


The evolution of novel Coronavirus and epidemic spread



BIO4159 – Evolutionary Ecology, University of Ottawa
11 March 2020

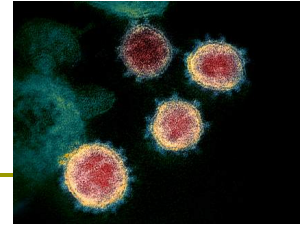
Rees Kassen
@ReesKassen; kassenlab.weebly.com

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Learning objectives

- ❑ Some facts about Coronavirus
- ❑ Understand how viruses make the shift from one species to another
- ❑ Understand the principles behind the SIR model
- ❑ Define R_0
- ❑ Explain why vaccination is effective

Coronavirus COVID-19 (SARS-2-CoV)

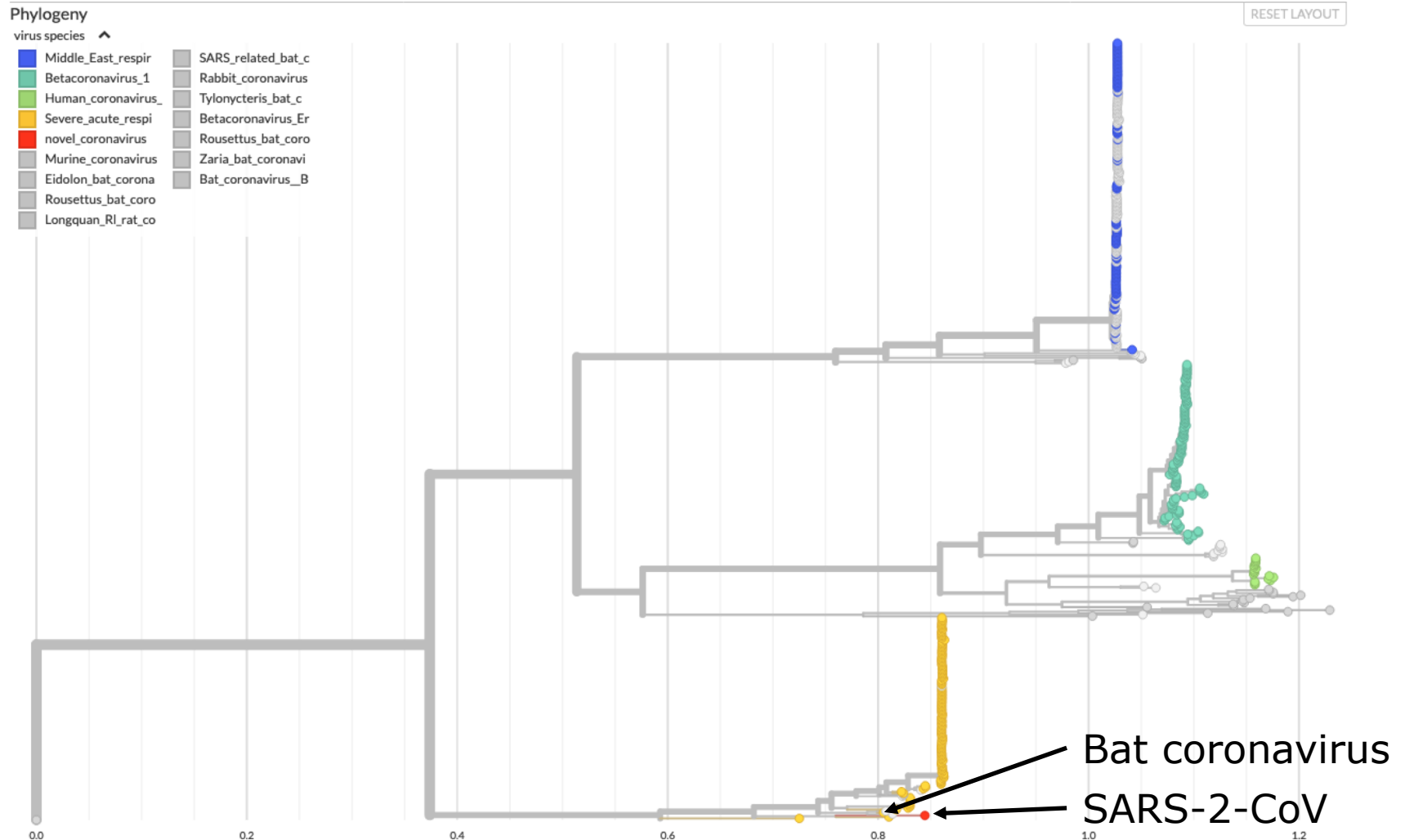


- Is a positive sense, single stranded, enveloped RNA virus
- Coronavirus refers to the crown-like (Latin: *corona*) viral envelope that can be seen with electron microscopy
- COVID-19 is the disease; SARS-2-CoV is the virus
- Transmission: respiratory
- Incubation period: mean 6.4 days (range of 2-12 days)
- Viral shedding can occur for ~ 7 days after recovery
- Mortality rate $\sim 2\%$, but highly uncertain and changes with age (seasonal flu $\sim 0.1\%$; SARS 10%)

The natural history of Coronavirus

- ❑ Coronaviruses are a family of RNA viruses that infect many different species of animals including camels, cattle, cats, and bats. And humans, of course.
