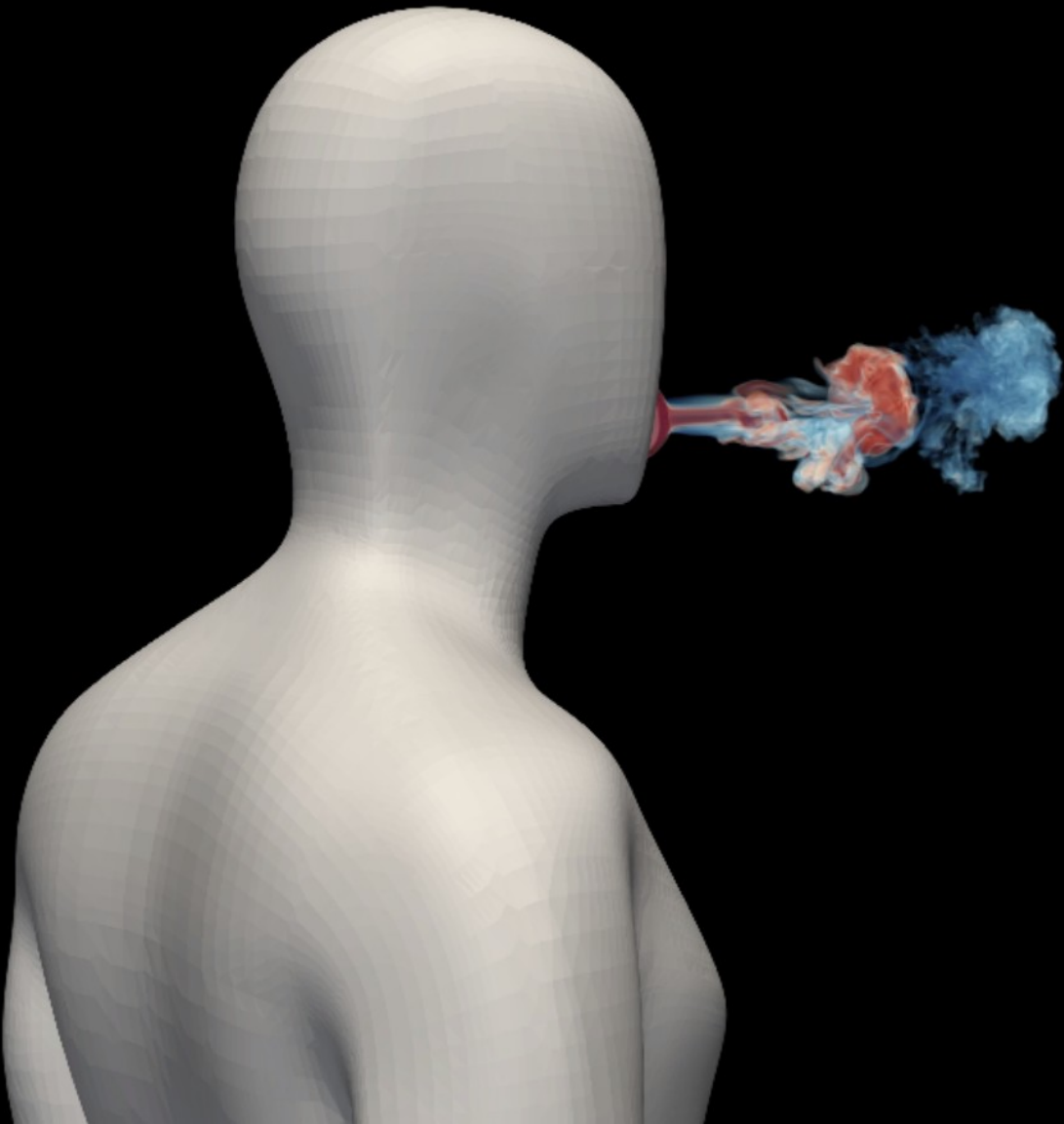


# Airborne transmission: the aerosol inhalation route of SARS-CoV-2

HiDATA webinar-Data Science in the Post-Covid World 11.5.2021  
Prof. Ville Vuorinen  
Aalto University

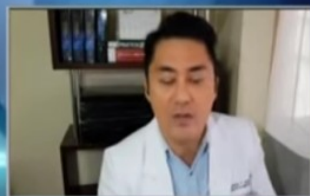


Aalto University  
School of Engineering



SUOMEN AKATEMIA

Via TVU Anywhere



THE DOCTOR IS IN

UNDERSTANDING HOW VIRUSES SPREAD

Dr. Freddie Gomez | ENT Surgeon/Med Talk Health Talk host

LIVE



## Safety Science

Available online 11 June 2020, 104866

In Press, Journal Pre-proof ?



# Modelling aerosol transport and virus exposure with numerical simulations in relation to SARS-CoV-2 transmission by inhalation indoors

Ville Vuorinen <sup>a</sup>✉, Mia Aarnio <sup>b, 1</sup>, Mikko Alava <sup>h</sup>, Ville Alopaeus <sup>c</sup>, Nina Atanasova <sup>b, i</sup>, Mikko Auvinen <sup>b</sup>, Nallannan Balasubramanian <sup>e</sup>, Hadi Bordbar <sup>g</sup>, Panu Erästö <sup>f</sup>, Rafael Grande <sup>d</sup>, Nick Hayward <sup>e</sup>, Antti Hellsten <sup>b</sup>, Simo Hostikka <sup>g</sup>, Jyrki Hokkanen <sup>m</sup>, Ossi Kaario <sup>a</sup>, Aku Karvinen <sup>l</sup>, Ilkka Kivistö <sup>l</sup>, Marko Korhonen <sup>h</sup>, Risto Kosonen <sup>a</sup>, Janne Kuusela <sup>n</sup>, Sami Lestinen <sup>a</sup>, Erkki Laurila <sup>a</sup>, Heikki J. Nieminen <sup>e</sup>, Petteri Peltonen <sup>a</sup>, Juho Pokki <sup>c</sup>, Antti Puisto <sup>h</sup>, Peter Råback <sup>m</sup>, Henri Salmenjoki <sup>h</sup>, Tarja Sironen <sup>j, k</sup>, Monika Österberg <sup>d</sup>



# 30/4/2021 Major change: WHO acknowledges short and long range aerosol inhalation as primary modes

<https://www.who.int/news-room/q-a-detail/coronavirus-disease-covid-19-how-is-it-transmitted>



World Health  
Organization

Health

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- Current evidence suggests that the virus spreads mainly between people who are in close contact with each other, typically within 1 metre (short-range). A person can be infected when aerosols or droplets containing the virus are inhaled or come directly into contact with the eyes, nose, or mouth.
- The virus can also spread in poorly ventilated and/or crowded indoor settings, where people tend to spend longer periods of time. This is because aerosols remain suspended in the air or travel farther than 1 metre (long-range).

People may also become infected by touching surfaces that have been

# Why Did It Take So Long to Accept the Facts About Covid?

May 7, 2021



# **Part 1: Background**

# Nature 2/2021: Superspreading drives the COVID pandemic (20:80 rule)

<https://www.nature.com/articles/d41586-021-00460-x>



# 712 confirmed infections on the Diamond Princess

<https://www.nytimes.com/2020/07/30/health/diamond-princess-coronavirus-aerosol.html>

## *Aboard the Diamond Princess, a Case Study in Aerosol Transmission*

A computer model of the cruise-ship outbreak found that the virus spread most readily in microscopic droplets light enough to linger in the air.



