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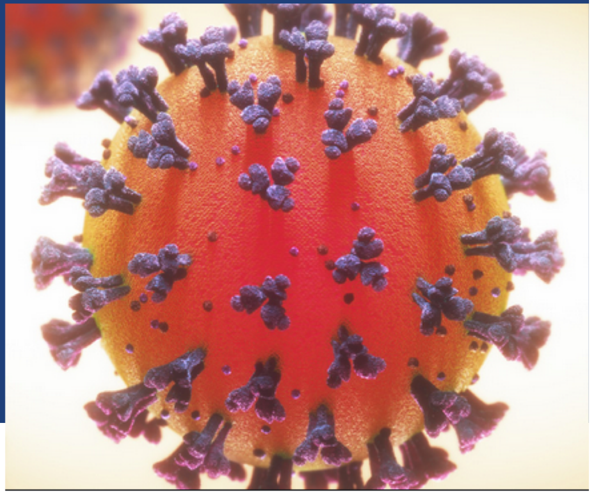
Covid-19 for physicist: why we have to act decisively

Jerome Faist



Disclaimer and preliminaries

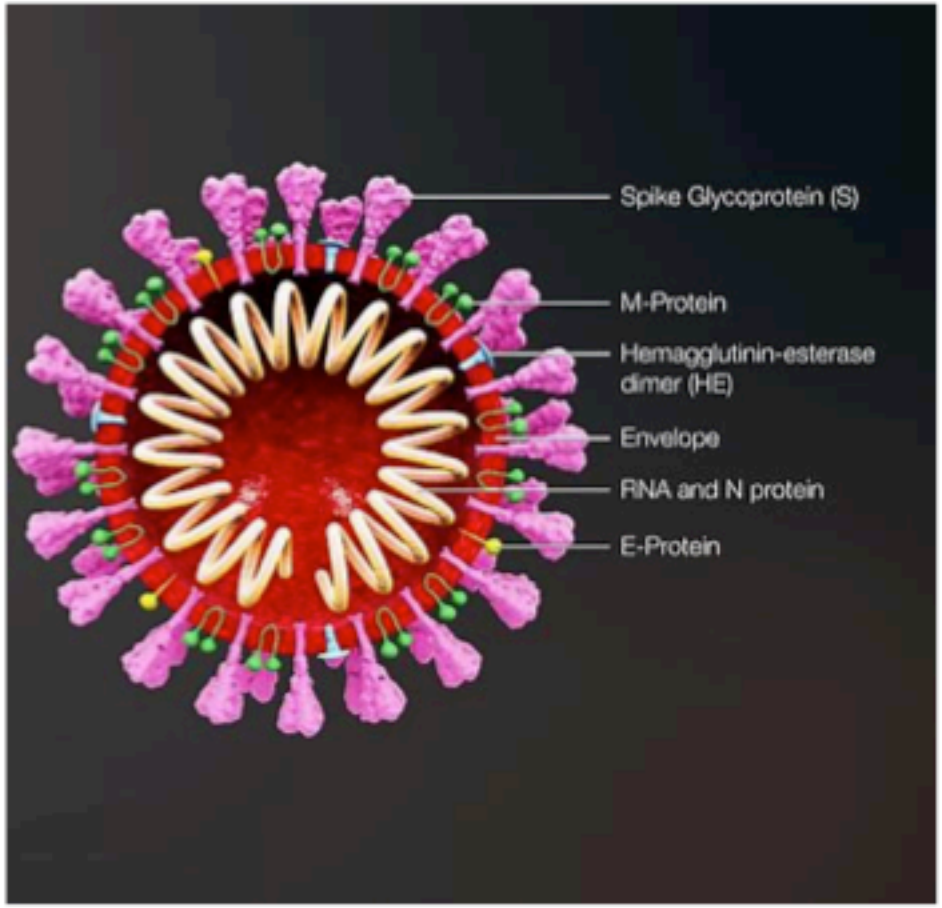
- This presentation draws on many sources, heavily on material gathered on WIkipedia, a presentation to the medical students in CHUV, and an article from Thomas Puyego as well as graphs from NZZ.
  - https://medium.com/@tomaspueyo/coronavirus-act-today-or-people-will-die-f4d3d9cd99ca
- In one aspect, it is meant to show the application of simple differential equations to the propagation of the Corona virus epidemic – but the author very much aware of the (over)simplifications that were done in the model.
- It is meant to feed an important health policy debate, but only represents the author's view (not the one of the institution) and does not claim any originality.
- As the author is a physicist and not an epidemiologist, it might contains errors that the author is happy to correct.
- Watch the excellent presentation on COVID-19 of our EPFL colleague Marcel Salathé

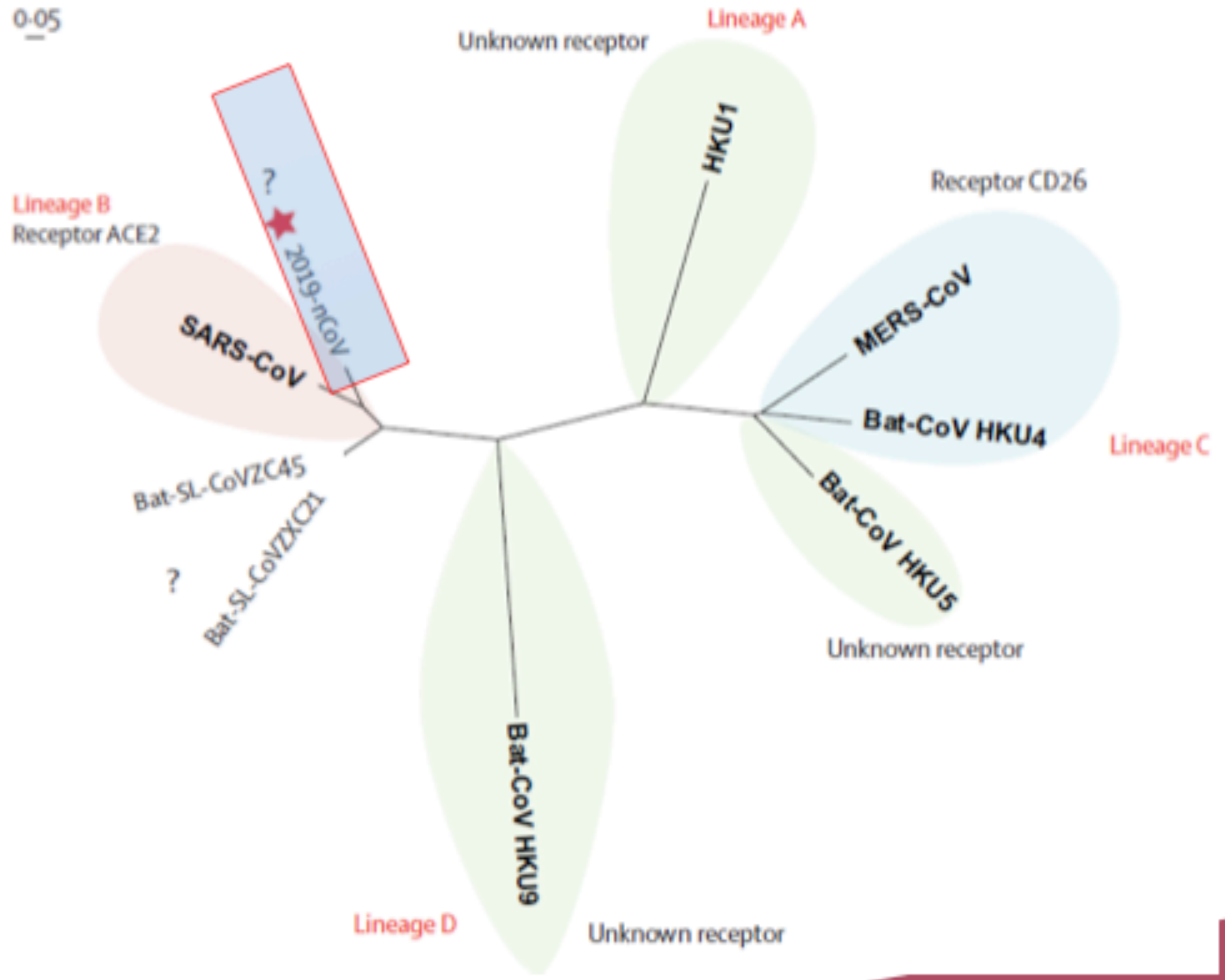
  https://tube.switch.ch/videos/29ca27b1

Key message

- Simple differential equations represent well the general features of the propagation of an epidemy
- The only way to control the Corona Virus is to adopt the drastic Chinese measures to bring down the number of infection to zero.
- It is feasible (China did it).

