutiny. Provost has established a cross-functional review committee (involving risk management personnel) that needs to approve prior Provost's approval.

Plans for Fall 2021

- Registration is underway; enrollment is still lagging relative to what is expected (was projected to be between that of Fall 2019 and Fall 2020)
- Expect to be back in “Learning Mode 1” (in person on campus)
- No classes offered in ASU Sync (but capacity to pivot as needed)
- Accommodations during the last two semesters have been via 1) the College/Dean based on CARES Act or 2) ASU HR based on ADA; starting in Fall 2021, accommodations will only be through ASU HR/ADA. All faculty and staff are expected to be back on campus.

SESE Community-wide Spring 2021 Activities

- SESE Community Conversations (Noon-1 PM on last Thursdays of March & April) – **The final CC in April will be on the State of SESE**
- SESE Colloquium (Wednesdays, 3:30-4:30 PM, weekly)
- Virtual Tea (Thursdays, 3:00-4:00 PM, weekly)
- Engineering Coffee (Fridays, 2:30-3:30 PM, weekly)
- Office hours with the director (weekly, 8-10 AM Fridays)
- Office hours with AD, Inclusive Community (3-4 PM Thursdays or by appt)

SESE and ASU resources and opportunities to connect and seek support

- Connect with Asian and Asian American associations and cultural groups here.
- ASU Counseling Services, which are available 7 days a week.
- Office Hours with SESE Director Wadhwa, Fridays from 8-10 AM MST by appointment (email Camelia.Skiba@ASU.EDU).
- Office Hours with SESE Associate Director of Graduate Initiatives, Hilairy Hartnett, Fridays from 9:30-10:30 AM MST (h.hartnett@asu.edu)
- Office Hours with SESE Associate Director for an Inclusive Community, Christy Till, Thursdays from 3-4 PM MST (cbtill@asu.edu)
- Get some comfort and distraction during Reali-TEA and Kittens, Thursdays 3-3:30 PM MST (karen.knierman@ASU.EDU)