E.g. Japan assumed airborne transmission from the beginning

# Avoid the “Three Cs”!

**1. Closed spaces** with **poor ventilation.**

**2. Crowded places** with many people nearby.

**3. Close-contact settings** such as close-range conversations.





# 2020: “Classical droplet transmission” → large droplets

Aerosols



Droplets

# 2021: “Modernized version” → aerosols

**Aerosols**

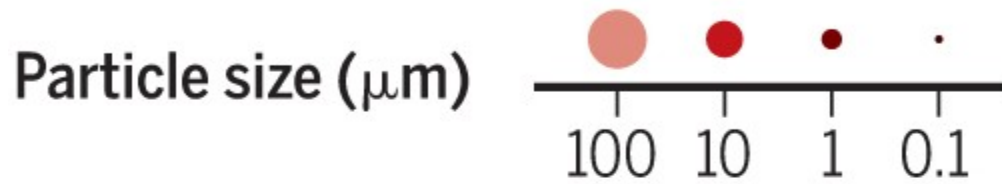


**Droplets**

Also cigarette smoke consists of aerosol particles



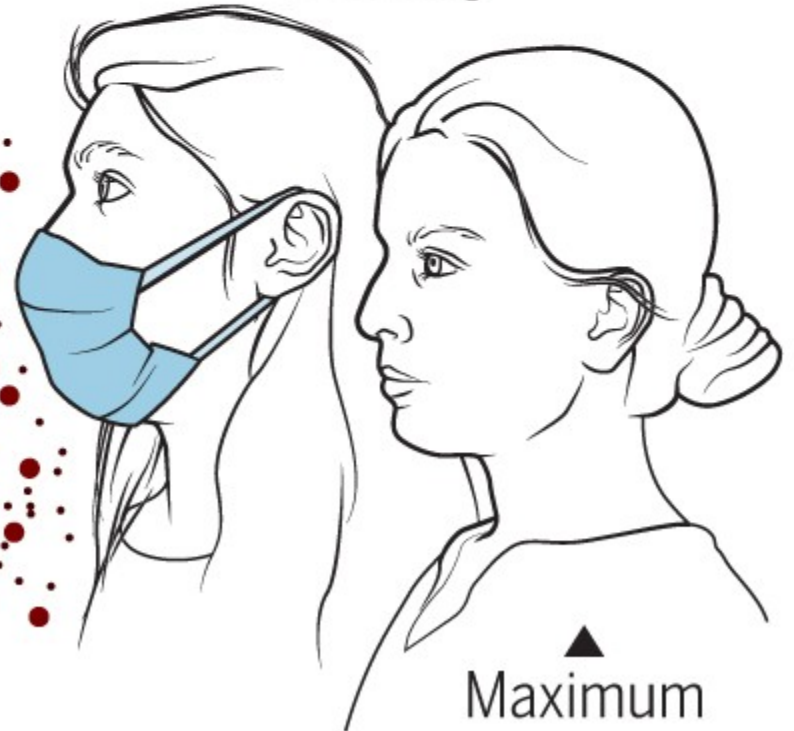
Infectious aerosol particles can be released during breathing and speaking by asymptomatic infected individuals. No masking maximizes exposure, whereas universal masking results in the least exposure.



**Infected, asymptomatic**



**Healthy**

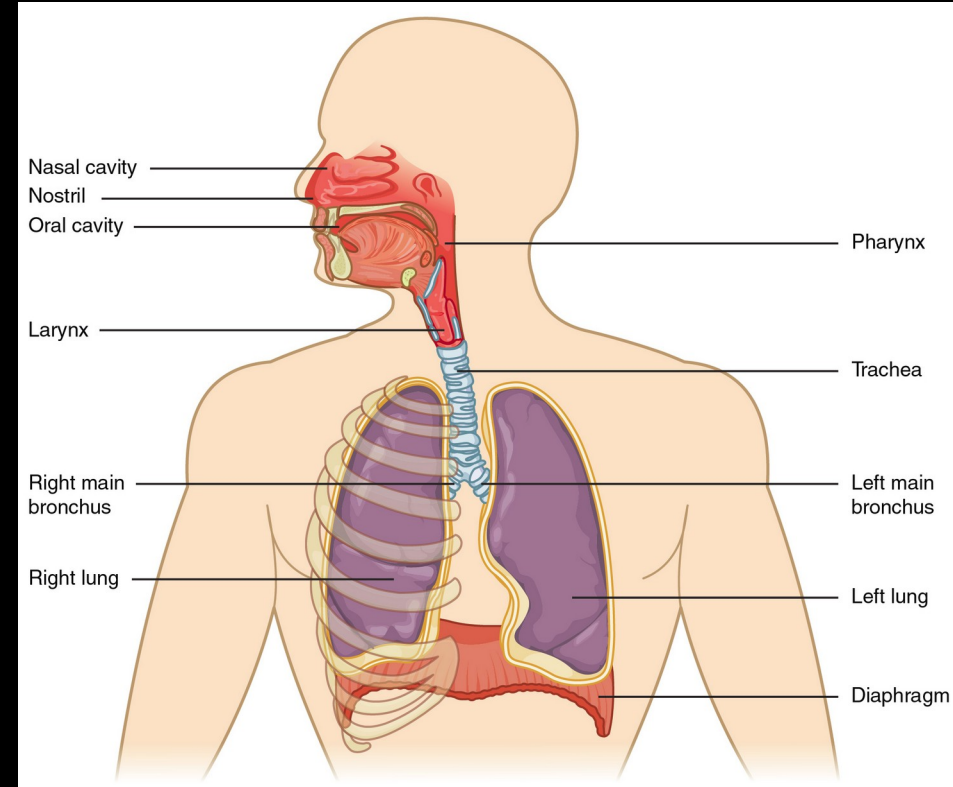
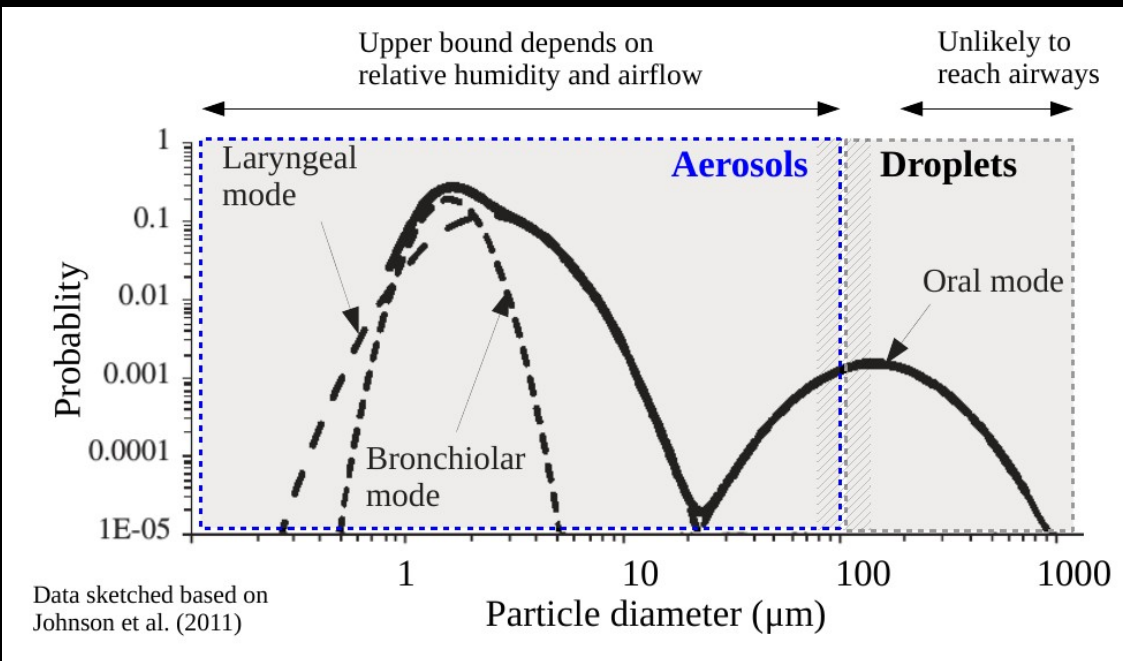