COVID 19 DISEASE (SARS-CoV2 : Betacoronavirus)





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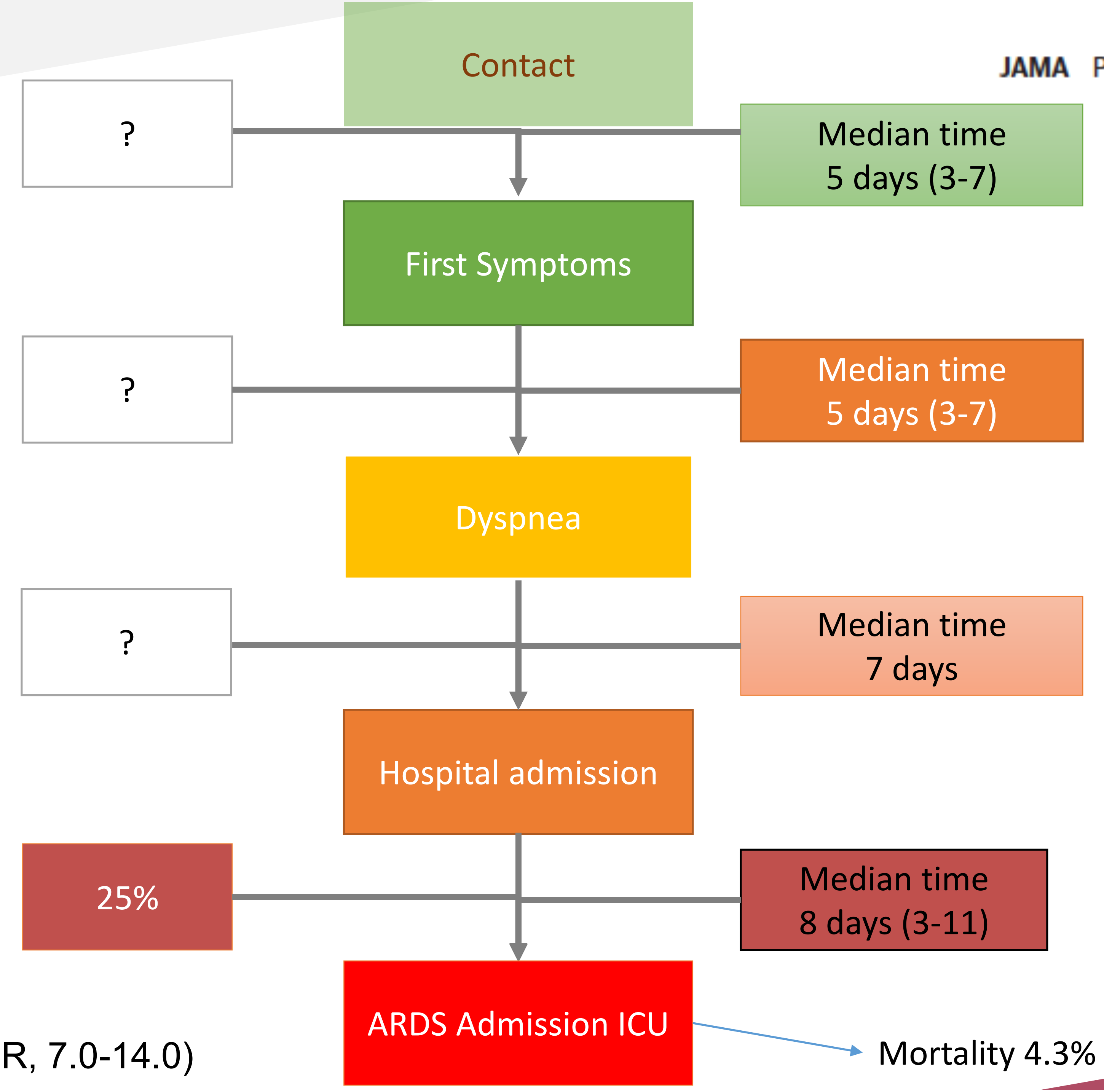
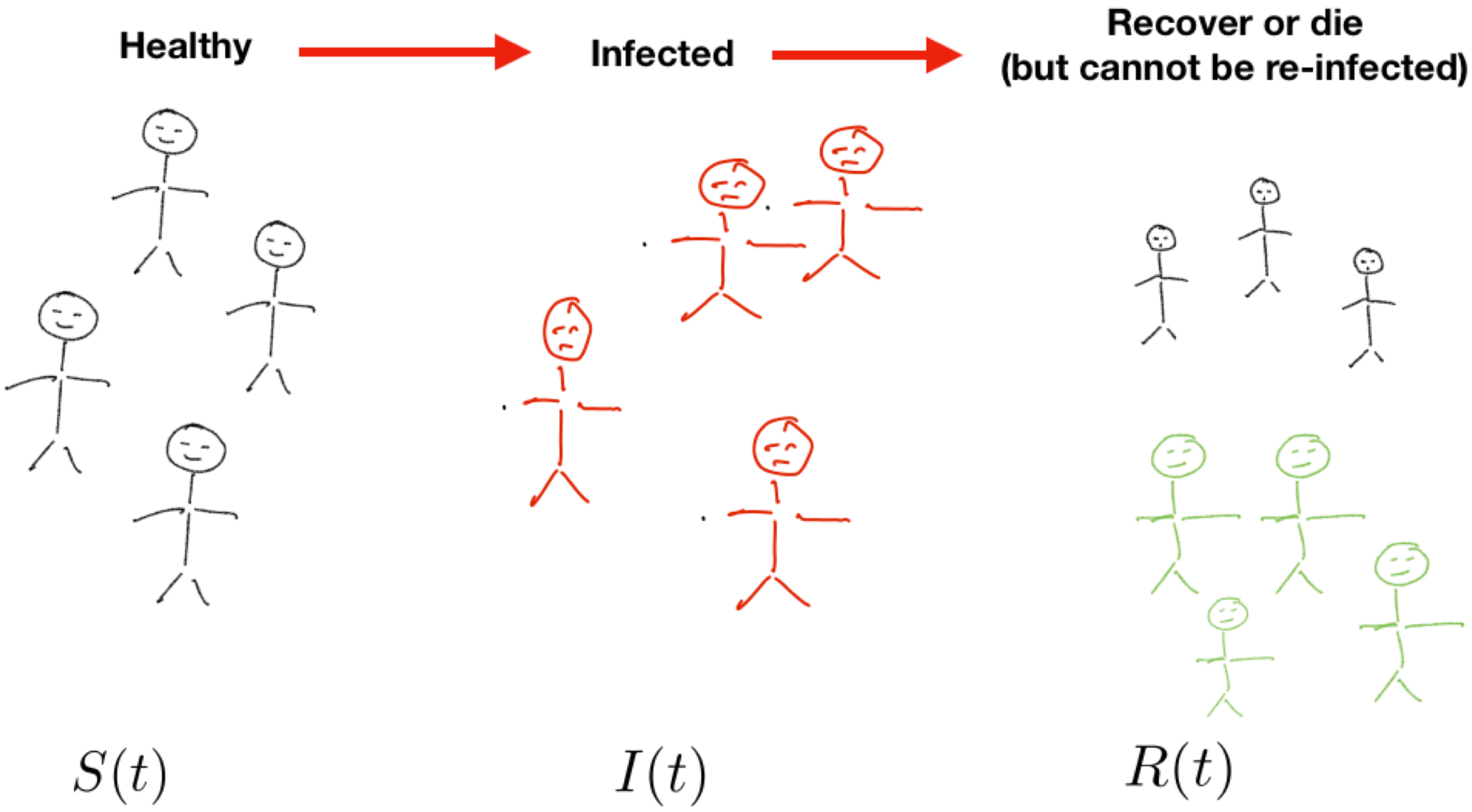


Hospital stay : 10 days (IQR, 7.0-14.0)

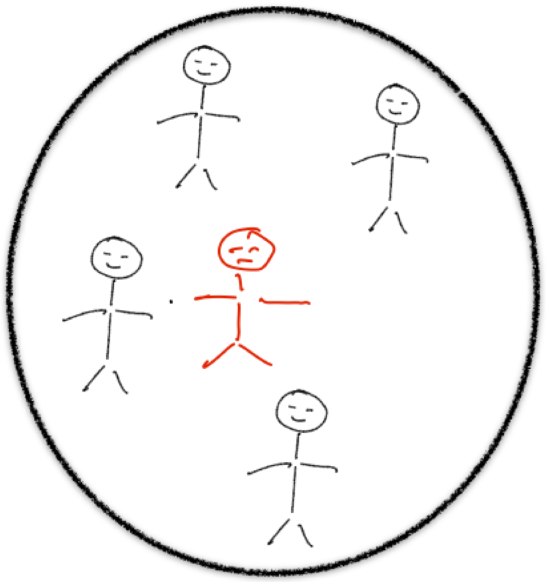
Corona virus infection, seen from a laser physicist perspective

$$N_{tot} = S(t) + I(t) + R(t)$$



Equations

- Infection rate



$$\frac{dI}{dt} = \beta \left(\frac{S}{N_{tot}} \right) I - \gamma I$$

Rate at which you infect

Fraction of population that can be infected

Rate at which people loose their infection

- Assumptions: total population is constant (neglect birth/ natural deaths)