- ❑ Coronaviruses can cause respiratory illnesses in humans that include the common cold as well as more severe diseases like Middle East Respiratory Syndrome (MERS) and Severe Acute Respiratory Syndrome (SARS)

SARS-2-CoV is a new virus that shares a most recent common ancestor with a bat coronavirus



<https://nextstrain.org/groups/blab/beta-cov> accessed 10 March 2020

How does a virus jump from bats to humans?

- ❑ The details remain unknown, except for the fact that SARS-CoV-2 infects human cells in the same way that SARS-CoV-1 (from the outbreak in 2002) does, only more efficiently
- ❑ The basics: the 'spikes' protruding from the viral surface bind to receptors on human cells called ACE2, undergo a transformational change, and then fuse the viral and human cell membranes

The evolution of novel viruses

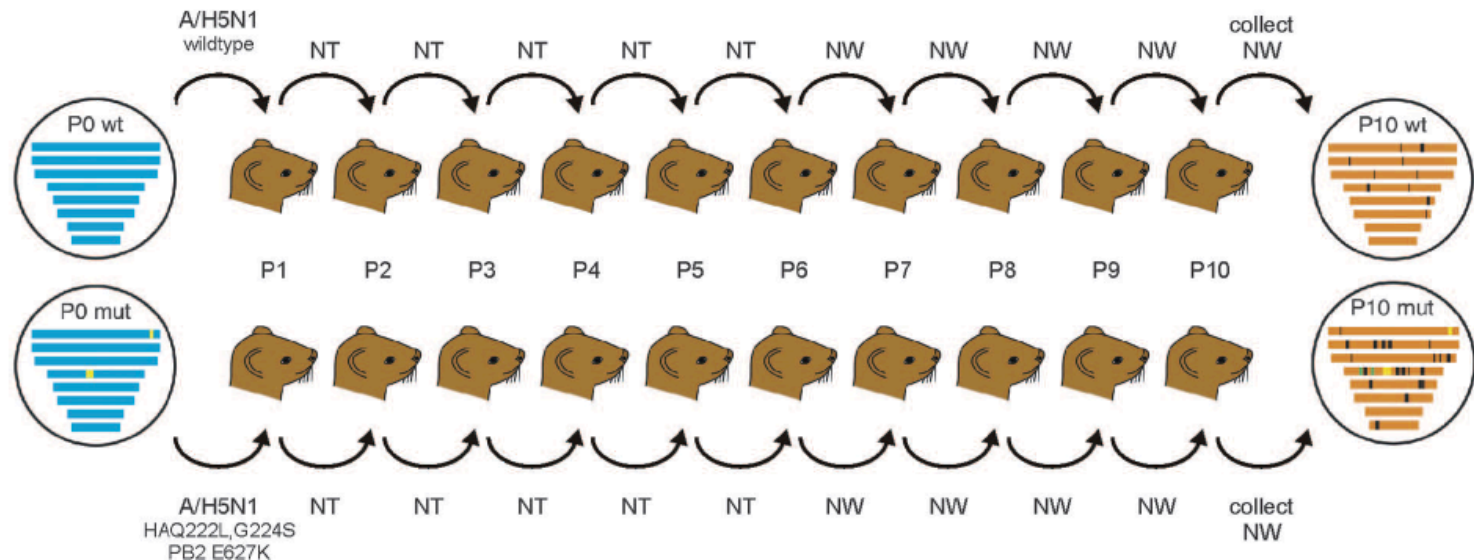
- ❑ Viruses circulating in animals sometimes jump species boundaries to infect humans
- ❑ This requires mutations that allow the virus to both *establish* (ie replicate) in a human cell and *transmit*, often through the air
- ❑ So-called 'zoonotic' infections (coming from animals) that can then be transmitted among humans are rare because multiple mutations are required