▲  
Maximum  
exposure

# Aerosols and droplets are formed along the respiratory tract

Johnson et al. 2011: size distribution

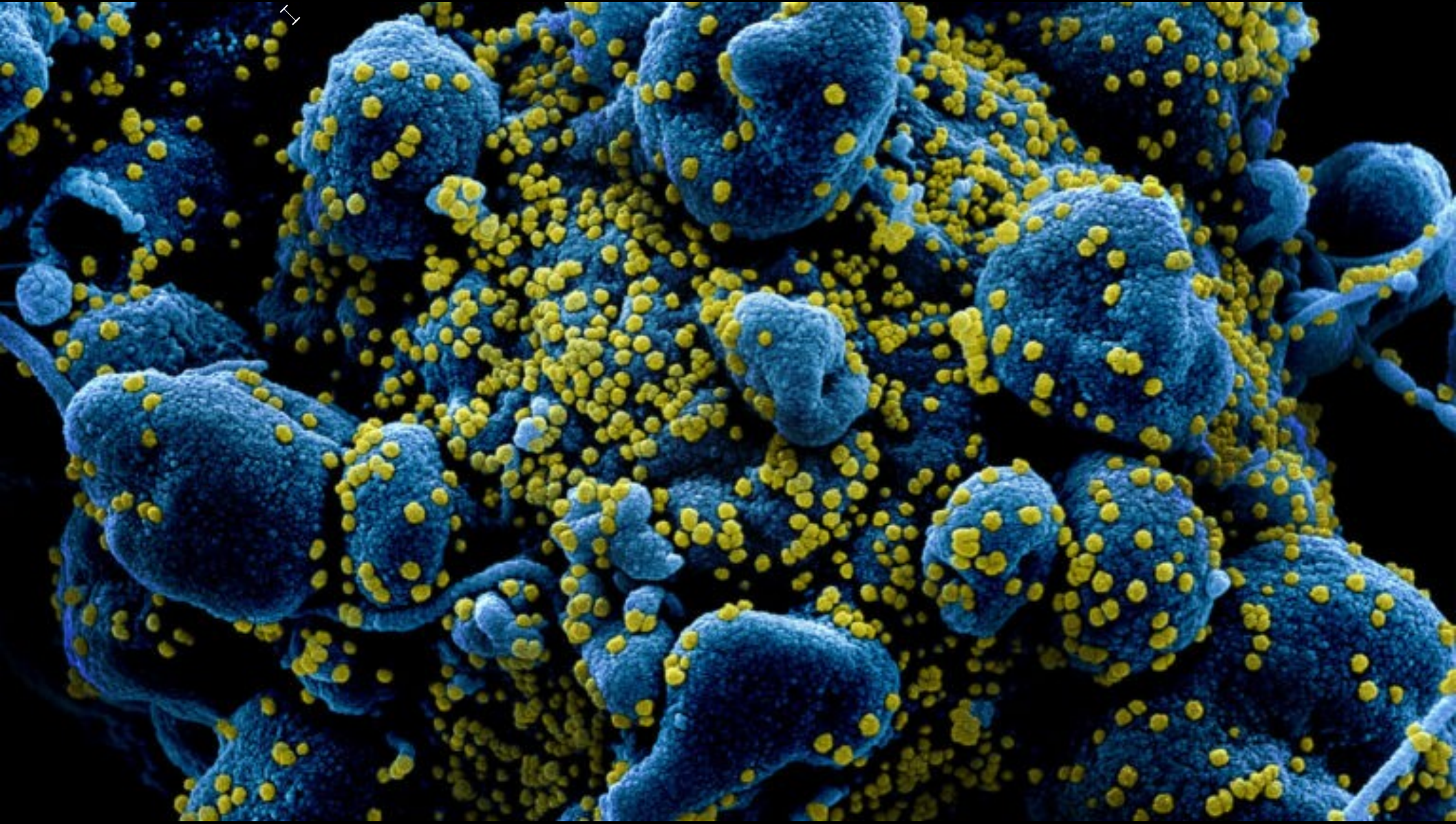
## ~100 aerosols per 1 large droplet



# How could an aerosol particle look like? SEM image of coronaviruses (yellow) on a cell (blue)

<https://www.statnews.com/2021/01/14/more-infectious-variants-could-make-things-much-worse/>

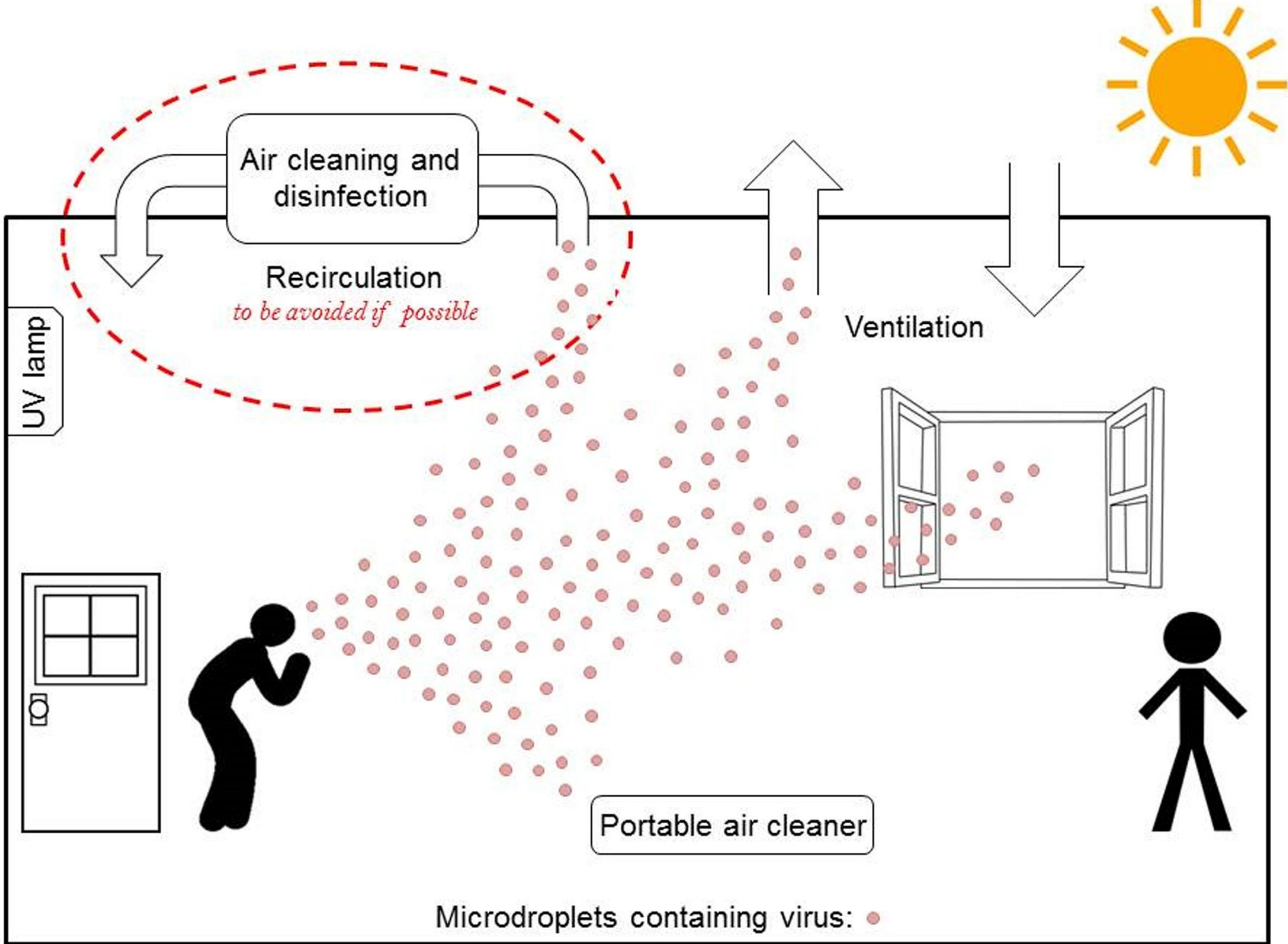
Virus size  $\sim 100 \text{ nm} = 0.0001 \text{ mm}$



# Aerosol concentrations can build-up in the air indoors



[https://en.wikipedia.org/wiki/Passive\\_smoking#/media/File:Smoke-by-a-window-in-a-pub.jpg](https://en.wikipedia.org/wiki/Passive_smoking#/media/File:Smoke-by-a-window-in-a-pub.jpg)