W. O. Kermack and A. G. McKendrick, 1927

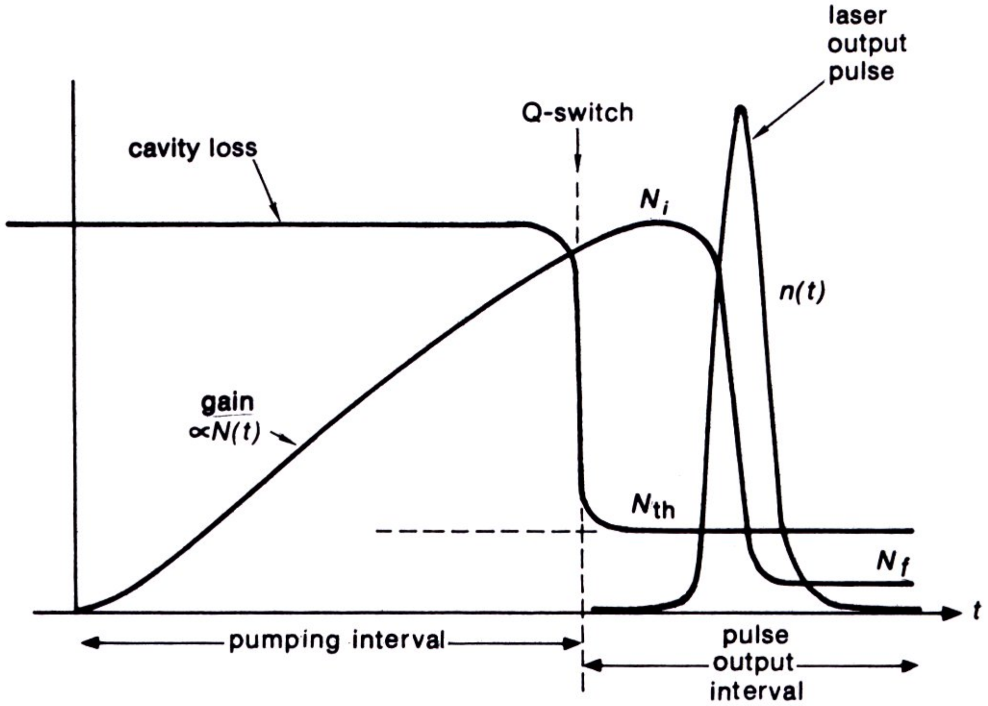
Very similar equation than the one of a Q-switched laser

Equation for the photon flux ϕ, population inversion ΔN

$$\frac{d\phi}{dt} = \frac{1}{\tau_p}\left(\frac{\Delta N}{N_{th}} - 1\right)\phi + \beta\frac{n}{\tau_{sp}}$$

Unfortunately...

But (happily) spontaneous emission (i.e random start of an epidemy) is rarer



A.Siegmann *Lasers*

For S = constant, the solution is exponential

- The solution is exponential

$$\frac{dI}{dt} = \left[\beta\left(\frac{S}{N_{tot}}\right) - \gamma\right] I$$

- Valid at the beginning of the epidemy, when $S \sim N_{tot}$

$$\frac{dI}{dt} = (\beta - \gamma)\, I$$

Numbers

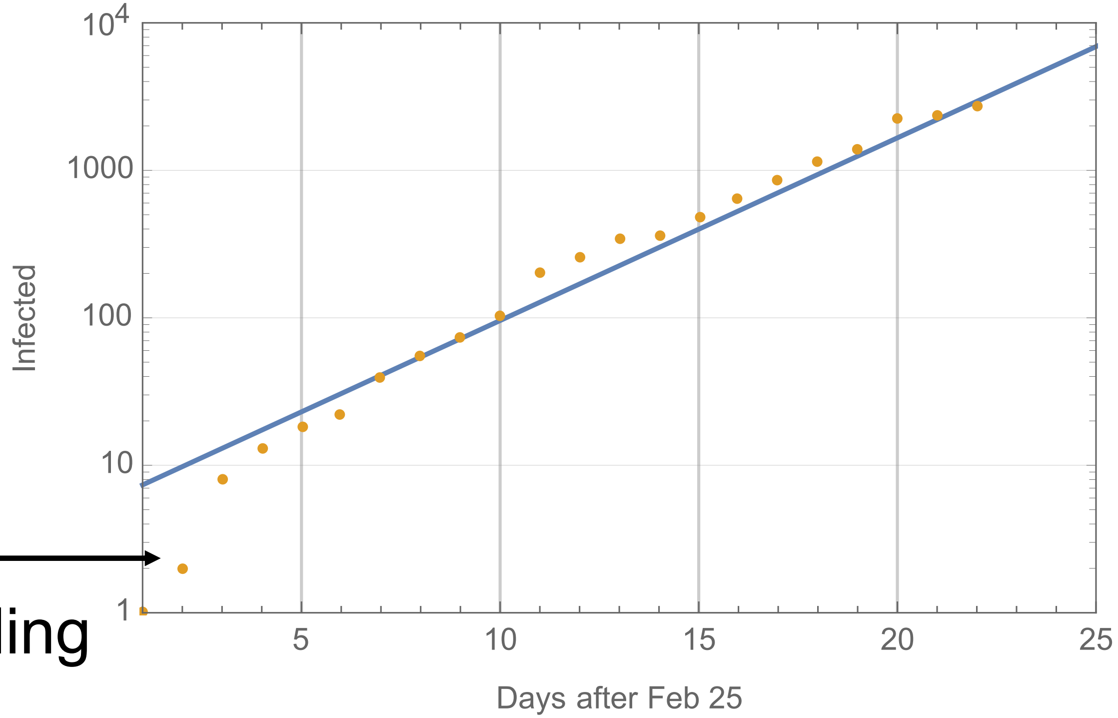
- The rate at which the patient loses its infection is assumed to be the inverse of the infection period (taken to be about 10days)

$$\gamma = 0.1 \text{ days}^{-1}$$

- If we assume an infection rate of

$$\beta = 0.43 \text{ days}^{-1}$$

- We get a good fit of the Swiss data
- And corresponds to the often quoted doubling of cases every 2-3 days