Example: the evolution of airborne transmission of influenza H5N1

- ❑ Animal influenza viruses occasionally infect humans but rarely spread widely because they cannot be transmitted through the air
- ❑ Following the H1N1 influenza outbreak of 2009, which was derived from pigs, questions arose as to how easy it would be for animal-derived flu viruses to be transmitted via aerosols and cause infection in humans

An experimental test: passaging avian H5N1 in ferrets

Herfst et al 2012. *Science* 336: 1534



- Targeted mutagenesis (to produce a high-titre shedding virus) + 10 passages was sufficient to generate viruses that could transmit through aerosols
- 5 mutations were necessary for aerial transmission
- Aerial transmission *can* evolve

Infection dynamics – the SIR model

- ❑ SIR stands for 'susceptible', 'infected', and 'recovered'
- ❑ We model the flow of people between these three states, assuming complete mixing in each category, no intermediate vectors (like a mosquito), and that recovered individuals are immune to the infection
- ❑ What follows is the simplest version of the SIR models and is meant to demonstrate basic principles only, not the actual dynamics of the current outbreak

SIR model basics

- $N = S + I + R$

- $\frac{dS}{dt} = -\beta \frac{SI}{N}$

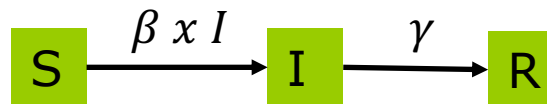
How often a susceptible-infected contact causes a new infection

- $\frac{dI}{dt} = \beta \frac{SI}{N} - \gamma I$

The rate at which an infected individual recovers

- $\frac{dR}{dt} = \gamma I$

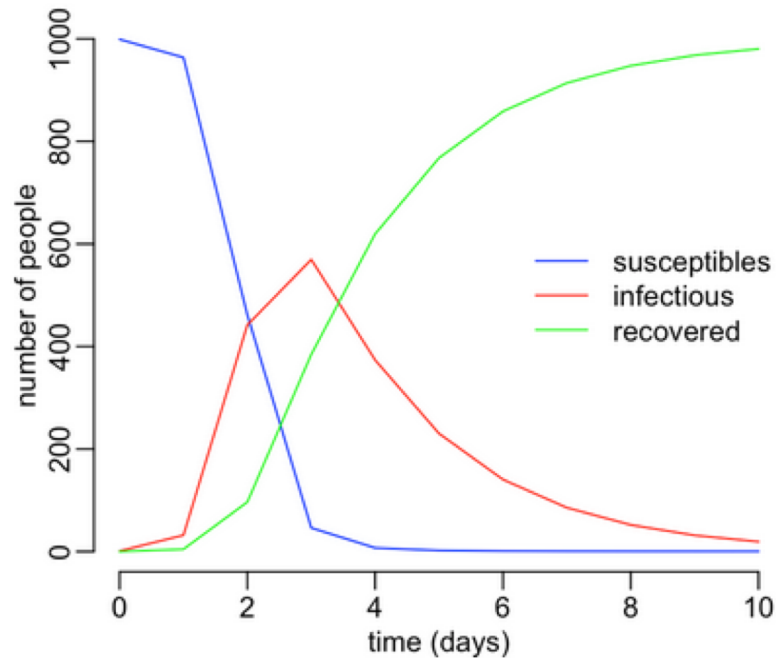
- Visually:



- $R_0 = \frac{\beta}{\gamma} N$

The basic reproductive ratio
- If $R_0 > 1$, then infected spread

The dynamics of infection

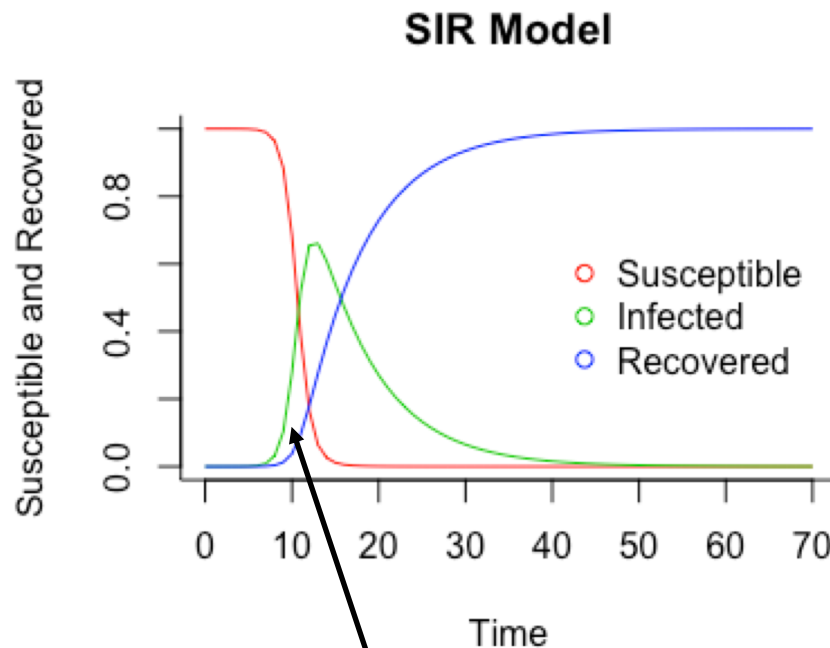


$$\beta = 0.004$$

$$\gamma = 0.5$$

Graphic from
<https://rpubs.com/choisy/sir>

The dynamics of infection



$$\beta = 0.004$$

$$\gamma = 0.5$$

Note the timeline has an arbitrary scale

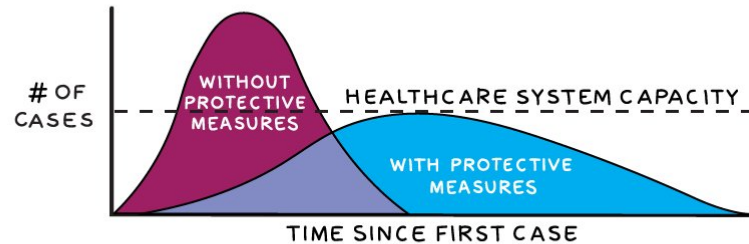
As of today (11 March 2020) we are here with COVID-19...in the exponential phase of the epidemic. In other words, infections are still increasing rapidly