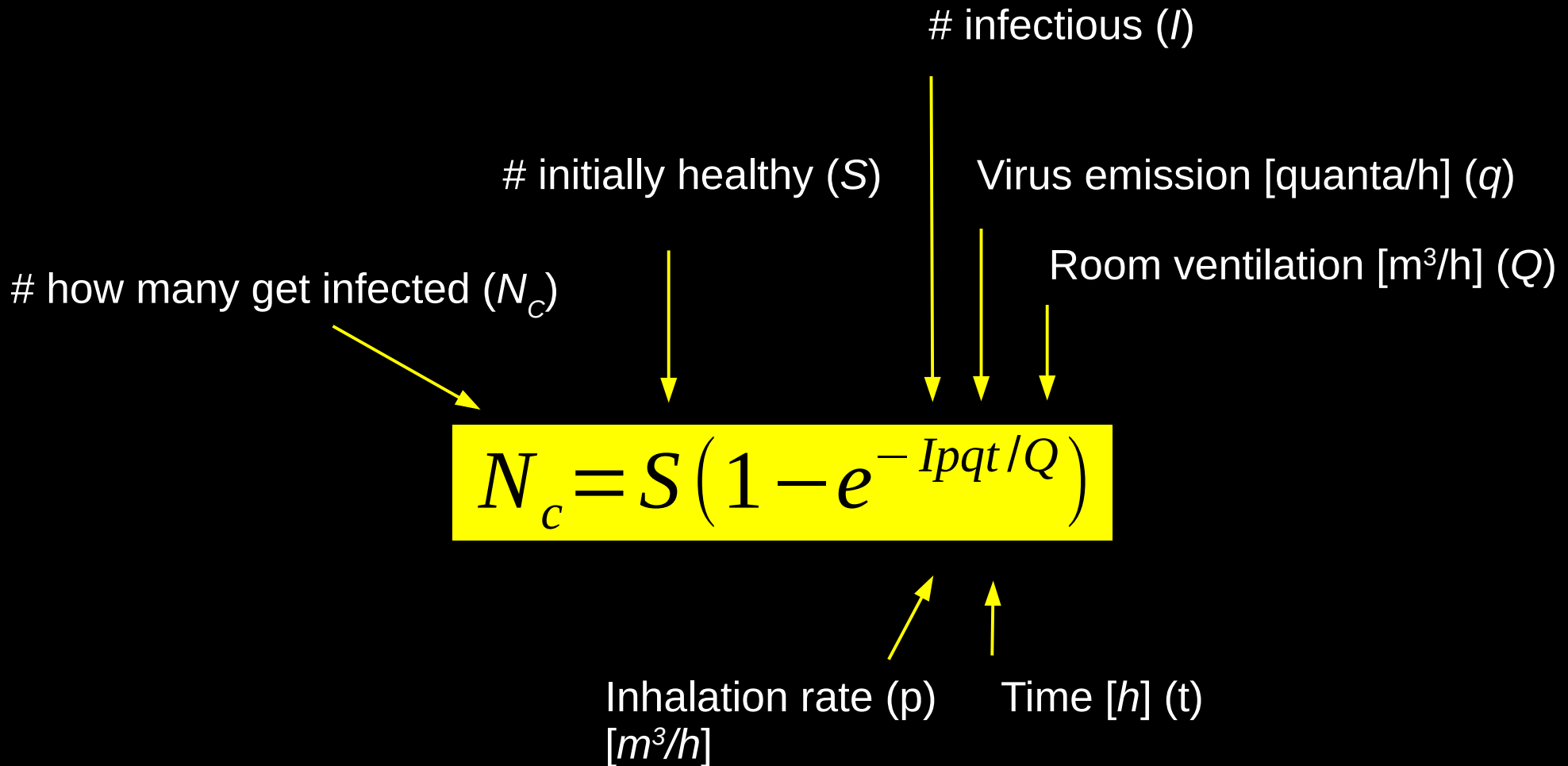


# How much do I need to inhale viral aerosols to get infected?



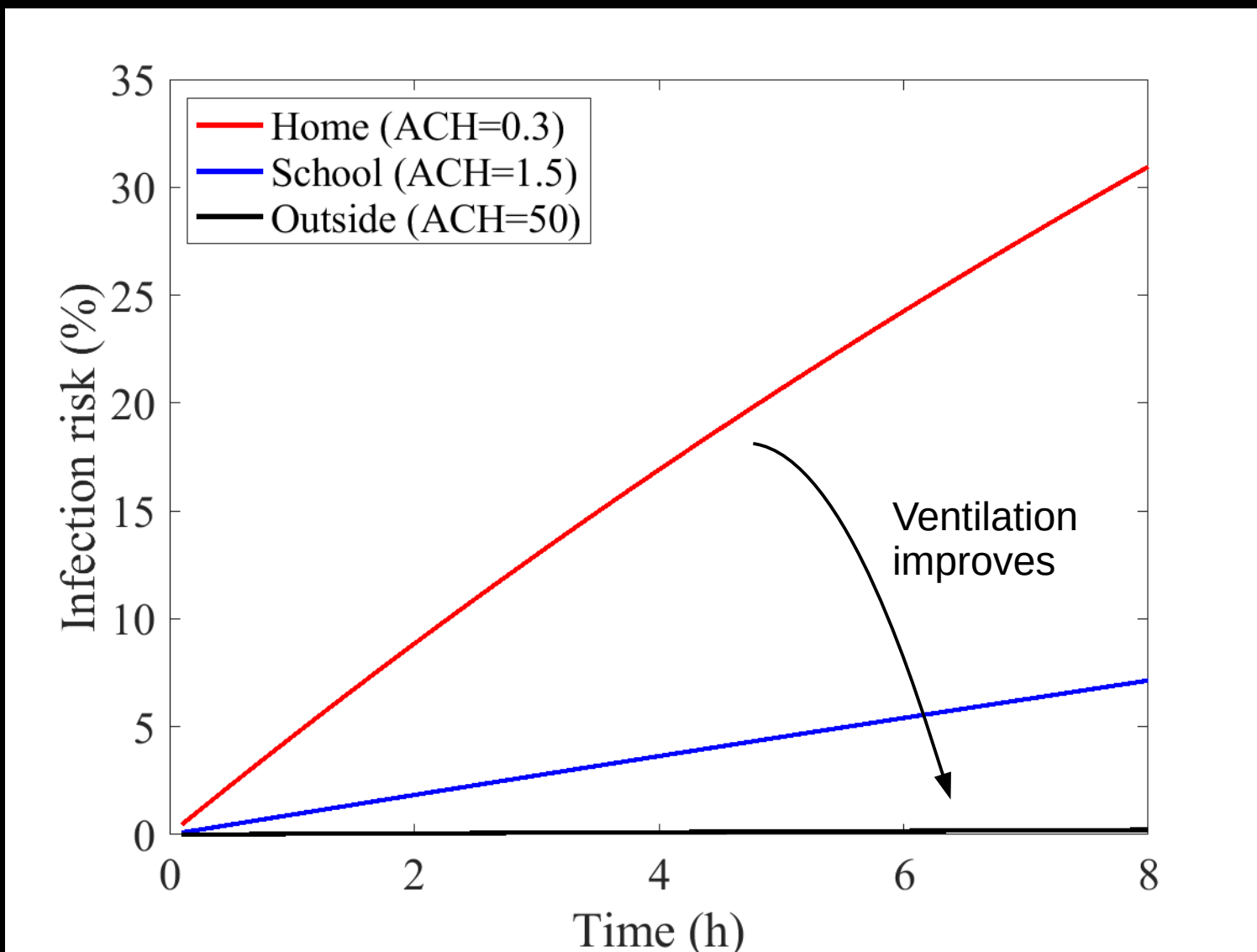
[https://en.wikipedia.org/wiki/Passive\\_smoking#/media/File:Smoke-by-a-window-in-a-pub.jpg](https://en.wikipedia.org/wiki/Passive_smoking#/media/File:Smoke-by-a-window-in-a-pub.jpg)

# Wells-Riley model can be utilized to estimate the infection risk from the air via inhalation



$$\text{Infection risk} = 100\% \times N_c / S$$

# Wells-Riley model takes into account the room ventilation rate, exposure time, activity etc



# Nature 2/2021 editorial

<https://www.nature.com/articles/d41586-021-00277-8>

EDITORIAL • 02 FEBRUARY 2021

## Coronavirus is in the air – there’s too much focus on surfaces

Catching the coronavirus from surfaces is rare. The World Health Organization and national public-health agencies need to clarify their advice.