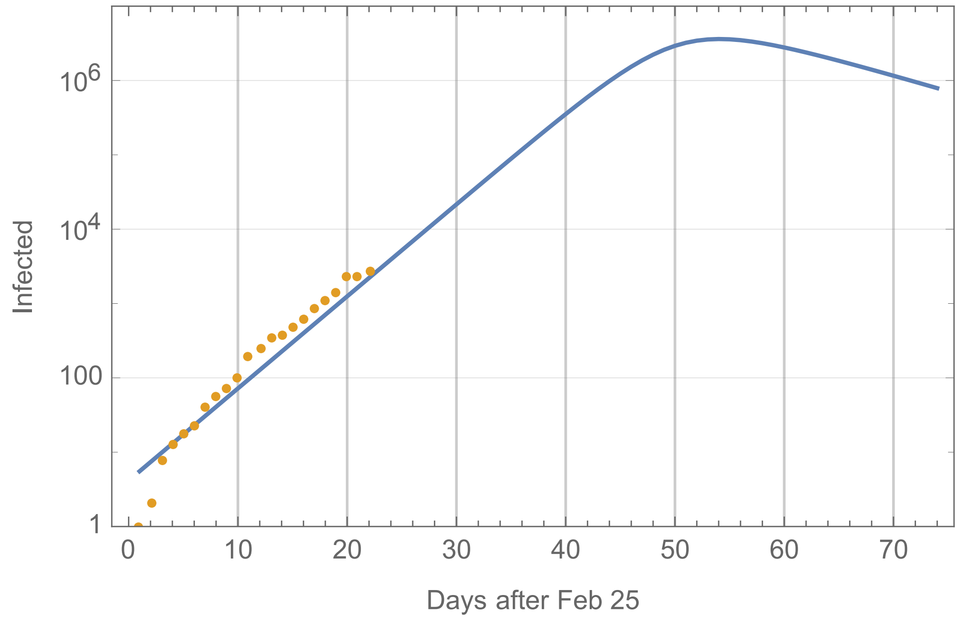


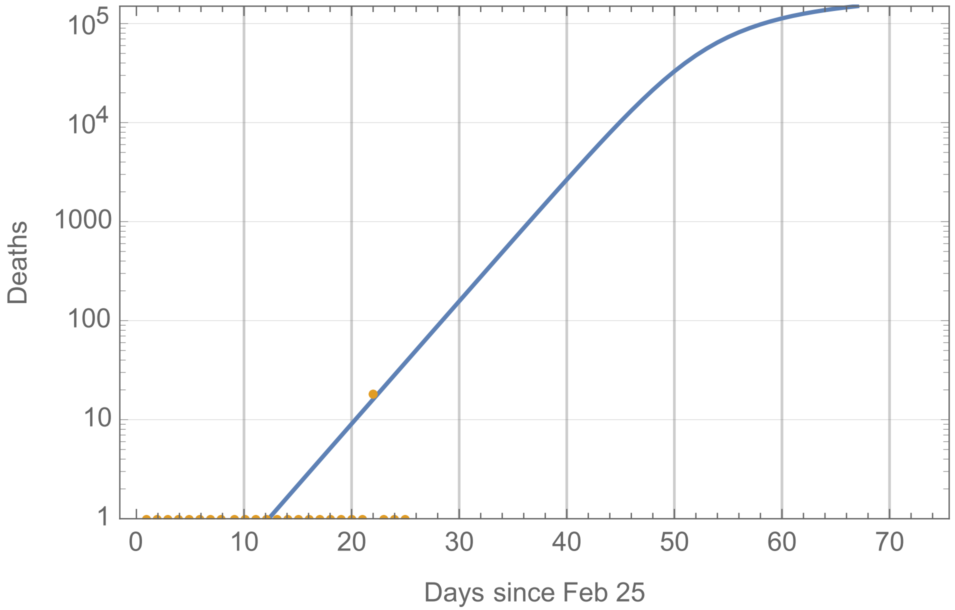
Interpretation

- β is the rate at which people infect each others
- It is a very key parameter for infectious diseases
- The value we have is actually very large, it corresponds to a time between two contaminations of $1/\beta = 2.32$ days
- The fact that it is much shorter than the infection period (10days) allow the illness to grow exponentially

What happens if you let the system evolve

- Bad (at least according to this simple model)
  - I got a good fit with 2.4% of death rate for the point of March 17 (18 deaths), which is the Chinese value





It means 150’000 deaths for Switzerland

- Hard to imagine, it is similar to Hiroshima or the fire bombing of Tokyo
- Need to control the epidemy

Could this model be too pessimistic?

- For sure, but unfortunately it is very unlikely that it is **enough** too pessimistic to significantly change the outcome
  - *Maybe we have much more infections that are completely silent.*
    - However, those would be picked up by countries like South Korea that are testing much more systematically. The problem is even if we are wrong by a factor of 5, this factor will start to count only when the country will have a very large infection rate. (It changes simply the mortality rate from 2.5% to 0.5%, but the numbers remain very large)
  - *Maybe the how weather slows down the epidemic?*
    - Yes but even if it cuts the transmission rate by 2 we simply take more time to get to the very large numbers
  - *Cluster effect are neglected (i.e. you probe only a much smaller portion of the population than assumed)?*
    - Again, those effects will only act by reducing somewhat the reproduction rate at the peak
- More sophisticated model are available – but they predict similar numbers
  - Look for example at https://neherlab.org/covid19/

The reproduction number R

- We rewrite the coefficient using the reproduction number R

$$\beta\left(\frac{S}{N_{tot}}\right)-\gamma=\gamma\left(\mathcal{R}-1\right)$$

- Such that

$$\mathcal{R}=\frac{\beta}{\gamma}\left(\frac{S}{N_{tot}}\right)$$

Fitting the Swiss data yields:

$$\mathcal{R}_0=\frac{\beta}{\gamma}=4.3$$

- Then if R>1, the infected population grows, if R<1, it decreases

Control the reproduction number via Herd immunity?

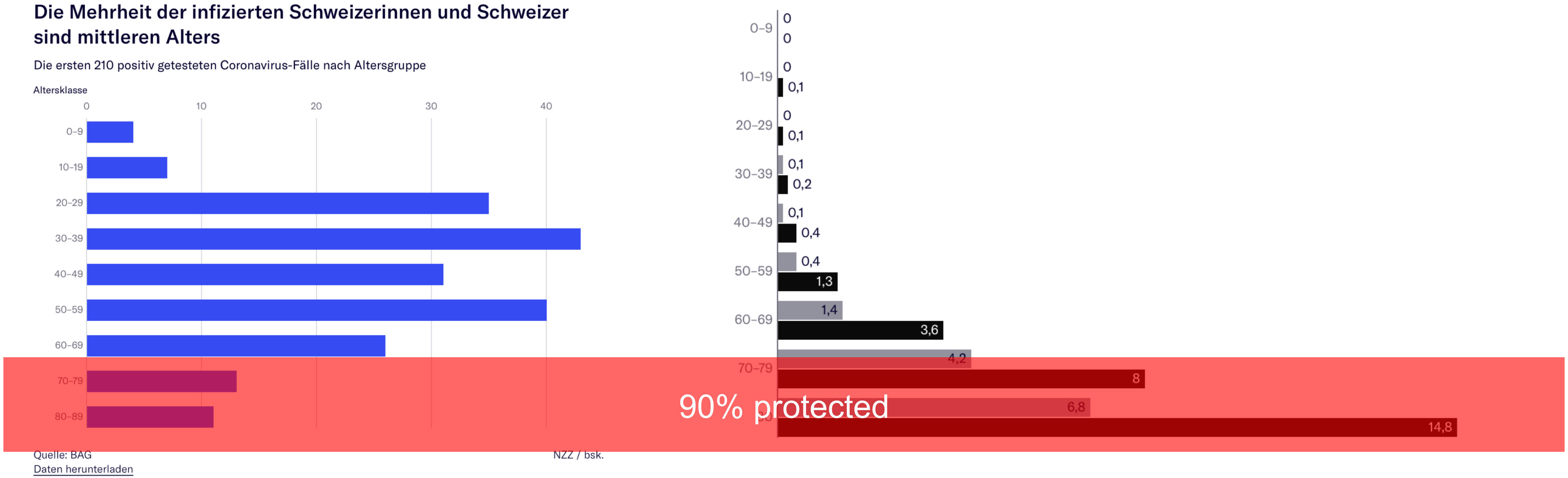
- When S decreases much below N_{tot} because many people have been infected then R goes below 1:

$$\mathcal{R} = \frac{\beta}{\gamma}\left(\frac{S}{N_{tot}}\right) = \mathcal{R}_0\left(\frac{S}{N_{tot}}\right)$$

- However, since R_0 = 4.3 we need a >75% of the population to be infected for the Herd immunity to kick in and drive R<1! (at least in this simple model)
- Finally it is not clear how long Herd immunity remains (maybe after a first illness you get a milder form of the illness and you are still contagious)

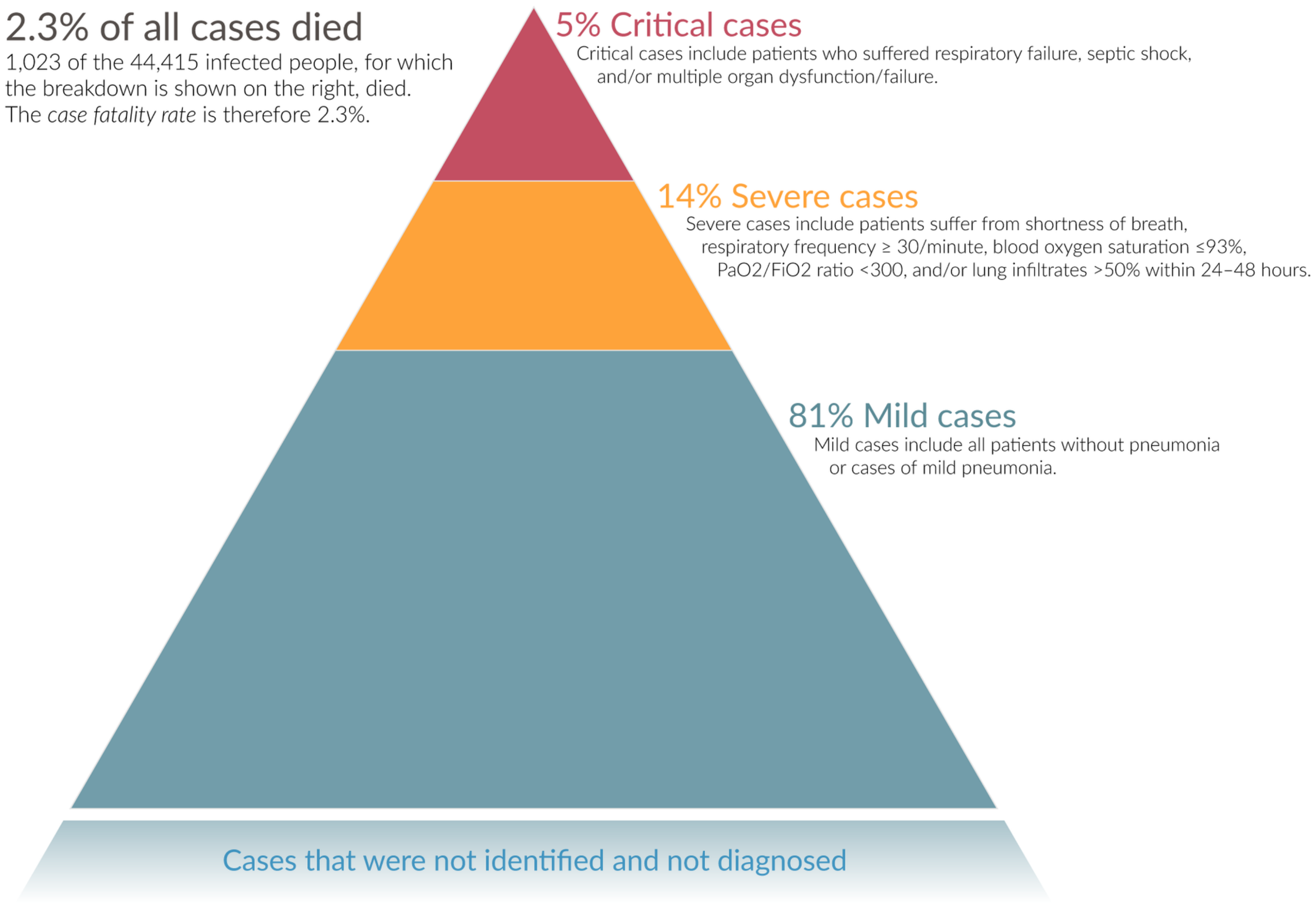
Protecting the vulnerable is not enough!!