Slowing the rate of spread of COVID-19 involves reducing β

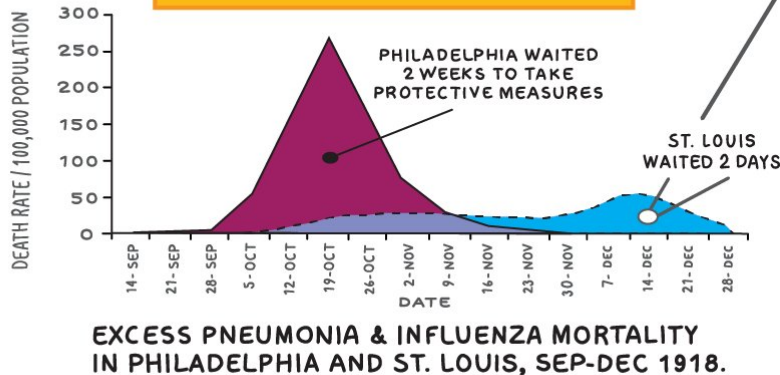
MINIMIZE THE IMPACT OF COVID-19

Adapted from CDC/ The Economist

**FLATTENING THE CURVE
IS A GOOD IDEA ...**



...BASED ON REAL DATA



**COMMUNITY-BASED
INTERVENTIONS IMPLEMENTED
QUICKLY IN ST. LOUIS WERE:**

- CLOSED SCHOOLS, CHURCHES, THEATERS AND DANCE HALLS
- BANNED LARGE PUBLIC GATHERINGS
- SOCIAL DISTANCING

STOP THE SPREAD BY:



**WASH
YOUR
HANDS**



**COVER
YOUR
COUGHS**



**STAY HOME
WHEN
YOU CAN**

SOURCE: HATCHETT, MECHER, LIPSITCH, 2007, PNAS

CC BY: @OLIVIAPHAMNOW

What happens if you vaccinate?

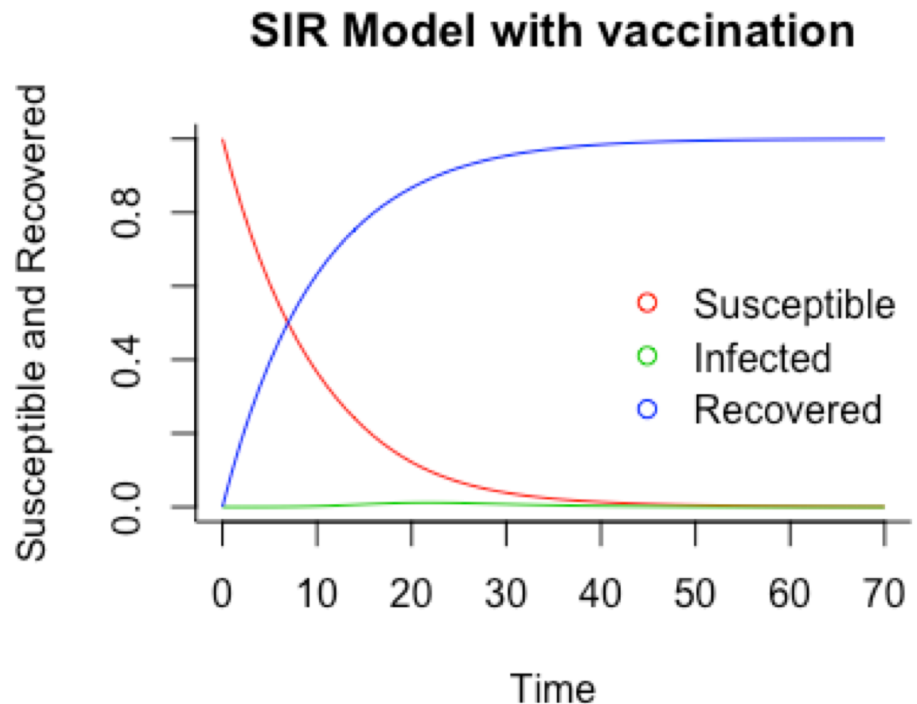
□ You effectively move S's into R's:

$$\square \frac{dS}{dt} = -\beta \frac{SI}{N} - vacc \times \frac{S}{N}$$

$$\square \frac{dI}{dt} = \beta \frac{SI}{N} - \gamma I$$

$$\square \frac{dR}{dt} = \gamma I + vacc \times \frac{S}{N}$$

So *if* we can get a vaccine, we can reduce infections



Some useful resources for understanding COVID-19

- ❑ <https://www.arcgis.com/apps/opsdashboard/index.html#/bda7594740fd40299423467b48e9ecf6>
- ❑ <https://nextstrain.org/ncov>
- ❑ https://art-bd.shinyapps.io/nCov_control/
- ❑ <https://www.cdc.gov/coronavirus/2019-ncov/about/index.html>