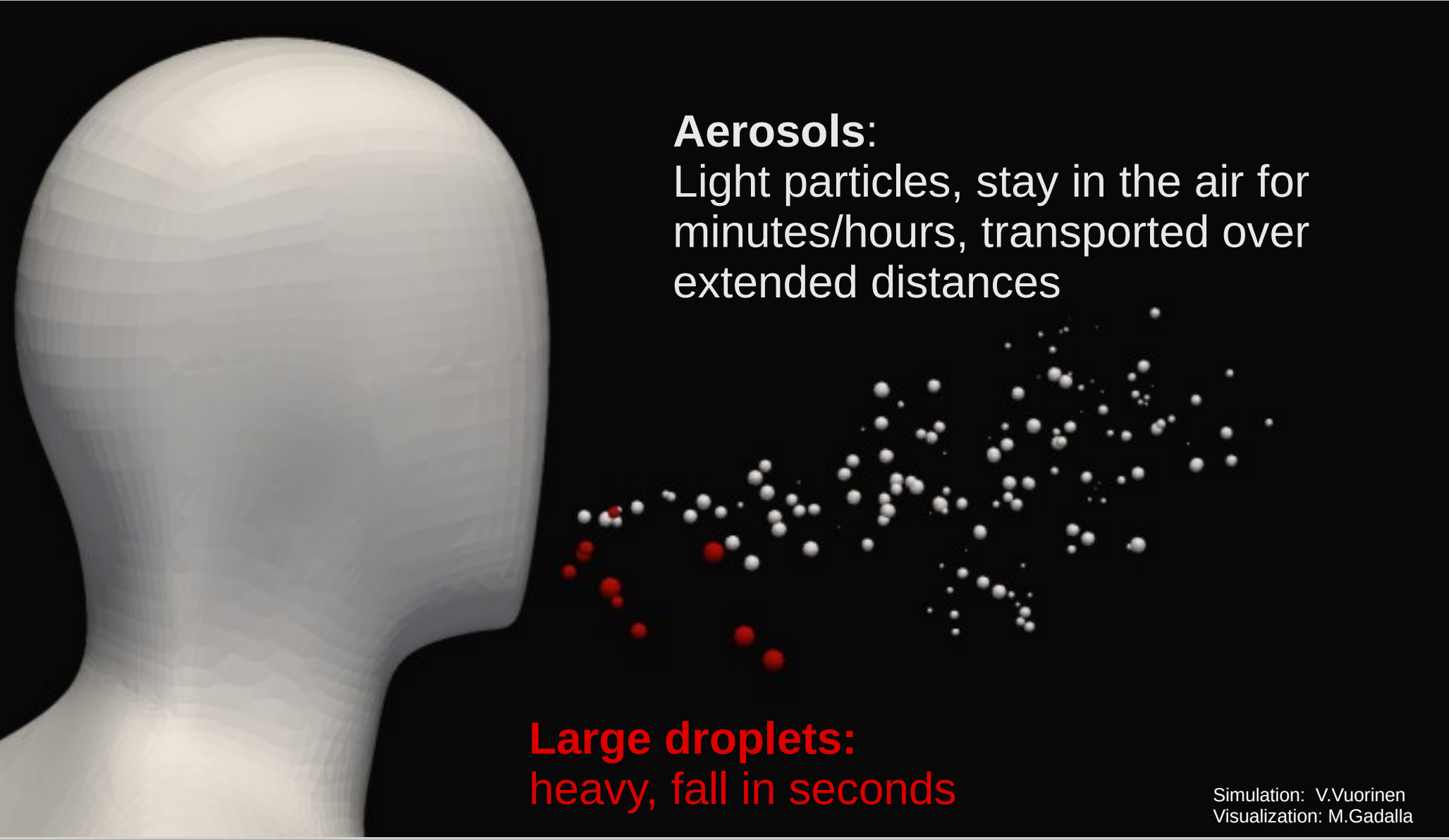
[PDF version](#)

### RELATED ARTICLES

**COVID-19 rarely spreads through surfaces. So why do we still do deep cleaning?**

**Mounting evidence suggests coronavirus is airborne, but health advice has not caught up**

# Part 2: Physics



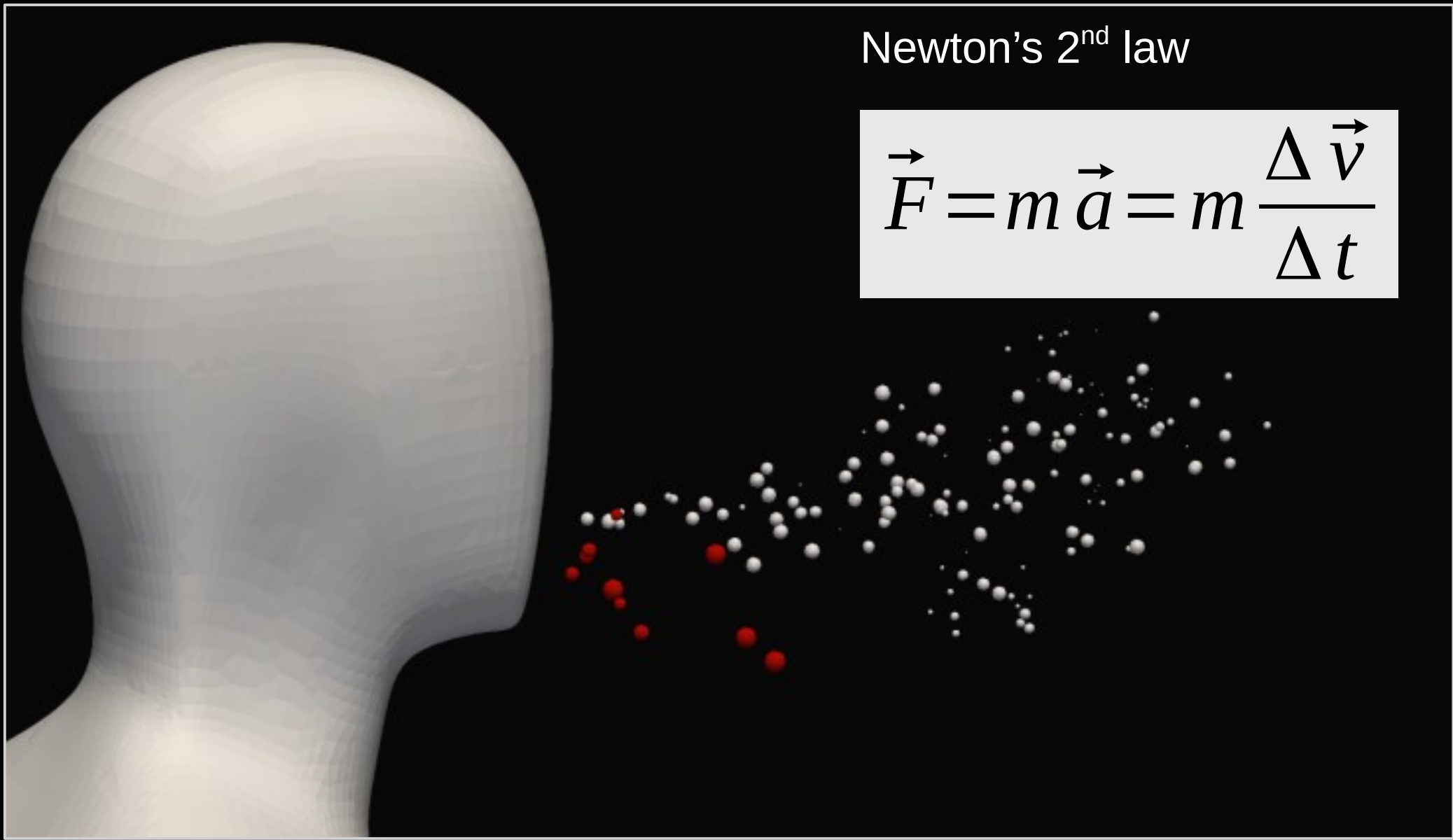
## Aerosols:

Light particles, stay in the air for minutes/hours, transported over extended distances