Leaving young people infected, using the herd immunity to kill the infection and protecting the old



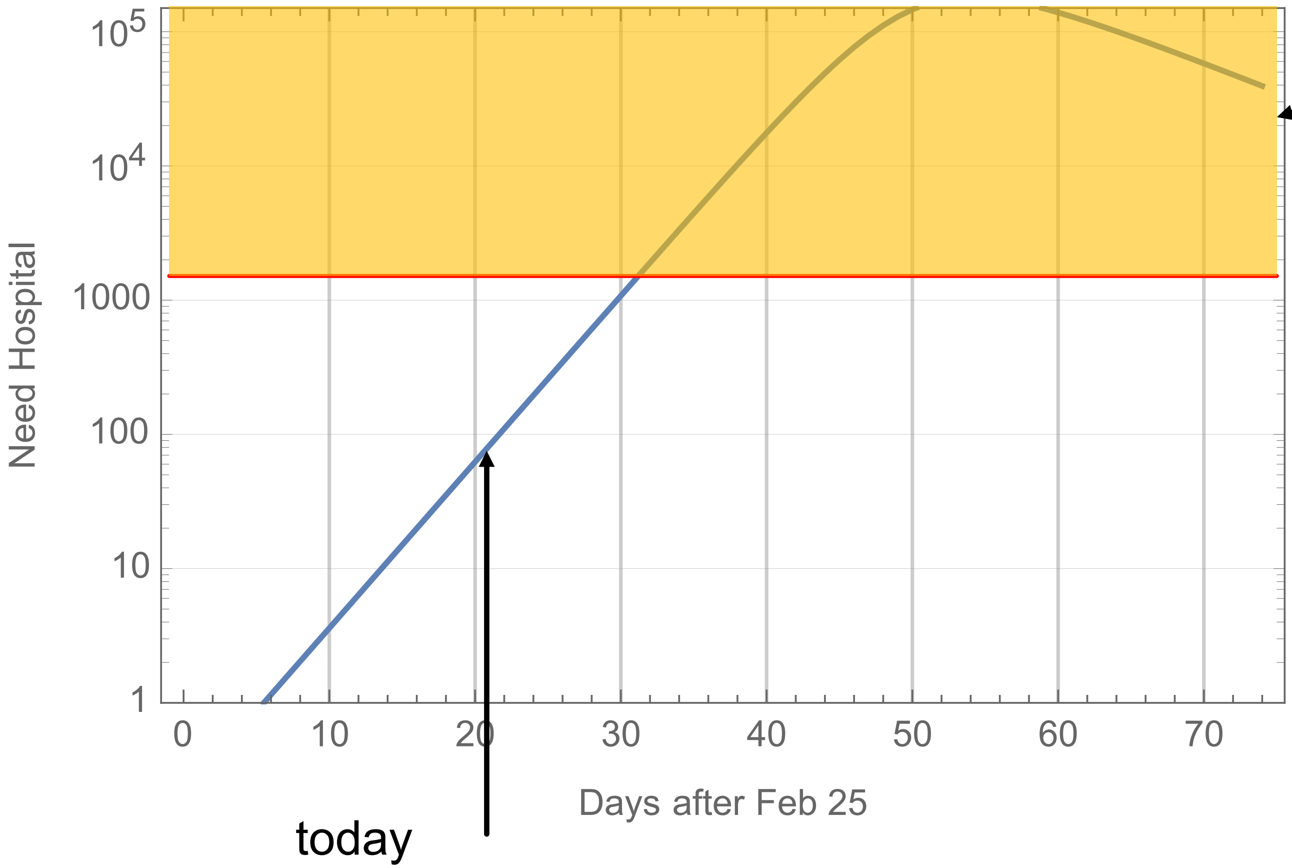
You decrease the death by ~60% only

What fraction of the cases need Hospital intensive care?



You also overload the system

- About 5% of the cases need Intensive care



System is overloaded
(War conditions)

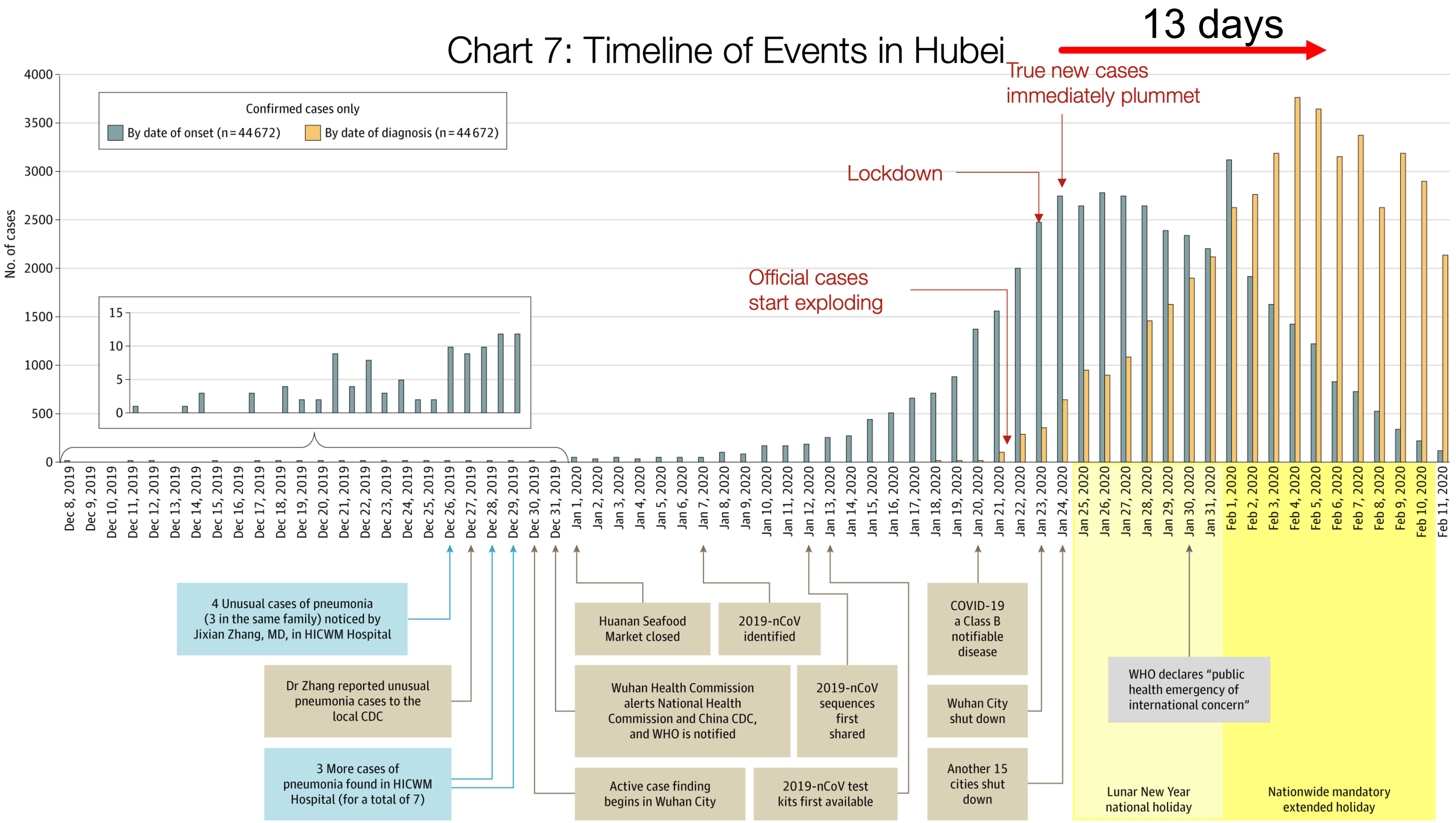
Number of intensive care beds in Switzerland (N ~1500) (very approximate)

And you still need to take care of the non-Corona patients!

Only way is the Chinese way: act on β

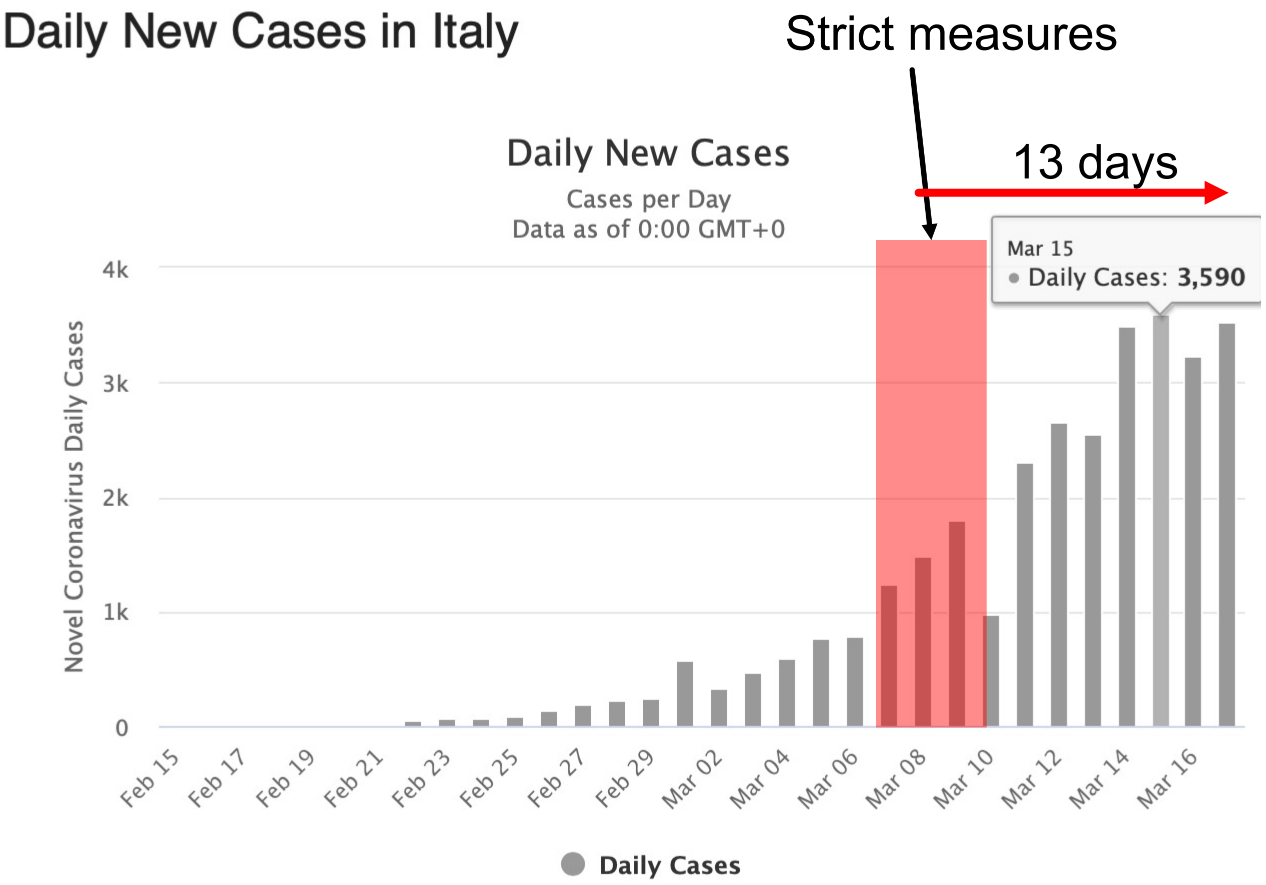
- Strongly reduce β
- The Chinese achieved a R_0 = 0.3, from an initial value of 4.3
- It means a reduction of more than 10x of β
  - However one nice feature is that β is proportional to the **square** of the density of people in any confined area (in this simple model), so it means a factor of 4 in density.
- The stronger the reduction, the faster the recovery
- However, measures take time to have an effect

Observed experimentally



Source: Tomas Pueyo analysis over chart from the [Journal of the American Medical Association](), based on raw case data from the Chinese Center for Disease Control and Prevention

Same in Italy



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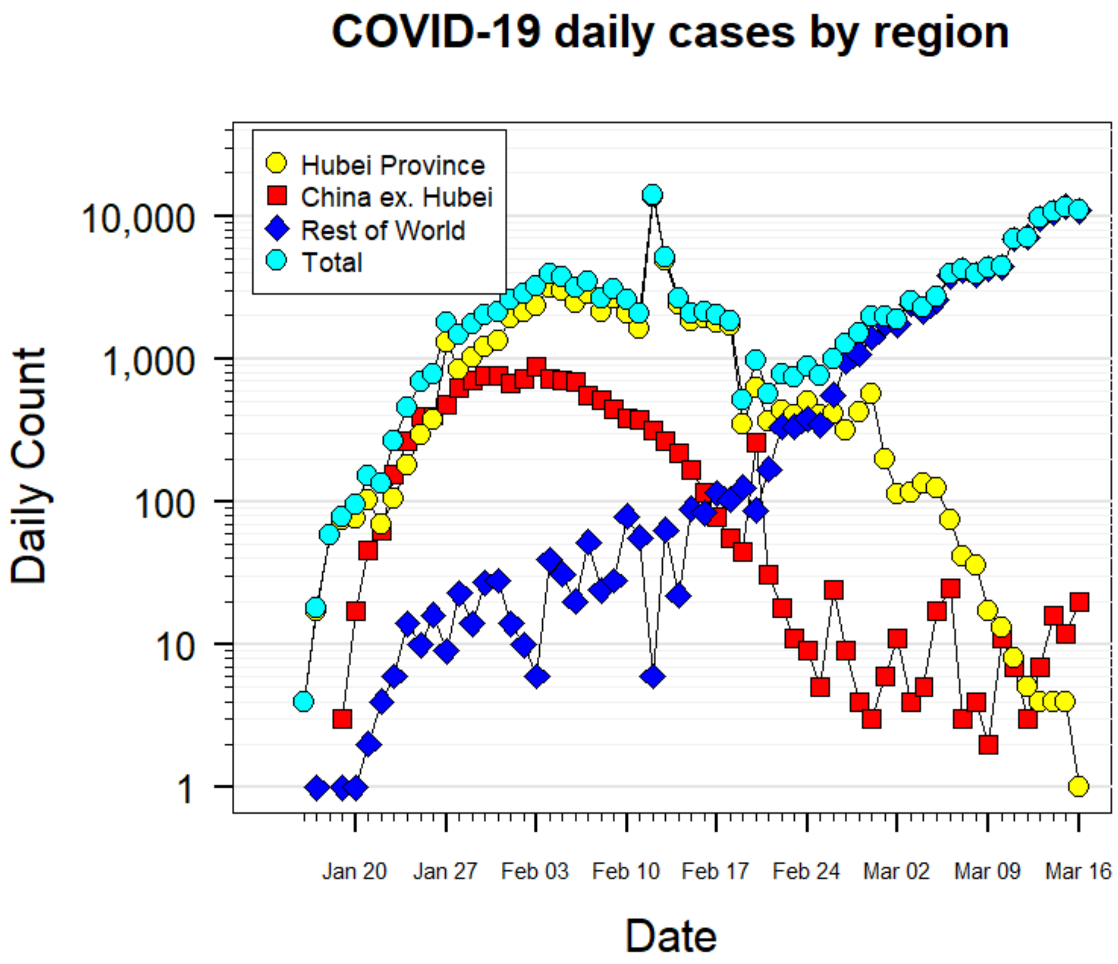
Strict measures work!



China did it, we can also!