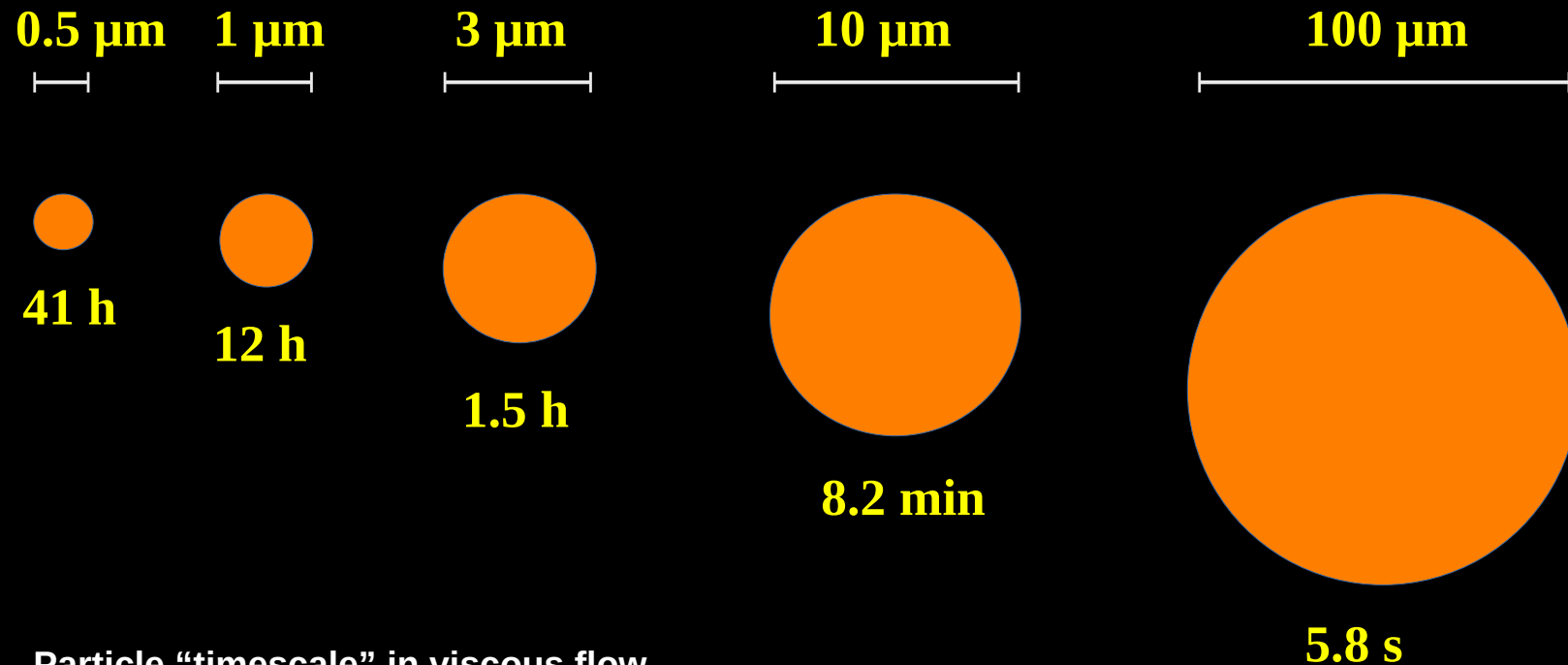
**Large droplets:**  
heavy, fall in seconds

Newton's 2<sup>nd</sup> law

$$\vec{F} = m \vec{a} = m \frac{\Delta \vec{v}}{\Delta t}$$



# Basic aerosol physics: Particle falling time from 1.5m height



Particle “timescale” in viscous flow

$$\tau_p = \frac{\rho_p d^2}{18\nu_g \rho_g}$$

Falling speed

$$v_p = \tau_p g$$


Falling time



$$t_s = h/v_p$$



## Aerosol vs droplet? → Fact checking revealed: a dramatic 100-year old error in medical textbooks

<https://www.sciencedirect.com/science/article/pii/S0195670121000074?via%3Dihub>

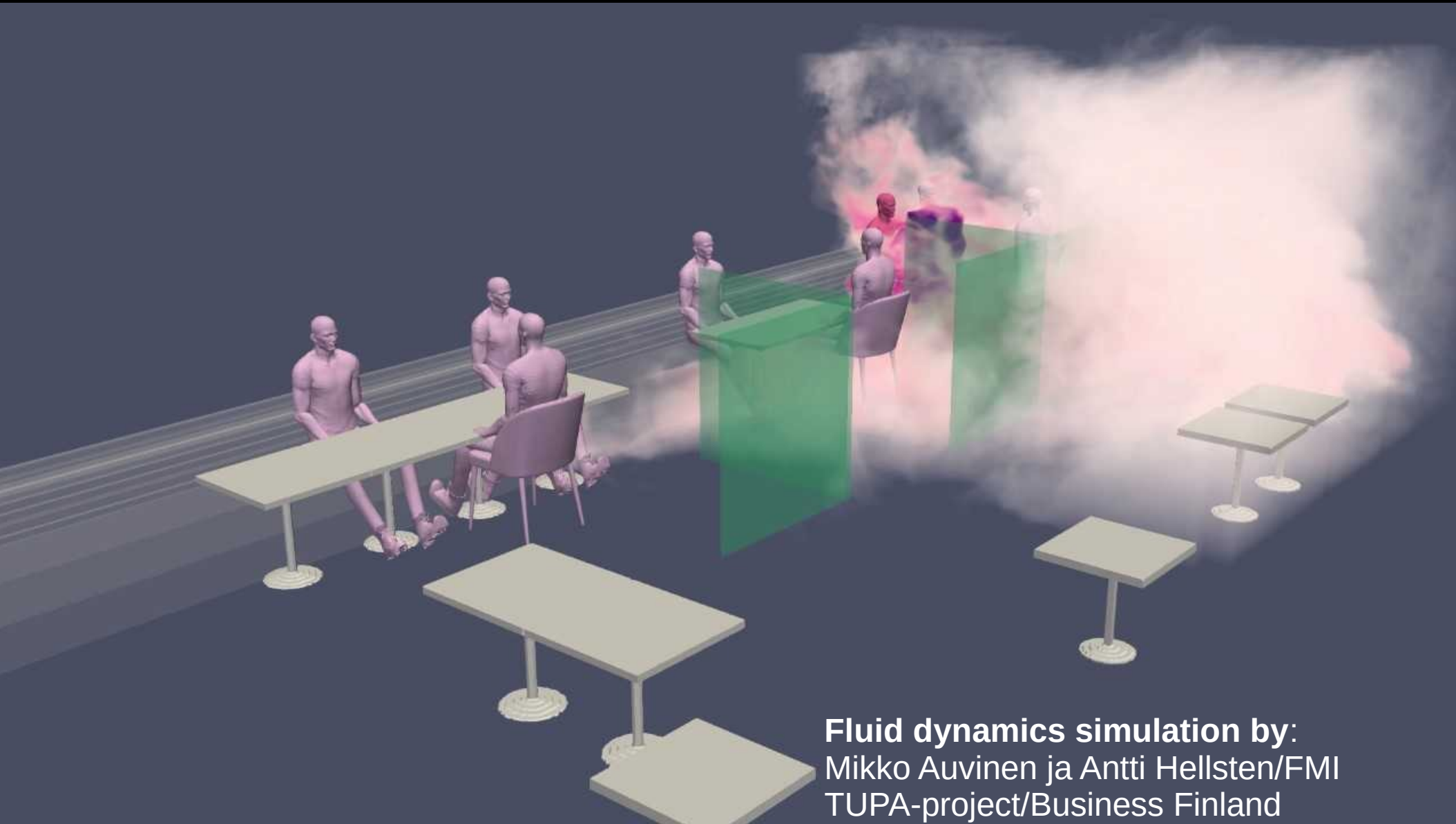
 University of Colorado Boulder

 MYTH	 FACT
1) Aerosols are droplets with a diameter of 5 $\mu\text{m}$ or less	1) Aerosols can be up to 100 $\mu\text{m}$ in size
2) Everything larger than 5 $\mu\text{m}$ falls within 1-2 m	2) A 5 $\mu\text{m}$ aerosol can travel hundreds of meters
3) If it's short range, then it can't be airborne	3) Short-range transmission is dominated by aerosols
4) The virus is only 0.1 $\mu\text{m}$ in size so masks won't work	4) Virus is carried in aerosols larger than 0.1 $\mu\text{m}$
5) Aerosols only matter for aerosol generating procedures	5) Talking and coughing are aerosol generating procedures

Slide courtesy of Prof. Linsey Marr

From our published paper in the Journal of Hospital Infection: J.W. Tang, W.P. Bahnfleth, P. Bluysen, G. Buonanno, S.J. Dancer, J.L. Jimenez, J. Kurnitski, Y. Li, S. Miller, C. Sekhar, L. Morawska, L.C. Marr, A.K. Melikov, W.W. Nazaroff, P.V. Nielsen, R. Tellier, P. Wargocki. Dismantling myths on the airborne transmission of severe acute respiratory syndrome coronavirus (SARS-CoV-2). *J. Hosp. Inf.*, 110, 89-96, 2021.  
<https://doi.org/10.1016/j.jhin.2020.12.022>