Source: wikipedia

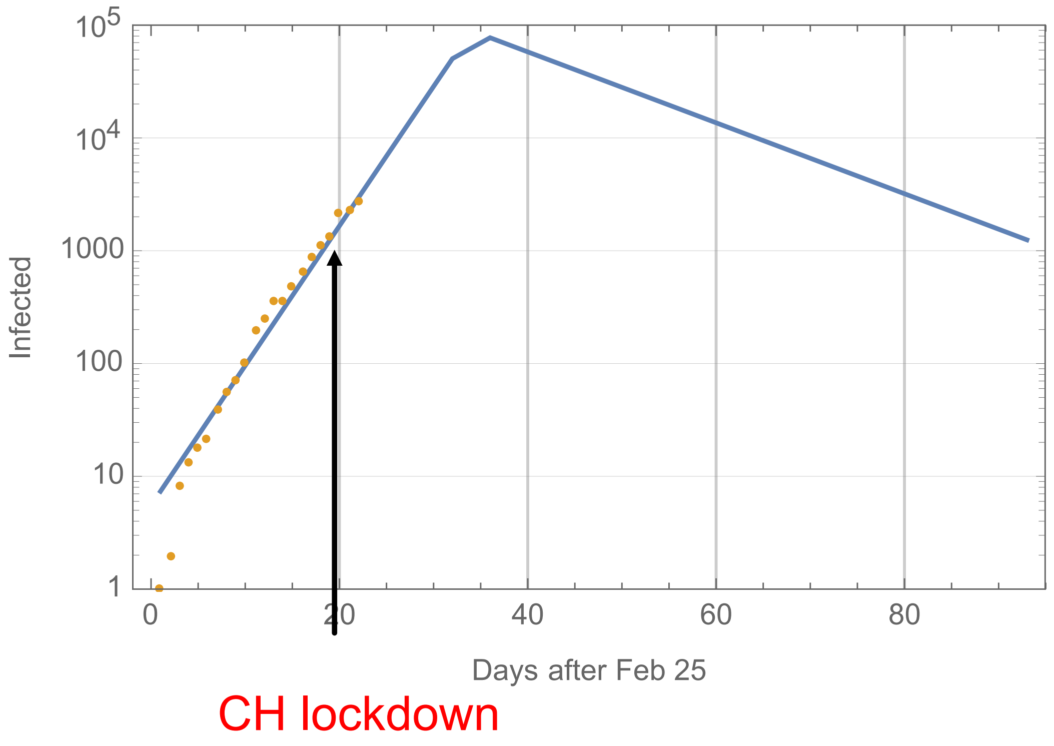
Model: what can we hope for Switzerland

- This model predictions may end up being widely off in either direction
- However they have a value by showing the importance of applying strictly the instruction of the federal council
- Assumptions:
  - Going into the “orange” alert did not change radically the behavior of the infection (beta unchanged) – this can be checked soon (but the data are unreliable now)
  - The decision of the federal council on Friday 13 decreased beta by a factor 2
  - The decision of the federal council on Monday 16 enabled us to go to the Chinese value (very optimistic unfortunately)
  - Assumed a delay of 13 days

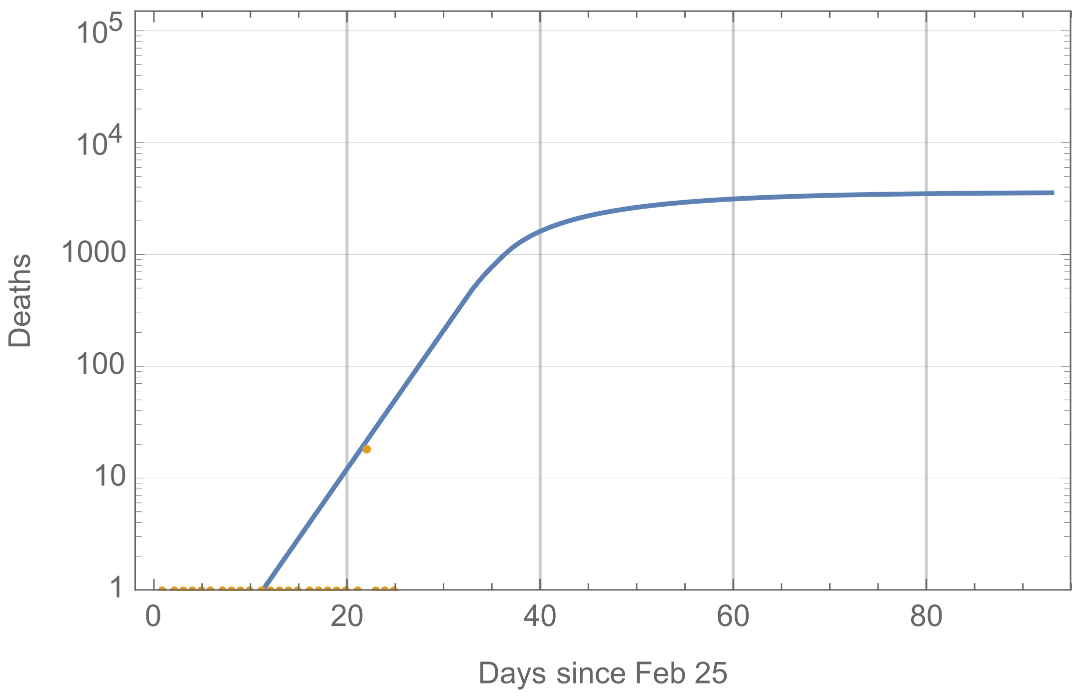
The situation will be very critical

- Close to Italy-like situation

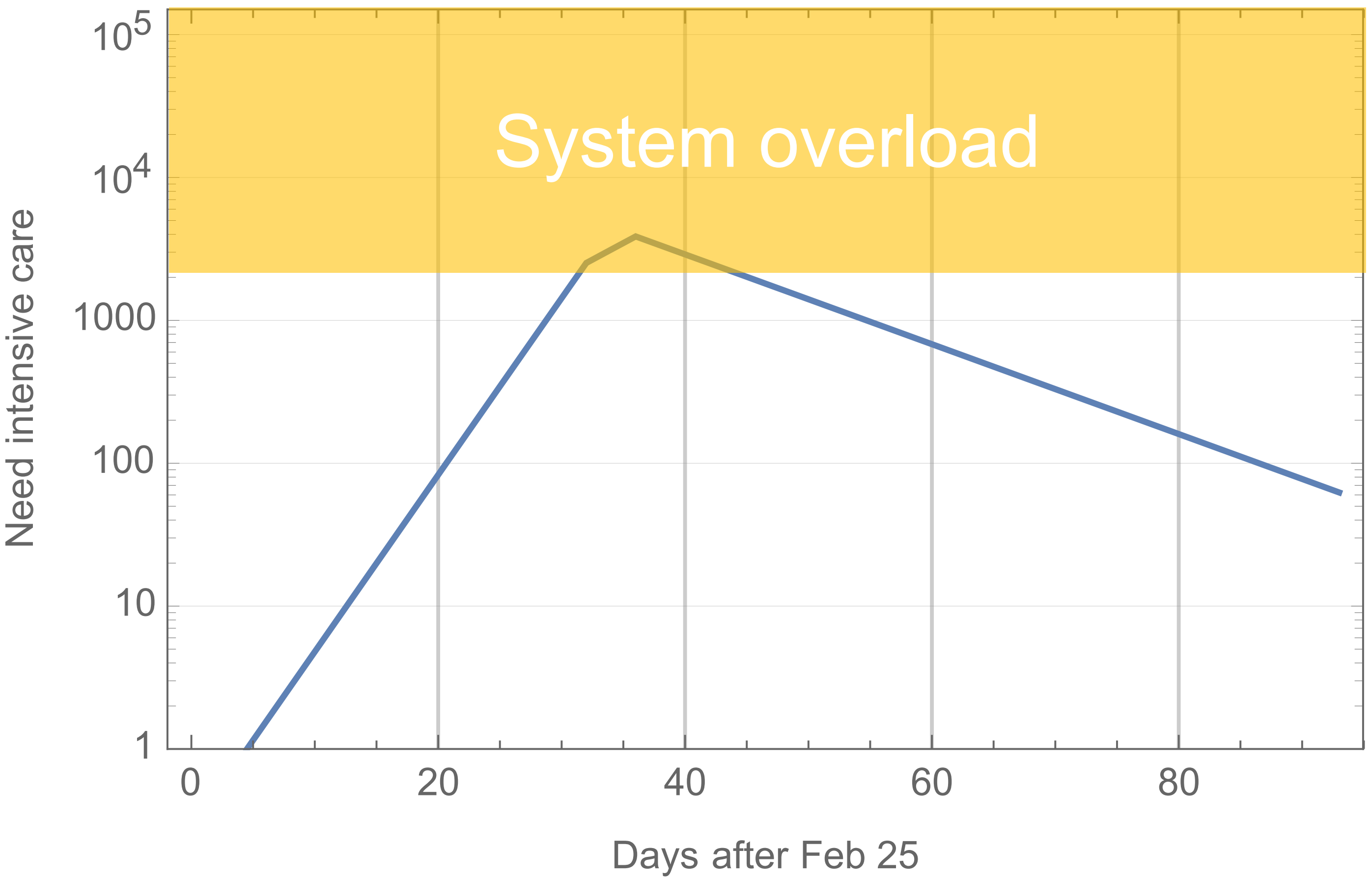
About 60’000 infections



About 3’000 deaths

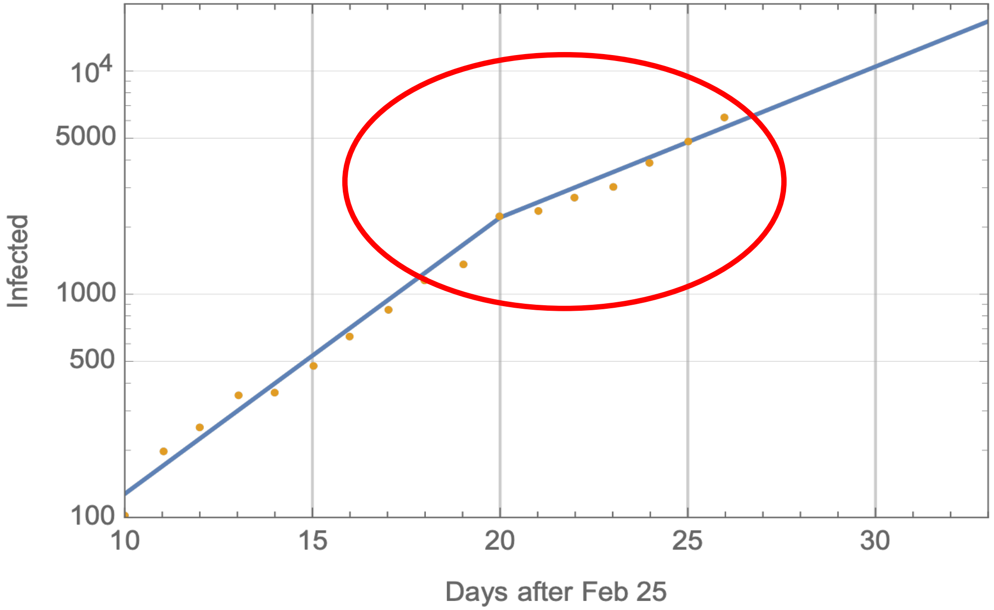


Situation in hospital will be extremely critical

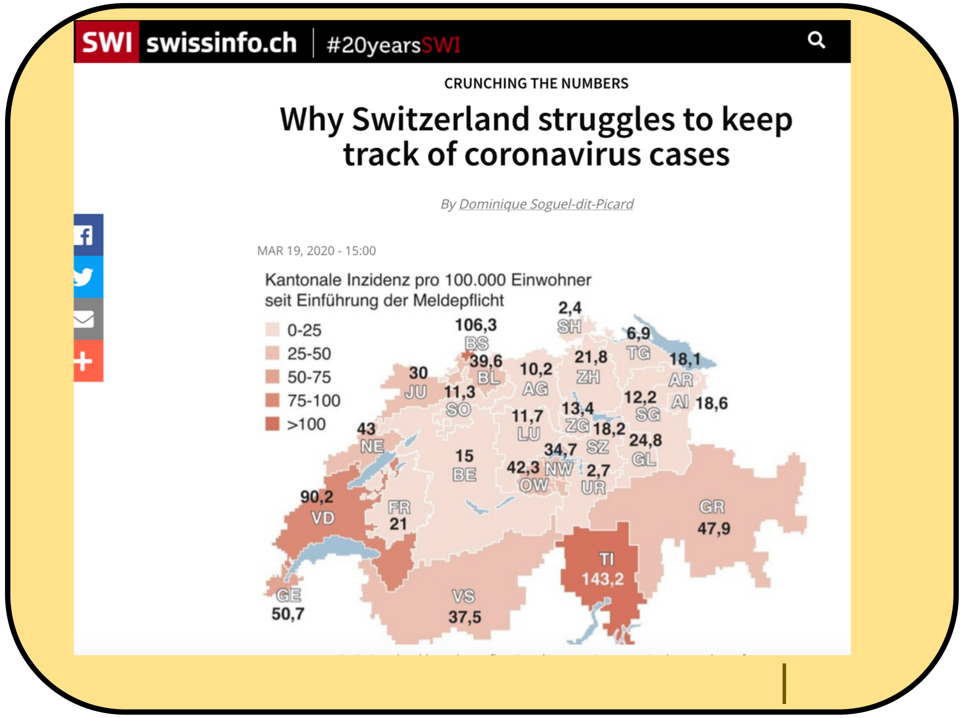


A bit of a rosier scenario

- Assume that the recent data are real and not statistical fluctuations but a change in behavior after the announcements March 6:



It could be a fluke unfortunately…



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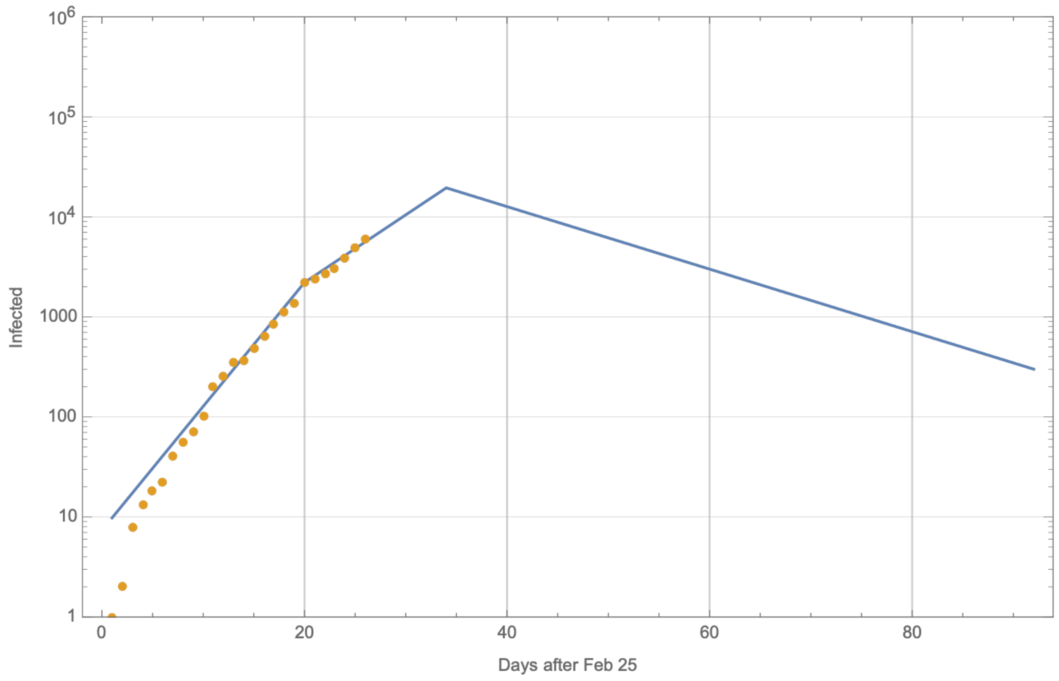

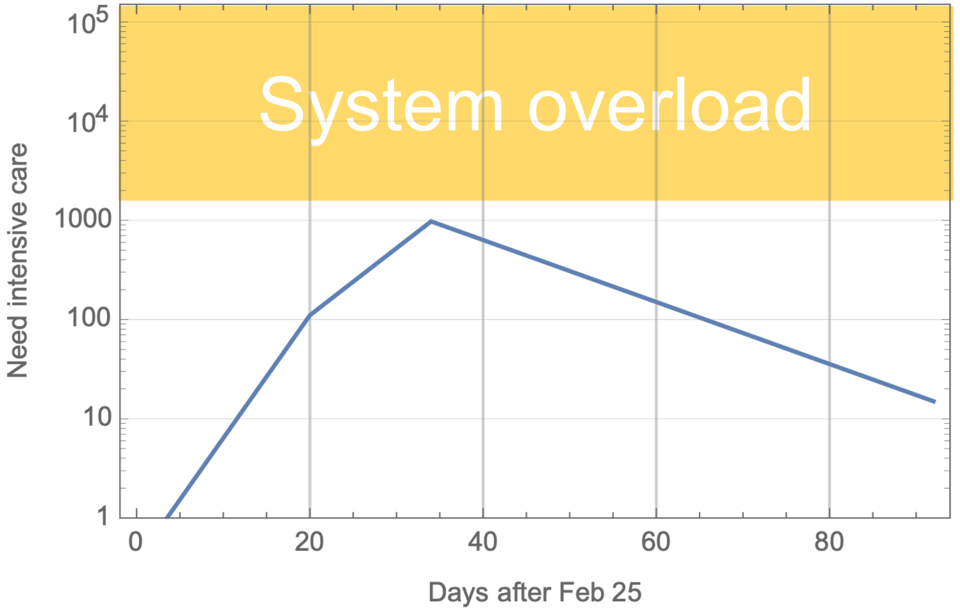

Conclusion

- So far, indications from abroad are that social distancing works
- The model suggest every possible effort should be done to decrease the transmission immediately, any delay is very costly
- Major disaster will be barely avoided, and only if the measures are followed strictly
- It is fundamental to apply the strongest measures quickly (basically that drive R<1) by lowering β

PLEASE DO YOUR PART: STAY HOME AT ALL COSTS

Measures

- 28/2/20: Besondere Lage
- 6/3/20: Schools remain open, protection of the at-risk and stronger measures
- 13/3/20: Stricter measures (
- 16/3/20: Exceptional situation “Ausserordenliche Lage”, Armee Mobilisiet Teilweise, t..