**To protect the people (FFP2/3) and e.g. to avoid superspreading:  
highly relevant to understand the size of infectious particles**



**Fluid dynamics simulation by:**  
Mikko Auvinen ja Antti Hellsten/FMI  
TUPA-project/Business Finland

# **Part 3: scientific arguments behind airborne transmission**

# THE LANCET: 4/2021

THE LANCET

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PDF [184 KB]

## Ten scientific reasons in support of airborne transmission of SARS-CoV-2

[Trisha Greenhalgh](#) • [Jose L Jimenez](#) • [Kimberly A Prather](#) • [Zeynep Tufekci](#) • [David Fisman](#) • [Robert Schooley](#)

Published: April 15, 2021 • DOI: [https://doi.org/10.1016/S0140-6736\(21\)00869-2](https://doi.org/10.1016/S0140-6736(21)00869-2) •



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[https://www.thelancet.com/journals/lancet/article/PIIS0140-6736\(21\)00869-2/fulltext#](https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(21)00869-2/fulltext#)

## THE LANCET: 4/2021

THE LANCET

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Ten scientific arguments on the predominance of SARS-CoV-2 airborne transmission

Trisha Greenhalgh 

Published: April 15, 2021

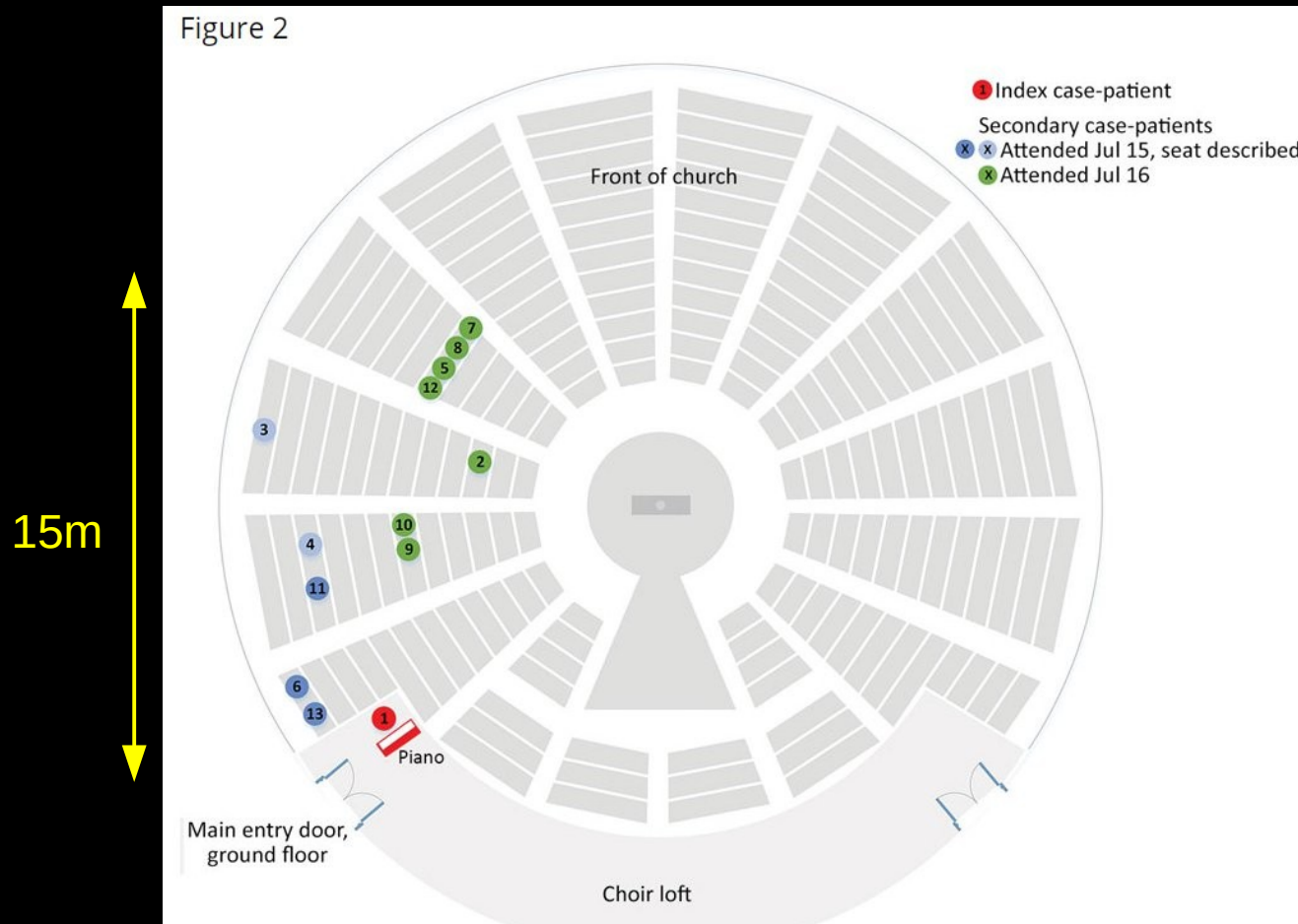
### 10 arguments on predominance of SARS-CoV-2 airborne transmission

- Transmission almost only indoors
- Superspreading
- Asymptomatic spreading
- Numerous long distance transmissions documented
- Infections with only droplet pre-cautions
- Infectious SARS-CoV-2 sampled in air
- SARS-CoV-2 sampled from hospital air filters
- Airborne transmission in animal experiments
- No counter-evidence
- Little/no evidence on other transmission modes (droplet/fomite)

# Epidemiologic Evidence for Airborne Transmission of SARS-CoV-2 during Church Singing, Australia, 2020

[https://wwwnc.cdc.gov/eid/article/27/6/21-0465\\_article](https://wwwnc.cdc.gov/eid/article/27/6/21-0465_article)

Figure 2



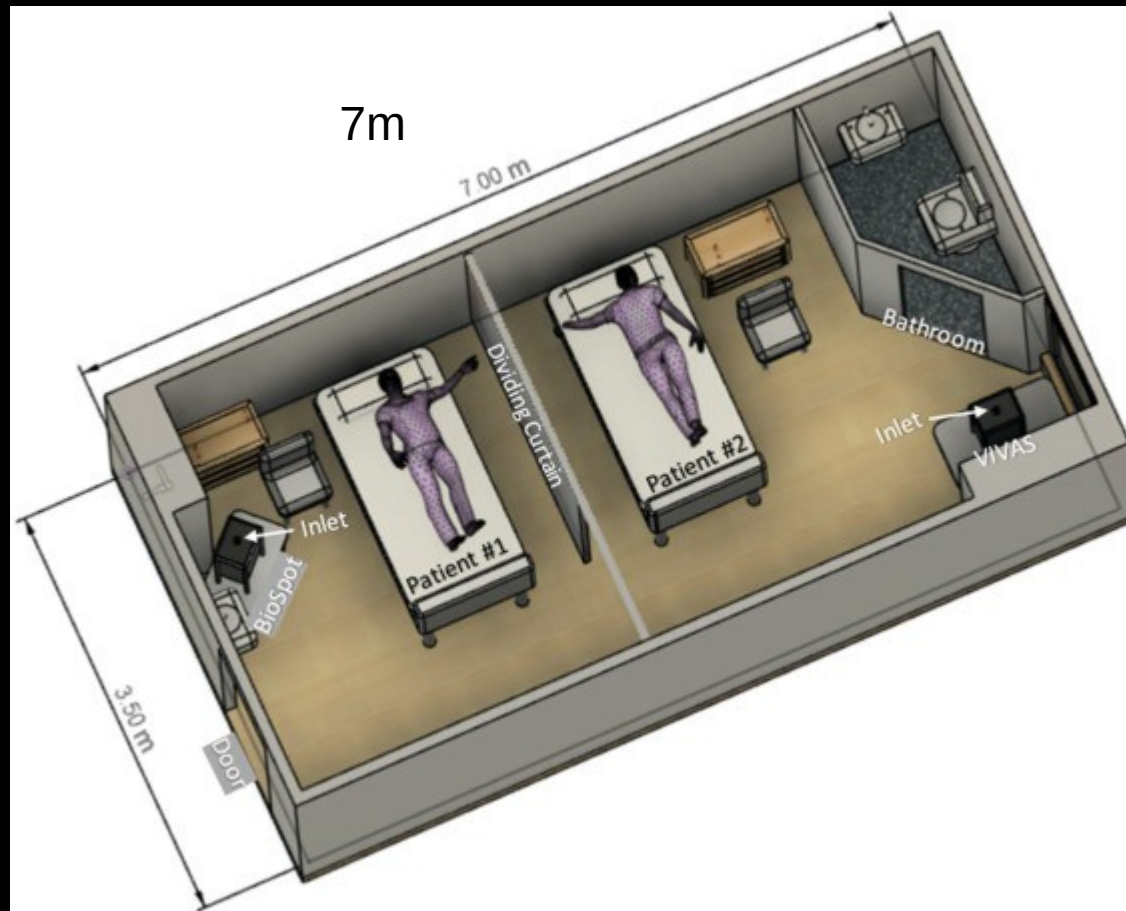
- 12 cases
- Upto 15m distance
- Video: no close contact
- Ventilation off

Lednický et al. (2020) **Viable SARS-CoV-2 in the air of a hospital room with COVID-19 patients**

[https://www.ijidonline.com/article/S1201-9712\(20\)30739-6/fulltext](https://www.ijidonline.com/article/S1201-9712(20)30739-6/fulltext)

Lednický et al. (2021) **Isolation of SARS-CoV-2 from the air in a car driven by a COVID patient with mild illness**

[https://www.ijidonline.com/article/S1201-9712\(21\)00375-1/fulltext](https://www.ijidonline.com/article/S1201-9712(21)00375-1/fulltext)



# Outdoor Transmission of SARS-CoV-2 and Other Respiratory Viruses: A Systematic Review

<https://academic.oup.com/jid/article/223/4/550/6009483>

**Table 1. Comparison of Respiratory Virus Transmission Outdoors Compared to Indoors Ordered by Virus Studied**

Outcome	Virus Studied	Estimate of Effect			Number of Participants in the Study
		Outdoor	Indoor	Relative Estimate of Effect	
Number of cases [14]	SARS-CoV-2	2/7324 cases	7322/7324 cases	<1% of transmissions happened outdoors	7324 cases, totaling 318 outbreaks
Number of cases [15]	SARS-CoV-2	4/103 cases	99/103 cases	5% of work-related cases occurred outdoors	103 possible work-related cases among a total of 690 local transmissions
Odds of transmission [16]	SARS-CoV-2	Raw data not available	Raw data not available	Odds of transmission in closed environments 18.7 (95% CI, 6.0–57.9) times greater than in open air	110 cases: 27 primary cases and 83 secondary cases
Number of super-spreading events and odds of transmission <sup>a</sup> [16]	SARS-CoV-2	1/7 super-spreading events	6/7 super-spreading events	Odds ratio of super-spreading in closed environments: 32.6 (95% CI, 3.7–289.5)	110 cases: 27 primary cases and 83 secondary cases
Number of cases [17]	SARS-CoV-2	95/10 926 cases	10 831/10 926 cases	<1% of transmissions happened outdoors	10 926 cases, totaling 201 events of transmission
Number of cases [18]	H1N1 2009 influenza	0/3 cases	24/29 cases	Of 32 total people in a holiday camp, 29 traveled together in a train wagon	32 people at a holiday camp
Mortality [19]	H1N1 1918 influenza	28/820 deaths sleeping in hammocks outside, 34.1 persons/1000	39/267 deaths sleeping in cabins inside, 146.1 persons/1000	Risk ratio 4.28 (95% CI, 2.69–6.81)	Total 1217 people on the ship

Indoors:Outdoors ~ 18.7

Abbreviations: CI, confidence interval; SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

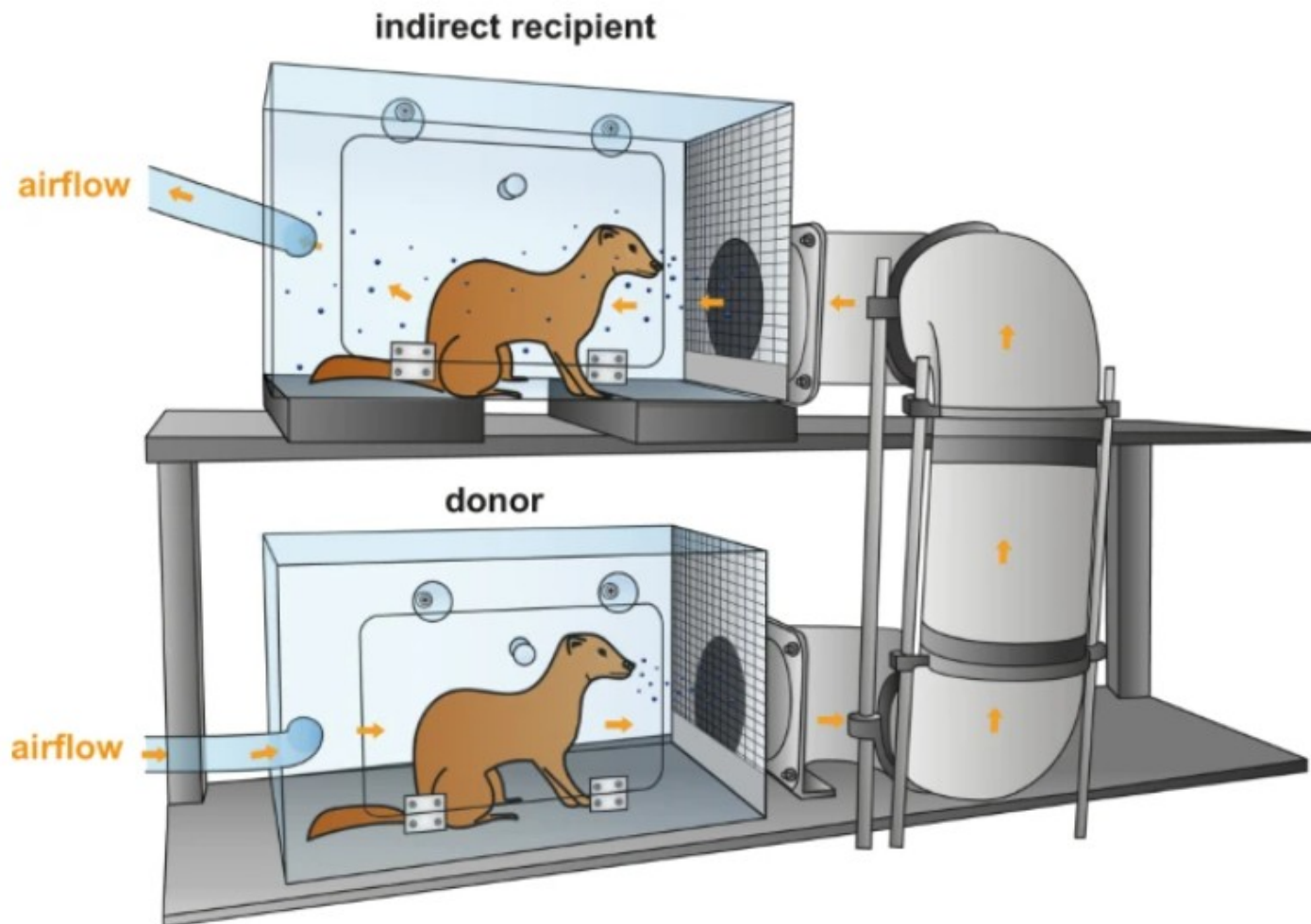
<sup>a</sup>Super-spreading defined as events where the number of secondary cases generated by a single primary case is greater than the 95th percentile of the distribution (ie, transmission to 3 or more persons).




# SARS-CoV and SARS-CoV-2 are transmitted through the air between ferrets over more than one meter

<https://www.nature.com/articles/s41467-021-21918-6>






**Fig. 1: Experimental transmission set-up.**





**World Health Organization (WHO)**  @WHO · 19. helmik.

Lower your risk from #COVID19 by combining these **5** precautions:

- 1** Wear a mask 
- 2** Clean your hands 
- 3** Keep physical distance 
- 4** Cough/sneeze away into your elbow 
- 5** Open windows as much as possible 

Multidisciplinary collaboration has indicated aerosol inhalation  
as a core transmission mode of COVID-19

Socratic paradox: “I understand that I don’t understand.”



**Aalto University**